International Centre for Radio Astronomy Research

The University of Western Australia
Achieving International Excellence

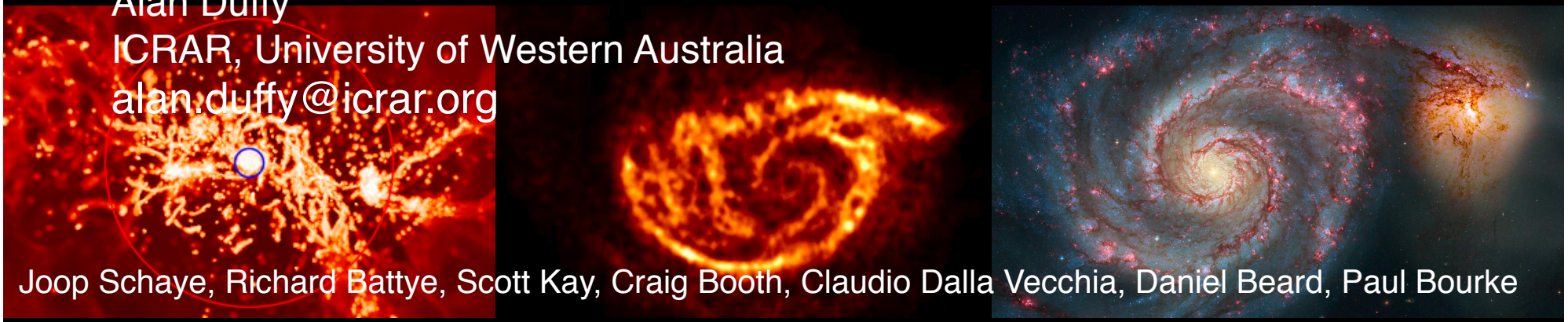
Curtin University of Technology

ICRAR is a partnership between The University of Western Australia and Curtin University of Technology

Visualising Neutral Hydrogen: A simulation perspective

Cape Town May 2010

Alan Duffy
ICRAR, University of Western Australia
alan.duffy@icrar.org



Joop Schaye, Richard Battye, Scott Kay, Craig Booth, Claudio Dalla Vecchia, Daniel Beard, Paul Bourke

International Centre for Radio Astronomy Research

Overview

OWLS

Creating HI in simulations

Visualising a Dwarf Galaxy

Cosmological Volumes

The Cosmic Web

OverWhelmingly Large Simulations

- Based in Sterrewacht, University of Leiden:
  - Joop Schaye (PI), Craig Booth, Claudio Dalla Vecchia, Marcel Haas, Andreas Pawlik, Debora Sijacki, Tom Theuns, Luca Tornatore, Freeke van de Voort, Rob Wiersma and Rob Crain

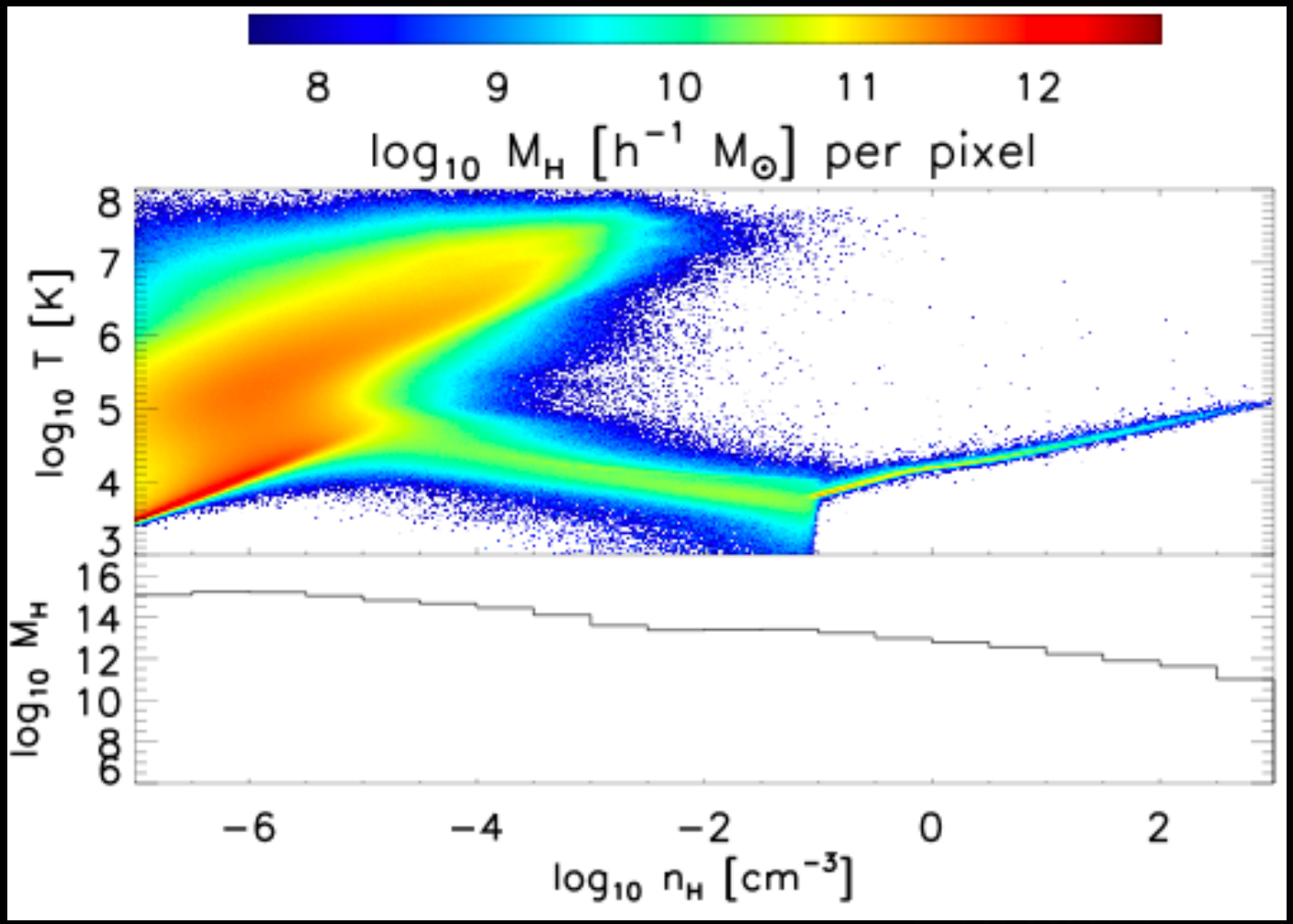
- LOFAR IBM Bluegene/L
- SPH-based code, Gadget 3
- 2 x 512^3 particles
- 25 Mpc/h (run to z=2):
  - m_{gas} = $1x10^6$ M_{sol}/h
  - softening = 2 kpc/h comoving (< 0.5 kpc/h proper)
- 100 Mpc/h (run to z=0):
  - m_{gas} = $9x10^7$ M_{sol}/h
  - softening = 8 kpc/h comoving (< 2.0 kpc/h proper)

- WMAP3 cosmology
- Repeat for different physics- star formation, IMF, SNe, AGN etc

International Centre for Radio Astronomy Research

Creating HI

Total Hydrogen

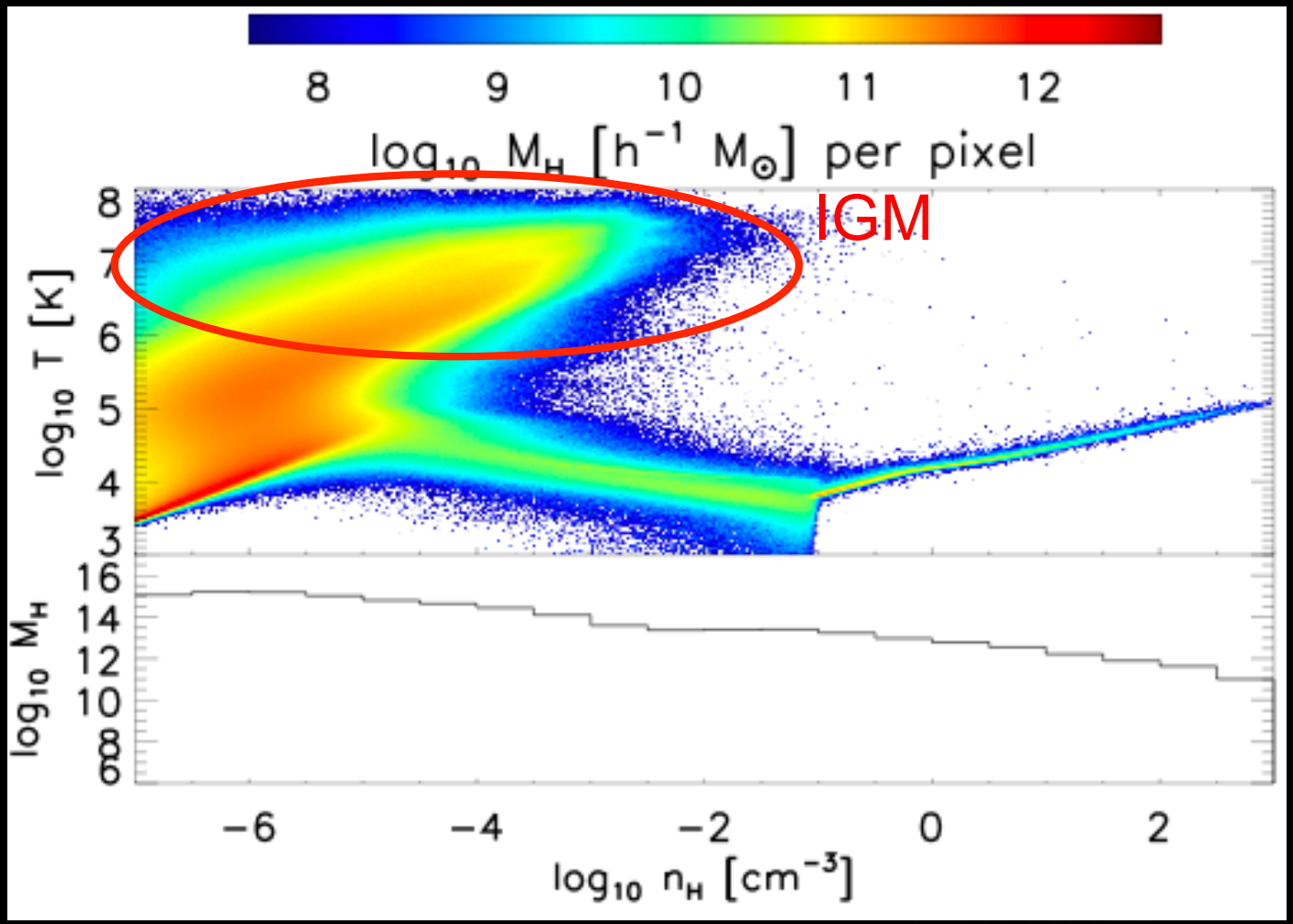


Simulations give a diverse array of gaseous states

International Centre for Radio Astronomy Research

Creating HI

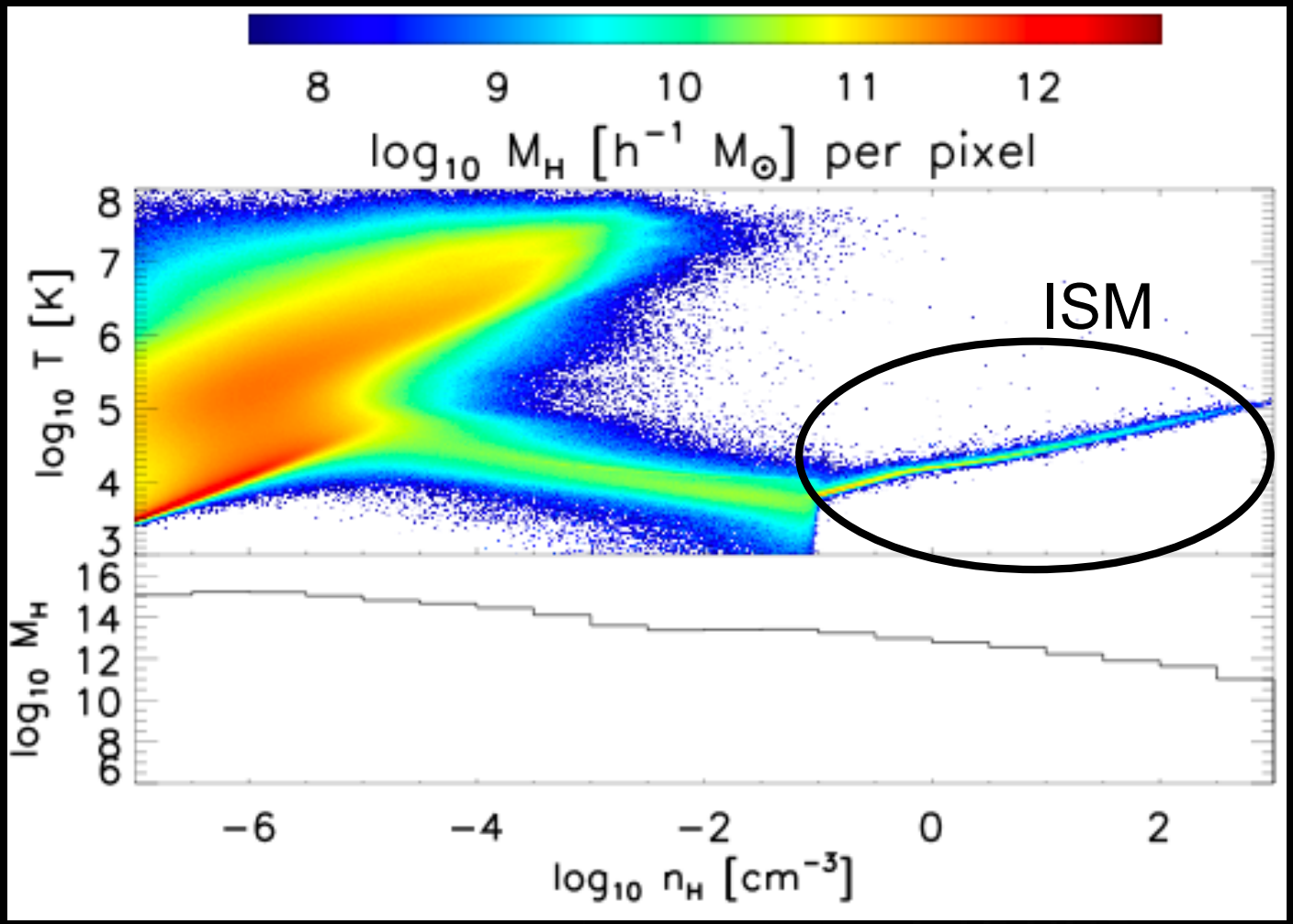
Total Hydrogen



International Centre for Radio Astronomy Research

Creating HI

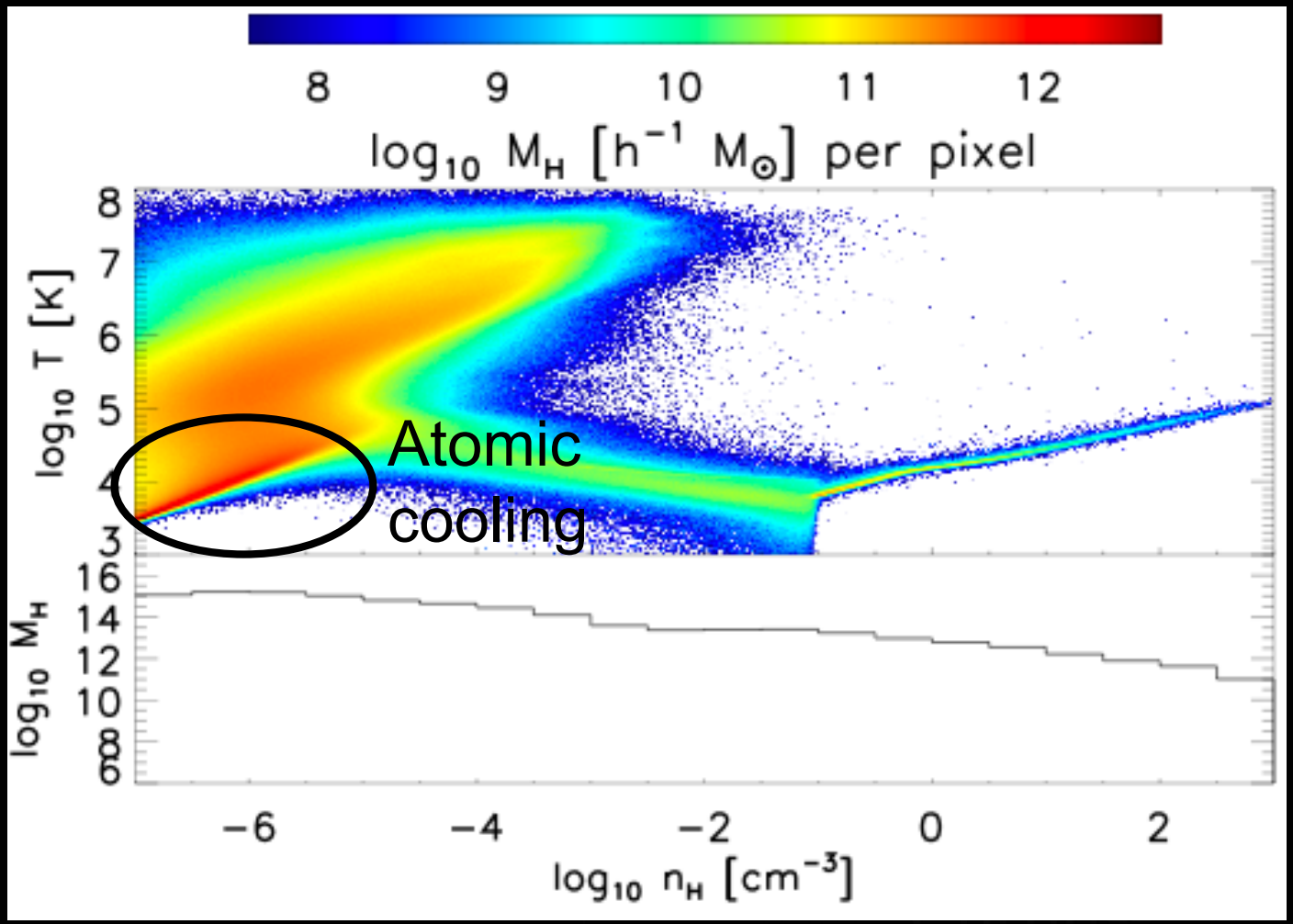
Total Hydrogen



International Centre for Radio Astronomy Research

Creating HI

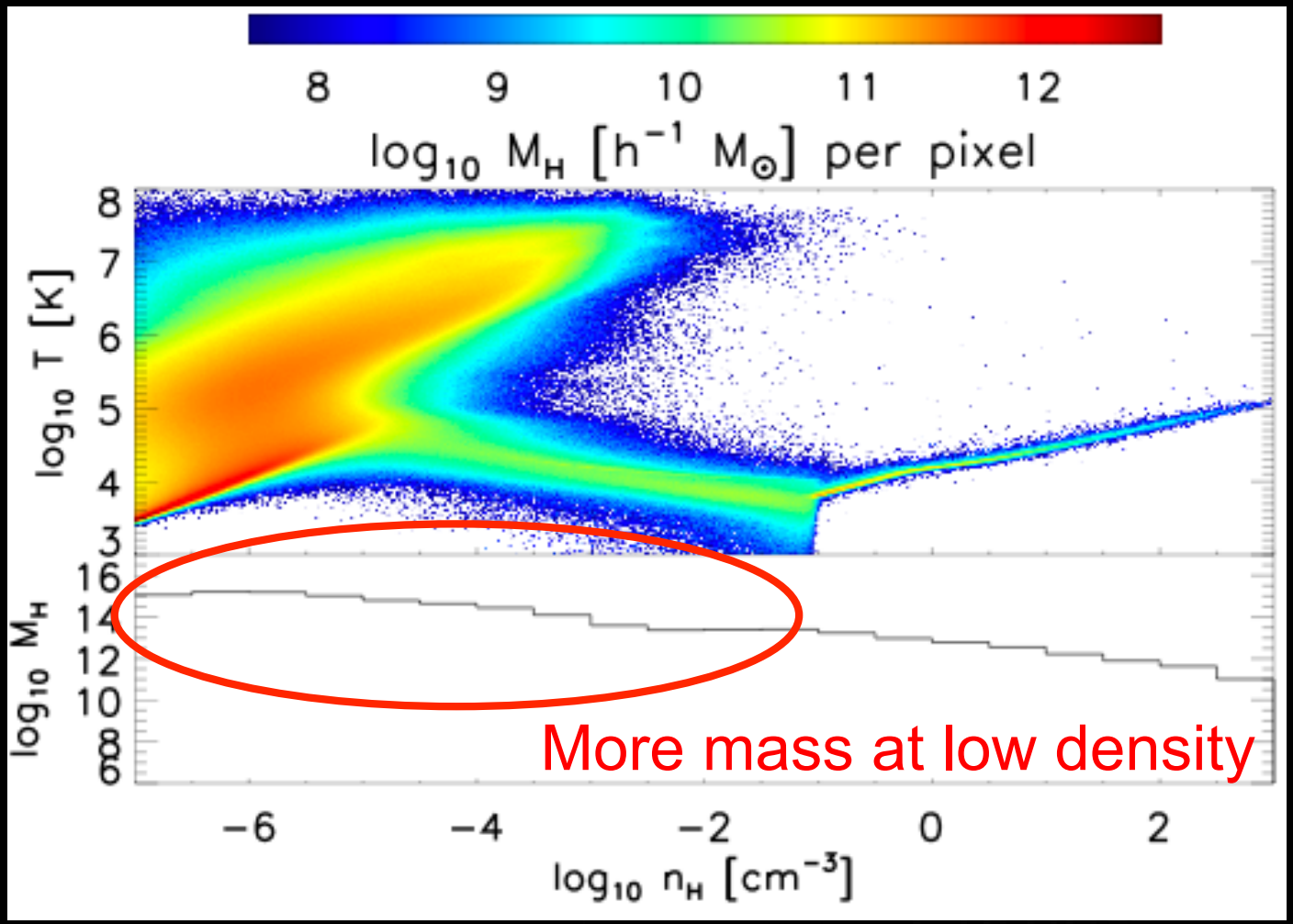
Total Hydrogen



International Centre for Radio Astronomy Research

Creating HI

Total Hydrogen



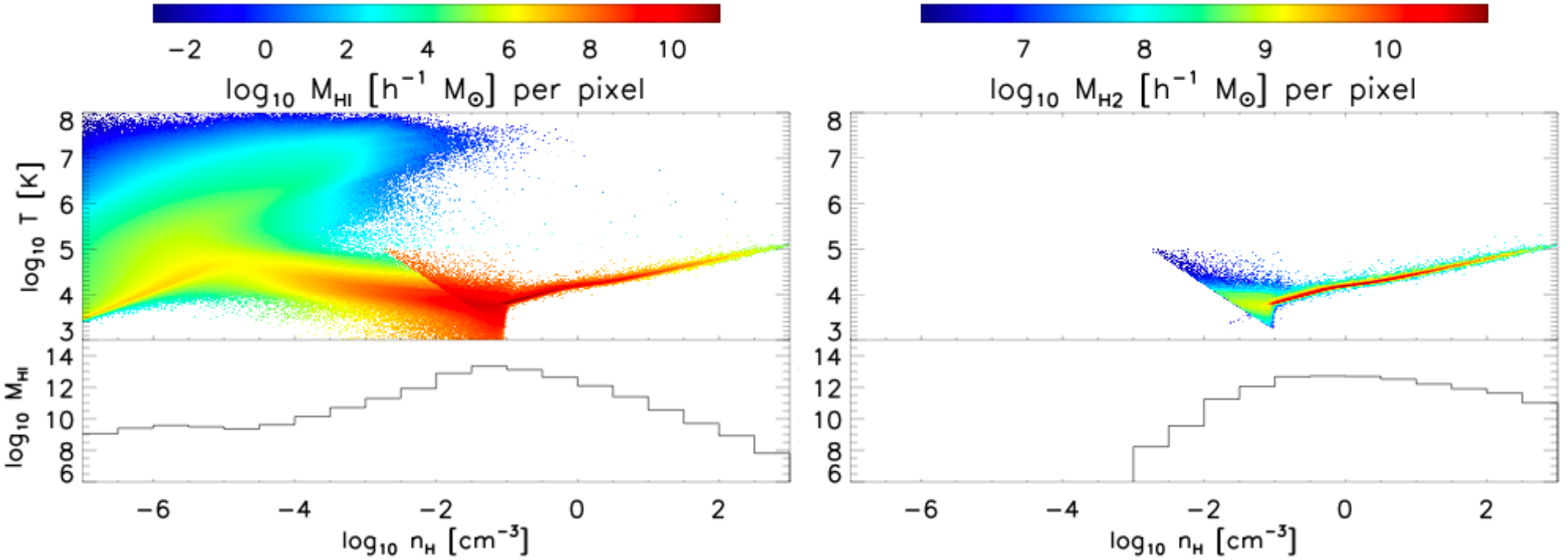
Aka the ‘missing baryons’

International Centre for Radio Astronomy Research

Creating HI

Neutral Hydrogen

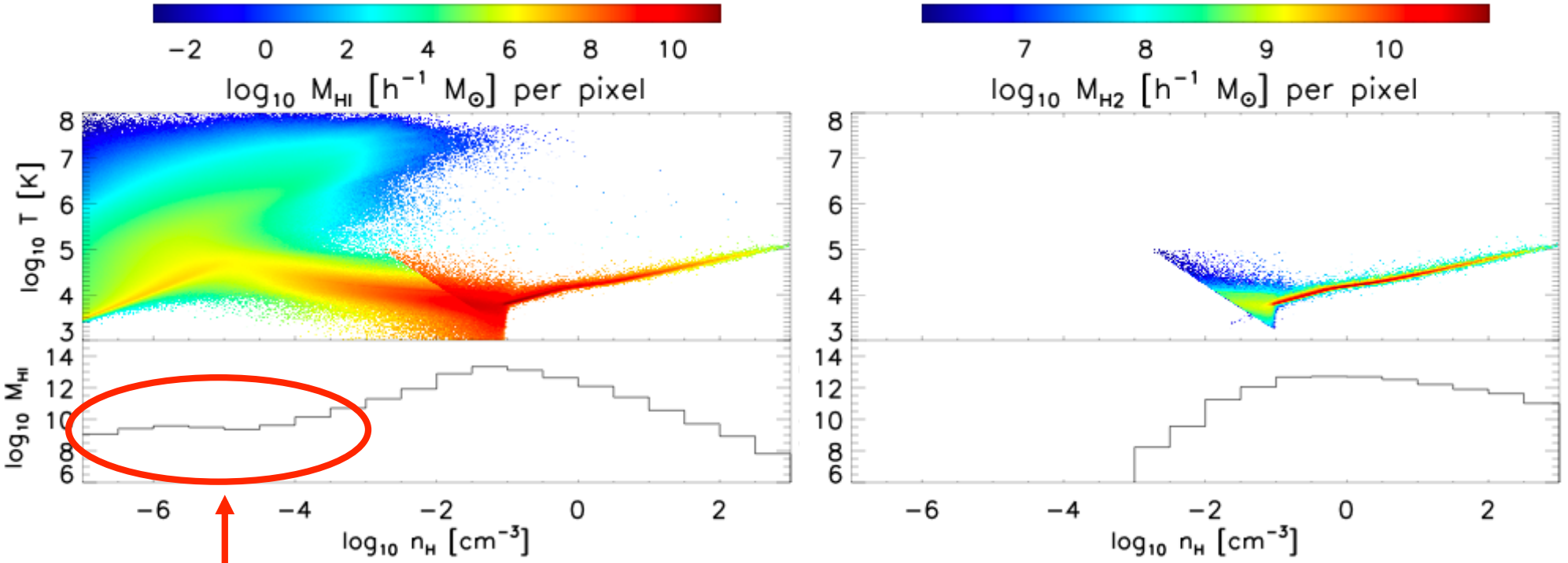
Molecular Hydrogen



International Centre for Radio Astronomy Research

Creating HI

Neutral Hydrogen

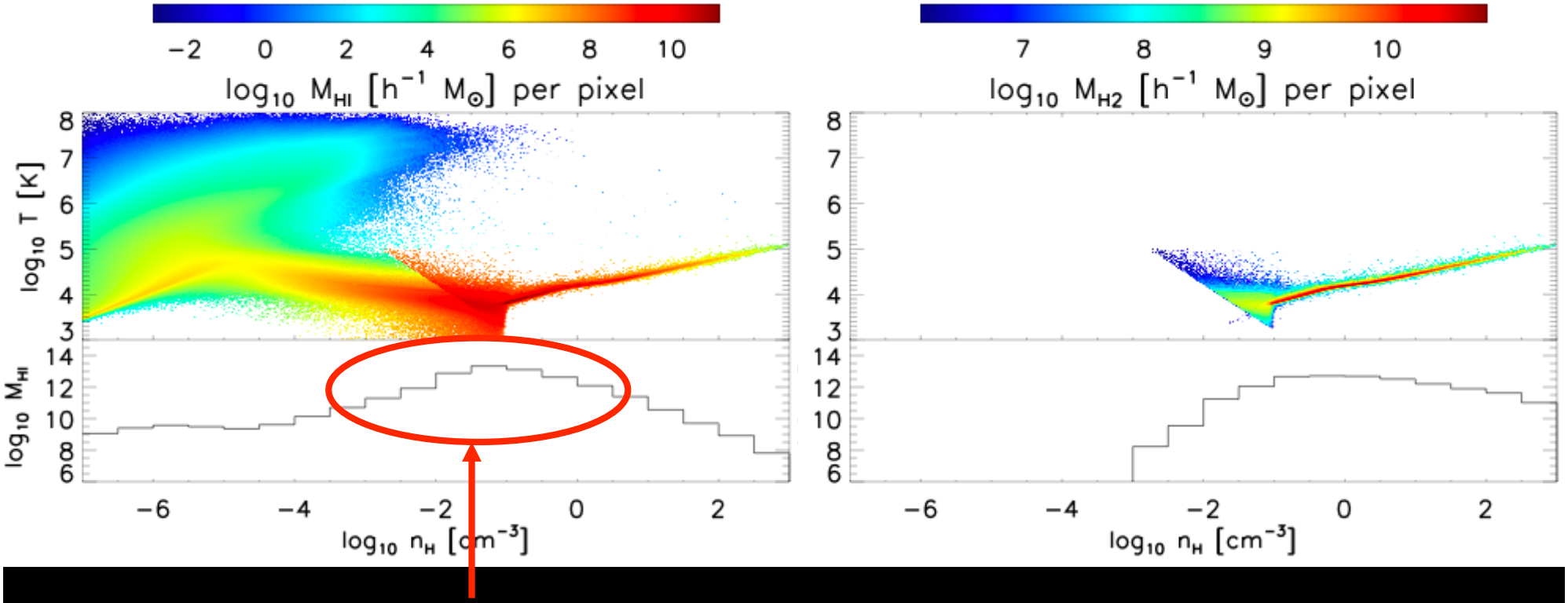


More Hydrogen balances lower neutral fraction

International Centre for Radio Astronomy Research

Creating HI

Neutral Hydrogen

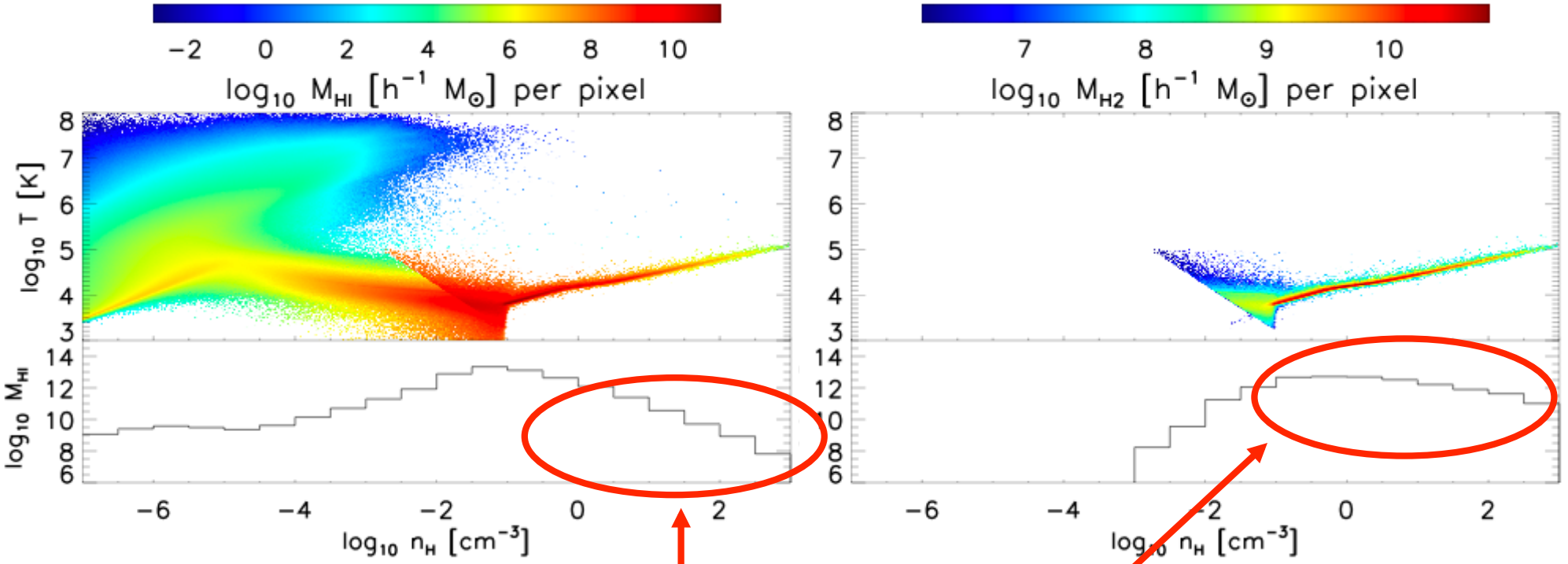


Most Hydrogen comes from gas near self-shielding limit

International Centre for Radio Astronomy Research

Creating HI

Neutral Hydrogen

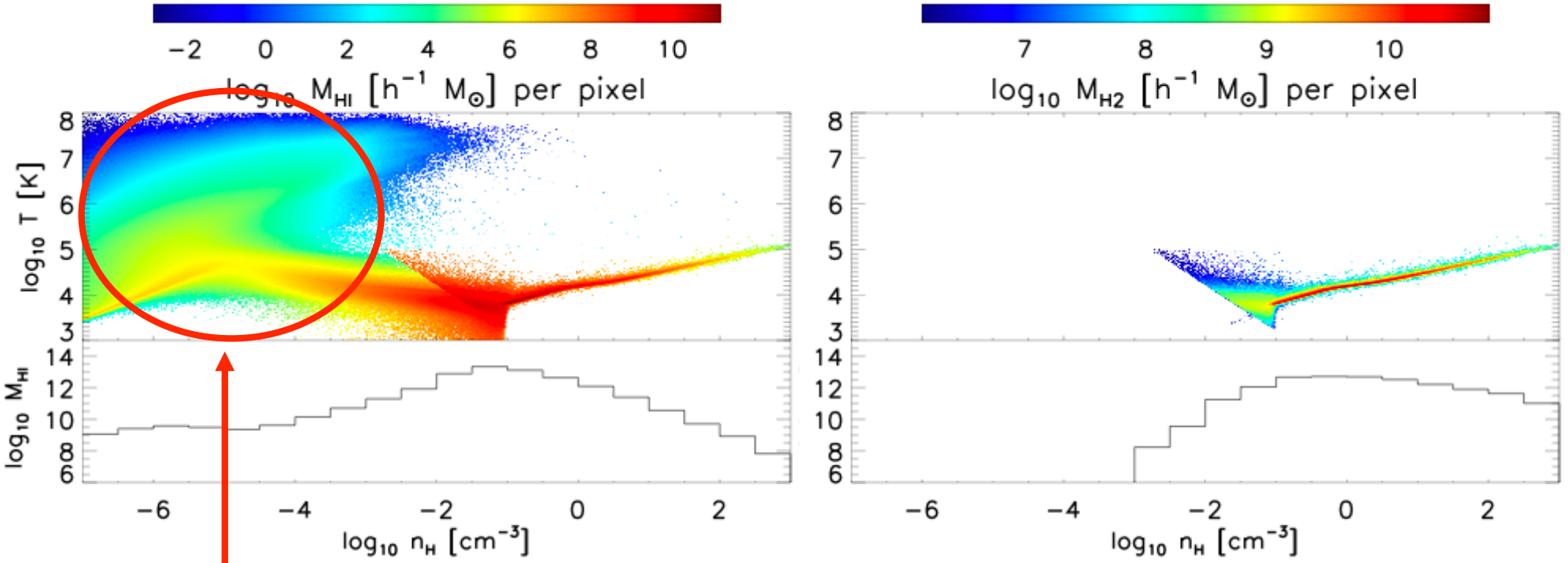


Neutral hydrogen is converted into molecular at higher densities

International Centre for Radio Astronomy Research

Creating HI

Optically Thin

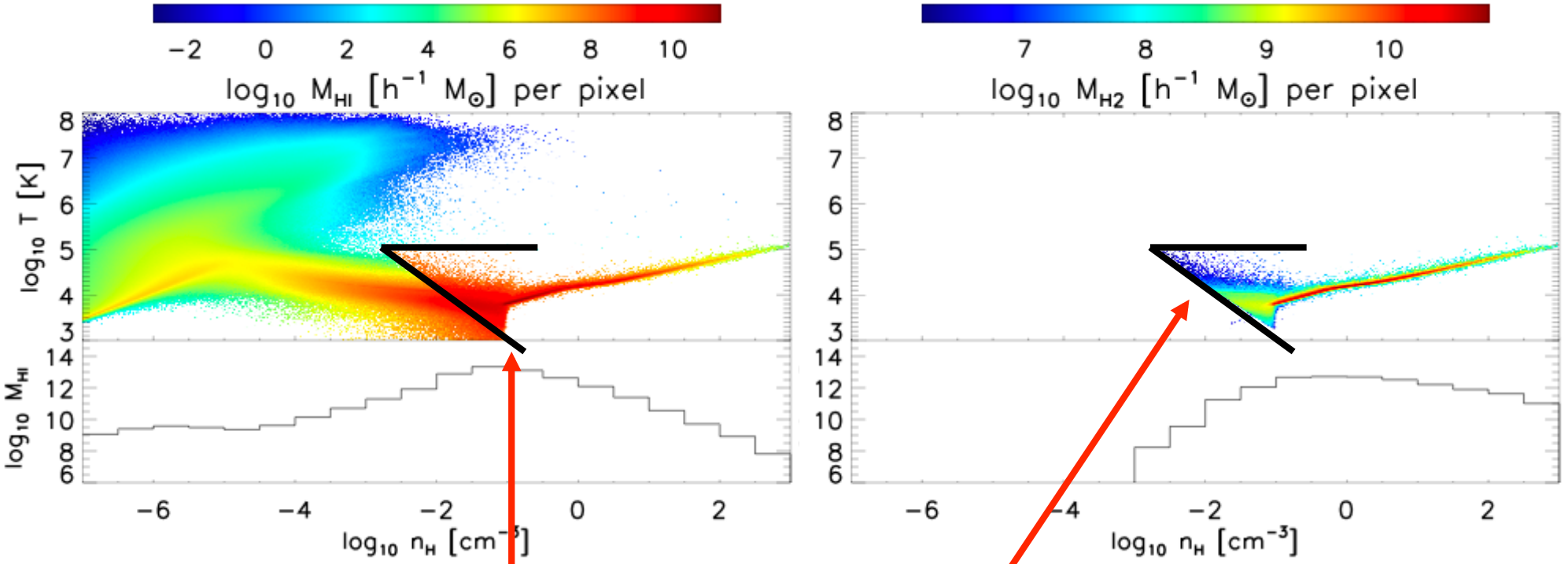


Assume Haardt-Madau (2001) UV/X-ray background for optically thin material

International Centre for Radio Astronomy Research

Creating HI

Self-shielding

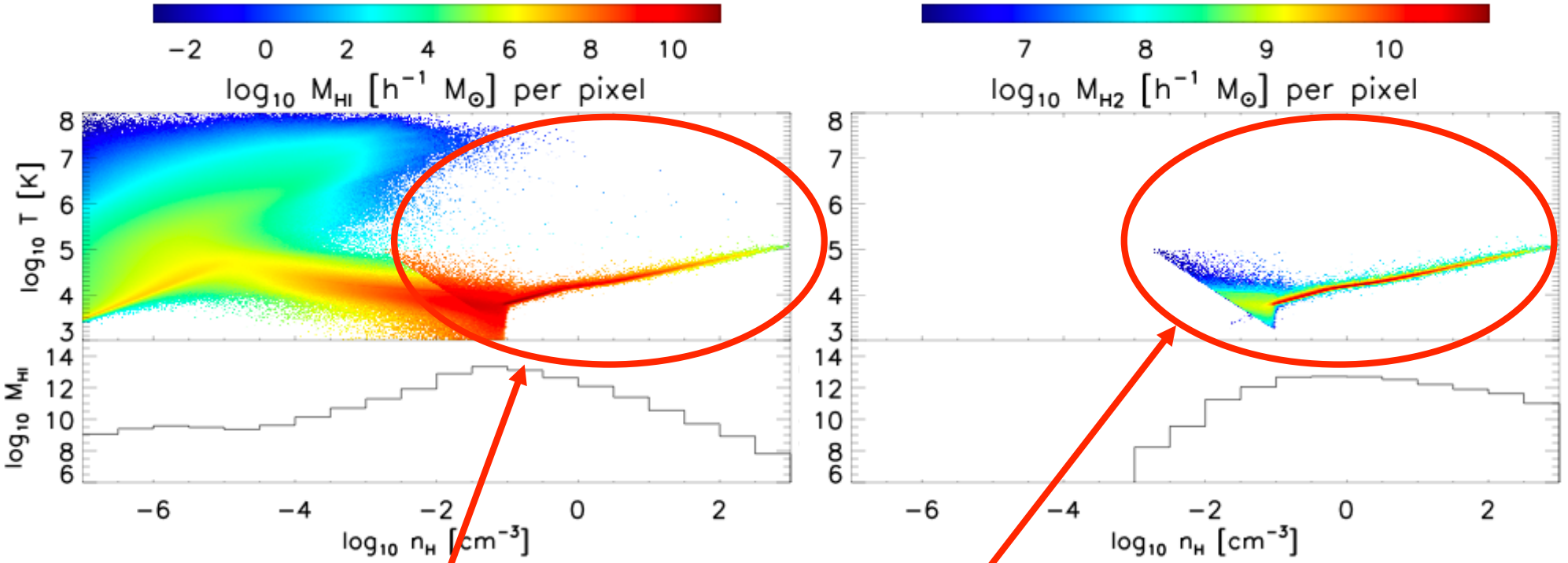


Onset of self-shielding given as a critical pressure, fit to the HIPASS mass function (only free parameter!)

International Centre for Radio Astronomy Research

Creating HI

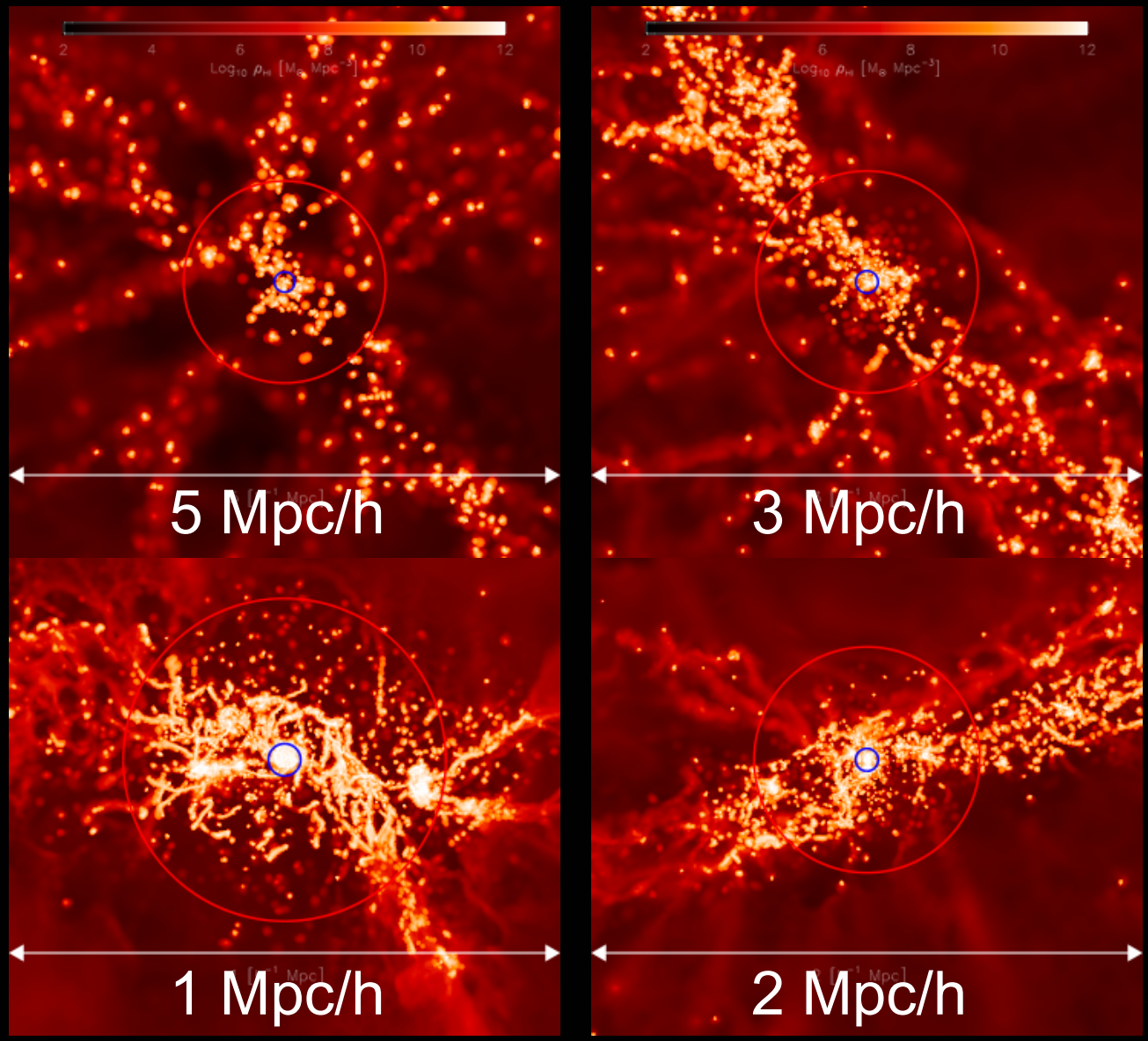
Molecular Hydrogen

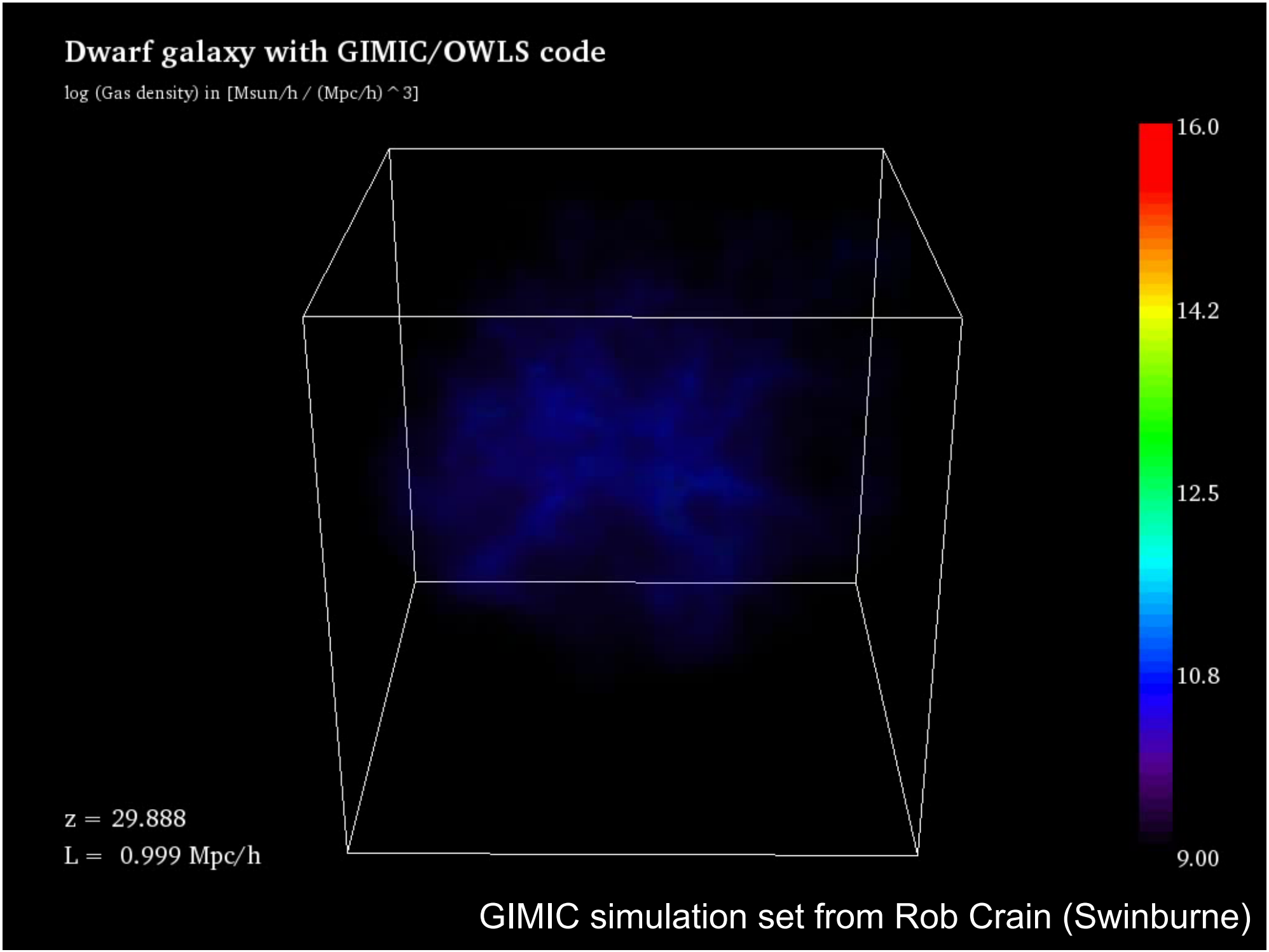


Ratio of neutral to molecular hydrogen given by pressure based empircal law from THINGS (Lerory et al 2008)
Shown in Gerhardt's talk

International Centre for Radio Astronomy Research

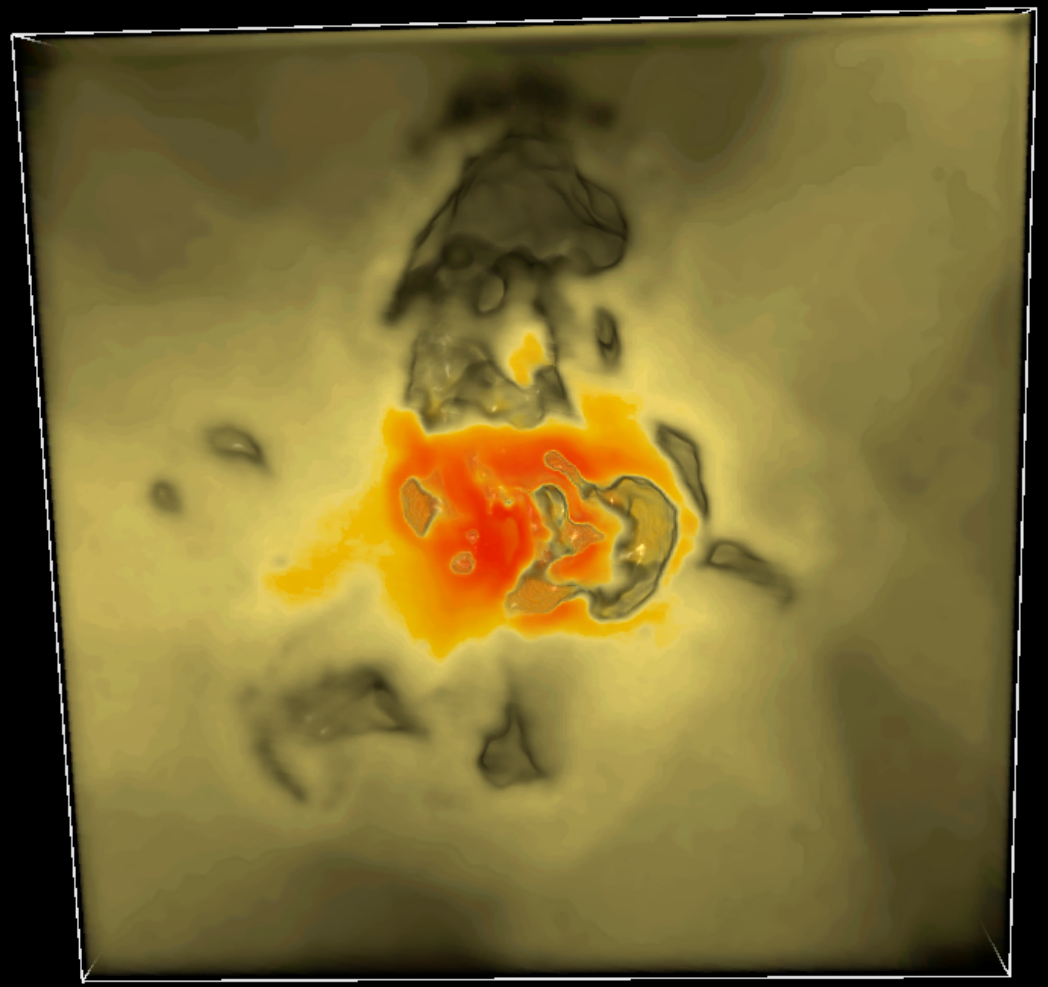
Visualising HI




Dwarf galaxy with GIMIC/OWLS code
log (Gas density) in [Msun/h / (Mpc/h) ^ 3]
16.0
14.2
12.5
10.8
9.00
z = 29.888
L = 0.999 Mpc/h
GIMIC simulation set from Rob Crain (Swinburne)

International Centre for Radio Astronomy Research

HI density of dwarf galaxy



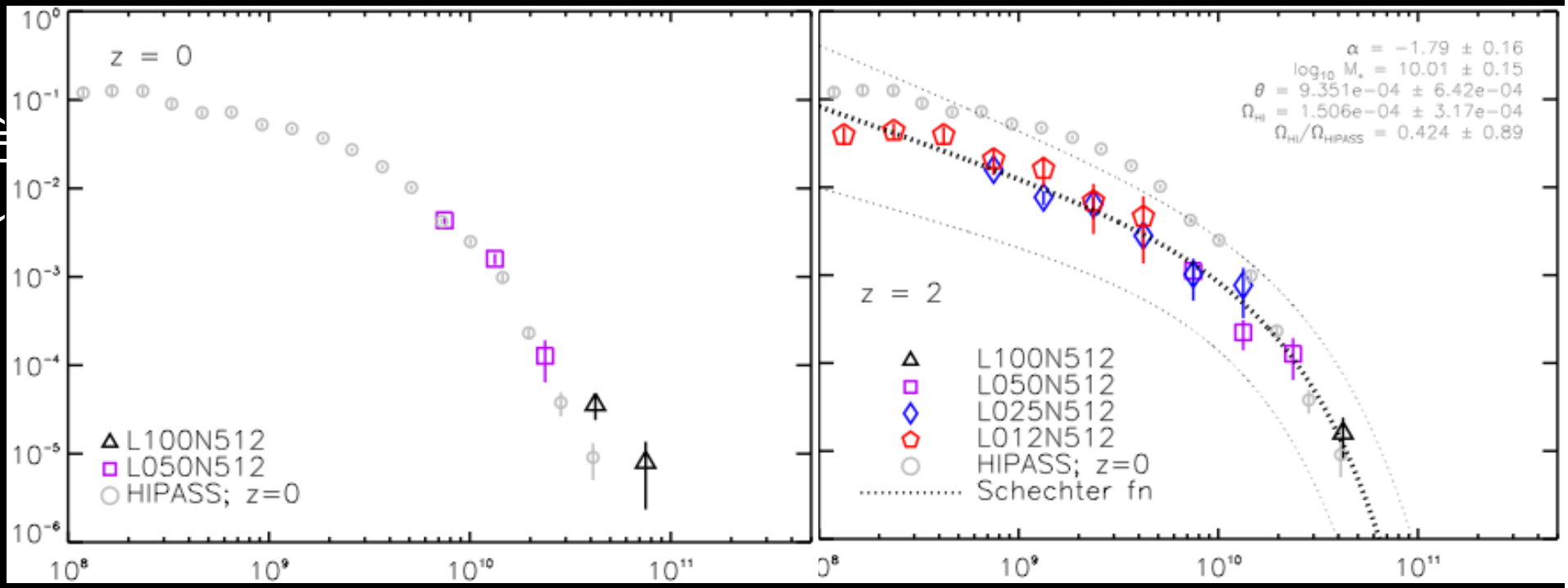
Visualisation effort with Paul Bourke (WASP) and Daniel Beard (UWA)

International Centre for Radio Astronomy Research

HI mass function

z = 0

z = 2



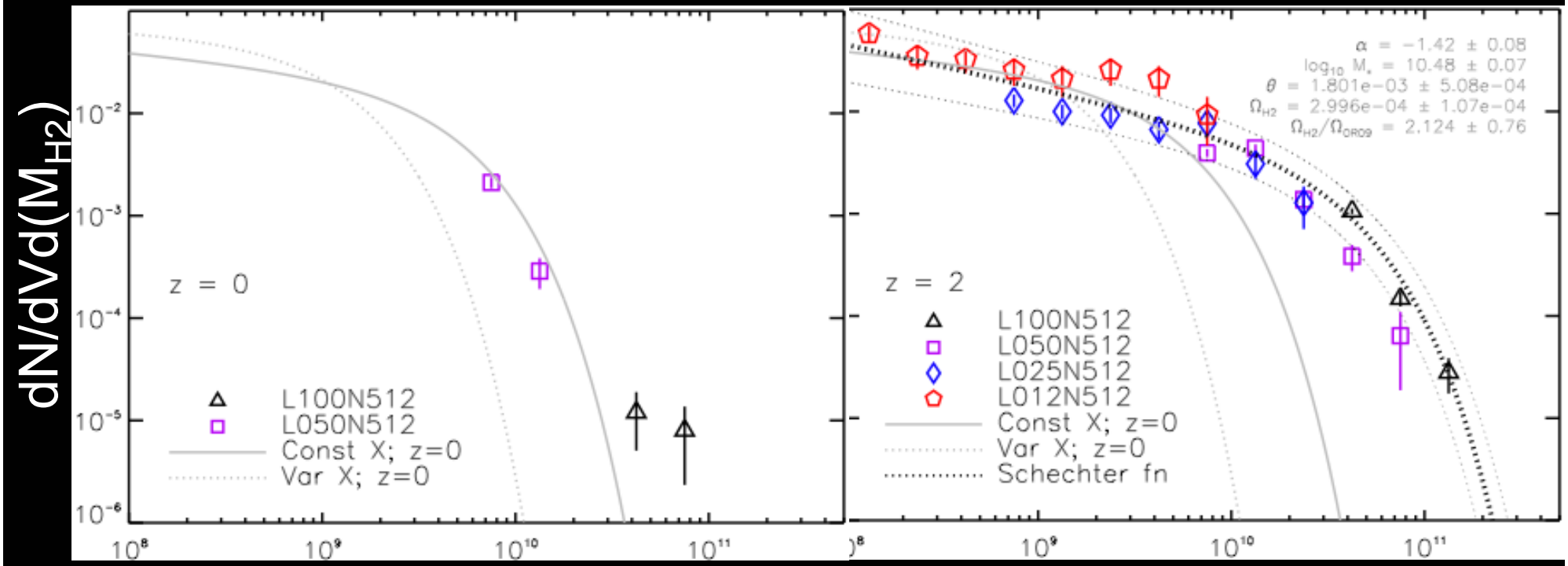
Local Universe is well matched - evolution to z=2 appears confined to faint end slope. Overall slight decrease in HI density

International Centre for Radio Astronomy Research

H_2 mass function

z = 0

z = 2

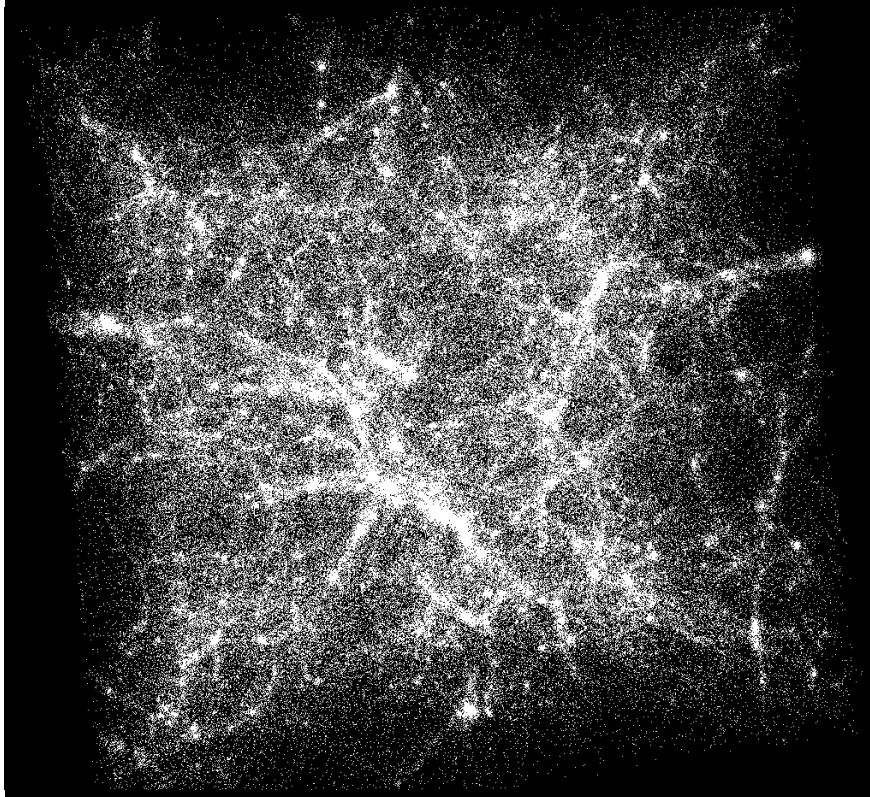


Local Universe is well matched - significant bright end evolution!

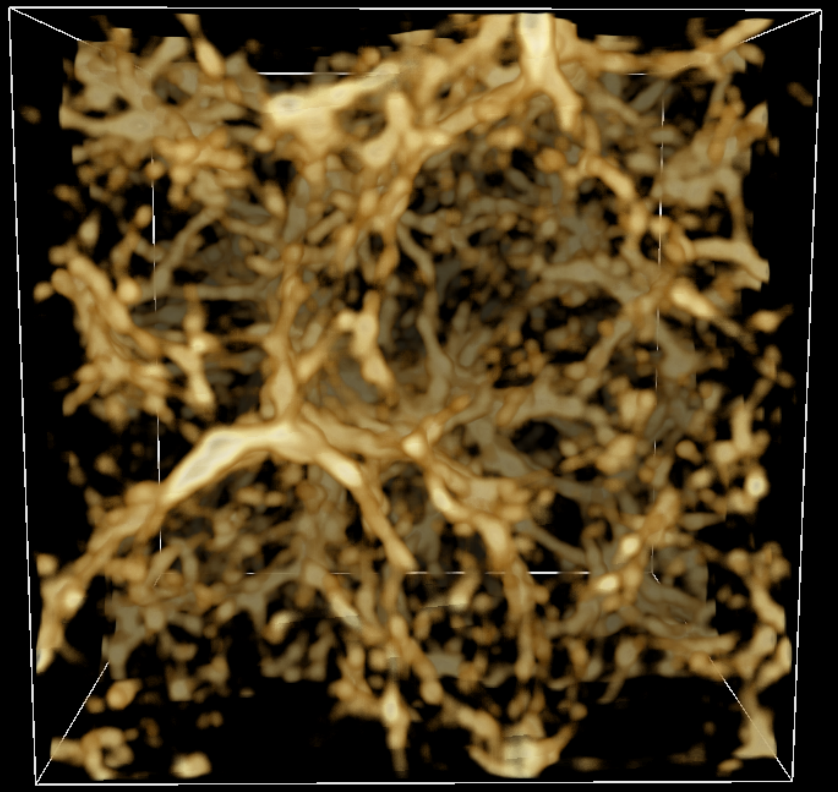
International Centre for Radio Astronomy Research

Cosmological Volumes

SPH points



‘Smoothed’ SPH points

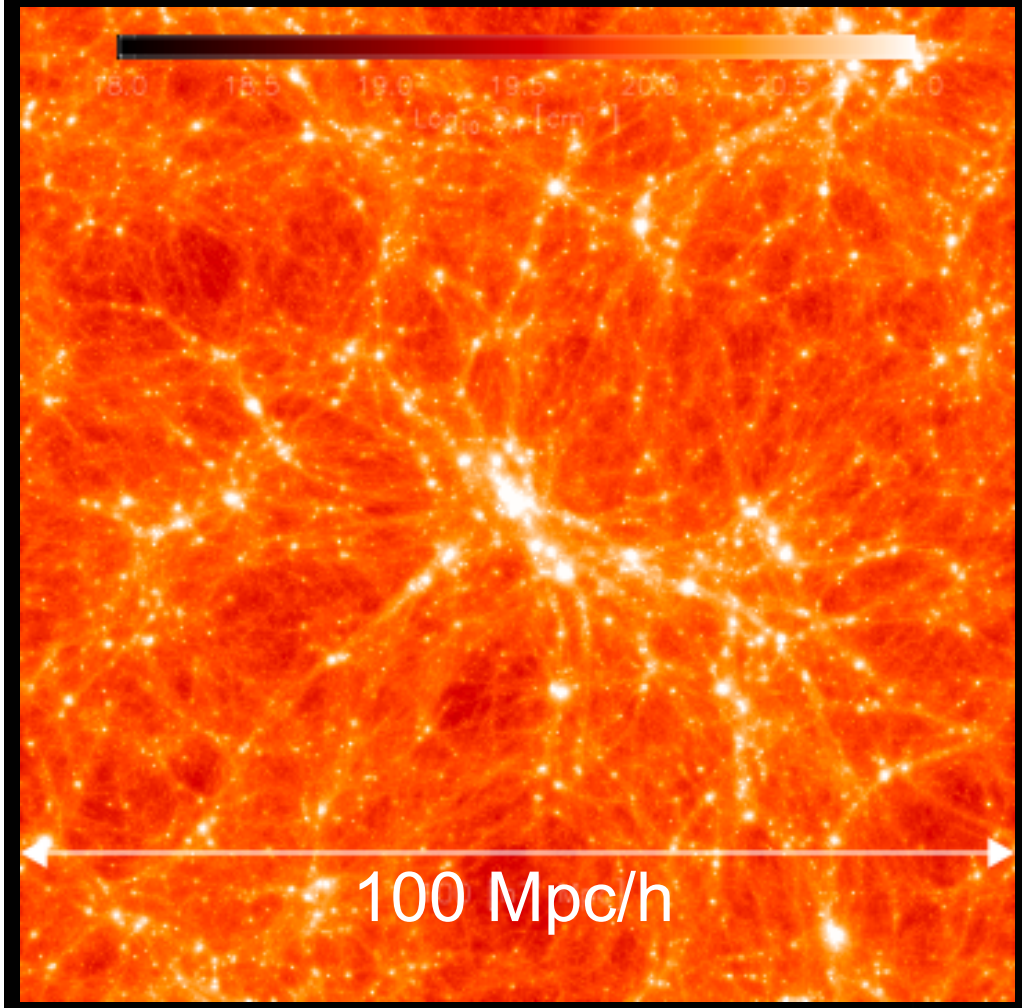


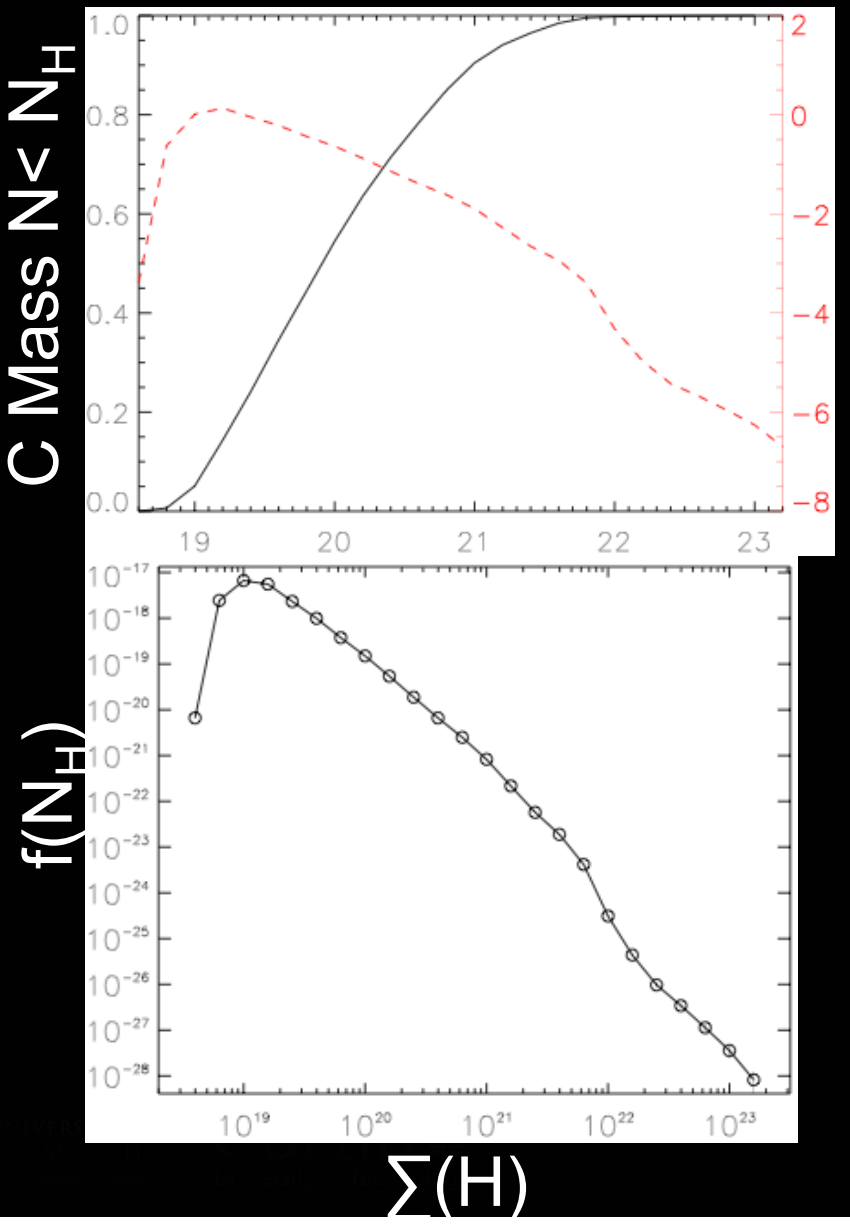
Visualisation effort with Paul Bourke (WASP) and Daniel Beard (UWA)

International Centre for Radio Astronomy Research

Cosmic Web

H Surface Density

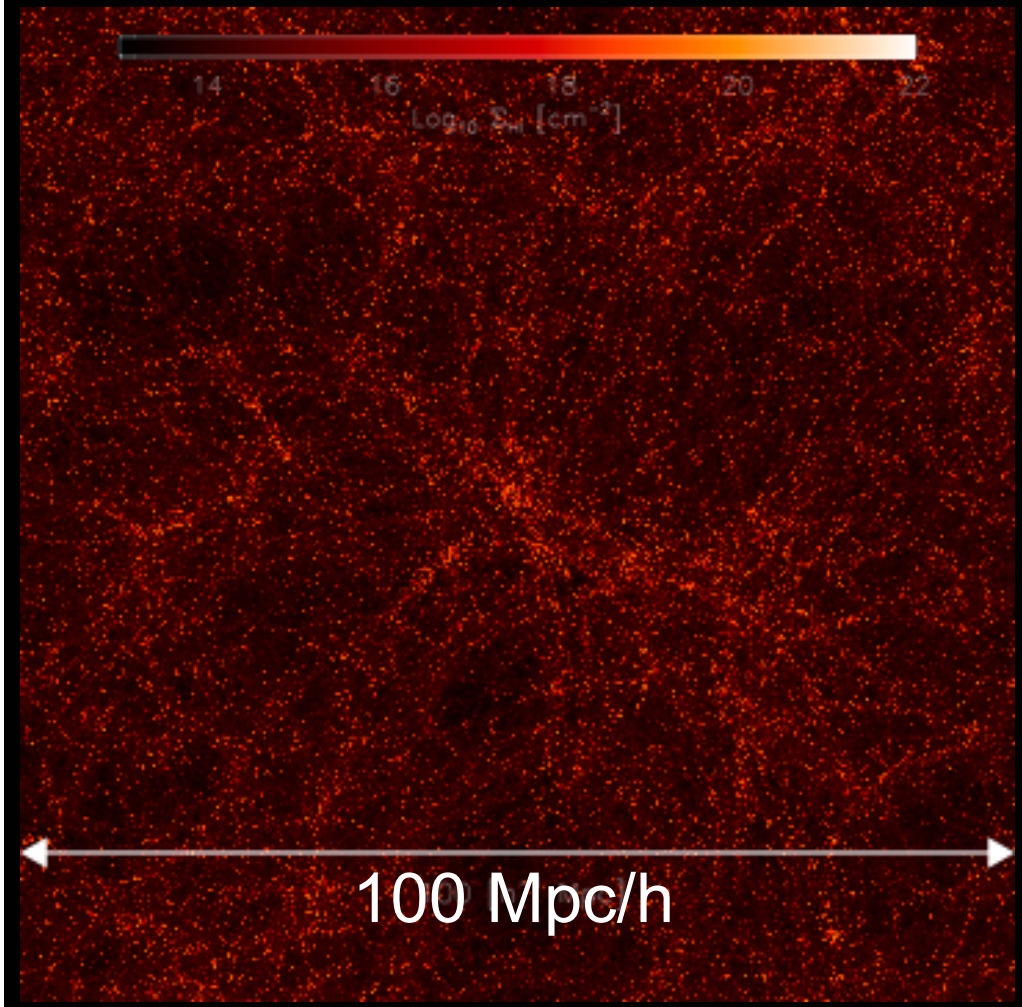


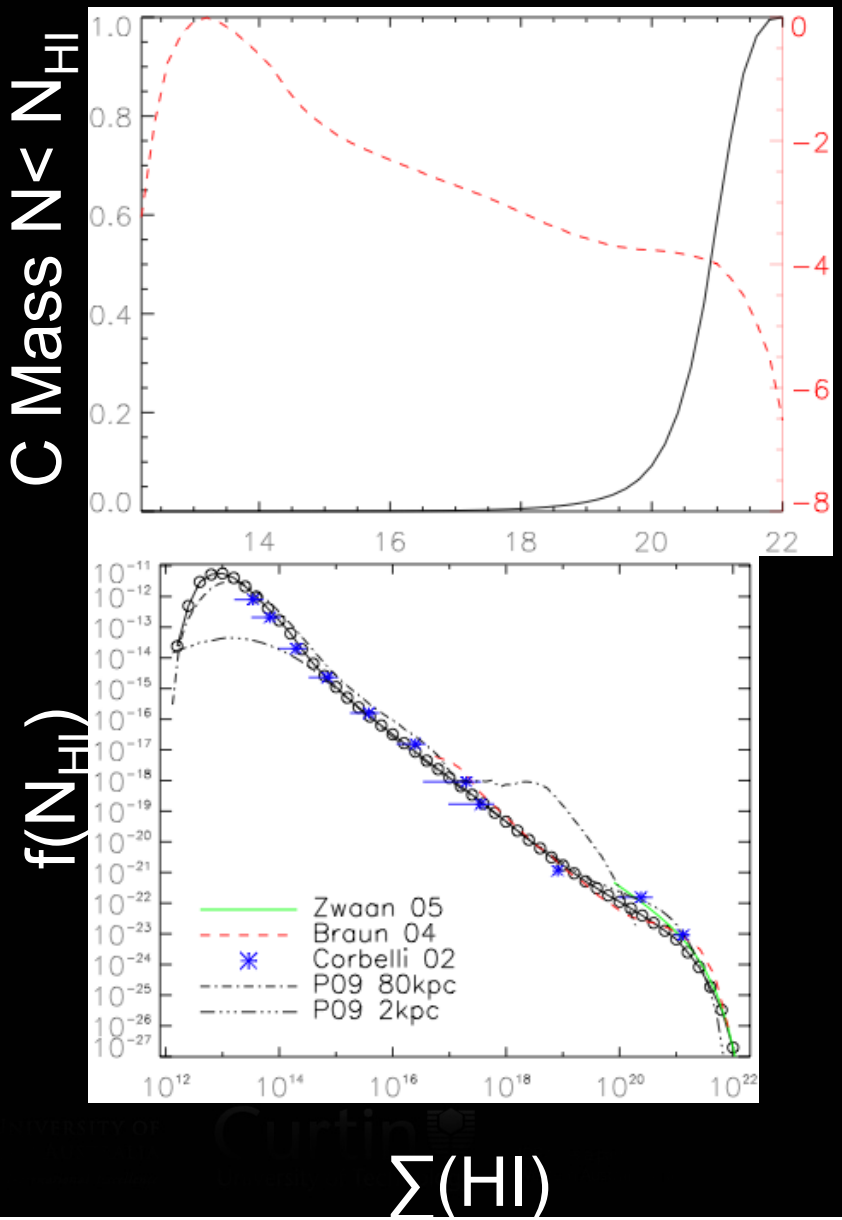


International Centre for Radio Astronomy Research

Cosmic Web

HI Surface Density

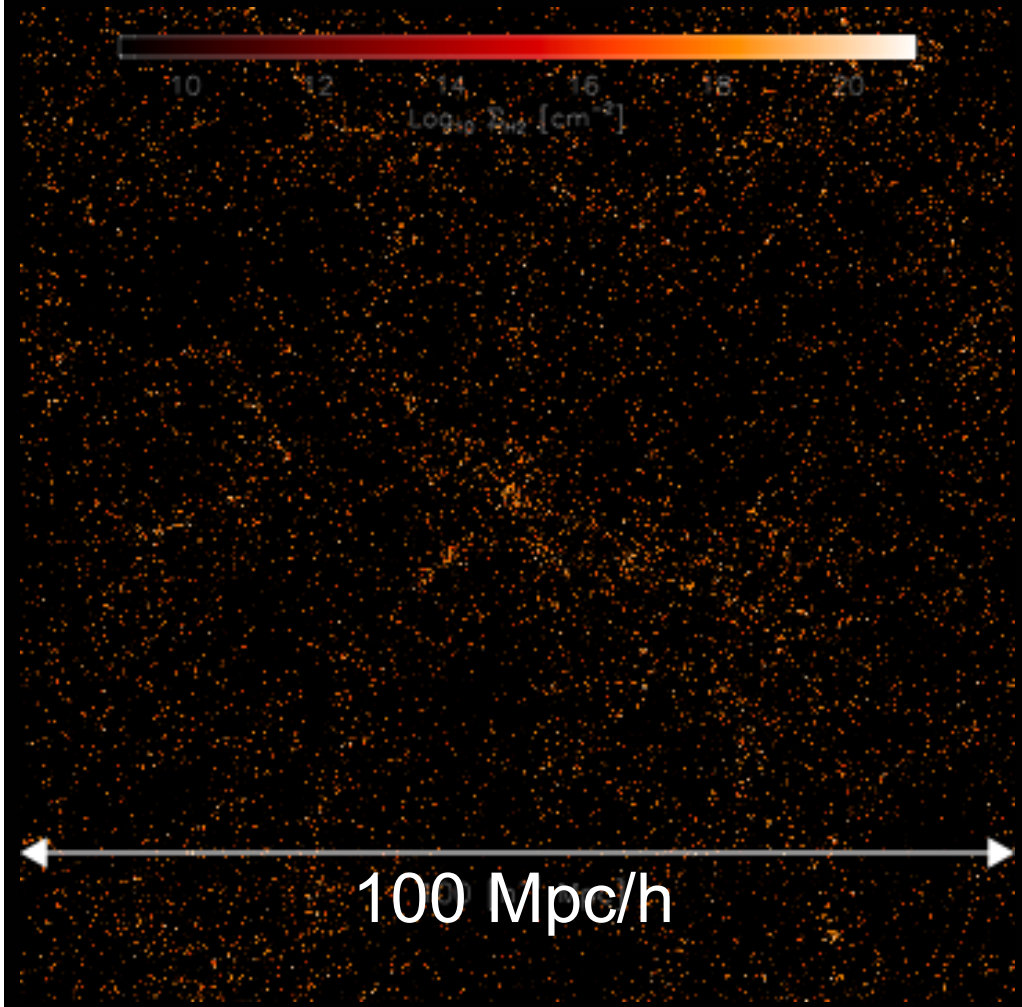


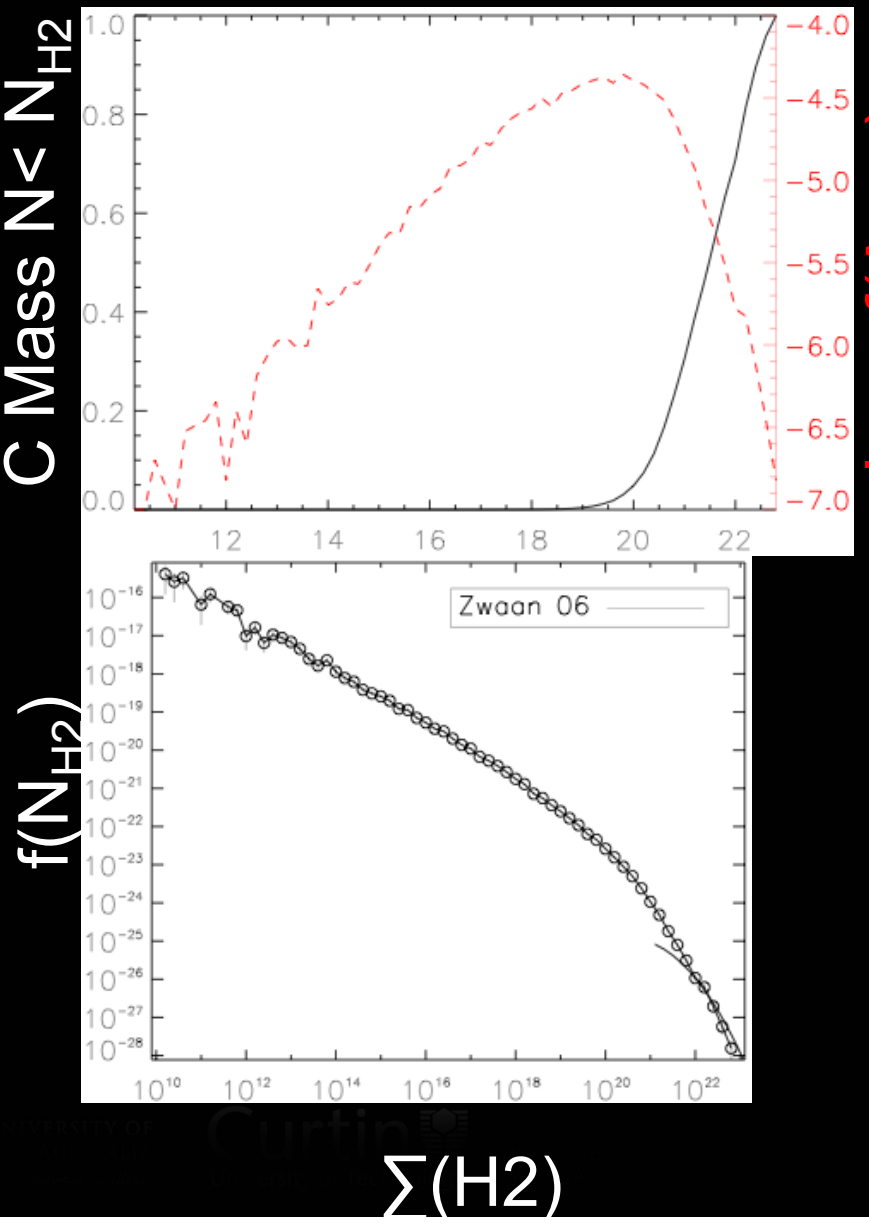


International Centre for Radio Astronomy Research

Cosmic Web

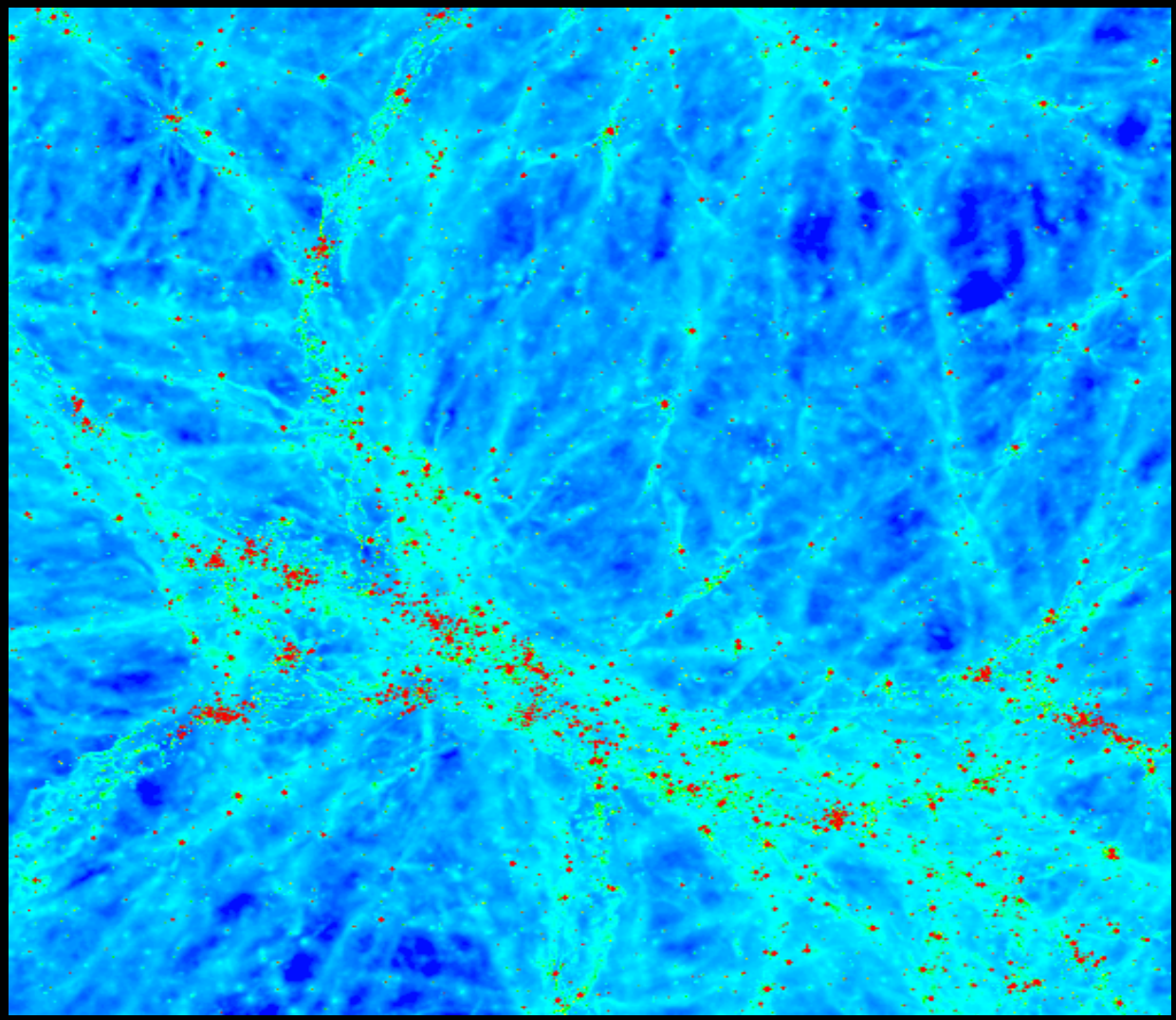
H_2 Surface Density





International Centre for Radio Astronomy Research

Detecting the Cosmic Web



Red points are ‘detections’ with a DINGO-like survey

Erwin’s MHONGOOSE?

Richard Dodson (ICRAR)

International Centre for Radio Astronomy Research

Conclusions

Hydro-simulations allow one to predict effects of AGN, SNe, differing IMF, etc

Can predict evolution in HI & H_2 mass functions as well as the column density distribution function

Crucial theoretical support for Cosmic Web surveys

Get a realistic distribution of galaxies for cosmological parameter constraints (Florian's talk)

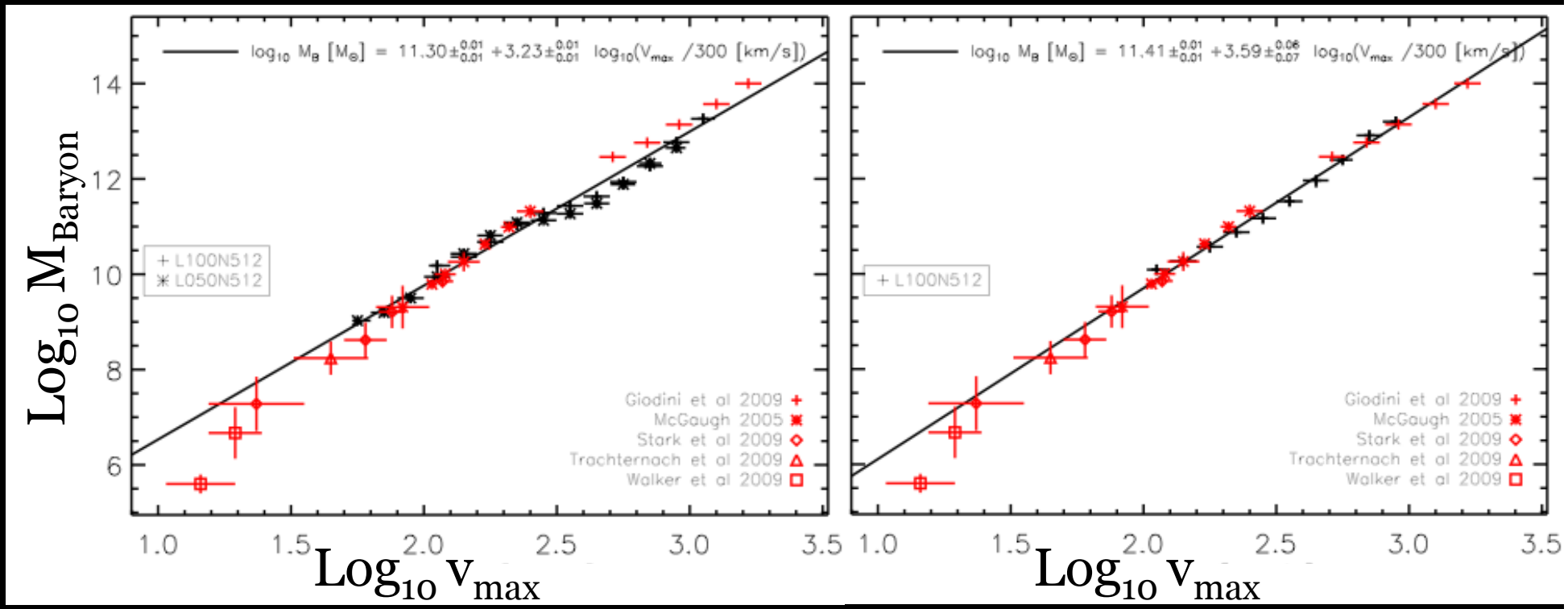
Great for outreach - a signature theme at ICRAR

International Centre for Radio Astronomy Research

Baryonic Tully-Fisher relation

SNe

SNe+AGN



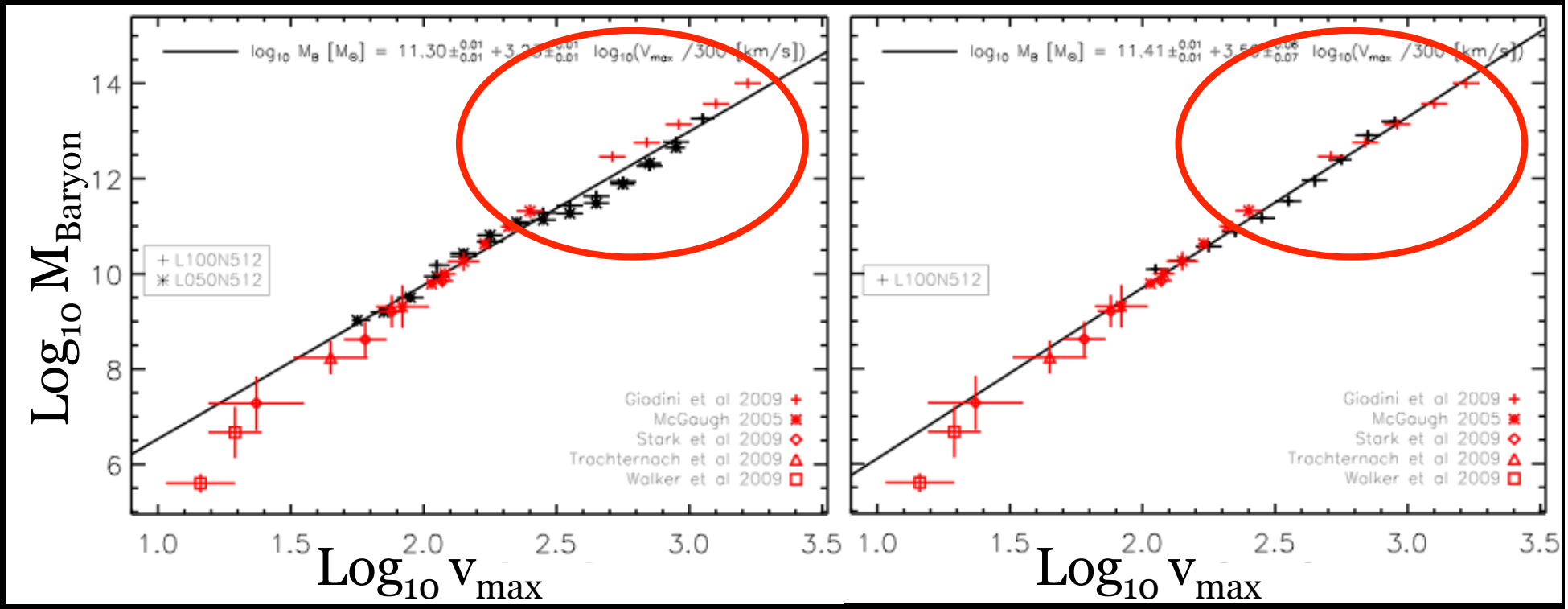
Benne and Sarah should be watching…

International Centre for Radio Astronomy Research

Baryonic Tully-Fisher relation

SNe

SNe+AGN



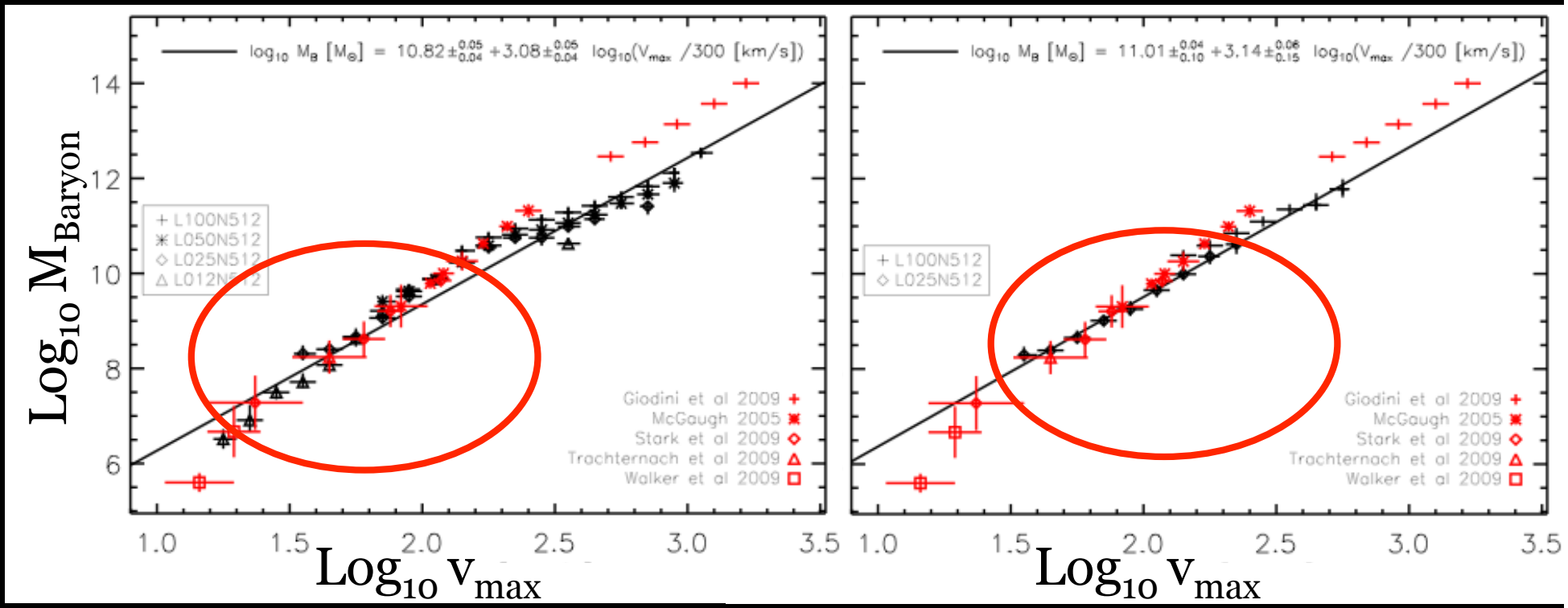
Above 200 km/s, for a given baryonic mass the velocity is to high without AGN!

International Centre for Radio Astronomy Research

Baryonic Tully-Fisher relation

SNe

SNe+AGN



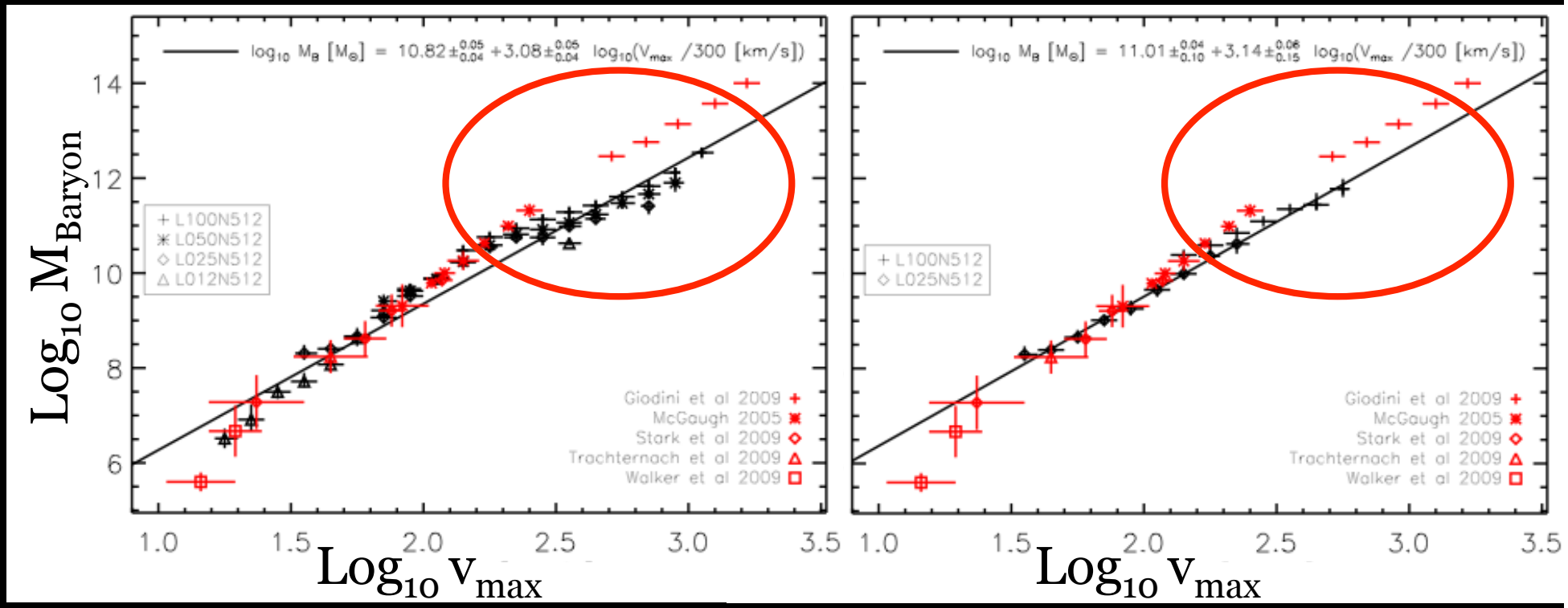
At z=2 the BTF agreement is spot on below 200 km/s

International Centre for Radio Astronomy Research

Baryonic Tully-Fisher relation

SNe

SNe+AGN



At z=2 the BTF agreement is spot on below 200 km/s
However, the disagreement at high velocities isn't resolved- the slope is now closer to 3 not 4! Evolution?

International Centre for Radio Astronomy Research

Viewing the Universe