Probing the halos of massive early-type galaxies...with the SLUGGS survey

Duncan Forbes, Swinburne University
How do massive elliptical galaxies form?
NGC 1407 GC metallicity profile

Forbes et al. 2011
The SLUGGS Survey

• 25 ellipticals and lenticulars drawn from the K-band luminosity function
• $10.0 < \log(M/M_\odot) < 11.5$
• Inner regions IFU-probed by ATLAS$^{3D}$
• $D < 30$ Mpc
• Completion in April 2015 (weather permitting)
• Sample and method, Brodie et al. (2014)
• Extends to globular cluster systems, Forbes et al. (2011)

Aim: understand early-type galaxy formation
DEIMOS on Keck as an IFU

Galaxy starlight spectra $1 < R_e < 3$
Globular clusters spectra $2 < R_e < 8$

Calcium Triplet lines at 8498, 8542 & 8662 Å
Velocity resolution $\sigma \sim 25$ km/s

Obtain: $V, \sigma, h_3, h_4$ velocity moment 2D maps
Obtain: metallicity 2D maps
In two-phase, inside-out galaxy formation: central regions formed in-situ, halo regions accreted ex-situ stars. 

$<1 R_e$ is only half (or less) of the story.

Assembly history is preserved in galaxy halos.
Accretion of satellites predicts halos with negative $[Z/H]$ gradients, slightly positive age and alpha gradients, kinematic transitions, radial orbits etc...

Johnson et al. 2008
NGC 2768

$V_{\text{rot}}$ [km/s]

$\sigma$ [km/s]

R [arcsec]

Red GCs
Starlight
Sauron IFU

R_{\text{eff}}
NGC 4365

Davis et al. 2001
Velocity map for NGC 4365

Arnold et al. 2014
Angular Momentum Profiles

Arnold et al. 2013
Angular momentum profiles

Foster et al. 2015
NGC 3377 has a fast core and slow halo. More consistent with an accreted (cosmological) halo than a major merger.

Romanowsky in prep.
Stellar Metallicity maps

NGC 5846, Pastorello et al. 2014
Metallicity Profiles

\[ \log \left( \frac{R}{R_e} \right) \]

\[ [Z/H] \text{[dex]} \]

\[ \sigma \text{[km/s]} \]

Pastorello et al. 2014
Metallicity 1-2.5 $R_e$ gradients vs mass

Pastorello et al. 2014
Stellar and GC metallicity profiles

Gradients 1-8 $R_e$ are shallower in massive galaxies

Pastorello et al. 2015
Orbits mostly tangential, not radial as predicted in growth by accretion

Pota et al. 2013
Elliptical galaxy predictions

Hirschmann et al. 2014
NGC 3115 stars and GCs

log (R/R_e) [dex]

[A] NGC 3115

Z/H [dex]

SKiMS - Kriging map
blue GCs - spec
red GCs - spec
GC Metallicity Gradients

$M_* \leq 10^{11} M_\odot$

$M_* > 10^{11} M_\odot$

$\log (R / R_e) \text{ [dex]}$

$[Z/H] \text{ [dex]}$

Pastorello et al. 2015
log \( \frac{R}{R_e} \) [dex] 

\[ -2.5 \quad -2.0 \quad -1.5 \quad -1.0 \quad -0.5 \quad 0.0 \quad 0.5 \quad 1.0 \]

\[ -2.5 \quad -2.0 \quad -1.5 \quad -1.0 \quad -0.5 \quad 0.0 \quad 0.5 \quad 1.0 \]

\[ [Z/H] \text{ [dex]} \]

NGC 4649

SKiMS - Kriging map
blue GCs - spec
red GCs - spec
$\log \left( \frac{R}{R_e} \right) \text{ [dex]}$

$[Z/H] \text{ [dex]}$

**NGC 3115**

- **SKiMS - Kriging map**
- **SKiMS - Data points**
- **blue GCs - spec**
- **red GCs - spec**

- $0.4t$
- $1.1t$
- $2.8t$
- $6.9t$
- $17.4t$
NGC 5846 Mass

Stars and GCs consistent with PNe (Deason 2012)

X-ray mass (Das 2008) too high

GC orbits are radial

Napolitano et al. 2014
Future progress

Galaxy mass and assembly history largely determine the properties of today’s massive galaxies.

How do we determine individual galaxy assembly histories?
(Formation time is not the same as Assembly time.)

The combination of kinematics and stellar populations info at large radii may offer a way to classify massive galaxies according to their assembly history (eg simulations by Naab and collaborators)
Media Sound Bites
massive ellipticals have:

CORES: COllapsed Regions that were Established in Situ

HALOS: Have Accreted Lots Of Stars
Conclusions

• SLUGGS survey of massive galaxy halos complete in 2015

• DEIMOS as an IFU can efficiently probe chemo-dynamics to 3 $R_e$ from stars and to 8 $R_e$ from globular clusters

• Centrally slow rotators tend to remain slow, while centrally fast rotators show diverse halo properties
  eg low mass NGC 3377 fast core, slow halo -> minor mergers

• Shallower stellar and GC metallicity halo gradients in high mass galaxies -> increased role of major mergers

• Need to extend 2D mapping to a larger mass range