Atomic gas in the halo of a massive proto-cluster galaxy: prospects for high-z HI studies

Bjorn Emonts

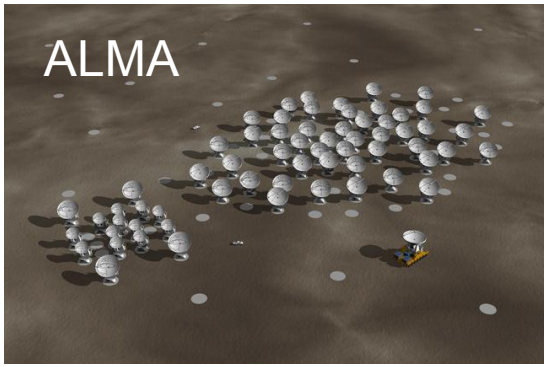
Centro de Astrobiología (CSIC-INTA), Madrid
National Radio Astronomy Observatory, Charlottesville

Credits

M. Lehnert, M. Villar-Martin, H. Dannerbauer, C. De Breuck, G. Miley, **J. Allison**, G. Van Moorsel, P. Guillard, B. Gullberg, N. Hatch, M. Mao, **E. Sadler**, R. Norris, R. Ekers, N. Seymour, C. Carilli, H. Rottgering, L. Pentericci, J. Vernet

HI absorption VLA P-band: M. Mao, F. Owen, **S. Curran**, G. van Moorsel

Emonts et al. 2016, Science, 354, 1128
Gullberg et al. 2016, A&A, 591, 73
Emonts et al. 2017, under review by team



RadioNet

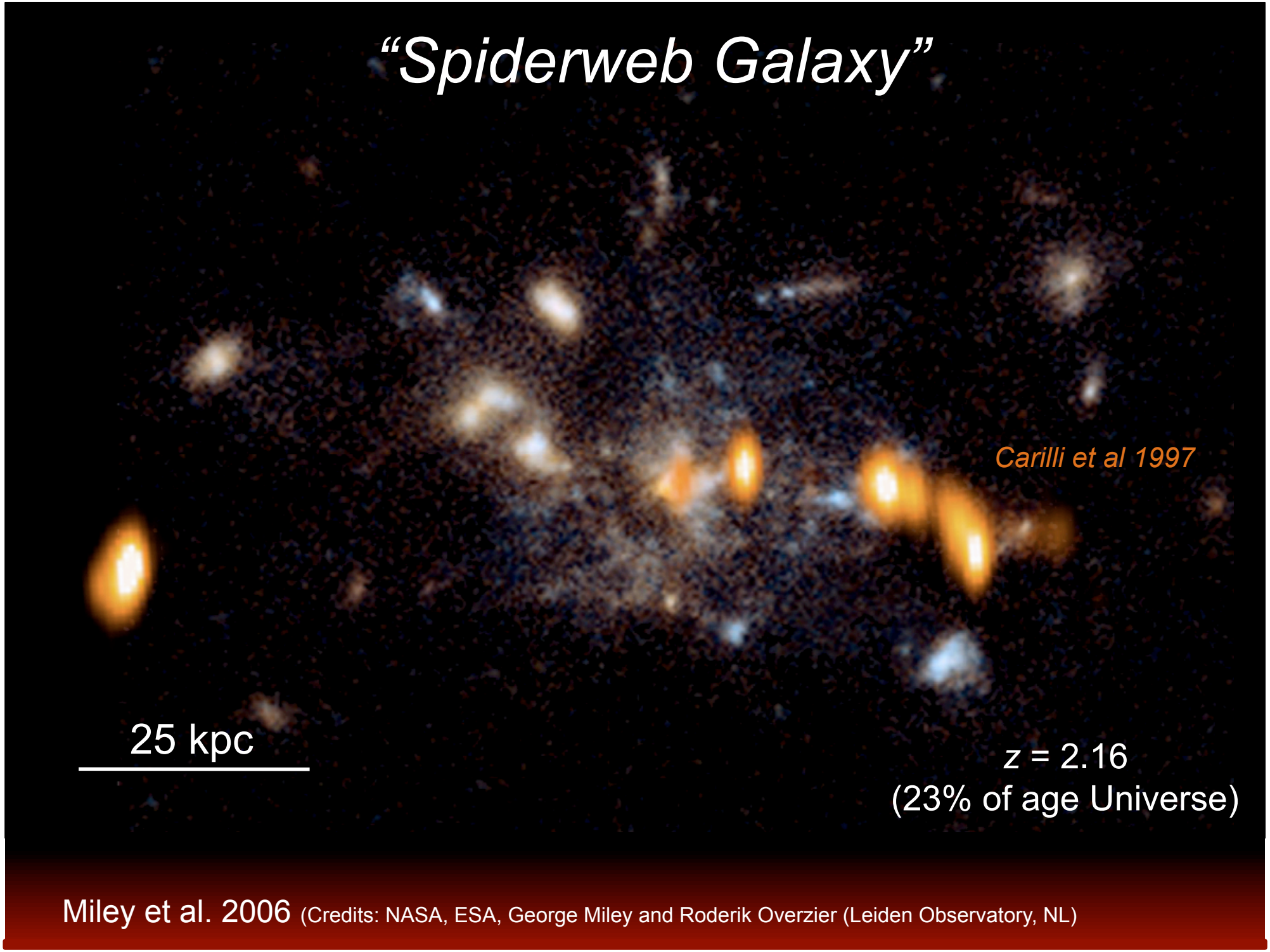
CENTRO DE ASTROBIOLOGÍA
Asociado al NASA Astrobiology Institute

GOBIERNO DE ESPAÑA

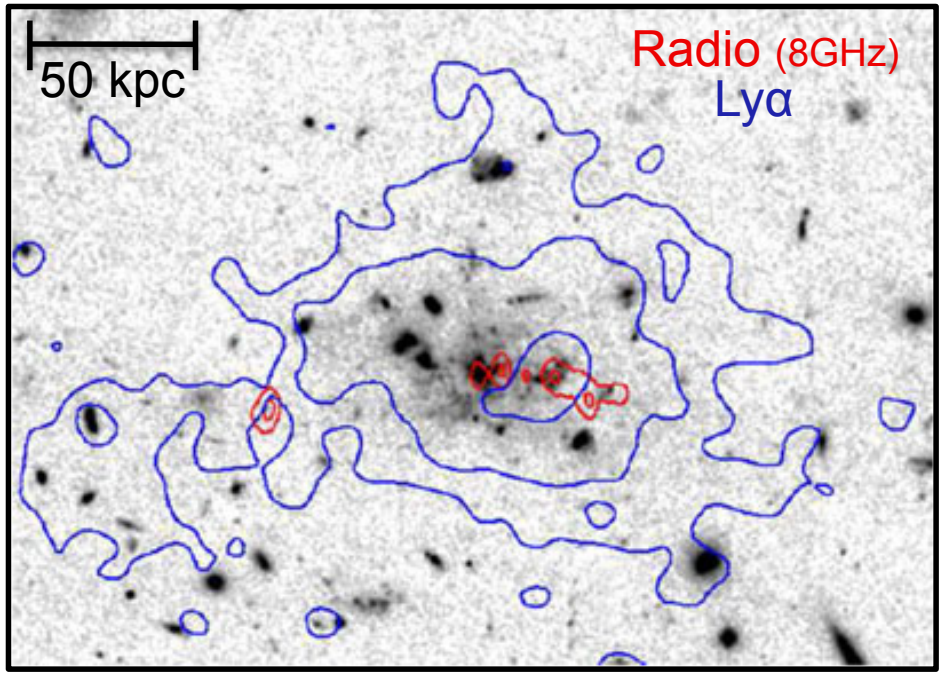
CSIC

INTA

Miley et al. 2006 (Credits: NASA, ESA, George Miley and Roderik Overzier (Leiden Observatory, NL)


"Spiderweb Galaxy"
Carilli et al 1997
25 kpc
z = 2.16
(23% of age Universe)
Miley et al. 2006 (Credits: NASA, ESA, George Miley and Roderik Overzier (Leiden Observatory, NL)

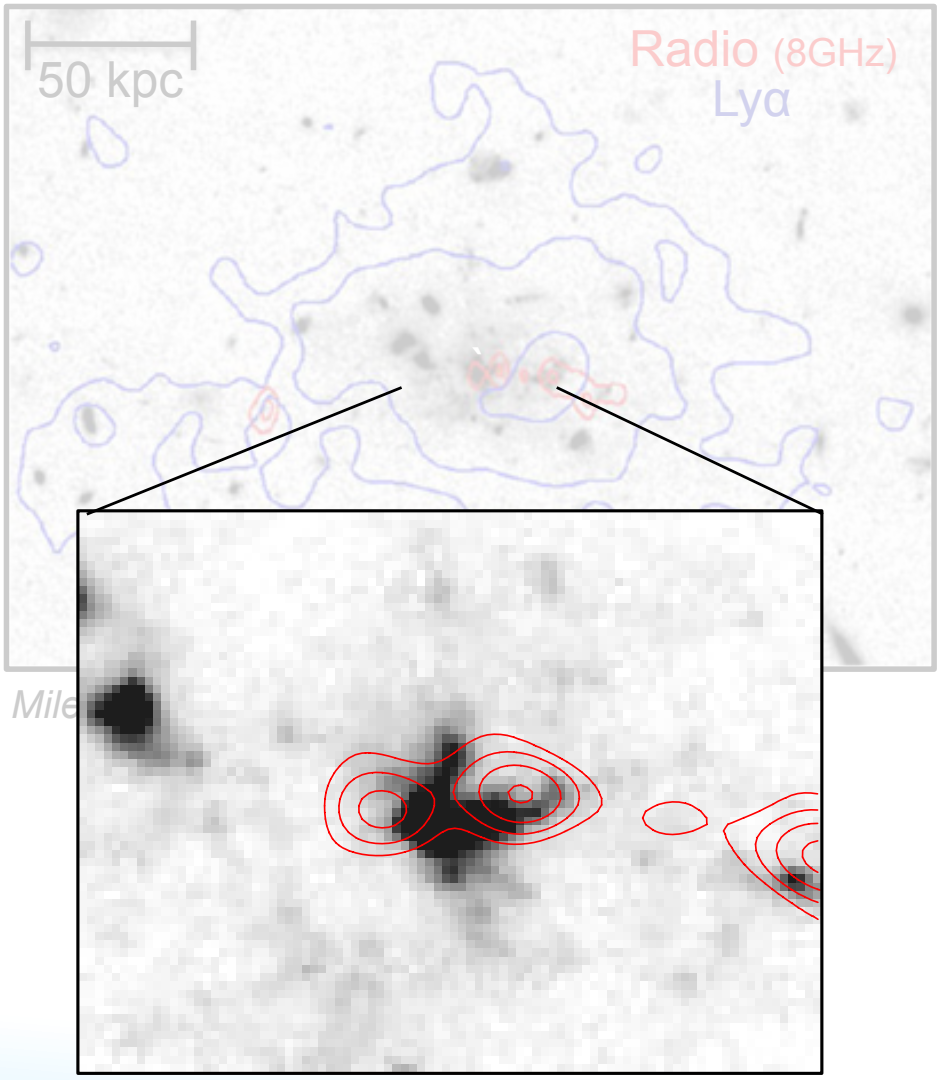
Radio galaxy at z=2.2



Miley+ (2006)

Spiderweb Galaxy

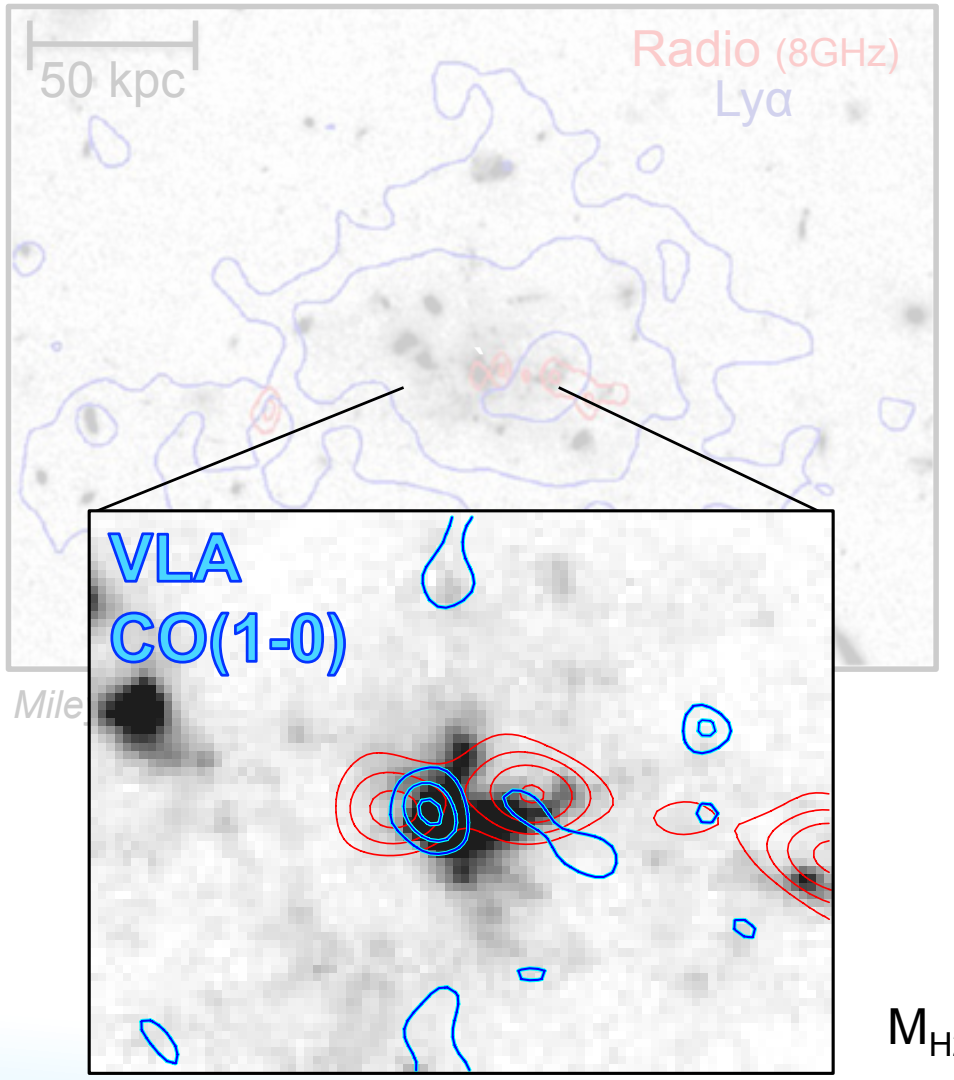
Radio galaxy at z=2.2



Spiderweb Galaxy

MRC1138-262

Radio galaxy at z=2.2

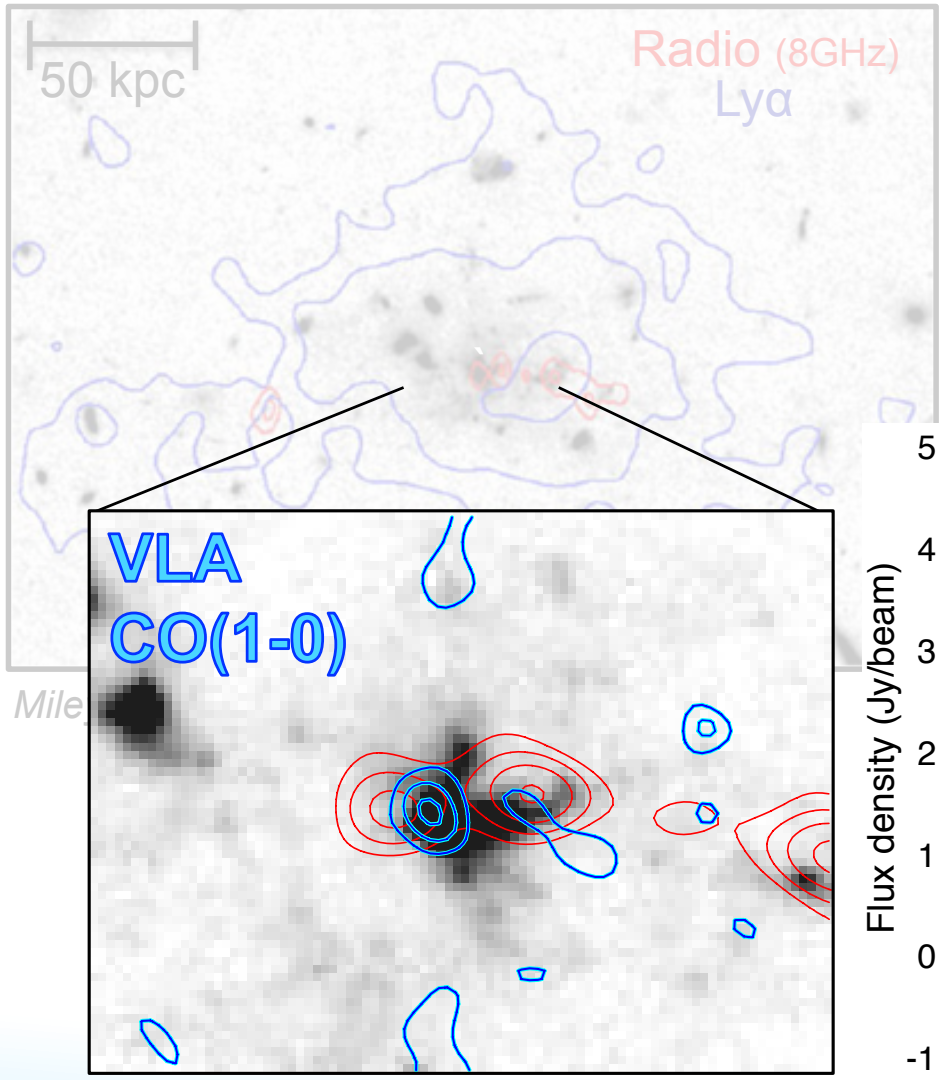


Spiderweb Galaxy

MRC1138-262

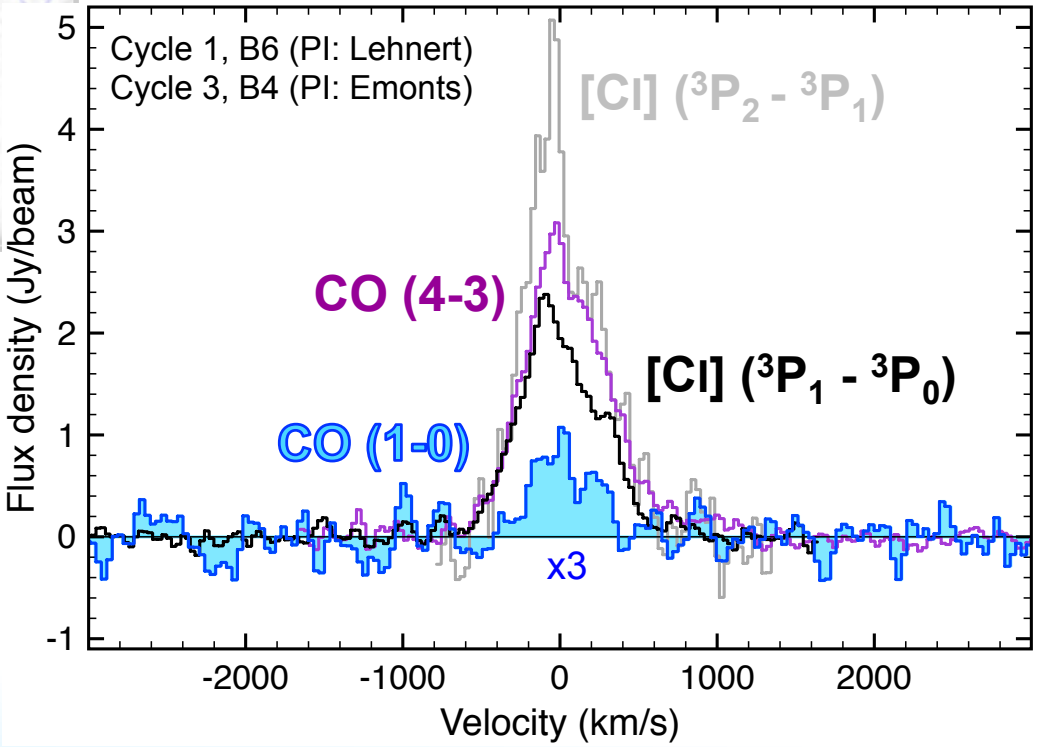
$M_{H2} \sim 2 \times 10^{10} (\alpha_{CO}/1)\ M_{\odot}$

Radio galaxy at z=2.2



Spiderweb Galaxy

MRC1138-262



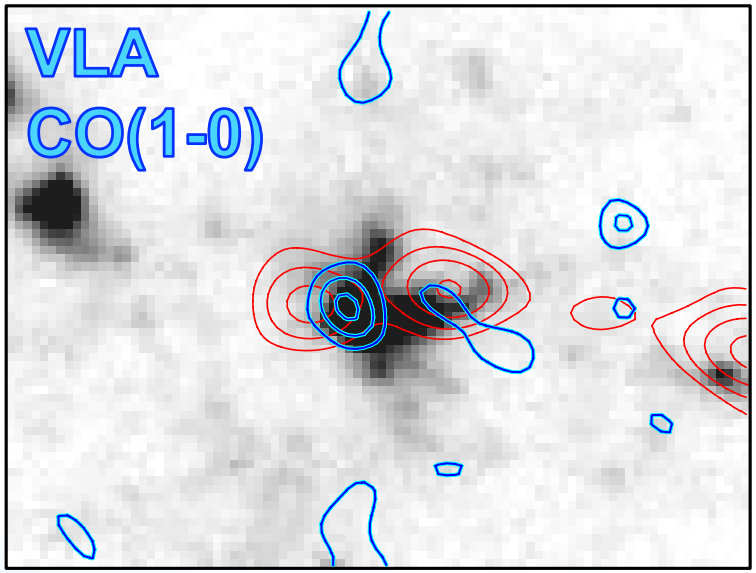
Emonts et al. 2017, under review

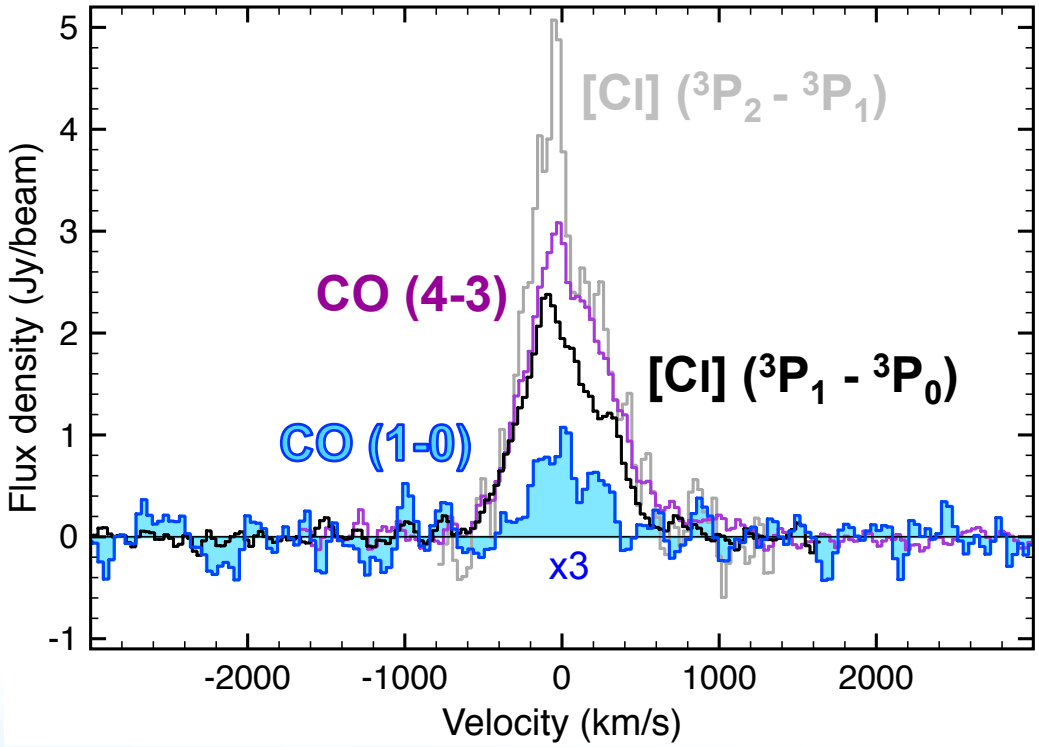
Radio galaxy at z=2.2

$L'_{[CI]\ 2\rightarrow1} / L'_{[CI]\ 1\rightarrow0} \sim 0.62 \rightarrow T_{ex} = 32K$

$L'_{CO(4-3)} / L'_{CO(1-0)} \sim 1.0 \rightarrow$ thermally excited

$L'_{[CI]\ 1\rightarrow0} / L'_{CO(1-0)} \sim 0.66 \rightarrow$ high relative [CI] abundance





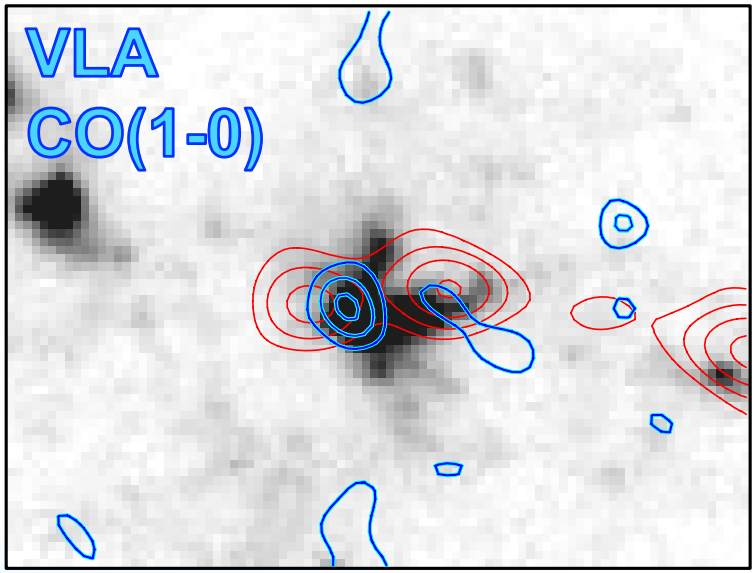
Emonts et al. 2017, under review

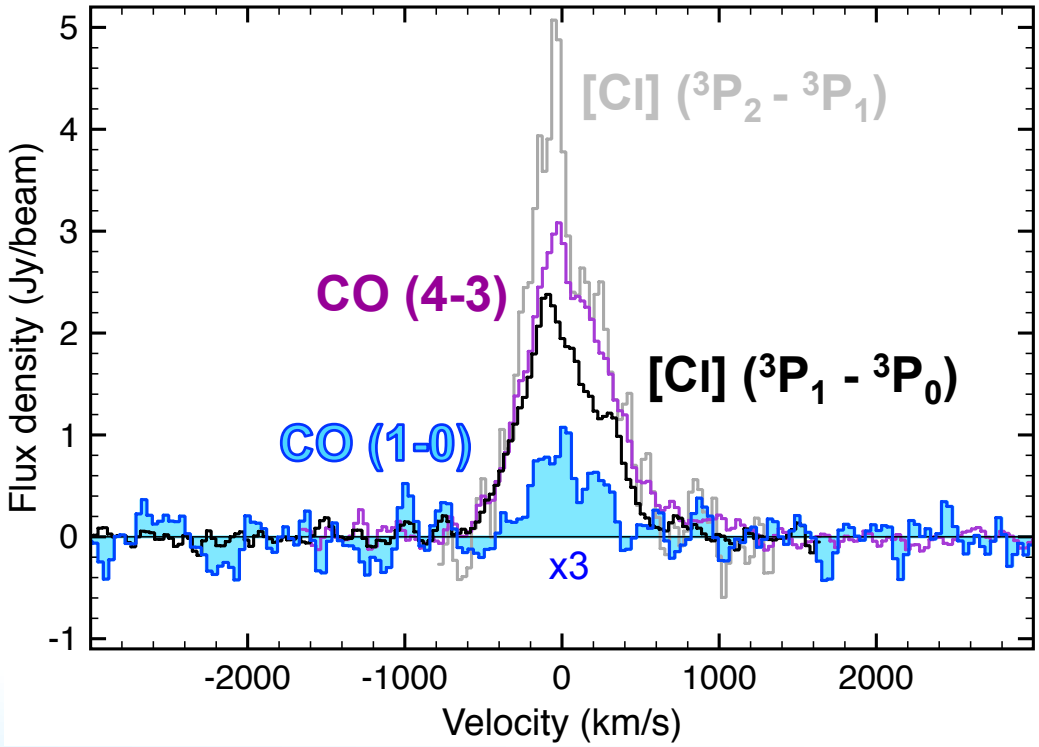
Radio galaxy at z=2.2

$L'_{[CI]\ 2\rightarrow1} / L'_{[CI]\ 1\rightarrow0} \sim 0.62 \rightarrow T_{ex} = 32K$

$L'_{CO(4-3)} / L'_{CO(1-0)} \sim 1.0 \rightarrow$ thermally excited

$L'_{[CI]\ 1\rightarrow0} / L'_{CO(1-0)} \sim 0.66 \rightarrow$ high relative [CI] abundance





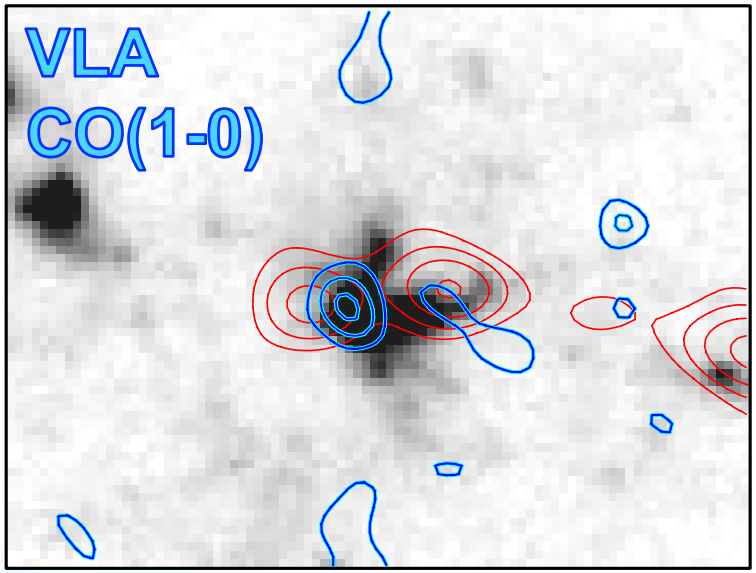
Emonts et al. 2017, under review

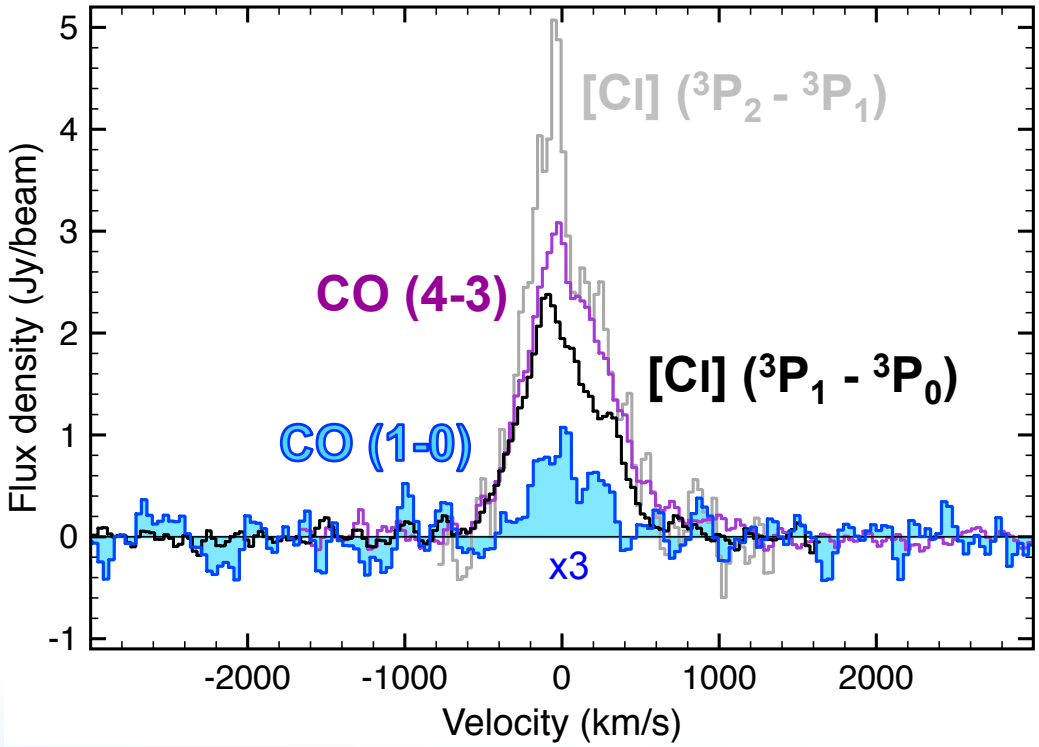
Radio galaxy at z=2.2

$L'_{[CI]\ 2\rightarrow1} / L'_{[CI]\ 1\rightarrow0} \sim 0.62 \rightarrow T_{ex} = 32K$

$L'_{CO(4-3)} / L'_{CO(1-0)} \sim 1.0 \rightarrow$ thermally excited

$L'_{[CI]\ 1\rightarrow0} / L'_{CO(1-0)} \sim 0.66 \rightarrow$ high relative [CI] abundance





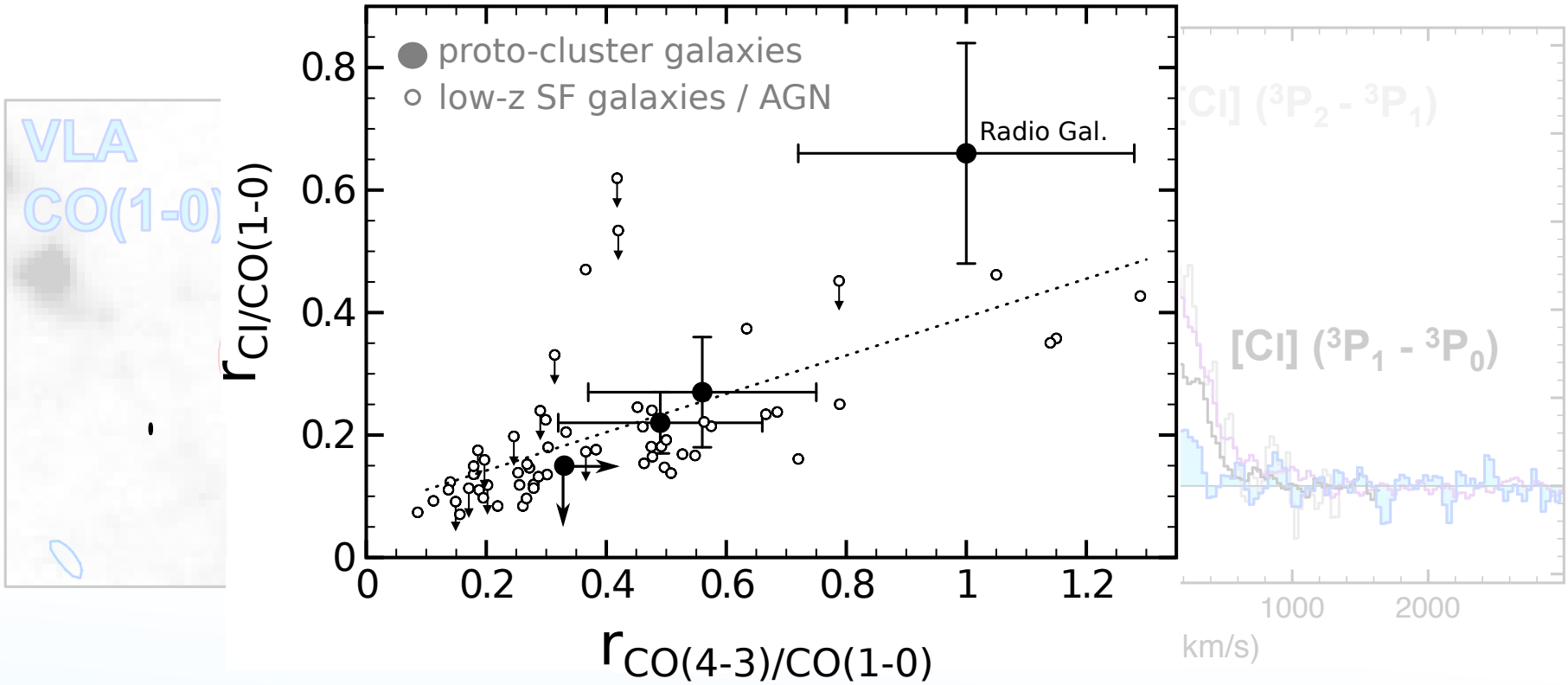
Emonts et al. 2017, under review

Radio galaxy at z=2.2

$L'_{[CI]\ 2\rightarrow1} / L'_{[CI]\ 1\rightarrow0} \sim 0.62 \rightarrow T_{ex} = 32K$

$L'_{CO(4-3)} / L'_{CO(1-0)} \sim 1.0 \rightarrow$ thermally excited

$L'_{[CI]\ 1\rightarrow0} / L'_{CO(1-0)} \sim 0.66 \rightarrow$ high relative [CI] abundance



Emonts et al. 2017, under review

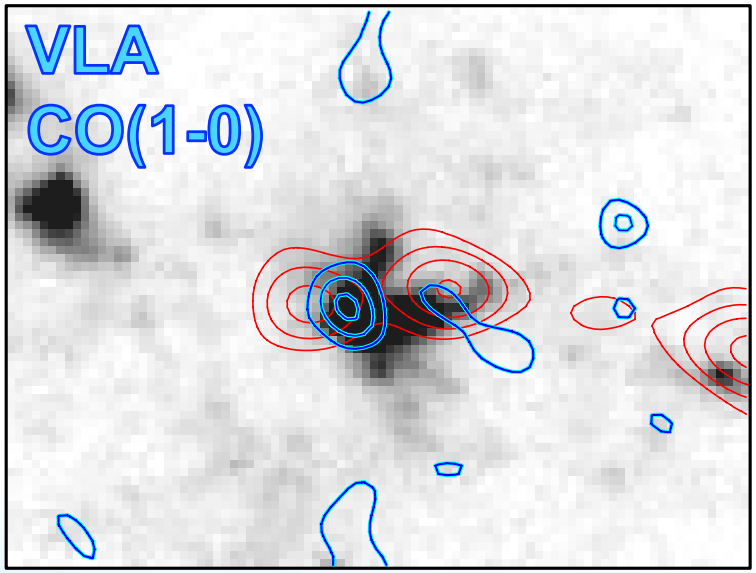
Radio galaxy at z=2.2

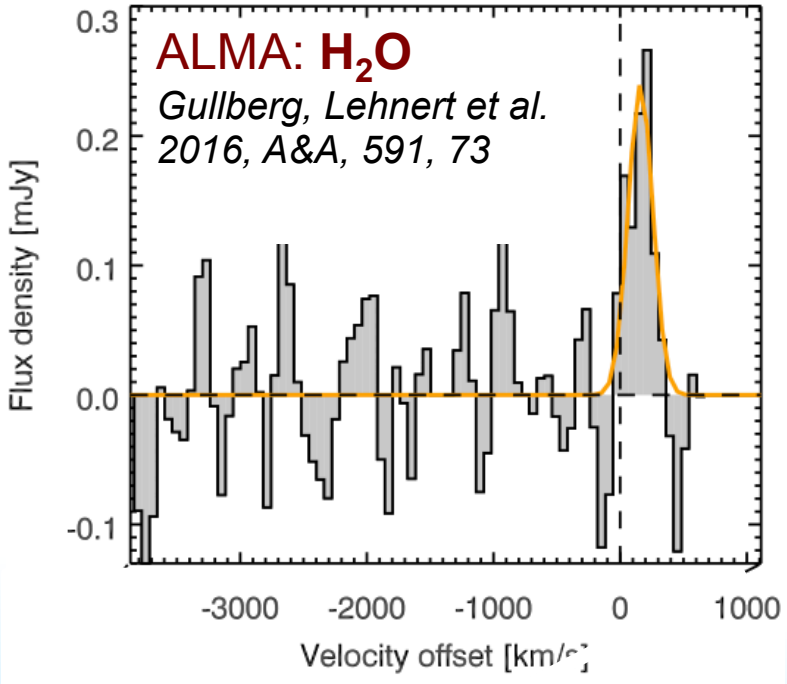
$L'_{[CI]\ 2\rightarrow1} / L'_{[CI]\ 1\rightarrow0} \sim 0.62 \rightarrow T_{ex} = 32K$

$L'_{CO(4-3)} / L'_{CO(1-0)} \sim 1.0 \rightarrow$ thermally excited

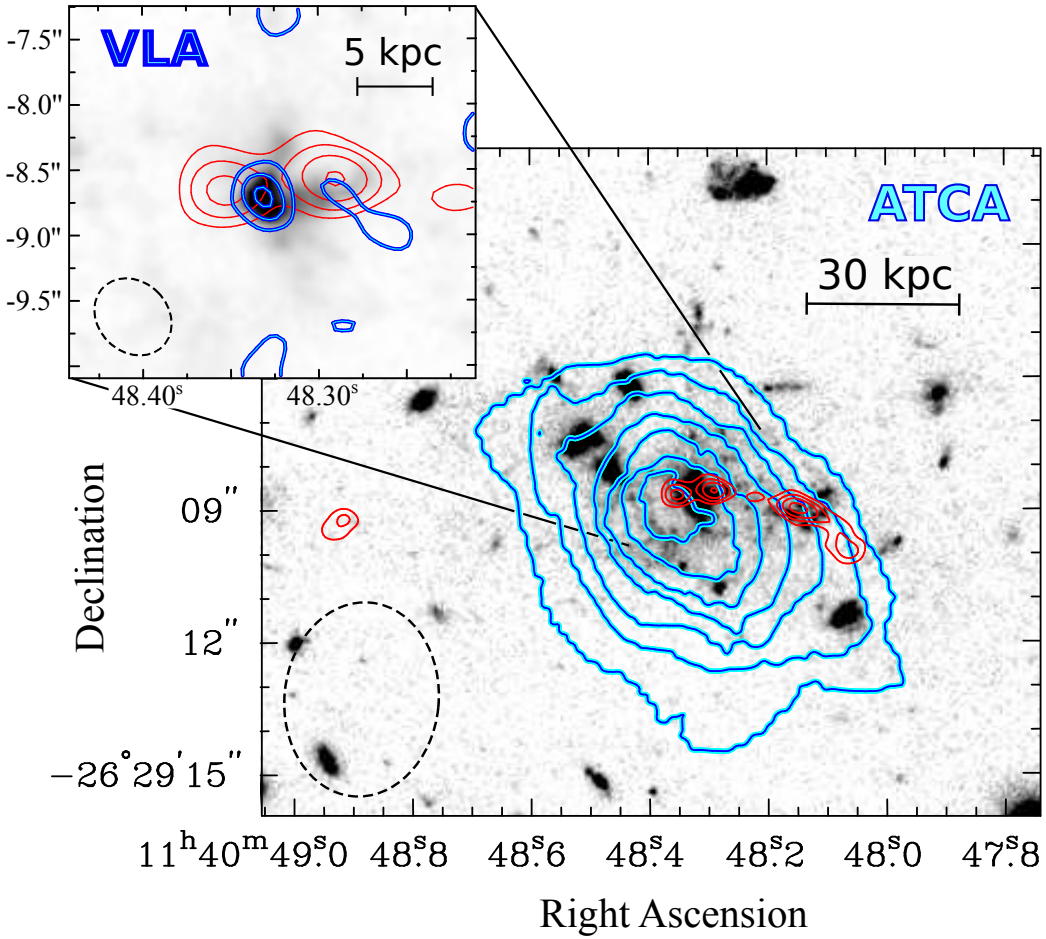
$L'_{[CI]\ 1\rightarrow0} / L'_{CO(1-0)} \sim 0.66 \rightarrow$ high relative [CI] abundance

H_2O along jet! → jet-induced cooling *(Gullberg et al. 2016, A&A, 591)*





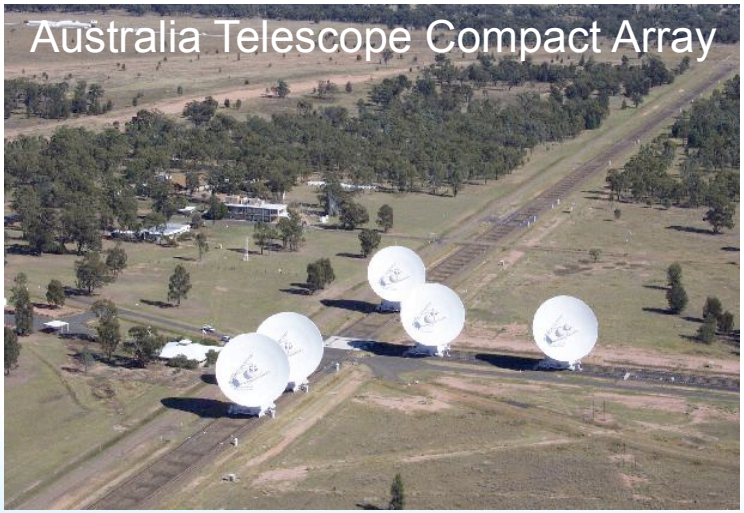
Cold molecular IGM



σ_{ATCA} = 0.085 mJy/bm

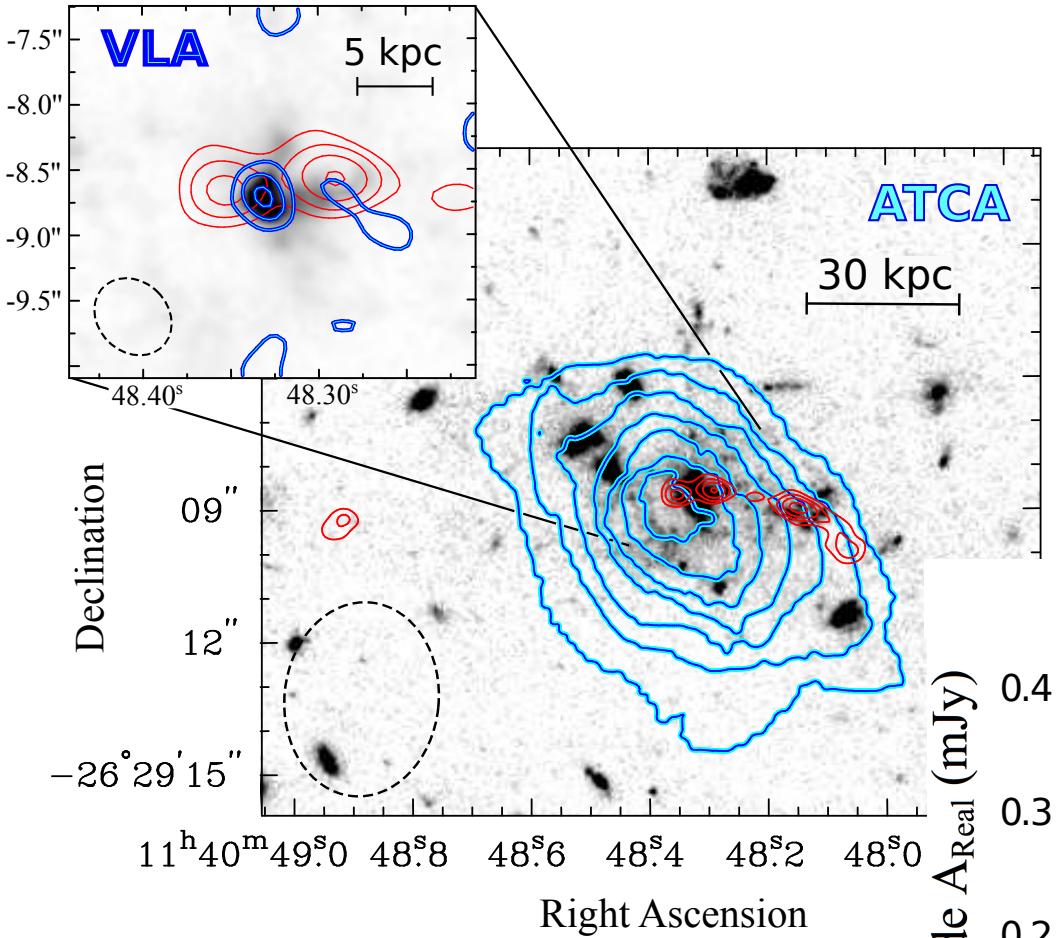
σ_{VLA} = 0.080 mJy/bm

ATCA sees 3x more flux!!

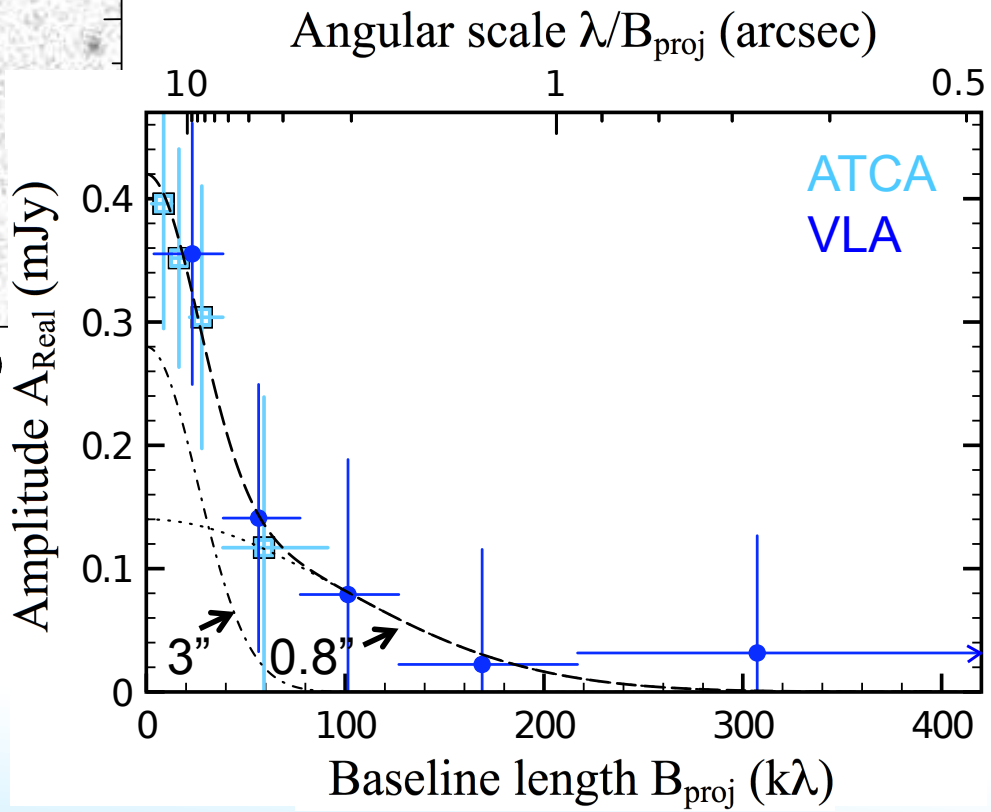


Emonts et al 2016, Science, 354, 1128

Cold molecular IGM



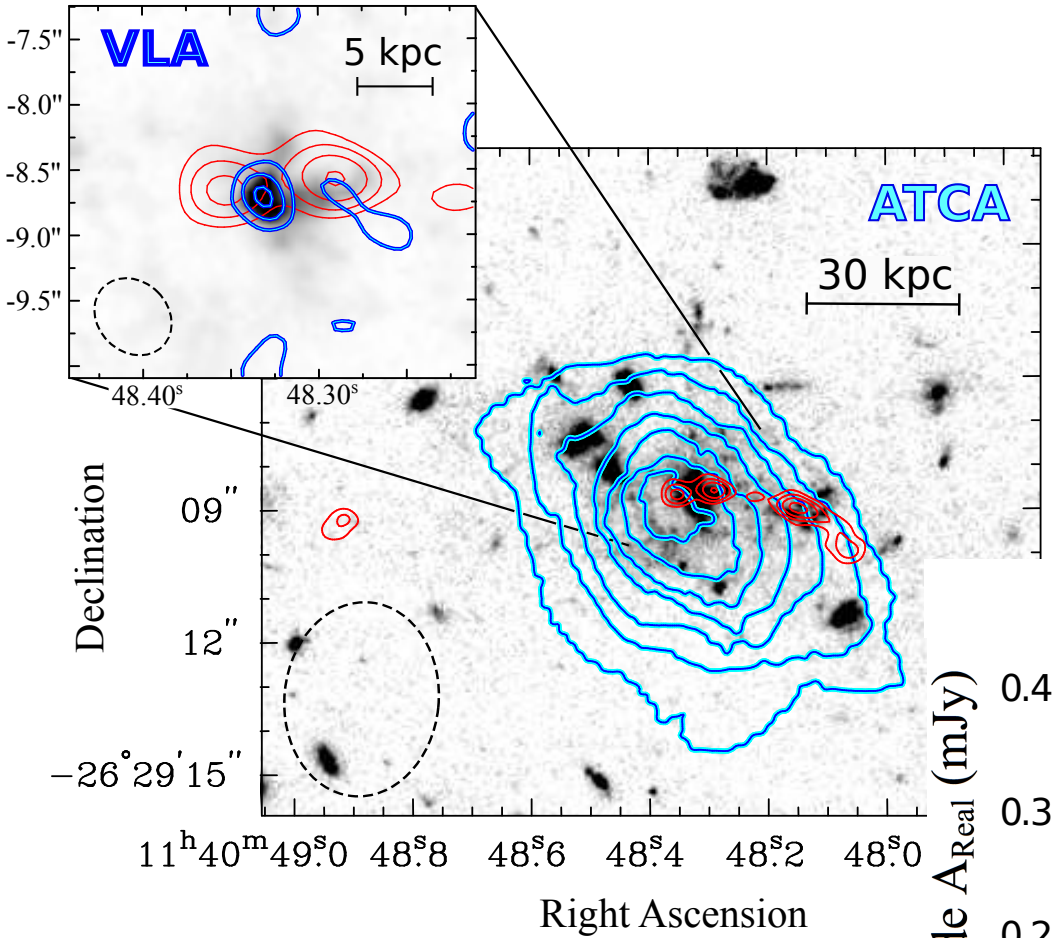
Low-surface-brightness!



σ_{ATCA} = 0.085 mJy/bm
σ_{VLA} = 0.080 mJy/bm

Emonts et al 2016, Science, 354, 1128

Cold molecular IGM

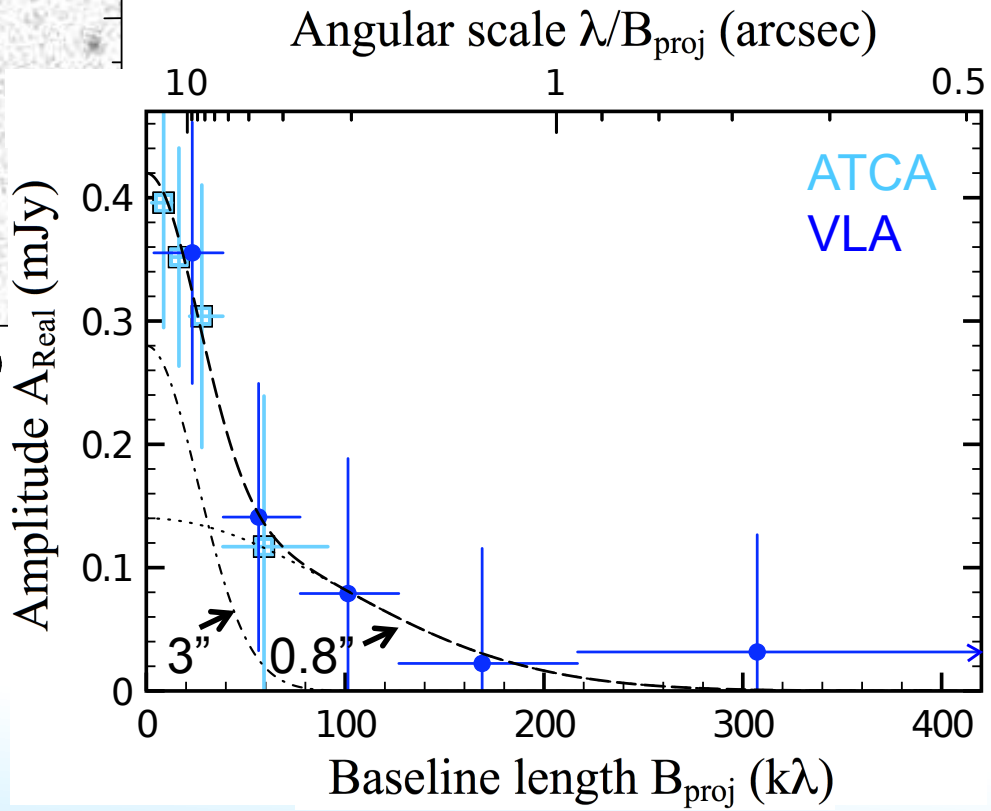


σ_{ATCA} = 0.085 mJy/bm
σ_{VLA} = 0.080 mJy/bm

Mm signal easily resolved out!

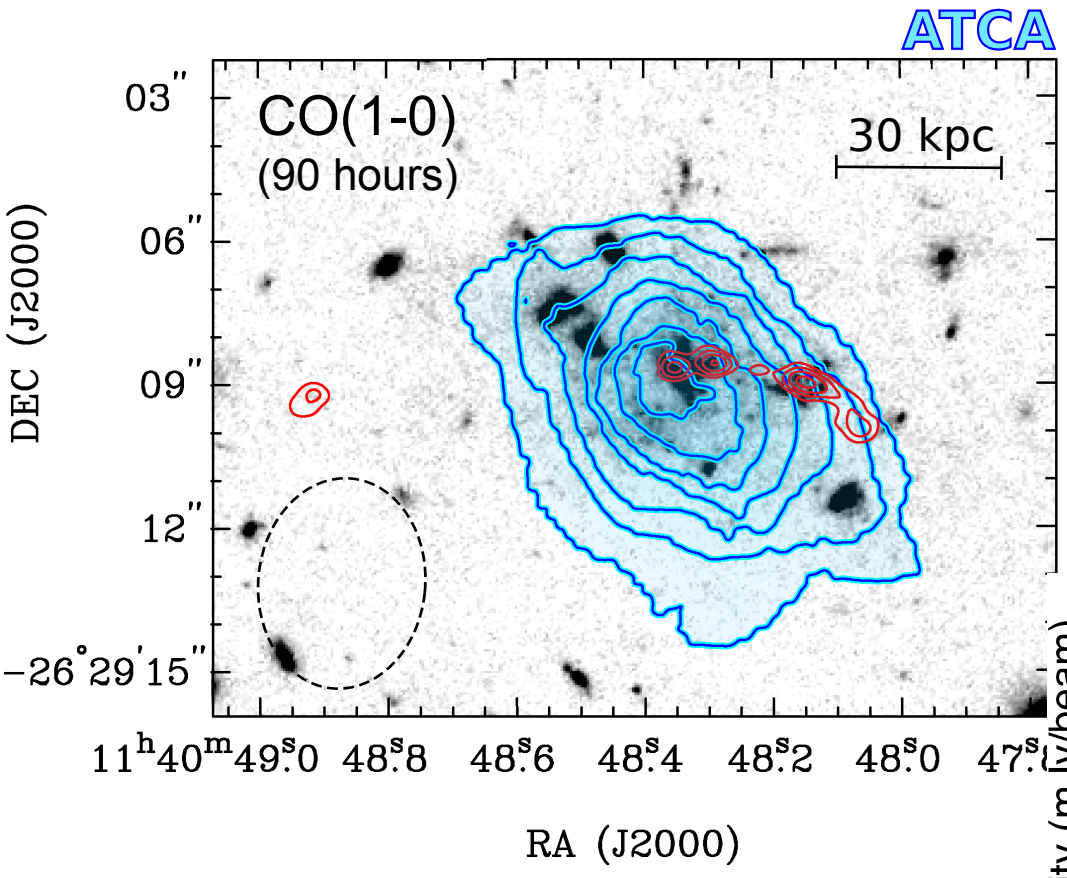
For example, at z=2,
1km baselines resolve out:

- CO(1-0) on >14 kpc scales
- CO(4-3) on >4 kpc scales!

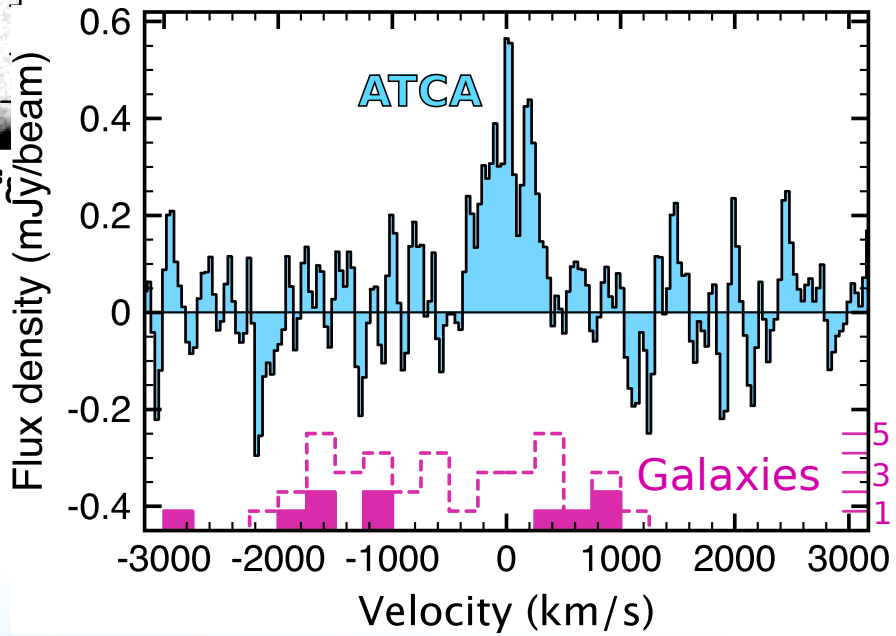


Emonts et al 2016, Science, 354, 1128

Cold molecular IGM



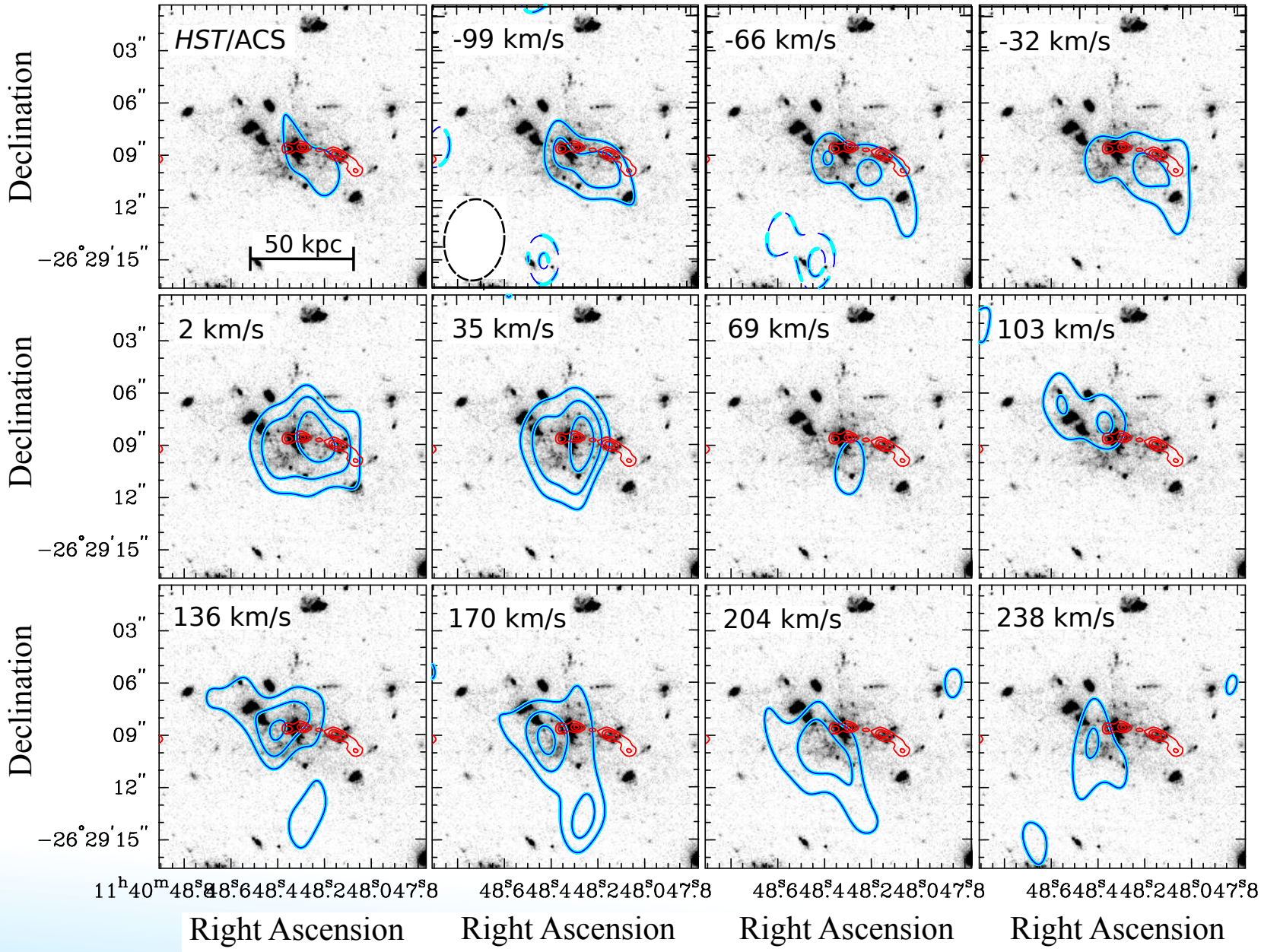
Spiderweb Galaxy



$M_{H2} \sim 1.5 \times 10^{11} (\alpha_{CO}/4)\ M_{\odot}$

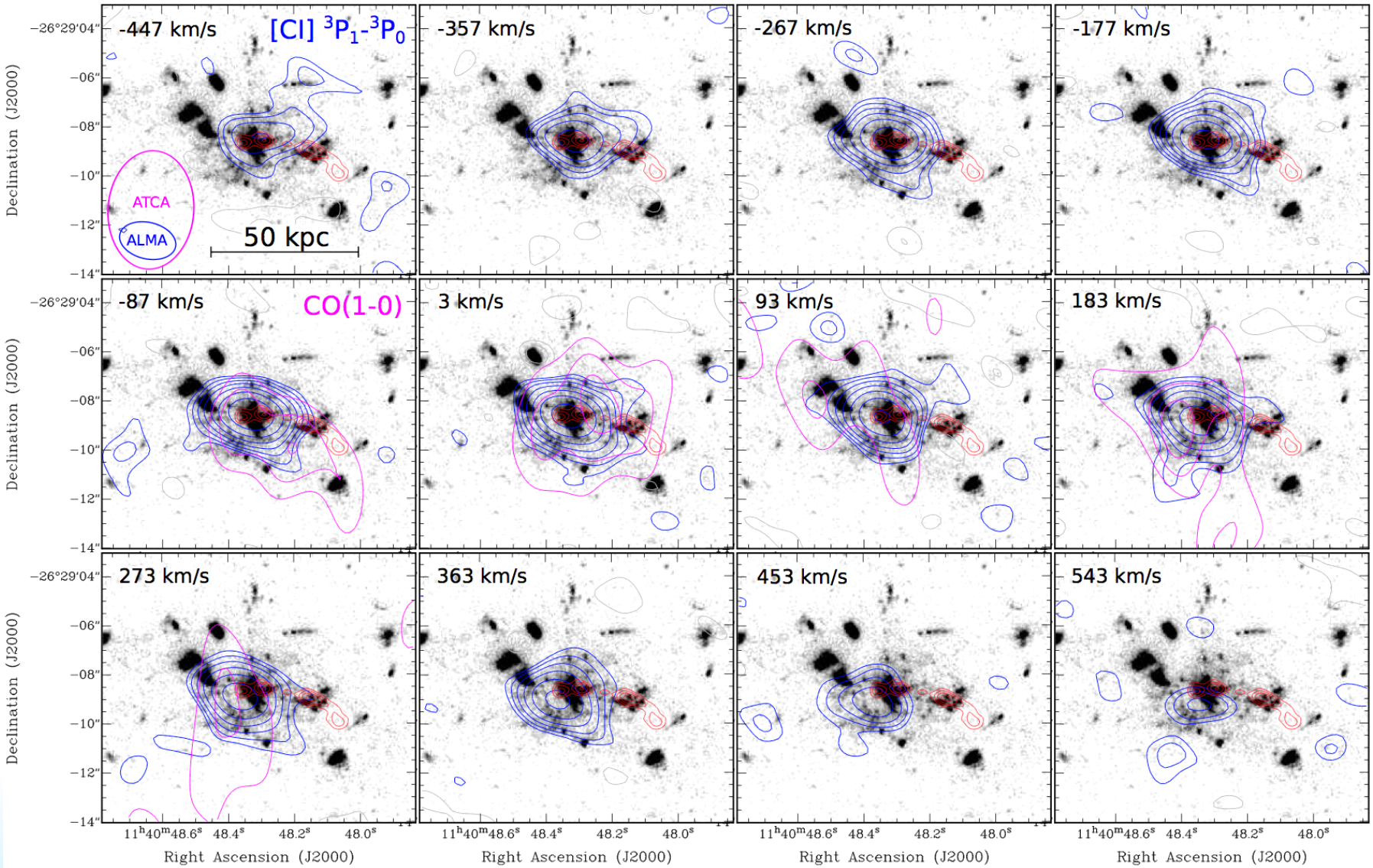
Emonts et al 2016, Science, 354, 1128

Cold molecular IGM



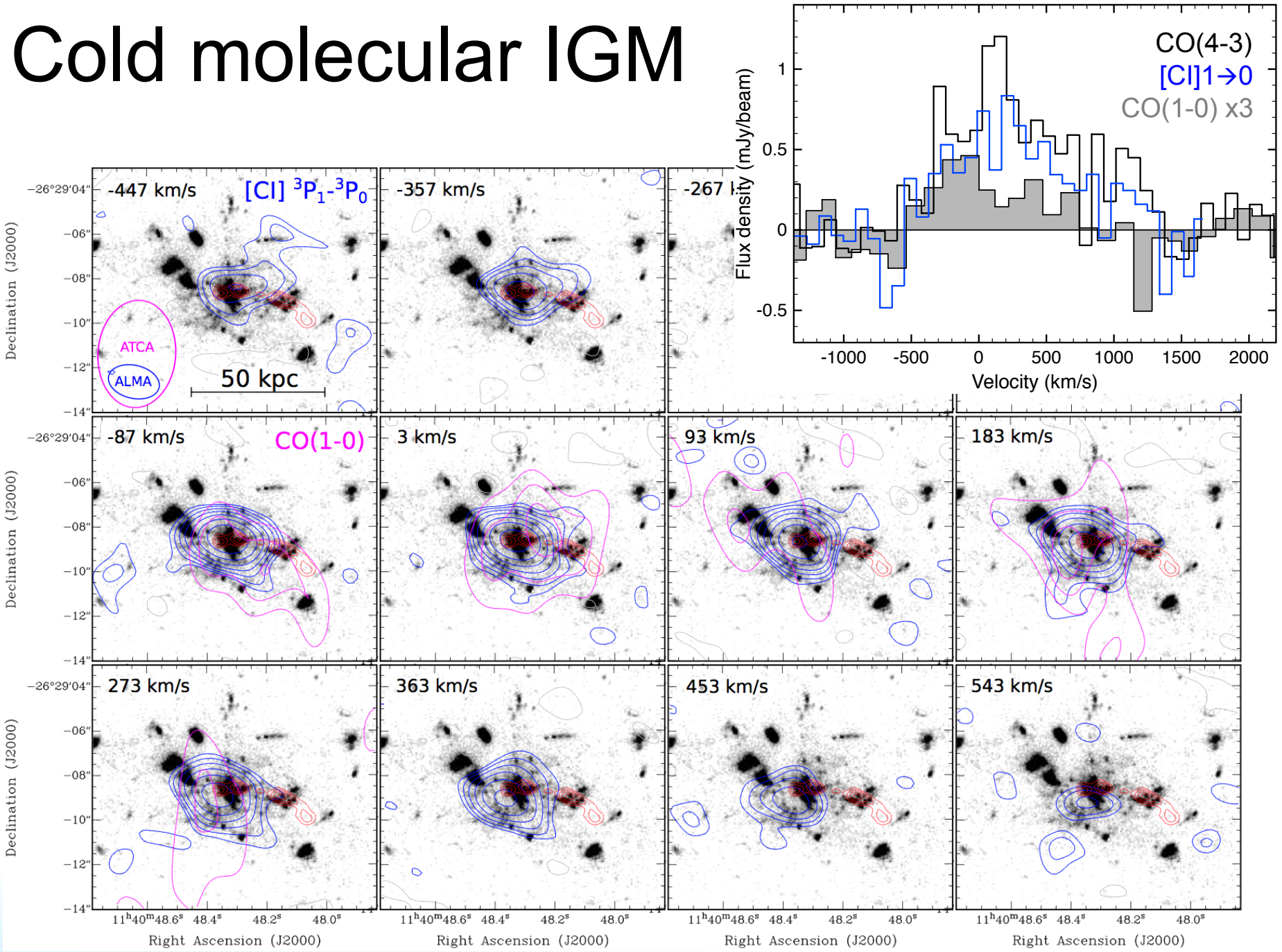
Contour levels: -3.5,-2.5, 2.5, 3.5, 4.5σ

Cold molecular IGM



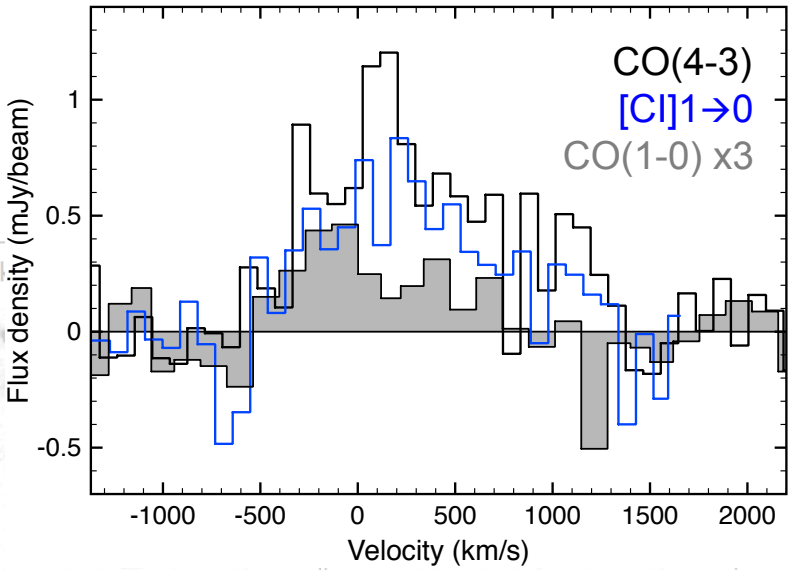
Emonts et al. 2017, under review

Cold molecular IGM



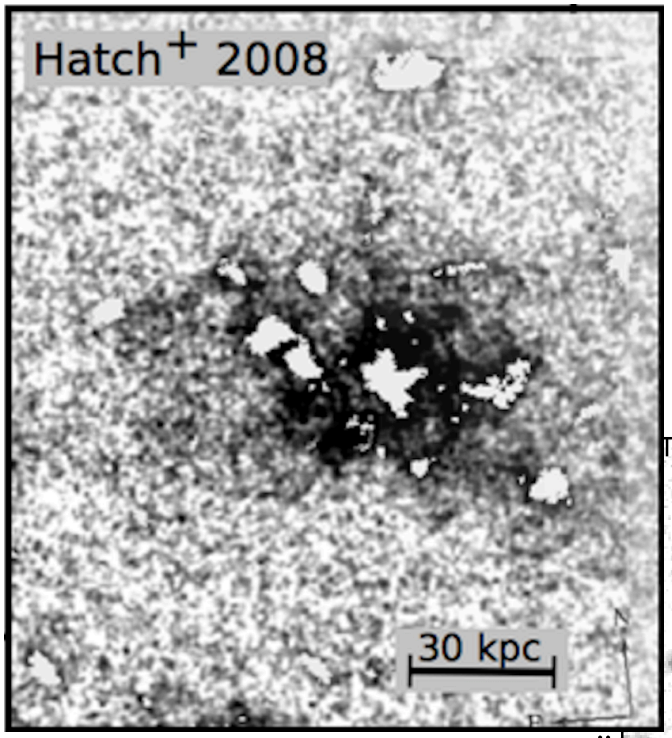
Emonts et al. 2017, under review

Cold molecular IGM

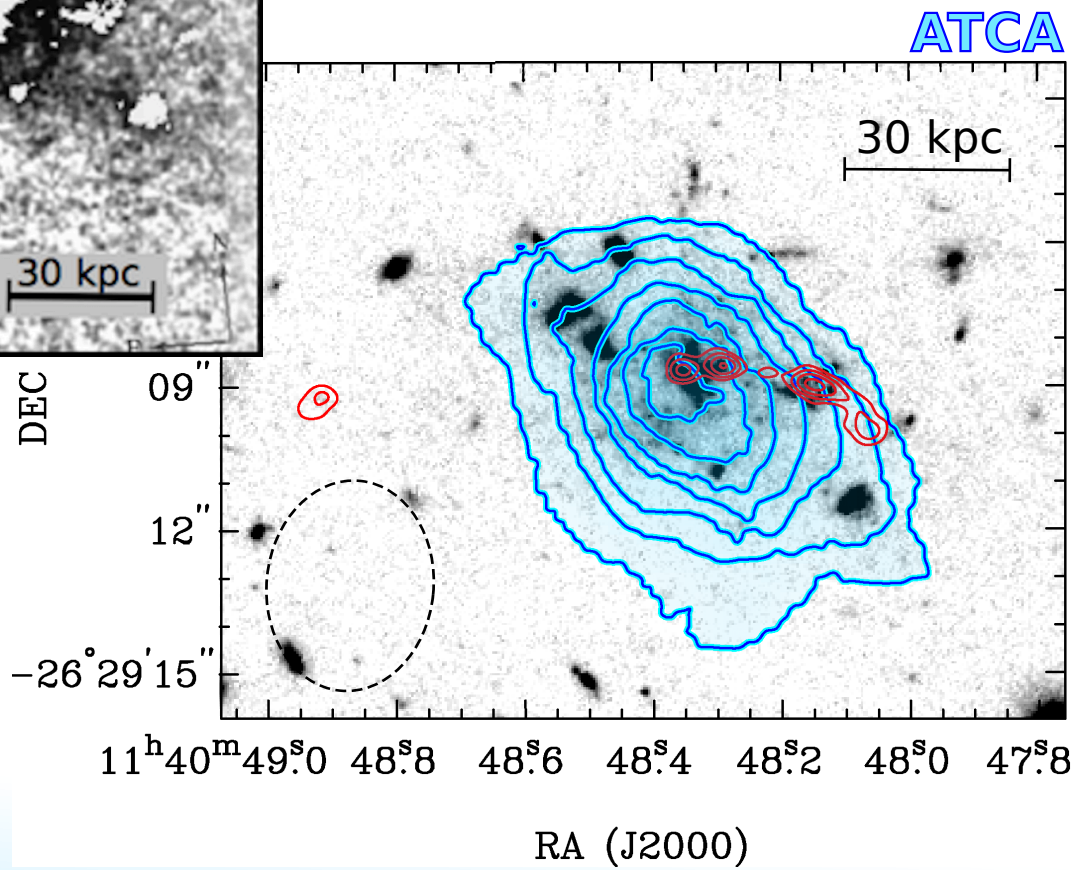


Emonts et al. 2017, under review

Cold molecular IGM



In-situ star formation across the IGM!



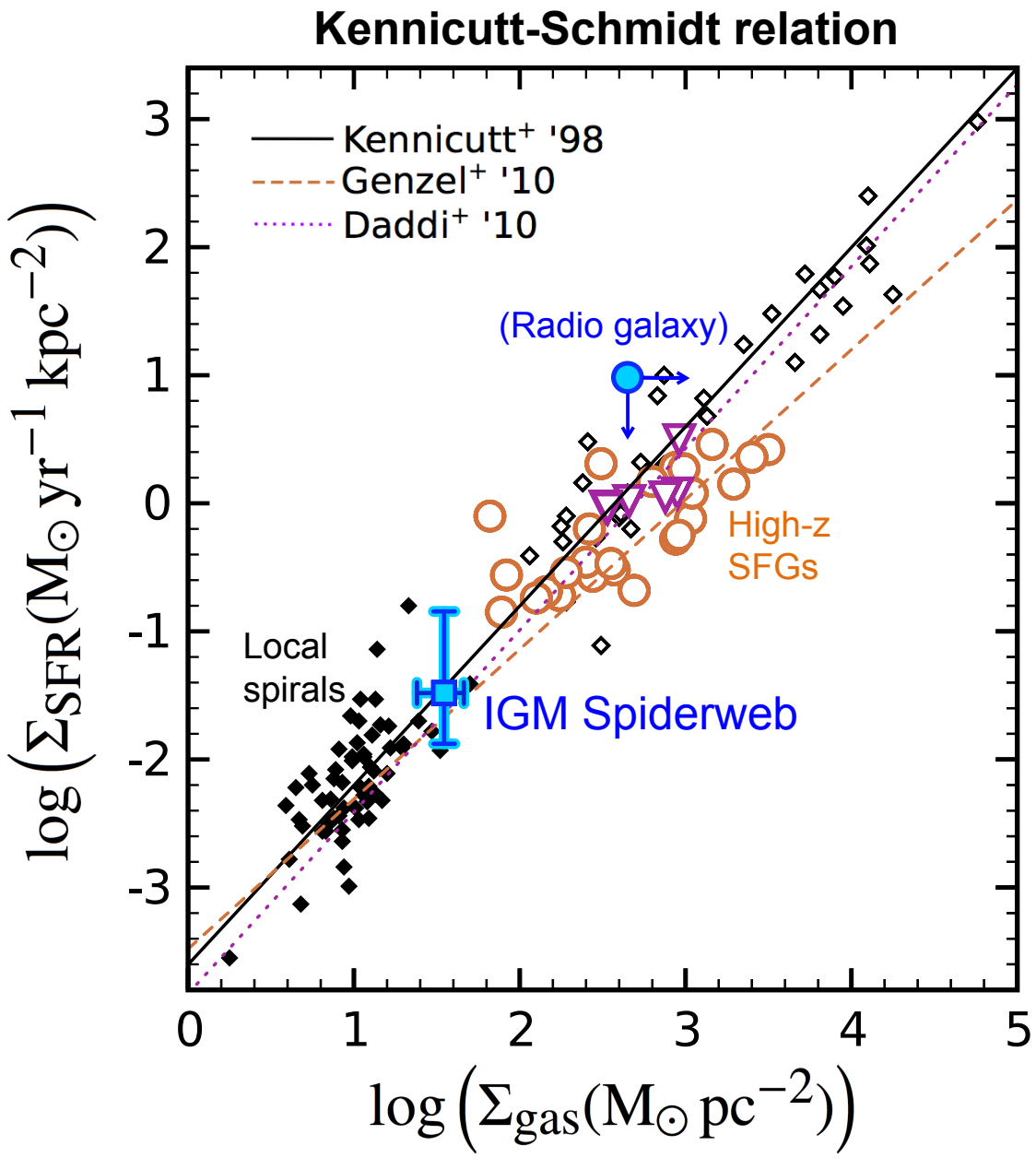
SFR_{IGM} ~ 142 $M_\odot$/yr

$M_{H2} = 1.5 \times 10^{11} (\alpha_{CO}/4)\, M_\odot$

Cold molecular IGM

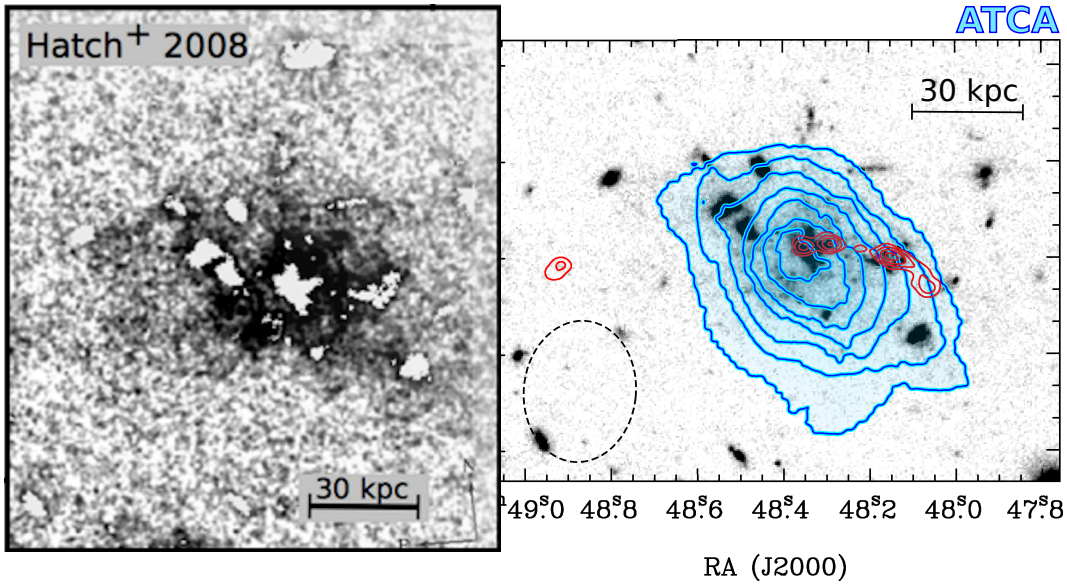
CO(1-0) drives
“in-situ” star formation

Gas depleted by z=1.6
→ stellar halo can age!



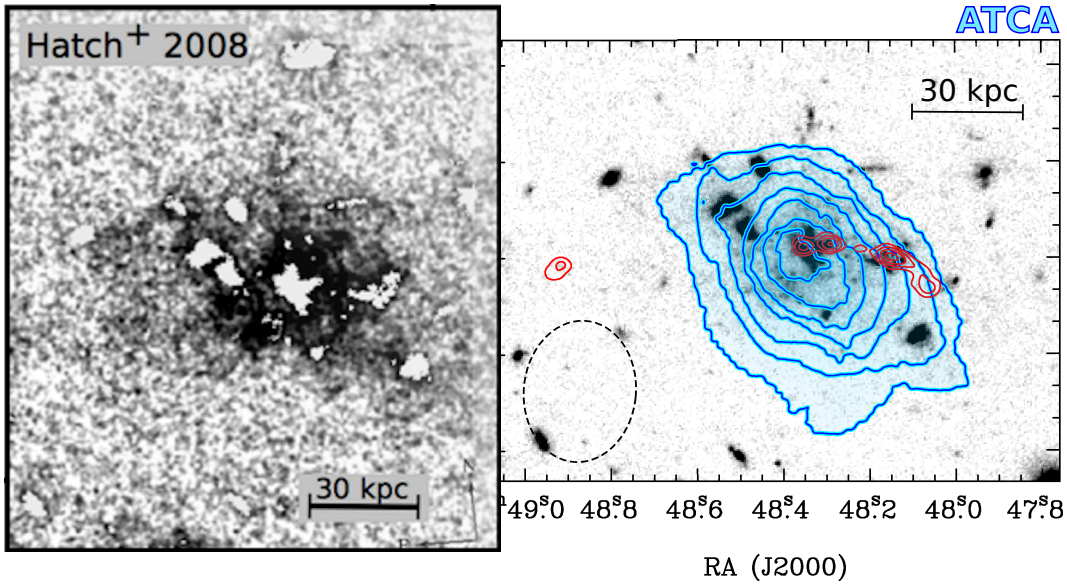
Emonts et al 2016, Science, 354, 1128

Cold molecular IGM

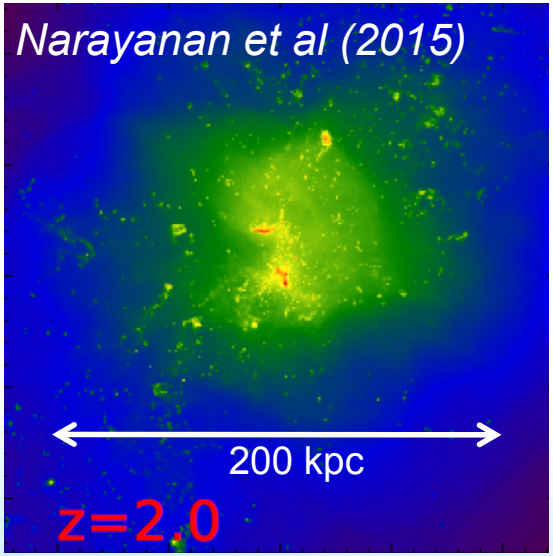


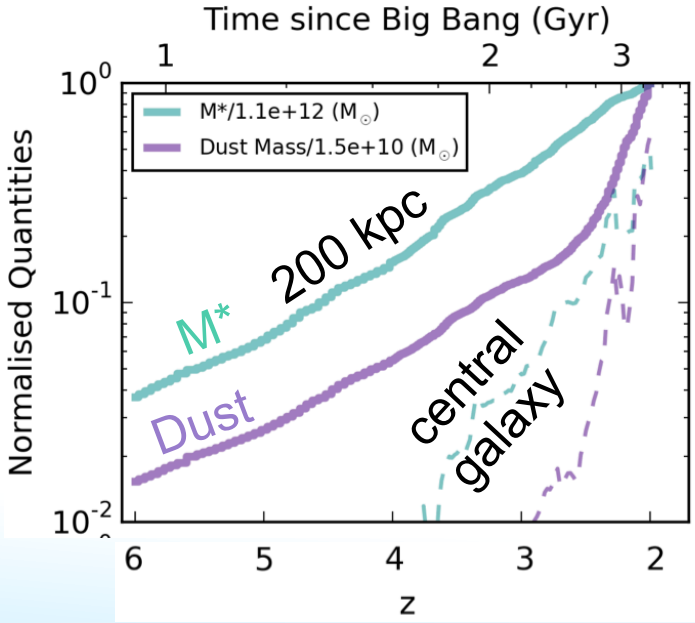
Early assembly of
giant cluster elliptical
out of enriched cold IGM

Cold molecular IGM

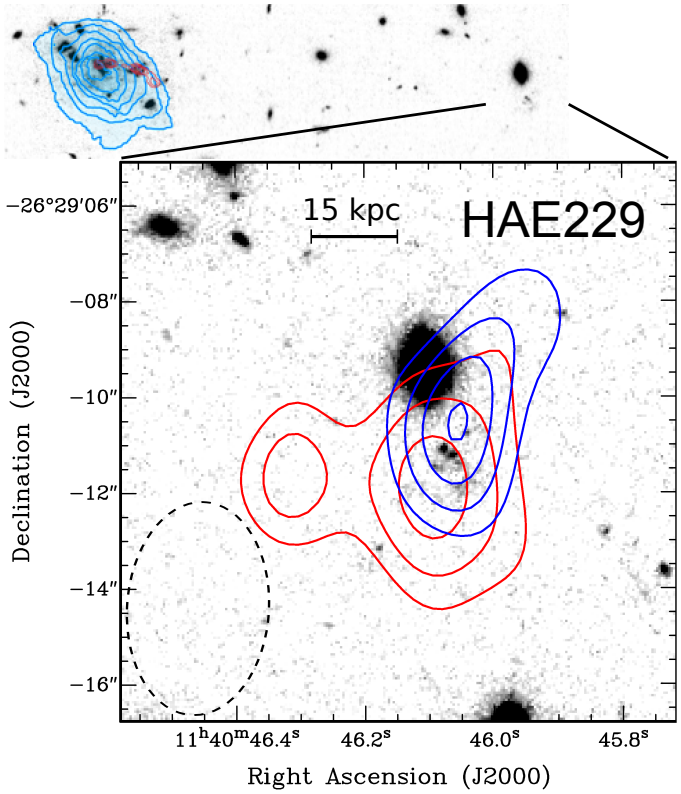


Early assembly of
giant cluster elliptical
out of enriched cold IGM





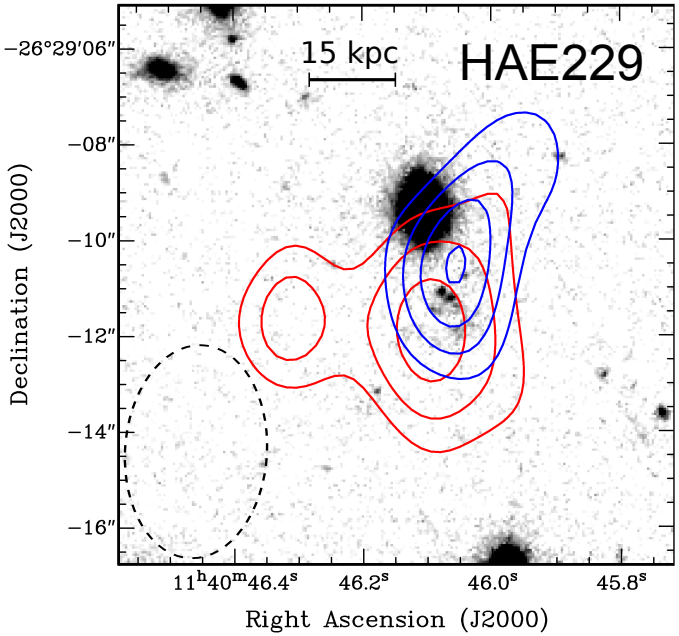
Cold Molecular Medium



Imaging CO(1-0) in larger Spiderweb cluster
COALAS: ATCA Large Project (PI: H. Dannerbauer)

Dannerbauer et al. 2017, arXiv 1701.05250

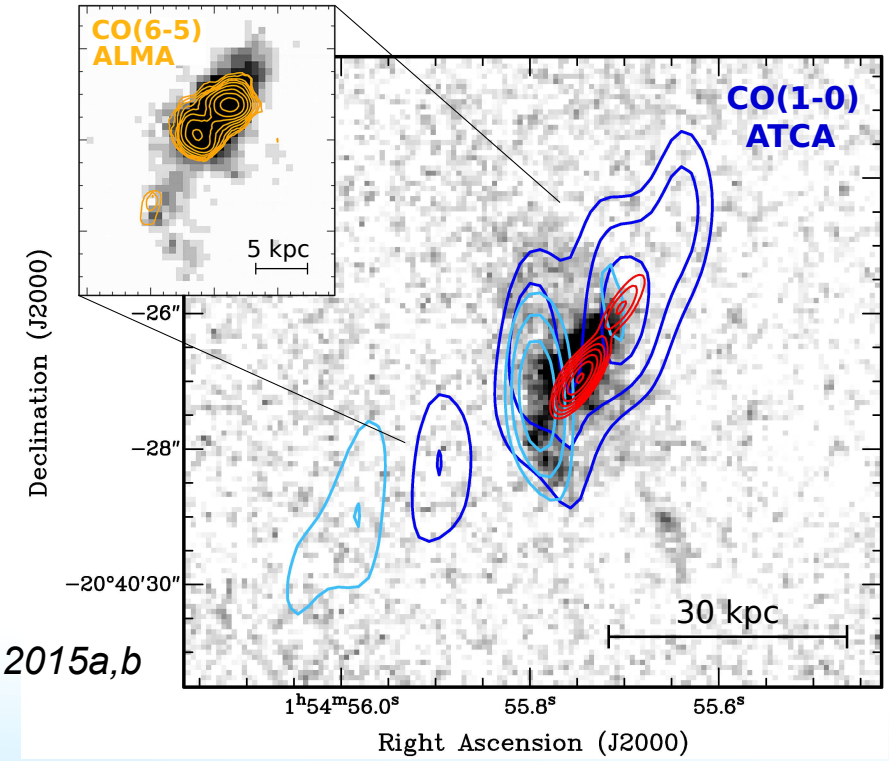
Cold Molecular Medium



Imaging CO(1-0) in larger Spiderweb cluster
ATCA Large Project (PI: H. Dannerbauer)

Dannerbauer et al. 2017, arXiv 1701.05250

Dragonfly Galaxy (z=1.9)
HYLIRG merger

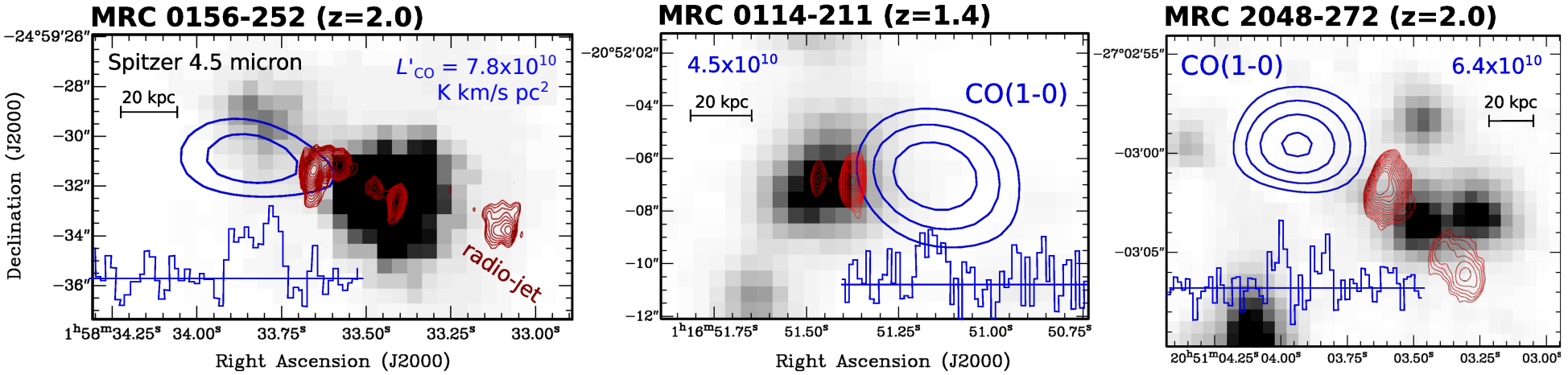


Emonts et al. 2015a,b

Cold Molecular Medium

Imaging CO(1-0) in larger Spiderweb cluster
ATCA Large Project (PI: H. Dannerbauer)

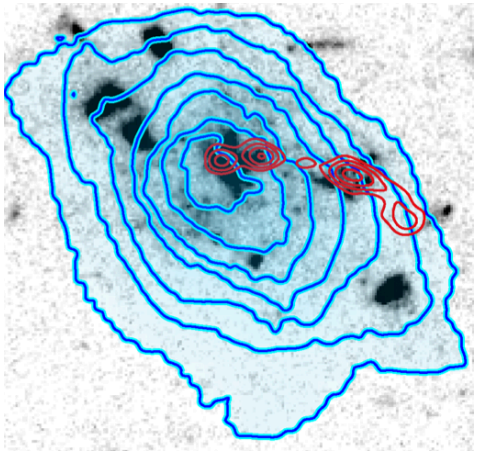
CO(1-0) halo reservoirs → jet-alignments!



Emonts et al. 2014, 2017

Emonts et al. 2015a,b

HI absorption at z~2
VLA P-band spectroscopy



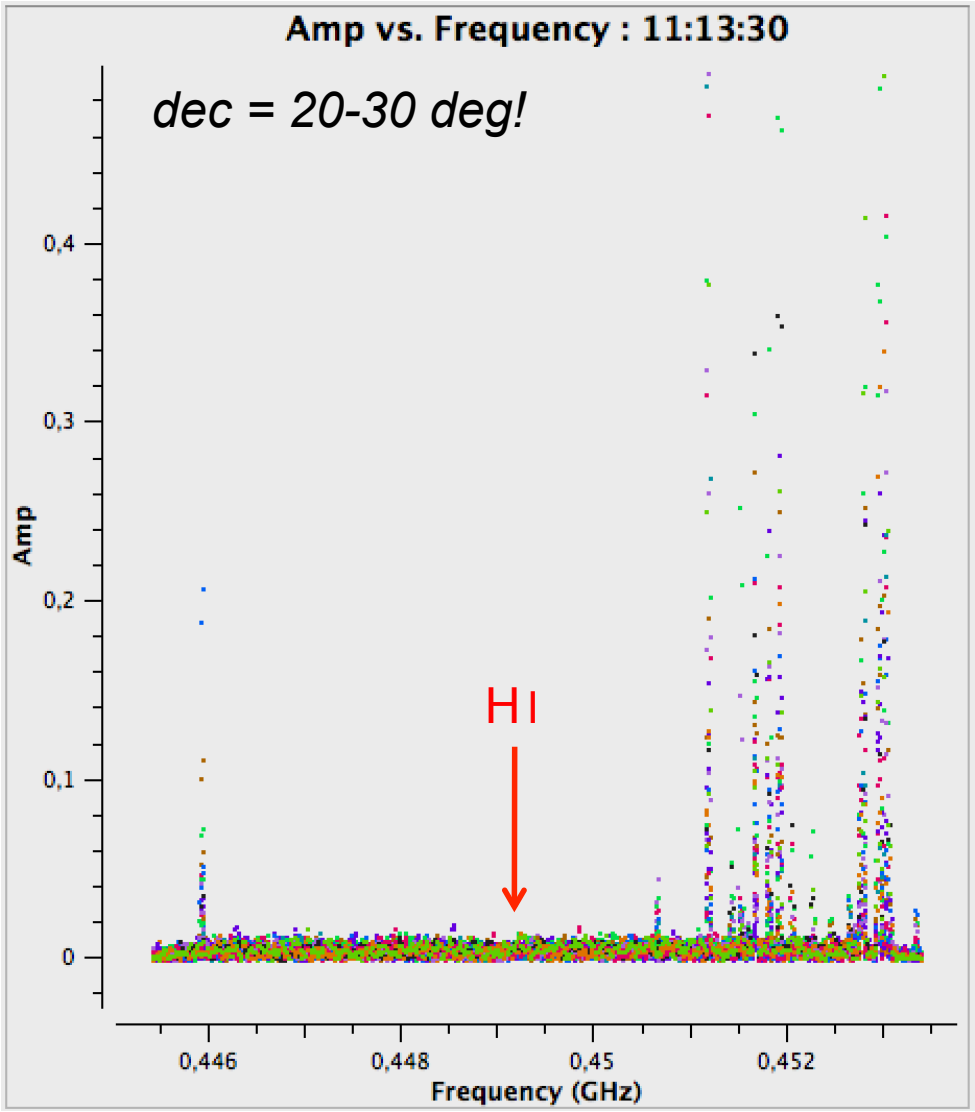
Minnie Mao
Frazer Owen
Steve Curran
Gustaaf van Moorsel

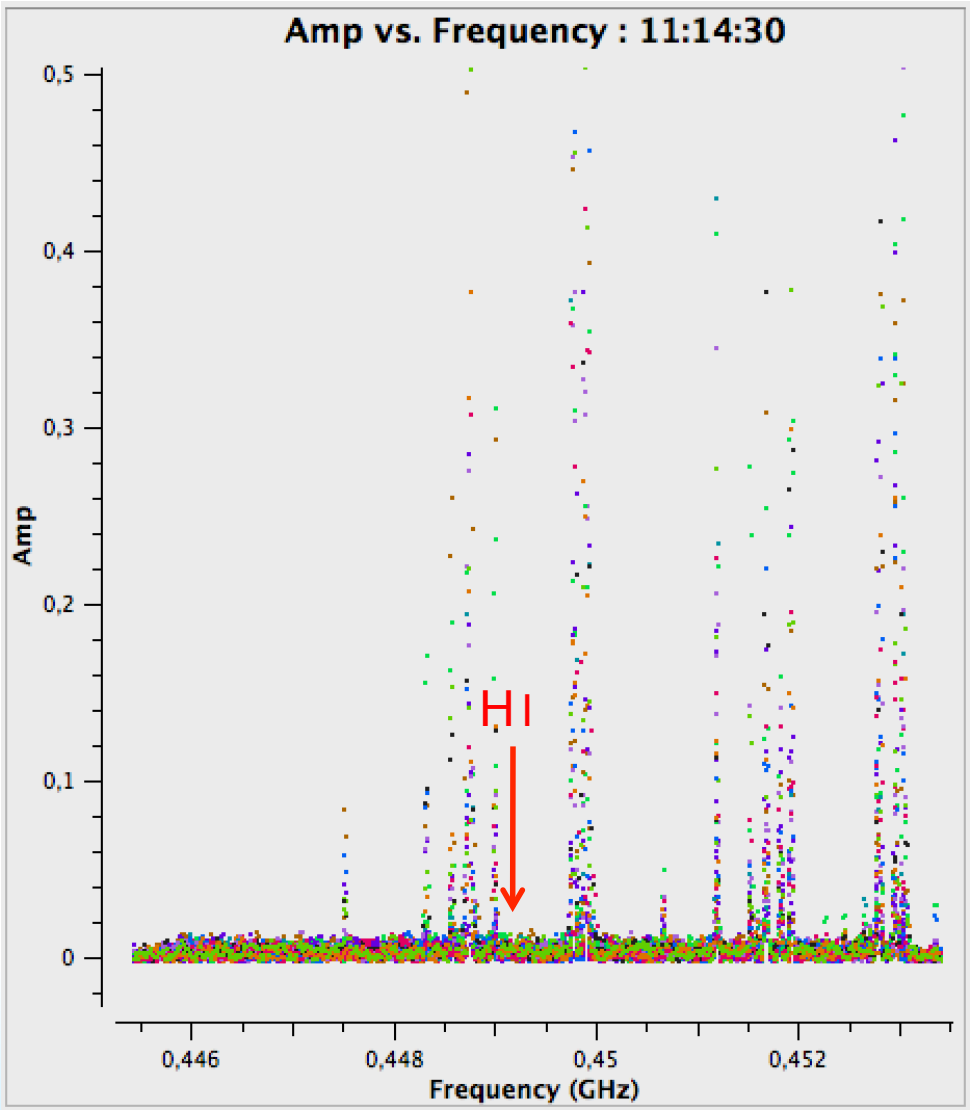
VLA P-band

Coverage: 230 – 492 MHz
Observations: 40 MHz / 15.6 kHz / full pol. (2x)

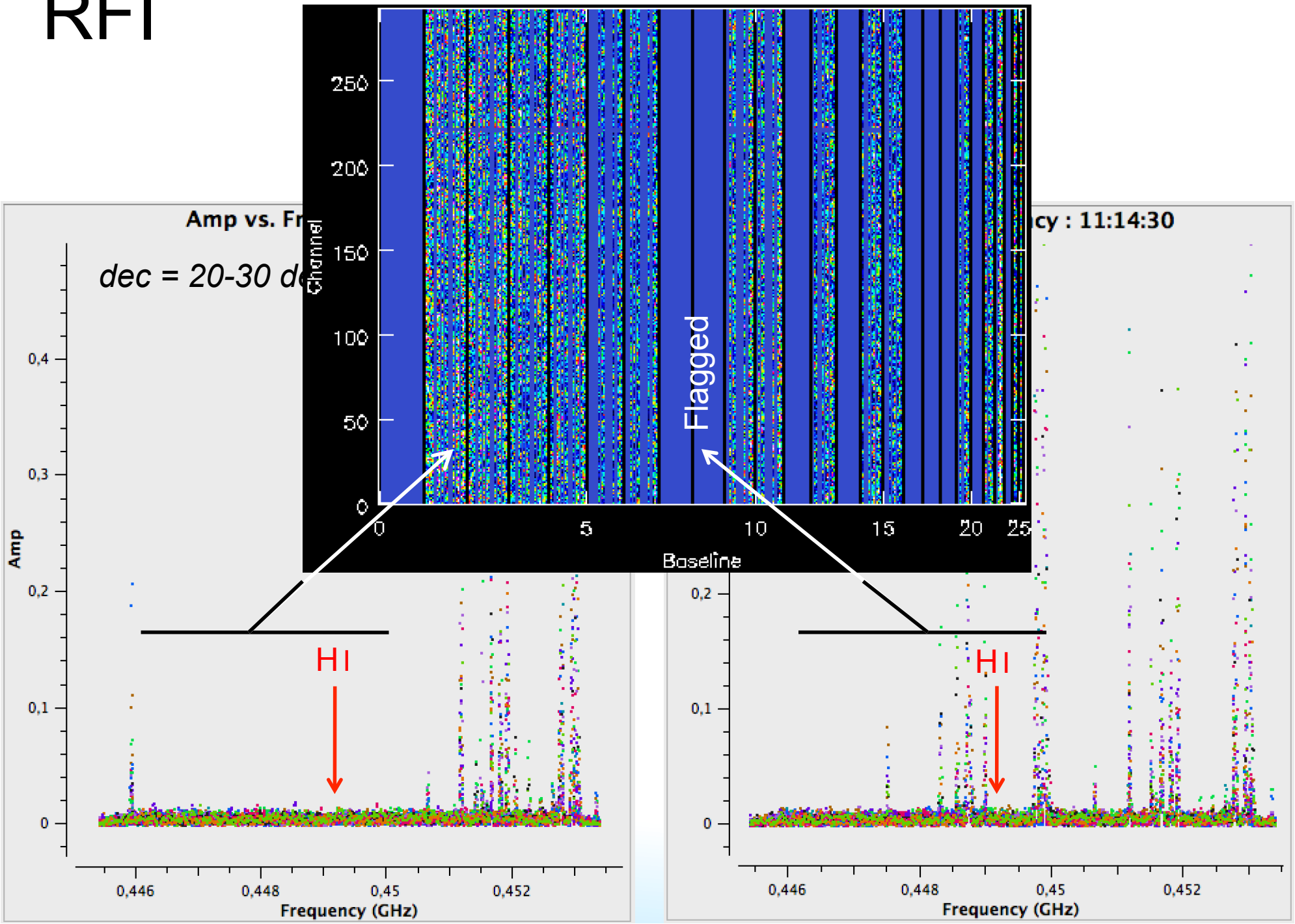
VLA P-band

Coverage: 230 – 492 MHz
Observations: 40 MHz / 15.6 kHz / full pol. (2x)

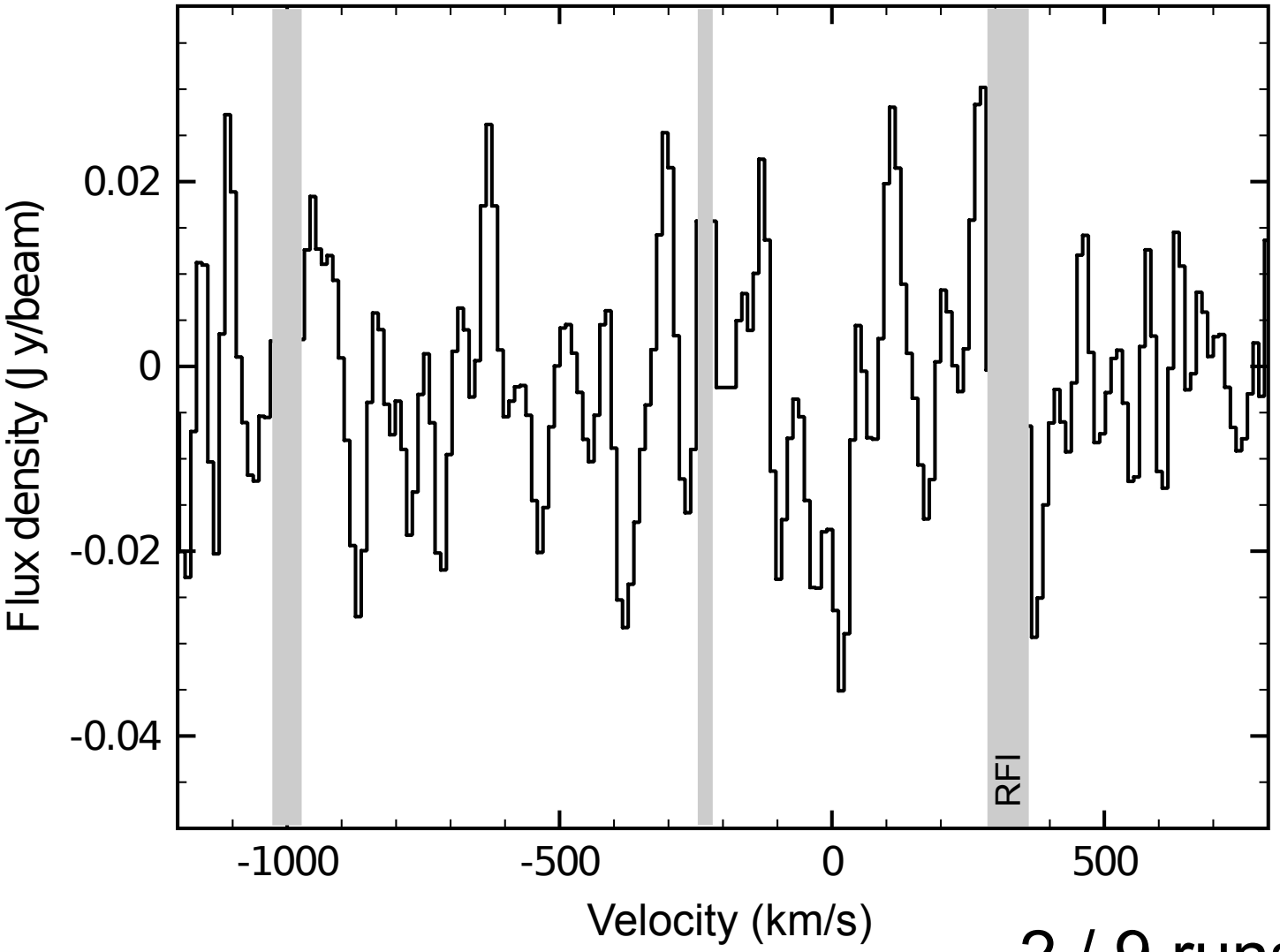




RFI


Amp vs. Fr
dec = 20-30 d
cy : 11:14:30
Channel
250
200
150
100
50
0
0
5
10
15
20
25
Baseline
Flagged
Amp
0,4
0,3
0,2
0,1
0
HI
0,446
0,448
0,45
0,452
Frequency (GHz)
HI
Frequency (GHz)

HI absorption in halo at z~2.2 ?



2 / 9 runs
(22% data)

Conclusions

VLA P-band spectroscopy works!

Cold Molecular Medium can be observed!
(but need dedicated low-surface-brightness observations!!)

Acknowledgement:
RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562


Thank you!
ALMA/ESO/NAOJ/NRAO