HI Galaxy Science with SKA and Pathfinders

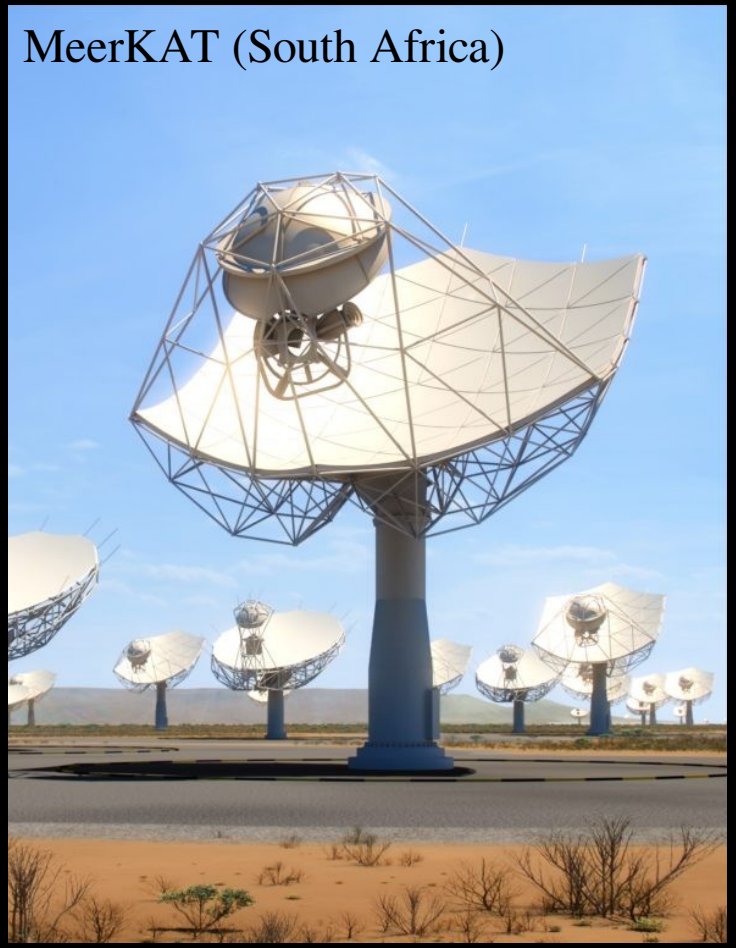
Federico Lelli
Arcetri Astrophysical Observatory

Why HI observations? What do we learn?

1. Galaxy Formation and Evolution

HI = main reservoir for star formation (SF) in galaxies

HI accretion & depletion history ↔ Galaxy SF history



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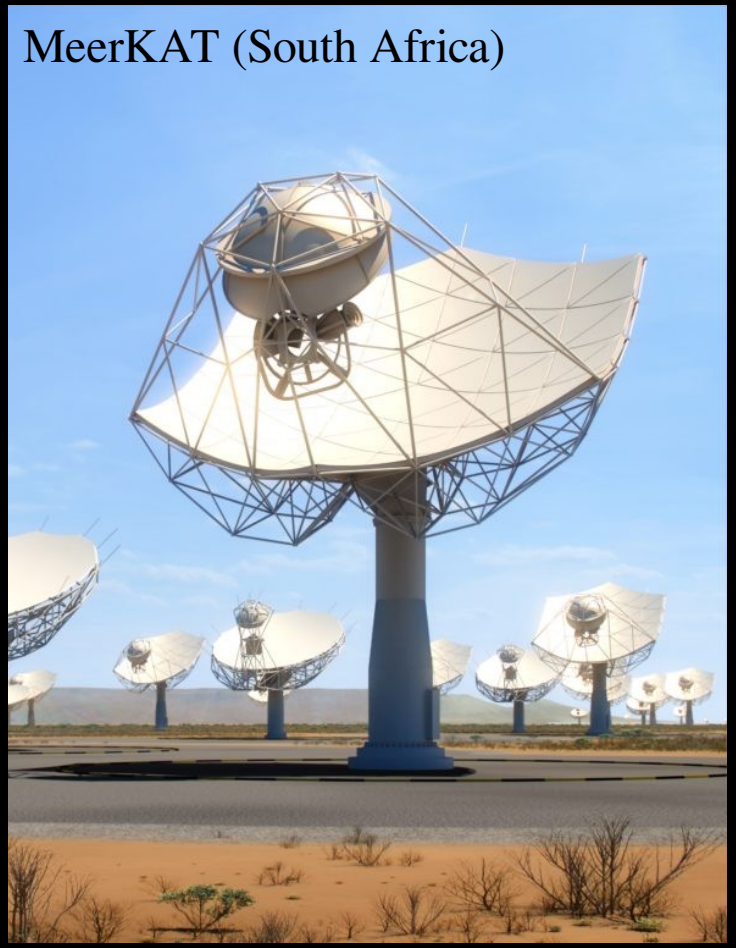
2. The Dark Matter Problem

HI = one of the best dynamical tracers (rotation curves)

Tests of dark matter models & modified gravity theories



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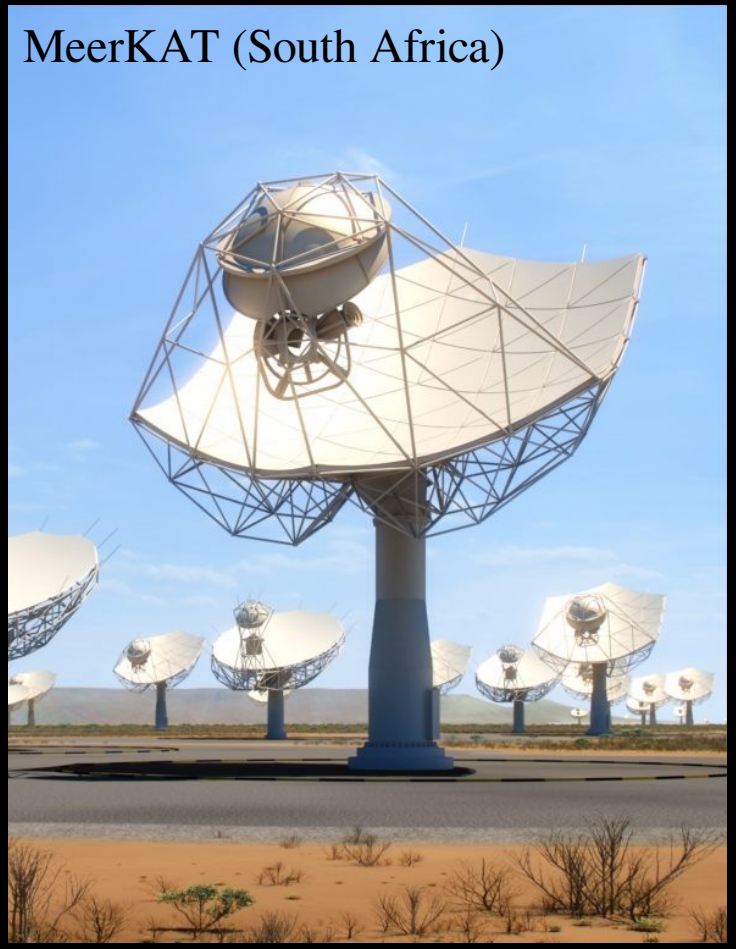
3. Cosmology & Large-Scale Structure

HI mass functions & HI cosmic density $\Omega_{HI}(z)$

Galaxy redshifts & TF distances → H_0, galaxy flows



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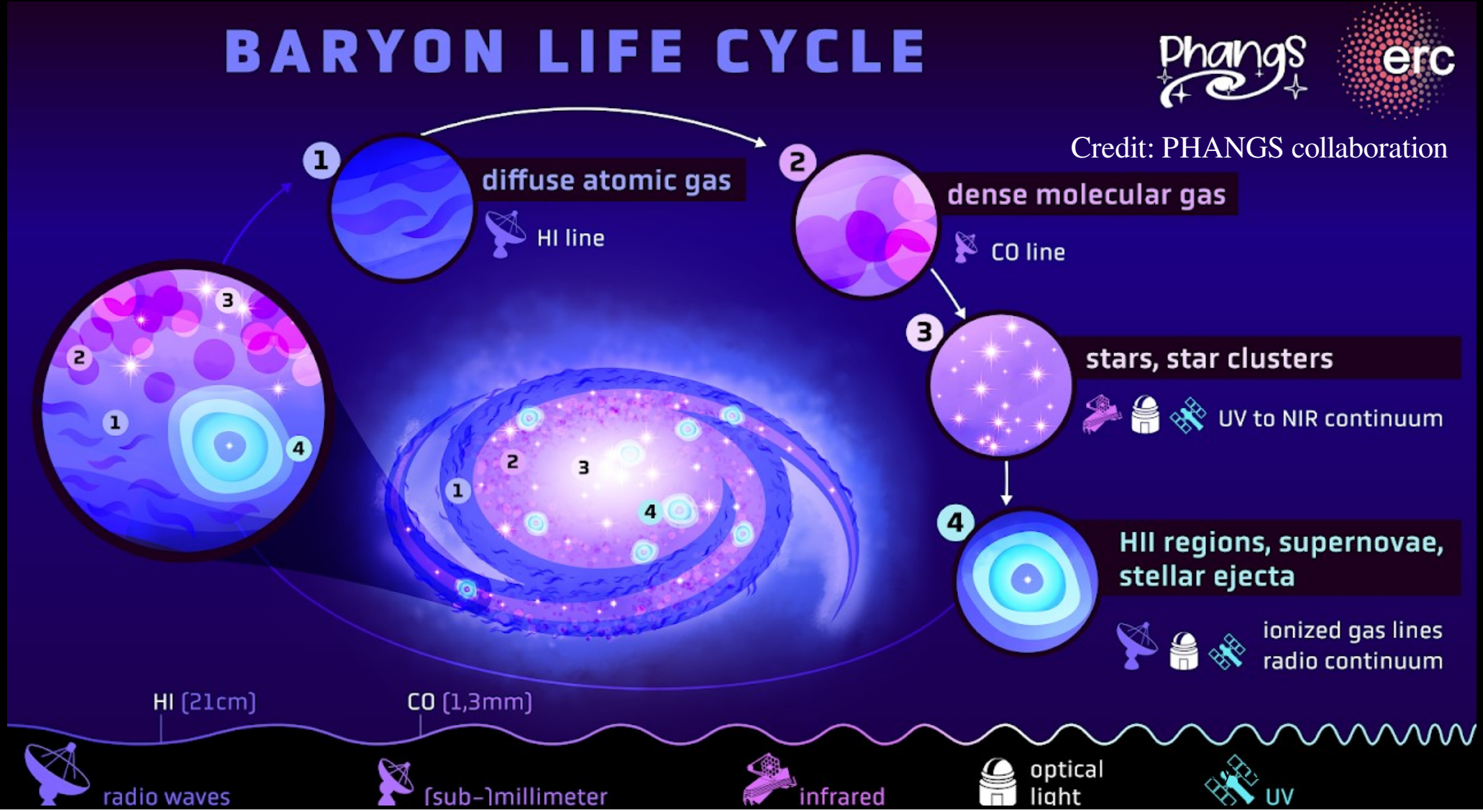
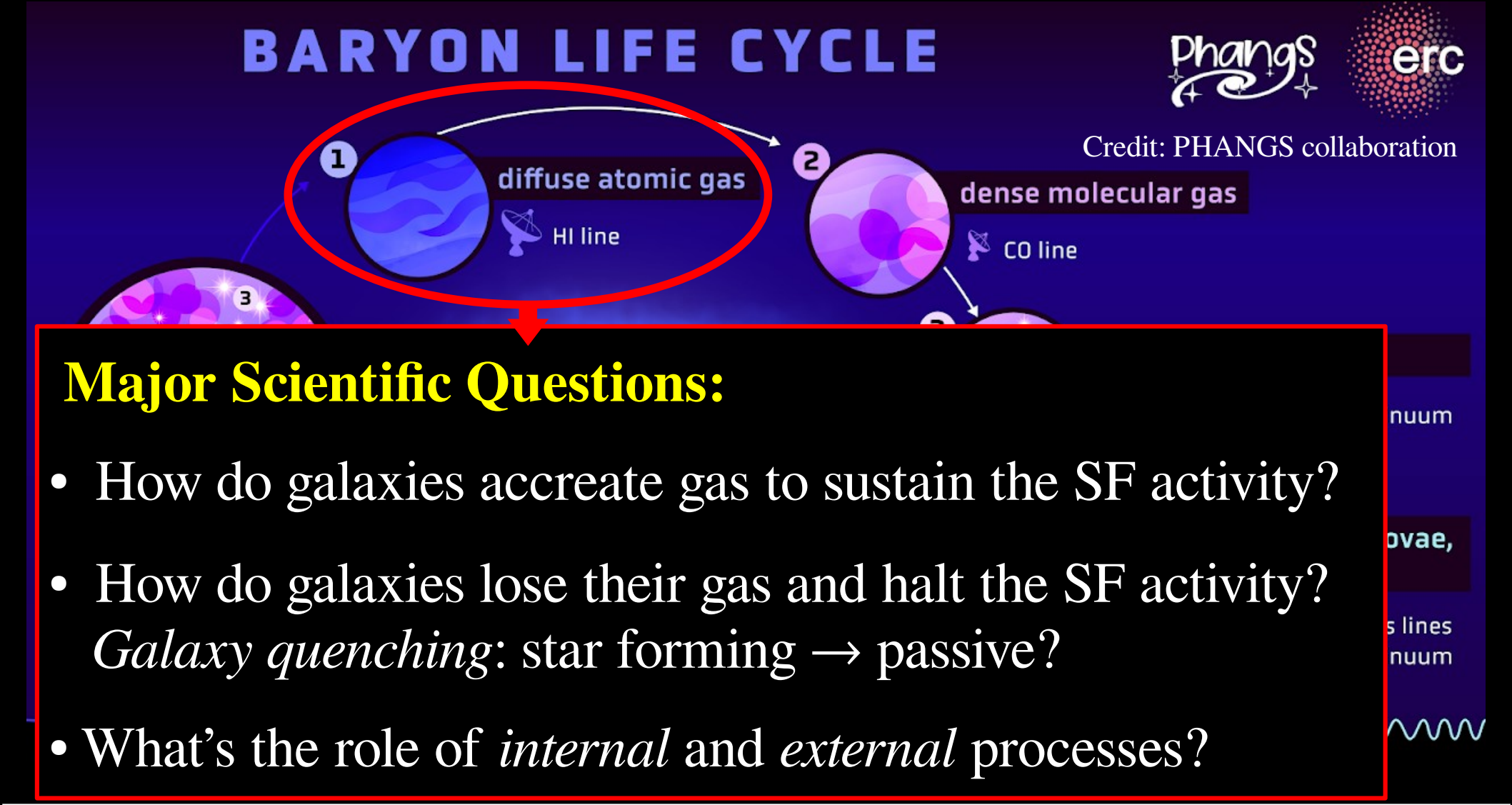
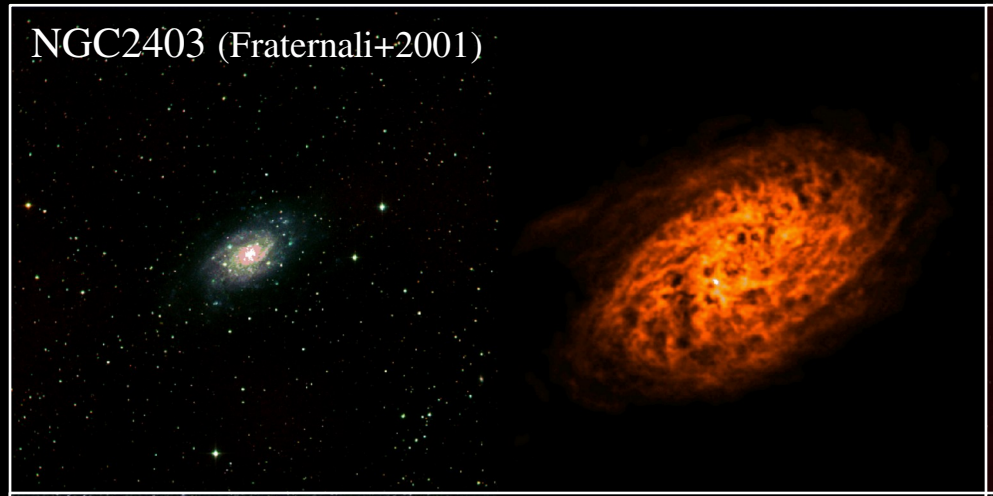

BARYON LIFE CYCLE
Phangs
erc
Credit: PHANGS collaboration
1
diffuse atomic gas
HI line
2
dense molecular gas
CO line
3
stars, star clusters
UV to NIR continuum
4
HII regions, supernovae, stellar ejecta
ionized gas lines
radio continuum
HI (21cm)
CO (1,3mm)
radio waves
[sub-]millimeter
infrared
optical light
UV

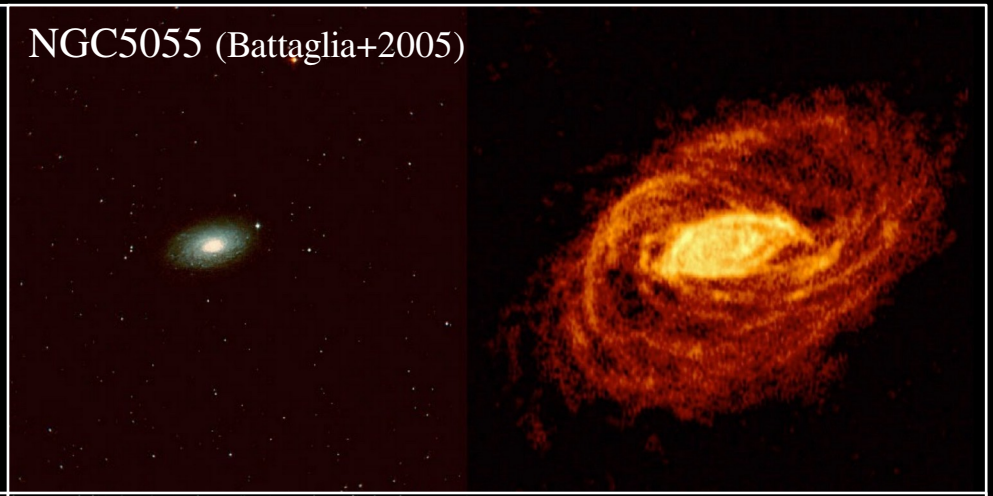


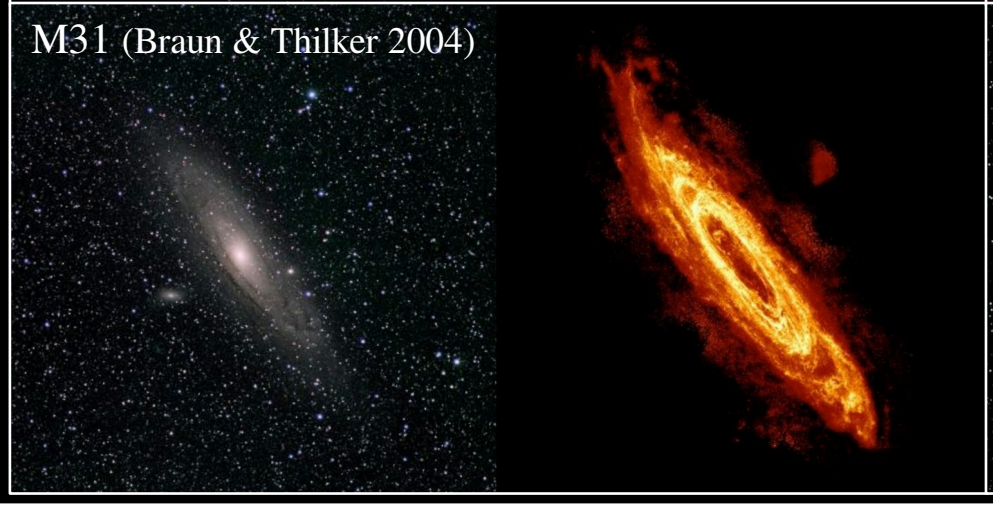
Major Scientific Questions:

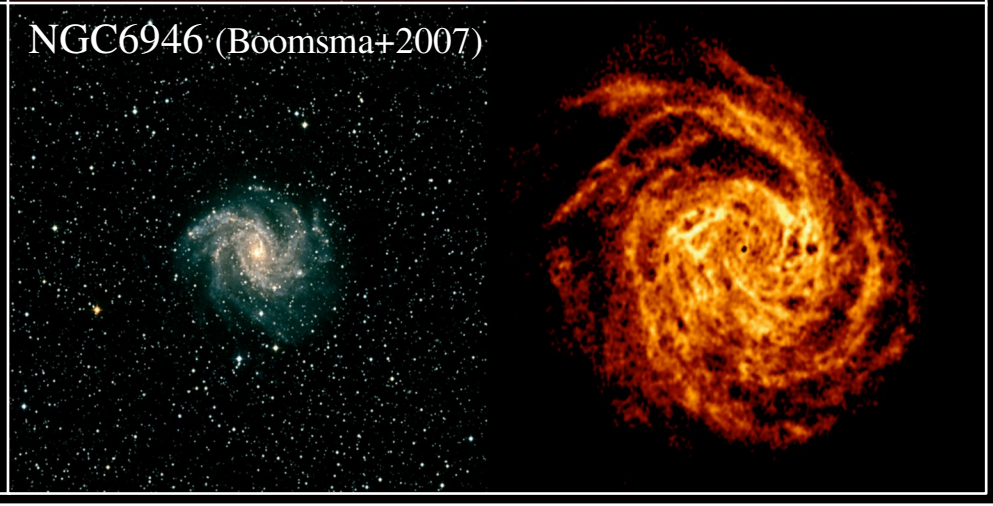
- How do galaxies accreate gas to sustain the SF activity?
- How do galaxies lose their gas and halt the SF activity?
  Galaxy quenching: star forming → passive?
- What's the role of *internal* and *external* processes?

Star-Forming Late-Type Galaxies: Extended HI disks



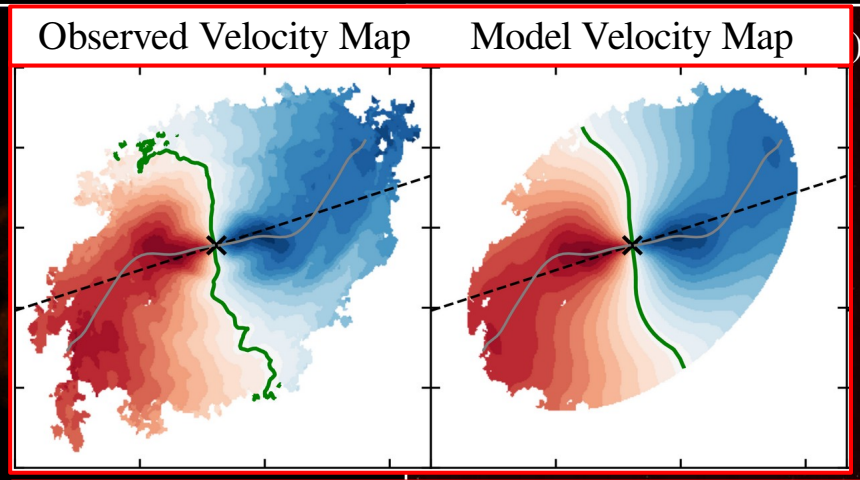


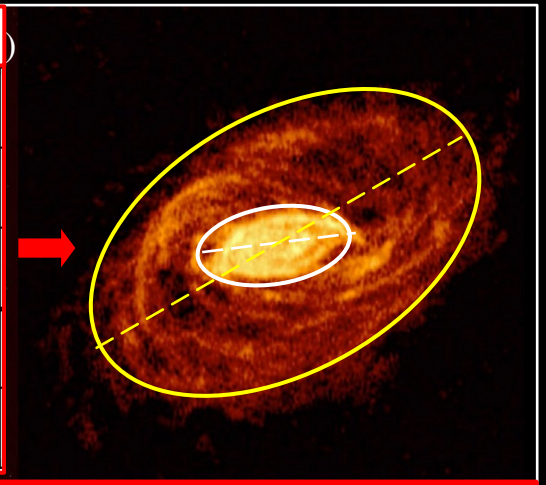




Star-Forming Late-Type Galaxies: Extended HI disks

NGC2403 (Fraternali+2001)





M31 (Braun & Thilker 2004)

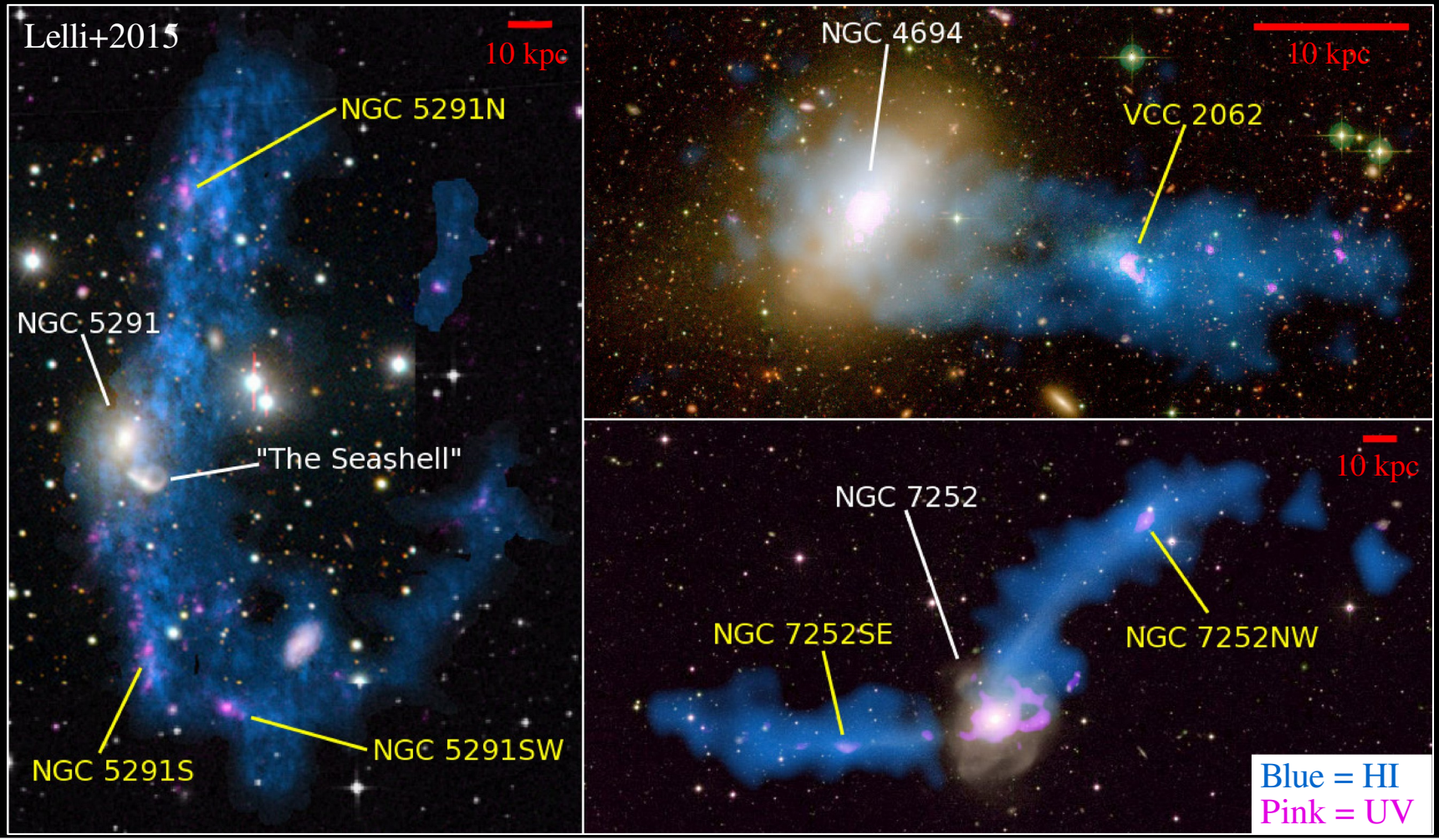
Warped HI disks:

Direction of the gas angular momentum changes from the inner to outer parts:

Possible signature of cold gas accretion?

(Sancisi 1976, Sancisi+2006)

Interacting Starburst Galaxies: HI Tidal Tails & Debris



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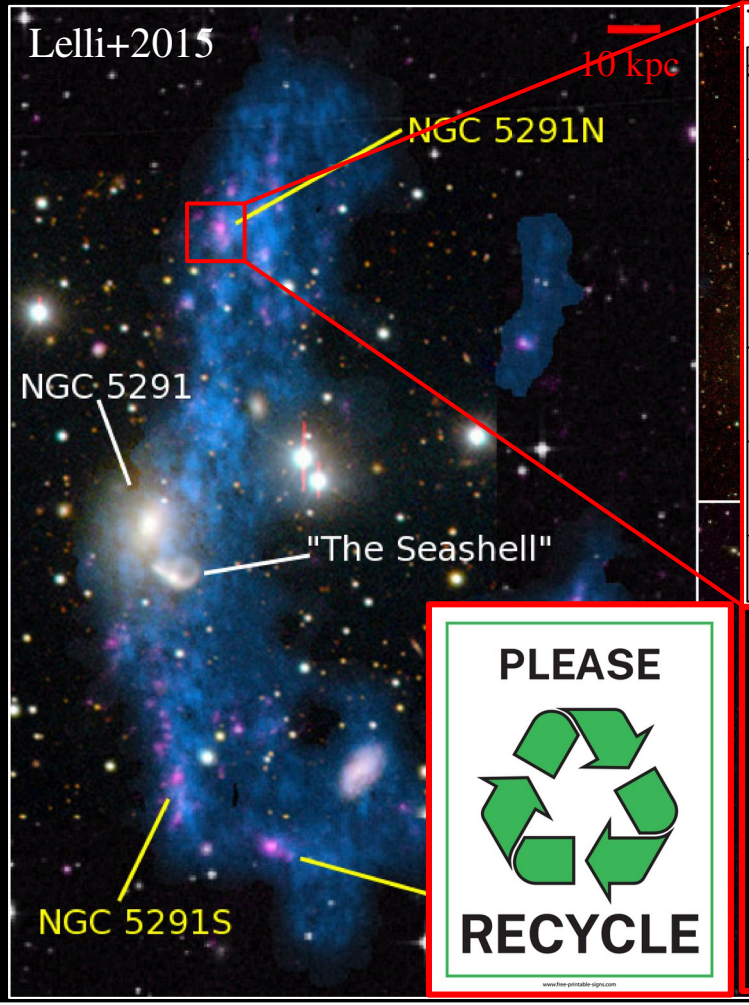
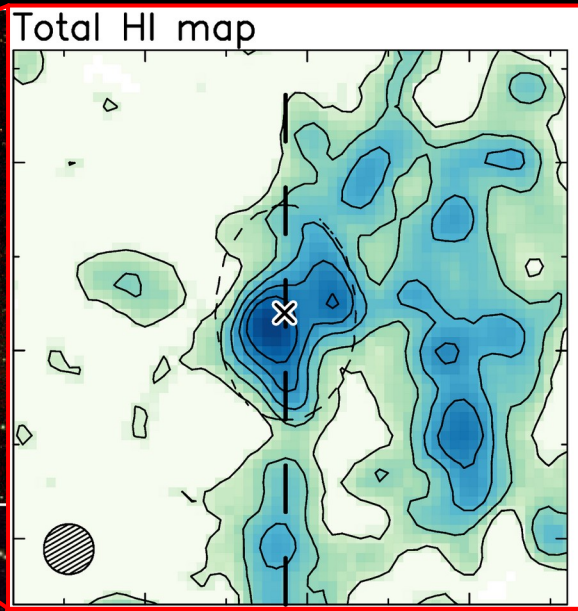
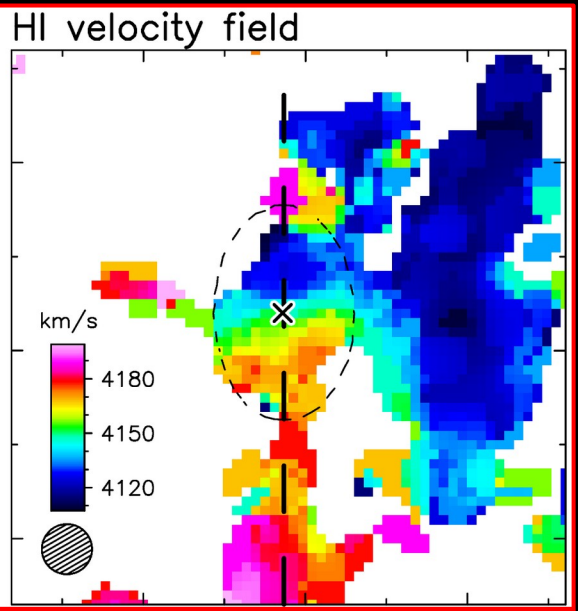




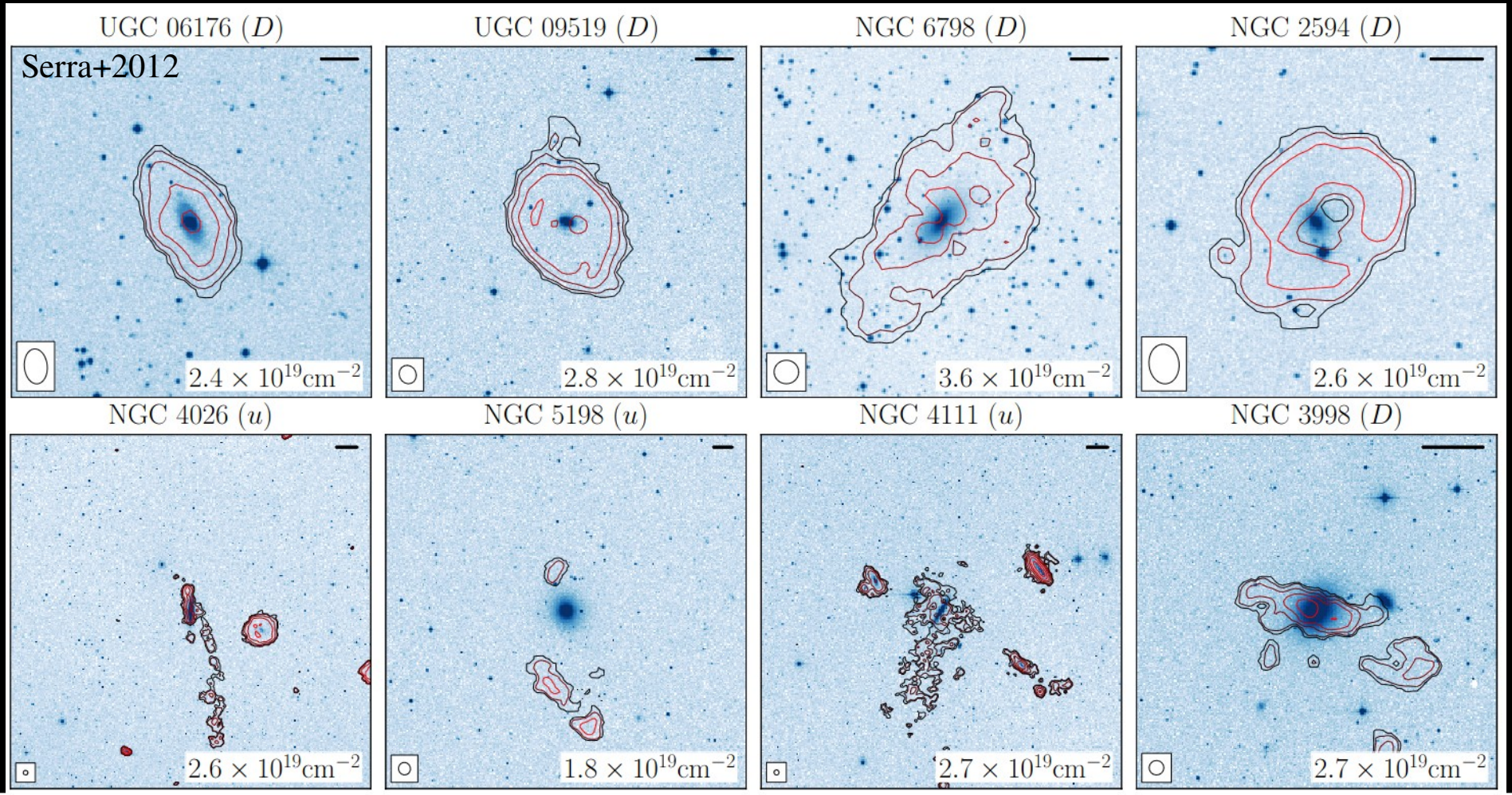


Tidal dwarf galaxies: recycled objects!

Are they common? Are they long lived?

Do they contain dark matter?

Quiescent Early-Type Galaxies: Low Density HI!



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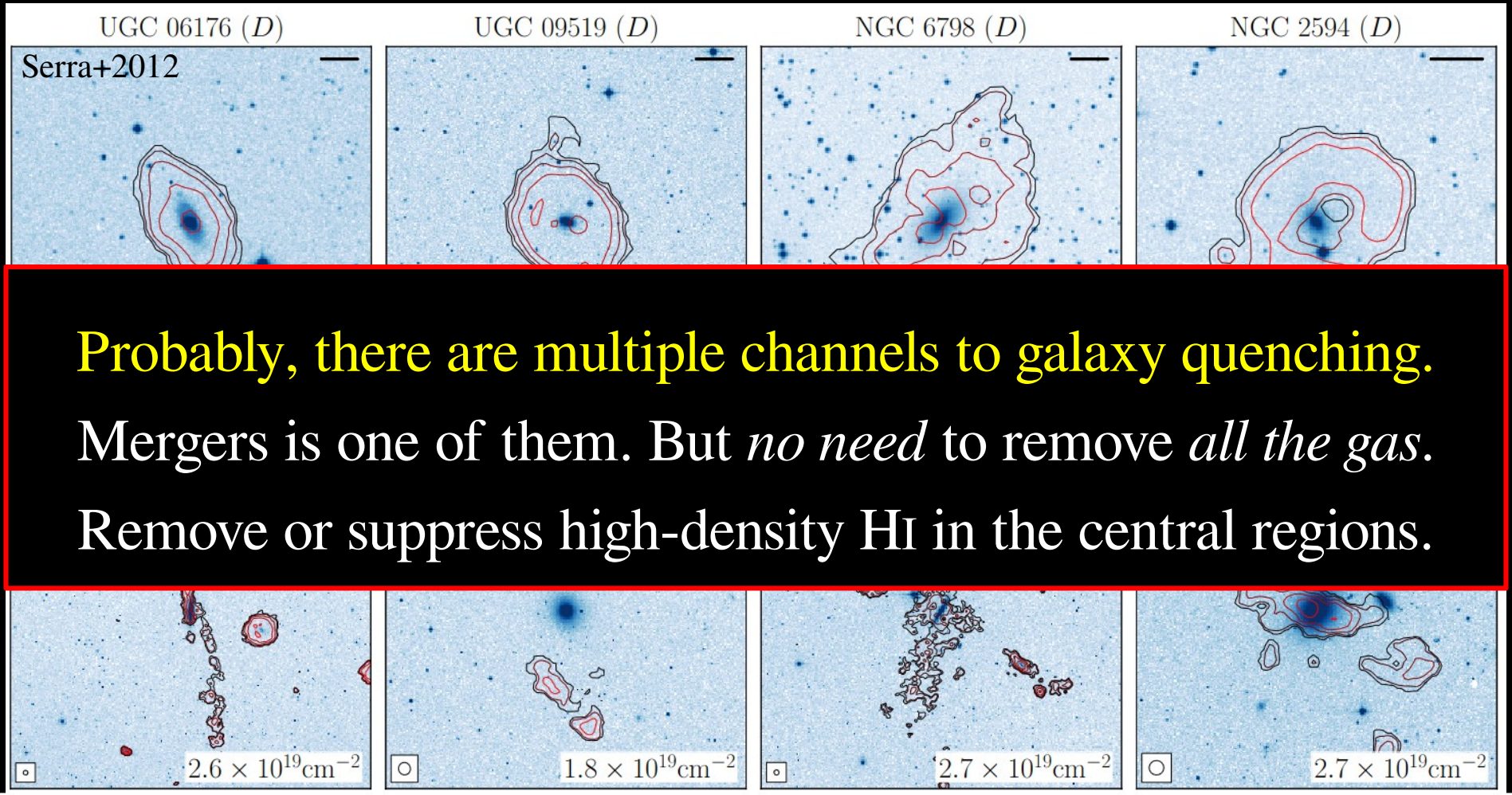
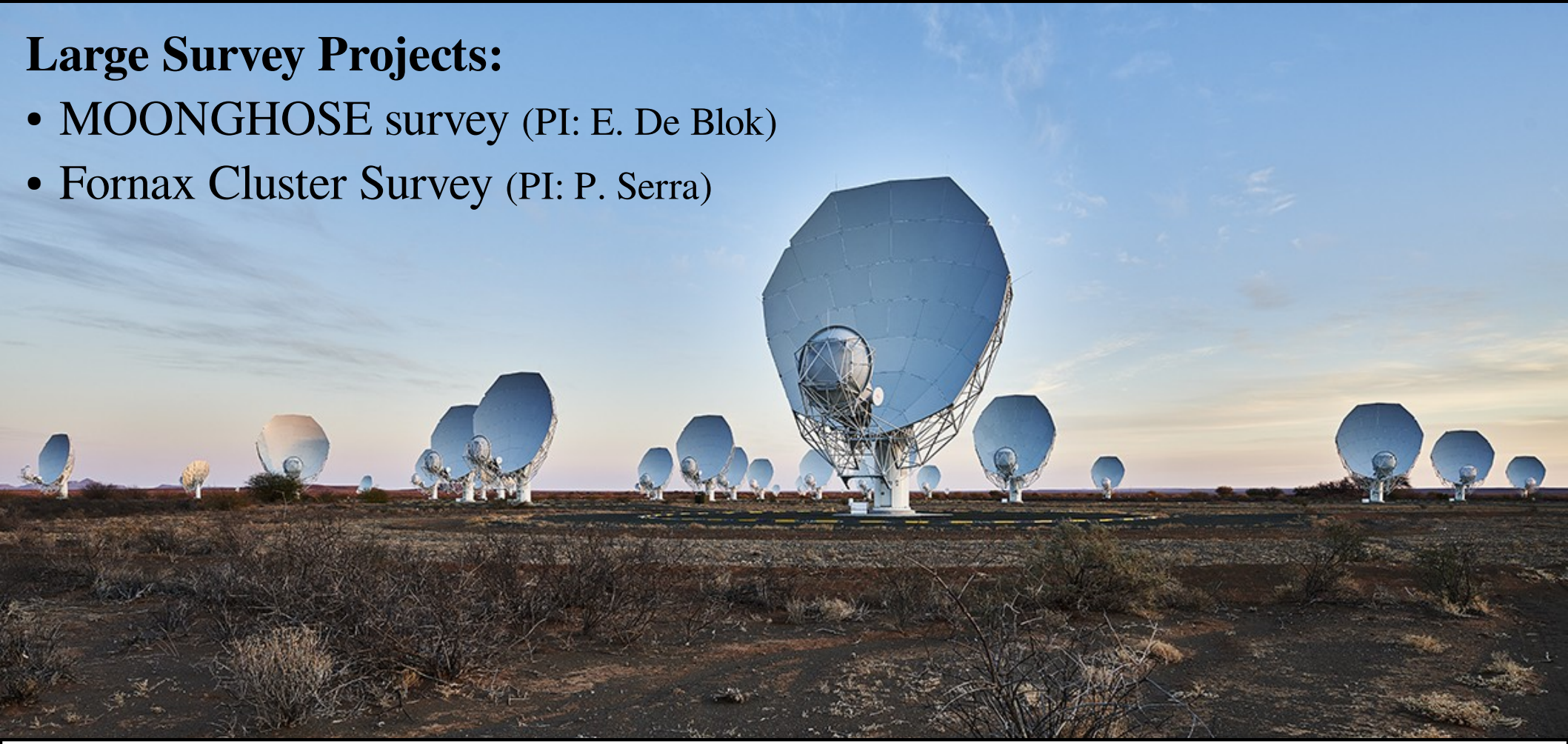


Probably, there are multiple channels to galaxy quenching.

Mergers is one of them. But *no need* to remove *all the gas*.

Remove or suppress high-density HI in the central regions.

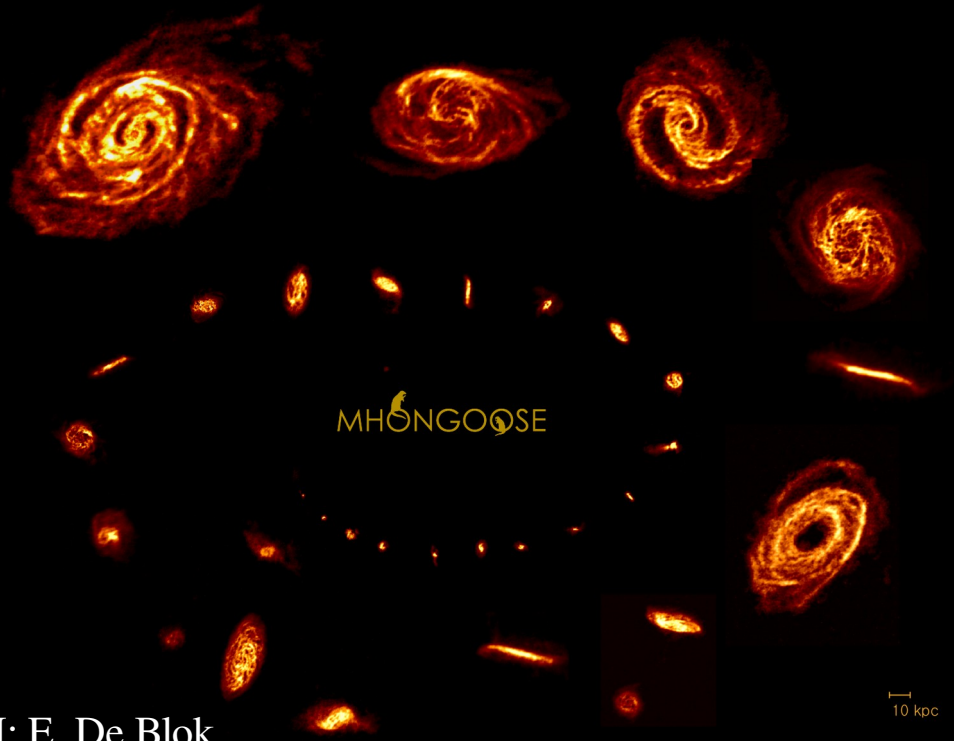
Ultradeep HI surveys with MeerKAT



Large Survey Projects:

- MOONGHOSE survey (PI: E. De Blok)
- Fornax Cluster Survey (PI: P. Serra)

Ultradeep surveys at z=0: MHONGOOSE



PI: E. De Blok

30 field galaxies with MeerKAT (55 hrs each)

$L_R \simeq 10^7 - 10^{11}\, L_\odot$; $M_{HI} \simeq 10^5 - 10^{11}\, M_\odot$

Goal: cold gas accretion at low column densities

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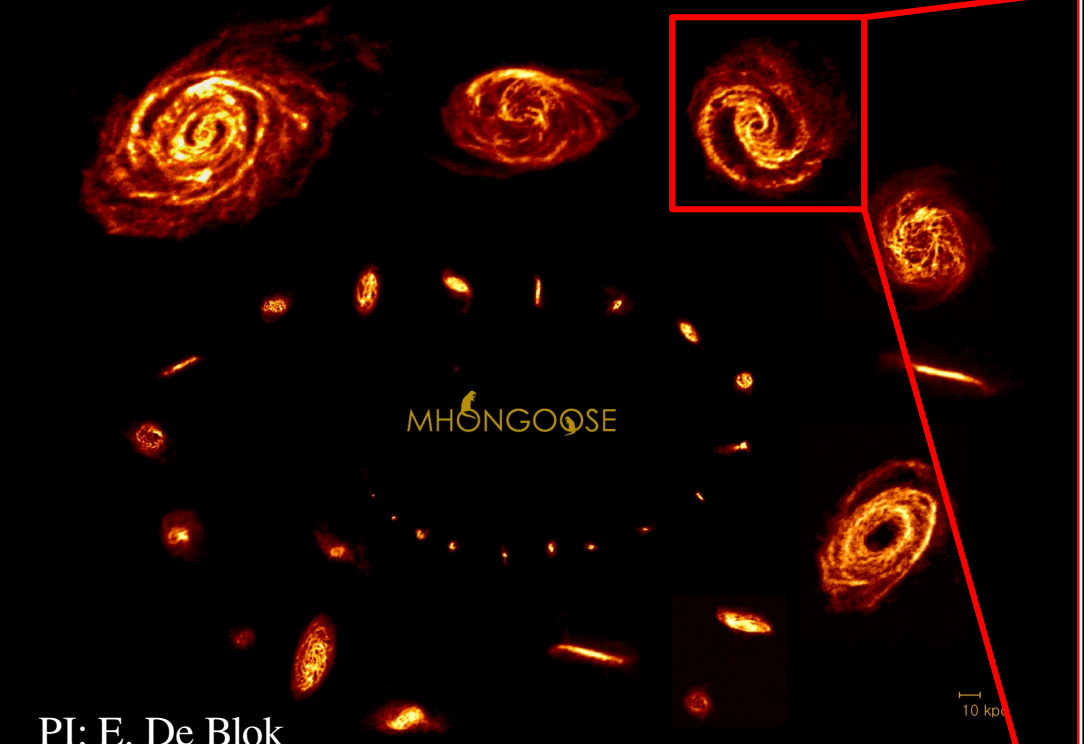

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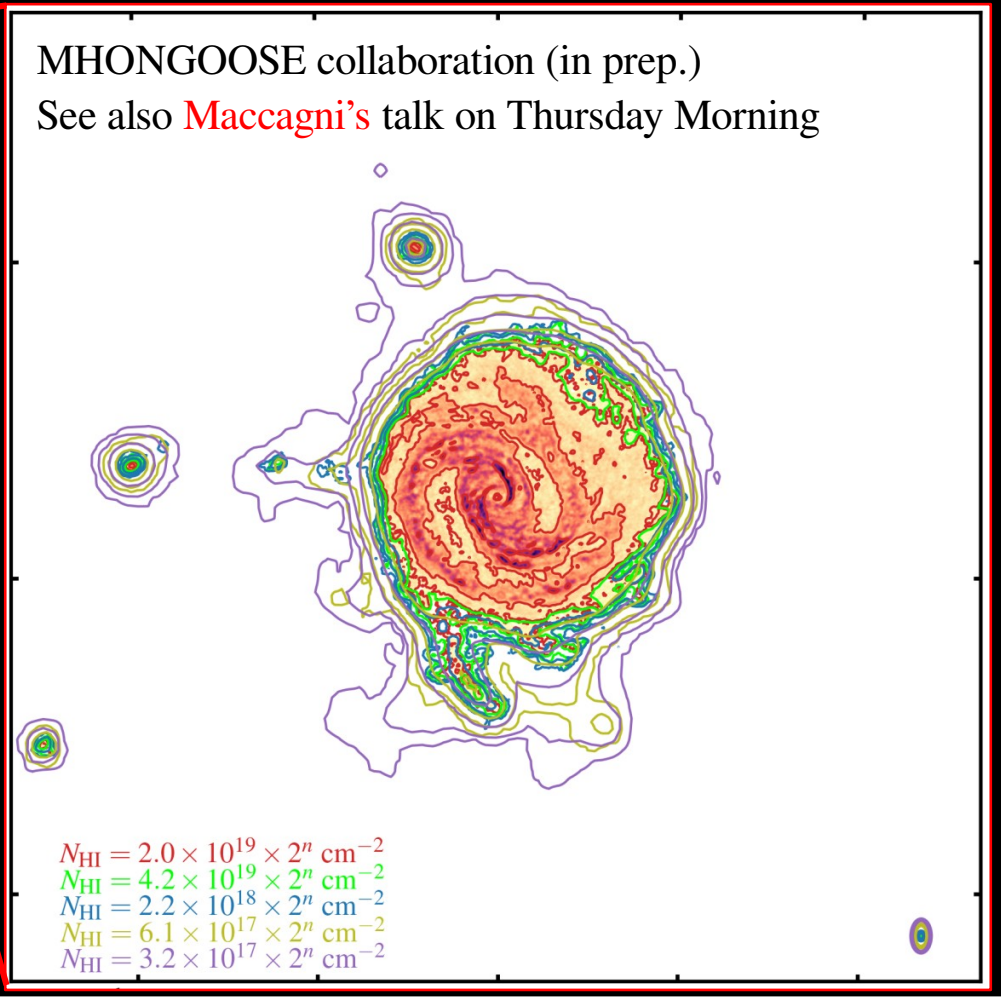
MHONGOOSE collaboration (in prep.)

See also Maccagni's talk on Thursday Morning



Ultradeep surveys at z=0: MHONGOOSE

Where's cold gas accretion?

No gas streams or filaments...

Problem for ΛCDM simulations?

Accretion *near* the HI disk from *local* cooling of the hot corona?

(Fraternali & Binney 2008; Marinacci+2010; Marasco+2013; Armillotta+2016, 2017)

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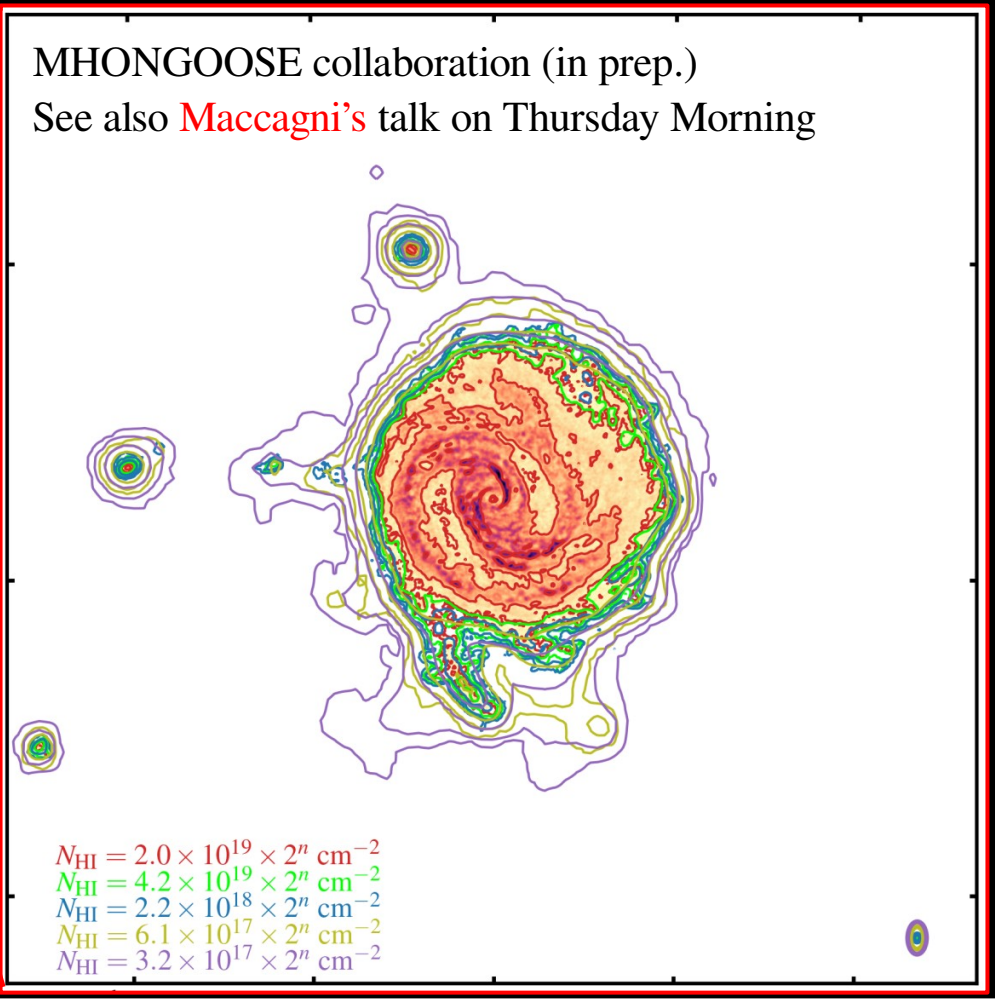
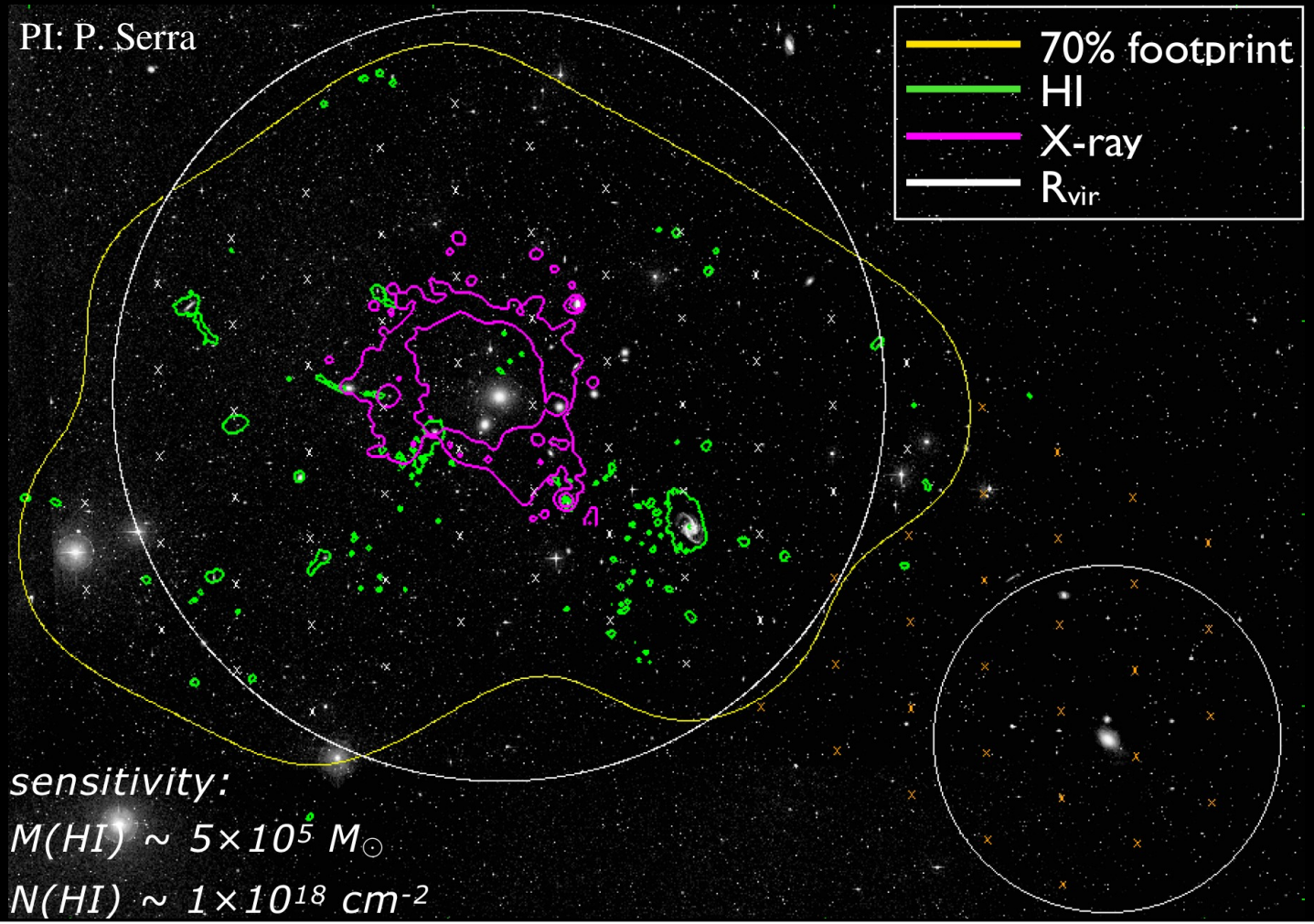


Ultradeep surveys at z=0: Fornax Cluster



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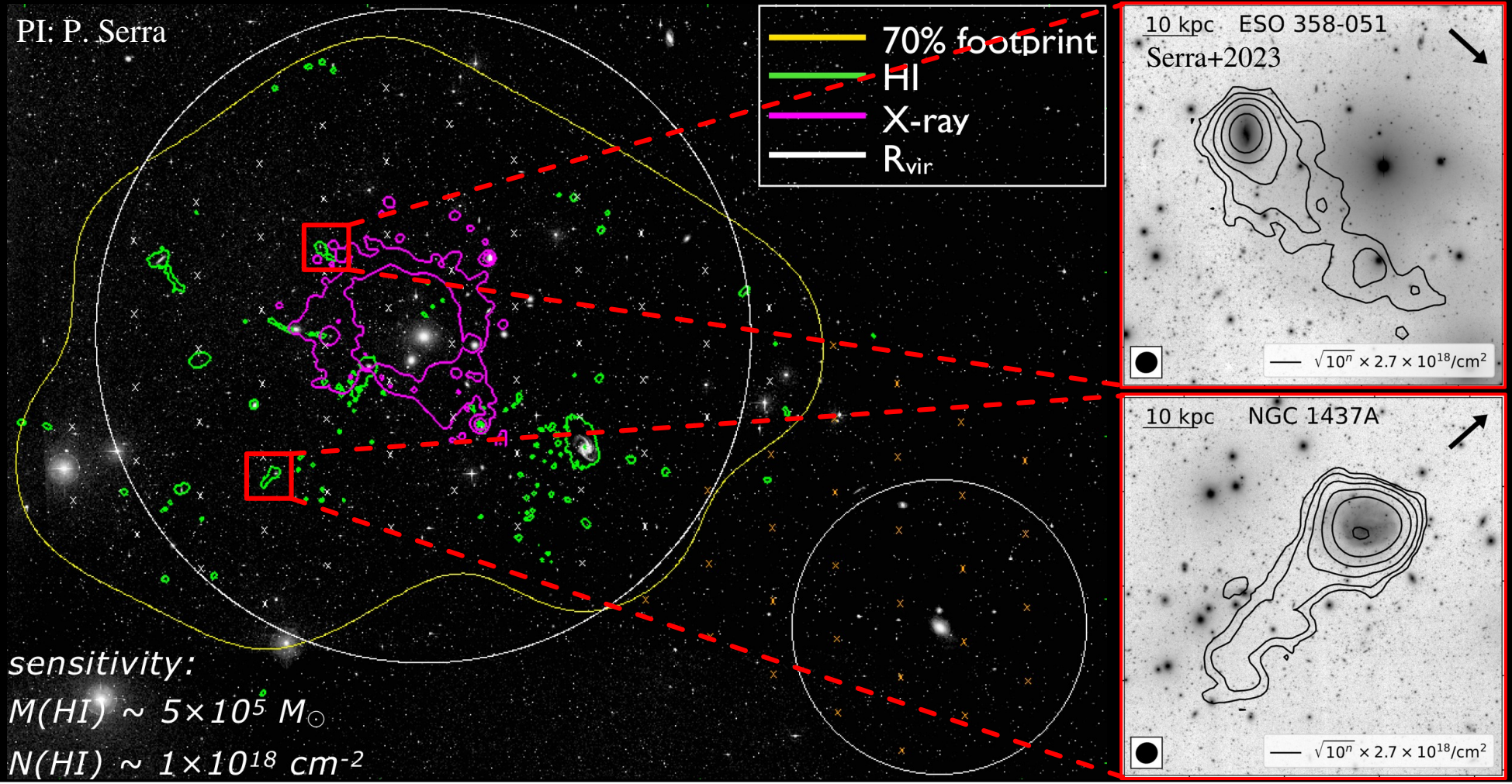


Ultradeep surveys at z=0: Fornax Cluster

PI: P. Serra

70% footprint
HI
X-ray
R_{vir}

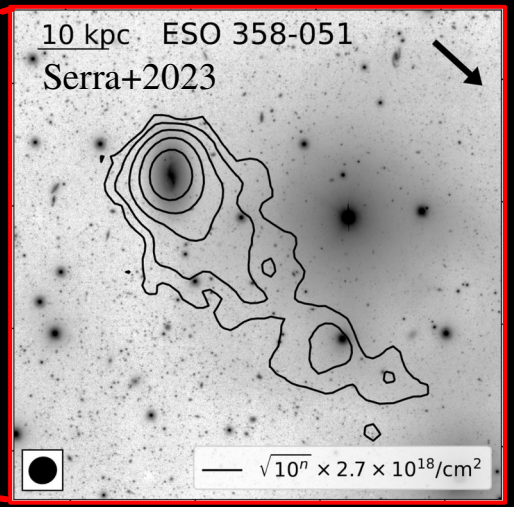
Gas stripping due to environment!

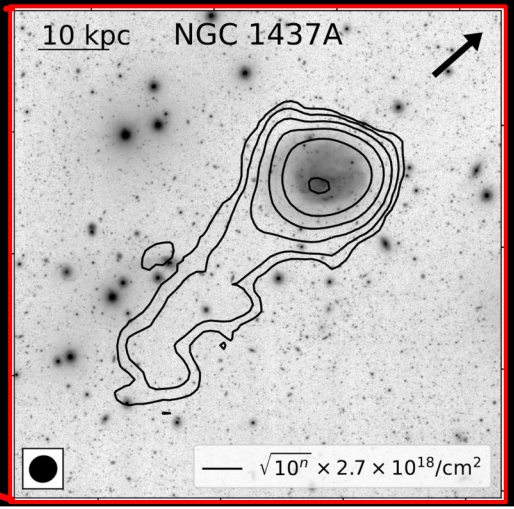
Ram pressure from ICM? Tidal interactions? Both?

Mass dependent process? Timescales?

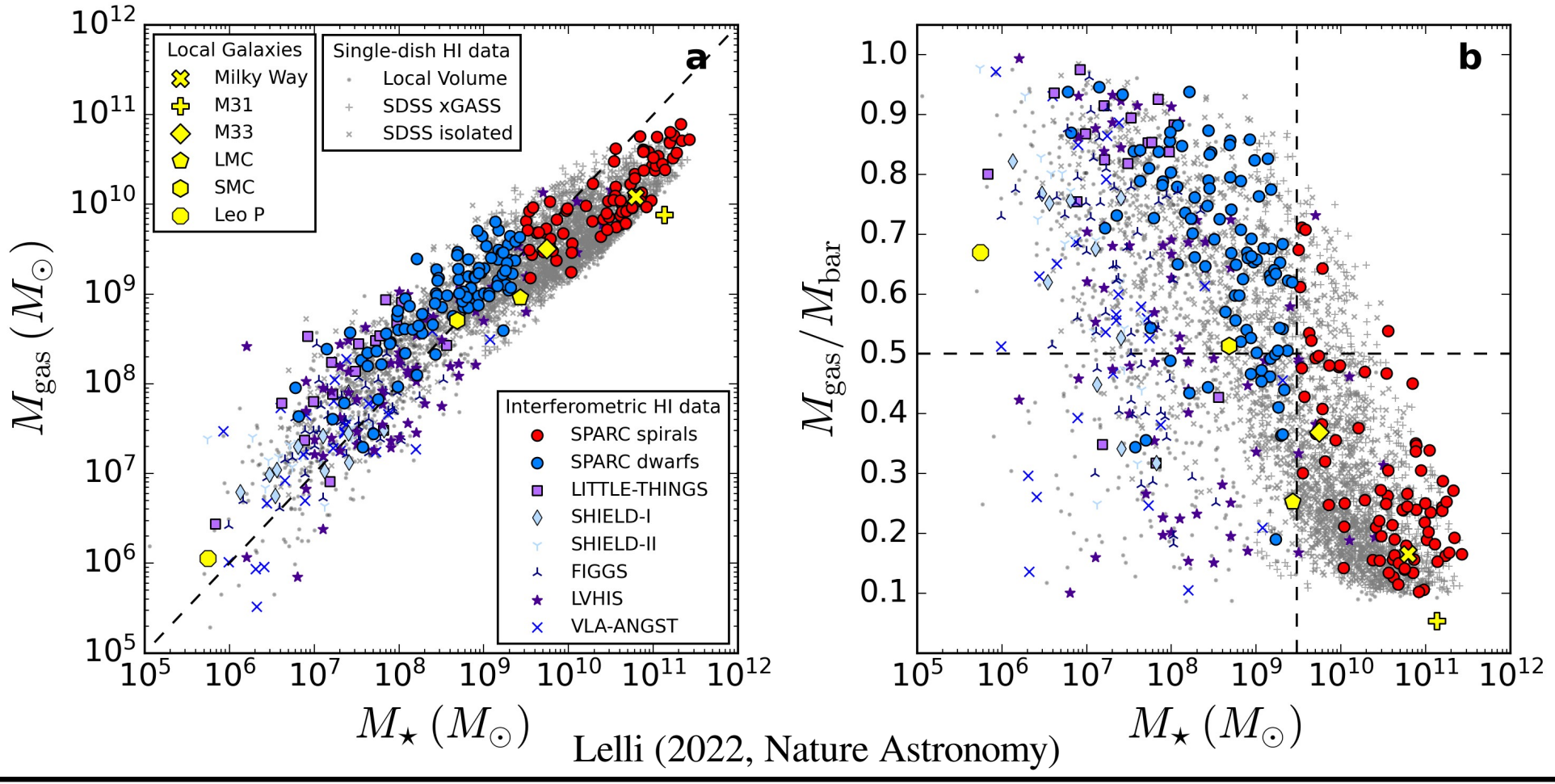
See Ignesti's, Serra's, Boselli's & Loni's talks tomorrow!

sensitivity:
$M(HI) \sim 5\times10^5\ M_\odot$
$N(HI) \sim 1\times10^{18}\ cm^{-2}$





Gas Content of Nearby Galaxies (z<0.05, D<200 Mpc)



Lelli (2022, Nature Astronomy)

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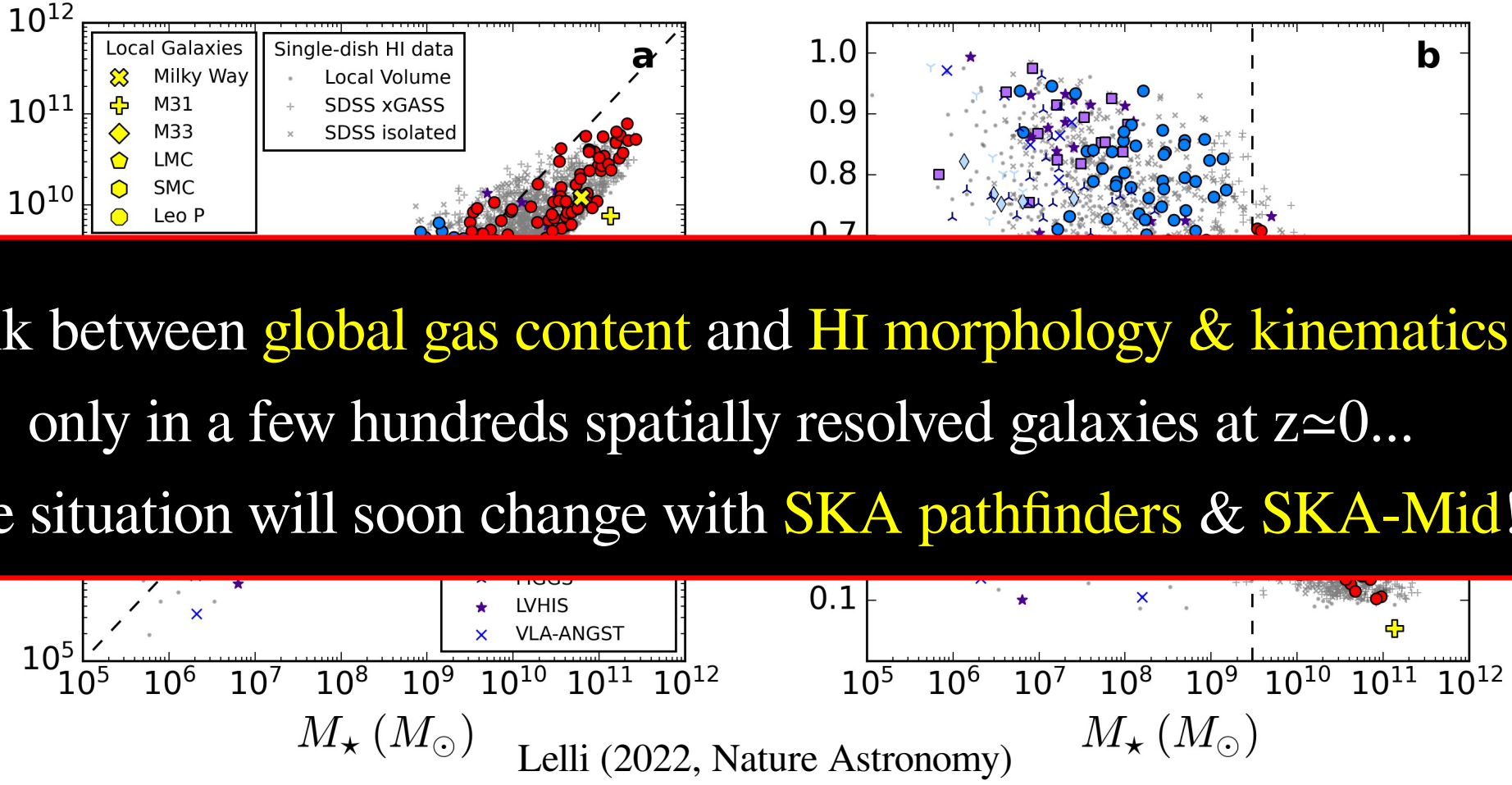


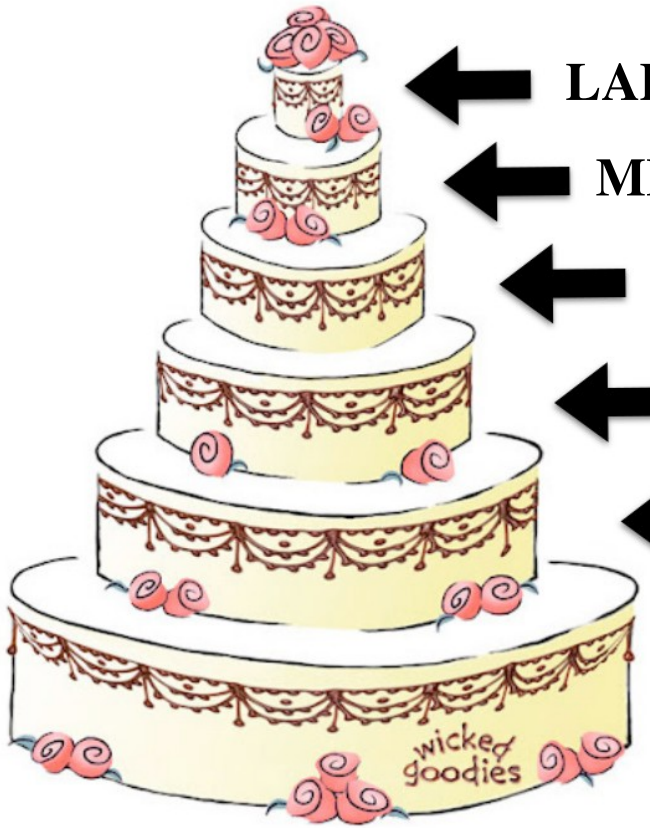
Link between global gas content and HI morphology & kinematics

only in a few hundreds spatially resolved galaxies at z≃0...

The situation will soon change with SKA pathfinders & SKA-Mid!

Lelli (2022, Nature Astronomy)

Ongoing blind HI surveys with SKA pathfinders



Sensitivity / Redshift

Survey Area

LADUMA: ~1 deg^2, z < 1.4

MIGHTEE-HI: ~20 deg^2, z < 0.5

} **MeerKAT**

DINGO: ~60 deg^2, z < 0.4 } **ASKAP**

AMES: ~130 deg^2, z < 0.1

AWES: ~2,000 deg^2, z < 0.1

} **WSRT-APERTIF**

WALLABY: ~14,000 deg^2, z < 0.1 } **ASKAP**

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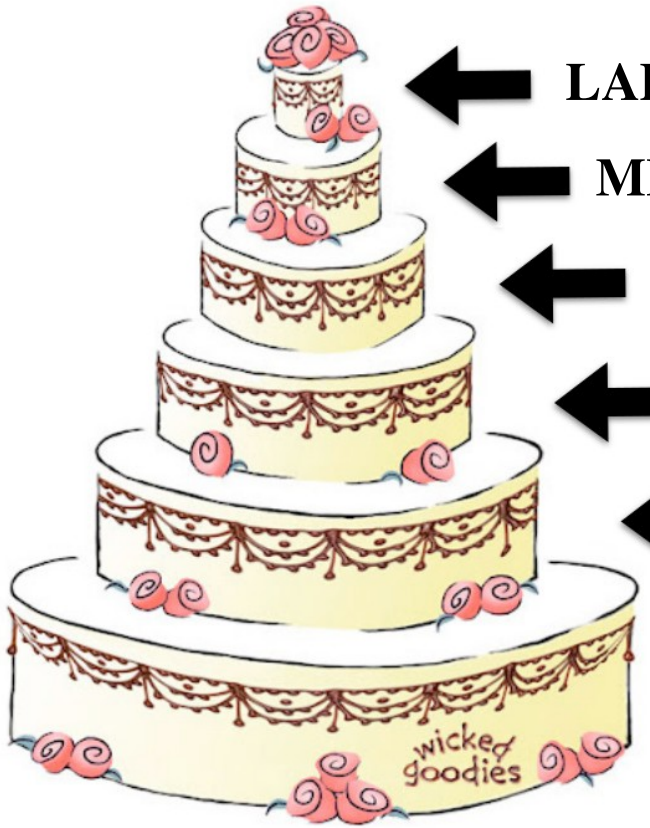

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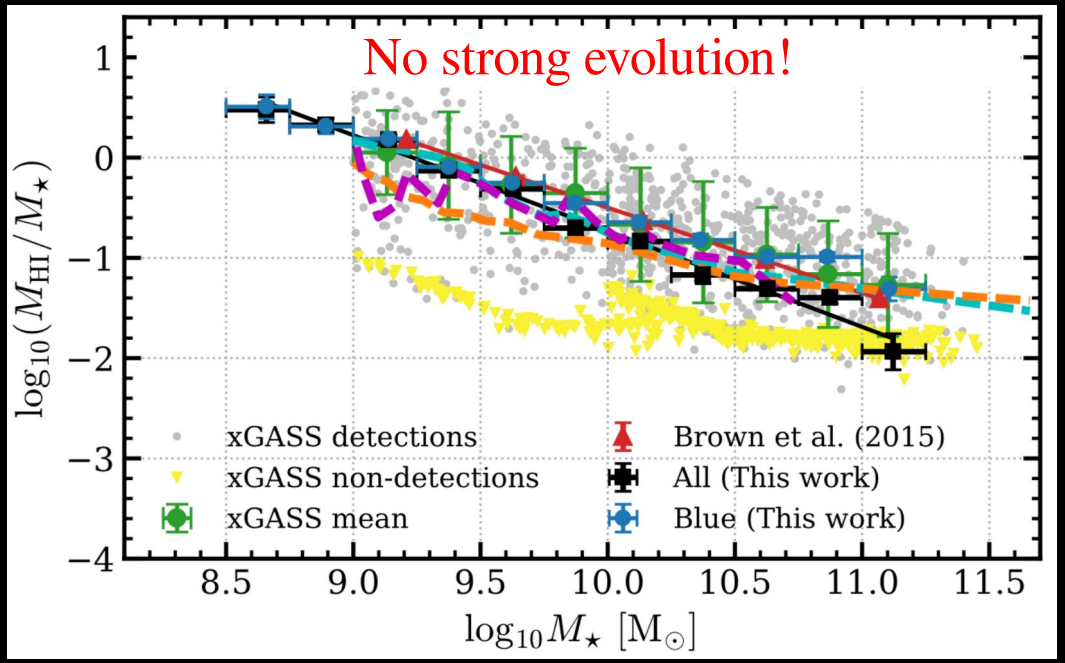
~210,000 HI-detected galaxies

~20,000 spatially resolved

Pushing to “high” z: HI spectral stacking experiments

DINGO: 0.04<z<0.09 (Rhee+2023)



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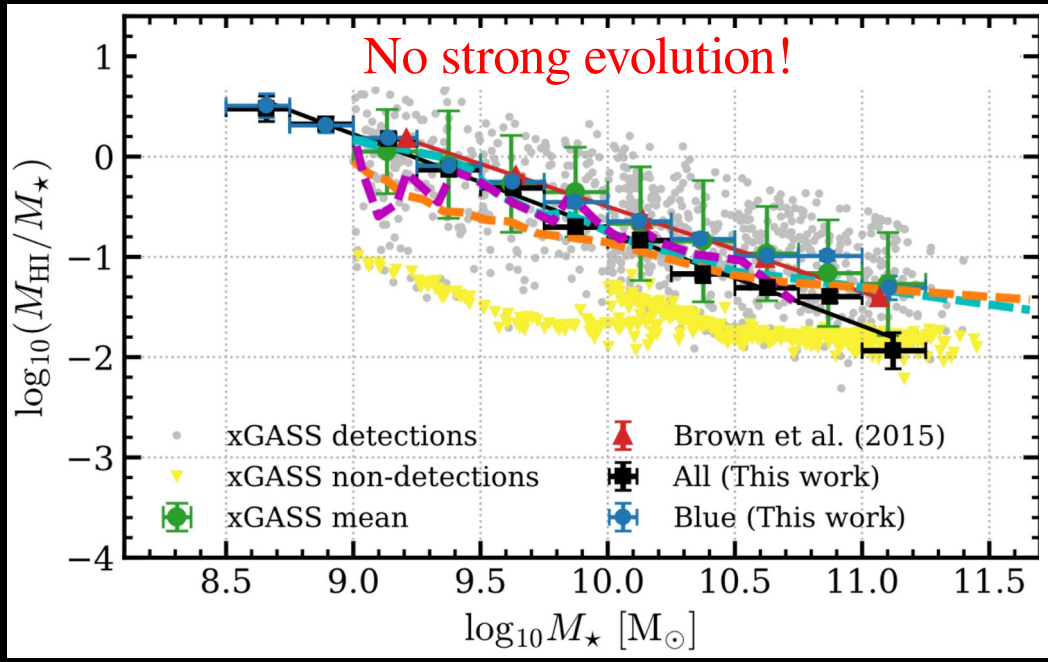
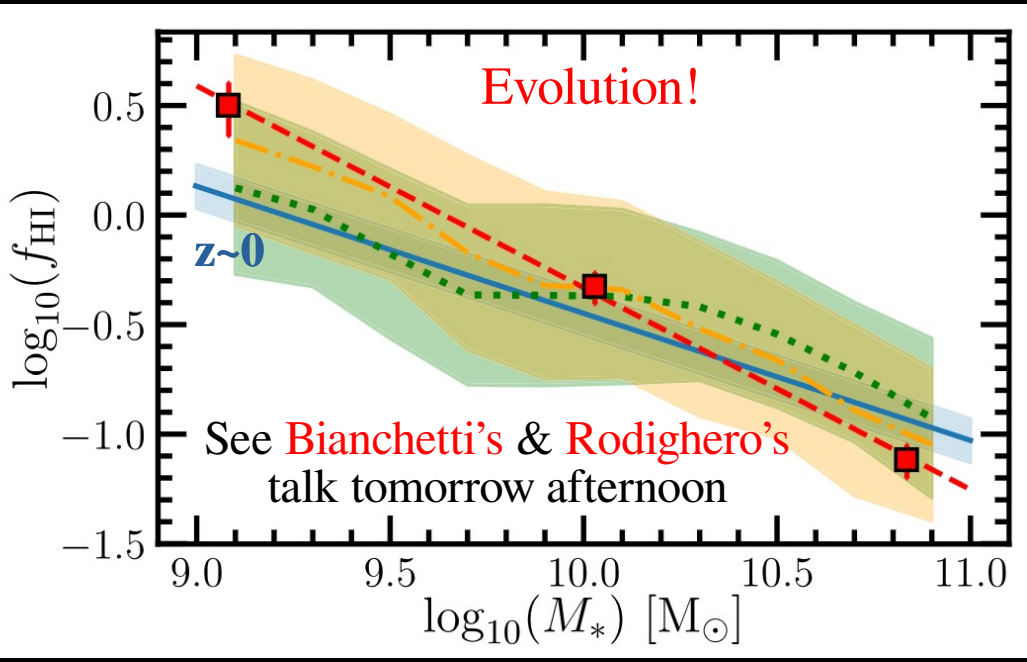


MIGHTEE-HI: 0.23<z<0.5 (Sinigaglia+2022)



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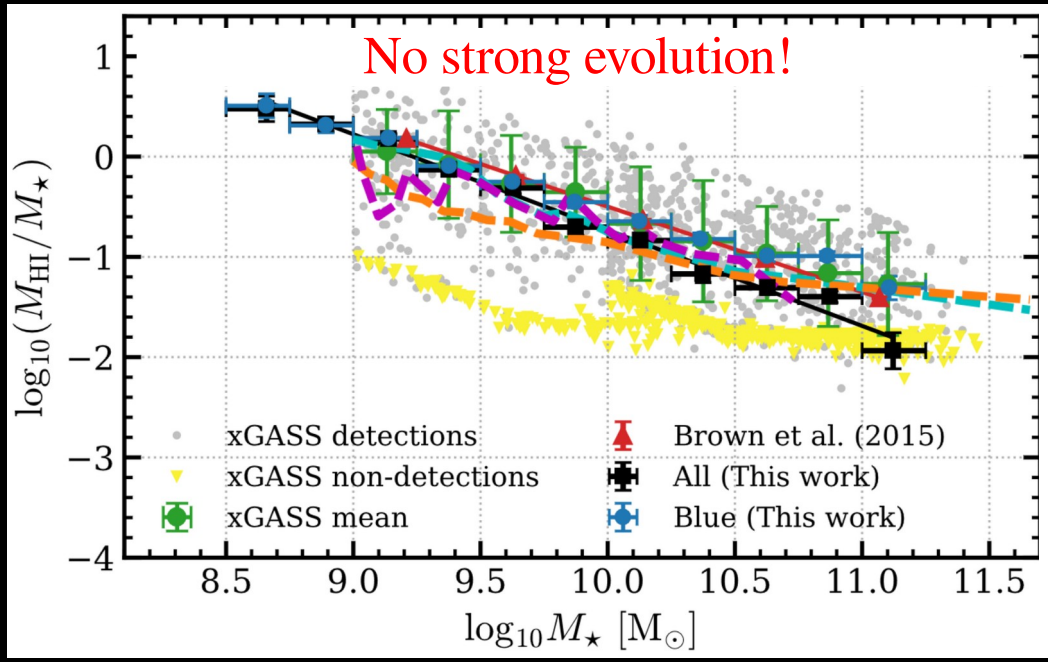

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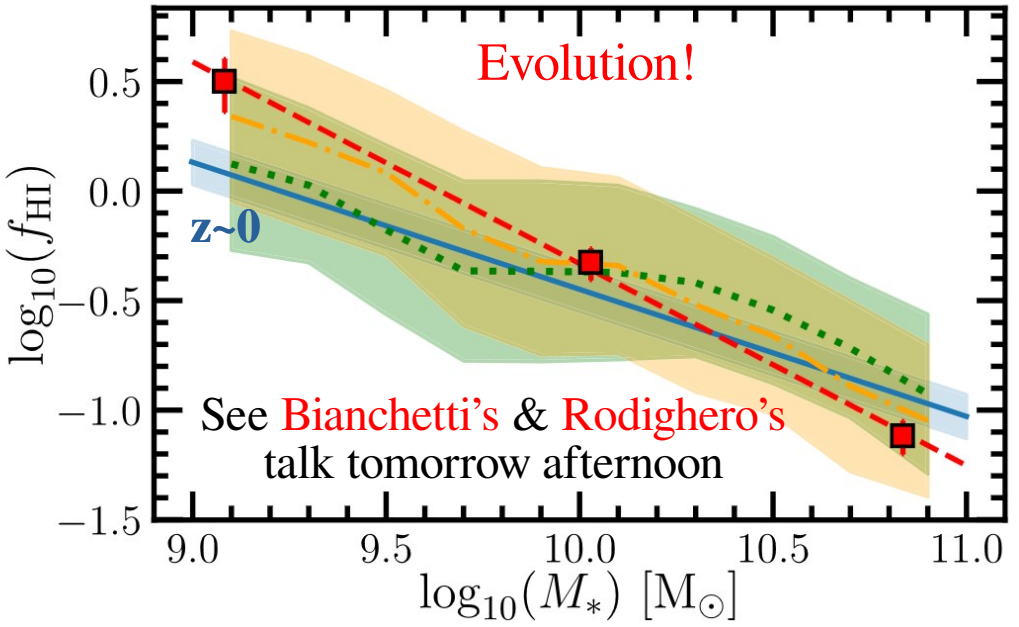


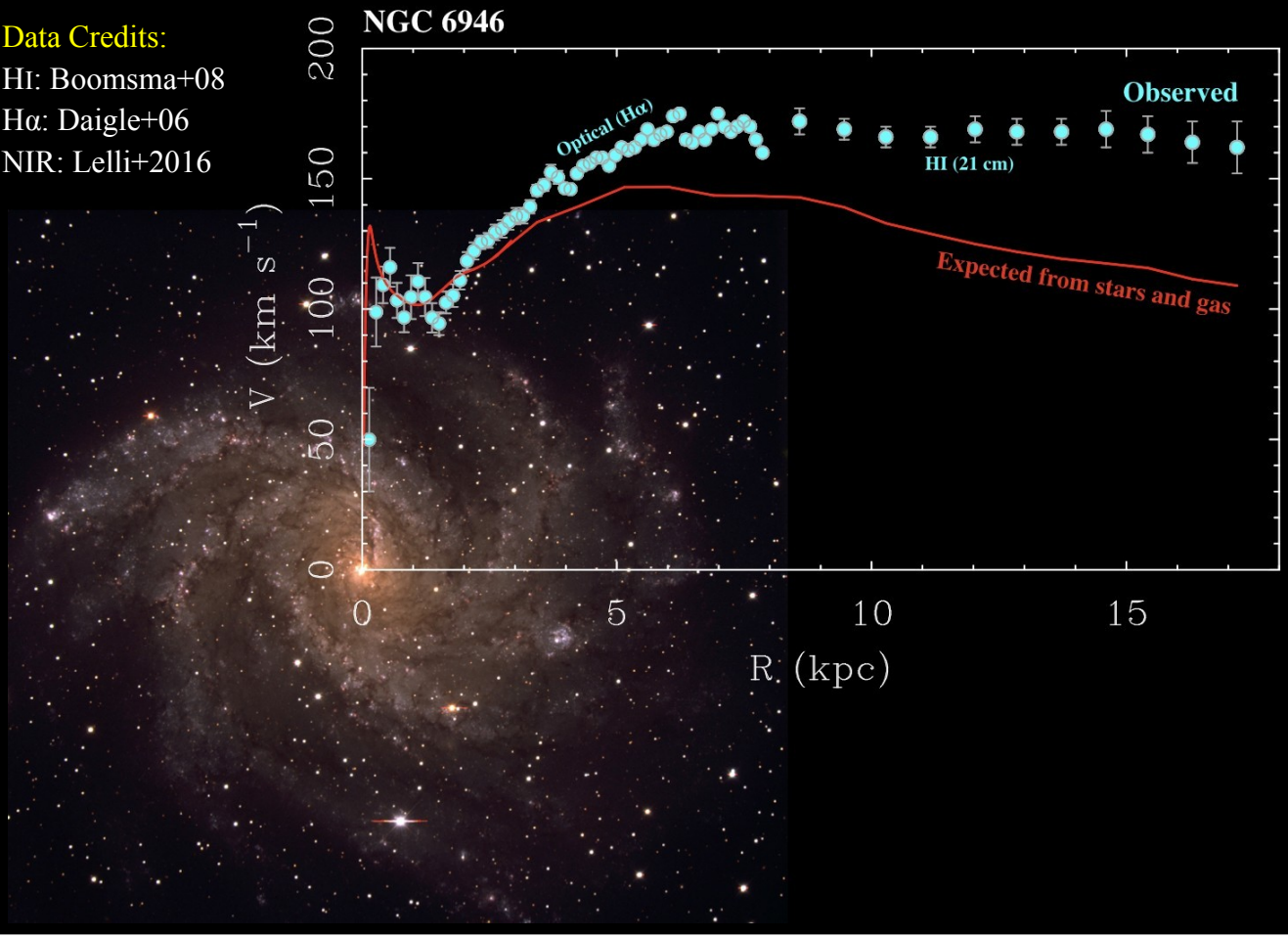
LADUMA: HI stacking up to z~1.4

SKA-Mid: HI direct detections up to z~1!

2. The Dark Matter Problem

HI Rotation Curves → DM-dominated Regime

Data Credits:
HI: Boomsma+08
Hα: Daigle+06
NIR: Lelli+2016



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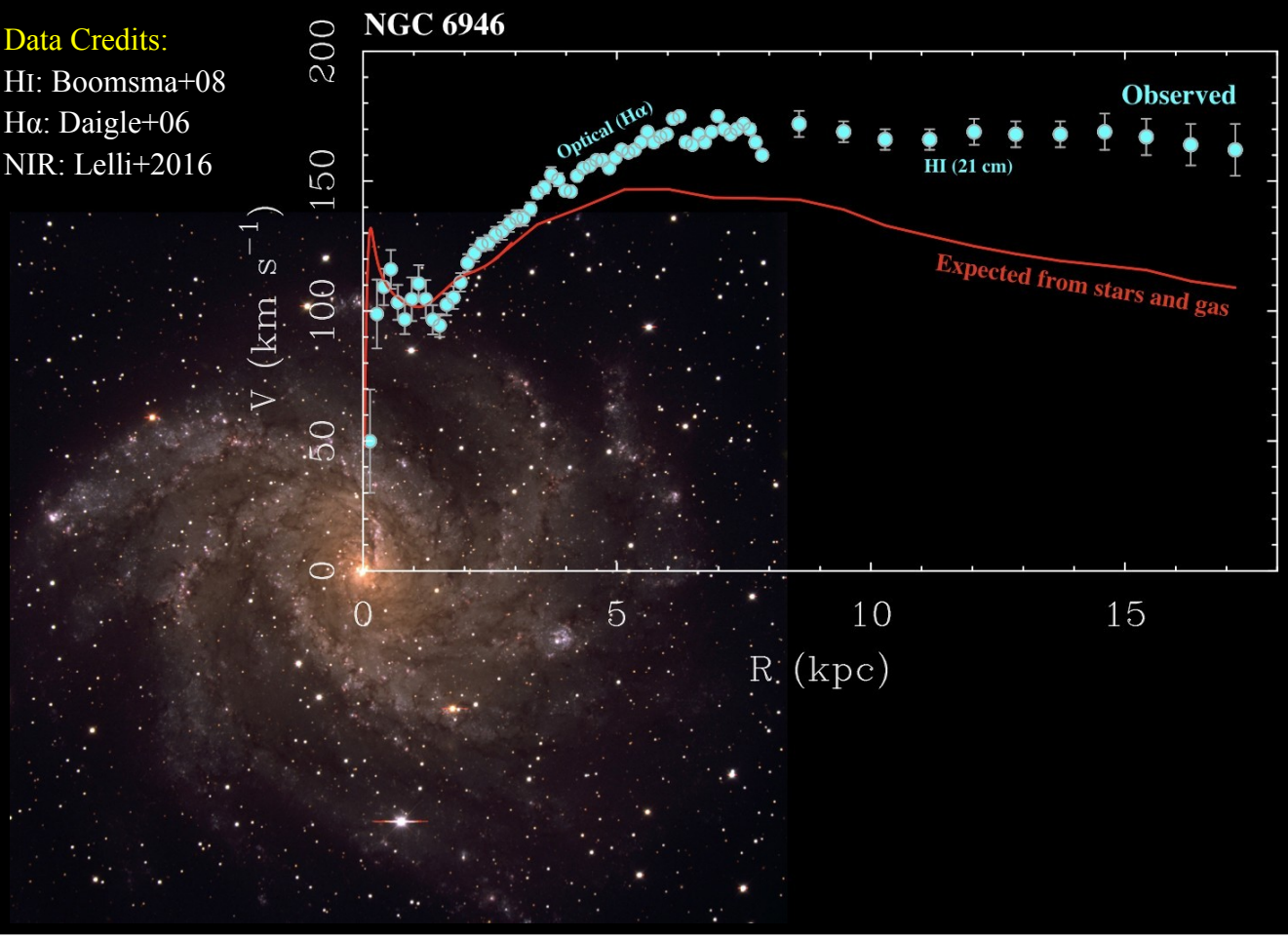

SPARC
Surface Photometry & Accurate Rotation Curves
(Lelli+2016)

Database of 175 disk galaxies
HI rotation curves
+
HI surface density profiles
+
NIR photometry (Spitzer)
=
Full mass models

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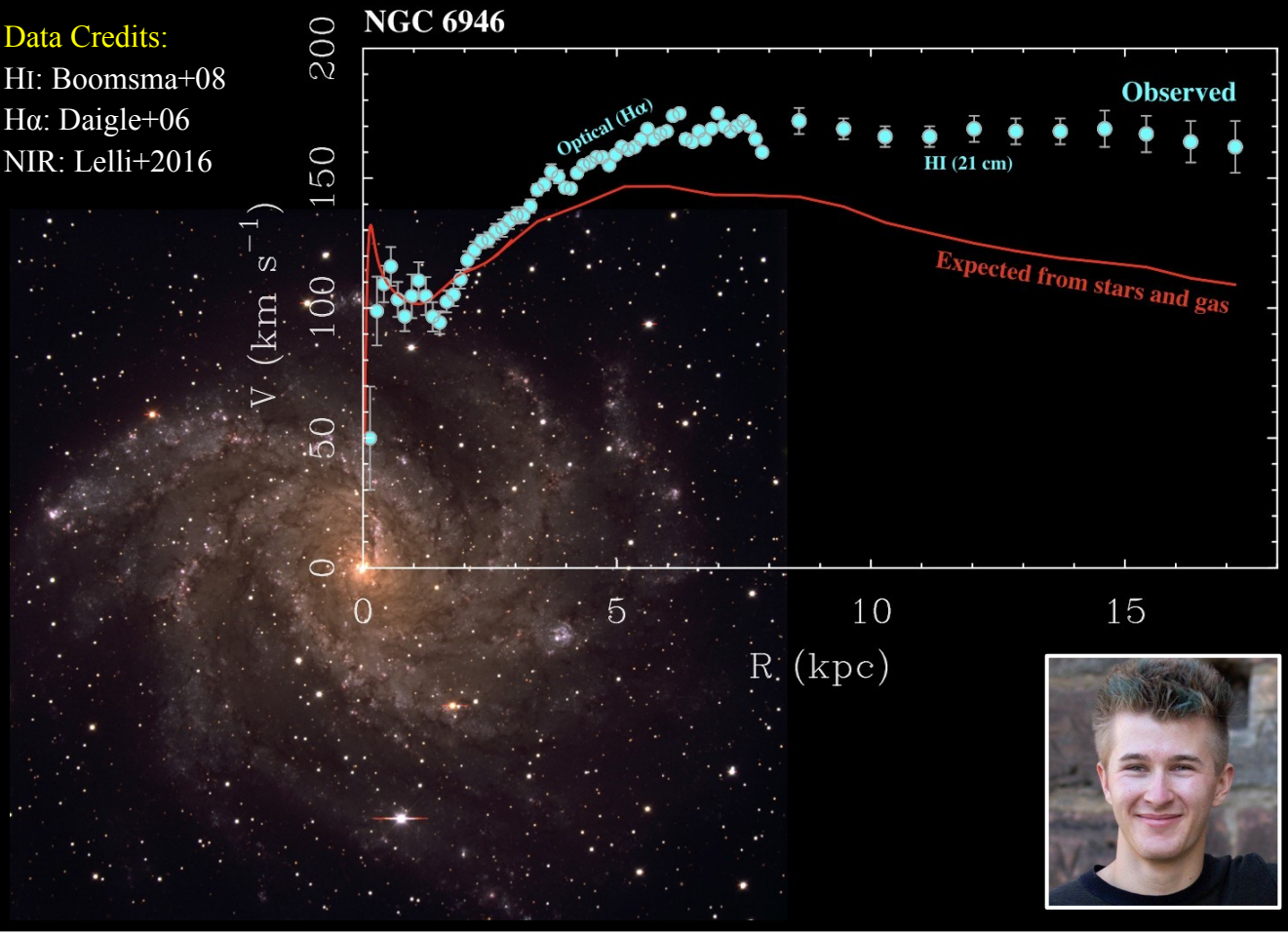

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Surface Photometry & Accurate Rotation Curves
(Lelli+2016)

Database of 175 disk galaxies
HI rotation curves
+
HI surface density profiles
+
NIR photometry (Spitzer)
=
Full mass models

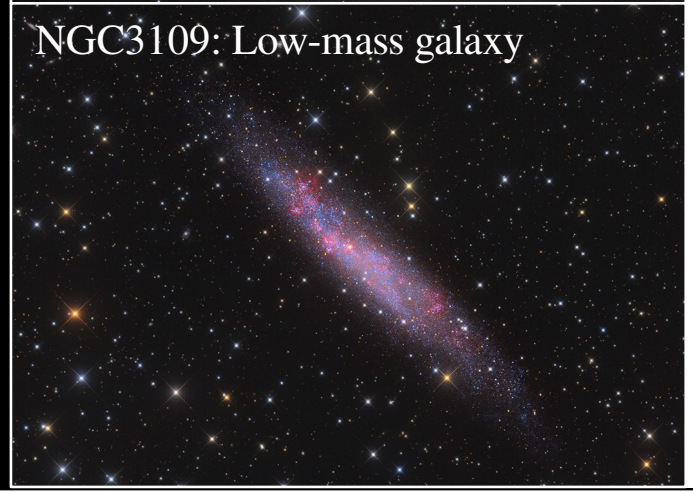
New SPARC-1k (~1000 gals)
see Haubner's talk tomorrow

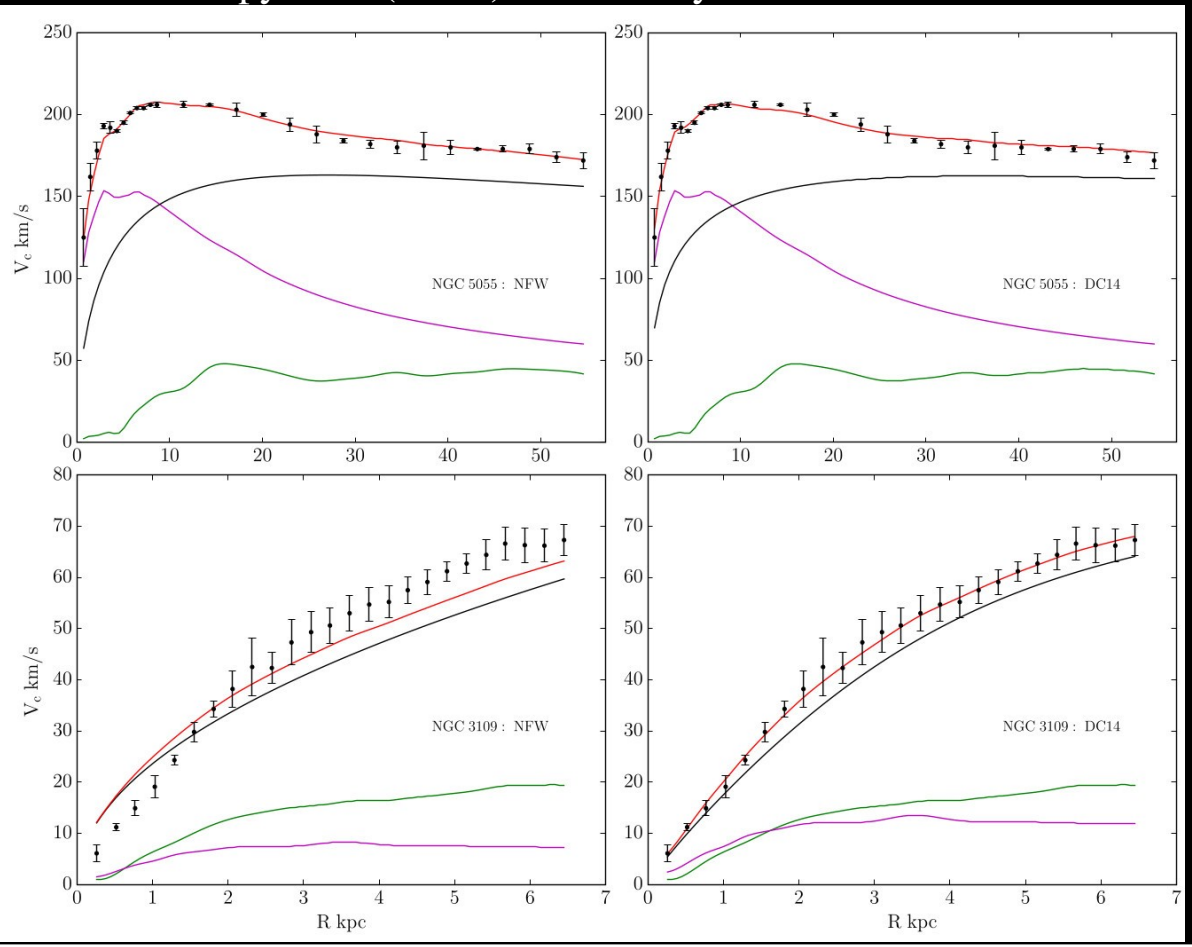
Testing different DM halo models

From Katz, Lelli et al. (2017)

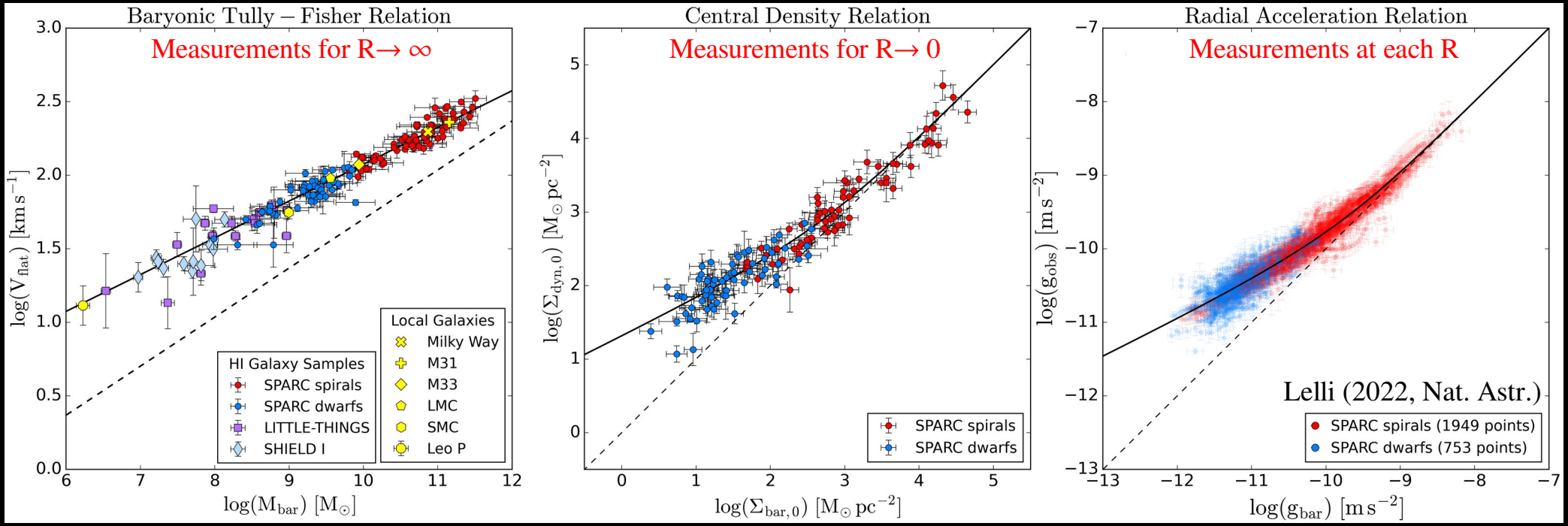
Cuspy Halo (NFW)

Baryonic-feedback-altered Halo





Empirical Dynamical Scaling Laws



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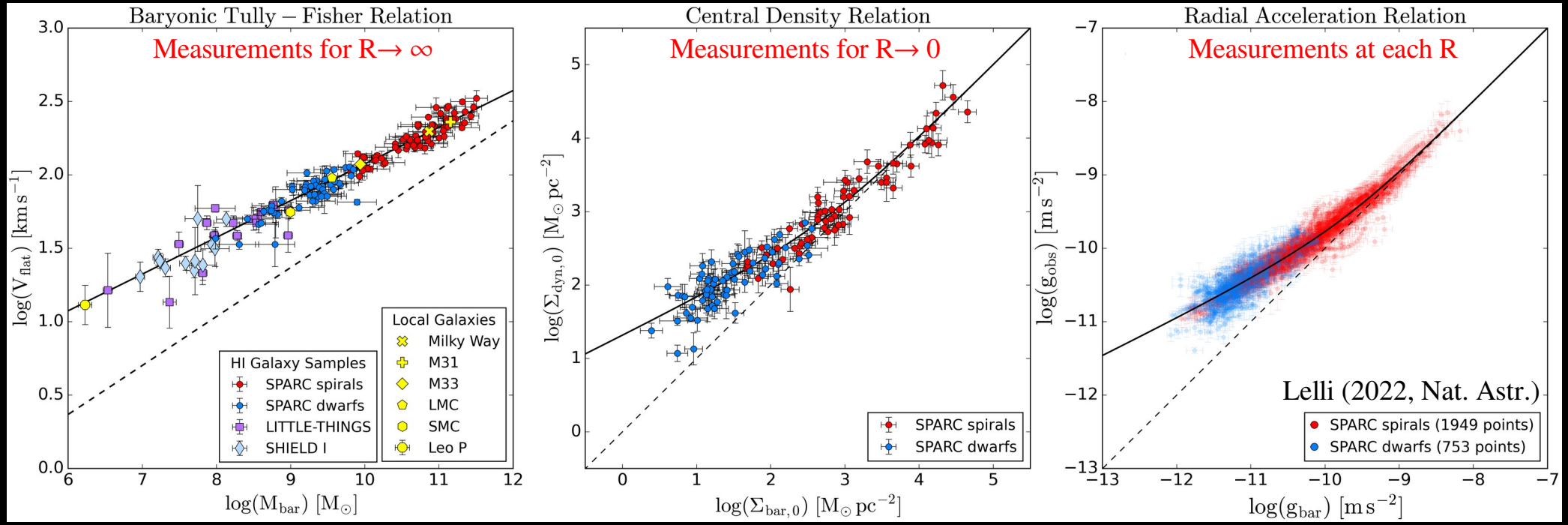
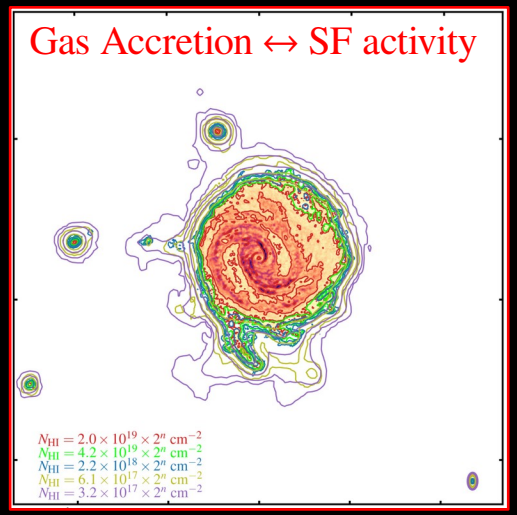
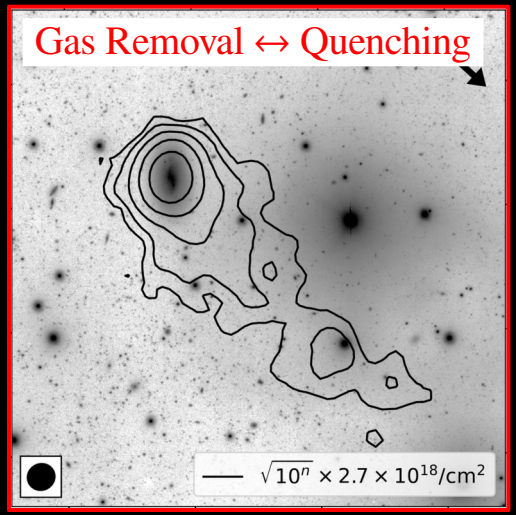
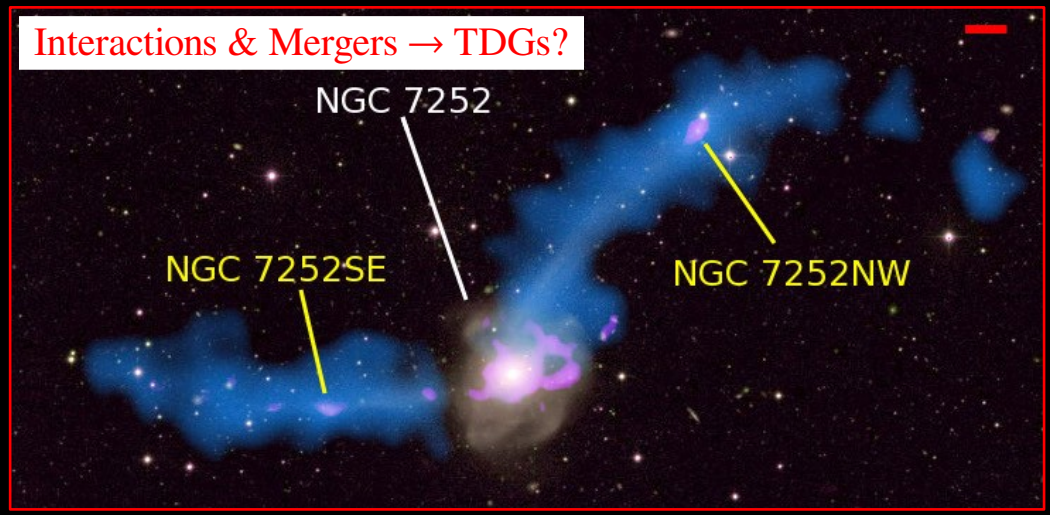


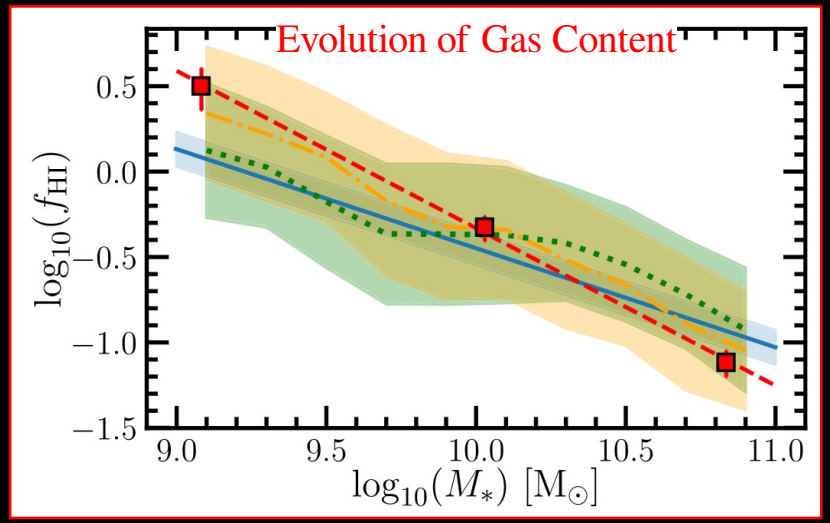
- Baryon-DM coupling at both global & local scales. What's driving it?
- Extremely tight: observed scatter ≃ uncertainties. What's the intrinsic scatter?
- Predicted a-priori by MOND (Milgrom 1983). Credit to alternatives to DM.

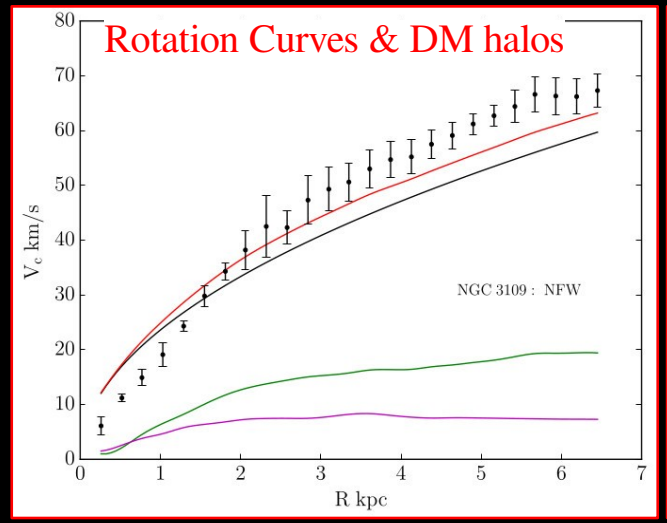


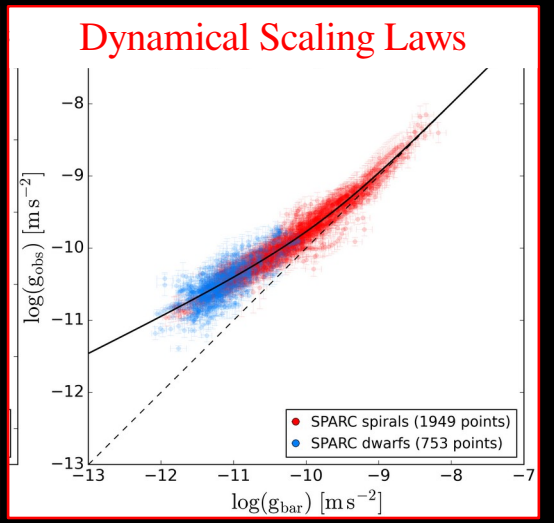




HI Galaxy Science with SKA-Mid will be very exciting!

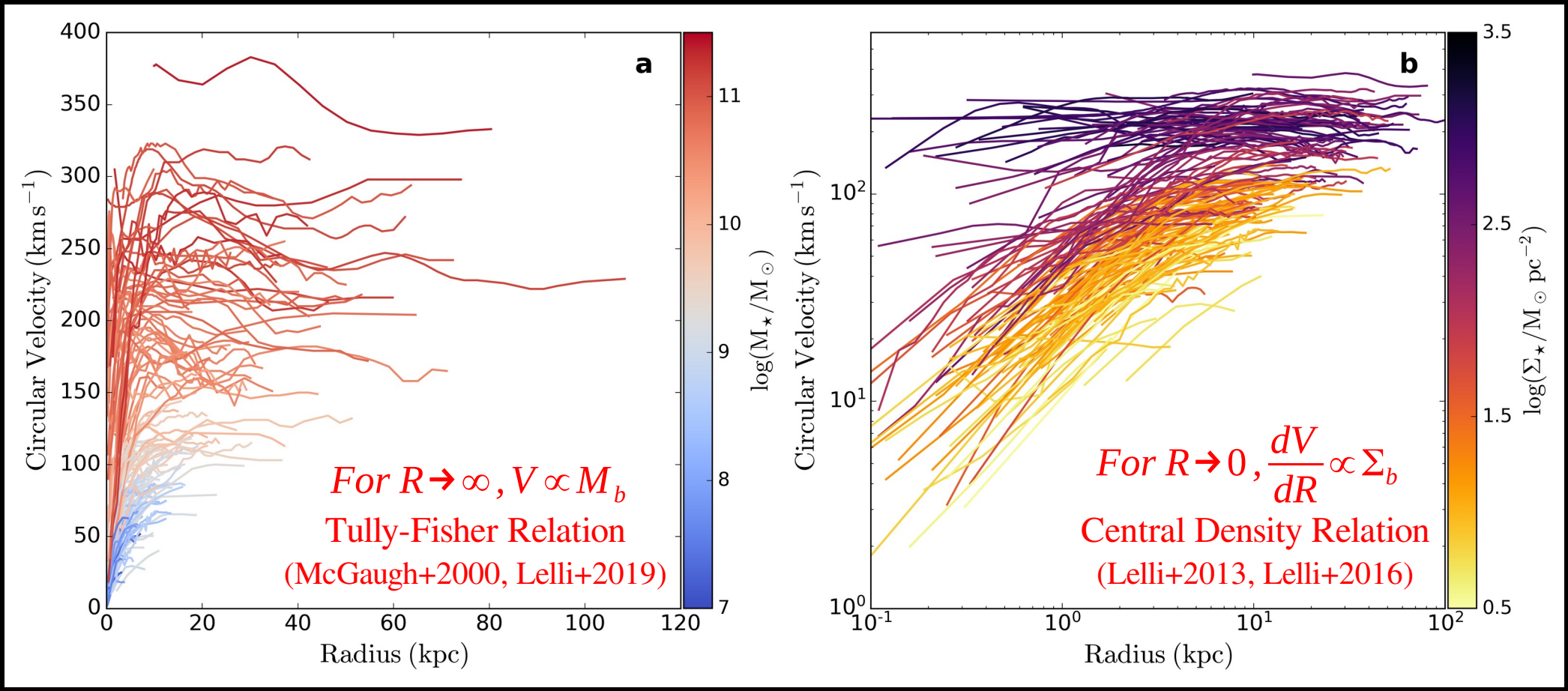






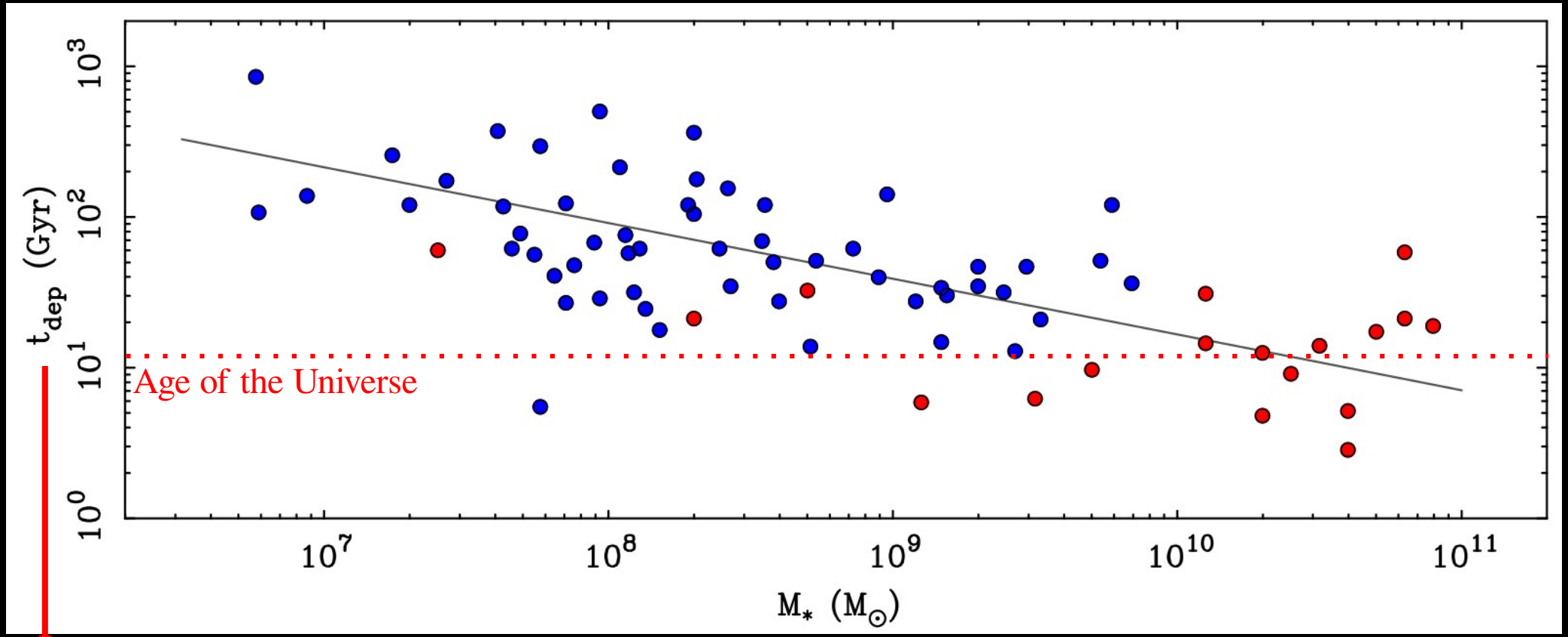
More Slides

Rotation Curve Shapes ↔ Baryon Distribution



Lelli (2022, Nature Astronomy)

Gas depletion times of nearby star-forming galaxies

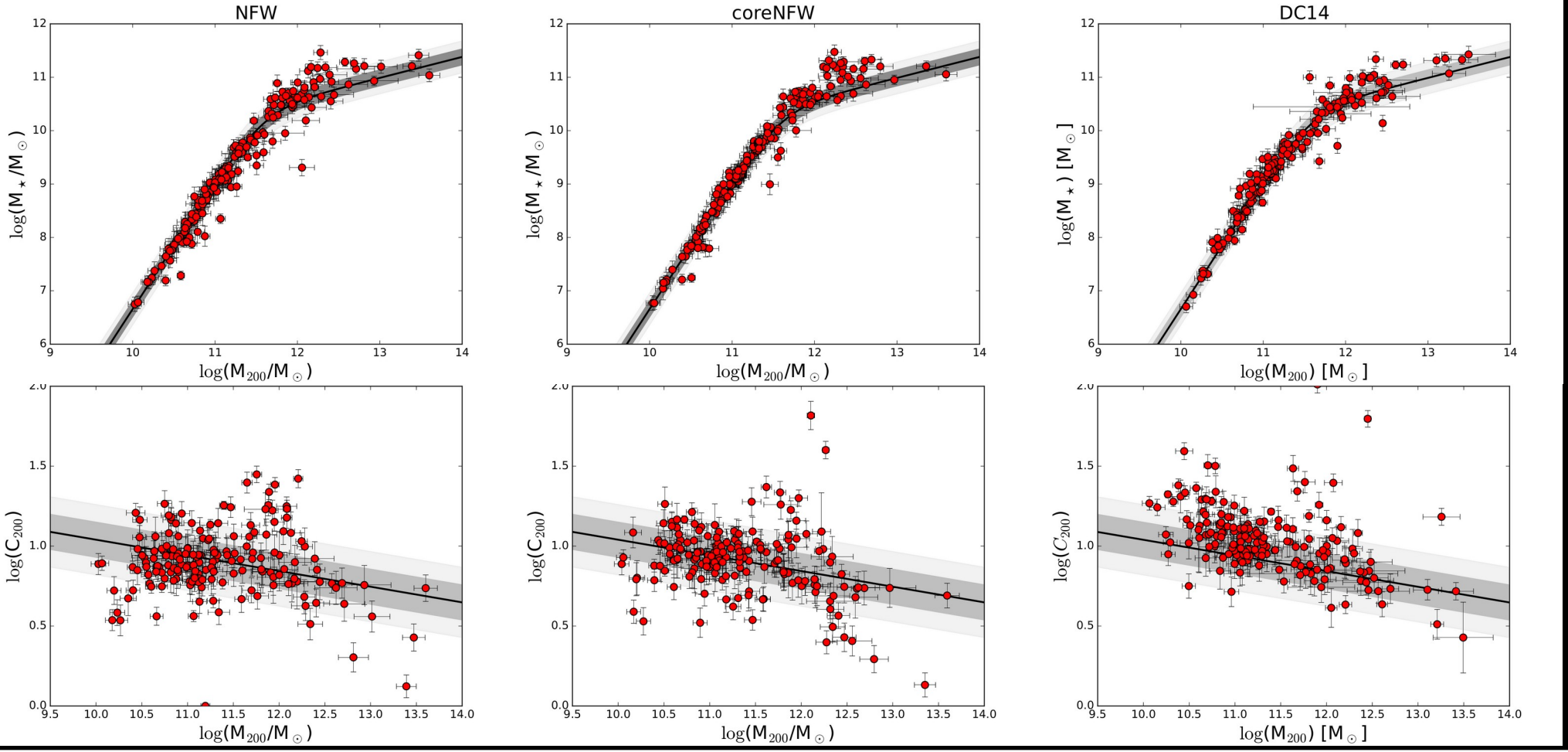


M_{gas}/SFR

McGaugh, Schombert, Lelli (2017, ApJ)

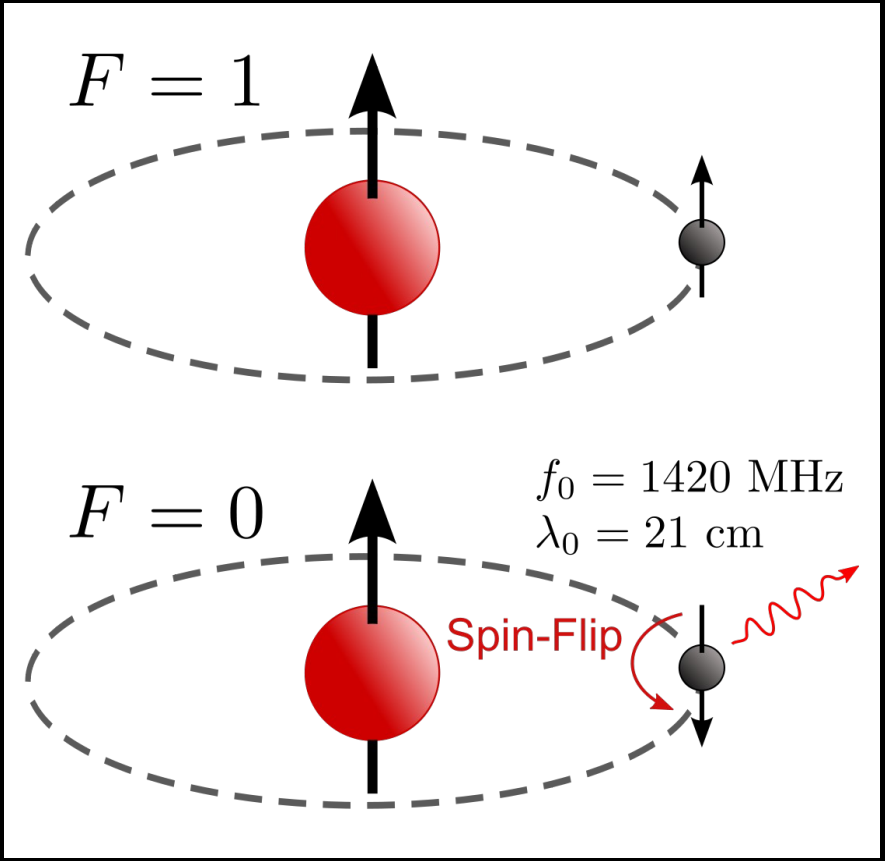
Halo Scaling Relations in ΛCDM

Li, Lelli et al. (2020)



The 21-cm line of Atomic Hydrogen (HI)

Hyperfine transition (known physics) → exact conversions to physical quantities!



In the optically thin case:

HI surface brightness → HI column density

$$N_{HI}[atoms/cm^2] = 1.83 \cdot 10^{18} \int_{line} T_b[K]\,dV\,[km/s]$$

HI flux or luminosity → HI mass (knowing D)

$$M_{HI}[M_\odot] = 2.36 \cdot 10^5\, D^2[Mpc] \int_{line} S_\nu[Jy]\,dV\,[km/s]$$

Rather unique situation in astrophysics!

Stellar masses, H_2 masses, SFRs require some astrophysical modeling and assumptions...