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 $\sim$ 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

$\omega$ 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)
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

D = 5.9 kpc
Terzan 5
(Ferraro+09)

Two HBs!

Bright HB/Faint HB

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) * GCs

High $\alpha$/Fe & low $\alpha$/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)
The cluster is invisible in DSS R due to strong absorption.
And more candidates ...

\[ K_s \text{-band image} \]

- VVV CL002
- VVV CL003
- VVV CL004

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

(l, b) & $V_{\text{los}}$ distribution
- Shape of grav. potential
- DM substructures
⇒ detailed spectroscopy is necessary
Spectroscopy of Pal 5 stream
Ishigaki, Hwang, Chiba & Aoki 2016

Identify and determine $V_{\text{los}}$ distribution along the stream
Constraining the mass of the MW halo

Ishigaki, Hwang, Chiba & Aoki 2016

Applicable to stellar streams in the bulge direction
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

Many Pop III would likely exist near the Galactic bulge

~ 1 Pop III / deg² 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 …