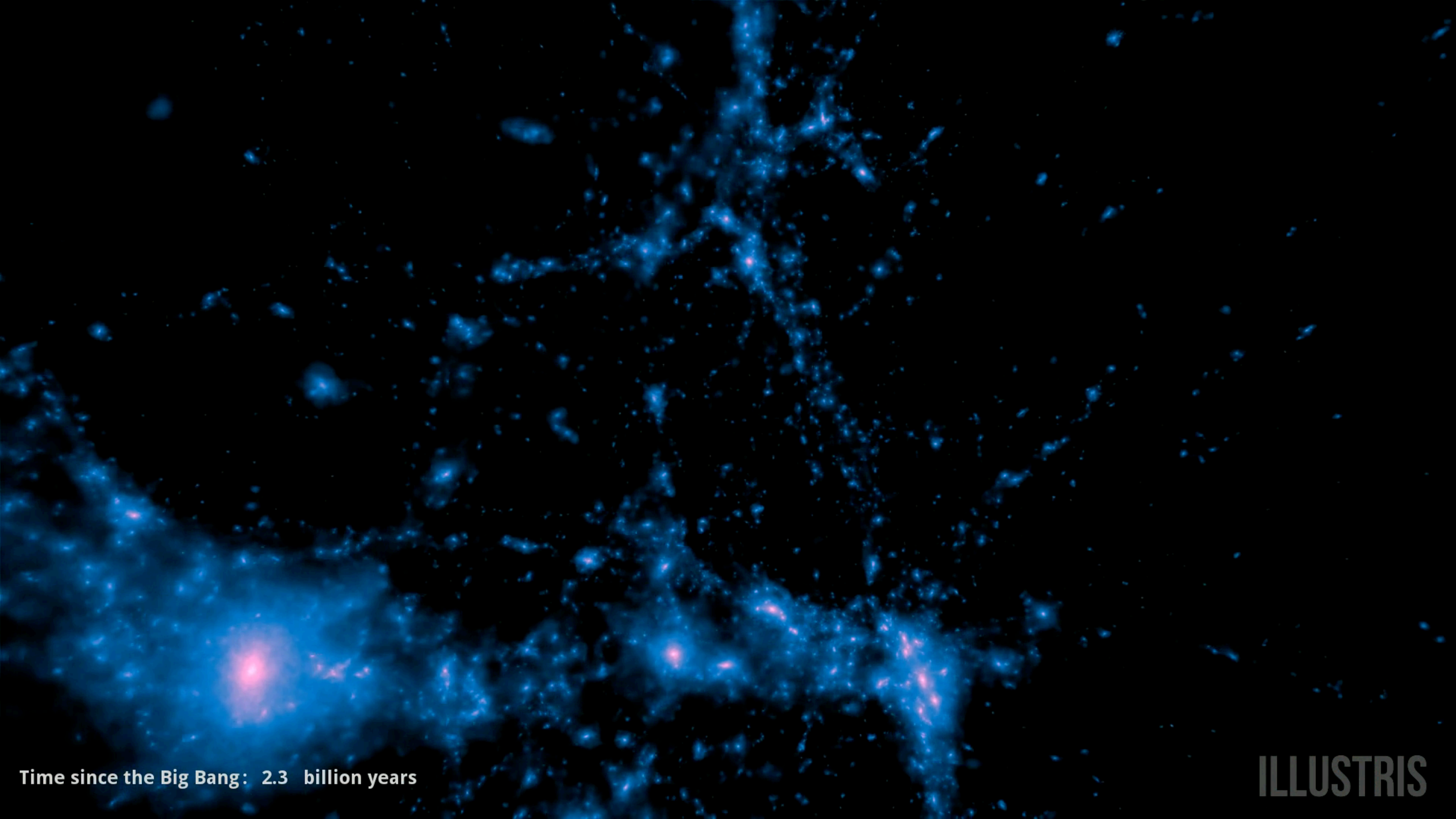


# Linking absorption and emission of the CGM with IMAGINE

Attila Popping

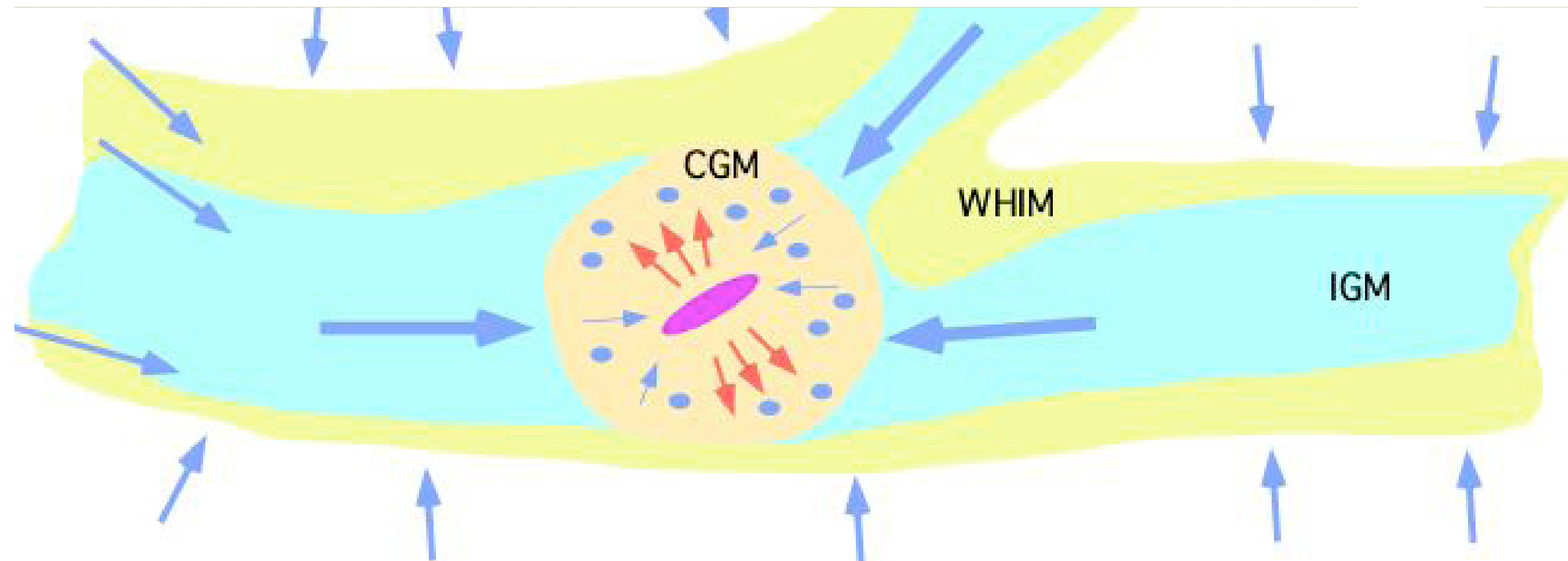


HI absorption 2017  
ASTRON - Dwingeloo, 14-16 June 2017

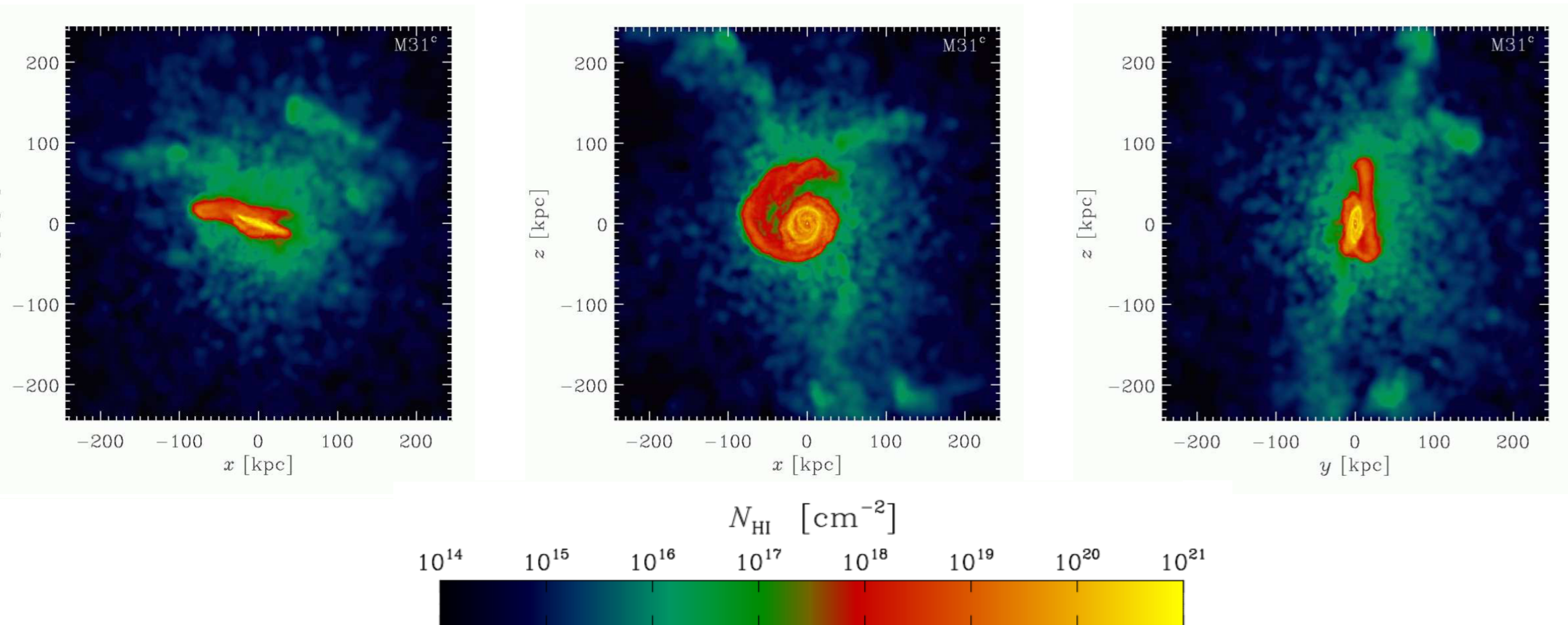


Time since the Big Bang: 2.3 billion years

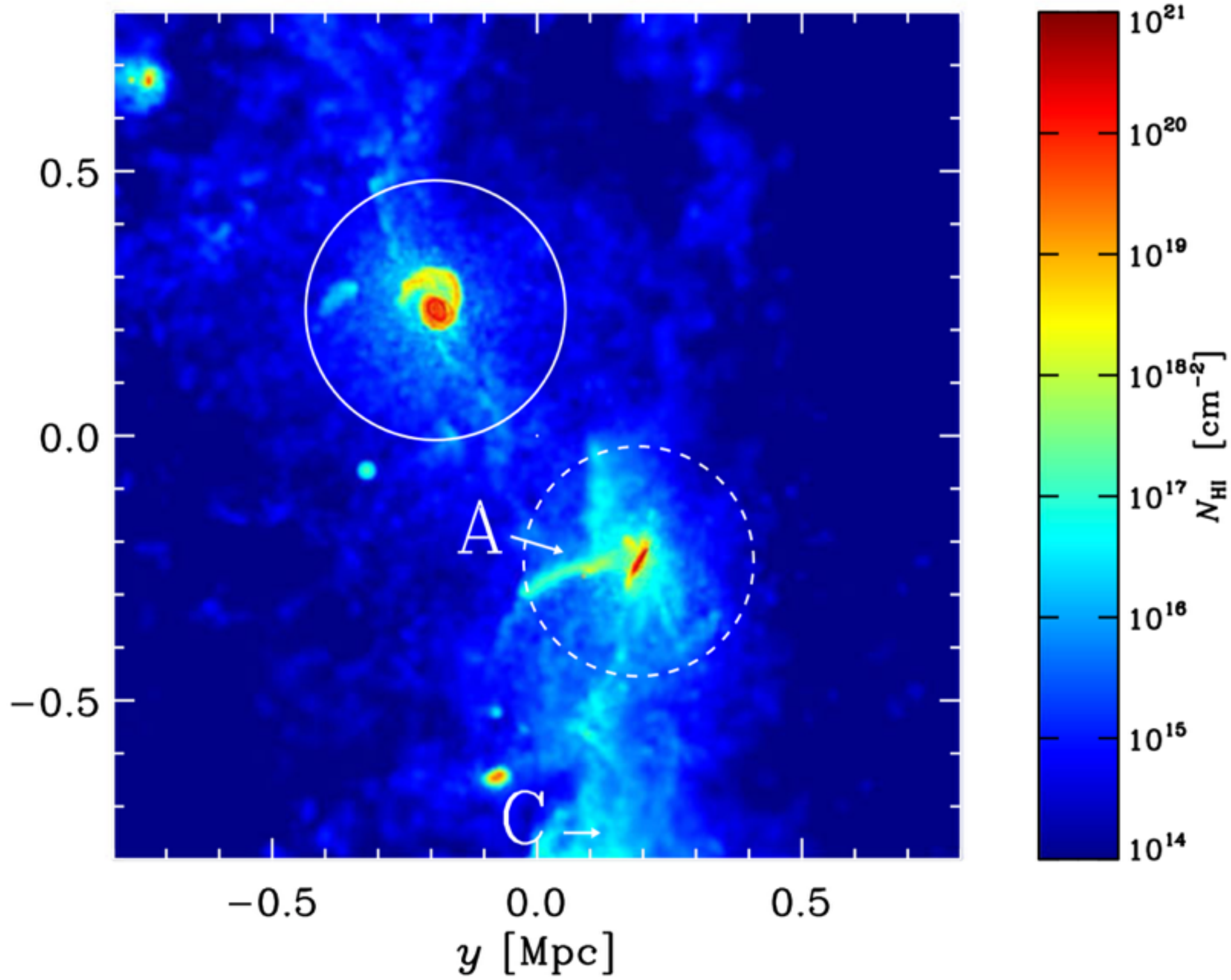
ILLUSTRIS



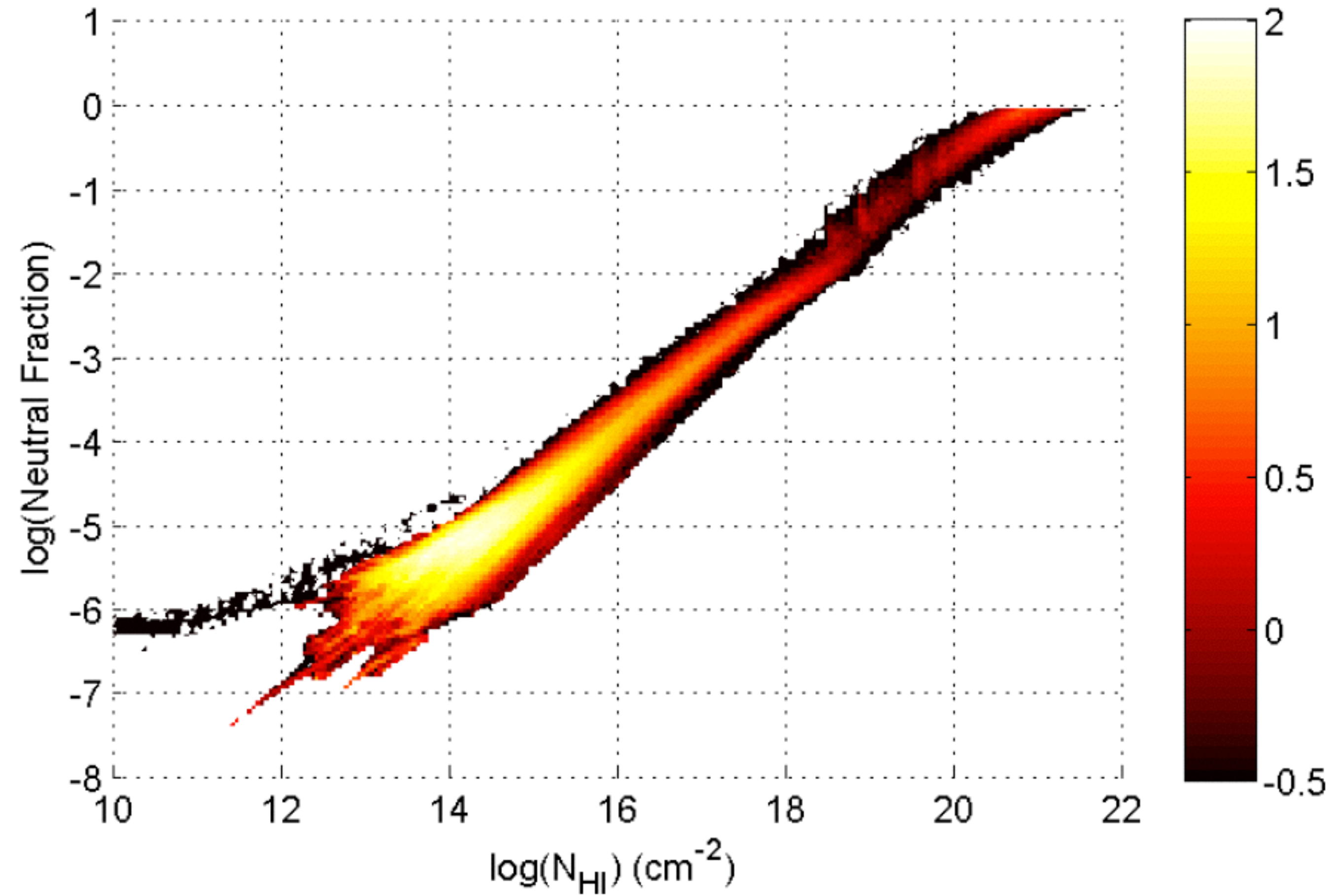
- IGM is an unexplored region
- Contains information about structure formation: e.g. tidal filaments
- Extended halo forms connection between IGM and galaxies; gas accretion (hot mode, cold mode), feedback processes
- Due to moderately high temperatures, most of the gas is ionised → **low neutral fraction**



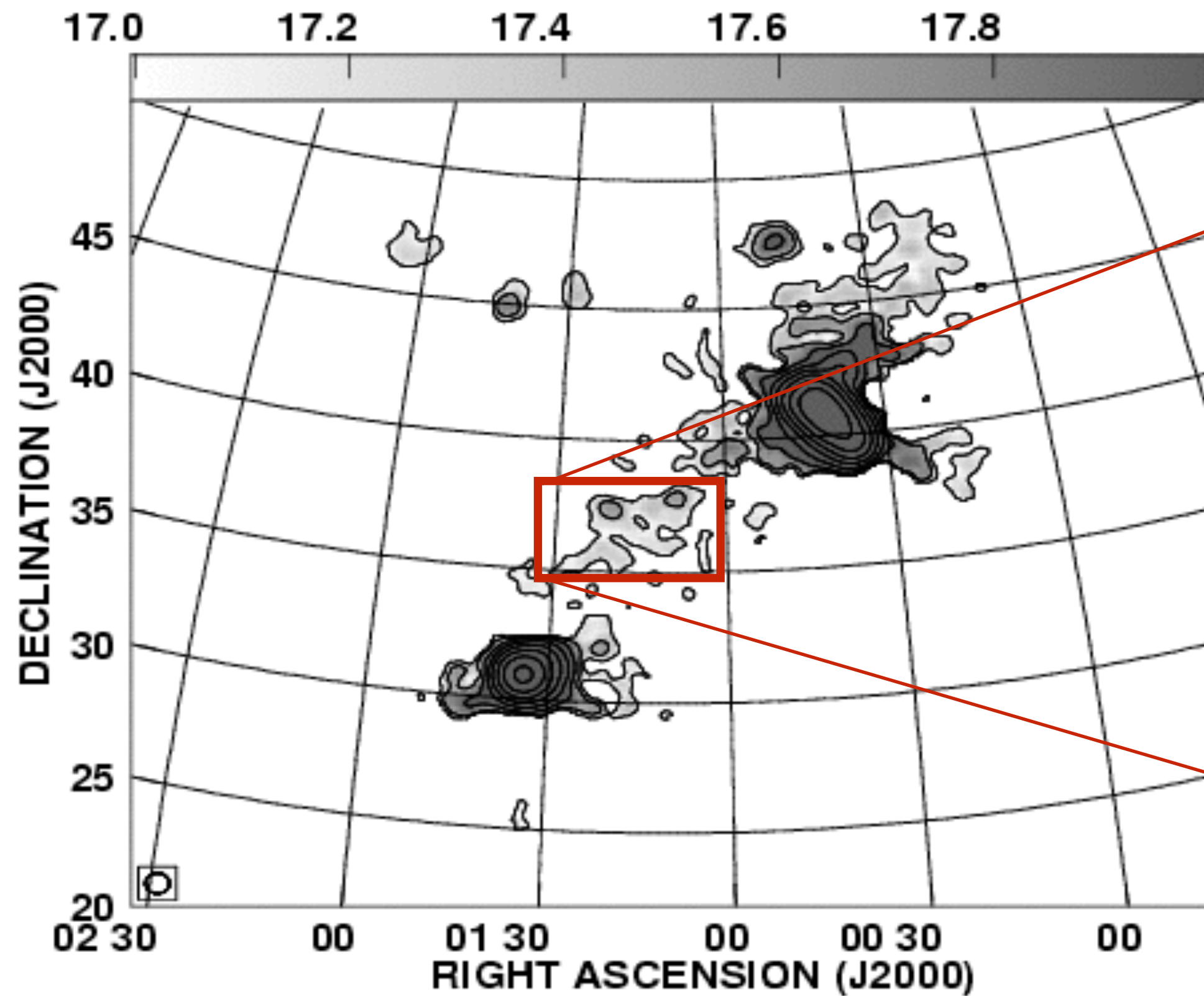
Nuza et al. 2014



Nuza et al. 2014

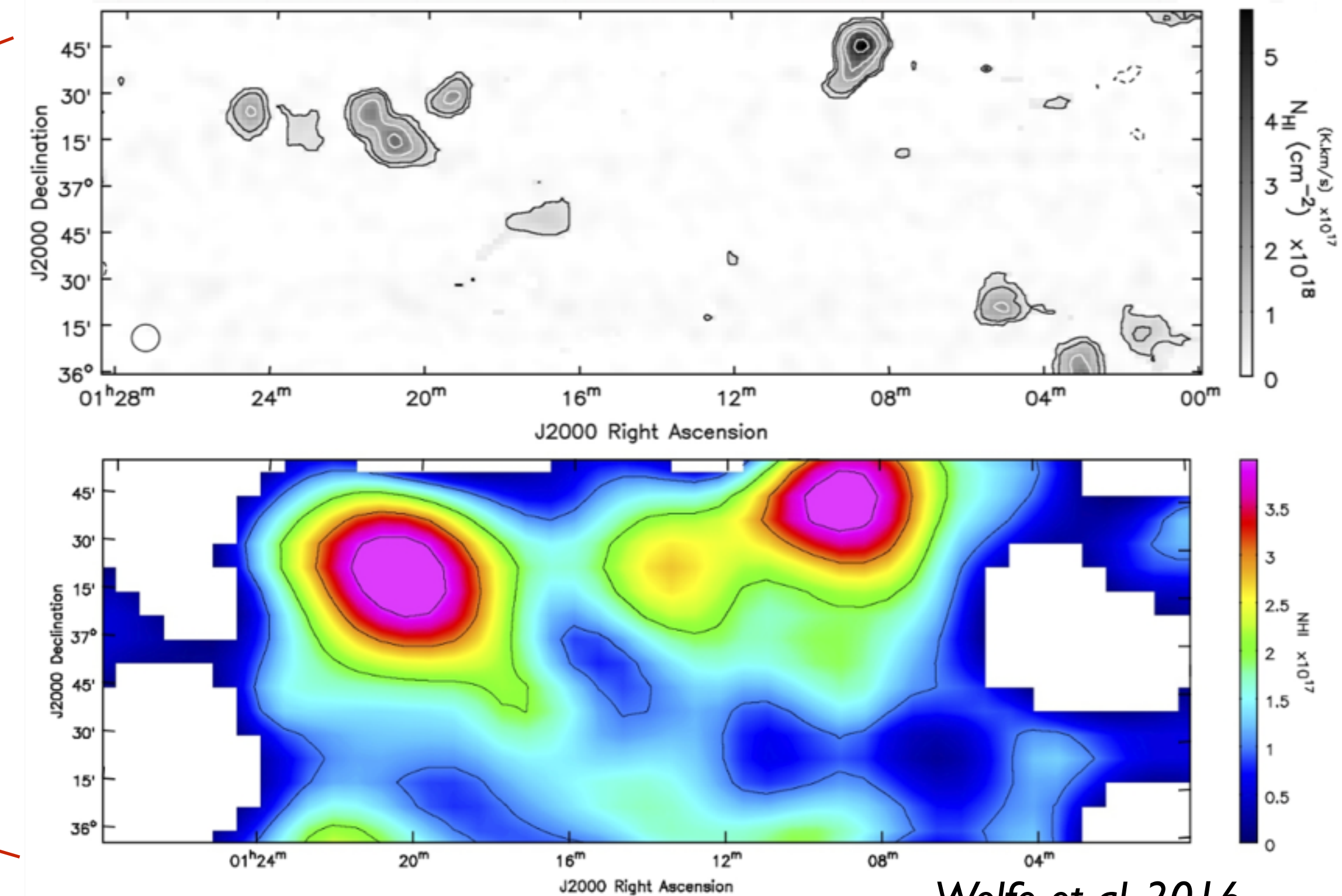


Popping et al. 2009



*Braun & Thilker 2004*

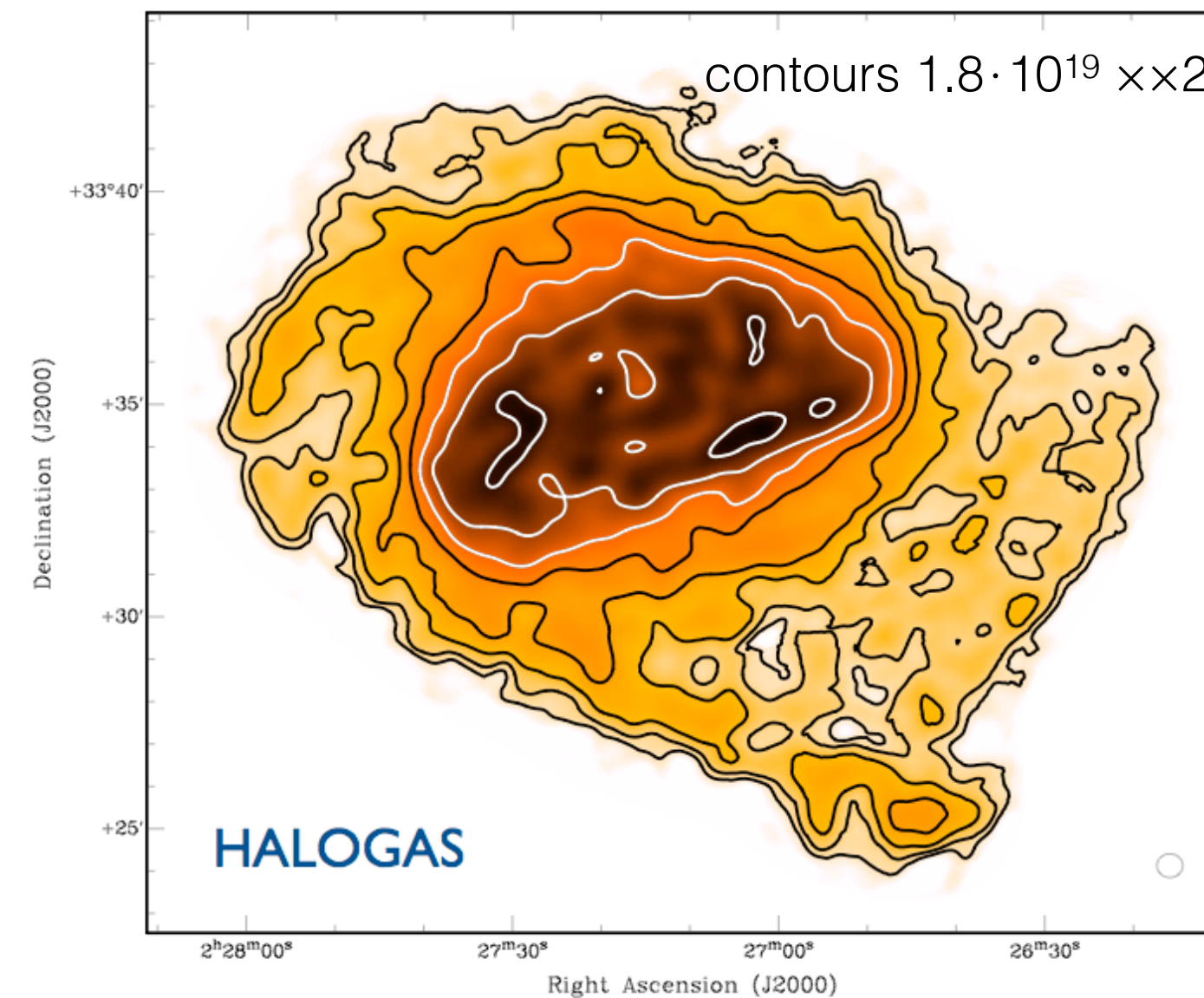
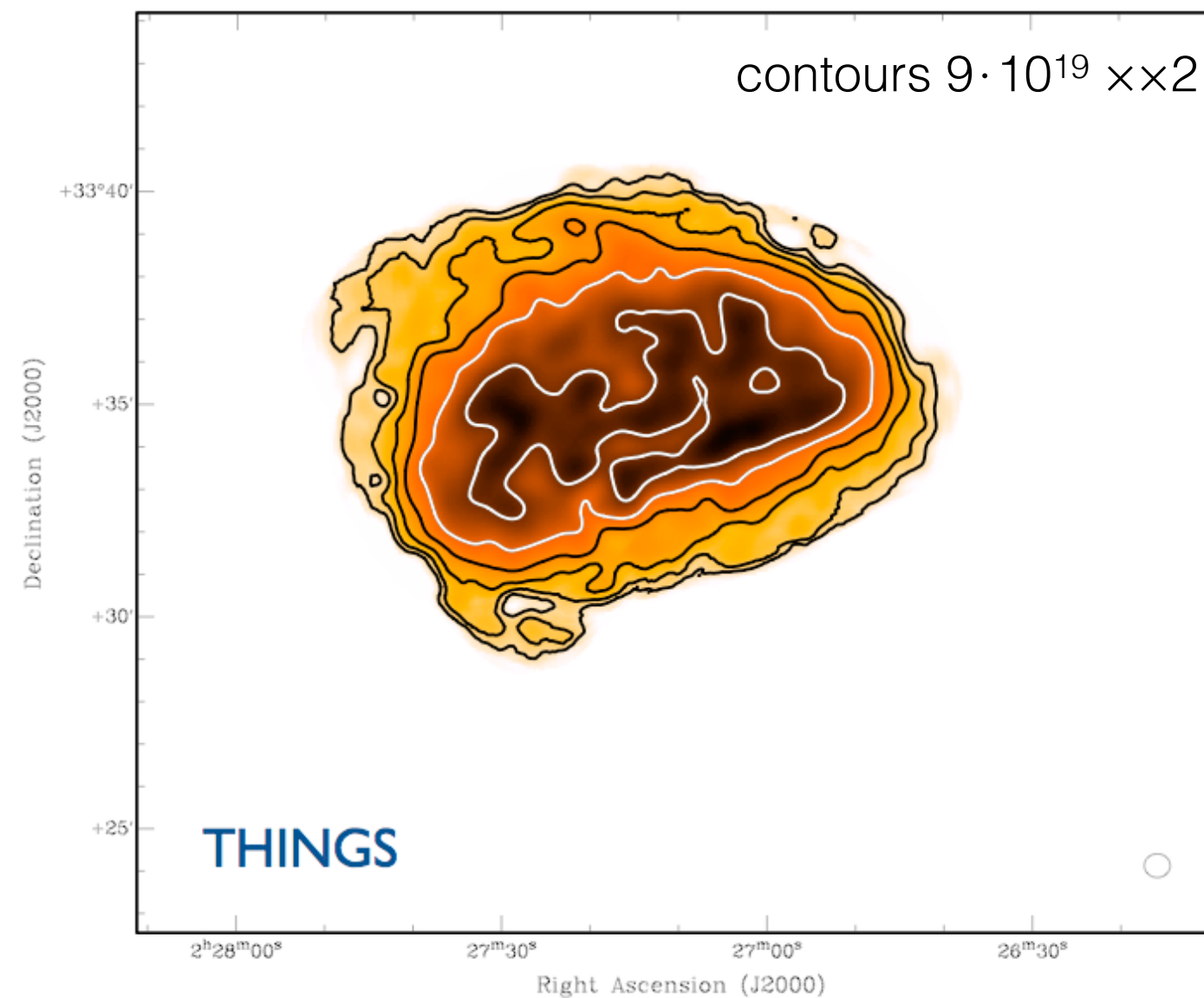
HI between M31 & M33 and to the northwest of M31  
 Very faint emission  $N_{HI} \sim 10^{17-18} \text{ cm}^{-2}$   
 WSRT used in single dish mode, very low resolution



*Wolfe et al. 2016*

12 square degrees between M31 and M33  
 9' GBT beam, 5 km/s  
 Gas is clumpy  
 Confirmed low  $N_{HI} \sim 10^{18} \text{ cm}^{-2}$

- PI George Heald (Heald et al 2011)
- 10 × 12h per target, to reach  $N_{\text{HI}} = \mathbf{1 \times 10^{19} \text{ cm}^{-2}}$  ( $3\sigma$ , 16 km s<sup>-1</sup>) at 30" resolution (cf. THINGS:  $5 \times 10^{19} \text{ cm}^{-2}$ )
- unresolved cloud mass sensitivity of  $\mathbf{2.7 \times 10^5}$  (D/10 Mpc)<sup>2</sup>  $M_{\odot}$
- Survey sample 24 galaxies (including NGC 891 & NGC 2403)
- Survey complete and summary papers in progress

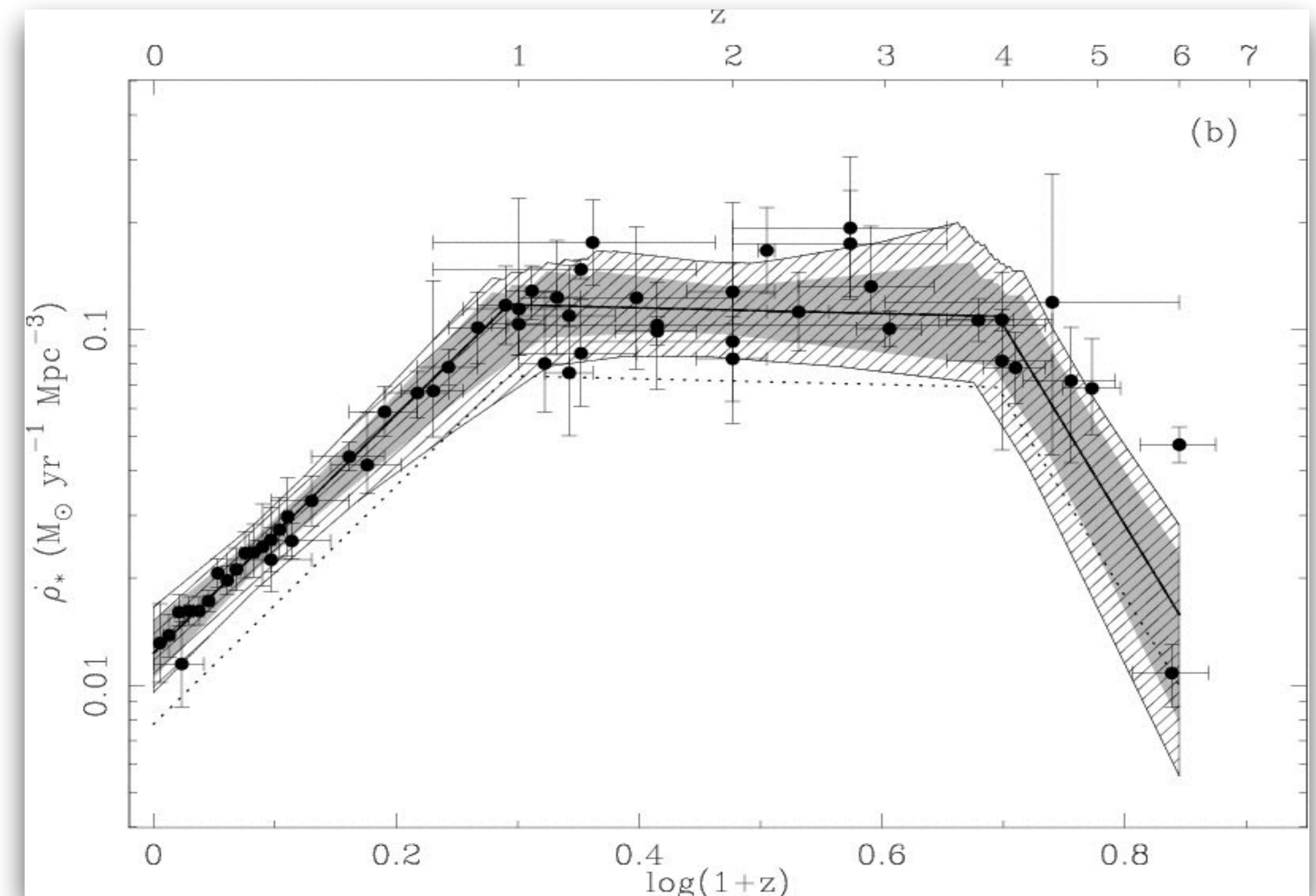


- Effort underway to collect full list of all clouds and streams in HALOGAS target fields
  - How many galaxies show signs of accretion? How much (and at what rate)? Clouds or diffuse? Co-rotating with the galaxy? Associated with star formation? ...
- Preliminary result already clear:  
A few features possibly attributable to cold accretion (in the form of HI)
  - but insufficient to fully balance SFR in a typical galaxy;
  - HALOGAS has not detected a large population of clouds with with  $M_{HI} > 10^5 M_{\odot}$
  - HALOGAS has not found significant amounts of low-column density HI not associated with SF (down to  $10^{19} \text{ cm}^{-2}$ )
  - NGC 891 is an extreme, atypical case



Accretion seemingly not predominantly in the form of clouds (down to current observational limits).

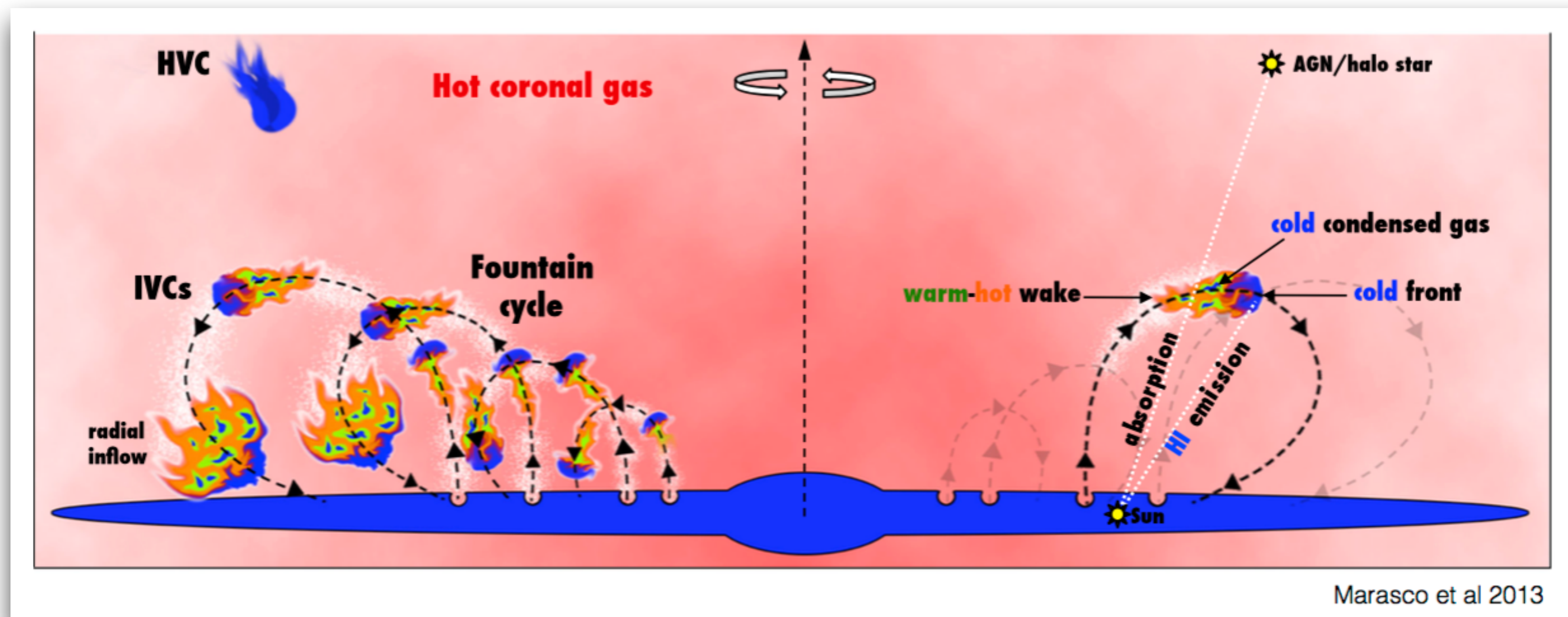
- Era of galaxy SFR decline?



*Hopkins & Beacom 2006*

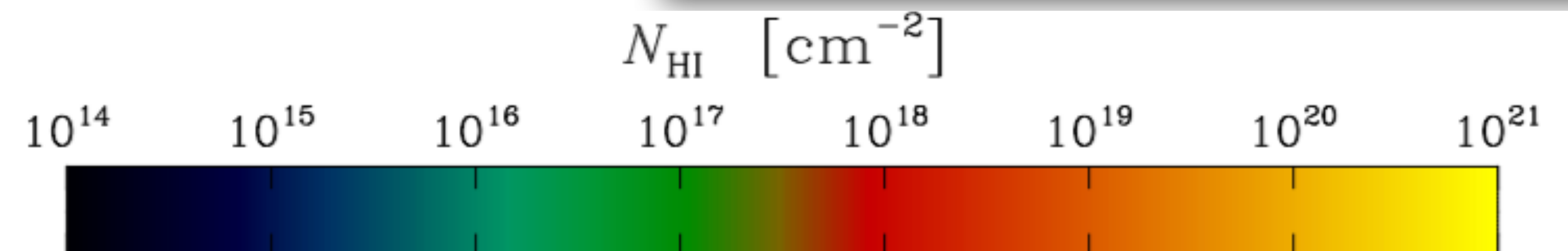
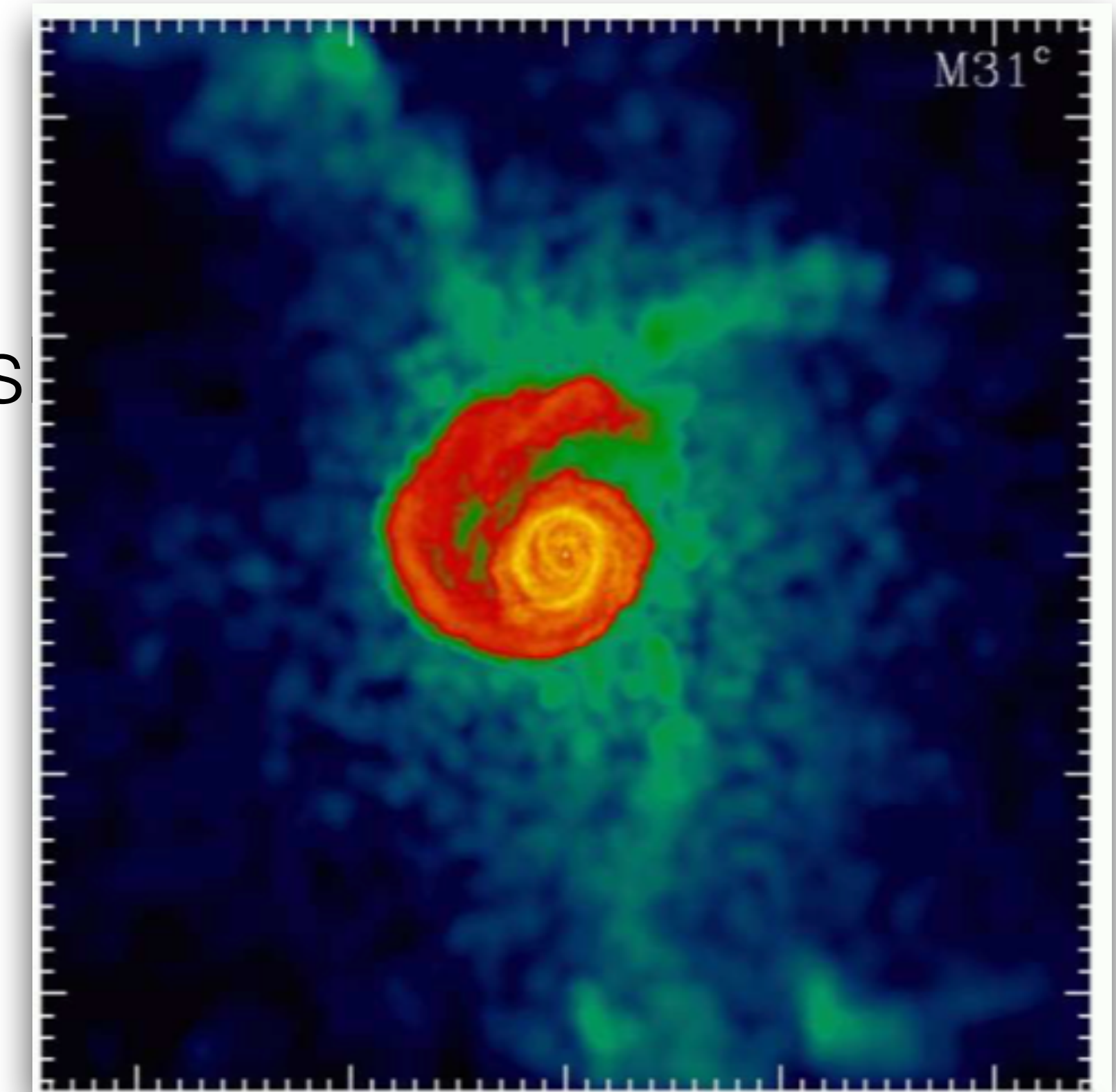
Accretion seemingly not predominantly in the form of clouds (down to current observational limits).

- Era of galaxy SFR decline?
- In the form of hot gas, and brought to the disk via fountain?

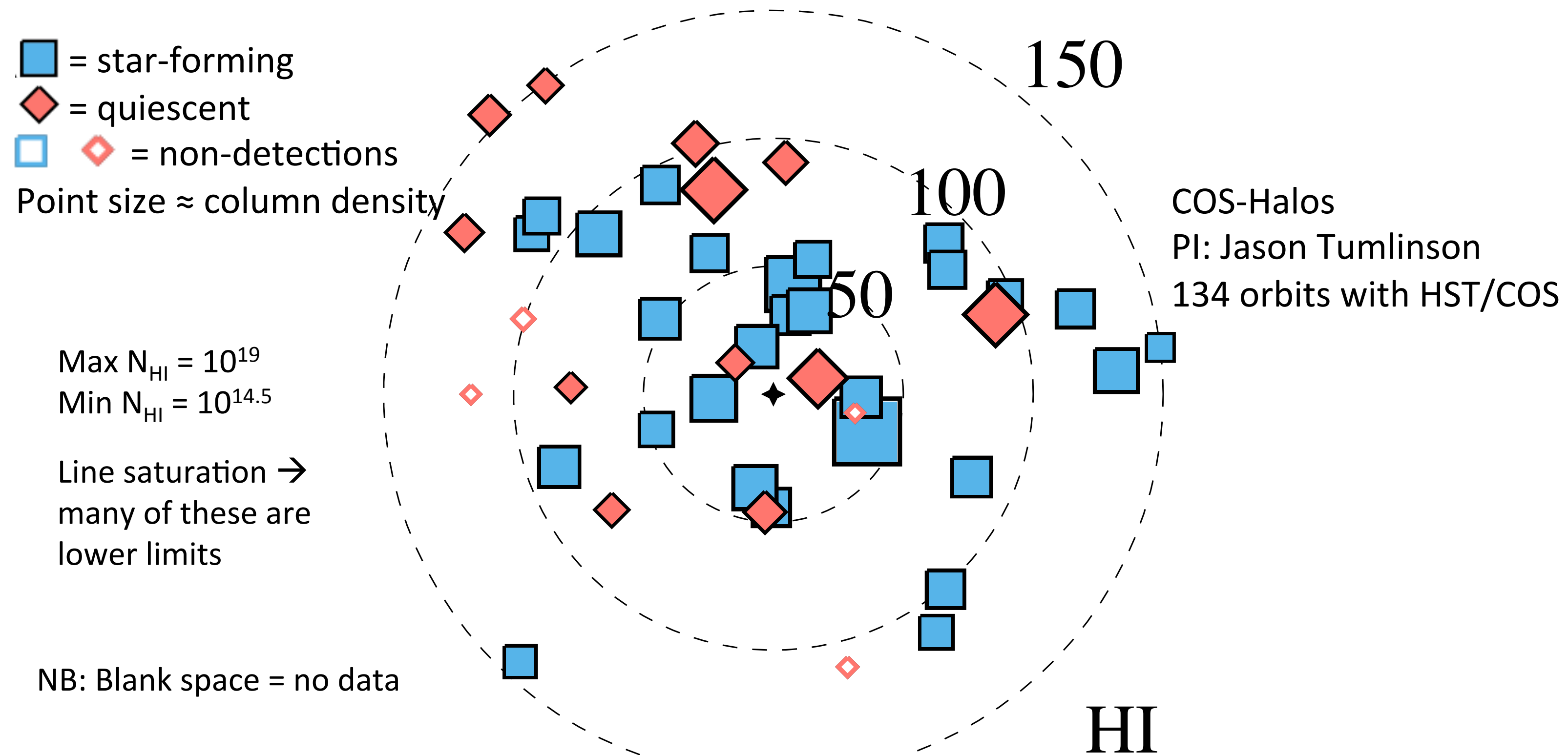


Accretion seemingly not predominantly in the form of clouds (down to current observational limits).

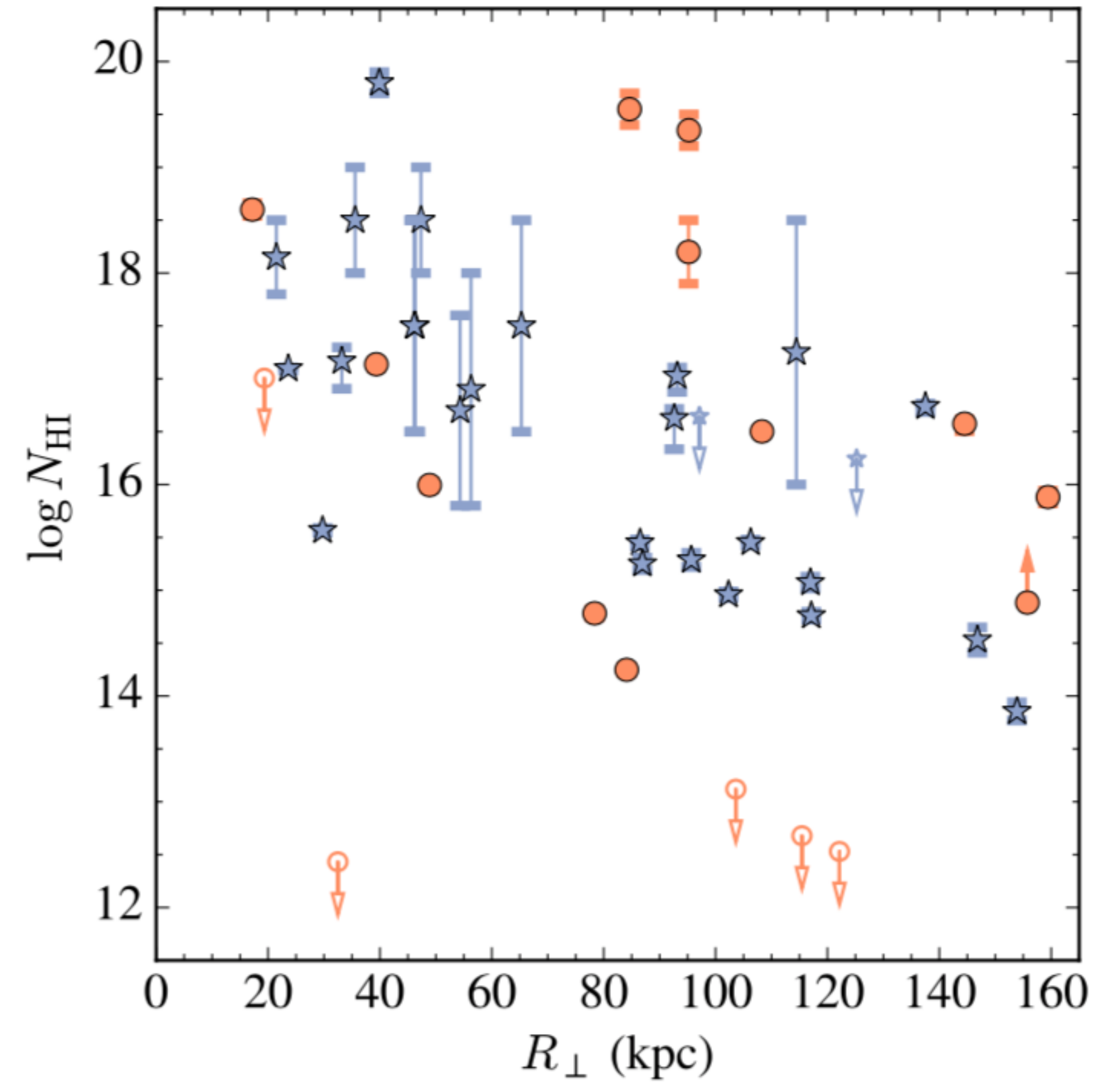
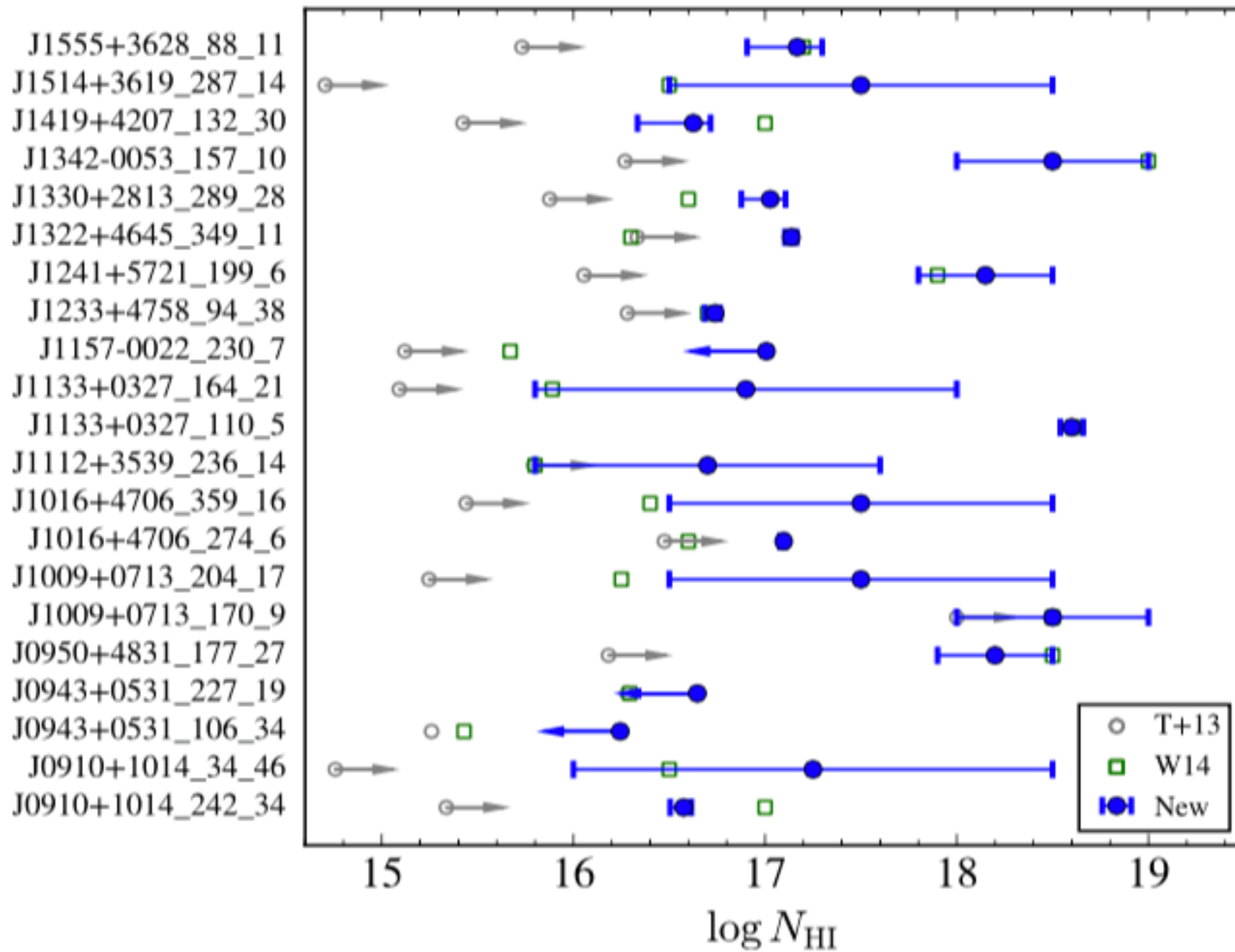
- Era of galaxy SFR decline?
- In the form of hot gas, and brought to the disc
- Happening at lower column densities?



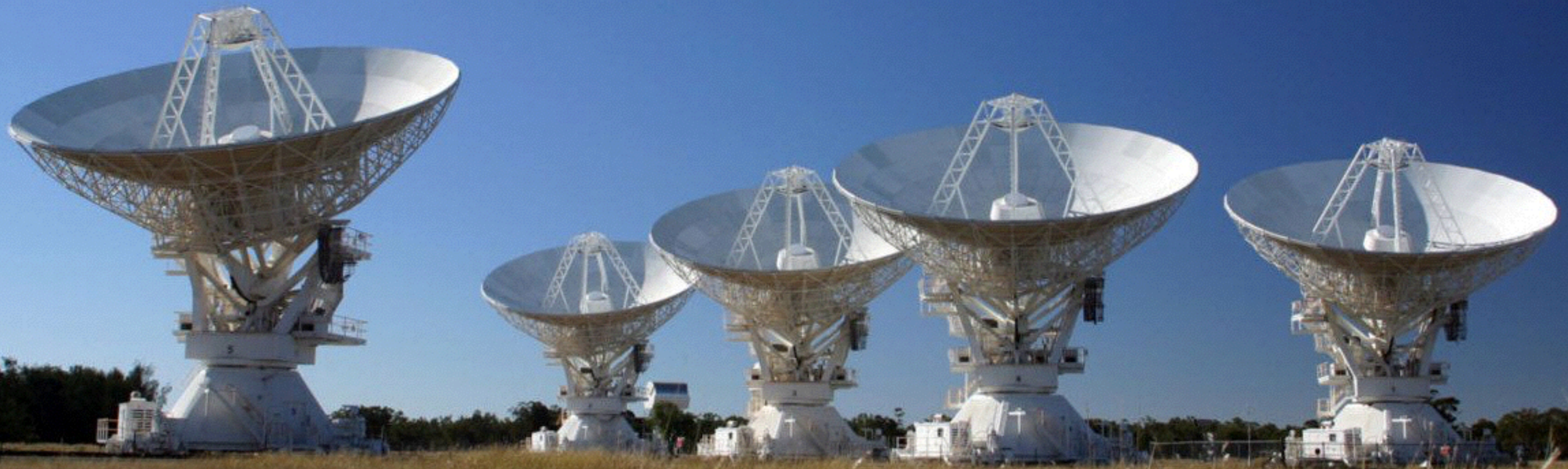
## Observed Properties of the CGM: The HI Gas



A cool ( $10^4$  K) medium with high covering fraction of  $N_{\text{HI}} > 10^{15} \text{ cm}^{-2}$  exists around nearly every  $L^*$  galaxy, **even ellipticals**, to 150 kpc.



# IMAGINE



Imaging Galaxies' Intergalactic and Nearby Environment

ATCA legacy project C3157

## **Imaging Galaxies Intergalactic and Nearby Environment**

PI: Attila Popping (ICRAR / UWA)

- Observe 28 spiral Galaxies and their direct environment
- Use 8 most compact configurations of ATCA (12 hours each)
- Total time 2688 hours
- $\text{NHI} \sim 2.5 \times 10^{17} \text{ cm}^{-2}$  over  $20 \text{ km s}^{-1}$ .
- resolution 1' to 2.5'



[www.imagine-survey.org](http://www.imagine-survey.org)

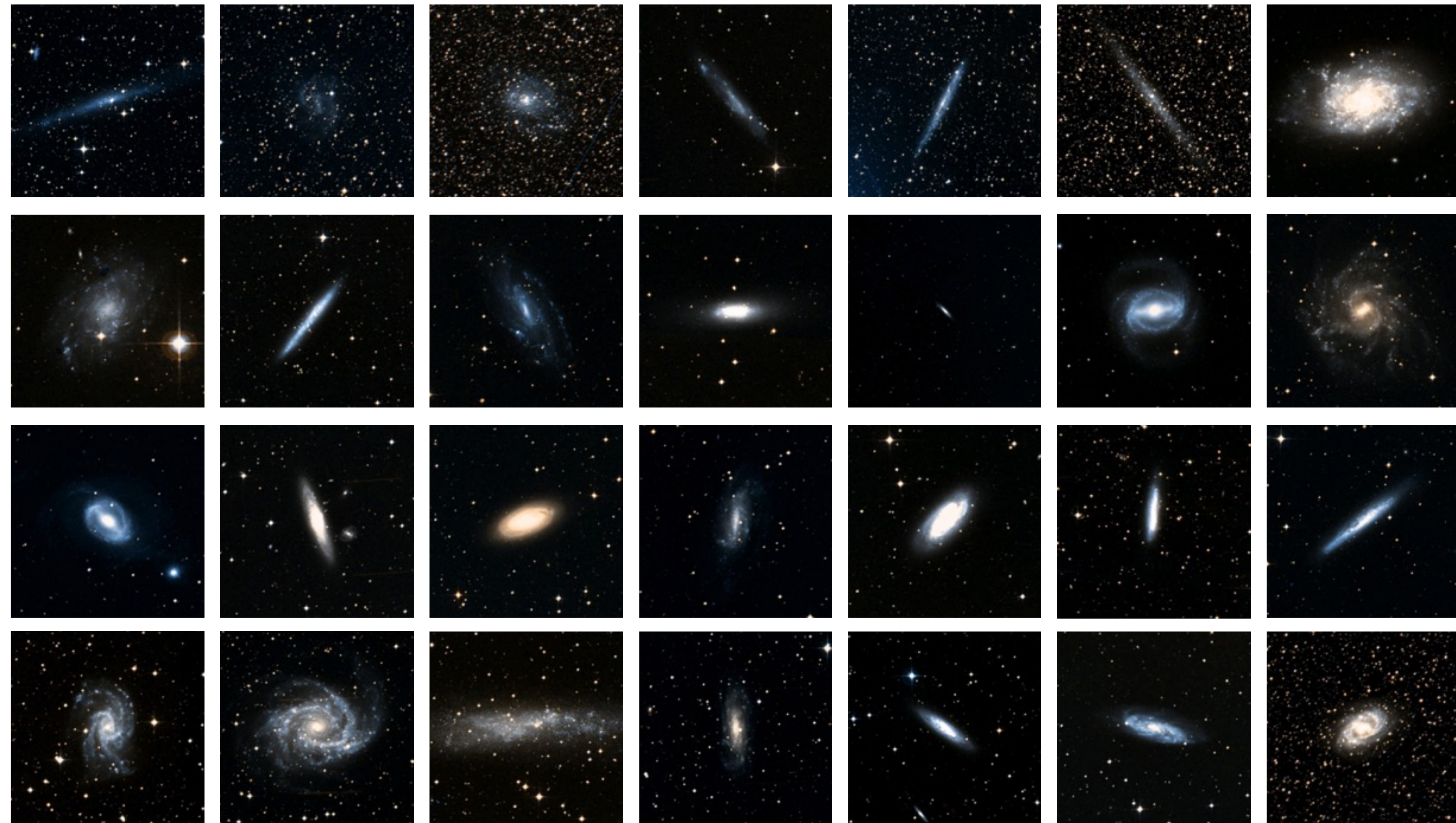
- Measure the extended gas content of galaxies to detect gas accretion and outflows.
- Determine the environment of gas accretion
- **Detect the densest peak of the underlying Cosmic Web.**
- Continuum source variability at low flux levels over the full survey area.
- Studies of warps and lopsidedness in spiral galaxies.
- Intervening HI absorption against background sources
- Studies of angular momentum.
- Lower column densities by stacking sight-lines in the halos of galaxies.
- Linear polarisation
- Circular polarisation
- OH mega-masers
- SKA-SDP testing
- ...



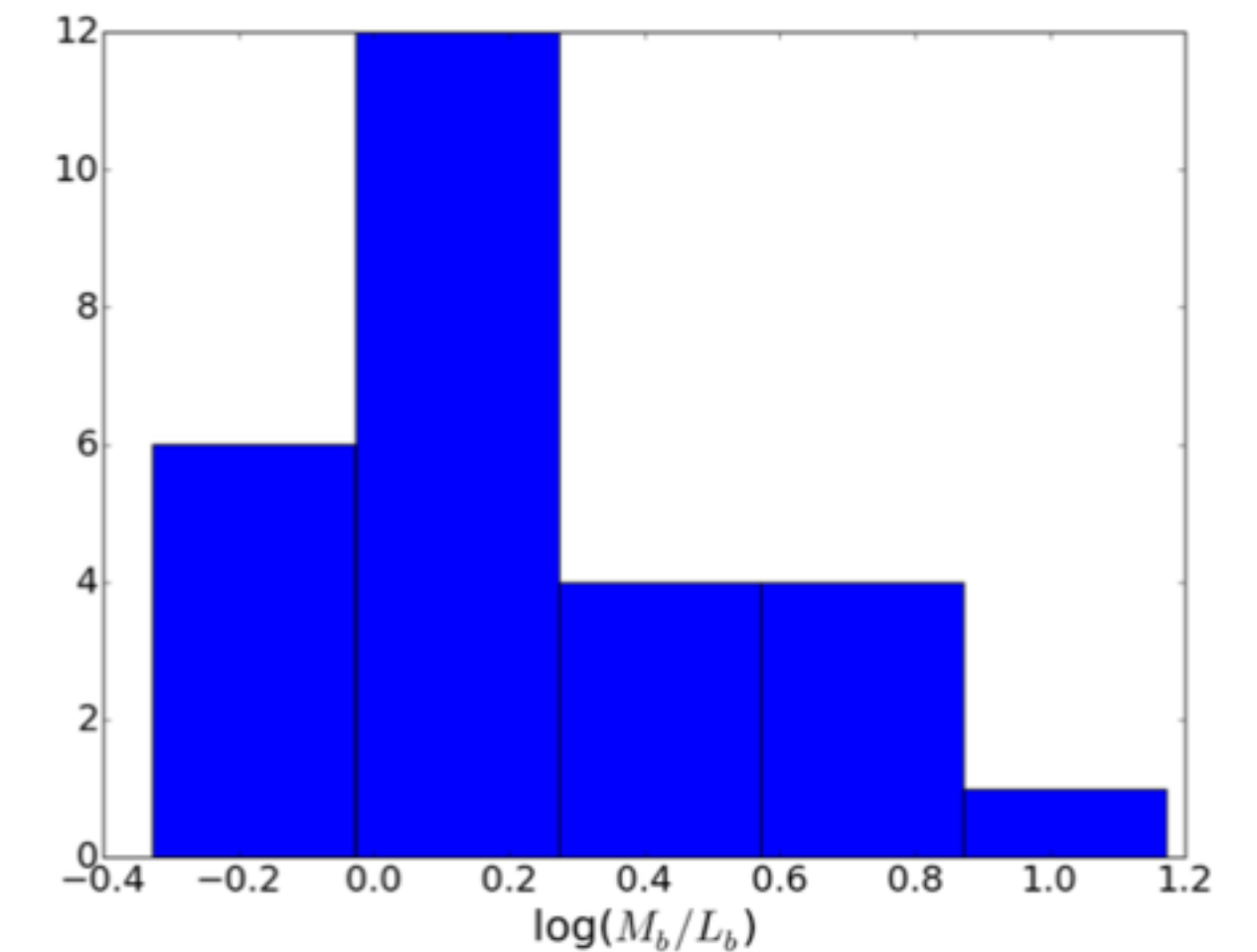
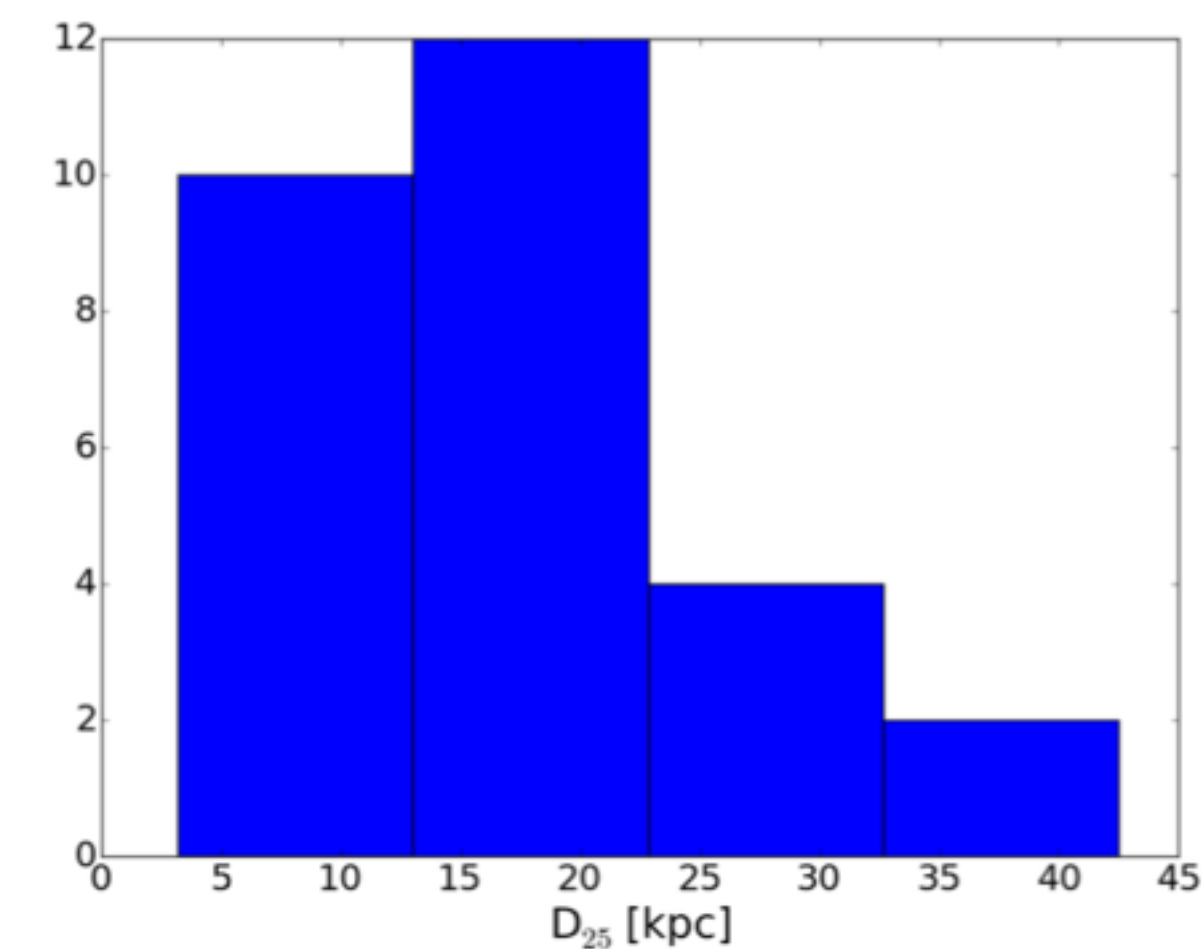
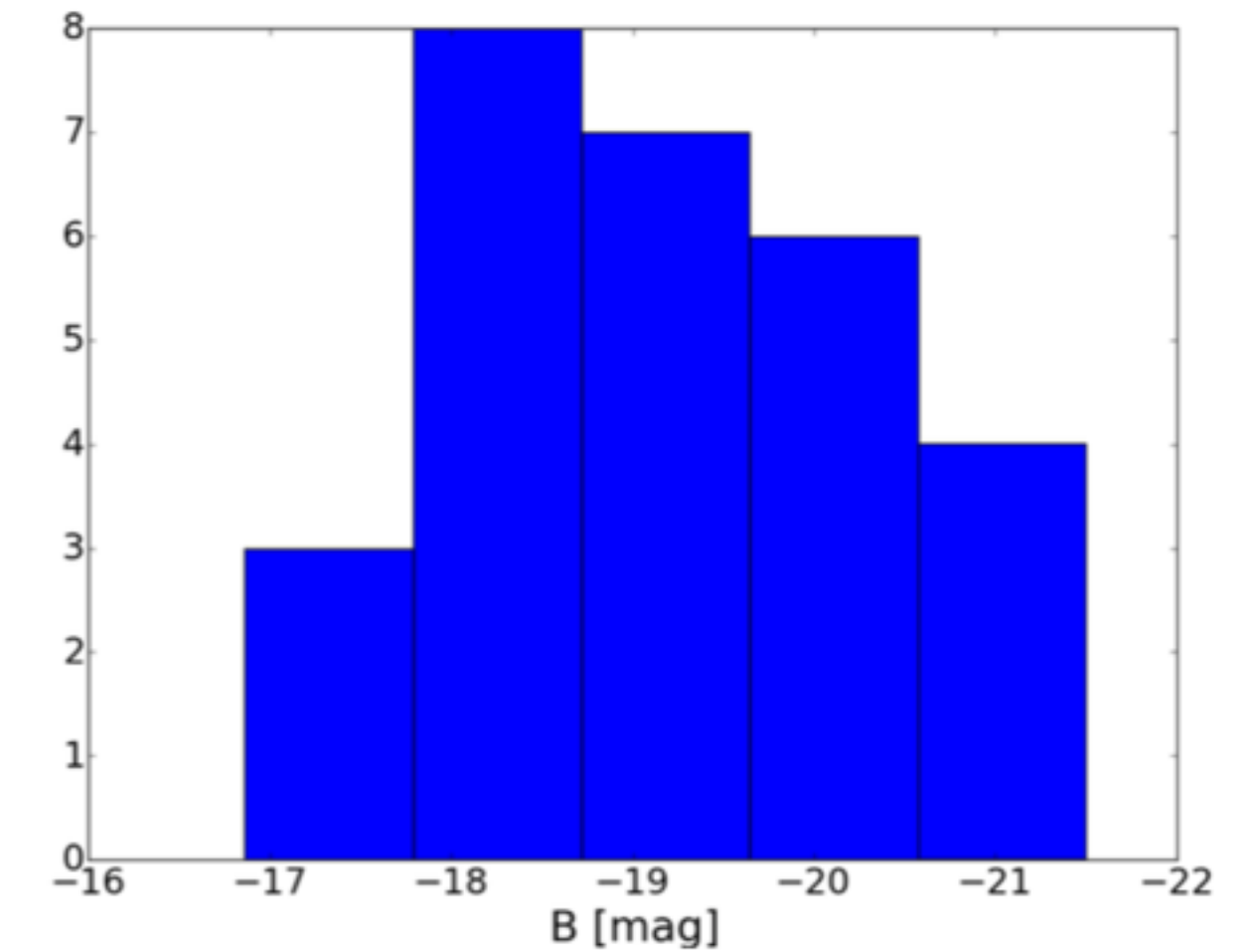
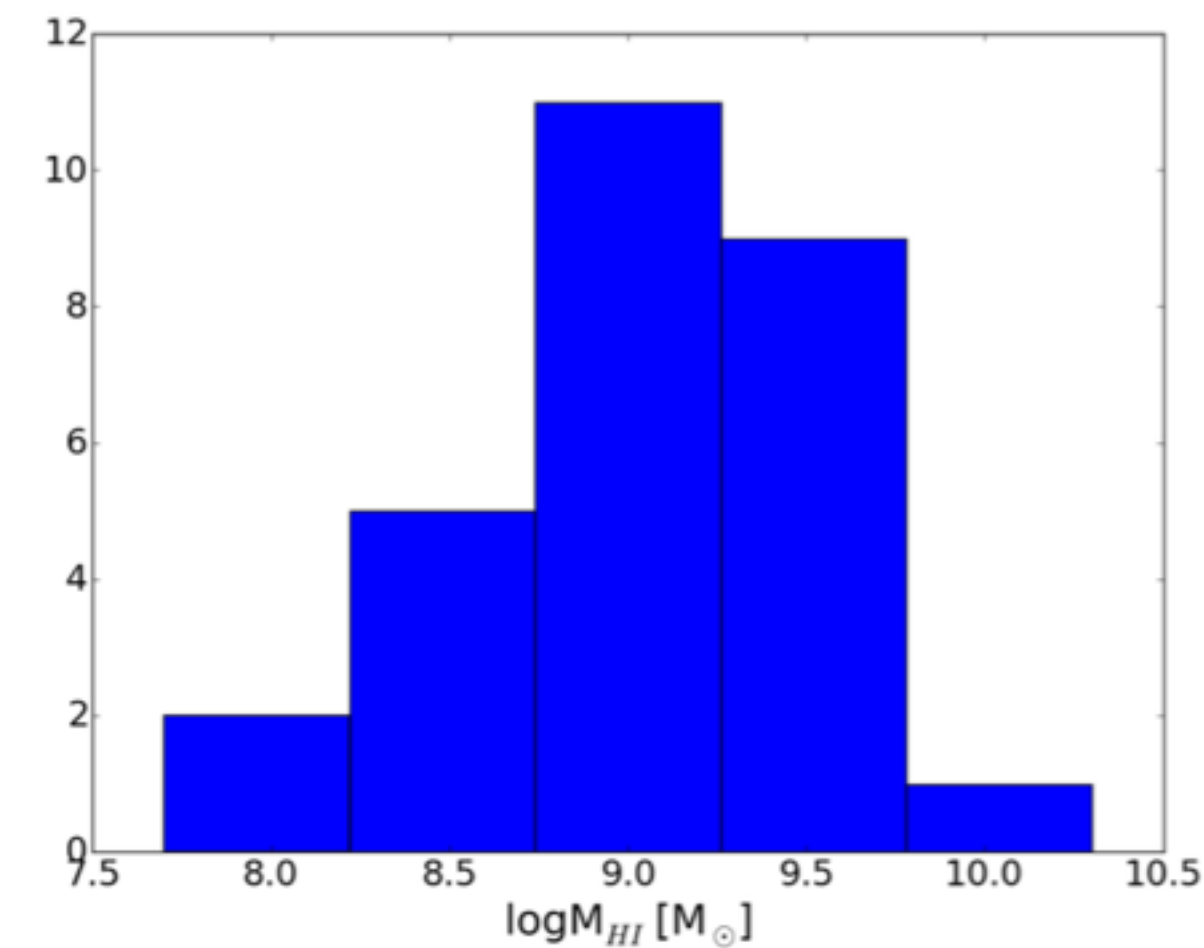
Craig Anderson  
Erwin de Blok  
Thanapol Chanapote  
Richard Dodson  
Jonah Gannon  
George Heald  
Jane Kaczmarek  
Dane Kleiner  
Baerbel Koribalski  
Karen Lee-Waddell  
Angel Lopez-Sanchez  
Juan Madrid  
Martin Meyer  
Vanessa Moss  
Danail Obreschkow

DJ Pisano  
Attila Popping  
Chris Power  
Jonghwan Rhee  
Aaron Robotham  
Amy Sardone  
Lee Spitler  
Lister Staveley-Smith  
Kevin Vinsen  
Jing Wang  
Tobias Westmeier  
Andreas Wicenec  
Christian Wolf  
Chen Wu

- NGC0024
- NGC0045
- NGC0625
- ESO154-023
- NGC1433
- NGC1512
- NGC1515
- NGC1617
- NGC1744
- NGC1792
- NGC2188
- ESO209-009
- NGC2835
- NGC2997
- NGC3109
- NGC3137
- NGC3175
- ESO214-017
- NGC3511
- ESO270-017
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- ESO138-010
- NGC6300
- IC5052
- NGC7090
- IC5201
- NGC7424
- NGC7793

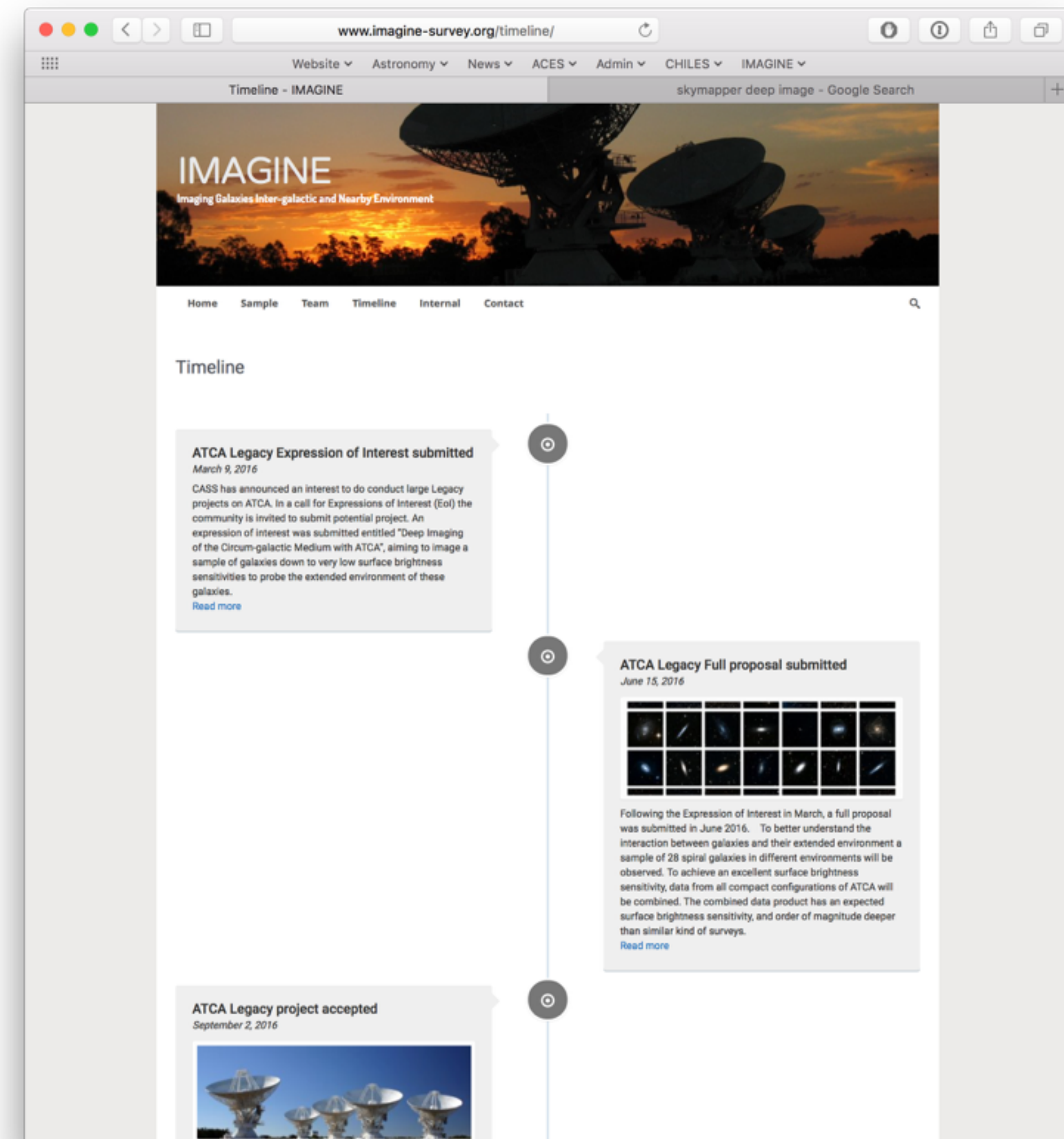


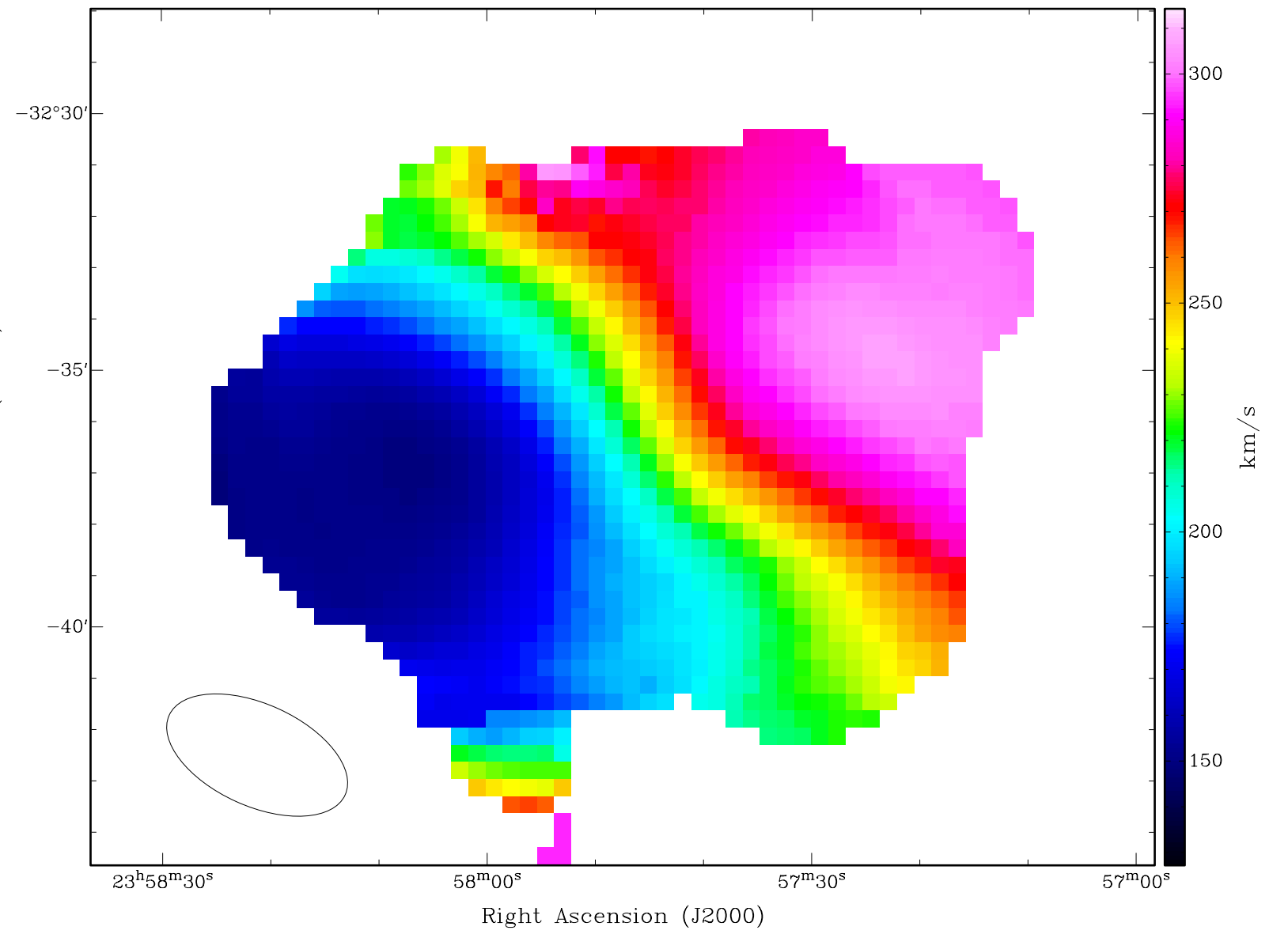
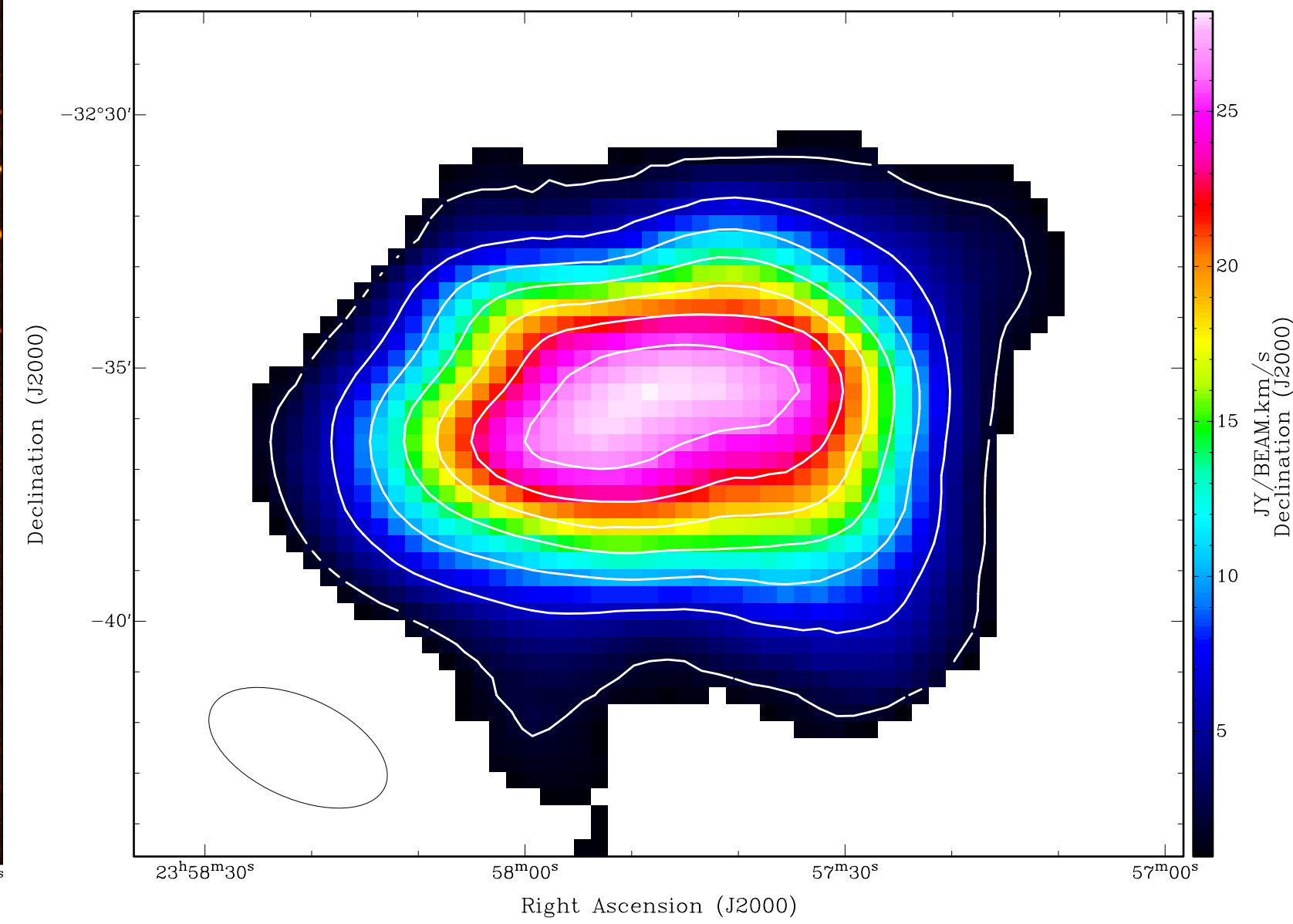
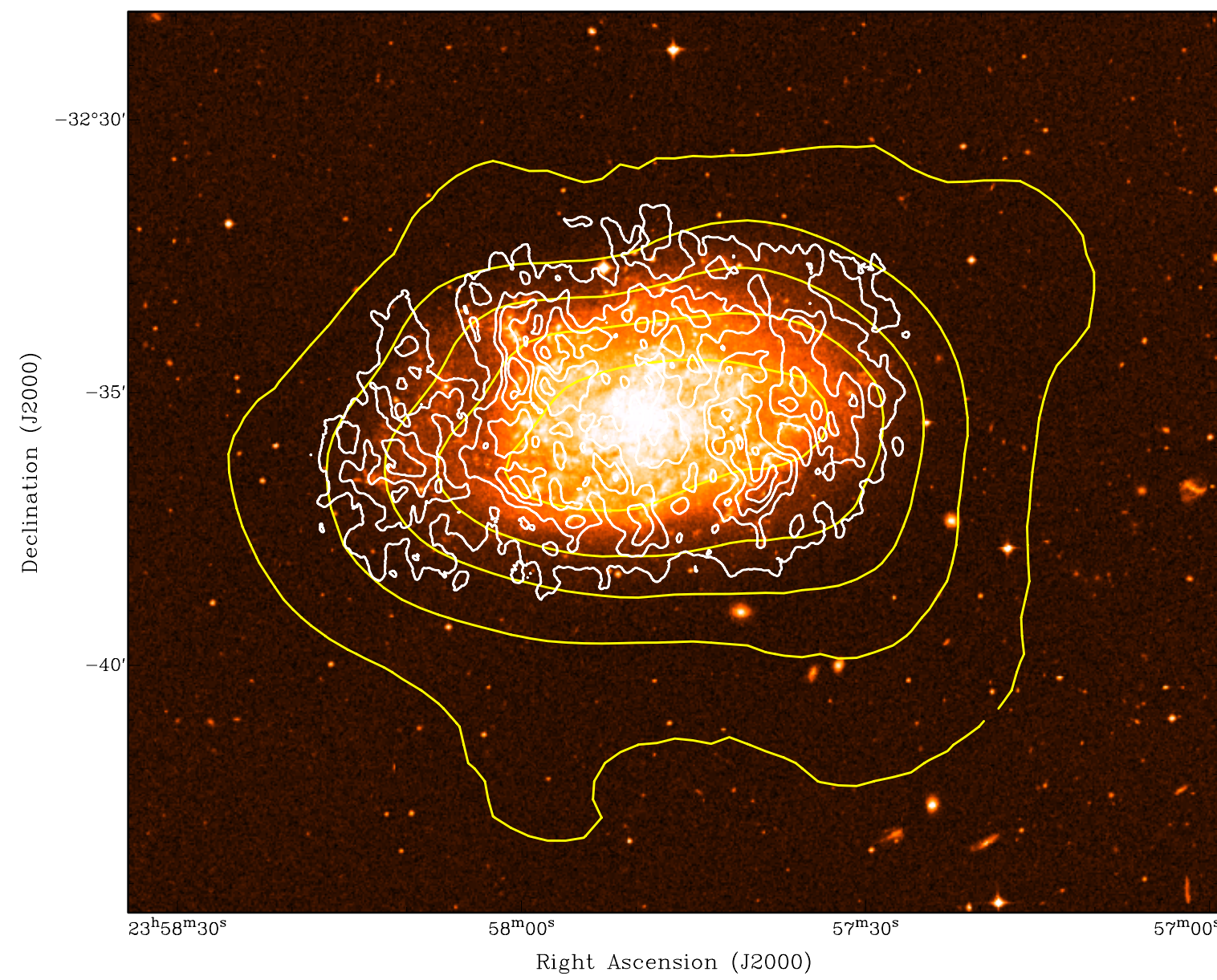
- Spirals
- Distance < 15 Mpc
- Declination < -20 degrees
- Optical diameter  $5' < D_{25} < 20'$
- Inclination 35 - 80 or 90 degrees
- HIPASS bounding box < 45 arcmin

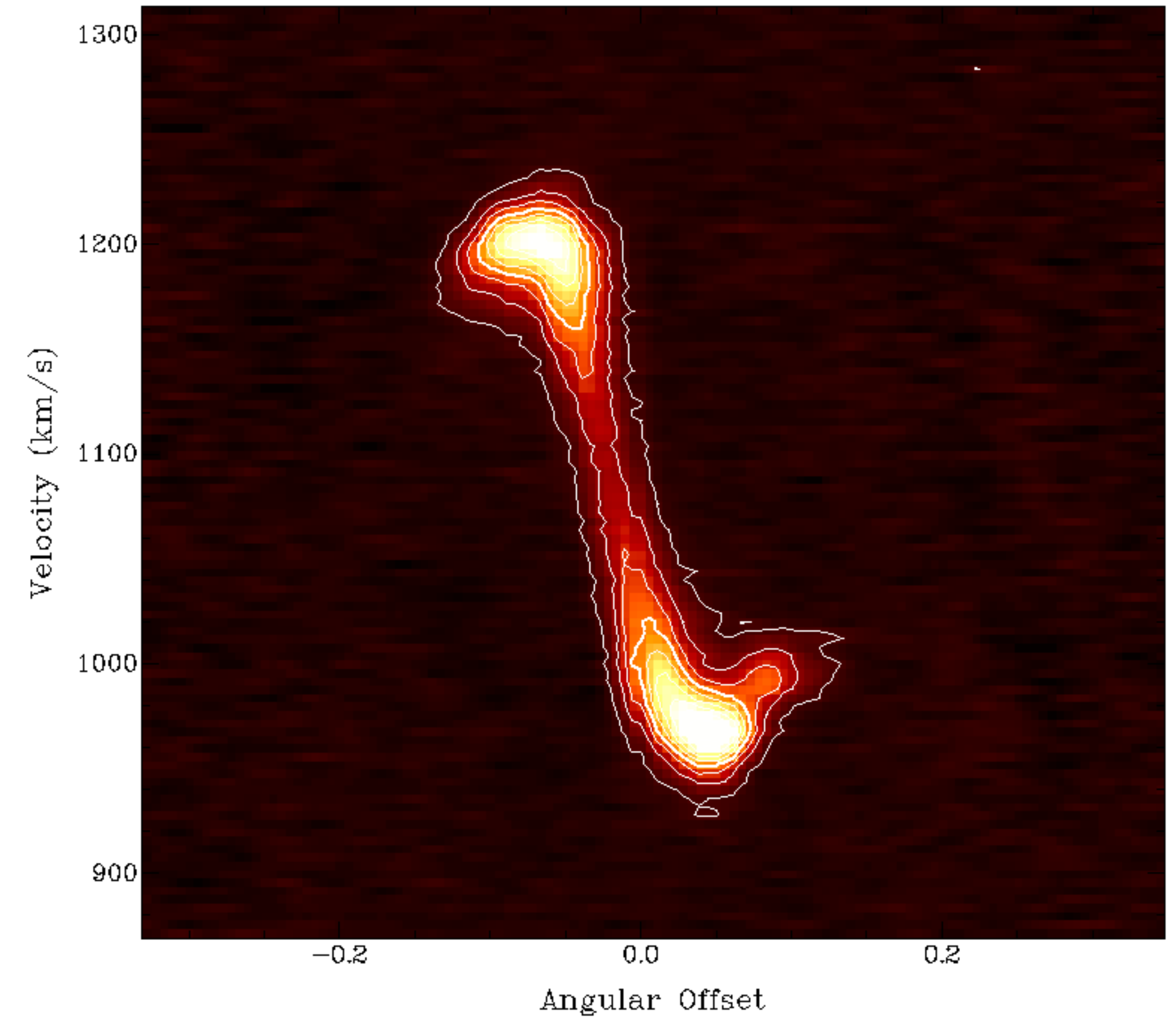
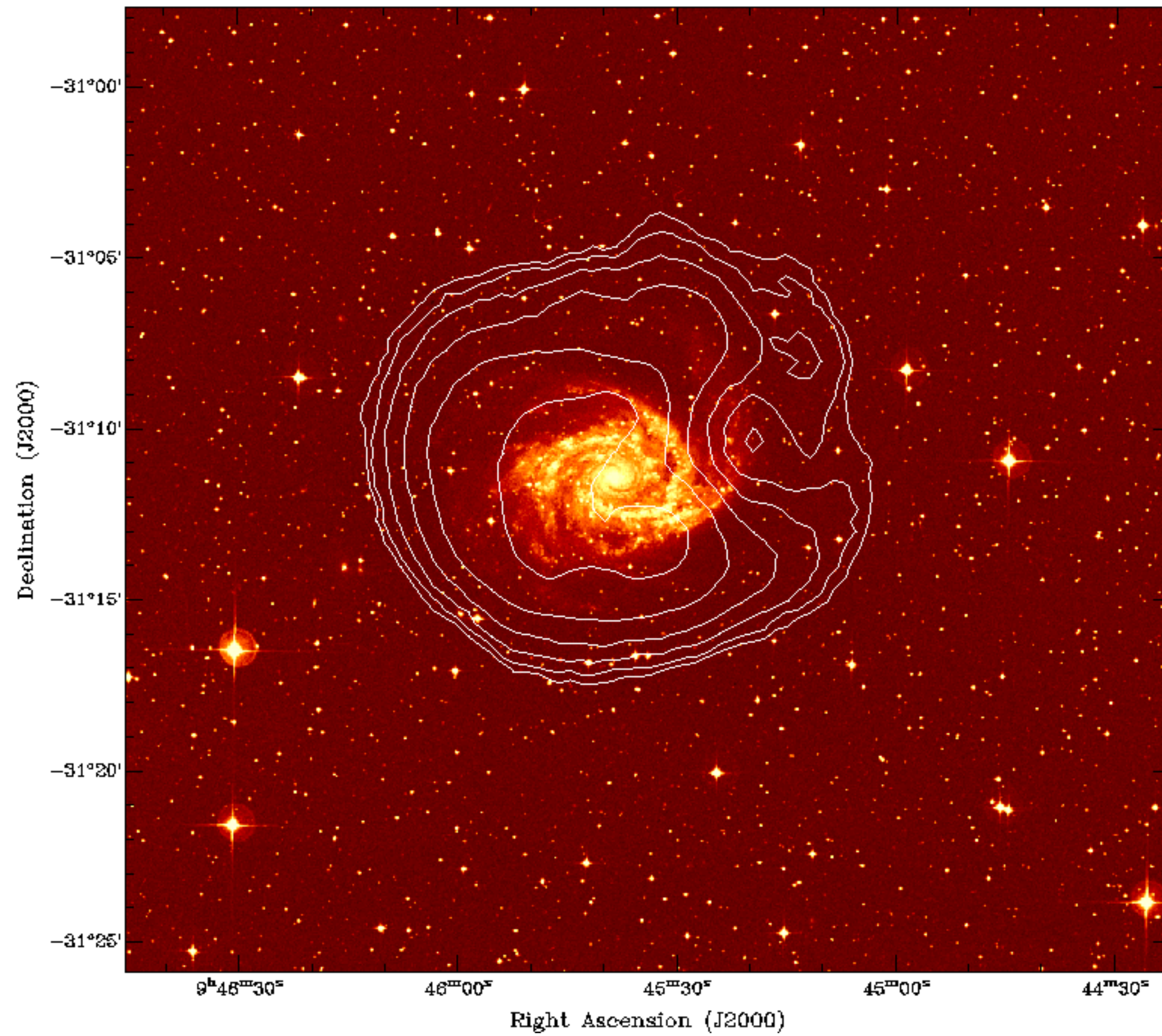


- Proposal submitted June 2016
- Proposal accepted Sep 2016
- Observations started in Oct 2016 (~450 hrs)
- ~300 hours scheduled in current semester
- complementary Parkes observations this semester (PI: DJ Pisano)
- Observations to be completed within two years
- Automated processing pipeline using MIRIAD
- Object detection and parameterisation with SoFiA

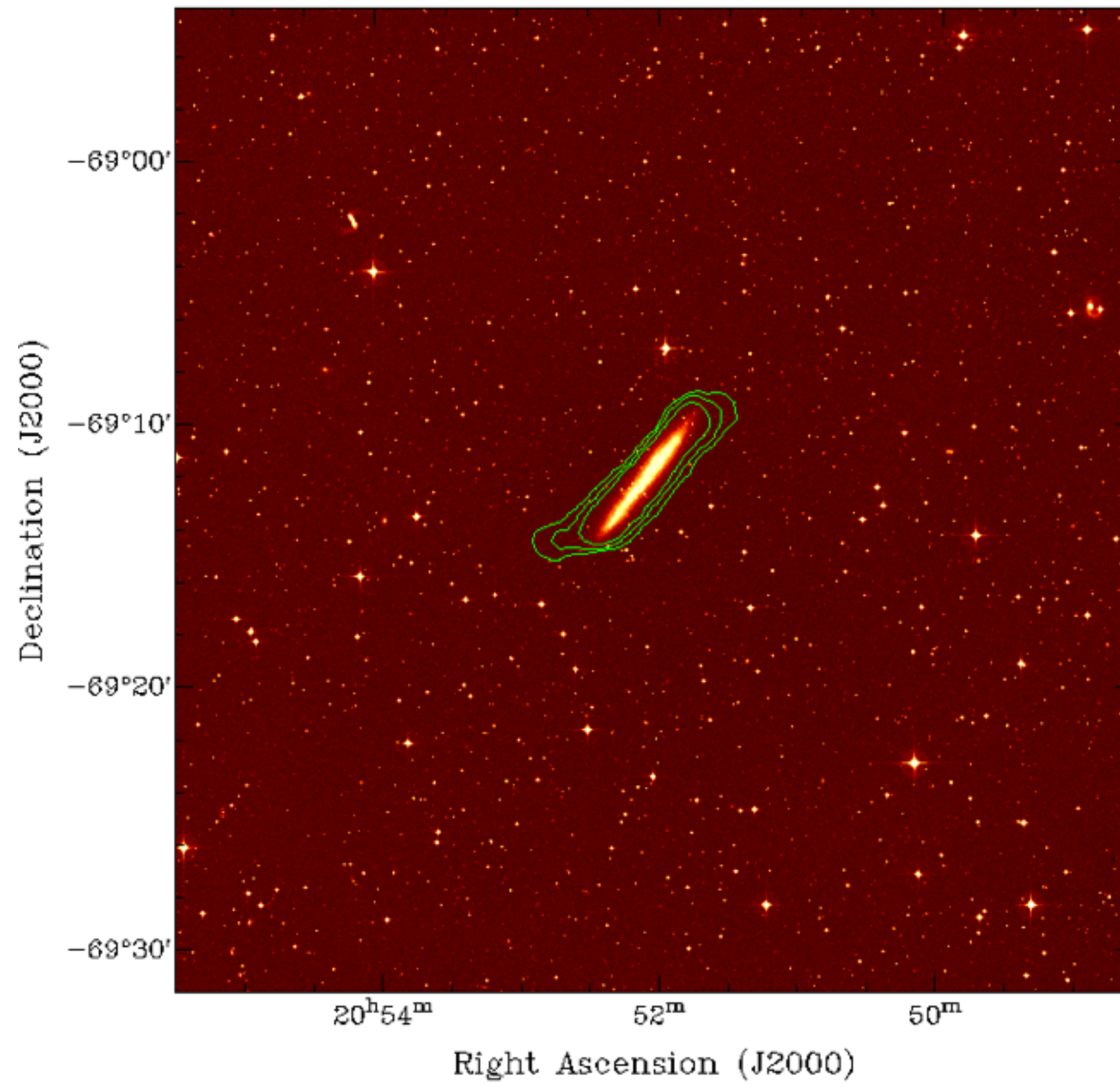
[www.imagine-survey.org/timeline](http://www.imagine-survey.org/timeline)





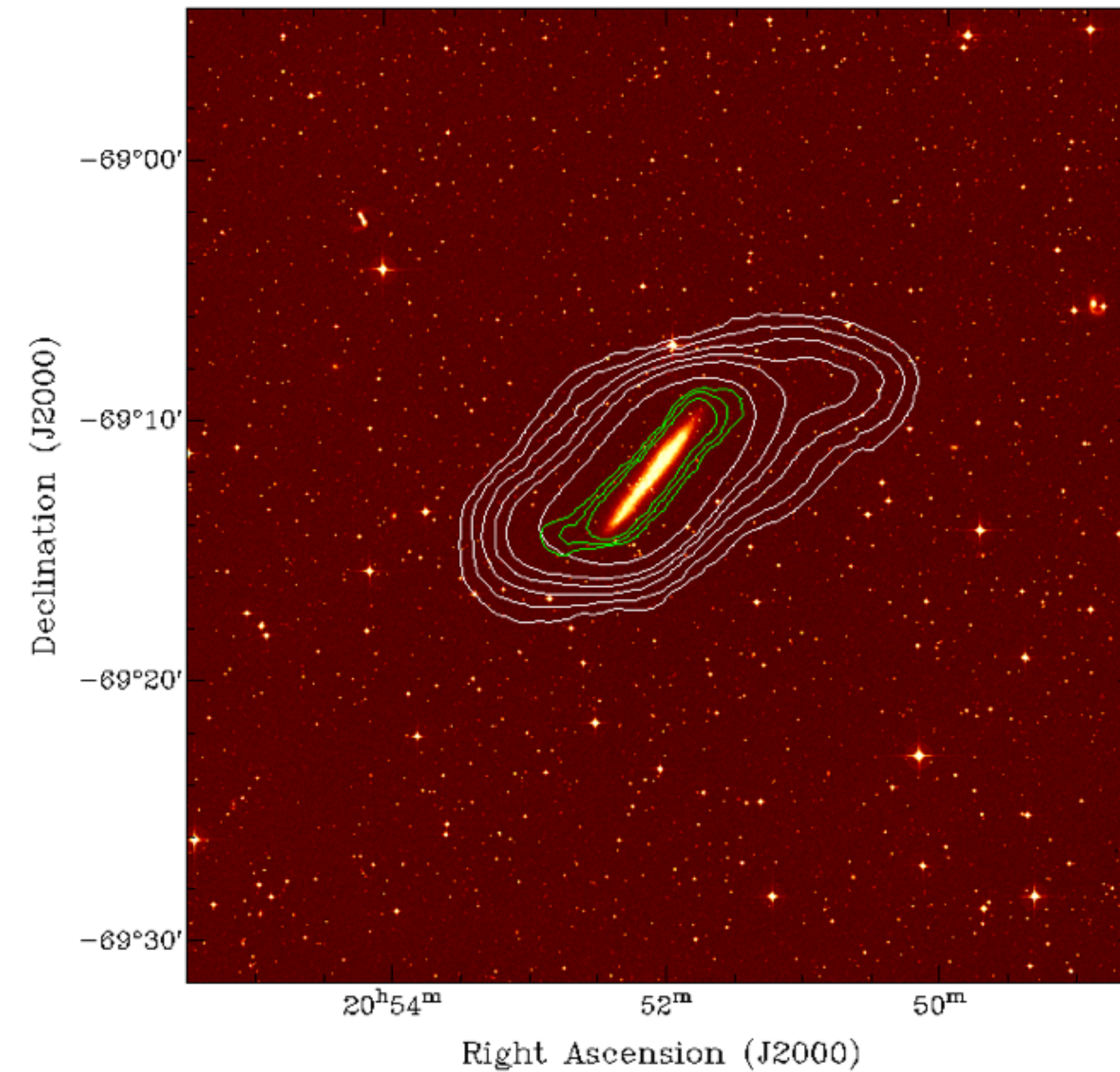


ATCA: 750B



white contours:  $N_{\text{HI}} = 1e18 - 1e19 \text{ cm}^{-2}$

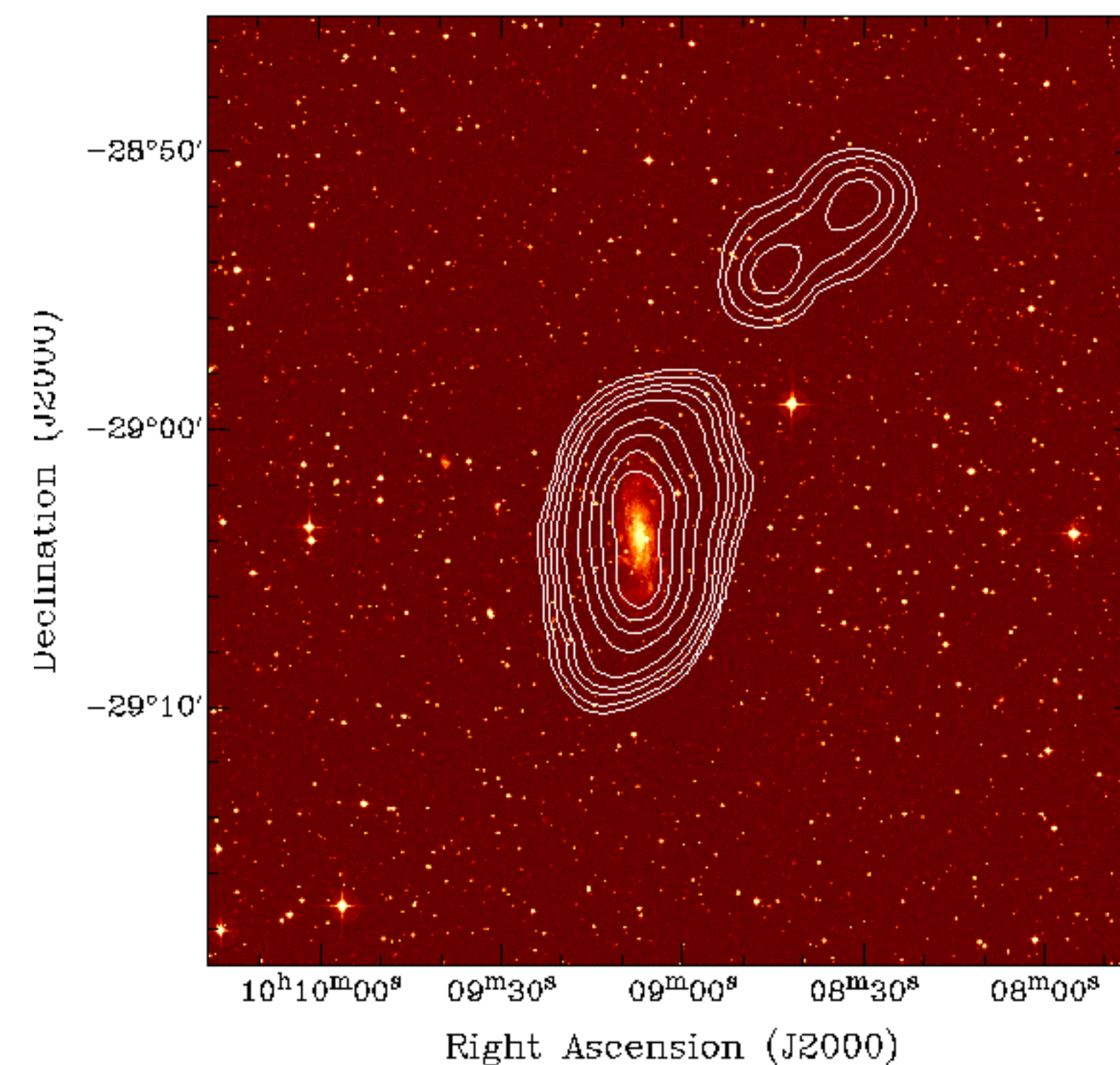
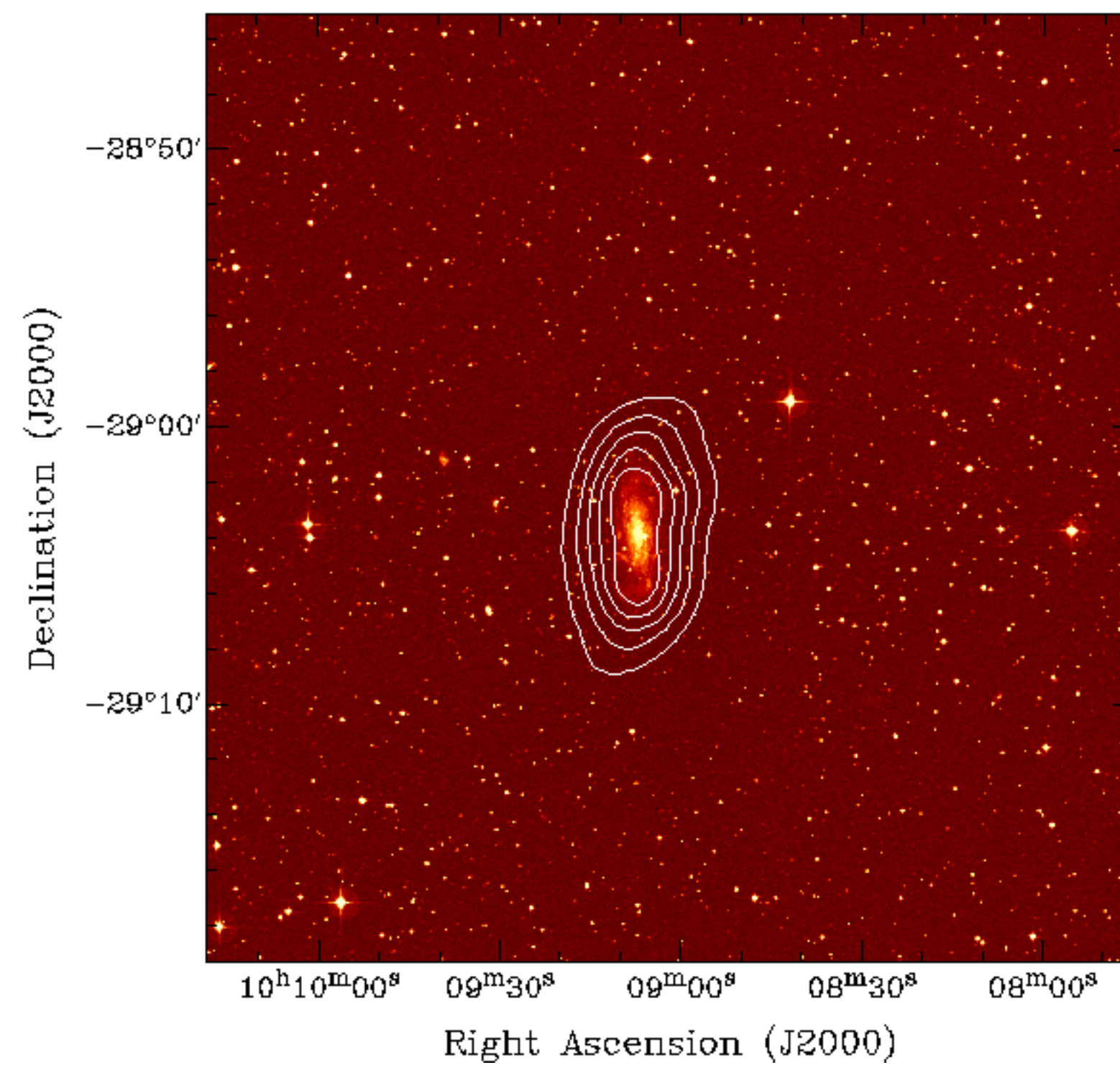
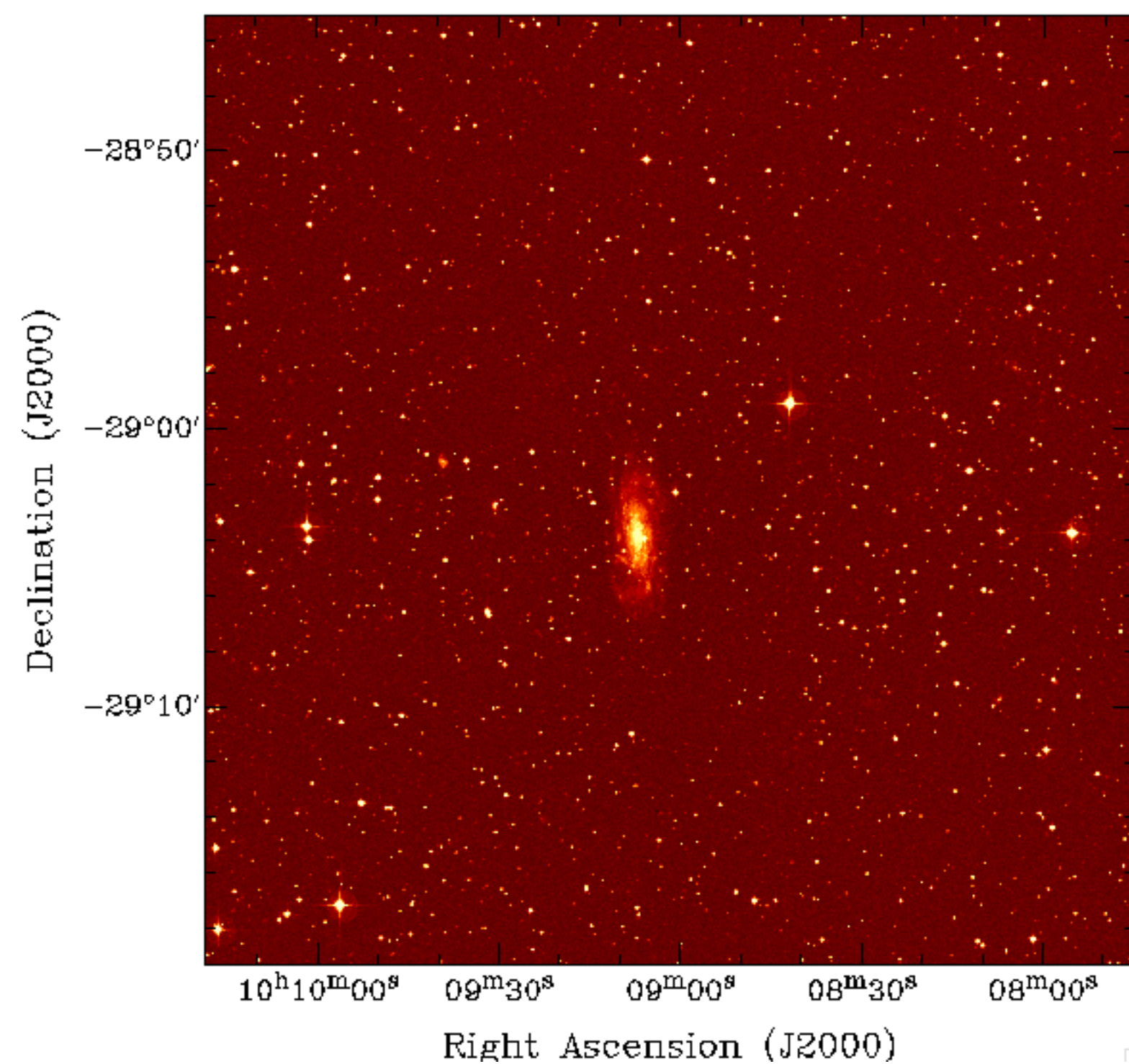
ATCA: h168 + h214



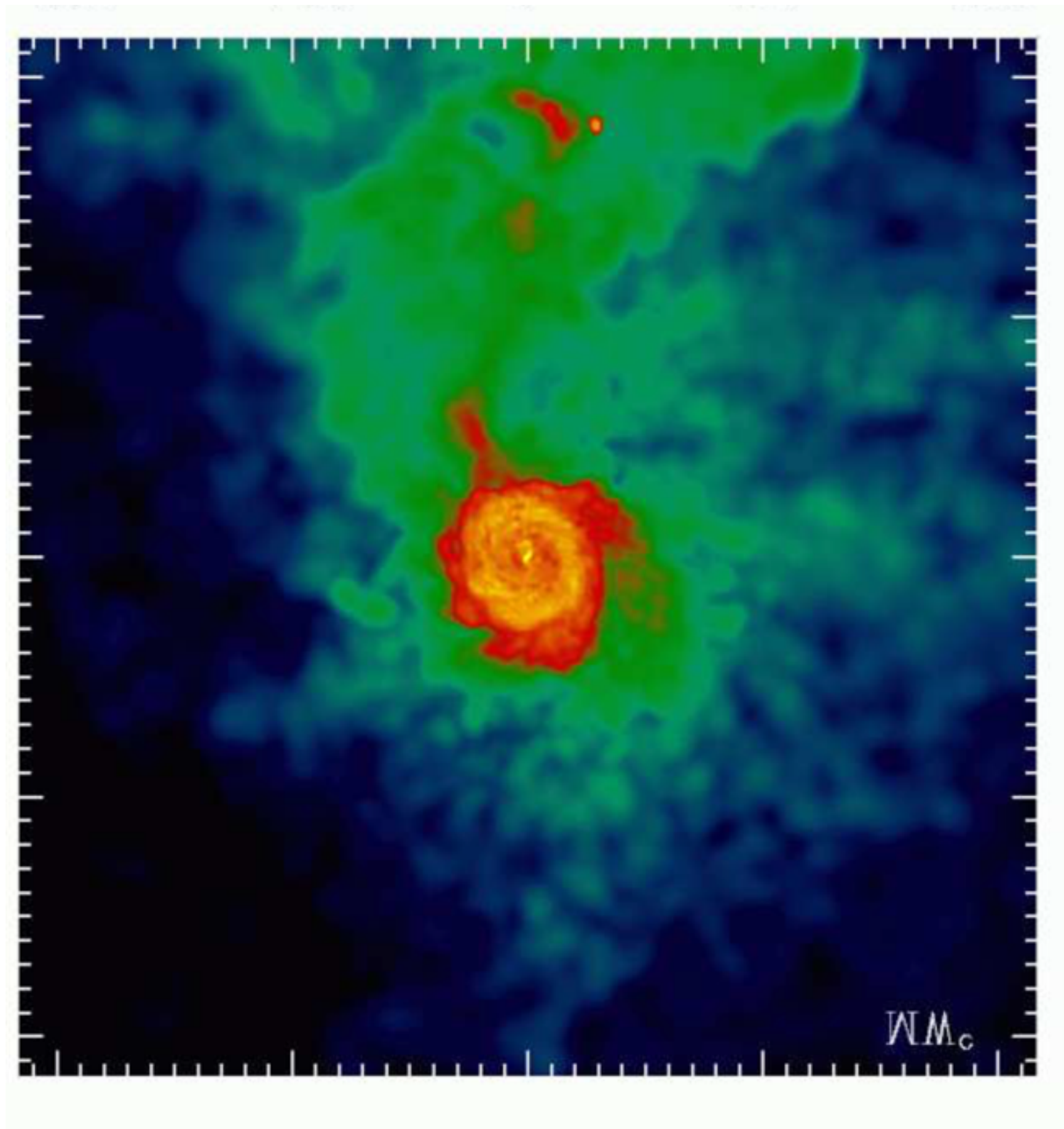
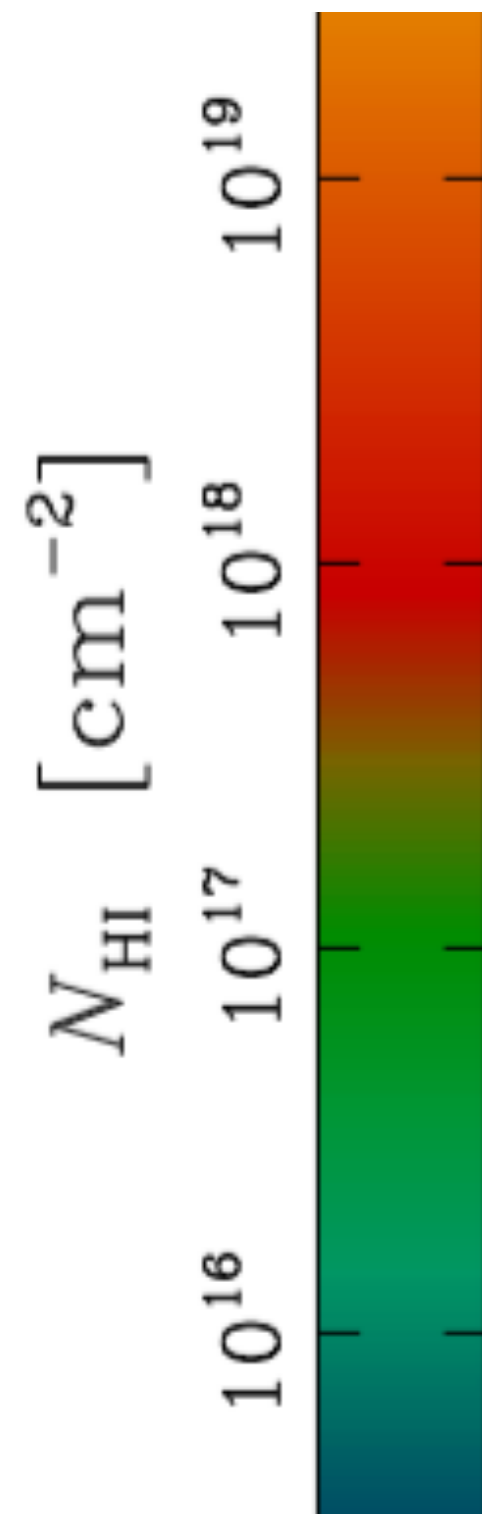
white contours:  $N_{\text{HI}} = 1e17 - 1e18 \text{ cm}^{-2}$

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

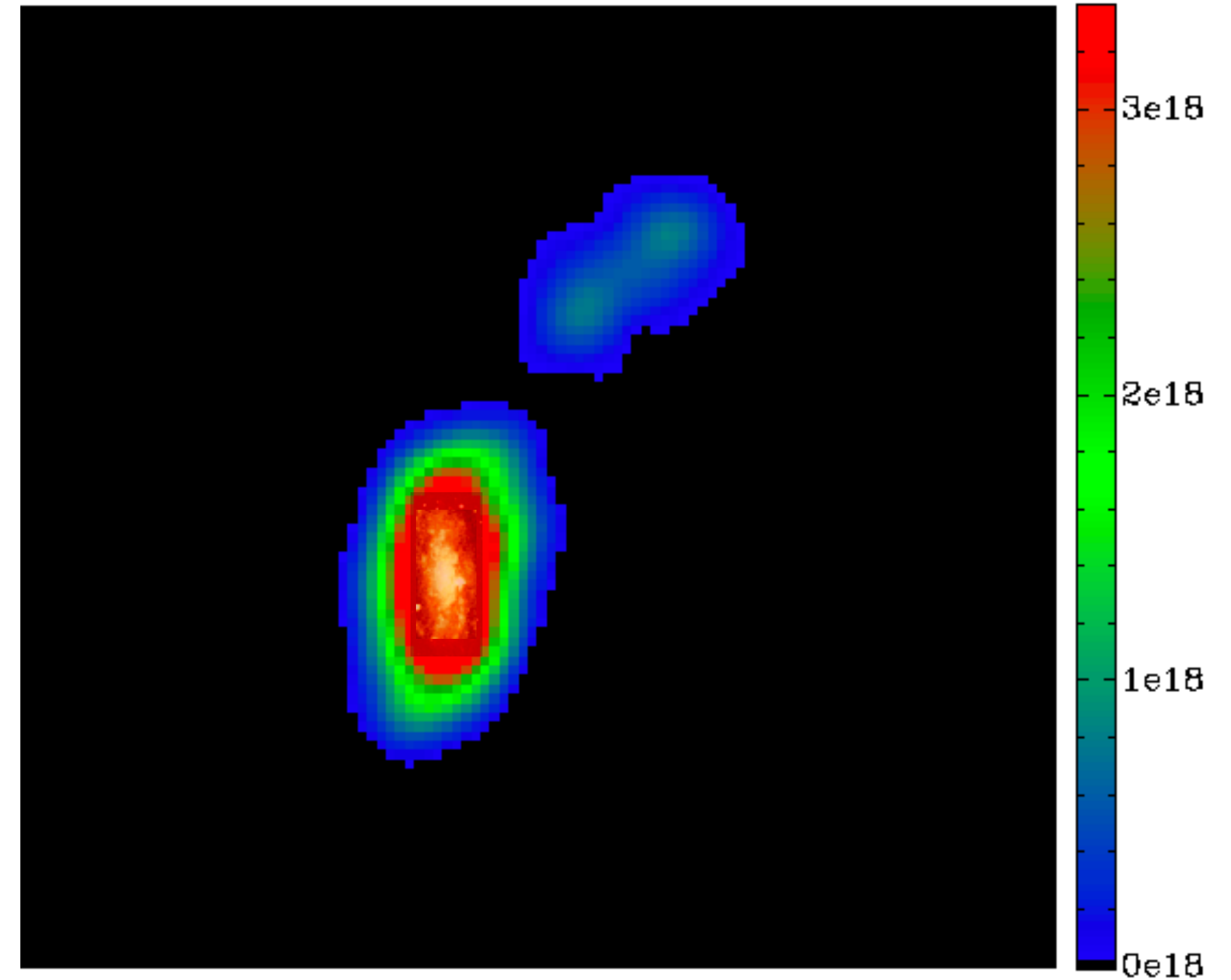
$N_{\text{HI}} \sim 10^{18} \text{ cm}^{-2}$



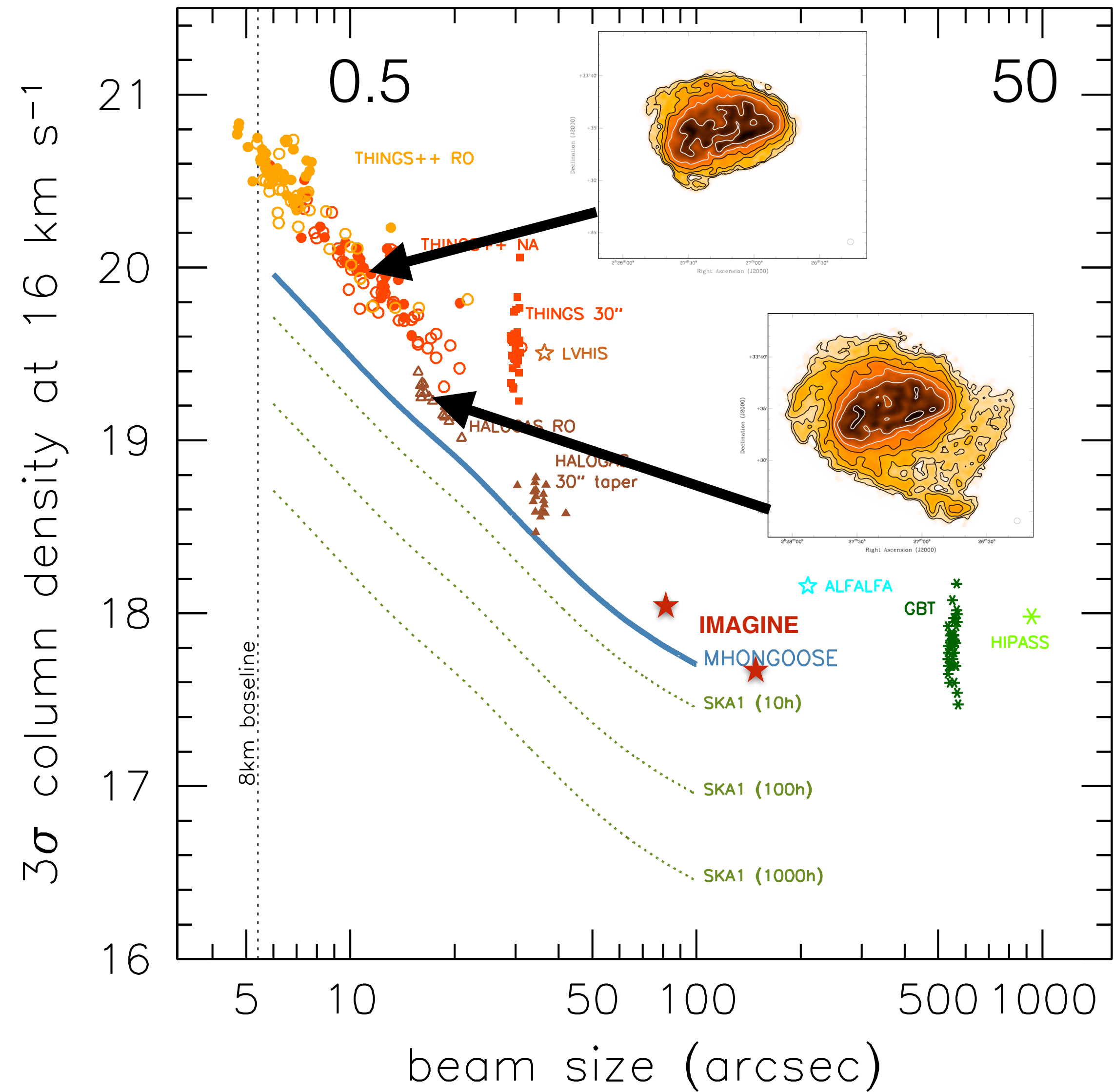




Nuza et al. 2014



IMAGINE



kpc for  
D=11 Mpc

- \* Understanding gas accretion is one of the fundamentals of Galaxy evolution
- \* To see gas accretion in HI column densities of  $N_{\text{HI}} \sim 10^{18} \text{ cm}^{-2}$  are required
- \* Such observations begin to link direct emission with absorption measurements
- \* New telescopes (SKA, FAST, etc) will really change this field
- \* We started the IMAGINE survey on ATCA which will set a benchmark for coming years



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