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## Notes:

First detection: Ibata et al. 1994

First detection in RR Lyrae: Ivezić et al. 2000

Important contribution + creation of the Sagittarius coordinates: Majewski et al. 2003

Bifurcation: Belokurov+06 and Koposov+12

### 

### Ibata, Gilmore & Irwin 1994

Serendipitous detection of an elongated, comoving group of stars using spectroscopy of K and M giants when looking at the low extinction regions near the bulge. Radial velocities taken with an accuracy of 9 km/s.

They detect a clump with vlos ~ 140 km/s with a velocity dispersion of ~10km/s, most prominent at l=5deg, b=-15deg. They then use the SMC-calibrated CMD to say that Sgr should be at 24 plus/minus 2 kpc from the Sun.

*“The good match with an SMC intermediate age stellar population CMD suggests that a significant intermediate age population is present in the Sagittarius dwarf; the weak extension towards the blue of the horizontal branch would imply that there is also an underlying old stellar population present. This also is typical of Galactic dwarf spheroidal satellites and implies that a significant population II variable star component should be present. “*

*“The close proximity to the Galactic Centre, the morphological appearance and the radial velocity of 140 km s~' indicate that this system is currently undergoing strong tidal disruption before being integrated into the Milky Way. The tidal limit for a bound system of similar dynamical mass to Fornax, at a distance of 16 kpc from the Galactic Centre, is ~0.5 kpc. As Sagittarius extends over at least 3 kpc, almost an order of magnitude larger than the tidal limit, it provides us with a snapshot of an early phase of the tidal destruction of a satellite galaxy.”*

### Sarajedini & Layden 1995

*“We present V7 CCD color-magnitude diagrams for the globular cluster M54 and the Sagittarius dwarf galaxy. These are used to derive the following quantities: [Fe/H]=-1.79±0.08 for M54 and [Fe/H]=-0.52±0.09 for Sagittarius. We find a metallicity dispersion of ±0.16 dex in M54, and we infer the possible existence of a [Fe/H] ~ -1.3 component in Sagittarius, which may have a metallicity dispersion as well. The mean reddening in the direction of M54 is E(B-V) =0.13 ±0.02. The distances to M54 and Sagittarius, determined using their horizontal branch magnitudes, are identical to within the uncertainties of existing RR Lyrae luminosity-abundance relations. This, together with positional and radial velocity arguments, suggests that M54 is physically associated with Sagittarius. We note that M54 is substantially brighter than the globular cluster members of the Fornax dwarf spheroidal galaxy, and that the metal abundance of Sagittarius is quite high for its estimated absolute magnitude.”*

*“metallicity dispersion of ±0.16±0.01 dex in M54. This result should be confirmed by high-quality spectroscopic abundance measurements.”*

*“we conjecture that the (mysterious) RHB represents some older or more metal-poor population, as compared with the Sgr red clump stars. [..] the dominant population in Sgr has an age of ^10 Gyr, which is consistent with a red clump HB morphology at [Fe/H]^-0.5 and a red HB at [Fe/H]^-1.3.”.*

*“it seems quite likely that M54 is itself a part of the Sgr dwarf galaxy. Perhaps it represents the oldest, most metal-poor, epoch of star formation in Sgr, essentially the nucleus about which the rest of the galaxy condensed. This raises the question of whether Sgr is a nucleated dwarf galaxy. However, the colors of these nuclei are usually very similar to that of the surrounding dwarf field stars, whereas M54 appears considerably bluer than the surrounding Sgr field. Thus, M54 is likely to be a more luminous version of Fornax-like globulars, rather than a galactic nucleus.”*

*“Clearly, (Sgr) its high abundance for its luminosity’*

### Da Costa, G. S.; Armandroff, T. E. 1995

*“we find [Fe/H]= — 2.00±0.08, -0.67±0.07, -1.28±0.12, -0.36±0.09, -1.70±0.11, -1.55±0.10, and —1.99±0.08 for Pal 15, NGC 6366, NGC 6626 (M28), Terzan 7, Arp 2, NGC 6715 (M54), and Terzan 8, respectively.”*

*“We note also that four of the clusters studied here (M54, Terzan 7, Arp 2, and Terzan 8) have locations in the sky, radial velocities, and distances that associate them with the recently discovered Sagittarius dwarf spheroidal galaxy.”*

*“We note also that the Sagittarius cluster system, if integrated into the galactic halo, will*

*contribute clusters to both the younger halo and old halo subsamples.”*

*“In these studies Ter 7 is found to be significantly younger than the globular cluster 47 Tue, by perhaps as much as 4 Gyr. [..] Terzan 7 is clearly kinematically and spatially a halo object, despite its high abundance. It then becomes the third such metal-rich halo cluster, after NGC 6366 (Da Costa & Seitzer 1989; Sec. 4.1.5 below) and Pal 12 (Sec. 4.1.8 below), to be identified. [..] This is not an unexpected result; for example, based on Gaussian fits to the overall cluster abundance distribution, Armandroff & Zinn (1988) estimated that approximately one halo cluster lay above the abundance cut. It does indicate however, that perhaps —3% of the Galaxy’s halo cluster system is relatively metal rich. Field halo stars with abundances comparable to NGC 6366 and Ter 7 are also known (e.g., Carney et al. 1990; Ryan, private communication) but whether these metal-rich field halo stars exist in the same relative proportion as the metal-rich halo clusters remains an open question at present. In this context it is also interesting to note that the field star members of the Sagittarius dwarf galaxy are relatively metal rich [mean abundance [Fe/H]= —1.0±0.3 from the spectroscopic measurements of Ibata et al. (1994); -1.1 ±0.3 from isochrone fitting to the color-magnitude diagram by Mateo et al. (1995); -0.52±0.09 from giant branch fits in a CM diagram by Sarajedini & Layden (1995)]. Consequently, when, or indeed if, this dwarf galaxy is fully disrupted and integrated into the Galaxy’s halo, it will contribute a population of what will be recognized only as relatively metal-rich stars with halo kinematics.”*

### Bassino, L. P.; Muzzio, J. C. 1995

M54: GC or nucleus of Sgr?

Against: too blue, too metal poor.

In favour: very luminous (comparable to the Fornax nucleus). If Sgr is a non-nucleated dwarf, it shouldn’t survive longer than 5.5 Gyr. It’s brightness is comparable to omega-cent (the authors toy with the idea that perhaps omega-cent was the nucleus of a now totally disrupted dwarf galaxy).

### Ibata, Rodrigo A.; Gilmore, Gerard; Irwin, Michael J. 1995

“*We have discovered a new Galactic satellite galaxy in the constellation of Sagittarius. The Sagittarius dwarf galaxy subtends an angle of - 10° on the sky, lies at a distance of 24 kpc and is comparable in size and luminosity to the largest dwarf spheroidal, Fornax. The new galaxy has many features in common with the other eight Galactic dwarf spheroidal systems, including an extended low-density spatial structure, a well populated red horizontal branch with a blue extension, and a substantial carbon star population. In terms of stellar populations it most closely resembles the Fornax dwarf, having a strong intermediate-age stellar component and evidence of a metallicity spread. Sagittarius is the nearest galaxy known and currently lies only - 16 kpc from the centre of the Milky Way. Isodensity maps show it to be markedly elongated along a direction pointing towards the Galactic Centre, and suggest that it has been tidally distorted. The close proximity to the Galactic Centre, the morphological appearance and the radial velocity of 140 km s"1 indicate that this system must have undergone at most very few close orbital encounters with the Milky Way. It is currently undergoing strong tidal disruption prior to being integrated into the Galaxy. We find that at least some of the four globular clusters, M54, Arp 2, Ter 7 and Ter 8, are associated with the Sagittarius dwarf galaxy, and will probably share the fate of their progenitor. The Sagittarius dwarf galaxy was found serendipitously using a combination of UK Schmidt Telescope sky survey plates, the APM automatic plate measuring facility and the Anglo-Australian Telescope multifibre spectrograph, AUTOFIB.”*

### Mateo et al. 1995a

We present deep CCD photometry of a field in the newly discovered dwarf spheroidal galaxy in Sagittarius (hereafter Sgr), and of a nearby control field. These data were used to produce color-magnitude (CM) diagrams reaching I ~ 22.3 in both fields. After statistically removing the field stars from the CM diagram we find that Sgr is dominated by a moderately old (age ~10 Gyr) population, significantly younger than a typical globular-cluster population. There is some evidence for a weak intermediate-age component or alternatively a population of blue stragglers. These results confirm that Sgr is a bona fide dwarf spheroidal galaxy, the ninth found orbiting the Milky Way. We have discovered nine short-period variables in the Sgr field, well in excess of the number found in the control field. Seven of these stars have similar apparent magnitudes and are almost certainly RR Lyr stars in Sgr. We have used the minimum-light colors of the RRab variables to determine the reddening of the Sgr field to be E(V-I) = 0.22, or E(B-V) = 0.18 for a normal extinction law. For an assumed RR Lyr luminosity of M\_v\_ = +0.6 we conclude that the distance of Sgr is 25.2+/-2.8 kpc. The properties of the Sgr giant branch and upper main sequence are consistent with a mean metallicity of [Fe/H]~ -1.1+/-0.3.

### Mateo et al. 1995b

We present time-series CCD photometry of a field in the newly discovered dwarf spheroidal galaxy in Sagittarius (hereafter Sgr), and of a nearby control field. These data, which consist of VI images obtained during the 1994 OGLE season, were used to identify and study variable stars in both fields. We discovered ten variable stars in the Sgr field, nine of which have light curves and periods consistent with RR Lyr stars or anomalous Cepheids. The control field contains four short-period contact eclipsing binaries, but no pulsating variables. The variables in the Sgr field include a bright RR Lyr star that is almost certainly located in front of Sgr in the galactic bulge, a short-period contact binary located near or within Sgr, and a short-period pulsating star that may either be a foreground halo RR Lyr star or an anomalous Cepheid within Sgr. The seven remaining variables in the Sgr field are RR Lyr stars with very similar mean apparent magnitudes; we conclude that they are members of Sgr. We estimate the total number of RR Lyr stars in Sgr to be 1930+730 if M\_v,sgr\_ = -13, or 310+/-120 if M\_v,sgr\_ = -11. The frequency of pulsating variables in Sgr is consistent with earlier conclusions that the galaxy consists of a predominant old (age ~> 10 Gyr) population.

### Mateo et al. 1996

They find Sgr material (based on photometry) 10deg away from the progenitor.

*“Either the stellar surface density in Sgr is remarkably uniform -the densities at radial distances of 4deg and 9.7deg (w.r.t. M54) are nearly identical- or the outer structure of Sgr is very clumpy. The latter conclusion is interesting because most tidal disruption models do not predict significant clumpiness as a satellite is torn apart.”*

They try to understand the material as being part of the normal dwarf (I think) but at 10deg it is the transition from dwarf to tidal tails. Could this explain their “equal density” problem?

### Alard 1996

They find 313 RR Lyrae clustered at a distance of ~24kpc in a 25 deg^2 field centred at l,b = 3,-7 deg (8 deg away from M54). They report then that these stars are too far based on the iso-contours of IGI94.

### Fahlman et al. 1996

They find main sequence stars of Sgr close in the sky to M55 (l,b = 8, -23 deg). They use isochrone fitting to say that the age of Sgr is >10Gyr, similar to the ages of Ter.7 and Arp 2.

### Whitelock, Irwin and Catchpole 1996

Near-infrared photometry is presented of 75 late-type giants in the direction of the Sagittarius dwarf galaxy. 71 of these are thought to be members of the galaxy; the other four are late-type M stars in the Bulge. The carbon stars and possible carbon stars have a wide range of properties. The reddest ones are similar to carbon stars in Fornax, while the bluest are more like those in Sculptor, Draco and Ursa Minor. A clearly defined giant branch indicates a metallicity slightly weaker than that of 47 Tuc and a value of [Fe/H] − 0.8 is estimated. The most luminous star which is a confirmed member of the dwarf galaxy is a carbon star with Mbol ~ −4.5. Four variable stars have been discovered; these are probably of the semi-regular and/or Mira type with periods of the order of 150 to 300 days.

### Zijlstra and Walsh 1996

Two planetary nebulae are shown to belong to the Sagittarius Dwarf Galaxy, on the basis of their radial velocities. This is only the second dwarf spheroidal galaxy, after Fornax, found to contain planetary nebulae. Their existence confirms that this galaxy is at least as massive as the Fornax dwarf spheroidal which has a single planetary nebula, and suggests a mass of a few times 107 M. The two planetary nebulae are located along the major axis of the galaxy, near the base of the tidal tail. There is a further candidate, situated at a very large distance along the direction of the tidal tail, for which no velocity measurement is available. The location of the planetary nebulae and globular clusters of the Sagittarius Dwarf Galaxy suggests that a significant fraction of its mass is contained within the tidal tail.

*“Mateo et al. suggested that the enlarged extent is more easily explained if the galaxy has already undergone an earlier encounter with the Galaxy which produced a long tidal tail (Piatek & Pryor 1995) extending on both the leading and trailing side (Moore & Davis 1994.”*

### Alcock et al. 1996

We report the discovery of 30 type a,b RR Lyrae (RRab) which are likely members of the Sagittarius (Sgr) dwarf galaxy. Accurate positions, periods, amplitudes and magnitudes are presented. Their distances are determined with respect to RRab in the Galactic bulge found also in the MACHO 1993 data. For R⊙ = 8 kpc, the mean distance to these stars is D = 22 ± 1 kpc, smaller than previous determinations for this galaxy. This indicates that Sgr has an elongated main body extending for more than 10 kpc, which is inclined along the line of sight, with its northern part (in Galactic coordinates) closer to us. The size and shape of Sgr give clues about the past history of this galaxy. If the shape of Sgr follows the direction of its orbit, the observed spatial orientation suggests that Sgr is moving away from the Galactic plane. Also, Sgr stars may be the sources of some of the microlensing events seen towards the bulge.

### Ibata et al. 1997

The Sagittarius dwarf spheroidal galaxy, the closest satellite galaxy of the Milky Way has survived for many orbits about the Galaxy. Extant numerical calculations modeled this galaxy as a system with a centrally-concentrated mass profile, following the light, and found that it should lose more than one-half of its mass every 2–4 orbits and be completely disrupted long before now. Apparently the Sagittarius dwarf spheroidal, and by implication other dSph galaxies, do not have a centrally concentrated profile for their dark matter. We develop a model in which the stars of the Sgr dwarf are embedded in a constant-density dark matter halo, representing the core of a tidally-limited system, and show that this is consistent with its survival. We present new photometric and kinematic observations of the Sagittarius dwarf

spheroidal and show these data are consistent with this explanation for the continued existence of this galaxy. The Sagittarius dwarf is being tidally distorted and is tidally limited, but is not disrupted as yet. The corresponding minimum total mass is 10^9 M⊙, while the central mass to visual light ratio ∼ 50 in Solar units.

Our new photographic photometry allows the detection of main-sequence stars of the Sagittarius dwarf over an area of 22◦ × 8◦. The Sagittarius dwarf is prolate, with axis ratios ∼ 3:1:1. For an adopted distance of 16 ± 2 kpc from the Galactic center on the opposite side of the Galaxy to the Sun, the major axis is ∼> 9 kpc long and is aligned approximately normal to the plane of the Milky Way Galaxy, roughly following the coordinate line ℓ = 5◦.

The central velocity dispersion of giant stars which are members of the Sagittarius dwarf is 11.4 ± 0.7 km s−1 and is consistent with being constant over the face of the galaxy. The gradient in mean line-of-sight velocity with position along the major axis, dv/db, is ∼ 0 km s−1/degree in the central regions and increases in amplitude to dv/db = −3 km s−1/degree over the outermost three degrees for which we have data. A first measurement of the proper motion of Sgr determines the component of its space velocity parallel to its major axis to be 250 ± 90 km s−1 , directed towards the Galactic Plane. We model these kinematic data to determine the orbit of the Sagittarius dwarf. Our best fit model has an orbital period of ∼< 1 Gyr and has the Sagittarius dwarf spheroidal close to perigalacticon. This period is shorter, by about a factor of >∼ 10, than the age of the bulk of its stellar population.

*“A robust conclusion, consistent with both analyses of globular cluster ages, is that an RR Lyrae population can occur in stellar systems with metallicities ∼ −1.5 dex that are as much as ∼ 5 Gyr younger than the classical old halo. Thus the detection of RR Lyrae stars in the Sagittarius dwarf spheroidal is indicative of a population of age greater than ∼ 10 − 12 Gyr.”*

*“The mass of the Sagittarius dwarf is not important for constraining the orbit, provided it is low enough that dynamical friction has not substantially modified the orbit over an orbital period. This limit is 4 × 109 M⊙ at the current Galactocentric distance; we argue below that this is satisfied.”*

*“Sagittarius dwarf can be regarded as test particles which all move on the same orbit. Numerical simulations (see §4 below) show that Galactic tides force a satellite galaxy into a prolate shape, and at pericenter the satellite’s longest axis is aligned along its orbit. However, this alignment with the orbit is only approximate, since the internal self-gravity in the dwarf will act to decelerate stars that lead the center of mass to lower energy orbits, and to accelerate stars that trail the center of mass to higher energy orbits. The prolate dwarf is thereby rotated about its center of mass such that the leading edge drops towards the Galactic center (see e.g., Oh et al. 1995). However, this is a small effect.”*

*“This fit is formally acceptable (reduced χ2 = 1.7), in spite of the systematic differences between the model and the mean velocity data. The curvature of the data near b = −15◦ is so extreme that no orbit in the above potential can be made to pass through the data points better than this.”*

*“Is it plausible that the Sagittarius dwarf spheroidal is a rotating body? Hargreaves et al. (1994a) found no significant rotation in the Sextans dSph, but discovered rotation about the long (major) axis of Ursa Minor (Hargreaves et al. 1994b). They speculated that the rotation in the latter case was attributable to tidally-induced streaming motions. In any case, the amplitude in UMi is a small fraction of the internal velocity dispersion. Thus, based on the precedent of the other dSphs, no significant internal streaming motion is expected in the Sagittarius dwarf. It is probable that the observed mean velocity is correctly representing that which is appropriate to determine the orbit of Sgr about the Galaxy. Nonetheless, we consider as a limiting case the possibility that the Sagittarius dwarf is flattened entirely by internal streaming, and that streaming is oriented so as to have the maximum possible effect on the observed mean stellar velocities. [..] We assume (maximally) that the apparent ellipticity of Sgr is the true ellipticity, and that the shape is determined entirely by rotation, with no Galactic tidal contribution. Then Fig 2 in Binney (1978) indicates that, if rotationally flattened with ellipticity q = 1 − a1/a3 ∼ 0.67, that the maximal streaming velocity in the Sagittarius dwarf is approximately equal to its velocity dispersion. For consistency with the model developed below, we further assume that Sgr rotates with a solid body rotation curve about a point near M54. In that case, the maximum rotation velocity corresponds to |Ωrot| ∼< 1 km/s/degree. [..] None of the models with major axis rotation in the range −1 km/s/degree < Ωrot < 1 km/s/degree fits the curvature in the velocity curve near b = −15◦ evident in Fig 10.”*

*“We note here that it is implausible that the Sagittarius dwarf has been recently captured by the Milky Way. For this to have happened, a non-destructive encounter of Sgr with a rather massive companion galaxy is required to perturb its orbit sufficiently. The apocenter we have derived is similar to the current distance of the Large Magellanic Cloud, but the current constraints on the orbit of the LMC (Jones, Klemola & Lin 1994) are not consistent with such a scenario.”*

*“The internal velocity dispersion in the satellite does not change significantly prior to disruption (the dispersion may in fact decrease during disruption) and the stellar surface density distribution remains well described by a King model until near total disruption [..] Piatek & Pryor found that, generically, the dwarf spheroidal is stretched along its orbit and compressed in the perpendicular directions.”*

*“Velasquez & White (1995) emphasize, however, that their orbit requires the Sgr galaxy to survive at least 10 pericentric passages before being almost entirely disrupted on the passage immediately preceding the present one. No mechanism to ensure the survival the Sgr dwarf prior to its current orbit is discussed. [..] These simulations concluded that the Sagittarius dwarf spheroidal should be rather easily disrupted, leading to the conundrum of its age being an order of magnitude greater than its predicted lifetime.”*

Apparently, at this point, everyone had problems keeping the Sgr remnant alive for so long. Is this because they were considering many orbits? Is this ok with just having 3 pericentres?

*“We propose below that the Sagittarius dwarf spheroidal is being tidally stretched along its major axis, which is aligned with its orbit, and is presently tidally limited. We present a self-consistent model with these properties.”*

Basically, they justify the robustness of Sgr with it having a large DM core that remained untouched. That increases the mass estimate from only light, and shields it. Is this necessary still?

***“Following Ostriker (1990), the absolute maximum amount of energy that could be imparted to the disk is the total orbital energy of the satellite, giving an increase of random energy of disk stars of ∆v^2 ∼ v^2 orbit MSgr/Mdisk, which is ∆v^2 ∼ 250^2 × 10−2 (MSgr/10^9 )(5 × 10^10/Mdisk) ∼ (45km/s)^2 . If all of this energy could be put into vertical heating, and the initial disk has σz ∼ 20 km/s dispersion, this would be increased to ∼ 50 km/s. Of course this is a highly unlikely event — the energy absorbed by the disk would be spread among its internal degrees of freedom, even neglecting the internal degrees of freedom of the satellite, and of the dark halo and the dissipation of gas. Binney (1992) has reviewed the role that accretion may play in the generation and sustaining of warps in disks. The mass that we have derived for the Sagittarius dwarf spheroidal is sufficiently high to suggest a role in the generation of the Milky Way warp, as suggested by Lin et al. (1996).”***

***“We argue that dynamical friction will not have induced significant orbital decay, and that it is unlikely that the Sagittarius dwarf spheroidal has been captured recently, so it has apparently survived many perigalacticon passages. [..] Thus, the measured velocity dispersion is a clear indication that the Sagittarius dwarf spheroidal did not have a much more massive progenitor. Furthermore, if it had been significantly more massive in the past, we would expect to find its ‘missing mass’ as a substantial population of Sagittarius dwarf debris — globular clusters and stars — along its dispersion orbit; however, this is not observed.”***

### Ng & Schultheis 1997:

A catalogue is presented with variable (RR Lyrae, semiregular and Mira) stars located inside field #3 of the Palomar-Groningen Survey at the outer edge of the Sagittarius dwarf galaxy. One of the semiregular variables is a carbon star, comparable with those found by Azzopardi et al. (1991). Serendipity provides the suggestion that their carbon stars might not be located inside, but behind the bulge in the Sagittarius dwarf galaxy.

### Layden & Sarajedini 1997:

We present a deep color-magnitude diagram in the V I passbands of the globular cluster M54, a member of the Sagittarius dwarf galaxy. The data extend below the cluster’s main sequence turn-off, allowing us to estimate the cluster’s age. We find that M54 is 0.5–1.5 gigayears older than the Galactic globulars M68 and M5. In absolute terms, the age is comparable to the published age estimates of the other member clusters Arp 2 and Terzan 8, but is significantly older than the member cluster Terzan 7. An age estimate of the Sagittarius field population relative to M54 suggests that M54 is ∼>3 Gyr older than the field. We discuss briefly the star formation history of the Sagittarius dwarf galaxy.

*“M54 has an age typical of Galactic globulars of its metallicity. [..] Comparing our absolute age for M54 with the age estimates for the dominant Sgr field population shown in Table 1 suggests that M54 is older than the metal-rich field population in which it is embedded.“*

***“As was the case for many of the Galactic satellite dwarf spheroidals (e.g., Smecker-Hane et al. 1994), Sgr managed to retain a significant portion of its gas for many Gyr, enabling the formation of Ter 7, and of the ∼4 Gyr field population.”***

### Walsh et al. 1997

“An abundance analysis is presented for both PN using empirical abundance determinations. The abundance pattern is very similar in both nebulae and both show an oxygen depletion of −0.4 dex with respect to the mean oxygen abundance of Galactic planetary nebulae and [O/H] = −0.6 . The Sagittarius PN progenitor stars are representative of the higher metallicity tail of the Sagittarius population. The pattern of abundance depletion is similar to that in the only other planetary nebula in a dwarf galaxy companion of the Milky Way, that in Fornax, for which new spectra are presented. However the abundances are larger than for Galactic halo PN suggesting a later formation age. The oxygen abundance of the Sagittarius galaxy deduced from its PN, shows similarities with that of dwarf ellipticals around M 31, advancing the notion that this galaxy was a dwarf elliptical before its interaction with the Milky Way.”

### Marconi et al. 1997:

We present V,I deep CCD photometry for three fields of the dwarf galaxy in Sagittarius (Sgr), located at l=5.6, b=-14.1. One of the fields is centered on the globular cluster NGC 6715 (M54), which lies in one of the dense clumps of the Sgr galaxy. Comparing the CMD of Sgr with those of globular clusters which are believed to be kinematically associated with the dwarf galaxy (Da Costa & Armandroff, 1995), we conclude that the stellar population of Sgr presents a spread in metallicity of -0.71 ≤[Fe/H] ≤-1.58, and that the dominant population (≃10 Gyr old) is extremely similar to the star content of the associated globular cluster Terzan 7. The estimated distance to Sgr is d≃24.55 Kpc.

NOTE: again, another mention to Ter.7 being formed from gas similar to that of the stars in Sgr. In this case, it seems inconsistent with previous papers. Terzan 7 mean metalicity is -0.32 dex ([LEAMAN 2012](https://iopscience.iop.org/article/10.1088/0004-6256/144/6/183)), cannot be 10 Gyr old. Current estimates put it at ~8 Gyr (Geisler 2007).

### Montegriffo et al. 1998:

We present deep V- and I-band CCD photometry of the globular cluster Terzan8, recently found to be a member of the globular cluster system of the Sagittarius dwarf spheroidal galaxy. We accurately estimate the metallicity of Terzan8, and provide the first direct determination of the colour excess toward this cluster. Our robust age estimate confirms that this cluster is indeed coeval with typical Galactic globulars of comparable metal content, and thus it is probably significantly older than at least two other Sagittarius clusters, Terzan7 and Arp2. The implications of this result on the star formation history of the Sagittarius galaxy are briefly discussed.

### Smith et al. 1998:

We plot the globular clusters of the Fornax galaxy and those associated with the Sagittarius dwarf spheroidal galaxy in the horizontal-branch type versus metallicity diagram. The horizontal-branch types for the Fornax clusters include corrections for red horizontal-branch stars from the field and are based on our recent work and new results in the literature. Fornax globular clusters continue to stand out as having red horizontal branches for their low ([Fe/H]D [2) metallicities, with no counterparts in either the outer Galactic halo or the Magellanic Clouds. The clusters associated with Sagittarius lie to the blue of the Fornax clusters, except for the metal-rich cluster Ter 7. Although the metallicities of the three metal-poor Sagittarius globular clusters are similar to those of the Fornax clusters, their horizontal branches are bluer and they lie in a region also populated by the old LMC and old halo clusters. Neither cluster system resembles the younger Galactic halo globular clusters, often suggested to have been accreted from disrupted dwarf spheroidal galaxies. Except for Ter 7, both the Fornax and Sagittarius globular clusters are metal-poor compared with their Galactic counterparts of the same horizontal-branch type. We Ðnd no correlation between HB type and other cluster properties such as central concentration, luminosity, central surface brightness, and estimated collision rate.

“M54 might have captured stars from the Sgr dwarf, and the shadow RGB and some of the blue horizontal-branch stars could have been acquired in this way. We note the large mass of M54 (10^6 Msun; Illingworth 1976) and its membership in the Sgr dwarf, which is experiencing tidal disruption by the Milky Way. (Note that the central velocity dispersion of the Sgr dwarf of 11.4 km/s [Ibata et al. 1997] Bica (1997), is less than that of M54, 14 km/s.) seeking to explain a metal-rich RGB in the metal-poor cluster HP 1, show that globular clusters in the bulge could capture stars. Alternatively, if Sgr experienced multiple bursts of star formation, it is possible that some stars formed bound to M54.”

### Ng 1998:

The photometric estimate of the metallicity and the age of the Azzopardi et al. (\cite{ALRW91}) carbon stars (Ng \cite{Ng97}) is revised to respectively Zem =~ em0.004 and ~ em0.1 Gyr. Under the hypothesis that the carbon stars are located at a distance related to the Sagittarius dwarf galaxy, the broad velocity dispersion of the stars can only be explained if they were formed out of Galactic material during a recent crossing of the Sagittarius dwarf galaxy through the Galactic plane.

### van den Bergh 1998:

The possibility that the **Sagittarius dwarf spheroidal might have formed as a Searle-Zinn fragment in the outer halo of the Galaxy** is discussed. Arguments in favor of this hypothesis are (1) the luminosity distribution of globular clusters in both Sagittarius and in the outer halo (Rgc>80 kpc) appear to be bimodal with peaks near Mv~-5 and -10, and (2) the globular clusters in both Sgr and the outer halo have a significantly larger age spread than do the globulars in the inner halo of the Galaxy. However, a counterargument is that only one of the four globulars associated with Sgr has the large half-light diameter that is diagnostic of outer halo clusters. The absence of globular clusters from all Local Group dwarf spheroidal galaxies fainter than Mv=-12 shows that their specific globular cluster frequency must be lower than it is in the Fornax dwarf spheroidal. This result suggests that Fornax may have had an unusual evolutionary history.

Searle-Zinn fragment (Searle & Zinn 1978): *“It is suggested that the halo clusters originated within transient protogalactic fragments that gradually lost gas while undergoing chemical evolution and continued to fall into the Galaxy after the collapse of its central regions had been completed.”*

This would imply something similar to monolithic collapse, which is mostly disfavoured.

### Mateo et al. 1998:

We have obtained deep photometric data in 24 fields along the southeast extension of the major axis of the Sagittarius dwarf spheroidal (Sgr dSph) galaxy and in four fields along the northwest extension. Using star counts at the expected position of the Sgr upper main sequence within the resulting color-magnitude diagrams, we unambiguously detect Sgr stars in the southeast over the range 10°-34° from the galaxy's center. If Sgr is symmetric, this implies a true major-axis diameter of at least 68°, or nearly 30 kpc if all portions of Sgr are equally distant from the Sun. Star counts parallel to the galaxy's minor axis reveal that Sgr remains quite broad far from its center. This suggests that the outer portions of Sgr resemble a stream rather than an extension of the ellipsoidal inner regions of the galaxy. The inferred V-band surface brightness (SB) profile ranges from 27.3 to 30.5 mag arcsec-2 over this radial range and exhibits a change in slope ~20° from the center of Sgr. The scale length of the outer SB profile is 17.2d, compared with 4.7d in the central region of Sgr. We speculate that this break in the SB profile represents a transition from the main body of Sgr to a more extended ``Sgr stream.'' By integrating the SB profile, we estimate that the absolute visual magnitude of Sgr lies in the range -13.4 to -14.6, depending on the assumed structure of Sgr; an upper limit to the luminosity of Sgr is therefore L~5.8×107 Lsolar. **This result lowers the M/LV ratio inferred for Sgr down to ~10, which is consistent with values observed in the most luminous dSph companions of the Milky Way.**

NOTE: first actual detection of the stream.

### Whitelock et al. 1999:

The luminosities of carbon stars in the Sagittarius Dwarf are derived from infrared photometry and compared with those of carbon stars in other galaxies. Several of them are large amplitude, probably Mira, variables and one shows obscuration episodes characteristic of galactic carbon stars with moderate mass-loss rates, e.g. R For and R Lep. **These variables are more like those found in the Magellanic Clouds than in dwarf spheroidals.**

### Bellazzini et al. 1999:

We present the first results of a large photometric survey devoted to the study of the star formation history of the Sagittarius dwarf spheroidal galaxy (Sgr dSph). Three wide strips (size ~ 9 x 35 arcmin ^2) located at ~ (l deg b deg) = (6.5;-16), (6;-14), (5;-12) have been observed. Each strip is roughly east-west oriented, nearly along the major axis of the galaxy. A control field (size ~ 9 x 24 arcmin ^2), located outside the body of Sgr dSph [~ (l deg b deg) = (354;-14)] has also been observed for statistical decontamination purposes. Accurate and well-calibrated V, I photometry down to V ~ 22 has been obtained for ~ **90 000 stars** towards the Sgr dSph and ~ 8000 stars in the control field. This is the largest photometric sample (covering the widest spatial extension) ever observed in the Sgr dSph up to now. The main new results presented in this paper are: (1) **the possible discovery of a strong asymmetry in the distribution of stars along the major axis, since the north-western arm of the Sgr galaxy (i.e. the region nearer to the Galactic bulge) apparently shows a significant deficiency of Sgr stars** and (2) the first direct detection of a very metal-poor (and presumably old) population in the Sgr stellar content. **Hints at a metallicity gradient towards the densest region of the galaxy are also reported.**

“The simultaneous presence of a clear sequence of blue stars (blue plume, see below) and carbon stars has been interpreted as evidence for the presence of a sparse population of stars significantly younger than Pop A (MUSKKK; WIC; Layden & Sarajedini 1997, hereafter LS97). Let us call this component Pop B, for brevity. The estimates of the absolute age of Pop B range from 4 (MUSKKK) to 1 Gyr (Ng 1997). [..] There are at least two (of the four) globular clusters associated with Sgr that are very metal-poor (Fe/H~-2) and significantly older than Pop A, i.e. M54 (MAL; LS97) and Terzan 8 (MoAL). This fact, coupled with the presence of RR Lyrae stars, suggests the existence of an old and metal-poor population in the galaxy. **However, a direct identification of such a component is still missing.**”

“Density distribution asymmetry along the major axis: The SGRWEST region (nearer to the Galactic bulge and the leading head of Sgr along its orbit, according to IGWIS) seems significantly deficient of Sgr stars with respect to SGR34. If this result is exact, it would be very difficult to find a physical mechanism other than tidal interaction with the Galaxy that can produce such an asymmetry in the density distribution of Sgr stars, also given the remarkable homogeneity of the stellar content. So, it can be considered as a clue suggesting that the tidal disruption of the Sgr galaxy is currently going on.”

“Pop A and Pop B stars have similar distributions: if the stars in the blue plume identified in the CMDs are associated with a younger population (Pop B) it must be concluded that (a) both episodes of star formation (Pop A and Pop B) occurred on large scales, comparable with the dimension of the galaxy itself (i.e. stars were formed everywhere nearly at the same epoch), or (b) a very efficient mechanism for star mixing has been at work in Sgr. The two-body relaxation time for this system is, as expected, much greater than one Hubble time for any reasonable assumption about the structure of the galaxy, so hypothesis (a) seems the most likely.”

### Burton & Lockman 1999:

We have measured the λ21 cm line of Galactic Hi over more than 50 square degrees in the direction of the Sagittarius dwarf spheroidal galaxy. The data show **no evidence of HI associated with the dwarf spheroidal** which might be considered analogous to the Magellanic Stream as it is associated in both position and velocity with the Large Magellanic Cloud. **Nor do the HI data show evidence for any disturbance in the Milky Way disk gas that can be unambiguously assigned to interaction with the dwarf galaxy**. The data shown here limit the Hi mass at the velocity of the Sagittarius dwarf to < 7000 M⊙ over some 18 square degrees between Galactic latitudes −13◦ and −18.◦5.

### Brown et al. 1999:

Chemical abundances in five stars in M54, a globular cluster associated with the Sagittarius dwarf galaxy, have been determined using high-resolution echelle spectra. We find the cluster to have [Fe/H]=-1.55 and possibly halo-normal abundance patterns, although the [O/Fe] and [alpha/Fe] ratios lie between solar and the normal halo values. One star shows the combination of low oxygen and enhanced Na and Al, symptomatic of deep mixing of ON-cycle and other proton-capture products; a second star shows a lesser degree of O depletion unaccompanied by Na and Al excesses. In the cluster Eu is also enhanced, indicating that about 30% of the Ba in the cluster is due to the r-process. In general, M54 is similar to globulars of comparable metallicity in the inner Galactic halo, despite its clear association with the Sagittarius dwarf spheroidal.

### Majewski et al. 1999:

As part of the Selected Areas Starcounts Survey, a CCD survey to V>21, we have obtained VI photometry of two fields at b=+/-40 deg aligned roughly with an extrapolation of the major axis of the Sagittarius dwarf spheroidal galaxy. Comparison of the color-magnitude diagram (CMD) for some of these fields with the CMDs of fields reflected about the Galactic l=0 deg meridian reveals an excess of stars at V\_0=17.85 and 0.9<(V-I)\_0<1.1 in the (l,b)=(11 deg,-40 deg) field. The excess stars have colors consistent with the Sgr red clump, and deeper CMD imaging in these locations shows evidence of a main-sequence turnoff (MSTO) at V=21, with the main sequence extending to the limit of our data (V=24). The surface brightnesses we derive from either the potential excess of red clump stars or the apparent excess of MSTO stars are consistent with each other and with the results of other surveys at this latitude. No similar excess appears in our northern Galactic hemisphere fields near the (l, b)=(353 deg, +41 deg) field. We have obtained spectroscopy of all 30 candidate red clump stars in the range 0.9<(V-I)\_0<1.1and 17.75<V\_0<17.95. The radial velocity distribution of the stars, while dissimilar from expectations of Galactic structure models, does not show a contribution by stars near the Galactocentric radial velocity seen in other studies near the Sgr core. It is difficult to reconcile a photometric result that is consistent with other explorations of the Sagittarius stream with a radial velocity distribution that is apparently inconsistent. In a companion paper, we discuss how some of the discrepancies are resolved if our potential Sgr detection corresponds to a different Sgr tidal streamer than that detected by most other surveys.

NOTE: farthest detection of the stream by that time, I think. Only other is Mateo 1998 but it was closer to the dwarf by some 10deg.

### Layden and Sarajedini 2000:

We present deep VI-band photometry of the globular cluster M54, a nearby field in the Sagittarius dwarf galaxy, and a control field. The color-magnitude diagrams reach well below the oldest main-sequence turnoffs, thus enabling an analysis of the galaxy's age-metallicity relation with unprecedented clarity. We also study the variable stars in the direction of M54. From 67 RR Lyrae variables, we confirm and improve on our previous estimates of the cluster horizontal branch magnitude, foreground reddening, and horizontal branch morphology. These values are used in determining the ages of M54 and the Sagittarius field populations. We confirm our previous result that M54 is the same age as Galactic globular clusters of similar metallicity. We also derive ages on a self-consistent scale for the other three globular clusters in Sagittarius. We find strong evidence for multiple episodes of star formation (or continuous star formation with a variable rate) in the field of Sagittarius. **We characterize the principal episodes with the ages 11, 5, and 0.5 through 3 Gyr and with [Fe/H] values of -1.3, -0.7, and -0.4, respectively**. On this scale, M54 has an age of 15 Gyr. Surprisingly, the age-metallicity relation we have derived for the galaxy as a whole is **described quite well by a closed-box chemical evolution model.** We also find that the populations associated with the Sgr field are clumped spatially around M54, and we consider several explanations for this phenomenon. **We again speculate that Sagittarius is a nucleated dwarf elliptical galaxy with M54 as its nucleus.**

### Cseresnjes et al. 2000:

We report the detection of ~ 1 500 RR Lyrae of Bailey type ab located in the Sagittarius dwarf galaxy (Sgr). These variables have been detected on two ESO Schmidt fields centred on (l,b)=(3.1deg ,-7.1deg ) and (6.6deg ,-10.8deg ), covering an area of ~ 50 deg2. We present a surface density map of Sgr based on the spatial distribution of these RRab, allowing us to trace its structure in a region that was still almost unexplored between b=-14deg and b=-4deg . We present the results of the fit of different models to the density profile of Sgr. The best fit to the core of Sgr is an exponential with a scale length of 4.1deg along the major axis. **When we look at the extension of Sgr we find a break (significant at the ~ 2sigma level) in the slope of the surface density along the main axis of Sgr**. The nearly flat (or at least very slowly decreasing) profile in the outer region of Sgr shows that this dwarf galaxy is probably extending even further out our fields. Based on observations obtained at the European Southern Observatory, La Silla, Chile

NOTES: **The break is at b~-9 deg and only once they corrected for the completeness of their sample (estimated with models). In principle it seems robust. In the V21 model, the L3p1w material seems to start more or less there. This flattening of the density profile could be a combination of the density profile of the remnant (goes down towards positive Gal. lat) and that of the L3p1w material (starts at b~-10deg and peaks at b~-2deg).**

### Bonifacio et al. 2000:

Two giants of the Sagittarius dwarf spheroidal have been observed with the UVES spectrograph on the ESO 8.2m Kueyen telescope, during the commissioning of the instrument. Sgr 139 has [Fe/H]=-0.28 and Sgr 143 [Fe/H]=-0.21, these values are considerably higher than photometric estimates of the metallicity of the main population of Sgr. We derived abundances for O, Na, Mg, Al, Si, Ca, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Y, Ba, La, Ce, Nd and Eu; the abundance ratios found are essentially solar with a few exceptions: Na shows a strong overdeficiency, the heavy elements Ba to Eu, are overabundant, while Y is underabundant. The high metallicity derived implies that the Sgr galaxy has experienced a high level of chemical processing. The stars had been selected to be representative of the two main stellar populations of Sagittarius, however, contrary to what expected from the photometry, the two stars show a very similar chemical composition. We argue that the most likely explanation for the difference in the photometry of the two stars is a different distance, Sgr 143 being about 2 Kpc nearer than Sgr 139. **This result suggests that the interpretation of colour - magnitude diagrams of Sgr is more complex than previously thought and the effect of the line of sight depth should not be neglected.** It also shows that spectroscopic abundances are required for a correct interpretation of Sgr populations. Based on public data released from the UVES commissioning at the VLT Kueyen telescope, European Southern Observatory, Paranal, Chile.

### Dinescu et al. 2000:

We have measured the absolute proper motion of the young globular cluster Pal 12 with respect to background galaxies, using plate material spanning a 40 yr time baseline, and measuring stars down to a magnitude V~22. The measured absolute proper motion has an uncertainty of 0.3 mas yr-1 in each coordinate. **Pal 12's young age for a globular cluster led to the hypothesis that the cluster originated in the Large Magellanic Cloud (LMC)** and was later captured by the Milky Way (Lin & Richer). Here we investigate this hypothesis using the complete kinematical data. We present the orbital characteristics of Pal 12 and compare them with those of the LMC and Sagittarius dwarf galaxy (Sgr). The present kinematical data suggest that, from the two parent candidates for Pal 12, Sgr presents a more plausible case for the host galaxy than the LMC. We explore this scenario in the context of the uncertainties in the orbits and using two different analyses: the direct comparison of the orbits of Pal 12 and Sgr as a function of time, and the analytical model of Sgr's tidal disruption developed by Johnston. We find that, within the present uncertainties of the observables, this scenario is viable in both methods. Moreover, both methods place this event at the same point in time. **Our best estimate of the time of Pal 12's tidal capture from Sgr is ~1.7 Gyr ago.**

NOTE: check if this is still the current understanding for Pal 12.

### Dudziak et al. 2000:

Radio continuum observations at 1.4, 4.8 and 8.6 GHz of the two Planetary Nebulae (PNe) in the Sagittarius dwarf galaxy reveal the elongated shape of Wray 16-423 and the extreme compactness of He 2-436. It is confirmed that He 2-436 is subject to local dust extinction. Photoionization models for both PNe are obtained from two different codes, allowing theoretical uncertainties to be assessed. Wray 16-423, excited by a star of effective temperature 1.07\*E5 K, is an ellipsoidal, matter-bounded nebula, except for a denser sector of solid angle 15%. He 2-436, excited by a 7\*E4 K star, includes two radiation-bounded shells, with the very dense, low-mass, incomplete, inner shell possibly corresponding to a transitory event. The continuum jump at the He+ limit ($lambda mbda22.8 nm) agrees with NLTE model stellar atmospheres, despite the Wolf-Rayet nature of the stars. Both stars are on the same (H-burning) evolutionary track of initial mass (1.2±0.1) Msolar and may be twins, with the PN ejection of Wray 16-423 having occured ~ 1500 years before He 2-436. The PN abundances re-inforce the common origin of the parent stars, indicating almost identical depletions with respect to solar for O, Ne, Mg, S, Cl, Ar, and K (-0.55±0.07 dex), and strong overabundances for carbon, particularly in He 2-436. He 2-436i lines consistently point to large identical overabundances for helium in both PNe. An excess nitrogen makes Wray 16-423 nearly a Type I PN. **These PNe provide a means to calibrate both metallicity and age of the stellar population of Sagittarius. They confirm that the youngest, most metal-rich population has an age of 5 Gyr and a metallicity of [Fe/H]=-0.55$, in agreement with the slope of the red giant branch.**

### Yanny et al. 2000:

A sample of 4208 objects with magnitude 15<g\*<22 and colors of main-sequence A stars have been selected from 370 deg2 of Sloan Digital Sky Survey (SDSS) commissioning observations. The data is from two long, narrow stripes, each with an opening angle of greater than 60°, at Galactic latitudes 36deg<|b|<63deg on the celestial equator. Relative photometric calibrations good to 2% and consistent absolute photometry allows this uniform sample to be treated statistically over the large area. An examination of the sample's distribution shows that these stars trace considerable substructure in the halo. Large overdensities of A-colored stars in the north at (l, b, R)=(350deg, 50°, 46 kpc) and in the south at (157, -58, 33 kpc) and extending over tens of degrees are present in the halo of the Milky Way. Ivezic et al. have detected the northern structure from a sample of RR Lyrae stars in the SDSS. Using photometry to separate the stars by surface gravity, both structures are shown to contain a sequence of low surface gravity stars consistent with identification as a blue horizontal branch (BHB). Both structures also contain a population of high surface gravity stars 2 mag fainter than the BHB stars, consistent with their identification as blue stragglers (BSs). The majority of the high surface gravity stars in the Galactic halo may be BS stars like these. A population of F stars associated with the A star excess in the southern structure is detected (the F stars in the northern structure at 46 kpc would be too faint for the SDSS to detect). From the numbers of detected BHB stars, lower limits to the implied mass of the structures are 6×106 Msolar and 2×106 Msolar, although one does not yet know the full spatial extent of the structures. **The fact that two such large clumps have been detected in a survey of only 1% of the sky indicates that such structures are not uncommon in the halo**. Simple spheroidal parameters are fit to a complete sample of the remaining unclumped BHB stars and yield (at r<40 kpc) a fit to a halo distribution with flattening (c/a=0.65+/-0.2) and a density falloff exponent of α=-3.2+/-0.3. Based on observations obtained with the Sloan Digital Sky Survey and with the Apache Point Observatory 3.5 m telescope, which is owned and operated by the Astrophysical Research Consortium.

### Ibata et al. 2001:

Two studies have recently reported the discovery of pronounced halo substructure in the Sloan Digital Sky Survey (SDSS) commissioning data. Here we show that this halo substructure is, almost in its entirety, due to the expected tidal stream torn off the Sagittarius dwarf galaxy during the course of its many close encounters with the Milky Way. This interpretation makes strong predictions on the kinematics and distances of these stream stars. Comparison of the structure in old horizontal branch stars, detected by the SDSS team, with the carbon star structure discovered in our own survey, indicates that this halo stream is of comparable age to the Milky Way. **It would appear that the Milky Way and the Sagittarius dwarf galaxy have been a strongly interacting system for most of their existence**. Once complete, the SDSS will provide a unique data set with which to constrain the dynamical evolution of the Sagittarius dwarf galaxy; it will also strongly constrain the mass distribution of the outer Milky Way.

NOTE: they try to predict the signal in SDSS of the Sgr stream. Nice plots.

### **Martinez-Delgado et al. 2001:**

Standard cosmology predicts that dwarfs were the first galaxies to be formed in the universe and that many of them merge afterward to form bigger galaxies such as the Milky Way. This process would have left behind traces such as tidal debris or star streams in the outer halo. We report here the detection of a very low density stellar system at 50+/-10 kpc from the Galactic center that could be related to the merger process. It could form part of the Sagittarius northern stream or, alternatively, could be the trace of a hitherto unknown dwarf galaxy. The dwarf galaxy in Sagittarius, the closest satellite of the Milky Way, is currently being tidally disrupted and is a ``living'' test for galaxy formation theories. The system found here is 60° away from the center of the Sagittarius galaxy. If it is really associated with this galaxy, it would confirm predictions of dynamical interaction models indicating that tidal debris from Sagittarius could extend along a stream completely enveloping the Milky Way in a polar orbit.

**NOTE: first proper detection of the leading arm (ra~+220 , dec~0 deg).**

### Vivas et al. 2001:

We have measured the periods and light curves of 148 RR Lyrae variables from V=13.5 to 19.7 from the first 100 deg2 of the Quasar Equatorial Survey Team RR Lyrae survey. Approximately 55% of these stars belong to the clump of stars detected earlier by the Sloan Digital Sky Survey. According to our measurements, this feature has ~10 times the background density of halo stars, spans at least 37.5deg by 3.5deg in α and δ (>=30 by >=3 kpc), lies ~50 kpc from the Sun, and has a depth along the line of sight of ~5 kpc (1 σ). **These properties are consistent with the recent models that suggest that it is a tidal stream from the Sagittarius dwarf spheroidal galaxy**. The mean period of the type ab variables, 0.58 days, is also consistent. In addition, we have found two smaller overdensities in the halo, one of which may be related to the globular cluster Pal 5.

NOTE: similar region to Martinez-Delgado et al. 2001

### Dohm-Palmer et al. 2001:

As part of the Spaghetti Project Survey, we have detected a concentration of giant stars well above expectations for a smooth halo model. The position (l~350deg, b~50deg) and distance (~50 kpc) of this concentration match those of the northern overdensity detected by the Sloan Digital Sky Survey. **We find additional evidence for structure at ~80 kpc in the same direction**. We present radial velocities for many of these stars, including the first published results from the 6.5 m Magellan telescope. The radial velocities for stars in these structures are in excellent agreement with models of the dynamical evolution of the Sagittarius dwarf tidal debris, whose center is 60° away. **The metallicity of stars in these streams is lower than that of the main body of the Sgr dwarf, which may indicate a radial metallicity gradient prior to disruption.**

*“The SPS is a photometric and spectroscopic survey designed to identify structure in the Galactic halo (Morrison et al. 2000). For this study, we use the modified Washington photometric system (Canterna 1976; Geisler 1984) to identify candidate red giants.”*

*“We performed 10,000 Monte Carlo simulations of 21 stars drawn from the smooth halo, including observational errors. The fraction of simulations that give the observed distribution of four stars near 50 kpc with a velocity dispersion of 32 km s1 and of two stars near 80 kpc with a velocity dispersion 21 km s1 was 11 in 10,000.”*

*“We performed 10,000 Monte Carlo simulations of 21 stars drawn from the smooth halo, including observational errors. The fraction of simulations that give the observed distribution of four stars near 50 kpc with a velocity dispersion of 32 km s1 and of two stars near 80 kpc with a velocity dispersion 21 km s1 was 11 in 10,000.”*

**NOTE: They even detect the leading arm in the northern hemisphere!!**

### Cseresnjes 2001:

We carried out a period analysis on ~ 3700 RR Lyrae stars on two Schmidt fields centred on (l,b)=(3.1deg, -7.1deg) and (6.6deg, -10.8deg) respectively, covering an area of ~ 50 deg2. These stars are distributed almost evenly between the Sagittarius dwarf galaxy (Sgr) and the Milky Way. For Sgr members, the average periods are < Pab>=0.574d and < Pc>=0.322d for RRab and RRc stars respectively. This places Sgr in the long-period tail of the Oosterhoff I group. We report the detection of 53 double-mode RR Lyrae stars (RRd) within our sample. The magnitude of 40 of these stars is consistent with membership in Sgr whereas 13 RRds are located within our Galaxy. We also found 13 RR Lyraes (5 in Sgr and 8 in the Galaxy) exhibiting two closely spaced frequencies, most probably related to non-radial pulsations. The period distribution of the RR Lyrae variables in Sgr is compared to those of other Milky Way satellites. **We find a remarkable similarity between the RR Lyrae populations in Sgr and the Large Magellanic Cloud (LMC), suggesting that these galaxies have similar horizontal branch morphologies. This may indicate that Sgr and the LMC started their formation under similar conditions.** **Using various photometric indicators, we estimate the metallicity of the RR Lyrae stars in Sgr and find < [Fe/H]> =~ -1.6 dex with a dispersion of ~ +/-0.5 dex around this value and a minor but significant population at ≲-2.0 dex. We do not find evidence for a spatial metallicity gradient in the RR Lyrae population of Sgr**. From the spatial distribution of RR Lyraes, we find that the main body of Sgr contains ~ 4200 RRab stars. Assuming that population gradients are negligible in Sgr, we find MV(Sgr) =~ -13.9+0.4-0.6 mag for the main body. If Sgr has been stripped of 50% of its mass through Galactic tides, as assumed by some models, it would imply a total absolute magnitude of ~ -14.7 mag for this galaxy. **Such a luminosity would be consistent with the empirical metallicity/luminosity relation for dwarf spheroidal galaxies.**

*“[..] This implies that the number of RRab stars associated with Sgr could be as high as ∼8400.”*

### Cole 2001

We present the Two Micron All Sky Survey (2MASS) (J-K, K) color-magnitude diagram for the region within 1° of the center of the Sagittarius dwarf spheroidal galaxy. Using the slope of the red giant branch (RGB), **we determine a mean metallicity for the main stellar population of [Fe/H]=-0.5+/-0.2**. The Sagittarius RGB possesses a blue tail that overlaps with the foreground Milky Way giant branch and suggests that approximately one-third of the RGB is more metal-poor than [Fe/H] ~ -1. Direct comparison with the Large Magellanic Cloud confirms the metal-rich nature of the bulk of the Sagittarius population. Our result is marginally consistent with the even higher metallicities determined from high-resolution spectroscopy.

### Alard 2001:

Metallicity gradients in the Sagittarius dwarf Galaxy (Sgr) are investigated by using infrared photometric data from the 2MASS survey. To search for metallicity effects, the giant branch in a field situated near the Center of the Sgr is compared to the giant branch in a field situated near its southern edge. The contamination of the Sgr giant branch by foreground Galactic stars is canceled by statistical subtraction of diagrams symmetrical in Galactic latitude. After subtraction it is possible to reconstruct the Sgr giant branch with excellent accuracy. The giant branch in the two fields have similar slopes but are shifted in color. Even after correction for the differential reddening between the fields, the shift in color between the branch remains, and is very significant. **This variation in the color of the giant branch corresponds to a metallicity variation of about -0.25 dex. The existence of a metallicity gradient in Sgr may indicate that there are two different stellar population in Sgr. One has low metallicity, and another one of higher metallicity has a smaller spatial extension.**

NOTE: yet another confirmation of a metallicity gradient (which is not seen in RR Lyrae…) apart from Dohm-Palmer+01 and Bellazzinni+99

### Newberg et al. 2002:

We identify new structures in the halo of the Milky Way from positions, colors, and magnitudes of five million stars detected in the Sloan Digital Sky Survey. Most of these stars are within 1.26d of the celestial equator. We present color-magnitude diagrams (CMDs) for stars in two previously discovered, tidally disrupted structures. The CMDs and turnoff colors are consistent with those of the Sagittarius dwarf galaxy, as had been predicted. In one direction, we are even able to detect a clump of red stars, similar to that of the Sagittarius dwarf, from stars spread across 110 deg2 of sky. Focusing on stars with the colors of F turnoff objects, we identify at least five additional overdensities of stars. Four of these may be pieces of the same halo structure, which would cover a region of the sky at least 40° in diameter, at a distance of 11 kpc from the Sun (18 kpc from the center of the Galaxy). The turnoff is significantly bluer than that of thick-disk stars, yet the stars lie closer to the Galactic plane than a power-law spheroid predicts. We suggest two models to explain this new structure. One possibility is that this new structure could be a new dwarf satellite of the Milky Way, hidden in the Galactic plane and in the process of being tidally disrupted. The other possibility is that it could be part of a disklike distribution of stars which is metal-poor, with a scale height of approximately 2 kpc and a scale length of approximately 10 kpc. The fifth overdensity, which is 20 kpc away, is some distance from the Sagittarius dwarf streamer orbit and is not associated with any known Galactic structure. We have tentatively identified a sixth overdensity in the halo. If this sixth structure is instead part of a smooth distribution of halo stars (the spheroid), then the spheroid must be very flattened, with axial ratio q=0.5. It is likely that there are many smaller streams of stars in the Galactic halo.

“*Note, however, that the turnoff color of the stars in S297+63−20.0 do not support the idea that they originated in the Sagittarius dwarf galaxy. The turnoff color also does not rule out an identification with the Sagittarius stream; if they are associated it would imply that the stellar populations changed along a stream”*

*“A comparison of the number of stars detected in the clump of red stars of S341+57−22.5 and S344+58−22.5 (in the adjacent stripe 11) with the number of similar stars in the Sagittarius dwarf indicate that we see about 1.5% of the present stellar mass of the Sagittarius dwarf in this 110 square degree area of the sky. This result assumes a constant clump star to stellar mass ratio between the Sagittarius dwarf and the stream.”*

### Martinez-Delgado et al. 2002:

Photometry of a large field around the young globular cluster Palomar 12 has revealed the main sequence of a low surface brightness stellar system. This main sequence is indicative of a stellar population that varies significantly in metallicity and/or age but in the mean is more metal-poor than Pal 12. Under different assumptions for the properties of this population, we find distances from the Sun in the range 17-24 kpc, which encompasses the distance to Pal 12, 19.0+/-0.9 kpc. The stellar system is also detected in a field 2° north of Pal 12, which indicates it has a minimum diameter of ~0.9 kpc. **The orbit of Pal 12, the color-magnitude diagram of the stellar system, their positions on the sky, and their distances suggest that they are debris from the tidal disruption of the Sagittarius dwarf spheroidal galaxy**. We discuss briefly the implications for the evolution of Sgr and the Galactic halo.

**NOTE: similar age to Terzan 7, but more metal poor (although other sources put it at the same metallicity).**

### Bellazzini et al. 2002

We present the first (V,V-I) color-magnitude diagram (CMD) for the poorly studied globular cluster NGC 5634. The CMD shows a steep red giant branch (RGB) and a predominantly blue horizontal branch (HB): both these characteristics suggest a low metal content for this cluster. From the position of the RGB in the CMD we estimate [Fe/H]=-1.94+/-0.10 and E(B-V)=0.06+/-0.01. The CMD presented here reaches V~=23, allowing us to obtain the first measure of the main-sequence turnoff (TO) VTO=21.22+/-0.15 for this cluster. By combining this figure with the apparent luminosity of the zero-age HB (ZAHB), VZAHB=17.90+/-0.10 we obtain ΔVHBTO=3.32+/-0.16, a value which is fully compatible with that derived for the bulk of Galactic globulars. We also derive a true distance modulus of (m-M)0=17.17+/-0.12, corresponding to a distance of ~27.2 kpc. Most interestingly, the cluster is shown to have position and radial velocity fully compatible with the orbit of the Sagittarius dwarf spheroidal galaxy (dSph). **The similarity between the stellar populations of the cluster and the Sagittarius globular Ter 8 and the metal-poor population of the Sagittarius dSph also suggests that NGC 5634 was a former member of this disrupting galaxy, torn off by the Galactic tidal field and now lost in the Sagittarius stream.**

NOTE: first mention to NGC 5634 as being a GC of Sgr.

### Dinescu et al. 2002

We have detected a population of predominantly blue (B-V<=1.1) stars in the direction l=167deg, b=-35deg (Kapteyn Selected Area [SA] 71) that cannot be accounted for by standard star count models. Down to V ~ 20 mag, the colors and magnitudes of these stars are similar to those of the southern overdensity detected by the Sloan Digital Sky Survey (SDSS) at l=167deg, b=-54deg and identified as stripped material from the Sagittarius dwarf spheroidal (Sgr dSph) galaxy. **We present absolute proper motions of the stars in SA 71, and we find that the excess blue stars represent a distinct, kinematically cooler component than the Galactic field, in reasonable agreement with predictions of Sgr dSph disruption models.** The density of the excess SA 71 stars at V~18.8 mag and B-V<=1.1 is within a factor of 2 of the density of the SDSS-south Sgr dSph stripped material and of that predicted by the Helmi & White disruption model. Three additional anticenter fields (SA 29, 45, and 118) show very good agreement with standard star count models.

### Kundu et al. 2002:

We describe first results of a spectroscopic probe of selected fields from the Grid Giant Star Survey (GGSS). Multifiber spectroscopy of several hundred stars in a strip of 11 fields along δ~-17deg, in the range 12 hr<~α<~17 hr, reveals a group of eight giants that have kinematical characteristics differing from the main field population but that as a group maintain coherent, smoothly varying distances and radial velocities with position across the fields. Moreover, these stars have roughly the same abundance, according to their MgH+Mgb absorption line strengths. Photometric parallaxes place these stars in a semiloop structure, arcing in a contiguous distribution between 5.7 and 7.9 kpc from the Galactic center. The spatial, kinematical, and abundance coherence of these stars suggests that they are part of a diffuse stream of tidal debris, and one roughly consistent with a wrapped, leading tidal arm of the Sagittarius dwarf spheroidal galaxy.

“*The proposed stream is most consistent with the debris stripped from Sgr “two passages ago.”*

NOTES: The data (8 giants) does not match in any way current models (V21) whereas it seems more consistent with the tails of their sample (Their fig. 1). Their 8 stars are in all sorts of distances, from 1kpc to 10 kpc from the Sun. Too close.

### Monaco et al. 2002:

We present V, I photometry of the Sagittarius (Sgr) dwarf spheroidal galaxy for a region of ~1deg×1deg, centered on the globular cluster M54. This catalog is the largest database of stars **(~493,000)** ever obtained for this galaxy. The wide area covered allows us to measure for the first time the position of the red giant branch (RGB) bump, a feature that has been identified in most Galactic globular clusters and only recently in a few galaxies of the Local Group. The presence of a single-peaked bump in the RGB differential luminosity function confirms that there is a dominant population in Sgr (Pop A). The photometric properties of the Pop A RGB and **the position of the RGB bump have been used to constrain the range of possible ages and metallicities of this population. The most likely solution lies in the range -0.6<[M/H]<=-0.4 and 4 Gyr<=age<=8 Gyr.**

“*The RGB-bump magnitude is mainly driven by the metal content and, to a lesser extent, by the age of the population.”*

*“The physical origin of the RGB-bump is well known: in the stellar interior during the first ascent of the giant branch, the H-burning shell is moving constantly outwards until it reaches the discontinuity in the H radial profile, left by the innermost penetration of the convective envelope inside the star. At the discontinuity, the luminosity of the star drops for a while, until the shell adapts to the new environment, and then it rises again in a regime of constant H content. Observationally, the RGB-bump appears as a peak in the differential luminosity function (LF), due to the non-monotonic evolution of the star in luminosity. It appears also as a jump and a change in slope of the integrated LF, due to the change in the evolutionary rate, caused by the sudden change of molecular weight of the material in which the H-burning shell is moving. According to Fusi Pecci et al. (1990), the change in the slope of the integrated luminosity function is the safest way to identify the location of the bump, since it makes use of stars contained in several magnitude bins (see also Ferraro et al. 1999, F99 hereafter).”*

### Bellazzini et al. 2003:

We demonstrate that there is a clear statistical correlation between the (X,Y,Z,Vr) phase-space distribution of the outer halo Galactic globular clusters (having 10 kpc<=RGC<=40 kpc) and the orbital path of the Sagittarius dwarf spheroidal galaxy (Sgr dSph), as derived by Ibata & Lewis. At least four of the sample of 35 globular clusters in this distance range were formerly members of the Sagittarius galaxy (at the 95% confidence level) and are now distributed along the Sagittarius Stream, a giant tidal structure that surrounds the Milky Way. This is the first instance that a statistically significant structure associated with the Sgr dSph has been detected in the globular cluster population of the Galactic halo. Together with the four well-known globular clusters that are located near the center of this tidally disrupting dwarf galaxy, these clusters constitute >~20% of the population of outer halo (RGC>=10 kpc) clusters. **The Sgr dSph was therefore not only an important contributor to the halo field-star population, but it also had a significant role in building up the globular cluster system of the Milky Way.**

### Bonifacio et al. 2003:

We report our recent results on the abundance ratios in our nearest neighbour: the Sgr dwarf spheroidal. Based on high resolution spectra obtained with UVES at the the Kueyen-VLT 8.2m telescope we measured abundance ratios for 12 giants in Sgr. The dominant population in our sample is of almost solar metallicity and characterized by an underabundance of alpha -process elements with respect to iron. The lack of alpha -element enhancement persists also for the most metal poor star of the sample ([Fe/H]=-0.8), suggesting a star formation which has been slow or bursting. The spectroscopic metallicity allows to resolve the age-metallicity degeneracy and we derive from the colour-magnitude diagram of the galaxy a very young age, of the order of 1 Gyr, or younger. The high metallicity and young age seem to point to a scenario in which star bursts are triggered by the passing of Sgr through the Galactic disc.

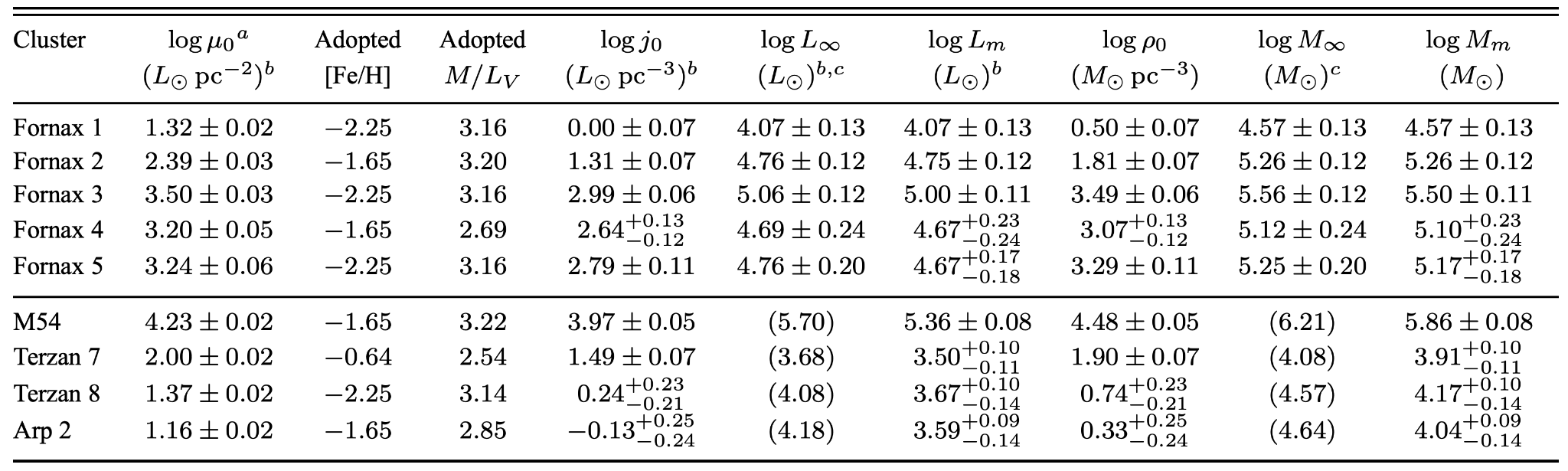
*“The sample of C Bulge stars of Azzopardi et al 1991 cannot belong to Sgr since their radial velocities do not support membership. They could however be stars formed in the starburst triggered in the Galactic disc, at the location where it was disturbed by the passage of Sgr (Ng 1997, 1998).”*

**NOTE: yet another mention to a population born <1Gyr ago (see also Layden and Sarajedini 2000). But see Hasselquist+21, where they say that the last star was born >~2Gyr ago.**

### Mackey & Gilmore 2003:

We present radial surface brightness profiles for all five globular clusters in the Fornax dwarf spheroidal galaxy, and for the four present members of the Sagittarius dwarf spheroidal galaxy. These profiles are derived from archival Hubble Space Telescope observations, and have been calculated using the same techniques with which we measured profiles in our previous studies of Large and Small Magellanic Cloud (LMC and SMC) clusters, apart from some small modifications. From the surface brightness profiles, we have determined structural parameters for each cluster, including core radii and luminosity and mass estimates. We also provide a brief summary of literature measurements of other parameters for these clusters, including their ages, metallicities and distances.

Our core radius measurements are mostly in good agreement with those from previous lower resolution studies, although for several clusters our new values are significantly different. The profile for Fornax cluster 5 does not appear to be well fitted by a King-type model and we suggest that it is a post-core-collapse candidate. We examine the distribution of cluster core radii in each of the two dwarf galaxy systems and compare these with the distribution of core radii for old LMC clusters. The three distributions match within the limits of measurement errors and the small-sample sizes. We discuss the implications of this in the context of the radius-age trend we have previously highlighted for the Magellanic Cloud clusters.

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### Bellazzini et al. 2003:

We use infrared Color Magnitude Diagrams from the 2-Micron All-Sky Survey (2MASS) to search for stars belonging to the tidal stream of the Sagittarius dwarf spheroidal galaxy (Sgr dSph) around selected Galactic globular clusters. Statistically significant detections are presented for the cases of **Pal 12 and NGC 4147, strongly supporting the idea that these clusters are associated with the Sgr** Stream and that they were previous members of the Sgr dSph galaxy.

### Newberg et al. 2003:

A new overdensity of A-colored stars in distant parts of the Milky Way's stellar halo, at a dereddened Sloan Digital Sky Survey magnitude of g0=20.3, is presented. Identification of associated variable RR Lyrae candidates supports the claim that these are blue horizontal branch stars. The inferred distance of these stars from the Galactic center is 90 kpc, assuming that the absolute magnitude of these stars is Mg0=0.7 and that the Sun is 8.5 kpc from the Galactic center. **The new tidal debris is within 10 kpc of the same plane as other confirmed tidal debris from the disruption of the Sagittarius dwarf galaxy and could be associated with the trailing tidal arm**. Distances to the Sagittarius stream estimated from M stars are about 13% smaller than our inferred distances. **The tidal debris has a width of at least 10° and is traced for more than 20° across the sky. The globular cluster NGC 2419 is located within the detected tidal debris and may also have once been associated with the Sagittarius dwarf galaxy.**

### Monaco et al. 2003:

We report on the discovery of a blue horizontal-branch (BHB) population belonging to the Sagittarius dwarf spheroidal galaxy. The sequence is clearly identified in the (V, V-I) color-magnitude diagram obtained for about 500,000 stars in the region of the globular cluster M54. The BHB morphology is similar to the analogous sequence in M54, but it is unambiguously associated with Sgr since (1) it is detected well outside the main body of the cluster, up to more than five tidal radii from the cluster center and (2) the BHB stars follow the radial distribution of the other stellar populations of Sgr. **This finding finally demonstrates that the Sgr galaxy hosts a significant (of the order of ~10%) old and metal-poor stellar population ([Fe/H]<~-1.3 age >~10 Gyr), similar to that of its oldest clusters (M54, Ter 8).** We also show that the Sgr BHB sequence found here is the counterpart of the analogous feature observed by Newberg et al. in the Sgr stream, in a field more than 80° away from the center of the galaxy.

### Majewski et al. 2003:

**We present the first all-sky view of the Sagittarius (Sgr) dwarf galaxy mapped by M-giant star tracers detected in the complete Two Micron All Sky Survey (2MASS).** Near-infrared photometry of Sgr's prominent M-giant population permits an unprecedentedly clear view of the center of Sgr. The main body is fitted with a King profile of limiting **major-axis radius 30°-substantially larger than previously found or assumed-beyond which is a prominent break in the density profile from stars in the Sgr tidal tails;** thus the Sgr radial profile resembles that of Galactic dwarf speroidal (dSph) satellites. Adopting traditional methods for analyzing dSph light profiles, we determine the brightness of the main body of Sgr to be MV=-13.27 (the brightest of the known Galactic dSph galaxies) and the total Sgr mass-to-light ratio to be 25 in solar units. However, we regard the latter result with suspicion and argue that much of the observed structure beyond the King-fit core radius (224') may be outside the actual Sgr tidal radius as the former dwarf spiral/irregular satellite undergoes catastrophic disruption during its last orbits. **The M-giant distribution of Sgr exhibits a central density cusp at the same location as, but not due to, the old stars constituting the globular cluster M54.** A striking trailing tidal tail is found to extend from the Sgr center and arc across the south Galactic hemisphere with approximately constant density and mean distance varying from ~20 to 40 kpc. A prominent leading debris arm extends from the Sgr center northward of the Galactic plane to an apogalacticon ~45 kpc from the Sun and then turns toward the north Galactic cap (NGC), from where it descends back toward the Galactic plane, becomes foreshortened, and, at brighter magnitudes, covers the NGC. The leading and trailing Sgr tails lie along a well-defined orbital plane about the Galactic center. The Sun lies within a kiloparsec of that plane and near the path of leading Sgr debris; thus, it is possible that former Sgr stars are near or in the solar neighborhood. We discuss the implications of this new view of the Sgr galaxy and its entrails for the character of the Sgr orbit, mass, mass-loss rate, and contribution of stars to the Milky Way halo. **The minimal precession displayed by the Sgr tidal debris along its inclined orbit supports the notion of a nearly spherical Galactic potential.** **The number of M giants in the Sgr tails is at least 15% that contained within the King limiting radius of the main Sgr body.** The fact that M giants, presumably formed within the past few gigayears in the Sgr nucleus, are nevertheless so widespread along the Sgr tidal arms not only places limits on the dynamical age of these arms but also poses a timing problem that bears on the recent binding energy of the Sgr core and that is most naturally explained by recent and catastrophic mass loss. Sgr appears to contribute more than 75% of the high-latitude, halo M giants, despite substantial reservoirs of M giants in the Magellanic Clouds. No evidence of extended M-giant tidal debris from the Magellanic Clouds is found. Generally good correspondence is found between the M-giant, all-sky map of the Sgr system and all previously published detections of potential Sgr debris, **with the exception of Sgr carbon stars, which must be subluminous compared with counterparts in other Galactic satellites in order to resolve the discrepancy.**

*”The relatively steady Sgr tidal tail density suggests a more or less constant mass-loss rate for the timescale represented by this portion of the tail.”*

*“Figure 13 shows the more significant of these apparent overdensities as a ‘‘ hump ’’ in the tidal tail distribution for 25 < Lambda < 50 [..] An apparent widening in the tail at these longitudes is also suggested by Figure 12 [..] If the ‘‘ hump ’’ in Figure 13 is related to a perigalacticon release event, then a symmetrically placed feature might be expected in the leading tail; unfortunately, this feature, if it exists, would lie close to the Galactic plane, where our data become more confused, although a larger density of stars at -50 < Lambda < -30 is not inconsistent with the data (see Fig. 12).”*

***“If, as is suggested by the Sgr disruption model of Ibata et al. (2001b), as well as the various pieces of evidence within the M-giant distribution discussed in Sect.6.4, the leading tidal arm penetrates back into the south Galactic hemisphere and crosses the trailing arm, we would expect an increased density of stars at about the longitudes where the excess density is observed. The presence of overlapping leading-arm debris could also lead to the observed widening of the apparent trailing arm at this point either through foreshortening or precessional displacement of the leading-arm material compared with the true trailing-arm stars. Radial velocities of stars in the hump should reveal a clear signal of this overlap. Early evidence from our M-giant radial velocity work suggest this may be the case (see also the discussion of overlapping Sgr tails in this part of the sky by Johnston et al. 1999b).”***

**NOTE: on the hump… V21 model predicts the crossing of the L1p2w material and the Trailing arm at the position where Majewski+03 observes this “hump”. Their second hypothesis seems more plausible.**

*“The apparently decreasing length of both leading and trailing M-giant tidal tails as we map them with progressively cooler giant star tracers (Fig. 14) suggests a mean stellar age/metallicity variation along the tidal tails.”*

“As discussed above, because M giants trace only recently formed tidal debris, they permit only estimates of a lower limit to the net stellar mass lost by Sgr and the fractional contribution of Sgr debris to the Milky Way halo. Moreover, in this discussion we have ignored the issue of whether a sizeable fraction of the stars within the Sgr King profile represent stars that have become unbound in the most recent perigalacticon passage along the lines of the scenario envisaged in x 4.3.3. Thus, the mass-loss limit estimated above pertains primarily to stars detached prior to the recent perigalacticon.”

**NOTE: Definition of the orbital plane of Sgr and the corresponding sky coordinates.**

### Tautvaišienė et al. 2003:

Chemical abundances in three giants in **Terzan 7**, a globular cluster associated with the Sagittarius dwarf galaxy, have been determined using high-resolution spectra obtained with the UVES spectrograph on the ESO 8.2 m Kueyen telescope. We find the overall metallicity of the stars to be **[Fe/H]=-0.61+/-0.07**, which is slightly higher than that previously evaluated from photometry and used for the age determination of this cluster. This metallicity yields an age of about **6 Gyr**, which is slightly lower than derived from previous estimates. The relative abundance ratios of various chemical elements to iron lie between those of its host galaxy's metal-poor and metal-rich stars and reveal an intriguing similarity to the pattern seen in the Large Magellanic Cloud.

### Martinez-Delgado et al. 2004:

The main aim of this paper is to report two new detections of tidal debris in the northern stream of the Sagittarius dwarf galaxy located at 45° and 55° from the center of the galaxy. Our observational approach is based on deep color-magnitude diagrams that provide accurate distances, surface brightness, and the properties of stellar population of the studied region of this tidal stream. The derived distances for these tidal debris wraps are 45+/-5 and 62+/-6 kpc, respectively. These detections are also strong observational evidence that the tidal stream discovered by the Sloan Digitized Sky Survey is tidally stripped material from the Sagittarius dwarf and support the idea that the tidal stream completely enwraps the Milky Way in an almost polar orbit. We also confirm these detections by running numerical simulations of the Sagittarius dwarf plus the Milky Way. This model reproduces the present position and velocity of the Sagittarius main body and presents a long tidal stream formed by tidal interaction with the Milky Way potential. The tidal streams of the model traces the last orbit of Sagittarius and confirms our observational detections. This model is also in good agreement with the available observations of the Sagittarius tidal stream. The comparison of our model with the positions and distances of two nonidentified halo overdensities discovered by the Sloan Digitized Sky Survey and the QUEST survey shows that they are actually associated with the trailing arm of the Sagittarius tidal stream. In addition, we identify the proper-motion group discovered by Arnold & Gilmore as a piece of the Sagittarius northern stream. We also present a method for estimating the shape of the Milky Way halo potential using numerical simulations. **From our simulations we obtain an oblateness of the Milky Way dark halo potential of 0.85**, using the current database of distances and radial velocities of the Sagittarius tidal stream. **The color-magnitude diagram of the apocenter of Sagittarius shows that this region of the stream shares the complex star formation history observed in the main body of the galaxy. We present the first evidence for a gradient in the stellar population along the stream, possibly correlated with its different pericenter passages.**

*“There is evidence of the presence of stellar populations of different ages in the Sgr tidal stream too. The detection of a significant RR Lyrae population associated with the northern stream (Ivezic´ et al. 2000; Vivas et al. 2001) is a strong indication of the presence of an old, metal-poor population. The identification of bright carbon stars (Ibata et al. 2001b) and a*

*bright M-giant population (Majewski et al. 2003) along the Sgr stream points to the presence of a metal-rich intermediate age population along the stream too. This is consistent with the CMD morphology of the SDSS stream by Newberg et al. (2002), which shows a conspicuous red clump of helium burning stars.”*

NOTES: they don’t really measure any population gradient. Instead, they justify the two [Fe/H] metallicities, ~-1.5dex, in the leading (Dohm-Palmer et al. (2001)) and trailing (Martı´nez-Delgado et al. (2002b)) arm with the fact that their model predicts material striped ~3Gyr ago at those positions. However, even if there was no new star formation before starting the stripping process, there would still be a metallicity gradient due to the fact that the more metal rich stars would have much higher bonding energies.

**NOTES: their model does not resemble the modern models in that their distribution around the MW is not consistent (in V21, the leading arm wraps faster and the trailing has a long tail reaching Rgc~100kpc). Also, they have stars stripped more than 5Gyr ago.**

### Bonifacio et al. 2004:

We report on abundances of O, Mg, Si, Ca and Fe for 10 giants in the Sgr dwarf spheroidal derived from high resolution spectra obtained with UVES at the 8.2 m Kueyen-VLT telescope. The iron abundance spans the range -0.8 ⪉ [Fe/H] ⪉ 0.0 and the dominant population is relatively metal-rich with [Fe/H]∼ -0.25. The α/Fe ratios are slightly subsolar, even at the lowest observed metallicities suggesting a slow or bursting star formation rate. From our sample of 12 giants (including the two observed by \citealt{B00}) we conclude that a substantial metal rich population exists in Sgr, which dominates the sample. The spectroscopic metallicities allow one to break the age-metallicity degeneracy in the interpretation of the colour-magnitude diagram (CMD). **Comparison of isochrones of appropriate metallicity with the observed CMD suggests an age of 1 Gyr or younger**, for the dominant Sgr population sampled by us. We argue that the observations support a **star formation that is triggered by the passage of Sgr through the Galactic disc, both in Sgr and in the disc.** This scenario has also the virtue of explaining the mysterious ``bulge C stars'' as disc stars formed in this event. The interaction of Sgr with the Milky Way is likely to have played a major role in its evolution.

### Cohen 2004:

We present a detailed abundance analysis for 21 elements based on high-dispersion, high spectral resolution Keck spectra for four members of the outer halo ``young'' Galactic globular cluster Palomar 12. All four stars show identical abundance distributions with no credible indication of any star-to-star scatter. However, the abundance ratios of the Pal 12 stars are very peculiar. There is no detected enhancement of the α-elements the mean of [Si/Fe], [Ca/Fe], and [Ti/Fe] is -0.07+/-0.05 dex, O/Fe is also solar, while Na is very deficient. The distribution among the heavy elements shows anomalies as well. These are inconsistent with those of almost all Galactic globular clusters or of field stars in the Galaxy. The peculiarities shown by the Pal 12 stars are, however, in good general agreement with the trends established by Smecker-Hane & McWilliam and by Bonifacio et al. for stars in the Sagittarius dwarf spheroidal (dSph) galaxy evaluated at the [Fe/H] of Pal 12. **This reinforces earlier suggestions that Pal 12 originally was a cluster in the Sgr dSph galaxy that during the process of accretion of this galaxy by our own was tidally stripped from the Sgr galaxy to become part of the extended Sgr stream.**

### Putman et al. 2004:

A possible gaseous component to the stream of debris from the Sagittarius dwarf galaxy is presented. We identify (4-10)×106 Msolar of neutral hydrogen along the orbit of the Sgr dwarf in the direction of the Galactic anticenter (at 36 kpc, the distance to the stellar debris in this region). This is 1%-2% of the estimated total mass of the Sgr dwarf. Both the stellar and gaseous components have negative velocities, but the gaseous component extends to higher negative velocities. **If associated, this gaseous stream was most likely stripped from the main body of the dwarf 0.2-0.3 Gyr ago during its current orbit after a passage through a diffuse edge of the Galactic disk** with a density greater than 10-4 cm-3. **This gas represents the dwarf's last source of star formation fuel and explains how the galaxy was forming stars 0.5-2 Gyr ago.**

NOTE: the location (last bit of the trailing arm in the south (galactic) before going behind the disc) and radial velocity of the HI gas seems consistent with the stellar stream.

### Majewski et al. 2004:

We have obtained moderate resolution (~6 km s-1) spectroscopy of several hundred M giant candidates selected from Two Micron All Sky Survey photometry. Radial velocities are presented for stars mainly in the southern Galactic hemisphere, and the primary targets have Galactic positions consistent with association to the tidal tail system of the Sagittarius (Sgr) dwarf galaxy. M giant stars selected from the apparent trailing debris arm of Sgr have velocities showing a clear trend with orbital longitude, as expected from models of the orbit and destruction of Sgr. **A minimum 8 kpc width of the trailing stream about the Sgr orbital midplane is implied by verified radial velocity members. The coldness of this stream (σv~10 km s-1) provides upper limits on the combined contributions of stream heating by a lumpy Galactic halo and the intrinsic dispersion of released stars, which is a function of the Sgr core mass.** We find that the Sgr trailing arm is consistent with a Galactic halo that contains one dominant, LMC-like lump; however, some lumpier halos are not ruled out. An upper limit to the total mass-to-light ratio of the Sgr core is 21 in solar units. **Evidence for other velocity structures is found among the more distant (>13 kpc) M giants. A second structure that roughly mimics expectations for wrapped, leading Sgr arm debris crosses the trailing arm in the southern hemisphere**; however, this may also be an unrelated tidal feature. Among the bright, nearby (<13 kpc) M giants toward the south Galactic pole are a number with large velocities that identify them as halo stars; these too may trace halo substructure, perhaps part of the Sgr leading arm near the Sun. The positions and velocities of southern hemisphere M giants are compared with those of southern hemisphere globular clusters potentially stripped from the Sgr system. **Support for association of the globular clusters Pal 2 and Pal 12 with Sgr debris is found, based on positional and radial velocity matches.** Our discussion includes description of a masked-filtered cross-correlation methodology that achieves better than 1/20 of a resolution element velocities in moderate-resolution spectra. The improved velocity resolution achieved allows tighter constraints to be placed on the coldness of the Sgr stream than previously established.

### Monaco et al. 2004:

We derived the distance to the central region of the Sagittarius (Sgr) dwarf spheroidal galaxy from the red giant branch tip. The obtained distance modulus is (m-M)0= 17.10 +/- 0.15, corresponding to a **heliocentric distance D= 26.30 +/- 1.8Kpc**. This estimate is in good agreement with the distance obtained from RR Lyrae (RR Ly) stars of the globular cluster M 54, located in the core of the Sgr galaxy, once the most accurate estimate of the cluster metallicity and the most recent calibration of the MV(RRLy) versus [Fe/H] relation are adopted.

### Vivas et al. 2005

Sixteen RR Lyrae variables from the QUEST survey that lie in the leading arm of the tidal stream from the Sagittarius dSph galaxy have been observed spectroscopically to measure their radial velocities and metal abundances. The systemic velocities of 14 stars, which were determined by fitting a standard velocity curve to the individual measurements, have a sharply peaked distribution with a **mean of 33 km s-1 and a standard deviation of only 25 km s-1. The [Fe/H] distribution of these stars has a mean of -1.76 and a standard deviation of 0.22**. These measurements are in good agreement with previous ones from smaller samples of stars. The mean metallicity is consistent with the age-metallicity relation that is observed in the main body of the Sgr dSph galaxy. The radial velocities and the distances from the Sun of these stars are compared with recent numerical simulations of the Sgr streams that assume different shapes for the dark matter halo. Models that assume a oblate halo do not fit the data as well as ones that assume a spherical or a prolate distribution. **However, none of the fits are completely satisfactory. Every model fails to reproduce the long extent of the stream in right ascension (36°, tip of the trailing arm close to the disc) that is seen in the region covered by the QUEST survey.** Further modeling is required to see if this and the other mismatches between theory and observation can be removed by judicial choices for the model parameters or instead rule out a class of models.

### Dinescu et al. 2005:

We have determined the absolute proper motion of the Sagittarius dwarf spheroidal galaxy (Sgr) from the Southern Proper Motion Catalog 3, by selecting red giant candidates from the Two Micron All Sky Survey. We obtain **μlcosb=-2.35+/-0.20 and μb=2.07+/-0.20 mas yr-1**. Using the same procedure, we also determine the absolute proper motion of the bulge in the region of the sky that overlaps with Sgr. For the bulge, we obtain μlcosb=-5.86+/-0.14 and μb=-0.59+/-0.14 mas yr-1, at l=7.6d and b=-21.2d. The absolute proper motions are on the International Celestial Reference System via Hipparcos Catalog stars.

### Monaco et al. 2005:

We present an analysis of the density profile in the central region of the Sagittarius dwarf spheroidal galaxy. A strong density enhancement of Sgr stars is observed. The position of the peak of the detected cusp is indistinguishable from the centre of M54. The photometric properties of the cusp are fully compatible with those observed in the nuclei of dwarf elliptical galaxies, indicating that the **Sgr dSph would appear as a nucleated galaxy independently of the presence of M54 at its centre.**

### Monaco et al. 2005:

We present iron and α element (Mg, Ca, Ti) abundances for a sample of 15 Red Giant Branch stars belonging to the main body of the Sagittarius dwarf Spheroidal galaxy. Abundances have been obtained from spectra collected using the high resolution spectrograph FLAMES-UVES mounted at the VLT**. Stars of our sample have a mean metallicity of [ Fe/H]=-0.41±0.20 with a metal-poor tail extending to [ Fe/H]=-1.52. The α element abundance ratios are slightly subsolar for metallicities higher than [Fe/H]⪆-1, suggesting a slow star formation rate.** The [ α/Fe] of stars having [Fe/H]<-1 are compatible to what observed in Milky Way stars of comparable metallicity.

### Bellazzini et al. 2006:

We present a statistically decontaminated Color Magnitude Diagram of a 1°× 1° field in the core of the Sagittarius dSph galaxy. Coupling this CMD with the most recent metallicity distributions obtained from high resolution spectroscopy we derive robust constraints on the mean age of the stellar population that dominates the galaxy (Pop A). Using three different sets of theoretical isochrones in the metallicity range -0.4≤ [M/H]≤ -0.7 and taking into consideration distance moduli in the range 16.90≤ (m-M)\_0≤ 17.20 **we find that the mean age of Pop A is larger than 5 Gyr, and the best-fit value is age = 8.0± 1.5 Gyr. Since Pop A provides the vast majority of the M giants that traces the tidal stream of Sgr dSph all over the sky, our estimate resolves the so called "M giant conundrum" (Majewski et al. 2003, ApJ, 599, 1082).** The time needed by the M giants that currently populates the stream to diffuse within the main body of Sgr and to reach the extremes of the tidal tails once torn apart from the parent galaxy (≃3{-}4 Gyr) can be easily accommodated into the time lapsed since their birth (≃5.5{-}9.5 Gyr).

### Kunder&Chaboyer09:

### Peñarrubia+11:

dSph is most likely pressure supported (no net rotation) as seen by line of sight velocities.

### Hasselquist et al. 2021:

APOGEE chemical analysis of several dwarfs in the MW.

Sgr: “*To select Sgr members, we take a similar approach to that of Hayes et al. (2020). We first only consider stars with [Fe/H] < 0.0, heliocentric distance greater than 10 kpc, and within ±30◦ of the plane of the Sgr stream (Majewski et al. 2003). Then, we make an initial selection in Vzs - Lzs plane, where Vzs and Lzs are the vertical velocity and angular momenta in the Sagittarius Galactocentric coordinate system, as derived and described in Majewski et al. (2003). We then make further selections in the φvel,s-Λs plane, where φvel,s is the velocity direction in the X and Y directions of the Sgr coordinate system and Λs is the longitude along the Sgr stream (Majewski et al. 2003; Hayes et al. 2020), to remove stars that are moving perpendicular to the stream. [..] we are primarily analyzing the abundance patterns of luminous giants (log(g) < 1.5).”*

*“Compared to the other dwarf galaxies (Figure 7), only Sgr extends to as high metallicities as the LMC. However, the metal-poor LMC stars have lower [α/Fe] (by ∼ 0.05- 0.1 dex) than the Sgr stars until [Fe/H] = -1.0, at which point the LMC increases its [α/Fe] abundance, whereas*

*the [α/Fe]-[Fe/H] abundance track of Sgr continues to decrease before becoming mostly flat. [..] As shown in Figure 7, only Sgr appears to show a similar increase in [(C+N)/Fe] as the LMC at [Fe/H] > -0.7, although this increase is not as steep as the increase in the LMC. [..] The [Ni/Mg] of the metal-rich LMC is slightly deficient as compared to the metal-rich Sgr stars, with the LMC stars lying in between the two MW sequences, and Sgr lying closer to the MW low-α sequence. [..] Such a change in slope is less evident in the [Ce/Mg]-[Mg/H] abundance patterns of Sgr, which has a flat [Mg/Fe] trend at high metallicity. ”*

*“[O/Mg] and [Si/Mg] for the LMC, and other dwarf galaxies, slowly decrease (by about 0.1 dex) over the range -1.3 < [Mg/H] < -0.5, with both the LMC and Sgr joining the MW trends at [Mg/H] > -0.5. This is either a result of metallicity-dependent Type II SNe yields for these elements (e.g., more Si and O relative to the MW at low metallicity), or a result of a slowly increasing Type II/Type Ia SNe fraction, as star formation was extended after the initial SF epoch. The [Fe/Mg] suggests the latter scenario is plausible, at least from -0.8 < [Mg/H] < -0.4, over which the [Fe/Mg] ratio slowly decreases as more Type II SNe contribute. The slightly enhanced [Ca/Mg] for the LMC and Sgr at these metallicities as compared to the MW stars is a result of Type Ia contribution to Ca, which is still substantial even with the starburst injecting many more Type II SNe products than at lower metallicities. These results suggest that Ca has a higher contribution from Type Ia SNe than Si (also see e.g., Tsujimoto et al. 1995; Hayes et al. 2018).”*

***“The chemistry of the Sgr dwarf has been studied by numerous authors (e.g., Chou et al. 2007; Sbordone et al. 2007; McWilliam et al. 2013; Hasselquist et al. 2017; Carlin et al. 2018; Hansen et al. 2018), with Hayes et al. (2020) analyzing the largest sample of core and stream stars using APOGEE DR16. In general, these analyses all find the [X/Fe] abundances of the more metal-rich stars in the Sgr core to be below the MW abundance trends. Interpretations of such sub-solar abundance ratios range from high Type Ia/Type II SNe ratio to toplight IMF. Here we analyze a sample of stars that is essentially an expanded sample of Hayes et al. (2020). While a detailed analysis of the spatial dependence of the chemical abundance patterns of Sgr is beyond the***

***scope of this work, we find that the Sgr stream sample is ∼ 0.5 dex more metal-poor than the main body sample (see e.g., Hayes et al. 2020). However, we verify that stars***

***with similar metallicities between the two samples have near-identical chemical abundance patterns (see §A.3 for more details). The α-elements in Sgr smoothly decline from -2.5 < [Fe/H] < -0.9, going from the MW “halo” high-α plateau at the metal-poor end to below the MW low-α “thin” disk trend at [Fe/H] = -0.9. Sgr begins this decline at a slightly higher metallicity than the MCs, but a lower metallicity than GSE. At [Fe/H] > -0.9, the [O/Fe], [Si/Fe] and [Ca/Fe] abundances are nearly flat at solar***

***or slightly sub-solar values, but the [Mg/Fe] abundance shows a slight increase followed by a decrease, as also observed in the SMC. The [α/Fe] abundance of Sgr at***

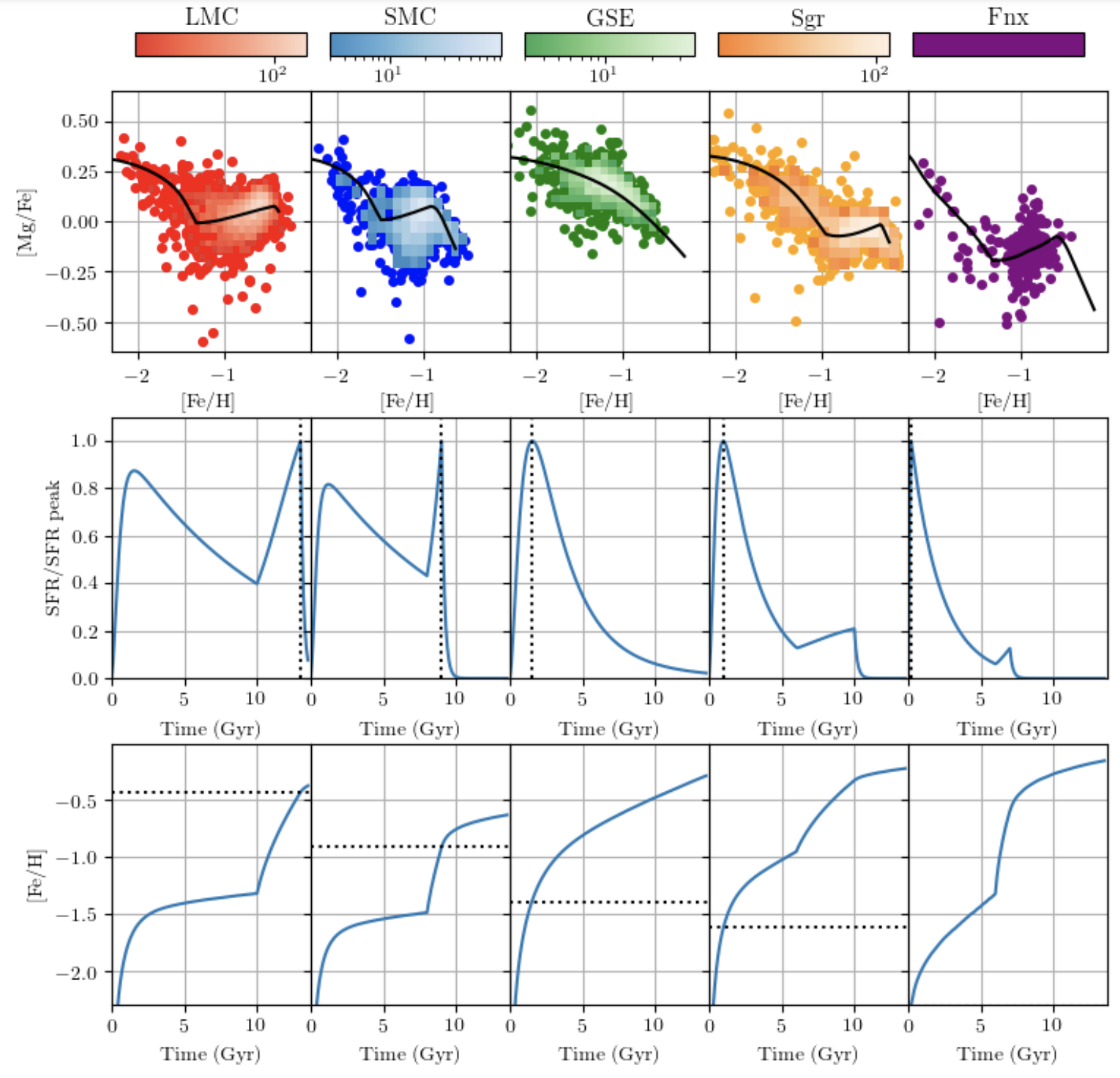
***[Fe/H] > -0.9 remains ∼ 0.1 dex below the LMC trend and MW low-α sequence. While Sgr extends to slightly higher values of [Fe/H] than the LMC, both galaxies enriched to nearly the same level of [Mg/H], with the Sgr abundance trend being deficient in [Fe/Mg] as compared to the MCs at [Fe/H] > -1.0, but enhanced at [Fe/H] > -1.0. The Sgr stars with [Mg/H] > -0.5 are very slightly enhanced in [Ca/Mg] as compared to the LMC, but otherwise the [Ca/Mg], [O/Mg], and [Si/Mg] patterns are nearly identical to those of the LMC.”***

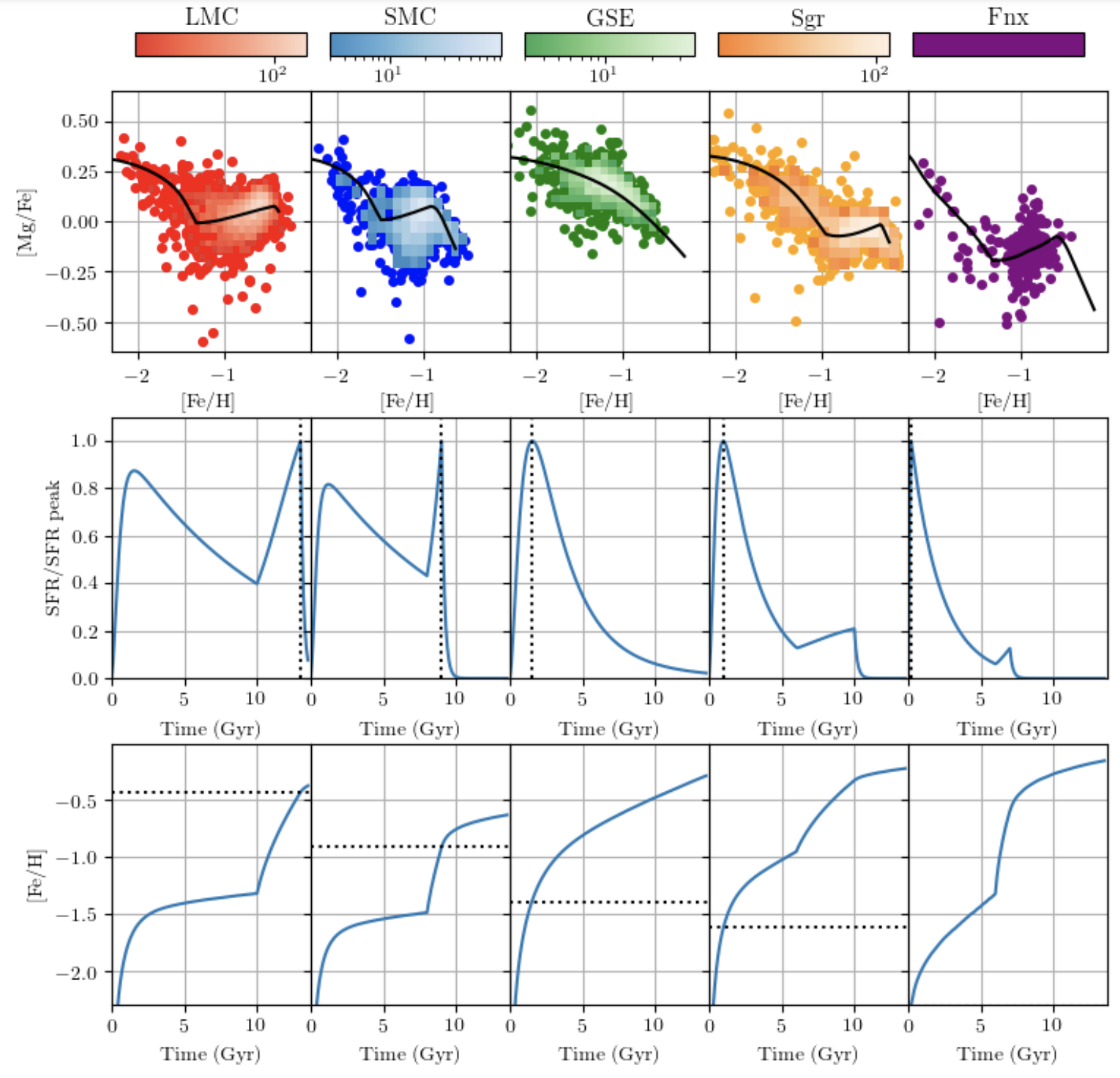
***“The α-element abundance patterns show that early on in its evolution, Sgr experienced relatively weak star formation as compared to the MW and GSE, but stronger than the MCs and Fnx. Sgr then evolved to a much higher Type Ia/Type II SNe ratio than the other dwarf galaxies, with a [Fe/Mg] ratio that is enhanced over the MCs and MW low-α sequence at [Mg/H] > -1.0. Despite this clear difference in early star formation efficiency, Sgr and LMC enrich to nearly the same levels of [Fe/H], with Sgr extending to metallicities that are ∼ 0.2 dex higher than the LMC. The increased early SFE and enhanced enrichment is unexpected in the paradigm of the mass-metallicity relationship (Kirby et al. 2011), as the Sgr dwarf was thought to be much less massive***

***than the LMC. However, the two galaxies do enrich to the same level of [Mg/H], implying the tension is somewhat reduced if [Mg/H] is used to track metallicity instead of [Fe/H]. To more accurately analyze where these two galaxies lie on the mass-metallicity relationship, we would need to better account for selection biases, which is beyond the scope of this work. Both the final metallicity and the early SFE seem to show Sgr behaving as though it were a fairly massive dwarf galaxy. The flat, or near-flat, in the case of Mg, [α/Fe]-[Fe/H] abundance patterns at [Fe/H] > -0.9 imply that Sgr did experience some extended SF, with an increase in Mg from Type II SNe preventing the [Fe/Mg] abundance from rising further. This extended star formation event could have been started as Sgr began falling into the MW. As shown in Hayes et al. (2020), the Sgr stream does not contain stars with [Fe/H] & -0.50, but the Sgr [α/Fe] abundance becomes flat with increasing [Fe/H] at [Fe/H] ∼ -0.9. So the extended star formation occurred before some stars were stripped as well as after, plausibly corresponding with pericenter passages through the disk of the MW (see also Ruiz-Lara et al. 2020a).”***

***“As described in §5.3, the relatively flat α-element abundance patterns at [Fe/H] > -0.8 suggest some kind of extended SFH. Both models find that a second star formation epoch, beginning some 5-6 Gyr into its evolution and rising above the declining trend from earlier times, is required in Sgr to produce the flatter or “hooked” abundance α-element abundance pattern. Without such a secondary peak, the chemical evolution tracks show monotonically decreasing [Si/Fe] or [Mg/Fe] with increasing [Fe/H], rather than the slight flattening of the observations. In the flexCE model, the sharp minimum of star formation at 5 Gyr produces the kink in the [Si/Fe]-[Fe/H] abundance track, slightly improving the fit to the data. In both models, this second SF epoch is not as***

***strong relative to the earlier epoch, in contrast to the MCs, and as such, the [α/Fe] ratio is not enhanced like it is in the MCs. The early chemical enrichment of Sgr was in between GSE and the MCs in both models (e.g., intermediate SFE), with Sgr enriching to [Fe/H] = -0.7 and -1.0 5 Gyr into its evolution for the flexCE model and the Lian model, respectively. After this point, the flexCE model favor a shorter, stronger burst, compared to a more sustained, weaker burst for the Lian model. In both models, Sgr effectively stops forming stars 10 Gyr into its evolution, which is consistent with observations of Sgr that show few or no young (age < 2-3 Gyr) stars (e.g., Siegel et al. 2007), as well as the [C/N] inferences shown in §4.6.”***





“The Sgr comparison is shown in the bottom-right panel of Figure 12. Neither model matches well with the Weisz et al. (2014) SFH of Sgr, though they agree well with each other. This could be due to the fact that our Sgr sample contains many stream stars, whereas Weisz et al. (2014) was looking at the main body of the galaxy, where the tidal interactions have preferentially removed many metal-poor stars, including into the streams. However, all of the star formation histories agree that Sgr formed nearly all of its stars by 3-4 Gyr ago. This is mostly in line with other photometric SFH studies, such as Siegel et al. (2007), although we do not find the metal-rich youngest populations that they find in the core. de Boer et al. (2015) find that the Sgr stream stars exhibit a tight age-metallicity relation, enriching to [Fe/H] = -0.7 by 5-7 Gyr ago, again consistent with both model results (see the bottom row of Figures 9 and 10). Our SFH here also qualitatively agrees with recent work by Garro et al. (2021), who analyzed the ages and metallicities of the globular cluster population of Sgr, including 12 new clusters discovered by Minniti et al. (2021). They find that Sgr formed its metal-rich (-0.9 < [Fe/H] < -0.3) globular clusters some 6-8 Gyr ago.”

# Models

## References

* [Helmi 2004](https://ui.adsabs.harvard.edu/link_gateway/2004ApJ...610L..97H/doi:10.1086/423340)
* [Law et al. 2005](https://ui.adsabs.harvard.edu/link_gateway/2005ApJ...619..807L/doi:10.1086/426779)
* [Law&Majewski 2010](https://ui.adsabs.harvard.edu/link_gateway/2010ApJ...714..229L/doi:10.1088/0004-637X/714/1/229)
* [Peñarrubia et al. 2011](https://arxiv.org/pdf/1011.6206.pdf)
* [Hernitschek et al. 2017](https://iopscience.iop.org/article/10.3847/1538-4357/aa960c/pdf)
* [Dierickx&Loeb 2017](https://iopscience.iop.org/article/10.3847/1538-4357/836/1/92/pdf)
* [Fardal et al. 2019](https://ui.adsabs.harvard.edu/link_gateway/2019MNRAS.483.4724F/doi:10.1093/mnras/sty3428)

## Notes

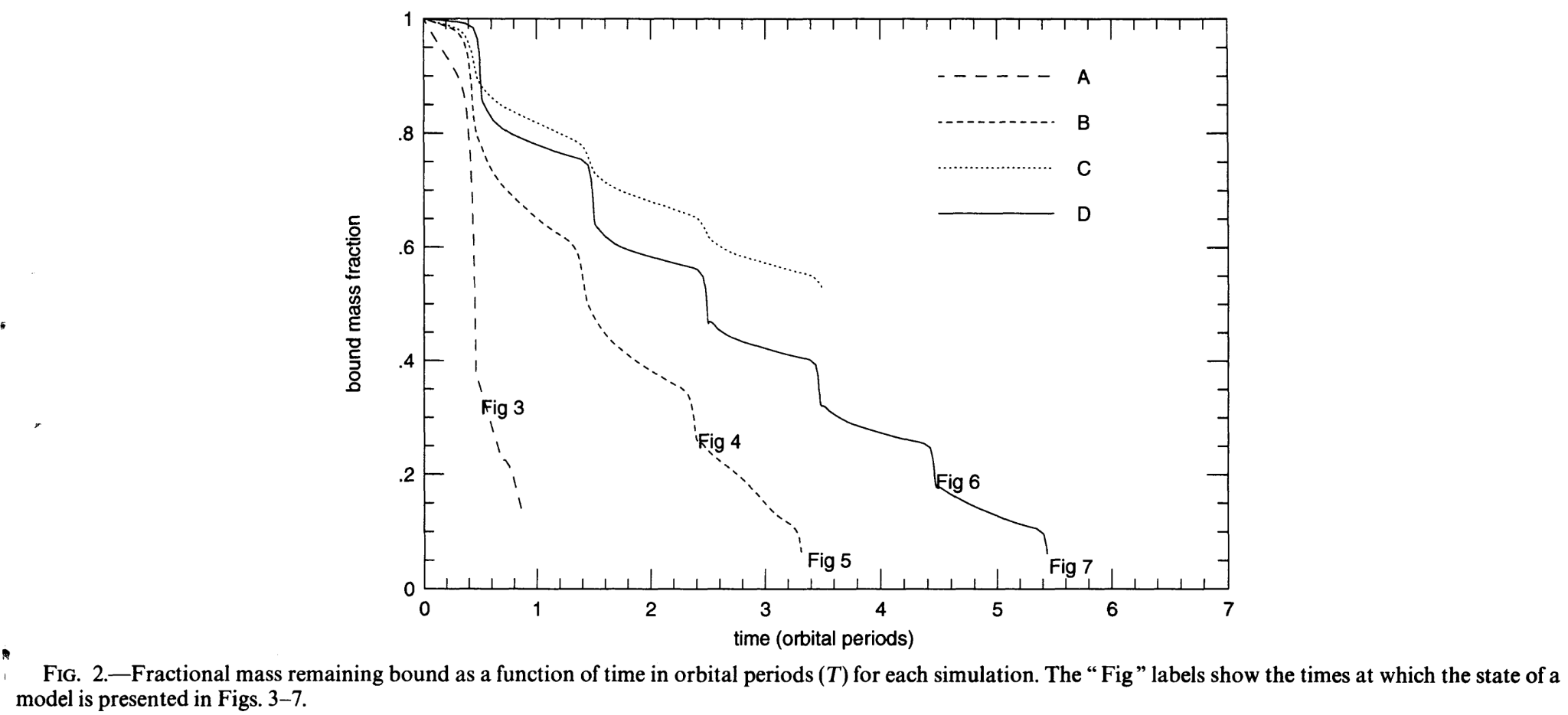
### Velázquex and White 1995

*“We use numerical simulations to test the feasibility of the suggestion by Ibata, Gilmore & Irwin that the excess population of stars which they discovered in the Sagittarius region may be the disrupted remains of a dwarf spheroidal galaxy. We find that a Fornax-like model for the pre-disruption system can indeed reproduce the data. However, the galaxy must be on a relatively short-period orbit with a pericentre of about 10 kpc and an apocentre of about 52 kpc, giving a current transverse velocity of 255 km/s and a period of ~ 760 Myr. Furthermore, disruption must have occurred predominantly on the last pericentric passage rather than on the present one. The data are consistent with transverse motion either towards or away from the Galactic plane. These results depend primarily on the rotation curve of the Galaxy and are insensitive to the mass distribution in its outer halo or to the mass of its disc.”*

*“ (iv) this orbit has a period of about 760 Myr so that Sagittarius completed more than 10 orbits before it was finally disrupted;”*

### Johnston, Kathryn V.; Spergel, David N.; Hernquist, Lars 1995

“*There are no striking differences between Figures 3-7, and each contour map (panel a) and velocity dispersion profile (panel b) compares well with the results reported in Ibata+94. Hence we cannot constrain the initial mass of the dwarf or its orbit [..].”*



### Edelsohn, D. J.; Elmegreen, B. G. 1997:

The interaction between the dwarf galaxy in Sagittarius and the Milky Way Galaxy has been modelled with a parallel computer implementation of an N-body treecode. Models are made that reproduce the observed position, size, velocity, proper motion and velocity gradient of the dwarf in its likely pre-disc encounter, and other models are studied in which the dwarf has just passed through the disc. Several observable differences between these cases are found. In the pre-collision case, the dwarf is bound to the Milky Way and it passed through the disc previously 1.7 x 108 yr ago in the anticentre direction. It will cross through the disc again in 3.5 x 107 yr. **Each disc crossing spins up the dwarf core and tidally stretches its outer envelope, leaving the core slightly less bound.** If such disc crossings are common for dwarfs near large galaxies, then the likely removal of gas from the dwarf at each crossing, combined with the observed high dark matter fraction for most dwarfs, implies that dark matter is not in the form of undetected cold gas. In the preferred model, the outer envelope of the dwarf includes the positions and velocities of the globular clusters NGC 6715, Terzan 7, Terzan 8 and Arp 2, which implies that these clusters could be fragments of a previously larger system. They could also be old detached star formation cores that formed in the Sagittarius dwarf during previous disc crossings.

NOTE: in this paper, they just drop a bound system into the MW. No time to create a stream or anything. Very simplistic set-up.

### 

### Ibata+97:

“*Apparently the Sagittarius dwarf spheroidal, and by implication other dSph galaxies, do not have a centrally-concentrated profile for their dark matter. We develop a model in which the stars of the Sgr dwarf are embedded in a constant-density dark matter halo, representing the core of a tidally-limited system, and show that this is consistent with its survival.*”

“*Three-Dimensional Shape. The red clump stars provide the most robust estimate of the line-of-sight depth, and from above the half-brightness depth is 1.2 kpc. This is remarkably similar to the minor axis parameters derived from the isopleth maps of Sec. 2.7, where the half-brightness minor axis diameter, for a distance of 25 kpc, is 2X550 pc. The three-dimensional shape of the Sgr dwarf is thus a prolate spheroid with axis ratios 3:1:1 and a long axis approximately in the plane of the sky and at constant longitude.*”

**We get a depth of 1.65 kpc (dispersion at a distance of ~27kpc), a height of 1.65º -> (disp in B at dist of 27kpc) ~2x0.4 kpc = 0.8kpc and a length of ~5º -> (disp of L at d=27kpc) ~2x1.2 = 2.4 kpc. Thus the ratio we get is ~3:2:1 (very rough numbers).**

### Ibata & Lewis1998:

Are dwarf spheroidal galaxies dark matter dominated? We present N-body simulations of the interaction between the Milky Way and its closest companion, the Sagittarius dwarf spheroidal galaxy, constrained by new kinematic, distance and surface density observations detailed in a companion paper. It is shown that there is no possible self-consistent solution to the present existence of the Sagittarius dwarf if its distribution of luminous matter traces the underlying distribution of mass. The luminous component of the dwarf galaxy must therefore be shielded within a small dark matter halo. Though at present we are unable to construct a fully self-consistent model that includes both the stellar and dark matter components, it is shown numerically that it is possible that a pure dark matter model, approximating the dark matter halo deduced for the Sagittarius dwarf from analytical arguments, may indeed survive the Galactic tides.

The orbit of the Sagittarius dwarf around the Milky Way is considered, taking into account the perturbative effects of the Magellanic Clouds. It is shown that at the present time, the orbital period must be short, ∼ 0.7 Gyr; the initial orbital period for a 109 M⊙ model will have been ∼ 1 Gyr. It is found that a close encounter with the Magellanic Clouds may have occured, though the chances of such an interaction affecting the orbit of the Sagittarius dwarf is negligible.

*“The effect of dynamical friction on the galaxy models we consider is significant, but not overwhelming. [..] The mean Galactocentric distance (averaged over an orbit) of the Sagittarius dwarf is >∼ 25 kpc, while the most massive models considered below have M∼10^9 M⊙; with these assumptions Tfric > 10 Gyr, so that such a model could have reduced its initial mean orbital radius by at most a factor of 2. Since Tfric is prop. to M^−1, models with M ∼ 10^8 M⊙ will hardly be affected at all.”*

“The present concentration of the stellar population in the Sagittarius dwarf is c ∼ 0.5 (IWGIS). The initial stellar concentration is, of course, unknown but may be estimated by comparison to other ellipsoidal galaxies. Of the Milky Way dSphs, the most concentrated is Sculptor, with c = 1.12 (Irwin & Hatzidimitriou 1995). As a firm upper limit we adopt a maximum initial concentration of c = 2.1 in our models. (The value c = 2.1 corresponds to a central value of (Ψ/σ^2)0 = 9 in the formalism of Binney & Tremaine 1987, which we follow below, where Ψ is the relative potential and σ is a model parameter related, but not equivalent, to the central velocity dispersion). This choice is conservative, since only dynamically very evolved stellar systems have significantly higher concentration.”

“It was observed that the models never evolved to a state with a higher central velocity dispersion; we therefore investigated models with velocity dispersion equal to, or higher than the observed present velocity dispersion of the dwarf.”

### Zhao 1998:

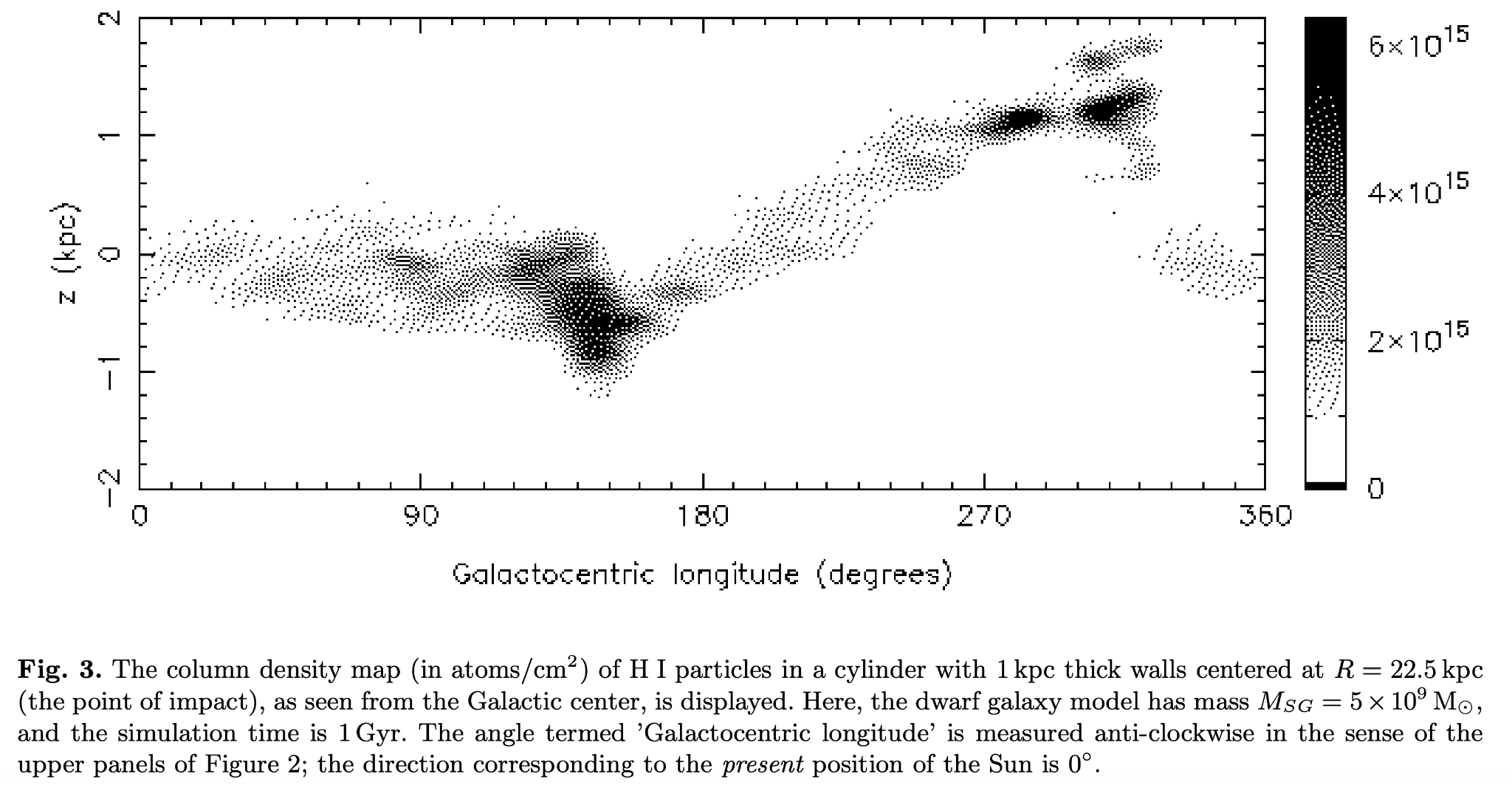
How has the “fluffy” core of the Sgr dwarf galaxy survived multiple strong shocks from the tidal force of the Galactic halo and disc since the formation of the core a Hubble time ago? A scenario that Sgr was deflected to its current orbit by the Magellanic Clouds after a rendezvous on the north Galactic pole 2 − 3 Gyrs ago is examined. **It is shown that the conditions of the collision fix both the sense of circulation of Sgr and the LMC around the Galaxy and the slope of the Galactic rotation curve.** The model argues that the two orthogonal polar circles traced by a dozen or so Galactic halo dwarf galaxies and globular clusters (LMC-SMC-Magellanic Stream-Draco-Ursa Minor along l ≈ 270o and M54-Ter 7-Ter 8-Arp 2-NGC 2419-Pal 15 along l ≈ 0 o) are streams of tidal relics from two ancient galaxies which was captured on two intersecting polar rosette orbits by the Galaxy. Our results favor the interpretation of microlensing towards the LMC being due to source or lens stars in tidal features of the Magellanic Clouds. We discuss direct and indirect observations to test the collision scenario.

They used the MCs to pose the following: Sgr doesn’t need a big core of DM protecting it. Instead, it lived at a large Lz/Energy orbit until the MCs kicked it inwards and the disruption really started. That in turn poses, based on the timing of this encounter, constraints on the mass distribution of the MW. This requires both LMC and Sgr to have been around for a very long time, since this encounter had to happen some 2–3 Gyr ago. This scenario seems unlikely today but it could be interesting to consider a more prolonged interaction Sgr-LMC.

### Ibata et al. 1998:

Hydrodynamical calculations undertaken to simulate the collisional interaction between the Sagittarius dwarf and the Galactic outer HI disk are presented, constrained by recently derived orbital and mass parameters for this dwarf galaxy. It is found that a significant distortion to the structure of the Galactic HI disk will be induced by the collision if the mass of the dwarf exceeds ∼ 10^9 M⊙; this value is consistent with an estimate derived by requiring

that the dwarf galaxy is sufficiently robust to survive tidal disruption until the present time. Though the precise details of the interaction are compromised in our simulations by the lack of a live Galactic halo, we find that for model masses >∼ 5 × 10^9 M⊙, prominent spiral arms and a substantial lopsidedness in the outer disk are produced. Furthermore, a noticeable warp-like structure is induced in the disk. Thus the Sagittarius dwarf may have significantly affected the star formation history and structure of the outer Galaxy. These simulations confirm the possibility of determining the current merging rate of low surface brightness, gas-poor dwarf galaxies of mass >∼ 10^9M⊙ onto giant spiral galaxies from careful analysis of observations of the structure of HI disks.



### Gómez-Flechoso 1999:

The existence of dwarf spheroidal galaxies with high internal velocity dispersions orbiting in the Milky Way raises questions about their dark matter content and lifetime. In this paper, we present an alternative solution to the dark matter dominated satellites proposed by Ibata & Lewis (1998) for the Sagittarius dwarf galaxy. We performed simulations of two kinds of N-body satellites: the first models (f-models) could correspond to satellites with high dark matter content and they represent initially isolated models. The second models (smodels) have either low or negligible dark matter content and they are constructed in a tidal field. In spite of being on the same orbits, the s-models are able to produce a better agreement with some observational constraints concerning Sagittarius. From our simulations, we can also infer that Sagittarius is in the process of being disrupted.

### 

### **Johnston et al. 1999**

We present a comparison of semianalytic models of the phase-space structure of tidal debris with measurements of average distances, velocities, and surface densities of stars associated with the Sagittarius dwarf galaxy, compiled from all observations reported since its discovery in 1994. We find that several interesting features in the data can be explained by these models. The properties of stars about +/-10 deg-15 deg away from the center of Sgr-in particular, the orientation of material perpendicular to Sgr's orbit and the kink in the velocity gradient-are consistent with those expected for unbound material stripped during the most recent pericentric passage ~50 Myr ago. The break in the slope of the surface density seen by Mateo, Olszewski, & Morrison at b~-35 deg can be understood as marking the end of this material. However, the detections beyond this point are unlikely to represent debris in a trailing streamer, torn from Sgr during the immediately preceding passage ~0.7 Gyr ago, as the surface density of this streamer would be too low compared with observations in these regions. The low-b detections are more plausibly explained by a leading streamer of material that was lost more that 1 Gyr ago and has wrapped all the way around the Galaxy to intercept the line of sight. The distance and velocity measurements at b=-40 deg reported by Majewski et al. in a companion paper also support this hypothesis. We determine debris models with these properties on orbits that are consistent with the currently known positions and velocities of Sgr in Galactic potentials with halo components that have circular velocities v\_circ=140-200 km s^-1. In all cases, the orbits oscillate between ~12 and ~40 kpc from the Galactic center with radial time periods of 0.55-0.75 Gyr. **The best match to the data is obtained in models where Sgr currently has a mass of ~10^9 M\_solar and has orbited the Galaxy for at least the last 1 Gyr, during which time it has reduced its mass by a factor of 2-3**, or luminosity by an amount equivalent to ~10% of the total luminosity of the Galactic halo. These numbers suggest that Sgr is rapidly disrupting and unlikely to survive beyond a few more pericentric passages. These conclusions are only tentative, because they rely heavily on the less certain measurements of debris properties far from the center of Sgr. **However, they demonstrate the immense potential for using debris to determine Sgr's dynamical history in great detail.**

NOTES: first model to account for striped material, not only the core. Interestingly, they discuss the different wrapps and how the transition from 3p material to 2p material in the trailing arm (in terms of Ramos et al. 2021) is seen as a break in the density as observed by Mateo et al. 1998. **From V21 model, we see that T3p1w is manly centred around b=-27deg, and that the transition to T2p1w happens more or less at b=-35deg.** They then say that the rest of the material (Majewski et al. 1999) at lower latitudes is the leading arm, which is not correct.

### 

### Jiang, Ing-Guey and Binney, James 2000:

Possible orbital histories of the Sgr dwarf galaxy are explored. A special-purpose N-body code is used to construct the first models of the Milky Way-Sgr dwarf system in which both the Milky Way and the Sgr dwarf are represented by full N-body systems and followed for a Hubble time. These models are used to calibrate a semi-analytic model of the Sgr dwarf's orbit that enables us to explore a wider parameter space than is accessible to the N-body models. We conclude that the extant data on the Sgr dwarf are compatible with a wide range of orbital histories. At one extreme the Sgr dwarf initially possesses ~10^11Msolar and starts from a Galactocentric distance RD(0)>~200kpc. At the other extreme the Sgr dwarf starts with ~10^9Msolar and RD(0)~60kpc, similar to its present apocentric distance. In all cases the Sgr dwarf is initially dark matter dominated and the current velocity dispersion of the Sgr dwarf's dark matter is tightly constrained to be 21+/-2kms-1. This number is probably compatible with the smaller measured dispersion of the Sgr dwarf's stars because of (i) the dynamical difference between dark and luminous matter, and (ii) velocity anisotropy.

NOTES: Their stream doesn’t look very realistic but they explore the Dark Matter mass loss for different orbits. Nothing on the stellar side.

### Helmi and White 2001:

We present two simple dynamical models for Sagittarius based on N-body simulations of the progressive disruption of a satellite galaxy orbiting for 12.5Gyr within a realistic Galactic potential. In both models the satellite initially has observable properties similar to those of current outlying dwarfs; in one case it is purely stellar while in the other it is embedded in an extended massive halo. The purely stellar progenitor is a King model with a total velocity dispersion of 18.9kms-1, a core radius of 0.44kpc and a tidal radius of 3kpc. The initial stellar distribution in the other case follows a King profile with the same core radius, a slightly larger total velocity dispersion and similar extent. Both these models are consistent with all published data on the current Sagittarius system, they match not only the observed properties of the main body of Sagittarius, but also those reported for unbound debris at larger distances.

NOTES: their stream is not that good, but is not terrible either. Most of their stars become unbound in the last 3 Gyr. I don’t see how they can claim a match with the data for a dwarf w/o DM since I97 demonstrated that such a system would not survive. Bit puzzled here. Also, like all the other models up to this point, they assume Sgr was always orbiting the MW. None consider it as an initially unbound dwarf.

NOTES! (from Majewski+03): *“From being able to identify two viable structural models, Helmi & White conclude that a long-lived Sgr is not ‘‘ in any way anomalous.’’ However, it should be noted that their models succeed by using a lighter Milky Way (asymptotic circular velocity for the flat rotation curve of only 186 km s1 and mass interior to present Sgr location*

*of 7:87 1010 M) and more benign Sgr orbit (larger, 70 kpc apocenter and longer, 1 Gyr period) than typically used by previous models.”*

### Bailin 2003:

Using recent determinations of the mass (0.4-2e9 Msun) and orbit of Sagittarius, I calculate its orbital angular momentum. From the latest observational data, I also calculate the angular momentum of the Milky Way's warp. I find that both angular momenta are directed toward l~270deg, b=0deg and have magnitude (2-8)×1012 Msolar kpc km s-1, where the range in both cases reflects uncertainty in the mass. The coincidence of the angular momenta is suggestive of a coupling between these systems. **Direct gravitational torque of Sgr on the disk is ruled out as the coupling mechanism. Gravitational torque due to a wake in the halo and the impulsive deposition of momentum by a passage of Sgr through the disk are still both viable mechanisms** pending better simulations to test their predictions on the observed Sagittarius-Milky Way system.

*“Ibata & Razoumov (1998) performed simulations which suggest that the passage of a sufficiently massive Sgr (5 × 109 M⊙) through the disk could produce a warp. Alternatively, its gravitational tides or the tides of a wake it produces in the dark halo could exert a warp-inducing torque on the disk.”*

*“There are three possibilities for the nature of the coupling. The first is a direct gravitational tidal torque by the satellite itself (Hunter & Toomre 1969), the second is the gravitational torque of a wake in the Galactic dark matter halo (Weinberg 1998; Tsuchiya 2002), and the third is an impulsive deposition of momentum to the gas disk by passage through it (Ibata & Razoumov 1998). The direct tidal torque for a satellite of mass m and distance r scales as m/r3. Therefore, the direct tidal effect of Sgr is no stronger than that of the LMC, whose direct tidal torque is not sufficient to induce the warp (Hunter & Toomre 1969). This means that the gravitational torque of Sgr itself cannot be the coupling mechanism. If the primary perturber is instead a wake in the halo, the strength of the torque scales as mwake/r3 wake. The mass of the wake scales as the mass of the satellite and as the density of the halo at the wake radius (Weinberg 1998). The wake develops at half the satellite’s orbital radius (Tsuchiya 2002). Therefore, for an isothermal halo, the strength of the torque scales as m/r5. In this case, the effect of Sagittarius is 10–50 times stronger than that of the LMC. ”*

### Law et al. 2004

N-body simulations are used to model the tidal disruption of the Sagittarius (Sgr) dwarf galaxy with constraints set by the positions and velocities of M giants in the Sgr tidal arms recently revealed by the Two Micron All-Sky Survey (2MASS). The simulated Sgr dwarf is placed on a variety of orbits within a Milky Way potential parameterized by variable circular velocities, halo flattenings and radial profiles. Two hundred separate test particle orbits have been used to explore a wide range of model Milky Way potentials and dwarf galaxy characteristics. The family of models is delimited by the data to a relatively narrow allowed range of parameters, and then input into N-body simulations. We present our best-fitting model, and discuss the orbital period, apoGalacticon distance, current space velocity, mass-to-light ratio, and other characteristics of the Sgr dwarf. In addition, we discuss the implications of this model for the flattening of the Galactic halo.

### Helmi 2004:

Recently, radial velocities have been measured for a large sample of M giants from the Two Micron All Sky Survey catalog, selected to be part of the Sgr dwarf leading and trailing streams. Here we present a comparison of their kinematics to models of the Sgr dwarf debris orbiting Galactic potentials, with halo components of varying degrees of flattening and elongation. This comparison shows that the portion of the trailing stream mapped so far is dynamically young and hence does not provide very stringent constraints on the shape of the Galactic dark matter halo. The leading stream, however, contains slightly older debris, and its kinematics provide for the first time direct evidence that the dark matter halo of our Galaxy has a prolate shape with an average density axis ratio within the orbit of Sgr close to 5/3 (q=1.25).

*“How old do streams have to be before they show noticeable dissimilarities due to variation in the Galactic dark halo shape? The kinematics of particles lost between 2 and 4 Gyr ago (Fig. 1, gray dots) already exhibit important and measurable differences. These are further highlighted in Figure 3, which plots the trend in the heliocentric radial velocity as a function of longitude for three different cases for particles lost in the last 4 Gyr.”*

### Johnston et al. 2005

M giants selected from the Two Micron All Sky Survey (2MASS) have been used to trace streams of tidal debris apparently associated with the Sagittarius dwarf spheroidal galaxy (Sgr) that entirely encircle the Galaxy. While the Sgr M giants are generally aligned with a single great circle on the sky, **we measure a difference of 10.4d+/-2.6d between the mean orbital poles of the great circles that best fit debris leading and trailing Sgr, which can be attributed to the precession of Sgr's orbit over the range of phases explored by the data set.** Simulations of the destruction of Sgr in potentials containing bulge, disk, and halo components best reproduce this level of precession along the same range of orbital phases if the potential contours of the halo are only slightly flattened, with the ratio of the axis length perpendicular to and in the disk in the range q=0.90-0.95 (corresponding to isodensity contours with qρ~0.83-0.92). Oblate halos are strongly preferred over prolate (qρ>1) halos, and **flattenings in the potential of q<=0.85 (qρ<=0.75) and q>=1.05 (qρ>=1.1) are ruled out at the 3 σ level. More extreme values of q<=0.80 (qρ<=0.6) and q>=1.25 (qρ>=1.6) are ruled out at the 7 and 5 σ levels, respectively.** These constraints will improve as debris with larger separation in orbital phases is found.

*“Visual inspection of this figure confirms the Helmi (2004a) conjecture that qualitative differences in the apparent thickening or precession of the most recent debris (i.e., yellow, magenta, and cyan points) are fairly small over the range of potential flattenings shown, especially for younger debris. However, it is premature to conclude that these effects do not lead to measurable variations in the disposition of the Sgr debris. We now demonstrate that orbital precession of even the most recent Sgr debris can be measured and used to discriminate between halo flattening models.”*

***“It is conceivable that internal rotation of Sgr perpendicular to the orbital motion could lead to a systematic offset between the angular momentum distributions of the leading (trailing) debris, mimicking orbital precession, but we do not consider this since no systematic rotation in Sgr’s core has been observed.”***

*“ (1) in general, the separation of poles derived for the leading and trailing simulated data should increase with increasing deviations from q = 1, (2) pole separation should be more dramatic for the oblate cases than the prolate cases, (3) the sense of precession in prolate potentials is opposite of that in oblate potentials, and (4) some (oblate-like) precession should be present even in the q = 1 case because of the presence of a disk component in our Galactic potential.”*

NOTES: the model looks pretty good. They find a clear correlation between pole separation (in degrees) and q (flattening). **Prolate halos should produce a negative pole separation, contrary to what is observed.**

### Law et al. 2005:

M giants recovered from the Two Micron All-Sky Survey have recently been used to map the position and velocity distributions of tidal debris from the Sagittarius (Sgr) dwarf spheroidal galaxy around the entire Galaxy. We compare this data set to both test-particle orbits and N-body simulations of satellite destruction run within a variety of rigid Milky Way potentials, and we find that the mass of the Milky Way within 50 kpc of its center should be (3.8-5.6)×1011Msolar in order for any Sgr orbit to simultaneously fit the velocity gradient in the Sgr trailing debris and the apocenter of the Sgr leading debris. **Orbital pole precession of young debris and leading debris velocities in regions corresponding to older debris provide contradictory evidence in favor of oblate/prolate Galactic halo potentials, respectively, leading us to conclude that the orbit of Sgr has evolved over the past few gigayears. In light of this discrepancy, we consider constraints from only the younger portions of the debris within three models of the flattening of the Galactic potential [q=0.90 (O), 1.0 (S), and 1.25 (P), i.e., oblate, spherical, and prolate] in our further N-body simulations**. On the basis of the velocity dispersion and width along the trailing tidal stream, **we estimate the current bound mass of Sgr to be MSgr=(2-5)×10^8 Msolar** independent of the form of the Galactic potential; this corresponds to a range of mass-to-light ratios (M/L)Sgr=14-36(M/L)solar for the Sgr core. Models with masses in this range best fit the apocenter of leading Sgr tidal debris when they orbit with a radial period of roughly 0.85 Gyr and have perigalactica and apogalactica of about 15 and 60 kpc, respectively. These distances scale with the assumed distance to the Sgr dwarf and the assumed depth of the Galactic potential. The density distribution of debris along the orbit in these models is consistent with the M giant observations, and debris at all orbital phases in which M giants are obviously present is younger (i.e., was lost more recently from the satellite) than the typical age of a Sgr M giant star.

“The exciting implication of the conclusion of the previous section—that no single orbit and/or potential can fit all the data—is that some evolution of Sgr’s orbit has occurred over the time since debris in the leading portion of the streamer, farthest in from Sgr, was released.”

“***As the potential moves from prolate to oblate, the orbit passes progressively nearer to the Sun, and line-of-sight velocities more closely reflect the full motion along the orbit. This explains why the simulated line-of-sight velocities in this region become more extreme with the oblateness of the potential.*** *Figure 13 also suggests that observed debris velocities in the leading region might be accounted for even in an oblate or spherical potential if the pericenter of Sgr’s orbit has decreased by a factor of order unity within the last 2–3 Gyr (from visual inspection of the figure), since such a decrease in pericenter of the Sgr dwarf over time could shift older Sgr debris out to greater distances from the Sun, corresponding to the greater pericenter of the dwarf on the passage during which the debris became unbound.*

*[..] Although* ***dynamical friction seems like the most favorable explanation*** *for the orbit evolution,* ***it does require Sgr to be an order of magnitude more massive just 2 Gyr ago****, and debris lost at that time in our mass-follows-light models would have a correspondingly larger dispersion in velocity (by a factor on the order of sqrt(10) = 3) and distance. Since the observed velocity dispersion in the debris in the discrepant, leading portion of the stream is actually quite similar to that seen in our simulations (17 km/s; see Fig. 10),* ***this suggests that, in addition to dropping our assumption of a single orbit for Sgr, we also have to move beyond modeling Sgr as a single-component system in order to fit the data.*** *Hence, while the mean trend in the leading streamer will tell us how much total mass needs to have been lost from Sgr, the low dispersion offers the additional opportunity of constraining how much more tightly the light matter is bound compared to the dark matter. A study of these combined effects is in progress.*”

NOTES: the contradicting constraints (velocity and pole separation) do not apply to the younger portion of the stream (i.e., recently stripped stars).

NOTES: old leading behaves as a prolate halo (i.e., passes far from the Sun), whereas young material shows signs of oblateness (i.e., positive orbital pole separation). However, V21 model has the leading arm behave properly by making the halo transition from oblate in the inner parts to prolate in the outer parts. But the V21 model has **very low mass** so the Dynamical Friction effect is not acting properly.

### Chou+07:

“(1) *the trailing arm is dynamically much better understood than the leading arm (Helmi 2004; Law et al. 2005) (2) the sorting of stars by dynamical age is much cleaner in the trailing arm than the leading arm*”

### Hernitschek+17

“*In more recent work, Belokurov et al. (2014) have demonstrated that the trailing arm of the Sgr stream can be traced out to its apocenter at ~100 kpc. They also give a fit of the stream’s leading arm to its apocenter at ~50 kpc.*”

Distances in this work are calculated as explained in Sesar+17 (Machine-learned Identification of RR Lyrae Stars from Sparse, Multi-band Data: The PS1 Sample): **most of the stars don’t have metallicity so they impose -1.5dex.**

### Dierickx+17: (Fig. 4 is wrong! Look only at Fig. 6).

*“If we apply these equations then the current position vector of the center of Sgr is rSgr,obs = - (16.1, 2.35, 6.12) kpc, in agreement with the values provided, e.g., by Law & Majewski (2010). The heliocentric radial velocity of Sgr has been measured as 140 ± 0.33 km s−1 (weighted mean of the estimates of the average velocities of Sgr,N and M54 in Table 5 of Bellazzini et al. 2008), and its proper motion in the equatorial coordinate system is (μα, μδ) = (−2.95 ± 0.18, −1.19 ± 0.16) mas yr−1 (Massari et al. 2013). Using these heliocentric velocity components, the Cartesian, right-handed Galactic space velocity (U, V, W) is calculated following Johnson & Soderblom (1987). Finally, these heliocentric space velocities are converted to the Galactic Rest Frame (GSR) by adding contributions from the local standard of rest and solar peculiar motions (Schönrich et al. 2010; Reid et al. 2014): This yields a current GSR velocity vector for Sgr of* ***vSgr,obs = (242.5, 5.6, 228.1) km s−1*** *and a total magnitude of the velocity of 333 ± 30 km s−1”*

“**Importantly, inferring the orbit from evolving a test particle backward in time does not capture tidal stripping effects on the progenitor halo. This approach is valid in the regime of low mass, low dynamical friction, and low stripping outlined by Jiang & Binney (2000), but cannot recover earlier infall phases for a progenitor with mass 109 Me. The initial mass of Sgr used by Law & Majewski (2010) is 6.4 × 108 Me, distinctly in the regime where dynamical friction is unimportant.**”

“A halo’s scale radius rs is related to its virial radius Rvir and concentration parameter c by the relationship rs = Rvir/c. As the halo accretes mass on its outskirts, the scale radius is maintained constant while the virial radius and the concentration parameter grow.”

In this work, the authors basically do a first exploration of parameters with a method similar to NBodyDirect (Gala) -> test particle simulations but at the same time the particles feel each other’s potential. With that, they can do a first fast exploration of the parameter space. Then, they run N-body models from the optimal point. No LMC but yes dynamical friction. Also, they start the simulations 8Gyr ago, putting Sagitarius at a Galactocentric distance of aprox. 150 kpc.

One of the main points they raise (from the first type of simulations) is only a small set of initial angular momentum at the moment when Sgr crossed the Virial radius of the MW are allowed. However, even if it is true, the values they derive do not take into consideration the interaction with the LMC. Which, as Vera-Ciro&Helmi13 shows, introduced a significant kick in the angular momentum of Sgr just right before the present time. Therefore, we cannot calculate the angular momentum at entry from the current phase-space of Sgr without taking LMC into account.

Their N-Body doesn’t much so nicely the data and also their plots are in RA-DEC, making it hard to compare to observations. However, the two-step strategy is something. NOTE: in the N-Body simulation, even though it starts from the same point, the orbit degradates much faster -> dynamical friction is more efficient than they anticipated in their simple recipe (Chandrasekar equation but with lots of assumptions). **Either their assumptions are wrong or their mass loss recipe is.**

### Fardal+19

Our median matches better with their Model A than the RR Lyrae from Sesar et al. 2017b (Table 1).

### Velokurov et al. 2021

*“The best-fit halo shape and orientation is indeed rather peculiar:* ***the inner part of the halo is moderately oblate, with axis ratio z : R ' 0.5 − 0.6, while the outer part is strongly prolate and misaligned with the principal axes of the disc.*** *It has long been recognised that the halo needs to be nonspherical in order to produce the observed morphology of the leading arm: in a spherical halo, it bends much more strongly, and the stream crosses the Galactic plane around the Solar radius, not at ∼ 10 − 15 kpc from the Sun as warranted by observations (see e.g. Belokurov et al. 2006; Yanny et al. 2009). Allowing the halo to be prolate (extending more along the z axis) in the outer part “unbends” the leading arm and moves its disc crossing point further out, while the additional flexibility allowed by misaligned principal axes improves the fit of the stream track. At the same time, the oblate inner part aligned with the disc shifts the distant portion of the trailing arm up (closer to the Galactic plane), improving the fit for both the distance and velocity at Λ < −100◦.”*

# Star formation and Metallicity Distribution

## References

* [Chou et al 2007](https://ui.adsabs.harvard.edu/link_gateway/2007ApJ...670..346C/doi:10.1086/522483)
* [Vivas et al 2005](https://ui.adsabs.harvard.edu/link_gateway/2005AJ....129..189V/doi:10.1086/426561)
* [Zhang 2017](https://ui.adsabs.harvard.edu/link_gateway/2017A&A...597A..54Z/doi:10.1051/0004-6361/201629051)
* [T. Tepper-Garcia and J. Bland-Hawthorn 2018](https://watermark.silverchair.com/sty1359.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAkwwggJIBgkqhkiG9w0BBwagggI5MIICNQIBADCCAi4GCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQMtauuK9-1Czfn2G4_AgEQgIIB_9tDI4kGovxbBp1y-0HoDFR6aTAqLjtMTE-rEz_b_fWCkfDQFMNEnzCAhCz9VqdZDImc77grmRowre6DlgKol6fGzNOik1vVIJ1-nr2tBS53Sh6BMW52H29uvU9GuKlnavKbDYK2sYJWZkgt9tgMNppg7xOVDGBWoTXxrvv4CxNrtflk32wC8nr1ZrEdKwGzoMnJOsOfAnGegUpOV_bE0vY0k7VENI2cNKWRbzzBuNRpzp1mj6COaG8zFQCEALlap8o2NYpsrvR8n5DeQaXSqpjetHX76E7lFa2tGOnzaLiiYqoA54VBwB5bdVfYKBH38O4wTi0RhKdji2MHNBjvLf1_M-eFozKEUVFFy5eZ-5uu1p19D5Nlldrmi5xAo1BmXxU6Py5Zhods02TP8nsjwmbOvVOmIC3uX5NIYIAfJJPs1LG6F_41G-XXvEbYNUbIF9k68JkhhdxRgNsE7gt5suuZ651n1aLI88XDAFQy39Mg7ICjVwmUQs5_uruhK9AuRxocLEyerJNJtjpwI29niKjt1ooZ8EjW3W8y97Tm7czBue_CPLy52xgQ3GFZXWbpjkl3kNfvH7lxKGZTENbJtfHod2ZmAYeIEK3jGgP2C1y1uaxszdujAafAWl9sj3TQri_R8Hv8_m_MaTkxuzDEbQrwehglCFvWQlFwvp7G9Tg)

## Notes

**It seems like its MDF spans from -2.0 to > -0.5 dex which suggests enrichment (Cacciari et al. 2002)**

### Chou+07:

“*In a recent reanalysis of the age-metallicity relationship in Sgr, Bellazzini et al. (2006a) find that the dSph may have enriched to near-solar metallicity as early as 6 Gyr ago, although a more recent analysis by Siegel et al. (2007) suggests a somewhat slower evolution to this enrichment level.*”

“*On the other hand, Bellazzini et al. (2006b) found significant differences in the relative numbers of blue horizontal-branch to red clump stars between the Sgr core and a position about 75 forward along the Sgr leading arm, an imbalance that suggests a significant metallicity variation along the Sgr stream.*”

The sample of Chou is extremely local. At that point, Enceladus was not known and, even if they selected stars according to their radial velocities (matching the models) that does not guarantee that they are from Sgr. The results of this study must be taken with care. They do have a sample of most likely members of the leading arm that is somewhat reasonable but still too few objects.

On the other hand, the analysis by Zhang+17 is more convincing. In their work, the gradient is almost nonexistent, especially for the Leading arm.

“*We derive a metallicity gradient [...] of* ***-(1.6 ± 0.4) × 10-6*** *dex deg-1 for the leading arm 1, and of -(1.3 ± 0.3) × 10-3 dex deg-1 for the trailing arm 1.*”

NOTE: there’s a difference between metallicity gradient within the arm and metallicity gradient w.r.t. the core of Sgr.

### Tepper-Garcia+18:

*“ We find that the gas stripping was 30–50 per cent complete at its first disc crossing ∼2.7 Gyr ago, then entirely stripped at its last disc crossing ∼1 Gyr ago.”*

# RR Lyrae

## References

* [Hernitschek et al. 2017](https://iopscience.iop.org/article/10.3847/1538-4357/aa960c/pdf)

## Notes

### Fardal+19

“the high-contrast three-dimensional view given by the RR Lyraes in Pan-STARRS1 (S17; Hernitschek et al. 2017) suggests that both the leading and trailing apocentres have two components at slightly different distances (their fig. 1).”

### Hernitschek+17



Fig.1: RRab stars within |B∣< 9º as obtained after fitting of the period (Sesar et al. 2017c). The Sgr stream is clearly visible up to ~130 kpc. The color indicates the median angular distance B˜ of a 5 ´ 5 kpc bin (in L˜ and D coordinates) from the Sgr orbital plane = B˜ 0 . This was chosen due to the high source density in some regions. In this figure, the angular coordinate L˜ runs from - 20 to 380 with repeated data points for L< ˜ 0 and L > ˜ 360 , to better show the distribution near L~ ˜ 0 . The locations of the Sun, Galactic anticenter, Sgr dSph, and the Virgo overdensity (Vivas et al. 2001; Newberg et al. 2003; Jurić et al. 2008) are indicated. The dashed line marks the position of the Galactic plane. The centroid for Sgr dSph was taken from Karachentsev et al. (2004). The Cetus stream should cross the Sgr stream at L~270º ,B~1º (Newberg et al. 2009). Evidence from our data is marginal.

“*The prior for Dsgr depends on L, and is uniform within (Dminprior(L) ), (Dmaxprior(L) ) as indicated in Figure 4 and listed in Tables 2 and 3. Whereas the prior is generally wide, a quite restrictive prior was chosen for 20<=L<30 and 30<=L<40, because the fit otherwise behaves poorly because of the background sources along these l.o.s.*”

**If the prior is chosen poorly, they might be biasing the results towards what is known.**

They look for the optimal parameters through MCMC given a model of the Halo. So, model-dependent and non-deterministic.

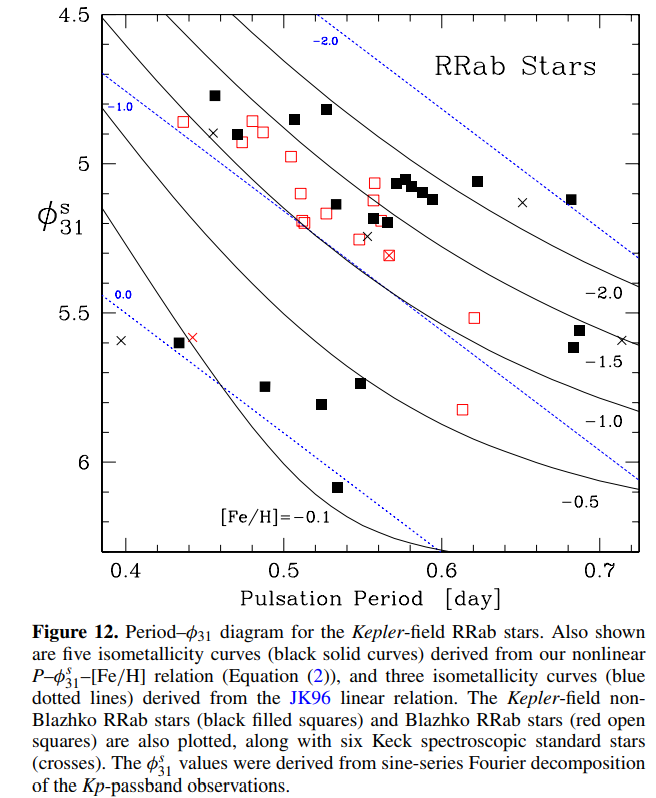
# RR Lyrae metallicity calibration

## References

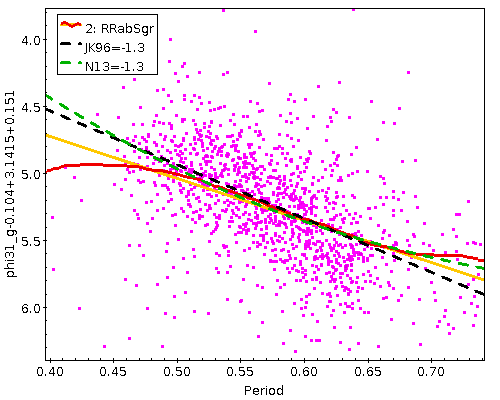
* Jurcsik & Kovacs 1996 (JK96)
* [Gratton et al. 2004](https://www.aanda.org/articles/aa/pdf/2004/27/aa0840.pdf)
* [Carretta et al. 2009](https://www.aanda.org/articles/aa/pdf/2009/47/aa13003-09.pdf)
* [Nemec et al. 2011](https://watermark.silverchair.com/mnras0417-1022.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAmwwggJoBgkqhkiG9w0BBwagggJZMIICVQIBADCCAk4GCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQMq1GU3J3jvictRJjNAgEQgIICHxIAUBA7SjaqYyH7n0fQDnq3TaKx6ES66eB6nCsHujAHCFezqhYot3v-TTj6O2oUThmbxc7cgTXQQ5qeBI6ltspURO28XGt3tkWo-SaHBfOvakrUB4yIevCJFtFyF1Vu6SxWbnjhJTONoY1_j05K0lhXnJJ4hBDj0X3UeIoOqGslCqTiTA_F-uQVN-Bynww1OpDpRA7jewVO7yv_kzmEQ18bJHexcVTzPhpY_Nt6bUQ_J7Q0i5jIdzEm35RrGLq27SMZCZvGGGwd469tMqpYviBUh2e5PzgKgJhPRL2x9vYyOoqjWJCrv07kK4nt4QkEmbASrN16bzseOS7RhzAXgrn5fP7GcPnmP5nv_K-aw8uACkW3tPAs5zxcBjP6P3LCpV6wVjRrgHZ3cVtFHwvSiFBuAKQdoDQ3qdfiHNVuQdN1YN899CHnEfDAs6fUuGwBLmN7gP-cSJ3bfBIUP-uZlX5ayxnhEHfdybhoTUUwG6qjsmMI9crkWuQV3dluC-kjbXNvWdaiTWmVE8bUMWJiYJJA_aqw1BhtmSOXOFJCD2rxfKo9ih1R3xOhgcOUDSHO-GlXnGzct8TXLA_-49dlf36ogk0MCDEiV_08wCsaL9BImp5QQ1w2Oh18voQYxOMmwvXz9JG0HZ7_MTIfvEdT7aR5aQ7XqczIh5auRKCC_FTathmlEzU9poplG9stcbMFvLrOg-SLhWDtP0Ky5-f8sg)
* [Nemec et al. 2013](https://iopscience.iop.org/article/10.1088/0004-637X/773/2/181/pdf)
* [Clementini et al. 2019](https://www.aanda.org/articles/aa/pdf/2019/02/aa33374-18.pdf)

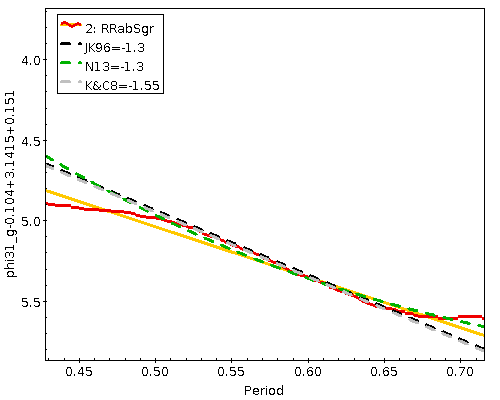
From Clementini+19 we learn that the metallicity is given using equations (2) and (4) of Nemec+13 for, respectively, RRab and RRc.

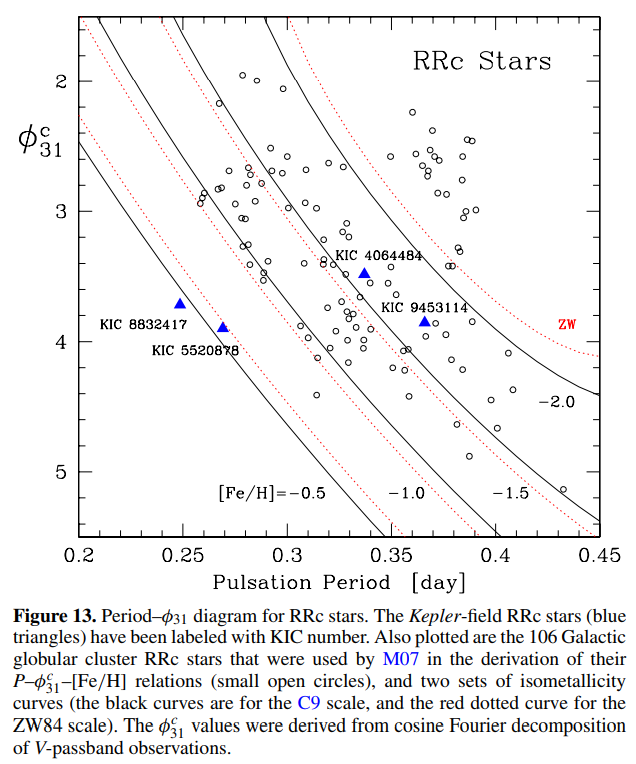
If we now go to Nemec+13, we see that the metallicities for RRab are computed in a non-linear way and thus the relation with the JK96 scale (bias by +0.3 wrt Zinn&West84, see Gratton+04) depends on the location in the Periods vs :



However, the stars selected by nGC3 fall predominantly at the regions where the relation JK96 to Nemec13 is almost one-to-one. Therefore, for most of our RRab, we need to subtract 0.3dex (-0.3) to put them in the Z&W84 scale. However, if we take the relation in Eq. (5) of Kunder&Chaboyer 2008, we can fit directly the metallicity in the Z&W84 scale -> [Fe/H]ZW~-1.55dex.





Regarding the RRc stars, the relation is linear and we can already see the offset wrt to Z&W84 in the following figure, also from Nemec+13:

When we take the mean metallicity of DPAC for RRc stars at distance > 17kpc (approx.) we get a [Fe/H]C9~-1.65. By solving for [Fe/H]ZW in (see Carretta+09):

[Fe/H]UVES = −0.413(±0.027) + 0.130 (±0.289)[Fe/H]ZW −0.356 (±0.108)[Fe/H]ZW^2

We obtain [Fe/H]ZW~ -1.69 (close to the metallicities derived by Viva+05).

With this, we get [Fe/H]ZW=-1.60dex for RRab (the dominant fraction, ~85%) and [Fe/H]ZW=-1.69dex for RRc (~15%).

However, if we use the relations used by Cseresnjes+01, we get [Fe/H]ZW=-1.57dex for RRab and [Fe/H]ZW=-1.62dex for RRc.

So, even though it seems like the RRc are more metal-poor either way, we can assume a constant metallicity at [Fe/H]ZW=-1.60 as a compromise among all the determinations. Plus, the Muraveva+18 relations are fitted with a largely dominated sample of RRab stars only.

# Bifurcation

## References

* [Belokurov et al. 2006](https://ui.adsabs.harvard.edu/link_gateway/2006ApJ...642L.137B/doi:10.1086/504797)
* [Koposov et al. 2012](https://ui.adsabs.harvard.edu/link_gateway/2012ApJ...750...80K/doi:10.1088/0004-637X/750/1/80)

Belokurov+06 shows the discovery of the bifurcation in the north galactic hemisphere (leading arm). Not much said about the nature of it apart from showing the morphology (projected) and that there is almost no separation in distance.

Koposov+12 reports that the bifurcation can also be seen in the south (trailing). Uses Gaussian fit to Beta histograms to follow the angular separation and widths from Lambda ~ -120deg to -80deg. **Uses SDSS photometry of the stars -5<Beta<5 vs 8<Beta<12 to argue that the faint branch has a much thinner sub-giant and red-branch regions. Also, that it does not have multiple turn off or a prominent red clump.** *This is not true!!*

“To check that the latter is not an artifact caused by low number statistics in the faint stream, we modeled the ratio of red clump to MSTO stars using a decomposition of the density profile into two Gaussians (as used for Figure 2). With 95% confidence, this ratio in the fainter stream is smaller than that in the brighter. This suggests the existence of a simpler and more metal-poor population in the fainter stream, and more complex and more metal-rich population in the brighter stream.”

This claim is sustained by the bright branch having a thicker MSTO at i-mags of ~21mag. Their figure is totally saturated so it is impossible to check if that is just an effect of downsampling. But the ratio should be robust to observational effects…

Then, they say that the plot (below) proves their point, that is, that the bright branch has significantly more metal-rich stars than the faint.

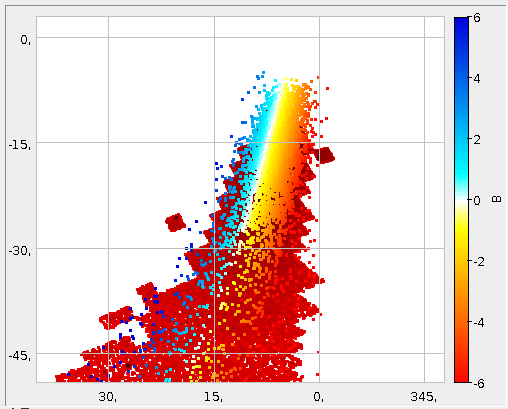
They advocate for two different streams with different properties based on incomplete CMD data. *Our results, although confirming the difference in mean metallicity, do show very similar CMDs between 2 branches.*

In this sense, Koposov discusses that the 2 wraps model (Fellhauer et al. 2006) does not produce a bifurcation in the south (plus, their trailing apocentre is far too close to the Sun thus their argument needs revision), whereas the model by Peñarrubia et al. 2010 doesn’t have population differences between the two branches (plus, it is not known whether it produces a bifurcation in the trailing arm).

# Others

## Sgr orbital plane

The first tests have shown a discrepancy in the determination of the pole of Sgr stream. However, this might be correct because, when colouring the stream by B\_sol we see that is not centred at zero:



We have also checked that the change used is coherent up to the level of 1e-5 degrees with the equations given in Belokurov+14.

It is centred, however, with the trailing tail, as it was intended.

