Probing GCs in the GC region with GLAO

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AO beginner!

Subaru/GLAO in Galactic Archaeology

- Resolved stars provide important information on galaxy formation and evolution
  - AO is important in resolving stars
- Stellar systems in the dense parts of the Galactic disk are largely hidden by dust absorption
  - NIR instrument with AO is important
- Wide-field mapping of stellar systems is essential in near-field cosmology
  - Wide-field NIR instrument with GLAO is an ultimate choice (i.e. ULTIMATE-SUBARU)

Globular Clusters (GCs)

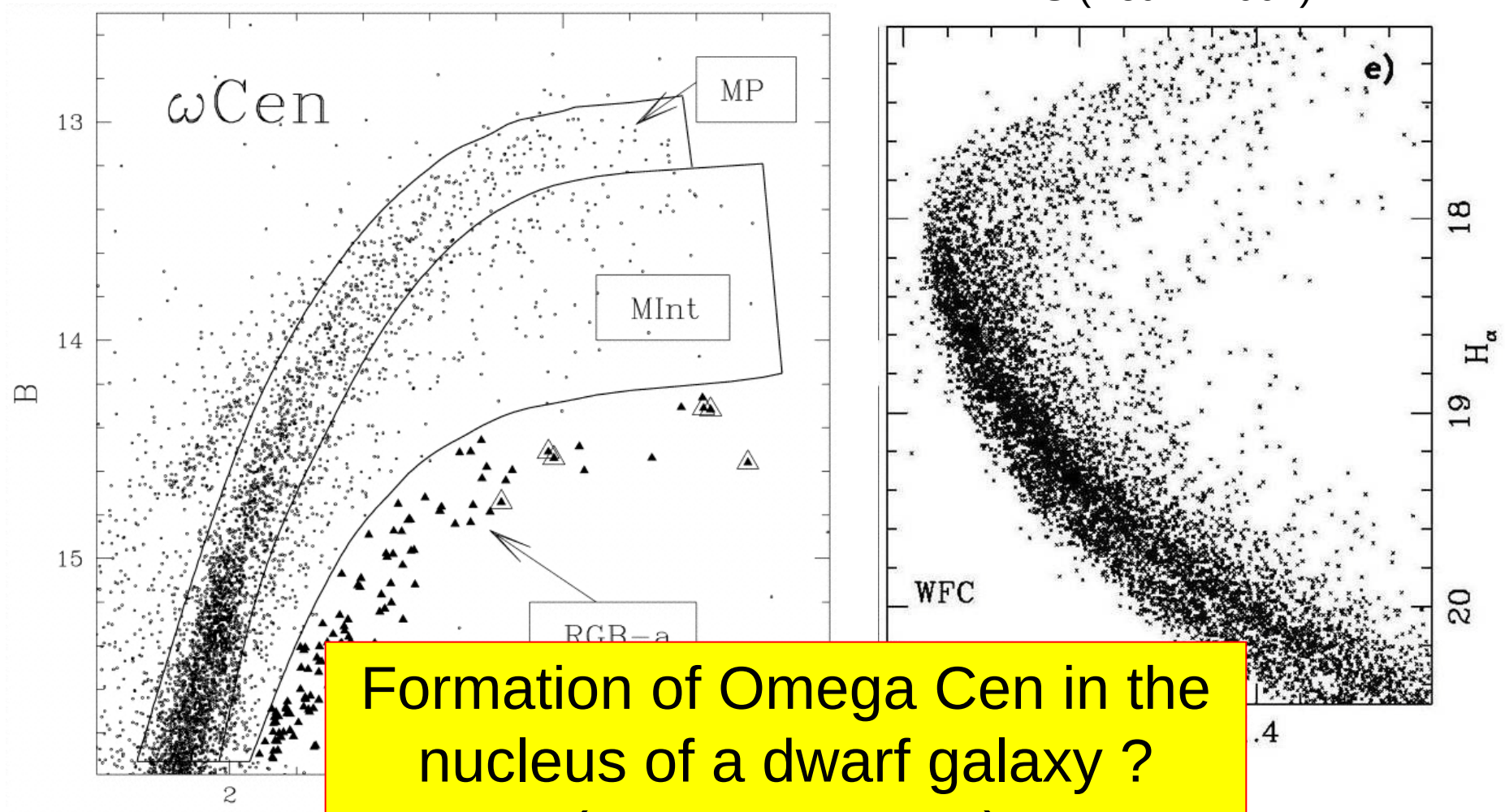
- Oldest in the Milky Way
  - N ~ 160 clusters are known
  - Tracers of Galactic past
- Single population?
  - Multiplicity in stellar pops.
  - Na-O anticorrelation
  - Extended HB
- Not all clusters are identified
  - GCs in the bulge direction are largely unclear

ω Centauri
M=5 x 10^6 Msun
Most massive cluster

Omega Cen
multiple stellar population

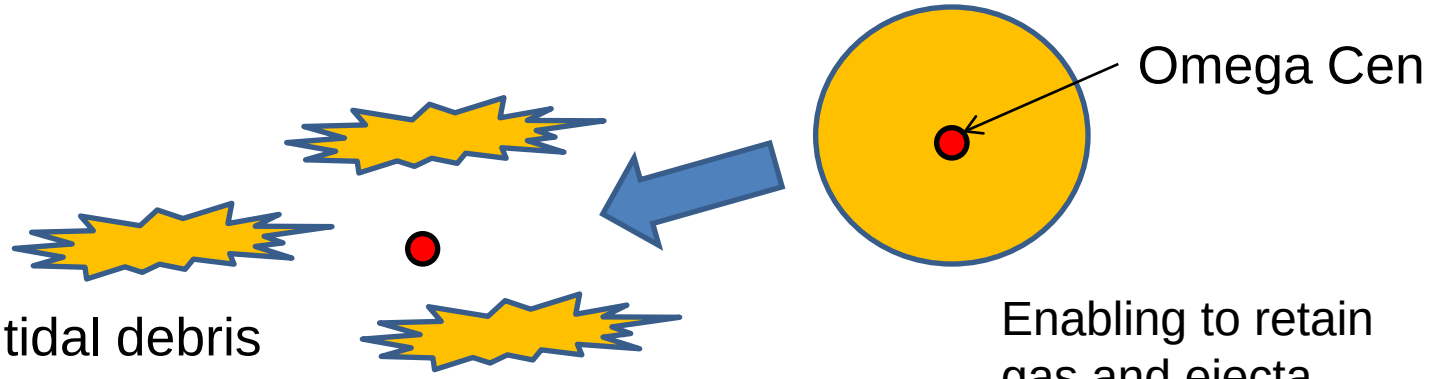
RGB (Ferraro+2002)

MS (Bedin+2004)



Formation of Omega Cen in the nucleus of a dwarf galaxy ? (Freeman 1993)

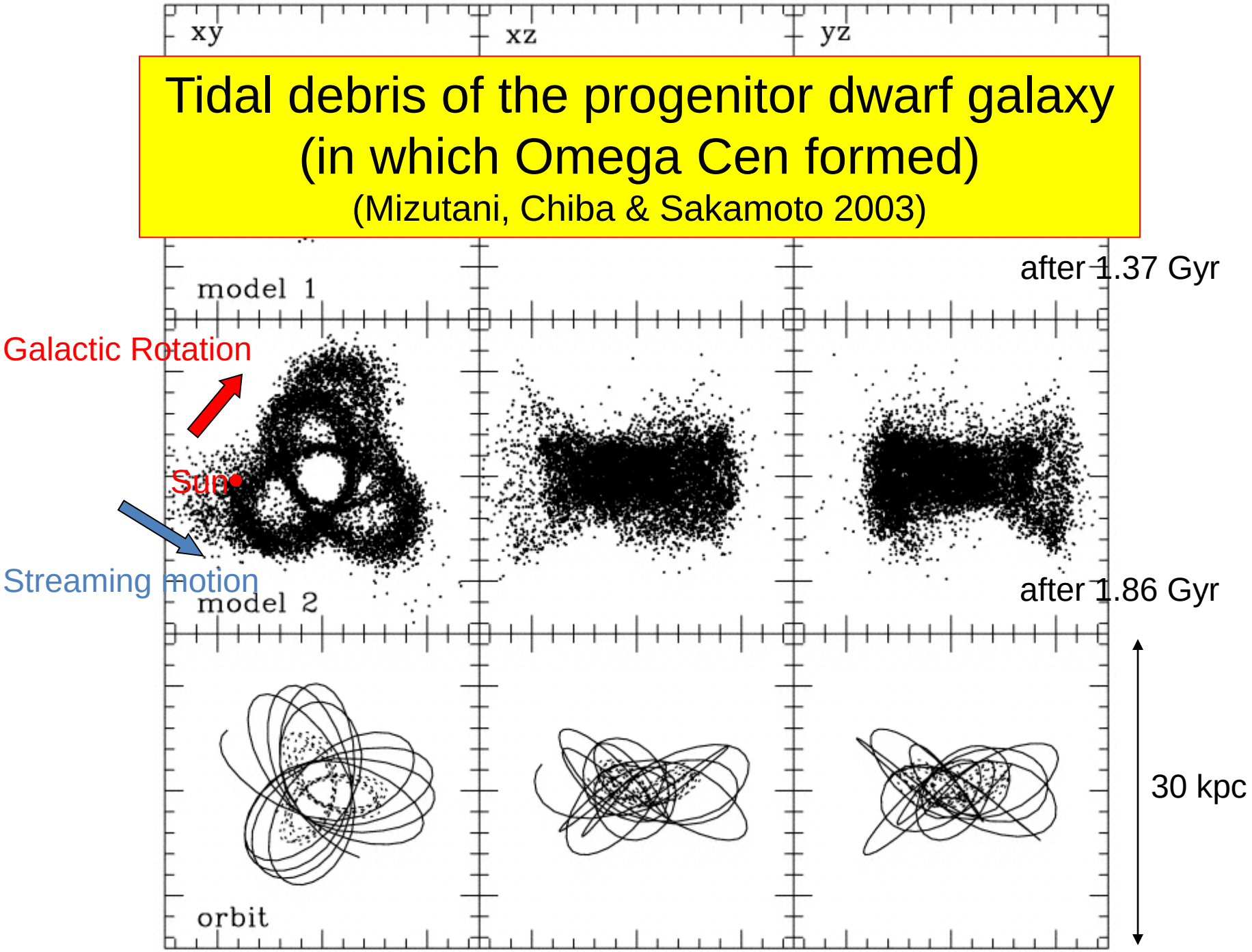
Progenitor dwarf galaxy



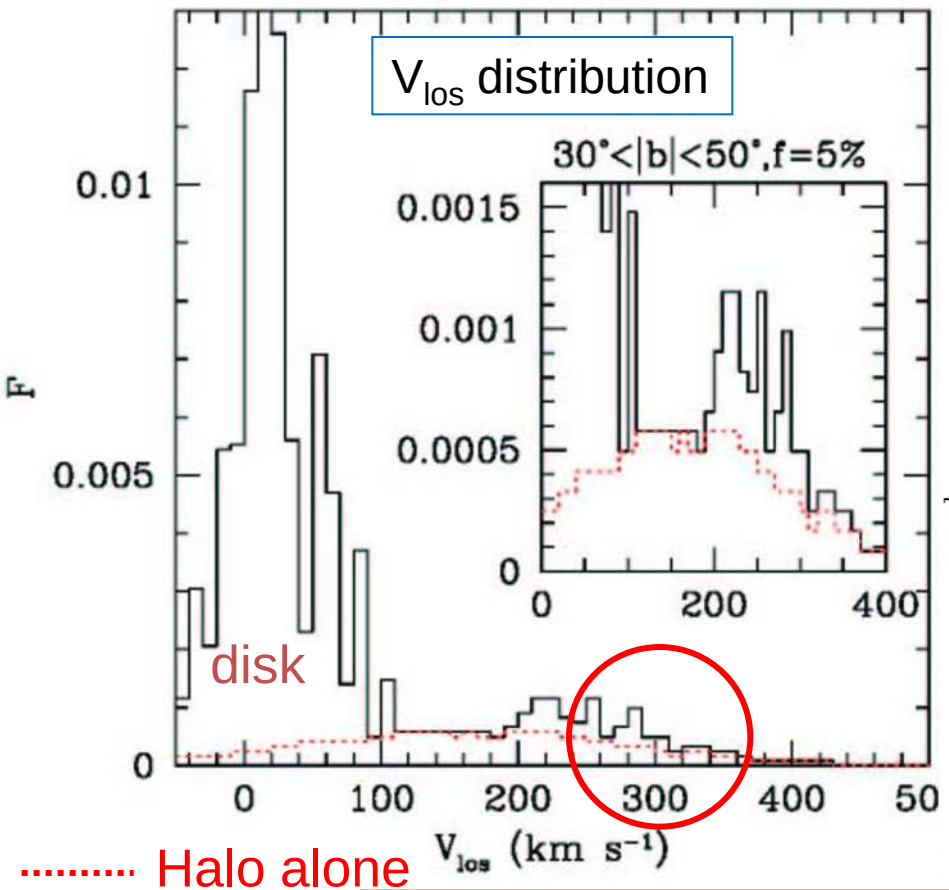
Enabling to retain
gas and ejecta
→ multiple SF

Tidal debris of the progenitor dwarf galaxy (in which Omega Cen formed)

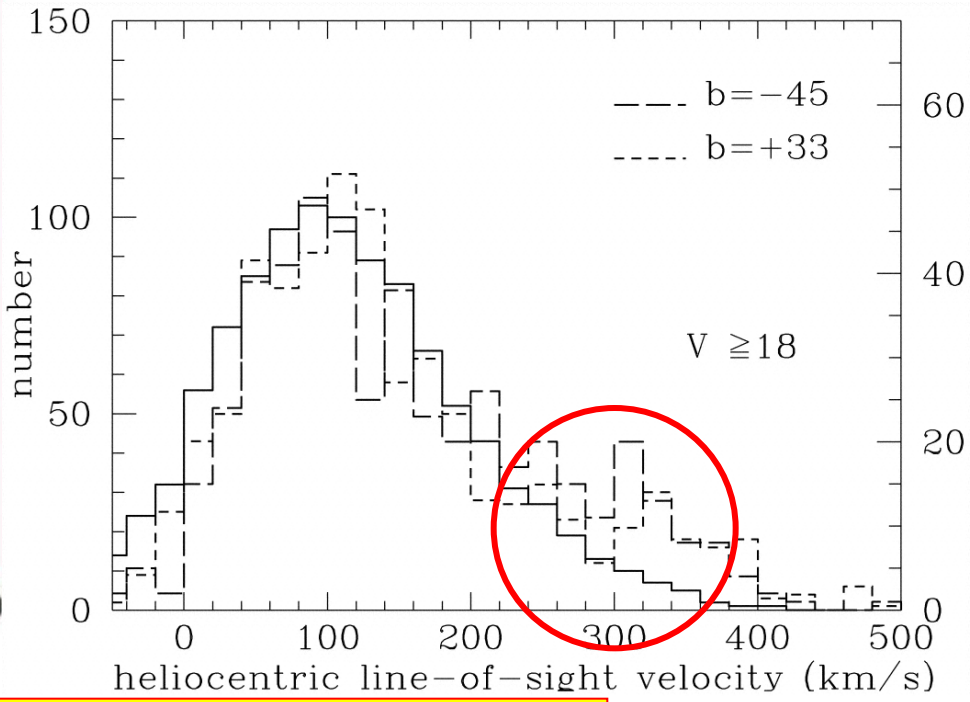
(Mizutani, Chiba & Sakamoto 2003)



Stellar kinematics towards Galactic latitude ~ 270 deg



Gilmore, Wyse, & Norris (2002)
RV survey of F/G stars
at l~270deg, 0.5<D<5kpc

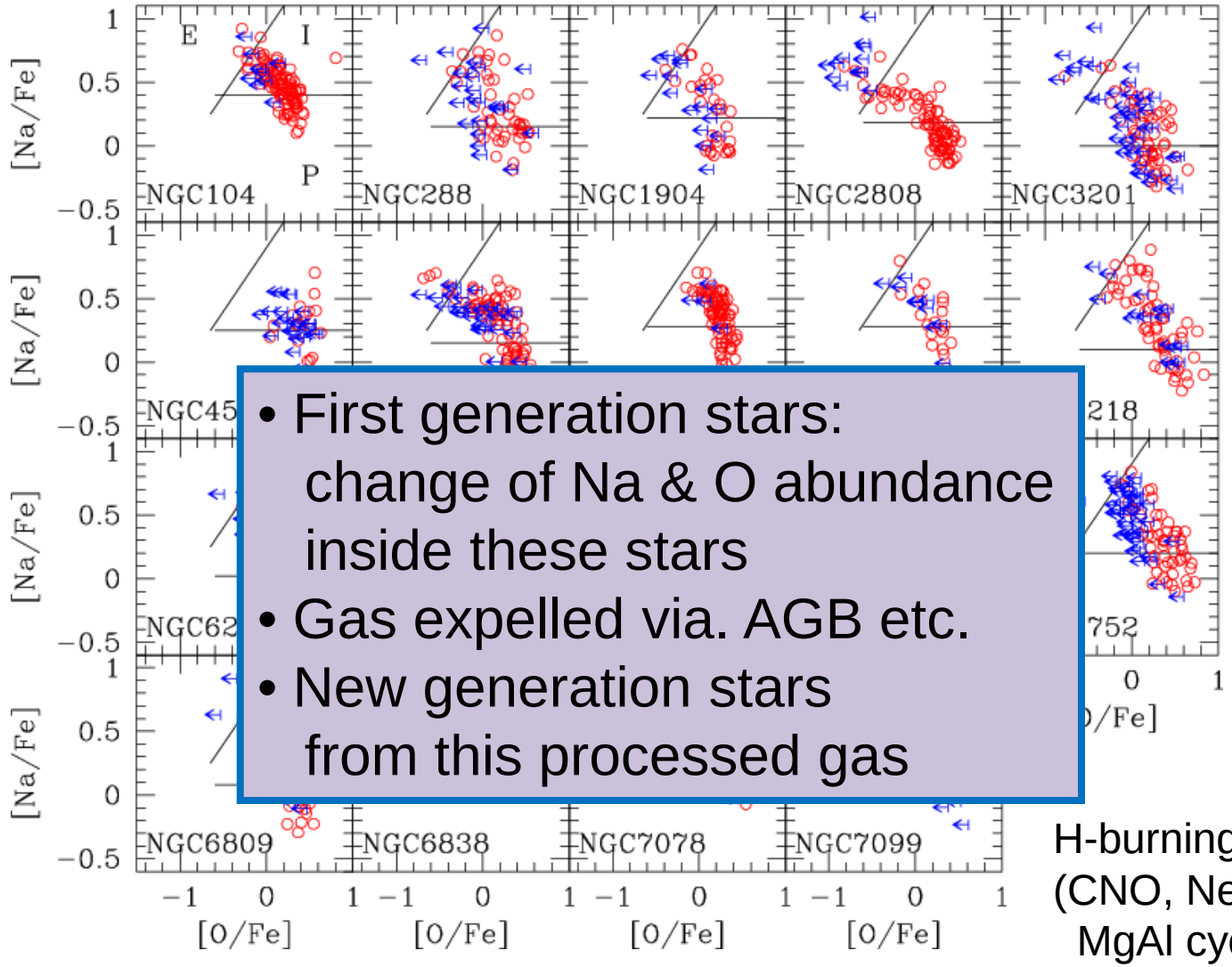


V_{los} ~ 300 km/s stream
at Galactic longitude ~ 270 deg
Important effects on Galactic kinematics

Na-O anticorrelation

(Carretta+ 2010)

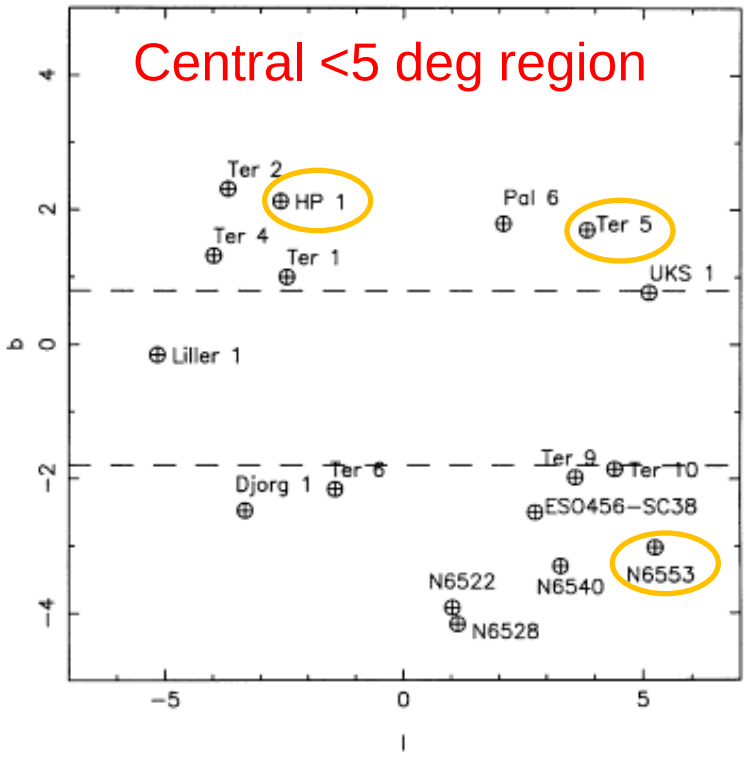
general properties of GCs ⇒ multiple population

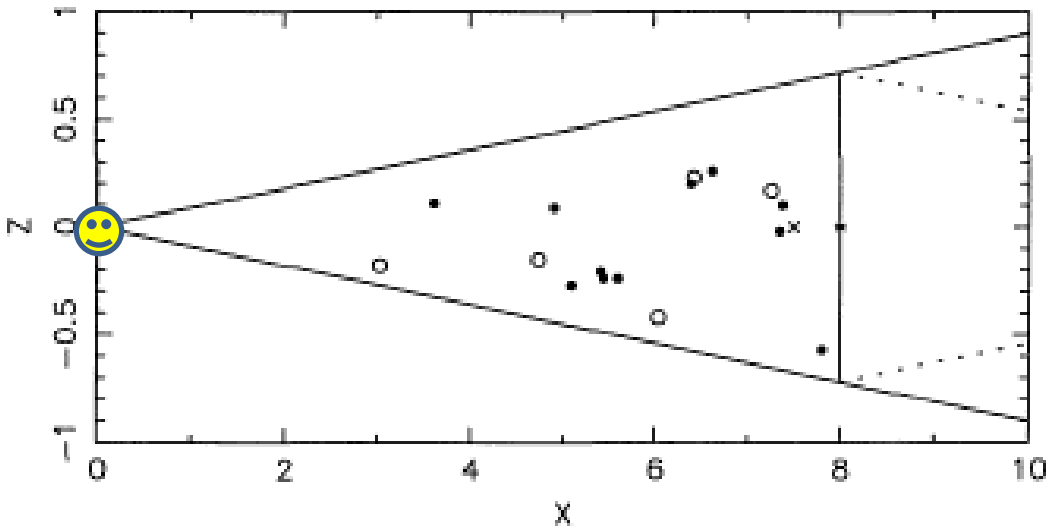


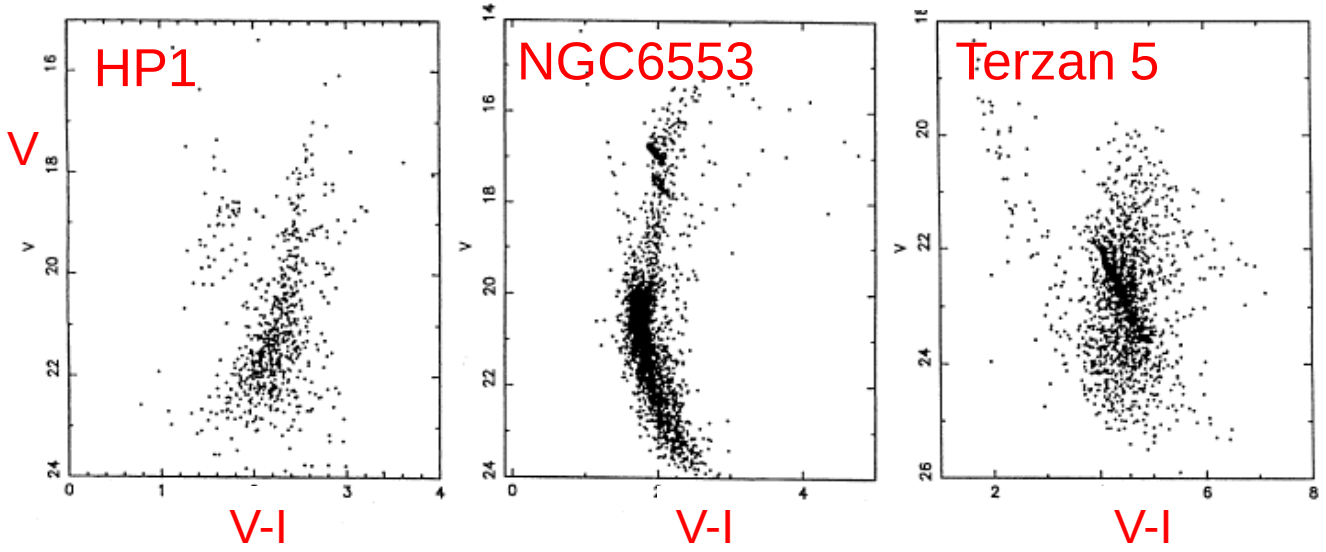
- First generation stars: change of Na & O abundance inside these stars
- Gas expelled via. AGB etc.
- New generation stars from this processed gas

H-burning at high T (CNO, NeNa, MgAl cycle)

GCs toward the Bulge (Barbuy+98)







- Yet unidentified GCs: N~20 and more
- Detailed stellar pops. are uncertain due to absorption in disk/bulge

The nature of these clusters?

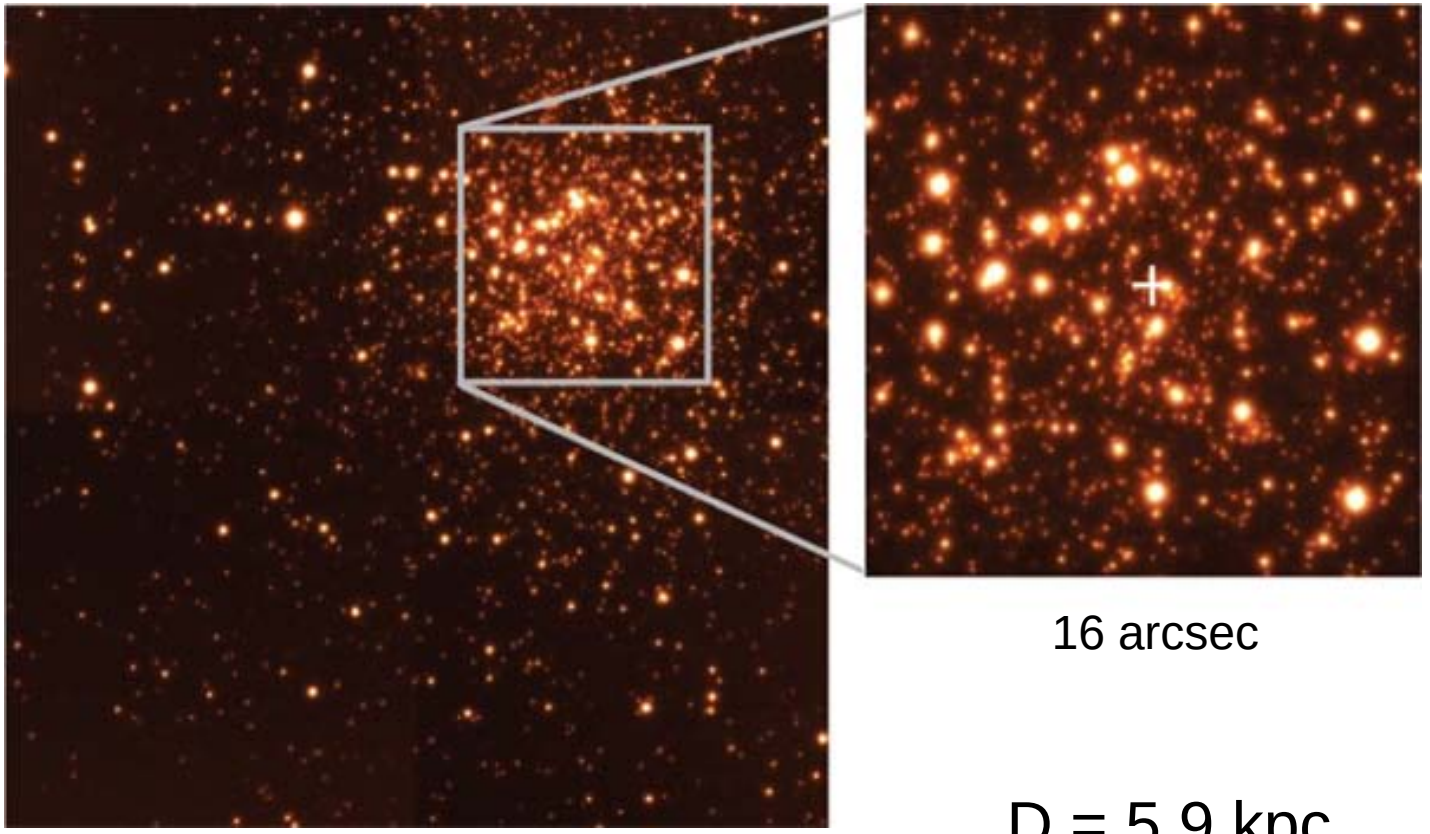
Fig. 2. Colour-magnitude diagrams of HP1 ([Fe/H] ~ -1.5), NGC 6553 ([Fe/H] ~ -0.2) and Terzan 5 ([Fe/H] ~ 0.0), for circular extractions of radius r < 24", r < 23" and r < 42" respectively.

Terzan 5

(Ferraro+09)

VLT, J & K, MAD

FWHM @K = 0.1 arcsec
@J = 0.24 arcsec



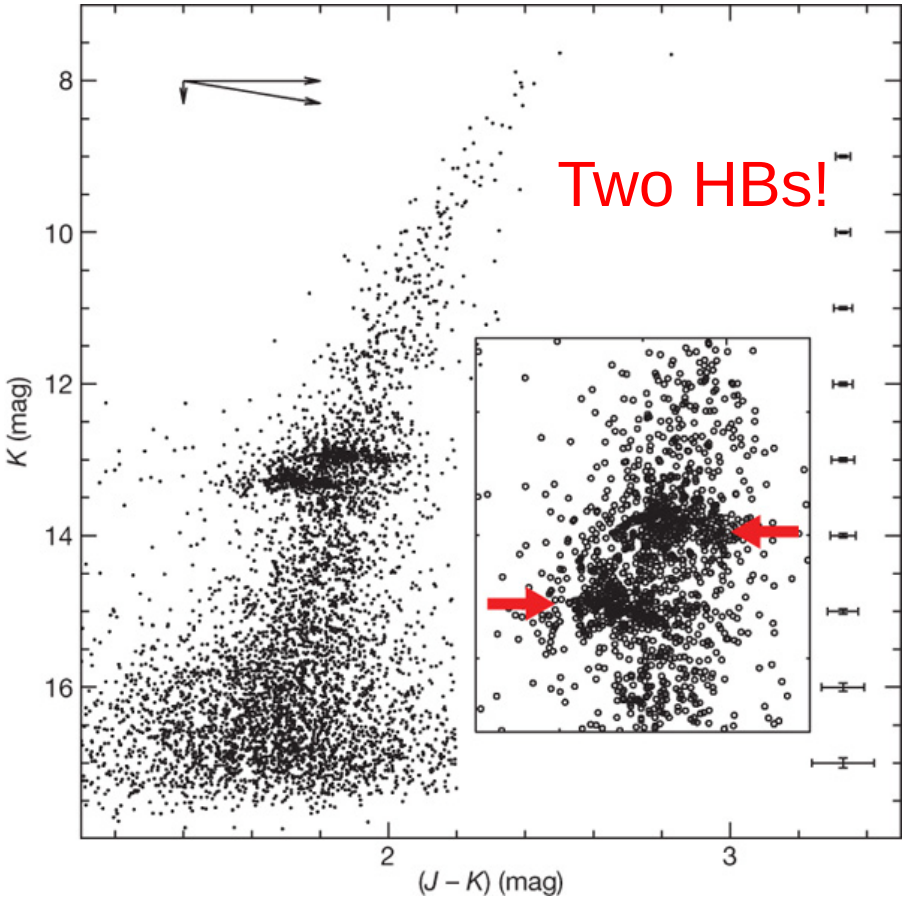
16 arcsec

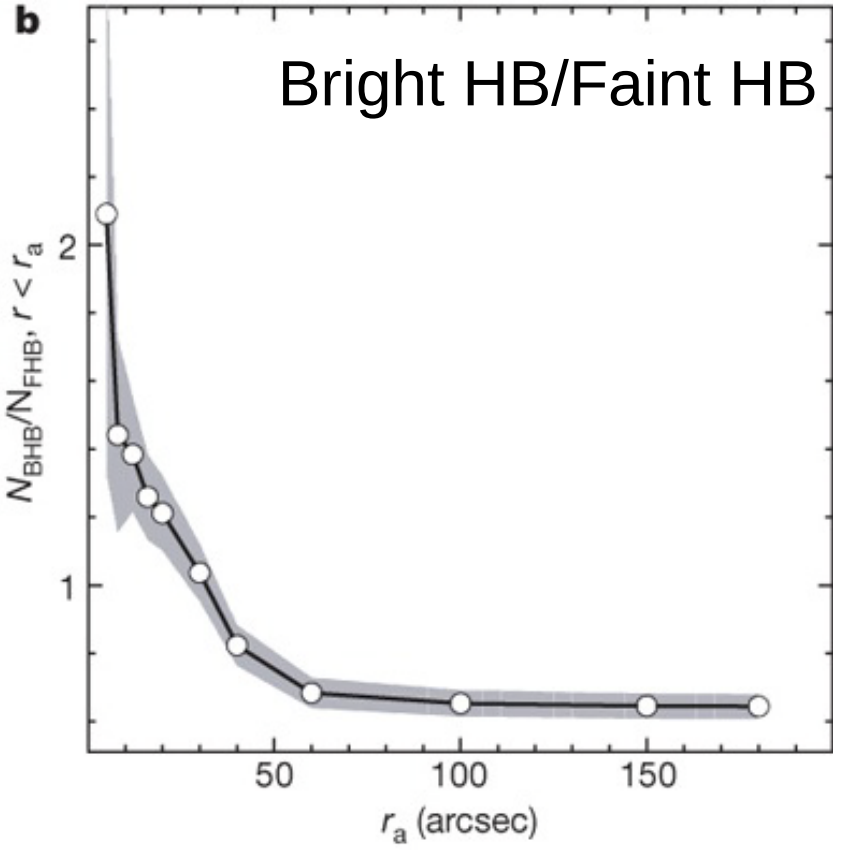
1 arcmin

D = 5.9 kpc

Terzan 5

(Ferraro+09)





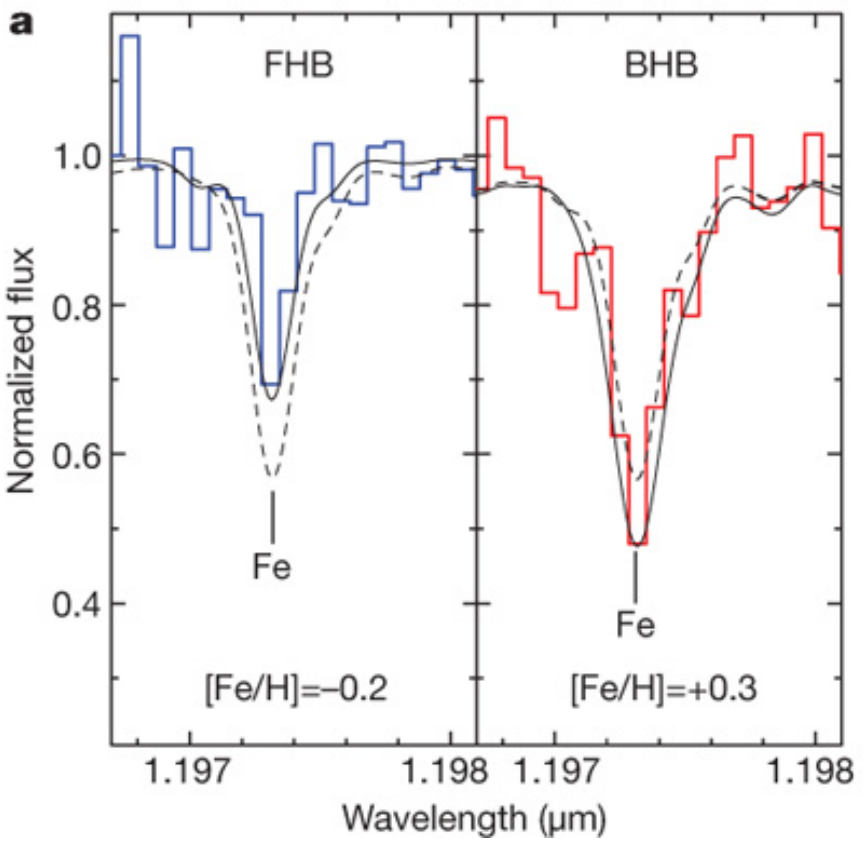
Bright HBs are more concentrated
（no diff for motions）

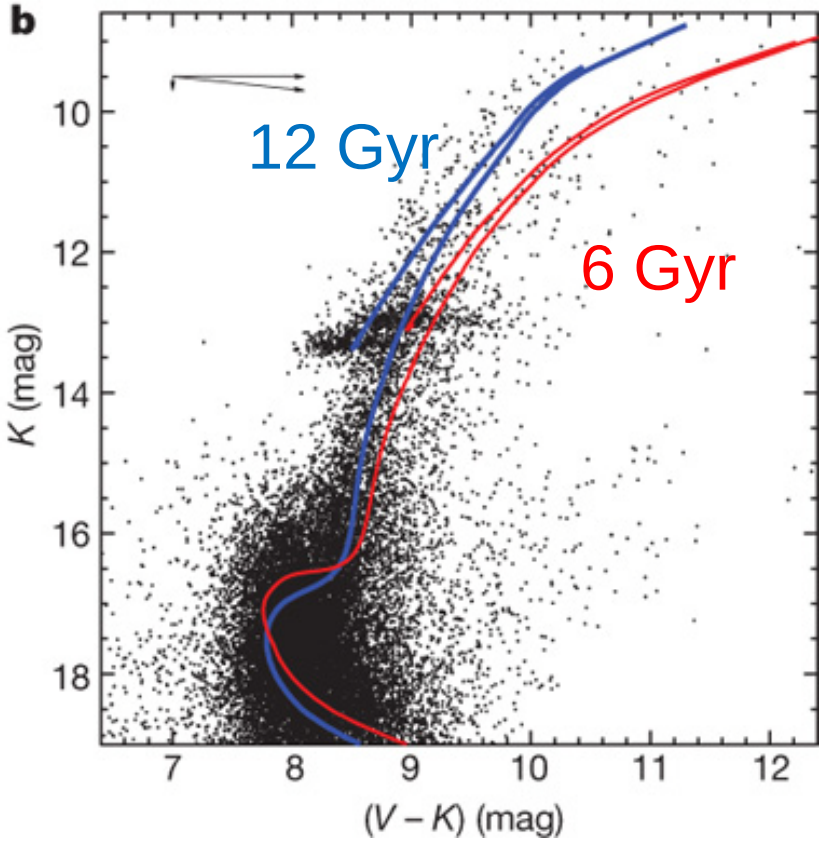
Terzan 5

(Ferraro+09)

Different metallicity

Different age





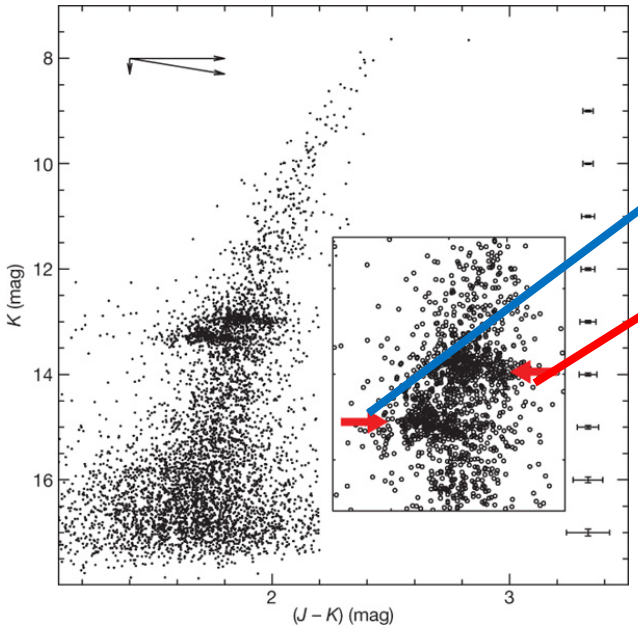
V-band from ACS/HST

Terzan 5

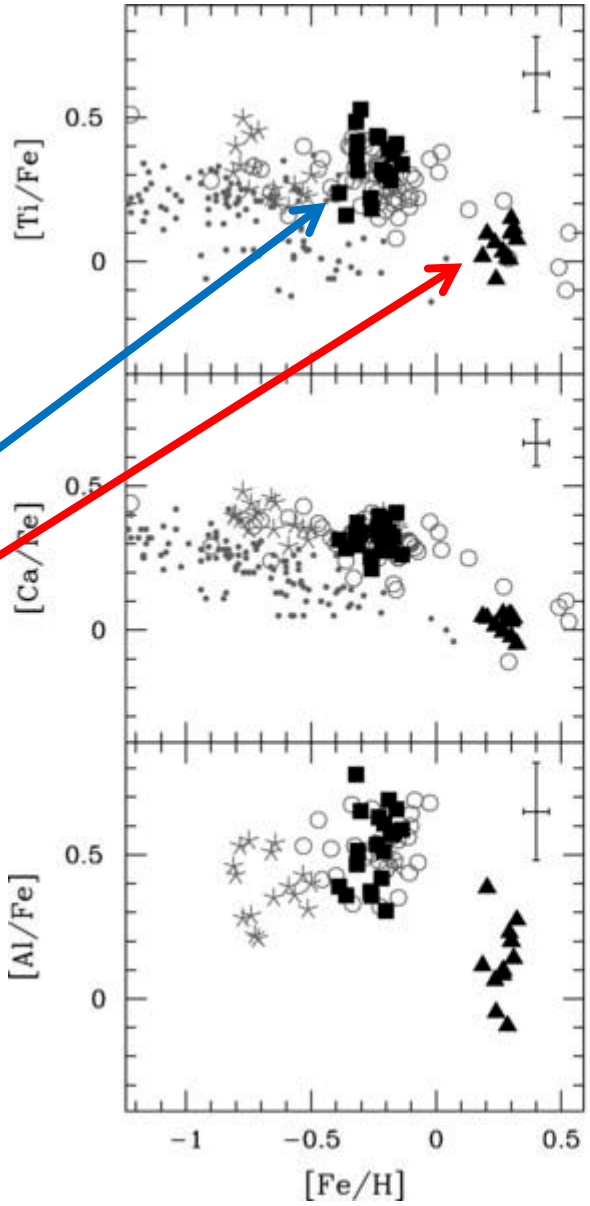
(Origlia+11, KeckII, NIRSPEC, R=25,000)

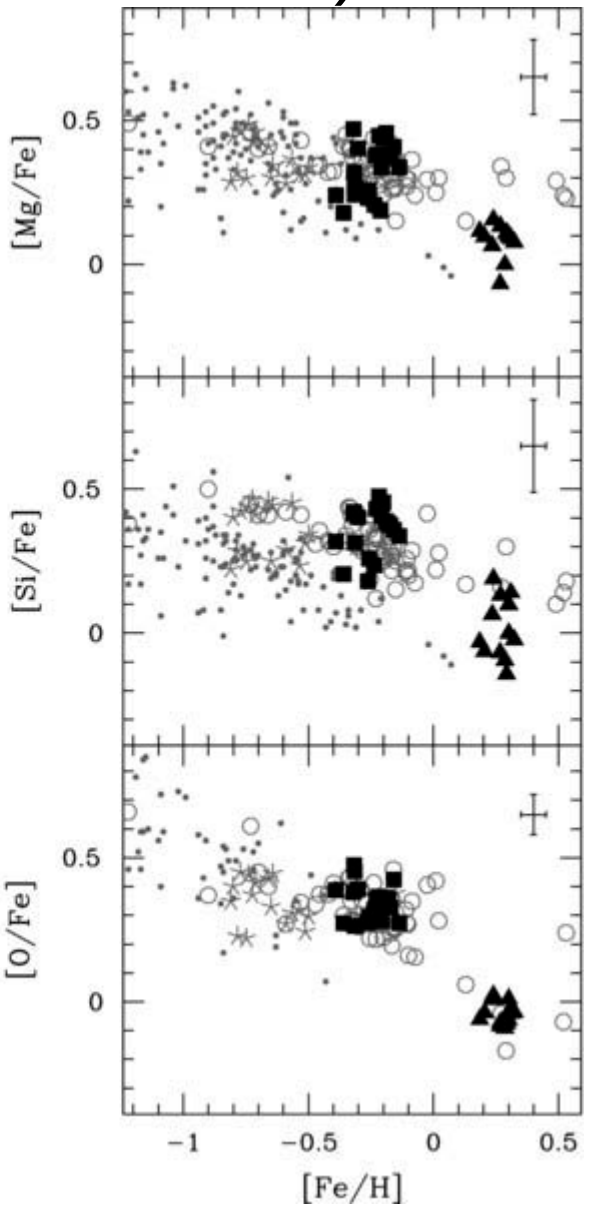
○ bulge
* GCs

High α/Fe & low α/Fe stars coexist



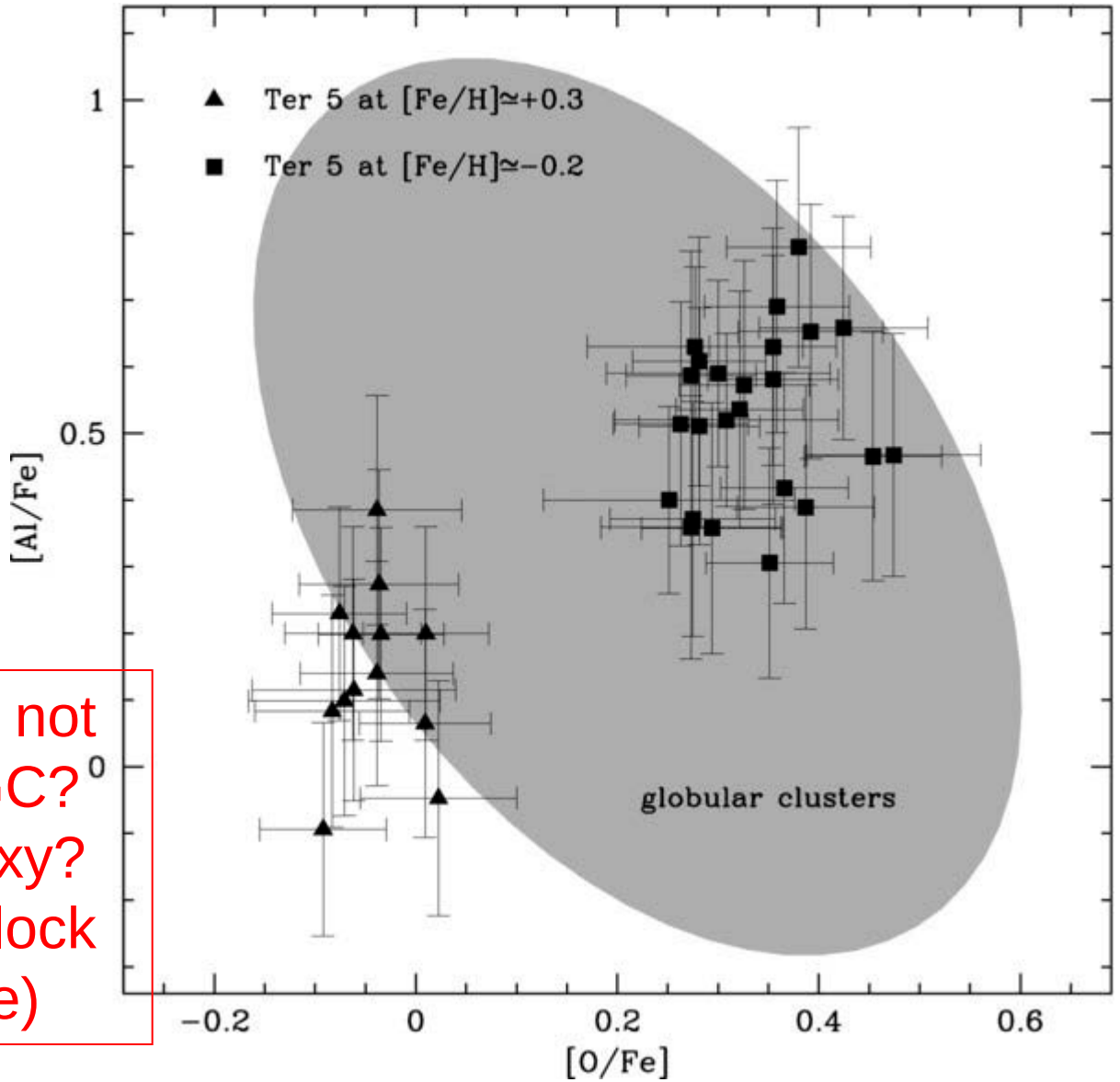
Building block of the Galactic bulge?





Terzan 5

(Origlia+11: KeckII, NIRSPEC)



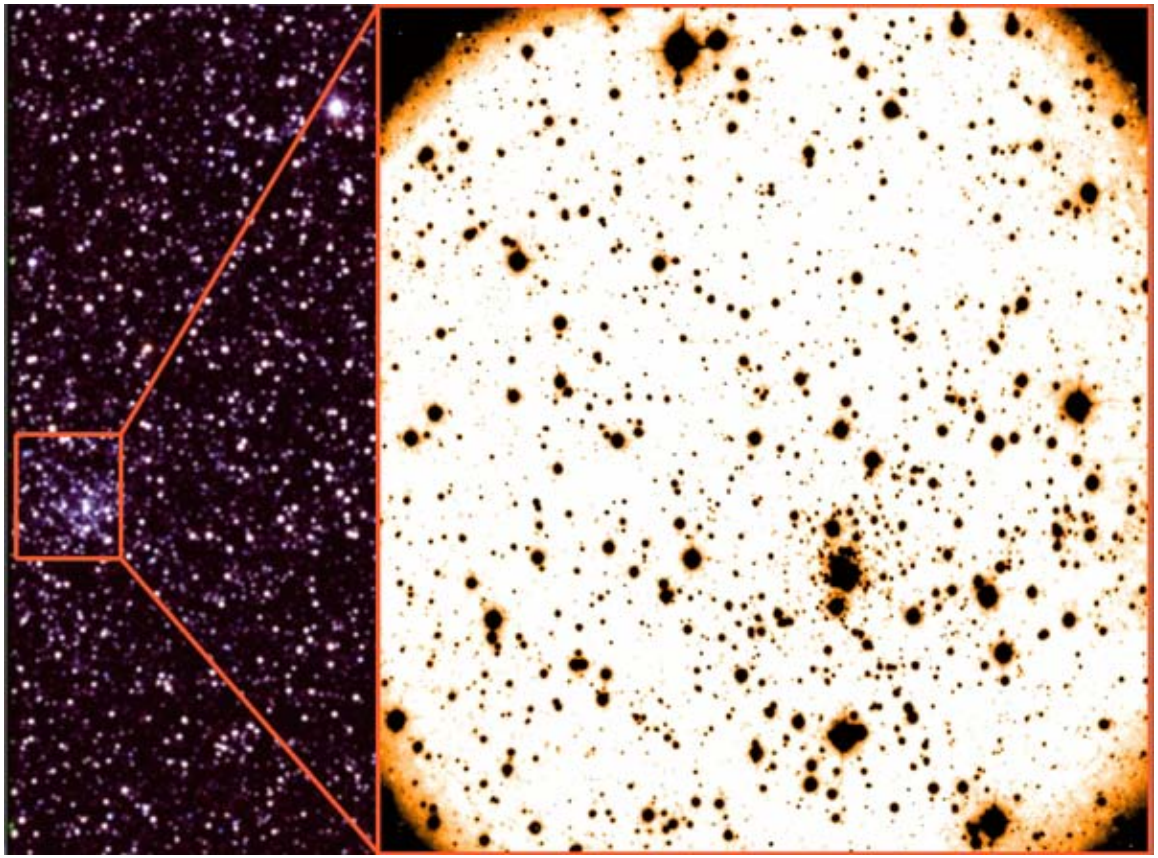
Terzan 5 is not a normal GC? Dwarf galaxy? (Building block of the bulge)

HP 1

(Ortolani+11)

VLT, J & K, MAD

Metal-poor bulge
globular cluster
[Fe/H] ~ -1

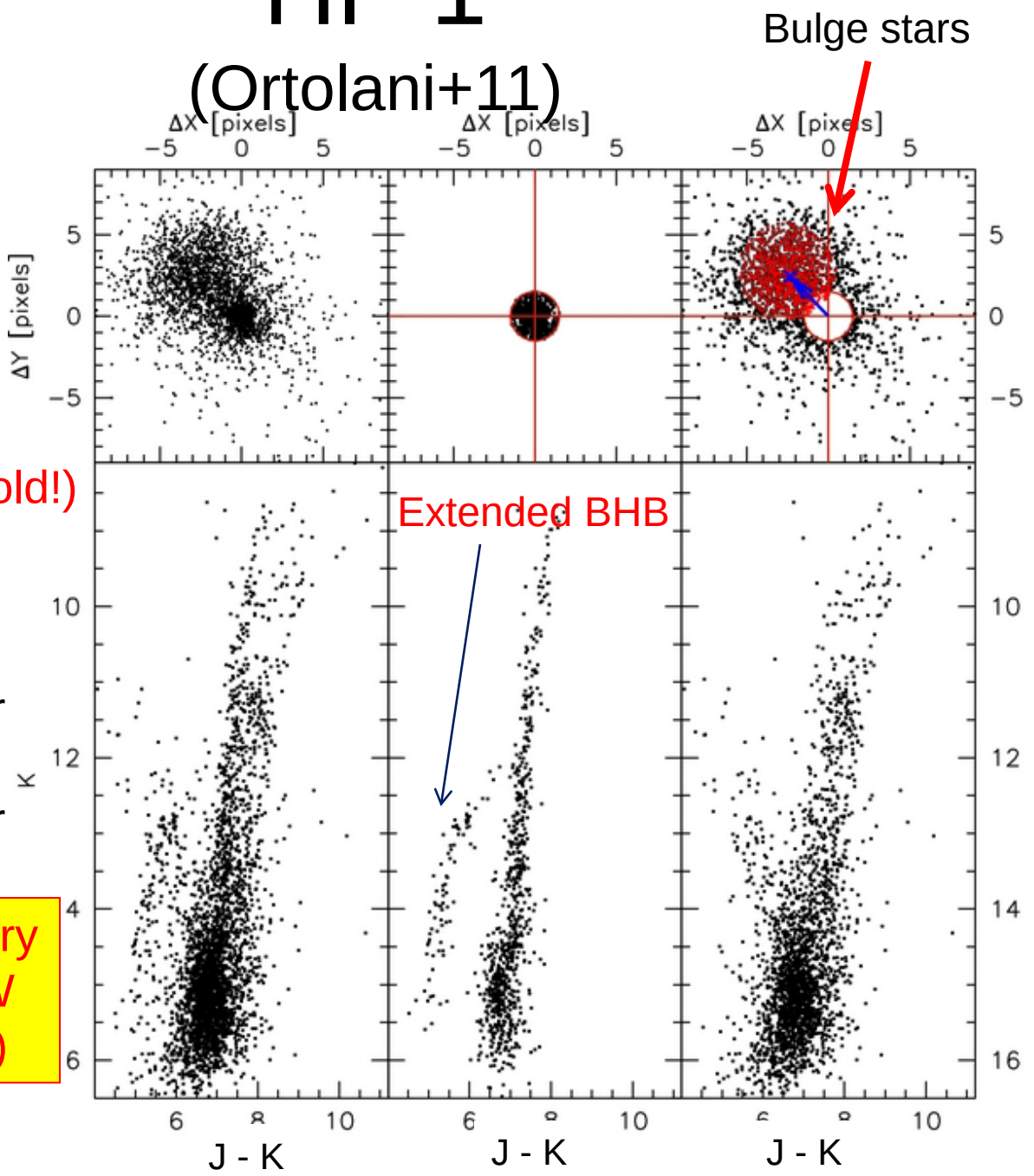


1.8 arcmin

HP 1

(Ortolani+11)

1st epoch:
NTT V image
Δt = 14.25 yr



[Fe/H]=-1.0
Age~13.7 Gyr (very old!)
D~6.8 kpc

$\mu_l$cosb
= -0.65±0.39 mas/yr

μ_b
= -1.34±0.39 mas/yr

HP1 formed in the very early stage of the MW (older than halo GCs)

EHB: Extended Horizontal Branch

Lee et al. 2007

- ~25% GCs show EHB
- Most of these GCs show multiple stellar populations
- He-enhanced 2nd generation stars

⇒reflecting the formation process in the nucleus of a dwarf galaxy?

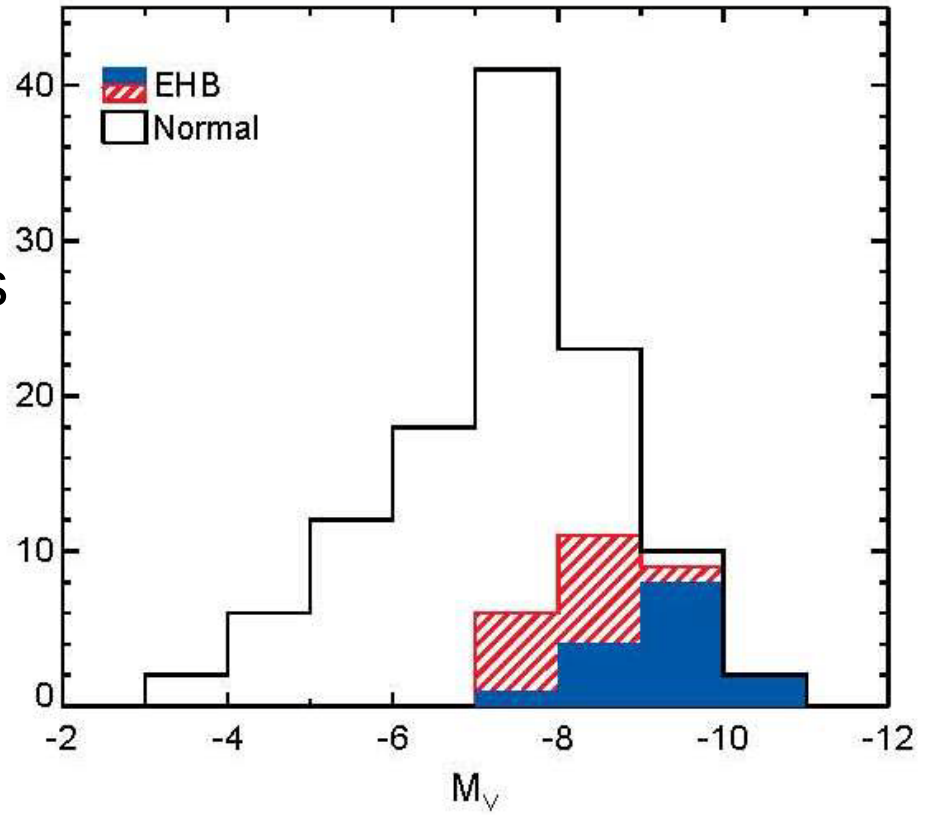
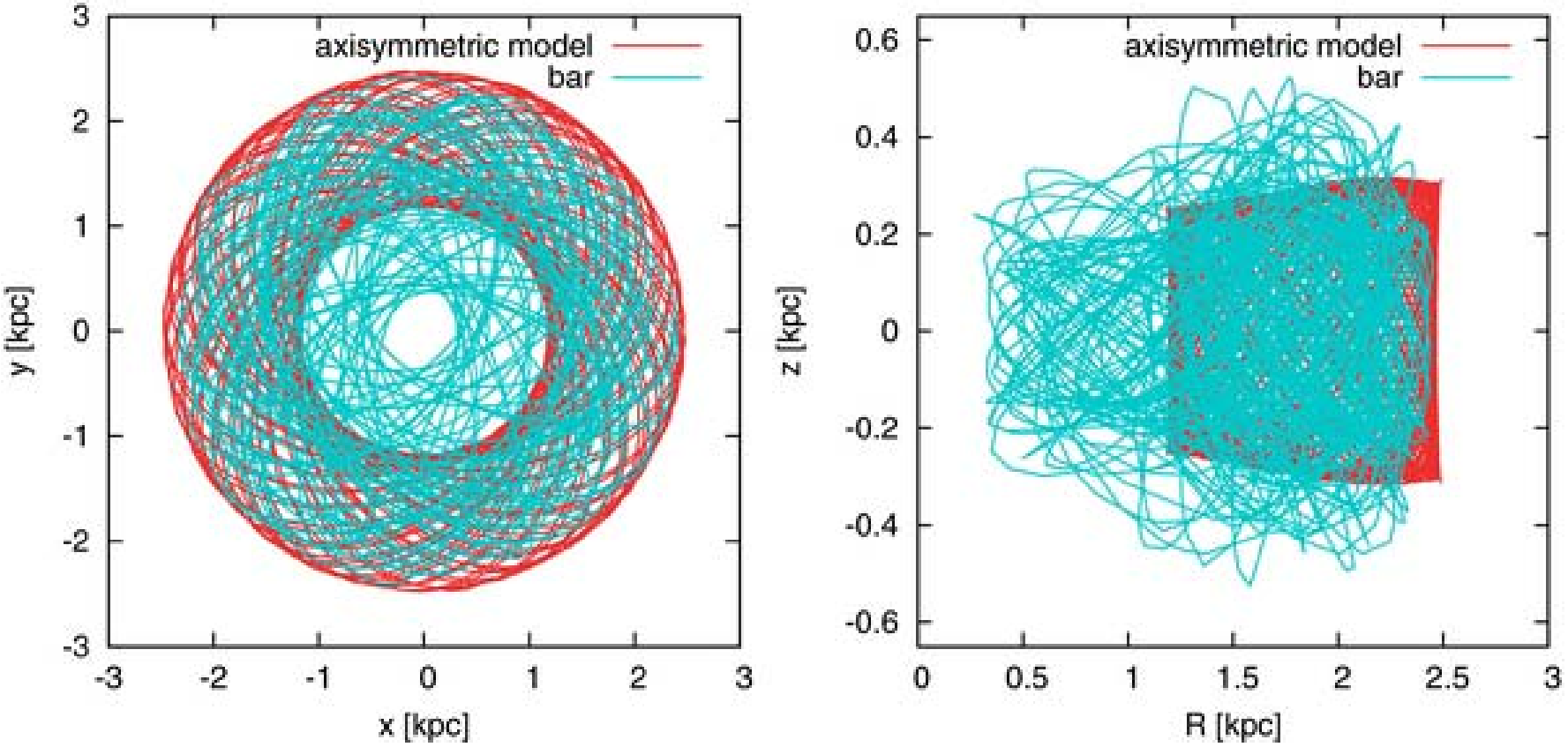


FIG. 1.— The histogram of M_V for 114 Milky Way GCs (data from Harris 1996). Blue and red are GCs with strongly and moderately extended HBs, respectively. EHB GCs are clearly brighter (more massive) than normal GCs.

HP 1

(Ortolani+11)

Possible orbit of HP1



Orbital motion of HP1 is confined near the GC

GCs (in the bulge direction)

- The origin of GCs is still very uncertain
- Known GCs in the bulge direction show peculiar properties
- But many GCs there are yet largely uncovered
  - These are probes of the bulge formation
- We want to know:
  - Metallicity distribution of the bulge GCs and their spatial/orbital dependence.
  - Age distribution of the bulge GCs and their spatial/orbital dependence.
  - Fraction of the bulge GCs having multiple stellar population.

Subaru/NIR+GLAO survey of GCs

- J,K imaging of candidate clusters
  - Source: 2MASS, Spitzer/IRAC (GLIMPSE), VISTA Variables in the Via Lactea (VVV)
  - K~20.0 & J~22.5 (2.5 mag fainter than the turn-off magnitude)

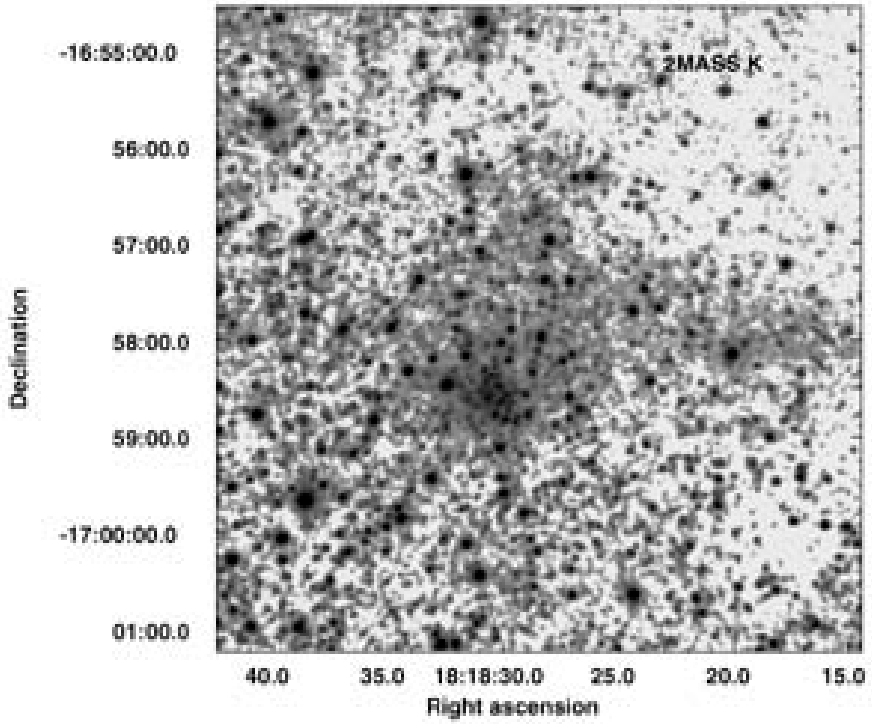
Search for candidate star clusters

Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE)

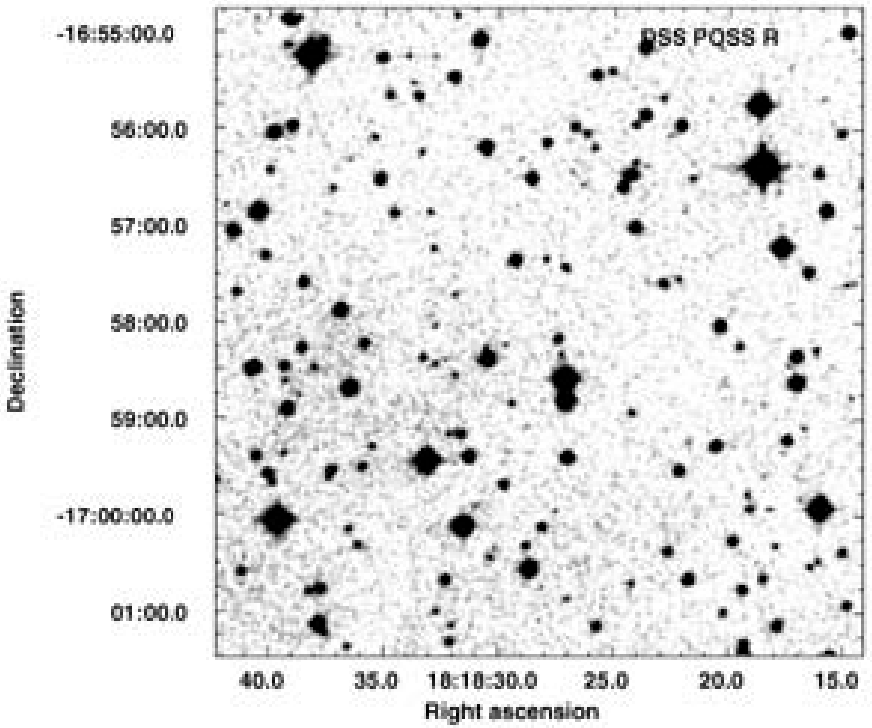
GLIMPSE-C02

(Strader & Kobulnicky 2008)

2MASS K



DSS R

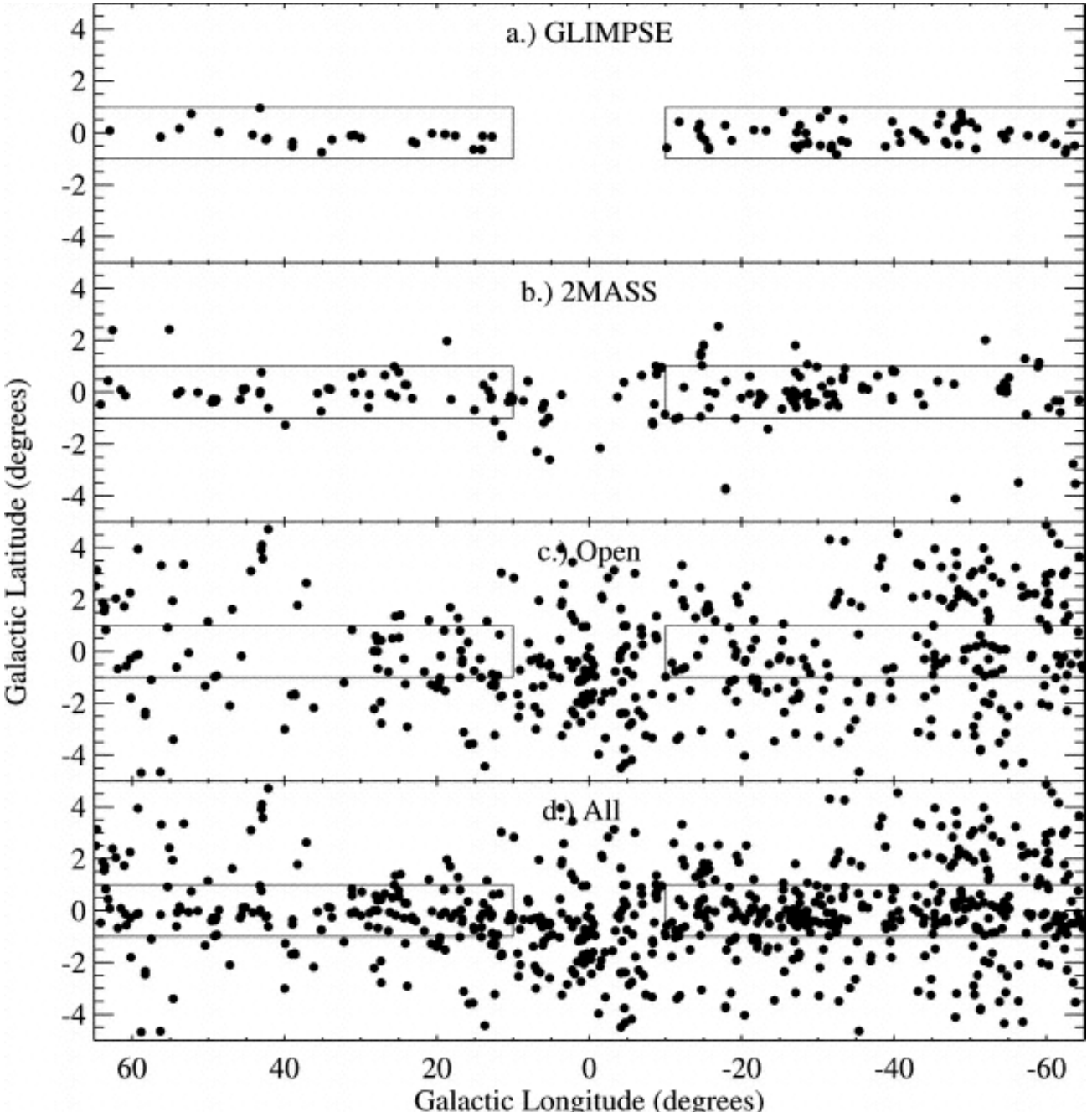


The cluster is invisible in DSS R
due to strong absorption

Candidate star clusters (Mercer+2005)

GLIMPSE

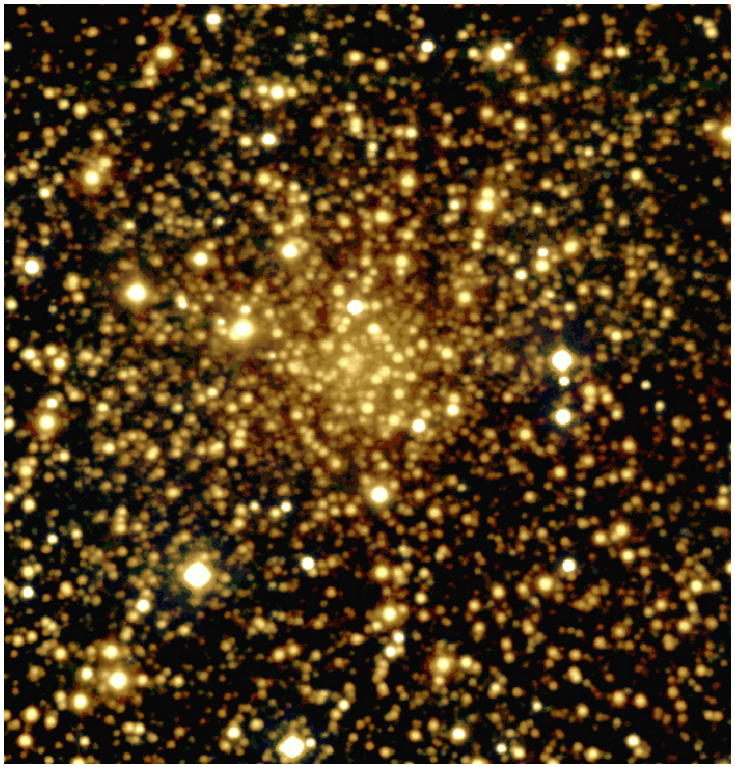
2MASS



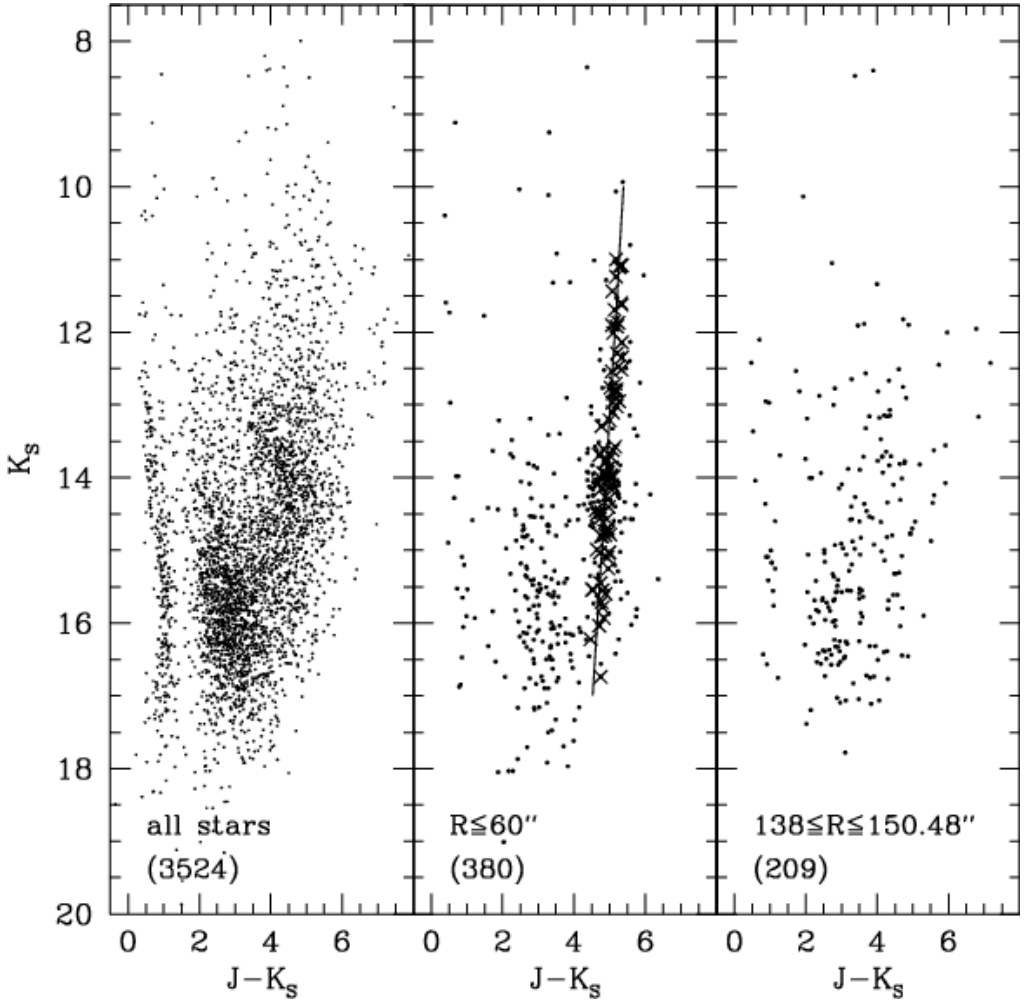
GLIMPSE-C02

(Kurtev+08)

SofI/NTT, JHK

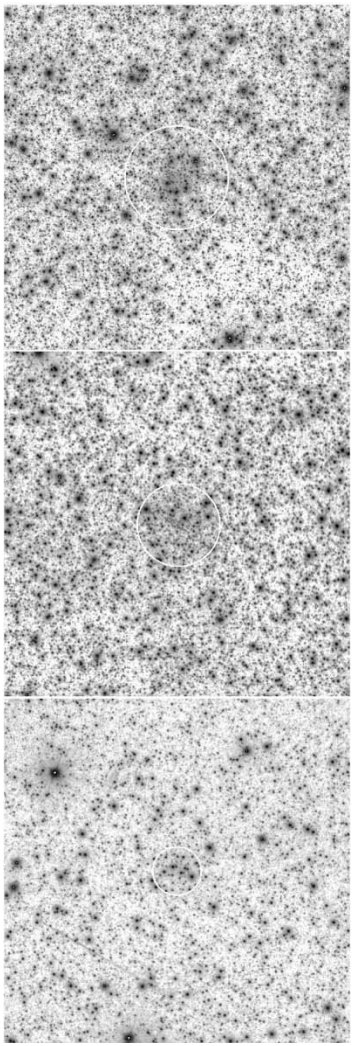


3 arcmin



And more candidates …

K_s-band image



VVV CL002

VVV CL003

VVV CL004

5 arcmin

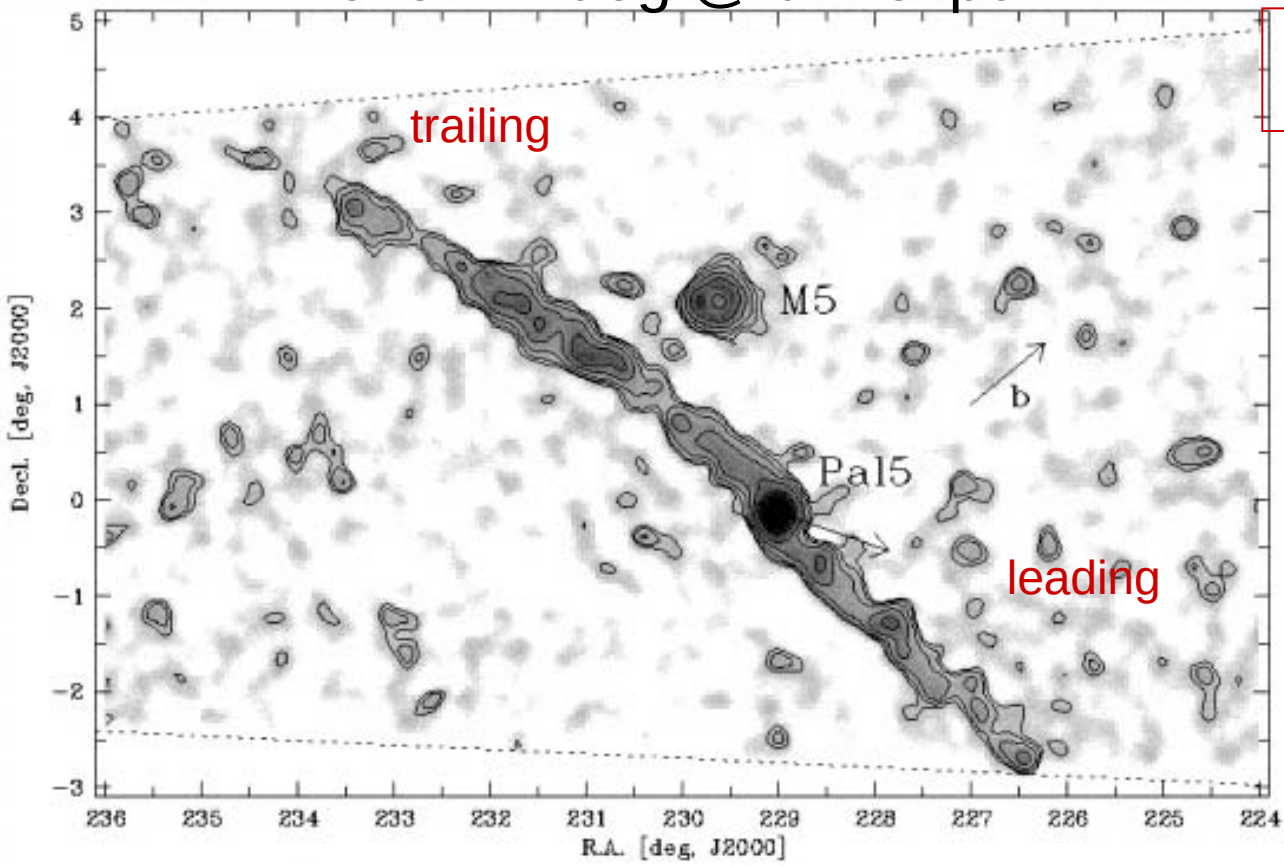
5 arcmin

Subaru/NIR+GLAO survey of GCs

- J,K imaging of candidate clusters with IRCS
  - Source: 2MASS, Spitzer/IRAC (GLIMPSE),
    VISTA Variables in the Via Lactea (VVV)
  - K~20.0 & J~22.5
    (2.5 mag fainter than the turn-off magnitude)
- Follow-up high-res spectroscopy
  - Metallicities and abundance ratios
  - Chemical evolution, relation with Bulge formation
  - True mass distribution in the Bulge through discovery and follow-up studies of stellar streams

Tidal stream from a globular cluster as a tracer of Galactic gravitational potential

Palomer 5
over 22 deg @ d~18kpc



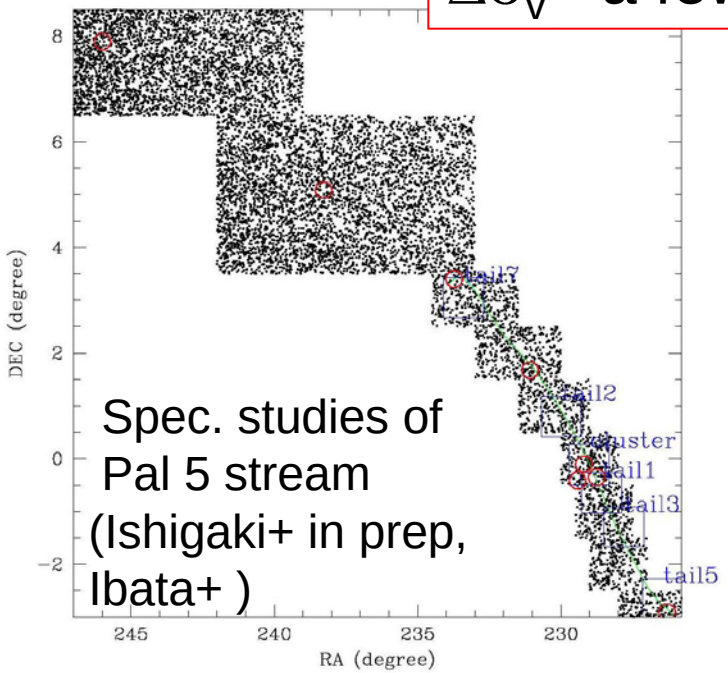
SDSS

Tidal stream from a globular cluster as a tracer of Galactic gravitational potential

(l, b) & V_{los} distribution
- Shape of grav. pot.
- DM substructures

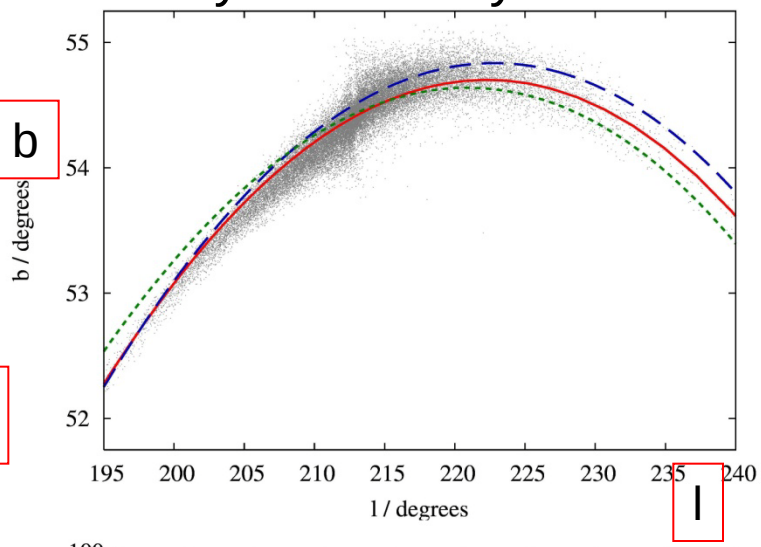
⇒detailed spectroscopy is necessary

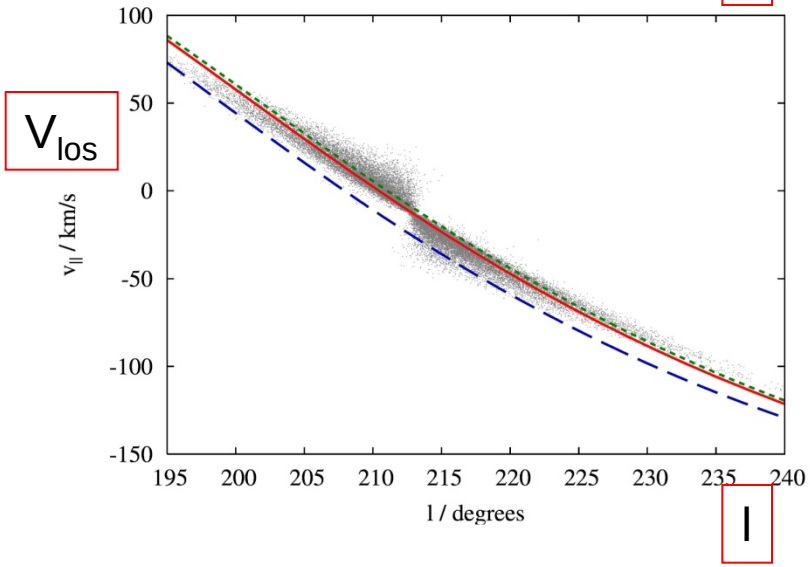
$\Delta\sigma_v$< a few km/s



Spec. studies of Pal 5 stream (Ishigaki+ in prep, Ibata+)

Eyre & Binney 2009





Possible answers to the questions

- Q1: Baseline of NIR instruments?
  - Op. 2 Wide-field NIR imager would be enough
- Q2: Optimal plate scale / FoV?
  - Large FoV is preferred. Better than 0.1”/pix is preferred
- Q3: Synergy with the TMT?
  - High-res spectroscopy will be important.
- Q4: Competition with other missions?
  - Probably no.

Summary

- The general properties of GCs in the GC region are yet largely uncertain
- Subaru/NIR+GLAO survey of candidate GC stars there will be very useful in understanding the nature of these GCs and their relation with Bulge formation