HIFI OBSERVATIONS OF NEBULAE AROUND EVOLVED STARS

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EVOLUTION OF AGB STARS AND PN FORMATION: THE ROLE OF DYNAMICS

AGB stars lose material $10^{-8} – 10^{-4}$ $M_\odot$ yr^{-1}

Increasing in the end of the phase –> ejection of layers outside the stellar core

Driving mechanisms: inner pulsation + radiation pressure onto grains

Enormous and cold red giant –> tiny and very hot blue dwarf in $\sim$ 1000 yr !

Spherical, slowly expanding AGB CSE –> PNe: axial symmetry, fast bipolar flows

IMPRESSIVE DYNAMICS

Most of the mass is now nebular, $\sim$ 1 $M_\odot$

$\sim$ 0.3 – 0.5 $M_\odot$ (in the polar caps) accelerated to 50 – 100 km s^{-1}

Most forces act during only 100 – 300 yr !!

Driving mechanism: shocks between fast post-AGB jets and the fossil AGB CSE

mm-WAVE OBSERVATIONS IN AGB CSEs, PPNe and PNe

VERY USEFUL, MANY QUANTITATIVE RESULTS   mainly from CO lines

AGB CSEs :

- Systematic measurement of $\dot{M}$, in several hundred objects
- Systematic studies of structure and dynamics, in $\sim$ 100 objects

  mostly spherical and isotropical expansion, V_{exp} = 5 – 25 km s^{-1}

Young PNe (or PPNe) :

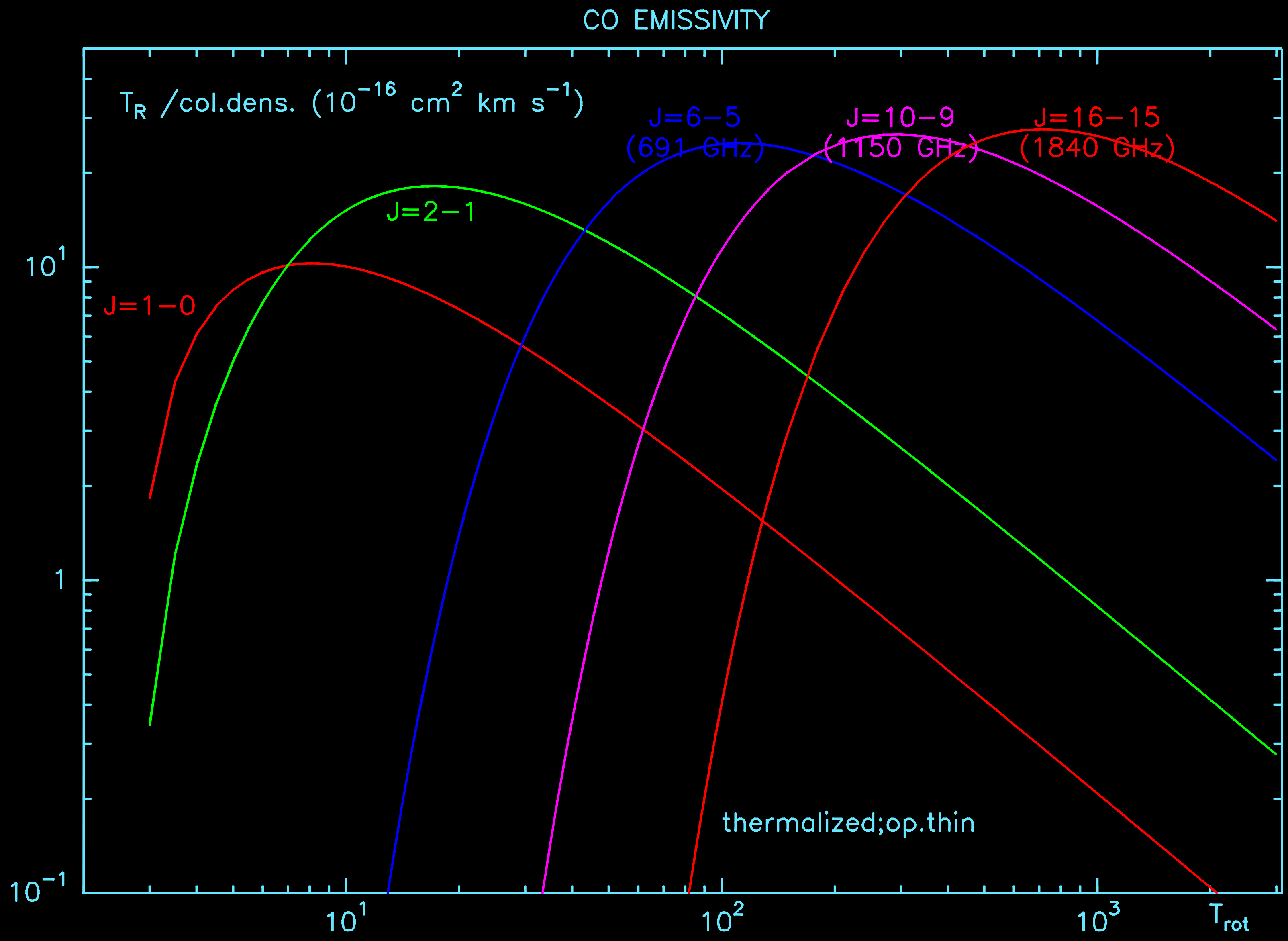
- Density, mass: Massive component: 0.1 – 1.5 $M_\odot$ (most of the total mass)
- General structure and dynamics:

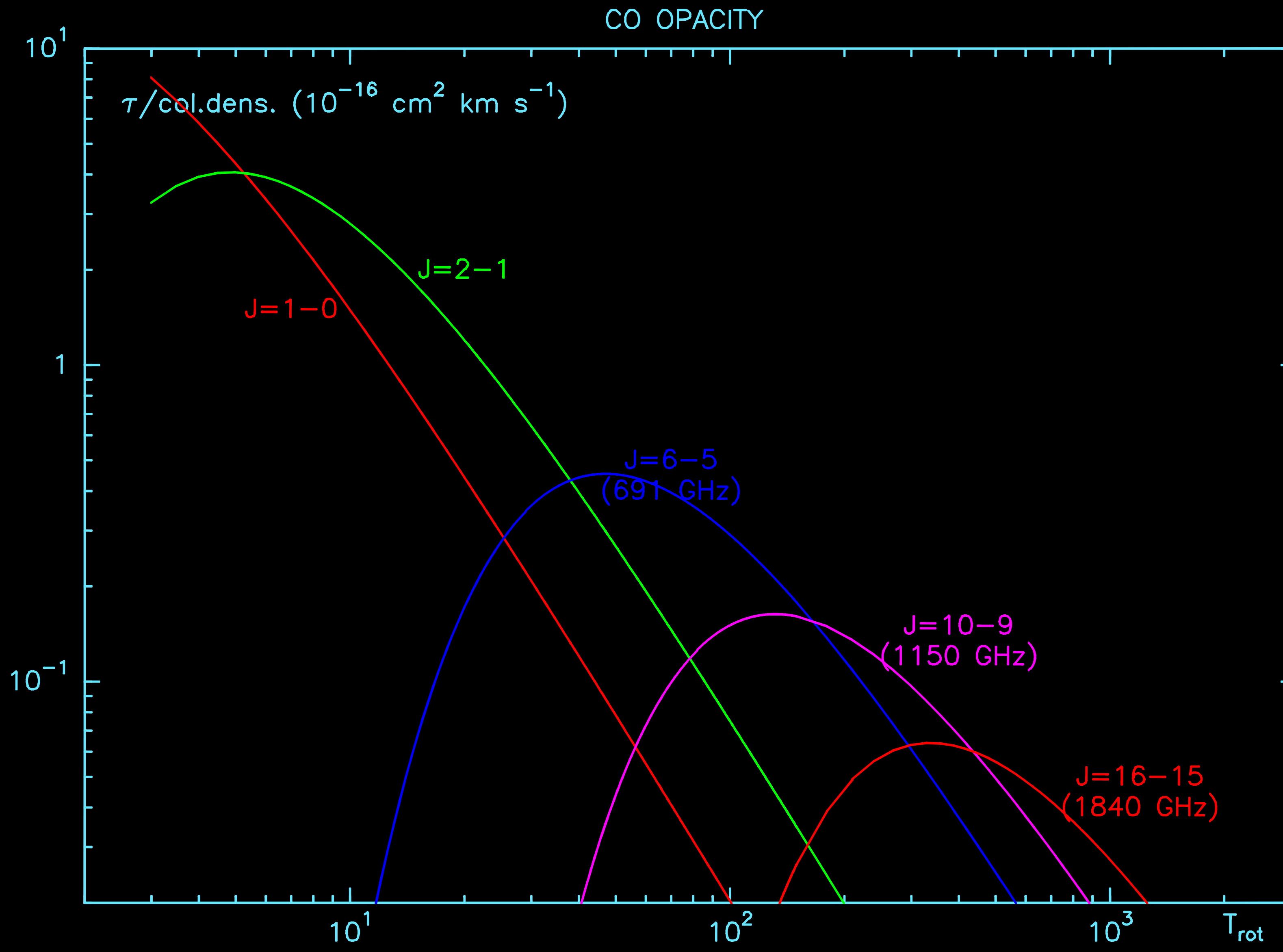
  Axial symmetry   bipolar flows $\perp$ disk or torus   (+ halo)

  Bipolar outflows: high axial velocities (30 – 400 km s^{-1}): post-AGB acceleration

  Disk (and halo): slow expansion ($\sim$ 10 km s^{-1}): typical AGB dynamics
- Too much momentum in the bipolar flows to be explained by radiation pressure
- One or two cases of disks in rotation

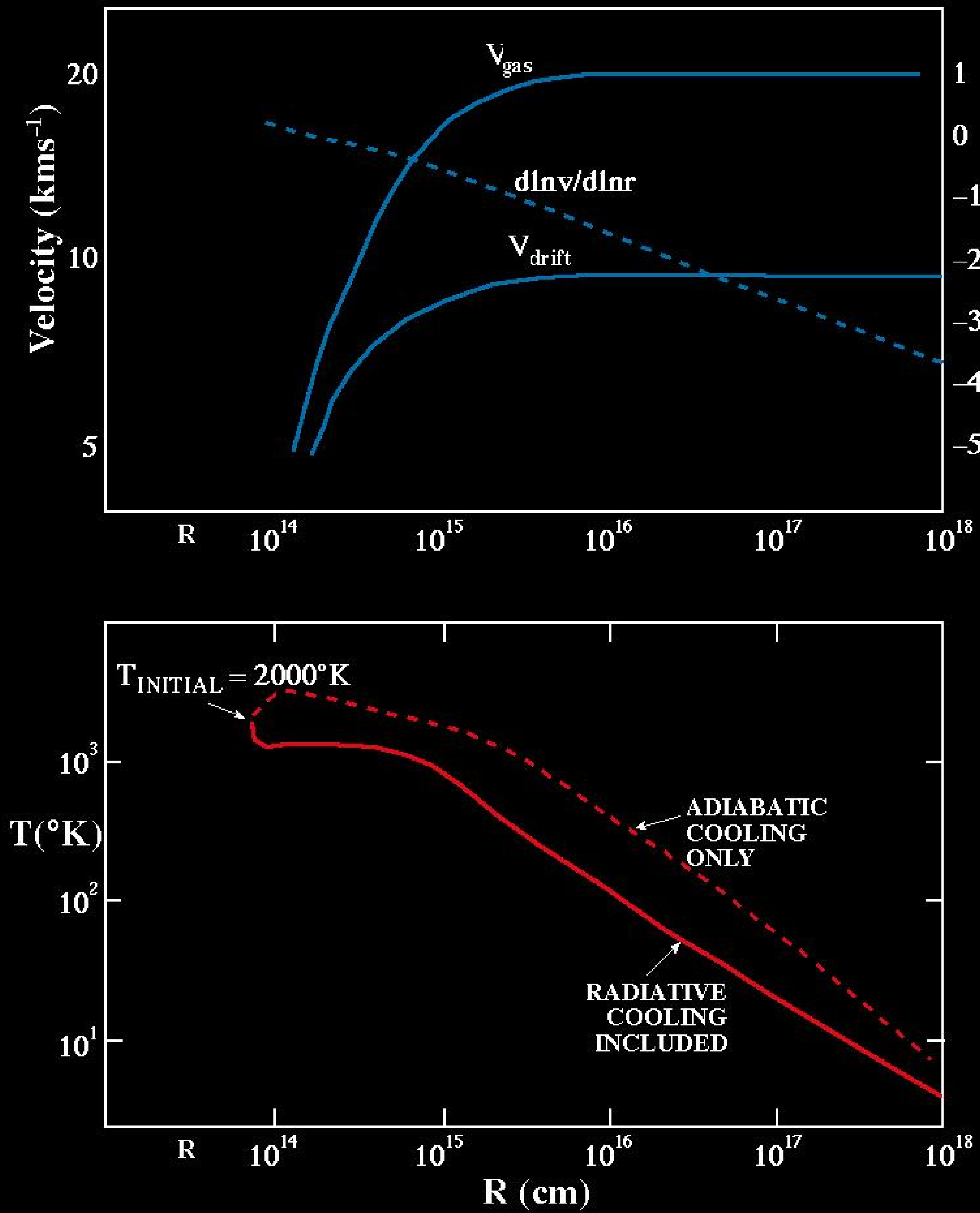
BUT: MM-WAVE LINES DO NOT SELECT WARM GAS



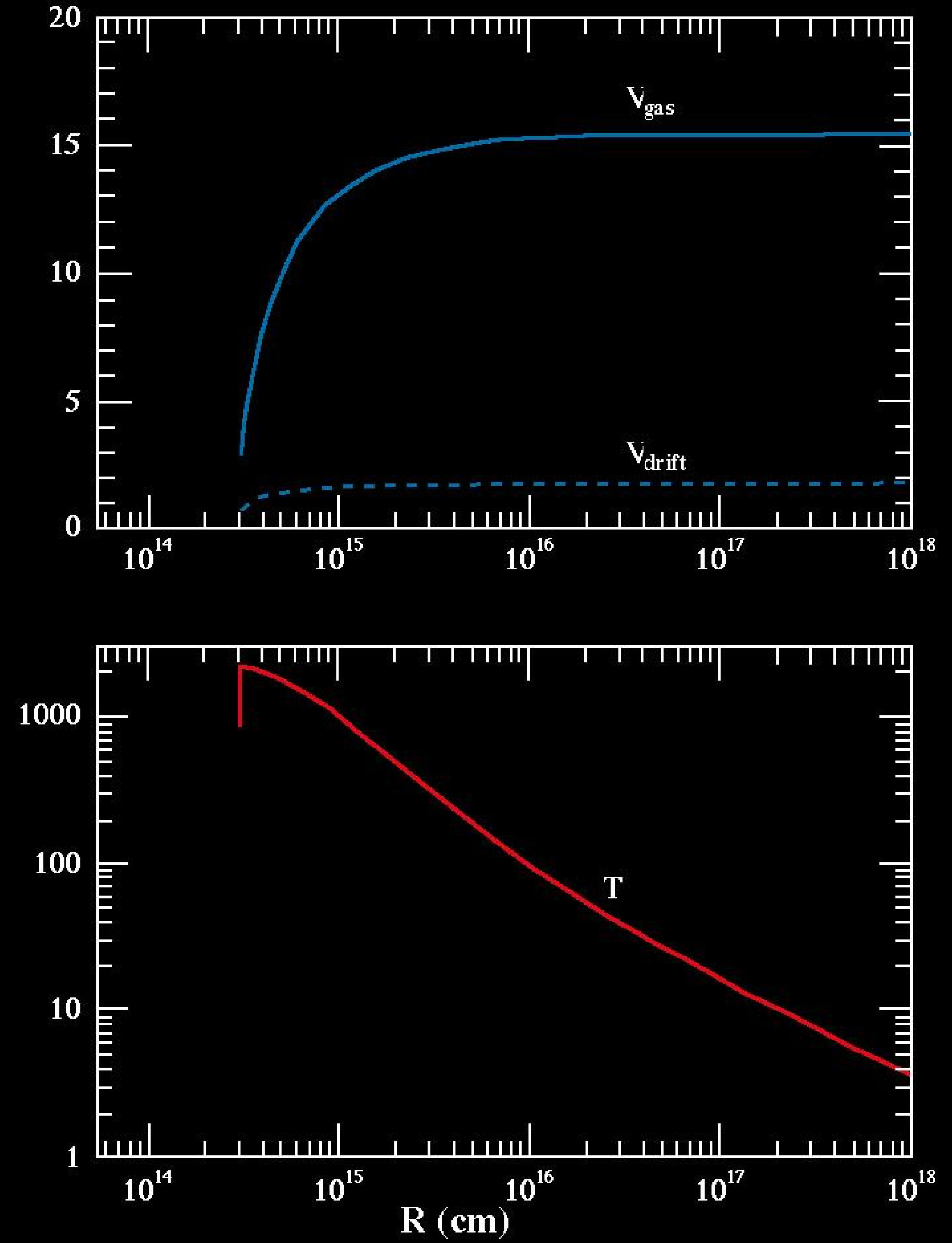


CO OPACITY
τ/col.dens. (10^-16 cm^2 km s^-1)
J=1−0
J=2−1
J=6−5
(691 GHz)
J=10−9
(1150 GHz)
J=16−15
(1840 GHz)
10^1
1
10^-1
10^1
10^2
10^3
T_rot

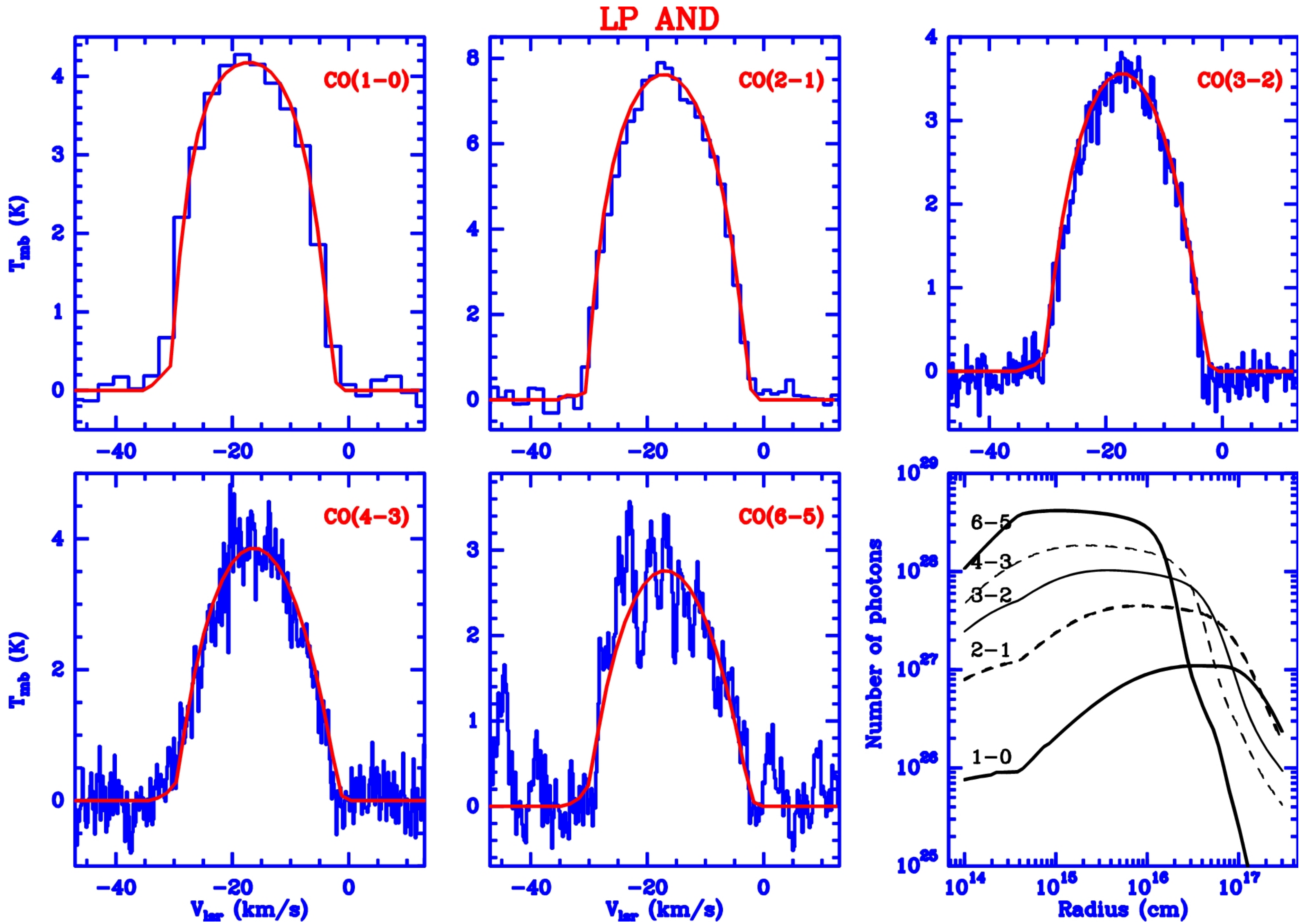
STRUCTURE OF AGB CIRCUMSTELLAR ENVELOPES



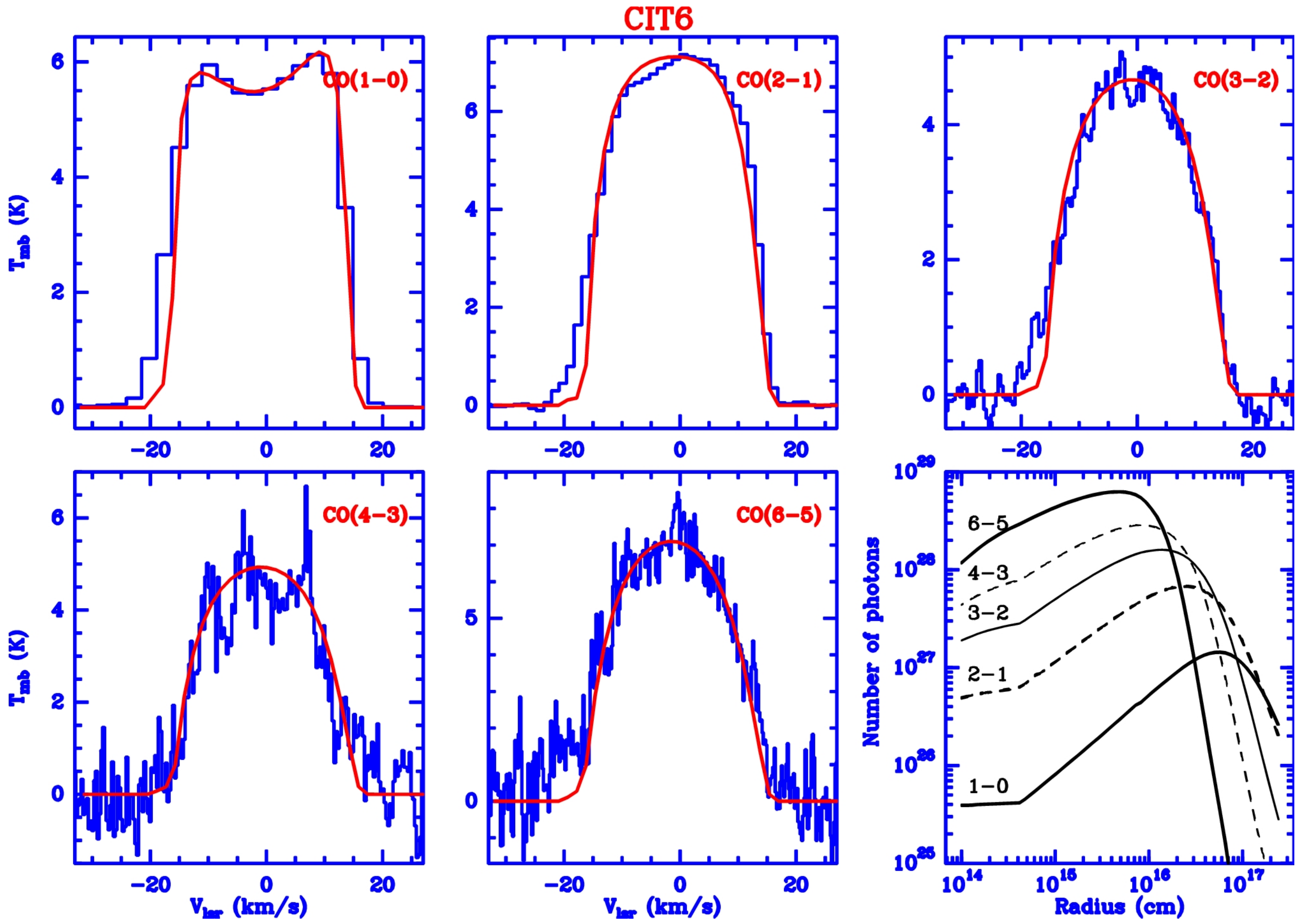
Goldreich & Scoville (1976)



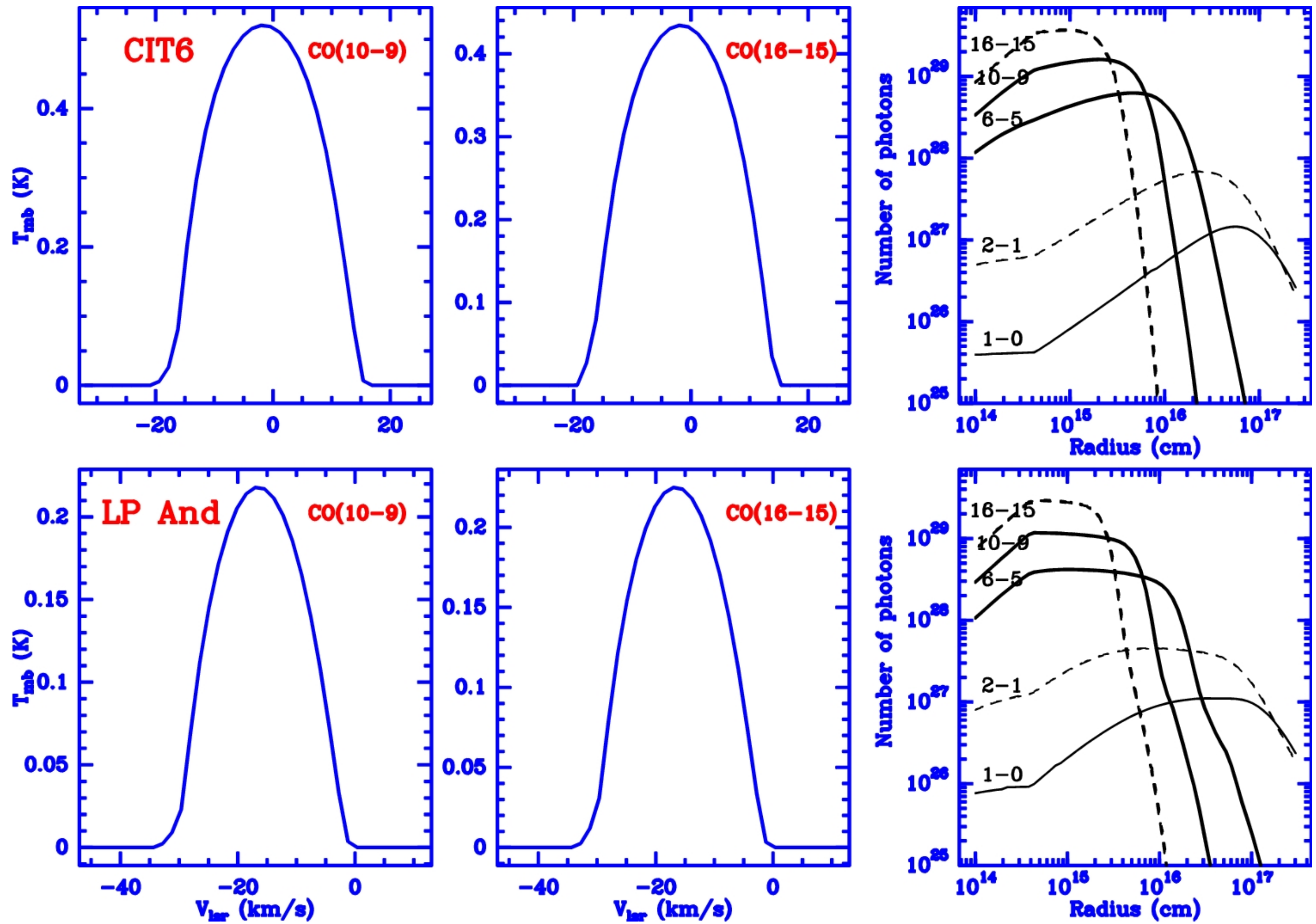
Justtanont et al. (1994)

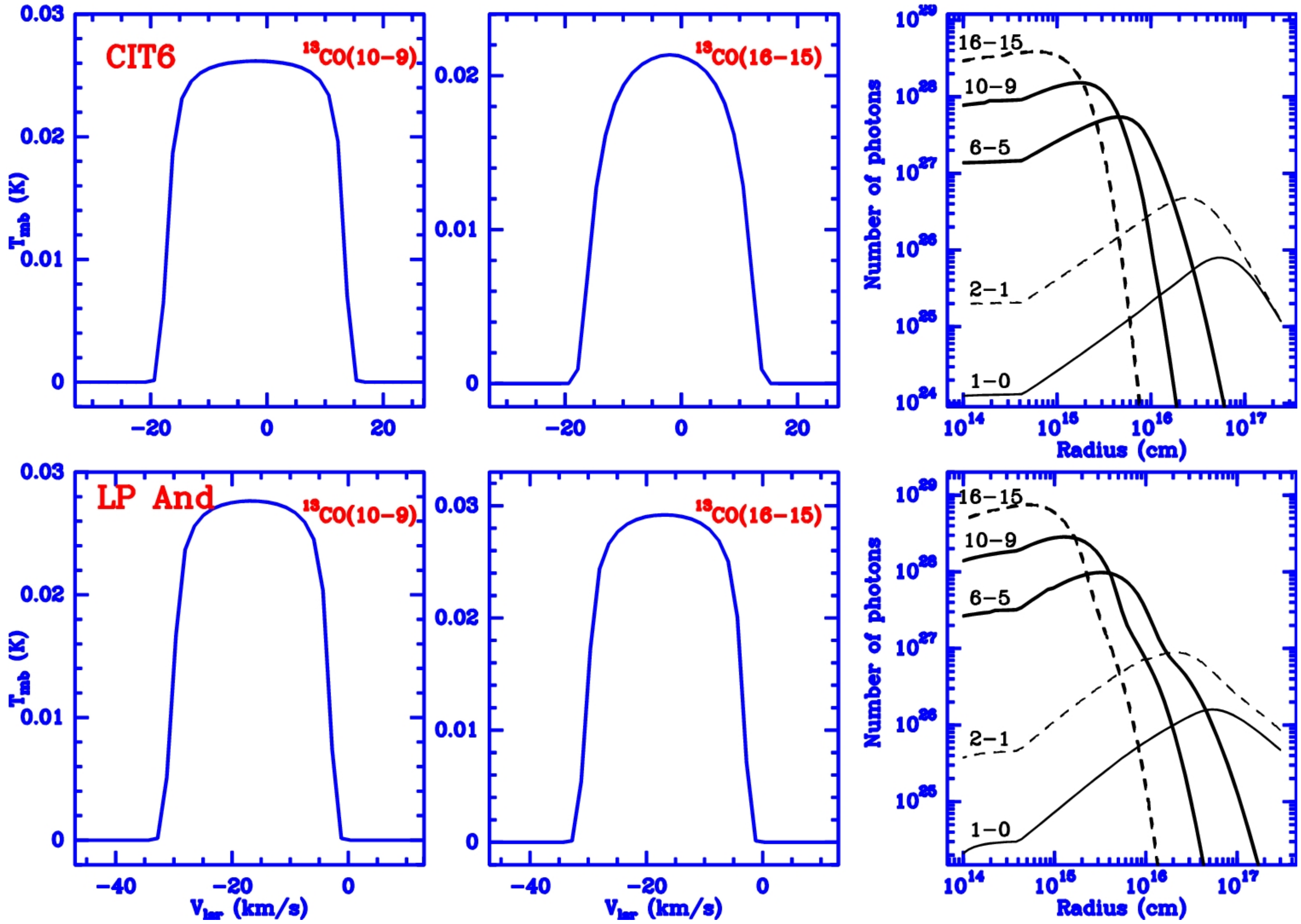


Teyssier et al. 2006 (A&A, 450, 167)



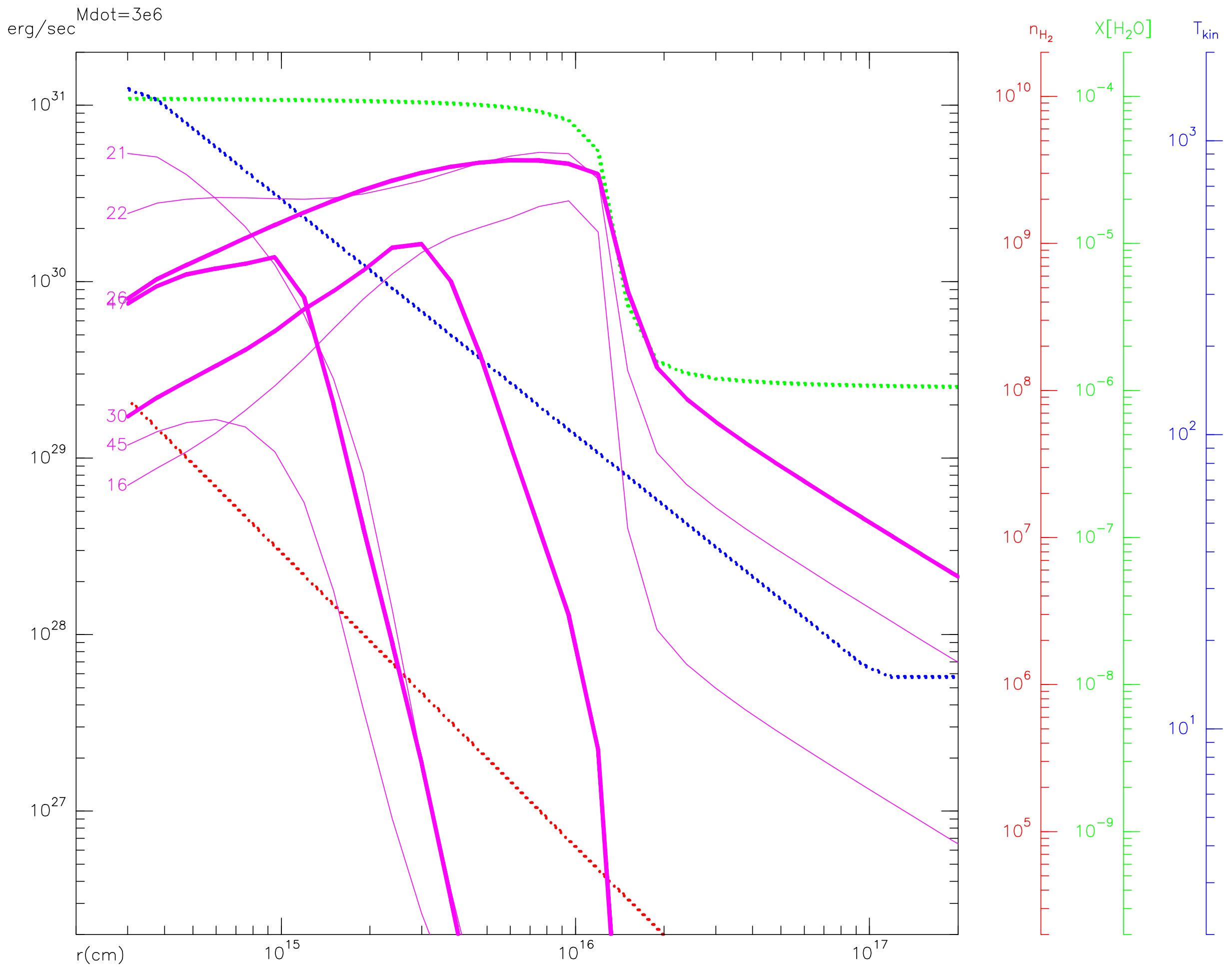
Teyssier et al. 2006 (A&A, 450, 167)


CIT6
CO(10−9)
CO(16−15)
LP And
CO(10−9)
CO(16−15)
T_mb (K)
V_lsr (km/s)
Number of photons
Radius (cm)
16−15
10−9
6−5
2−1
1−0



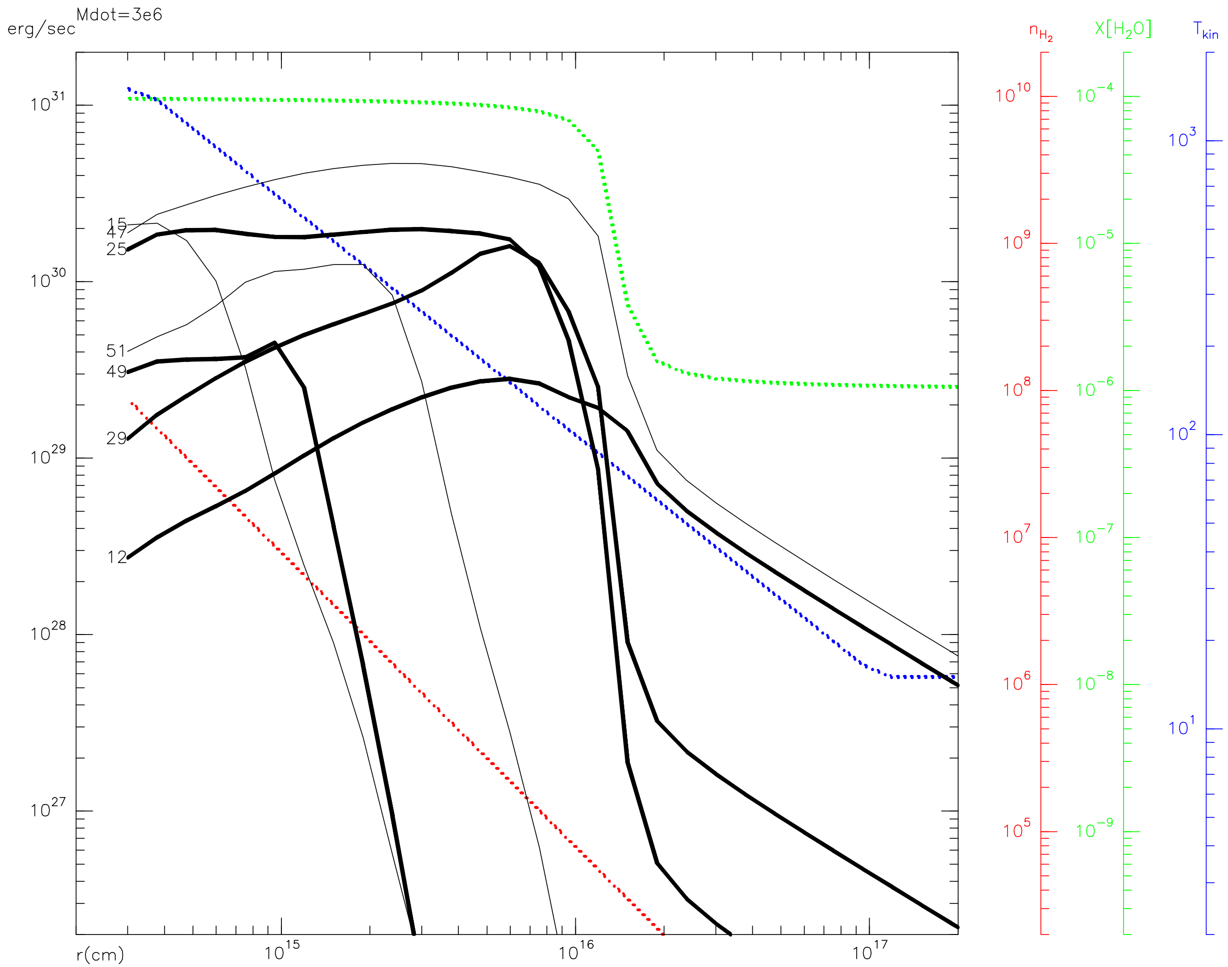
CIT6
^{13}CO(10−9)
^{13}CO(16−15)
LP And
T_{mb} (K)
V_{lsr} (km/s)
Number of photons
Radius (cm)
16−15
10−9
6−5
2−1
1−0

para-H_2O EMISSIVITY IN O-rich AGB CSEs

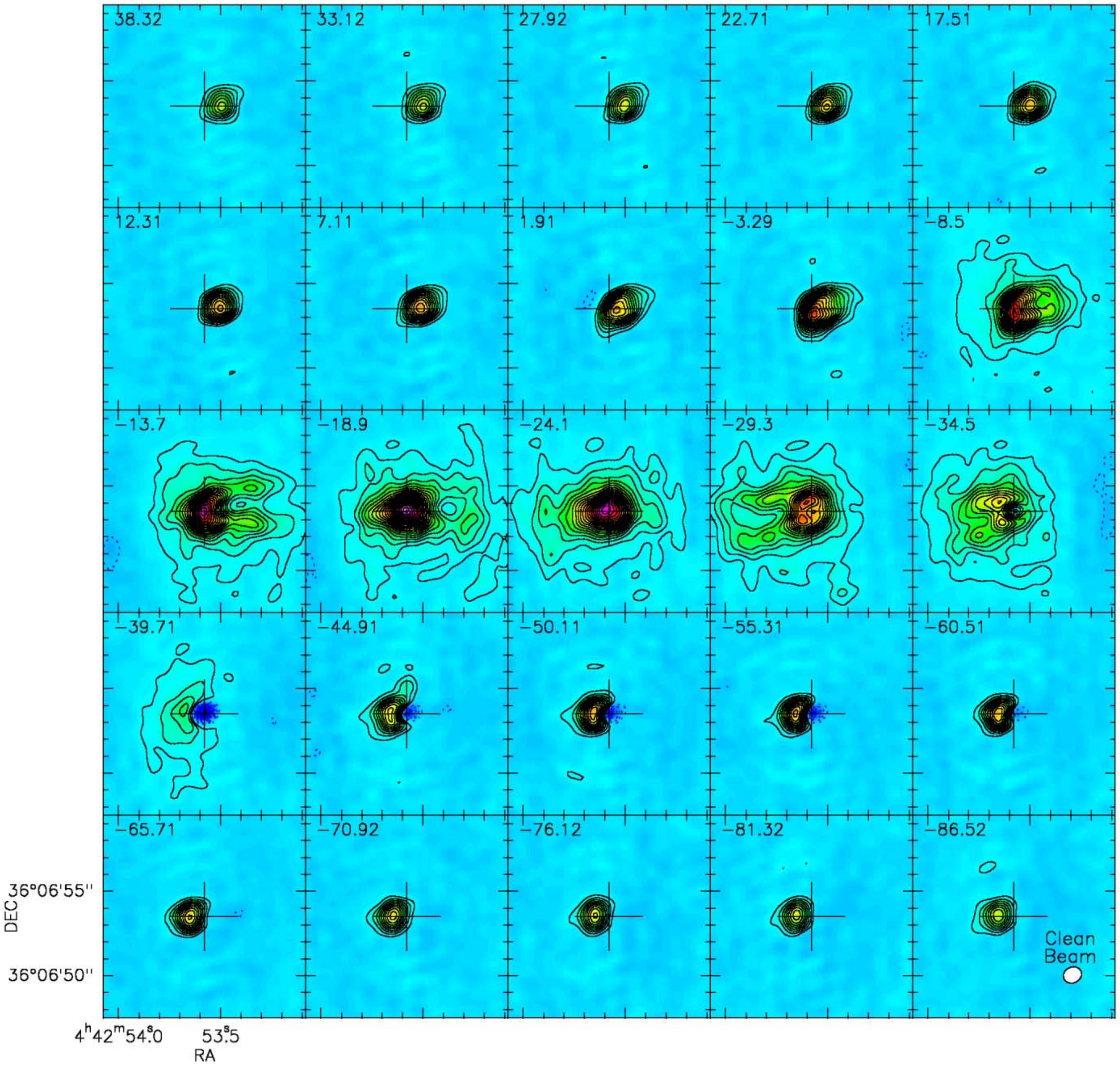


para water, lines: 16: $2_{1,1}-2_{0,2}$; 21: $5_{2,4}-4_{3,1}$; 22: $2_{0,2}-1_{1,1}$; 26: $1_{1,1}-0_{0,0}$; 30: $4_{2,2}-4_{1,3}$; 45: $5_{3,3}-6_{0,6}$; 47: $6_{3,3}-6_{2,4}$.

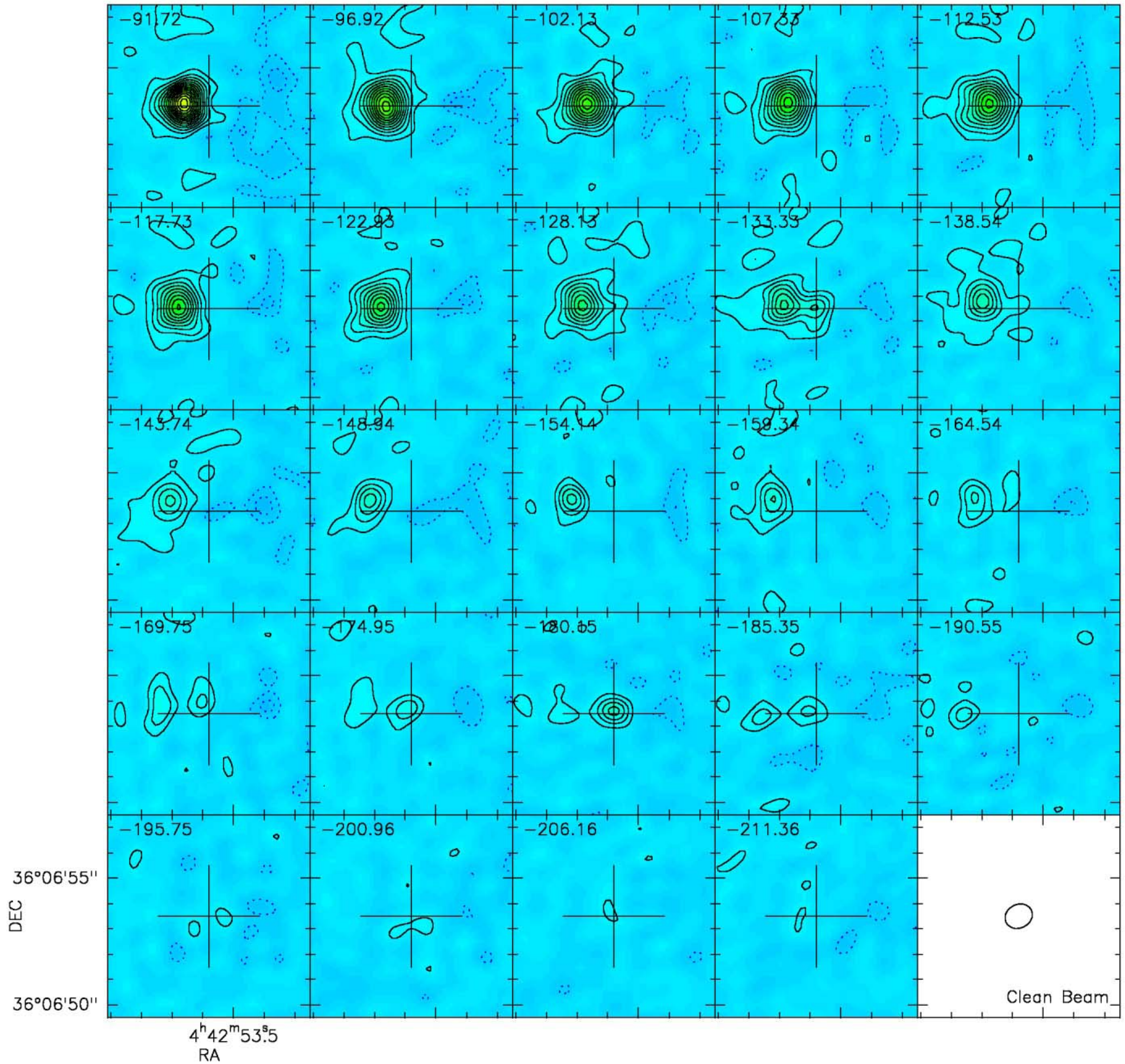
ortho-H_2O EMISSIVITY IN O-rich AGB CSEs



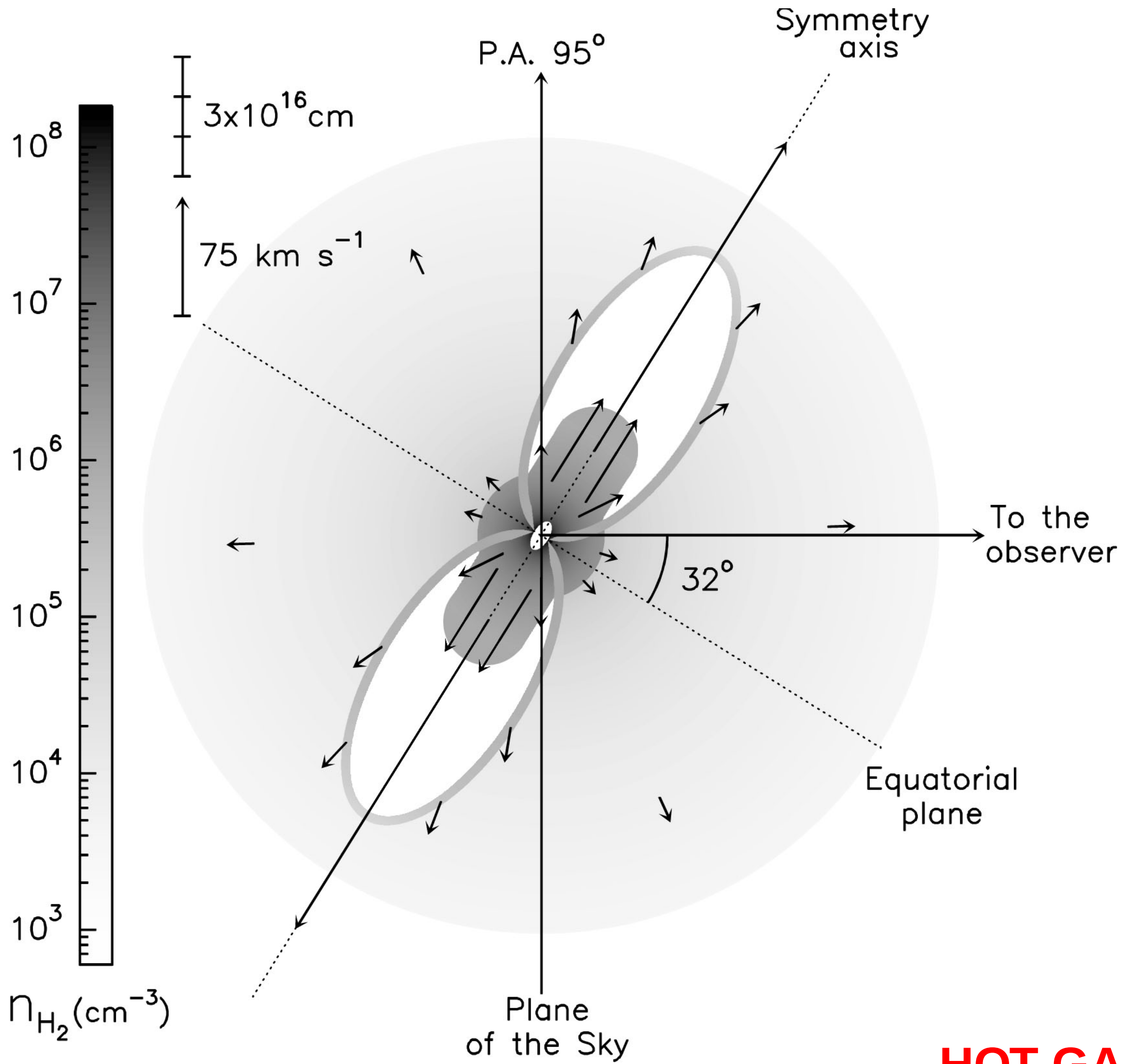
ortho water, lines: 12: $1_{1,0}-1_{0,1}$; 15: $5_{3,2}-4_{4,1}$; 25: $3_{1,2}-2_{2,1}$; 29: $3_{2,1}-3_{1,2}$; 47: $3_{0,3}-2_{1,2}$; 49: $7_{3,4}-7_{2,5}$; 51: $5_{3,2}-5_{2,3}$.



CRL 618, CO J=2–1 (Sánchez Contreras et al. 2004)



−91.72
−96.92
−102.13
−107.33
−112.53
−117.73
−122.93
−128.13
−133.33
−138.54
−143.74
−148.94
−154.14
−159.34
−164.54
−169.75
−174.95
−180.15
−185.35
−190.55
−195.75
−200.96
−206.16
−211.36
Clean Beam
36°06'55''
36°06'50''
DEC
4h42m53.5s
RA



Diffuse, slow shell:

$\dot{M} \sim 10^{-5}$ $M_\odot$ yr^{-1}, during 2500 yr

T_k: from 50 to 15 K

Dense, slow shell:

$\dot{M} \sim 2\ 10^{-4}$ $M_\odot$ yr^{-1}, during 500 yr

T_k: from 350 to 50 K

Axial cavities:

T_k = 200 K

Very fast outflow:

T_k: from 500 to 50 K

Very high momentum

Multiple jets and ejection events

HOT GAS ≡ RECENTLY SHOCKED GAS

but, poorly studied !

WARM REGIONS IN AGB CSEs, PPNe AND PNe

- Inner layers of AGB CSEs

Shock waves from the photosphere + grain formation (& radiation pressure)

WHERE MASS LOSS FROM AGB STARS ACTUALLY OCCURS

- Recently shocked regions

Thin, warm regions

PROBABLY DRIVING THE MASSIVE FAST OUTFLOWS AND WIDE LOBES

But: are shocks always necessary?

- Inner rotating disks

PROBABLY RESPONSIBLE FOR post-AGB JETS (as in forming stars)

Probably very often present in PPNe, but only one good identification

CRUCIAL TO UNDERSTAND THE AGB AND post-AGB EVOLUTION

HIFI OBSERVATIONS OF AGB CSEs AND YOUNG PNe

- 450 - 1900 GHz   665 μ – 158 μ

  ABLE TO PROBE WARM GAS   (100 – 2000 K,   CO J=6–5 –> J=16-15)

  Many lines of H_2O: a key molecule

- High spectral resolution

  ABLE TO STUDY DYNAMICALLY ACTIVE COMPONENTS

  and to identify them

- Very well suited for systematic studies   (surveys of sources/lines)

  No atmosphere, good calibration, long project (possible follow-ups)

  Before ALMA and SOFIA

- Very good conditions for the analysis

  Known symmetry and dynamics (particularly for AGB CSEs)

  Large velocity gradients: LVG models, detection of inner layers (in spite of high τ)

  Many intense lines

HIFI GTKP:

“H_2O AND CO OBSERVATIONS OF AGB ENVELOPES, PPNe AND PNe”

Systematic observations of (mainly) CO and H_2O 17 frequency tunings, 220 hr

Coordinator: V. Bujarrabal

3 ^{12}CO lines: J = 6–5, 10–9, 16–15

3 ^{13}CO lines: J = 6–5, 10–9, 16–15

$\sim$ 30 H_2O lines

- ortho and para
- forbidden and intense lines
- low, mid, high excitation (including vibrationally excited) + some probable masers
- also $H_2^{18}O$, $H_2^{17}O$, HDO

+ some HCN lines and PACS full frequency scans in three stars

HIFI GTKP:

“H_2O AND CO OBSERVATIONS OF AGB ENVELOPES, PPNe AND PNe”

AGB circumstellar envelopes (CSEs)

- 9 O-rich stars

  H_2O in 5 stars very in detail
- 2 S-type stars
- 13 C-rich stars

  H_2O in IRC +10216 in detail

Young PNe

- 5 O-rich nebulae
- 5 C-rich nebulae

5 red/yellow super/hypergiants

  H_2O in VY CMa very in detail

HIFI-PACS Open Time KP: “LINE SURVEYS OF EVOLVED STARS”

WIDE FREQ. SCANS IN EVOLVED STARS

focused on HIFI band 6 and PACS full freq. surveys ...still working on the proposal !!

Coordinators: J.R. Pardo, J. Cernicharo; DAMIR, CSIC, Spain

TELESCOPE TIME: $\sim$ 300 hr

SOURCES:

IRC +10216: all HIFI bands + PACS full frequency

VY CMa, NGC 7027, CRL 618, IK Tau, OH 231.8+4.2: HIFI band 6 + PACS

Others?: PACS

OBJECTIVES:

Study of innermost regions of AGB and young PNe

Inventory of lines in the FIR

Search for vibrational bands of heavy molecules