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

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in collaboration with:

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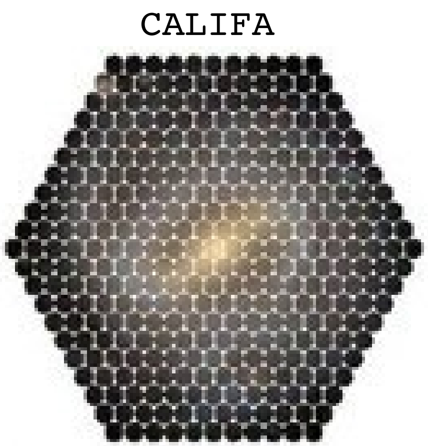
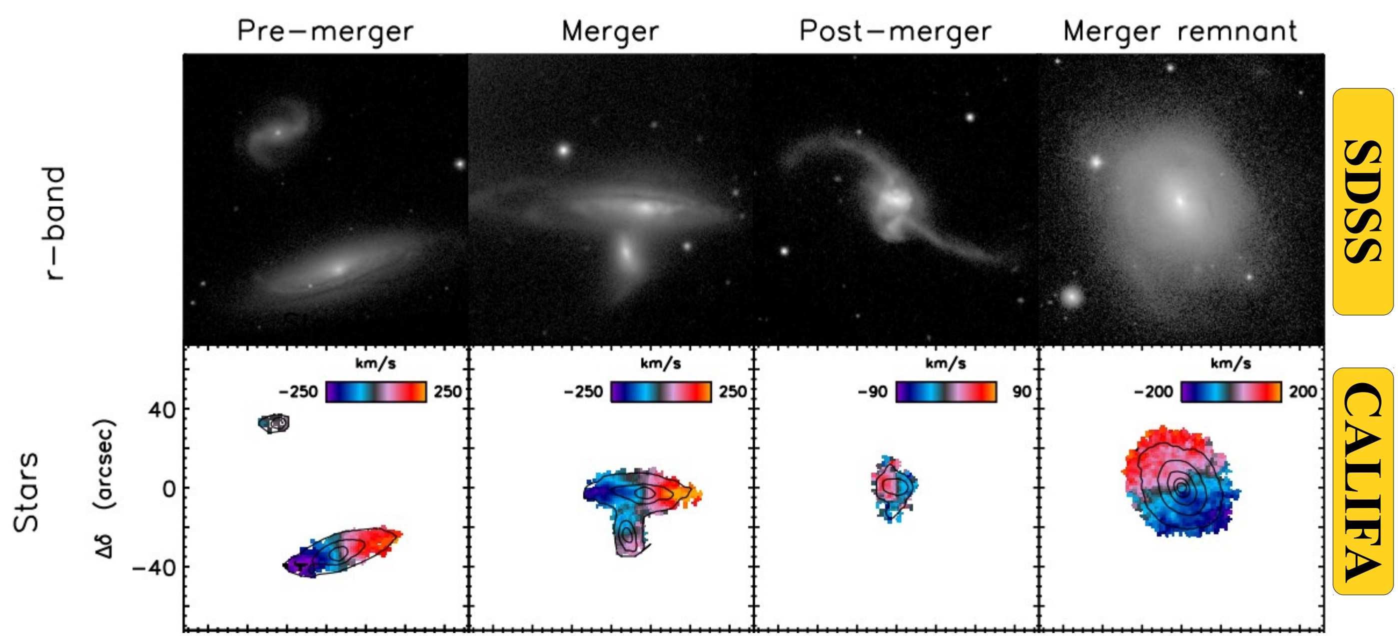
# Why study galaxy dynamics?

- Mass is key
  - From kinematics (e.g., IFU) → total Φ → total mass distribution
  - Mass drives galaxy evolution



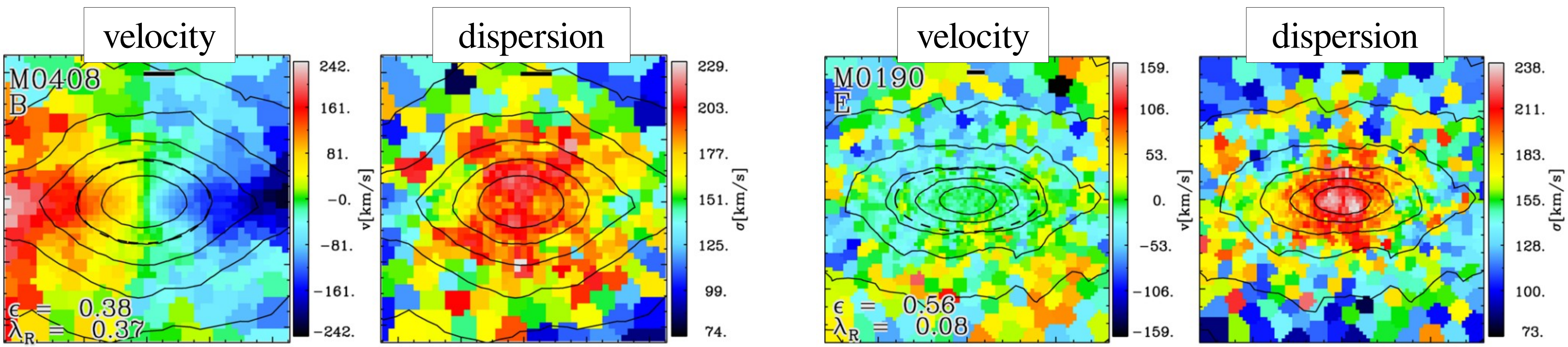

- Dynamical state → *fossil* of the formation history
  - Merger phase imprinted in stellar kinematics
  - From kin. signatures → galaxy evolution




Barrera-Ballesteros+15

# Dynamical state → *fossil* formation history

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




Naab+2014

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

↓

**Isotropic rotator**

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

↓

**(radial) anisotropy**

# Dynamical state → *fossil* formation history

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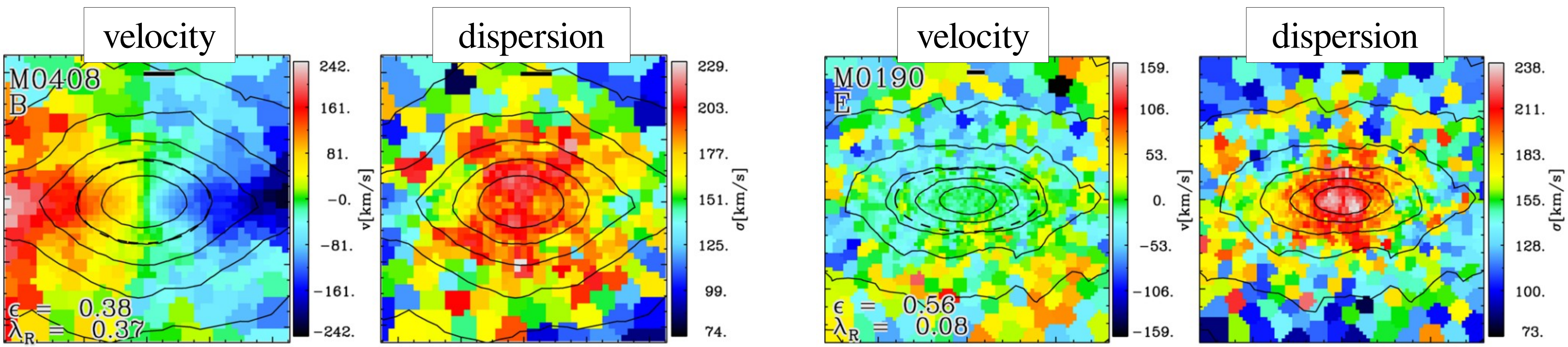


Naab+2014

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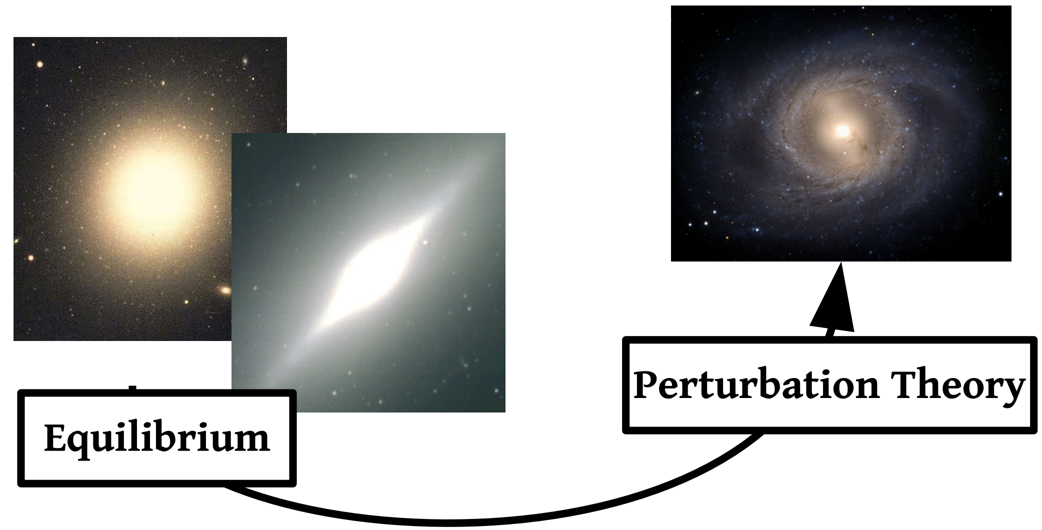
**Need to characterize dynamical state from data!**

Isotropic rotator

(radial) anisotropy

# 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

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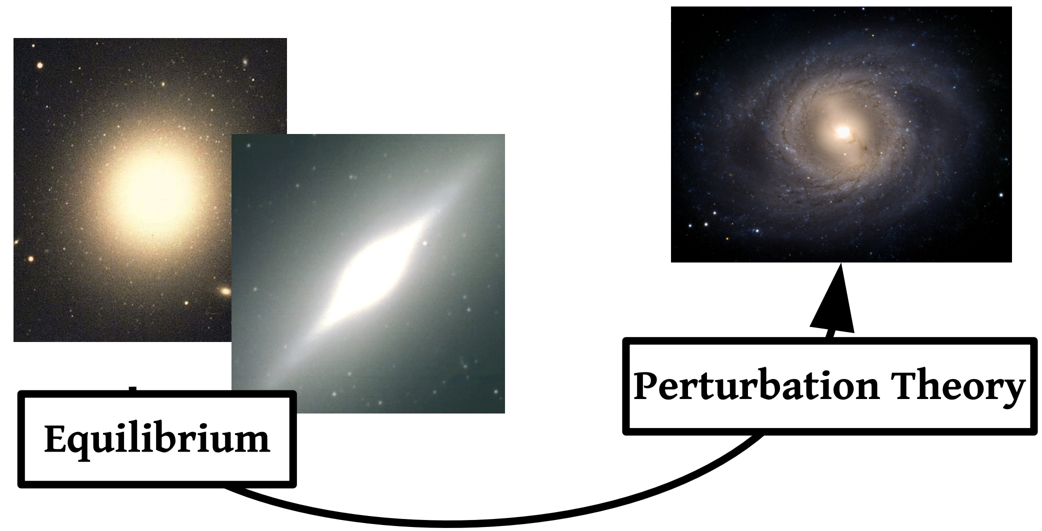


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$$f = f(\mathbf{x}, \mathbf{v}):$$ probability of finding a star at (**x**,**v**)

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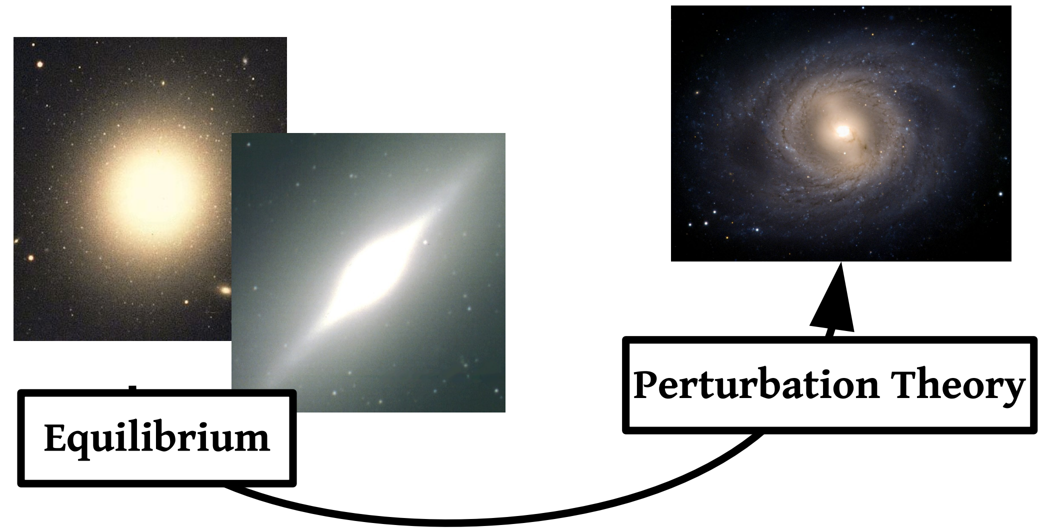



- Two approaches:

  ~~i) Fit data w. simple models (e.g., Jeans')~~

  ii) Constrain the galaxy's orbital structure

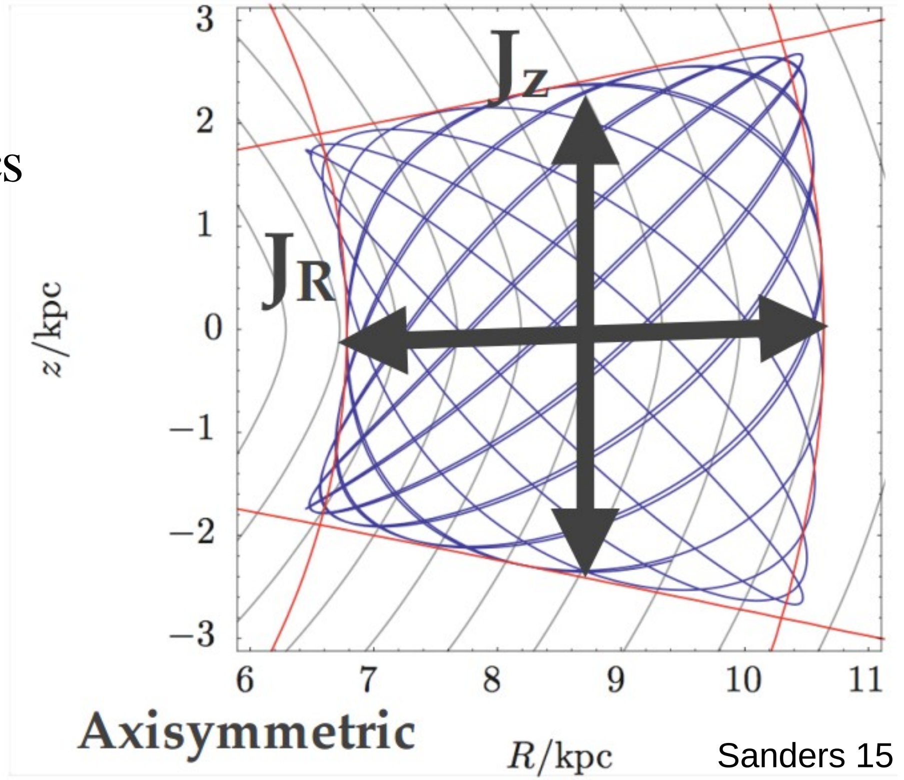
**The DF completely determines the dynamical state**

$f = f(\mathbf{x}, \mathbf{v})$: probability of finding a star at (**x**,**v**)

# Distribution Functions for early-type galaxies

*Posti, Binney, Nipoti & Ciotti 2015*
*Posti et al in prep.*

- Analytic & fast physical models
- Self-consistent (ρ-Φ) pair, axisymmetric and rotating models
- Models for bulges, dark haloes, stellar discs



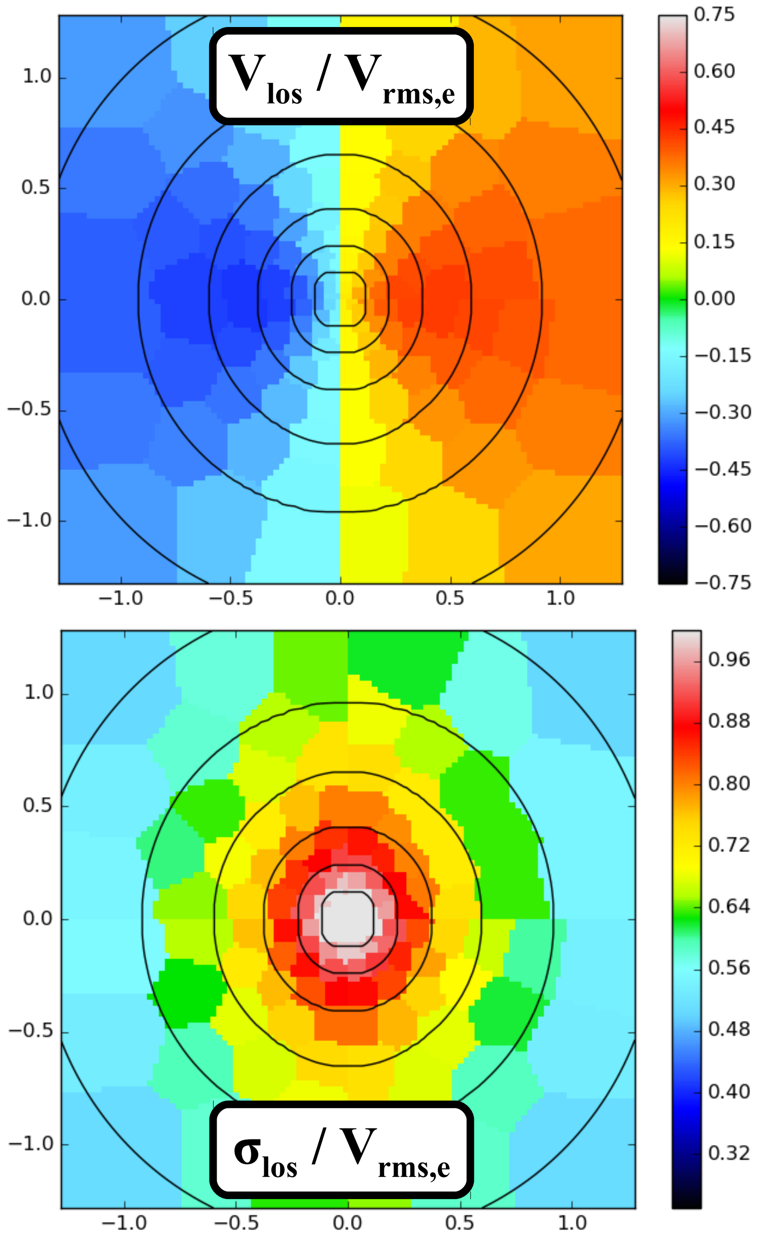

NEW Action-angle coordinates (**θ**, **J**)

$$f(\mathbf{x}, \mathbf{v}) \Rightarrow f(\mathbf{J})$$

**Critical advantage:**

Self-consistent multi-component models

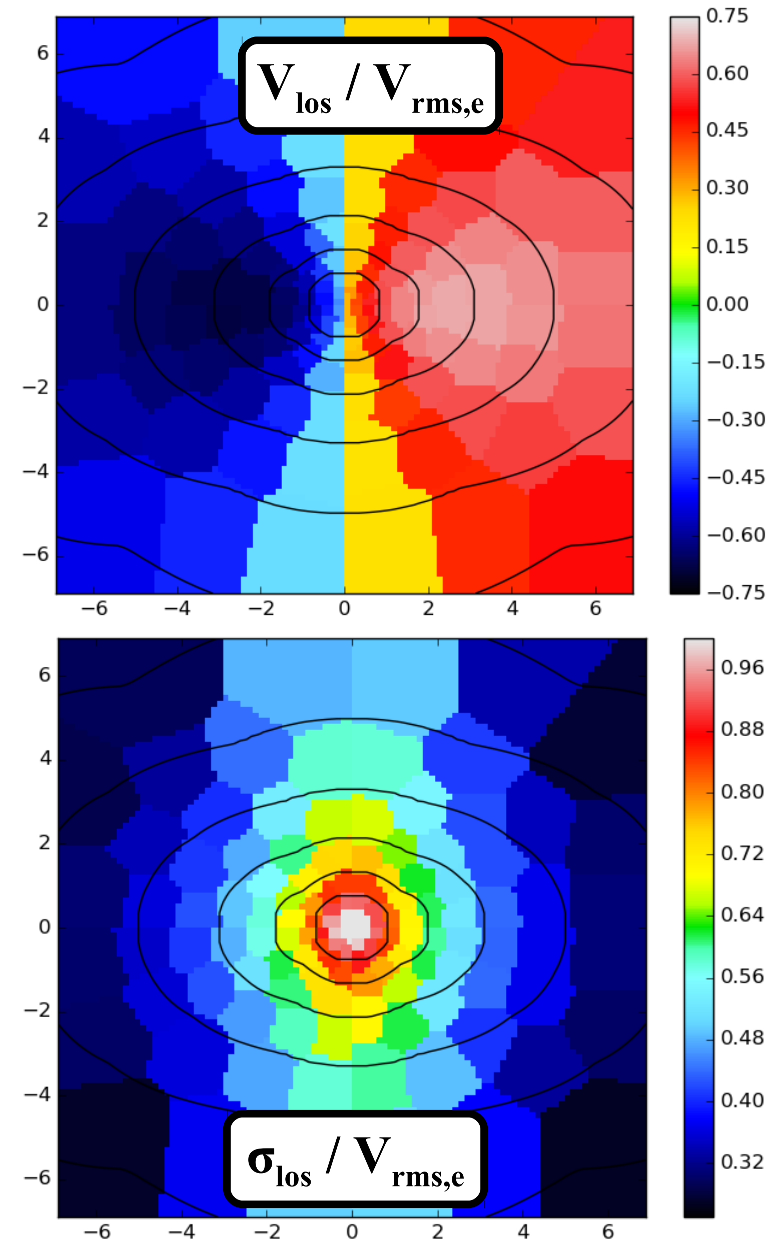
# Models → Mock Observations




**1-component models**

Spherical Slow-rotator

Oblate Fast-rotator



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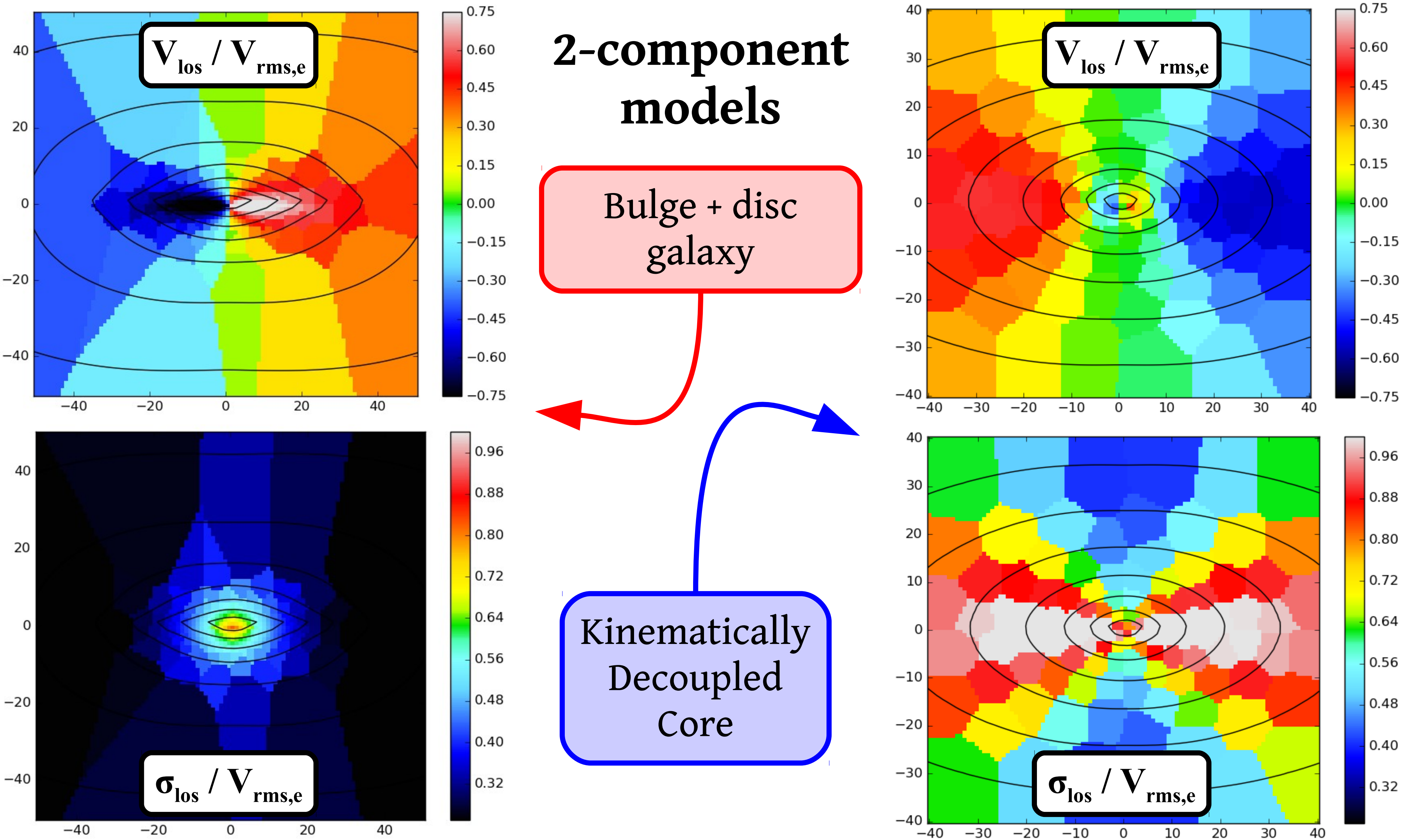
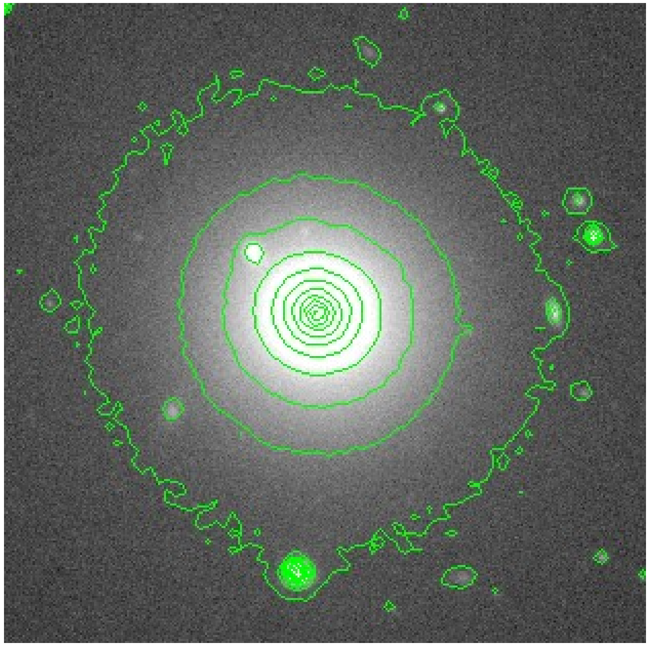
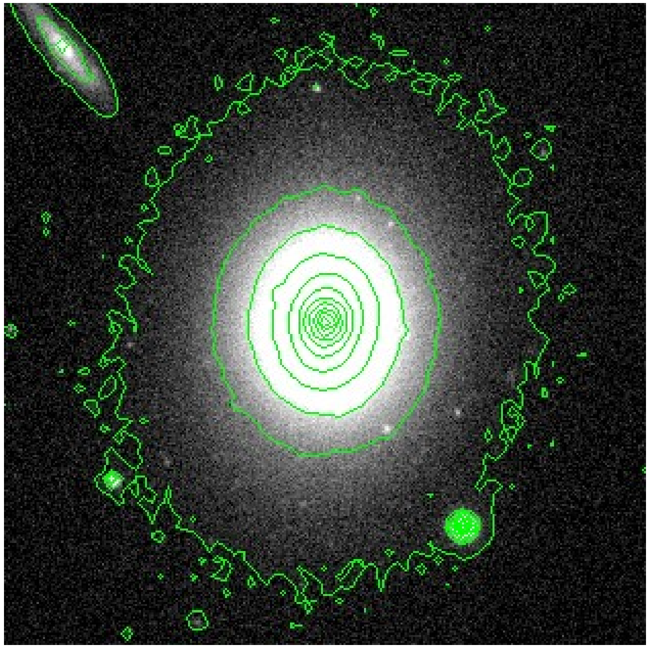


# 2 ellipticals in CALIFA



NGC 6125

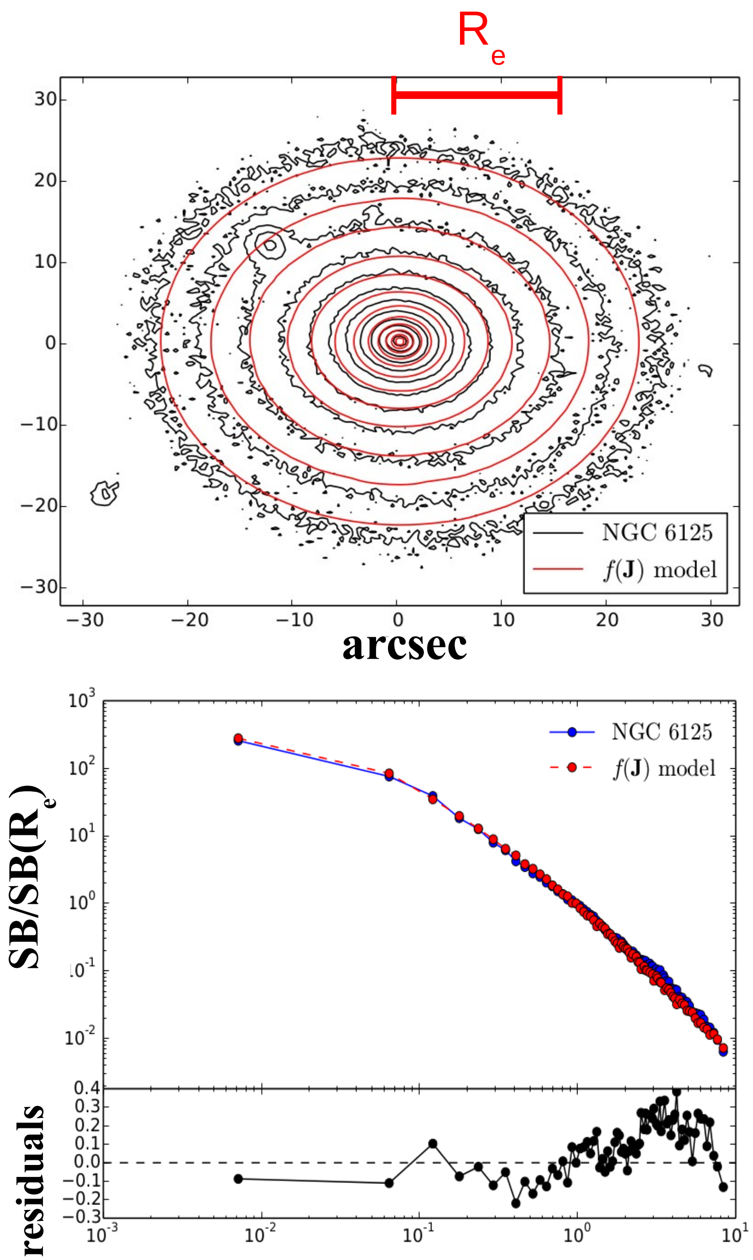
D~66 Mpc
E1, slow rotator



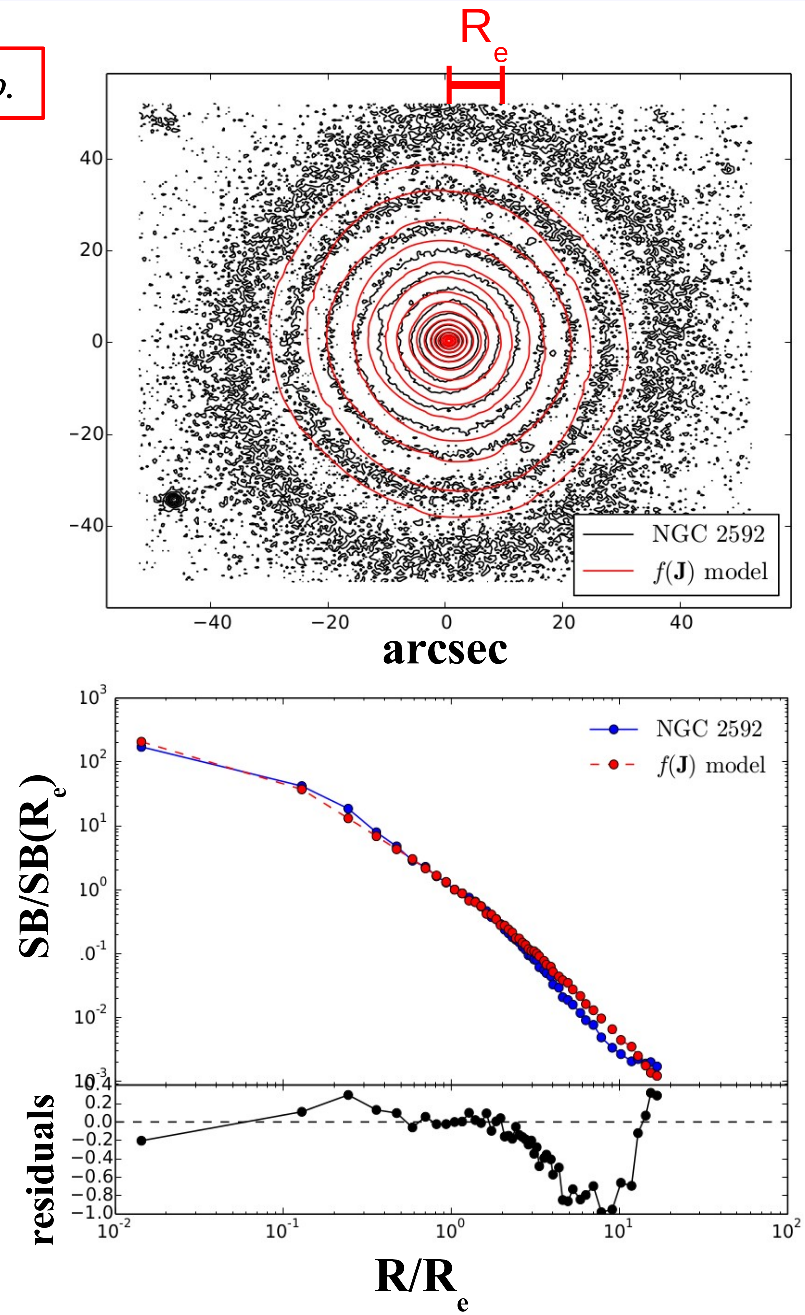
NGC 2592

D~28 Mpc
E4, fast rotator

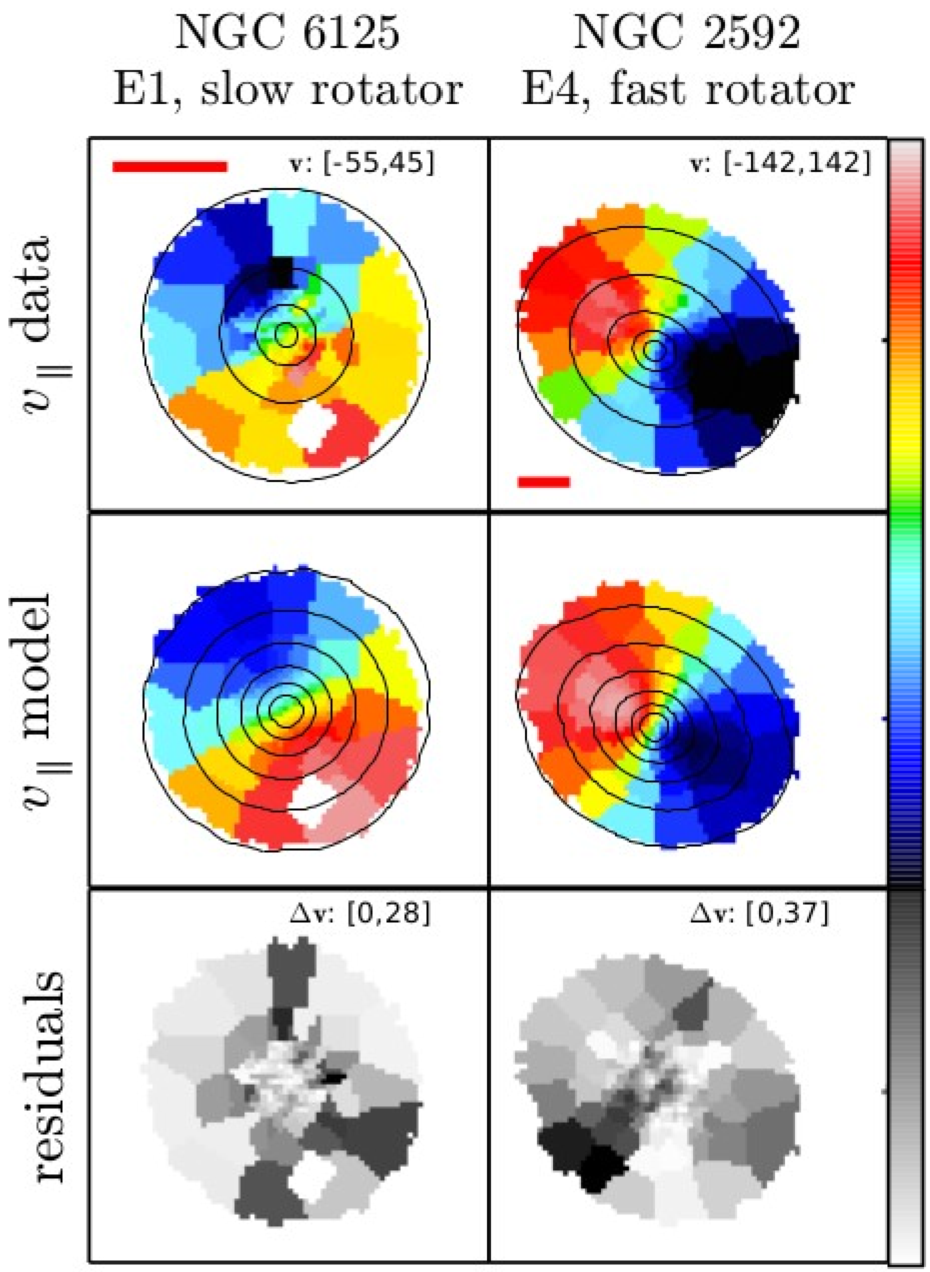
# Light distribution




*Posti et al in prep.*

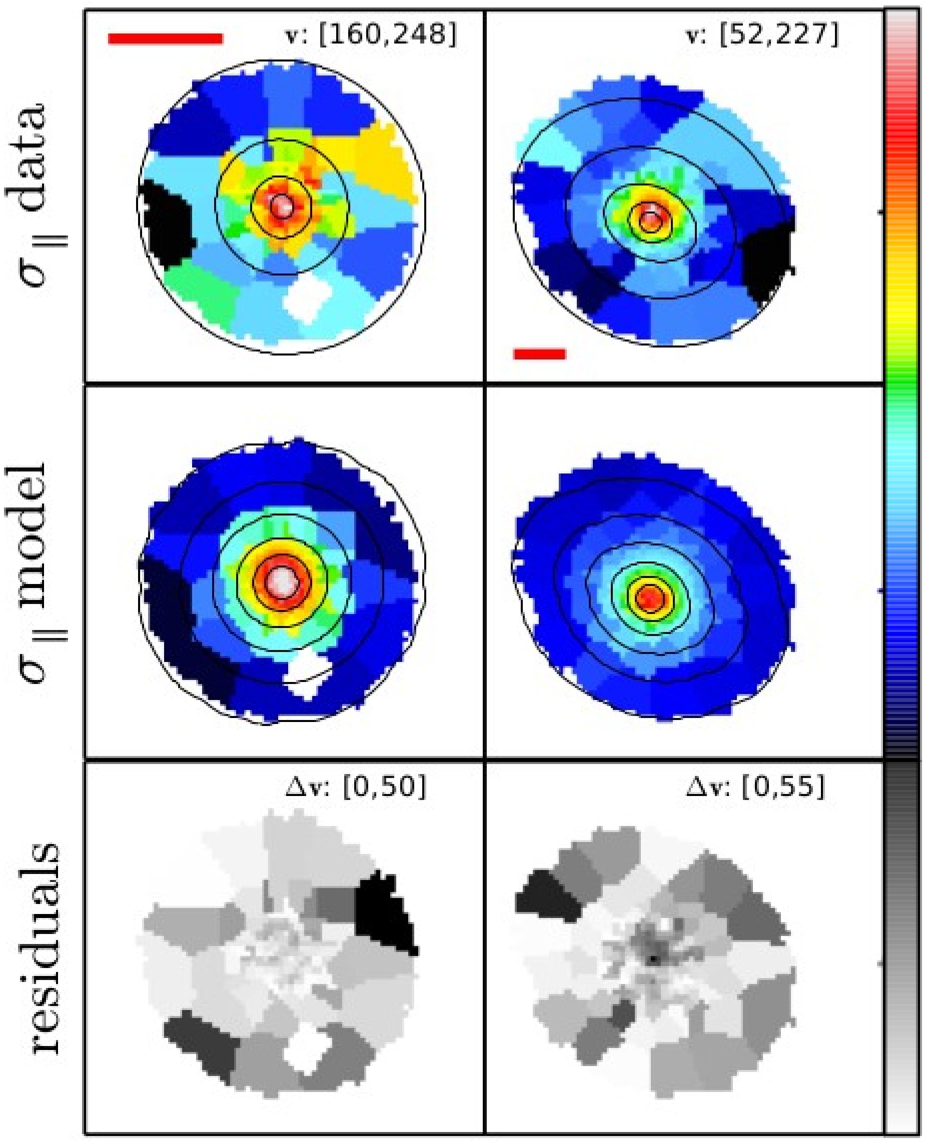


# 2D kinematics: rotation




*Posti et al in prep.*

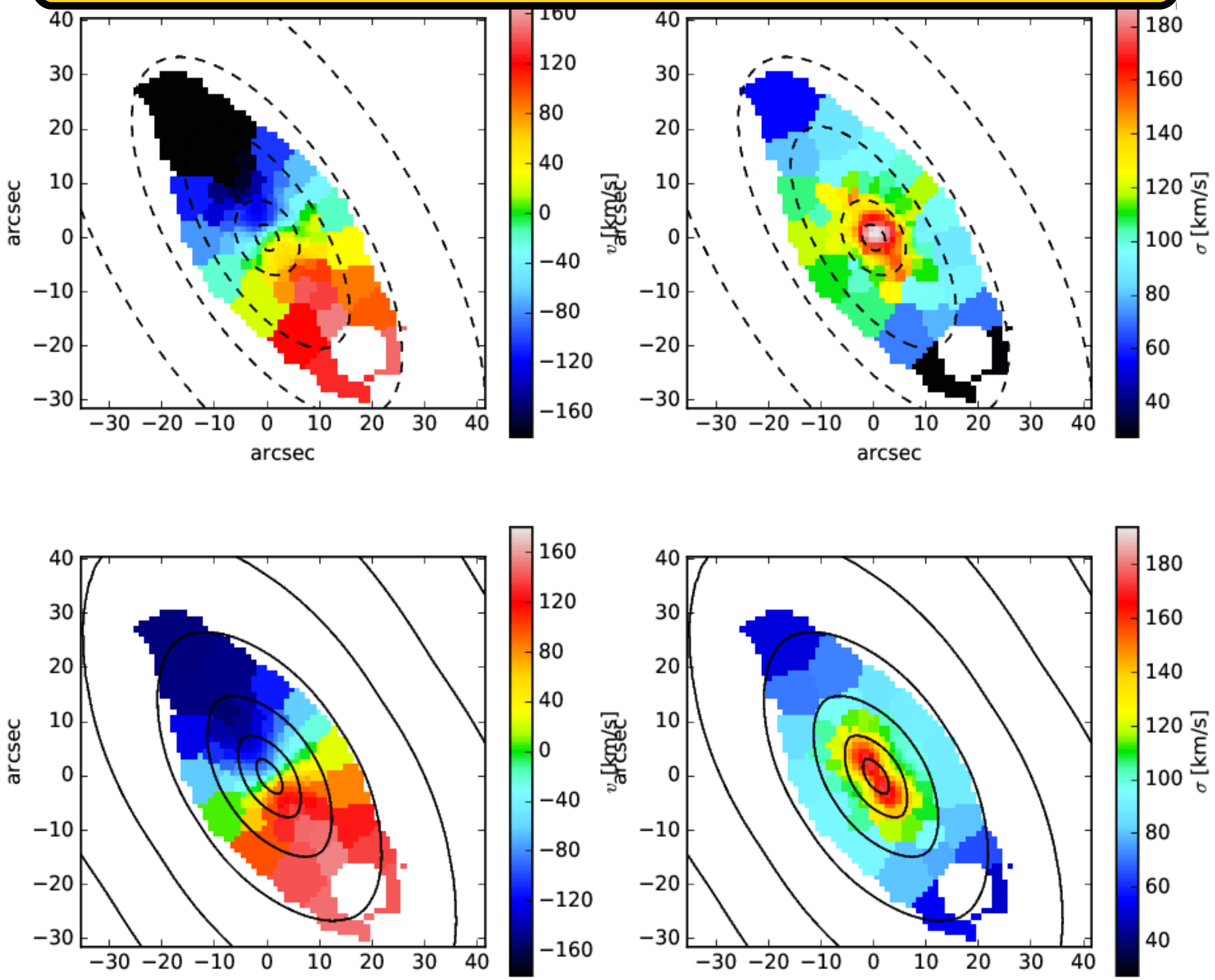
# 2D kinematics: v. dispersion




*Posti et al in prep.*

# Multi-component models: a lenticular galaxy

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

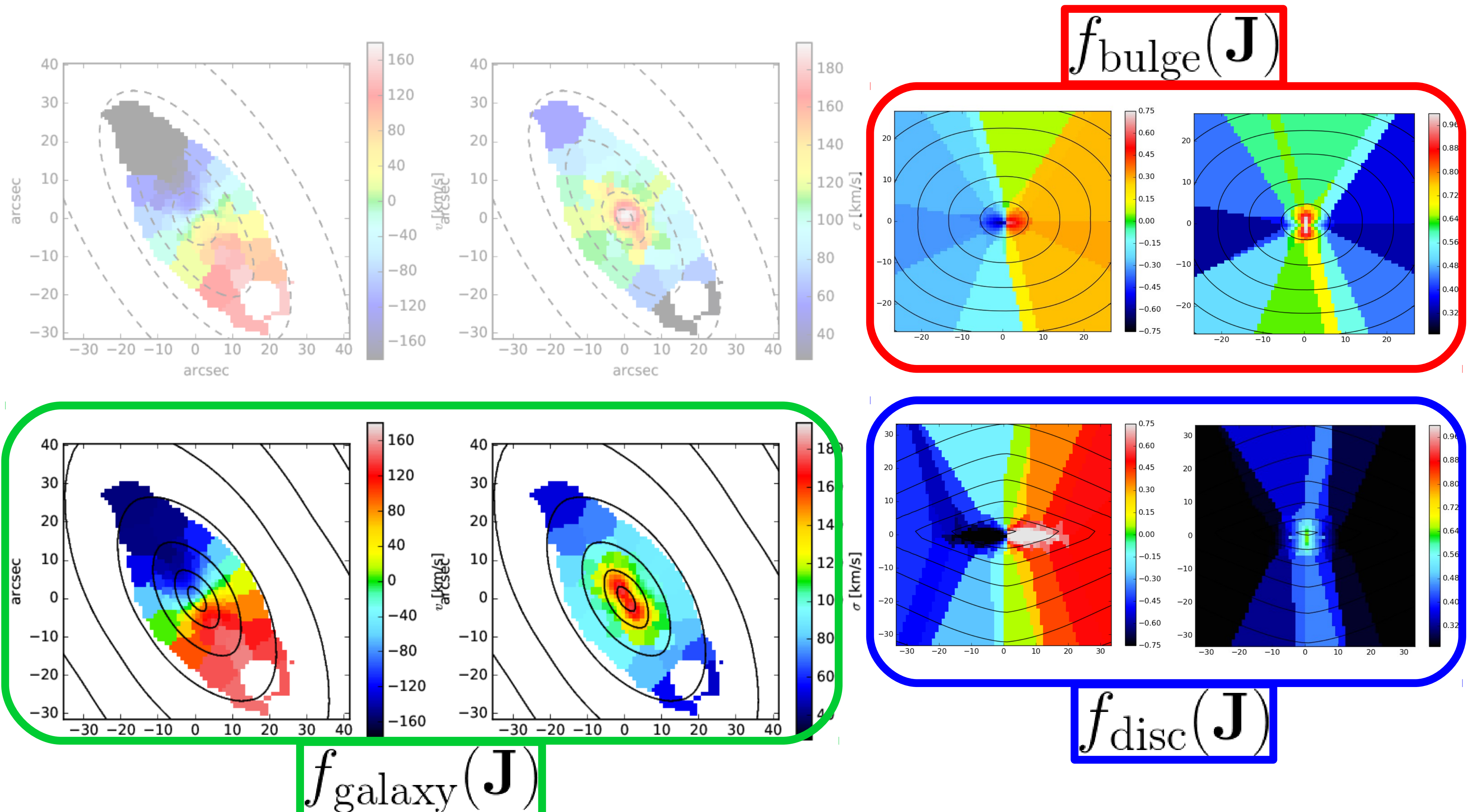



**MODEL: $f_{galaxy}(\mathbf{J}) = f_{bulge}(\mathbf{J}) + f_{disc}(\mathbf{J})$**

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

<u>In the total self-consistent Potential $\Phi$</u>

# Multi-component models: a lenticular galaxy



# Conclusions

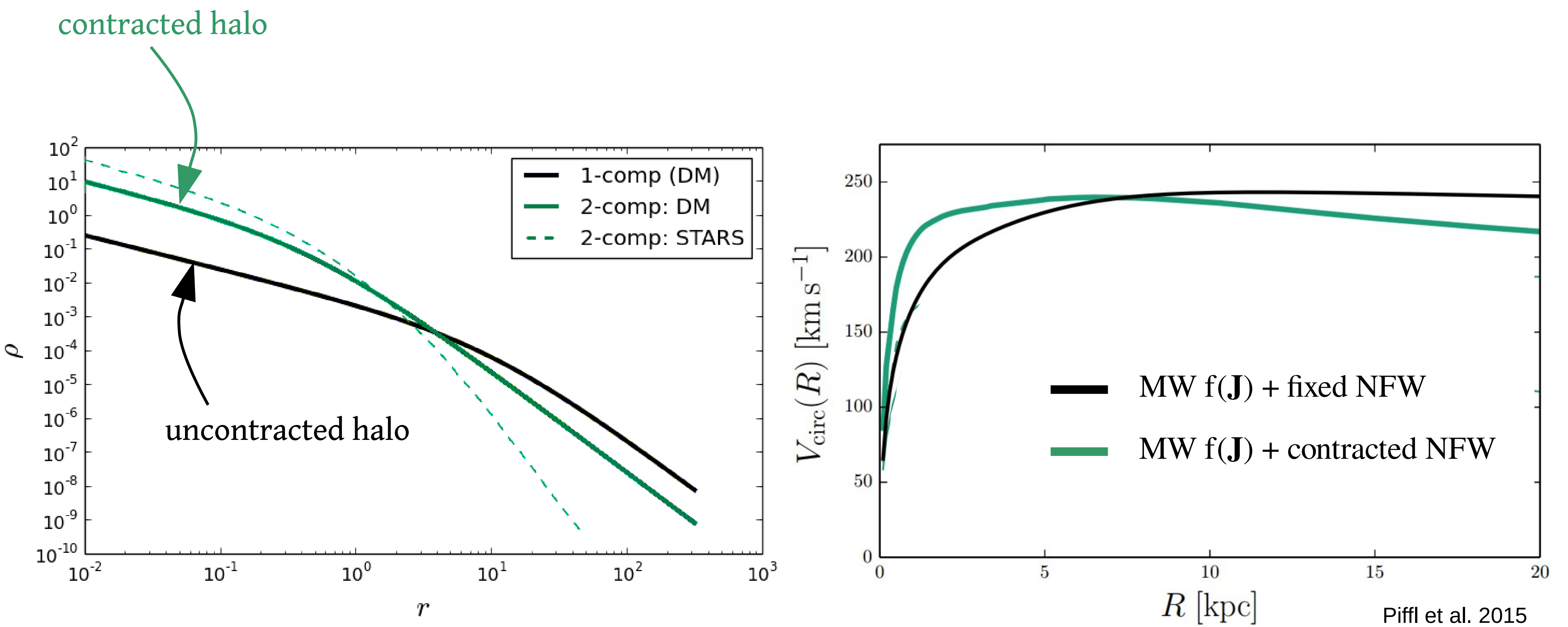
*Posti et al. 2015*
*Posti et al in prep.*

- 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)

# Multi-component models: halo contraction




Piffl et al. 2015

- f(**J**) models to study the shape of the MW's dark halo: <u>mildly oblate</u> q~0.7-0.8 (Piffl+2015,Binney&Piffl 2015)

# Rotating models

$$f(\mathbf{J}) = f_+(\mathbf{J}) + k f_-(\mathbf{J})$$

Only contributing to density

Only contributing to angular momentum

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