Self-consistent dynamical models for early-type galaxies in the CALIFA Survey

Lorenzo Posti
University of Groningen (the Netherlands), University of Bologna (Italy)

in collaboration with:
G. van de Ven (MPIA), J. Binney (Oxford),
C. Nipoti & L. Ciotti (Bologna), M. Lyubenova (Groningen)
Why study galaxy dynamics?

• Mass is key
  - From kinematics (e.g., IFU) $\rightarrow$ total $\Phi$ $\rightarrow$ total mass distribution
  - Mass drives galaxy evolution

• Dynamical state $\rightarrow$ fossil of the formation history
  - Merger phase imprinted in stellar kinematics
  - From kin. signatures $\rightarrow$ galaxy evolution

Barrera-Ballesteros+15
Dynamical state \(\rightarrow\) fossil formation history

- Numerical models of galaxy evolution:
  - Binary merger / cosmological simulations

- fast rotator
- morphology: disc
- \(\leq 1\) (wet) major mergers

- slow rotator
- morphology: spheroid
- many (dry) major mergers

Isotropic rotator
(radial) anisotropy
Dynamical state → fossil formation history

- Numerical models of galaxy evolution:
  - Binary merger / cosmological simulations

- fast rotator
- morphology: disc
- ≤1 (wet) major mergers

- slow rotator
- morphology: spheroid
- many (dry) major mergers

Need to characterize dynamical state from data!
Dynamical models

- Equilibrium models
  - Good description of (regular) galaxies
  - Base for perturbation theory

- Two approaches:
  i) Fit data w. simple models (e.g., Jeans')
  ii) Constrain the galaxy's orbital structure
Dynamical models

- Equilibrium models
  - Good description of (regular) galaxies
  - Base for perturbation theory

- Two approaches:
  i) Fit data w. simple models (e.g., Jeans')
  ii) Constrain the galaxy's orbital structure

\[ f = f(x, v): \text{ probability of finding a star at } (x,v) \]
Dynamical models

- Equilibrium models
  - Good description of (regular) galaxies
  - Base for perturbation theory

- Two approaches:
  i) Fit data w. simple models (e.g., Jeans')
  ii) Constrain the galaxy's orbital structure

The DF completely determines the dynamical state

\[ f = f(x, v) : \text{ probability of finding a star at } (x, v) \]
Distribution Functions for early-type galaxies

- Analytic & fast physical models
- Self-consistent ($\rho-\Phi$) pair, axisymmetric and rotating models
- Models for bulges, dark haloes, stellar discs

**NEW**
Action-angle coordinates ($\theta, J$)

$$f(x, v) \Rightarrow f(J)$$

**Critical advantage:**
Self-consistent multi-component models
Models → Mock Observations

1-component models

Spherical Slow-rotator

Oblate Fast-rotator
Models → Mock Observations

2-component models

Bulge + disc galaxy

Kinematically Decoupled Core
2 ellipticals in CALIFA

NGC 6125
D~66 Mpc
E1, slow rotator

NGC 2592
D~28 Mpc
E4, fast rotator
Light distribution

Posti et al in prep.
2D kinematics: rotation

Posti et al in prep.
2D kinematics: v. dispersion

Posti et al in prep.
Multi-component models: a lenticular galaxy

**DATA:** NGC6427, S0, fast-rotator

In the total self-consistent Potential $\Phi$

$$f_{\text{galaxy}}(J) = f_{\text{bulge}}(J) + f_{\text{disc}}(J)$$

**MODEL:** $f_{\text{galaxy}}(J) = f_{\text{bulge}}(J) + f_{\text{disc}}(J)$
Multi-component models: a lenticular galaxy

$f_{\text{bulge}}(J)$

$f_{\text{disc}}(J)$

$f_{\text{galaxy}}(J)$
Conclusions

- Equilibrium models → link local dynamics w. galaxy formation history

- IFU data can constrain the galaxy's DF!
  (provided that degeneracies are taken care of)

- Action-dependent DFs for multi-component systems
  (e.g., for kinematical bulge/disc decomposition)

Posti et al. 2015
Posti et al in prep.
• $f(J)$ models to study the shape of the MW's dark halo: mildly oblate $q \sim 0.7-0.8$ (Piffl+2015, Binney&Piffl 2015)
Rotating models

\[ f(J) = f_+(J) + k f_-(J) \]

Only contributing to density

\[ f_-(J) = \tanh \left( \frac{\chi J_\phi}{J_0} \right) f_+(J) \]

Only contributing to angular momentum