A New Stellar Population in the Bulge And a New Survey

R. Michael Rich (UCLA),

Andrea Kunder(AIP), Christian Johnson (CfA), Andreas Koch (ZAH),
Ortwin Gerhard (MPIA), Juntai Shen (Shanghai Observatory),
HongSheng Zhao (St. Andrews), John Kormendy (UT Austin), Will Clarskon (IU)
Roberto de Propris (ESO and FINCA), Livia Origlia (Bologna)
Annie Robin (Besancon), Mario Soto (STScI)

HST Legacy

Our new picture of the Galactic Central Bulge

The Bulge has a “bar structure” and is internally complex

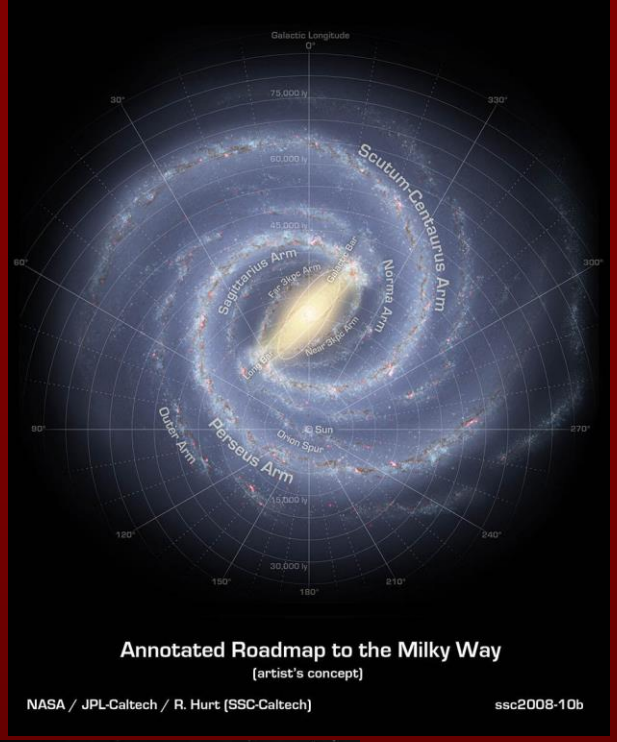
Evidence from ages and composition support the idea that the bulge is older than 10 billion years (10 Gyr)

But the bar appears to have formed from a disk, and that process should be slow.

Some features remained unexplained. How did the bulge survive infall of dark matter?

“bars”

non-barred “classical”



M104 (Hubble)

“classical”

Our bulge is X-shaped/boxy

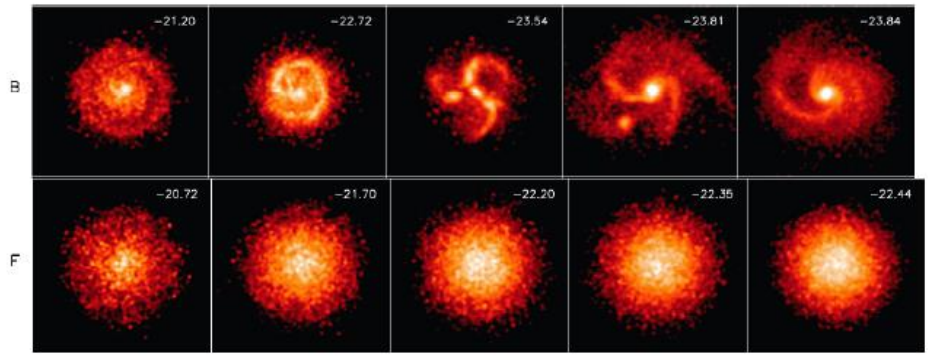
NGC 4710 (Hubble)

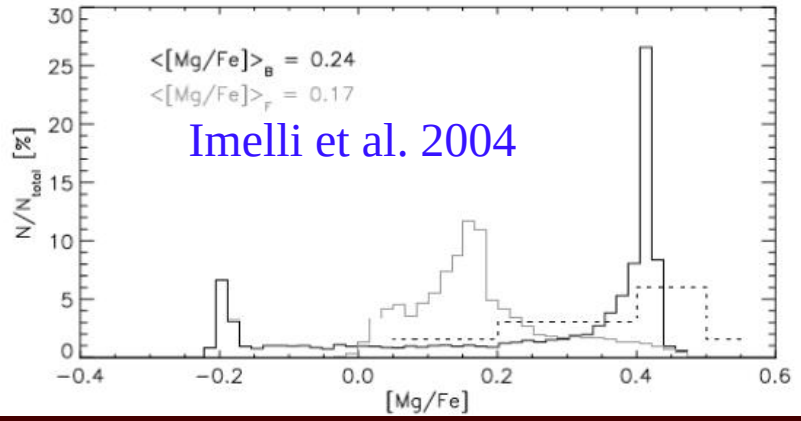
NGC 4565

“boxy/ X-shaped”

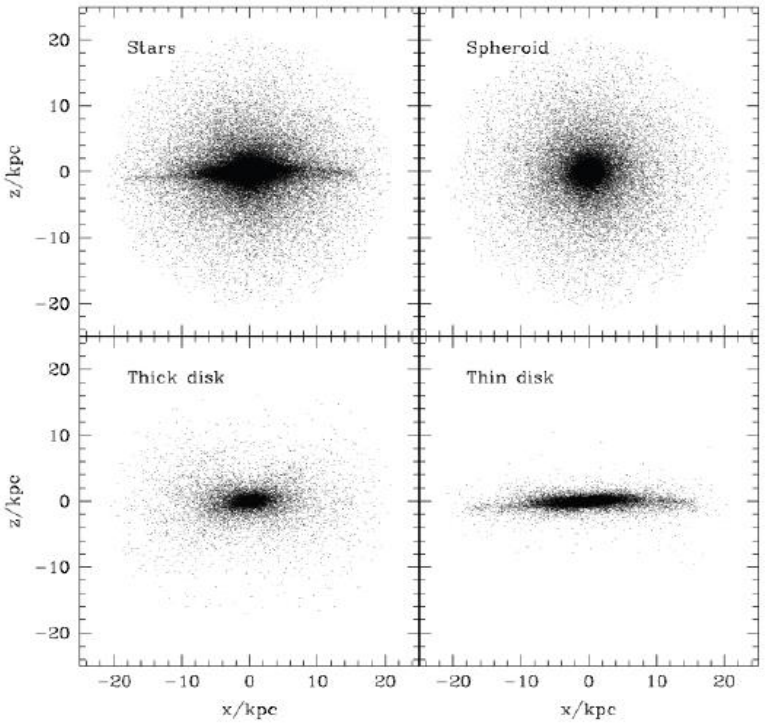
Formation of the bulge? Classical merger? Or clumps?

Multiple star forming clumps might produce kinematic subgroups with distinct chemical or dynamical fingerprints.





Abadi 2003



Imelli et al. 2004; Elmegreen et al. (2008) See also Inoue et al. 2013, Elmegreen et al.

Or N-body bar?

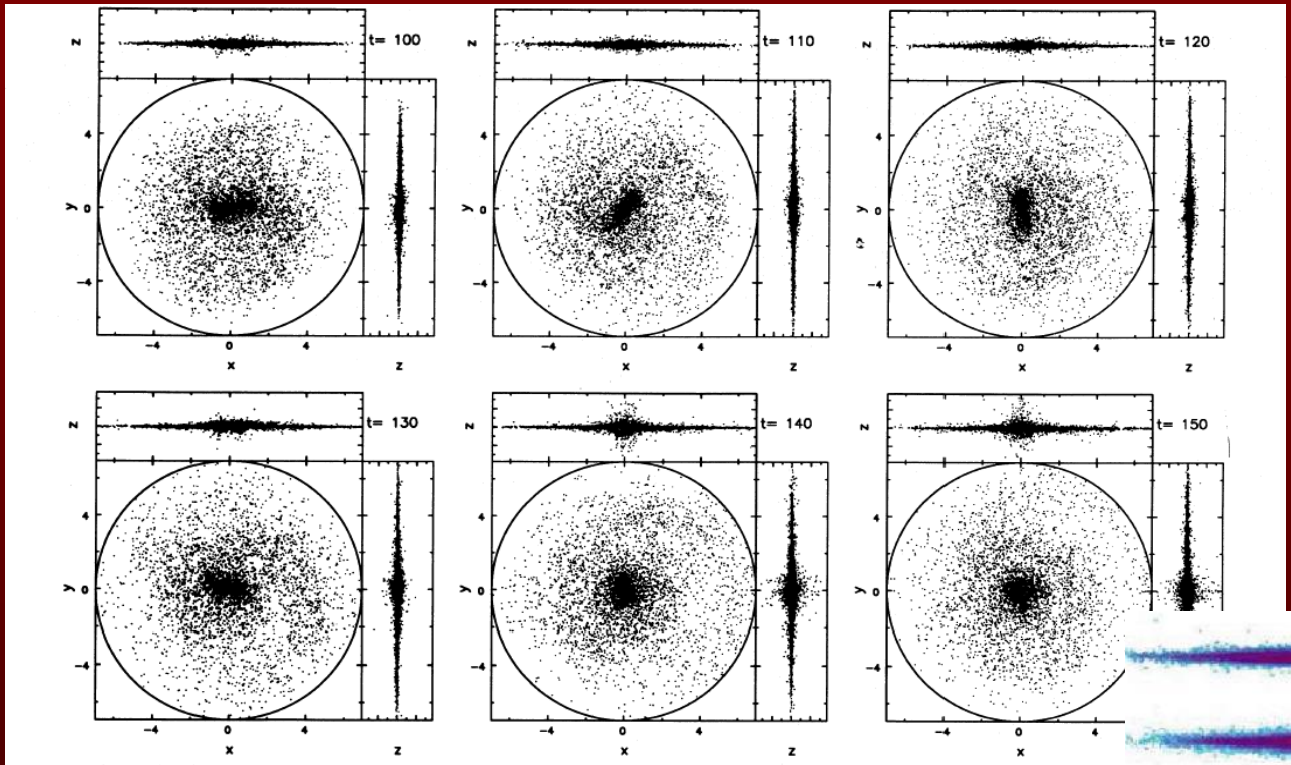
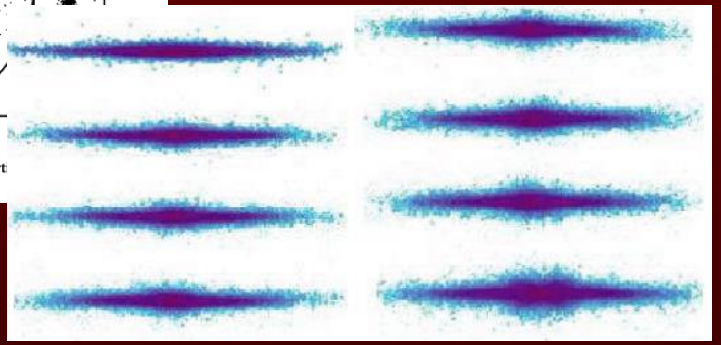


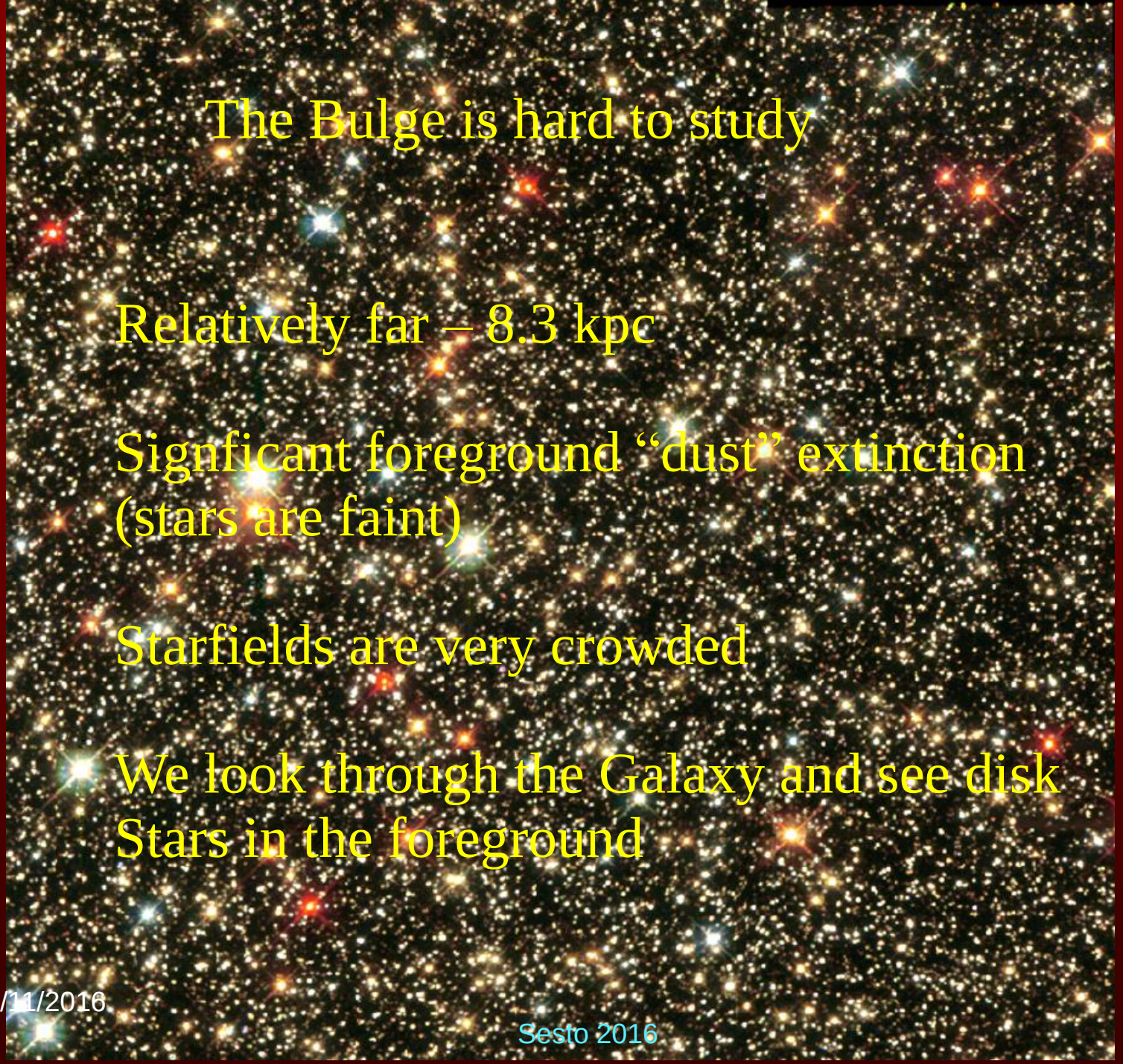
FIG. 6.—The evolution of a three-dimensional model in which a 5% central mass is grown from time 100 to time 140. The whole calculation volume is shown, but only one part bar dissolves abruptly between times 130 and 140, forming a spheroidal bulgelike feature at the center.

Combes 09- bar resurrection via gas inflow

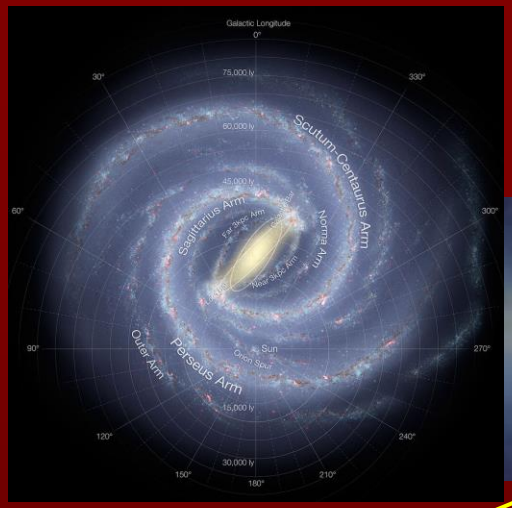


Vertical thickening of the bar into a bulge would leave no abundance gradient in the z-direction.

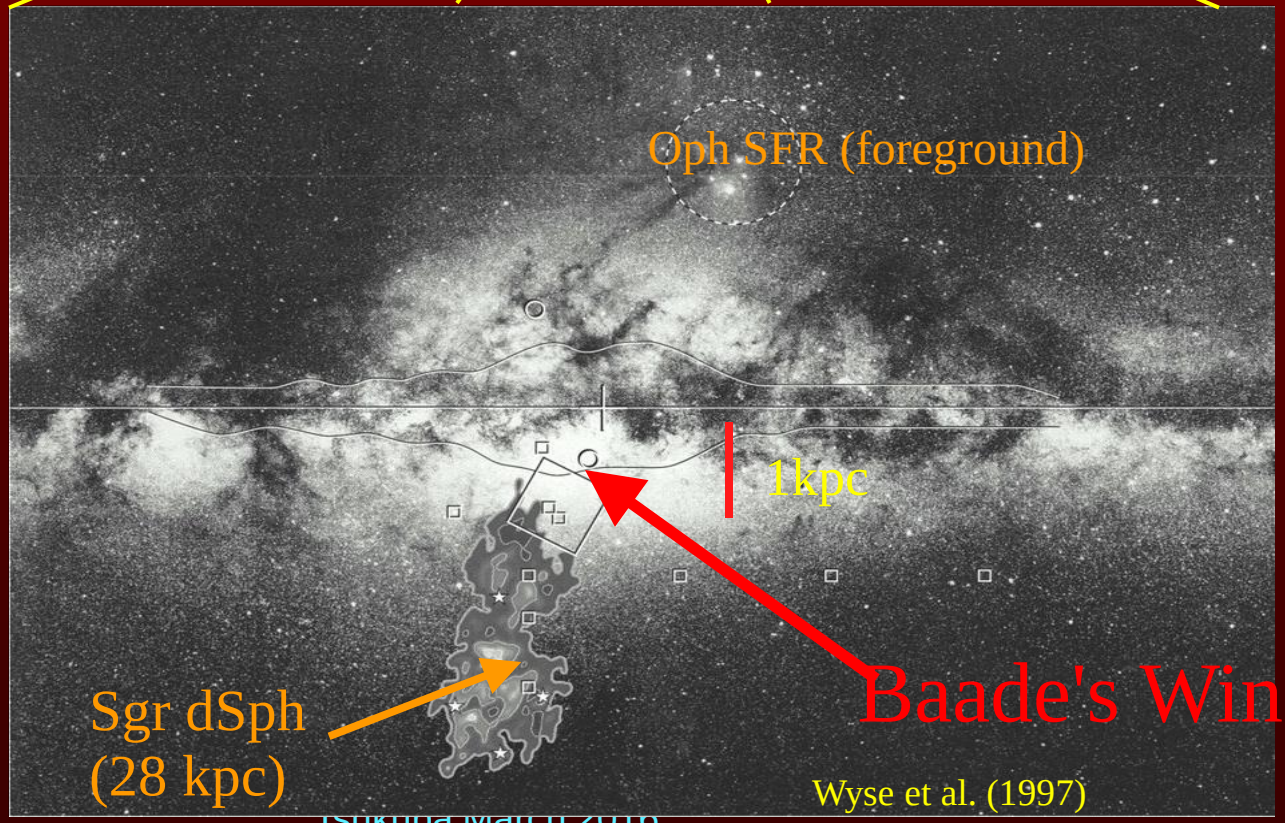
Sesto 2016


The Bulge is hard to study
Relatively far – 8.3 kpc
Signficant foreground “dust” extinction (stars are faint)
Starfields are very crowded
We look through the Galaxy and see disk Stars in the foreground

Bulge in Context

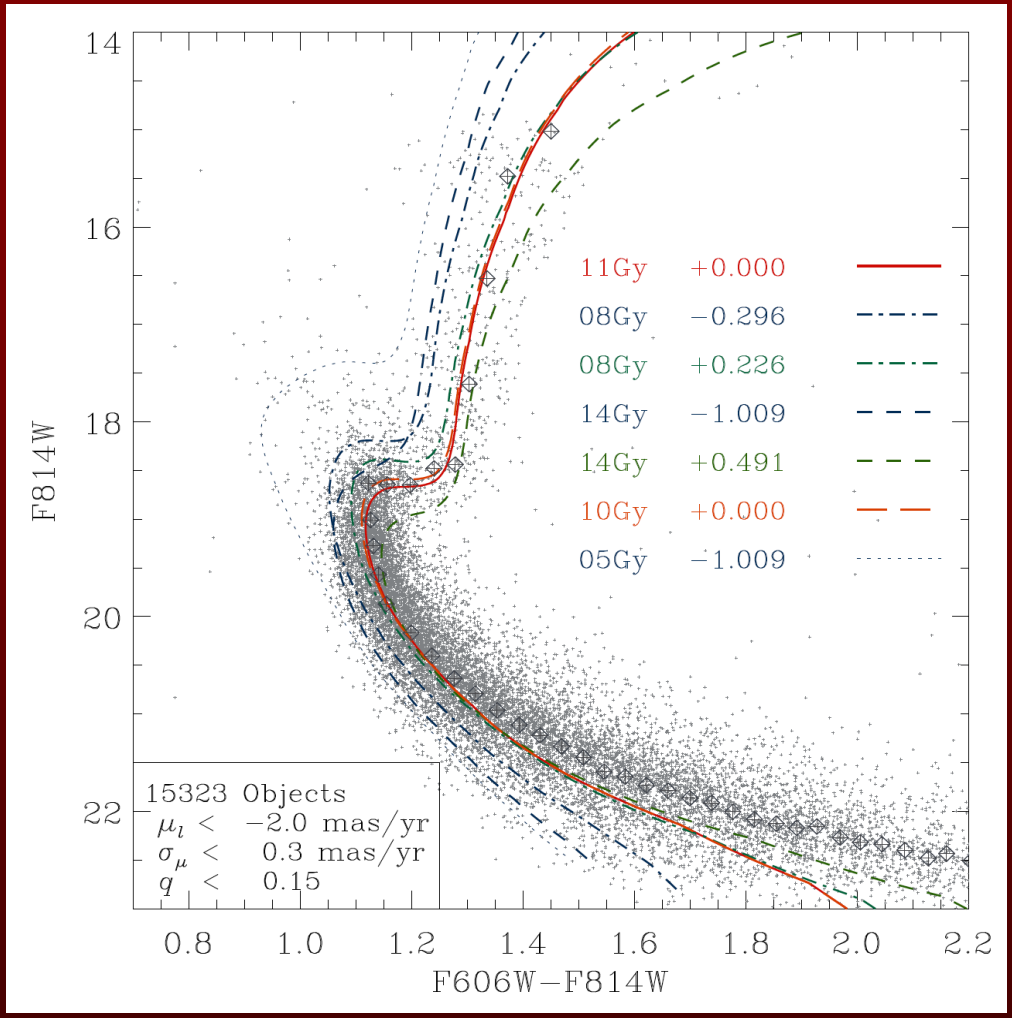


2MASS



Courtesy J. Fulbright

Age constraint from PM separation



~99% of bulge older than 5Gyr; pure 10+ Gyr likely (Clarkson+ 08, 11); Brown et al. 2010; 2016 (HST Treasury survey)

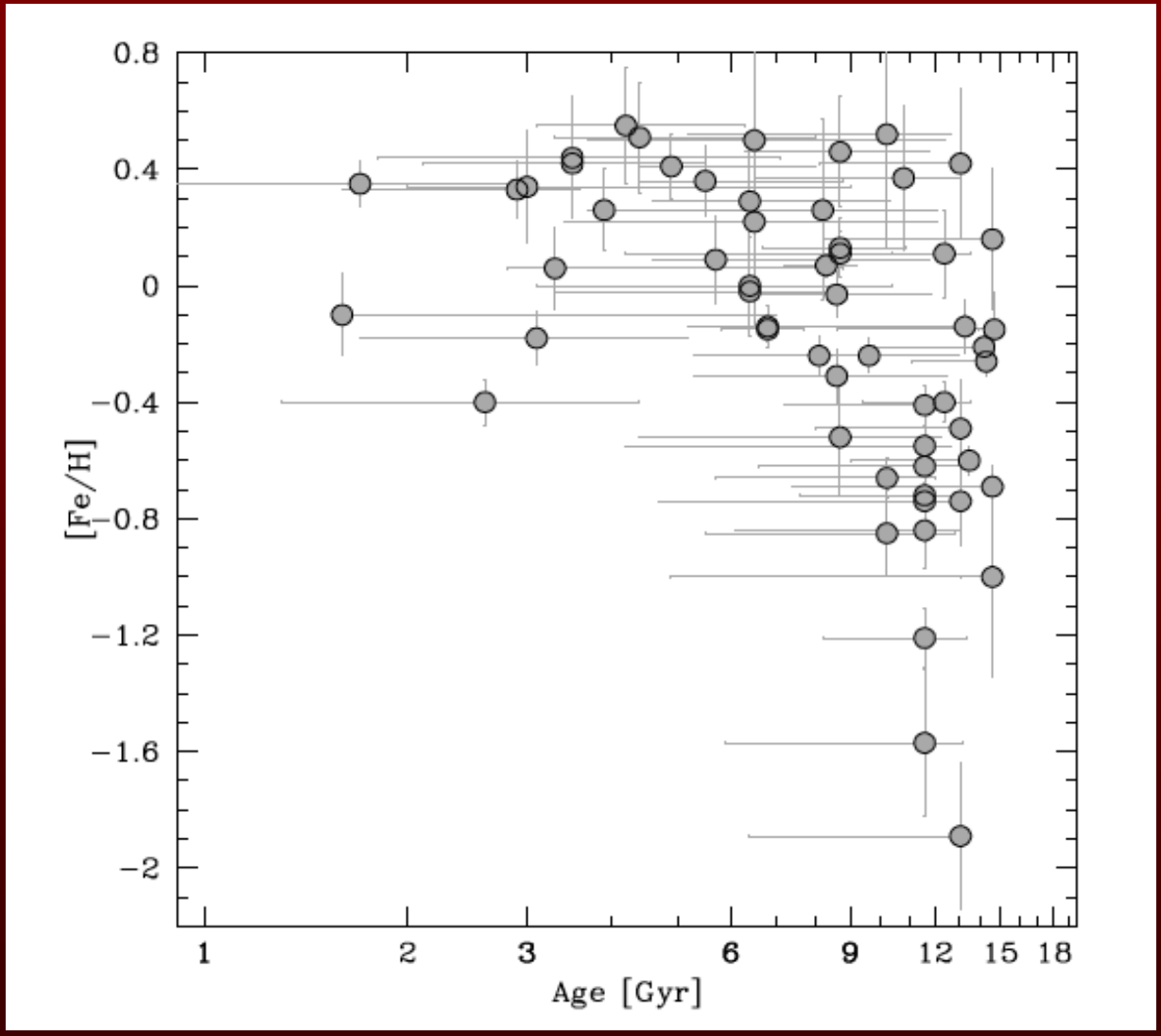
Age still controversial

Bulge dwarfs brightened by microlensing

[Fe/H] , log g Teff

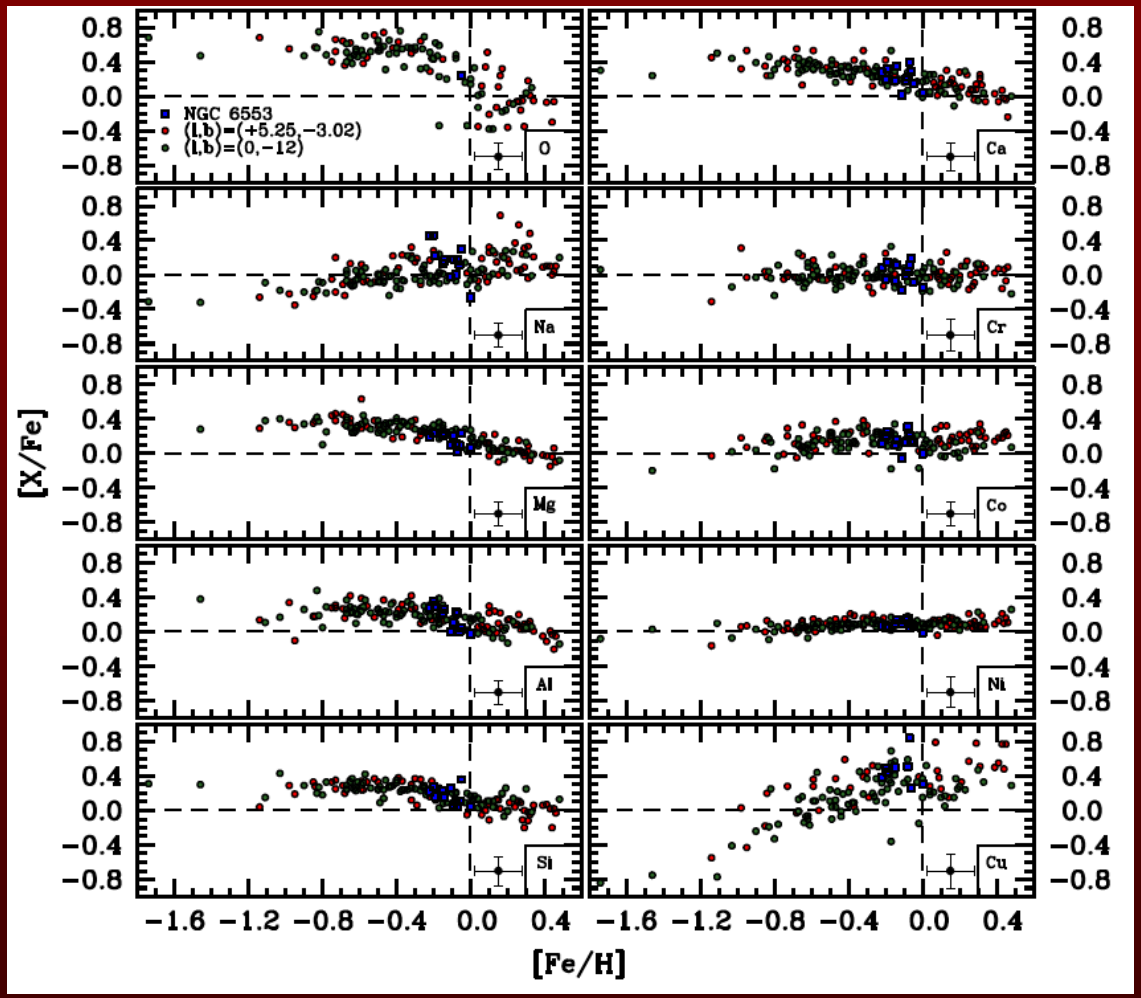
Age from the HR diagram

25% “young??”



Bensby et al. 2013

Chemistry supports early, rapid enrichment



Johnson et al. 2014

Kinematics

The Bulge Radial Velocity Assay (BRAVA)

CTIO 4m + hydra, 9,500 M giants

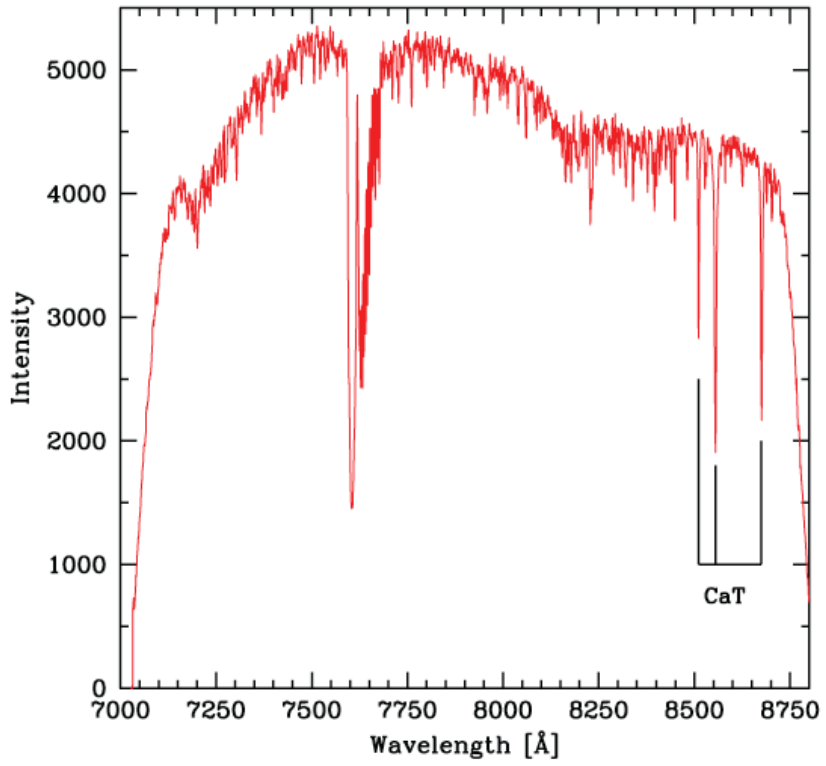


Figure 9. Wavelength-calibrated spectrum of a velocity outlier in our sample with a heliocentric velocity of 447 km s^{-1}. The CaT lines are labeled in the spectrum for reference.

Is there a bar?

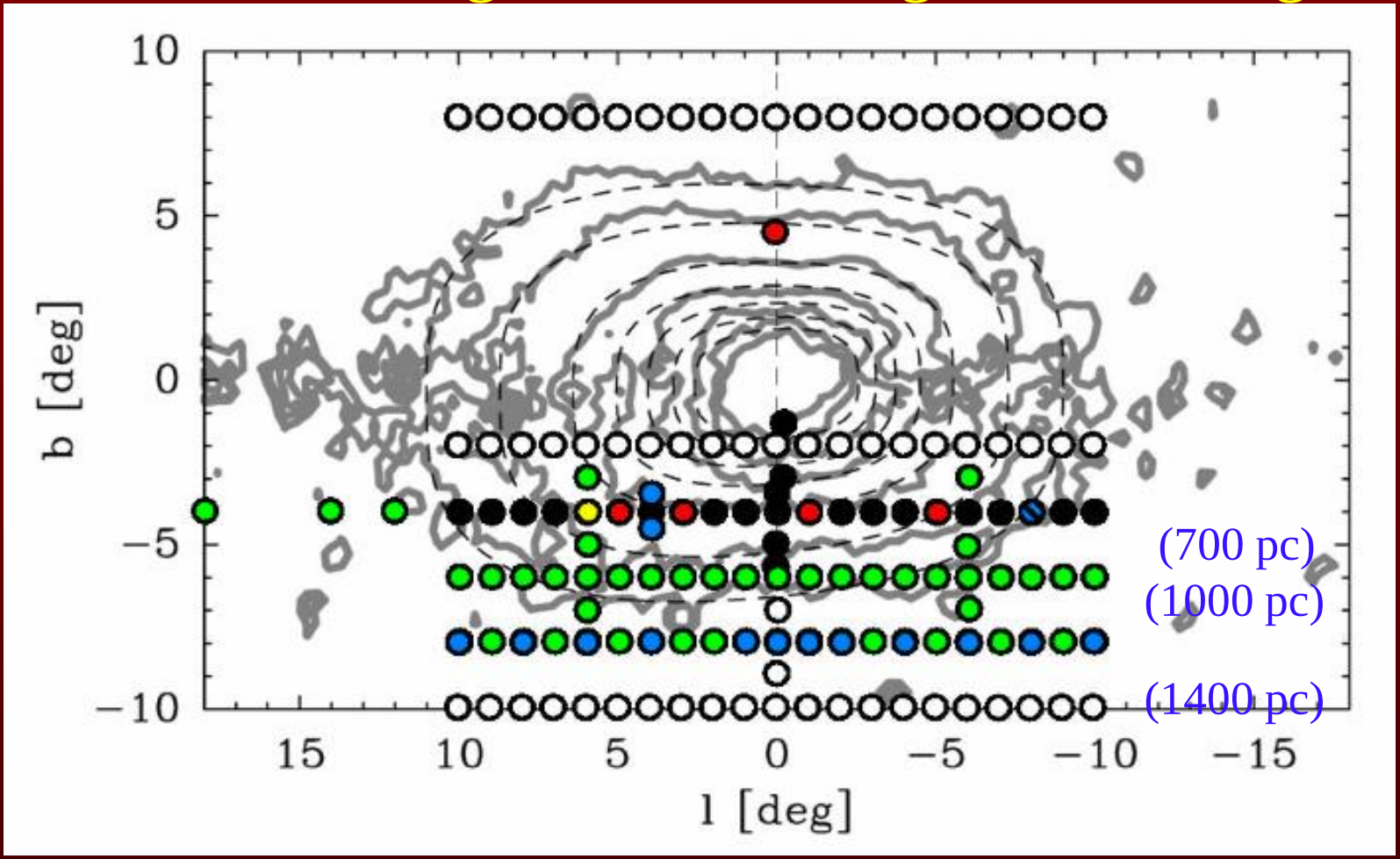
Is there a “classical” bulge?

Is there substructure, even a hidden ingested dwarf galaxy?

Is there a kinematic “cold” rapidly rotating young population?

Rich et al. 2007;
Kunder et al. 2012

Observe the bulge with an extragalactic vantage

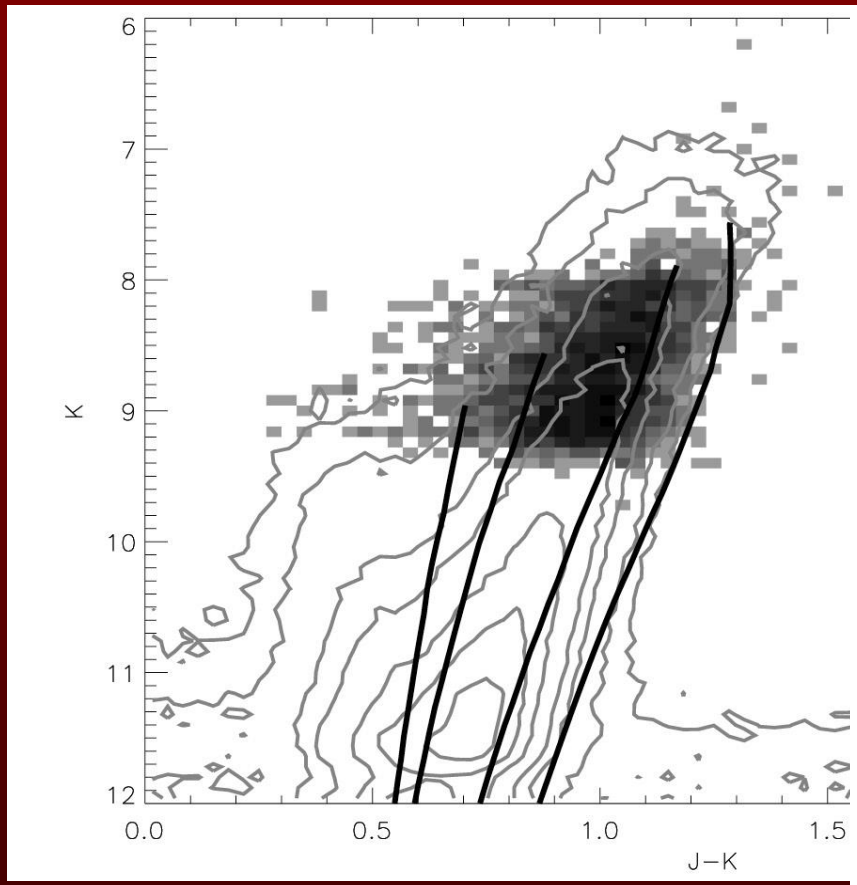


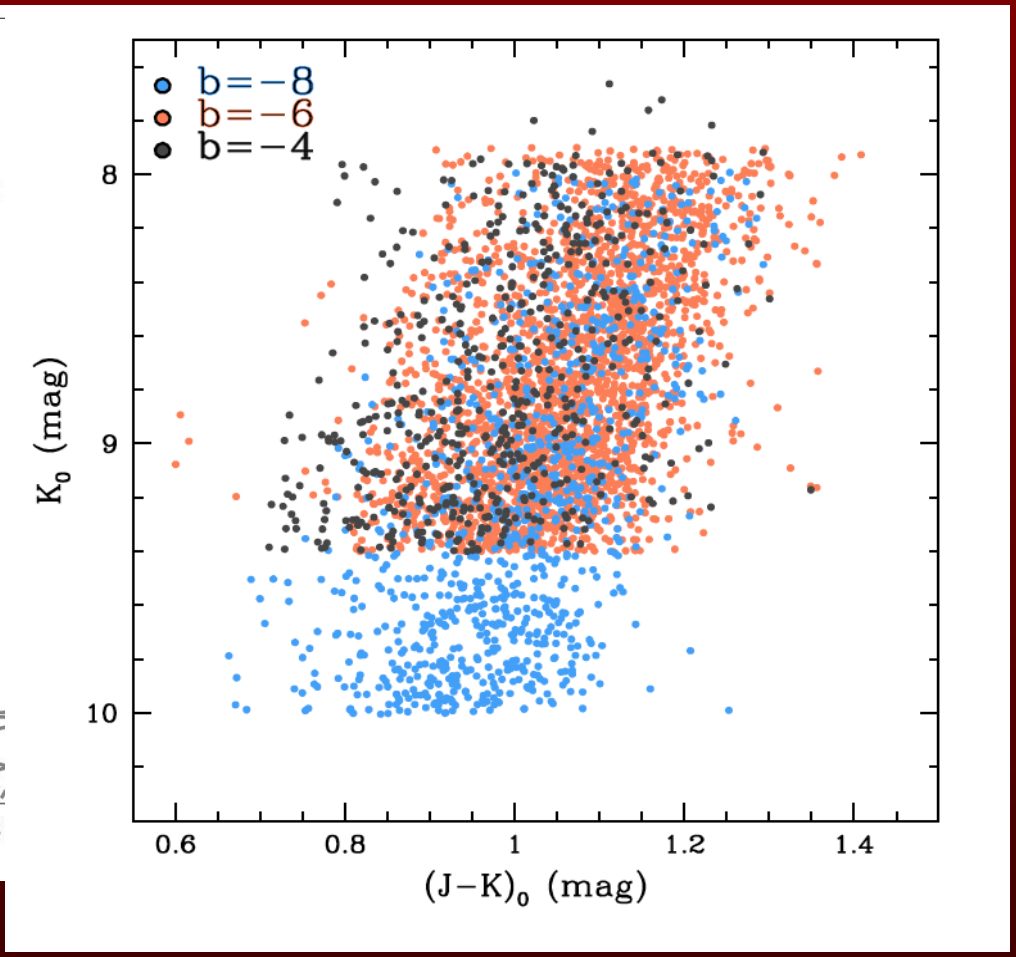
Survey Fields 2005: blue 2006: red 2007: green

Goal: Grid of fields at 1 deg intervals, covering 10x10 deg box, pushing as close to plane as possible

Select the brightest red giants

From 2 micron-All-sky survey

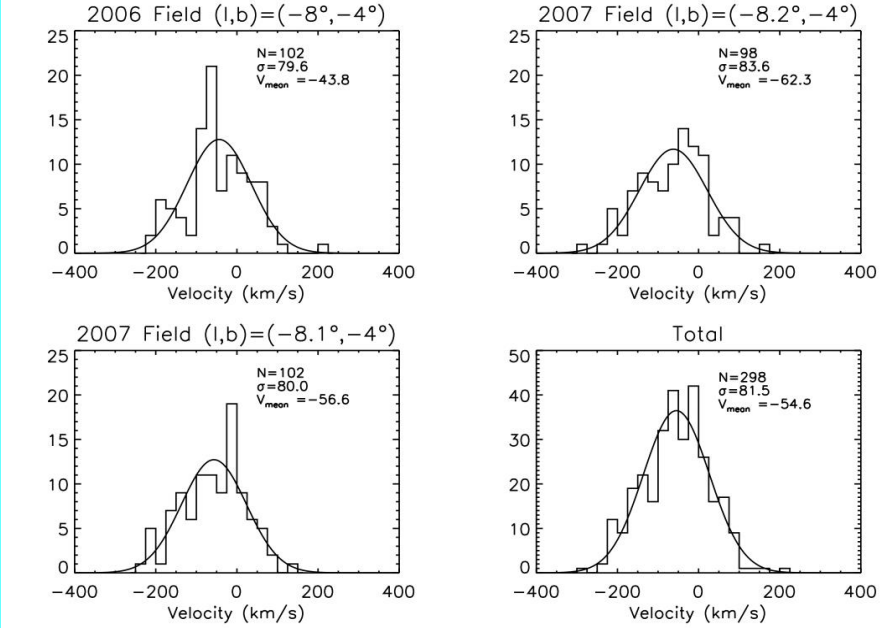


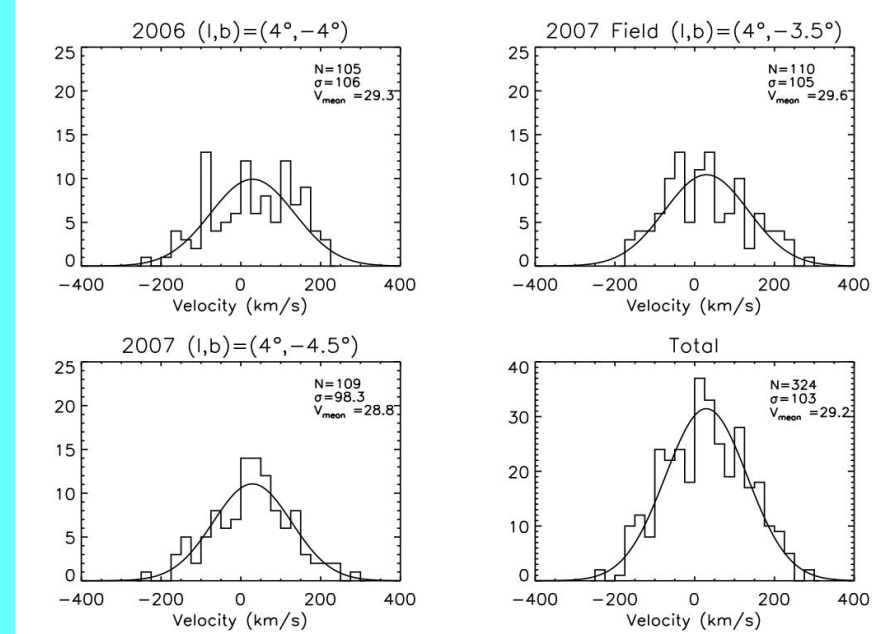


Howard et al. 2008 b=-4 dereddened

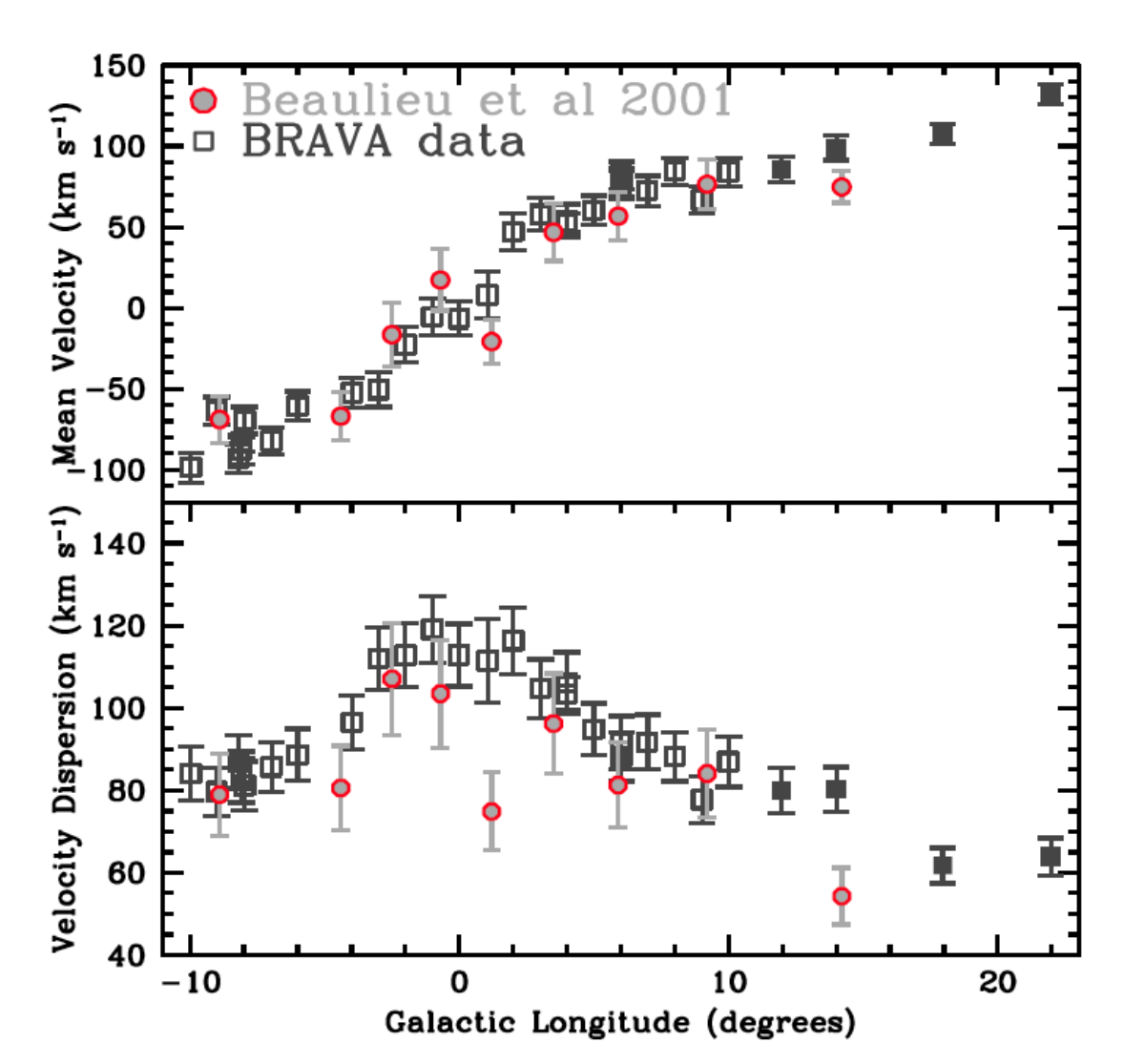
Kunder et al. 2011, new sample

No confirmed stellar streams- “substructure”

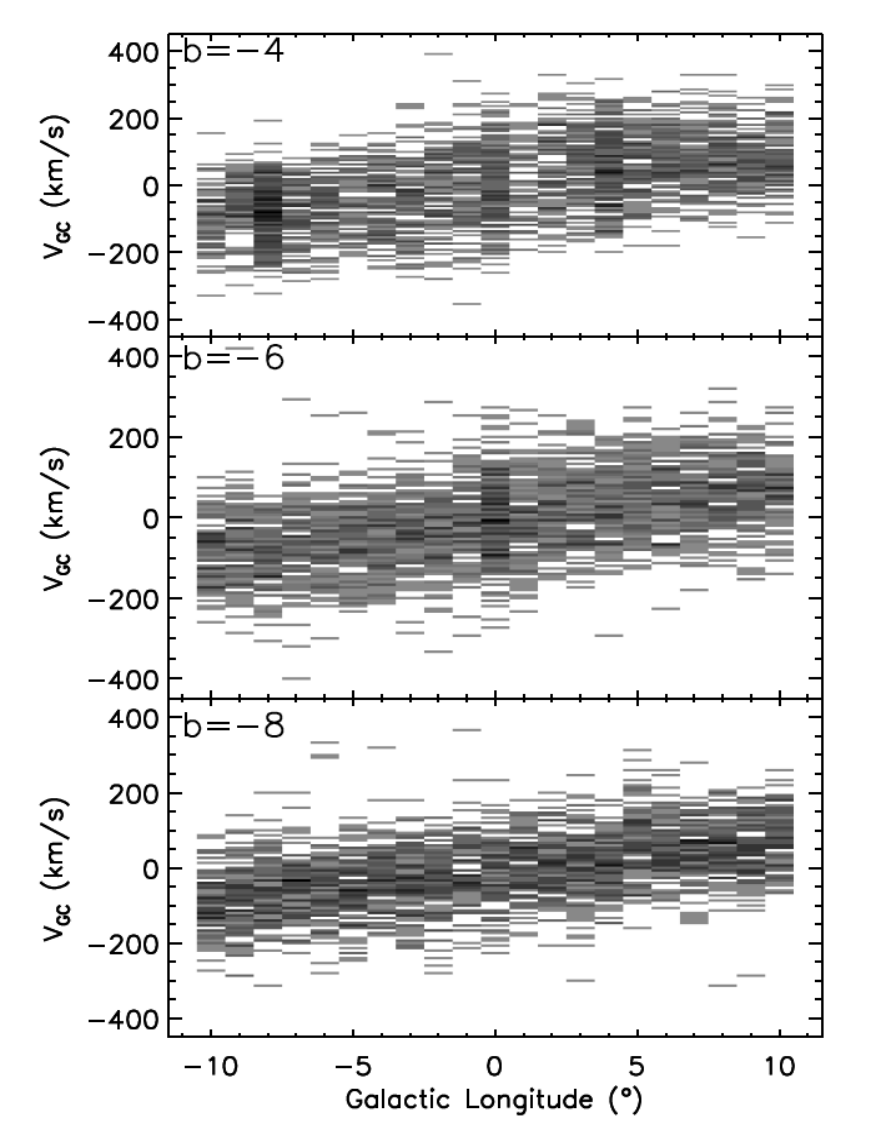


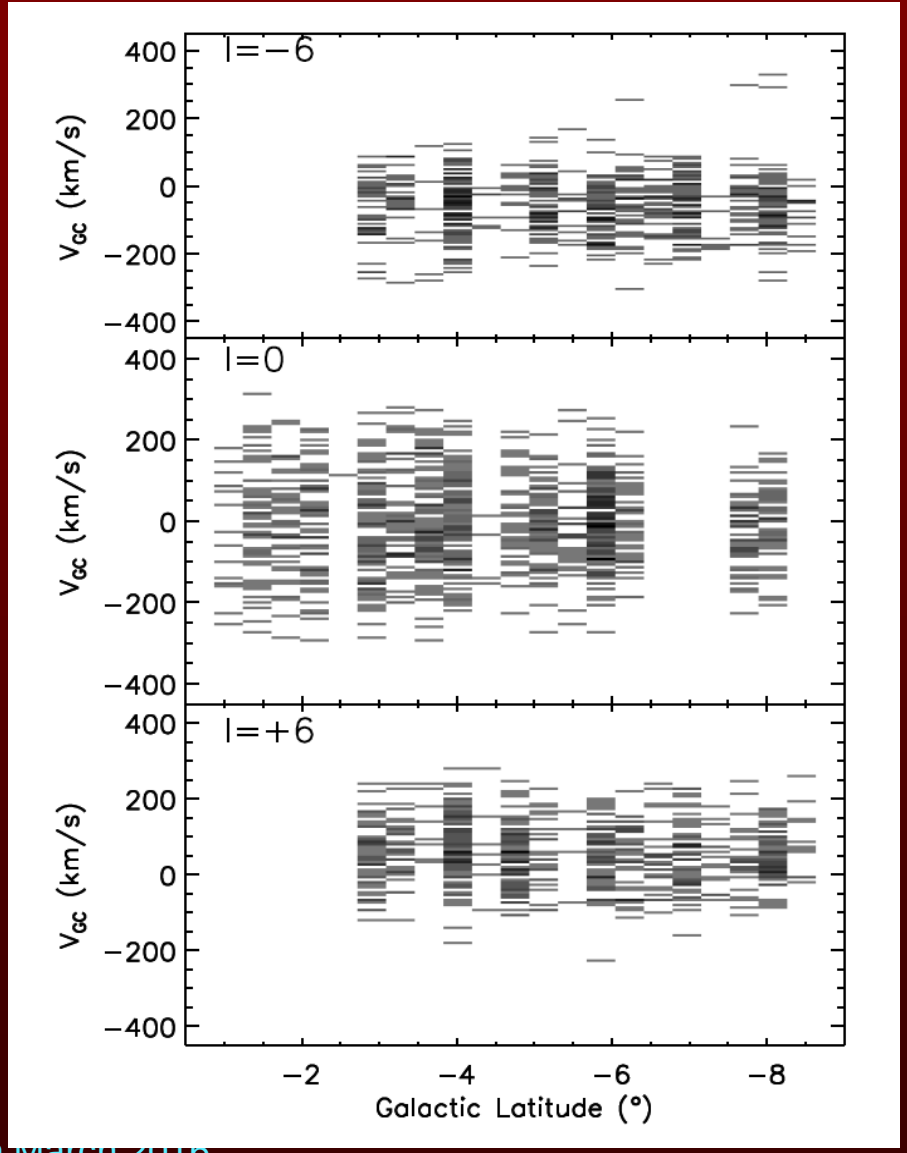


BRAVA yields stellar rotation curve and Dispersion profile

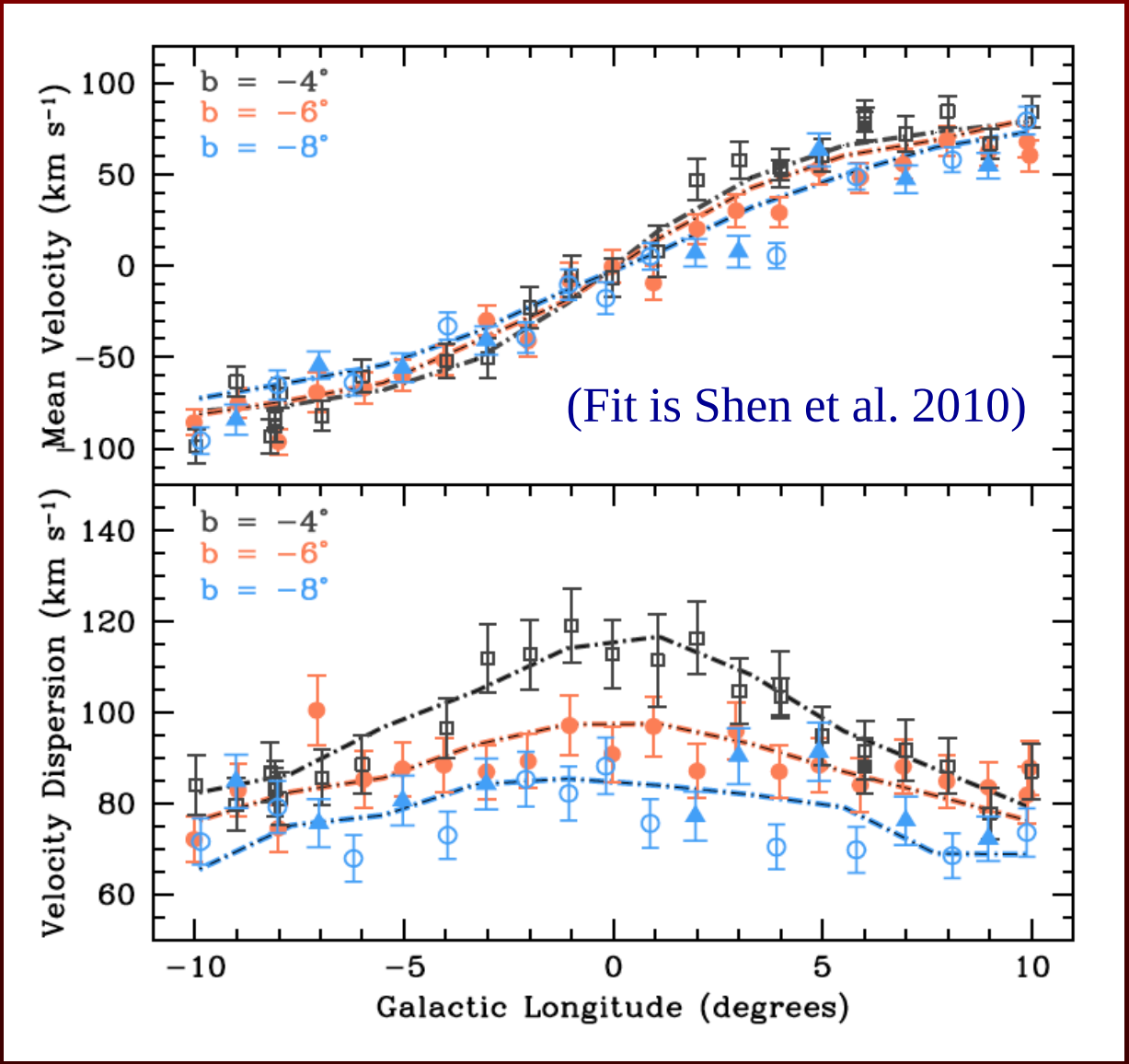


The rotation speed is independent of Galactic latitude
No hot component at 1kpc for “classical bulge”





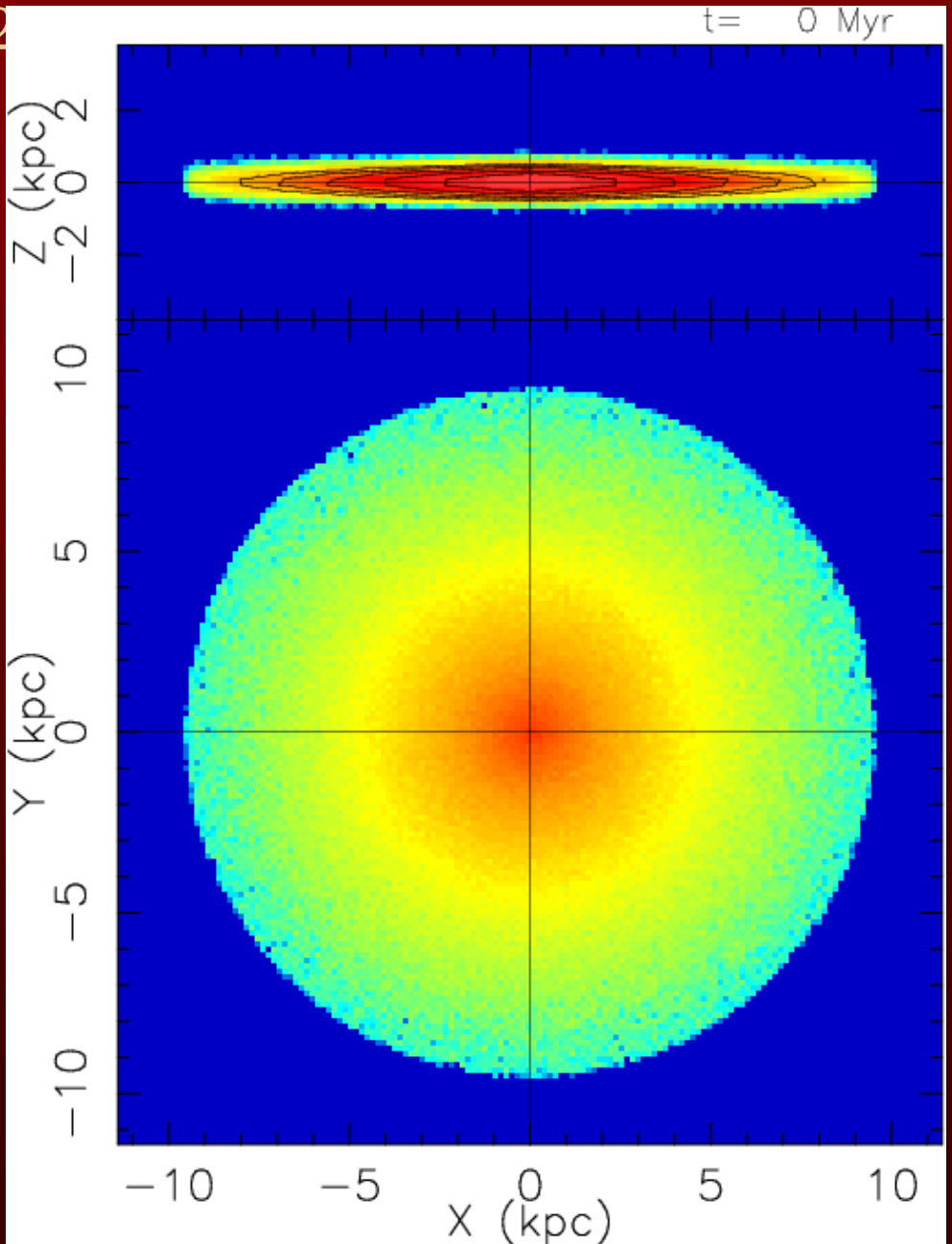
“Cylindrical” rotation consistent with the velocity field of a rotating “bar”.



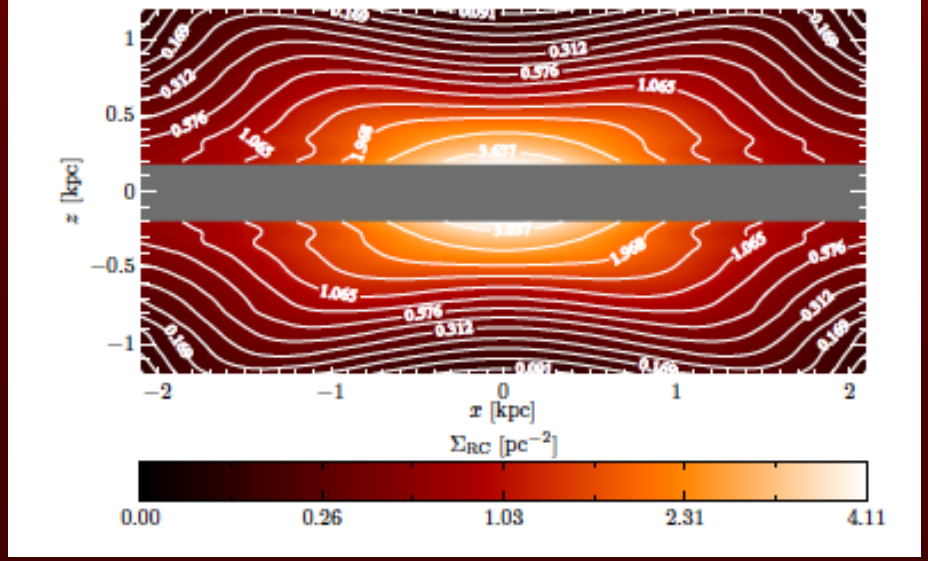
Modeling the Milky Way Bulge

Shen, Rich et al. 2

- A simple model of the Galactic bulge matches the BRAVA data extremely well in almost all aspects:
  - $b = -4^o$ major axis
  - $b = -8^o$ degree major axis
  - $l = 0^o$ degree minor axis
  - Surface density
  - **Shen, J., RMR, Kormendy** et al 2010, ApJL



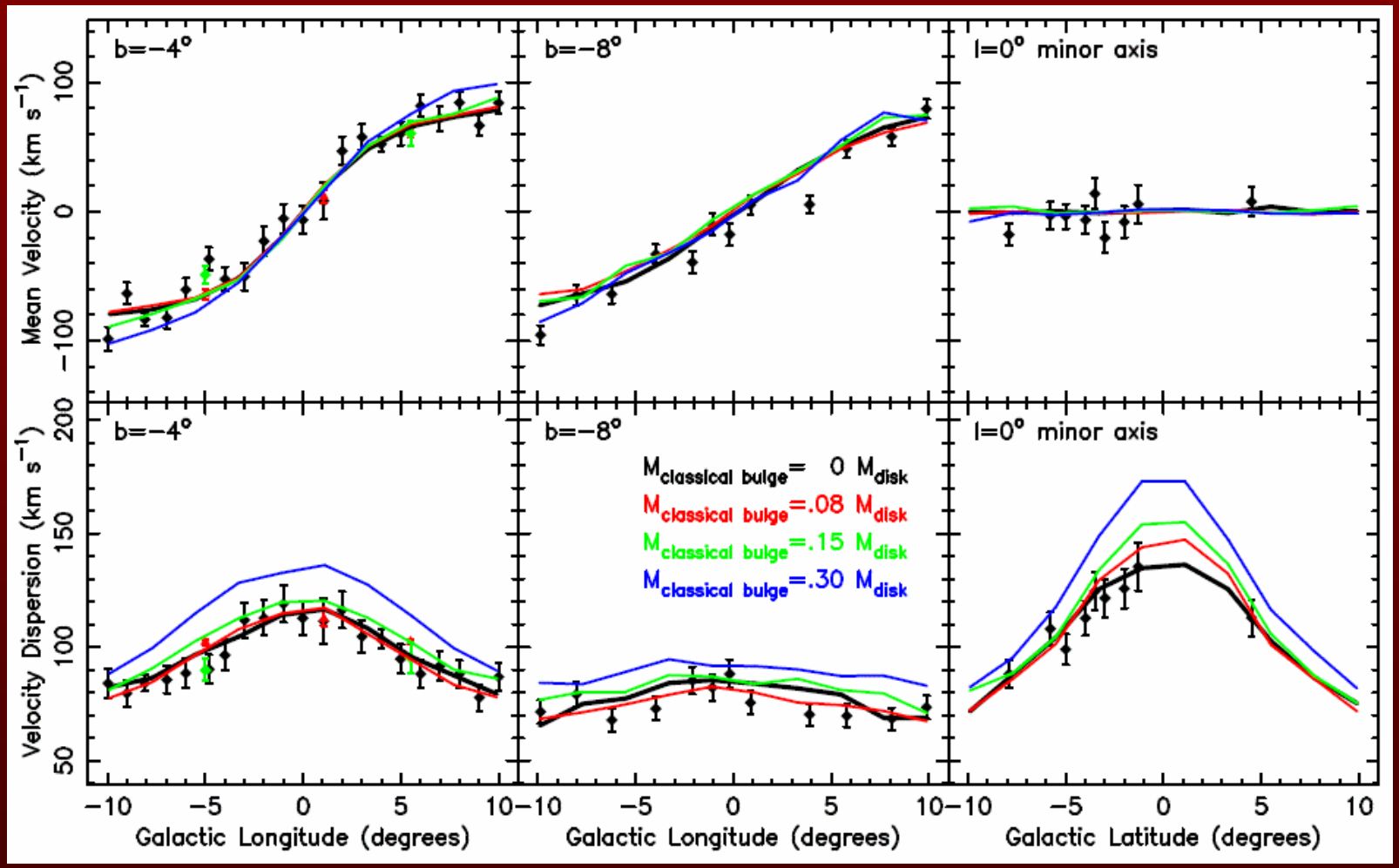
The infrared VVV survey dataset is modeled to reveal an X-shaped bar/bulge in the Milky Way, explaining earlier observations.



27.3º alignment
X is 400pc off plane
10:6.3:2.6 axis ratio

Wegg & Gerhard 2013

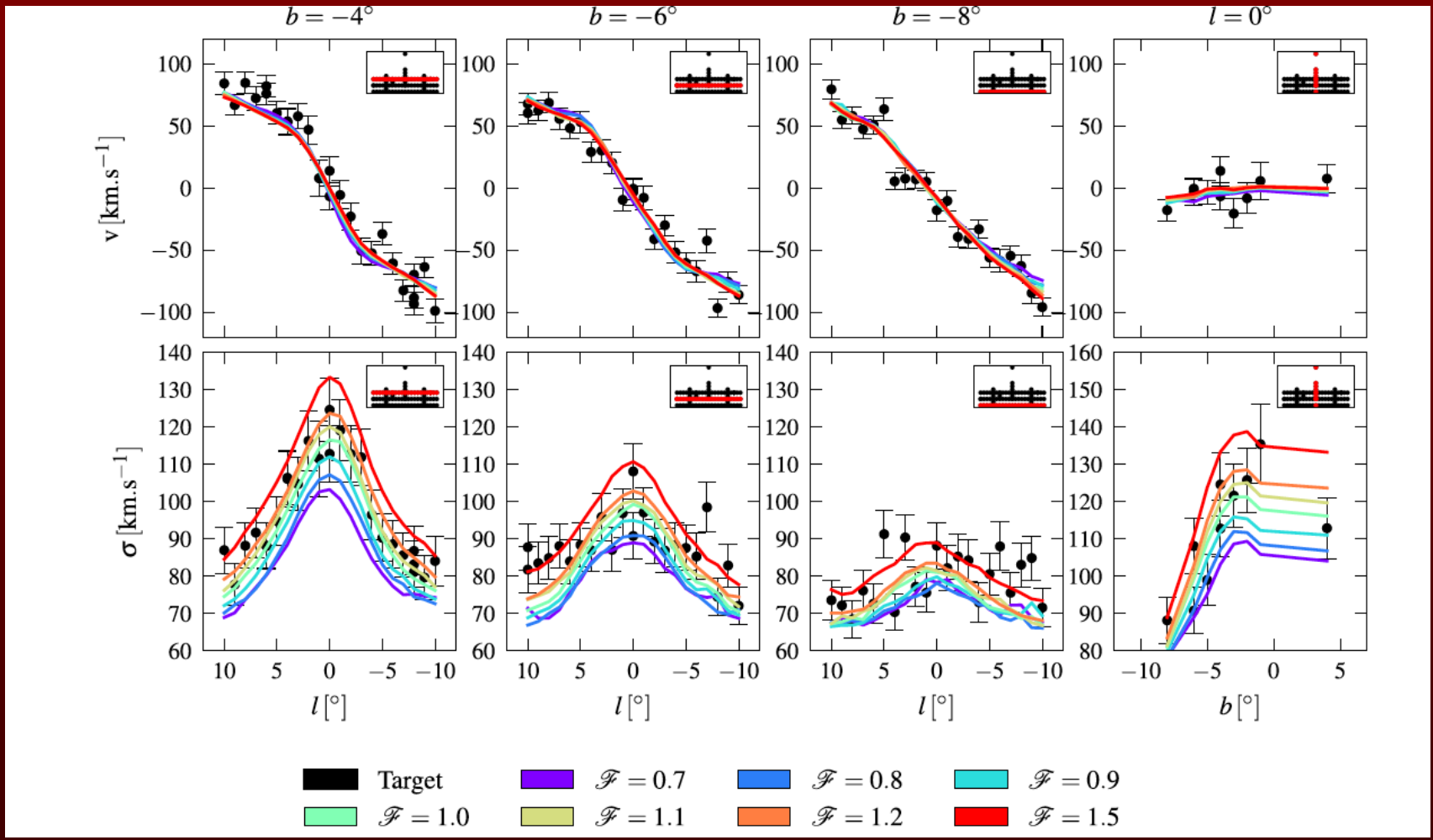
A Significant Classical Bulge is Excluded



The data excludes a pre-existing classical bulge with mass >~ 10% Mdisk

See also Ness et al. 2012,2013; APOGEE

Fitting the N-body X bulge to BRAVA constrains the stellar mass in the bulge/bar (F units of 10^{10} $M_\odot$)



Portail, Wegg, Gerhard 2015

Fits are insensitive to dark matter fraction

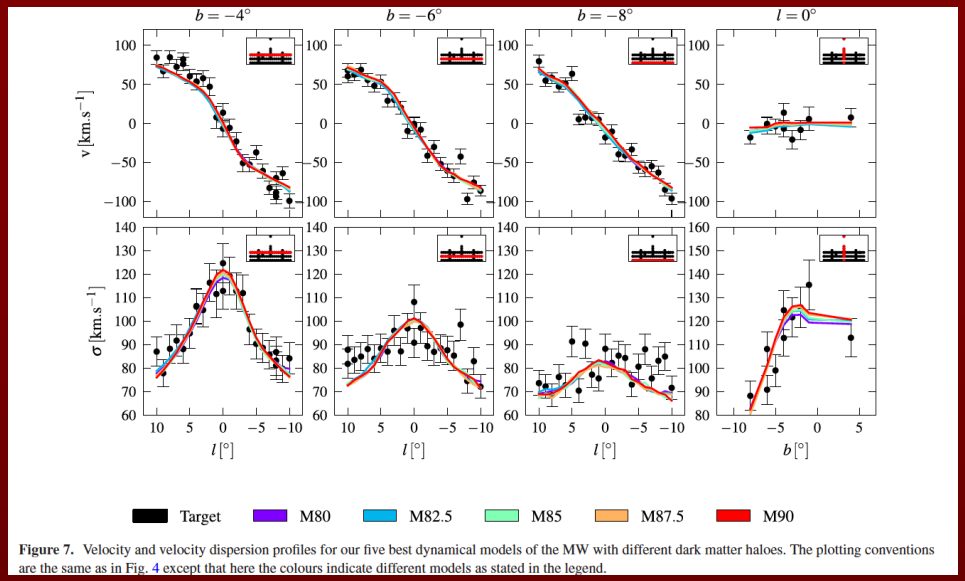


Figure 7. Velocity and velocity dispersion profiles for our five best dynamical models of the MW with different dark matter haloes. The plotting conventions are the same as in Fig. 4 except that here the colours indicate different models as stated in the legend.

But depend on IMF;
Salpeter ruled out

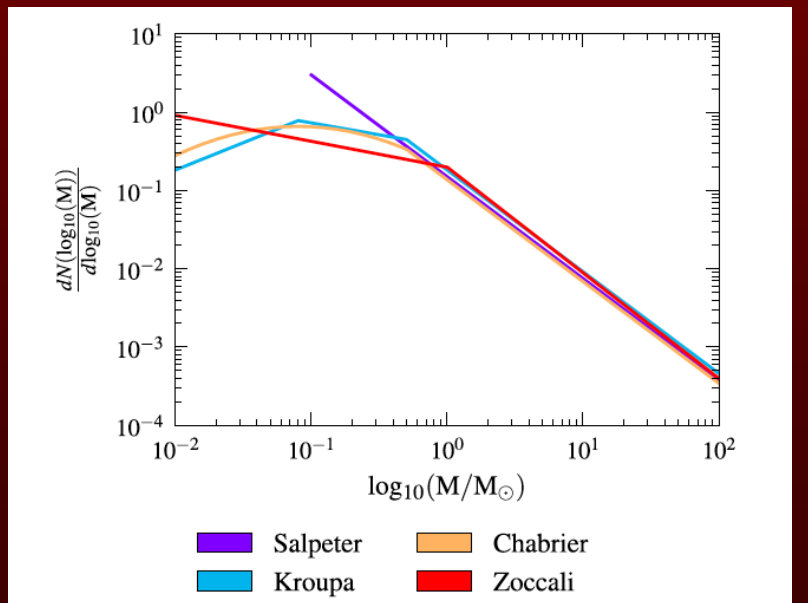
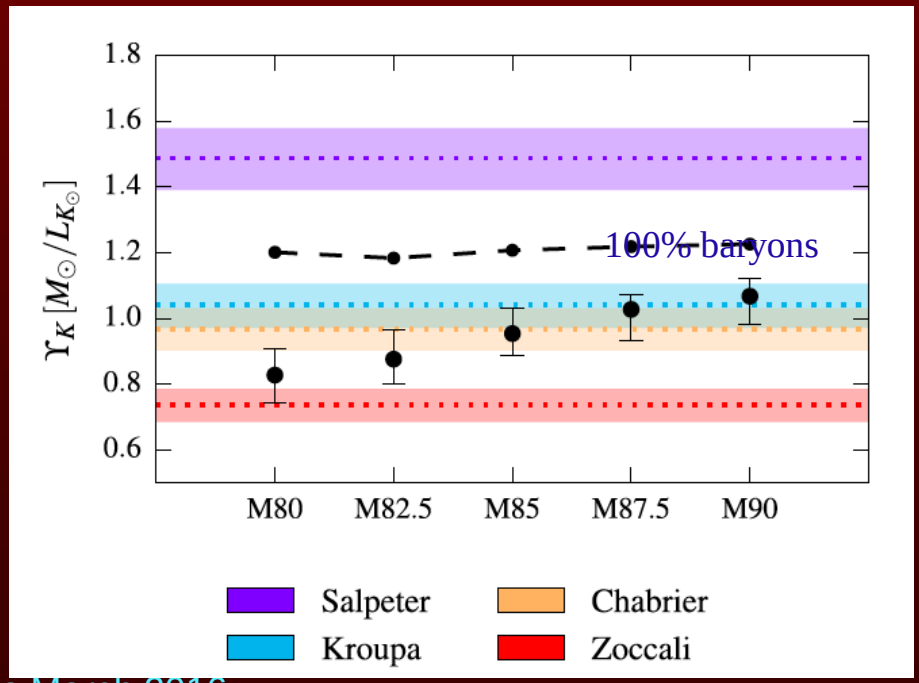
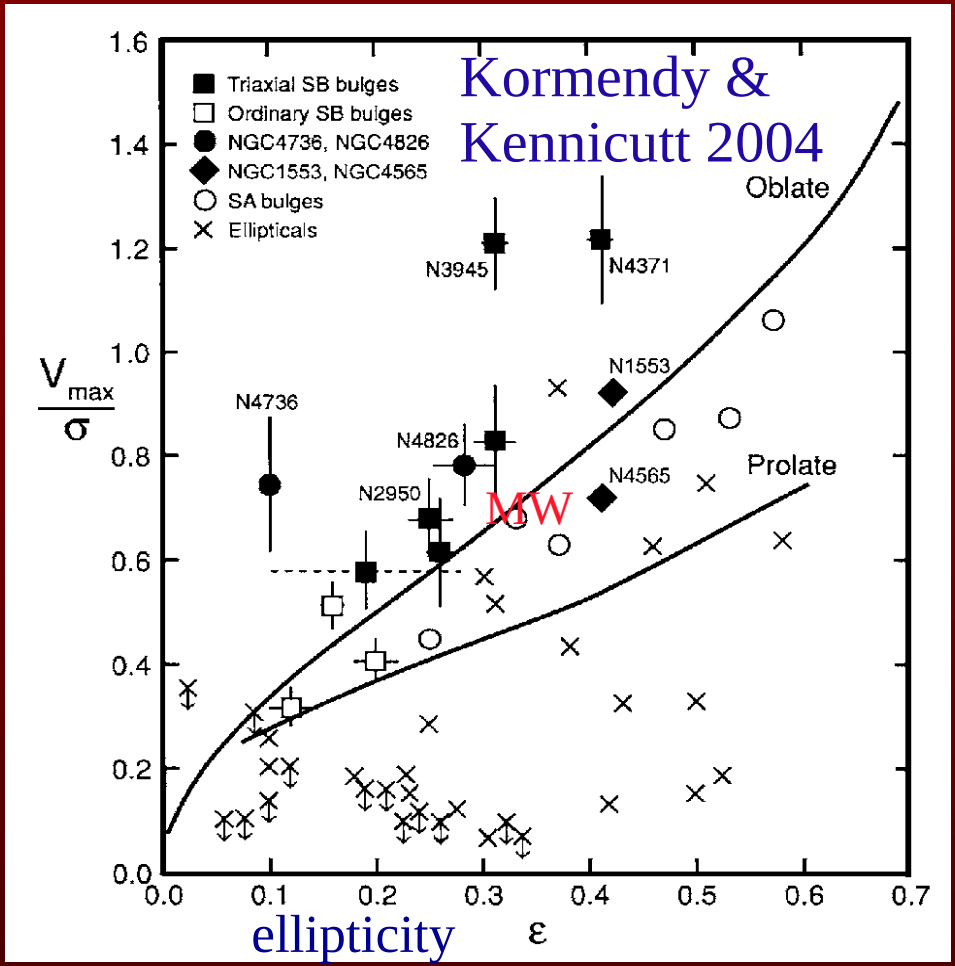


Figure 14. Plot of the logarithmic form of the different IMF used in this study (Salpeter 1955; Zoccali et al. 2000; Kroupa 2001; Chabrier 2003).

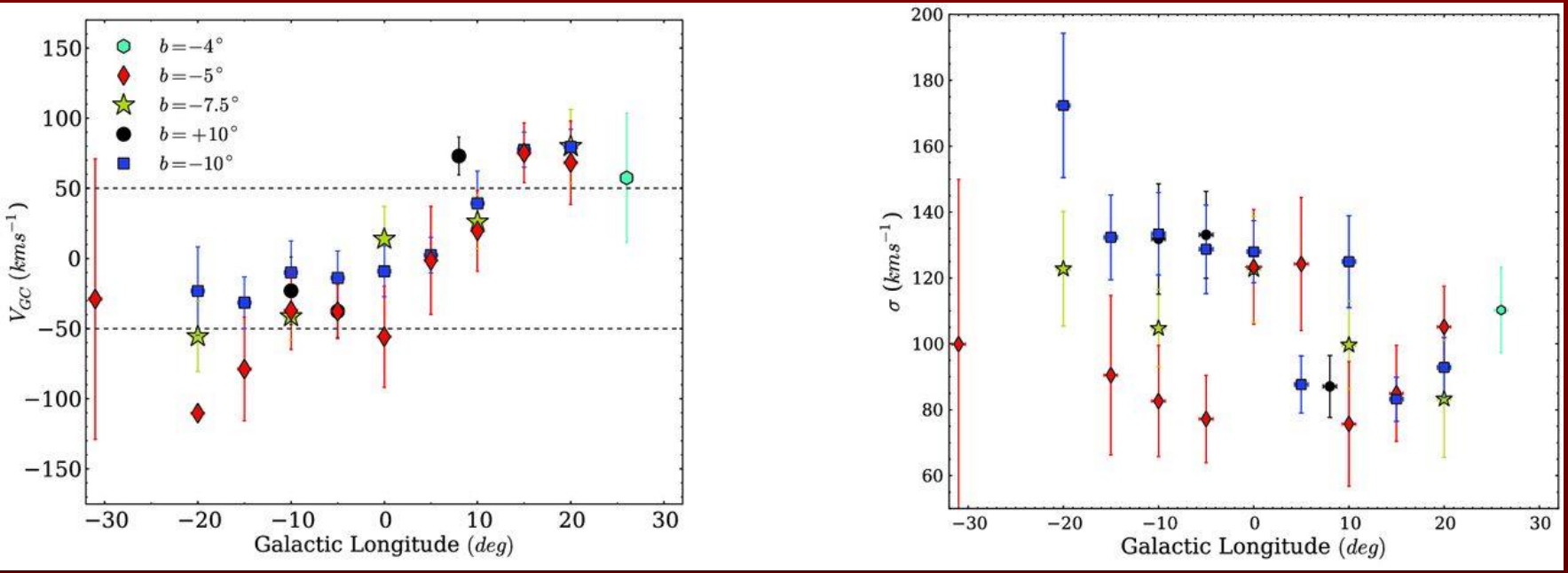


Portail, Wegg, Gerhard 15

The Milky Way shares much in common with NGC 4565 (peanut bulge, abundance gradient) BRAVA places Milky Way on Binney plot.

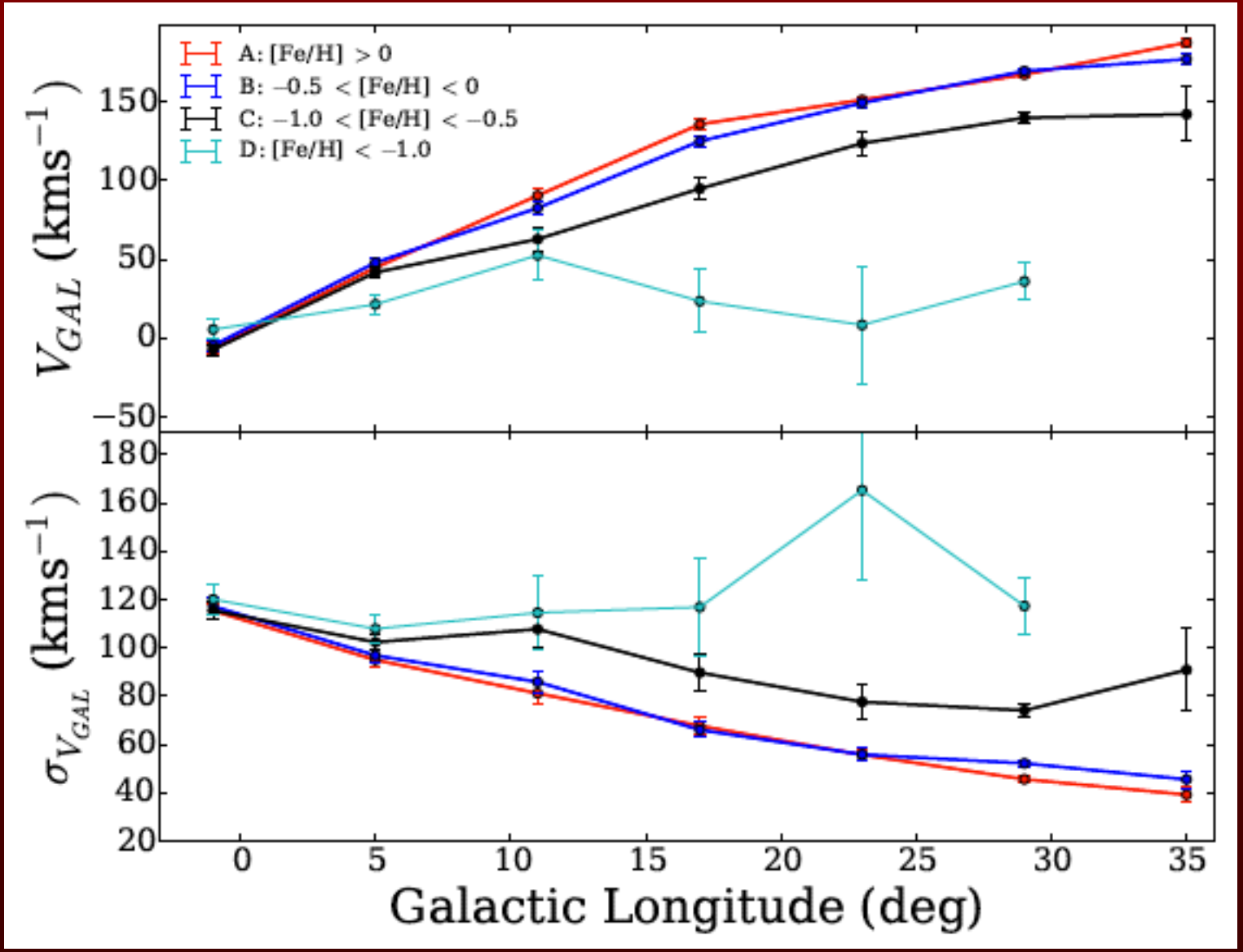


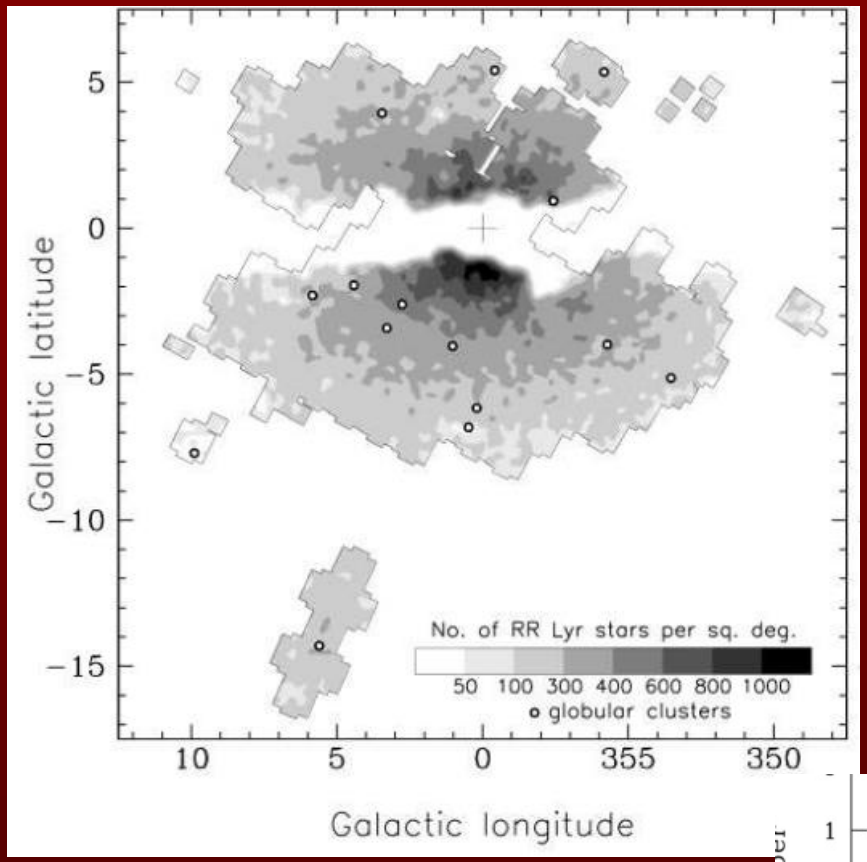
All populations in the bulge exhibit rotation, Even metal poor K giants – [Fe/H] < -1



Ness et al. 2012

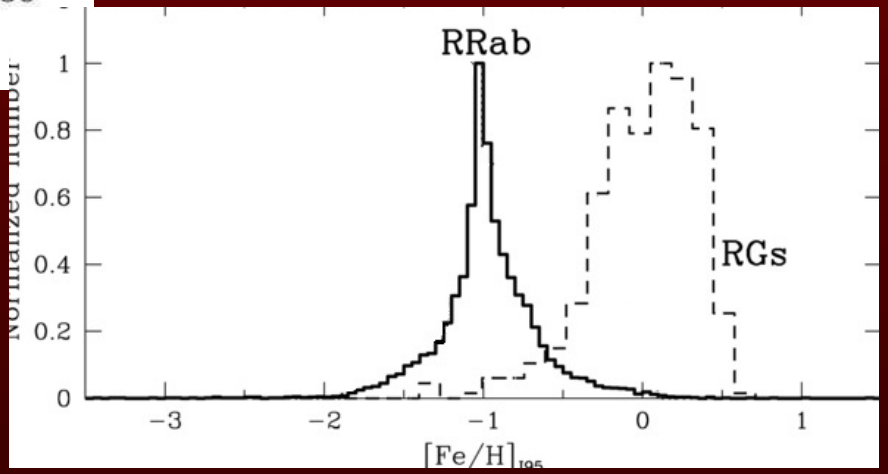
ARGOS also shows rotation





While K giants<-2 in the bulge are known, they are not a true bulge population (e.g. Hawes et al. 2015; Koch et al. 2015). RR Lyraes are ubiquitous and metal poor

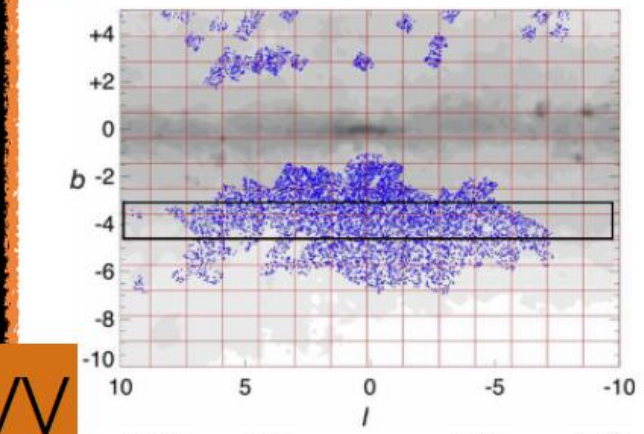
Early work (Walker & Terndrup 1991)

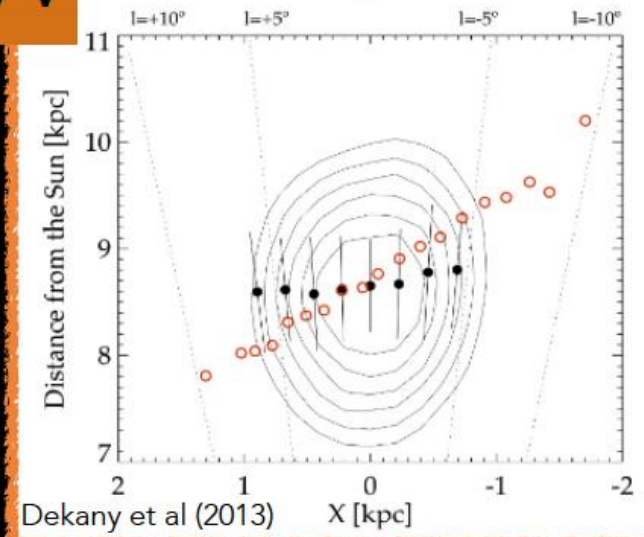


Pietrukowicz et al. 2012, 15

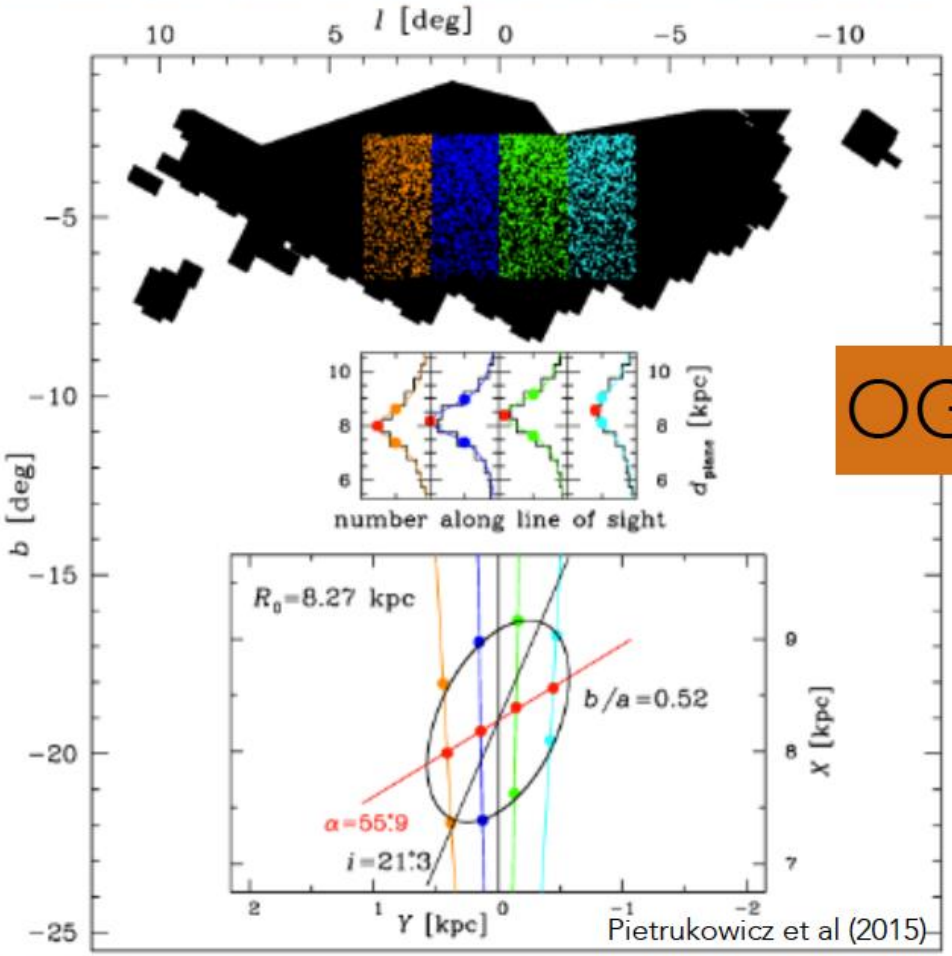
Present tension about spatial distribution of RRs

VVV



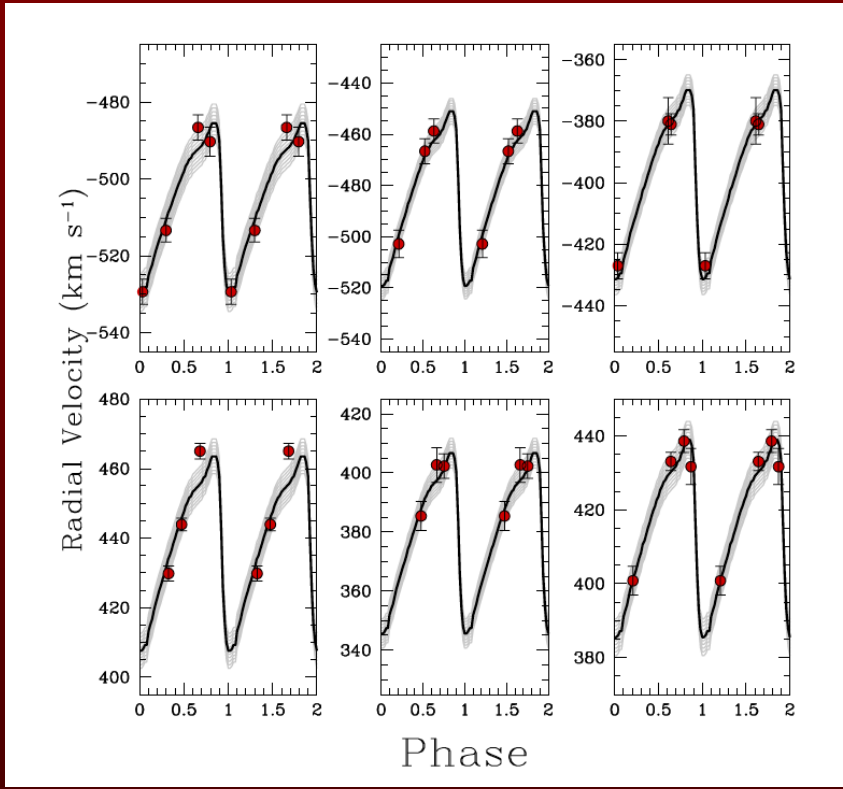


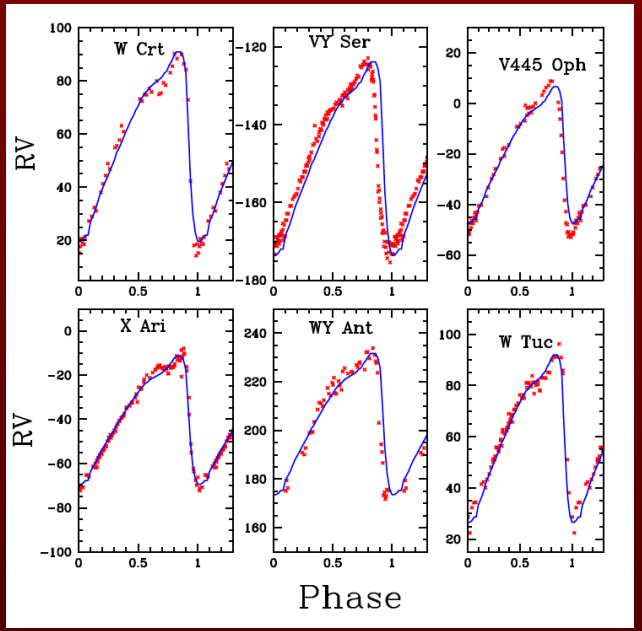
OGLE



Slide: A. Kunder

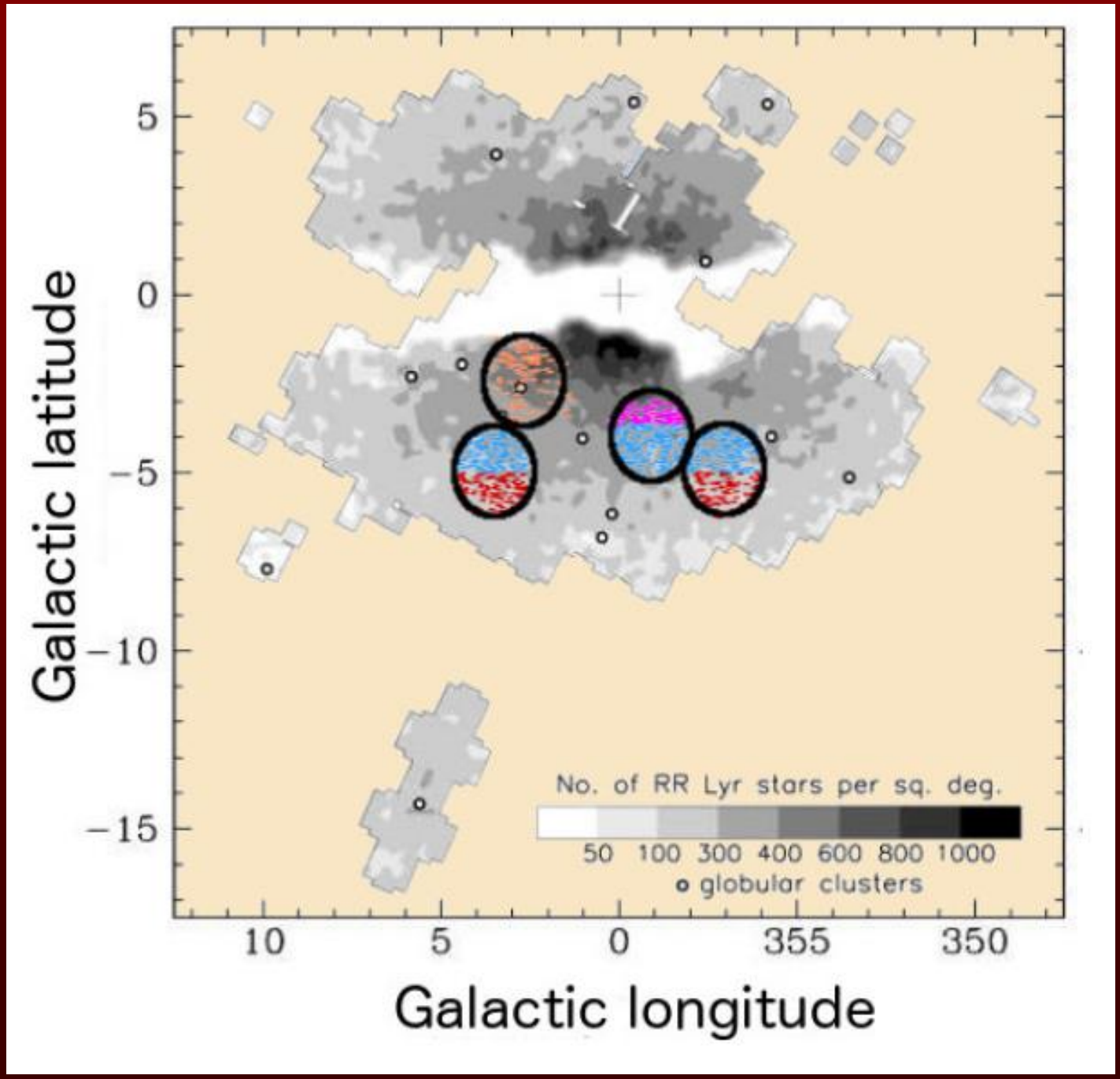
BRAVA-RR Survey



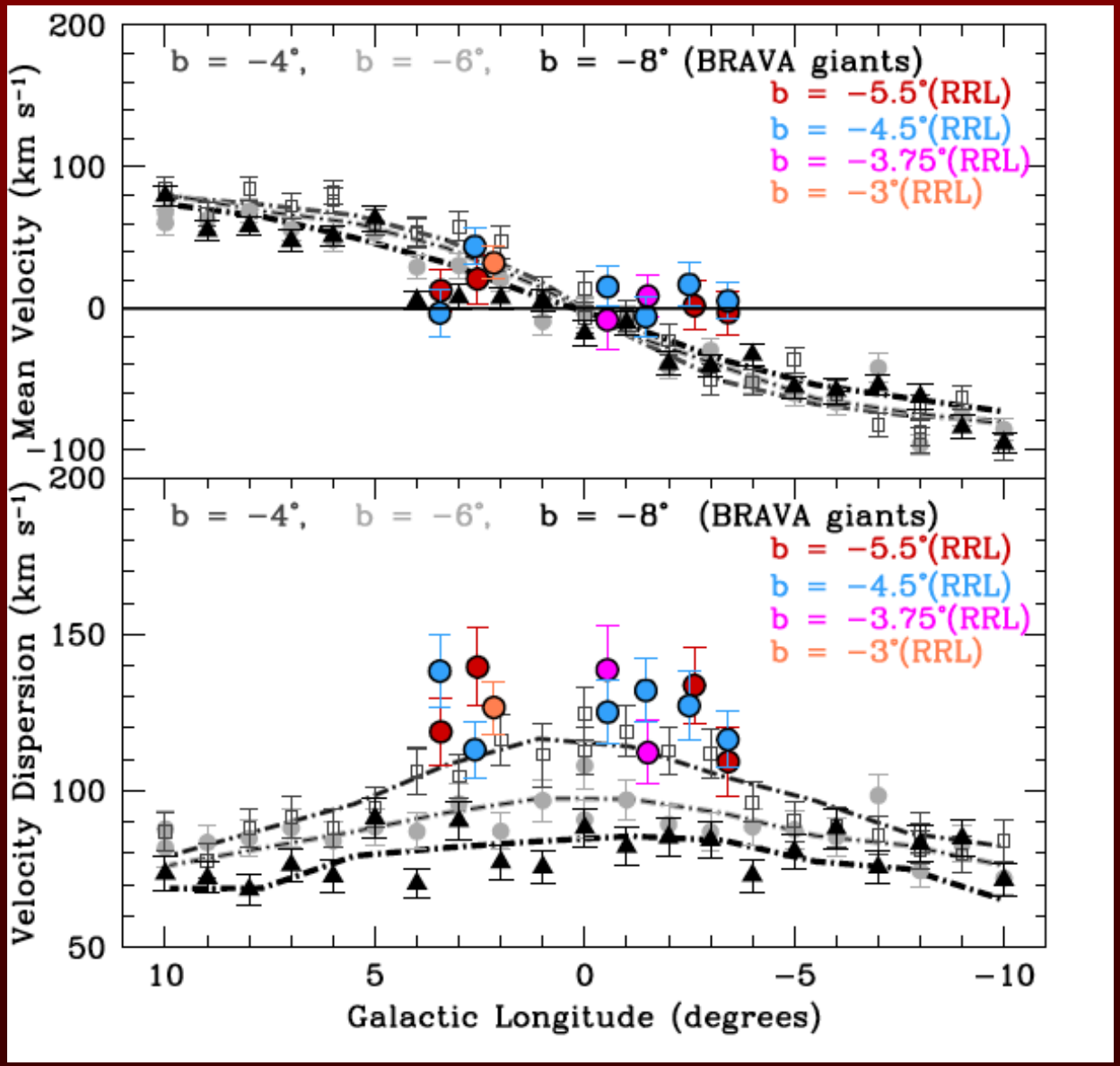


946 radial velocities using AAOMEGA on AAT. Stellar systemic velocities to ~ 5 km/sec independent of light curve uncertainty

Kunder et al. 2016

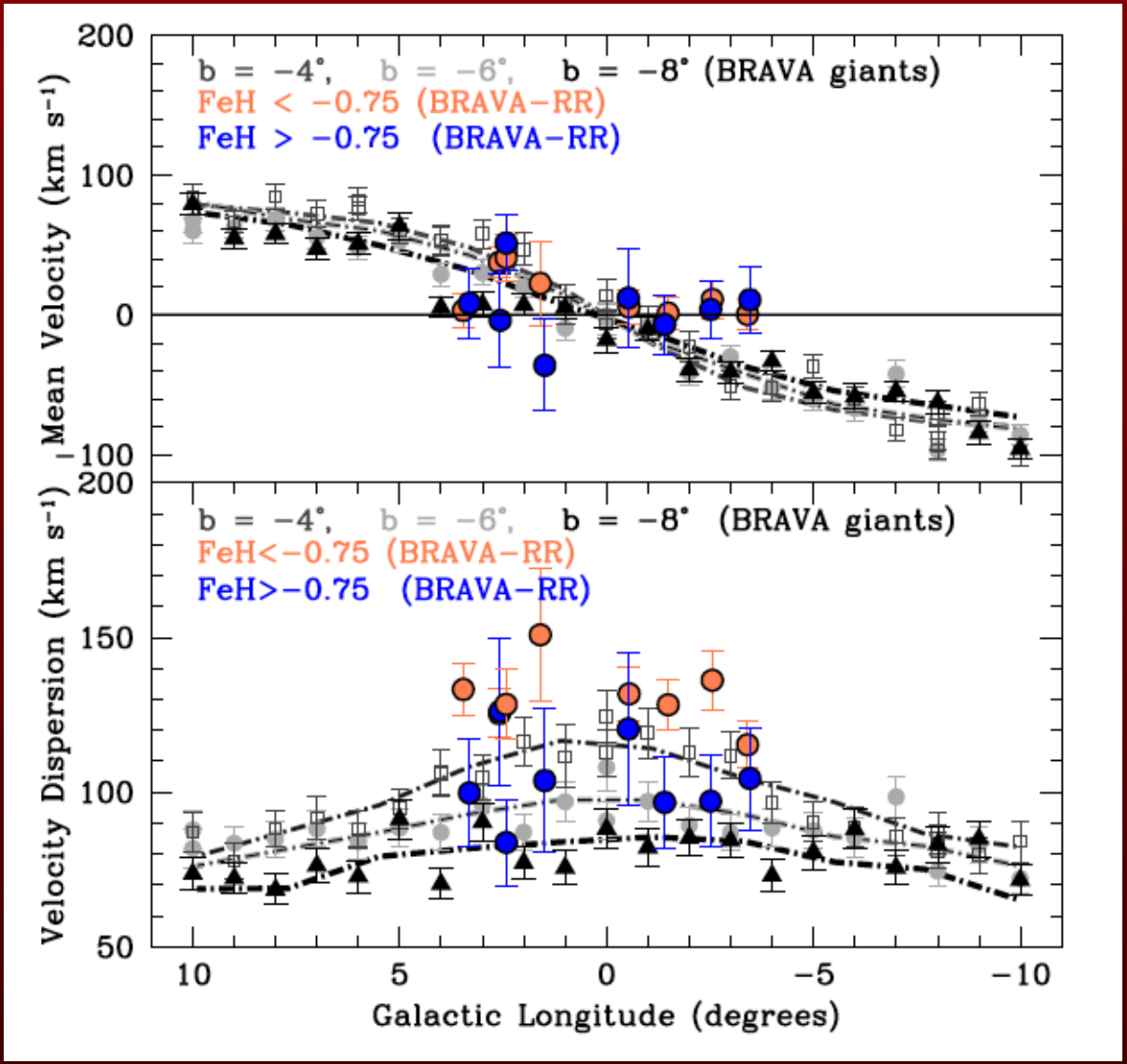

Galactic latitude
5
0
−5
−10
−15
10
5
0
355
350
Galactic longitude
No. of RR Lyr stars per sq. deg.
50 100 300 400 600 800 1000
globular clusters

No rotation in the bulge RR Lyraes

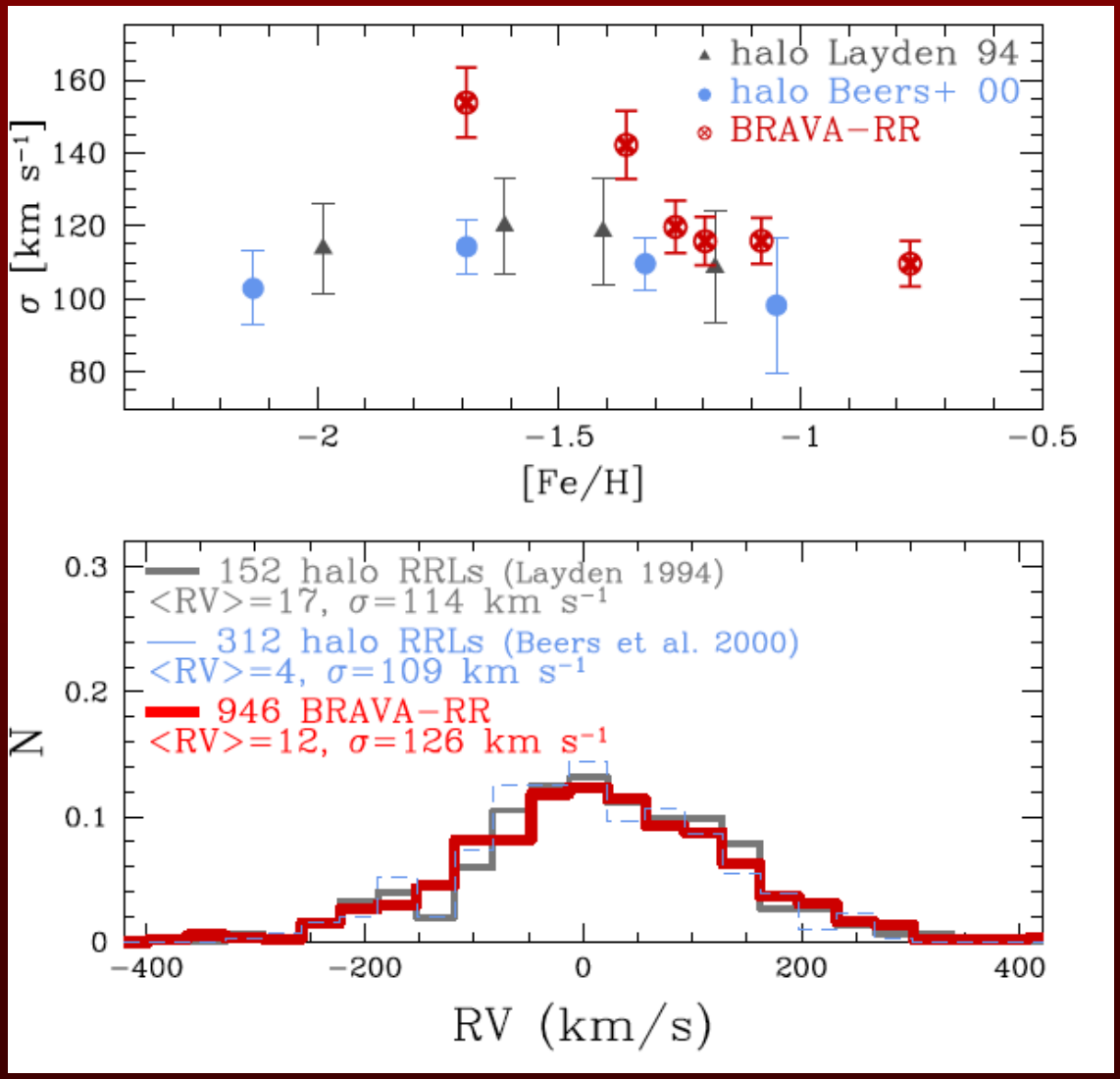


Kunder, Rich et al. 2016 ApJL

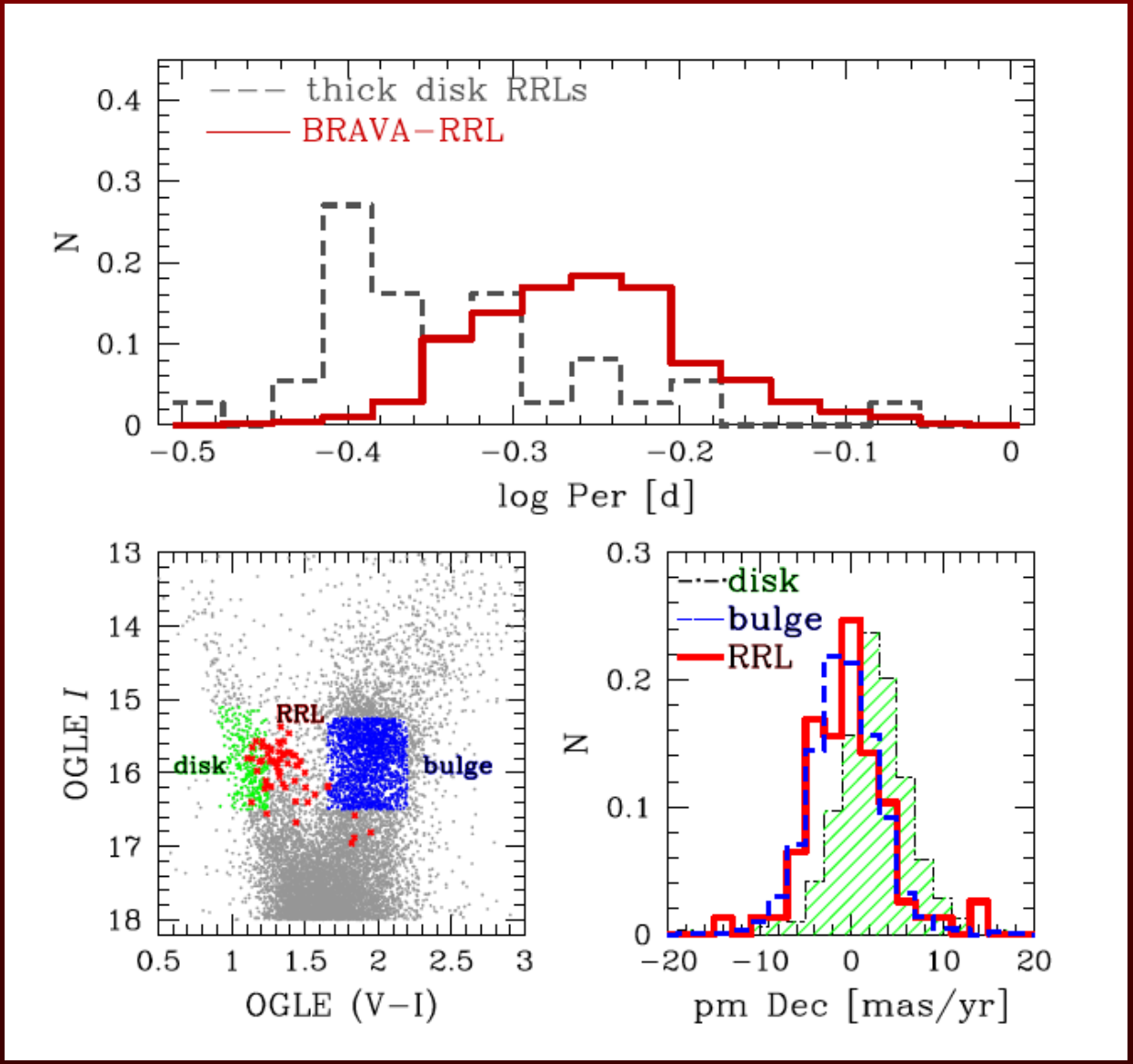
Metal poor has higher dispersion; no rotation diff



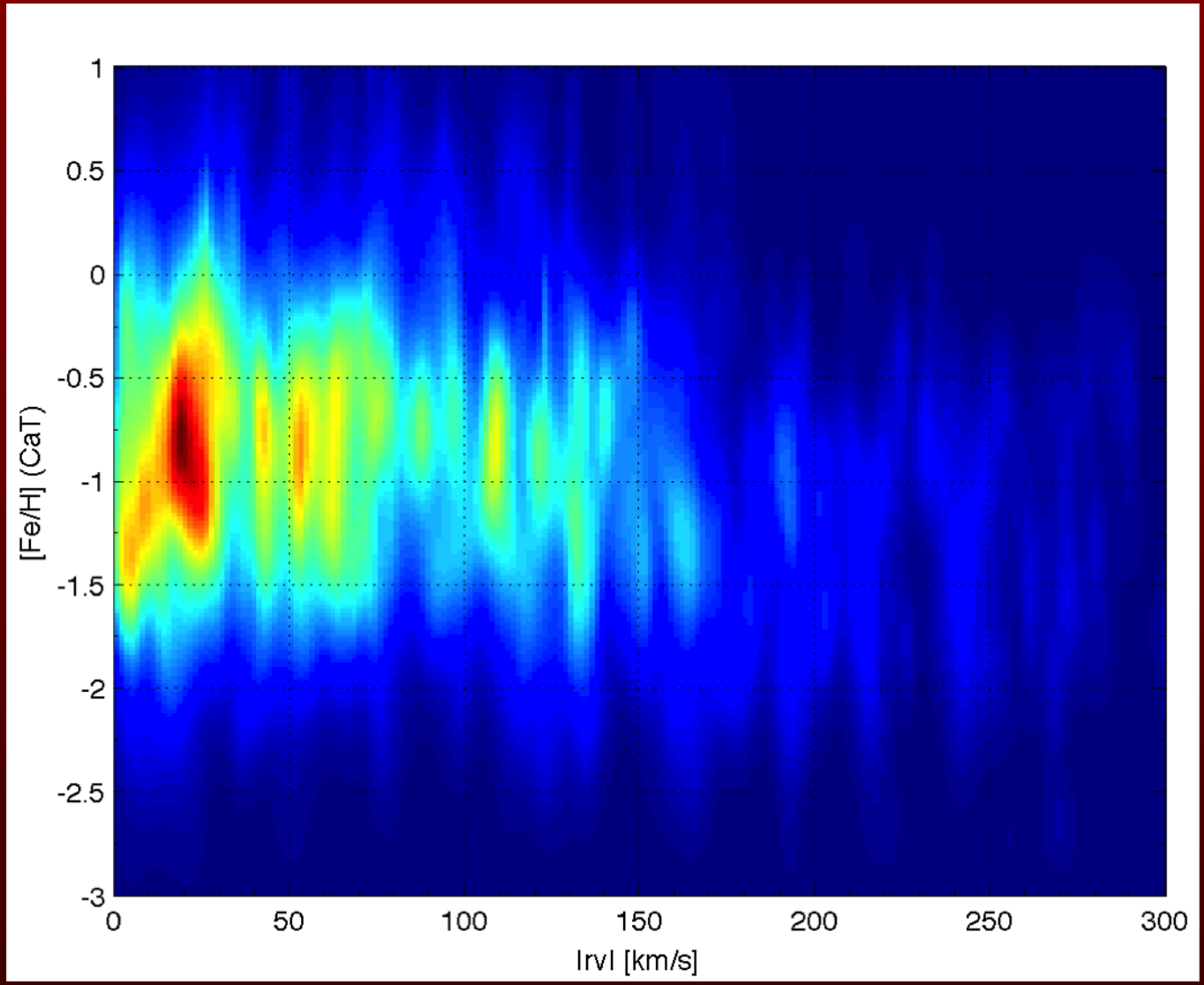
Trend between dispersion, metallicity

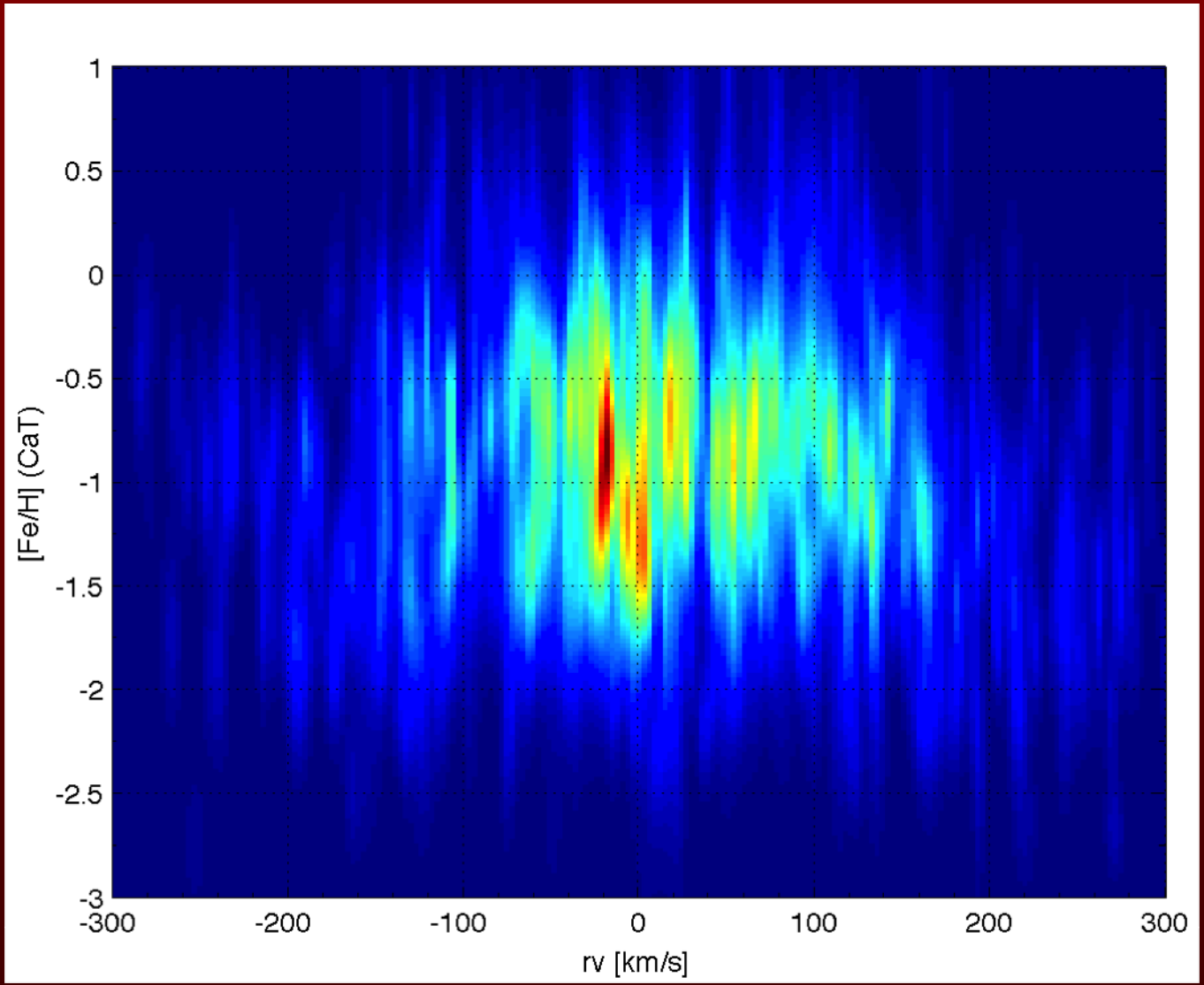


Bulge members by period and proper motion

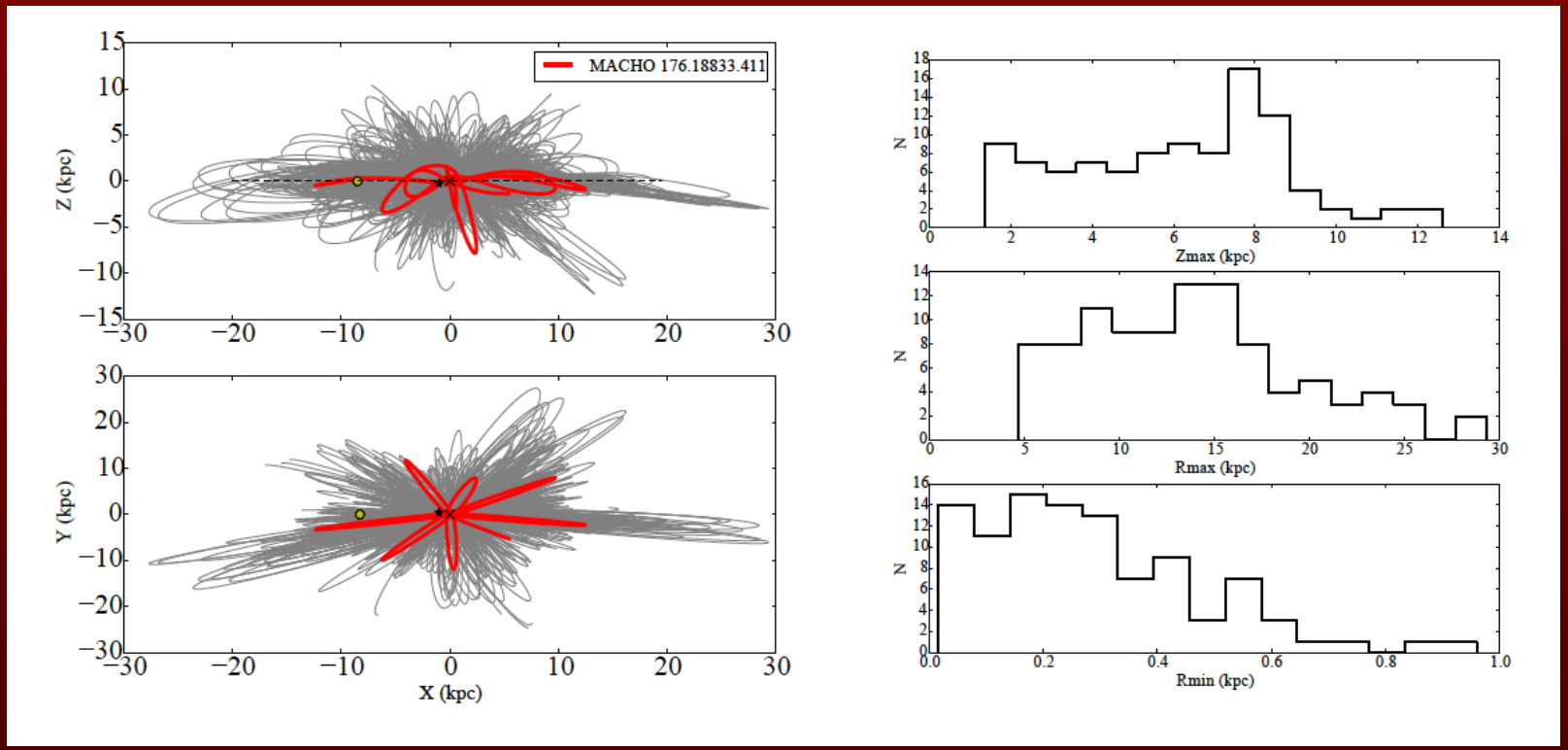


Preliminary Ca T results (A. Koch et al. in prep)
Hints of substructure



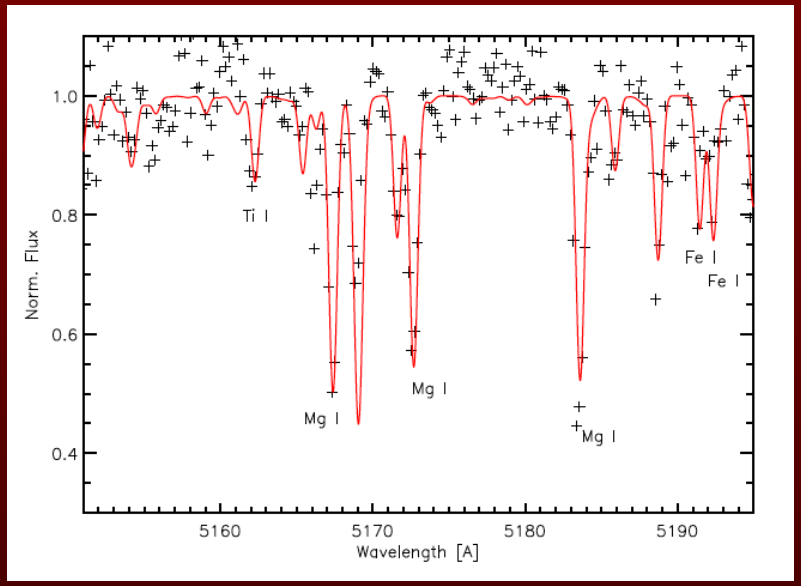

1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
[Fe/H] (CaT)
-300
-200
-100
0
100
200
300
rv [km/s]

MACHO 176.18833.411 has RV=-372 km/s, space velocity -482 km/sec!



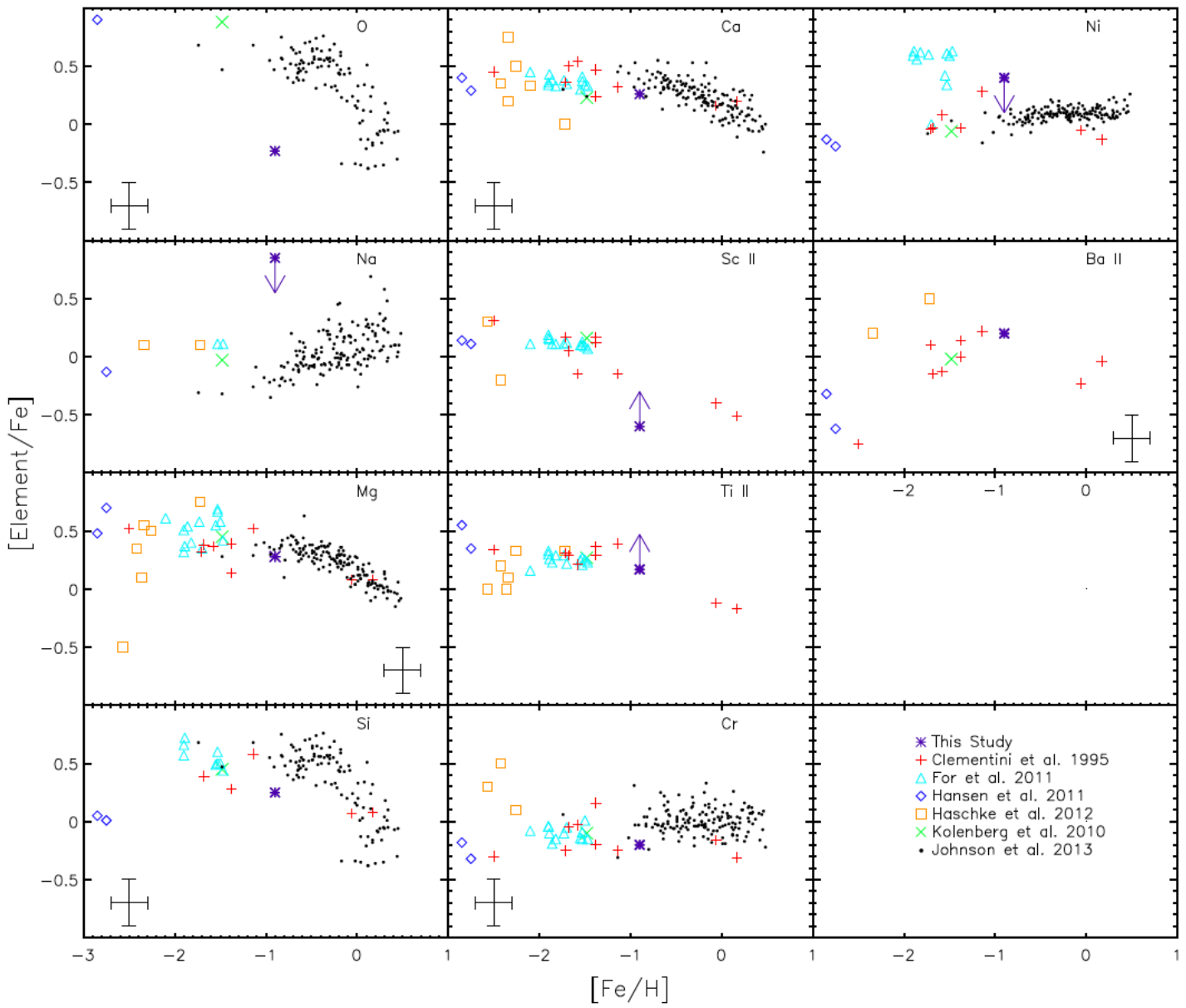
Kunder et al. 2015

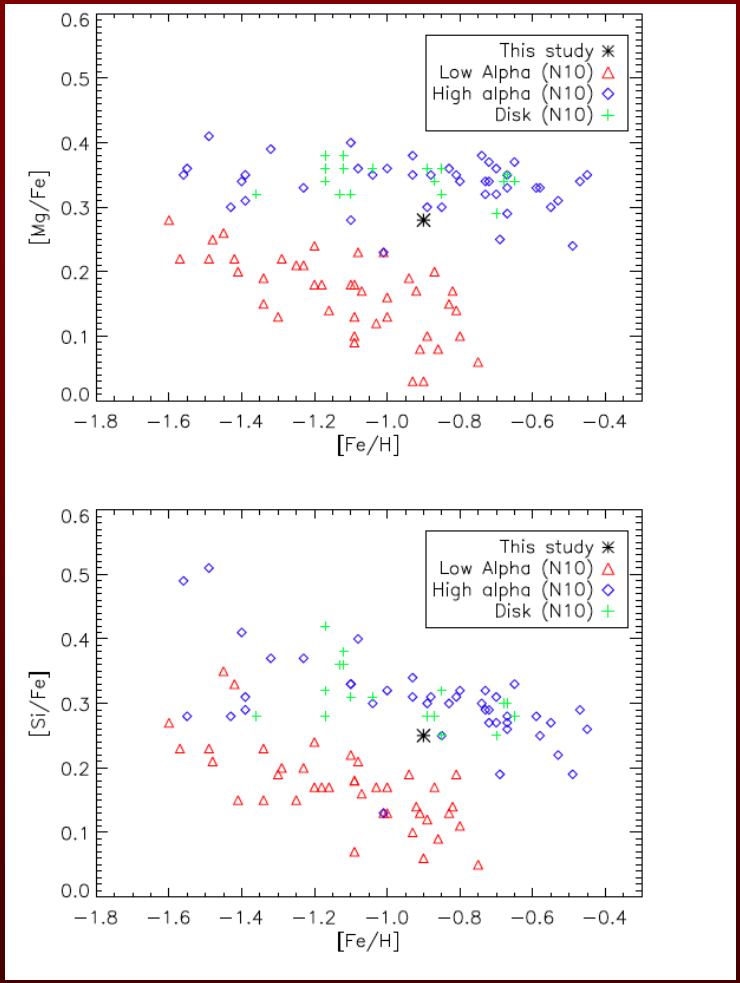
Keck/ESI spectrum: [Fe/H]=-0.9

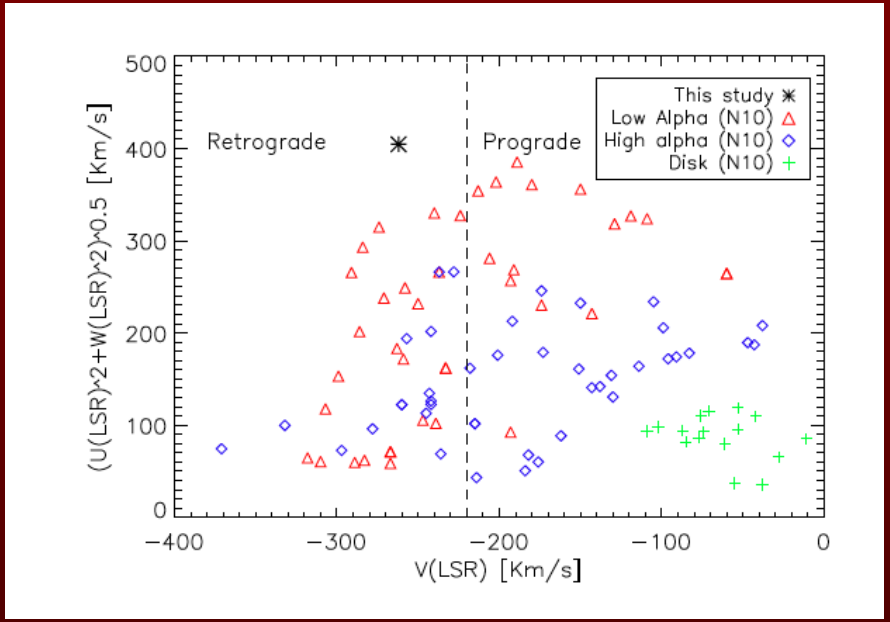


Element, X	[X/Fe]	No. lines
O I	−0.23	3
Na I	< 0.85	2
Mg I	0.28 ± 0.21	4
Si I	0.25	1
Ca I	0.26 ± 0.1	6
Sc II	> −0.6	1
Ti II	< 0.17	4
Cr I	-0.2^{wa}	2.5
Ni I	< 0.4	1
Ba II	0.2 ± 0.0	2

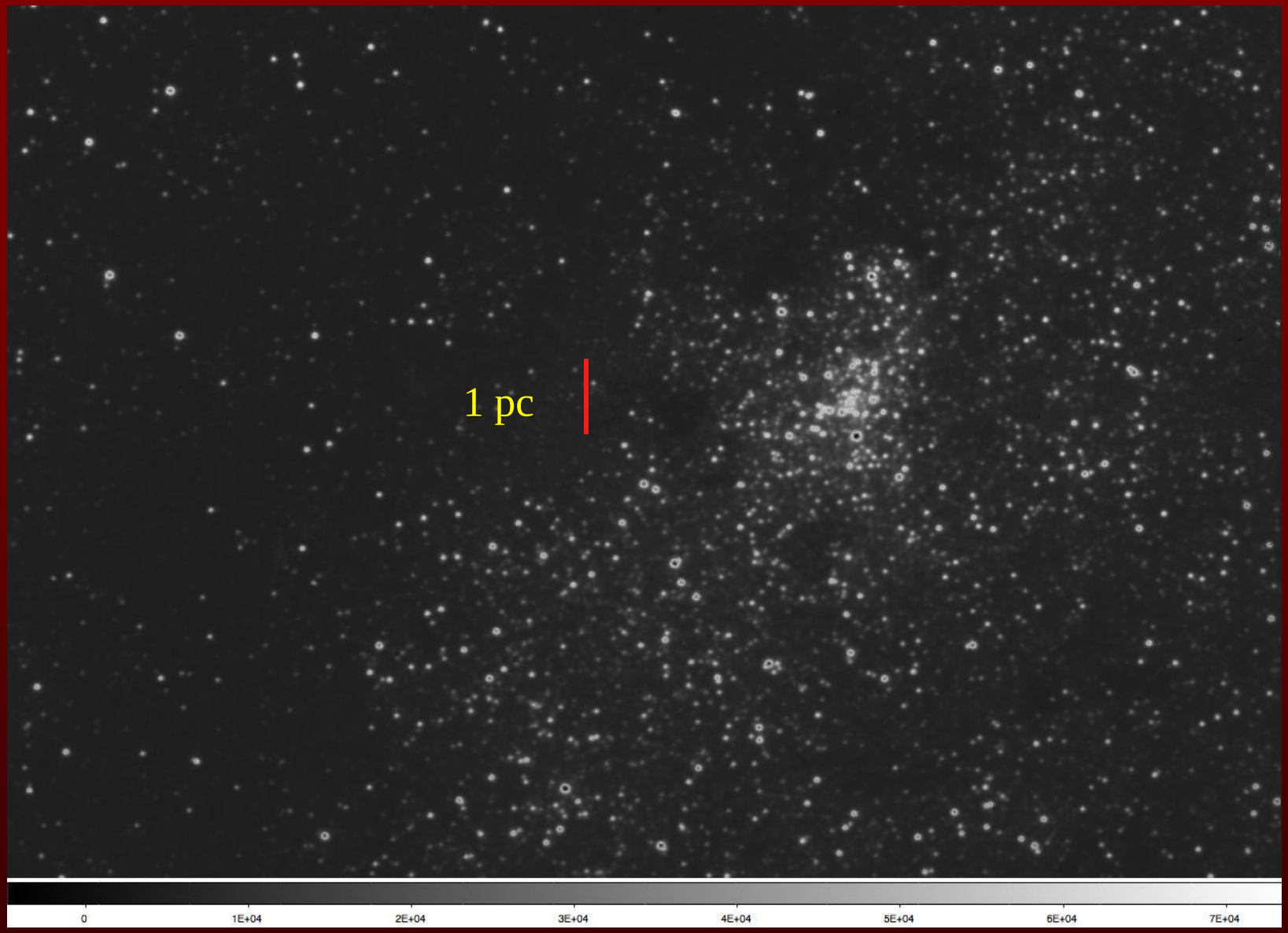
Chemical tagging ambiguous



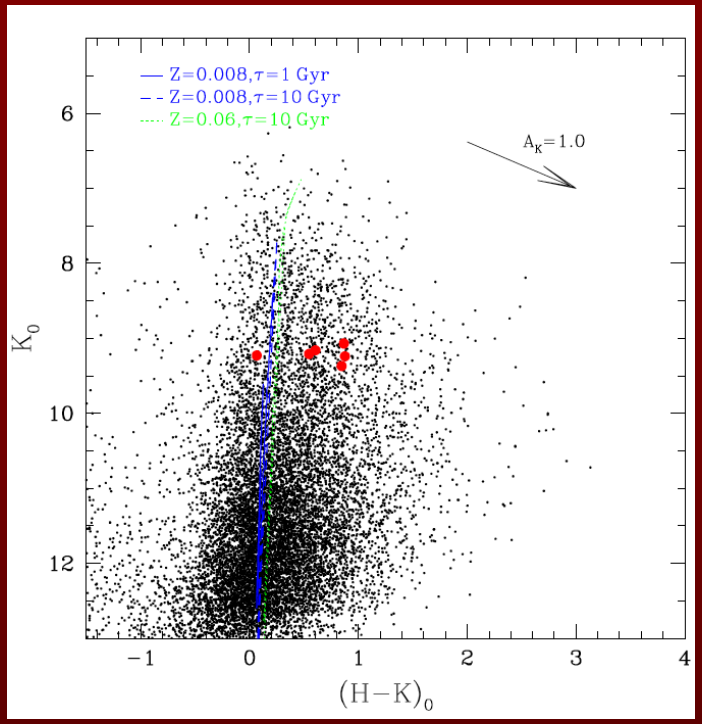

This study
Low Alpha (N10)
High alpha (N10)
Disk (N10)
[Mg/Fe]
[Fe/H]
[Si/Fe]
[Fe/H]

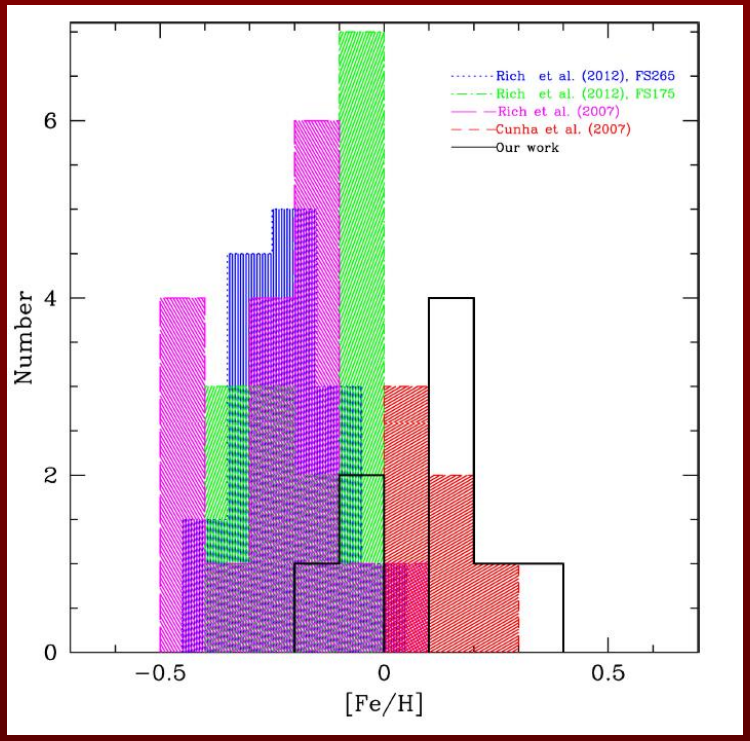

Retrograde
Prograde
This study
Low Alpha (N10)
High alpha (N10)
Disk (N10)
(U(LSR)^2+W(LSR)^2)^0.5 [Km/s]
V(LSR) [Km/s]

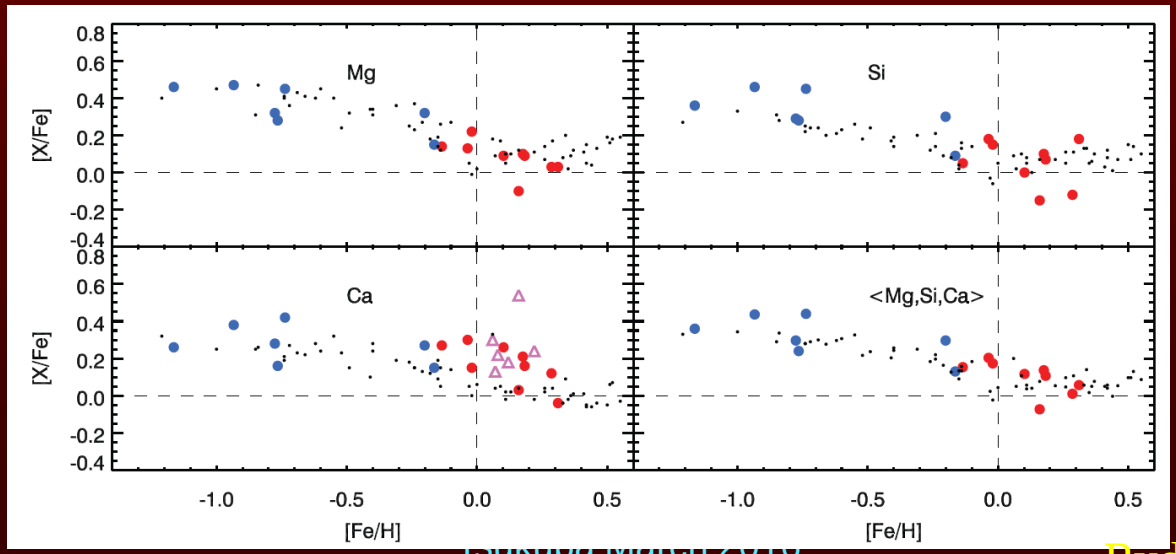
Galactic center has old, metal rich giants



The center seems a lot like the bulge







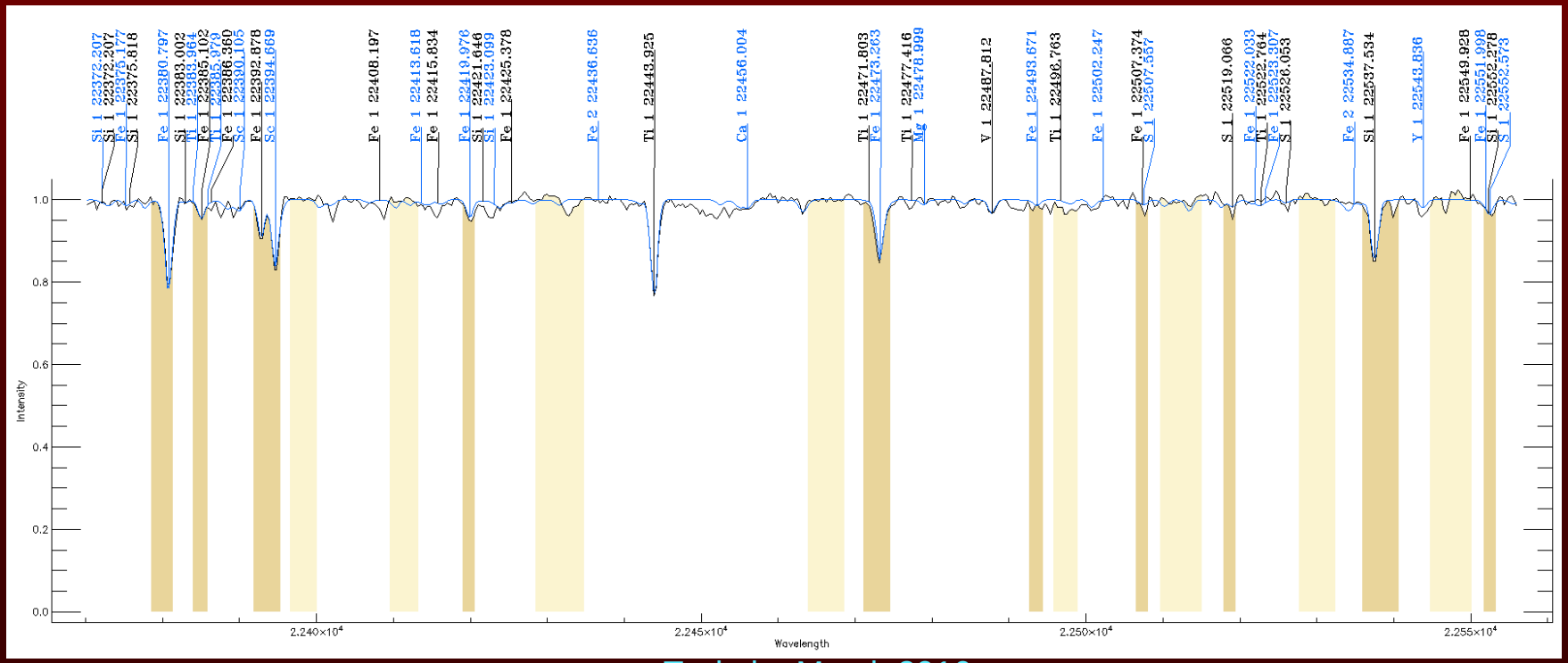
Tsukuba March 2016

Ryde & Shultheis 2014

gc10812 (teff = 3817 K , logg=0.7)

[Fe/H] = -1.15, [Si/Fe] = 0.5, and carbon and nitrogen are supersolar

Other alphas on the way



M19= NGC 6273

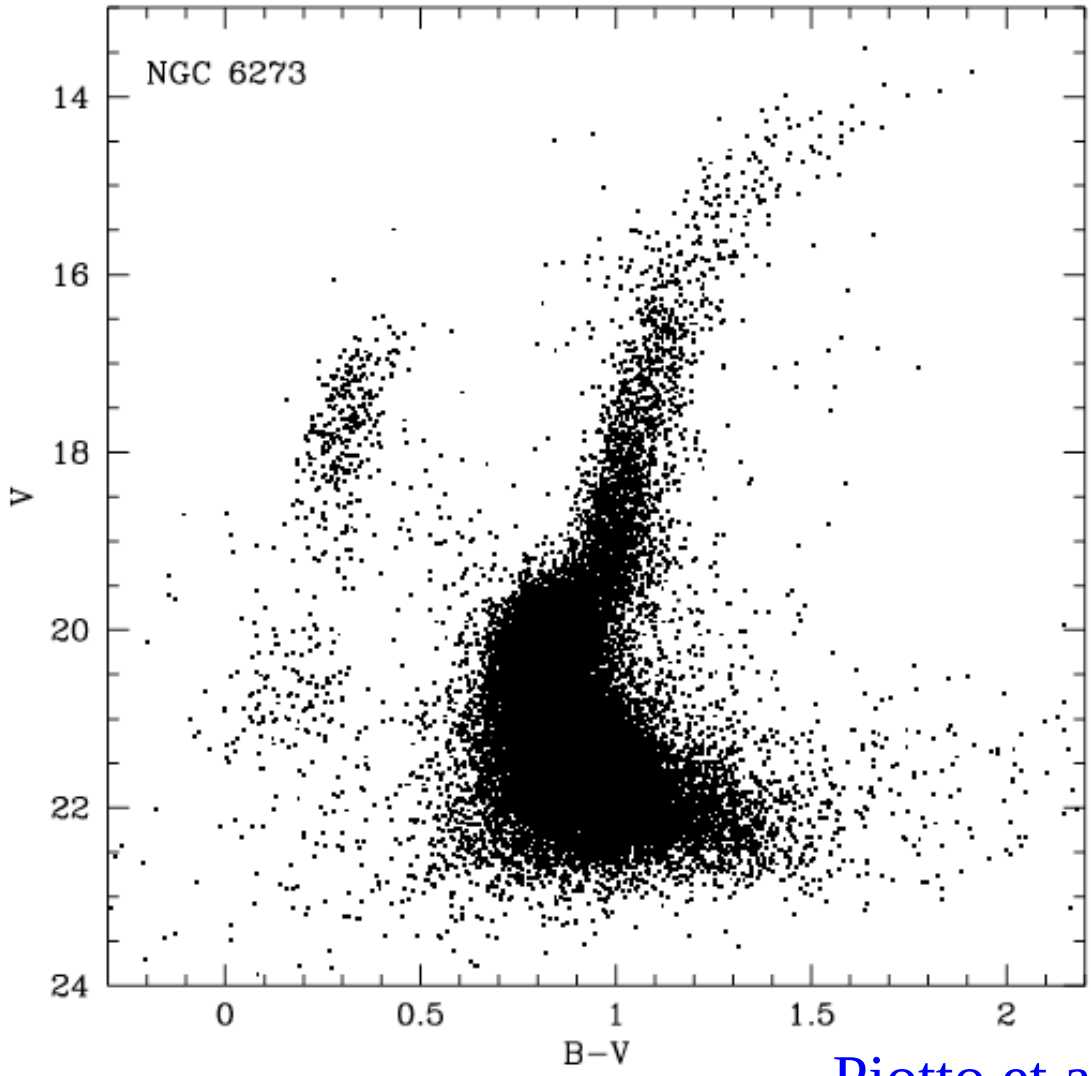
The next ω Cen

The Astronomical Journal, 150:63 (21pp), 2015 August doi:10.1088/0004-6256/150/2/63

A SPECTROSCOPIC ANALYSIS OF THE GALACTIC GLOBULAR CLUSTER NGC 6273 (M19)*

Christian I. Johnson[1,6], R. Michael Rich[2], Catherine A. Pilachowski[3], Nelson Caldwell[1], Mario Mateo[4], John I. Bailey, III[4], and Jeffrey D. Crane[5]

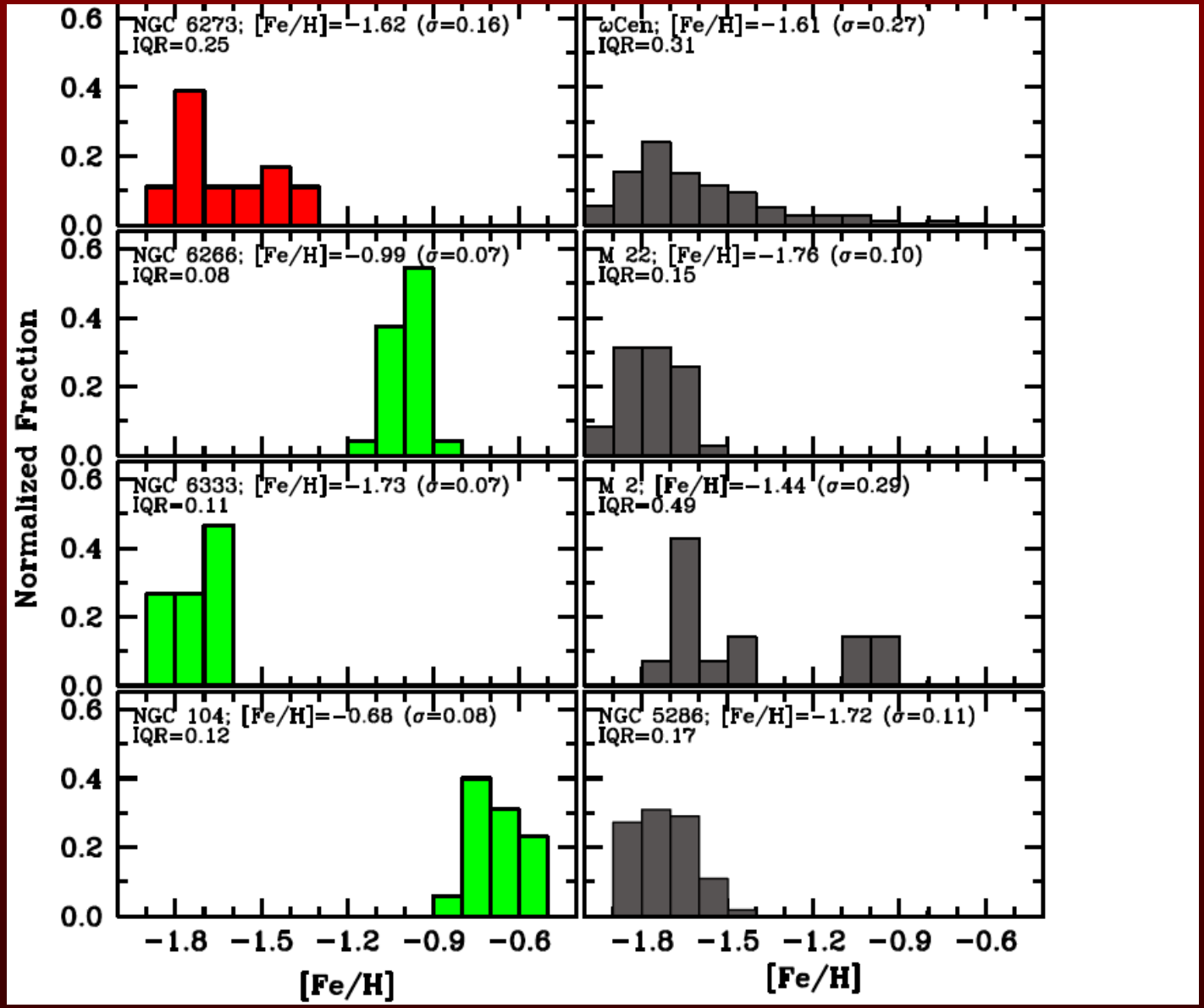
[1] Harvard–Smithsonian Center for Astrophysics, 60 Garden Street, MS-15, Cambridge, MA 02138, USA; cjohnson@cfa.harvard.edu, ncaldwell@cfa.harvard.edu
[2] Department of Physics and Astronomy, UCLA, 430 Portola Plaza, Box 951547, Los Angeles, CA 90095-1547, USA; rmr@astro.ucla.edu
[3] Astronomy Department, Indiana University Bloomington, Swain West 319, 727 East 3rd Street, Bloomington, IN 47405-7105, USA; catyp@astro.indiana.edu
[4] Department of Astronomy, University of Michigan, Ann Arbor, MI 48109, USA; mmateo@umich.edu, baileyji@umich.edu
[5] The Observatories of the Carnegie Institution for Science, Pasadena, CA 91101, USA; crane@obs.carnegiescience.edu
Received 2015 May 10; accepted 2015 June 22; published 2015 July 30

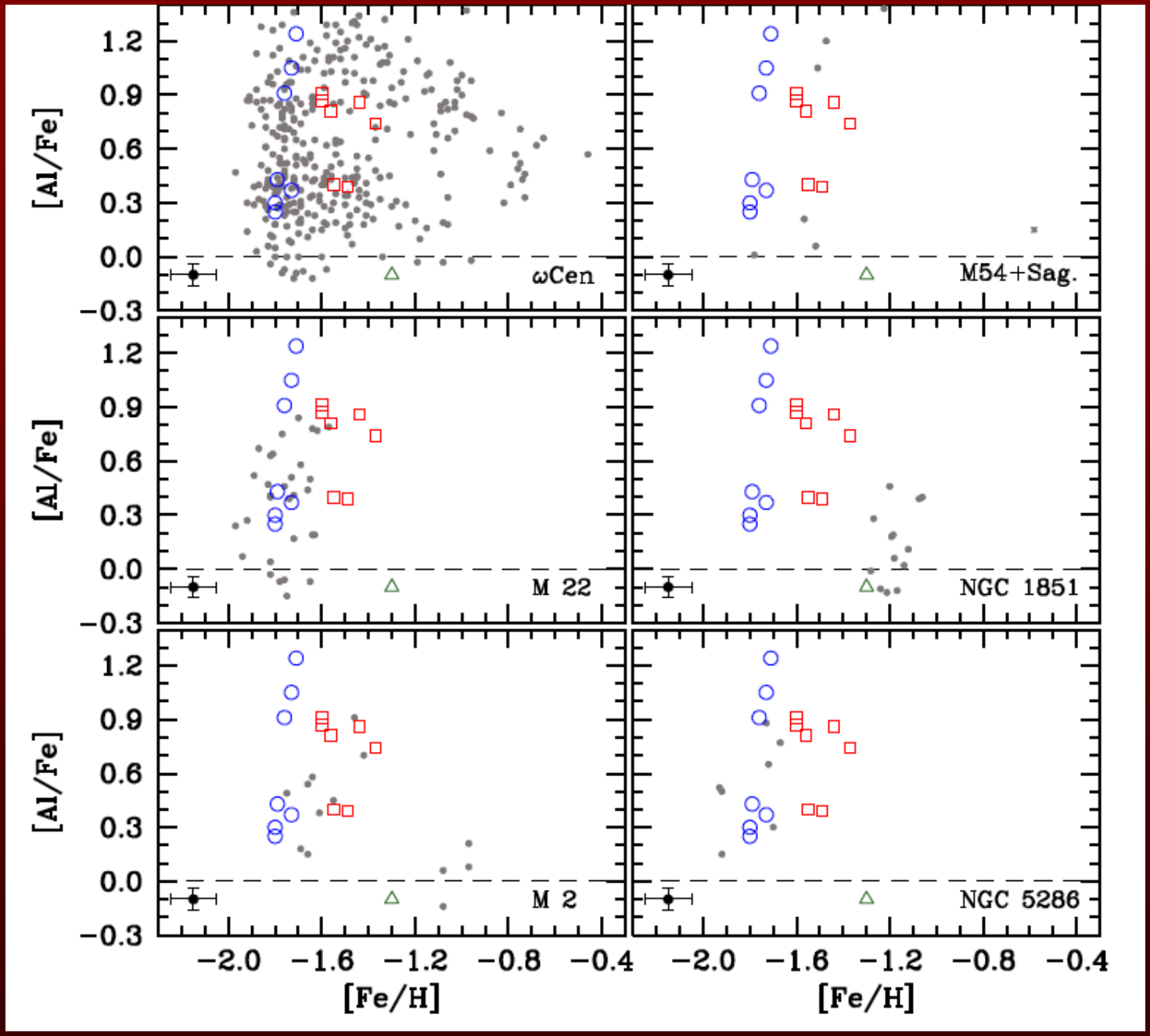


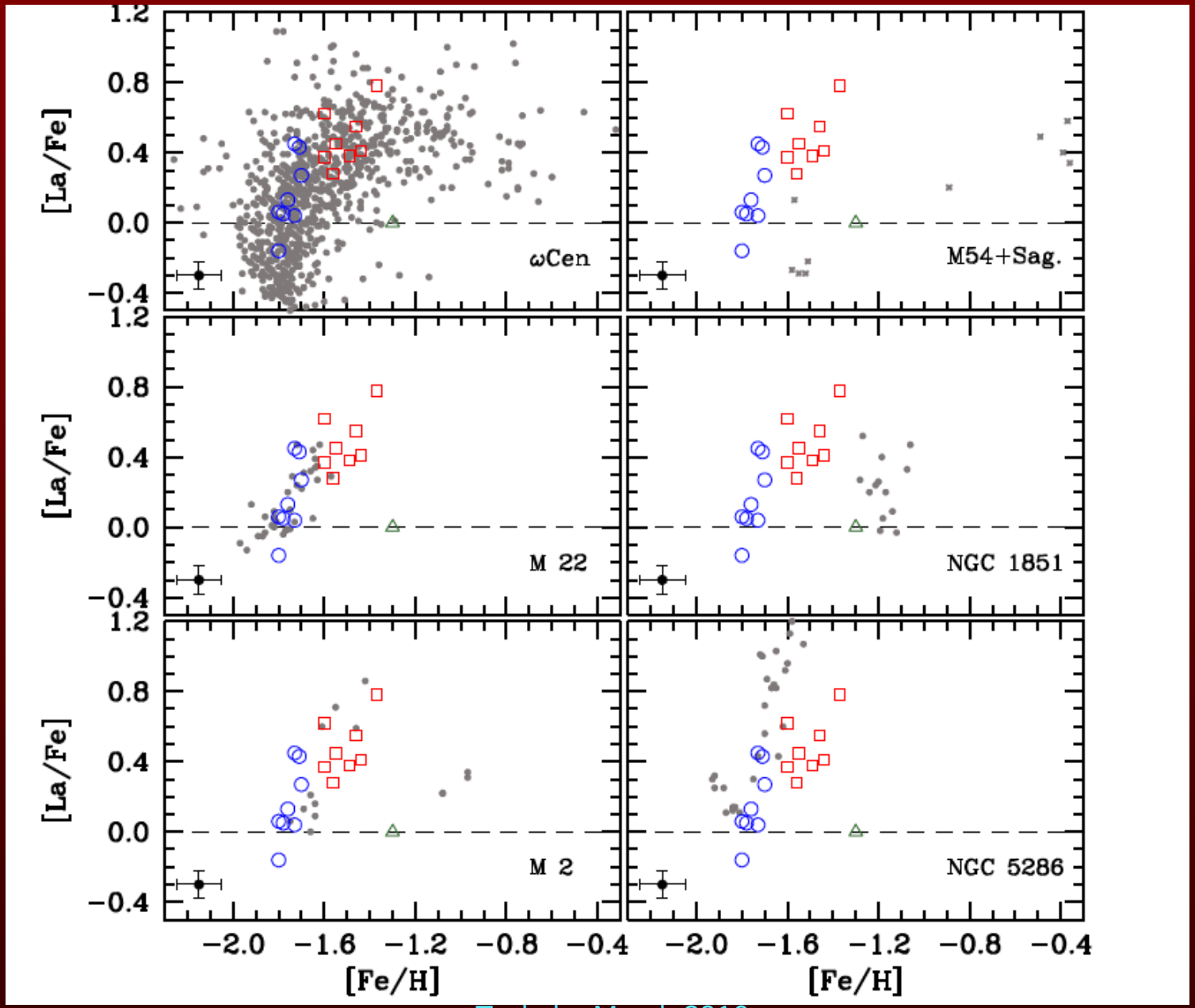
Piotto et al. 99

FIG. 1.—Color-magnitude diagram for ~28,000 stars in the central region of NGC 6273. All the stars identified in the Planetary Camera and in the three Wide Field Cameras are shown.

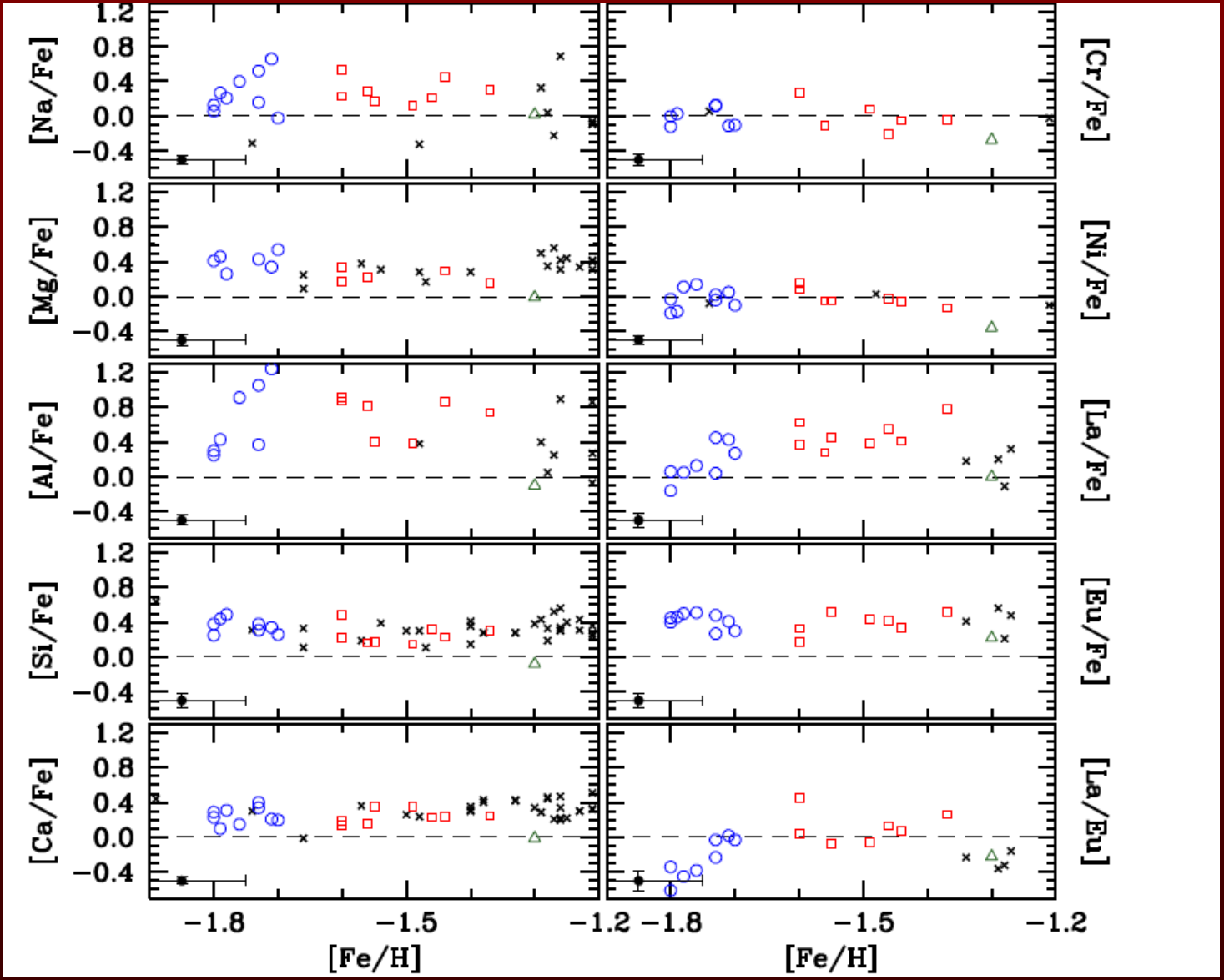
NGC 6273 has one of the largest [Fe/H] spreads



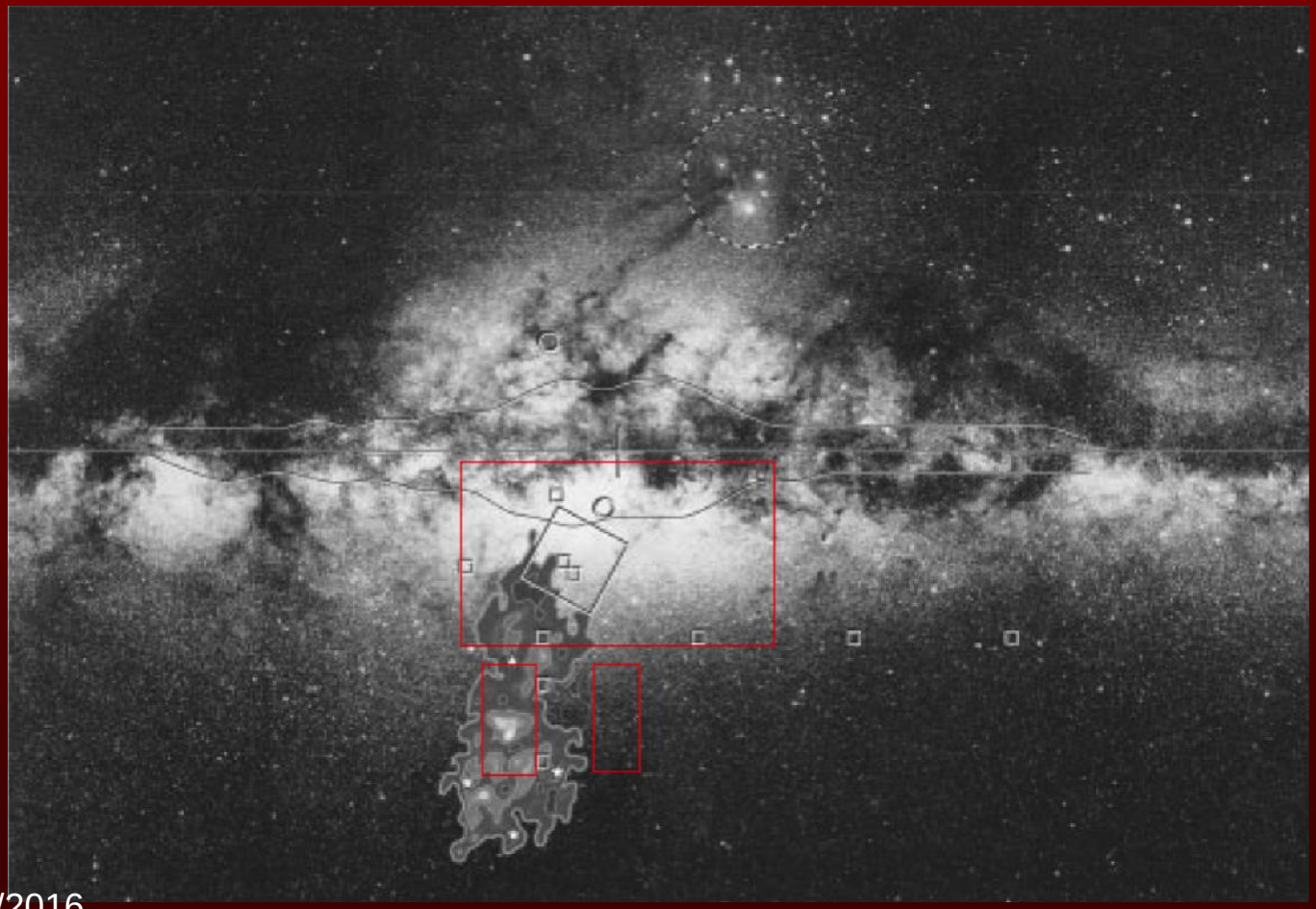

[Al/Fe]
[Fe/H]
ωCen
M54+Sag.
M 22
NGC 1851
M 2
NGC 5286
1.2
0.9
0.6
0.3
0.0
−0.3
−2.0
−1.6
−1.2
−0.8
−0.4


[La/Fe]
[Fe/H]
ωCen
M54+Sag.
M 22
NGC 1851
M 2
NGC 5286
1.2
0.8
0.4
0.0
−0.4
−2.0
−1.6
−1.2
−0.8
−0.4

NGC 6273 vs metal poor bulge field



Blanco DEcam Bulge Survey

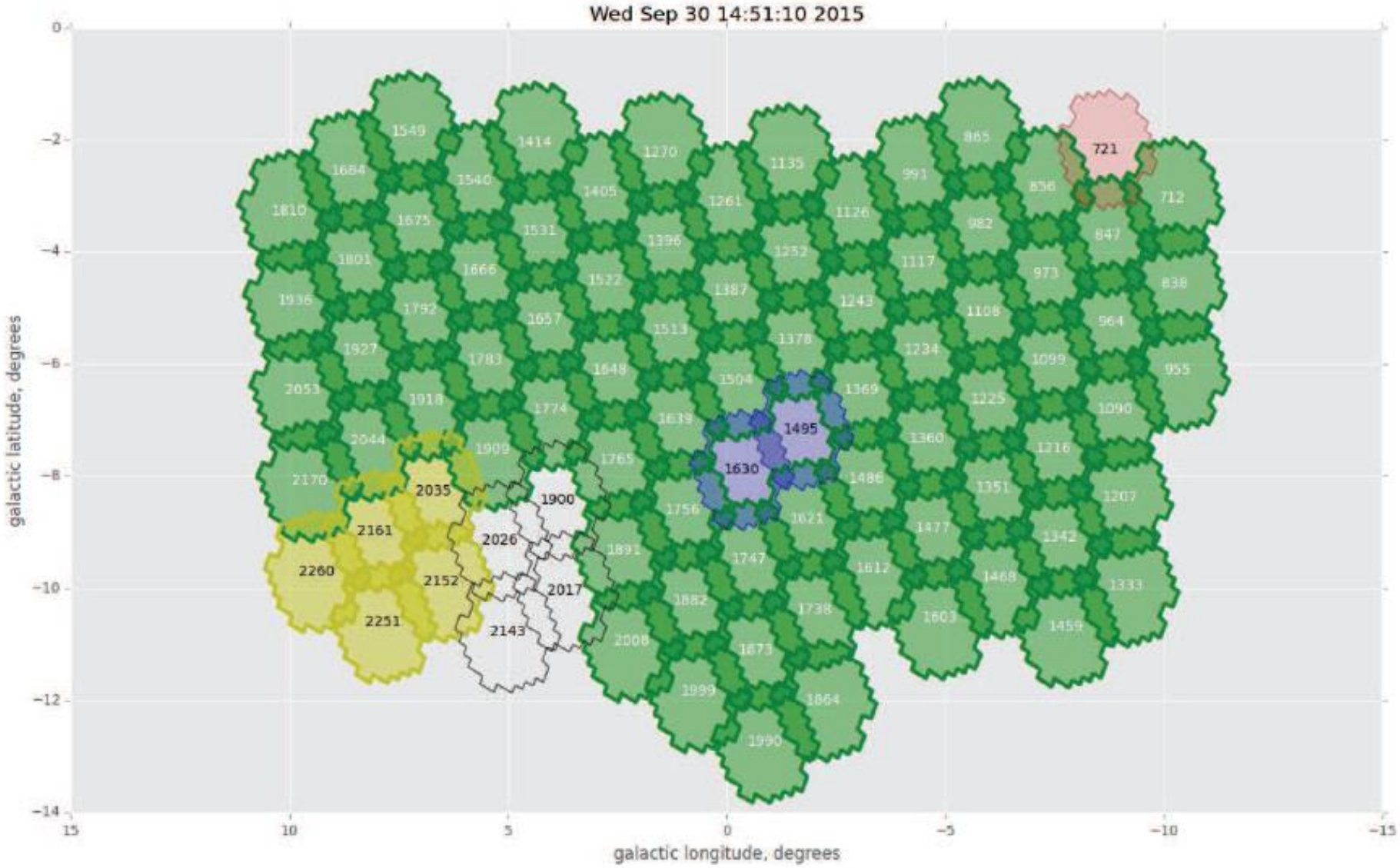


2015 progress on BDBS

Dark Energy Camera at CTIO Blanco 4m telescope. 3 sq. deg. field of view, 62 CCDs ugrizY SDSS colors imaging at 0.2”/pixel

Motivation: g-i color is far better at metallicity measurement than J-K

Coverage as of 1/16



DECam – the Dark Energy Camera

- CTIO 4m + DECam
  - ~36% the collecting area of LSST
  - 3 sq deg field of view
    - ~31% the field of view of LSST
  - Seeing-limited
  - 520 MPix
    - ~16% the pixel-count of LSST

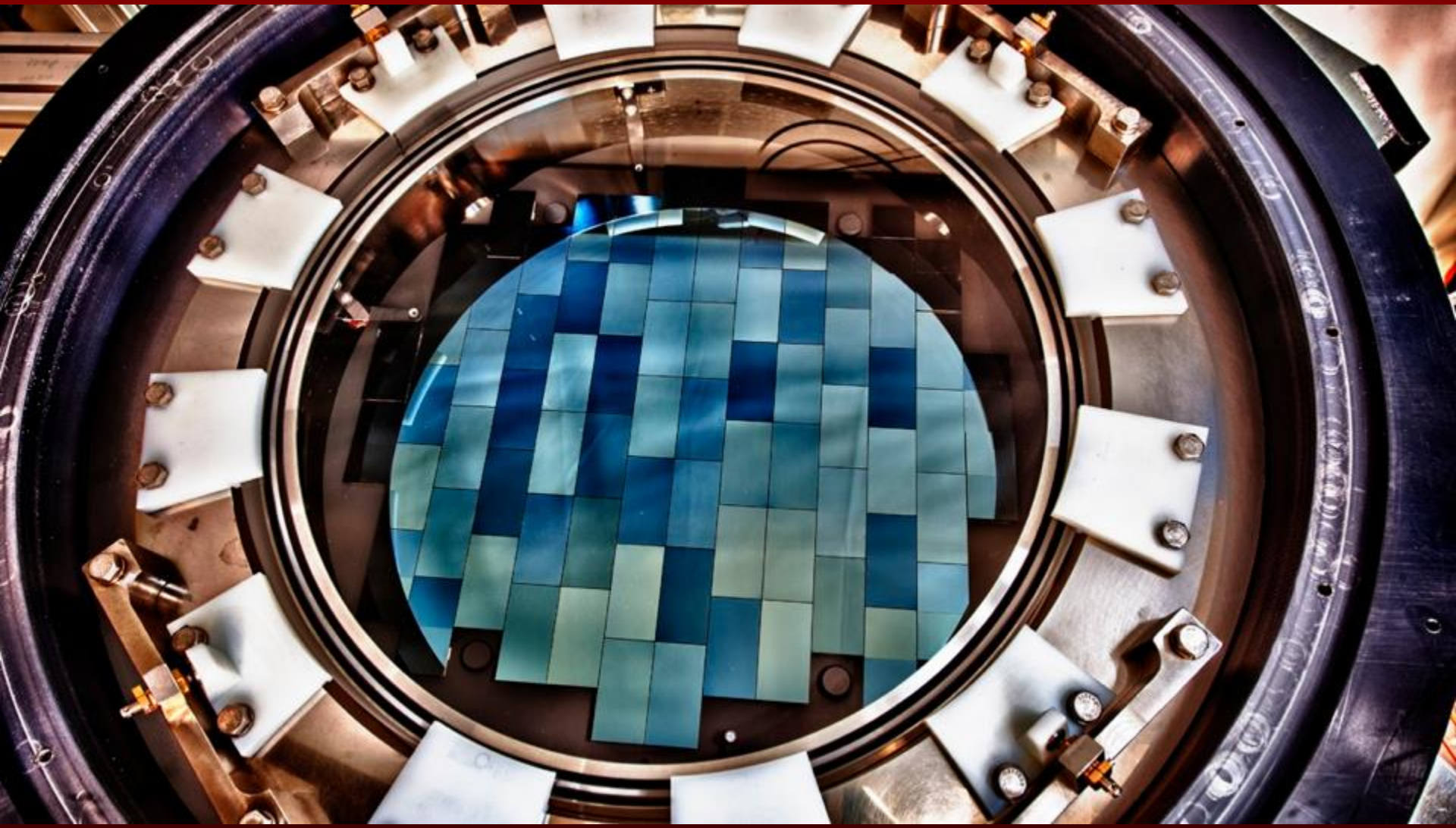
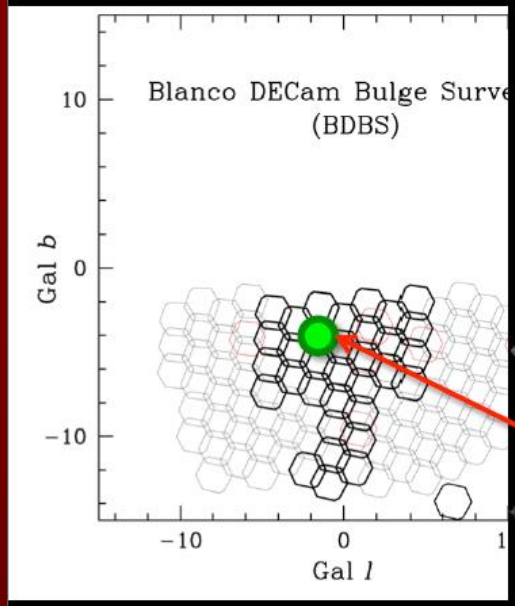


Image: W. Clarkson

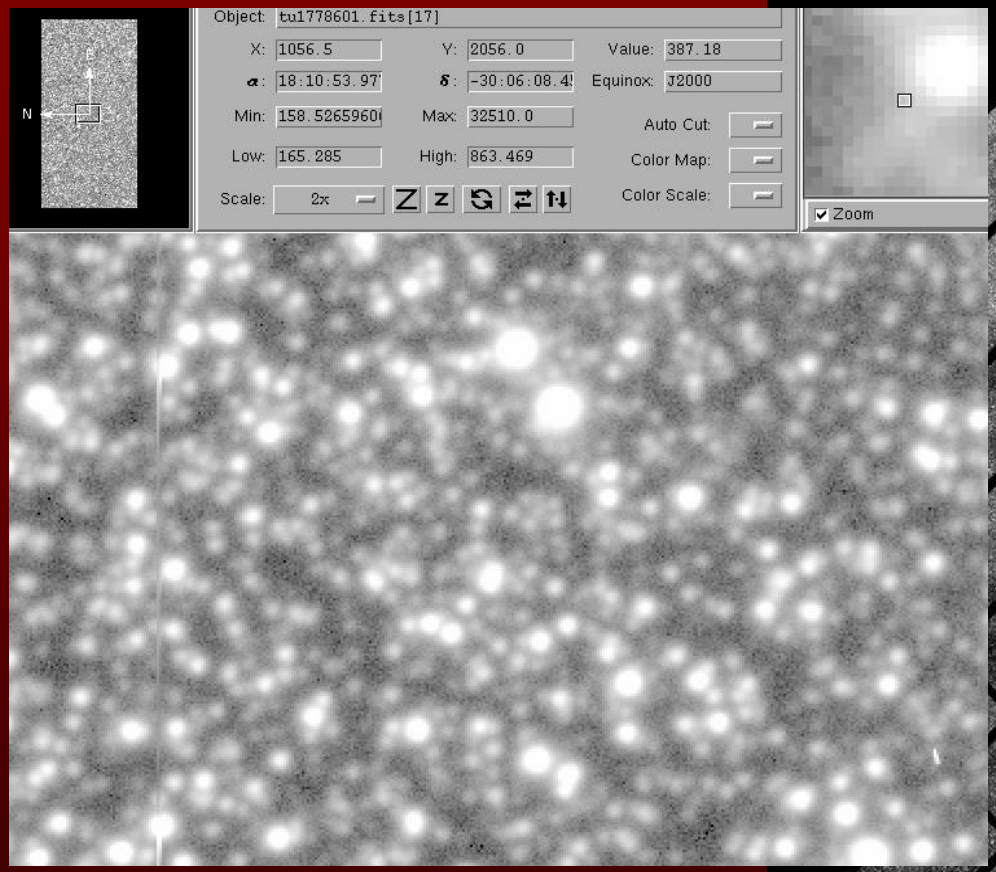
3/11/2016

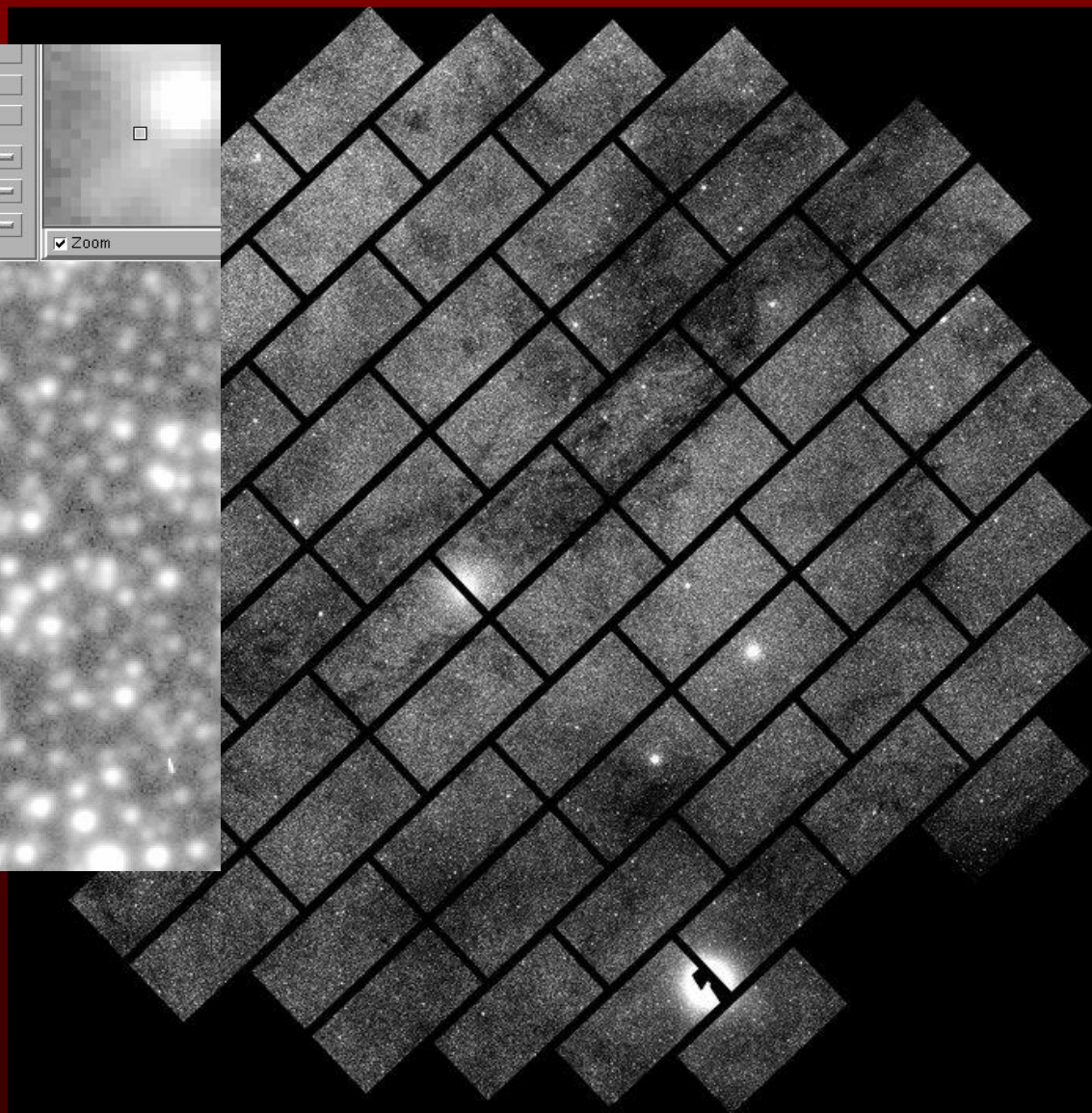
Image: W. Clarkson



3/11/2016

BDBS operates in quite a crowded regime:





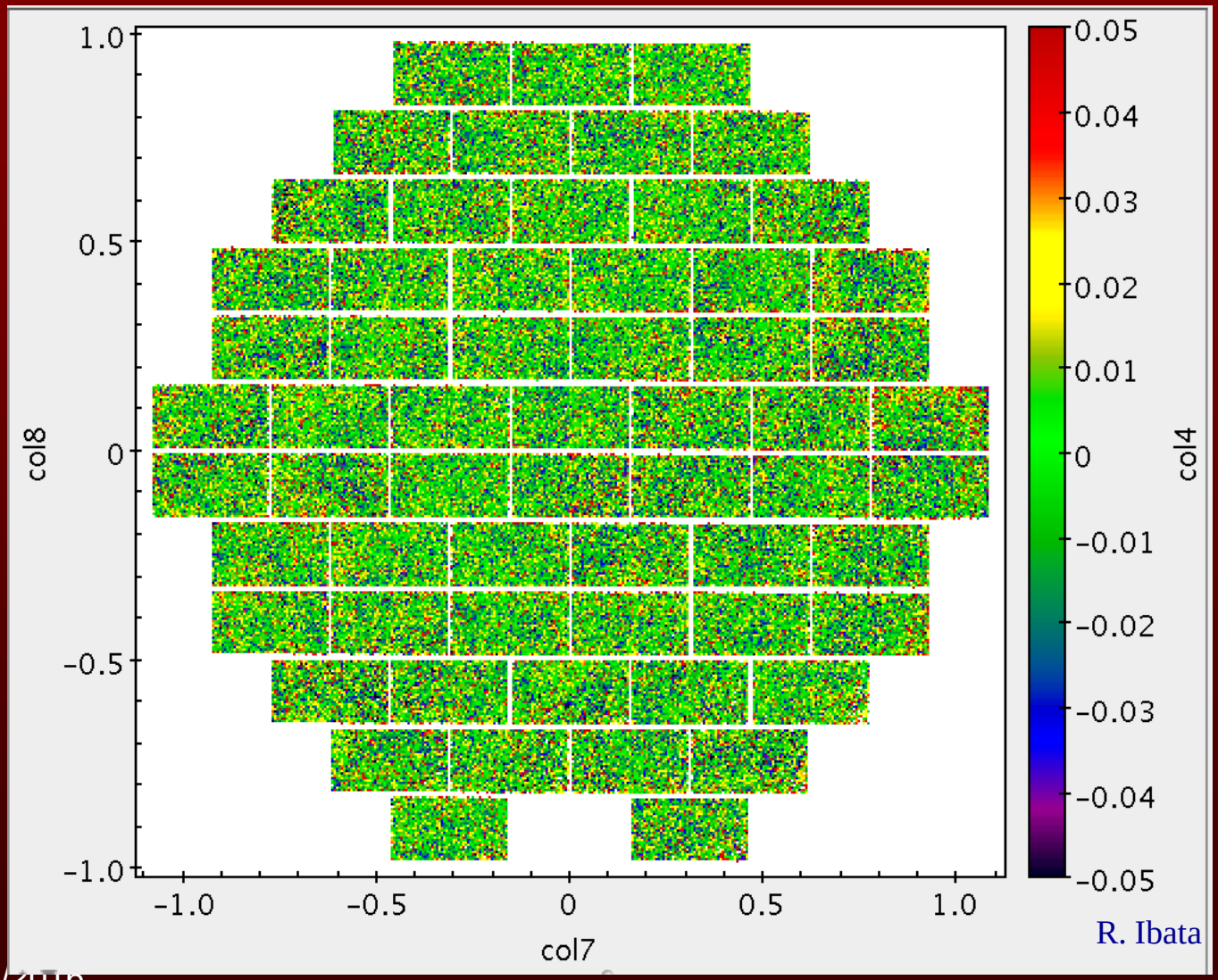
The Blanco DECam Bulge Survey (BDBS)

- Processing the full dataset:
- 2013A: 126,514 chip-images
  - ~5 TB uncompressed
- Full area: DOPHOT
  - Developing initial catalog
- Other approaches tested on select fields.

Images processed on the Quarry-II infrastructure at Indiana University.

With hundreds of cores, takes about 1 week for the entire dataset.

Three approaches to photometry underway CASU (Ibata; complete), DoPhot (Johnson), Daophot(Clarkson). Present catalog has 10^9 stars



Sesto 2016

Preliminary photometric calibration using Panstarrs1 (R. Ibata, N. Martin)

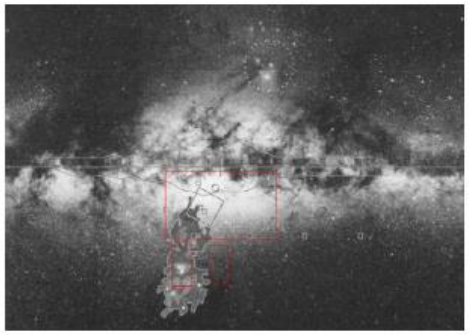
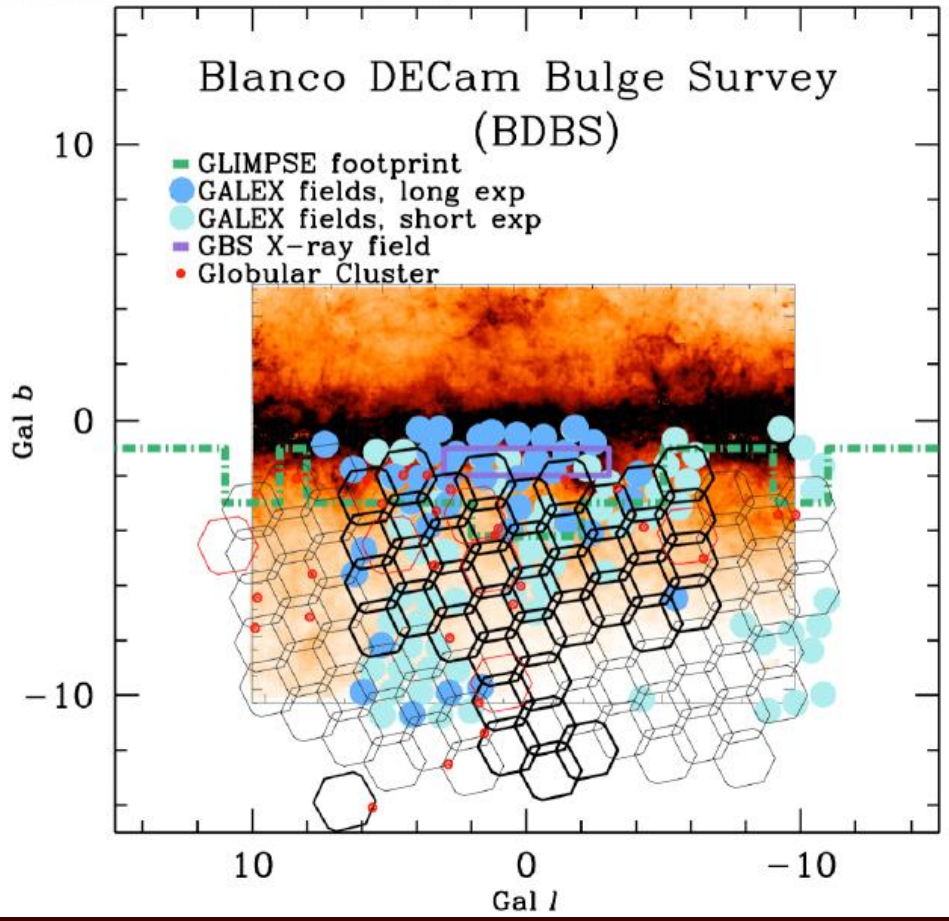
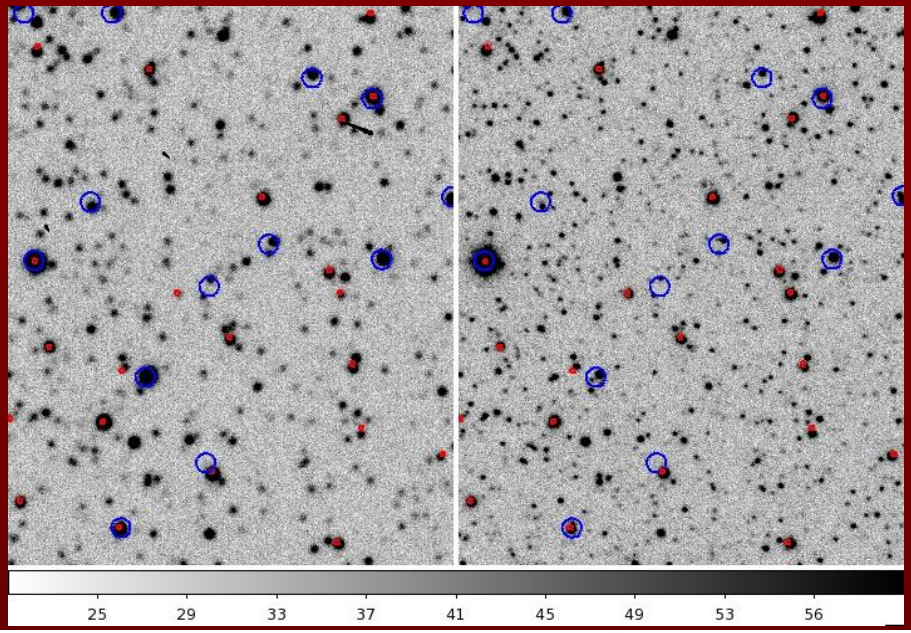


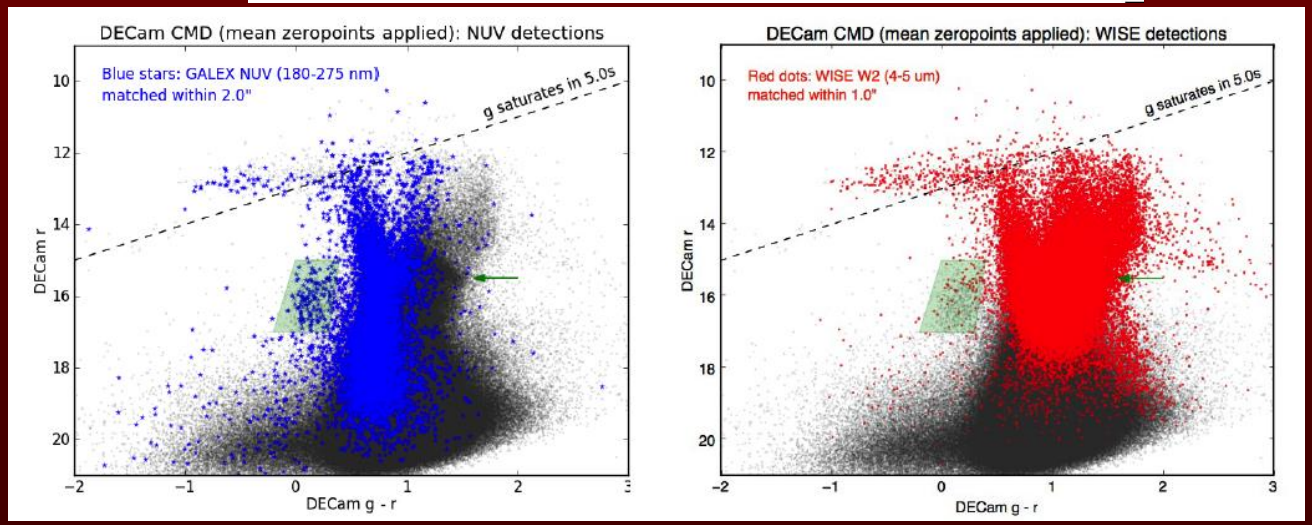
Figure 1-(Left) Visible light image of the Milky way with the bulge and Sgr dwar galaxy (illustrated as a blobby structure below the bulge) superimposed (Wyse, Gilmore, & Franx 1997). The red square regions cover the approximate location of the Blanco DECam bulge survey illustrated below.



BDBS has complete overlap with WISE, GLIMPSE (Spitzer), partial overlap GALEX- rich array of space datasets

Match Galex, WISE





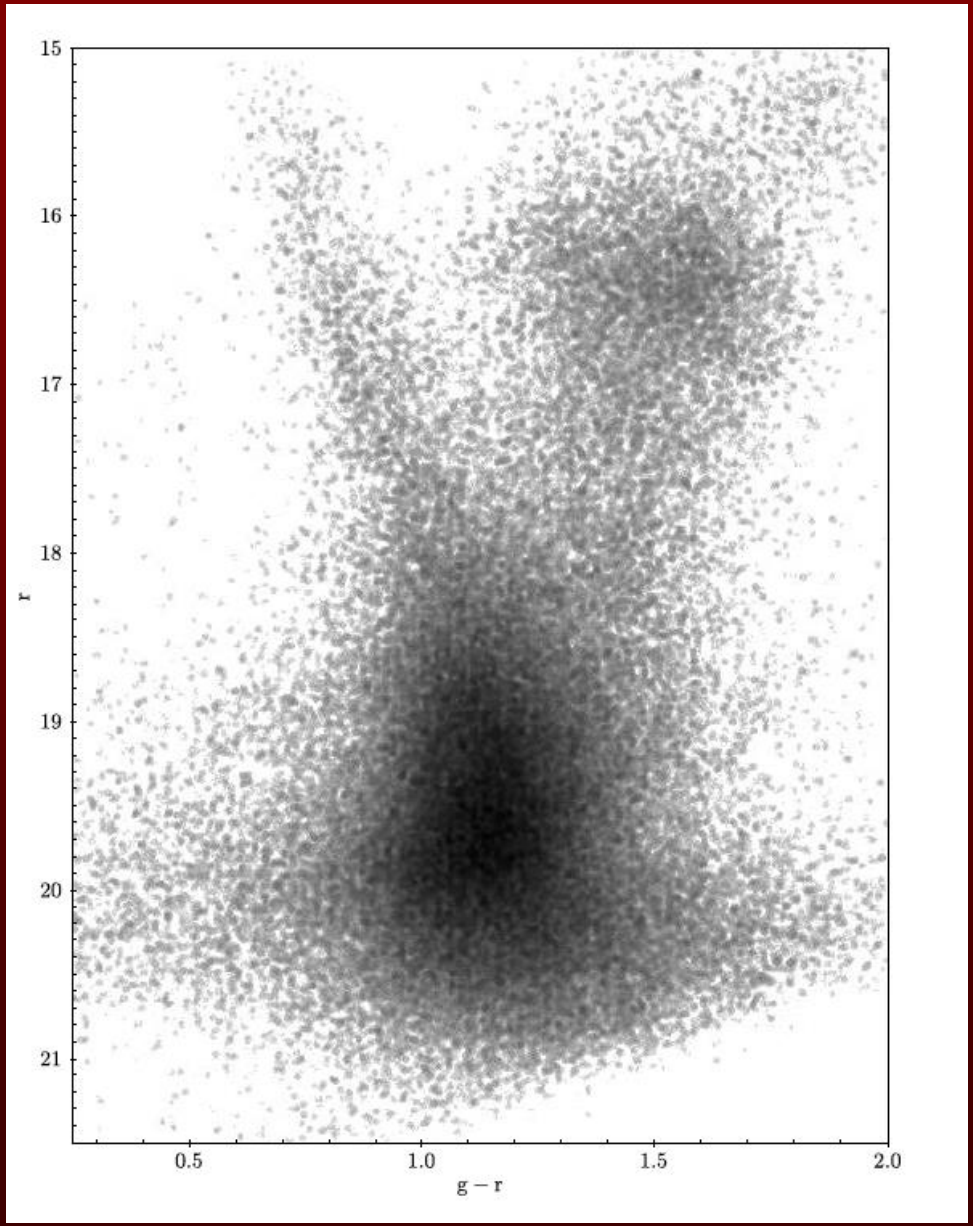
Reductions by C. Johnson and Will Clarkson

3/11/2016

Science Goals

- Produce a community catalog and image server to be served by PTI (IU)
- Separate the bulge from the foreground disk, background halo by statistical subtraction and proper motions
- Map bulge structures (bar, X) as a function of age, metallicity; photometric metallicities for abundance gradient
- Produce a map of the Sagittarius dwarf spheroidal galaxy core
- Search for streams and substructure in the bulge
- Search for ultra-metal poor stars in the bulge region
- Use proper motions to explore the kinematics of the bar and X structure and to search for a “classical” bulge component

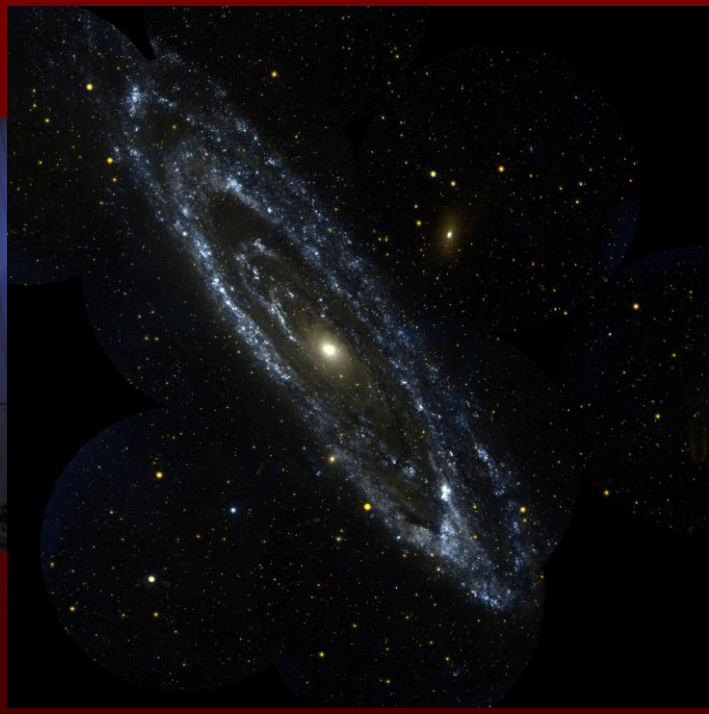
Preliminary CMD near Baade's Window



Sesto 2016

Halos and Environments of Nearby Galaxies (HERON)

Galaxy Evolution Explorer

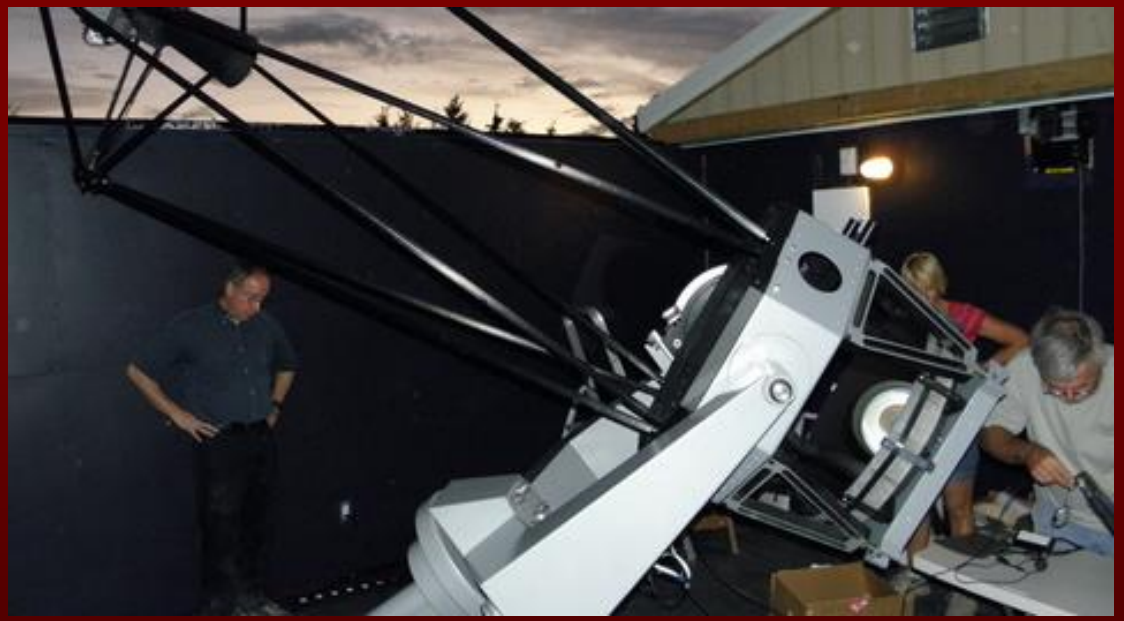


A 20-inch = 0.5m UV telescope

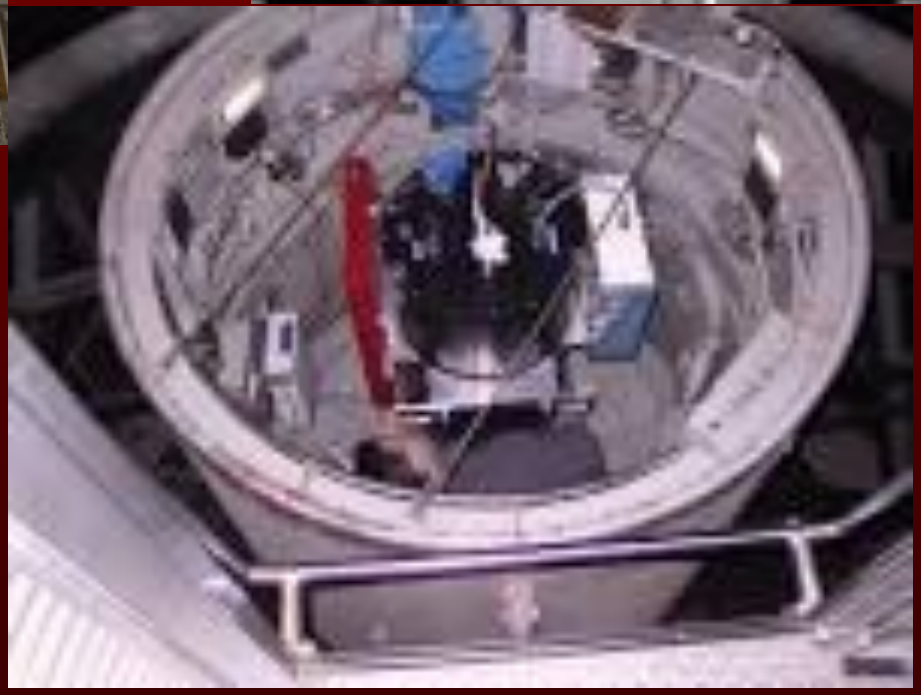
The Calypso Telescope
1.2m telescope at Kitt Peak

The Centurion 28-inch

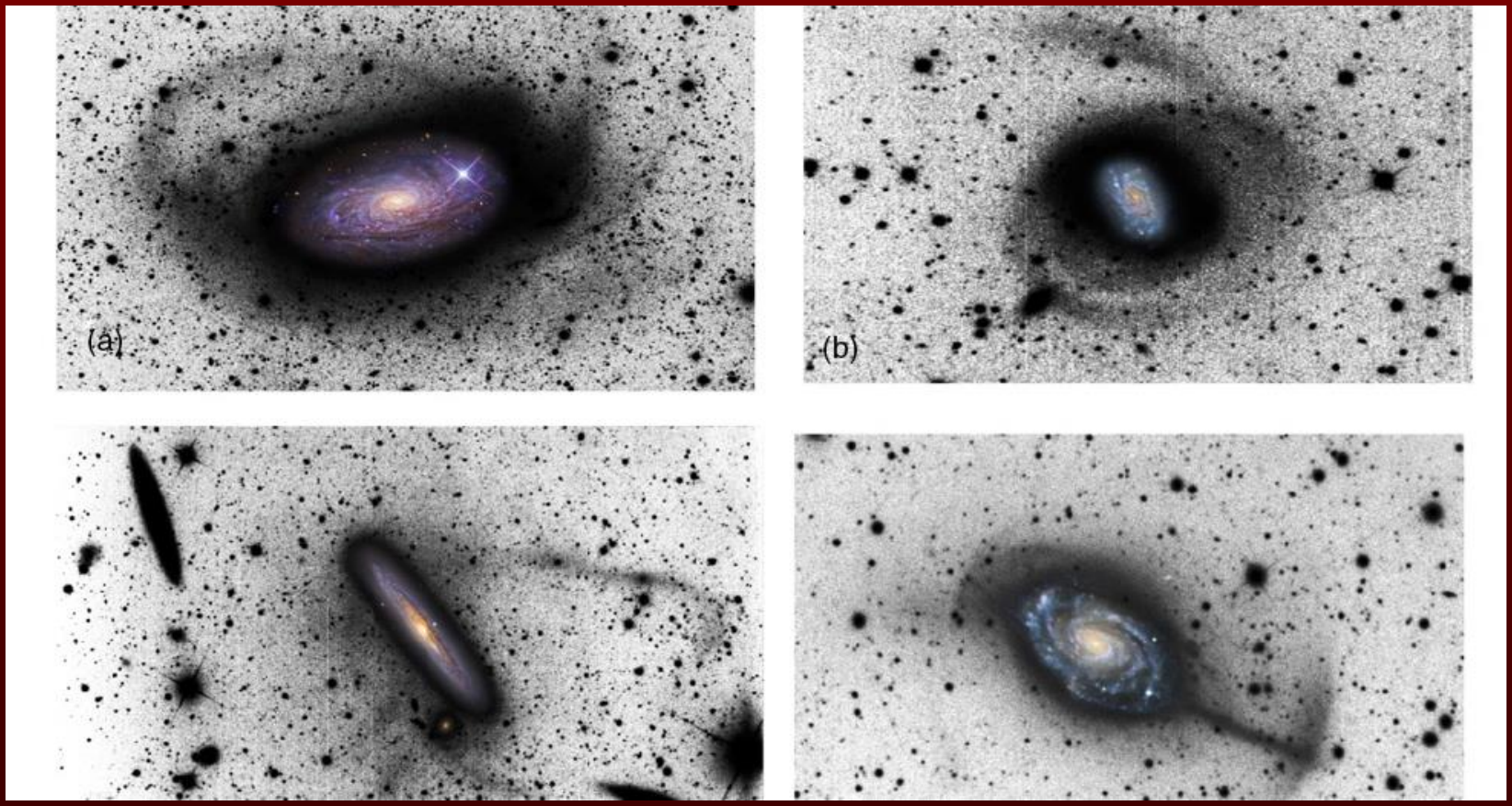
designed and built by Jim Riffle

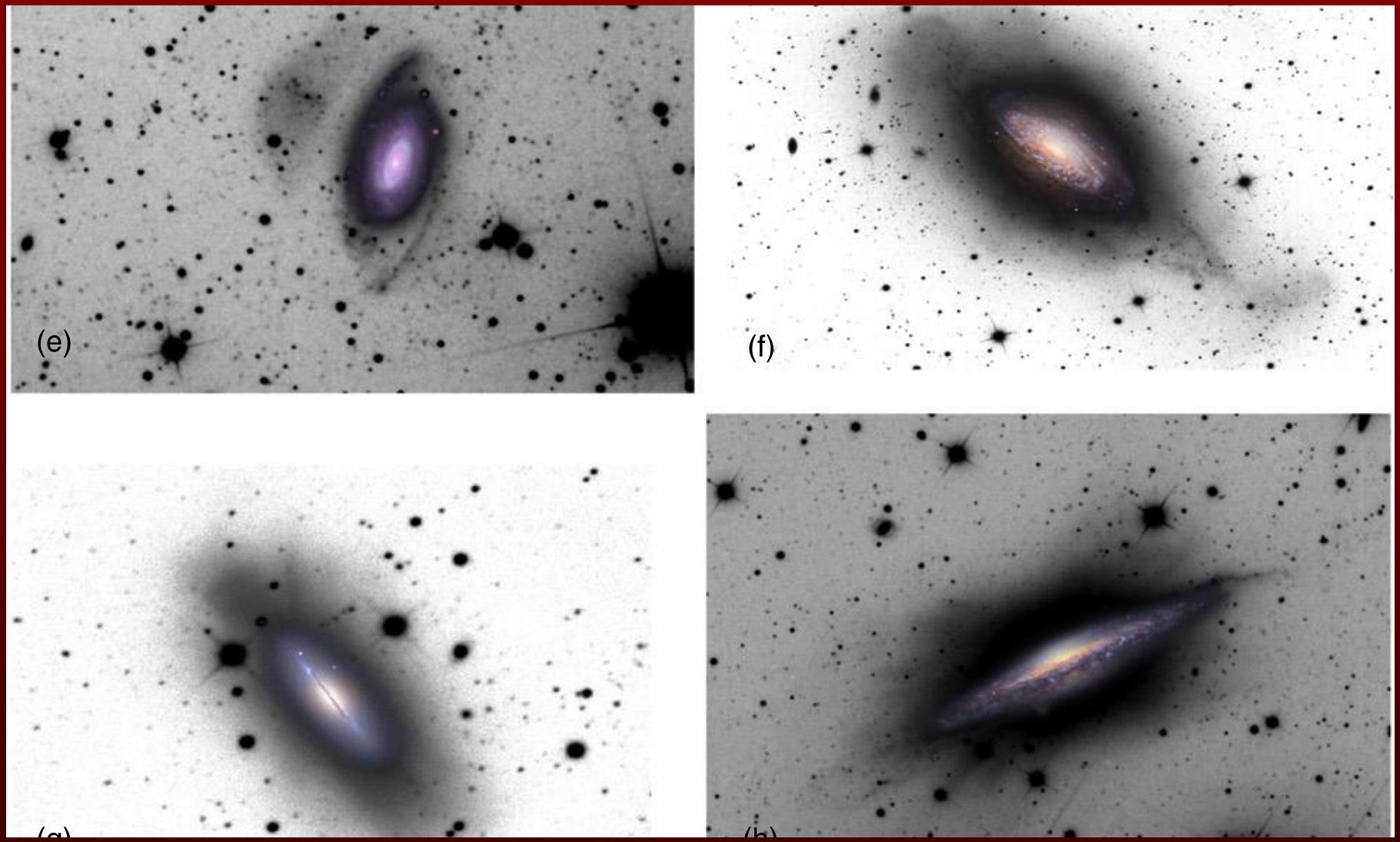


f/3.2 Hyperbolic primary
3 3element Ross Corrector

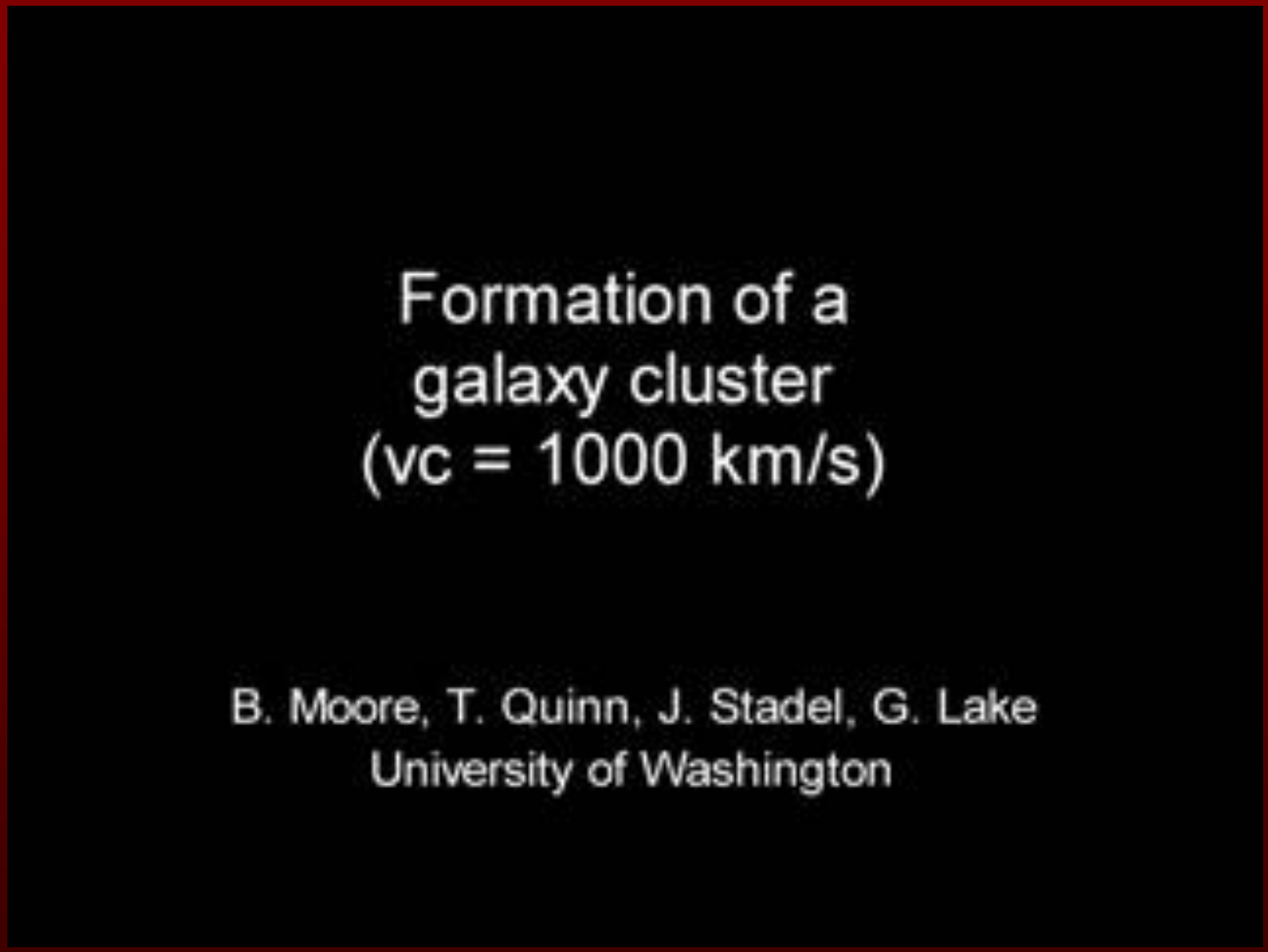


Martinez-Delgado 2010

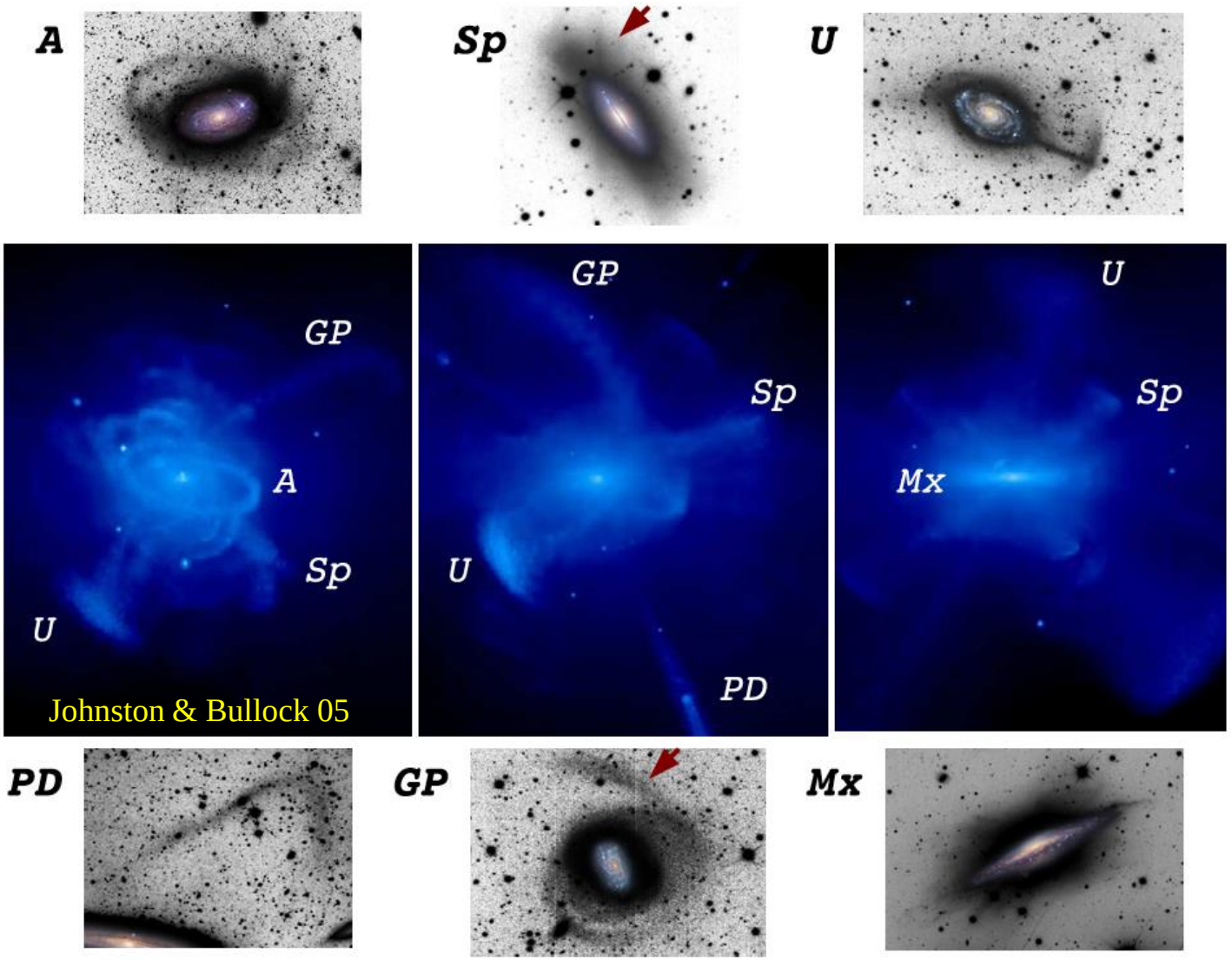


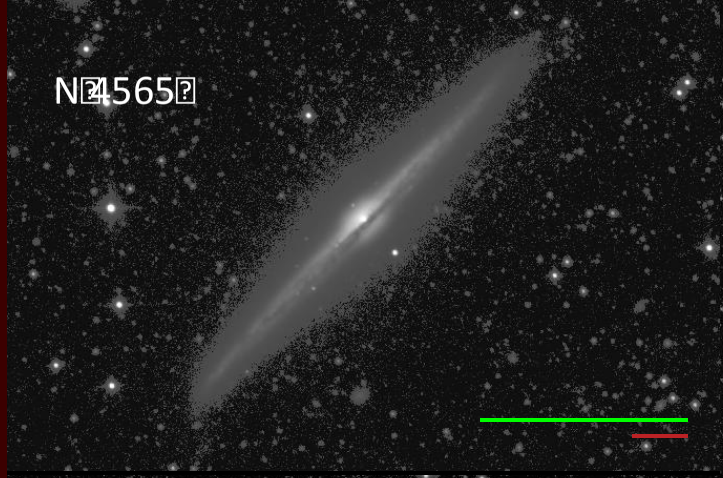

(e)
(f)
(g)
(h)

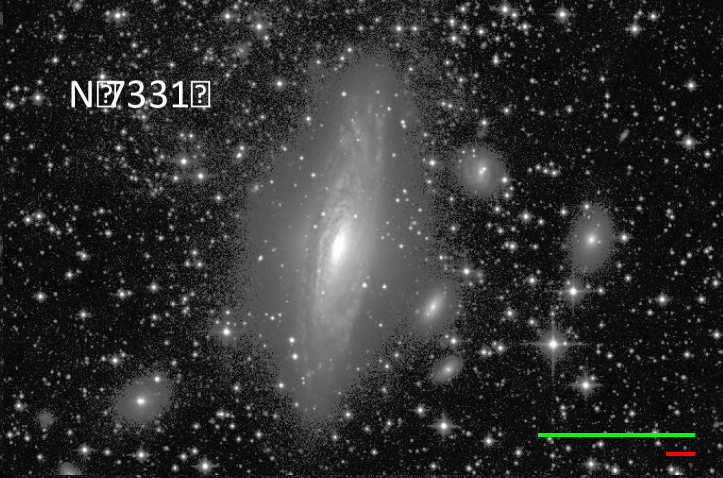
Why this is important

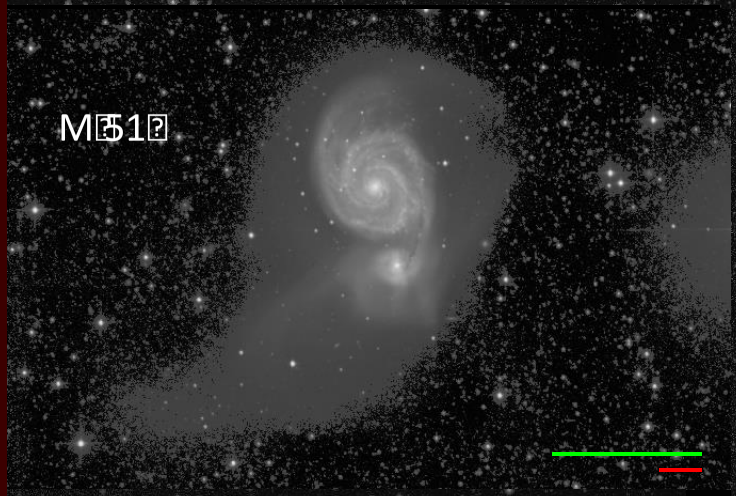


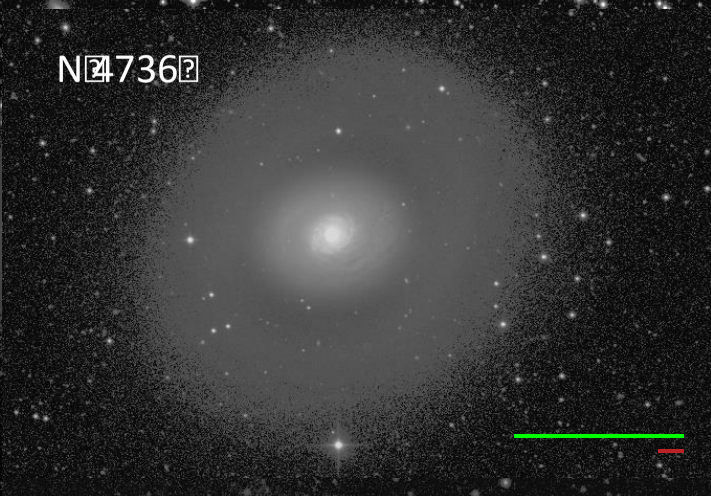
Cosmological models predict infalling galaxie

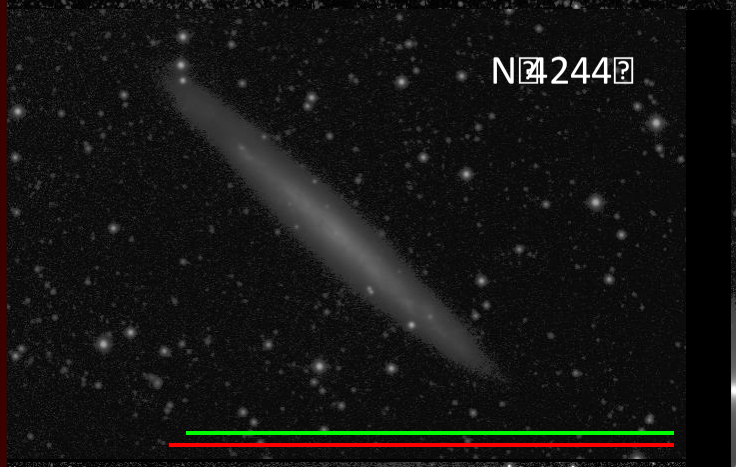


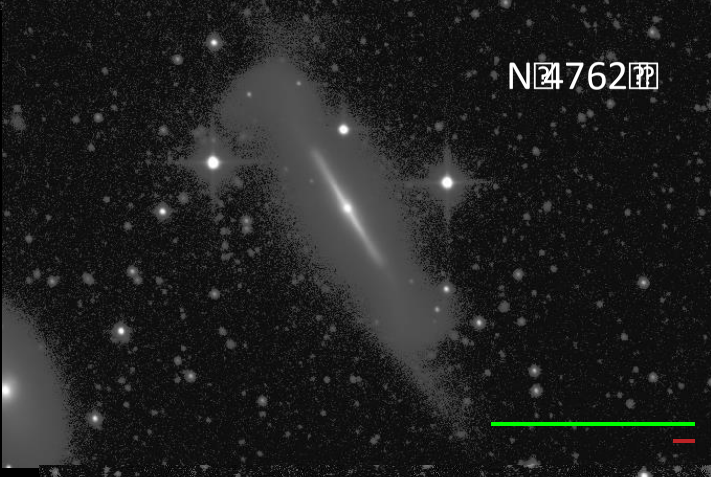

N4565


N7331


M51


N4736


N4244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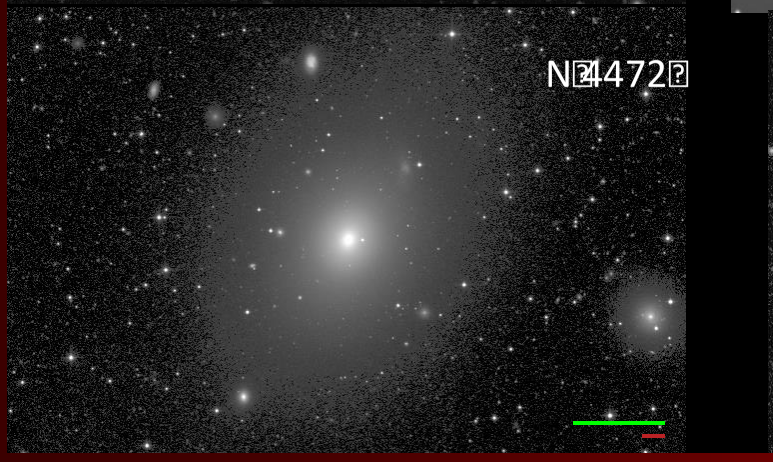
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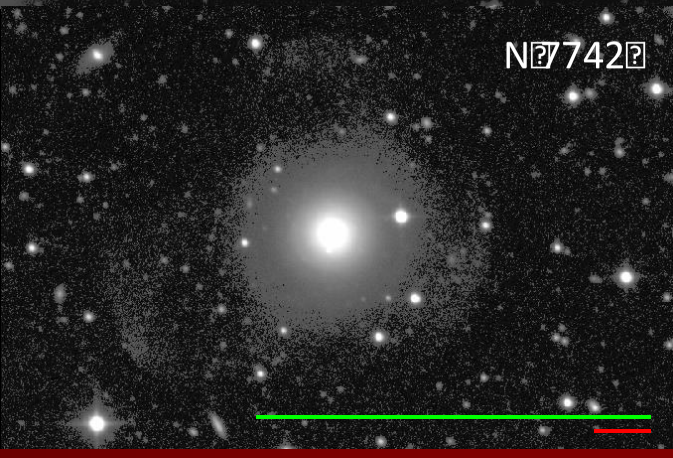
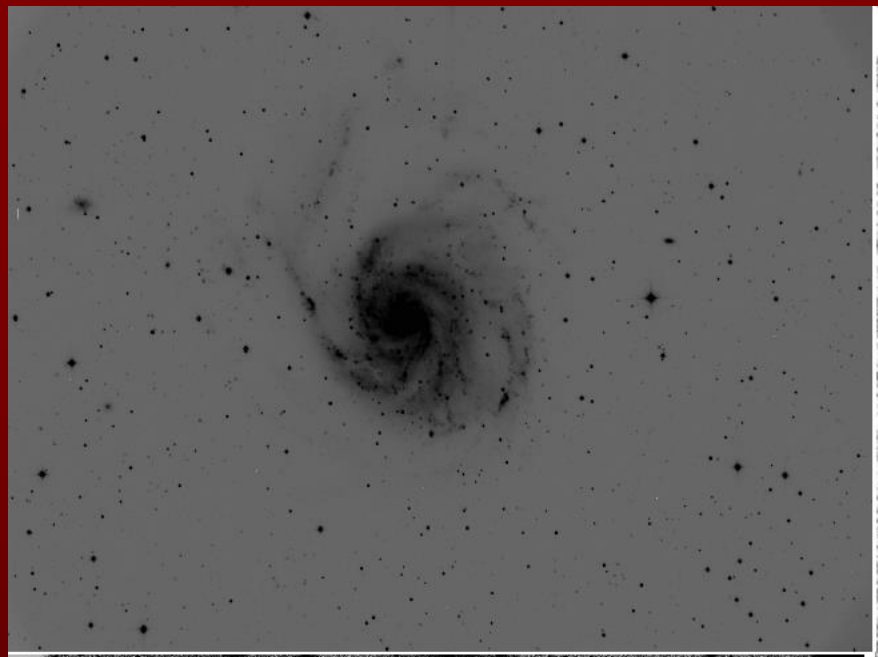
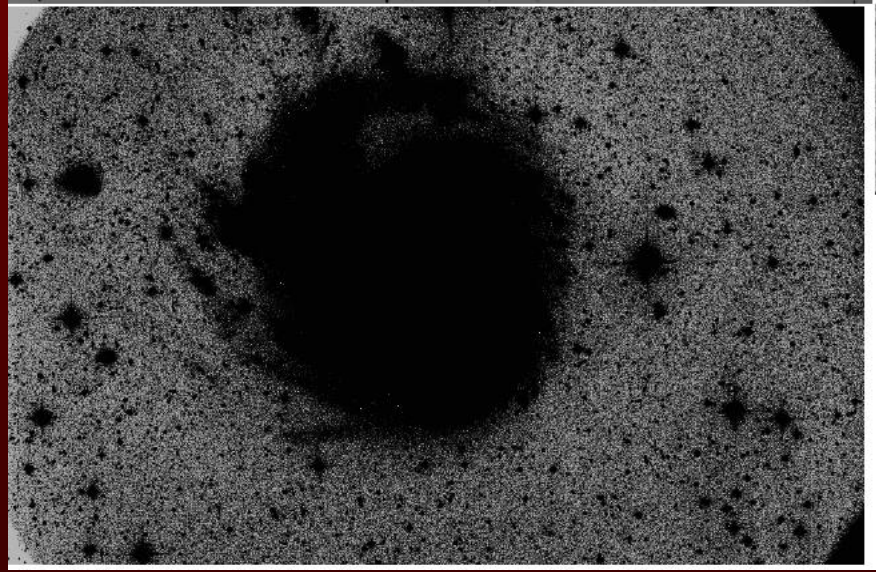
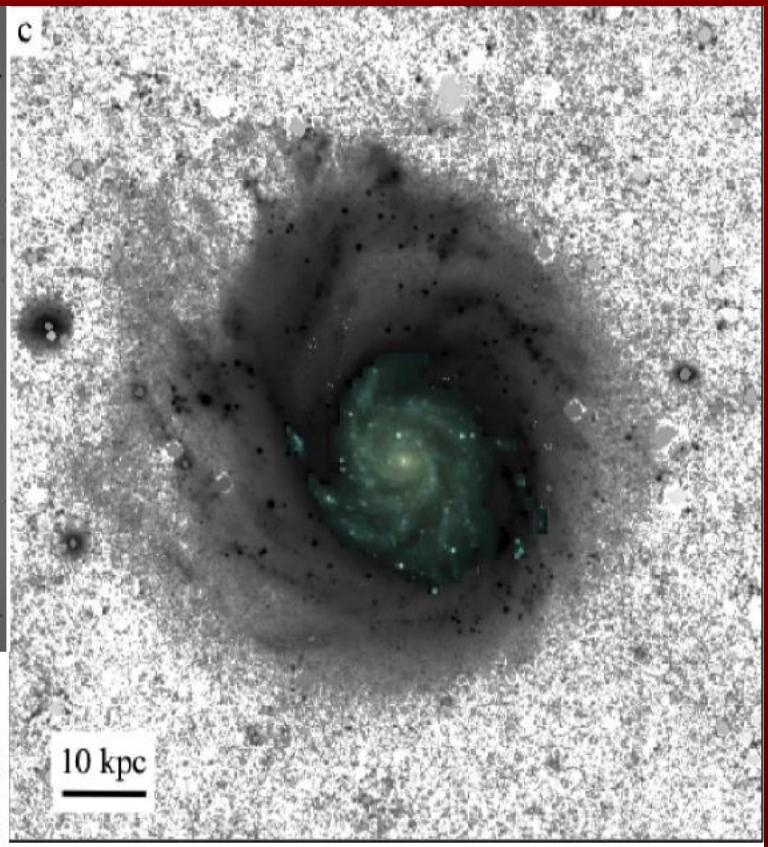

N7742

Competition: The Dragonfly Array (Yale, Toronto) Operating at New Mexico Skies

8 Canon 6” f/1.2 IS II lenses







35 Hours Dragonfly

vs 40 min Heron

NGC 4449 A remarkable nearby galaxy (proposed for Subaru/HSC)

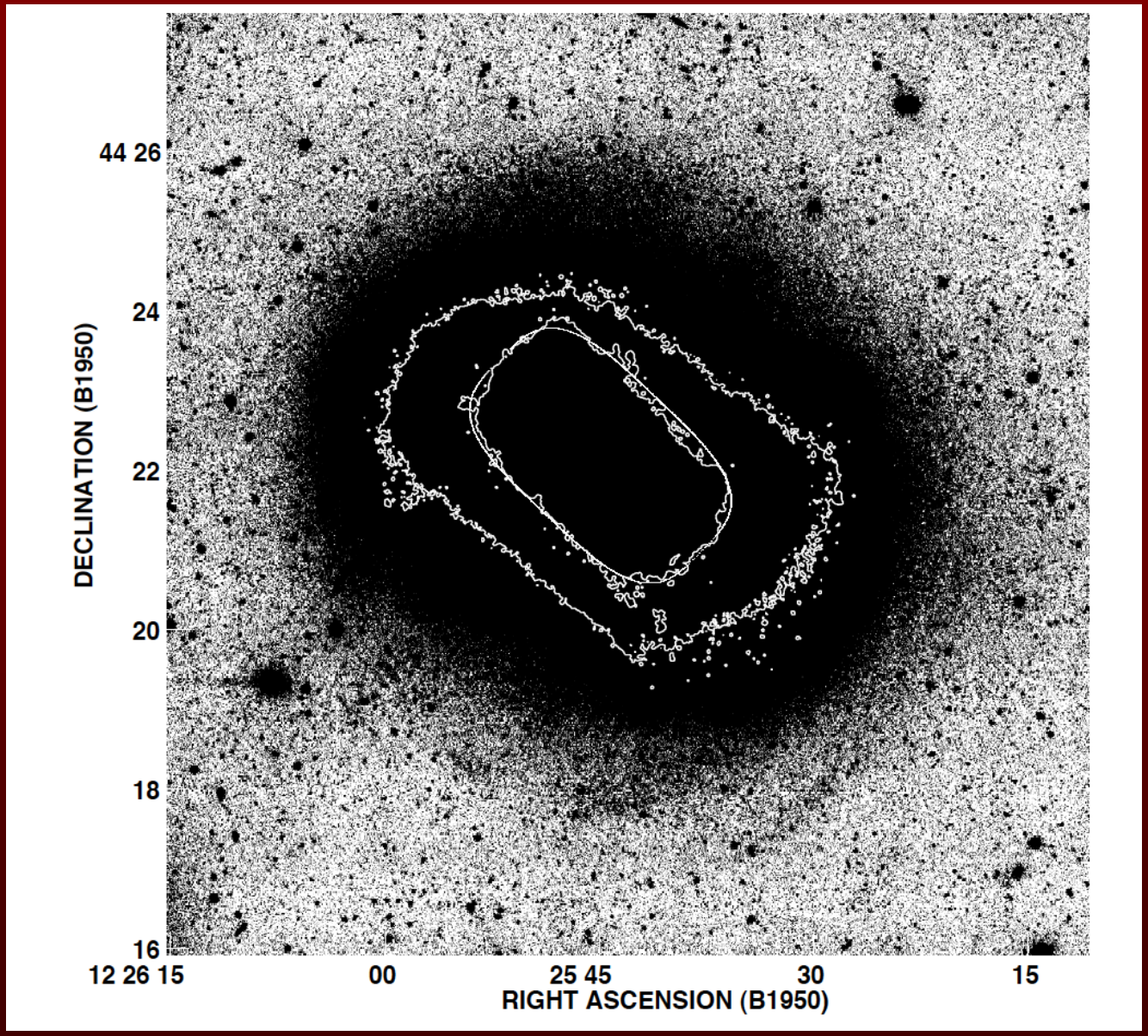
- Magellanic starburst, M_v=-18
- Compact, massive nucleus (no evidence of black hole); Boker et al. (200)
- HST imaging finds $(m-M)_0$=27.91, extended red (old) halo population (Annibali et al. 2008) with young and old globular clusters (Annibali et al. 2010, 2011)

Centurion 28-inch telescope

- f/3.1 with SBIG STL 11000M CCD at prime focus
- Excellent for imaging low surface brightness structures
- Collaboration with F. Longstaff (UCLA Anderson School)

NGC 4449

- 12h +44
- Extensive HI structures
- UV emission only in the core
- 2x LMC; not in group (nearest companions 40 kpc distant)



Hunter et al. (1999)

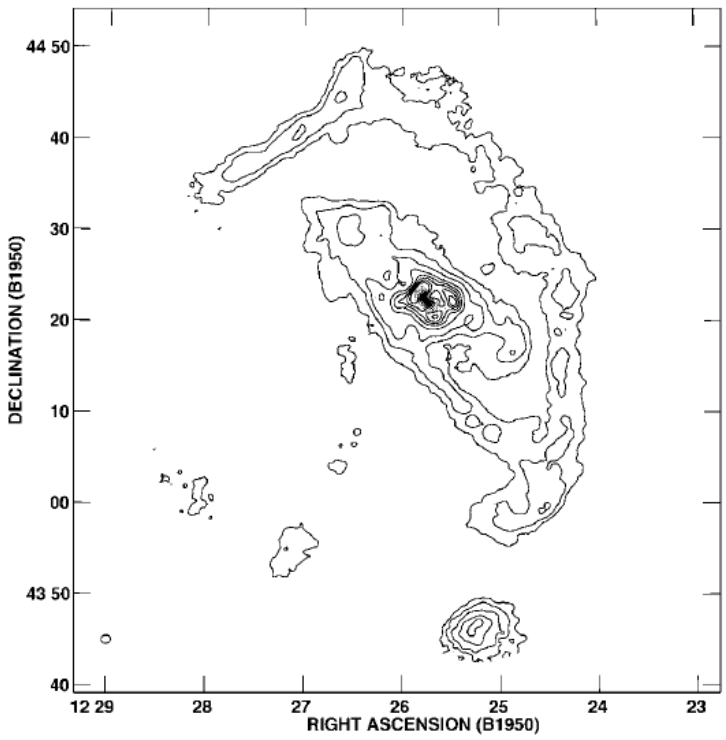
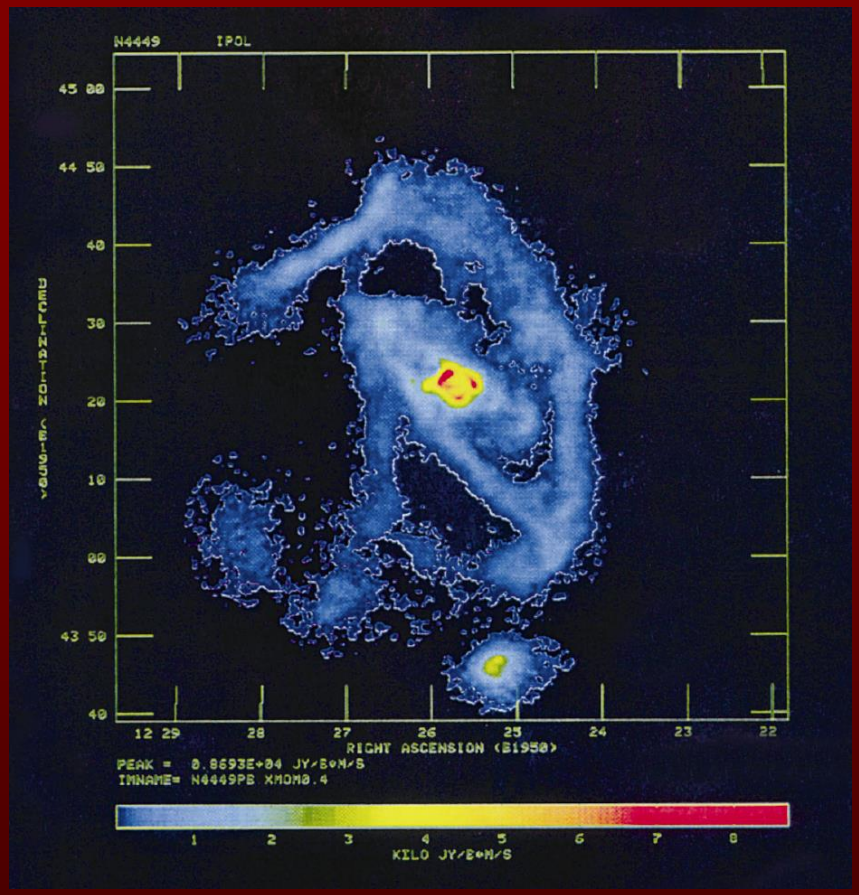
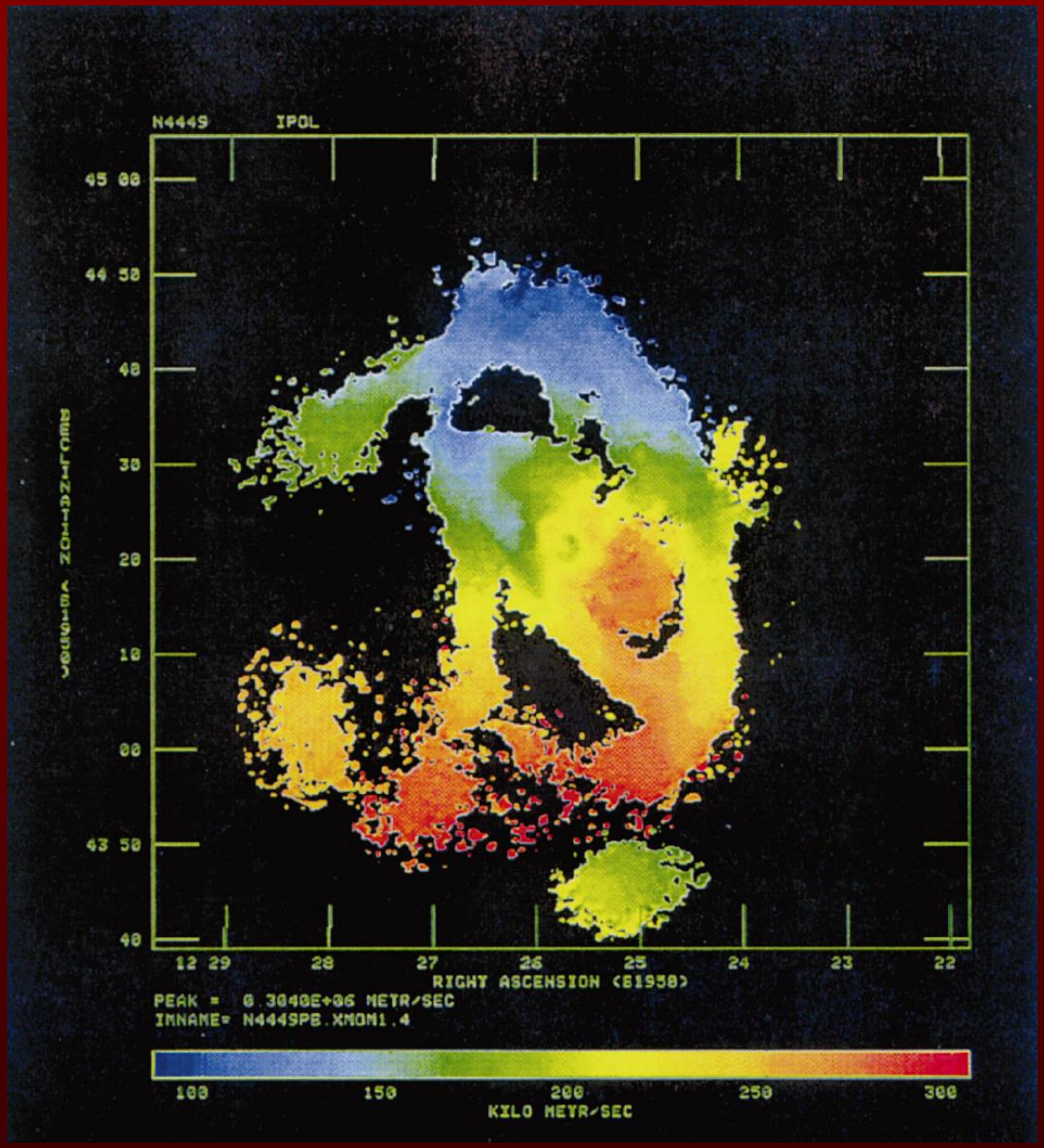


FIG. 2.—Contour map of the integrated H I distribution superposed on a gray-scale optical image of the galaxy. The contour levels are 0.7, 1.7, 3.4, 6.8, 10.2, 13.6, 17.0, and 20.4 × 10^{20} cm^{-2}. The FWHM of the beam is shown in the bottom left-hand corner of the plot. The optical image was obtained through a filter centered at 6440 Å with an FWHM of 95 Å.



HI maps Hunter et al. 1998


N4449 IPOL
45 00
44 50
40
12 29
28
27
26
25
24
23
22
RIGHT ASCENSION (B1950)
PEAK = 0.3040E+06 METR/SEC
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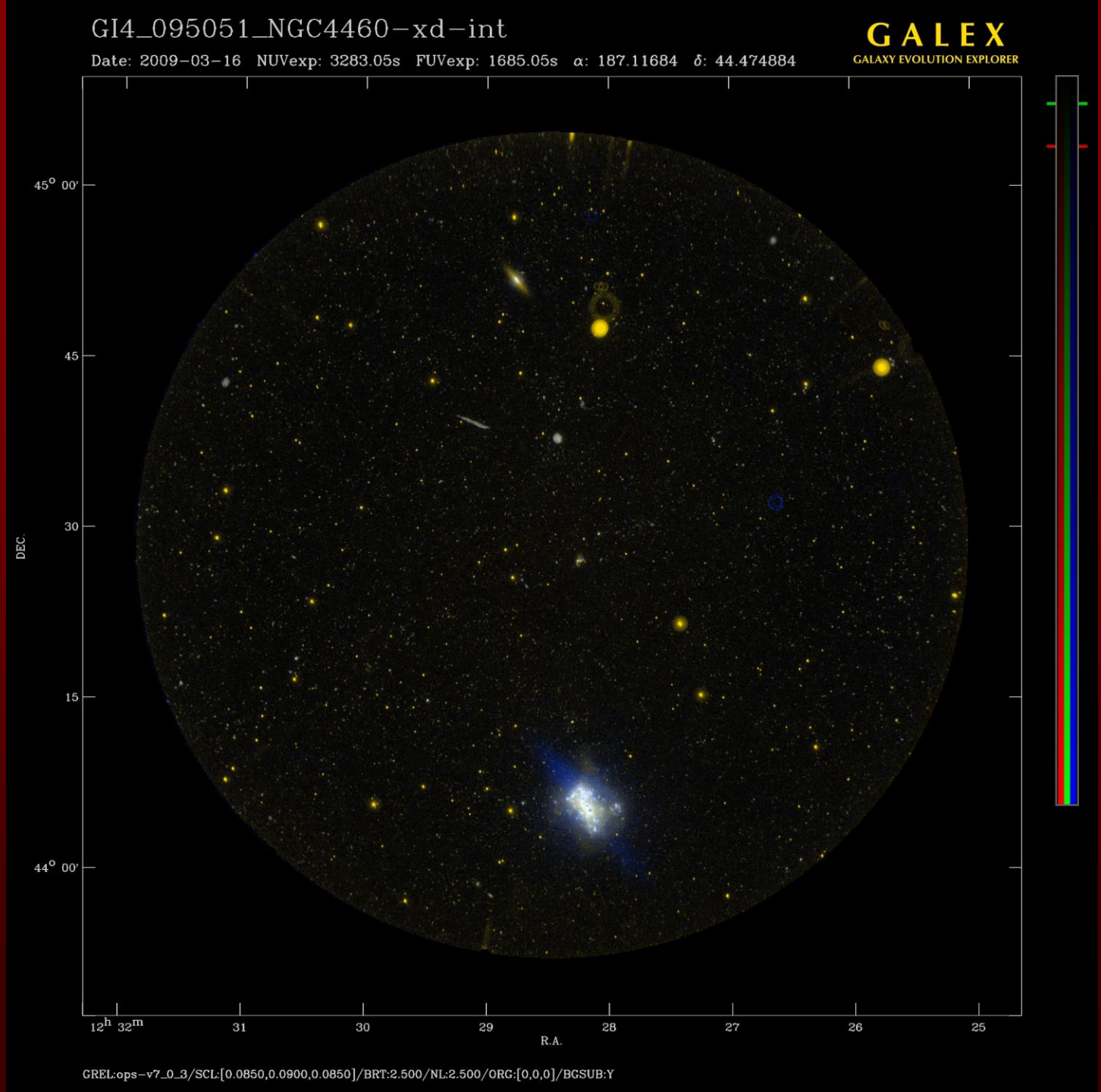
100
150
200
250
300
KILO METR/SEC

Galex 2-color
Image
M. Seibert


GI4_095051_NGC4460-xd-int
Date: 2009-03-16 NUVexp: 3283.05s FUVexp: 1685.05s α: 187.11684 δ: 44.474884
GALEX
GALAXY EVOLUTION EXPLORER
45° 00′
45
30
15
44° 00′
DEC.
12h 32m
31
30
29
28
27
26
25
R.A.
GREL:ops-v7_0_3/SCL:[0.0850,0.0900,0.0850]/BRT:2.500/NL:2.500/ORG:[0,0,0]/BGSUB:Y

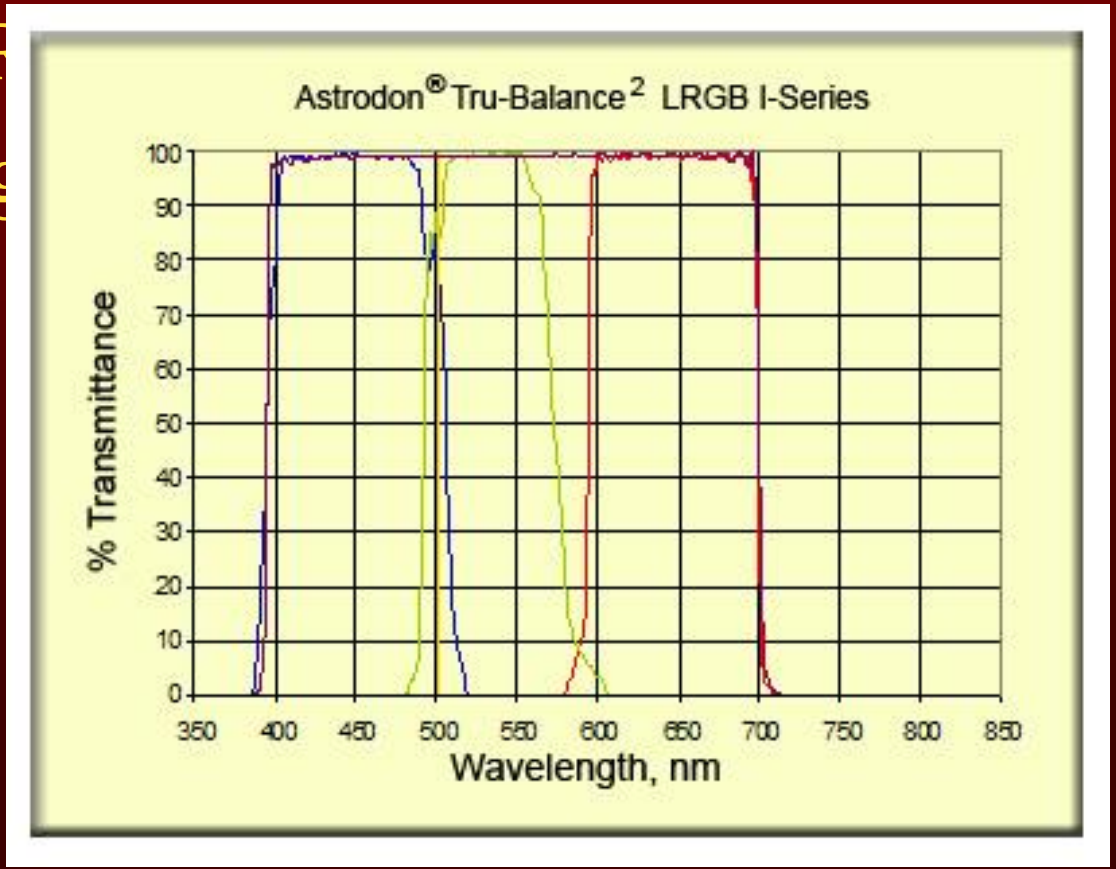
F. Longstaff

F. Longstaff

Observations

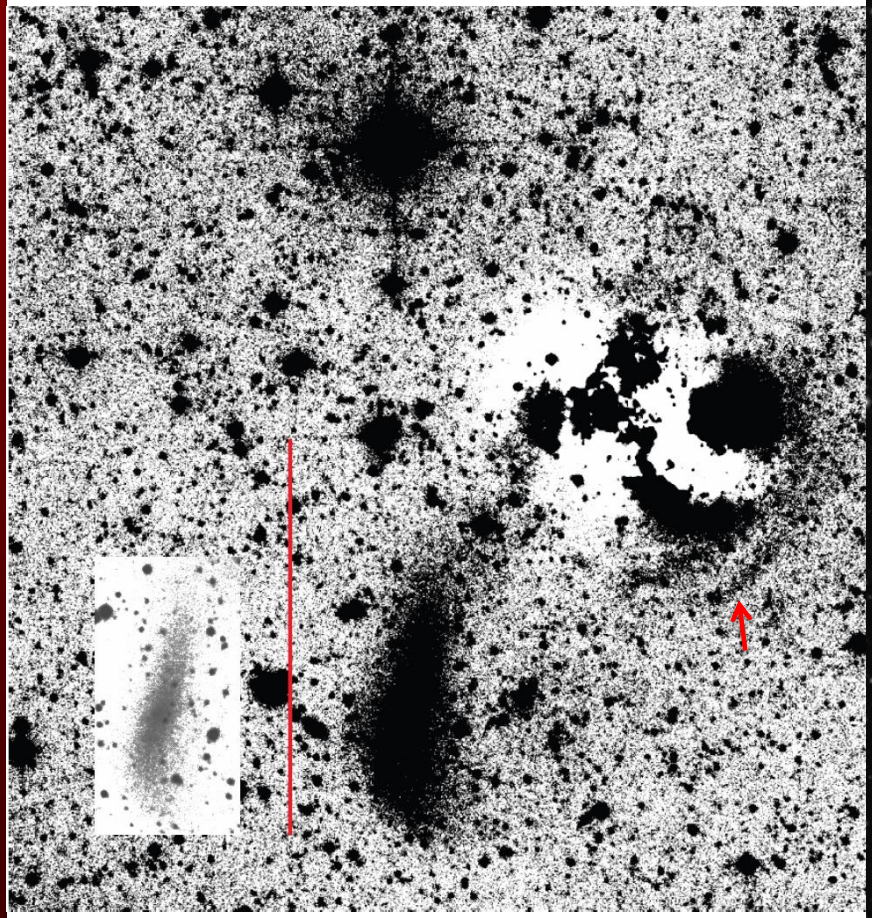
- 3.12 hr Luminance 31 May – 2 June 2012
- 45 min each B, R
- Calibration using

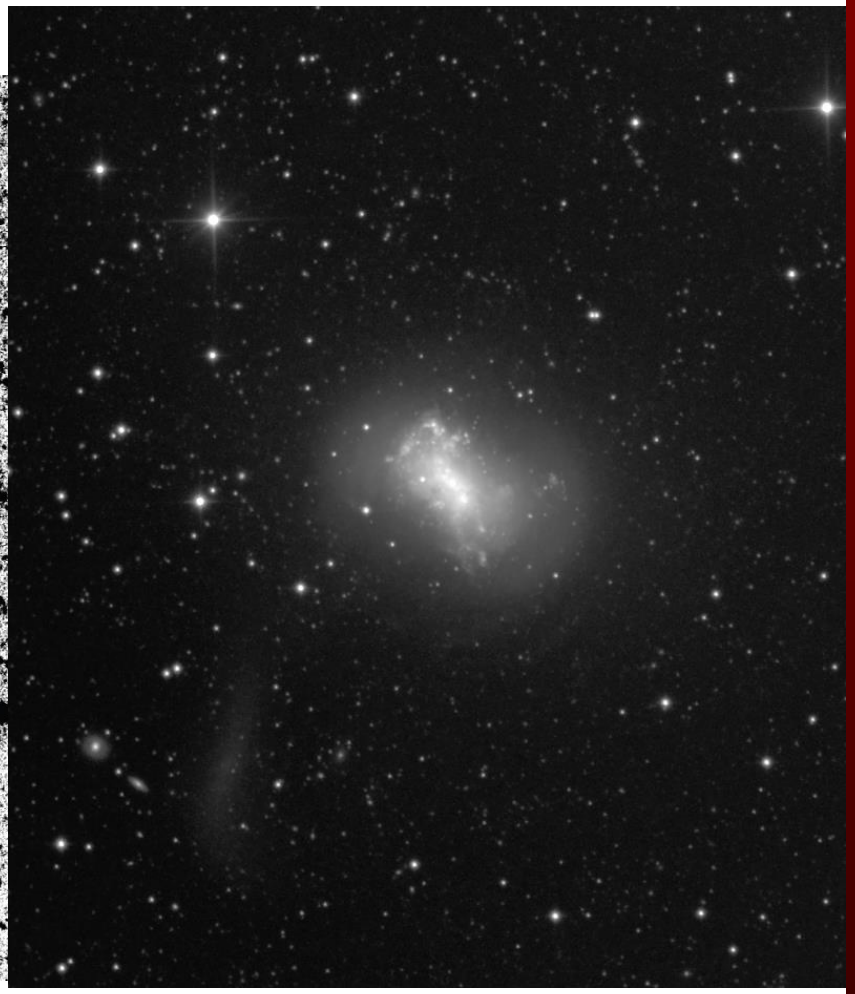
SDSS imagery (to



Model halo surface brightness using ELLIPSE in IRAF and subtract

M_v=-13.4 g-r=0.5 (Like Fornax dSph)





Scale bar = 10 kpc N up, East left

AIC has M_v=-8.9

Subaru 8m image From Martinez-Delgado et al. 2011

LETTER

doi:10.1038/nature10837

A tidally distorted dwarf galaxy near NGC 4449

R. M. Rich[1,2], M. L. M. Collins[3], C. M. Black[1], F. A. Longstaff[2,4], A. Koch[5], A. Benson[6] & D. B. Reitzel[1,7]

NGC 4449 is a nearby Magellanic irregular starburst galaxy[1] with a B-band absolute magnitude of −18 and a prominent, massive, intermediate-age nucleus[2] at a distance from Earth of 3.8 megaparsecs (ref. 3). It is wreathed in an extraordinary neutral hydrogen (H I) complex, which includes rings, shells and a counter-rotating core, spanning ~90 kiloparsecs (kpc; refs 1, 4). NGC 4449 is relatively isolated[5], although an interaction with its nearest known companion—the galaxy DDO 125, some 40 kpc to the south—has been proposed as being responsible for the complexity of its H I structure[6]. Here we report the presence of a dwarf galaxy companion to NGC 4449, namely NGC 4449B. This companion has a V-band absolute magnitude of −13.4 and a half-light radius of 2.7 kpc, with a full extent of around 8 kpc. It is in a transient stage of tidal disruption, similar to that of the Sagittarius dwarf[7] near the Milky Way. NGC 4449B exhibits a striking S-shaped morphology that has been predicted for disrupting galaxies[7,8] but has hitherto been seen only in a dissolving globular cluster[9]. We also detect an additional arc or disk ripple embedded in a two-component stellar halo, including a component extending twice as far as previously known, to about 20 kpc from the galaxy's centre.

We obtained deep imaging of NGC 4449 during the time period 29 May 2011 to 1 June 2011, in the course of commissioning a 0.7-m telescope[10] designed to study low-surface-brightness structures in the vicinity of other galaxies. We discovered the profoundly tidally distorted dwarf galaxy NGC 4449B, and recover an additional lower-luminosity arc or disk ripple, deeper in its halo (Fig. 1). Our photometry reveals that the original exponential halo terminates in a dumb-bell-shaped shelf, beyond which we measure a de Vaucouleurs $r^{1/4}$ surface brightness profile to 20 kpc (here r is the angular distance from the centre of NGC 4449). (Figs 1 and 2). Although we do not measure a change in the $g - r$ colour of the outer halo, the break in structure might imply a different origin for the $r^{1/4}$ component.

The lower-luminosity arc or ripple mentioned above is revealed by subtracting a model halo profile, but can also be clearly seen in unprocessed images (Fig. 1) and is also faintly visible and noted in earlier images[1]. However, we detect no additional components of a putative shell system as might be expected if this arc were part of a typical shell complex (even induced via an unusual collision geometry[11,12]). The arc or ripple might plausibly be a disk ripple, owing its origin to the interaction with NGC 4449B or a different event[13]. The ripple is

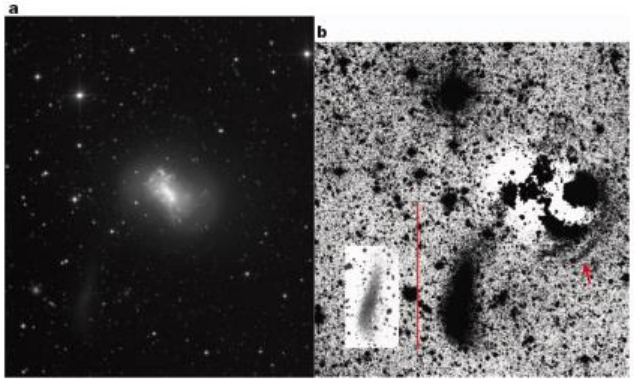
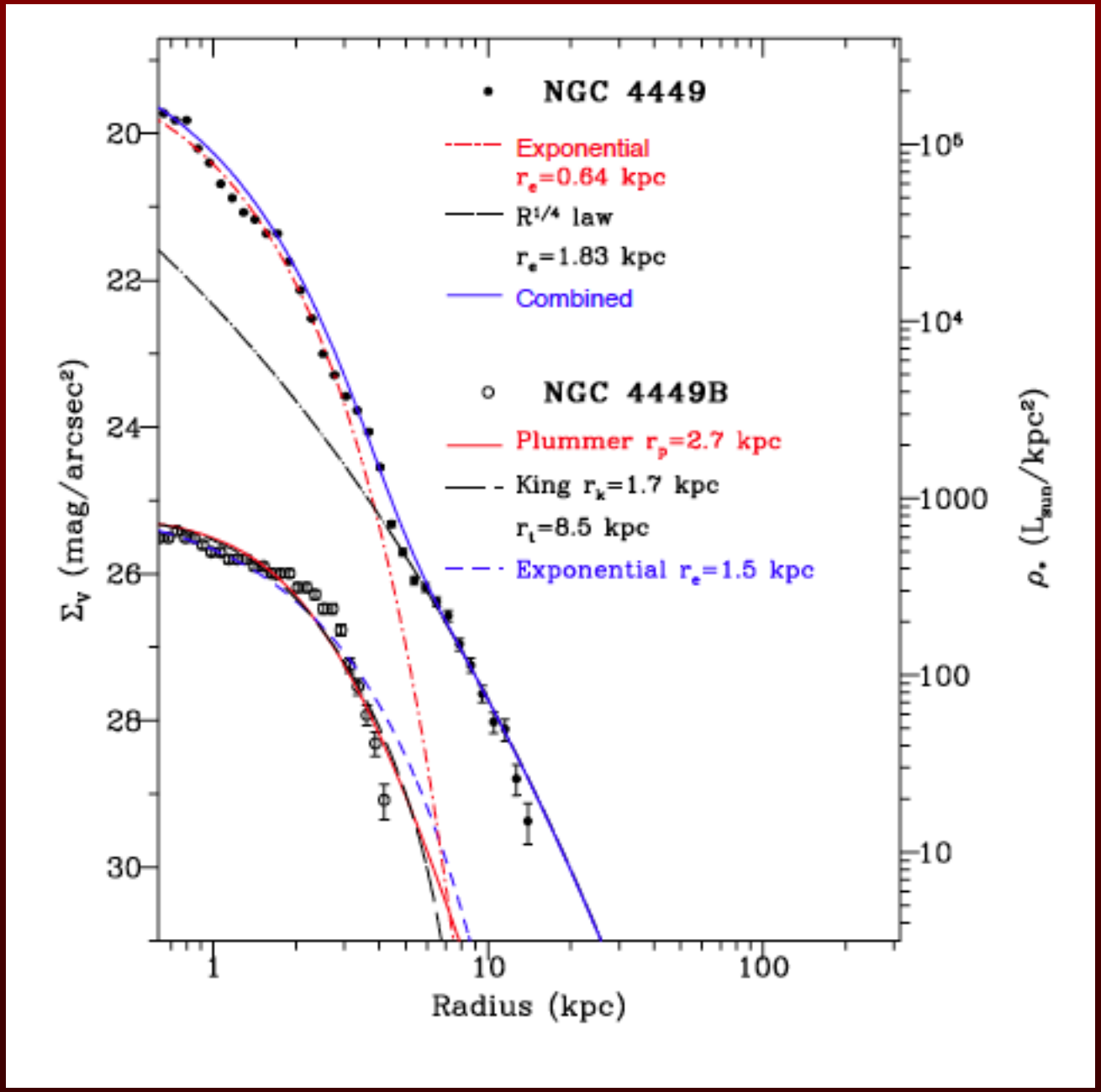
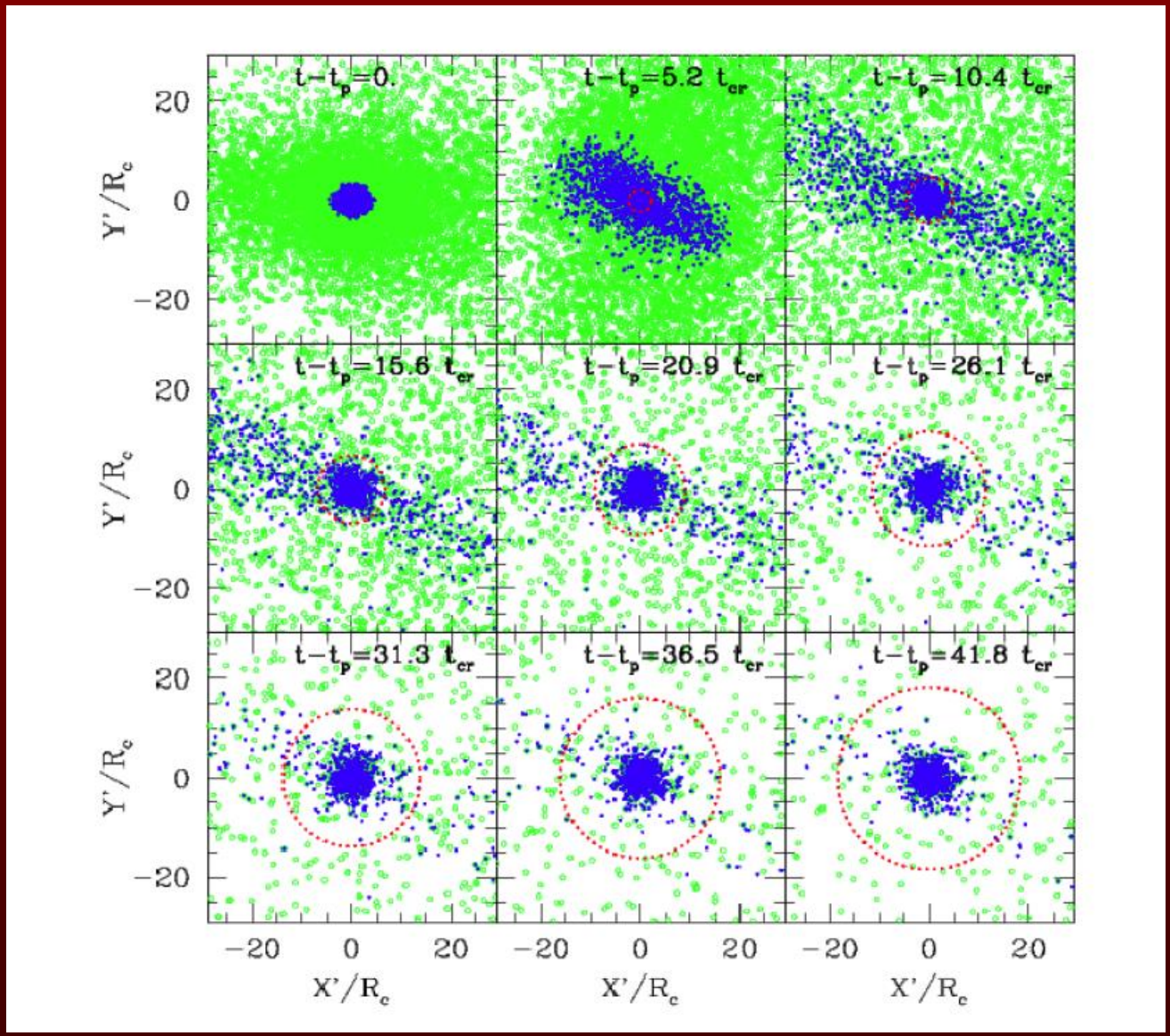


Figure 1 | Image and halo-subtracted imagery of NGC 4449. a, Positive image of NGC 4449 and NGC 4449B. (This is a 3.2-h luminance filter image from an STL 11000m camera, obtained using the Saturn Lodge 0.7-m Centurion[10] telescope.) **b**, Image (same scale as **a**) obtained by subtracting from **a** a model halo, using ELLIPSE within IRAF. Image shows detail of NGC 4449B, including a plume extended northwestwards towards the nucleus of NGC 4449. Inset, a softer stretch, revealing the S-shape distortion characteristic of a galaxy that has undergone tidal disruption. The fainter arc/disk ripple (indicated with a red arrow) can be easily seen to the southwest of the nucleus, and can be recovered as well in **a**. The arc/ripple lacks the edge or counter-arc structures characteristic in classical shells. A well defined shelf in the halo of NGC 4449 is evident in **a** and can be clearly seen in the surface brightness profile of Fig. 2. North is up, east is left. The red scale bar is 10 arcmin = 11.11 kpc, adopting a distance[1] of 3.82 Mpc for NGC 4449. Integration times were 3.2 h in a broadband Astrodon I-series Luminance (L) filter and 45 min each in the B and R filters. The wide L filter is a square pass filter spanning 400–700 nm that yields the deepest images, while the B and R filters are square pass filters covering 400–500 nm and 600–700 nm, respectively. Because NGC 4449 is within the SDSS footprint, we use catalogued SDSS stars to calibrate B and R to SDSS g and r photometry. The total r magnitude for NGC 4449B was obtained by calibrating the L filter to SDSS r with the total magnitude from ELLIPSE, after subtracting stellar sources from the footprint of the dwarf.

[1]Department of Physics and Astronomy, 430 Portola Plaza, Box 951547, University of California, Los Angeles, California 90095-1547, USA. [2]Polaris Observatory Association, Frazier Park, California 93225, USA. [3]Max-Planck-Institut für Astronomie, Königstuhl 17, Heidelberg D-69117, Germany. [4]UCLA Anderson School of Management, 110 Westwood Plaza, Los Angeles, California 90095-1481, USA. [5]Zentrum für Astronomie der Universität Heidelberg, Landessternwarte, Königstuhl 12, 69117 D-Heidelberg, Germany. [6]Department of Astronomy, California Institute of Technology, MC 249-1, 1200 East California Boulevard, Pasadena, California 91125, USA. [7]Griffith Observatory, 2800 East Observatory Road, Los Angeles, California 90027, USA.


NGC 4449
Exponential
r_e=0.64 kpc
$R^{1/4}$ law
r_e=1.83 kpc
Combined
NGC 4449B
Plummer r_p=2.7 kpc
King r_k=1.7 kpc
r_t=8.5 kpc
Exponential r_e=1.5 kpc
Σ_V (mag/arcsec^2)
ρ_* (L_{sun}/kpc^2)
Radius (kpc)
20
22
24
26
28
30
10^5
10^4
1000
100
10
1
10
100

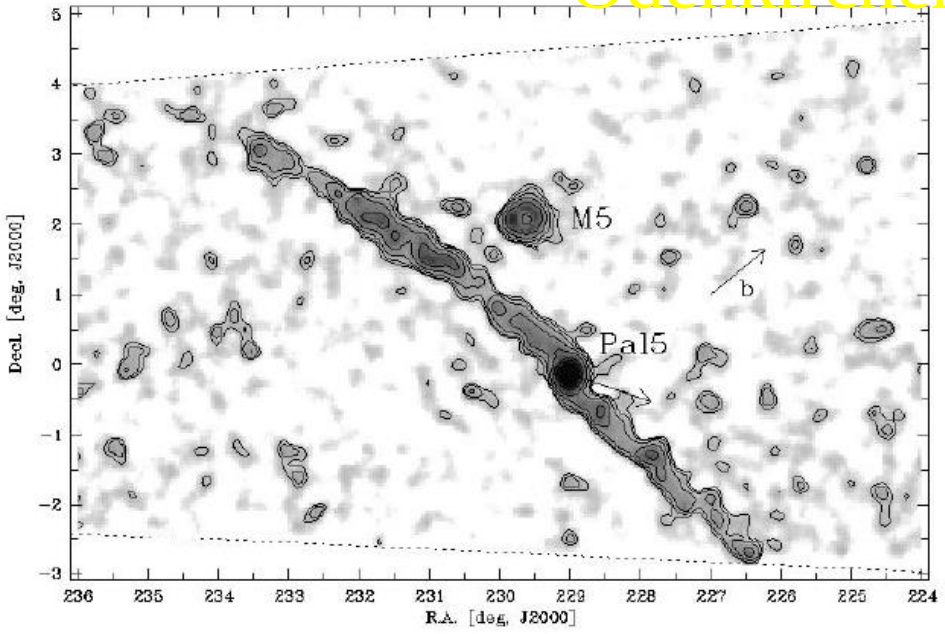


Penarrubia et al. 2009

Timescale Arguments

Dwarf pre-encounter radius adopted ~ 200 pc, sigma_v=10 km/sec
Morphology evolution timescale ~10^8 yr
(time from closest encounter with nucleus of NGC 4449

Odenkirchen et al. 05



Also 10^8

LETTER

doi:10.1038/nature10837

A tidally distorted dwarf galaxy near NGC 4449

R. M. Rich[1,2], M. L. M. Collins[3], C. M. Black[1], F. A. Longstaff[2,4], A. Koch[5], A. Benson[6] & D. B. Reitzel[1,7]

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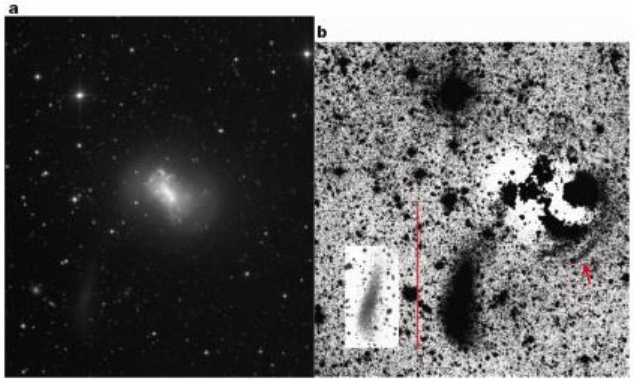

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DiscoveryNews.

Perpetrator of Galactic Hit-and-Run Found

By Irene Klotz | Wed Feb 8, 2012 01:42 PM ET

Scientists have discovered why the irregularly shaped and hydrogen-shrouded starburst galaxy known as NCG 4449, located 12.4 million light years away, is so weird. It bears scars from a past close encounter with a newly discovered companion dwarf galaxy.

The evidence exonerates another previously known companion galaxy, DDO 125, which is located about 130,000 light years away from NCG 4449. Instead, new observations of NGC 4449 taken between May 29 and June 1, 2011 (made in the course of commissioning a new 0.7-meter telescope at Saturn Lodge Observatory, Calif.) turned up what scientists call "a profoundly tidally distorted" dwarf galaxy NGC 4449B.

ANALYSIS: Colliding Galaxies Erupt with Violent Beauty

But no Hubble time….

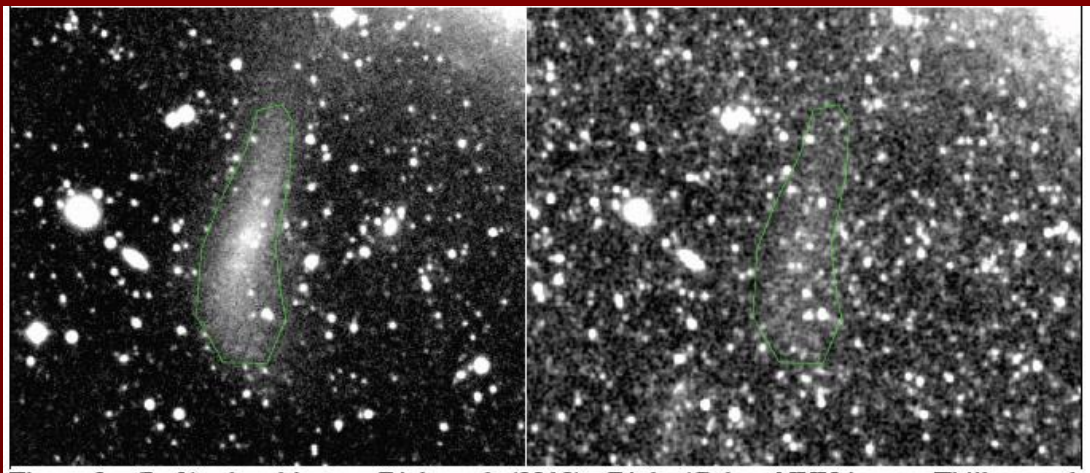


Figure 2- (Left) r-band image; Rich et al. (2012). Right (Galex NUV image; Thilker et al. 2012). The dwarf is very faintly detected in the NUV; applying Abramason et al. models finds consistency with a 400 Myr old quenched starburst (see text and predicted CMD in Figure 4). It would be interesting to search for substructure in the dwarf, as well as population gradients.

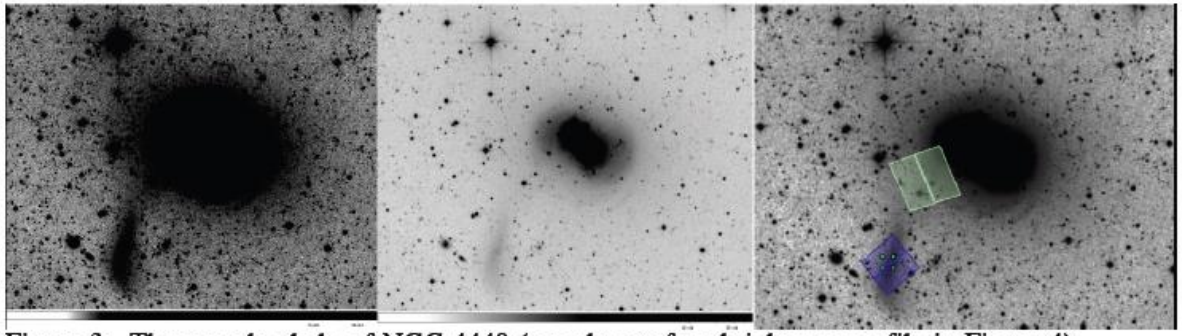
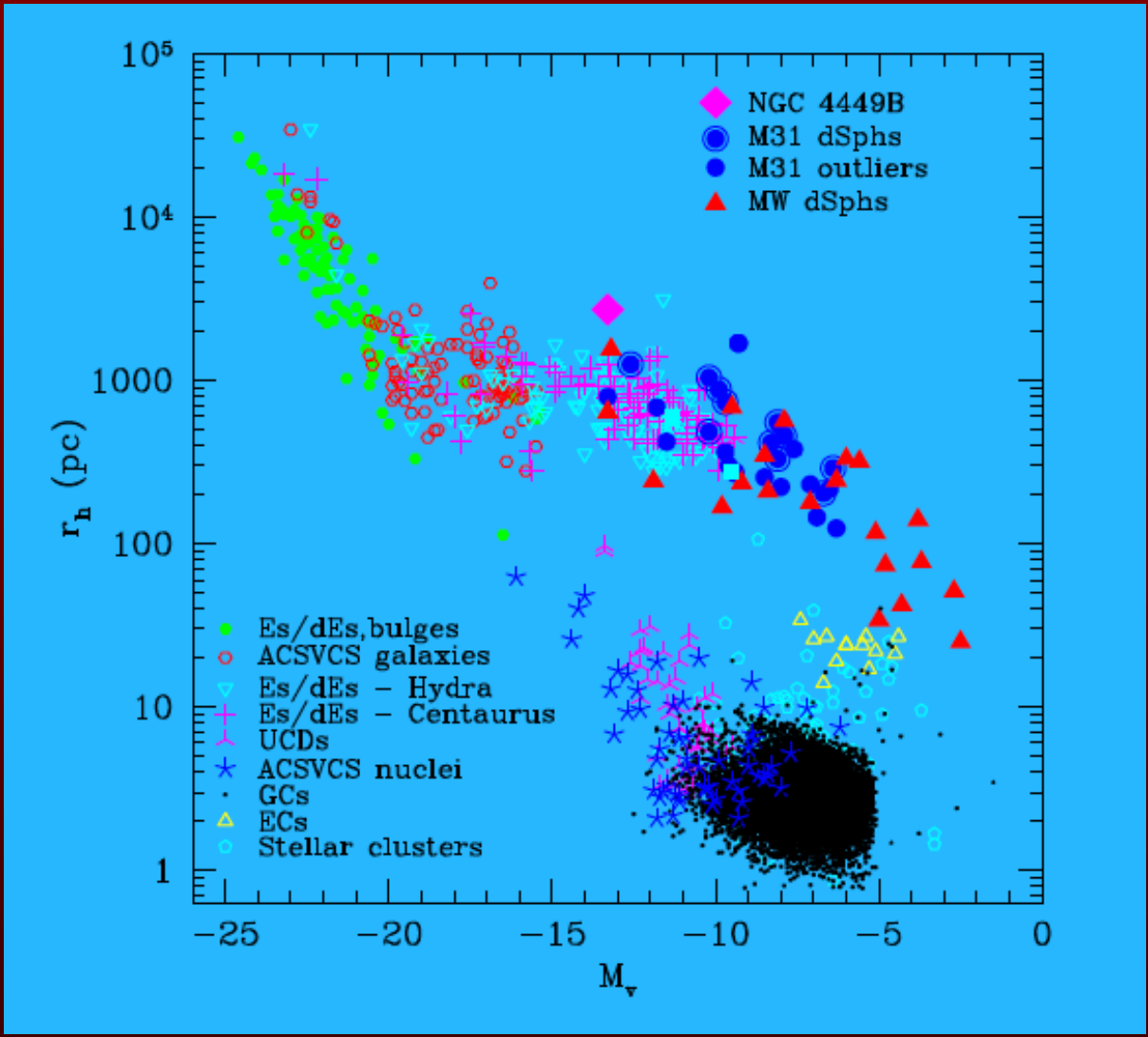


Figure 3: The complex halo of NGC 4449 (see also surface brightness profile in Figure 4). The lefthand panel shows a deep stretch; notice the elliptical outer isophotes of the $r^{1/4}$ halo. The middle panel shows the bounded, somewhat irregular dumbbell-shaped inner (exponential) halo, first described by Hunter et al. (1999); notice the difference in position angle between the inner and outer halos *and the m=2 brightness distribution in the "disk" in the middle panel*. Righthand image shows a possible placement of the FOV of the HST detectors, with WFC3 placed on the dwarf nucleus, and ACS straddling the two halo components of NGC 4449, orient=100°.



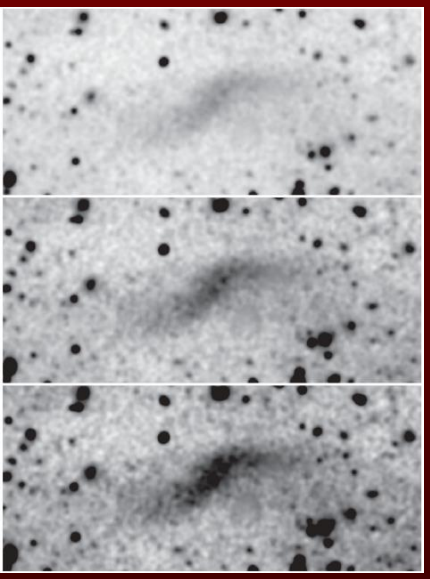
Misgeld & Hilker 2011

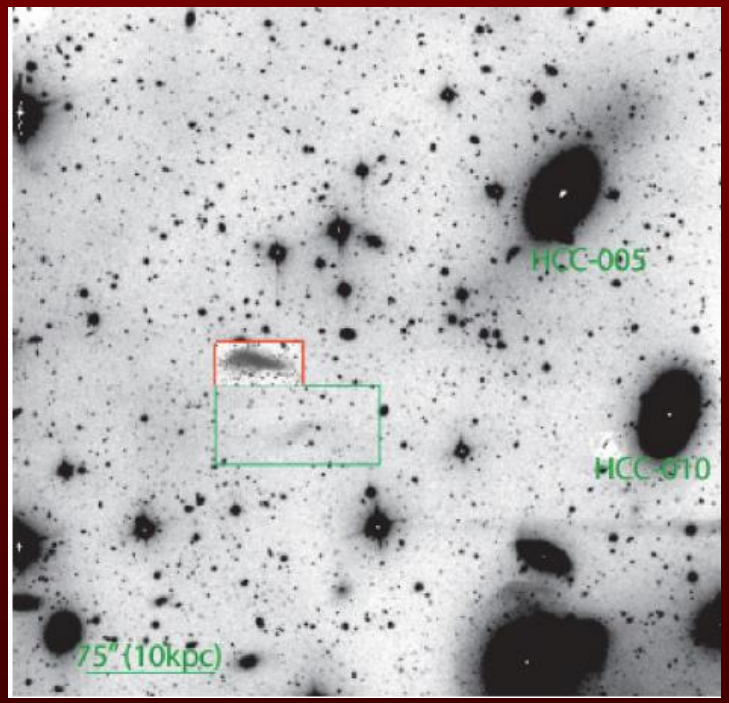
THRESHING IN ACTION: THE TIDAL DISRUPTION OF A DWARF GALAXY BY THE HYDRA I CLUSTER*

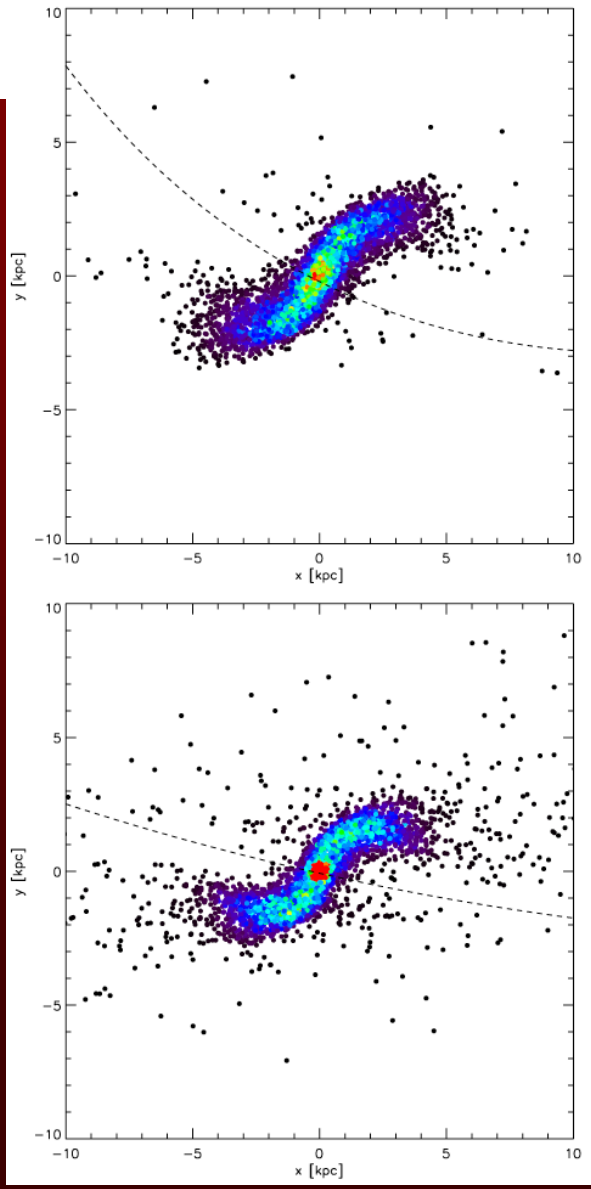
Andreas Koch[1], Andreas Burkert[2,3,8], R. Michael Rich[4], Michelle L. M. Collins[5], Christine S. Black[4], Michael Hilker[6], and Andrew J. Benson[7]

[1] Zentrum für Astronomie der Universität Heidelberg, Landessternwarte, Königstuhl 12, D-69117 Heidelberg, Germany; akoch@lsw.uni-heidelberg.de
[2] Universitätssternwarte der Ludwig-Maximilians Universität, Scheinerstr. 1, D-81679 München, Germany
[3] Max-Planck Institute for Extraterrestrial Physics, Giessenbachstrasse, D-85748 Garching, Germany
[4] Department of Physics and Astronomy, University of California Los Angeles, Los Angeles, CA, USA
[5] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
[6] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany
[7] Department of Astronomy, Caltech, Pasadena, CA, USA

Received 2012 March 28; accepted 2012 July 11; published 2012 July 25



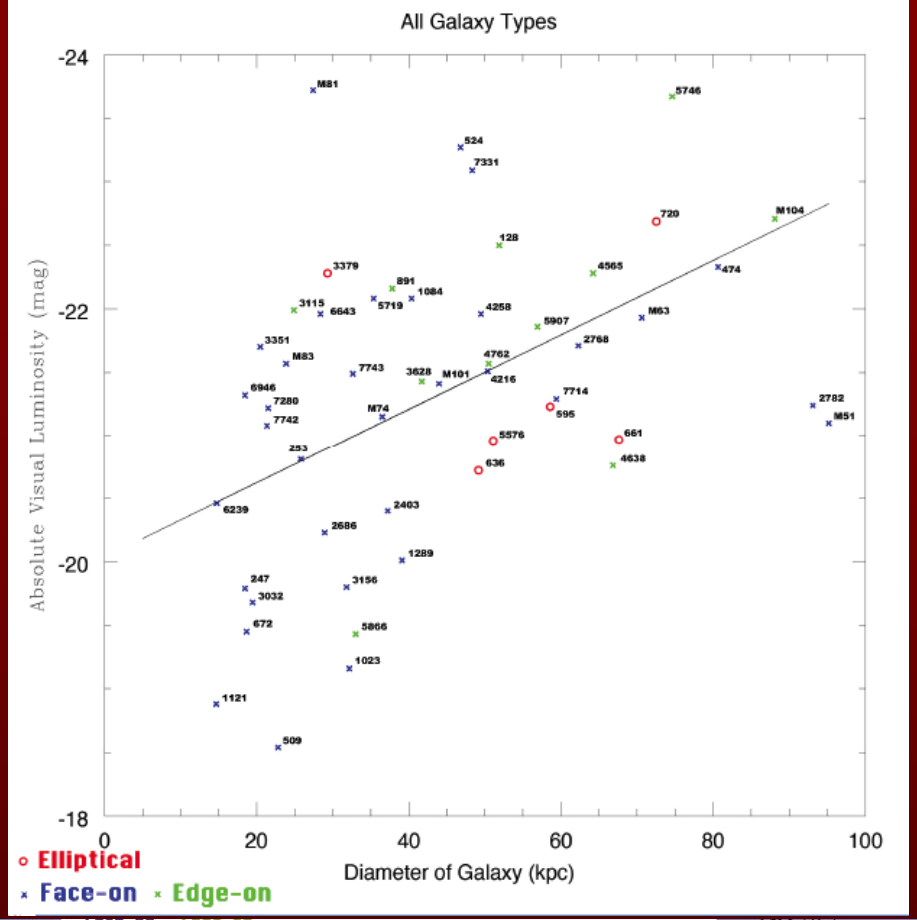




NGC 205+ tidal tails

F. Longstaff

More discoveries on the way


All Galaxy Types
Absolute Visual Luminosity (mag)
-24
-22
-20
-18
0
20
40
60
80
100
Diameter of Galaxy (kpc)
M81
5746
524
7331
720
M104
128
3379
4565
474
891
1084
3115
6643
5719
4258
5907
M63
3351
2768
M83
4762
7743
3628
M101
4216
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M74
M51
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253
636
4638
6239
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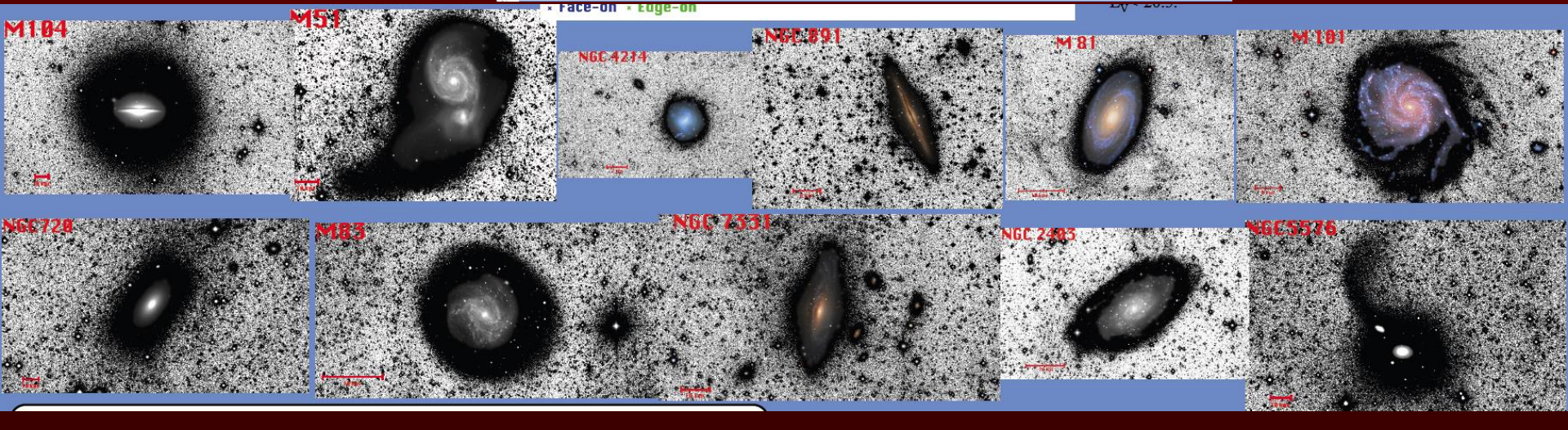
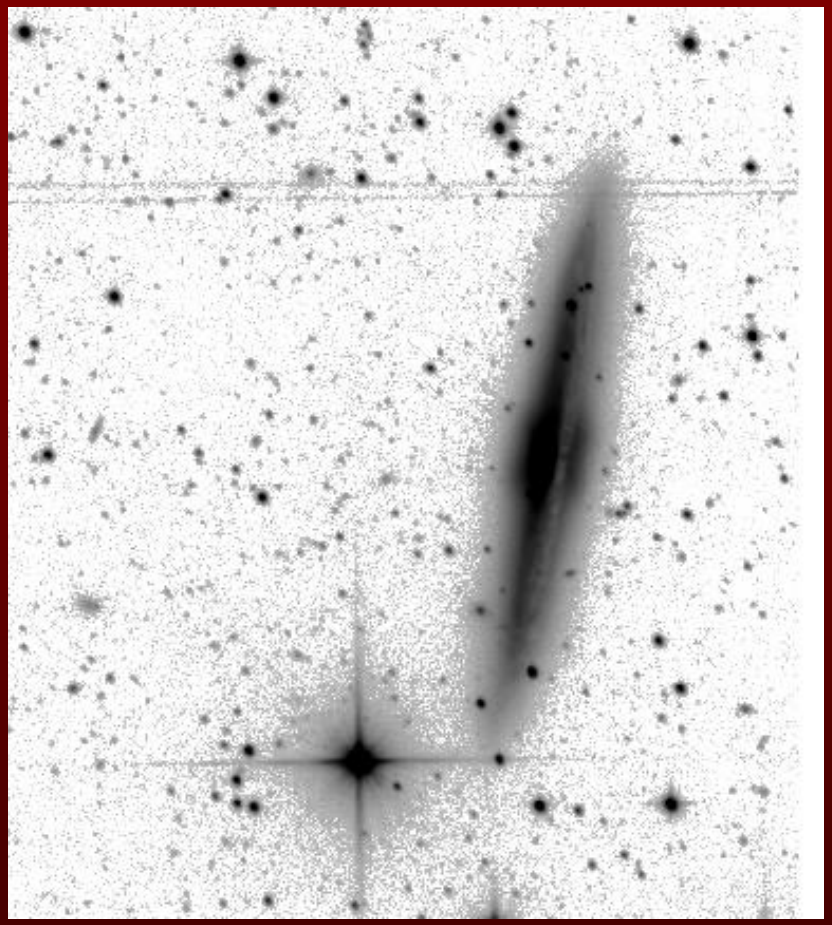
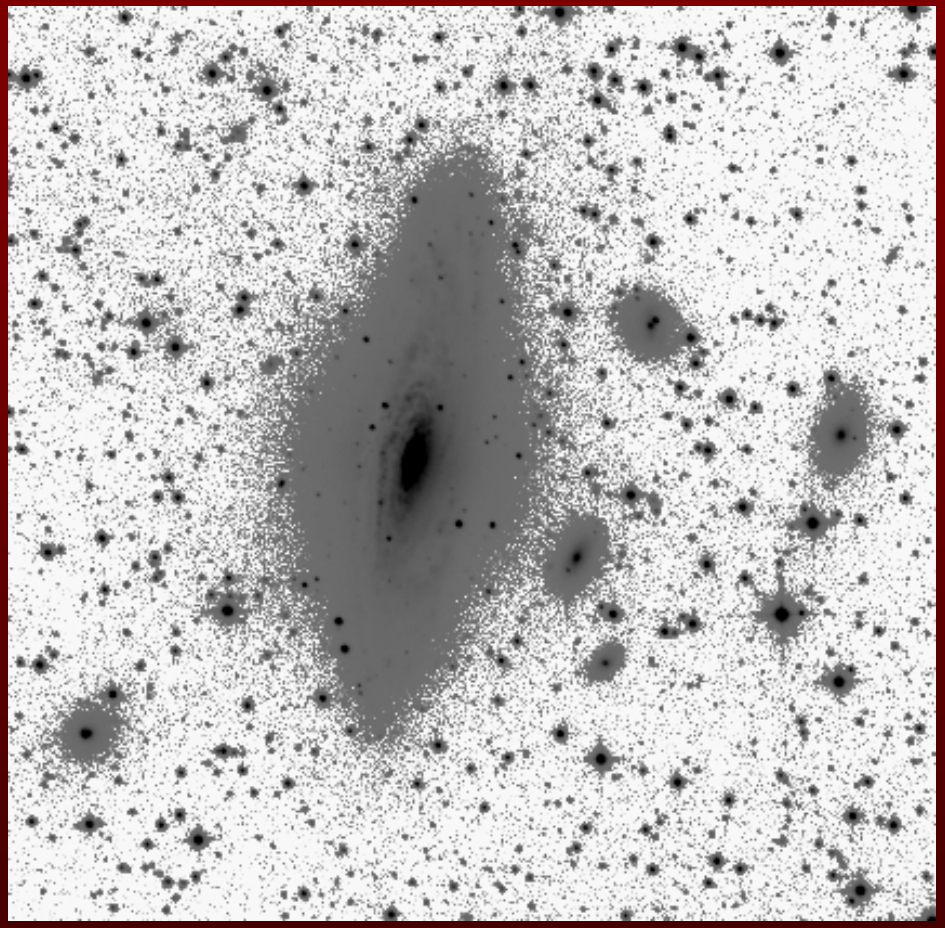
1121
509
Elliptical
Face-on
Edge-on


M104
M51
NGC 4214
NGC 891
M 81
M 101
NGC720
M83
NGC 7331
NGC 2403
NGC5576

Disk-origin galaxies may lack extended halos



Boxy-peanut NGC 5746



Classical bulge NGC 7331

Wise Observatory, Tel Aviv University