Massive Galaxy Scaling Relations through Cosmic Time

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Leveraging 3D-HST Grism Redshifts to quantify photo-z performance

Bezanson+2015b (arXiv:1510.07049)
Scaling Relations without dynamics infer evolution and transformation

van der Wel+2014
PROS: What do we learn from adding dynamics?

Velocity dispersion is the most stable property for individual galaxies in “inside-out” galaxy evolution

e.g. talks from Sirio Belli, Paul Torrey, and Guillermo Barro
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AND stellar velocity dispersion is a fundamental parameter to understanding galaxy evolution.

Related to stellar populations
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Related to stellar populations

Ages, abundances, (SFR)

\[ \sigma \]

Velocity dispersion related to IMF

low mass IMF slope

\[ \sigma \]
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Related to stellar populations

- Ages, abundances, (SFR)
- Velocity dispersion related to IMF
- Low mass IMF slope
- Stellar Mass (from SEDs)

Dynamics can test stellar mass estimates

E.g. Drew Newman’s talk
PROS: What do we learn from adding dynamics?

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- Related to stellar populations:
  - Ages, abundances, (SFR) vs. Velocity dispersion

- Velocity dispersion related to IMF:
  - Low mass IMF slope vs. Velocity dispersion

- Dynamics can test stellar mass estimates:
  - Stellar Mass (from SEDs) vs. Dynamical Masses

- (mostly) direct comparison to simulations
- Connect total baryonic + dark matter to observables
- Black Holes

... and so on...
CONS?

it is hard. . . (z=2 is VERY high redshift for this!)

- requires extreme/special cases (e.g. Drew Newman’s talk)
- or heroic telescope campaigns (e.g. Sirio Belli & Trevor Mendel’s talks)
- scaling relations connect “hard” measurements (sigma) to “easy” measurements (photometric properties)
The Fundamental Plane: “Fundamental” Scaling relation for elliptical galaxies

$R_e / I_0 = 1.40$ 

Quenched SDSS galaxies $0.05 < z < 0.07$

Hyde & Bernardi, 09 FP

$R_e \propto \sigma^{1.40} I_e^{-0.76}$

Djorgovski & Davis 1987
Dressler et al. 1987
The Fundamental Plane:
“Fundamental” Scaling relation for elliptical galaxies

- Can be predicted from the Virial Theorem
- Even without structural evolution, the normalization of the fundamental plane will change through cosmic time for passively evolving galaxies

\[ R_e \propto \sigma^2 I_e^{-1} \]
The Mass Fundamental Plane:
A more “Fundamental” Scaling relation for *Evolving* galaxies

- Normalization depends on stellar to total mass ratio
- *Sensitive to dark matter*

[Spectral Energy Distribution (SED)]

\[
\log \text{Velocity Dispersion} \rightarrow M/L \rightarrow \log \text{Stellar Mass Surface Density (Surface brightness \times M*/L)} \rightarrow \log \text{Effective Radius}
\]
How do the Fundamental Planes for Quiescent Galaxies Evolve?

Dramatic Evolution - partially due to passive evolution

Bezanson+2013
The Mass Fundamental Plane can be used to study the structural evolution of quiescent and star forming galaxies — *perfect for an evolving population*

* BUT - small numbers, especially for Star-Forming galaxies

* How does this build up? How does the slope/normalization evolve?
CHOMP+LEGA-C Surveys (0.4<z<1.0):
Deep Spectroscopy of Massive Galaxies over half of Cosmic Time

\[
\begin{aligned}
z \sim 0 & \\
0.4 < z < 0.6 & \\
0.6 < z < 1.0 &
\end{aligned}
\]

**CHOMP**

*Color-blind Hectospec Observations of Massive Progenitors*

*PI: R. Bezanson*

~1000 galaxies, MMT-Hectospec

\[ M* > 3 \times 10^{10} \text{ Msun} \]

**LEGA-C**

*Large Early Galaxy Astrophysics Census*

*PI: A. van der Wel*

Survey Scientists: R. Bezanson, C. Pacifici, A. Gallazzi

~3000 galaxies, VLT-VIMOS

\[ M* > 2 \times 10^{10} \text{ Msun} \]
focus on LEGA-C:
THIS is SDSS at $z=1$
Dynamics from Gas and Stars in LEGA-C
Now with thousands of galaxies we will directly measure absorption and emission line kinematics and probe the buildup of scaling relations.
A taste of the LEGA-C sample:

Star-Forming Galaxies

Quiescent Galaxies