Deep Mapping of Diffuse HI with FAST

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SKA summer school, Xiamen – 2026/8/22

UNIVERSITÀ DEGLI STUDI FIRENZE

DIPARTIMENTO DI FISICA E ASTRONOMIA

MW-WINDS

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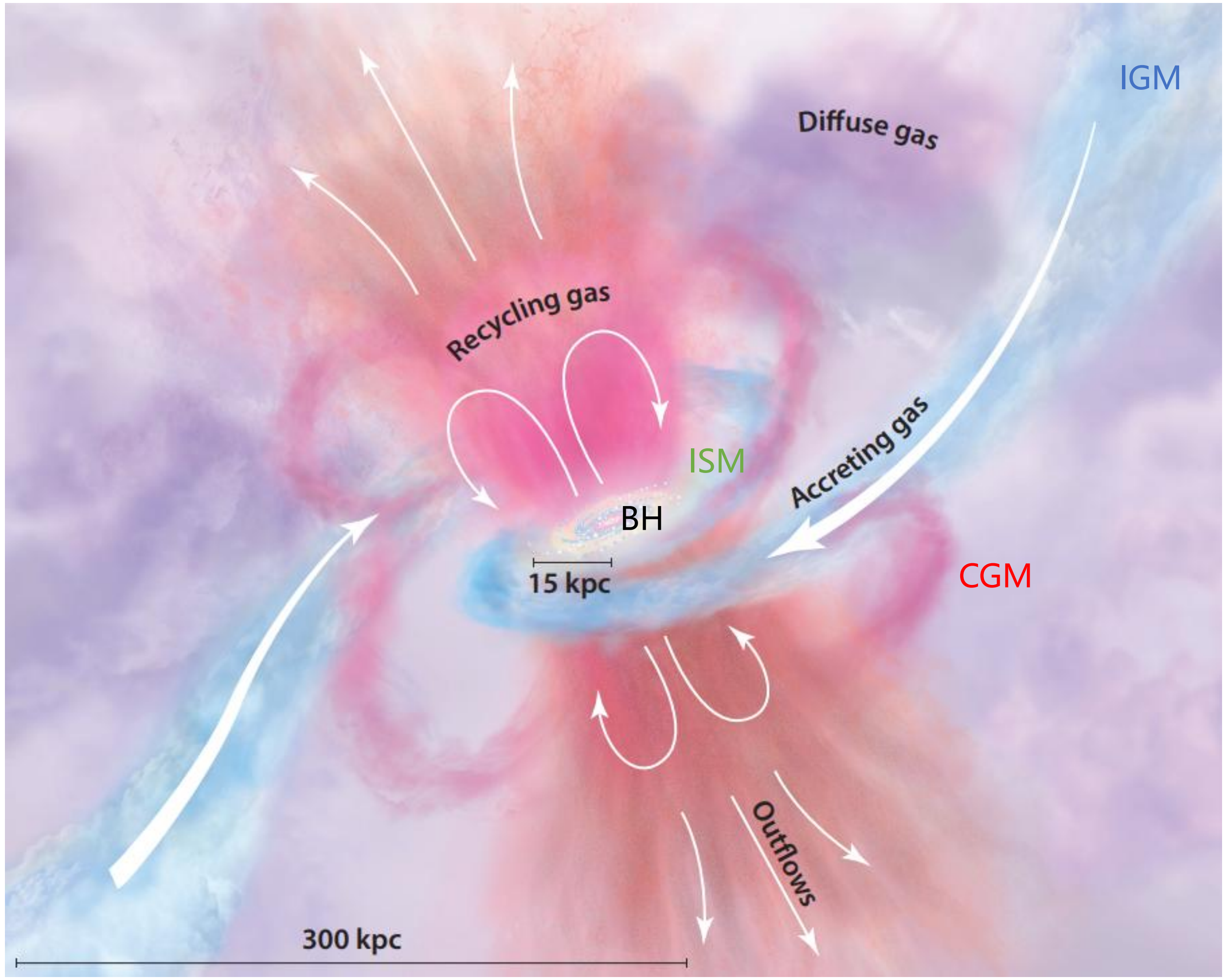
Multi-scale Baryon Cycle



Tumlinson et al. (2017)

Intergalactic Medium (IGM)

Gas accretion

Interstellar Medium (ISM)

Star formation
AGN

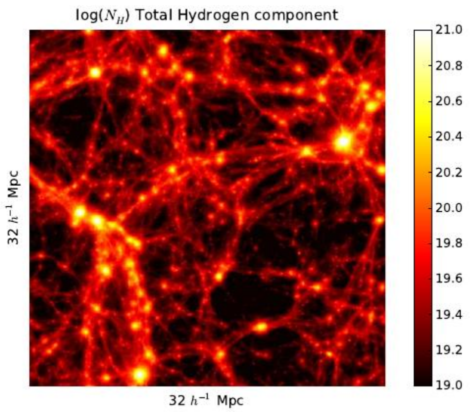
Recycling

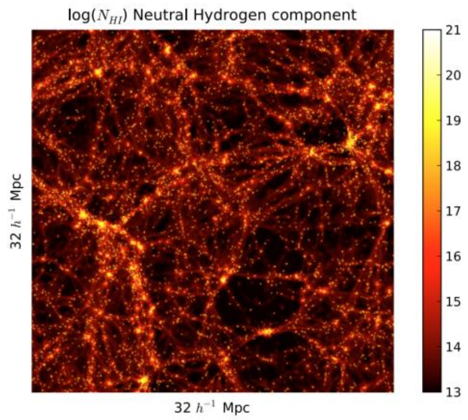
Circumgalactic Medium (CGM)

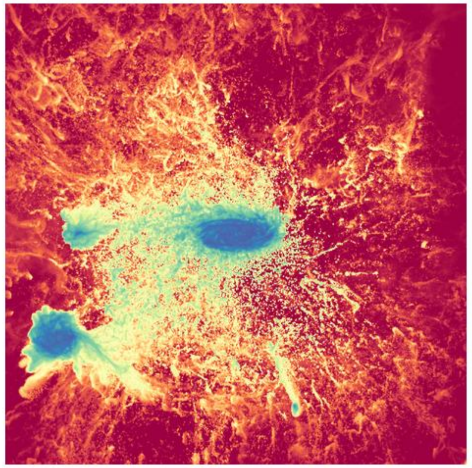
From pc to Mpc scales

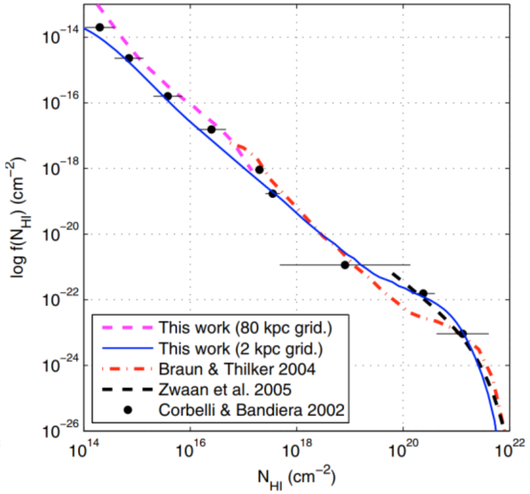
HI?

Simulated HI across Scales





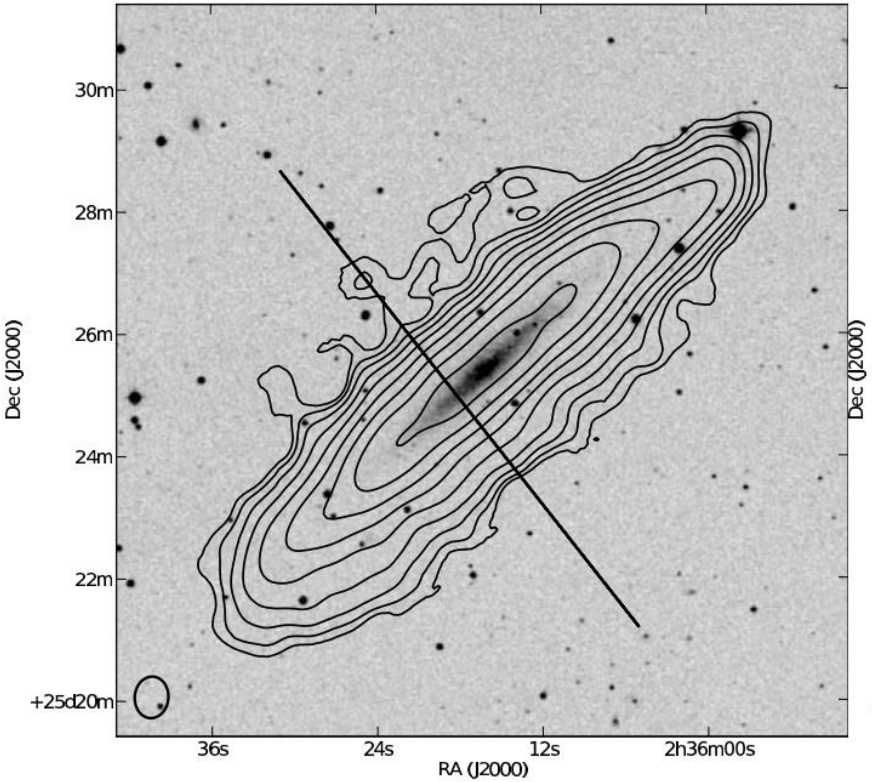


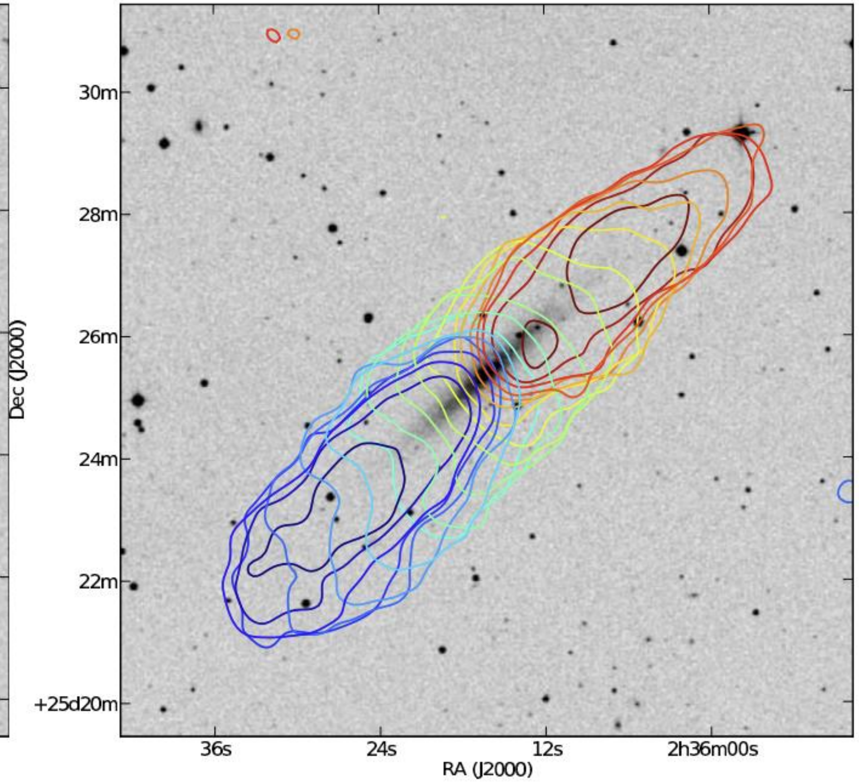


Popping et al. (2015); van de Voort et al. (2019)

- Cosmic web / Mpc: 10^{13}–10^{17} cm^{-2}
- CGM / tidal gas / –200 kpc: 10^{16}–10^{19} cm^{-2}
- Main H I disk / 1–50 kpc: 10^{19}–10^{21} cm^{-2}

HALOGAS





Heald et al. (2011)

- HALOGAS / WSRT

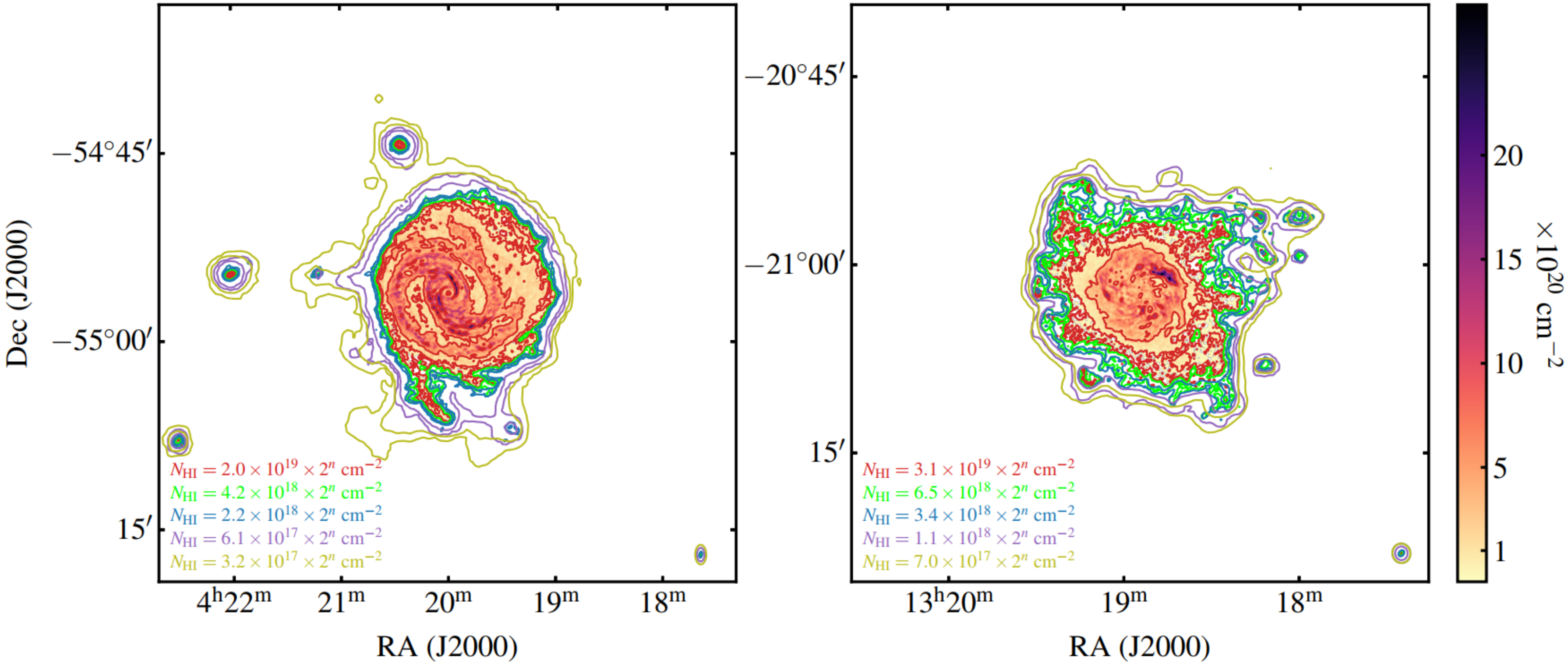
— 22 nearby disks;
≈120 h per target;

typical $N_{HI} \sim 10^{19} \mathrm{cm}^{-2}$

over 16–20 $\mathrm{km\ s}^{-1}$

at 90”

MHONGOOSE



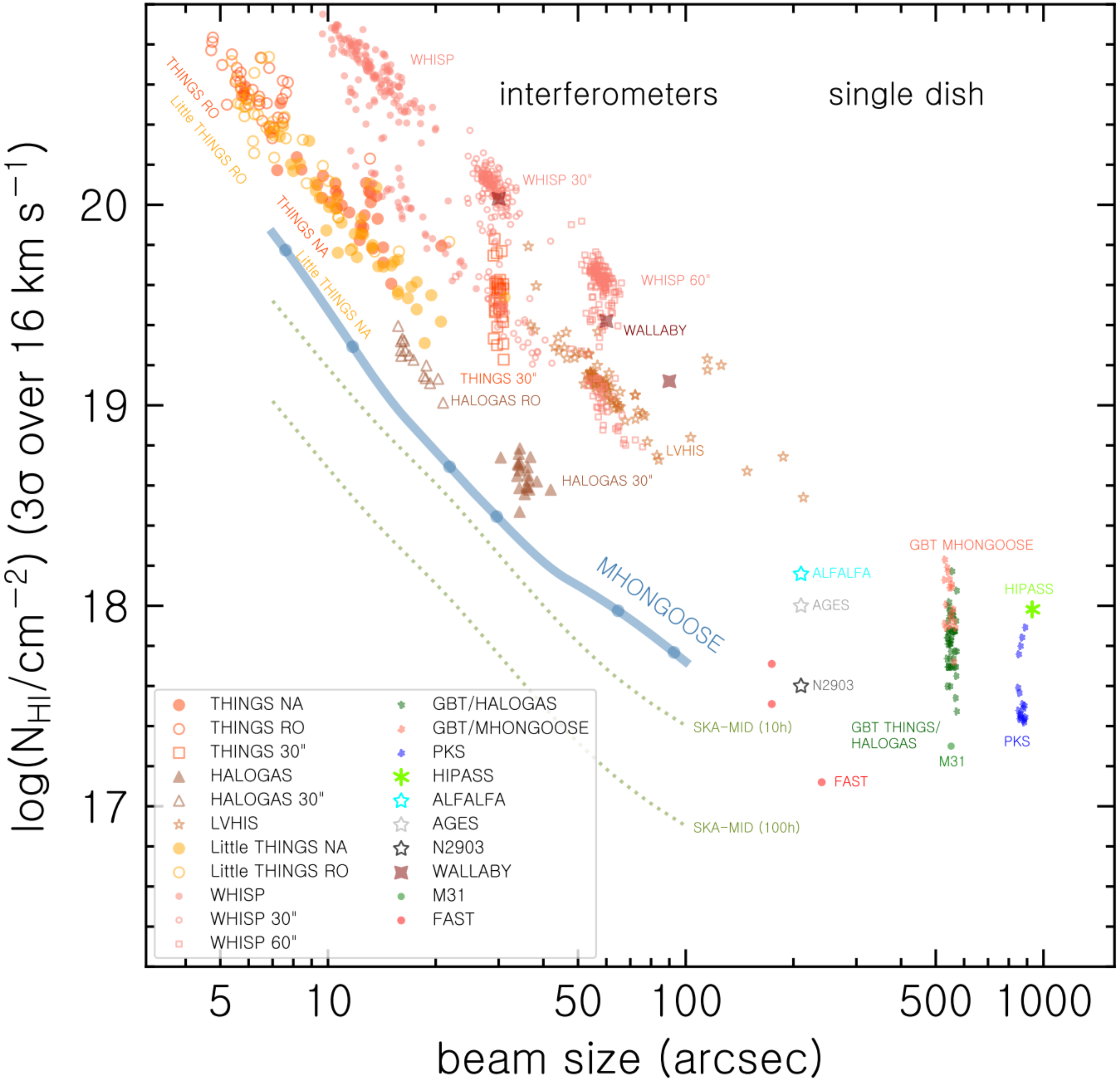
De Blok et al. (2024)

- MHONGOOSE / MeerKAT

— 30 galaxies
55 h per target

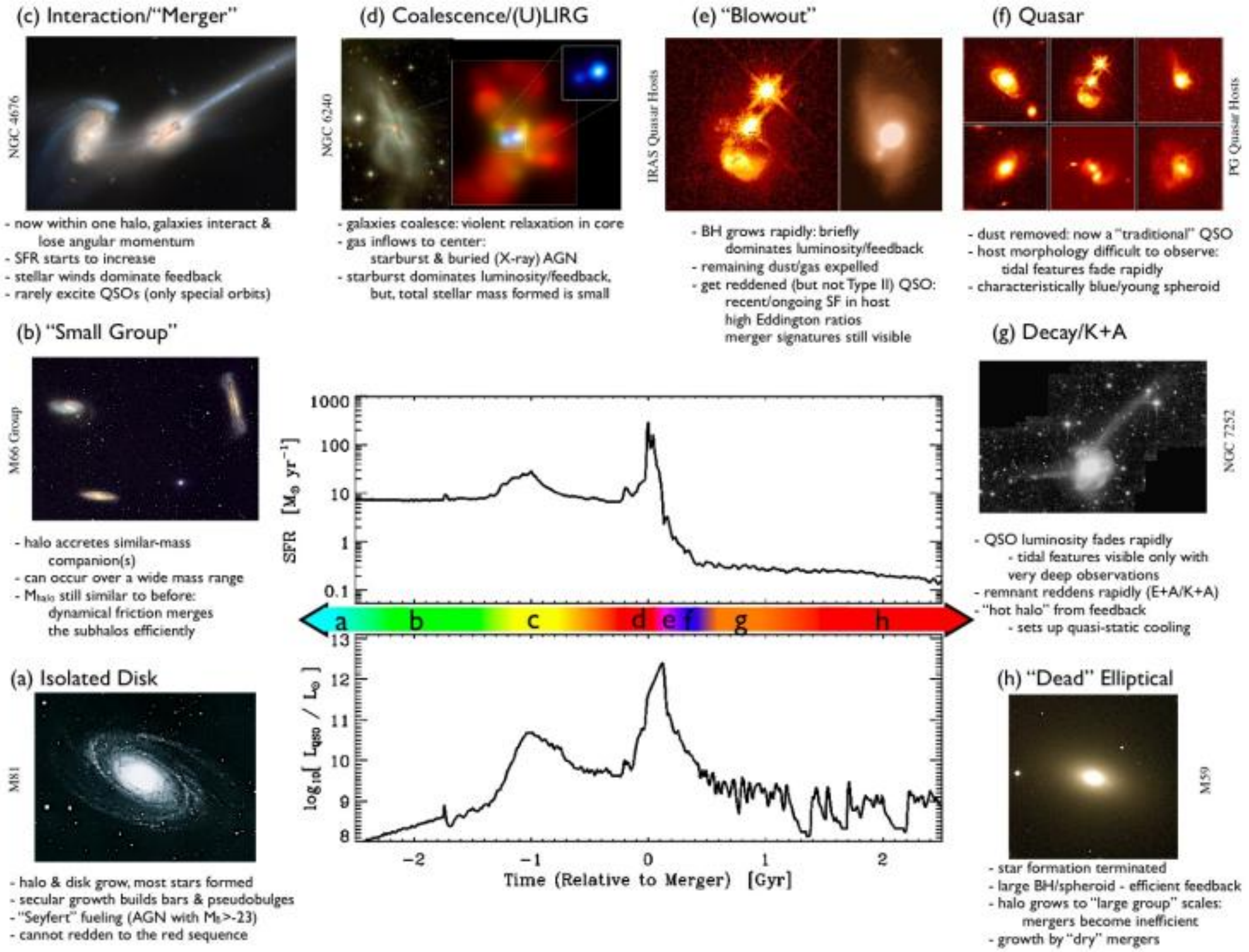
At 3σ / $\mathrm{km\ s^{-1}}$:

$5 \times 10^{17} \mathrm{cm}^{-2}$ at 90″
$4 \times 10^{19} \mathrm{cm}^{-2}$ at 7″



De Blok et al. (2024)

Galaxy Interactions

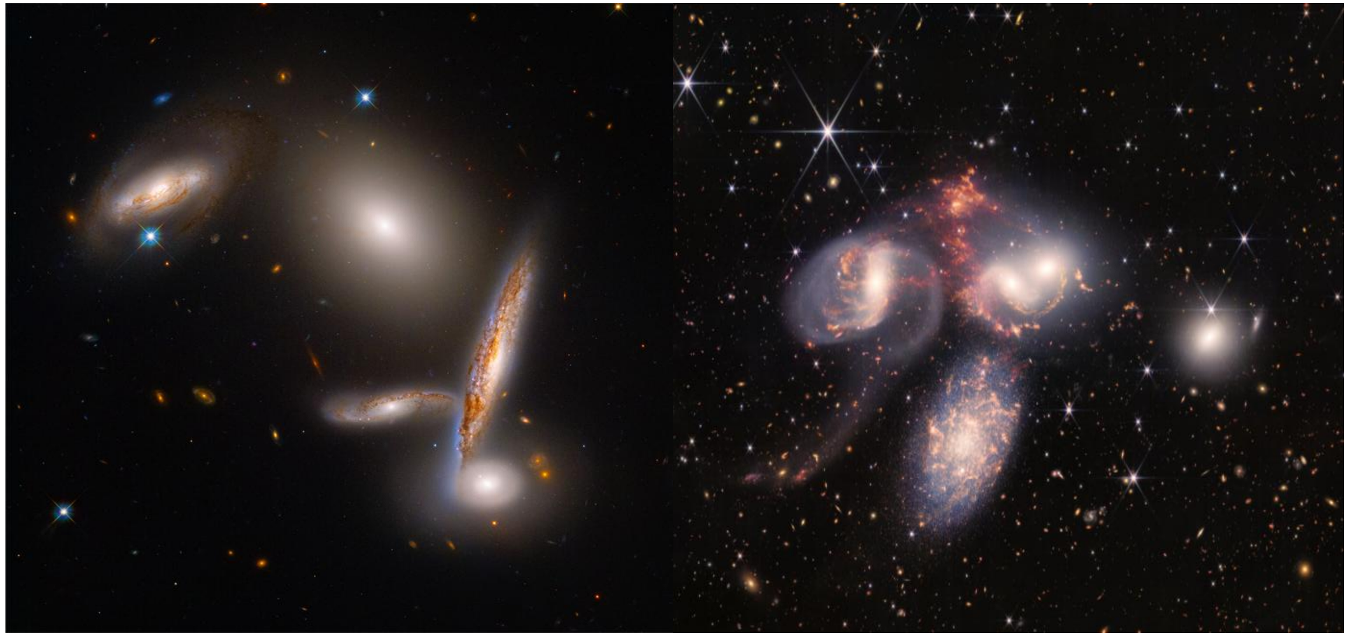


Hopkins et al. (2008)

- Enhancement of star formation
- Triggering of AGN
- Re-distribution of metals and gas...

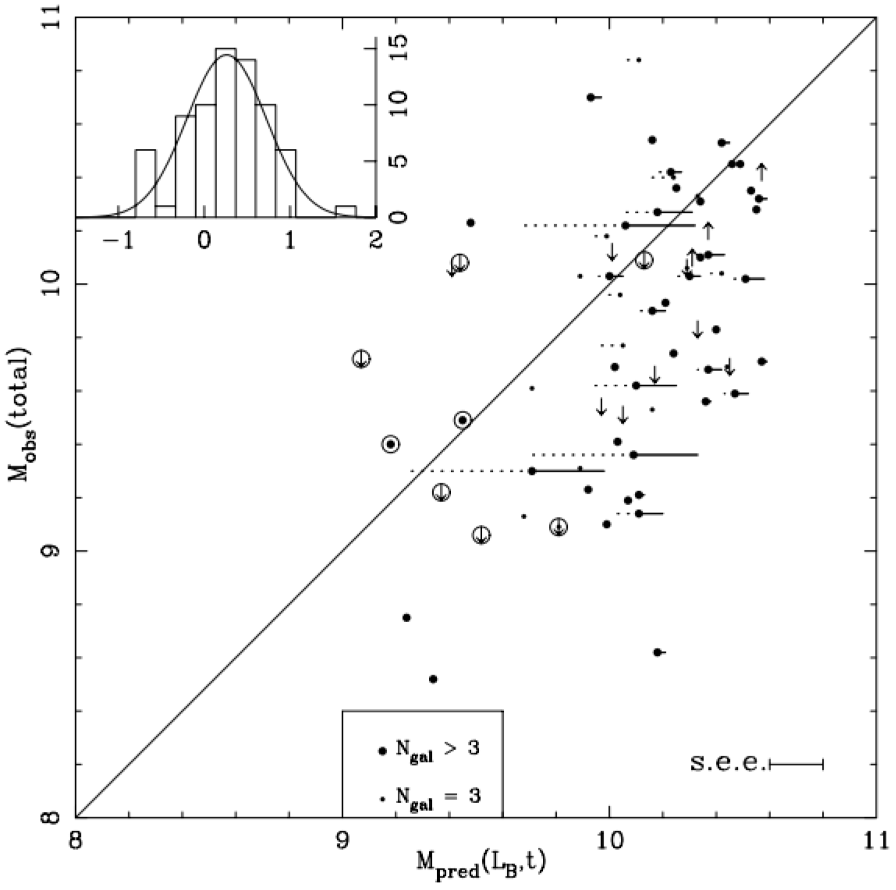
Galaxy interactions could significantly affect the baryon cycle

Hickson Compact Groups

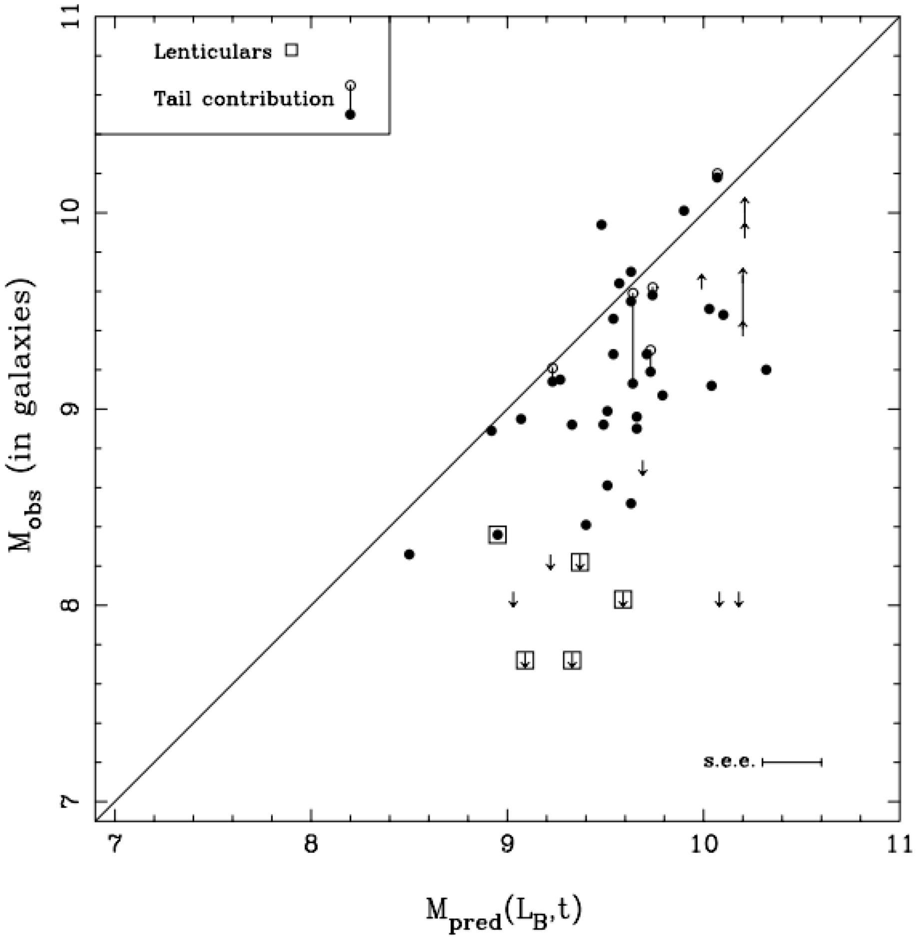


- Small number of members (3-10) with a low velocity dispersion ($\overline{\sigma}$ ~200 km/s)
- Similar to cores of dense clusters
- Unique and interesting laboratories for studying galaxy interaction and baryon cycle

HI Deficiency in HCGs

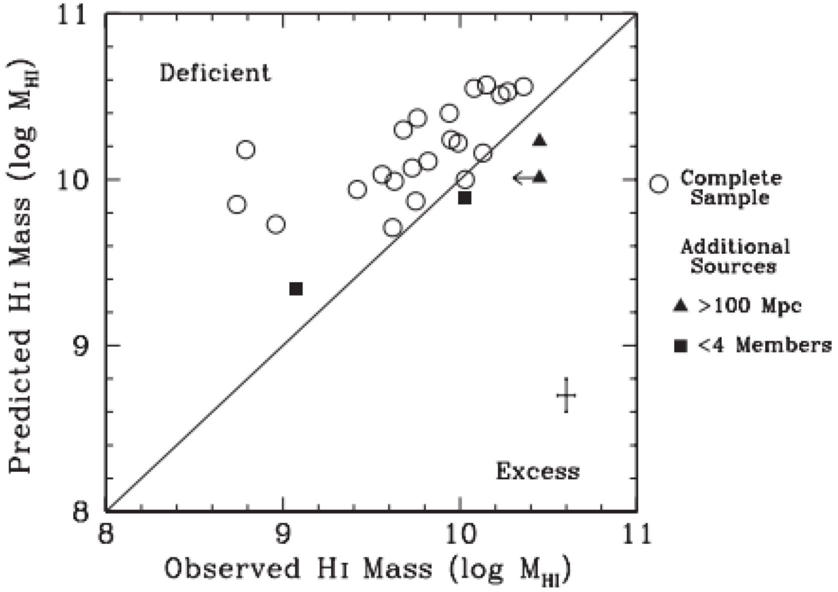


$$\log M_{\rm HI}\, h_{70}^2/M_\odot = 0.94 \log L_{\rm B}\, h_{70}^2/L_\odot + 0.18,$$

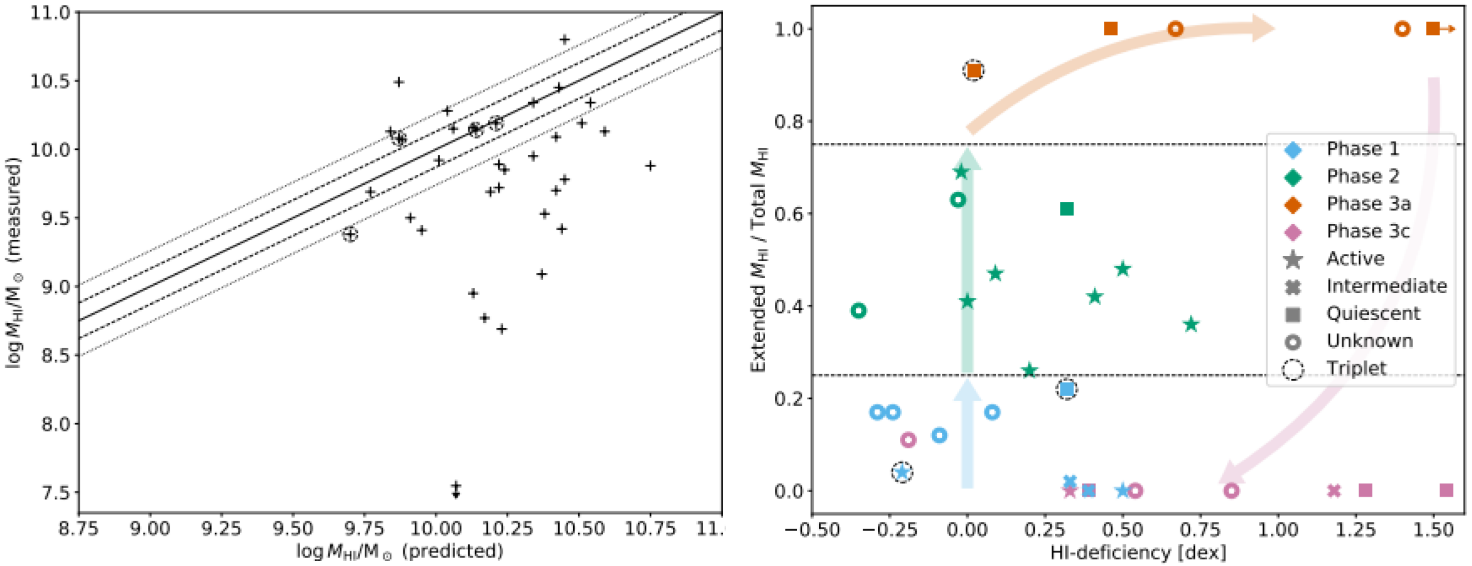


Verdes-Montenegro et al. (2001)

HI Deficiency in HCGs

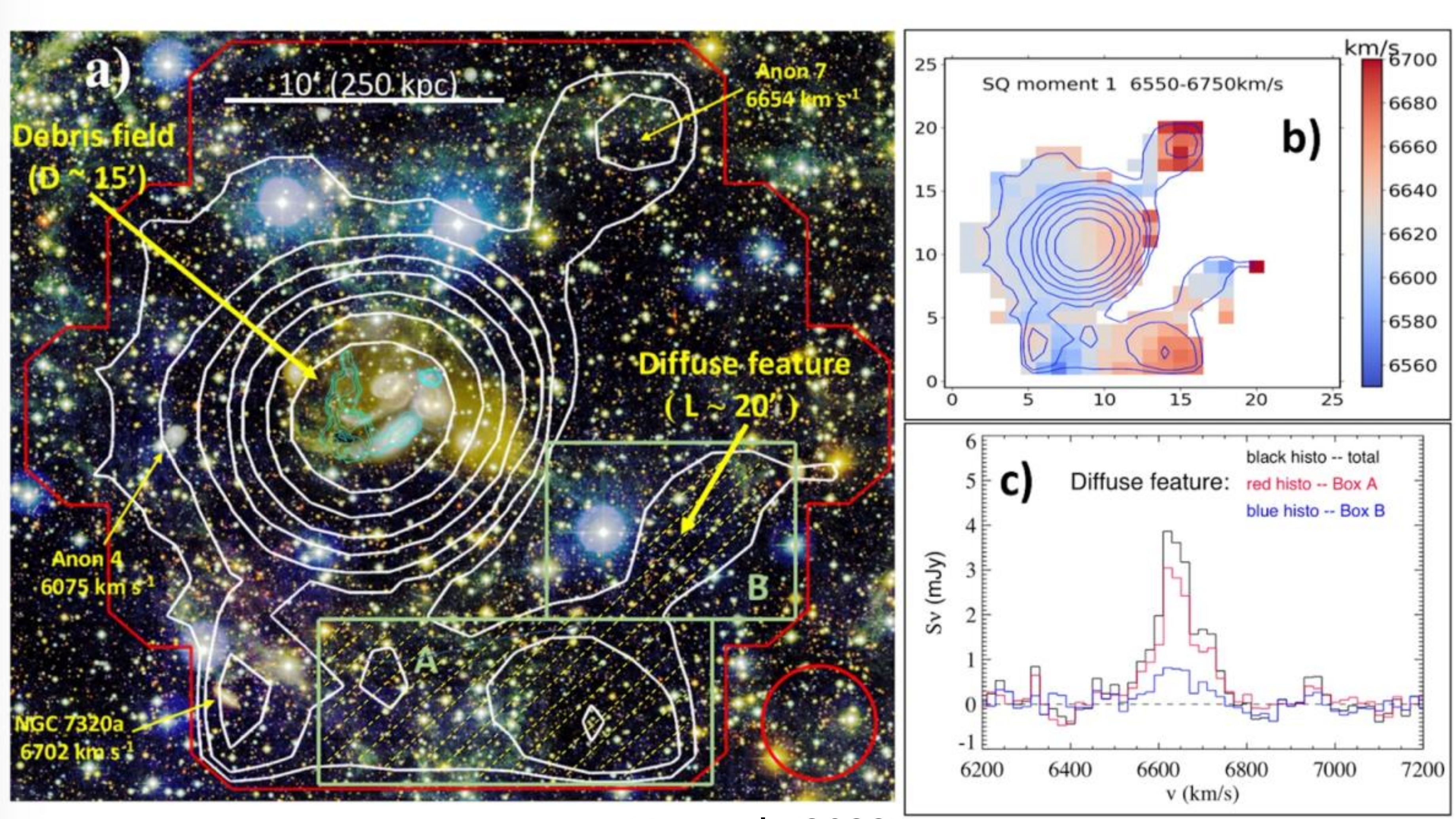


Borthakur et al. (2001)



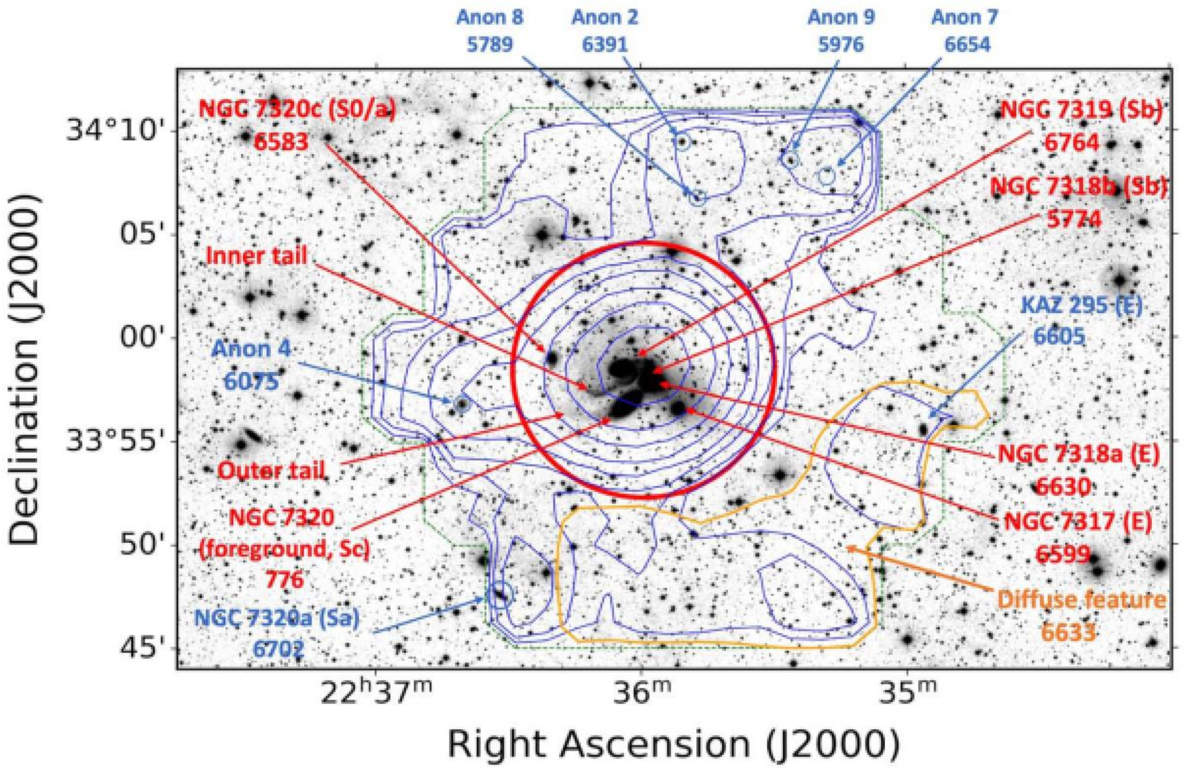
Jones et al. (2023)

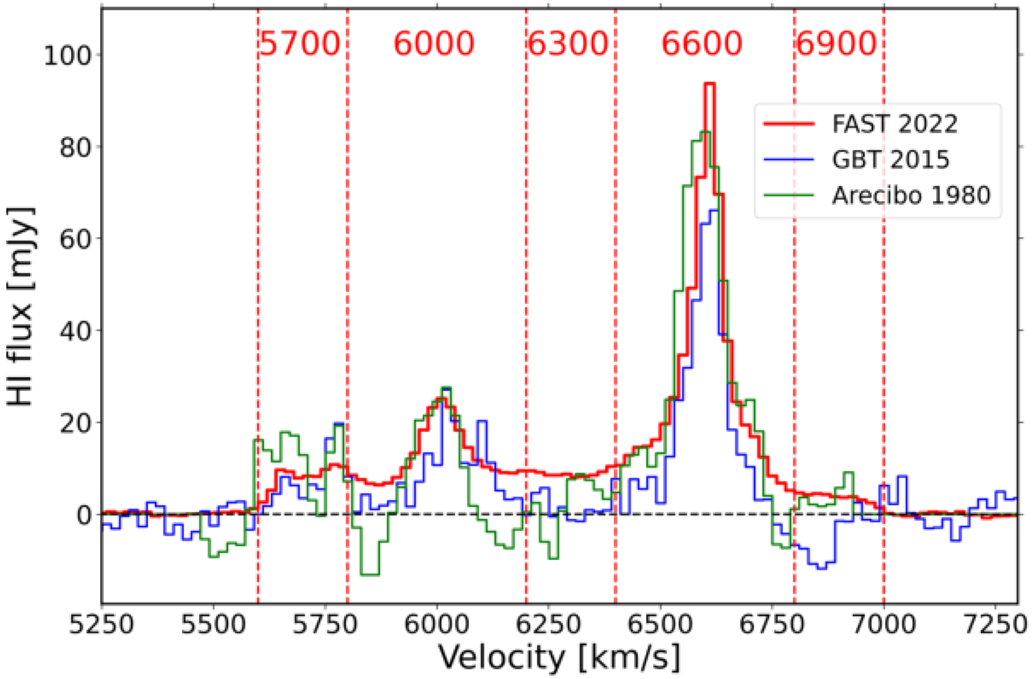
Diffuse HI of Stephan’ s Quintet



Xu et al. (2022)

Diffuse HI of Stephan’s Quintet





Cheng et al. (2023)

Key Questions

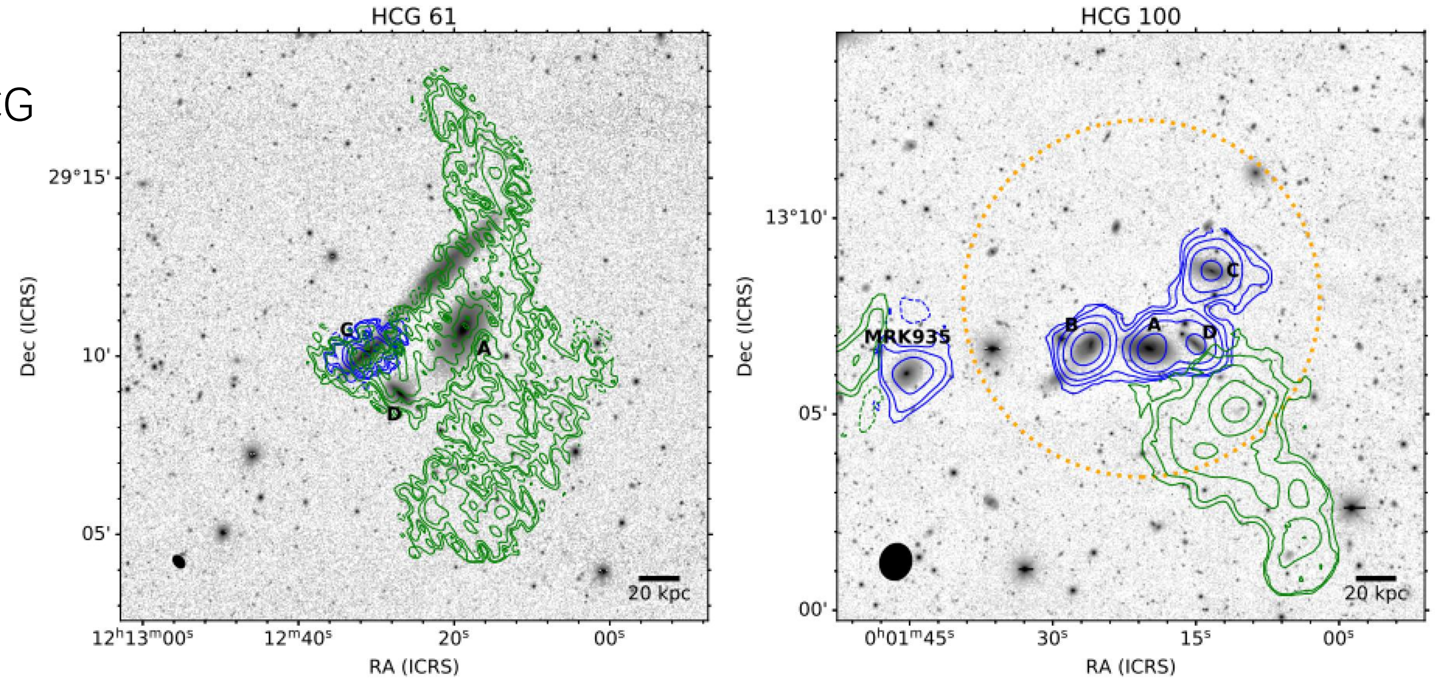
- Where is the HI in HCGs? In diffuse gas?
- Does the large-scale diffuse gas commonly exist around HCGs?
- What is the origin of the diffuse gas? Early galaxy interaction or cosmic web

Deep Mapping of Diffuse HI Gas in Intragroup Medium of Hickson Compact Groups

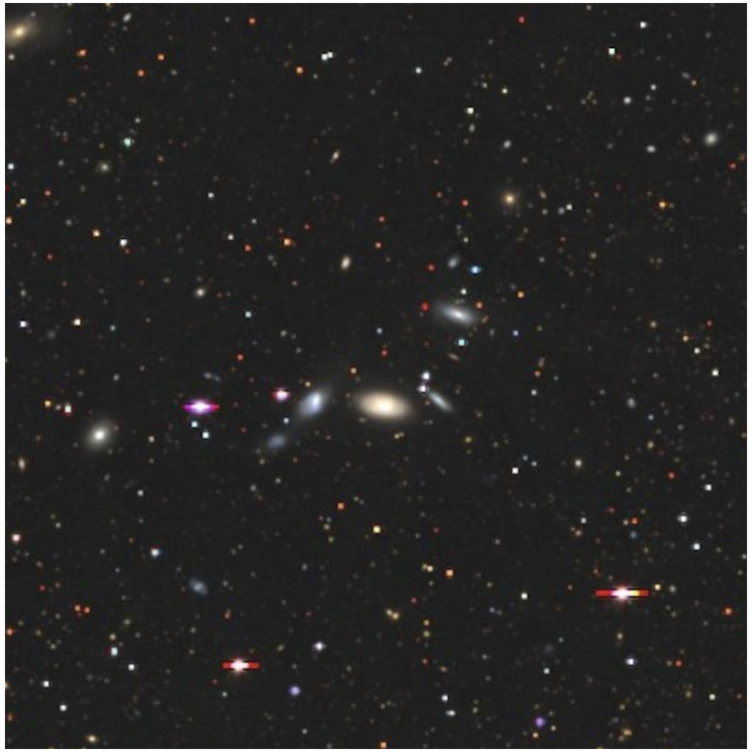
Targets:
HCG 31, HCG 61, HCG 92 (SQ), HCG 97, HCG 100

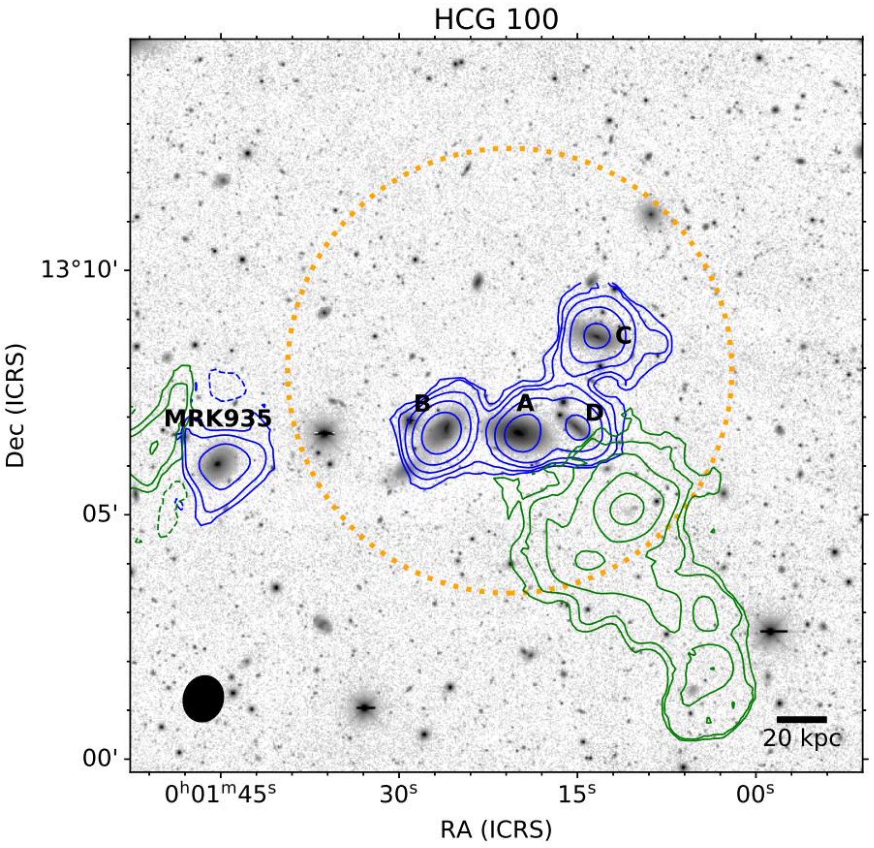
Observations:

- FAST:
  - HCG 61, 100 (PI: **Q. Yu**)
  - HCG 92 (PI: C.K. Xu)
  - HCG 31 ,97 (PI: A. Sorgho)
- MeerKAT:
  - HCG 31, 97 (PI: L. Verdes-Montenegro)



HCG 100





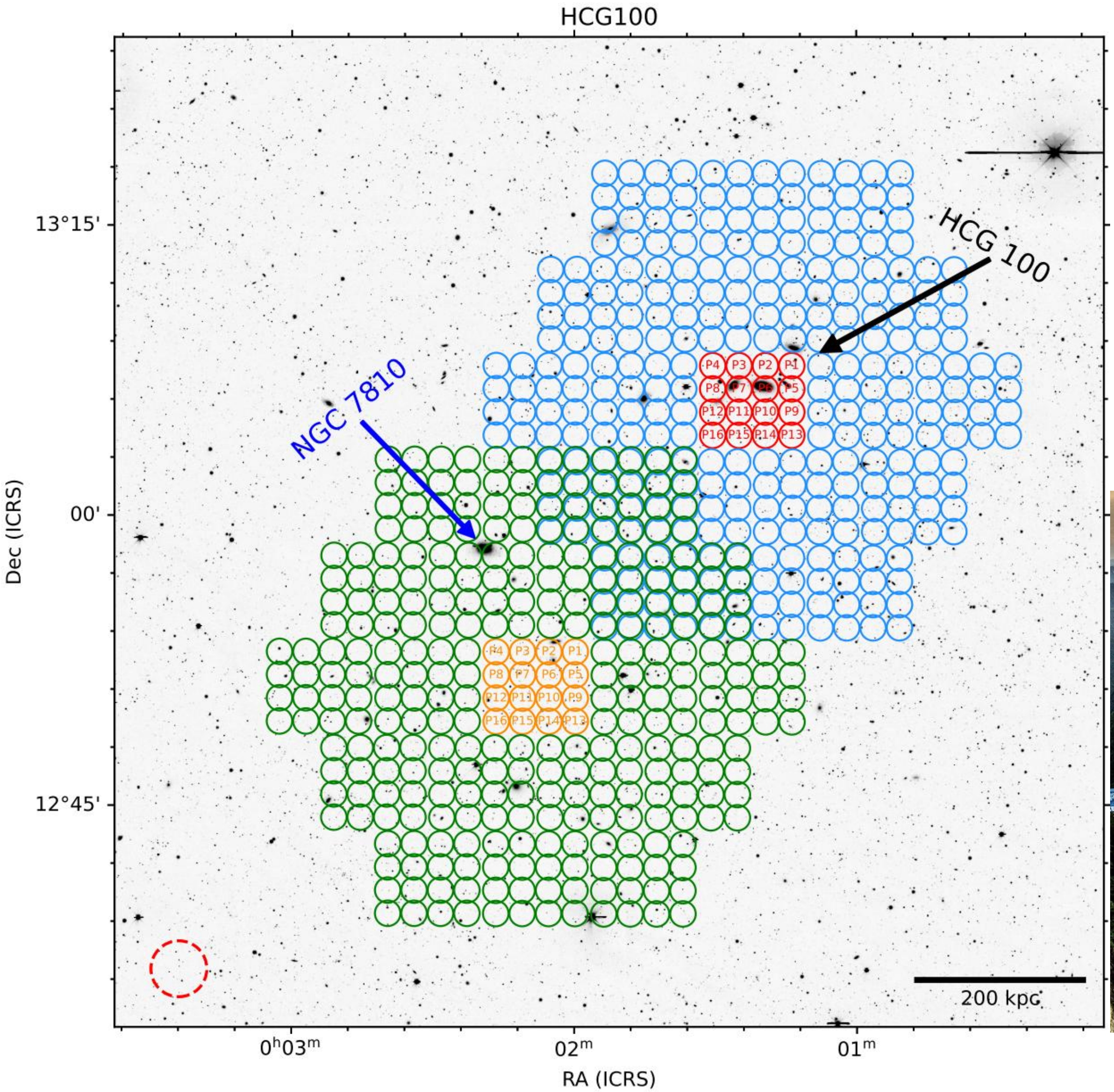
4 spiral galaxies @ $z = 0.0178$

Distance ~77 $\pm$ 5 Mpc

VLA: HI tail extending ~130 kpc to the SW of the core

Tidal dwarf galaxies in HI tail

FAST Observations

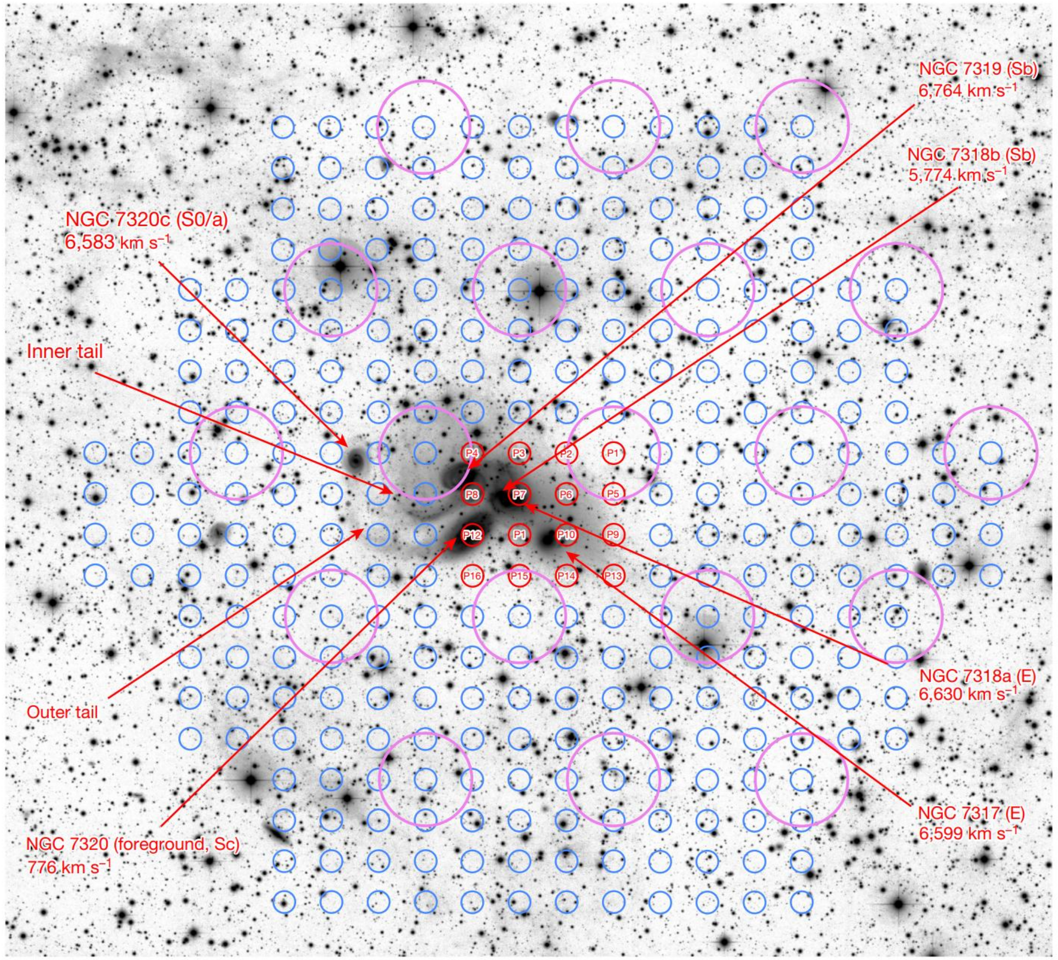


Field: 30’×57’; 19-beam receiver

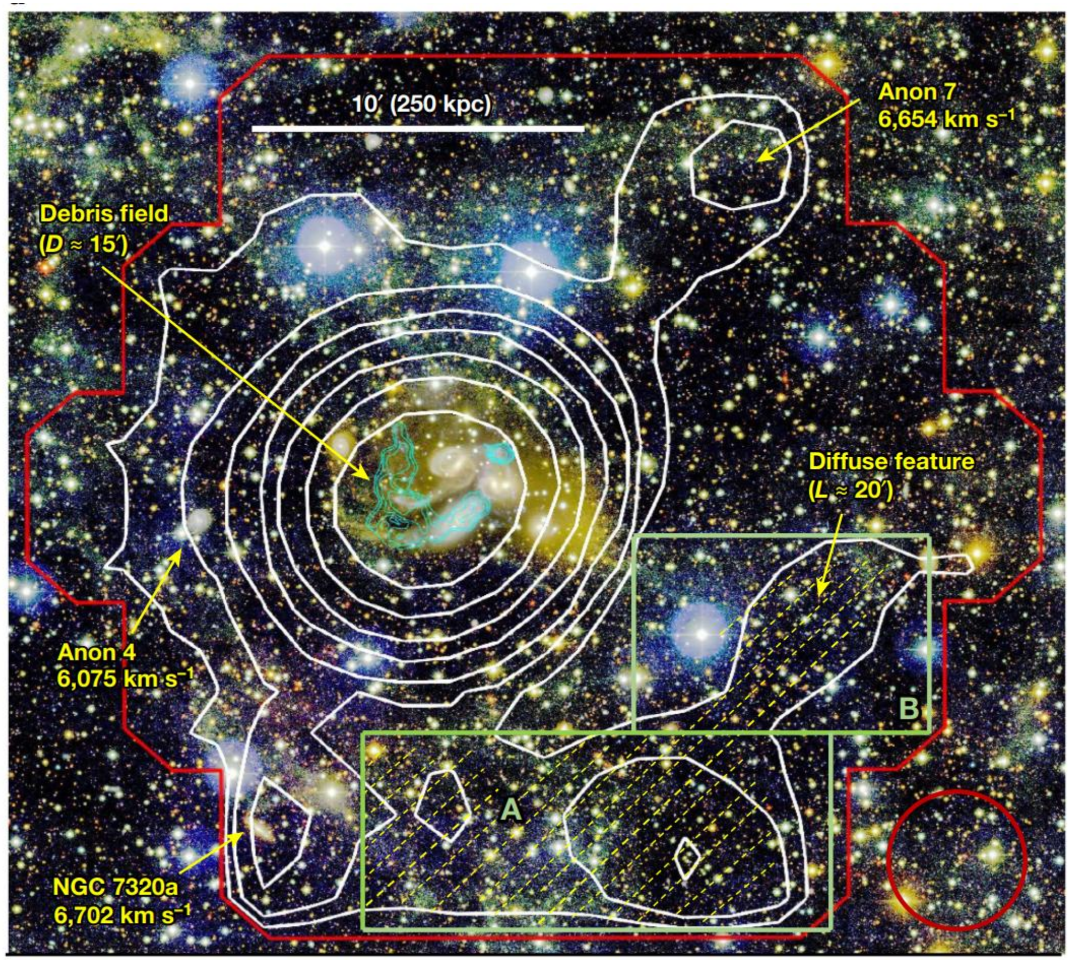
Sensitivity: $1\sigma\ N_{\rm HI}\sim 4.8\times10^{16}\ \rm cm^{-2}$ per 20 km/s channel

Beamsize: 4’

FAST Observations



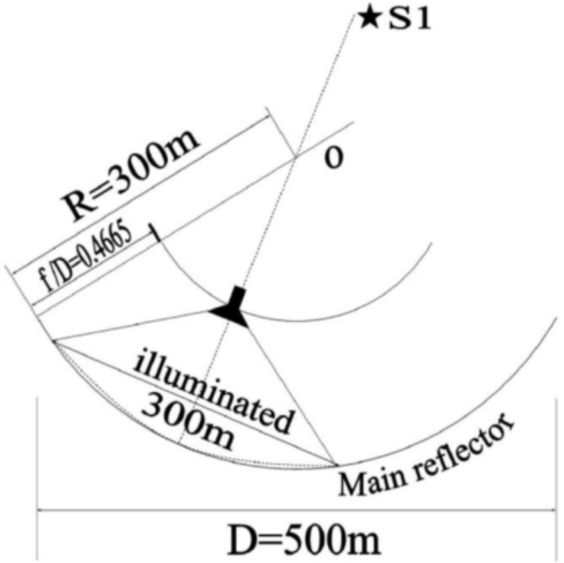
?



Xu et al. (2022)

Calibration

噪音管定标： 电响应 $P \rightarrow$ 天线亮温度T_a

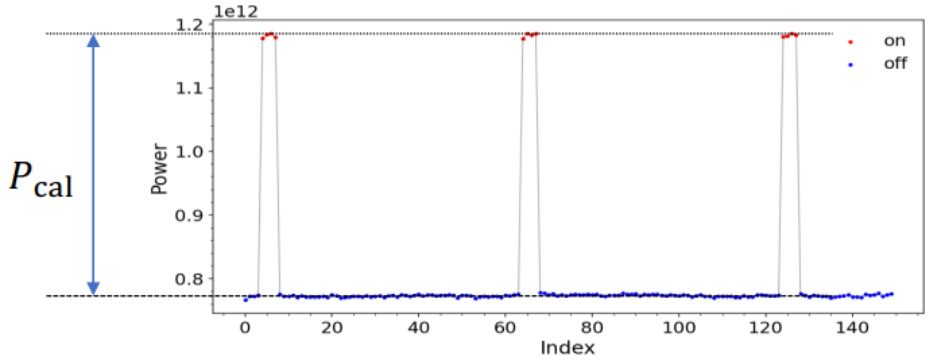


接收机记录的电响应 $P \propto I(\nu) A_{eff} \delta\Omega$

亮温度：黑体辐射 $T_a = I(\nu) c^2 / 2k\nu^2$

$P \propto T_a$

注入已知温度的噪音管(cal)来定温度：

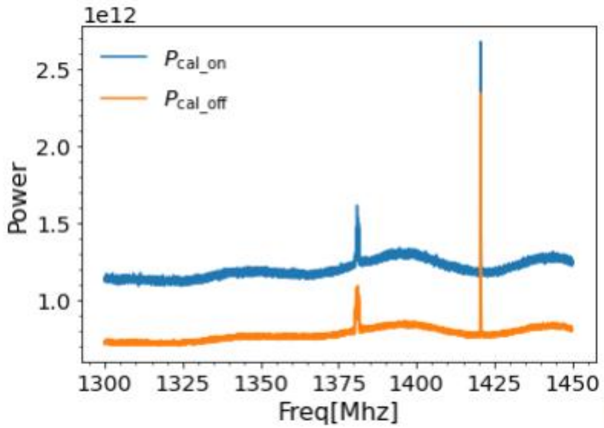


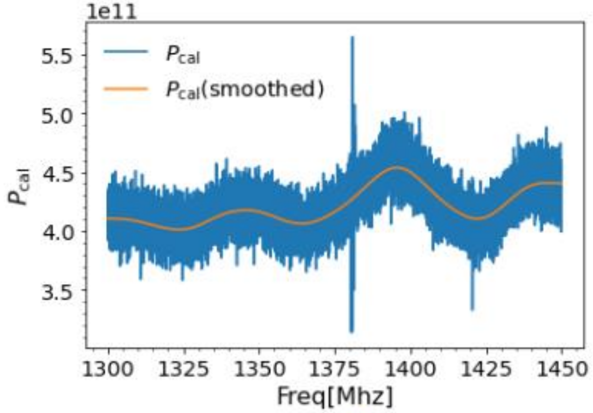
$$\frac{P}{T_a} = \frac{\Delta P}{\Delta T_a} = \frac{P_{\rm cal}}{T_{\rm cal}}$$

已知

Credit: Yingjie Jing

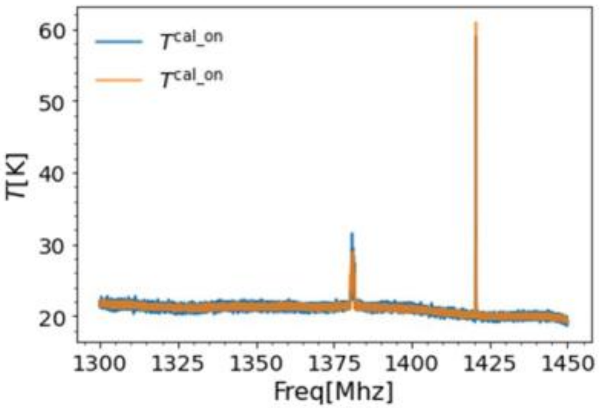
Calibration

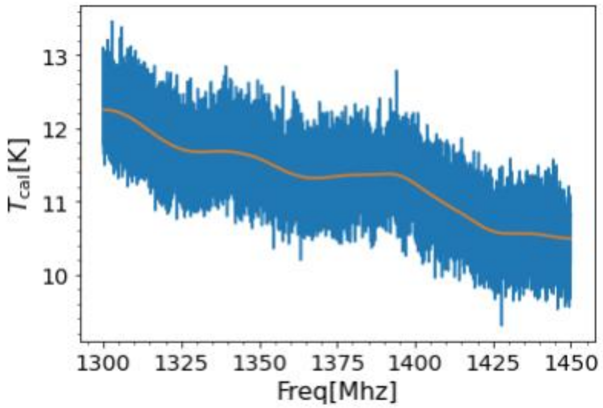




$$T_a^{cal\_off} = \frac{P_{cal\_off}}{P_{cal}} T_{cal}$$

$$T_a^{cal\_on} = \frac{P_{cal\_on}}{P_{cal}} T_{cal} - T_{cal}$$





Calibration

求 T_{src}

$$T_{\mathrm{a}} = \underbrace{T_{rec} + T_{\mathrm{gr}} + T_{\mathrm{atm}} + T_{\mathrm{CMB}} + T_{\mathrm{BG}} + T_{\mathrm{sw}}}_{T_{everything\_else}} + T_{src}$$

$T_{src} \rightarrow T_{src}^{line}$, T_{src}^{conti}

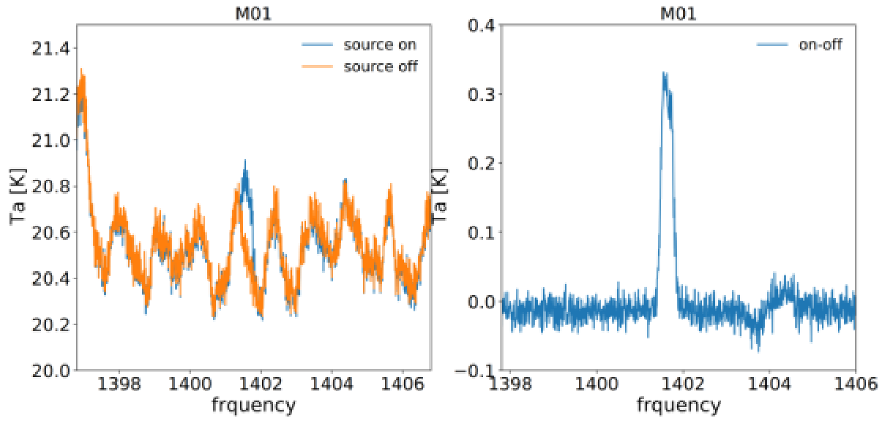
方法一：选择无源的“空场”作为off点

$$\left.\begin{aligned} T_{\mathrm{a}}^{\mathrm{src\_on}} &= T_{everything\_else} + T_{src} \\ T_{\mathrm{a}}^{\mathrm{src\_off}} &= T_{everything\_else} \end{aligned}\right\} T_{src} = T_{\mathrm{a}}^{\mathrm{src\_on}} - T_{\mathrm{a}}^{\mathrm{src\_off}}$$

可再用低阶多项式拟合去除T_{src}^{conti}

- Position Switching, 源上-源外(OnOff)
- Beam Switching

➢ 一般Tracking点源时采用
➢ OTF或Drift时off点不易选择(测试中)

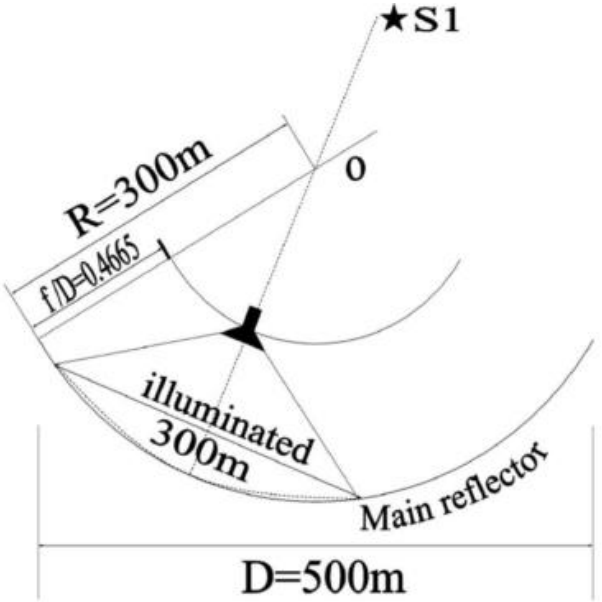


Baseline and standing wave

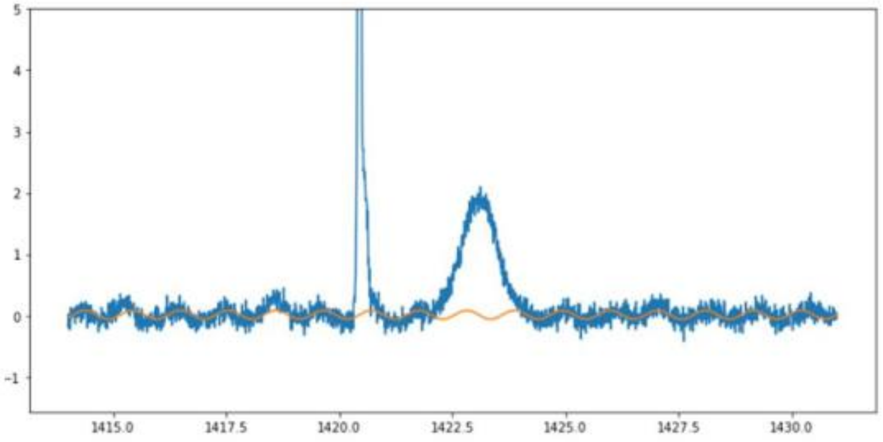
驻波T_{sw}拟合

主要来自反射面与馈源舱之间(距离约138米)

两端固定驻波：$f = nc/2L \approx n * 1.08Mhz$



- 直接用多项式+正弦函数直接拟合
  - 把$1.08Mhz$作为初值
  - 驻波幅度随频率有变化，适用较短区间或分段拟合



Flux Calibration

修正望远镜的增益并转换为流量密度　$K \longrightarrow \mathrm{Jy}/Beamsize$

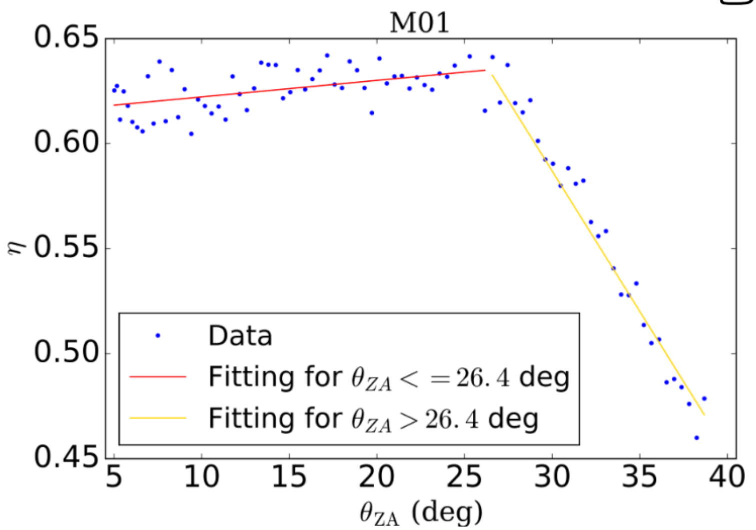
$$\frac{T}{Flux} \equiv G = \eta G_0 = \eta A_{eff}/2 \qquad \eta = \begin{cases} a\,\theta_{\mathrm{ZA}} + \mathrm{b},\ 0^\circ \le \theta_{\mathrm{ZA}} \le 26.4^\circ \\ c\,\theta_{\mathrm{ZA}} + \mathrm{d},\ 26.4^\circ < \theta_{\mathrm{ZA}} \le 40^\circ \end{cases}$$

观测定标源(Calibrator)：$\frac{T_{\mathrm{cali}}}{Flux_{\mathrm{cali}}}$

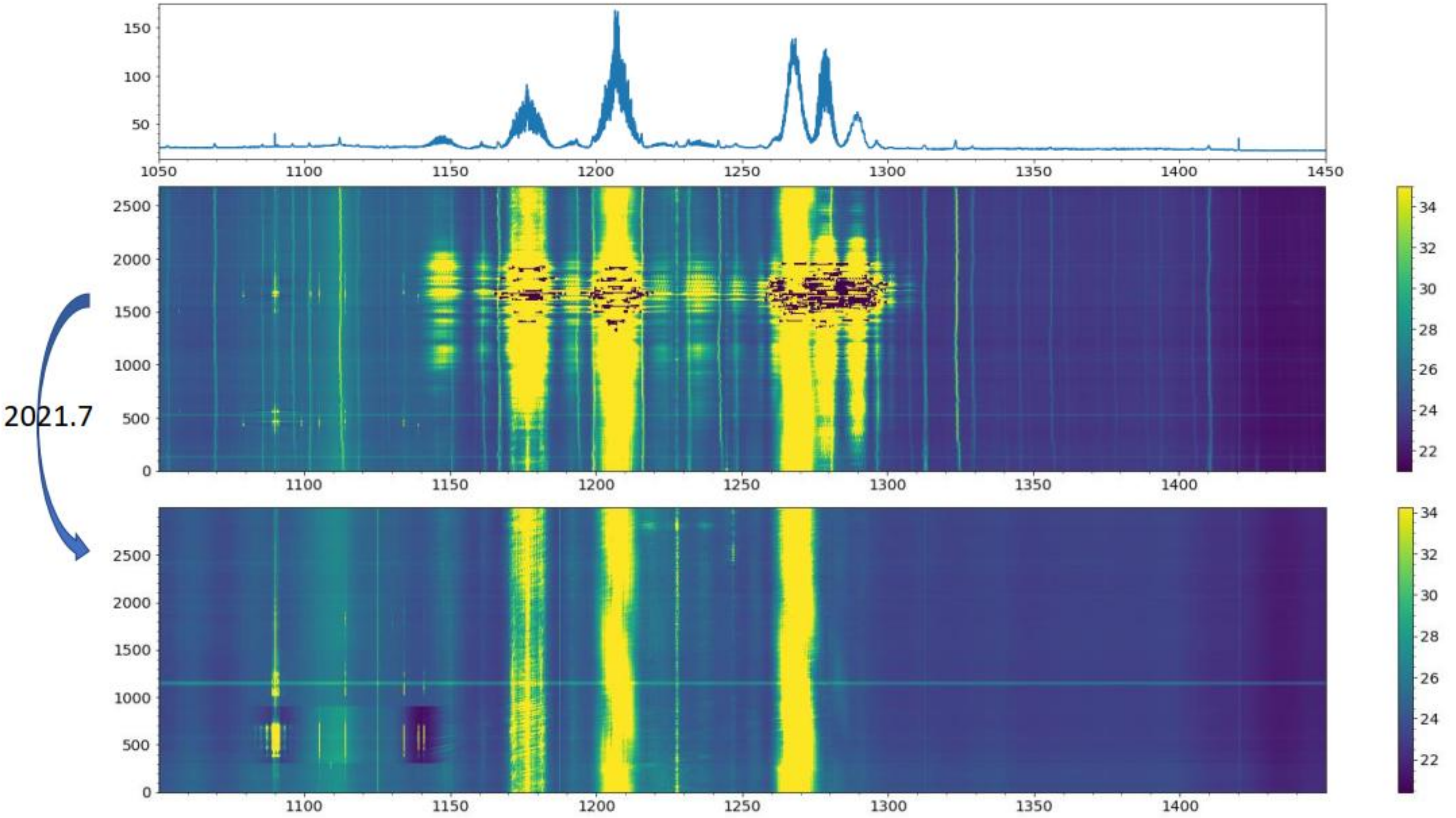
噪音管定标

已知

(Jiang et al. 2020)



RFI (Radio Frequency Interference,射频干扰)



Doppler correction

$$z \equiv \frac{\lambda_{obs} - \lambda_0}{\lambda_0} = \frac{f_0 - f_{obs}}{f_{obs}}$$

$$\frac{v_{opt}}{c} = \frac{f_0}{f} - 1 = z$$

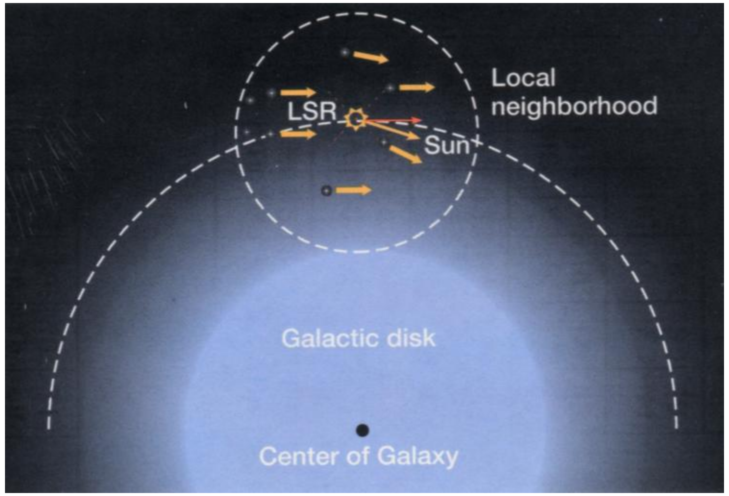
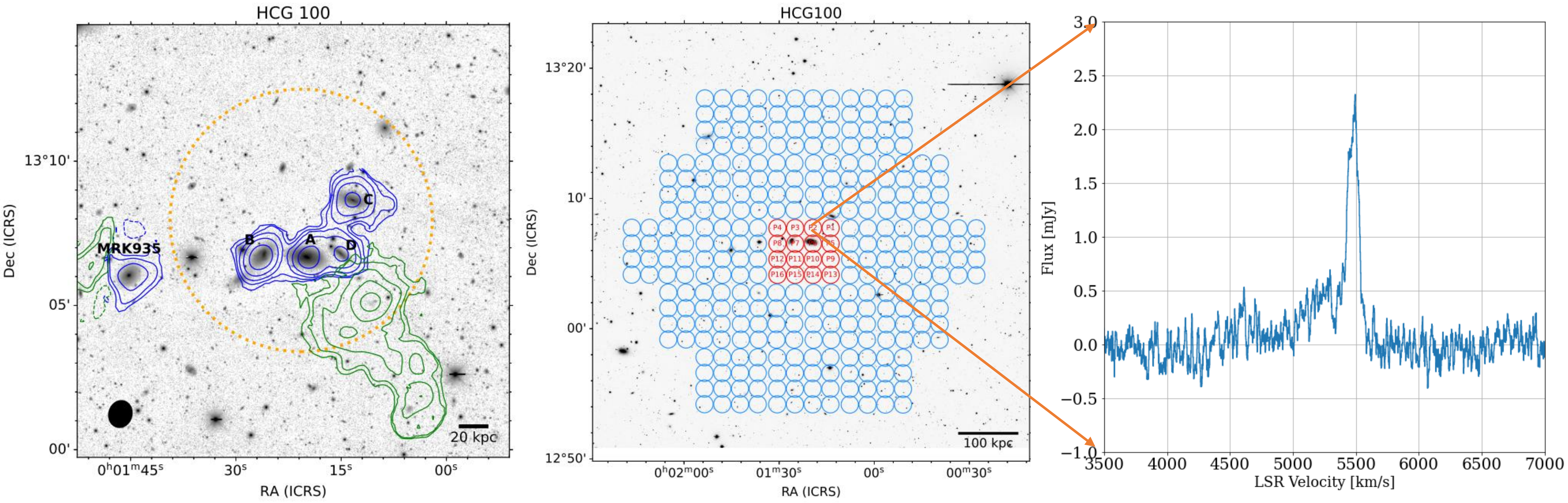


Table 7.1.1: Velocity Rest Frame Designations

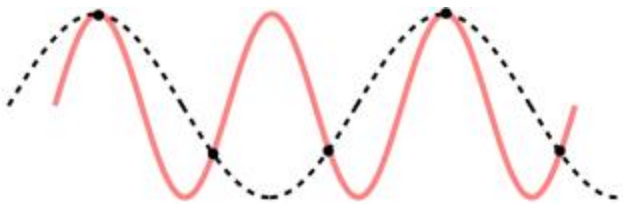
Rest Frame Name	Rest Frame	Correct for	Max. Amplitude (km/s)
Topocentric	Telescope	Nothing	0
Geocentric	Earth Center	Earth rotation	0.5
Earth-Moon Barycentric	Earth+Moon center of mass	Motion around Earth+Moon center of mass	0.013
Heliocentric	Center of the Sun	Earth orbital motion	30
Barycentric	Earth+Sun center of mass	Earth+Sun center of mass	0.012
Local Standard of Rest (LSR)	Center of Mass of local stars	Solar motion relative to nearby stars	20
Galactocentric	Center of Milky Way	Milky Way Rotation	230
Local Group Barycentric	Local Group center of mass	Milky Way Motion	100
Virgocentric	Center of the Local Virgo supercluster	Local Group motion	300
Cosmic Microwave Background	CMB	Local Supercluster Motion	600

https://www.atnf.csiro.au/people/Tobias.Westmeier/tools_hihelpers.php#restframes

FAST Observations



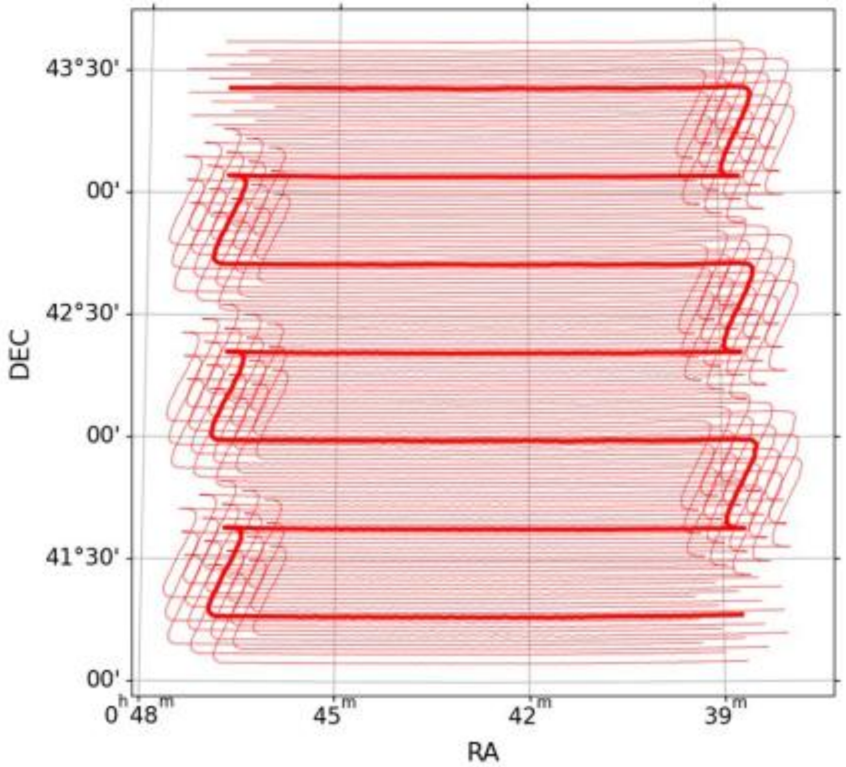
Gridding



Nyquist Sampling 采样频率$f_s > 2f$

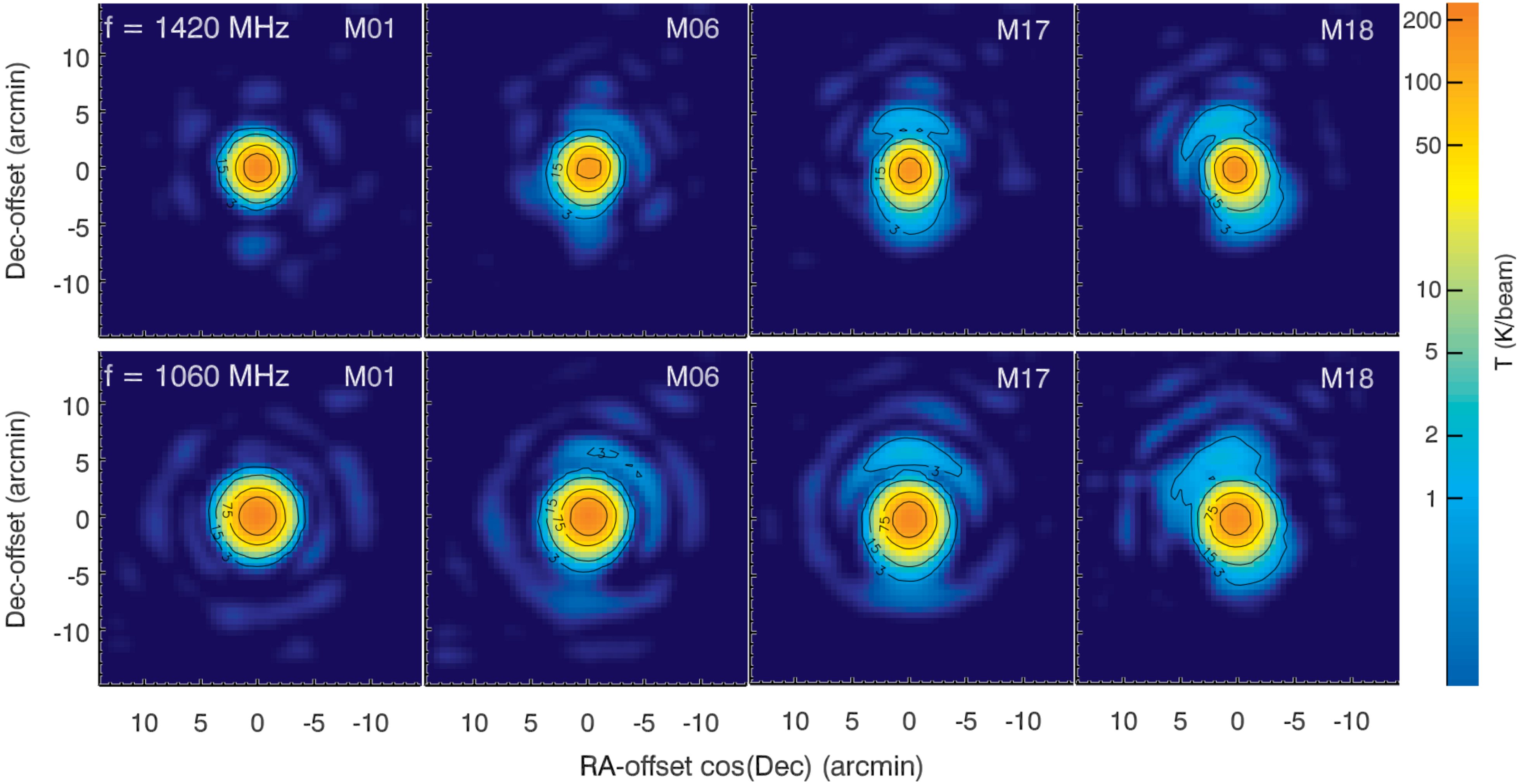
- Nyquist(每个 Beam size > 2 个采样点)

$$\theta_{\rm row} = \left(\frac{\lambda_{\rm obs}}{2D}\right) \times 0.9 - \delta$$
$$\simeq \left(\frac{27826}{D(m)\nu_{\rm obs}({\rm GHz})}\right) - \delta \text{ arcsec}$$



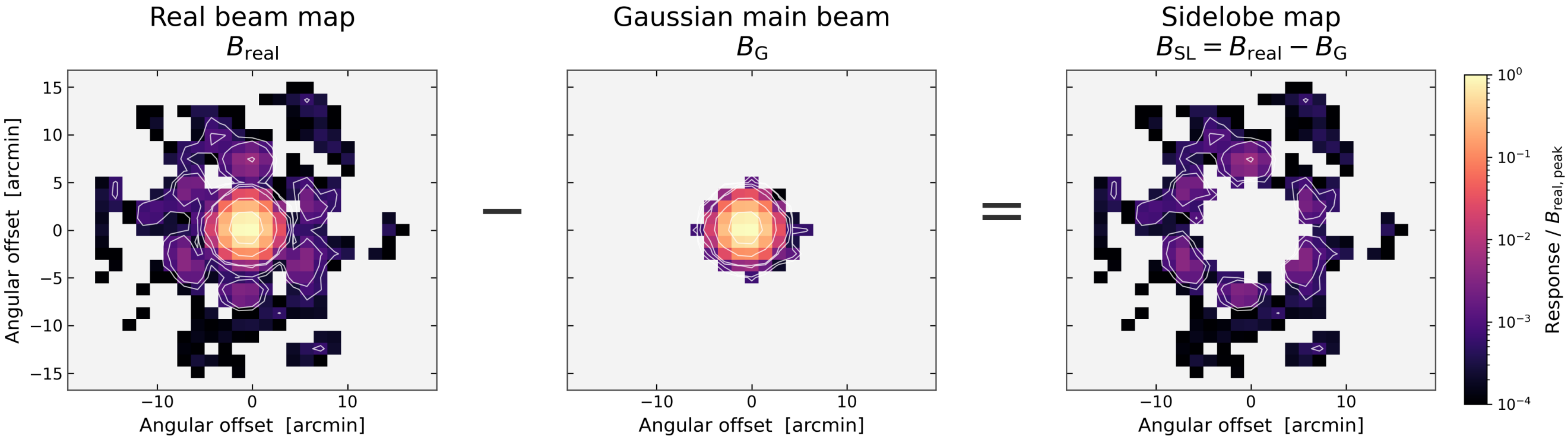
Mangum et al. 2007

Sidelobe Correction

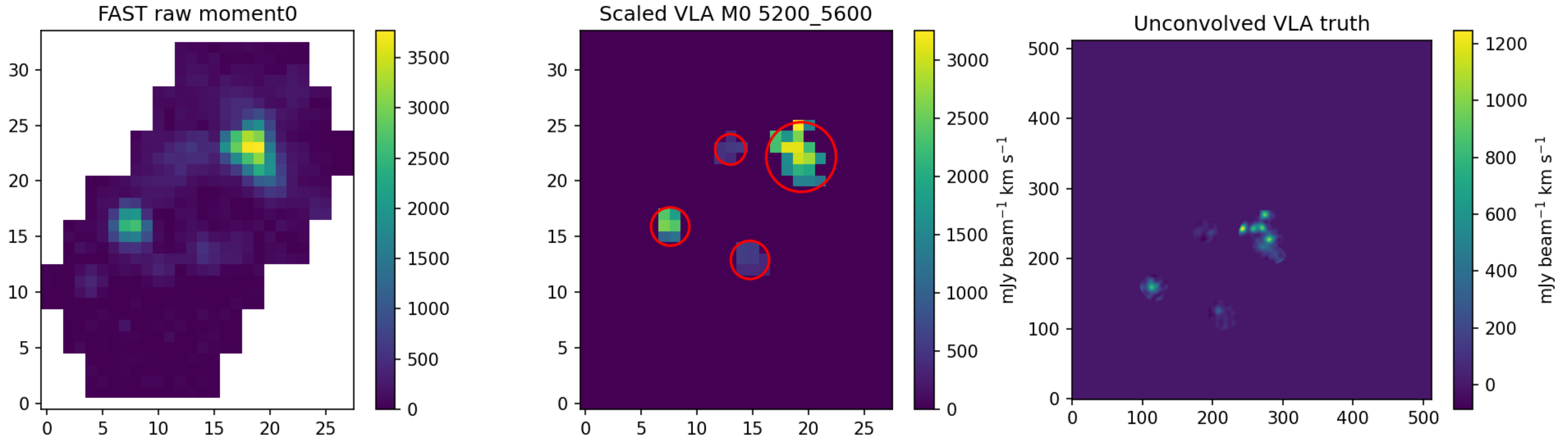


Jiang et al. (2019)

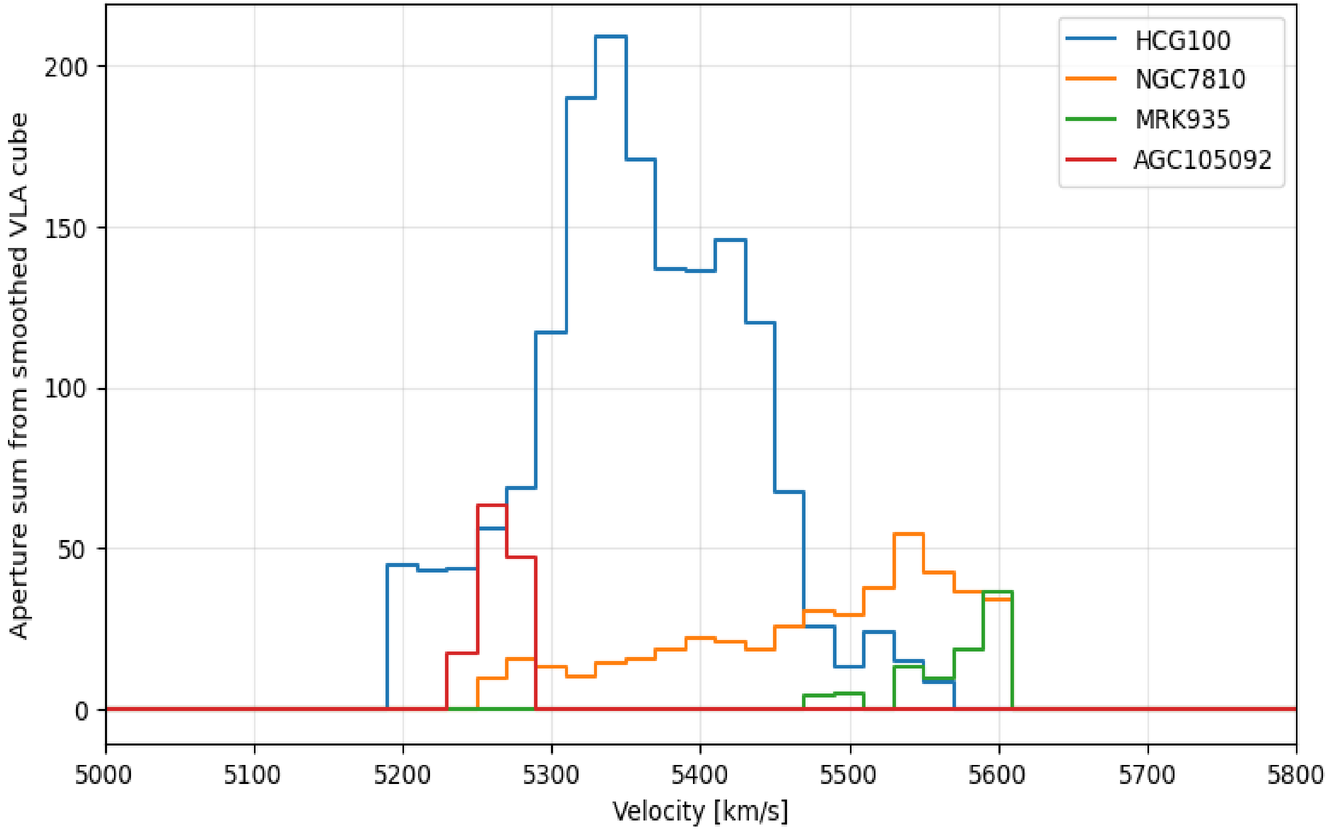
Sidelobe Correction



Sidelobe: Truth Map



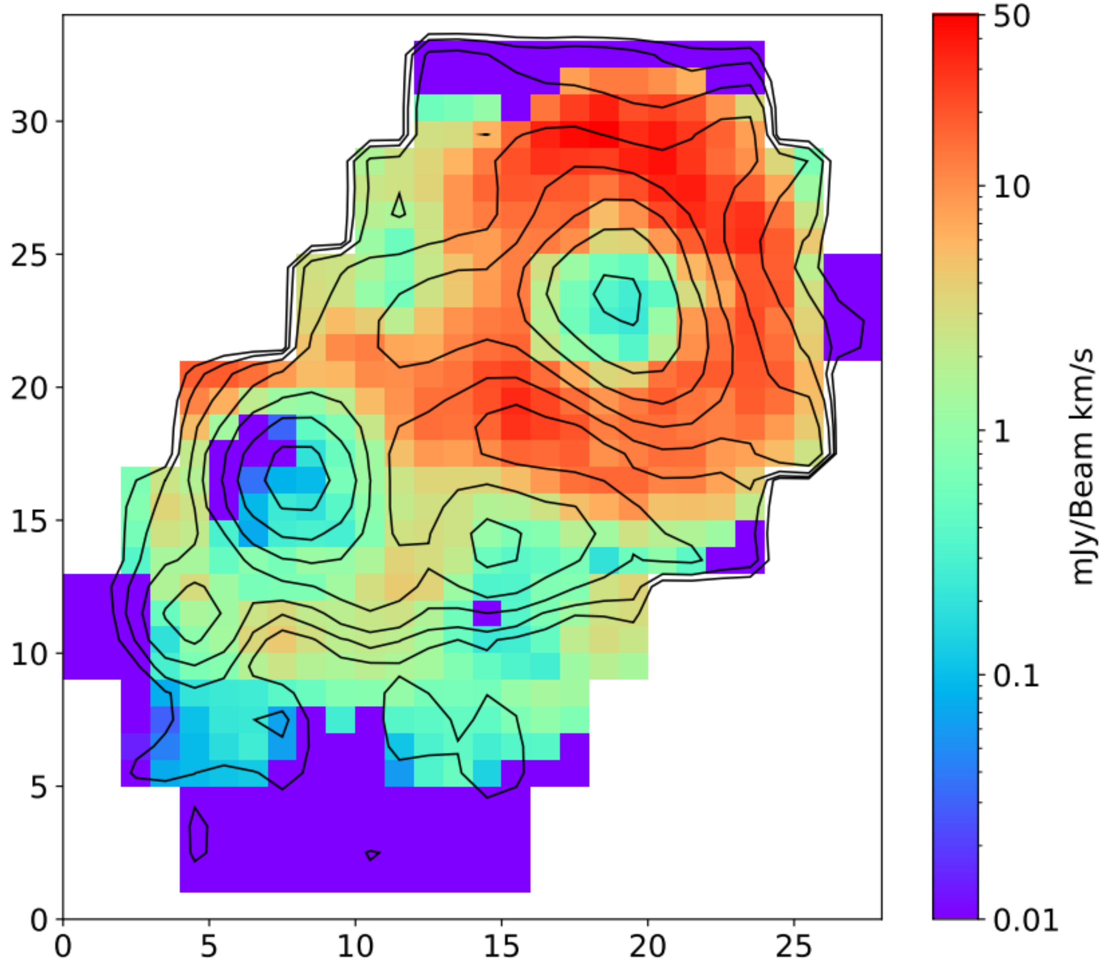
Sidelobe: Scaling by HI Spectrum



$$S_{\mathrm{side}}(x,y,v) = \sum_s C_s(v), M_{\mathrm{side},s}(x,y),$$

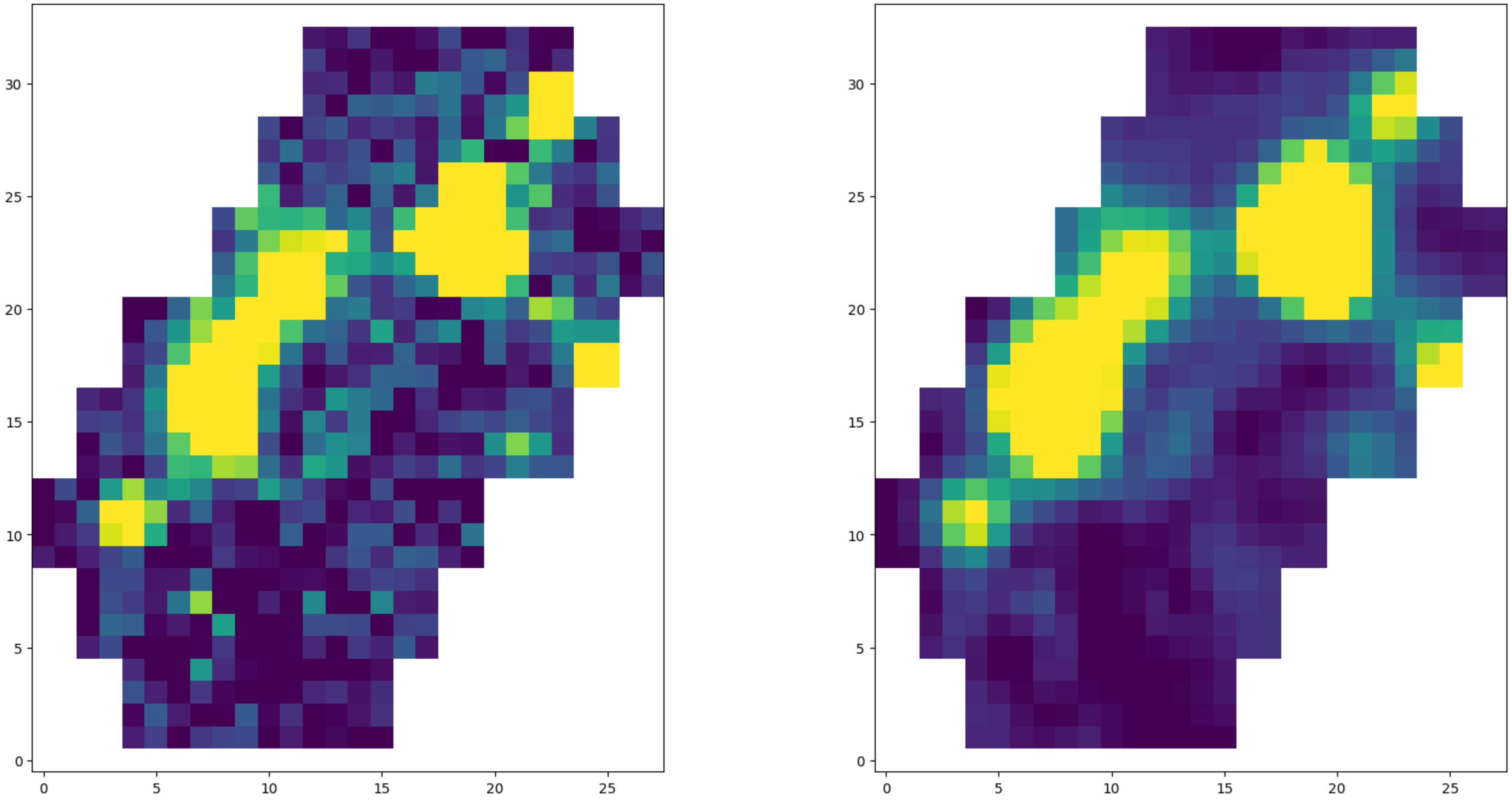
$$C_s(v) = S_s(v)/S_{s,5200-5600}$$

Sidelobe Contribution

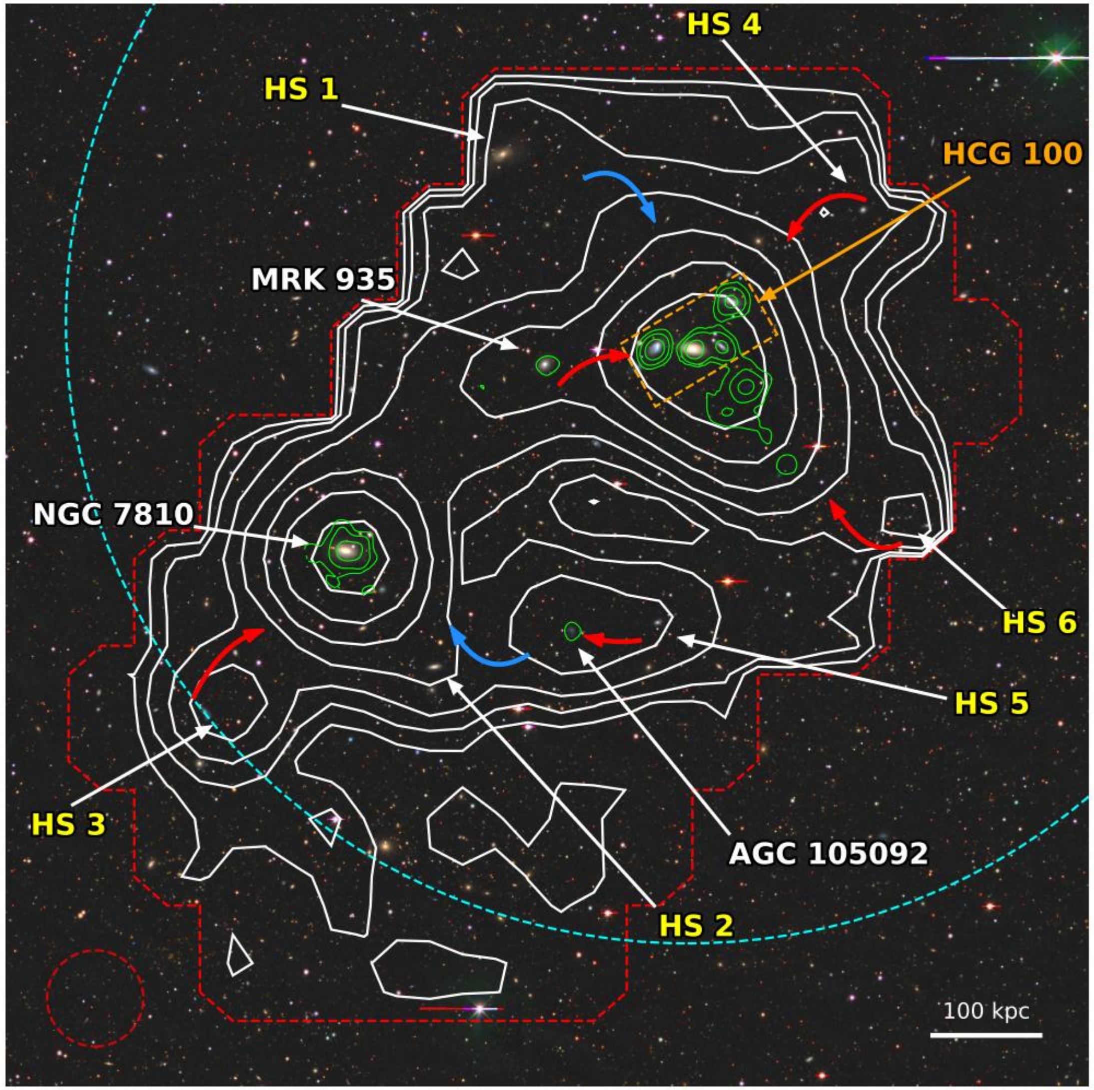


Yu et al. (2026)

Smoothing



Results: HI Column density and mass



Yu et al., 2026, ApJL, 1007, L32

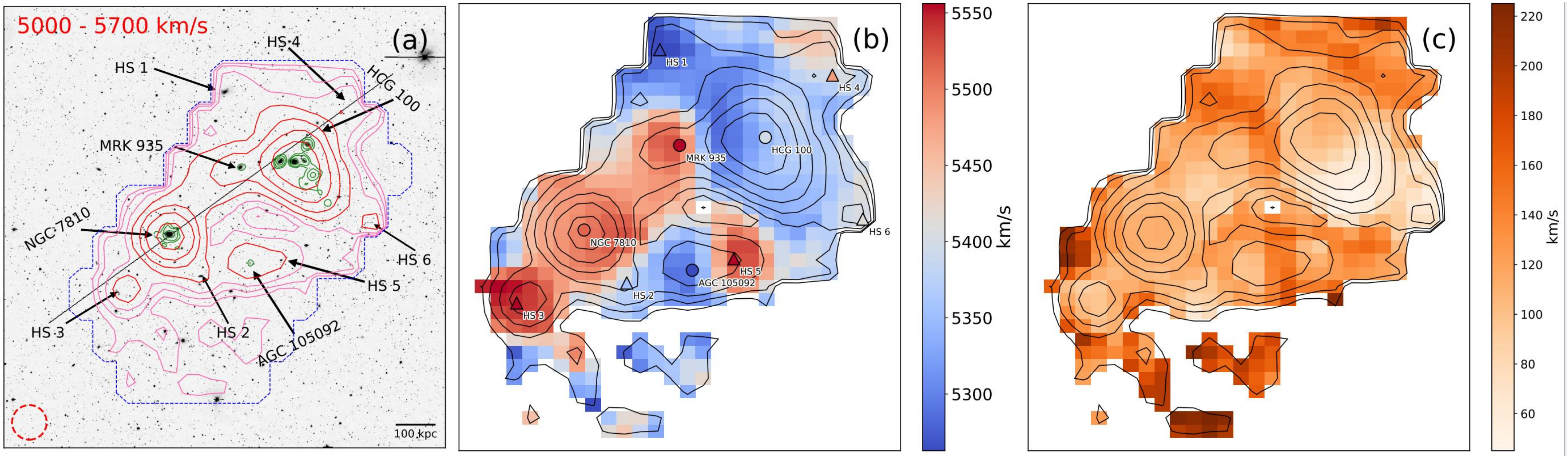
HI emission in 5000-5700 km/s
Projected length: ~1 Mpc

HI column density:
VLA: $\sim 9.3 \times 10^{19} cm^{-2}$ (3σ over 700 km/s)
FAST: $\sim 8.6 \times 10^{17} cm^{-2}$ (3σ over 700 km/s)

HI mass:
VLA: $(1.45 \pm 0.17) \times 10^{10} M_{\odot}$
FAST: $(3.10 \pm 0.31) \times 10^{10} M_{\odot}$

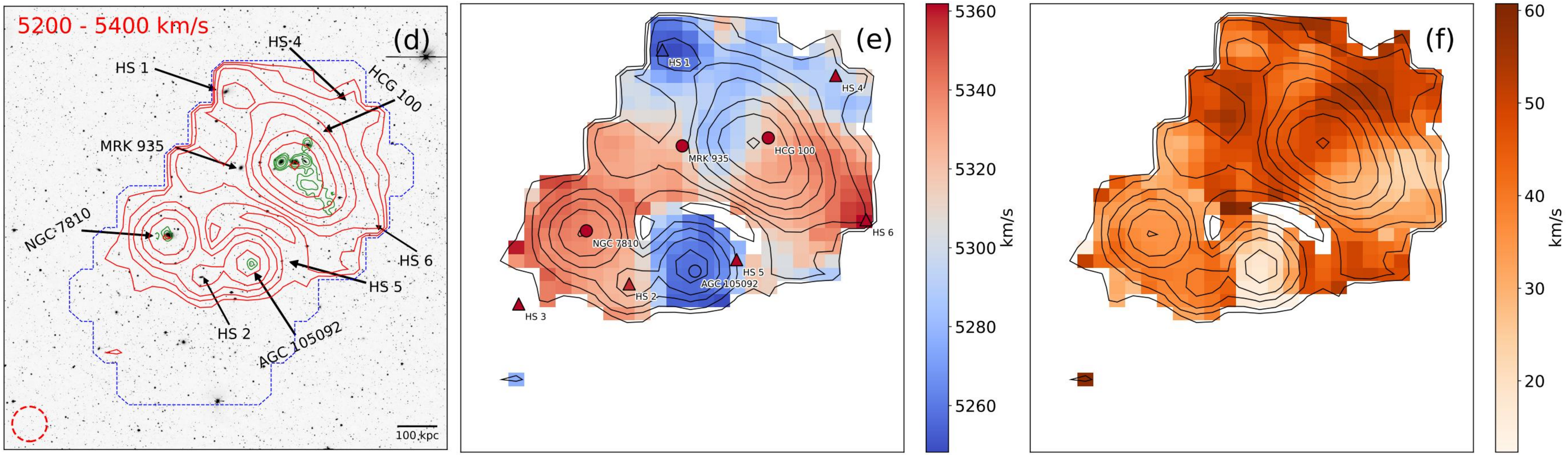
~40-50% diffuse HI resides outside galaxies

Moment Maps



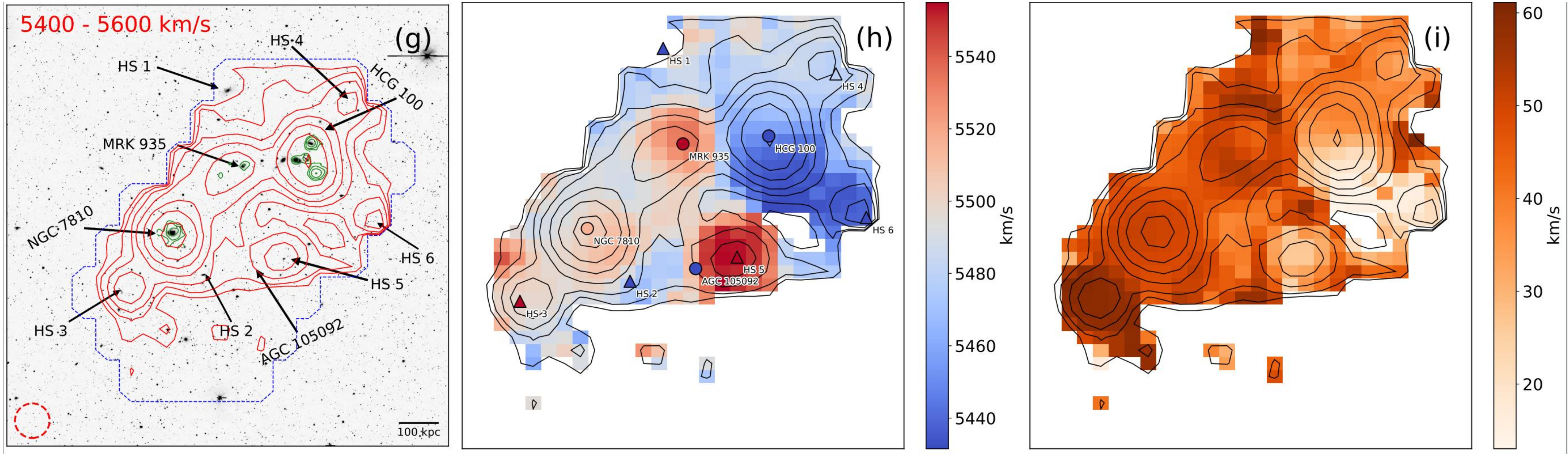
Yu et al. (2026)

Component 5300 km/s

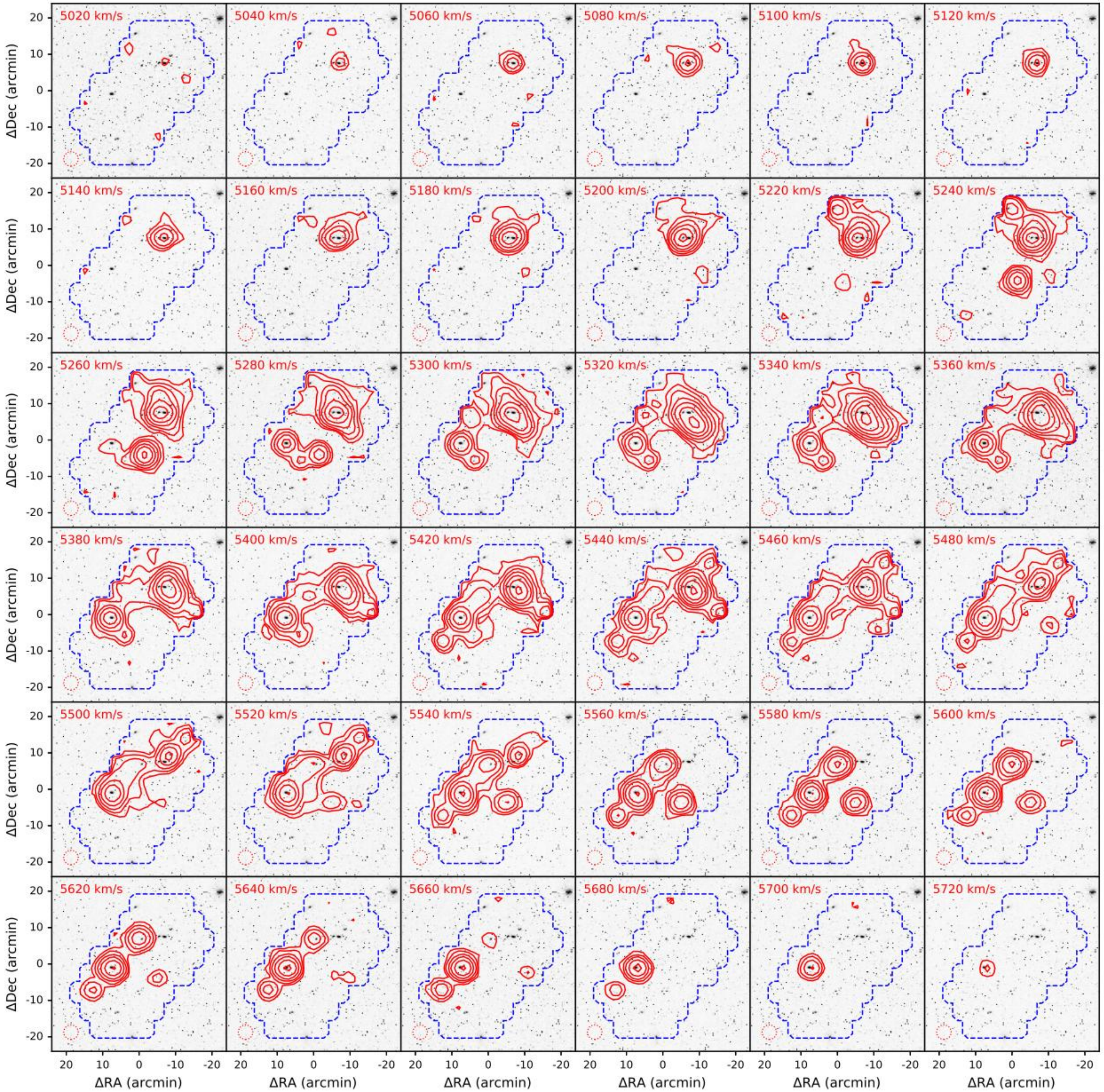


Yu et al. (2026)

Component 5500 km/s

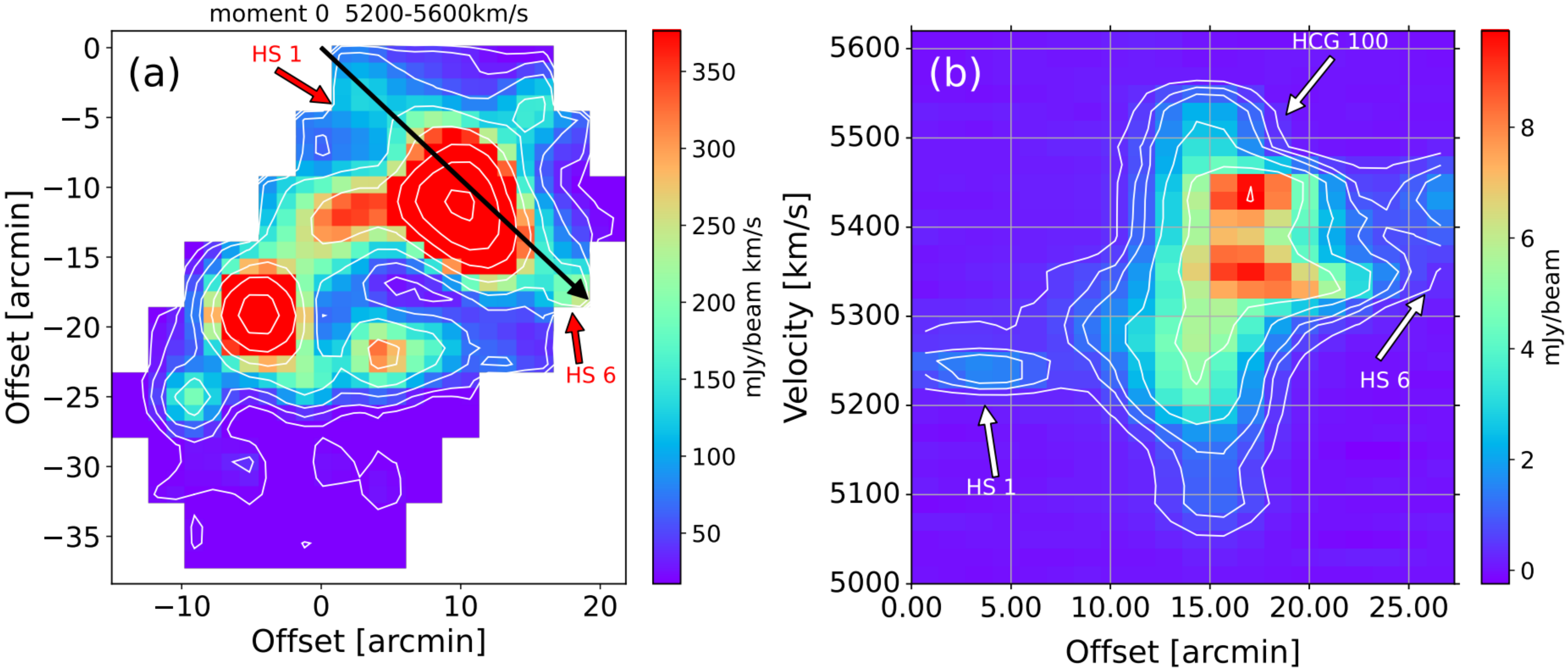


Yu et al. (2026)


5020 km/s
5040 km/s
5060 km/s
5080 km/s
5100 km/s
5120 km/s
5140 km/s
5160 km/s
5180 km/s
5200 km/s
5220 km/s
5240 km/s
5260 km/s
5280 km/s
5300 km/s
5320 km/s
5340 km/s
5360 km/s
5380 km/s
5400 km/s
5420 km/s
5440 km/s
5460 km/s
5480 km/s
5500 km/s
5520 km/s
5540 km/s
5560 km/s
5580 km/s
5600 km/s
5620 km/s
5640 km/s
5660 km/s
5680 km/s
5700 km/s
5720 km/s
ΔDec (arcmin)
ΔRA (arcmin)

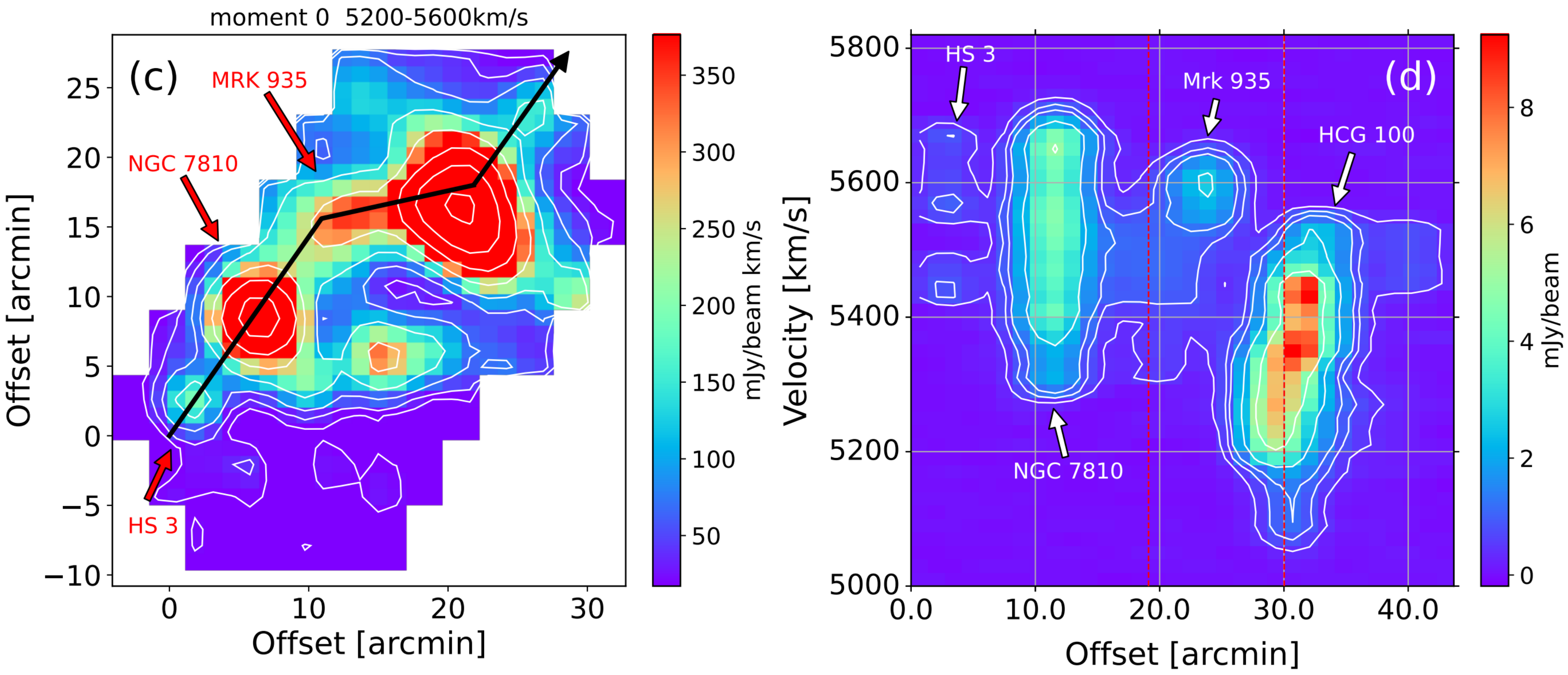
Yu et al. (2026)

PV-diagram



Yu et al. (2026)

PV-diagram



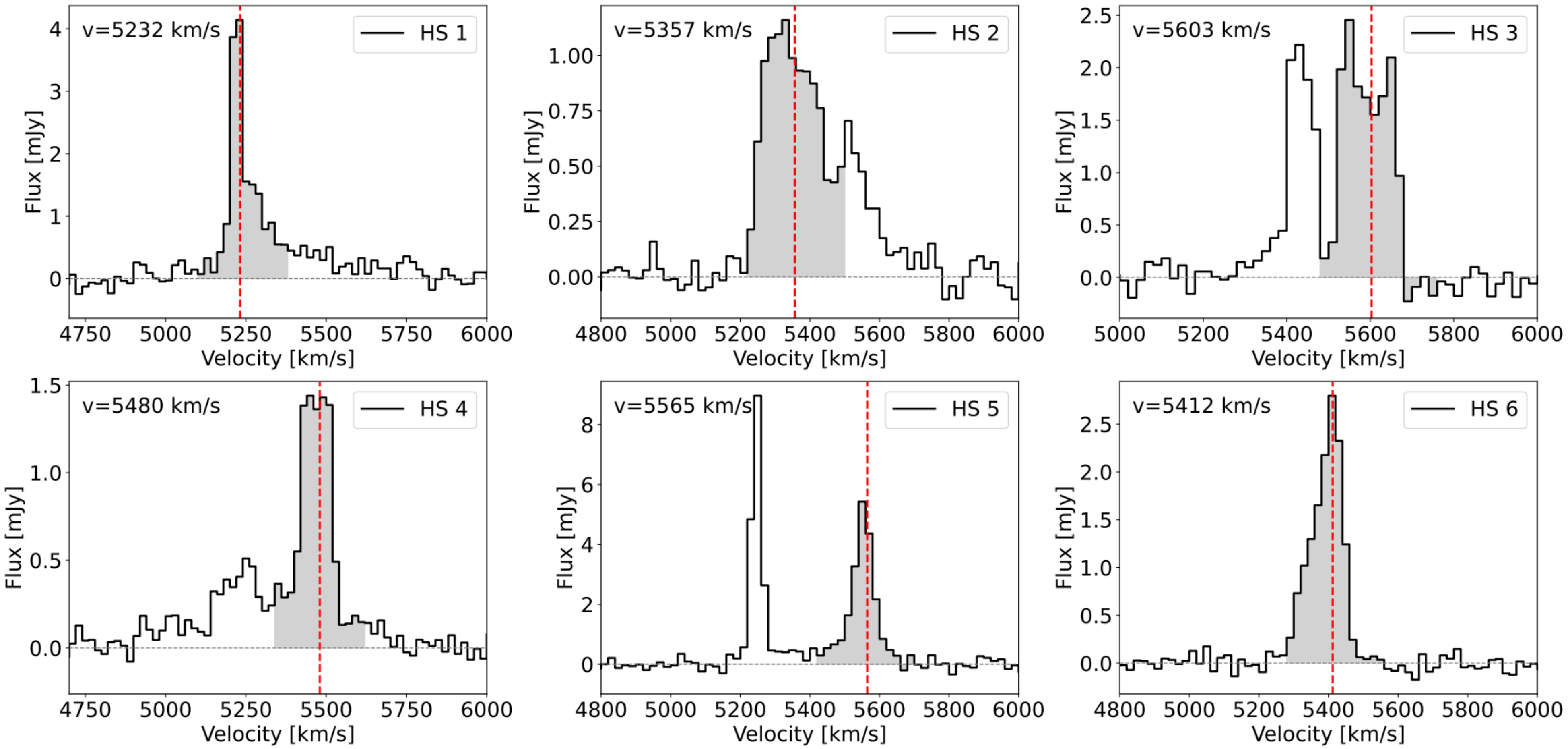
Yu et al. (2026)

Origin of the Diffuse HI

- Stripped HI gas from past interactions?

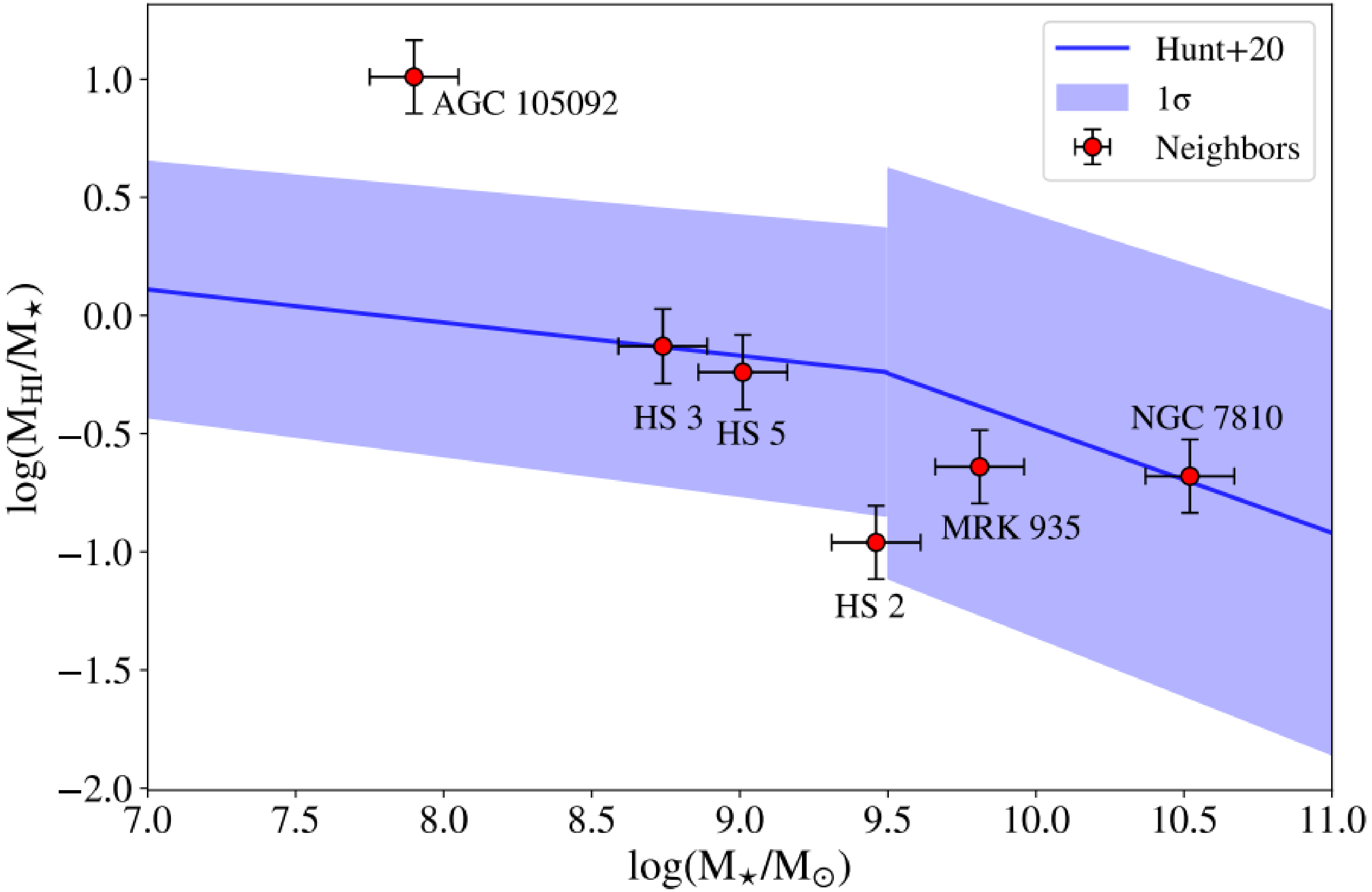
- Pristine gas accreted from large-scale structure?

New HI Sources



Yu et al. (2026)

HI Fraction of Neighboring Galaxies



Yu et al. (2026)

HI fractions of galaxies surrounding HCG 100 are consistent with star-forming galaxies in the local Universe

Origin and Fate of the Diffuse HI

Stripped gas or accreted gas

Low density HI exists >1 Gyr?

Fuel star formation or be ionized?

Deep high-resolution observations

Simulations across many scales

for multiphase gas

Summary

1. We detect a diffuse HI structure extending over ~1 Mpc around HCG 100 , with column density down to $8.6 \times 10^{17} cm^{-2}$.
2. The extended structure contains $\sim 1.4 \times 10^{10} M_{\odot}$ of diffuse neutral gas, implying that up to ~40-50% of the HI gas resides outside galaxies.
3. The large-scale diffuse HI may originate from large-scale tidal debris or gas accretion from the surrounding large-scale structure.
4. Our results demonstrate that massive reservoirs of diffuse neutral gas can persist on megaparsec scales around galaxy groups for extended periods.