SOFIA observations of far-infrared hydroxyl emission toward classical ultracompact HII/OH maser regions

T. Csengeri, K. Menten, M. A. Requena-Torres, F. Wyrowski, R. Güsten,
H. Wiesemeyer, H.-W. Hübers, P. Hartogh, and K. Jacobs

Max Planck Institute for Radioastronomy, Bonn

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SOFIA Early Science, Csengeri et al. (2012) A&A 542, L8

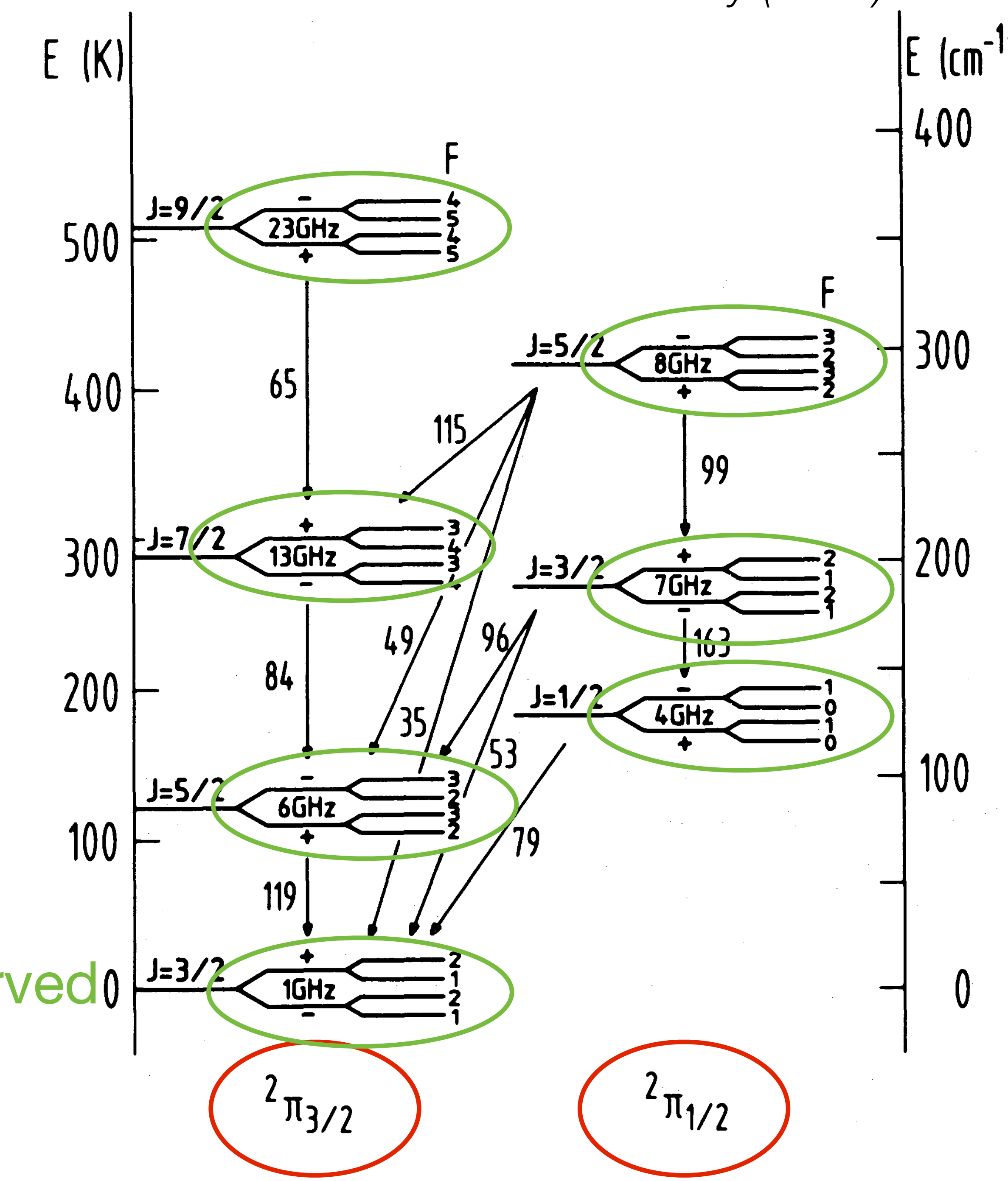
Outline

- Why to care about OH emission?
  - One of the first molecules detected in the radio: OH
  - The OH molecule can constrain the H_2O chemistry
- Rotational lines of OH: in the far-IR - compared to Herschel/HIFI, SOFIA/GREAT reaches higher frequencies with good spectral resolution: *unexplored territory*
- OH observations in SOFIA Early Science
- Models: envelope models (RATRAN), OH radio lines (Cesaroni & Walmsley 1991 model)
- Conclusion of the Early Science project
- Outlook: OH observations from Cycle I

Radio lines of OH

- OH: first interstellar molecule detected at radio wavelengths (Weinreb et al. 1963)
- “18 cm radio lines” of OH identified (Weinreb et al. 1965)
- radio interferometry:
  - origin: maser spots (0.”05)
- Hyperfine structure (HFS) transitions from higher rotational levels have also been detected (4 to 23 GHz)

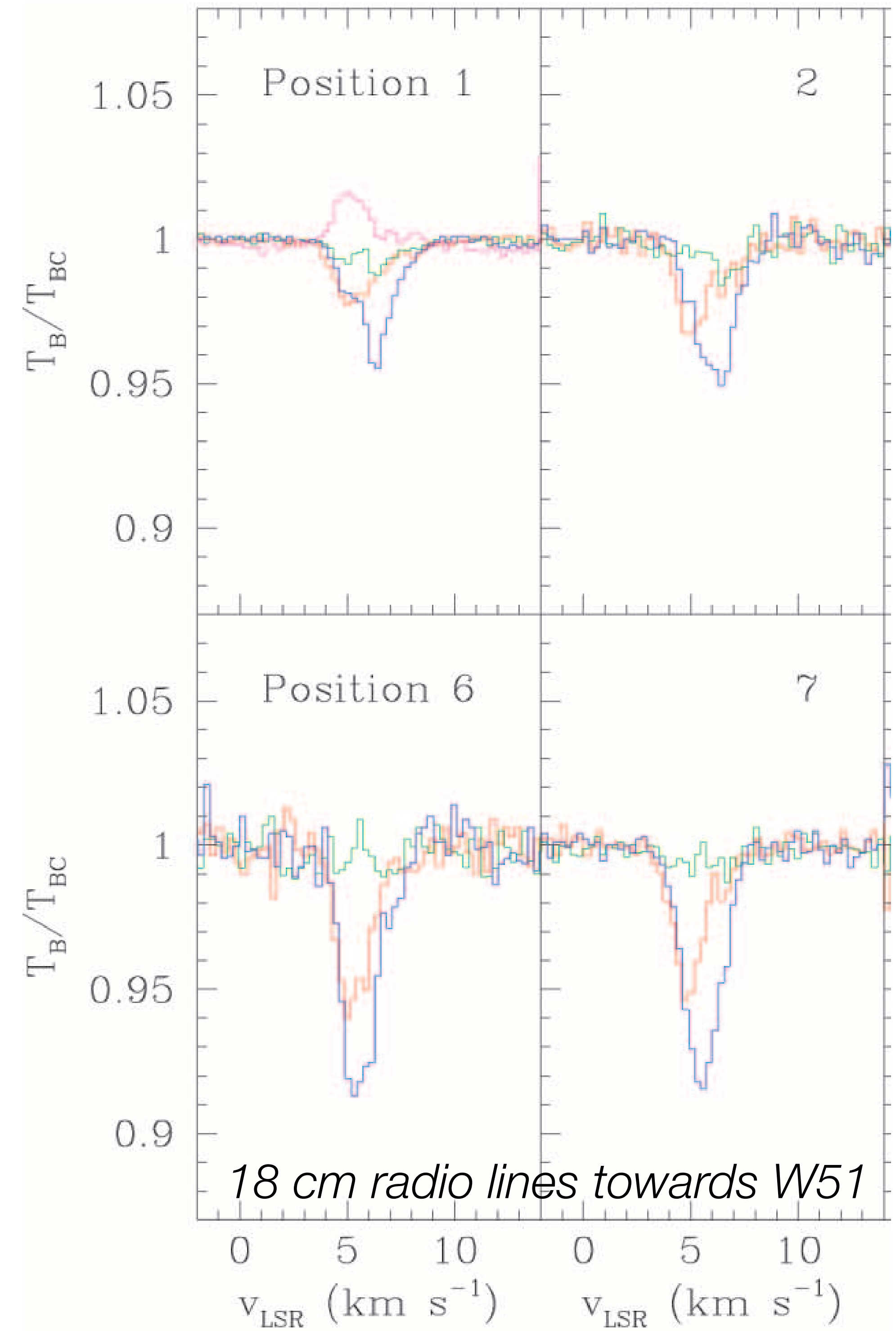
Cesaroni & Walmsley (1991)



Radio lines of OH: anomalous HFS ratio

- Radio HFS lines of OH are not in LTE
  - anomalous HFS ratio
  - emission and absorption
  - stimulated emission (masers)
- Very high critical density ($n>10^8$ cm^{-3})
- Transitions between the HFS levels are sensitive to the far-IR radiation field, and the density
  - ➡ sensitive tracers of the physical conditions
- Excitation mechanism not well understood

Neufeld et al. (2002)

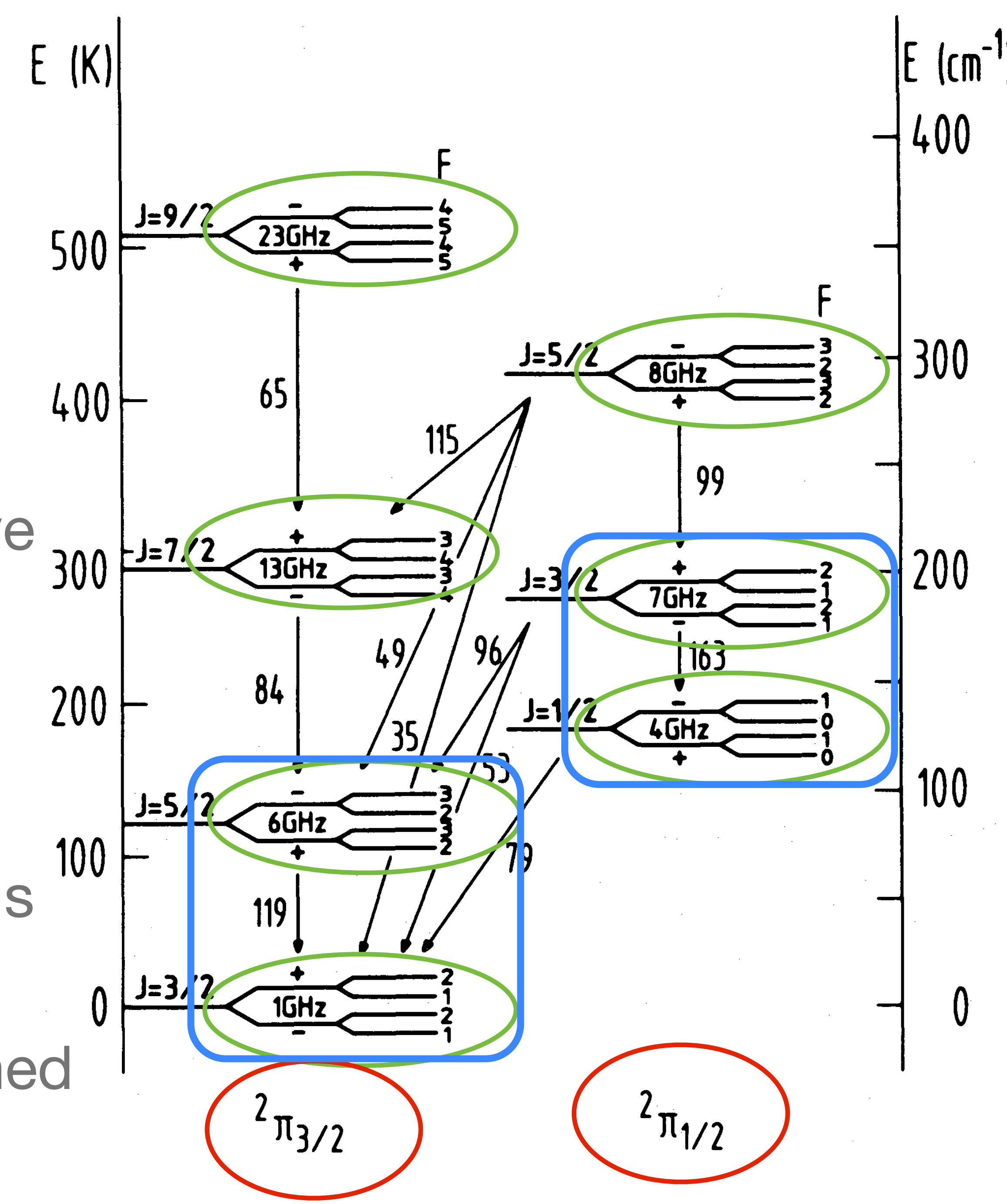


18 cm radio lines towards W51

Excitation conditions of OH

- Two ladders:
  different mechanisms are important for masing
  - $2\Pi_{1/2}$ ladder: *collision*
  - $2\Pi_{3/2}$ ladder: *radiation*
- maser emission in $2\Pi_{3/2}$ ladder: radiative excitation + collisional de-exctation
- far-IR line overlap + radiative pumping:
  - problematic to models
- Cesaroni & Walmsley (1991): OH models revisited
- ultimately N(OH) and X(OH) is constrained

Cesaroni & Walmsley (1991)

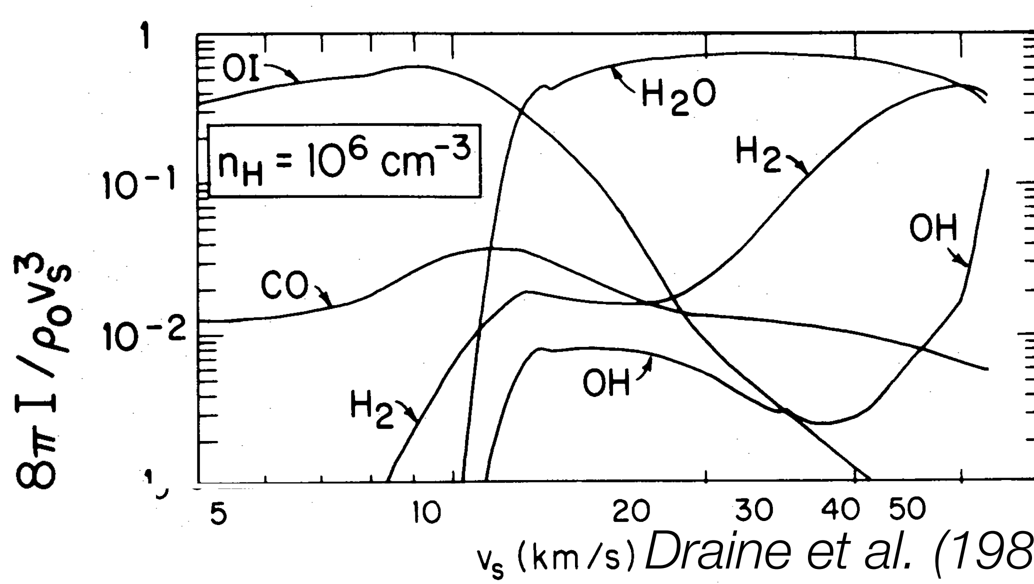


OH is chemically related to water

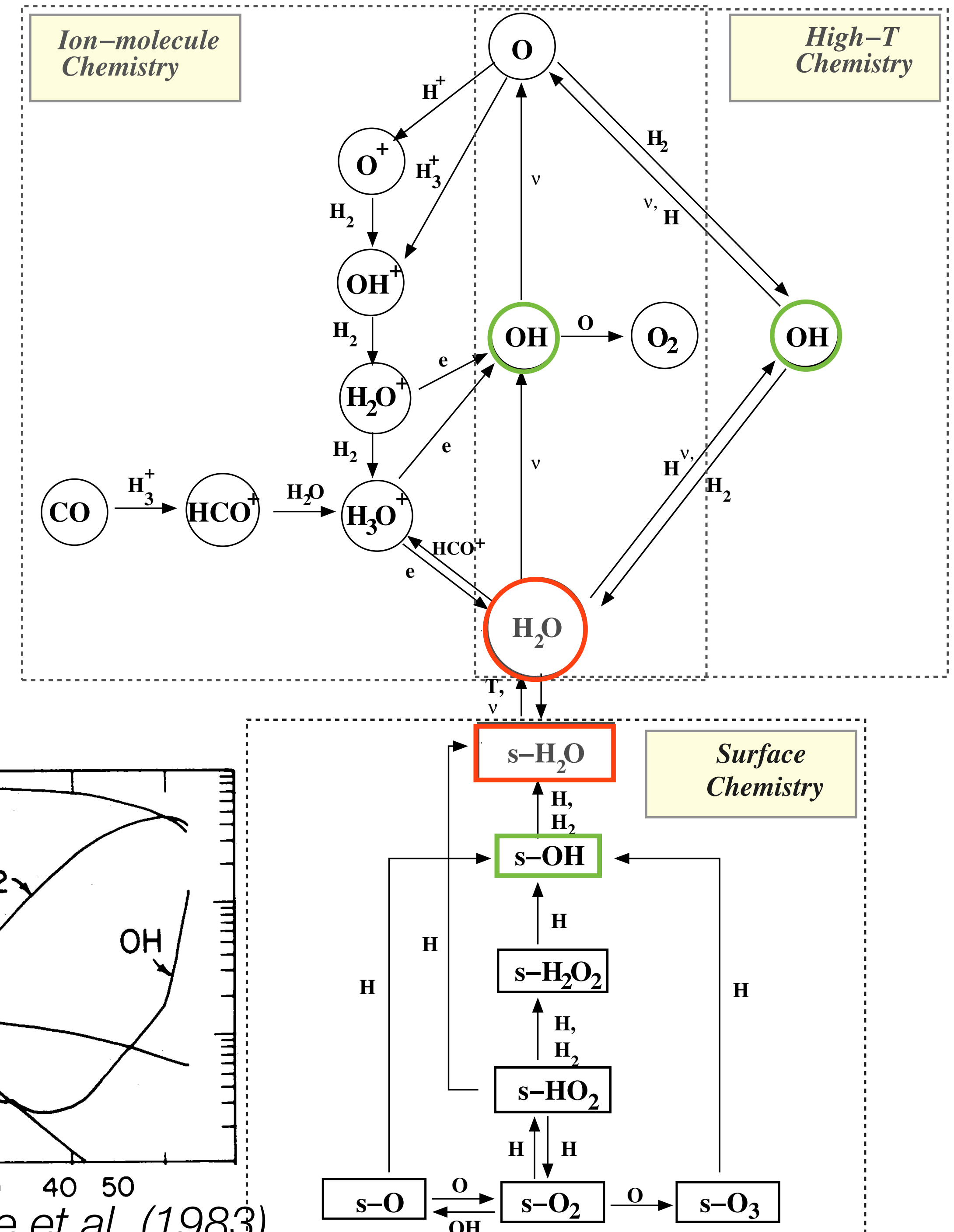
- The hydroxyl radical (OH) is closely linked to H_2O
- formation and destruction:

  $OH + H_2 \Leftrightarrow H_2O + H$

- byproduct of the H_2O photodissociation process in the presence of UV photons.
- OH can constrain the water chemistry
- important cooling line of the ISM (among [O I], [C II], CO, H_2O)
- constrain the cooling budget of shocks



Draine et al. (1983)

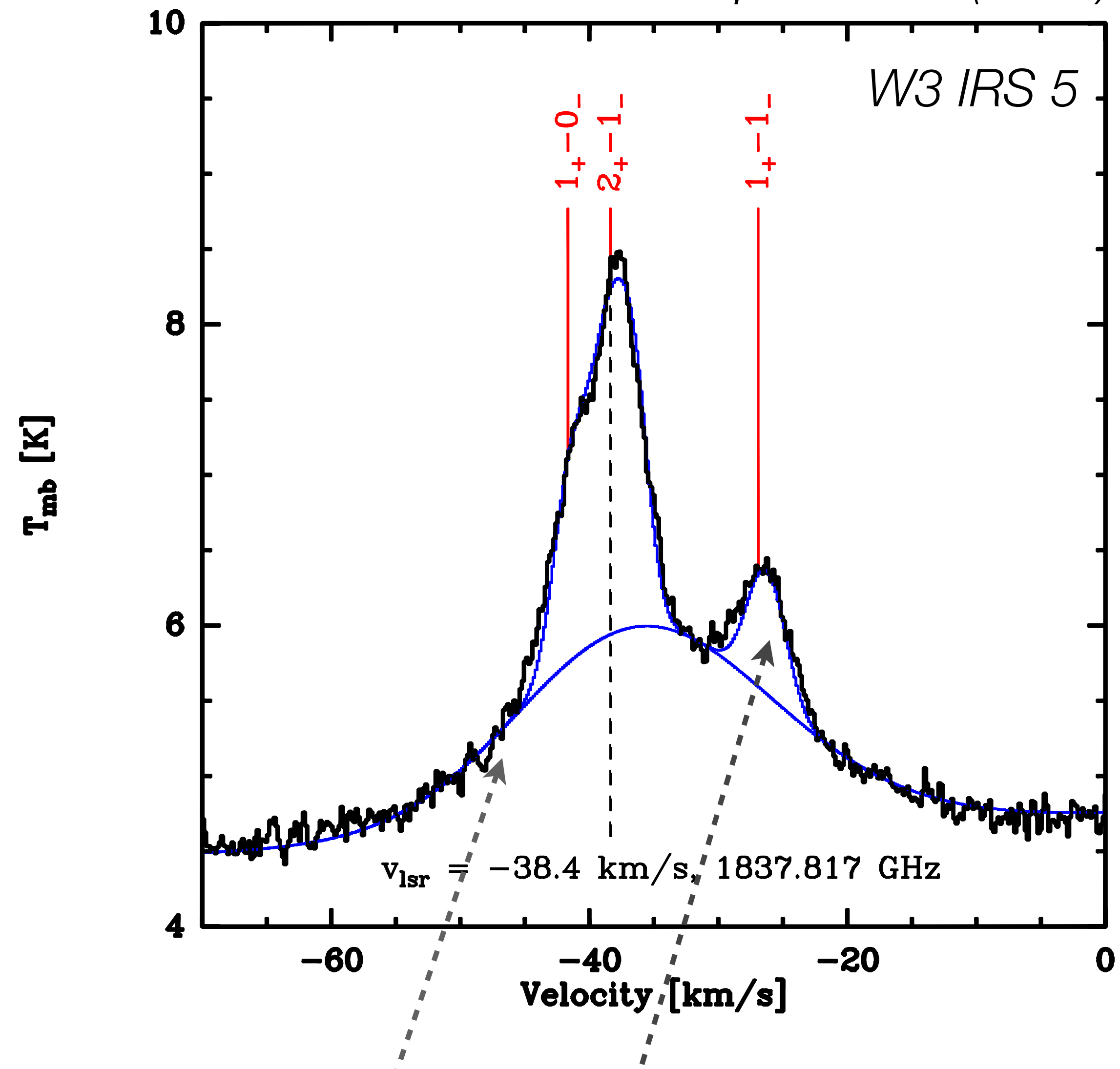


van Dishoeck et al. (2011)

Observations of the rotational lines of OH

- First observations of the far-IR OH lines: KAO and ISO
- Herschel/PACS
- But...OH is detected in various environments: maser spots, envelopes, shocks
    - ➡ the line profile needs to be spectrally resolved to distinguish between broad/ narrow component
    - ➡ the HFS lines to study LTE conditions
- Herschel/HIFI: first spectrally resolved OH lines (163.1 µm)
- OH/H_2O ratio: constrain chemistry

Wampfler et al. (2011)

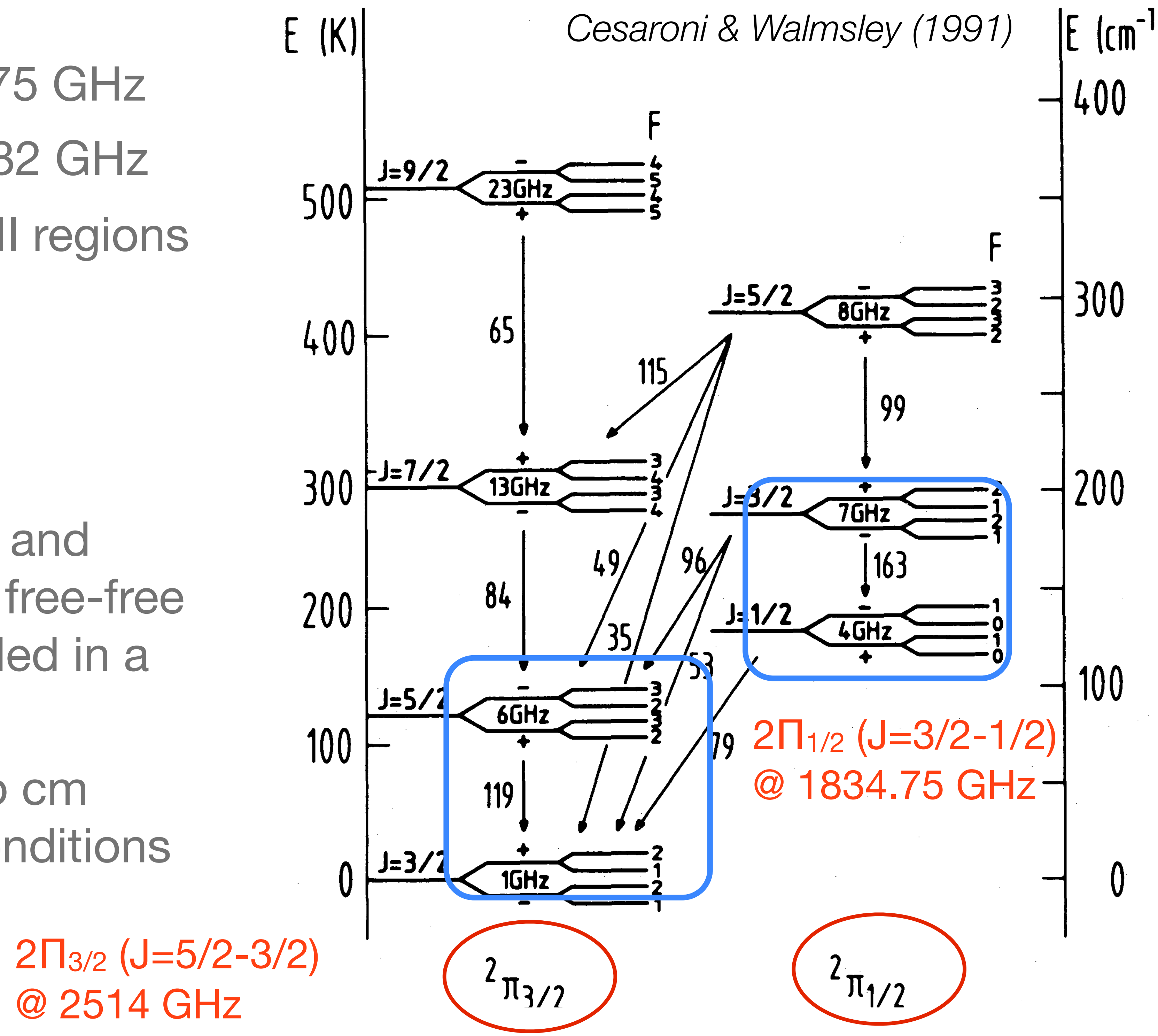


broad + narrow component:

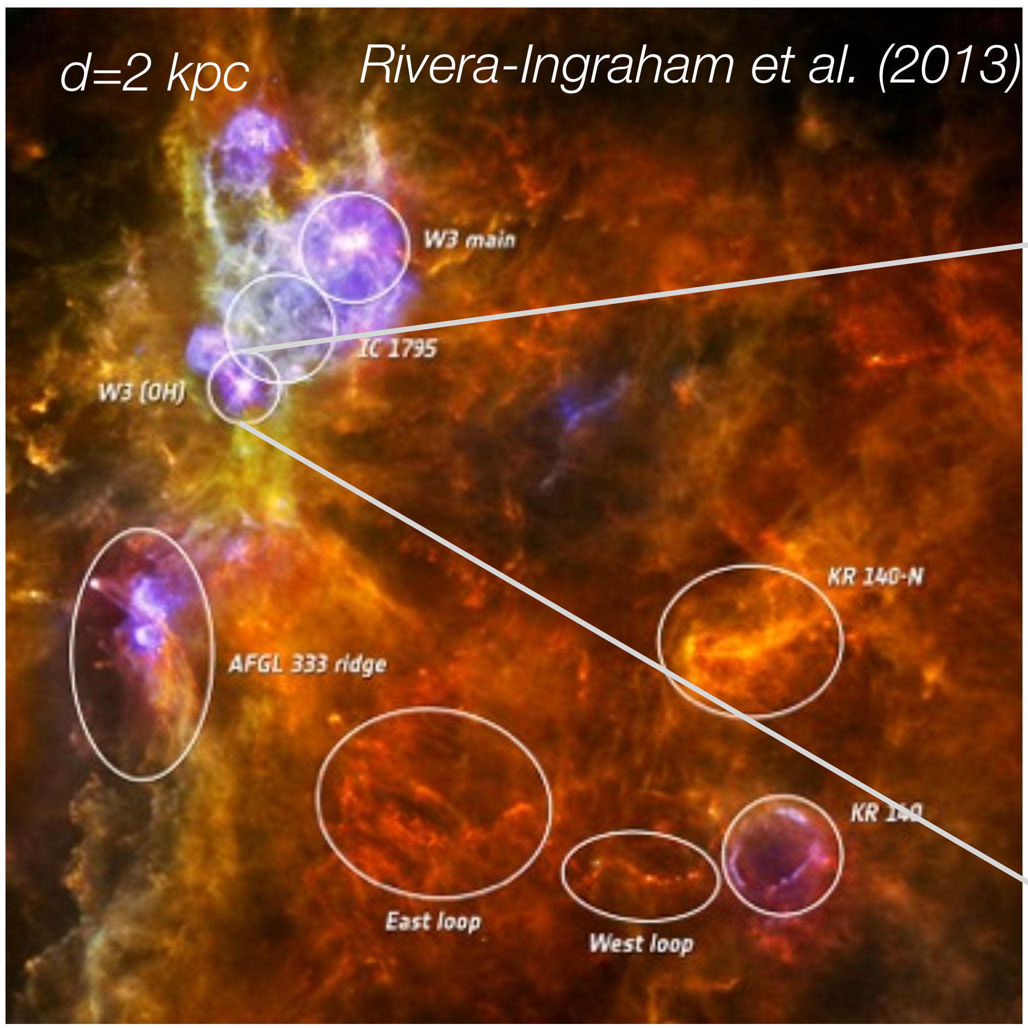
outflow+envelope origin

Motivation

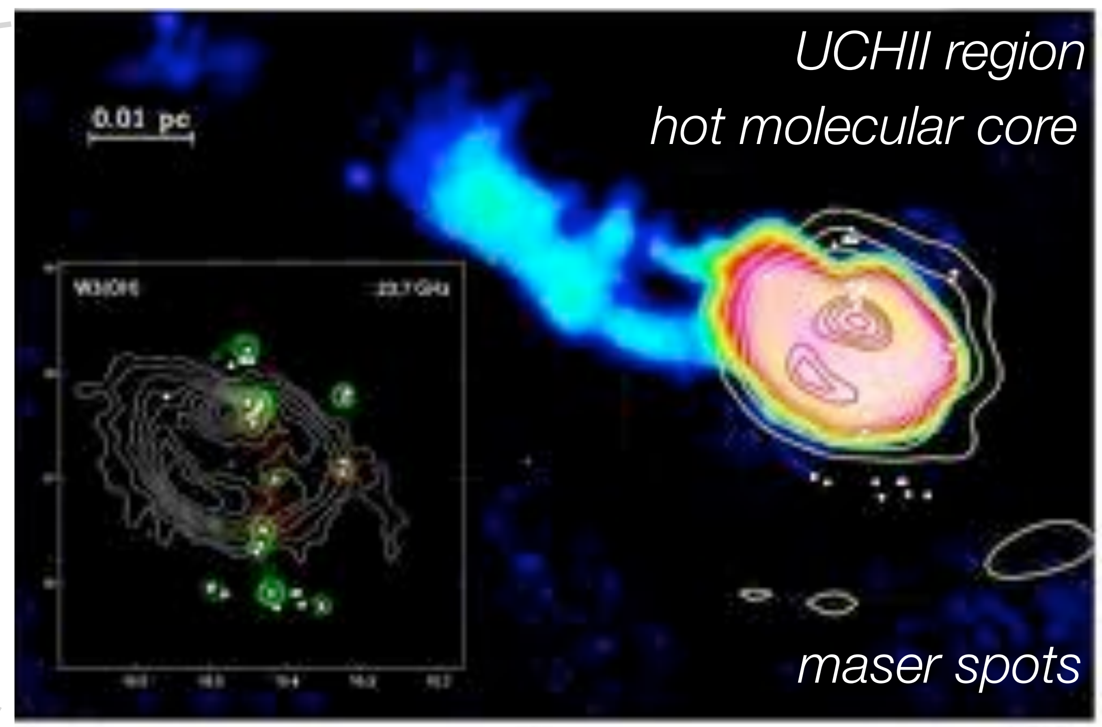
- $2\Pi_{1/2}$ (J=3/2-1/2) @ 1834.75 GHz
  @ 1837.82 GHz
- Targets: (ultra) compact HII regions
  - W3(OH)
  - NGC7538 IRS1
  - G10.62-0.39
- (ultra) compact HII: young and compact sources of radio free-free emission, but still embedded in a dusty envelope
- Goal: combined with radio cm transitions the physical conditions can be constrained



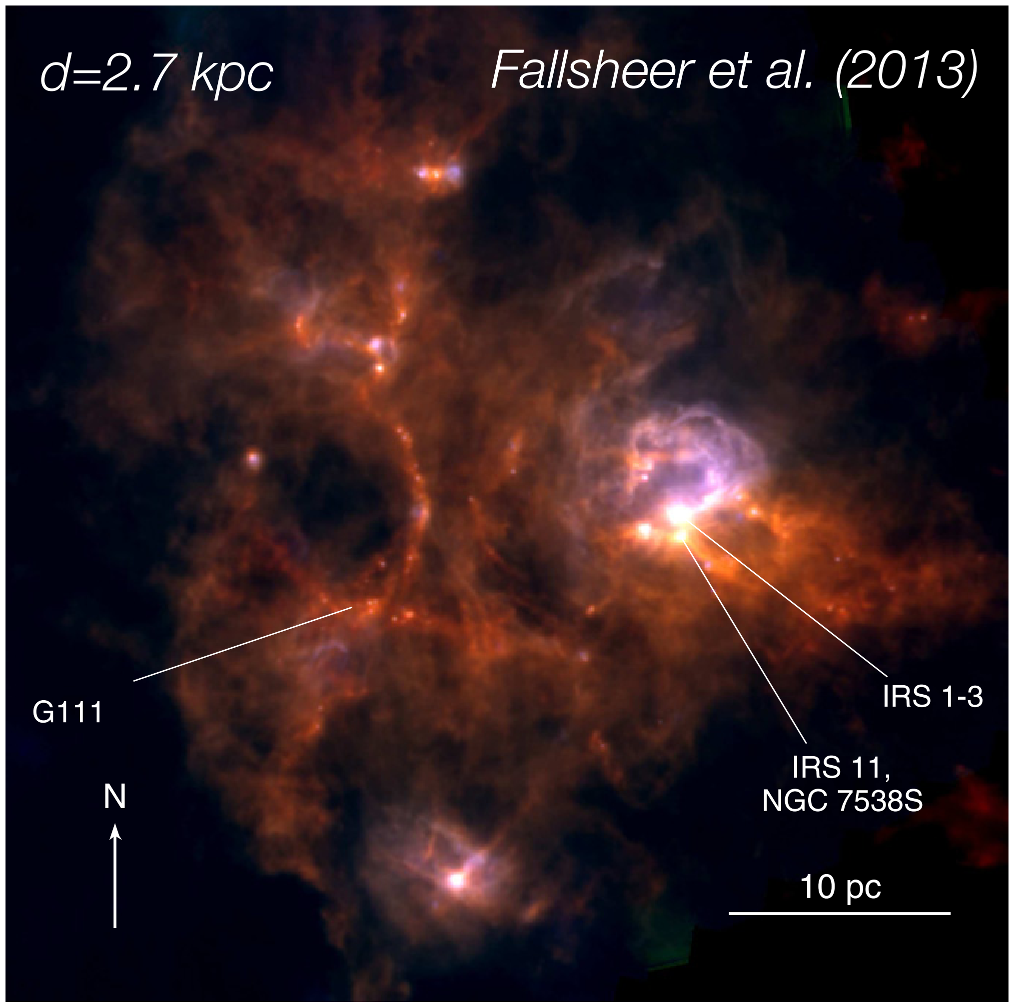
Typical UC-HII regions: W3(OH)



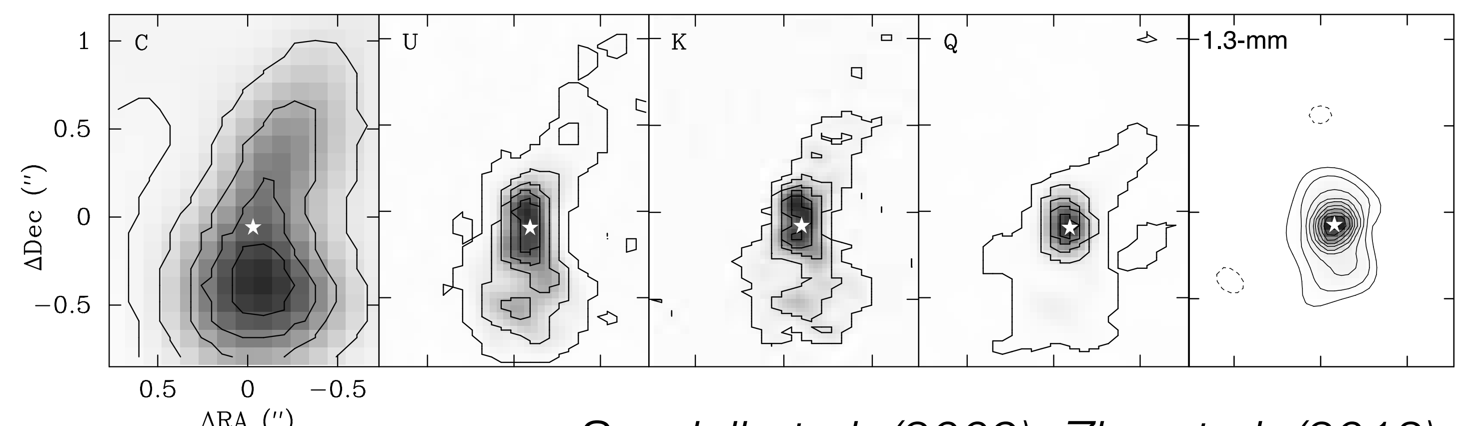
- W3 Giant Molecular Complex (*Herschel)*
- W3(OH) at high angular-resolution:



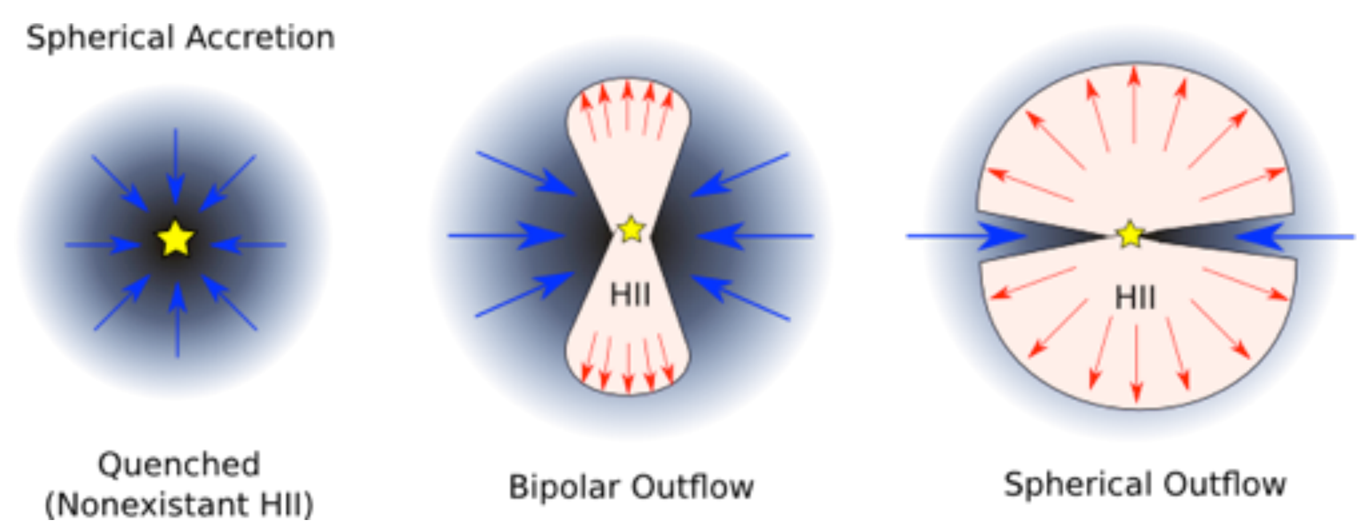
Typical UC-HII regions: NGC 7538



- NGC 7538 complex
- NGC7538 IRS 1 source: radio emission from ionized, collimated jet (HCHII region) + dust cores



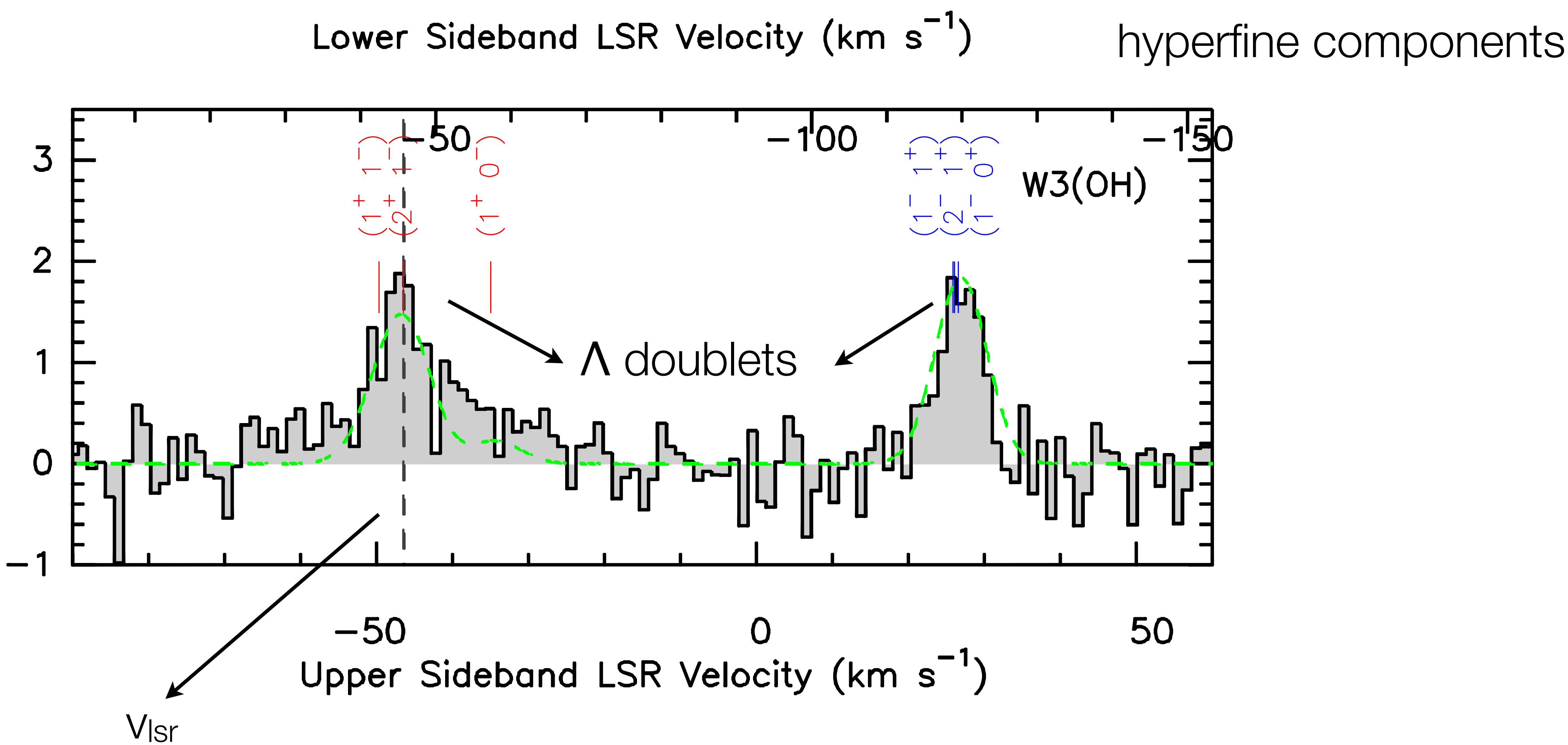
Sandell et al. (2009), Zhu et al. (2013)



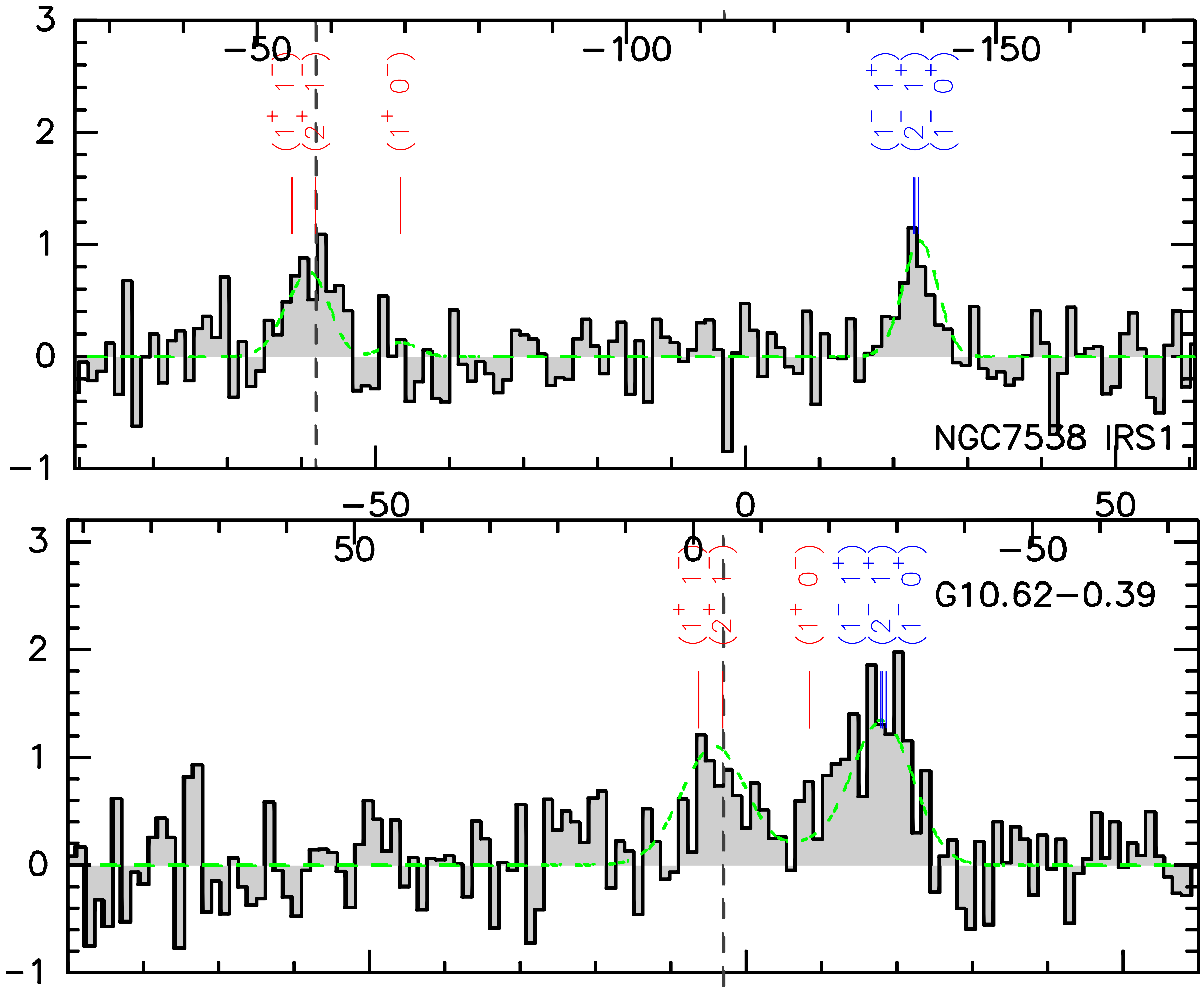
- The targeted sources probe the latest stage of the early evolution of high-mass (proto)stars

SOFIA/GREAT spectra – **W3(OH)**

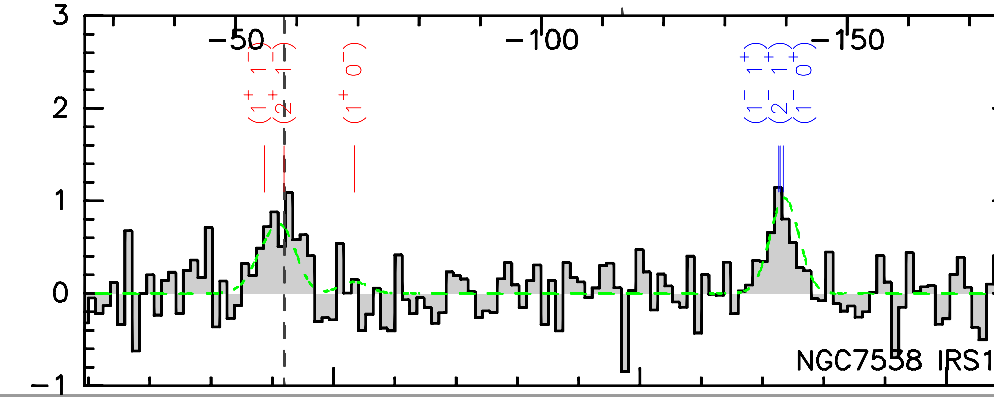
- SOFIA/GREAT: DSB receiver ➡ both the 1837 and 1834 GHz lines can be recorded!



SOFIA/GREAT spectra – **NGC7538 IRS1, G10.62-0.39**

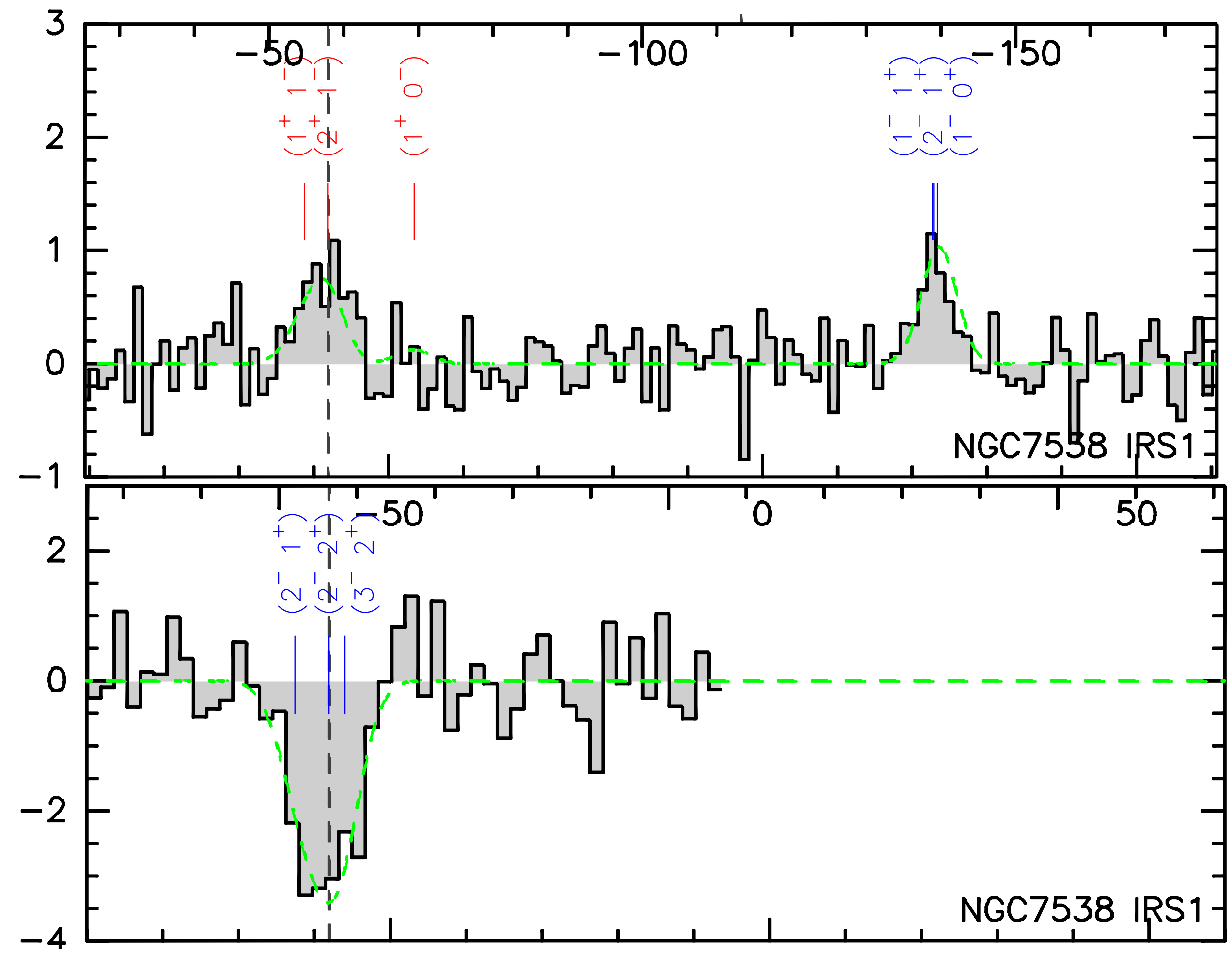


OH line parameters



- Gaussian line profiles
- HFS fit to the spectra in CLASS:

Source	Position		$T_{mb,RJ}$	v_{lsr}	Δv	Total τ	T_{ex}
	RA[J2000]	Dec[J2000]	[K]	km s^{-1}	km s^{-1}		[K]
W3(OH)	02:27:03.90	61:52:24.6	1.83 ± 0.34	–45.70 ± 0.31	7.54 ± 0.87	0.1–2	40.2–5.1
G10.62–0.39	18:10:28.64	–19:55:49.5	1.34 ± 0.29	–3.17 ± 0.51	9.50 ± 1.15	0.1–5	30.2–3.7
NGC7538 IRS1	23:13:45.36	61:28:10.5	1.04 ± 0.34	–57.80 ± 0.43	5.46 ± 1.00	0.1–5	24.1–3.5



- S/N of the data allows a rough estimate of these parameters
- Line parameters consistent with Plume et al. (1997)

  ➡ origin of dense turbulent medium

- presence of a broad component?

  < 0.4 K

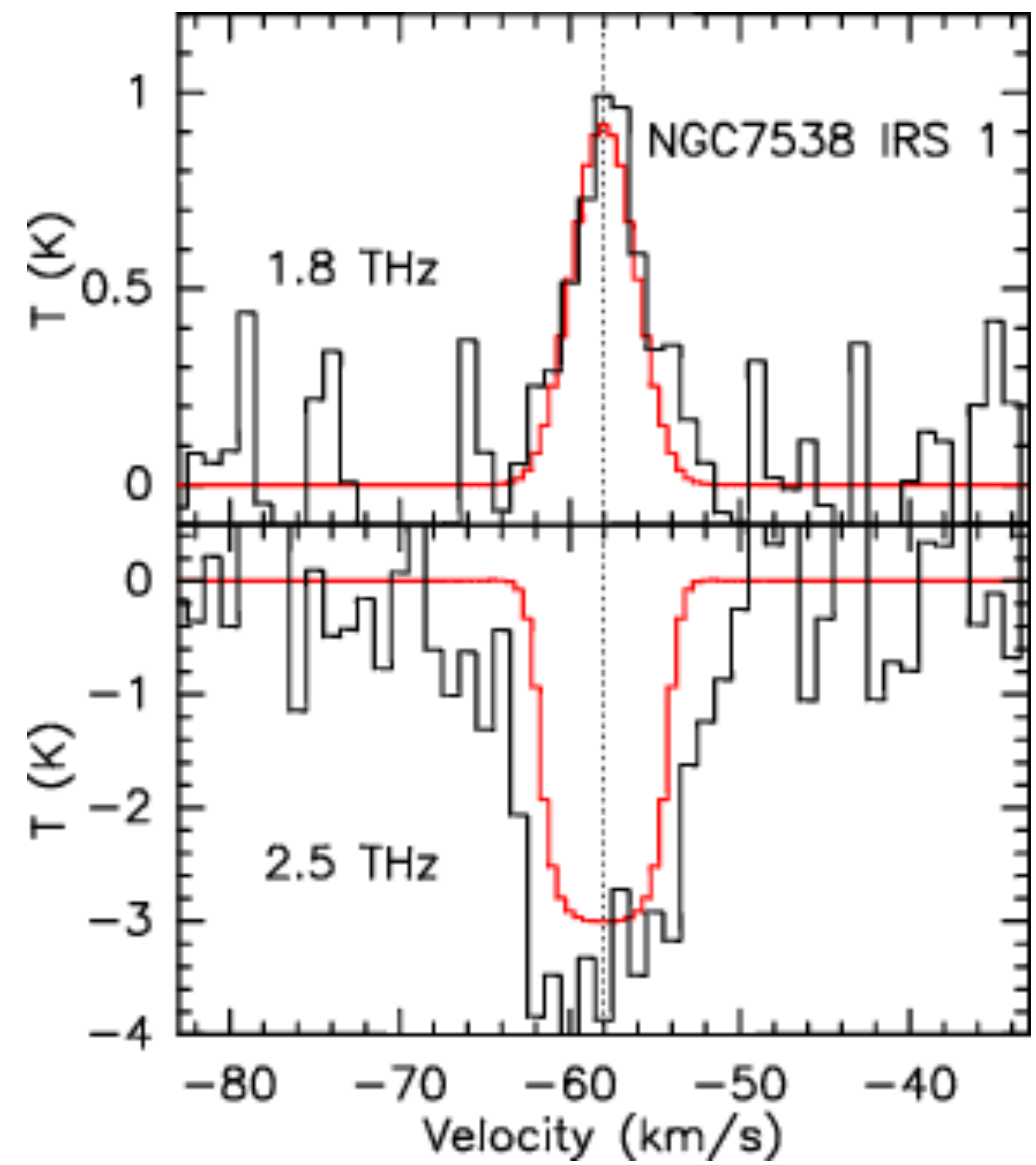
- 2.5 THz line observed in absorption towards NGC7538 IRS1

Models: NGC7538 IRS 1

- OH: very high critical density
  - ➡ $n > 10^8$ cm^{-3}, LTE may not apply
- Envelope model: RATRAN

Hogerheijde & van der Tak (2000)

- Dust parameters:
  - L = 1.3 x 10^5 $L_\odot$ *van der Tak et al. (2000)*
  - n_0=5.3 x 10^4 cm^{-3}; p = -1.0
  - X(OH) = 0.8 x 10^{-8}
- RATRAN does not treat line overlap and overlap effects
- good fit to the observed lines!

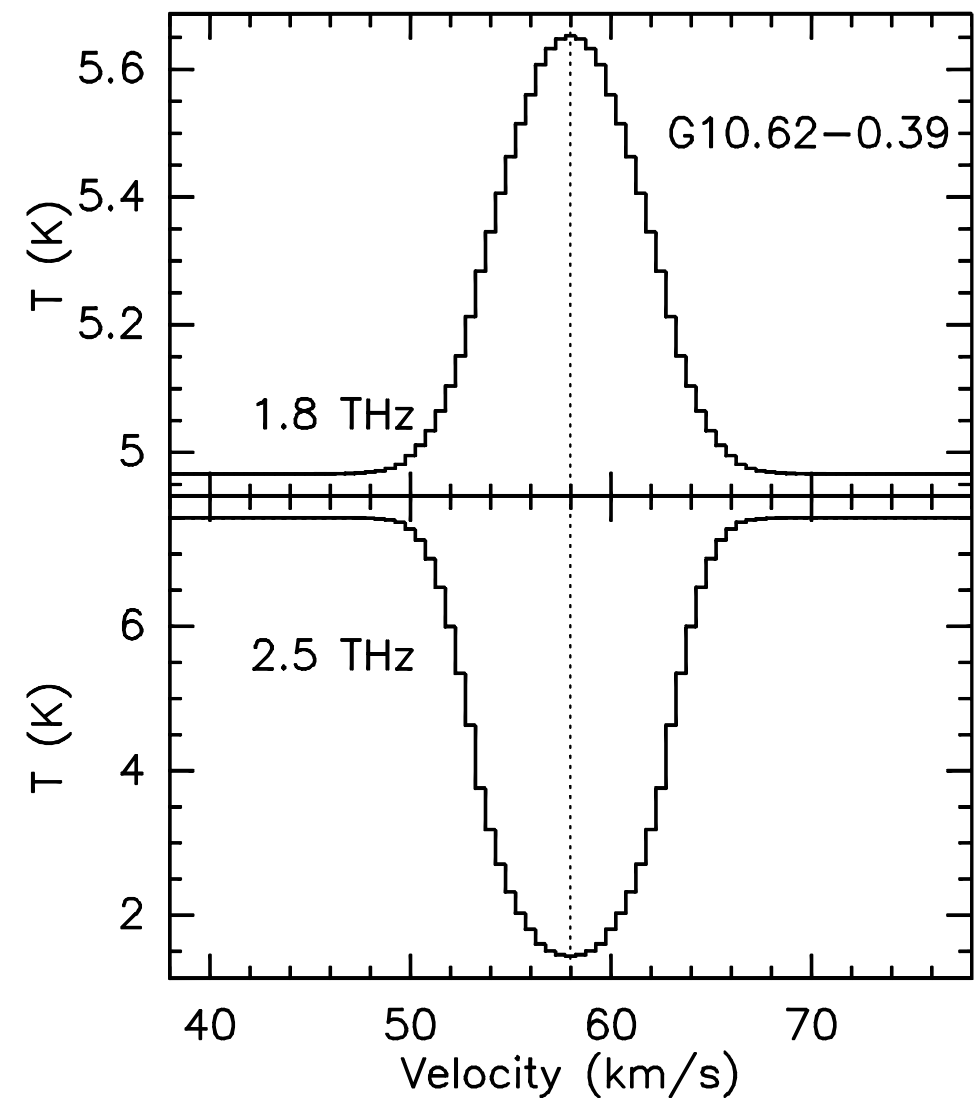


OH emission in NGC7538 IRS1: well reproduced by an envelope model!

Models: G10.6-0.39

- Envelope model: RATRAN

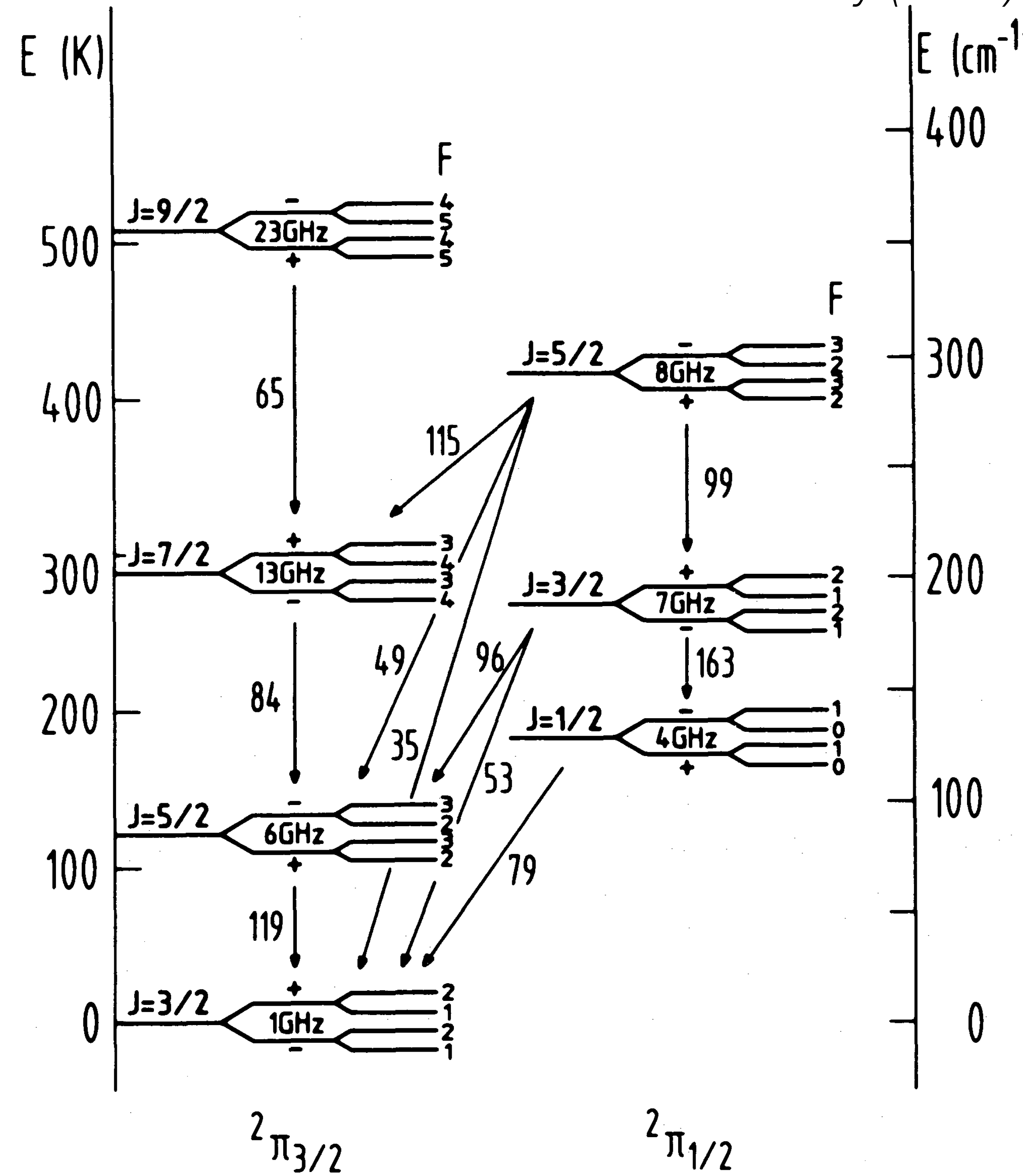
- Dust parameters: *van der Tak et al. (2000)*
  - $L = 1.3 \times 10^5\ L_\odot$
  - $n_0 = 5.3 \times 10^4\ cm^{-3}$; $p = -1.0$
  - $X(OH) = 0.8 \times 10^{-8}$
- underestimating the observed lines



Models considering the radio lines

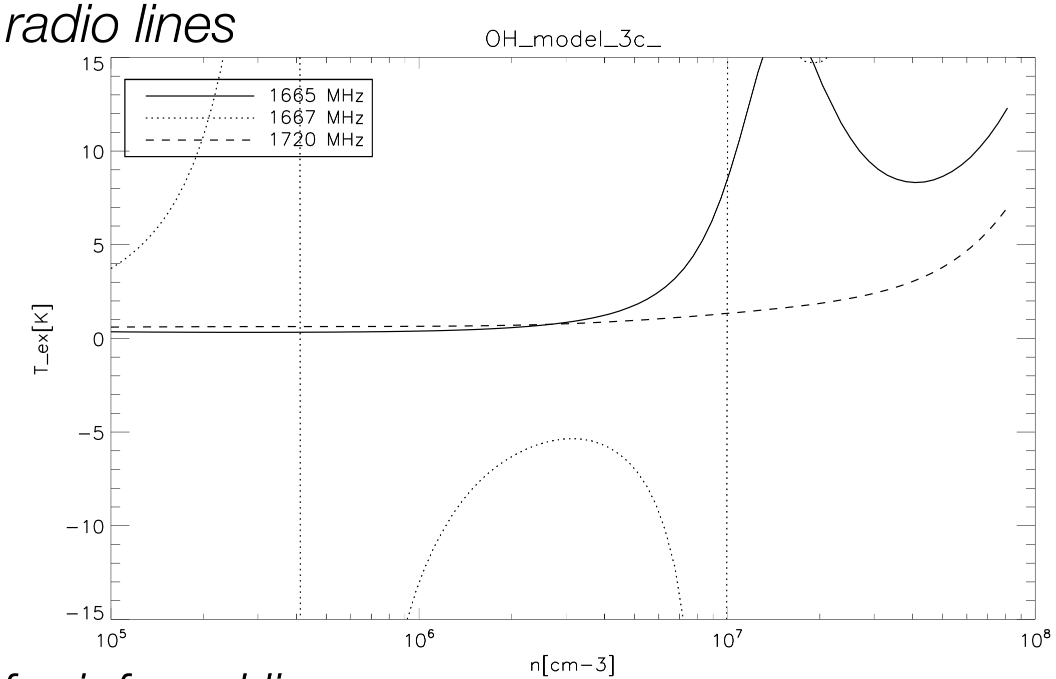
- the masing radio OH lines: transitions between the HFS levels are sensitive to the far-IR radiation field, effects of line overlap need to be considered
- Cesaroni & Walmsley (1991) LVG model:
  - far-IR radiation field
  - line overlap
- qualitatively explains the behavior of the radio lines

Cesaroni & Walmsley (1991)

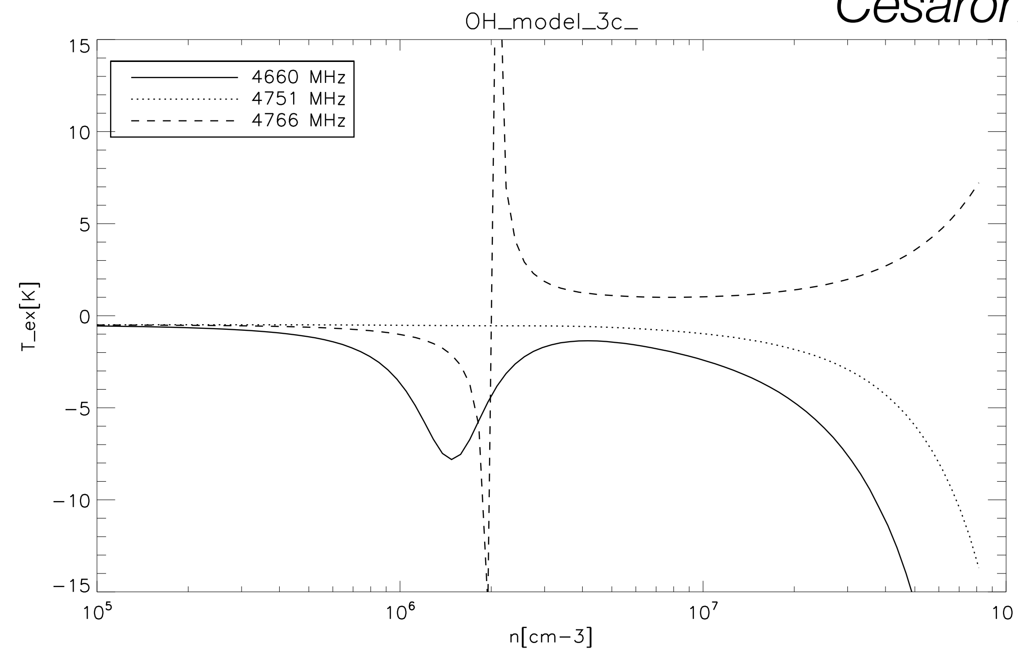


Models considering the radio lines

radio lines



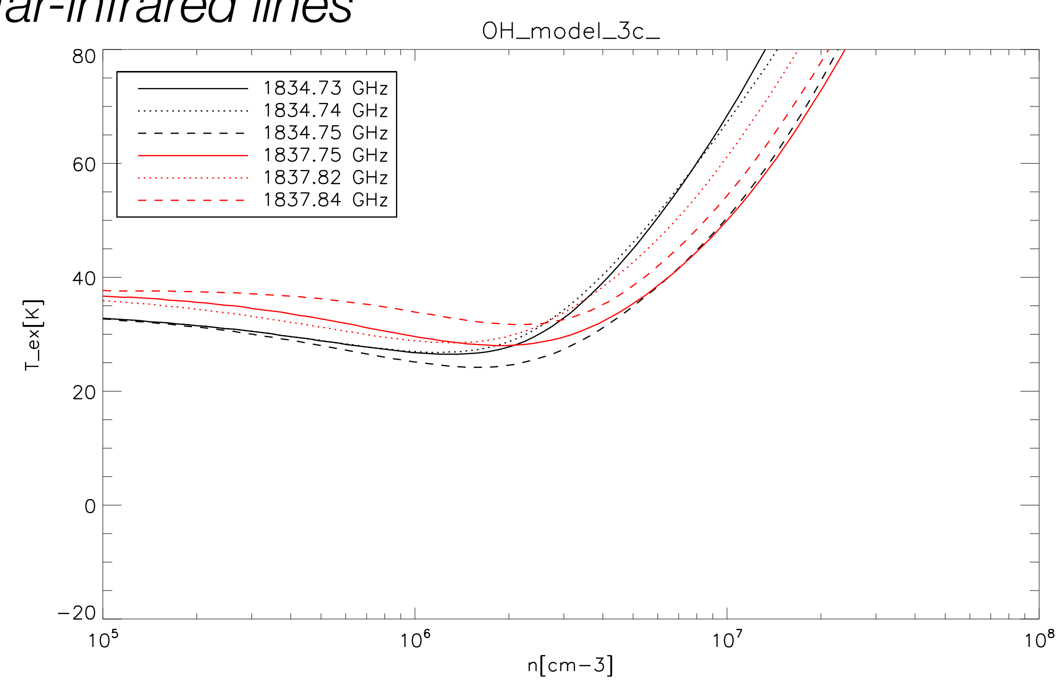
Cesaroni & Walmsley (1991)

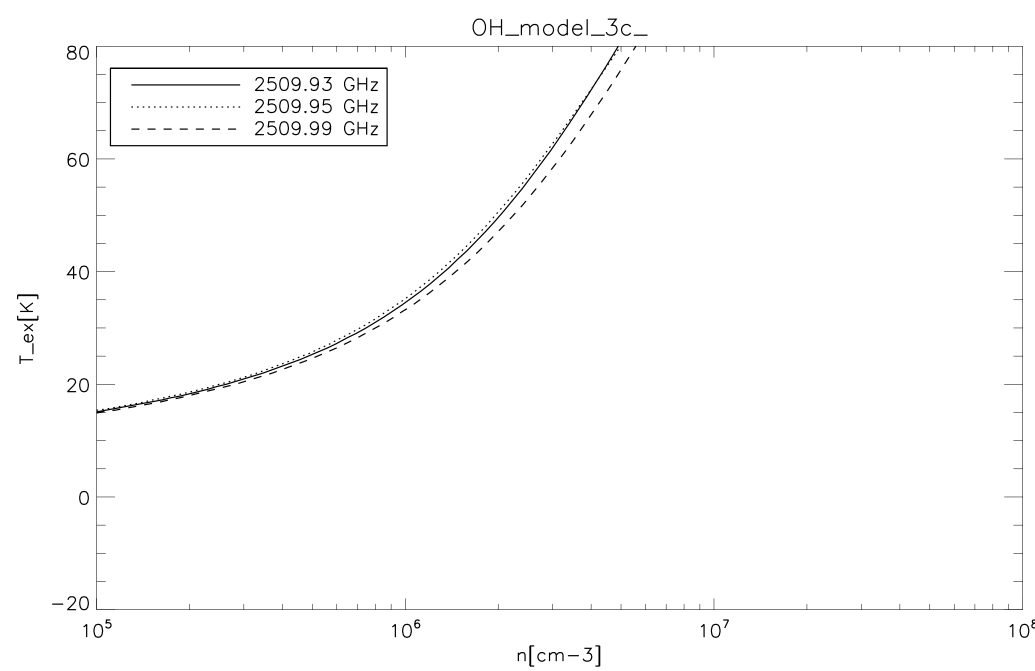


<u>models for W3(OH)</u>
$T_{dust} = T_{gas} = 151$ K
internal dust+line overlap

R=0.01 pc
200 km s^{-1} pc^{-1}
$X(OH) = 2 \times 10^{-7}$

far-infrared lines

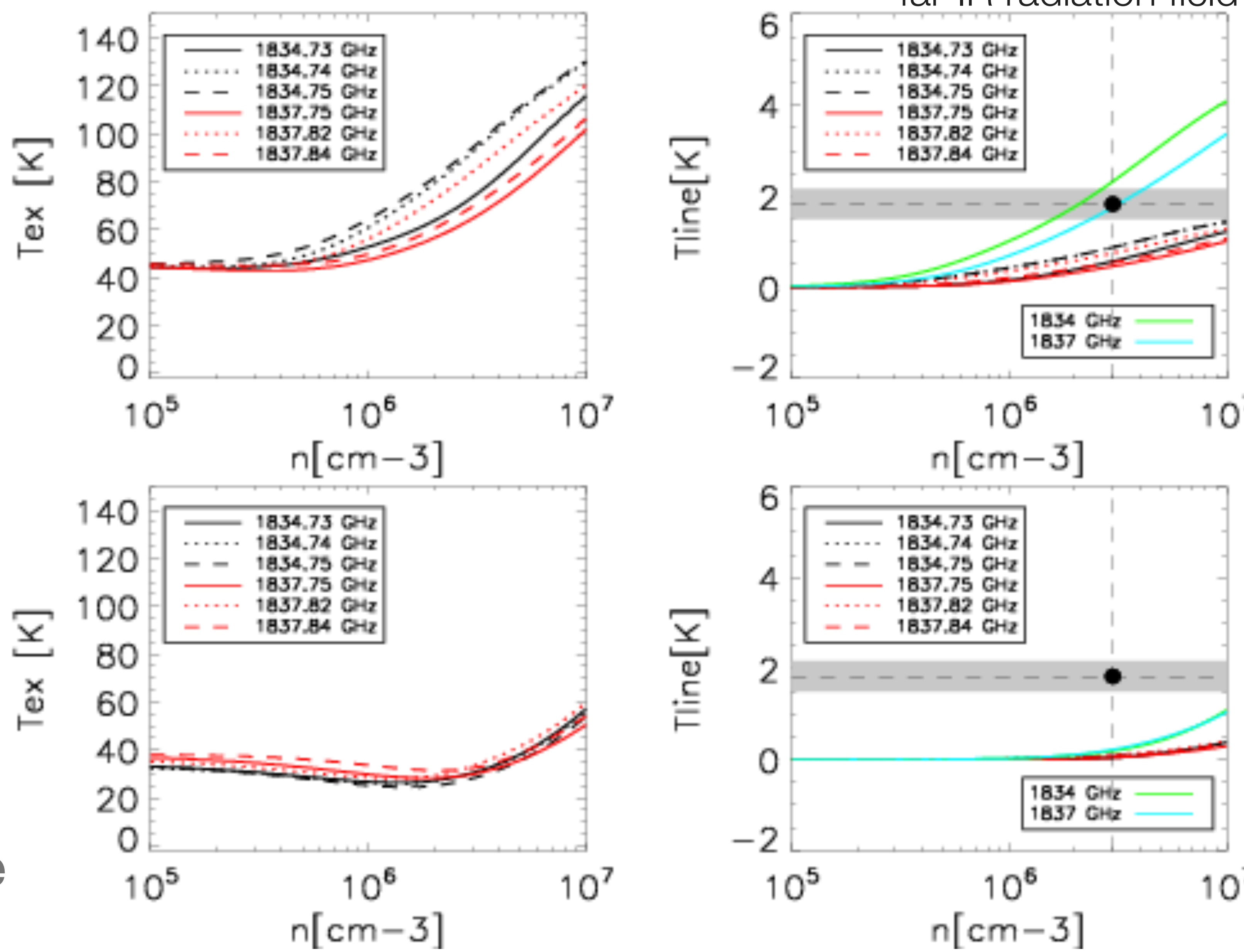




Models considering the radio lines

- Cesaroni & Walmsley model: qualitatively reproduce the radio OH lines for W3(OH)
- Including far-IR radiation field: good correspondence to the observed line intensities at n~2-3 x 10^6 cm^{-3}
- Excluding far-IR radiation field: underestimating the line intensity
- Considering the envelope component (RATRAN): underestimates the line intensity

far-IR radiation field



without far-IR radiation field

OH emission in W3(OH): from the UCHII region and not the nearby hot-core, W3(H_2O)!

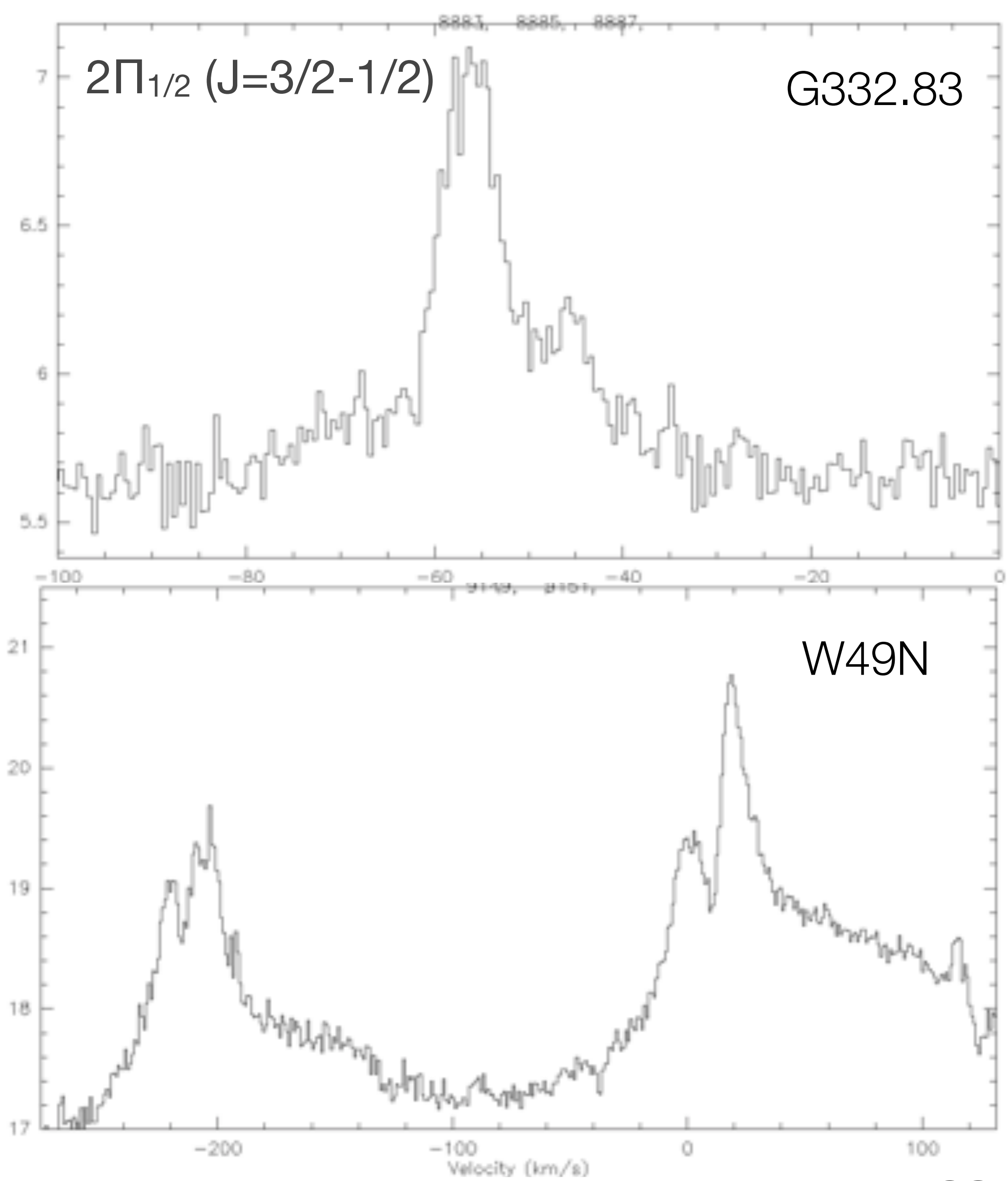
Conclusions

- the far-infrared rotational lines of OH detected $2\Pi_{1/2}$ (J=3/2-1/2)

  -> both doublets spectrally resolved
- the $2\Pi_{3/2}$ (J=5/2-3/2) line is in absorption
- Models:
  - low OH abundance envelope: good for NGC7538 IRS 1
  - not sufficient for W3(OH) and G10.62-0.39
    - additional high-density, high OH abundance component is needed
  - W3(OH): The emission from W3(OH) comes predominantly from the UCHIIR and not from the hot core.
  - RATRAN modeling yields for the dense component $n(H_2)=\sim 3\times 10^6$ cm^{-3}
  - accounting for pumping by the FIR radiation field emitted by hot dust is needed

Outlook

- More OH lines observed towards typical UC-HII regions
- sources also observed with Herschel



	$2\Pi_{1/2}$ (J=3/2-1/2) 1837 GHz	$2\Pi_{3/2}$ (J=5/2-3/2) 2504 GHz
G10.47	✓	✓
G34.26	✓	✓
W49N	✓	✓
W49B	✓	✓
W33A	✓	
G332.83	✓	✓

Outlook

Next steps:

- Include the latest collisional rate coefficients in the Cesaroni & Walmsley model
- Calibrate the radio lines to the far-infrared rotational lines of OH
- derive OH abundances in the various components: envelopes, shocks and outflows
- Cycle I data: reduction and data analysis in progress...