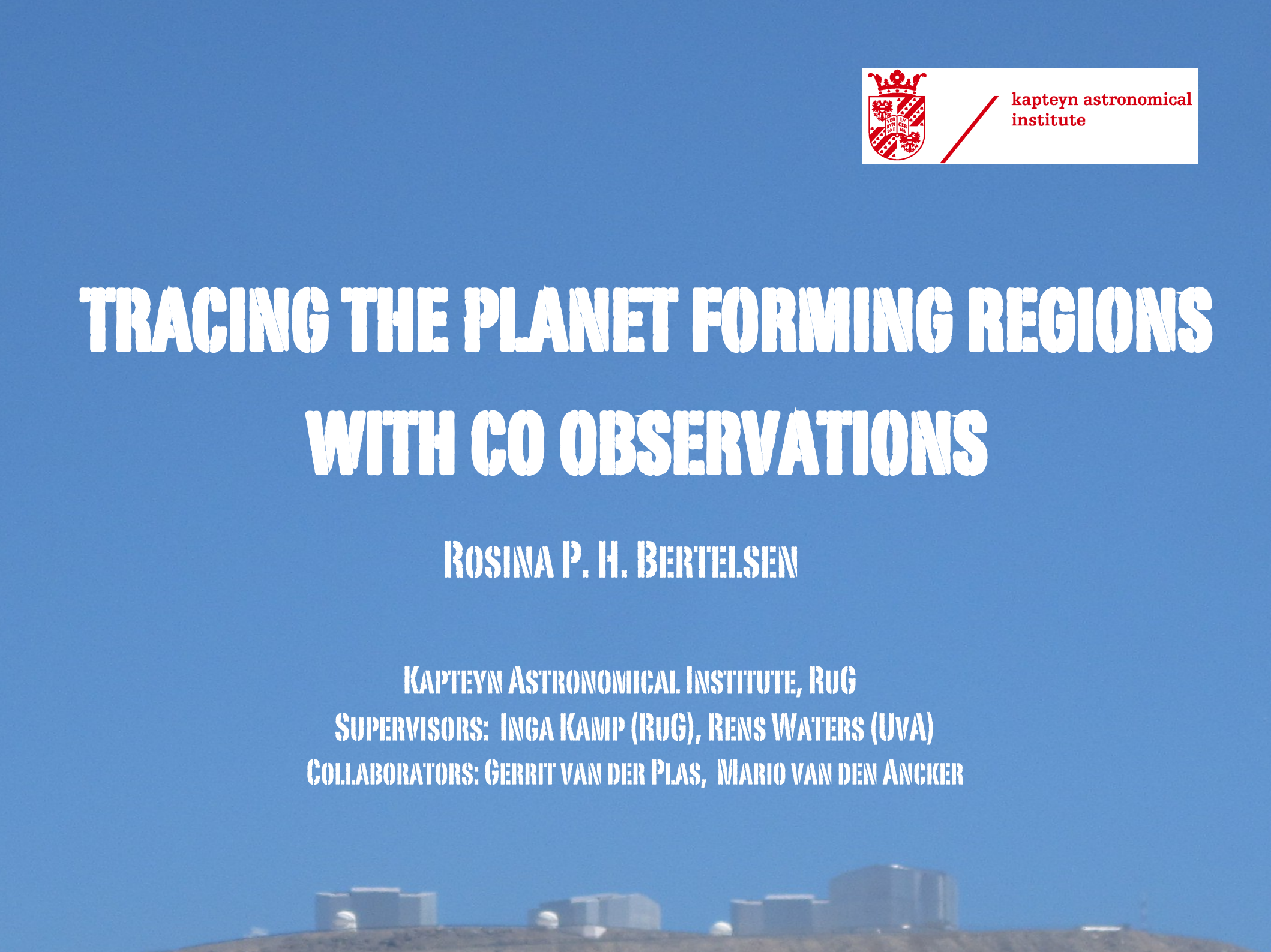


TRACING THE PLANET FORMING REGIONS WITH CO OBSERVATIONS

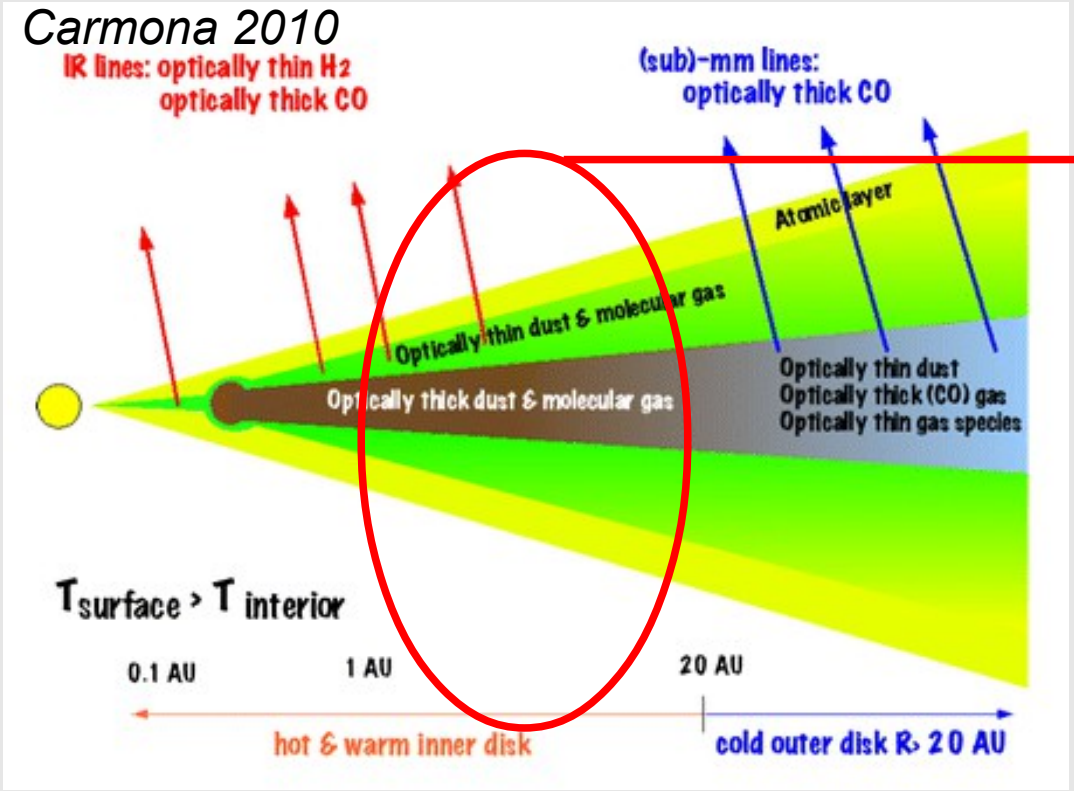
ROSINA P. H. BERTELSEN

KAPTEYN ASTRONOMICAL INSTITUTE, RUG
SUPERVISORS: INGA KAMP (RUG), RENS WATERS (UVA)
COLLABORATORS: GERRIT VAN DER PLAS, MARIO VAN DEN ANCKER

Overview

- CO ro-vibrational lines and disk geometry
- Motivation
- Observations
- Preliminary results
- Summary

CO as a tracer



Planet forming regions → CO ro-vibrational lines

CO 2.3 μm

CO 4.7 μm

CO sub-mm

H_2 UV

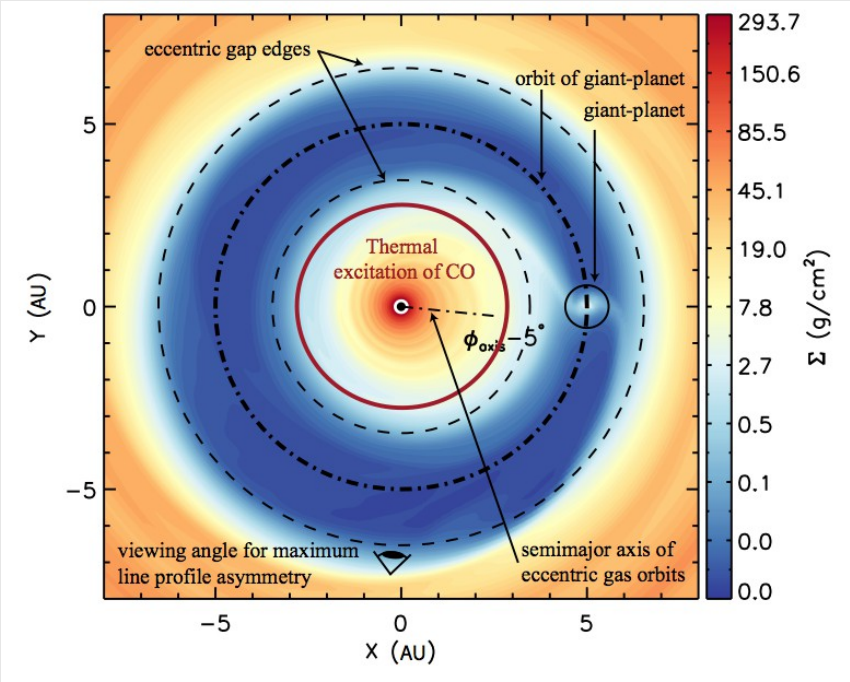
H_2 NIR

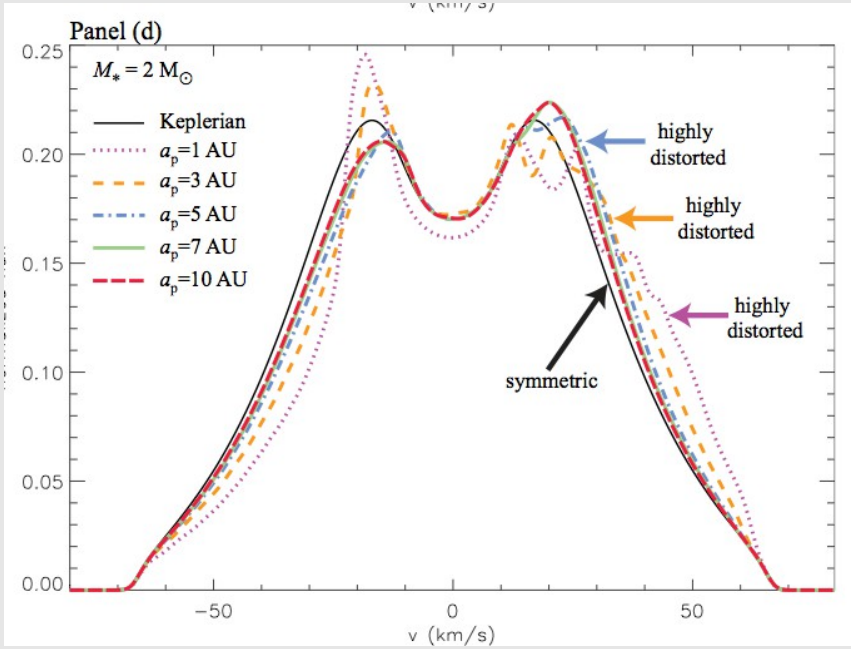
H_2 MIR

CO sub-mm (Δv = 0), pure rotational.
CO 2.3 μm (Δv = 2), ro-vibrational overtone.
CO 4.7 μm (Δv = 1), ro-vibrational fundamental.

Detecting signatures of planet formation

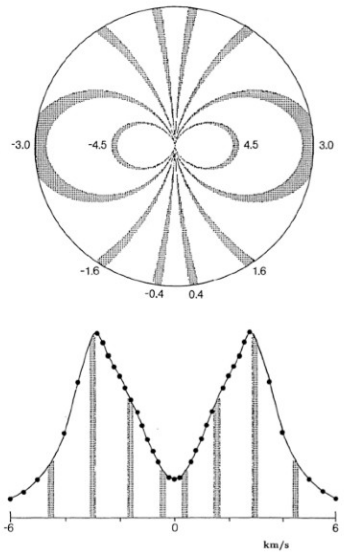
CO ro-vibrational lines emitted from the disk can show the presence of disk eccentricity caused by planet (Regàly et al. 2010, 2011, 2014).





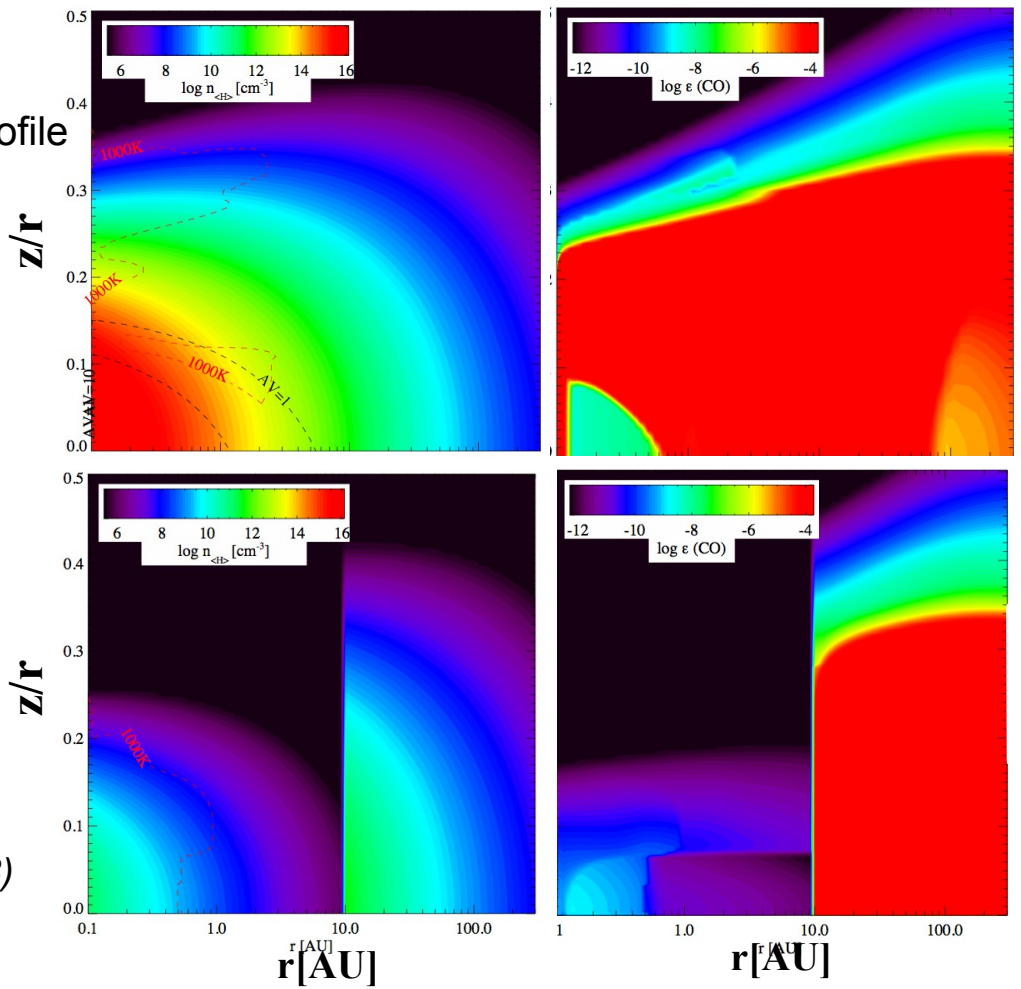
Line profiles as gap tracers

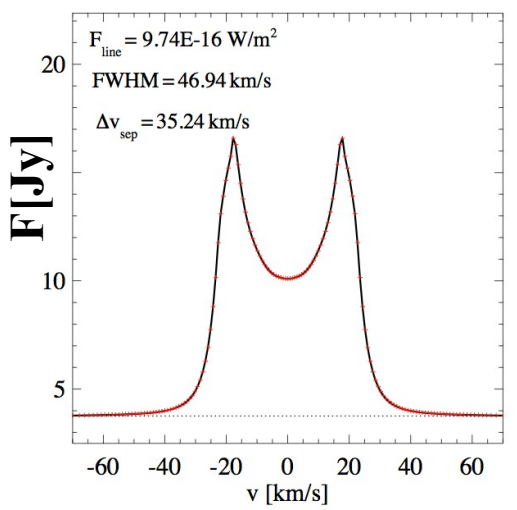
Disk in rotation
→ Lines broadened
→ double-peaked profile

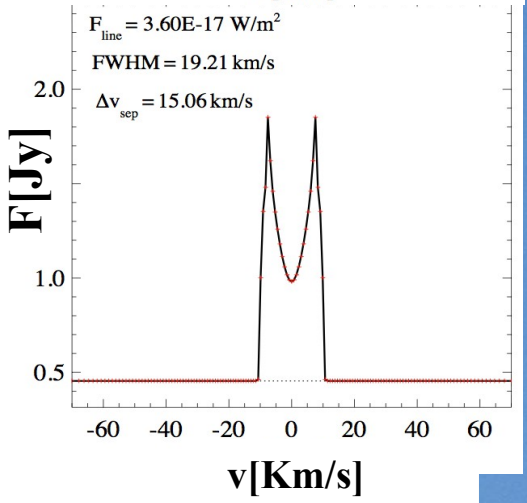


Beckwith & Sargent (1993)

Gas volume density **CO abundance** **Line profile**



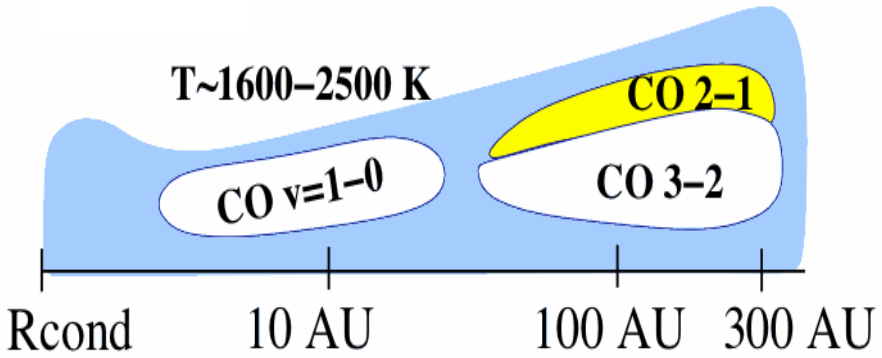




ProDiMo model of HaeBe disk (Own archive)

CO and flat/flaring disks

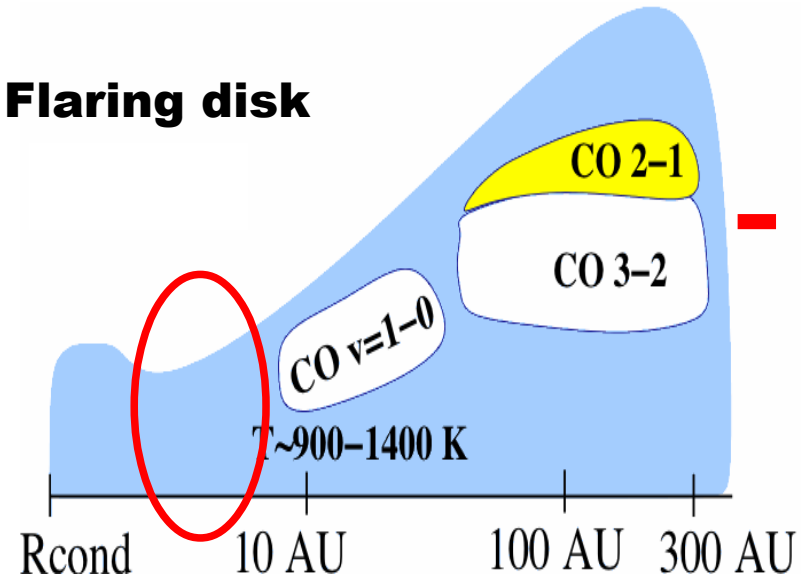
Flat disk



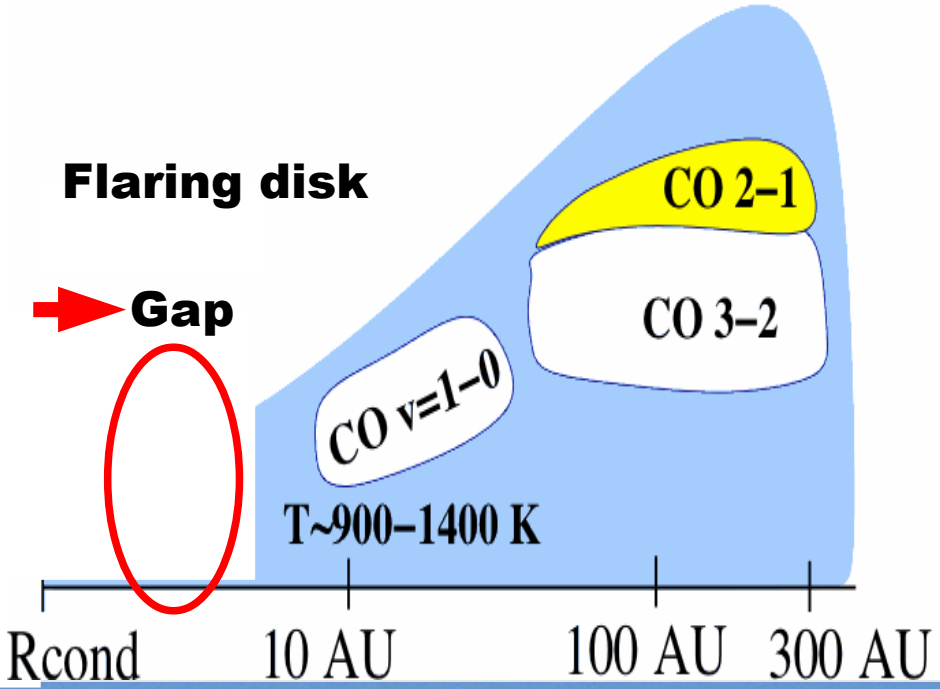
For flaring disks CO ro-vibrational emission starts further out *(van der Plas et al. 2009)*.

→Flaring disks all have gaps? *(Maaskant et al. 2013).*

Flaring disk

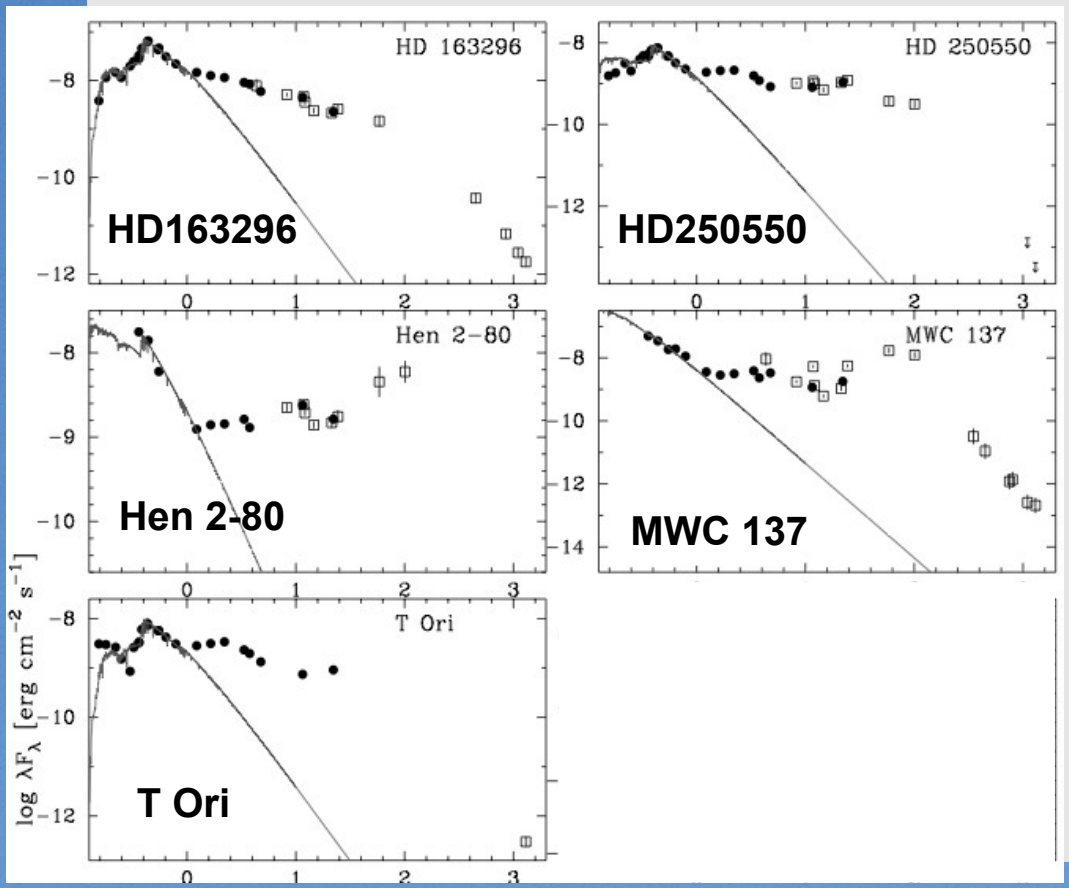


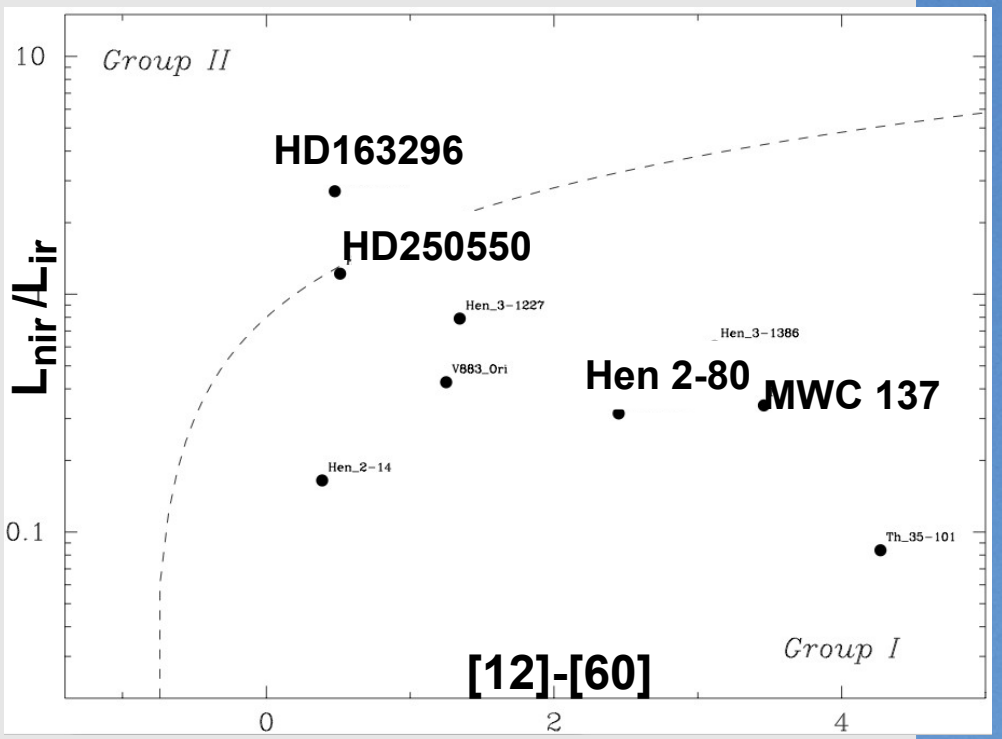
Flaring disk



Sample Selection

- From the list of HAeBe candidates by Thé et al. (1994).
- Bright (M>6) targets (to get high S/N).
- Observable from the southern hemisphere (CRIRES/VLT).
- Preference to Meeus et al. 2001 Group I targets (under represented in previous studies)

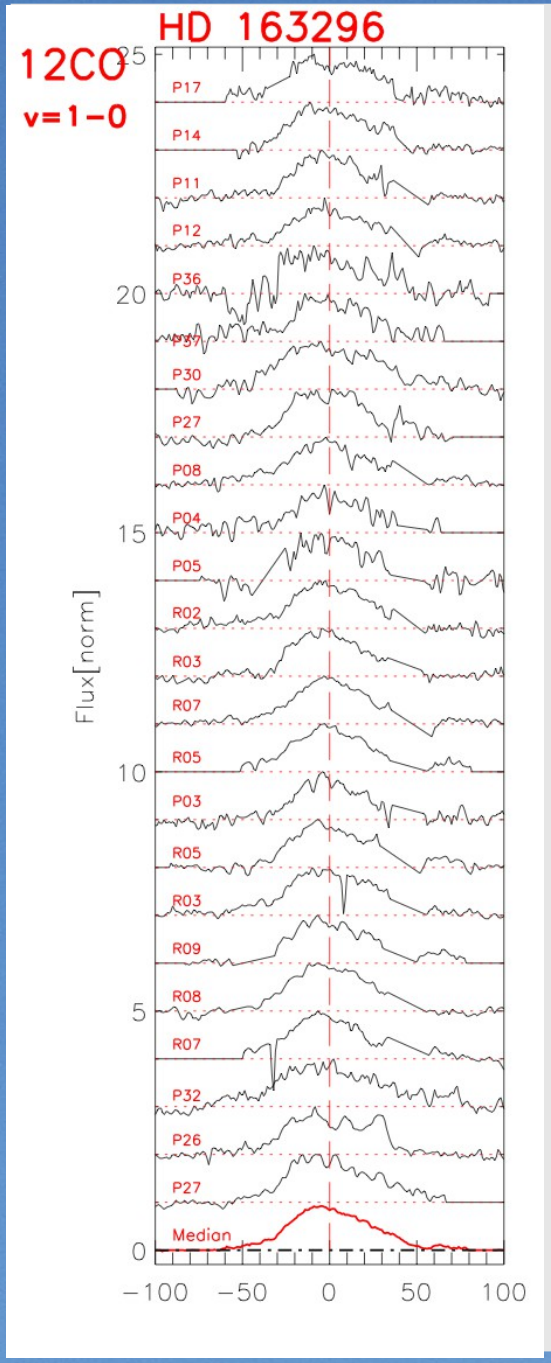




Similar to van Boekel (2003), Acke & van den Ancker (2004)

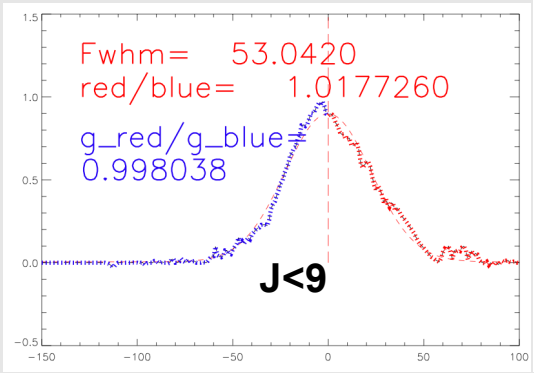
Observations

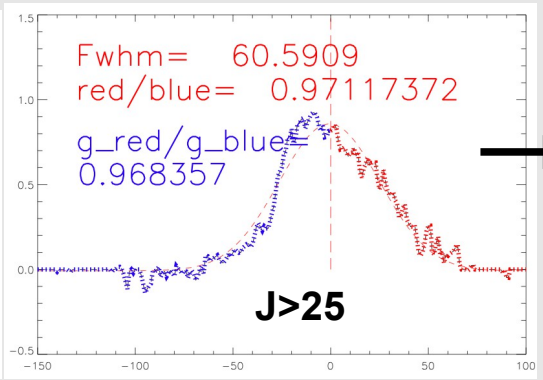
Instrument:	VLT-CRIRES
Date:	5^{th} and 6^{th} of March 2012
Wavelength:	6 settings, incl. many CO ro-vib transitions [4.5-5 μm]
Slit:	0.2”
Sources:	HD163296, HD250550, Hen 2-80, MWC137, T Ori, (Hen 3-1227, Hen 3-1386, Hen 2-14, Th 35-101, V883 Ori)
Detections:	CO ro-vib emission from 4 (5) of our sources, 12CO v=1-0, v=2-1, 13CO v=1-0 CO ro-vib absorption from 2 sources HI recombination lines from 9 sources,



HD163296

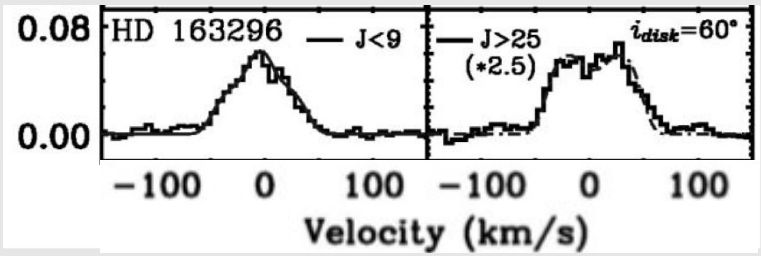
A3Ve, incl=46º,dist=119 pc, M*=2.3



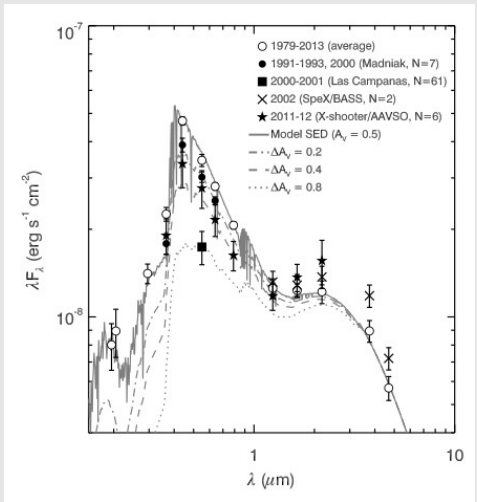


HW10%
LJ: 50.2 km/s
HJ: 54.5 km/s

CO onset:
LJ: 0.4 AU
HJ: 0.35 AU
Peak sep →
CO outer radius:
2.4 AU

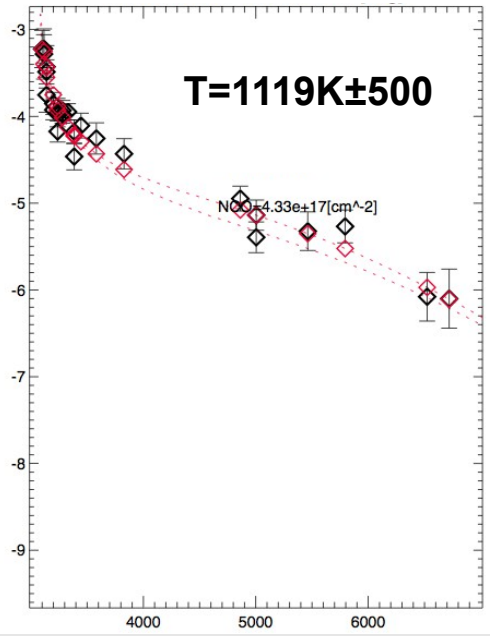


Blake & Boogert. (2004)



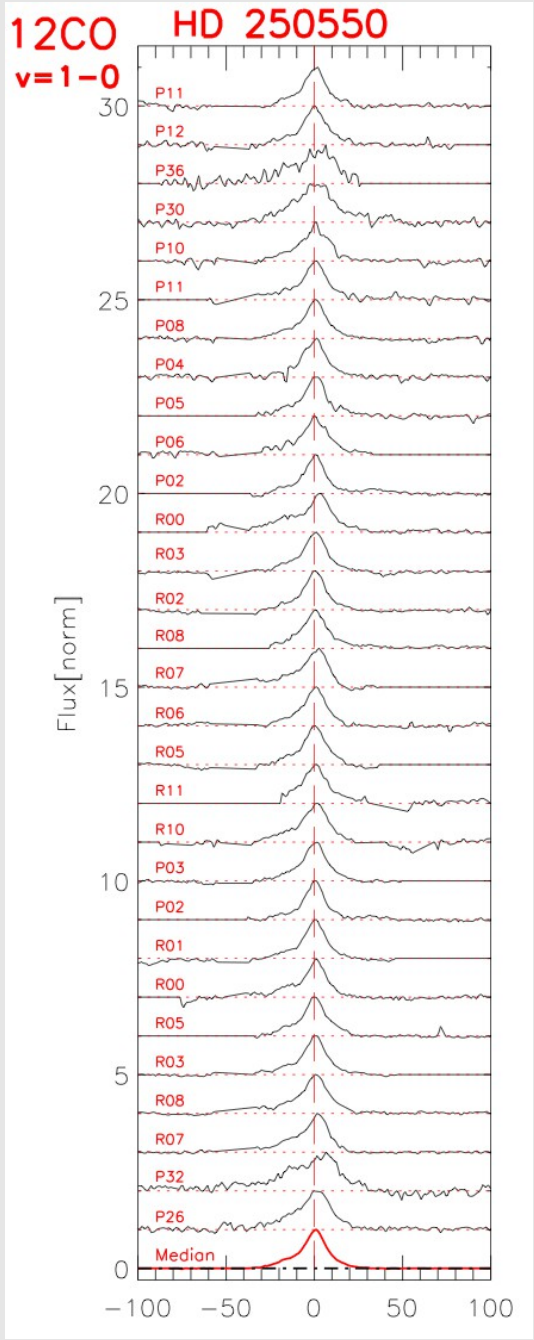
HD 163296 has variations in NIR brightness on timescales of years (Sitko et al., 2008, Ellerbroek et al. 2014).

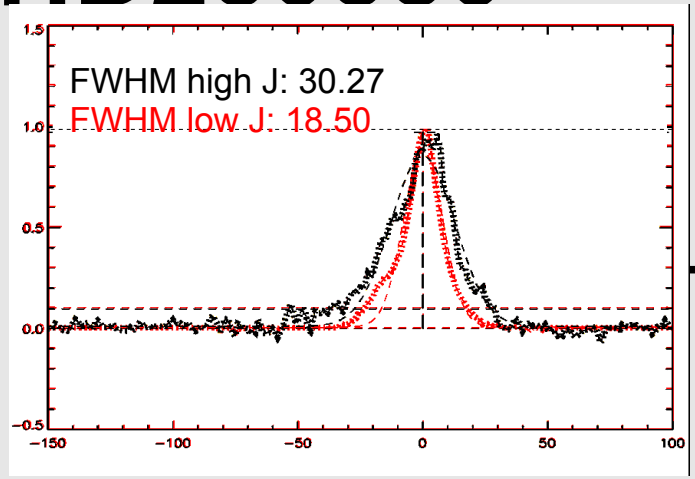
Boltzmann diagram



HD250550

B8-A0IVe, incl=10º,dist=280 pc, M*=3.6

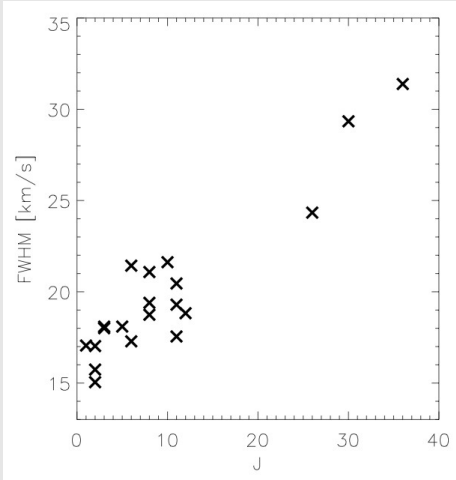


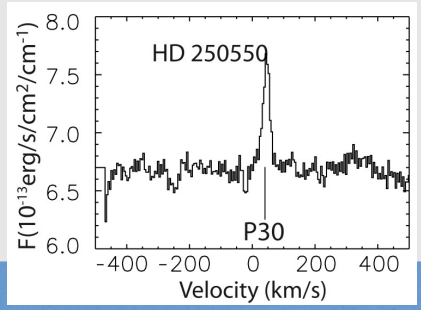


HW10%
LJ: 17 km/s
HJ: 31 km/s

CO onset:
LJ: 0.33 AU
HJ: 0.1 AU

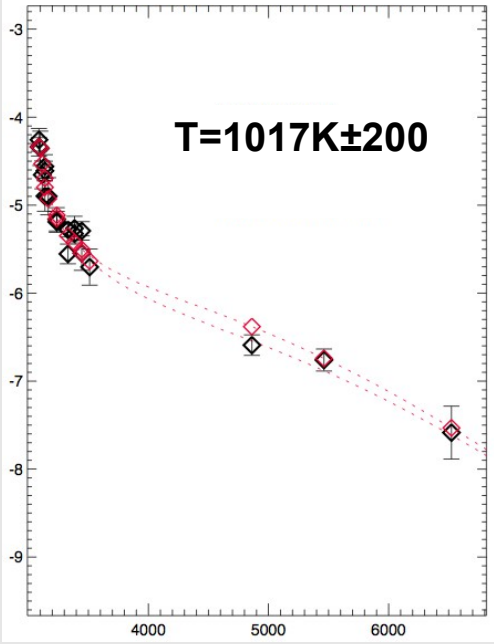
Average incl. →
CO onset:
LJ: 4.9 AU
HJ: 1.5 AU





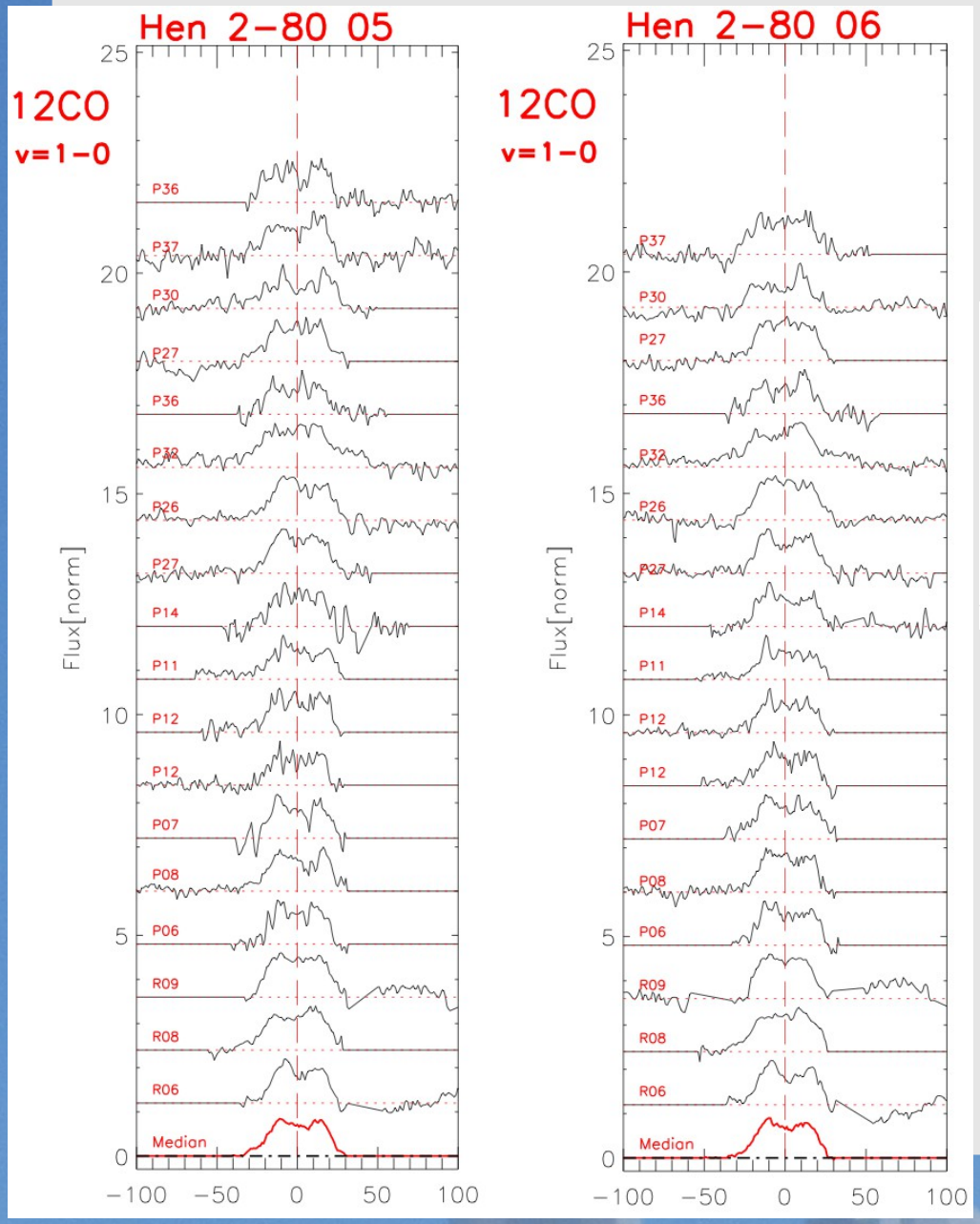
Brittain et al. (2007)

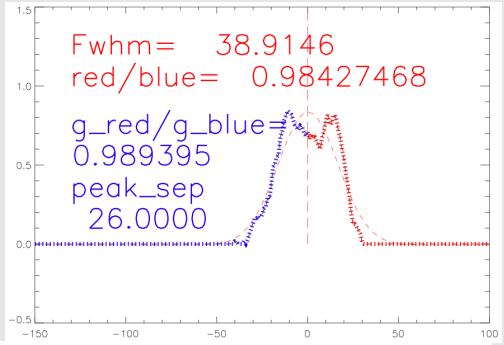
Boltzmann diagram

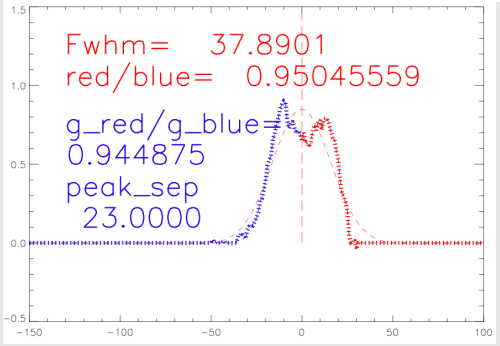


Hen 2-80

B6Ve, incl=??,dist>750 pc, M*~6?





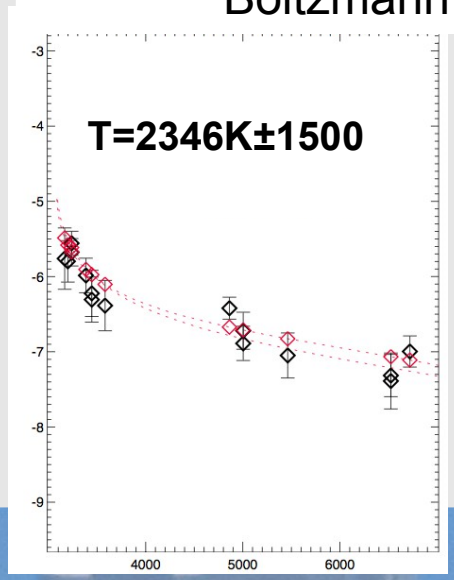


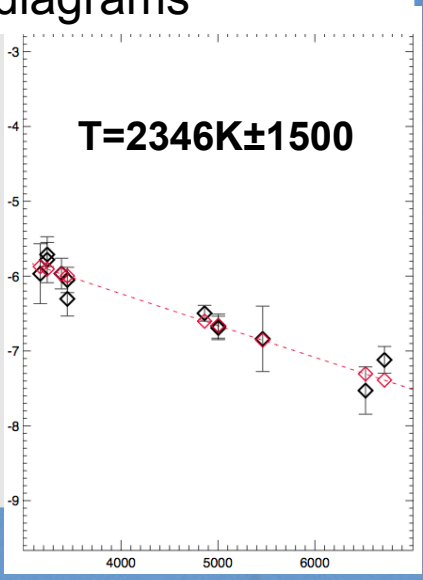
<u>HW10% (assume incl 42º)</u>
05: 30.0 km/s
06: 27.5 km/s

<u>CO onset:</u>
05: 2.6 AU
06: 3.1 AU

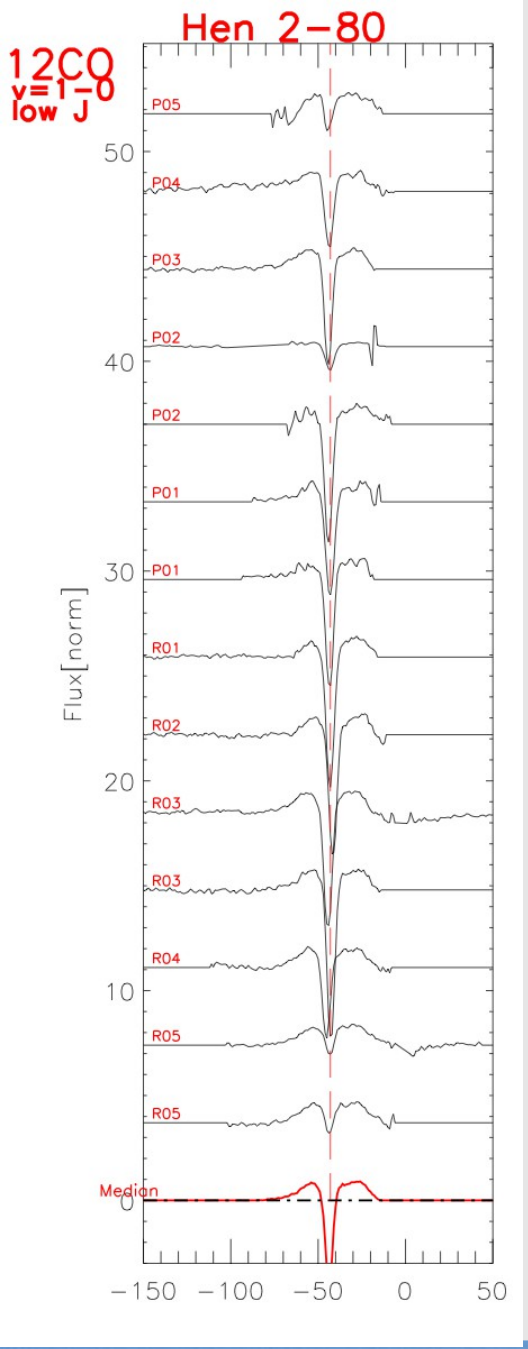
Peak sep →
CO outer radius:
05: 3.5 AU
06: 4.5 AU

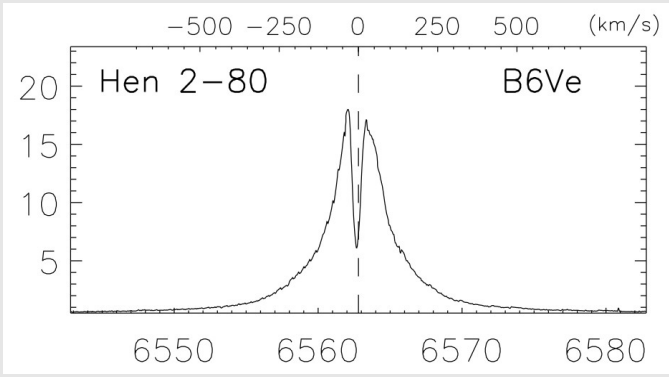
Boltzmann diagrams



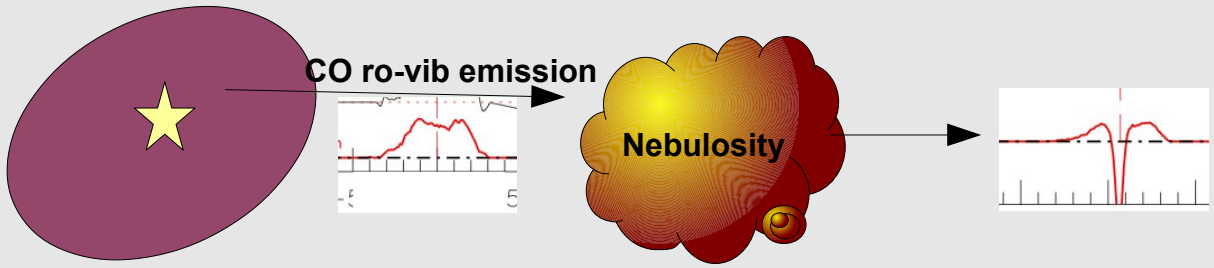


Hen 2-80 - absorption





Carmona et al. (2010) collected optical spectra with CRIRES. H*α* line also showing central absorption.



Has a surrounding infrared emission nebulosity

Summary

•We have collected IR data sample from CRIRES VLT that includes 5 HAeBe stars and have confirmed CO ro-vib emission from four of these.

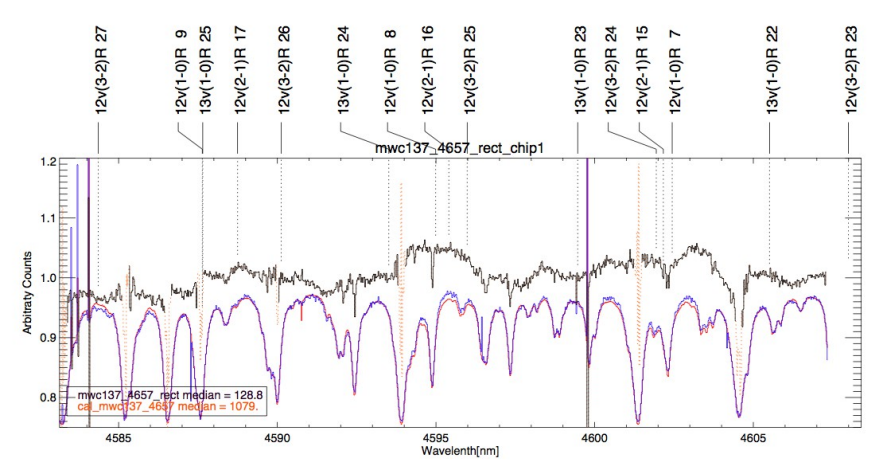
• The line profiles from HD163296 shows wide line profiles (lines emitted close to star) with somewhat different shape than previously observed. If confirmed, could be tied to the variability of the source (Sitko 2008, Ellerbroek 2014).

•HD250550 shows quite narrow single peaked line profiles (almost face on incl., Fedele 2011). The lines show a clear increase in line width with rising J value. Higher J values trace radii closer to the star. Line profile asymmetries are present → Several components?

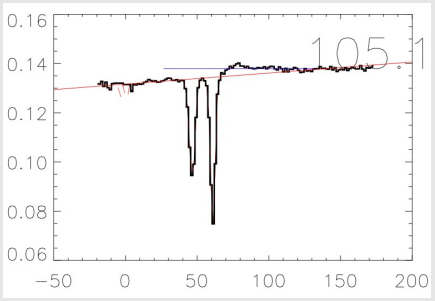
•Hen 2-80 is the only source in our sample that shows clear double peaked profiles. Peak seperation (if we assume 'typical' inclination= 42º) indicates emitting region at larger radii than the two other sources.

•Work underway and paper in preperation...

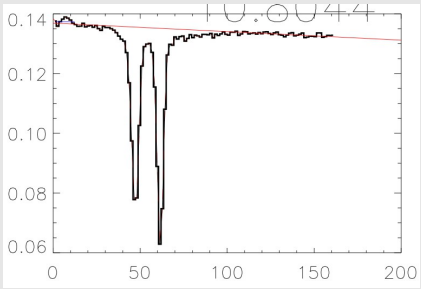
MWC 137



R0



R1

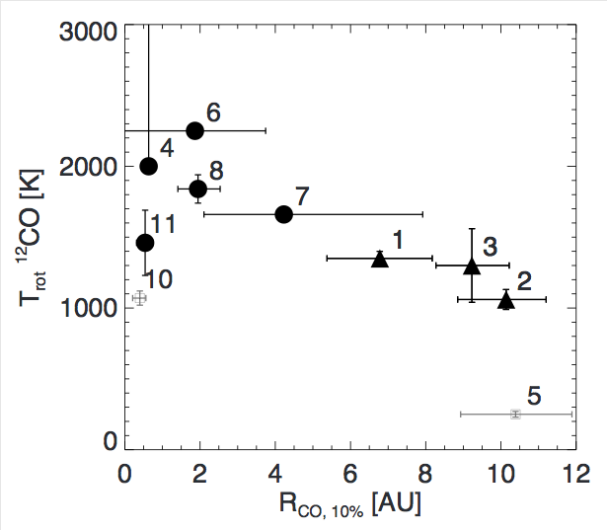


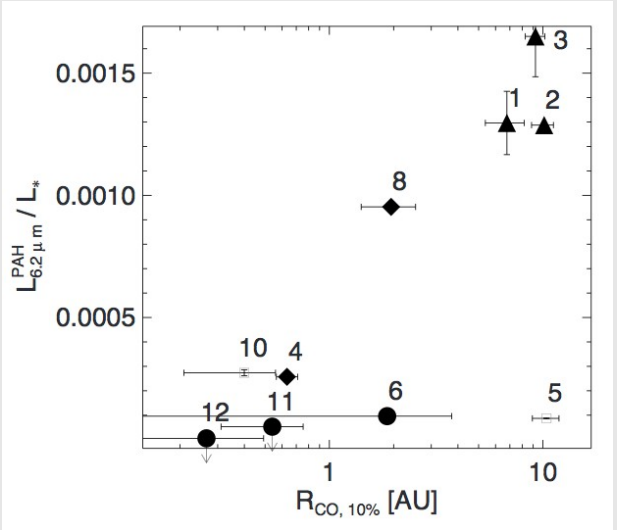
Consistent with multiple absorbing clouds...

First overtone CO band head emission.... najita & carr 2003, Oksala et al. (2013), Gib...

Line width versus temperature

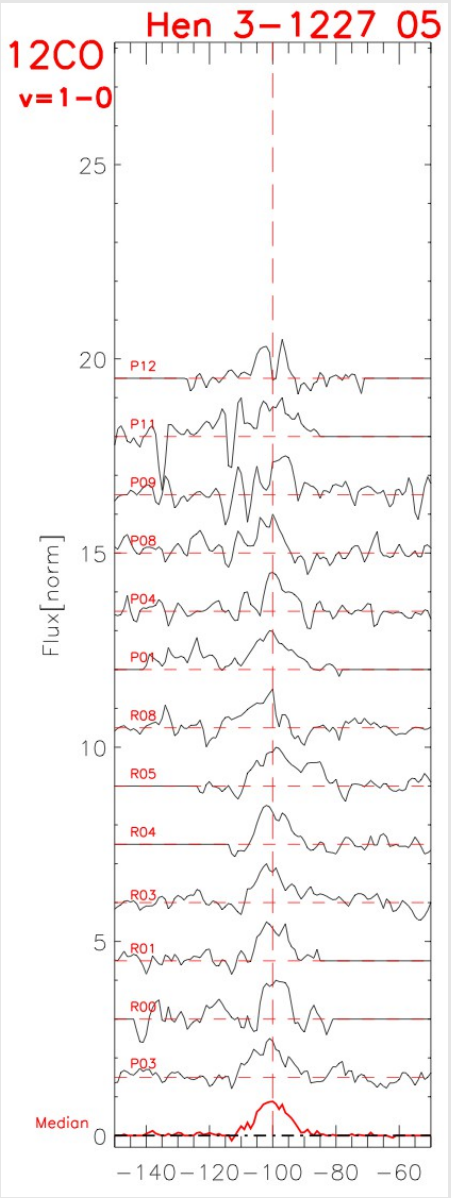
Hd163296:
fwhm=54km/s
HD250550:
Fwhm= 19 km/s
Hen 2-80
05 fwhm= 39
06 fwhm= 38

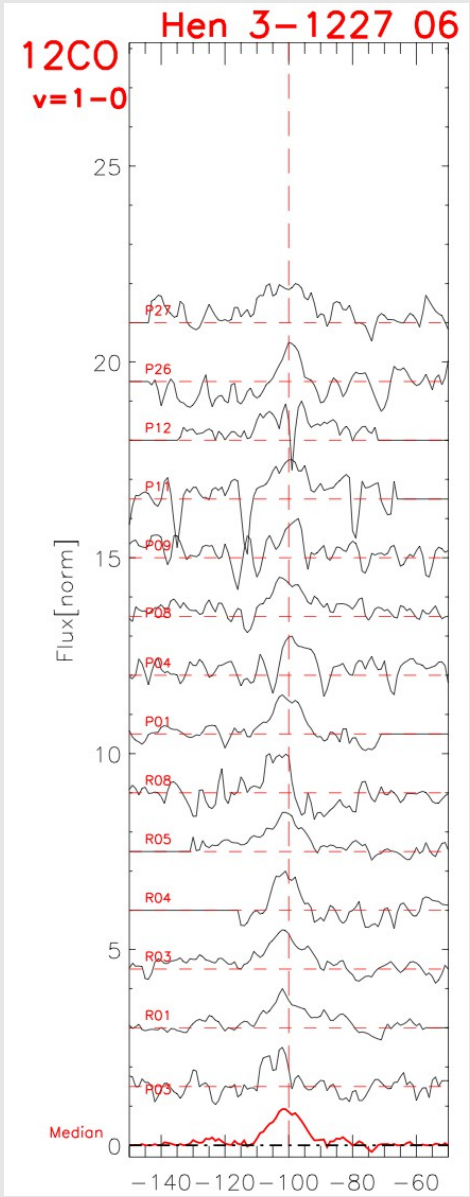


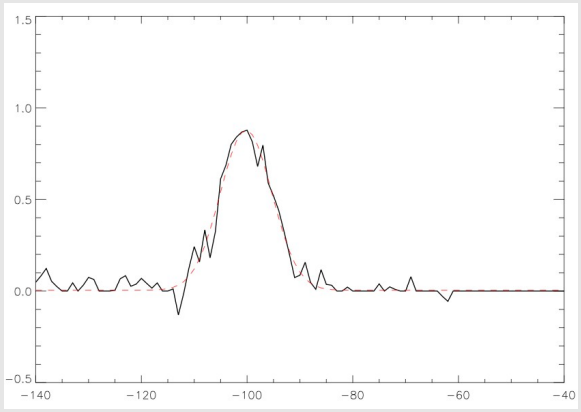


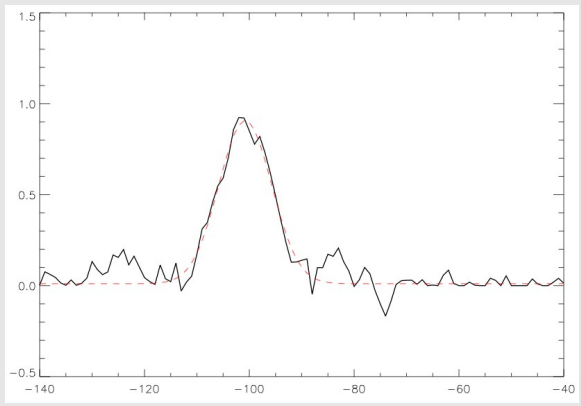
Van der Plas thesis

Hen 3-1227


Hen 3−1227 05
12CO
v=1−0
Flux[norm]
P12
P11
P09
P08
P04
P01
R08
R05
R04
R03
R01
R00
P03
Median
−140 −120 −100 −80 −60


Hen 3−1227 06
12CO
v=1−0
Flux[norm]
P27
P26
P12
P11
P09
P08
P04
P01
R08
R05
R04
R03
R01
P03
Median
−140 −120 −100 −80 −60



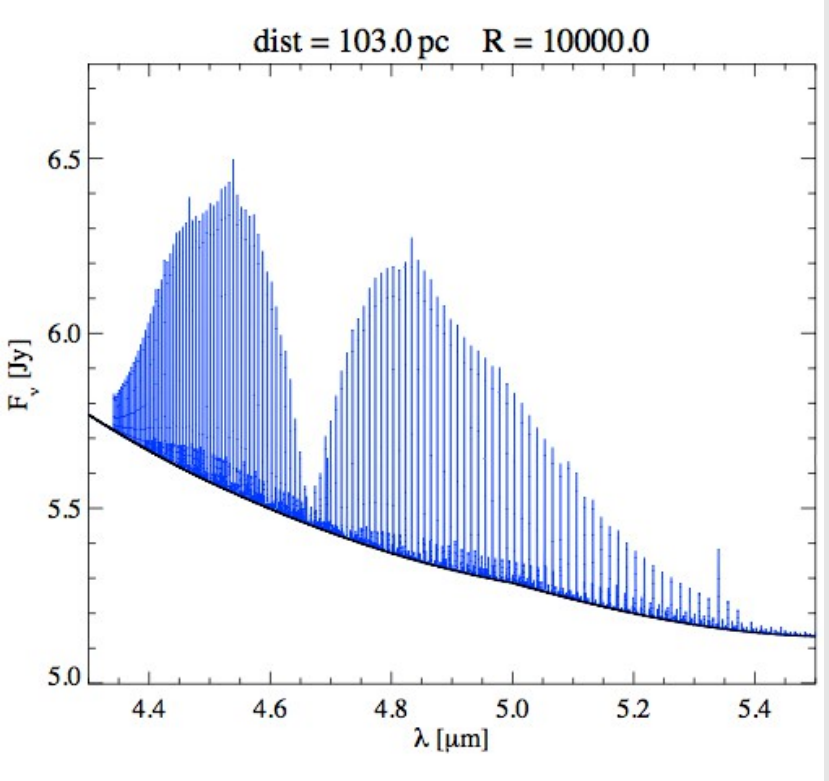


CO ro-vibrational transitions

R-branch (ΔJ = +1); right
P-branch (ΔJ = -1); left

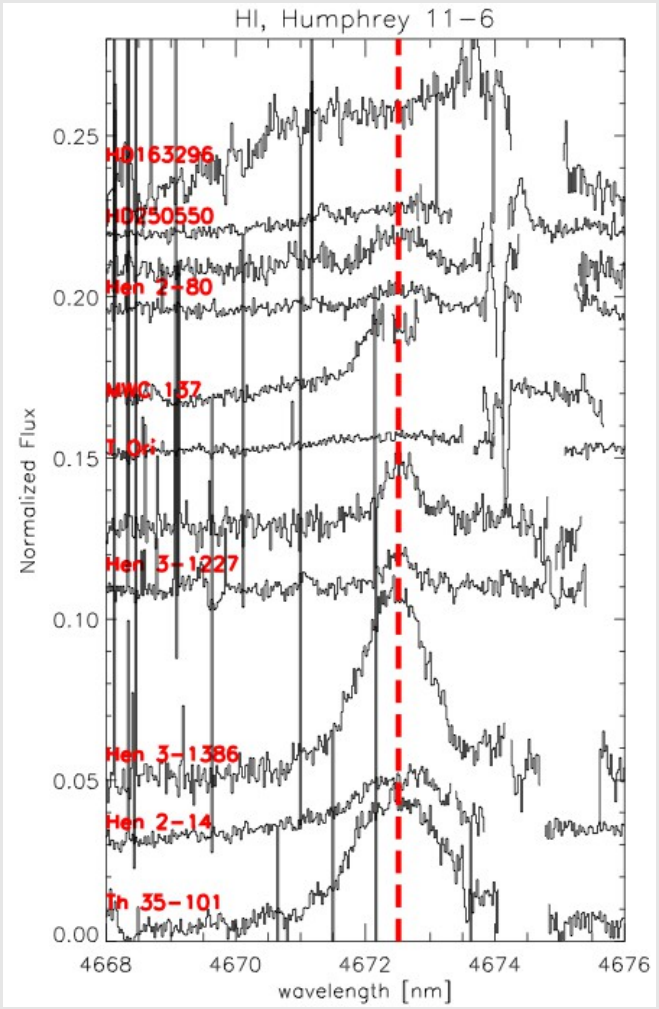
CO sub-mm (Δv = 0), pure rotational.
CO 4.7 μm (Δv = 1), ro-vibrational fundamental.
CO 2.3 μm (Δv = 2), ro-vibrational overtone.

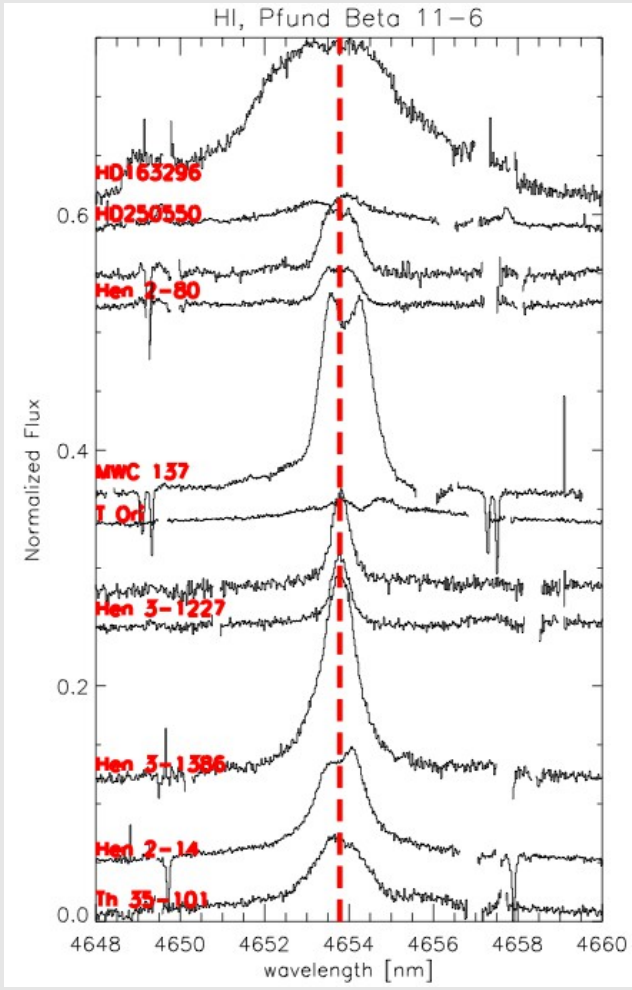
the CO ro-vib transitions have energies in the range:
0 – 18821 cm^{-1} (2.3 eV)



ProDiMo model, own archive

HI lines


HI, Humphrey 11–6
HD163296
HD250550
Hen 2-80
MWC 137
T Ori
Hen 3-1227
Hen 3-1386
Hen 2-14
Th 35-101
Normalized Flux
0.25
0.20
0.15
0.10
0.05
0.00
4668
4670
4672
4674
4676
wavelength [nm]


HI, Pfund Beta 11–6
HD163296
HD250550
Hen 2-80
MWC 137
T Ori
Hen 3-1227
Hen 3-1386
Hen 2-14
Th 35-101
Normalized Flux
0.6
0.4
0.2
0.0
4648
4650
4652
4654
4656
4658
4660
wavelength [nm]