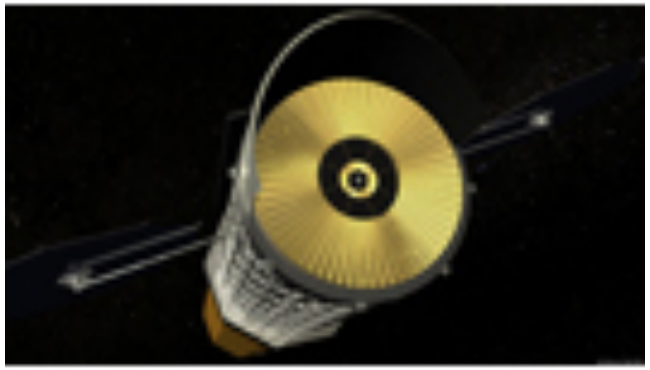
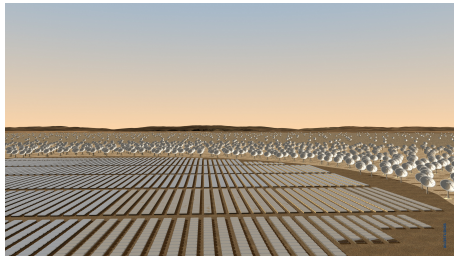
Galaxy Evolution & Cosmology: IXO & SKA Synergies



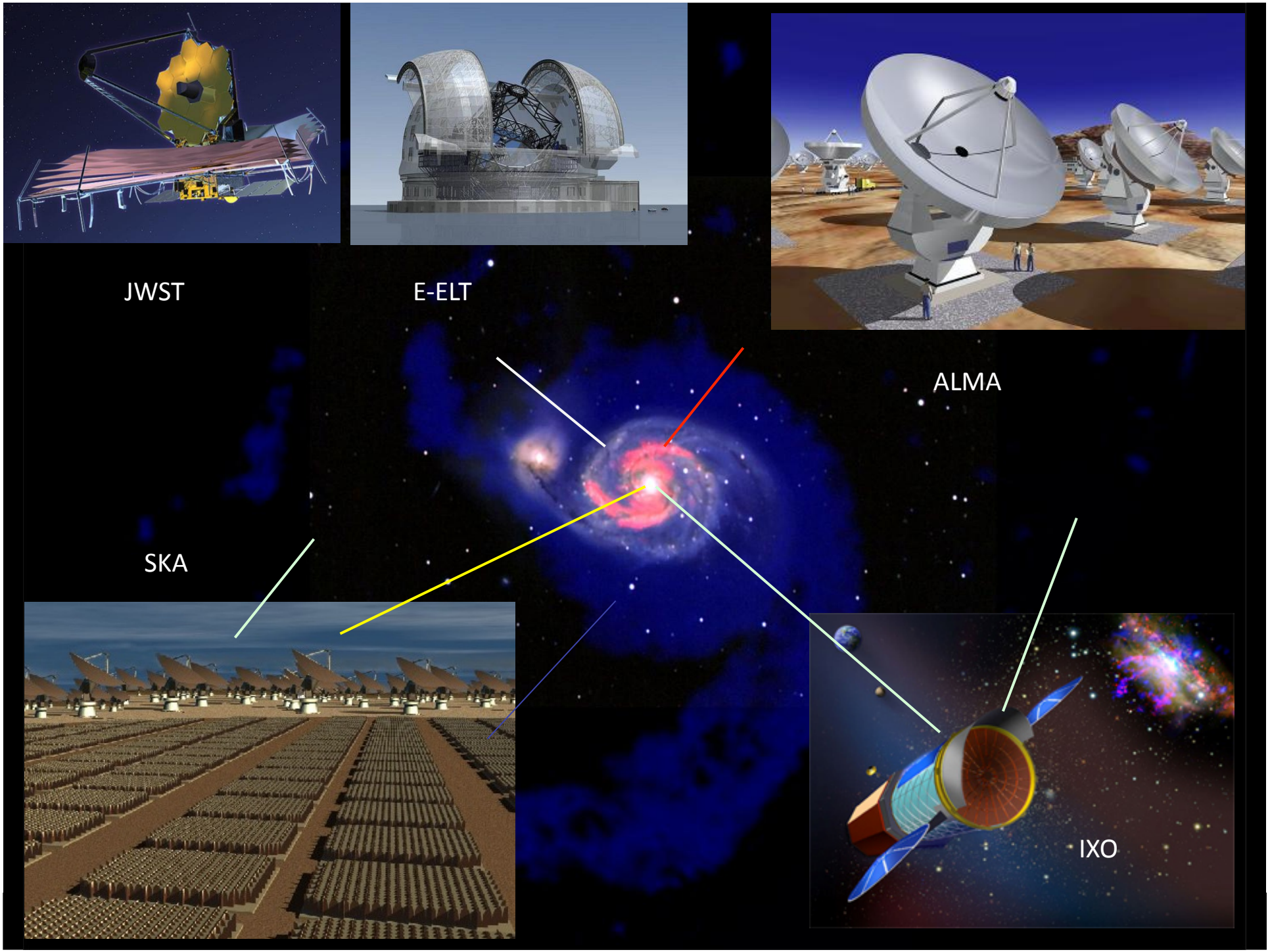
2010 to ~2020

80 to 250 dishes Phase 0 to 1, LOFAR to ~10-xLOFAR (radio quiet)

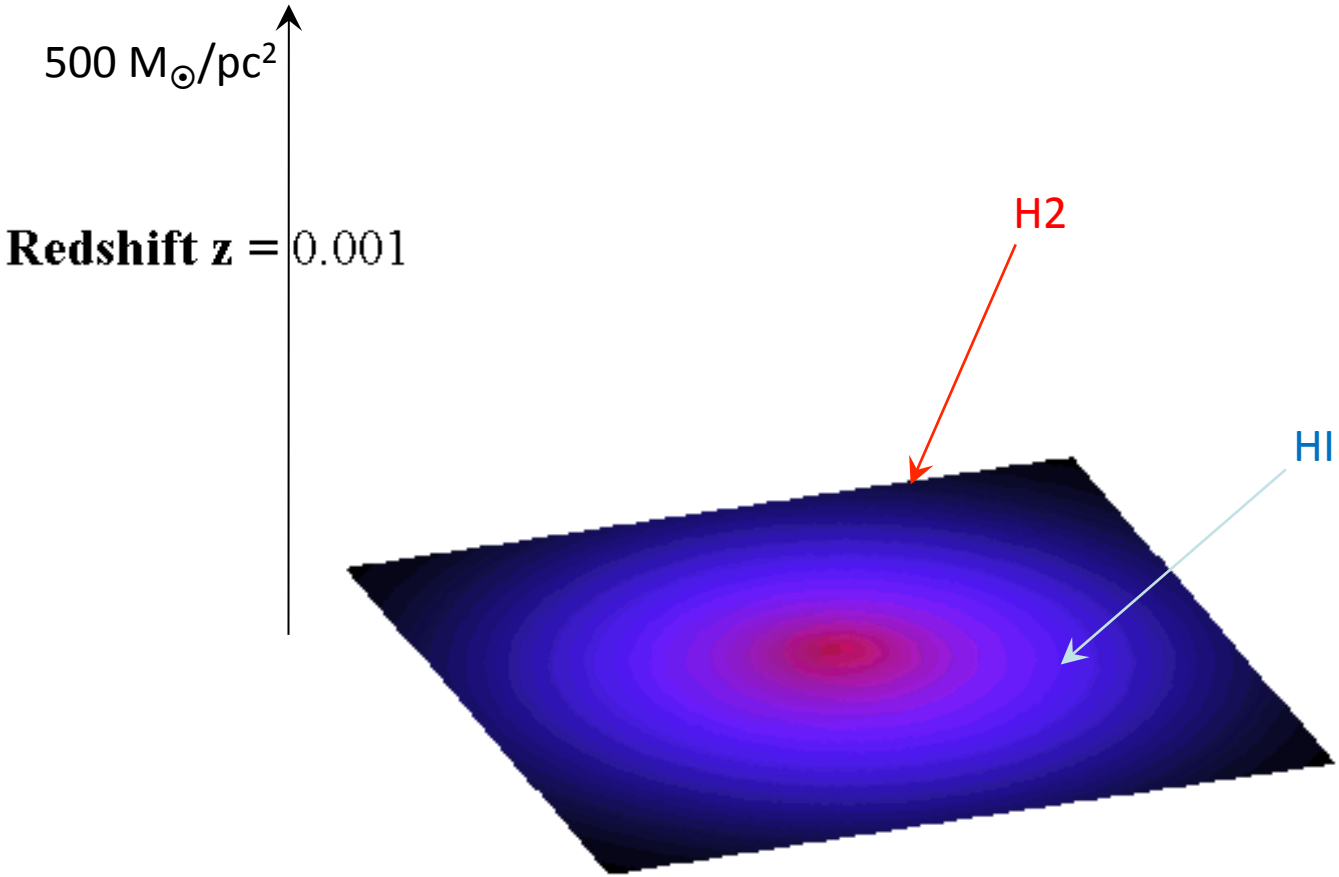


to 2500 dishes; to ~50xLOFAR plus 250 AA stations Phase-2

SKA Phase-0 2010, Phase-1 2016-2019, Phase-2 2019-2022

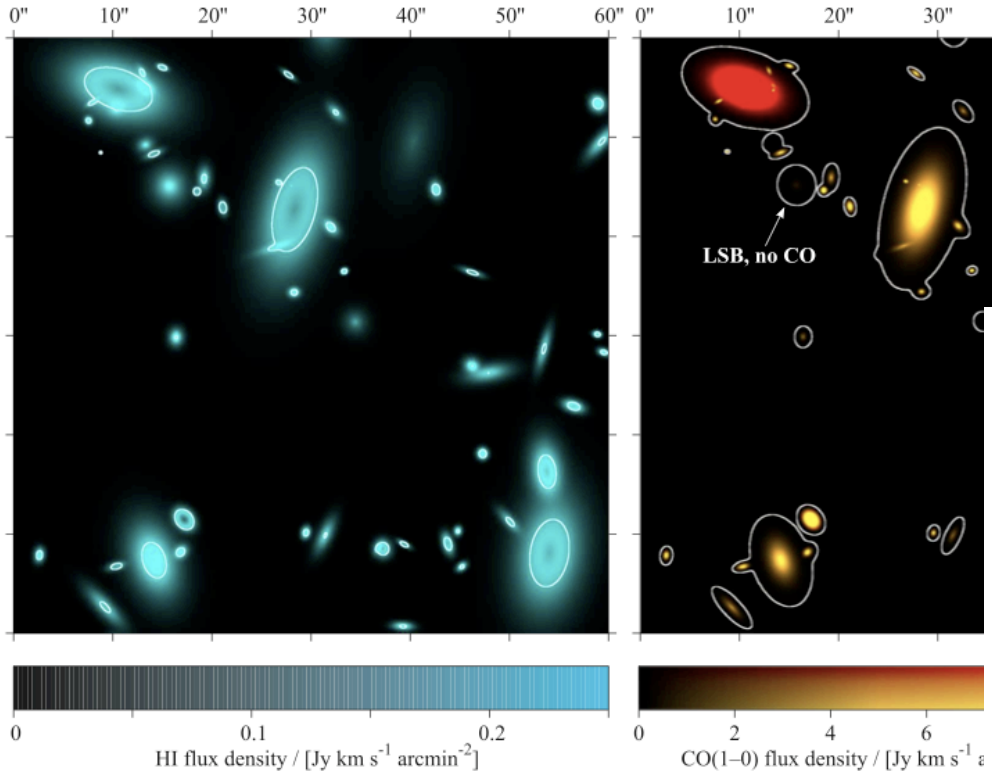

JWST
E-ELT
ALMA
SKA
IXO

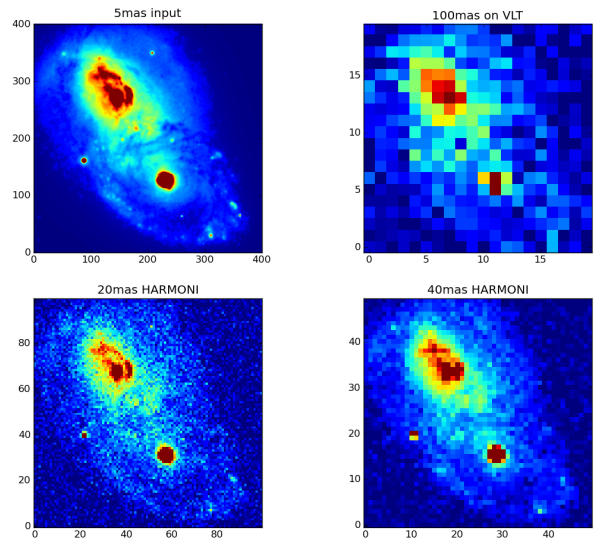
Galaxy Evolution (Milky Way)



Obreschkow et al. 2009 (ApJ 698); Obreschkow et al. 2009 (ApJ 703)

SKA/ALMA/E-ELT synergy on galaxy evolution



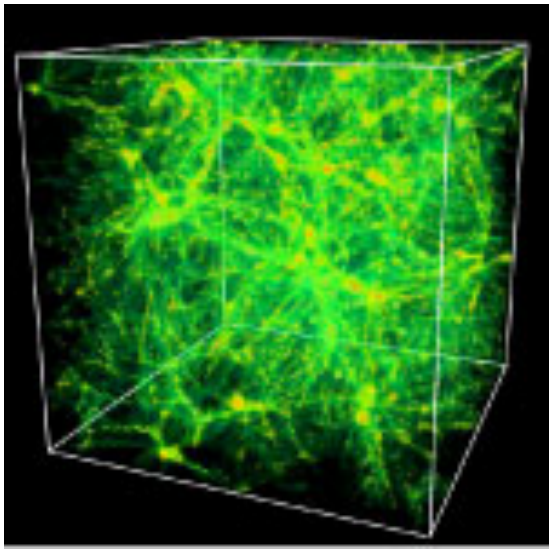


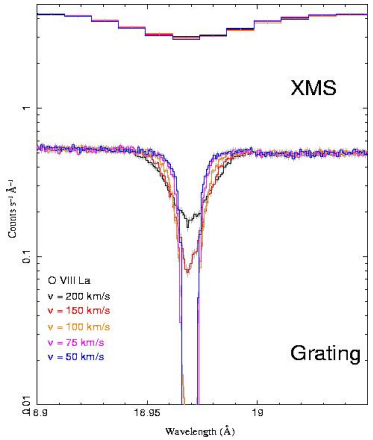
ALMA and SKA are natural IFUs

E-ELT IFU will map out individual HII regions

These facilities will map out the History of baryons **in galaxies**

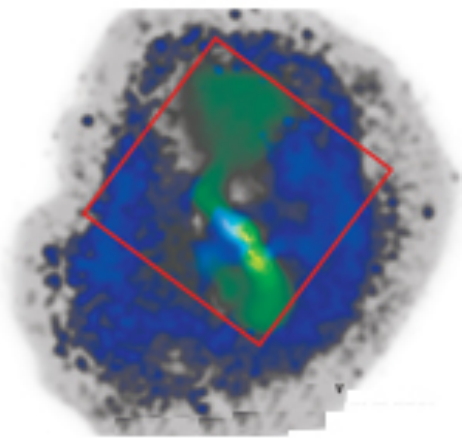
Baryons in the IGM&ICM: IXO&SKA





IXO detects WHIM

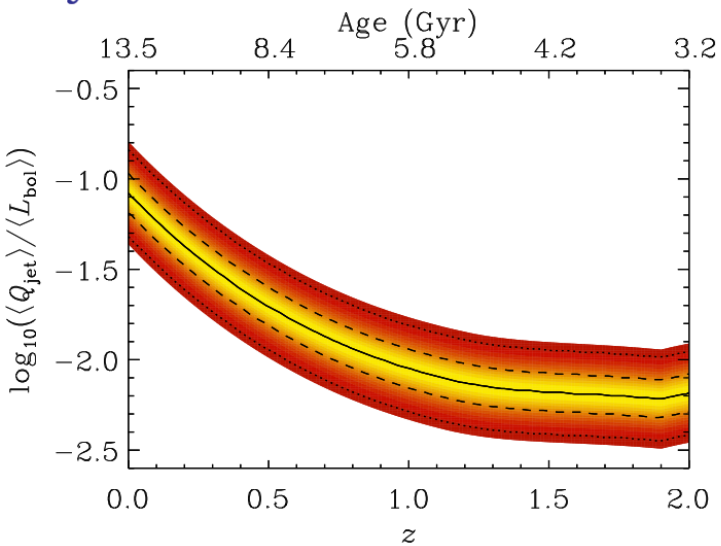
SKA contributes
- n_e from DM of Xgal giant pulses
- Synchrotron emission from accretion shocks
- HI to N_H~10^{20} m^{-2}

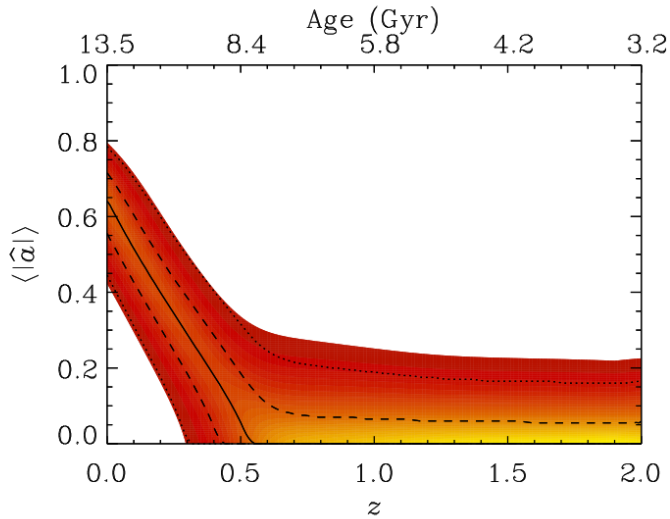


IXO measures flow velocities and energies in hot phases

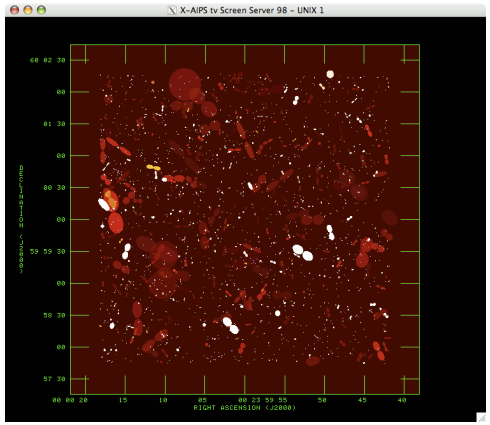
SKA contributes
- Jet-fed and shock-induced synchrotron
- SZ
- B-fields

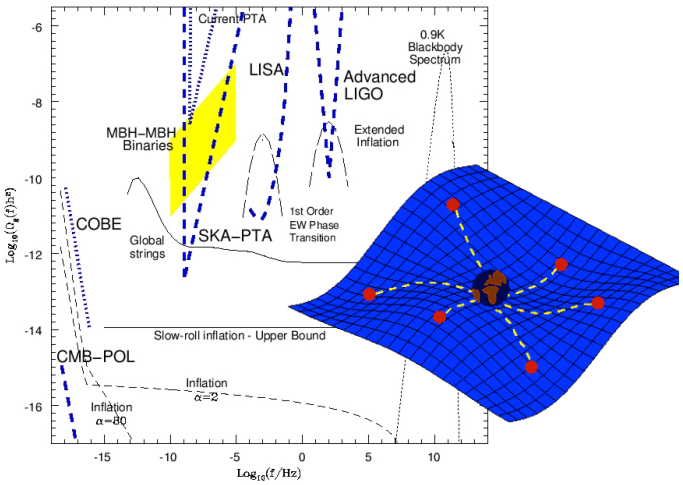
Feedback & Black Hole Spin: SKA & IXO

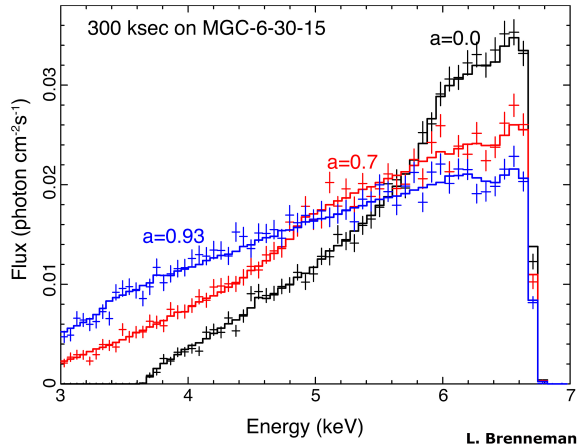




Martinez-Sansigre & Rawlings (2010)

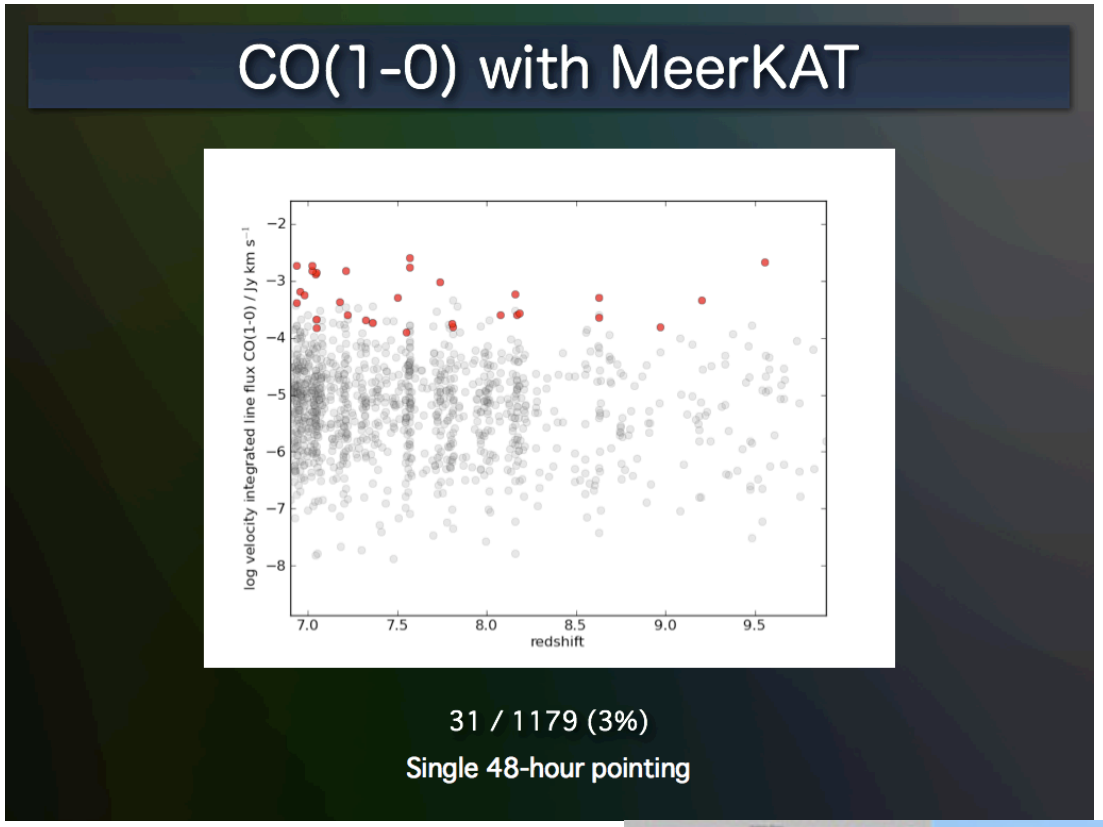






Conventional and unconventional SKA experiments, complemented by IXO

First Galaxies



CO(1-0) is hard, requiring internally-heated objects to overcome CMB

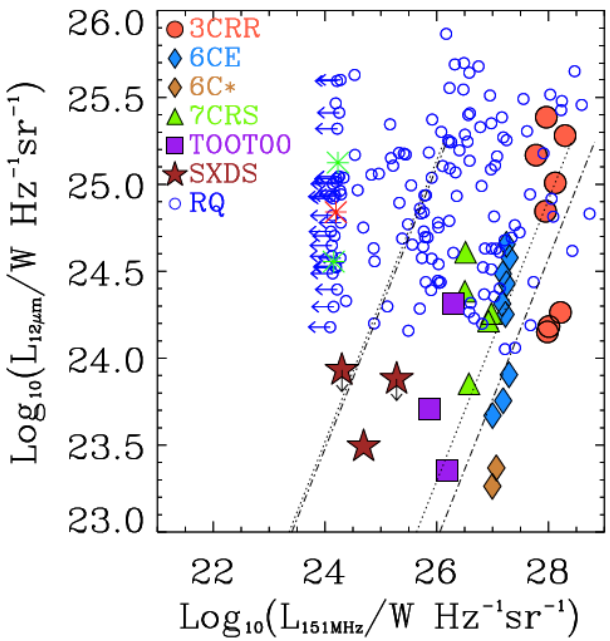
The Promise of MeerKAT/SKA$_1$: ~5/20-times faster than eVLA

Red is 5 sigma in 1 channel

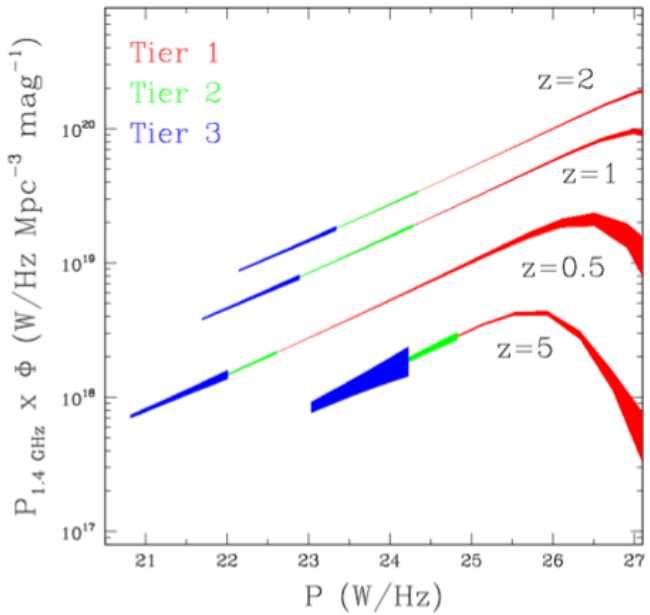
2009 Dec 3

First fringes

First SMBHs: SKA & IXO



Fernandes et al (2010)

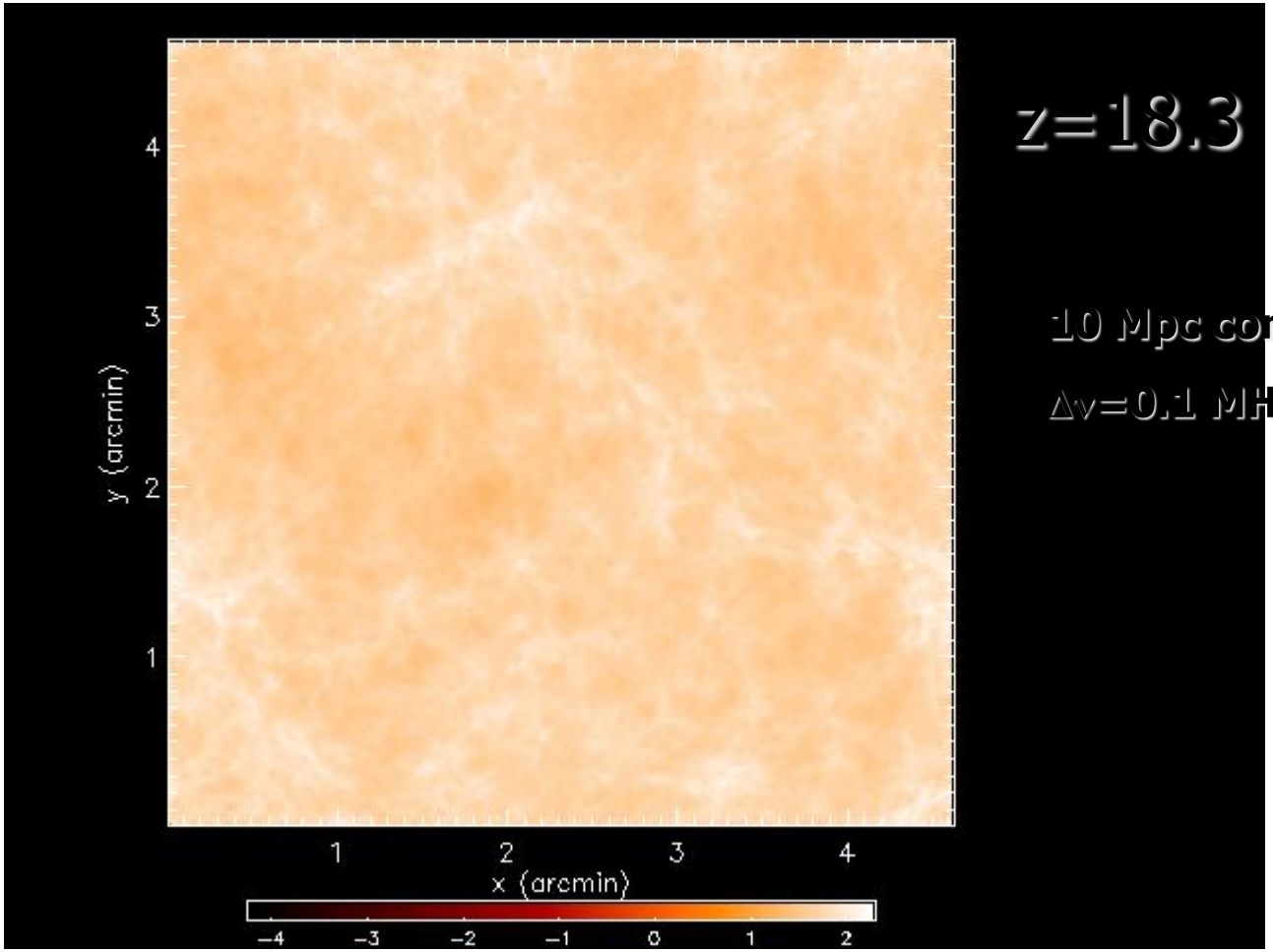


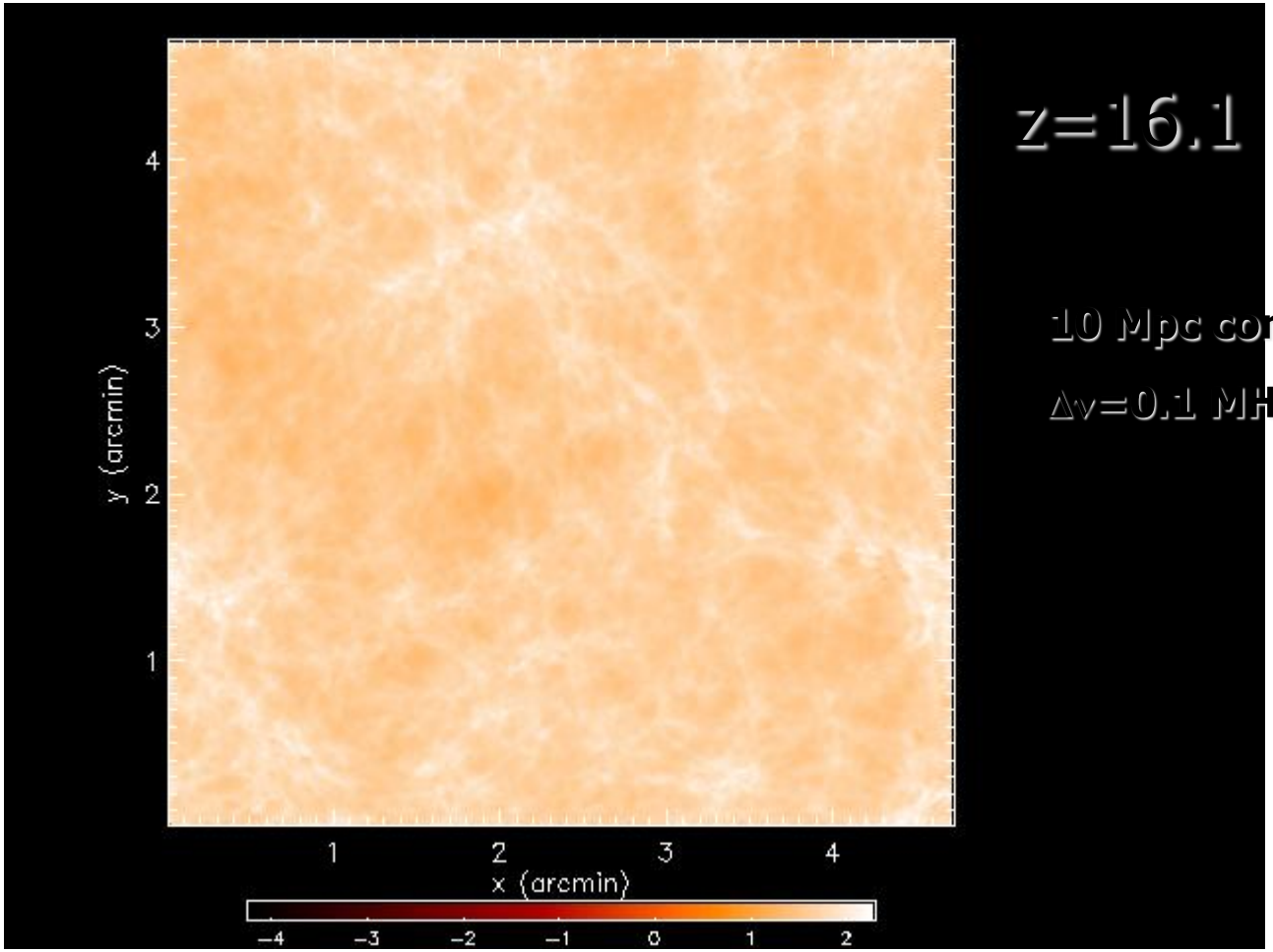
From van der Hayden & Jarvis et al.
MeerKAT proposal: SKA_1 does Tier 2 (1μJy) all-sky in a few months, and Teir 3 (0.1μJy) at ~1000 deg^2/yr; z=2 to 7 is ΔLog(P)~10

SKA_1 will find ALL the first SMBHs, but (because of favourable k-correction) IXO will measure their accretion rates

Epoch of Re-ionization

Furlanetto et al. (2003)

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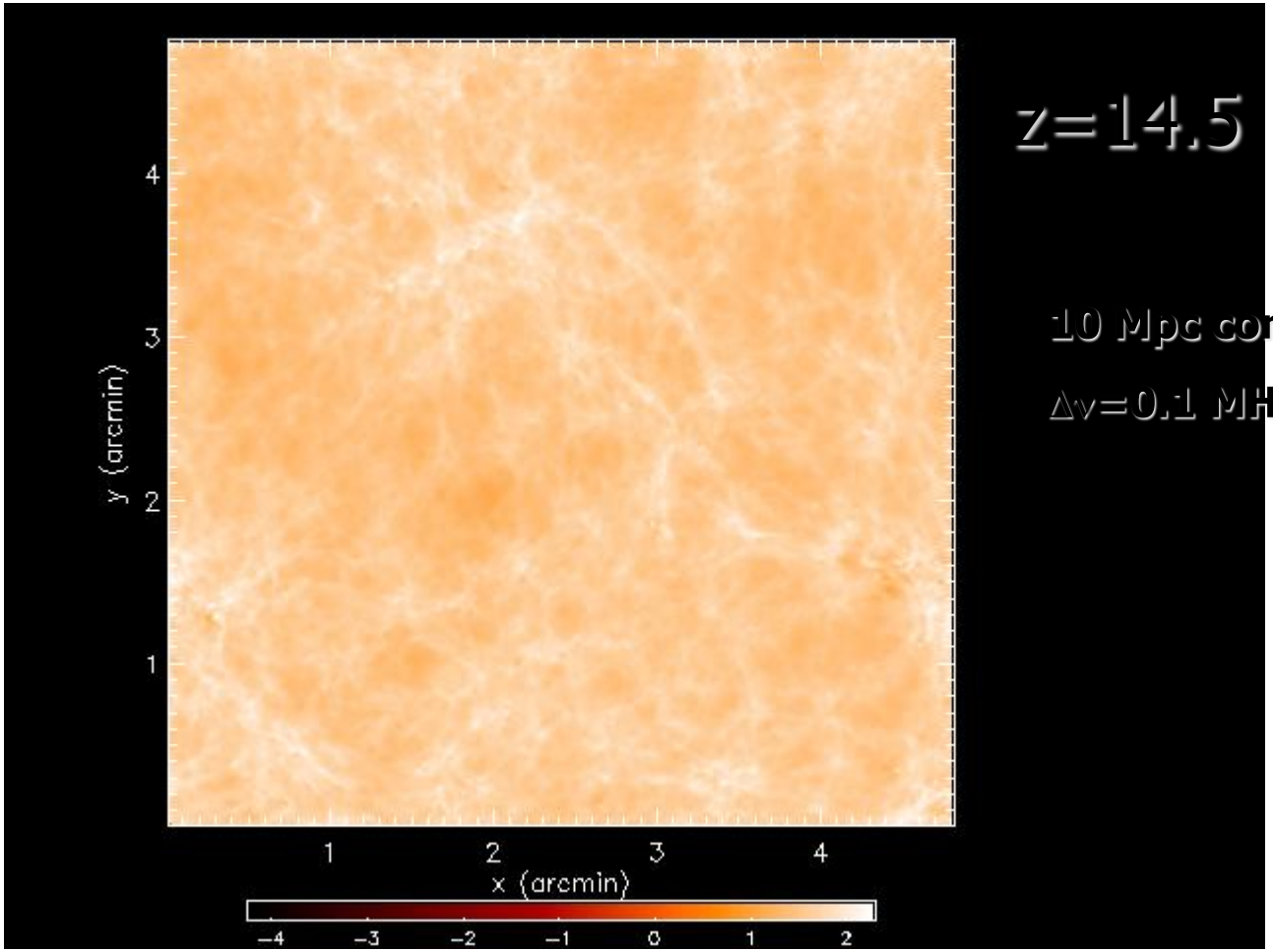
10 Mpc comoving
Δν=0.1 MHz
y (arcmin)
x (arcmin)
1
2
3
4
−4
−3
−2
−1
0
1
2


z=14.5
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Δν=0.1 MHz
y (arcmin)
x (arcmin)
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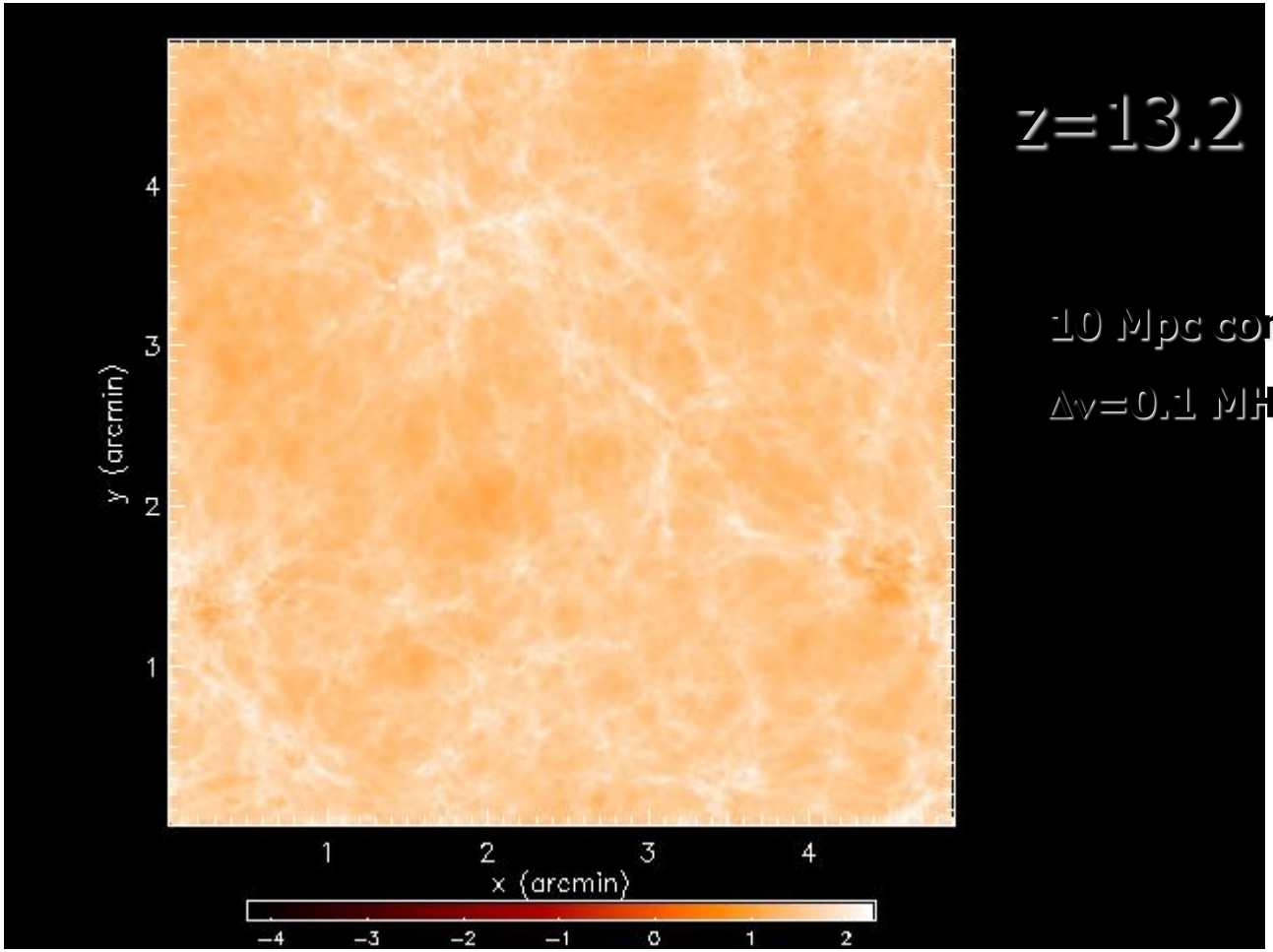
3
4
−4
−3
−2
−1
0
1
2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10 Mpc comoving
Δν=0.1 MHz
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x (arcmin)
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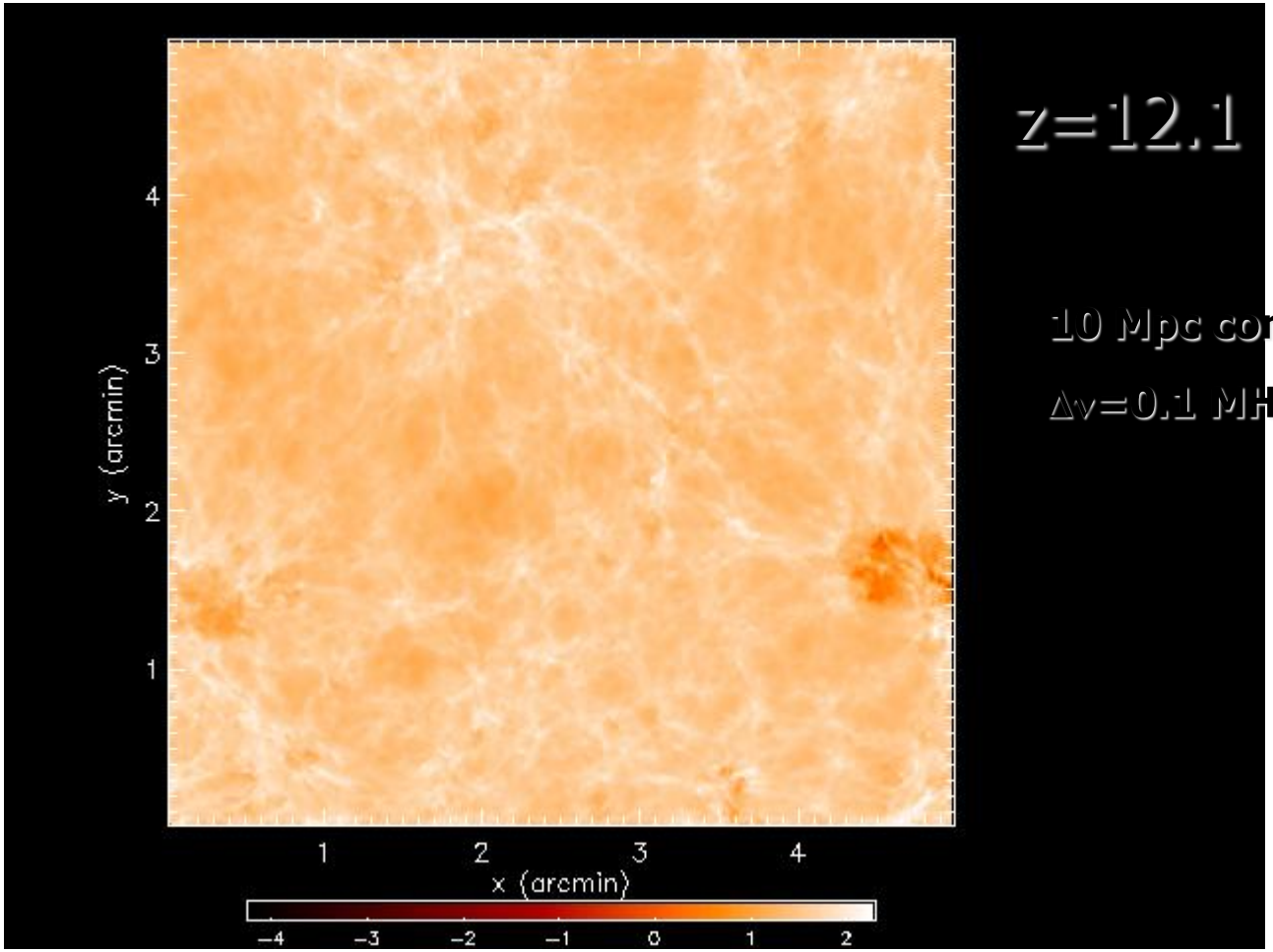
2
3
4
−4
−3
−2
−1
0
1
2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Δν=0.1 MHz
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x (arcmin)
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3
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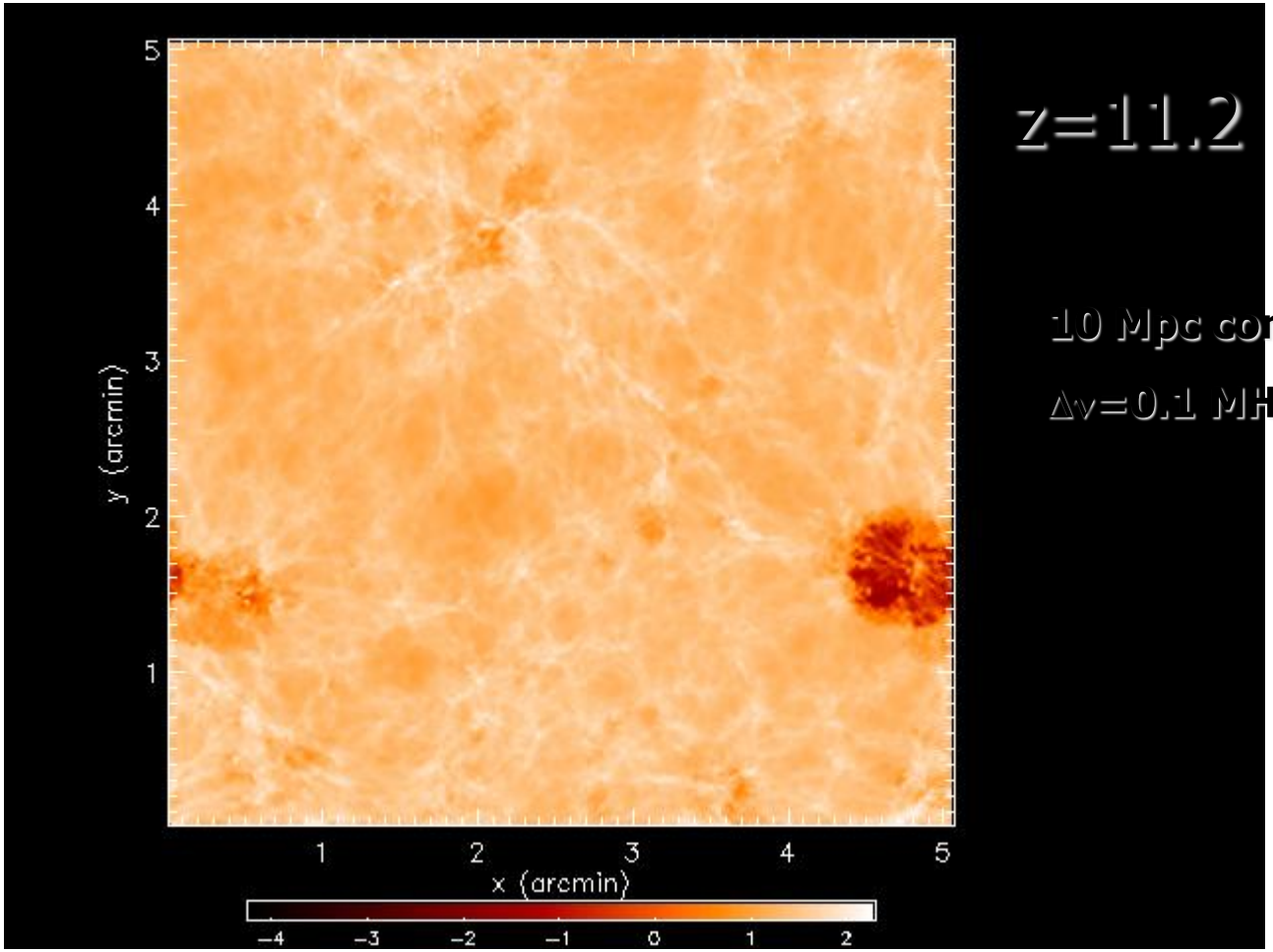
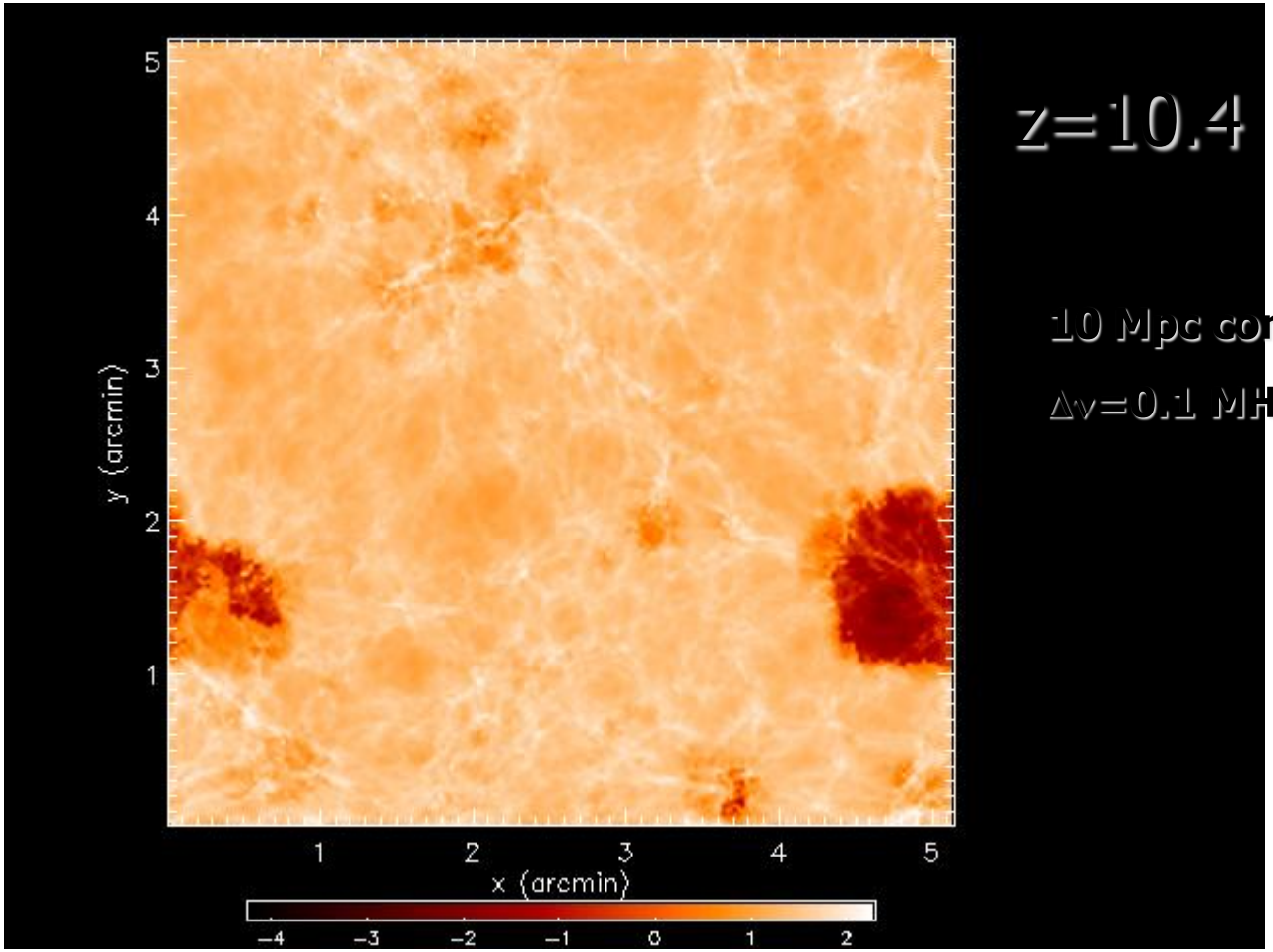
−2
−1
0
1
2


z=11.2
10 Mpc comoving
Δν=0.1 MHz
y (arcmin)
x (arcmin)
1
2
3
4
5
−4
−3
−2
−1
0
1
2


z=10.4
10 Mpc comoving
Δν=0.1 MHz
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x (arcmin)
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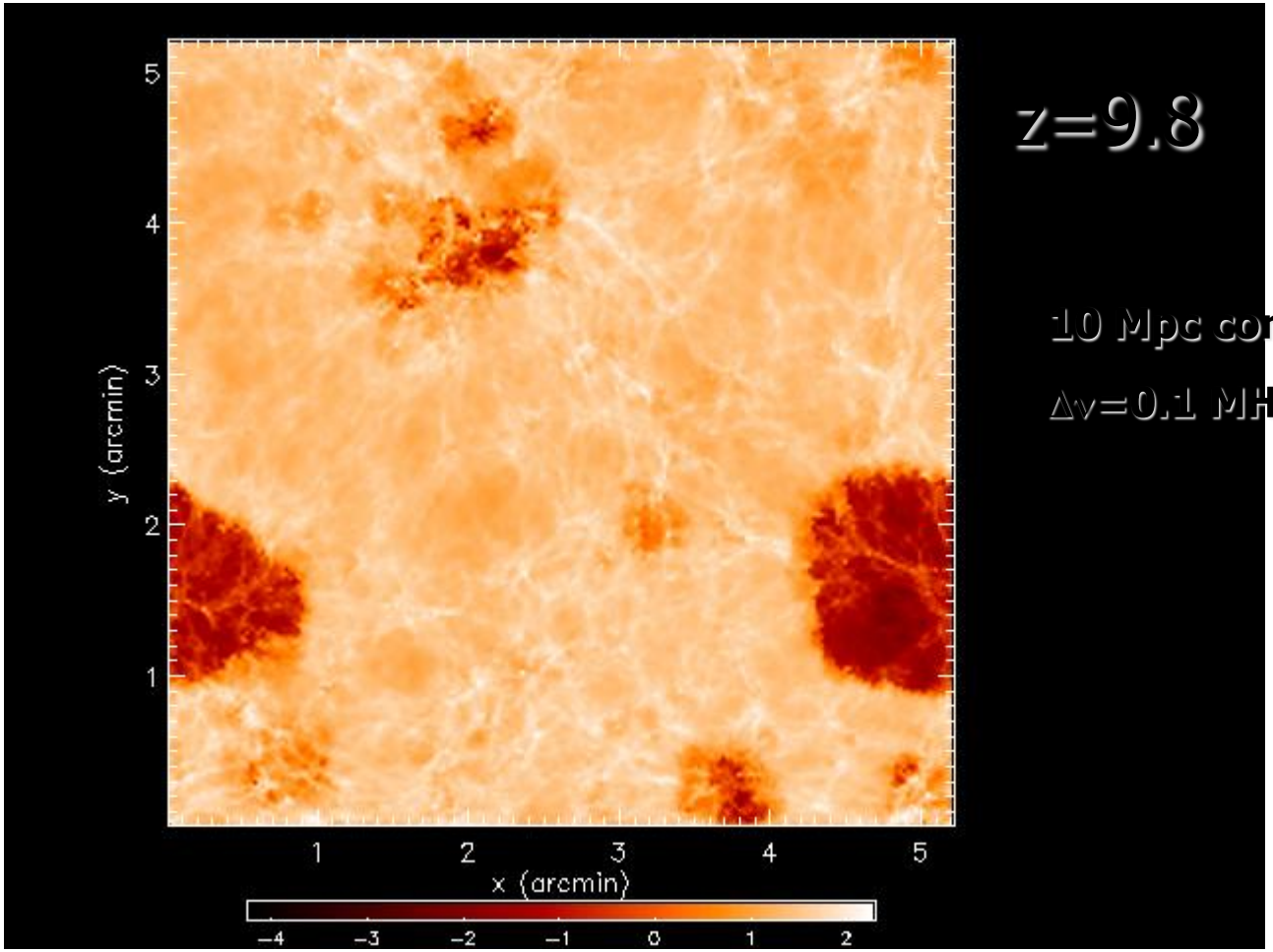
2
3
4
5
−4
−3
−2
−1
0
1
2


z=9.8
10 Mpc comoving
Δν=0.1 MHz
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x (arcmin)
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3
4
5
−4
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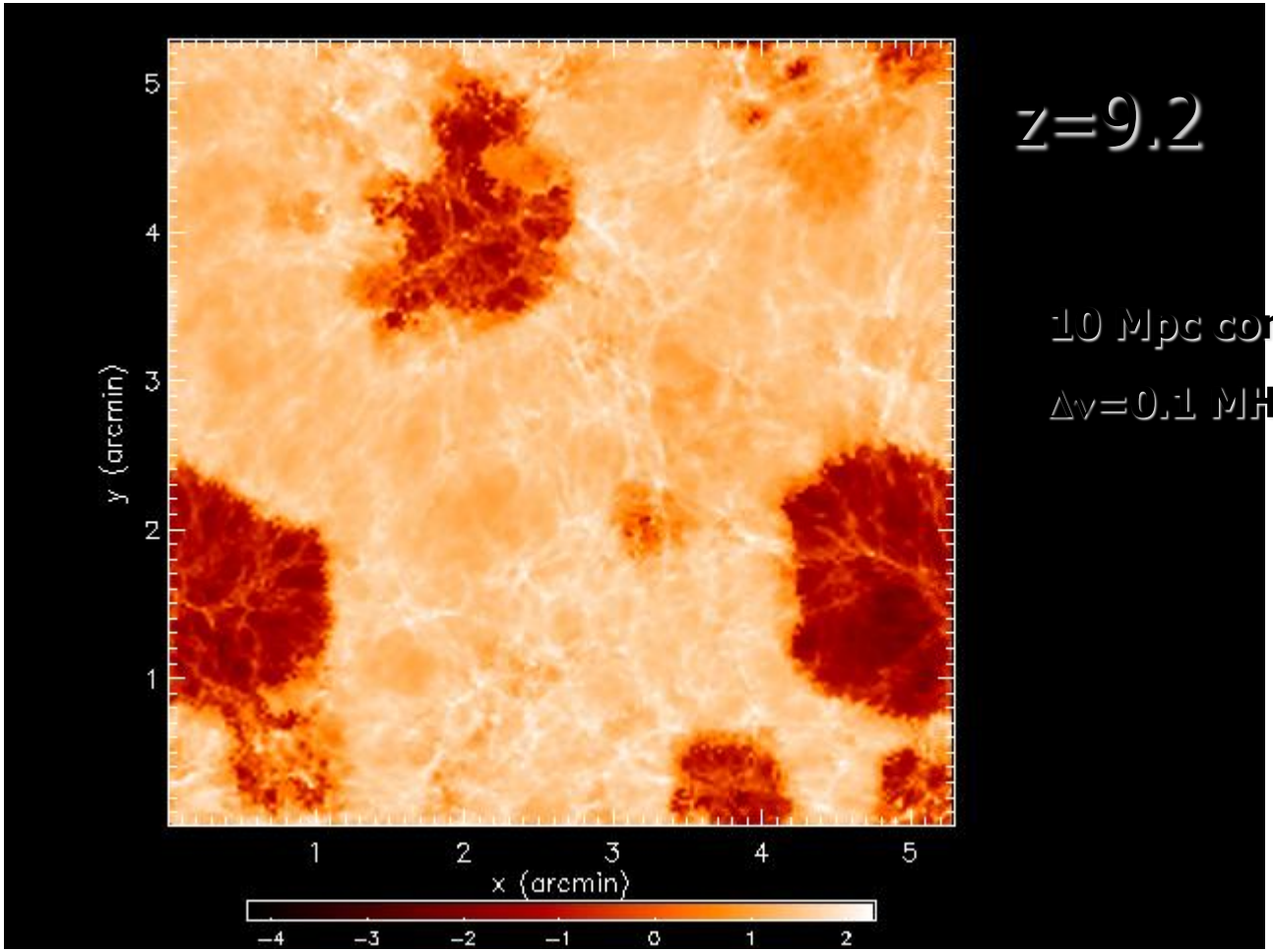
−2
−1
0
1
2


z=9.2
10 Mpc comoving
Δν=0.1 MHz
y (arcmin)
x (arcmin)
1
2
3
4
5
−4
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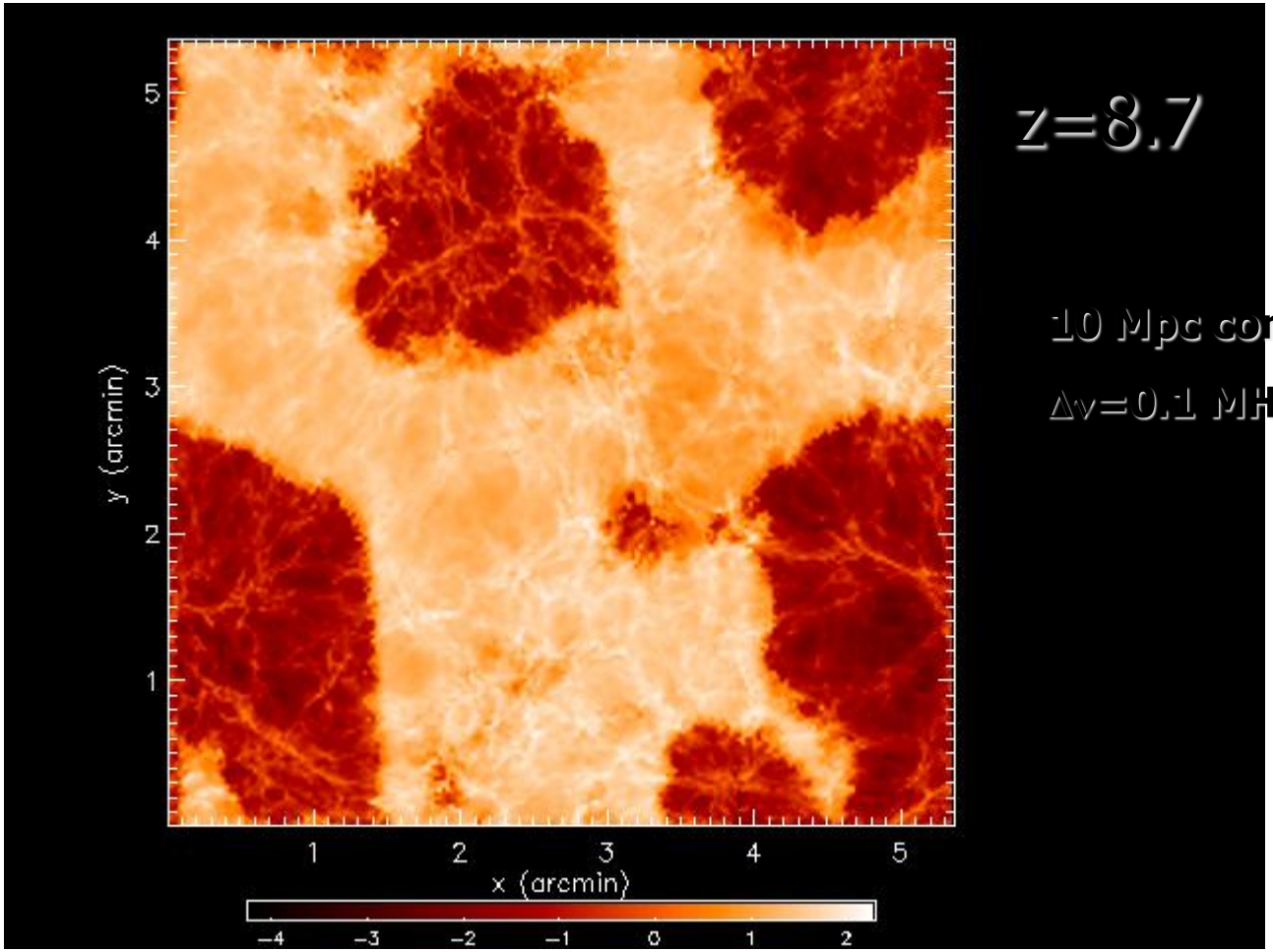
−2
−1
0
1
2


z=8.7
10 Mpc comoving
Δν=0.1 MHz
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x (arcmin)
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3
4
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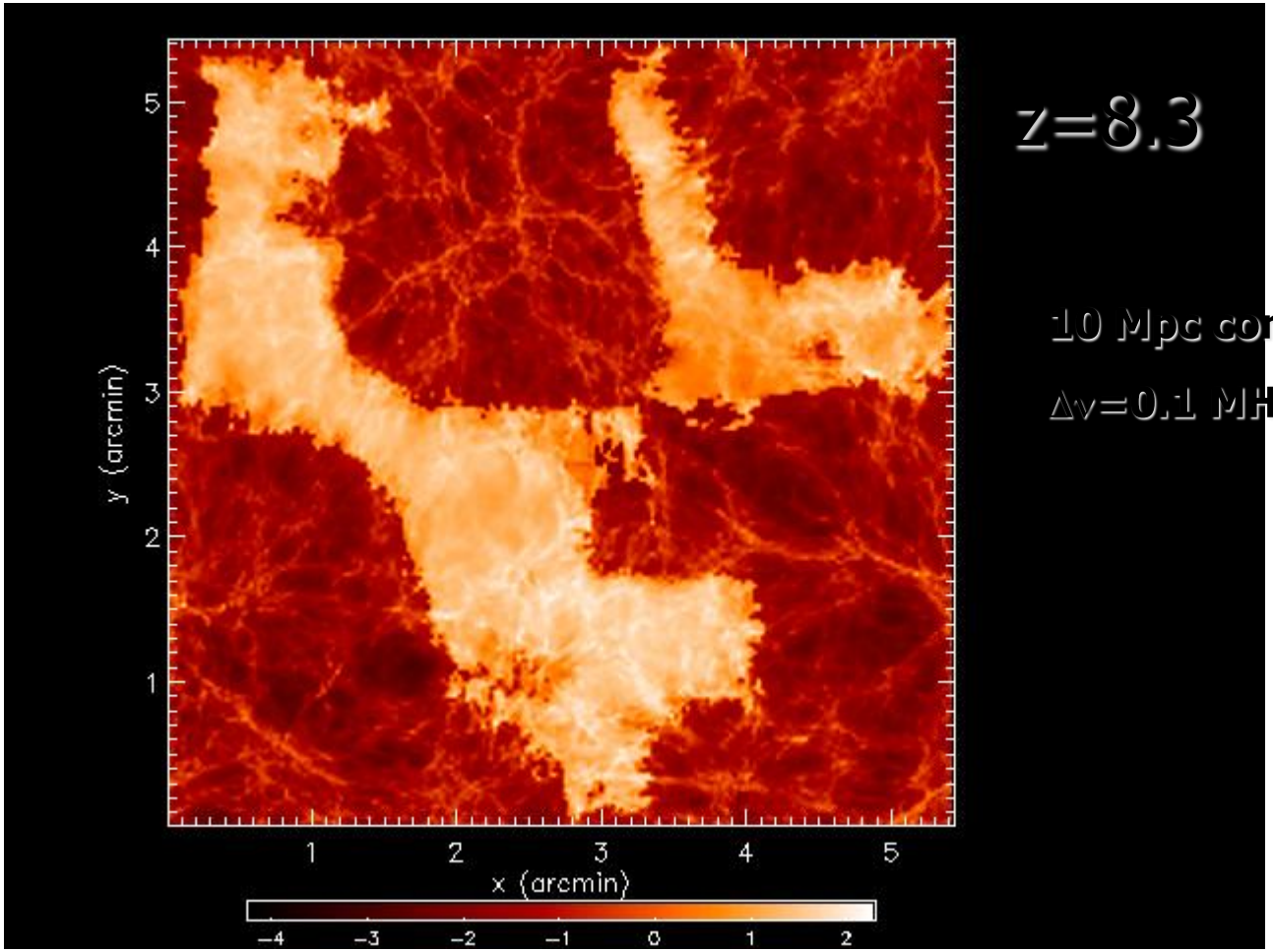
−2
−1
0
1
2


z=8.3
10 Mpc comoving
Δν=0.1 MHz
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x (arcmin)
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3
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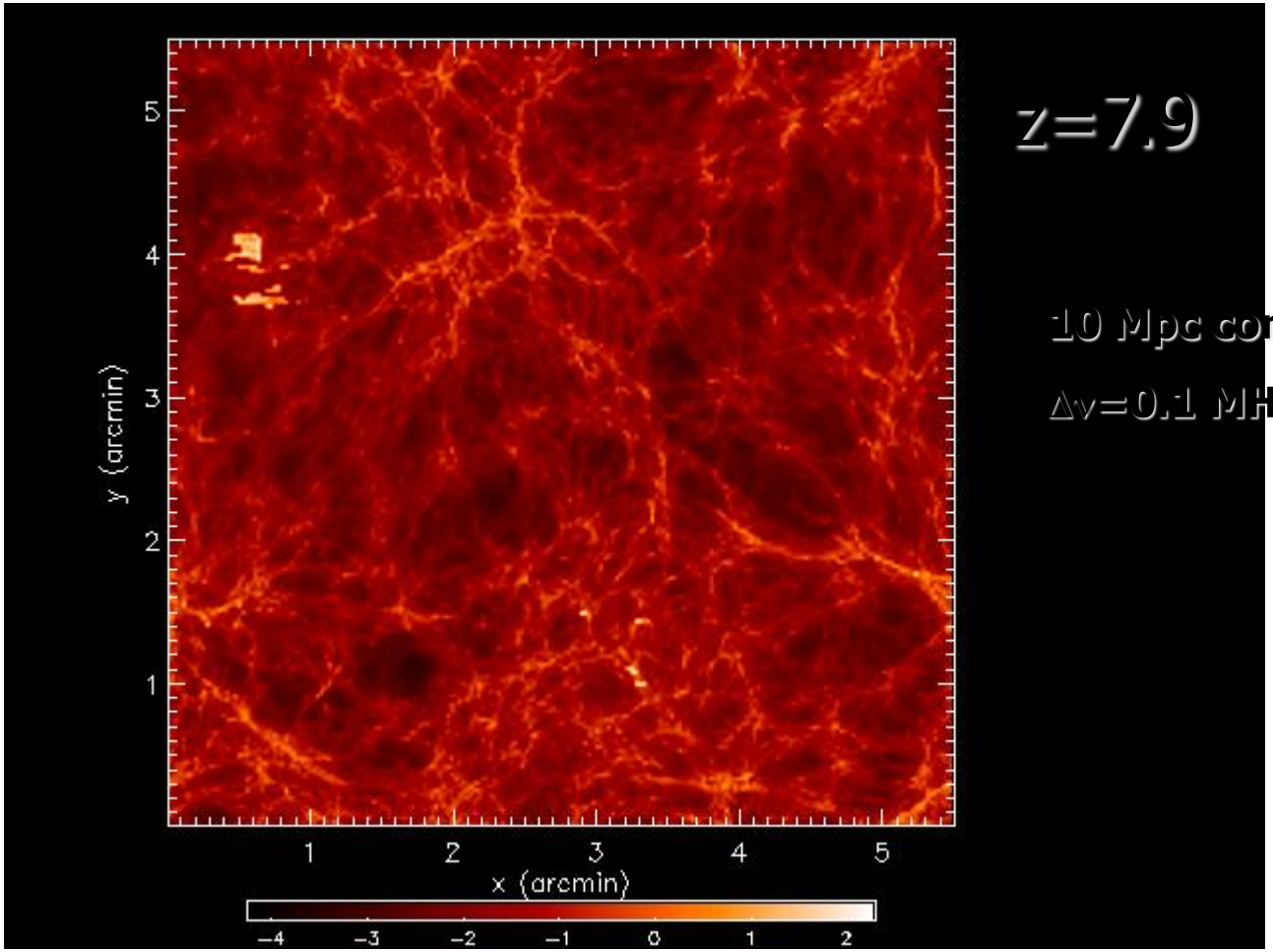
−2
−1
0
1
2


z=7.9
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Δν=0.1 MHz
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x (arcmin)
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2
3
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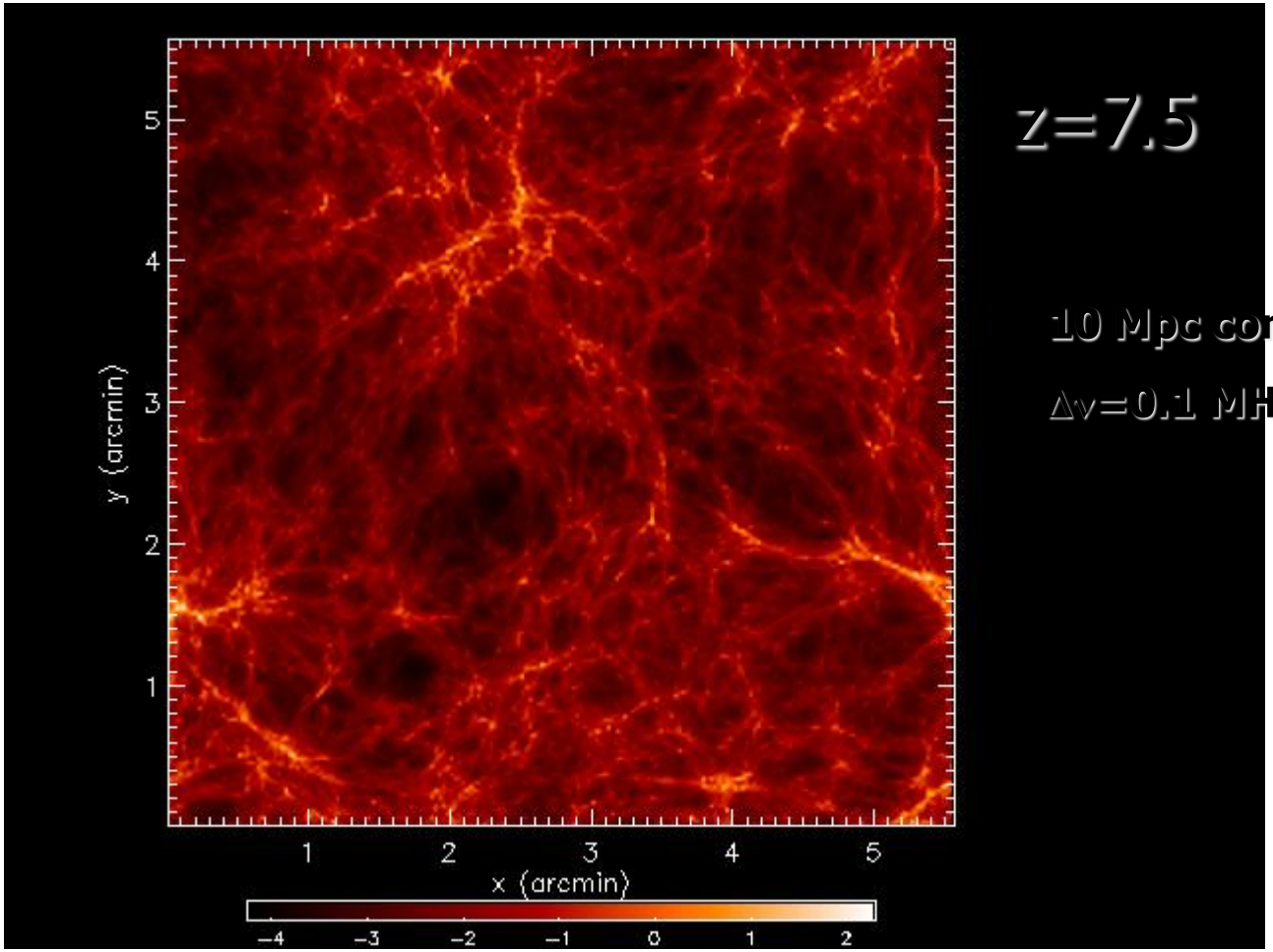
−2
−1
0
1
2


z=7.5
10 Mpc comoving
Δν=0.1 MHz
y (arcmin)
x (arcmin)
1
2
3
4
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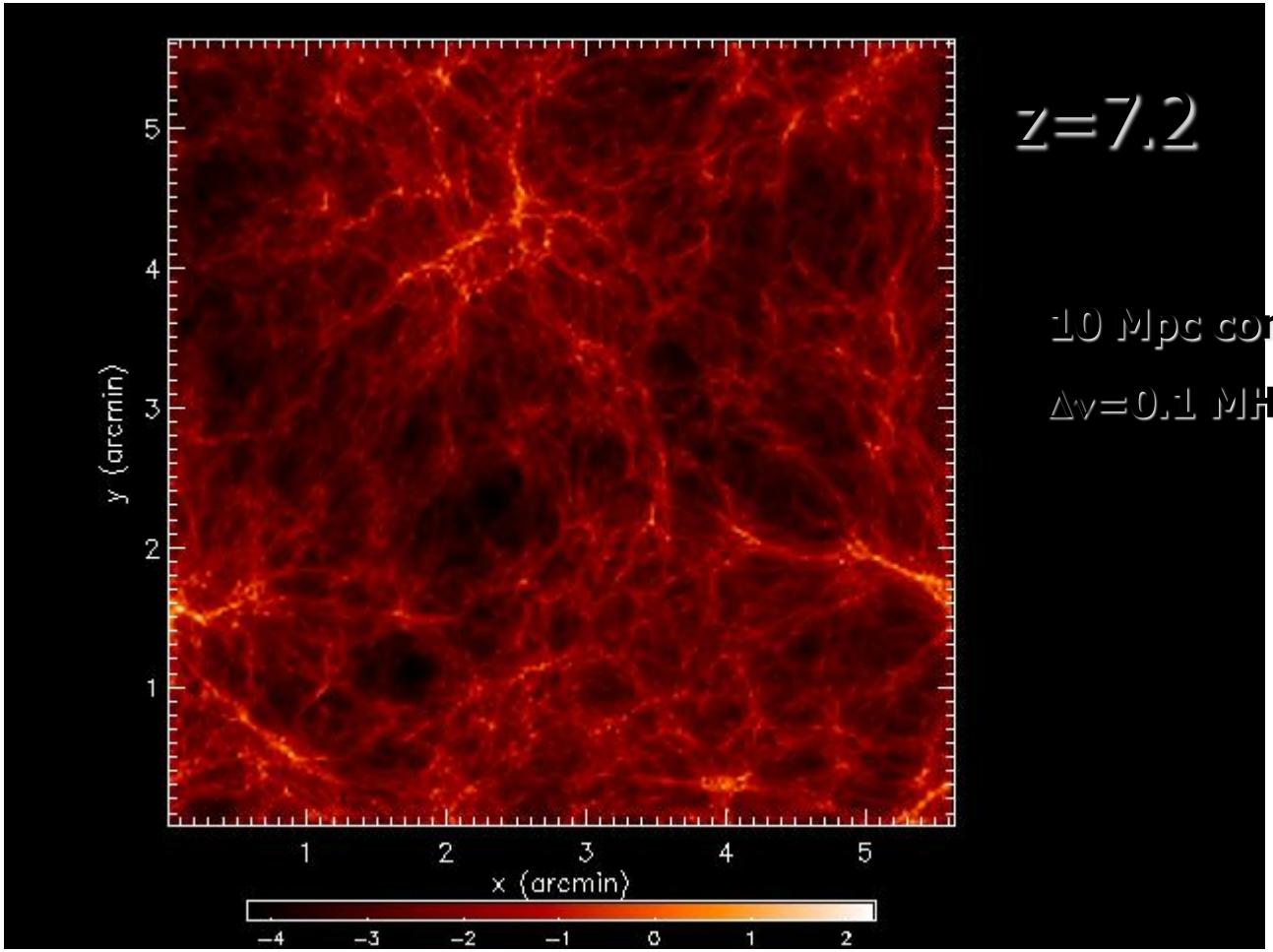
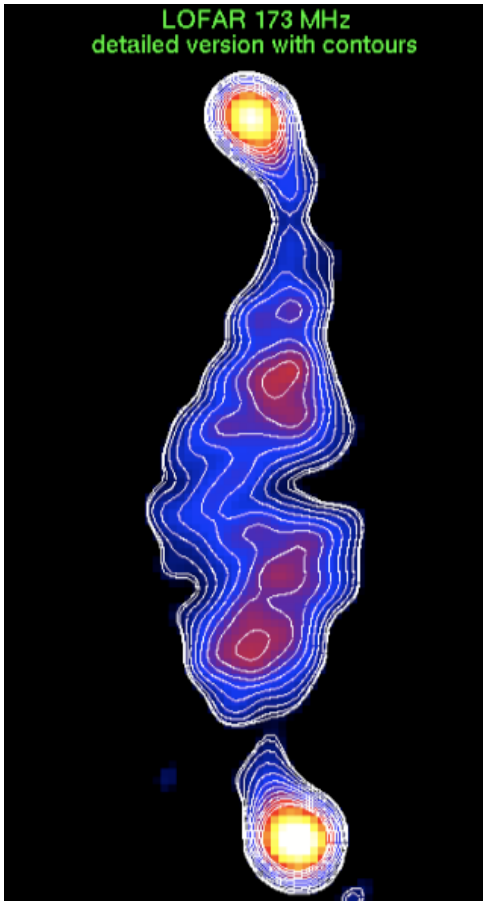
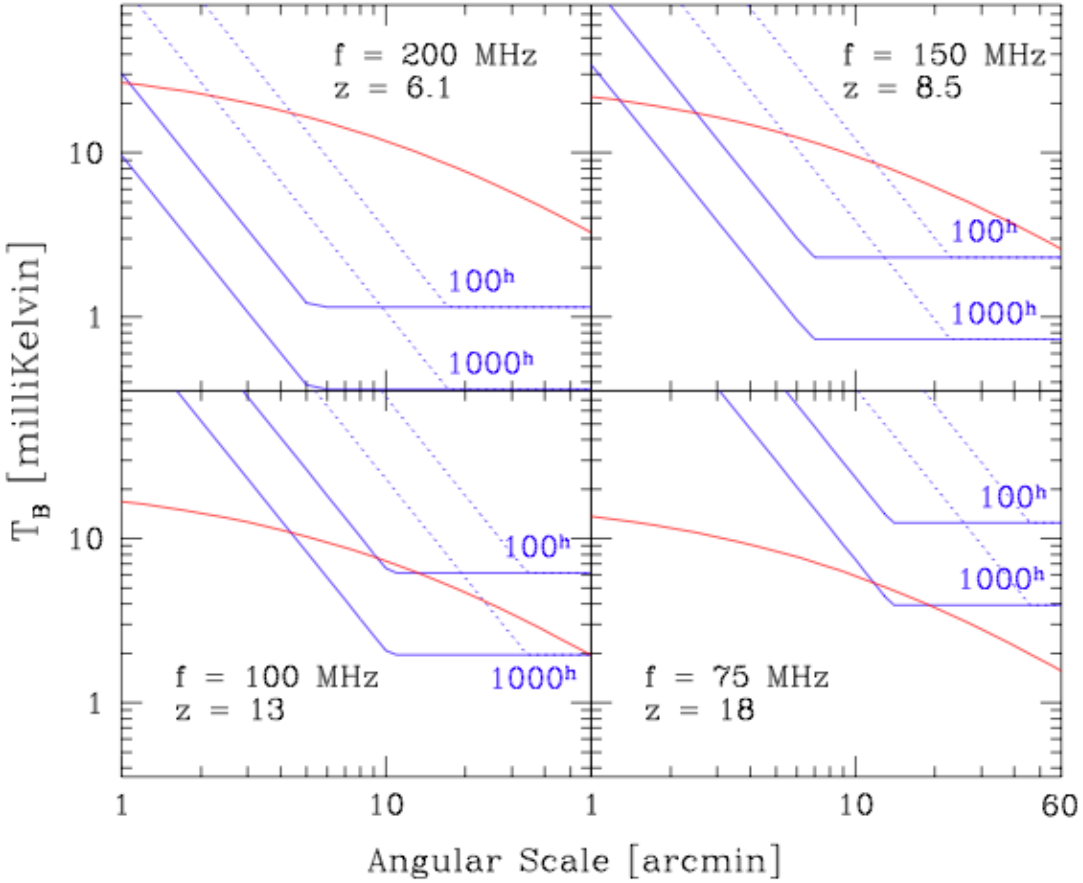
−2
−1
0
1
2


z=7.2
10 Mpc comoving
Δν=0.1 MHz
y (arcmin)
x (arcmin)
1
2
3
4
5
−4
−3
−2
−1
0
1
2

LOFAR (SKA0) is working!



EoR Signature should be detectable with SKA0 (e.g. LOFAR)



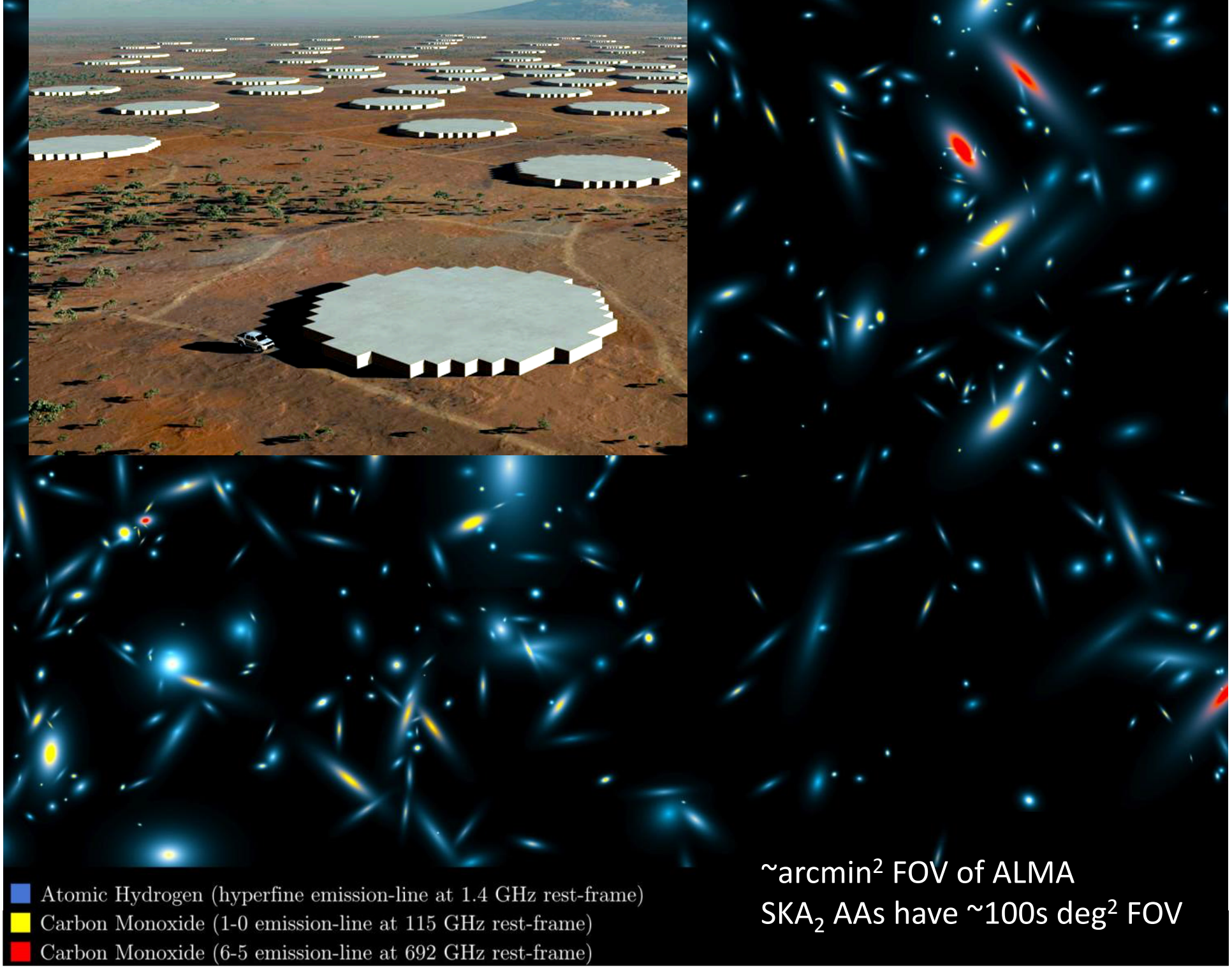
SKA_1 to be constructed 2016-2019

KEY SCIENCE

- History of Hydrogen: EoR to now
- Gravitation, Gravitational Waves and Nuclear Eqn of State via Pulsars
- Transients and the unknown.

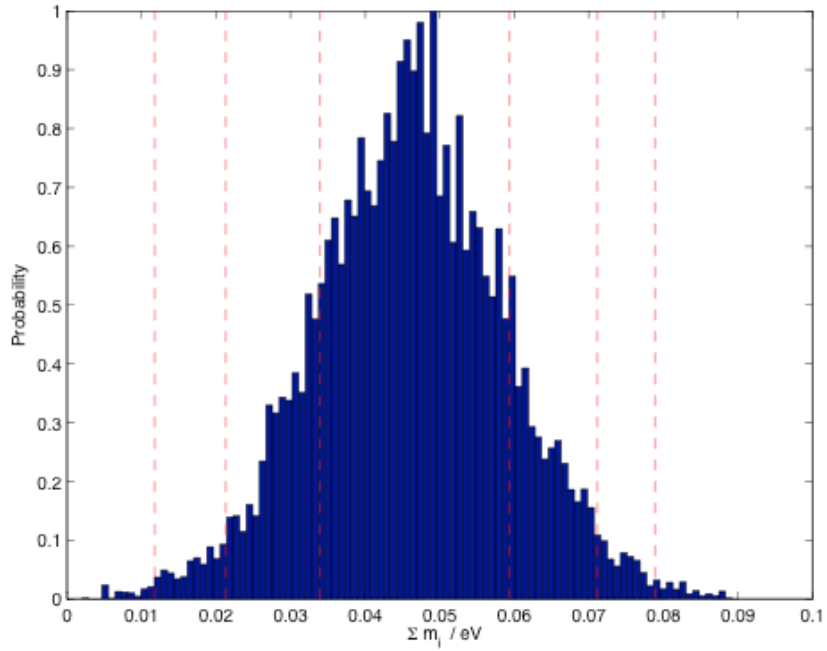
CAPABILITIES

- 70-450 MHz AAs, ~10xLOFAR sensitivity, ~1 arcsec resolution
- ~250 15-m (0.45-15 GHz) dishes, ~3xeVLA sensitivity, <0.1 arcsec resolution

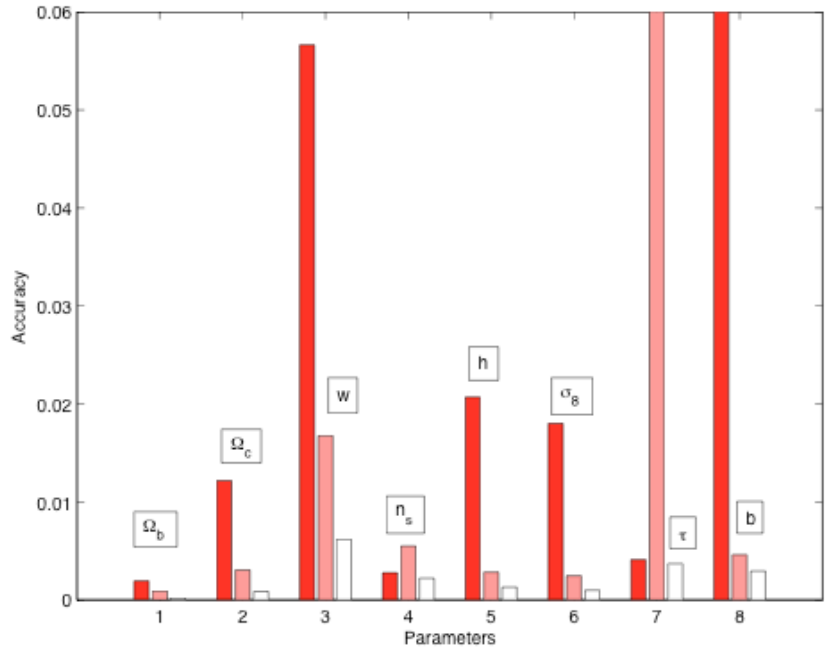

Atomic Hydrogen (hyperfine emission-line at 1.4 GHz rest-frame)
Carbon Monoxide (1-0 emission-line at 115 GHz rest-frame)
Carbon Monoxide (6-5 emission-line at 692 GHz rest-frame)
~arcmin² FOV of ALMA
SKA₂ AAs have ~100s deg² FOV

Fundamental Physics with Billion-galaxy SKA HI surveys (and *P(k)*: BAOs and *z*-distortions)

Abdalla & Rawlings (2007)



Abdalla, Blake & Rawlings (2009)



Again great complementarity with E-ELT: e.g. high-*z* SNe & CODEX

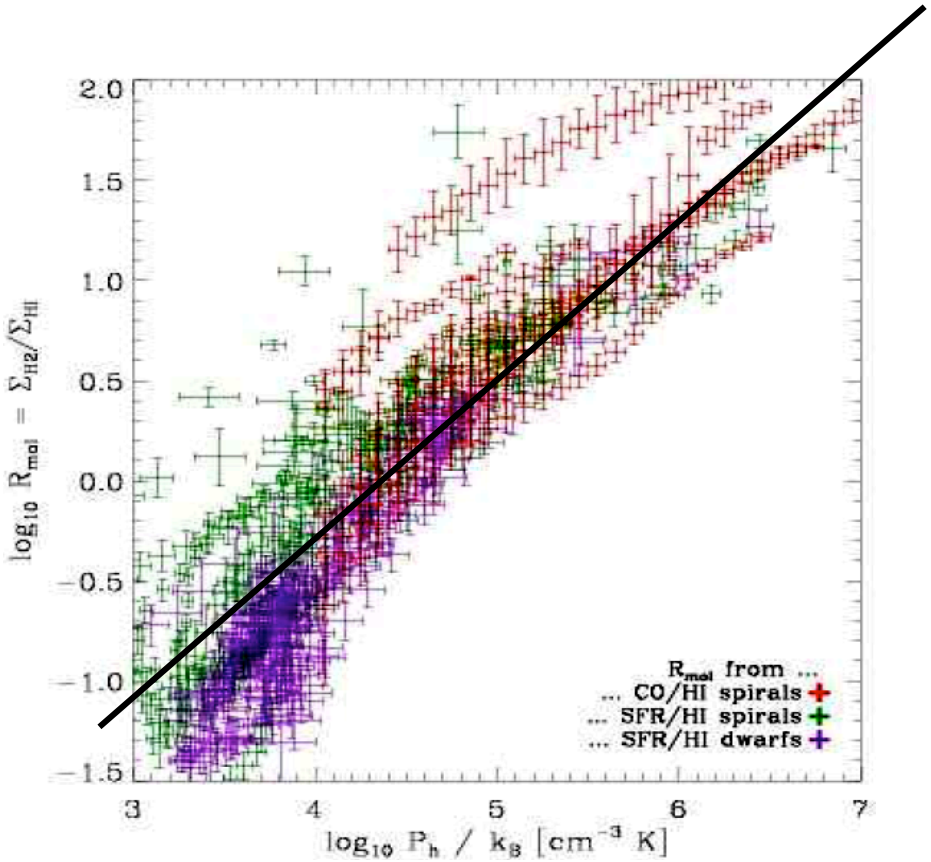
Concluding remarks

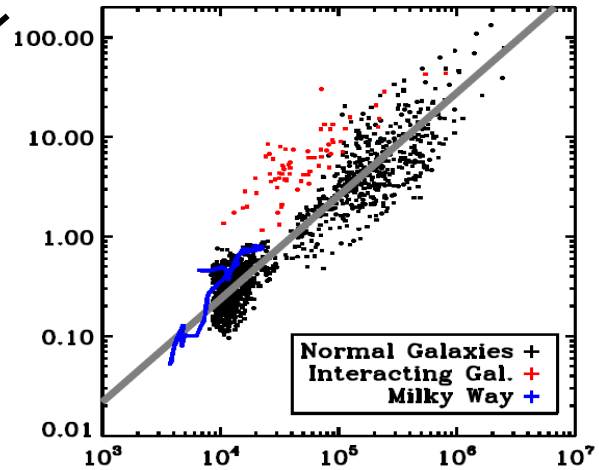
- For galaxy and black hole evolution, JWST/E-ELT+ALMA+SKA+IXO are ALL needed, and will be operating together

- Joint science cases urgently need developing (lots of simulation tools in place)

May 10-14 Crete

Key Physics I: Pressure-driven molecularization





$$\frac{\Sigma_{H_2}(r)}{\Sigma_{HI}(r)} = [P(r)/P_*]^\alpha$$

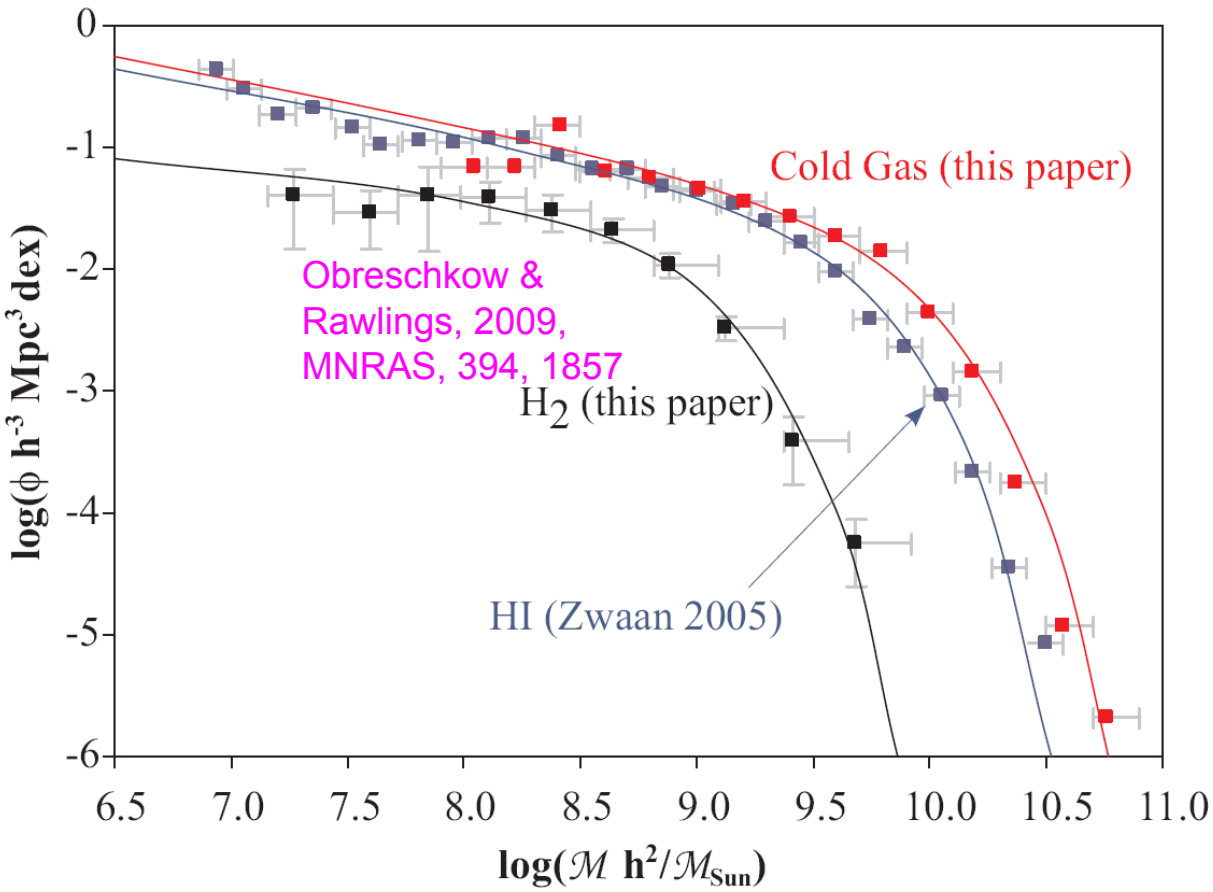
$$P_* = 2.35 \cdot 10^{-13} \text{ Pa}$$

$$\alpha = 0.8$$

$$P(r) = \frac{\pi}{2} G \Sigma_{gas}(r) \left(\Sigma_{gas}(r) + f_\sigma(r) \Sigma_{stars}^{disk}(r) \right),$$

Leroy et al. 2008 (AJ 136); Blitz & Rosolowsky 2006 (ApJ 650); Elmegreen (1989) gives underlying physics (GMC condensation, H_2 formation, radiation).

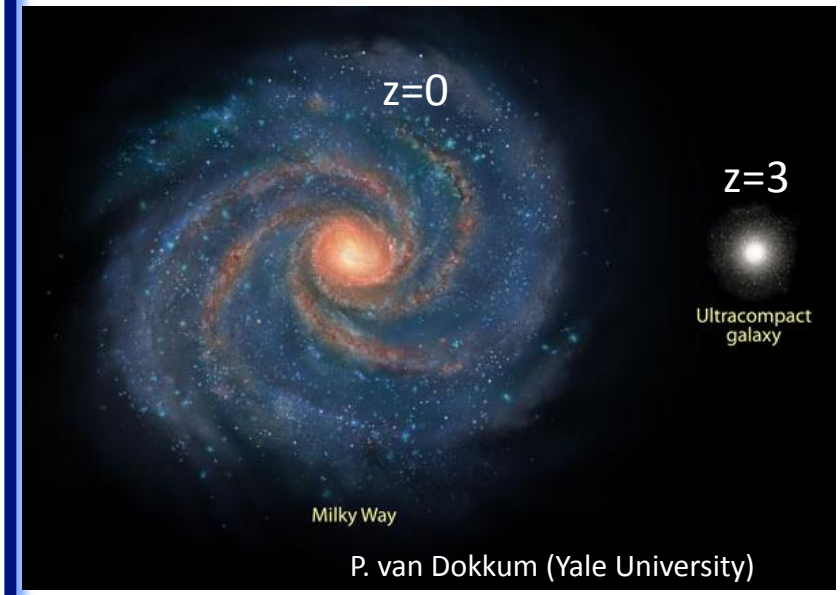
Physical Model at z=0

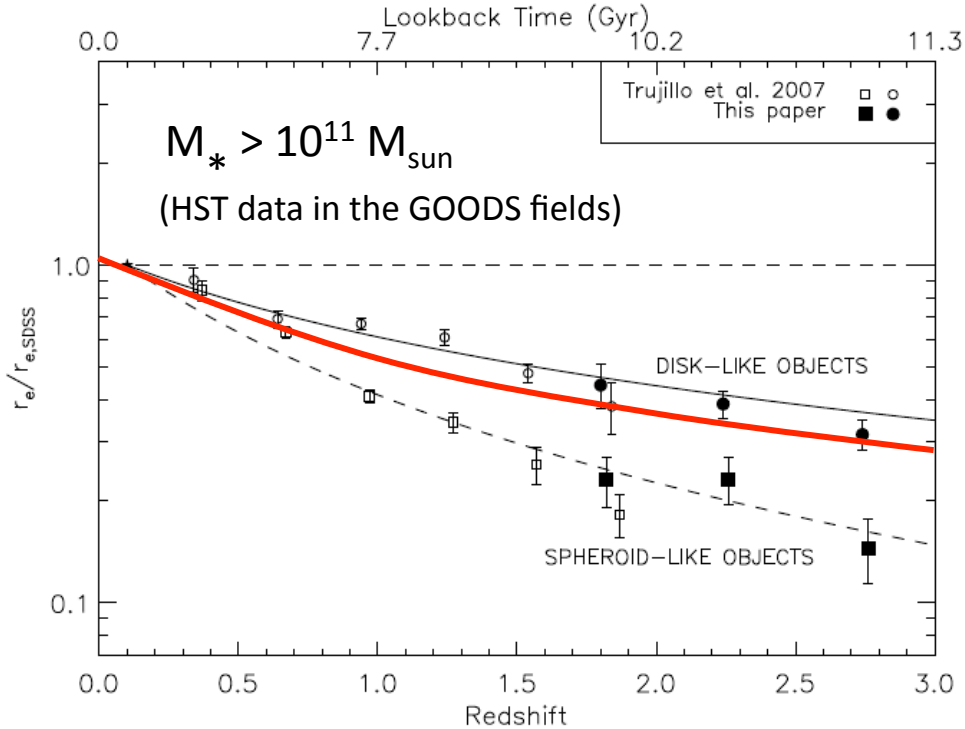


Obreschkow et al. (2009a)

- Variable $X=H_2/CO$ critical to this work (OR2009): essentially X has to be lower in low-mass galaxies
- Just one tunable parameter *was* then needed in the end: overall normalization of cold gas needs reducing by a factor 1.45 - [reasonable allowing for an ionized (warm) component of H.]
-

Key Physics II: growth of galaxies





$$r_{\rm vir}^3 \propto M_{\rm vir}/[\Omega_{\rm m}(1+z)^3 + \Omega_\Lambda] \quad \Longrightarrow \quad r_{\rm disc} \propto (1+z)^{-1}$$

Observations: e.g. Bouwen et al. 2004 (ApJL 611); Trujillo et al. 2006 (ApJ 6 50); Buitrago et al. 2008 (ApJL 687)
Theory: e.g. Gunn & Gott 1972 (ApJ 176); Fall & Efstathiou 1980 (MNRAS 193)

Crude predictions

$\Sigma_{H_2} / \Sigma_{HI} \propto P^{0.8}$

$r \propto (1+z)^{-1} \leftrightarrow P \propto (1+z)^2$

$\Omega_{H_2} / \Omega_{HI} \propto (1+z)^{1.6}$

Potential to explain:

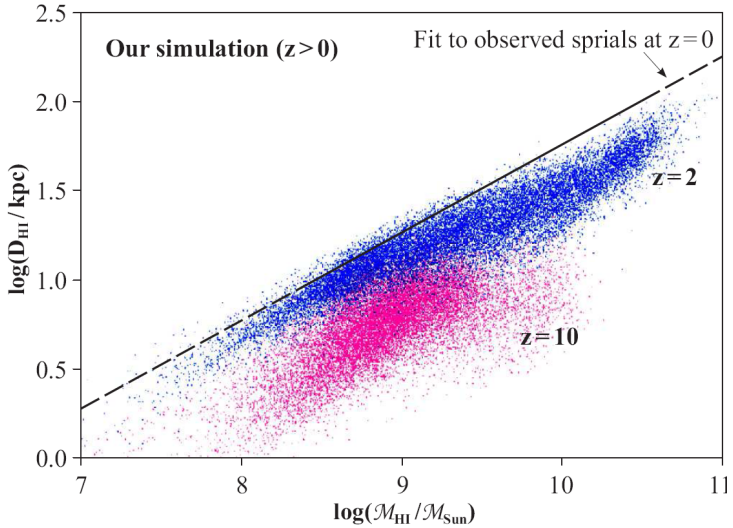
- Strong CO-emission at high z
- Weak cosmic evolution of Ω_{HI}
- Increase in SFR with redshift

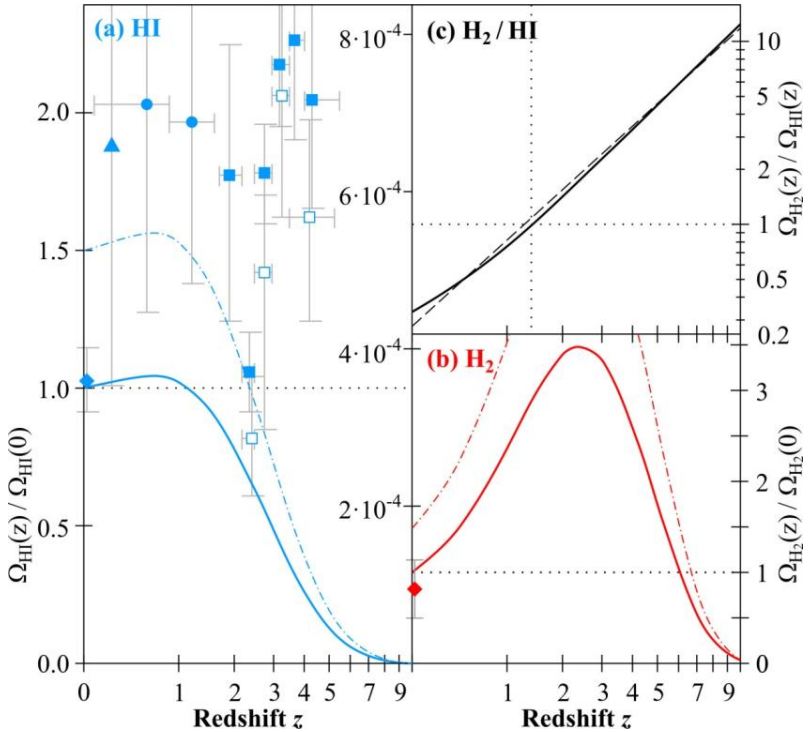
But, this neglects:

- Evolution of the galaxy MF
- Evolution of Ω_{HI+H2}
- Turbulence at high z
- Mergers
- Metallicity evolution
- UV-dissociation from SF (?)

Obreschkow et al. 2009 (ApJL 696)

Predictive at high-z





Obreschkow et al. 2009 (ApJL 696)

$$\Omega_{H_2}/\Omega_{HI} \propto (1+z)^{1.6}$$