HI and CO absorption against the cores of Brightest Cluster Galaxies

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The cores of clusters

The cores of most clusters of galaxies contain dense intracluster gas that has a cooling time comparable to the age of the cluster.

However, observations do not show strong evidence for the naïve expectation of this cooling. But how is the cooling suppressed?

This classic “cooling flow problem” needs some additional heating. But where from?

AGN Feedback is the answer to this question!

The AGN shines the light….

The energy generated by cold gas reaching the central, supermassive black hole acts to heat the cooling gas at larger radii (5-100kpc) and suppress the amount of gas reaching the core.

This AGN activity can be traced through the radio, X-ray, optical and MIR/FIR *emission* of the Brightest Cluster Galaxy (BCG) and its immediate environment.

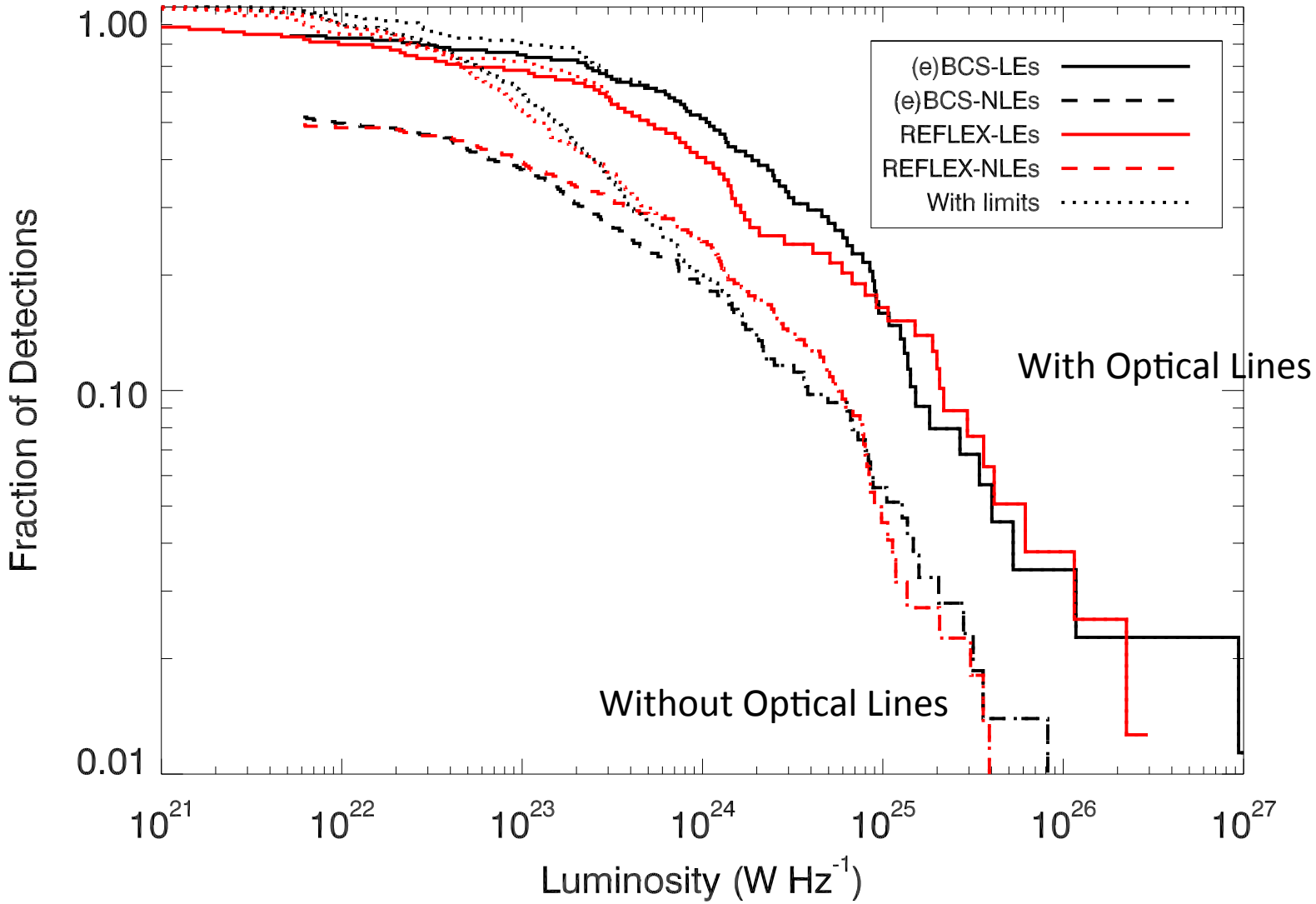
It can also be traced through its *absorption* as well.

Atomic Hydrogen

There is a long and illustrious literature on the search for **associated** HI absorption in radio galaxies (as we have heard this week!) and, given that ALL BCGs with significant X-ray cooling have an associated radio source, BCGs can be regarded as a subset of this more diverse population.

Also we can define a control sample of BCGs from an X-ray selected of clusters irrespective of the radio power so we get a different perspective.

1.4GHz Radio luminosity function of BCGs with and without lines

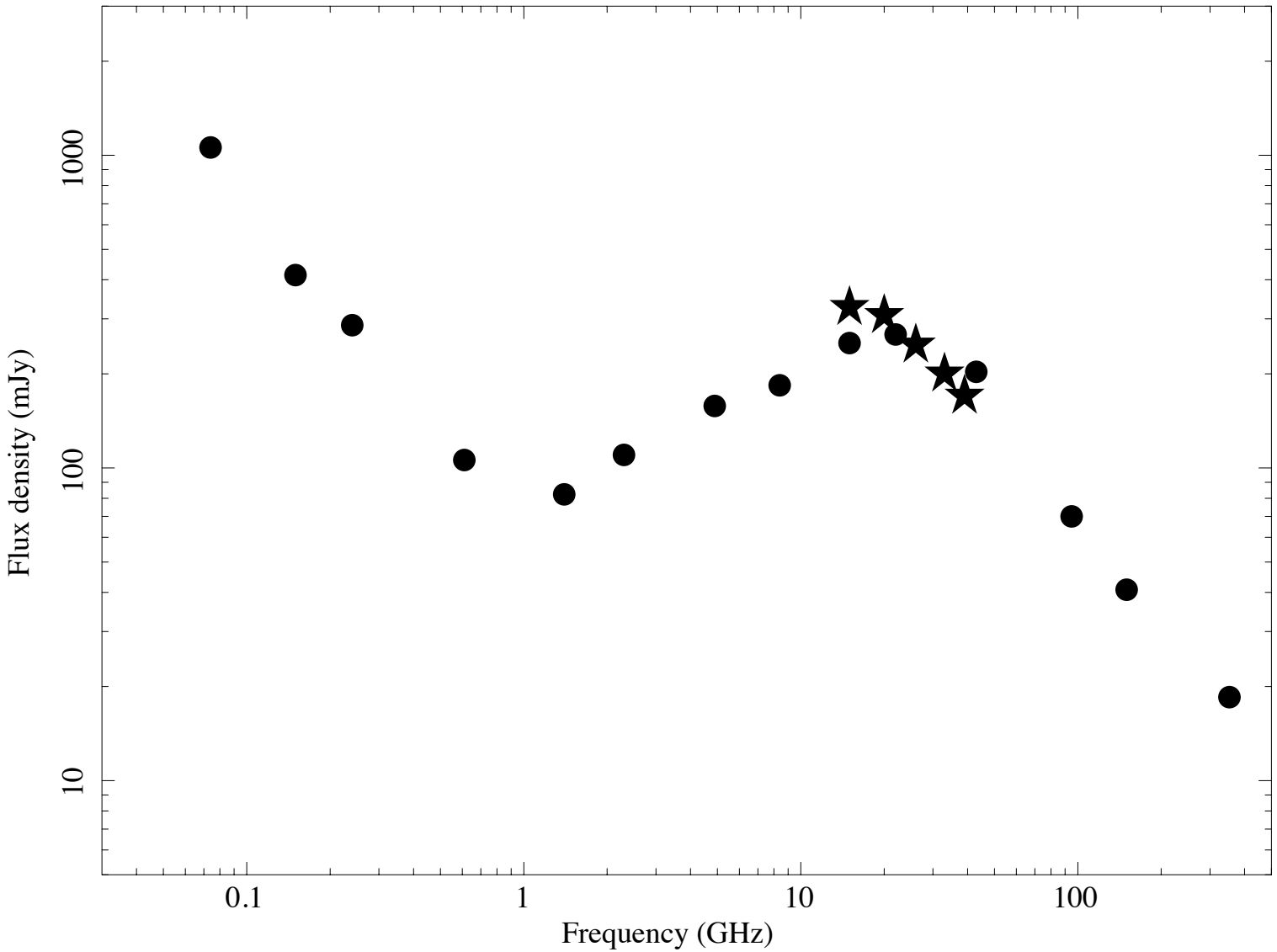


Hogan et al (2015)

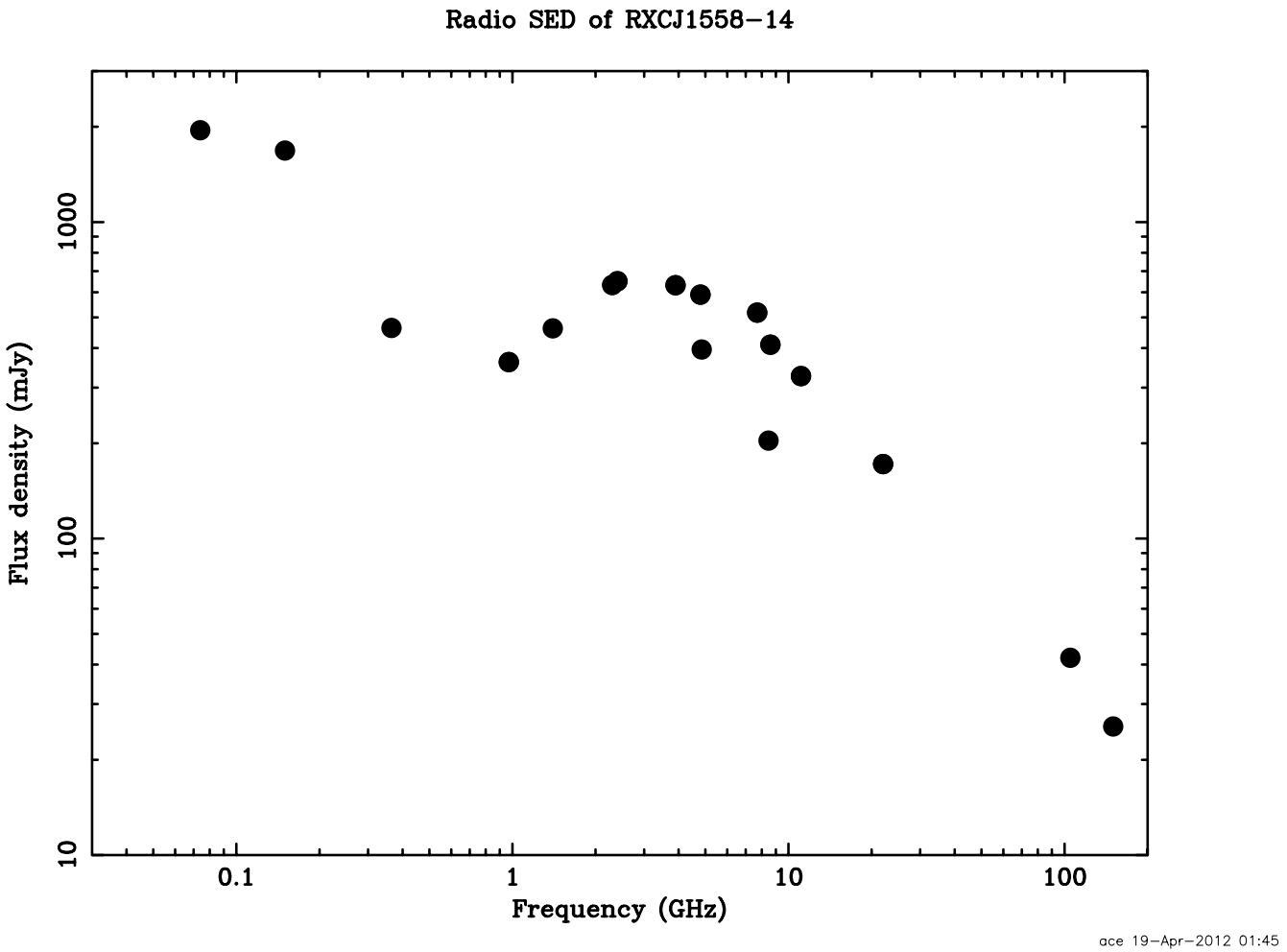
BCG radio sources

The radio SEDs of this BCG population themselves are especially diverse!

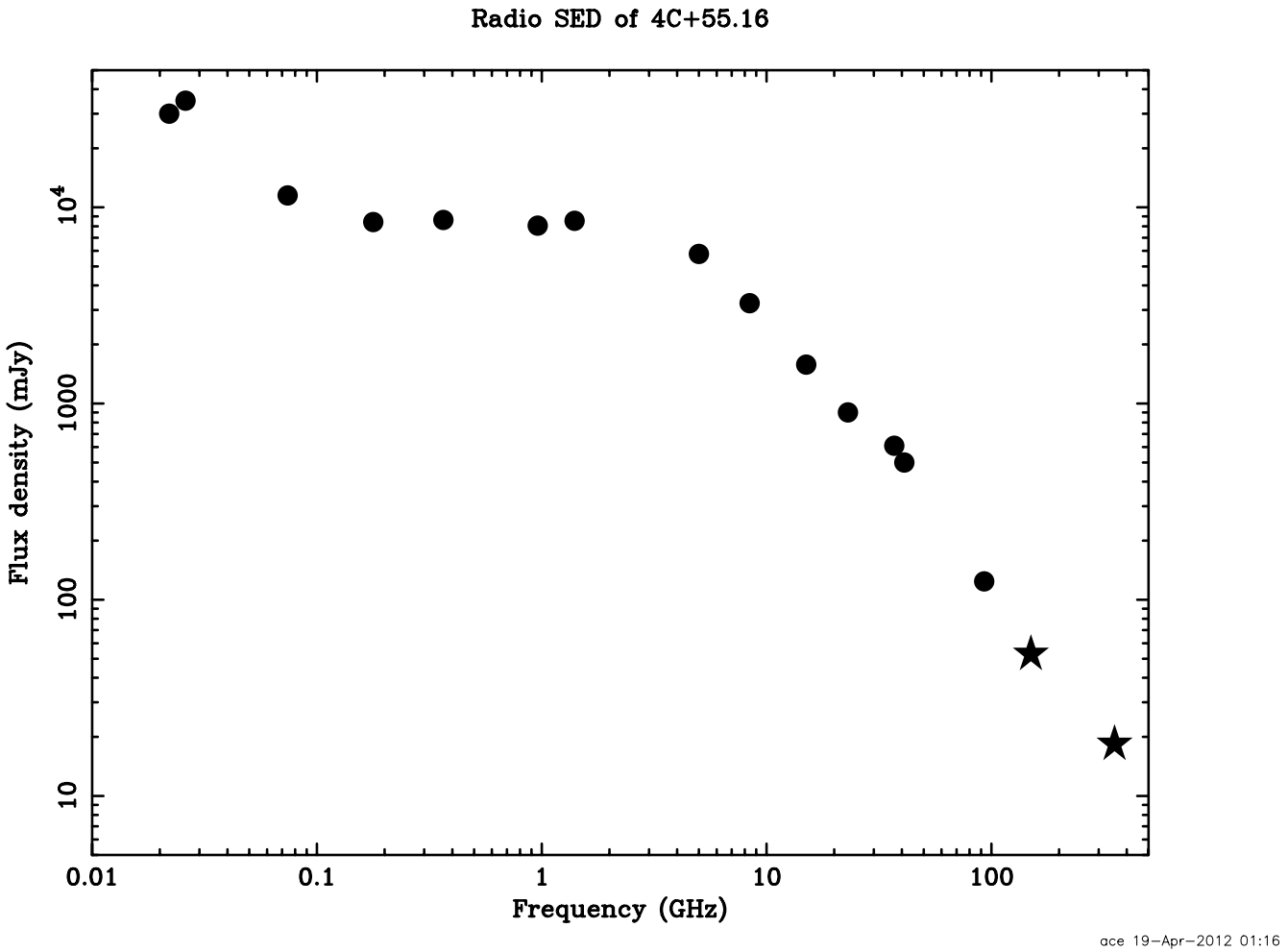
Radio SED from Hogan et al (2015)



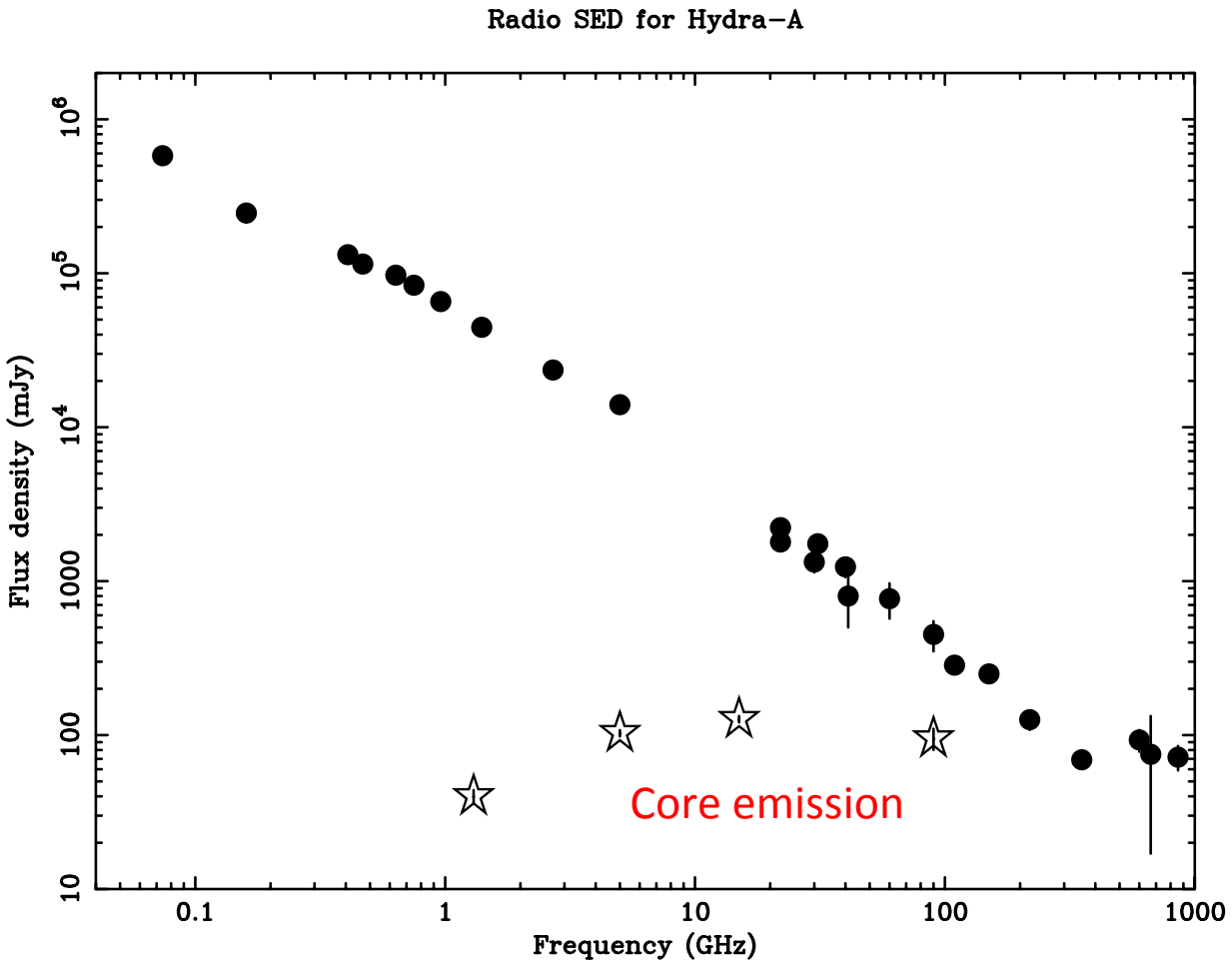
Radio SED from Hogan et al (2015)



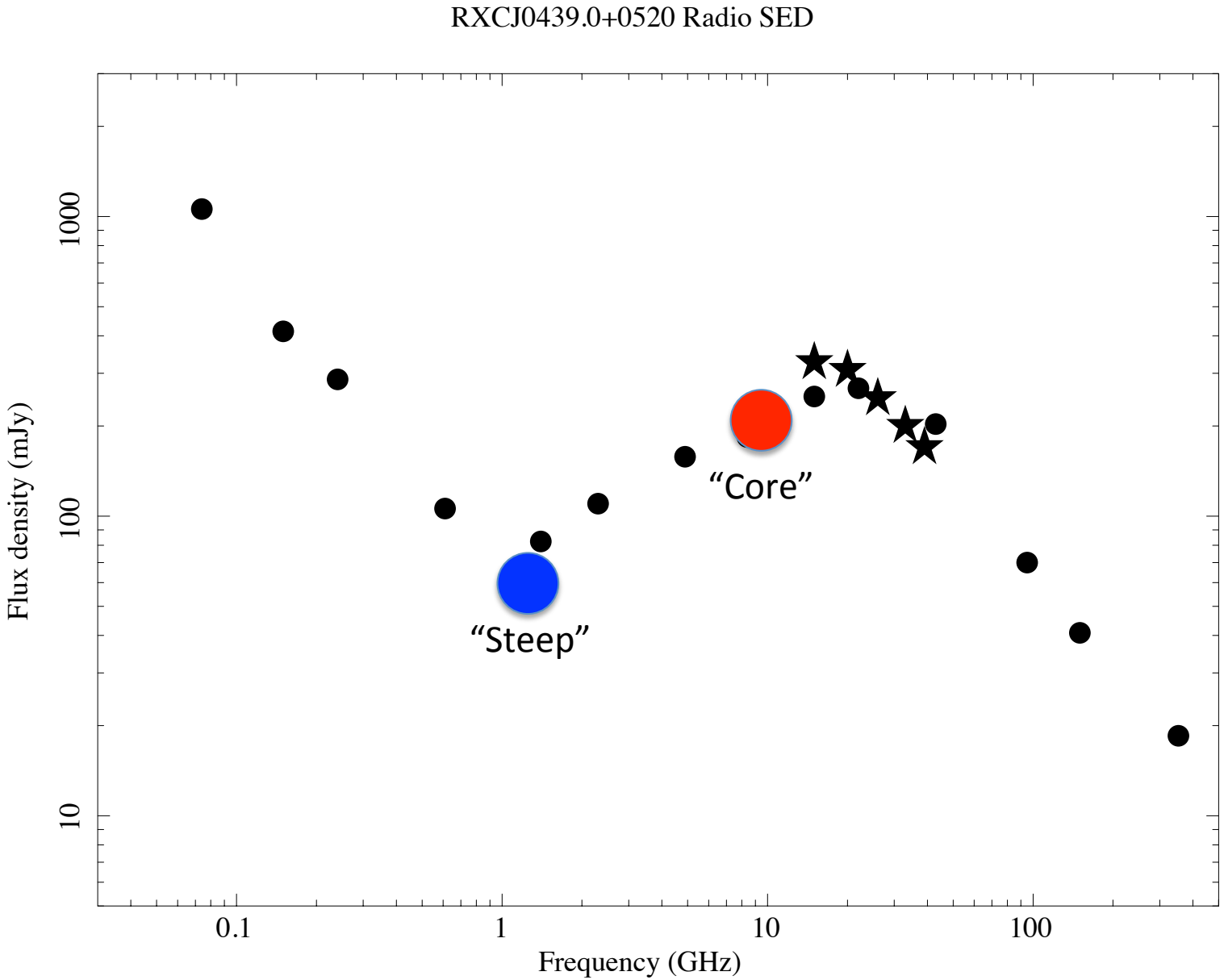
Radio SED from Hogan et al (2015)

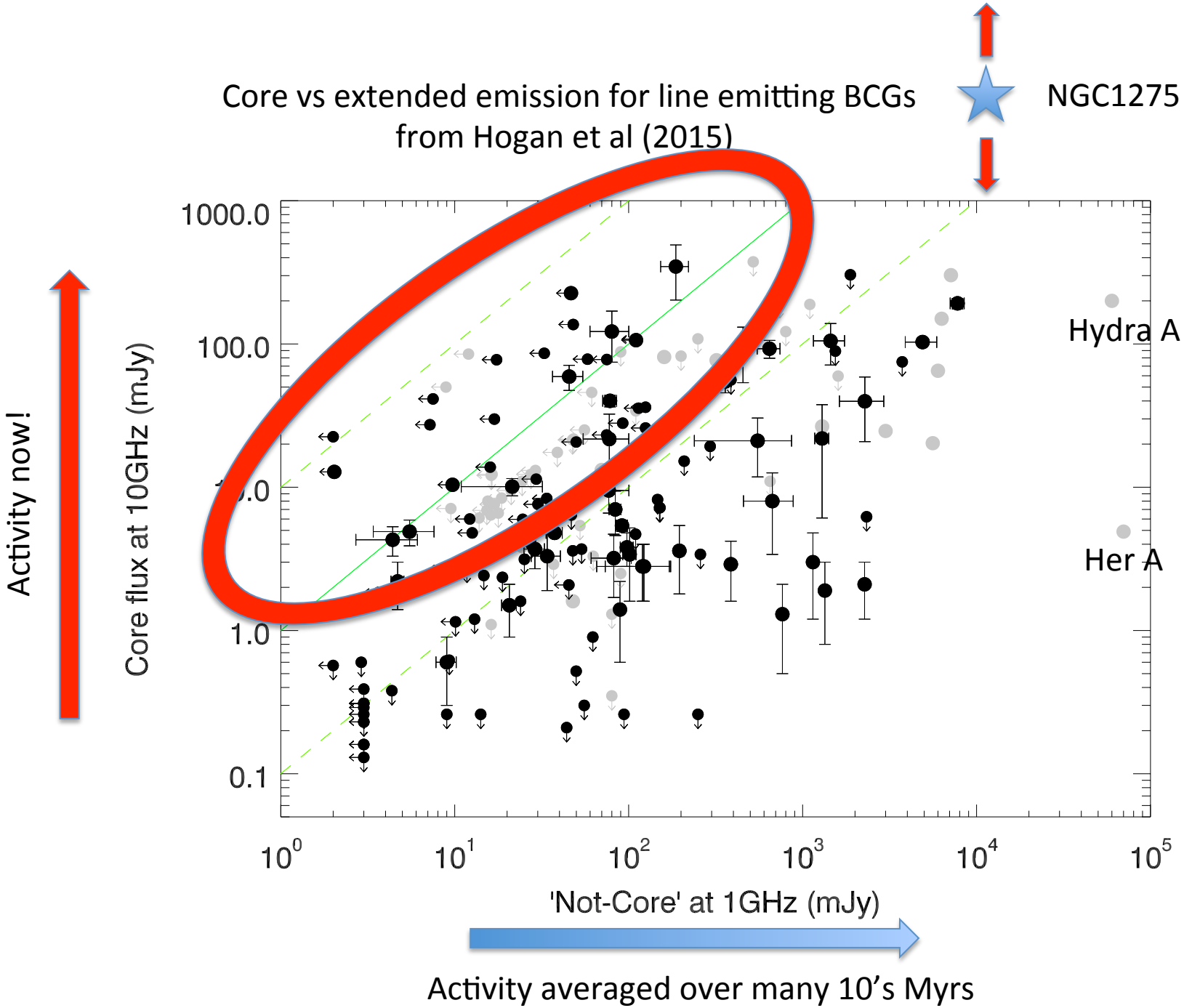


Radio SED from Hogan et al (2015)

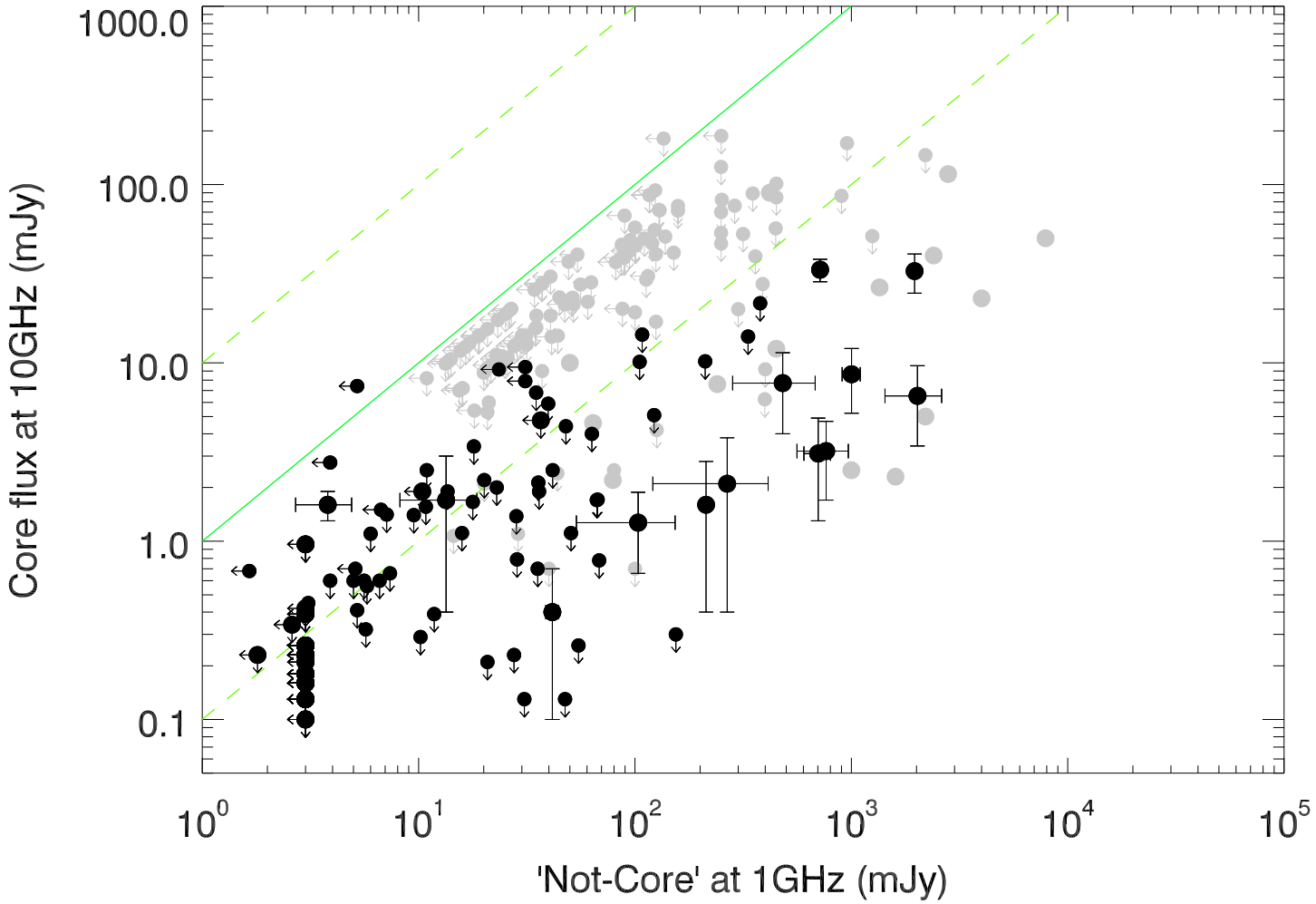


How do you interpret such strange spectra?!

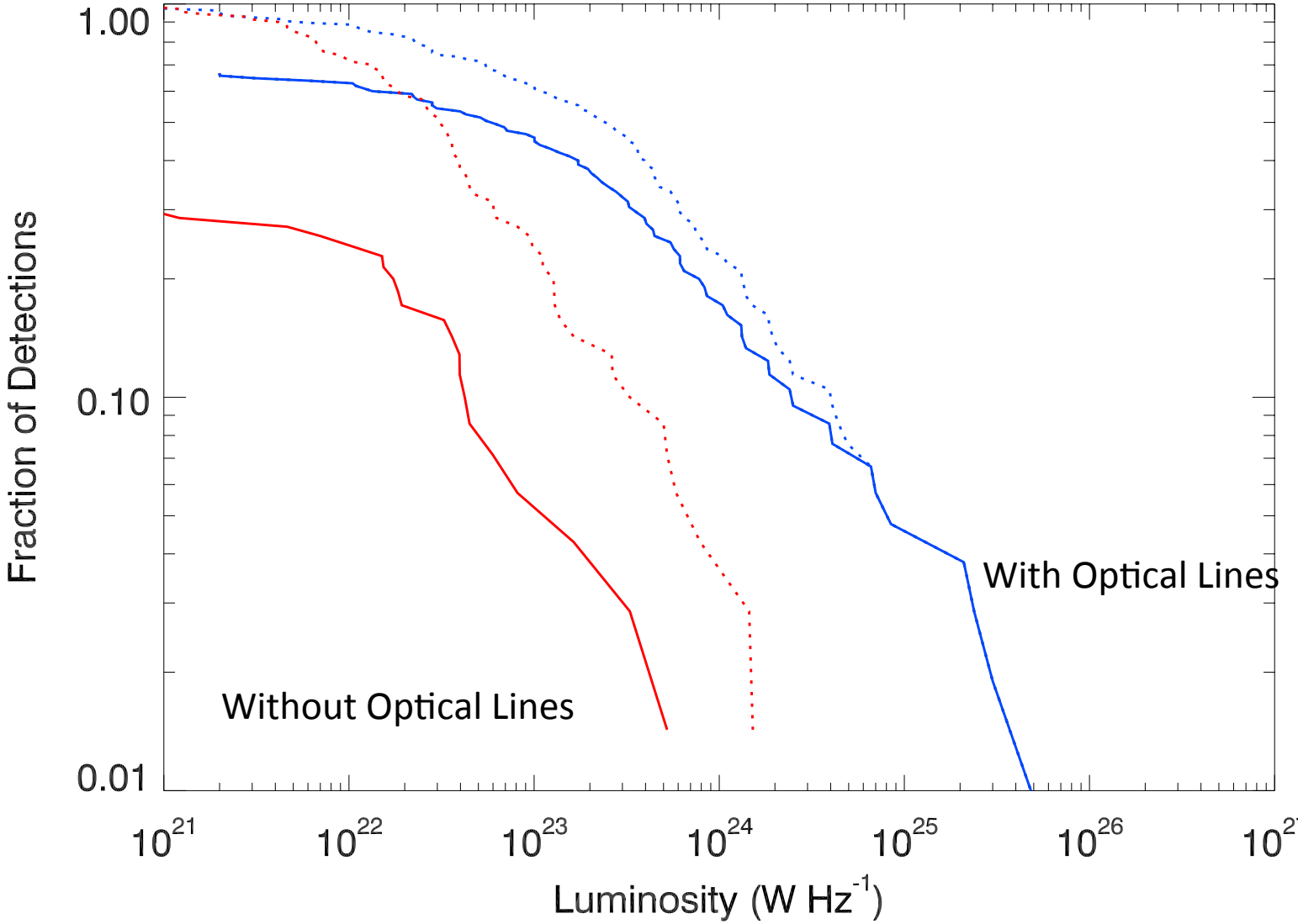



Core vs extended emission for line emitting BCGs
from Hogan et al (2015)
NGC1275
Hydra A
Her A
Activity now!
Core flux at 10GHz (mJy)
1000.0
100.0
1.0
0.1
10^0
10^1
10^2
10^3
10^4
10^5
'Not-Core' at 1GHz (mJy)
Activity averaged over many 10's Myrs

Core vs extended emission for non-line emitting BCGs
from Hogan et al (2015)

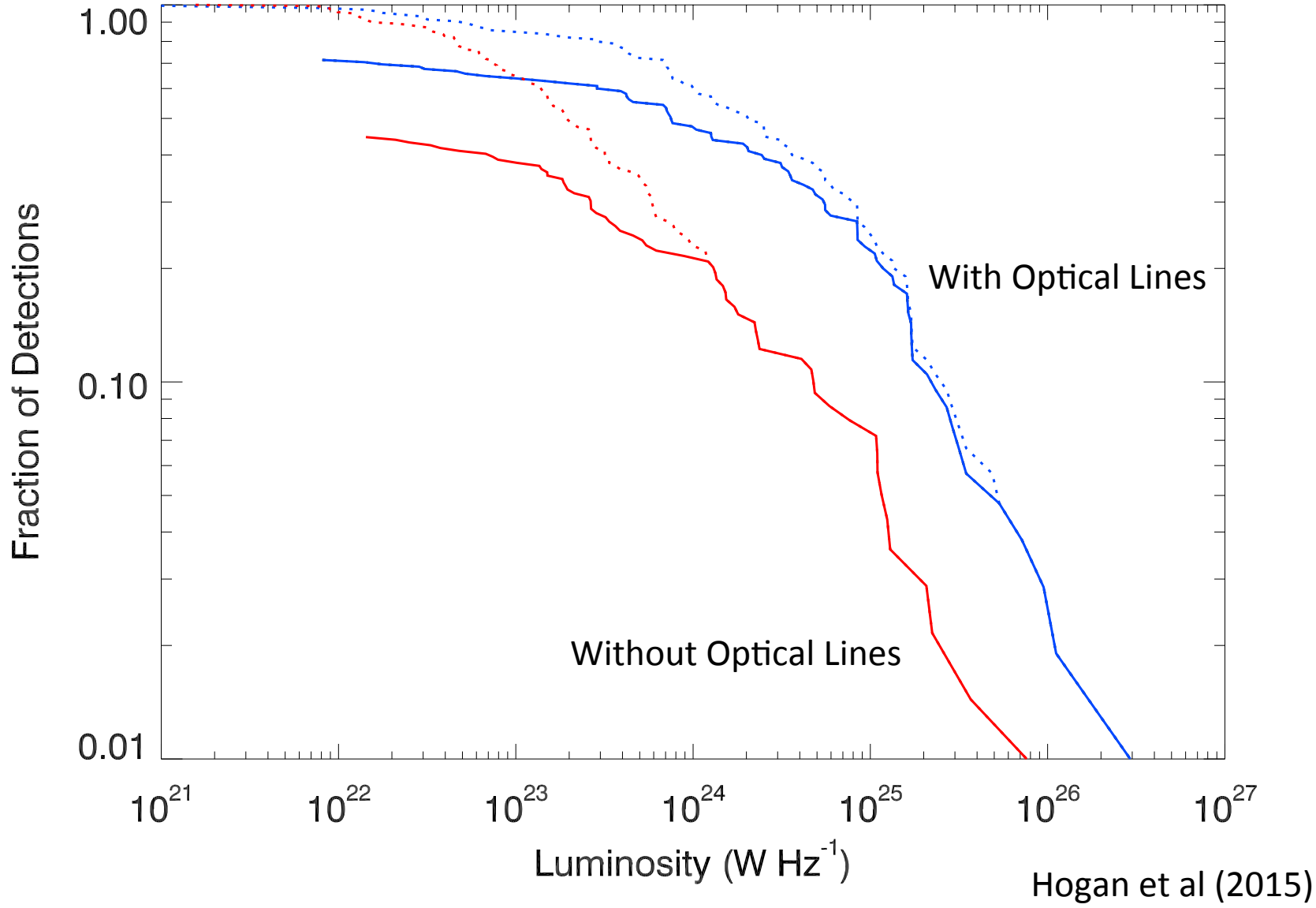


10GHz Radio luminosity function of cores with and without lines



Hogan et al (2015)

1GHz Radio luminosity function of steeper spectrum emission with and without lines



Hogan et al (2015)

Picking core dominated sources

The majority of the fits in the simple SED analysis recovered a “core” flux that is consistent with the VLBA flux recovered on <50mas.

These *undiluted* core dominated sources offer an interesting opportunity to search for HI in a single line of sight through the cold gas clouds that must be present in the core without needing very long baselines.

Mining the literature

There are a number of BCGs with well studied radio sources that have HI in absorption:

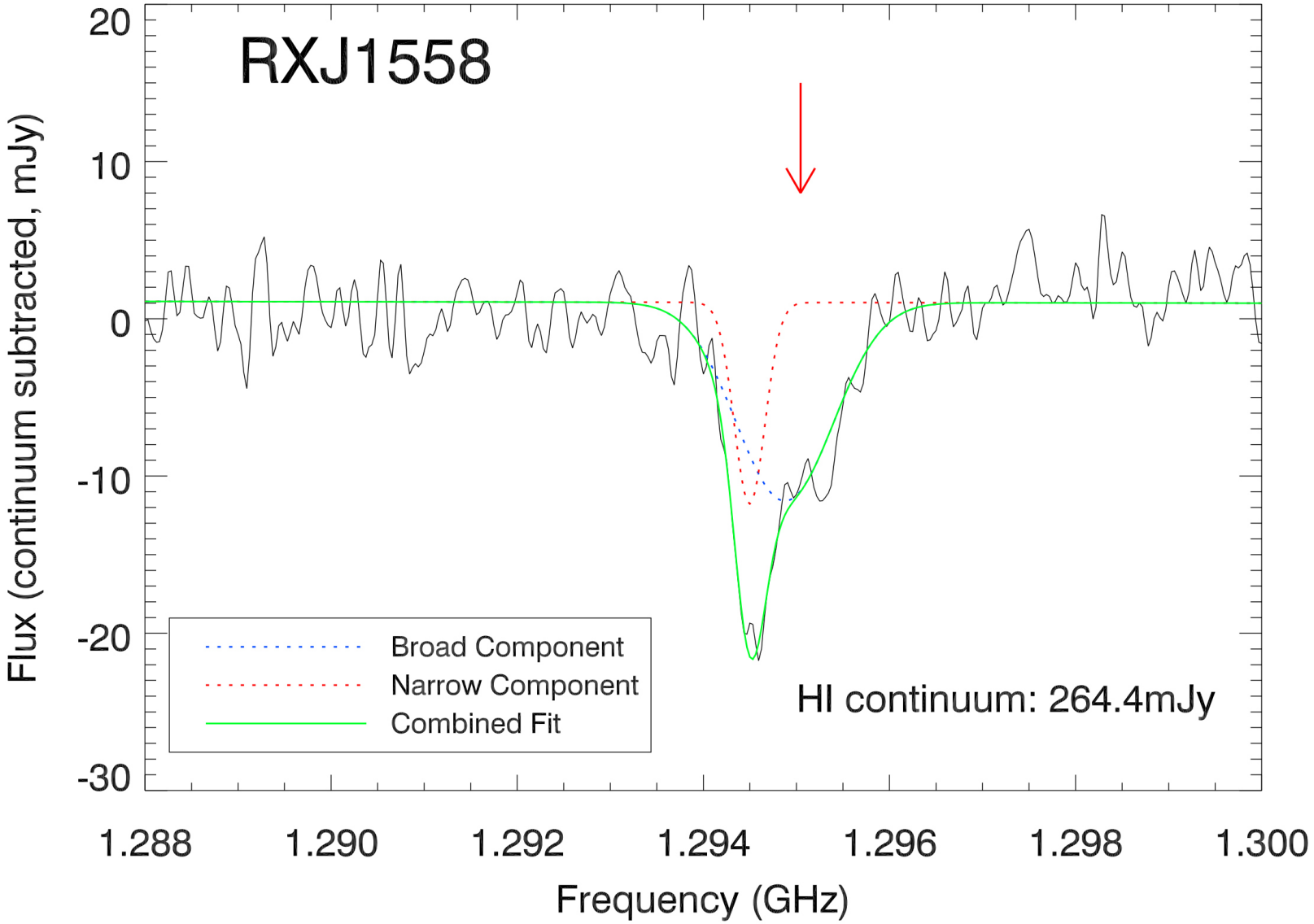
Hydra-A

A2597

Cygnus-A

PKS1555-14

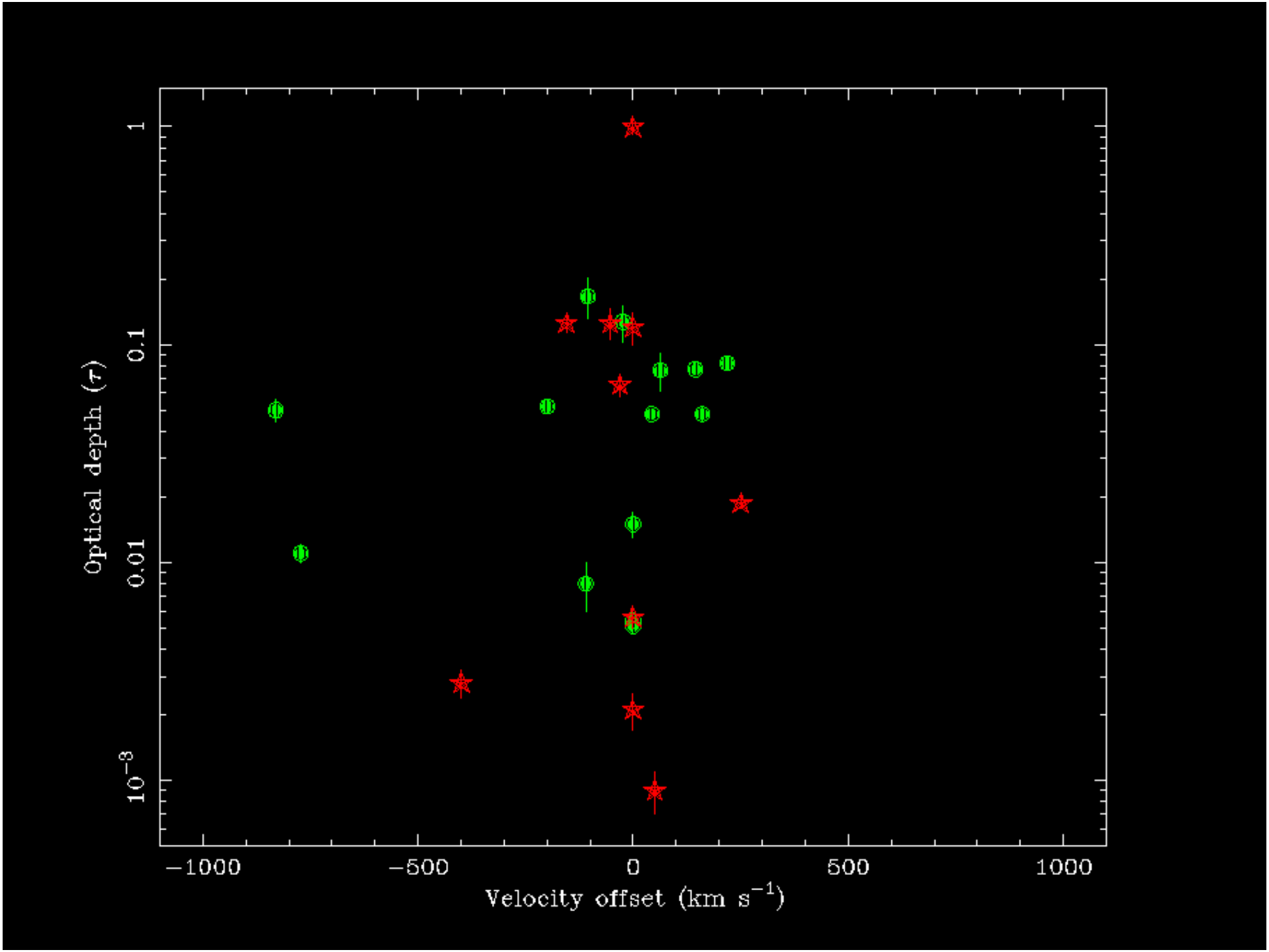
…and some lesser known ones totally 8 BCGs.

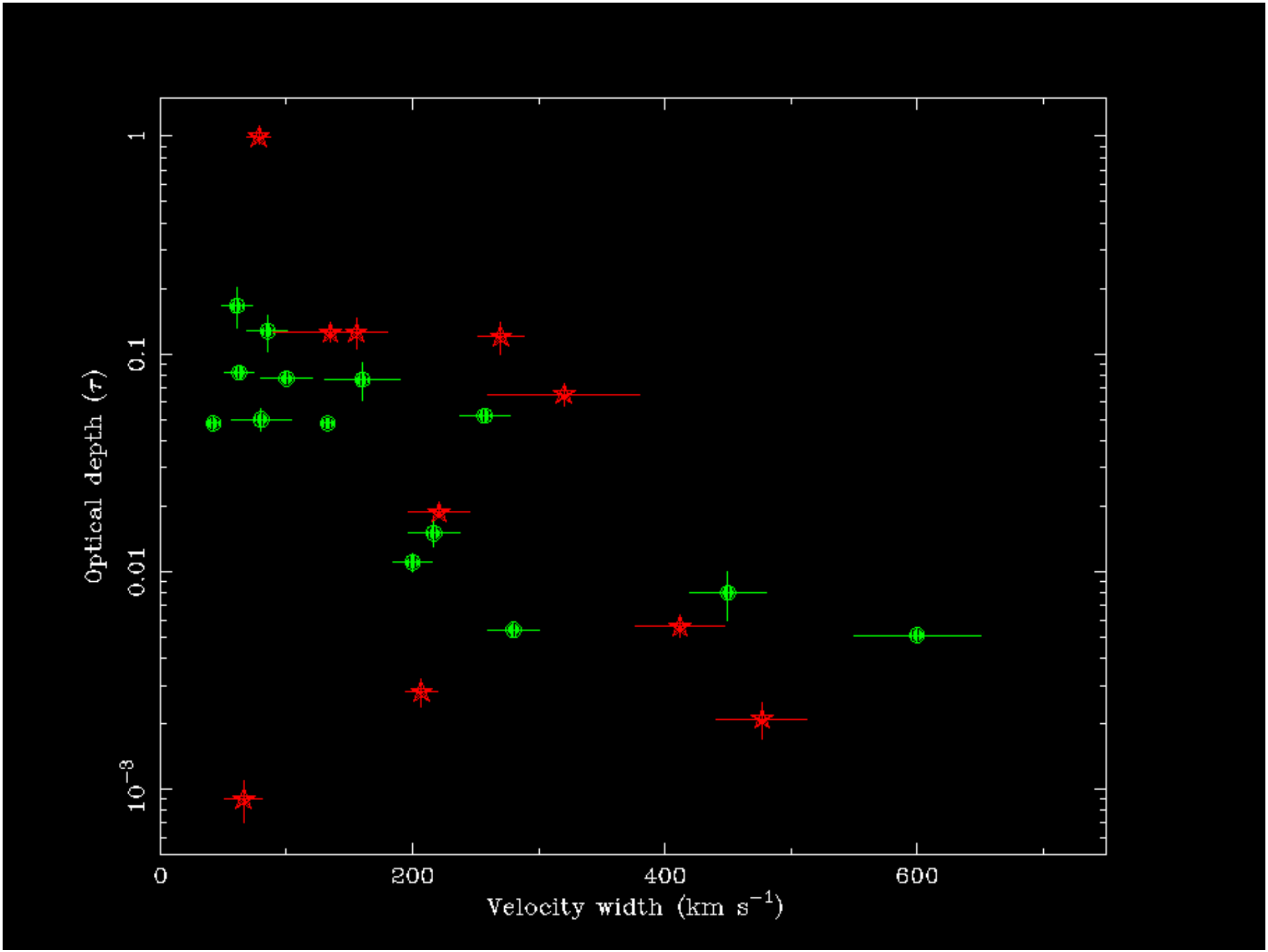

RXJ1558
Flux (continuum subtracted, mJy)
20
10
0
-10
-20
-30
1.288
1.290
1.292
1.294
1.296
1.298
1.300
Frequency (GHz)
Broad Component
Narrow Component
Combined Fit
HI continuum: 264.4mJy

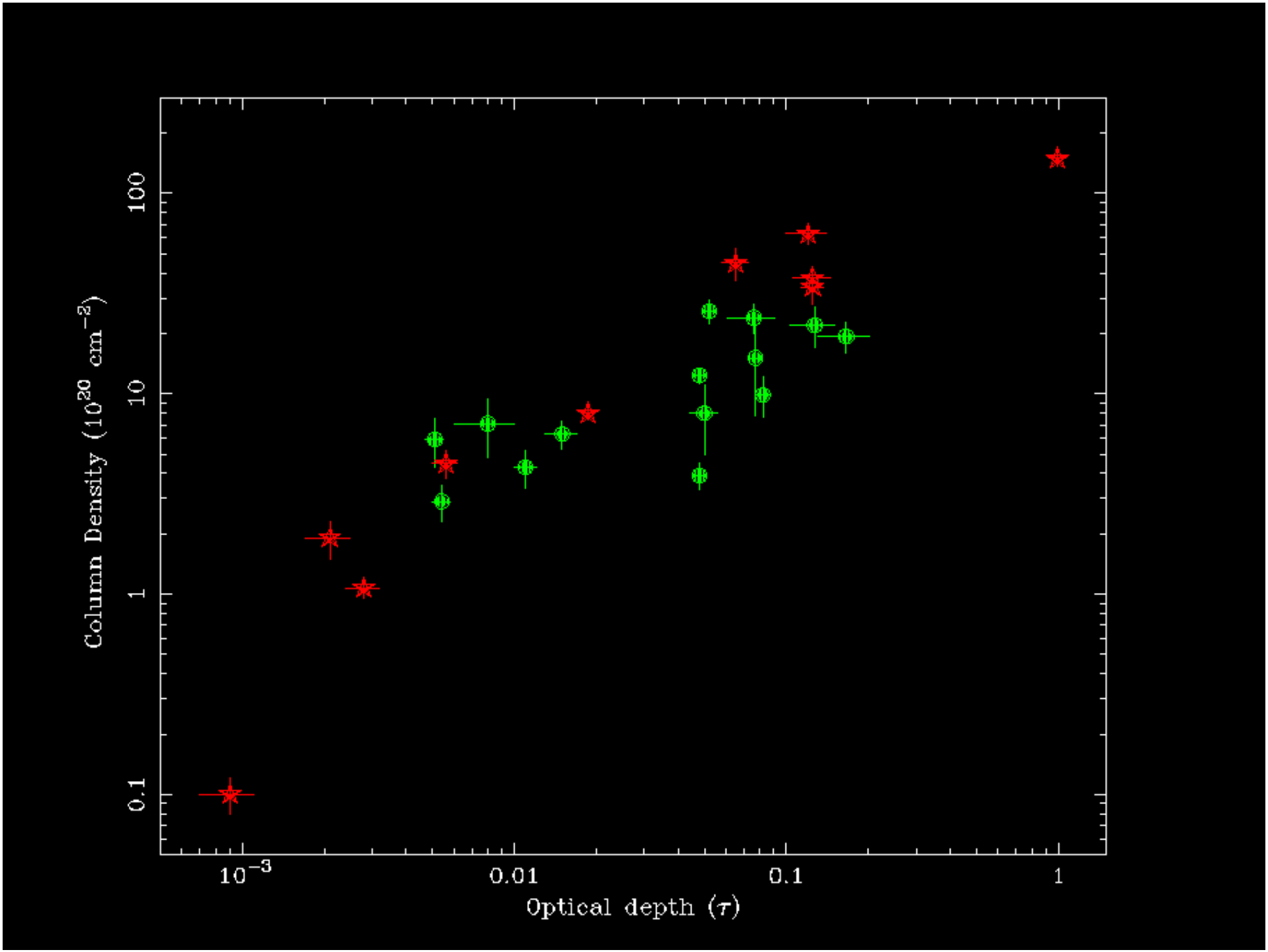
A multi-telescope campaign

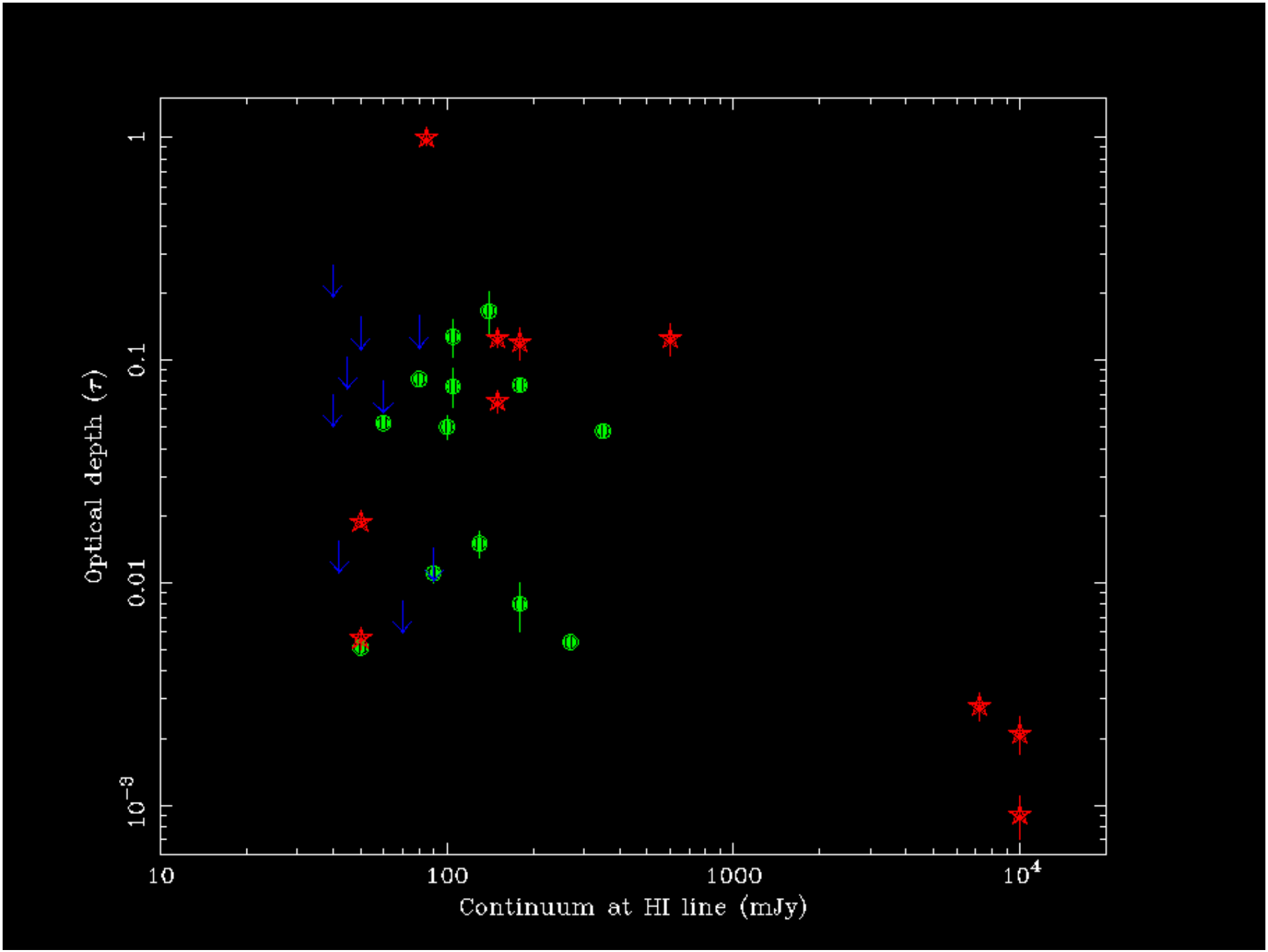
Over the past 6 years we have used ATCA, WSRT and JVLA to study a sample of 26 core dominated sources that are brighter than 40mJy at 1.4GHz.

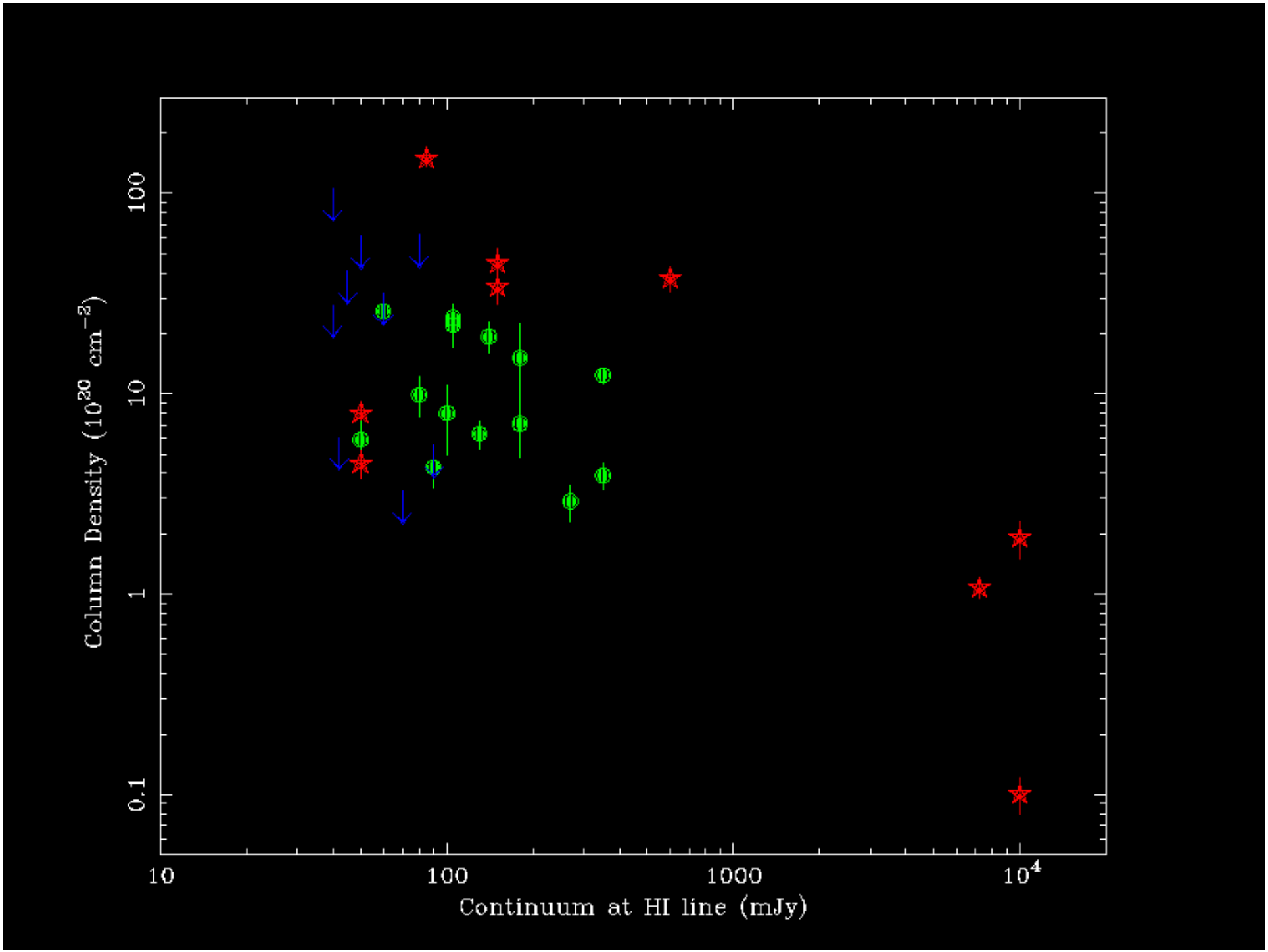
The success rate for this sample is ~50% (13 of 26) bringing our total to 21 HI detections.

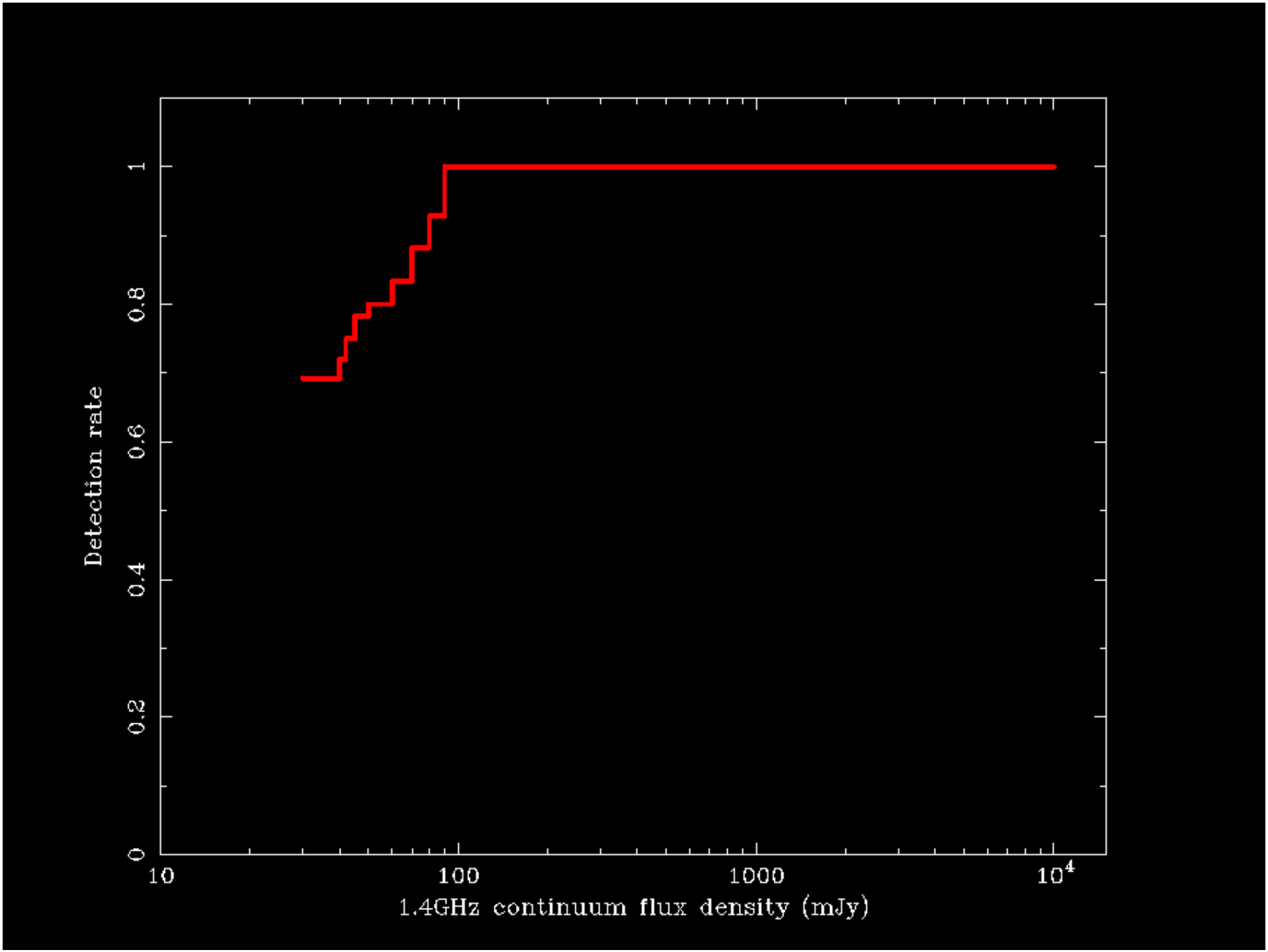

Optical depth (τ)
1
0.1
0.01
10^{-3}
−1000
−500
0
500
1000
Velocity offset (km s^{-1})

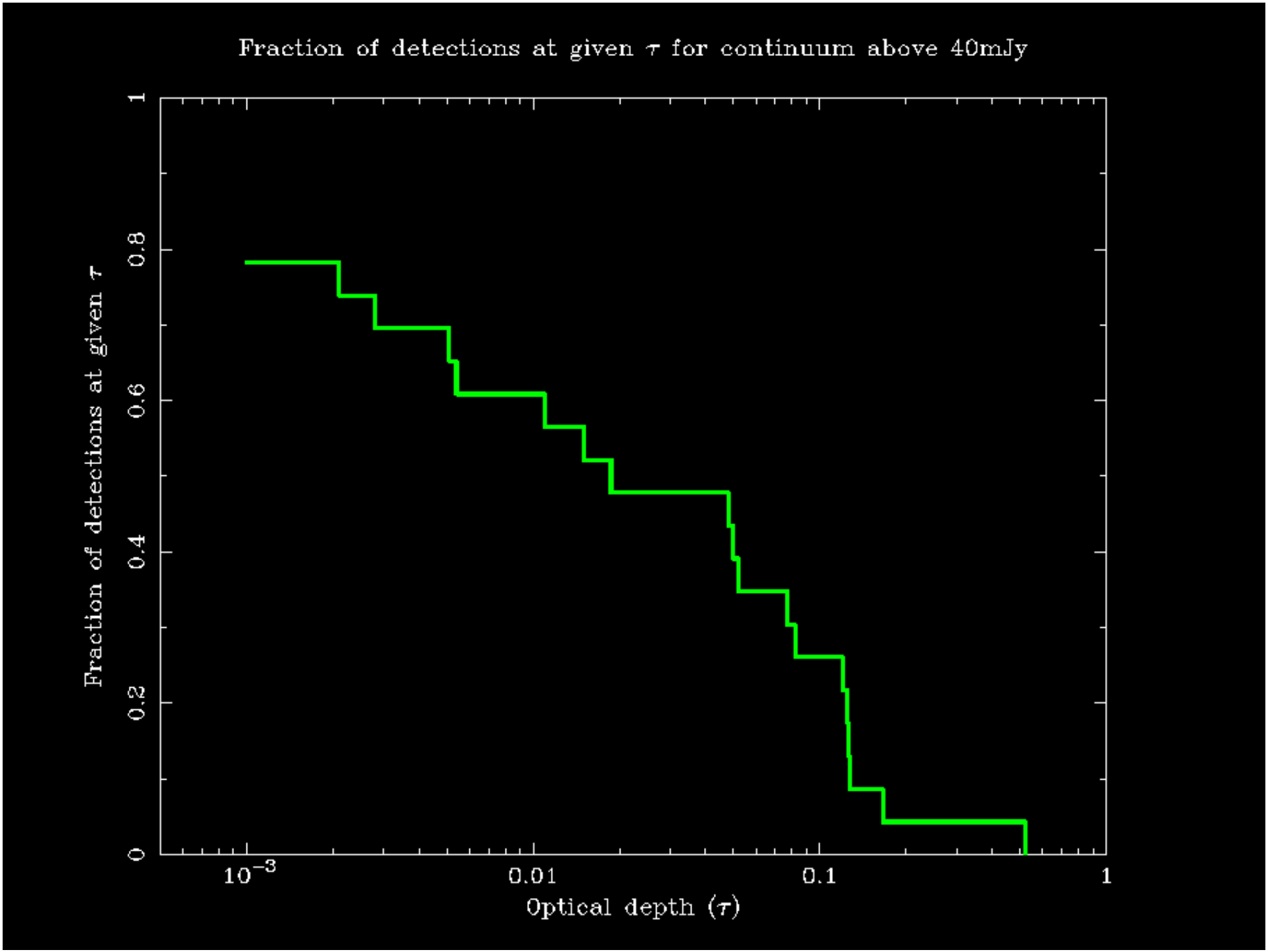

Optical depth (τ)
1
0.1
0.01
10^{-3}
0
200
400
600
Velocity width (km s^{-1})

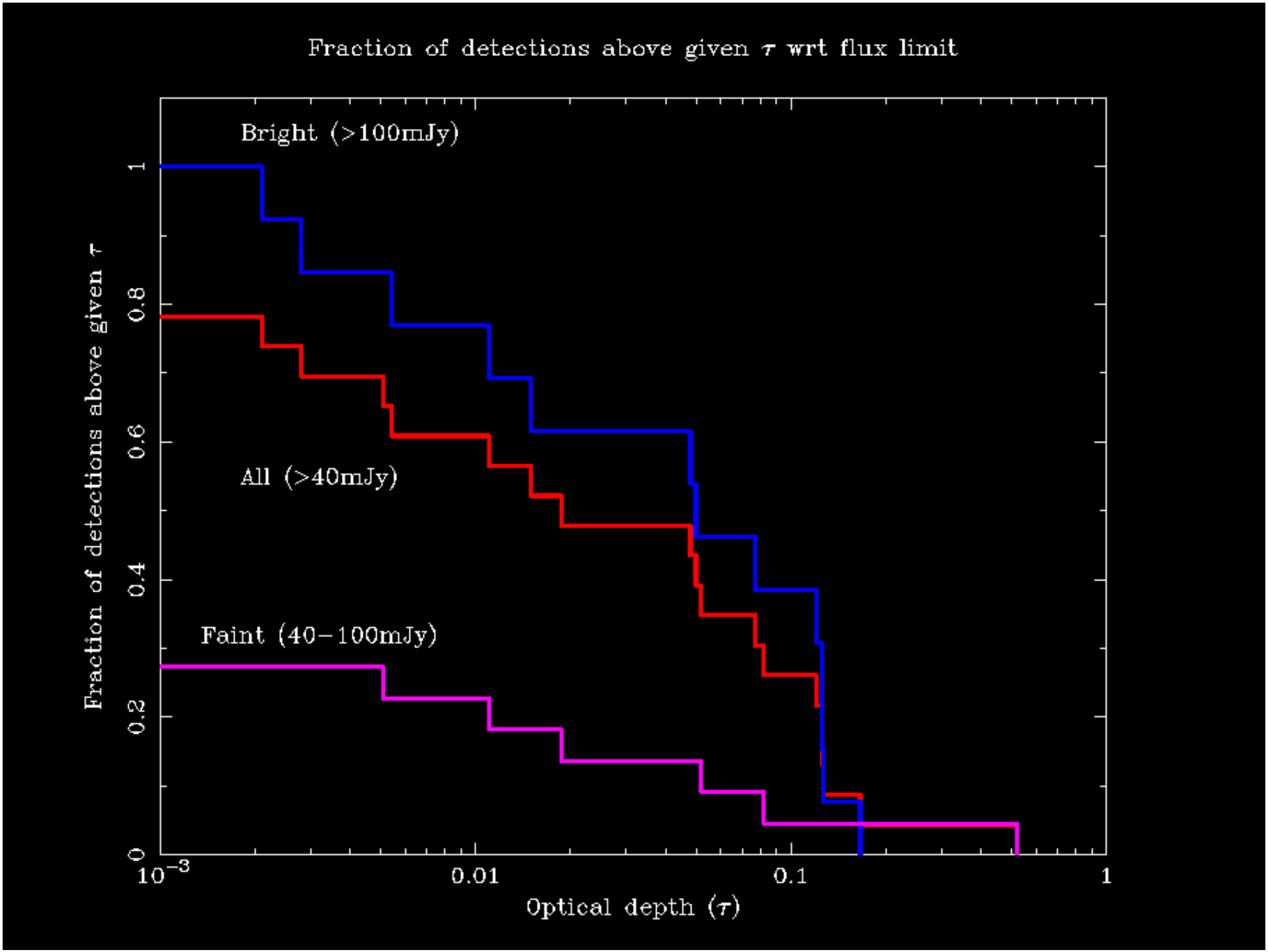

Column Density (10^{20} cm^{-2})
100
10
1
0.1
10^{-3}
0.01
0.1
1
Optical depth (τ)


Optical depth (τ)
1
0.1
0.01
10^{-3}
10
100
1000
10^4
Continuum at HI line (mJy)


Column Density (10^{20} cm^{-2})
100
10
1
0.1
10
100
1000
10^4
Continuum at HI line (mJy)


Detection rate
0
0.2
0.4
0.6
0.8
1
10
100
1000
10^4
1.4GHz continuum flux density (mJy)


Fraction of detections at given τ for continuum above 40mJy
Fraction of detections at given τ
0
0.2
0.4
0.6
0.8
1
10^-3
0.01
0.1
1
Optical depth (τ)


Fraction of detections above given τ wrt flux limit
Bright (>100mJy)
All (>40mJy)
Faint (40−100mJy)
Fraction of detections above given τ
0
0.2
0.4
0.6
0.8
1
10^−3
0.01
0.1
1
Optical depth (τ)

Doing the same for CO

Mike Hogan was able to confirm that the core emission in the majority of the core dominated BCGs extends into the mm/sub-mm with a relatively flat spectrum.

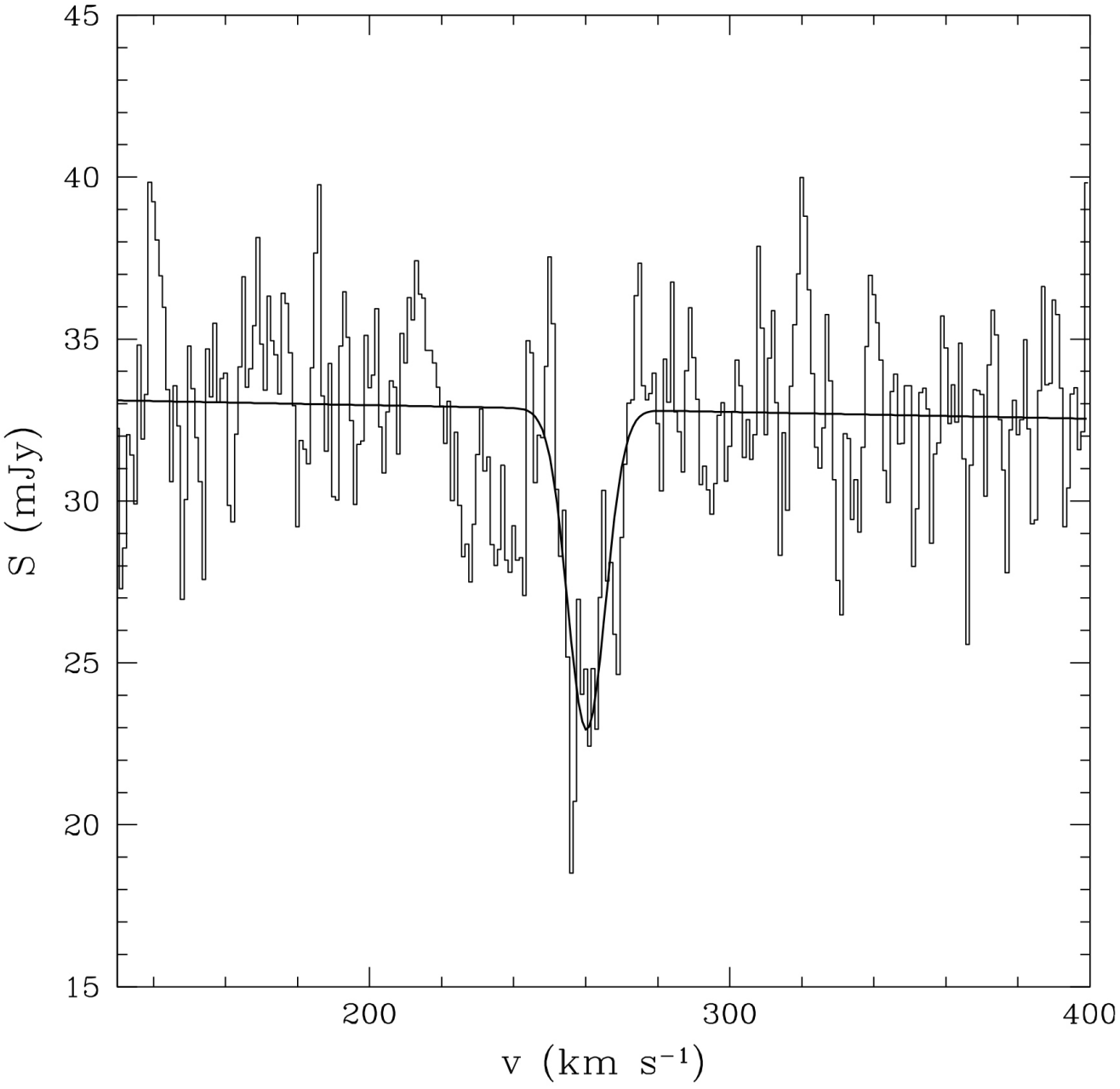
Therefore we can perform the same absorption experiment for CO against these cores with ALMA.

The surprising first detection!

The first detection of CO absorption with ALMA was in NGC5044 which was a surprise as the radio core in this system is relatively weak.

However, a very inverted, variable mm/sub-mm core is present in NGC5044 and a CO(2-1) detection against the 50mJy core was published in David et al (2014).

CO(2-1) Absorption in NGC5044 from David et al (2014)

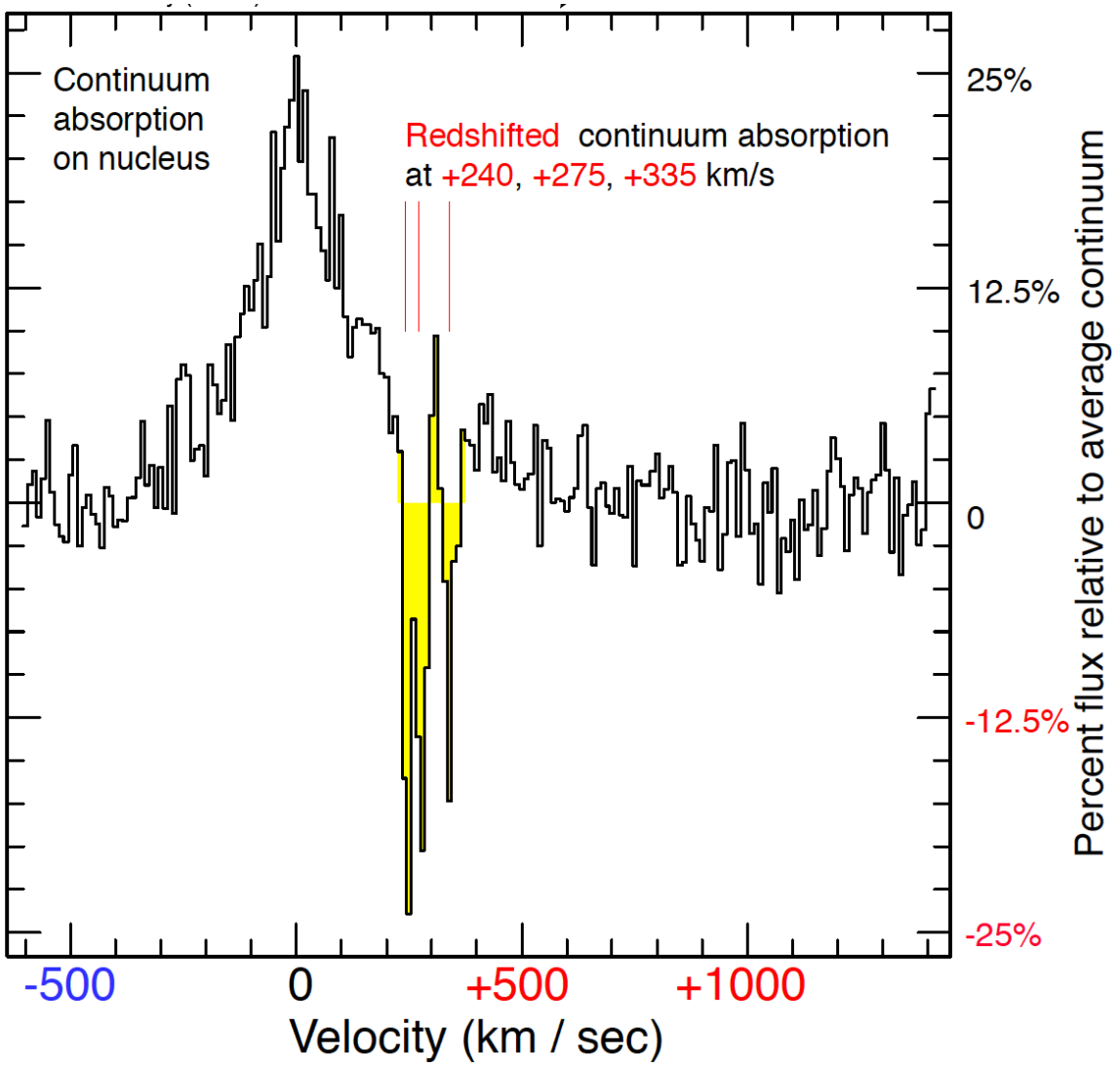


The less surprising second detection!

The second detection of CO absorption in a BCG was in A2597 where a clear, complex HI detection was known from VLBA (Taylor et al 1999).

The ALMA data show three narrow, redshifted absorbers (i.e. infalling) and are presented in Tremblay et al (2016).

CO(2-1) Absorption in A2597 from Tremblay et al (2016)

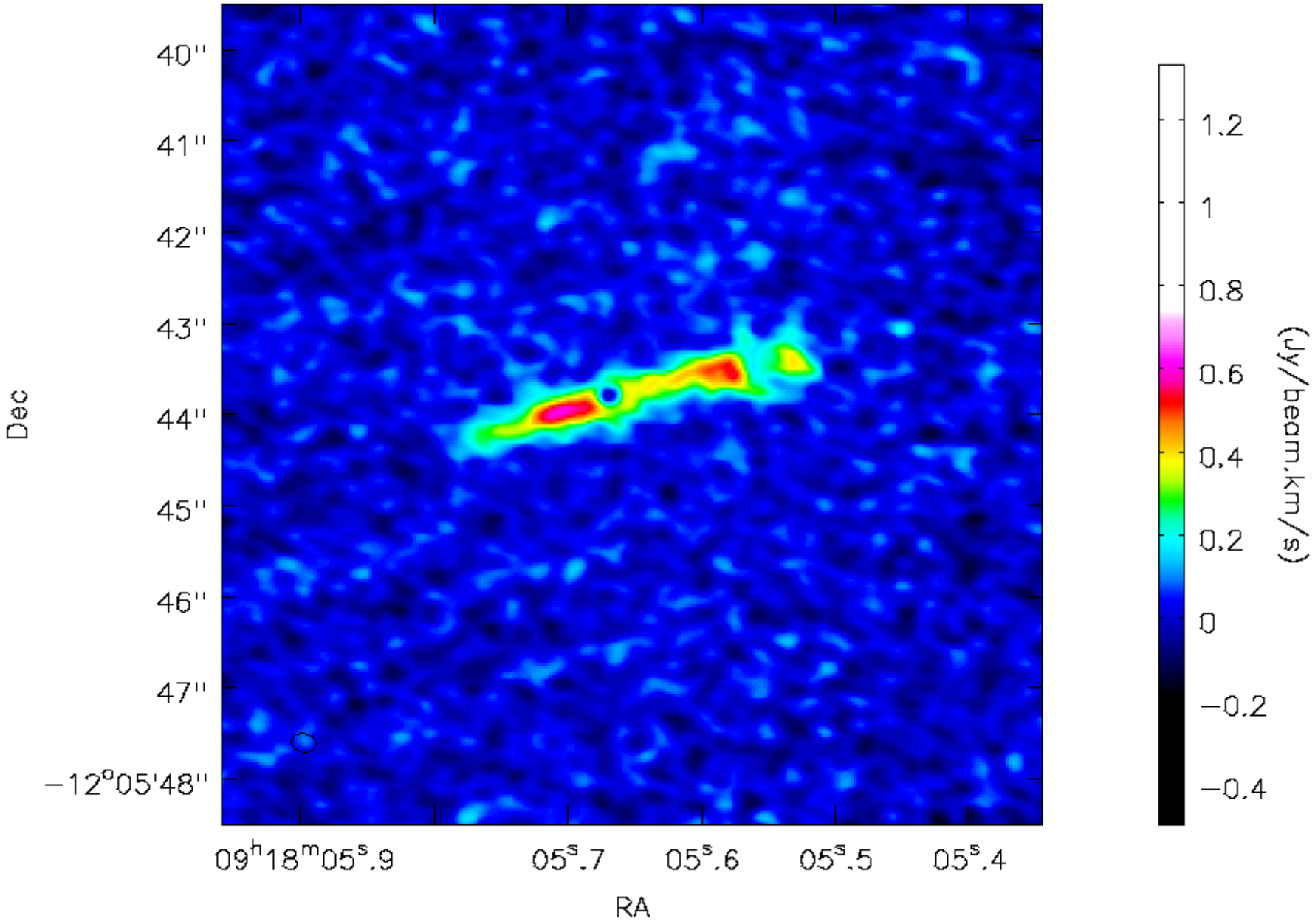


The least surprising third detection!

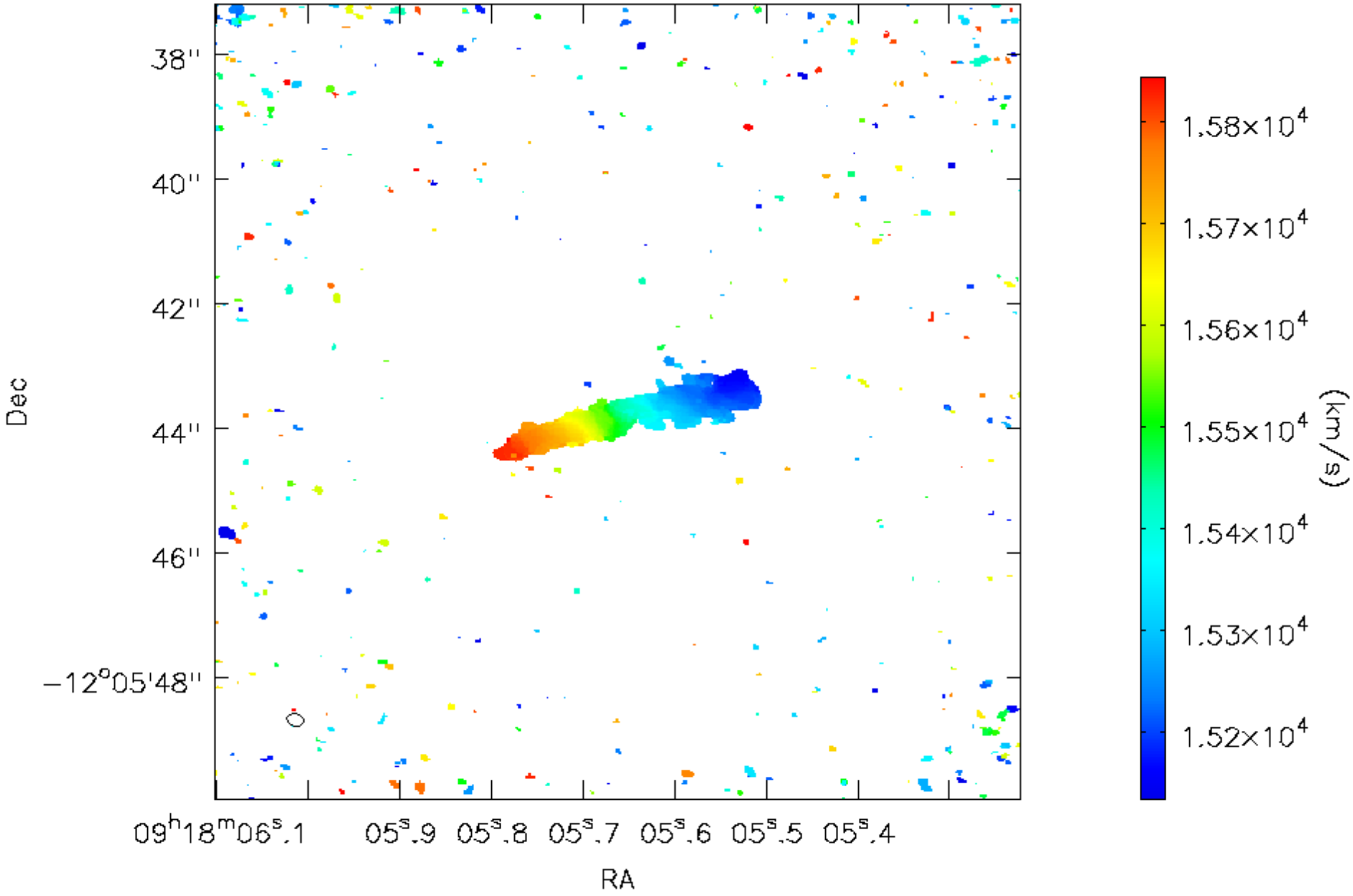
The third detection of CO absorption in a BCG is in Hydra-A where a deep, broad HI detection was known from VLBA (Taylor 1996).

The ALMA data shows one very narrow absorber at rest with the BCG and consistent with absorption through the edge on gas disk we observe in this galaxy.

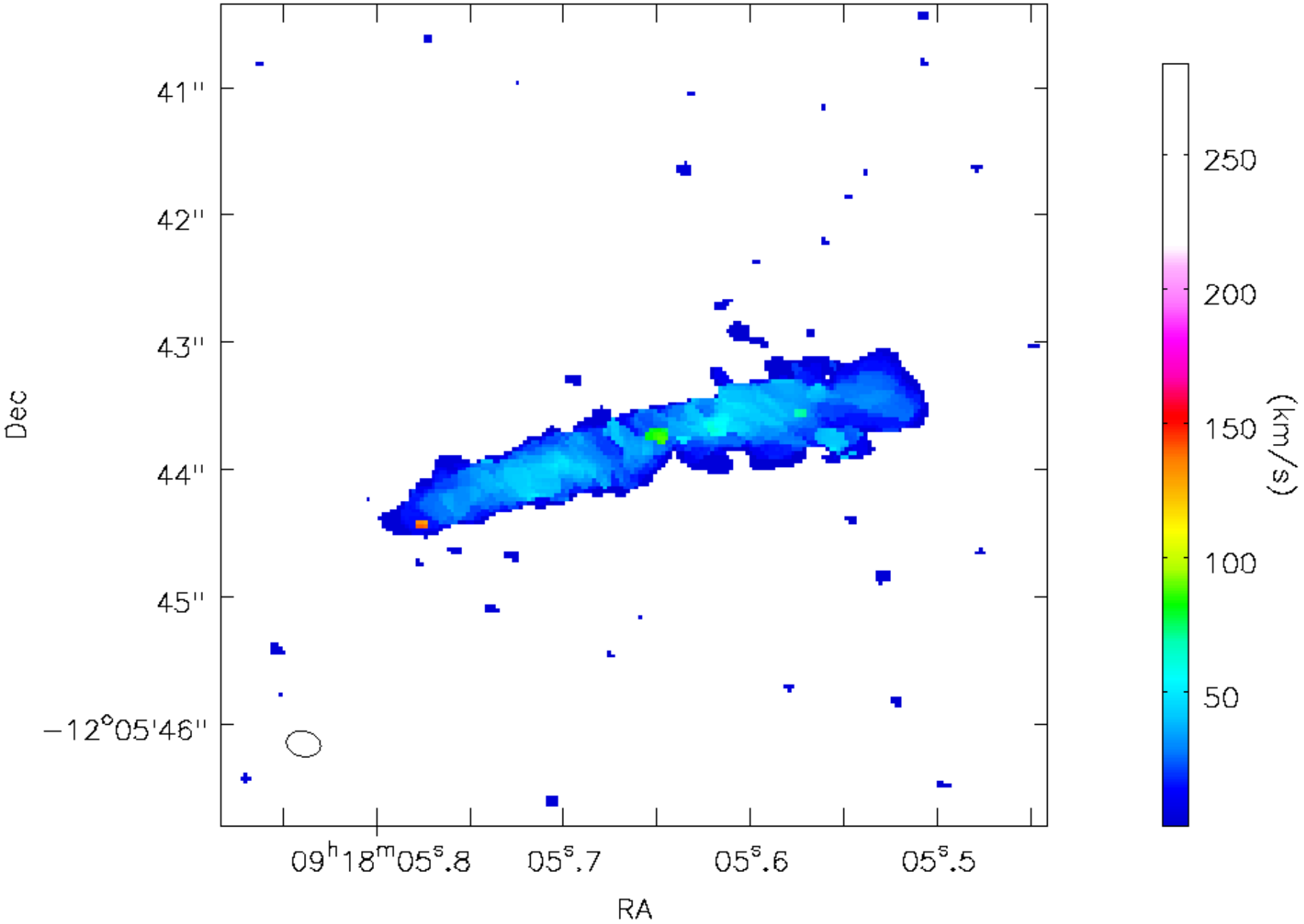
ALMA CO(2-1) intensity map of Hydra-A



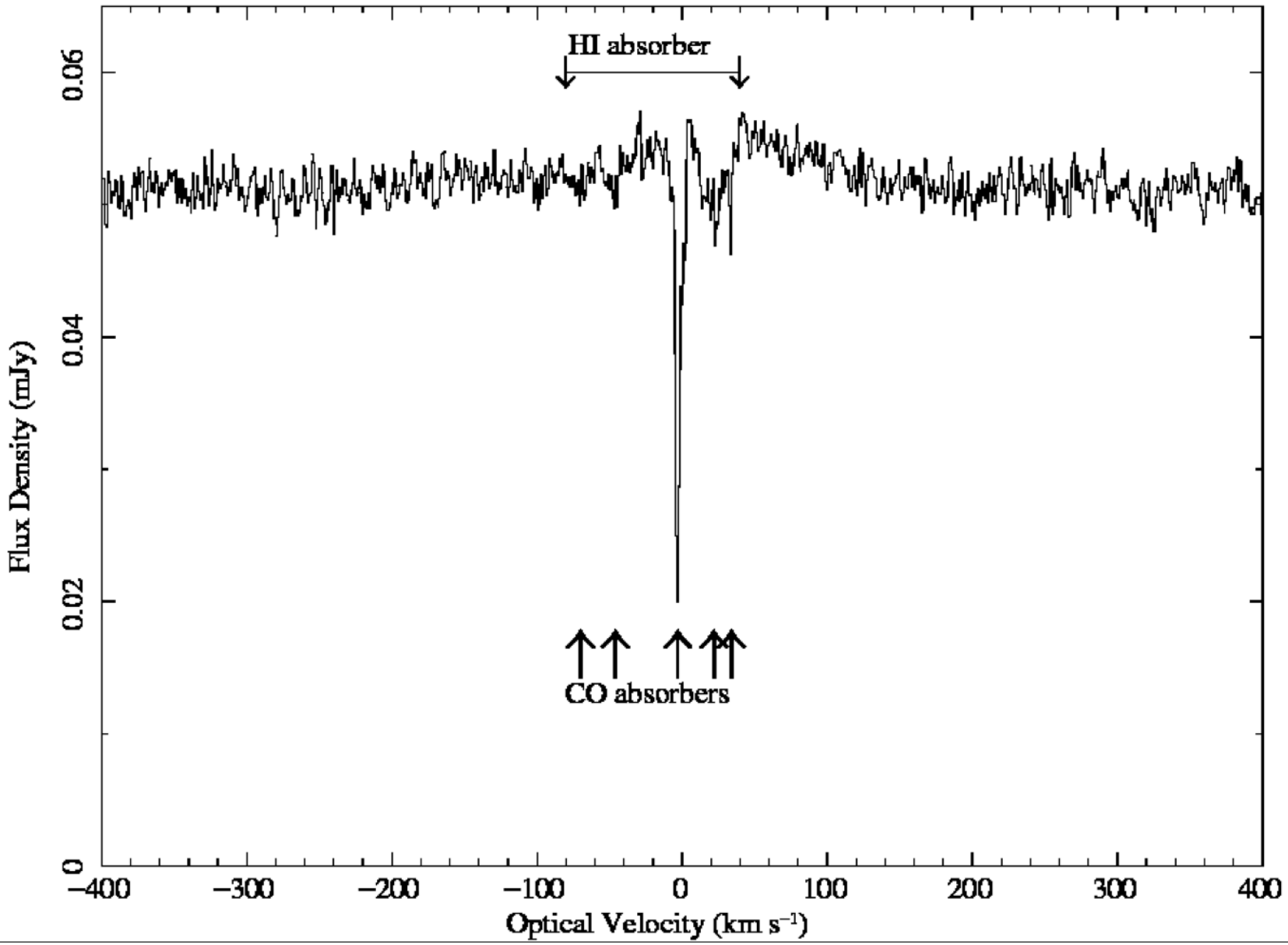
ALMA CO(2-1) velocity map of Hydra-A



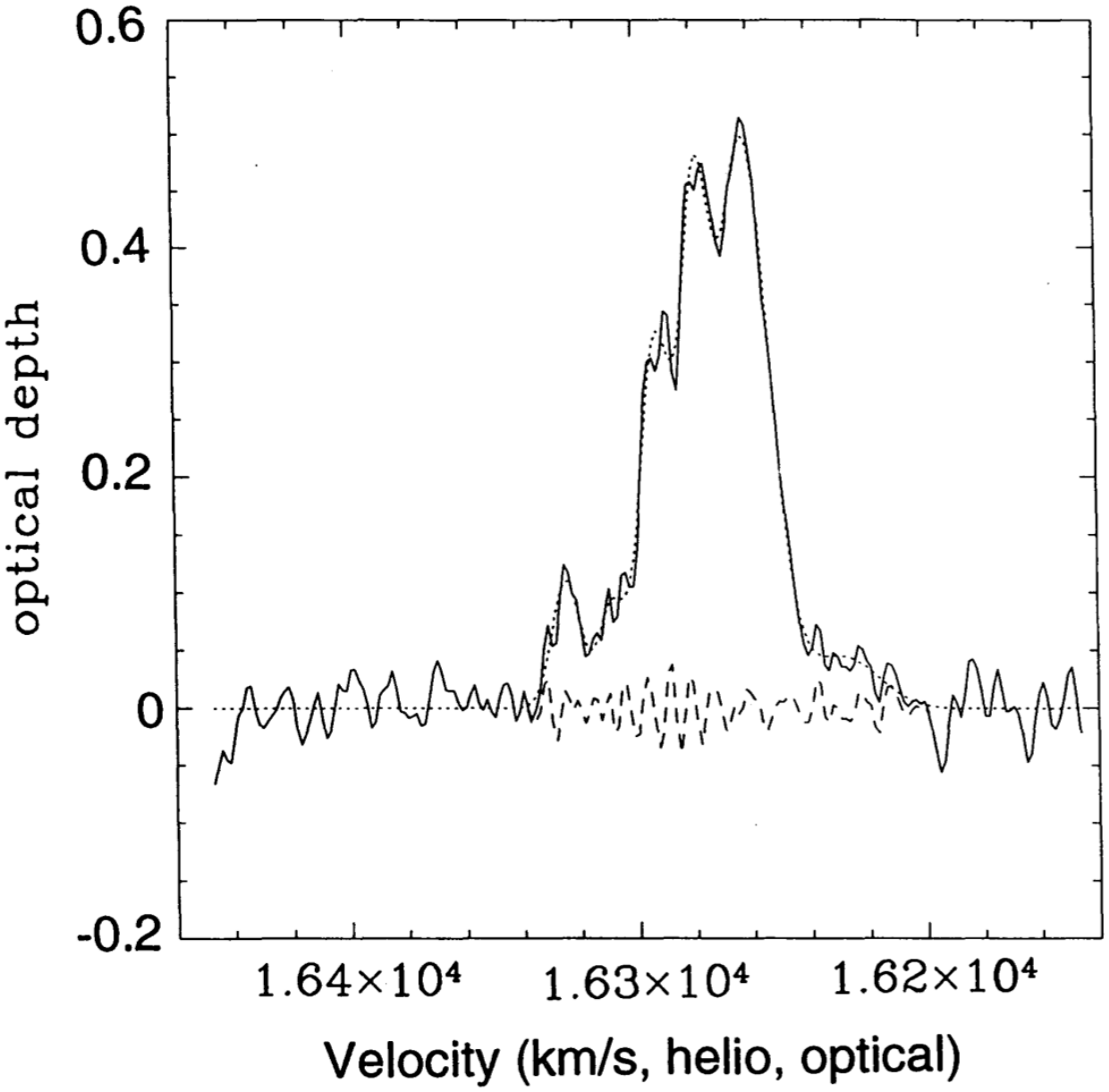
ALMA CO(2-1) line width map of Hydra-A



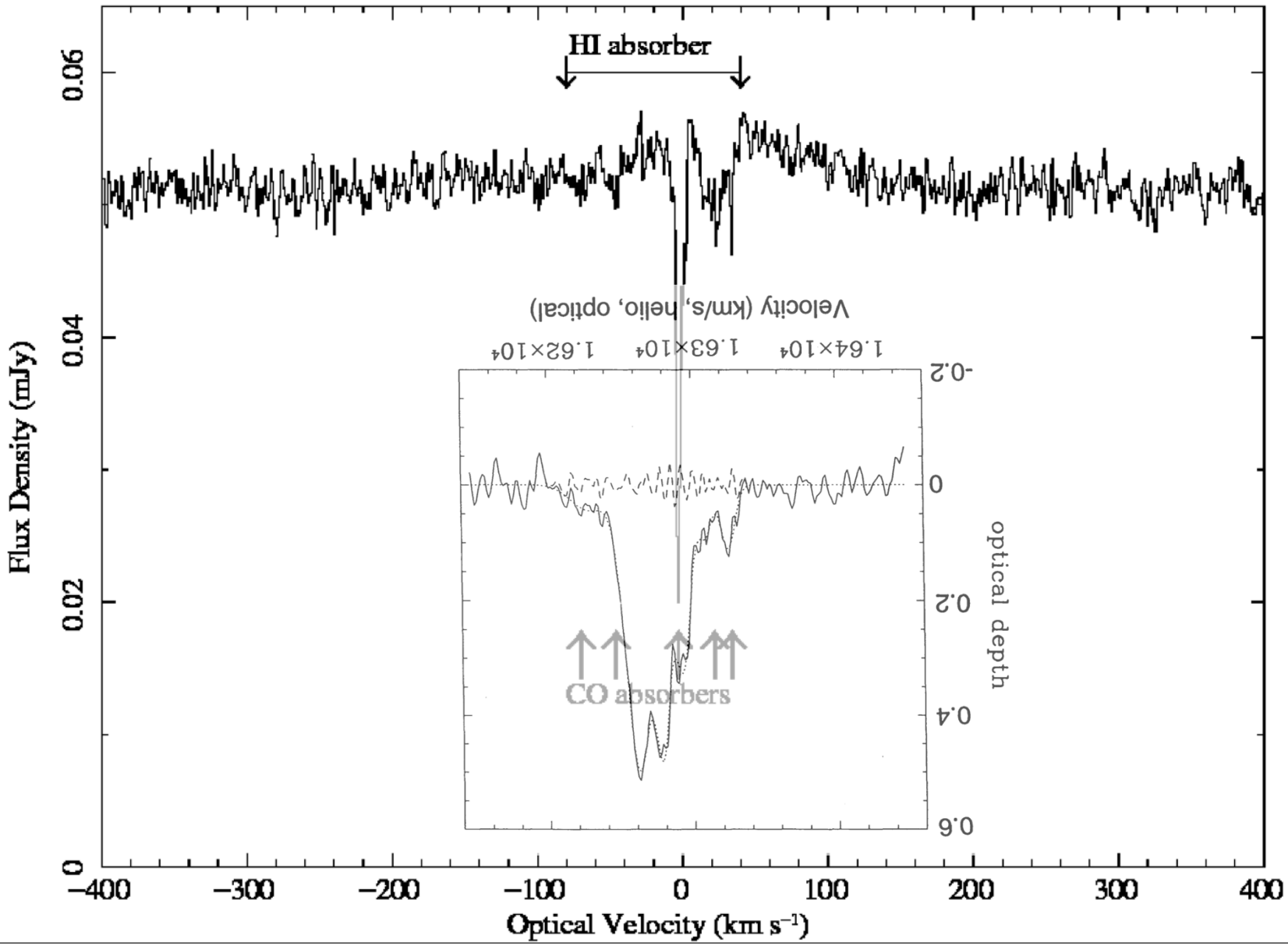
ALMA CO(2-1) core spectrum of Hydra-A



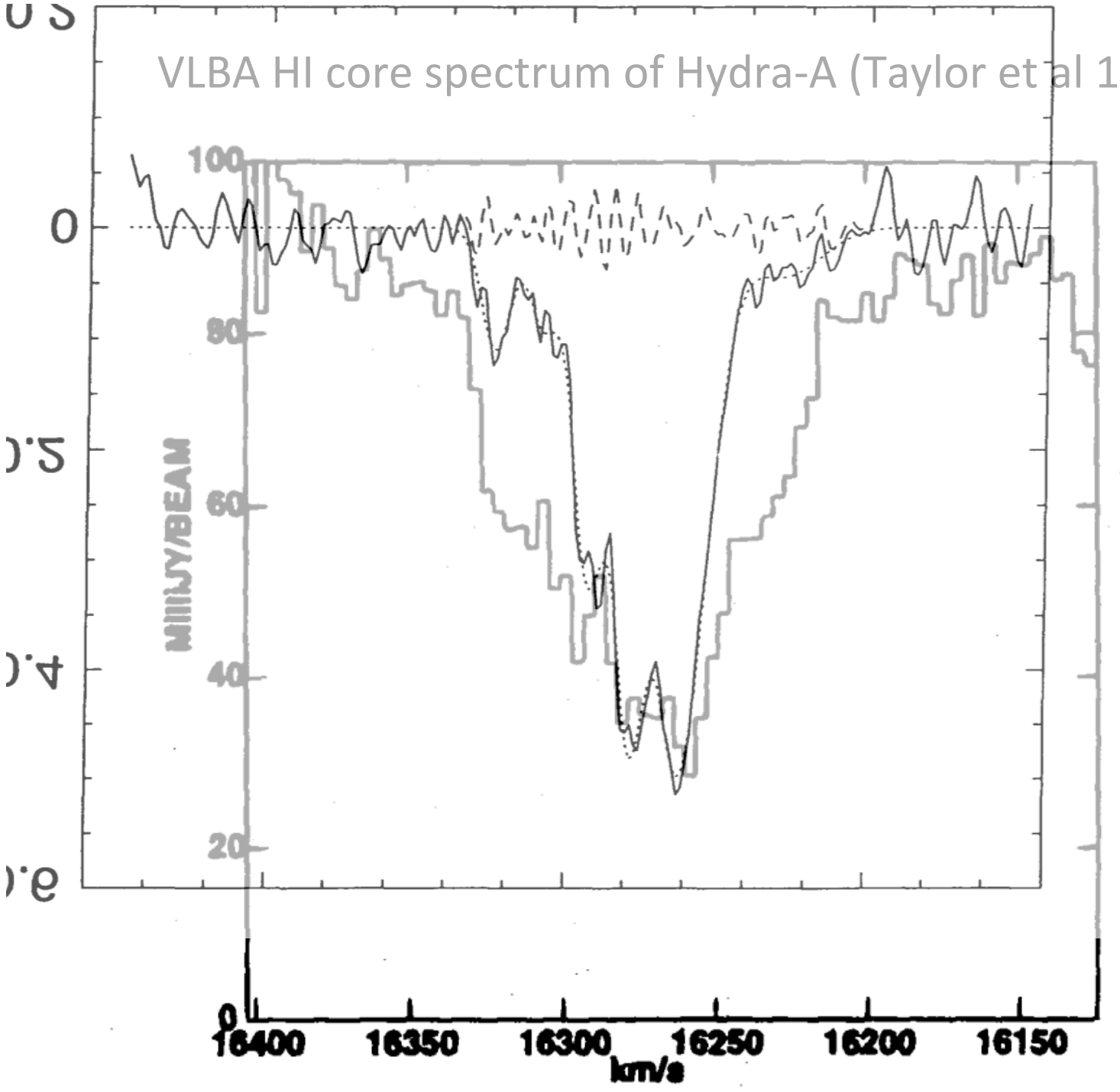
VLA HI core spectrum of Hydra-A (Dwarakanath et al 1995)



ALMA CO(2-1) core spectrum of Hydra-A



VLBA HI core spectrum of Hydra-A (Taylor et al 1996)



Where next?

There are at least 20 BCGs with cores >15mJy at 90-115GHz that could be observed in almost any conditions to search for CO(1-0) absorption.

We have a pending ALMA proposal in to observe these sources plus the three existing CO(2-1) detections to provide the first comprehensive census for CO absorption for a sample with 18 with an HI detection or limit.

WATCH THIS SPACE….!

Conclusions

We are entering an era where we can determine the mechanics of “Cold Accretion” from the macroscopic (emission) to the microscopic (single cloud absorption) scales.