Lessons from Low-Frequency Spectral Line Observations

Jeremy Darling

(CASA, University of Colorado)

Low Energy Excitation

Case Studies:

- **Formaldehyde absorption of the CMB**
- **HI 21 cm and OH 18 cm Line Surveys**

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Kyle Willett (Colorado)*
Ting Yan (Colorado)
Benjamin Zeiger (Colorado)

General Concerns: Low Energy Lines

Low energy (frequency) transitions are slow ($A_{ij} \propto \nu^3$)

⇒ Metastable states are common

Slight imbalances in rates of higher energy transitions lead to large nonthermal populations in low energy states

(Boltzmann factors for low-energy states are 1-ε thanks to ≥ 2.73 K radiation field)

Pumping cycles are not intuitive and rely on the detailed structure of many states and the rates connecting them (A_{ij}, C_{ij})

Lyα pumping of 21 cm line ("easy")

H_2 collisional pumping of H_2CO (medium)*

IR pumping of OH (difficult)*

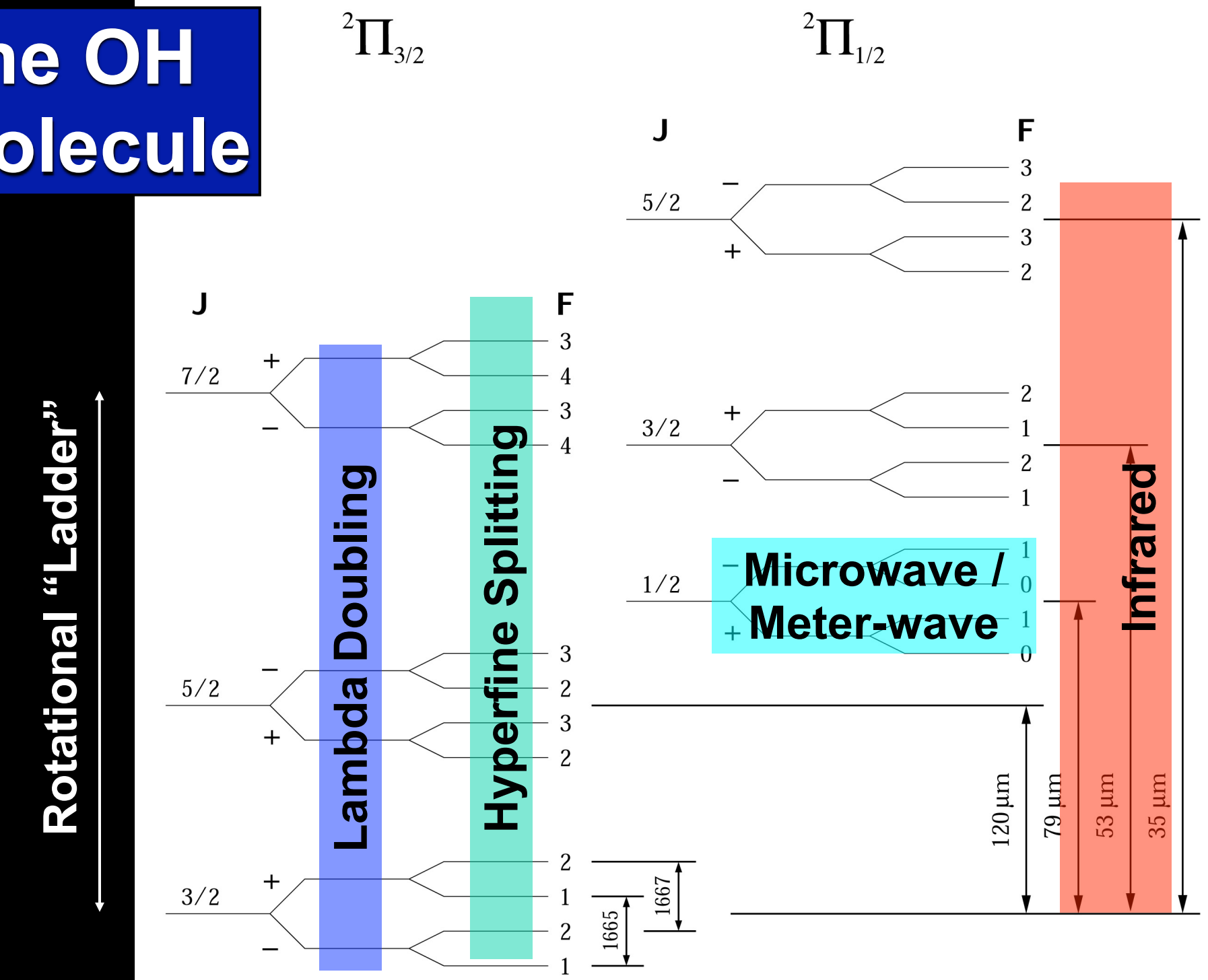
We simply do not know what bright maser or other nonthermal lines will appear at low frequencies

Foregrounds for HI 21 cm

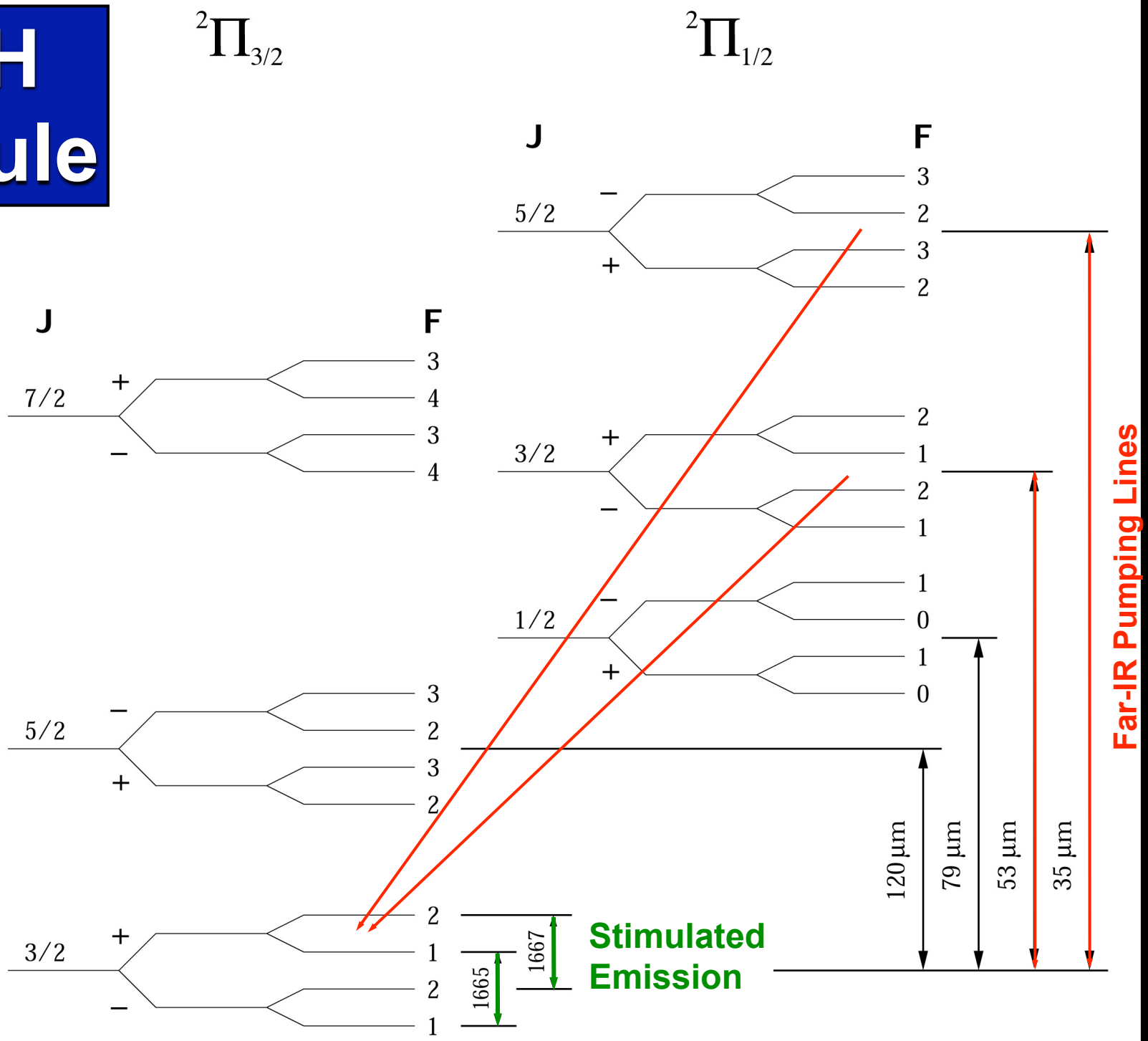
Science

* Was *not* predicted.

The OH Molecule



The OH Molecule



Galactic H_2CO

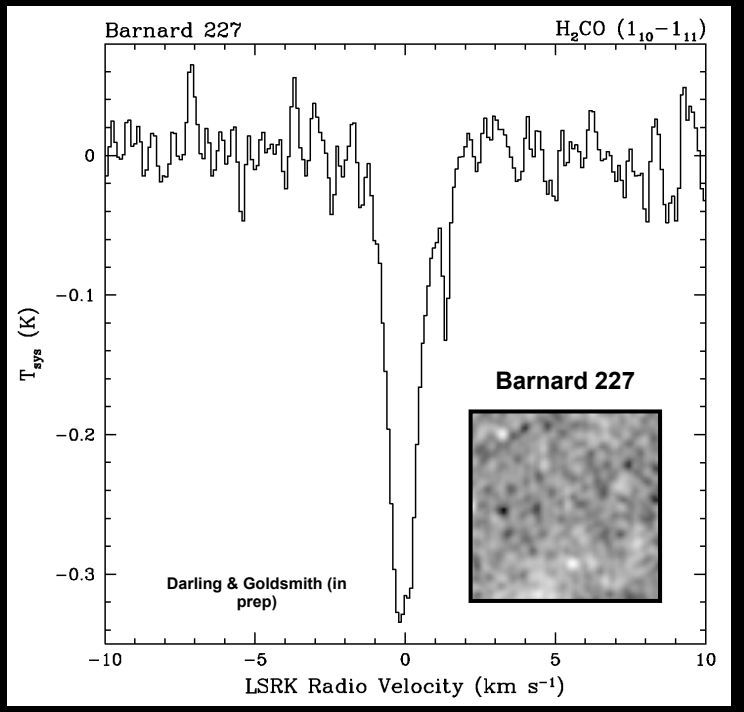
Dark Clouds:

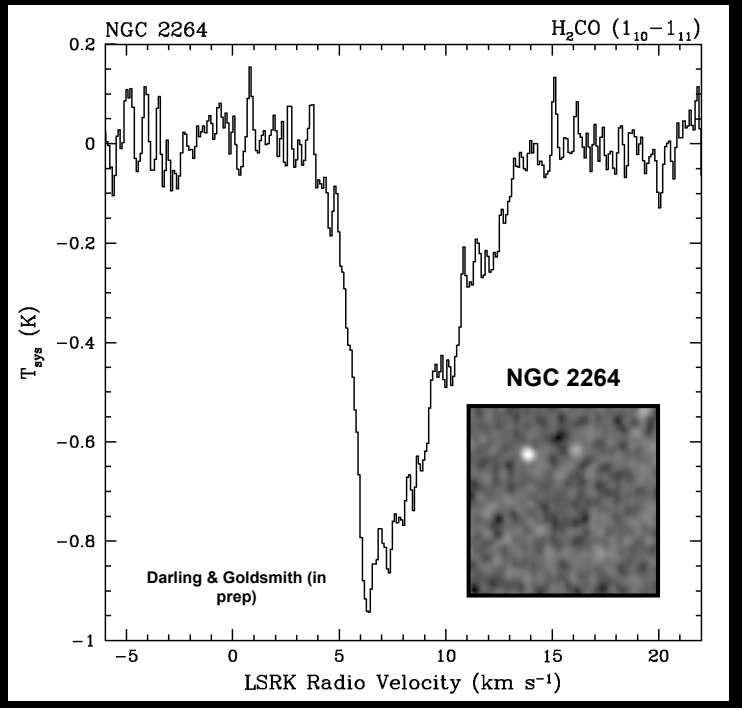
- "Anomalous" H_2CO absorption

  (e.g. Palmer *et al*. 1969)

- Absorption in multiple cm lines

- No radio continuum source!





H_2CO: The DASAR

L ight (**M**icrowave)
A mplification by
S timulated
E mission of
R adiation

Inversion:
"Heating" of lines
$T_x >> T_{kin}$

Pump required:
Chemical, collisional, radiative

D arkness*
A mplification** by
S timulated
A bsorption of
R adiation

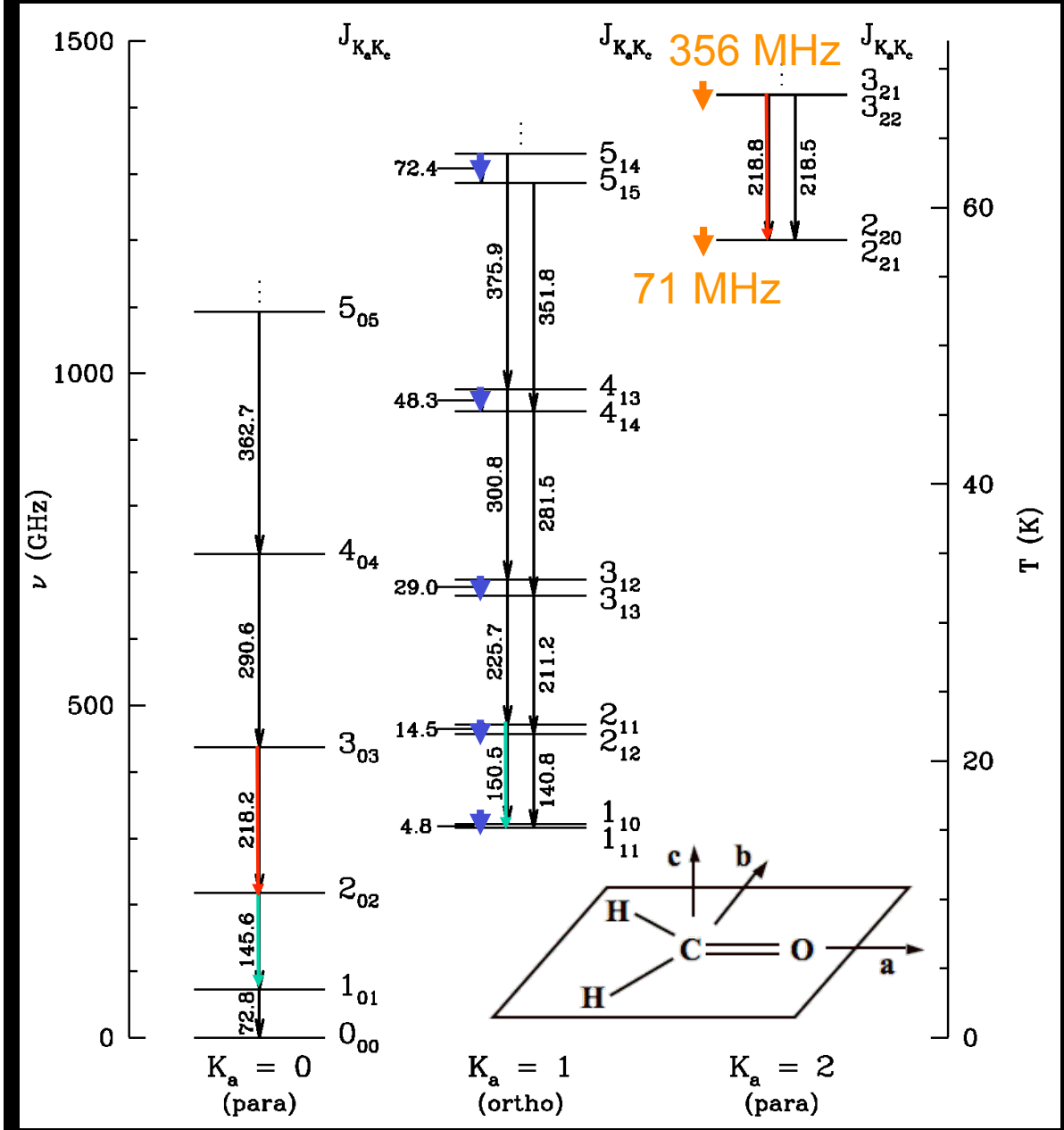
Townes *et al* (1953)

Anti-Inversion:
"Cooling" of lines
$T_x < T_{CMB}$

Pump required:
Collisions with H_2

*Not really dark.
**Not a true amplification.

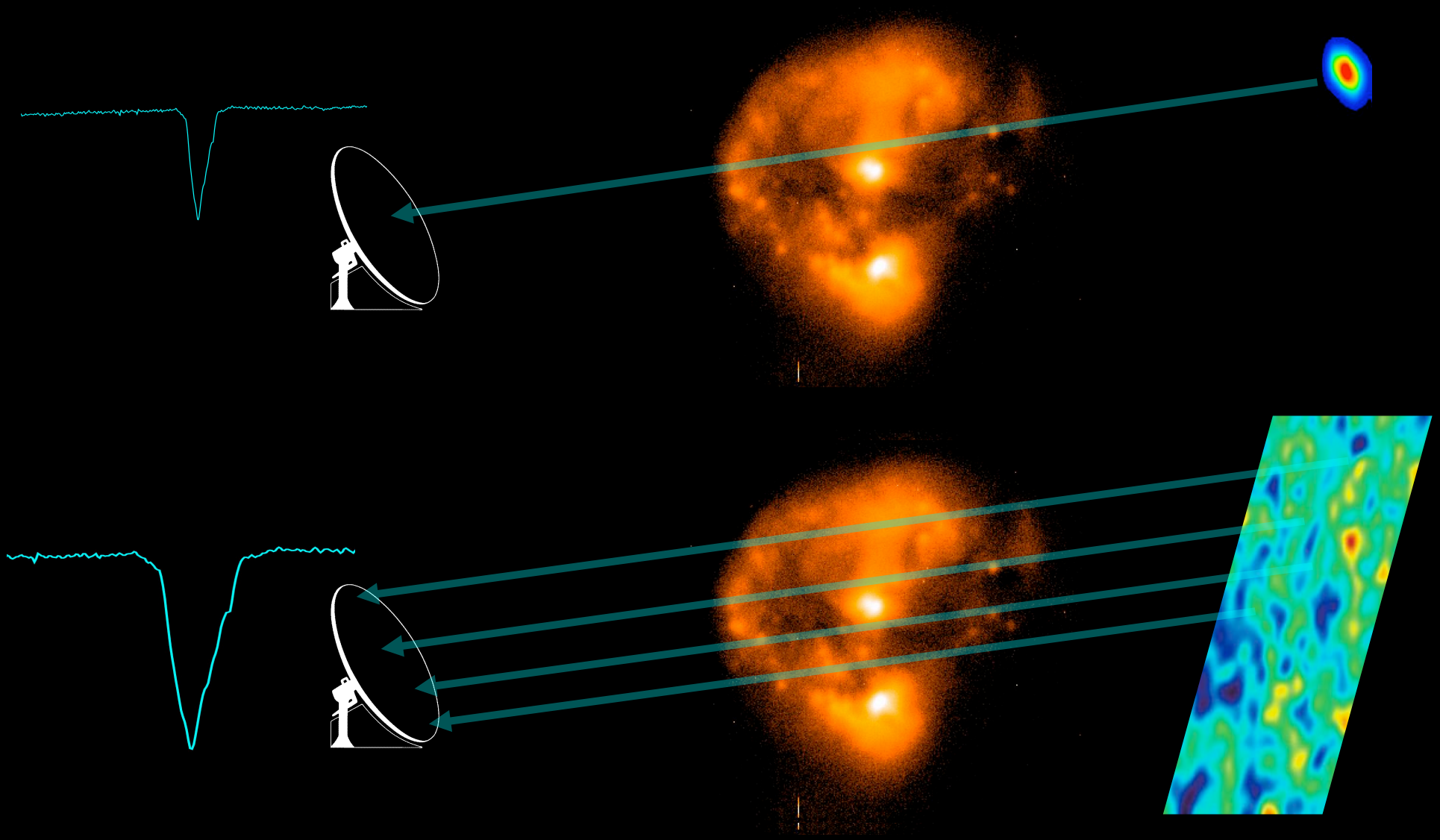
H_2CO Energy Level Structure



- Anti-inverted (cm) line ratios yield $n(H_2)$, nearly independent of T_{kin}. **T_x ~ 1 K**
- Line ratios between species give ortho:para ratio
  ⇒ H_2CO formation channel (hot/cold; gas/dust)
- Line ratios from different K_a ladders of a given species (ortho/para) yield T_{kin}
- Low frequency (m-wave) transitions: T_x ~ 10 mK

$T_{CMB} - T_x \sim T_{CMB} = (1+z)\ 2.73$ K

H_2CO Absorption Against the CMB



H_2CO: The DASAR

The CMB is the ultimate illumination source:

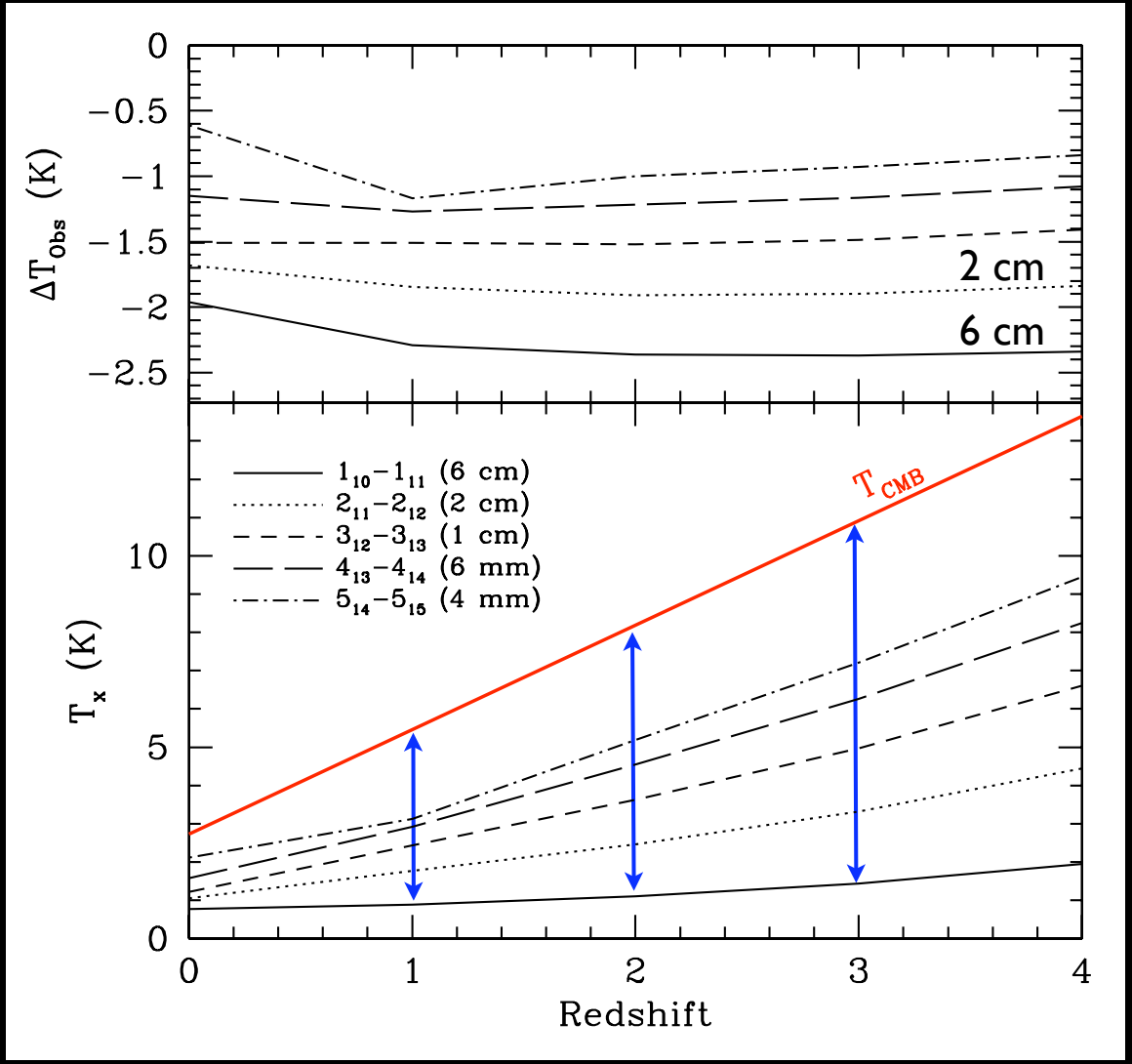
- **Behind everything**
- **Everywhere**
- **Uniform on arcsec scales**

H_2CO absorption against the CMB offers an unrivaled probe of dense molecular gas, independent of redshift!

A H_2CO deep field would produce immediate precise redshifts and positions of a *mass-limited* survey of star-forming galaxies, automatically omitting AGN.

Anti-Inversion versus Redshift

- The rest-frame temperature decrement increases with redshift
- The observed temperature decrement is nearly *independent* of redshift!
- Absorption is redshift-independent



HI 21 cm and OH 18 cm Case Studies
(Absorption and Emission)

Targeted Surveys
- Known targets
- Known redshifts
- Issue is candidate selection

Targeted "Blind" Surveys
- Known targets
- Unknown redshifts
- Issues: candidate selection, bandwidth, RFI
- * How do we know if we have or have not detected something?

Truly "Blind" Surveys
- Unknown targets
- Unknown redshifts
- Issues: areal coverage, bandwidth, RFI, host identification

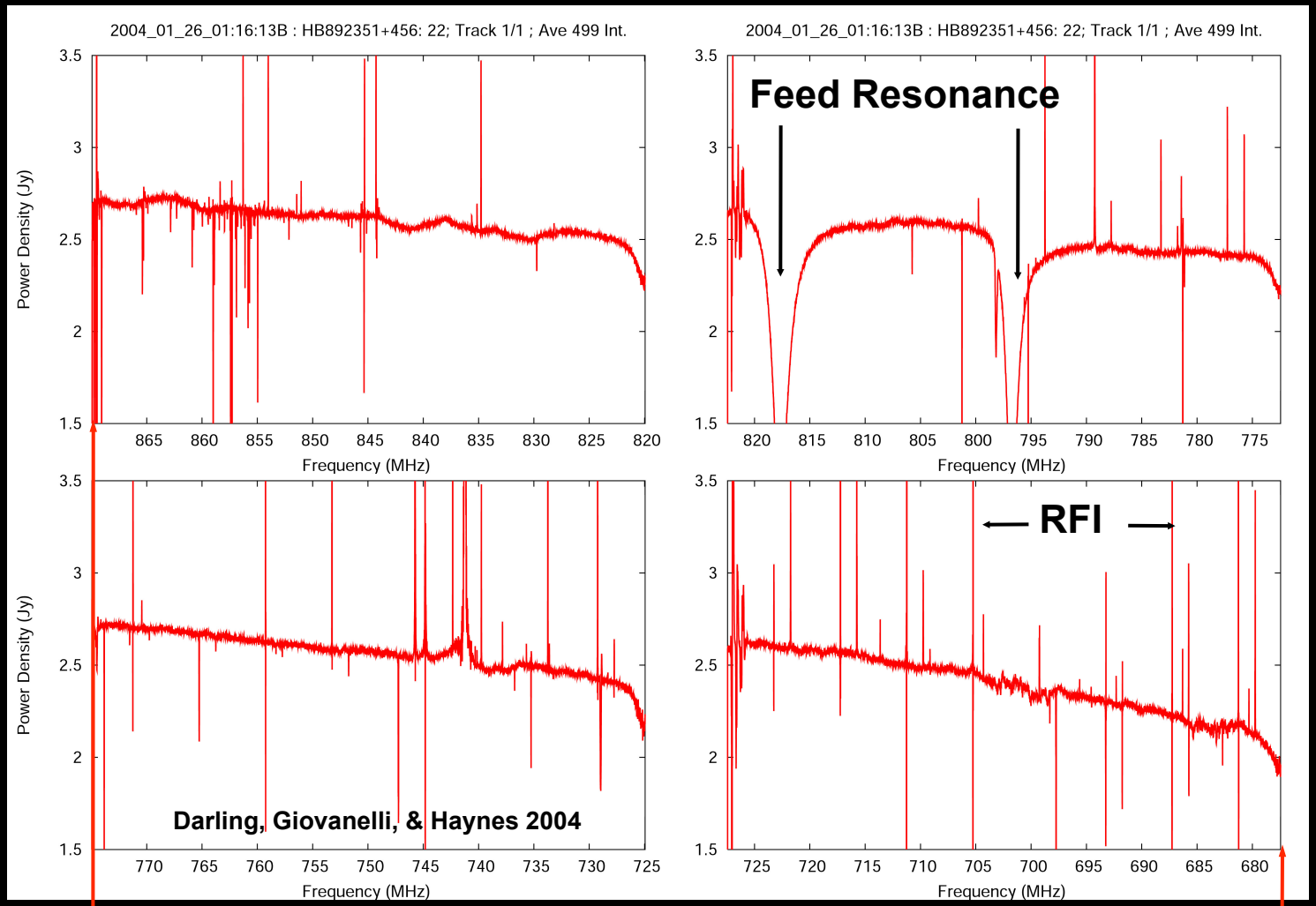
Green Bank Blind HI Survey:

Observe 200 MHz at 800 MHz with 6 kHz (~2 km s^{-1}) resolution

$\lambda / \Delta\lambda$ **= 132,000**

BW/λ **= 0.25**

Radio Freq Interference (RFI) is problematic and reduces z coverage

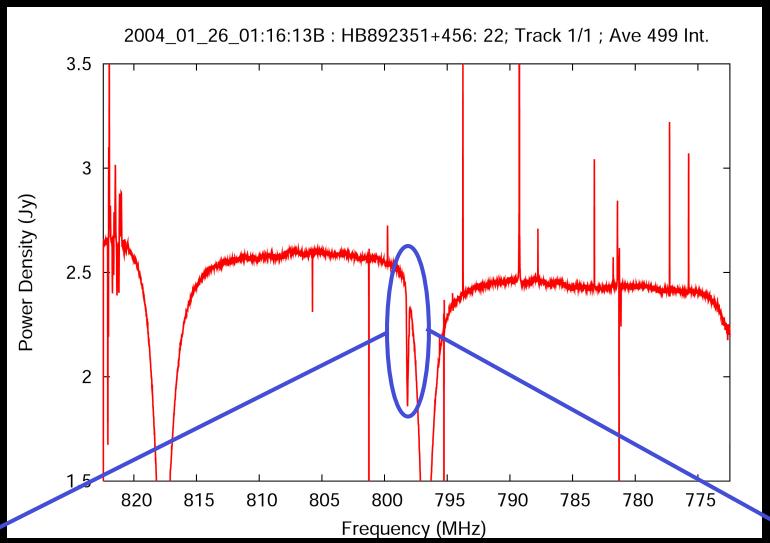


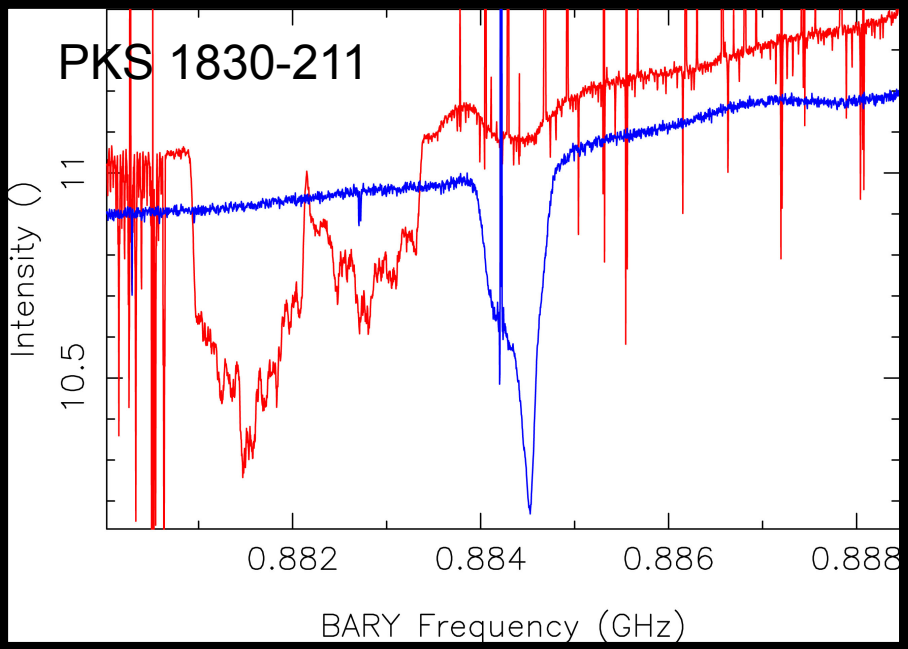
z = 0.63
t_l = 5.9 Gyr
t_U = 7.8 Gyr

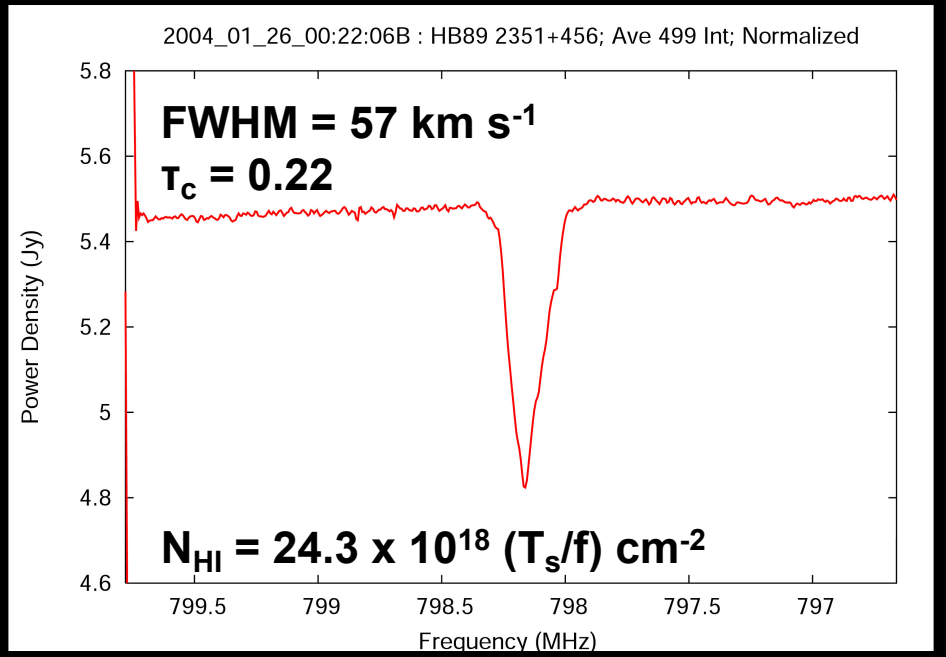
2.2 Gyr, 1.2 Gpc

z = 1.1
t_l = 8.1 Gyr
t_U = 5.6 Gyr

The Search for Molecular Absorbers



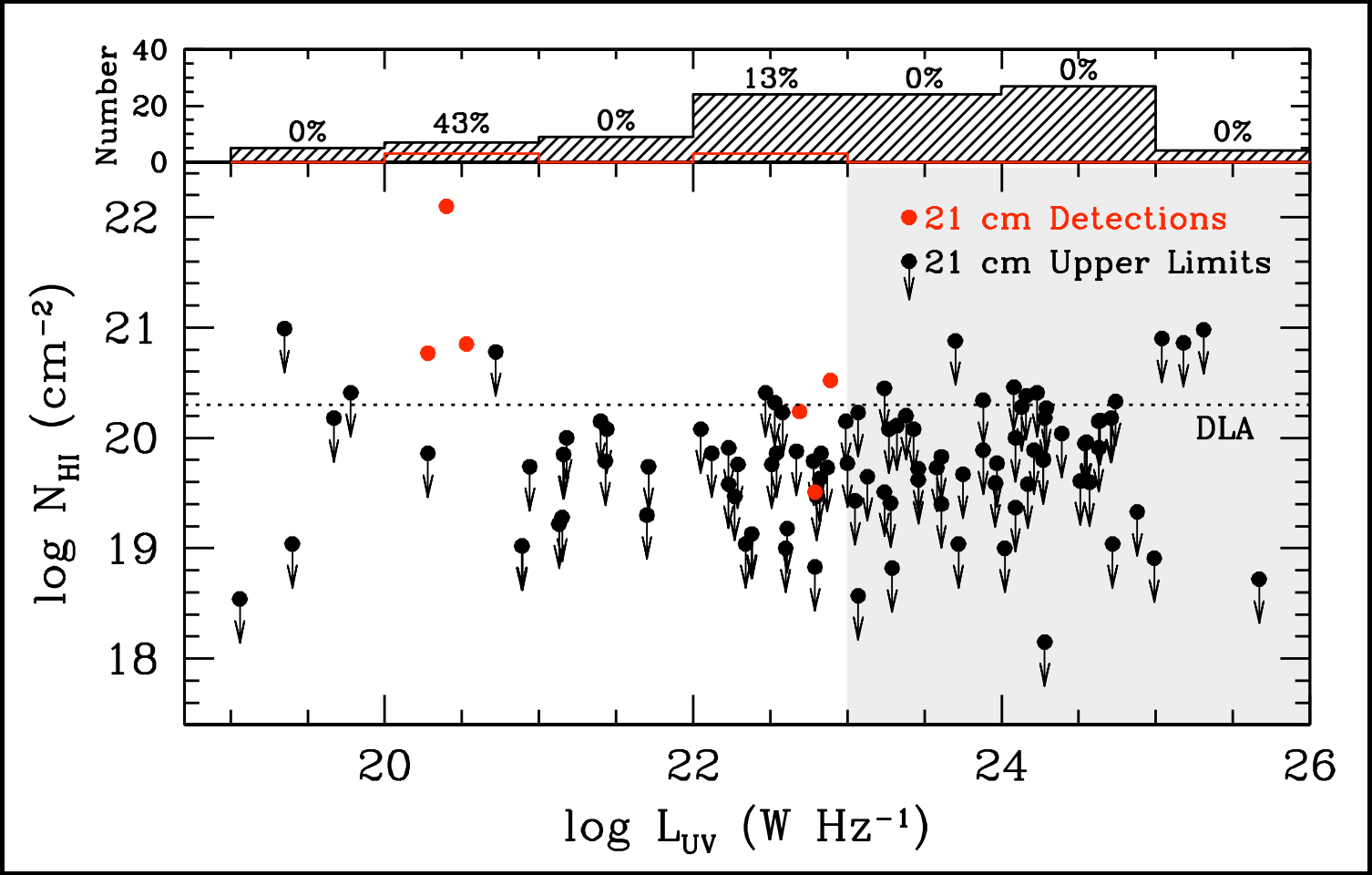




A Proximity Effect on HI Absorption

Survey of 107 compact radio sources for intrinsic HI absorption:

- Detection rate depends on UV luminosity
- UV luminosity threshold depends on radio source size



* See Grasha poster *

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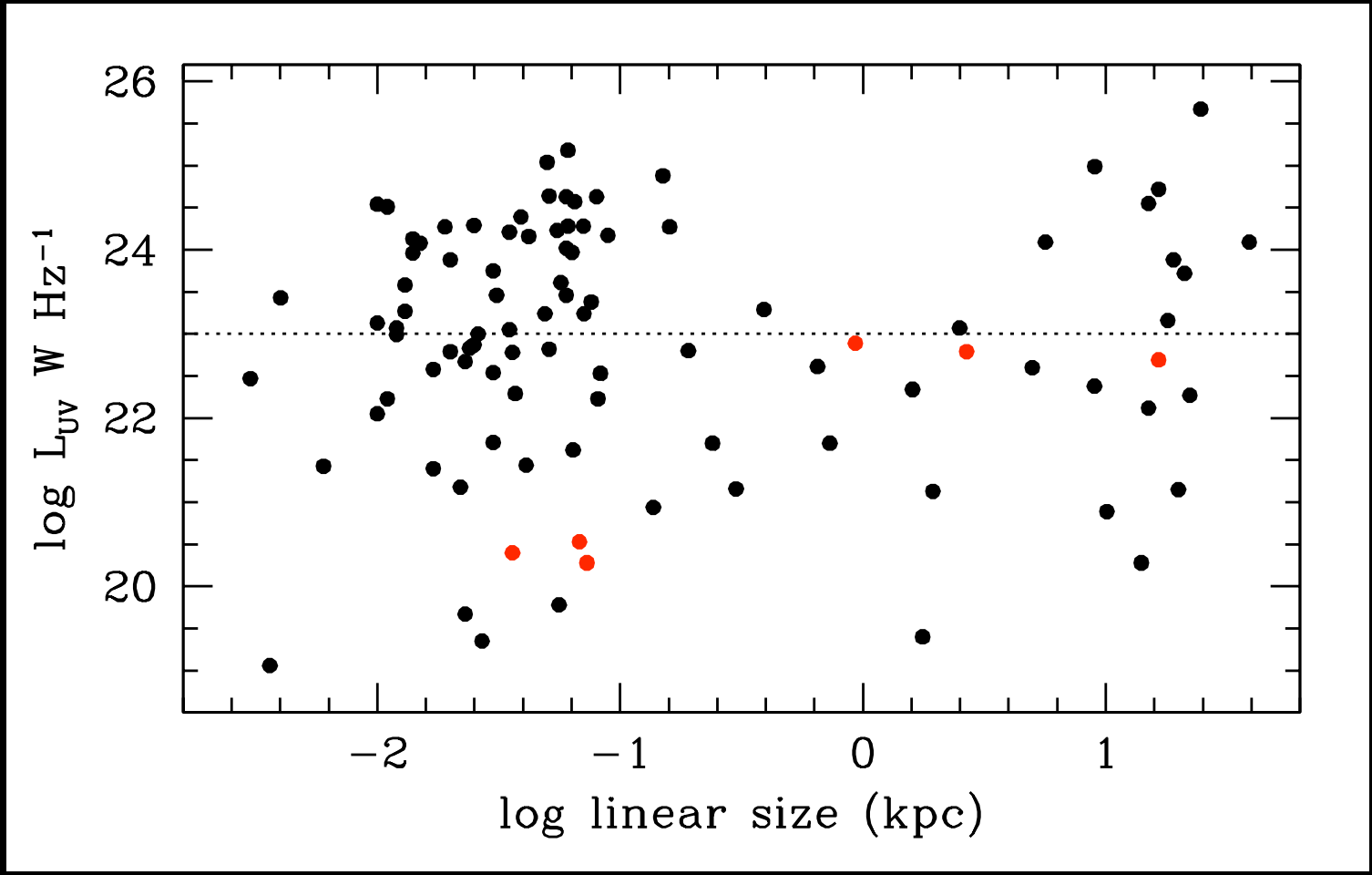
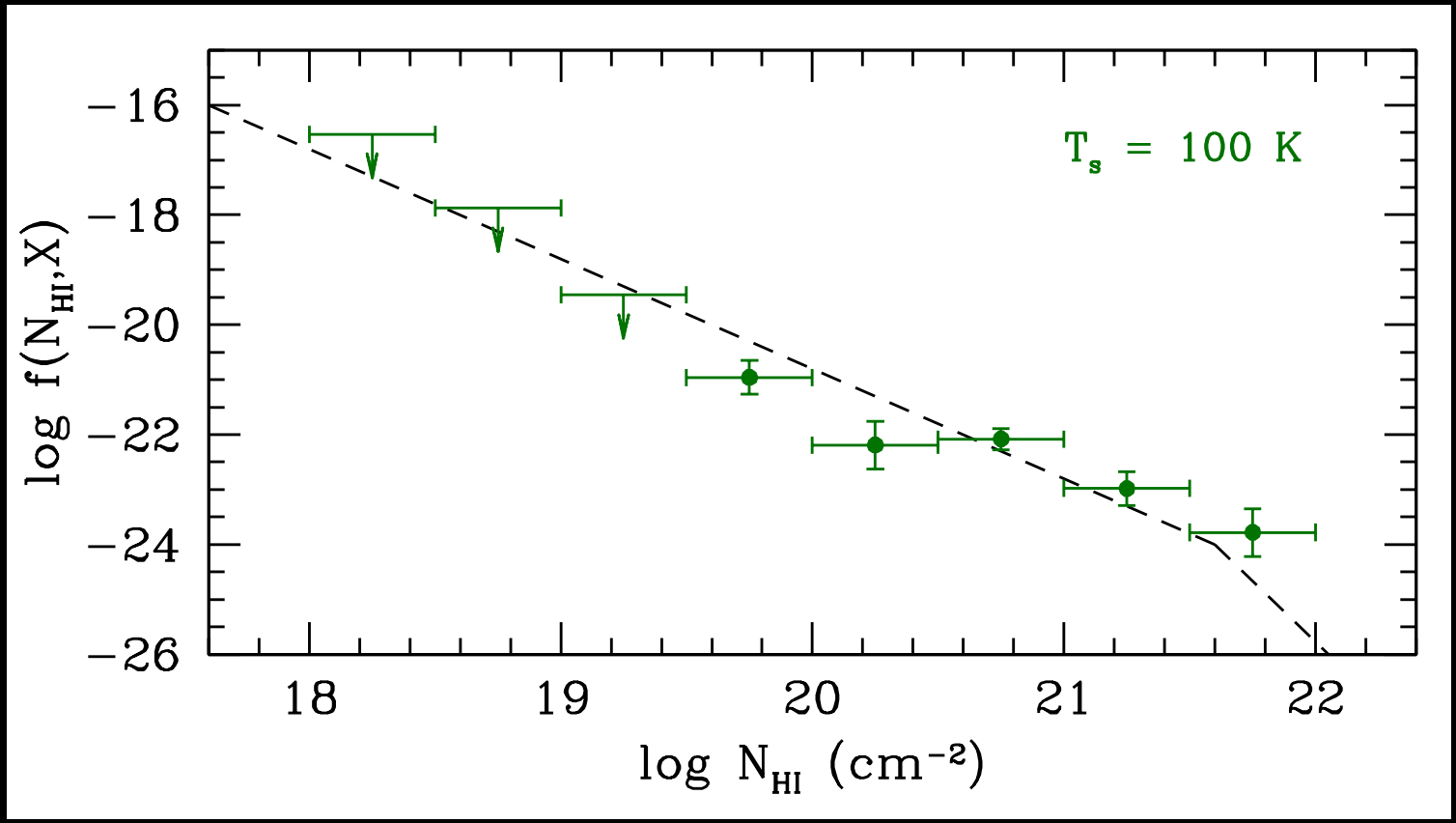


* See Grasha poster *

The Cosmic Distribution of HI

Survey of 186 compact radio sources for intervening HI absorption:

- Obtain the column density distribution function f(N)
- Ultimately we will be able to constrain T_{spin}

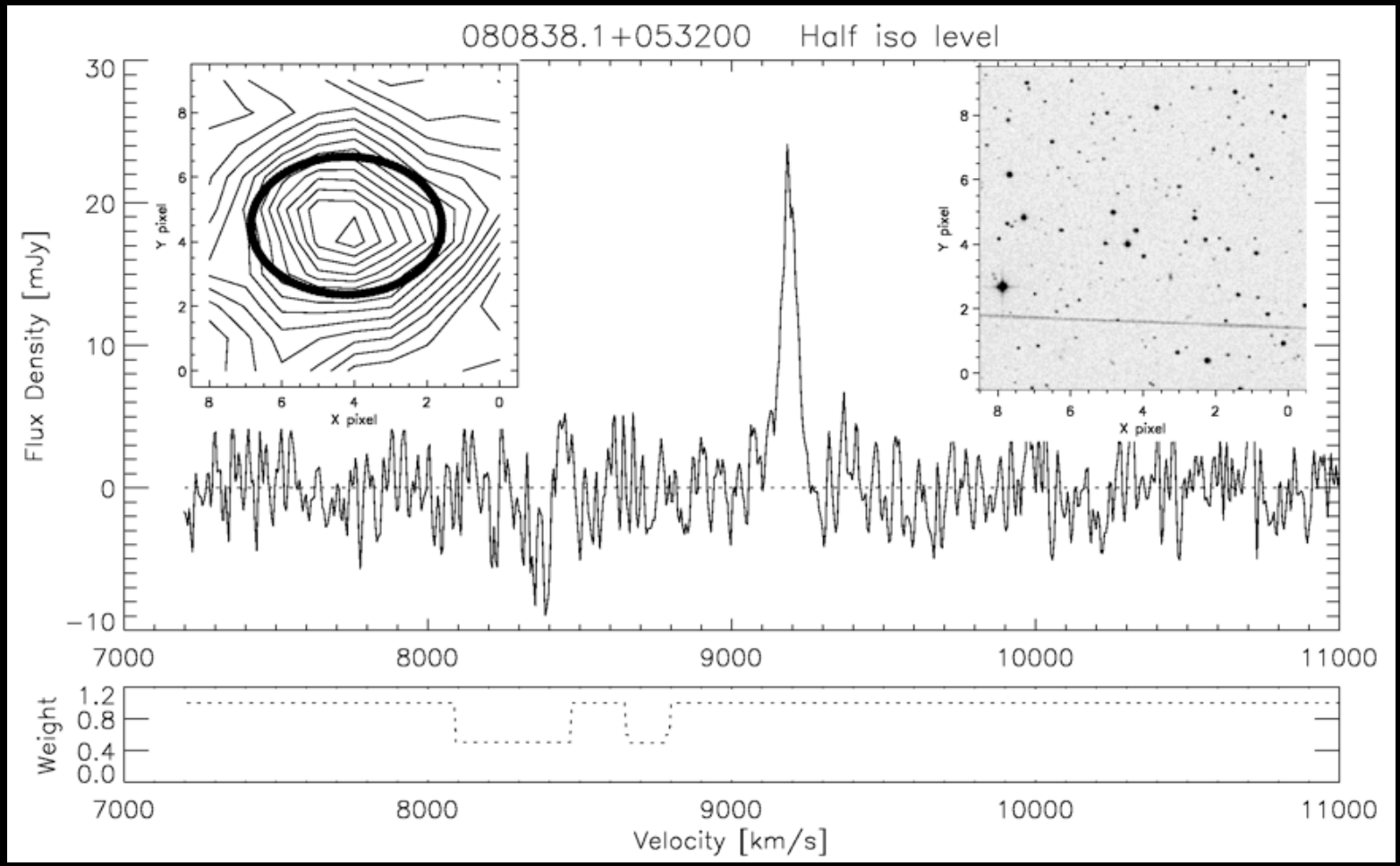


Broken power-law: Prochaska & Wolfe (2009)

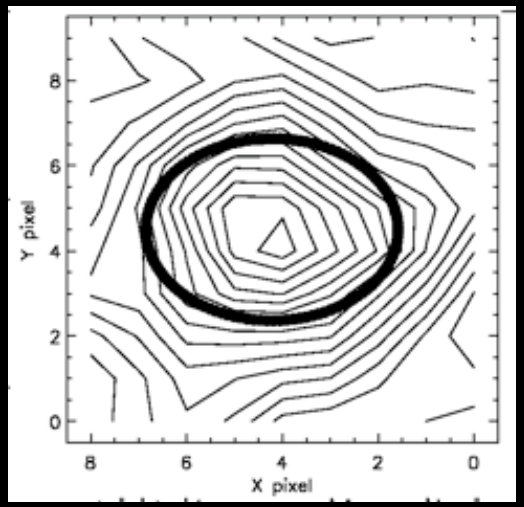
* See Grasha poster *

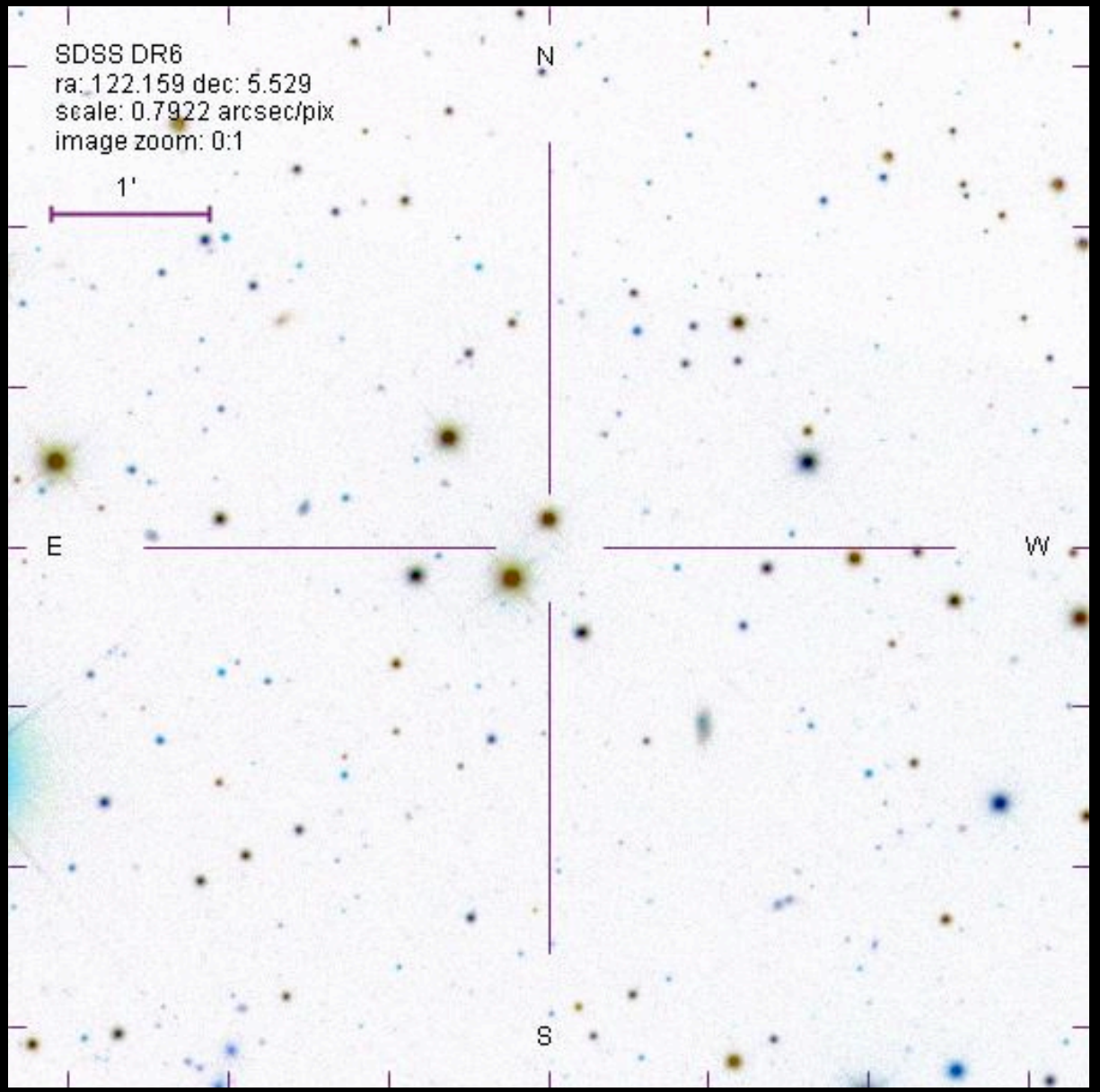
Nonthermal Line "Spoofing"
An ALFALFA Case Study

The Arecibo Legacy Fast Arecibo L-band Feed Array (ALFALFA) Survey:
7000 deg^2 HI 21 cm *emission* survey



Nonthermal Line "Spoofing"
An ALFALFA Case Study





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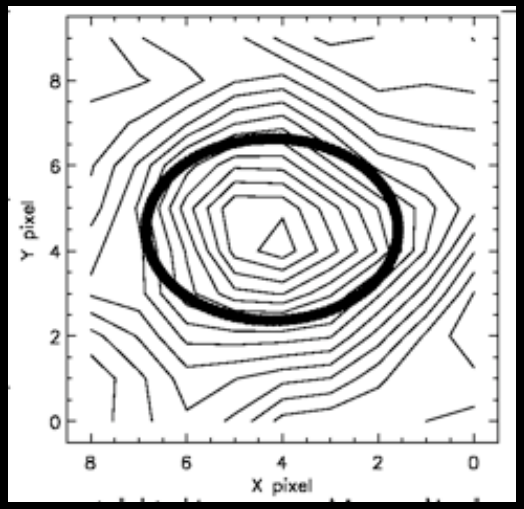

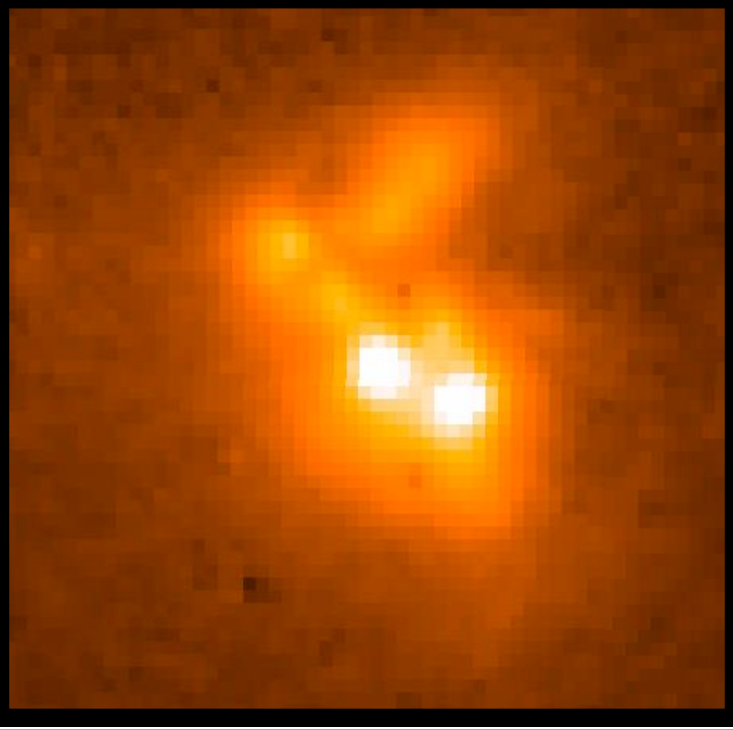

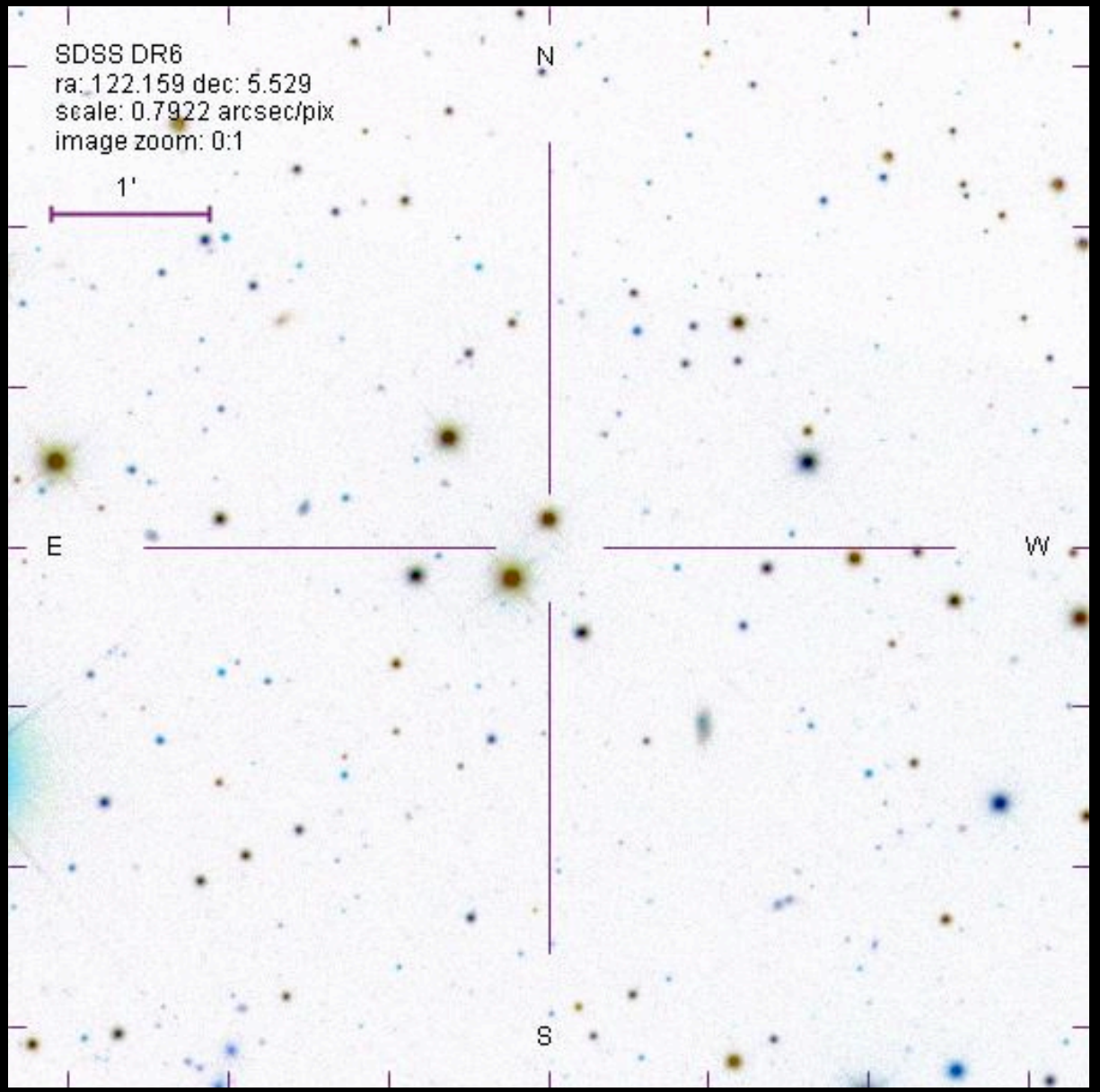

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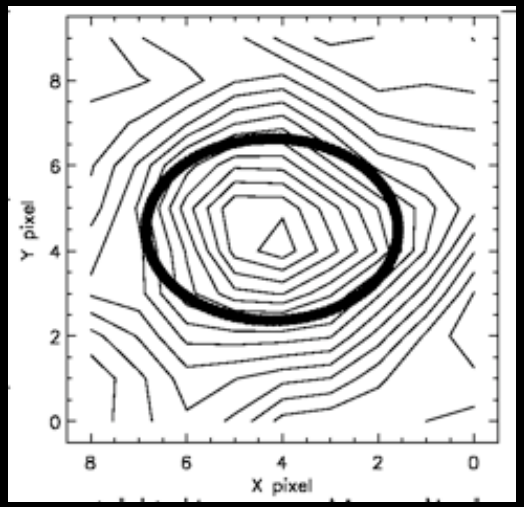

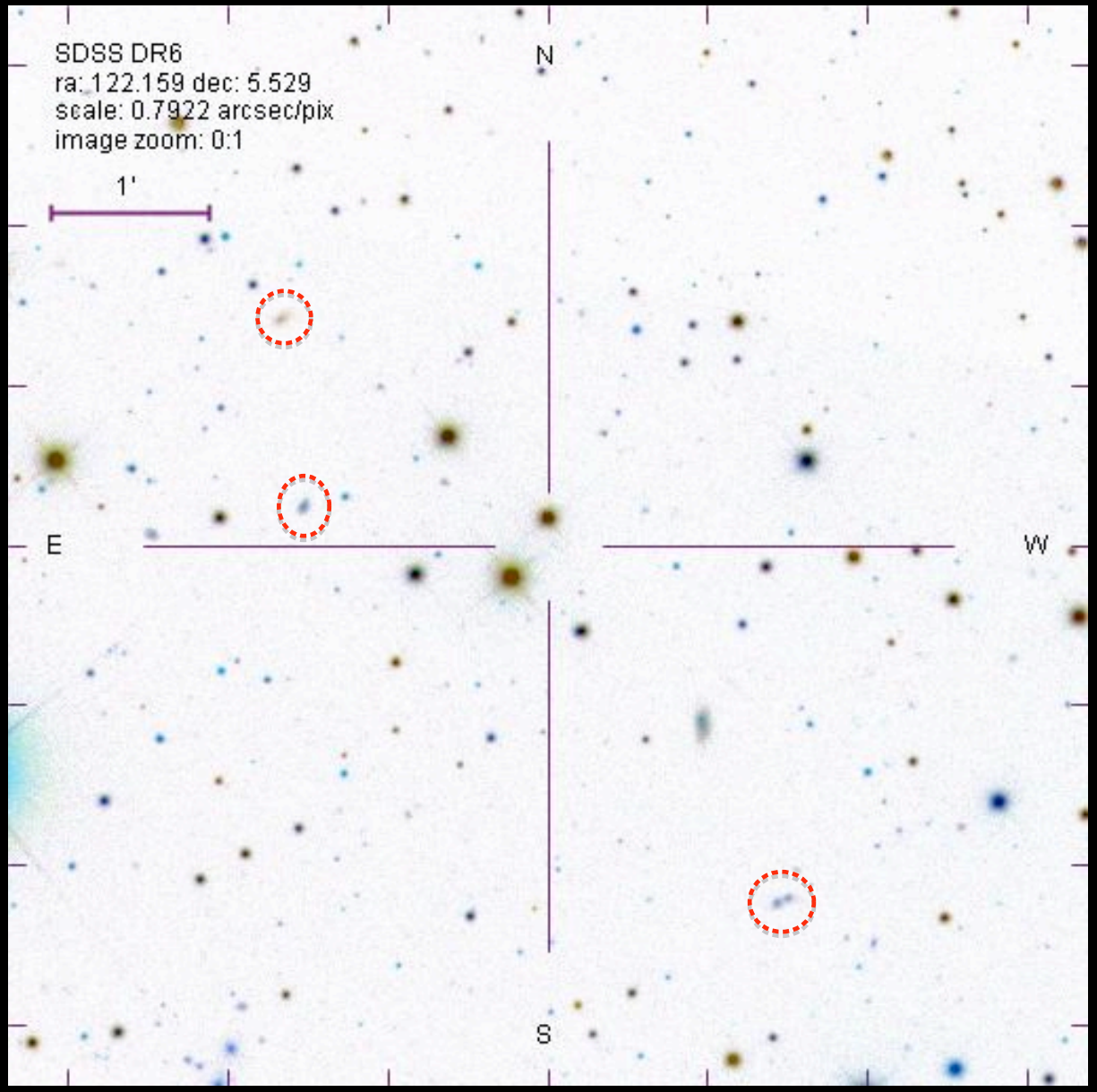

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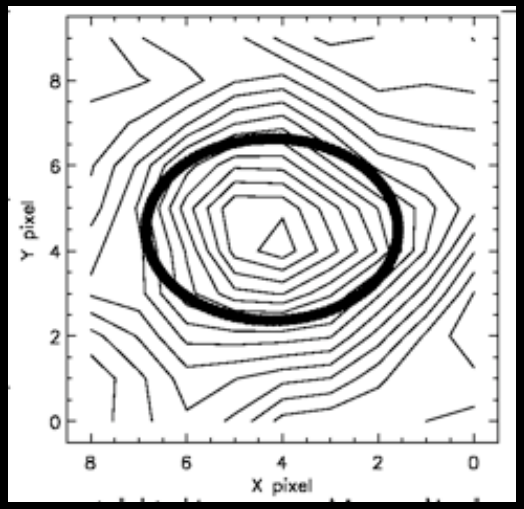

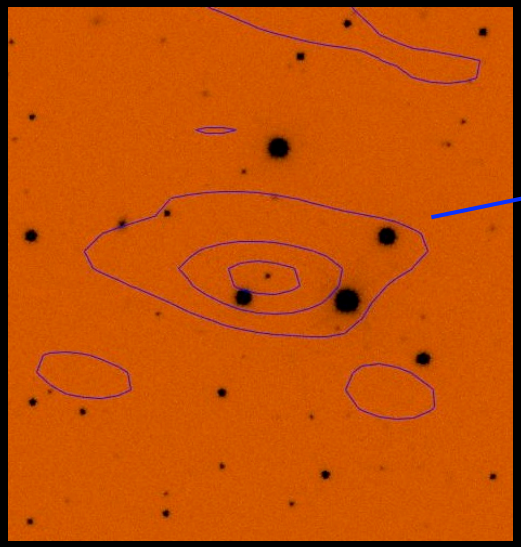

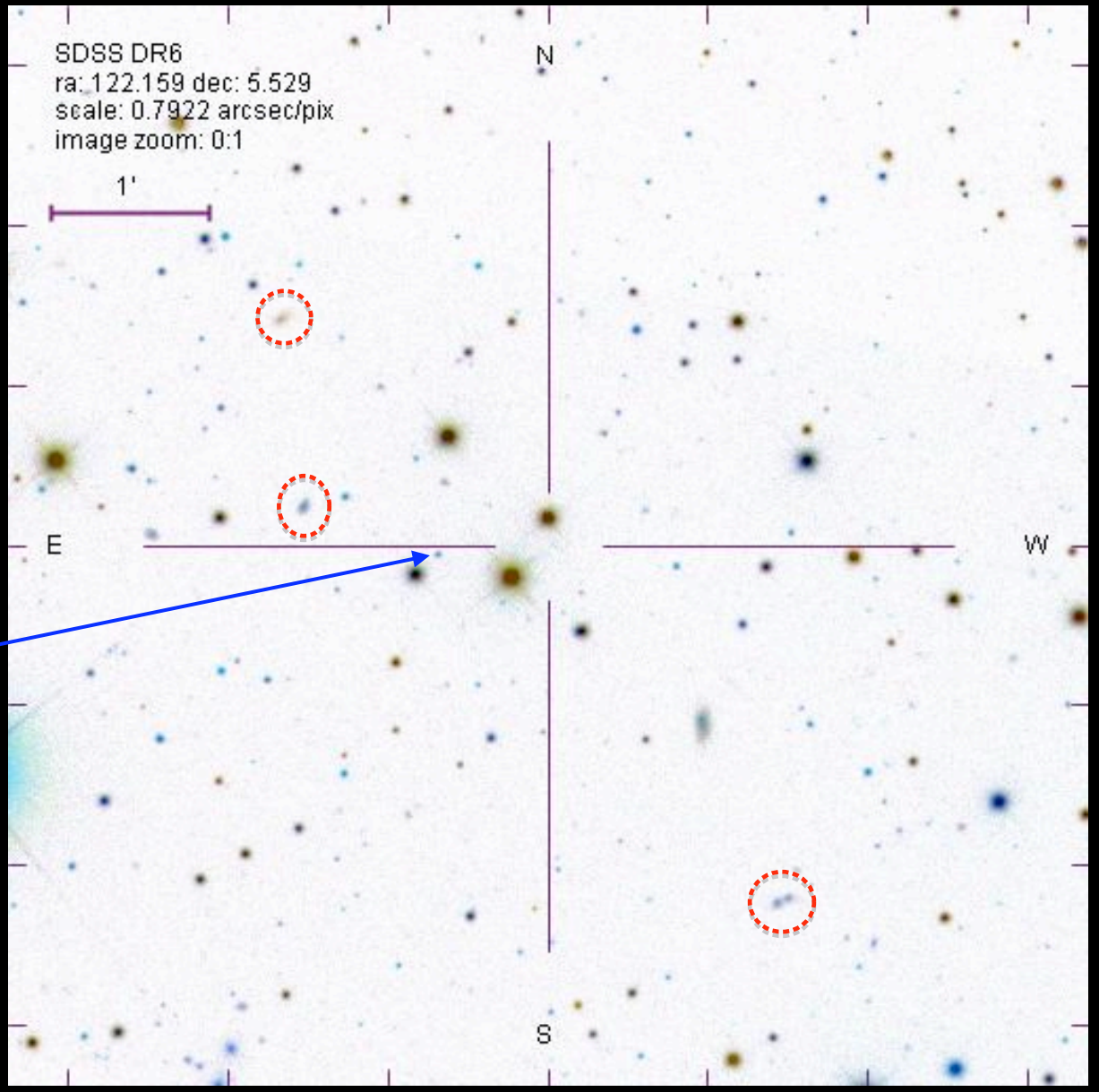

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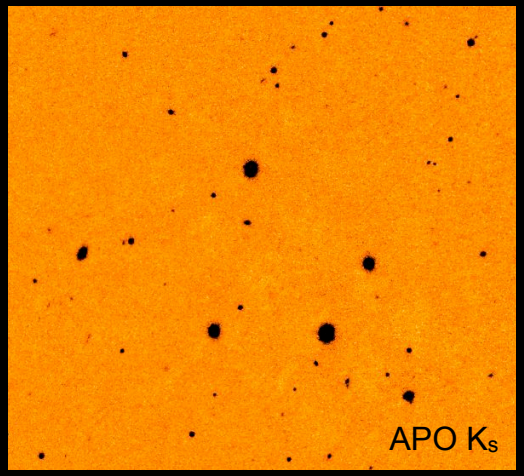
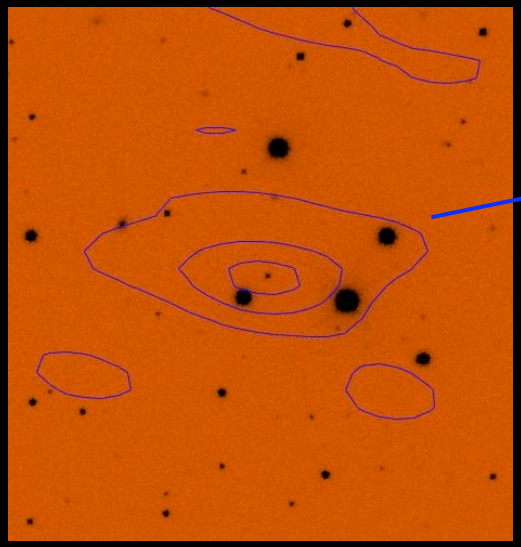
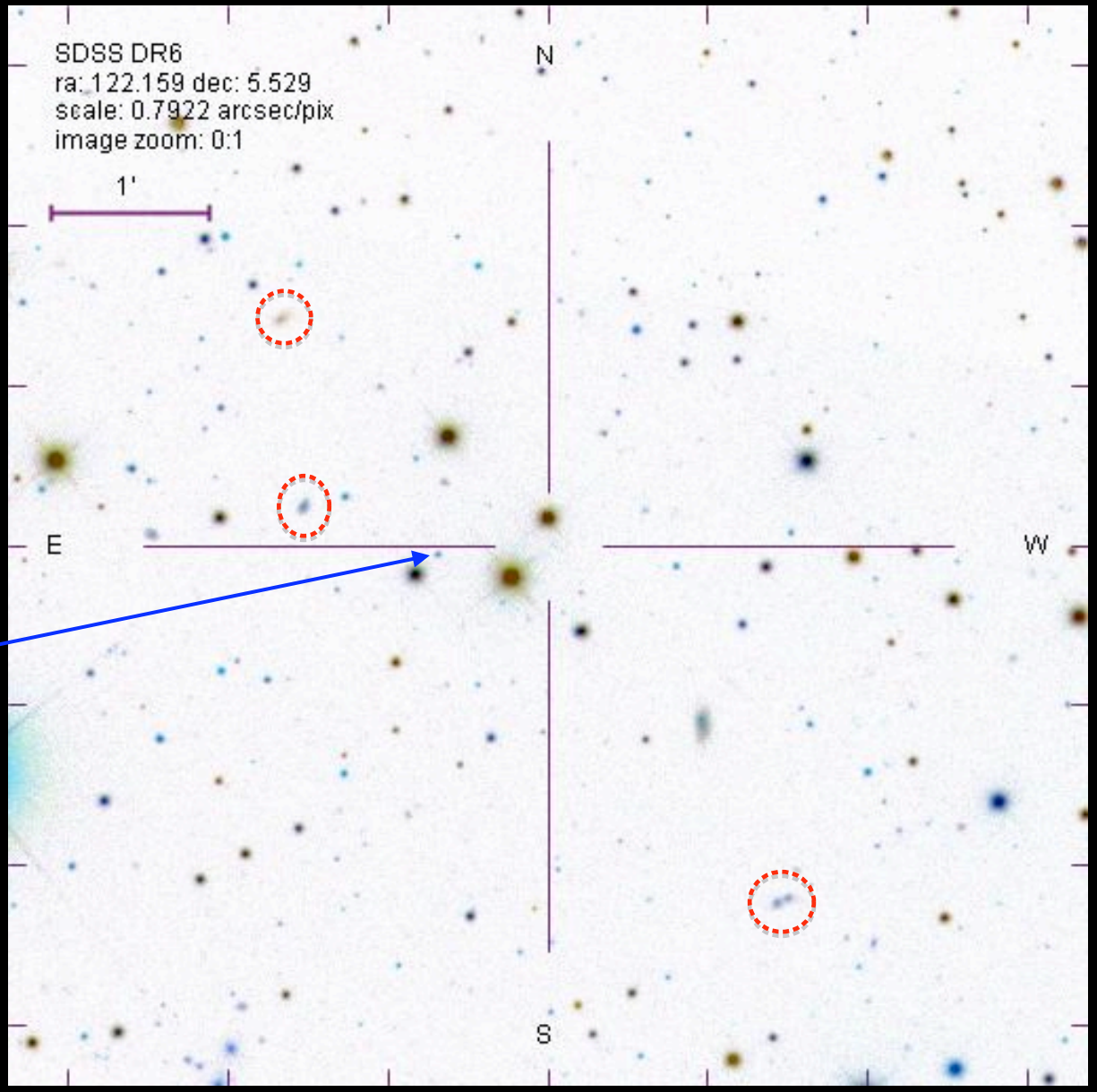


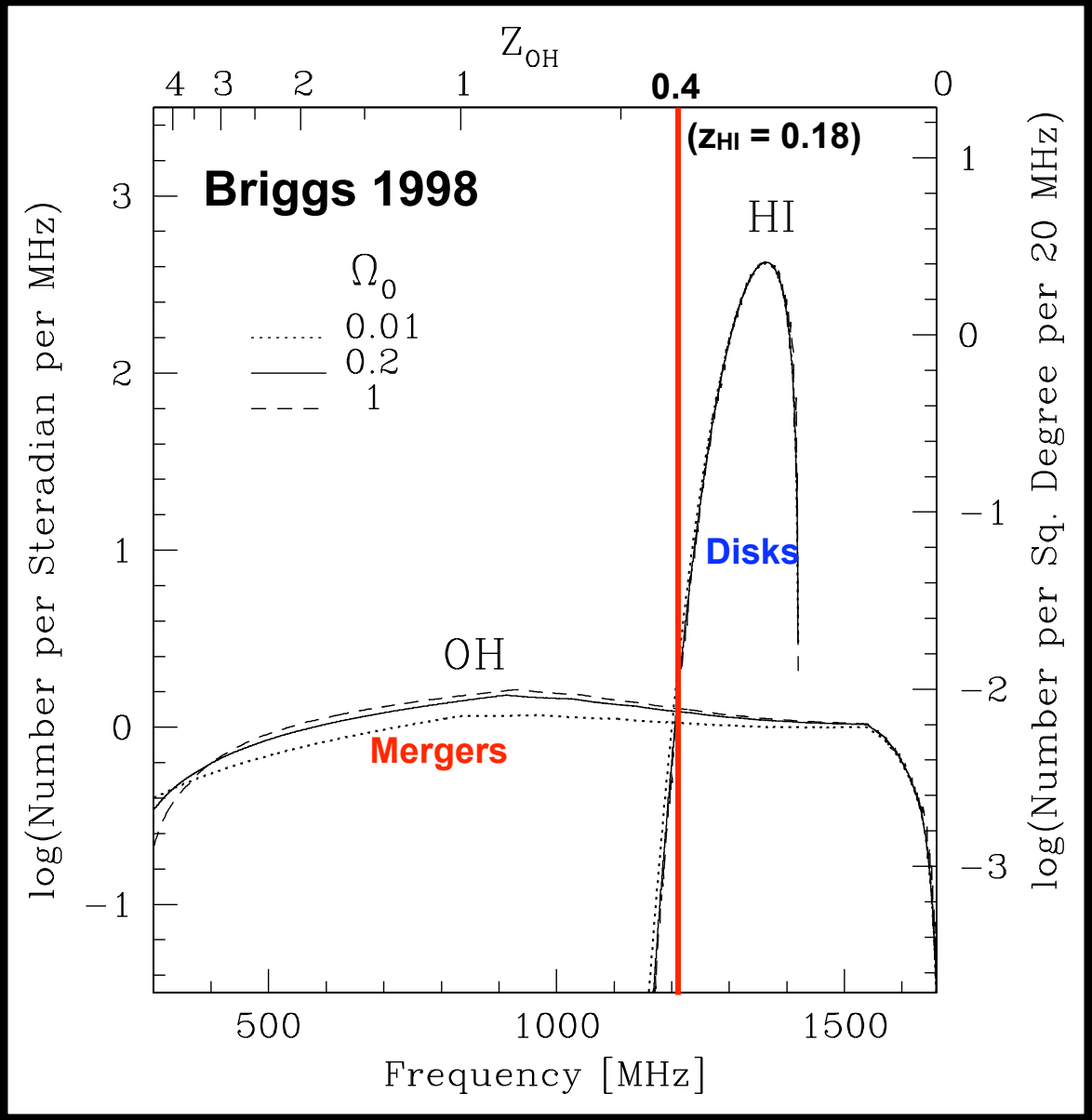




Nonthermal Line "Spoofing"
An ALFALFA Case Study

For a fixed sensitivity, OH megamasers will *dominate* HI 21 cm line surveys above some redshift!

Briggs 1998
Darling & Giovanelli 2002



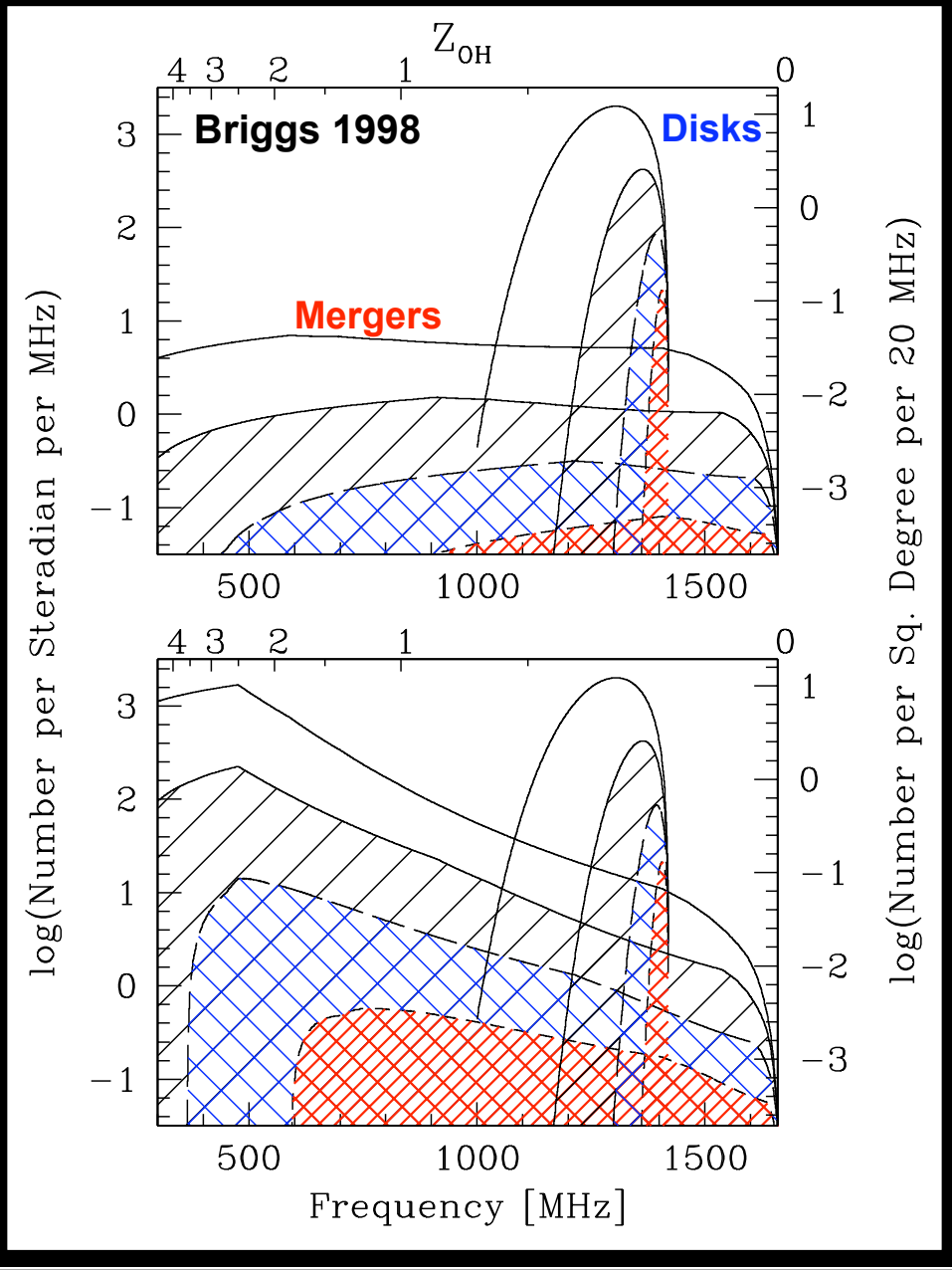
Nonthermal Line "Spoofing"
An ALFALFA Case Study

For a fixed sensitivity, OH megamasers will *dominate* HI 21 cm line surveys above some redshift!

Increasing sensitivity moves the crossing point to higher redshift.

A survey for HI is a survey for OH, major mergers, and extreme starbursts.

Briggs 1998
Darling & Giovanelli 2002



* See Willett poster *

Summary

Low Frequency Spectral Lines

- Surprises are likely
- Foregrounds to EoR HI 21 cm studies
- New science

Case Studies

- Formaldehyde absorption of CMB
  - Foregrounds
  - Distance-independent probe of dense molecular gas
- HI 21 cm absorption lines:
  - RFI issues
  - Proximity effect
  - f(N) and T_{spin}
- OH Megamasers
  - HI survey contaminant
  - Tracer of merging and star formation