Imaging Galaxies' Intergalactic and Nearby Environment

Attila Popping

PHISCC 2017
Pune, 7 February 2017

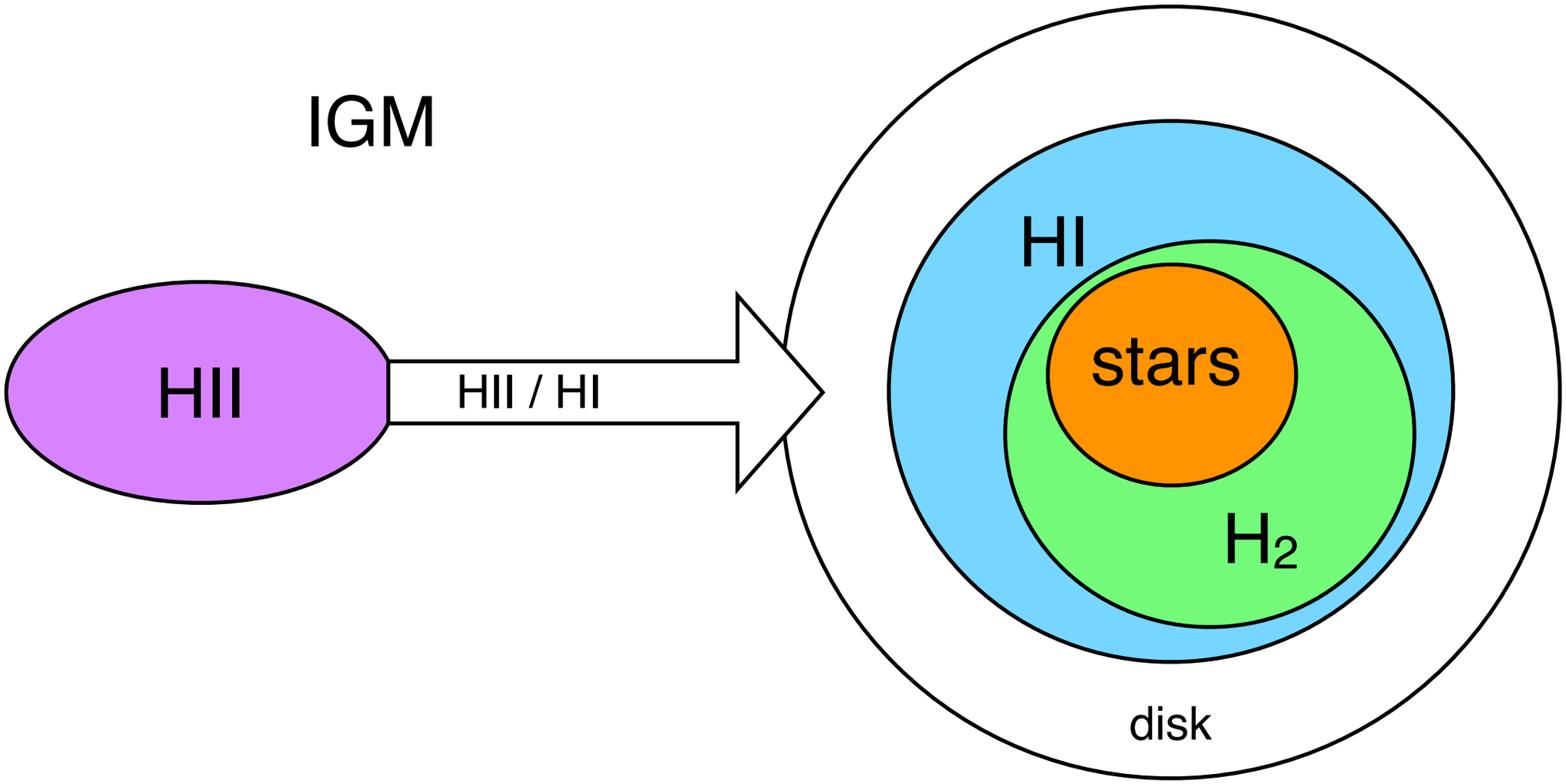
International Centre for Radio Astronomy Research

CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

THE UNIVERSITY OF WESTERN AUSTRALIA

Credit: ESO/L. Calçada/ESA/AOES Medialab

Simple model of galaxy evolution

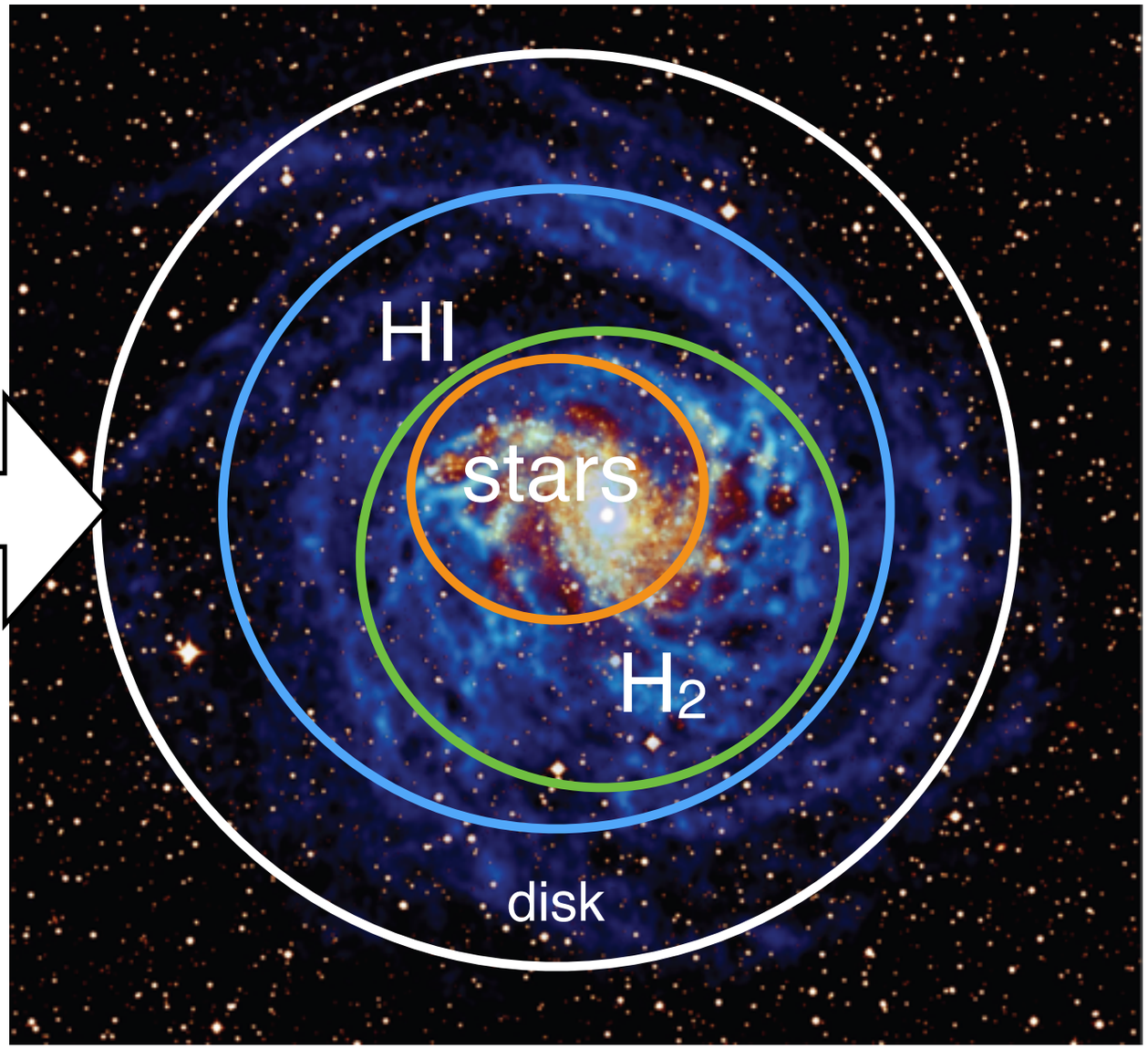


Simple model of galaxy evolution

IGM

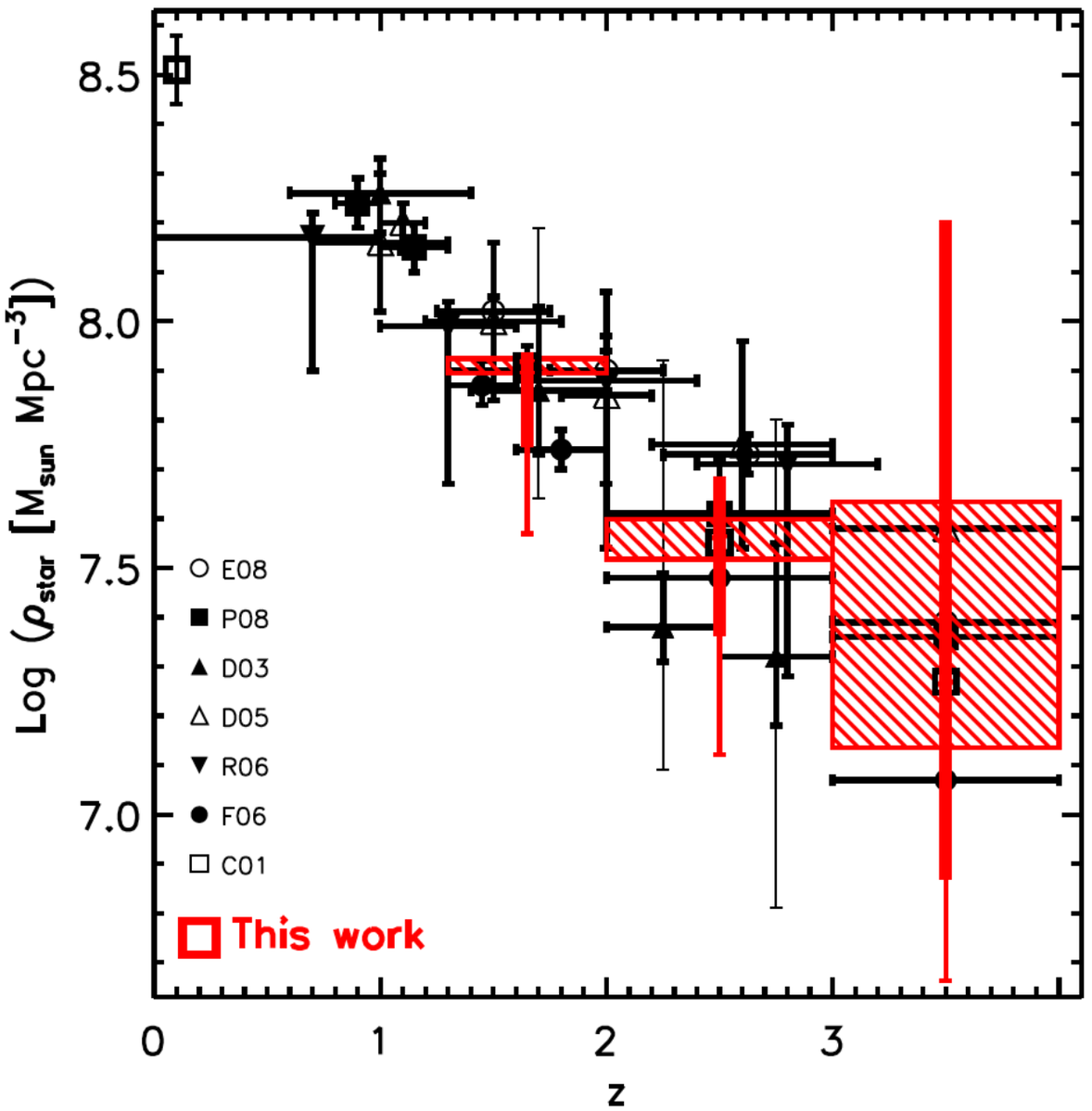
HII

HII / HI



Stellar Mass

stars



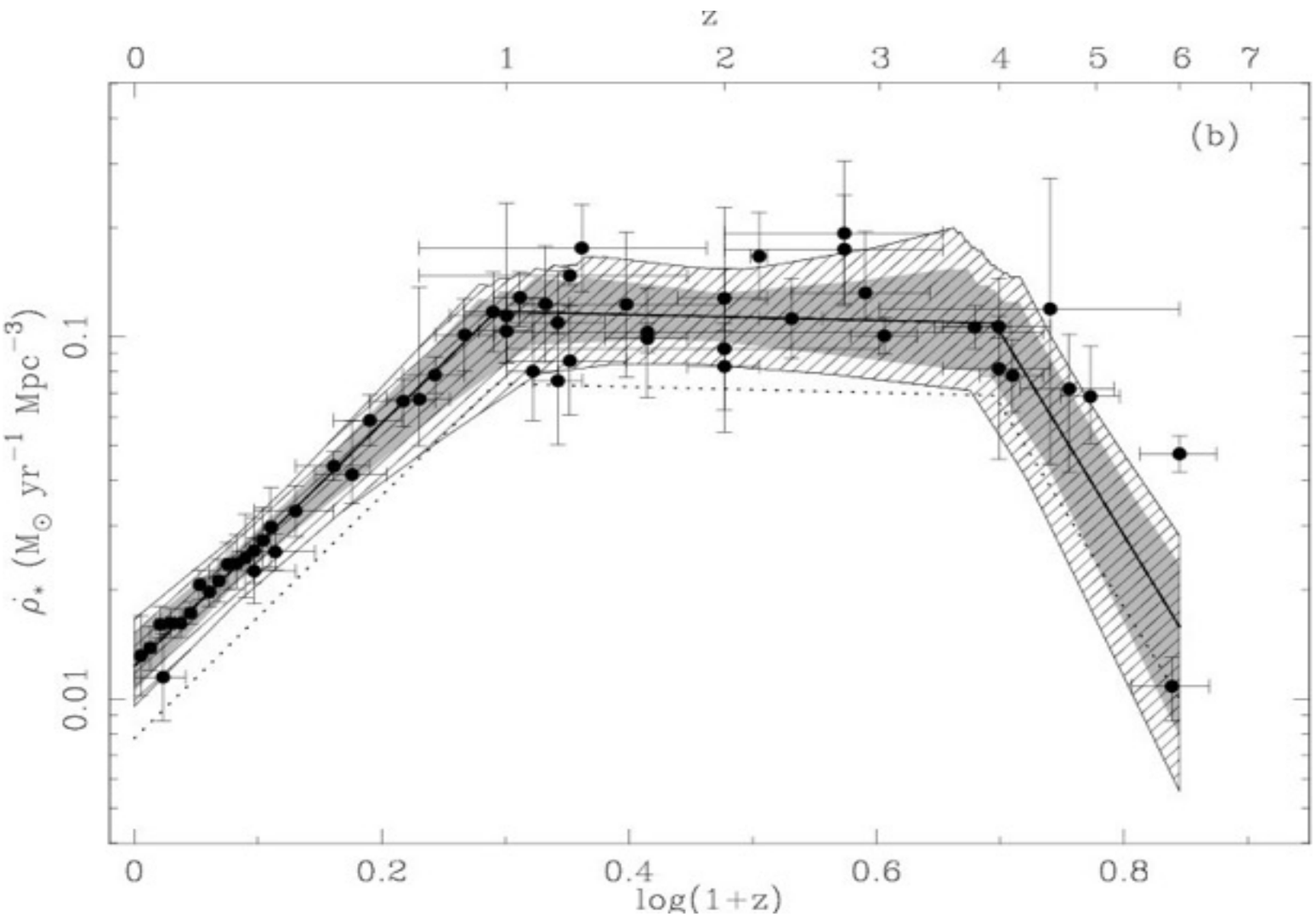
Marchesini et al. 2008

Stellar mass locked in galaxies increases with time

Star Formation

Cosmic star formation drives the stellar mass growth

stars



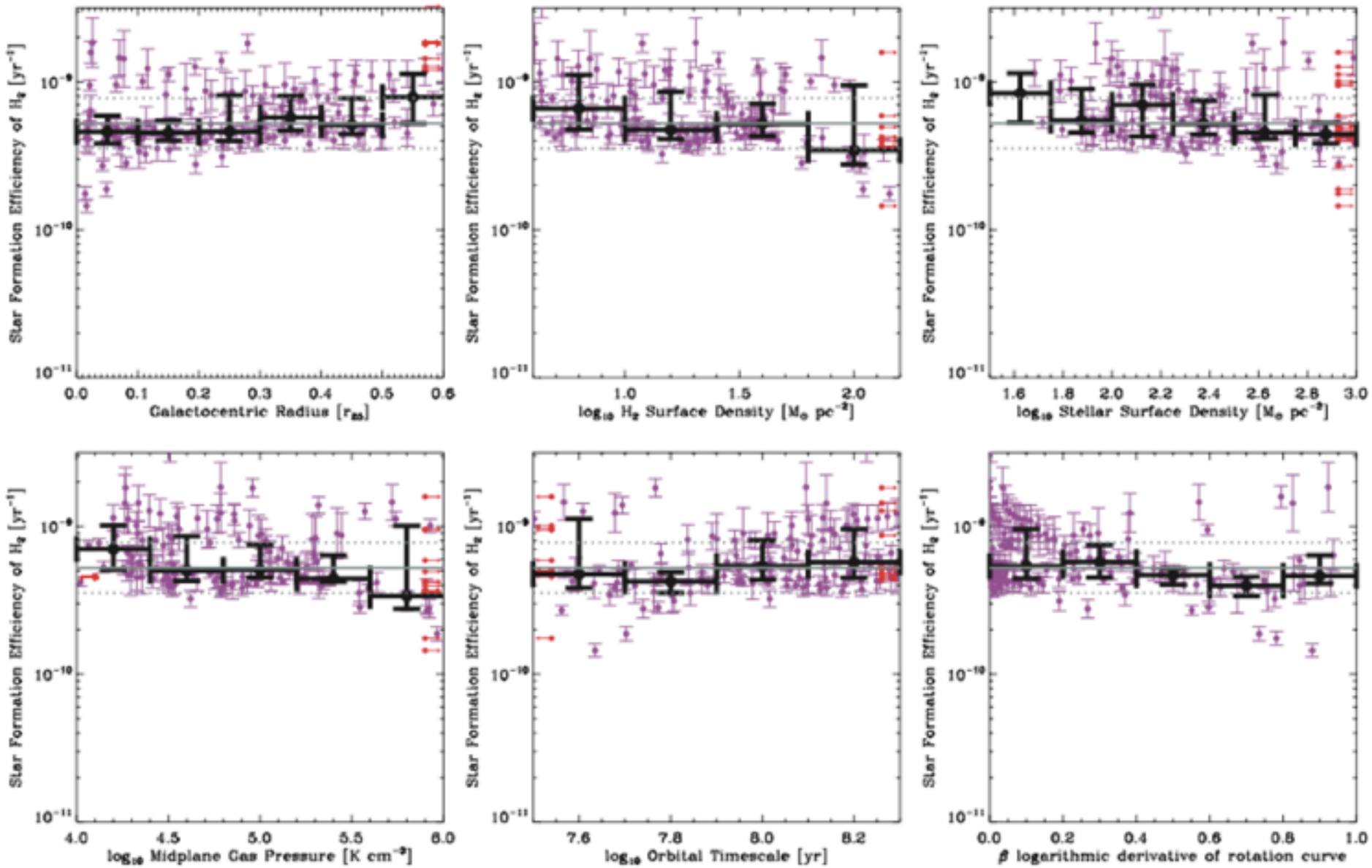
Hopkins & Beacom 2006

What drives the star formation history?

Molecular Gas

H_2

SFE (H_2)



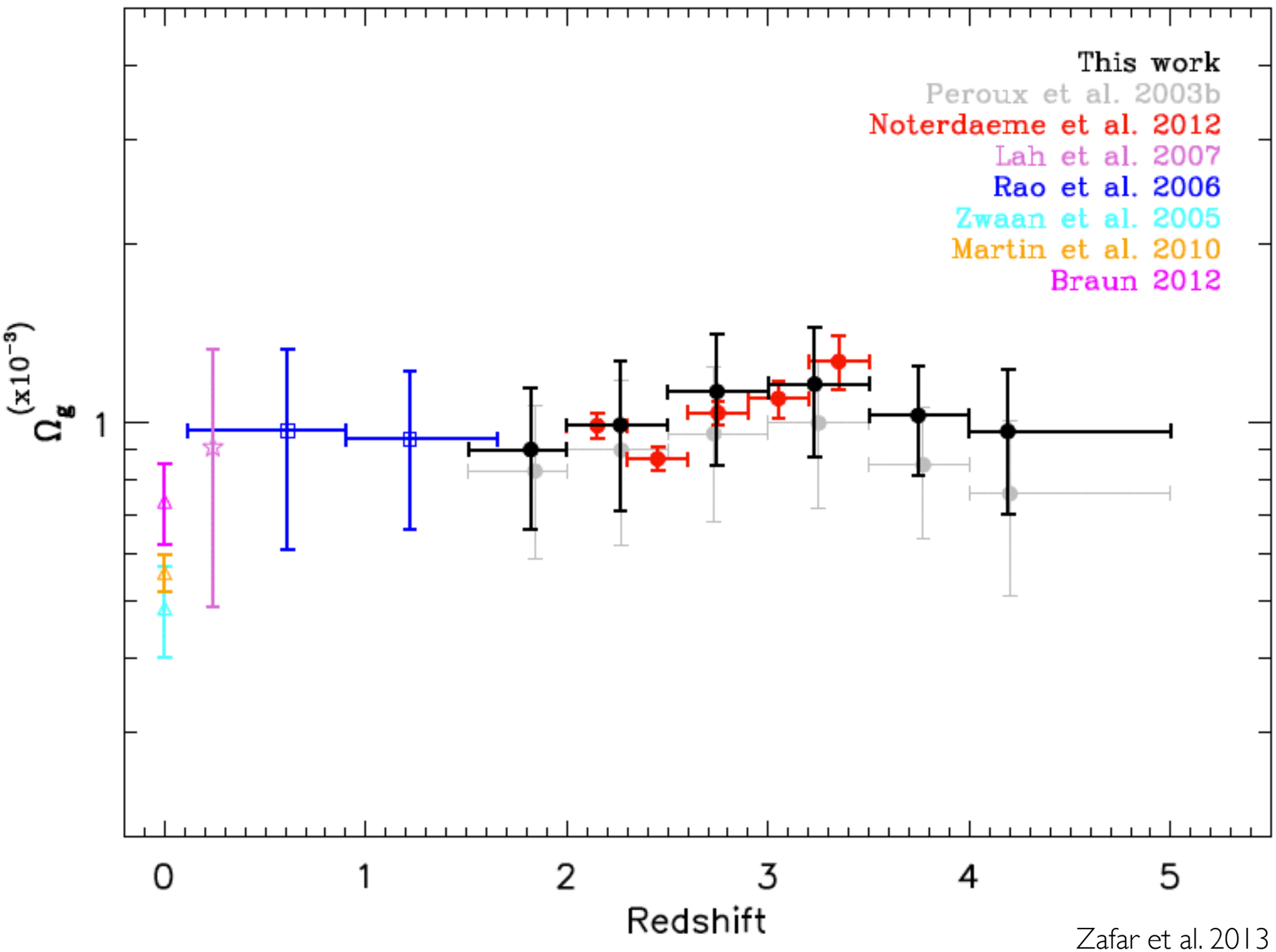
Star formation efficiency is very constant at z=0

Molecular gas is a transition phase that should be replenished at all times.

Leroy et al. 2008

Neutral Hydrogen

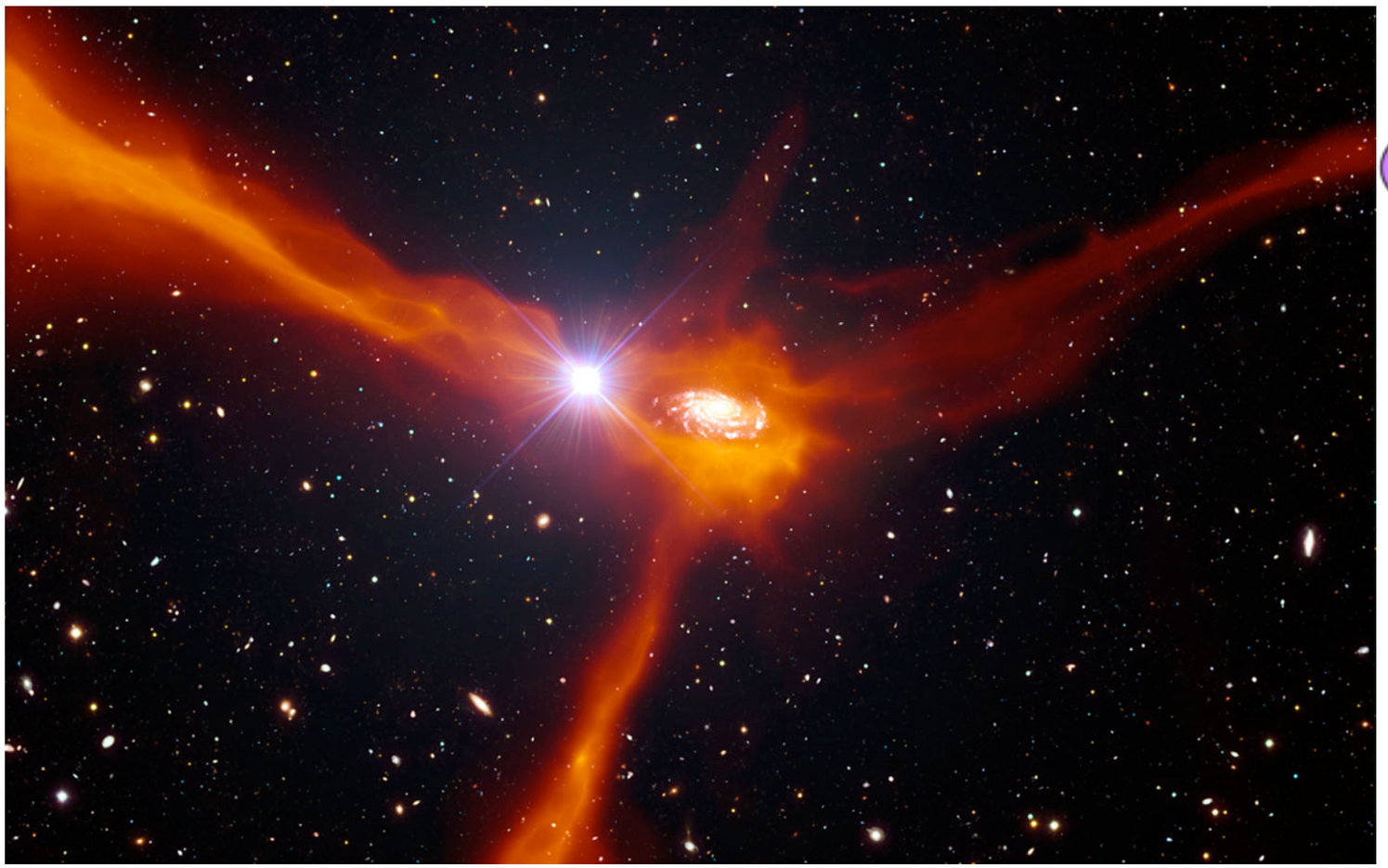
HI

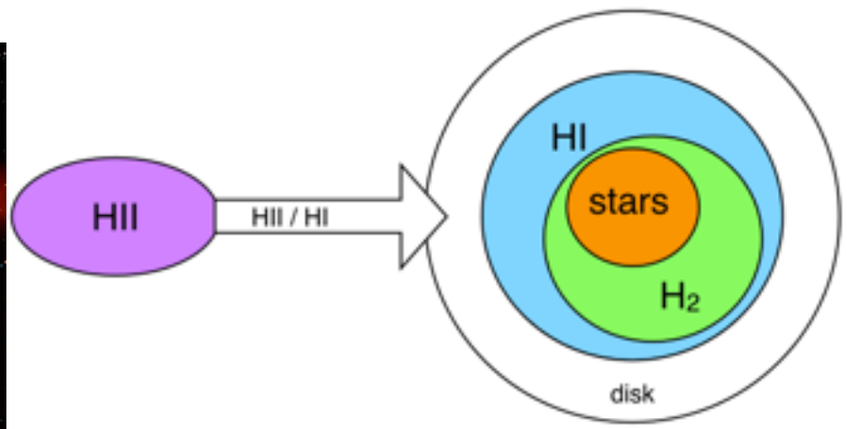


Zafar et al. 2013

Where is the gas . . . ?

The observed evolution of the cosmic and "local" star formation requires a large gas reservoir and gas accretion from the intergalactic medium at all redshift





Credit: ESO/L. Calçada/ESA/AOES Medialab

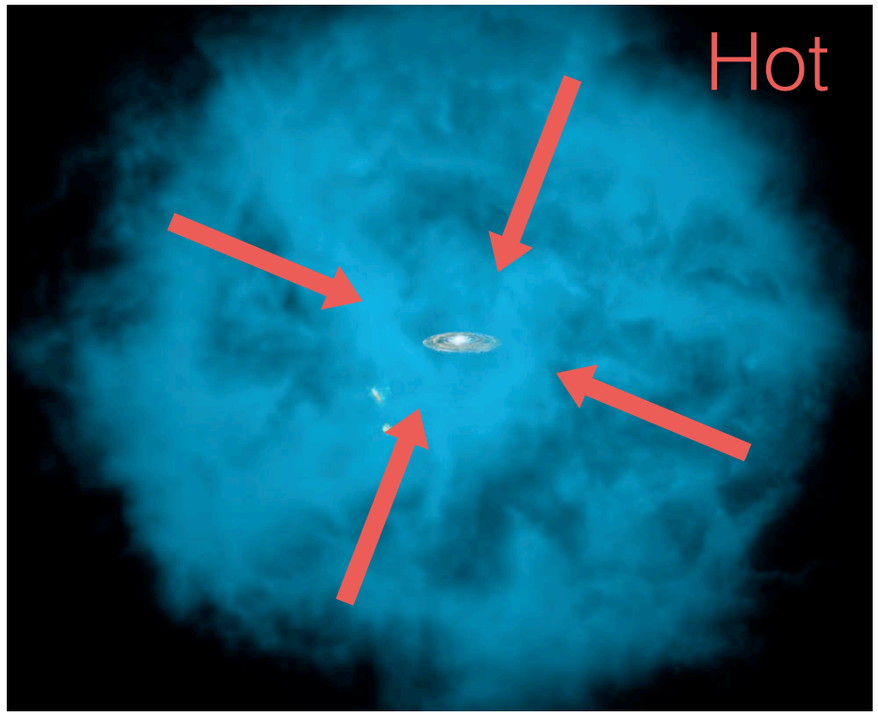
Forms of accretion

- Many simulations predict that gas is accreted by galaxies in two forms
  (e.g. Birnboim & Dekel 2003, Keres et al. 2005, 2009).

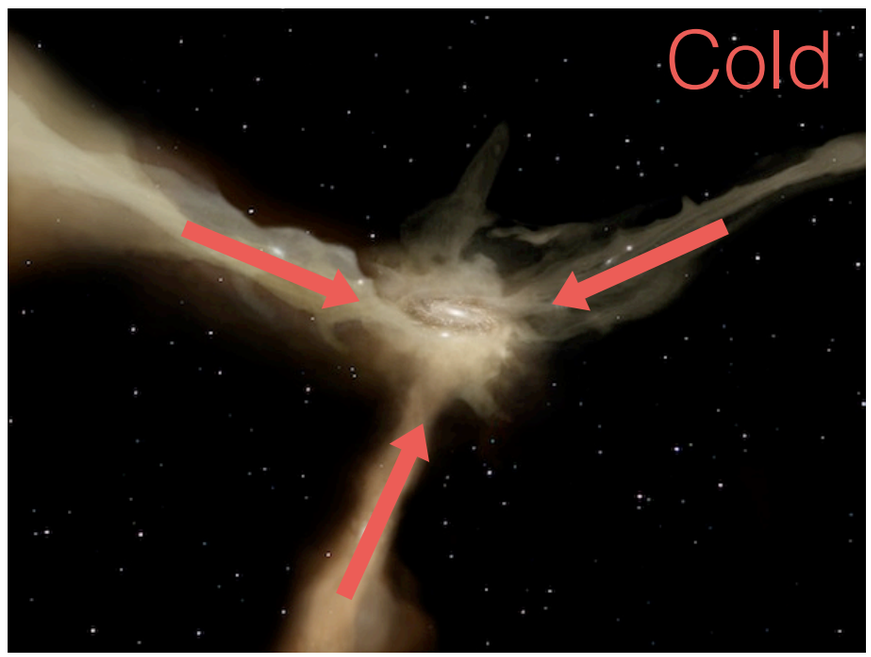
- Hot accretion flows are gas that is shock-heated to the virial temperature; $T > 10^5$ K

- Cold accretion flows remain below T_{vir}, $< 10^5$ K, and falls onto galaxy along filaments.

- At z=0, cold mode should be dominant for $M_{halo} \leq 10^{11} M_\odot$ and in low density environments.



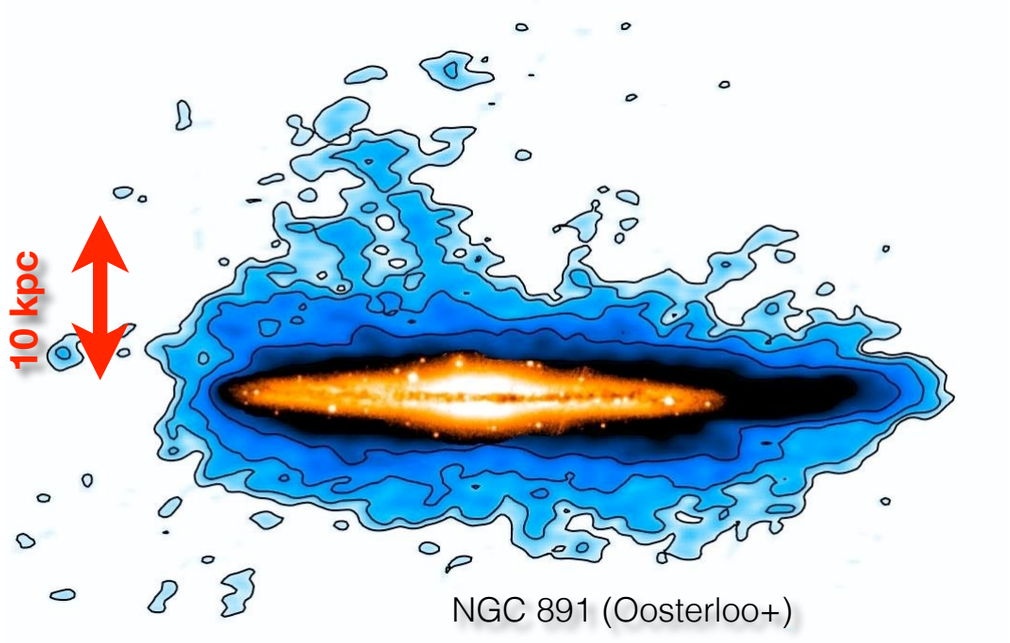
Credits: NASA/CXC/M.Weiss/Ohio State/A Gupta et al



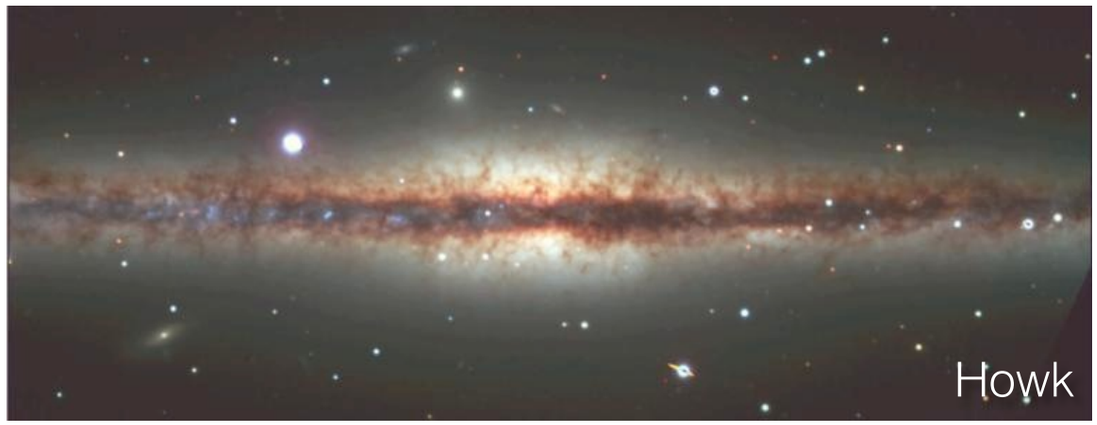
Credit: ESA-AOES Medialab

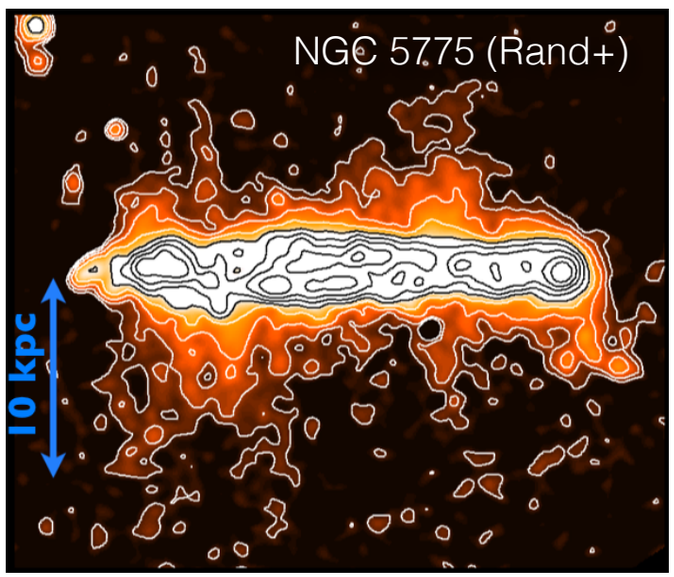
Multi-phase extraplanar gas

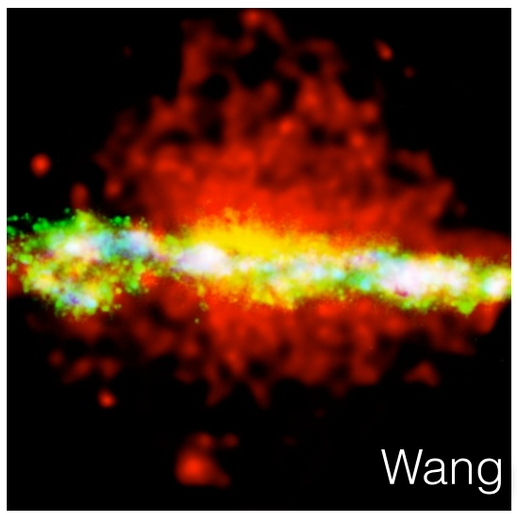
Deep observations of (edge-on) spirals show thick, vertically extended, multi-phase layers of gas, dust, and magnetic fields



NGC 891 (Oosterloo+)


Howk

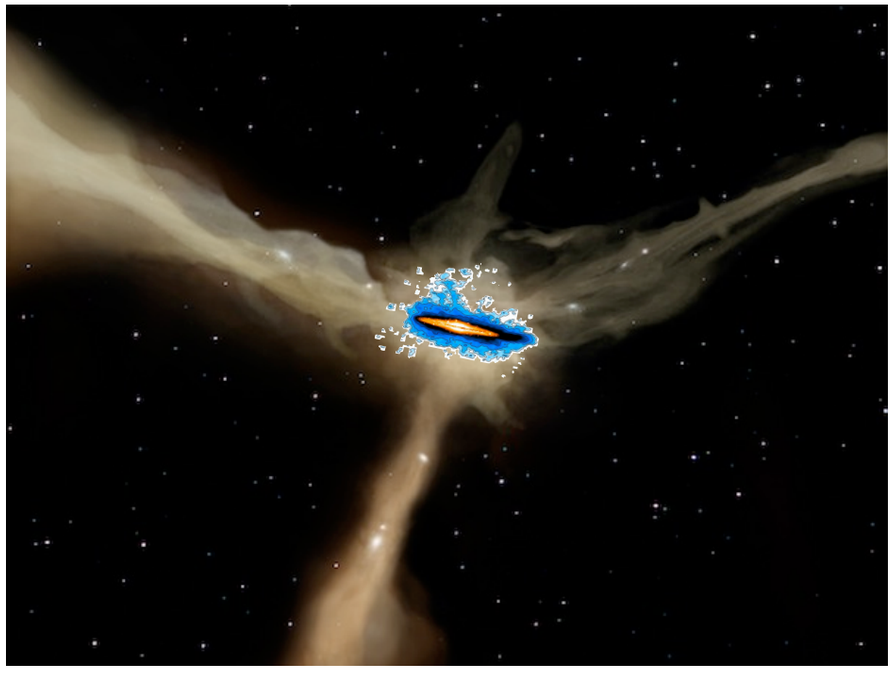



Wang

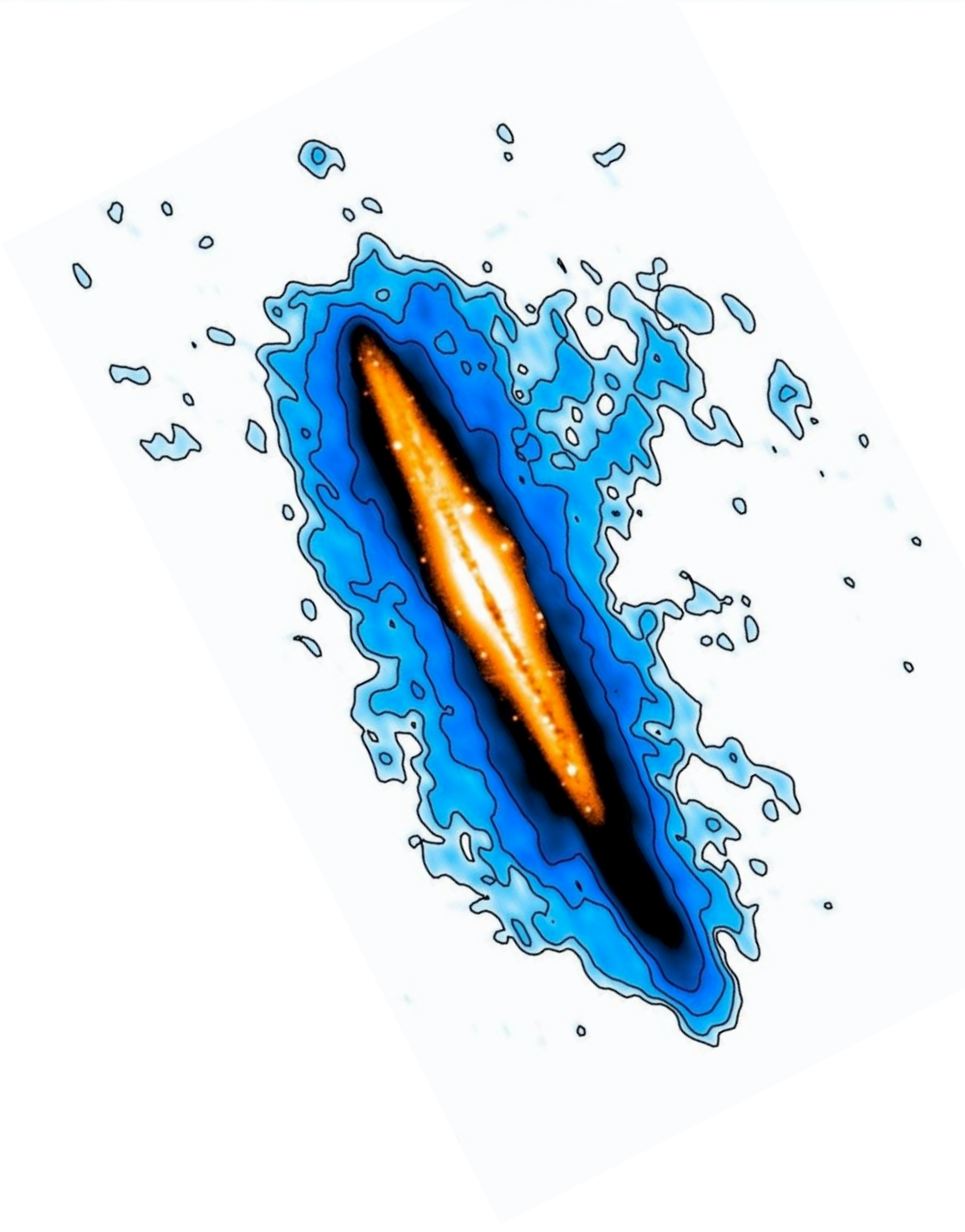

Hoopes

Questions:

- What is the nature of extra-planar gas in galaxies
- What is the importance of (cold) accretion and can we detect it

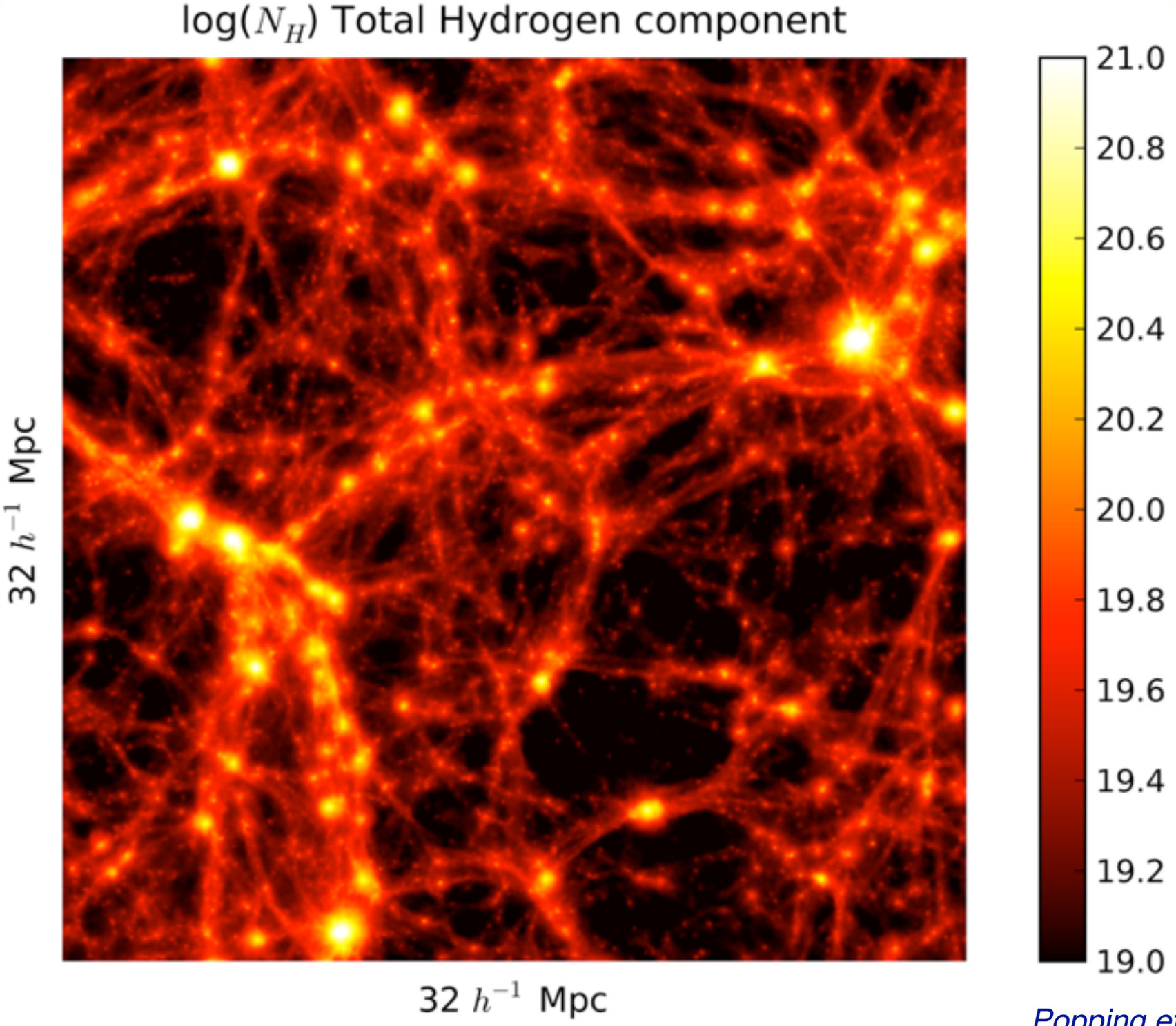


(ESA-AOES Medialab)



NGC 891 (Oosterloo+)

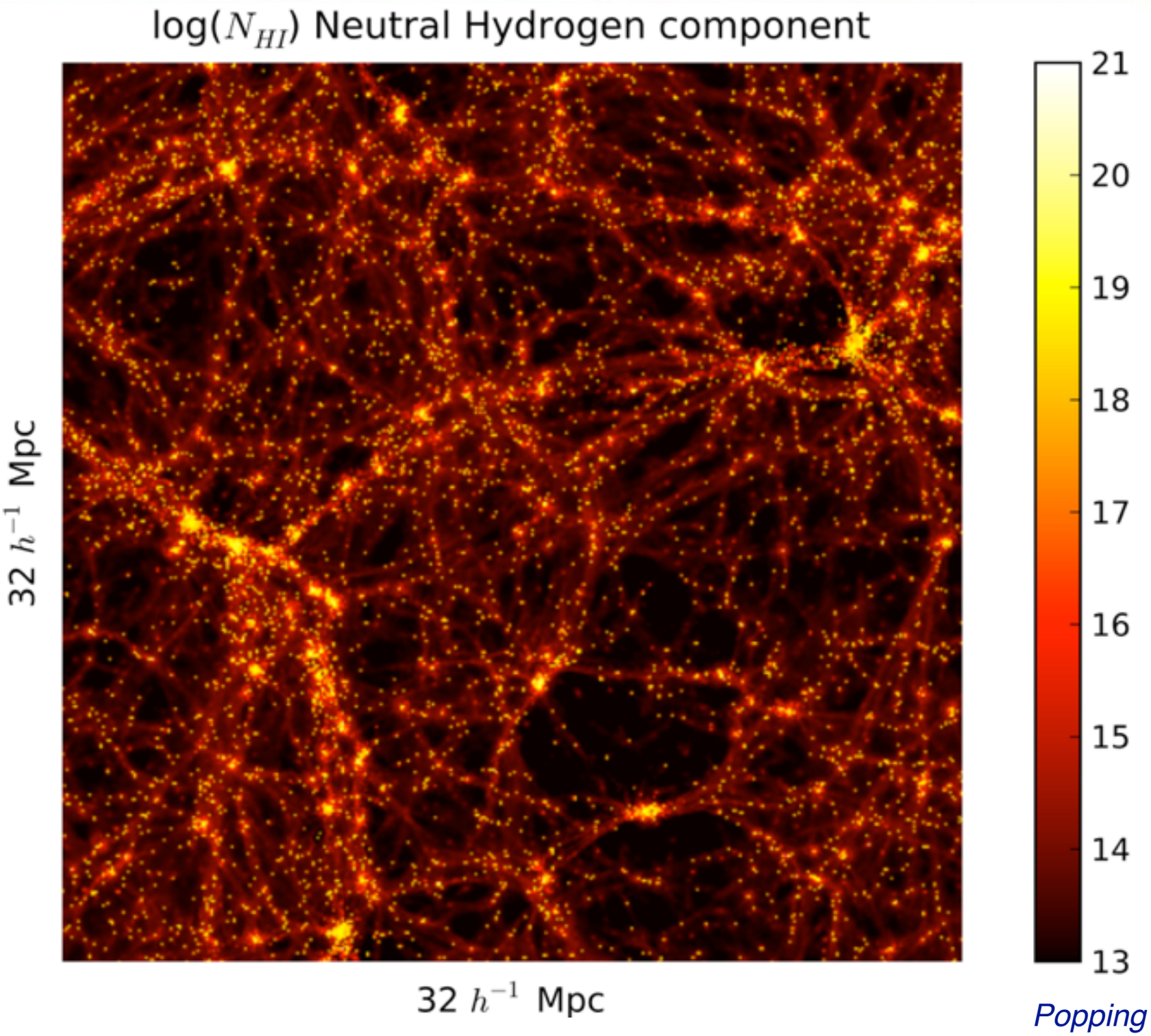
Simulated Gas



SPH simulation

Popping et al. 2009

Simulated HI Gas



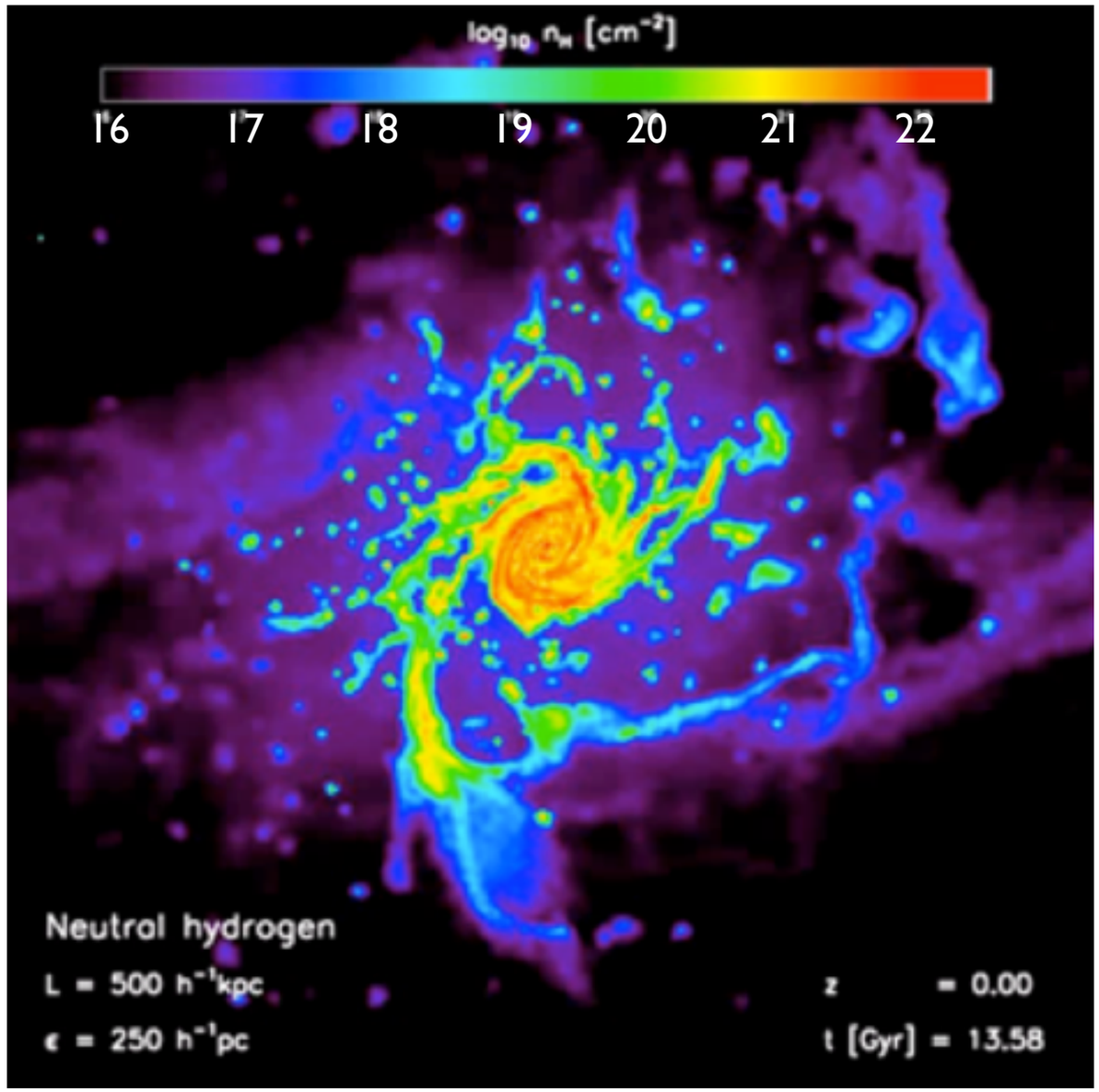
SPH simulation

Popping et al. 2009

Individual galaxies

Gas in the extended halo of galaxies is clumpy

$N_{HI} \sim 10^{18\text{-}19}$ cm^{-2} required at ~kpc resolution to detect and resolve the environment of individual galaxies.



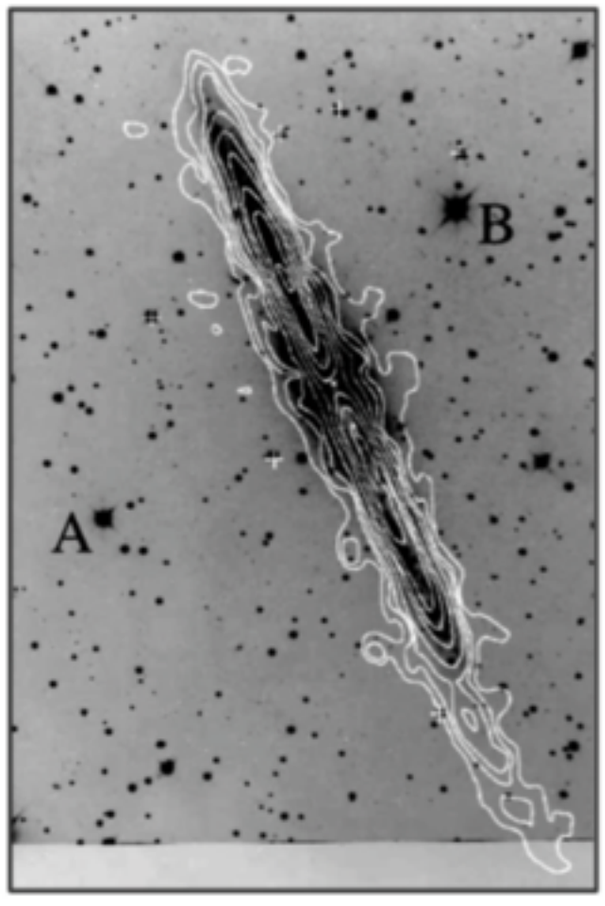
GIMIC: Crain et al.

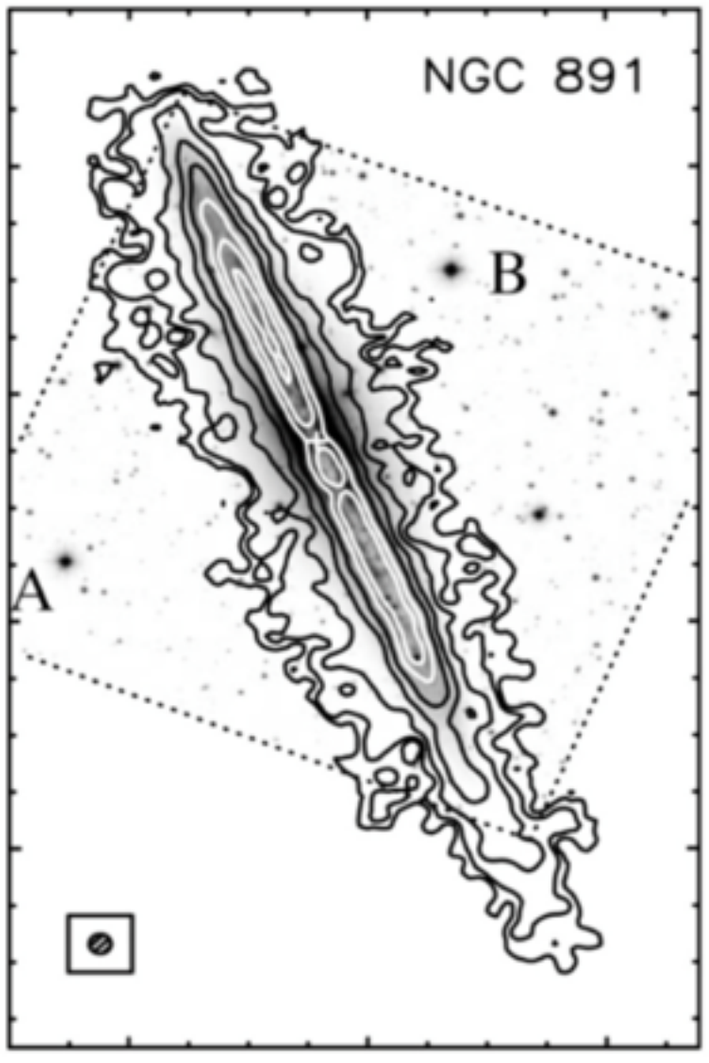
Improving observations

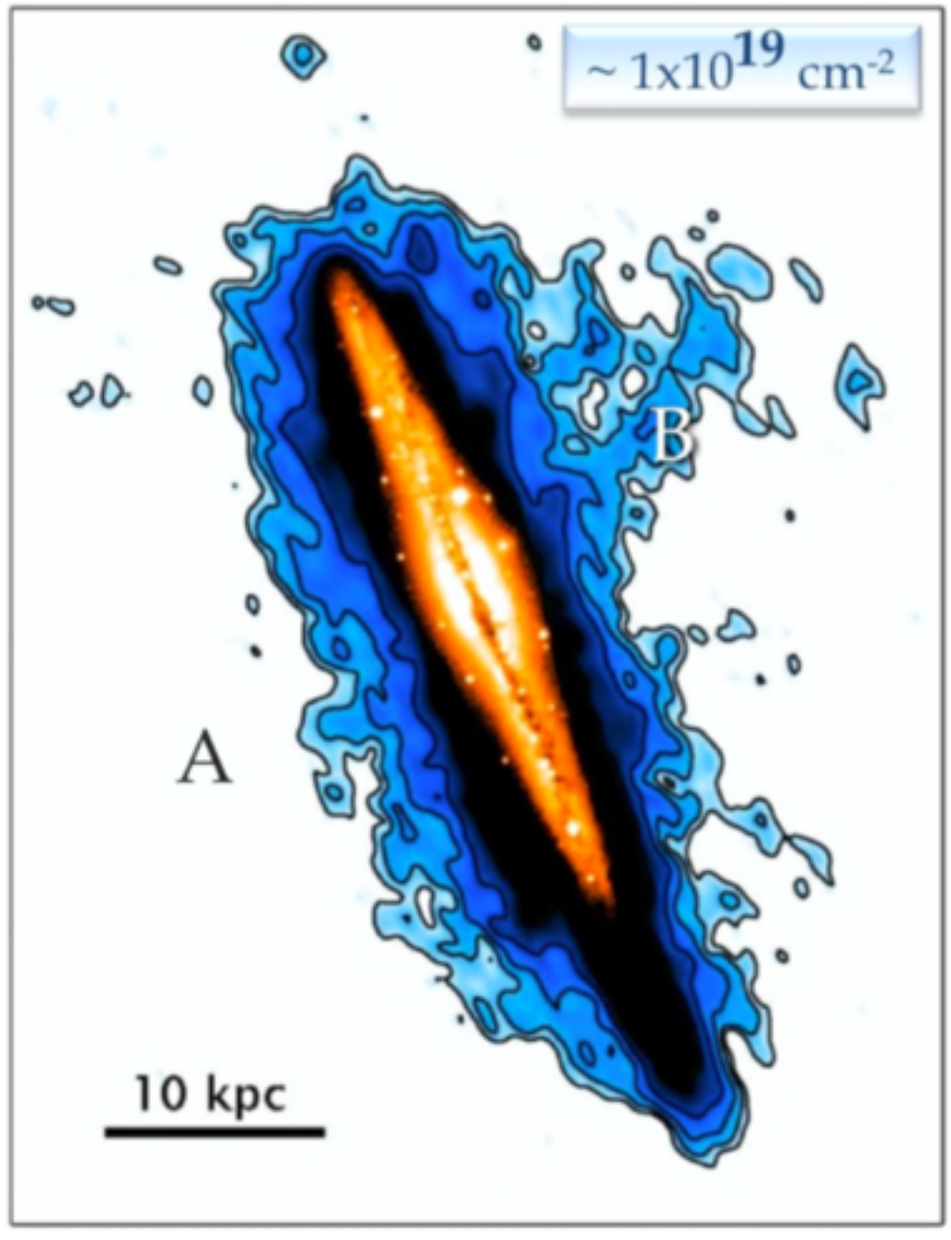
1979: *Sancisi & Allen* → 1997: *Swaters et al.* → 2007: *Oosterloo, Fraternali & Sancisi*

Minimum column density

~ $1x10^{21}$ cm^{-2} | ~ $1x10^{20}$ cm^{-2} | ~ $1x10^{19}$ cm^{-2}







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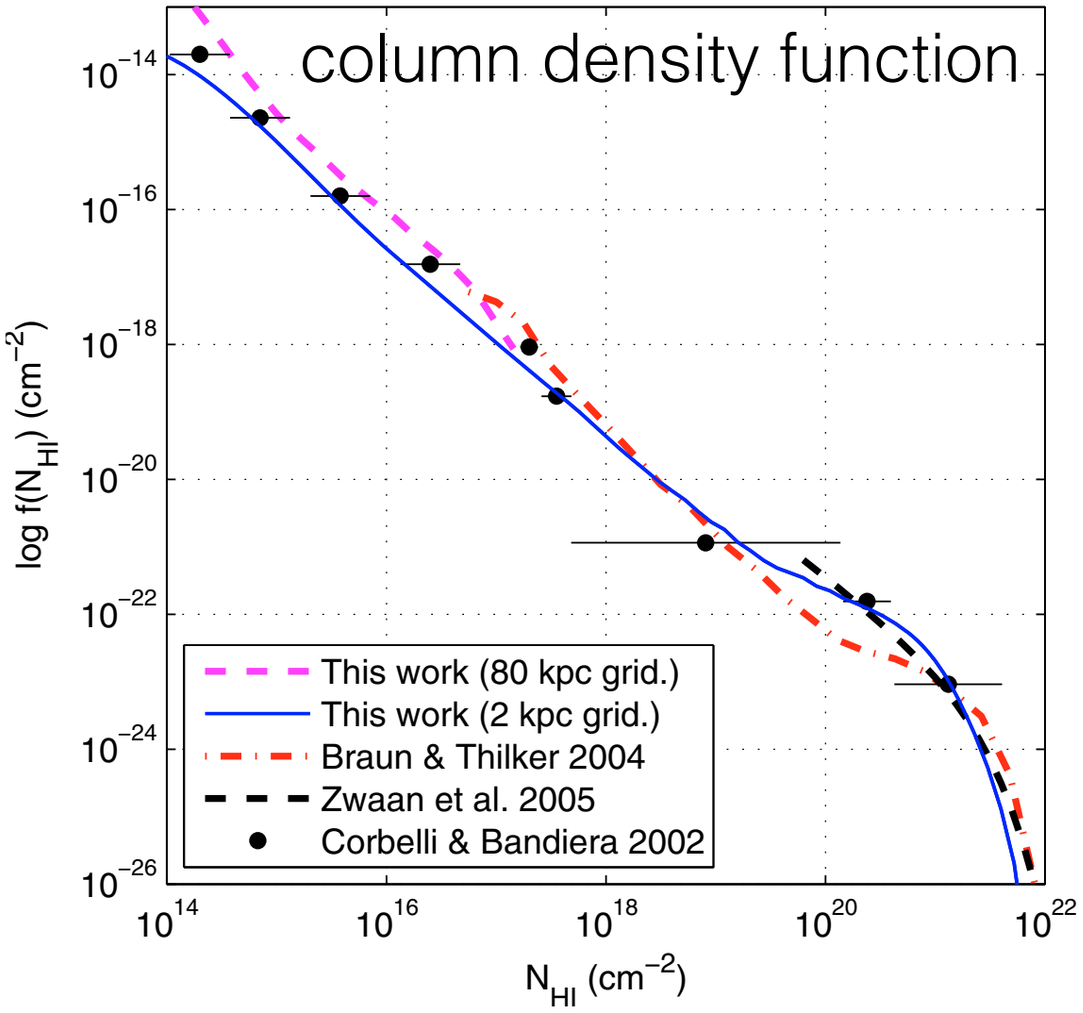
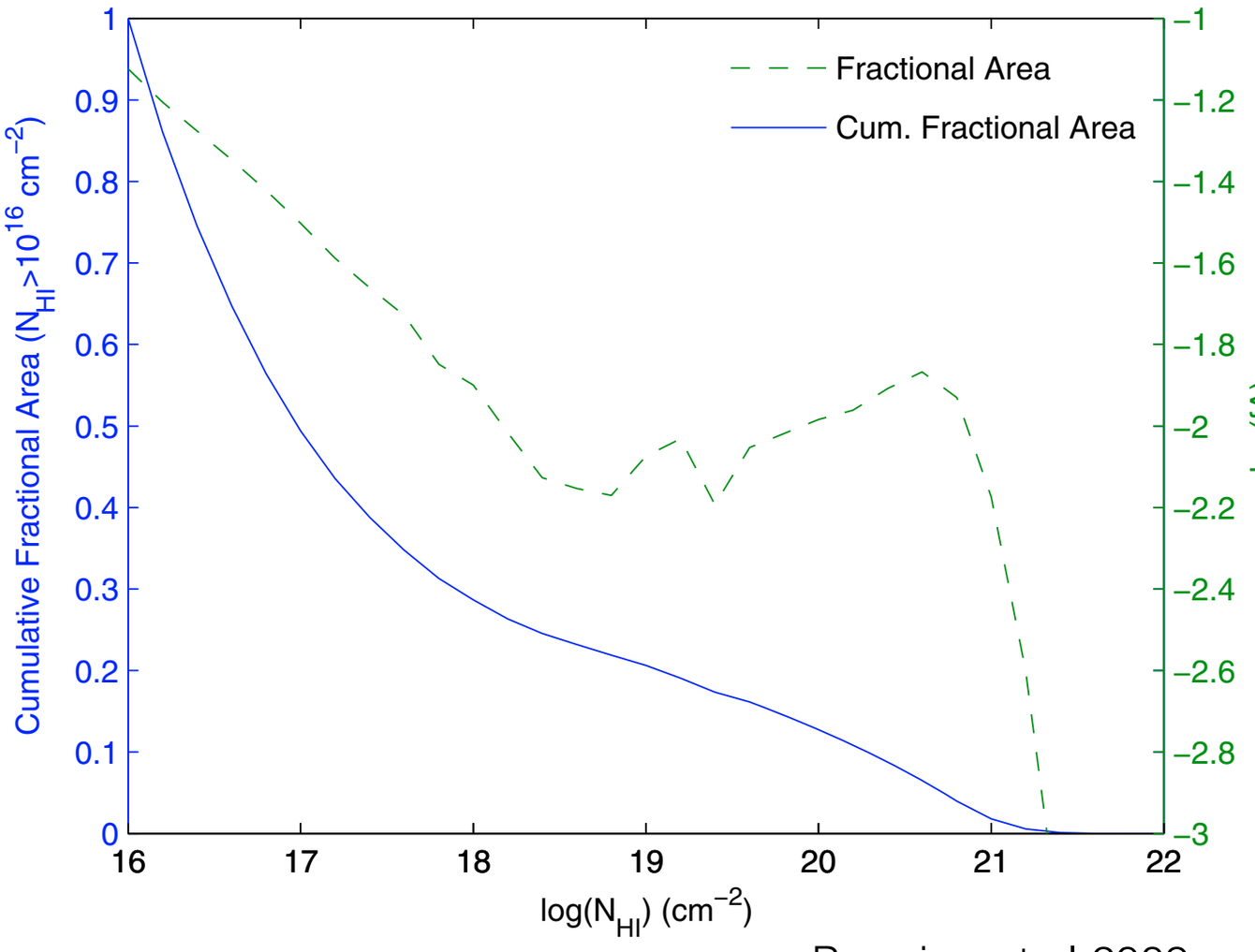
HI distribution function

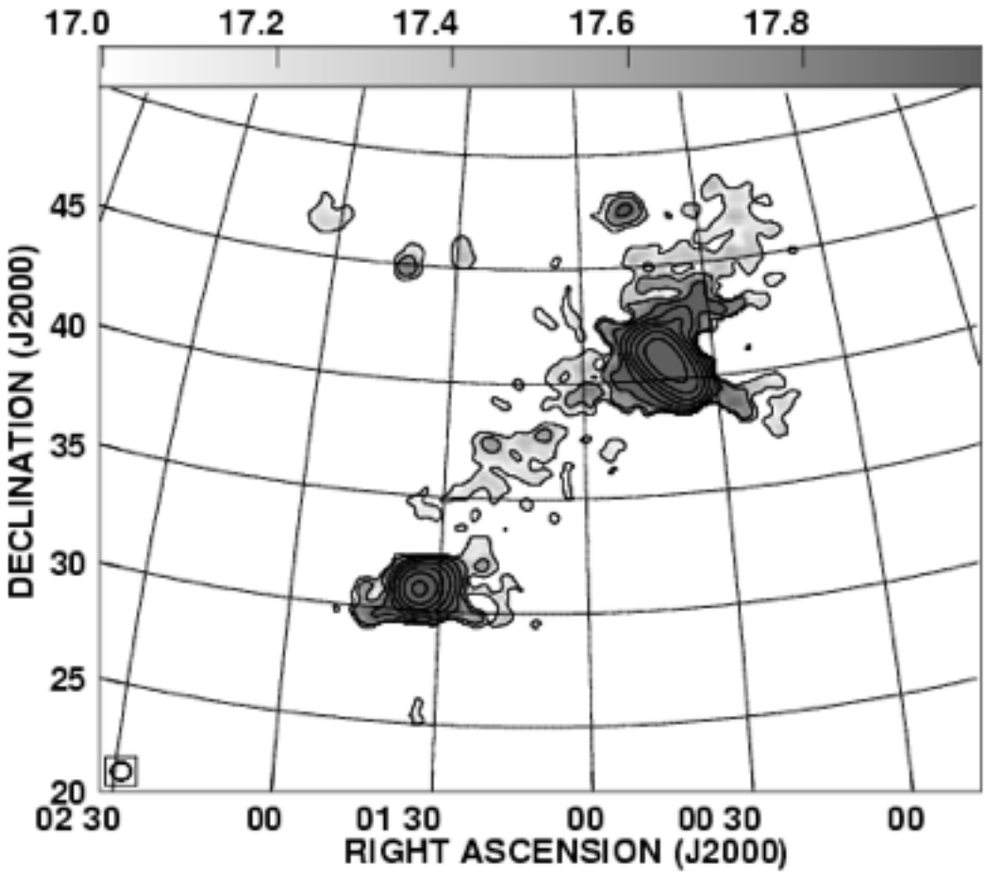


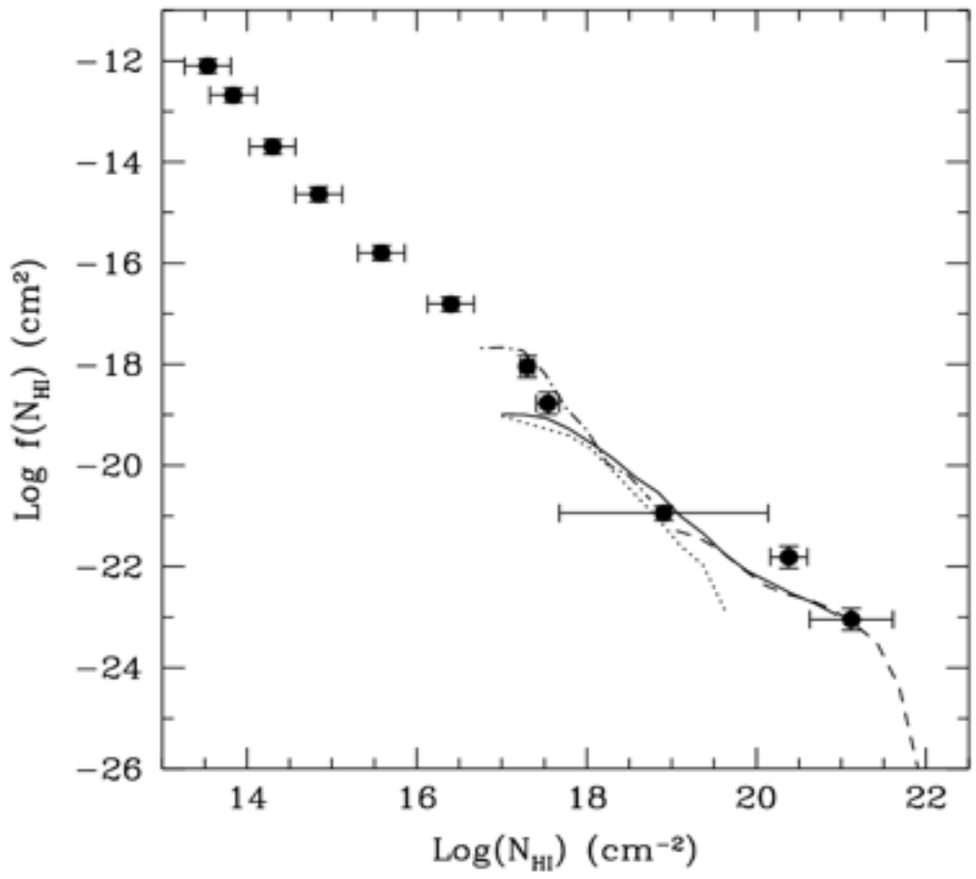


Popping et al 2009

At 10^{17} cm^{-2} area is twice that at 10^{19} cm^{-2}
but virtually nothing is known about the morphology

HI Filaments





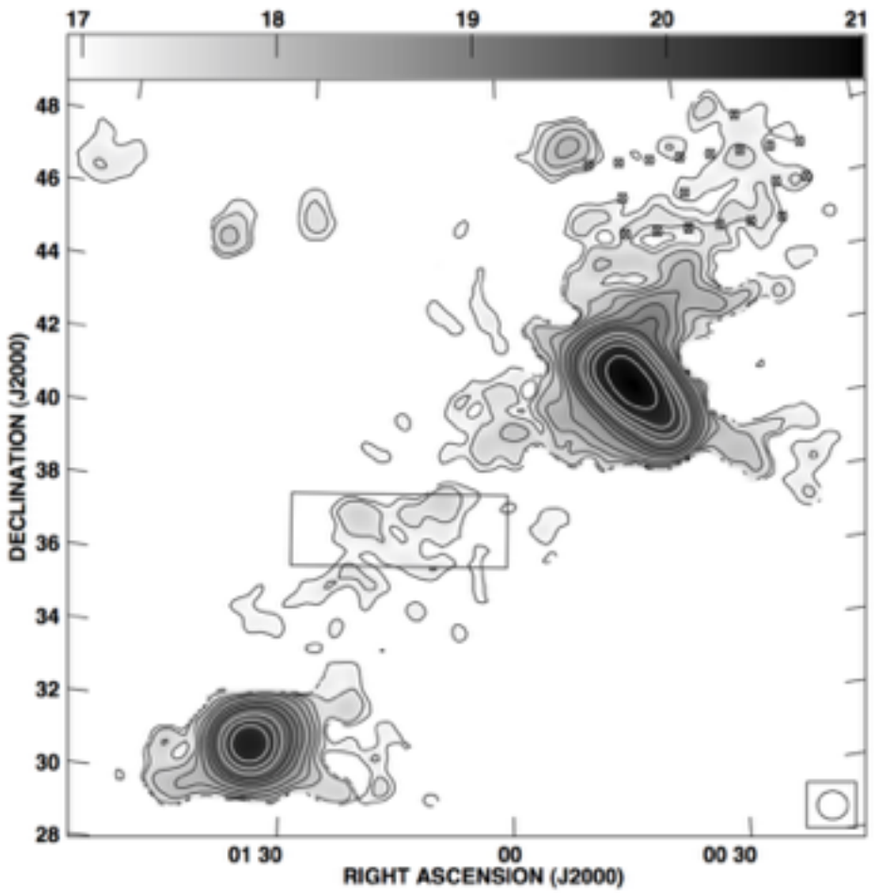
HI between M31 & M33 and
to the northwest of M31

Braun & Thilker 2004

Very faint emission NHI~10^{17} cm^{-2}

WSRT used as an array of single dish telescopes

A Deep GBT survey

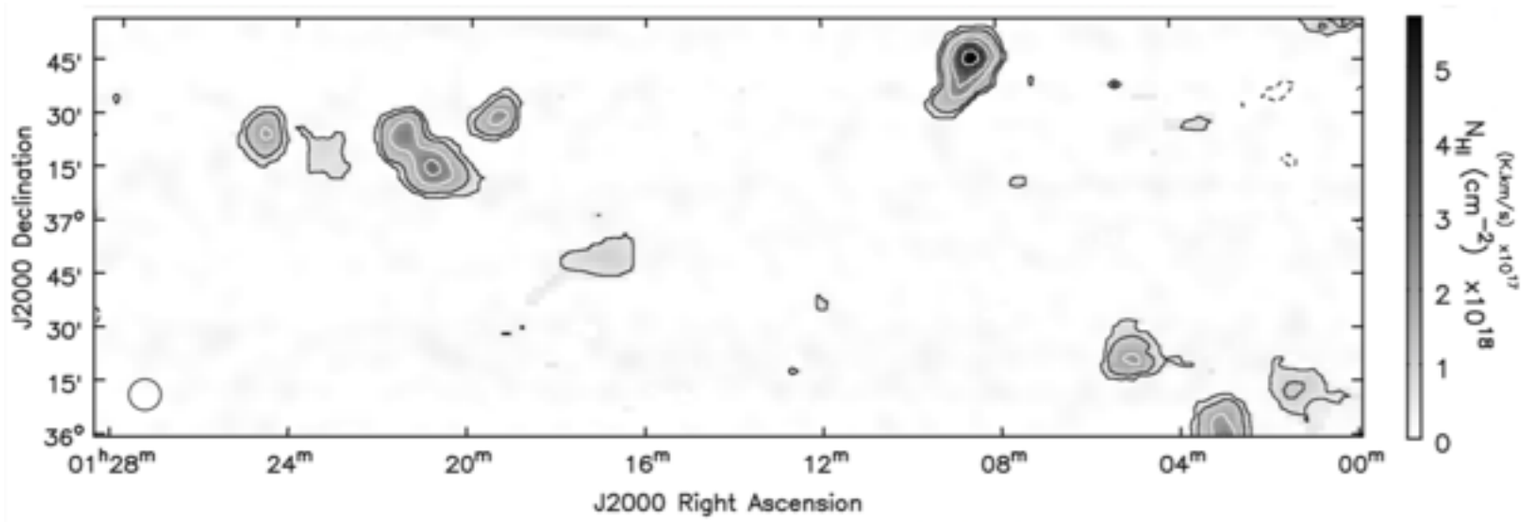


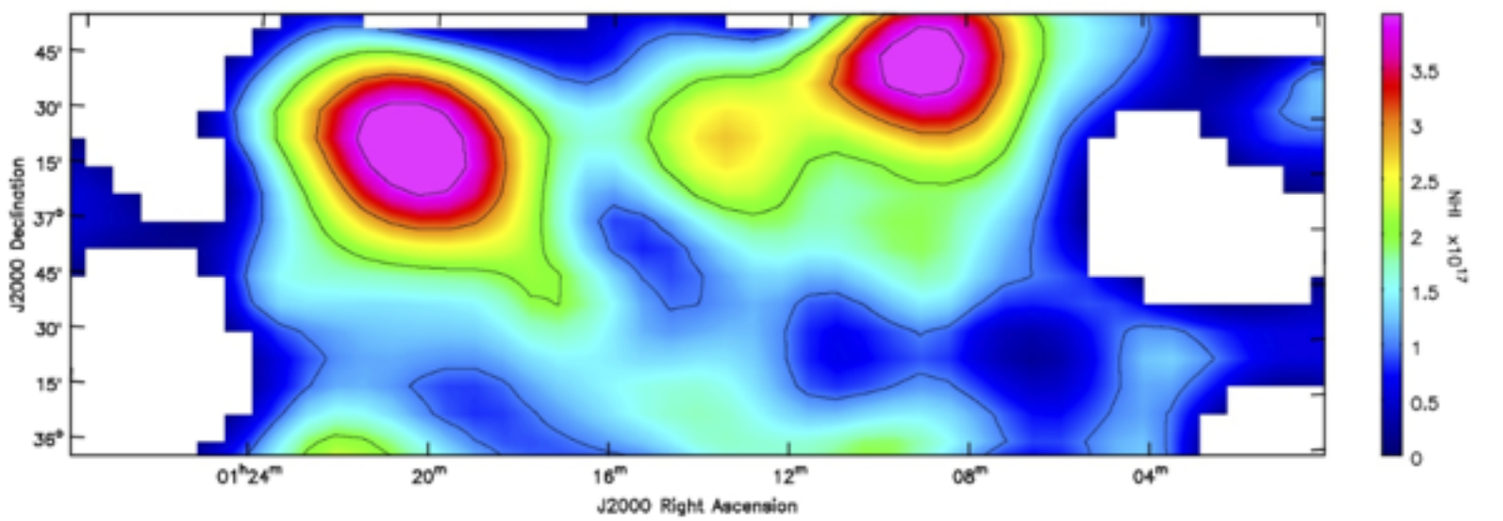
12 square degrees between M31 and M33

NHI ~ 2x10^{17} cm^{-2}

9’ GBT beam, 5 km/s

Deep pointing to the northwest of M31





Wolfe et al. 2016

ATCA: New opportunities

Wouldn't it be nice to image the environment of not one, but a whole sample of galaxies down to N_{HI}~10^{18} cm^{-2}. And even better, do this with an interferometer to have decent resolution….

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
- NHI~2.5x10^{17} cm^{-2} over 20 km s^{-1}.
- resolution 1’ to 2.5’

www.imagine-survey.org

IMAGINE Science

- **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.**
- Missing satellite problem.
- Continuum source variability at low flux levels over the full survey area.
- Studies of warps and lopsidedness in spiral galaxies.
- Studies of HI in absorption by using bright 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
- …

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IMAGINE team

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Aaron Robotham
Amy Sardone
Lee Spitler
Lister Staveley-Smith
Kevin Vinsen
Jing Wang
Tobias Westmeier
Andreas Wicenec
Christian Wolf
Chen Wu

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IMAGINE sample

NGC0024
NGC0045
NGC0625
ESO154-023
NGC1433
NGC1512
NGC1515
NGC1617
NGC1744
NGC1792
NGC2188
ESO209-009
NGC2835
NGC2997
NGC3109
NGC3137
NGC3175
ESO214-017
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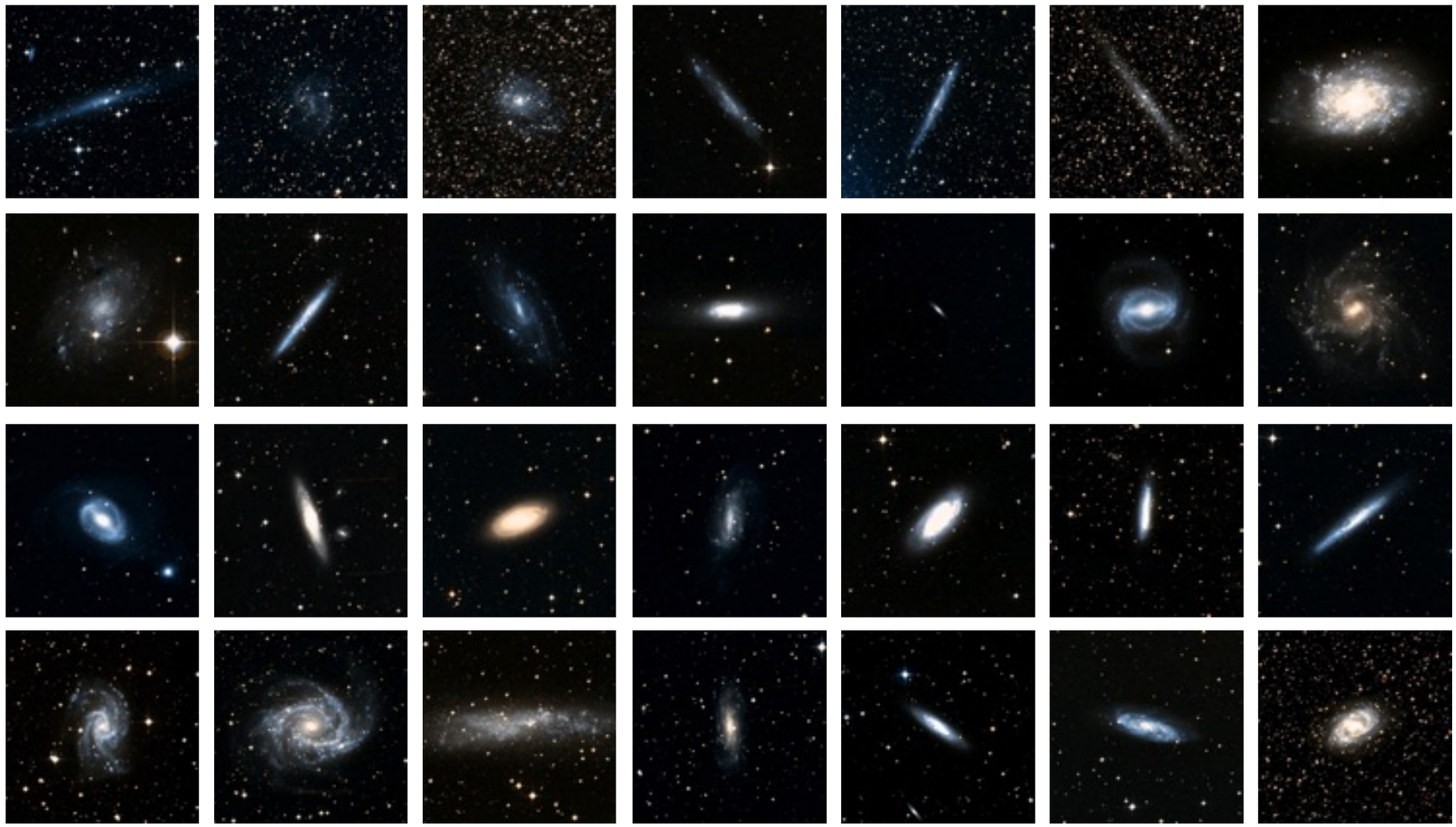
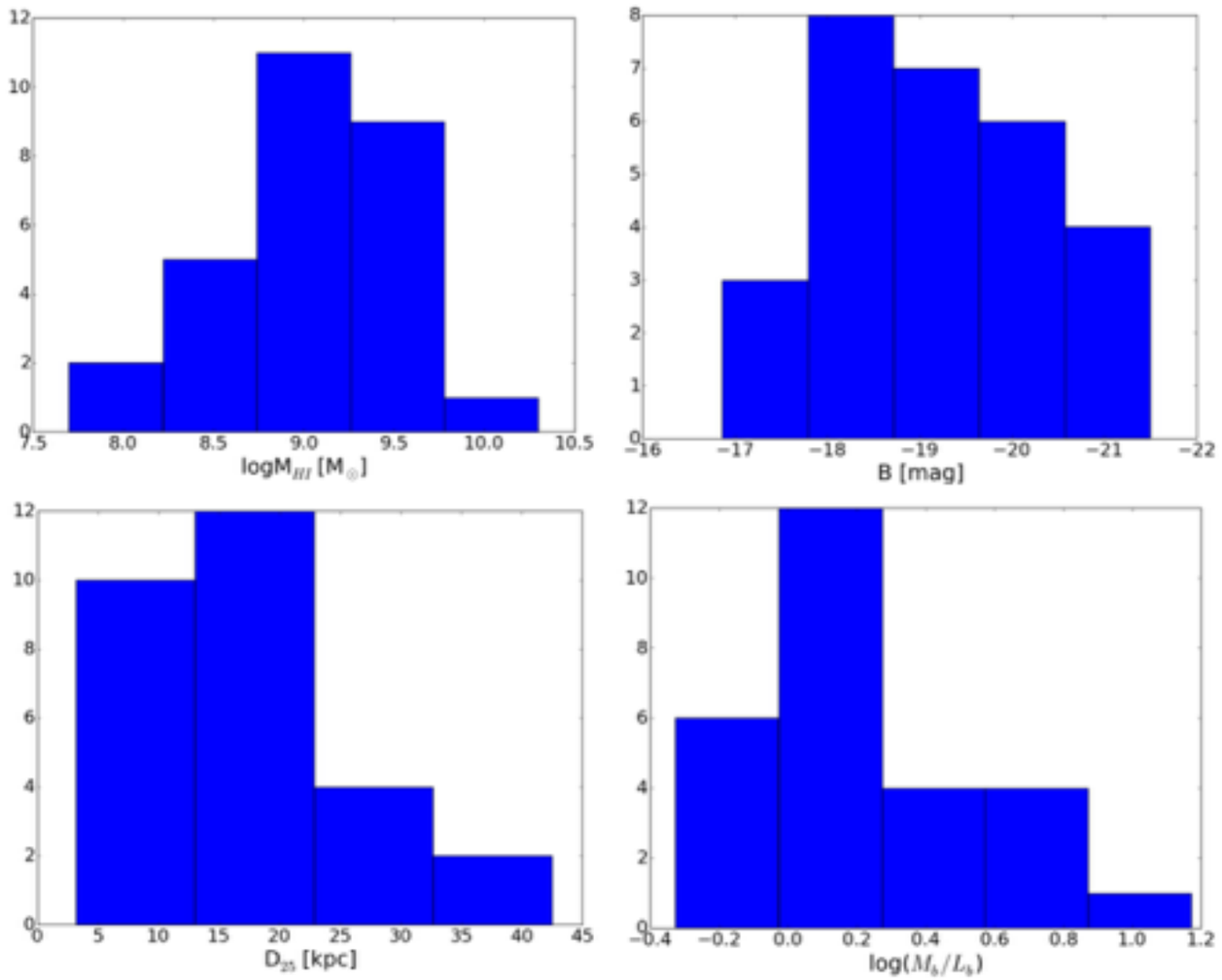
ESO274-001
ESO138-010
NGC6300
IC5052
NGC7090
IC5201
NGC7424
NGC7793



IMAGINE sample

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



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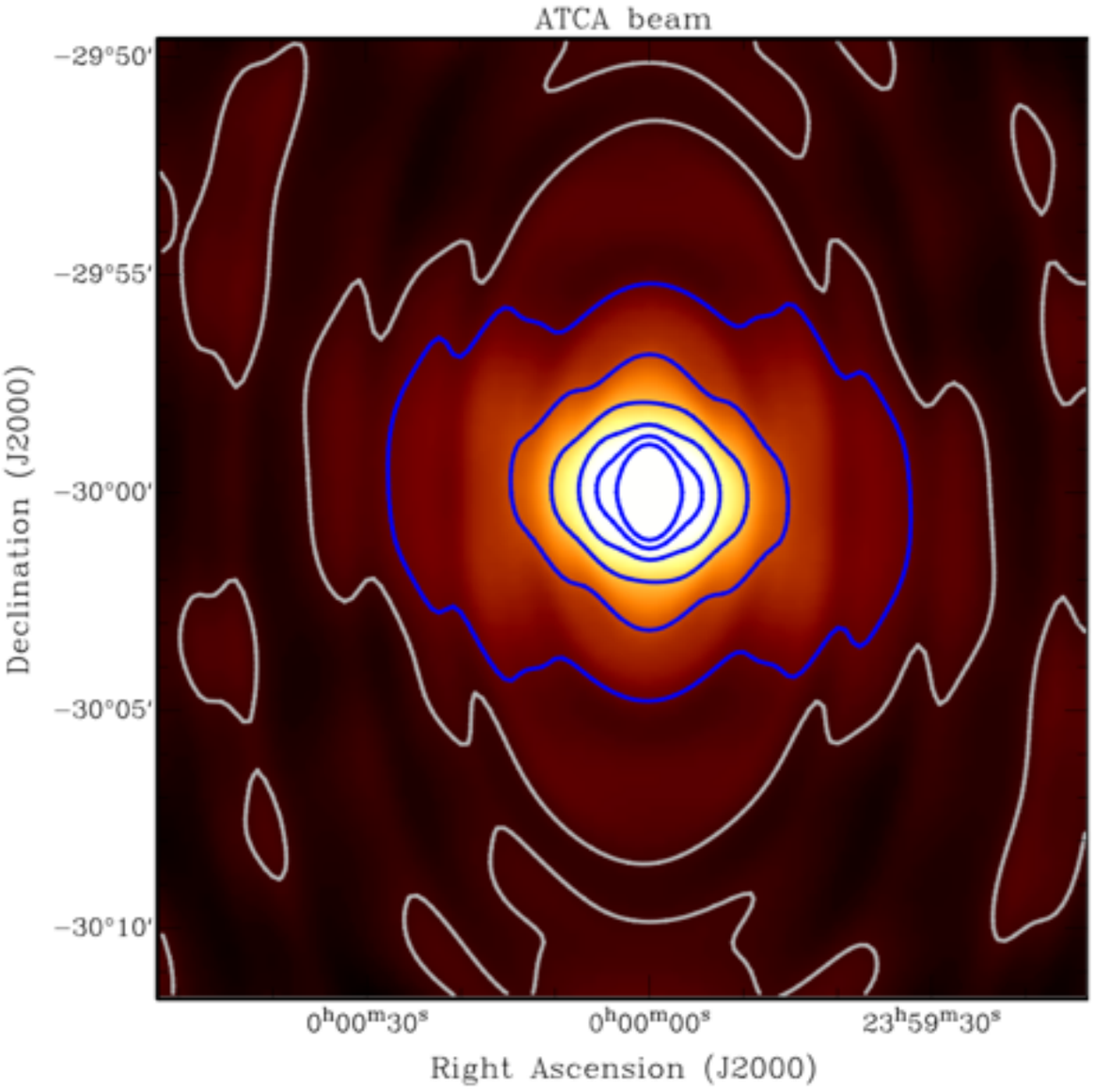
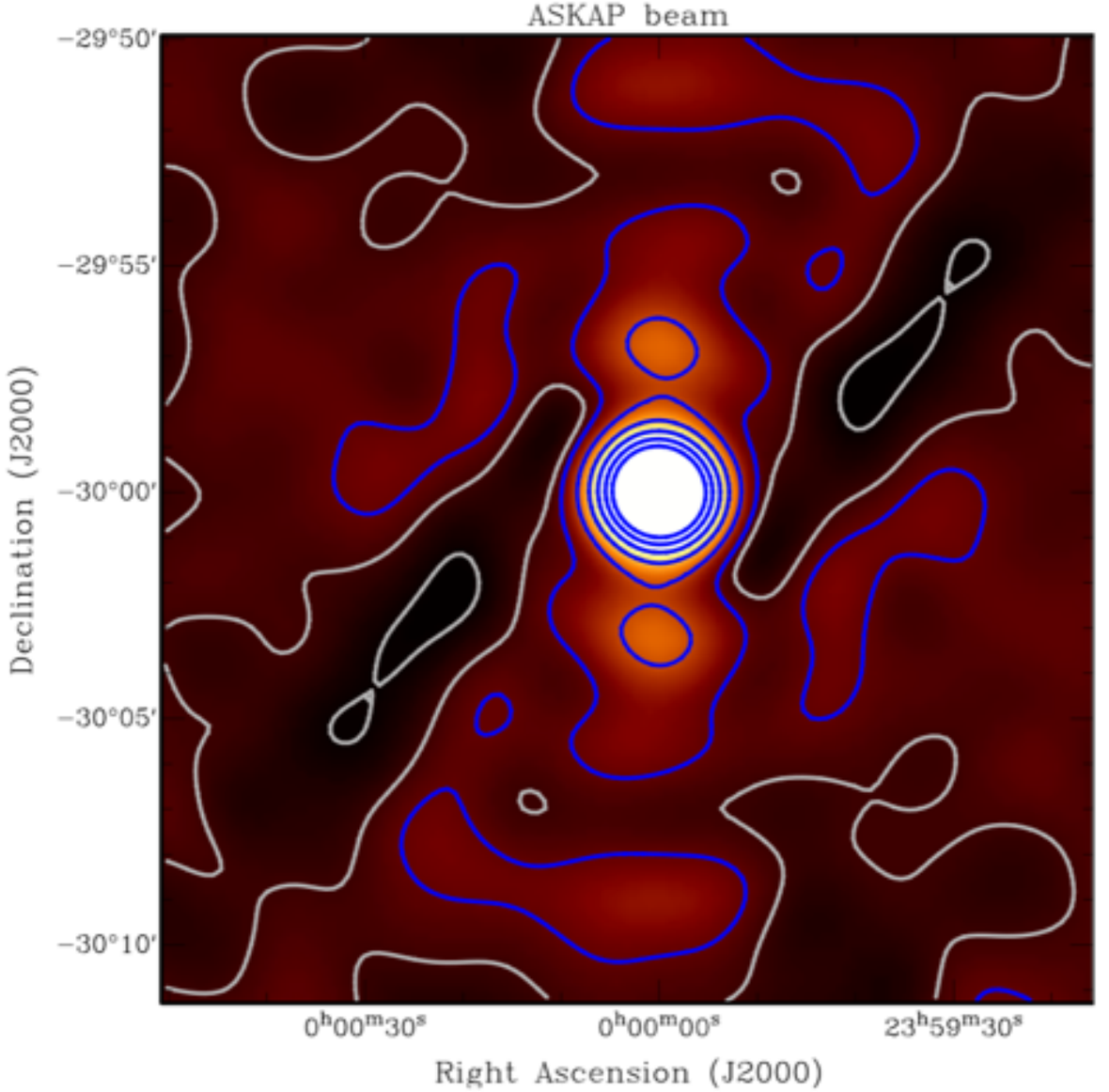
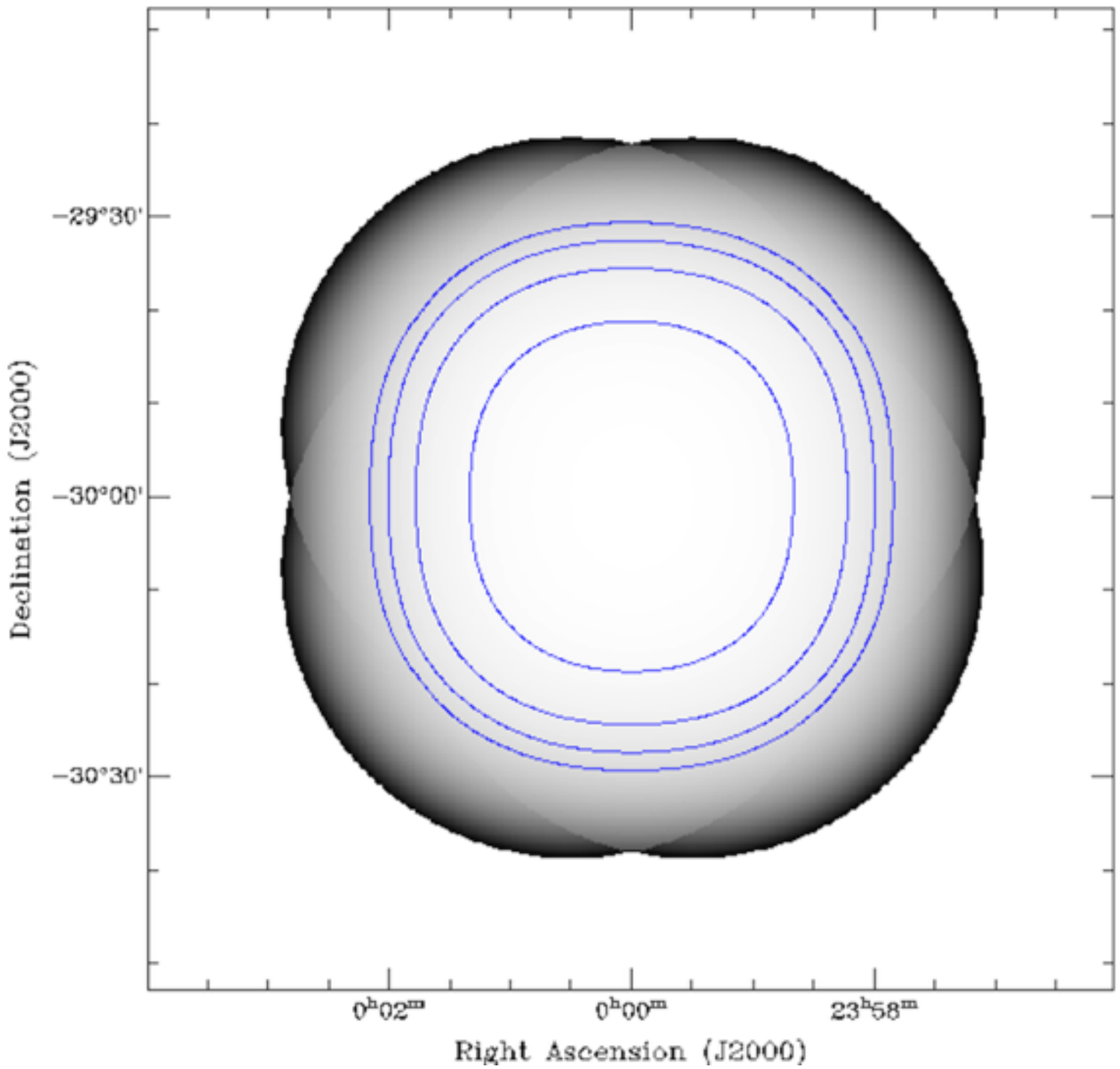
IMAGINE Point Spread Function





IMAGINE Field of View



Status update

- Observations started in Oct 2016 (H168)
- Continued in Jan 2016 (EW368 & 750b)
- About 350 hours observed
- Observations will finish in the next two years

www.imagine-survey.org

Other efforts

- Computing: Dec 2016 awarded 250,000 hours on Magnus
  - automated processing
  - DiLuiGe workflow
  - implement other science cases

- Single dish: Dec 2016 applied for Parkes time
  - fill the zero spacings
  - get extra sensitivity
  - extend the area out to the virial radius

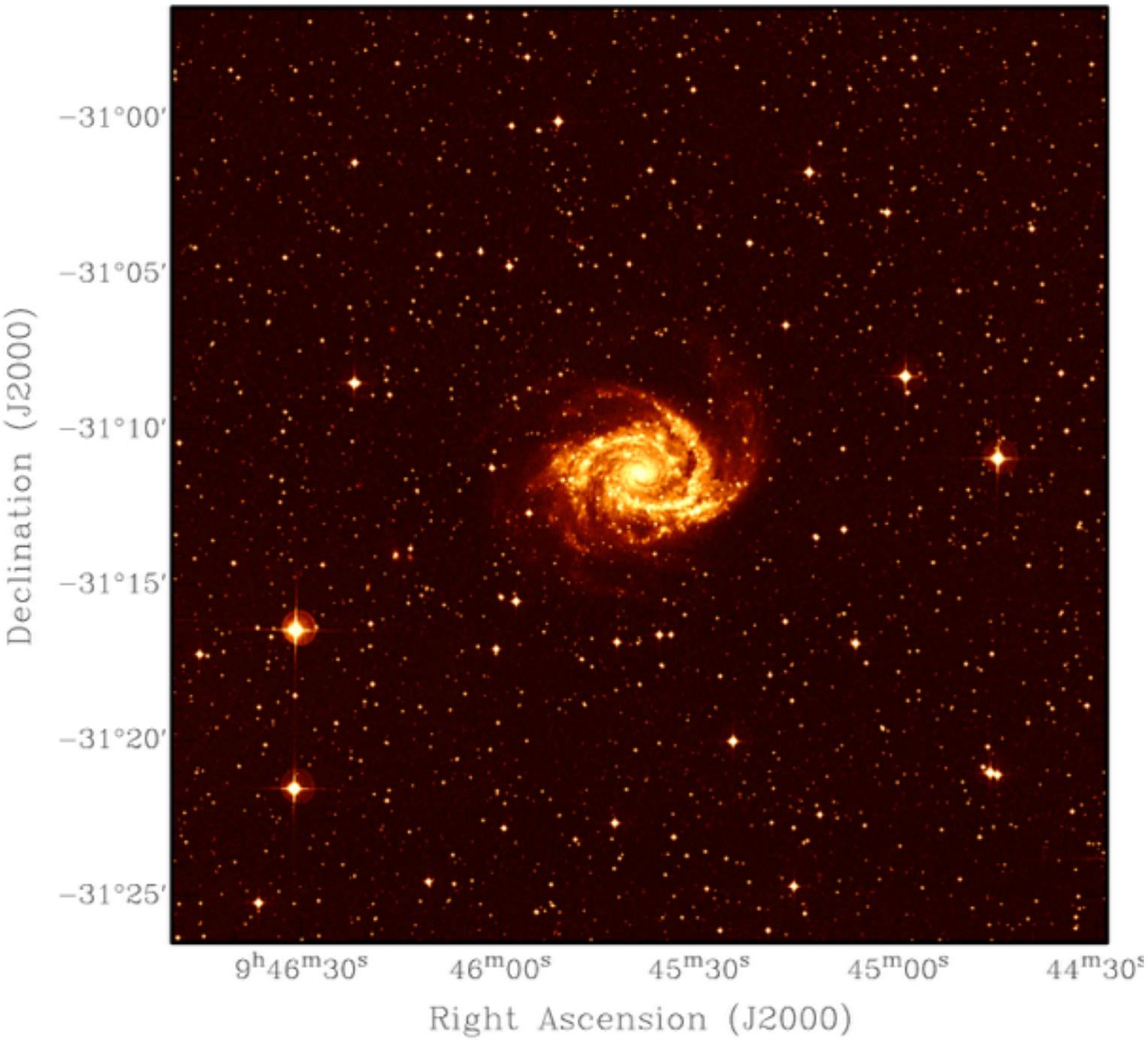
- Low surface brightness optical data
  - IMAGINE galaxies prioritised by Skymapper
  - IMAGINE galaxies targets for StarFox and Huntsman

StarFox

StarFox is a 100mm aperture Vixen astrograph refracting telescope designed to detect ultra-low surface brightness structure [<28$Mag\ Arcsec^{-2}$].

NGC2997: Jonah Gannon

NGC2997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−31°05′
−31°10′
−31°15′
−31°20′
−31°25′
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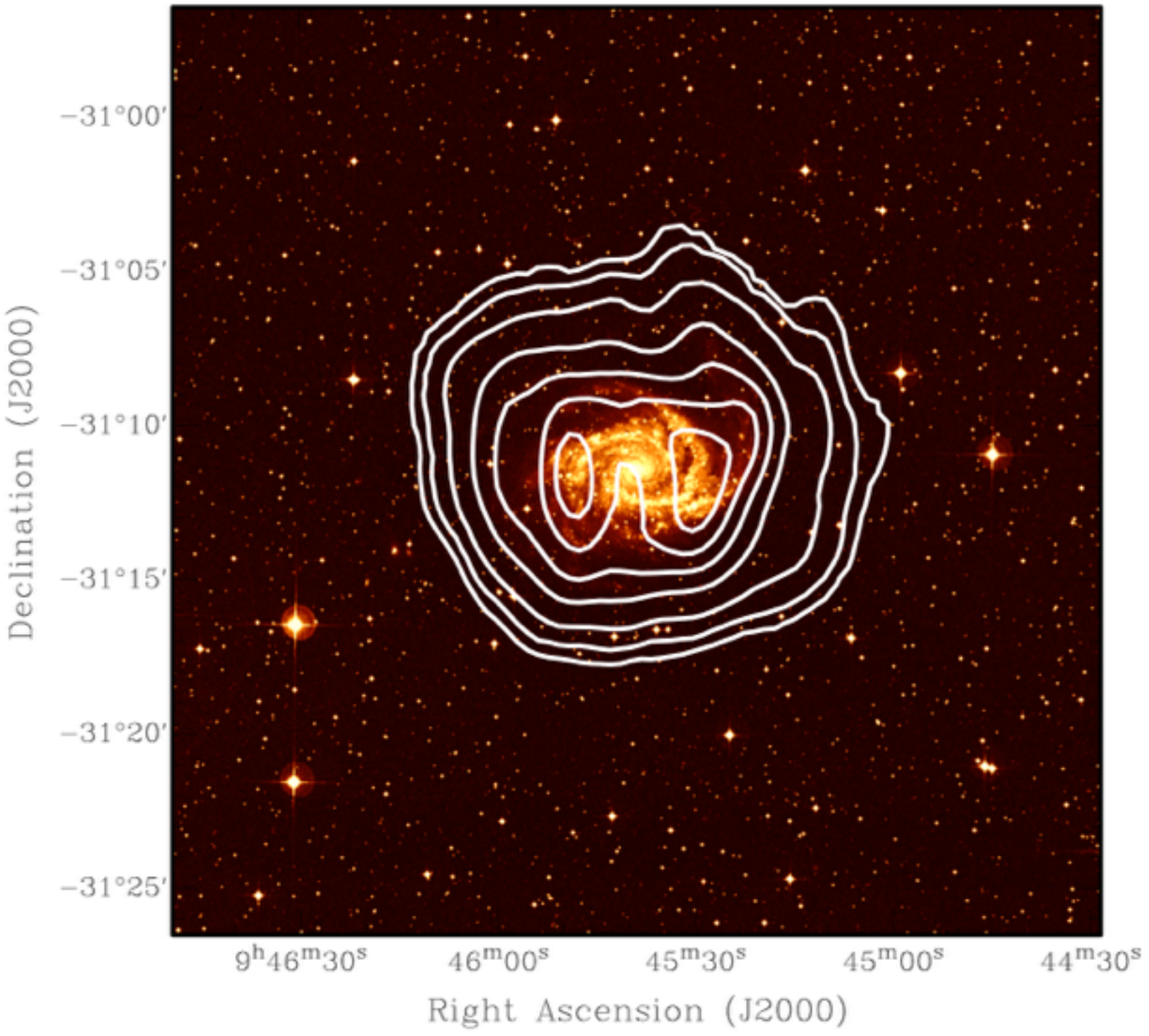
9h46m30s
46m00s
45m30s
45m00s
44m30s
Right Ascension (J2000)

NGC2997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46m00s
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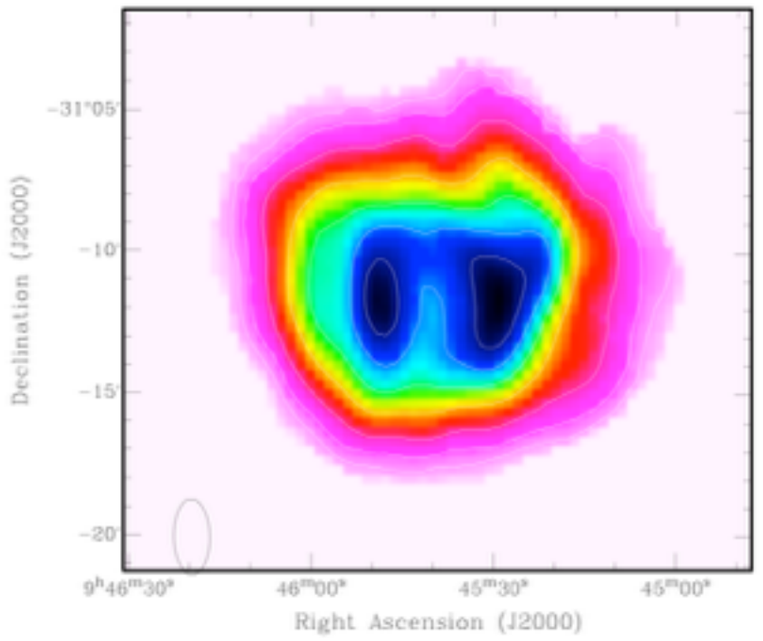
45m00s
44m30s
Right Ascension (J2000)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−10′
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Declination (J2000)
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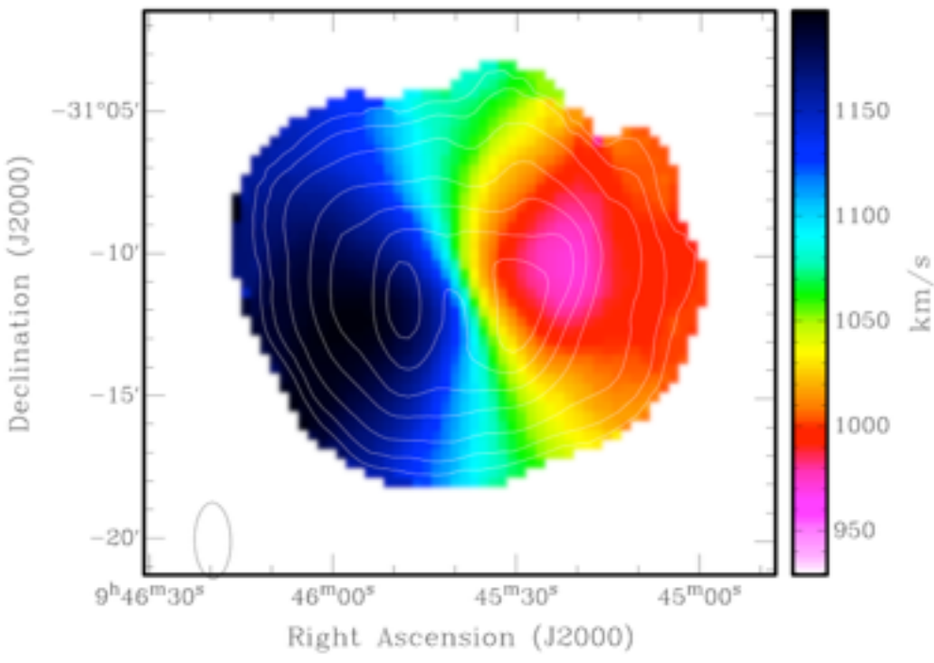
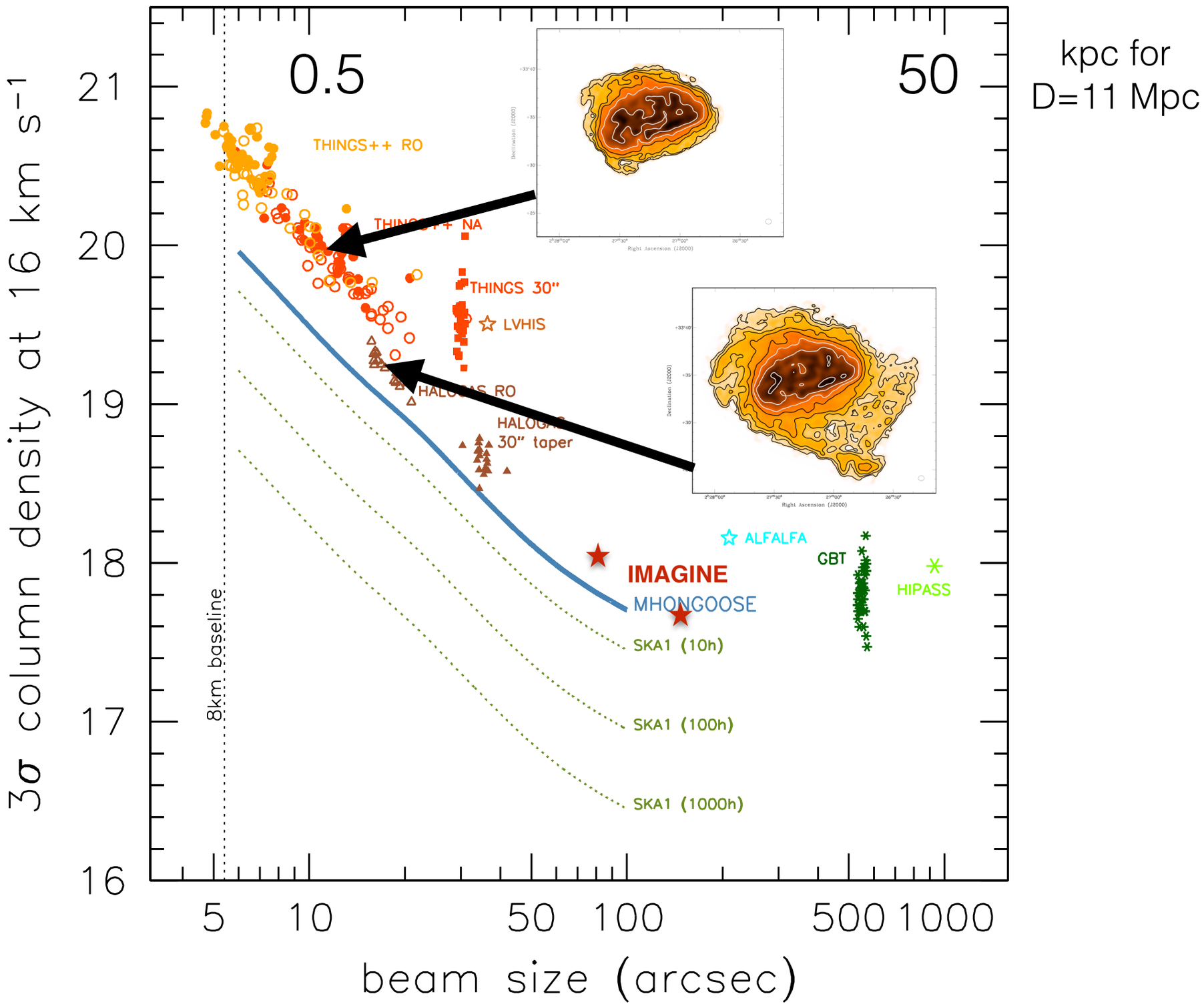
46m00s
45m30s
45m00s
Right Ascension (J2000)


−31°05′
−10′
−15′
−20′
Declination (J2000)
9h46m30s
46m00s
45m30s
45m00s
Right Ascension (J2000)
1150
1100
1050
1000
950
km/s

sensitivity comparison



Conclusion

- Understanding gas accretion is one of the fundamentals of Galaxy evolution
- To see gas accretion in HI column densities of N_{HI}~10^{18} cm^{-2} are required
- 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

- If you have access to telescopes the can provide the diffuse optical component of these fields, please let me know
- If you think data of this survey is useful for your science, please let me know