Deciphering the origin of globular clusters near the Galactic bulge + more

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ULTIMATE-Subaru 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)

Topics

- Globular clusters in the Galactic bulge
- Stellar streams
- Pop III candidates

1. Origin of Globular Clusters

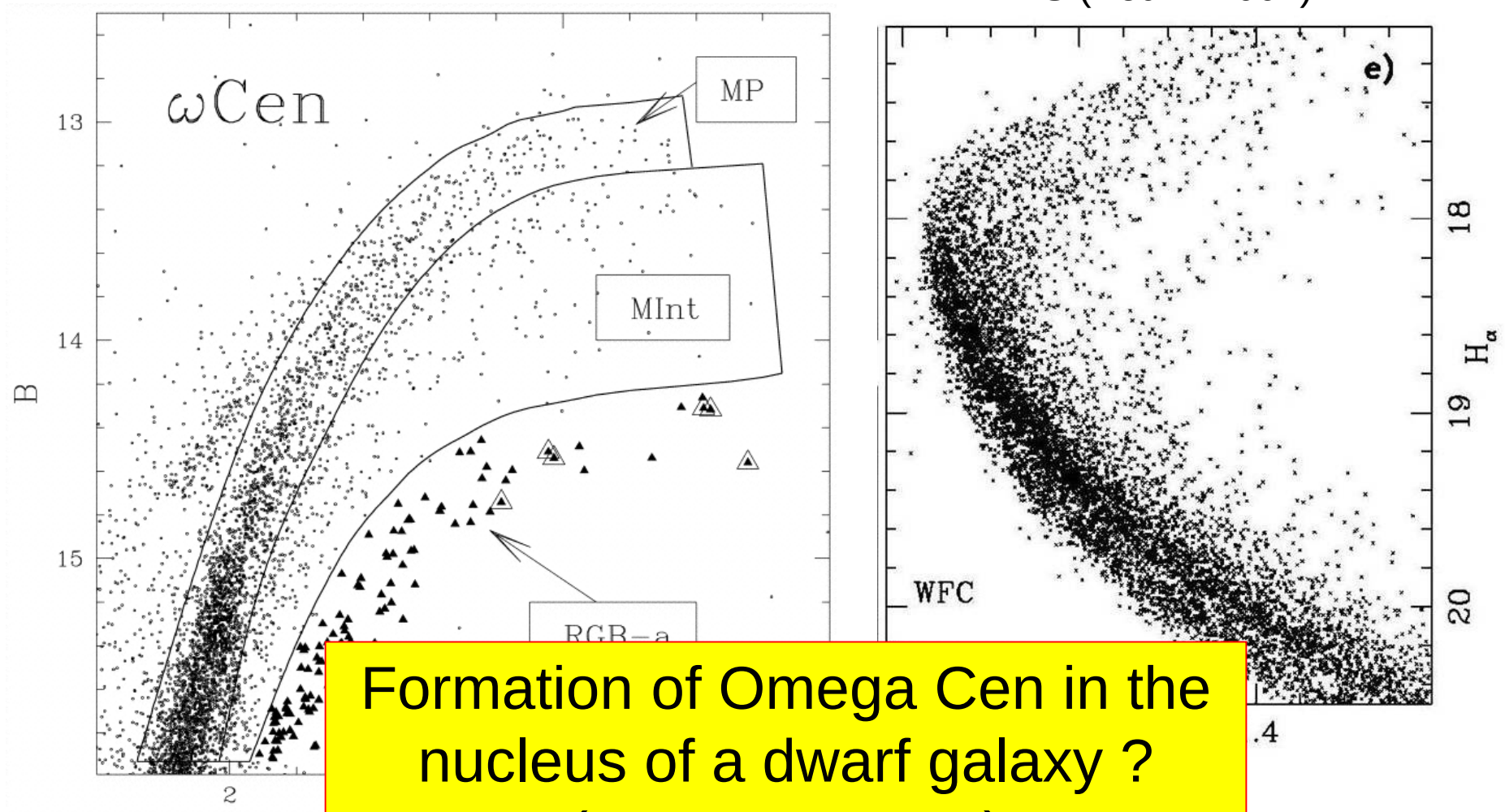
- Oldest in the Milky Way
  - N ~ 160 clusters are known
  - Tracers of Galactic past
- Single population?
  - Multiplicity in stellar pops.
  - Na-O anti-correlation
- Not all clusters are identified
  - GCs in the bulge are largely unclear

ω Centauri
$M=5 \times 10^6$ Msun
Most massive cluster

Omega Cen
multiple stellar population

RGB (Ferraro+2002)

MS (Bedin+2004)

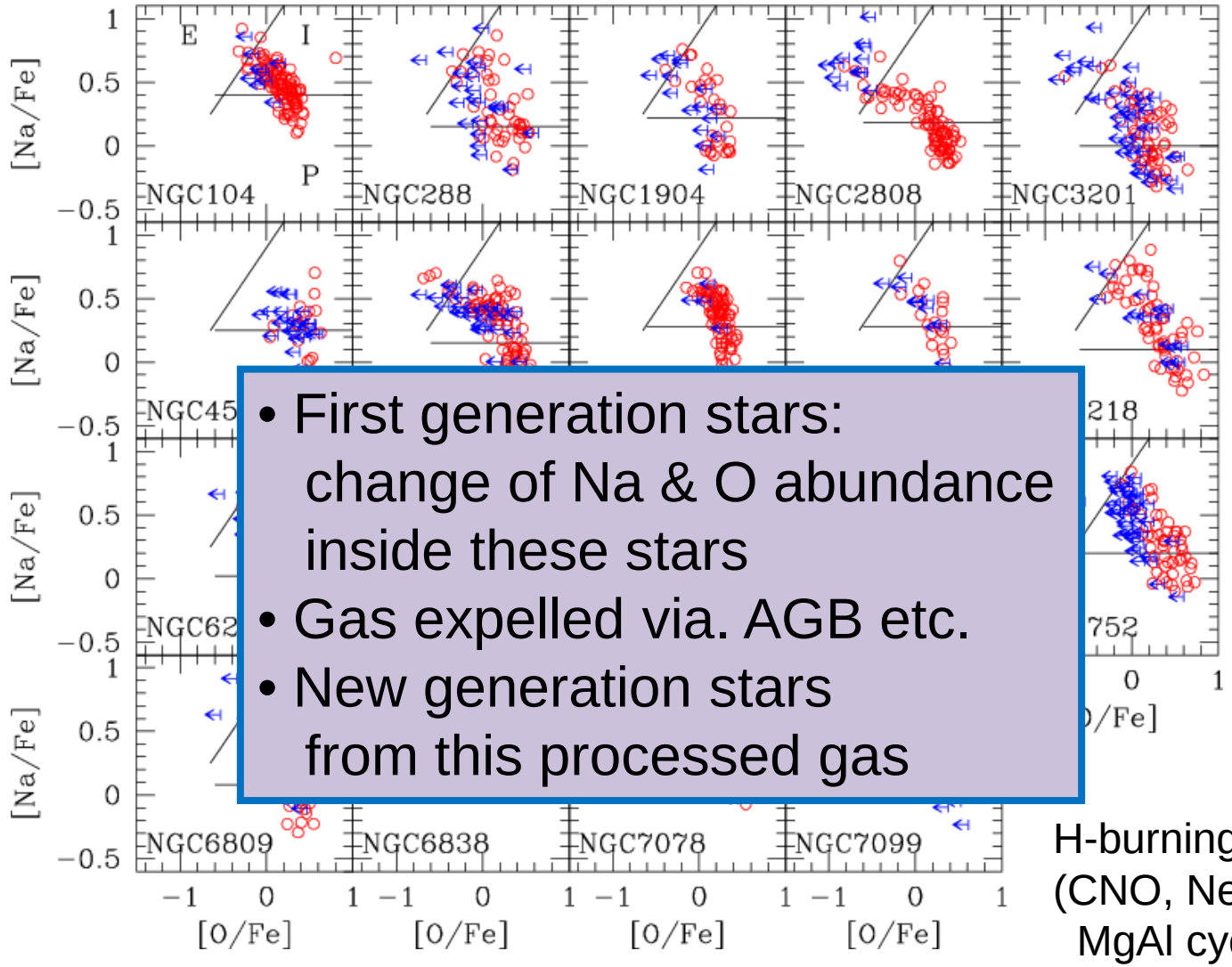


Formation of Omega Cen in the nucleus of a dwarf galaxy ? (Freeman 1993)

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

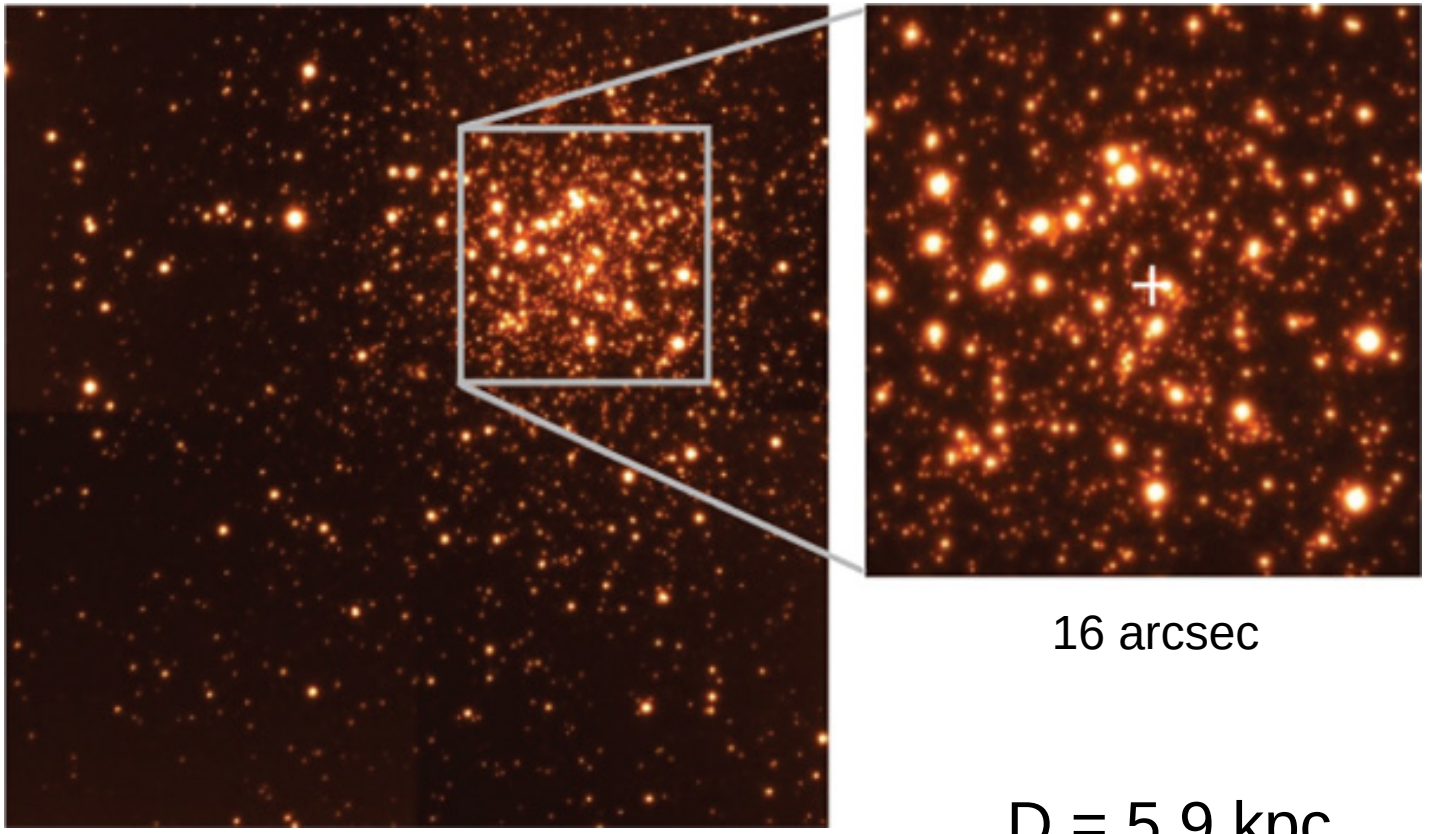
H-burning at high T (CNO, NeNa, MgAl cycle)

Terzan 5

(Ferraro+09)

VLT, J & K, MAD

FWHM @K = 0.1 arcsec
@J = 0.24 arcsec

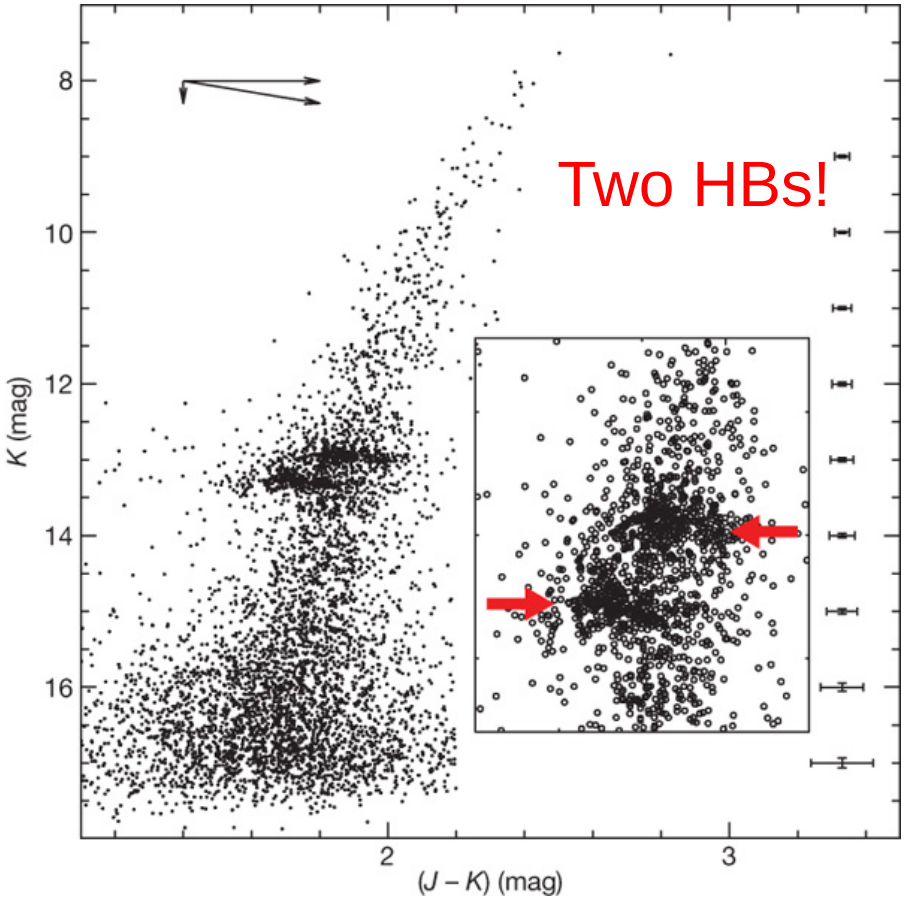


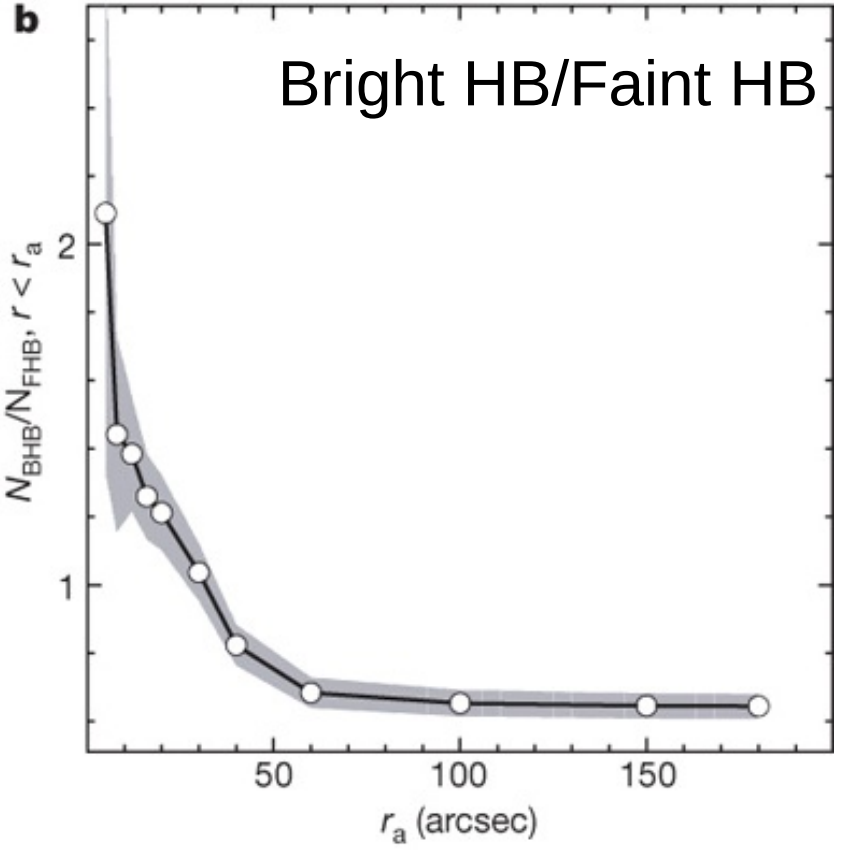
16 arcsec

1 arcmin

D = 5.9 kpc

Terzan 5
(Ferraro+09)



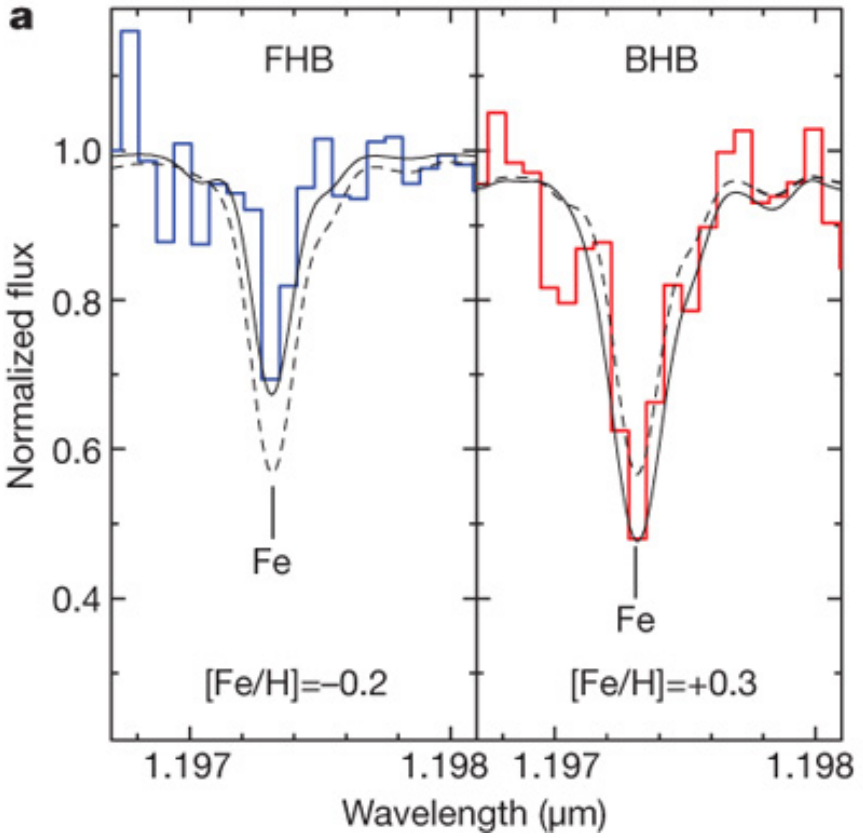


Bright HBs are more concentrated
（no diff for motions）

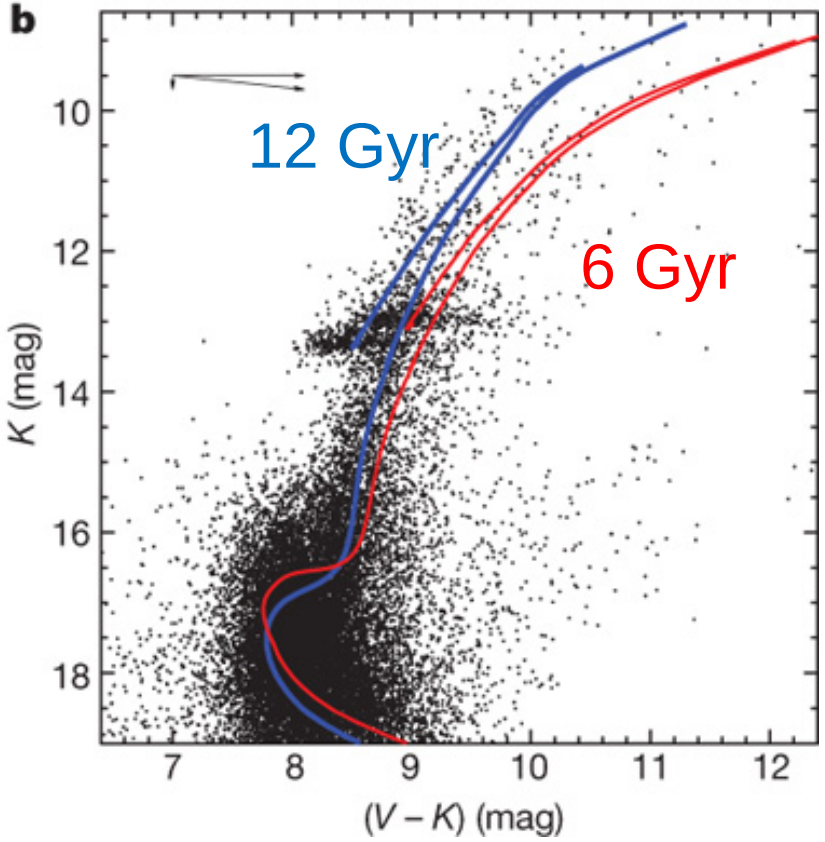
Terzan 5

(Ferraro+09)

Different metallicity



Different age



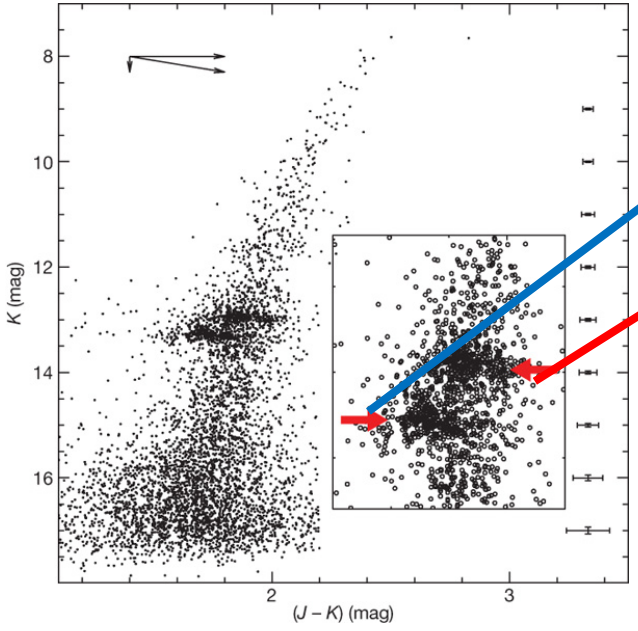
V-band from ACS/HST

Terzan 5

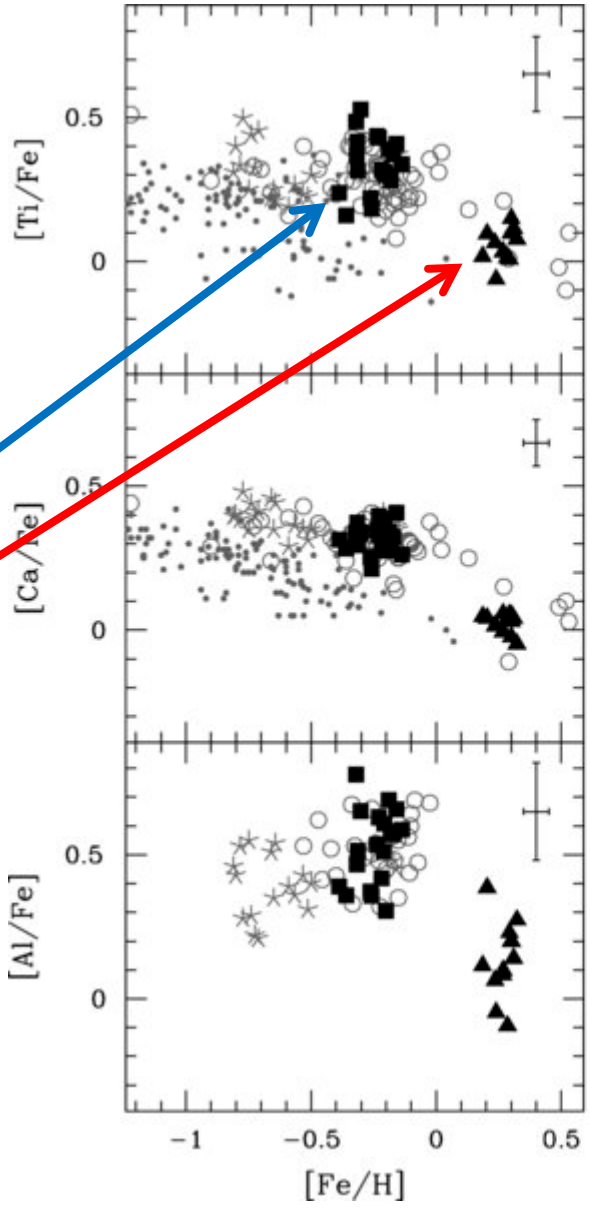
(Origlia+11, KeckII, NIRSPEC, R=25,000)

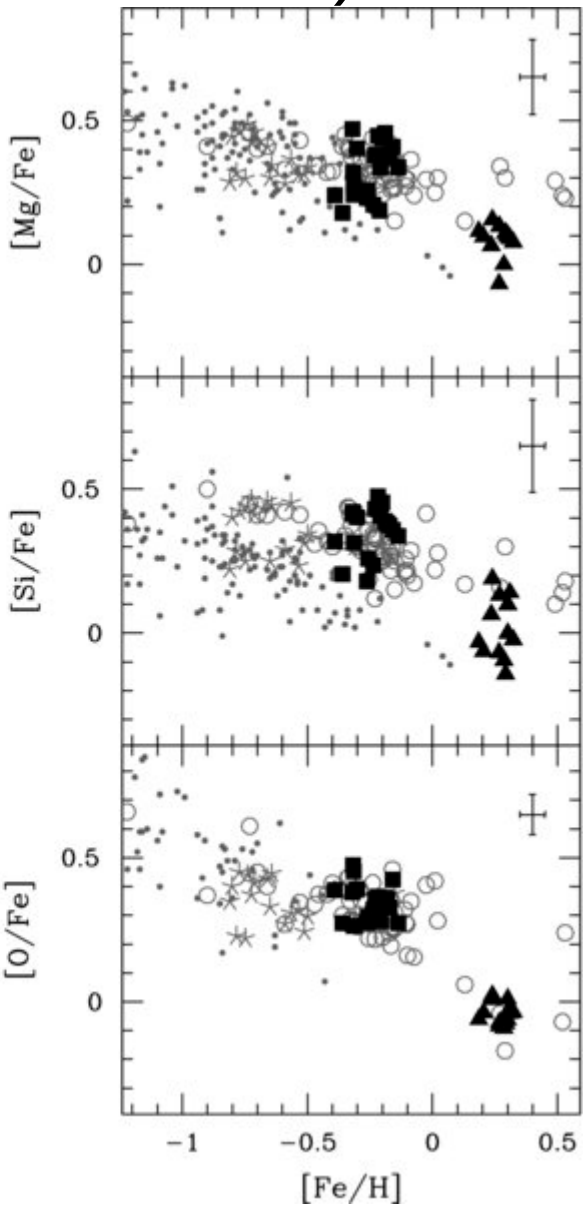
○ bulge
* GCs

High α/Fe & low α/Fe stars coexist



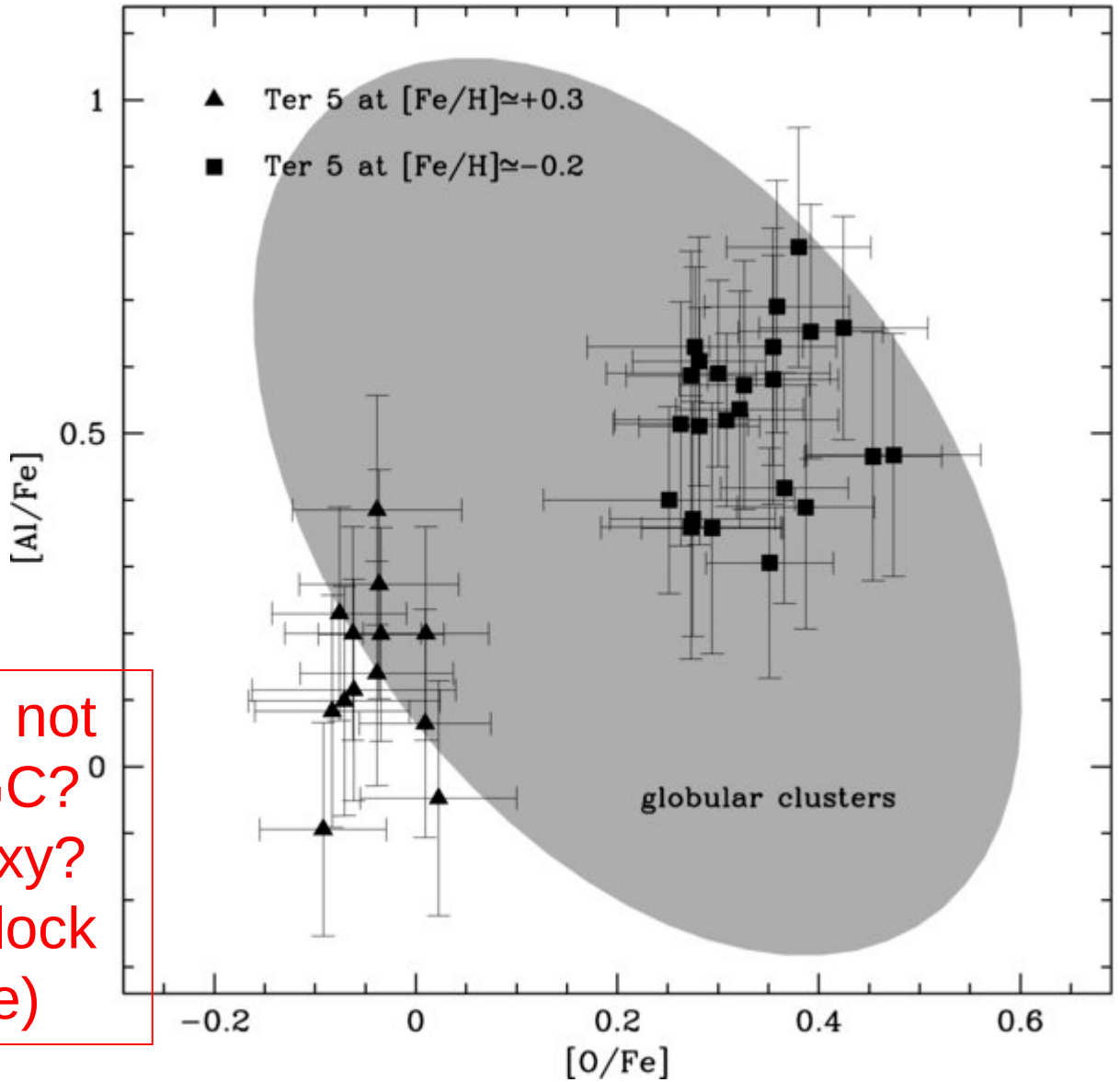
Building block of the Galactic bulge?





Terzan 5

(Origlia+11: KeckII, NIRSPEC)



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

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 veiled
  - These are probes of the bulge formation
- We want to know:
  - Metallicity and age distributions of the bulge GCs and their spatial/orbital dependence.
  - Fraction of the bulge GCs having multiple stellar population.
  - Comparison with field stars in the bulge.

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)

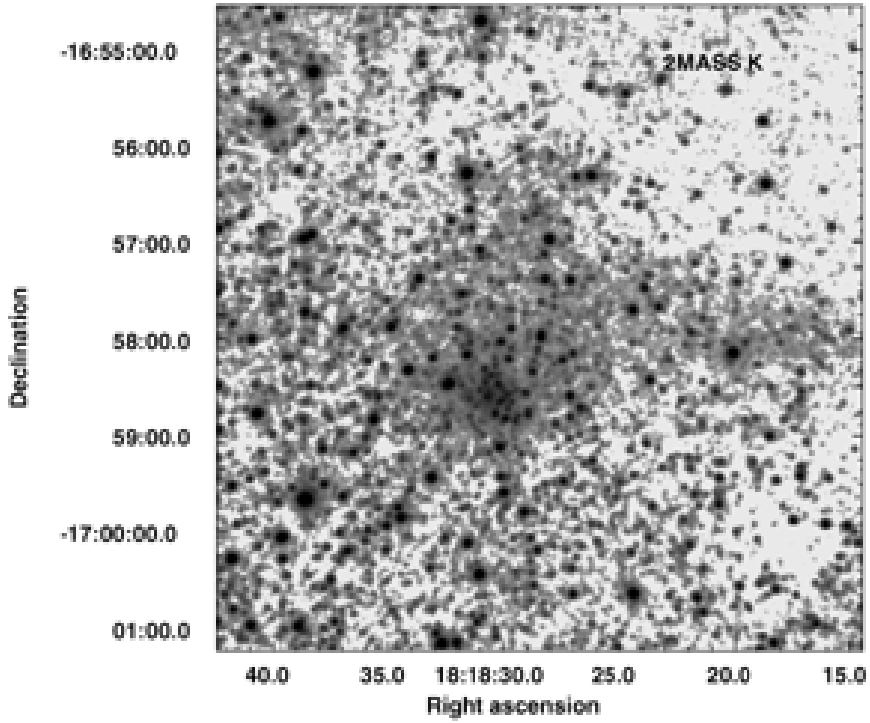
Search for candidate star clusters

Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE)

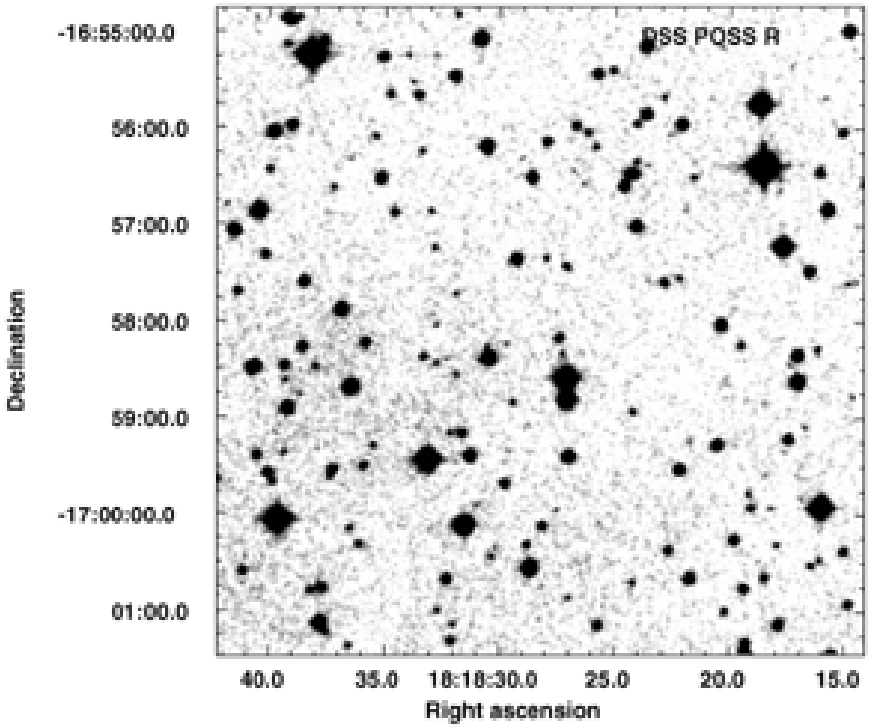
GLIMPSE-C02

(Strader & Kobulnicky 2008)

2MASS K



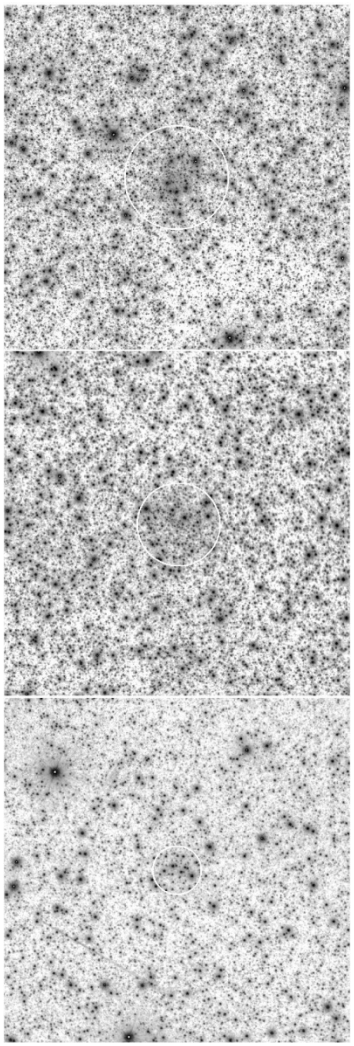
DSS R



The cluster is invisible in DSS R
due to strong absorption

And more candidates …

K_s-band image



VVV CL002

VVV CL003

VVV CL004

5 arcmin

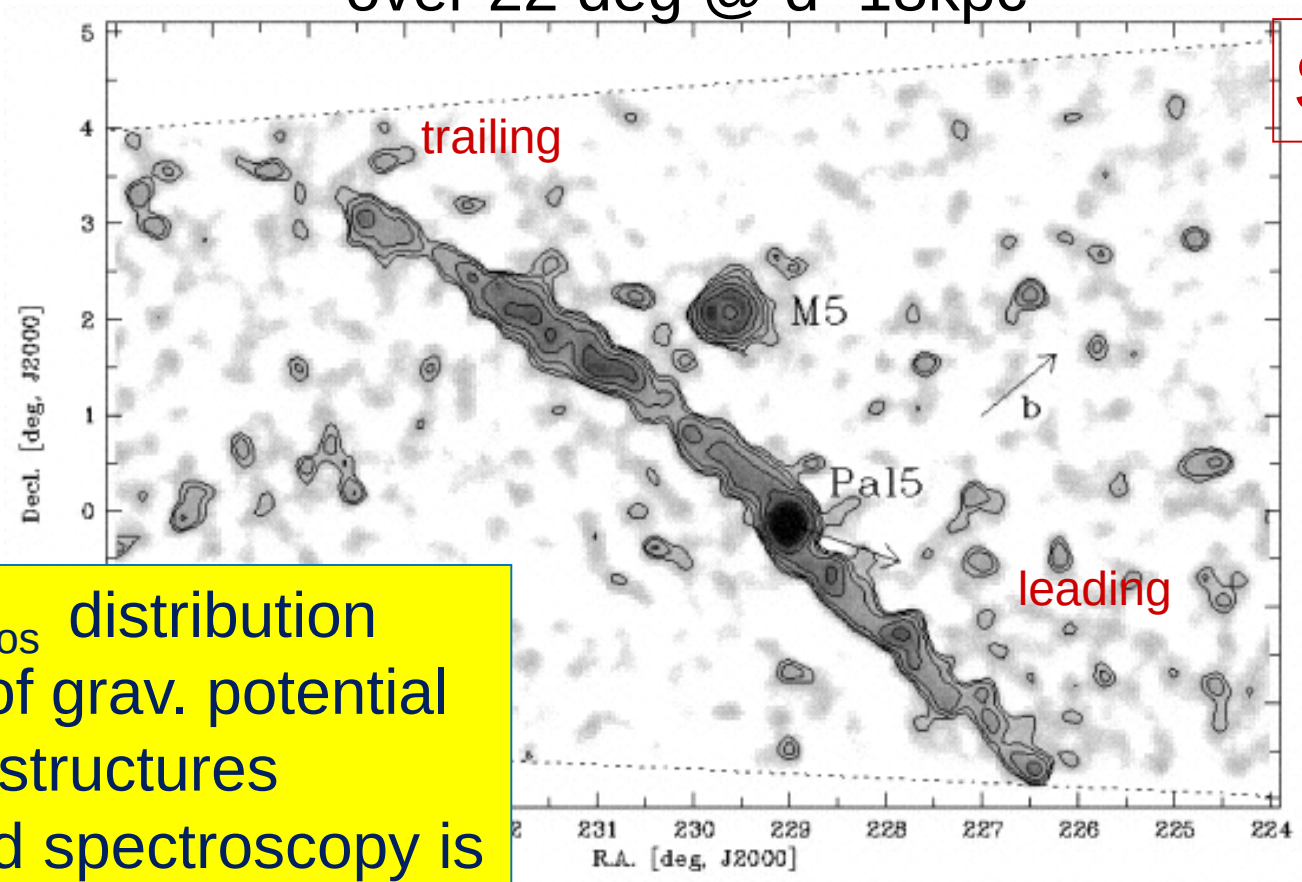
5 arcmin

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 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

2. Stellar streams
~ Tracer of Galactic gravitational potential ~

Palomer 5
over 22 deg @ d~18kpc



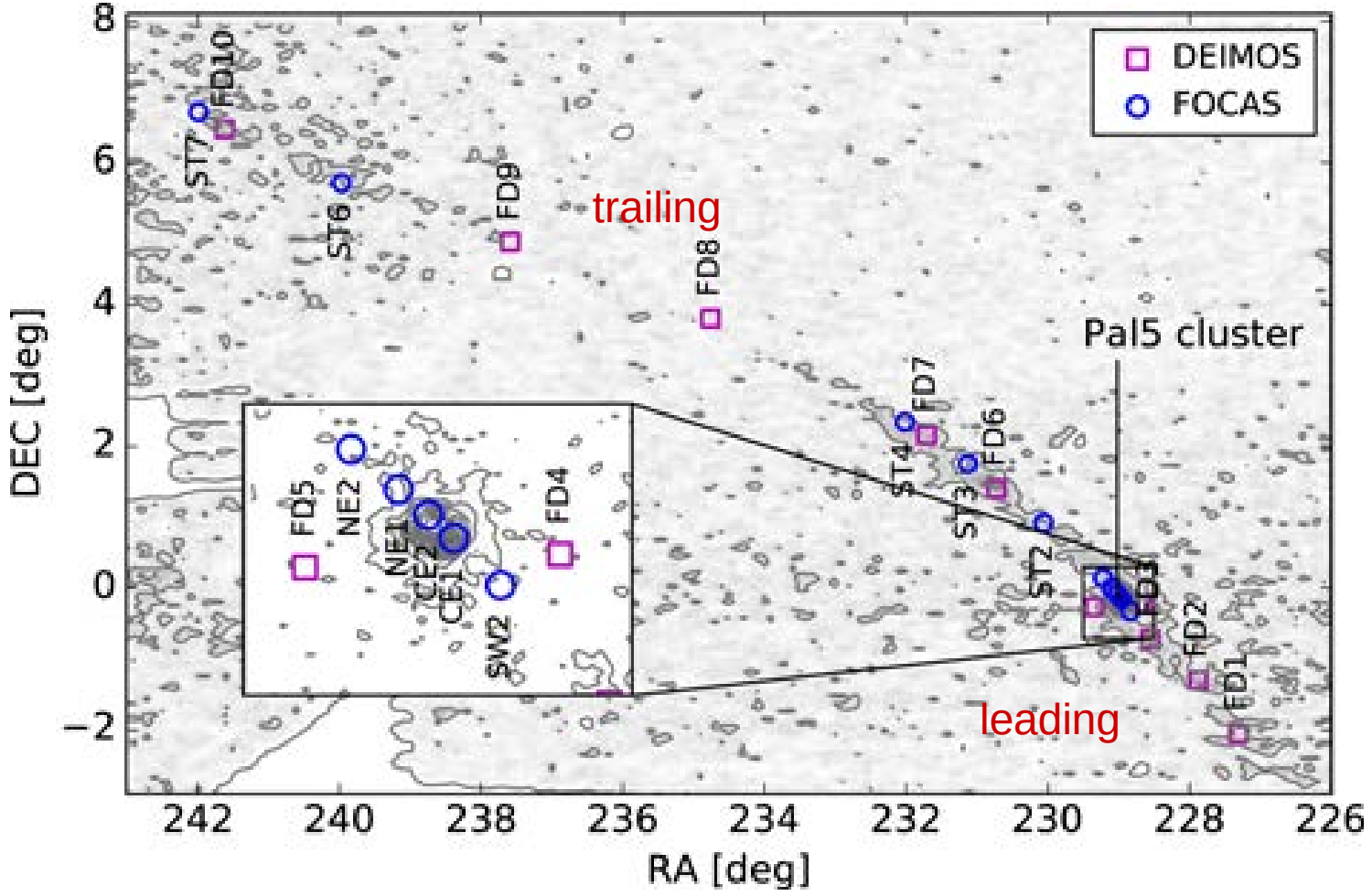
SDSS

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

⇒detailed spectroscopy is necessary

Spectroscopy of Pal 5 stream

Ishigaki, Hwang, Chiba & Aoki 2016



Identify and determine V_los distribution along the stream

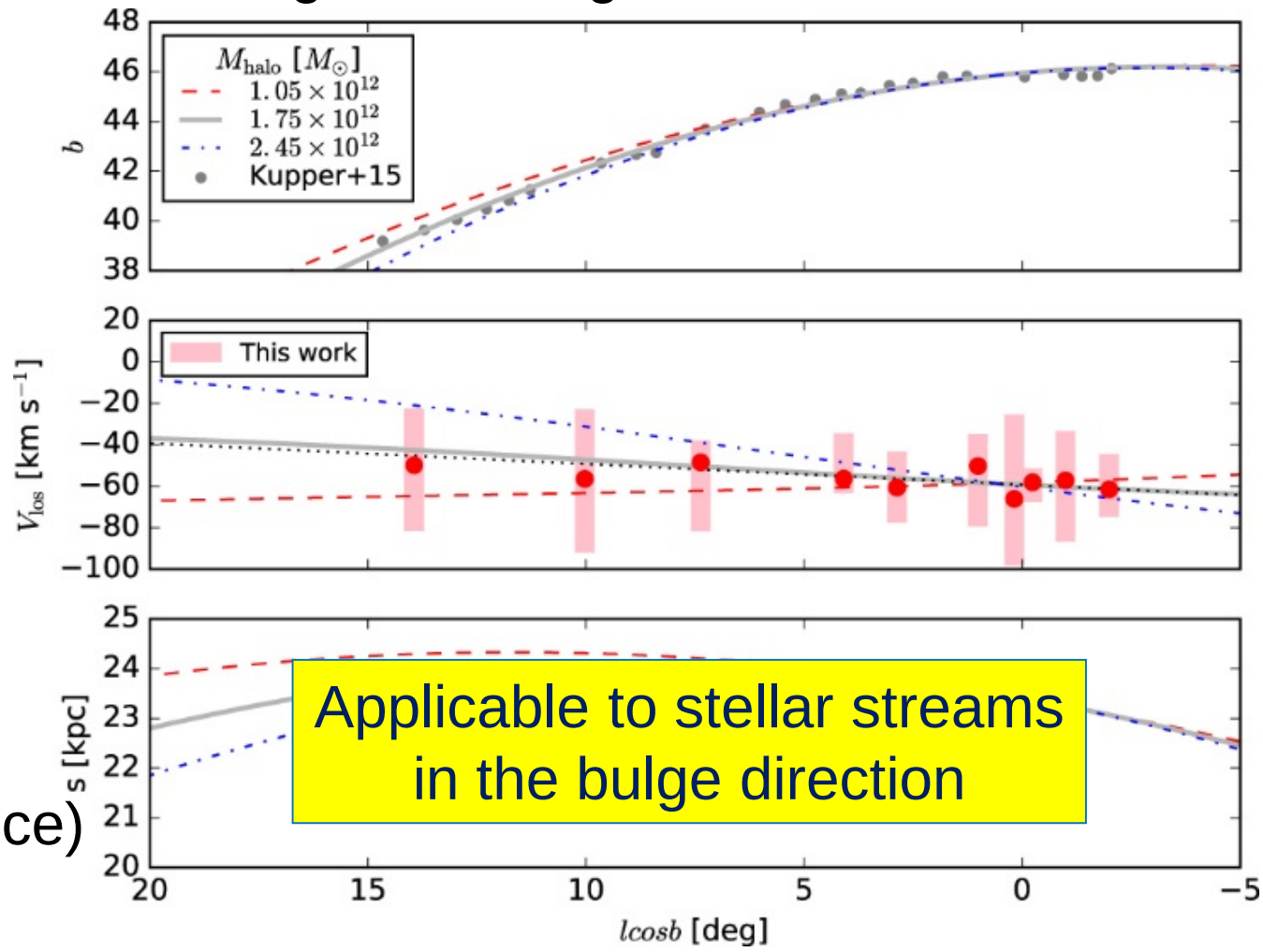
Constraining the mass of the MW halo

Ishigaki, Hwang, Chiba & Aoki 2016

b

V_los

s (distance)

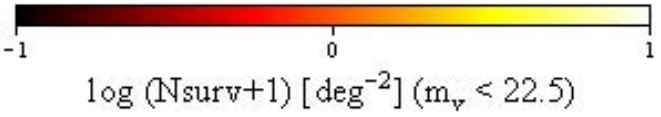


Applicable to stellar streams in the bulge direction

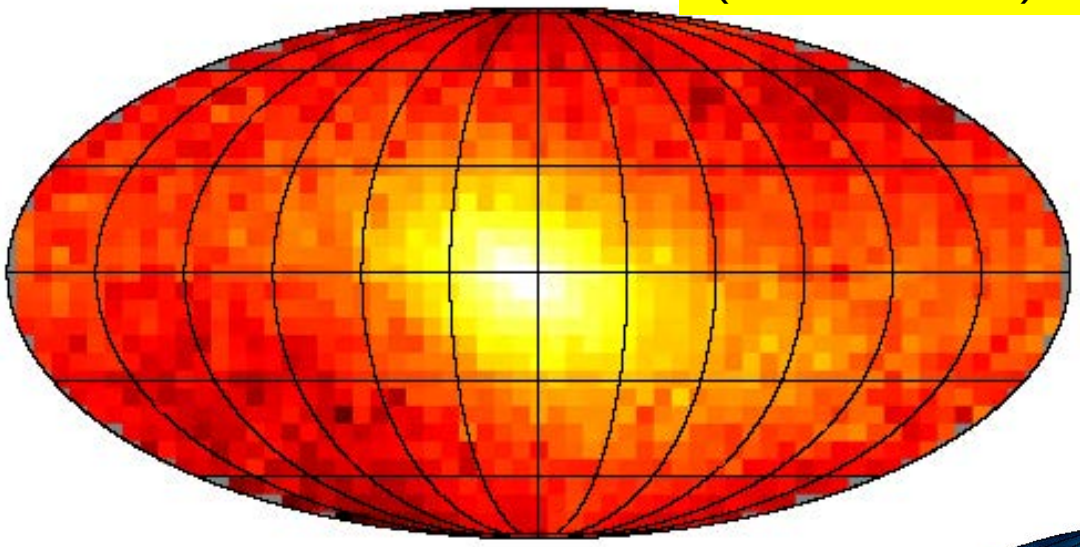
l cos b

3. Where are the Pop III stars?

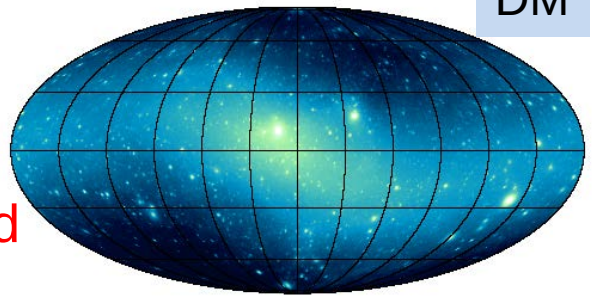
Ishiyama et al. 2016
Cosmological simulation



Distribution of Pop III candidates
(M < 0.8 Msun) with m_V <22.5



DM



Many Pop III would likely exist
near the Galactic bulge

~ 1 Pop III / deg^2 can be detected

Systematic search for Pop III

- HSC NB319 (CaH+K) survey of high-latitude regions (for lower contamination of field stars)
  - Selecting Pop III candidates
  - Spectroscopic follow up with DEIMOS, HDS
- GLAO-IR survey of the low-latitude, bulge region with spectroscopy
  - Selecting Pop III candidates with Low-res spec
  - Spectroscopic follow up with DEIMOS, HDS, HROS

Summary

GLAO-IR survey of the bulge region

- The nature of GCs in the bulge
- Gravitational field using stellar streams
- Search for Pop III candidates

Possible answers to the questions

- Q1: Key science/observations?
  - Observations of stellar populations in the bulge
- Q2: Which instruments, WFC/MOS/IFU?
  - OK that WFC is 1st priority
- Q3: GLAO + MOIRCS
  - Not sure…
- Q4: Which survey design sounds best?
  - Not sure …