Wide Field Spectroscopic Campaign of Star Clusters in Nearby Galaxies?

Narae Hwang
Korea Astronomy & Space Science Institute

in collaboration with
Myung Gyoong Lee, Miho Ishigaki, Masashi Chiba, Hong Soo Park, Sungsoon Lim, and Others
Where’s Wally?
Astronomical Tracers: Globular Clusters (GCs)

• The most ancient stellar system in galaxies
• Ubiquitous : Found in all types of galaxies
• Brightest, readily identifiable objects in galaxies

• Good tracers of…:
  – Stellar Population – SSP assumption
  – Kinematics – Internal kinematics of galaxies

• Easy to define the size
Size distribution of GCs

- GCs: mostly as large as $2 < R_h < 4$ pc
Size Distribution of M51 SCs

• Sum of 3 Gaussians
  – 1\textsuperscript{st}: r=2.27 ± 0.03 pc (σ=1.90 pc) : MW GC like
  – 3\textsuperscript{rd}: r=7.51 ± 0.30 pc (σ=1.38 pc) : ESCs

• ESCs are GC-like star clusters with systematically larger than (typical) GCs (in MW)
MW GCs: Age-[Fe/H]-Size vs Rgc

- **Age:**
  - All old for $R_{\text{GC}} < 10\text{kpc}$
  - A large spread: 7-14 Gyrs for $10 < R_{\text{GC}} < 20\text{kpc}$

- **[Fe/H]:**
  - A large spread:
  - Only low[Fe/H] for $R_{\text{GC}} > 60\text{kpc}$

- **Size ($r_h$):**
  - Larger for large $R_{\text{GC}}$
  - Only large ones for $R_{\text{GC}} > 60\text{kpc}$

- **MW 'ESCs'** – outer halo/low metal

- Figure courtesy of MGLee

New ESCs in NGC 6822

- 4 new ESCs in the halo of ‘well isolated’ dIrr galaxy NGC 6822 by Hwang et al. (2005, 2011) based on Wide-Field CFHT/MegaCam data
- + 3 more clusters by Huxor et al. (2013)
Wide Field Survey of NGC 6822
Hwang+(2005;2011)

Huxor+(2013)
New ESCs in NGC 6822

- CFHT i band thumbnails (37”x37”)
- Compact/Unresolved HVII and Extended New SCs
- C3 looks similar to HVIII

Hwang+2011: Fig.2
Spectroscopy of NGC 6822 ESCs

- Gemini-South/GMOS (GS-2011B-Q-16, PI: N. Hwang)
- B600_G5323 grating + 0.75” slit
- Exposure: 700sec x 4 (C1) ~ 1800sec x 8 (C3)
- Spectral coverage: 3900—6500 A @ 0.92A/pixel, <S/N>~20-30
- Hwang et al. (2013, in preparation)
NGC 6822 ESCs: Velocities

• Radial velocity distribution of ESCs, HCs, and C-stars in NGC 6822
• C-stars from Demers+(2006)
• ESCs are not rotating as C-stars do
NGC 6822 ESCs: Age/Metallicity

- ESCs are older than about 8-10 Gyr
- $r>20'$: low metal only
- $r<20'$: low+high metal
- $r>20'$ $\rightarrow$ $[\text{Fe/H}] <-1.5$, $t > 10$ Gyr
ESCs: Primordial Component of NGC6822

- Ages: older than 8-10 Gyr
- \([\text{Fe/H}] < -1.5\)
- Located in the outer part of the galaxy
  \((r > 15' \text{ or } 5 \text{ times of main body size})\)

ESCs – Where are they from?

*ESCs may have formed in dwarf galaxies!*

\(\rightarrow\) consistent with Hurley & Mackey (2010)
Tracers of What?

- GCs
  - Stellar Populations of Galaxies – SSP
  - Internal Kinematics of Galaxies

- ESCs
  - Accretion of dwarf galaxies?
M31—Stellar Streams & ESCs

- Giant spiral galaxy (Type Sb) in Local Group
- Giant stellar streams and many dwarf satellites
- Regarded as remnants of many merger-like events

(Ibata et al., 2005)
Spatial Distribution of M31 ESCs

- ESCs are widely scattered around M31 (Huxor+2008, 2011)
PANDAS Survey: M31 ESCs & Stellar Streams

- Mackey et al. (2010)
- Red – compact GCs
- Blue – Extended GCs (about 20?)

- Argues for spatial correlation of stellar streams with GC positions
- Needs further observational check!
Example in MW: Pal 5 & stellar stream

Ivezic et al. 2012; substructures in the Milky Way

A unique tracer of:

- The global mass distribution of the Galaxy
- Dark matter subhalos in the Galactic halo
Palomar 5

• A low-mass globular cluster
  – \((l,b) = (0.85, 45.86)\)
  – \(d_\odot \sim 23\) kpc
  – \([Fe/H] = -1.4\)
  – \(~11.5\) Gyr

• The long and thin tidal tails
  – trailing tail: > 23° (Carlberg+12)
  – leading tail: > 6° (Grillmair+06)

SDSS DR8 photometry (Carlberg et al. 2012)
Subaru/FOCAS spectroscopy

- Ishigaki, Hwang, Chiba 2013 in preparation
- Observation at 29-30 June 2011
- $\lambda \sim 7900$-$8700$ including the Ca II triplet absorption lines
- $R \sim 7000$
- $g_0 \sim 16$-$20$ mag, S/N$\sim 20$
- 10 FOCAS fields
Stellar density map constructed from SDSS DR9 photometric data

Subaru/FOCAS spectroscopy

°: Observed with Subaru/FOCAS

NE1 (10), NE2(8), SW2(8)
ST3 (7)
ST3 (8)
ST4 (7)
ST2 (8)

CENTER1(21), CENTER2(26)

Stellar density map constructed from SDSS DR9 photometric data
Radial velocities of the candidate members along the stream

- The simple model for the Galactic potential:
  \[ \Phi(r) = v_c^2 \ln(r) \]

- Radial velocity variation of several 10s km/s along the stream as predicted from the presence of clumpy dark matter subhalos? (Yoon+11)
Tidal stream from a globular cluster as a tracer of Galactic gravitational potential

> Theoretical modeling approach to investigate (Kogawa & Chiba, private comm.):

• Shape of $\Phi$ or global density profile [for $\Phi_{\text{halo}} \propto \ln(x^2+y^2/p^2 + z^2/q^2)$]

• Dark halo substructures (Binney 2008; Eyre & Binney 2009)

> Based on $(l, b)$ & $V_{\text{los}}$ distribution for stream stars

> Currently in progress led by M. Chiba (Tohoku Univ. Japan)
PANDAS and the Next Step

• Key words
  – Wide Field
  – High Spatial or Spectral Resolution

• PANDAS + ngCFHT
  – Large Legacy project to investigate...
    • ESCs & Stellar Streams
    • Kinematics of halo components
    • DM halo distribution
    • the accretion history
    • Etc.
Possible Future Project by Mauna Kea Community

- Subaru + ngCFHT
- HSC Survey of M31 Halo (including ESCs + Stellar Streams)
- Spectroscopic Follow-up w/ ngCFHT

Figure: Proposed HSC 2013 tilts in M31’s outer halo over ~230 deg² (~130 pointings).
Summary

• *Wide Field Spectroscopic + Imaging* capabilities are *two crucial keys* to future science cases on
  – Physical & chemical properties of star clusters
  – Kinematics of halo components
  – Formation and evolution of (late type) galaxies

• *ngCFHT initiative* combined with existing and/or future Mauna Kea facilities will play a vital role in
  the next decade

• Korean community has a very keen interest in the development of future Mauna Kea facilities
Thank you!
Size – Luminosity Relation

Hwang+2011: Fig. 7
Heterogeneous Populations

• (At least) Two Populations appear to exist
• Bright: UCDs, DGTOs, wCen, N2419, etc.
  – Remnants of dwarf galaxies
  – Star cluster merger (Fellhauer & Kroupa 2002; Assman+2011)
• Faint: ESCs, a few GCs in MW (Sag dSph), LMC
  – Survival of ESCs in dwarf galaxies (Hurley & Mackey 2010)
  – Relaxation-driven Expansion (Gieles+2011).