HI Galaxies: science results from centimetre wavelength SKA precursors

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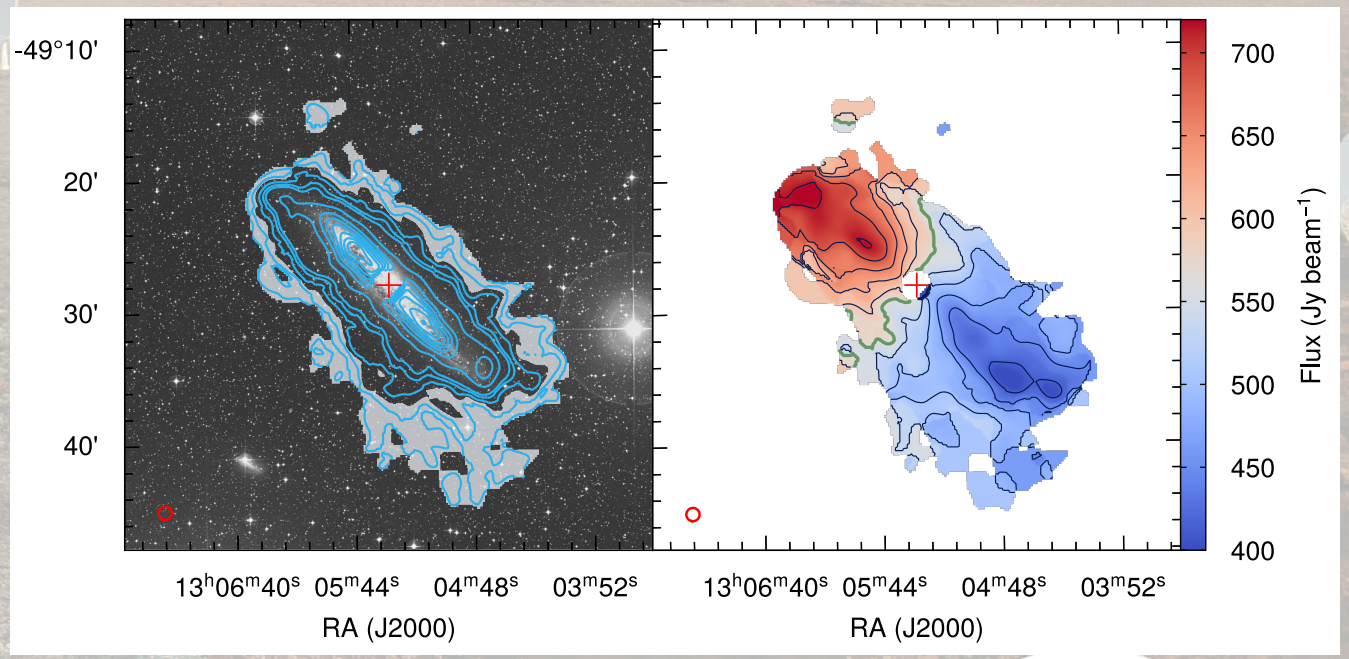
Why study HI?

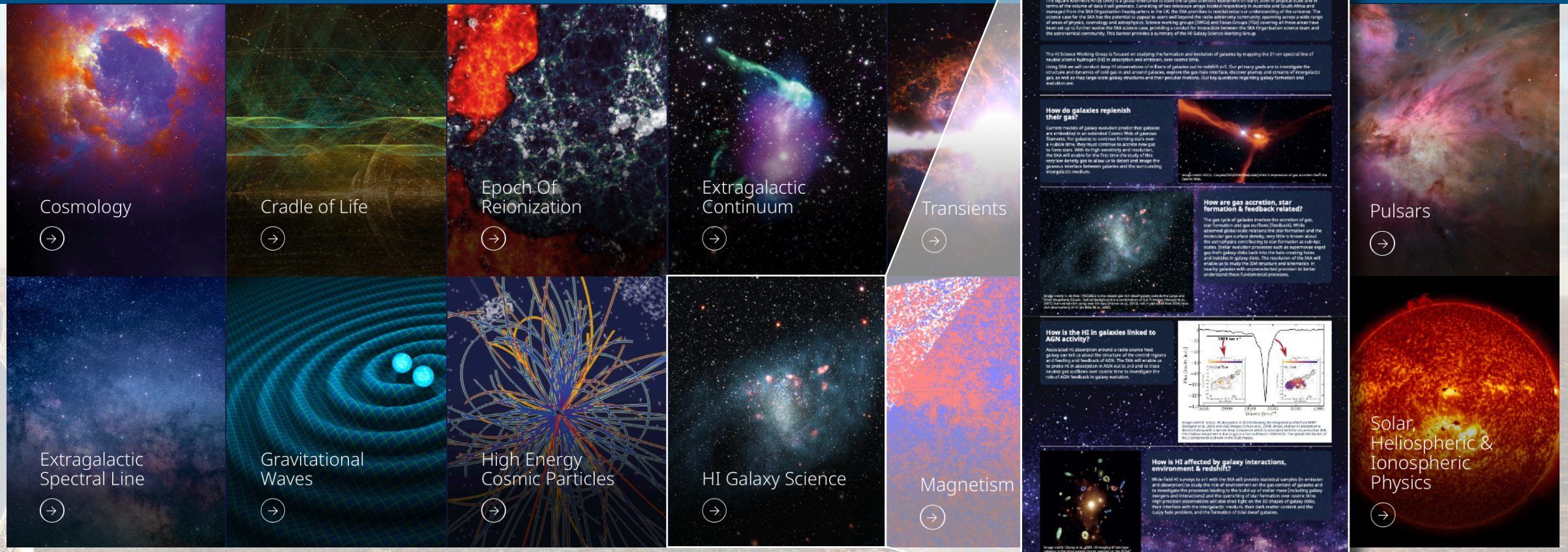
- Neutral atomic hydrogen (HI) is the fundamental fuel for star formation in galaxies
- Sensitive probe of the dark matter halo in a galaxy
- Traces a history of past interactions
- Scaling relations provide insight into baryonic cycle in galaxies: HI mass vs HI size, stellar mass, SFR, sSFR, etc

- How is HI linked to star formation galaxy disks & related to kinematics
- How does accretion fuel star formation
- What is the fate of HI in environmental
- How do HI scaling relations vary with



NGC 4945; Ianjamasimanana et al (2019)

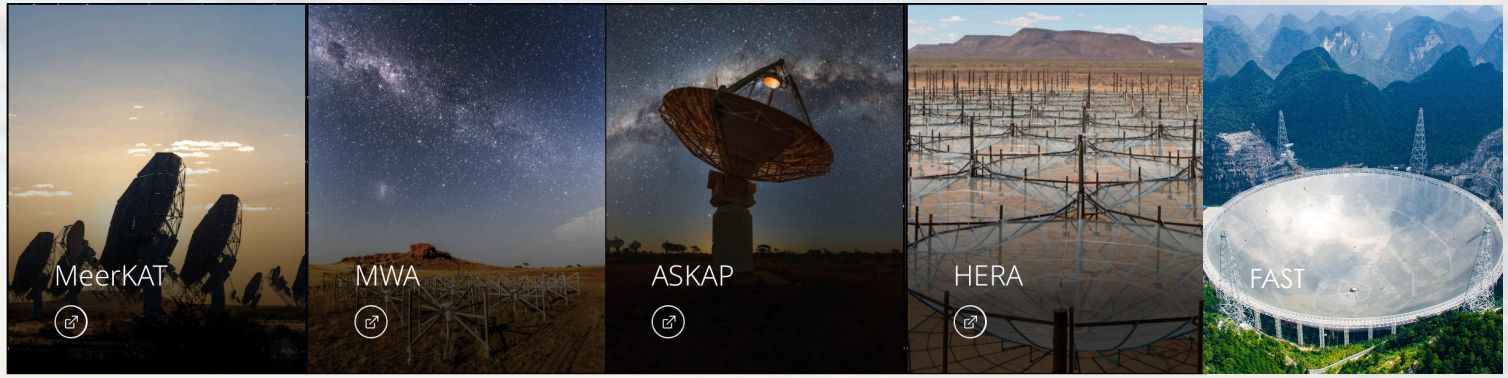
SKA Science Community



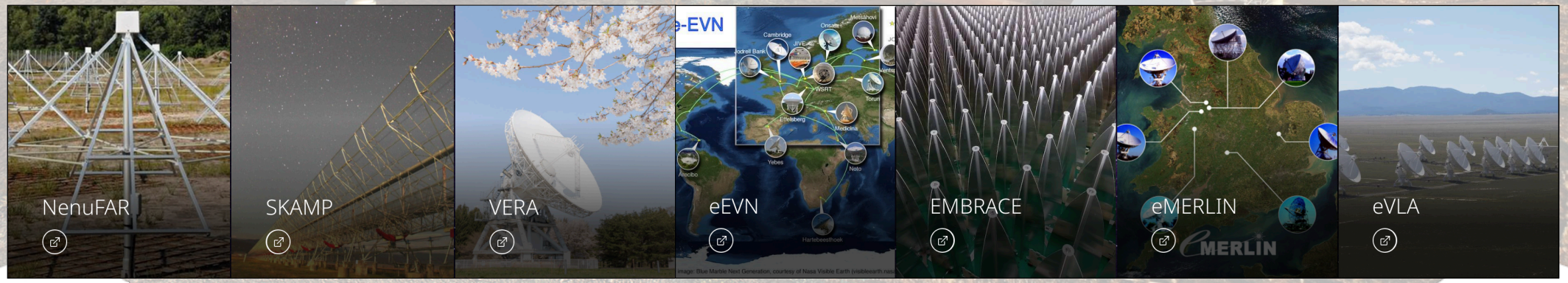
- How do galaxies replenish their gas?
- How are gas accretion, star formation, and feedback related
- How is the HI in galaxies linked to AGN activity?
- How is HI affected by galaxy interactions, environment, & redshift

A global family of precursor and pathfinder facilities

Precursors:



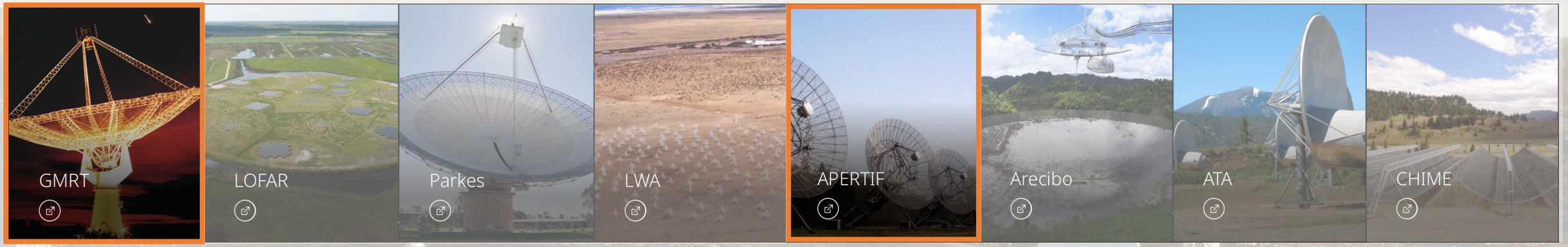
Pathfinders:



A global family of precursor and pathfinder facilities

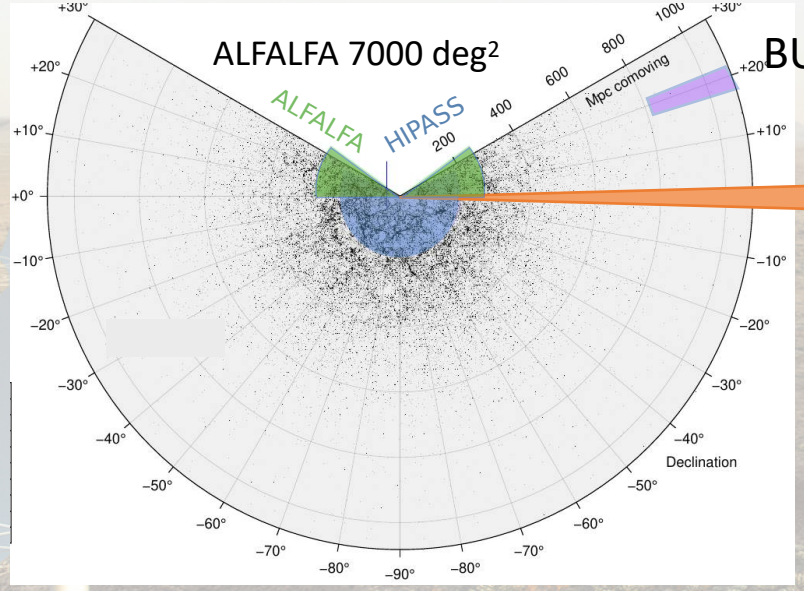
Precursors:

Pathfinders:



HI surveys with SKA pathfinders: pushing instrumentation limits

- Untargeted HI surveys



BUDHIES: z~0.2

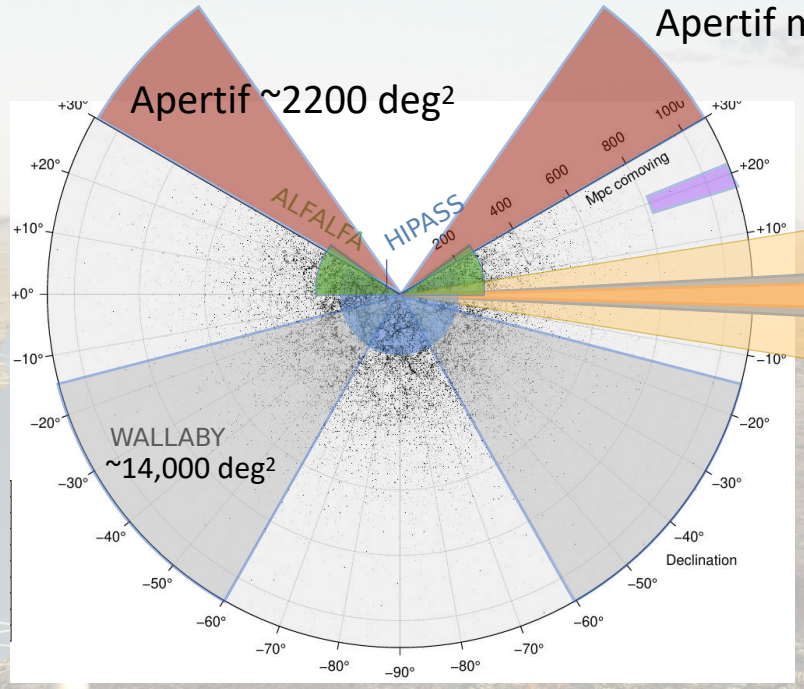
CHILES ~0.25 deg²

z~0.5

- Previous generation of HI studies
  - Pointed HI observations
  - Wide-area unresolved HI surveys
  - CHILES: upgraded EVLA

HI surveys with SKA precursors: a tiered approach

- Untargeted HI surveys



Apertif medium-deep ~160 deg²

MIGHTEE-HI ~20 deg²

CHILES

z~0.5

LADUMA

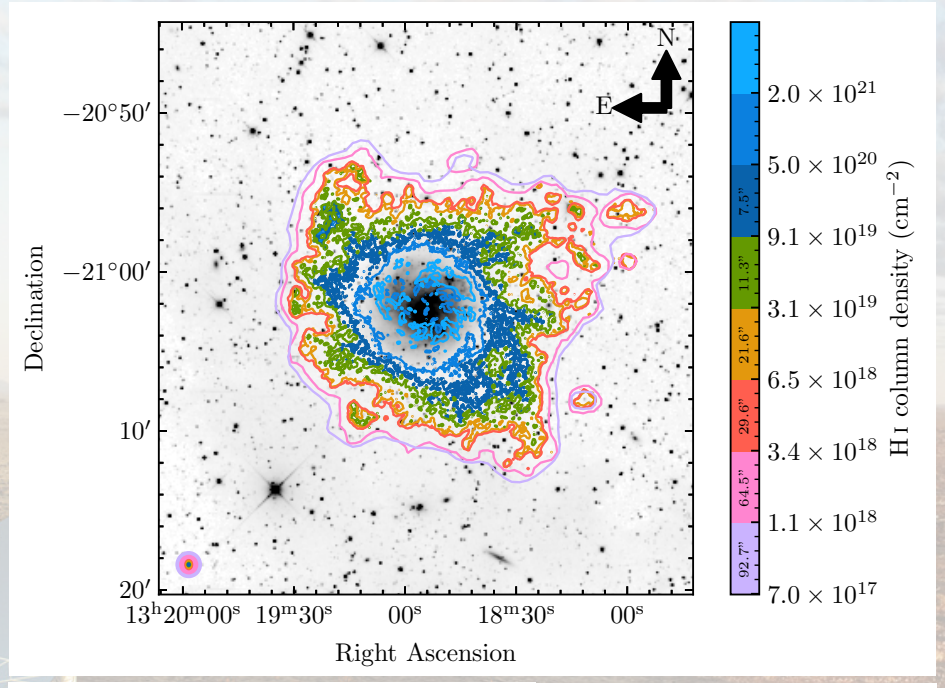
z=1.4

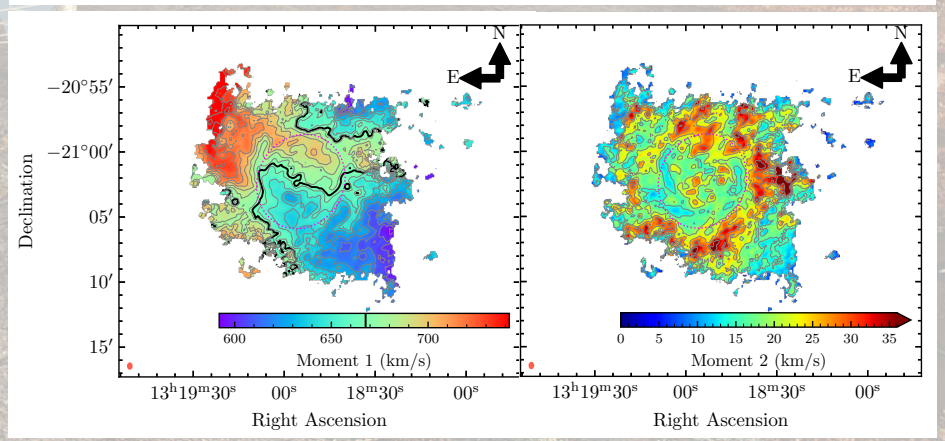
- New generation of HI surveys enabled by tech advances with new SKA precursors
- Improved surface brightness & resolution
- Wide-area; medium-deep; deep

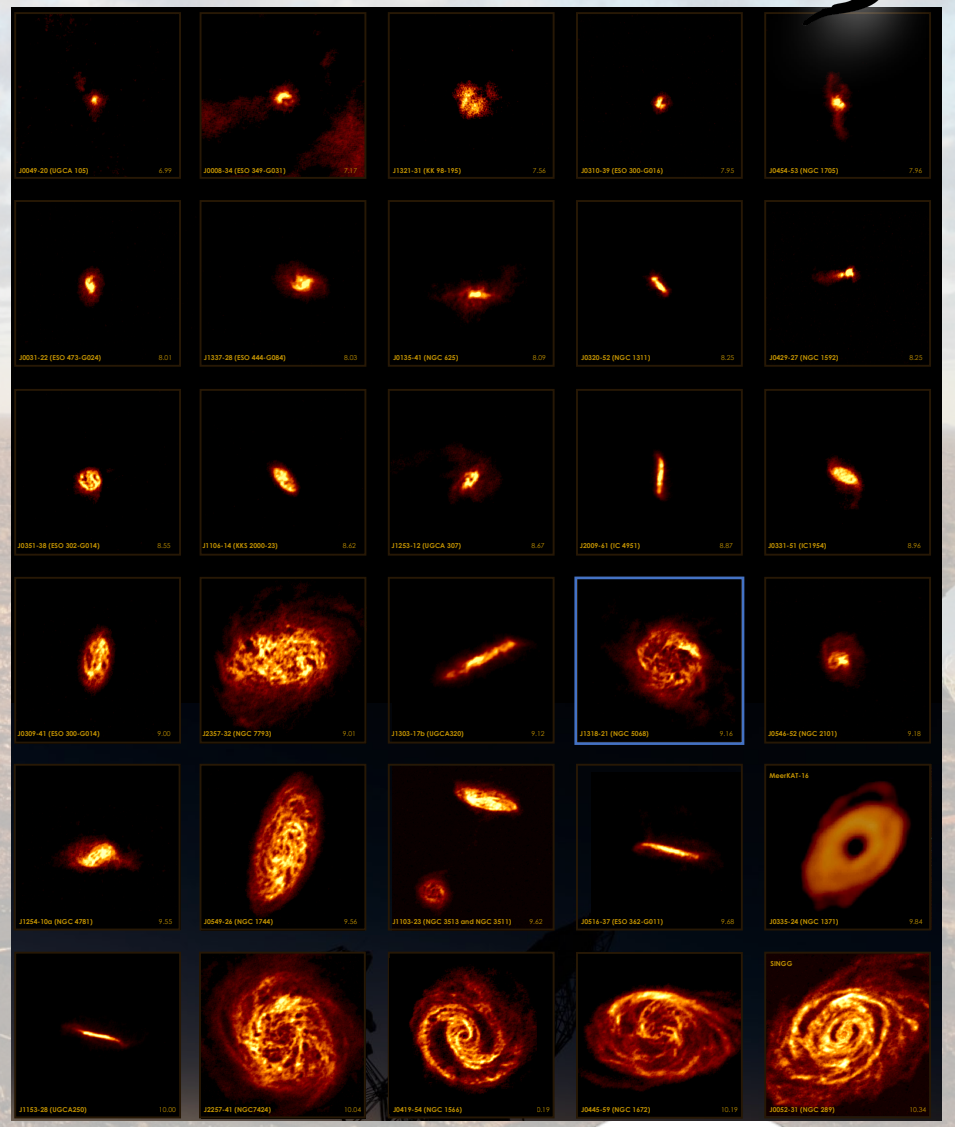
MHONGOOSE: Single dish sensitivity but at interferometric resolution

MeerKAT:

- Study HI accretion & link with star formation
- 30 nearby field disk & dwarf galaxies
- HIPASS detected/ SINGG
- M_{HI} ~ 10^7-10^{11}
- Each 55h
- HI column density limit of ~5x10^{17} cm^{-2} (3σ/16 km/s)



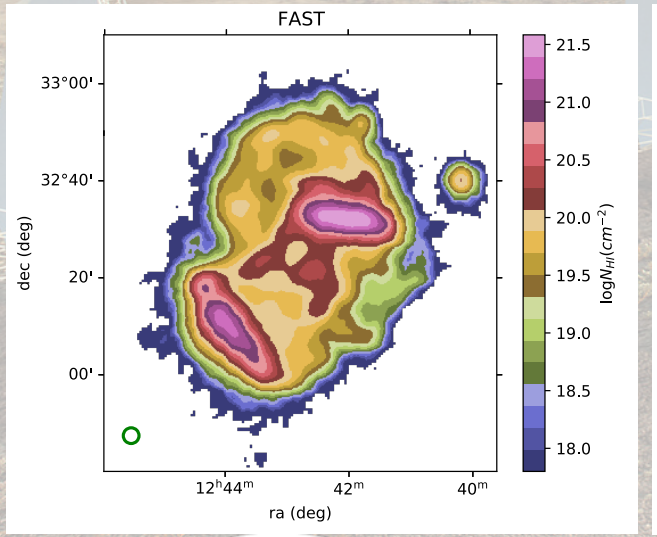


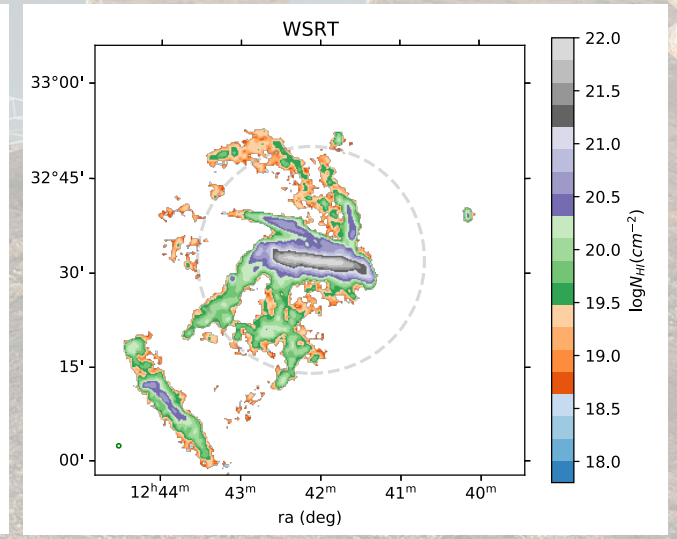


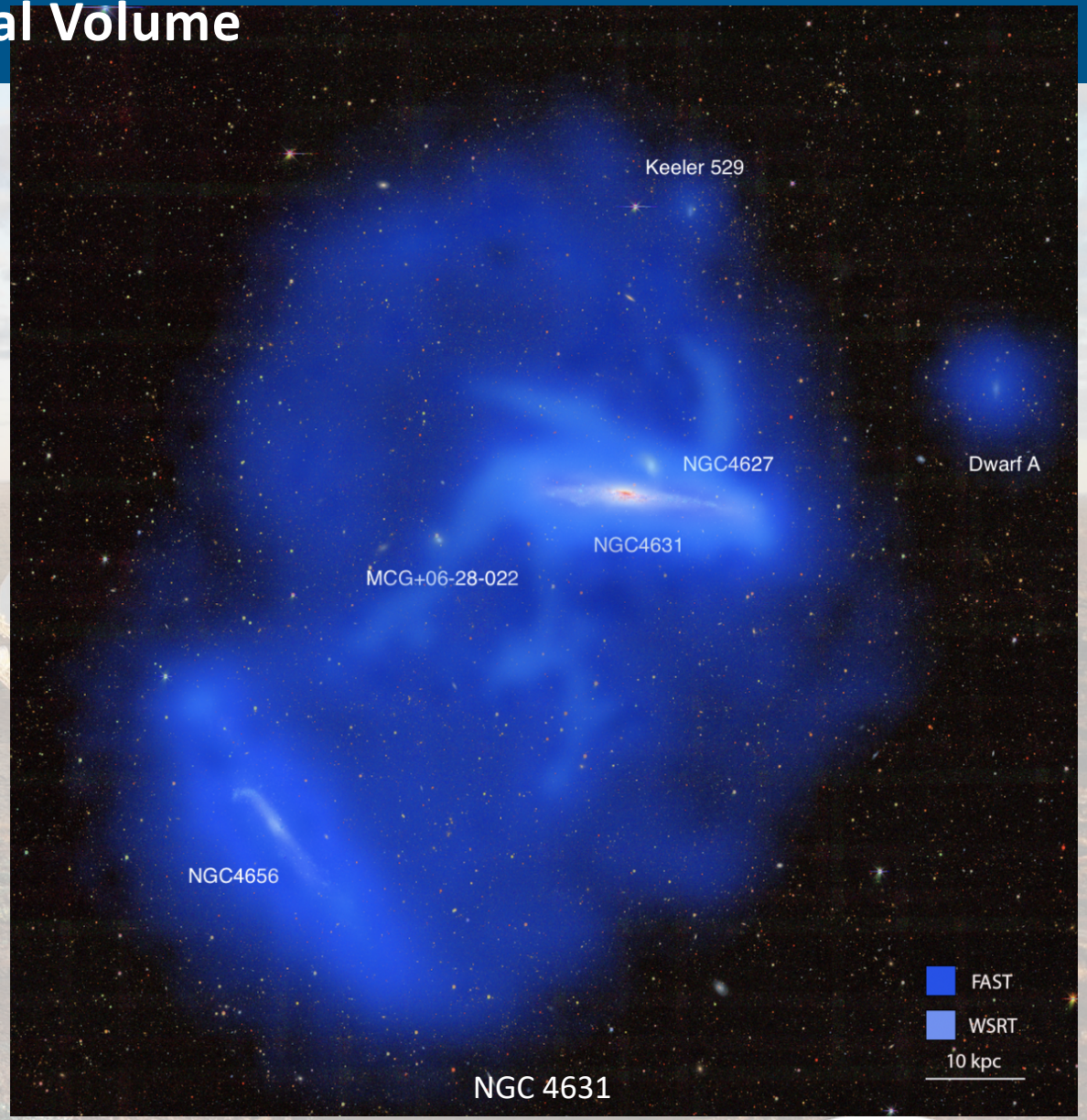
Healy et al, in prep

FEASTS: HI in/surrounding galaxies in the Local Volume

- FAST: 2.4 deg^2 in 4.47 hours
- Combine single dish & interferometric data
- Low surf brightness gas >25% of total mass
- Separate warm and cool HI; argue that the HI is cooling out of the intragroup medium





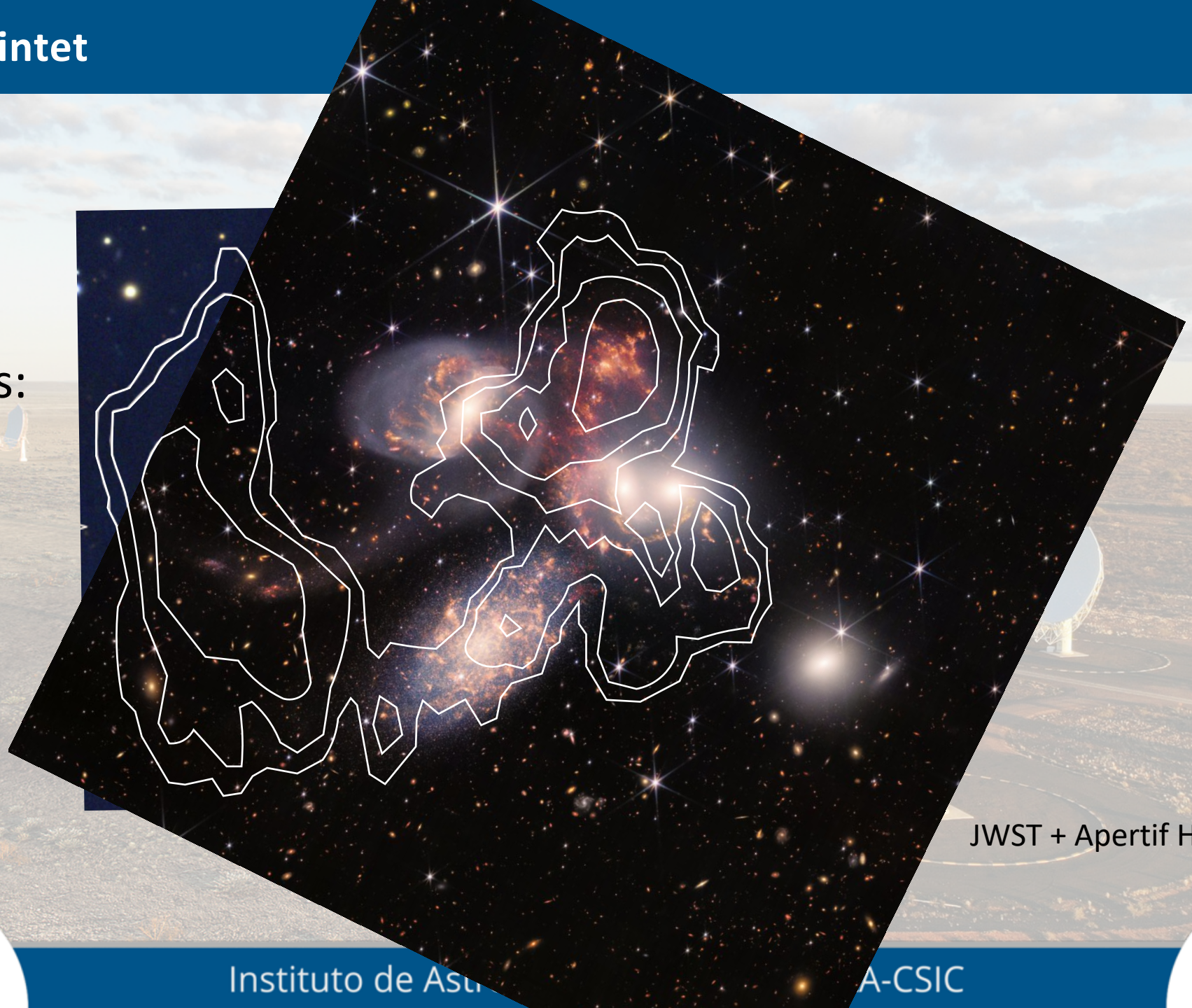


Wang et al (2022)

Stephan's Quintet

VLA

Group observations: quantify the amount of intragroup HI; tidal debris; gas processing



JWST + Apertif HI contours

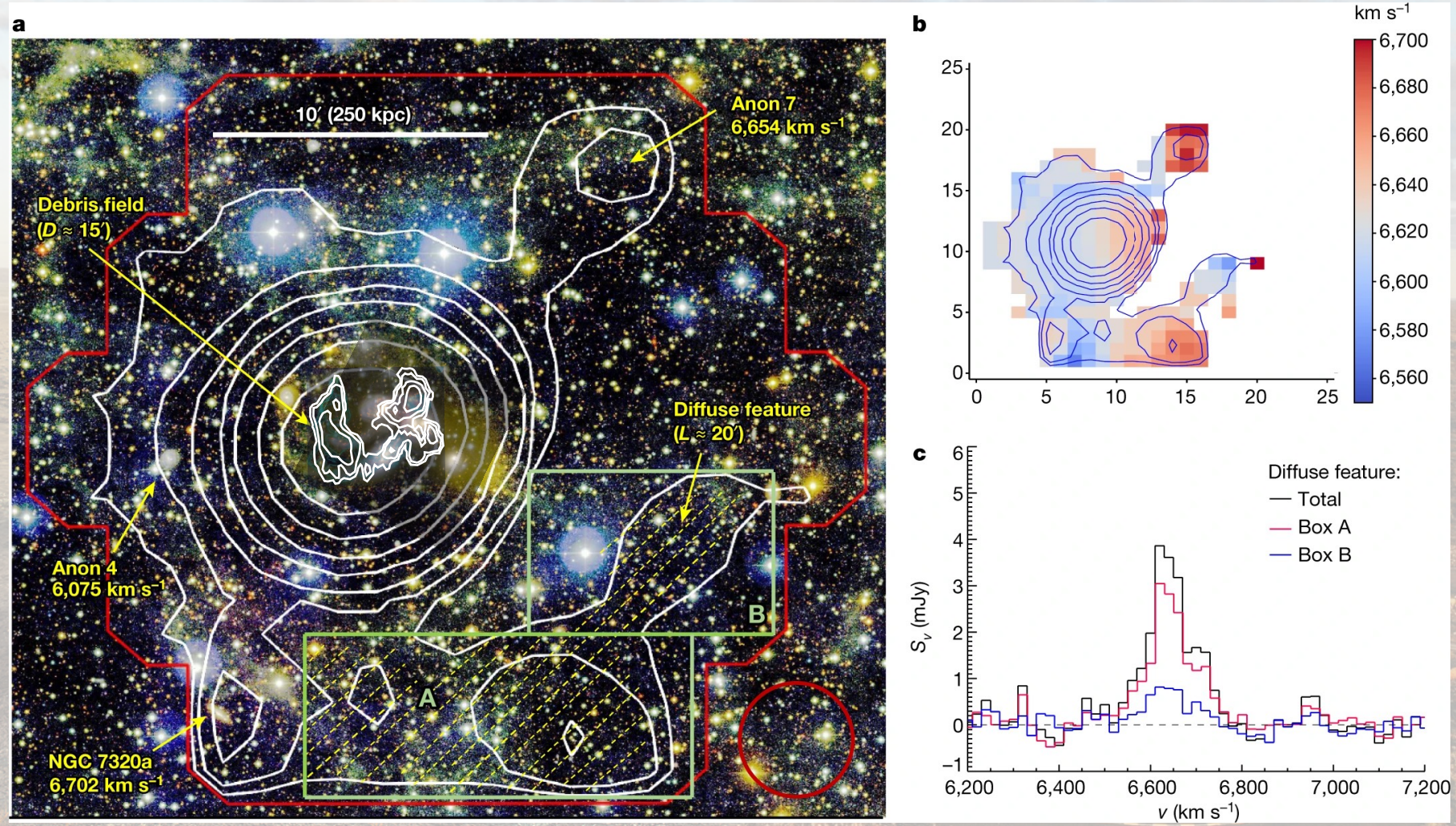
Stephan's Quintet

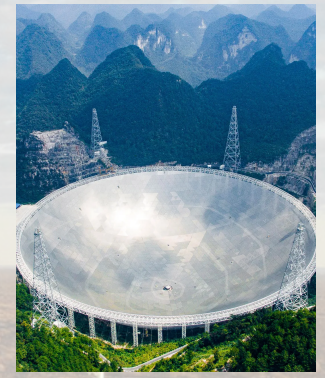
FAST

Nature
Xu et al (2022)

0.6 Mpc
HI debris field

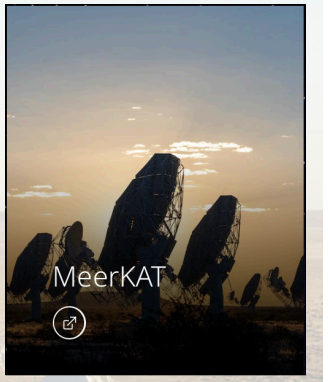
$N_{HI} = 7.4 \times 10^{17}\,cm^{-2}$
(at 5.5σ level)



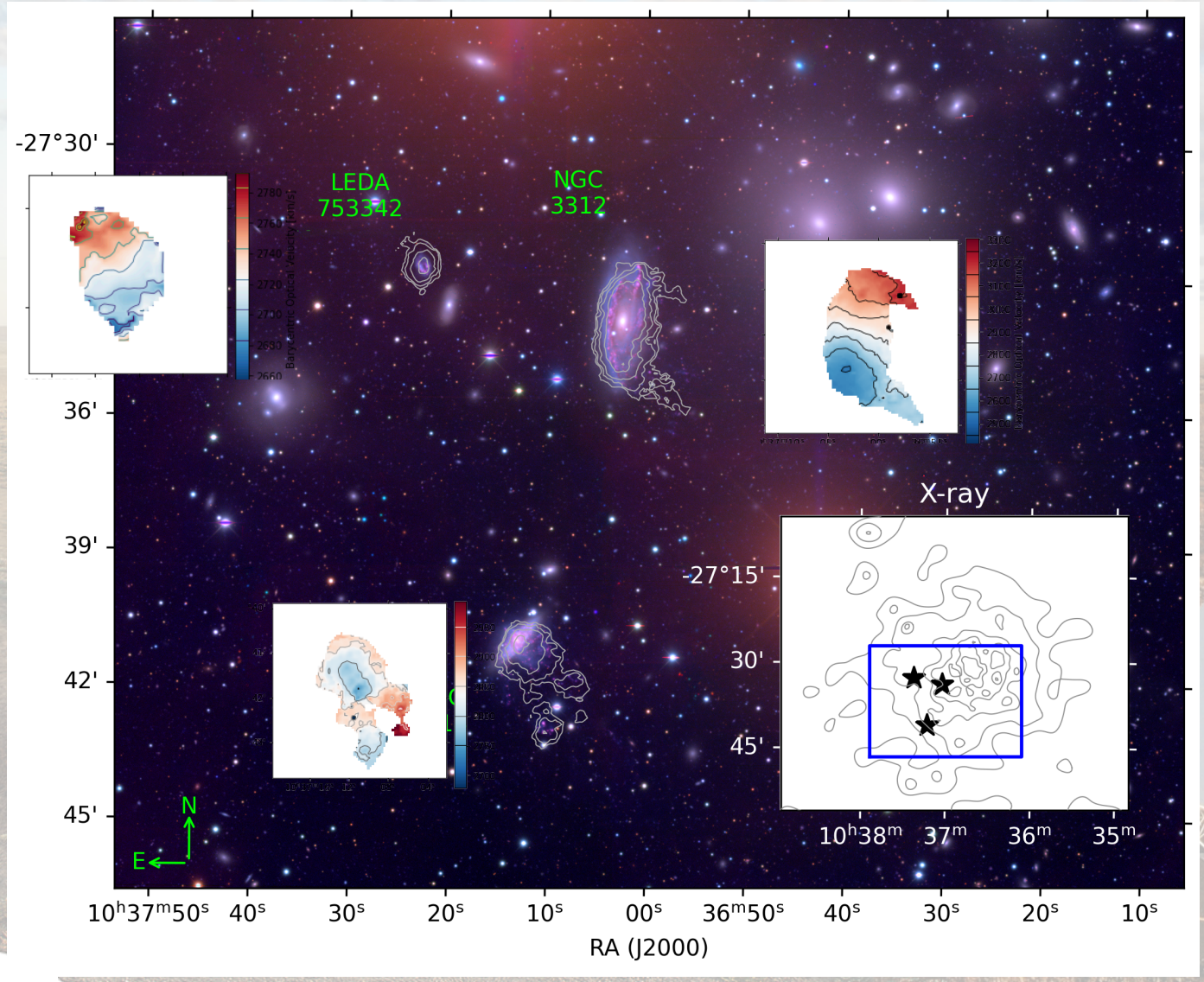


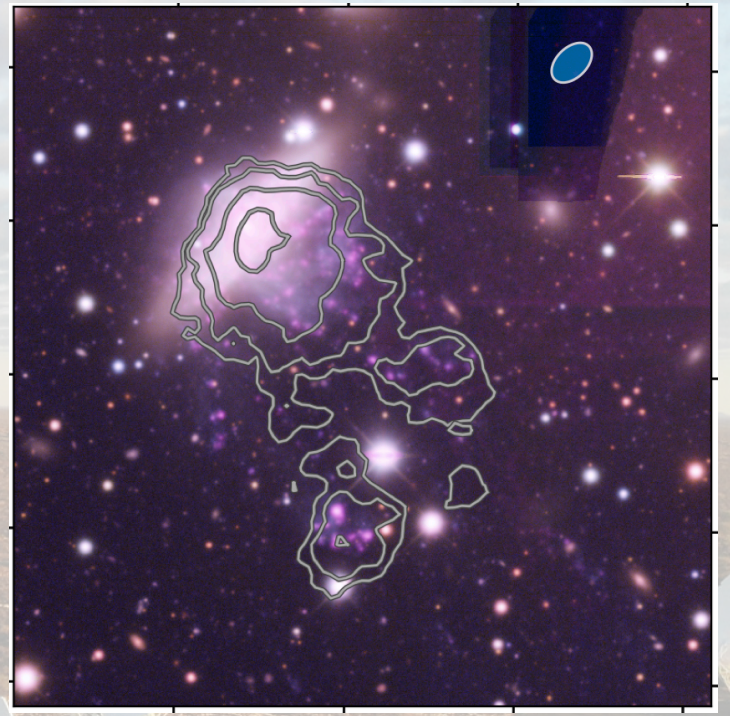
More FAST results see also:
Zhu et al (2022)
Wang et al (2022)

Galaxy Clusters with MeerKAT: prevalence of ram pressure stripping & jellyfish galaxies



Hess et al (2022)

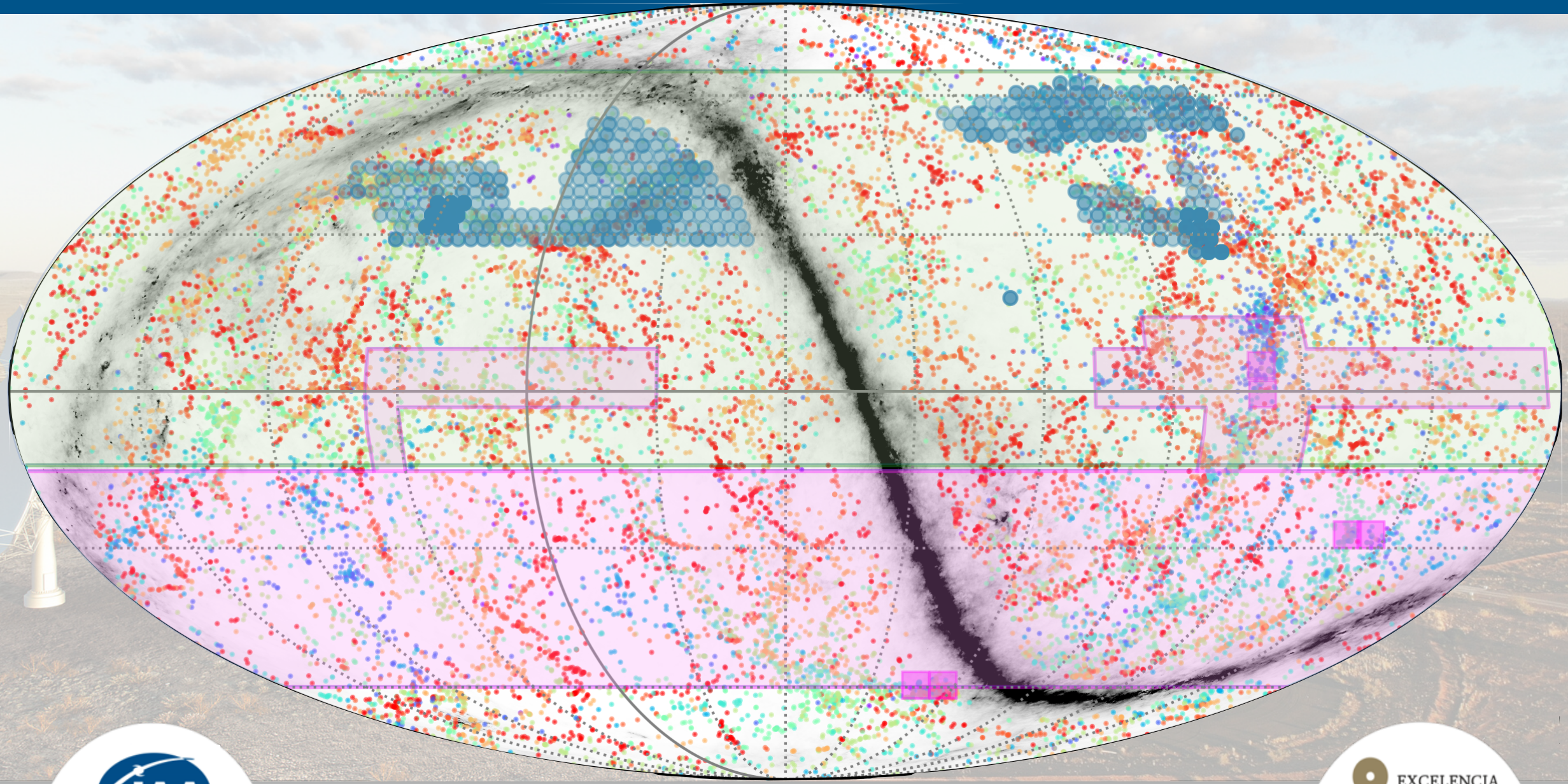




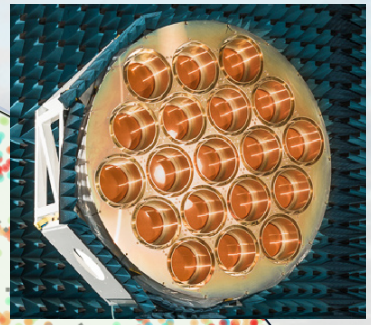
MeerKAT HI + DECam Halpha:

- HI and star forming tails
- NGC 3314a/b: 2 galaxies in projection
- Drag: galaxies have past cluster pericenter

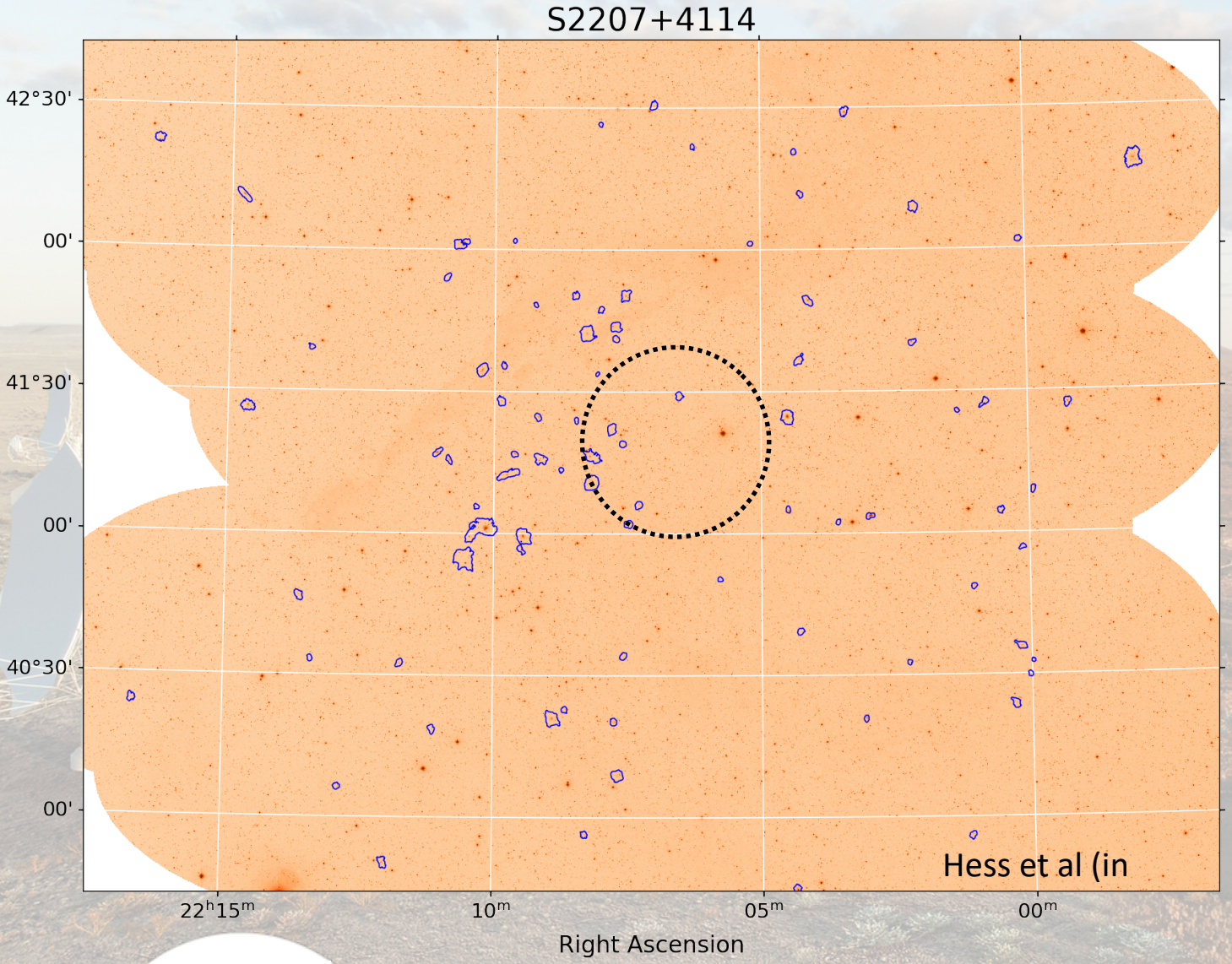
WIDE AREA SURVEYS: Apertif, WALLABY, CRAFTS

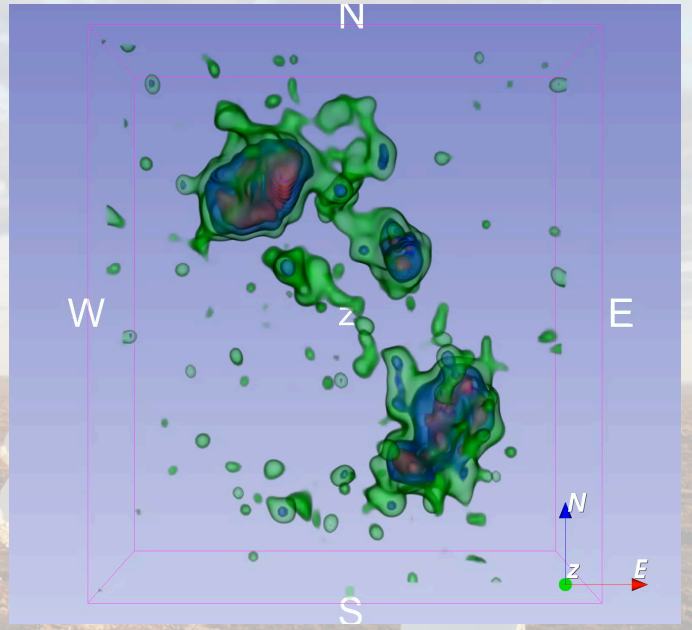


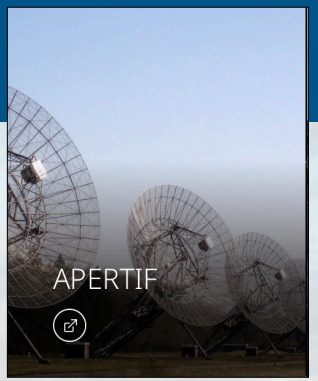
WIDE AREA SURVEYS: Apertif, WALLABY, CRAFTS



APERTIF: An unbiased view of HI across environments





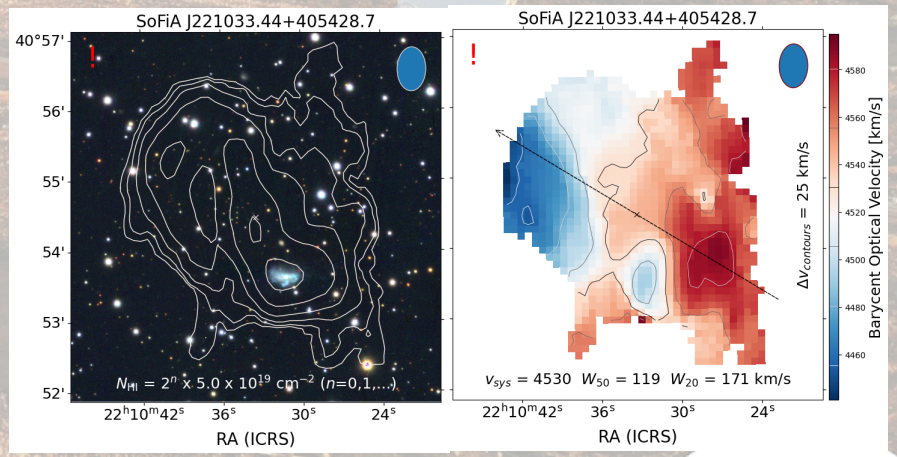


DR1:
Adams et al (2022)

van Cappellen et al (2022)

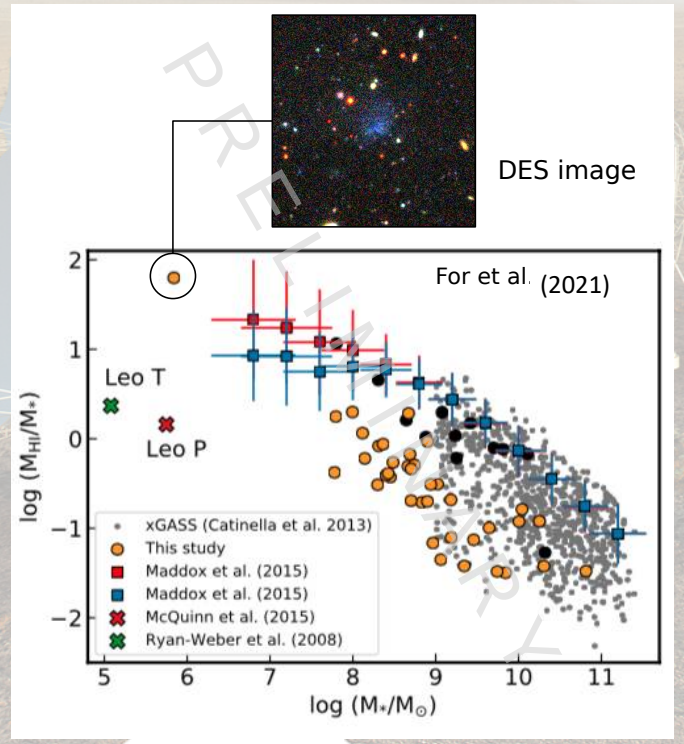
Denes et al (2022)

Kutkin et al (2022)

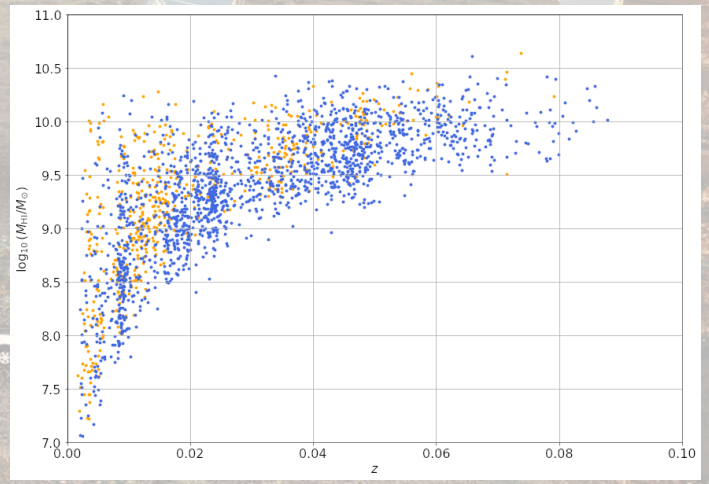


WALLABY: Census of gas rich galaxies in the local (southern) Universe

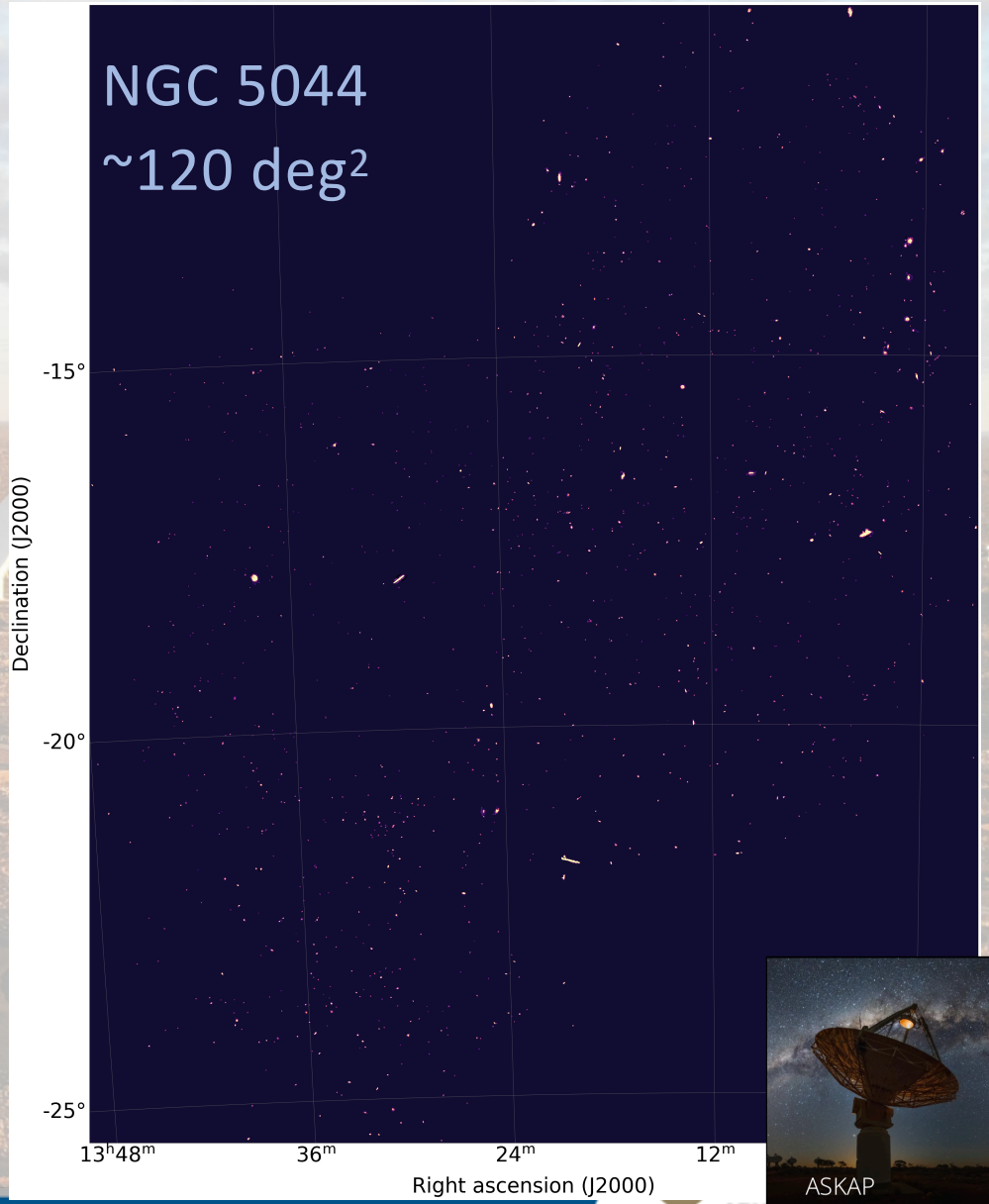
- Unbiased view of HI in galaxies with environment
- Dwarf galaxies: dark matter halo mass/distribution
- Galaxy kinematics: quantifying frequency of warps; how bars funnel gas in center of galaxies



25+ papers and counting on from Early Science + Phase 1 + Phase 2...



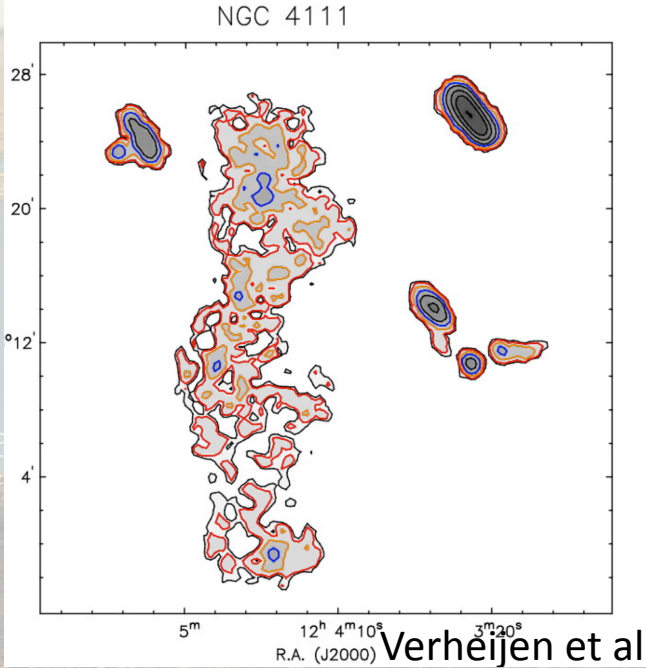
DR1; Westmeier et al (2022)



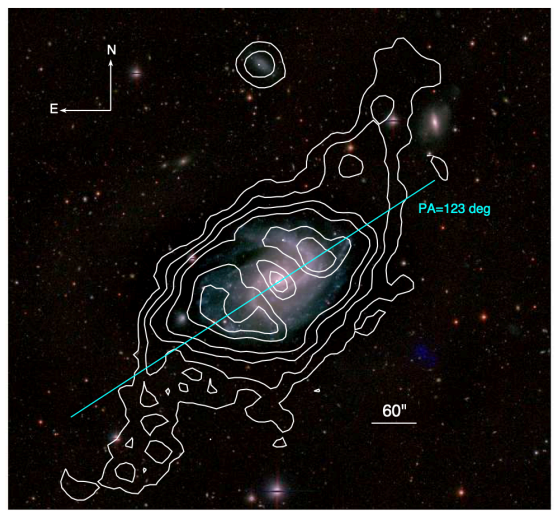
Medium-deep HI surveys: Apertif MDS & MIGHTEE-HI

- Tens to hundreds of deg^2
- Fills the niche between wide and deep surveys
- Good depth; good area; good resolution; great ancillary data

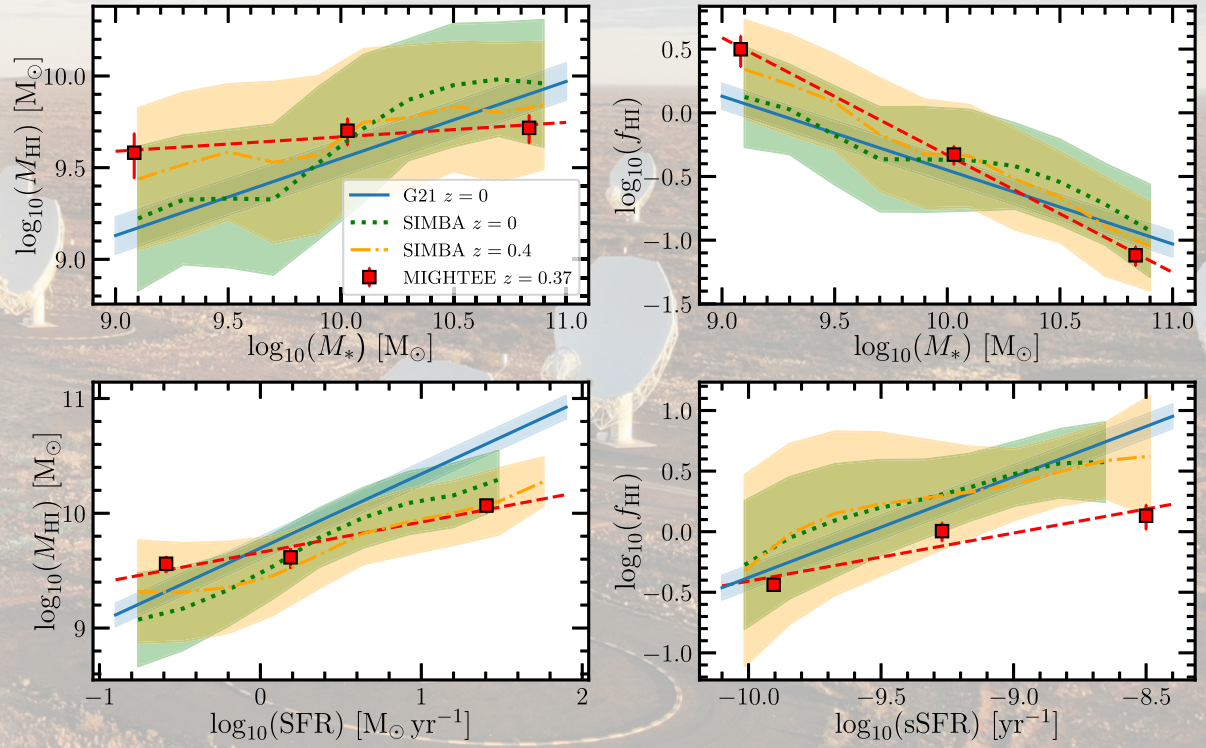
See also:
Ranchod et al (2021)
Ponomareva et al (2021, in prep)
Rajohnson et al (2022)



Verheijen et al

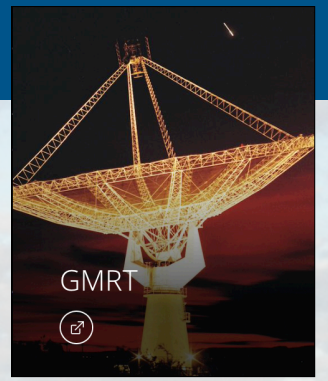


Maddox et al (2021)

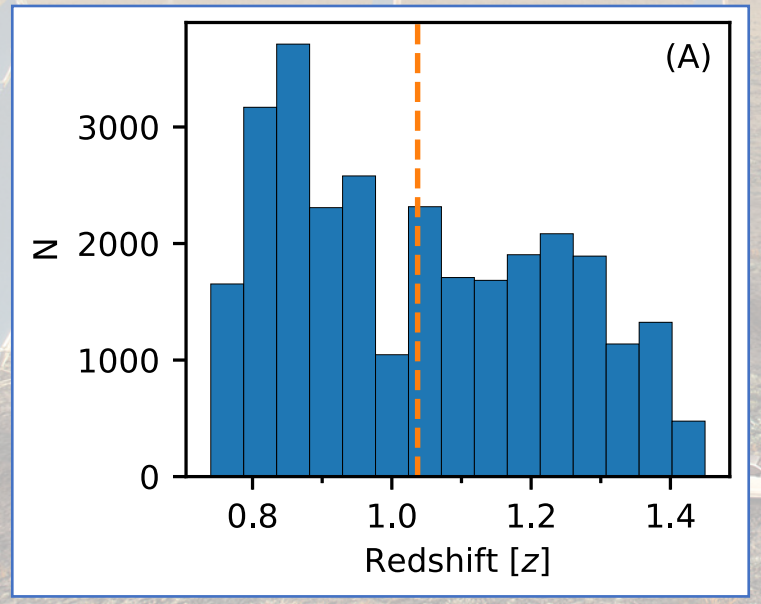


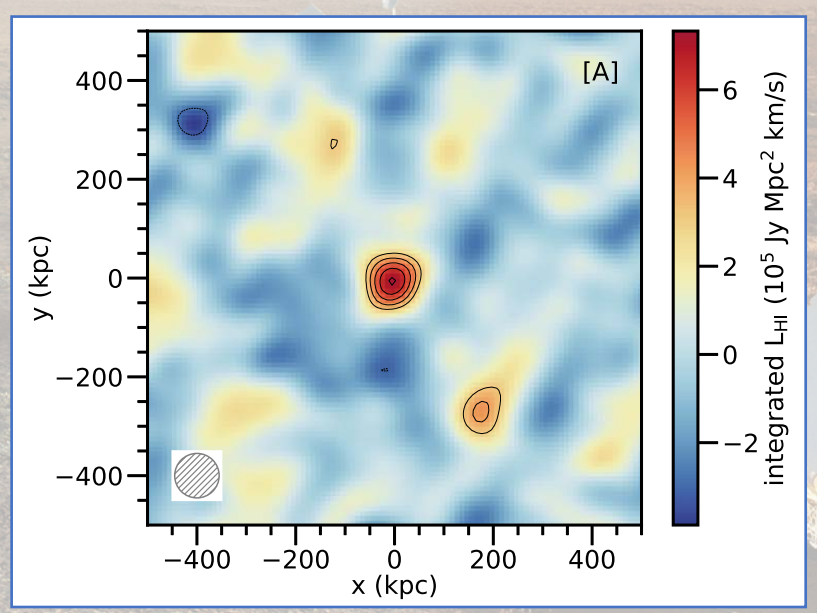
Sinigaglia et al (2022)

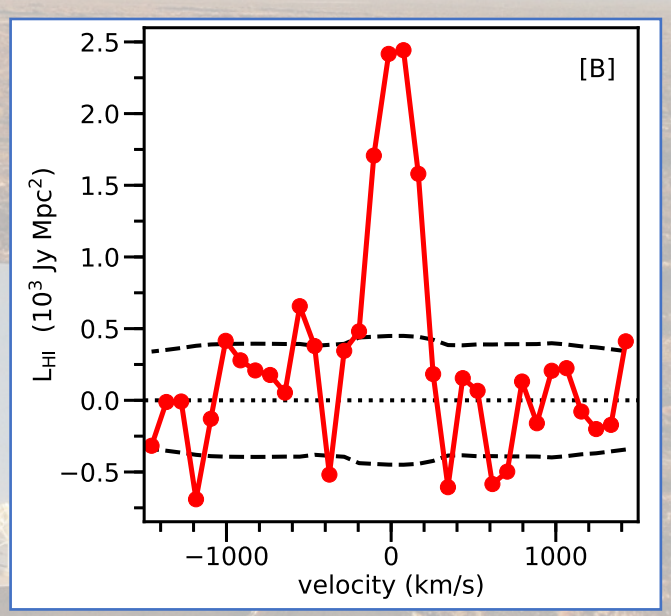
GMRT DEEP2 stacking: HI detection at z=1 !



- Stacking 11,419 galaxies with spectroscopic redshifts $\langle M_* \rangle = 10^{10}\,M_\odot$
- 510 hours between 7 pointings
- $\langle M_{HI} \rangle = 1.3\times10^{10}\,M_\odot$ at $\langle z \rangle = 1$; significantly more than $\langle M_{HI} \rangle = 3.9\times10^{9}\,M_\odot$ at $\langle z \rangle = 0$



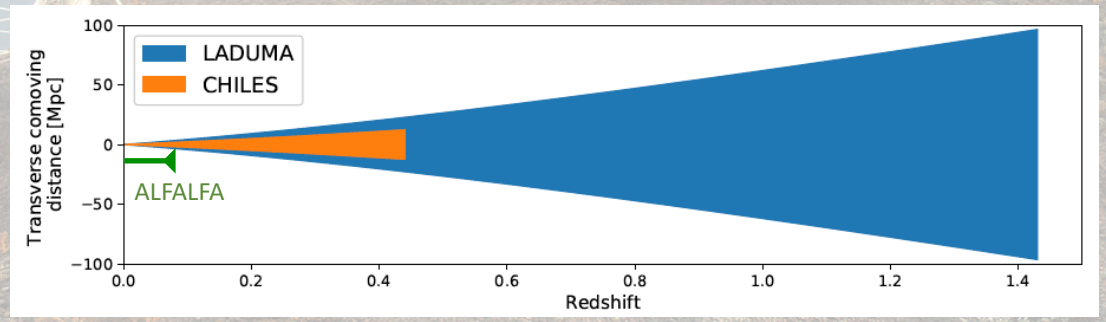


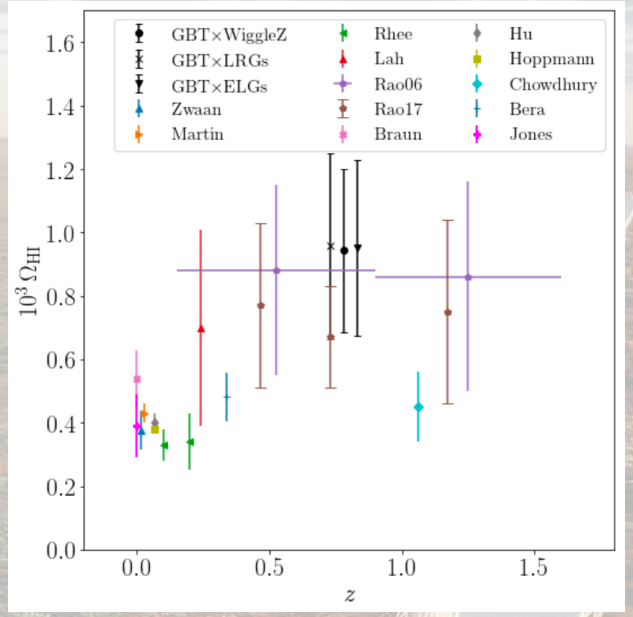


Chowdhury et al (2022, 2020)

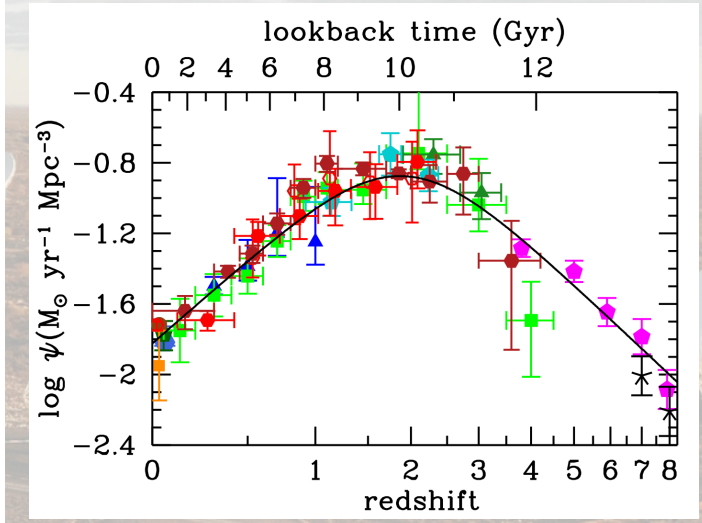
DEEP HI SURVEYS: CHILES, LADUMA, DINGO

- Single pointing surveys >1000 hours on JVLA, MeerKAT, ASKAP
- Science goals
  - Cosmic evolution in Ω_{HI}; HI mass function, HI scaling relations, Tully-Fisher, HI with environment





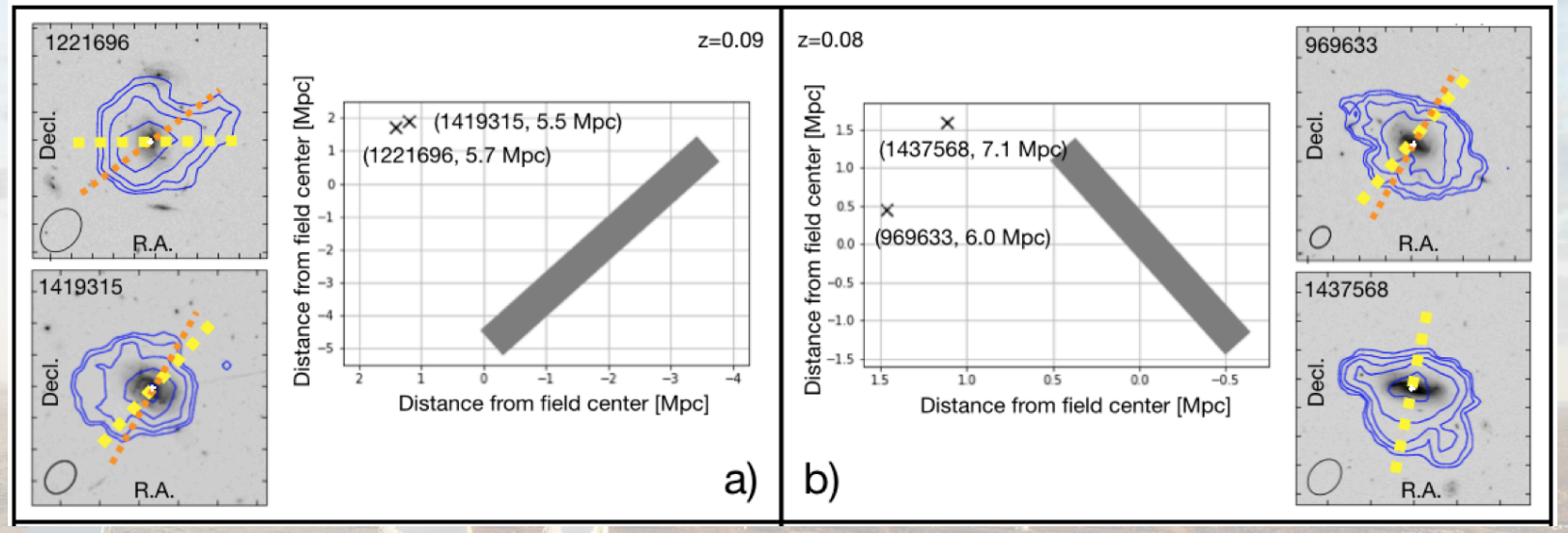
Wolz et al (2021)



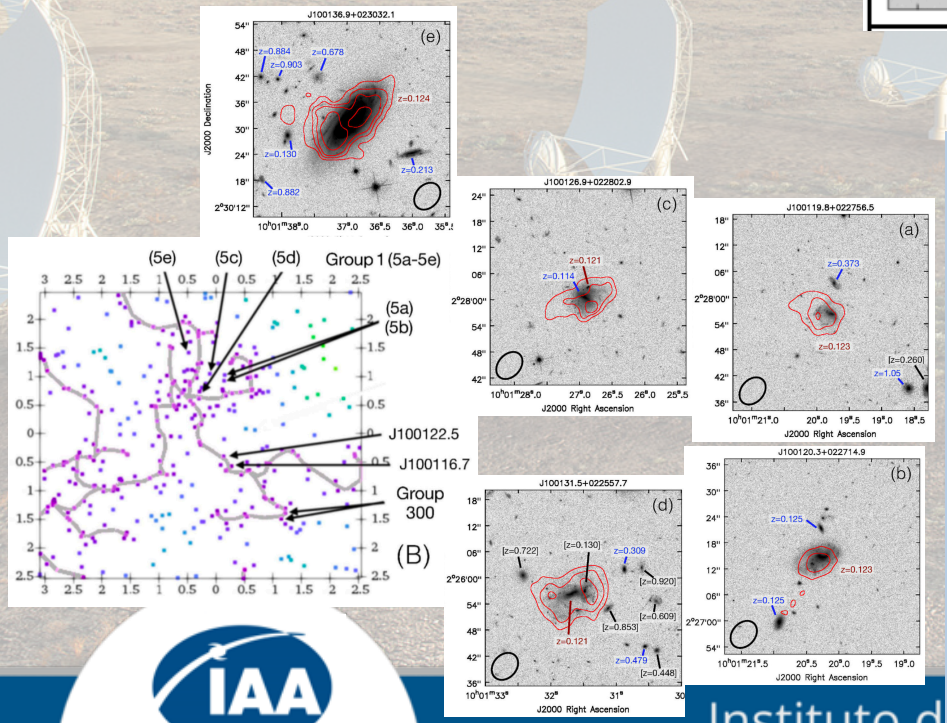
Madau & Dickinson (2014)

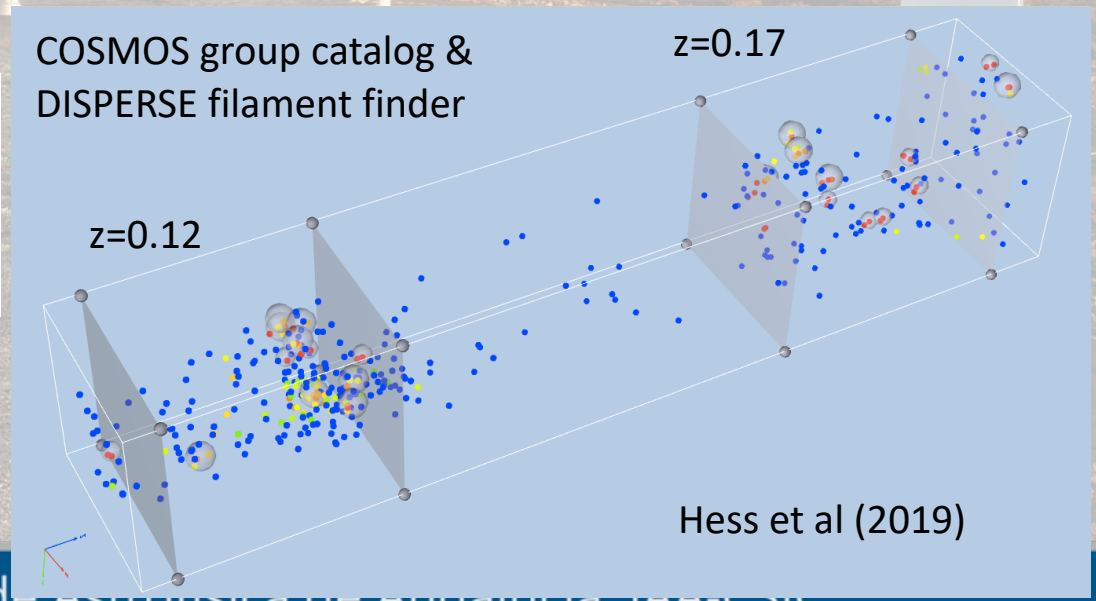
CHILES: Resolved galaxies in different environments

- Low HI mass: aligned with filaments $10^{9.5}$ $M_\odot$
- High HI mass: anti-aligned with filaments



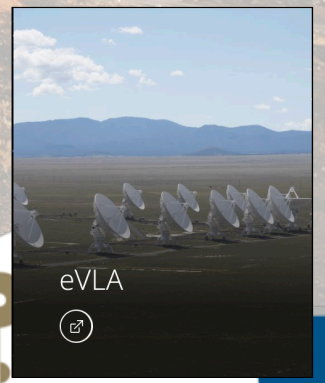
Blue Bird et al (2019)



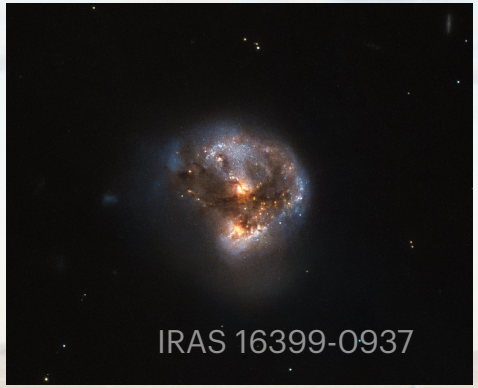


Hess et al (2019)

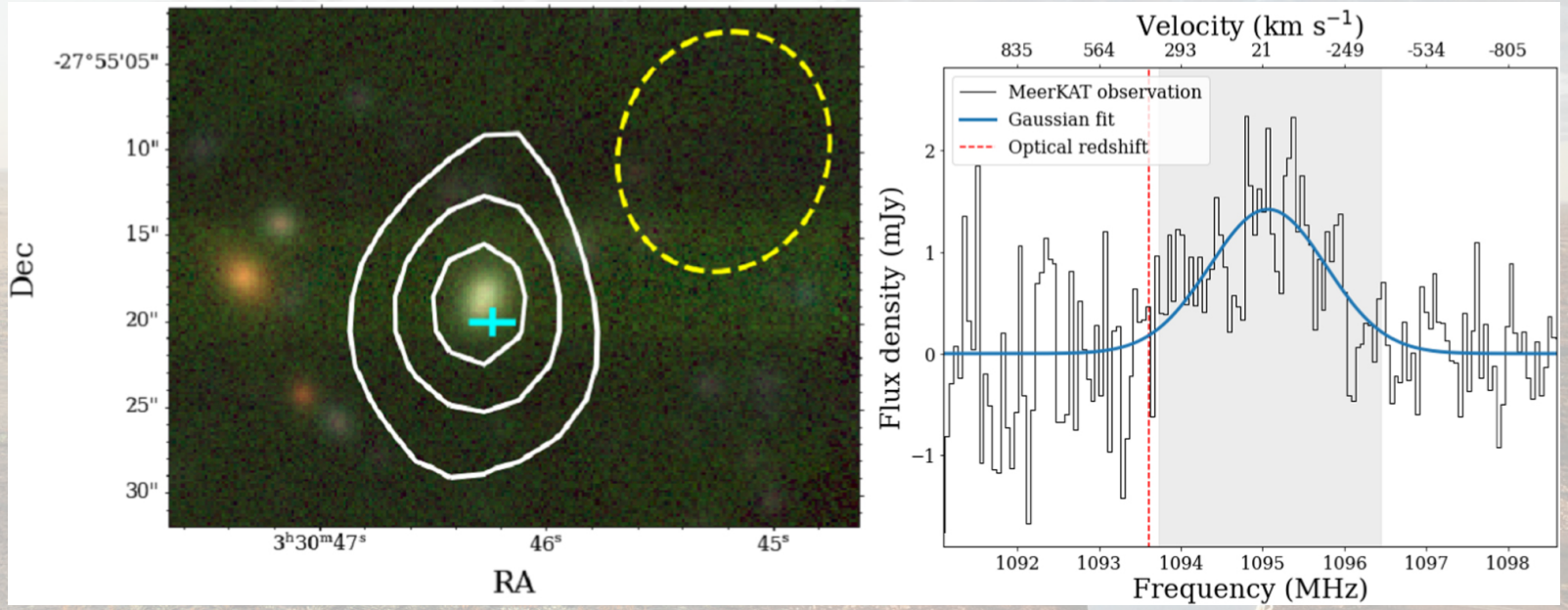
See also MIGHTEE-HI Tudorache et al (2022)



LADUMA: Highest redshift untargeted detection of OH megamaser at z=0.526



- 1667 MHz line redshifted into L-band (z>0.12)



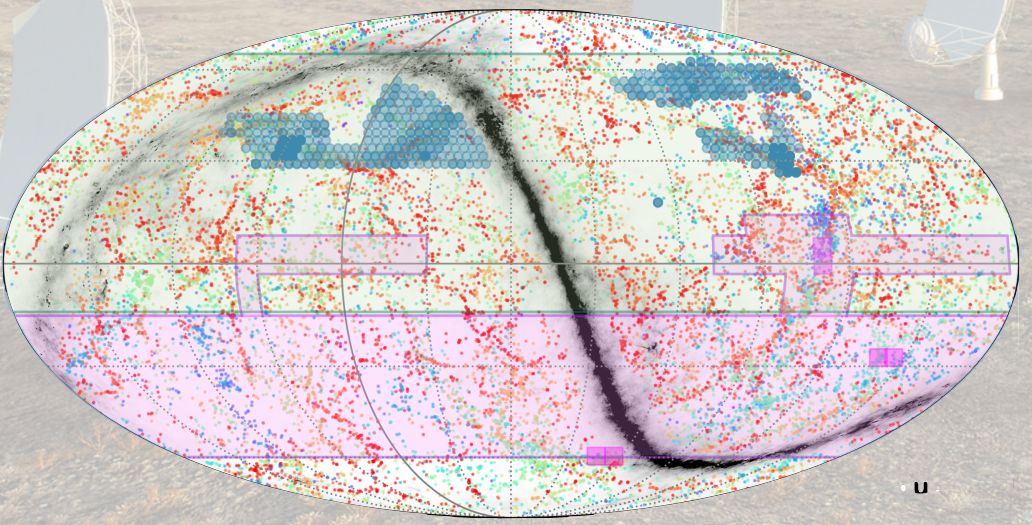
Glowacki et al (2022)

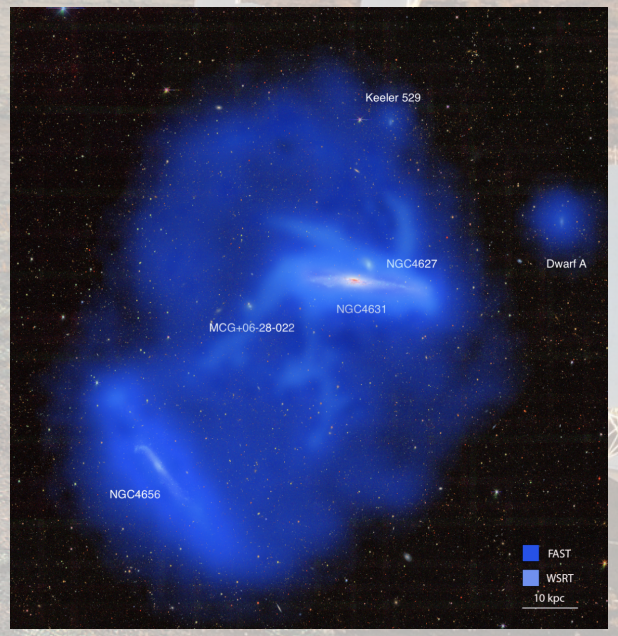
See also OHM discovered by Hess et al (2021) with Apertif

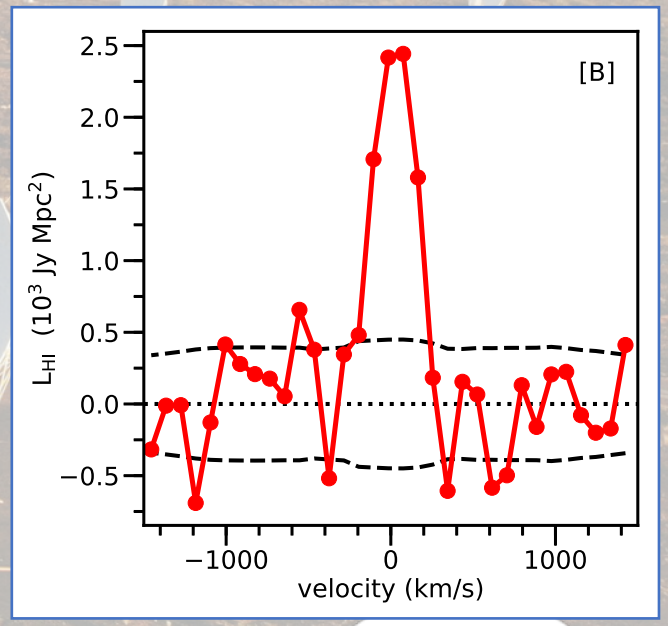
- First untargeted OH maser detection beyond z=0.5
- Host galaxy is ULIRG with $L_{FIR} \sim 1.6 \times 10^{12} L_{\odot}$
- OHMs are tracers of the cosmic merger rate

Science highlights

- Combining high surface brightness sensitivity (single dish or interferometers with lots of short baselines) with high resolution imaging
- Untargeted wide-area observations present an unbiased view of HI in a range of environments; what types of galaxies contain HI
- Pushing well beyond the local Universe

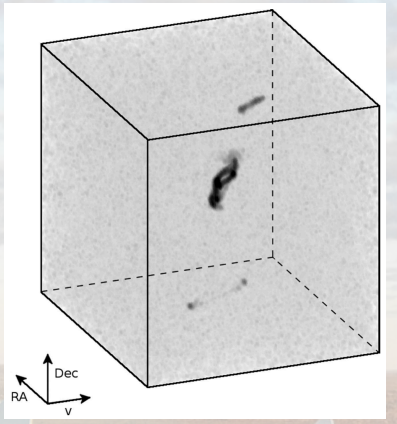


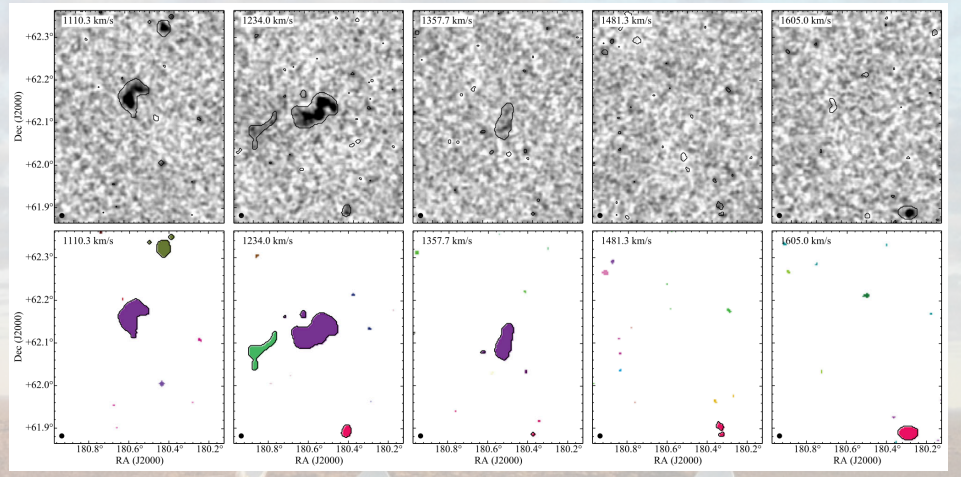




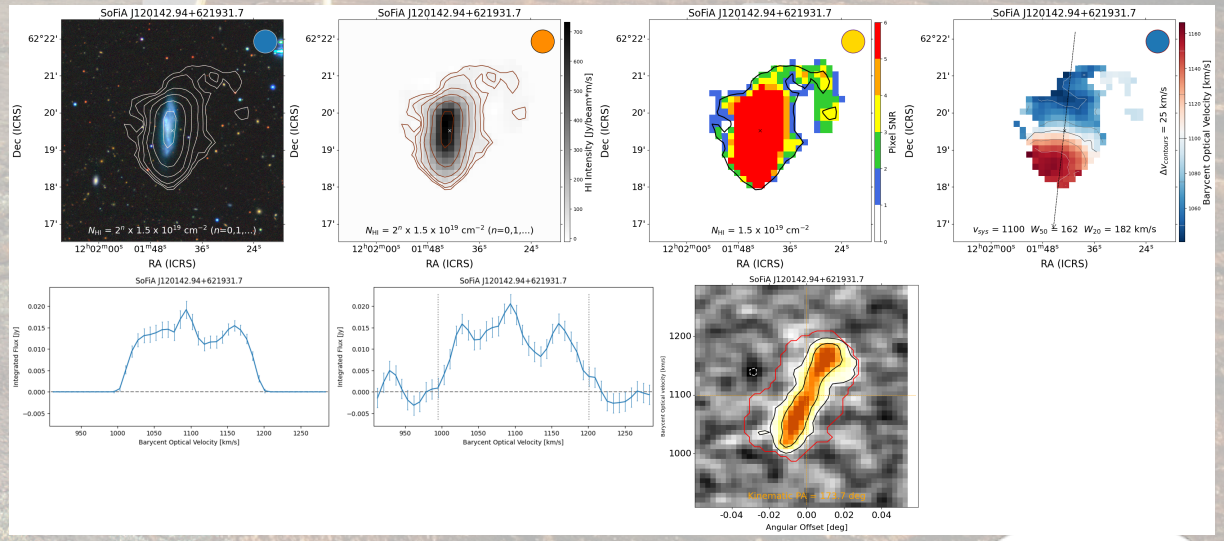
HI TOOLS: Source finding, source characterization, and data visualization

- Source Finding Application (SoFiA)
  - Identify, catalog, parametrize sources in a noise dominated cube
  - Well vetted in SKA SDC2
- SoFiA Image Pipeline:
  - Convert SoFiA output catalogs and FITS files to publication quality images



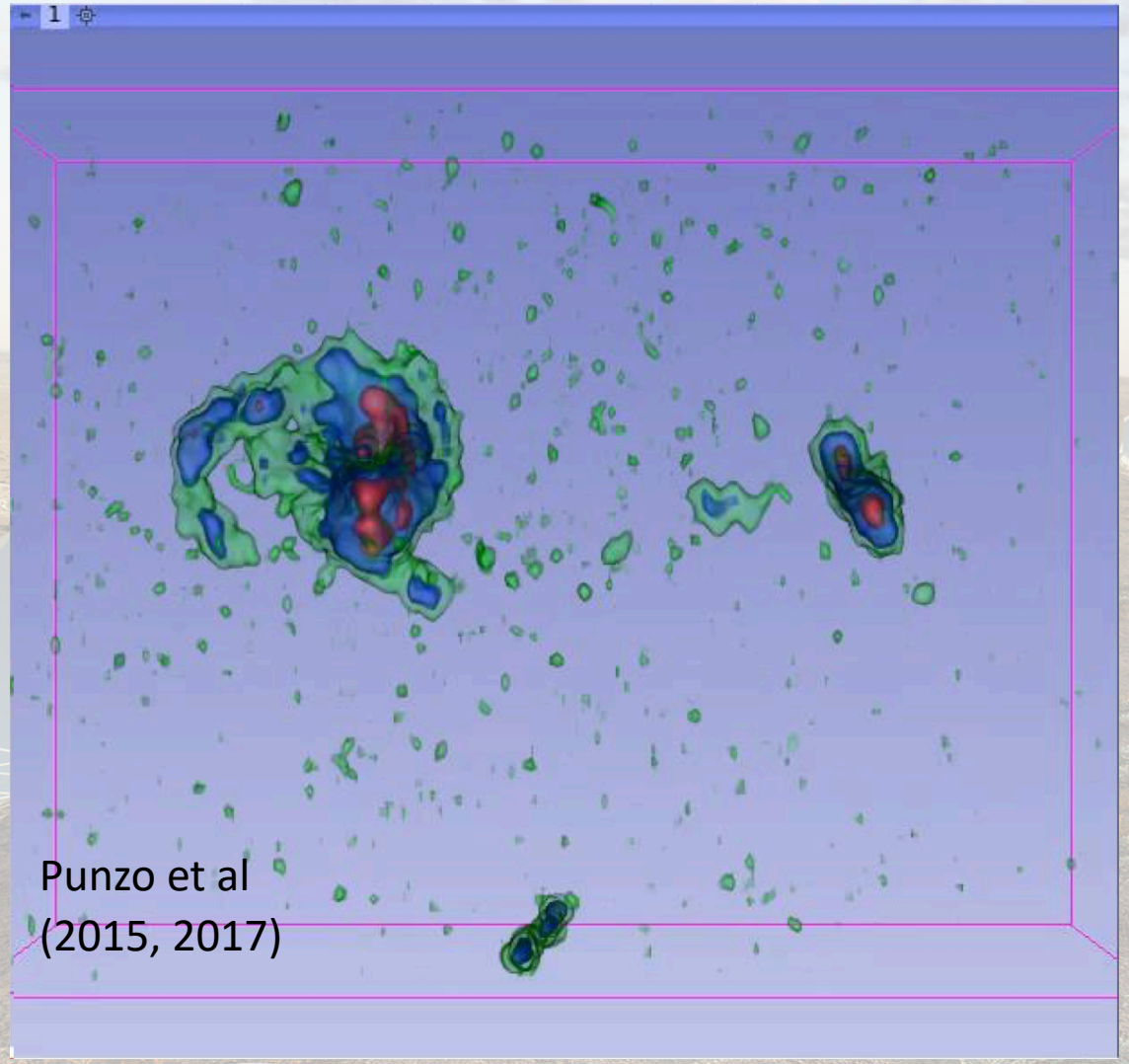


Serra et al (2015); Westmeier et al (2021)

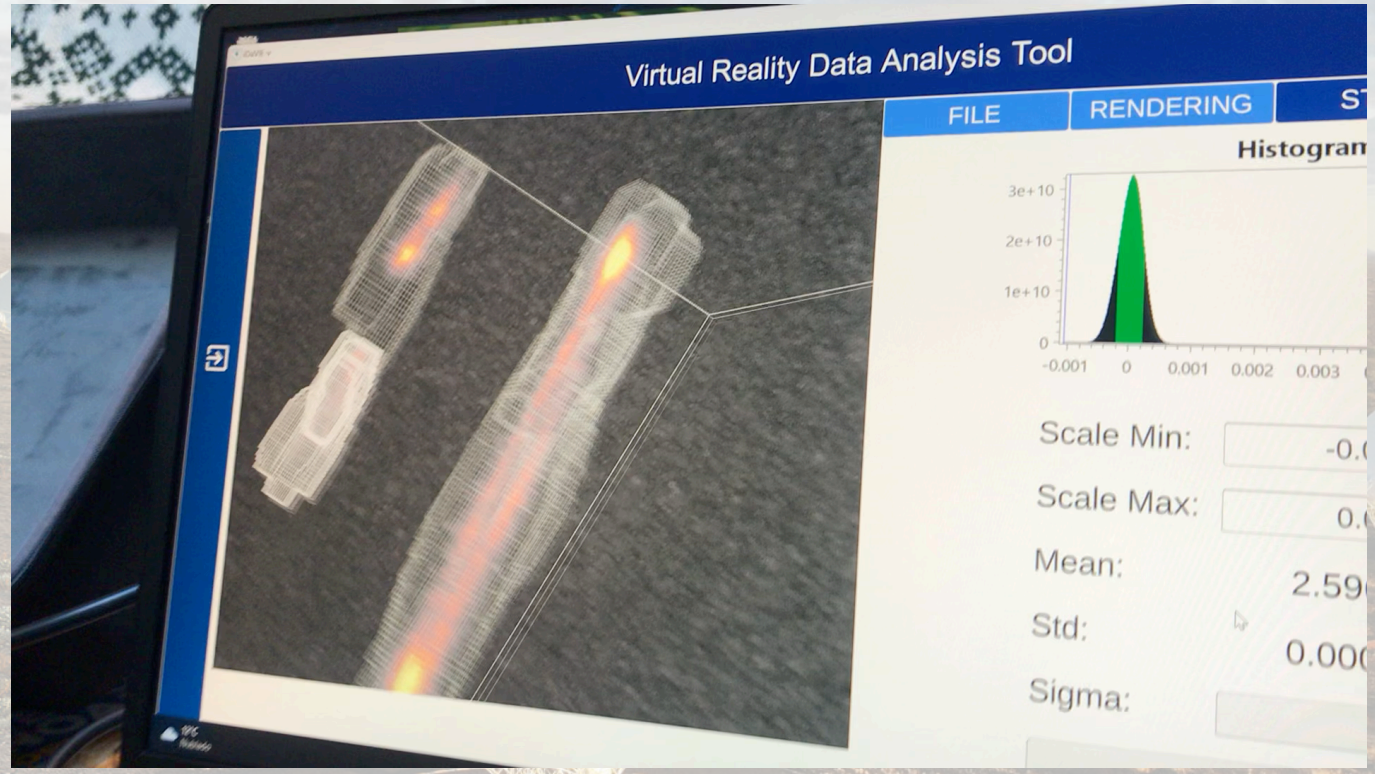


Hess et al (2022)
https://github.com/kmhess/SoFiA-image-pipeline

HI TOOLS: Source finding, source characterization, and data visualization



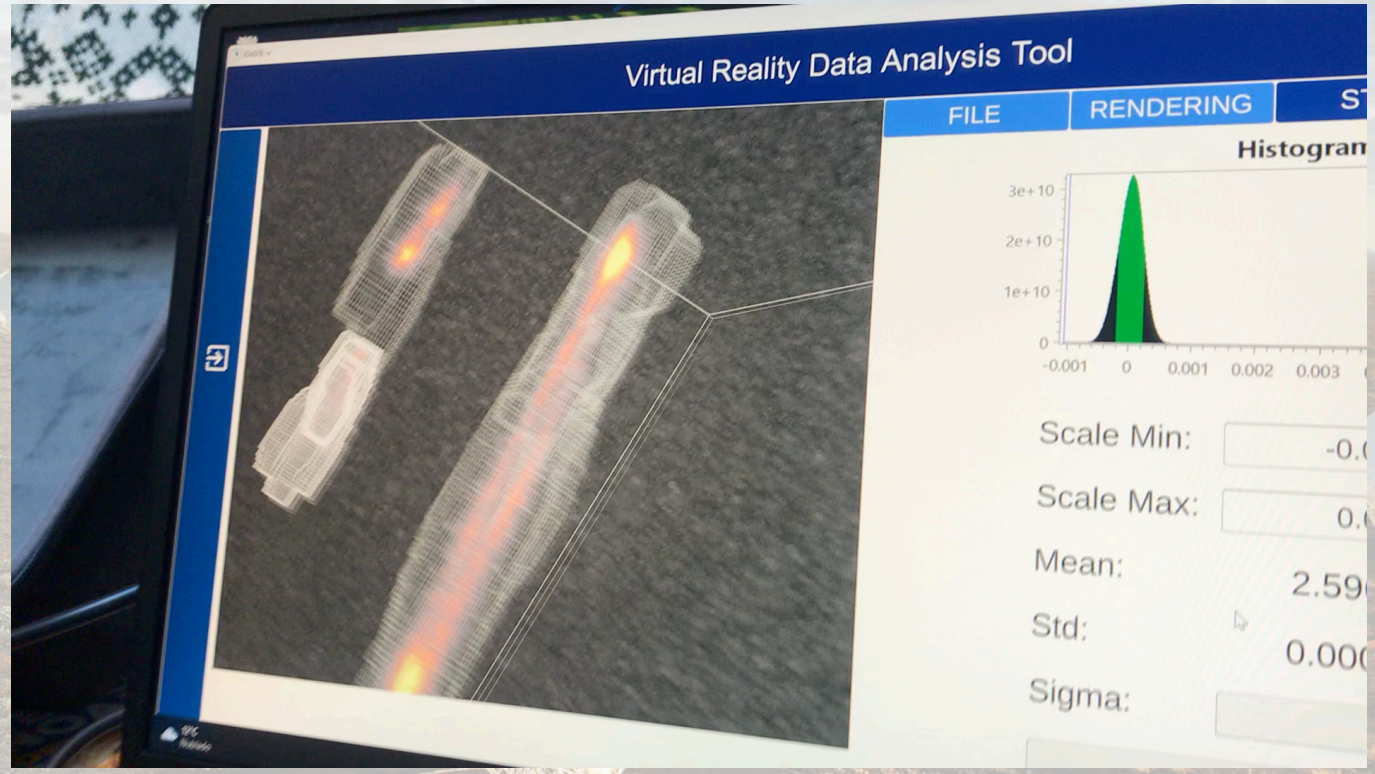
Punzo et al
(2015, 2017)



iDAVIE: Jarrett et al (2021)
https://idavie.readthedocs.io/en/latest/

HI TOOLS: Source finding, source characterization, and data visualization

(2015, 2017)



iDAVIE: Jarrett et al (2021)
https://idavie.readthedocs.io/en/latest/

Conclusions

- Surveys with precursors are combining high surface brightness sensitivity (single dish or interferometers with lots of short baselines) with high spatial resolution
- Untargeted wide-area observations present an unbiased view of HI in a range of environments; what types of galaxies contain HI
- Pushing well beyond the local Universe

- Tools for HI surveys; maximizing science from large data volumes are being developed and tested now -- demonstrating success with current surveys