Final Presentation

Kinematics and Membership of the SMC Norther Over-Density (SMCNOD)

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Summary of work

Papers

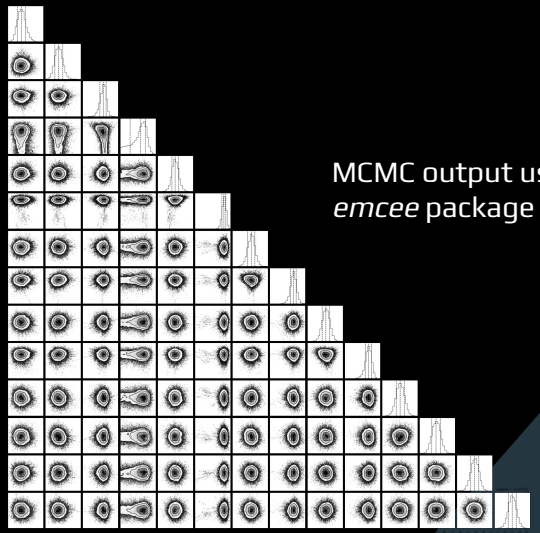
Discovery, Follow-up study, Methods...

Research Data

- S5: Kinematics, metallicity and membership probability of SMCNOD
- OGLE-IV: Variable stars, origin of SMCNOD

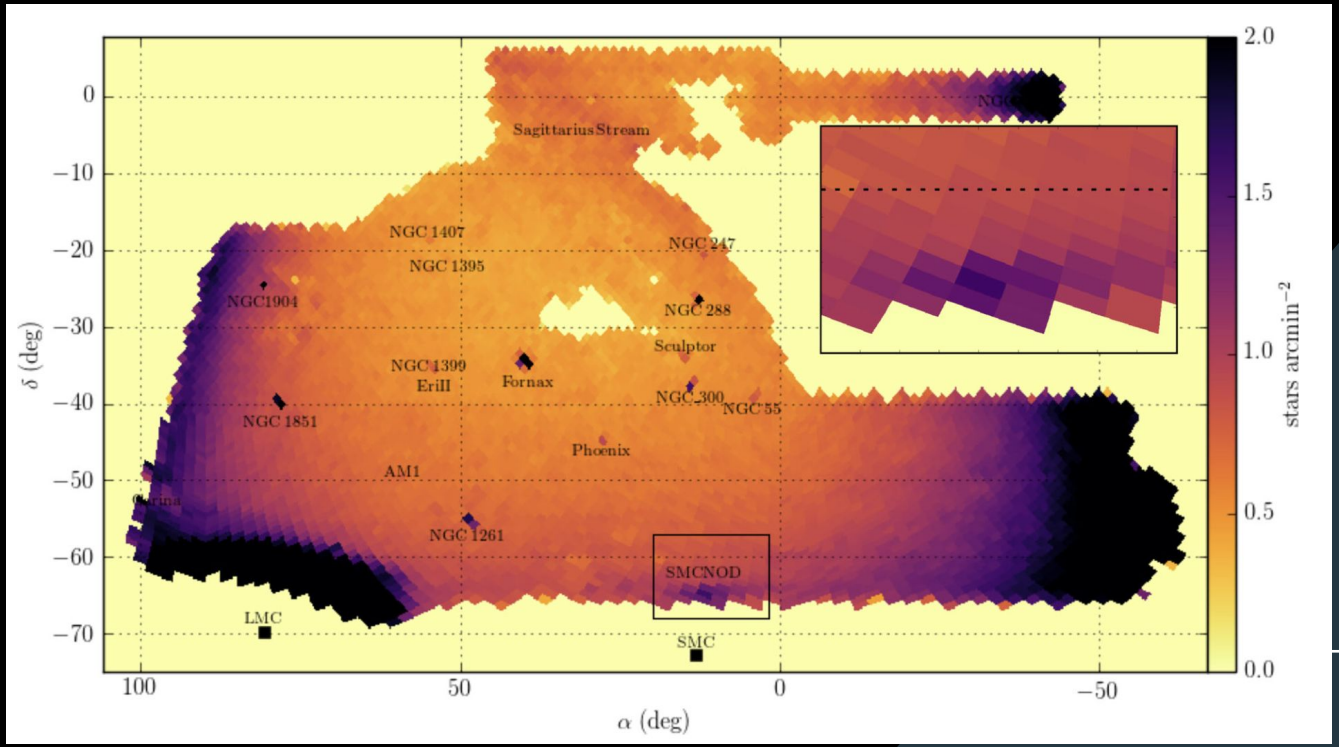
Methods/Tool

- GMM, Markov chain Monte Carlo, (and more?)



MCMC output using *emcee* package

SMCNOD

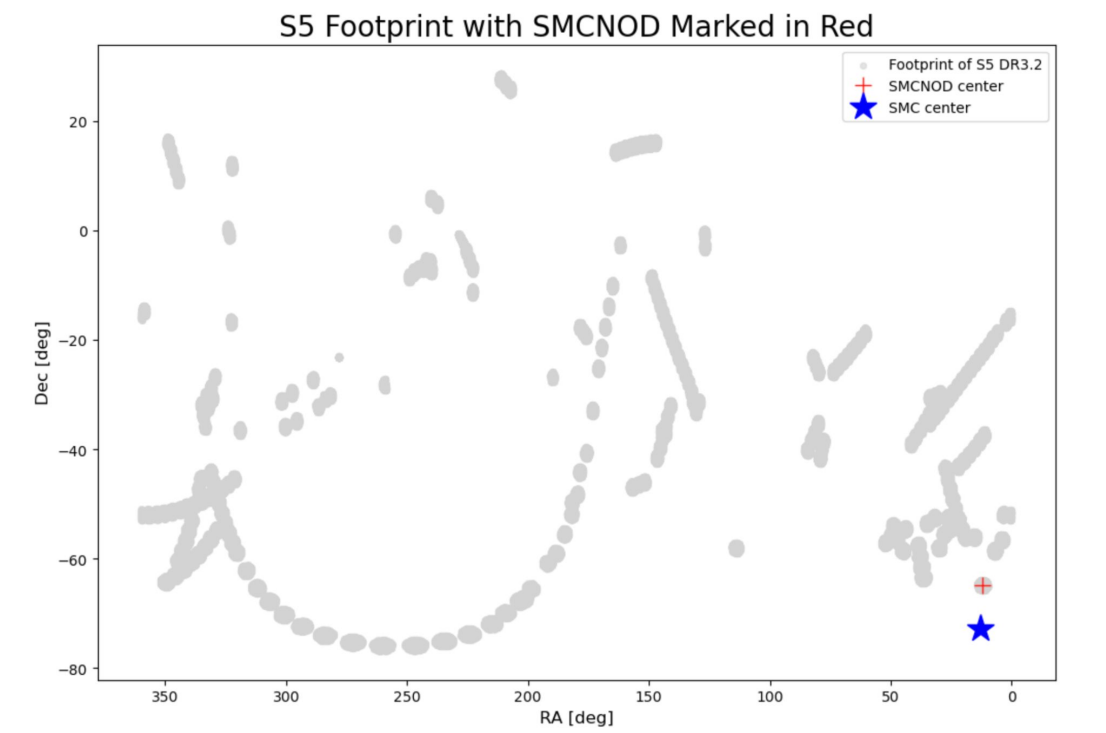


- indistinguishable in **age, metallicity** and **distance** from the nearby SMC stars
- Primarily composed of intermediate-age stars
  (6 Gyr, Z = 0.001)
- Small fraction of young stars
  (1 Gyr, Z = 0.01)

(Pieres et al. 2017)

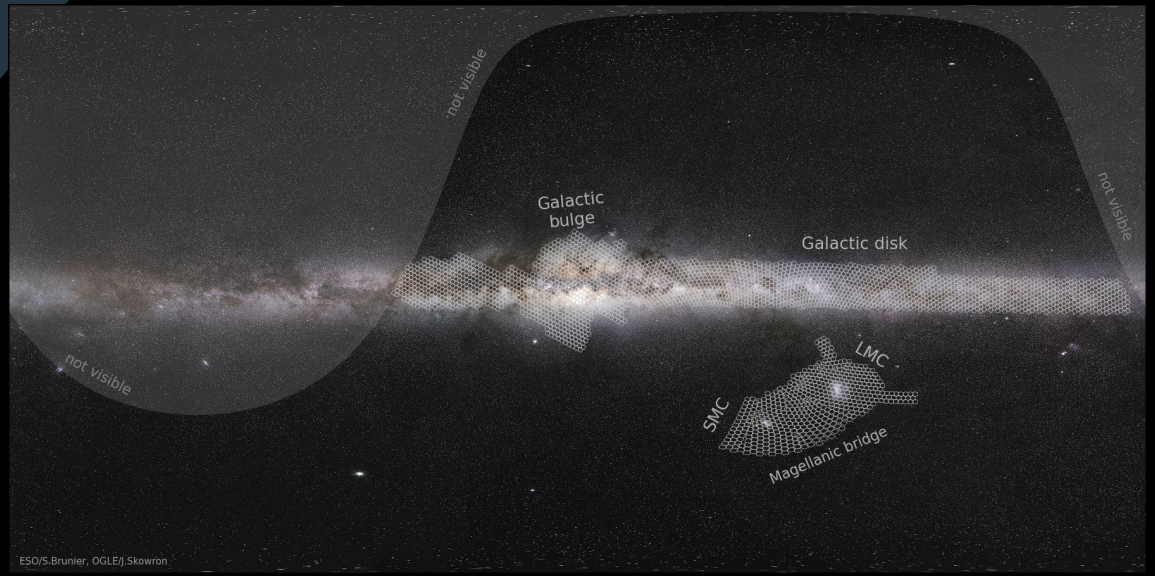
- (RA, Dec) ~ (12°, -64.8°)
- Half-light radius: ~ 120.4 arcmin

S5: Southern Stellar Stream Spectroscopic Survey



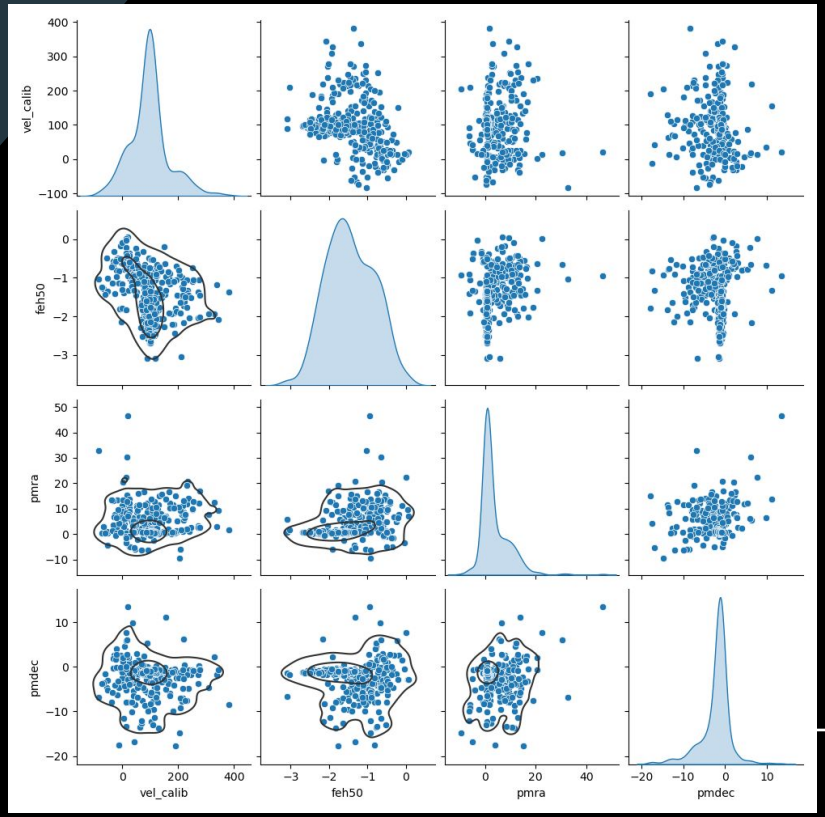
- a spectroscopic survey of stars in the stellar streams of the Southern sky
- Aim: mapping their kinematics and chemistry
- Instrumentation: AAOmega spectrograph on the 3.9m Anglo-Australian Telescope (AAT), fed by the Two Degree Field (“2dF”) fiber positioner facility.

OGLE-IV (Optical Gravitational Lensing Experiment)



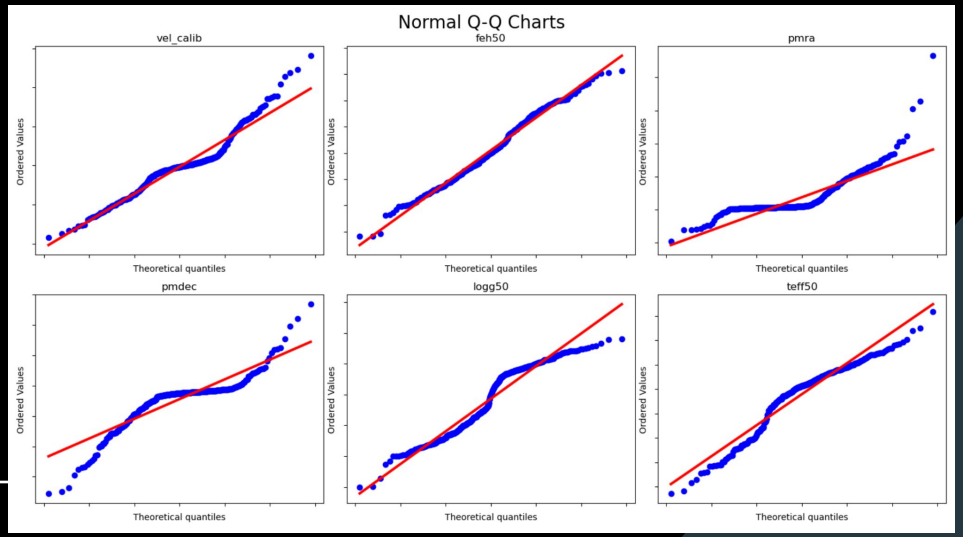
- Goal: searching for the dark matter with ***microlensing phenomena***
- Most natural locations: the Magellanic Clouds & the Galactic Bulge
- OGLE observations are conducted in the ***I*** and ***V-passbands*** of the Johnson-Cousins photometric system

EDA - Data exoploration



Two Questions:

- How many components are there in data?
- What distribution do parameters follow?

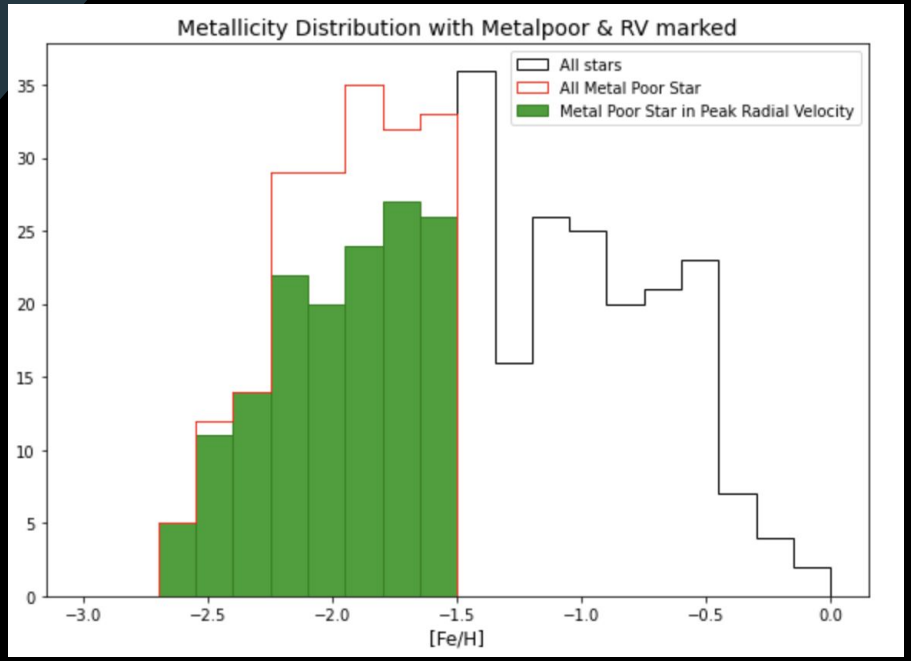


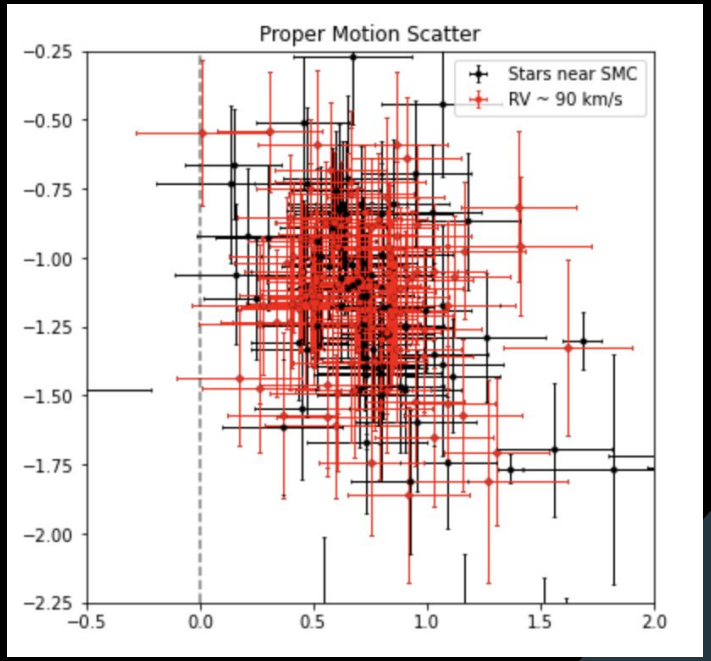
Objective Member Selection

Selection criteria:

Good SNR & low RV error

Peak selection: RV + PM





Method

- We model the candidate stars as a gaussian mixture model containing SMCNOD and 2 BGs.

  Total like-lihood (L):

$$\mathcal{L} = f_{\mathrm{SMCNOD}}\mathcal{L}_{\mathrm{SMCNOD}} + f_{\mathrm{bg1}}\mathcal{L}_{\mathrm{bg1}} + f_{\mathrm{bg2}}\mathcal{L}_{\mathrm{bg2}}$$

- The proper motion term is modeled as a multivariate Gaussian:

$$\ln \mathcal{L}_{\mathrm{PM}} = -\frac{1}{2}(\chi - \overline{\chi})^{\top} C^{-1} (\chi - \overline{\chi}) - \frac{1}{2} \ln\left(4\pi^2 \det C\right)$$

$$\chi = (\mu_\alpha \cos\delta, \mu_\delta) \; \bar{\chi} = \left(\overline{\mu_\alpha \cos\delta}, \overline{\mu_\delta}\right)$$

- Covariance Matrix:

$$C = \begin{bmatrix} \epsilon^2_{\mu_\alpha \cos\delta} + \sigma^2_{\mu_\alpha \cos\delta} & \epsilon^2_{\mu_\alpha \cos\delta \times \mu_\delta} \\ \epsilon^2_{\mu_\alpha \cos\delta \times \mu_\delta} & \epsilon^2_{\mu_\delta} + \sigma^2_{\mu_\delta} \end{bmatrix}$$

Full Likelihood Model

- 16 Parameters, 2 backgrounds
  * pgal = fraction of stars in the galaxy
  * pbg1 = fraction of stars in the 1st background component
  * pmra = Heliocentric proper motion, RA of the galaxy in mas/yr
  * pmdec = Heliocentric proper motion, Dec of the galaxy in mas/yr
  * vhel = mean velocity of the galaxy in km/s
  * lsigv = log10 the velocity dispersion of the galaxy in km/s
  * feh = mean metallicity of the galaxy in dex
  * lsigfeh = log10 the metallicity dispersion of the galaxy in dex
  * vbg1, lsigvbg1, fehbg1, lsigfeh1 = same parameters for 1st background component
  * vbg2, lsigvbg2, fehbg2, lsigfeh2 = same parameters for 2nd background component

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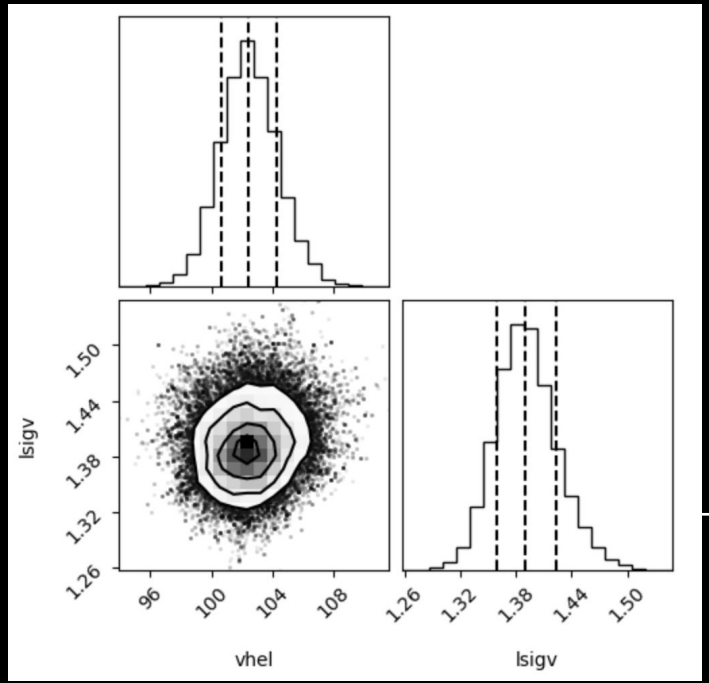
- Comparisons with previous model & different MCMC packages (emcee and dynesty)

Bayesian sampling methods: **emcee** and **dynesty**

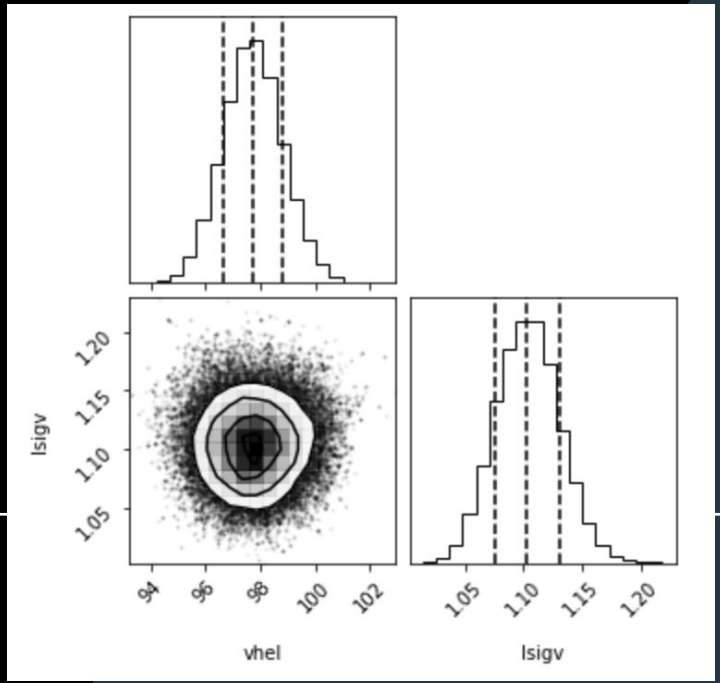
	emcee Affine-invariant multiple walkers	dynesty Dynamic nested sampling
Pros	Easiest to start with	Computes the evidence Think about priors
Cons	Not the most efficient sampler	10x slower than other methods. Careful choosing priors

Posterior distribution - Radial Velocity

	Quality cut stars	Member stars
vhel	102.296(+/-1.878)	97.716(+/-1.085)
sigv	24.001(+/-1.821)	12.691(+/-0.787)



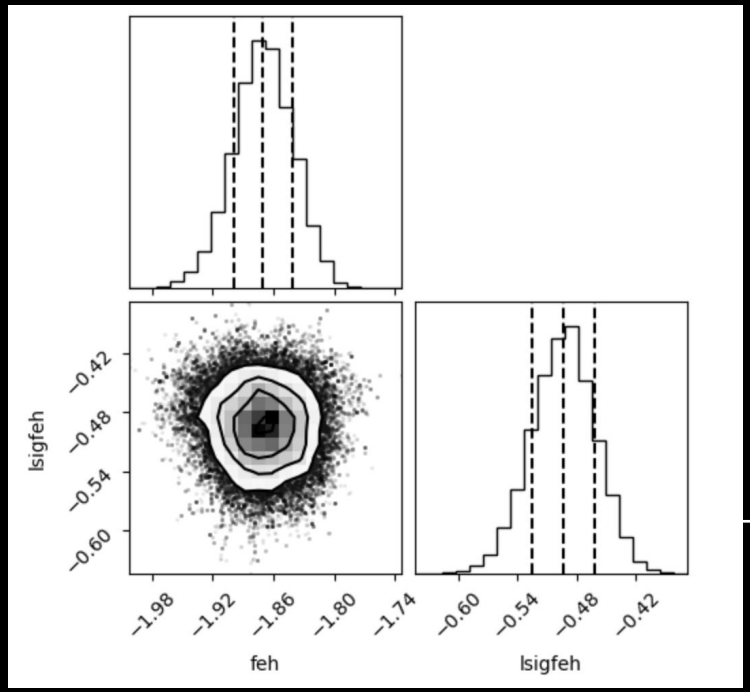
Quality cut stars



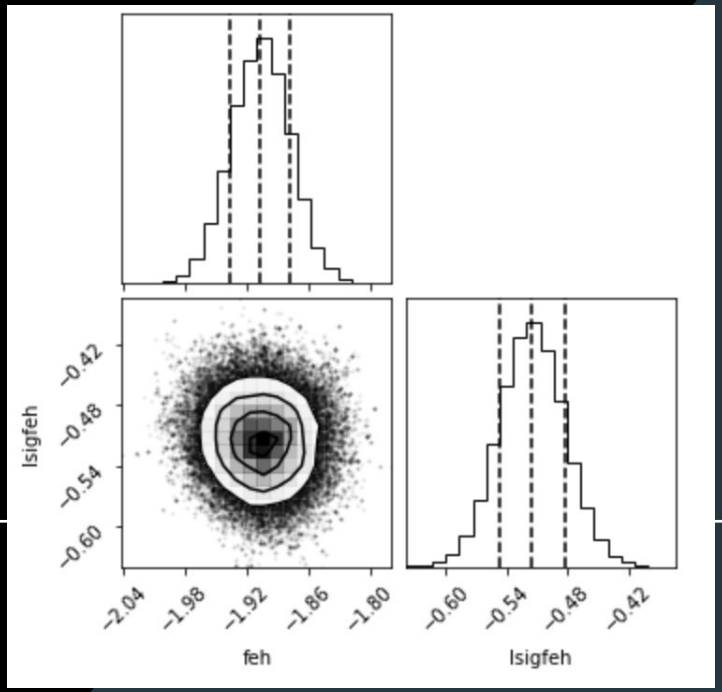
Selected Member stars

Posterior distribution - Metallicity

	Quality cut stars	Member stars
feh	-1.900(+/-0.029)	-1.906(+/-0.029)
sigfeh	-0.516(+/-0.034)	0.305(+/-0.023)



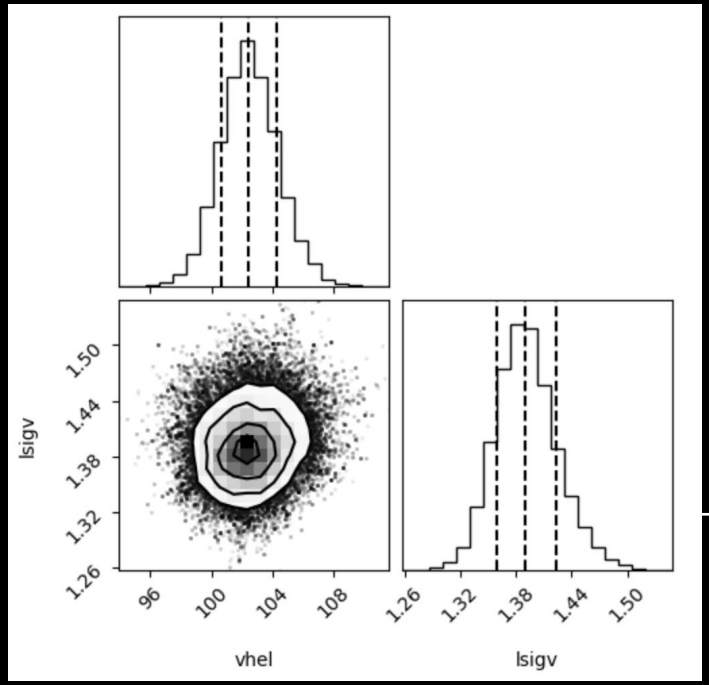
Quality cut stars



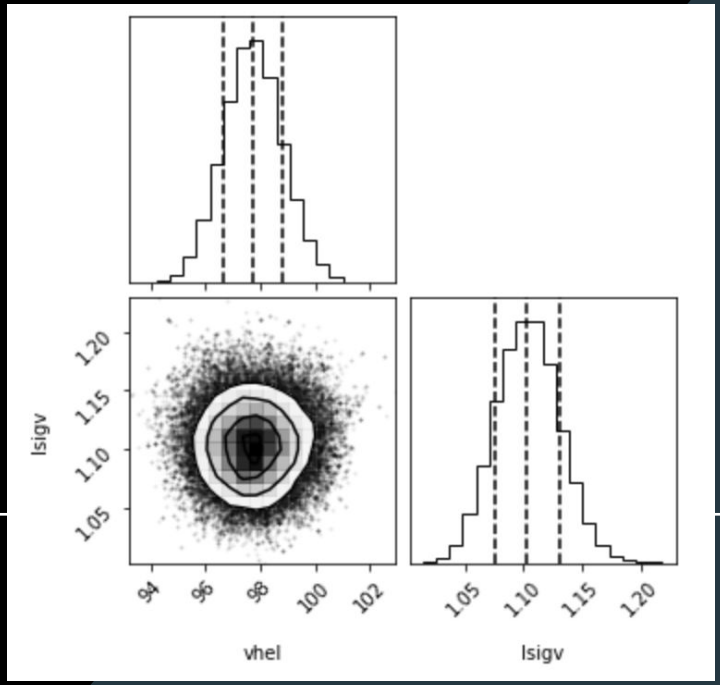
Selected Member stars

Posterior distribution - Proper Motions

	Quality cut stars	Member stars
pmra	0.703(+/-0.016)	0.702(+/-0.016)
pmdec	-1.123(+/-0.017)	-1.124(+/-0.017)



Quality cut stars



Selected Member stars

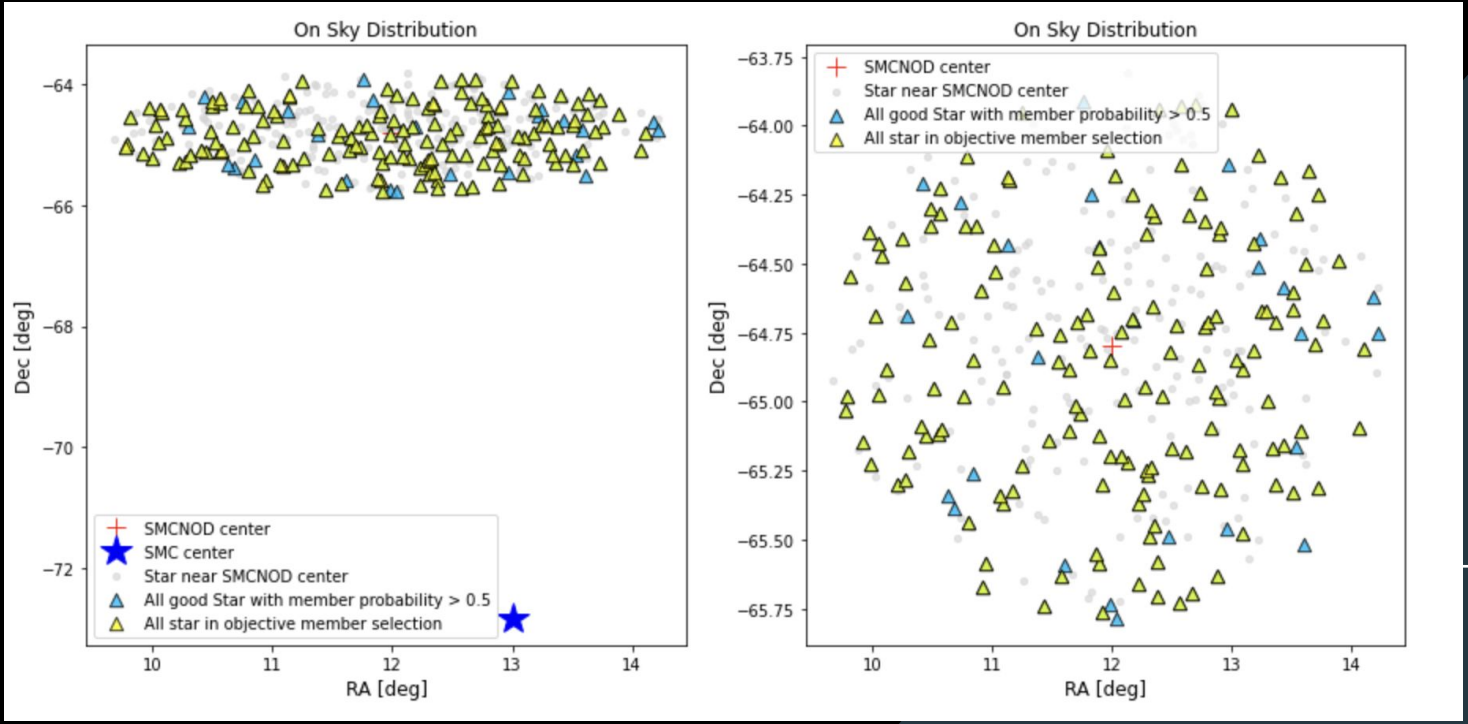
Results compared with previous model

	Full model (emcee)	Full model (dynesty)	RV, [Fe/H] only model
vhel	102.296(+/-1.878)	102.408(+/-1.852)	98.745(+/-1.141)
lsigv	1.380(+/-0.033)	1.378(+/-0.030)	1.102(+/-0.034)
sigv	24.001(+/-1.821)	23.871(+/-1.657)	12.596(+/-0.981)
feh	-1.900(+/-0.029)	-1.901(+/-0.027)	-1.883(+/-0.036)
lsigfeh	-0.516(+/-0.034)	-0.515(+/-0.033)	-0.488(+/-0.045)
sigfeh	0.305(+/-0.024)	0.306(+/-0.023)	0.325(+/-0.033)
pmra	0.703(+/-0.016)	0.702(+/-0.016)	-
pmdec	-1.123(+/-0.017)	-1.124(+/-0.017)	-

Overall, the posterior parameters using emcee is similar to dynesty. Compared with previous model with RV and [Fe/H] only, rv of full model is higher, with larger uncertainties.

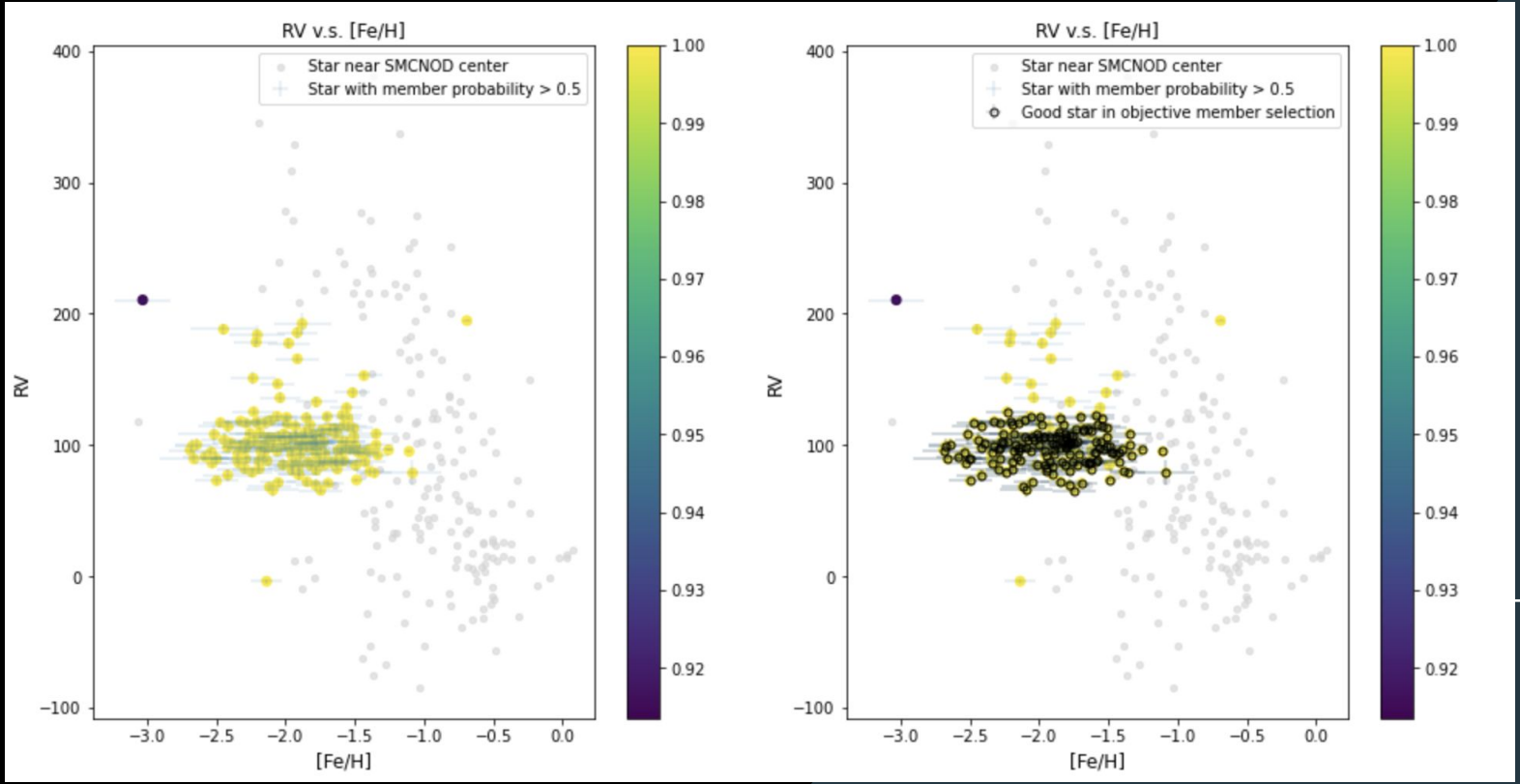
Membership Probability

p = (gal*pgal) / [(gal*pgal)+(1-pgal)*bg]

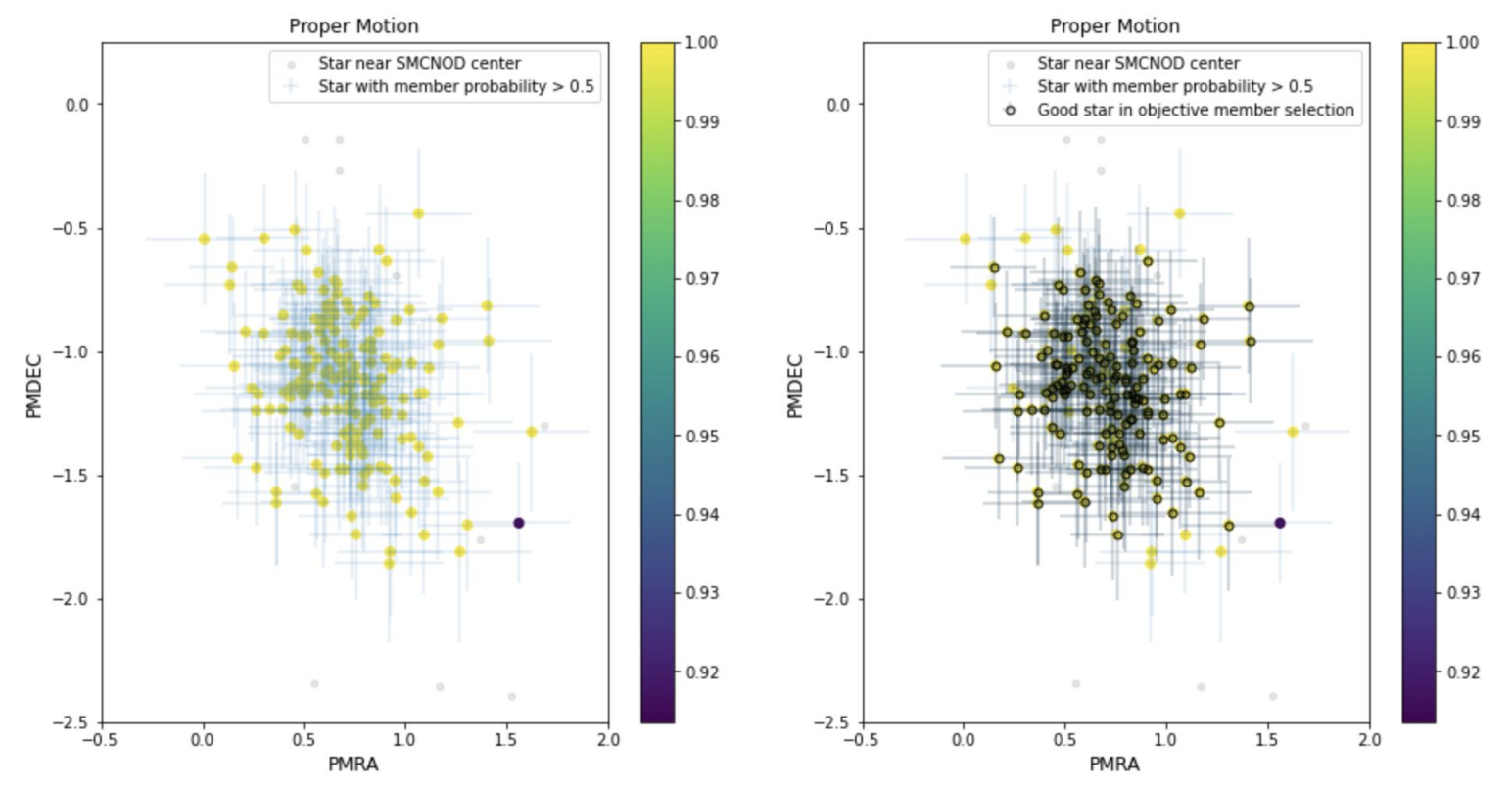


- SMCNOD high-quality sample: 371
- P > 0.5: 176
- P > 0.999: 175

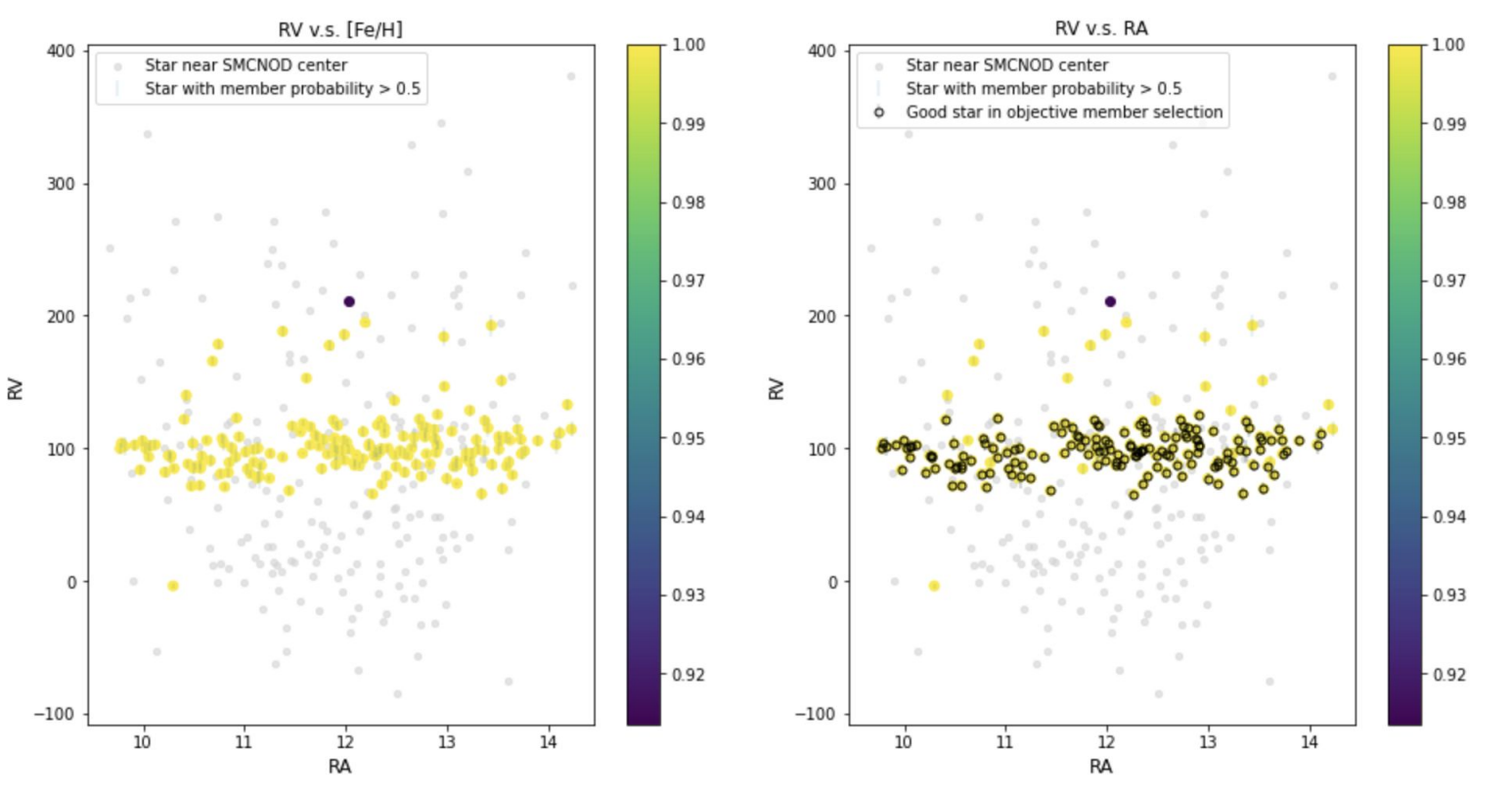
RV v.s [Fe/H]


RV v.s. [Fe/H]
Star near SMCNOD center
Star with member probability > 0.5
RV
[Fe/H]
RV v.s. [Fe/H]
Star near SMCNOD center
Star with member probability > 0.5
Good star in objective member selection
RV
[Fe/H]

Proper Motions



RV v.s RA


RV v.s. [Fe/H]
Star near SMCNOD center
Star with member probability > 0.5
RV
RA
RV v.s. RA
Star near SMCNOD center
Star with member probability > 0.5
Good star in objective member selection
RV
RA

Possible Origin of SMCNOD

Past LMC - SMC encounter

- **Result:** enhanced star formation activity in both SMC & LMC
- **Implication:** the SMCNOD consists of material that was tidally stripped from the SMC.

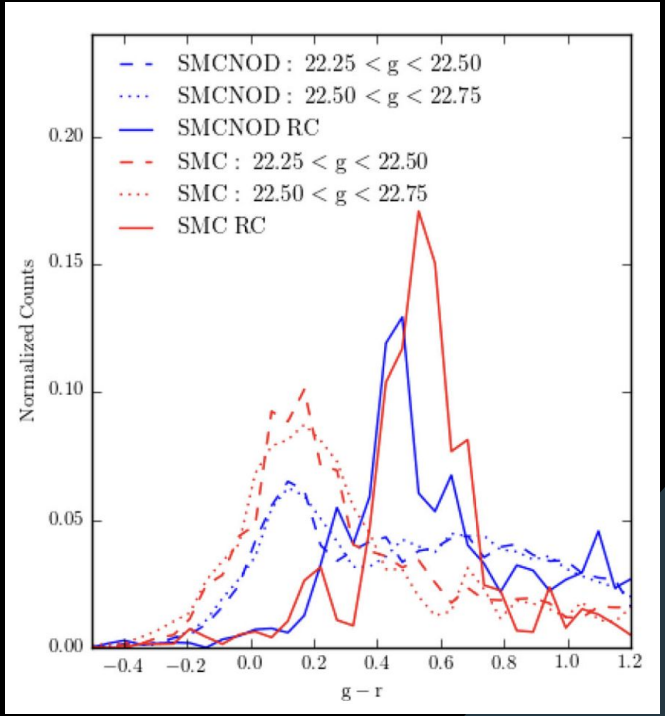
Resonant stripping in dwarf-dwarf encounters

- **Result:** formation of shells comparable with the SMCNOD.

SMCNOD is a small dwarf galaxy currently orbiting around and/or being tidally disrupted by the SMC

- **Implication:** a fairly low metallicity and a narrower age distribution for the SMCNOD in comparison with the SMC.
- **Investigation**: variable stars & association with SMCNOD

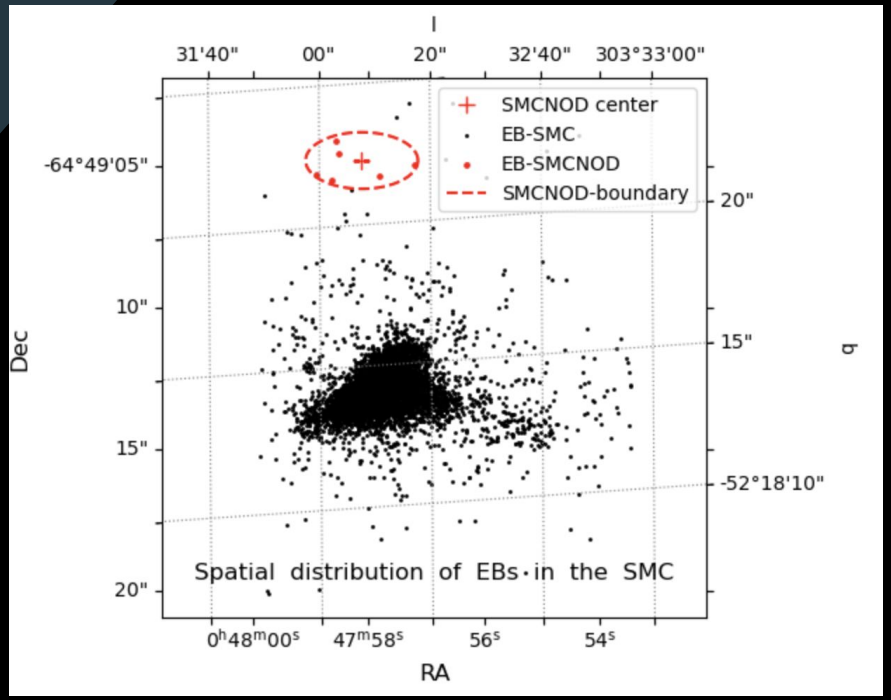
using spatial distribution and distances



Histograms in bins of colour, filtered by the CMD mask for the SMCNOD

(Pieres et al. 2017)

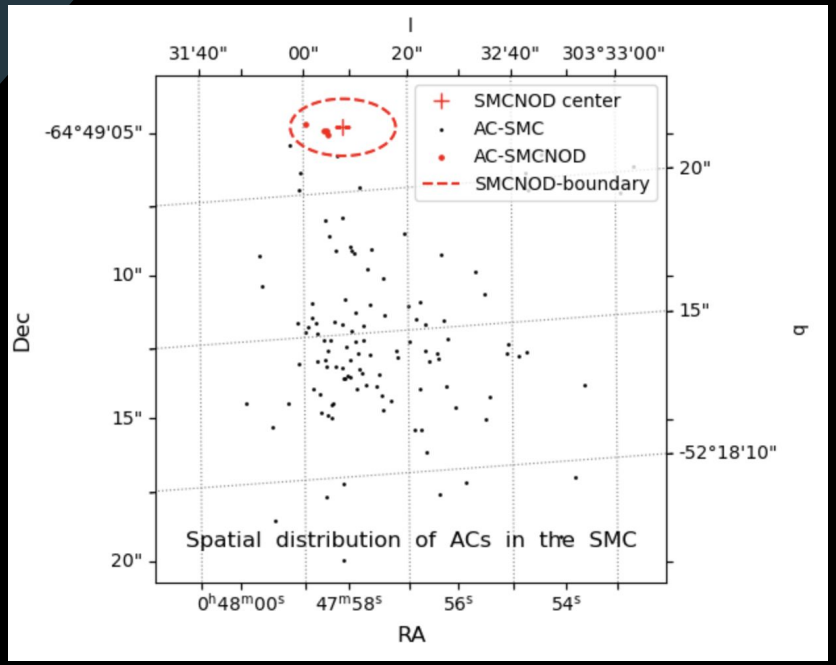
Eclipsing Binaries



ID	R.A. [deg]	Dec [deg]	I [mag]	V [mag]	P [day]
6268	6.93404	-65.31314	16.627	17.133	1.3383077
6319	8.65396	-65.49322	14.731	15.543	3.6228675
6334	9.18079	-64.10989	16.028	17.152	1.5717865
6349	9.44271	-64.54739	16.021	17.157	4.0081439
7162	14.01704	-65.36956	13.998	15.247	0.8175277
7856	17.87579	-64.95067	16.061	19.000	1.9892185

- Testing stellar evolution theory & constraining the rate of mass transfer and mass loss.
- 6 EBs: alll belong to the eclipsing detached/semi-detached subtype
- similar I-band magnitudes

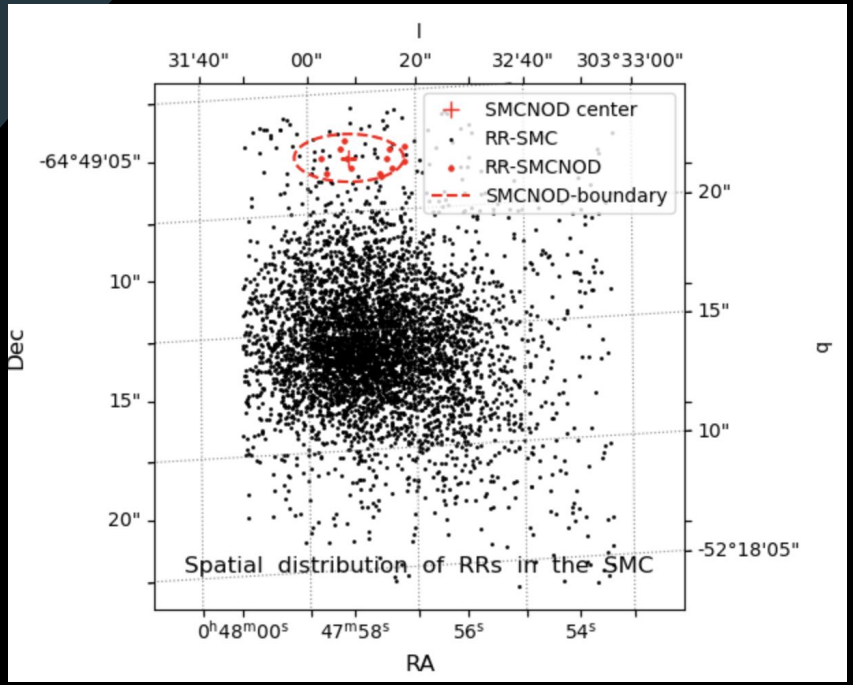
Anomalous Cepheids



ID	mode	R.A. [deg]	Dec [deg]	d [kpc]	σ_d [kpc]
016	F	7.55325	-64.69511	59.48	3.89
027	1O	9.83200	-64.90775	66.58	4.50
031	F	10.12183	-64.93772	68.46	4.49
034	F	10.24825	-65.06083	62.97	3.97

- Radial pulsators with short pulsation periods
- Unusual: paucity of ACs in other border regions of the SMC
- 4ACs: most likely members of an intermediate-age population

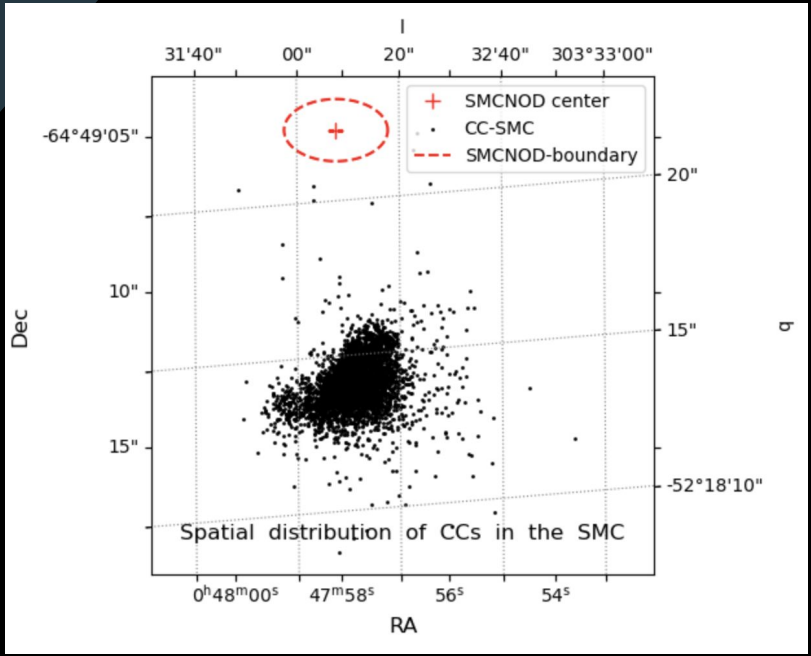
RR Lyrae stars



ID	R.A. [deg]	Dec [deg]	d [kpc]	σ_d [kpc]	[Fe/H]	$\sigma_{[Fe/H]}$
3542	8.78842	-64.83892	66.73	2.82	-1.98	0.45
3633	9.43142	-65.45781	60.39	2.16	-1.72	0.31
3851	10.96179	-64.44103	59.76	1.82	-1.70	0.14
3941	11.47646	-64.06644	5.85	0.17	-1.29	0.04
3973	11.73700	-64.80486	56.10	2.45	-1.27	0.49
4054	12.19496	-65.20972	59.31	2.04	-0.78	0.29
4566	15.55129	-65.45931	64.63	2.20	-2.18	0.25
4581	15.63971	-65.54542	57.70	1.87	-1.59	0.22
4685	16.24354	-64.84886	17.29	0.51	-1.72	0.07
4738	16.63004	-64.40250	76.23	3.03	-2.50	0.39
4777	16.94008	-65.23344	61.27	2.16	-2.05	0.29
4960	18.25642	-64.33211	71.51	2.39	-2.27	0.23
4965	18.30121	-64.92725	60.01	1.82	-1.56	0.14

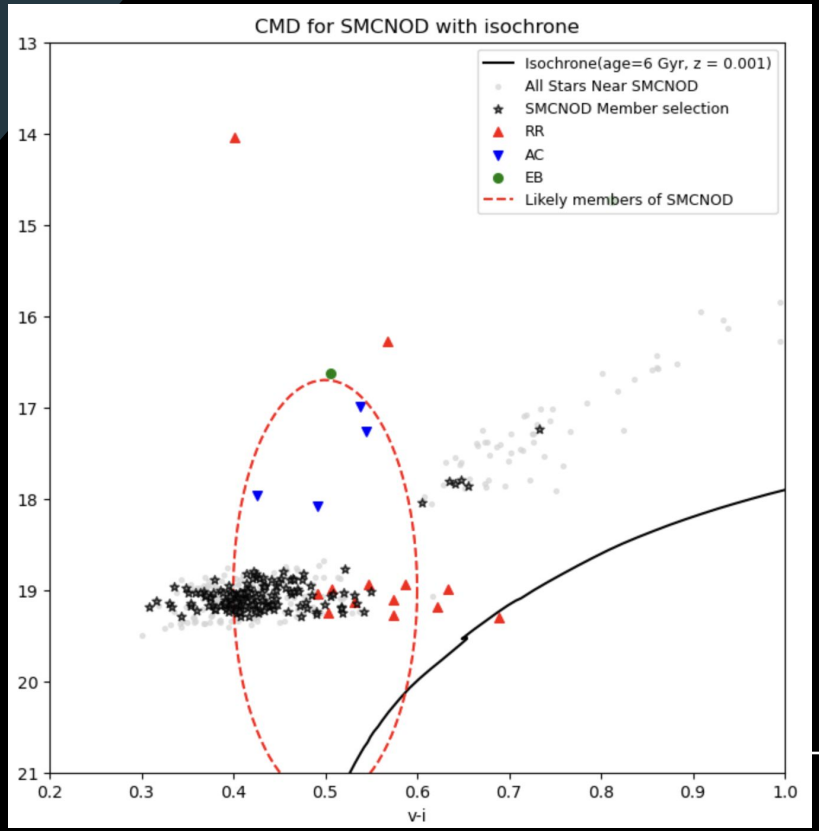
- study stellar pulsations and evolution
- unambiguous indicators of populations older than 9 Gyr
- 13 RR Lyrae stars: 8 are consistent with the assumed scale height for the SMCNOD

Classical Cepheids



- None of the CCs overlap with the SMCNOD.
- Most of them are concentrated in the central regions with very few located in the outskirts of SMC
- Lack of CCs: lack of stars with age < a few hundred million years.

CMD for SMCNOD with isochrone



- Most Likely Members of SMCNOD:

  4 spatially concentrated Anomalous Cepheids

  8 evenly dispersed RR Lyrae stars

- Based on its variable stars density, we agree with the conclusion in Pieres et al. 2017 of a modest overdensity in intermediate-age stars in the SMCNOD

Thank you & Discussions?