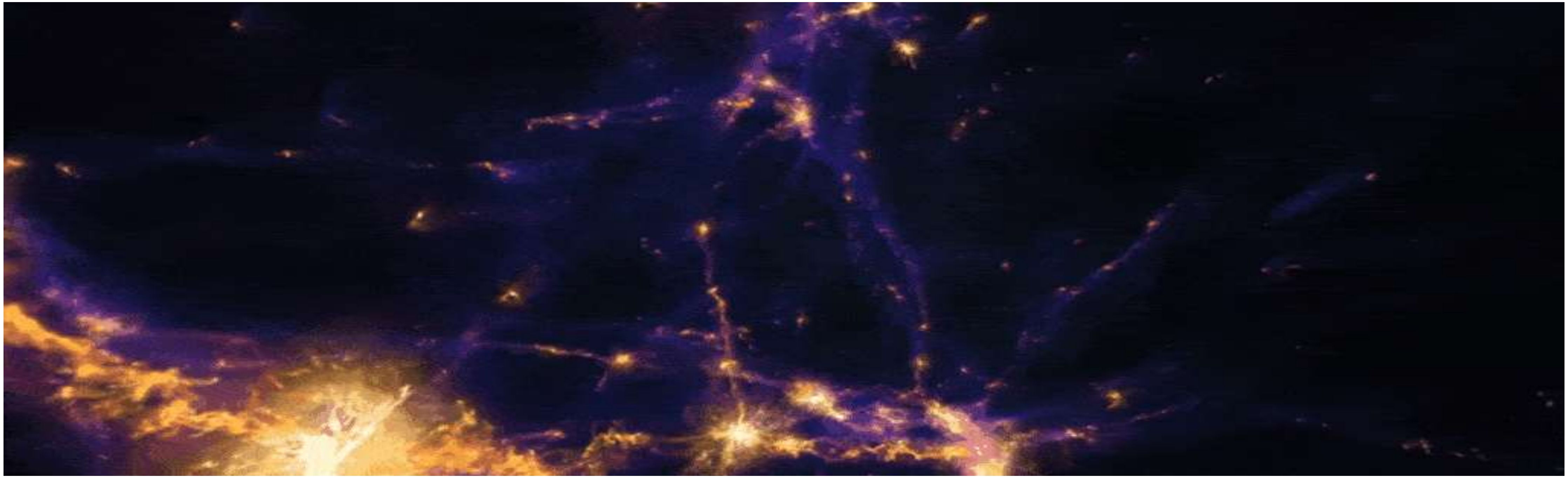
中性氢星系观测研究



朱明
国家天文台
FAST 运行和发展中心
2026-08-20

提纲

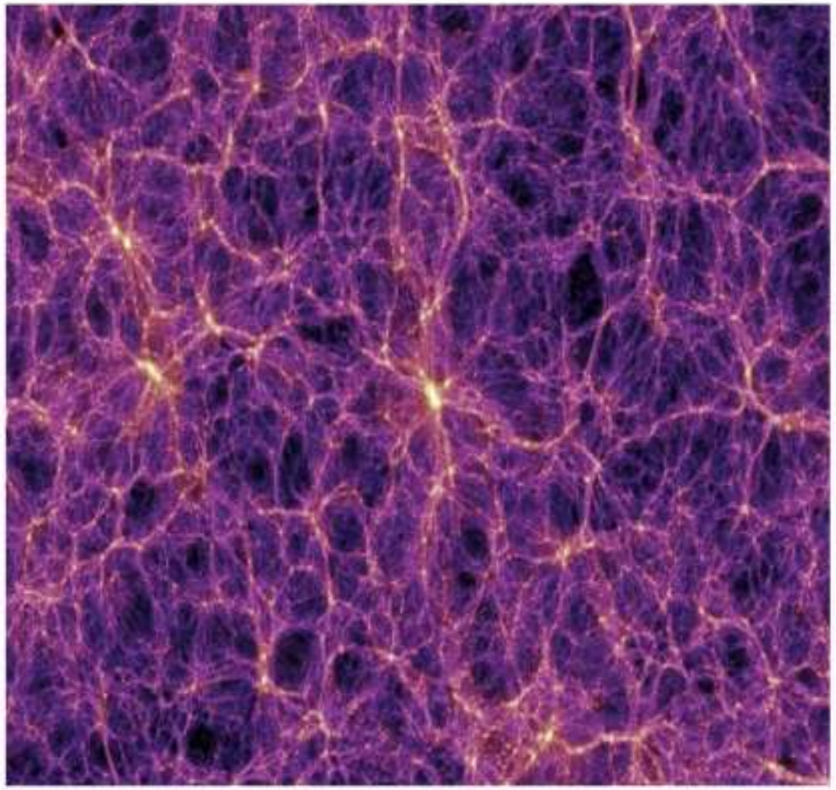
1. 单个中性氢星系的成图观测

2. 中性氢星系非成图观测– 中性氢巡天

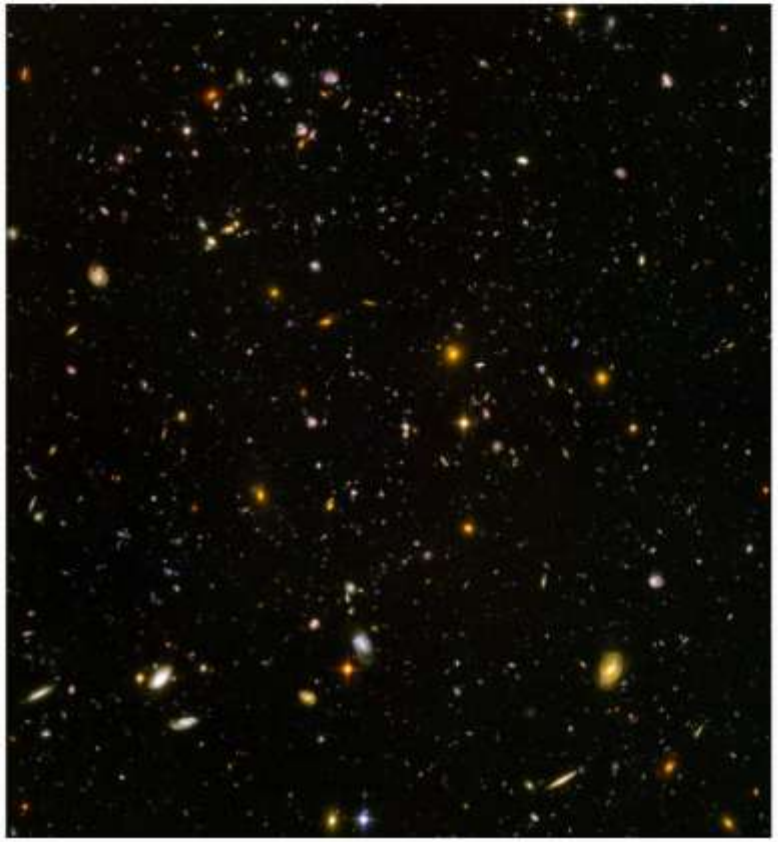
HI is better chaser of Dark Matter?

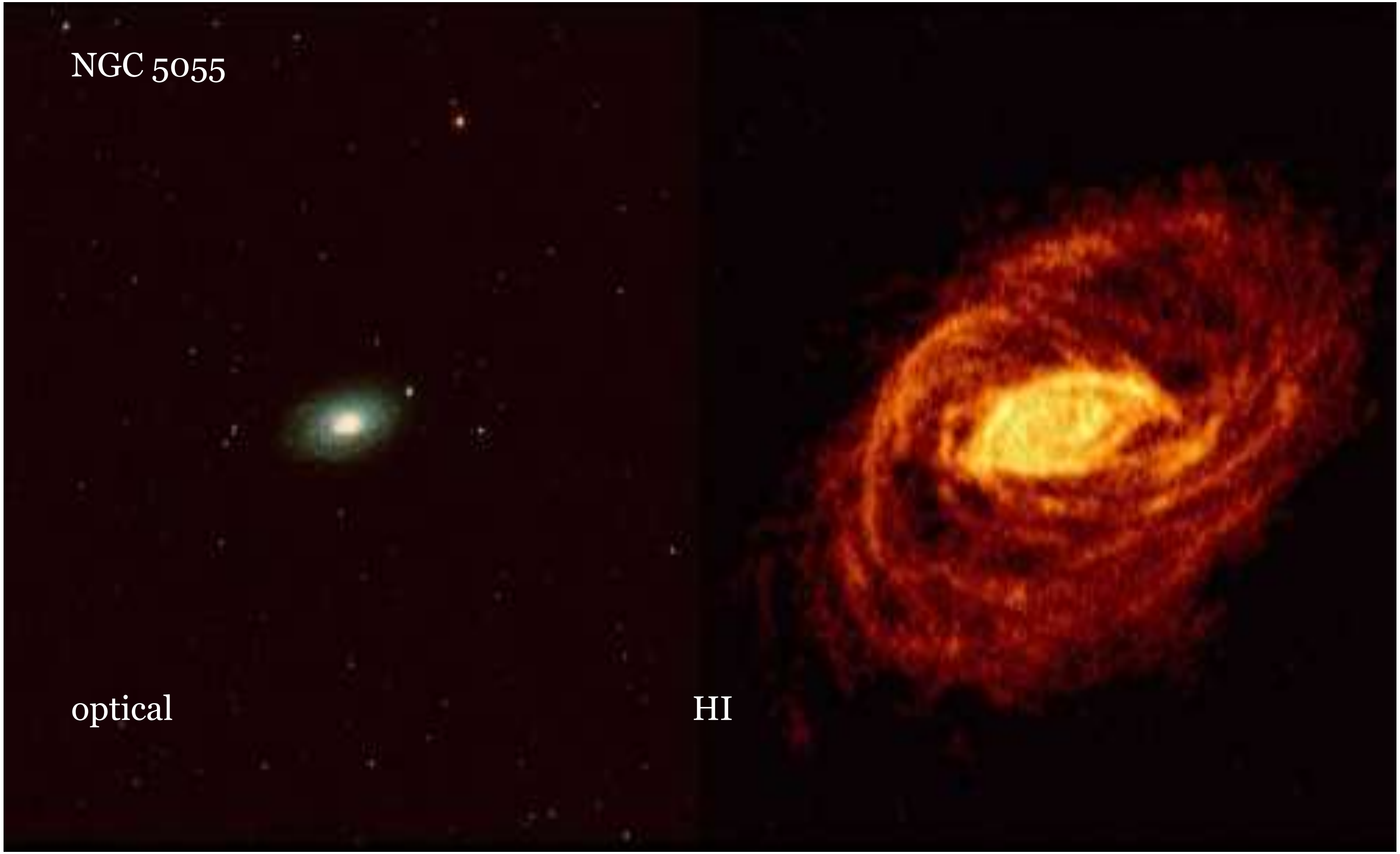
cosmology with HI surveys

we predict this...

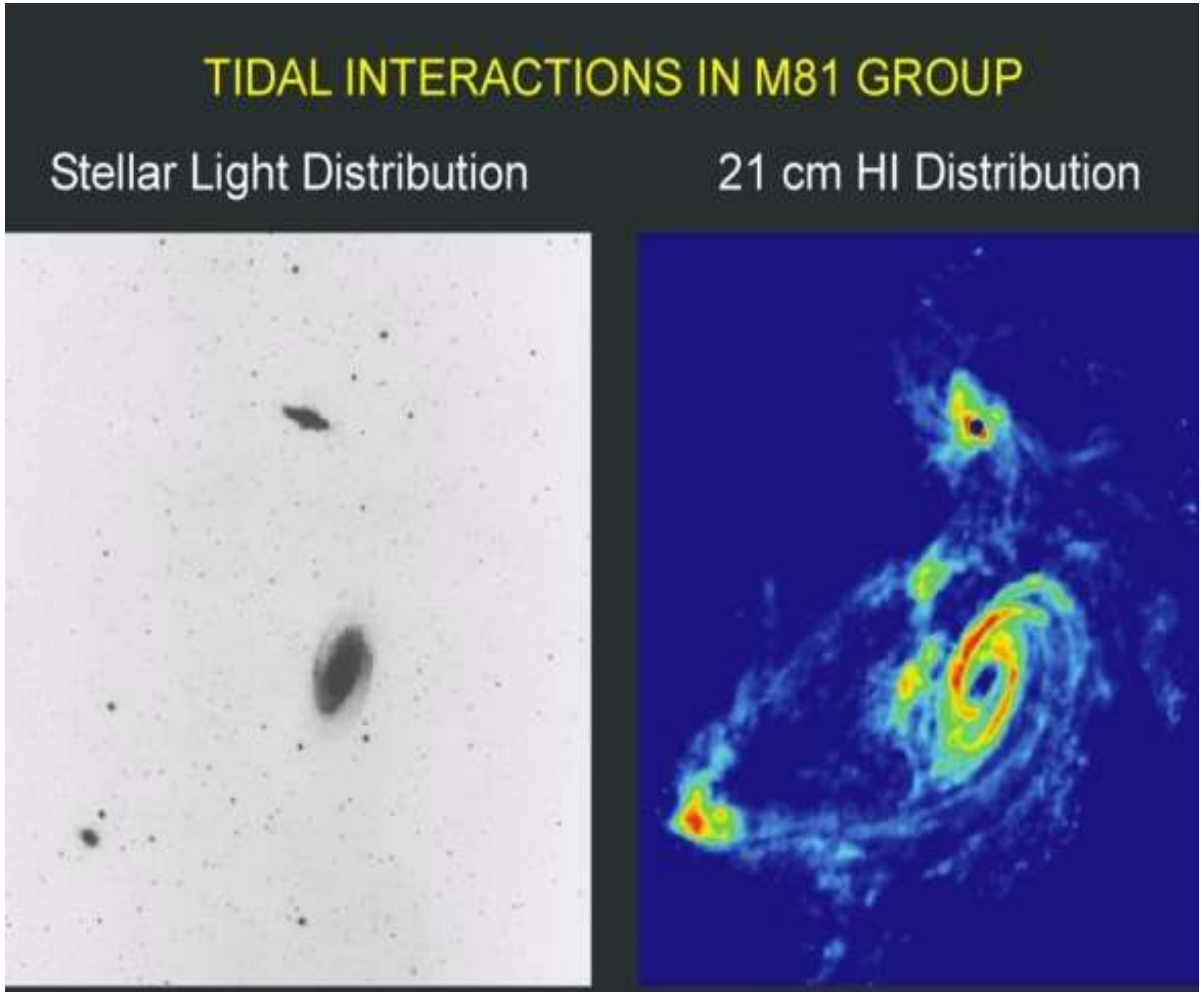


... but we measure this

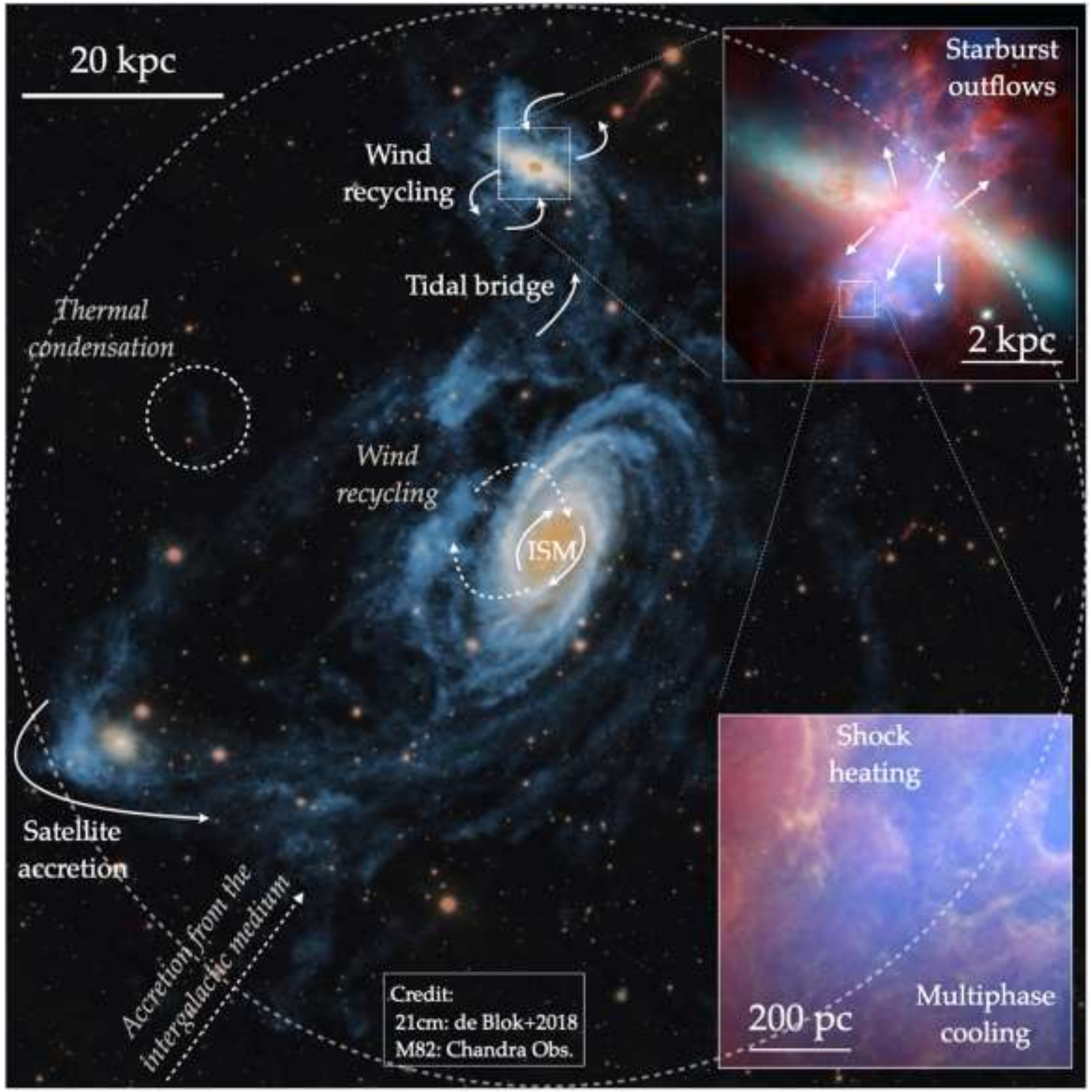



NGC 5055
optical
HI

中性氢研究内容

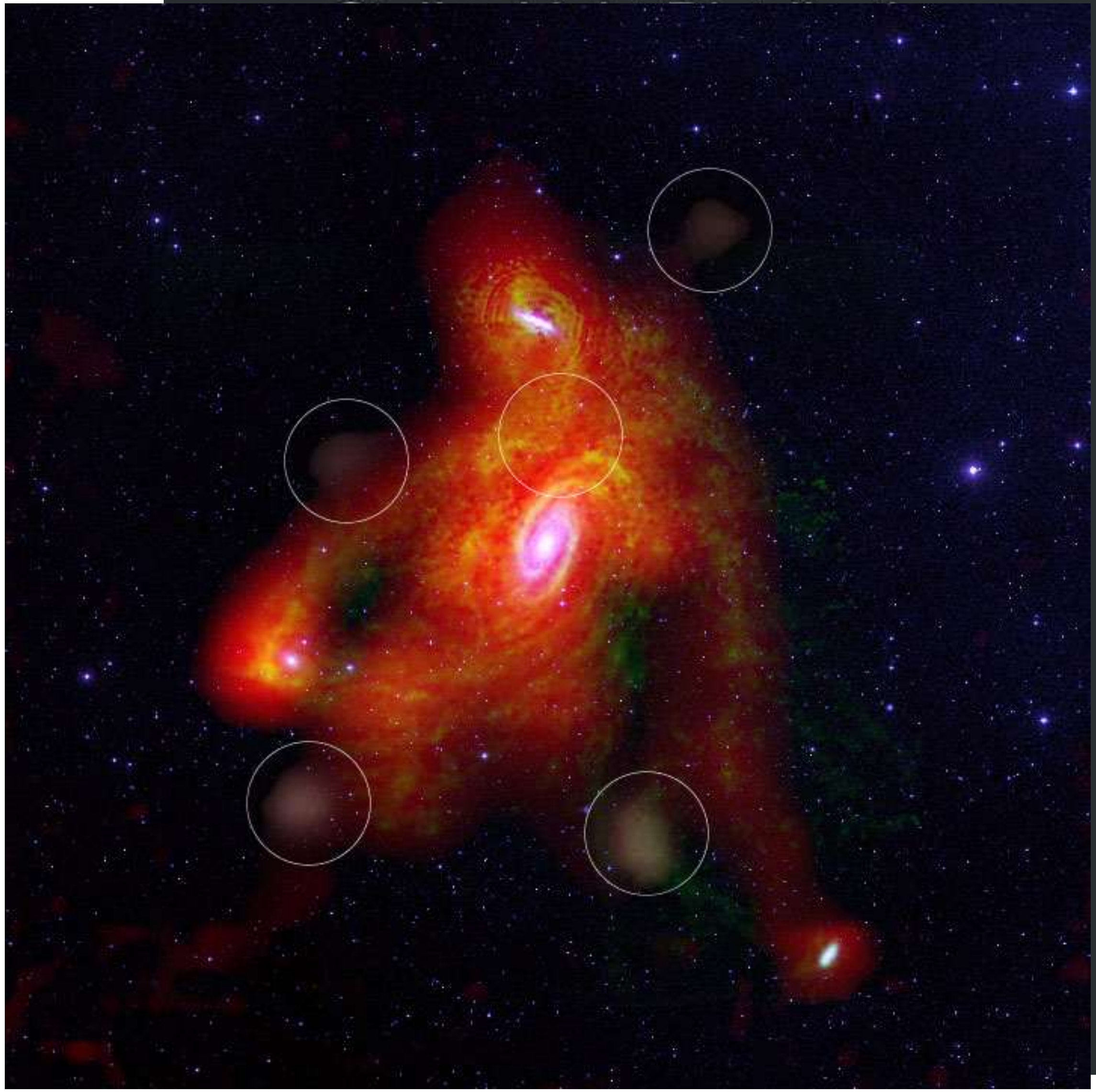


TIDAL INTERACTIONS IN M81 GROUP
Stellar Light Distribution
21 cm HI Distribution

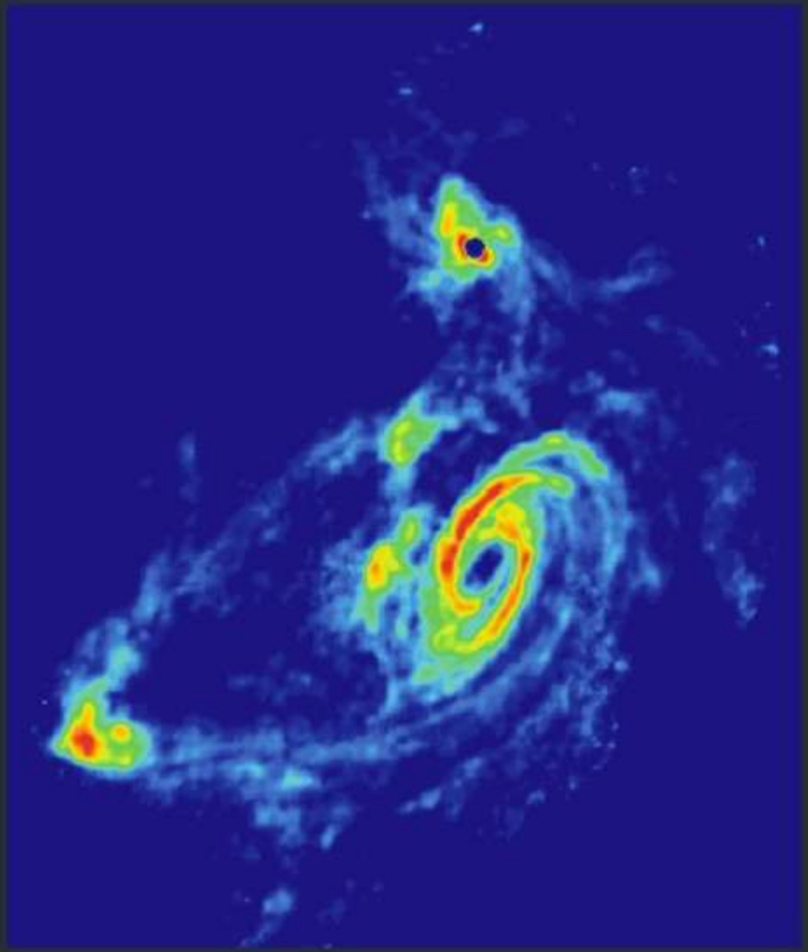


20 kpc
Wind recycling
Tidal bridge
Thermal condensation
Wind recycling
ISM
Satellite accretion
Accretion from the intergalactic medium
Starburst outflows
2 kpc
Shock heating
Multiphase cooling
200 pc
Credit:
21cm: de Blok+2018
M82: Chandra Obs.

TIDAL INTERACTIONS IN M81 GROUP



21 cm HI Distribution



Credit: Chynoweth et al and NRAO/AUI

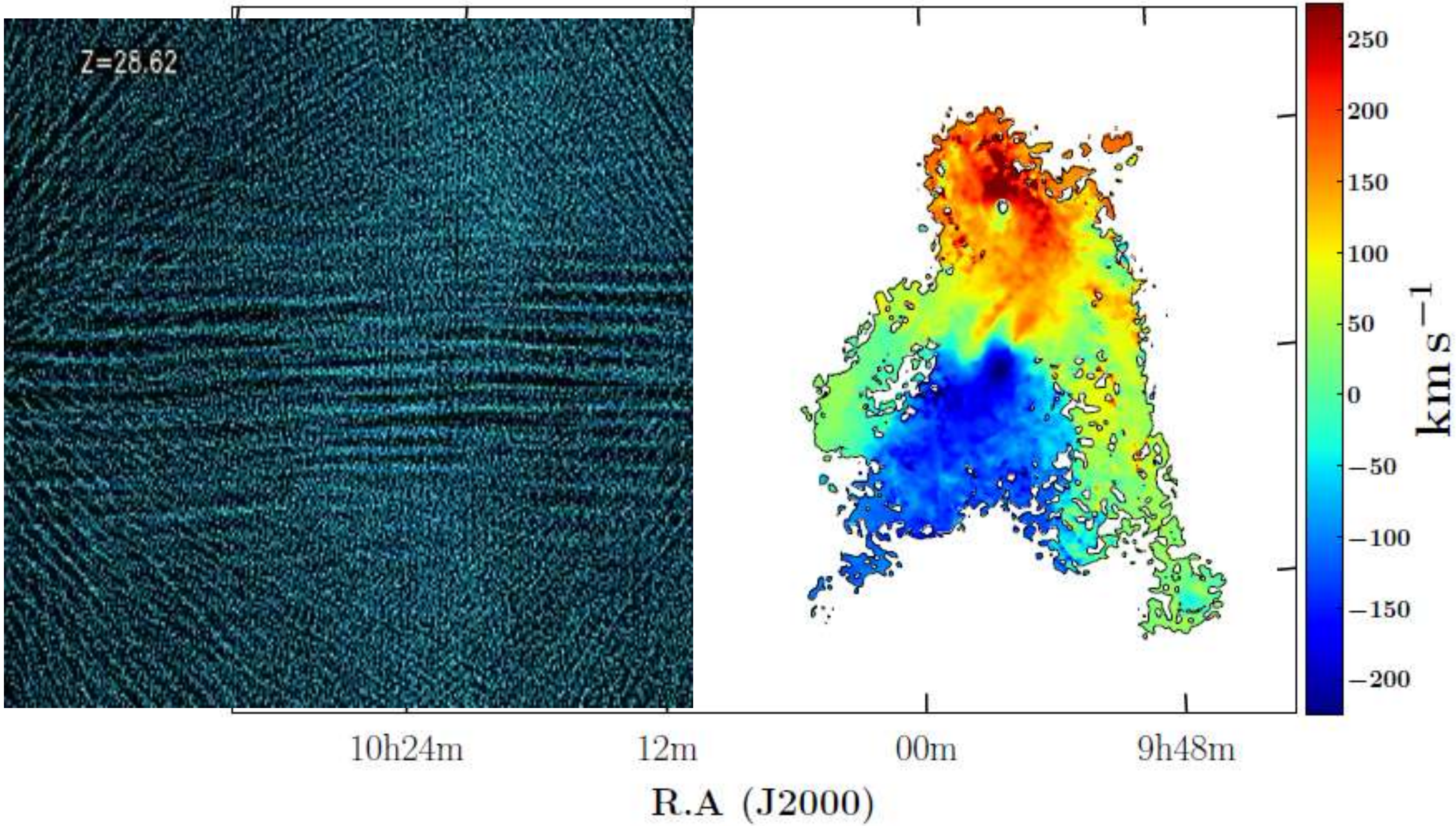
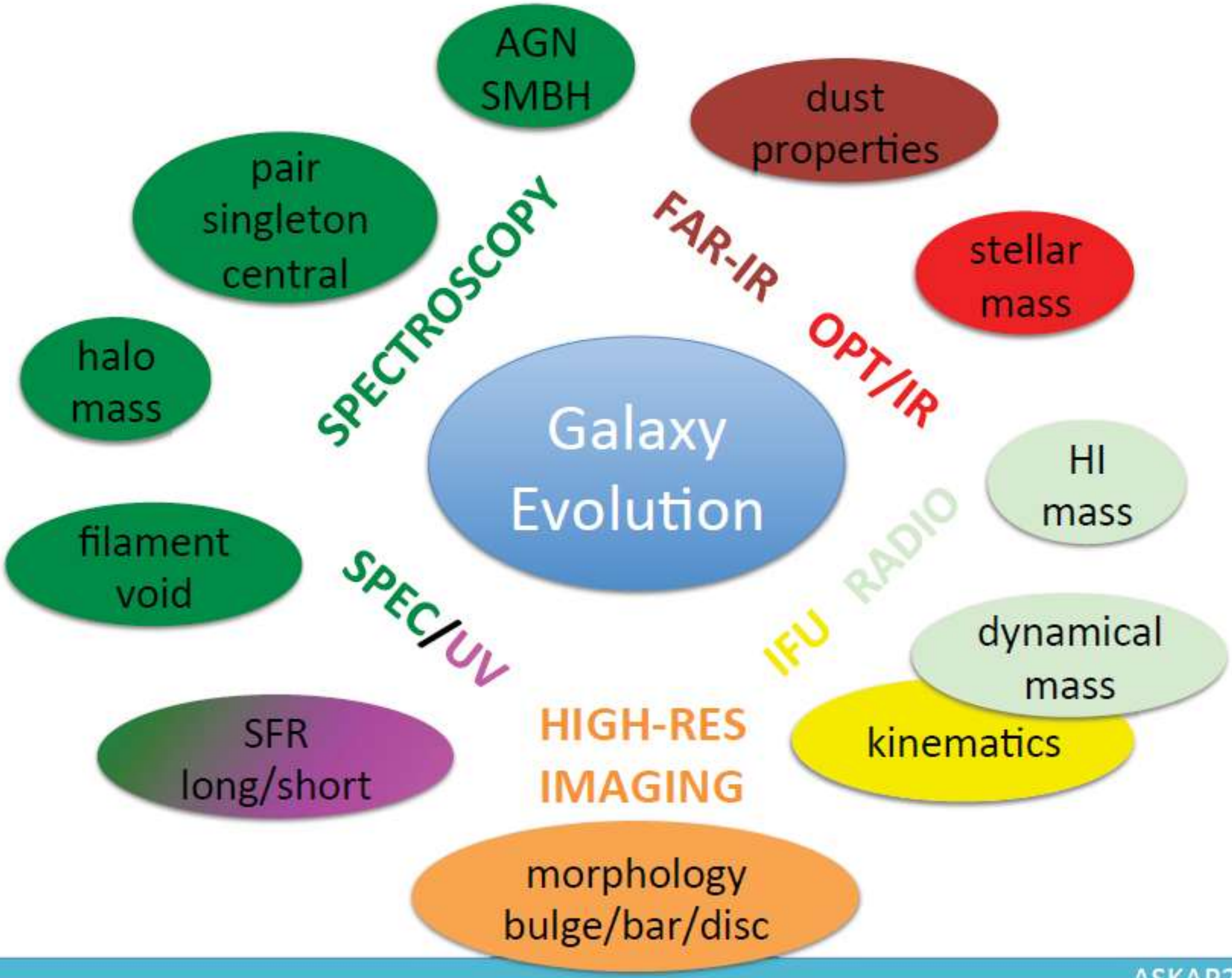
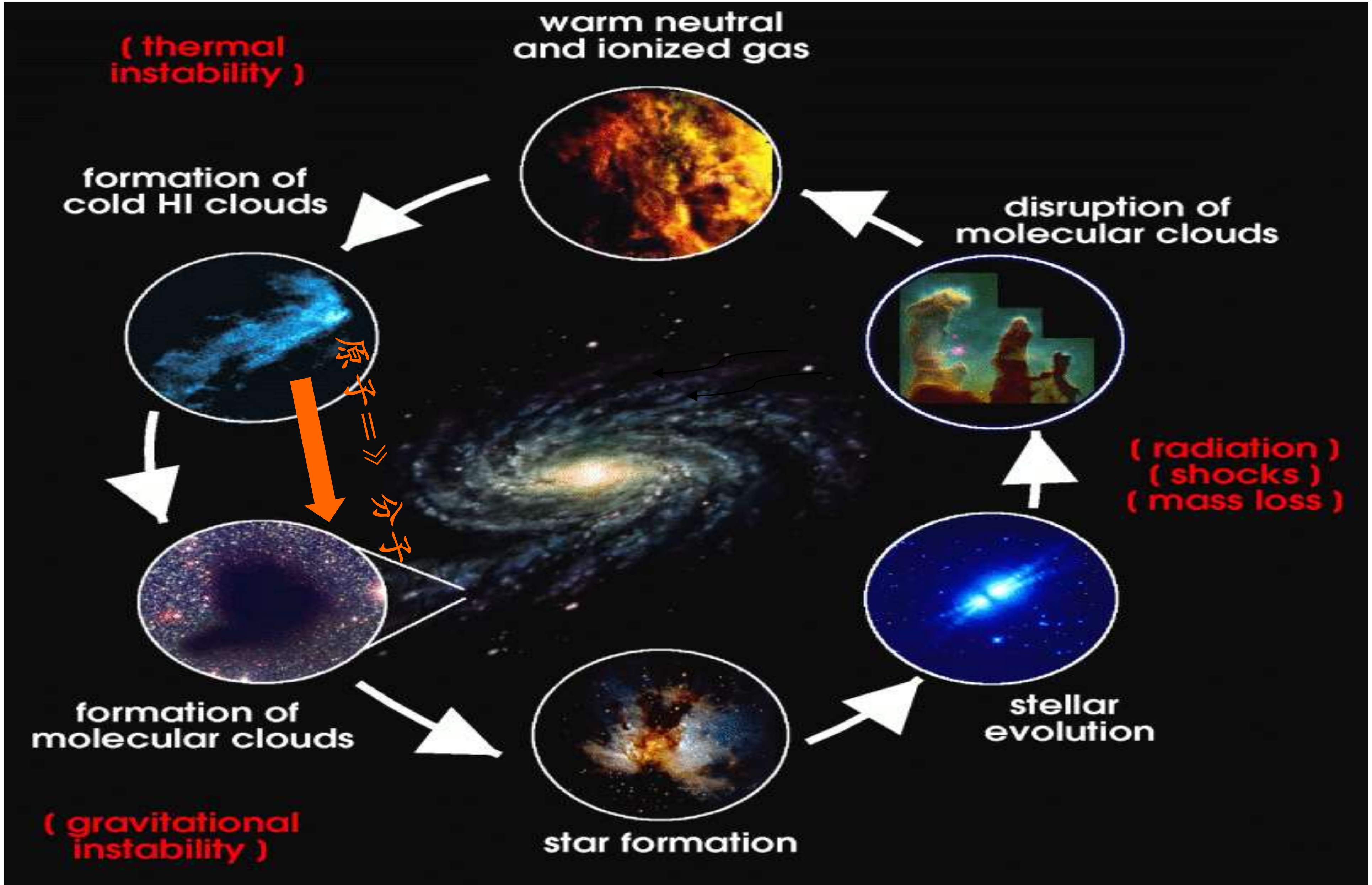


Figure 10. The intensity weighted velocity field of the M81 group derived from the DRAO 1.8′ resolution datacube. The contour corresponds to the $1 \times 10^{19}\,\mathrm{cm}^{-2}$ column density level.


AGN
SMBH
dust
properties
pair
singleton
central
SPECTROSCOPY
FAR-IR
stellar
mass
halo
mass
OPT/IR
Galaxy
Evolution
HI
mass
RADIO
filament
void
SPEC/UV
IFU
dynamical
mass
SFR
long/short
HIGH-RES
IMAGING
kinematics
morphology
bulge/bar/disc

ASKAP2016

星际介质的生命周期

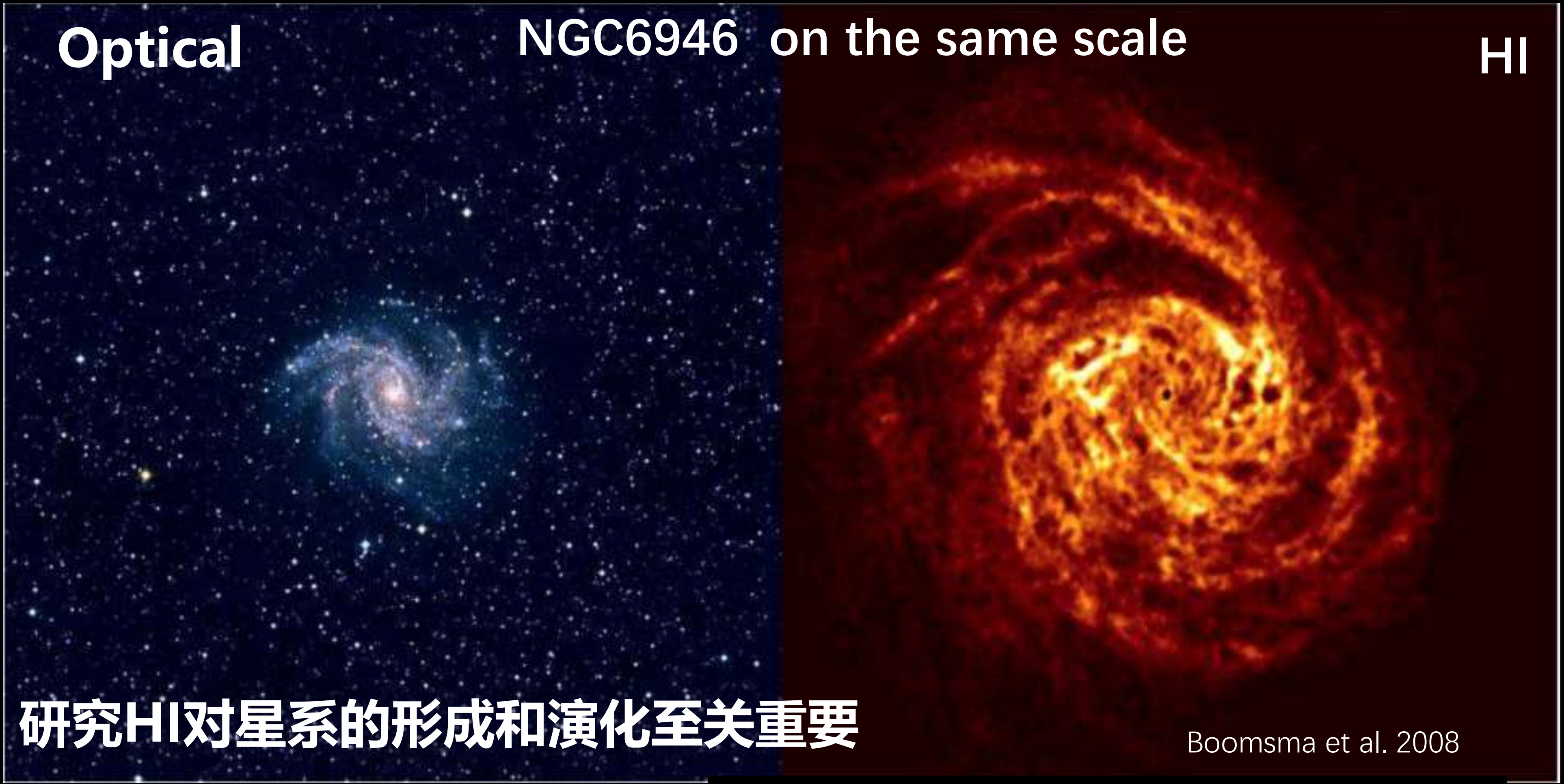


warm neutral
and ionized gas
(thermal
instability)
formation of
cold HI clouds
disruption of
molecular clouds
原子=》分子
(radiation)
(shocks)
(mass loss)
formation of
molecular clouds
stellar
evolution
(gravitational
instability)
star formation

星系形成和演化相关的HI科学问题

- 1）暗物质的性质；
- 2）HI的旋转曲线在测量暗物质分布的能力。

- 3）气体是如何进入到暗晕中，并在星系中如何分布的？星系如何失去气体？
- 4）恒星形成率与气体含量的规律及其演化，恒星活动如何改变气体的分布？
- 5）星系并合对气体分布的影响
- 6）HI的含量/分布与星系质量、暗晕质量，大尺度环境的关系等性质的关系，以及随红移的演化
- 7）近邻宇宙中矮星系中的HI含量

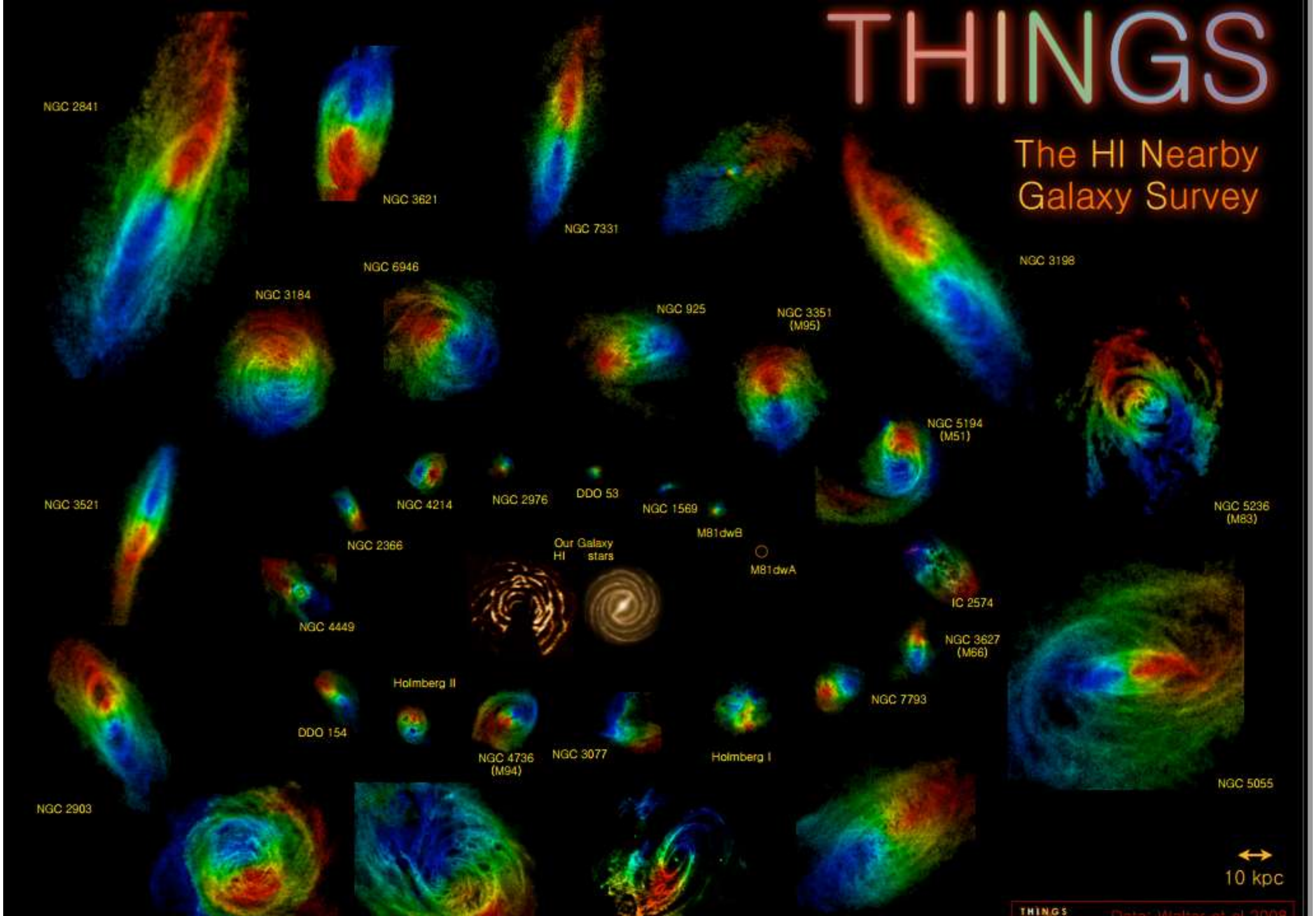


- 星系怎样获得气体?
- HI、分子氢、电离气体间的相互作用，以及和恒星形成、熄灭间的关系
- HI和星系环境间的关系
- AGN回馈和恒星形成回馈对HI的影响

- **星系中的HI的分布、结构和动力学特性**
- **星系的HI质量函数**
- **宇宙网格中，如纤维结构中的HI**
- **搜寻理论预测的暗星系**
- **暗物质缺失星系**

随红移的演化　**需要大样本、高空间分辨率、深场HI巡天**

THINGS
The HI Nearby Galaxy Survey
NGC 2841
NGC 3621
NGC 7331
NGC 4826 (M64)
NGC 3198
NGC 6946
NGC 3184
NGC 925
NGC 3351 (M95)
NGC 5194 (M51)
NGC 5236 (M83)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 1569
M81dwB
NGC 2366
Our Galaxy
HI stars
M81dwA
IC 2574
NGC 4449
NGC 3627 (M66)
Holmberg II
NGC 7793
DDO 154
NGC 4736 (M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc
NGC 628 (M74)
NGC 5457 (M101)
NGC 3031 (M81)
NGC 2403
Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)


THINGS
The HI Nearby Galaxy Survey
NGC 2841
NGC 3621
NGC 7331
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NGC 6946
NGC 3184
NGC 925
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NGC 5194 (M51)
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NGC 2976
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Our Galaxy
HI stars
M81dwA
IC 2574
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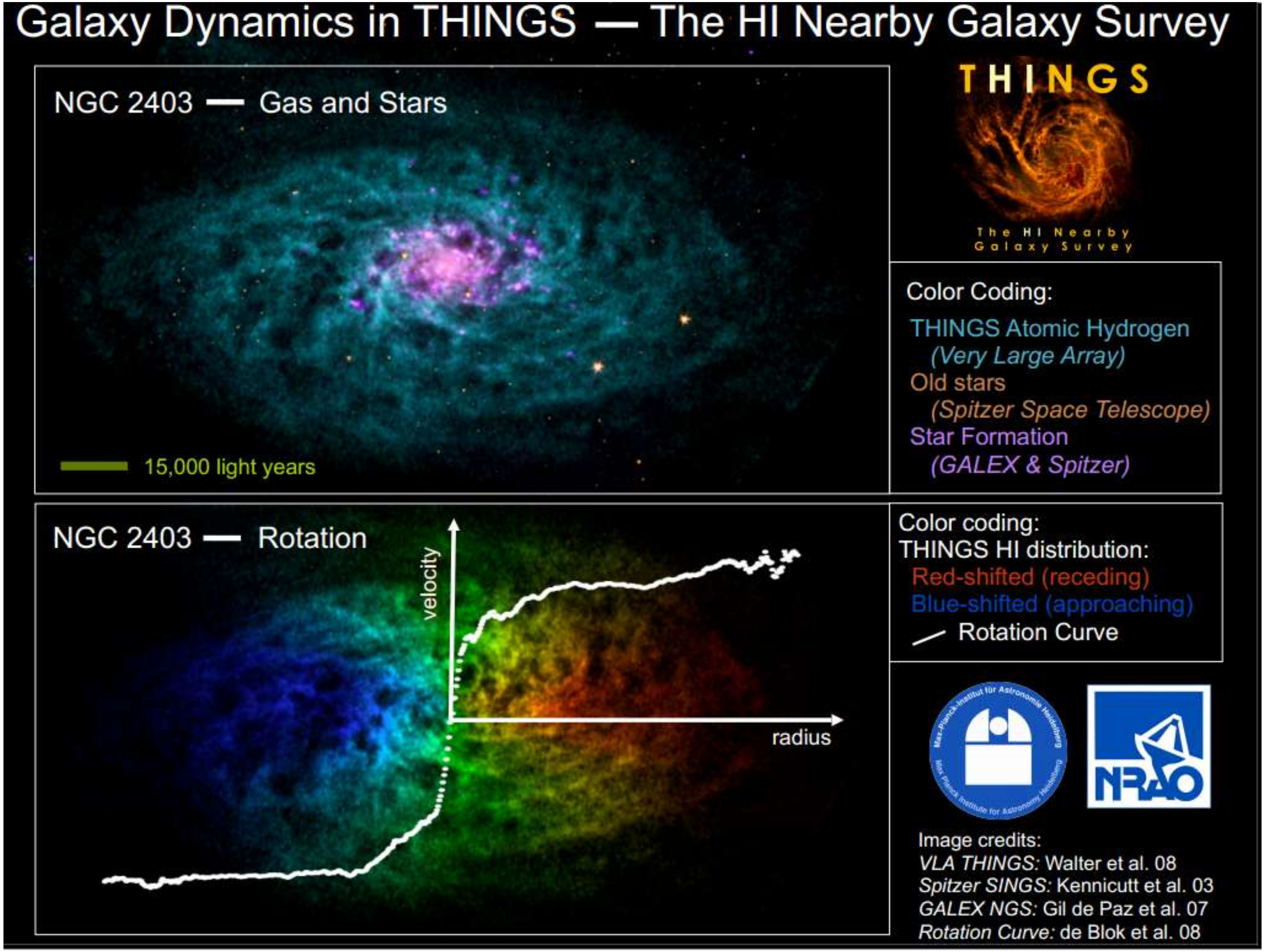
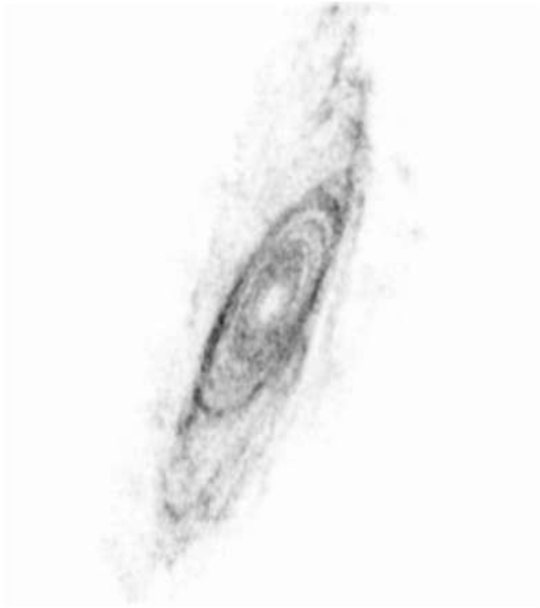
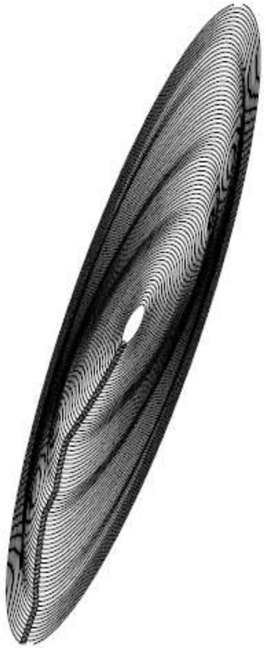
NGC 3627 (M66)
Holmberg II
NGC 7793
DDO 154
NGC 4736 (M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc


Galaxy Dynamics in THINGS — The HI Nearby Galaxy Survey
NGC 2403 — Gas and Stars
15,000 light years
THINGS
The HI Nearby Galaxy Survey
Color Coding:
THINGS Atomic Hydrogen
(Very Large Array)
Old stars
(Spitzer Space Telescope)
Star Formation
(GALEX & Spitzer)
NGC 2403 — Rotation
velocity
radius
Color coding:
THINGS HI distribution:
Red-shifted (receding)
Blue-shifted (approaching)
Rotation Curve
NRAO
Image credits:
VLA THINGS: Walter et al. 08
Spitzer SINGS: Kennicutt et al. 03
GALEX NGS: Gil de Paz et al. 07
Rotation Curve: de Blok et al. 08

Tilted Rings



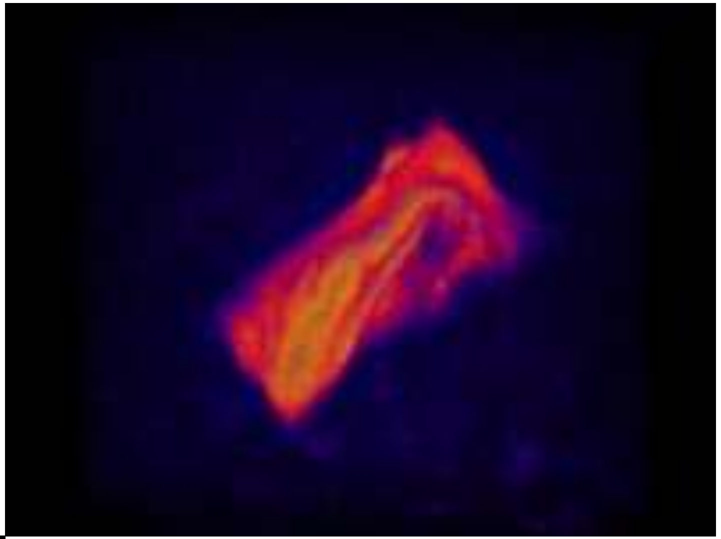


- Model galaxy with concentric rings with center (x,y) and systemic velocity V_{sys} each with their own i, PA, and V

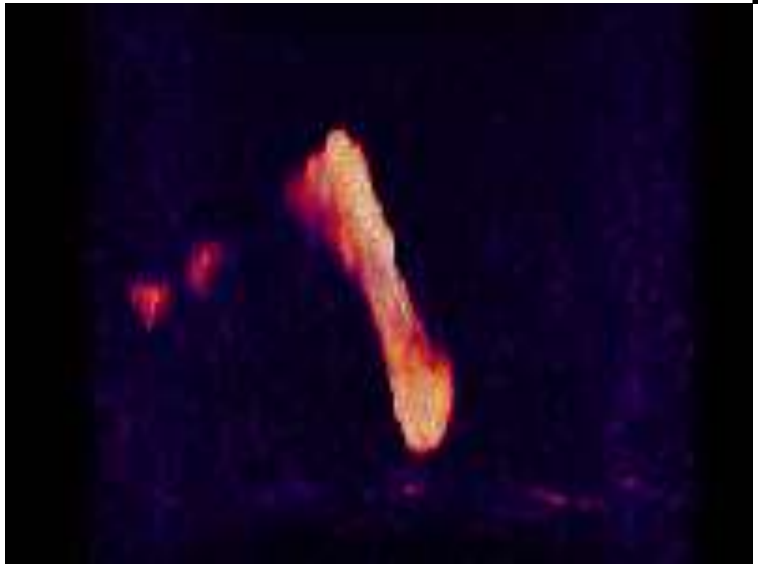
$$\mathbf{V(x,y) = V_{sys} + V_C(R)\,\sin(i)\cos(\theta)}$$

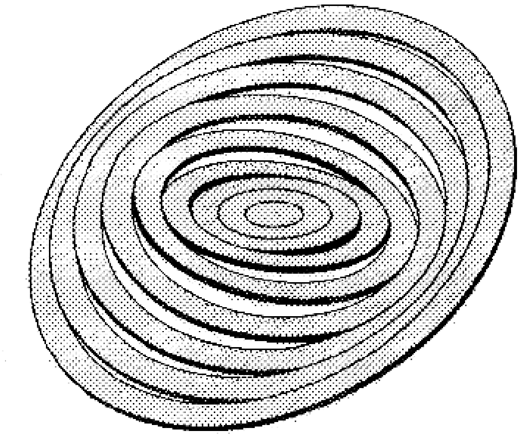
复杂的HI盘结构

NGC300

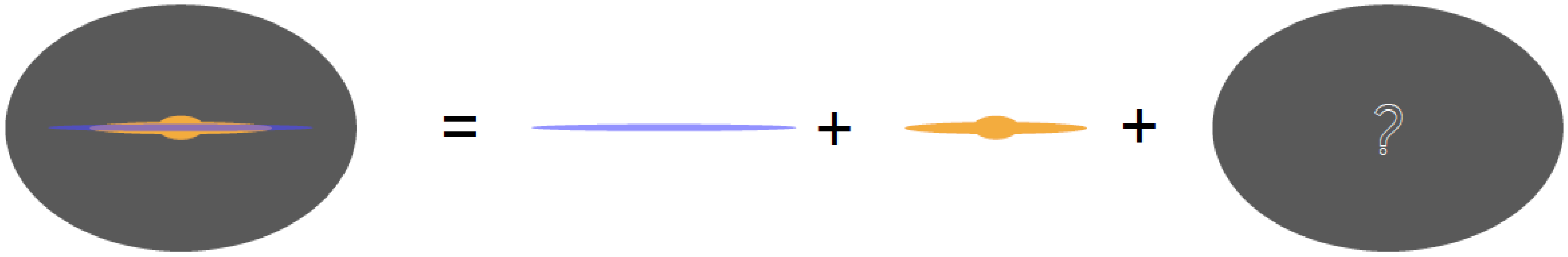


NGC55





Mass Models

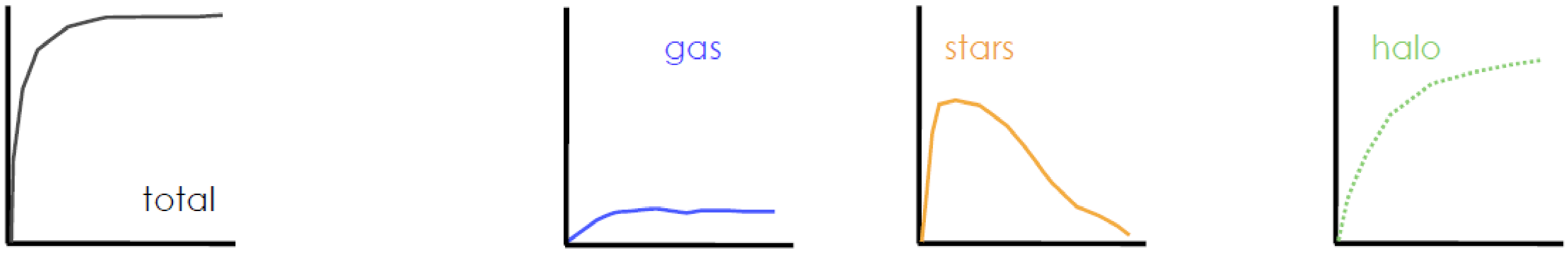


$$M_{tot} = M_{gas} + M_{disk} + M_{halo}$$

$1.4 M_{HI}$ (gas) $\quad \Upsilon_*$ (disk)

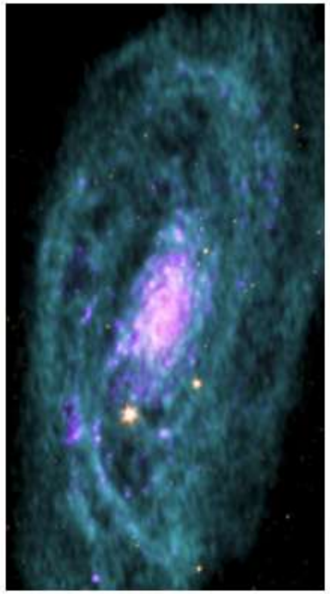
here: based on 3.6mu Spitzer

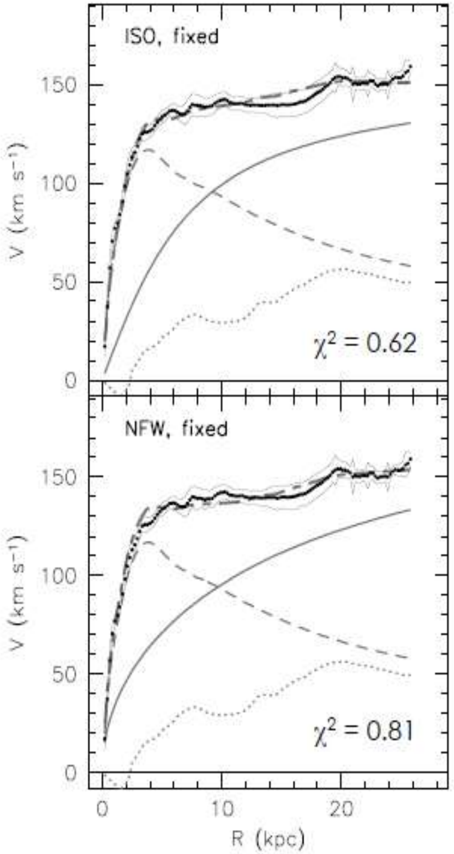
$$V^2_{tot} = V^2_{gas} + V^2_{disk} + V^2_{halo}$$

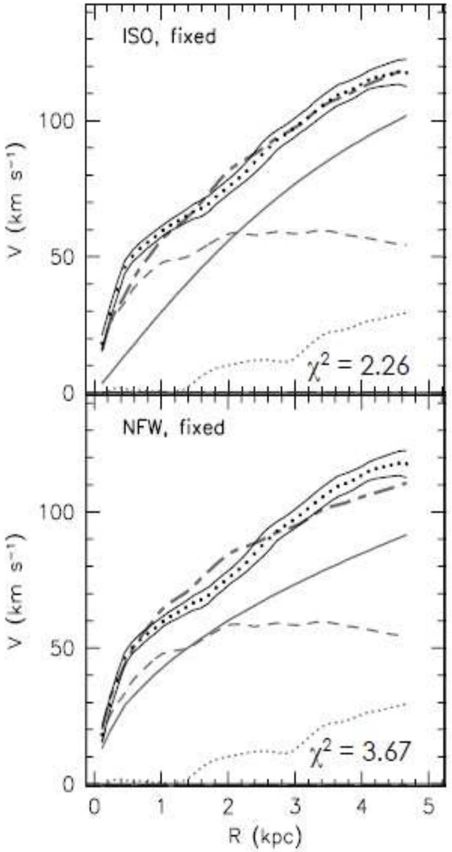


Credit:
Erwin de Blok

Examples

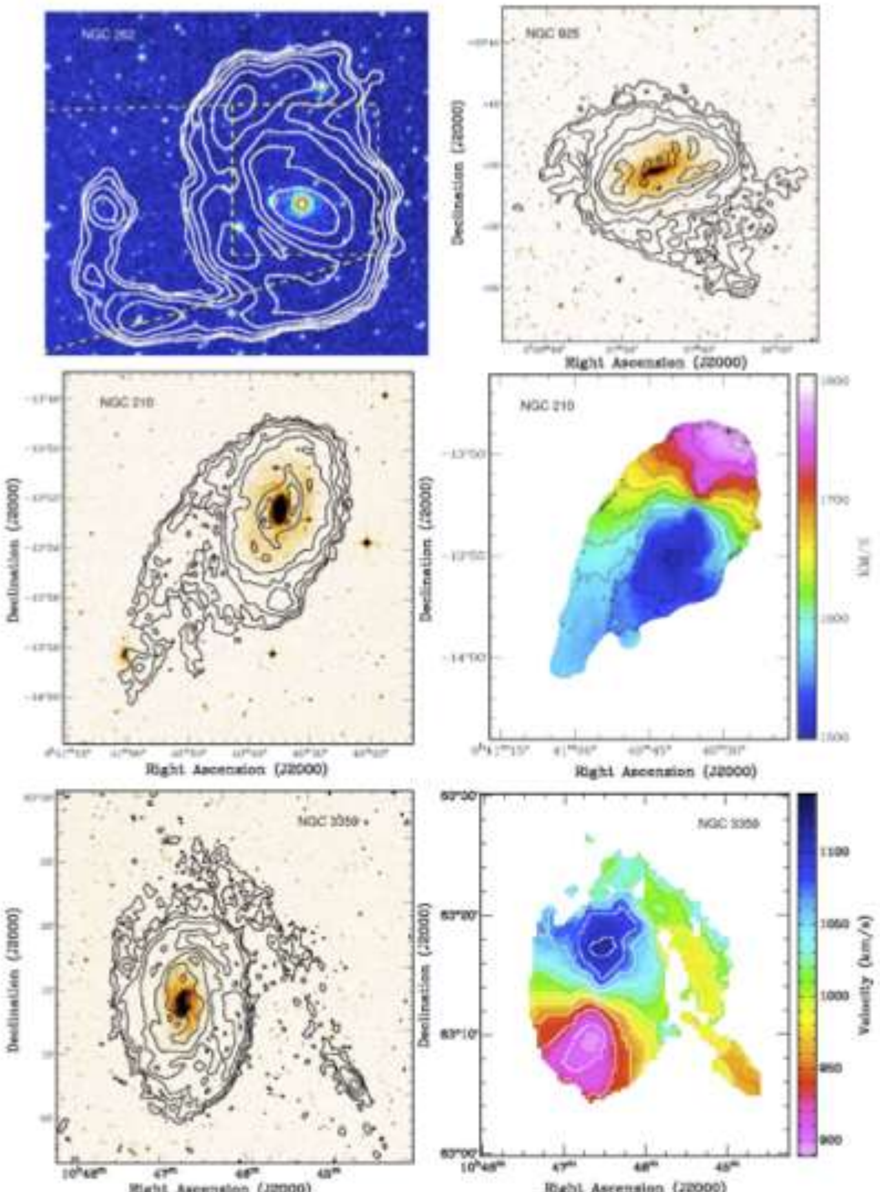


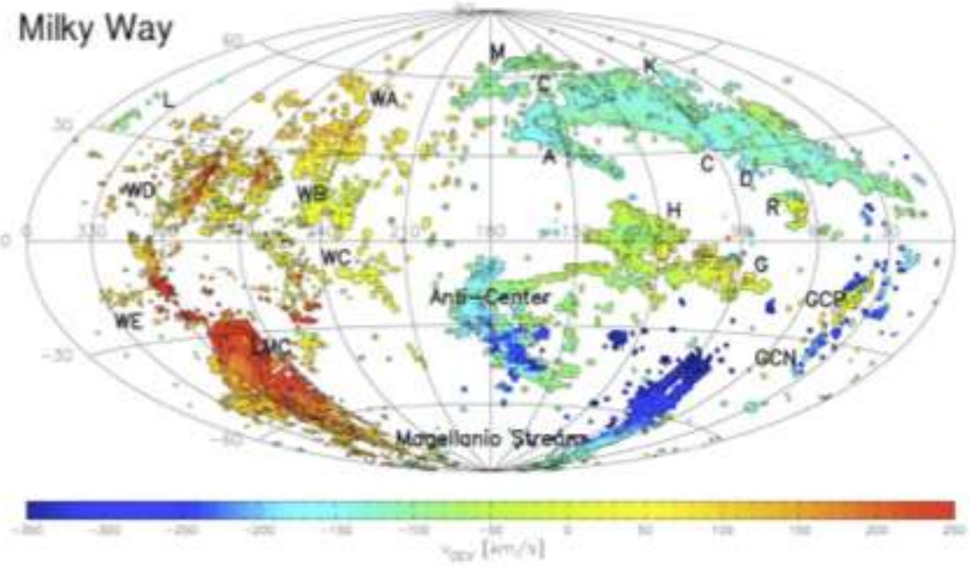


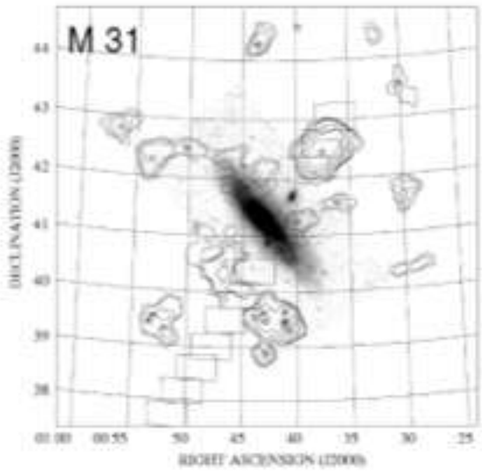


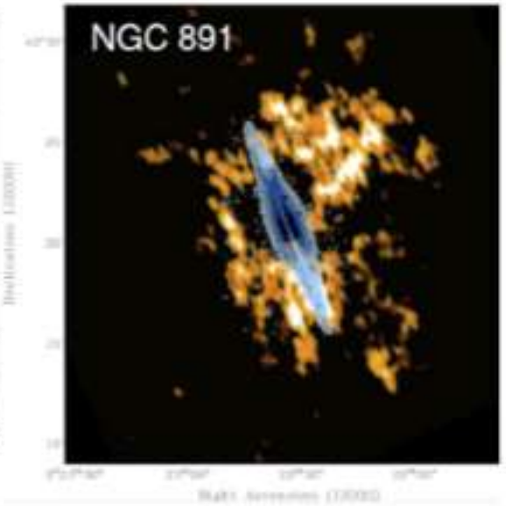
Credit:
Erwin de Blok

星系的气体吸积



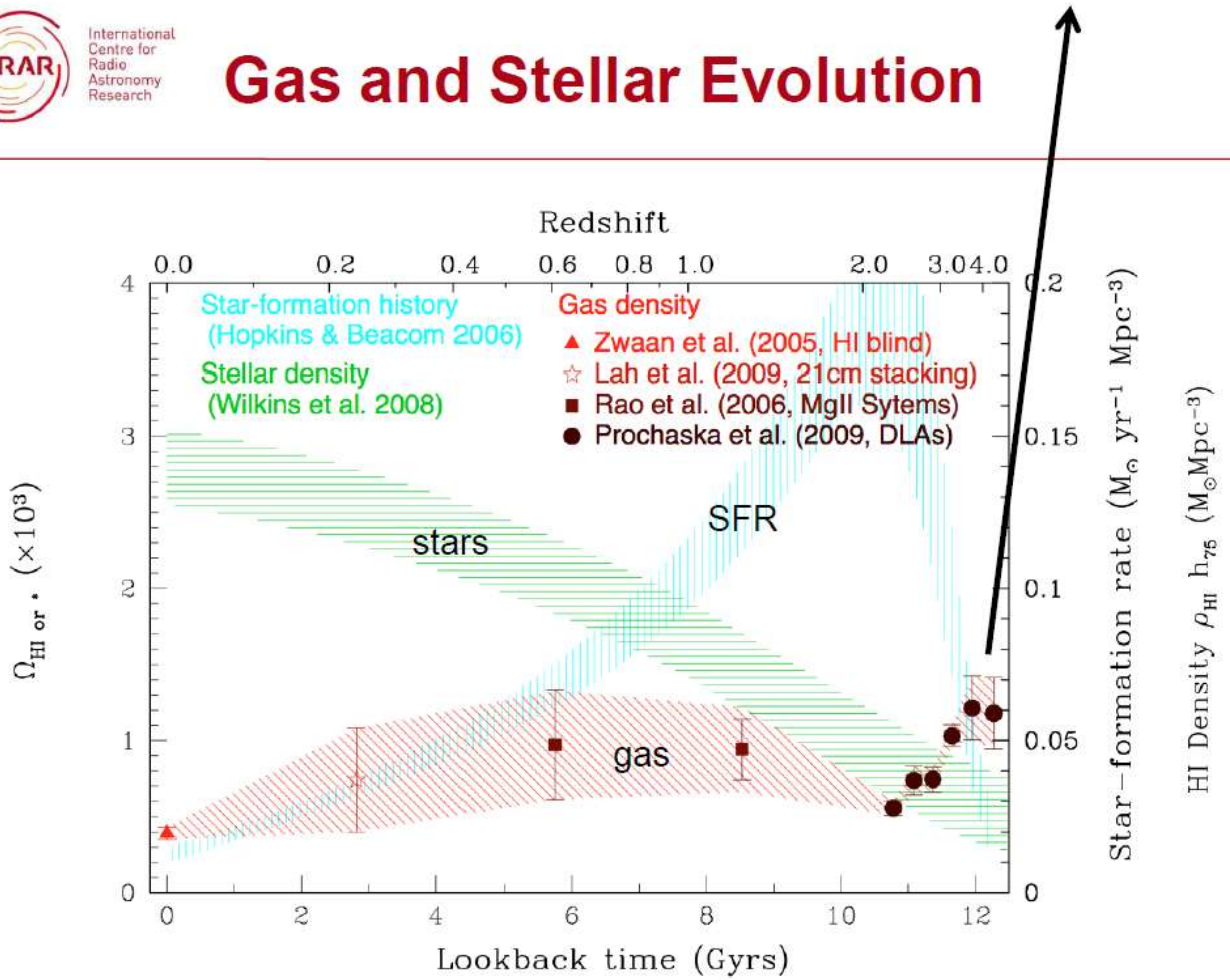






Sancisi et al. 2008

Gas and Stellar Evolution



Simon Driver

M106 （NGC4258） from NASA Astronomy Picture of the Day

Image Credit: NASA, ESO , NAOJ, Giovanni Paglioli; Assembling and processing: R. Colombari and R. Gendler

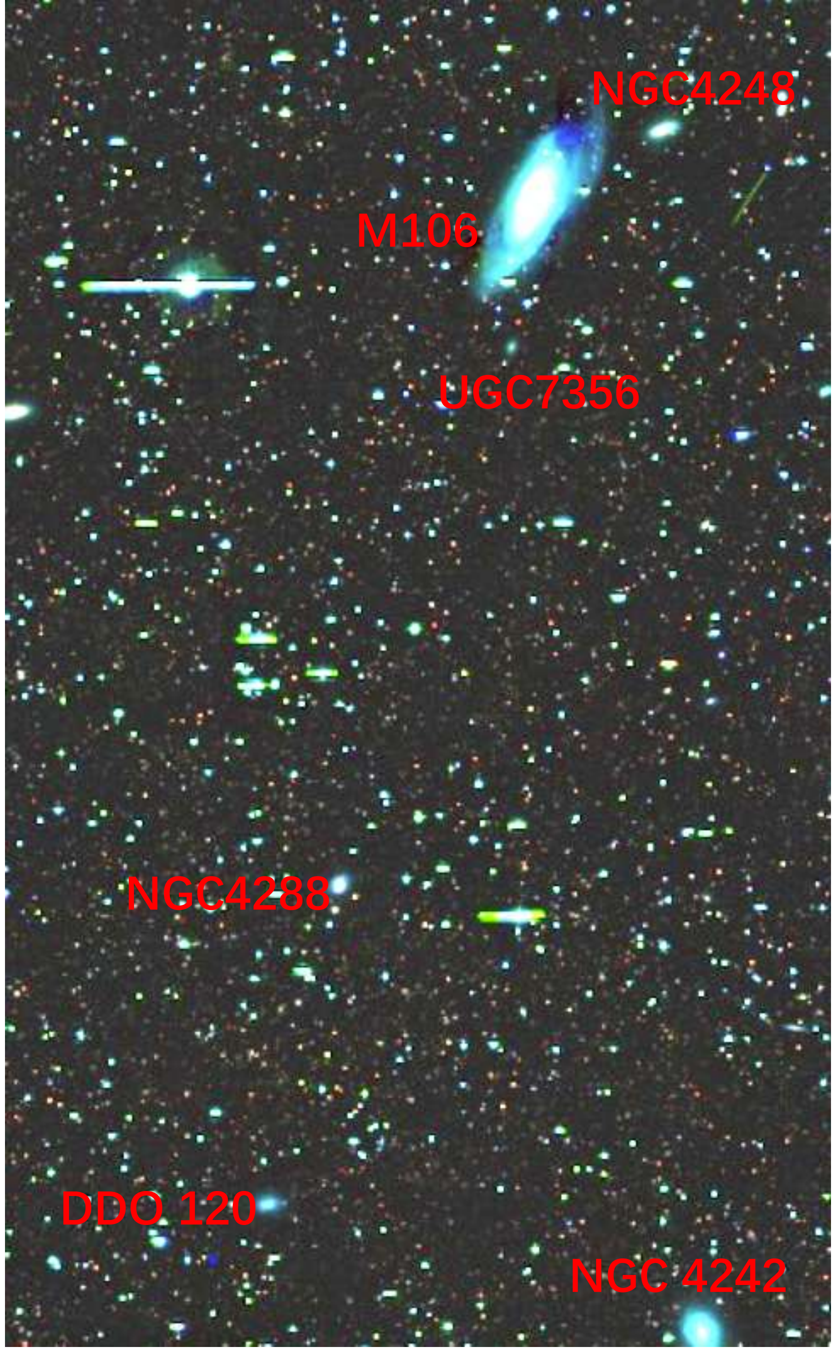
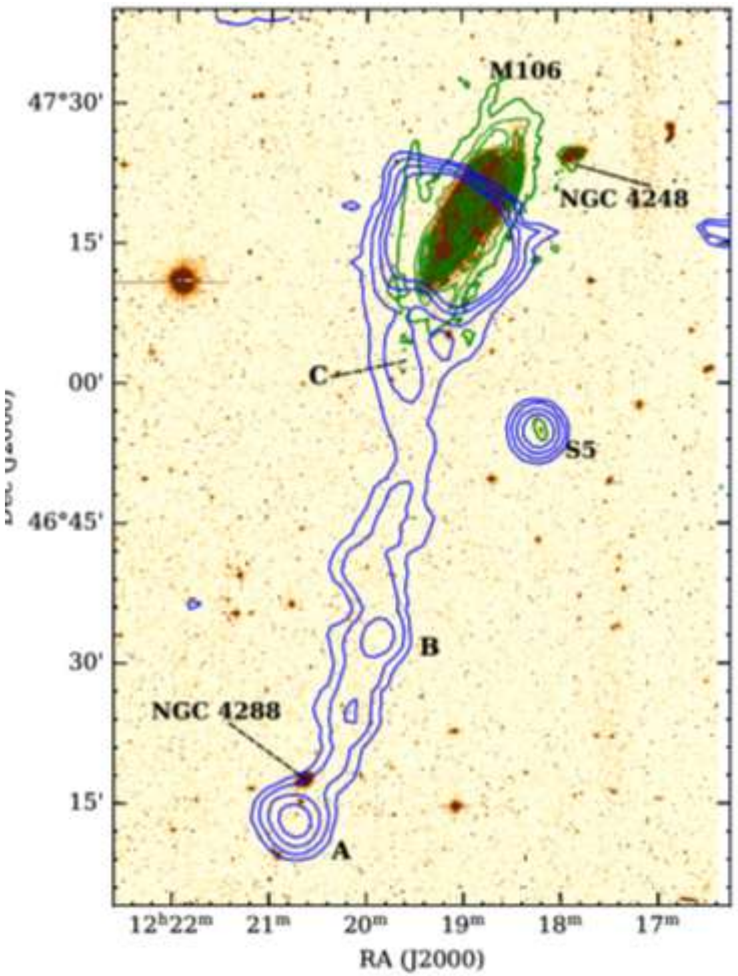


image from: www.legacysurvey.org

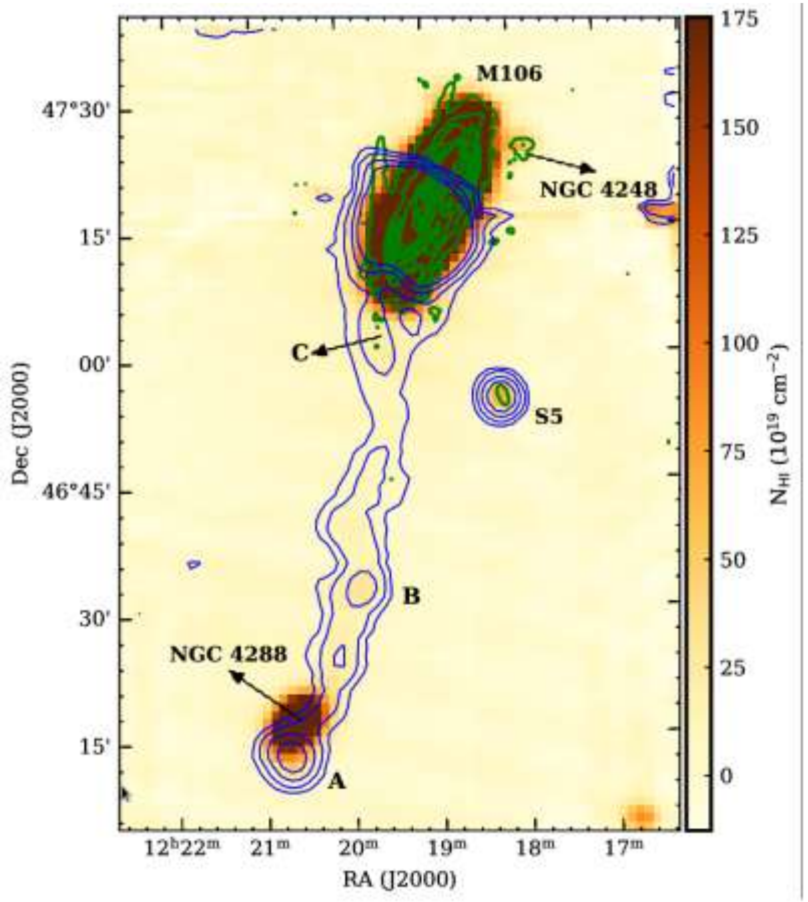


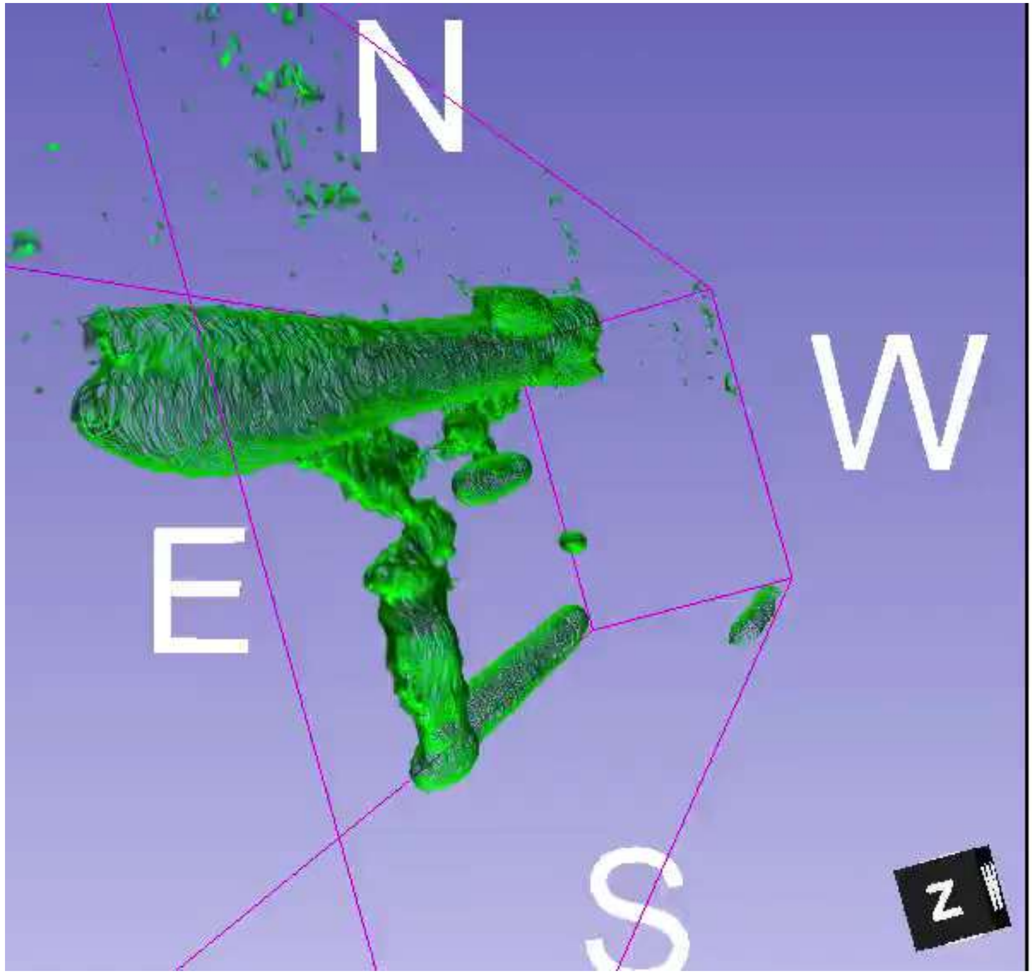
FAST map of M106

Zhu et al. 2021 ApJL

The integrated intensity map of M106 region overlaid on a DECaLs optical image. The blue contours are FAST data integrated over 334–455 km s^{-1} and contour levels are 0.18, 0.36, 0.72, and 1.26 Jy km s^{-1} (0.18 Jy km s^{-1} corresponds to 5.2×10^{18} cm^{-2}). Green contours are HALOGAS images (integrated over 200–750 km s^{-1}), contour levels start at 1×10^{19}, and increments by 5.41×10^{20} cm^{-2}.

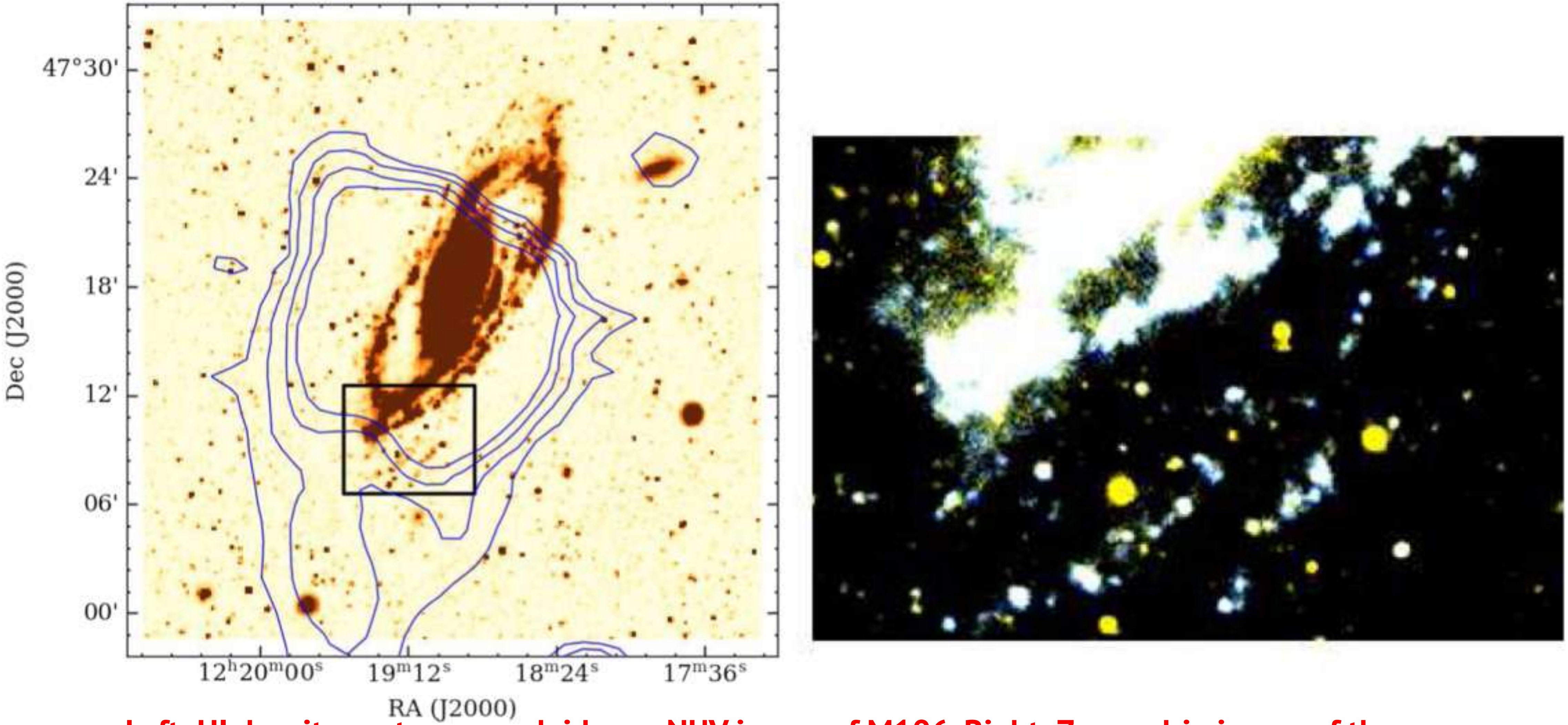
- Deep FAST map of M 106 region. Col density 5x10^17 cm-2





Zhu et al
2021
ApJLetter

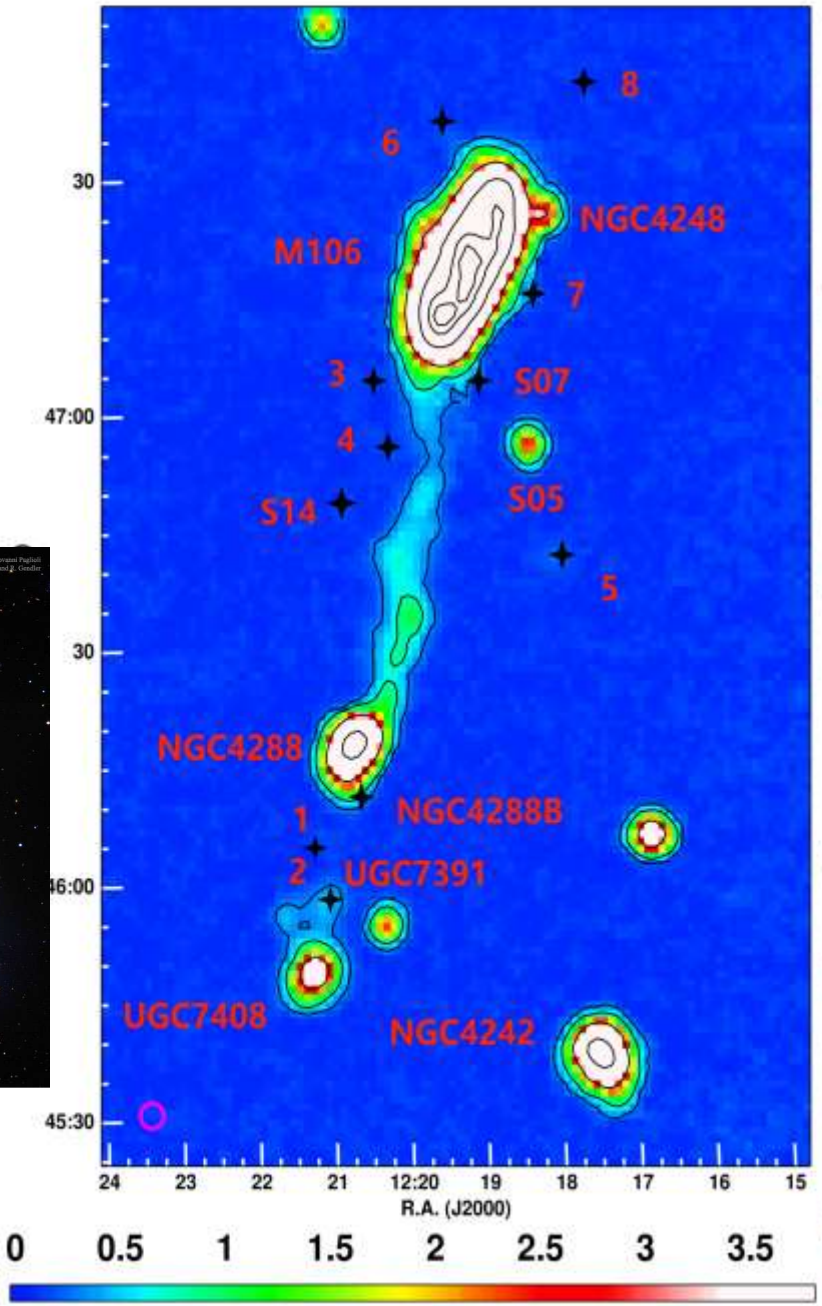
Accretion Stream trigging star formation

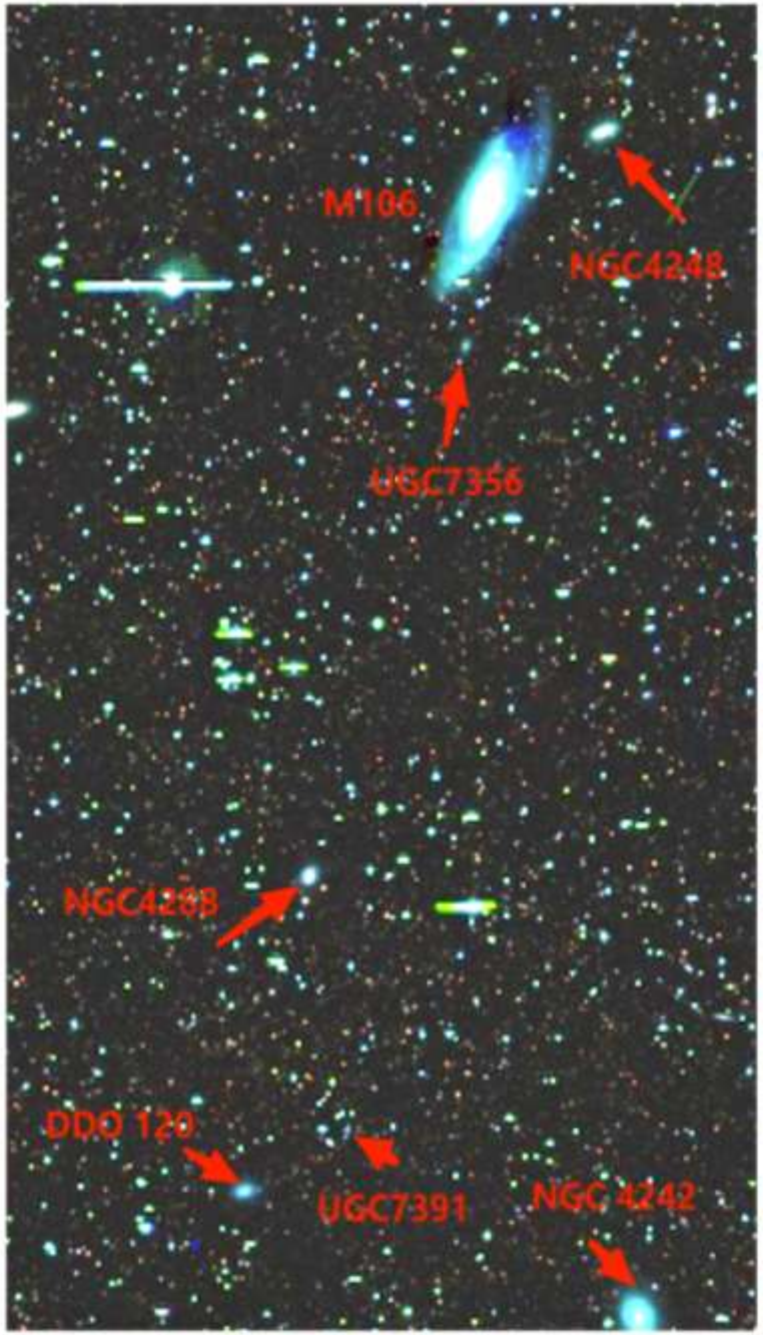


Left: HI density contours overlaid on a NUV image of M106. Right: Zoomed-in image of the area contained in the black rectangle with FUV data in blue and NUV data in yellow

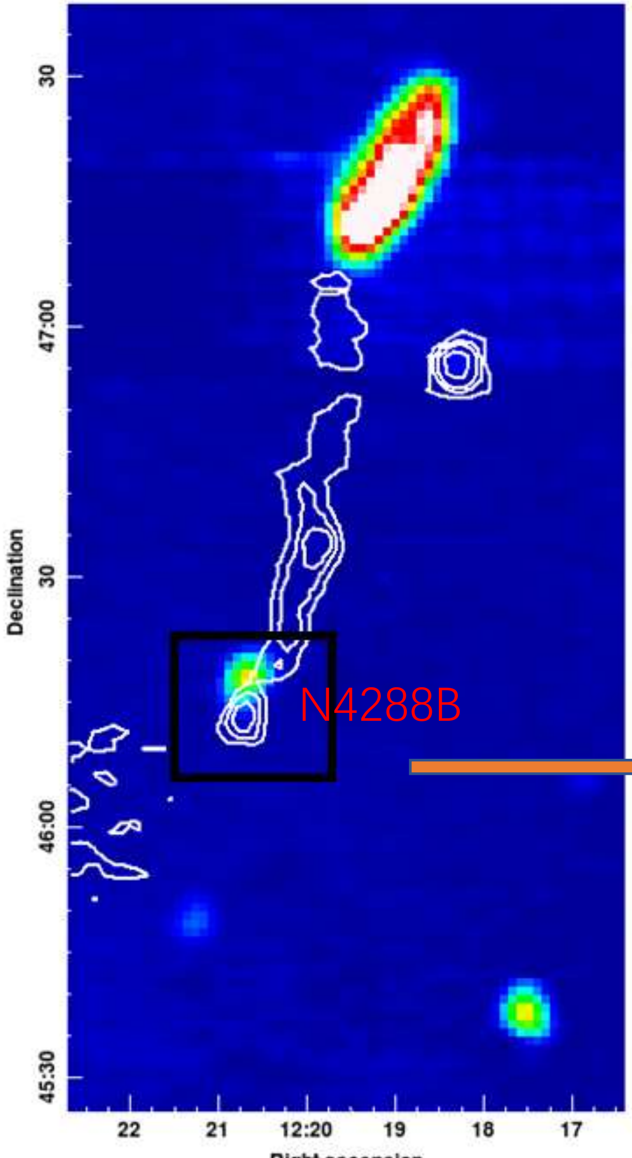
M 106 group

Zhu etal. 2021 ApJL
Liu et al. 2024 MNRAS

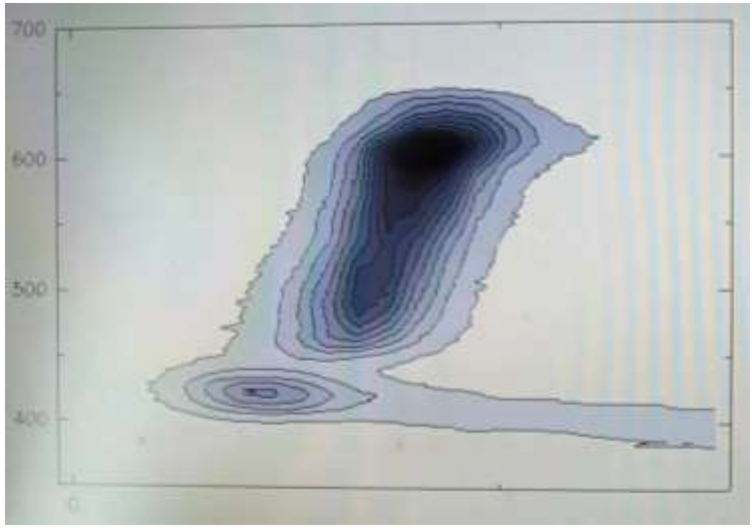




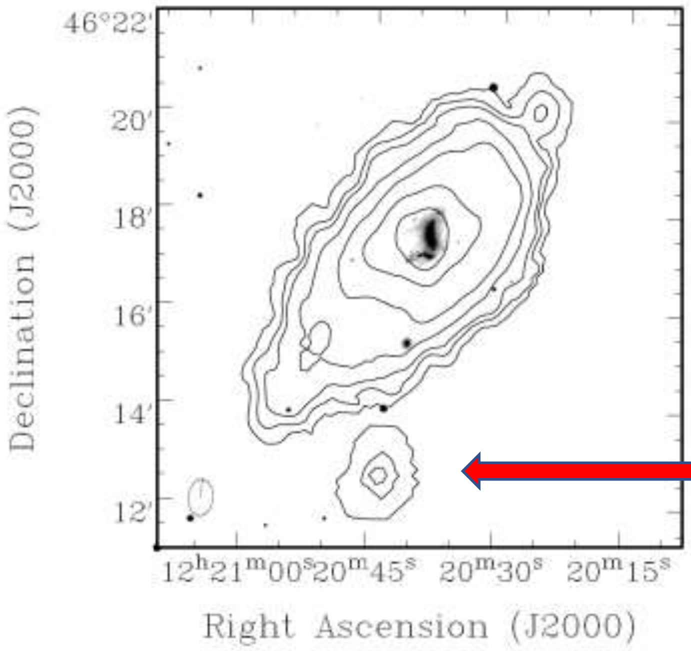
Accretion sources



NGC 4288—LMC type satellite



PV diagram cut through N4288 and N4288B

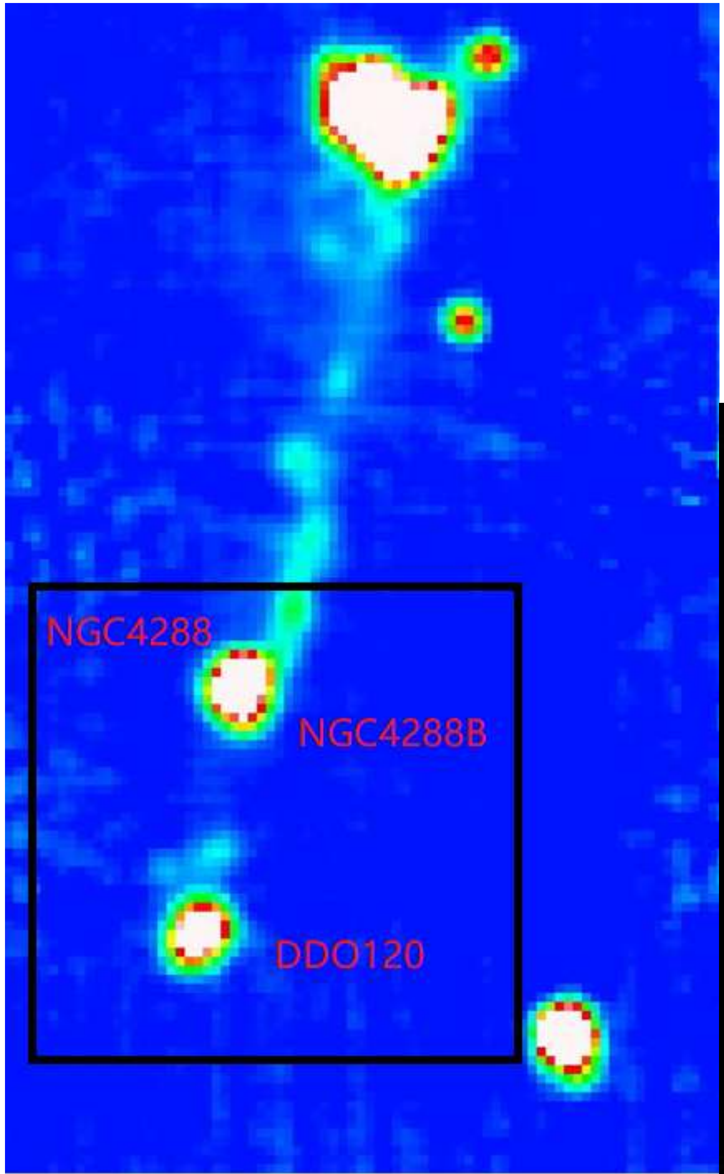


N4288B
No optial counter-part
M*< 10^6Msun

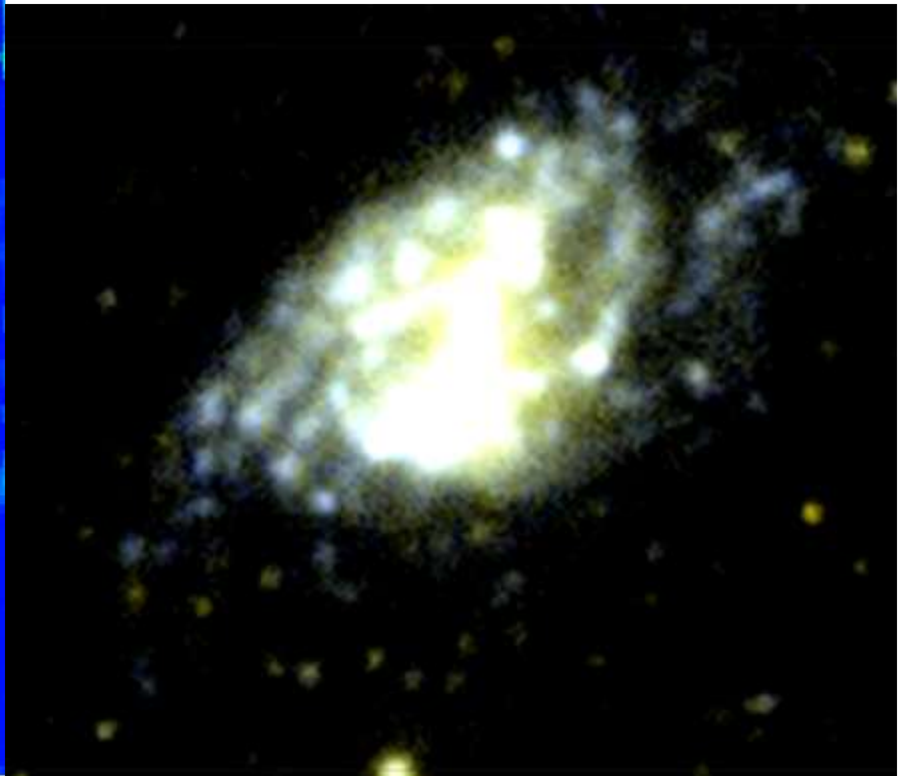
Kovac et al. (2009)

Accetion source NGC 4288

Ingteracting with DDO 120?

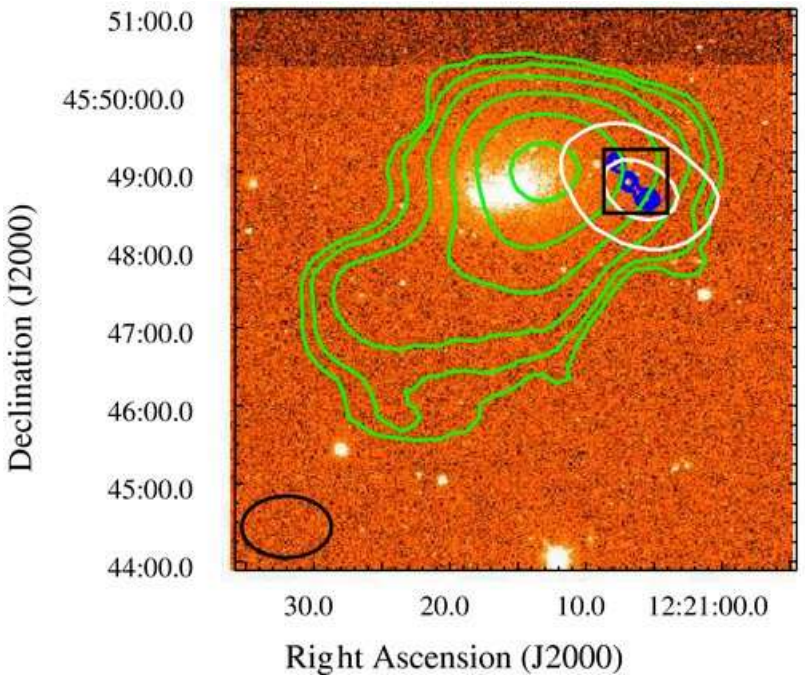


UV image of N4288 from GALEX

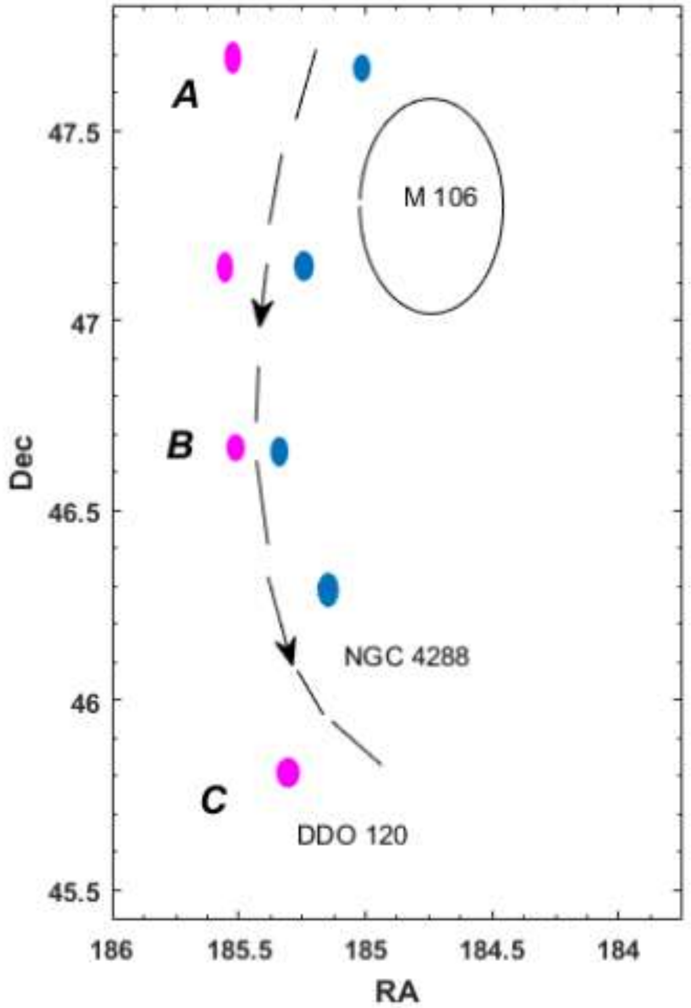


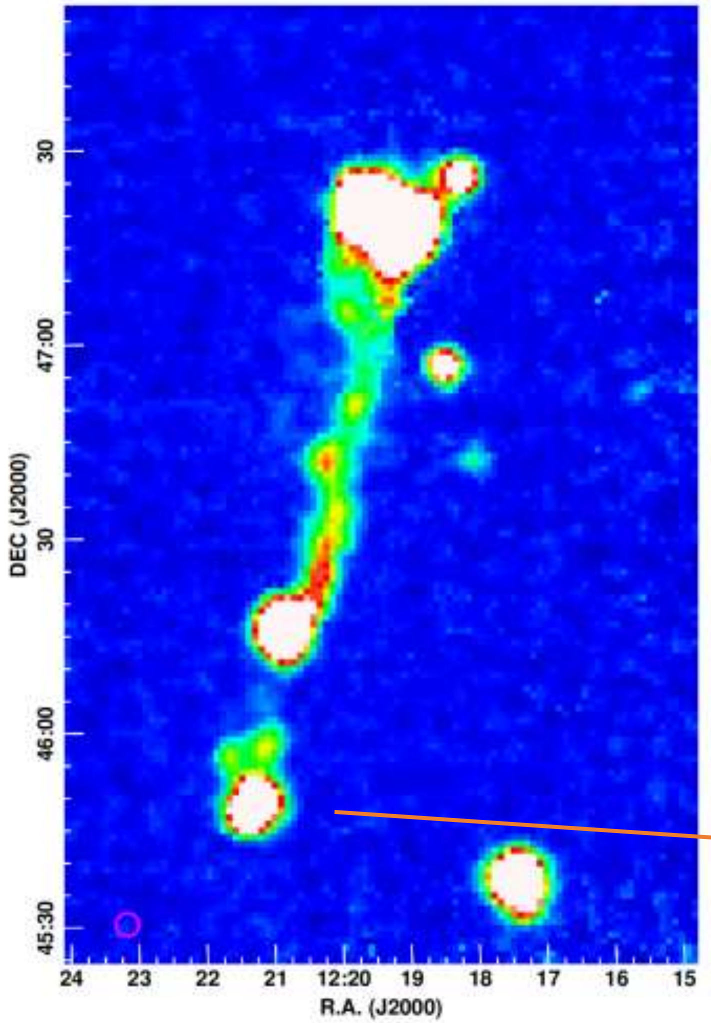
VLA HI map of DDO 120

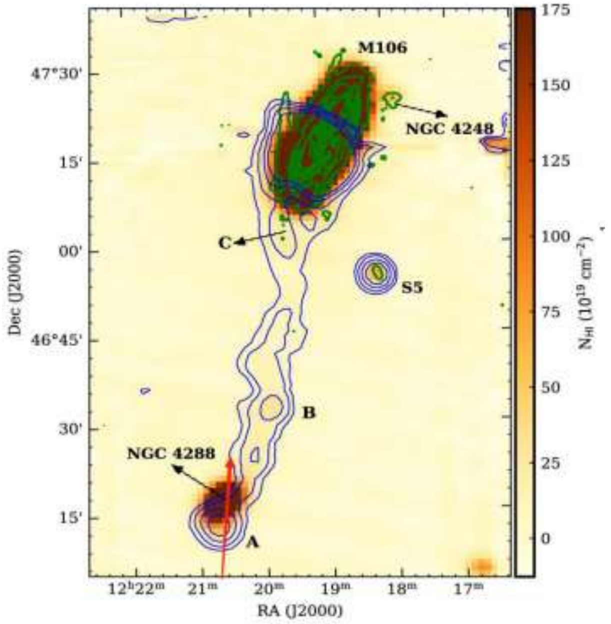
Borthakur et al. (2011)

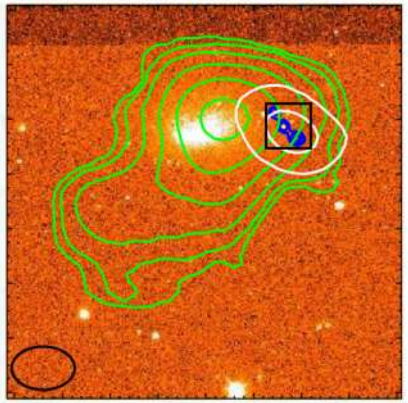


HI stream, Analog of the Megillanic stream?

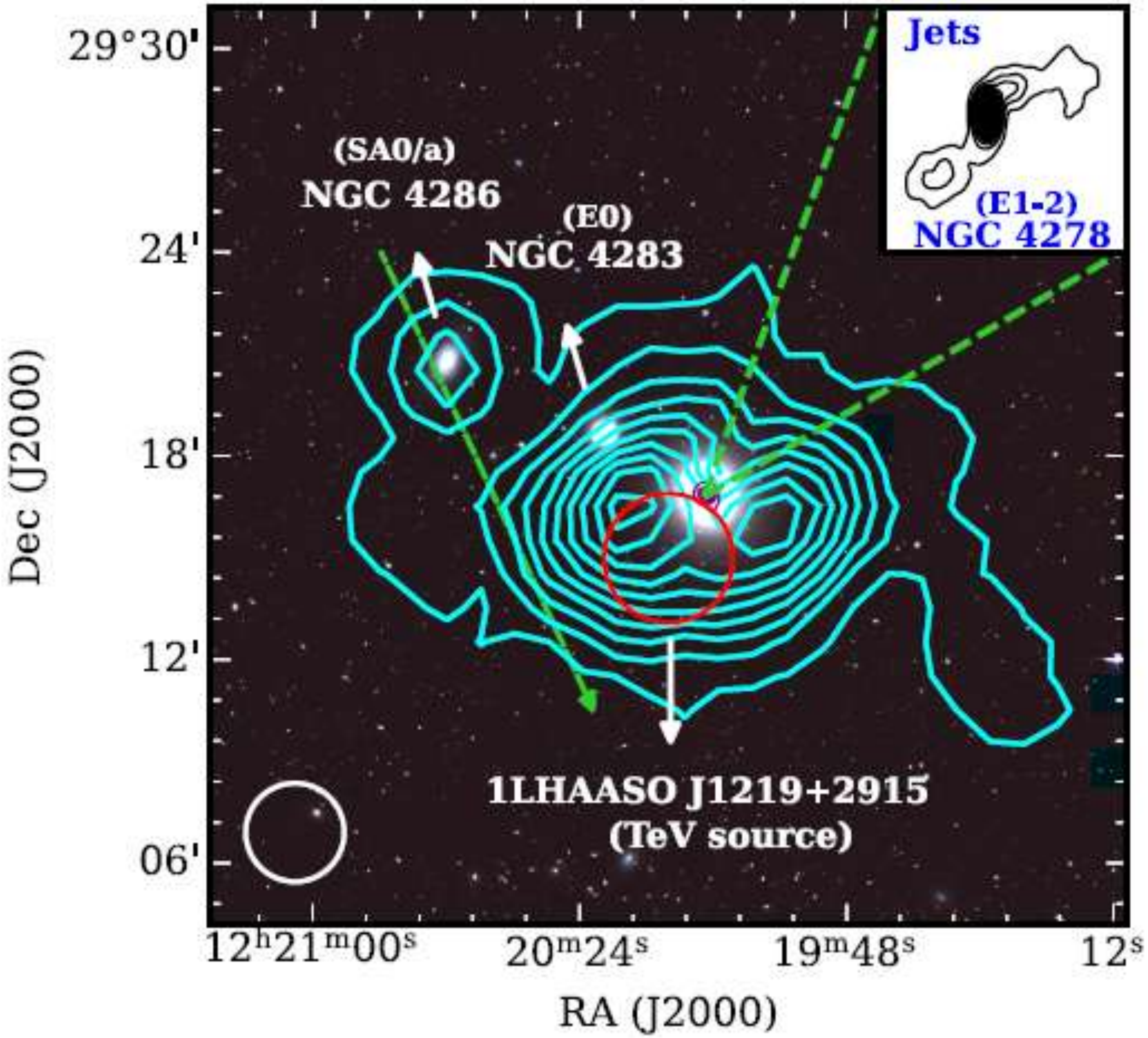








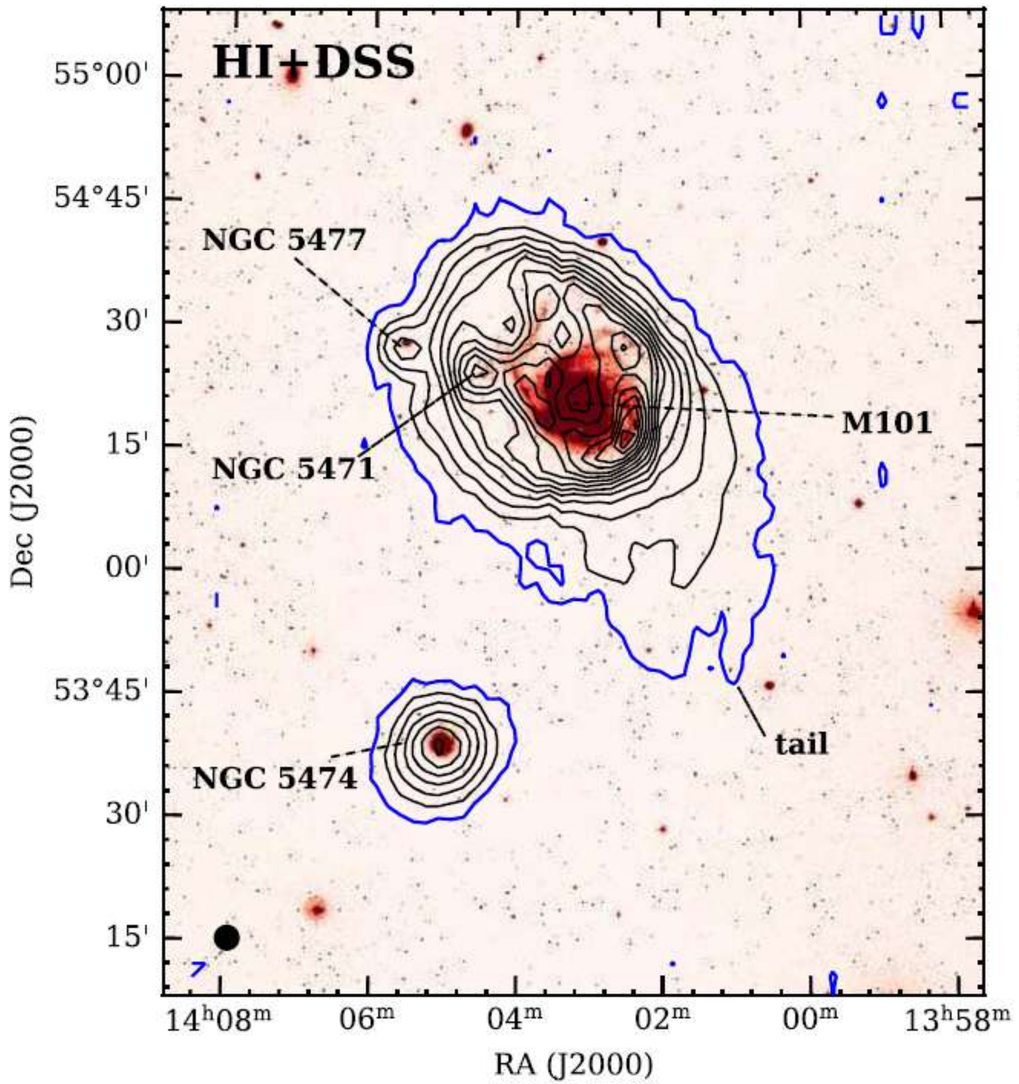
FAST 揭示 NGC 4278 中的气体吸积

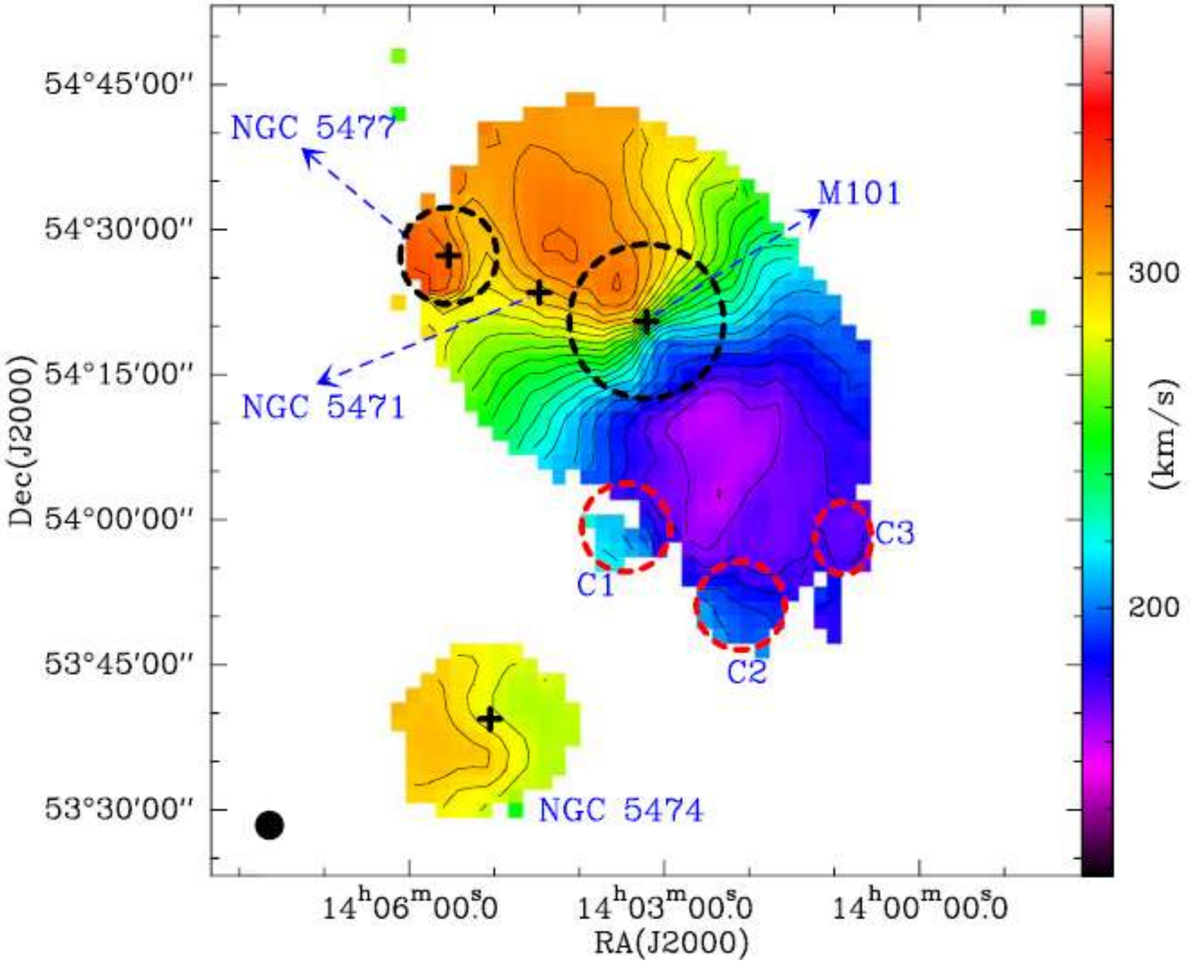


Xu et al. ApJ, 2026

FAST发现椭圆星系NGC4278中的AGN是由于吸积伴星系的物质所产生的。为AGN的产生提供了一种新方式。同时，发现TeV的伽马射线与吸积的气体相关。

M101– FAST HI map



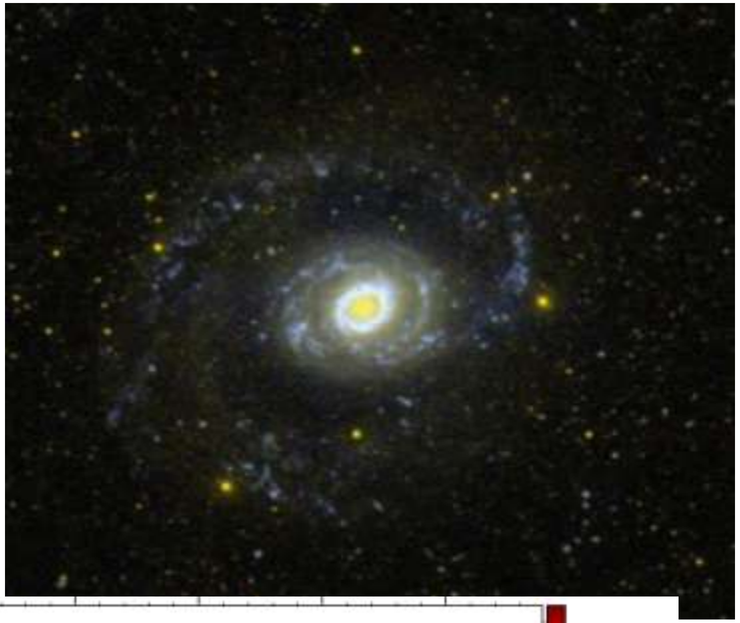


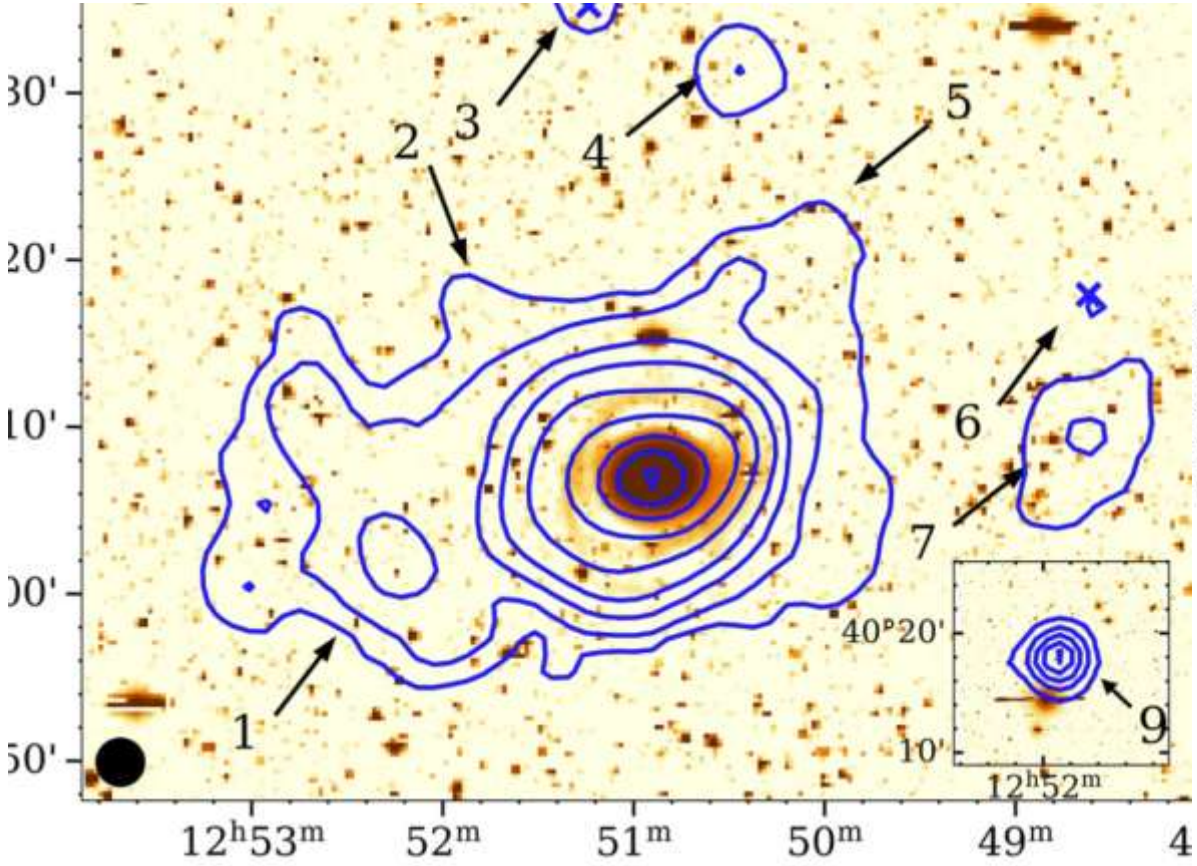
1. **Xu**, et al., 2021, ApJ

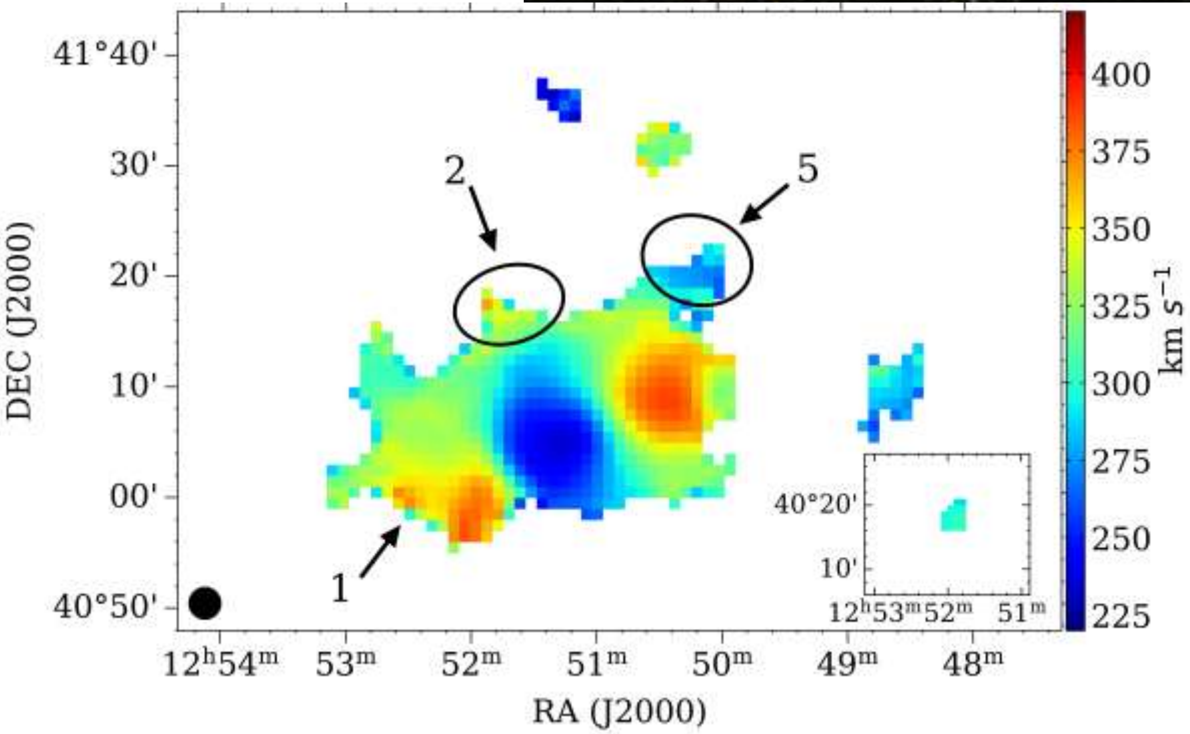
M94 猫眼星系

M94:
FAST HI view

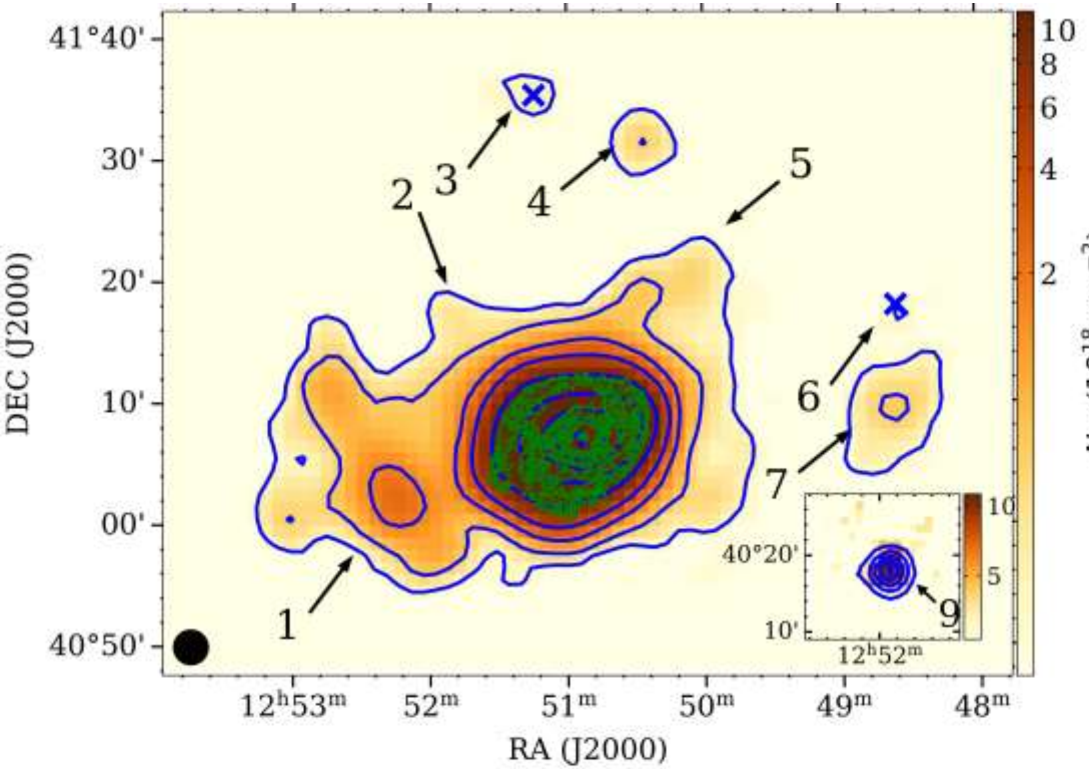
(Zhou Ruilei etal. 2023 ApJ)



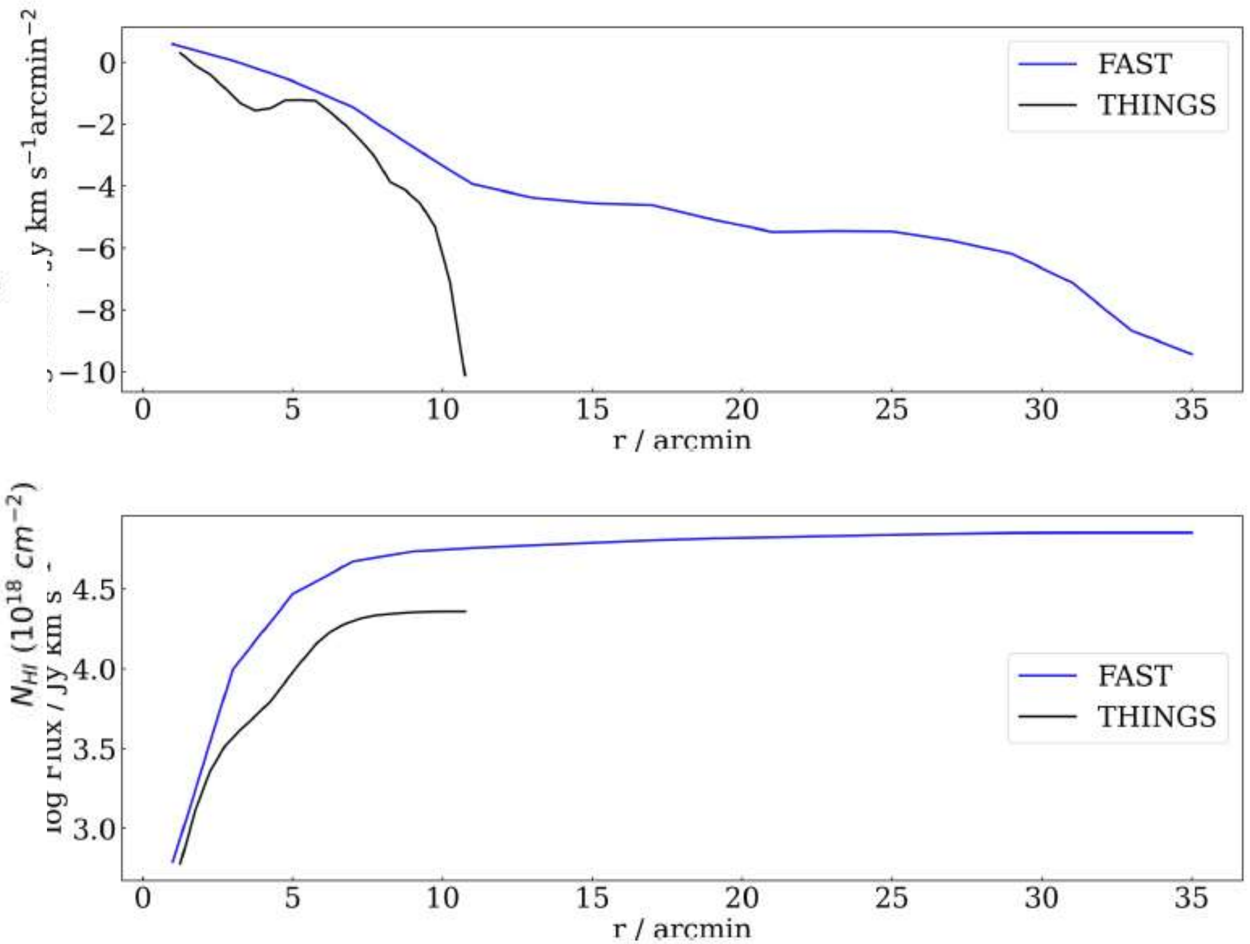




M94: FAST detect much more diffuse gas than VLA

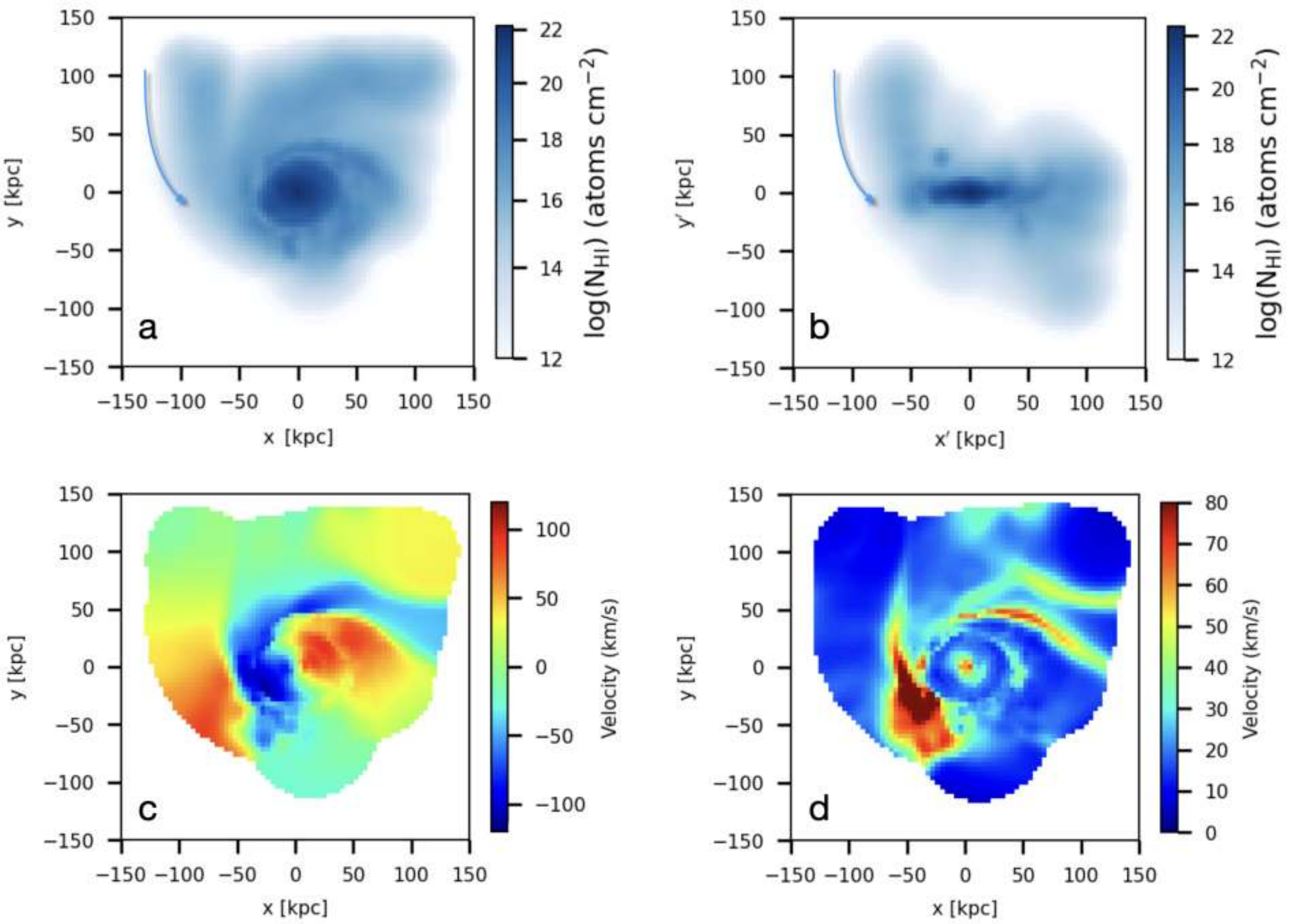


H I IN M94 WITH FAST

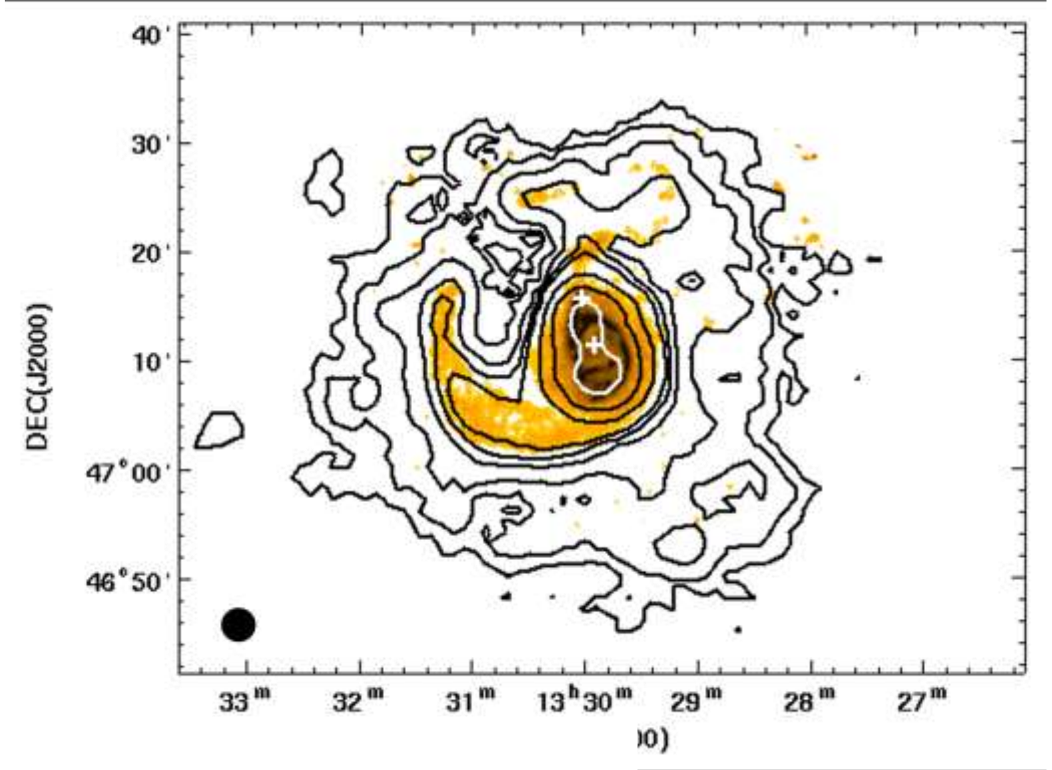


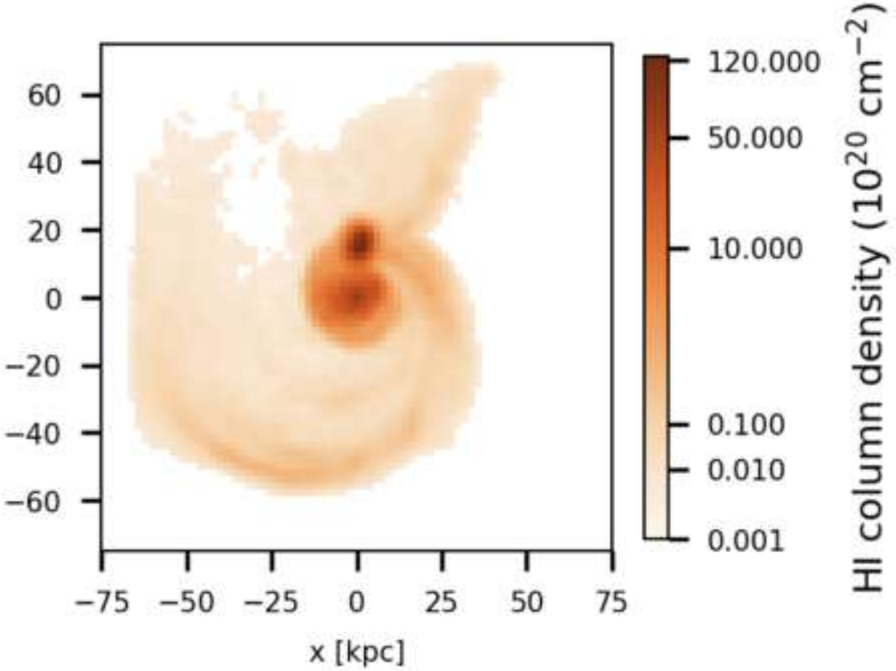
Model fitting M94

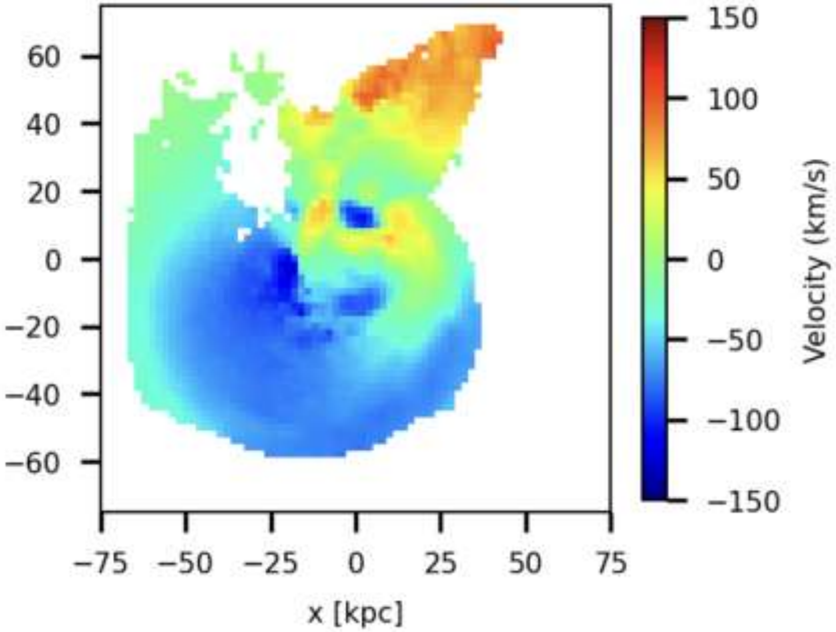
(Zhou etal. 2023)



M 51: FAST real extended gas (Yu, Zhu et al.2023)

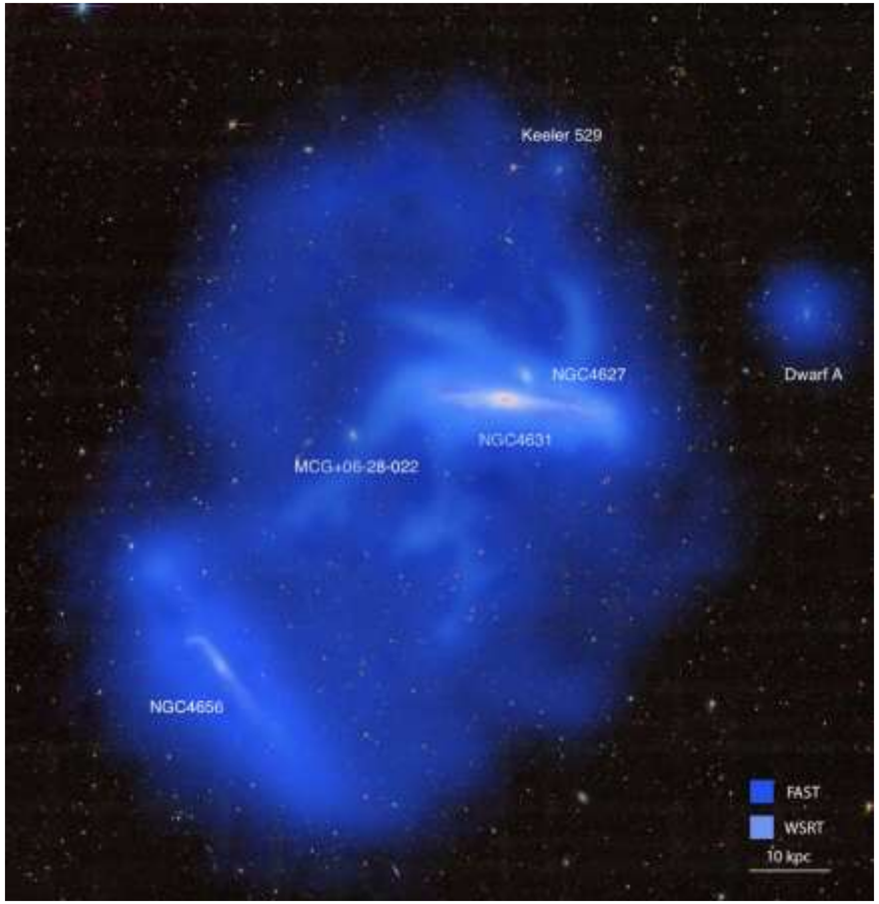




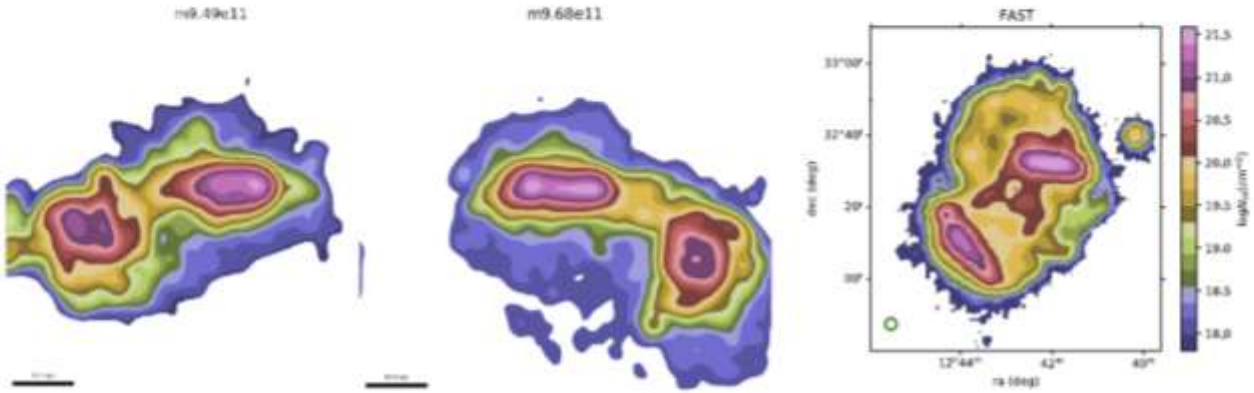


FAST + WSRT HI map of NGC 4631/56

Wang etal. ApJ (2023)

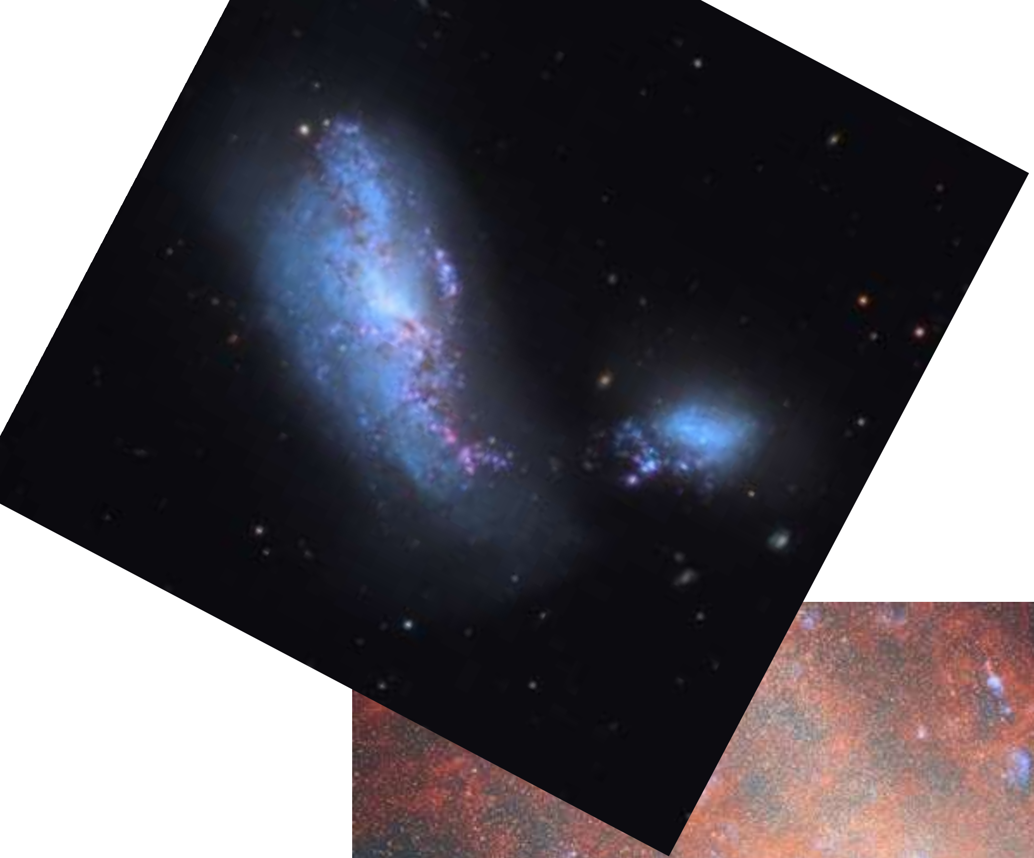


cosmology simulations find that gas accreted from the CGM during the merger could contributes 30-40 percent to the gas bridge (Sparre et al. 2022)

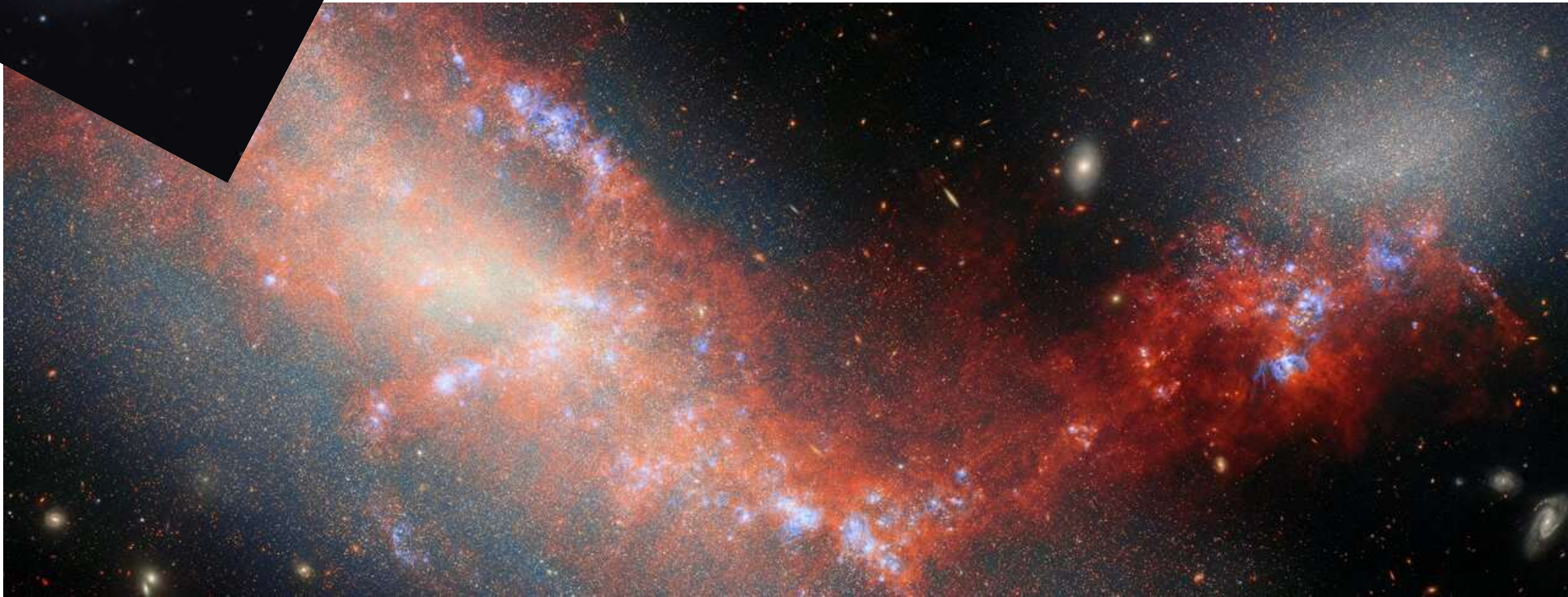


Credit: Kang Xi

NGC4485/90

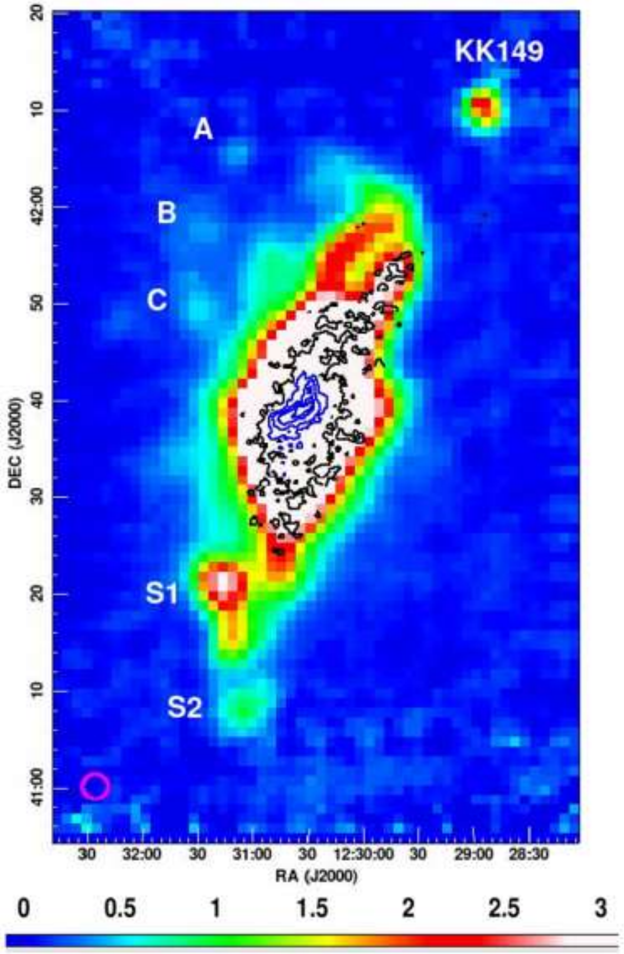


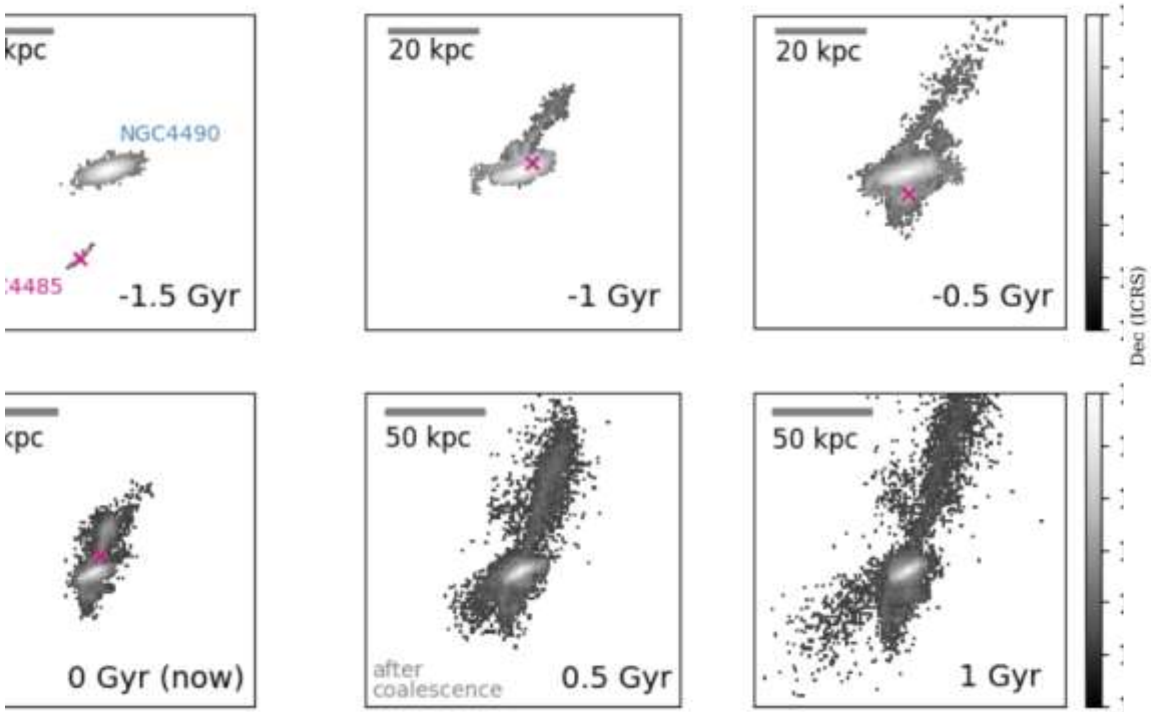
[ESA/Webb Picture of the Month]



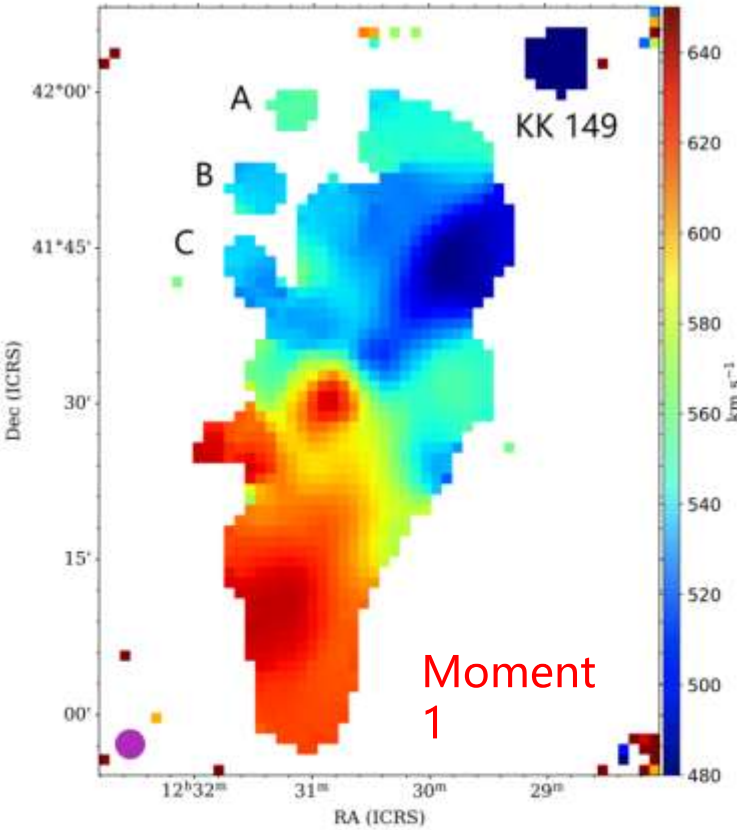
FAST Mapping of N4490/85

Liu，Zhu et al. 2023 MNRAS

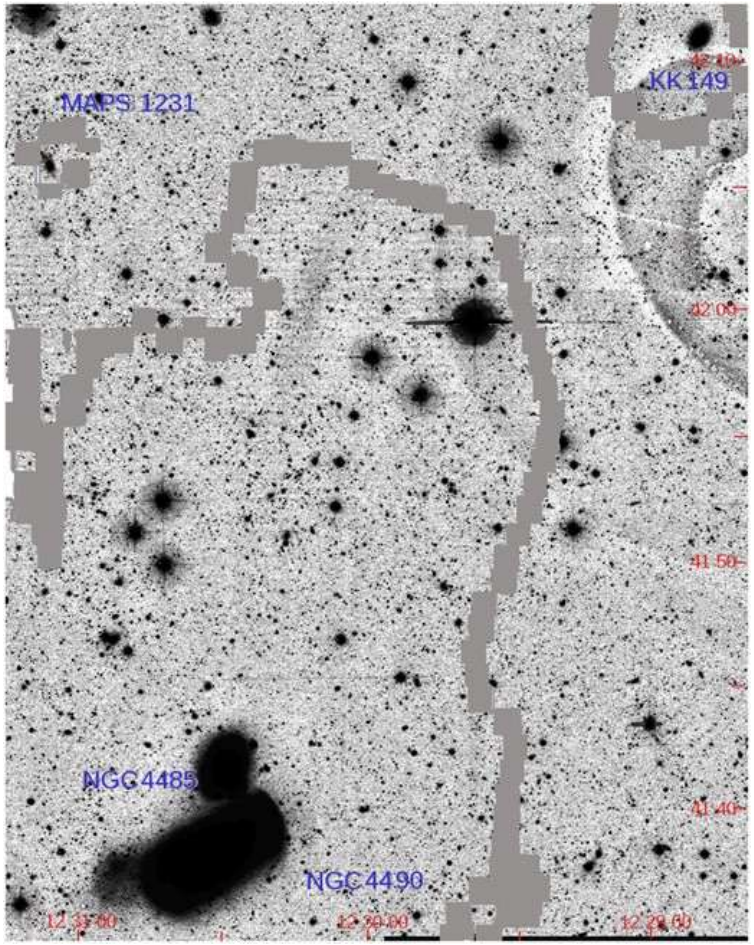




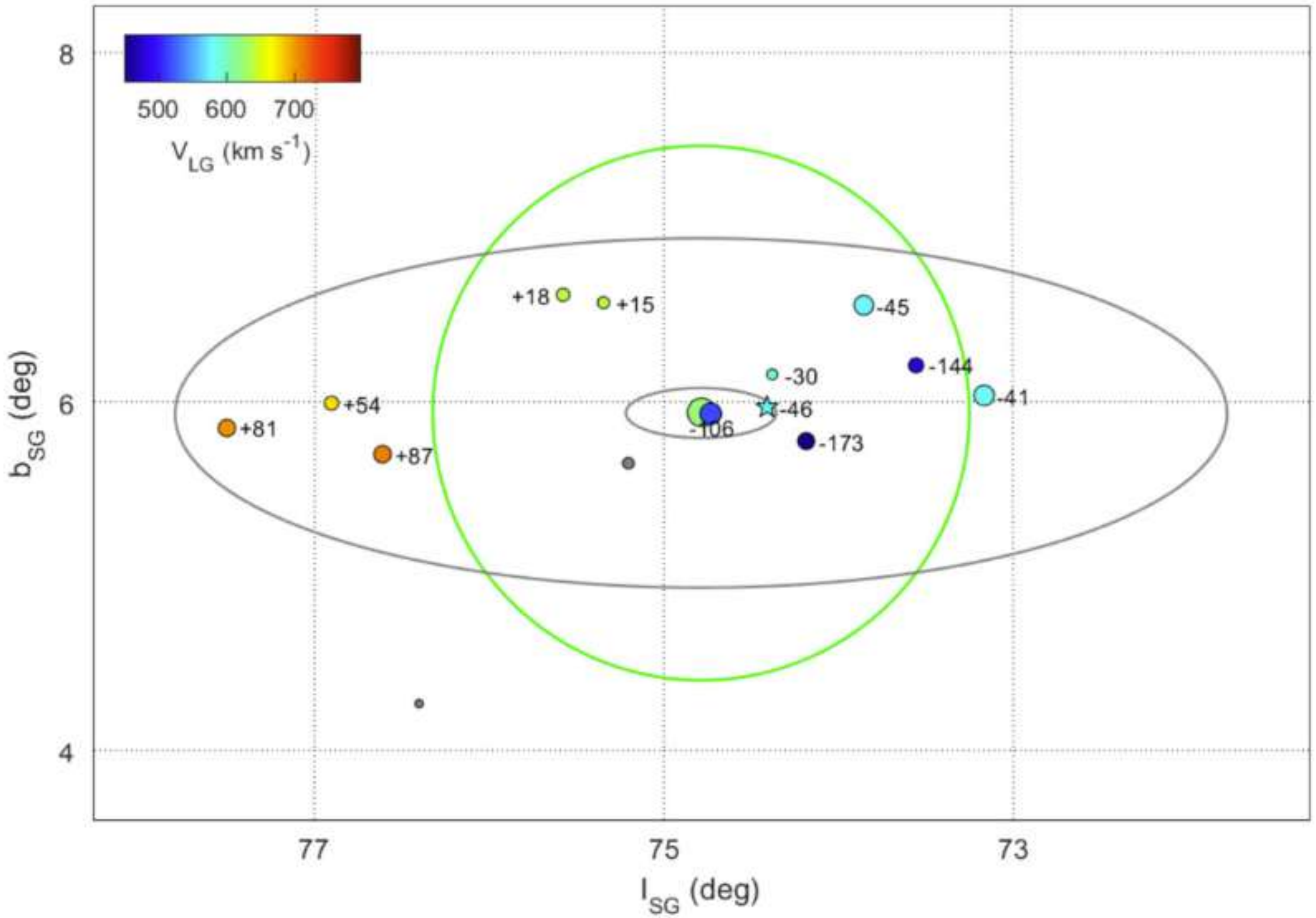
Pearson et al. 2018



Co-rotating gas and satellite structure around NGC 4490 (Karachentsev & Kroupa 2024)

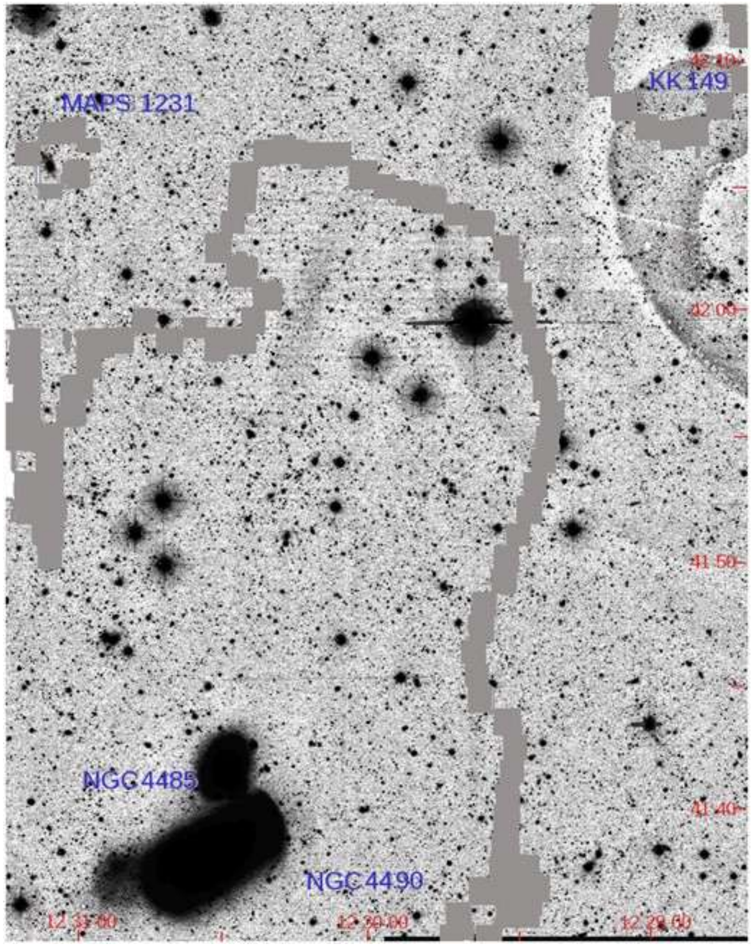


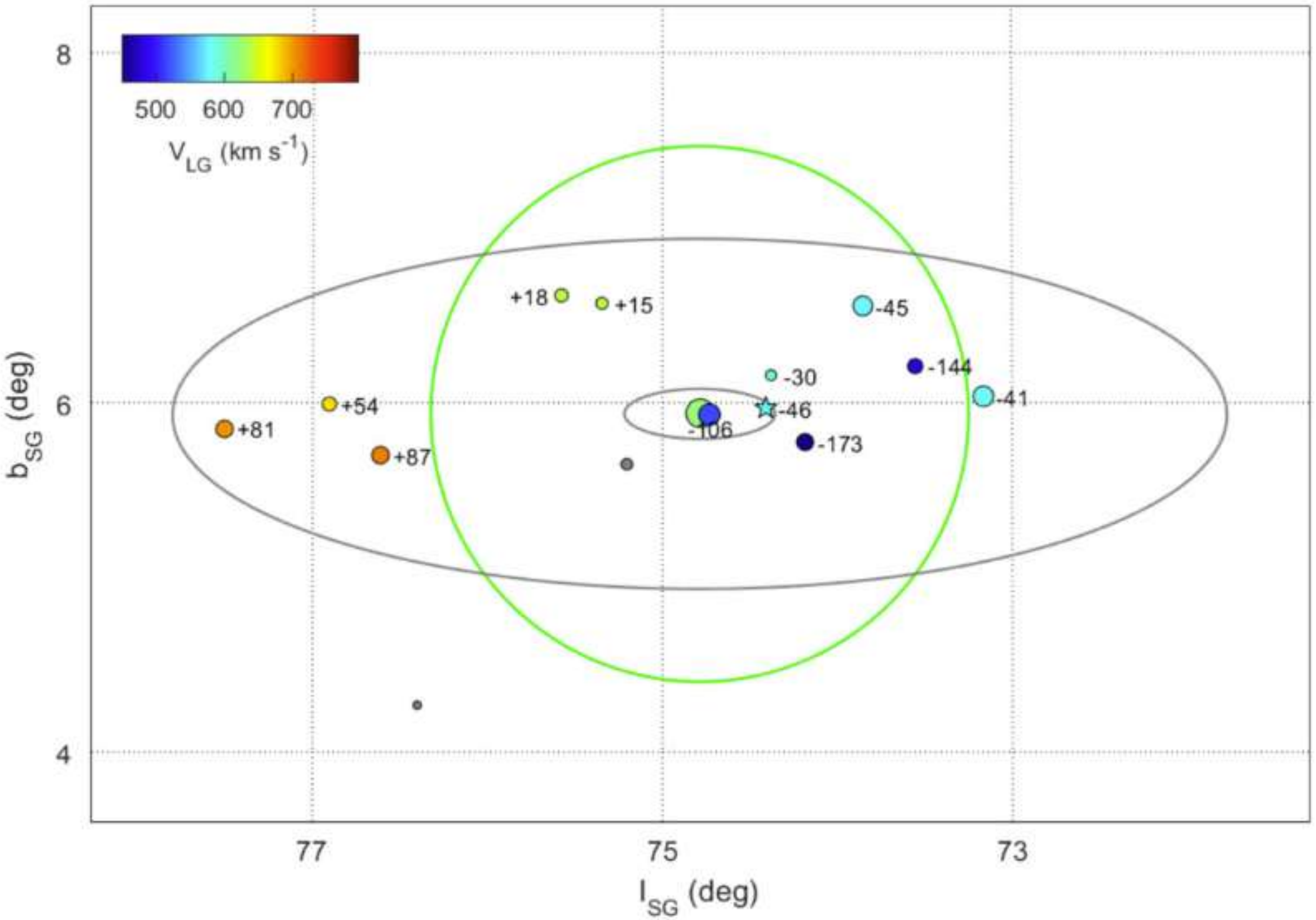
Co-rotating structures around NGC 4490/85



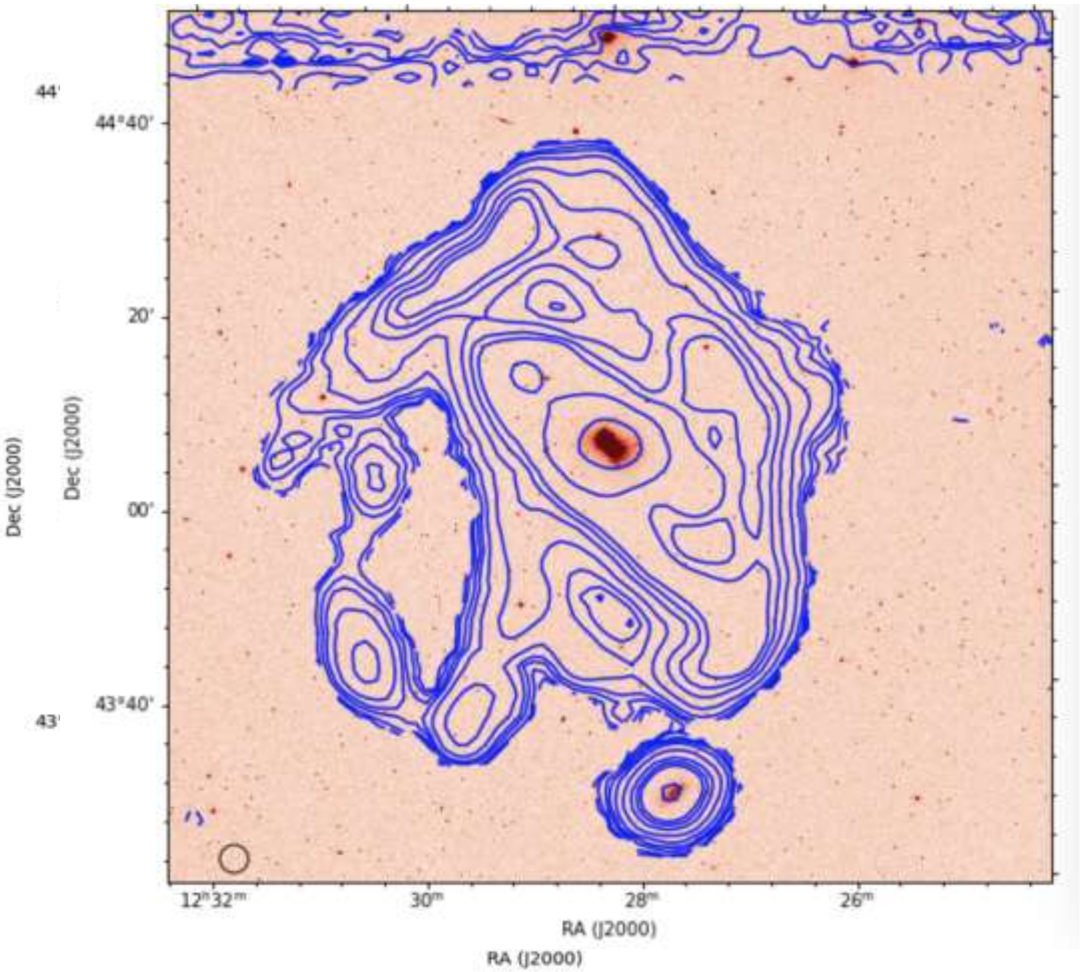
Co-rotating gas and satellite structure around NGC 4490 (Karachentsev & Kroupa 2024)

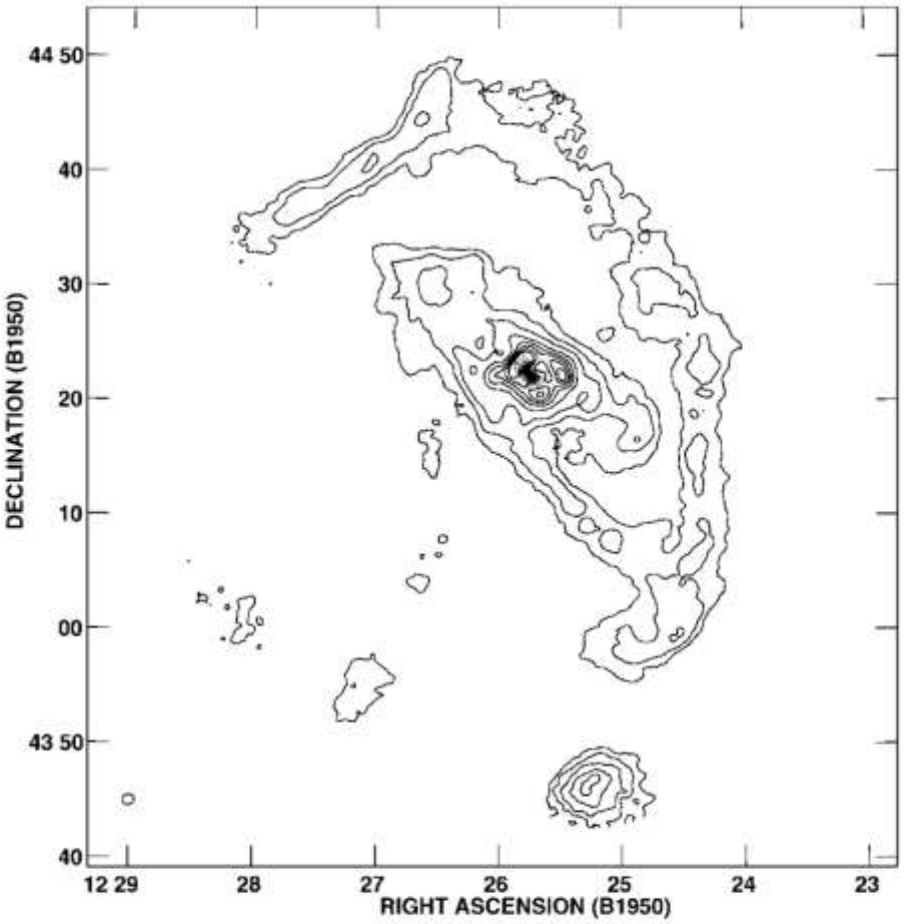
Co-rotating structures around NGC 4490/85





NGC 4449: Huge HI evelope (Ai et al. 2023)





NGC4449
3D visualization

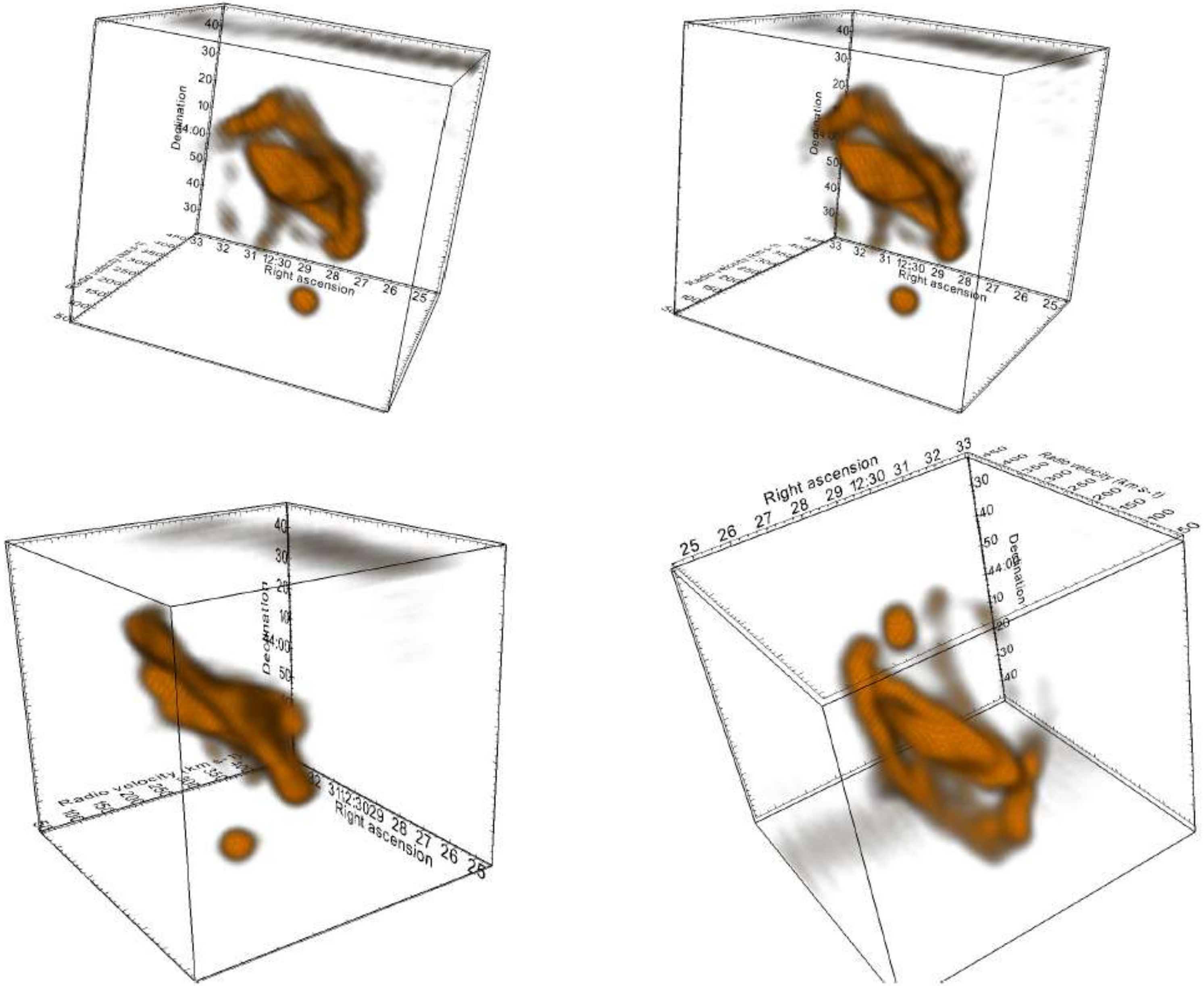
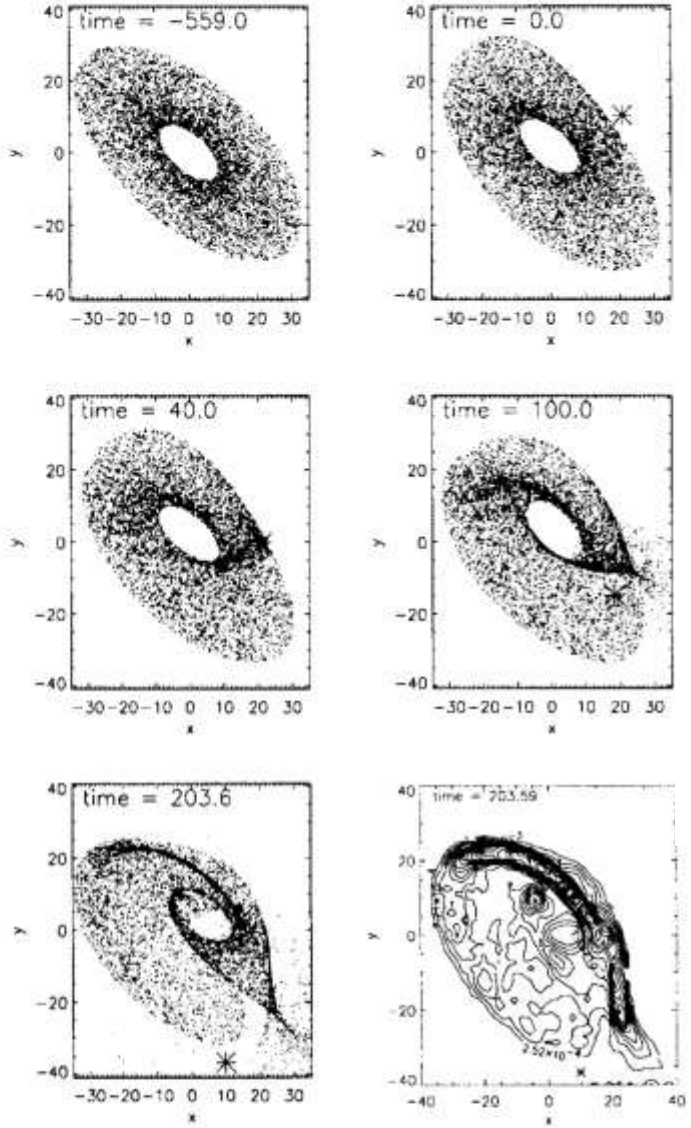
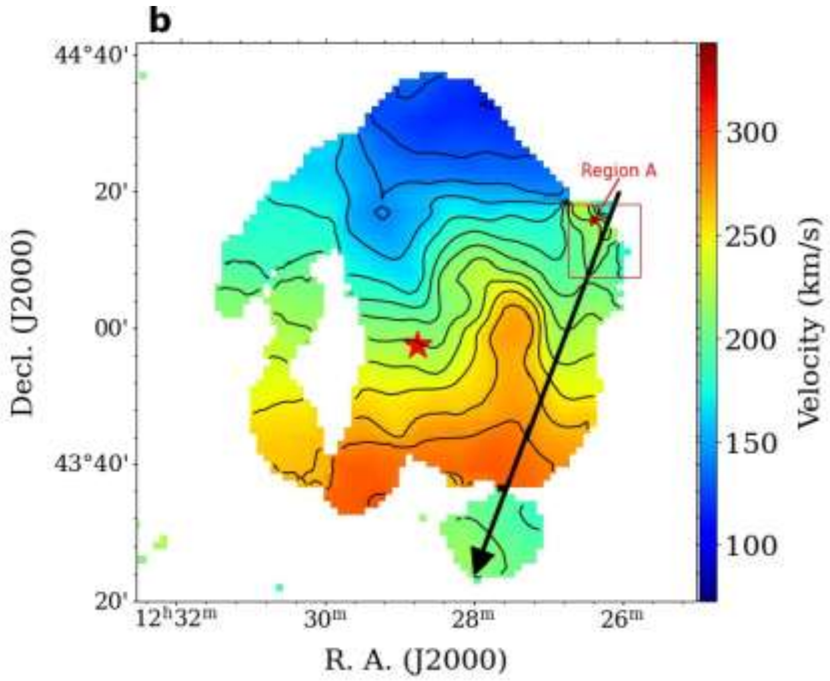


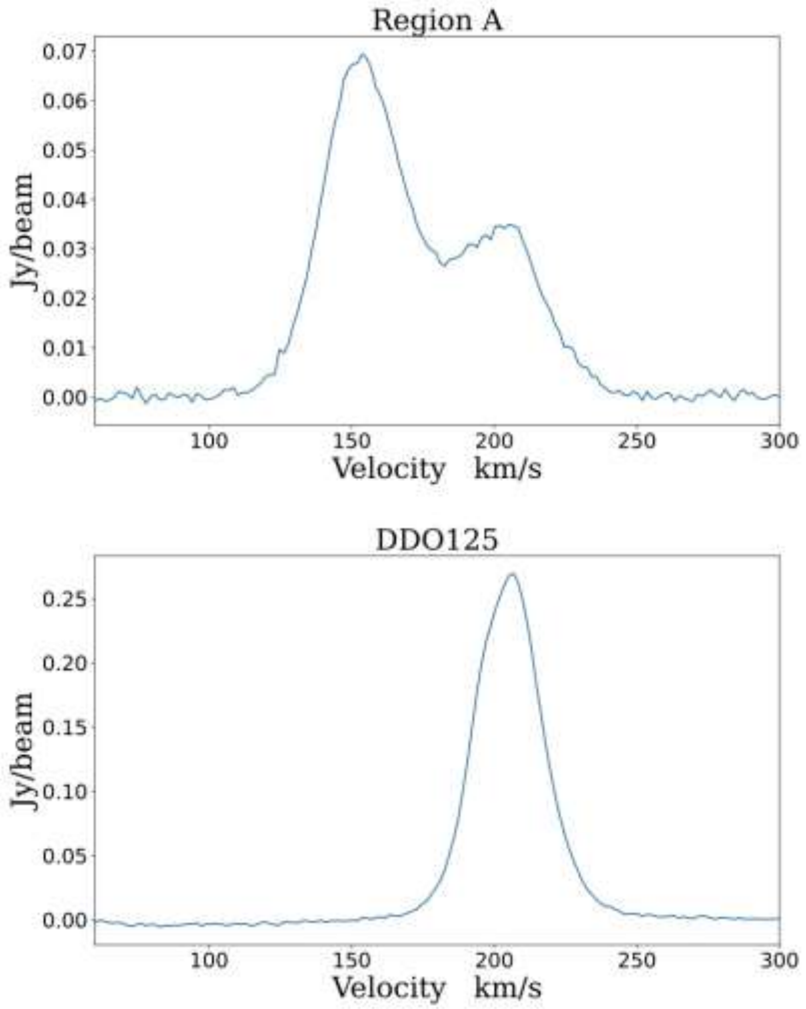
Figure 2. A 3D exhibition of NGC4449 in different angles of view.

Possible Origin of NGC4449 HI Disc

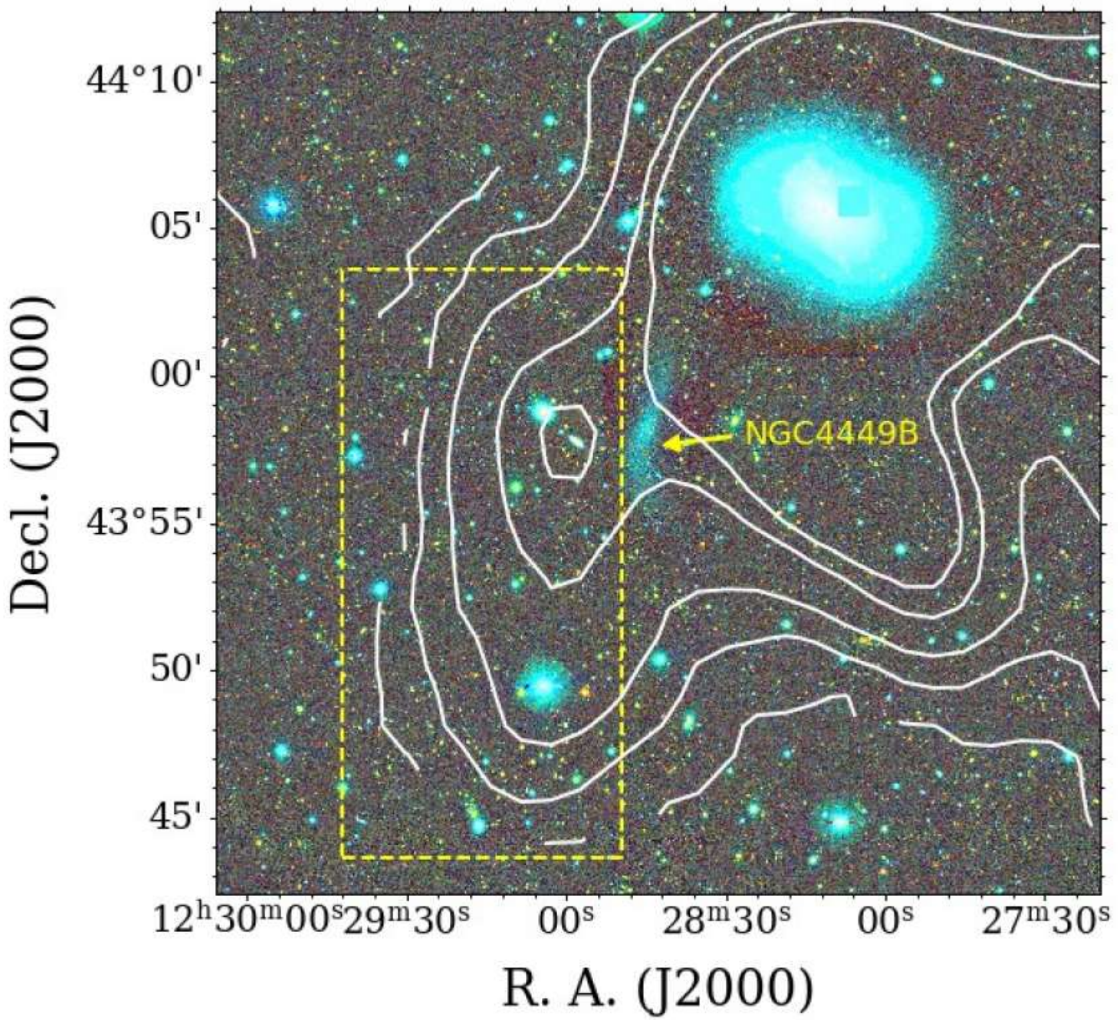




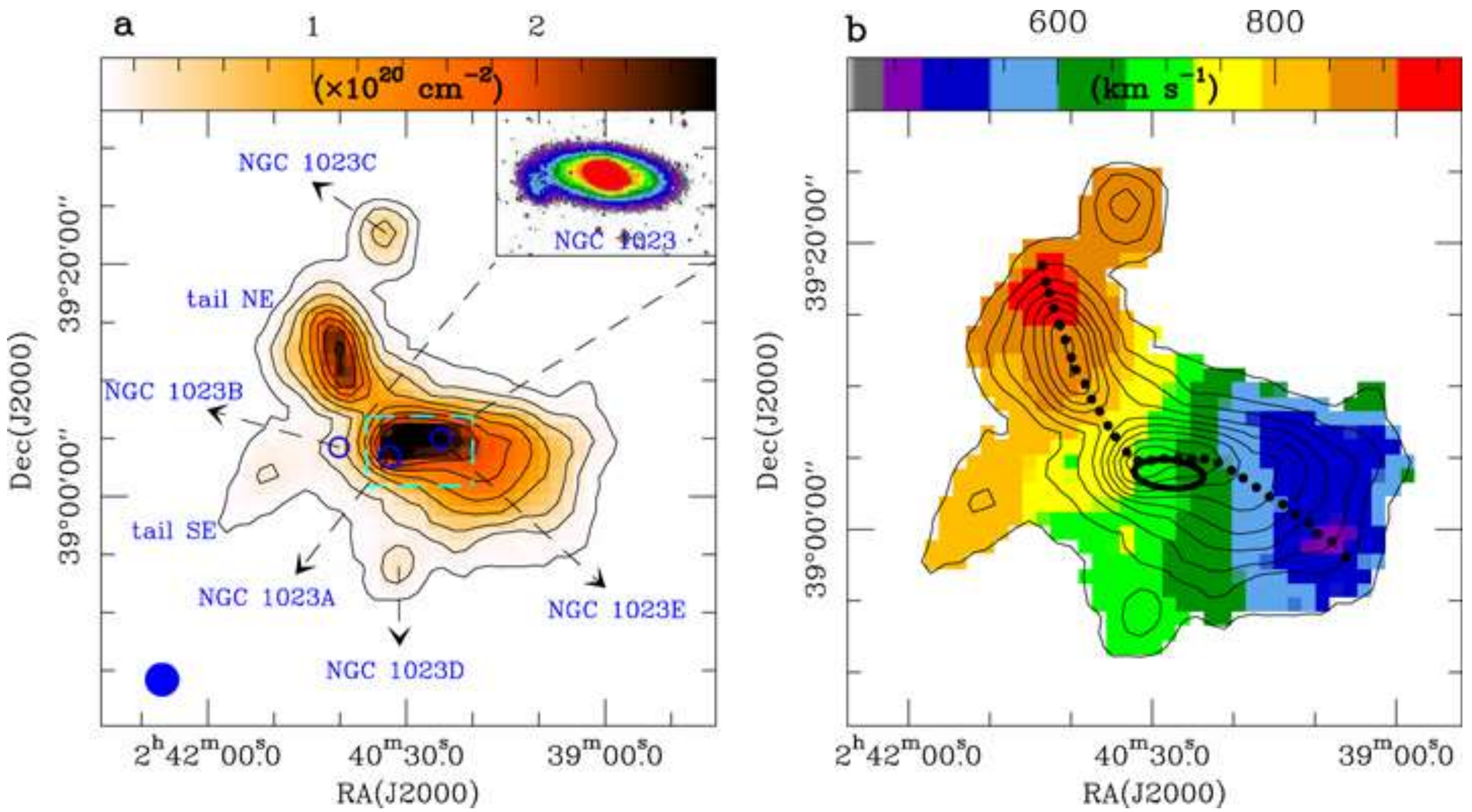
(N-body simulation by Theis & Kohle (2001)



Gas stripped from distrupted dwarf galaxy

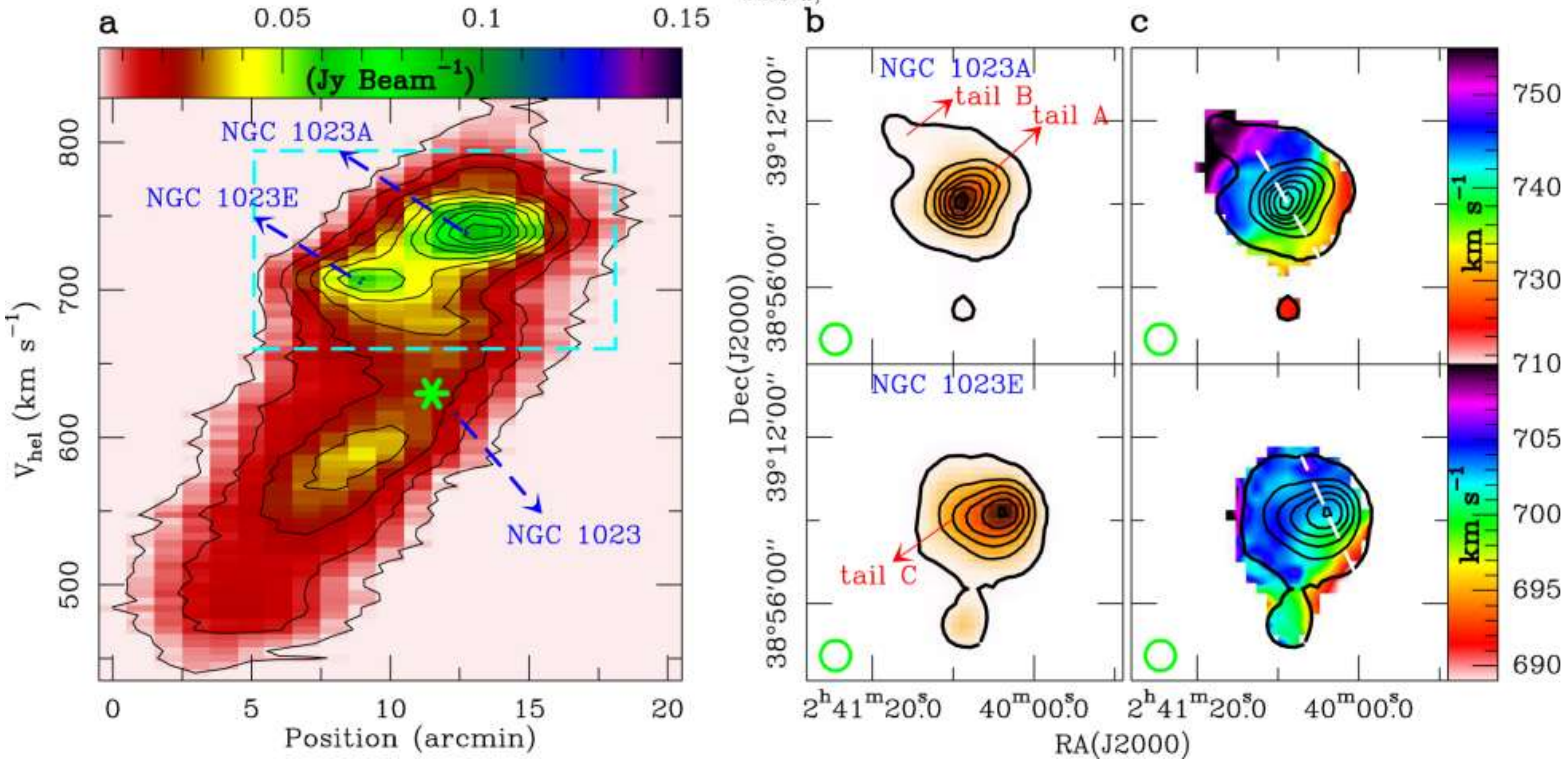


Formation of S0 galaxy （Xu etal. 2023)

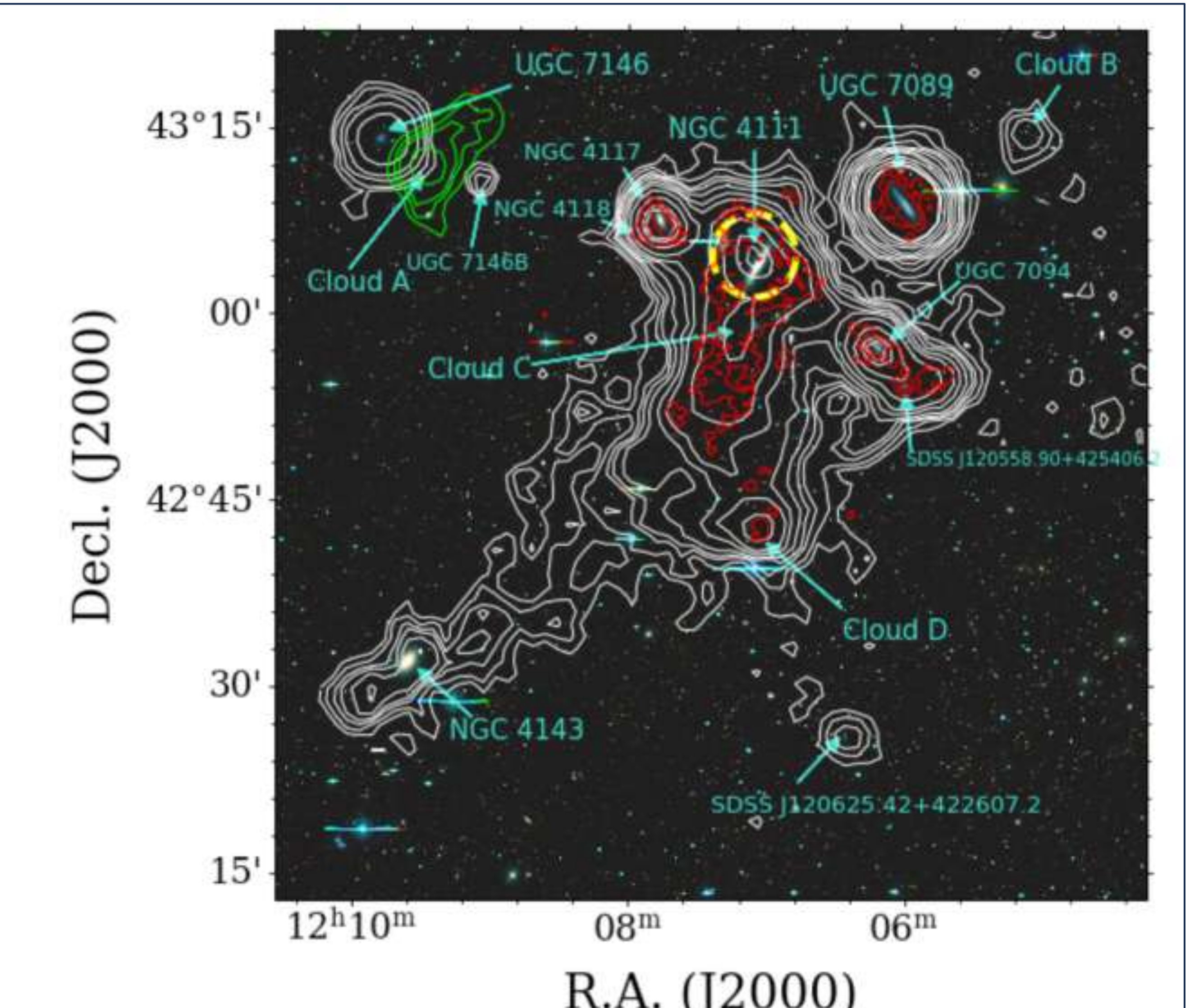


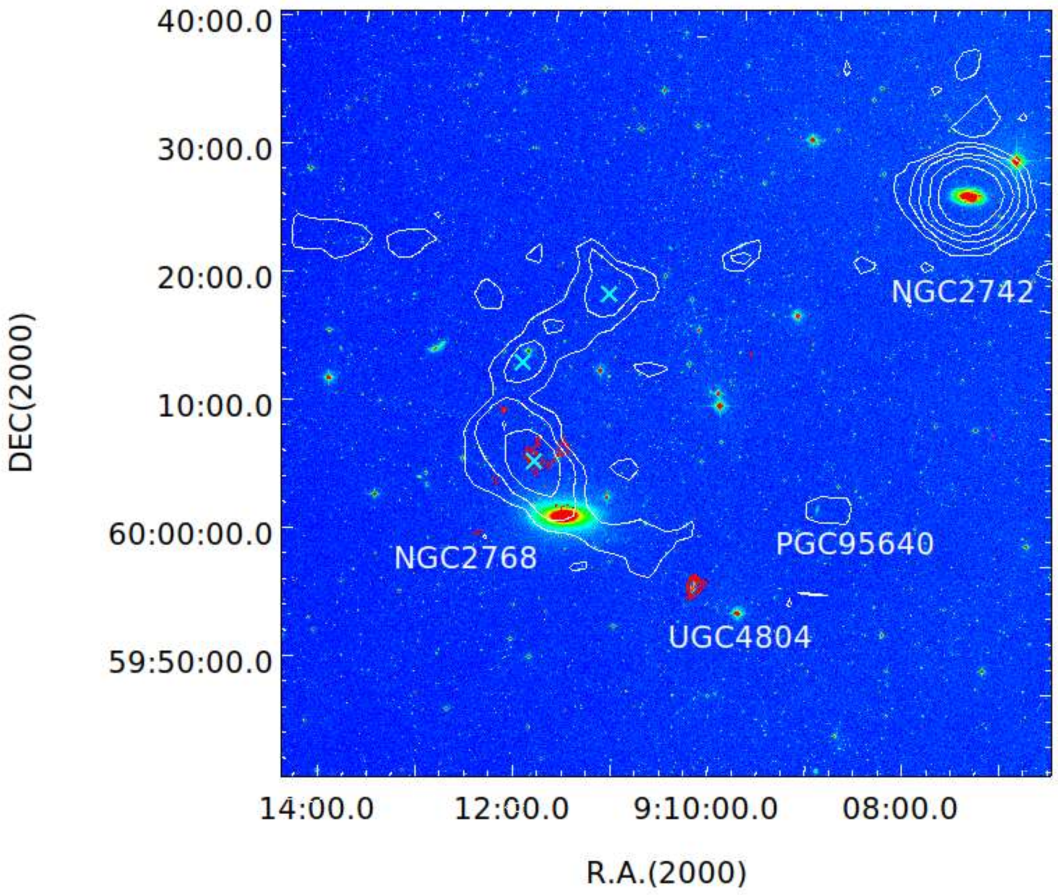
NGC1023

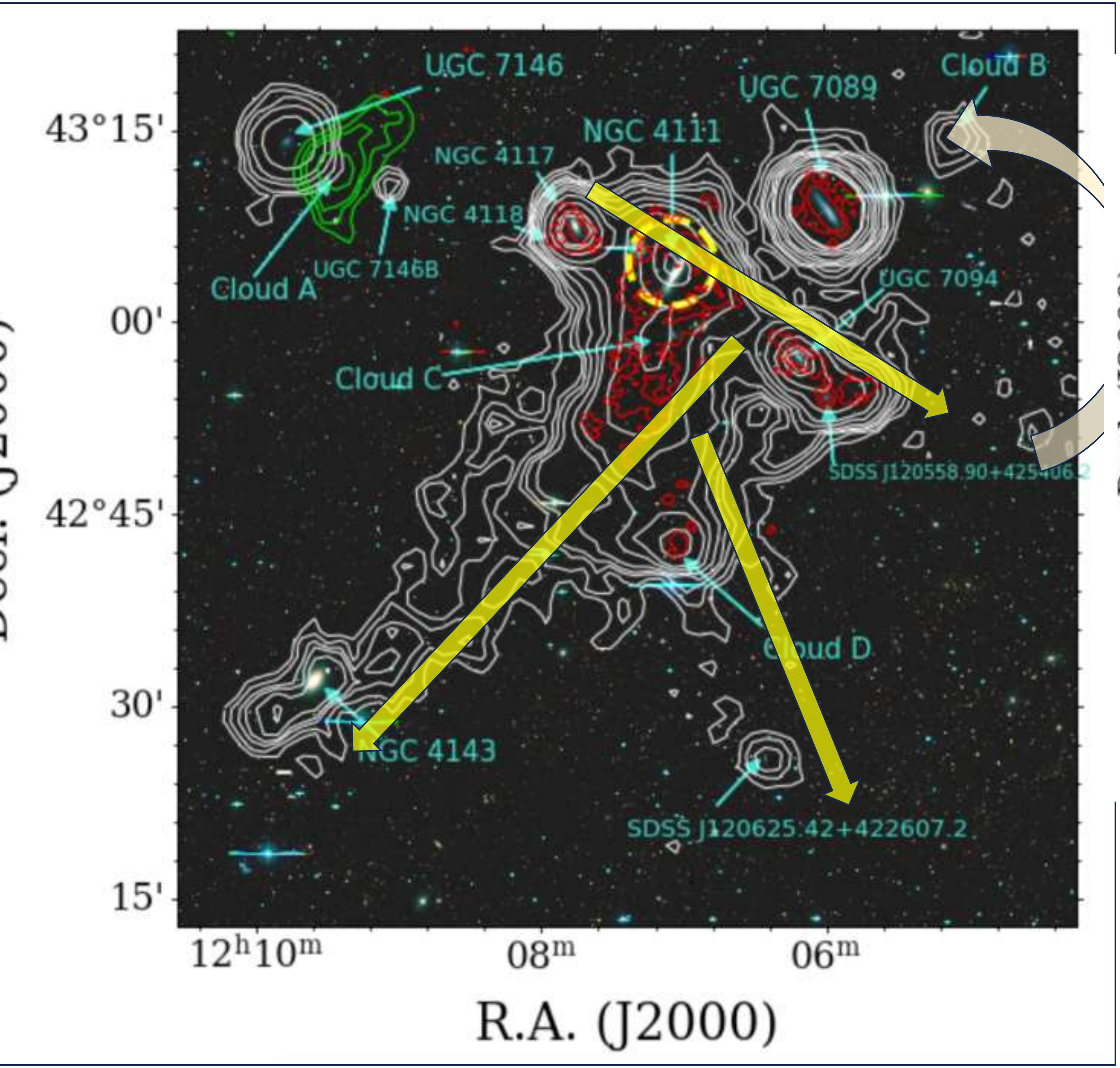
rifield,

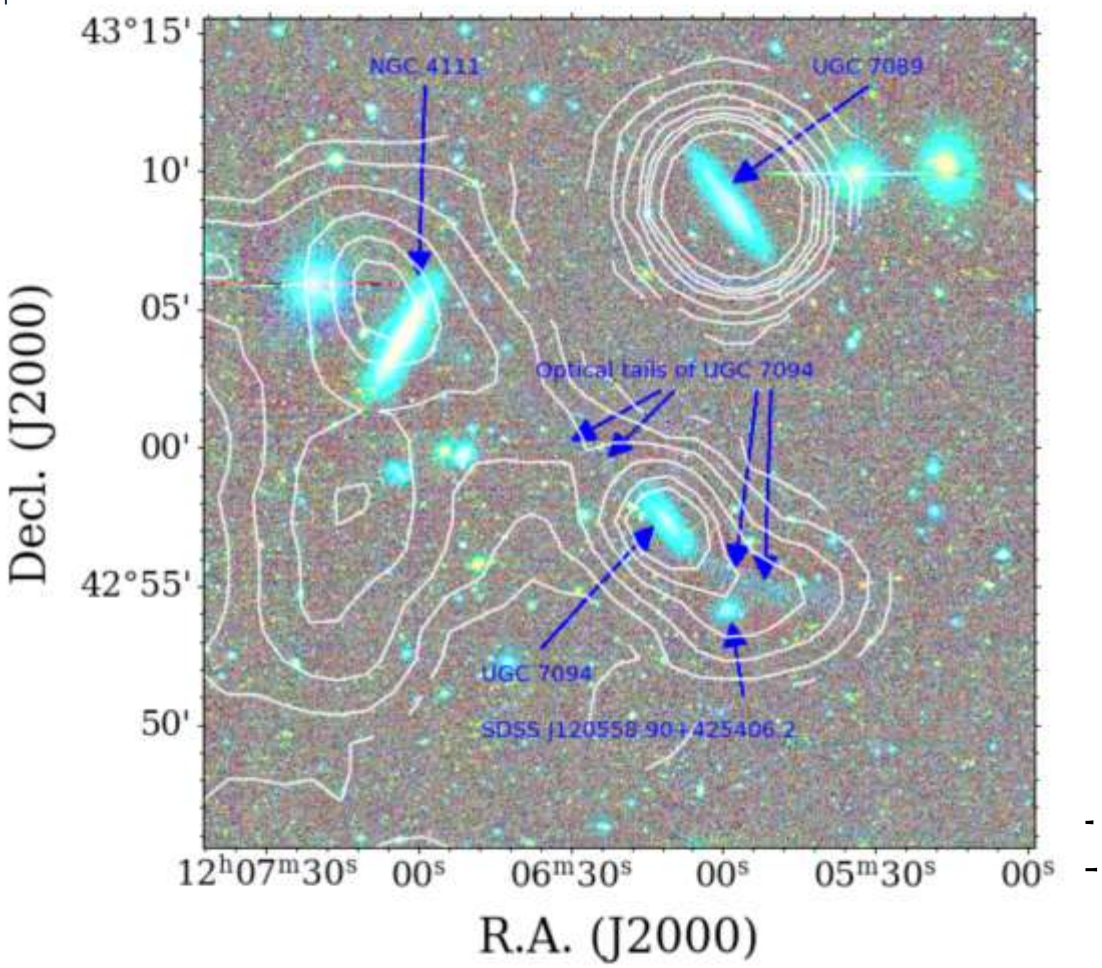


More S0 example: NGC 4111 and NGC 2768

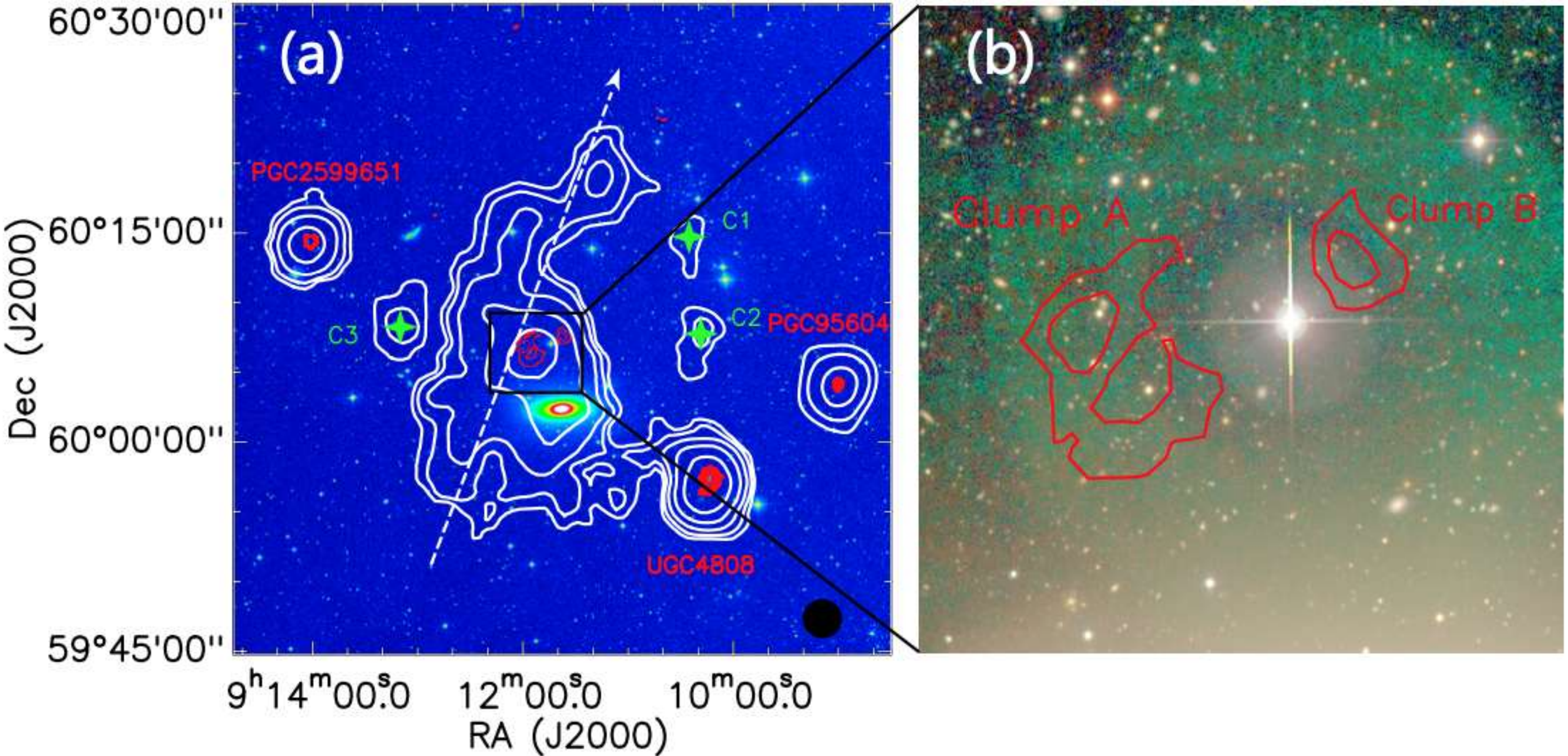





UGC 7146
Cloud B
UGC 7089
NGC 4111
NGC 4117
NGC 4118
UGC 7146B
Cloud A
UGC 7094
Cloud C
SDSS J120558.90+425406.2
Cloud D
NGC 4143
SDSS J120625.42+422607.2
43°15'
00'
42°45'
30'
15'
12h10m
08m
06m
R.A. (J2000)

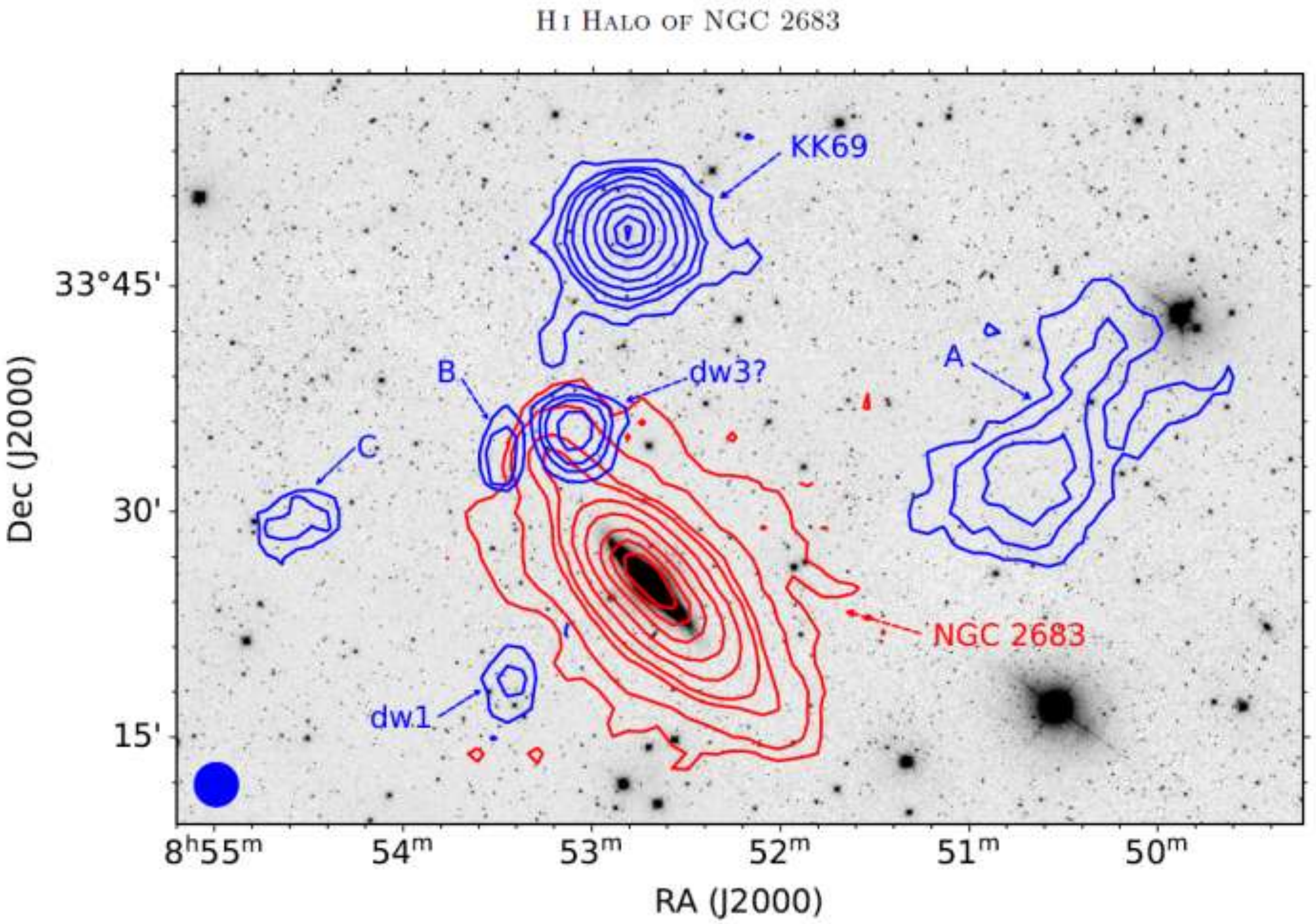

NGC 4111
UGC 7089
Optical tails of UGC 7094
UGC 7094
SDSS J120558.90+425406.2
43°15'
10'
05'
00'
42°55'
50'
Decl. (J2000)
12h07m30s
00s
06m30s
00s
05m30s
00s
R.A. (J2000)

NGC2768文章 （ApJ，Yu et al. 2025）



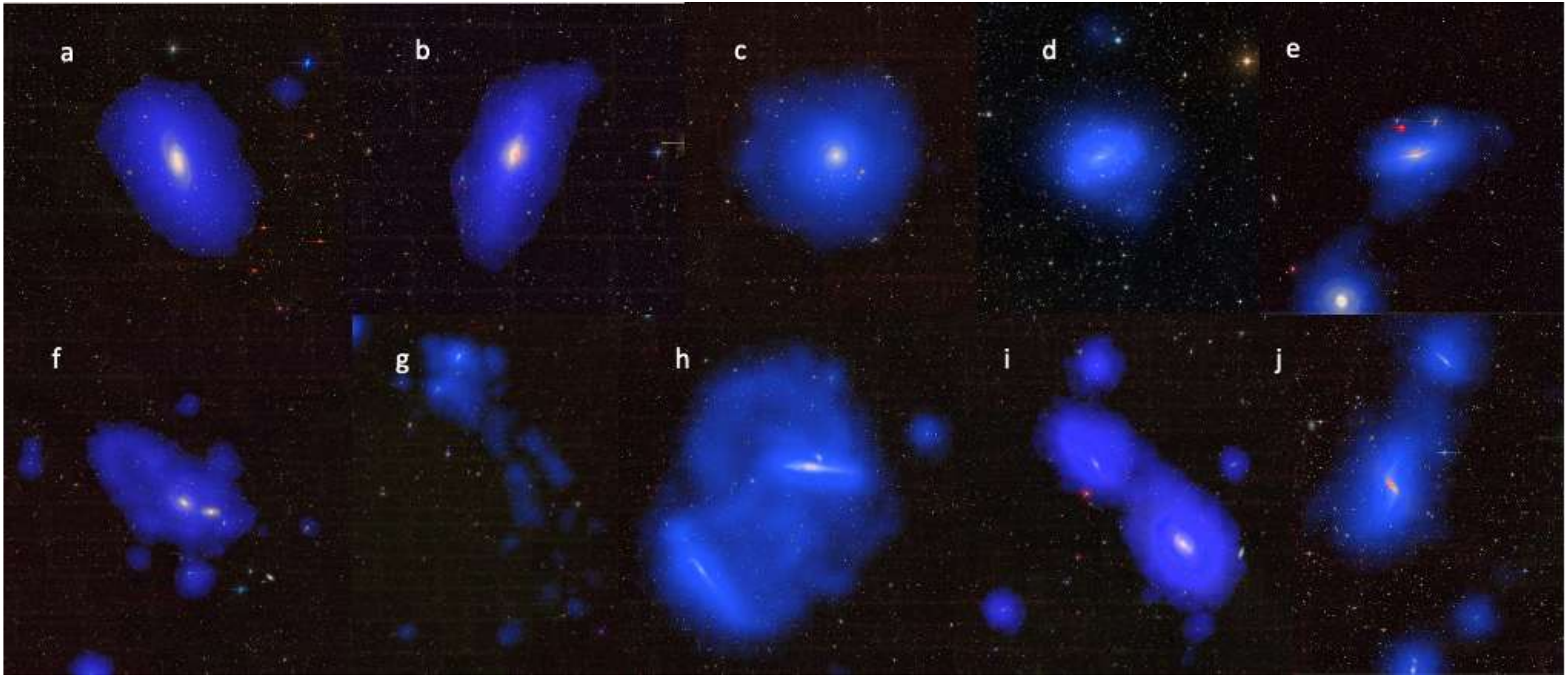
Halo gas in NGC2683

Jiao,Zhu etal. 2025



FEASTS （王菁 等）

（FAST Extended-Atlas-of- Selected-Targets Survey)

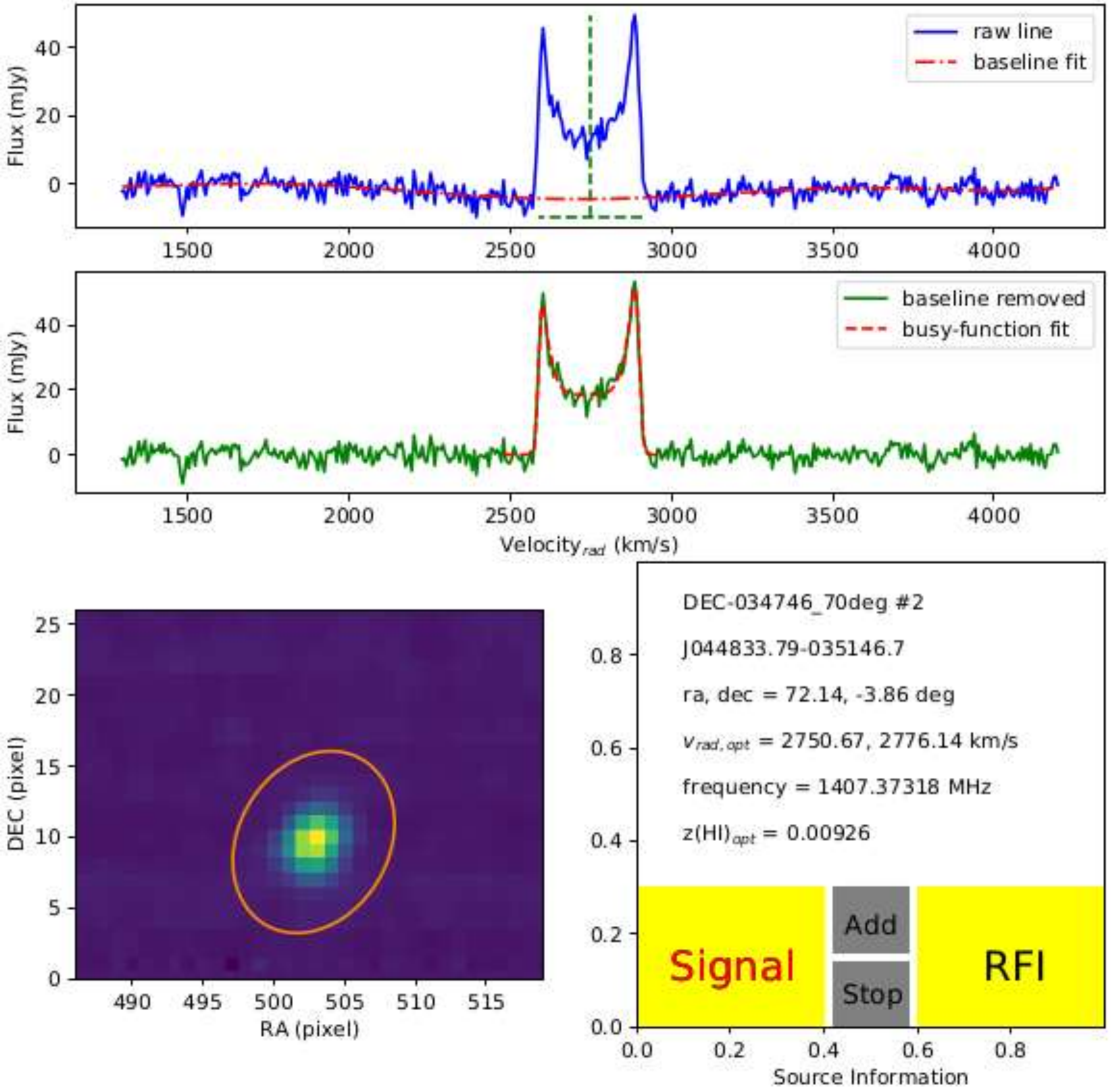


提纲

1. 单个中性氢星系的成图观测

2. 中性氢星系非成图观测– 中性氢巡天

中性氢星系的谱线



raw line
baseline fit
Flux (mJy)
baseline removed
busy-function fit
Flux (mJy)
Velocity$_{rad}$ (km/s)
DEC (pixel)
RA (pixel)
DEC-034746_70deg #2
J044833.79-035146.7
ra, dec = 72.14, -3.86 deg
$v_{rad, opt}$ = 2750.67, 2776.14 km/s
frequency = 1407.37318 MHz
z(HI)$_{opt}$ = 0.00926
Signal
Add
Stop
RFI
Source Information

利用21cm谱线测量HI气体质量

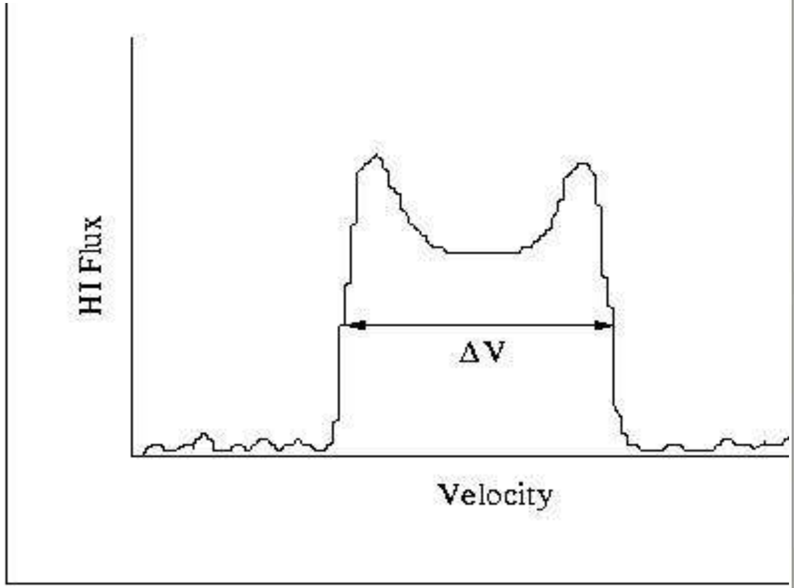
- 光薄时，测到的积分流量 $\int F_v dv \propto \int \frac{M_{HI}}{D^2} dD$
- **和气体温度无关**
- 对于已知距离的一块云，D是常数，流量就正比于质量，比如对于河外星系来讲，我们测到的HI的云的发射，其中的各个部分到我们的距离可以近似认为是一样的

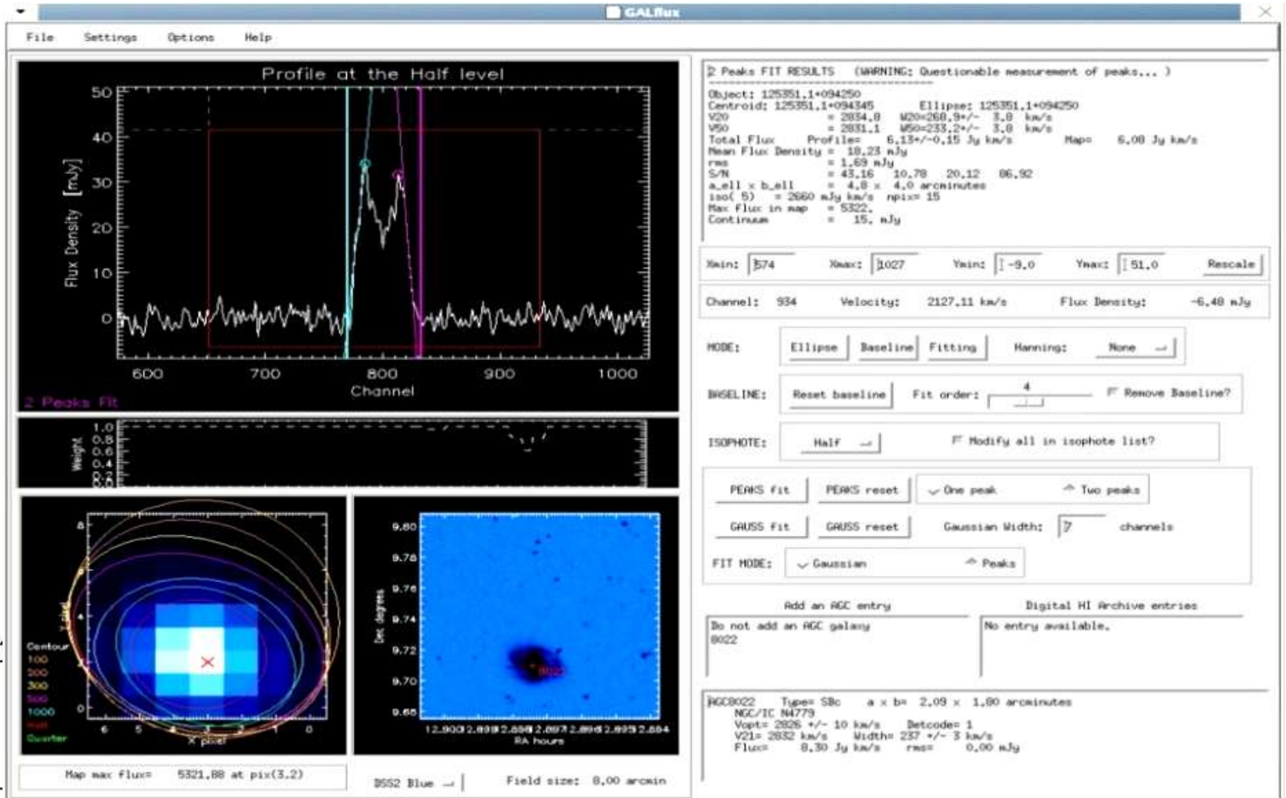
$$\left(\frac{M_{H}}{M_{\odot}}\right) \approx 2.36 \times 10^{5} \left(\frac{D}{\mathrm{Mpc}}\right)^{2} \int \left[\frac{S(v)}{\mathrm{Jy}}\right] \left(\frac{dv}{\mathrm{km\ s^{-1}}}\right)$$

- 而对于河内，流量和质量之间的关系则要复杂一些，因为我们测到的流量是视线方向上的所有气体，距离差异很大
- 光厚时(部分冷的HI气体CNM)，由流量可以得到HI气体的质量下限

单天线中性氢谱线--FAST

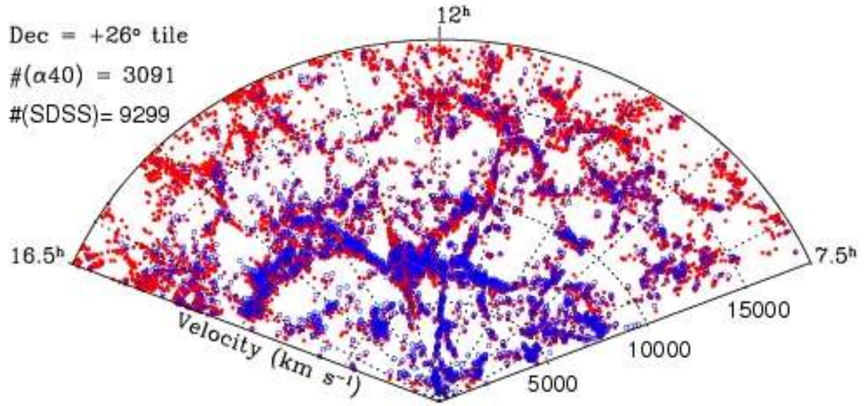
- Distance from recessional velocity, cz
  - Hubble flow: D[Mpc] = cz[km s^{-1}] / H_0[km s^{-1} Mpc^{-1}]
- Dynamic mass from line width
  - M_{dyn} (r<R) ≈ V_{rot}^2 R / G



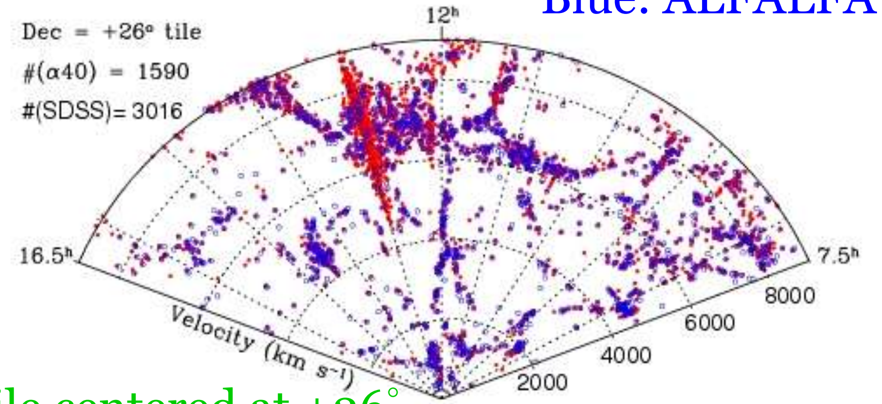


ALFALFA HI survey （Haynes + 2018）

- Detect 31500 HI sources
- Large amount of optical galaxies have not been detected in HI (only 3% have HI)



Red: SDSS
Blue: ALFALFA



4° tile centered at +26°

Previous HI surveys

HI-blind surveys

- HIPASS (HI Parkes All sky survey): $z<0.04$, N~6000
- ALFALFA (Arecibo Legacy Fast ALFA Survey): $z<0.06$, N~31,500

Targeted observations

- GASS (GALEX Arecibo SDSS Survey) $z<0.05$, N~800
- RESOLVE (REsolved Spectroscopy Of a Local VolumE): $z<0.023$, N~1600
- HIGHz (A Survey of the Most Hi-Massive Galaxies at z ~0.2): z=0.17-0.25, N=40

Targeted resolved observations on smaller samples:

- THINGS (The HI Nearby Galaxy Survey): N=34, D<15Mpc
- VIVA (VLA Imaging of Virgo in Atomic gas): N=53, D~16Mpc
- BUDHIES (Blind Ultra Deep HI Environmental Survey): N~150, z~0.2
- CHILES (COSMOS HI Large Extragalactic Survey): N~300, $z<0.45$

都不能同时满足大样本、高空间分辨率、深场，且都为低红移

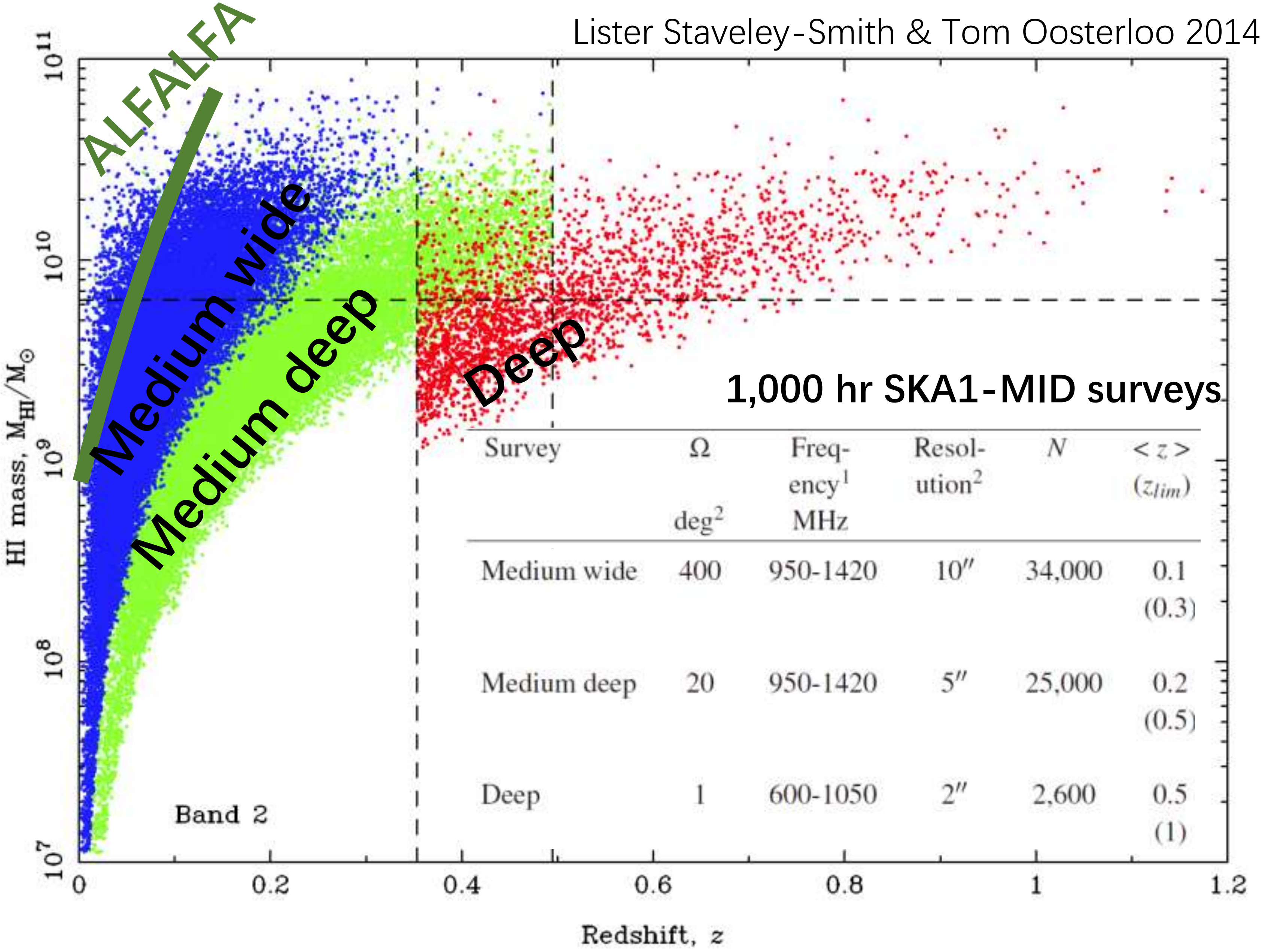
中性氢巡天进展对比表

巡天项目	望远镜	天区覆盖 (deg²)	灵敏度 (mJy/beam)	红移范围	源数量	主要特点/局限
HIPASS	Parkes	~30,000	~13	z < 0.042	~5,000	首个全天HI巡天，但灵敏度低，难以探测低质量星系
ALFALFA	Arecibo	~7,000	~2.4	z < 0.06	~31,500	灵敏度显著提升，但仍受限于天区覆盖和低质量端探测能力
FASHI	**FAST**	**~19,500**	**~0.57**	**z < 0.09** **0.25<z<0.41**	**156,411**	**迄今最大、最深的单口径HI巡天，样本规模远超以往**
WALLABY	ASKAP	~1,000 (计划~75%天区)	~1.6	z < 0.1	~5,000 (早期)	干涉阵，空间分辨率高，可分辨HI结构，但天区有限
MIGHTEE	MeerKAT	~20	~0.1	z ~ 0.1–0.5	~1,200	深场探测，可至z~0.5，但天区极小，受宇宙方差影响
CHILES	VLA	~0.45	~0.05	z ~ 0.1–0.5	~1,200	极高空间分辨率，但天区极小，受宇宙方差影响
LADUMA	MeerKAT	~0.6	~0.05	z ~ 0.1–1.0	~500	最深HI巡天之一，但天区极小，受宇宙方差影响

单口径与干涉阵巡天对比

特征	单口径巡天 (HIPASS/ALFALFA/FASHI)	干涉阵巡天 (WALLABY/MIGHTEE/CHILES/LADUMA)
天区覆盖	数千至数万平方度	通常 < 100 平方度
灵敏度	中等至极高 (FASHI最佳)	极高
红移范围	本地宇宙 ($z < 0.1$)	可至 $z \sim 1.0$
空间分辨率	低 (波束 ~ 3′)	高 (角秒级)
主要优势	大样本、完备性好、抗宇宙方差	可分辨星系结构、精确匹配光学对应体
主要局限	无法分辨内部结构、存在混淆问题	天区小、受宇宙方差影响大

单口径+干涉阵协同是未来



Survey	Ω deg^2	Frequency[1] MHz	Resolution[2]	N	$<z>$ (z_{lim})
Medium wide	400	950-1420	10″	34,000	0.1 (0.3)
Medium deep	20	950-1420	5″	25,000	0.2 (0.5)
Deep	1	600-1050	2″	2,600	0.5 (1)

SKA将同时提供**大样本**、**高空间分辨率**的**深场**HI巡天数据，以及**随红移的演化**

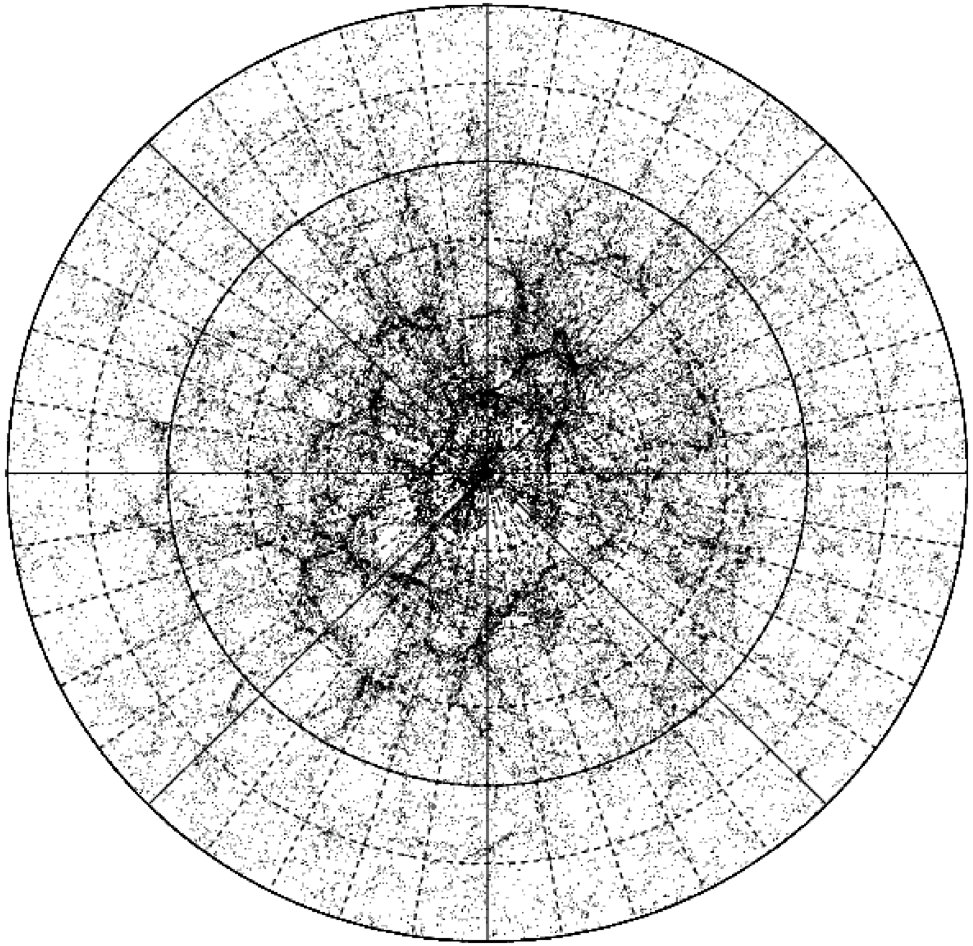
Wallaby (WIDEBAND ASKAP L-BAND LEGACY ALL-SKY BLIND SURVEY)

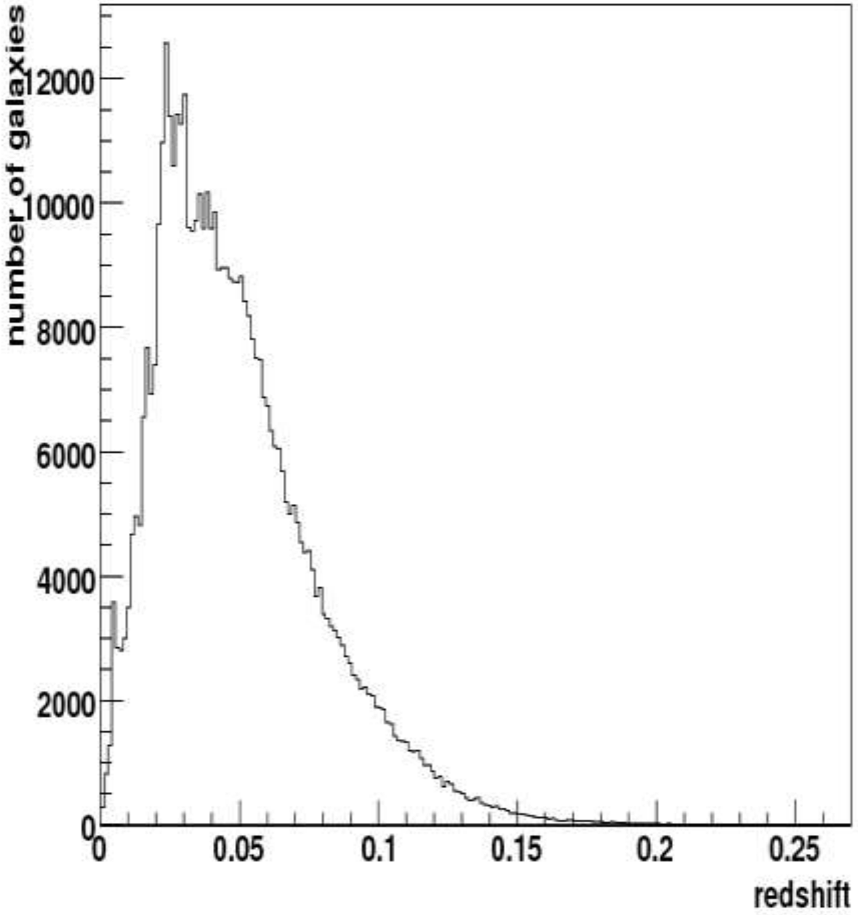
Principal Investigators: B. S. Koribalski (ATNF) & L. Staveley-Smith (ICRAR/UWA)

Wallaby: summary

- *Angular resolution*: 10-30 arcsec
- *Area*: 3π
- *Bandwidth*: 300 MHz (z=0 to 0.26)
- *Frequency resolution*: 18.3 kHz (4 km s^{-1})
- *RMS flux density (0.1 MHz)*: 0.7 mJy/beam
- *RMS column density sensitivity (0.1 MHz)*: 1.7×10^{19} cm^{-2}
- Cube volume: 6 PB (uv data 50 PB)

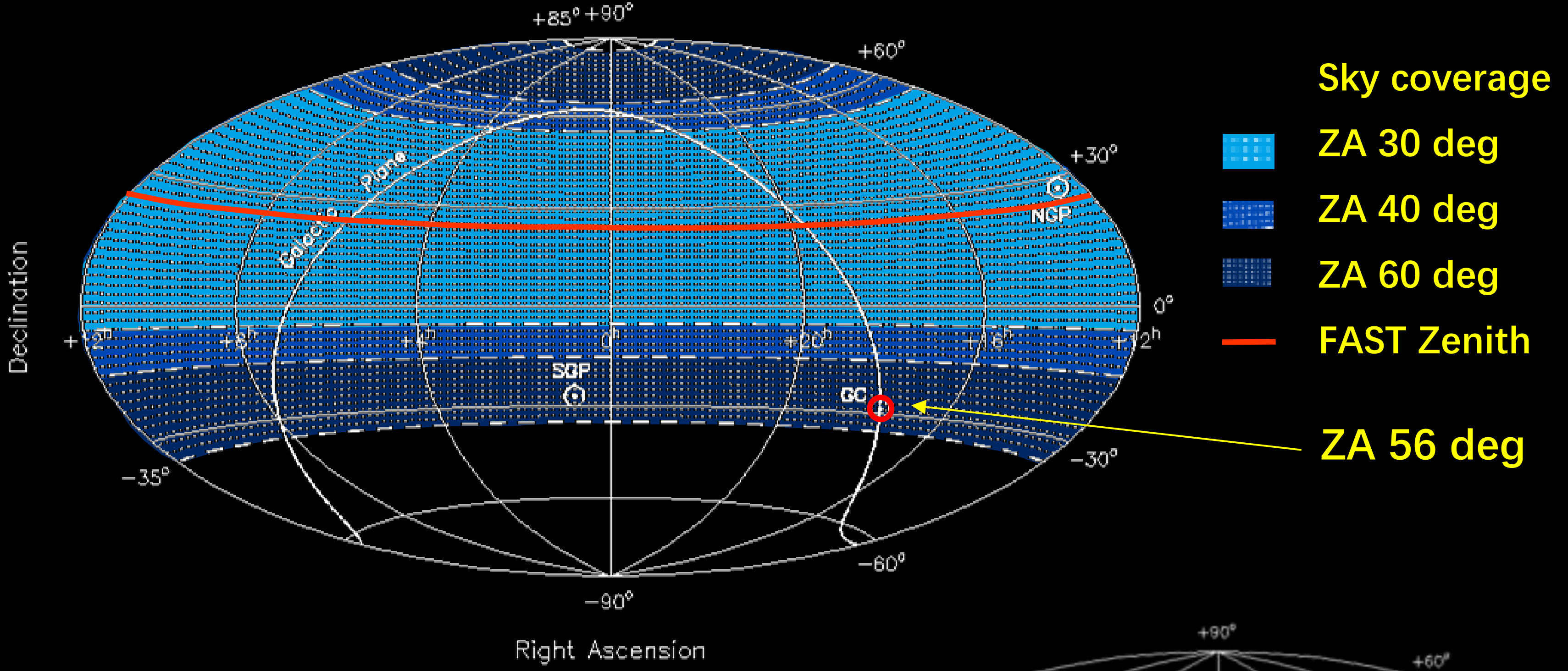
Wallaby: Simulated sky and redshift distribution
(Beutler)



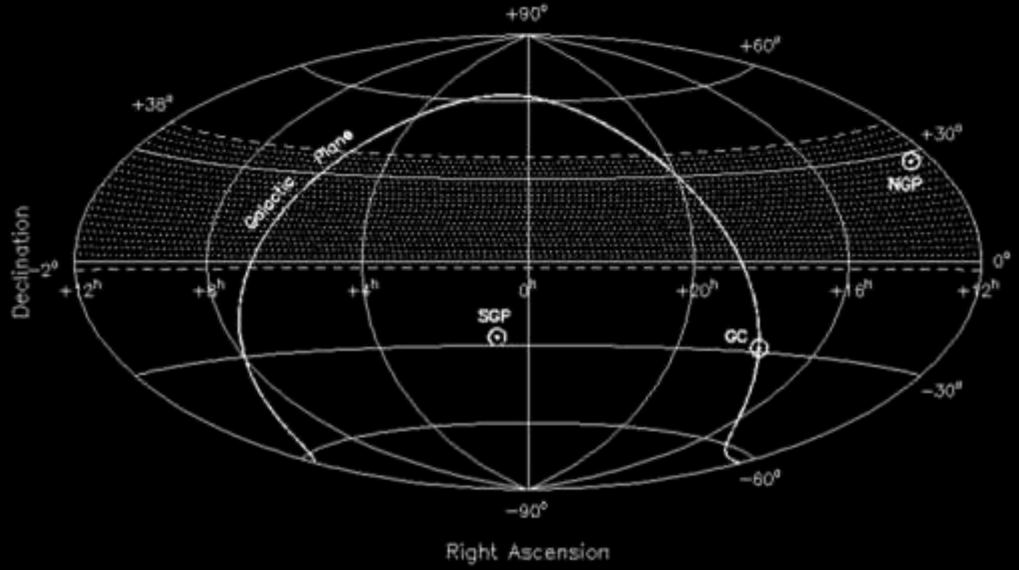


500,000 galaxies

Opening angle - sky coverage

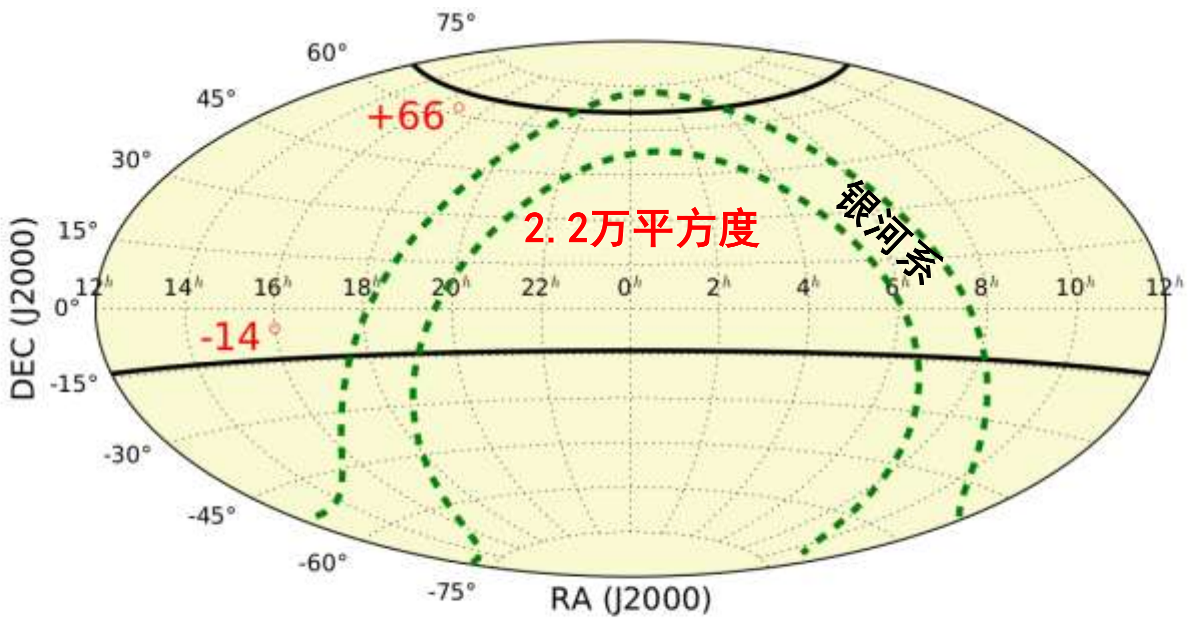


Sky coverage
FAST vs. Arecibo

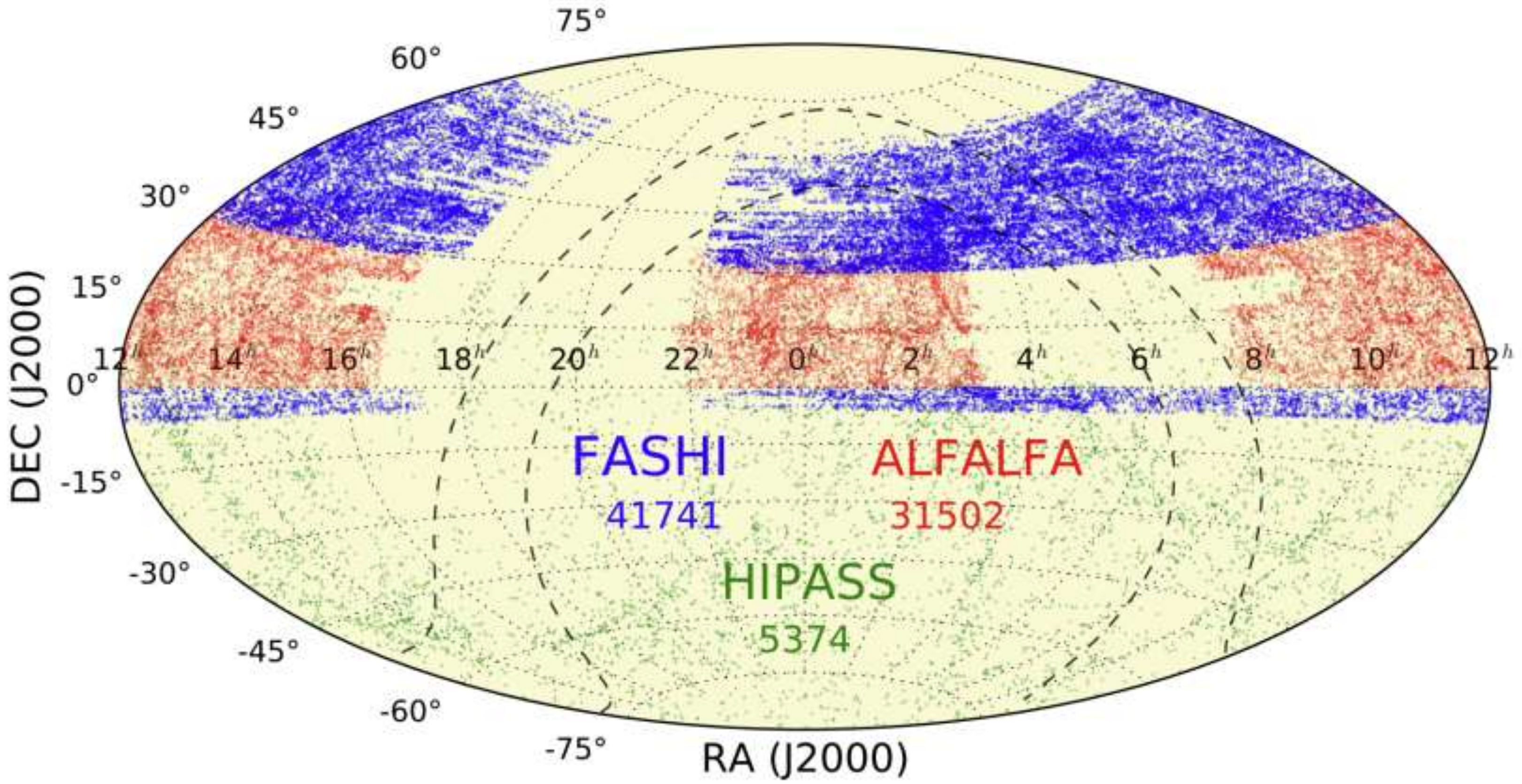


“法师”中性氢星系巡天项目

- ✓ “法师”： FAST All Sky HI survey (FASHI)
- ✓ 利用中国天眼对~2.2万平方度的天空进行深度覆盖、频率范围为1050-1450 MHz；
- ✓ 2020年8月份-今天；
- ✓ 探测到十万多颗中性氢星系样本；

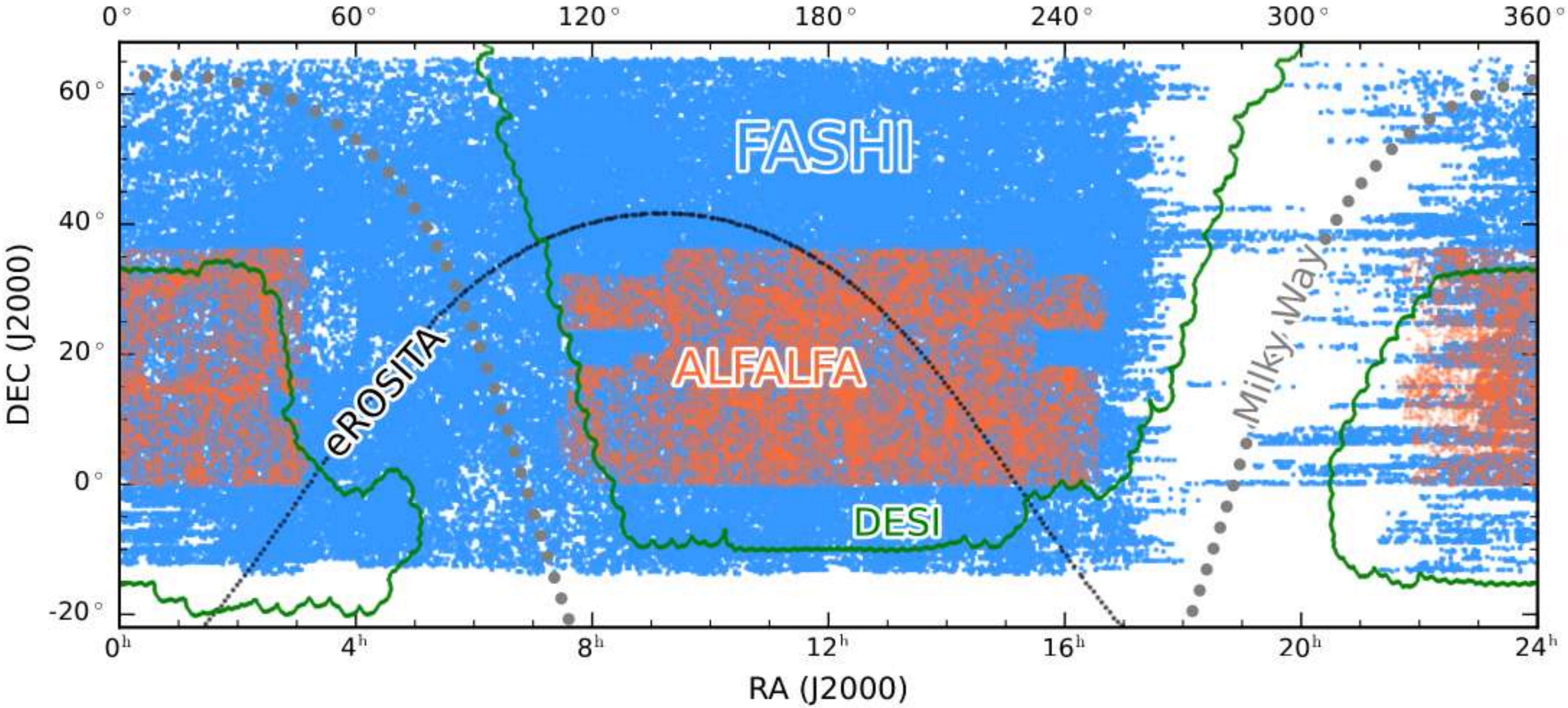


FAST中性氢星系巡天——FASHI（法师）



中国天眼FAST，仅用3年（2020年8月-2023年7月）就完成了约7600平方度的巡天工作，发现了**41741**个中性氢星系样本，数量和质量远超ALFALFA。

FASHI DR2中性氢星系样本分布



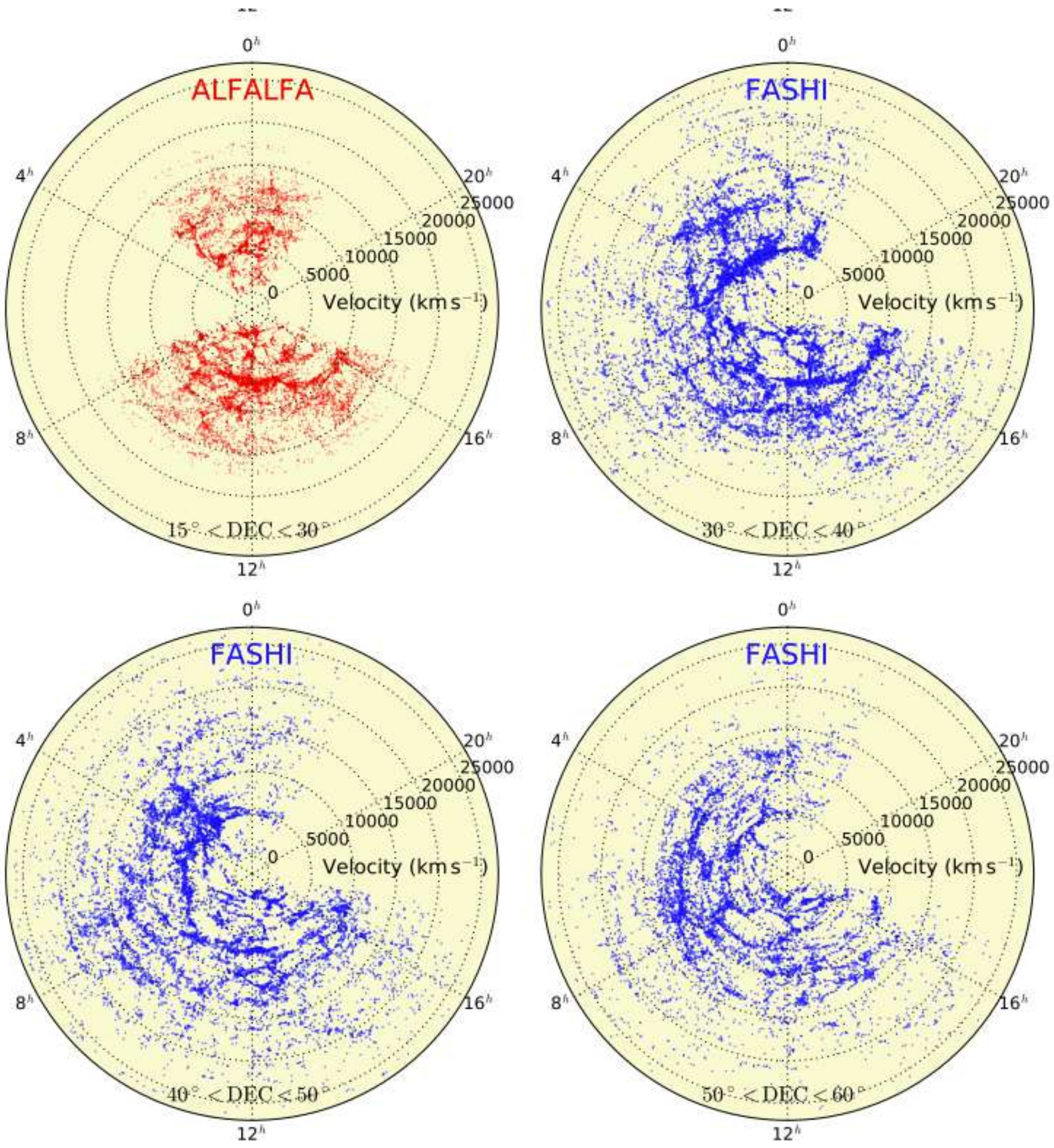
FASHI — 19500平方度，15.6万个源； ALFALFA — 7000平方度，3.1万个源

Zhang et al. 2026， SCPMA

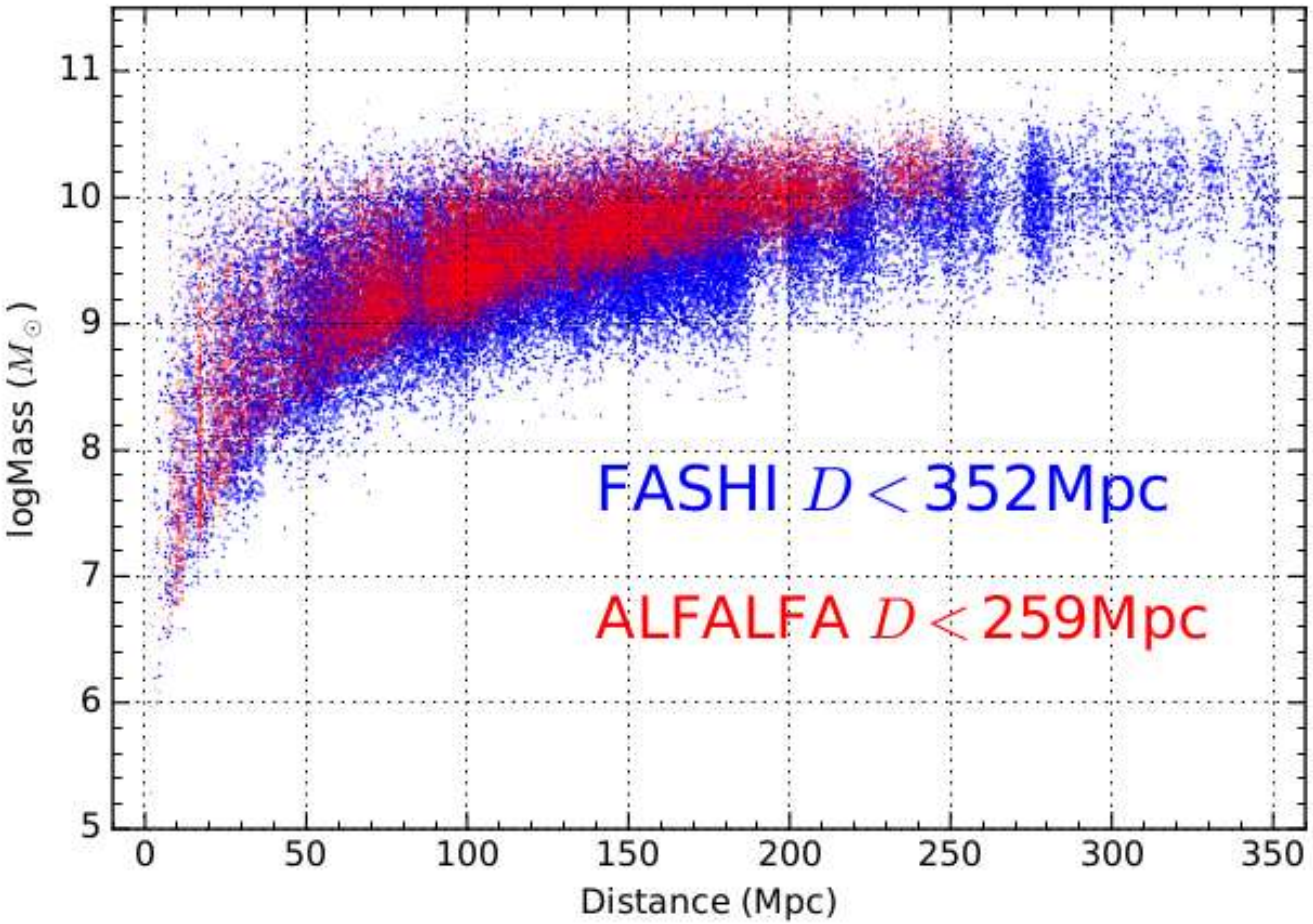
法师中性氢巡天的重要意义

- ✓ 为星系宇宙学研究领域提供了最大样本的中性氢星系数据；
- ✓ 为近邻星系的中性氢气体分布和大尺度结构的研究提供最大样本的数据；
- ✓ 对研究中性氢质量函数、限制暗物质的性质、发现未知的暗弱星系等课题具有重要的意义
- ✓ 中性氢巡天的同时，可以搜寻和研究高红移羟基巨脉泽源、中性氢吸收线星系等；
- ✓ 法师巡天覆盖部分银河系，可以研究银河系的延展结构、高速云和电离氢区等；

The large-scale structure distribution 15◦ < DEC < 60◦ and volume extending over to ~26323 km s−1 .



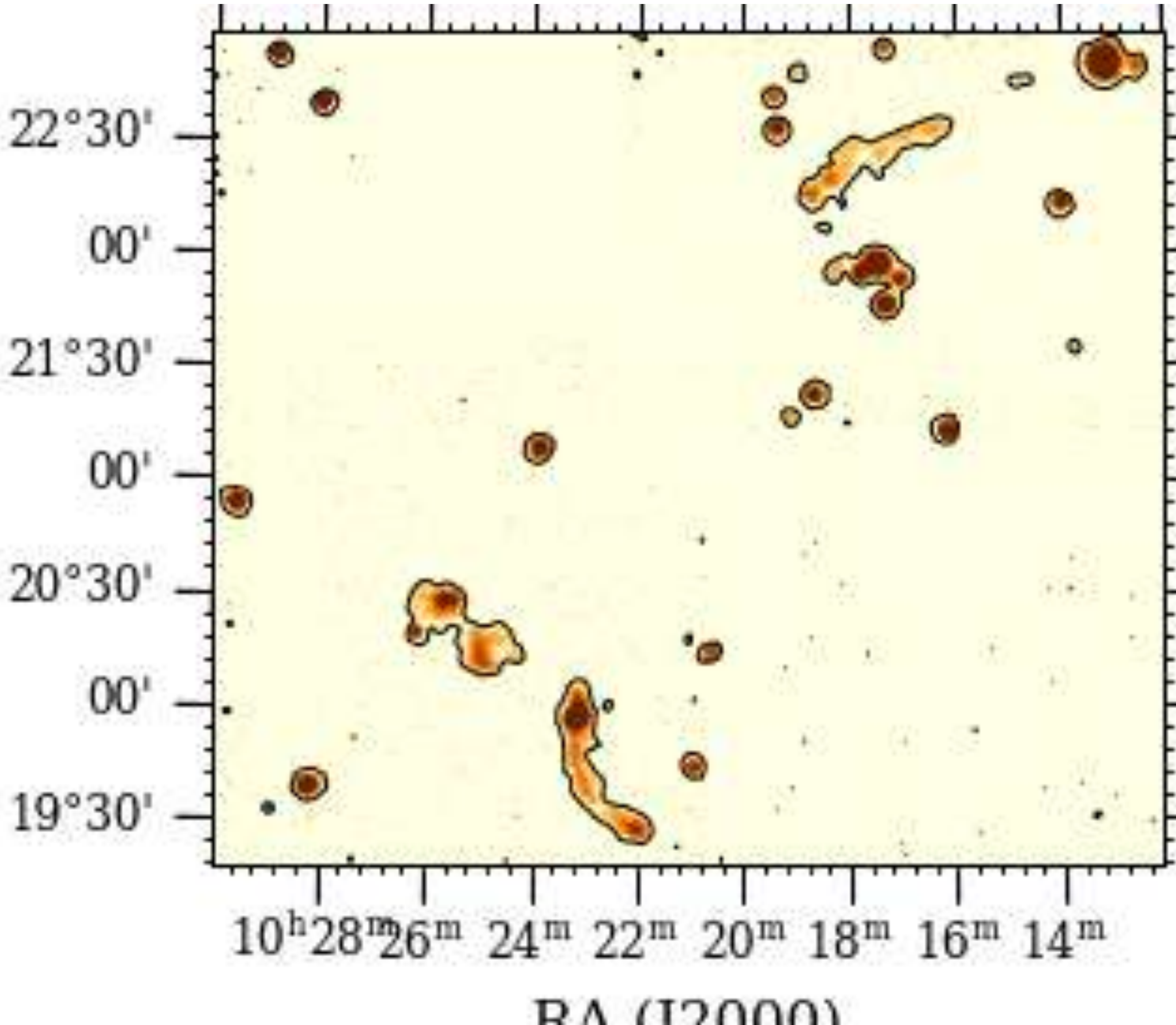
法师看得更远、更深入

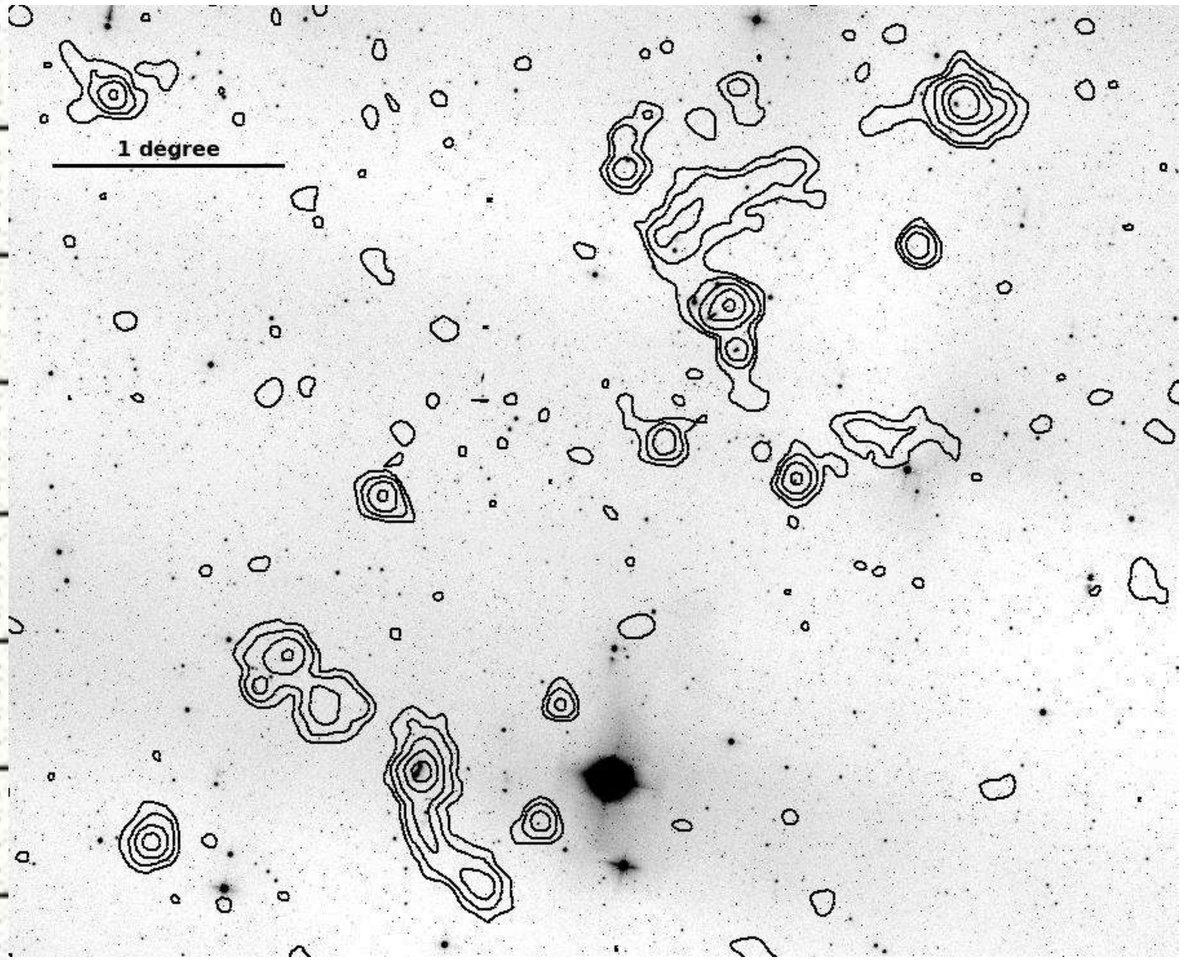


FASHI $D < 352$Mpc
ALFALFA $D < 259$Mpc
logMass ($M_\odot$)
Distance (Mpc)
11
10
9
8
7
6
5
0
50
100
150
200
250
300
350

FAST 成图观测与 Arecibo 数据比较 (NGC 3227, NGC 3190 groups)

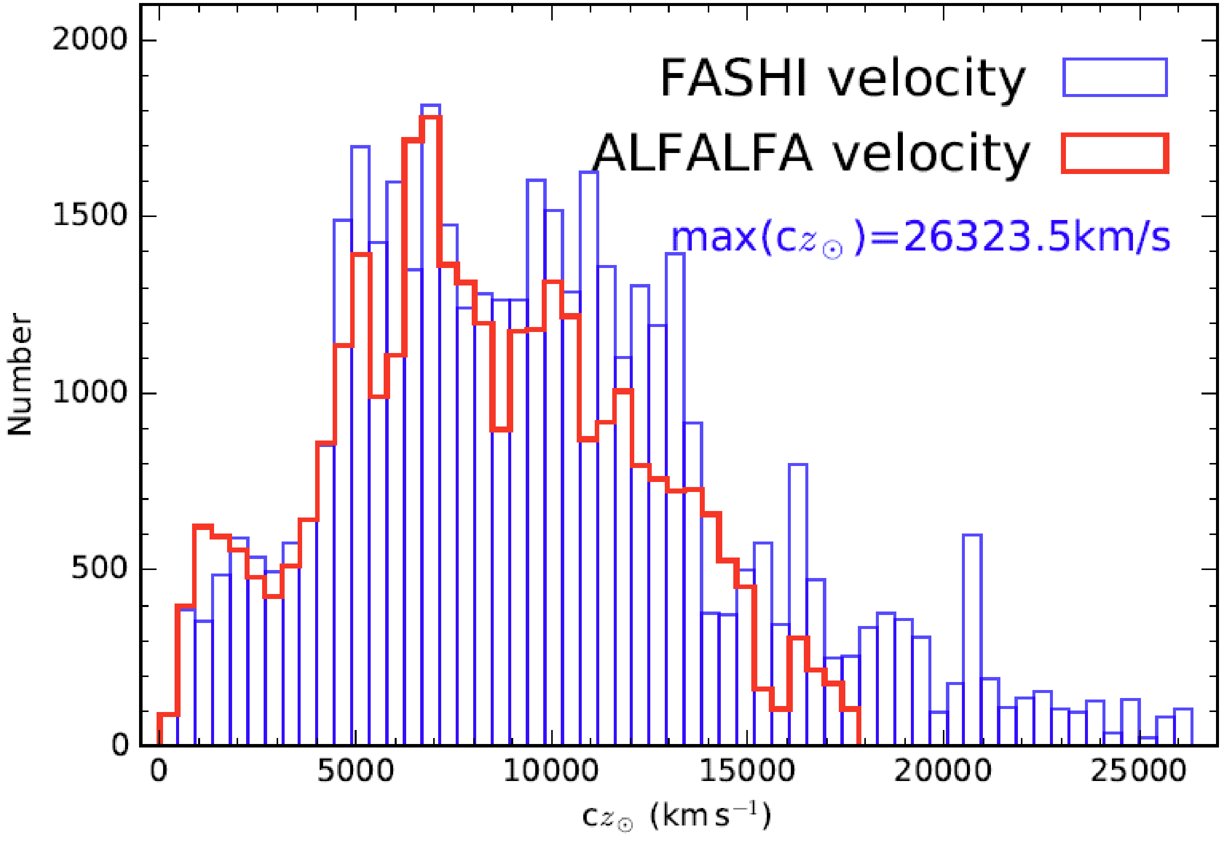
（Luke Leisman+ 2016）

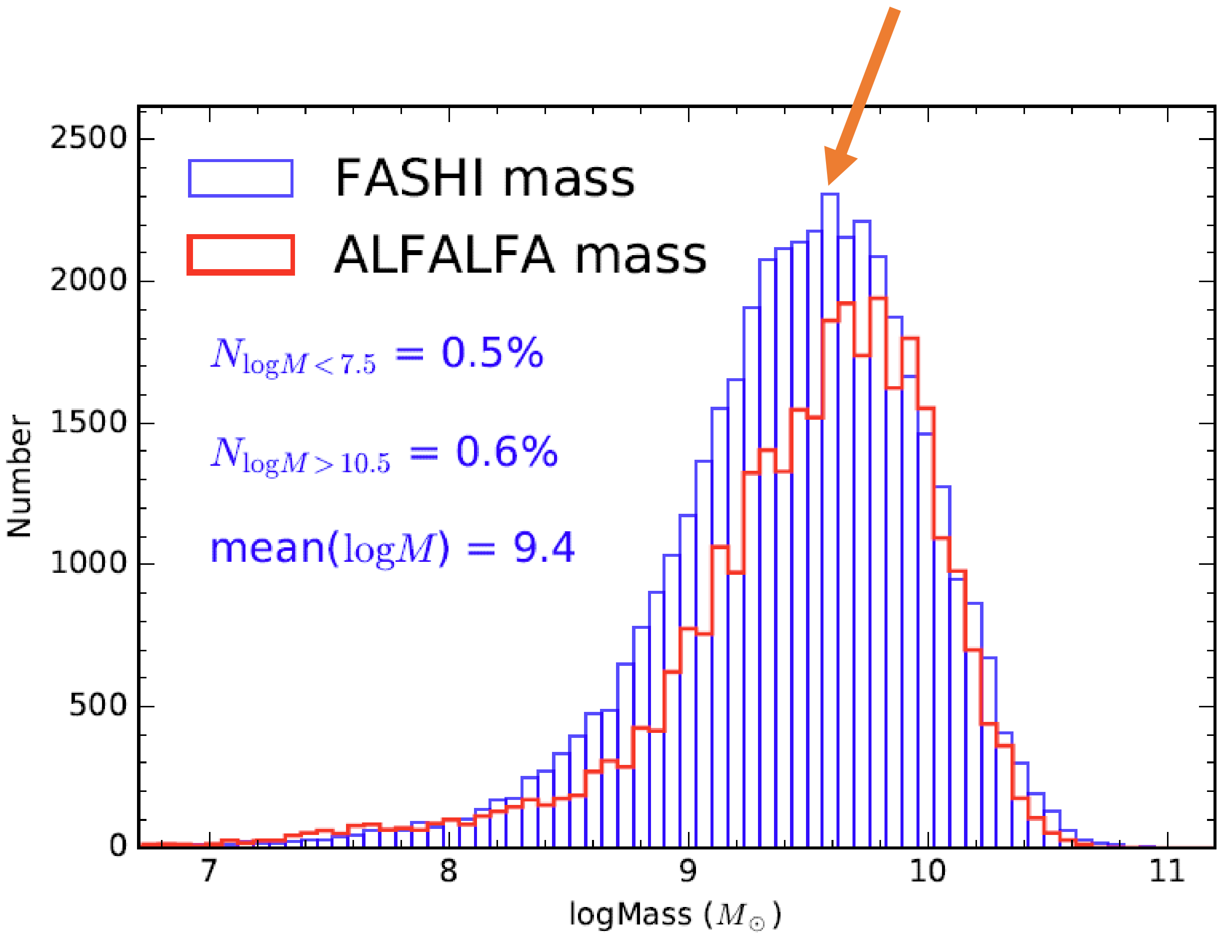




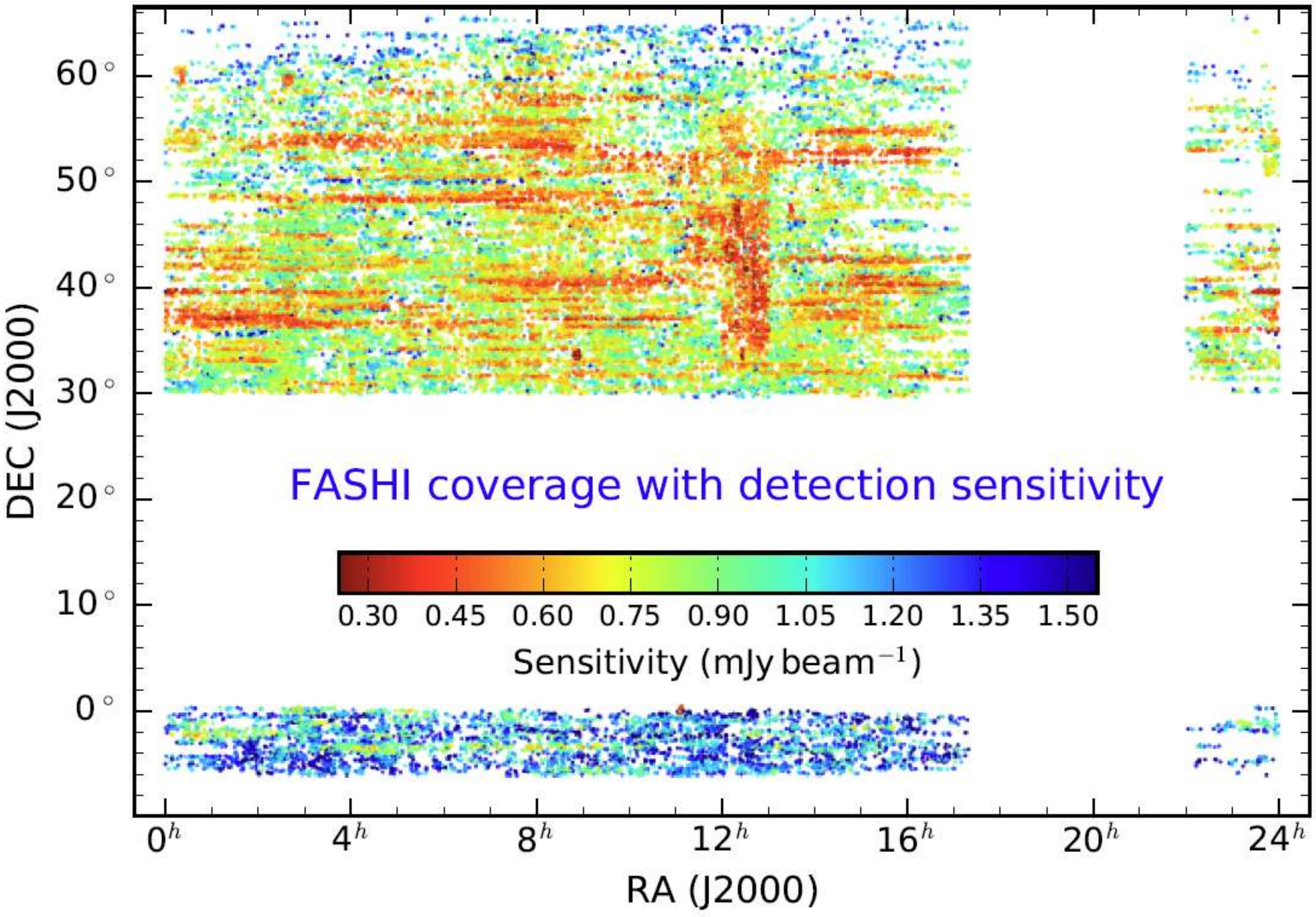
FAST detect more dwarf galaxies

Detection limit 350 Mpc ➔ 3x10^9 Msun



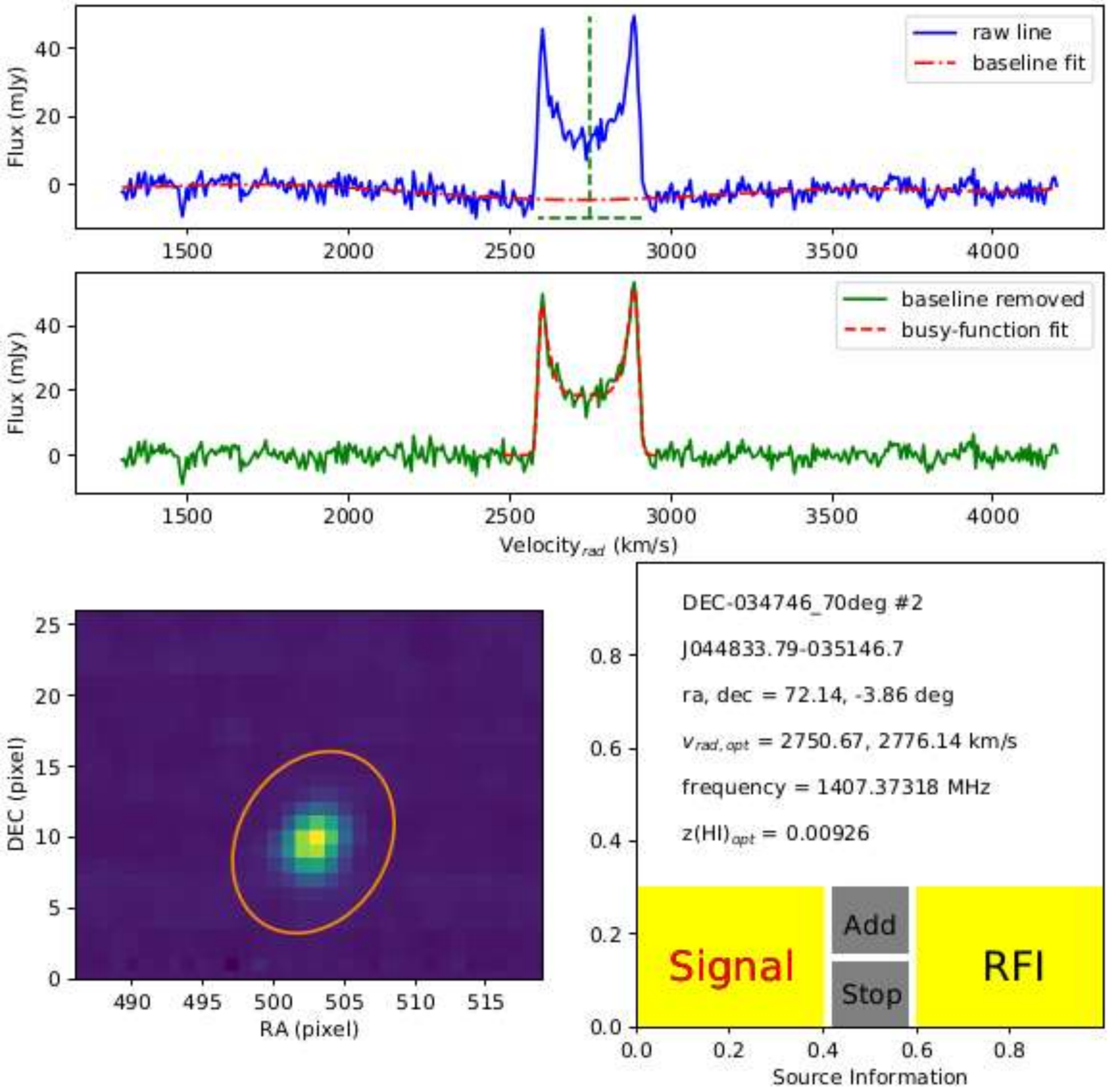


Caveats



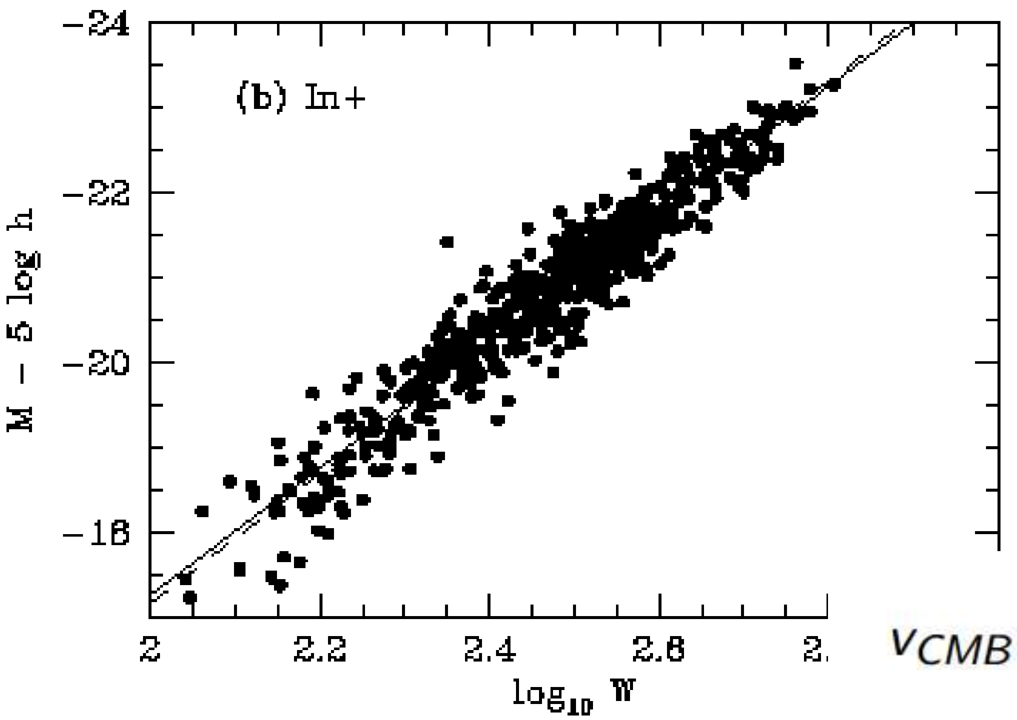
FASHI coverage with detection sensitivity
0.30 0.45 0.60 0.75 0.90 1.05 1.20 1.35 1.50
Sensitivity (mJy beam^{-1})
DEC (J2000)
60° 50° 40° 30° 20° 10° 0°
RA (J2000)
0^h 4^h 8^h 12^h 16^h 20^h 24^h

处理后的谱线



raw line
baseline fit
Flux (mJy)
baseline removed
busy-function fit
Velocity$_{rad}$ (km/s)
DEC (pixel)
RA (pixel)
DEC-034746_70deg #2
J044833.79-035146.7
ra, dec = 72.14, -3.86 deg
$v_{rad,opt}$ = 2750.67, 2776.14 km/s
frequency = 1407.37318 MHz
$z(HI)_{opt}$ = 0.00926
Signal
Add
Stop
RFI
Source Information

Tully-Fisher 关系定星系距离及本速度场（Peculiar Velocity



Tully & Fisher 1977

$$v_{CMB} = H_0 \times d + v_{peculiar\ radial} \quad (1)$$

$$m - M = 5log_{10}(d(Mpc)) + 25 \quad (2)$$

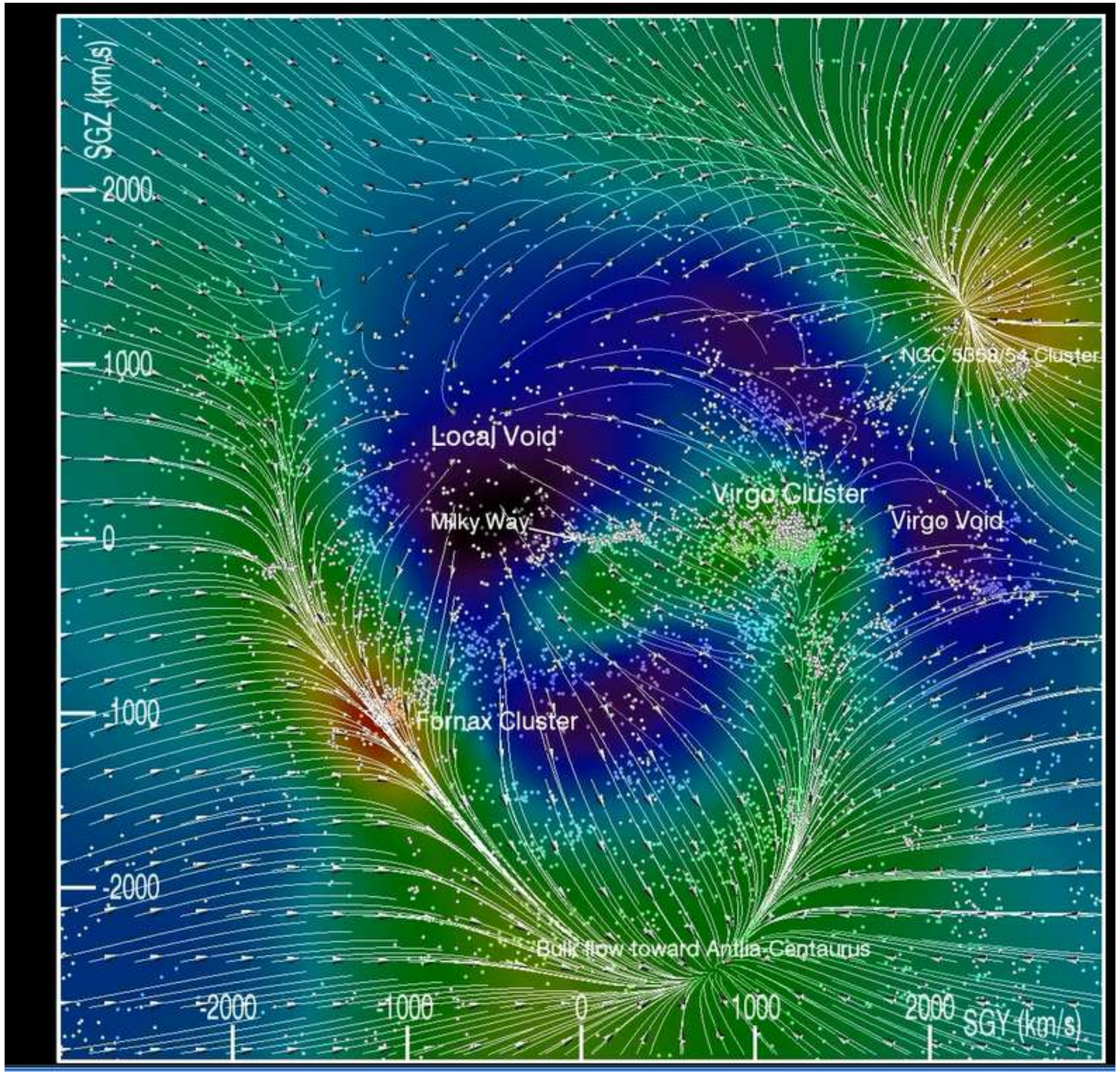
1. m $\leftrightarrow$ Photometry Observations
2. M $\leftrightarrow$ Tully-Fisher relation: $L \propto v_{HI}^{\alpha}$
   Calibrations (Tully & Fisher 1977)

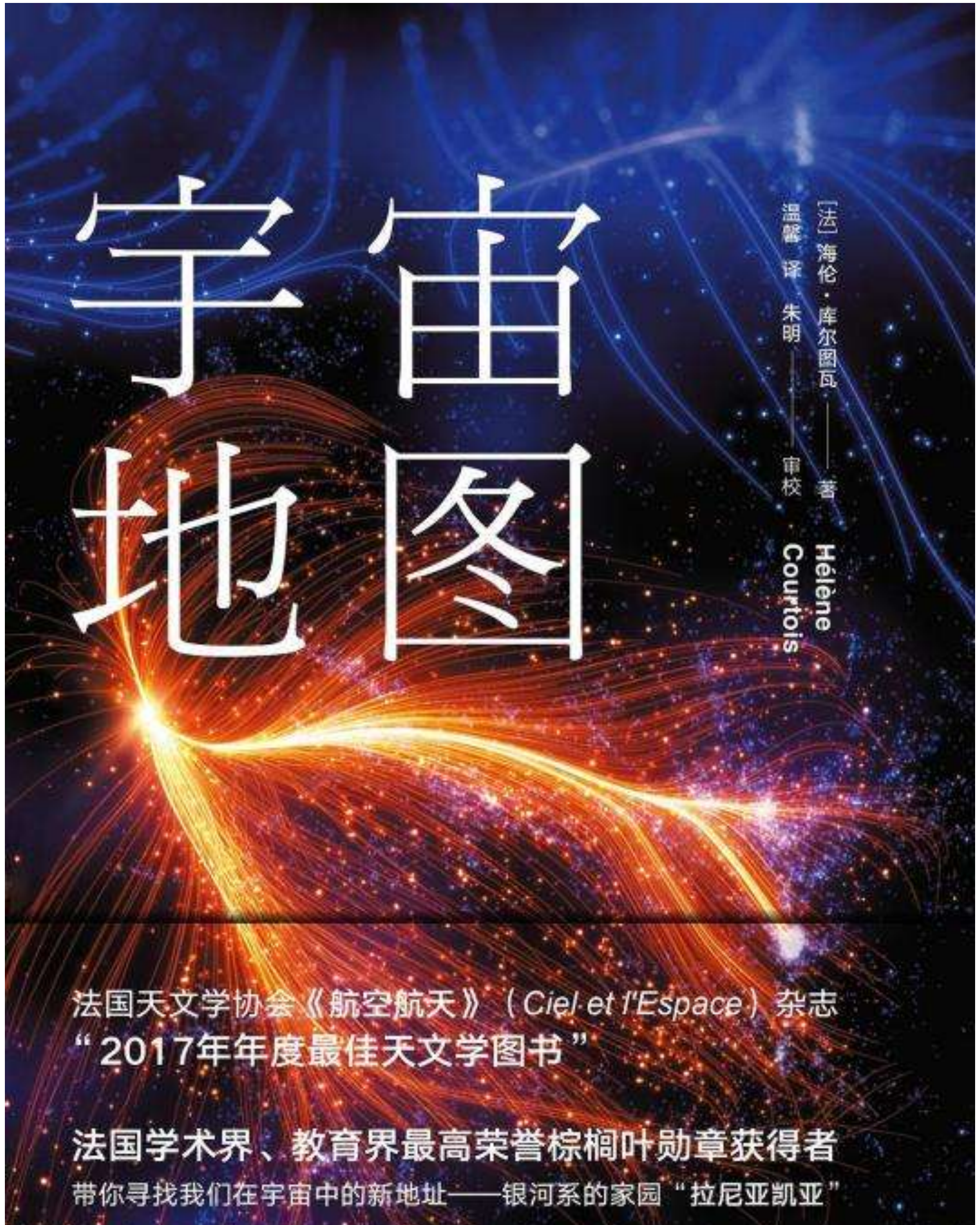
$\hookrightarrow$ **d** $\rightarrow$ $v_{peculiar\ radial}$ $\rightarrow$ Cosmic Flows

Accurate HI + photometry

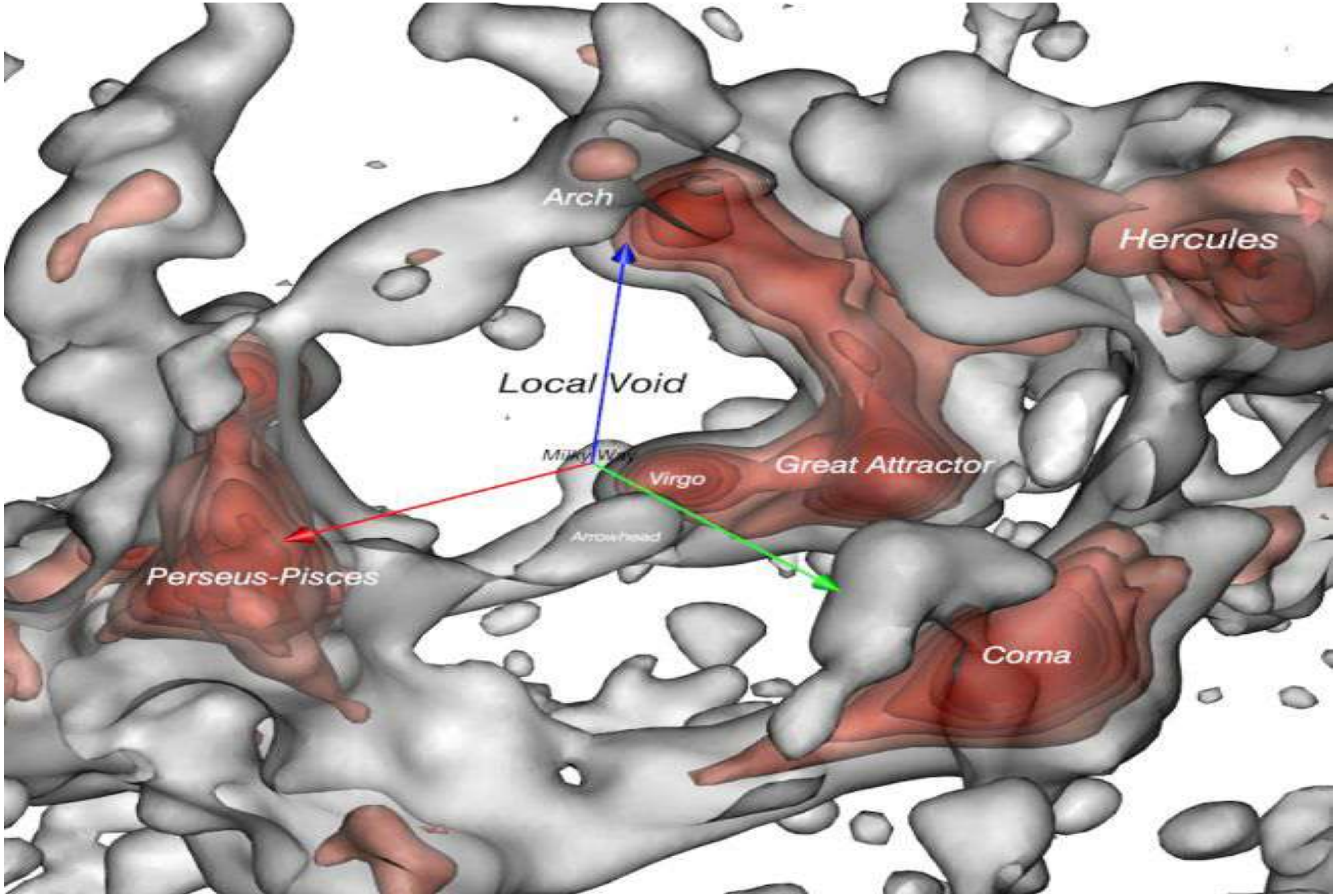
近邻宇宙速度场 Comic flows

Courtois et al. 2013



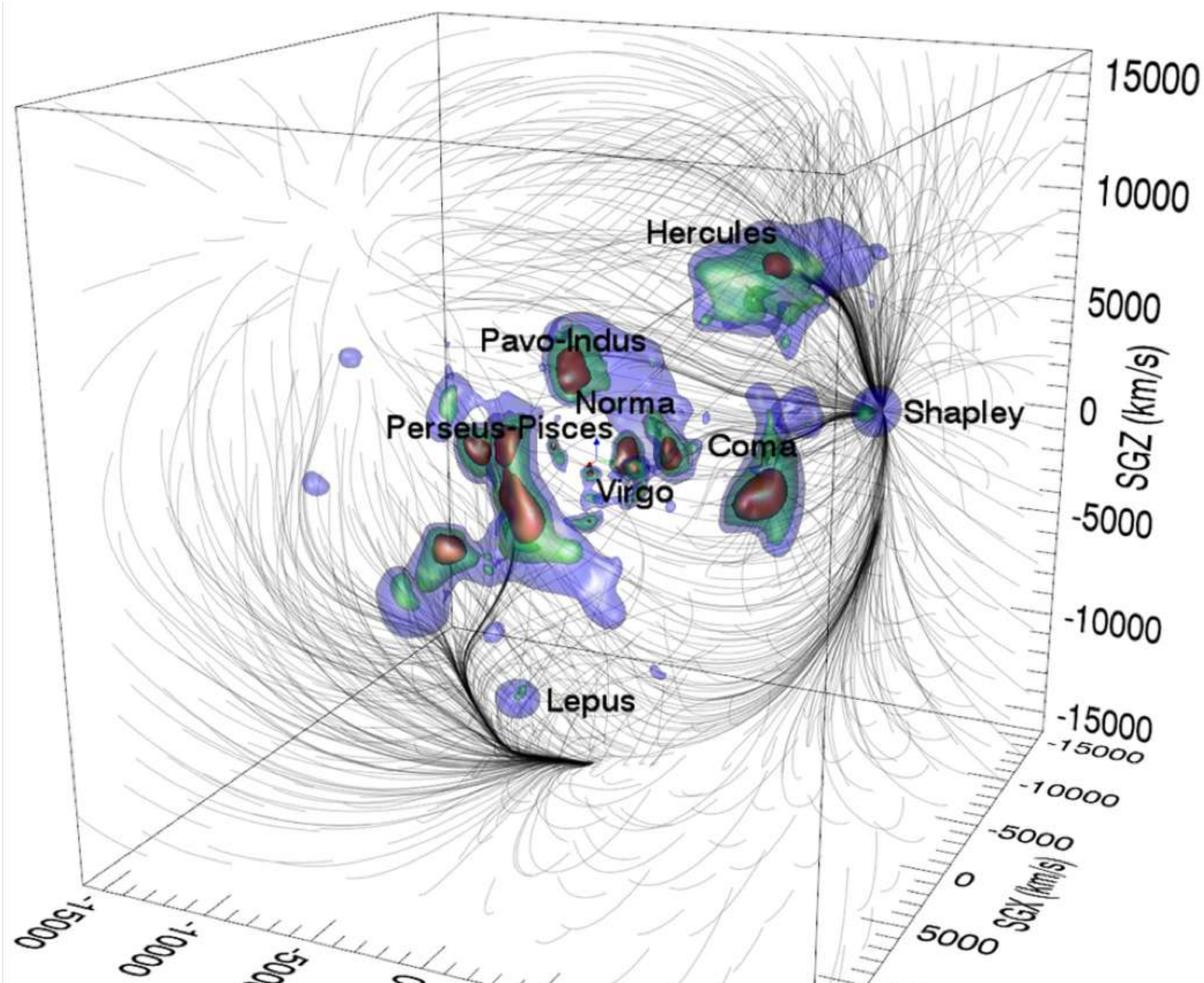


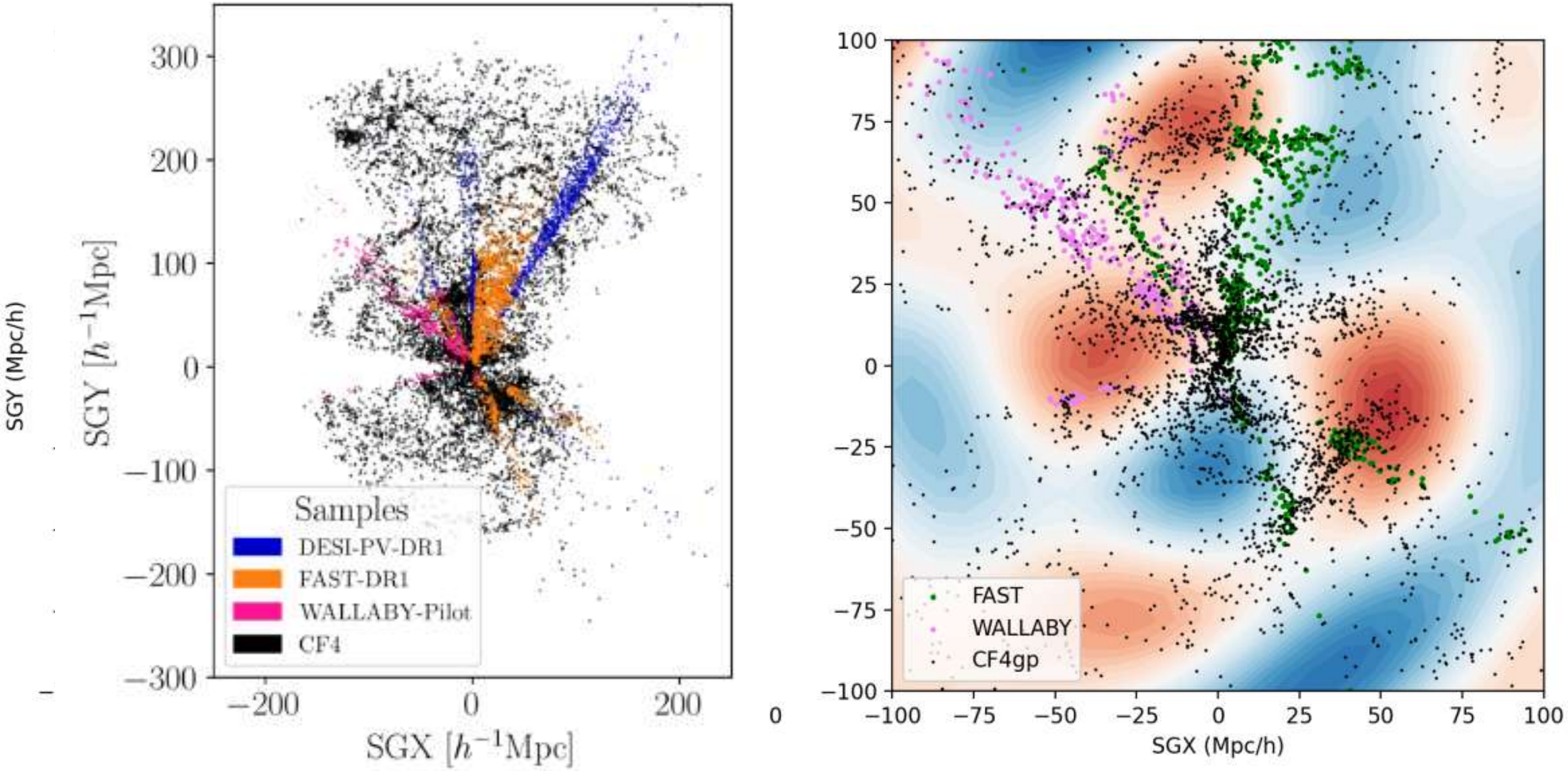
Mass distribution in the local Universe



Tully et al. 2019

Tully et al 2014, Nature





测量本地宇宙的大尺度结构 （H.M. Courtois, J. Mould, A. Dupuy, C. Zhang 2025）

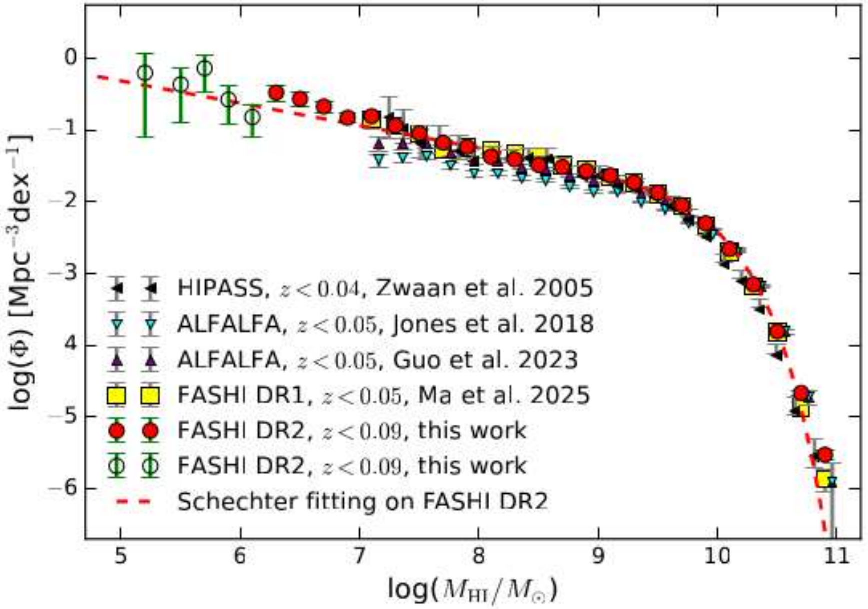
引力速度场的重建有助于研究本地宇宙的动态演化过程，揭示宇宙大尺度结构中的动力学现象

什么是中性氢质量函数（HIMF）？

中性氢质量函数（HIMF） 描述的是：**单位宇宙体积内，不同 HI 质量星系的数密度分布**。

$$\phi(M_{\rm HI}) = \frac{dN}{dV \cdot d\log M_{\rm HI}}$$

通俗理解：HIMF 是宇宙 HI 星系的"人口普查"——回答"宇宙中不同'体重'（HI 质量）的星系各有多少？"

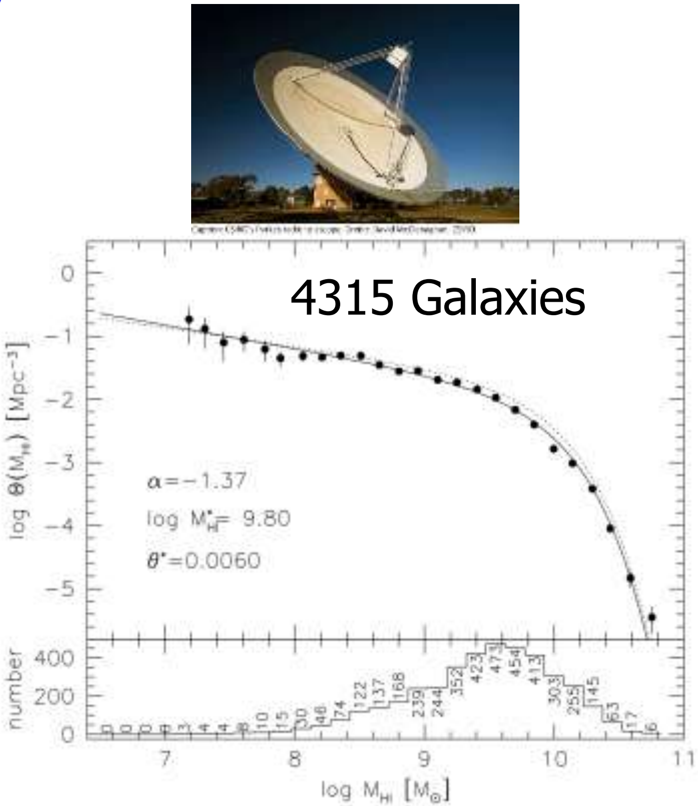


为什么测量 HIMF 很重要？

重要性	核心科学问题
① 揭示冷气体"家底"	不同质量星系对宇宙 HI 总储量的贡献是多少？
② 检验暗物质晕的气体占据率	低质量暗物质晕中是否存在可探测的 HI？
③ 约束星系形成模型	理论模拟能否正确预测星系的 HI 含量？
④ 测量宇宙 HI 密度 $\Omega_{\rm HI}$	宇宙中 HI 气体的总储量是多少？
⑤ 研究环境对 HI 的影响	不同环境（团簇、场、空洞）中 HI 分布有何差异？

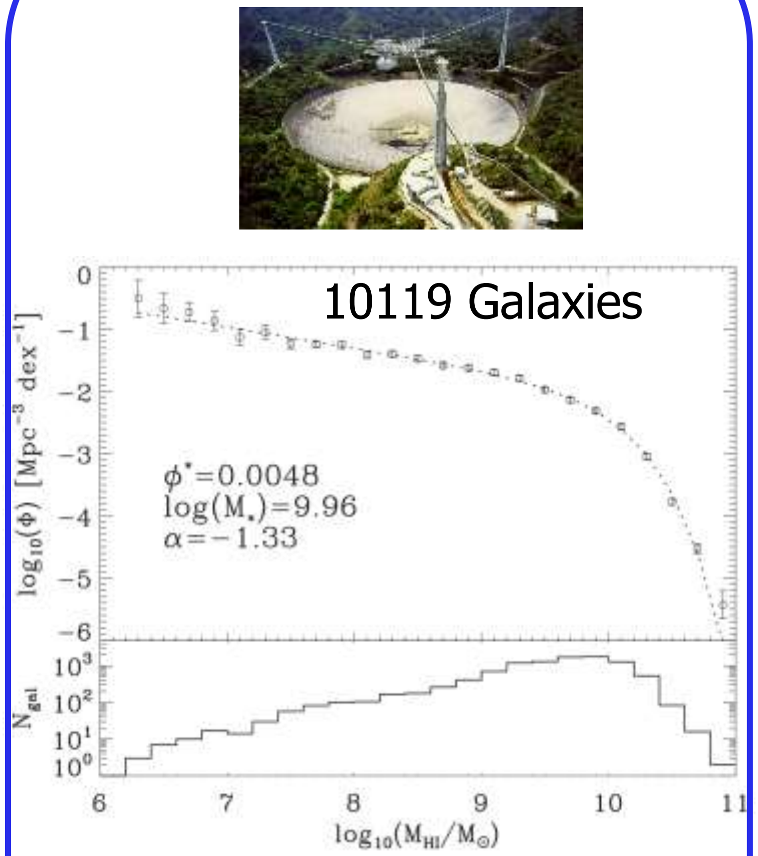
中性氢质量函数的测量

HIPASS



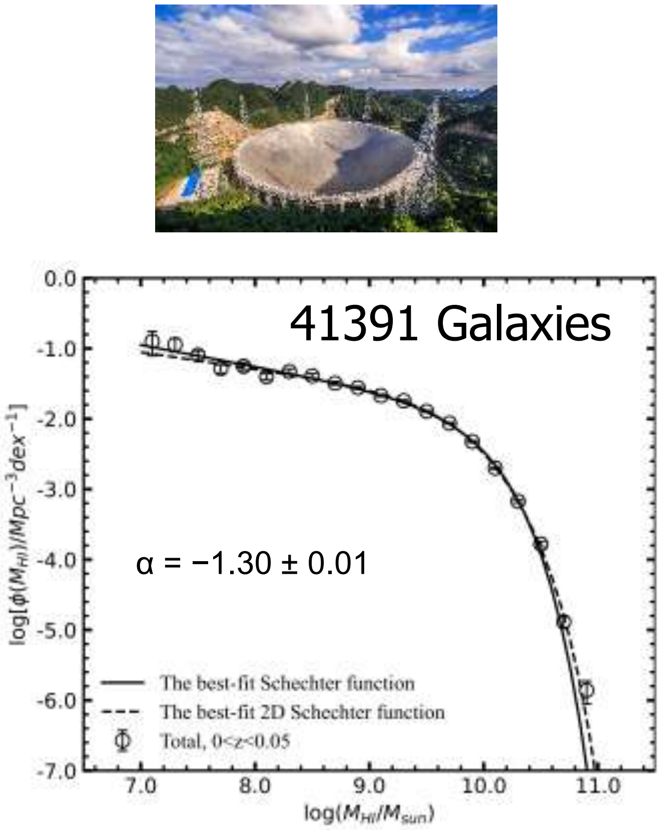
Zwaan et al. (2005)

ALFALFA



Martin et al. (2010)

FASHI

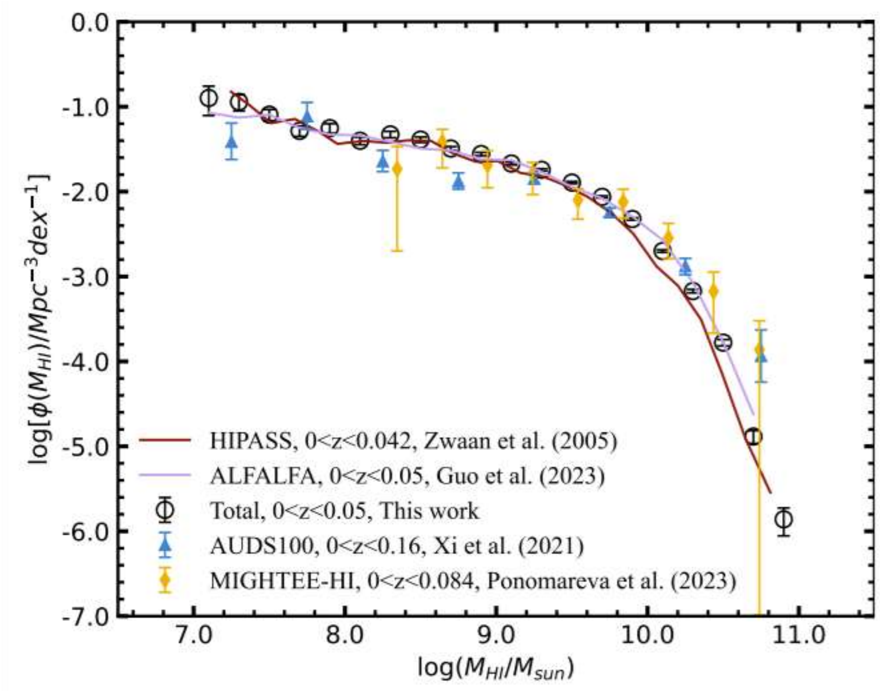


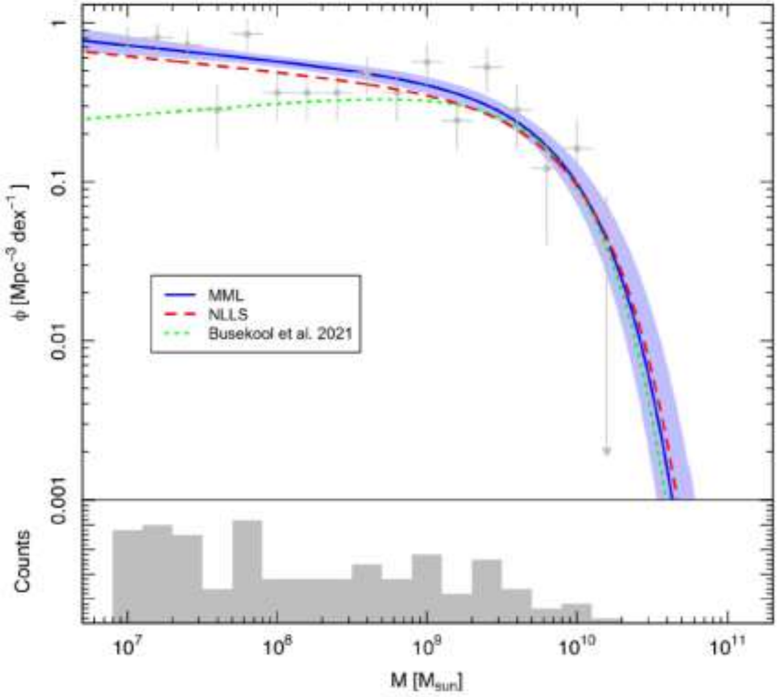
Ma, Guo, Zhang et al. (2025)

HI mass function

Ma etal. arxiv2411.09903

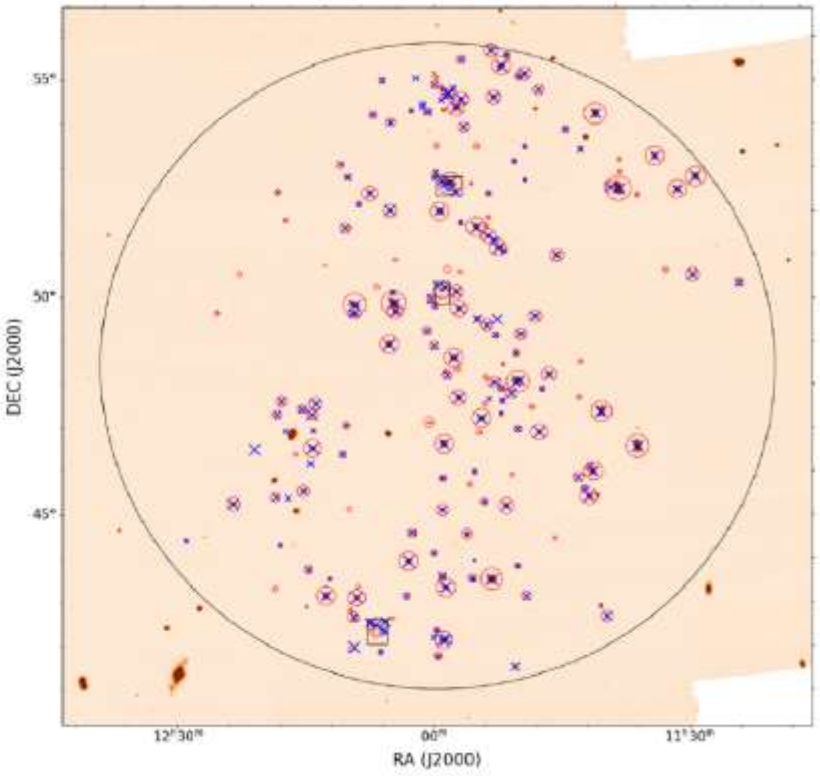
Uma cluster: slope=-1.1

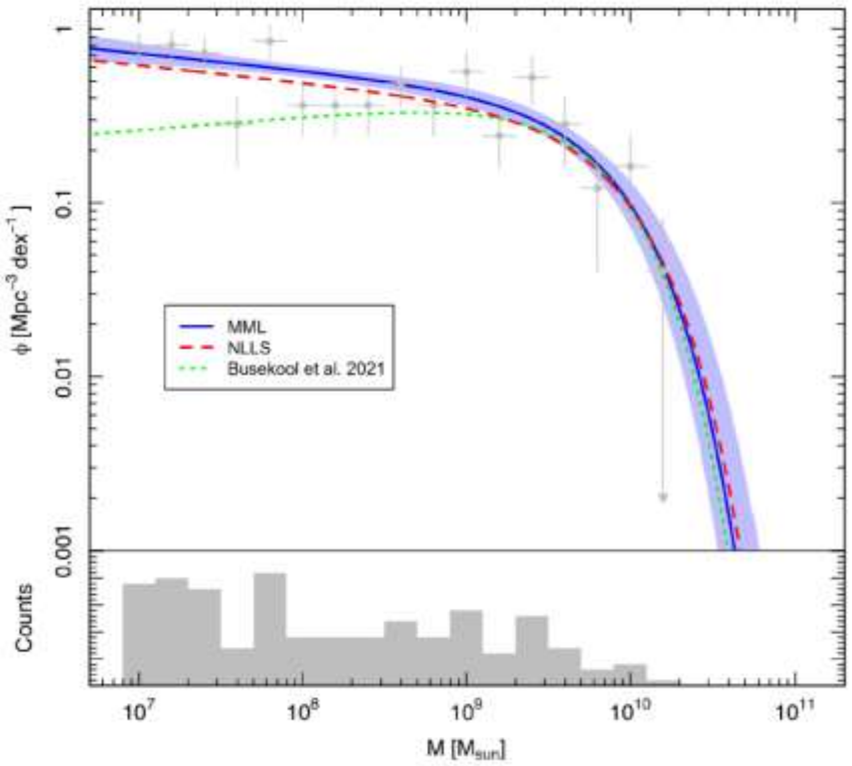




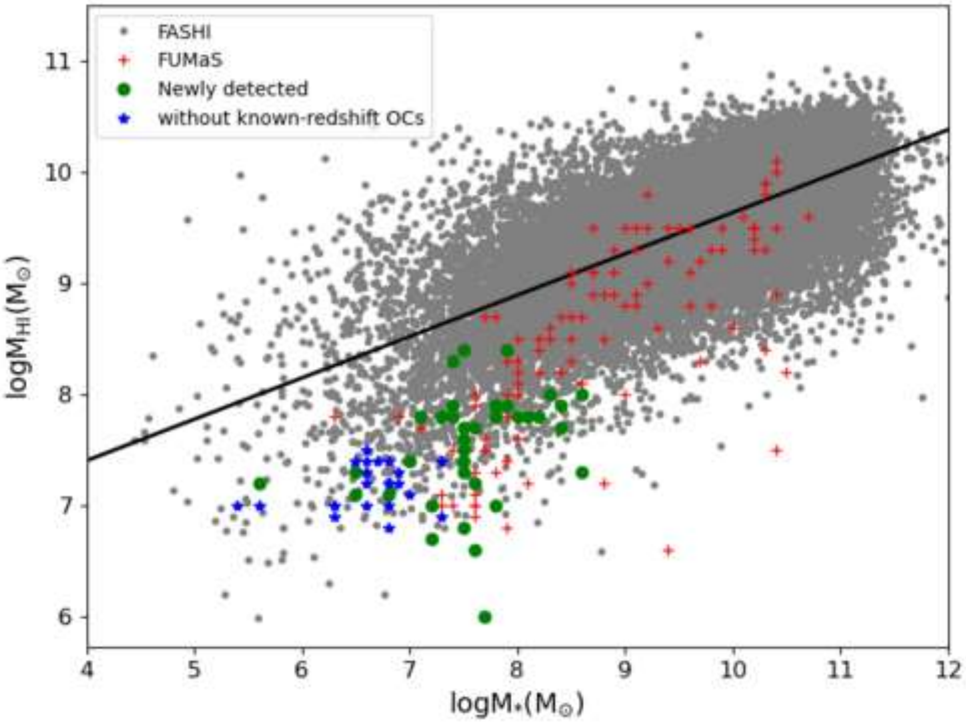
Yu, Zhu etal. 2025

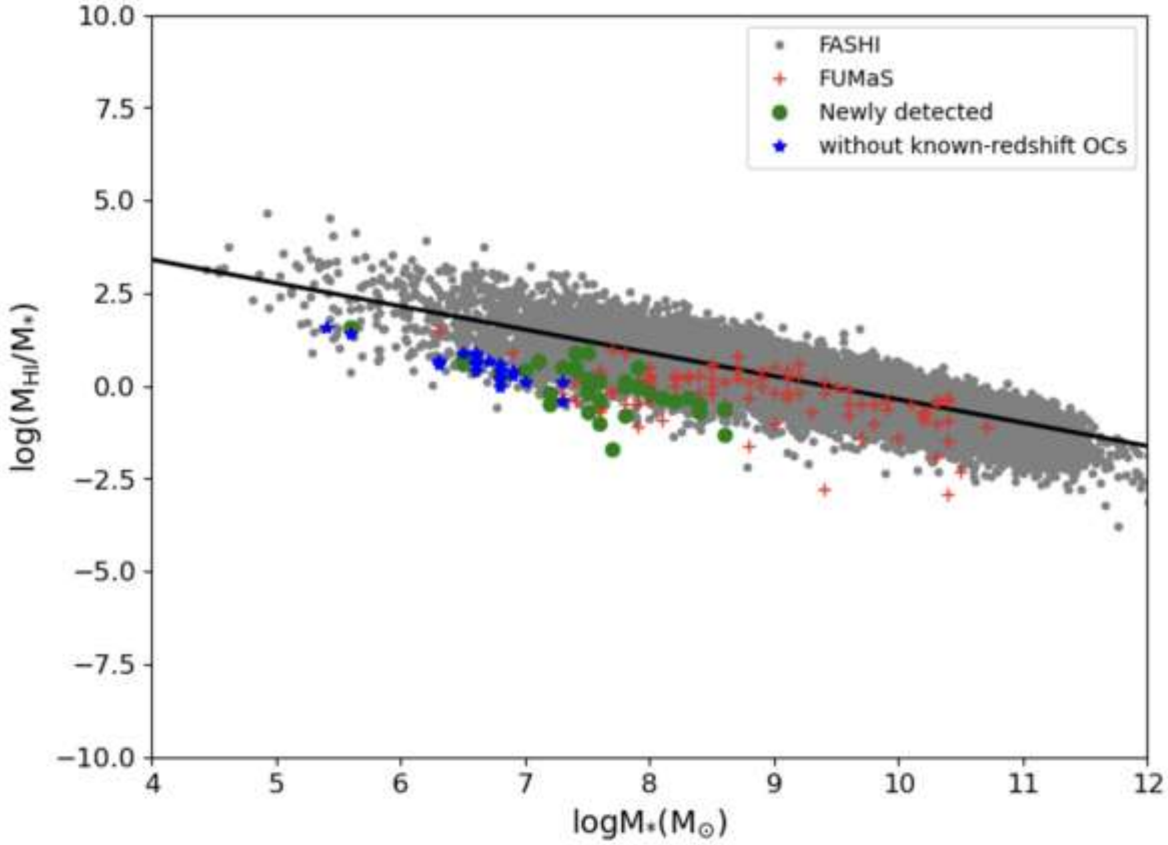
HIMF in Ursa Major Cluster （Yu etal.2025)



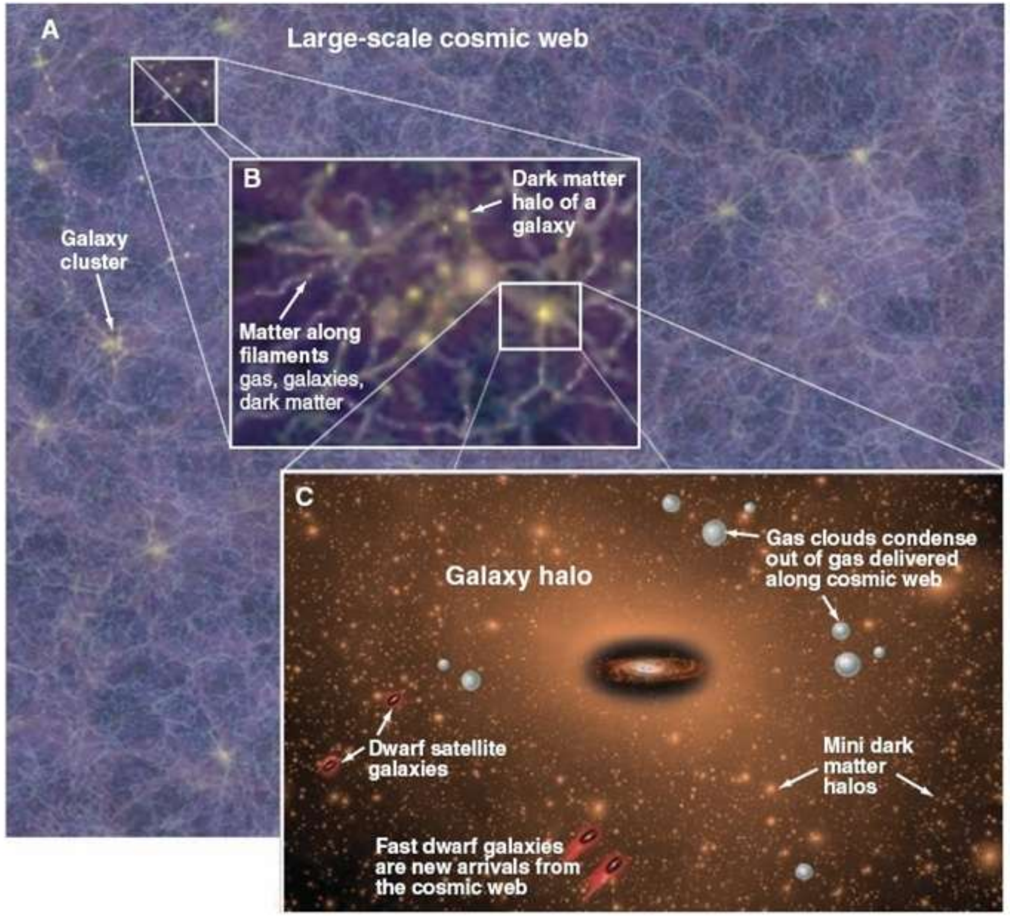


MHI/M* ratio --环境效应





Cosmic web in the local universe

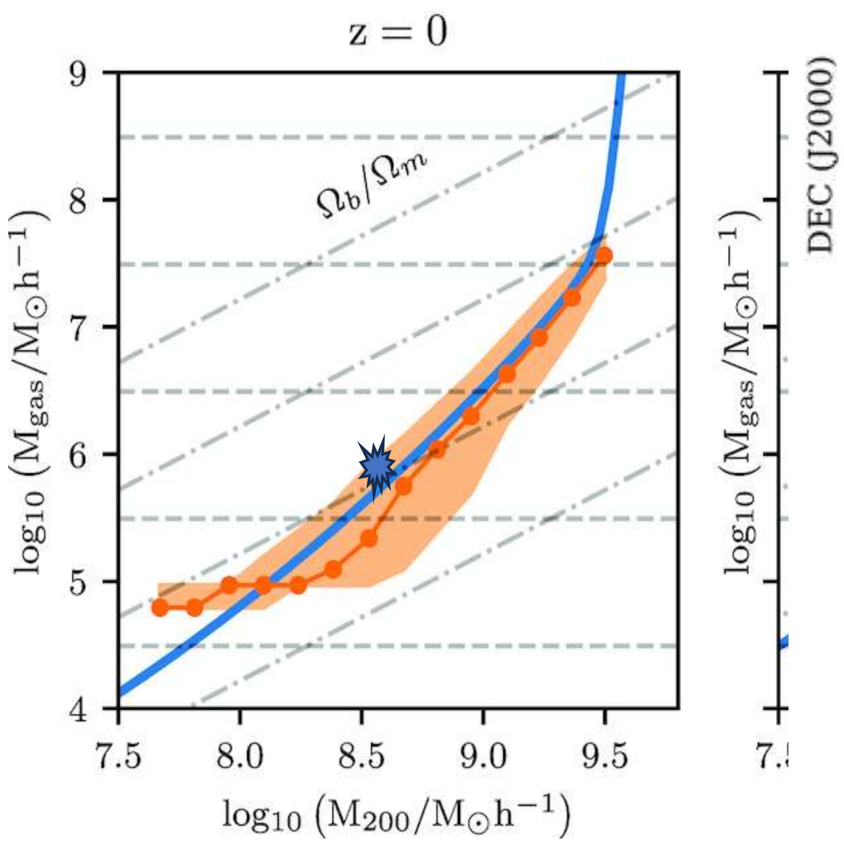


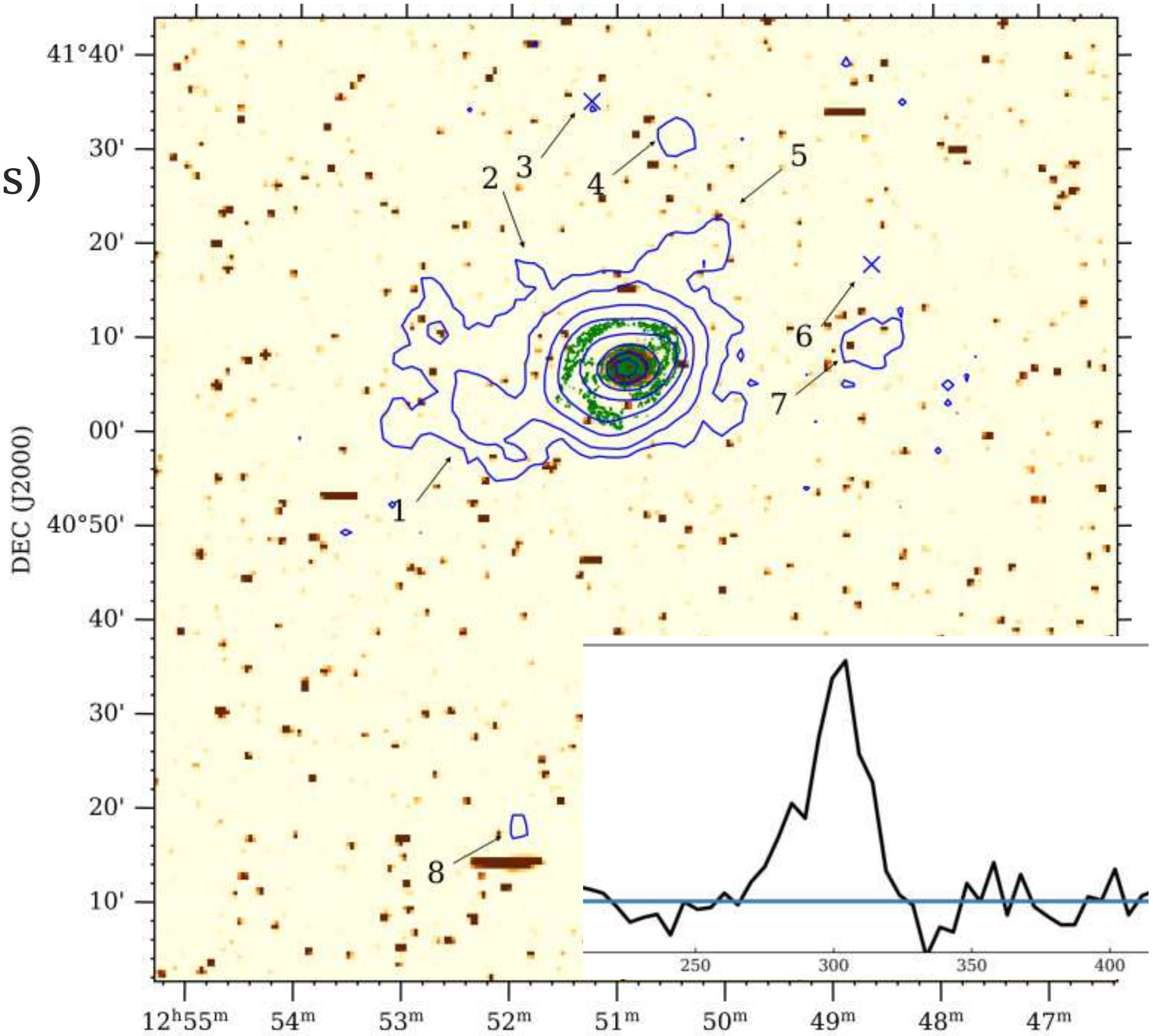
Ibata and Lewis (2008) Sciences 319, 50

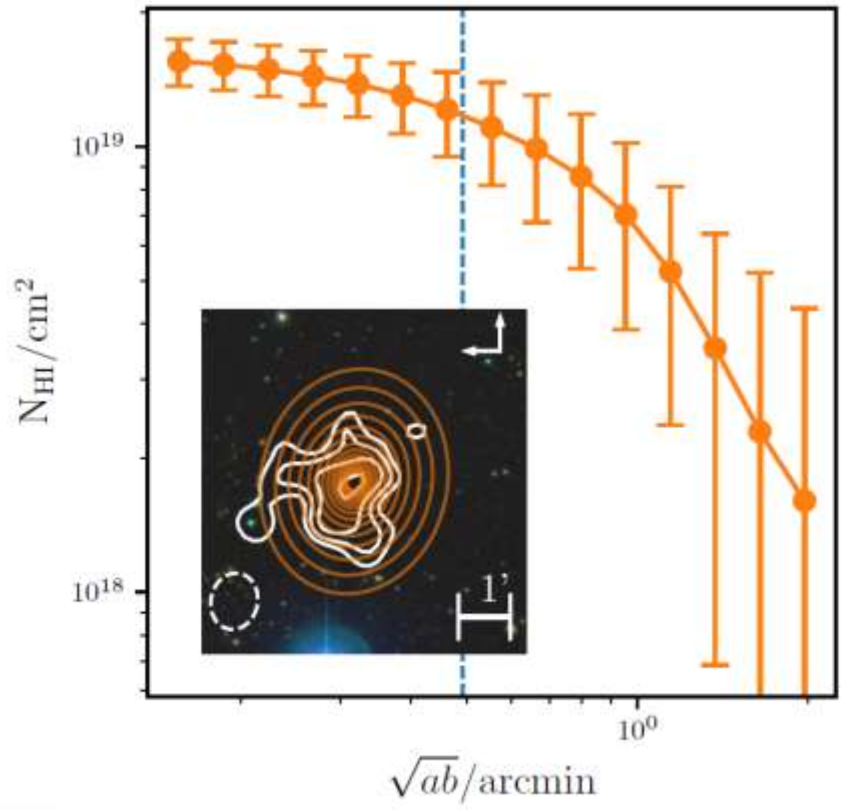
Dark galaxy or RELHIC?

(REionization–Limited H I Clouds)

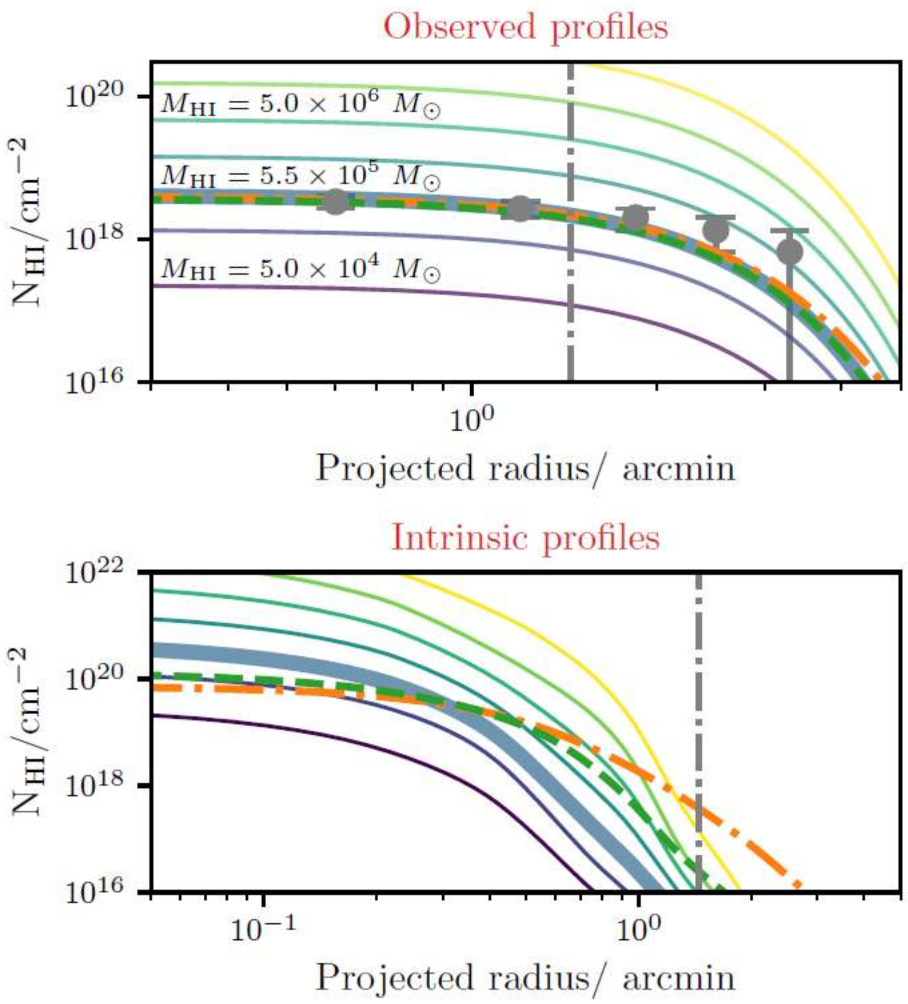
Benitez-Llambay & Frenk 2020 (MNRAS)





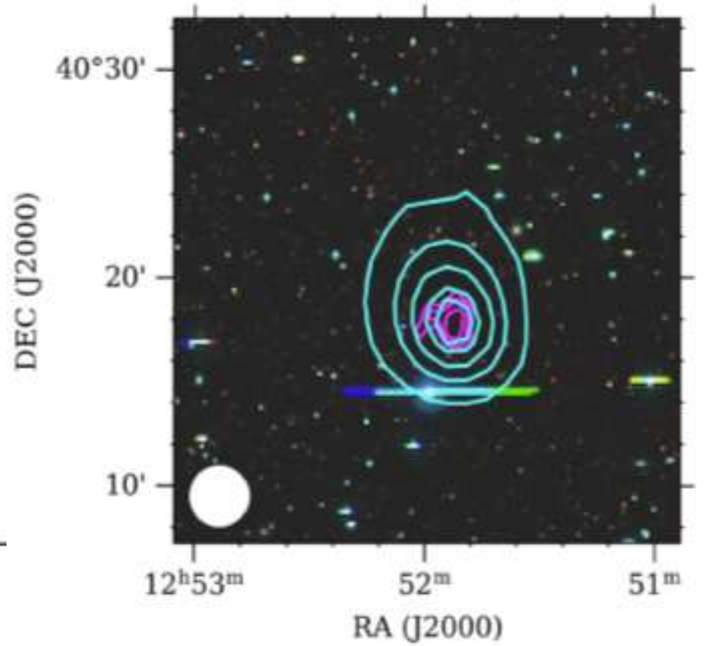


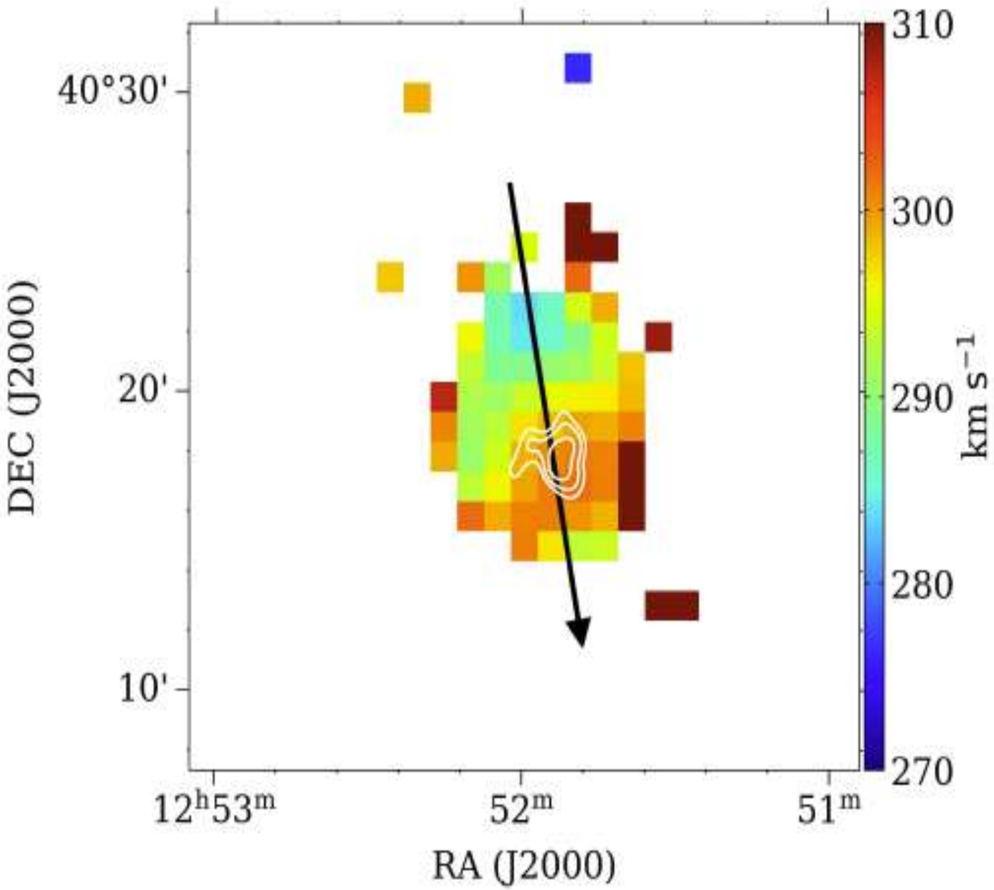
ently dis-
co tent with being a ΛCDM RELHIC. We find that CL-9's properties are consistent with the system being a RELHIC, as recently argued by Z23. The match between the model column densities and observations, together with the large projected distance between CL-9 and M94, the round shape of CL-9's isocontours, the lack of a luminous counterpart, the small broadening of the emission line, and the total HI mass make CL-9 the first firm RELHIC candidate in the local Universe. The analysis of this system demonstrates the potential of these

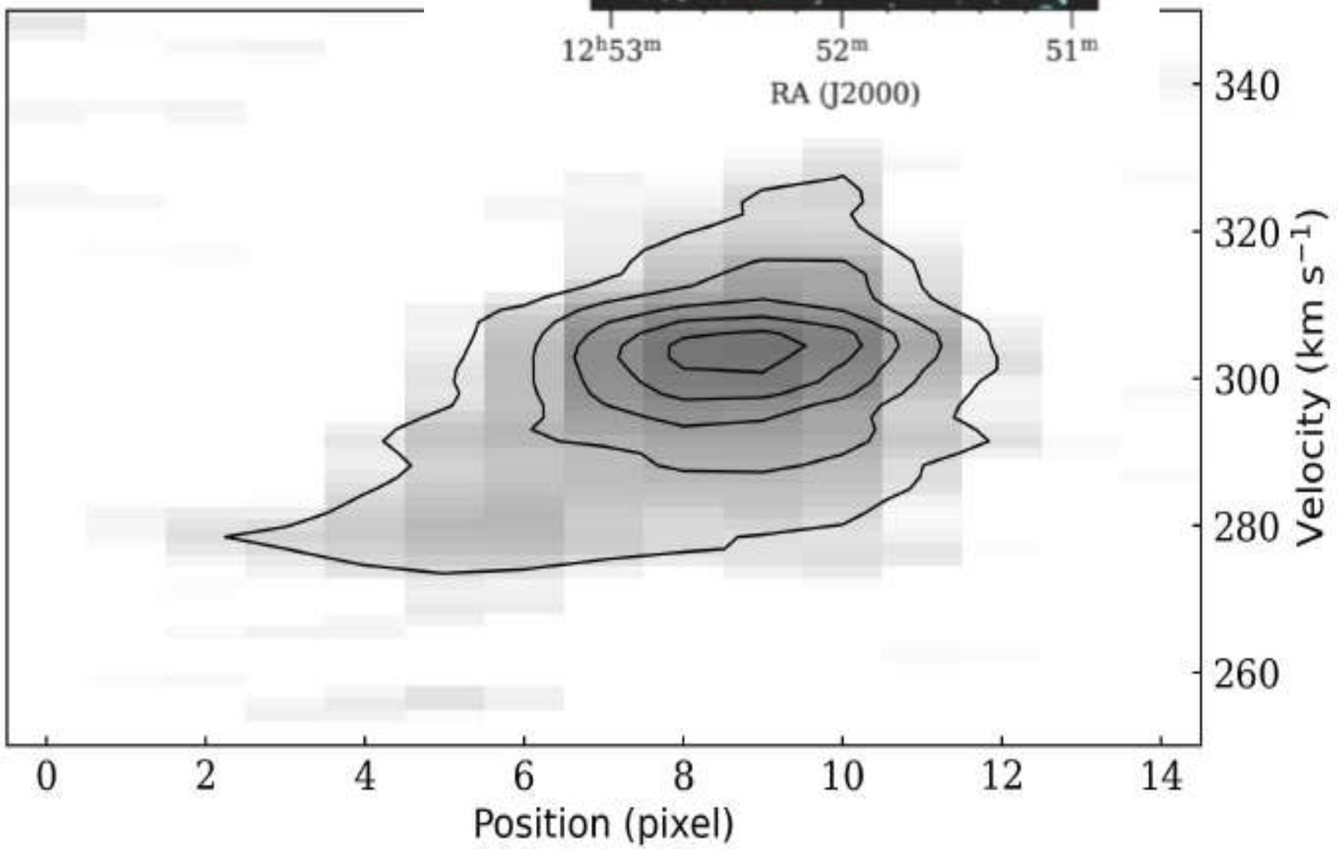


Benítez-Llambay & Navarro 2023

FAST 后续观测 cloud-9
（Zhou et al. 2026）

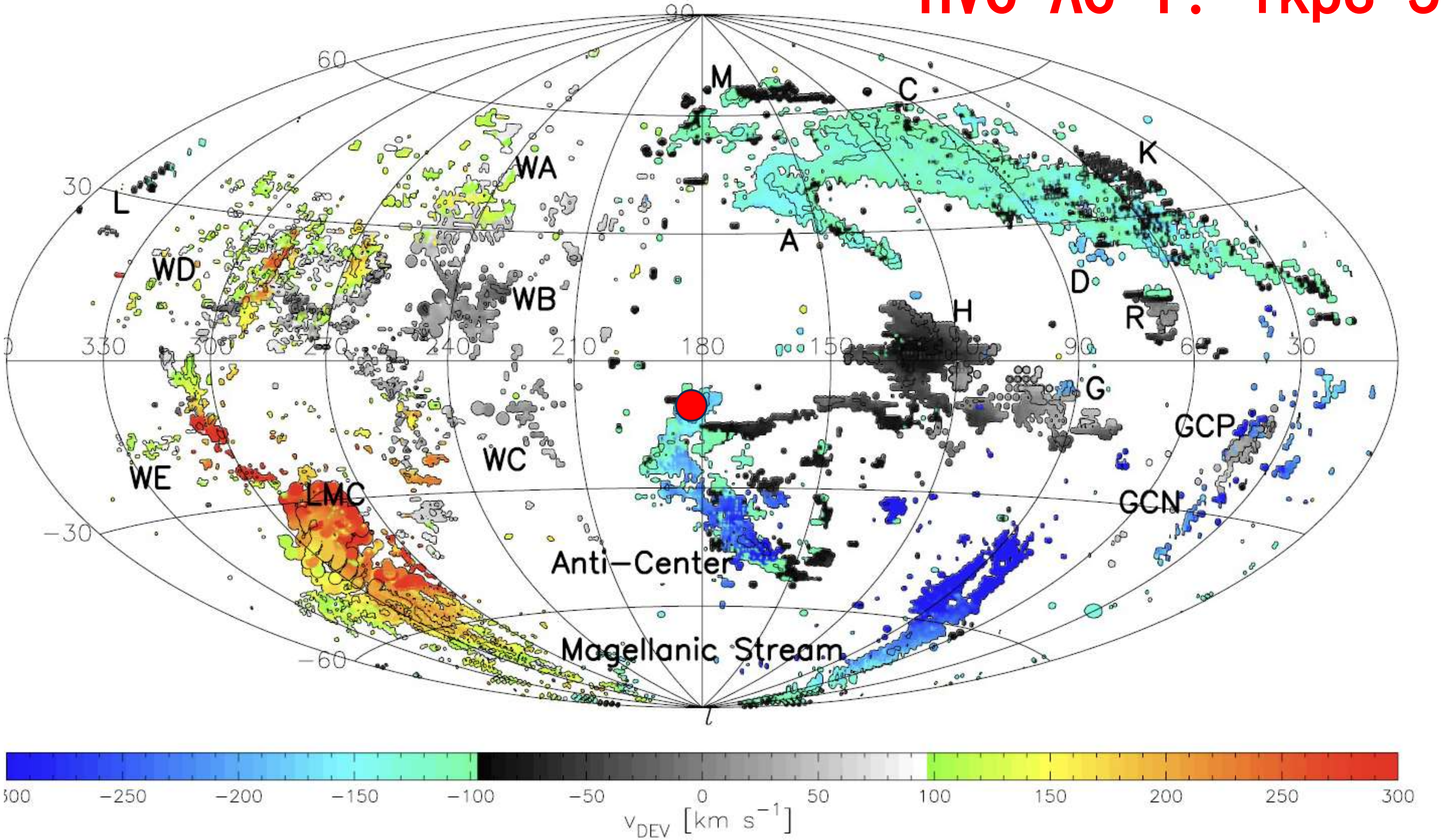






高速气体云为潜在暗星系

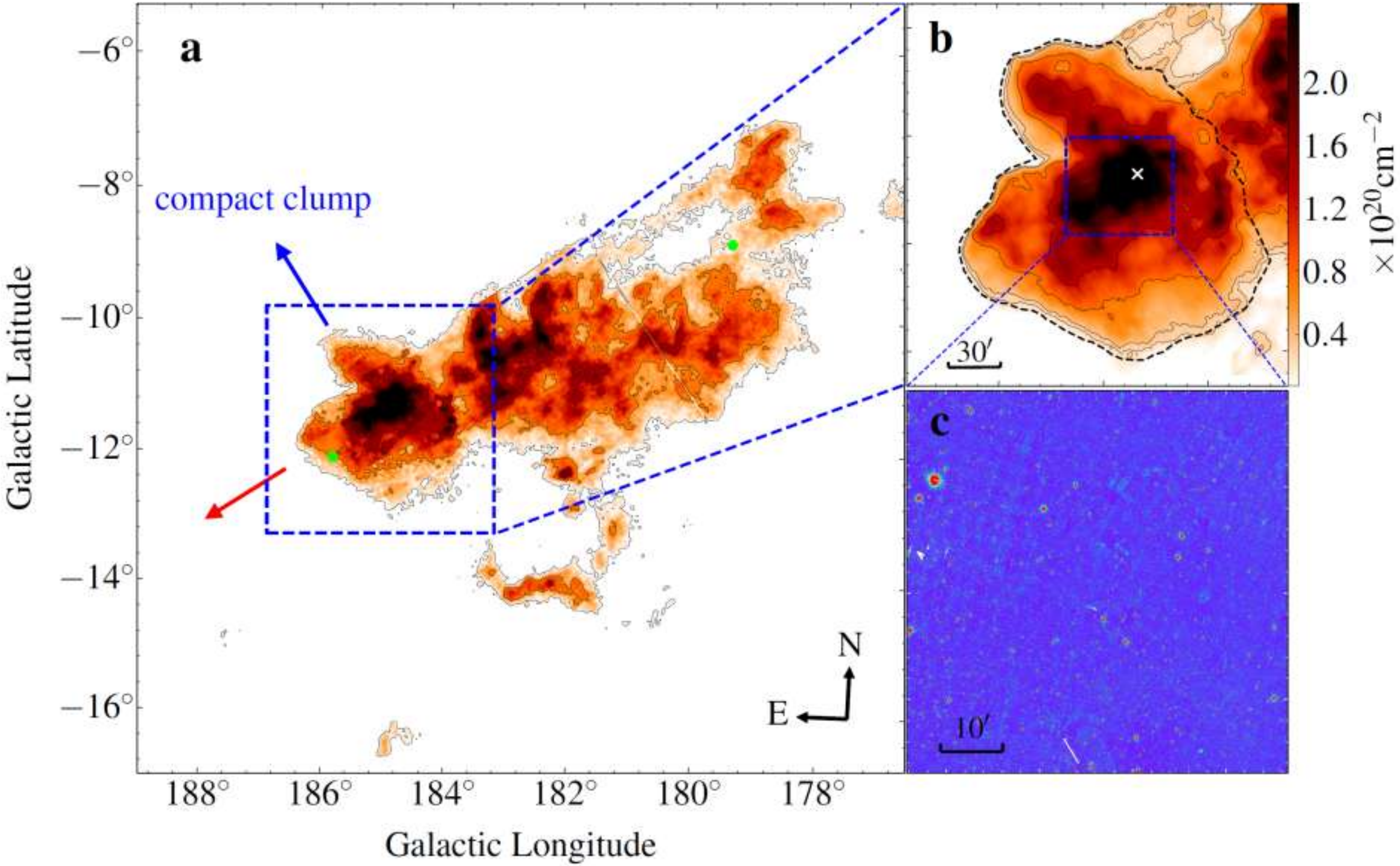
HVC AC-I：1kpc–500kpc



Hulsbosch & Wakker 1988; Morras et al. 2000

高速气体云为潜在暗星系

HVC G185.0-11.5



Liu et al. Science Advances, 2025

系统速度:
-193 km/s

尺度:
4*4 deg^2

柱密度:
3.8*10^{20} cm^{-2}

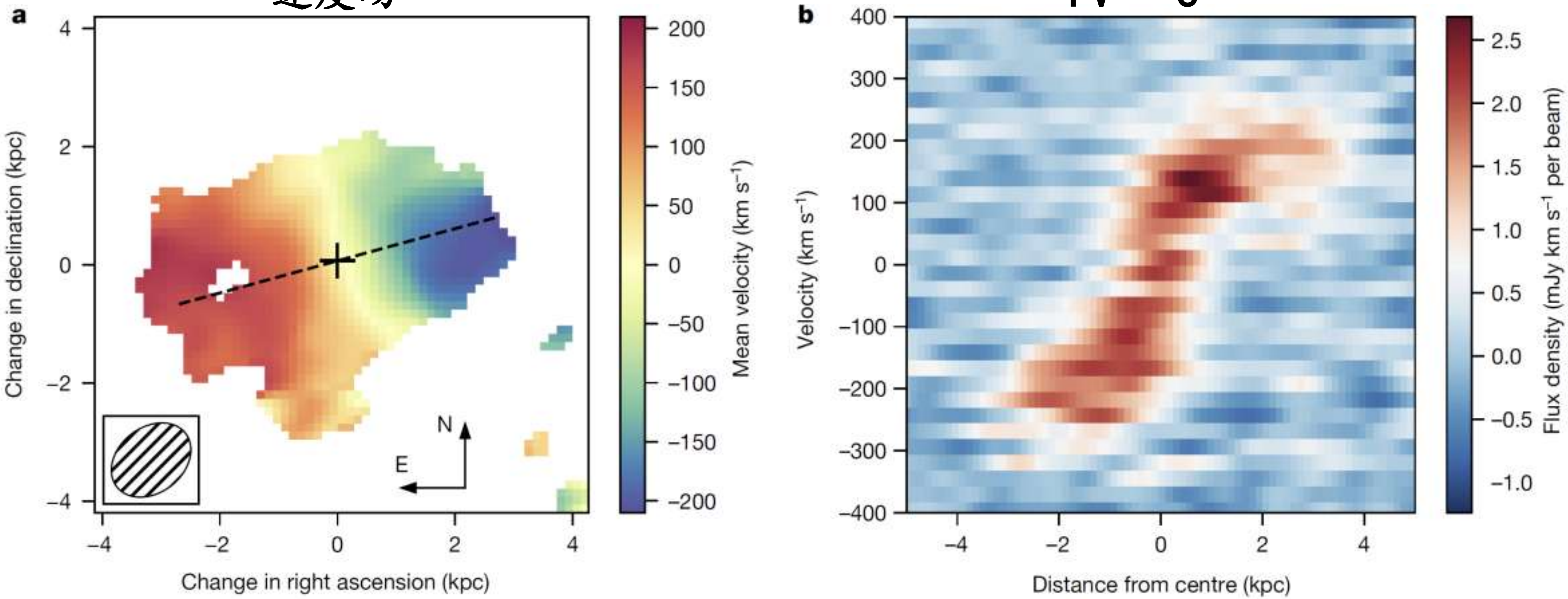
总流量:
6200 Jy km/s

高速气体云为潜在暗星系

A cold, massive, rotating disk galaxy 1.5 billion years after the Big Bang

速度场

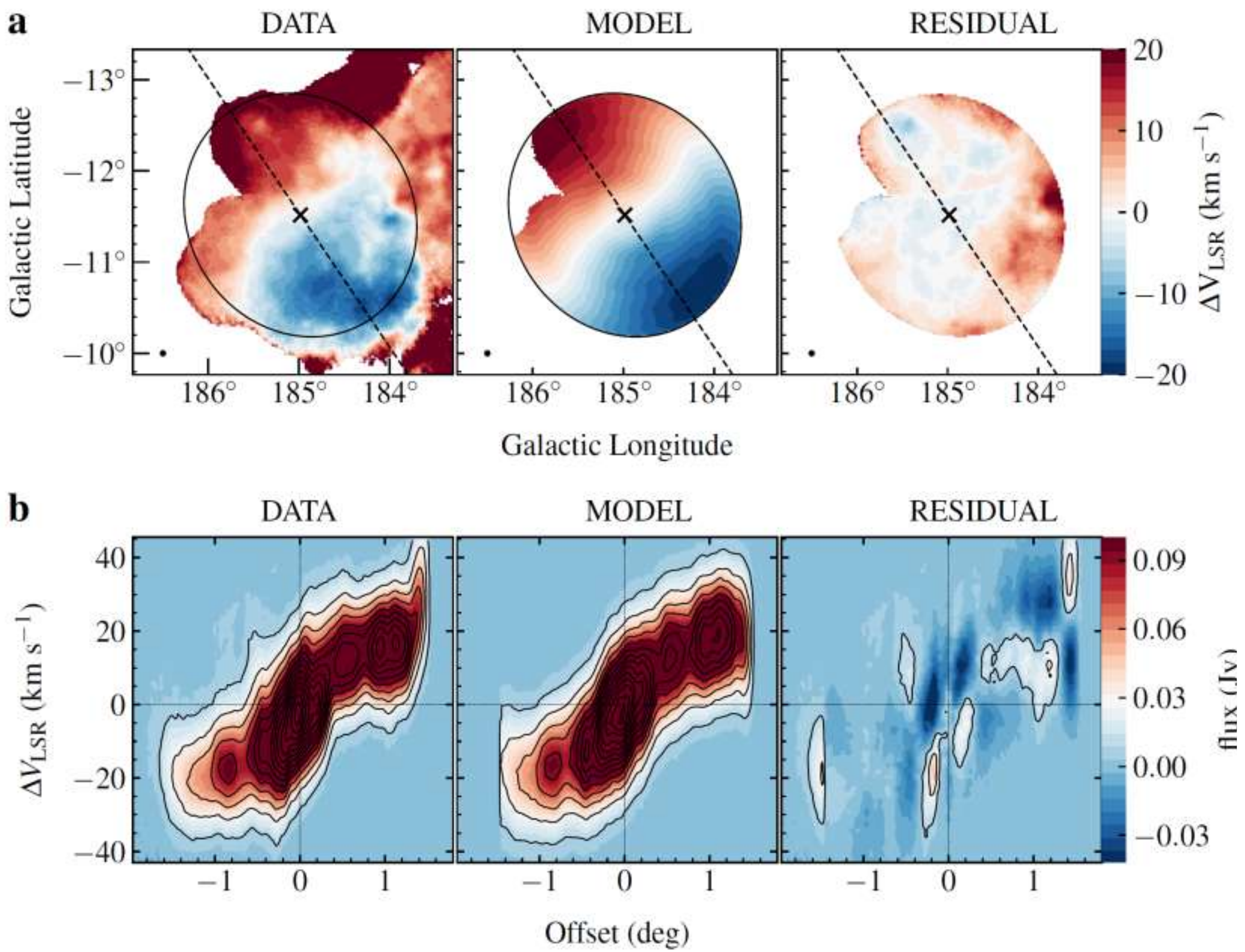
PV "S"



Neeleman et al. Nature, 2020

高速气体云为潜在暗星系

HVC G185.0-11.5



星系特征1

星系特征2

发现 KK153

AASTEX ULTRA-FAINT DWARF GALAXY IN THE LOCAL GROUP: KK153

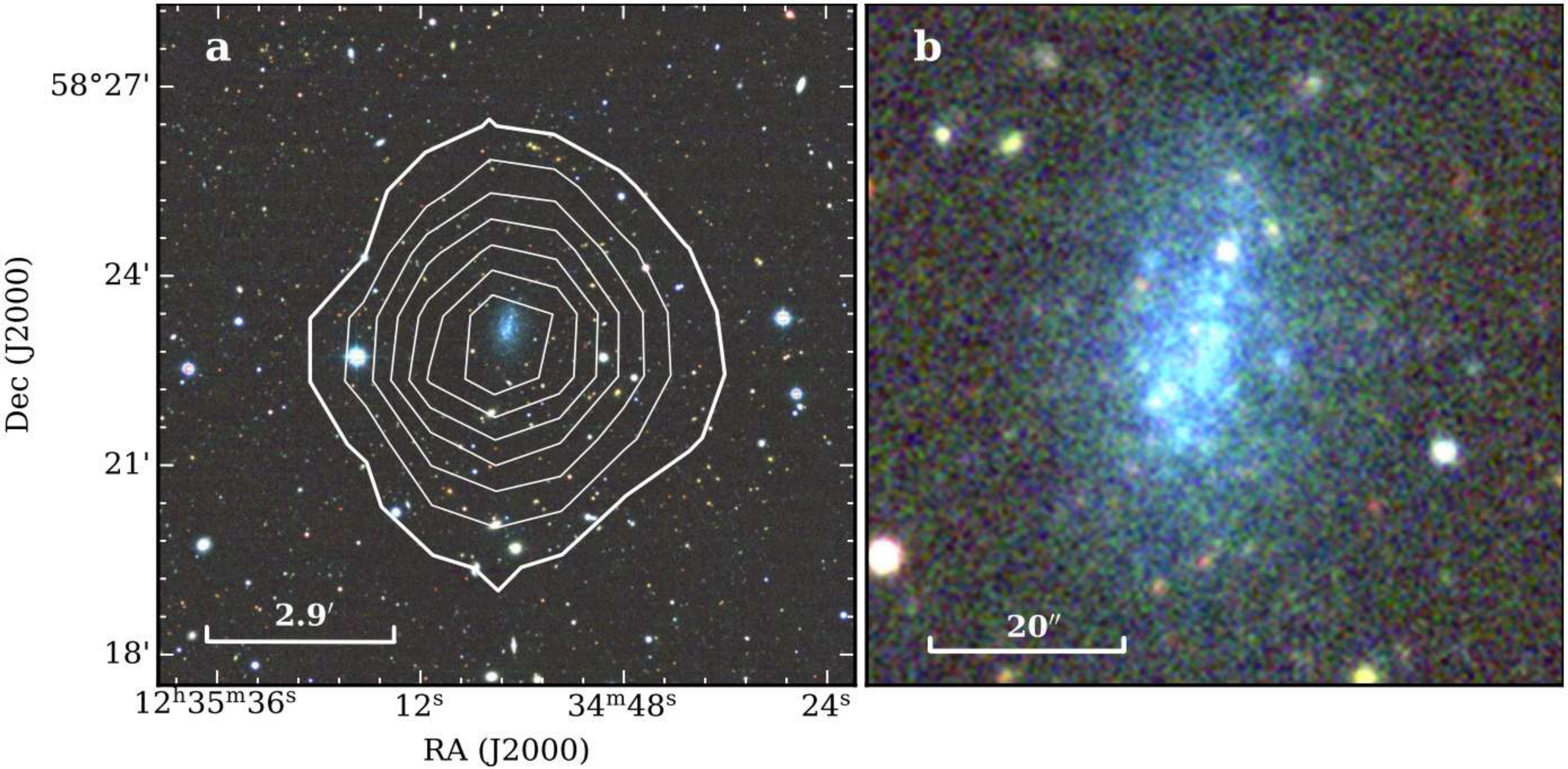
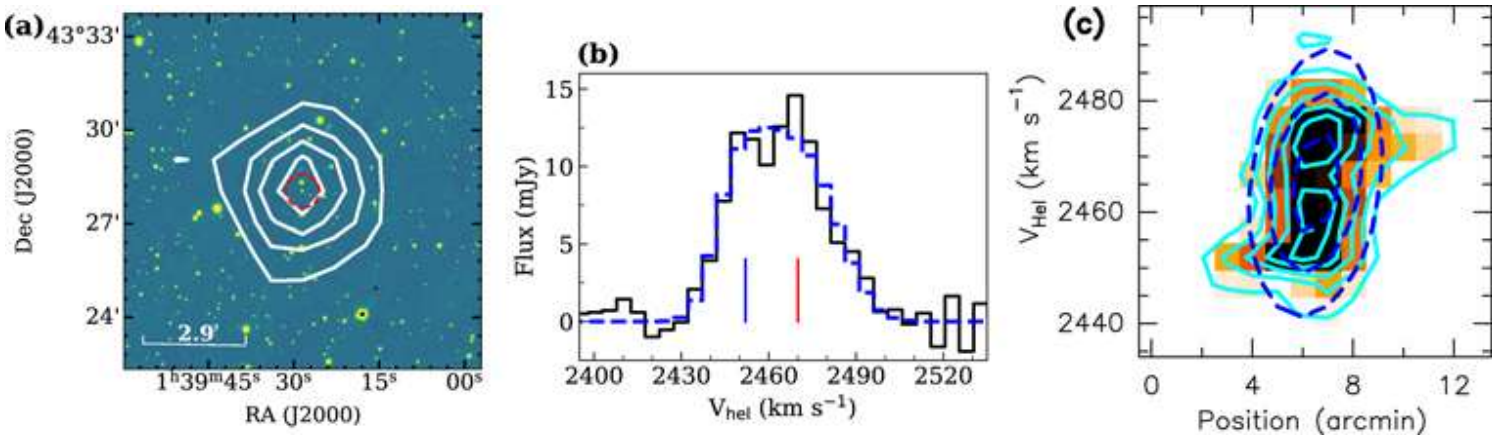


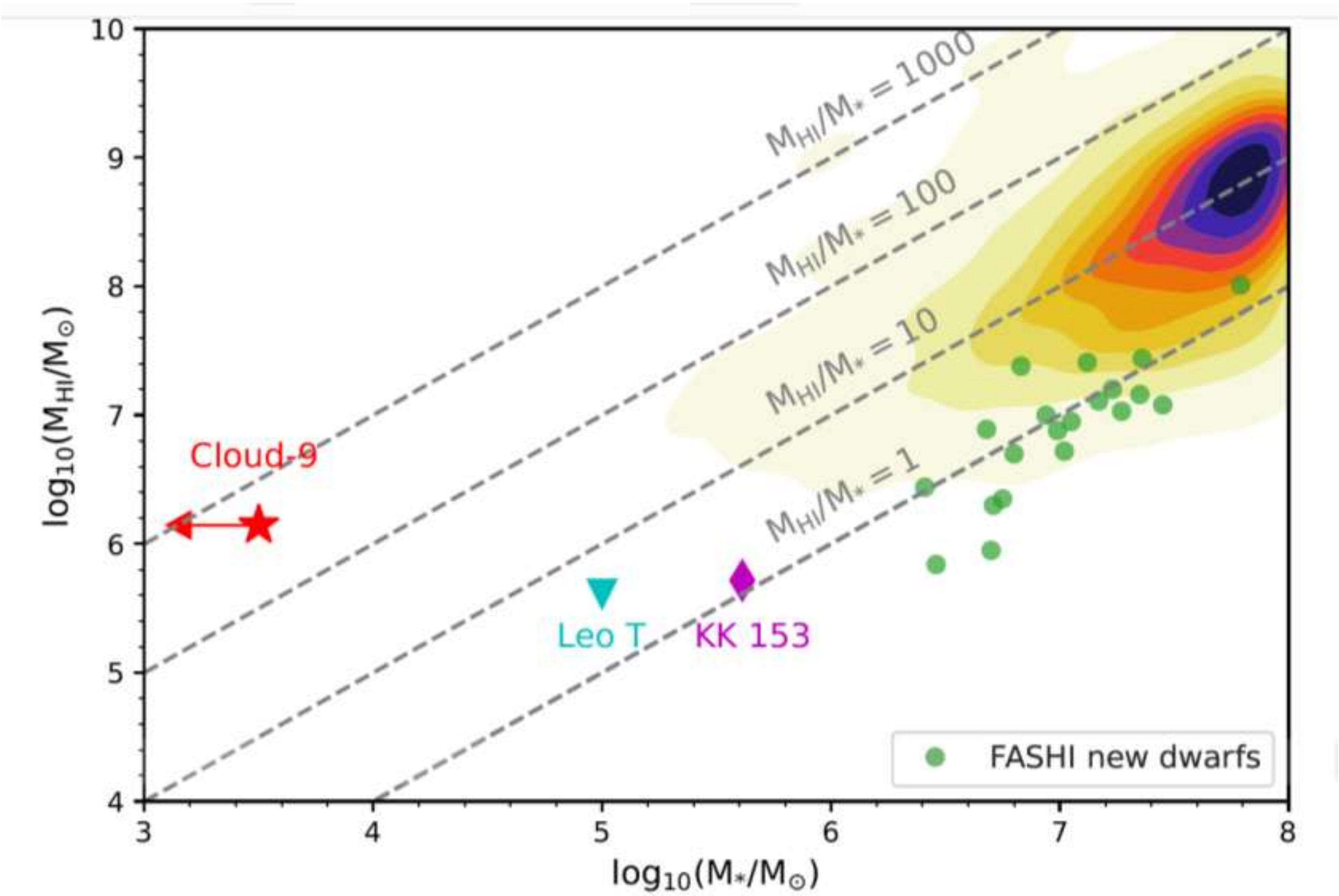
Figure 1. a, H I column-density map of KK153 from the FAST observation shown in white contours overlaid on the DESI-RGB (g, r, z) imag in color scale. The white contours begin at 4.2×10^{17} cm^{-2} (3σ) in steps of 2.0×10^{18} cm^{-2}. **b**, the zoom-in DESI-RGB image of KK153.

“Almost Dark Galaxy” （Xu, Zhu etal. 2023, ApJL)



FAST 中性氢星系巡天发现一个暗星系候选体FAST J0139+4328。其HI
谱线具有双峰结构，PV 图程现S 状结构，表明其中性氢是分布在一个气体盘
上，后续观测发现这是一个极暗弱星系。

暗星系、弱星系的宇宙学意义



(Anand et al. 2025)

Galaxies without optical Counterpart (Kang et al. 2022)

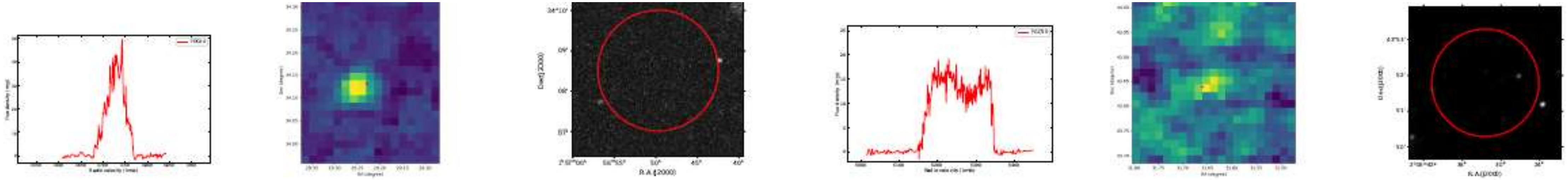
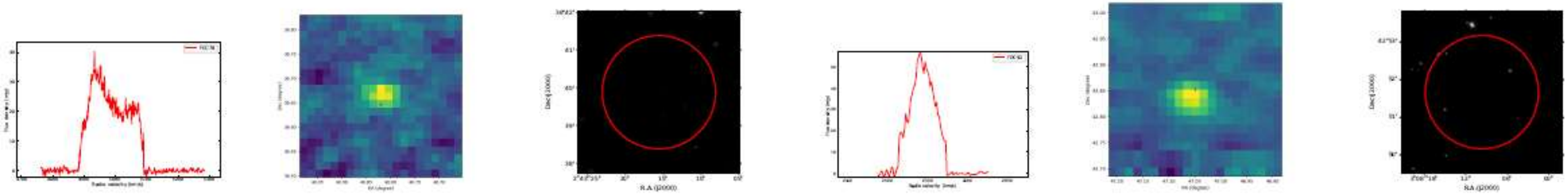
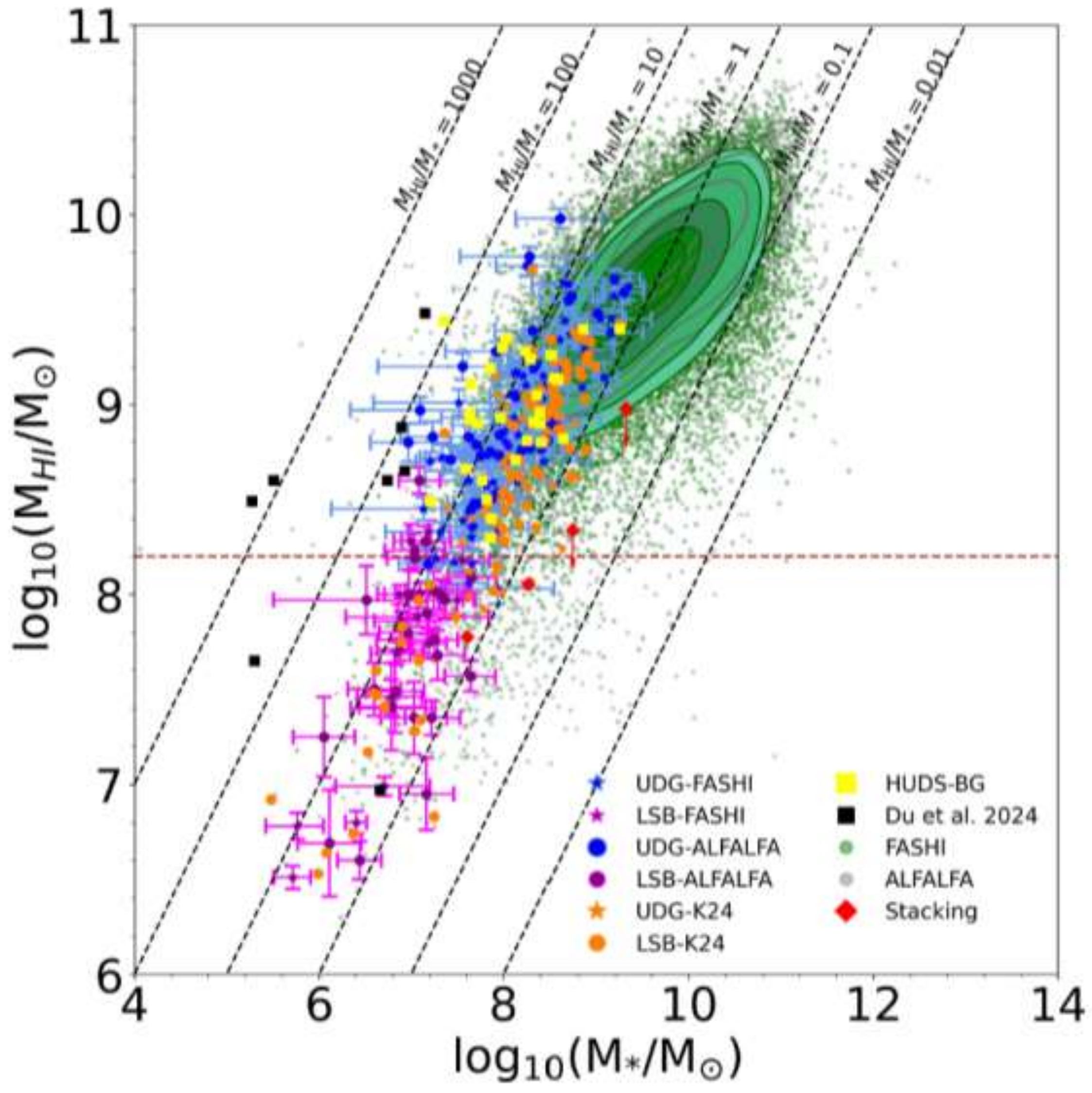
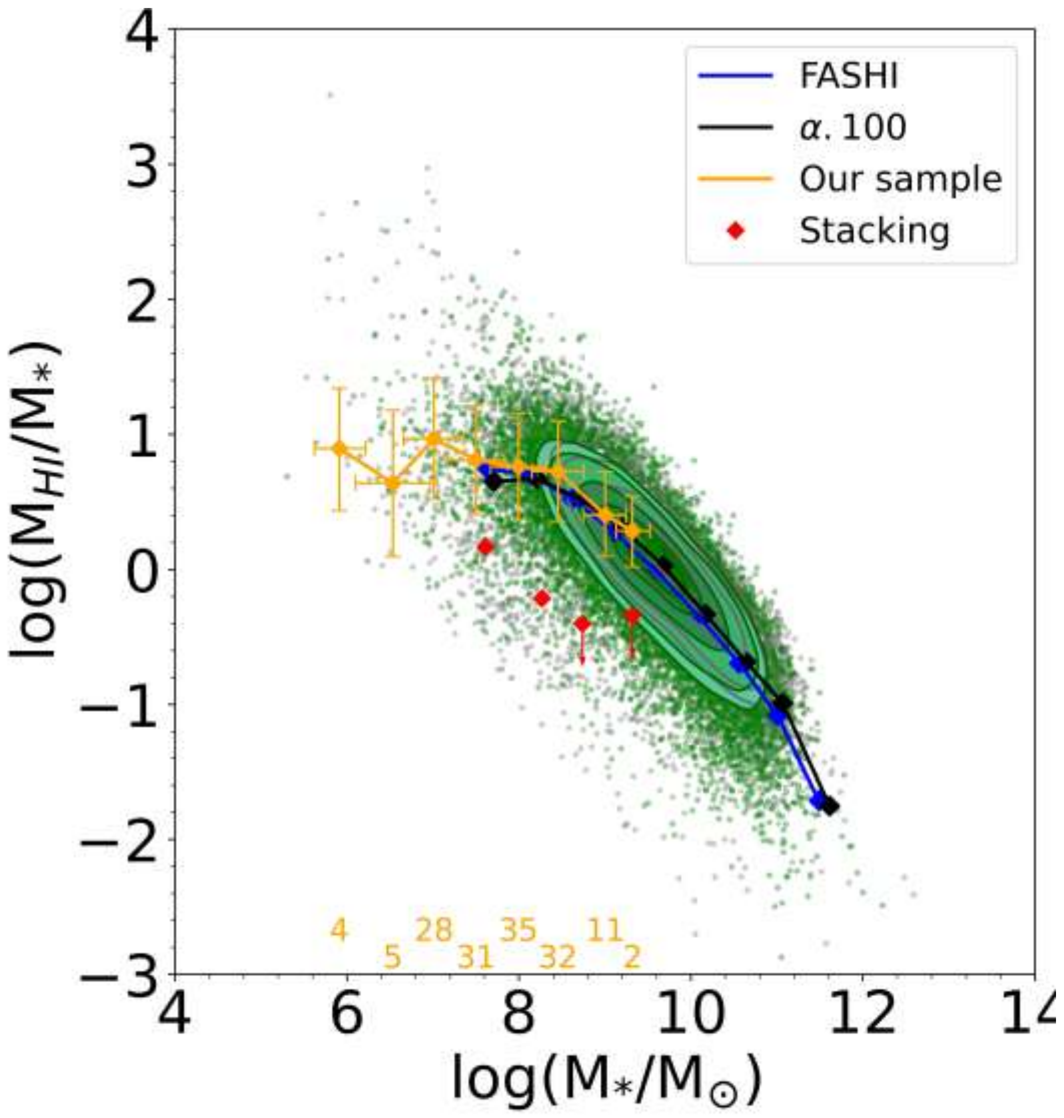


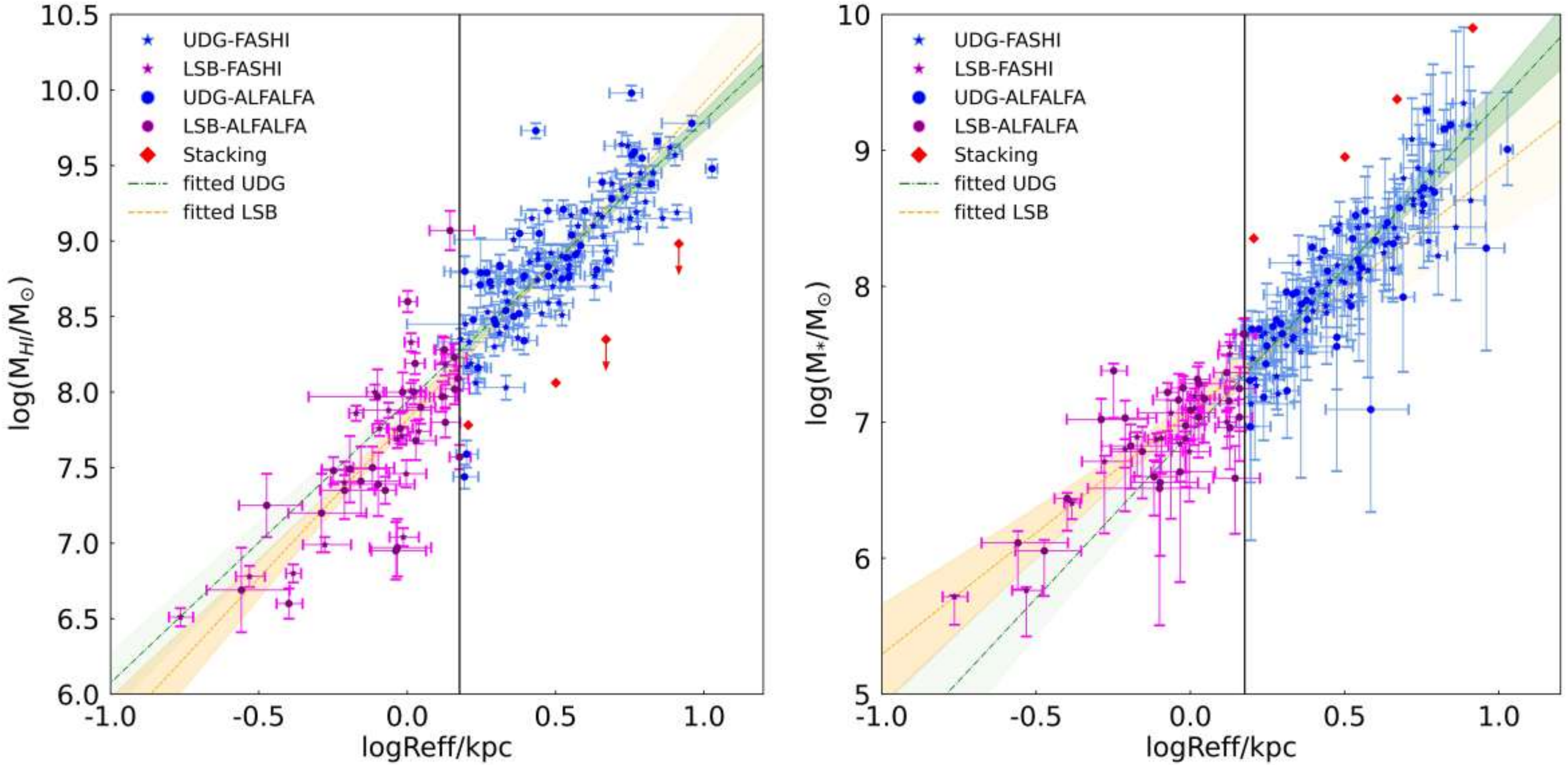
Fig. 11: Left and middle plot show HI source spectrum line, HI intensity mappings,respecitively and its counterparts image in unWISE W1/W2 NEO6 band in right panel,Left and middle plo show HI source spectrum line, HI intensity mappings,respecitively, and its counterparts image i unWISE W1/W2 NEO6 band in right panel.



H I study of a large sample of ultra-diffuse galaxies (Zhou et al. 2026 ApJ)

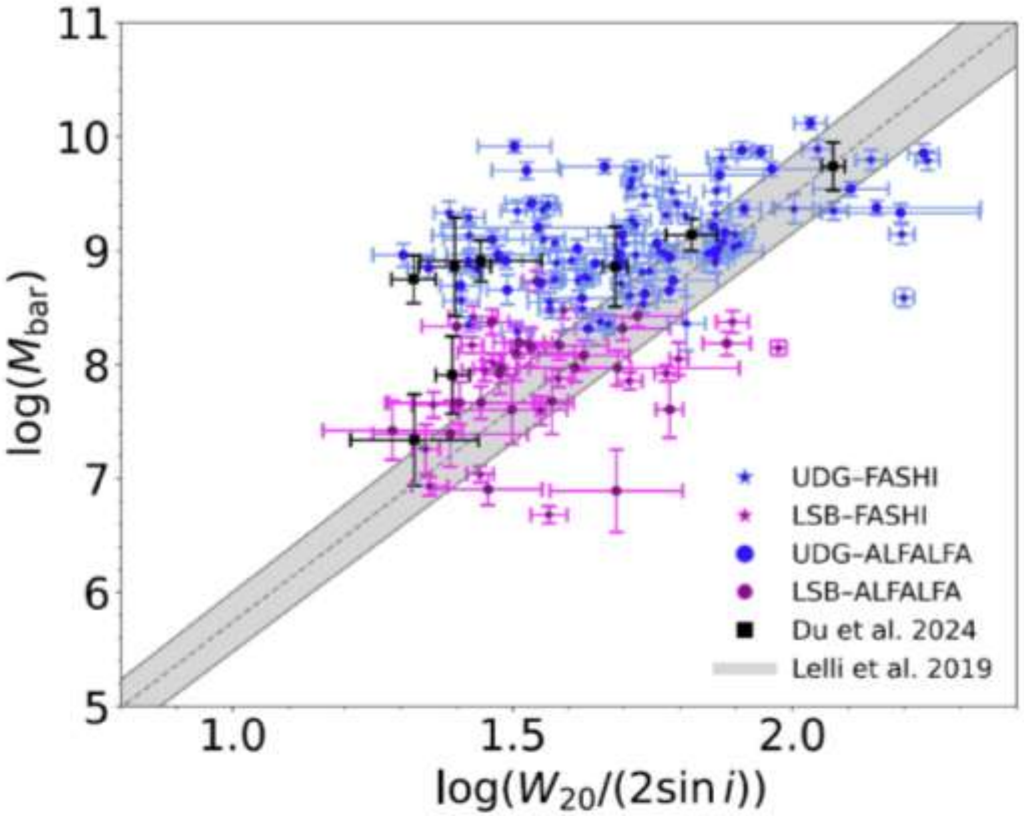




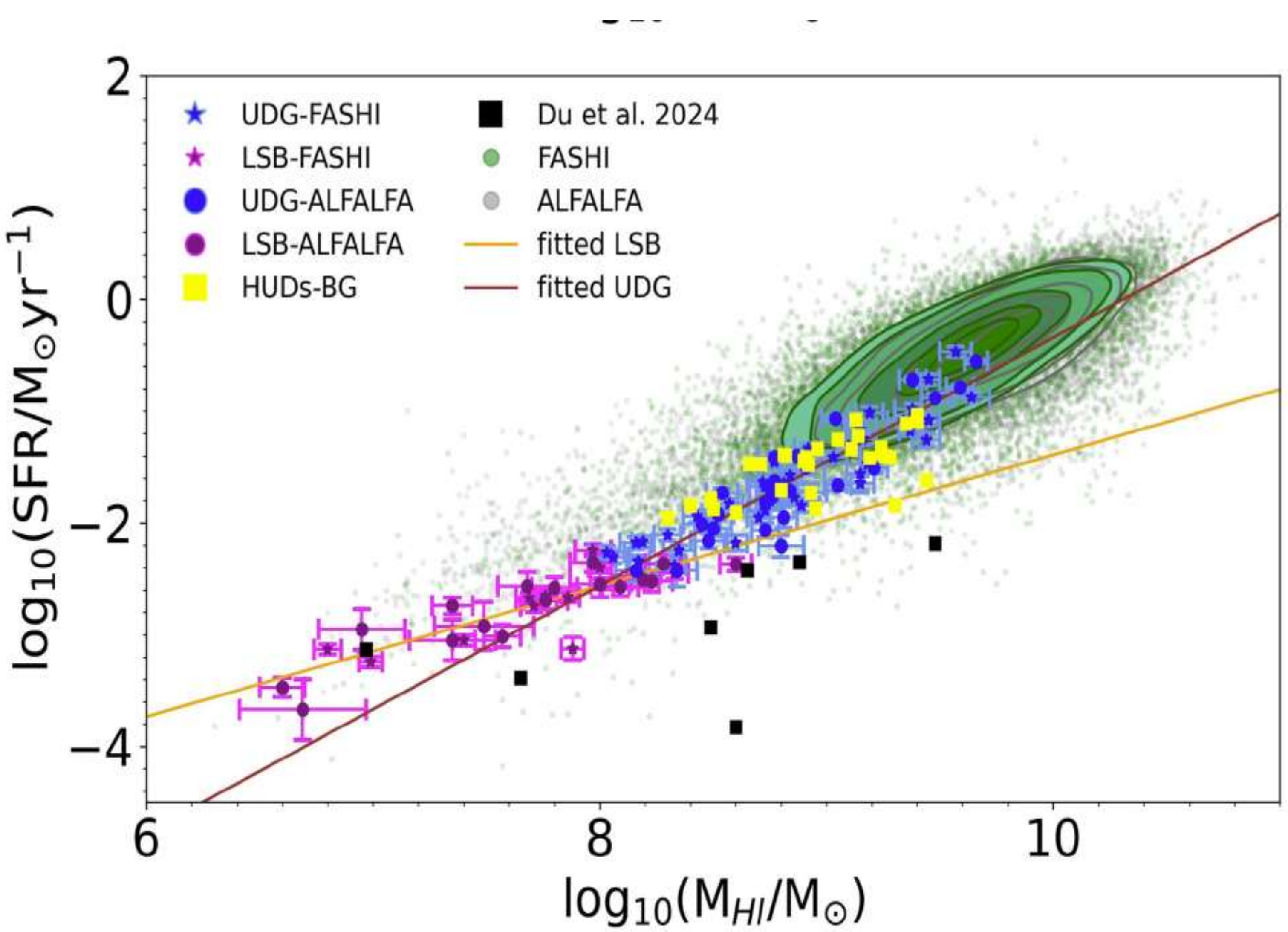


UDG-FASHI
LSB-FASHI
UDG-ALFALFA
LSB-ALFALFA
Stacking
fitted UDG
fitted LSB
log(M$_{HI}$/M$_\odot$)
logReff/kpc
log(M$_*$/M$_\odot$)
logReff/kpc

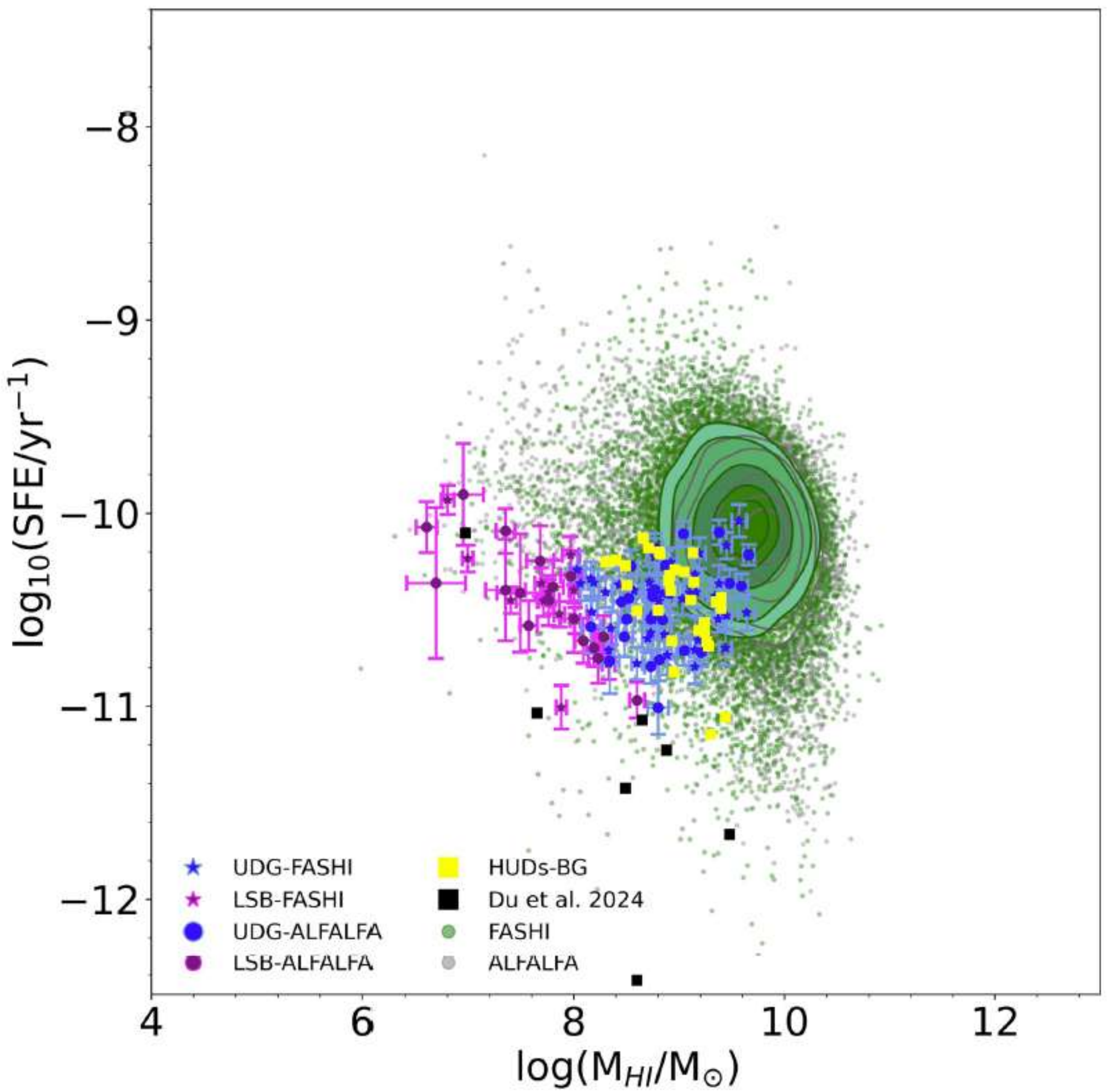
Tully – Fisher relation



star formation rate



Star formation efficiency



Summary

1. FASHIsurvey has found over 150000 HI sources
2. Found some dark galaxy canidates
3. Found large amount diffuse gas in nearby galaxies
4. Found much more tidal features in many interacting systems - 星系相互作用是更普遍的存在，应该在星系演化中起重要作用