COMPLEX NON-EQUILIBRIUM CHEMISTRY IN THE SHOCK ACCELERATED OUTFLOW OF THE PRE-PLANETARY NEBULA OH231.8+4.2

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ABSTRACT

- Evolved stars are:
  - Primarily responsible for ISM (InterStellar Medium) enrichment
  - Efficient factories of molecules
- We present preliminary results on the chemistry study towards OH231.8+4.2 an Oxygen rich envelope/star
- Observations:
  - IRAM 30 meters antenna and its new generation EMIR receivers
  - Milimeter survey from 79 GHz to 350 GHz
- OH231.8+4.2 shows a particularly rich chemistry (probably strongly affected by Shock induced chemistry)

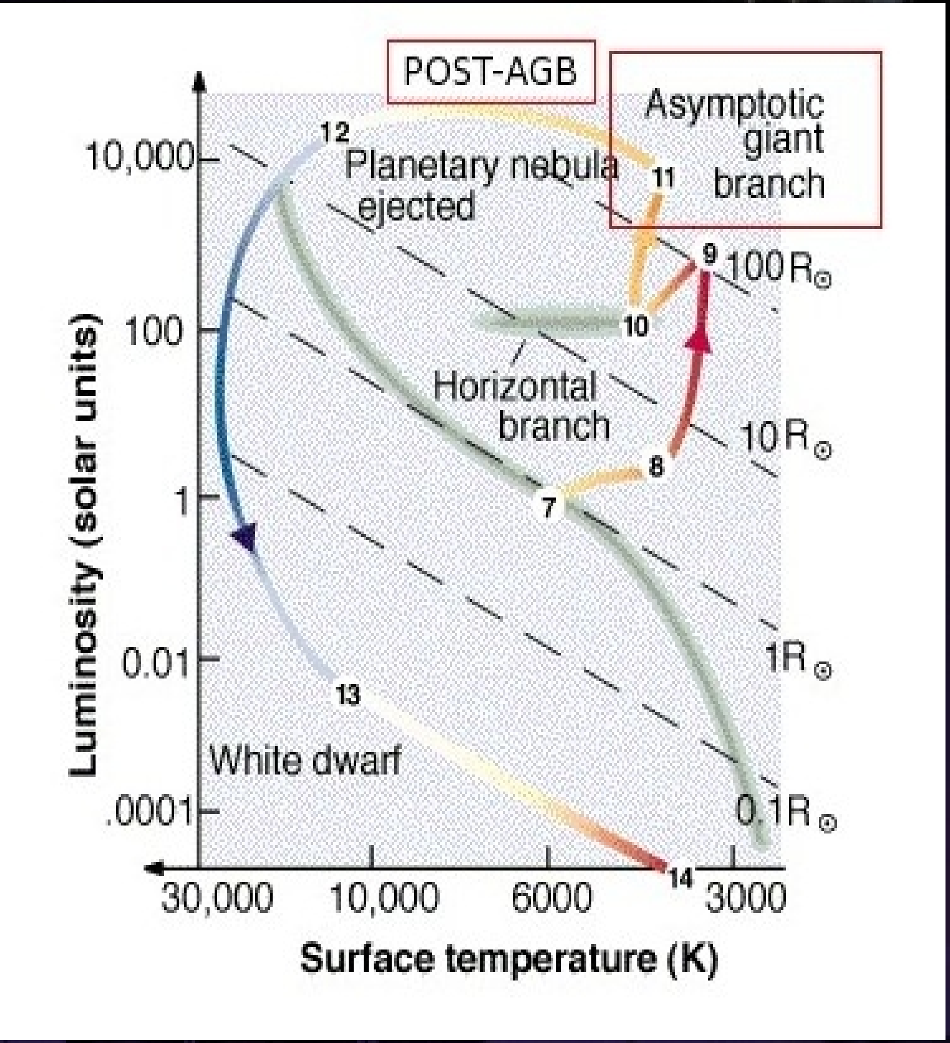
EVOLVED SUN-TYPE STARS

- Stars ranging from: 0.8 - 8 $M_\odot$
- AGB (Asimpthotic Giant Branch) phase:
  - Mass loss: $dM/dt \sim 10^{-8} - 10^{-4}\ M_\odot$
  - Expanding spherical symmetric envelope:

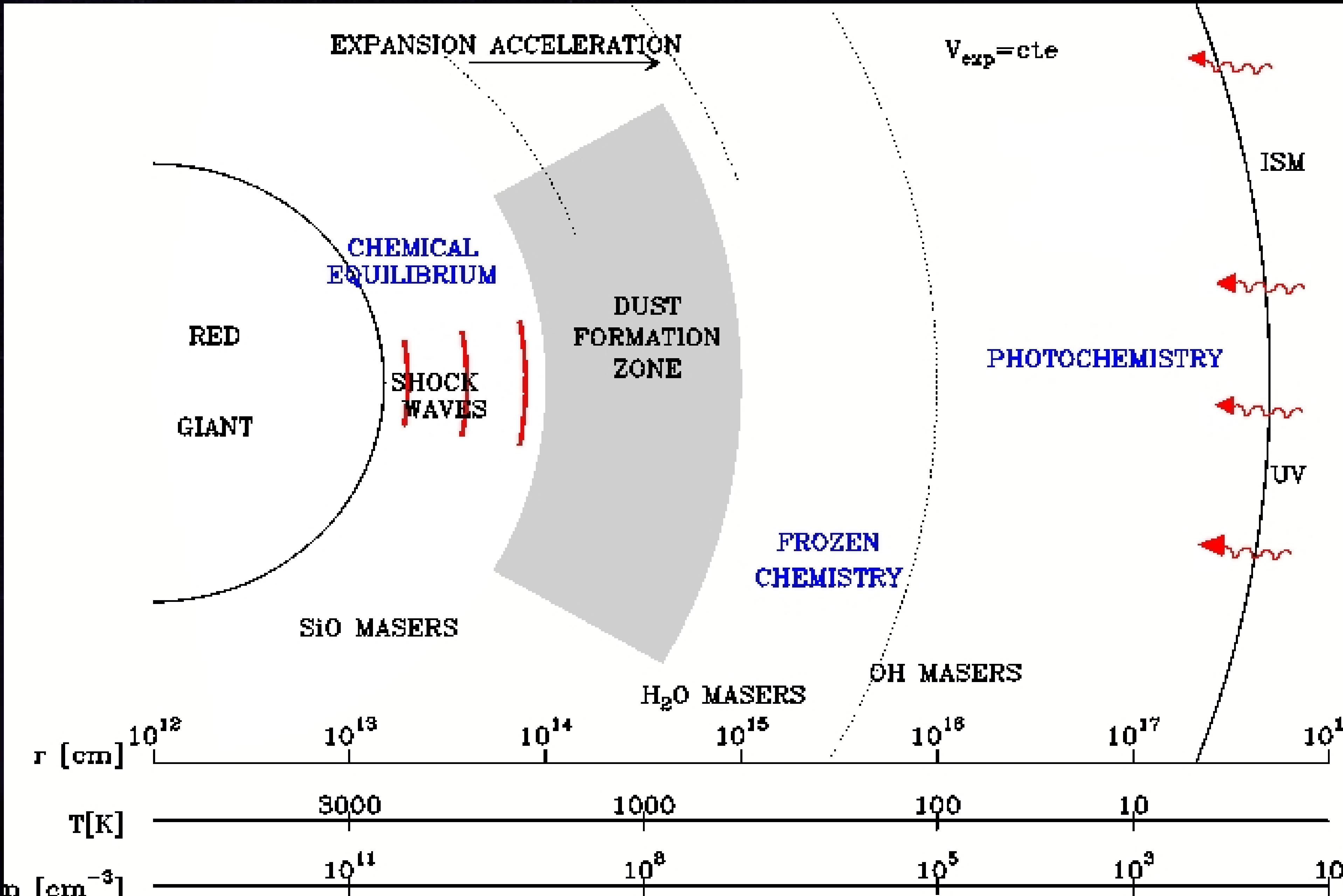
    $v_{exp} \sim 5 - 30$ km/s

- Post-AGB phase:
  - Mass loss stops
  - Detached & expanding envelope
  - High-velocity winds: v ~ 100 – 1000 km/s
  - Spherical symmetry break up

- In both cases molecular gas is the predominant component



TYPICAL STRUCTURE OF AGB ENVELOPES



C-RICH VS O-RICH

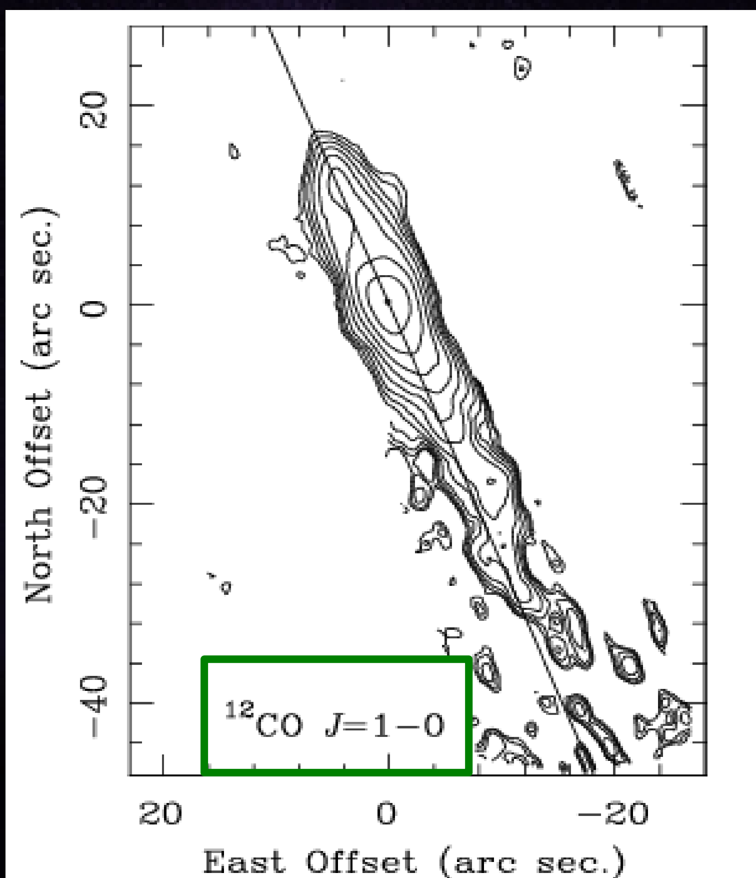
- C-Rich stars: [C]/[O] > 1
- O-Rich stars: [C]/[O] < 1
- Carbon & Oxigen react to form all CO as possible, and Oxygen remains to form new compounds in case of O-rich stars
- So far today Carbon rich stars and their envelopes are the most studied: IRC+10216 (Cernicharo et al., 2010), CRL618 (J.R.Pardo et al., 2007)
- Typical molecular content in C-rich: HCN, HNC, CS, SiS, HC_3N (Bujarrabal et al., 1994)
- Typical molecular conten in O-rich: SiO, SO, SO_2 (Bujarrabal et al., 1994)

OH231.8 + 4.2. GENERAL OVERVIEW

- Bipolar nebula + QX Pup (AGB Mira, M9III) + A0V companion
- Some properties of the molecular envelope:

$$dM/dt \sim 10^{-4}\,M_{\odot}\ ,\ T = 20\ K,\ n \sim 10^{3} - 10^{5}\ cm^{-3}\ ,\ M_{envelope} \sim 1\ M_{\odot}$$

Plateau de Bure Interferometer Map (IRAM)



(Alcolea et al., 2001)

Hubble Space Telescope image

(Sánchez Contreras et al., 2004)

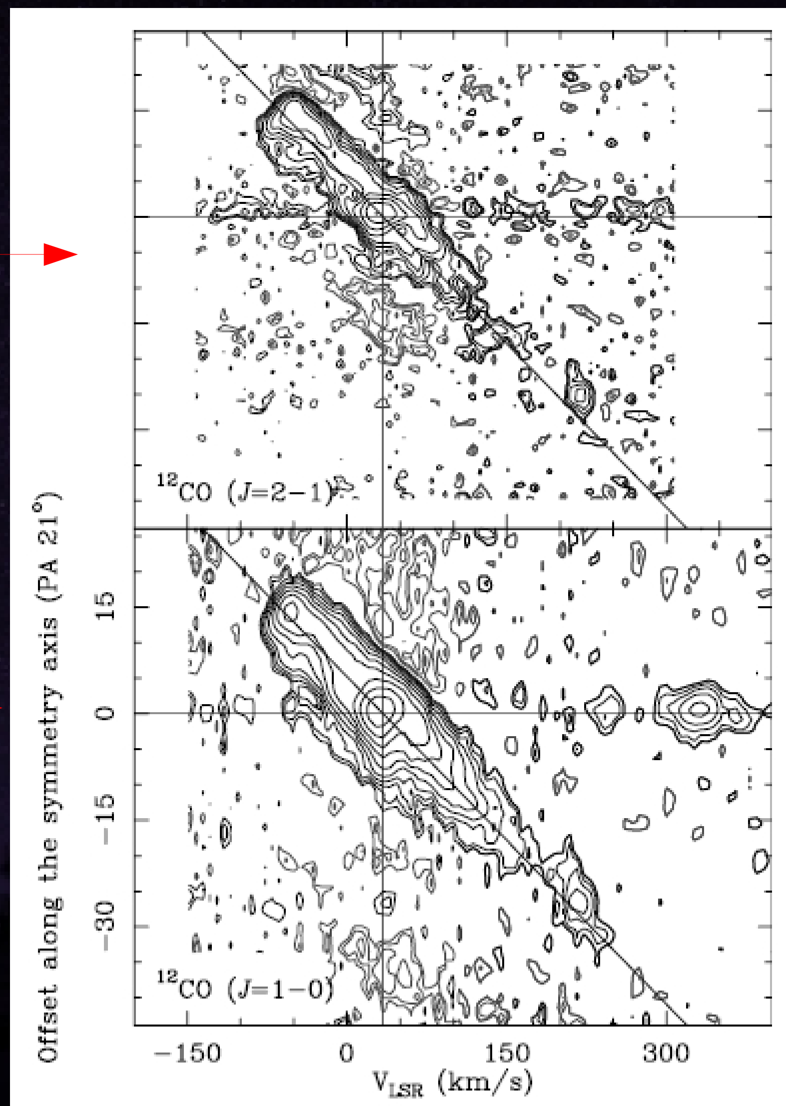
OH231.8 + 4.2. VELOCITY GRADIENT

- High-velocity gradient range:

Velocity-position map (PdBI IRAM)

^{12}CO (J=2-1)

^{12}CO (J=1-0)



(Alcolea et al., 2001)

EXPLANATION

AGB envelope

+

Fast bipolar wind

t_{kin} ~ 1000 yr

Elongated shape

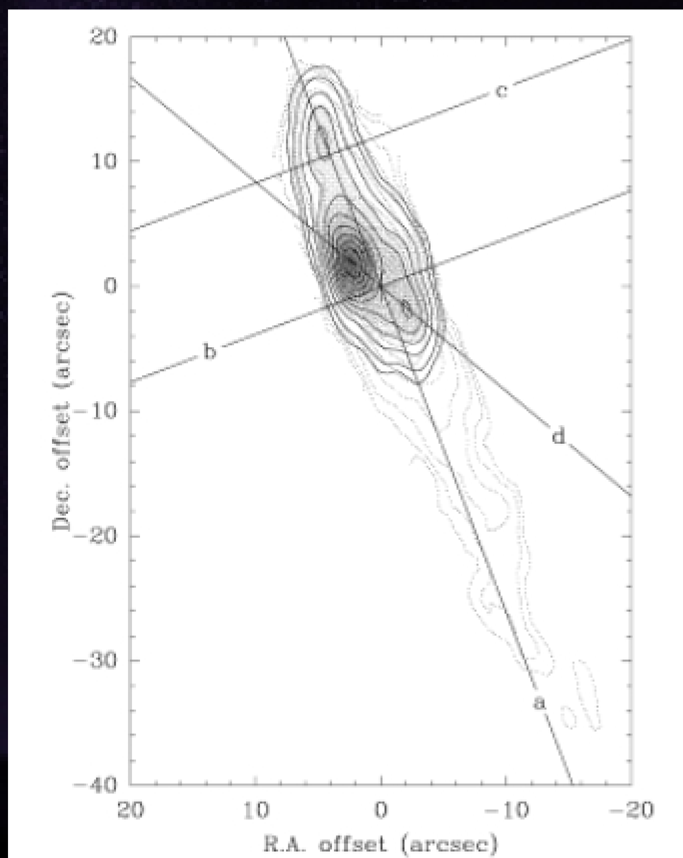
Acceleration

OH231.8 + 4.2. CHEMISTRY

- Rich and peculiar chemistry
- HNC, HCN, CS, NH_3, HCO+, OCS, SiO, SO, SO_2

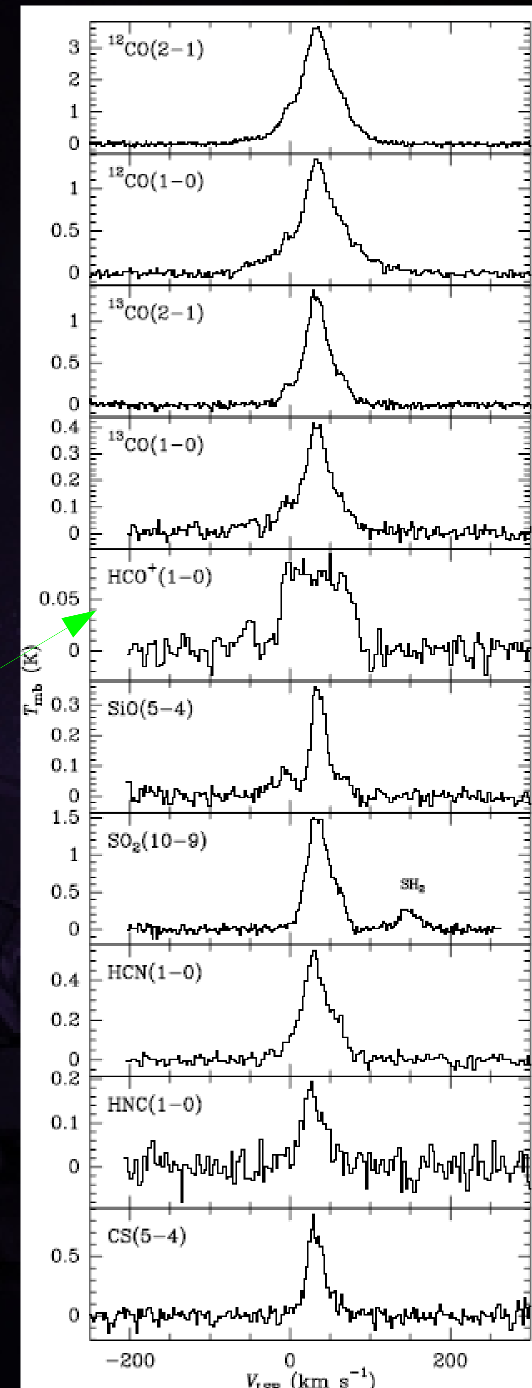
(Morris et al., 1987)

- Shocks are maybe important to explain chemistry



(Sánchez Contreras et al., 2000)

HCO+
J=1-0



(Sánchez Contreras et al., 1997)

OBSERVATIONS

- On-going observations (3 runs in 2009, 2010, 2011) with the 30 meters antenna of IRAM (Institute de Radioastonomie Milimétrique) in Pico de Veleta, Granada (Spain)

- EMIR "state of the art" single pixel heterodyne receivers (Carter et al., 2012)
- Covering 8 GHz simultaneously

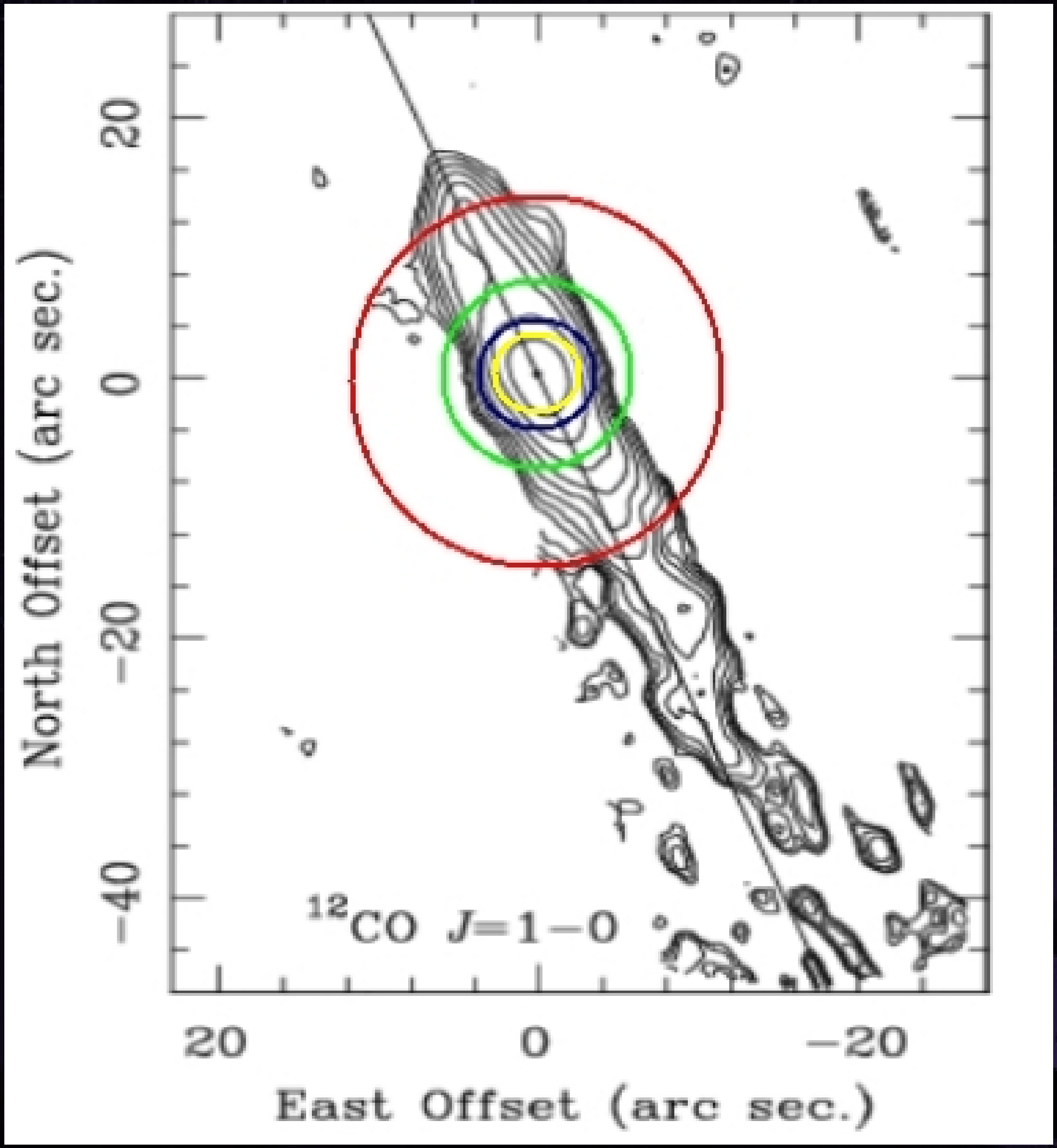
Frequency (GHz)	HPBW(arcsec)	Feff(%)	Beff(%)
86	29	95	81
145	16	93	74
210	11	94	63
260	9	88	53
340	7.5	81	35

- Backends and resolutions:

Backends	Channel width
4 MHz	4 MHz
WILMA	2 MHz
FTS	195,50 kHz
VESPA	3.3 kHz-1.25MHz

Typical widths:
2 MHz ~ 1.5 – 7.5 km/s
OH231 lines ~ 50 – 100 km/s

OBSERVATIONS: BEAM SIZE



Including the dense central parts and partially covers the fast bipolar outflows

RED: Beam at 90 GHz

GREEN: Beam at 150 GHz

BLUE: Beam at 250 GHz

YELLOW: Beam at 340 GHz

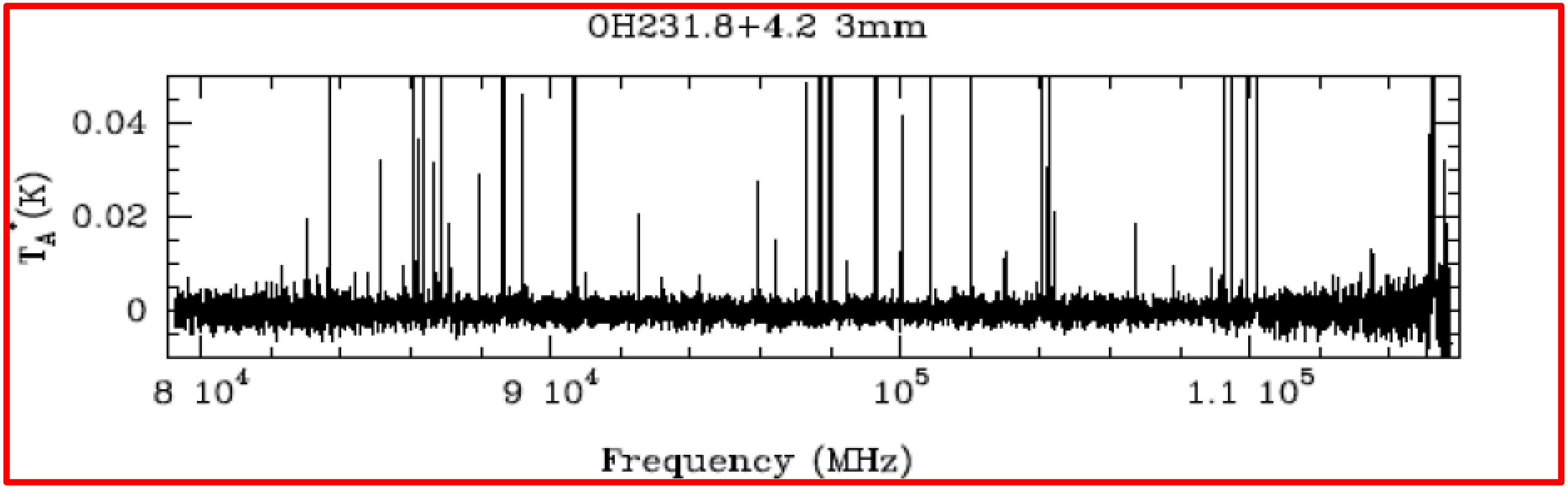
OBSERVATIONAL RESULTS

- Summary of the observational results:

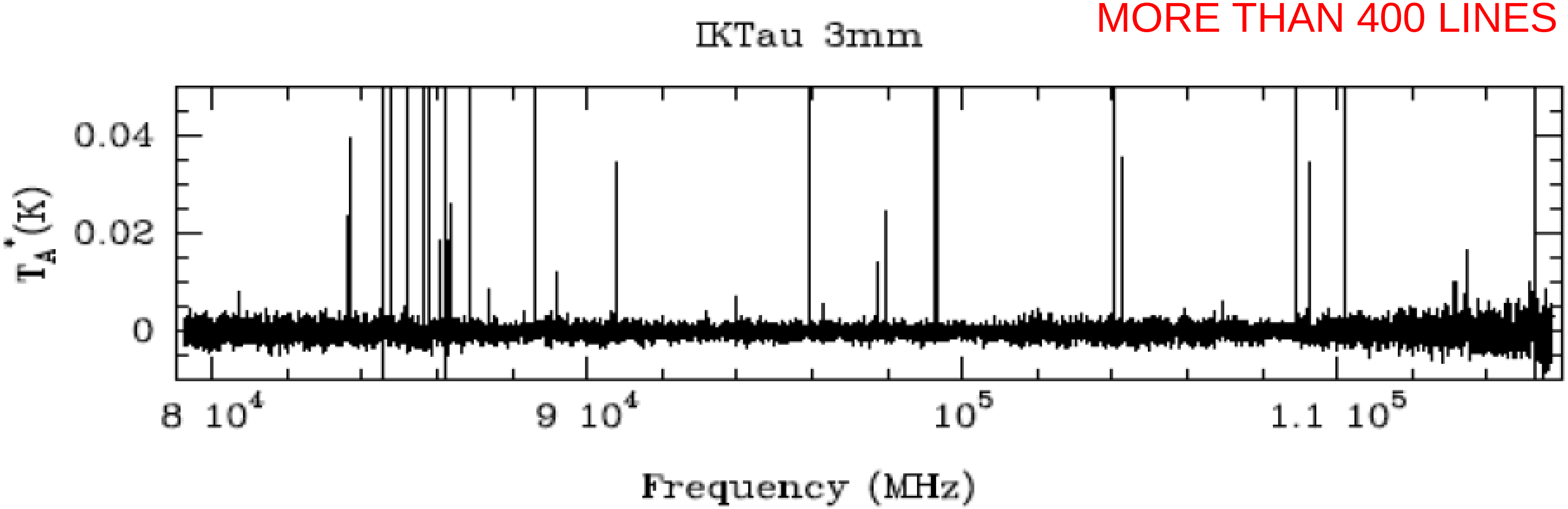
Source	Band	Fobs (GHz)	Nº Setups	Texp (s)	RMS (mK)	Opacity
IKTau	E090/3mm	79.2-115.7	5	118300	1-2	0.09-0.21
IKTau	E150/2mm	128.3-167.6	14	162230	1-4	0.04-0.26
IKTau	E330/0mm	258.3-348.9*	17	77100	7-16	0.24-0.79
OH231.8+4.2	E090/3mm	79.2-115.7	5	105500	1-2	0.07-0.21
OH231.8+4.2	E150/2mm	128.3-167.6	13	142960	1-4	0.03-0.24
OH231.8+4.2	E330/0mm	258.3-348.9**	15	61250	9-20	0.17-0.76

- We have:
  - 33 spectra (36 for IKTau)
  - 131 GHz of total width (138 GHz for IKTau)
  - > 400 lines
  - ~ 3 lines / GHz
  - 3mm & 2mm fully covered
  - 0mm 50% covered
  - 1mm not covered (yet)

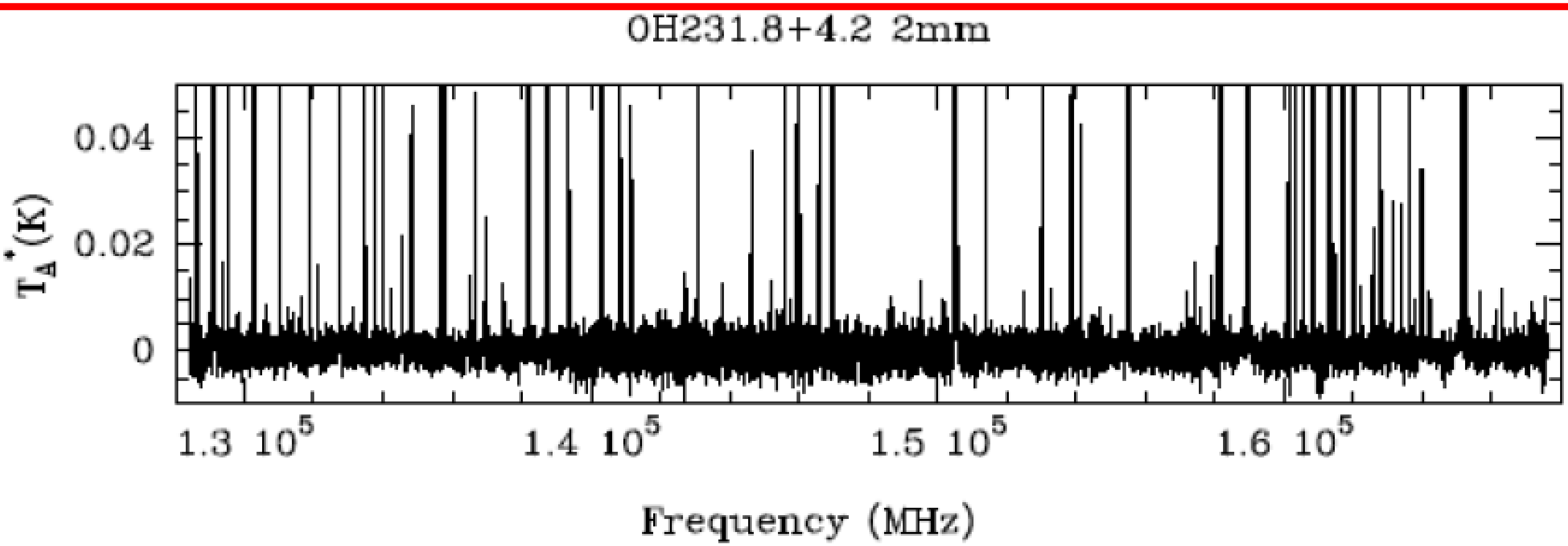
OBSERVATIONAL RESULTS: THE SURVEY



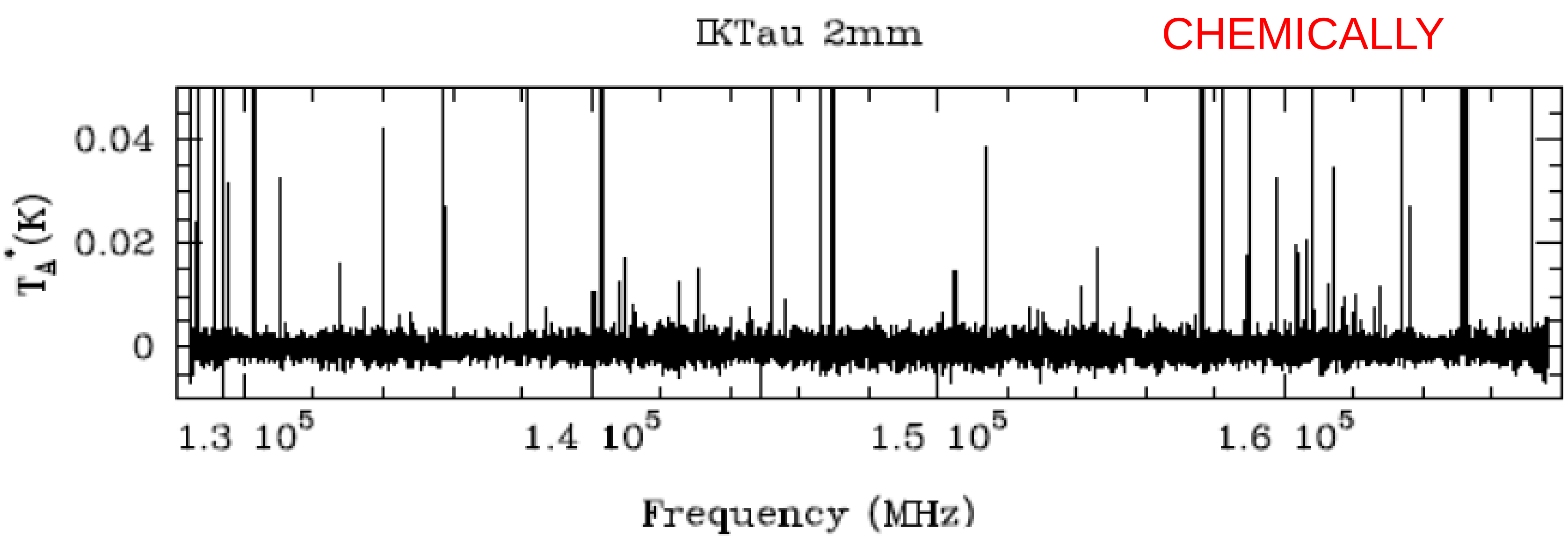
MORE THAN 400 LINES



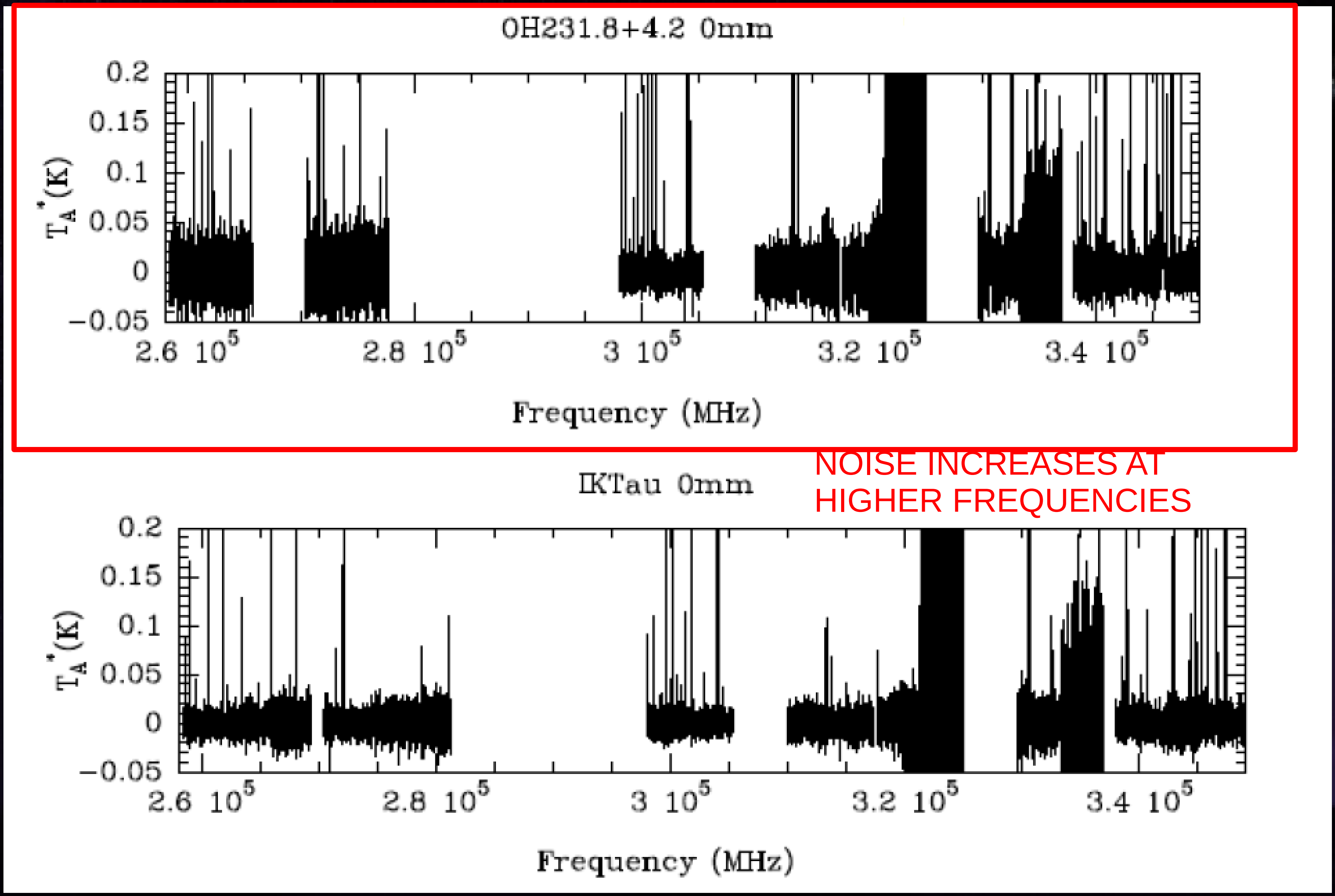
OBSERVATIONAL RESULTS: THE SURVEY



NOT SO POOR CHEMICALLY



OBSERVATIONAL RESULTS: THE SURVEY



LINE IDENTIFICATION: THE PROCEDURE

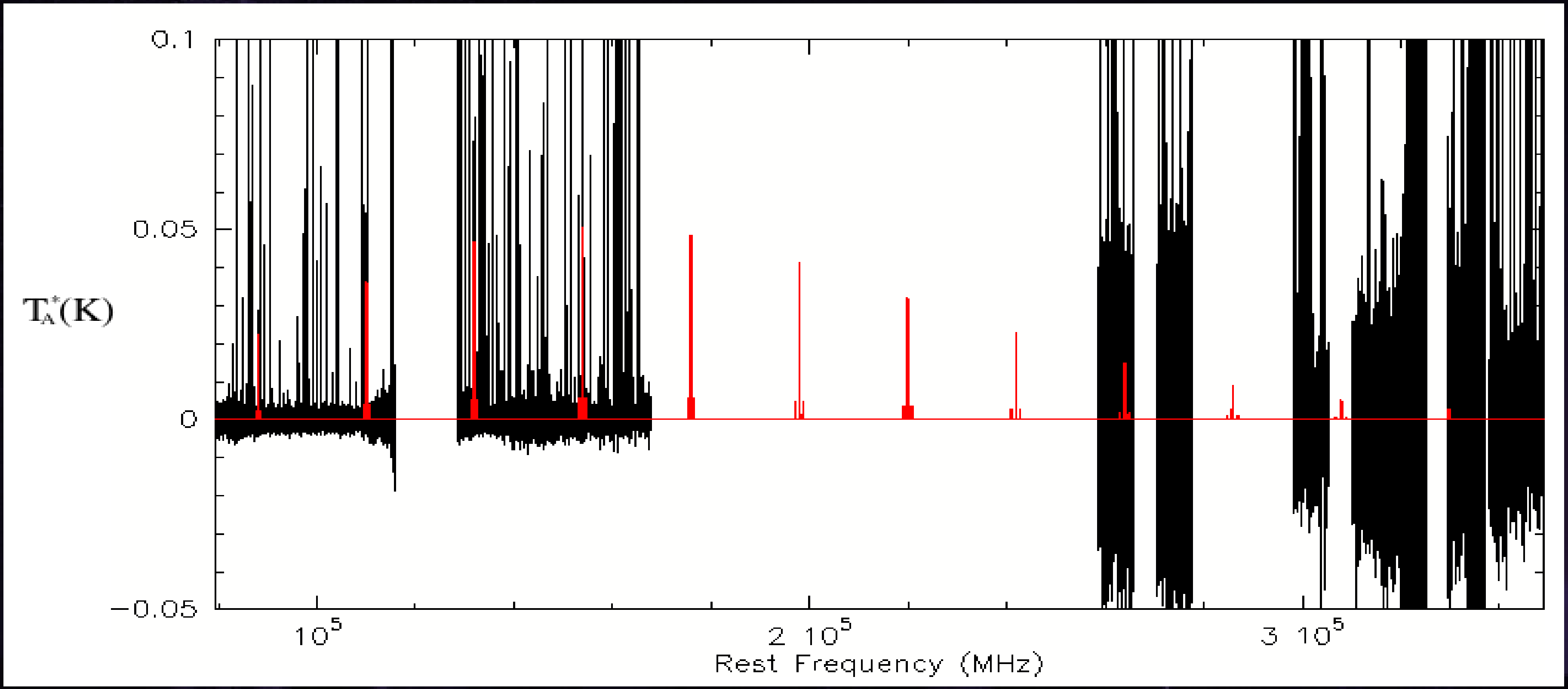
- Line identification procedure:
  1) Establishing frequency of the line within a $\Delta\nu$~4MHz
  2) Search in catalogues: CDMS, JPL, J. Cernicharo personal catalogue
  3) Select a candidate within following criteria:
     - Previously detected
     - Upper level energy of the transition
     - Einstein coefficient
     - Species complexity
  4) Compare with synthetic spectra

Confirm species, identifying several transitions for the same molecule for firm confirmation

LINE IDENTIFICATION: SYNTHETIC SPECTRA

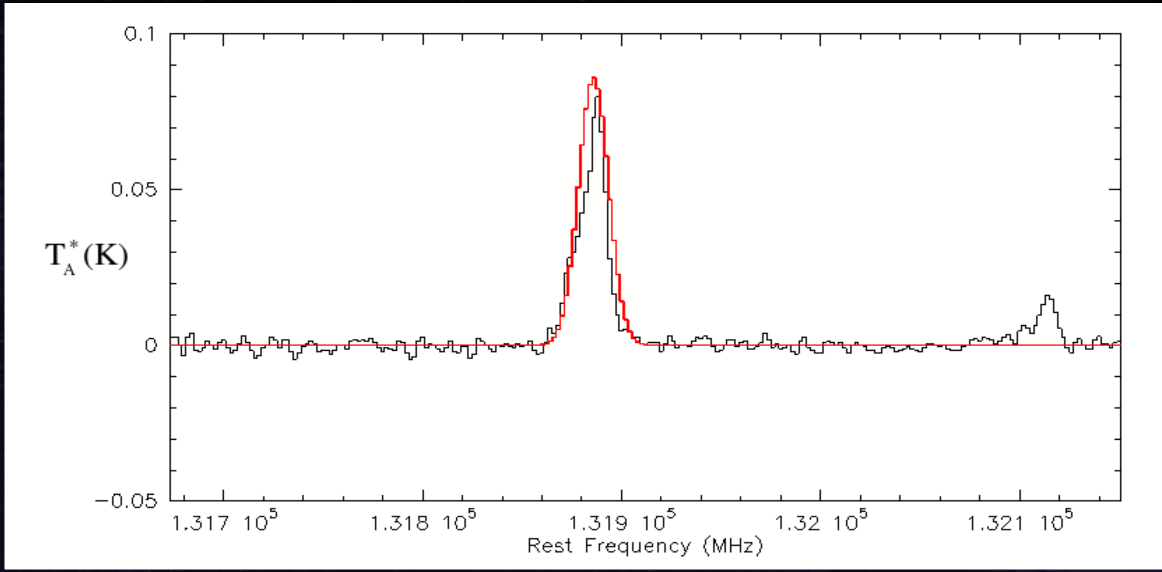
- Using MODSOURCE task from CLASS software (http://iram.fr/IRAMFR/GILDAS/)

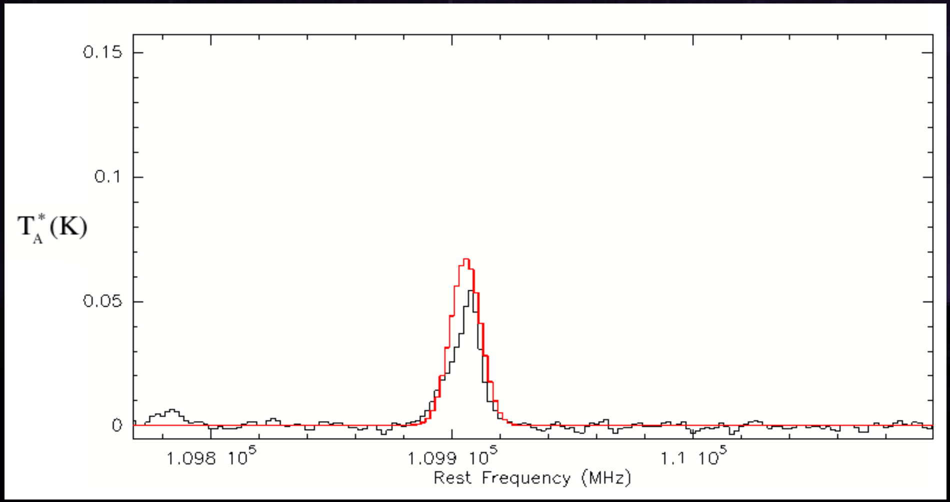
HNCO model sample:

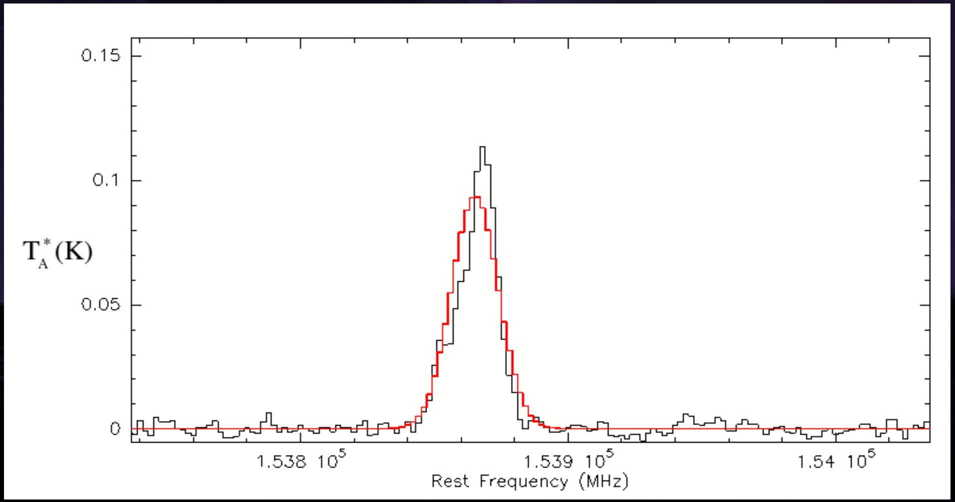


LINE IDENTIFICATION: SYNTHETIC SPECTRA

HNCO model sample:







PRELIMINARY ANALYSIS: ROTATIONAL DIAGRAMS

- Population diagrams or Rotational diagrams give rotational temperature and column density for a specific molecular specie and allow to constraint input values for the sinthetic spectra creation
- Under Local Thermodynamic Equilibrium (LTE) -> Collisional excitation
- Equation (Goldsmith & Langer, 1991):

$$\frac{N_2}{N_1} = \frac{g_2}{g_1} exp(-\frac{h\nu_o}{kT})$$

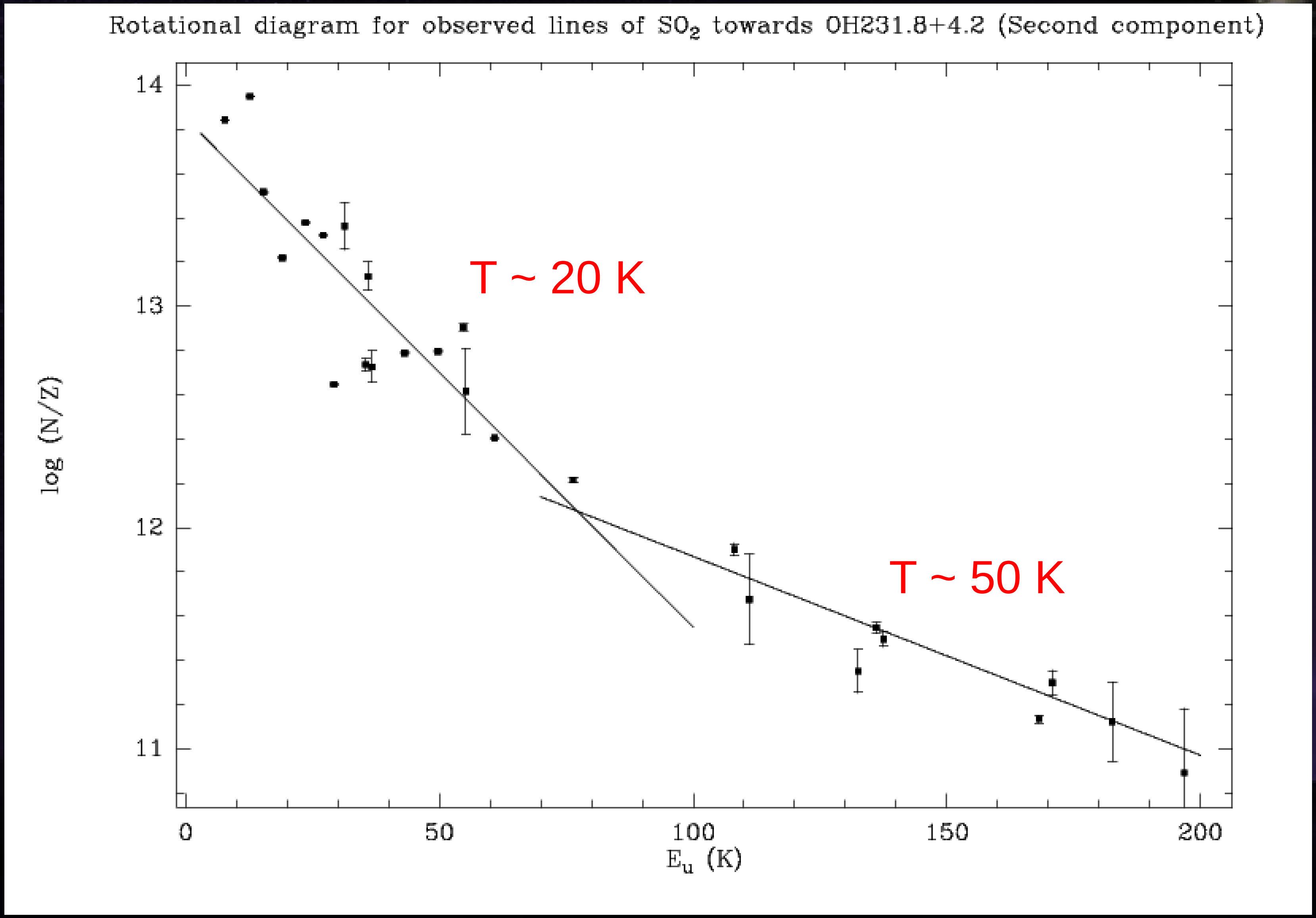
With: $T = T_{ex}$ → Under LTE: $T_{ex} = T_{rot}$

$$\log \frac{3kW}{8\pi^3 \nu S_{ul} \mu^2} = \log \frac{N}{Z_{rot}} - \frac{\log e}{kT_{rot}} E_u$$

T_{rot} , N from fitting

ANALYSIS: ROTATIONAL DIAGRAMS

- Rotational diagram for SO_2 towards OH231.8 + 4.2:



LINE IDENTIFICATION: RESULTS

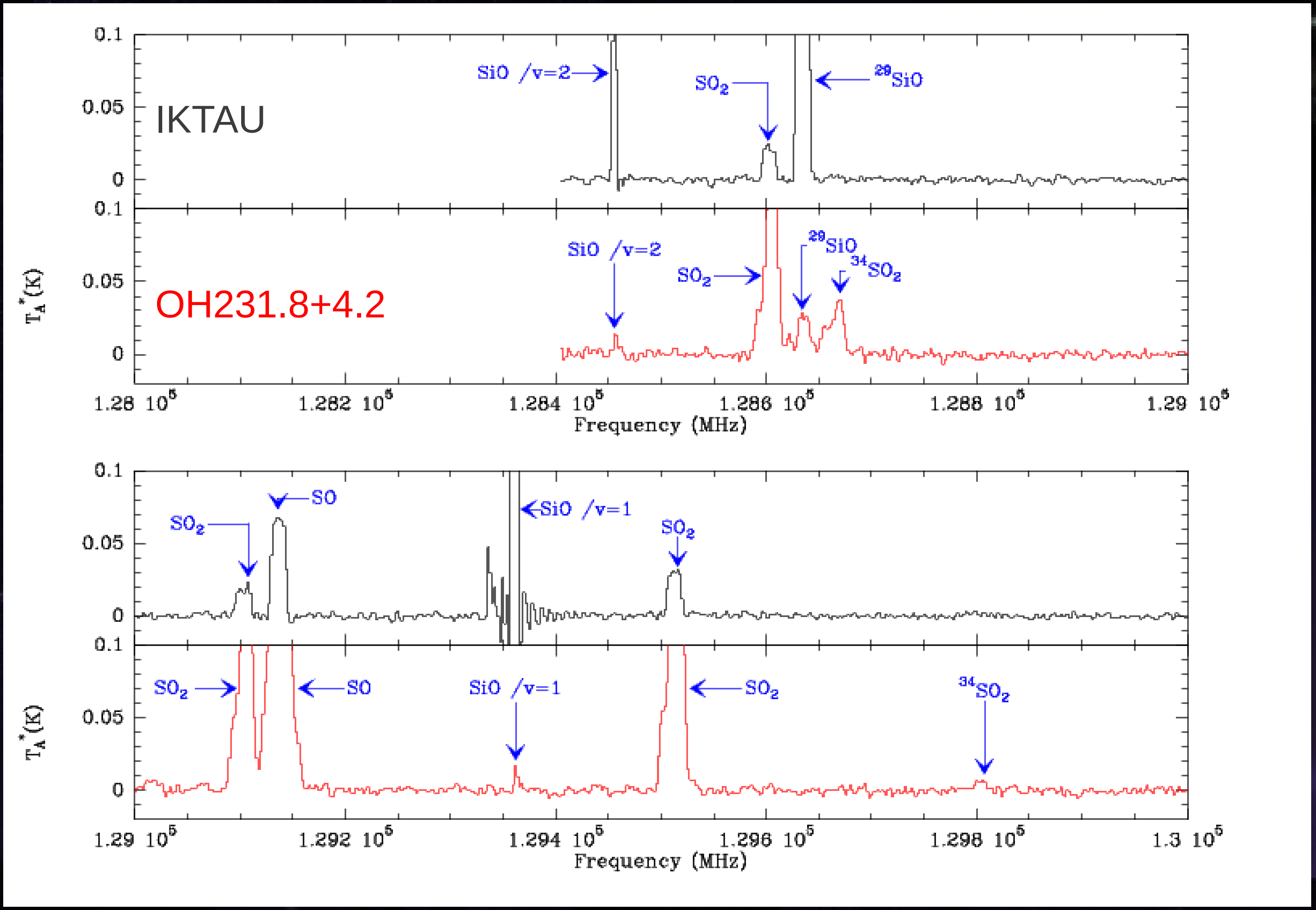
OH231.8+4.2:

- 69% lines identified
- Thermal lines: CO, CS, SiO, SO, SO_2, HCN, HNC, HCO+, OCS, NS, SiS, H_2CO, H_2S, HNCO, PS, NO, N_2H+, HC_3N...
- Maser lines: SiO
- Tentative detections: PO, C3H, SO+, CN ...
- Many Uis (UnIdentified lines) → ¿Complex molecules: CH_3OH, CH_3OCHO?

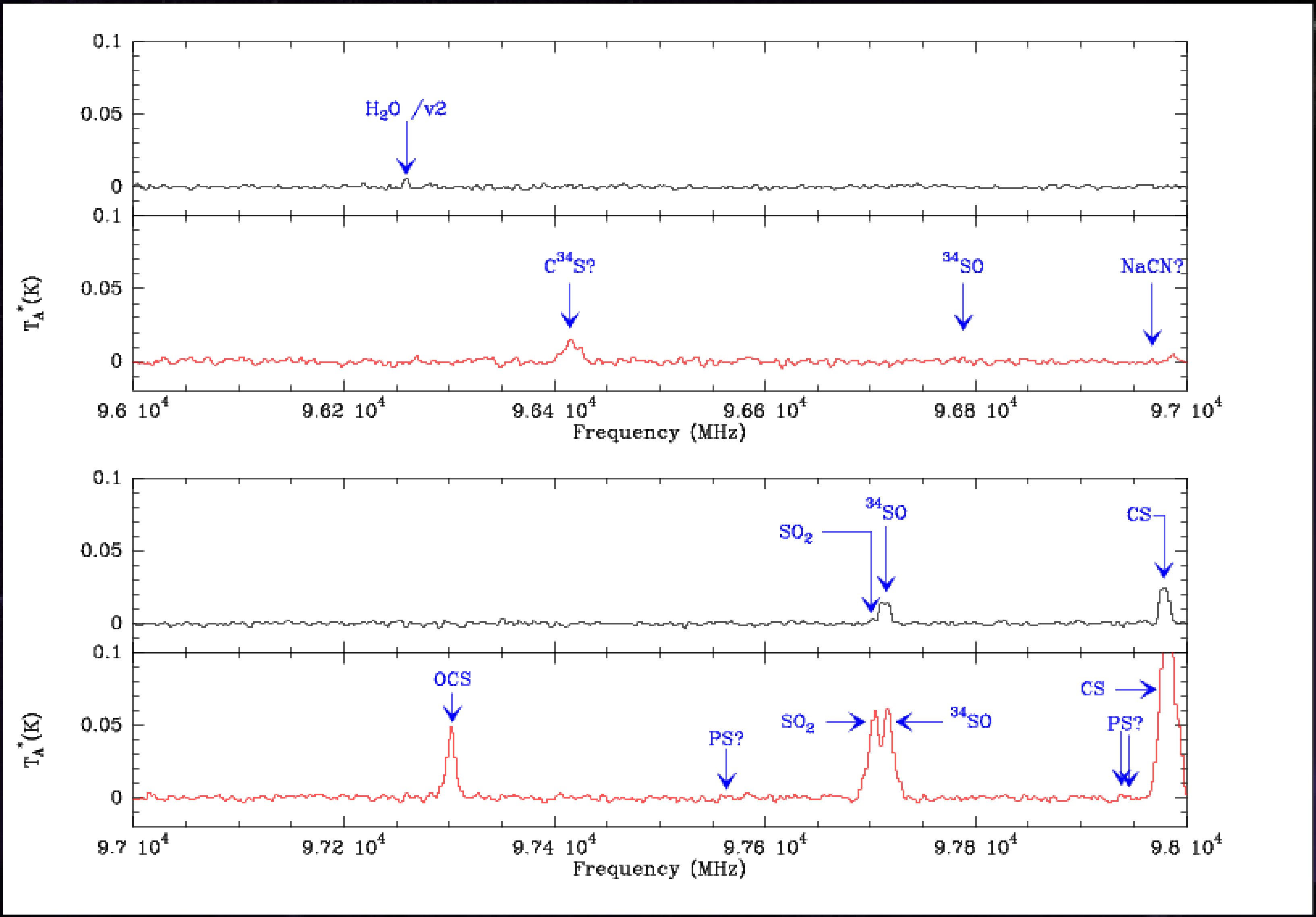
IKTAU:

- 54% lines identified
- Thermal lines: CO, SiO, SiS, SO, SO_2, HCN, HNC, HCO+, CS, CN, NaCl, H_2CO, PS, PN...
- Maser lines: SiO and H_2O
- Tentative detections: KCN, NaCN ...

PRELIMINARY RESULTS: OH231.8+4.2 VS IKTAU



PRELIMINARY RESULTS: OH231.8+4.2 VS IKTAU



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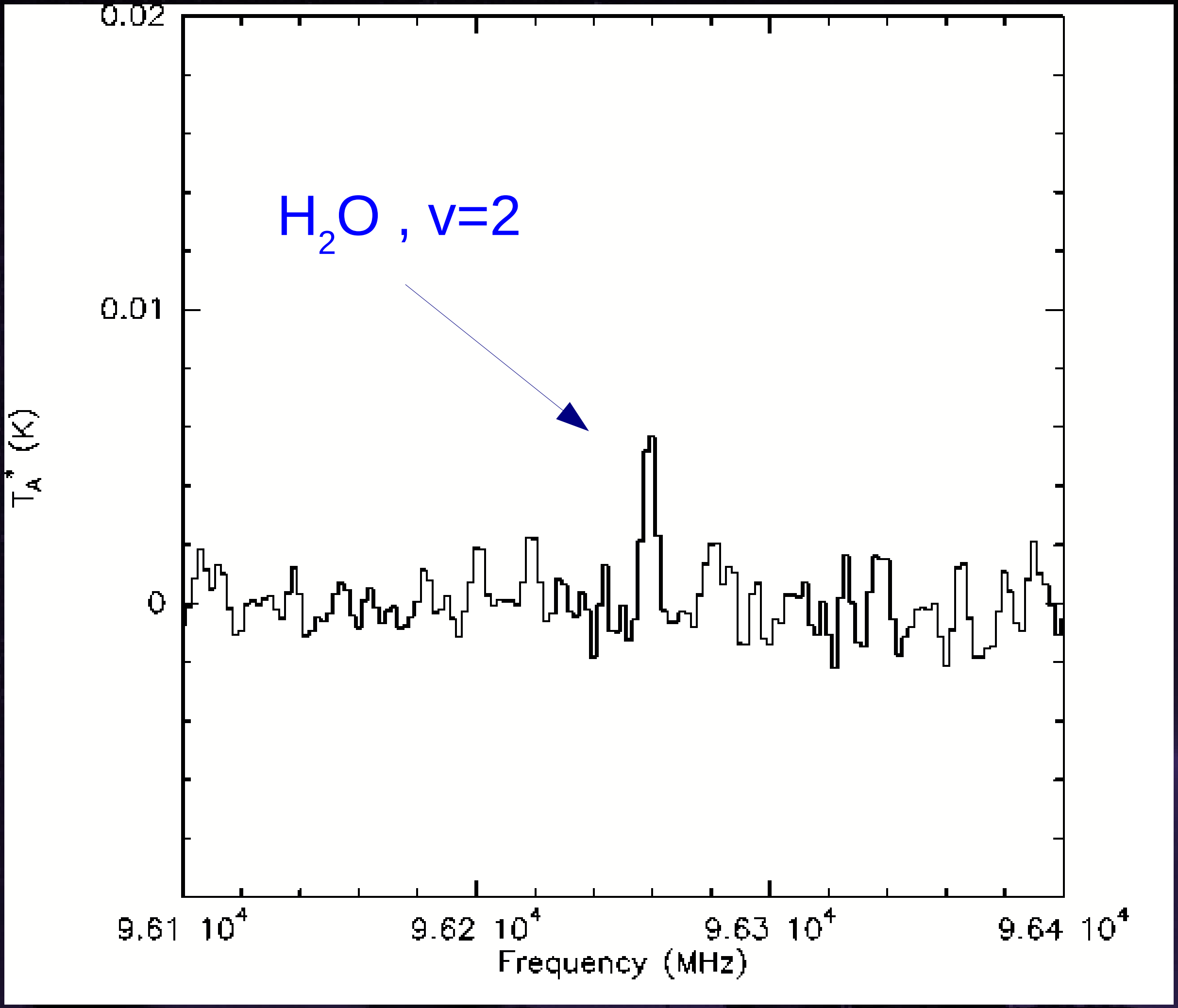

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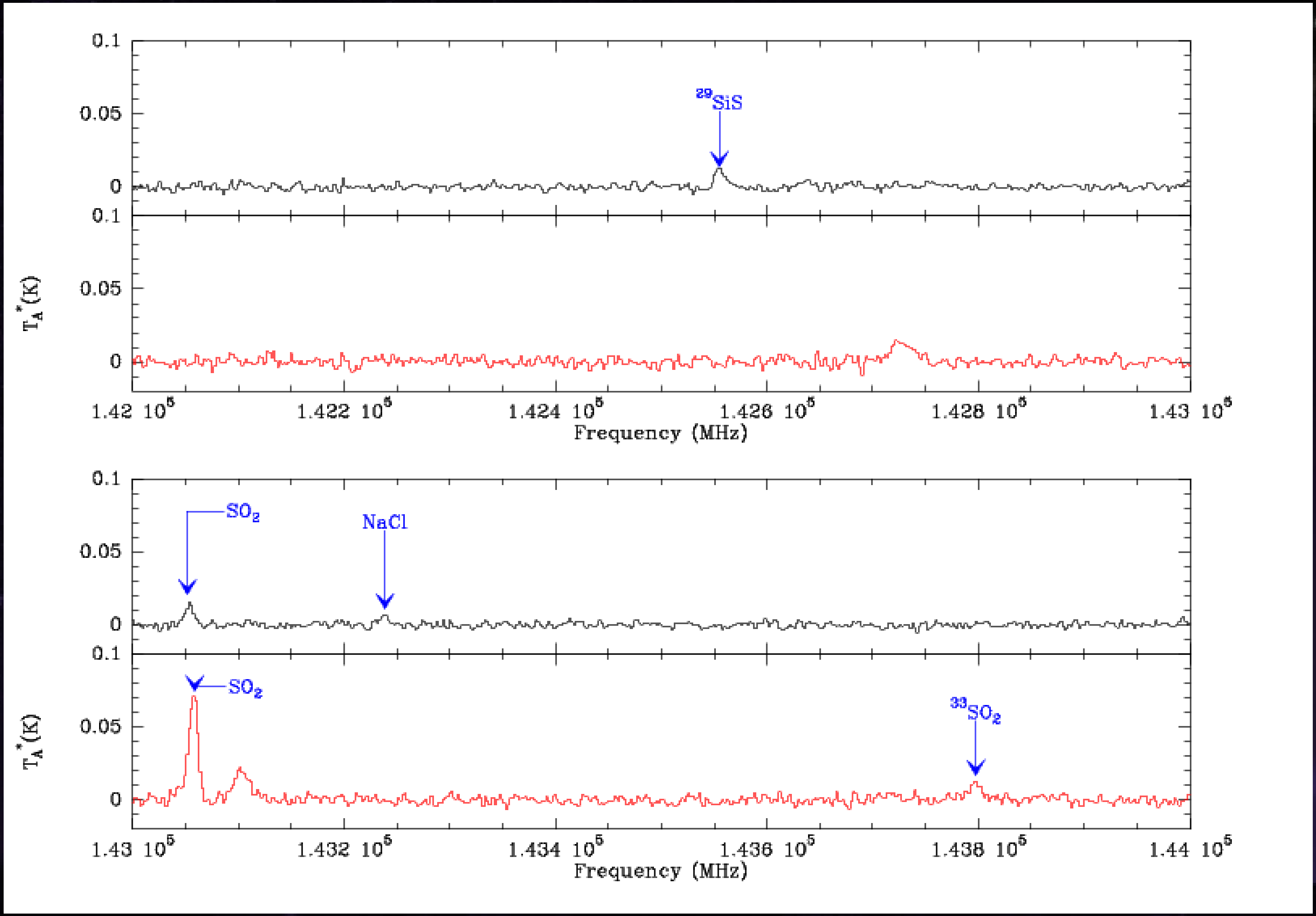
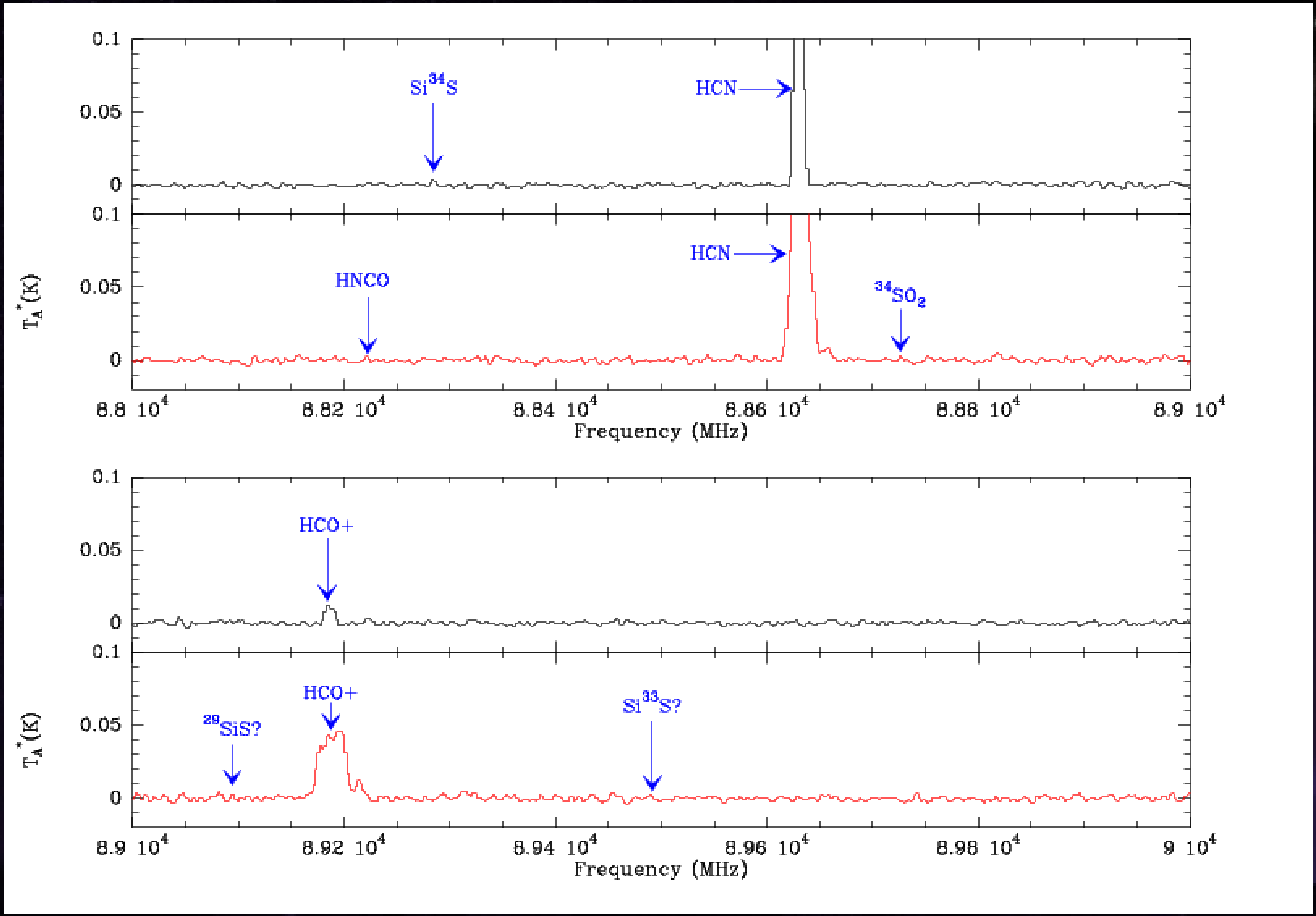
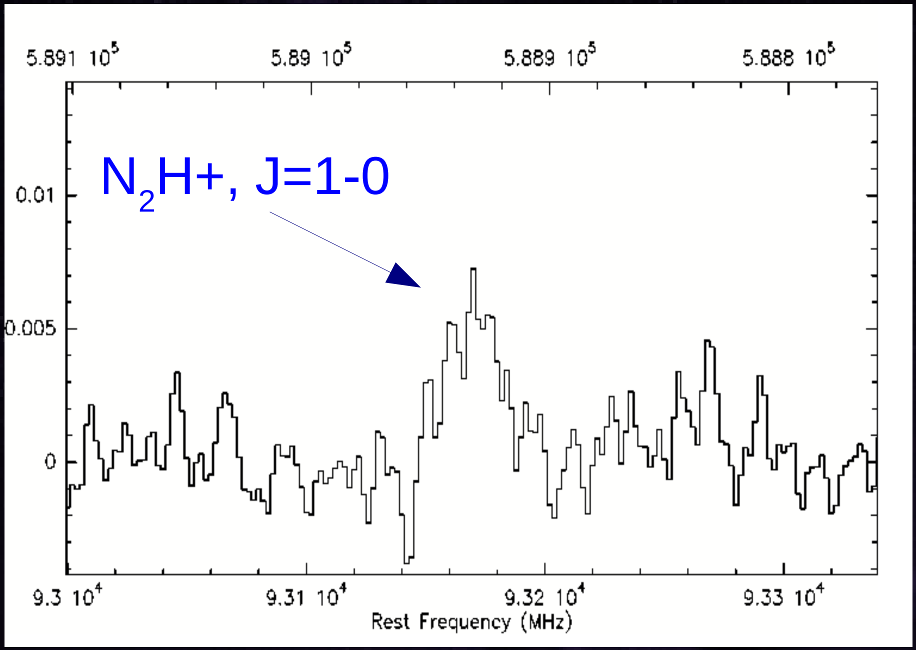


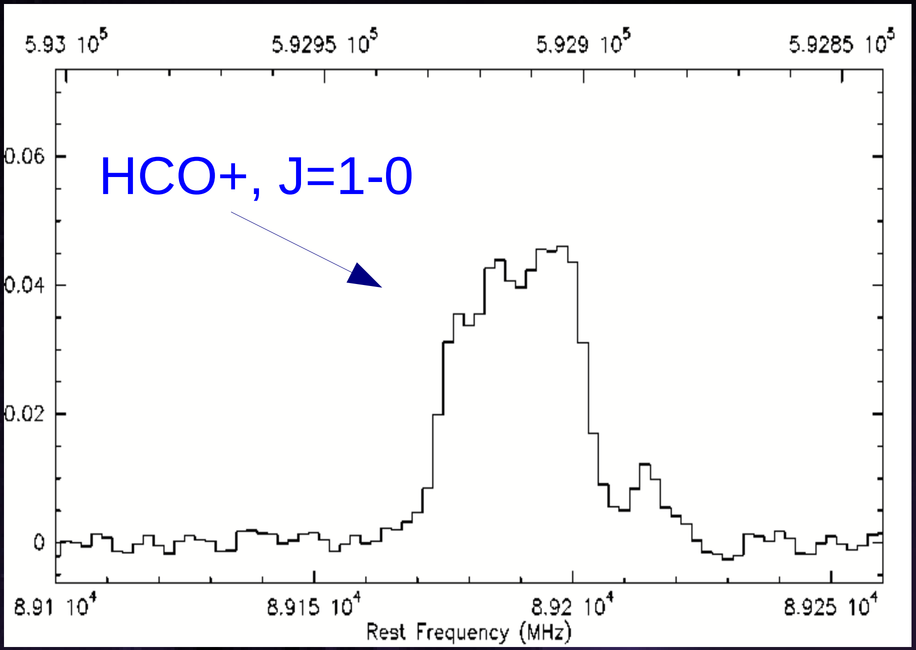
PRELIMINARY RESULTS: OH231.8+4.2 VS IKTAU



PRELIMINARY RESULTS: OH231.8+4.2 VS IKTAU

- Broad profiles of ion lines:





PRELIMINARY ABALYSIS: ABUNDANCES

- 1st order characteristics abundances based on simple LTE calculations
- We assume this:

$X(^{13}CO) \sim 2 \times 10^{-5}$ $T_{rot,\ OH231} \sim 20$ K $T_{rot,\ IKTAU} \sim 20$ K

Molecule	OH231 Abundance	IKTau Abundance
SO_2	3×10^{-6}	4×10^{-7}
SO	2×10^{-6}	4×10^{-7}
H_2S	1.7×10^{-6}	***
HCN	3.4×10^{-8}	1.3×10^{-7}
HNCO	3.1×10^{-8}	$< 4 \times 10^{-9}$
HCO+	1.6×10^{-8}	4×10^{-9}
HNC	1.5×10^{-8}	4×10^{-9}
HC_3N	3×10^{-9}	$< 4 \times 10^{-9}$
N_2H+	2×10^{-9}	$< 1 \times 10^{-9}$

QUALITATIVE ANALYSIS

- OH231.8 + 4.2 shows:

Less abundant SiO lines (compared with IKTau)

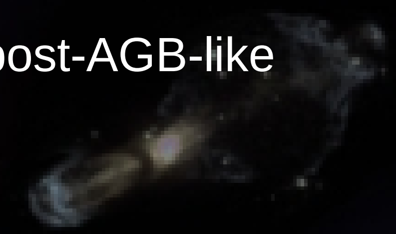
No NaCl or H_2O lines

→ Probably low density at the inner parts of the envelope

More abundant ions lines

→ Shock induced chemistry

SUMMARY



- OH231.8+4.2 is a peculiar object: AGB central star + A0V companion + post-AGB-like envelope
- Fast winds & shocks
- Chemistry predominantly affected by shocks

FUTURE WORK:

- Complete the survey
- Complete identification
- Derive X(r) ⟶ from non-LTE radiative transfer model using more realistic structure of the envelope
- Comparison with predictions from chemical models