Presented by:

RAFFAELE **PASCALE**

Collaborators:
Francesca Annibali
Monica Tosi
Michele Bellazzini
Federico Marinacci
Carlo Nipoti

Hydrodynamical *N*-body simulations of the local dwarf galaxies NGC 5474 and DDO 68

Astrophysics Talk

02/03/21

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Outlines

The "putative" bulge of NGC 5474

- An off-set bulge: constraints from observations
  - Initial conditions of the simulations

Results:

- Is the bulge of 5474 a bulge at all?
  - On-plane and satellite simulations
    - The SW overdensity

DDO 68: A multiple merger at dwarf scales

- Mophological peculiarities
  - The XMD DDO 68

Results:

- New hydrodynamical *N*-body models
  - Low metallicity as a the result of a merger?

NGC 5474

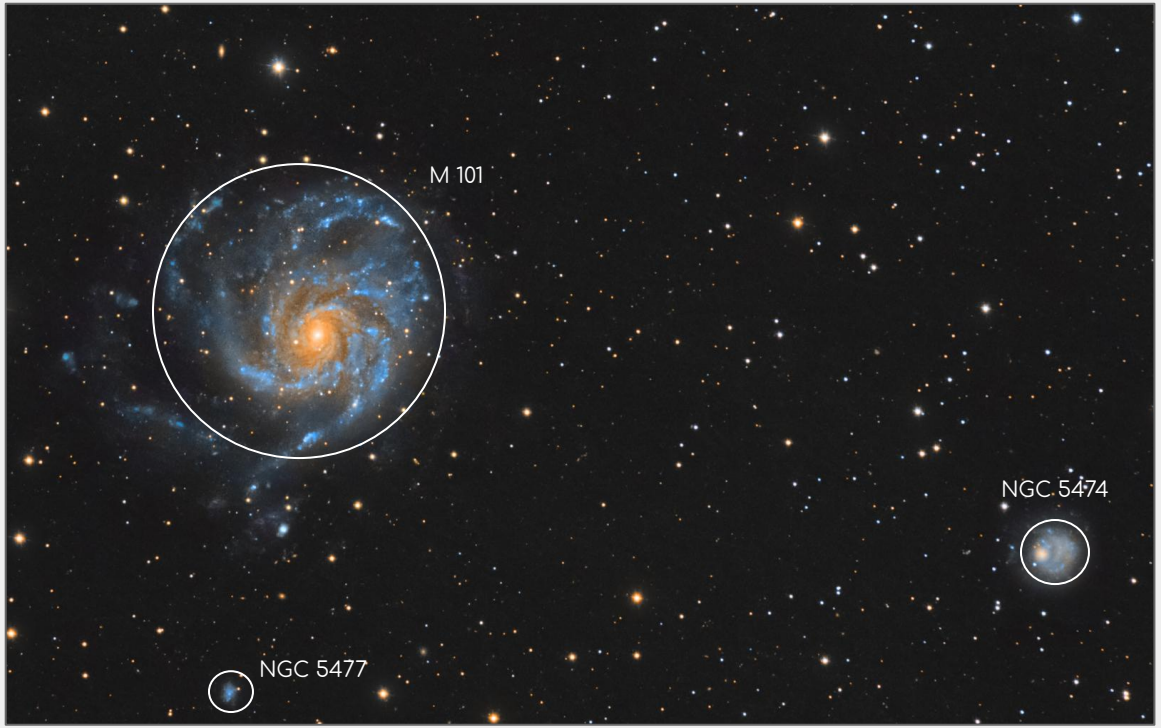
DDO 68

NGC 5474

- Satellite of M 101 (d=6.98 Mpc)
- Peculiar star forming galaxy

Peculiarities:

- Off-set bulge
- SW-overdensity of old stars
- Warped HI



Credits:
https://www.astrobin.com/1c969n/E/?nc=all

Credits: T.A. Rector/University of Alaska Anchorage, H. Schweiker/WIYN and NOIRLab/NSF/AURA

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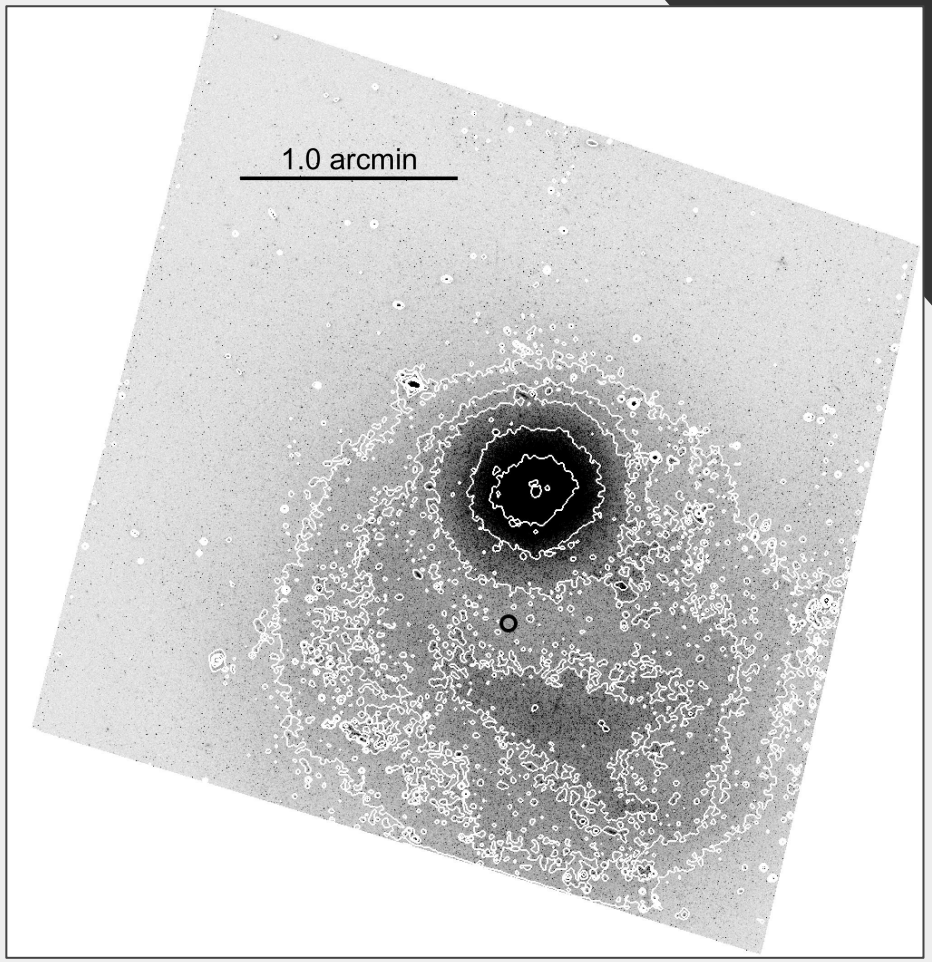
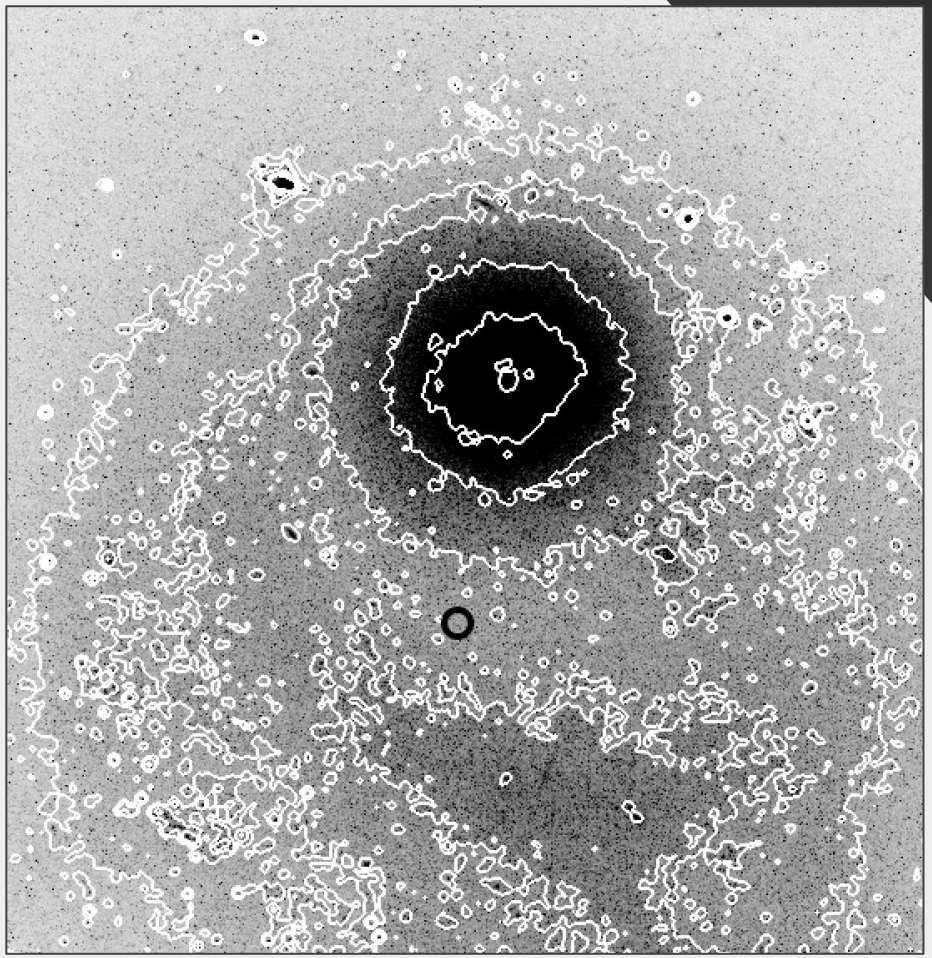


- Off-set of 1 kpc between the optical center and the kinematic centres of the HI and Hα discs
- Structural properties of the bulge very similar to the ones of a dE
- Very regular and round spatial distribution
- Overdensity of stars extending to the opposite direction of the bulge

Bellazzini et al. (2020)



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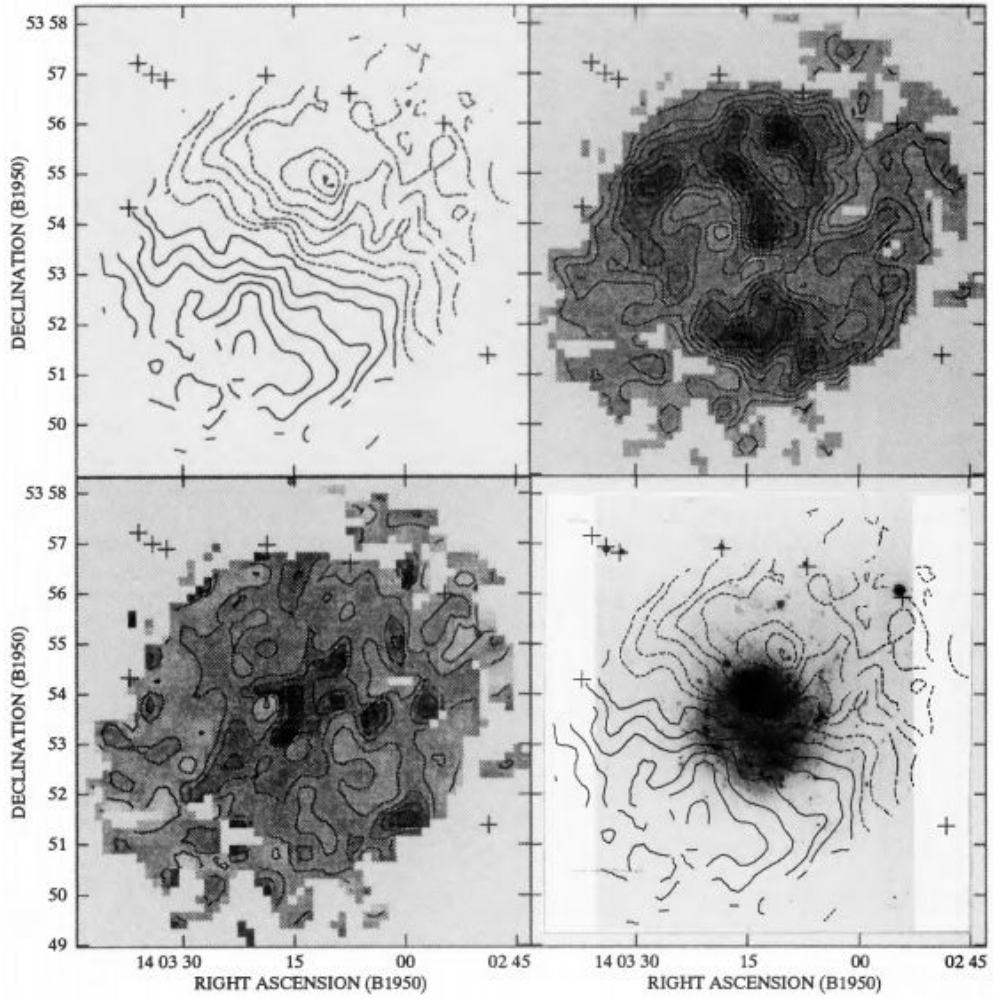
Rownd et al. (1994)



- Gas kinematics traced by HI emission
- Regular velocity field over a region 6 kpc wide from the kinematic center
- Low-inclination (i ~21°)
- Warped HI disc
- Is the HI velocity field compatible with the presence of a massive stellar component?

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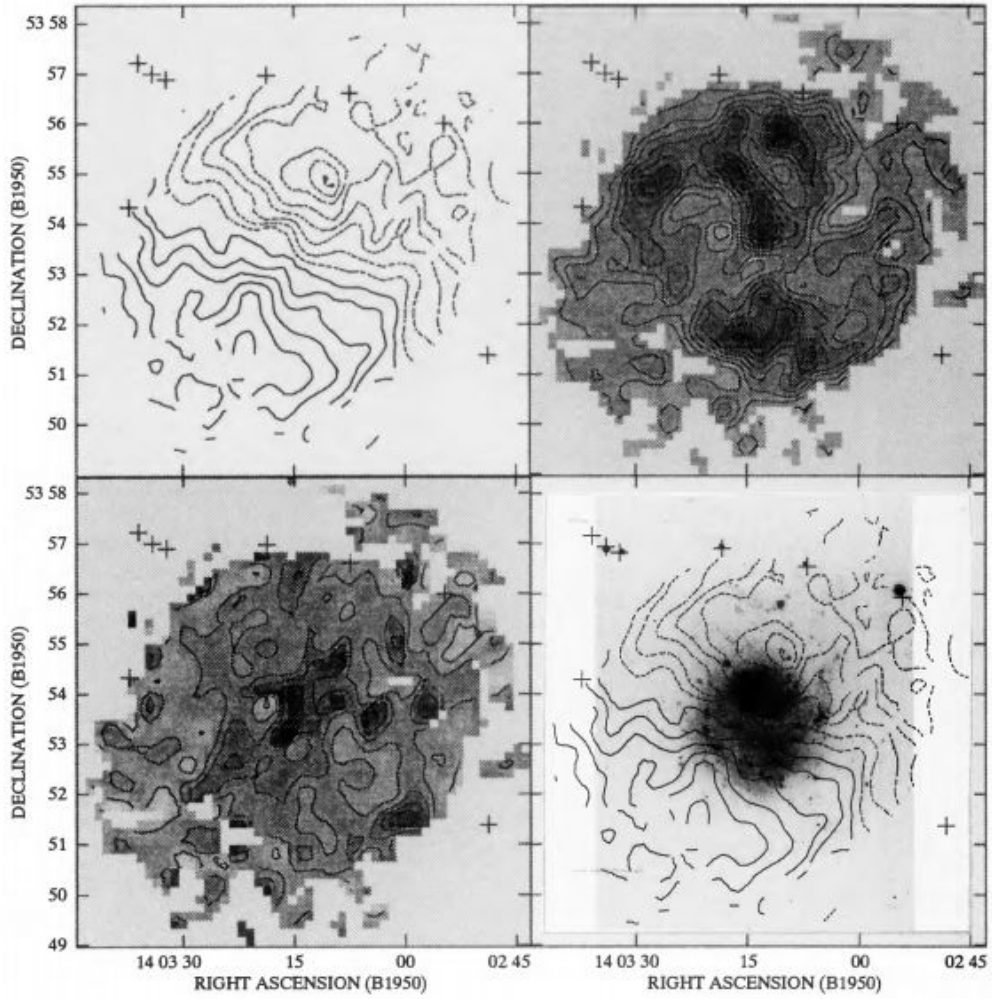
Rownd et al. (1994)



Is the bulge of NGC 5474 a bulge at all?

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The galaxy model of NGC 5474

- Dark-matter halo

$$\rho_{\rm dm}(r) = \frac{4\rho_{\rm s}}{\frac{r}{r_{\rm s}}\left(1+\frac{r}{r_{\rm s}}\right)^2}$$

- Stellar disc

$$\Sigma_{\star}(R) = \frac{M_{\star}}{4\pi h_{\star}^2} e^{-\left(\frac{R}{h_{\star}}\right)}$$

- Gas disc

$$\Sigma_{\rm gas}(R) = \frac{M_{\rm gas}}{4\pi h_{\rm gas}^2} e^{-\left(\frac{R}{h_{\rm gas}}\right)}$$

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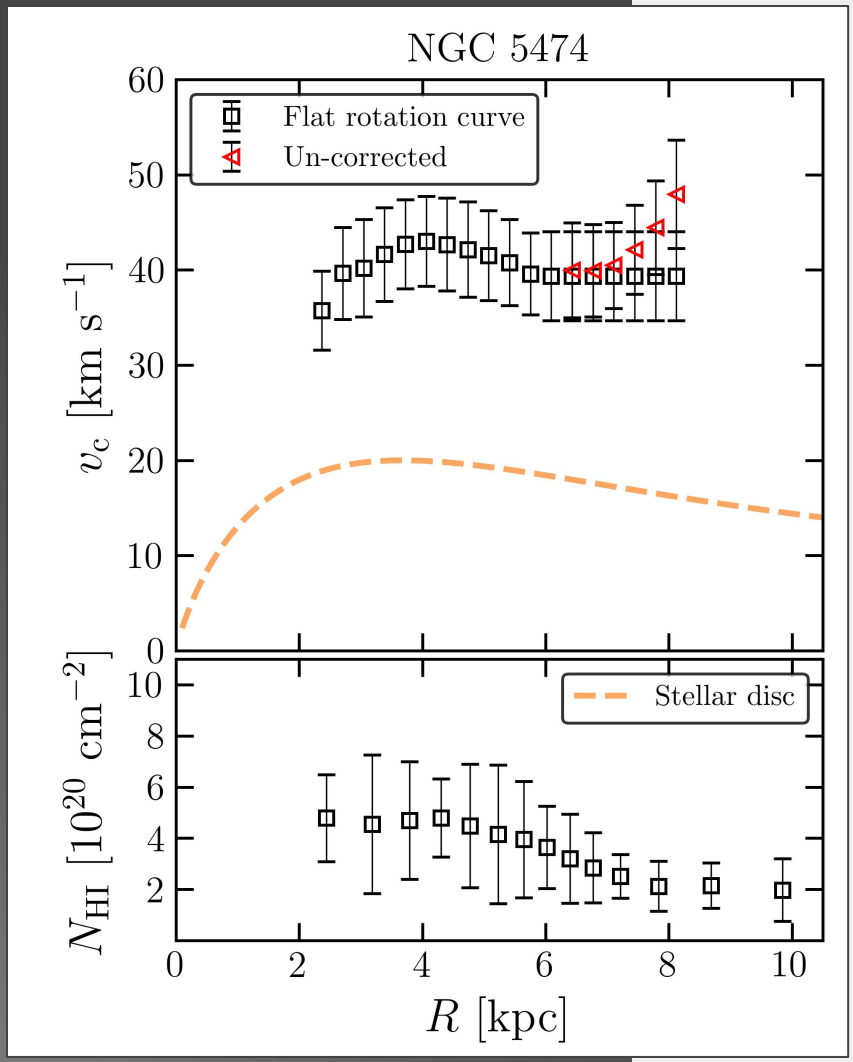

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(Fisher & Drory 2010)

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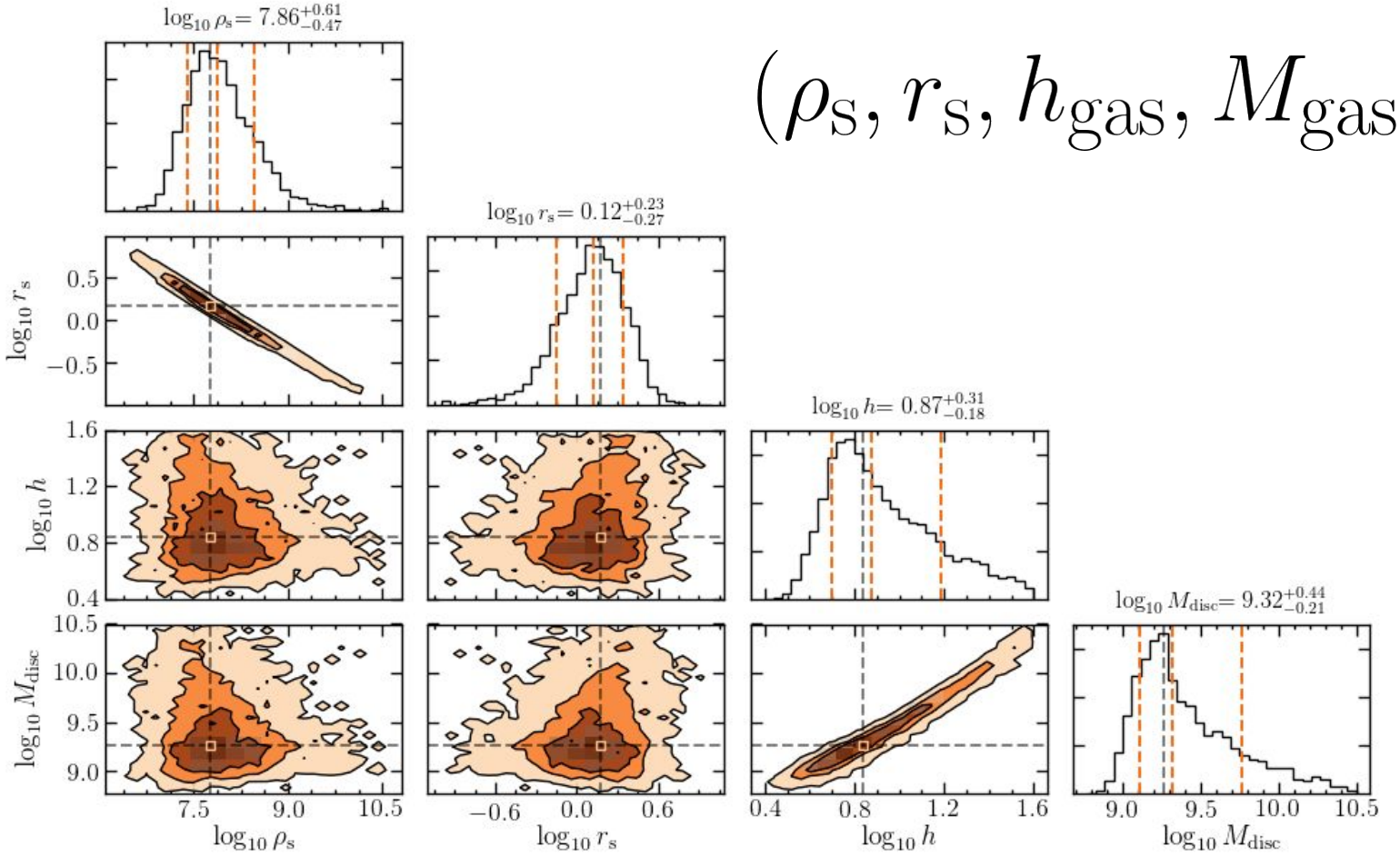
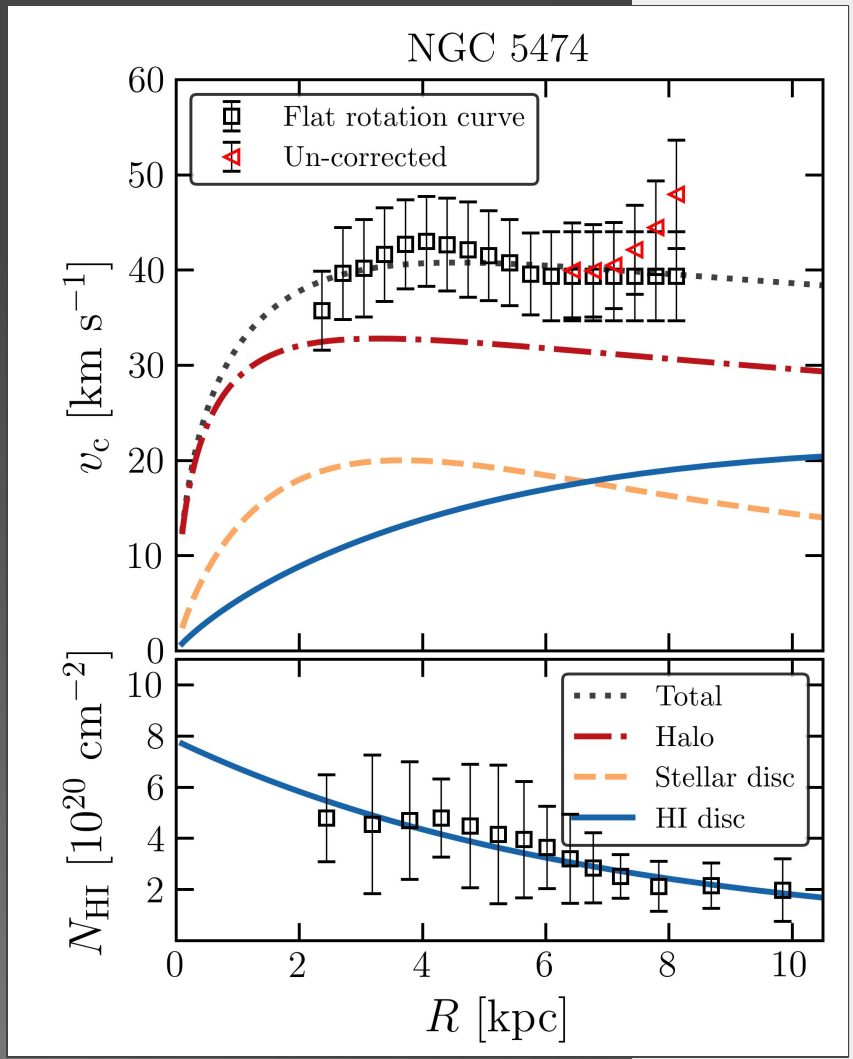


$$(\rho_{\rm s}, r_{\rm s}, h_{\rm gas}, M_{\rm gas})$$



The galaxy model of NGC 5474

- Dark-matter halo

$$\rho_{\rm dm}(r) = \frac{M_{\rm dm}}{2\pi}\frac{a}{r(a+r)^3}$$

- Stellar disc

$$\Sigma_\star(R) = \frac{M_\star}{4\pi h_\star^2 z_\star} e^{-\left(\frac{R}{h_\star}\right)} \mathrm{sech}\left(\frac{z}{z_\star}\right)$$

- Gas disc

$$\Sigma_{\rm gas} = \frac{M_{\rm gas}}{2\pi h_{\rm gas}^2} e^{-\left(\frac{R}{h_{\rm gas}}\right)} = \int_{-\infty}^{+\infty} \rho_{\rm gas}(R,z)\mathrm{d}z$$

Pascale et al. (2020)

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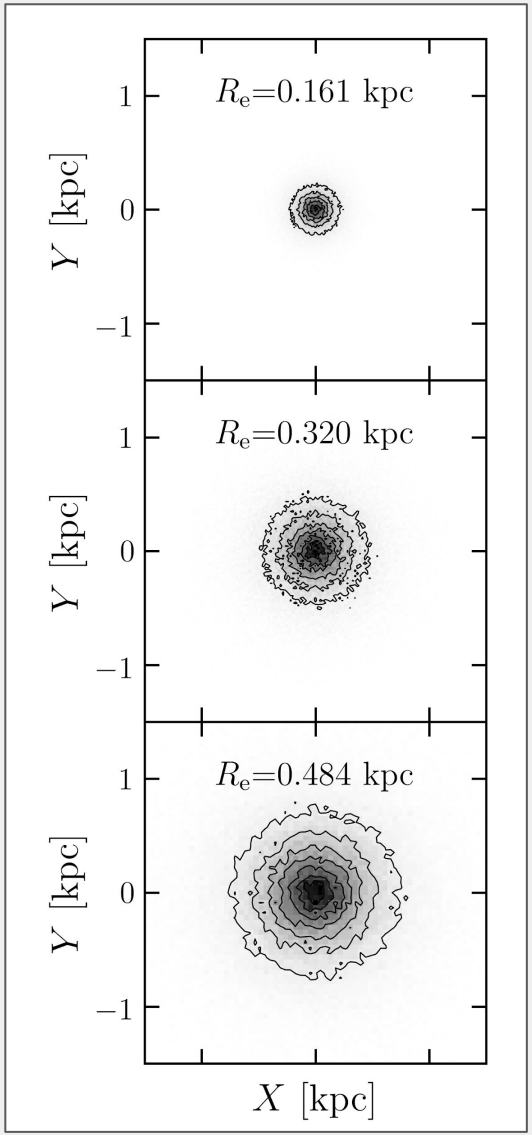

The PB model

$$\Sigma(R) = M_{\rm PB}\Sigma_0 e^{-b_m\left(\frac{R}{R_e}\right)^{\frac{1}{m}}}$$

- Structural properties from Bellazzini et al. (2020)

On-plane simulations (only stars)

- Set of 12 simulations exploring different sizes (Re) and masses of the PB (MPB)
- Explore multiple scenario (external origin, real bulge ...)

Satellite simulations (+dark matter)

- Alternative scenario where the PB is a satellite galaxy of NGC 5474
- The PB is embedded with a dark-matter halo as a dE
- Off-set reproduced by projection effects

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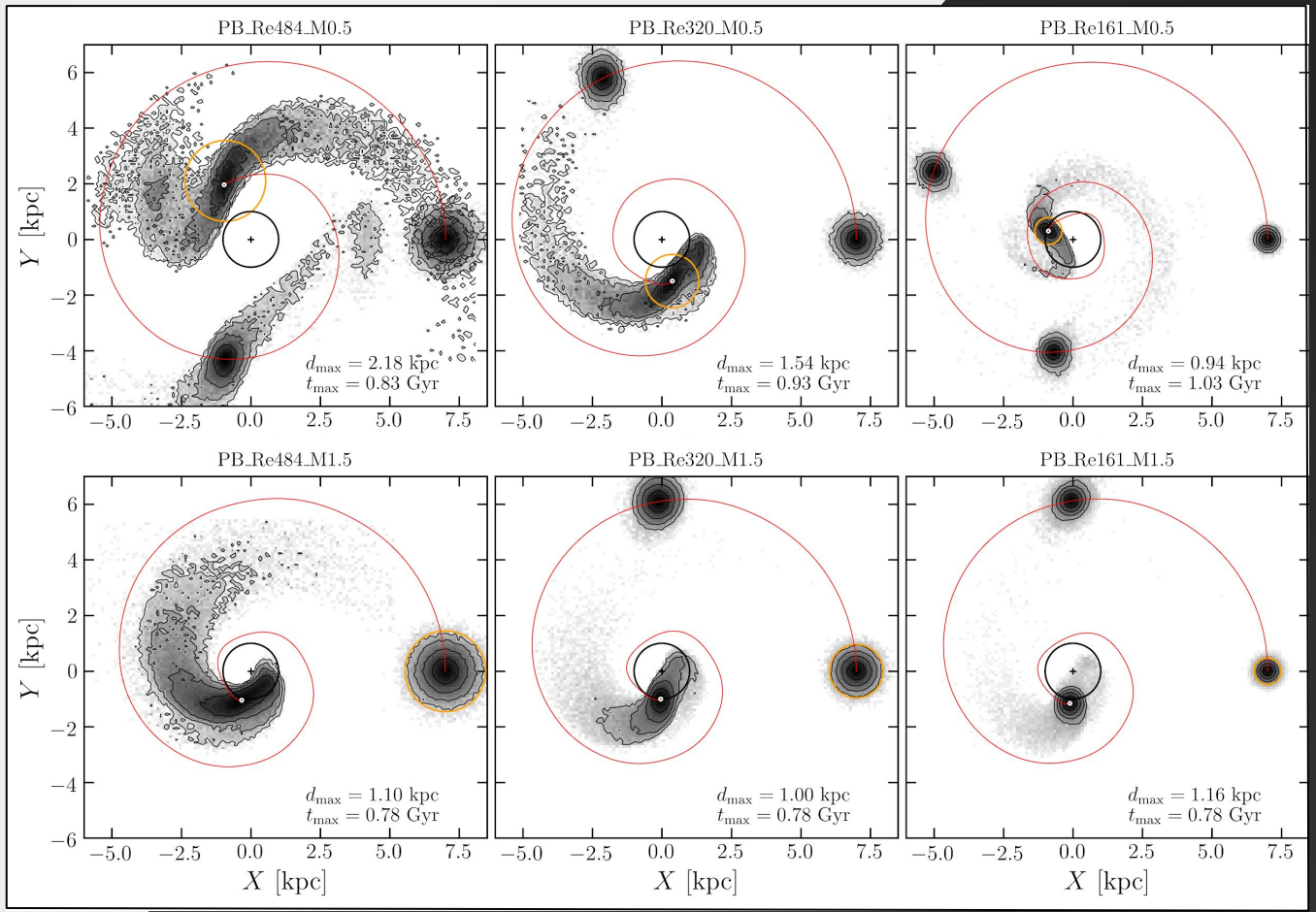
Selection of 6 out of 12 simulations.

- Massive and extended PB disrupted by tidal force field
- Formation of tidal tails, severe mass loss, development of elongated structure
- Small PB do not increase their size enough

Decreasing PB size →

Decreasing PB mass →



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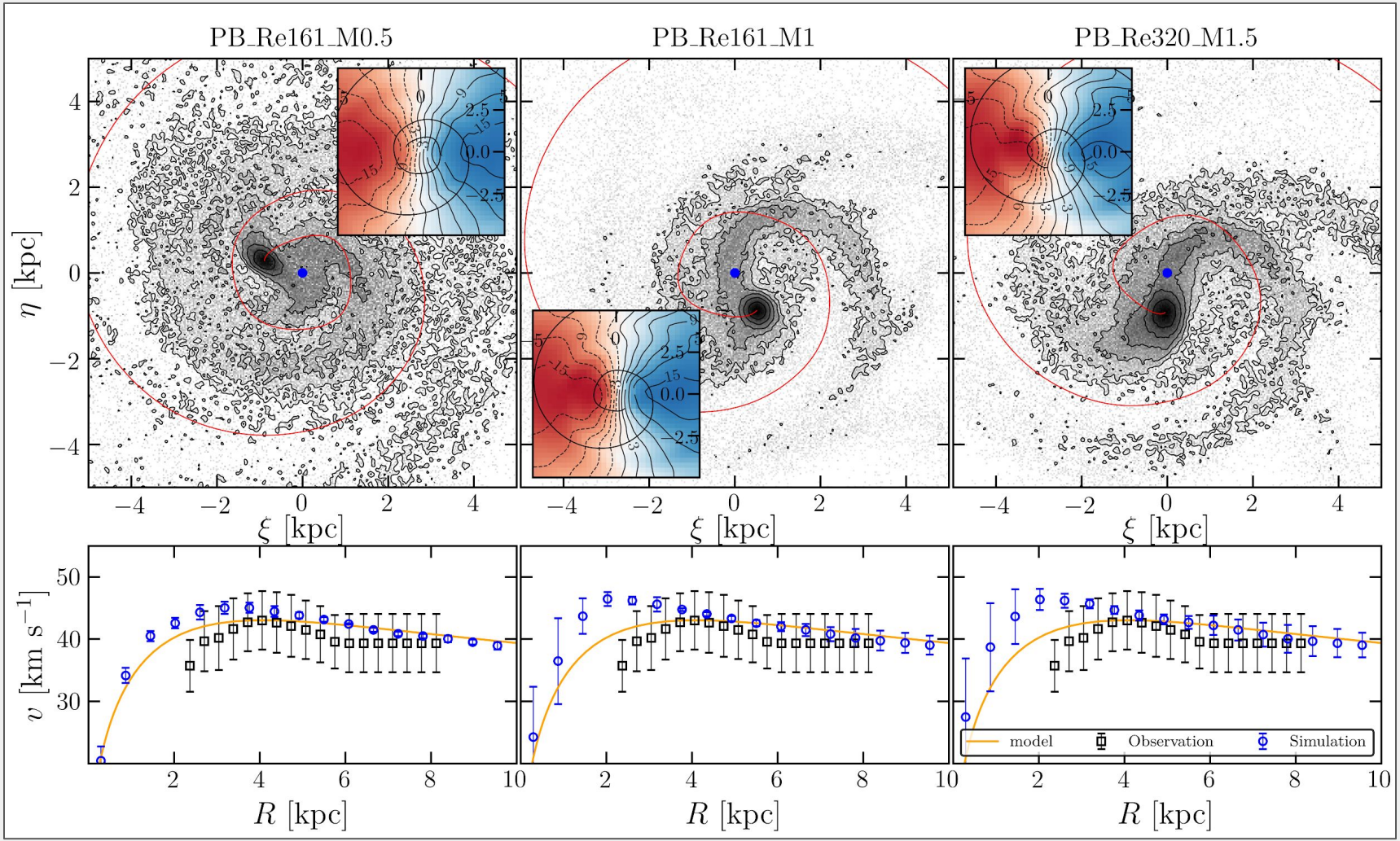
Pascale et al. (2020)



Pascale et al. (2020)

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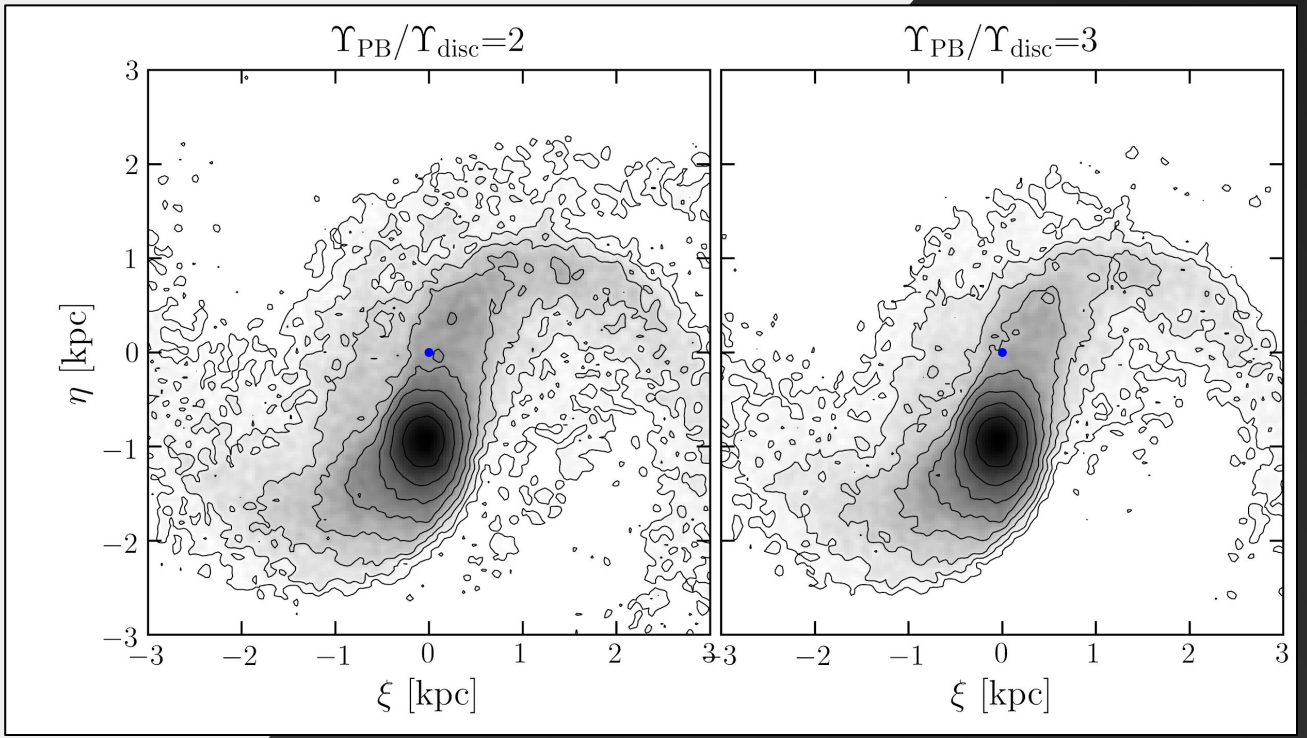
Summary

- Extended PB: disrupted (no matter the initial mass)
- Small PB: too small
- Intermediate size PB: too flattened
- Disequilibrium features developed after few 100 Myr



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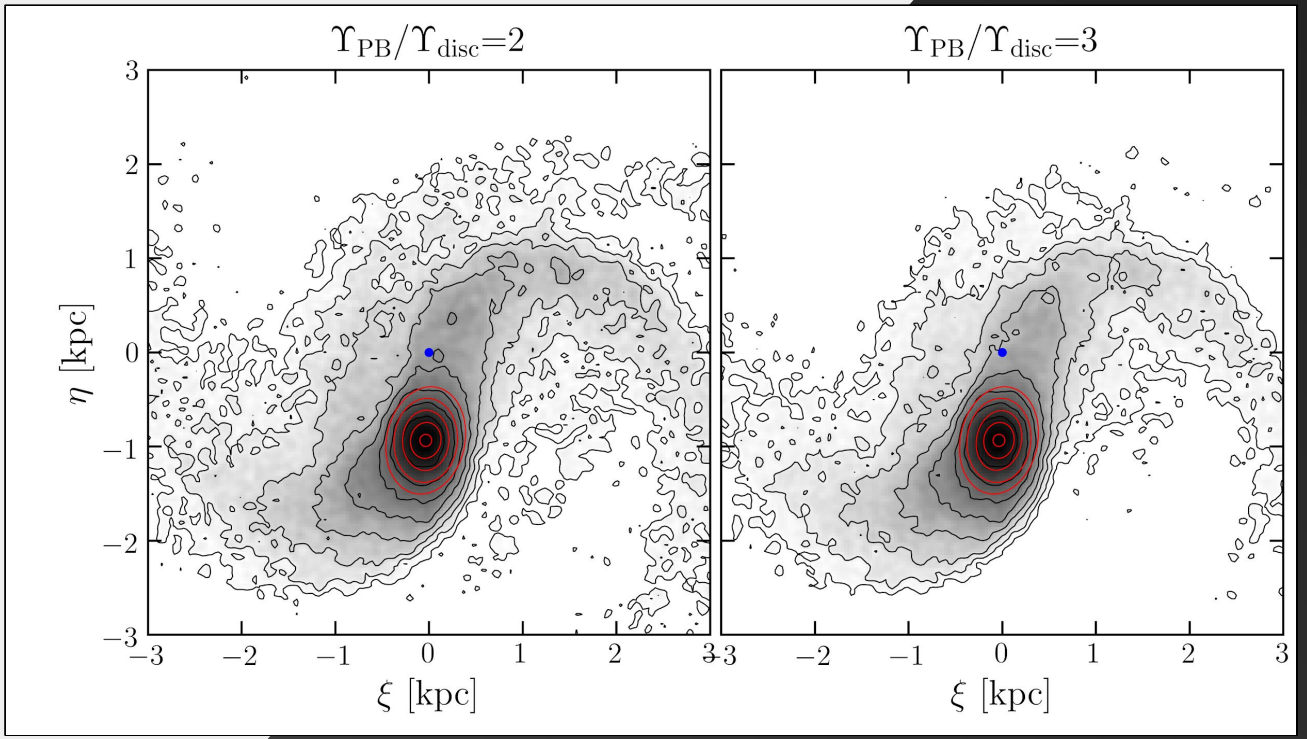

axis-ratio ~ 0.7 - too flattened

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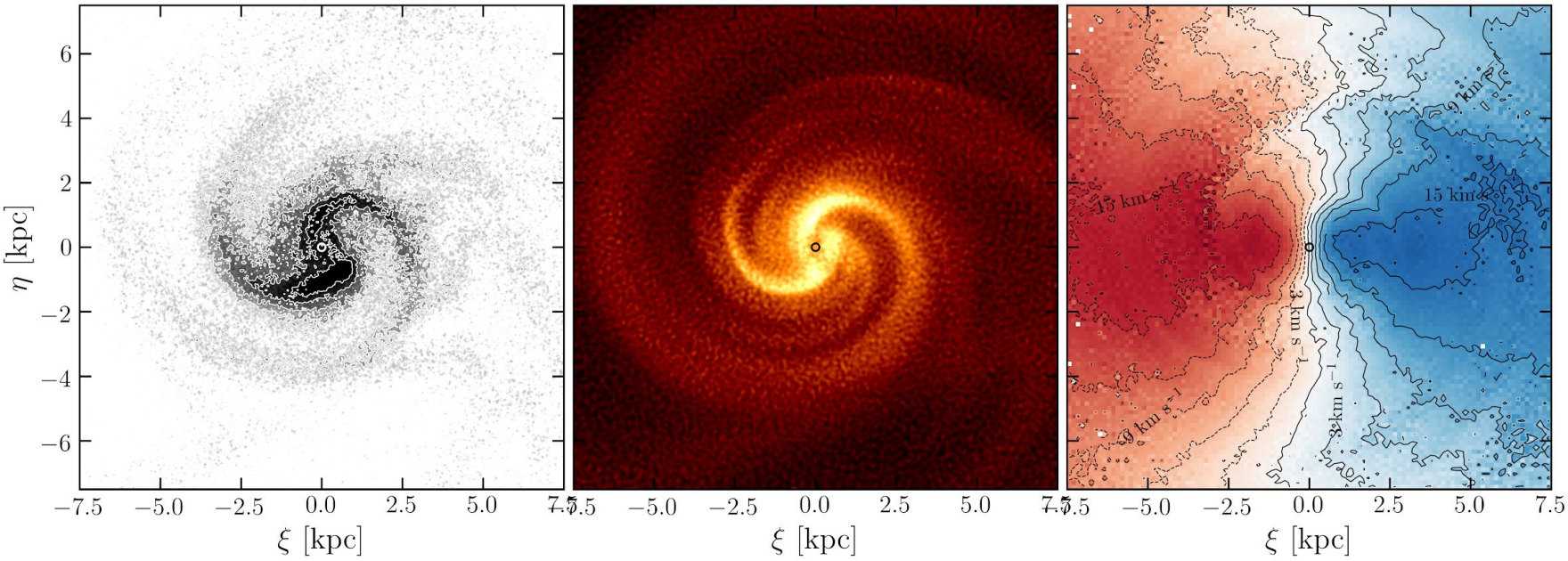
By product of the simulations: the SW-overdensity



Pascale et al. (2020)

- Stellar overdensity of stars compatible with the accretion of an external component of mass and sizes similar to the PB
- Smooth velocity field (once downgraded to observations)

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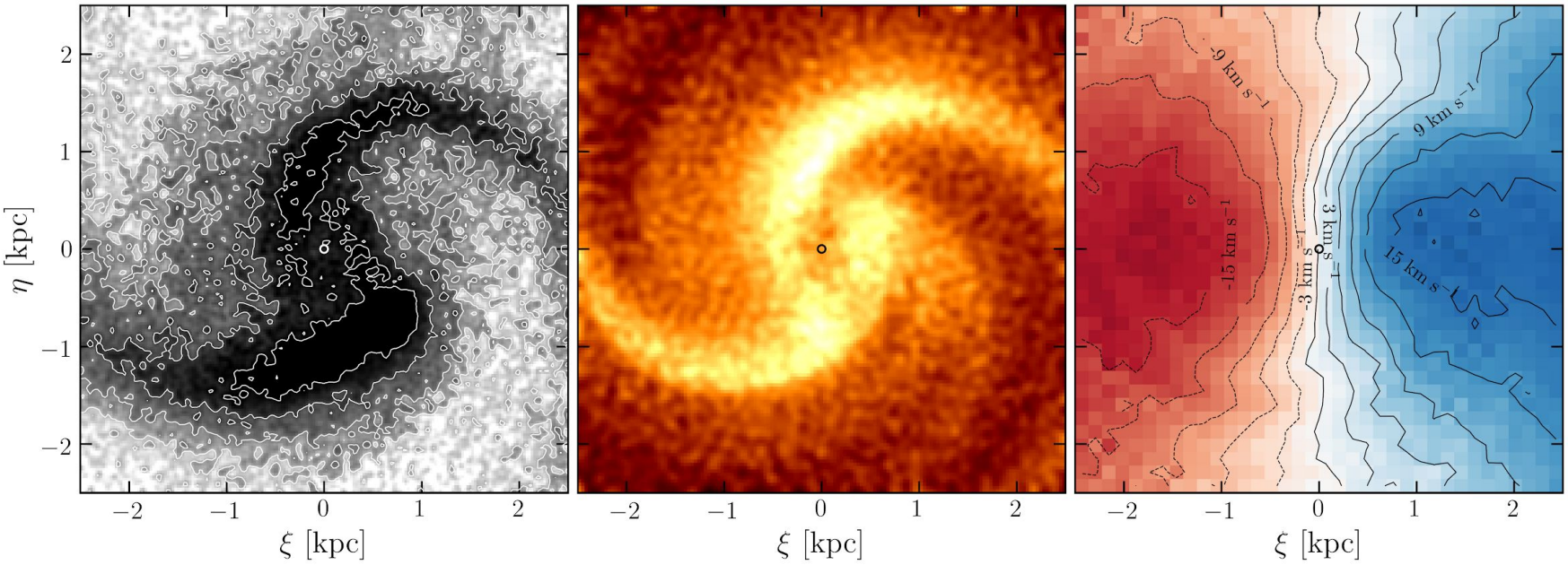

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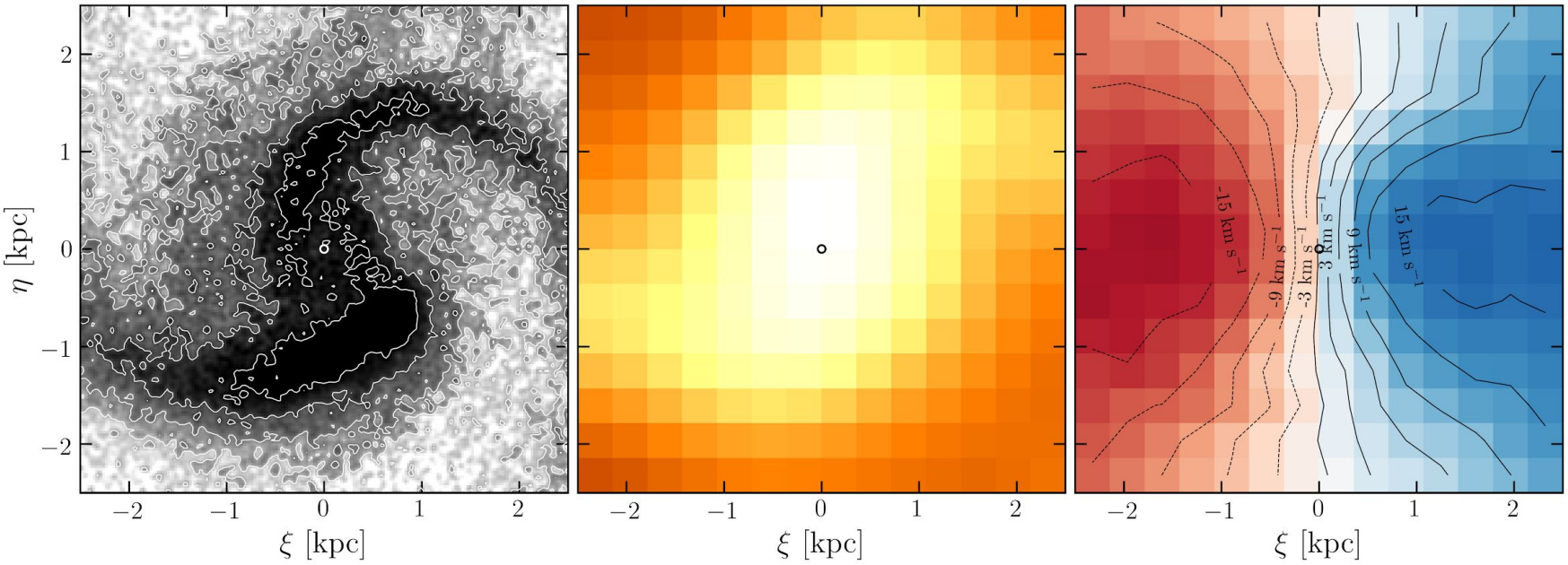

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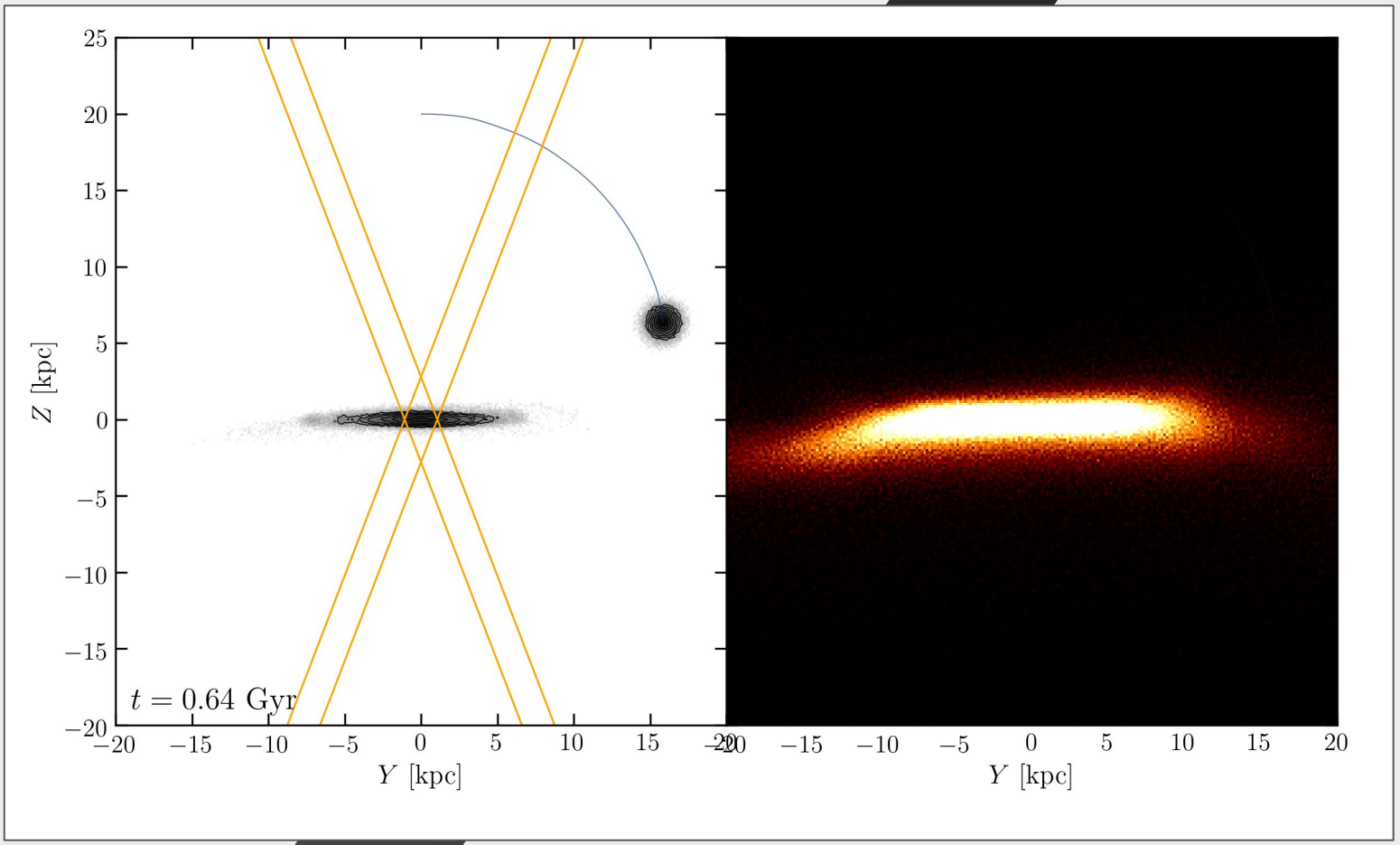
Satellite simulations



Pascale et al. (2020)

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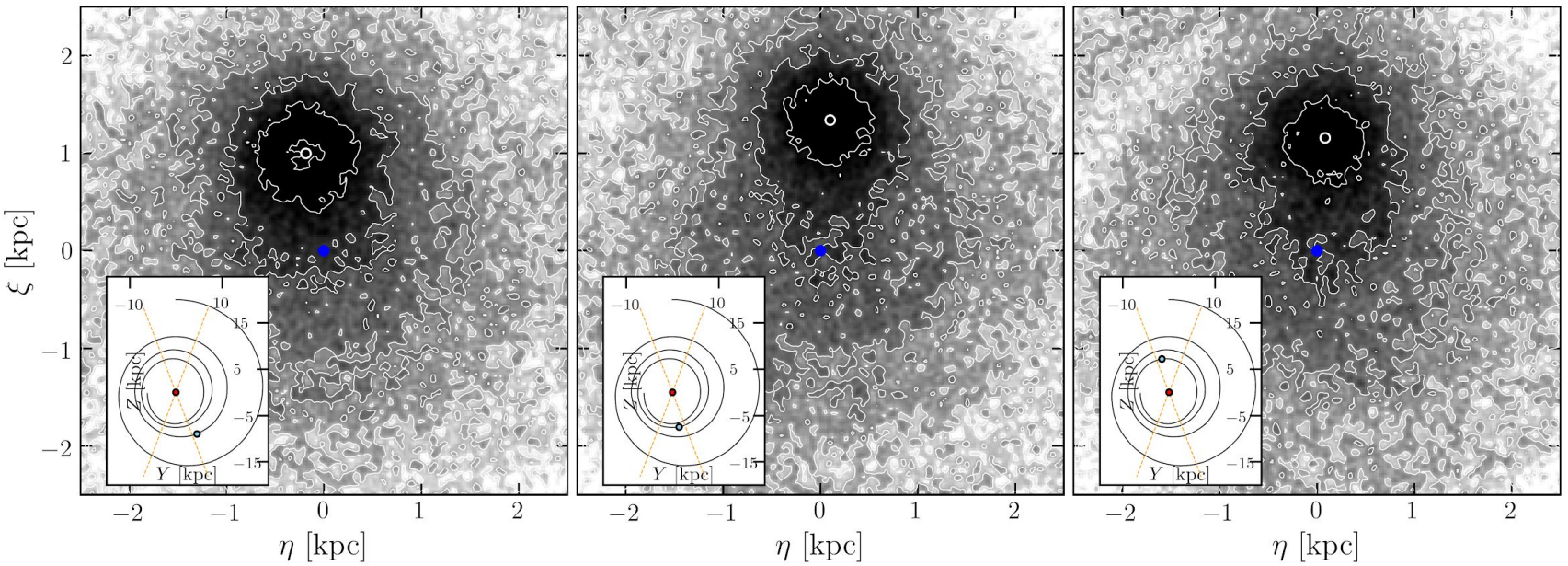
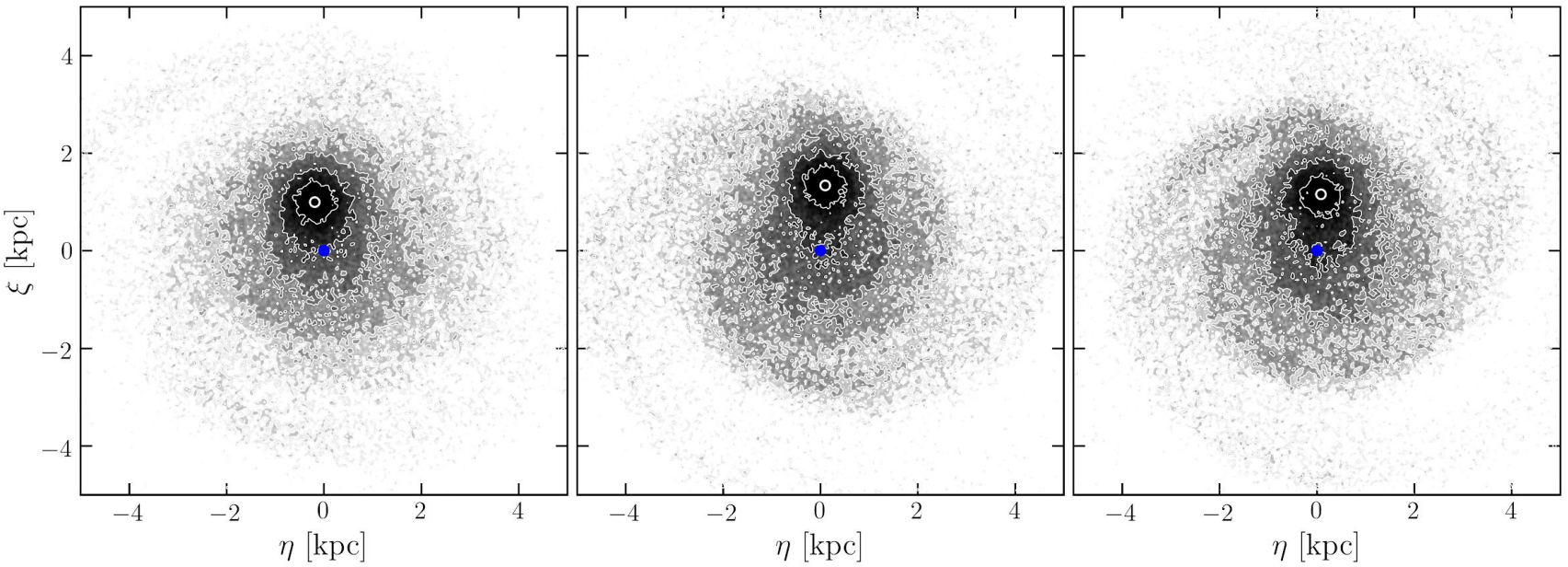


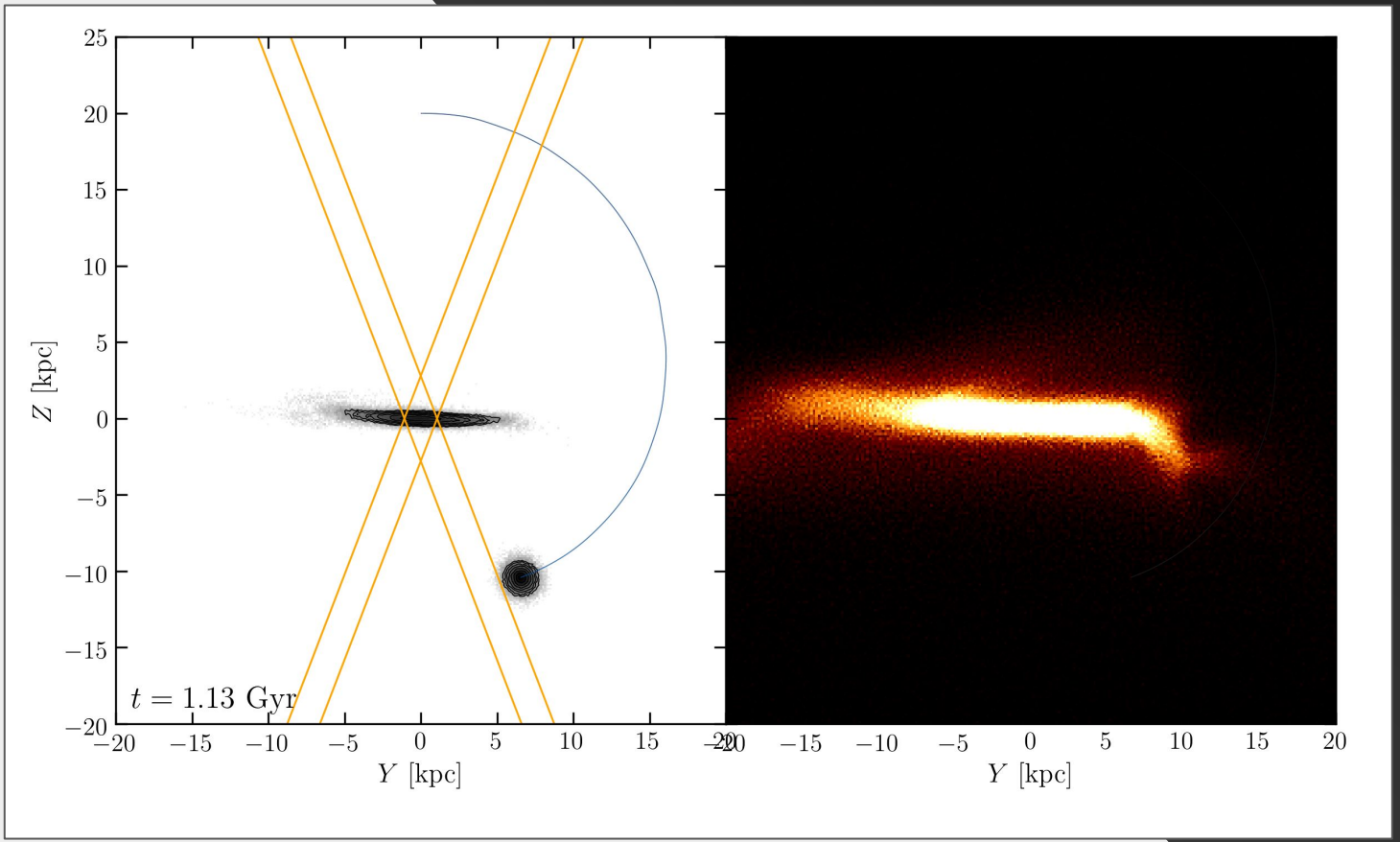
- The PB is embedded with dark-matter such to resemble the properties of a dE (NGC 205)
- The off-set can be easily reproduce by projection effects.
- PB particles twice as luminous than the stellar disc

Pascale et al. (2020)

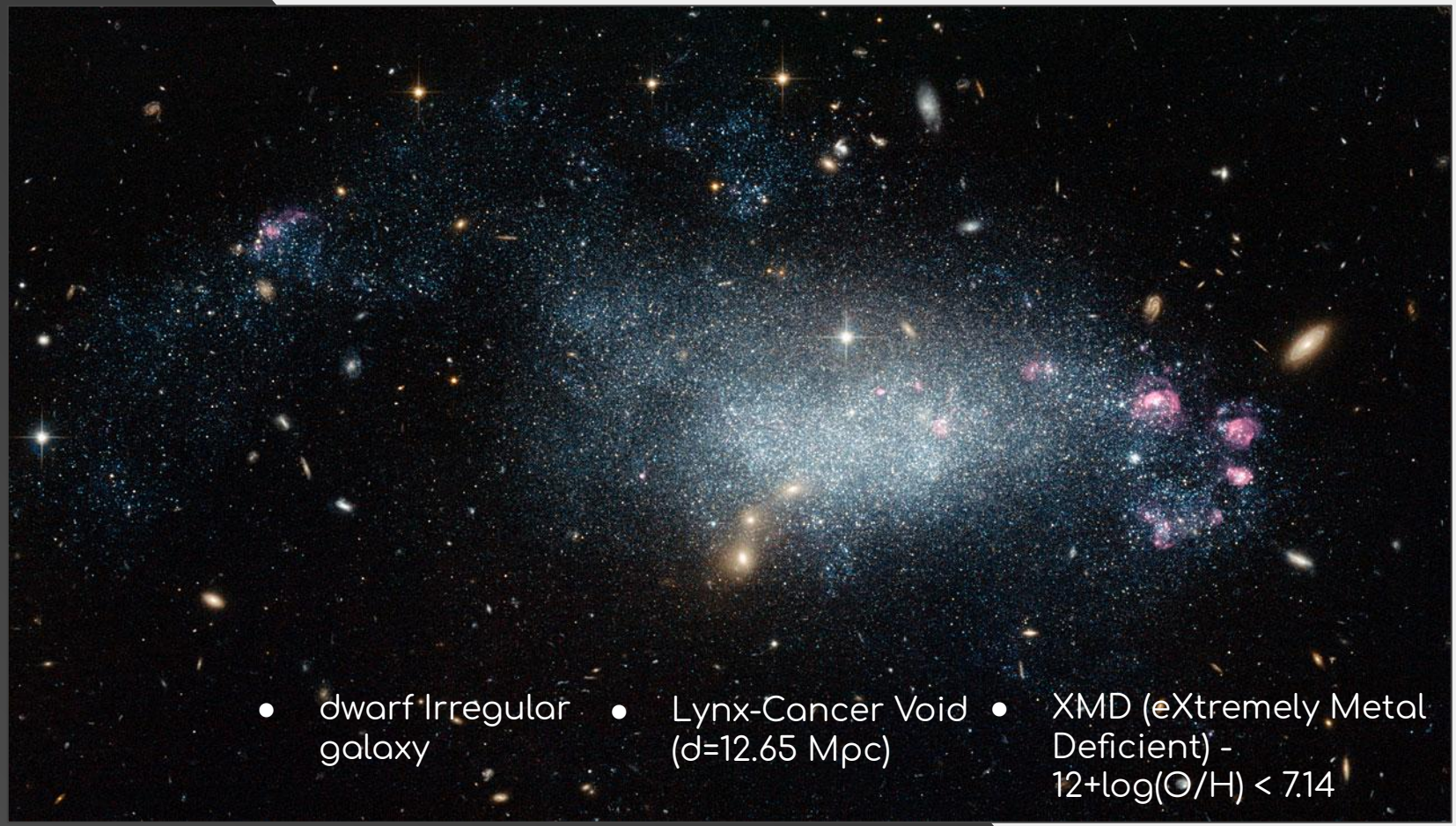


- Formation of spiral arms

Pascale et al. (2020)



- Formation of spiral arms
- Warped gas disc



- dwarf Irregular galaxy
- Lynx-Cancer Void (d=12.65 Mpc)
- XMD (eXtremely Metal Deficient) - 12+log(O/H) < 7.14

DDO 68

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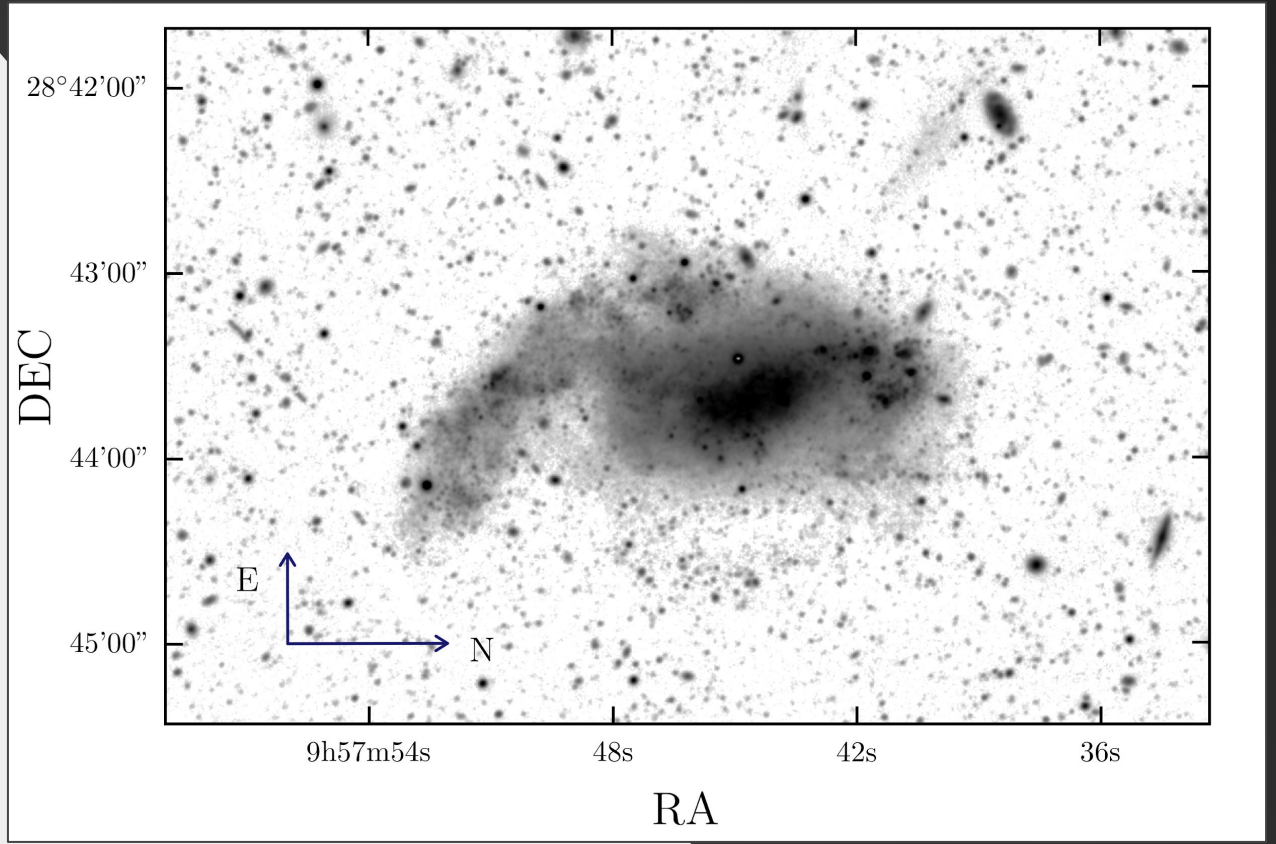

Pascale et al. (2021) to be sub.

DDO 68

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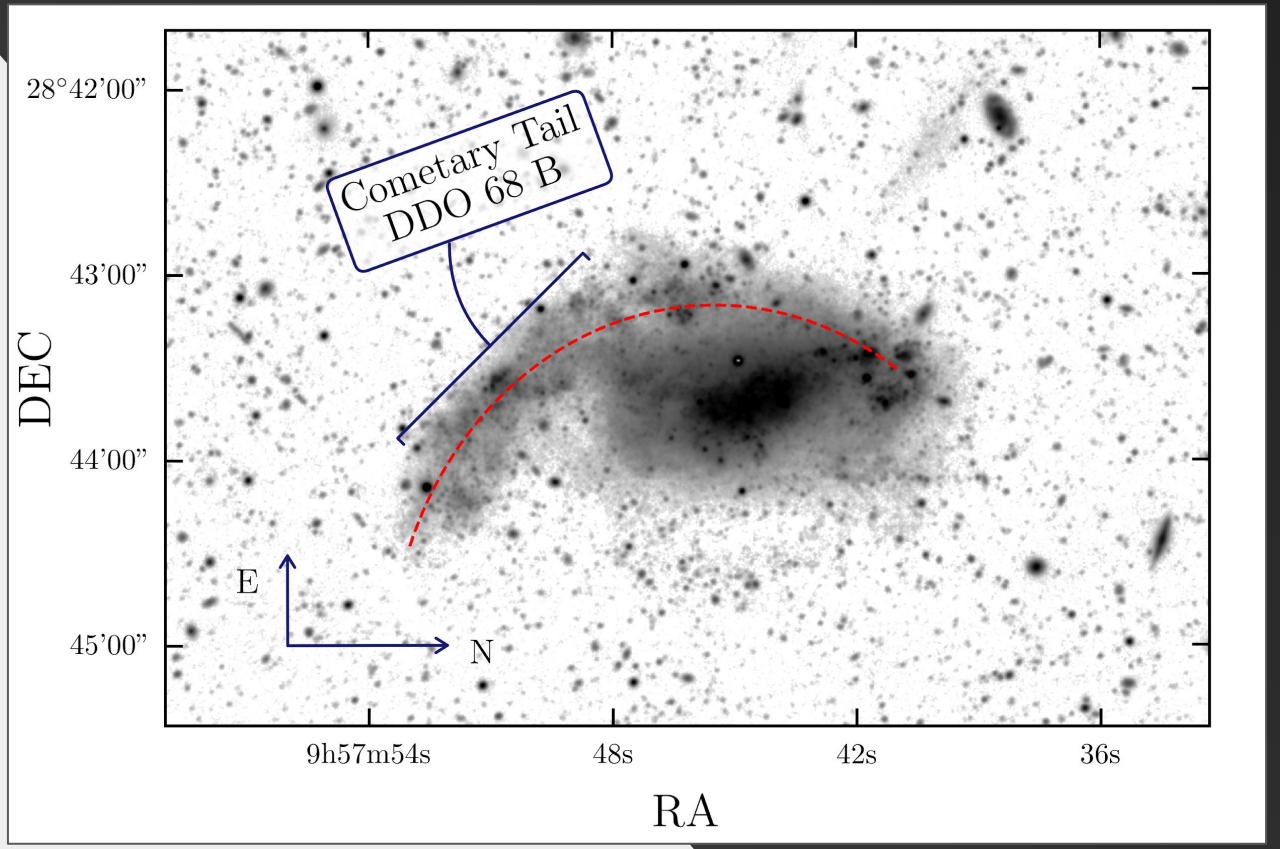
DDO 68

Cometary tail (DDO 68 B)

Bright and massive stream of young stars. Ongoing merger?



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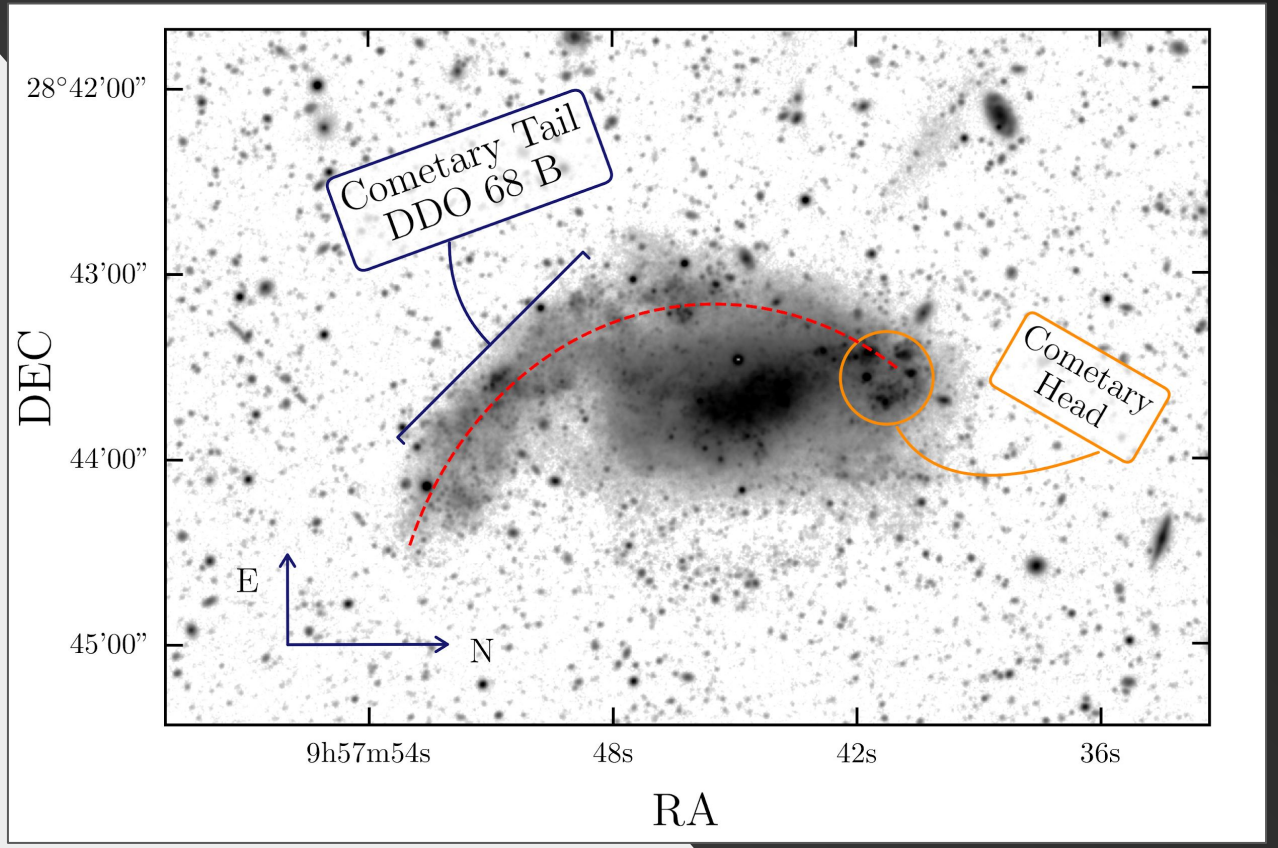
Cometary head

Group of HII regions. Extension of the Tail?



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DDO 68

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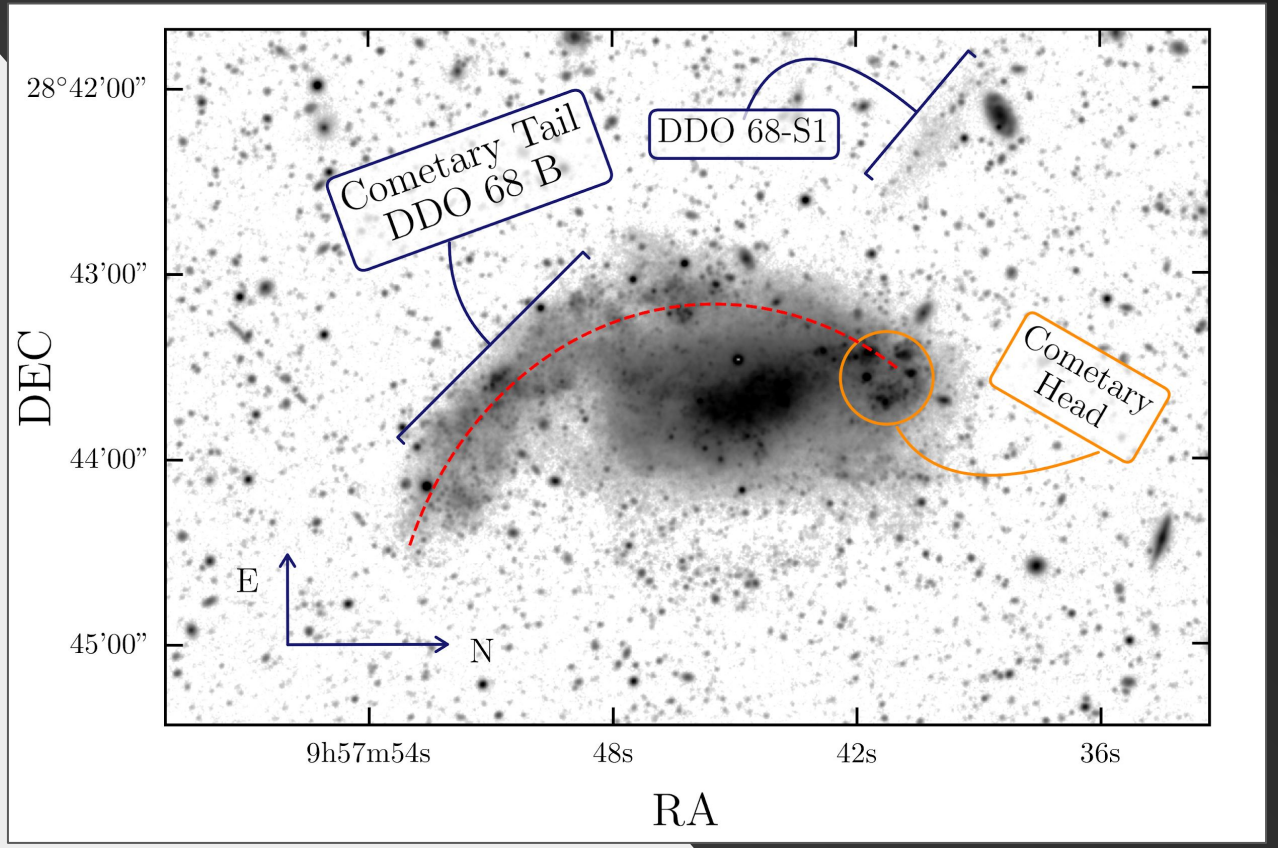
Stellar straem DDO 68-S1
stream of old stars (>2 Gyr) extending 5 kpc to the north-east



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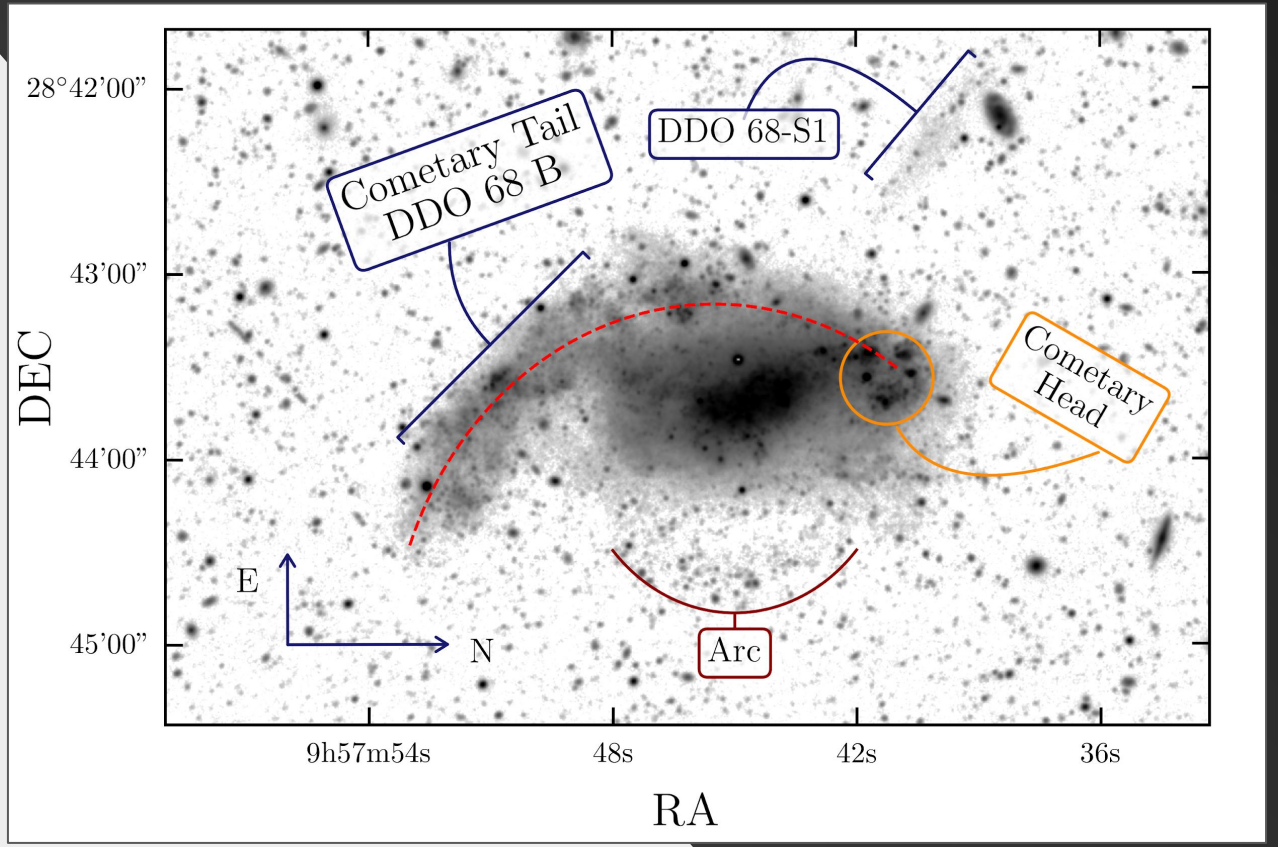
Arc
Arc-like structure of young and old stars to the west



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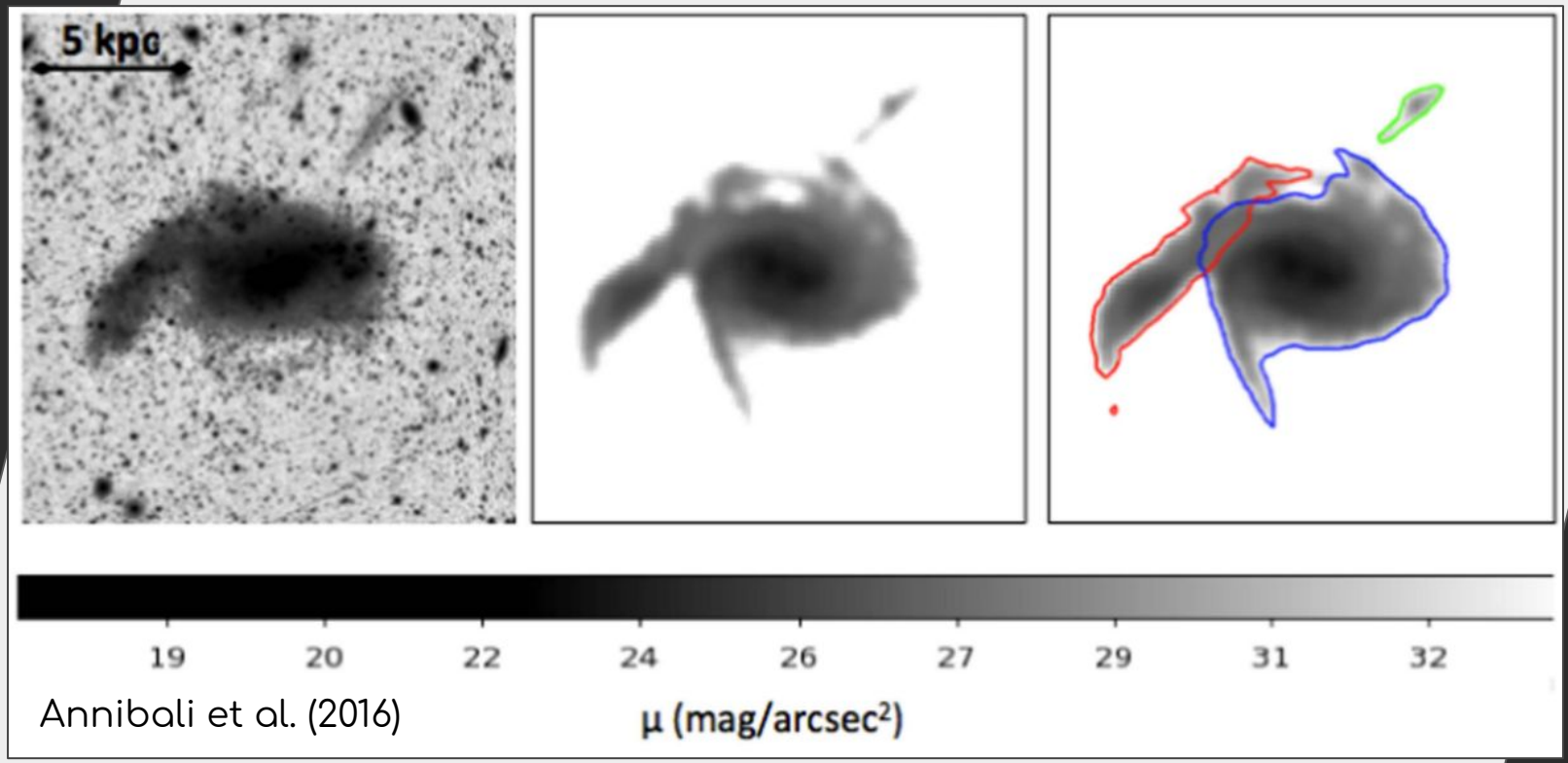

Annibali et al. (2016)

- Morphology compatible with a merger with two galaxies 1/10 and 1/150 as massive as DDO 68

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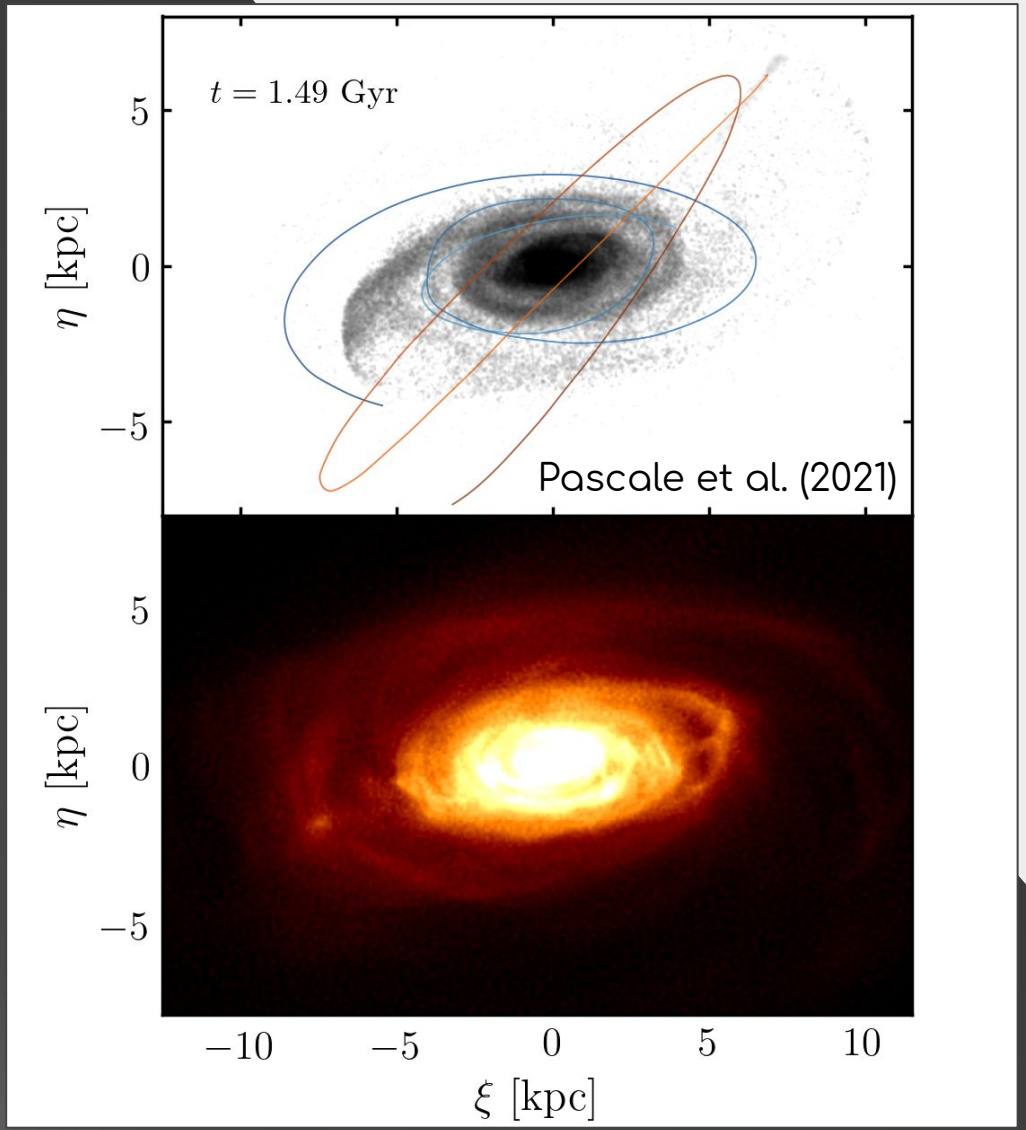

Ingredients of the simulations:

- DDO 68
- Satellite R - the Tail
- Satellite P - the stream S1

- Gas physics
- Self-gravity of stars and gas
- Metallicity distribution

Outcome:
The structure of DDO 68 is reproduced from the Tail to the Head

Satellite R is almost immediately stripped of its gas by ram pressure

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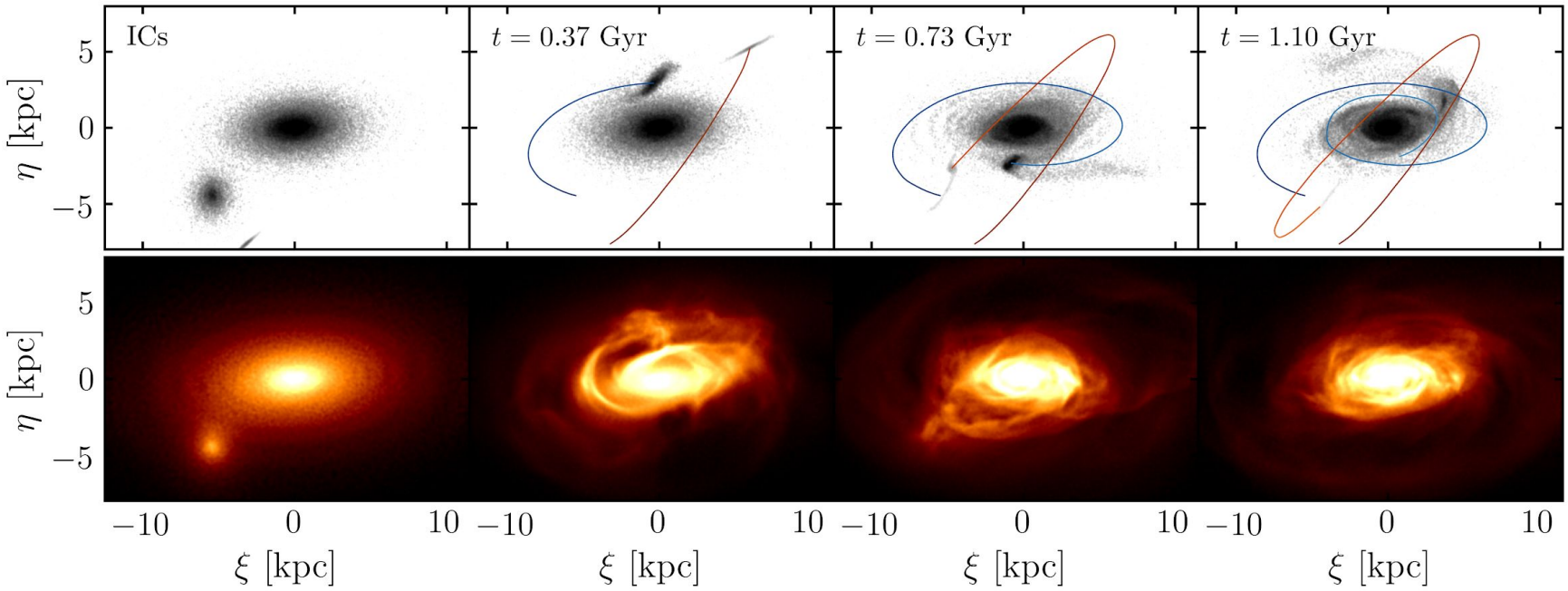

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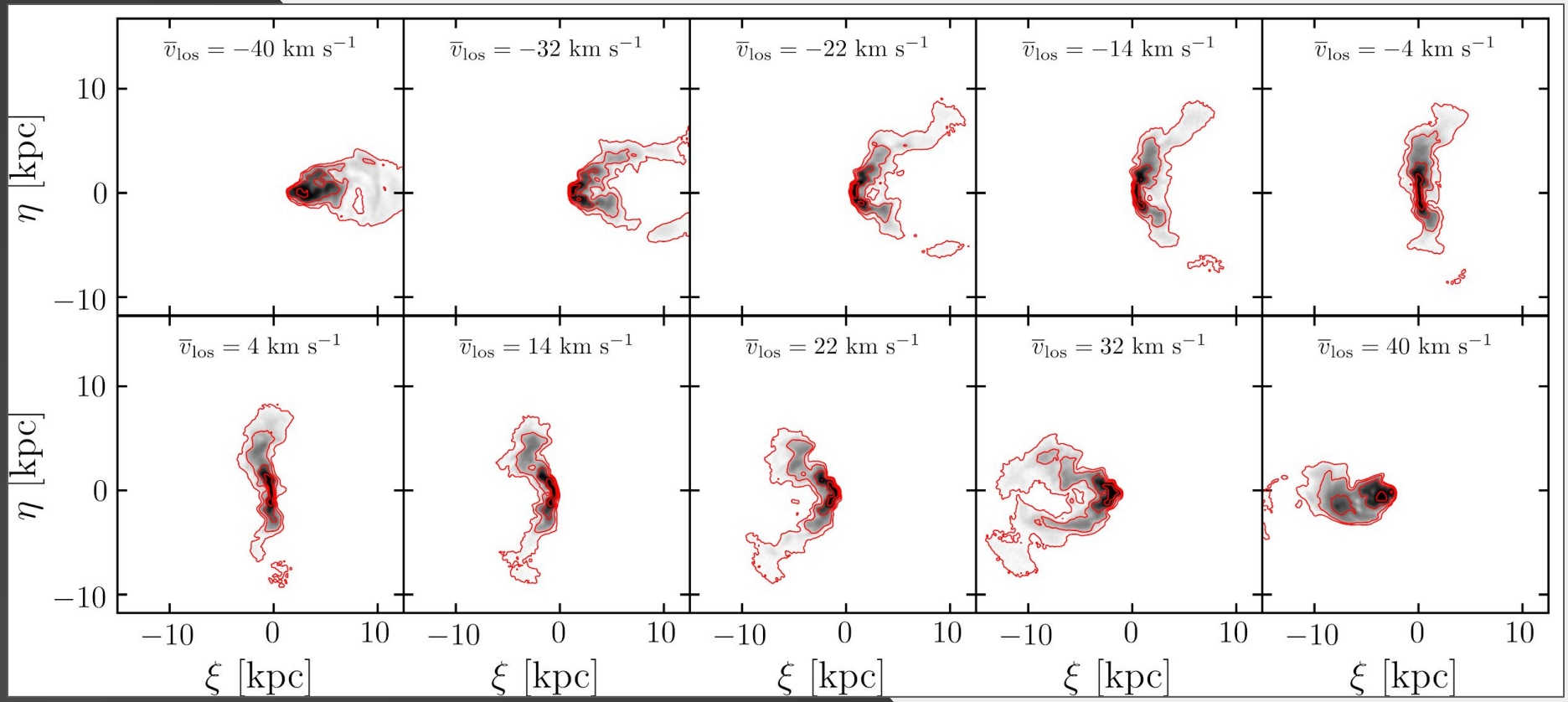

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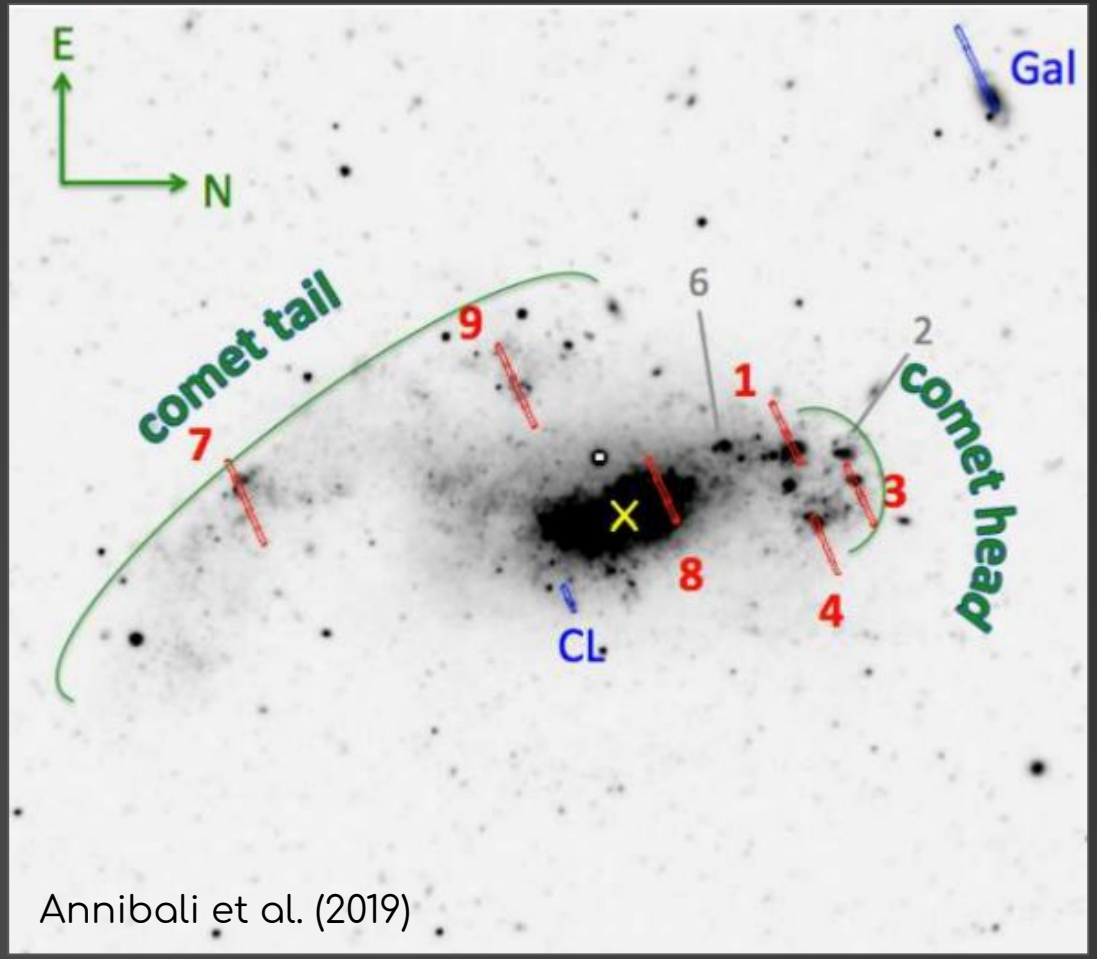
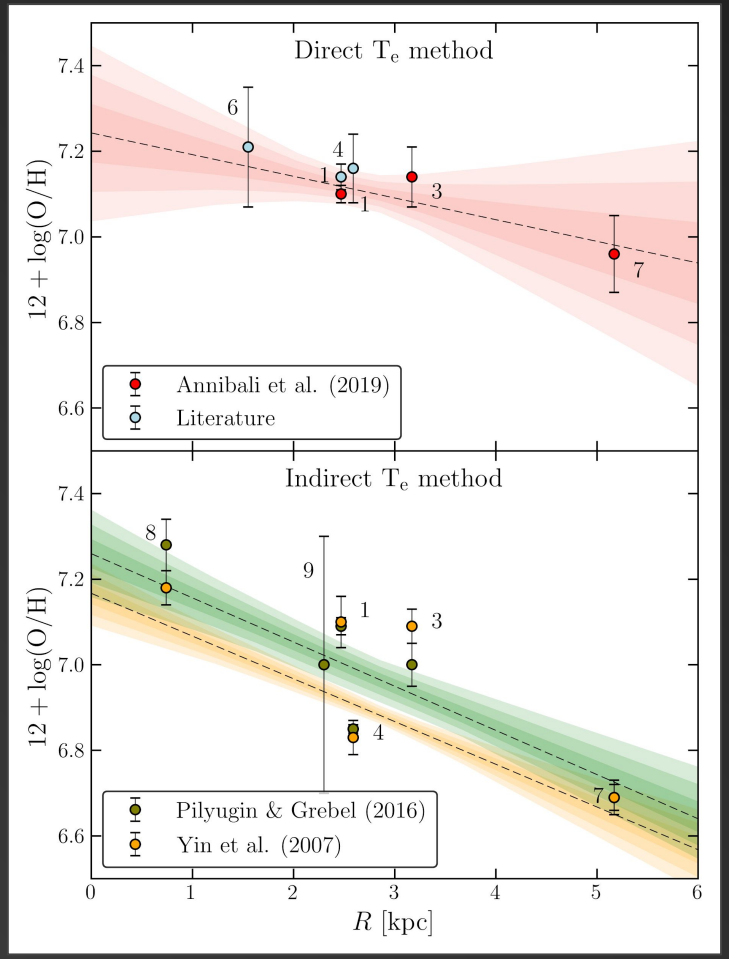


Annibali et al. (2019)



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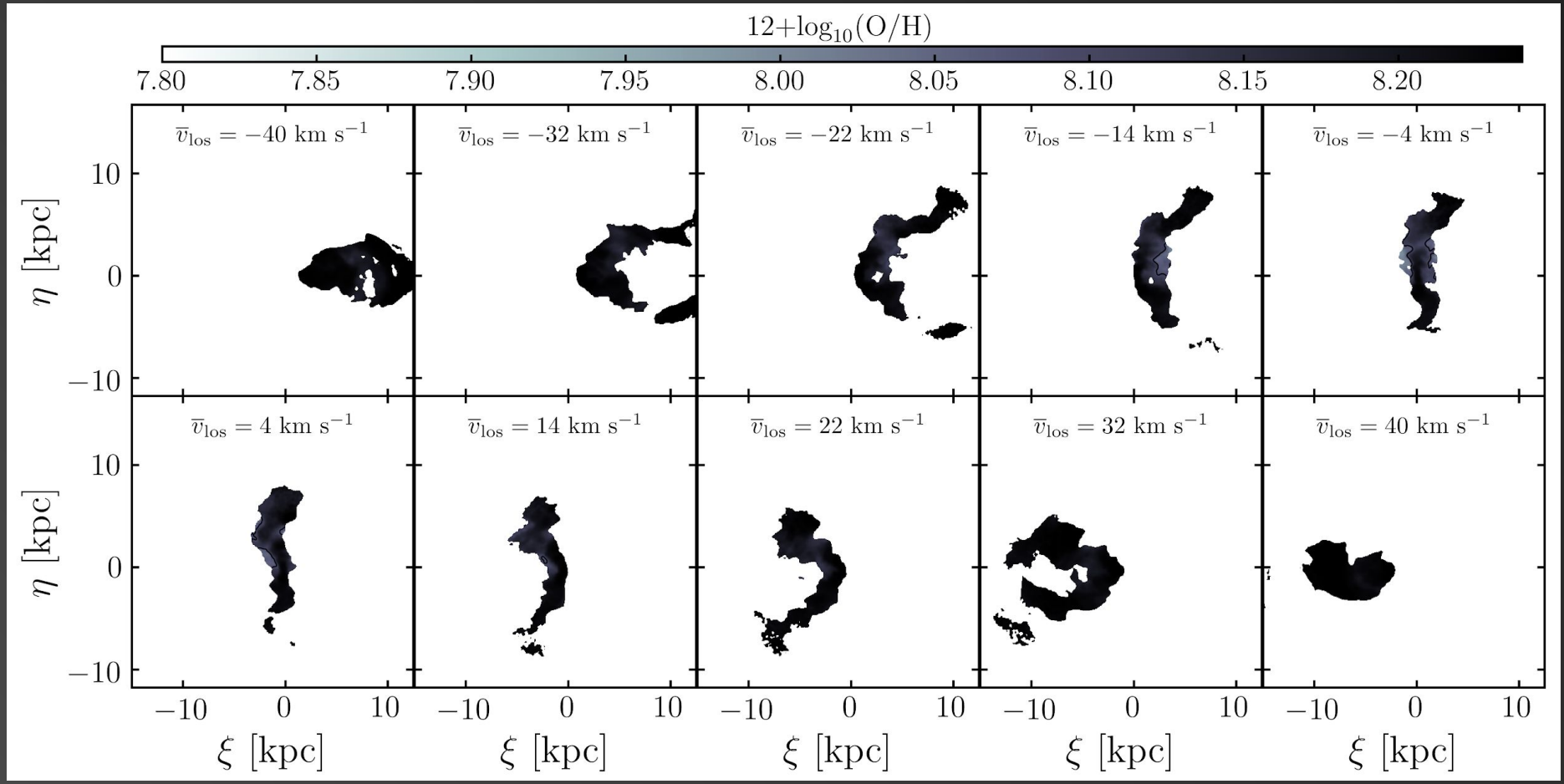

Pascale et al. (2021)

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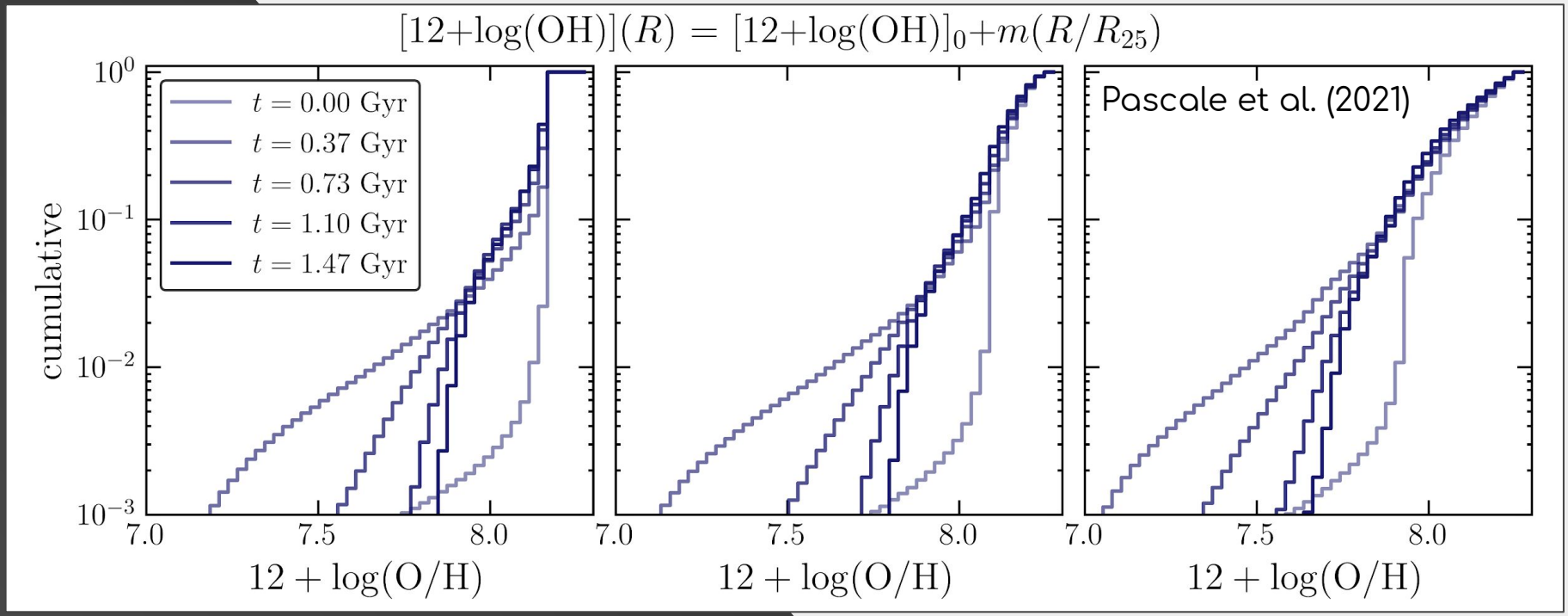

- Initial metallicity of DDO 68 12+log(O/H)=8.2 (expected value from MZR)
- Preliminary results: dilution not efficient over large time scales.

  If t<300Myr (~time of impact), 1% of the gas mass have 12+log(O/H)<7.5

TO DO

- Increase initial gas mass of the accreted satellite

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Conclusions

NGC 5474

Is the bulge of NGC 5474 a bulge? **Probably not**

- Impossible to reproduce an equilibrium configuration at 1 kpc from the center
- SW-overdensity reproduced by simulations
- Alternative scenario: off-set reproduced by projection effects

DDO 68

New simulations of the multiple merger of DDO 68

- Stellar structure and gas kinematics reproduced by simulations
  - Progenitor masses:
    ddo 68 -> 10^10 Msun
    cometary Tail -> ~10^9 Msun
    stream S1 -> ~10^8 Msun
    - Dilution not the driving cause of the low metallicity