Carbon radio recombination lines in extragalactic sources

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Key Science of Extragalactic CRRLs

- relative abundance of neutral gas phase (large population of sources)
- density, temp, pressure of cold gas
- transition from HI to H_2
- contributions to [CII] cooling line

First we need to make an extragalactic inventory!

EXTRAGALACTIC SURVEY

TYPES OF OBJECTS

STARBURSTS
COMPTON THICK AGN
COMPACT (CSS) RADIO AGN
MERGERS / ULIRGS
INFLOWS/OUTFLOWS

SURVEY SPECIFICATIONS

TIER-1 HBA SURVEY
8 HOURS/POINTING
NORTHERN SKY

S(150 MHZ) > 1 JY
PEAK TAU < 10^{-3} (10 LINES)
100s OF OBJECTS

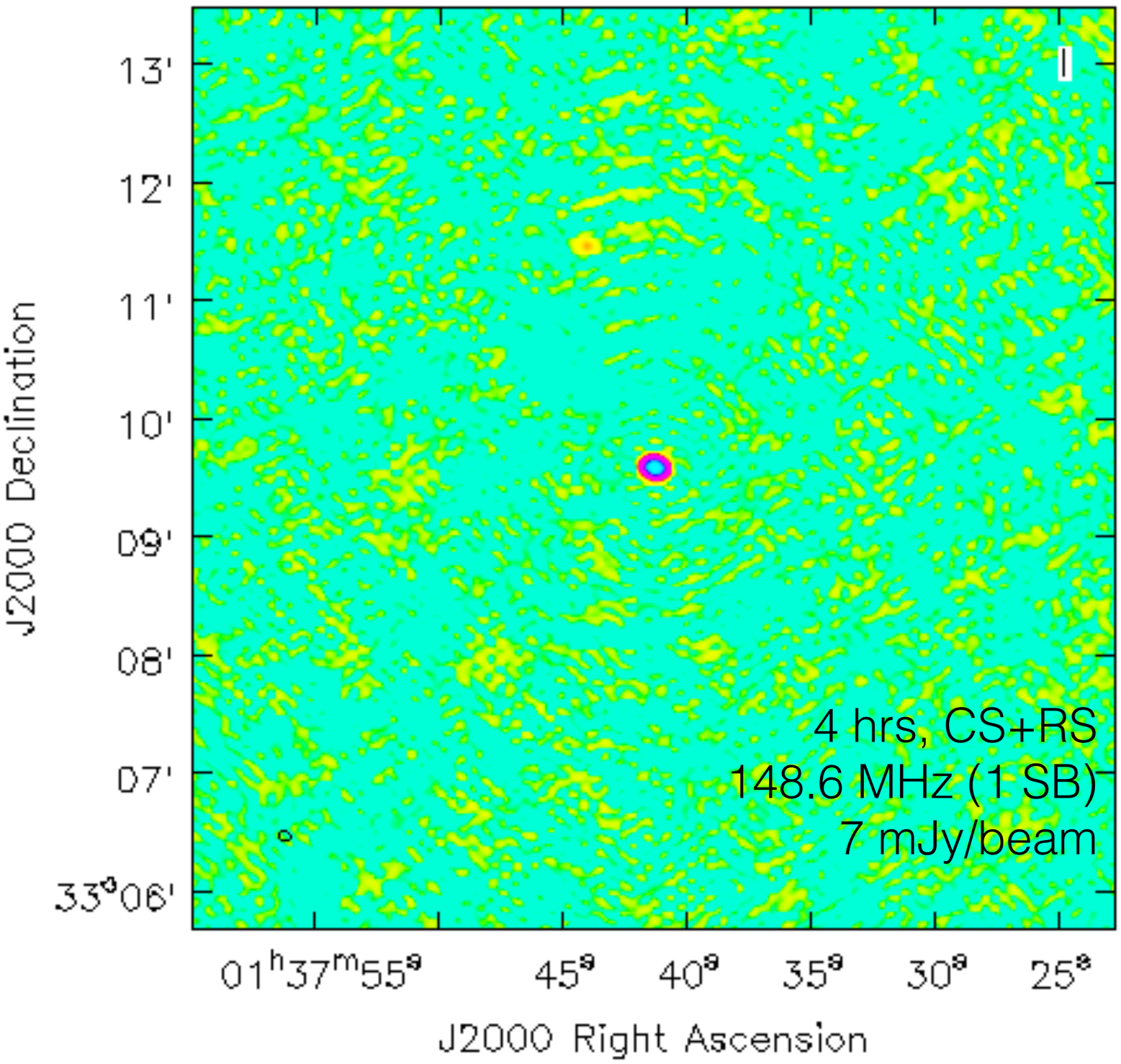
3C 48

calibrator
S(150MHz) ~ 65 Jy

z = 0.367
ULIRG (high far-IR)
CO detected (Scoville+ 1993)
I(CO(0-1)) = 2.4 K km/s

HBA:
10hr, 110-190 MHz
~60 Cα lines

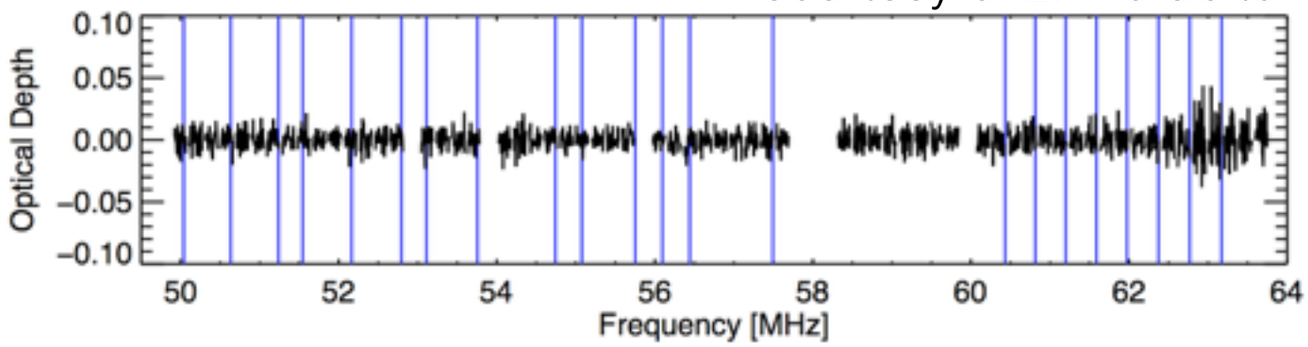
LBA:
6 hr, 30-78 MHz
~300 Cα lines



Understanding our spectra

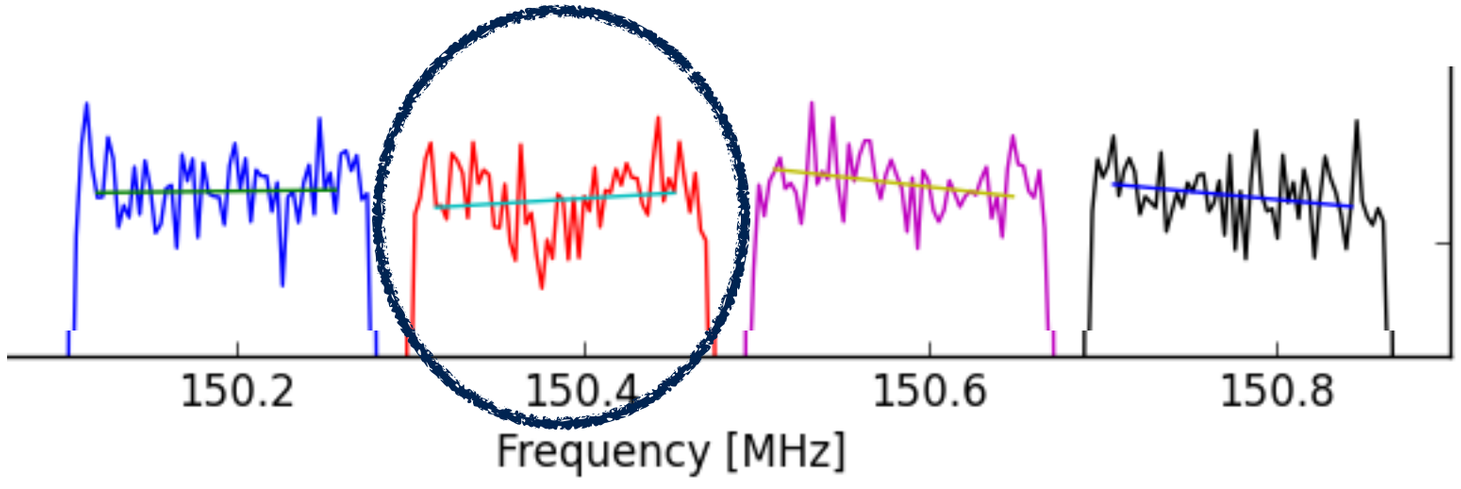
M82 LBA spectrum

courtesy of L. Morabito

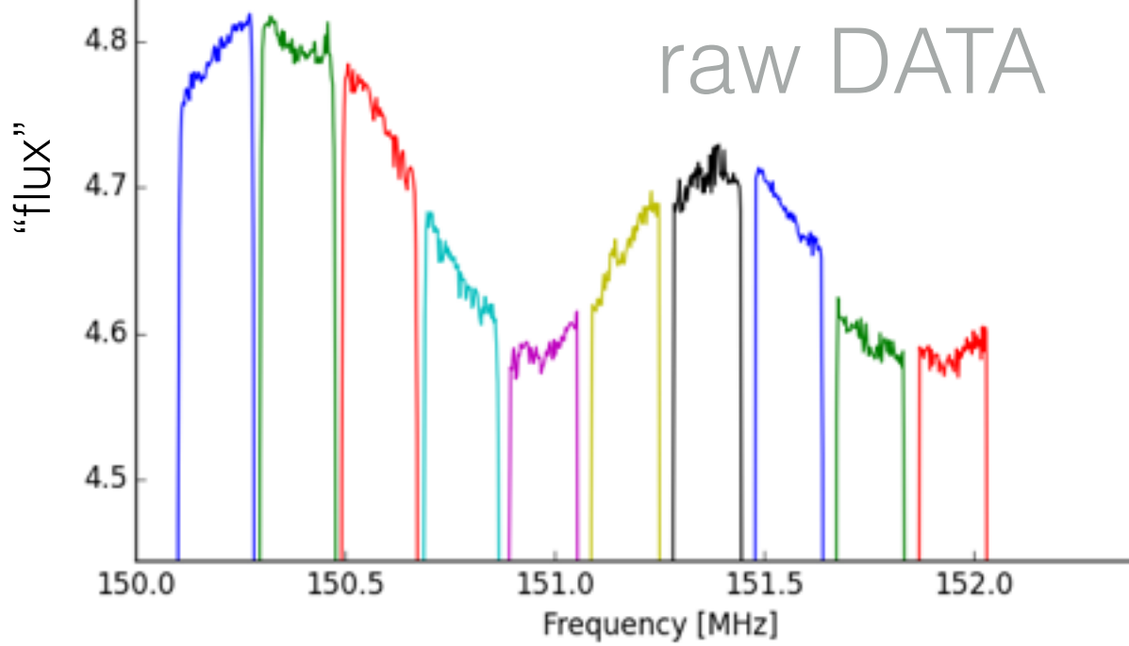


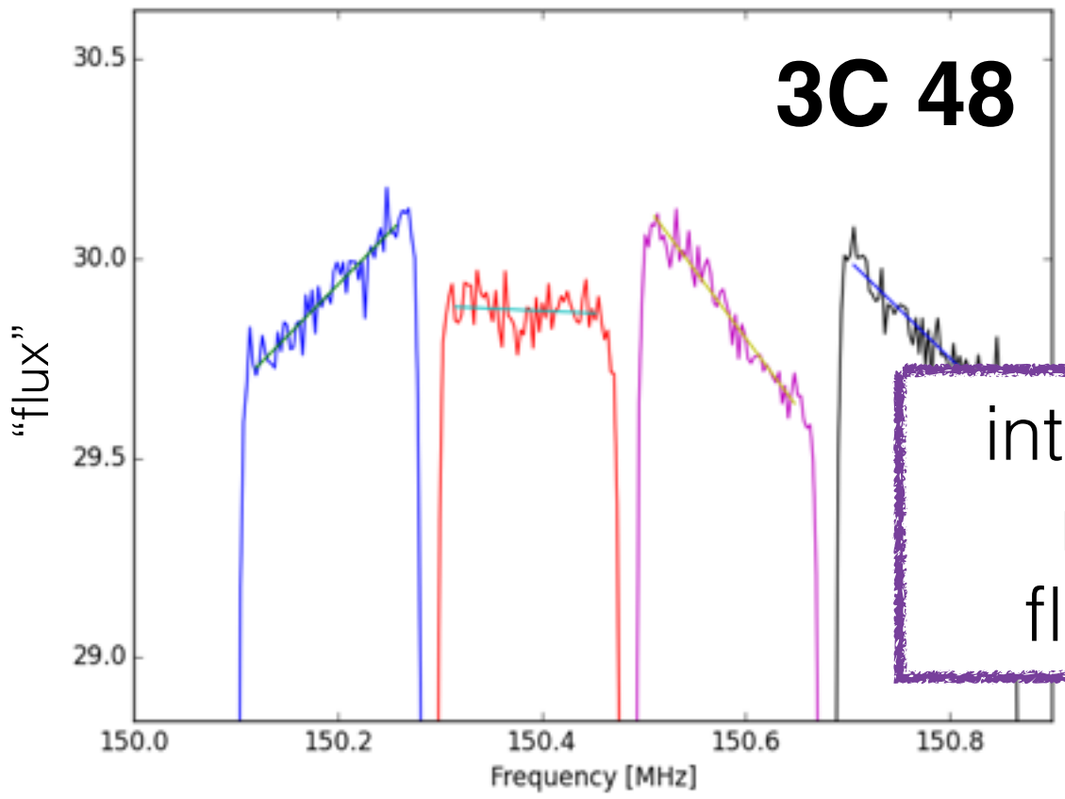
- subbands fit with 1 or 2 D polynomials

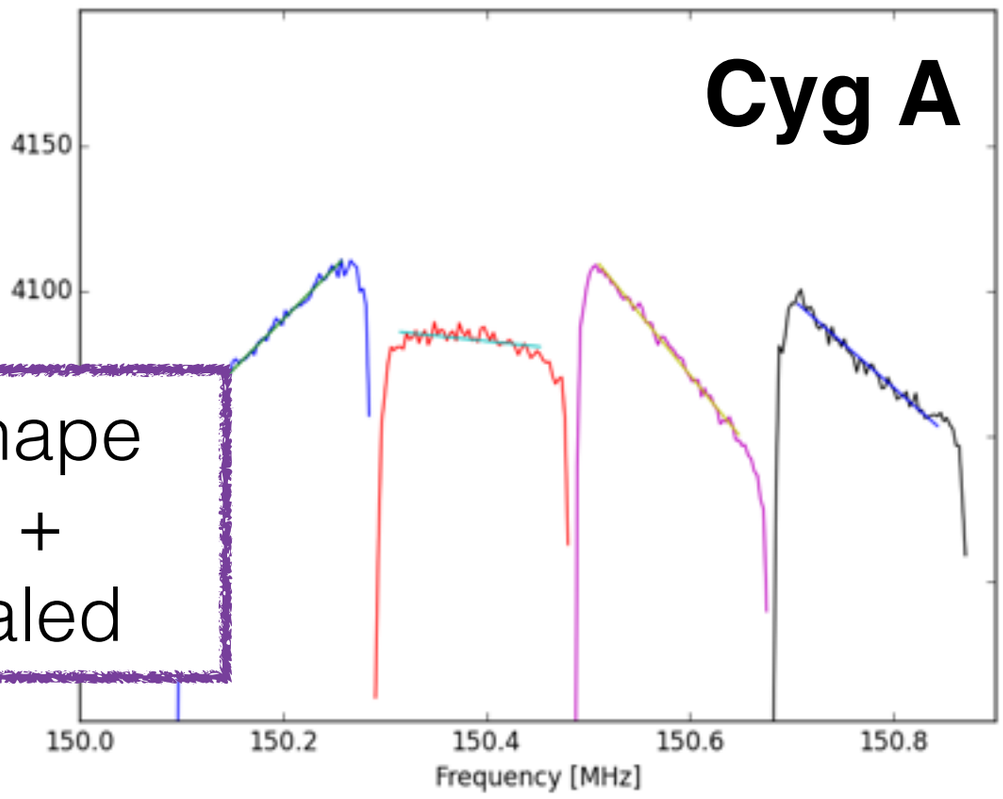
- evidence of larger scale features?



Sub-Bandpass Response







intrinsic shape remains + flux rescaled

Data reduction strategy

solve amp + phase
1 channel /SB
CS only

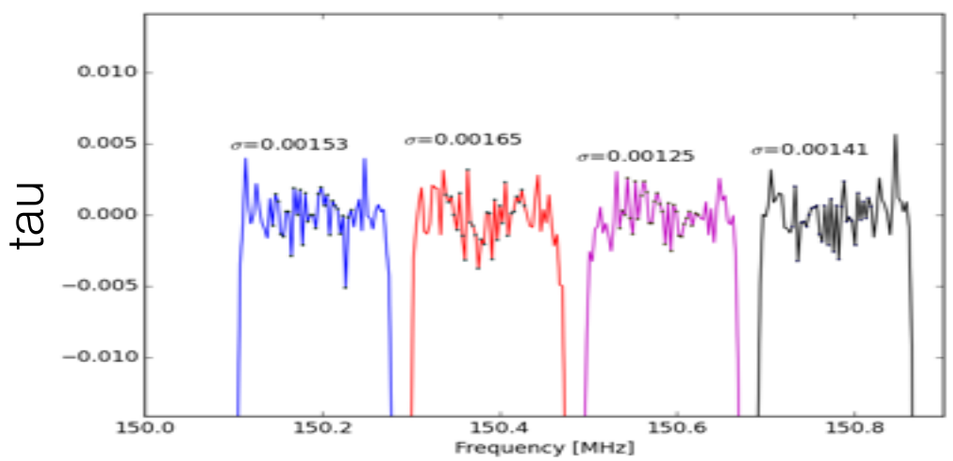
→ apply to unaveraged SB (64 channels/SB)

→ image each channel

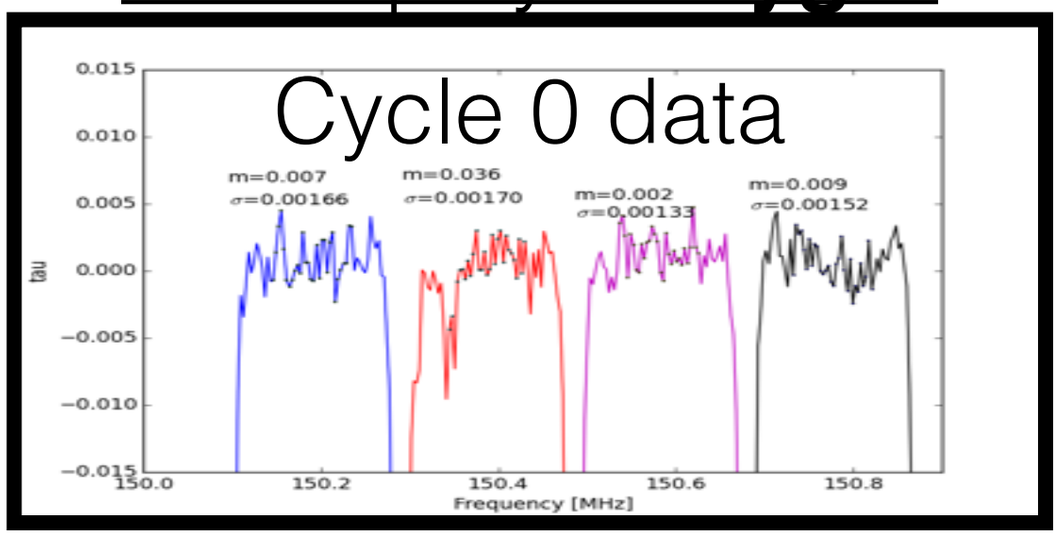
→ extract flux to create spectrum

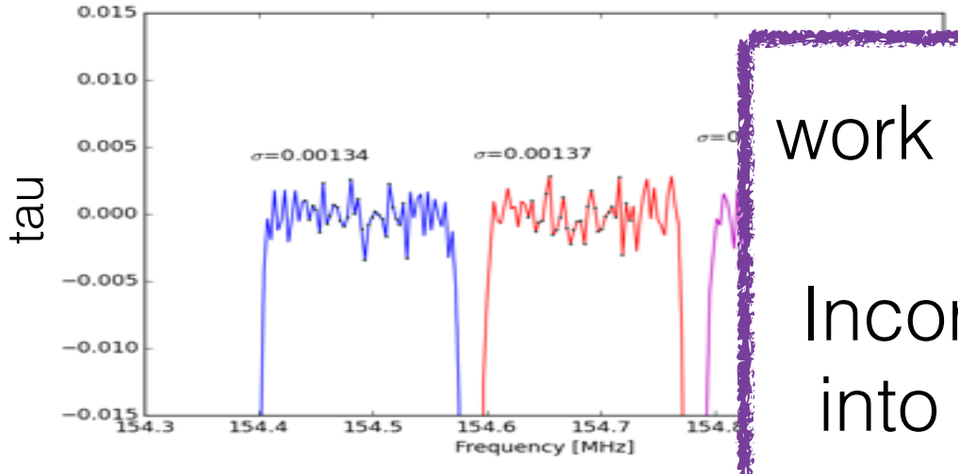
3C 48 Spectra

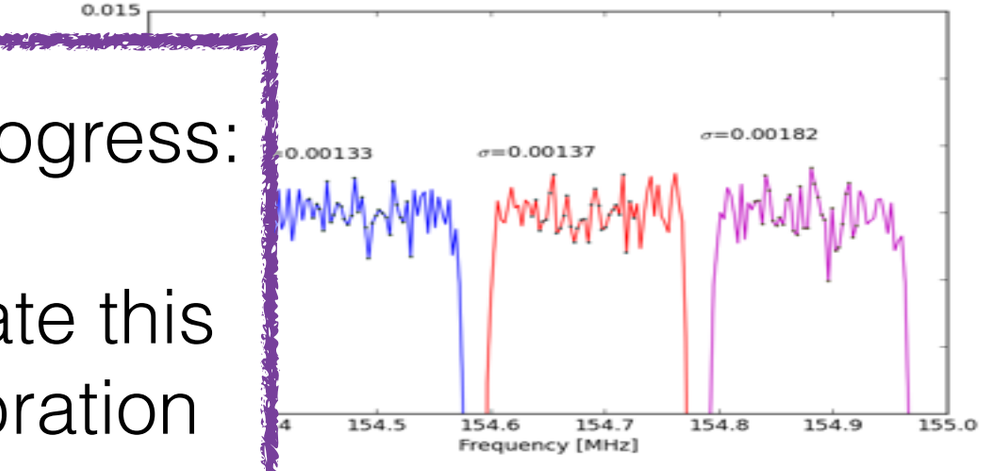
Fit 1D poly



Fit 1D poly to **Cyg A**

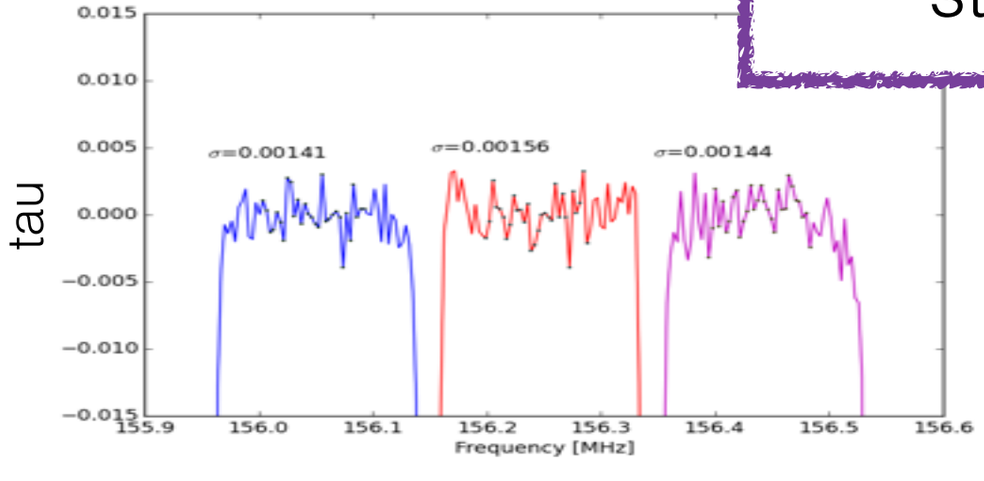


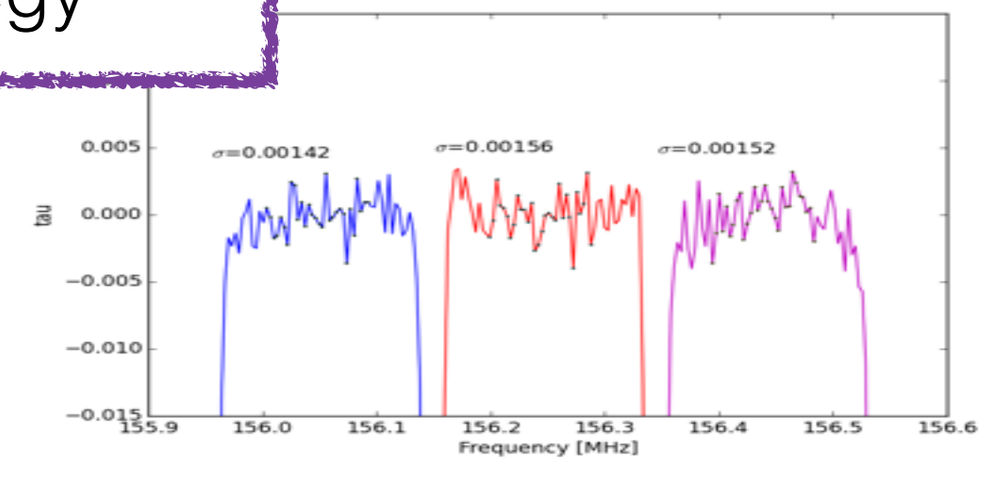




work in progress:

Incorporate this into calibration strategy

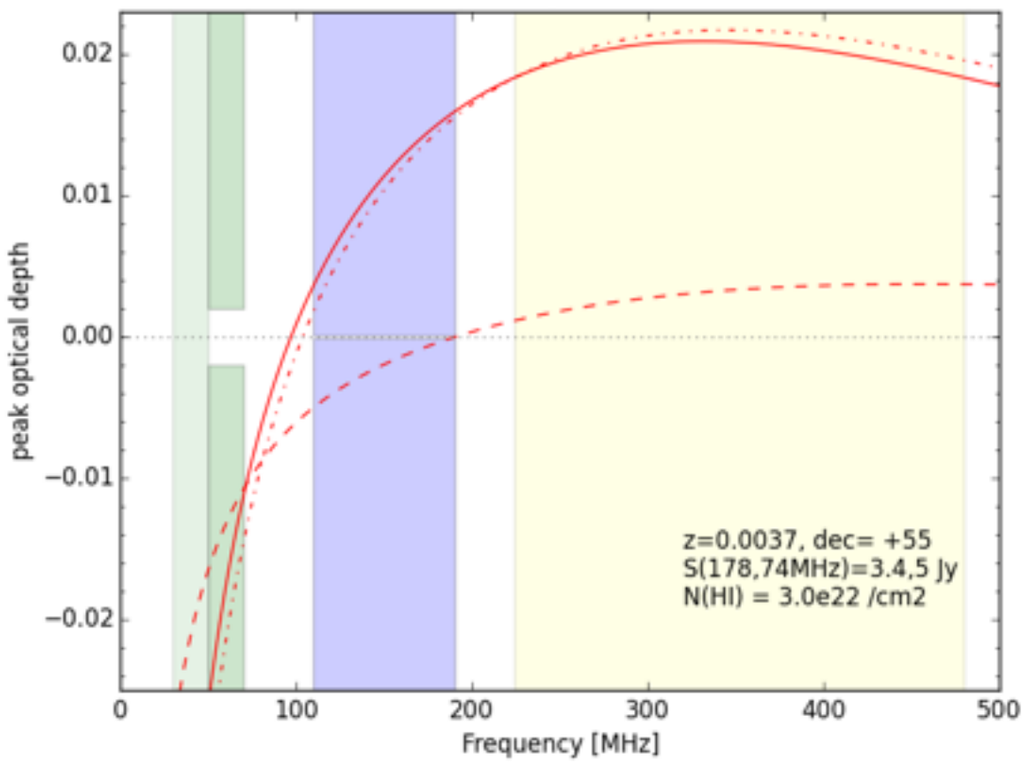




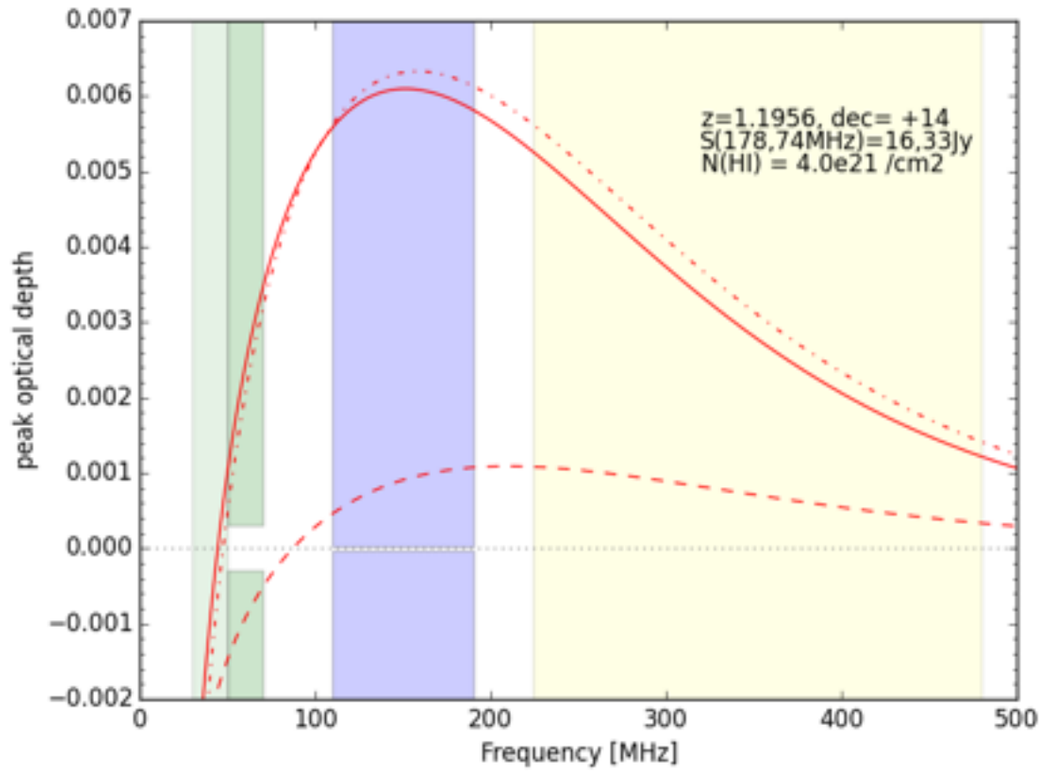
PILOT SURVEY SHORT LIST

ID	z	dec[°]	N(HI)[cm^{-2}]	S(178,74)[Jy]	galaxy	nucleus
3C 190	1.20	+14	4E+21	16, 33	merger	QSO,CSS
NGC 3079	0.004	+55	3E+22	3.4, 5	edge-on spiral	Comp Th
3C 236	0.101	+34	5E+20	11, 10.7	starburst	Giant, CSS
ARP 299	0.010	+59	3.1E+21	2, 3.2	merger	Comp Th
4C +29.30	0.065	+30	4.7E+21	2, 5	elliptical	CSS
NGC 3628	0.003	+14	2.1E+22	1, 1.9	spiral, outer dust lane	Sy?
3C 293	0.045	+31	1.5E+21	14, 30	MOHEG	FRI
4C +12.50	0.122	+12	2.6E+21	4.6	ULIRG	CSS
B2 0902+34	3.38	+34	4.4E+20	2.0	HyLIRG/ proto-elliptical	HzRGs
NGC 6240	0.025	+02	1.3E+22	2.1	ULIRG	(2) LINER, Comp Th

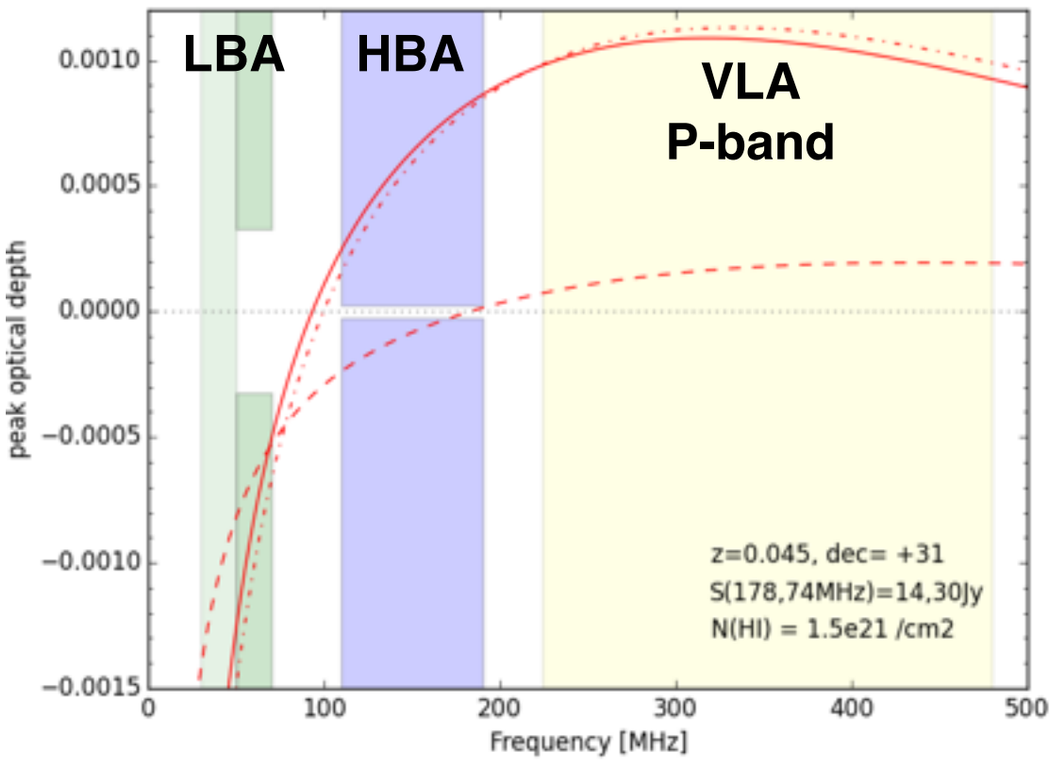
NGC 3079



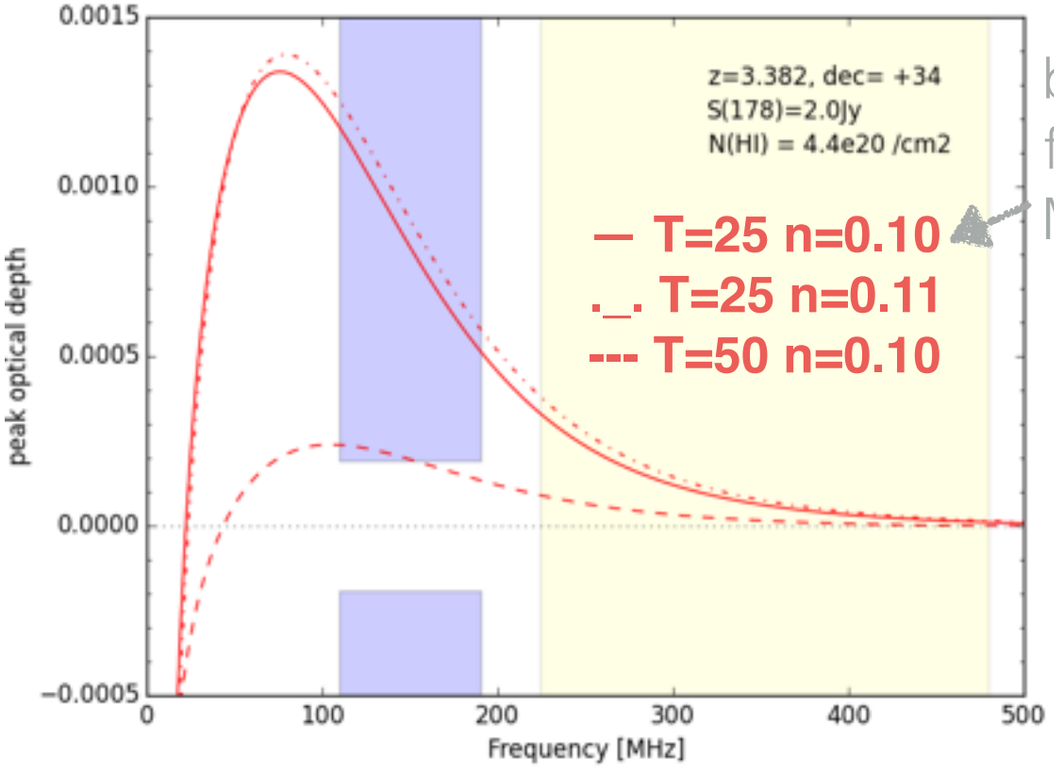
3C 190



3C 293



B2 0902+34



3C 190

z = 1.195
S(150 MHz) ~19 Jy

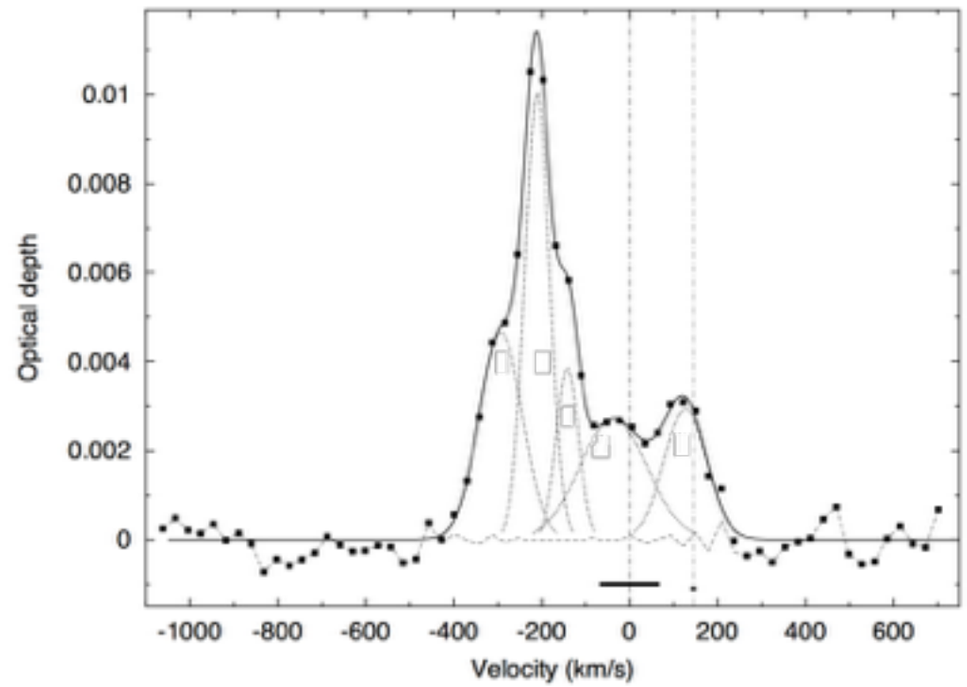
CSS (~ 4”)
hotspots 22 kpc apart

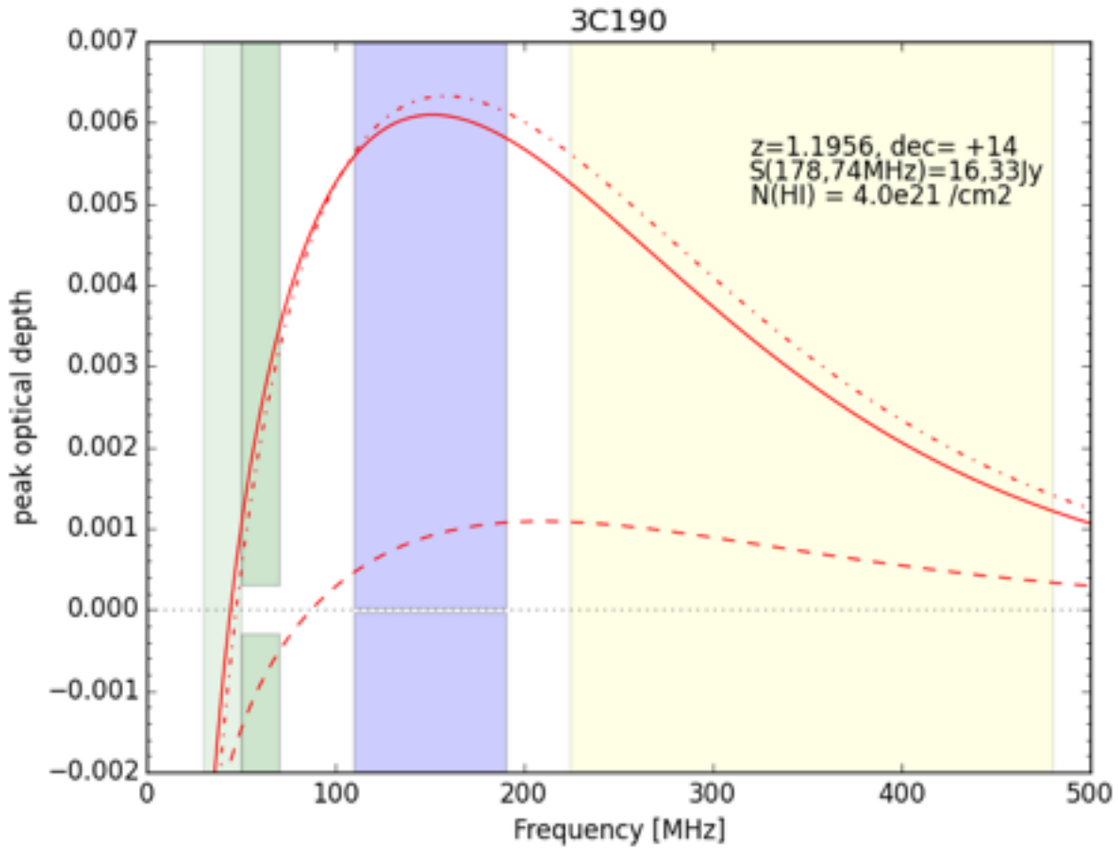
evidence of recent or current merger

HI absorption:
most narrow feature
  delta v = 60 km/s
  tau_peak = 0.01
  N(HI) = 4e21 /cm2

HBA+LBA proposed

H I absorption
Ishwara-Chandra + 2013





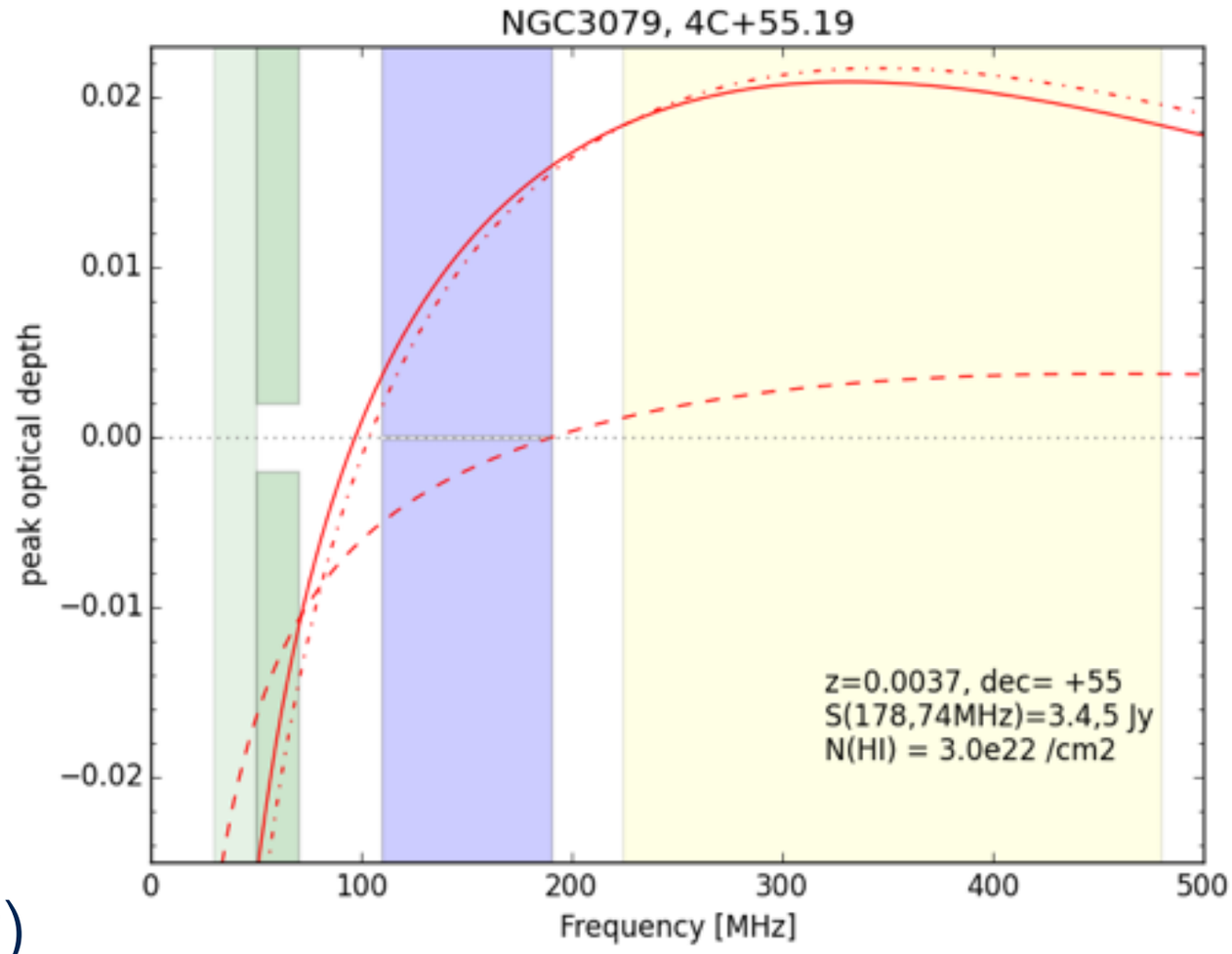
NGC 3079

z = 0.0037 (~20 Mpc)
S(150 MHz) ~ 4 Jy

edge-on spiral
interaction with nearby companion
Seyfert 2
Compton Thick (N(H) ~ 1e25 /cm2)

CO disk of emission from r=100-400pc
HI absorption
  2 narrow peaks, delta v ~ 140 km/s
  tau_peak = 0.8 (+ optically thick)
  N(HI) = 3e22 /cm2

HBA observations (PI: Eskil), LBA proposed



3C 293

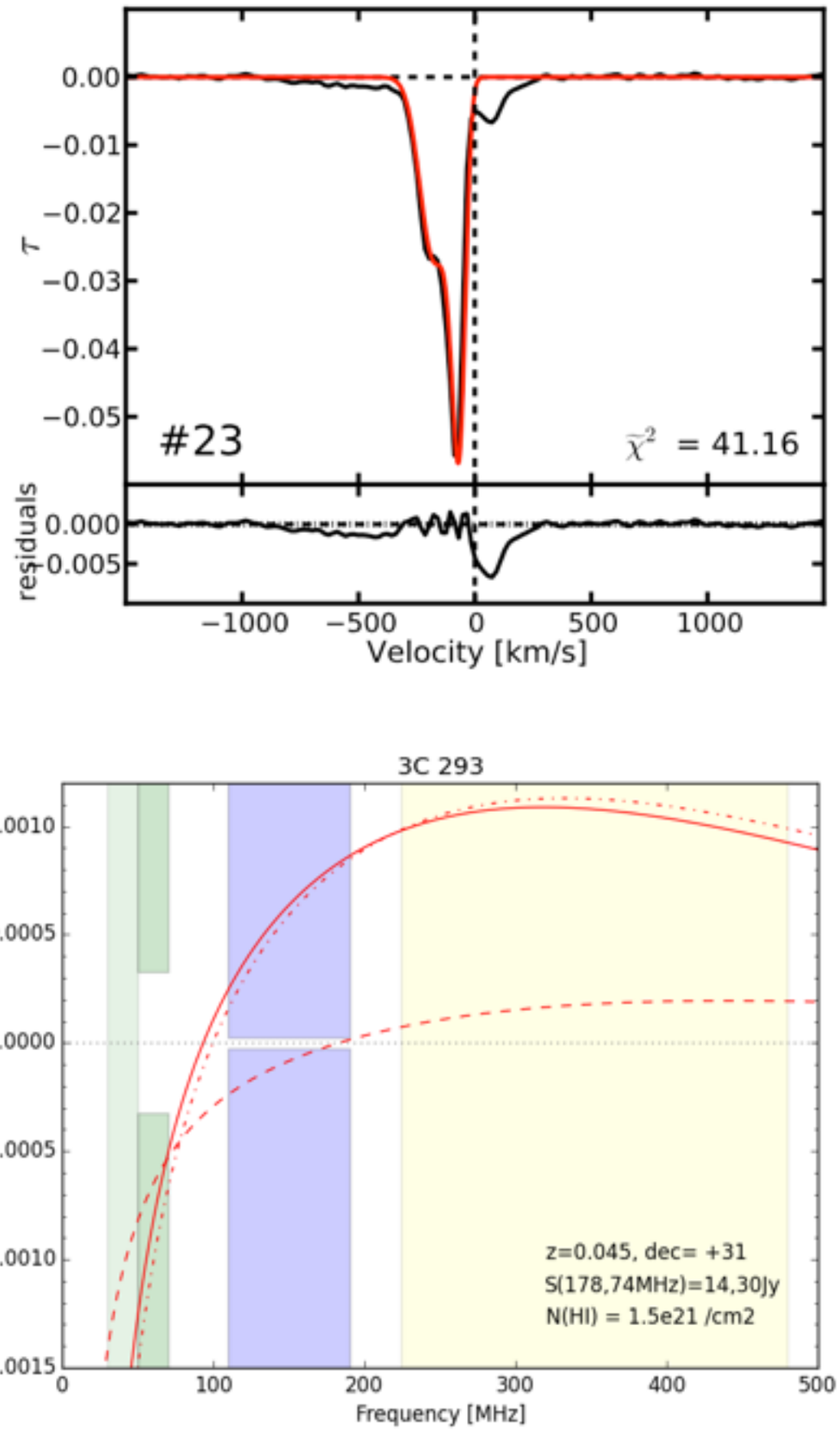
z = 0.045
S(150 MHz) ~ 15 Jy

double-double radio galaxy
jet-driven fast outflow

mid IR H2 rotational line detection
CO emission in central ~6 kpc
(Evans+ 1999)
HI absorption (Gereb+ 2015)
  delta v = 100 km/s
  tau_peak = 0.057
  N(HI) = 1.5e21 /cm2

HBA (to be taken April, PI: Brienza)

HI absorption (Gereb+ 2015)



Conclusions

RRL will provide an unprecedented probe
of cold gas in galaxies

developing calibration strategies
to process via pipeline

3C 190, NGC 3079, 3C 293
are the best extragalactic candidates to search