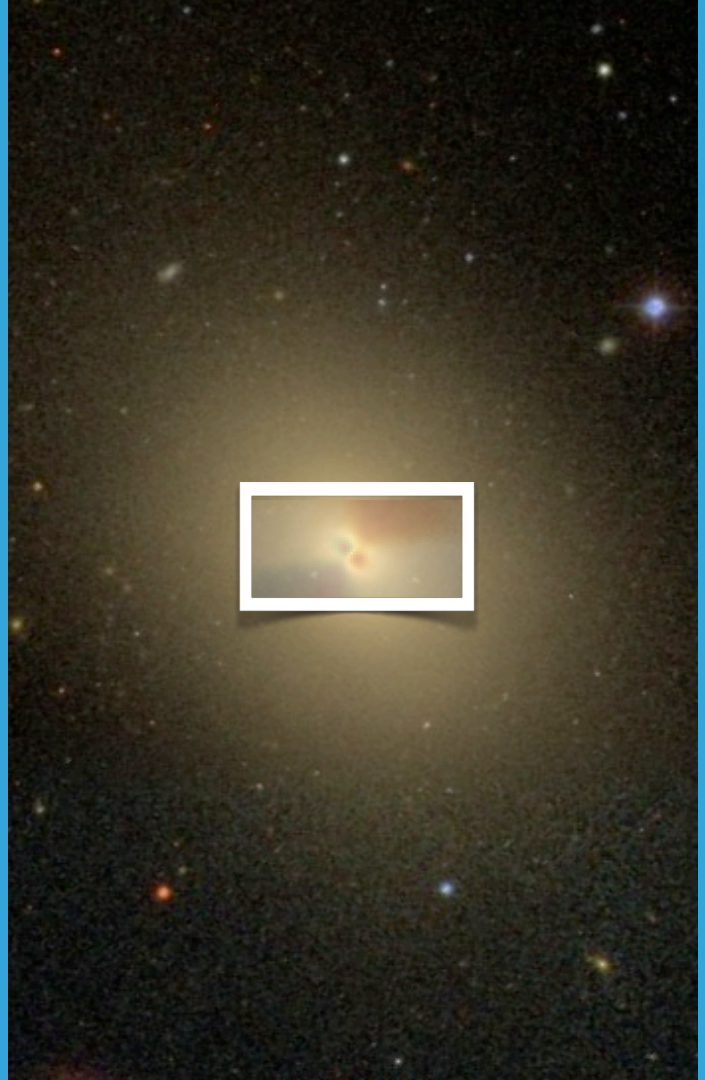
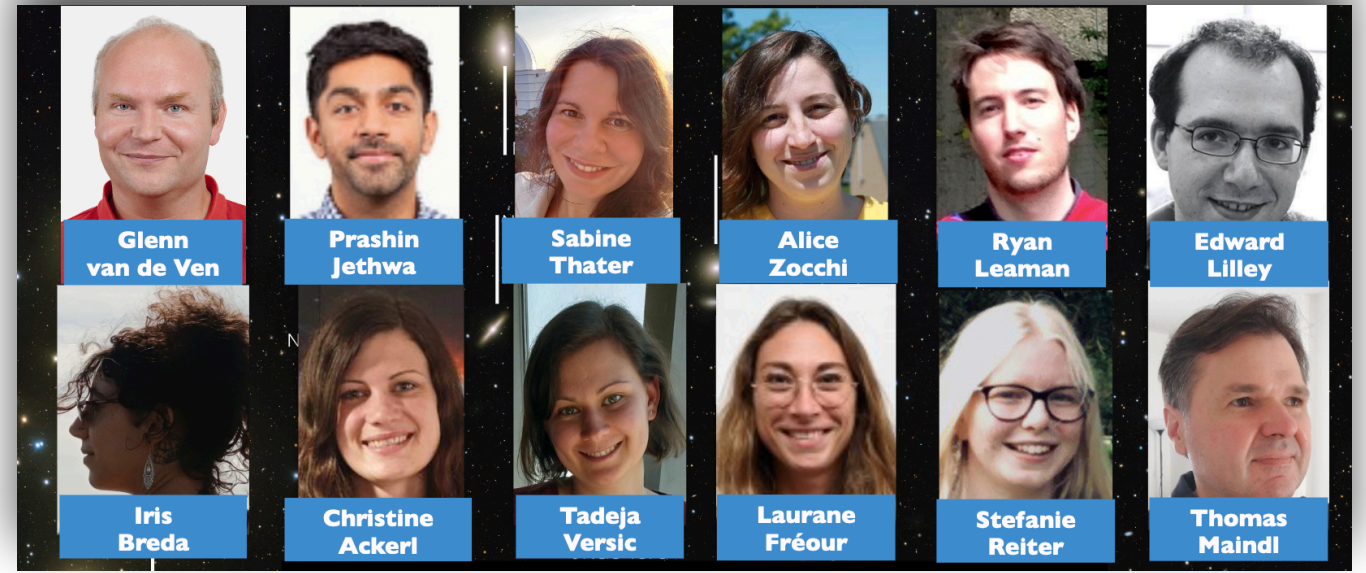


A DYNAMICAL PICTURE OF SUPERMASSIVE BLACK HOLES AND SPHEROIDS

Sabine Thater (University of Vienna)

DYNamics, Age and Metallicity Indicators Tracing Evolution



DYNAMITE team in Vienna

https://www.univie.ac.at/dynamics/

WHY GALAXY DYNAMICS?

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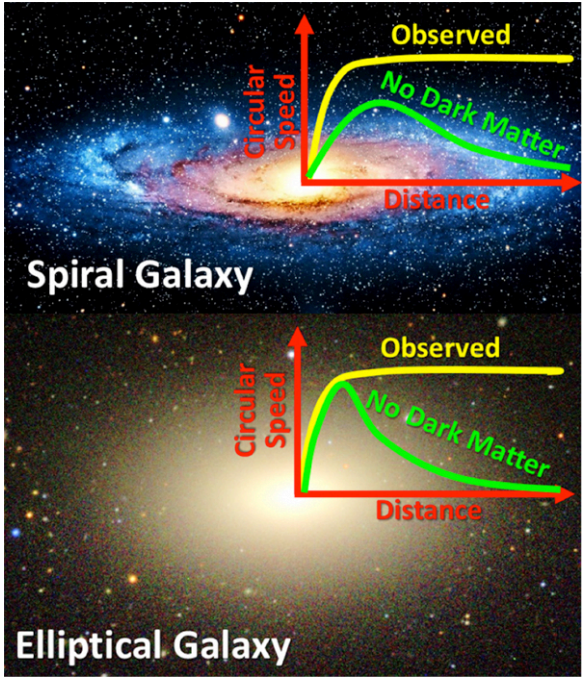
Image credit: M. Cappellari & Sloan Digital Sky Survey



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Problem: Galaxies have luminous and dark components

$$\Phi_{total} = \Phi_* + \Phi_\bullet + \Phi_{DM}$$

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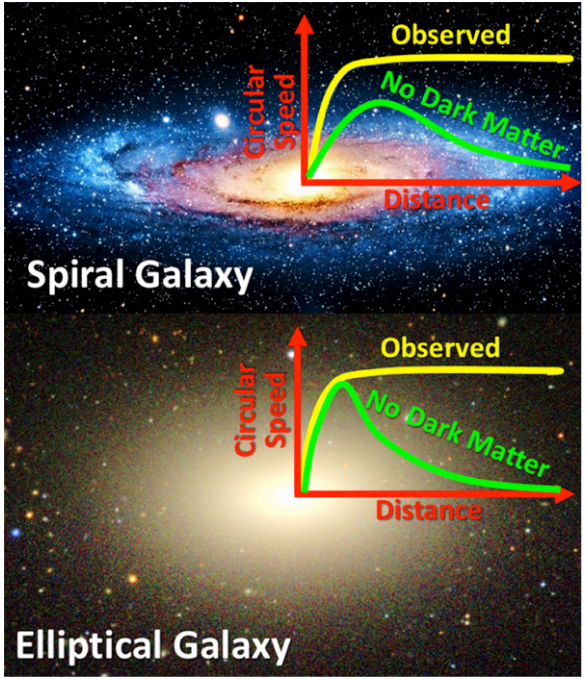

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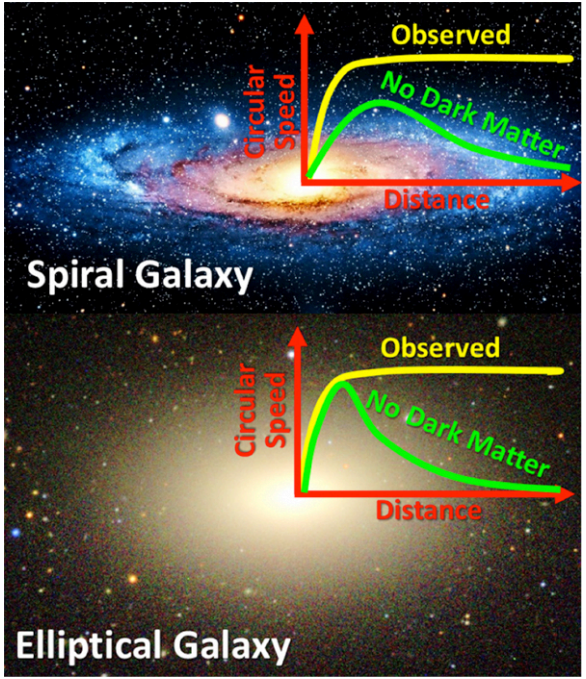

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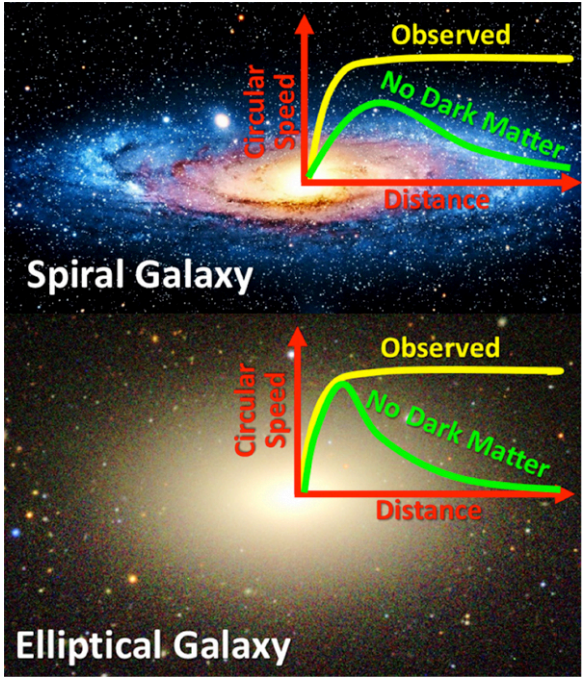

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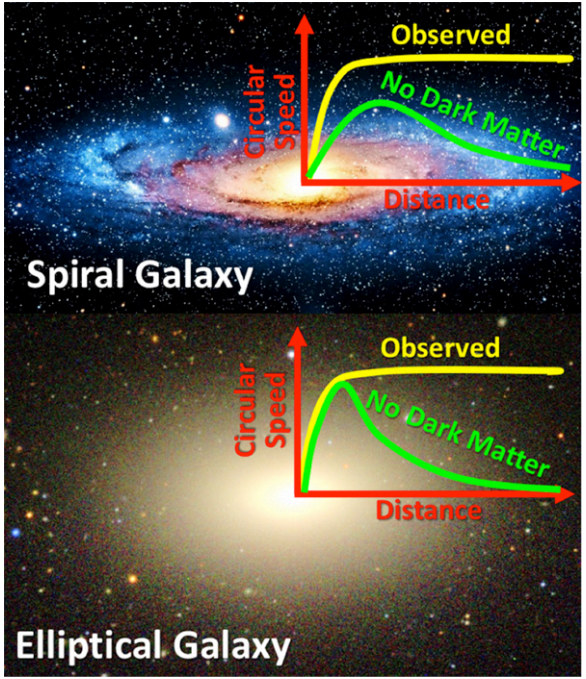

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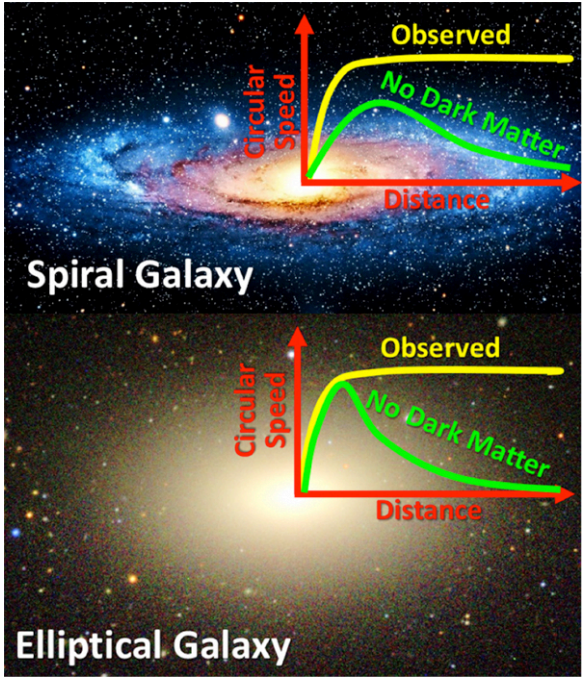

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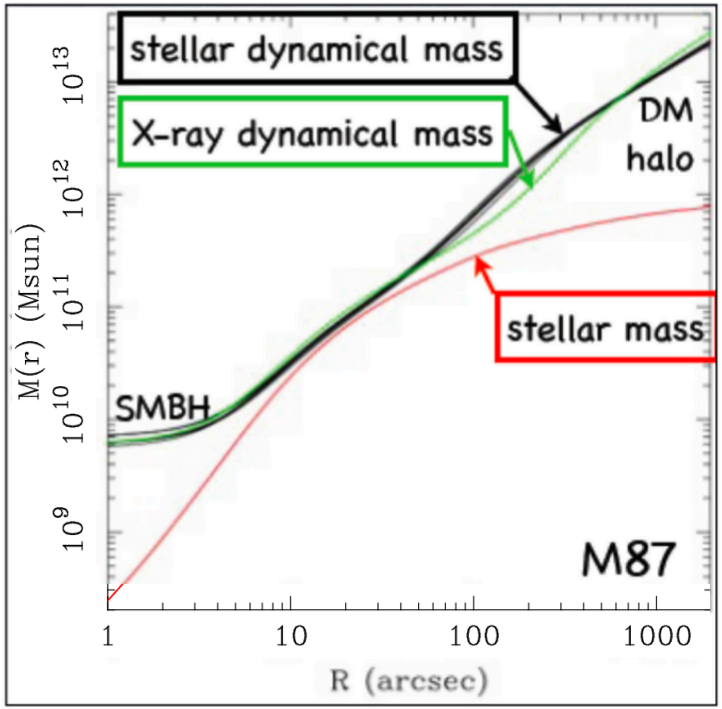
Gebhardt & Thomas (2009)



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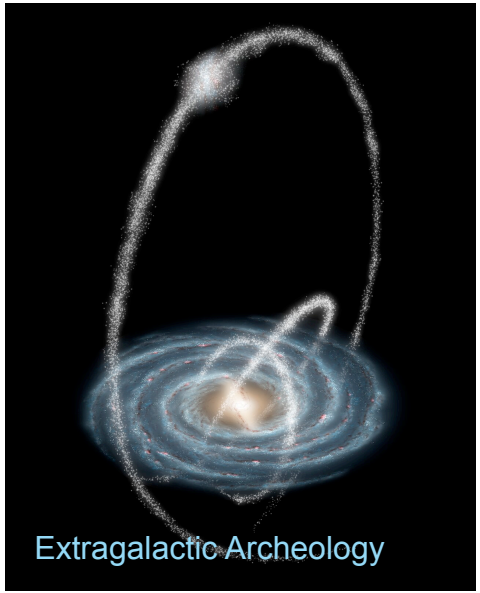
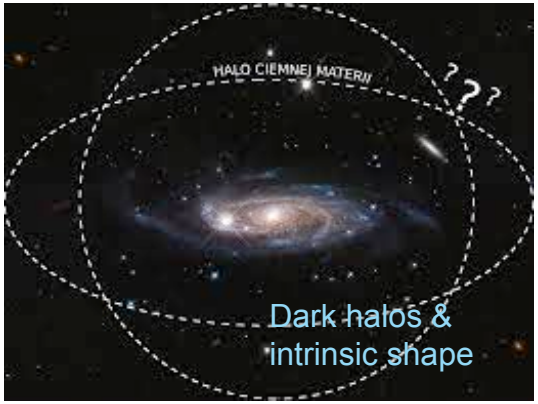
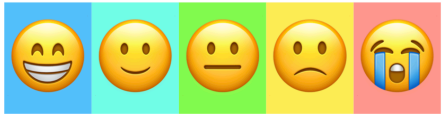




OVERVIEW OF DYNAMICAL MODELLING METHODS

(credits to Prashin Jethwa)

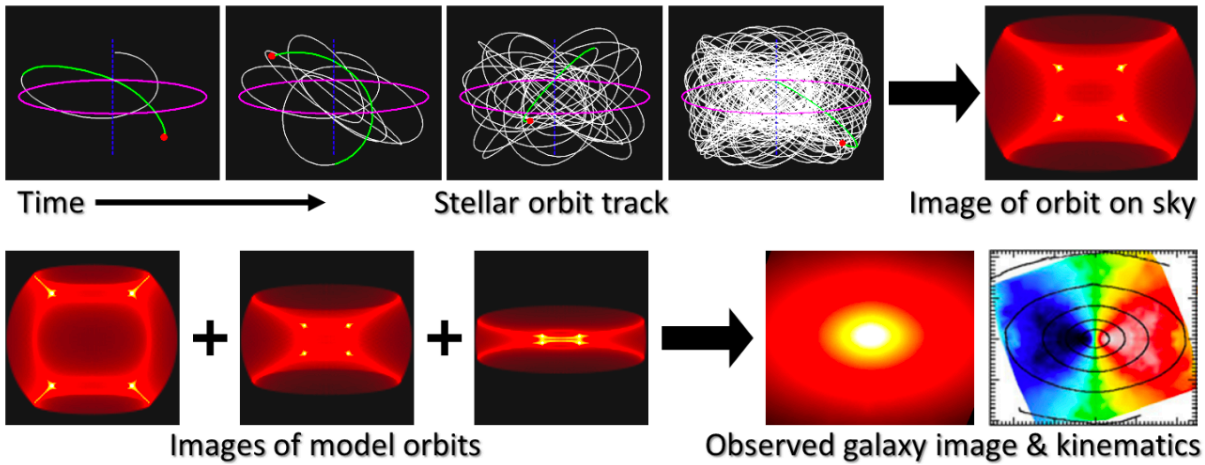


- Dynamical model: observables → DF $f(\mathbf{x}, \mathbf{v})$ and potential ϕ
- Types of dynamical model:

	Recover DF?	Strong Assumptions?	Speed	Use of data
Jeans' Model	😭	😭	😄	😭
Analytic DF	🙂	😕	🙂	😐
Orbit-based Model	😄	🙂	😐	🙂
Made to Measure	😄	😄	😭	🙂

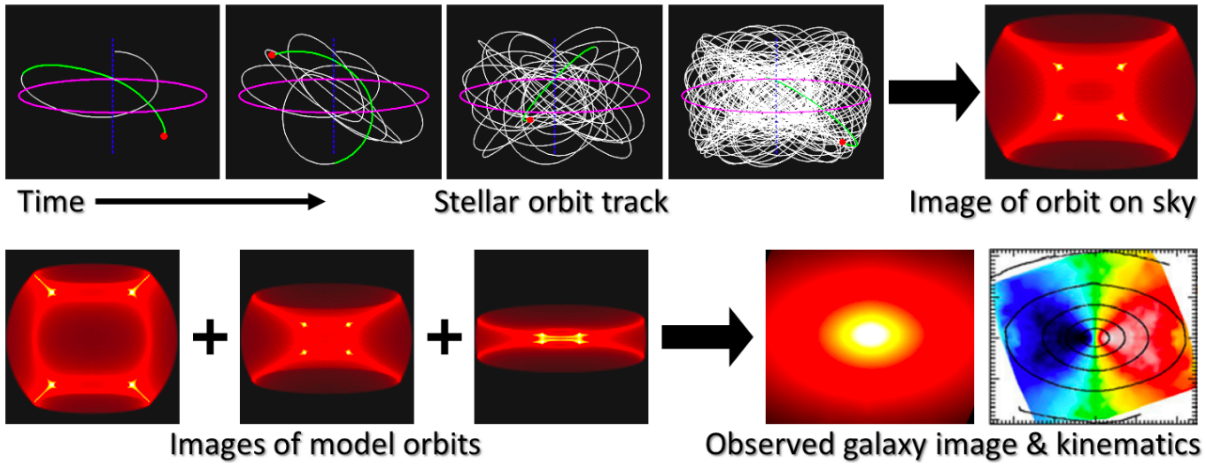
- more for collisional and/or non-equilibrium …

SCHWARZSCHILD DYNAMICAL MODELLING



SCHWARZSCHILD DYNAMICAL MODELLING

- Orbit-superposition method (**Schwarzschild 1979**)
- Based on the assumed **galaxy potential** (luminous+dark) an orbit library is calculated and for each orbit the observables are stored
- By fitting to the observed **surface brightness and kinematic data**, a superposition that best represents the data is constructed



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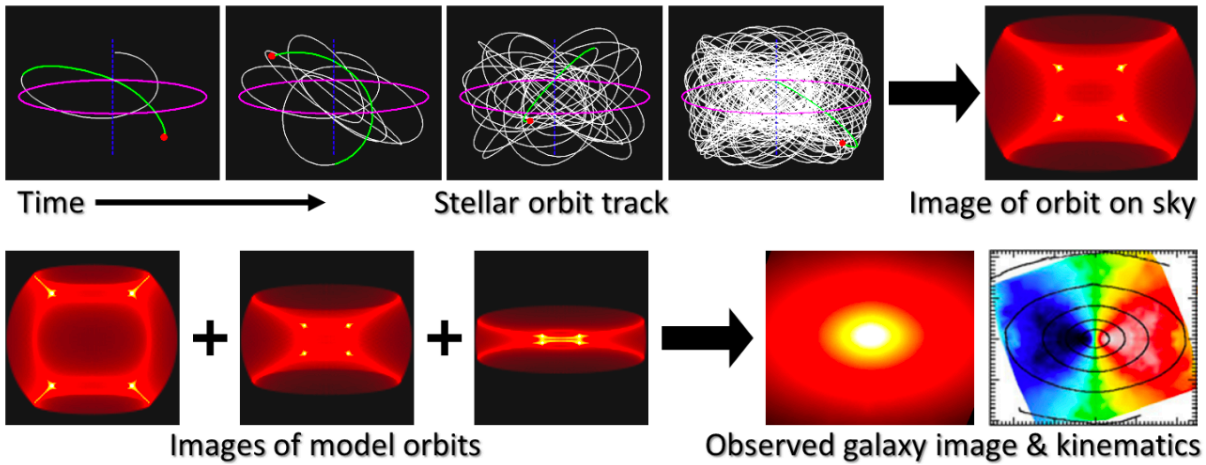

It is possible to study the intrinsic dynamical structure of galaxies in detail!

DYNAMITE

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- **Goal**: study the assembly history of galaxies by combining the knowledge from **dynamics** (through orbital distribution) with **age** and **metallicity** from population synthesis models

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- **Goal**: study the assembly history of galaxies by combining the knowledge from **dynamics** (through orbital distribution) with **age** and **metallicity** from population synthesis models

- DYNAMITE is the successor of the famous **triaxial** Schwarzschild orbit-superposition code by **van den Bosch et al. (2008)**;
  it is written in Fortran and Python

- DYNAMITE is a publicly released, flexible & user-friendly tool; we regularly add new features and work hard to make it more efficient

From data to dark mass with DYNAMITE

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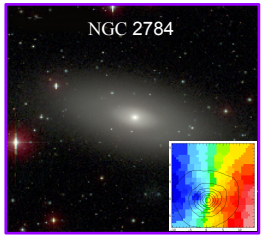
e.g. Thater et al. 2019, 2023a



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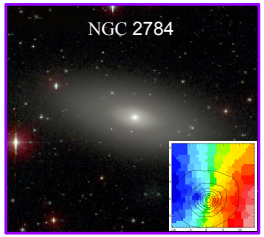

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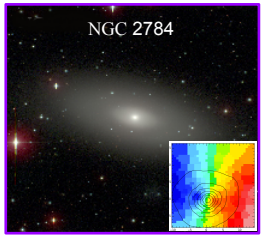

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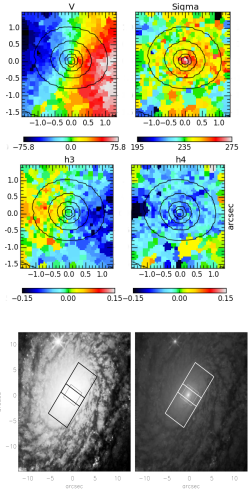
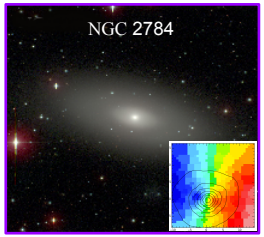


dynamical tracer (stars) which is accelerated by the black hole



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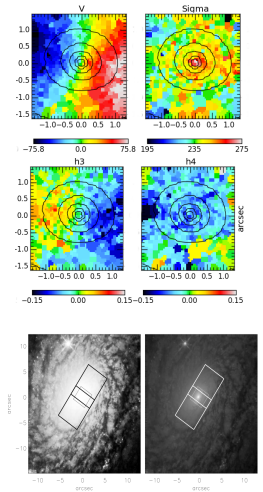

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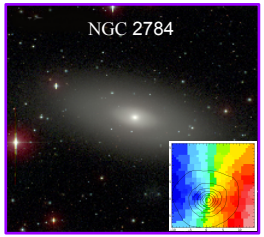

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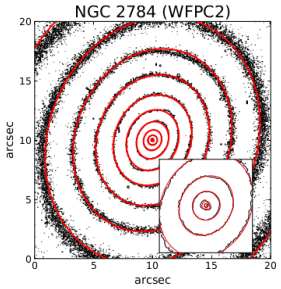

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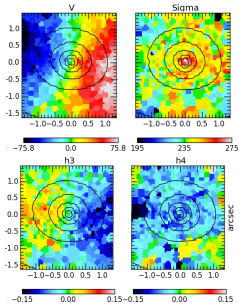

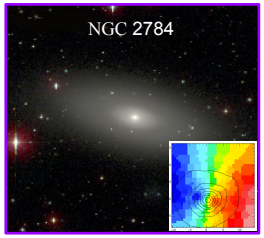

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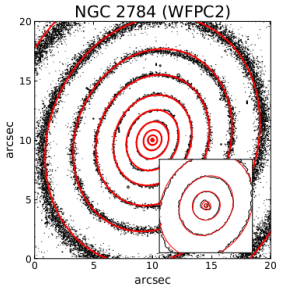

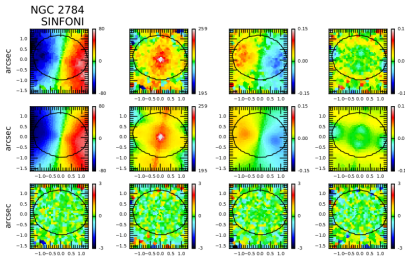

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Schwarzschild modelling

The potential of stars and gas on scales of the black hole sphere of influence is modelled, with the central mass as a free parameter

SCHWARZSCHILD MODELS OF NEARBY GALAXY SURVEYS

	DYNAMITE	Galaxy Type	N galaxies with orbit-superposition models	
CALIFA Survey	CALIFA	ETGs & LTGs	300	**Zhu et. al 2018**
ATLAS 3D	Atlas3D	ETGs	63 (out of 260)	**Thater et al. 2023b** (full sample in prep)
MANGA	MANGA	ETGs	149	**Jin et al. 2020**
sami galaxy survey	SAMI	ETGs	161	**Santucci et al. 2022**
F3D	Fornax3D	ETGs & LTGs	18	**Ding et al. 2023**
			Total = 691	

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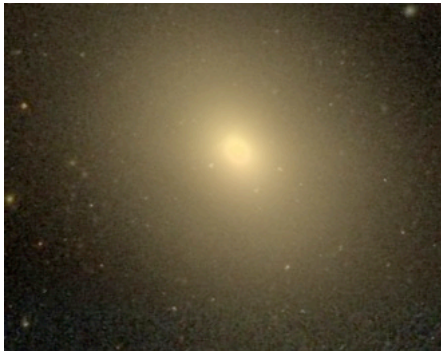
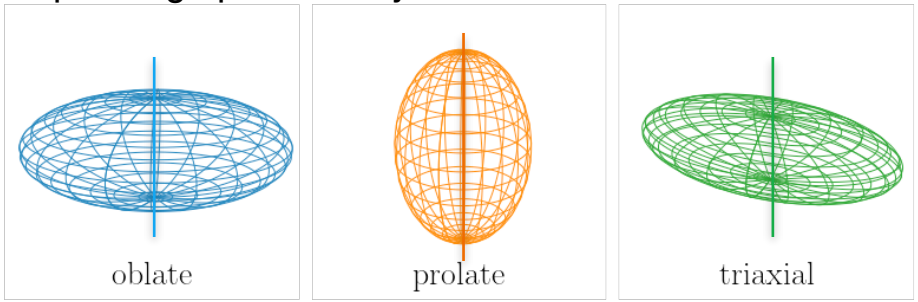
GALAXY INTRINSIC SHAPES

Galaxies that appear elliptical on the sky …



… may be **intrinsically** oblate, prolate, or triaxial, depending upon their symmetries



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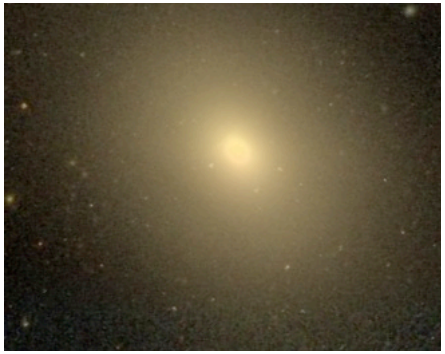

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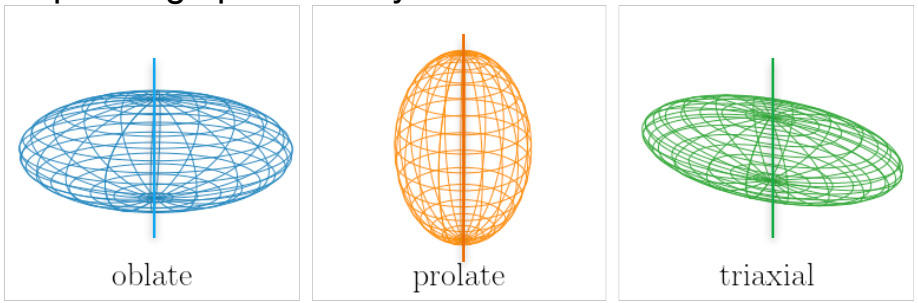
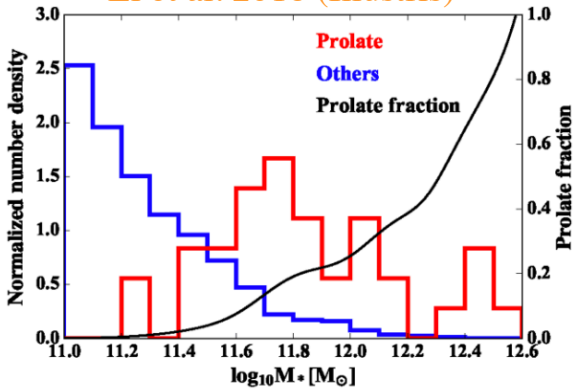
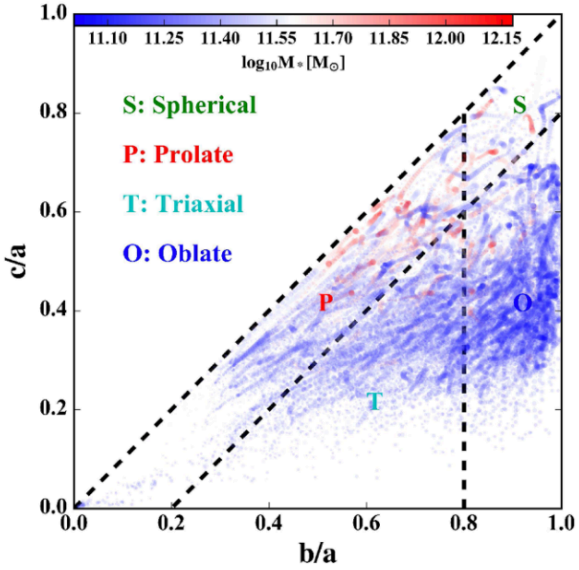
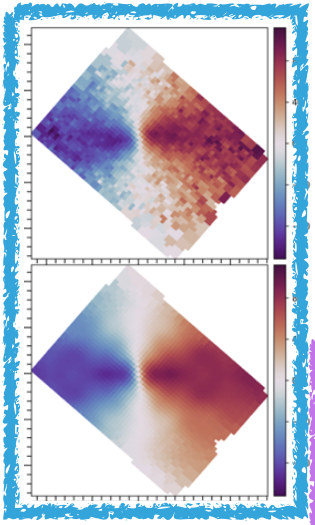


Li et al. 2018 (Illustris)



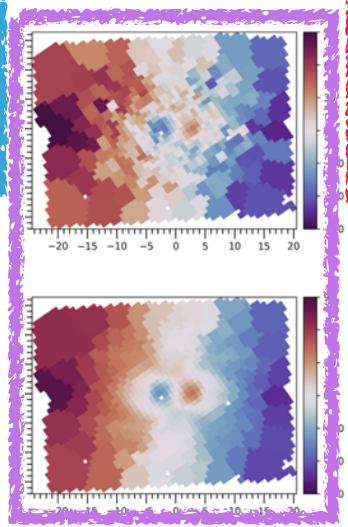


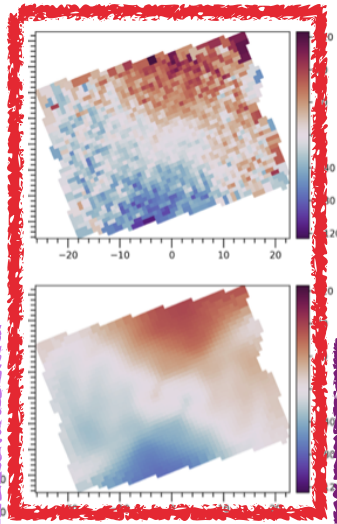
A WEALTH OF KINEMATICS



Fast (regular) rotator

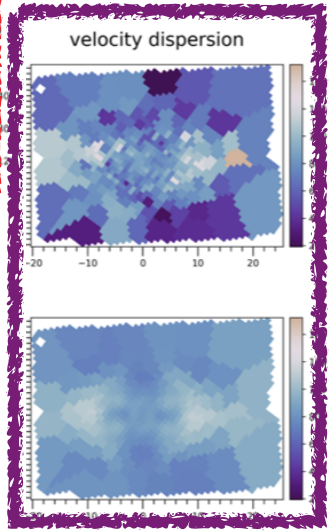
Kinematically decoupled core





Slow rotator

2sigma



e.g. Krajnovic et al. 2011/2013

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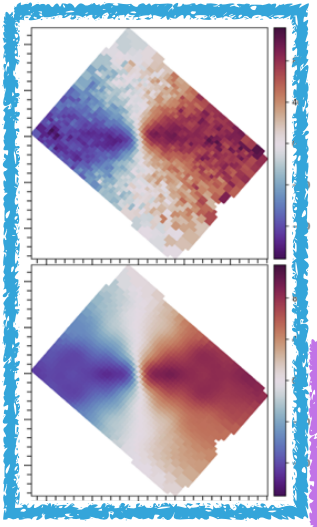

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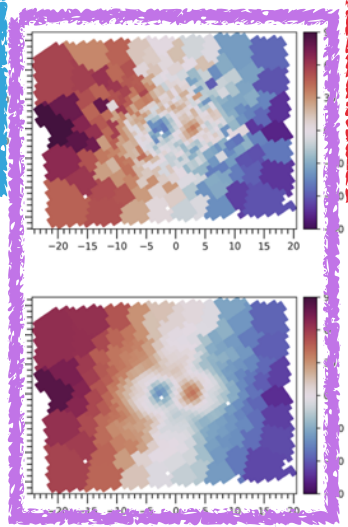

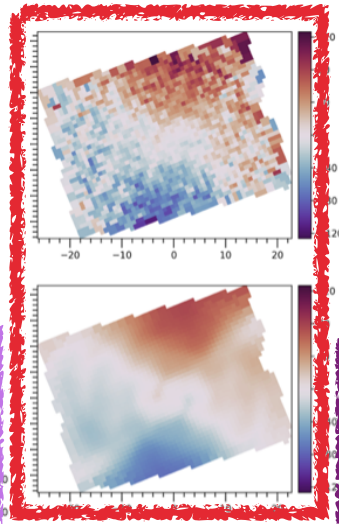

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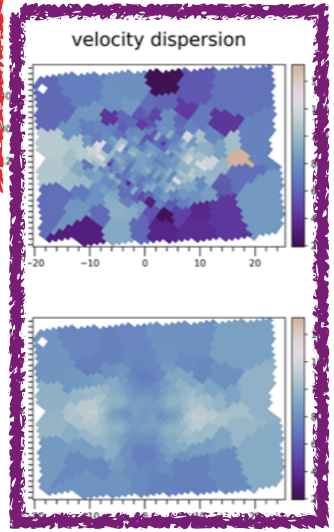


Slow rotator

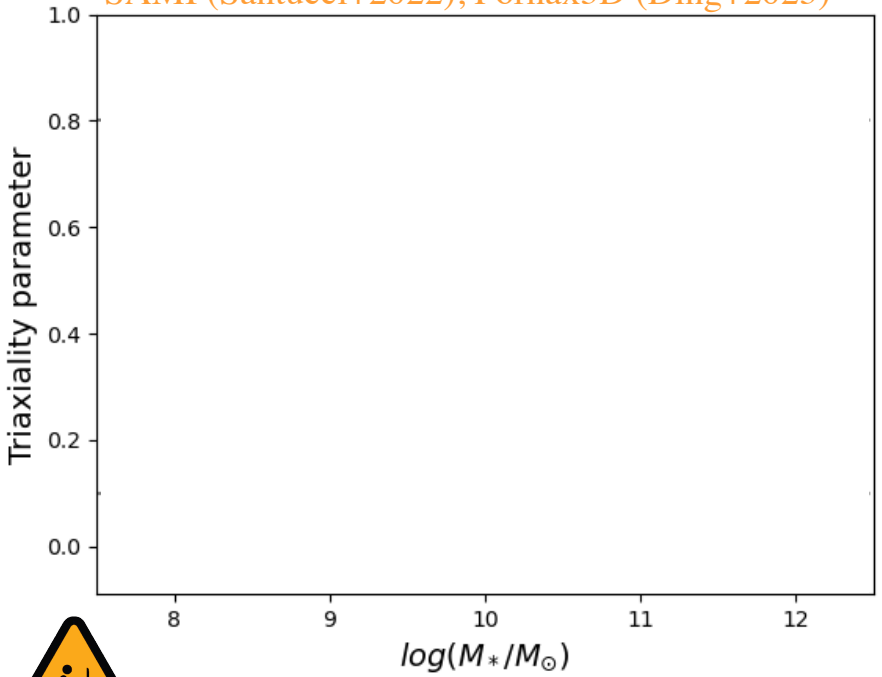
ATLAS3D (Cappellari et al. 2011)

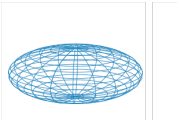
- 260 ETGs within the local volume (d<42 Mpc)
- Stellar masses > $6\times10^9 M_\odot$
- Wealth of kinematical, dynamical and stellar population studies
- High S/N kinematics available

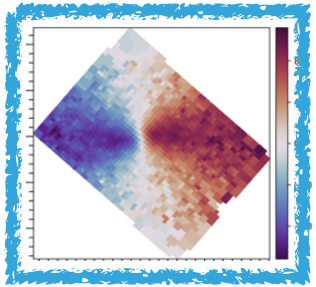
e.g. Krajnovic et al. 2011/2013

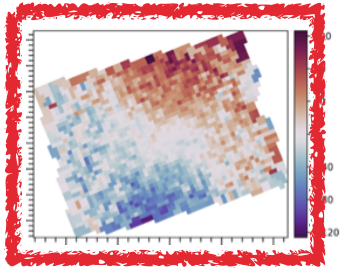
GALAXY INTRINSIC SHAPES

Thater+2023b, extension in preparation,
SAMI (Santucci+2022), Fornax3D (Ding+2023)









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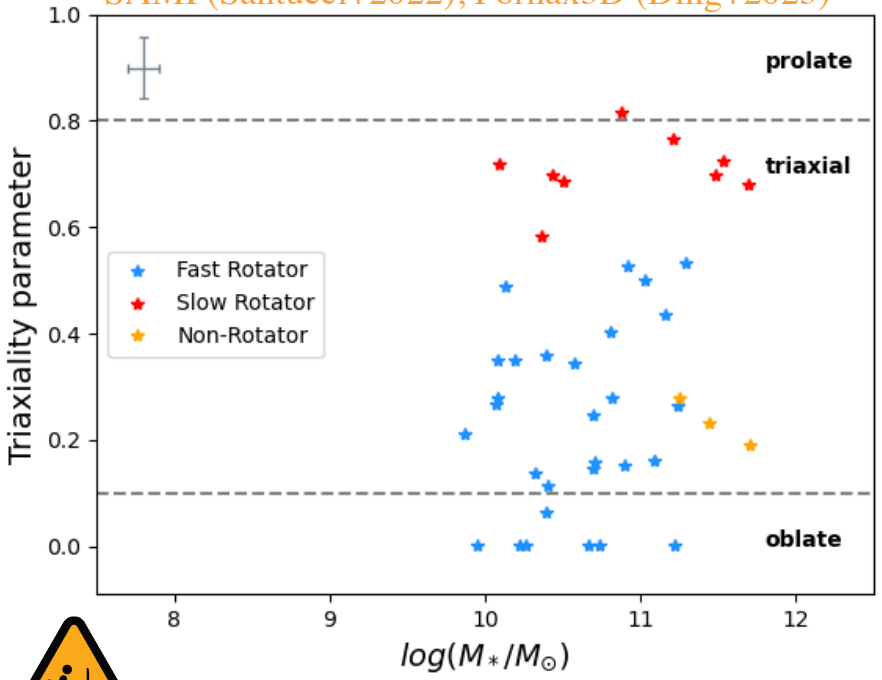

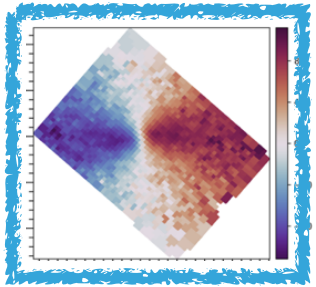

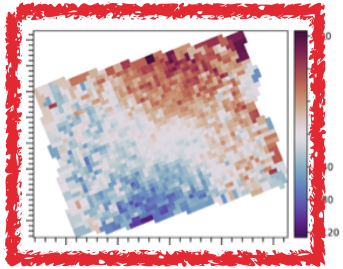

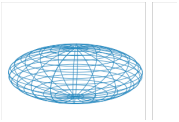

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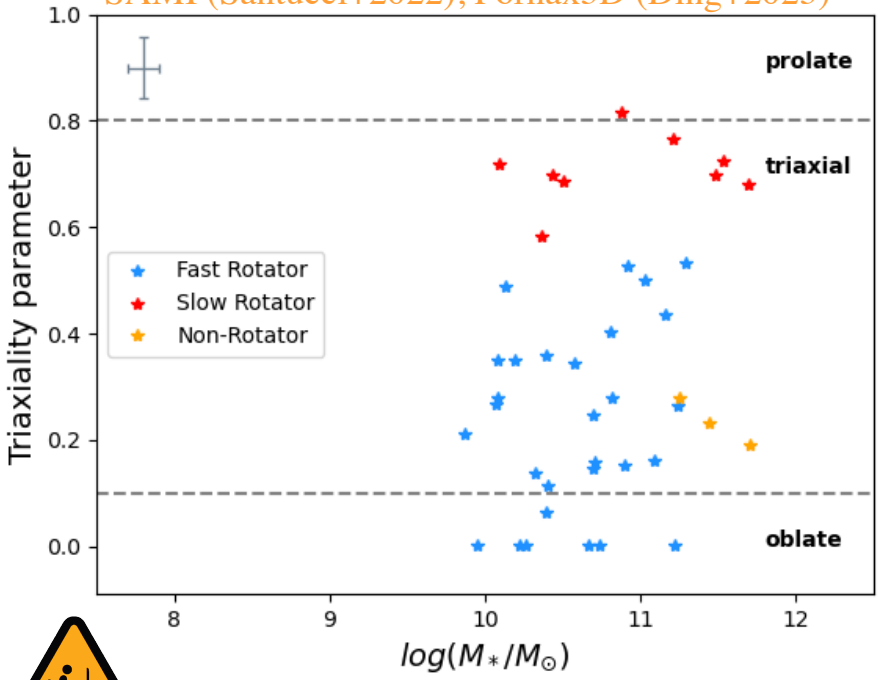

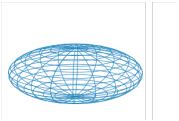

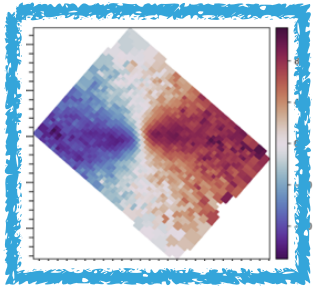

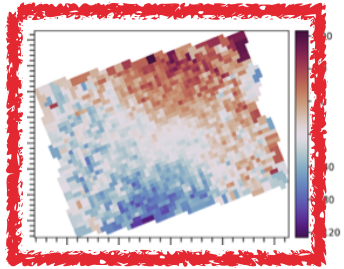

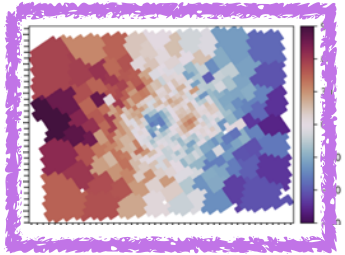

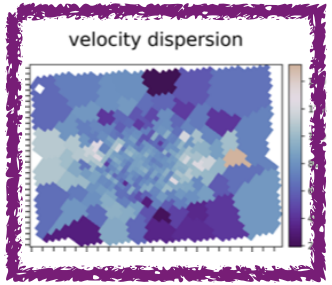

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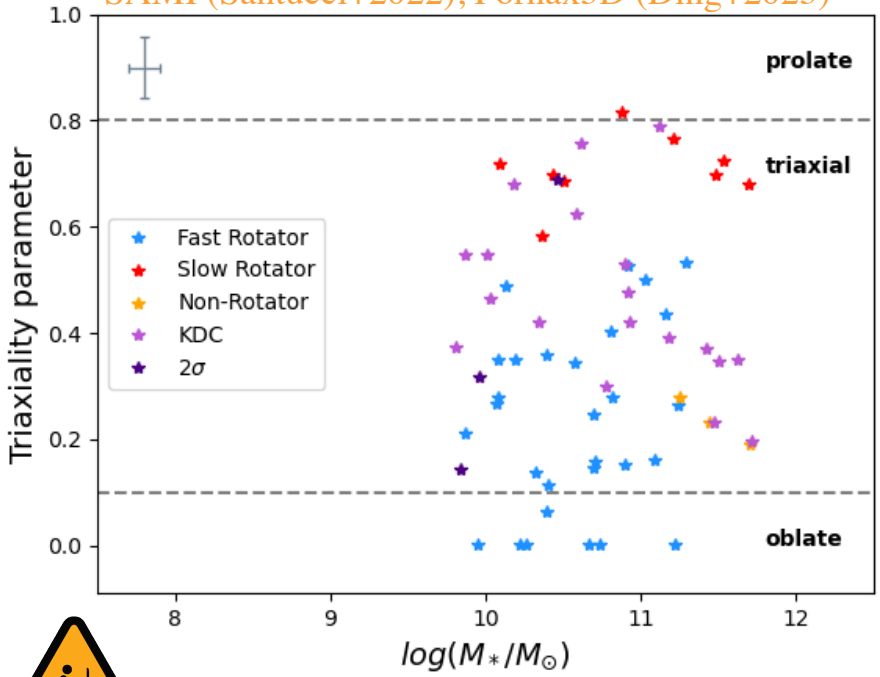

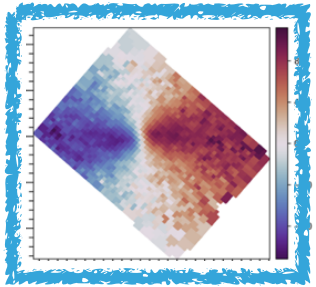

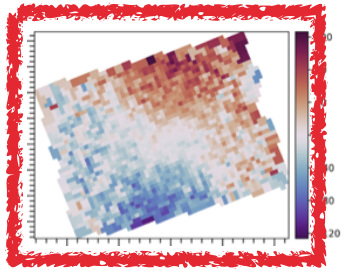

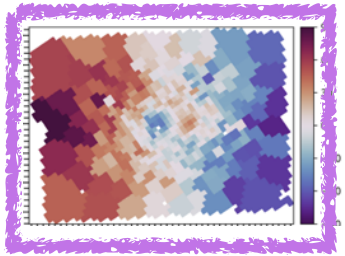

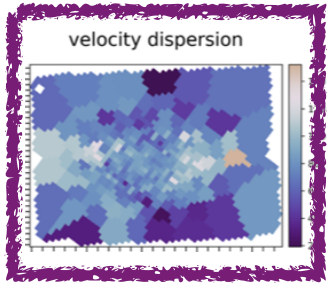

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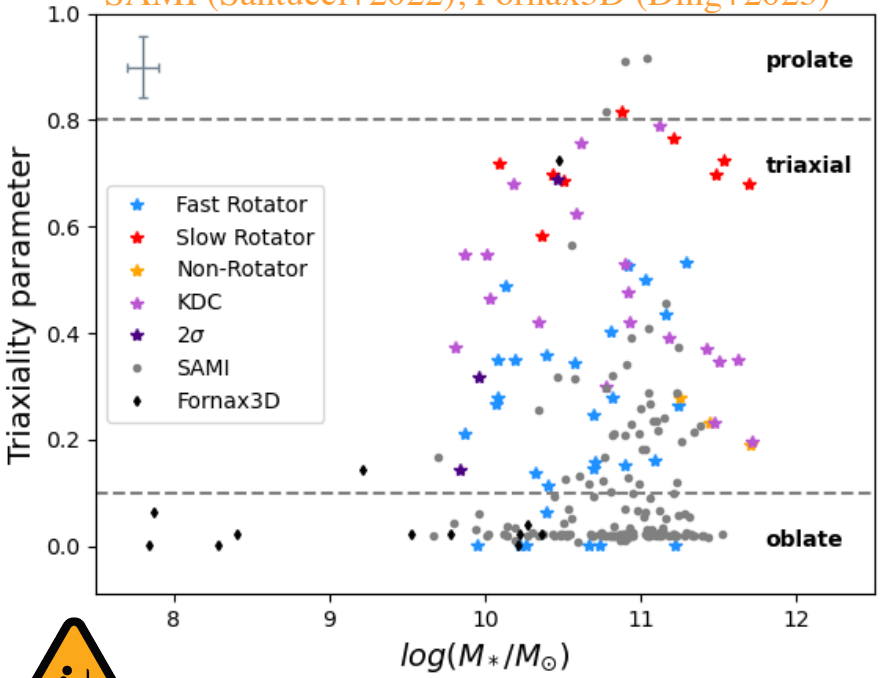

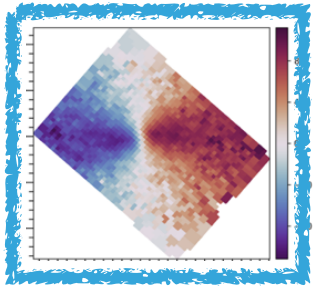

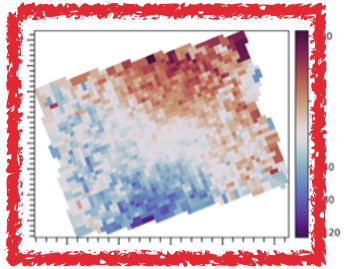

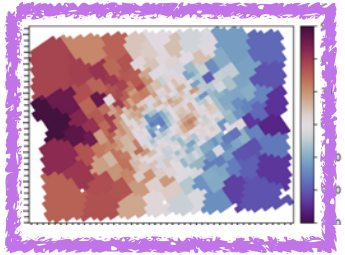

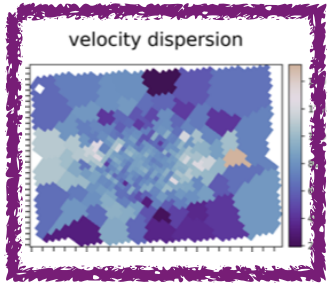

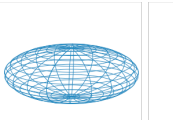

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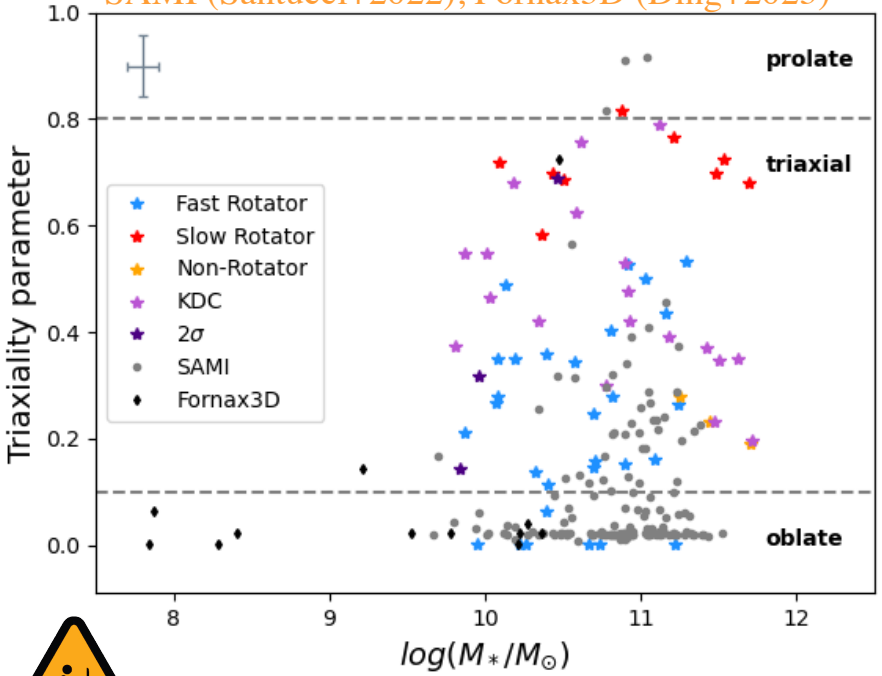
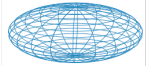
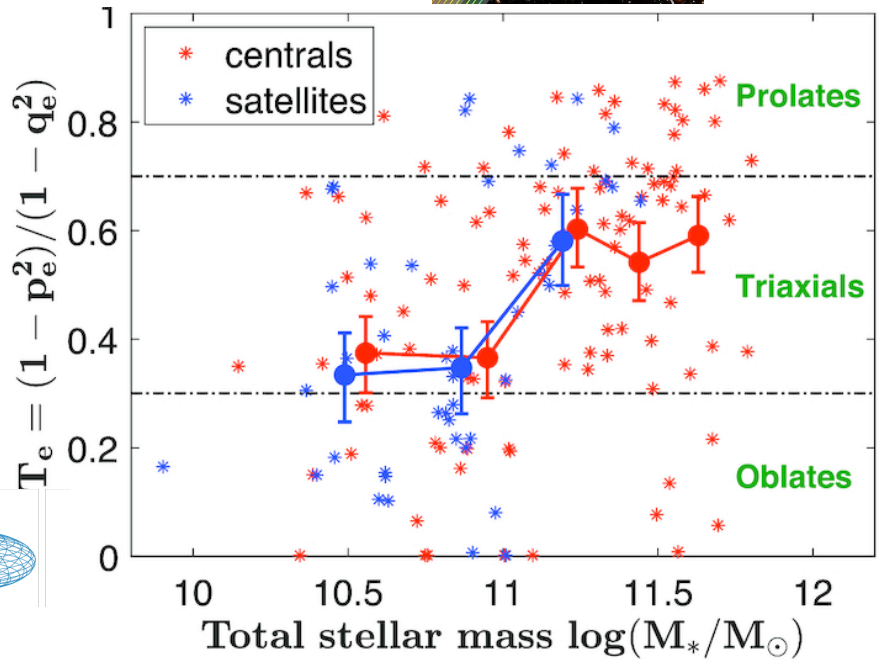




Jin+2020



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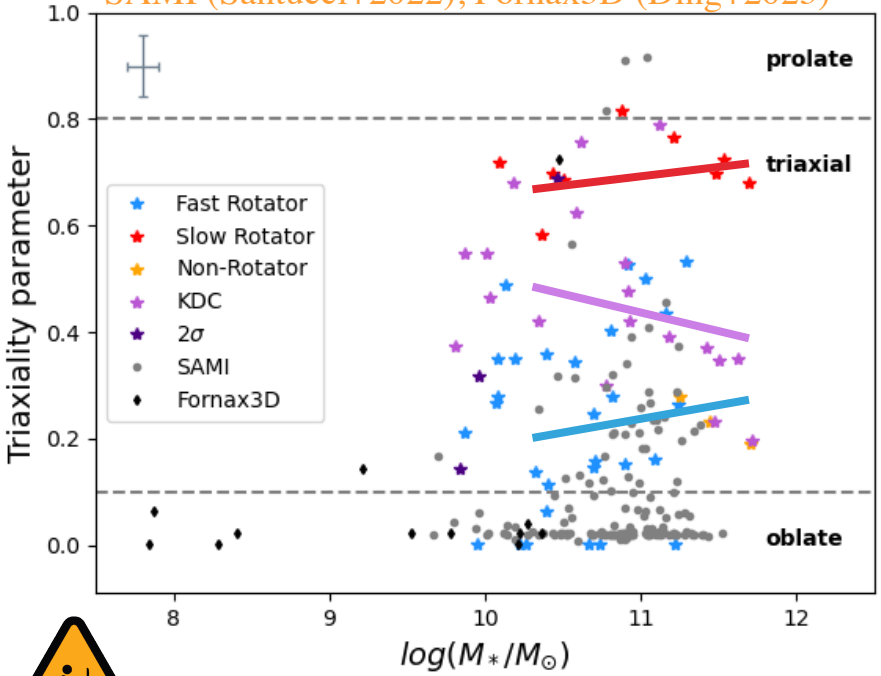

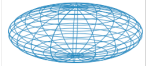

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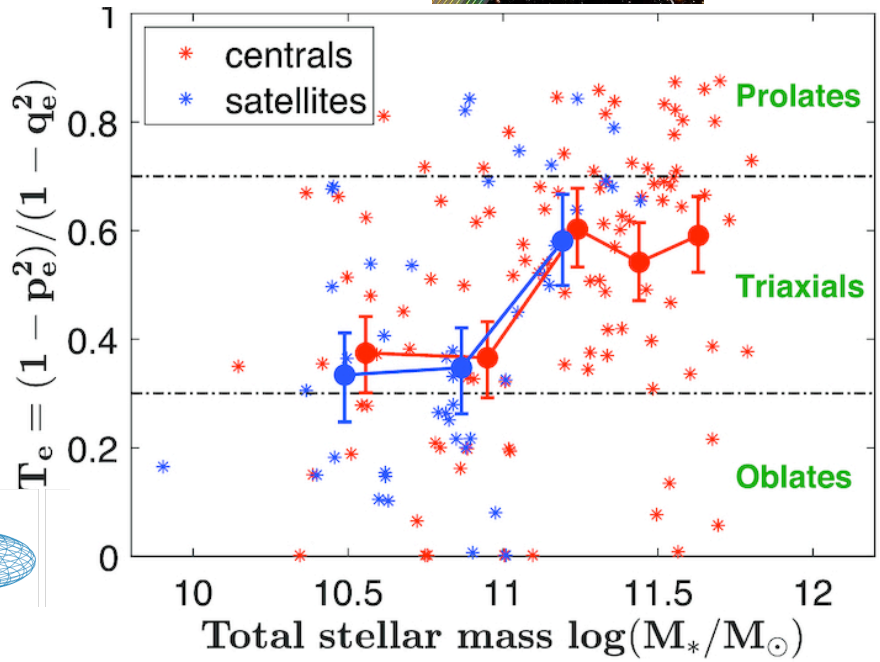
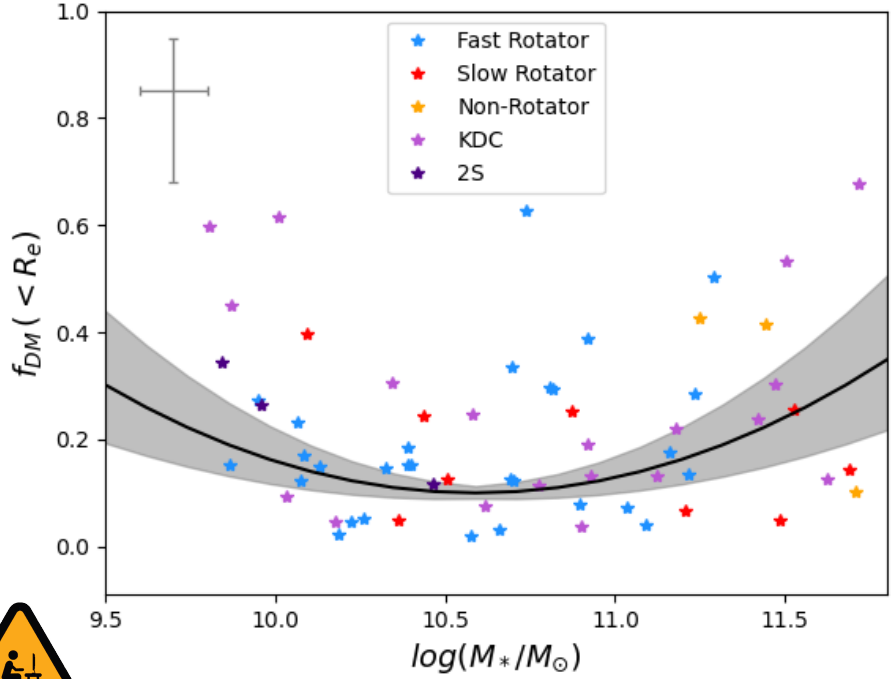


DARK MATTER FRACTIONS F_{DM}

Thater et al. (in prep.)



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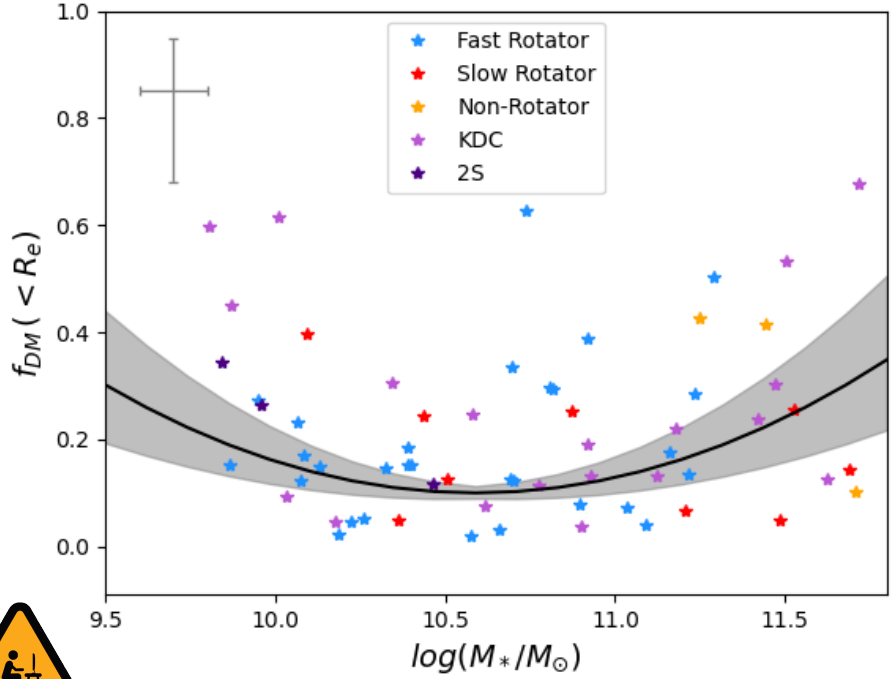
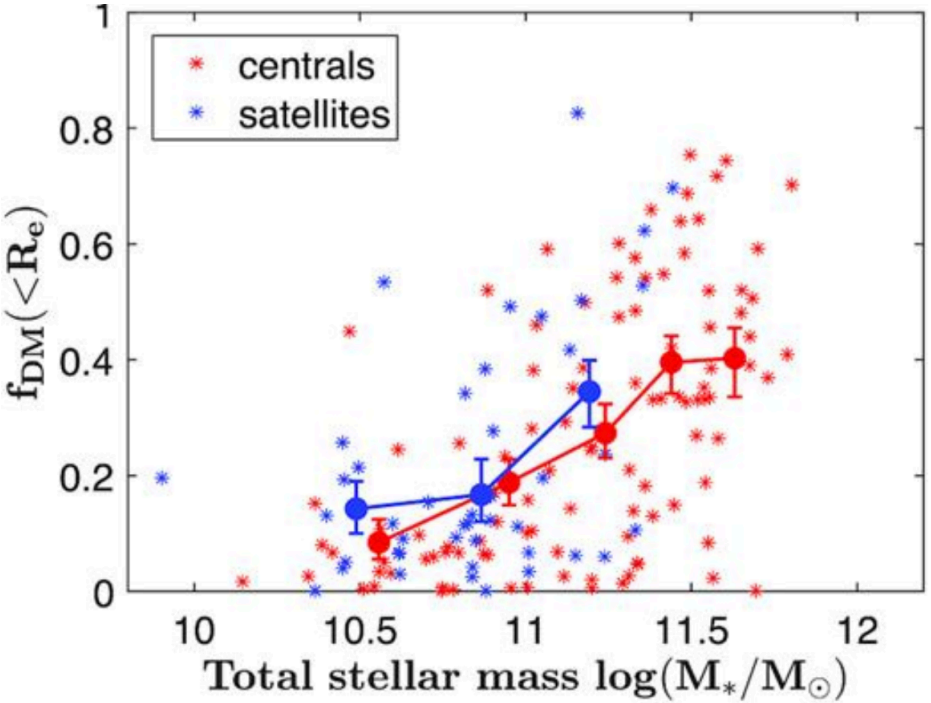


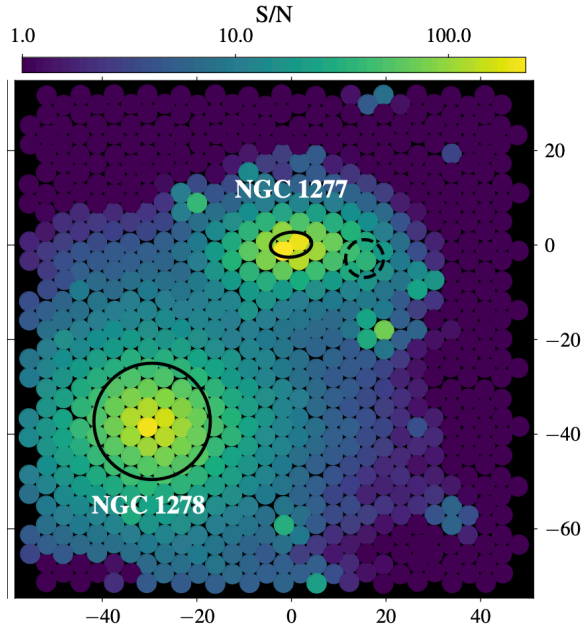
Jin et al. 2020



HOW CAN WE REDUCE THE UNCERTAINTIES IN F_{DM}?

Deep observations

Comerón+2023



See talk by **Sebastian Comerón** (Tuesday)

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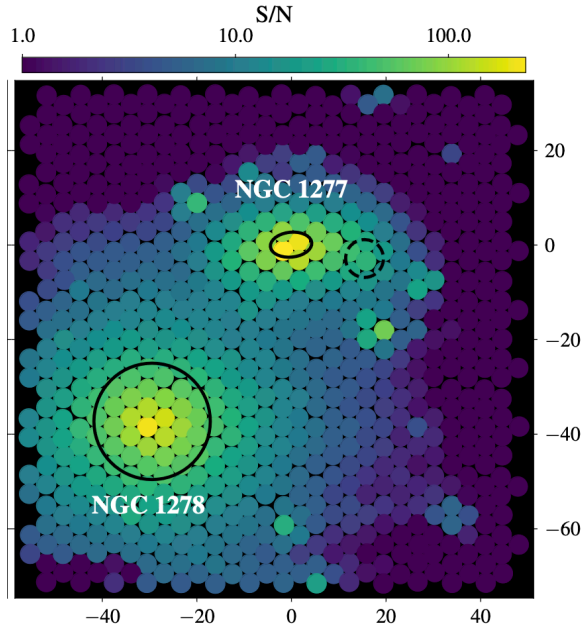
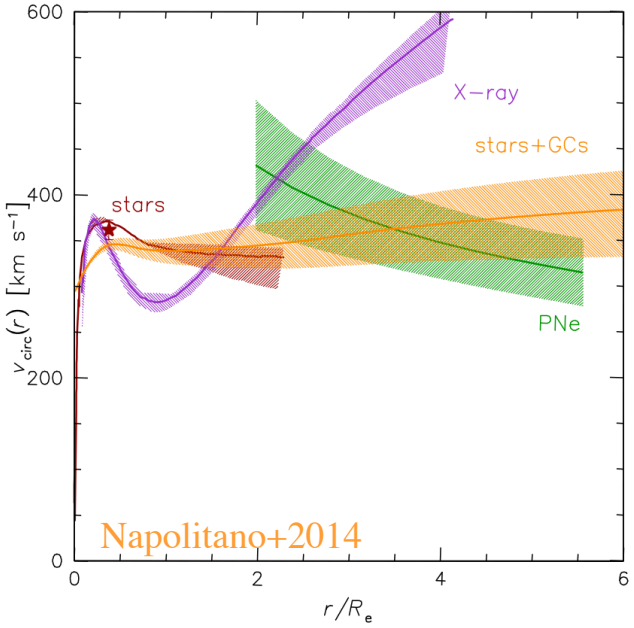


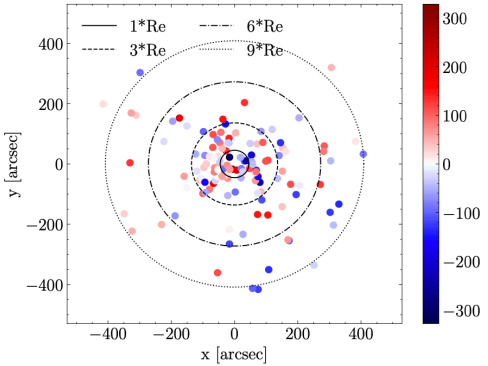
Combine multiple different tracers

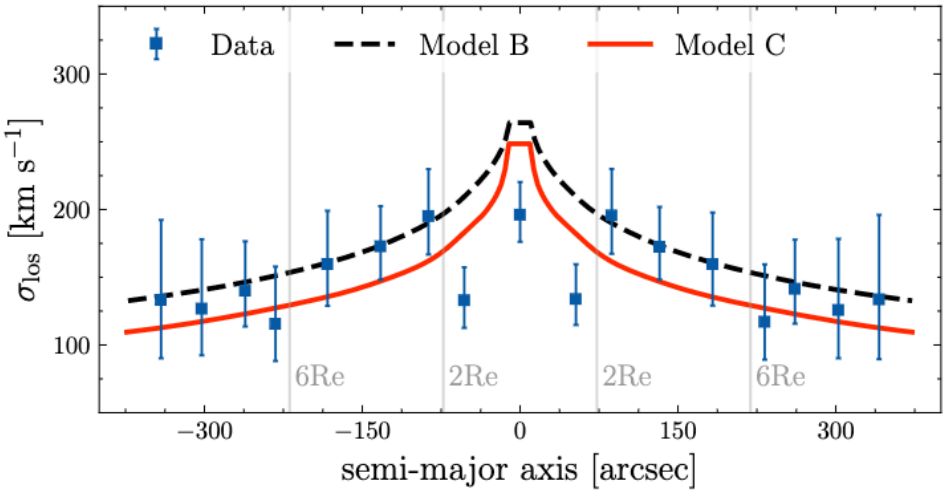


MODELLING GLOBULAR CLUSTERS IN THE SLUGGS SURVEY

Veršič, S.T., et al. (submitted)

Robust estimates of the total mass distribution, parametrised with a double power-law profile, for 12 ETGs. This was done, by modelling the GCs from the SLUGGS survey (⟨RGC, max⟩ ~ **8Re**) with dynamical discrete Jeans modelling.





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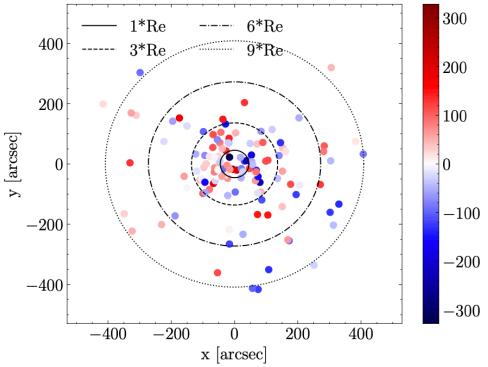

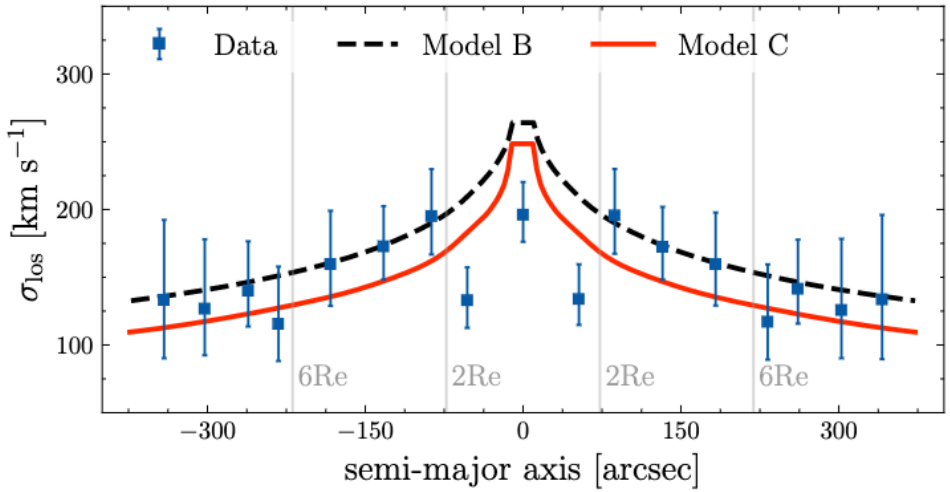

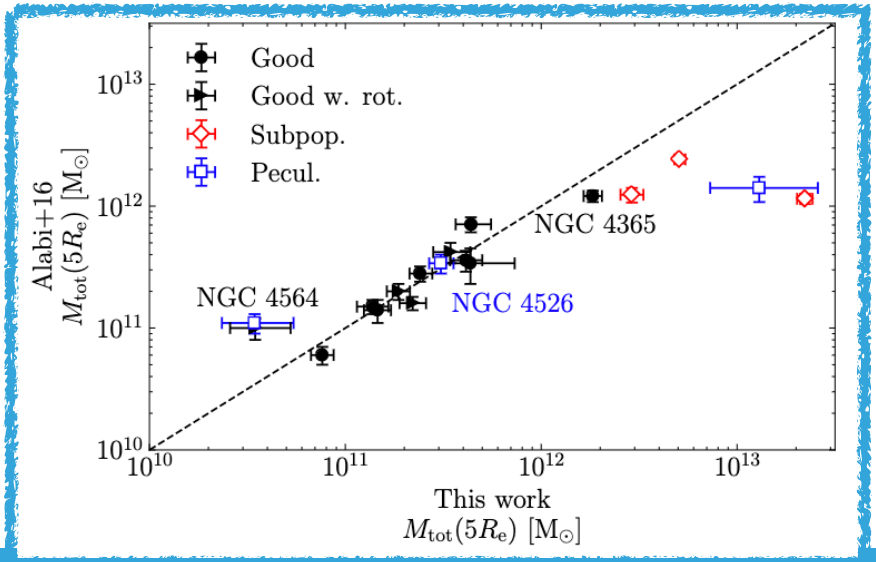

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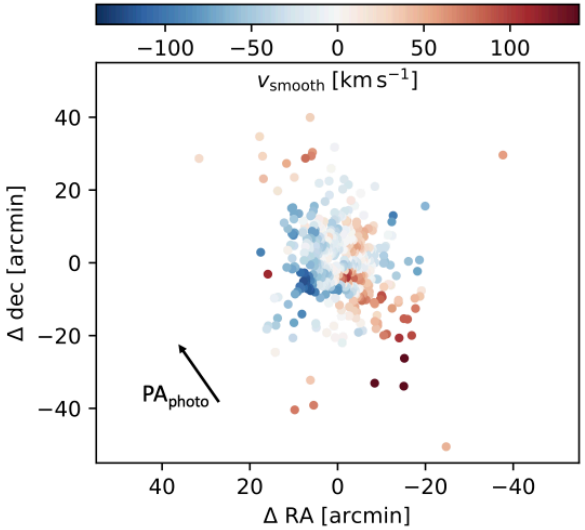
Cen A

GCs within 40 kpc



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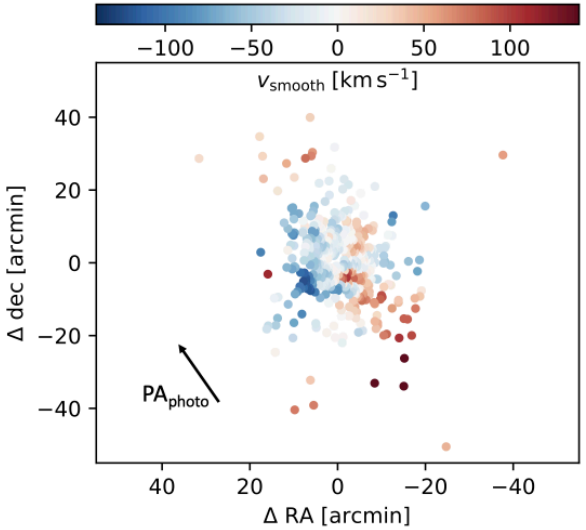

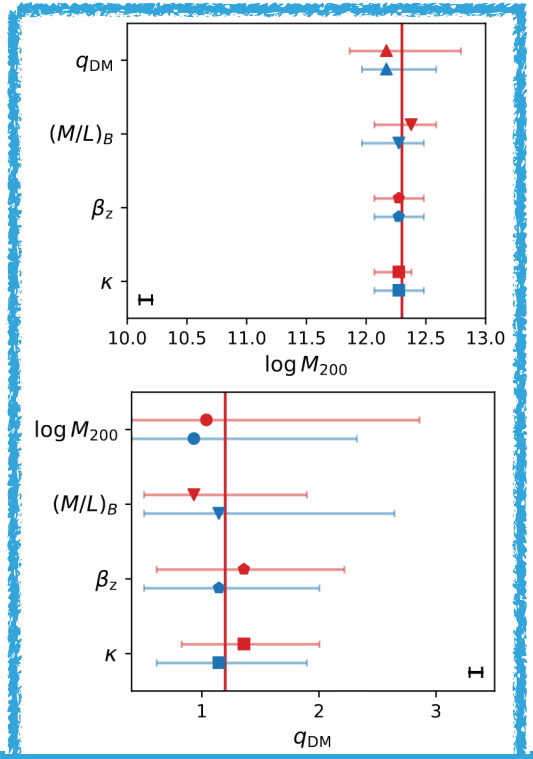

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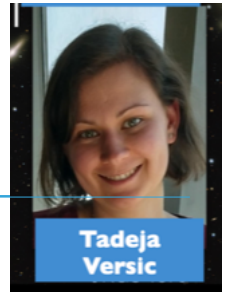

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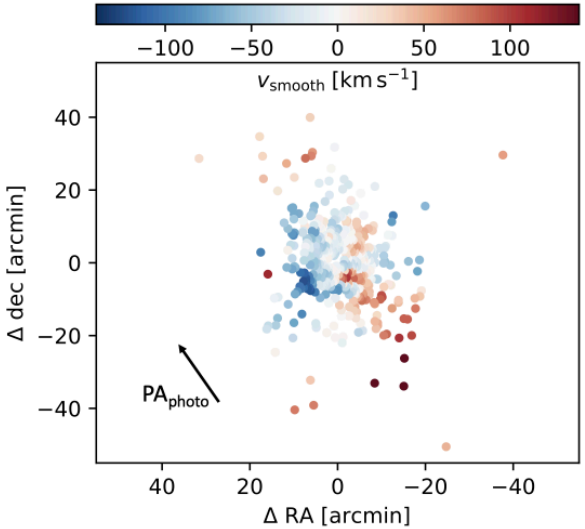

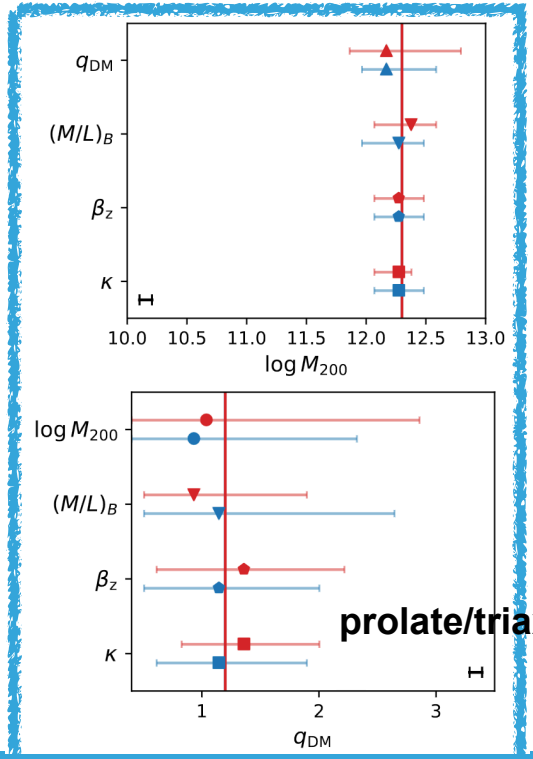

MAGPI: DYNAMITE AT HIGHER REDSHIFT

Goal: understanding the physical processes responsible for the rapid transformation of galaxies in this epoch
(MAGPI PIs: C. Foster, K. Harbonne, C. Lagos, T. Mendel, E. Wisnioski)

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MAGPI

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Derkenne, Santucci, Poci, ST et al. (in prep.)

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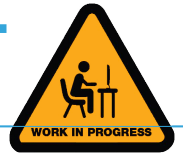

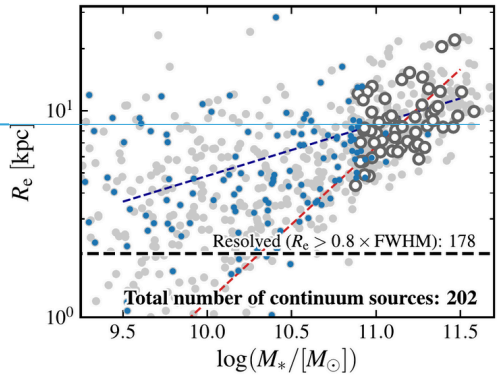

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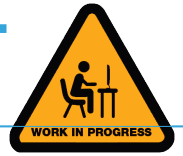

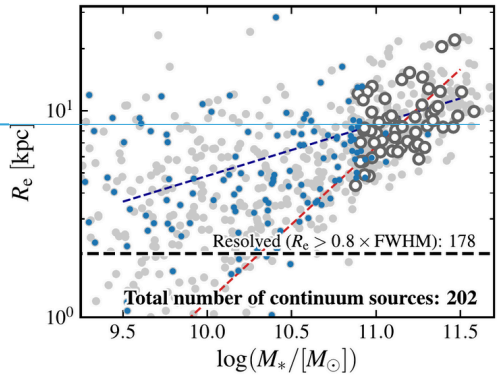

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Stellar kinematics

DYNAMITE models

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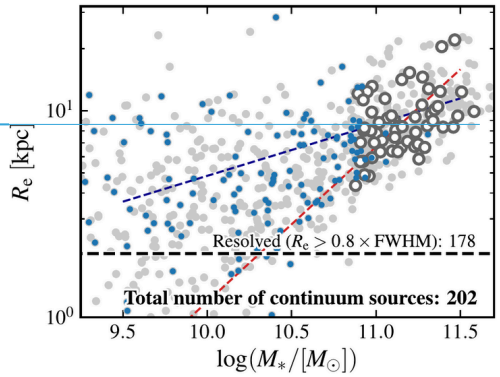
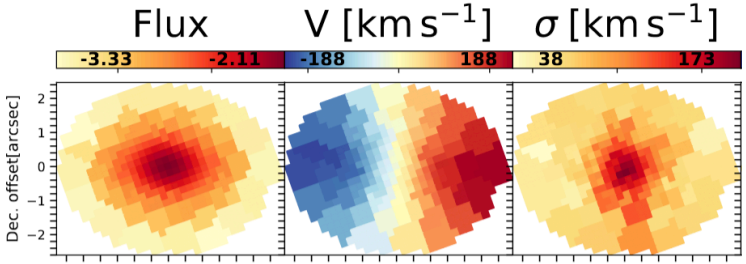


Goal: understanding the physical processes responsible for the rapid transformation of galaxies in this epoch
(MAGPI PIs: C. Foster, K. Harbonne, C. Lagos, T. Mendel, E. Wisnioski)

Stellar kinematics



DYNAMITE models

Derkenne, Santucci, Poci, ST et al. (in prep.)

MAGPI

- MUSE large programme
- 60 massive central galaxies and their 118 satellite galaxies with resolved stellar and gas properties
- Lookback time: 4 billion years (z=0.3)

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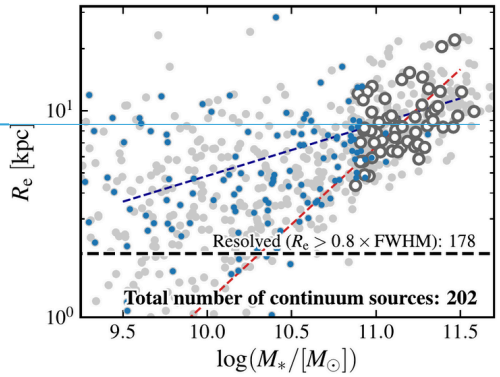

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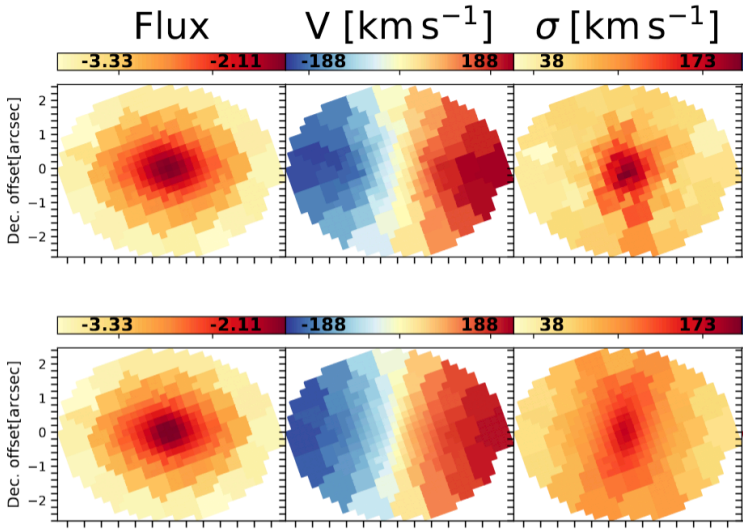

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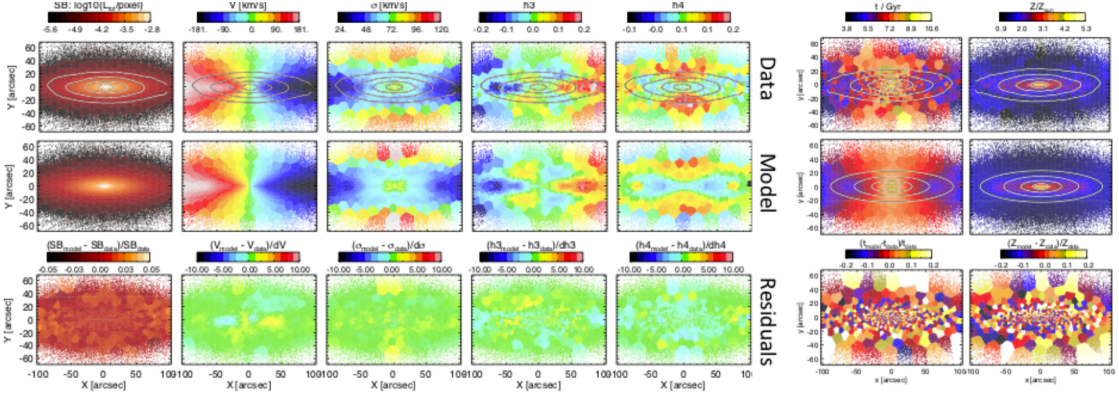
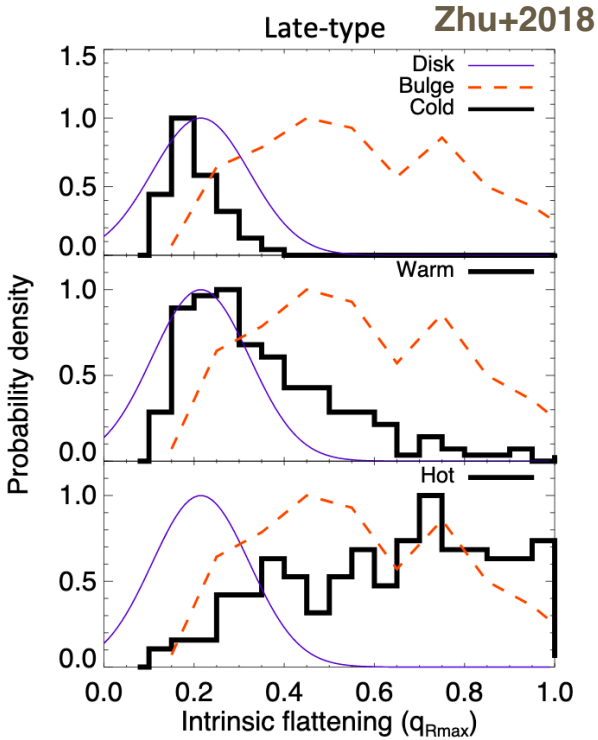


Zhu+2020



SUPERMASSIVE BLACK HOLES

- About 150 successful dynamical mass measurements in the nearby universe
- “Supermassive black hole” (10^6 - 10^{10} $M_\odot$)
- Upper limits: The black hole sphere of influence could not be resolved
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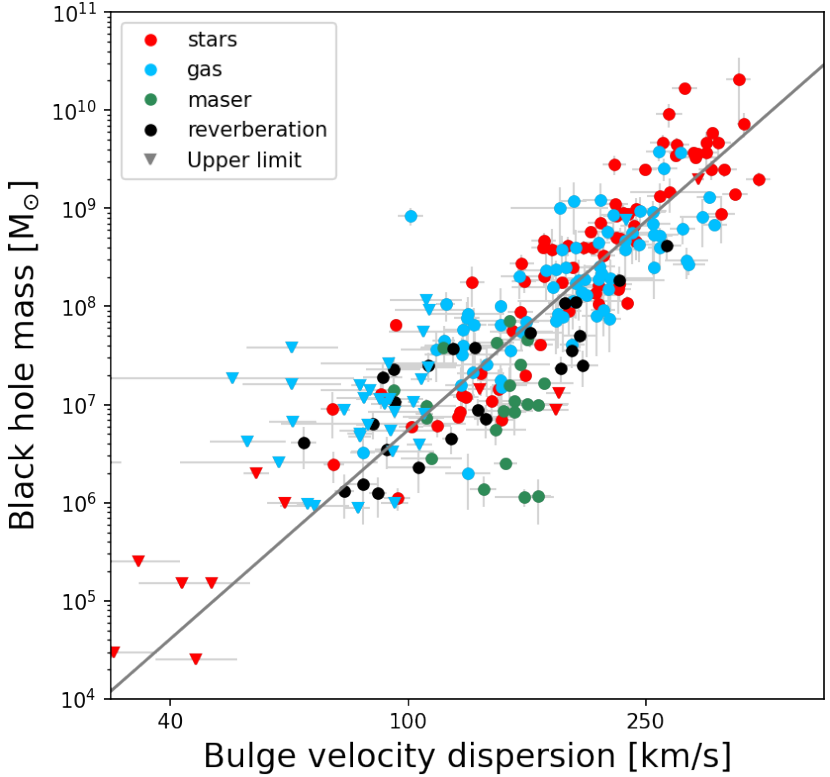

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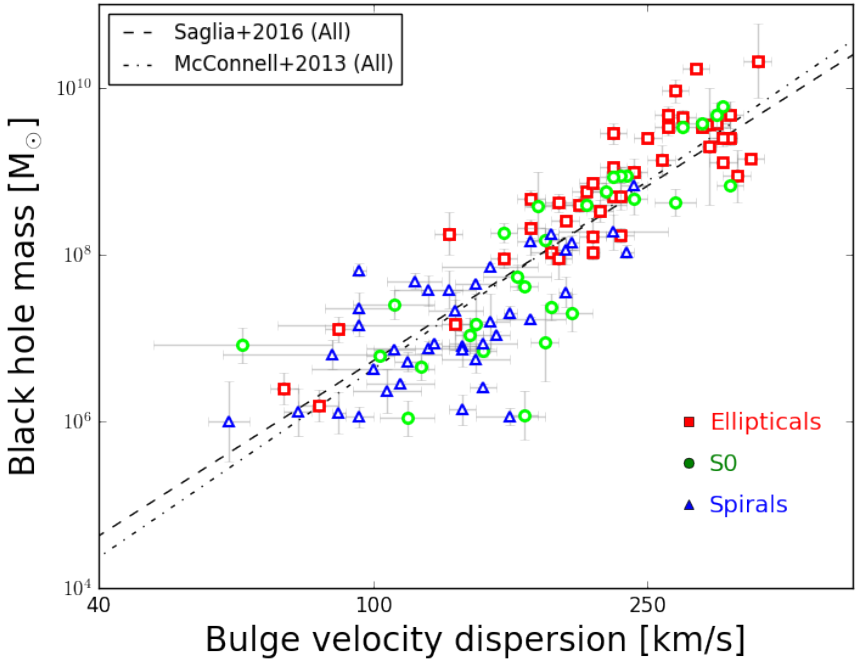
IS THE INHOMOGENEITY PROBLEMATIC?



Thater+2017, Krajnovic+2018,
Thater+2019, Thater (in prep.)

Thater et al.2020, 2021, 2022a
(adapted from Kormendy & Ho 2013

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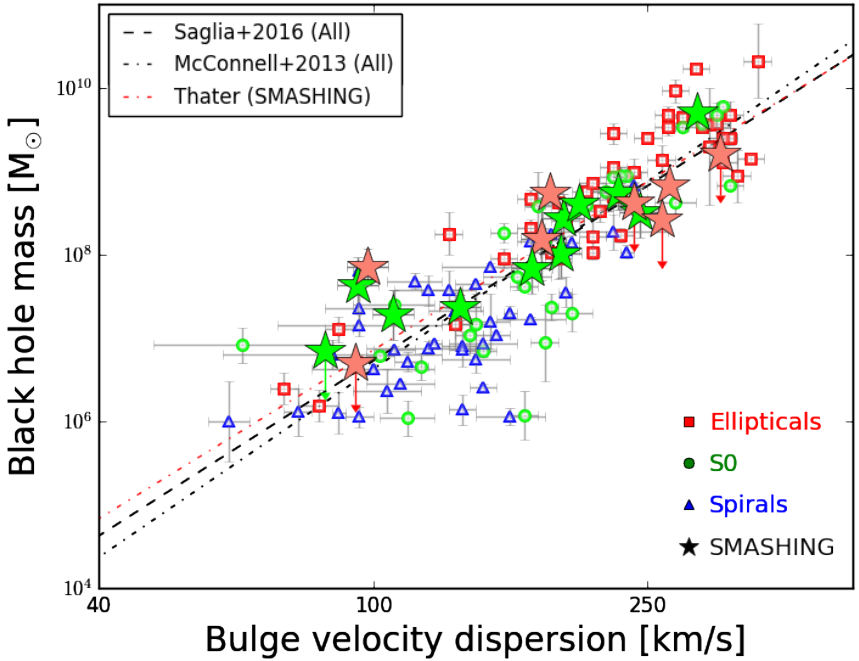

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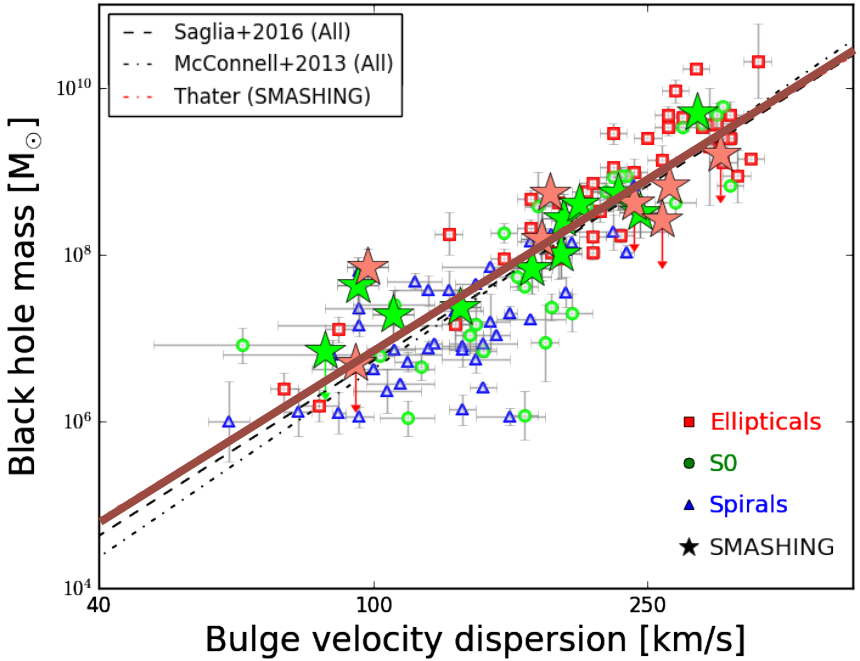

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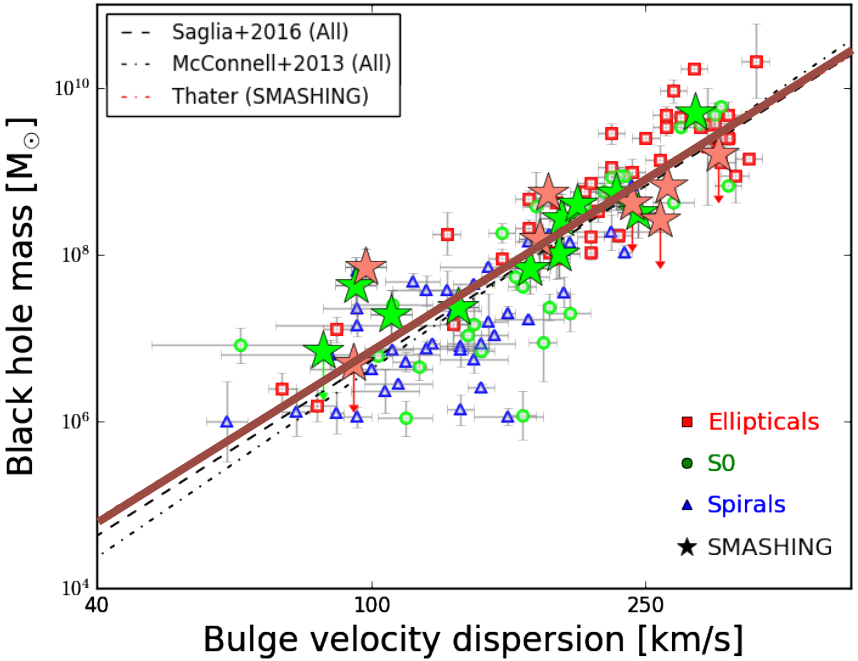

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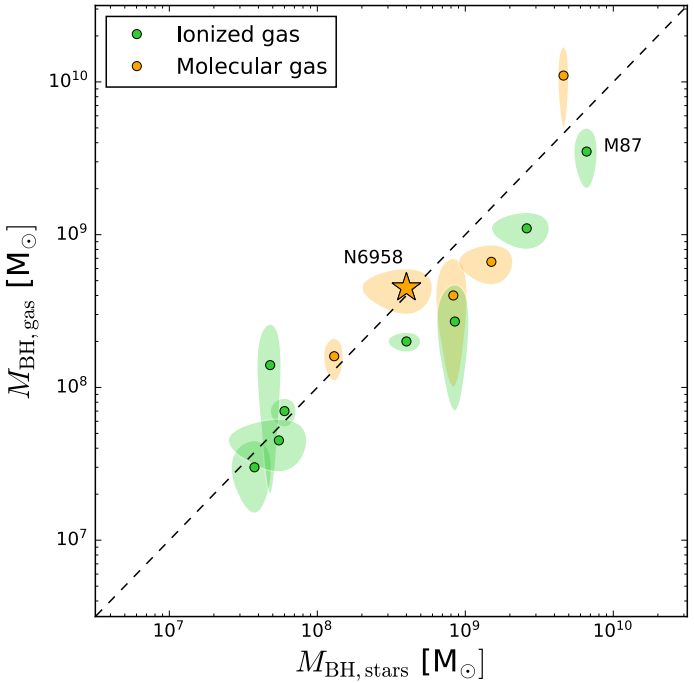

Thater et al.2020, 2021, 2022a
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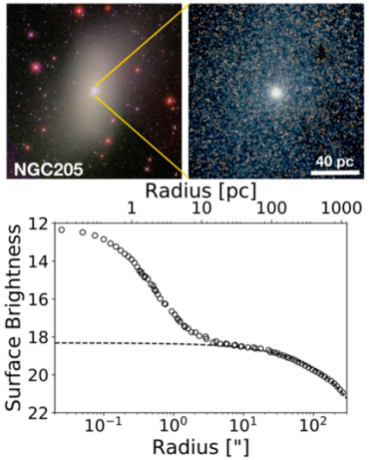
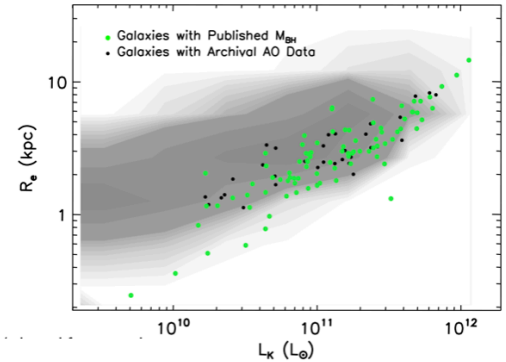
INCOMPLETE CENSUS DYNAMICAL GALAXY MODELS

- Nuclear star clusters



Neumeyer et al. 2020

- Less compact galaxies

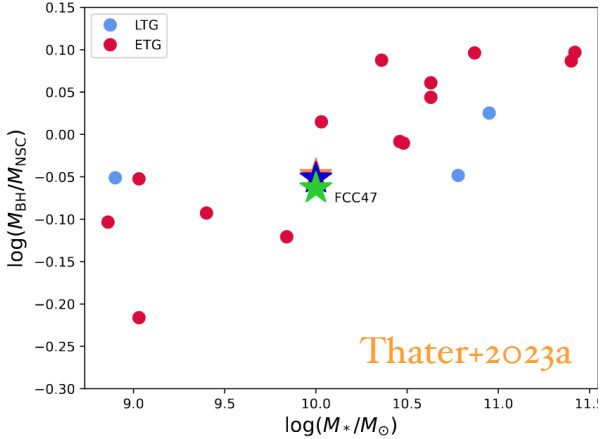


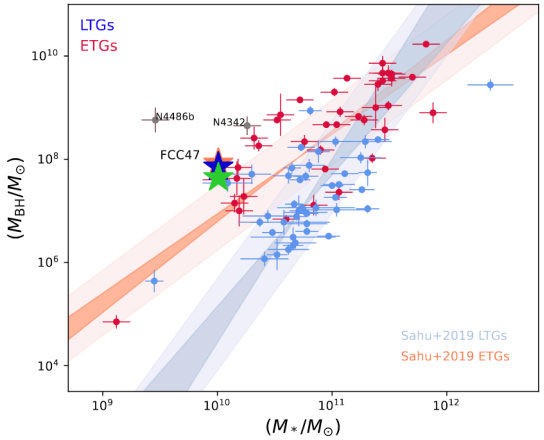
Walsh et al. (in prep.)

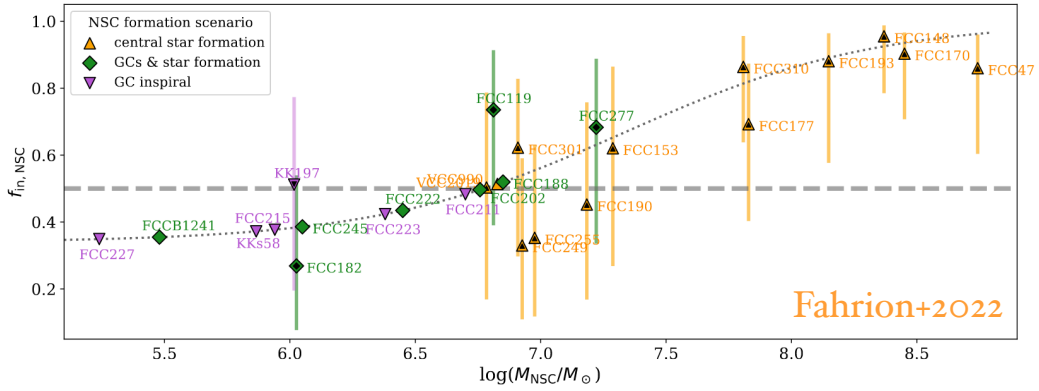
- Barred galaxies

NASA, ESA, and The Hubble Heritage Team STScI/AURA)

NUCLEAR STAR CLUSTERS







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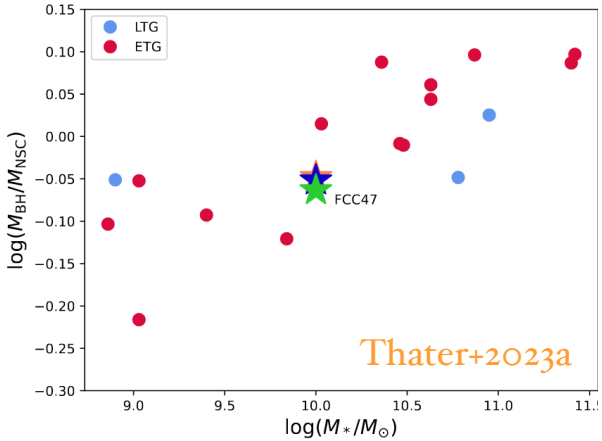

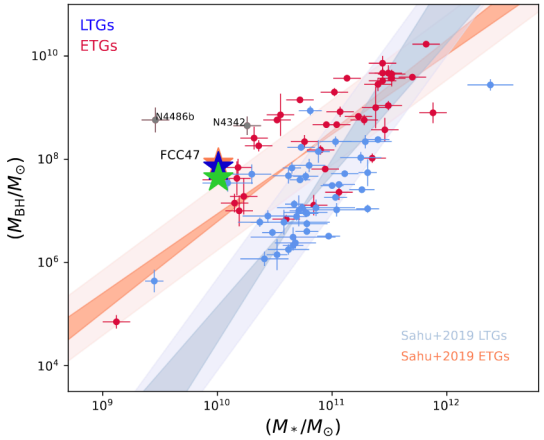

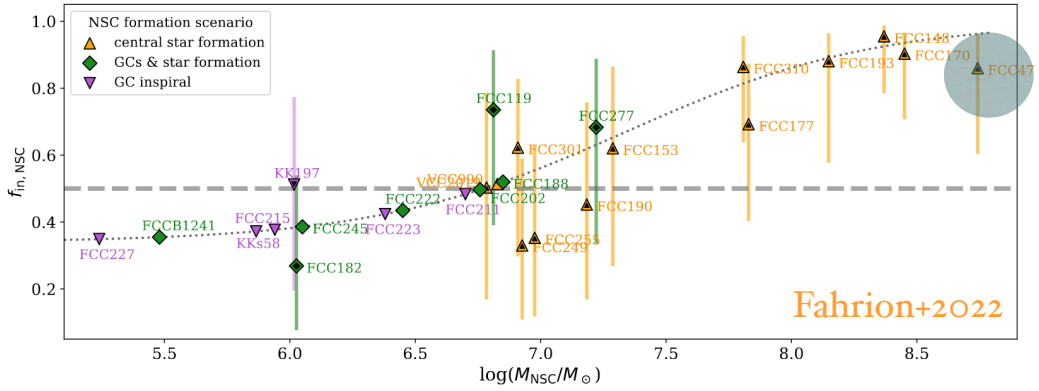

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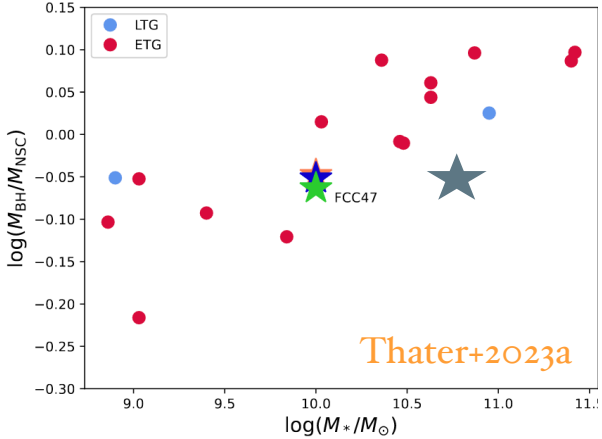
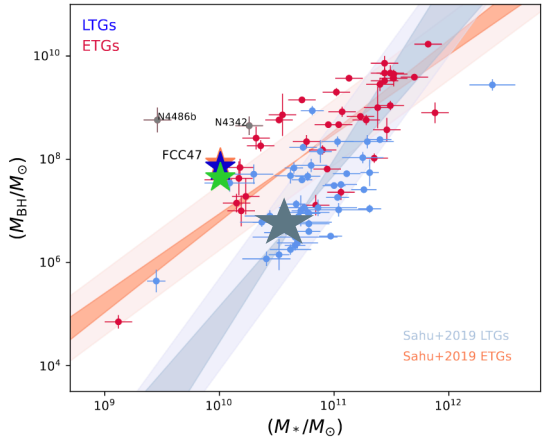
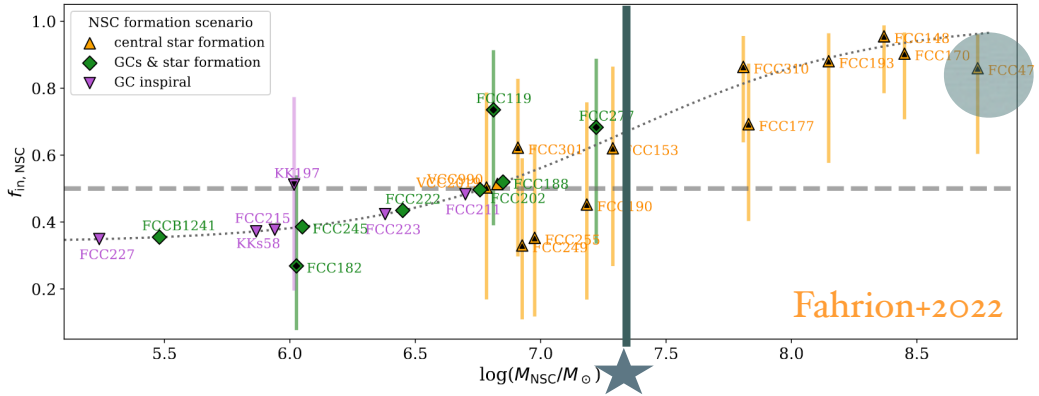




MW



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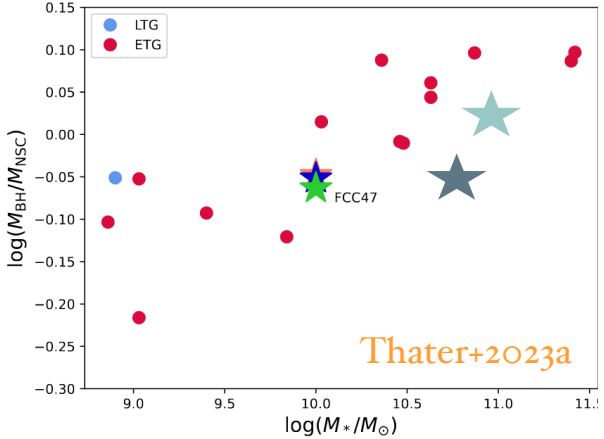
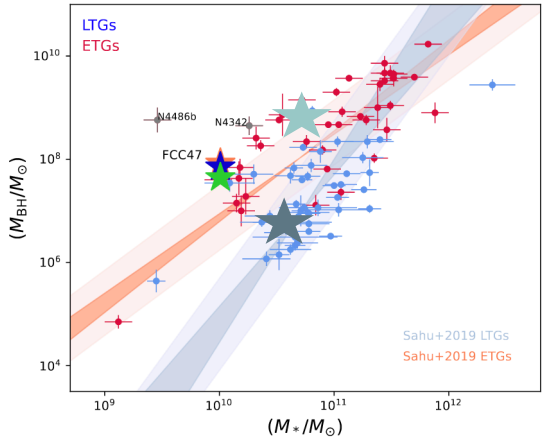
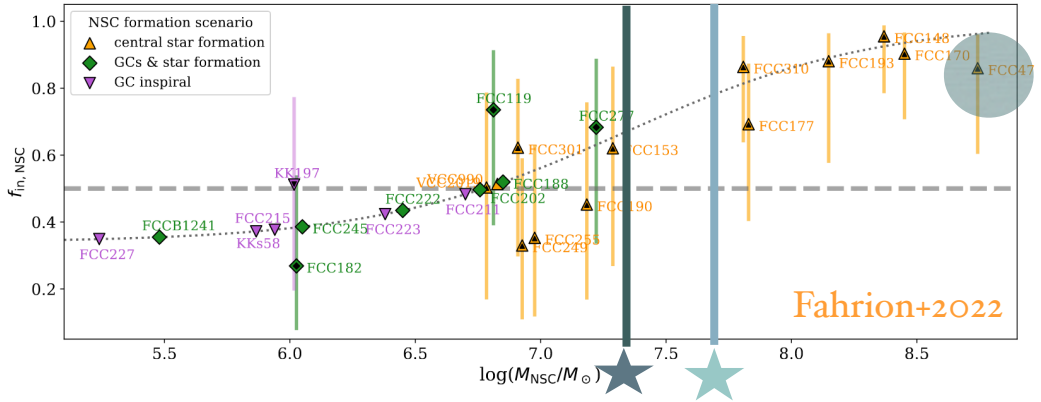


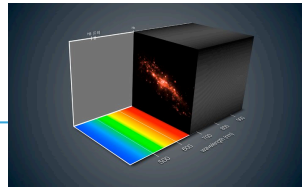


MW

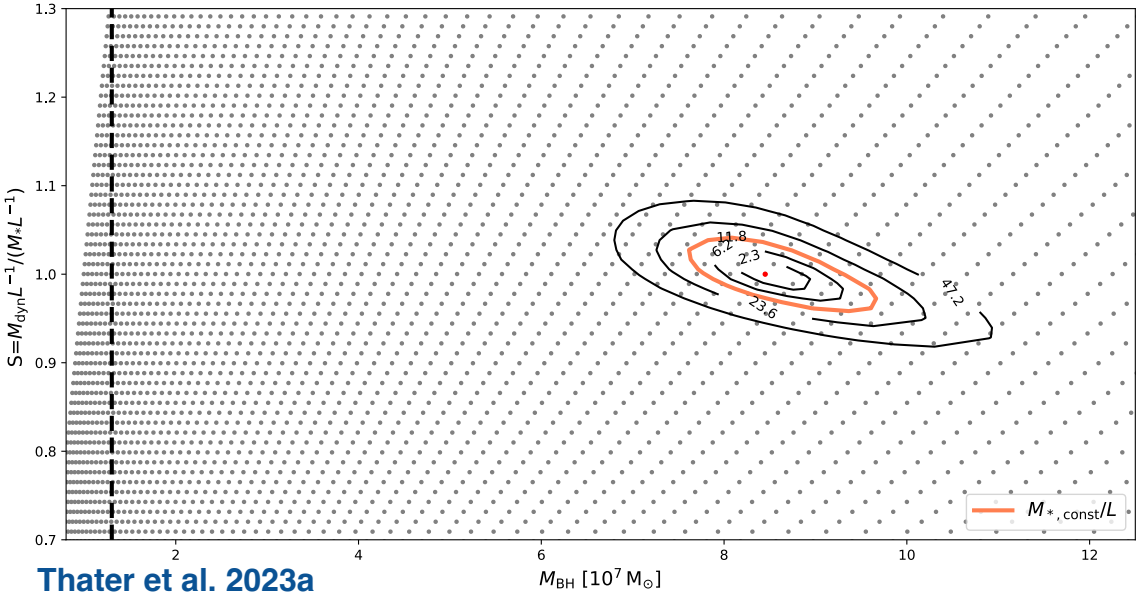
M31



M_{BH} AND THE IMPORTANCE OF STELLAR POPULATIONS



Constant M/L



Thater et al. 2023a

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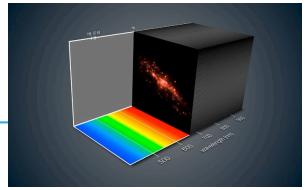
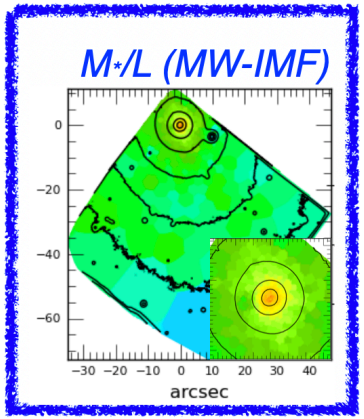
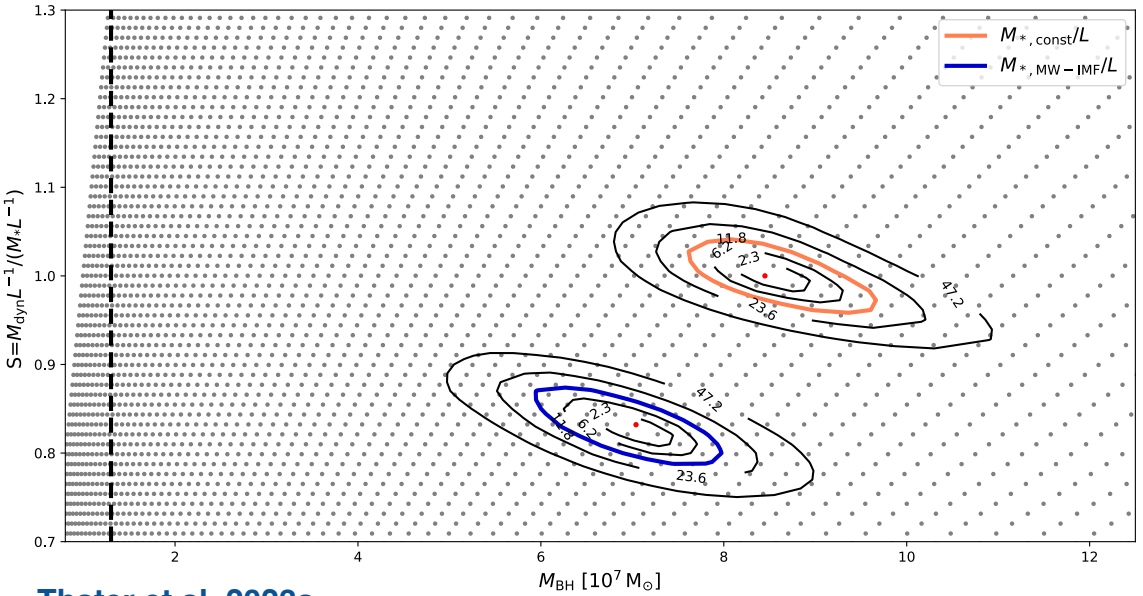




Constant M/L

Varying M/L & fixed IMF (M_{BH} ↓20%)



Thater et al. 2023a

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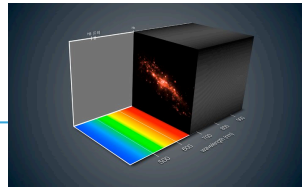
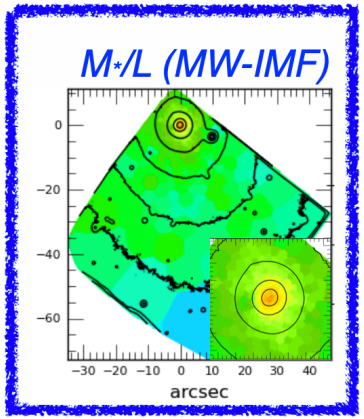
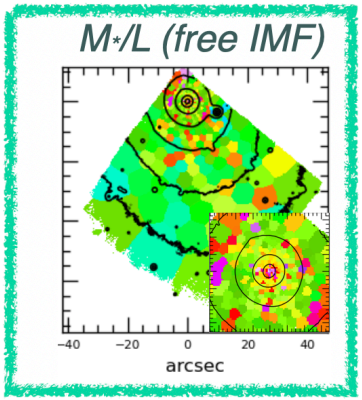


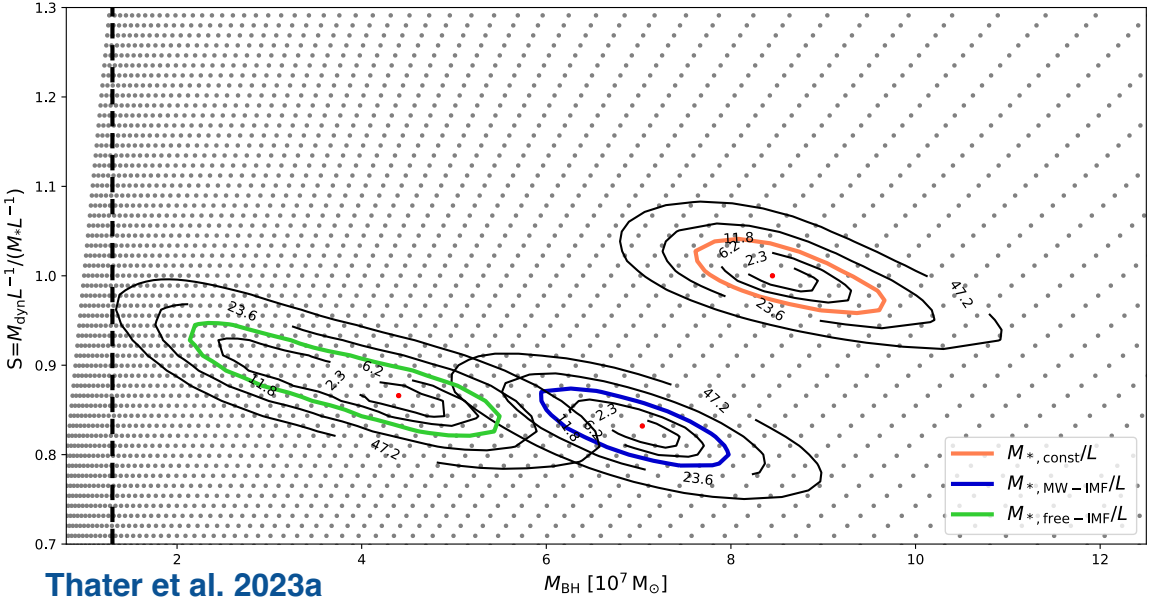




Constant M/L

Varying M/L & fixed IMF (M_{BH} ↓20%)

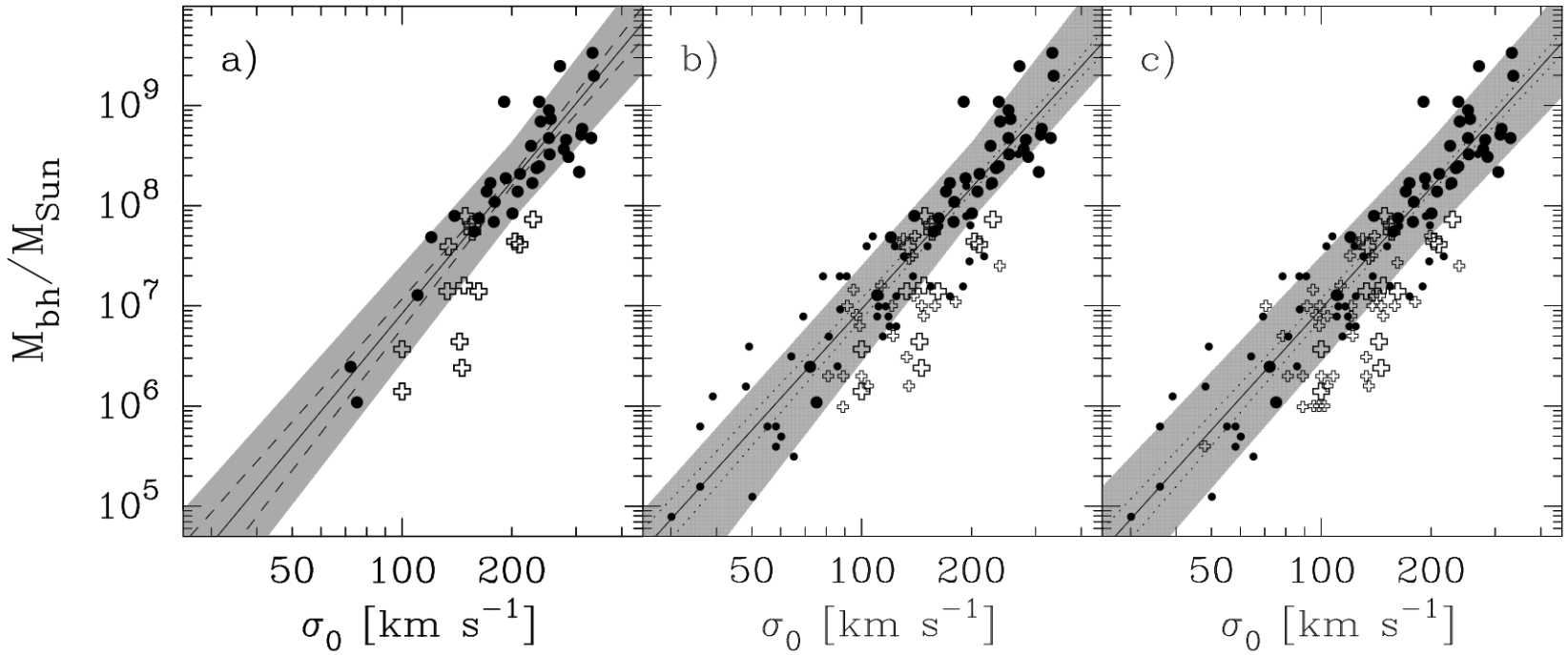
Varying M/L & varying IMF (M_{BH} ↓50%)



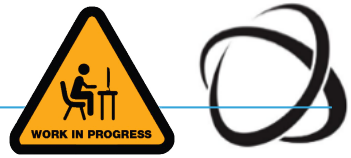
Thater et al. 2023a

BARRED GALAXIES ARE OFFSET FROM THE SCALING RELATIONS

Graham & Li 2009



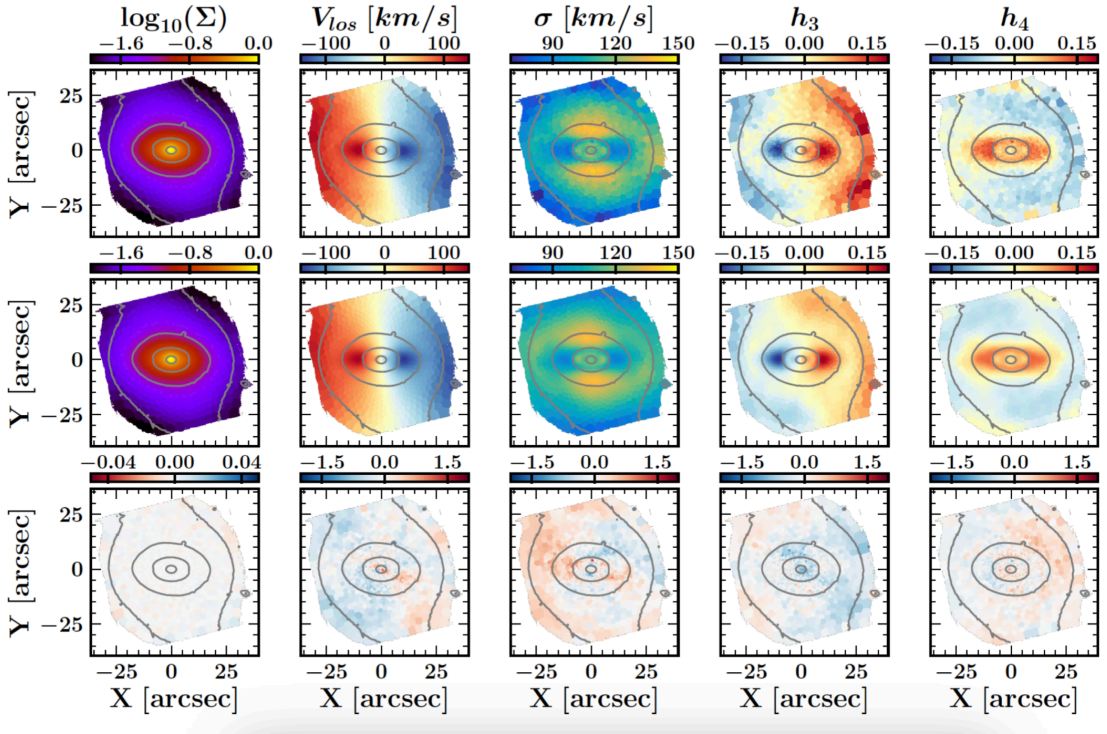
MODELLING BARRED STRUCTURES



Best fitting bar model using TIMER survey

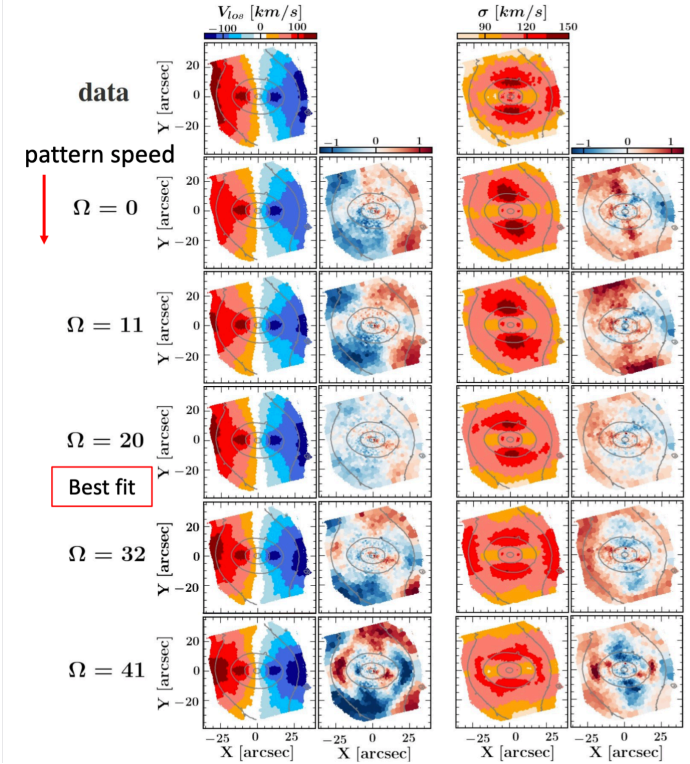
data

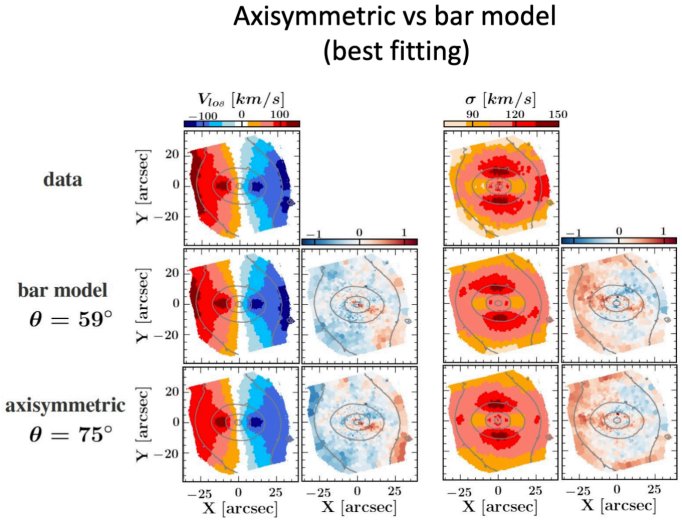
model



Tahmasebzadeh, …, ST et al. (in prep.), but also Valluri & Vasiliev 2020

MODELLING BARRED STRUCTURES





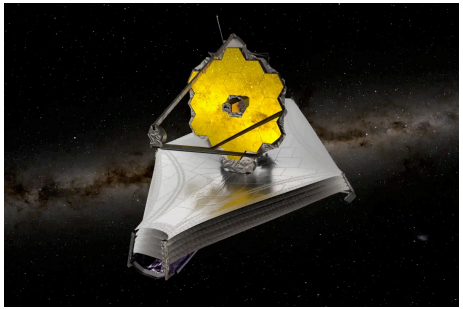
Inclination angle of NCG4371:

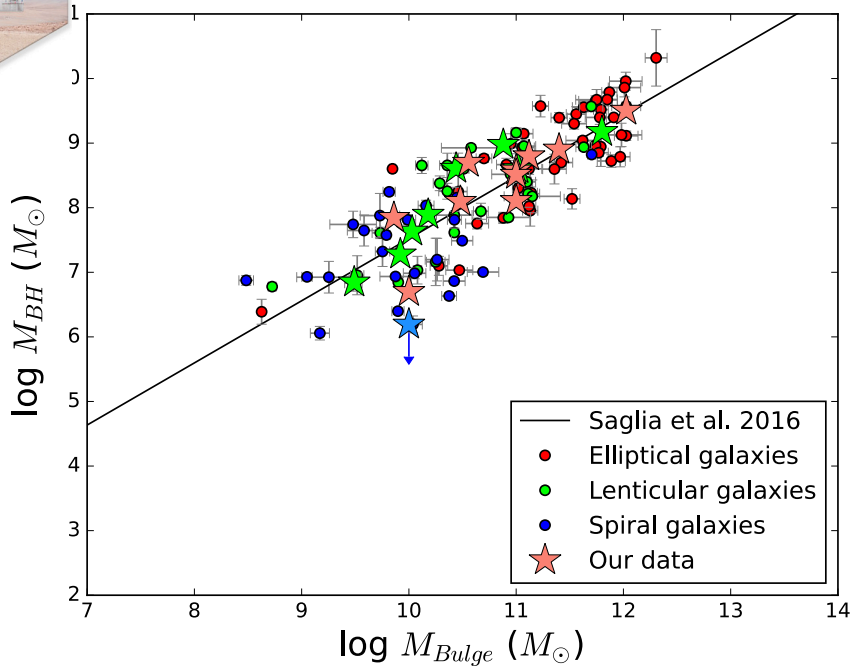
Erwin et al 2008 (~ 58)

Gadotti et al 2016 (~ 60)

Tahmasebzadeh, …, ST et al. (in prep.)

THE FUTURE IS BRIGHT!





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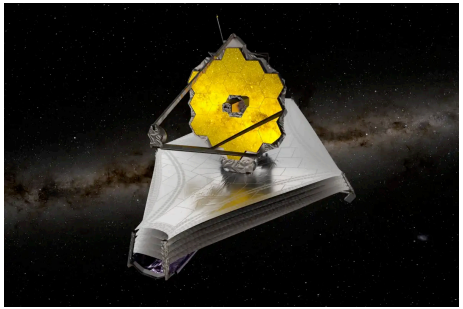

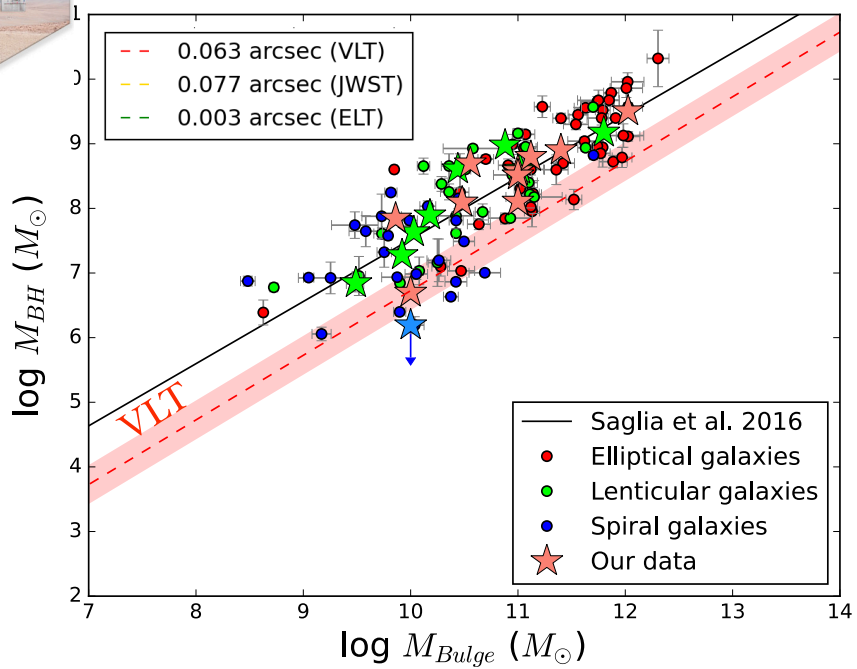

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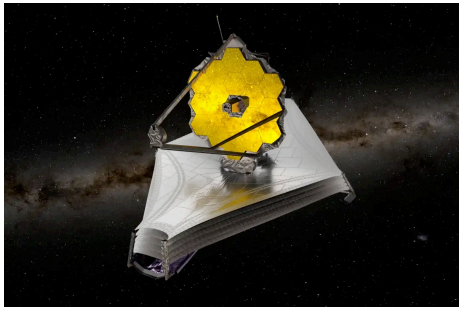

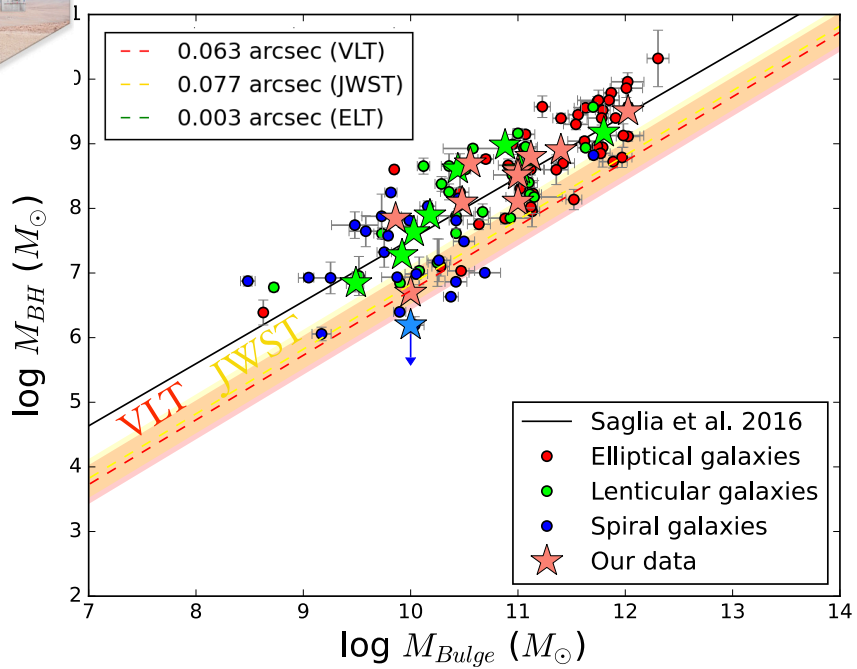

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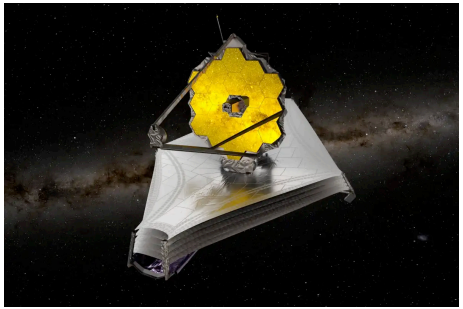

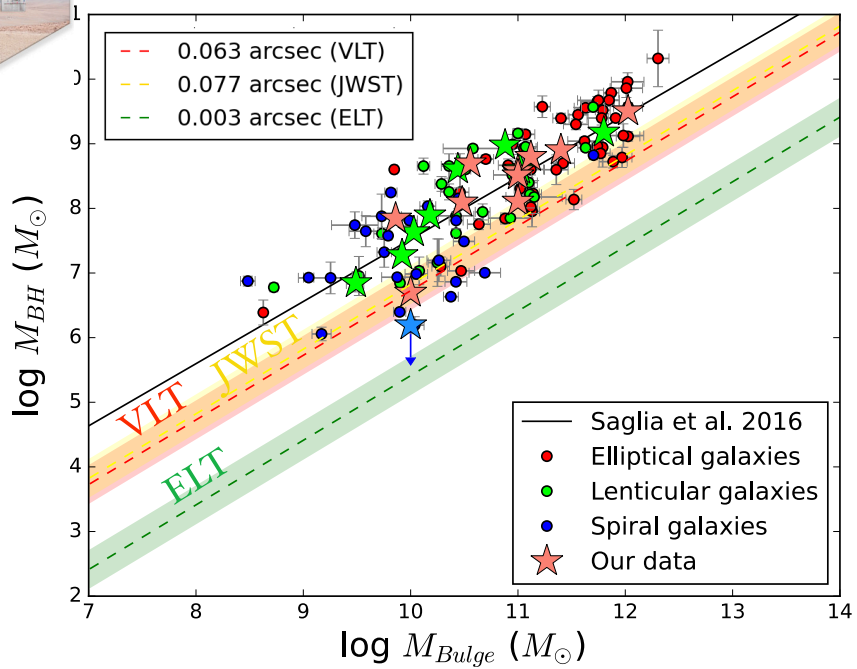

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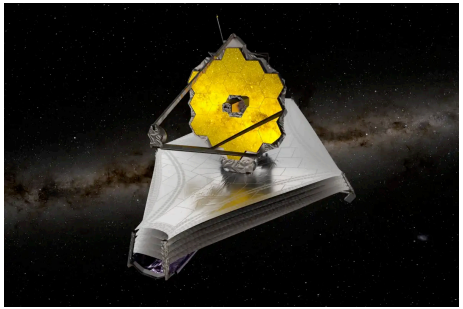
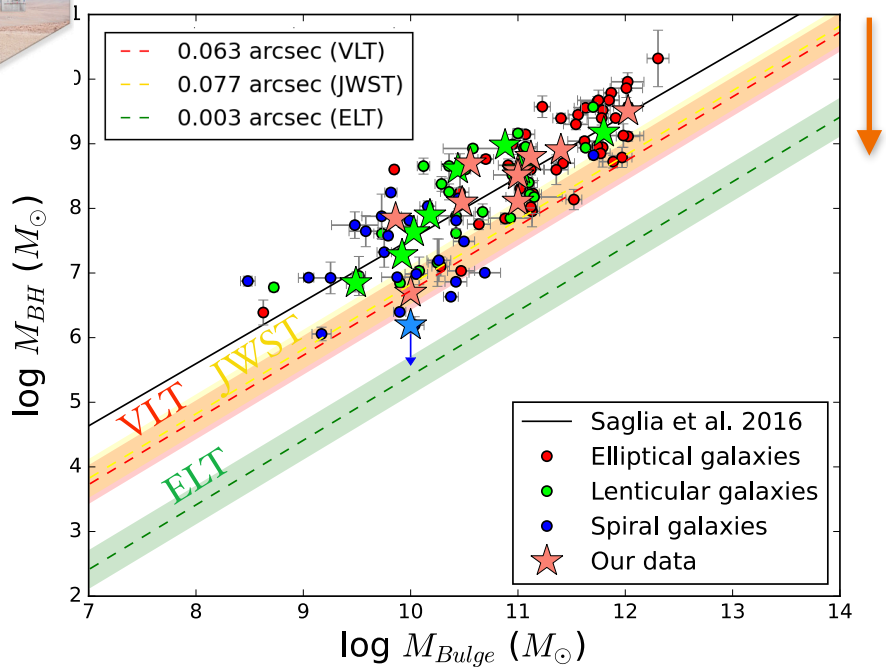




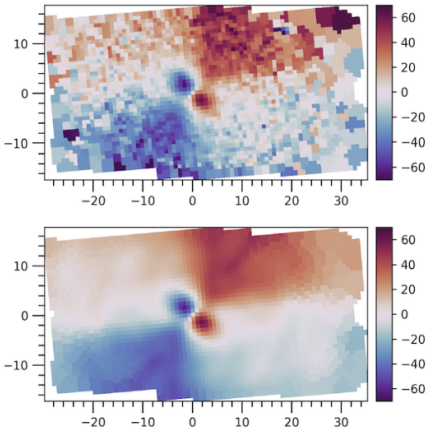
More than one Magnitude lower!

TAKE HOME

DYNAMITE allows the dynamical modelling of complex triaxial features such as kinematically decoupled components.

Although the ATLAS^{3D} kinematics only cover 1Re we can see the u-shape trend in the **dark matter fraction**. Improvements require stellar kinematics at larger radii or the simultaneous modelling of stellar kinematics and discrete tracers.

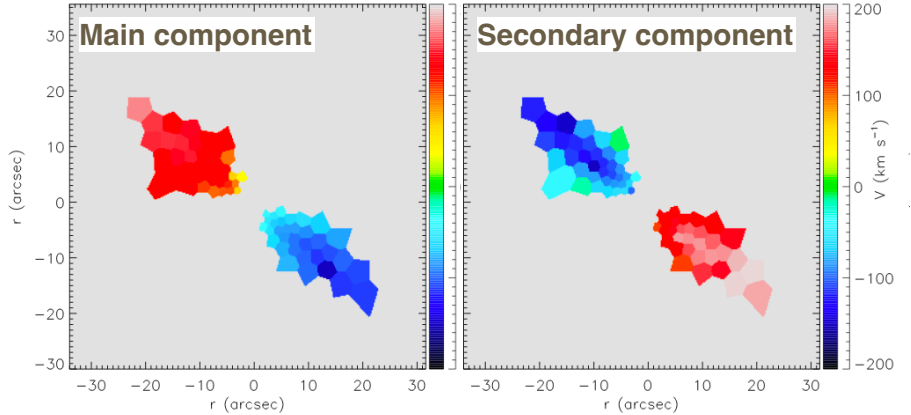
Orbit-superposition modelling allows us to **disentangle different galaxy components,** like bar, NSC, etc. and study them in detail



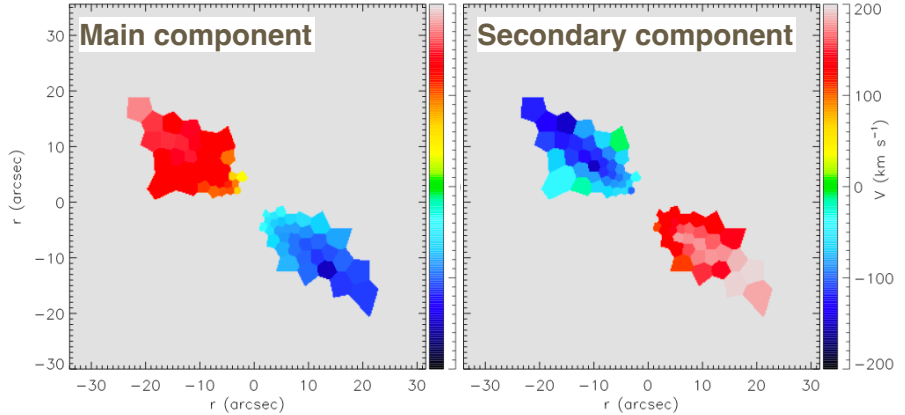
JOIN US IN CAPE TOWN NEXT YEAR!

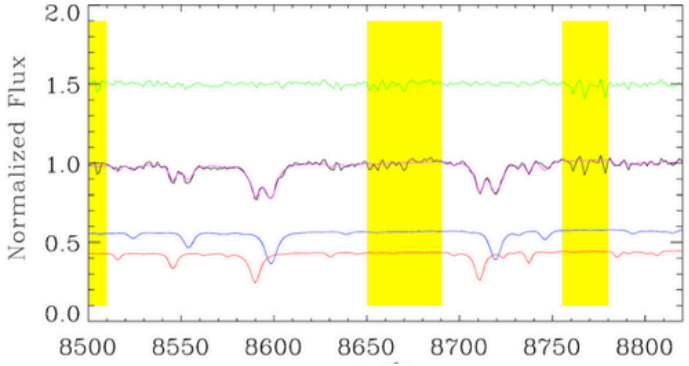
Detailed LOSVDs <——> counter-rotating galaxies

Detailed LOSVDs <—–> counter-rotating galaxies



Detailed LOSVDs <—–> counter-rotating galaxies





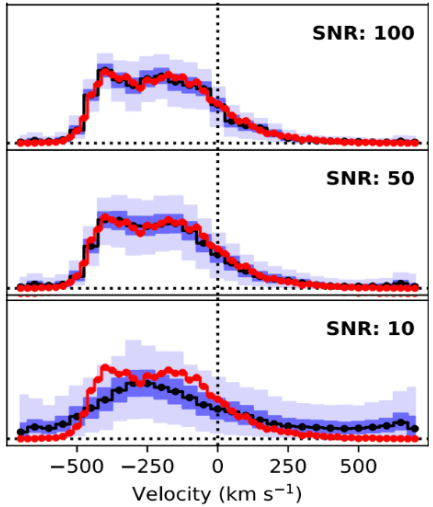
IC 719 (Pizella+2018) , Thater et al. (in prep.)

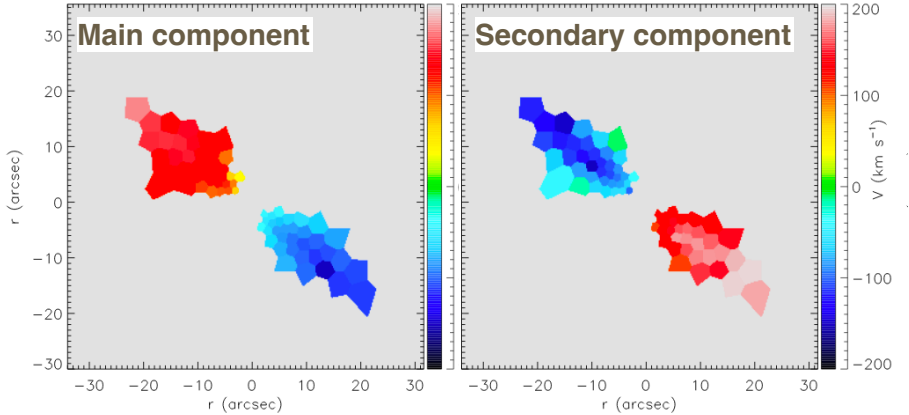
Detailed LOSVDs <—–> counter-rotating galaxies

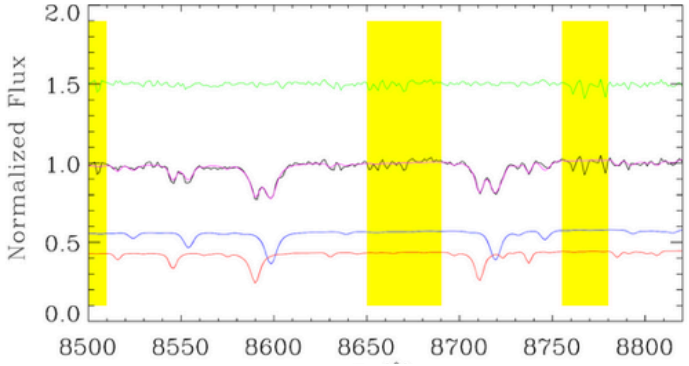
What LOSVD information can we extract from the spectrum?

- currently: Gauss-hermite
- soon: much, much more details
  - Histograms
  - B-splines

BAYES LOSVD
Jesus Falcon Barroso &
Marie Martig







IC 719 (Pizella+2018) , Thater et al. (in prep.)

Orbit mirroring bug fixed

Thater et al. (2022b)