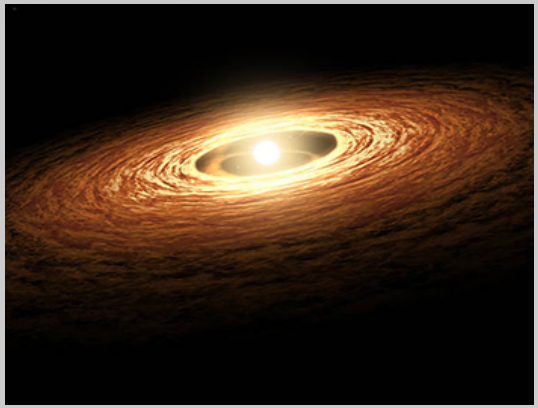
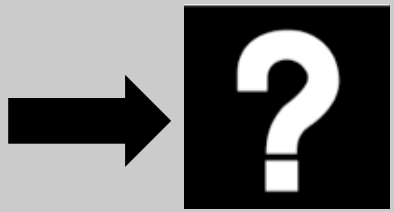
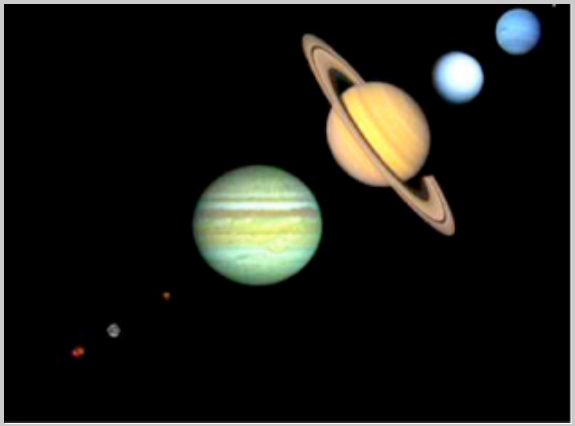
Observation of Warm Gas in Pre-planetary Disks: Interpreting their SEDs



Courtesy of NASA/JPL-Cal Tech



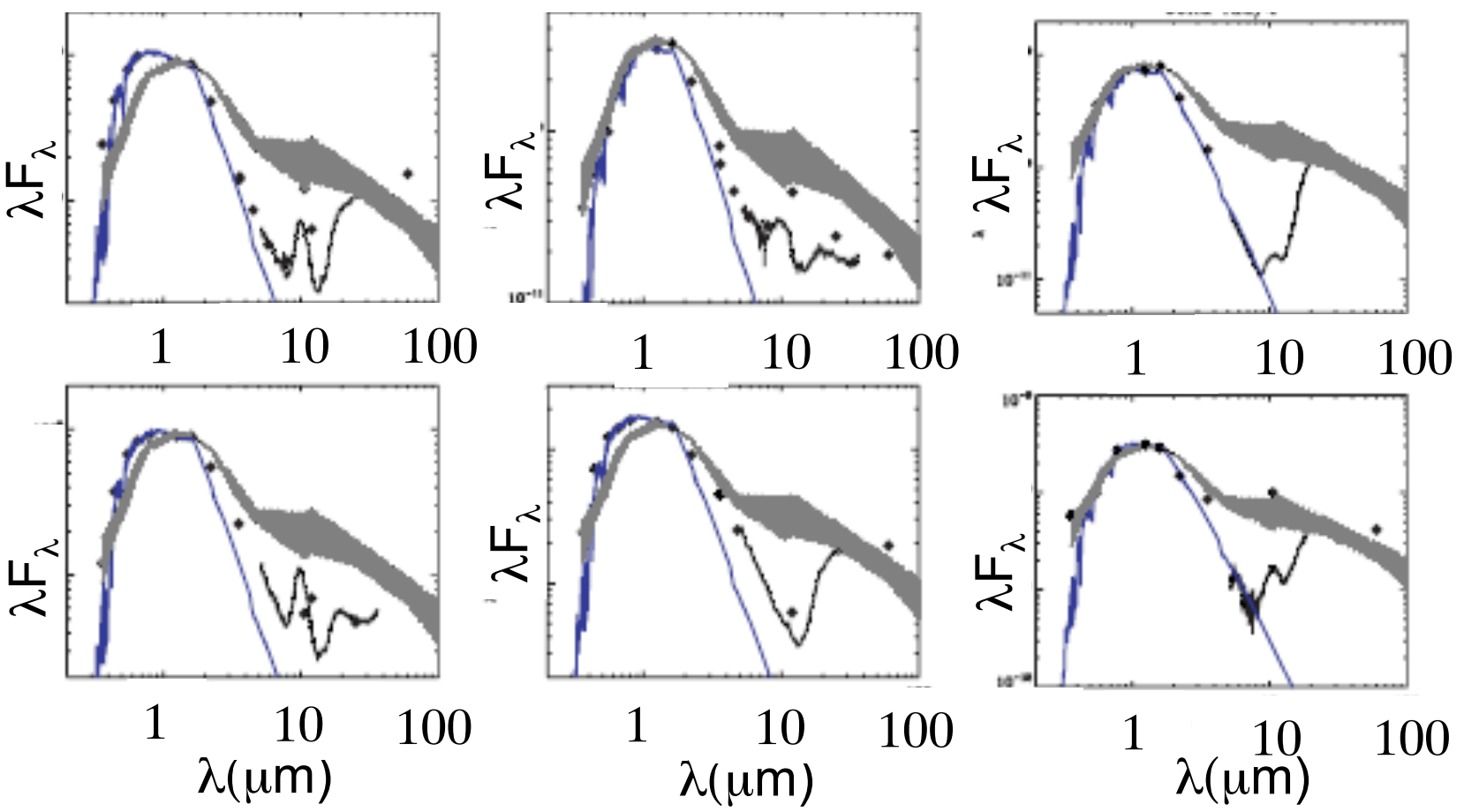


Courtesy of NASA/JPL-Cal Tech

Sean Brittain, Matt Troutman (Clemson University), Joan Najita (NOAO), John Carr (NRL)

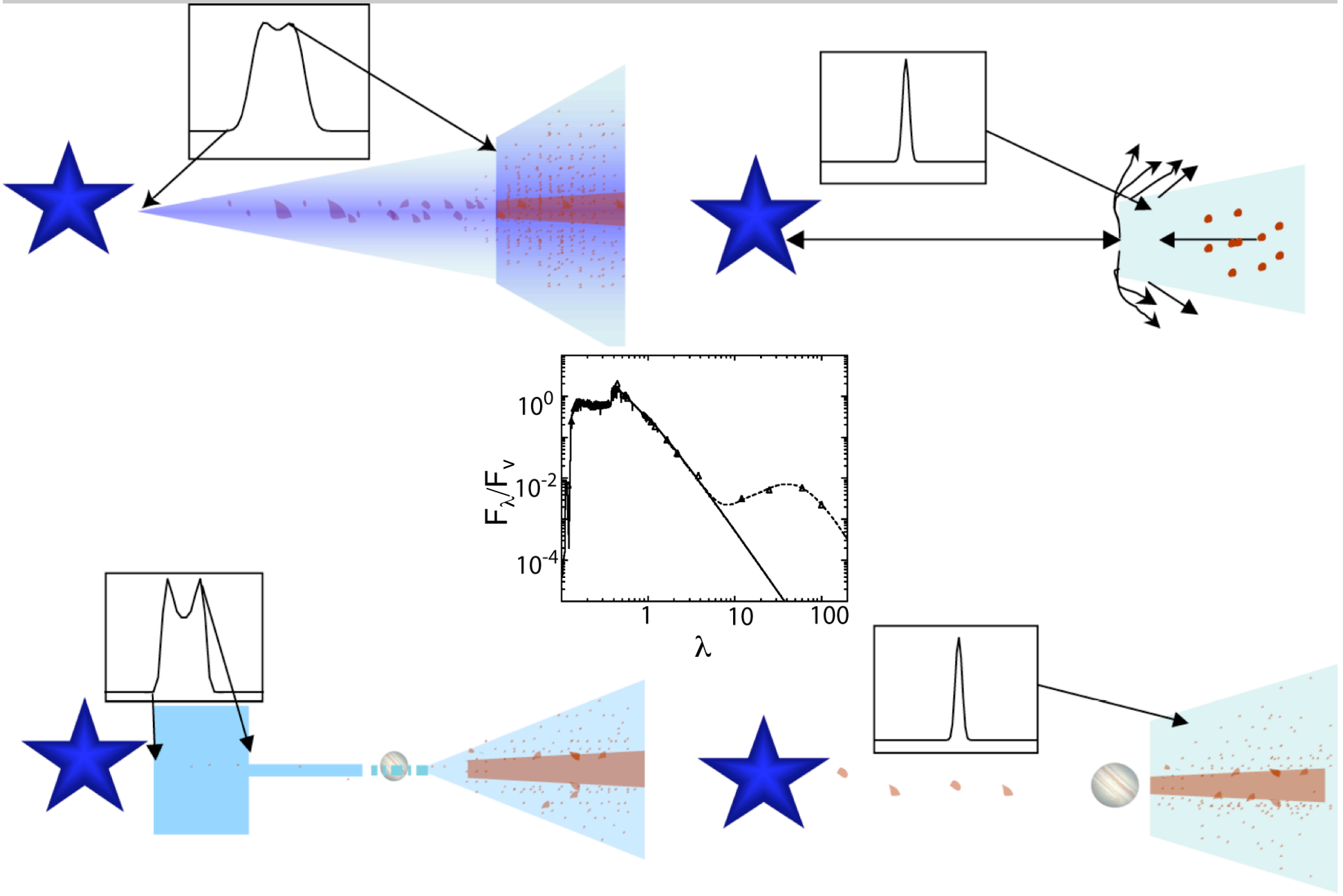
From Circumstellar Disks To Planets, November 2009

SEDs of Transition Objects



Najita et al 2007

Gas in Transitional Disks



Studying gas in disks

1. Excitation of gas
2. Kinematic structure of gas lines
3. Spatial structure of gas lines

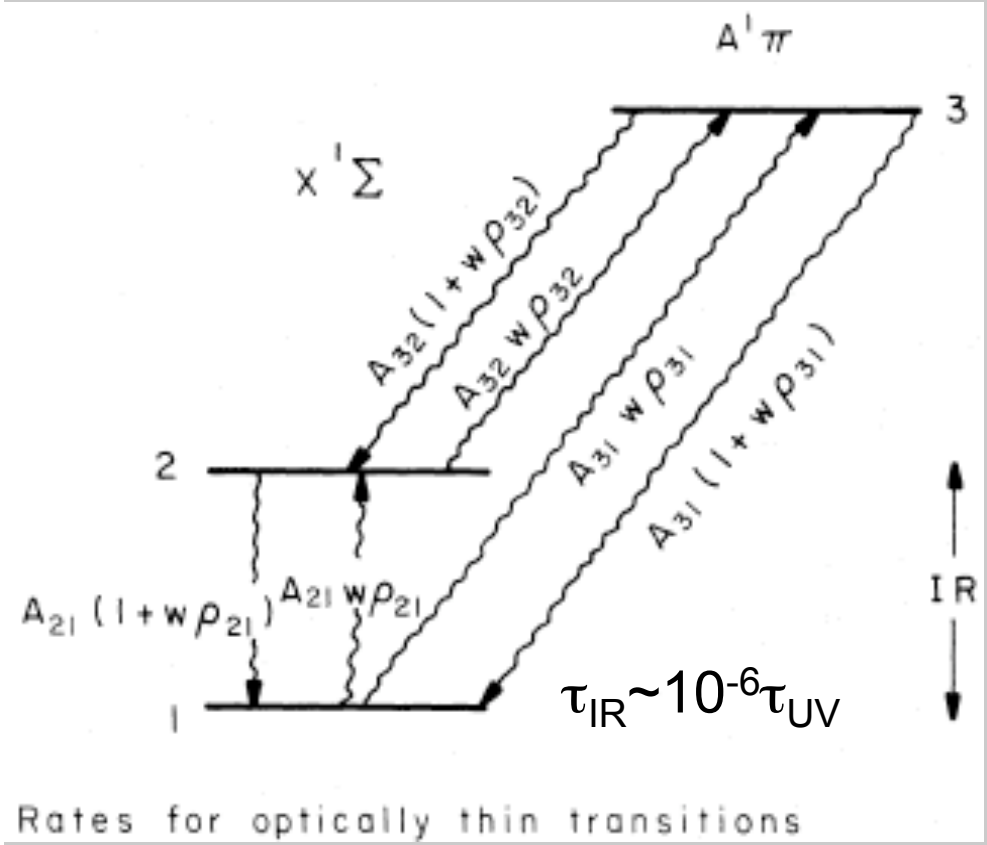
The Excitation of CO

Does the non-detection of CO emission indicate that the gas is missing or that it is not sufficiently excited to be seen?

1) Temperature structure of disk

2) Excitation mechanism of gas

The Excitation of CO



Rates for optically thin transitions

Krotkov et al. 1980

Notation:

$Aw\rho = B\not{\rho} = g$

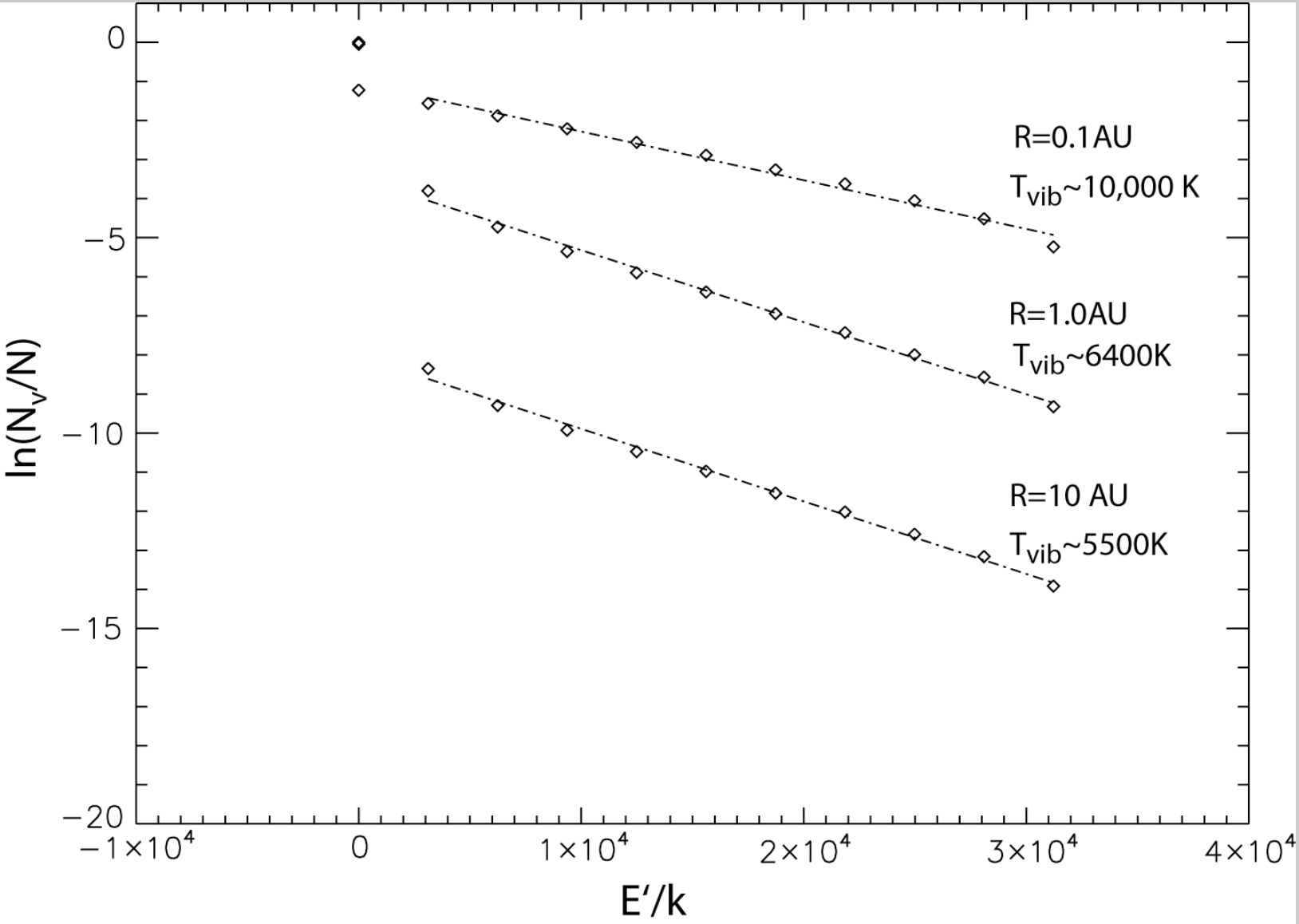
$$g = \frac{\pi e^2}{mc^2}\lambda^2 f_{ij}(\pi F_\lambda)\ photons\ s^{-1}\ molecule^{-1}$$

$$\dot{n}_{v=0} = -n_X^{v=0} g_{X-A}^{0-0} + n_A^{v=0}\left(g_{A-X}^{0-0} + A_{A-X}^{0-0}\right) = 0$$

$$\dot{n}_{v=1} = -n_X^{v=1} g_{X-A}^{1-0} + n_A^{v=0}\left(g_{A-X}^{0-1} + A_{A-X}^{0-1}\right) = 0$$

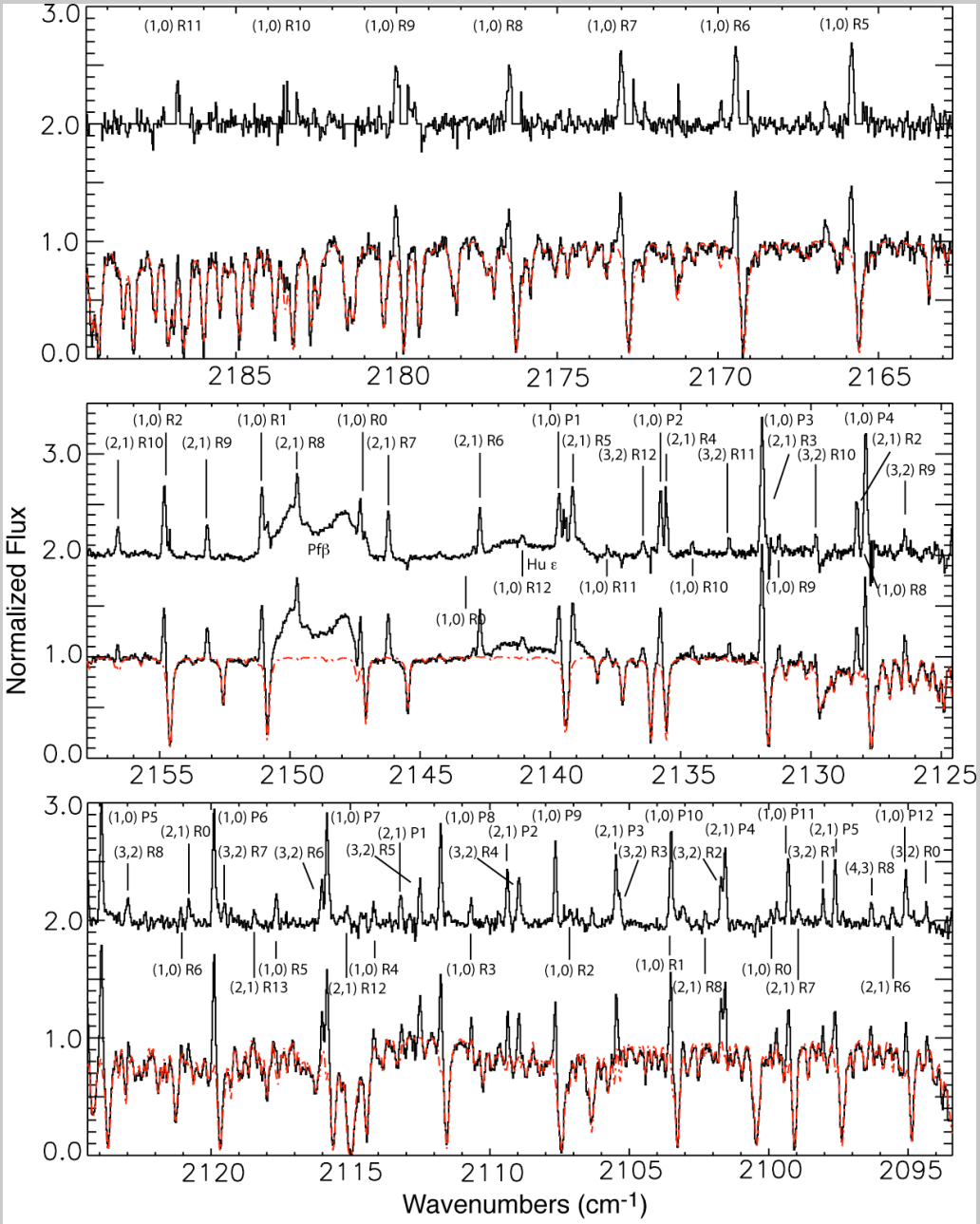
$$\frac{n_0}{n_1} \approx \frac{g_{A-X}^{1-0}}{g_{A-X}^{0-0}} \approx \frac{F_{A-X}^{1-0}}{F_{A-X}^{0-0}} \propto e^{-\theta/T}$$

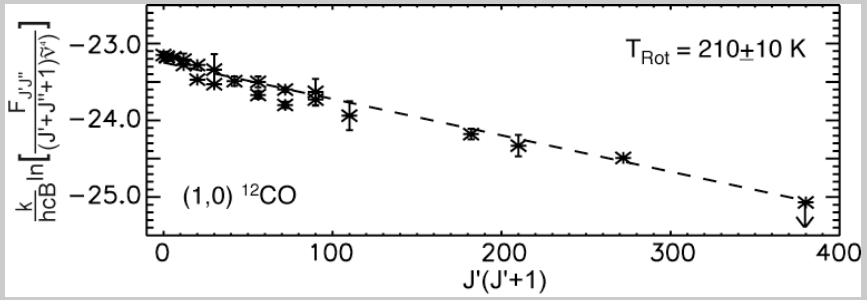
UV Fluorescence

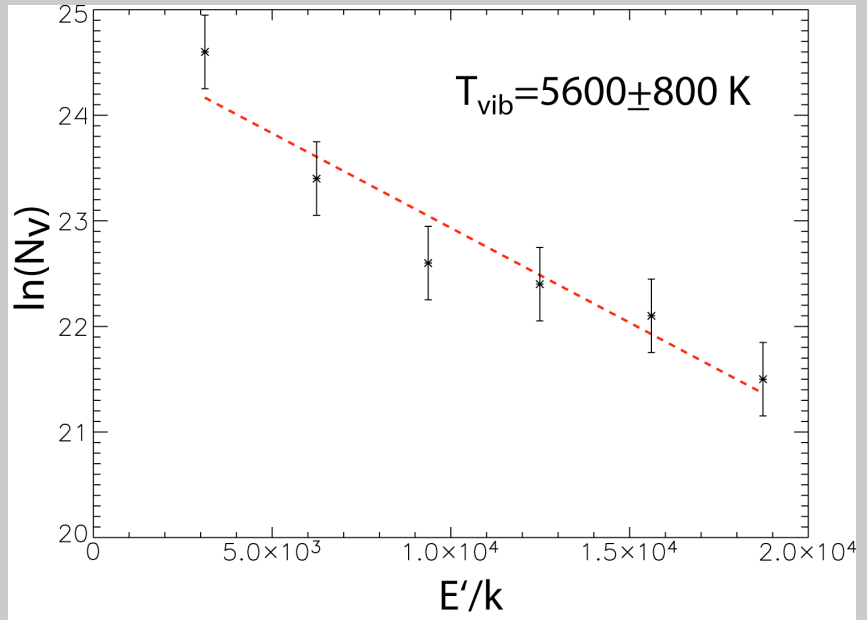


Brittain et al. 2007

HD 141569

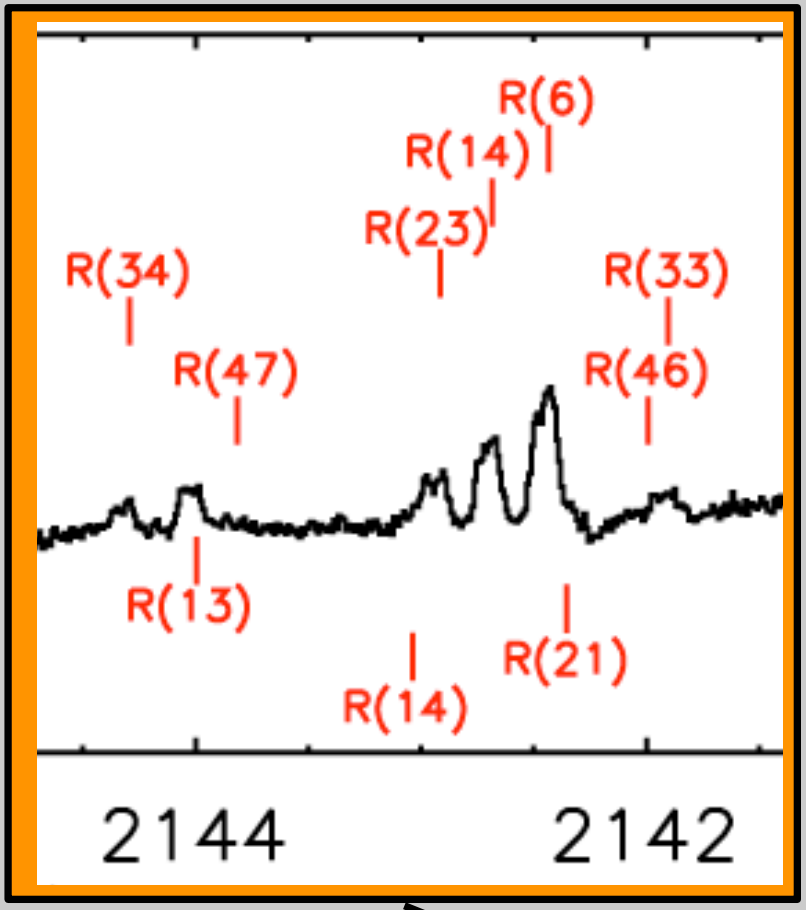




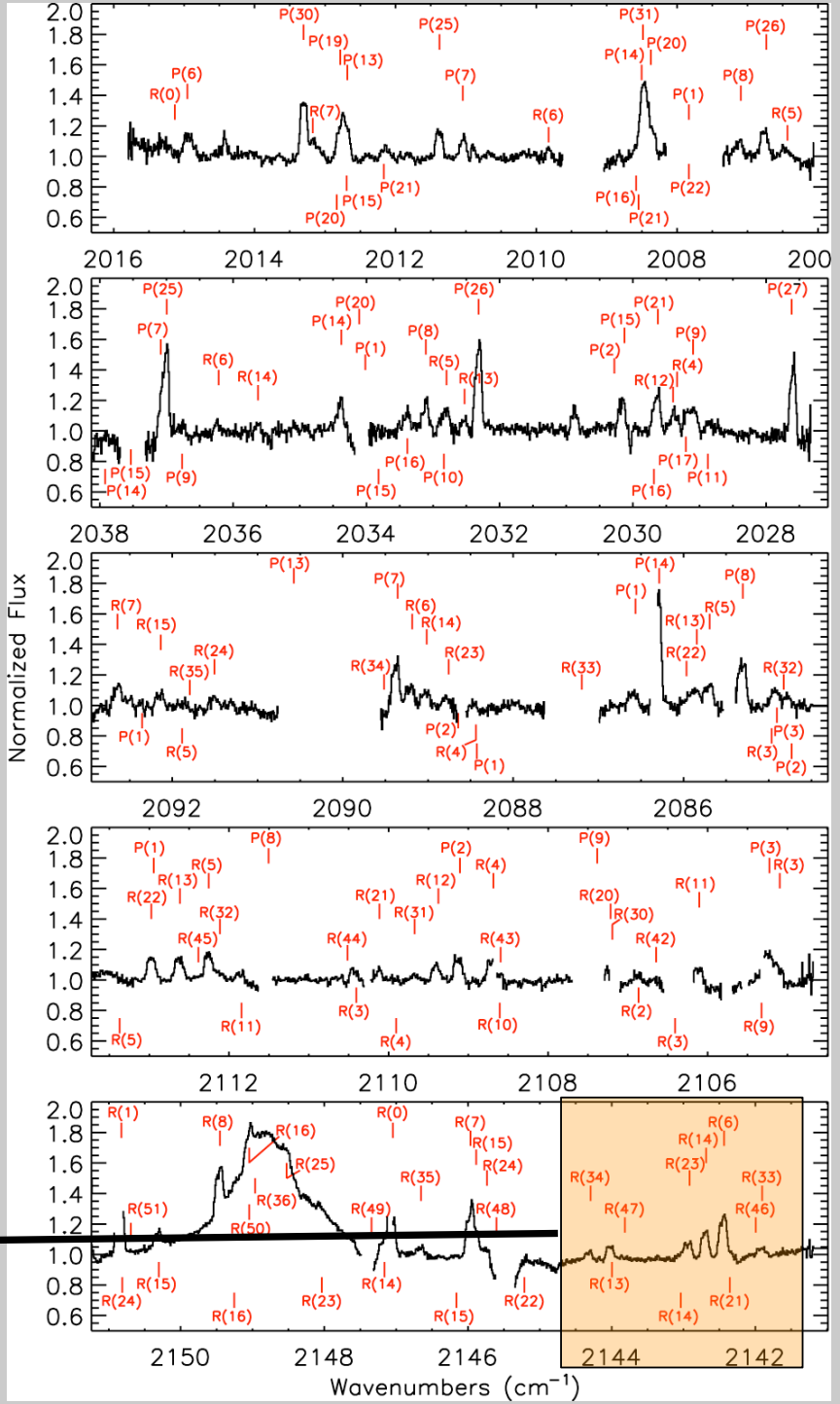


Brittain et al. 2003, 2007 (see also Goto et al. 2006), Lewis et al. 2009

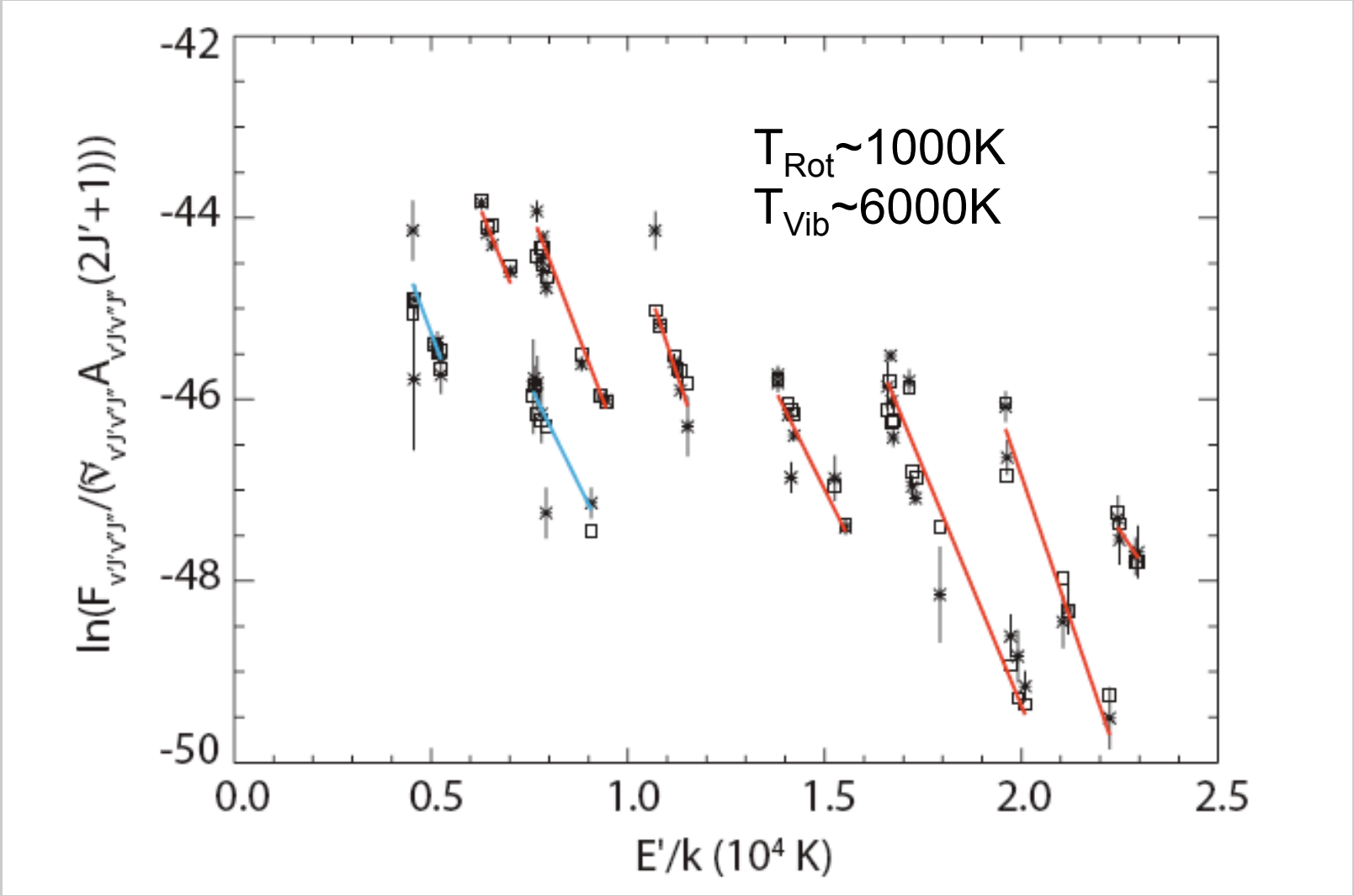
HD 100546



Brittain et al. 2009 (see also van der Plas et al. (2009)

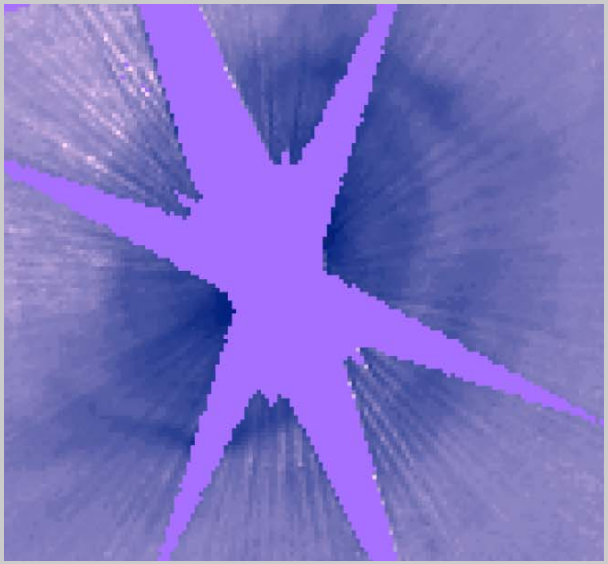


HD 100546

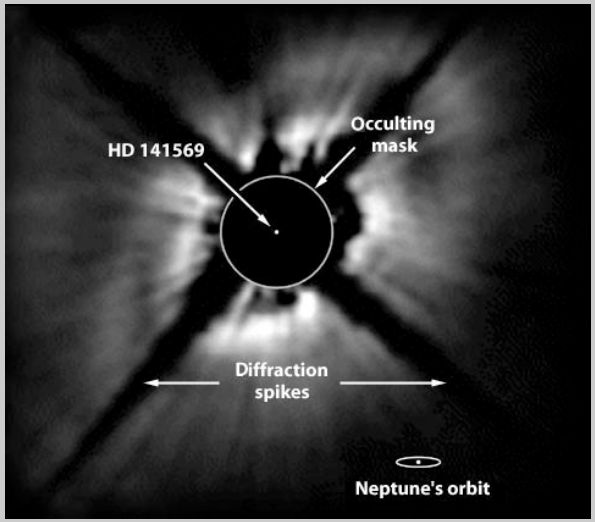

T_{Rot}~1000K
T_{Vib}~6000K
-42
-44
-46
-48
-50
0.0
0.5
1.0
1.5
2.0
2.5
E'/k (10^4 K)
$\ln(F_{v'J'v''J''}/(\tilde{\nu}_{v'J'v''J''}A_{v'J'v''J''}(2J'+1)))$

HD 100546 vs HD 141569

T_{eff}~10,000 K	T_{eff}~10,000 K
~10Myr	~5Myr
T(CO) = 1000 K	T(CO) = 200 K



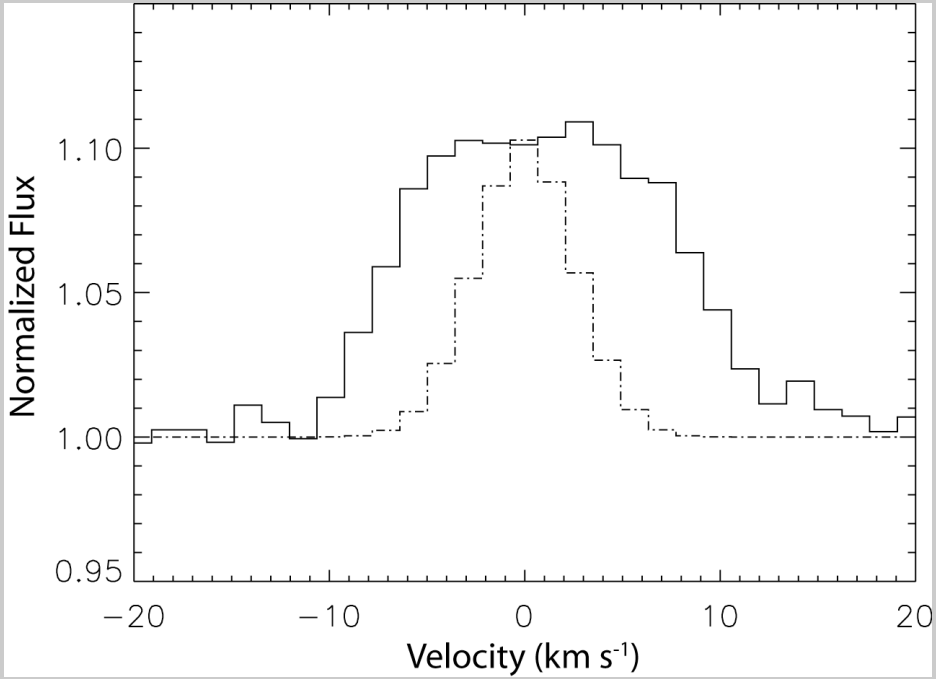
Grady et al. 2005

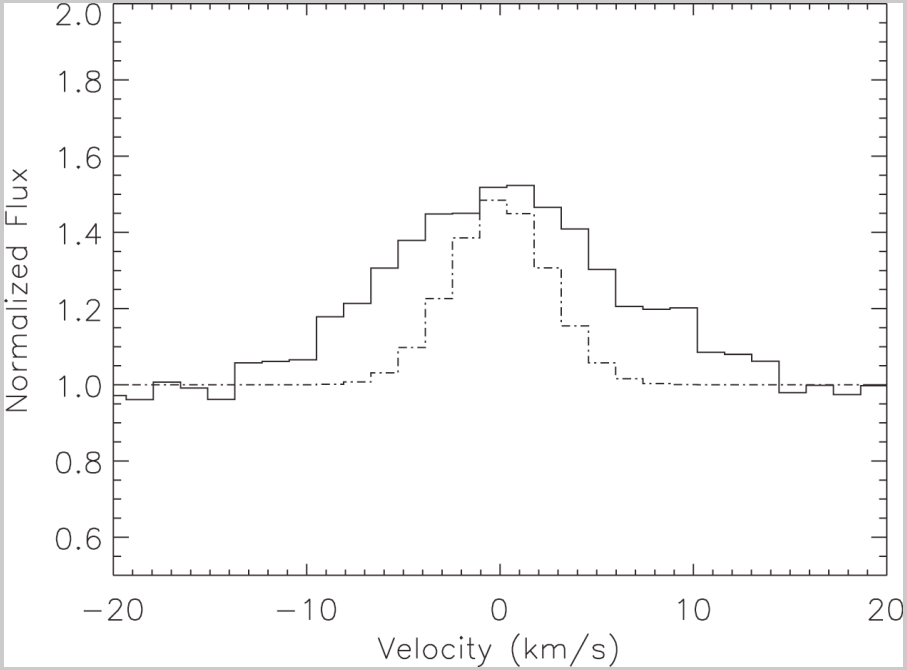


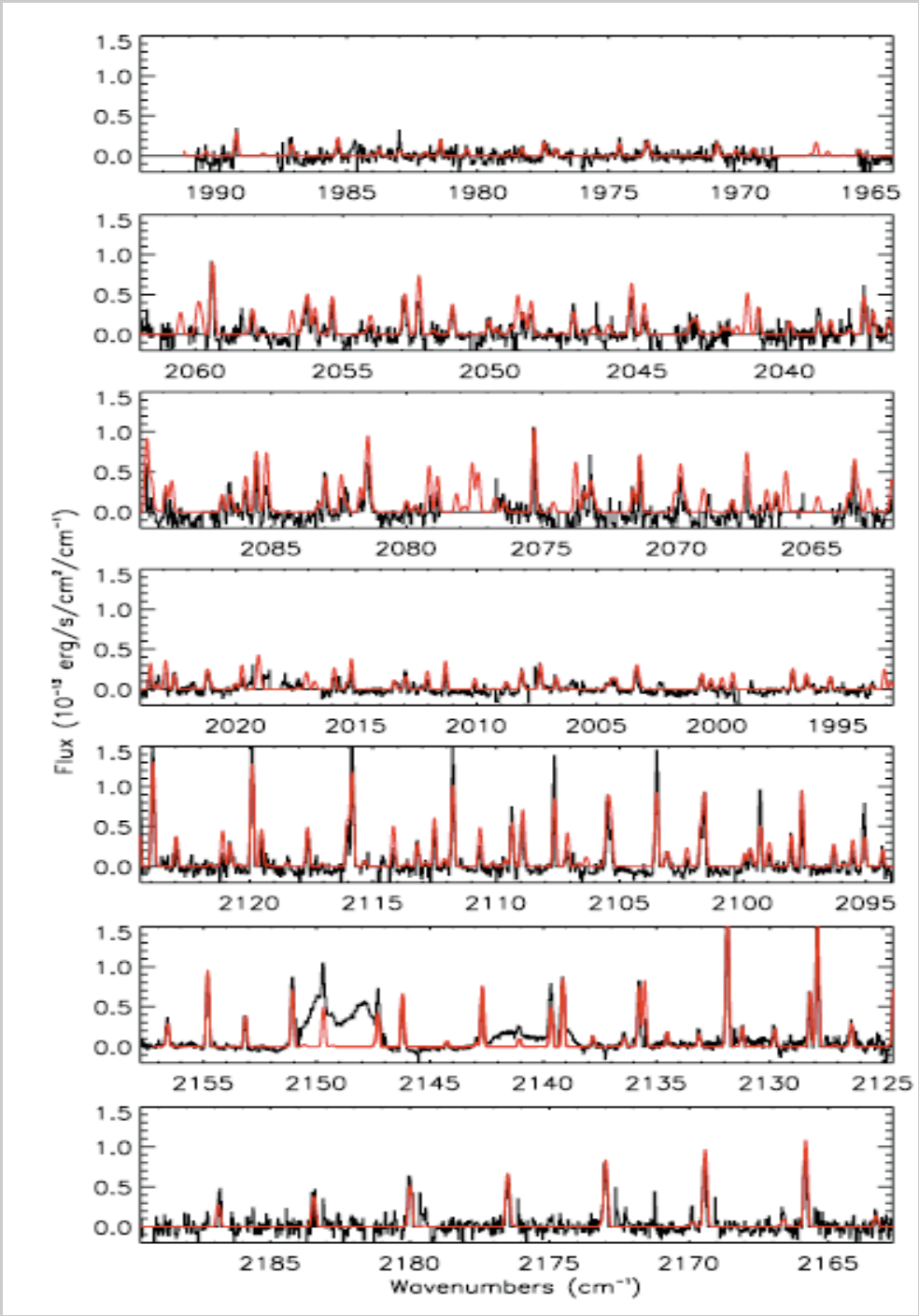
A. Weinberger, E. Becklin (UCLA), G. Schneider (Univ. of Arizona), and NASA.

Kinematic Structure of Emission Lines

CO Line Profiles

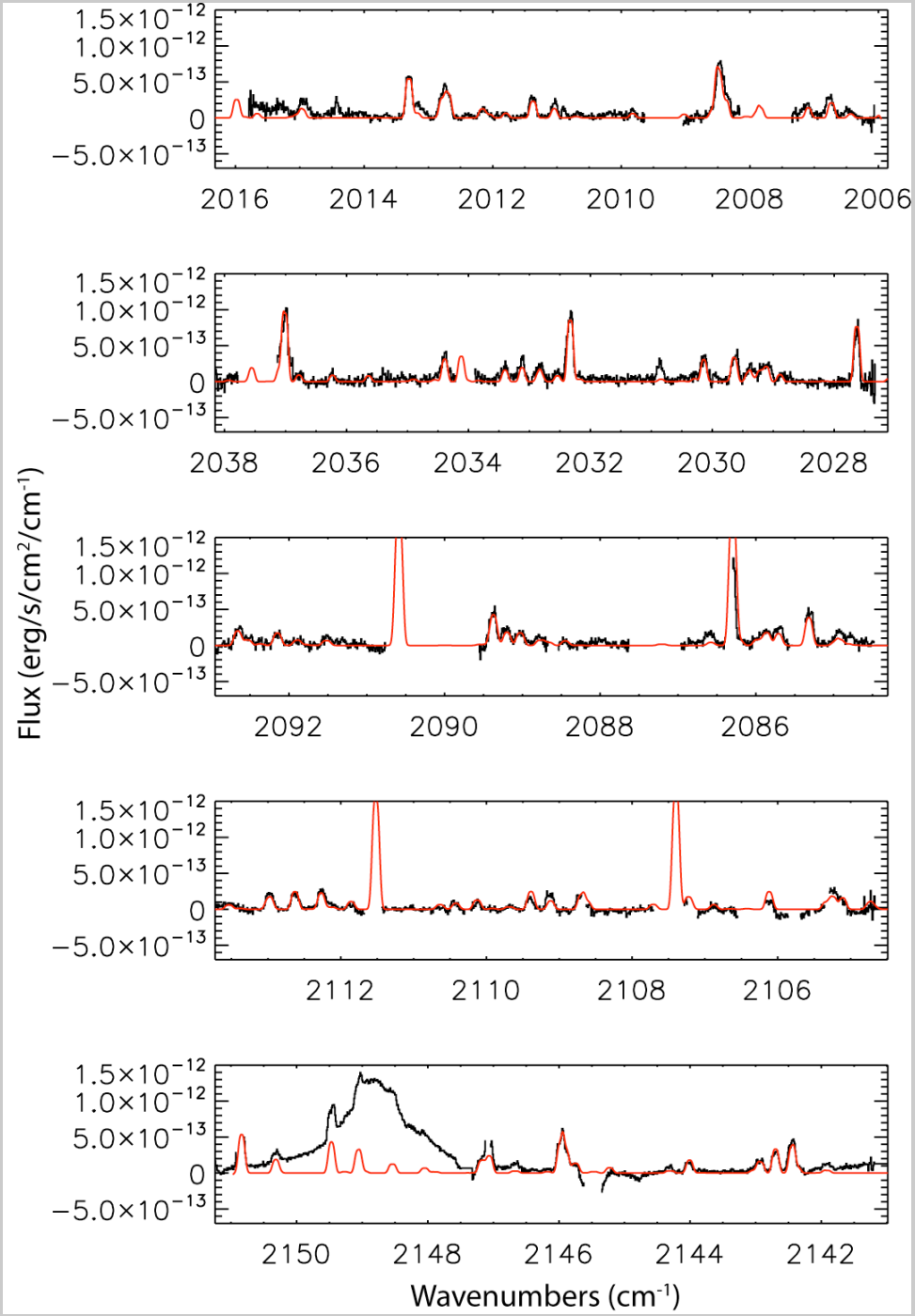






HD 141569

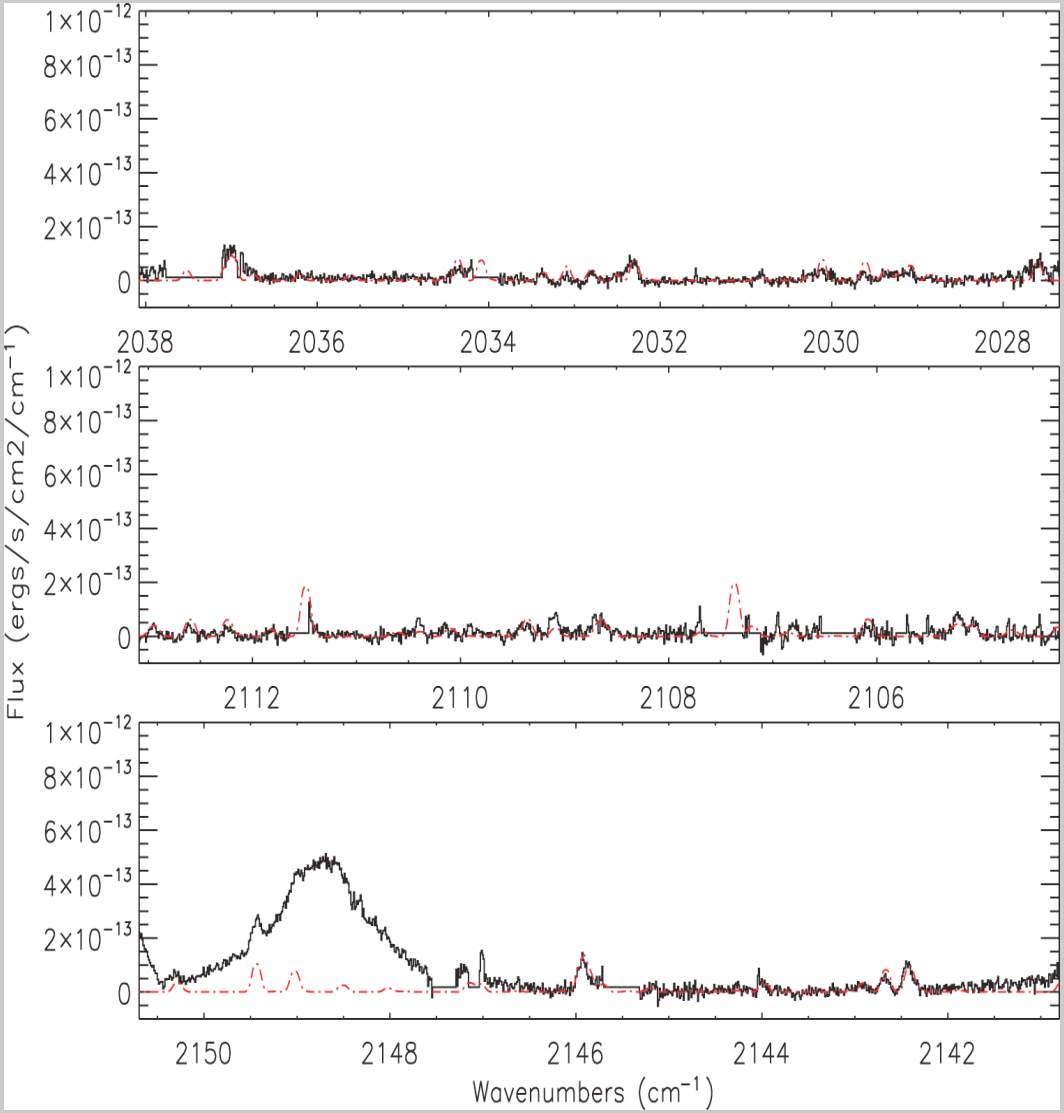
- R_{in}(CO)=9 AU
- R_{out}(CO)~50 AU
- $T(r)=200\ (r/9AU)^{-0.25}$ K



HD 100546

- R_{in}(CO)=13 AU
- R_{out}(CO)~100 AU
- T(r)=1400 (r/13AU)$^{-0.35}$ K

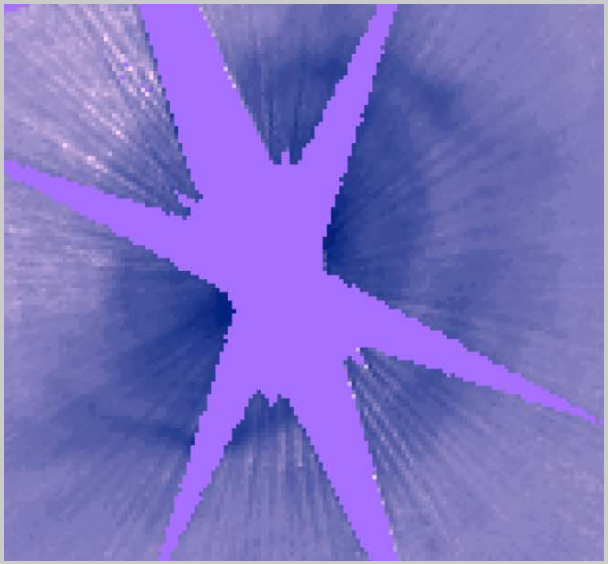
HD 97048



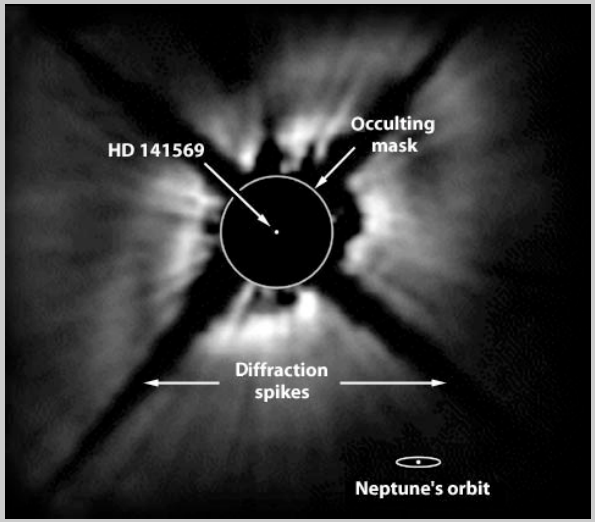
- R_{in}(CO)=8 AU
- R_{out}(CO)~100 AU
- T(r)=1500 (r/8AU)$^{-0.25}$ K

HD 100546 vs HD 141569

T_{eff}~10,000 K	T_{eff}~10,000 K
~10Myr	~5Myr
T(CO) = 1000 K	T(CO) = 200 K
R_{in}=13 AU	R_{in}=9 AU

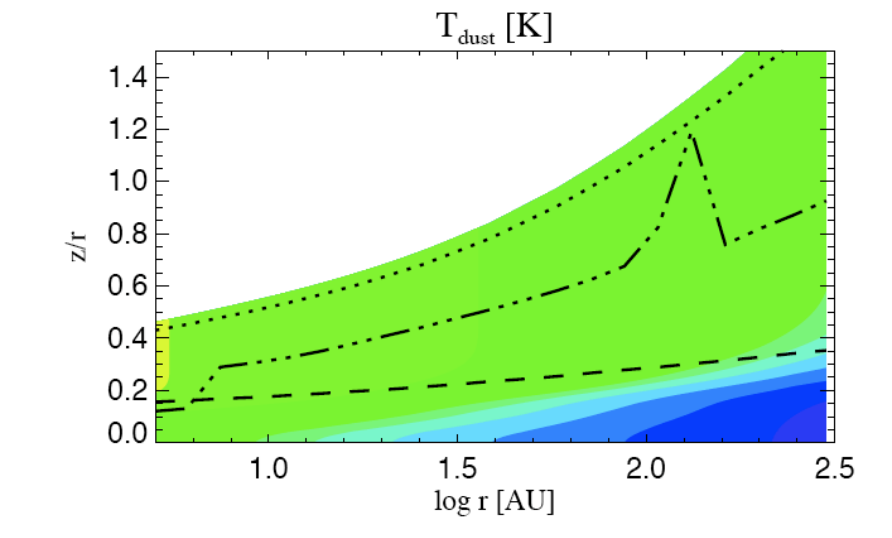


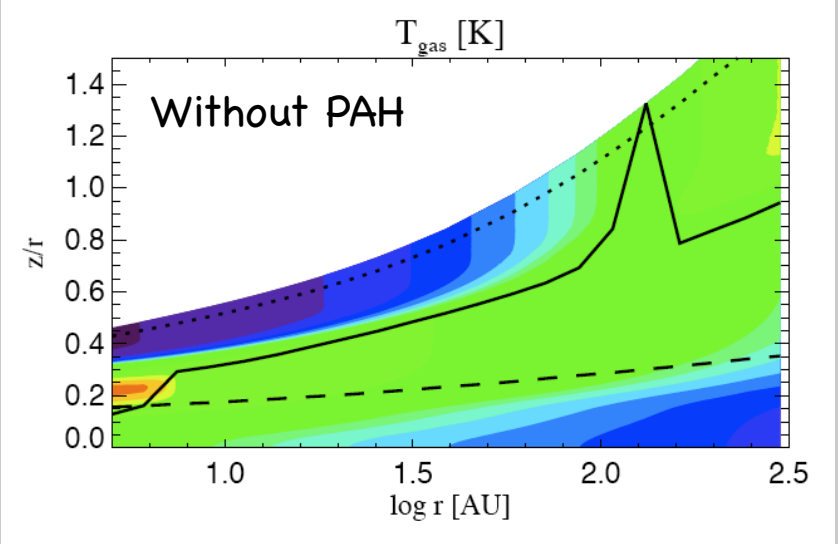
Grady et al. 2005

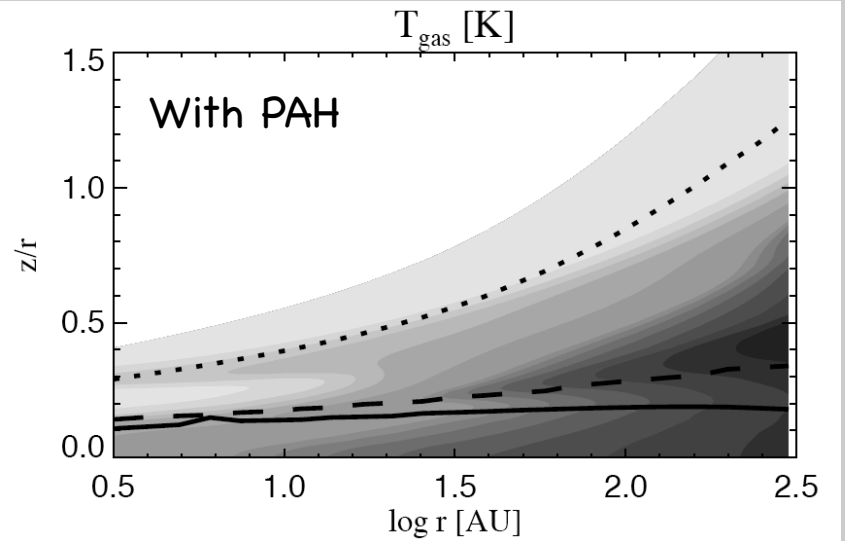


A. Weinberger, E. Becklin (UCLA), G. Schneider (Univ. of Arizona), and NASA.

HD 100546 vs HD 141569





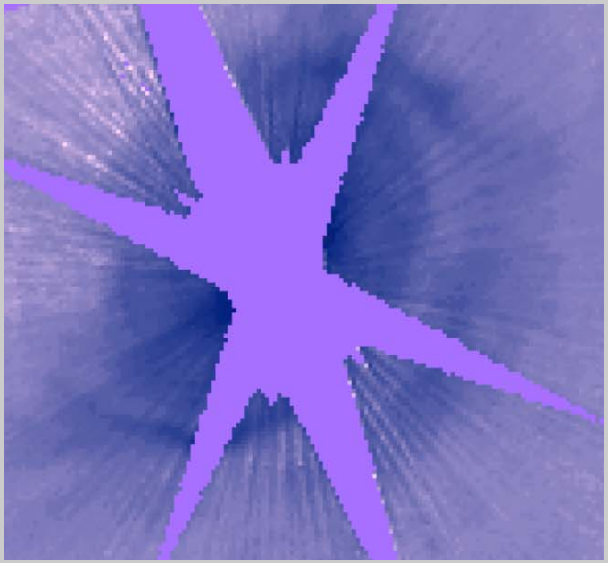


Kamp et al. (2005)

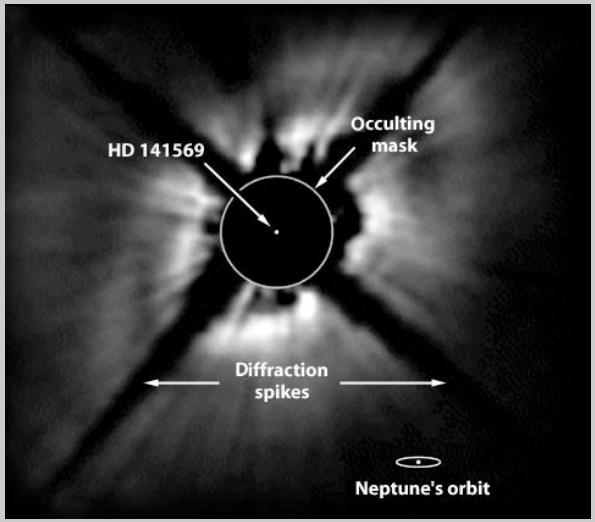
HD 100546 vs HD 141569

T_{eff}~10,000 K	T_{eff}~10,000 K
R_{in}=13 AU	R_{in}=9 AU
~10Myr	~5Myr
T(CO) = 1000 K	T(CO) = 200 K
L_{PAH}/L_{UV}=6.4E-3[a]	L_{PAH}/L_{UV}=5.3E-4[a]

a) Acke et al. 2004



Grady et al. 2005

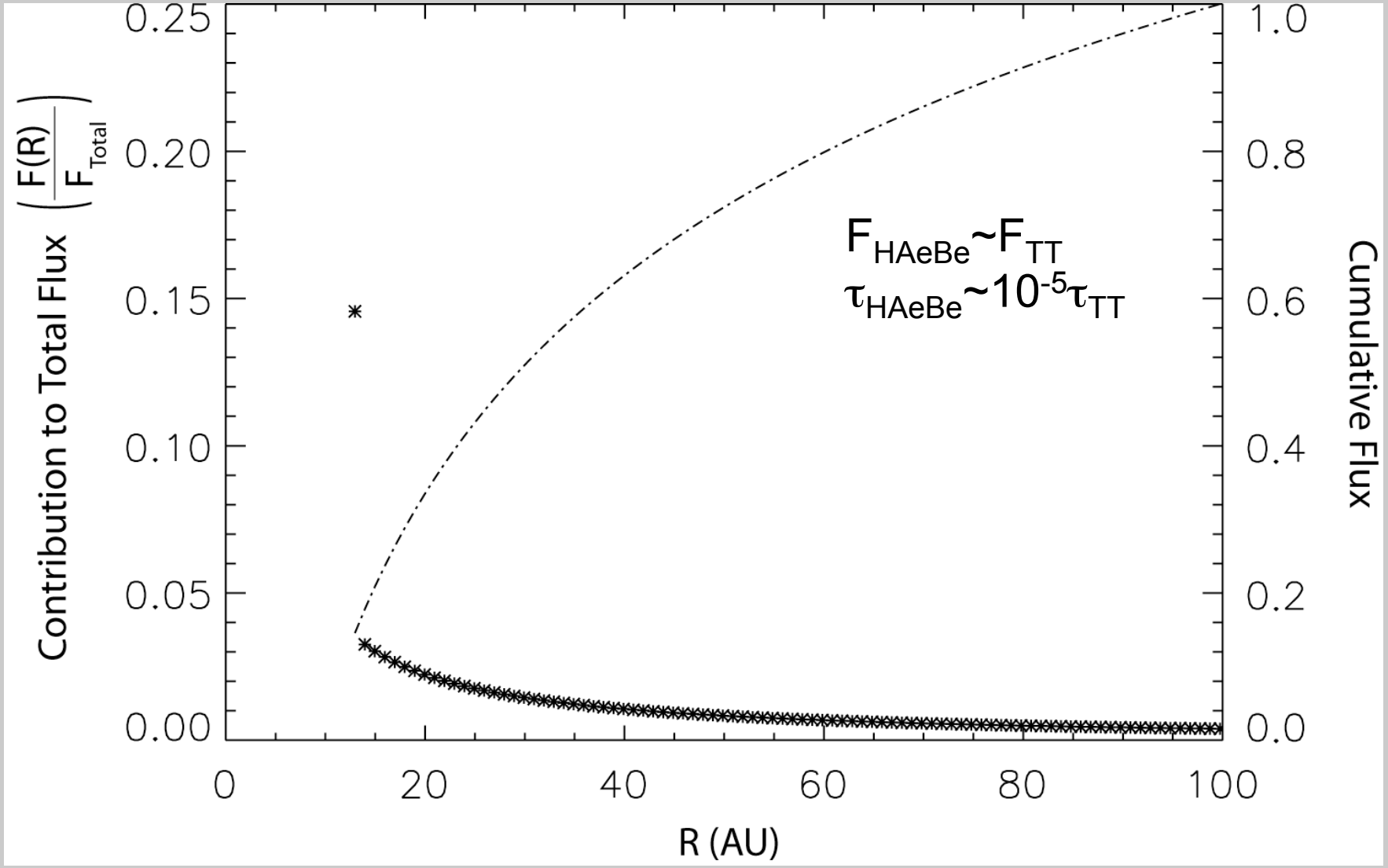


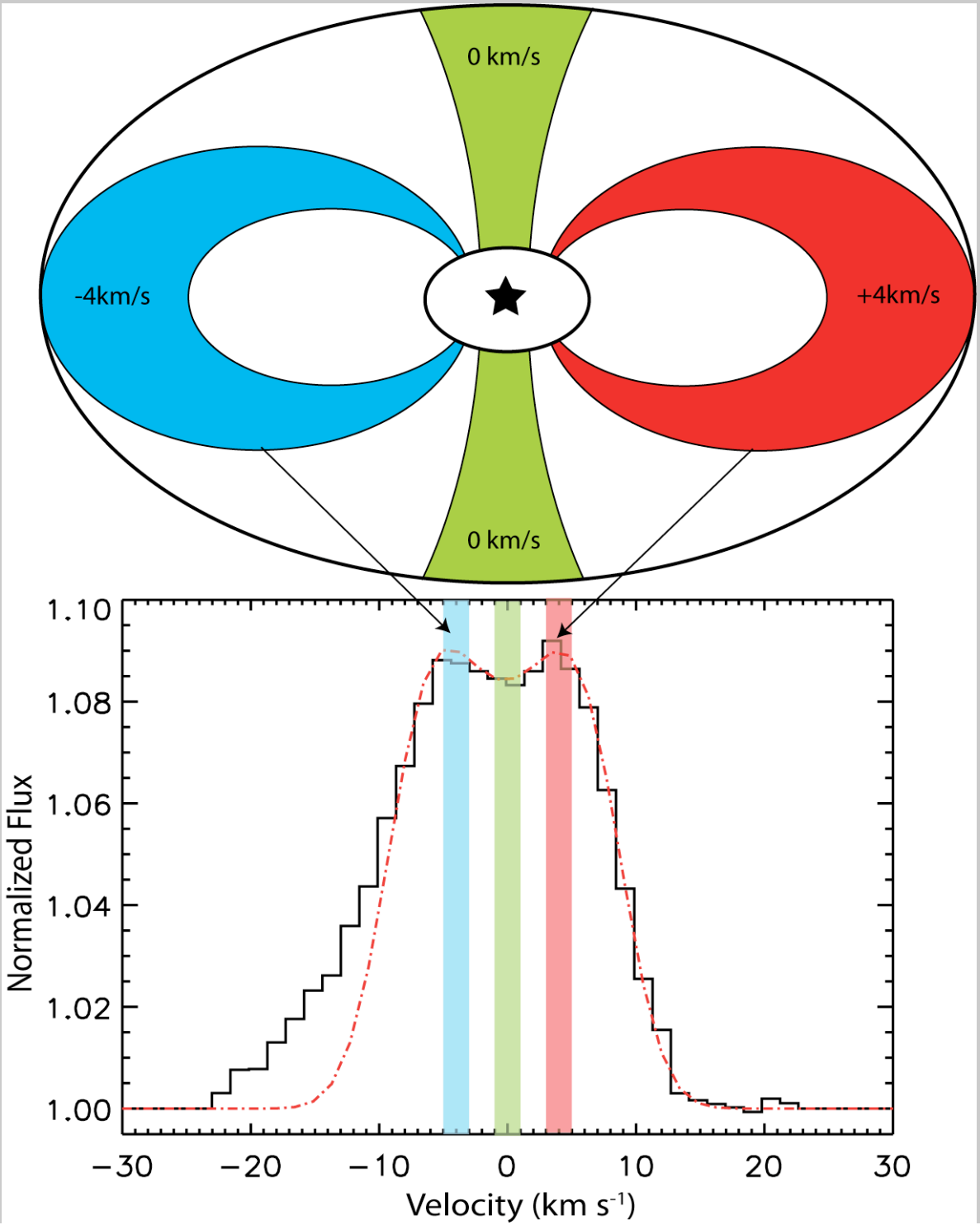
A. Weinberger, E. Becklin (UCLA), G. Schneider (Univ. of Arizona), and NASA.

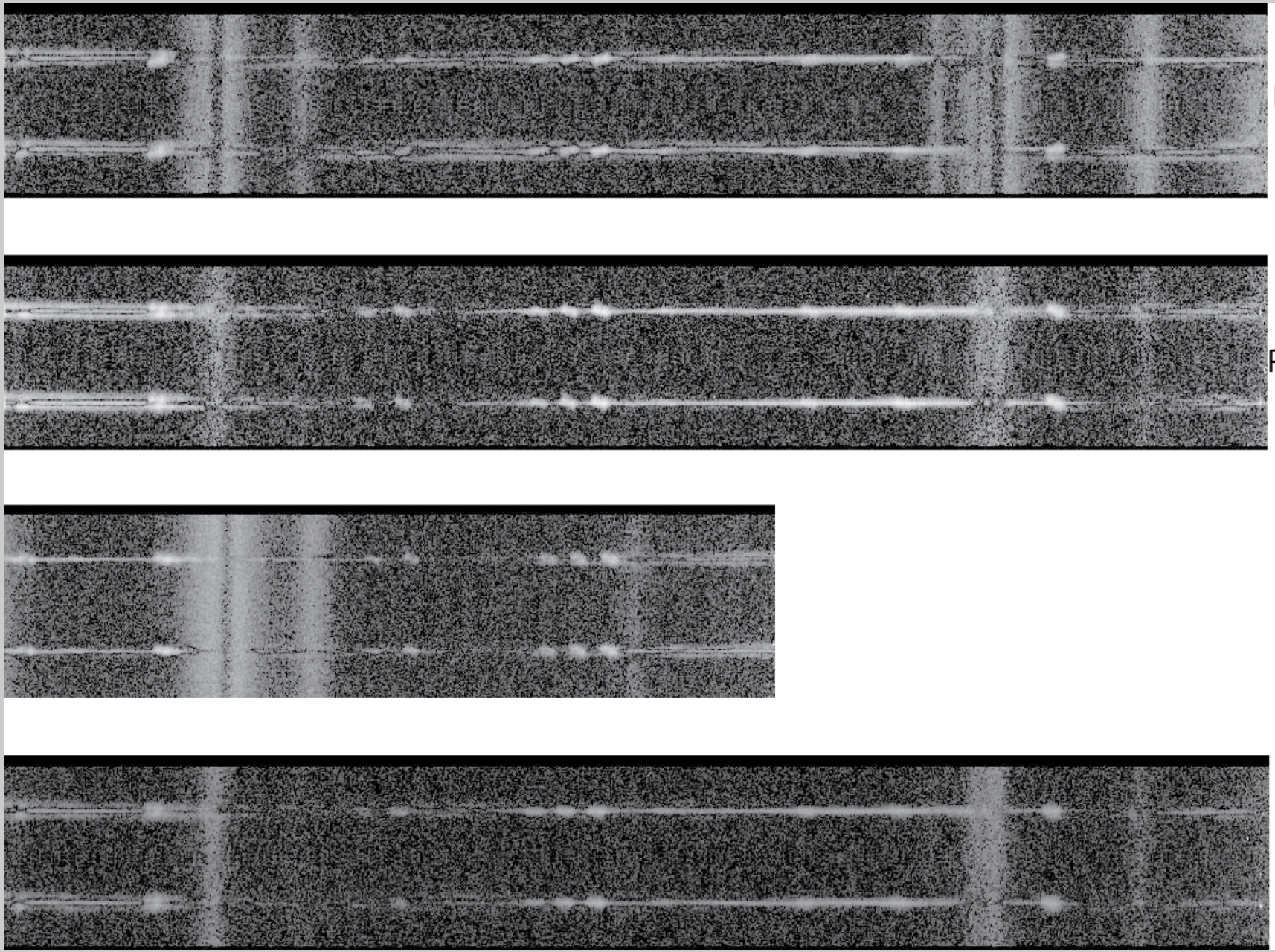
Spatial Structure of Emission Lines

(B39-Troutman et al. , B41-van der Plas et al.)

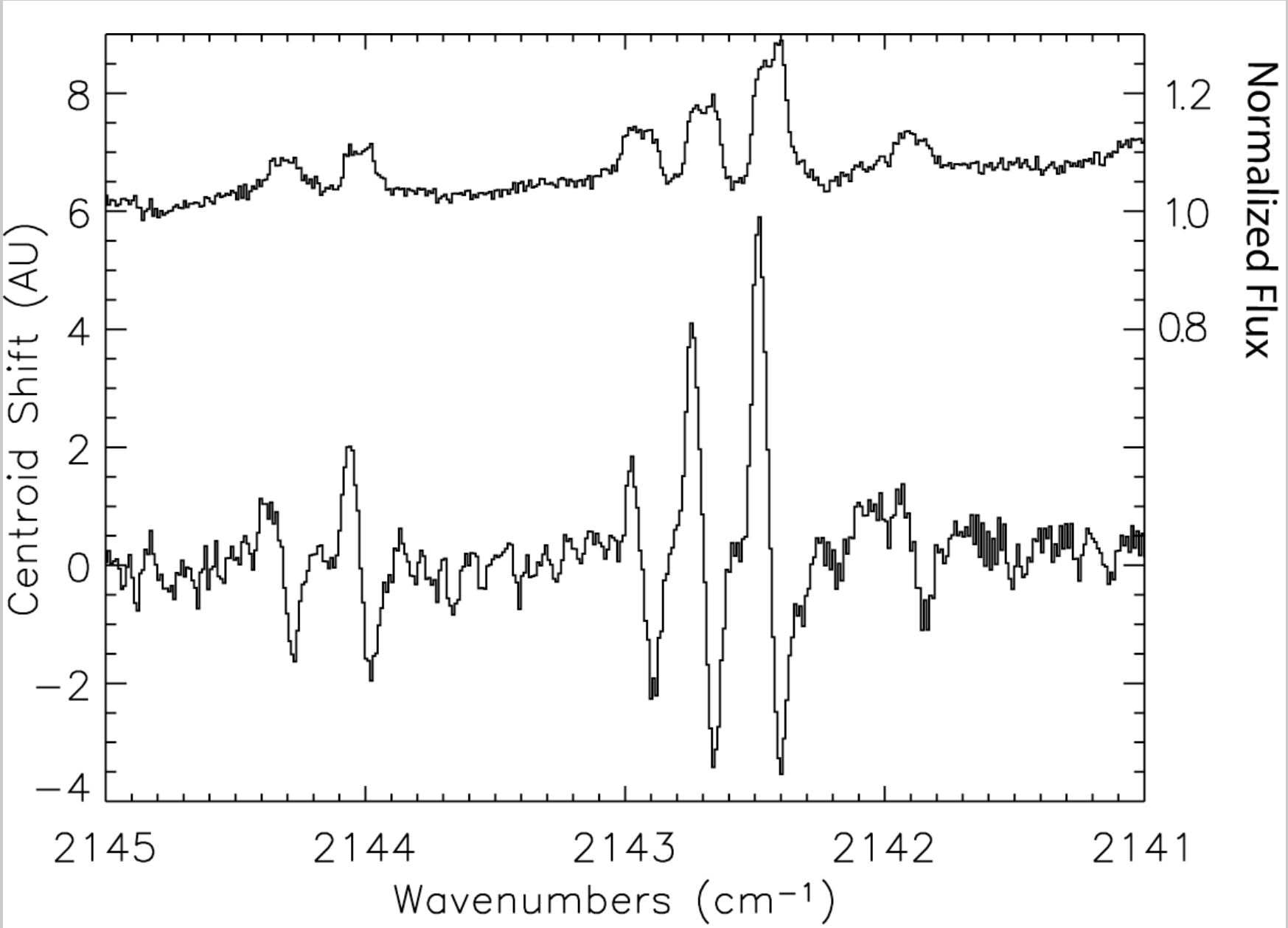
HD 100546


Contribution to Total Flux $\left(\frac{F(R)}{F_{Total}}\right)$
Cumulative Flux
R (AU)
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
$F_{HAeBe} \sim F_{TT}$
$\tau_{HAeBe} \sim 10^{-5} \tau_{TT}$

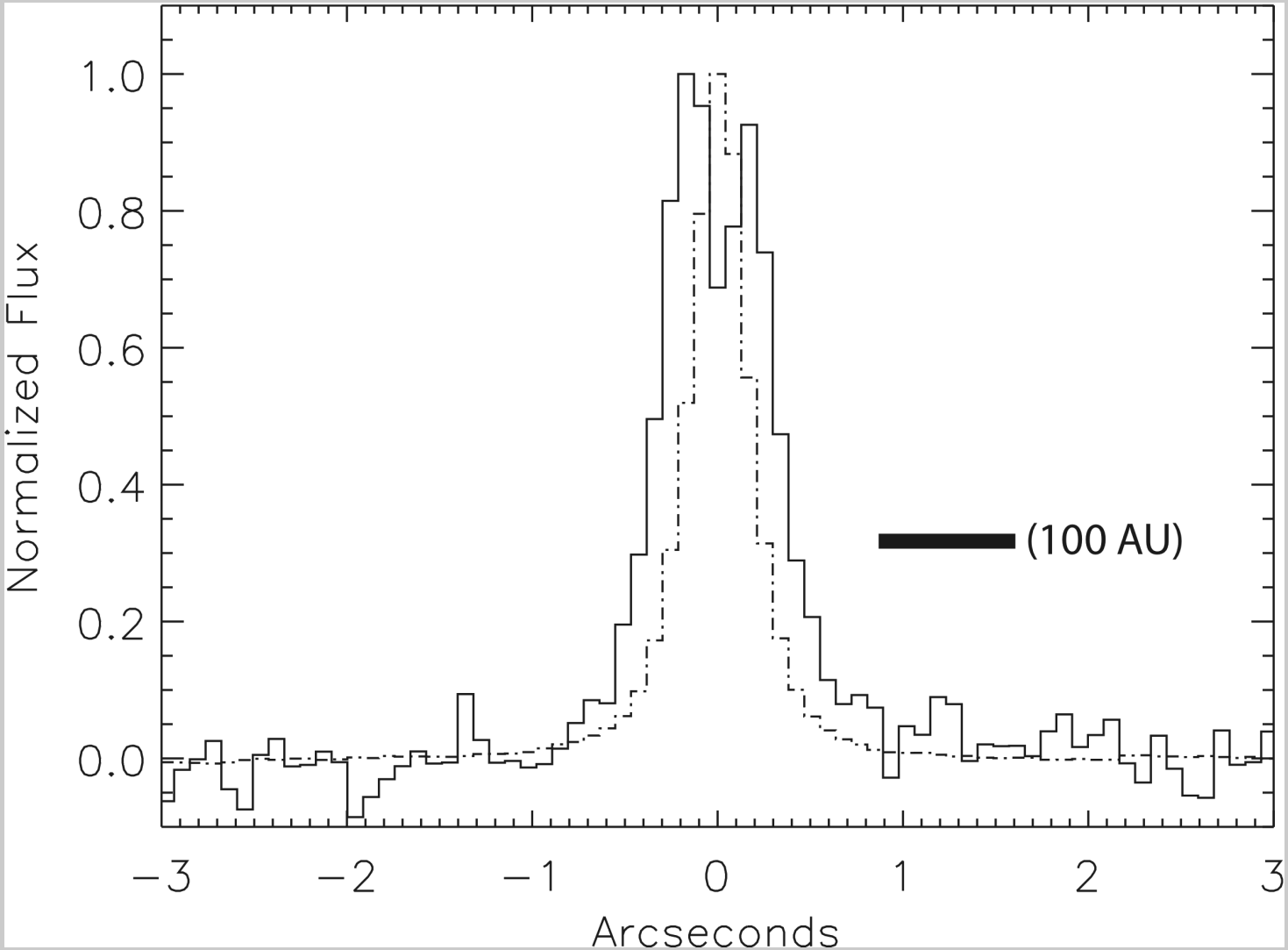

0 km/s
-4km/s
+4km/s
0 km/s
1.10
1.08
1.06
1.04
1.02
1.00
Normalized Flux
−30
−20
−10
0
10
20
30
Velocity (km s-1)


PA=307deg
PA=127deg
PA=90deg
PA=37deg

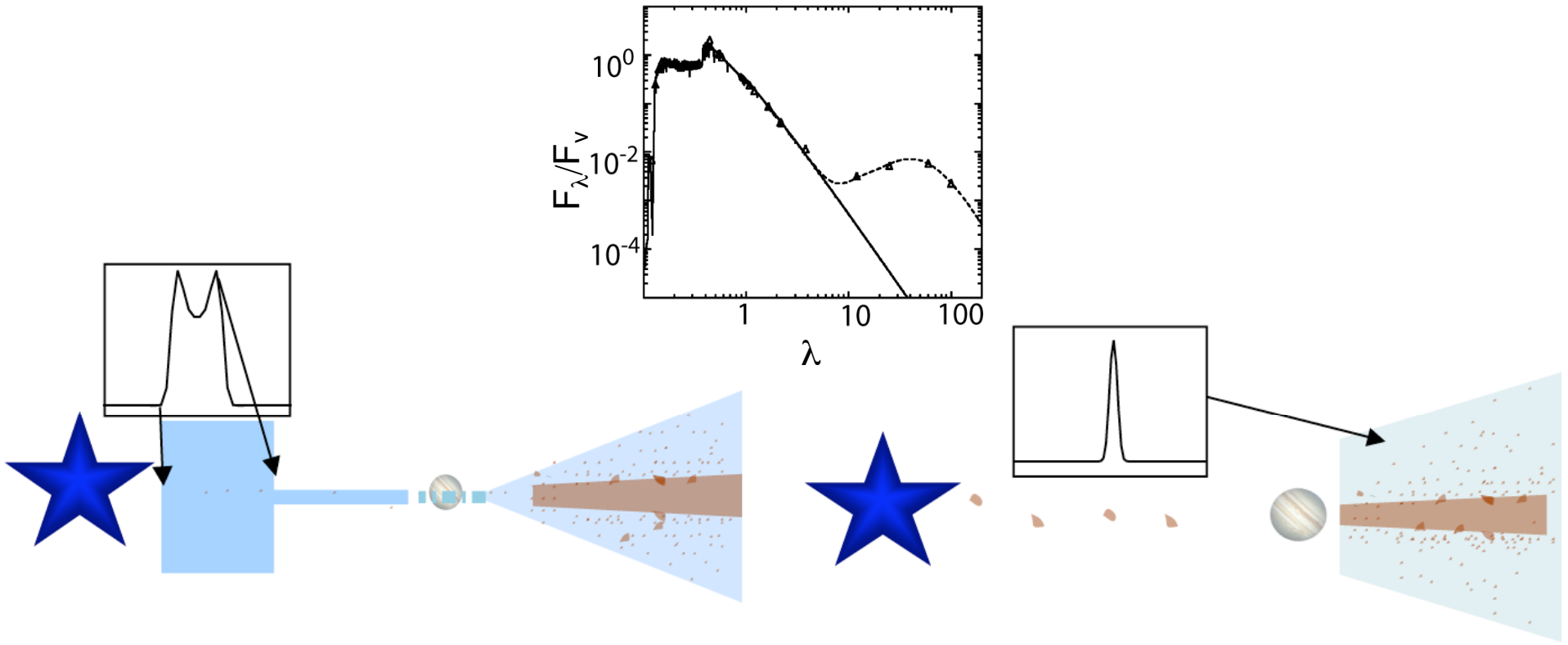
HD 100546


Centroid Shift (AU)
8
6
4
2
0
−2
−4
Normalized Flux
1.2
1.0
0.8
2145
2144
2143
2142
2141
Wavenumbers (cm⁻¹)

HD 100546



Gas in Transitional Disks



Conclusions

1. CO emission is a sensitive probe of warm gas in the inner disk
2. Evidence that temperature of CO set by photoelectric heating.
3. Spatially resolved PSF of HD100546 and HD141569 confirm the excitation modeling.
4. Evidence suggests the presence of a massive planet in the inner disk around HD100546
5. Does the inner disk reflect an OH-rich/CO poor region?