Unveiling the **sources of disk heating**

in spiral galaxies
with the **CALIFA** survey

Francesca Pinna

Instituto de Astrofísica de Canarias
Universidad de la Laguna

fpinna@iac.es

2016 April, 13th

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

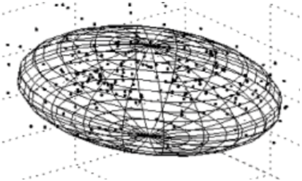
- **Constraining the SVE (Stellar Velocity Ellipsoid)**
  for $\gtrsim$ 50 observed/simulated galaxies
- **Find the shape along the Hubble sequence**

The science goals

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

SVE

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



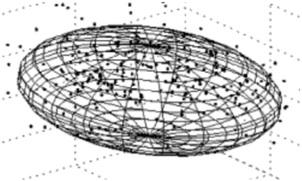
Velocity Ellipsoid. (Branham, 2004).

The science goals

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

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).

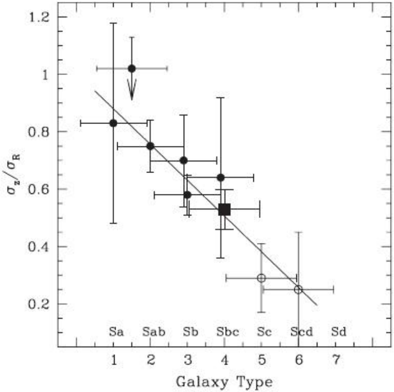
Why?

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

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

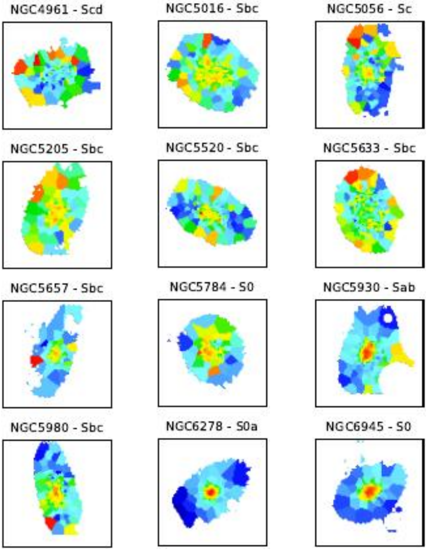
Previous works

- 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

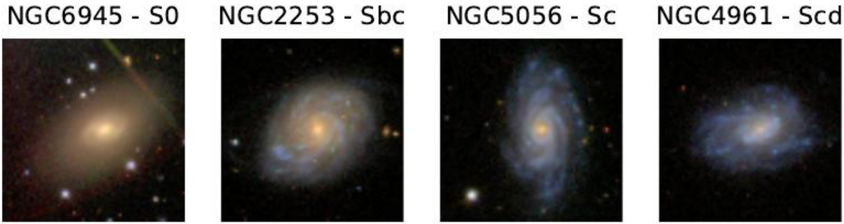
NGC2253 - Sbc

NGC5056 - Sc

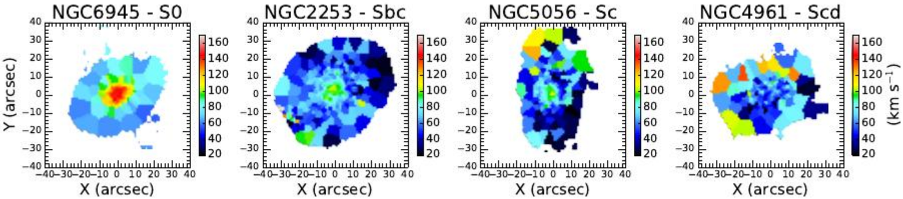
NGC4961 - Scd

The sample:
examples from CALIFA

SDSS images

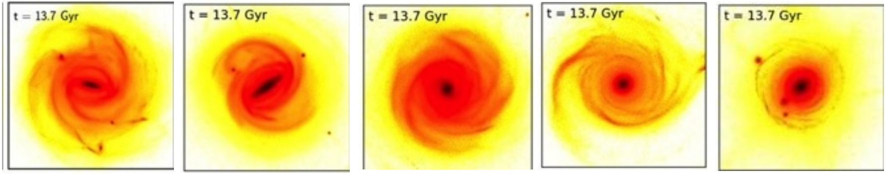


CALIFA σ maps



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

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

The Thin Disk Model

Exponential Models for Velocity Dispersion

Velocity Dispersion in the line of sight

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

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

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

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

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

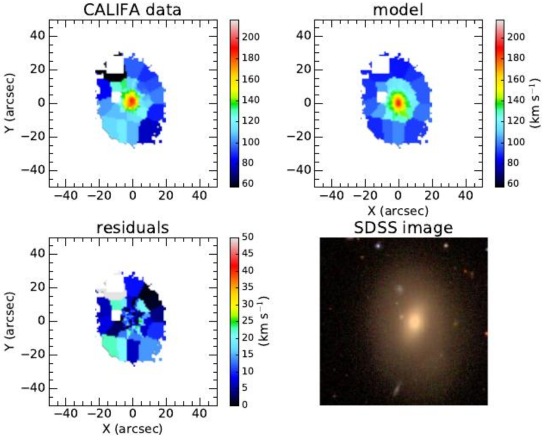
Preliminary results

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



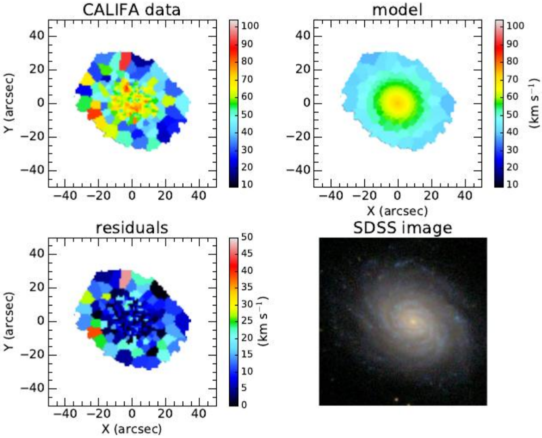
Preliminary results

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



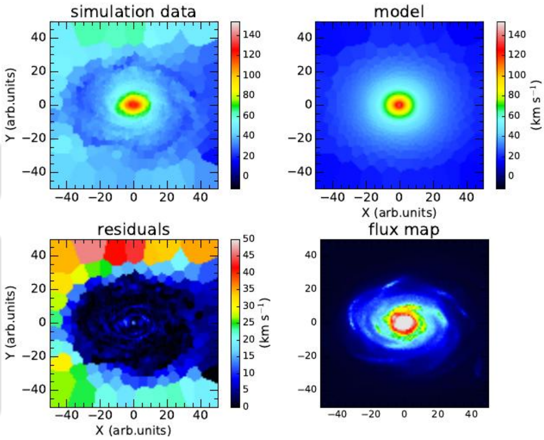
Preliminary results

A simulated galaxy

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

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

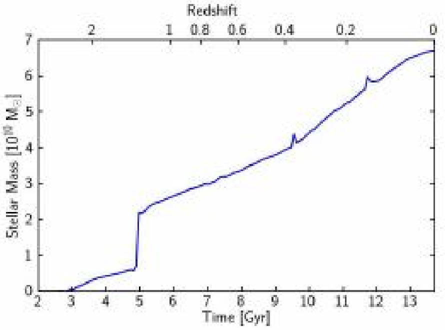
- Why the result is higher than what expected?
- What does this galaxy have in common with NGC7623?

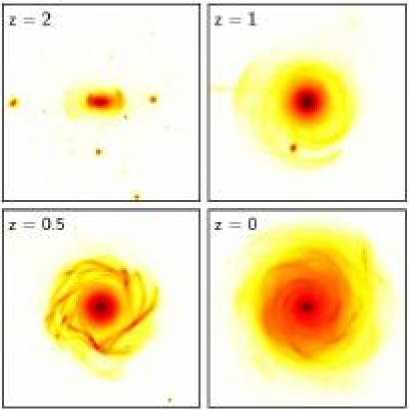


Preliminary results

A simulated galaxy

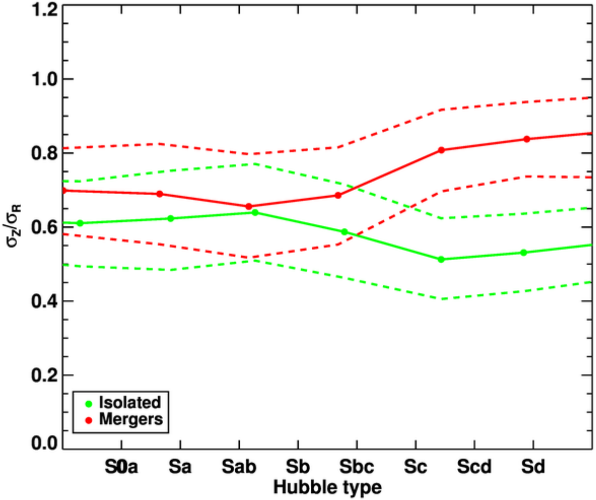
The evolution history: mergers





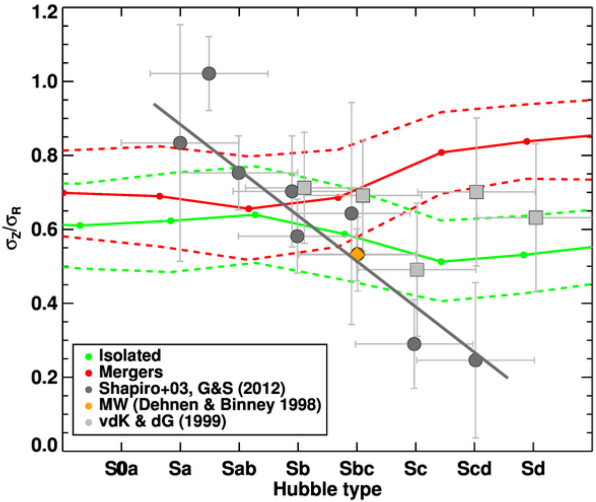
Discussion

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



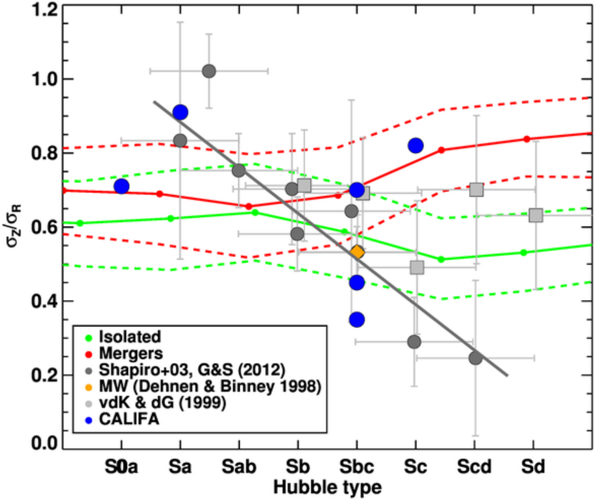
Discussion

- 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
  - Different/same Hubble types show much different σ profiles
    $\Rightarrow$ different evolution histories

Conclusions

- Velocity dispersions in galaxies outskirts are still uncharted waters
  - σ measurements are not easy
  - Different/same Hubble types show much different σ profiles
    $\Rightarrow$ different evolution histories
- The SVE is a valid tool to make predictions about the disk evolution history
  - Early-types: more isotropic SVE
  - Late-types: less isotropic SVE
  - Mergers can break this tendency, especially for late-types

Conclusions

- Velocity dispersions in galaxies outskirts are still uncharted waters
  - σ measurements are not easy
  - Different/same Hubble types show much different σ profiles $\Rightarrow$ different evolution histories
- The SVE is a valid tool to make predictions about the disk evolution history
  - Early-types: more isotropic SVE
  - Late-types: less isotropic SVE
  - Mergers can break this tendency, especially for late-types
- 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