COOL BUDHIES: the interplay of gas, star-formation activity, and environment around two clusters at z~0.2

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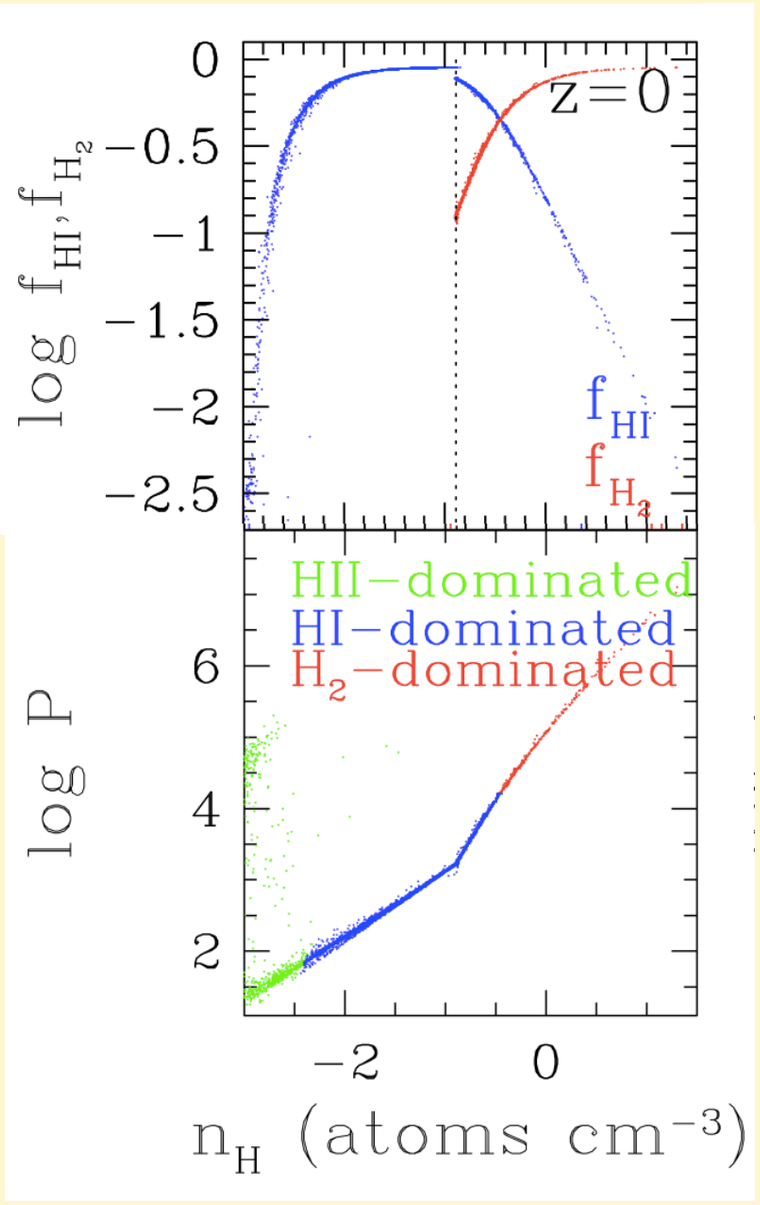
Evolving Galaxies in Evolving Environments
Bologna, 17 September 2014

with Min Yun (advisor) and:

BUDHIES: Marc Verheijen, Jacqueline van Gorkom, Bianca Poggianti*, Yara Jaffé, Aeree Chung, Ximena Fernández

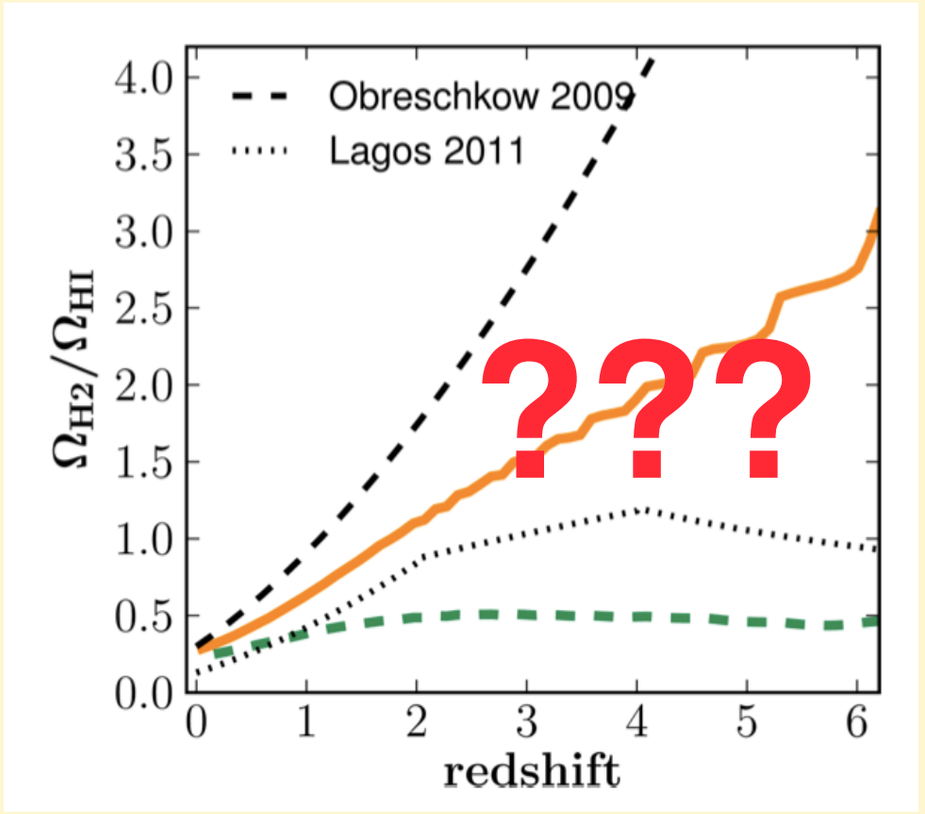
LMT: David Hughes, Peter Scholerb, Miguel Chávez, Grant Wilson, Gopal Narayanan, Neal Erickson, David Sánchez, Milagros Zeballos, Alfredo Montaña, Miguel Velazquez, Victor de la Luz, Andrew Battisti, Chris Thibodeau, Kevin Harrington, and more.

Cold Gas in Galaxies



Davé+ 2013

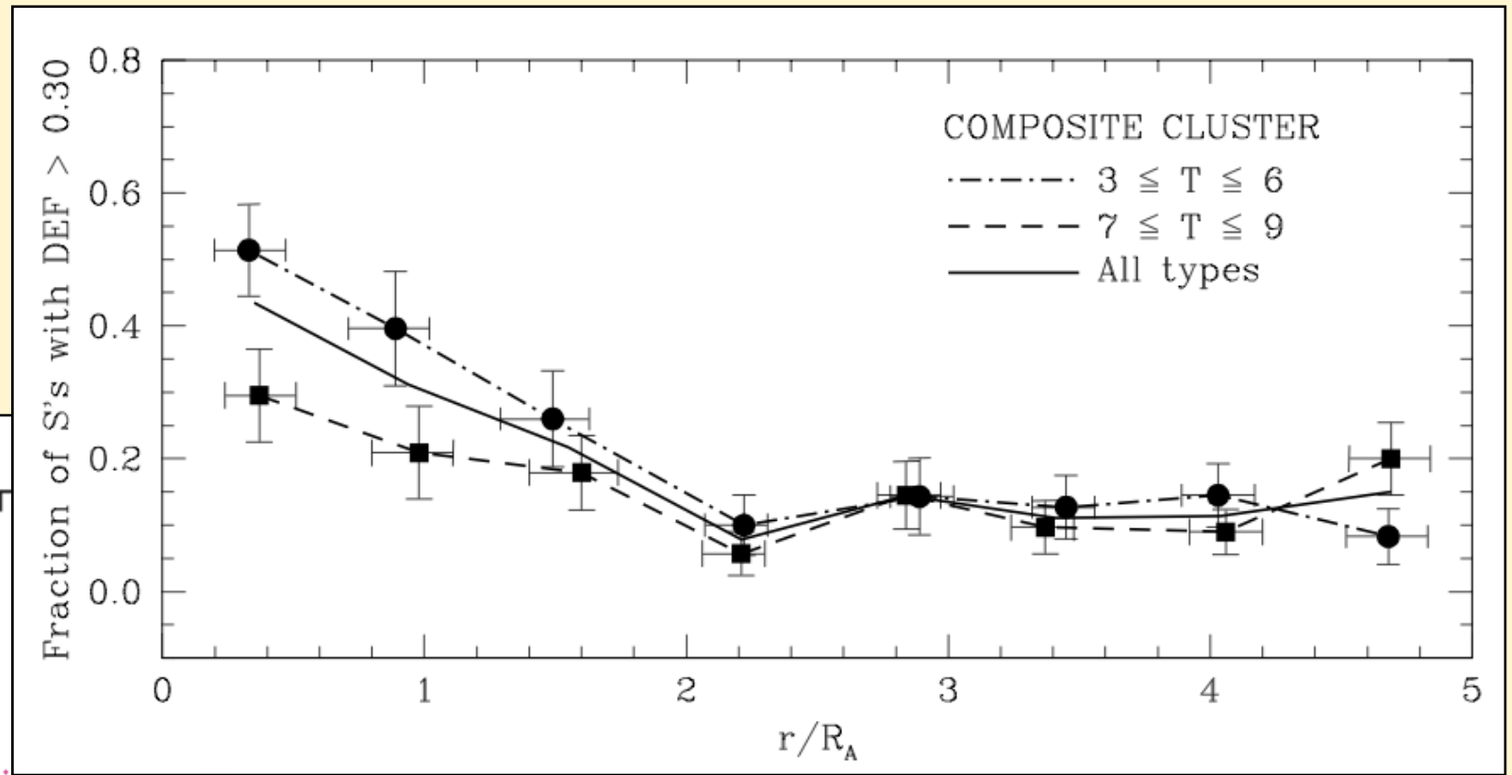
- Cold gas: molecular + atomic (HI)
- Atomic -> Mol. -> Stars. Process is complex and poorly understood (e.g., Leroy+ 2008, Bigiel+ 2008)
- Unlike H_2, HI measurements very scarce beyond the local Universe



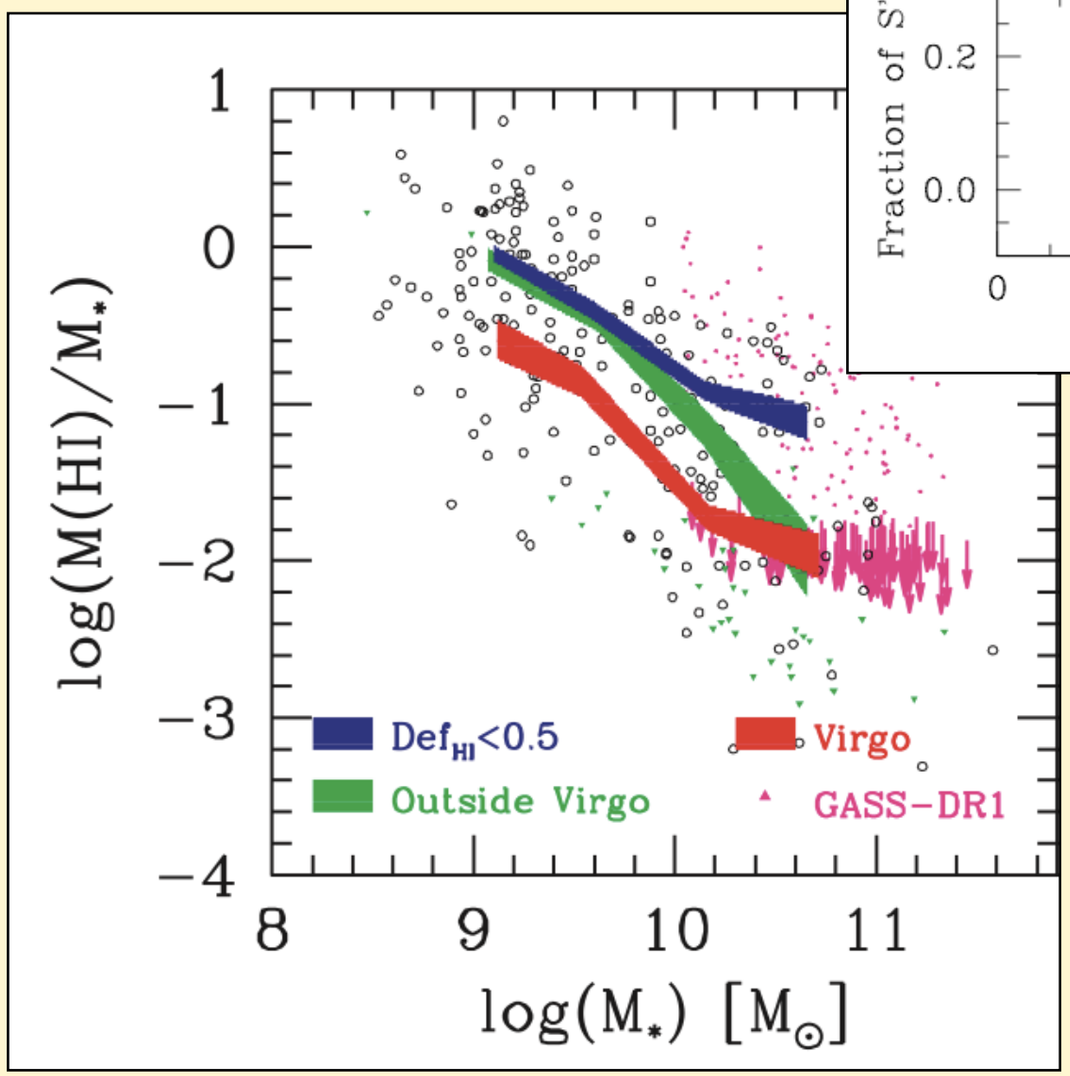
Popping+ 2014

Cold Gas in Galaxies - HI vs Environ.

- Cluster environ. efficient at removing HI



Solanes+ 2001

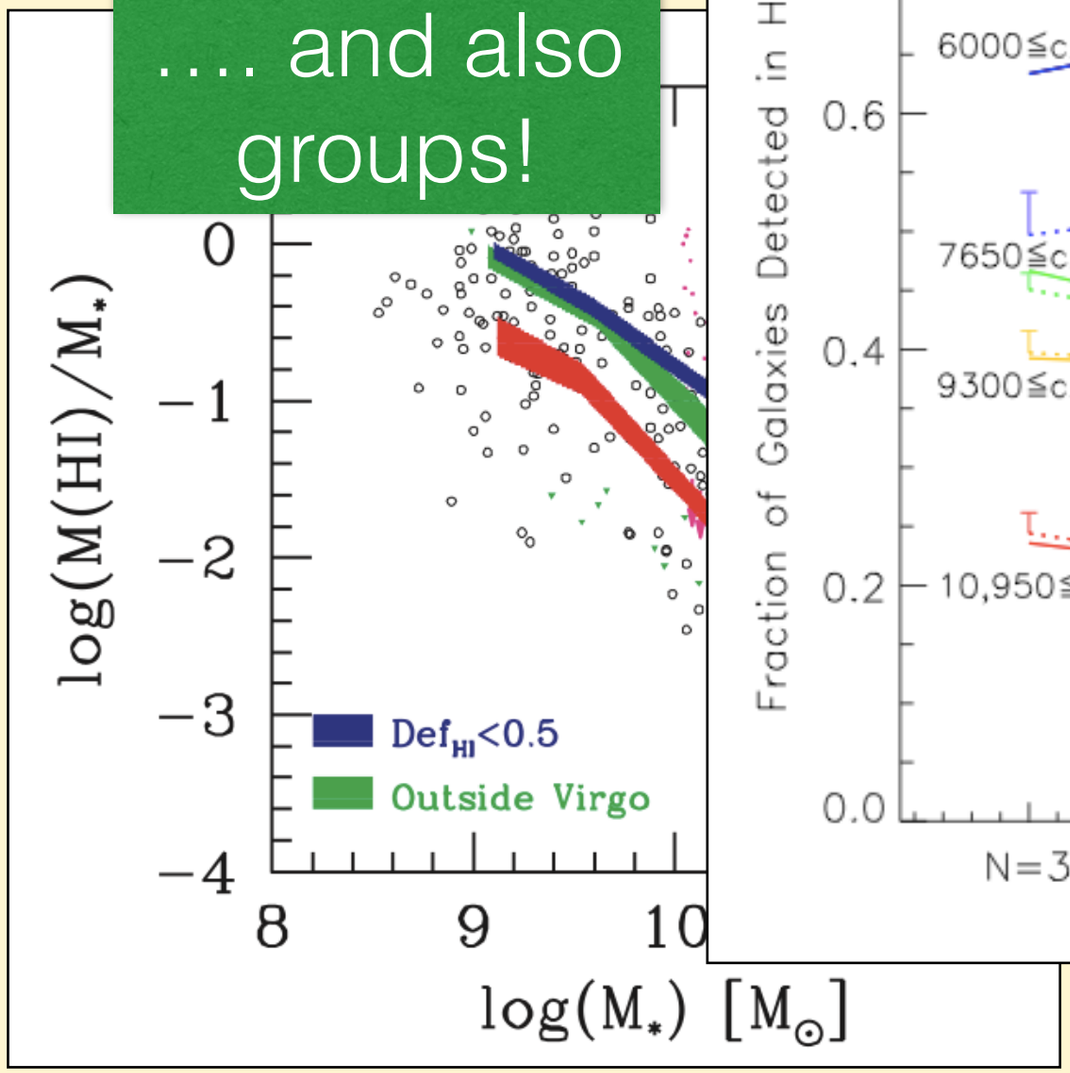


Cortese+ 2011

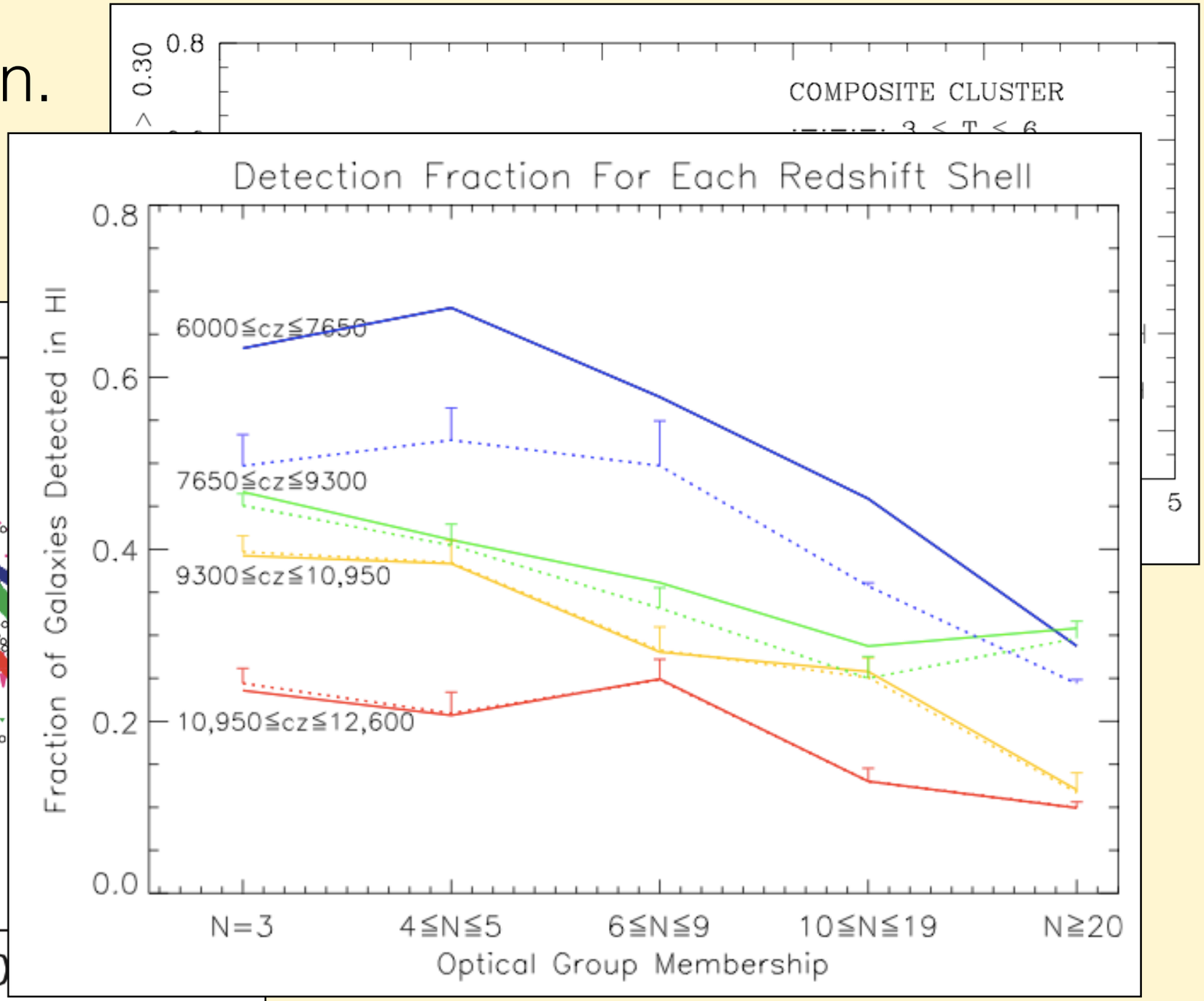
Cold Gas in Galaxies - HI vs Environ.

- Cluster environ. efficient at removing HI

….. and also groups!



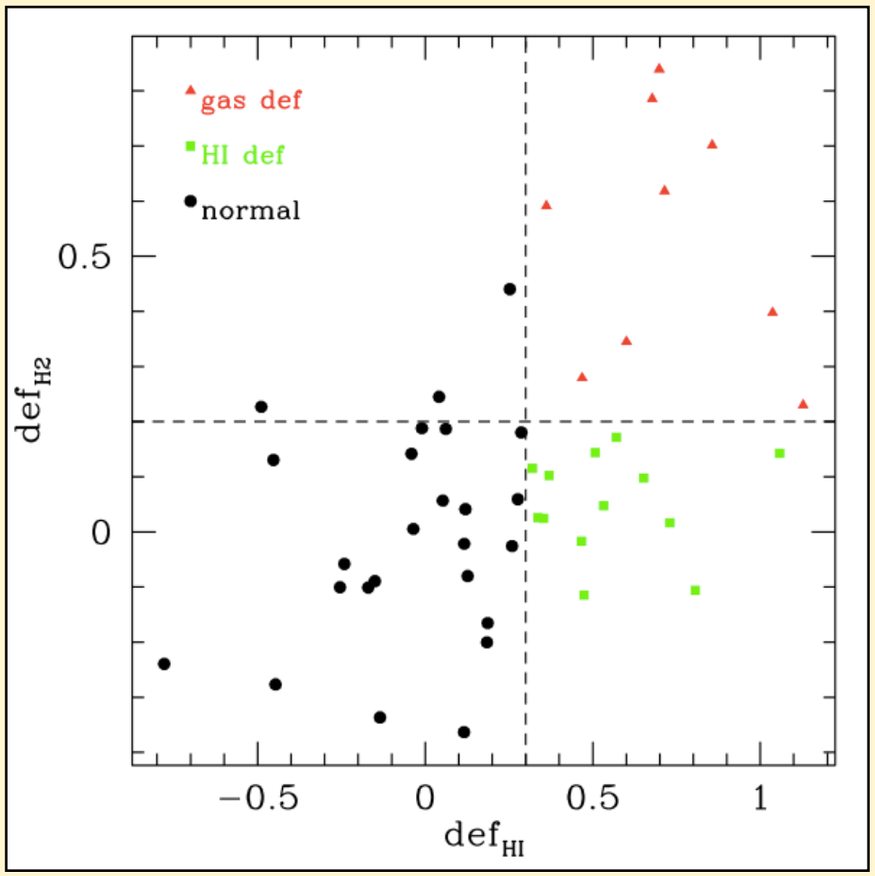
Cortese+ 2011



Hess & Wilcots 2013

Cold Gas in Galaxies - CO vs Environ.

- Def in H_2 correlates with HI

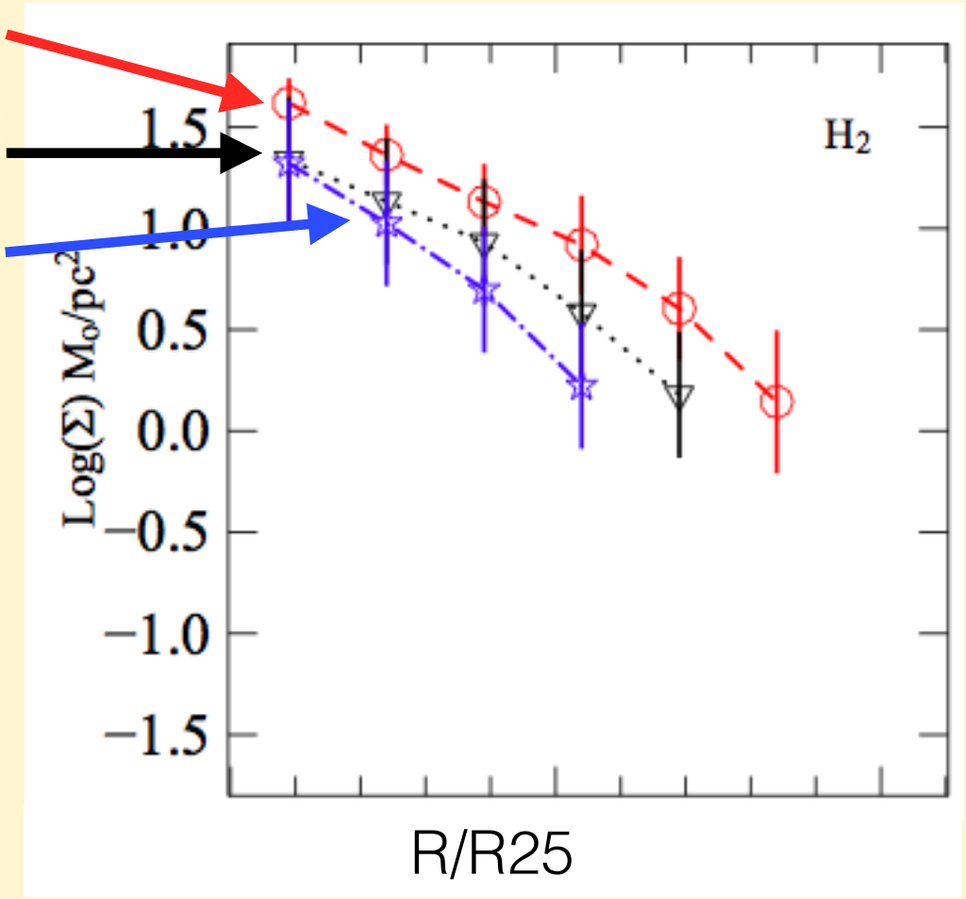


Fumagalli+ 2009

No HI Def

Mod. HI Def

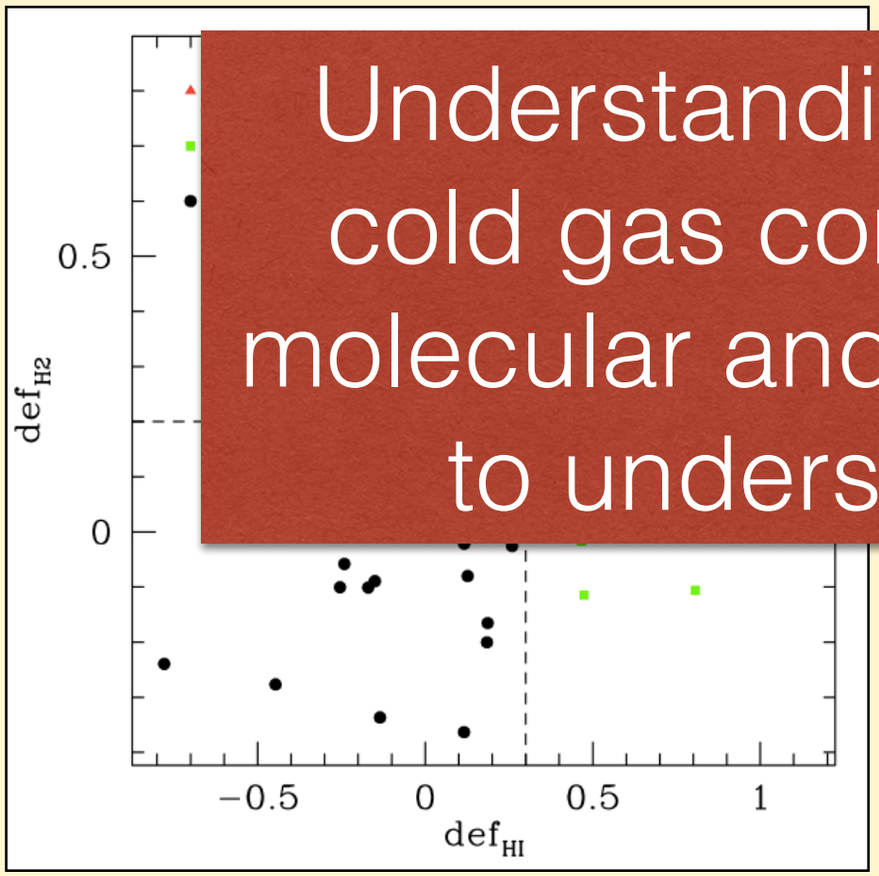
High HI Def



Pappalardo+ 2012

Cold Gas in Galaxies - CO vs Environ.

- Def in H_2 correlates with HI

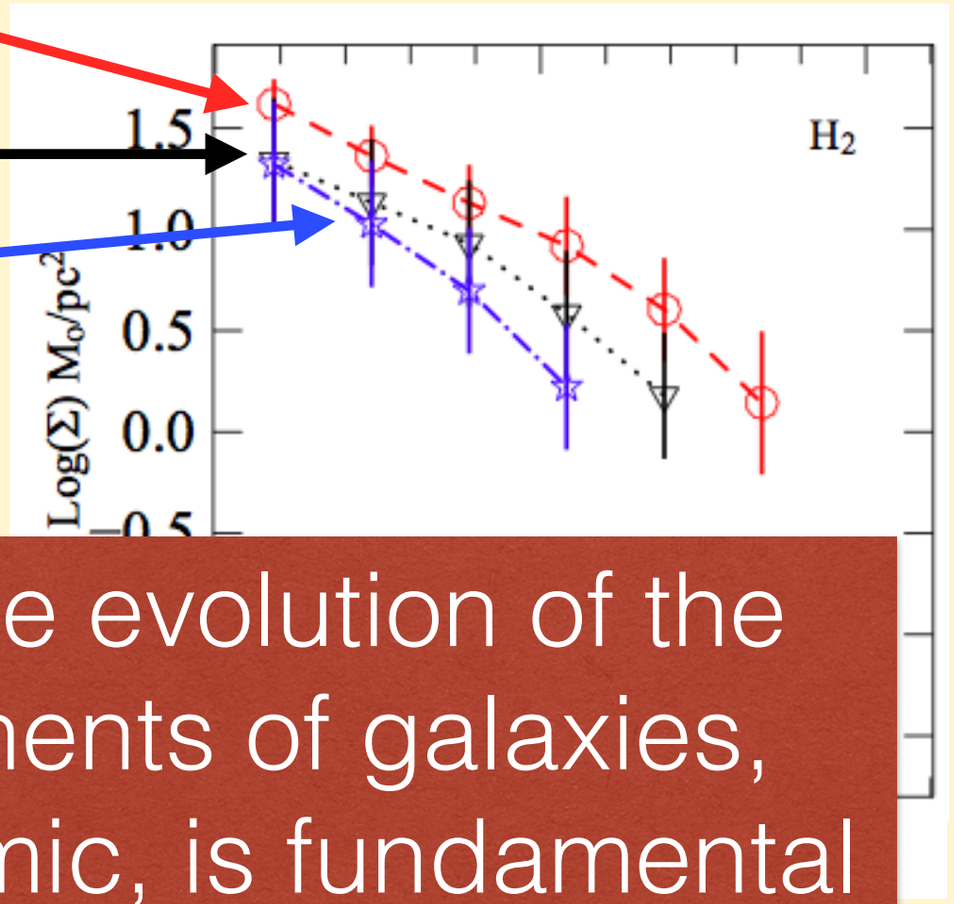


Fumagalli+ 2009

No HI Def

Mod. HI Def

High HI Def

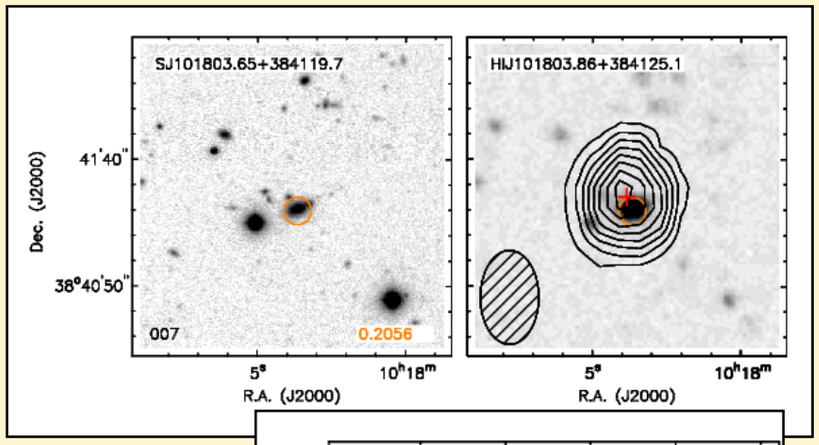


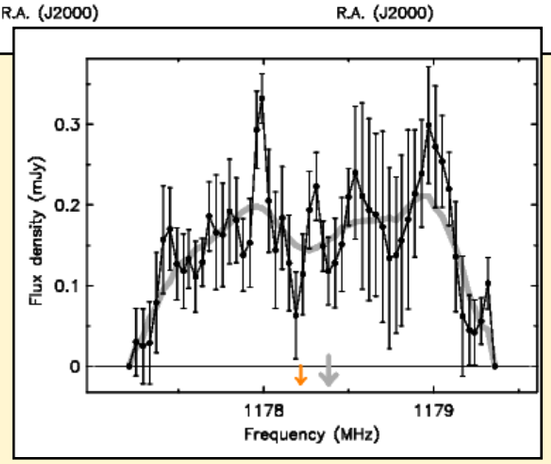
012

Understanding the evolution of the cold gas components of galaxies, molecular and atomic, is fundamental to understanding their SFHs.

BUDHIES

- **B**lind **U**ltra-**D**eep **HI** **E**nvironment **S**urvey (Verheijen+ 2007, Jaffé+ 2012)
  - A2192 (z=0.1875) & A963 (z=0.206)
- WSRT: > 2000hr combined for two clusters
  - 5σ det thresh: $M_{HI} \gtrsim 2x10^9 M_\odot$
  - Detections: ~160
- Also ~1000 spec-z from WHT + WIYN, GALEX, INT B- and R-band, UKIRT JHK, *Spitzer* IRAC + MIPS all over ~1 sq deg.
- Complement to Cosmos HI Large Extragalactic Survey (CHILES; Fernández + 2013)





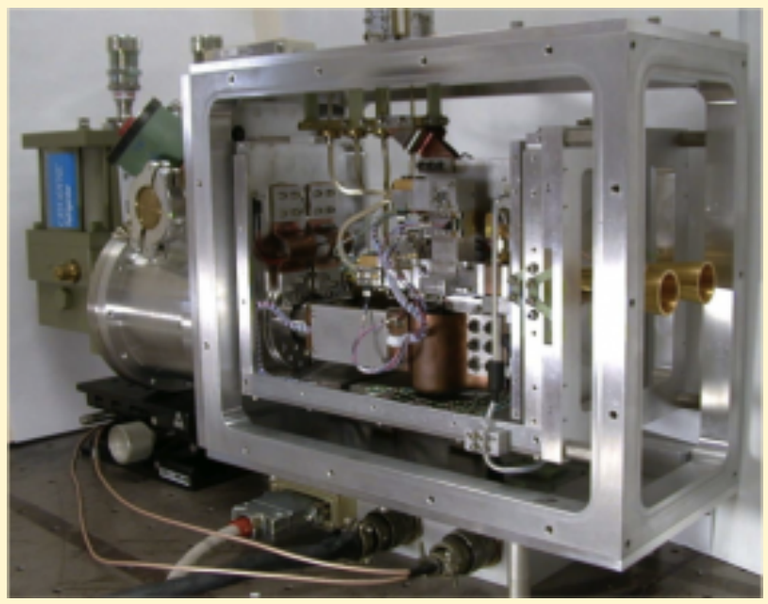
Large Millimeter Telescope

- 50 m telescope on summit of Sierra Negra (Mexico)
  - Alt: 4600 m (15,092 ft)
  - Collaboration between UMass + INAOE
  - Instruments:
    - AzTEC: 1.1mm bolometer array camera
    - Redshift Search Receiver (RSR): 3 mm wide-band spectrometer

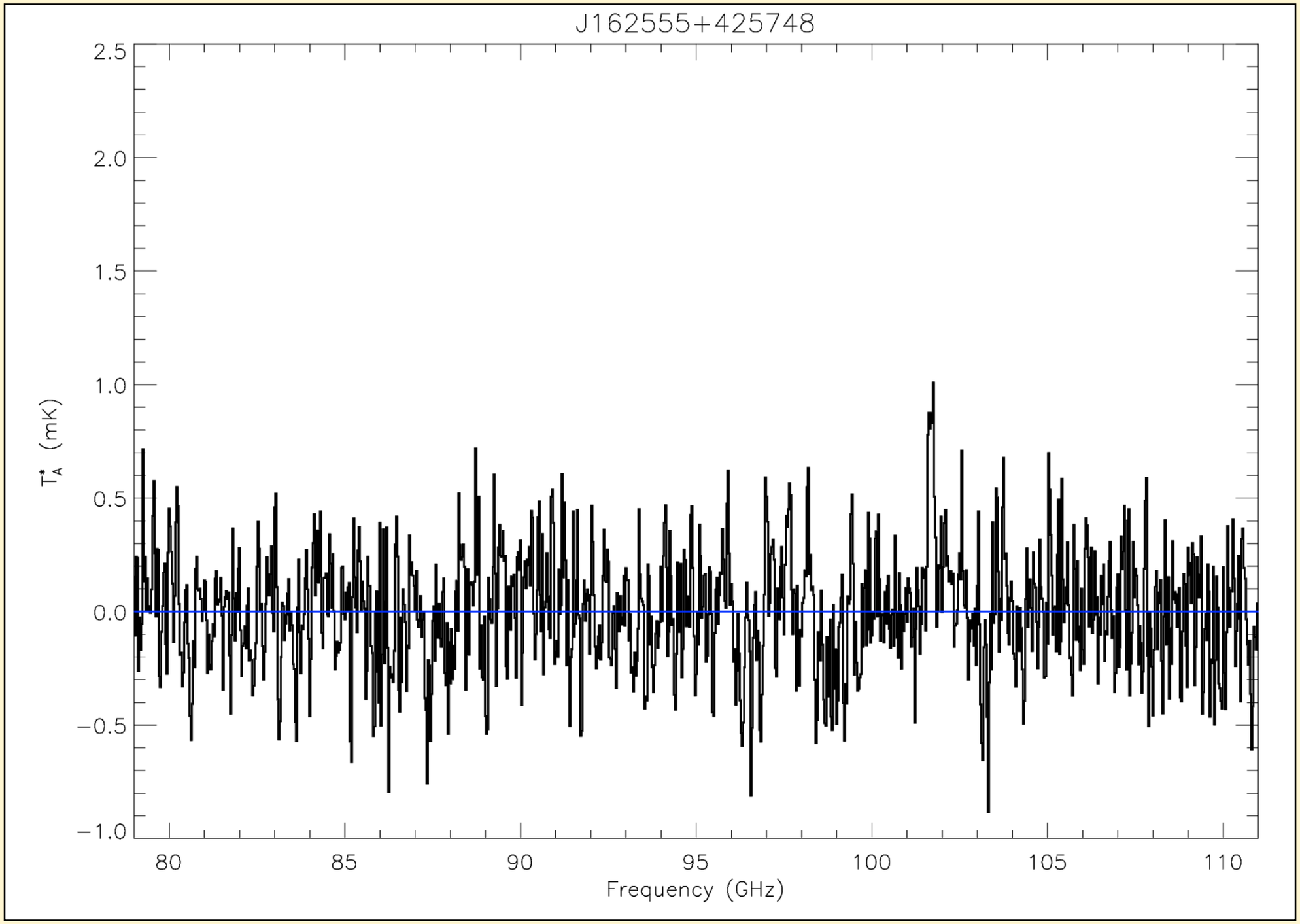
- Early Science 2 (ES2) phase in Mar-Jun 2014, as 32m telescope.

COOL BUDHIES: A Pilot Study with the LMT

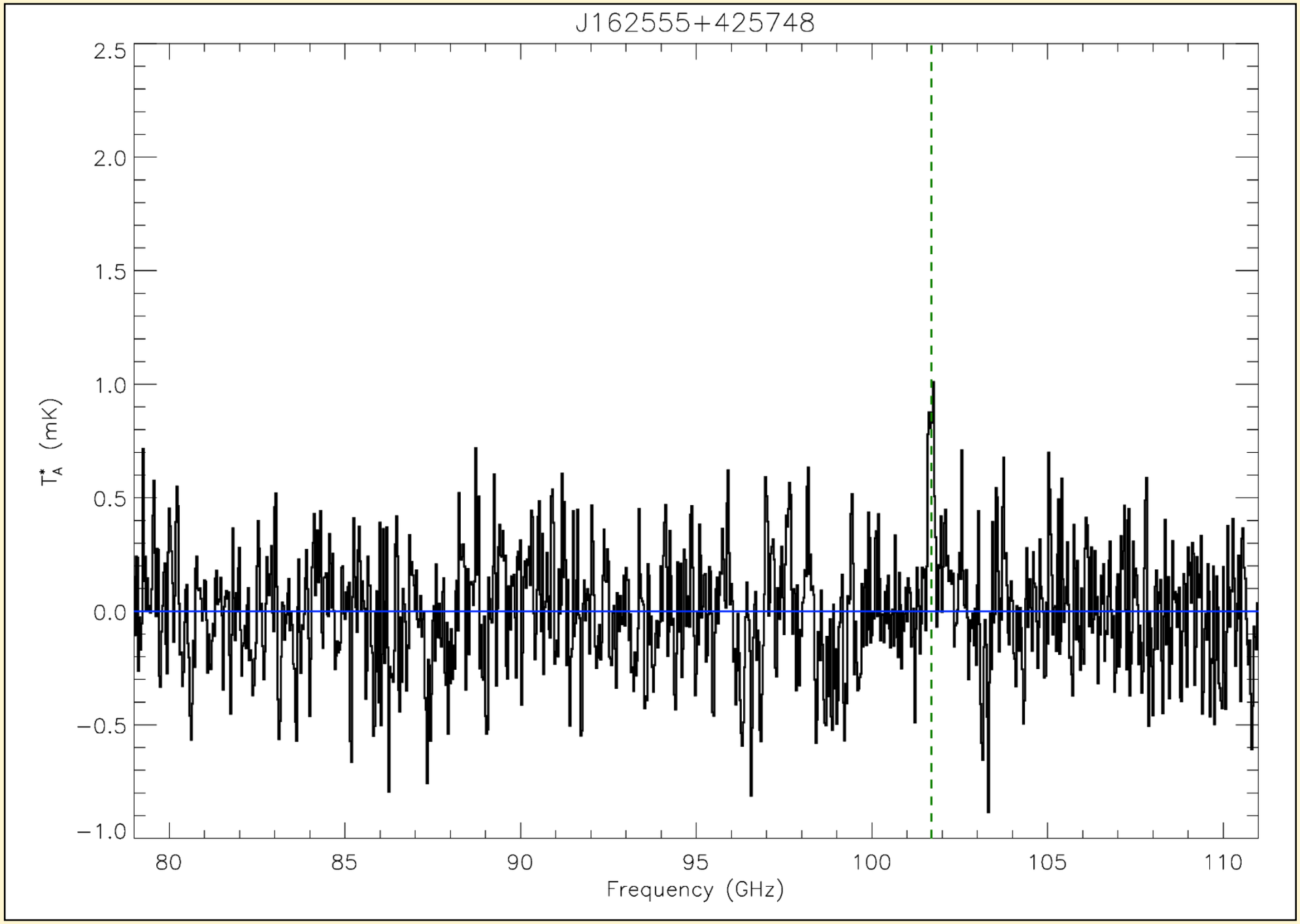
- **CO O**bservations with the **L**MT of **BUDHIES**
- Obs. 25 galaxies in/around BUDHIES clusters with the RSR for ES2 Season in Mar/Apr 2014
  - ~Half HI selected
  - ~Half lacking HI detections, but MIPS [24] selected
  - All have spec-z from optical and/or HI
- Integrate ~1hr on each to detect ^{12}CO J=1-0 emission line
- spect. resolution ~100 km/s
- very stable baselines from 77-111 GHz



RSR Data


J162555+425748
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
T_A^* (mK)
80
85
90
95
100
105
110
Frequency (GHz)

RSR Data


J162555+425748
2.5
2.0
1.5
1.0
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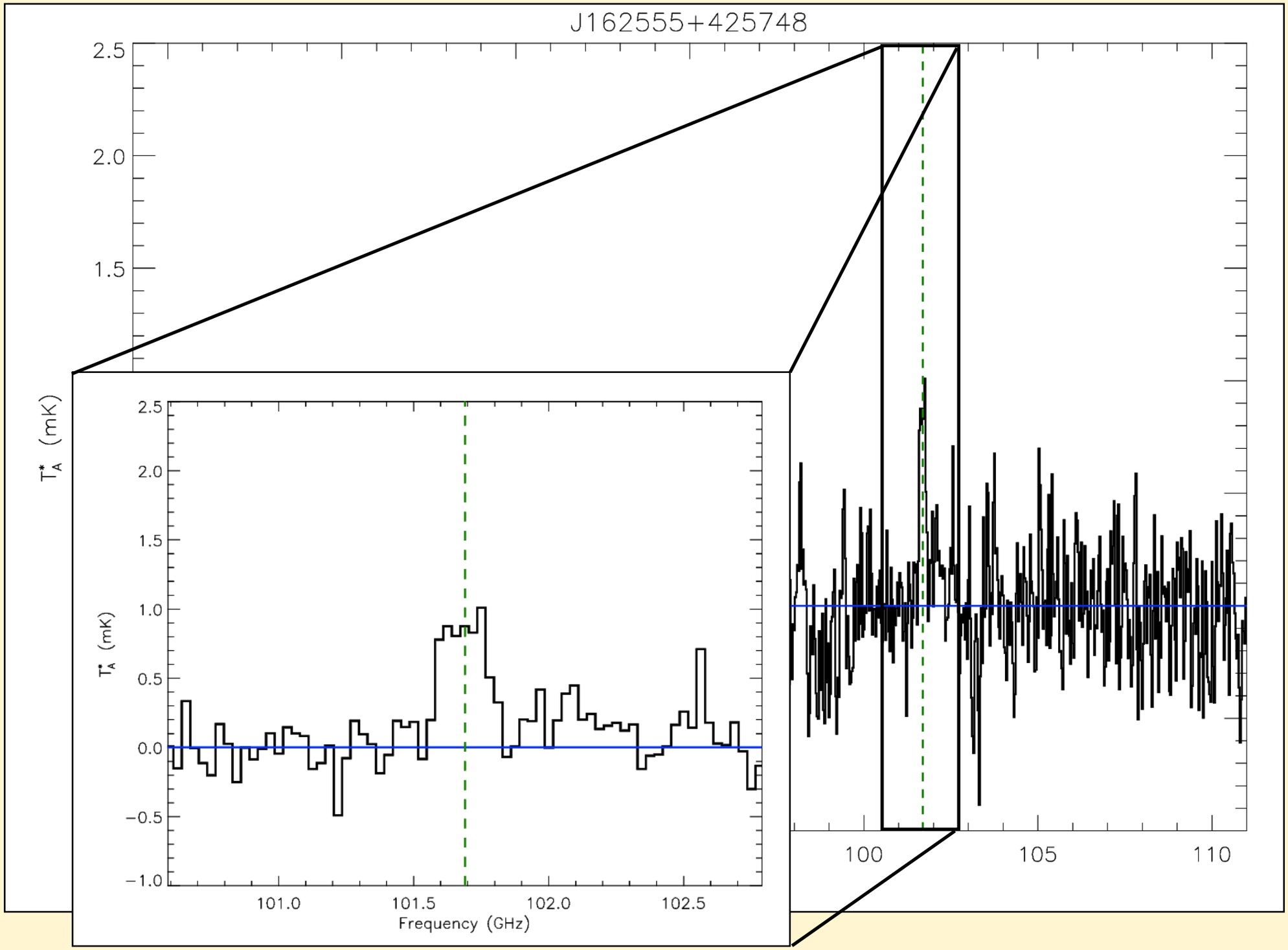
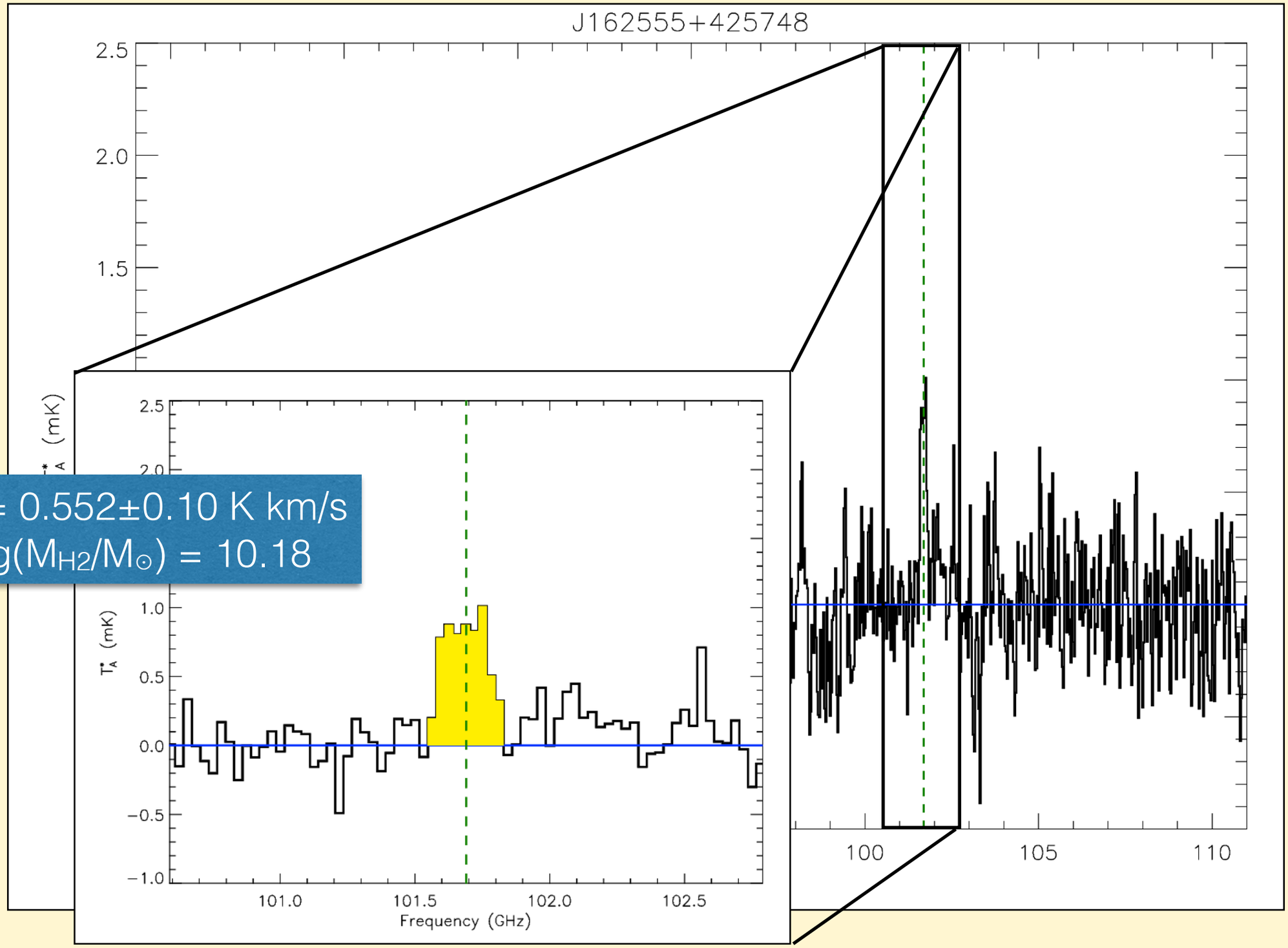
−1.0
T_A^* (mK)
80
85
90
95
100
105
110
Frequency (GHz)

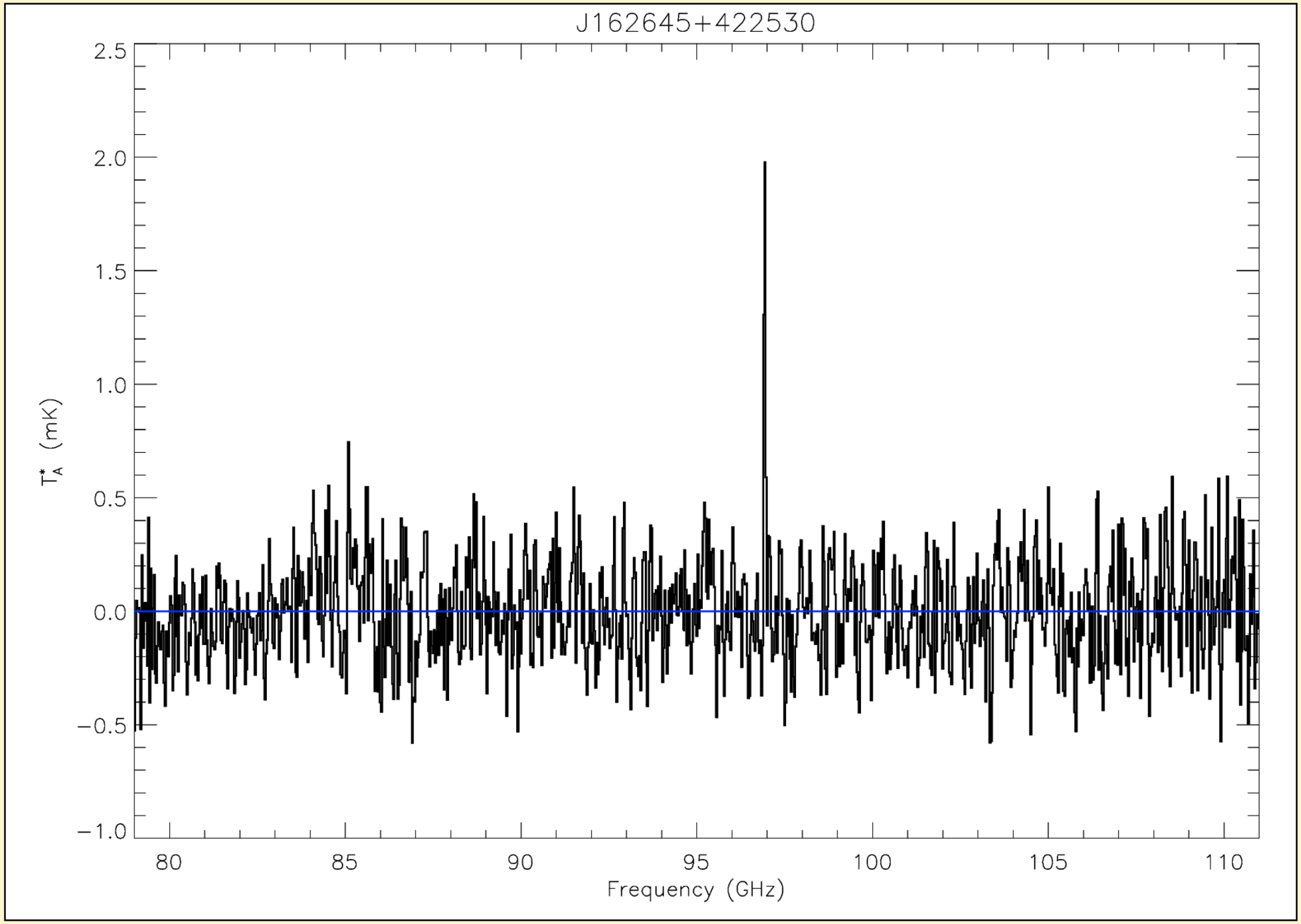
RSR Data


J162555+425748
2.5
2.0
1.5
T_A^* (mK)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
T_A^* (mK)
101.0
101.5
102.0
102.5
Frequency (GHz)
100
105
110

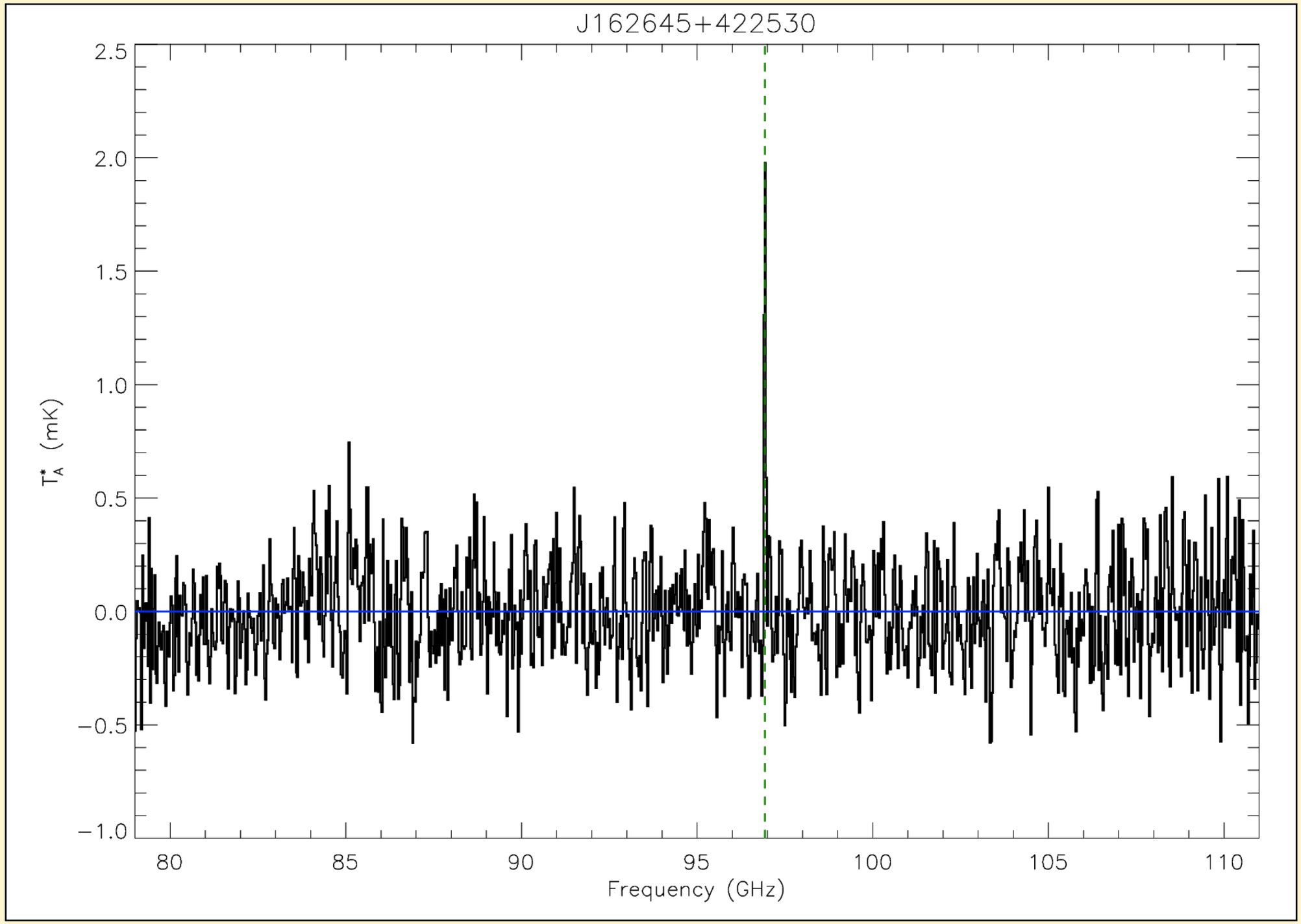
RSR Data


J162555+425748
2.5
2.0
1.5
(mK)
2.5
2.0
1.0
0.5
0.0
−0.5
−1.0
T_A^* (mK)
101.0
101.5
102.0
102.5
Frequency (GHz)
100
105
110
I_{CO} = 0.552±0.10 K km/s
log($M_{H2}/M_\odot$) = 10.18

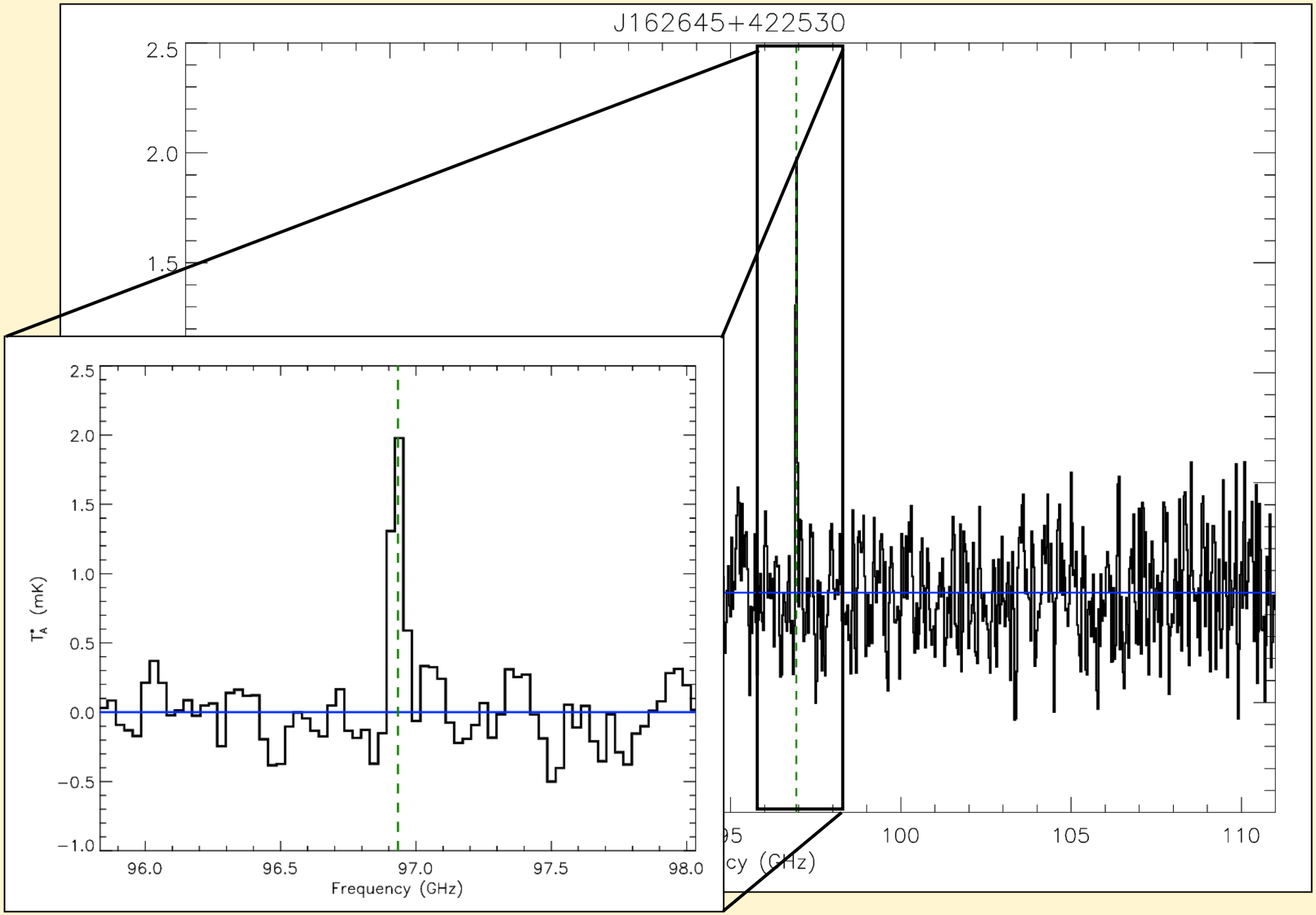
RSR Data


J162645+422530
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
T_A^* (mK)
80
85
90
95
100
105
110
Frequency (GHz)

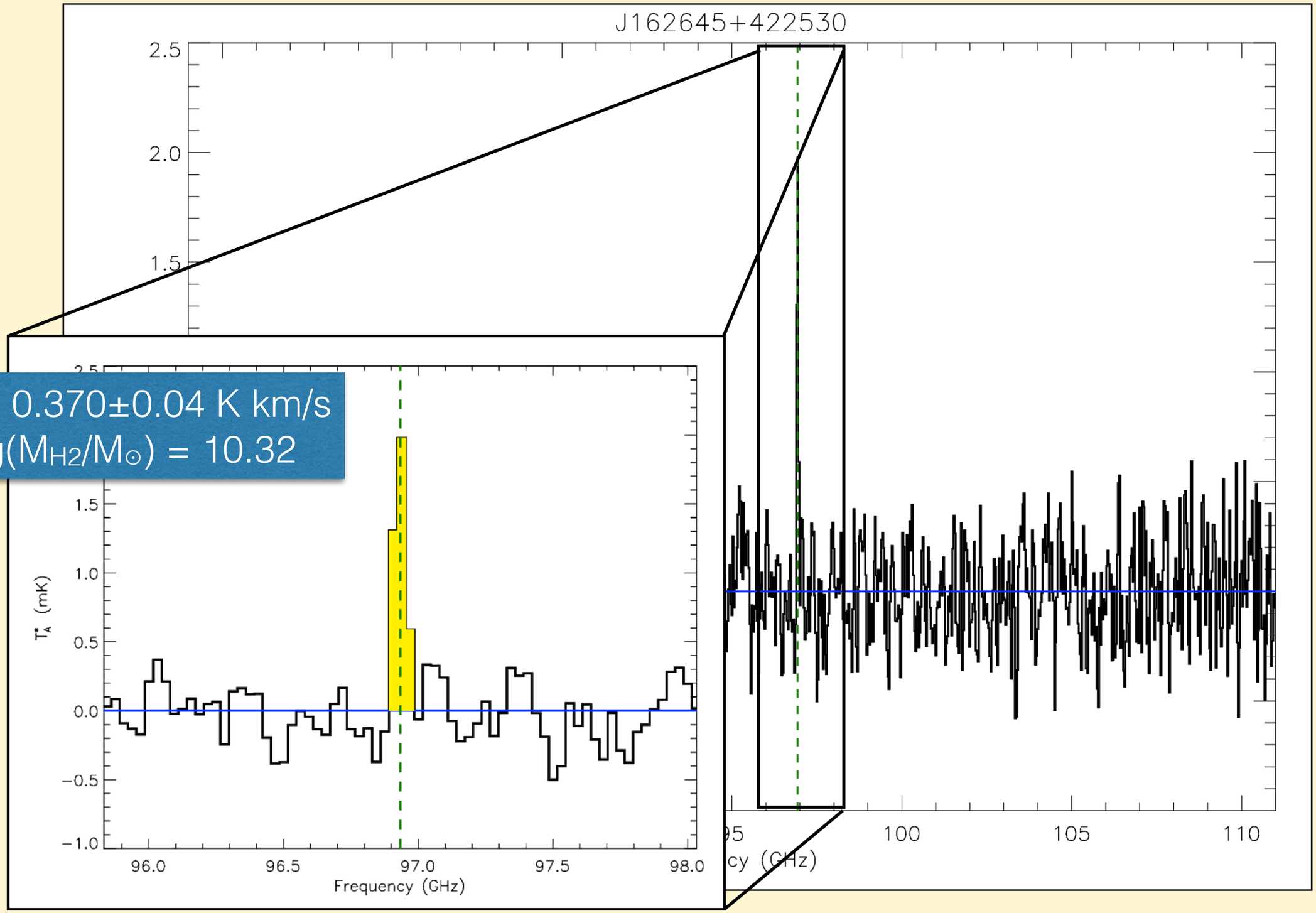
RSR Data


J162645+422530
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
T_A^* (mK)
80
85
90
95
100
105
110
Frequency (GHz)

RSR Data

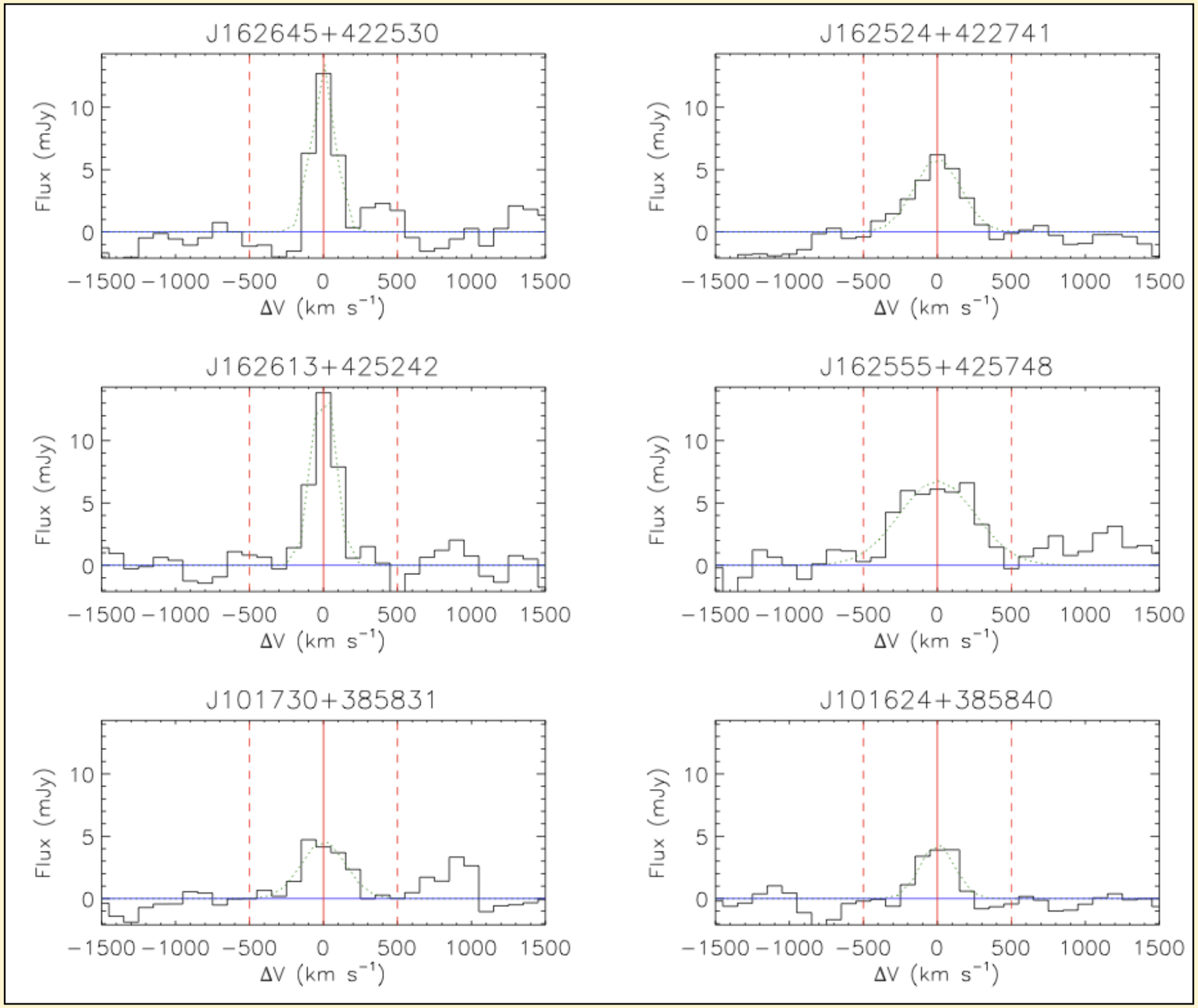

J162645+422530
2.5
2.0
1.5
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
T_A^* (mK)
96.0
96.5
97.0
97.5
98.0
Frequency (GHz)
95
100
105
110
cy (GHz)

RSR Data

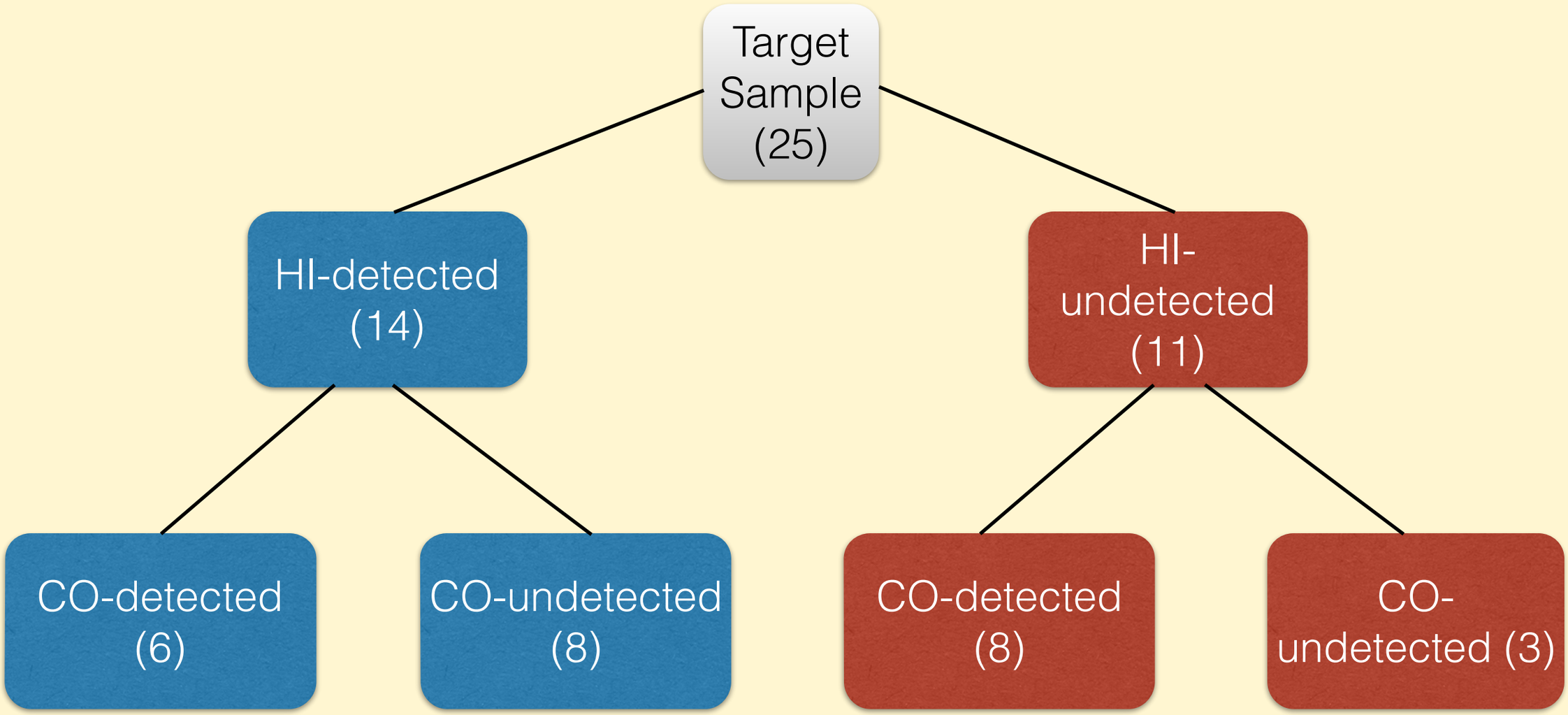


I_{CO} = 0.370±0.04 K km/s
$\log(M_{H2}/M_\odot)$ = 10.32

RSR Data


J162645+422530
J162524+422741
J162613+425242
J162555+425748
J101730+385831
J101624+385840
Flux (mJy)
ΔV (km s⁻¹)
10
5
0
−1500 −1000 −500 0 500 1000 1500

RSR Detections and Non-detections



6 detected in both CO and HI

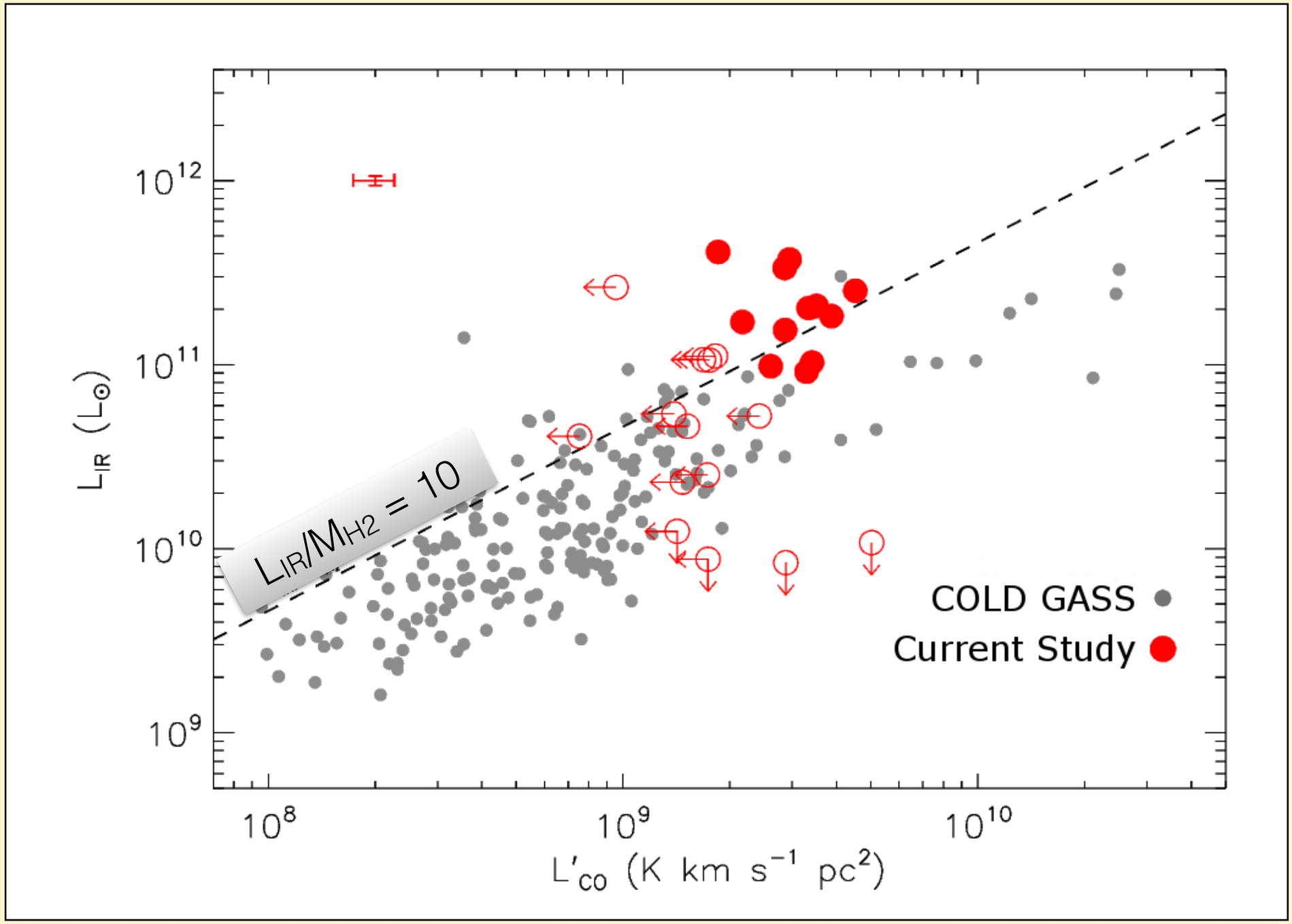
CO non-detections have upper lim:

$M_{H2} \gtrsim 5x10^9 M_\odot$

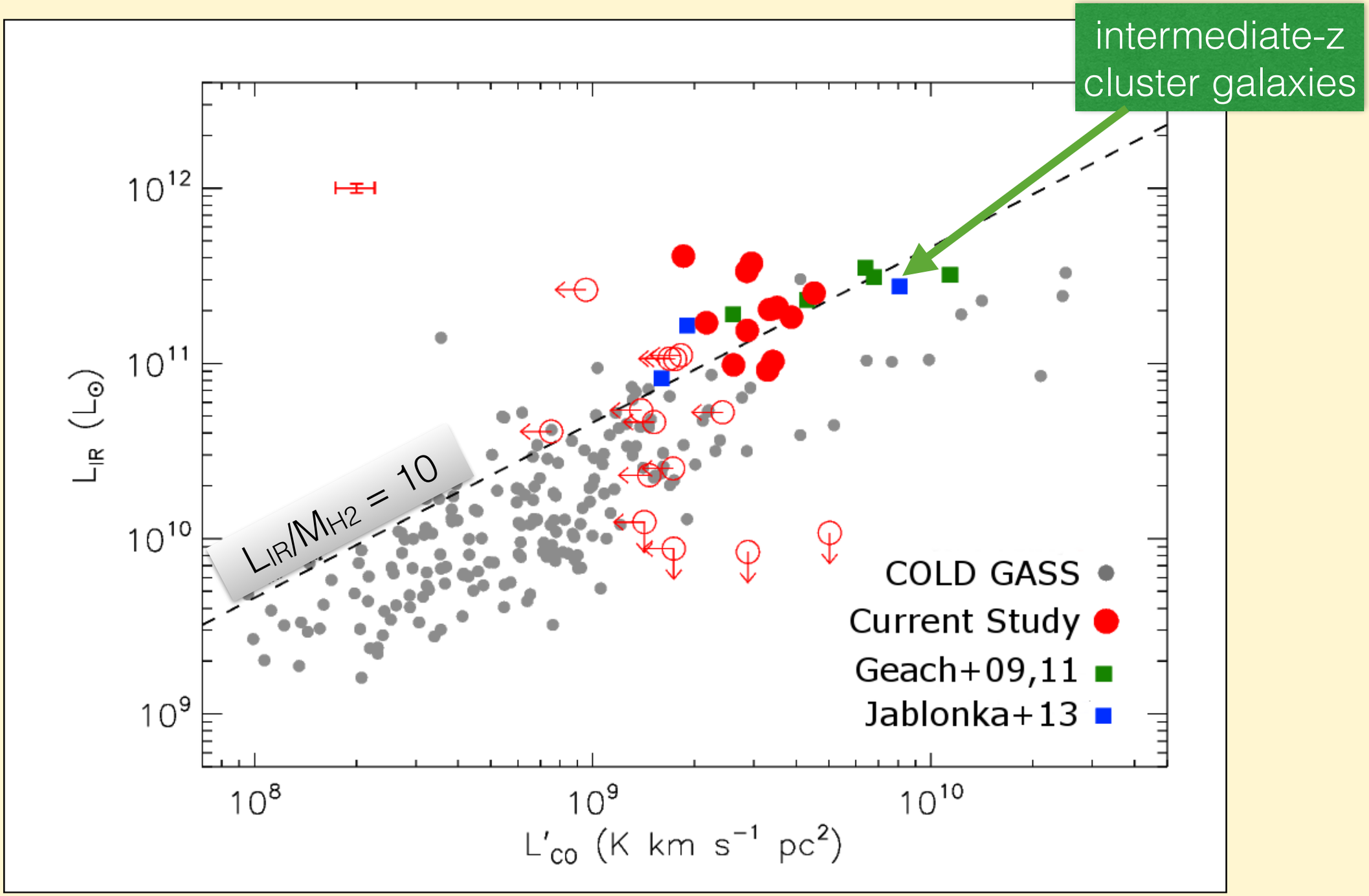
COLD GASS Reference Sample

- 365 galaxies at $z \leq 0.05$ observed in HI, CO, GALEX, and with SDSS spectroscopy (Saintonge+ 2011)
- Supplement with WISE (Wright+ 2010)
  - M_* from WISE 1 + 2 (Eskew+ 2012)
  - L_{IR} from WISE [22] (Murphy+ 2011)

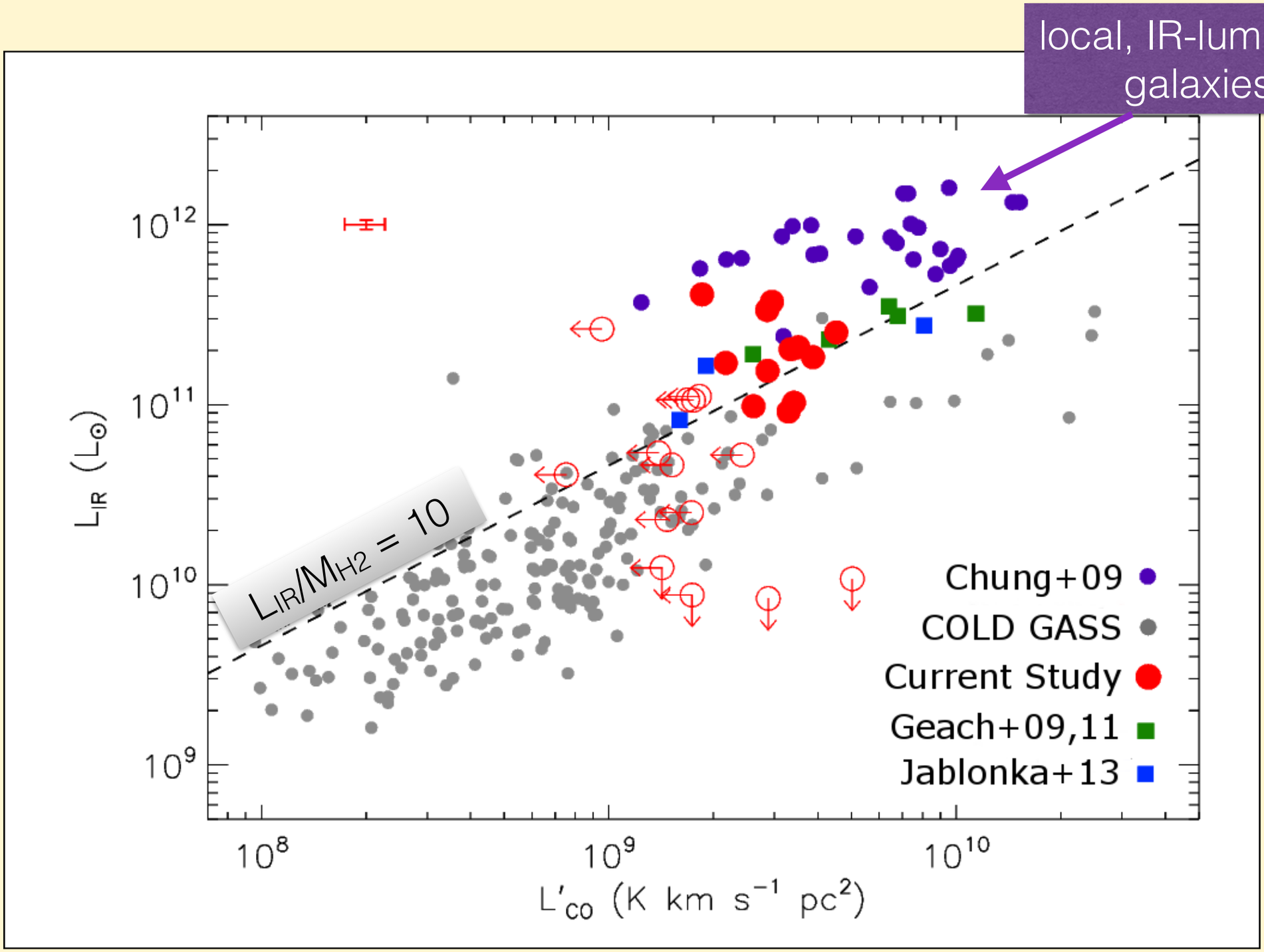
L_{IR} vs L_{CO}


10^{12}
10^{11}
10^{10}
10^{9}
L_{IR} ($L_\odot$)
$L_{IR}/M_{H2} = 10$
COLD GASS
Current Study
10^{8}
10^{9}
10^{10}
L'_{CO} (K km s^{-1} pc^2)

L_{IR} vs L_{CO}

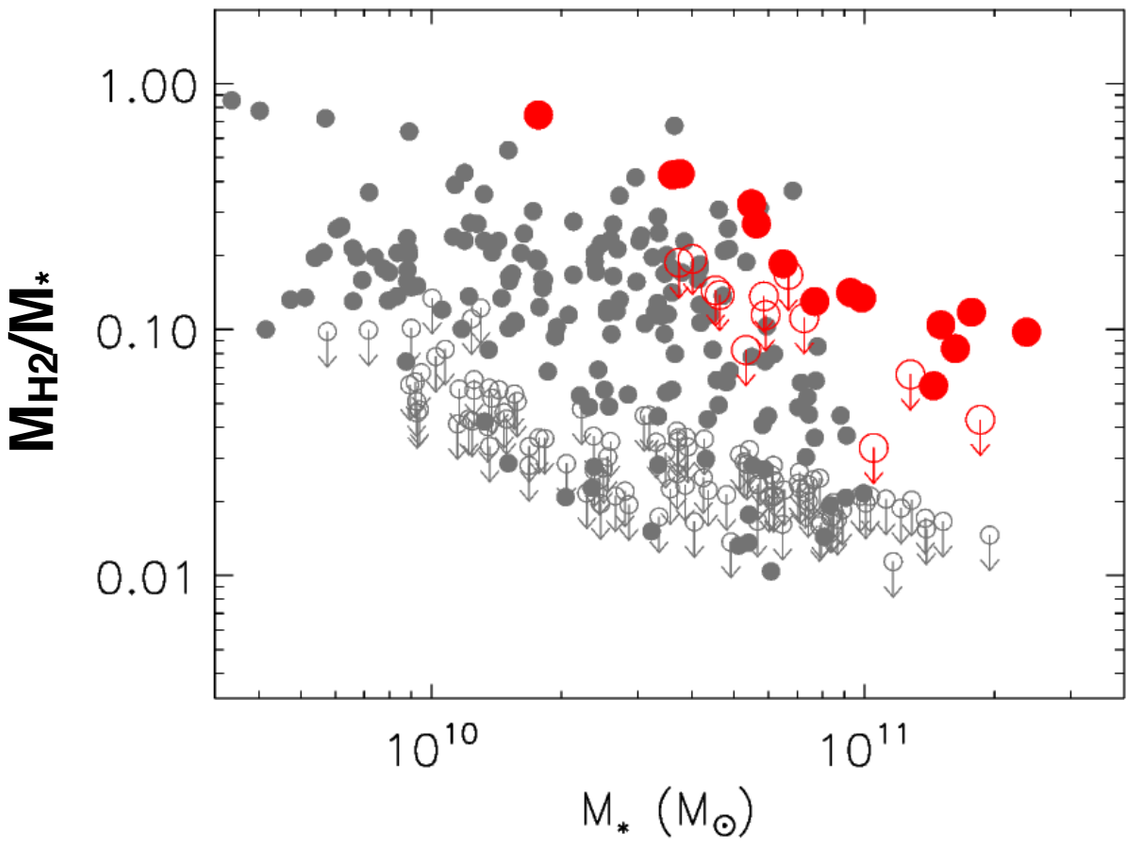

intermediate-z cluster galaxies
10^{12}
10^{11}
10^{10}
10^{9}
L_{IR} ($L_\odot$)
$L_{IR}/M_{H2} = 10$
COLD GASS
Current Study
Geach+09,11
Jablonka+13
10^{8}
10^{9}
10^{10}
L'_{CO} (K km s^{-1} pc^2)

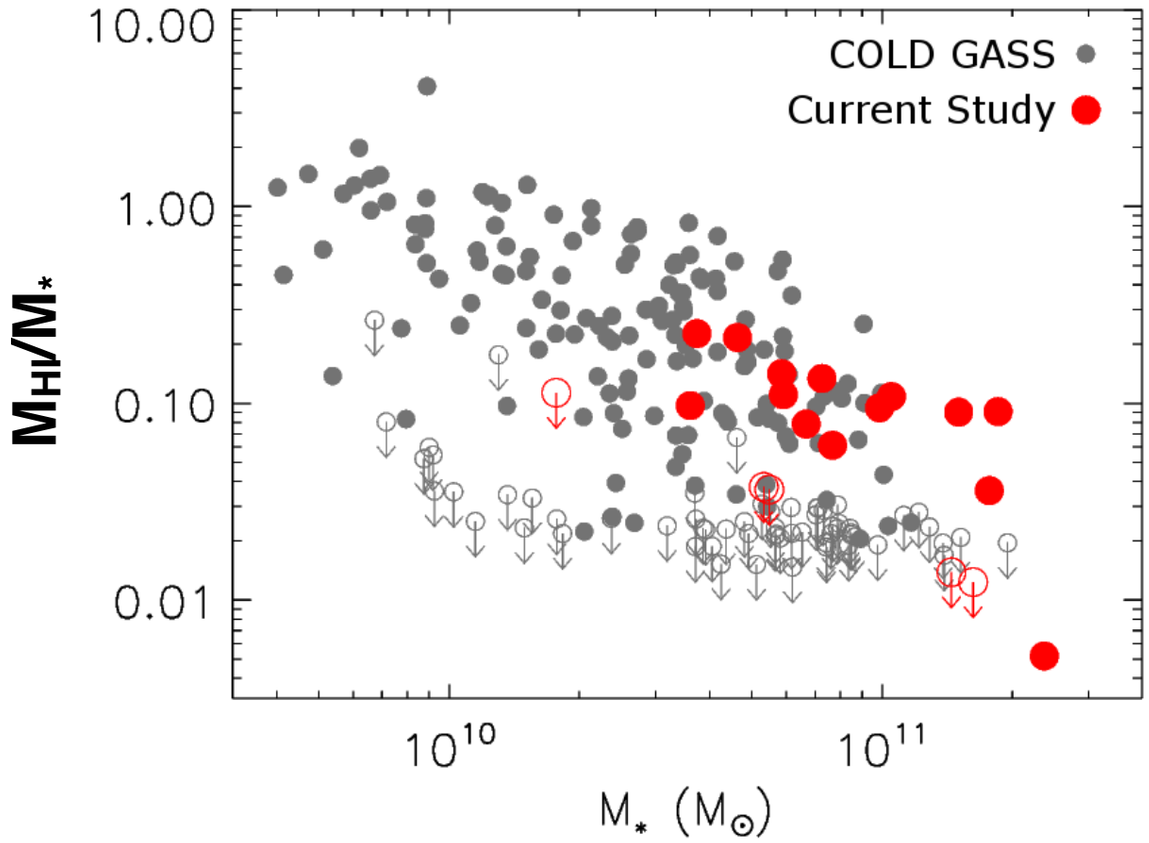
L_{IR} vs L_{CO}



Cybulski+ in prep

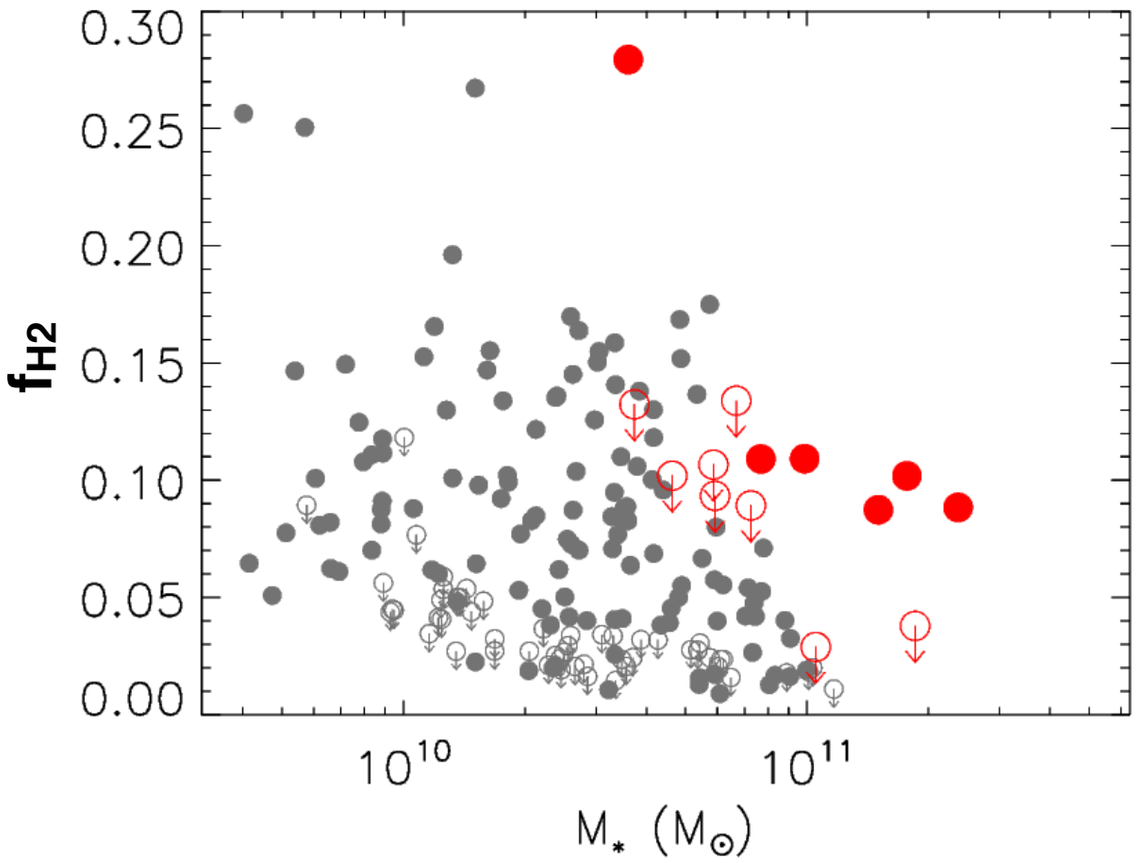
Molecular & Atomic Gas Mass

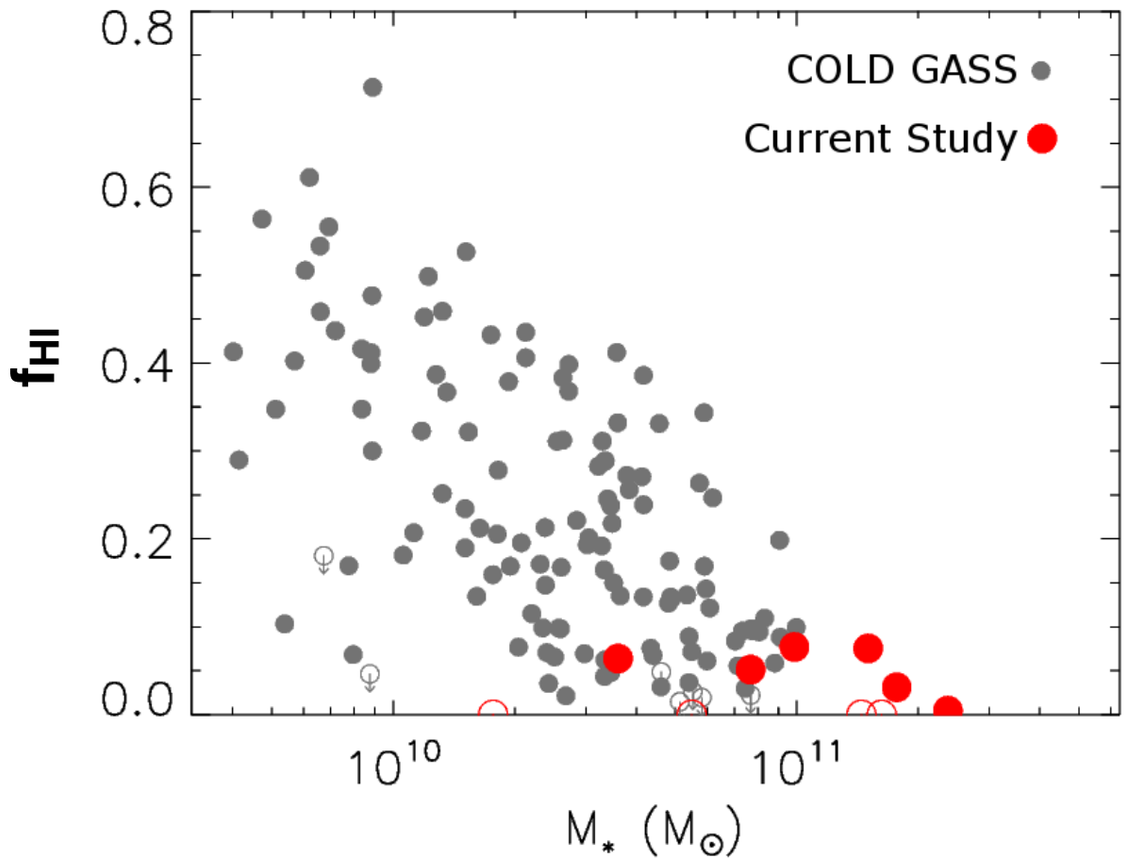




Cybulski+ in prep

Gas Fractions



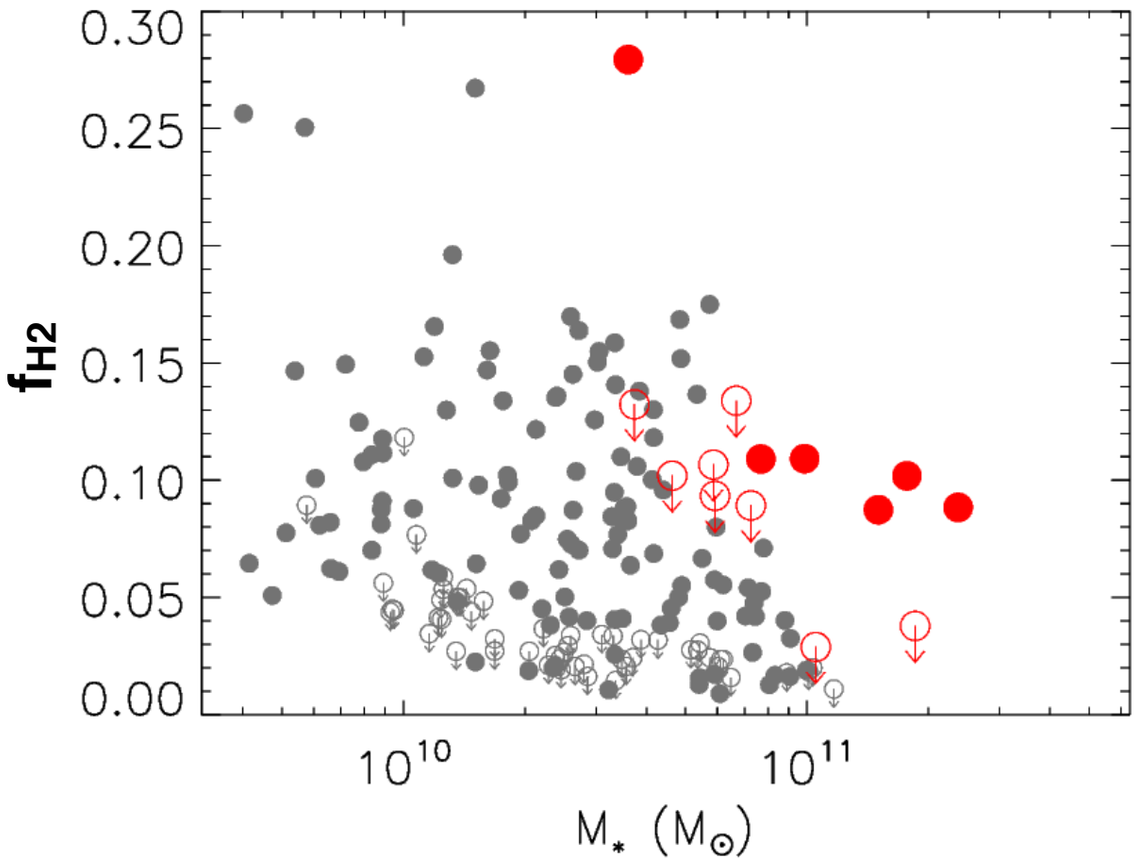


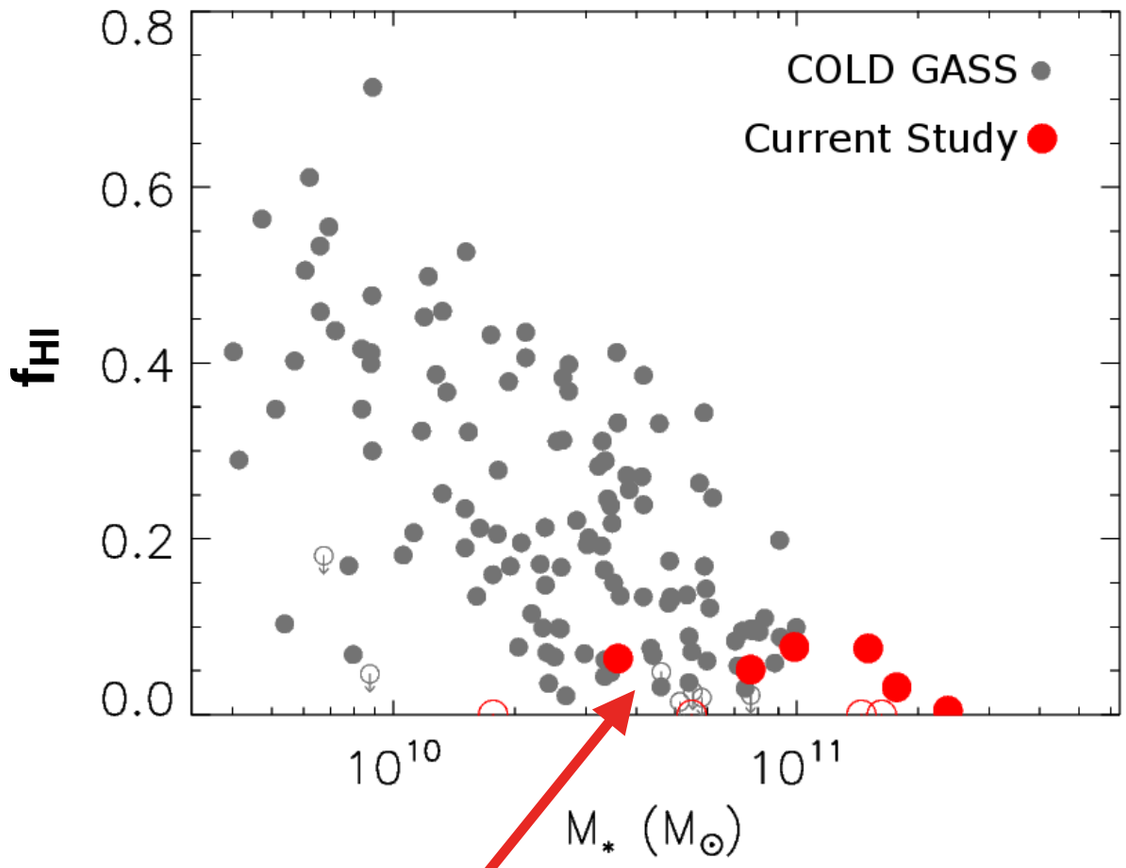
Cybulski+ in prep

$$f_{H2} = M_{H2}/(M_{H2} + M_{HI} + M_*)$$

$$f_{HI} = M_{HI}/(M_{H2} + M_{HI} + M_*)$$

Gas Fractions





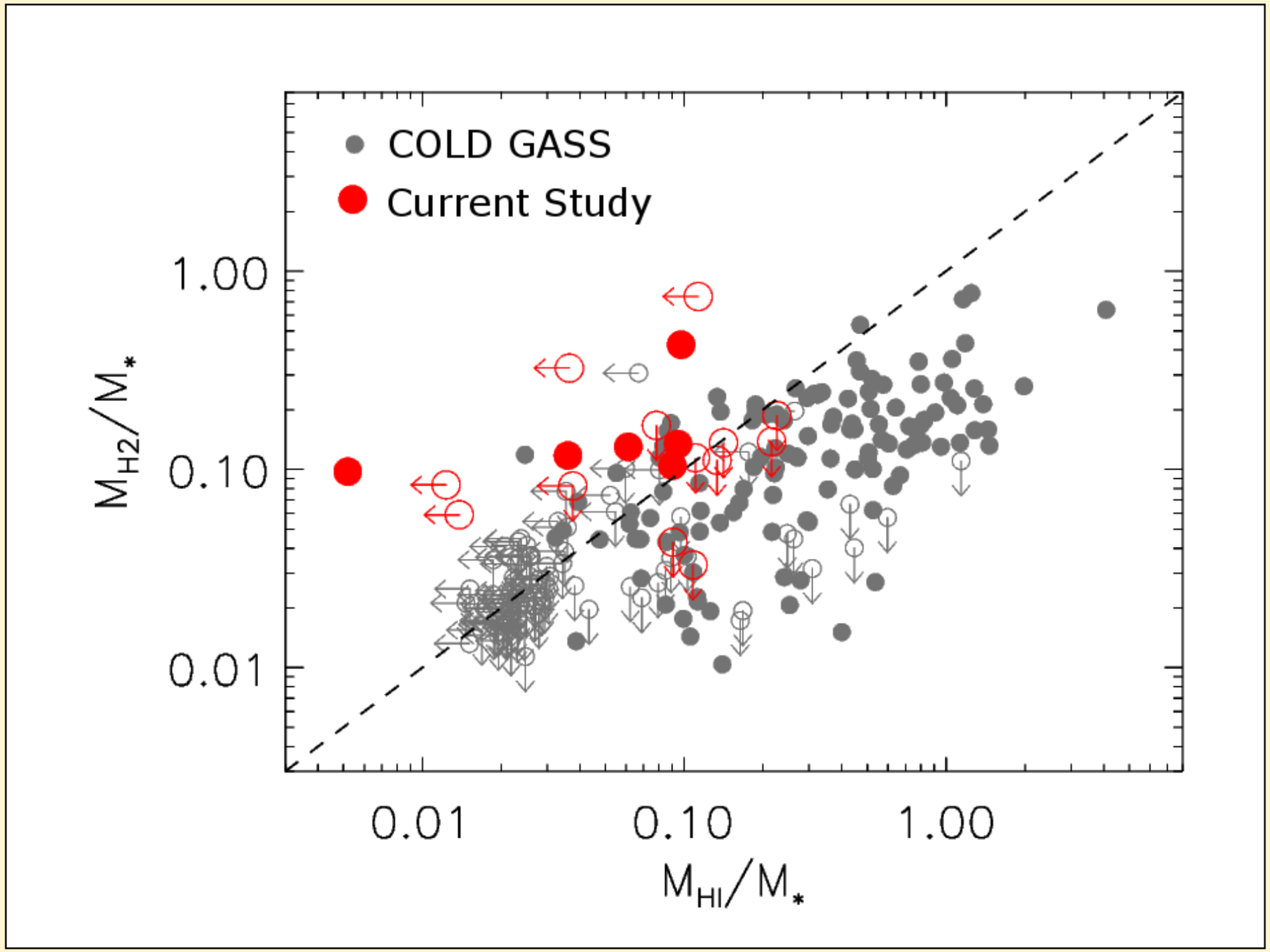
Cybulski+ in prep

$$f_{H2} = M_{H2}/(M_{H2} + M_{HI} + M_*)$$

$$f_{HI} = M_{HI}/(M_{H2} + M_{HI} + M_*)$$

Due to stripping of HI in clusters?

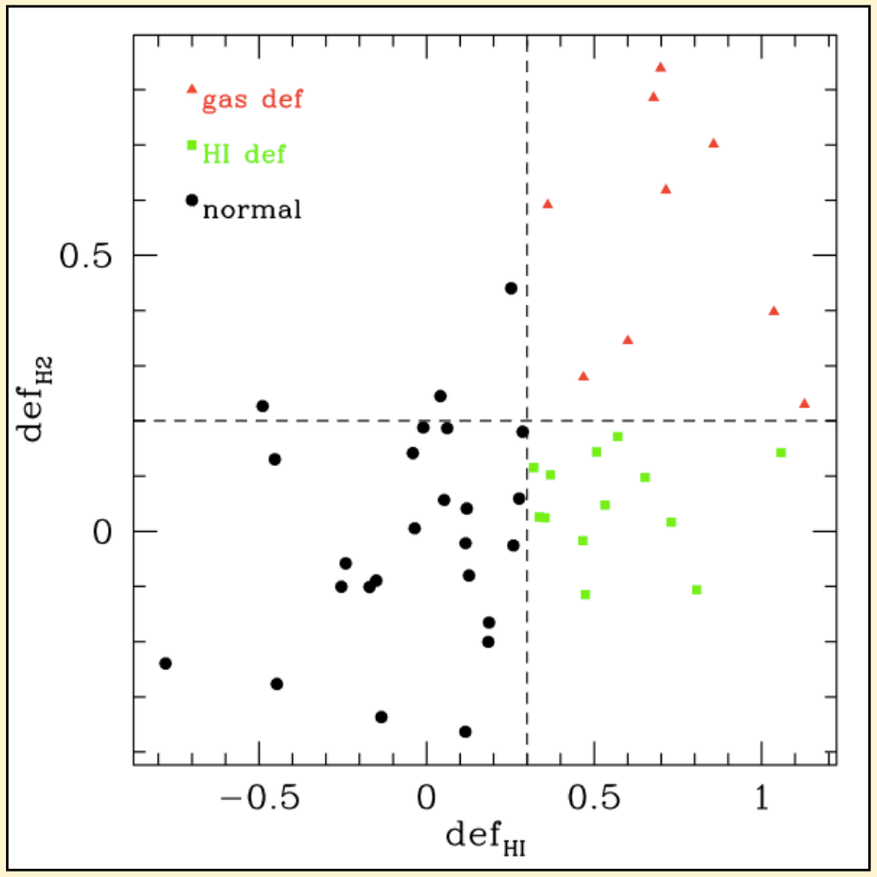
Mol. vs Atomic Gas



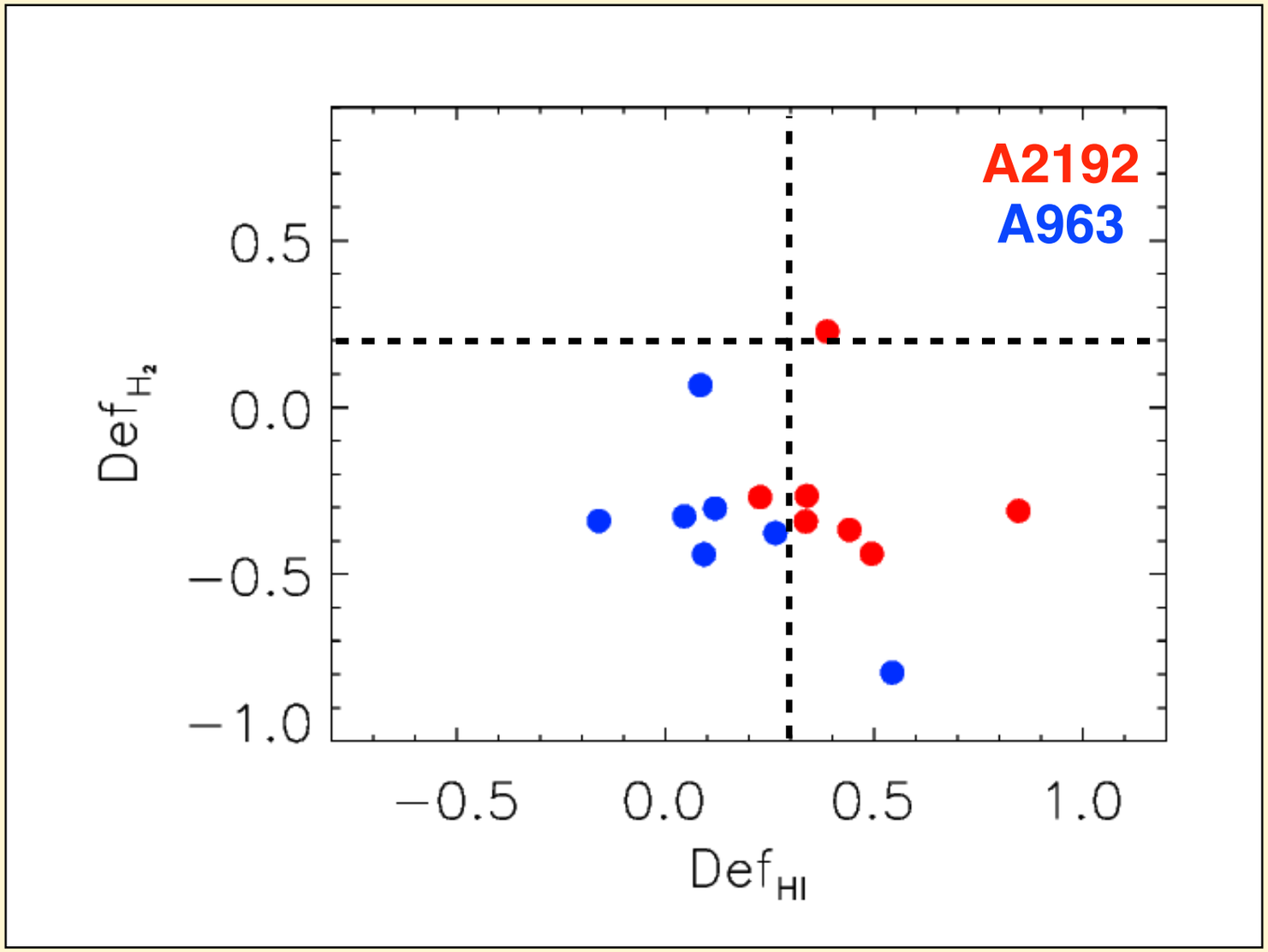
Cybulski+ in prep

MoI. vs Atomic Gas Deficiencies

- still see lack of HI-rich, H_2-deficient galaxies (but based on calibrations for local Universe!)



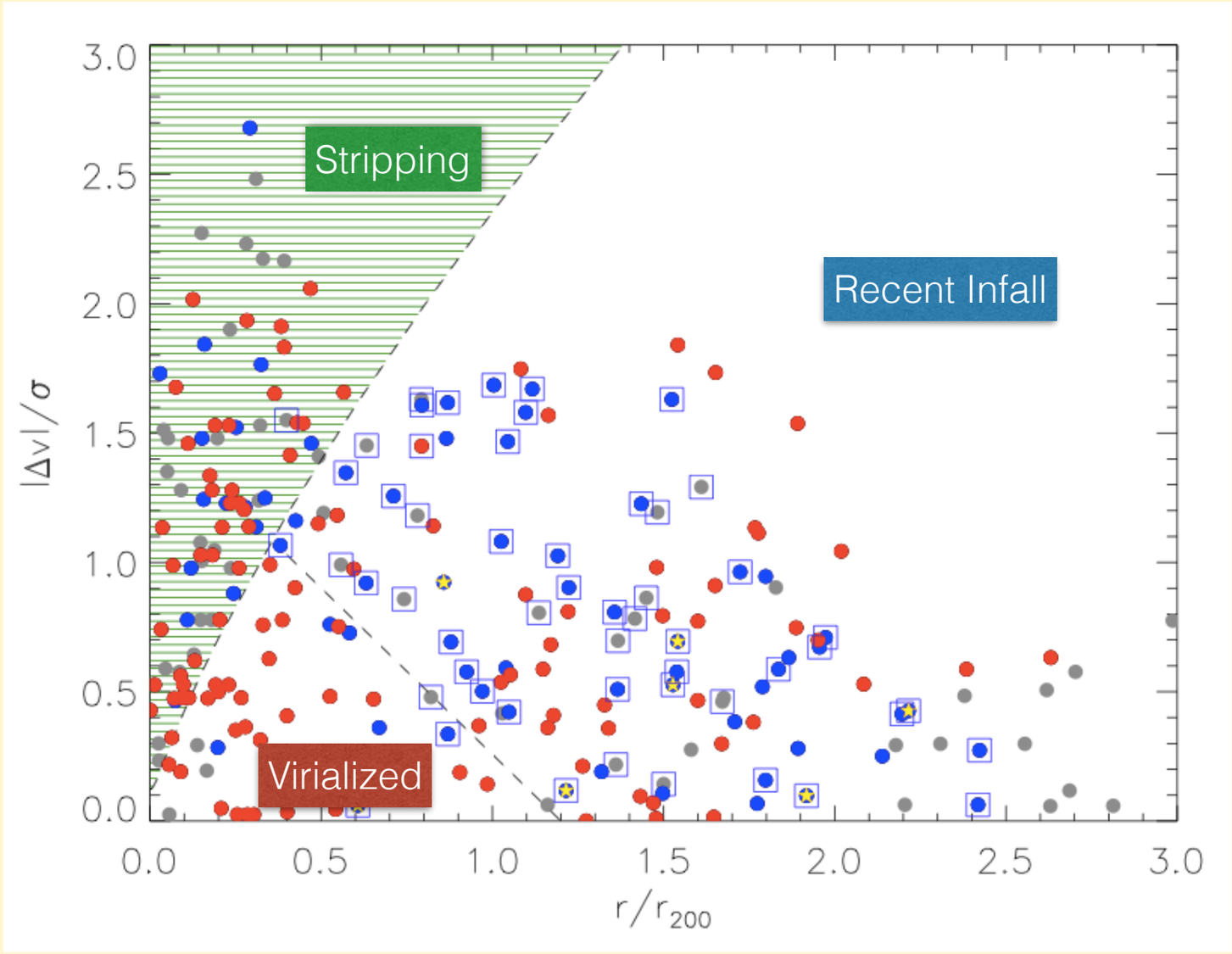
Fumagalli+ 2009



Cybulski+ in prep

Next Steps

- Proposed follow-up CO observations for LMT ES3 (October 2014-May 2015)
- 43 targets in A963, examine susceptibility of H_2 to ram-pressure stripping (comp. to HI)



A963 projected phase space plot adapted from Jaffé et al., in prep

Summary

- Only 25 galaxies so far, but the most extensive mapping of total cold gas (molecular + atomic) in cluster galaxies beyond the local Universe

- Primarily H_2-dominated galaxies, due to selection bias and/or stripping of HI

- Follow-up obs. in ES3 will dramatically improve statistics.

#egee2014

COOL BUDHIES: for an understanding of SF evolution, total cold gas (molecular + atomic) matters!

COOL BUDHIES: the Large Millimeter Telescope works, and is ready to contribute to studies of gas and dust in galaxies.

COOL BUDHIES: of course our acronym contains multiple acronyms.