Galaxy dynamics with statistical HI samples in the SKA era

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In collaboration with
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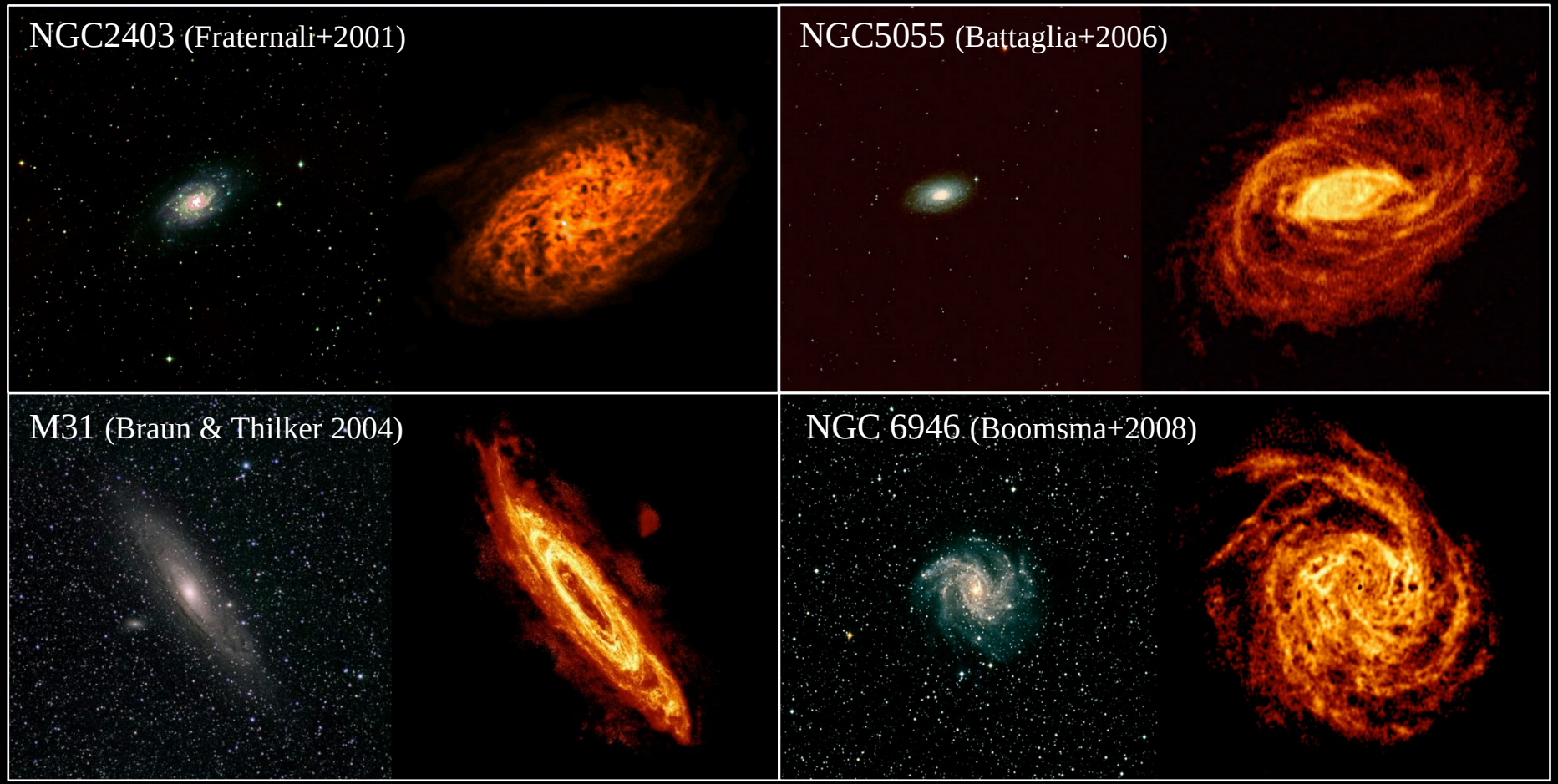
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

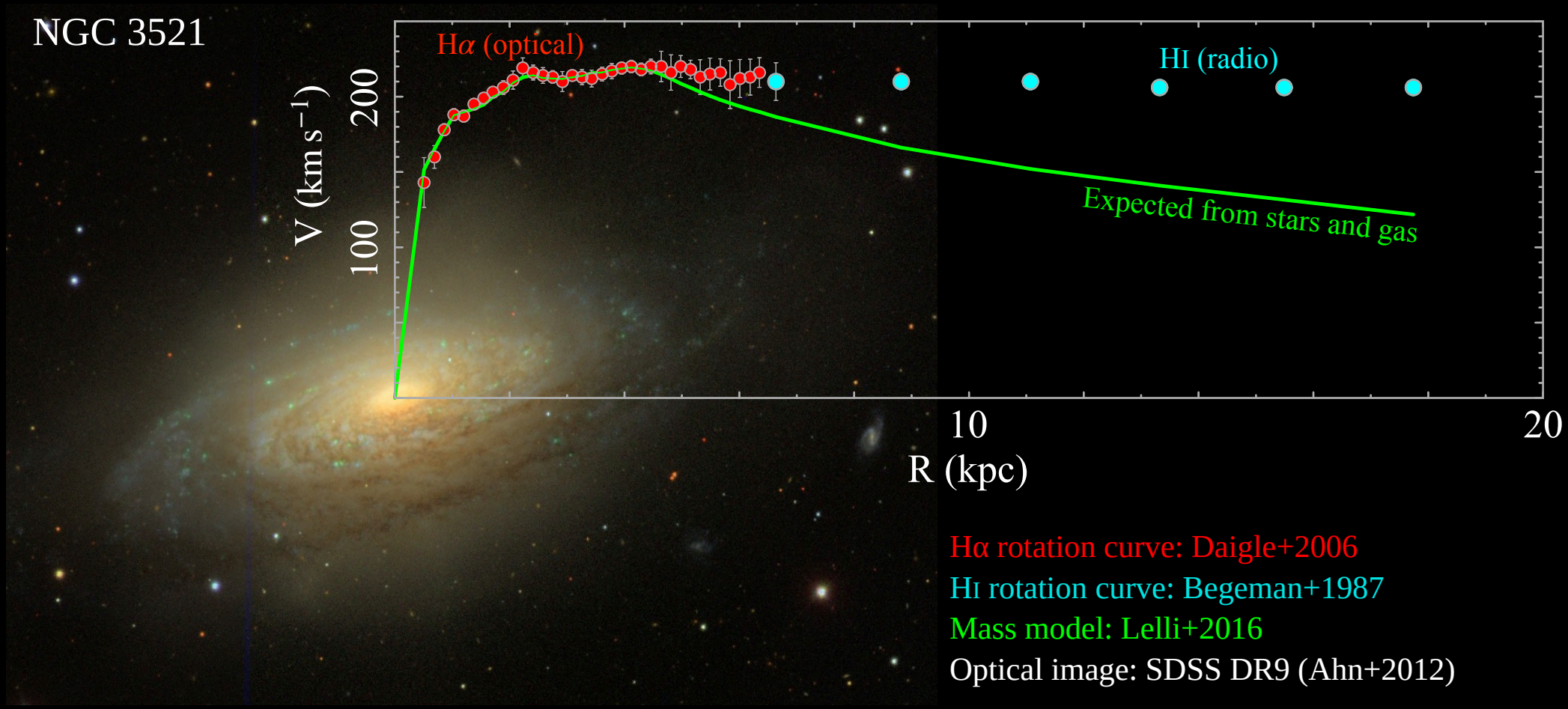
UNIVERSITÀ DEGLI STUDI FIRENZE

NGC 289 (Mike Selby)

HI line: ideal tracer for galaxy dynamics



Extended HI rotation curves: DM effect!



Hα rotation curve: Daigle+2006
HI rotation curve: Begeman+1987
Mass model: Lelli+2016
Optical image: SDSS DR9 (Ahn+2012)

SPARC – Current state of the art

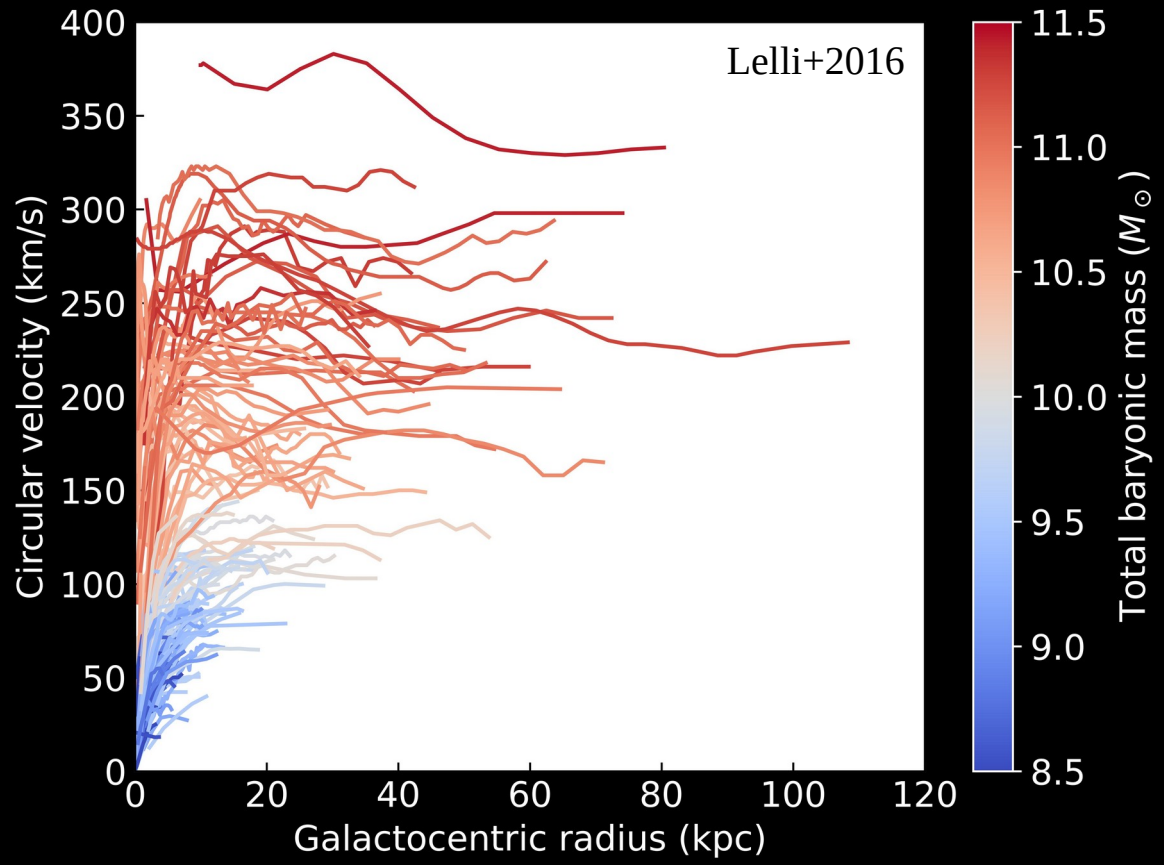
Surface Photometry & Accurate Rotation Curves

Database with 175 disk galaxies

astroweb.cwru.edu/SPARC

1. Spatially resolved HI data

From > 50 papers and PhD theses
Gas mass distribution
Extended rotation curves



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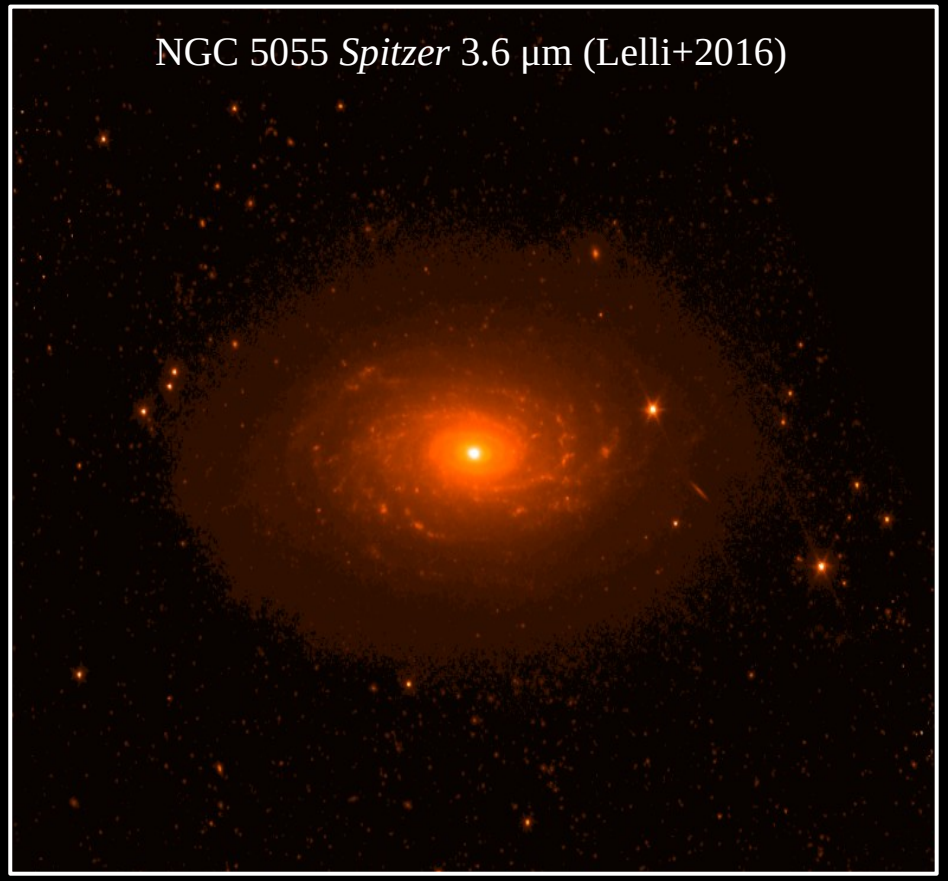
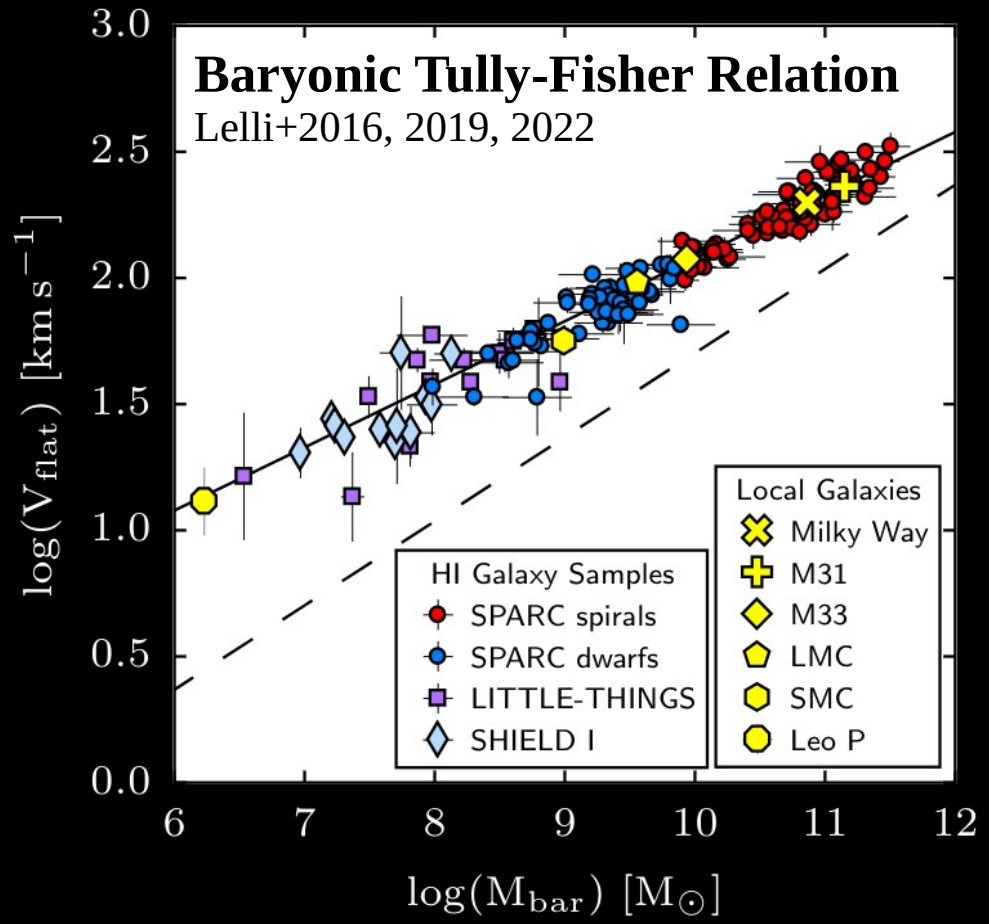
2. Near-infrared photometry

From our team using *Spitzer* 3.6 μm
Stellar mass distribution
Minimized effects of dust and SF



Results – Dynamical laws



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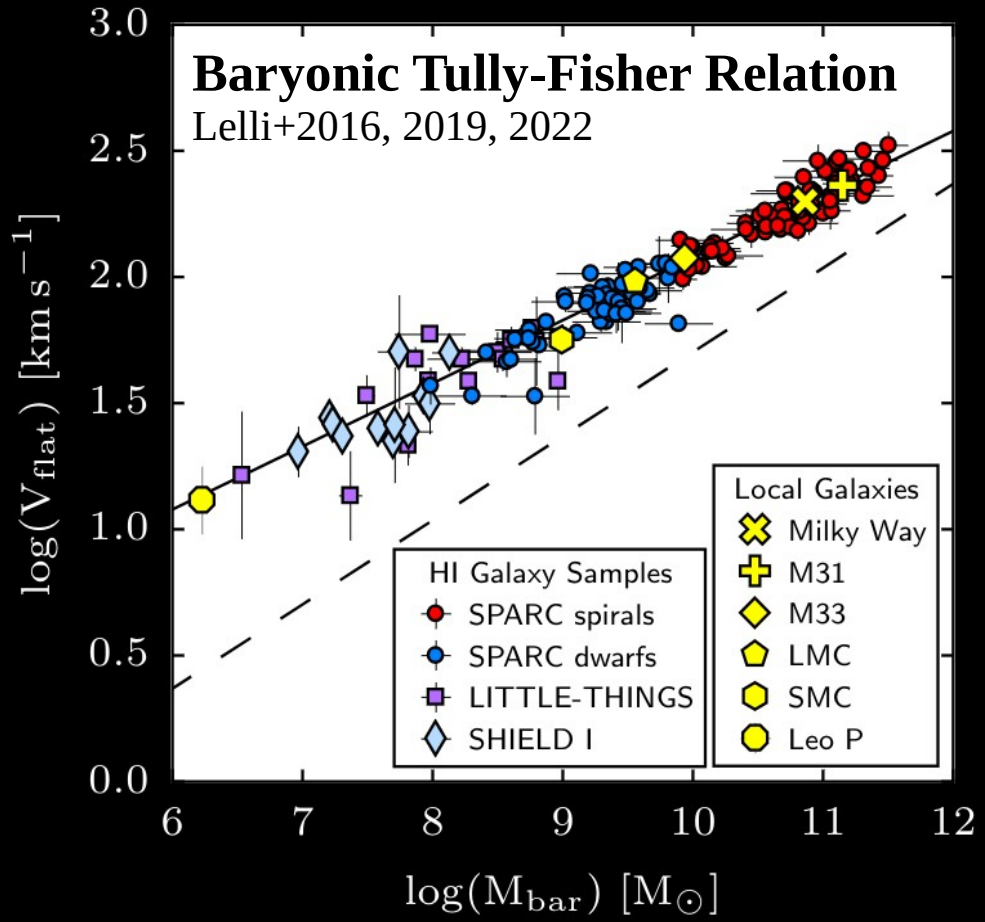

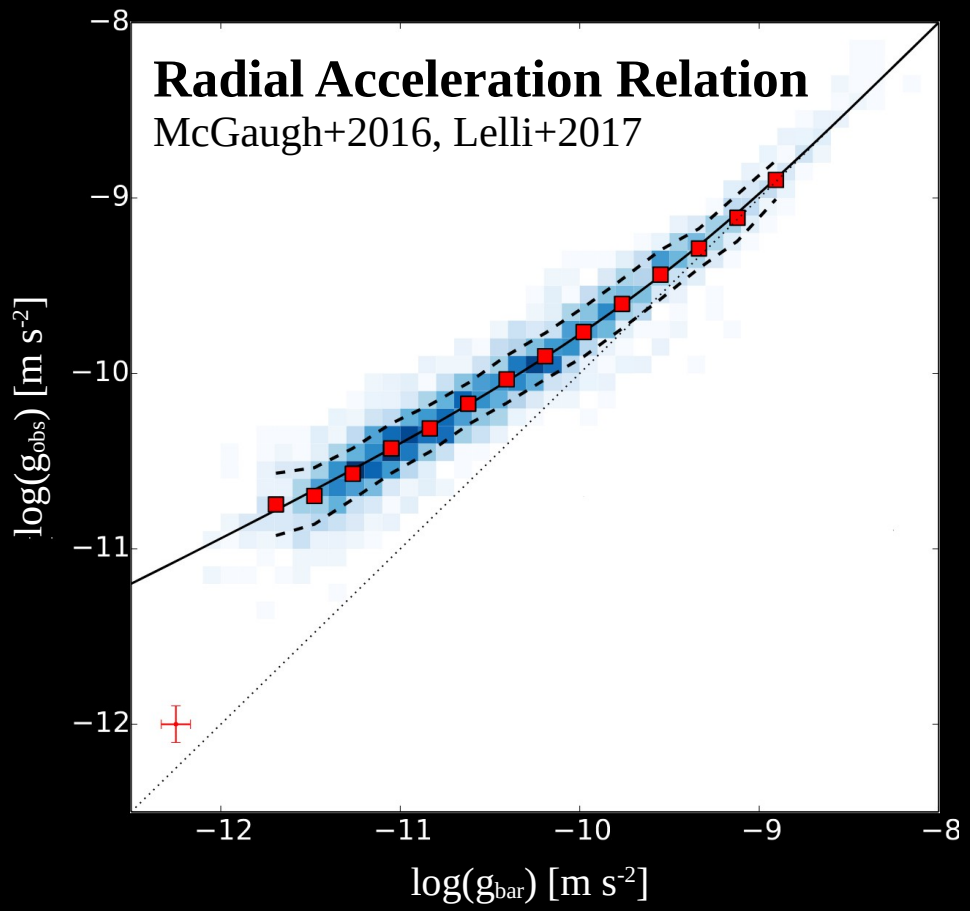

SPARC
Surface Photometry & Accurate Rotation Curves

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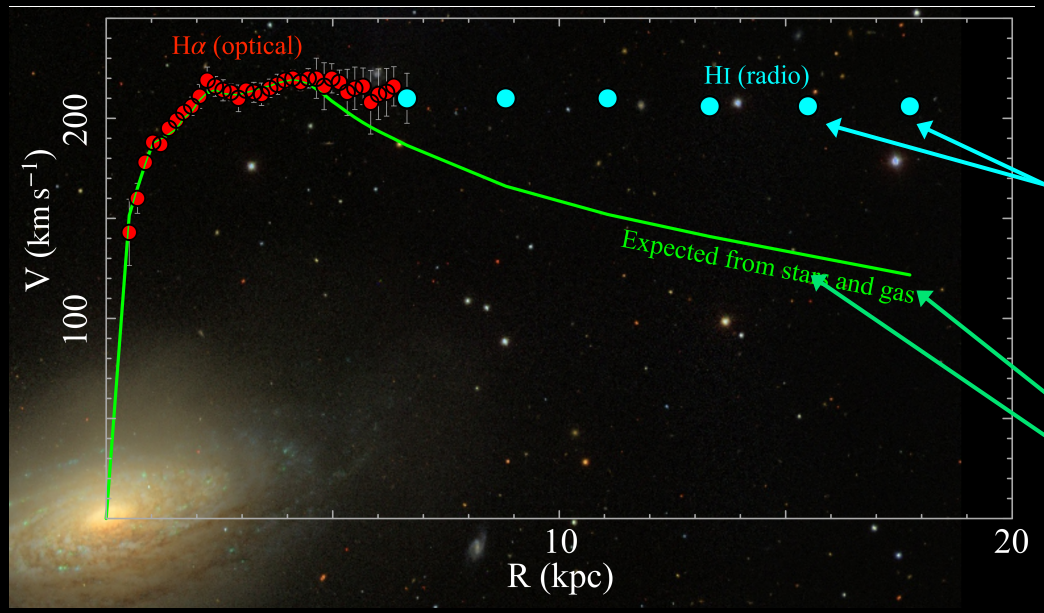

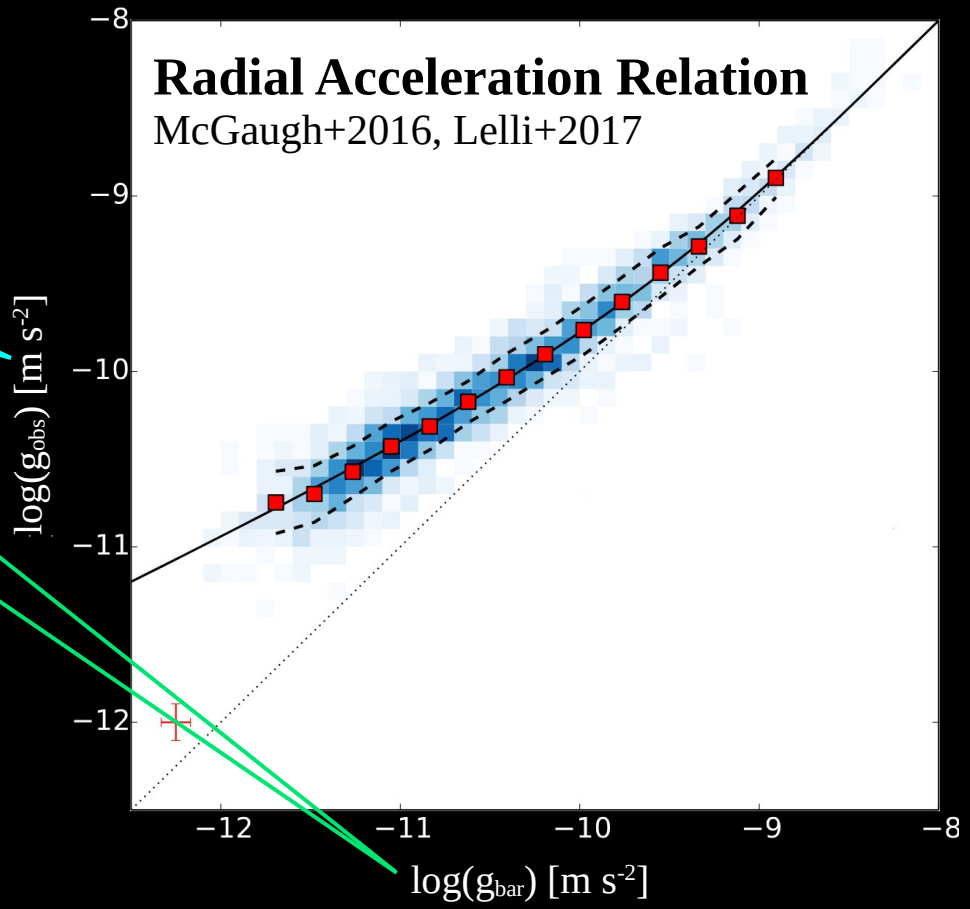

Results – Dynamical laws

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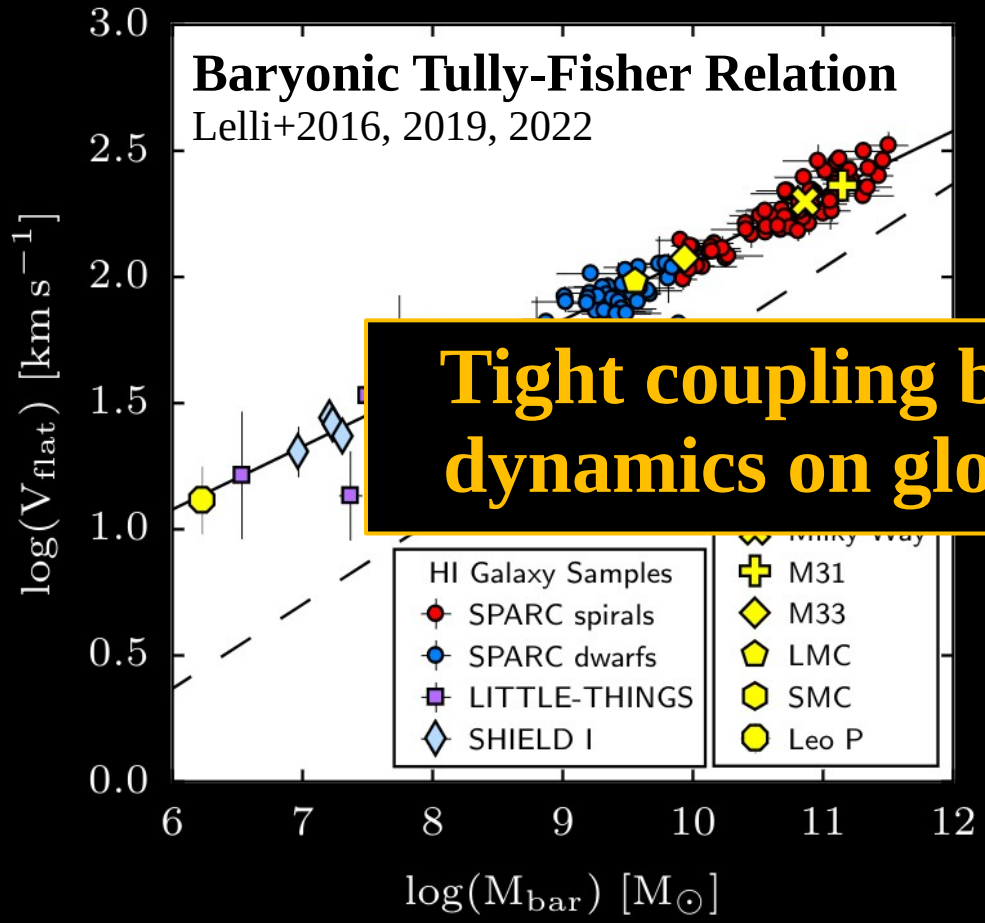
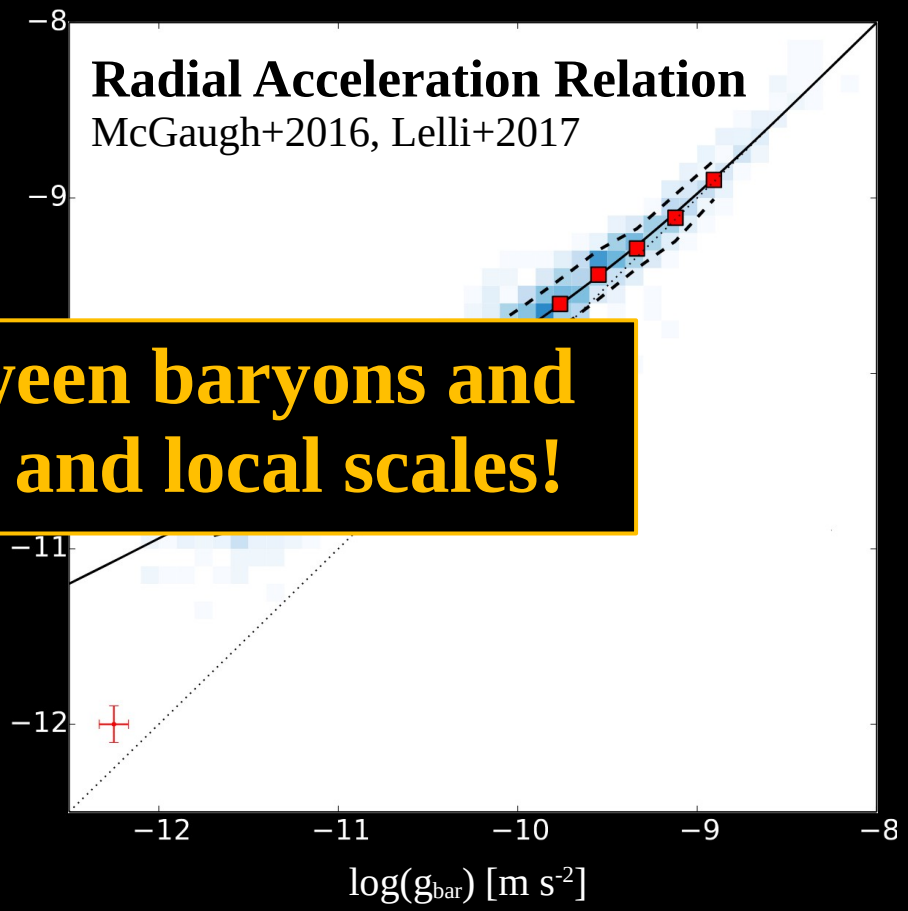
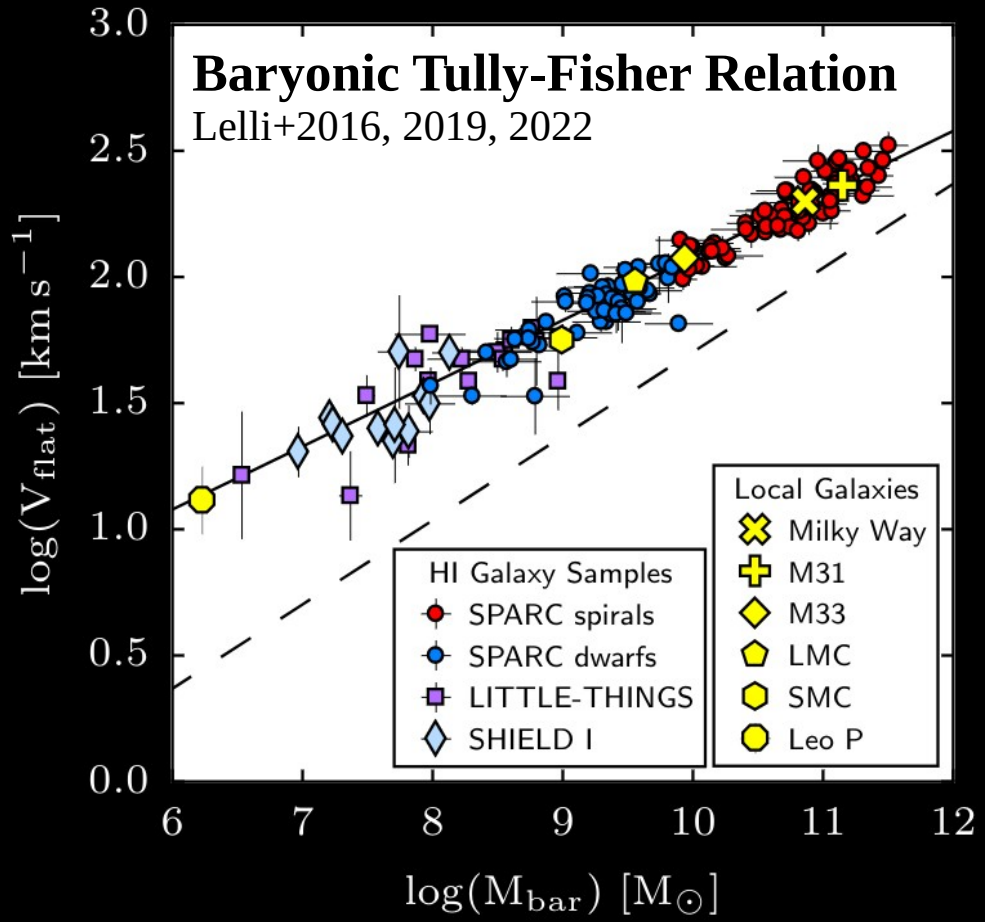
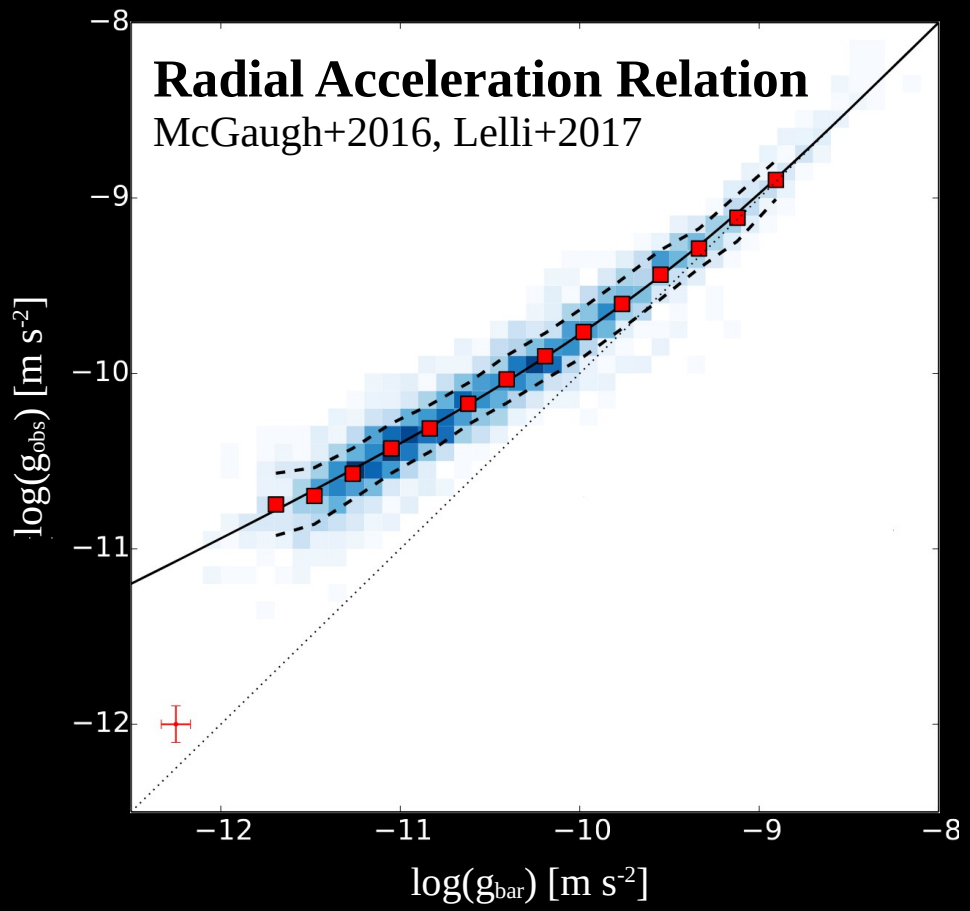




Tight coupling between baryons and dynamics on global and local scales!

Results – Dynamical laws





BIG-SPARC: Broad Inventory of Galaxies

Konstantin Haubner
(PhD candidate)

Federico Lelli
(INAF – Arcetri)

Enrico Di Teodoro
(Univ. of Florence)

Europe: HI dynamics

- Rotation curves
- Gas density profiles
- ^{3D}Barolo fitting code
  (Di Teodoro & Fraternali 2015)

Francis Duey
(PhD candidate)

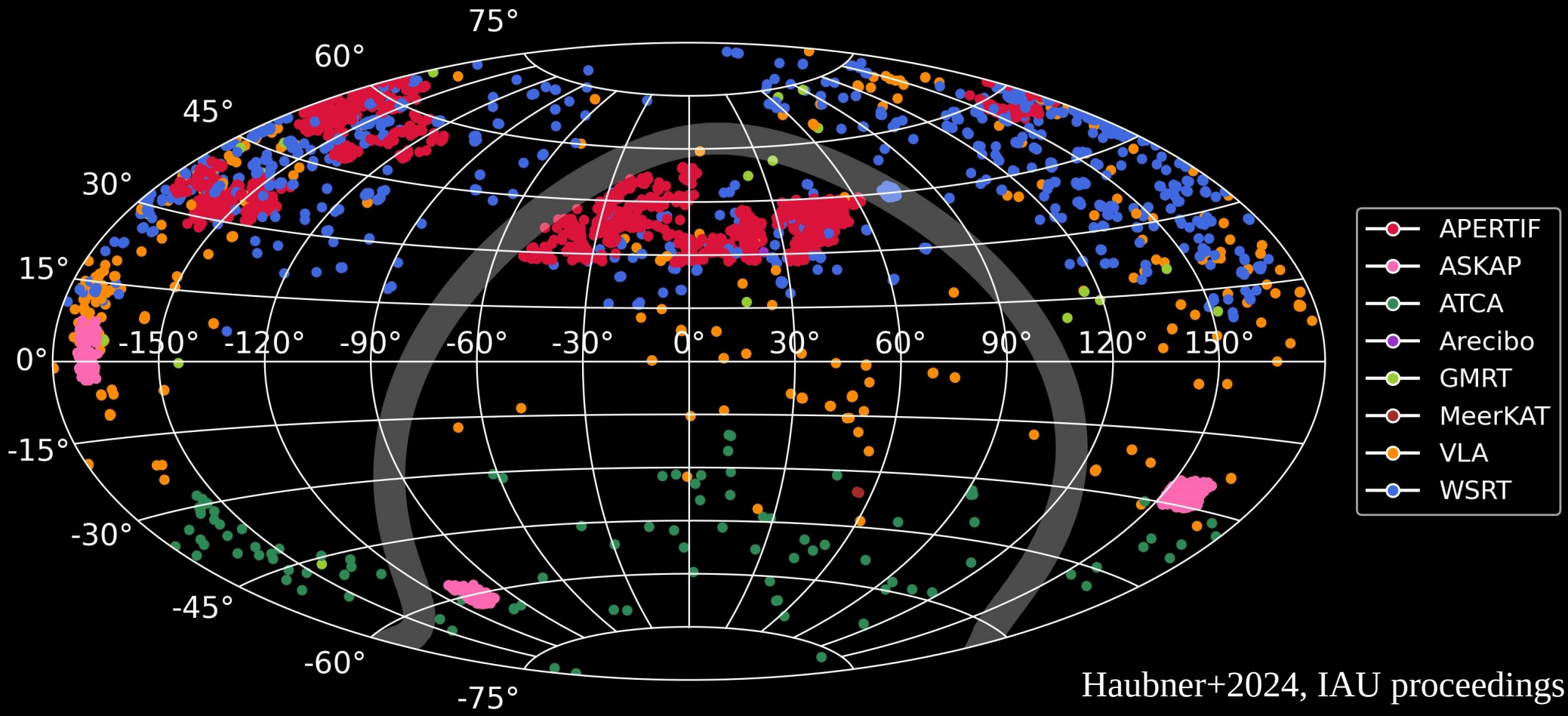
Stacy McGaugh
(Case Western, Cleveland)

James Schombert
(Univ. Of Oregon)

US: NIR surface photometry

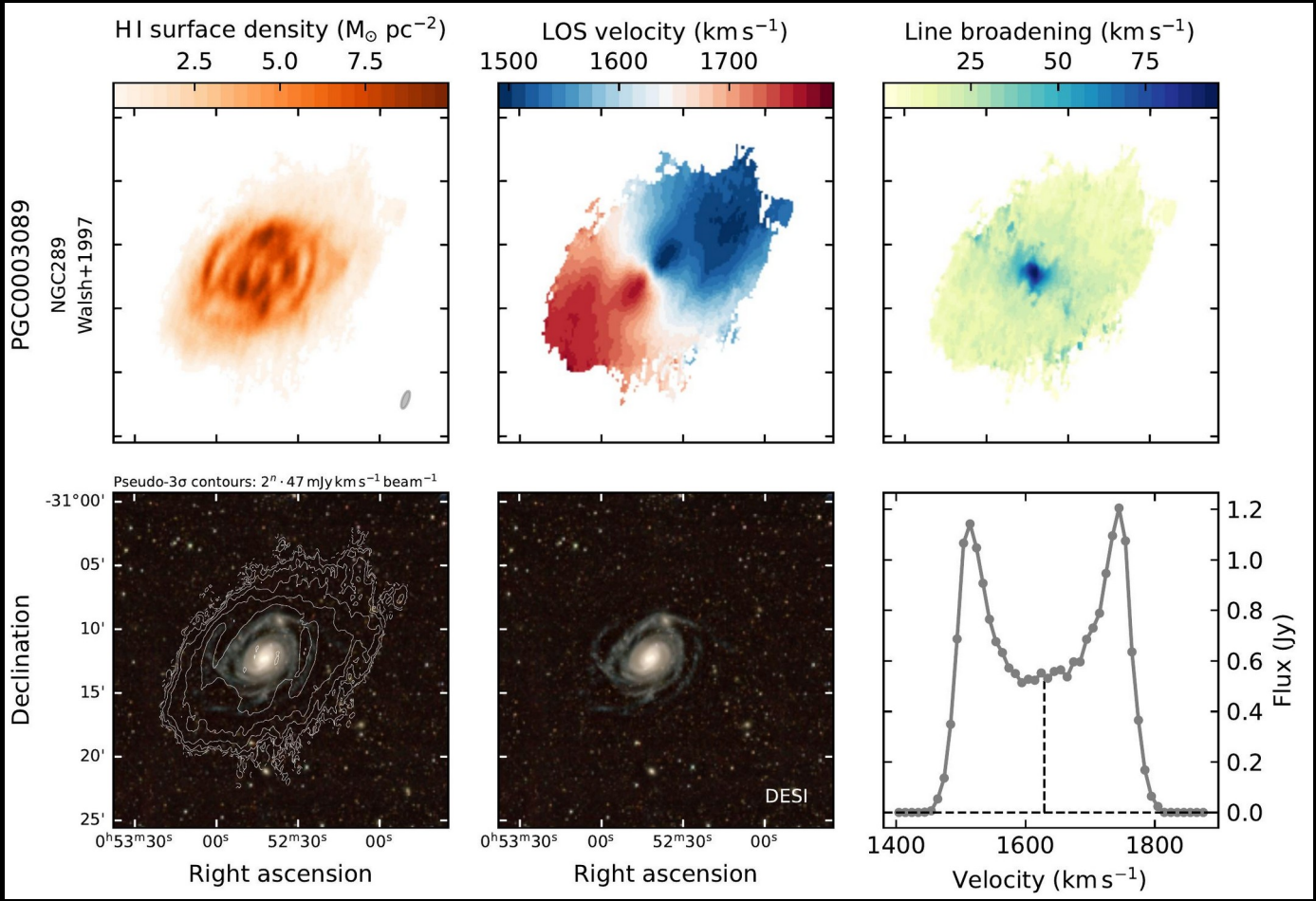
- Stellar mass density profiles
- *WISE* W1 (all-sky coverage)
- NIR stellar population models
  (Duey+2024; Duey+2025)

BIG-SPARC: ~4000 galaxies with HI data



Haubner+2024, IAU proceedings

Moment Maps and Global HI Profile



PGC 3089
NGC 289
(ATCA; Walsh+1997)

Distances for BIG-SPARC galaxies

Primary distances

- ~260 galaxies with distances from Cepheids, TRGB, SBF, SNIa, SNII, masers

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Group/cluster membership

- ~200 galaxies that belong to overdensities: Virgo, Fornax, Ursa Major, Hydra, Norma

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Flow distances

- Hubble flow with corrections for peculiar velocities
- **How to assign uncertainties to flow distances?**

Uncertainties on flow distances

Haubner+2025, A&A (2025A&A...696A.185H)

- ~2000 galaxies with primary distances from EDD (Tully+2023)

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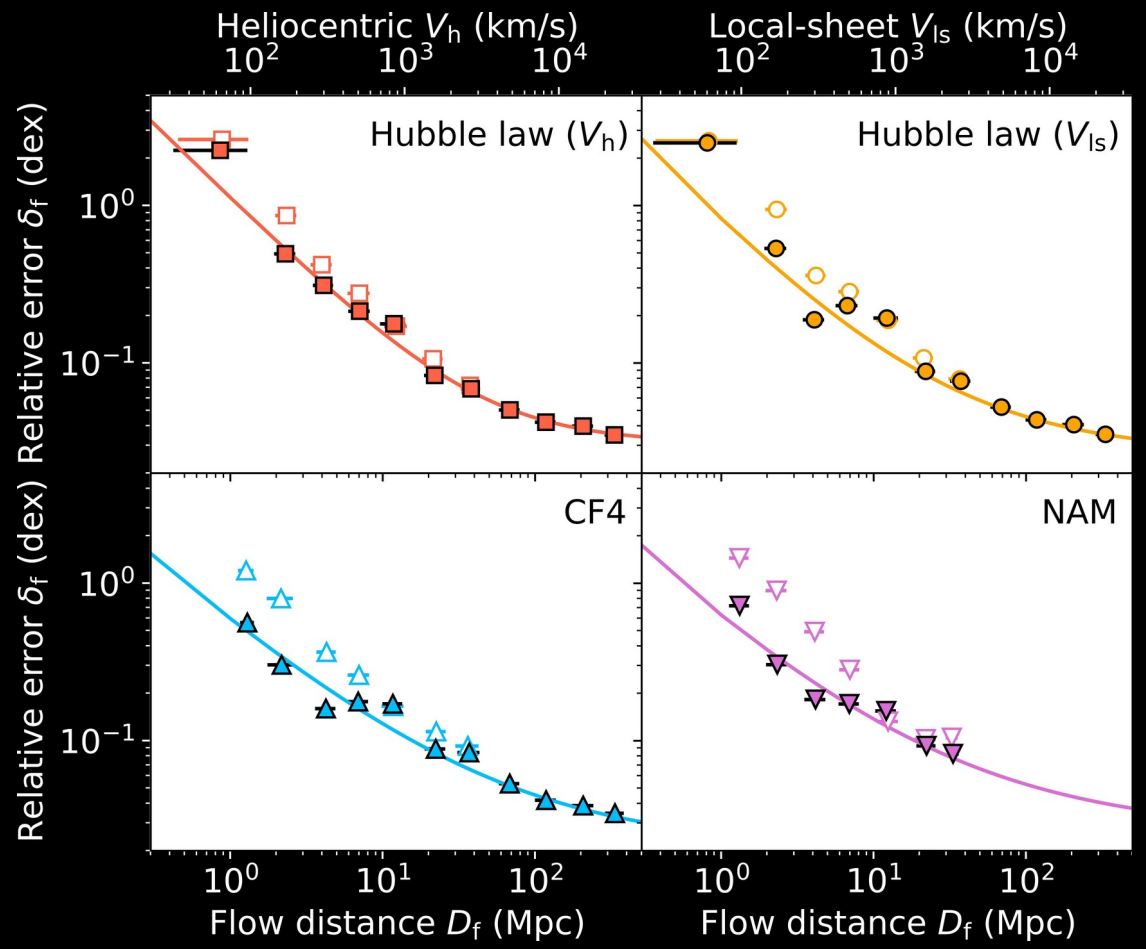
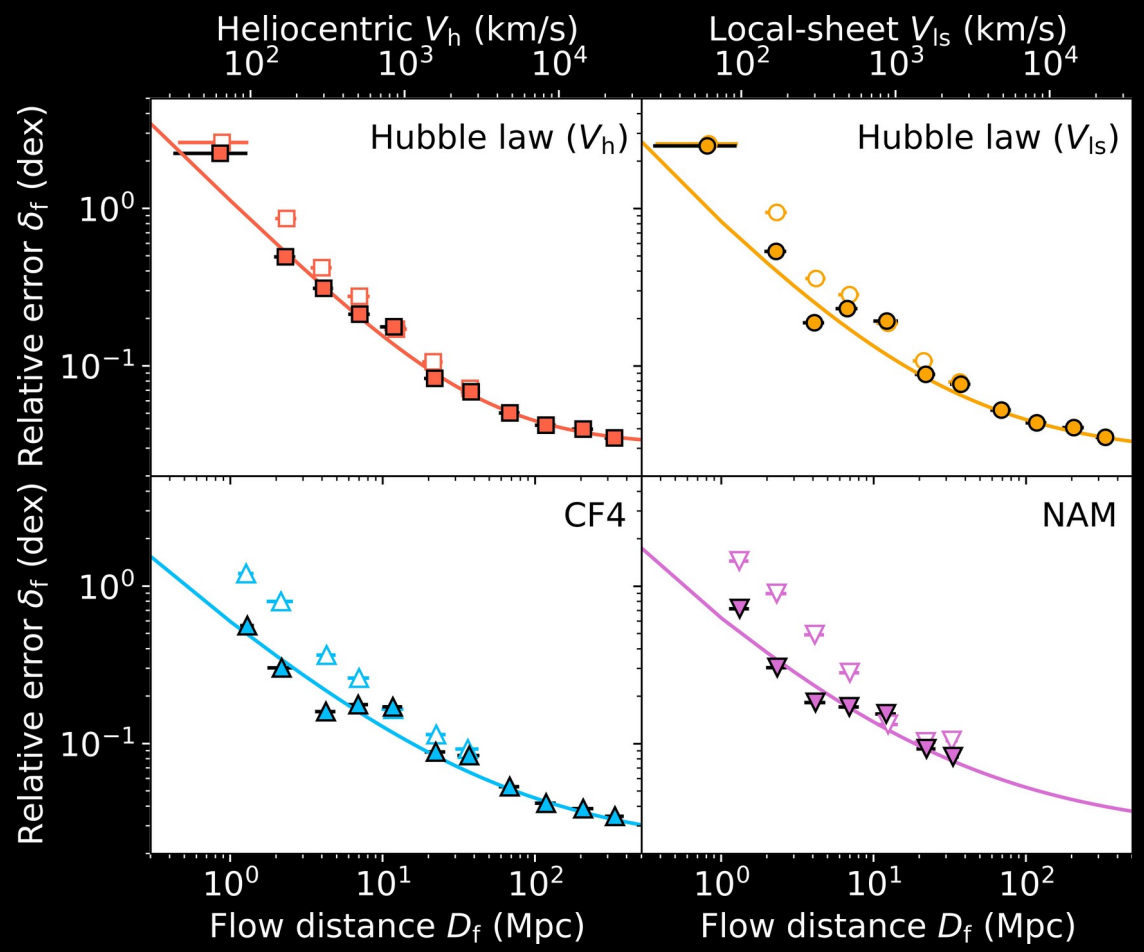
- compare primary distances with flow distances from 4 models



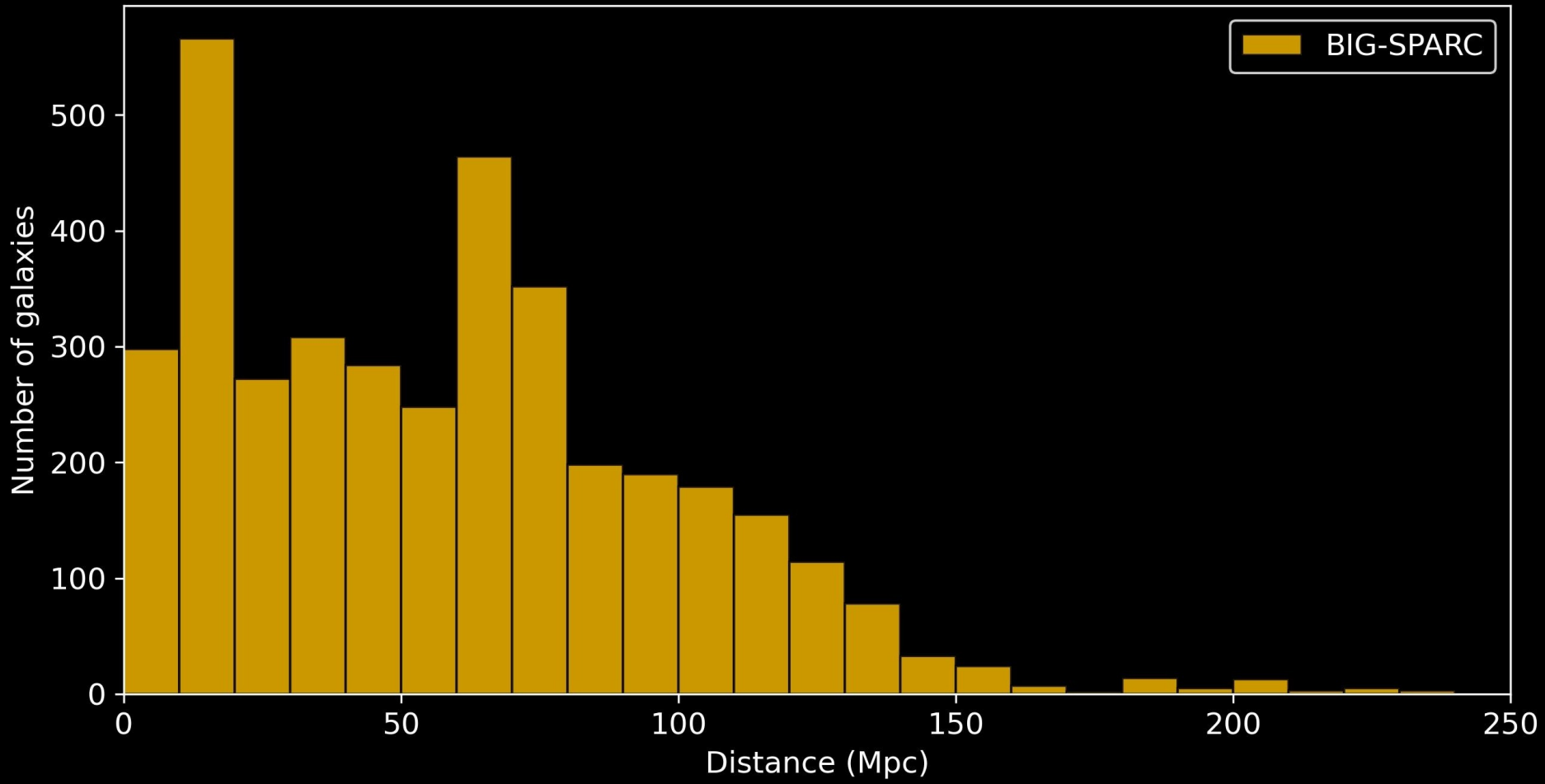
Uncertainties on flow distances

Haubner+2025, A&A (2025A&A...696A.185H)

- ~2000 galaxies with primary distances from EDD (Tully+2023)
- compare primary distances with flow distances from 4 models
- special treatment of the sky area around the Virgo cluster
- **Simple functions and tables to calculate uncertainties!**



BIG-SPARC: Distances



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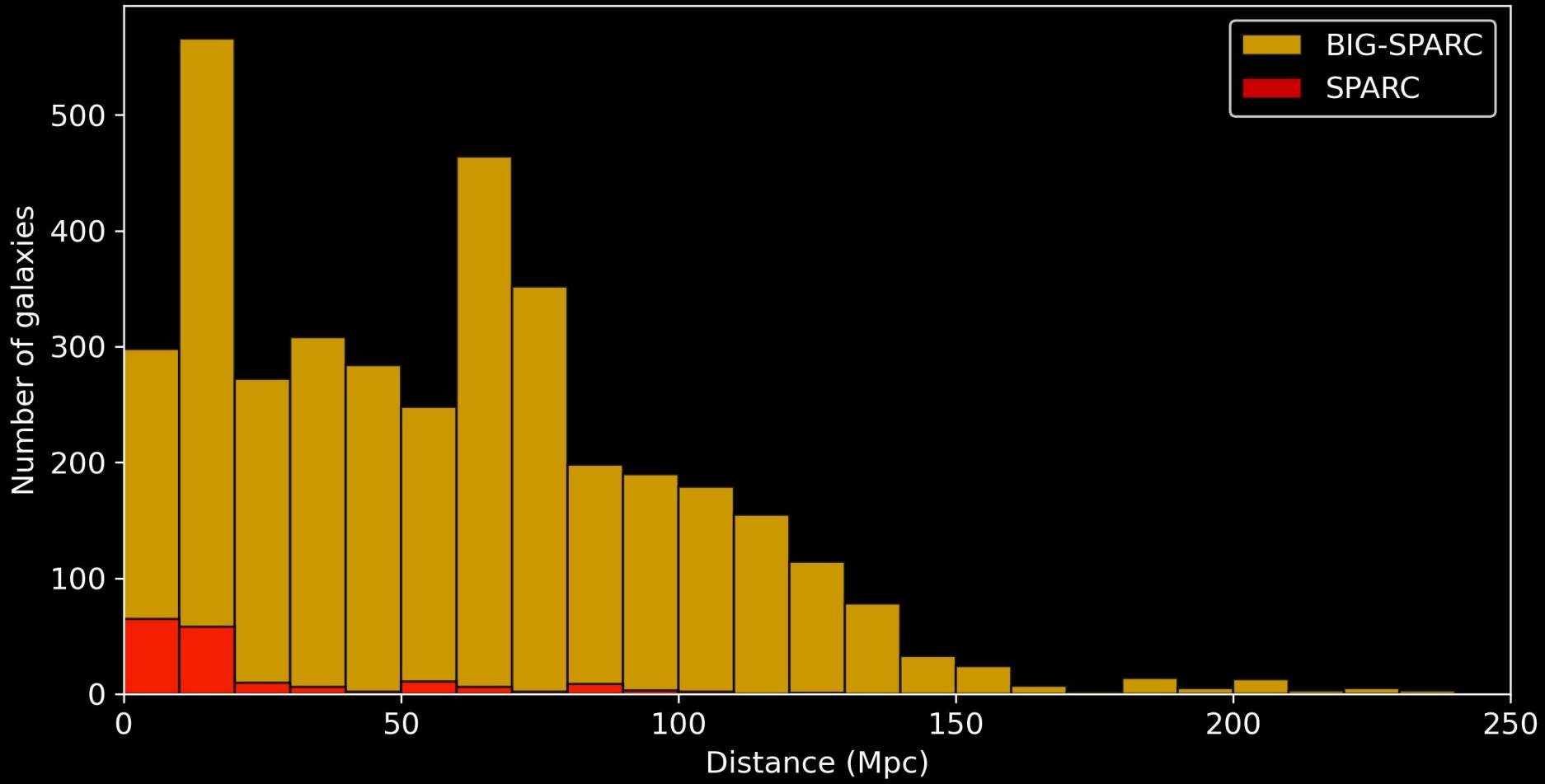
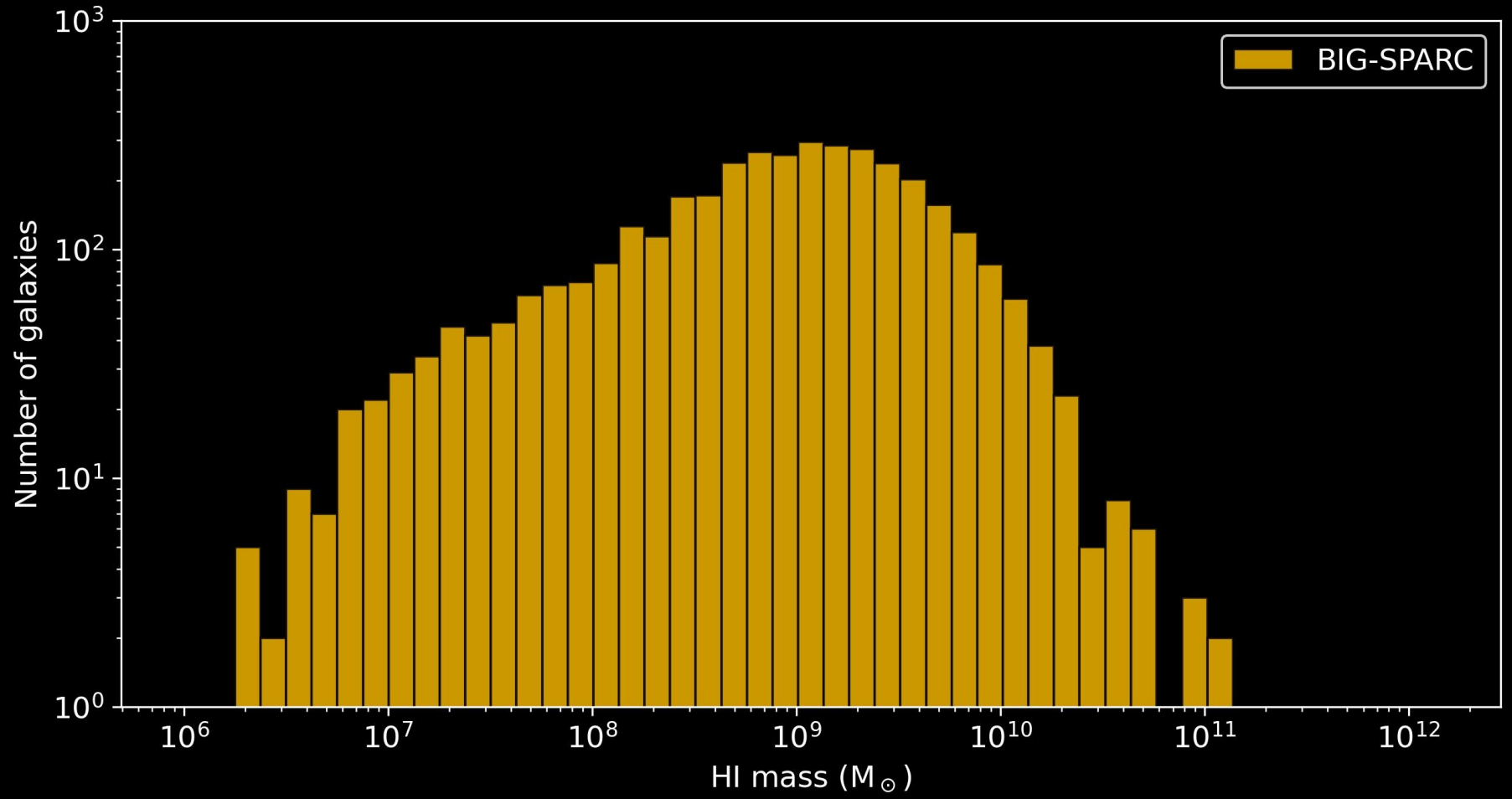
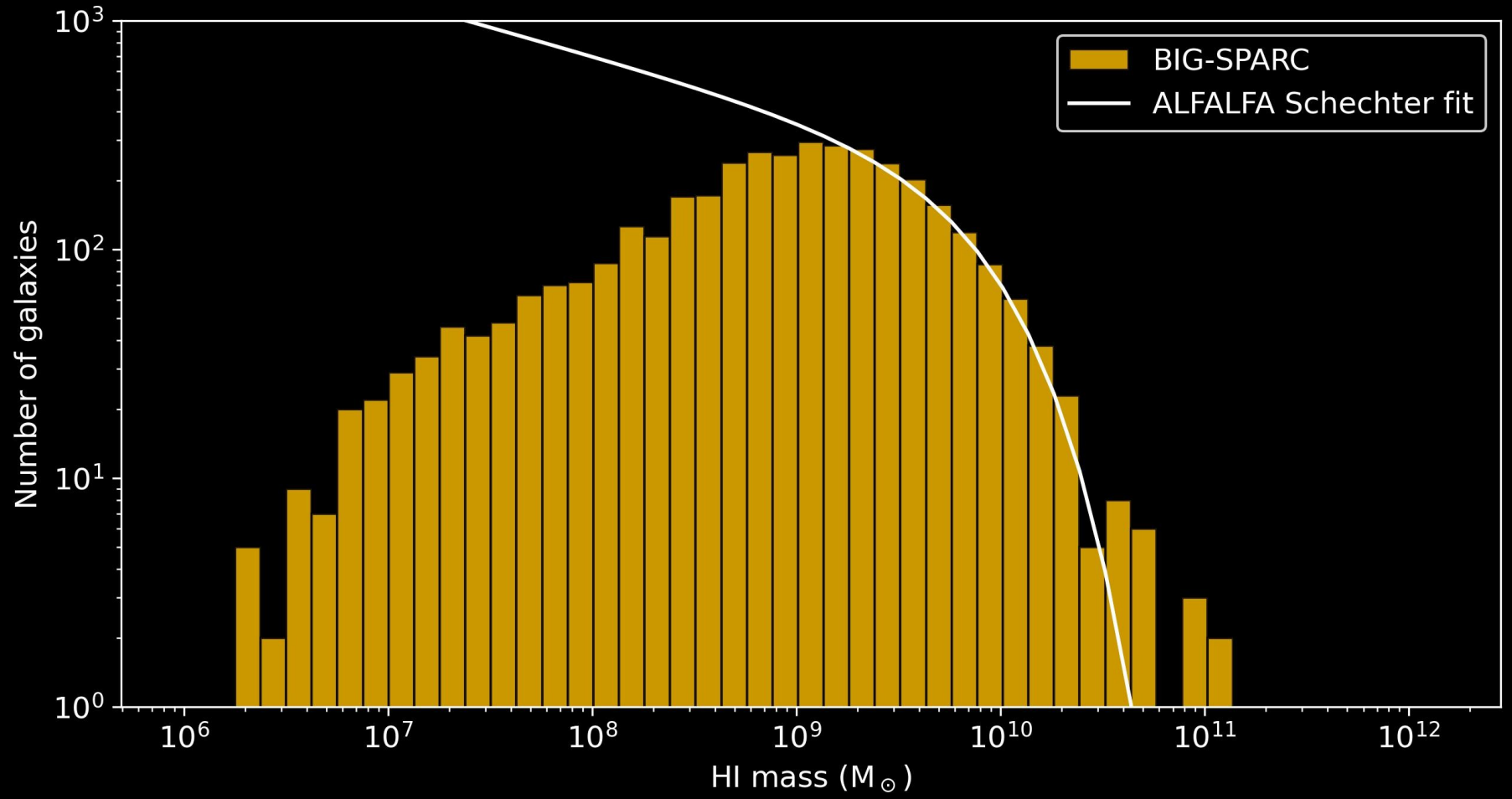


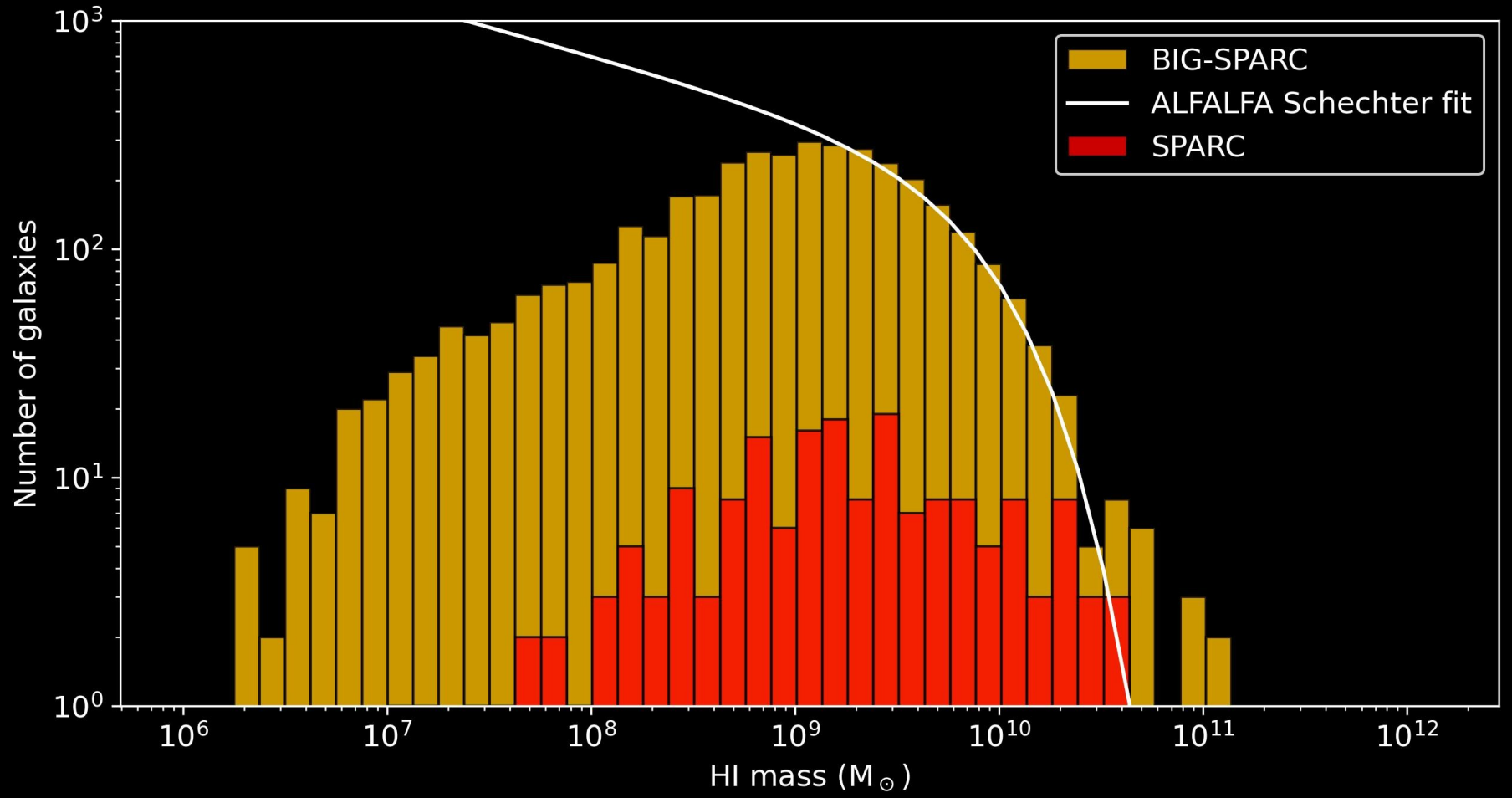
BIG-SPARC: HI masses



BIG-SPARC: HI masses



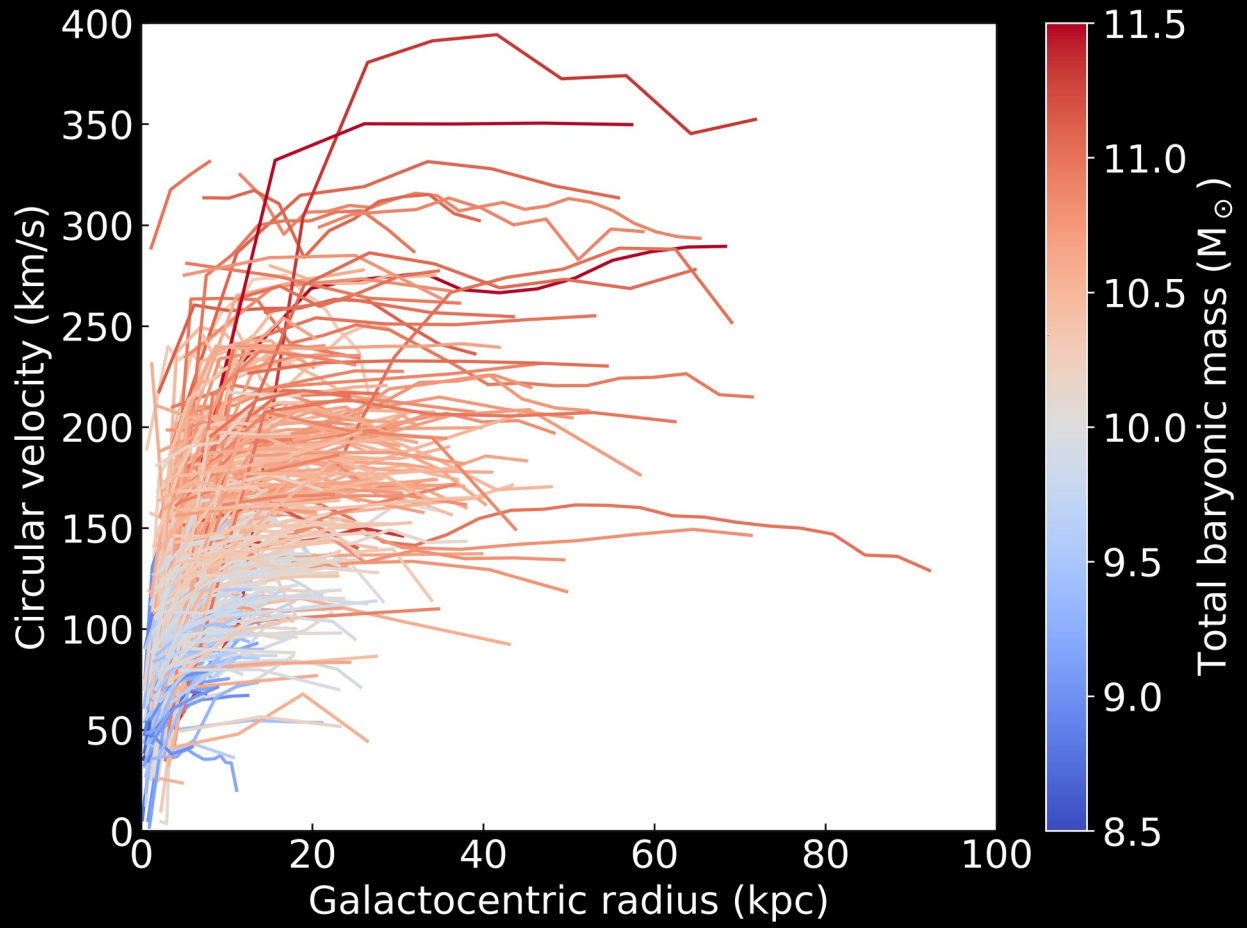
BIG-SPARC: HI masses



BIG-SPARC: Rotation Curves

Automated ^{3D}Barolo fits

- Disk geometry (center, PA, *i*)
- Rotation curves
- Gas surface density profiles
- Gas velocity dispersion prof.



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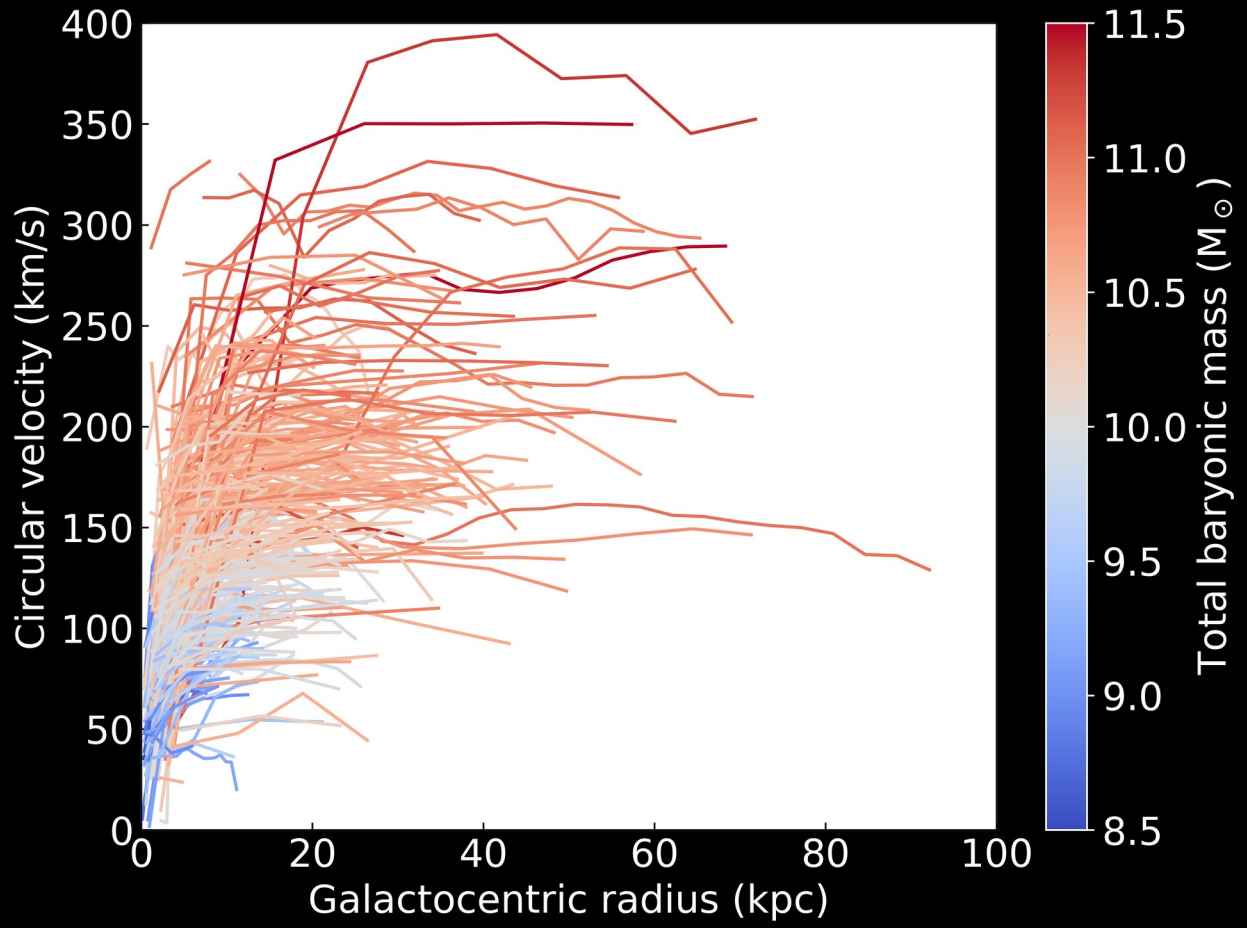
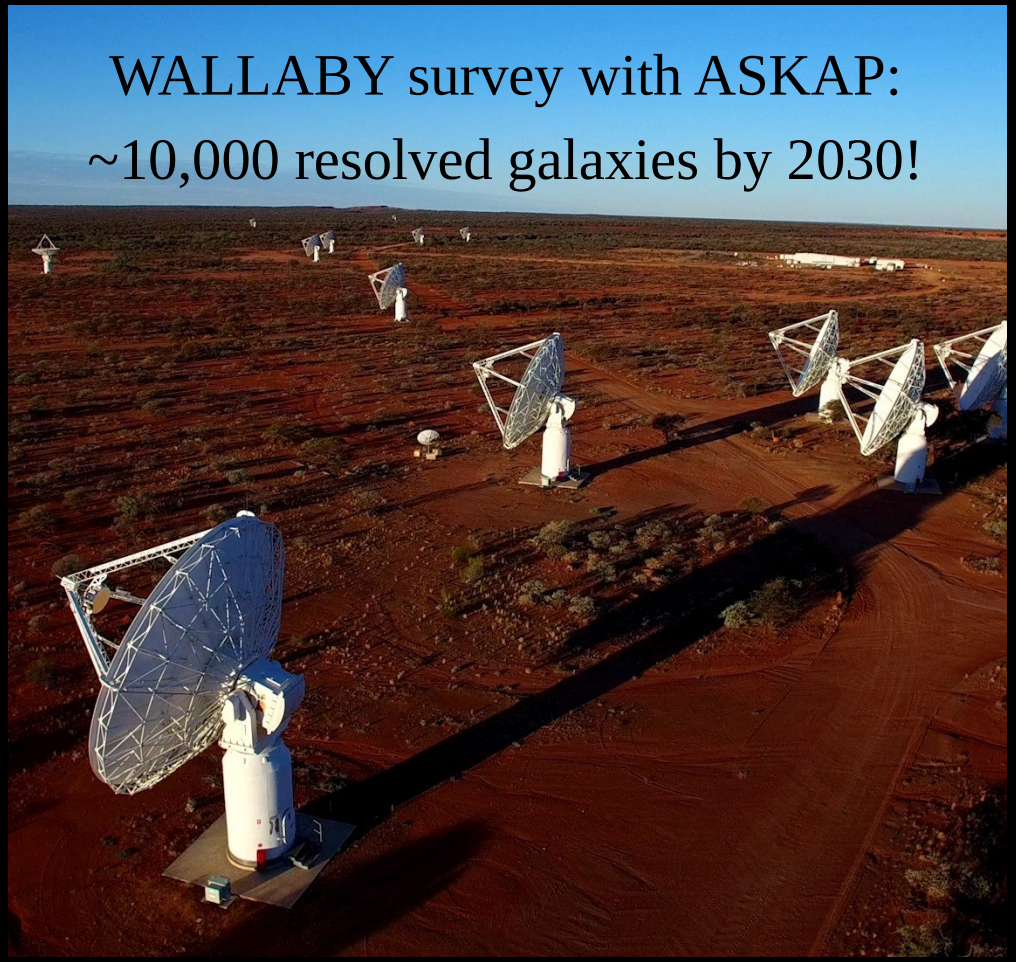
Visual assessment

- ~60% of fits acceptable, **1383 galaxies** (see figure)
- ~40% of fits need manual adjustment (often geometry)



BIG-SPARC is an intermediate (necessary) step!



Chapter in **Advancing Astrophysics with the SKA – II**

Testing dark matter models and modified gravity theories with spatially resolved H I observations

Federico Lelli,[1] Antonino Marasco,[2] Timothy A. Davis,[3] Nathan Deg,[4]
Jonathan Freundlich,[5] Gyula I. G. Jòzsa,[6,7] Peter Kamphuis,[8] Pavel E. Mancera Piña,[9]
Stacy S. McGaugh,[10] Amidou Sorgho[11] and Kristine Spekkens[4]

Advertisements!

Fixed-term researcher position (TD) at Arcetri

- Dynamics of high-z galaxies (ALMA, JWST, VLA)
- Application deadline 14 December

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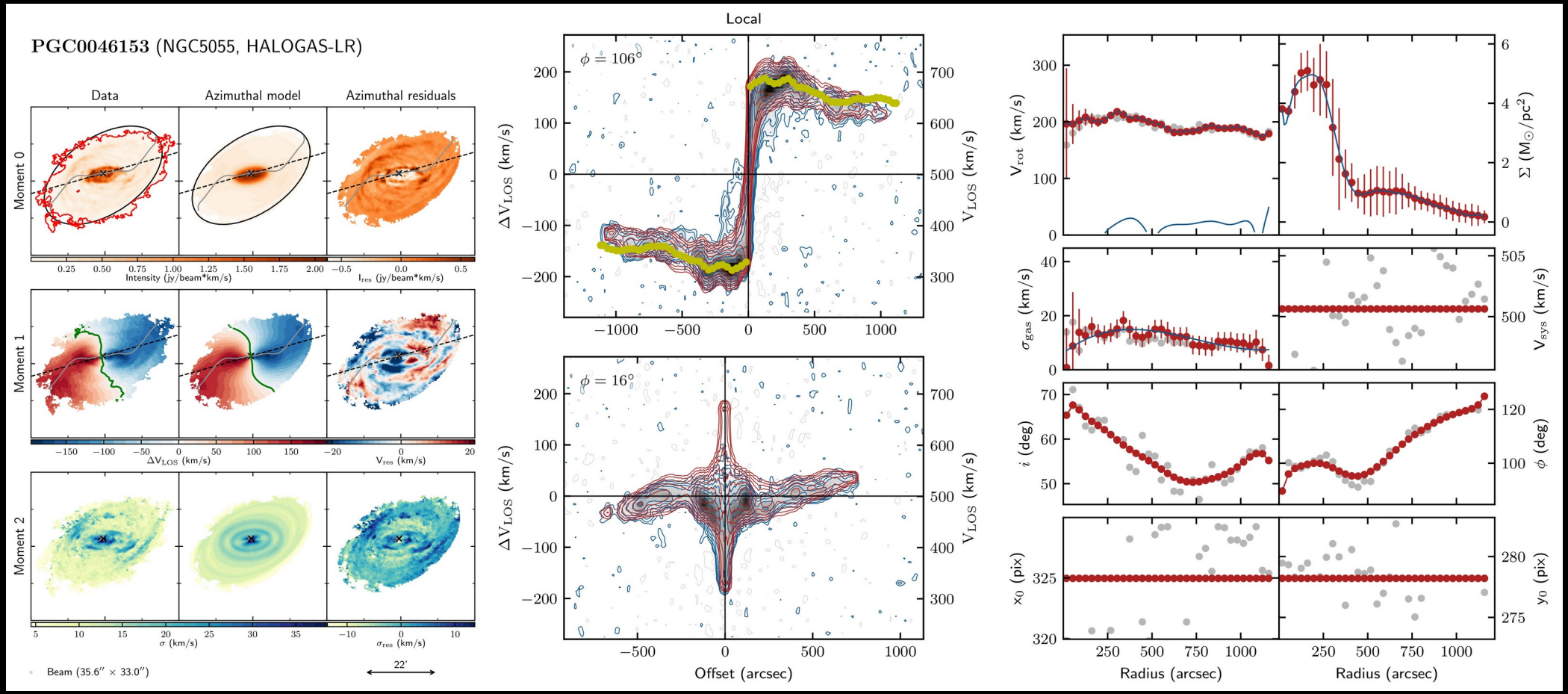
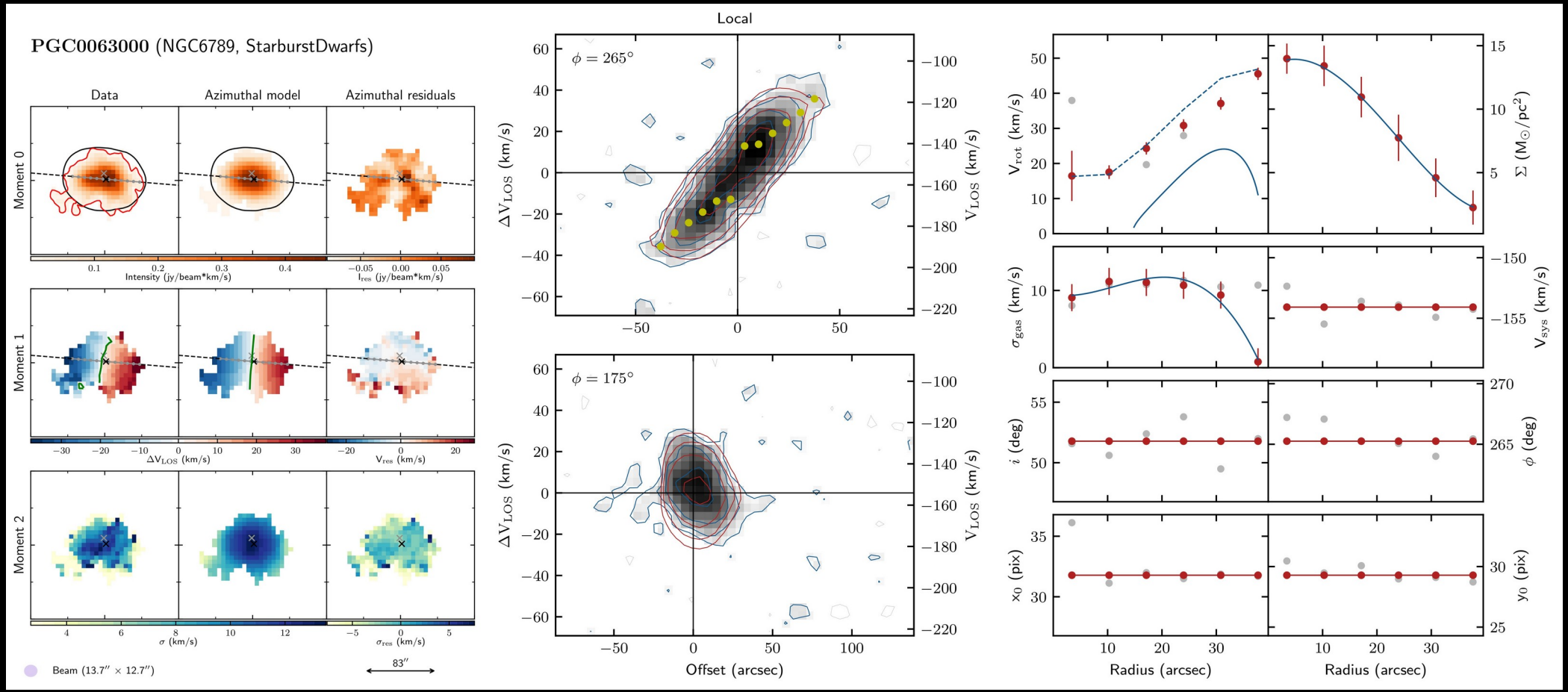
More postdoc positions (~6) will be open soon!

- Consolidator grant from FIS (*Fondo Italiano per la Scienza*)
- Galaxy dynamics at both low and high z!

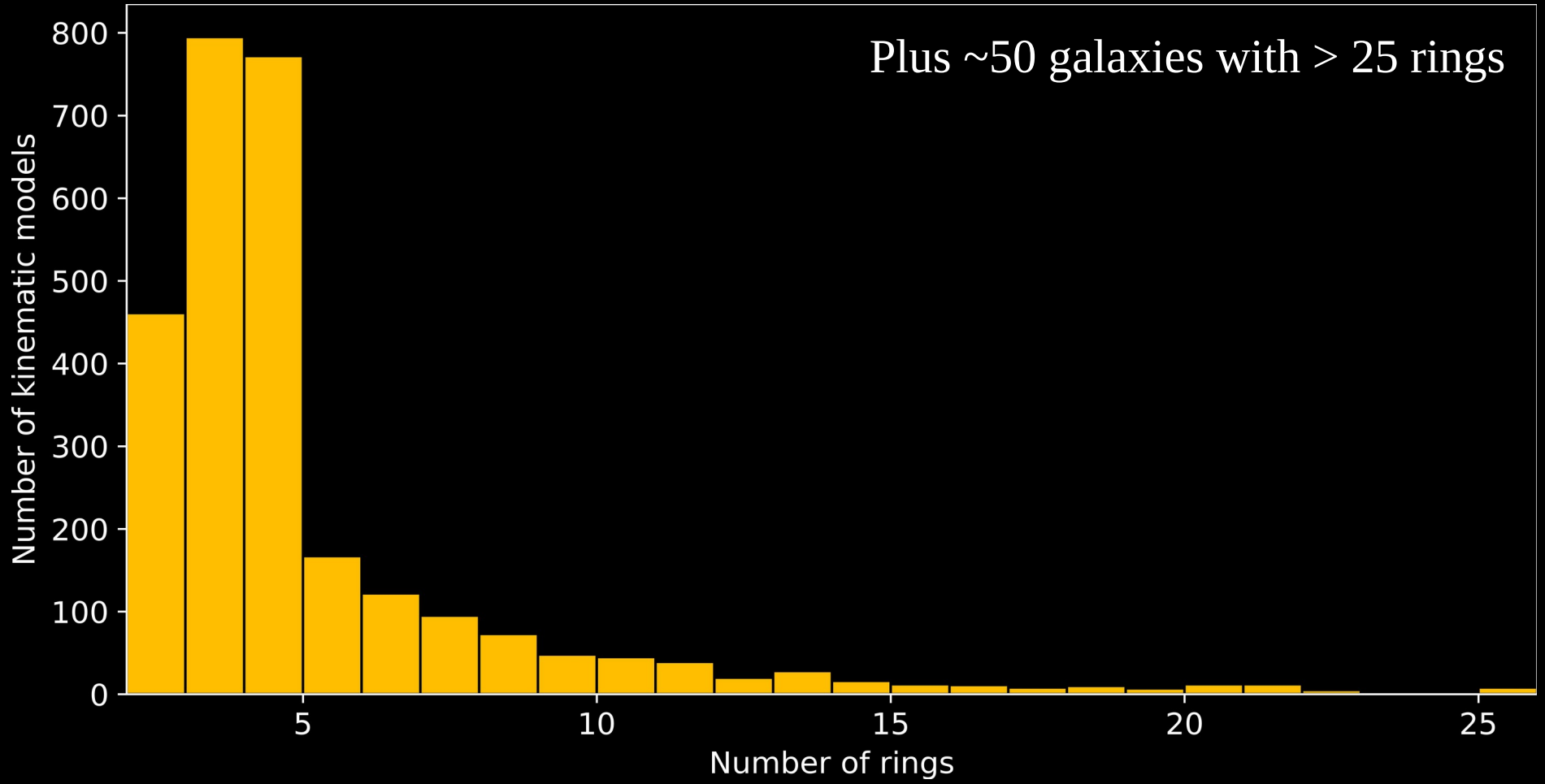
3D kinematic modeling: Disks warps



3D kinematic modeling: Pressure support



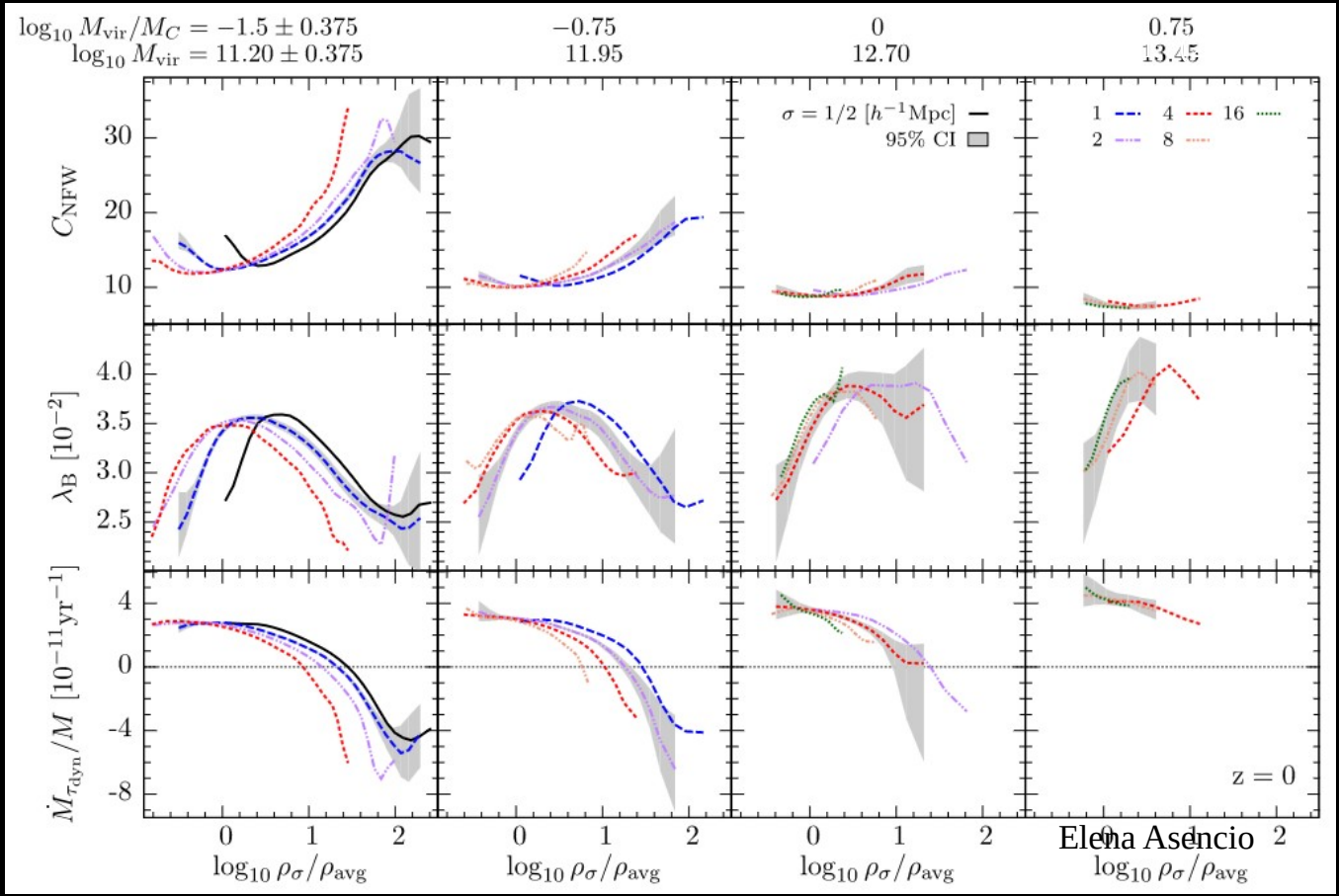
BIG-SPARC: Resolutions Elements



Environmental Variation of Dark Halos

Halo properties depend on formation history

1. More massive halos in larger env. densities
2. Concentration increases with env. density
3. Prolateness decreases with env. density



Elena Asencio

^{3D}Barolo Kinematic Modeling

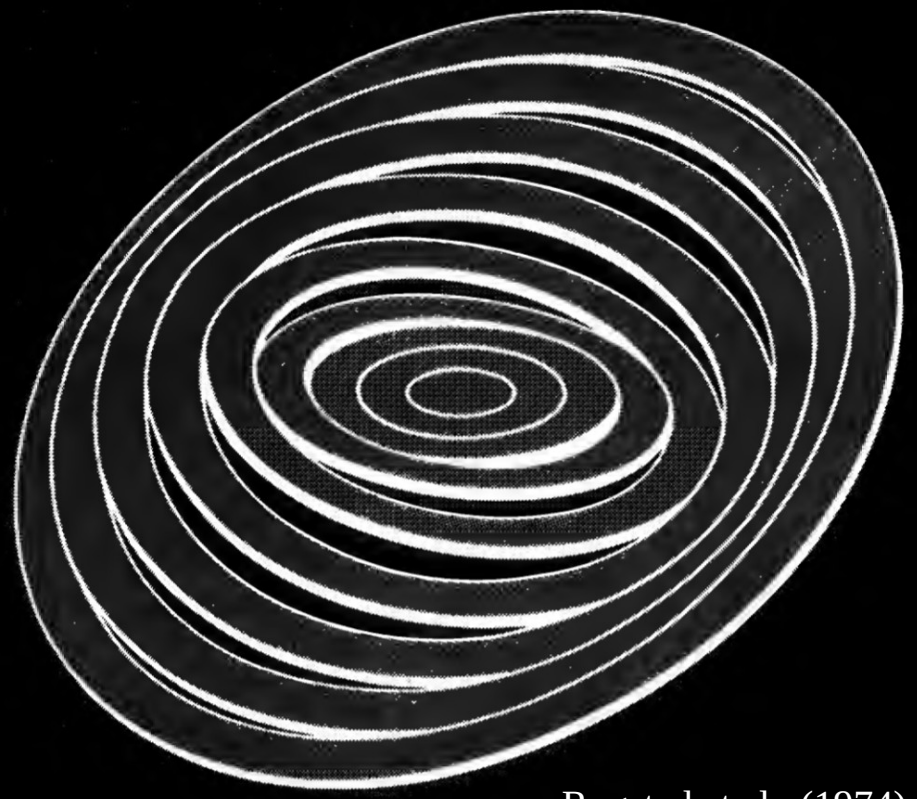
3D tilted ring model

- Number of rings set by spatial resolution
- Each ring with own set of parameters

Main algorithm steps

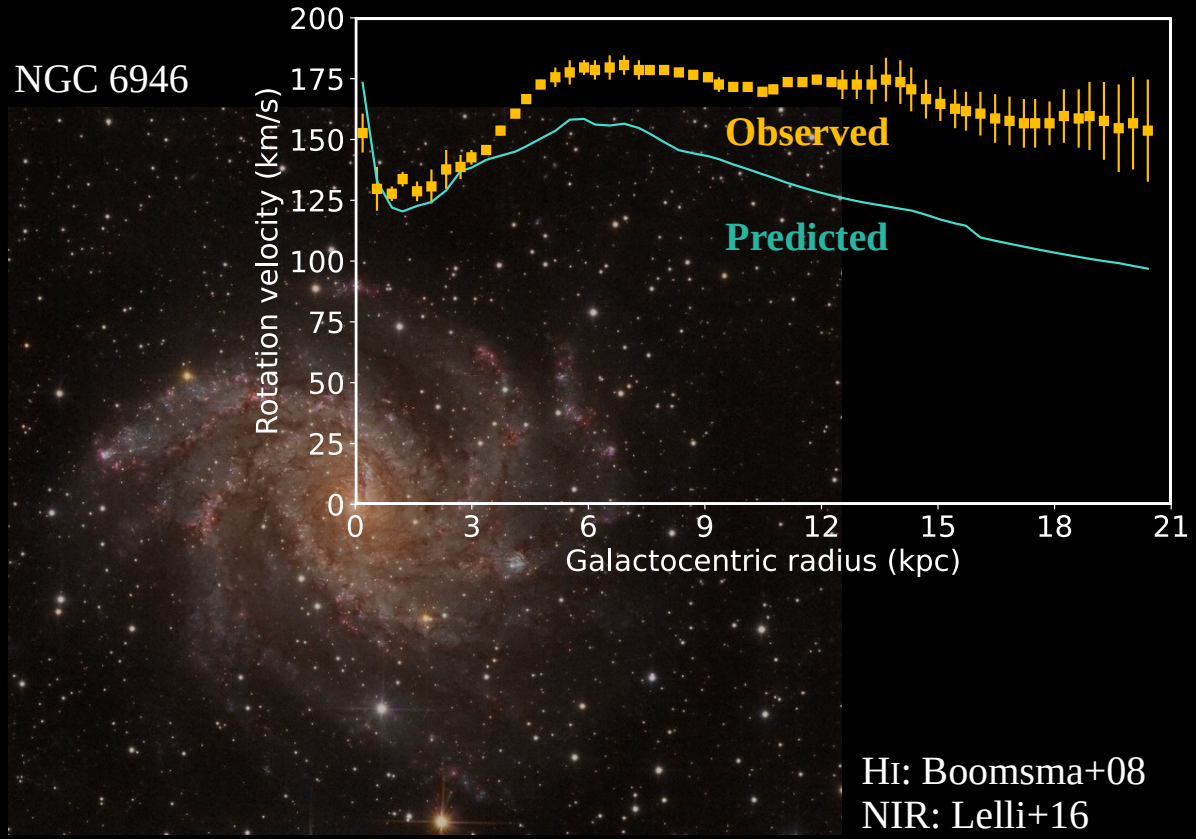
1. Build 3D disk model and project onto sky
2. Convolve with observational resolution
3. Calculate residuals

- **Instrumental effects taken into account!**



Rogstad et al. (1974)

Why studying galaxy dynamics?



HI: Boomsma+08
NIR: Lelli+16

The Dark Matter Problem

- Measure rotation curves
  → gravitational potential
- DM halos, particle models
- Modified gravity theories

Galaxy Formation & Evolution

- Angular momentum
- Non-circular motions
- Disk stability ↔ star formation
- Gas turbulence ↔ feedback

BIG-SPARC HI Data

^{3D}Barolo source finding

- 3817 galaxies in total
- **Factor ~22 increase compared to SPARC!**

Cross-matching

- PGC or NED
- ~2% without known optical counterpart

Haubner+2024, IAU proceedings

Cube Source	Telescope	Number of Galaxies
Apertif	WSRT-APERTIF	1721
WALLABY DR1	ASKAP	484
WHISP	WSRT	336
Atlas^{3D}	WSRT	282
Bluedisk	WSRT	174
PPZoA	WSRT	153
Hickson Compact Groups	VLA	84
LVHIS	ATCA	71
VIVA	VLA	55
VGS	WSRT	43
PHANGS-VLA	VLA	39
HALOGAS	WSRT	36
LITTLE THINGS	VLA	32
THINGS	VLA	32
EDGES	VLA	29
Ursa Major Cluster	WSRT	25
HIX	ATCA	25
EveryTHINGS	VLA	22
SAURON	WSRT	21
LSB Galaxies	VLA, WSRT	20
FIGGS	GMRT	20
Starburst Dwarfs	VLA, WSRT	11
MeerKAT Fornax Cluster	MeerKAT	3
Individual Studies	GMRT, VLA, WSRT, Arecibo	93
Total		3817