Unveiling the **sources of disk heating**

in spiral galaxies with the **CALIFA** survey

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The Work

PhD Thesis
Instituto de Astrofísica de Canarias:
with Jesús Falcón-Barroso (IAC)

Working group at the IAC

TRACES OF GALAXY FORMATION:
www.iac.es/proyecto/traces/

External collaboration

Marie Martig (MPIA)
Glenn van de Ven (MPIA)
Mariya Lyubenova (RUG)
Ryan Leaman (MPIA)
& CALIFA collaboration

The science goals

- **Constraining the SVE (Stellar Velocity Ellipsoid)**
  for $\gtrsim 50$ observed/simulated galaxies
- **Find the shape along the Hubble sequence**

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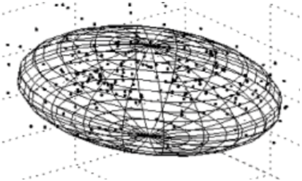
SVE

- **velocity dispersion** (σ)
  The statistical dispersion of velocities from the mean
- **SVE**
  Ellipsoid with semi-axes σ_r, σ_ϕ, σ_z



Velocity Ellipsoid. (Branham, 2004).

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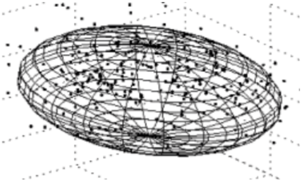

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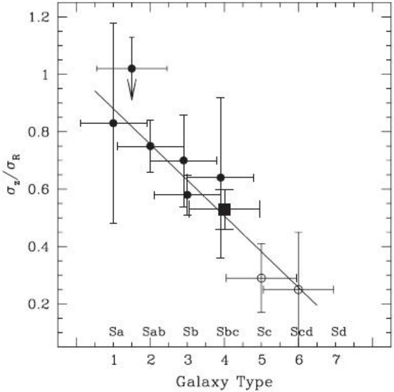
Why?

Potential to unveil the **heating sources for the disk**:

- *giant molecular clouds - mergers* $\rightarrow$ 3D agents (**isotropic**)
- *spiral arms - bars* $\rightarrow$ planar agents (**anisotropic**)

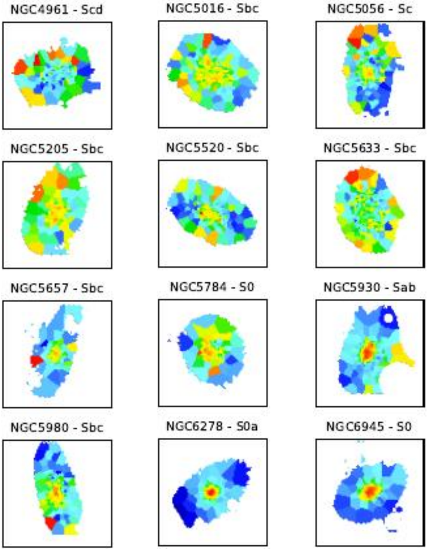
Previous works

- Gerssen J. & Shapiro K., 2012
  SVE as a function of Hubble types
  - **3D agents**: early-types
  - **radial agents**: late-types



- The DiskMass Survey VI, 2013
  - "**kinematic flaring of the disk**"
  - possible scenarios:
    - an *increase in the disk M/L*
    - *a flared disk*
    - disk heating due to a *massive DM halo*

The sample:
observational data from CALIFA



30 DISK GALAXIES

- *Hubble types*: from S0 to Scd
- $20^\circ < i < 70^\circ$
- $R_{max} > 2R_{eff}$
- $M_* > 10^9 M_\odot$
- $n_{bins} > 100$

Velocity dispersion maps

The sample:
examples from CALIFA

SDSS images

NGC6945 - S0

NGC2253 - Sbc

NGC5056 - Sc

NGC4961 - Scd

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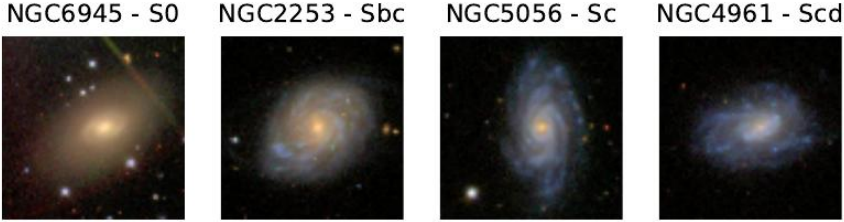
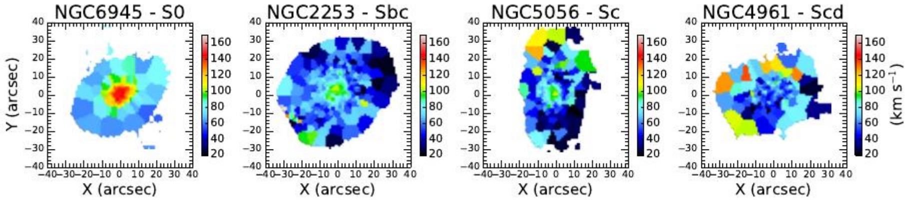
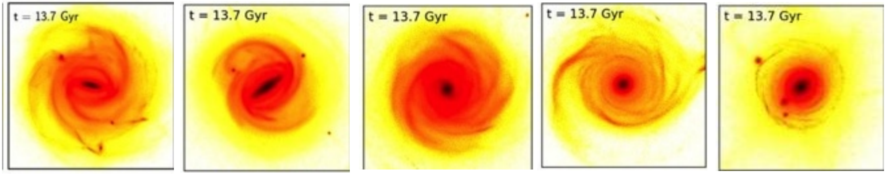


CALIFA σ maps



The **sample**:
from simulations

- Technique in 2 steps (Martig et al. 2009, 2012)
  1) Extract merger and accretion history from large scale cosmological simulations
  2) Re-simulate a few halos at higher resolution (150 pc, a few 10^6 stellar particles per galaxy)
- Sample of 30 galaxies
  - $10^{10} \lesssim M_* \lesssim 10^{11}$
  - selected only on halo mass + in isolated environment



The Thin Disk Model

Exponential Models for Velocity Dispersion

Velocity Dispersion in the line of sight

$$\sigma^2_{LOS}(r,\phi) = \sigma^2_r(r)\sin^2\phi\sin^2 i + \sigma^2_\phi(r)\cos^2\phi\sin^2 i + \sigma^2_z(r)\cos^2 i$$

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Bulge(B)+Disk(D) model: for $j = r,\phi,z$ $\quad \sigma^2_j = \sigma^2_{j,B} + \sigma^2_{j,D}$

fitting the full radial range - MCMC method (emcee, python)

For the BULGE

$$\sigma_{r,B}(r) = \sigma_{r,0,B}\, e^{-r/h_{\sigma,r,B}}$$

$$\sigma^2_{\phi,B}(r) = \sigma^2_{r,B}(r)\frac{R_b^2 + r^2/2}{R_b^2 + r^2}$$

$$\sigma^2_{z,B}(r) = \sigma^2_{r,B}(r)(1 - \beta_{z,B})$$

For the DISK

$$\sigma_{r,D}(r) = \sigma_{r,0,D}\, e^{-r/h_{\sigma,r,D}}$$

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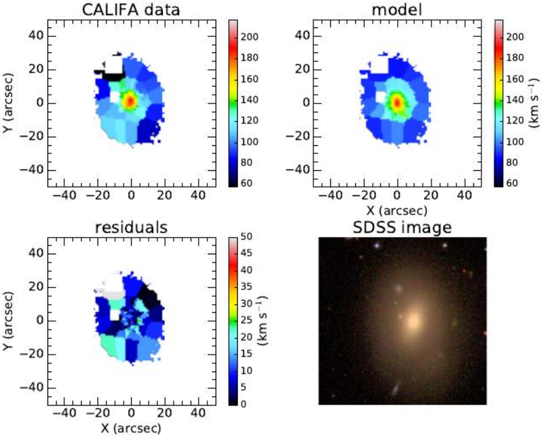
Results

An early-type

NGC7623 (S0)

$$\left(\frac{\sigma_z}{\sigma_r}\right)_{disk} \simeq 0.70\,(-0.05, +0.06)$$

- SVE near isotropy
  $\Rightarrow$ 3D agents
  - GMCs, Mergers
- Expected for early-types

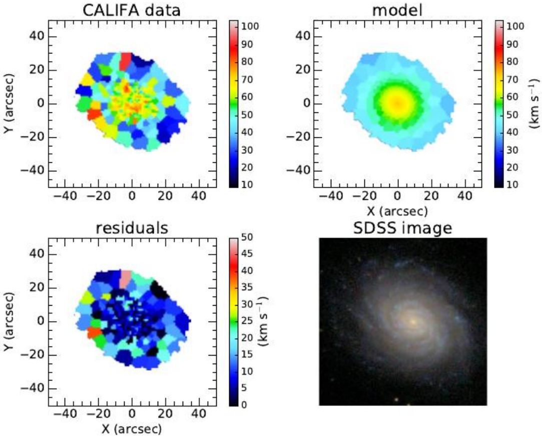


Results
A late-type

NGC5016 (Sbc)

$$\left(\frac{\sigma_z}{\sigma_r}\right)_{disk} \simeq 0.3\,(-0.2, +0.3)$$

- Anisotropic SVE
  $\Rightarrow$ radial agents
  - Spiral arms
- Expected for late-types



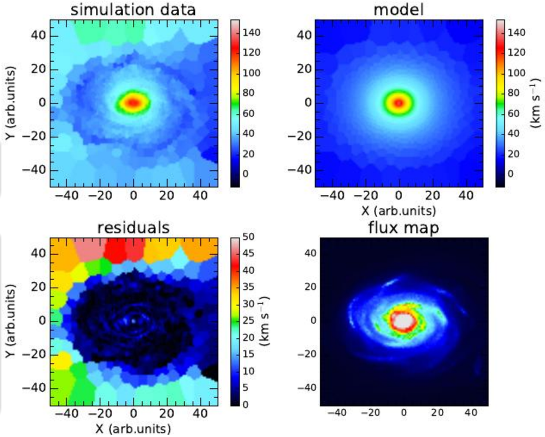
Results

A simulated galaxy

An **Sb**
from **simulations**

$$\left(\frac{\sigma_z}{\sigma_r}\right)_{disk} \simeq 0.71\,(\pm 0.01)$$

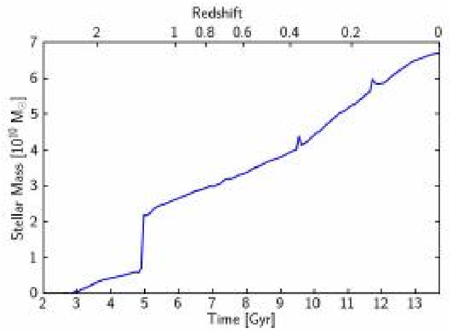
- Why the result is higher than what expected?
- What does this galaxy have in common with NGC7623?

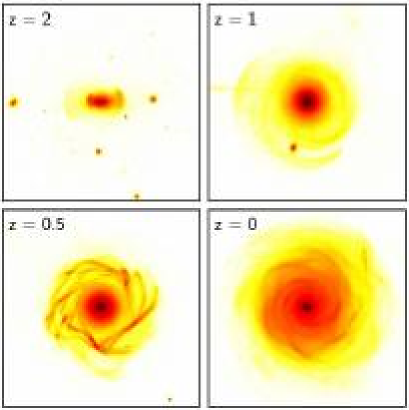


Results

A simulated galaxy

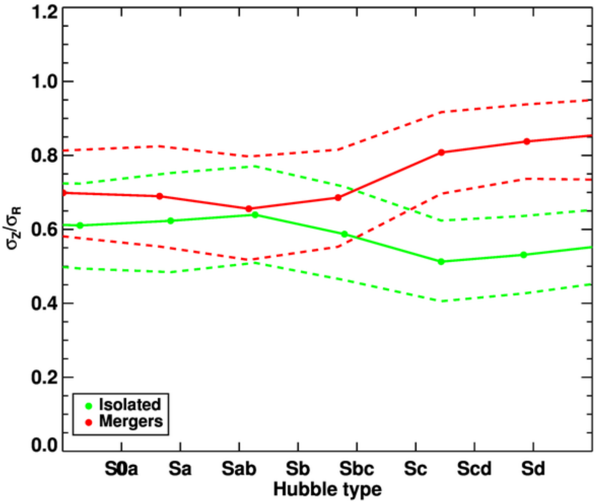
The evolution history: mergers





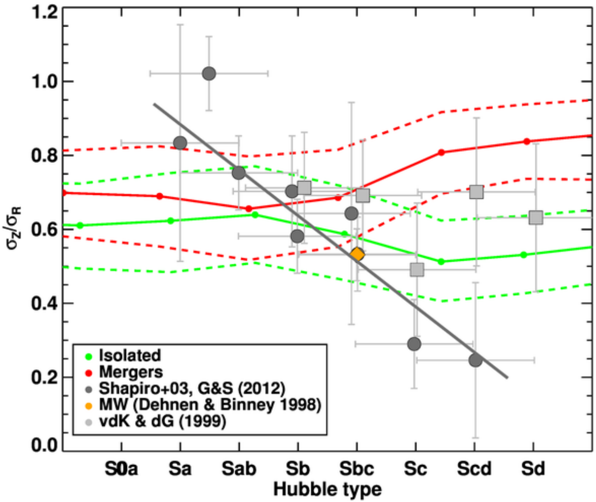
Discussion

- From simulations: *How mergers affect the SVE?*



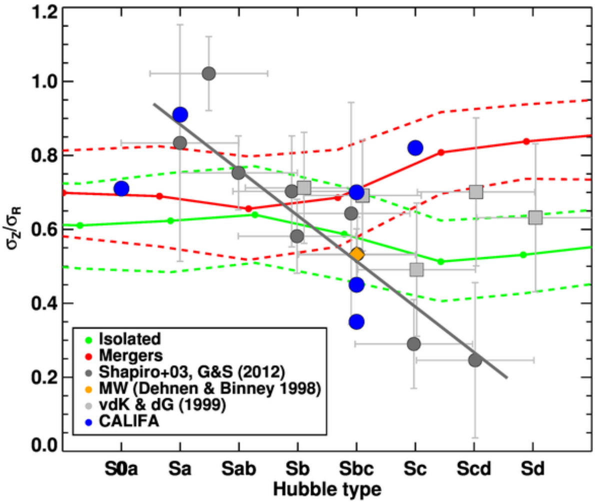
Discussion

- Simulations + previous observations



Discussion

- Simulations + previous observations + some CALIFA galaxies



Conclusions

- Velocity dispersions in galaxies outskirts are still uncharted waters
  - σ measurements are not easy
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- Velocity dispersions in galaxies outskirts are still uncharted waters
  - σ measurements are not easy
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  - Early-types: more isotropic SVE
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- Outlook
  - Extend the analysis to the 30 CALIFA galaxies
  - and in the future to a larger sample and deeper data (MaNGA, MUSE)

Thank you
for
your attention

MCMC minimization

to find the parameters of the model

1. R_b: break radius for the **rotation curve**

→can be found **fitting V data**

Velocity in the line of sight

$$V(r,\phi) = v_\phi(r)\cos\phi\sin i$$

$$v_\phi(r) = v_\phi(R_e)\frac{r}{R_e}\sqrt{\frac{R_b^2 + R_e^2}{R_b^2 + r^2}}$$

MCMC minimization (emcee, python)

- 40 walkers
- 2000 chains

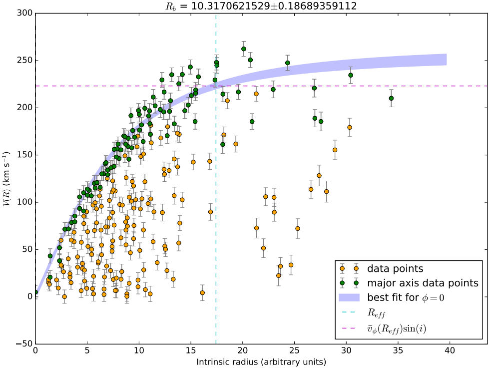

Figure: *NGC2639: Rotation curve fit.*

MCMC minimization

to find the parameters of the model

2. **fitting the σ_{LOS} profile**: 2×3 free parameters

- $\sigma_{r,0}$: σ_r in the center
- $h_{\sigma,r}$: radial scale length for σ
- $\beta_z = 1 - \left(\frac{\sigma_z}{\sigma_r}\right)^2$: σ anisotropy in the meridional plane

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MCMC minimization (emcee, python)

- 500 walkers, 1e5 chains
- constraints imposed on the parameters:

$$\begin{aligned} \sigma_{r,0,B} &> \sigma_{r,0,D} \\ 0.5 h_{\sigma,r,B}\left(\frac{h_{r,D}}{h_{r,B}}\right) &\lesssim h_{\sigma,r,D} \lesssim 1.5 h_{\sigma,r,B}\left(\frac{h_{r,D}}{h_{r,B}}\right) \\ \beta_{z,B} &< \beta_{z,B} \end{aligned}$$

MCMC minimization

to find the parameters of the model

- **emcee (python)**
- 500 walkers
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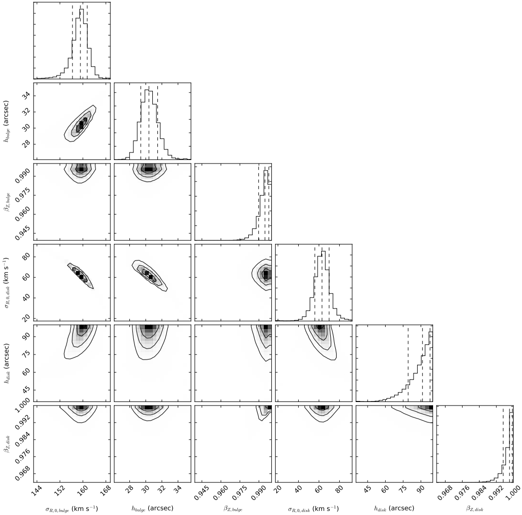

Gerssen J. & Shapiro K., 2012

most clear spiral structure: lowest σ_R

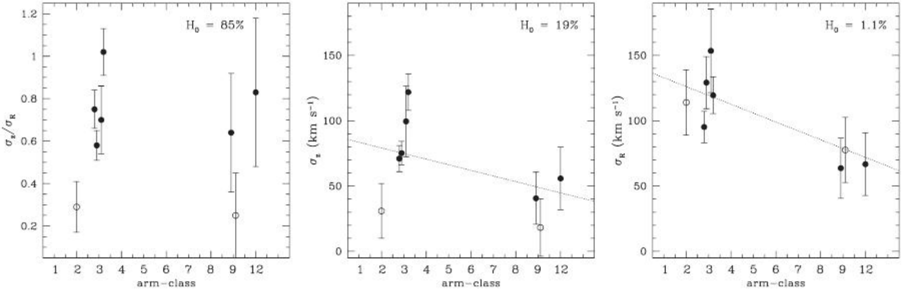

Figure 8. The velocity ellipsoid shape and magnitudes as a function of arm class, as defined in Elmegreen & Elmegreen (1987) to quantify the orderliness of spiral structure from flocculent (class 1) to grand-design (class 12). Note that there is no arm class 10 and 11 (cf. fig. 1 in Elmegreen & Elmegreen 1987). Left: the velocity ellipsoid shape is not correlated with arm class. Middle: the vertical magnitude of the ellipsoid decreases with arm class. Right: there is a clear trend between arm class and radial component, as expected from the Toomre Q criterion, see text. Note that for plotting purposes we have added small offsets to galaxies with the same arm class.

CALIFA
σ
profiles