The TIMER Project: Time Inference with MUSE in Extragalactic Rings

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(ESO)

on behalf of the TIMER team

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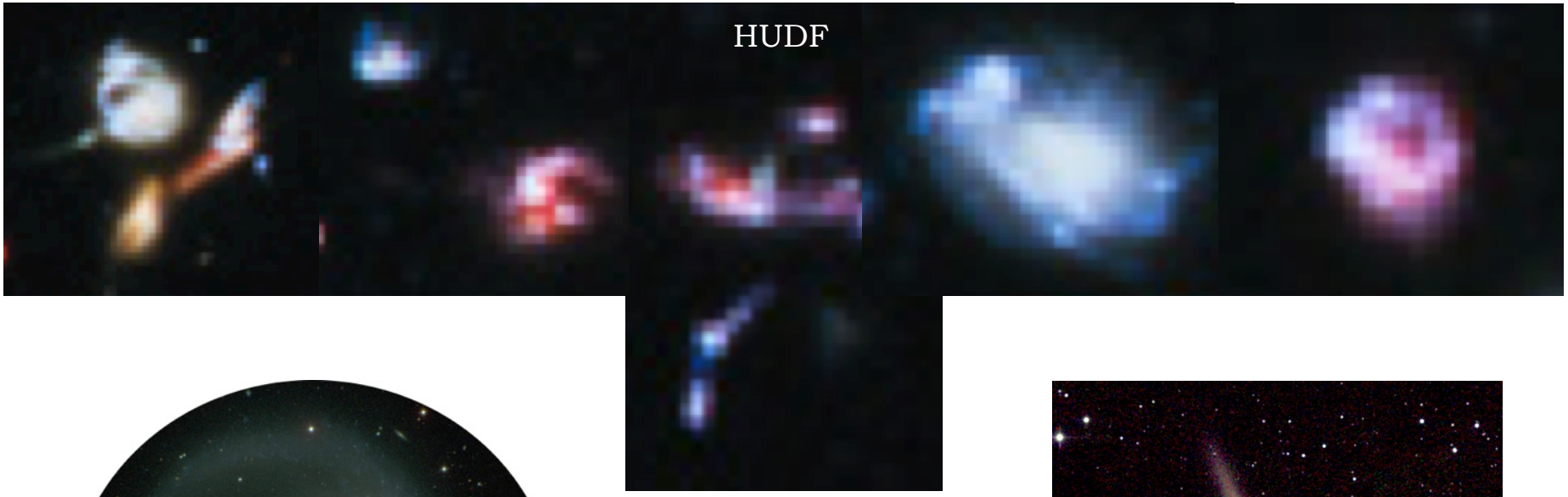
The Formation of Galaxy Discs

- When galaxy discs became dynamically mature?

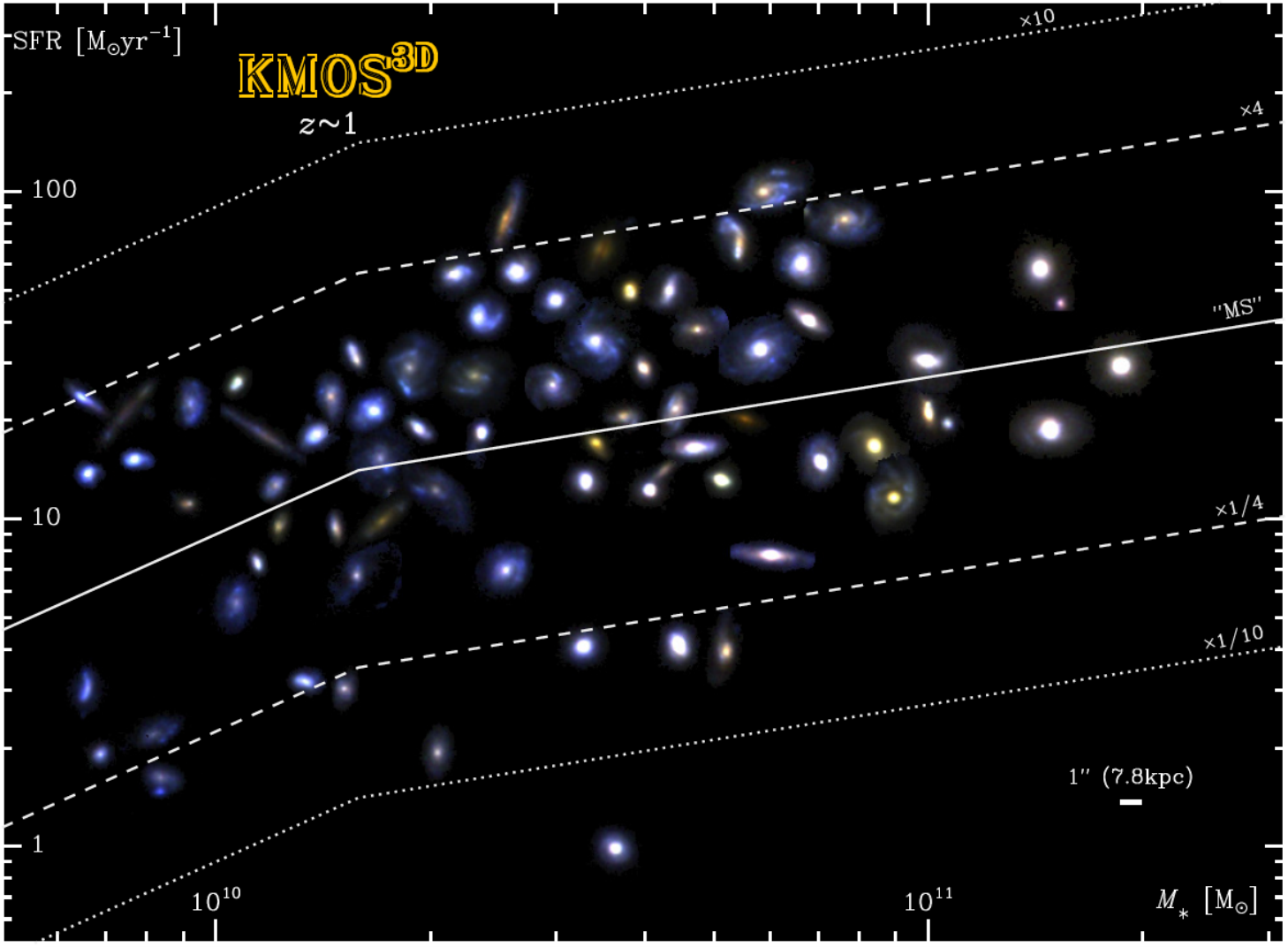


NGC 1433 – CGS

NGC 891 – 2MASS

The Formation of Galaxy Discs

- Wisnioski+2015: ~600 galaxies at $0.7 < z < 2.7$



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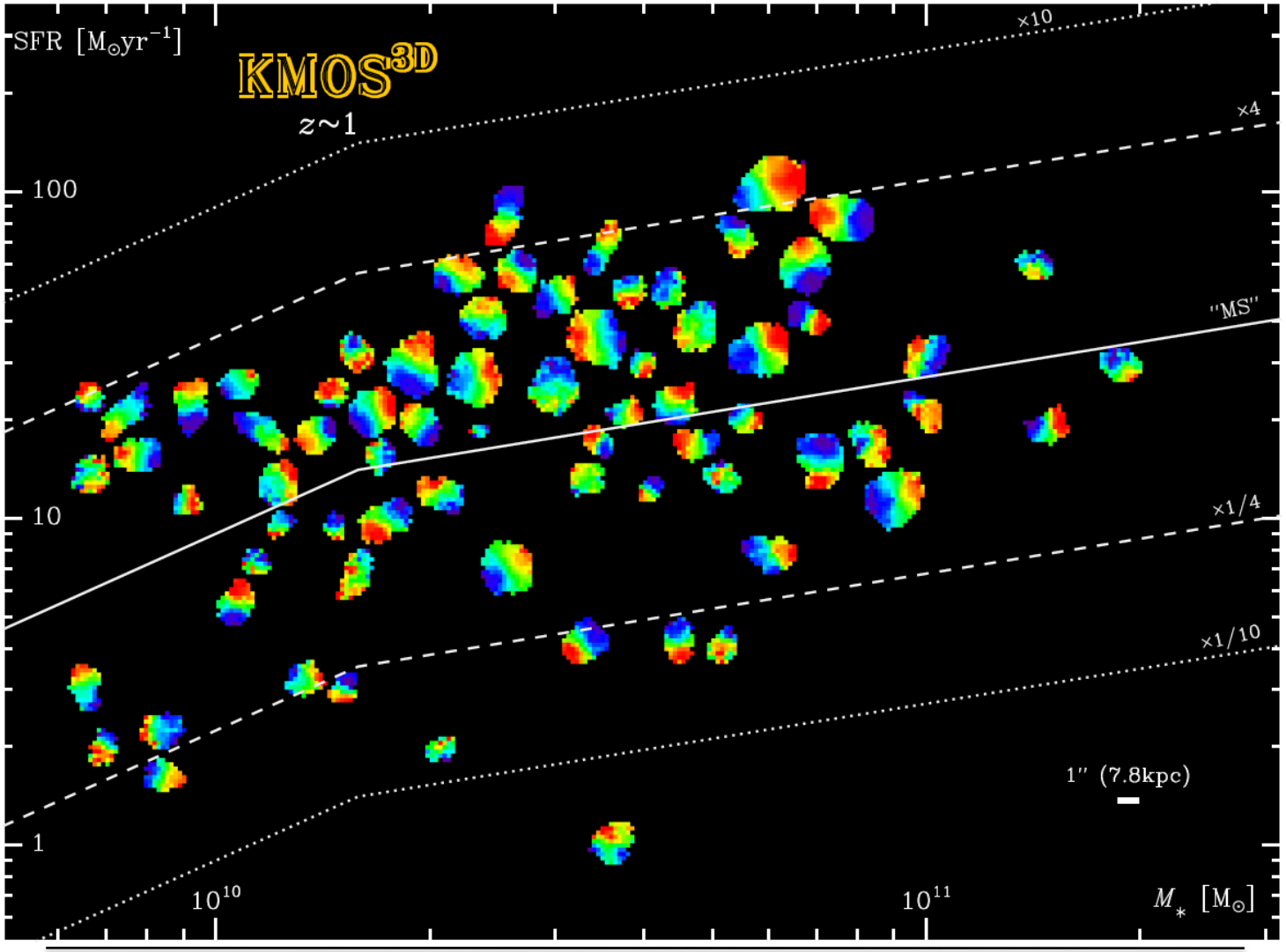

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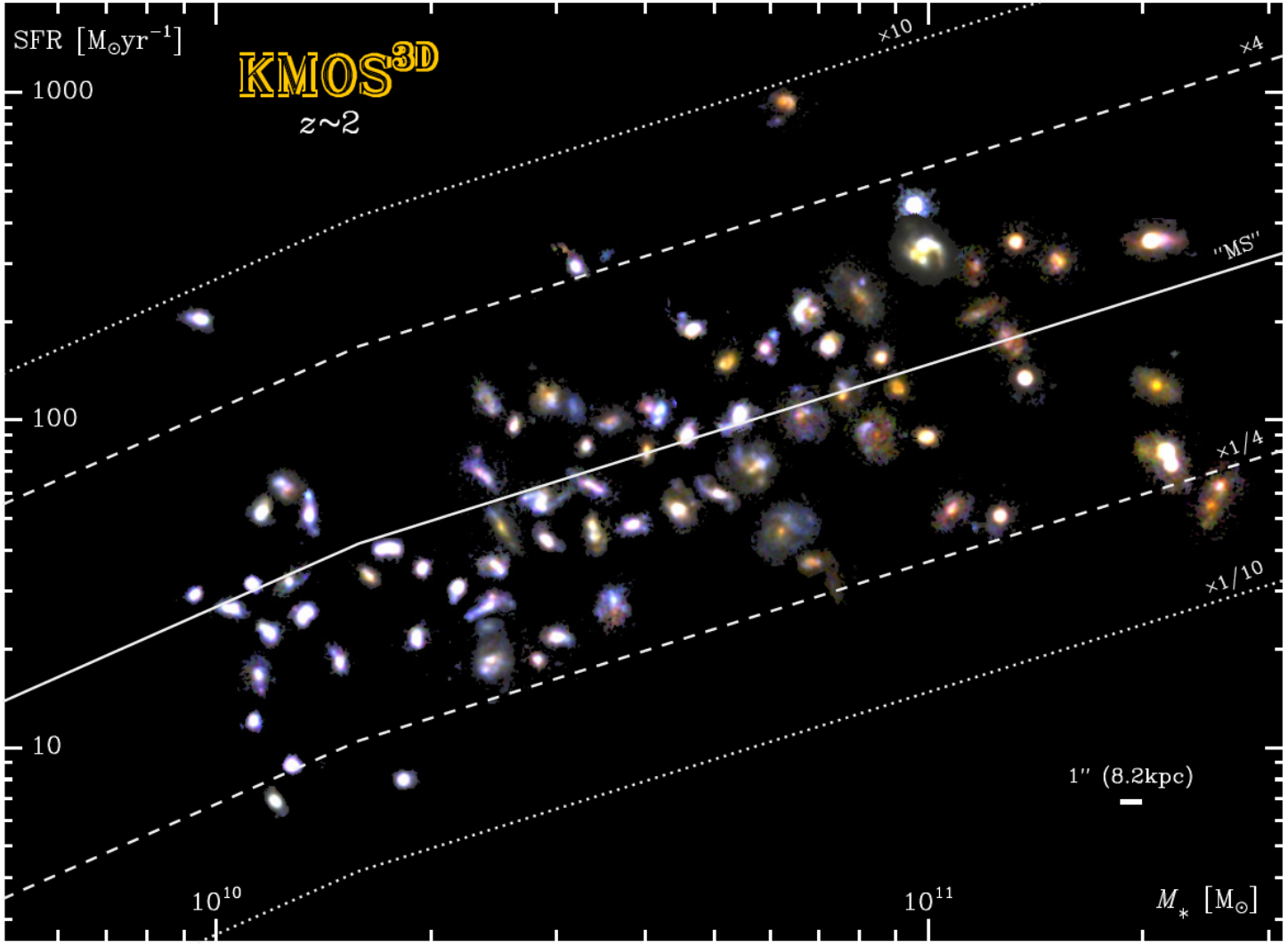

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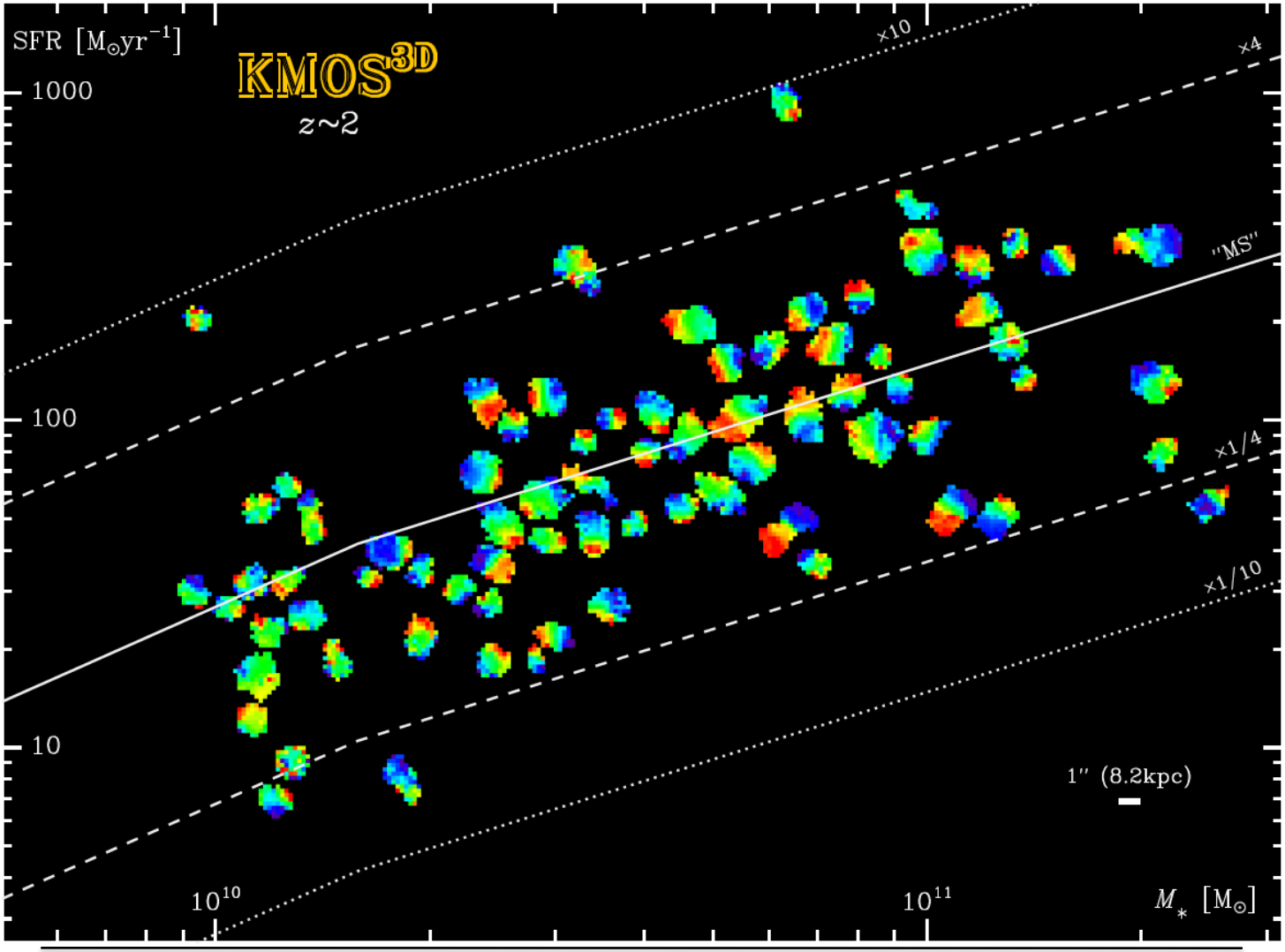


The Formation of Galaxy Discs

- Wisnioski+2015: ~600 galaxies at $0.7 < z < 2.7$

  - 70% of galaxies at $z \sim 1$ have discs
  - 47% at $z \sim 2$
  - More massive galaxies develop discs earlier (downsizing)
  - Discs are turbulent compared to local discs: low v/σ

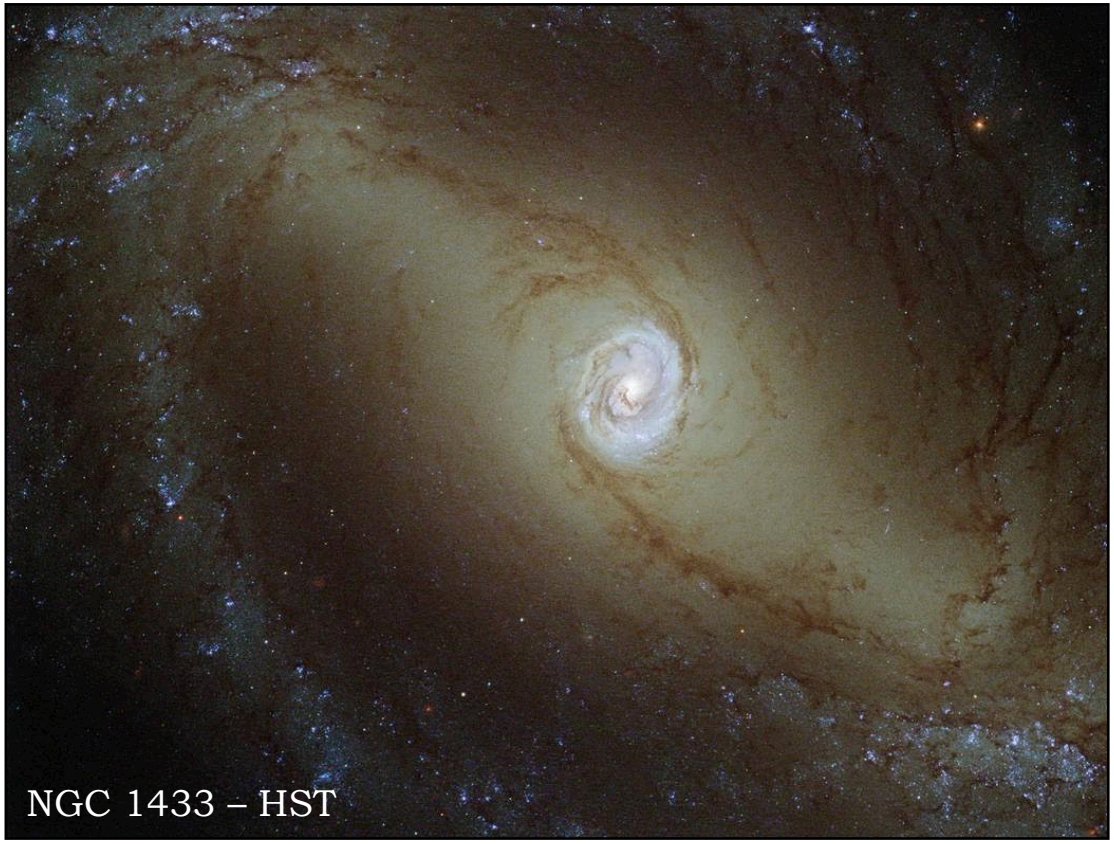
- Difficulties

  - Measurements from Hα
  - Poor spatial sampling
  - Rodrigues+2017: find only a third of galaxies with virialised discs at $z \sim 1$ using same dataset

Bar-Driven Secular Evolution

- Bars in disc galaxies drive some of the major physical processes that shape galaxy properties

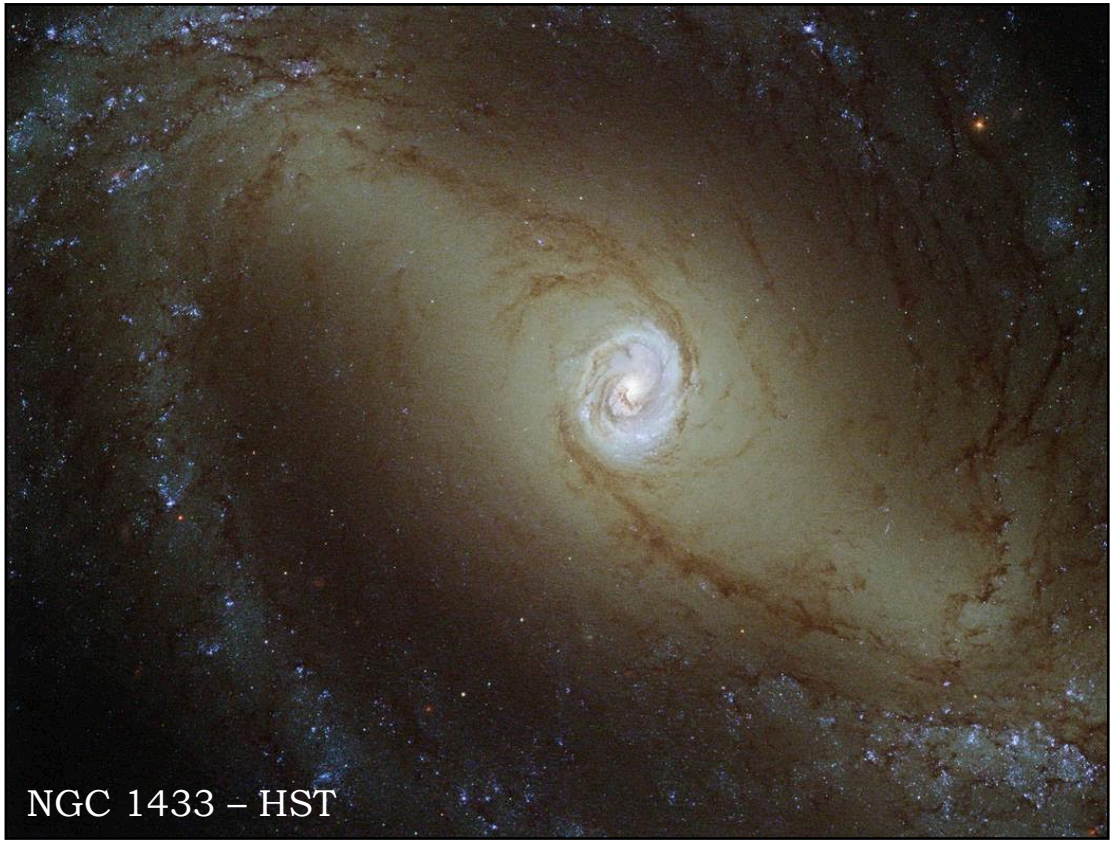
- Nuclear stellar rings and inner discs are built from gas brought to inner regions by bars



Bar-Driven Secular Evolution

- The star formation history of the nuclear ring tells us when the bar formed and pushed gas to the inner regions

- Therefore, it also tells us when the main disc became dynamically mature enough to develop a bar



MUSE Science Verification

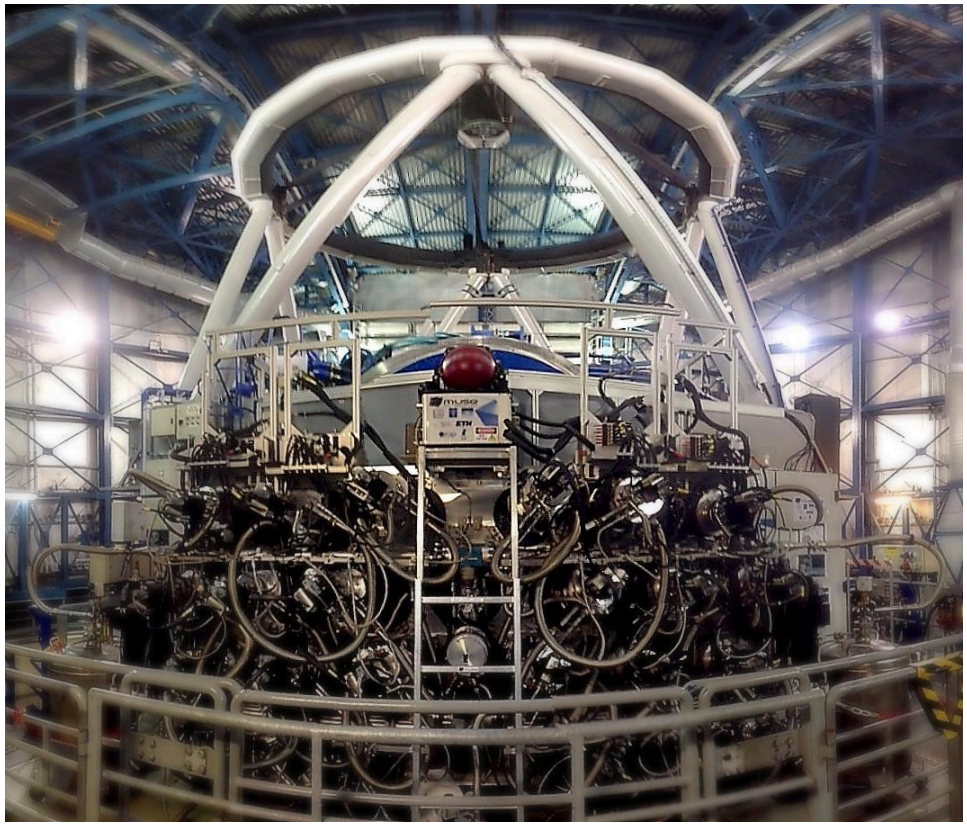
MUSE tells the story of NGC 4371: The dawning of secular evolution

2015 A&A 584, 90

Dimitri A. Gadotti[1], Marja K. Seidel[2,3], Patricia Sánchez-Blázquez[4], Jesus Falcón-Barroso[2,3], Bernd Husemann[5], Paula Coelho[6], and Isabel Pérez[7,8]

Multi Unit Spectroscopic Explorer on the VLT

- 1 arcmin squared
- 0.2” spaxels
- 90 000 spectra per pointing
- from 480 to 930nm
- R from 1770 to 3590

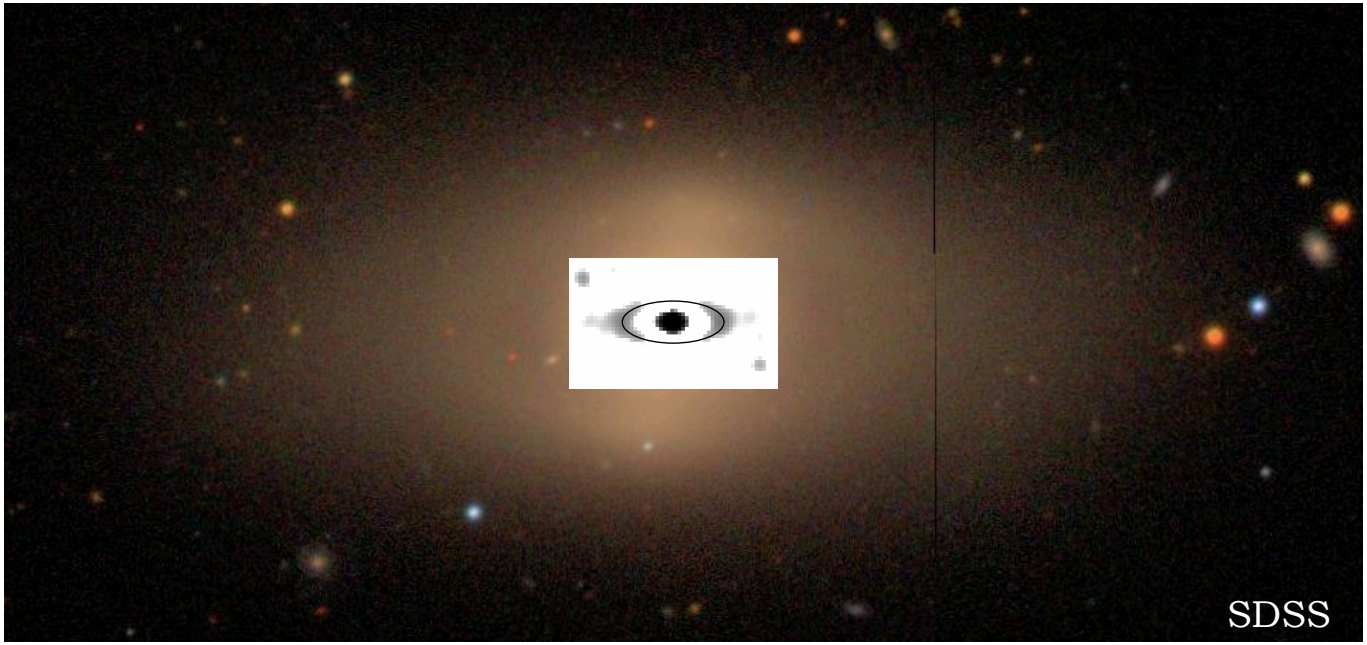


MUSE Science Verification

- A massive barred galaxy (log $M_\star/M_\odot$ = 10.8) in the core of the Virgo cluster, with very little gas and current star formation

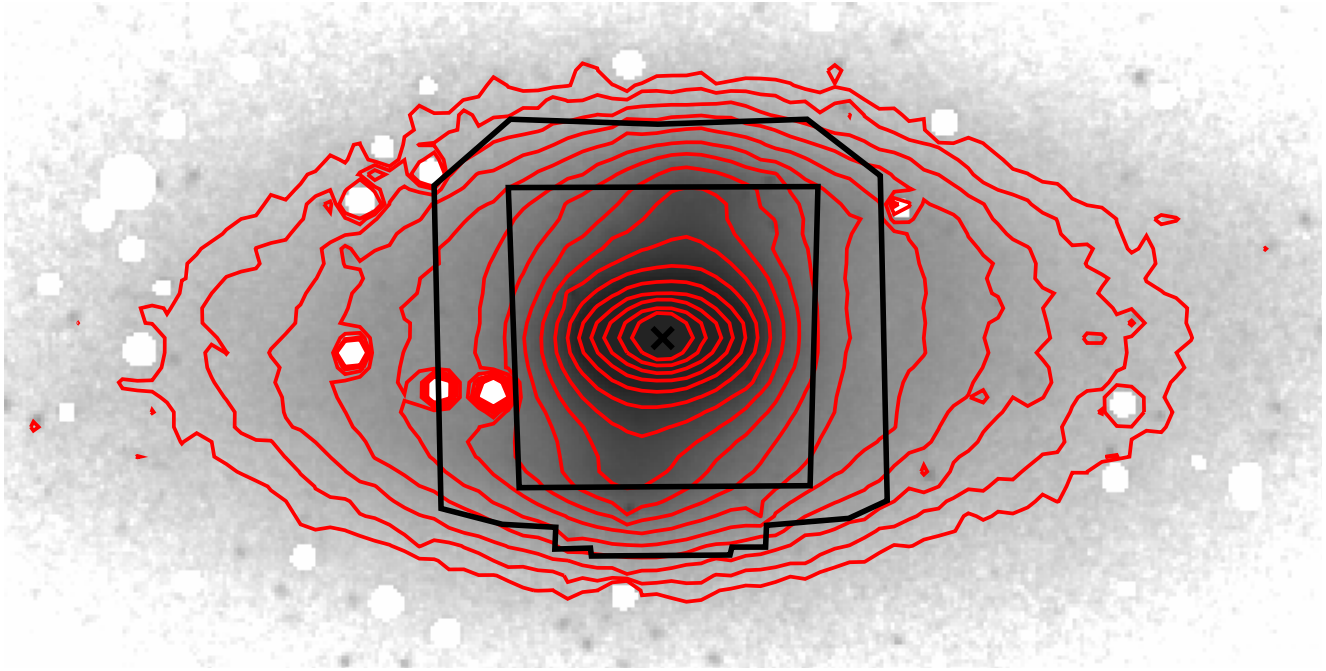
MUSE Science Verification

- Unsharp masking clearly reveals nuclear ring (see also Erwin+1999)



MUSE Science Verification

- MUSE field (inner trapezoid) covers almost the whole bar diameter



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- Stellar population in nuclear ring vastly dominated by stars older than 10 Gyr
  - Bar had to be there already to push gas inward

- Bar formation redshift is thus *at least* $z \approx 1.8$ ($1.4 < z < 2.3$)
  - This sets a benchmark as to when massive galaxies formed their bars: galaxies less massive than NGC 4371 ($\log M_\star/M_\odot = 10.8$) form their bars at lower z (see Sheth+2012).

- Bar in NGC 4371 seems to be a robust structure

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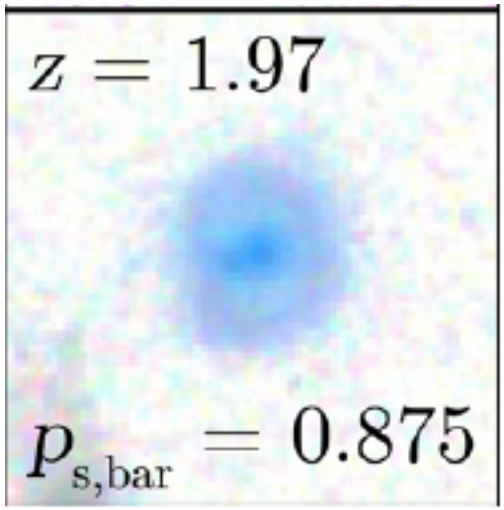
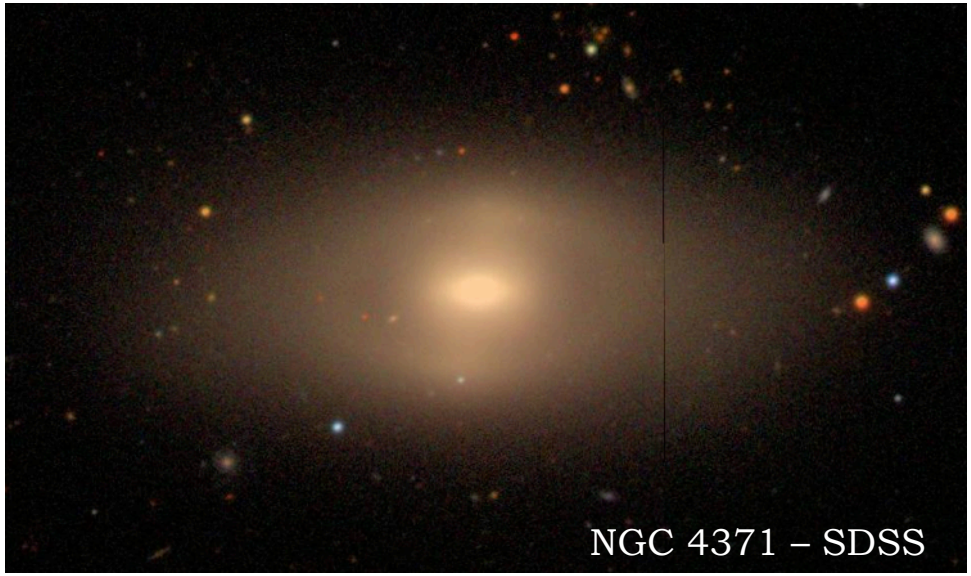
NGC 4371 is thus a likely fossil record of the most distant and oldest barred galaxies known to date



Simmons+2014



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An important implication is that NGC 4371 has a dynamically mature disc already at $z \approx 1.8$, since bars seem to form only when at least part of their host discs reach such dynamical state (in qualitative agreement with Wisnioski+2015)

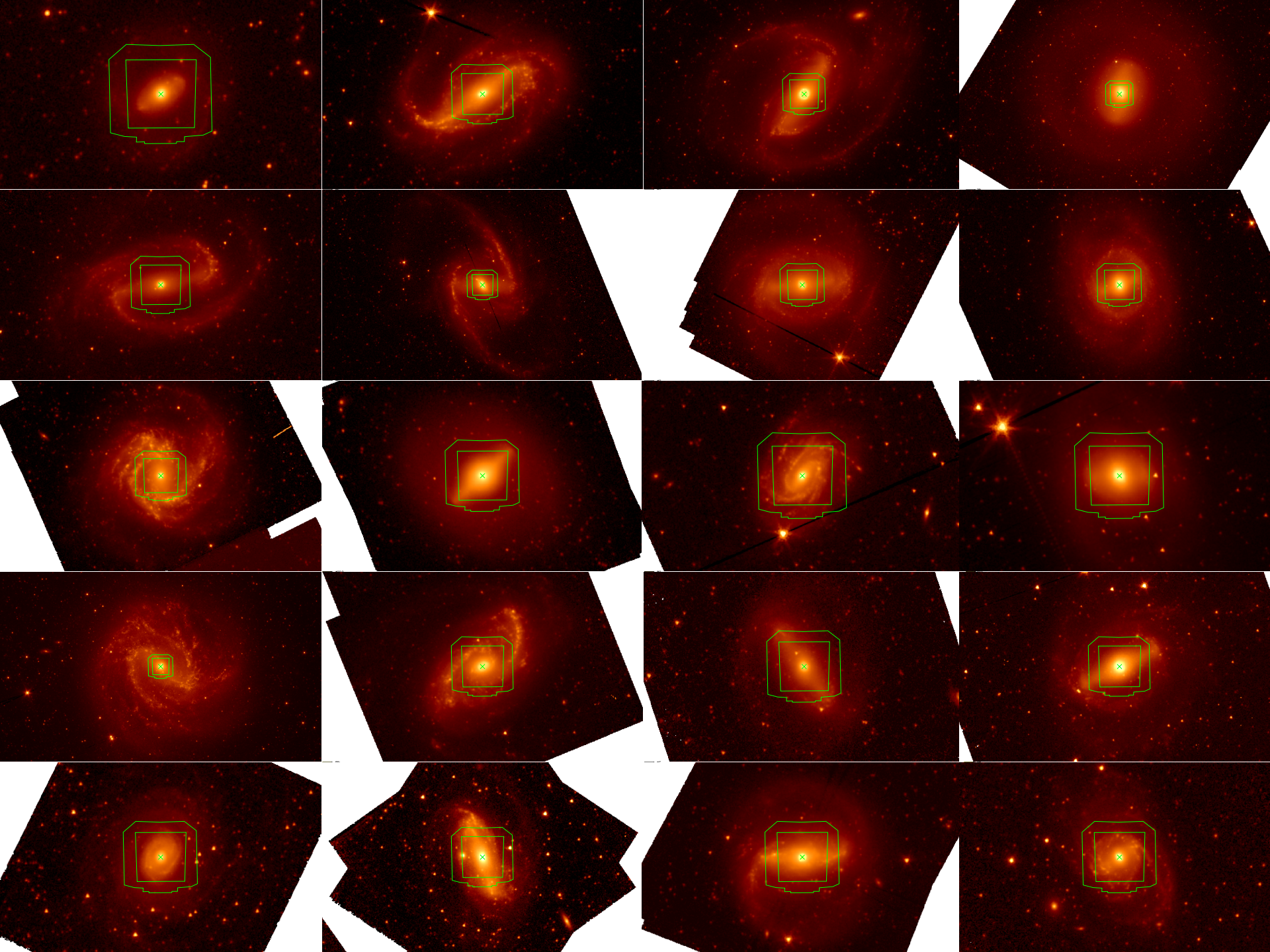
The TIMER Project

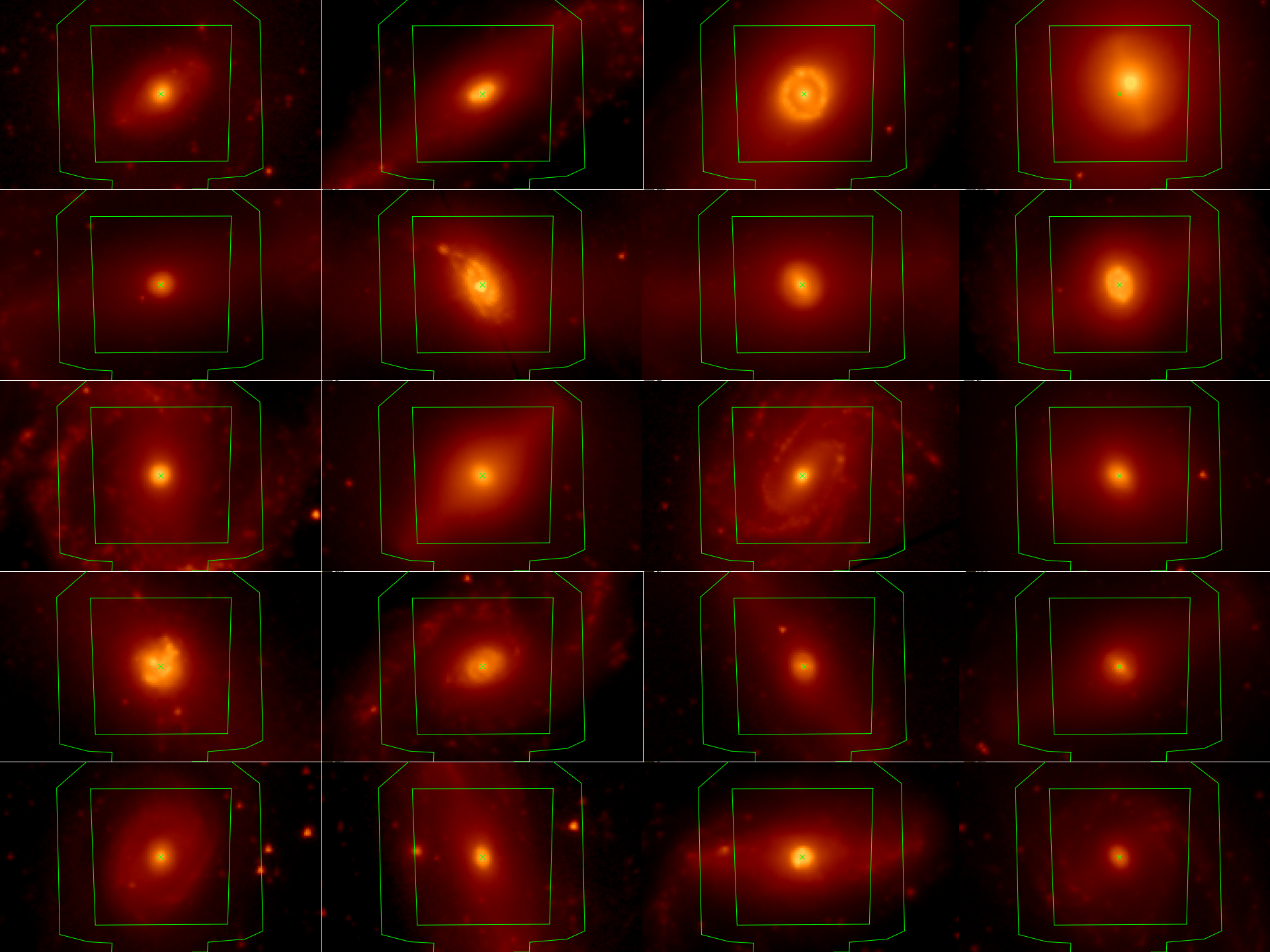
- **T**ime **I**nference with **M**USE in **E**xtragalactic **R**ings (Gadotti+2018)

  - A survey of the central region of 24 nearby barred galaxies (d ~ 20Mpc) with MUSE

  - All galaxies with bar-built nuclear structures, e.g., nuclear rings and inner discs

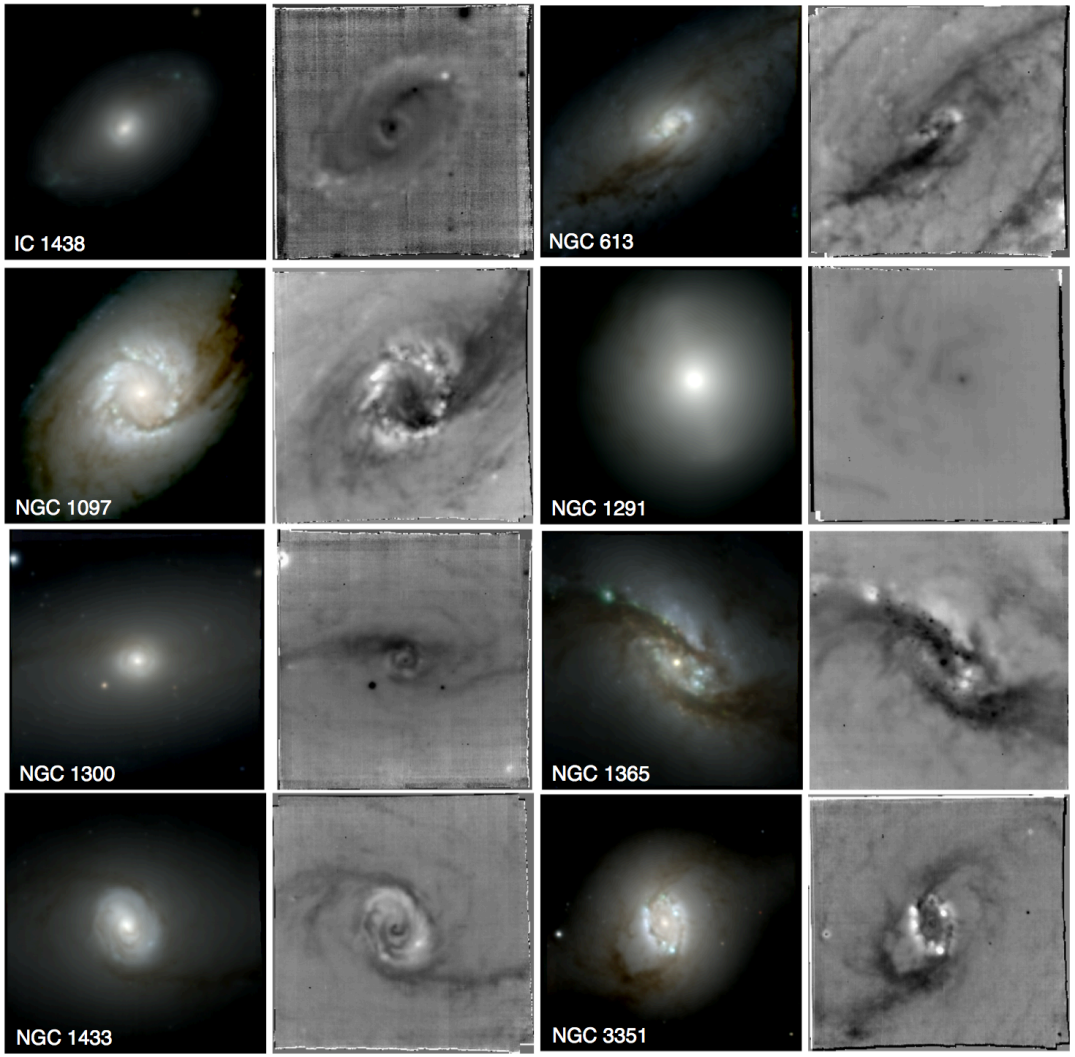
  - Important legacy value



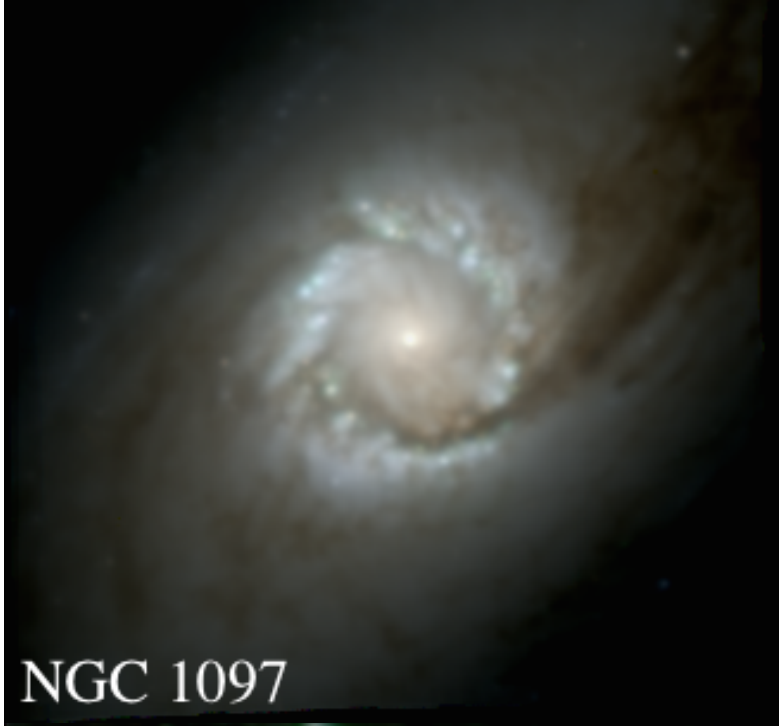


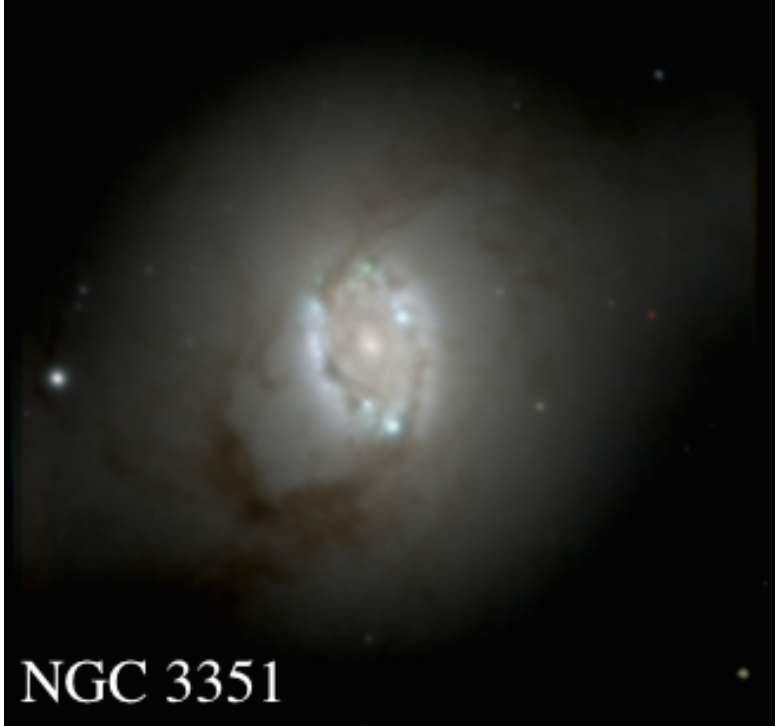
The TIMER Project

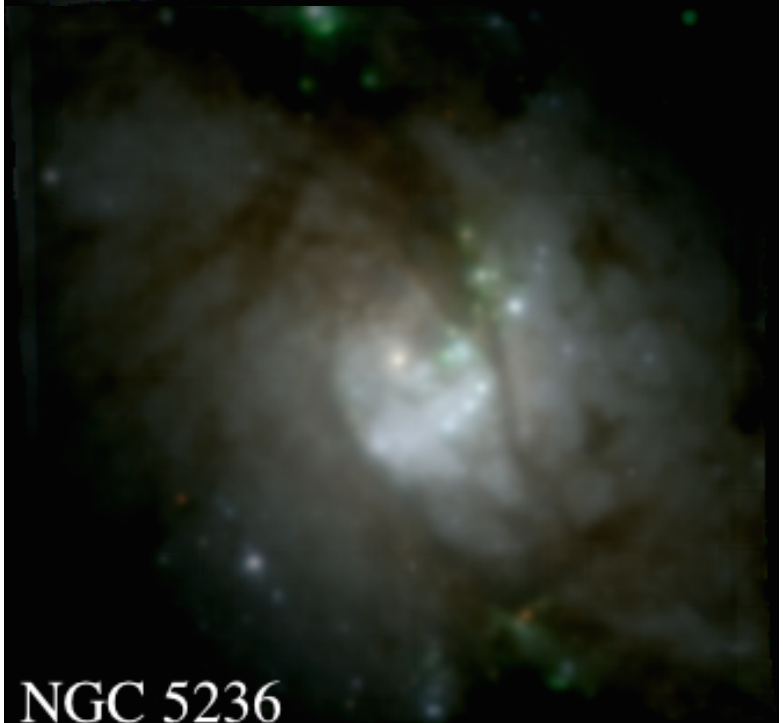
- Colour composites and maps highlight MUSE superb imaging quality



Gadotti+2018


NGC 1097


NGC 3351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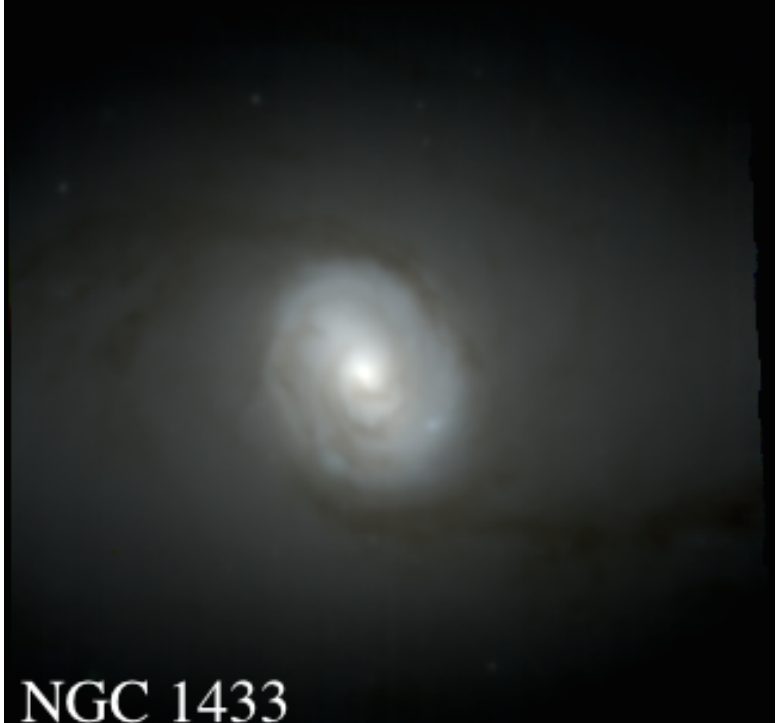
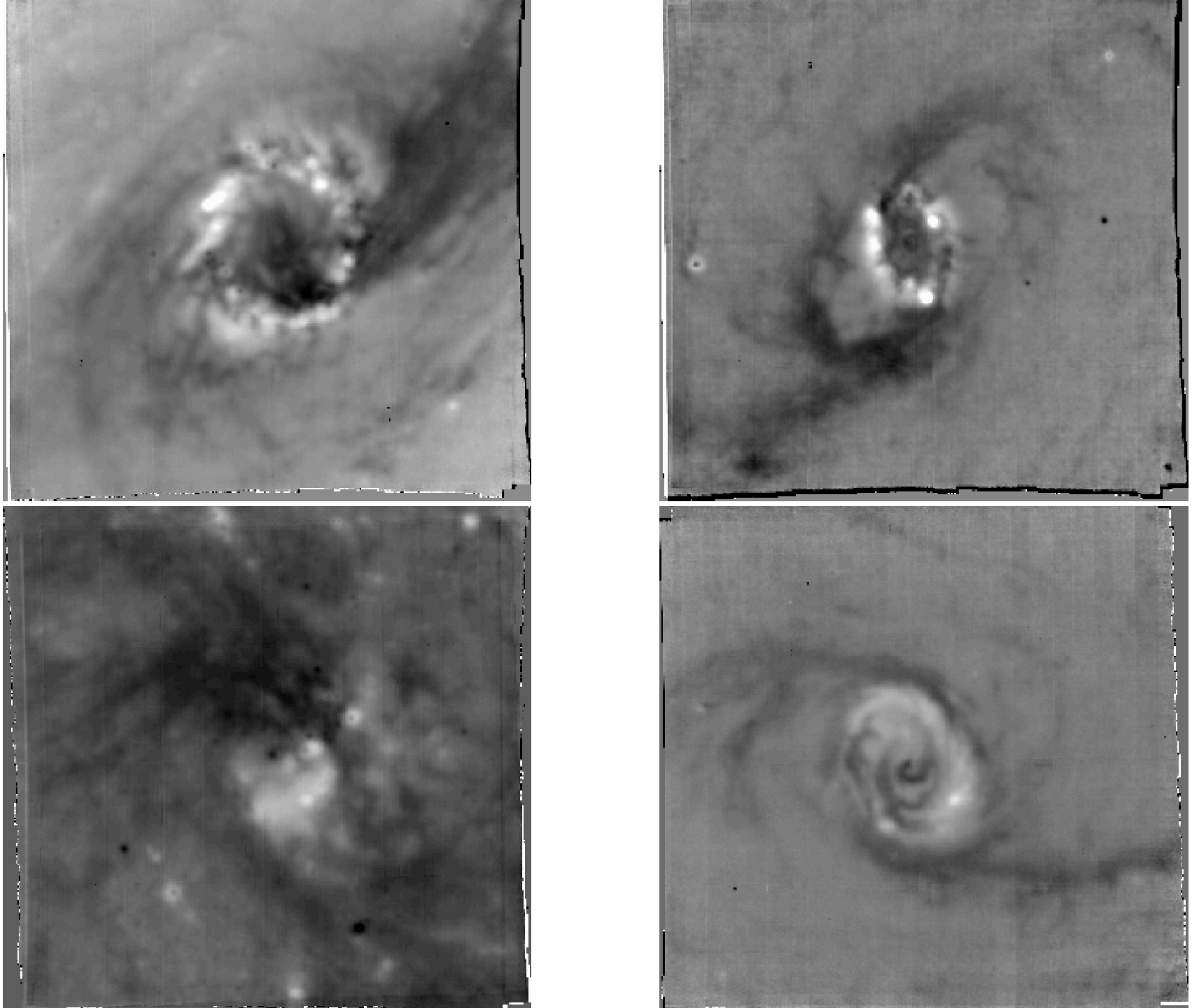

NGC 1433



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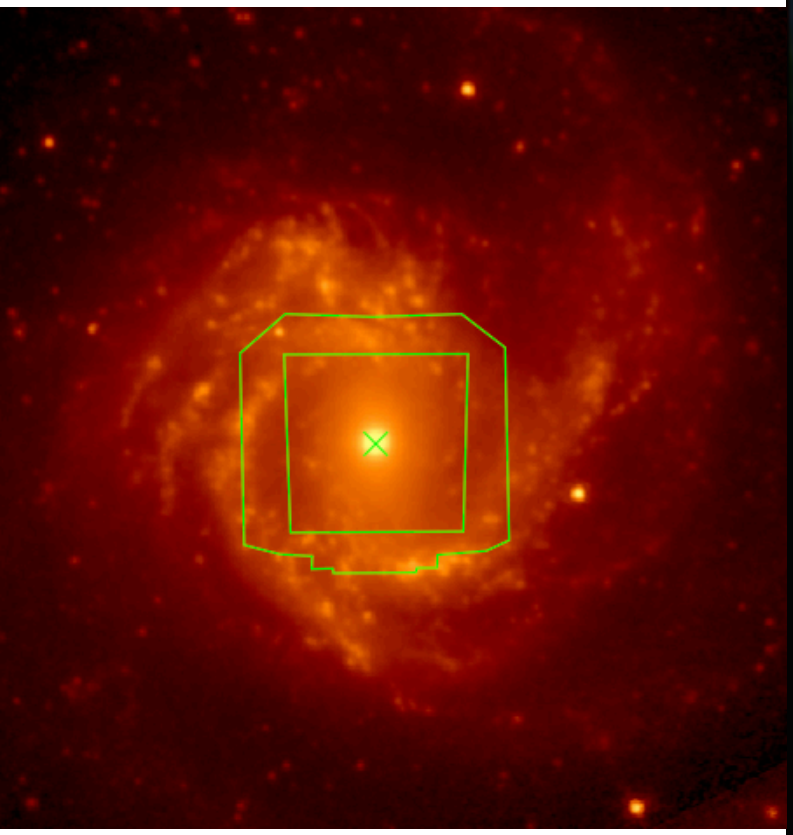

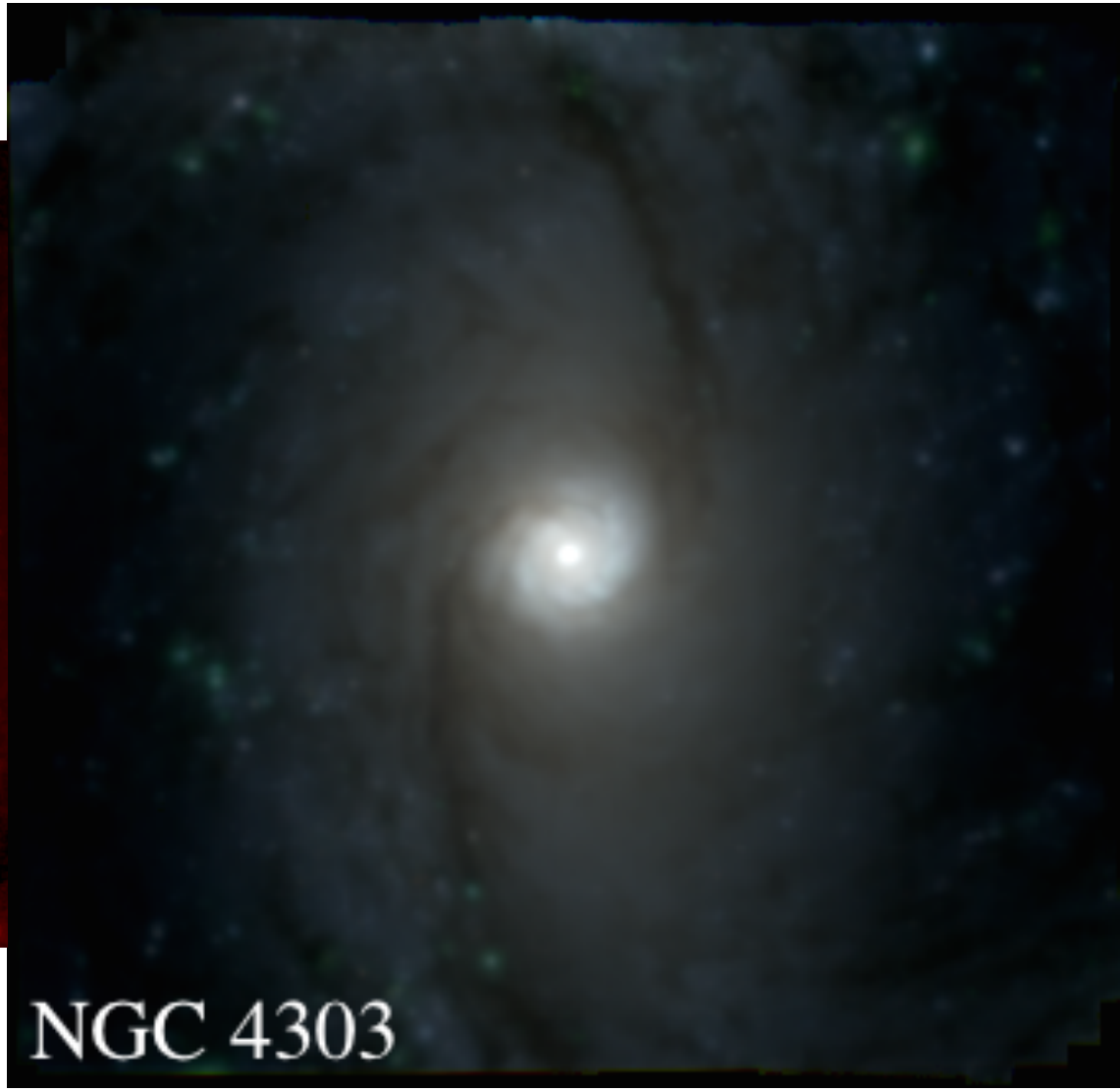

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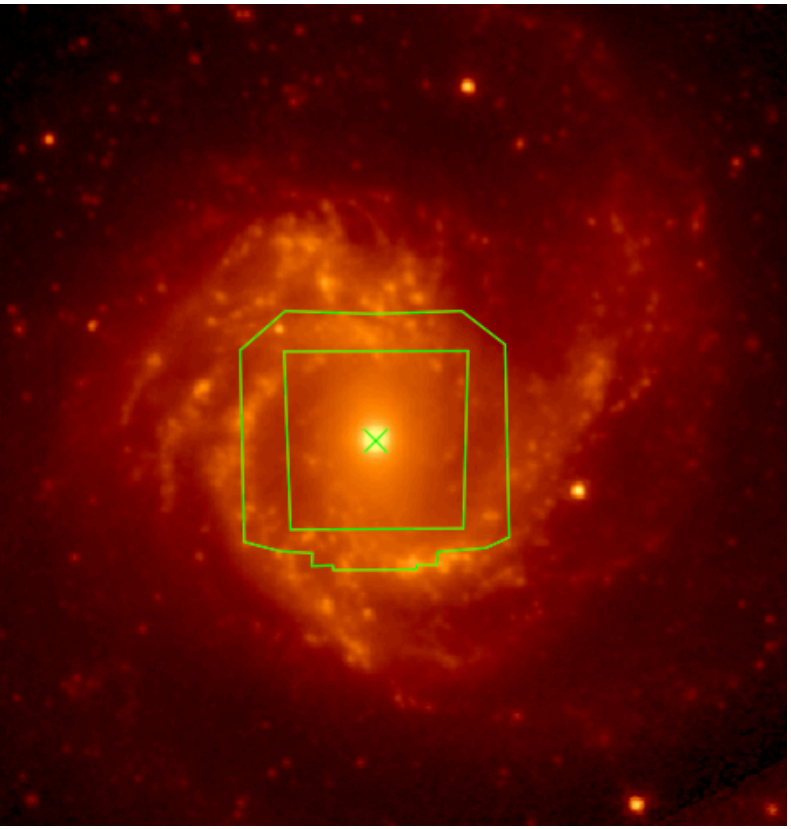

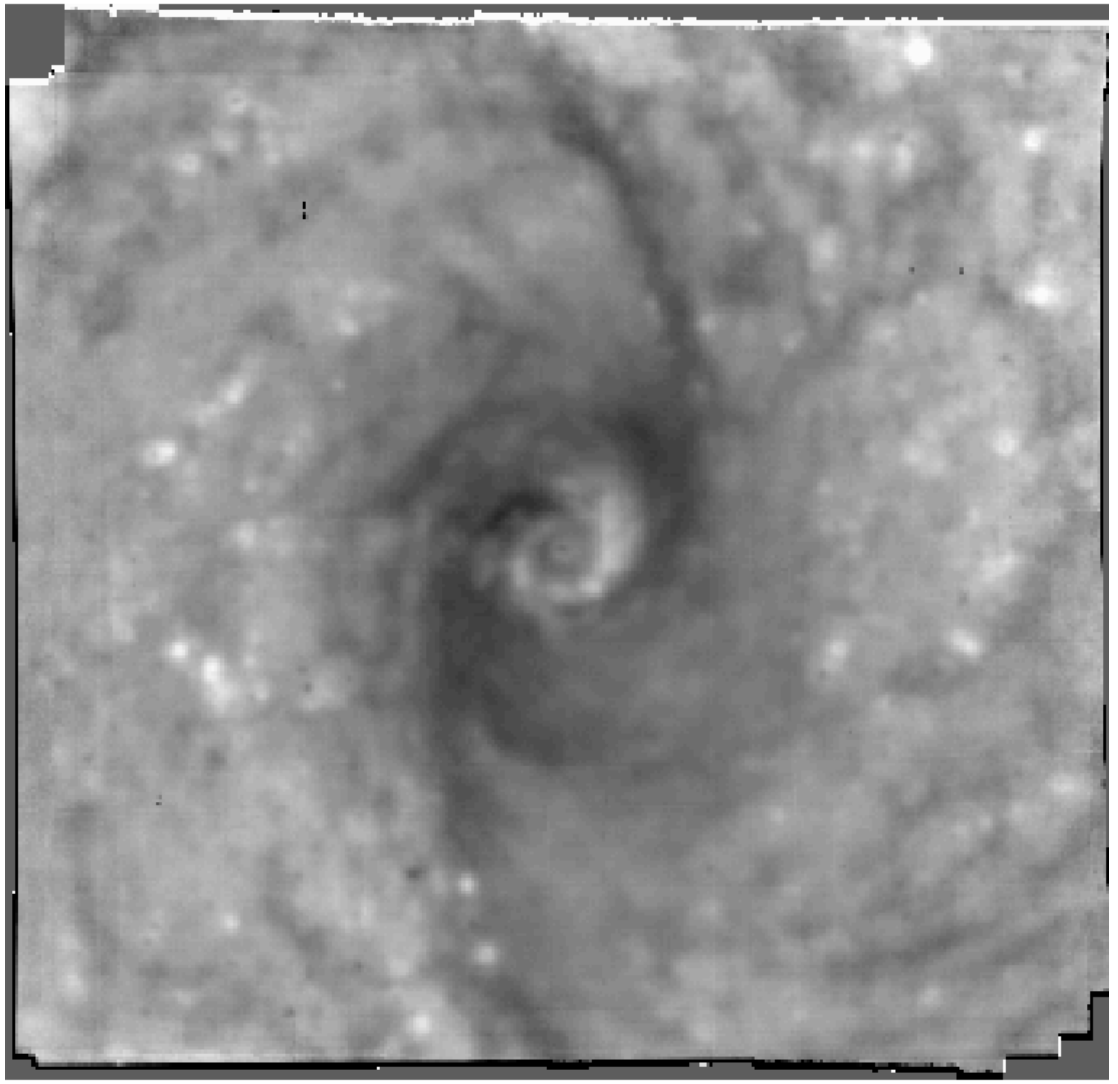

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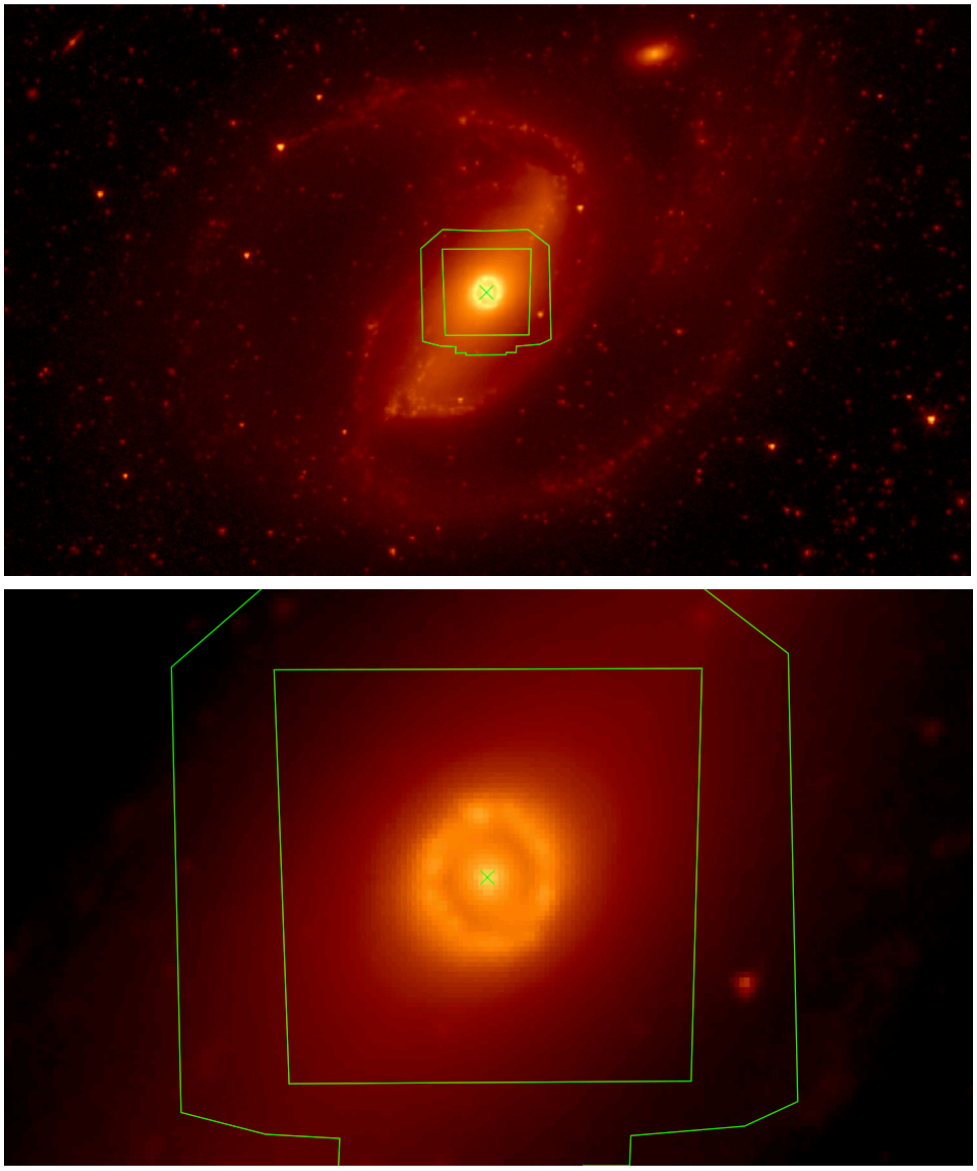


The TIMER Project

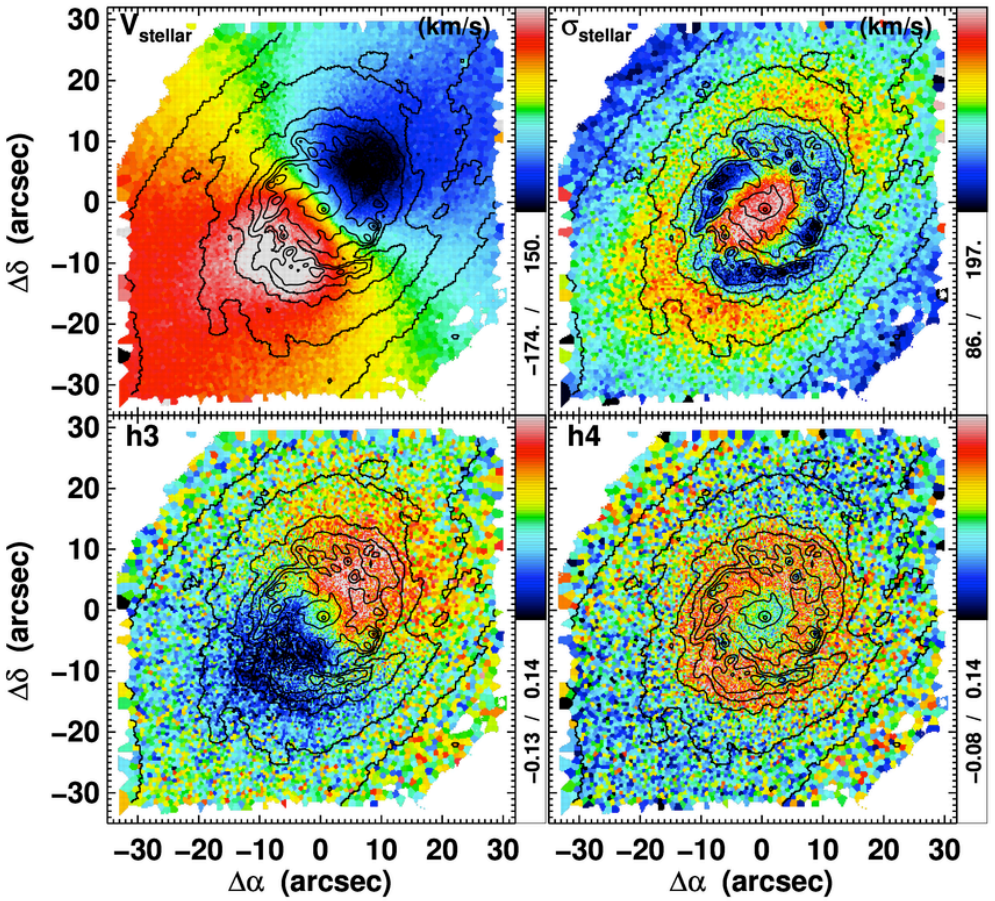
The TIMER Project

- Kinematic maps reveal inner component with:

1. high radial velocity and low velocity dispersion
2. near-circular orbits (from v-h_3 anti-correlation)
3. and separate from the main disc (from high values of h_4)

- Consistent with the picture in which inner discs are built from bar-driven gas inflow

NGC 1097



Gadotti+2018

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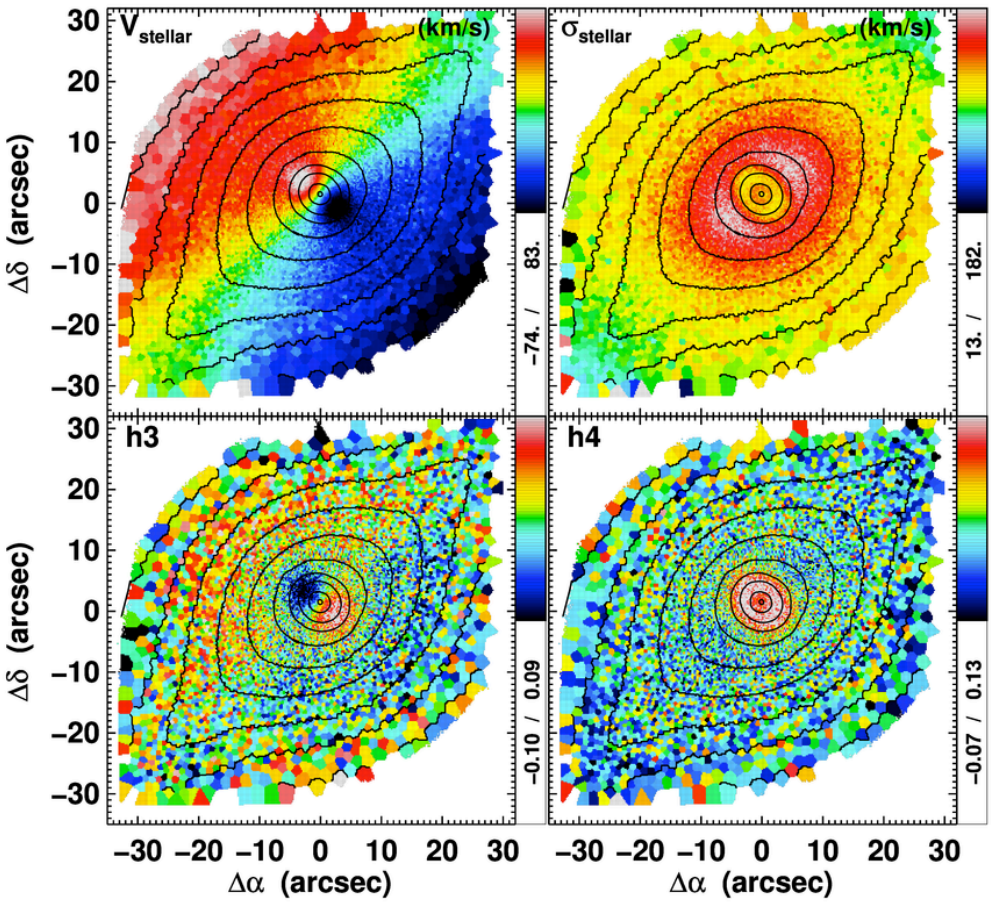
NGC 4643



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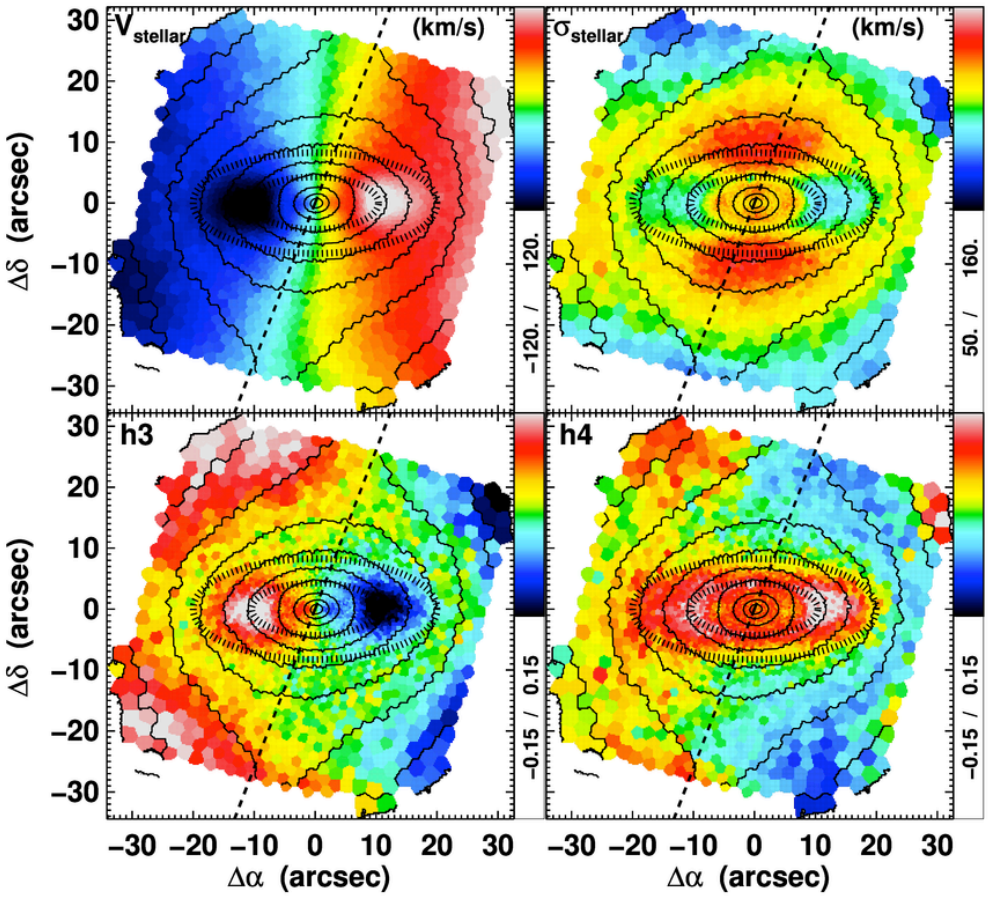
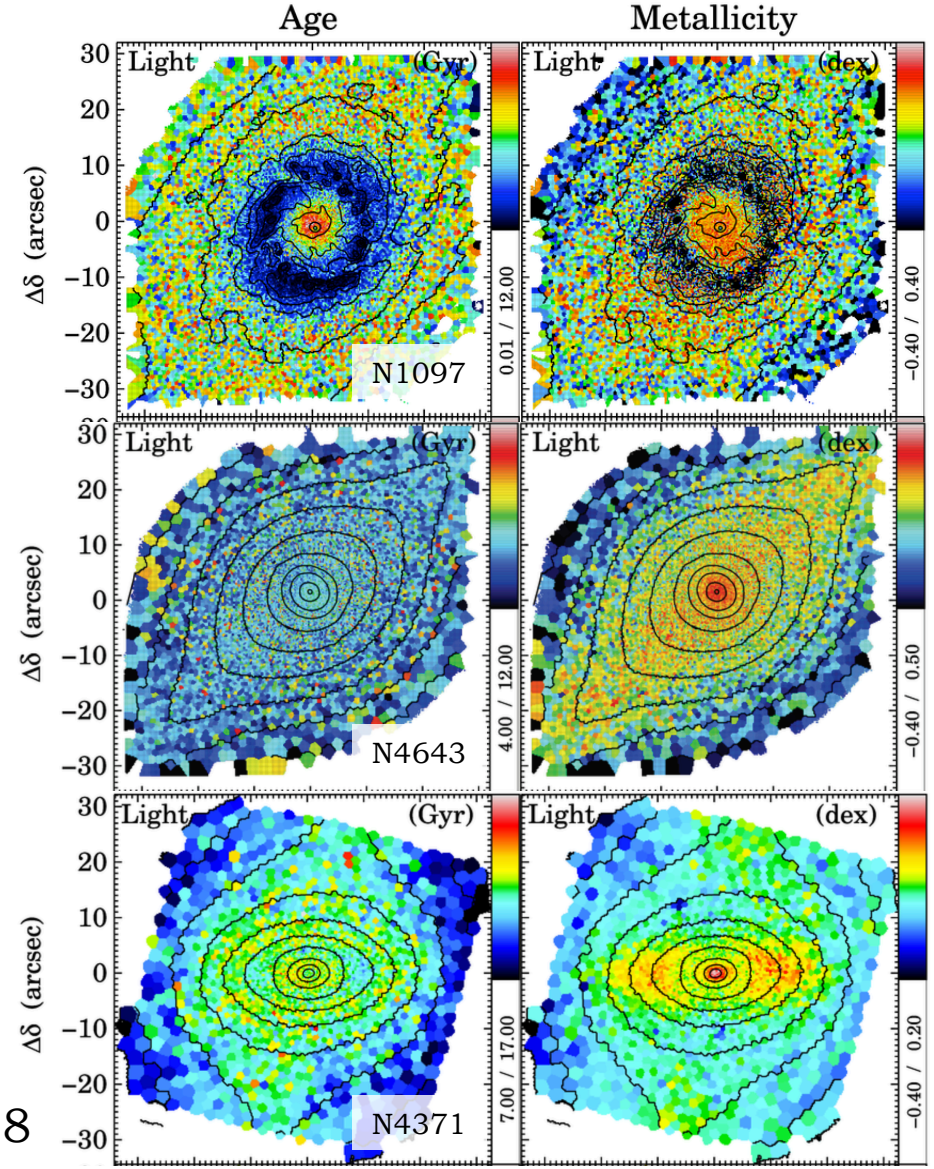
NGC 4371



Gadotti+2015

The TIMER Project

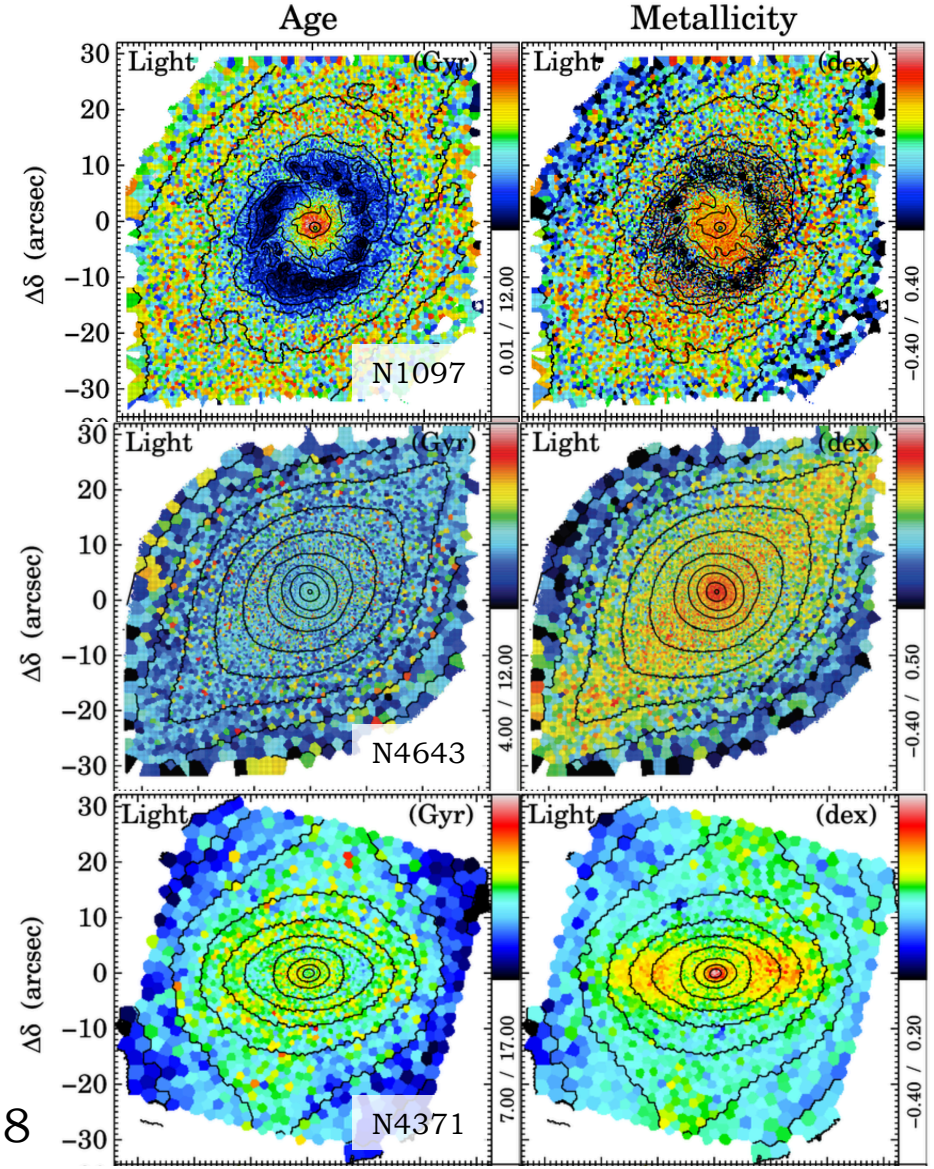
- Maps of mean stellar age and metallicity reveal central metal-rich component
- In NGC 1097, this component is also the oldest, and the nuclear ring is the youngest and most metal-poor component
- Gas feeding the nuclear ring is not pre-processed in the galaxy and likely comes from the low-mass companion (see also Seidel+2015 for the case of NGC 7552)
- Nuclear ring acts as an efficient barrier to the gas inflow



Gadotti+2015,2018

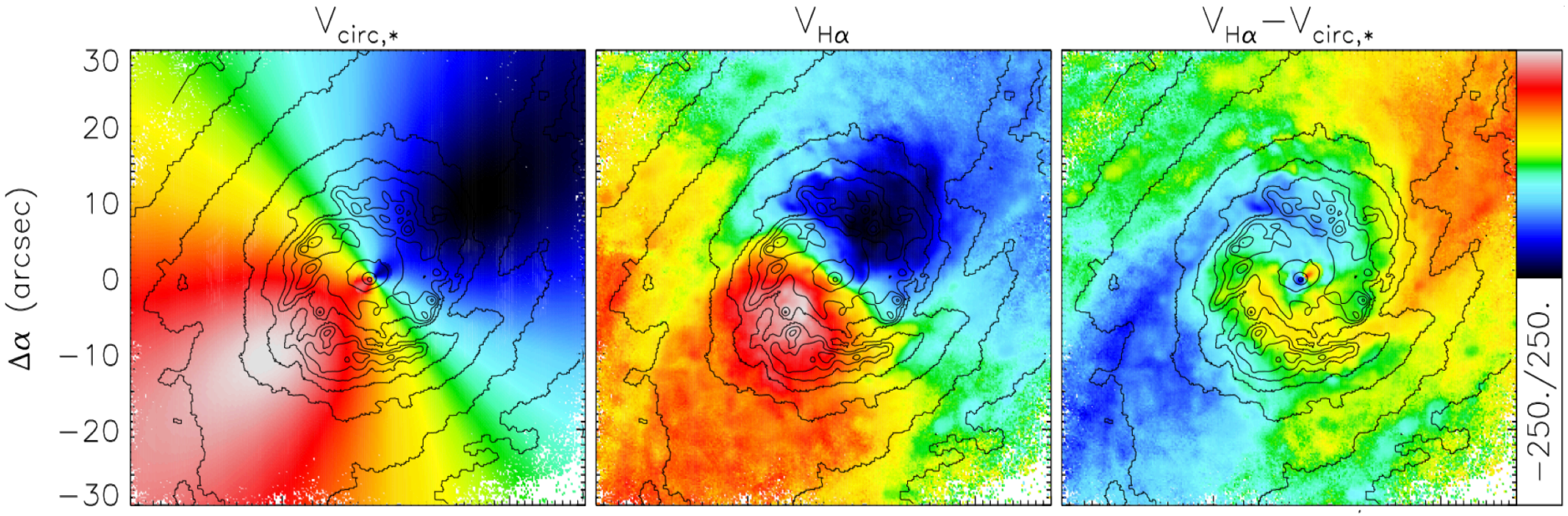
The TIMER Project

- Bar-built nuclear structures can have a range of ages and chemical content



Gadotti+2015,2018

The TIMER Project

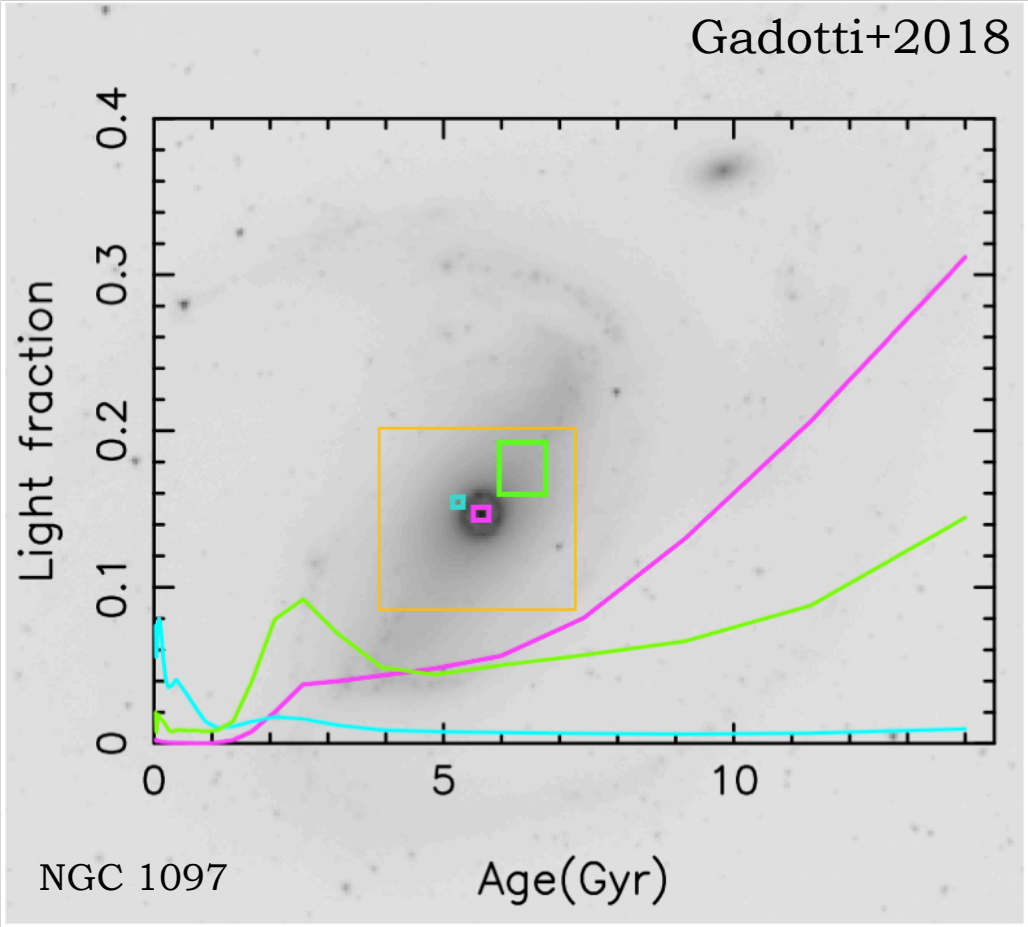


NGC 1097

Gadotti+2018

- Stellar dynamical modelling provides circular velocity
- Combined with gas velocity field from Hα emission allows one to see streaming motion along the bar

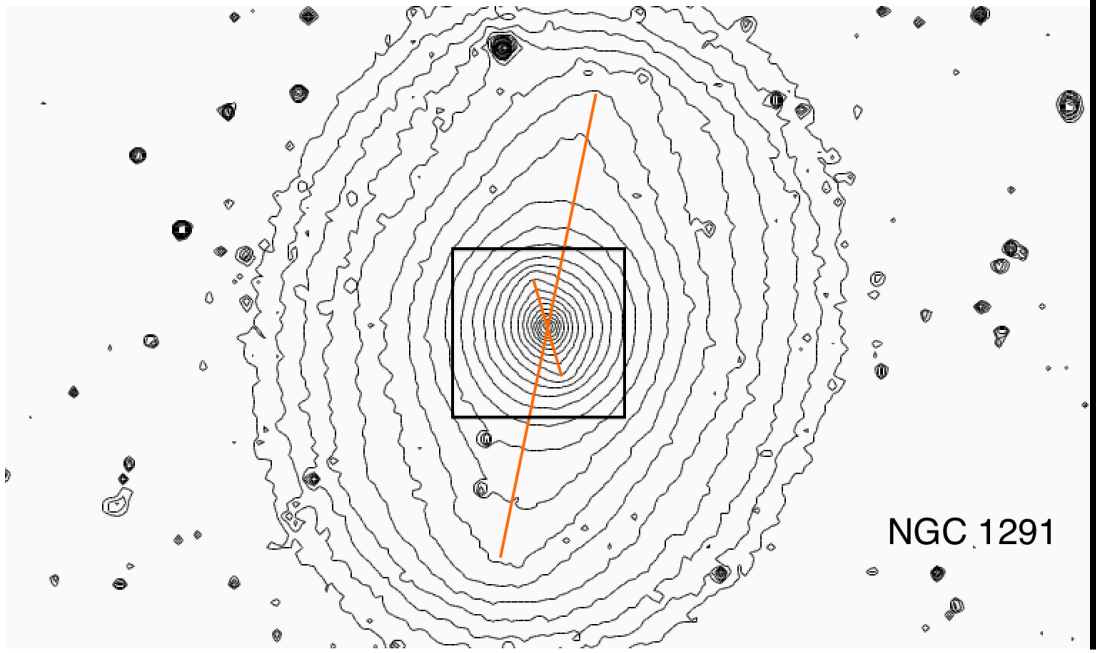
The TIMER Project

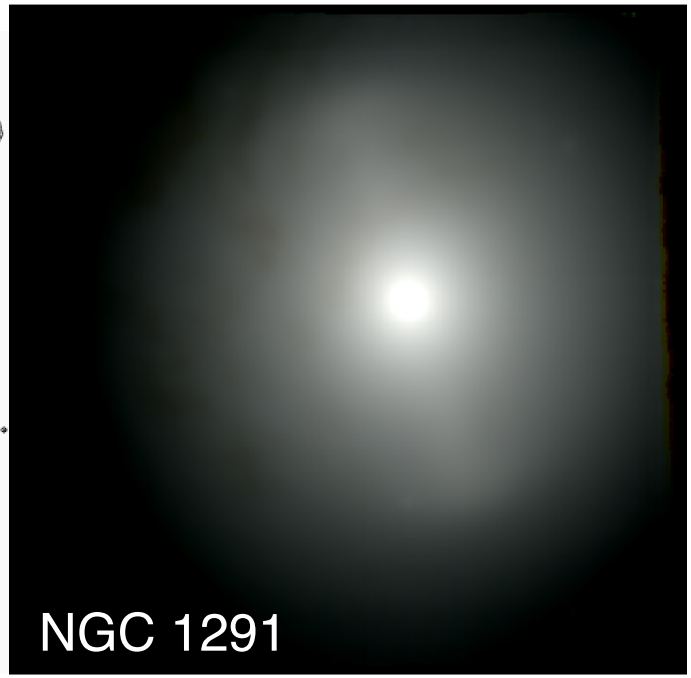


- Spatially-resolved star formation histories provide further clues to galaxy assembly

Inner Bars Also Buckle

Méndez-Abreu+2018





Inner Bars Also Buckle

Méndez-Abreu+2018

- h4 profile along inner bar shows minima that are signatures of a box/peanut
- Inner bars are governed essentially by the same physical processes as large-scale bars