Observations and Modeling of Molecular Emission from Protoplanetary Disks

John H. Lacy

Department of Astronomy, University of Texas, Austin, TX

collaborating with

Daniel Jaffe, Matthew Richter, Martin Bitner, Thomas Greathouse, Joan Najita, John Carr

for observations

Samuel Harrold, Milos Milosavljevic, Dan Watson

for modeling

TEXES
the Texas Echelon Cross Echelle Spectrograph

a cross-dispersed mid-infrared spectrograph

capable of $R = 100{,}000$ at $\lambda = 5\text{-}25\ \mu\mathrm{m}$

uses a 36-in long echelon grating as primary disperser

groove spacing = 0.3 in, giving 0.66 cm^{-1} order spacing

instantaneous spectral coverage ~ 0.5%

slit width ~ 2 λ/D, slit length ~ 15 λ/D, Nyquist sampled

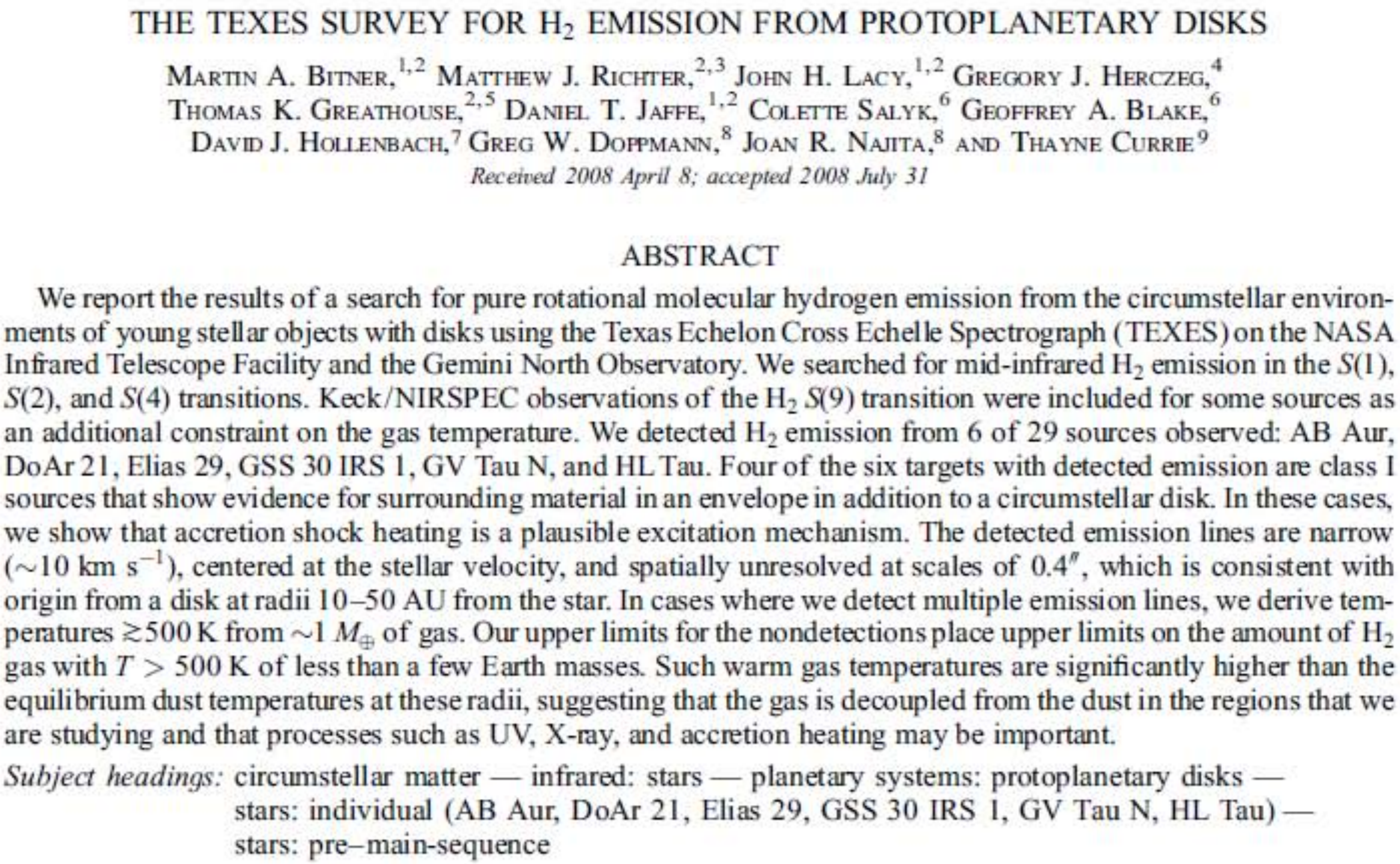
echelle cross-disperser can be used alone for R ~ 15,000

background photon-noise limited with overall QE ~ 5%

used on IRTF and Gemini North


Altair
built in/fabriqué au Canada
built in/fabriqué au Canada
Altair
NRC CNRC
EXIT

Rotational emission lines of H_2 promised to provide a probe of the gas distribution and temperature



THE TEXES SURVEY FOR H_2 EMISSION FROM PROTOPLANETARY DISKS

Martin A. Bitner,[1,2] Matthew J. Richter,[2,3] John H. Lacy,[1,2] Gregory J. Herczeg,[4]
Thomas K. Greathouse,[2,5] Daniel T. Jaffe,[1,2] Colette Salyk,[6] Geoffrey A. Blake,[6]
David J. Hollenbach,[7] Greg W. Doppmann,[8] Joan R. Najita,[8] and Thayne Currie[9]

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ABSTRACT

We report the results of a search for pure rotational molecular hydrogen emission from the circumstellar environments of young stellar objects with disks using the Texas Echelon Cross Echelle Spectrograph (TEXES) on the NASA Infrared Telescope Facility and the Gemini North Observatory. We searched for mid-infrared H_2 emission in the $S(1)$, $S(2)$, and $S(4)$ transitions. Keck/NIRSPEC observations of the H_2 $S(9)$ transition were included for some sources as an additional constraint on the gas temperature. We detected H_2 emission from 6 of 29 sources observed: AB Aur, DoAr 21, Elias 29, GSS 30 IRS 1, GV Tau N, and HL Tau. Four of the six targets with detected emission are class I sources that show evidence for surrounding material in an envelope in addition to a circumstellar disk. In these cases, we show that accretion shock heating is a plausible excitation mechanism. The detected emission lines are narrow ($\sim$10 km s^{-1}), centered at the stellar velocity, and spatially unresolved at scales of $0.4''$, which is consistent with origin from a disk at radii 10–50 AU from the star. In cases where we detect multiple emission lines, we derive temperatures $\gtrsim$500 K from $\sim$1 $M_\oplus$ of gas. Our upper limits for the nondetections place upper limits on the amount of H_2 gas with $T > 500$ K of less than a few Earth masses. Such warm gas temperatures are significantly higher than the equilibrium dust temperatures at these radii, suggesting that the gas is decoupled from the dust in the regions that we are studying and that processes such as UV, X-ray, and accretion heating may be important.

Subject headings: circumstellar matter — infrared: stars — planetary systems: protoplanetary disks —
stars: individual (AB Aur, DoAr 21, Elias 29, GSS 30 IRS 1, GV Tau N, HL Tau) —
stars: pre–main-sequence

AB Aur spectra

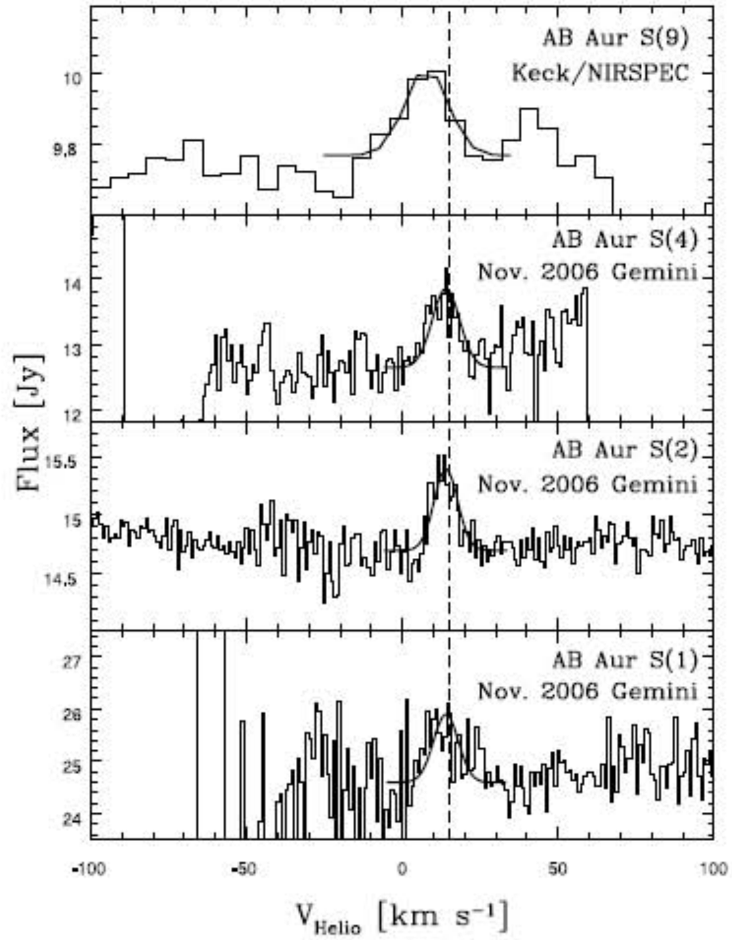


FIG. 1.— AB Aur NIRSPEC/Keck *S*(9) and TEXES/Gemini *S*(4), *S*(2), *S*(1) data from 2006 November observations overplotted with two-component model fit. The dashed line shows the stellar velocity (Thi et al. 2001). The increased noise in the *S*(1) spectrum blueward of the position of the *S*(1) line is caused by a telluric feature.

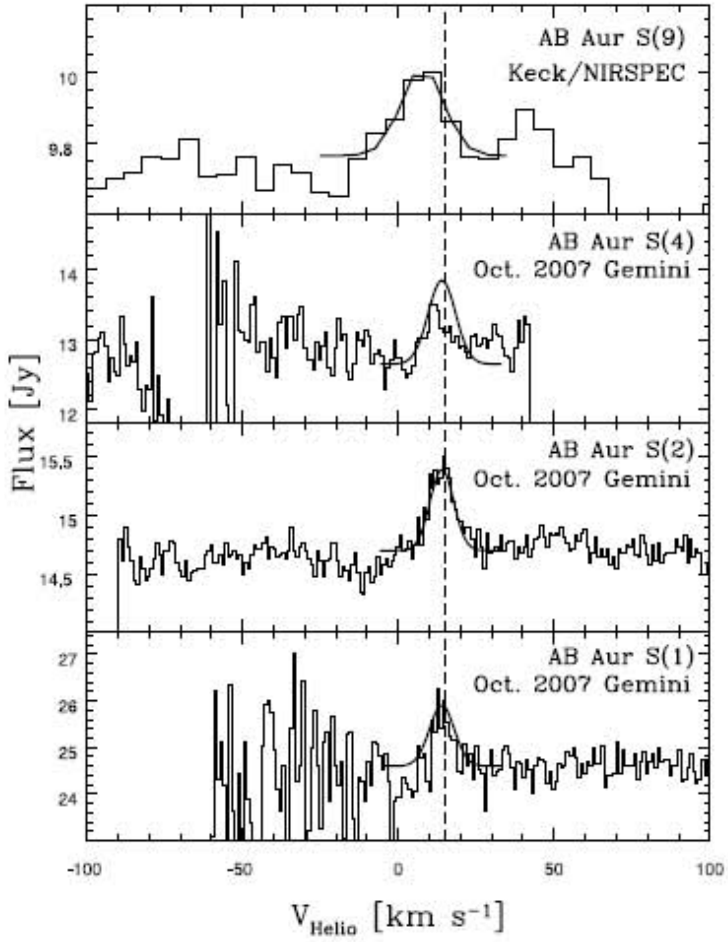


FIG. 2.—AB Aur NIRSPEC/Keck *S*(9) and TEXES/Gemini *S*(4), *S*(2), *S*(1) data from 2007 October observations overplotted with the two-component model fit derived using 2006 November data. The *S*(1) and *S*(2) lines are consistent with our 2006 November observations; however, the *S*(4) line appears weaker. The dashed line shows the stellar velocity (Thi et al. 2001). The increased noise in the *S*(1) spectrum blueward of the position of the *S*(1) line is caused by a telluric feature.

H_2 rotational excitation temperature

The emitting H_2 is at a temperature of ~550K.

Line profiles indicate that it is at r ~ 10 AU.

Gas heated by collisions with dust which is heated by starlight should not be this hot at this distance.

The hot gas probably lies in the UV or x-ray heated surfaces of the disks.

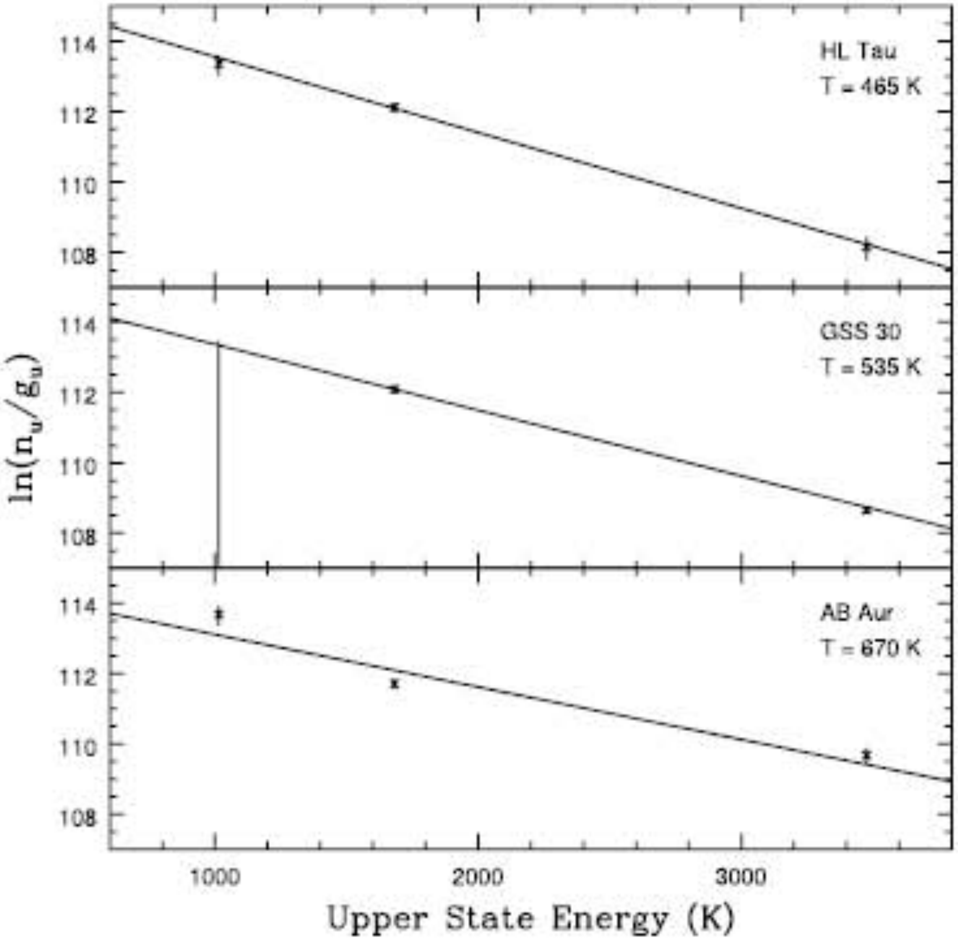
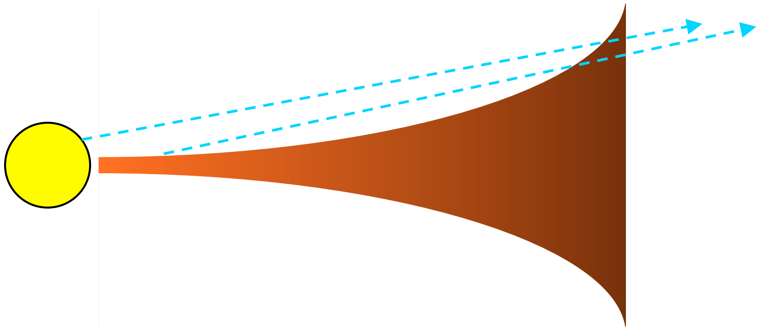


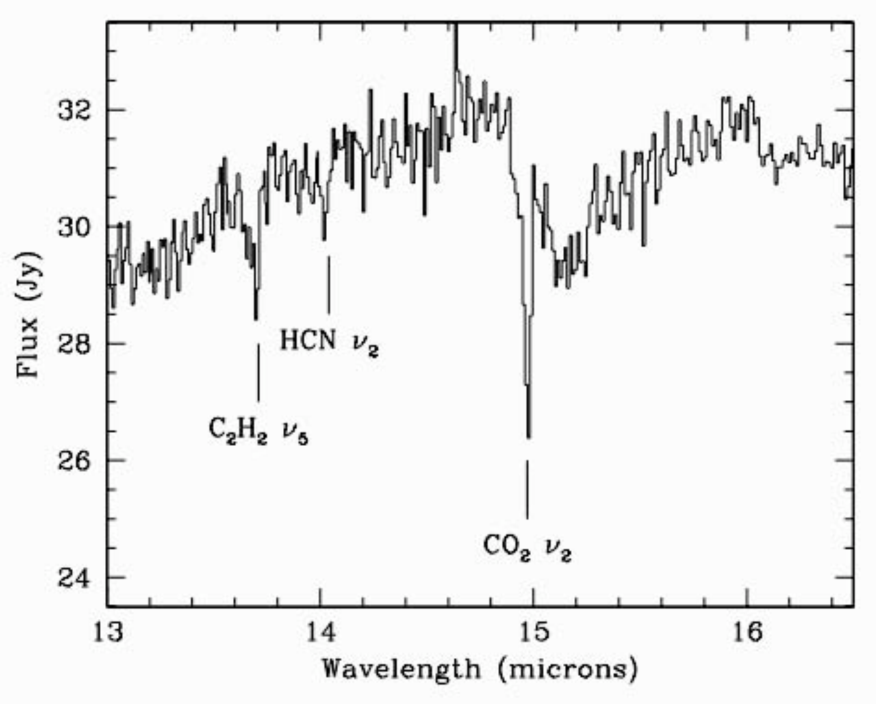
FIG. 8.—Excitation diagrams for the three sources in our sample where we have observations of all three mid-infrared H_2 transitions and detections of at least two. The points are based on Gaussian fits to each of the transitions and are plotted with 1 σ error bars. The overplotted lines show the best-fit single temperature.

Molecular absorption through a nearly edge-on disk

Spitzer IRS found molecular band absorption toward a T Tauri star with an IR companion

C_2H_2, HCN, CO_2 seen in absorption, but unresolved at R = 600





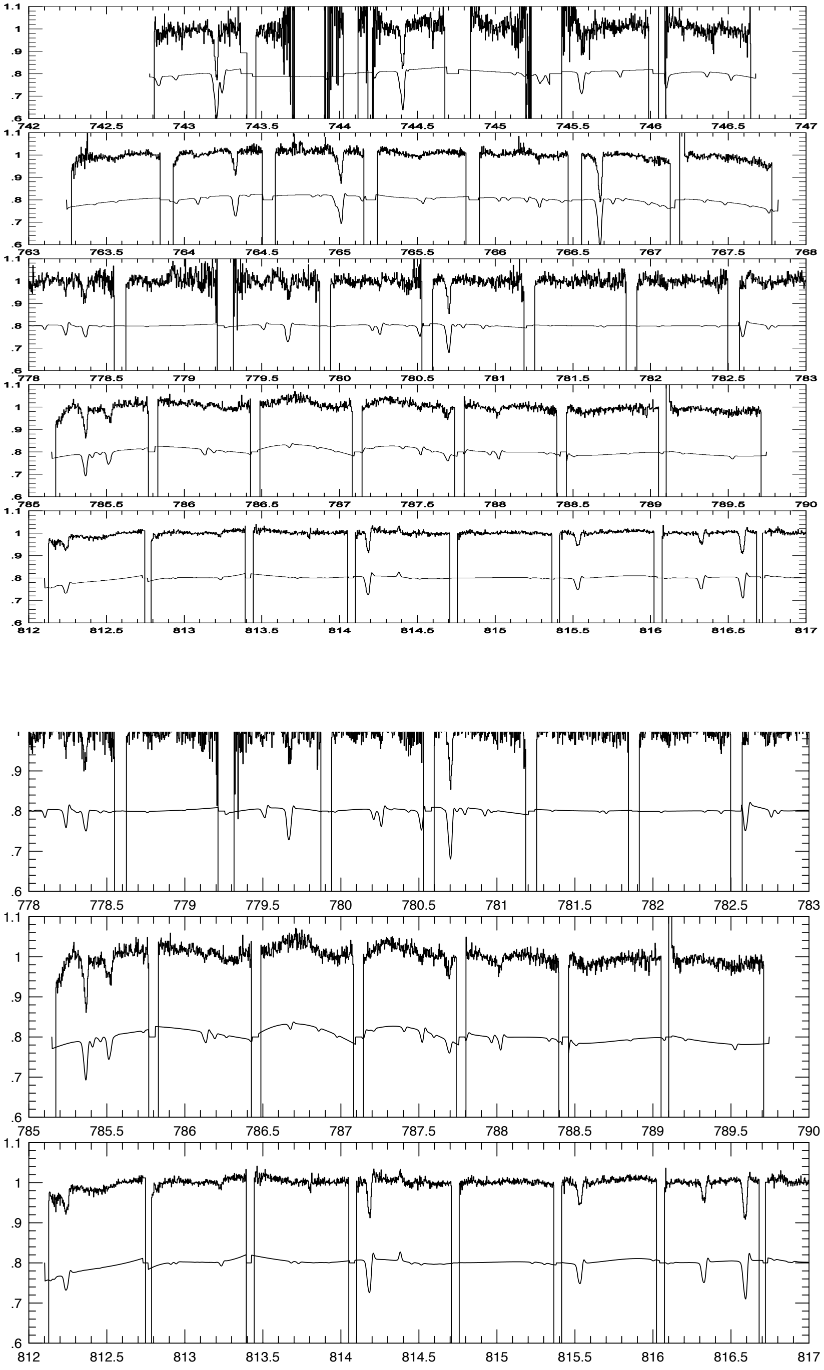
GV Tau N:
An edge-on T Tauri disk (Najita et al.)

Lines are due to C_2H_2, HCN, NH_3, H_2, and probably HNCO

Gas is warm:

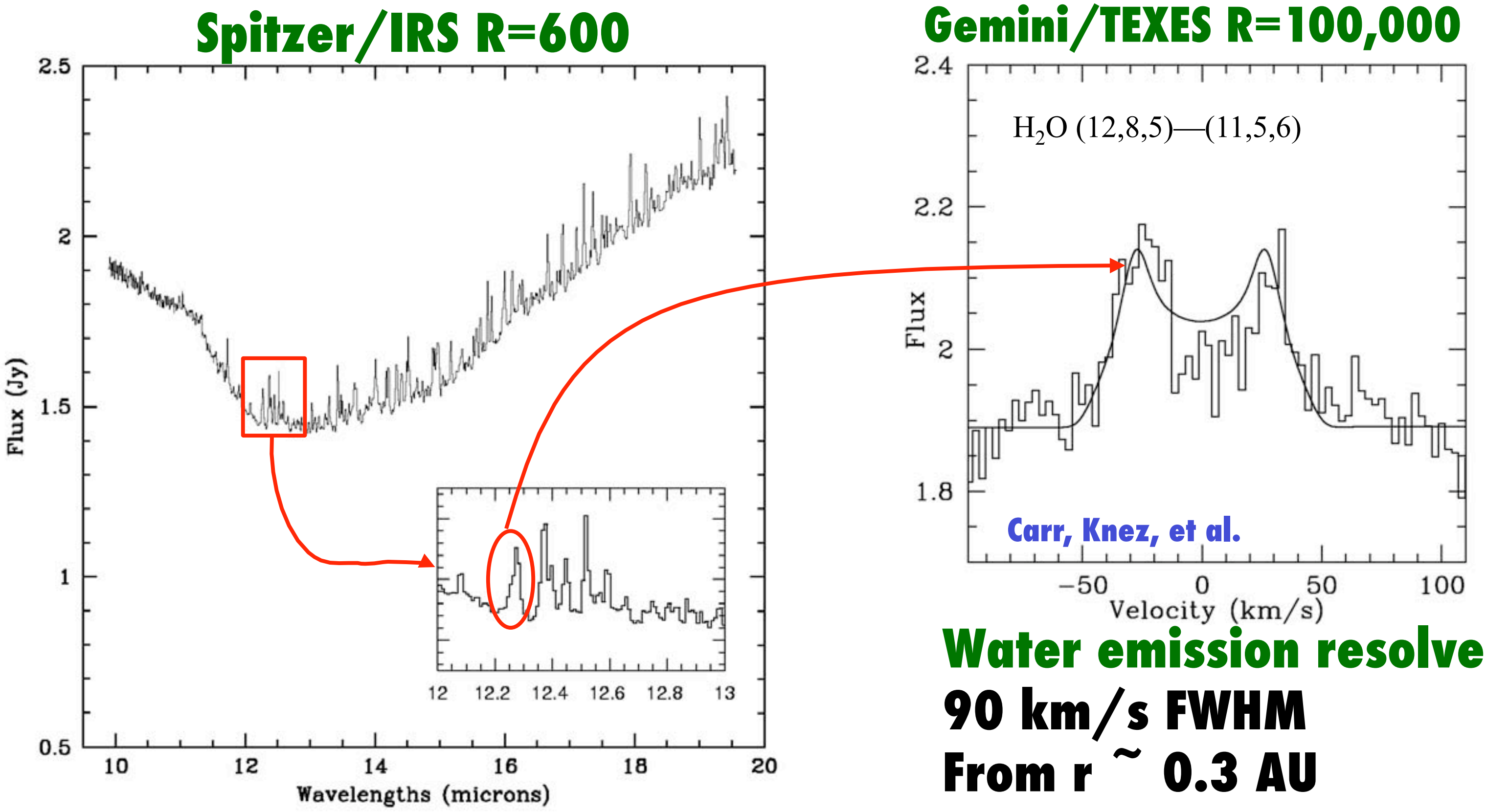
$T_{rot} \sim 500K$

Weak inverse P-Cygni emission is seen in some lines



GN-2006B-Q-35: Knez et al., GN-2007B-C-7: Carr et al.

H_2O emission in T-Tauri Disks



Spitzer/IRS R=600

Gemini/TEXES R=100,000

Carr, Knez, et al.

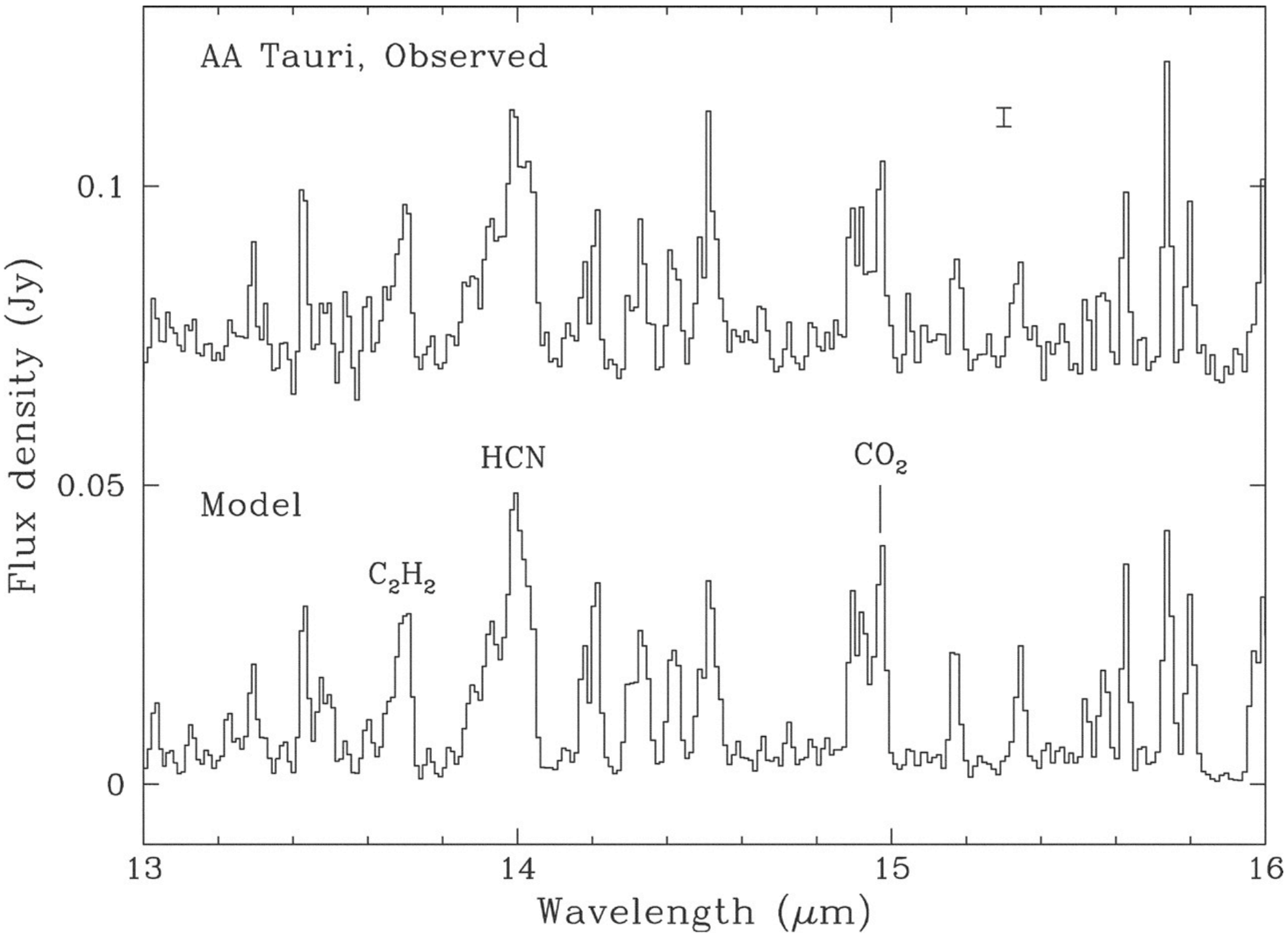
Water emission resolved:

90 km/s FWHM

From r ~ 0.3 AU

Line profiles, temperatures, and emitting areas indicate origin in planet formation region of disk

Fig. 2. Comparison of the observed spectrum of AA Tauri to the combined model spectrum (11)



J. S. Carr et al., Science 319, 1504 -1506 (2008)

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Disk model

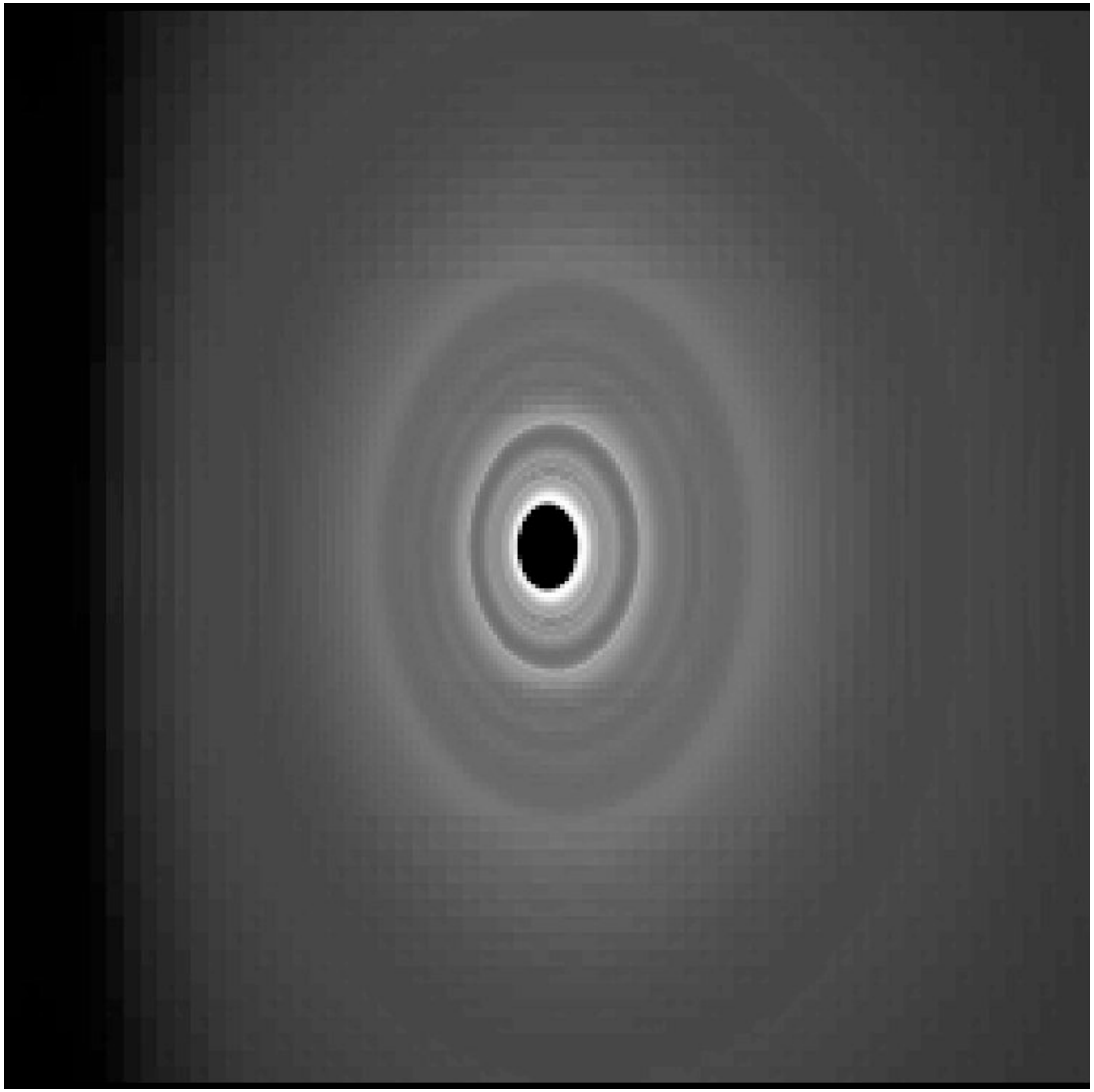
The molecular emission is difficult to model because the gas above the dust photosphere is at too low density for collisions to thermalize the vibrational level populations.

We need a non-LTE radiative transfer and molecular excitation model.

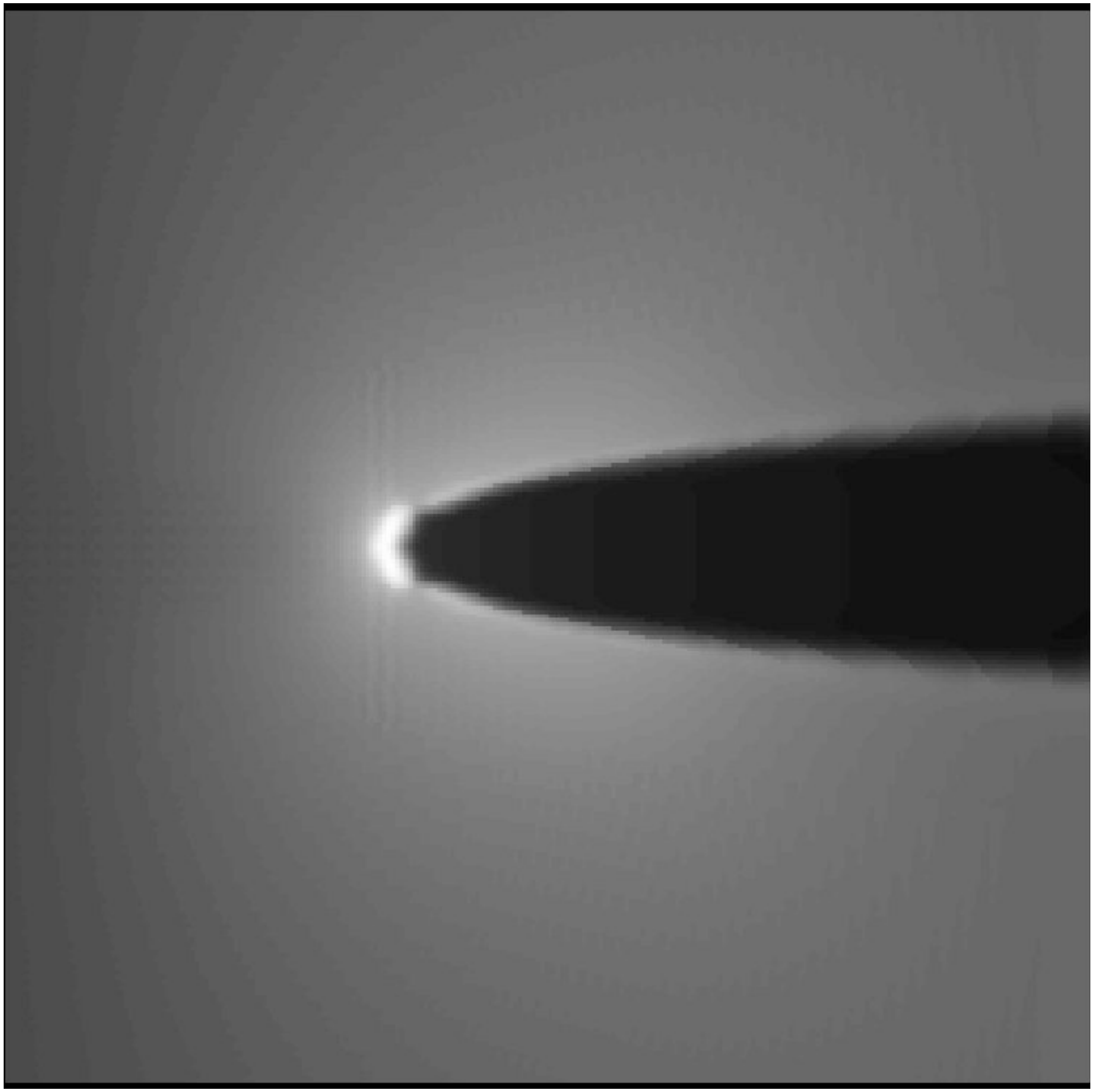
We first model the disk structure, which is determined by radiative transfer in dust and hydrostatic equilibrium.

We then calculate the molecular excitation and emission, assuming the rotational levels are in LTE, and including collisional and radiative excitation of the vibrational levels.

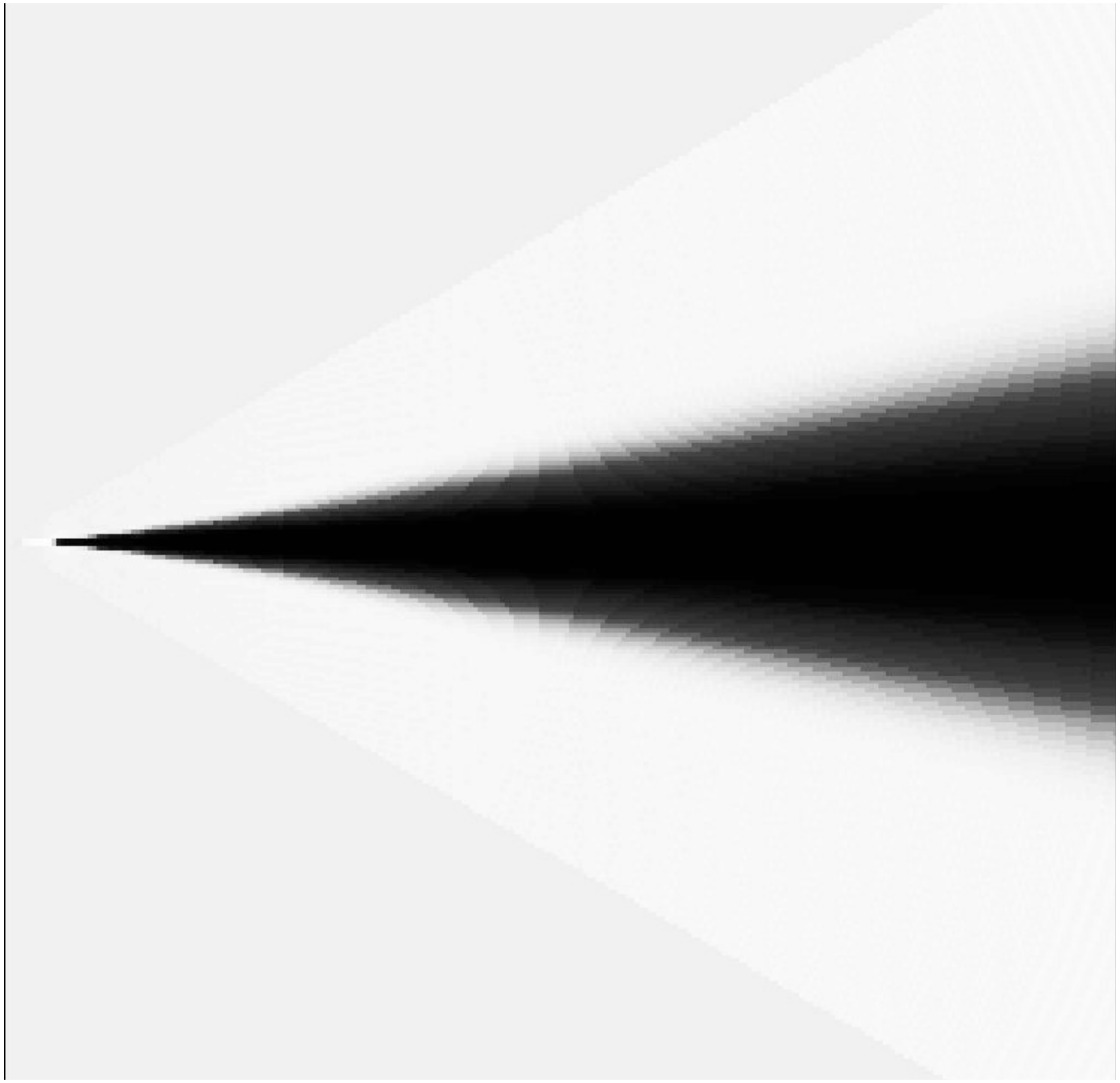
Model dust emission image



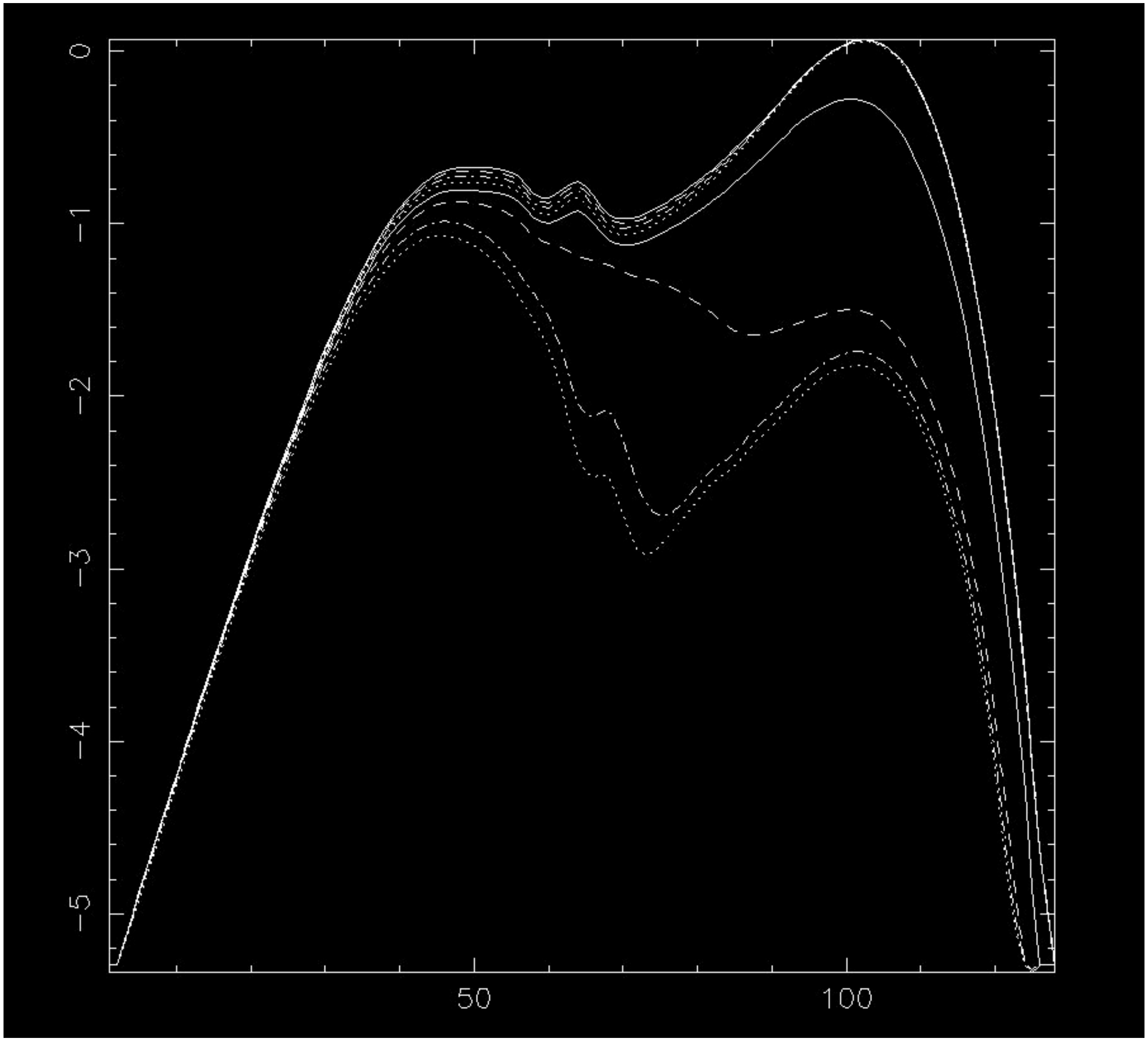
Scattered and emitted light from disk



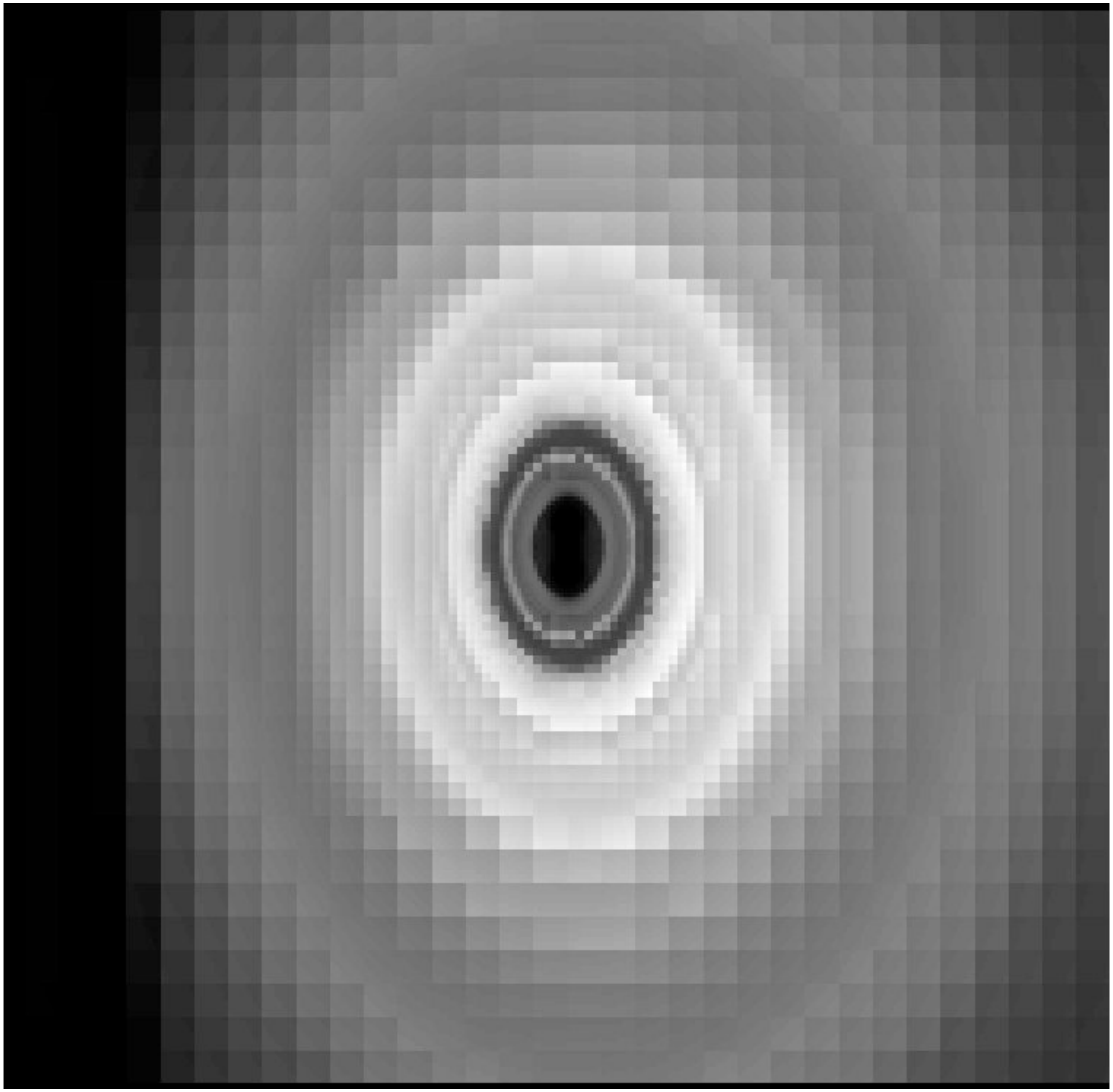
Model disk illumination



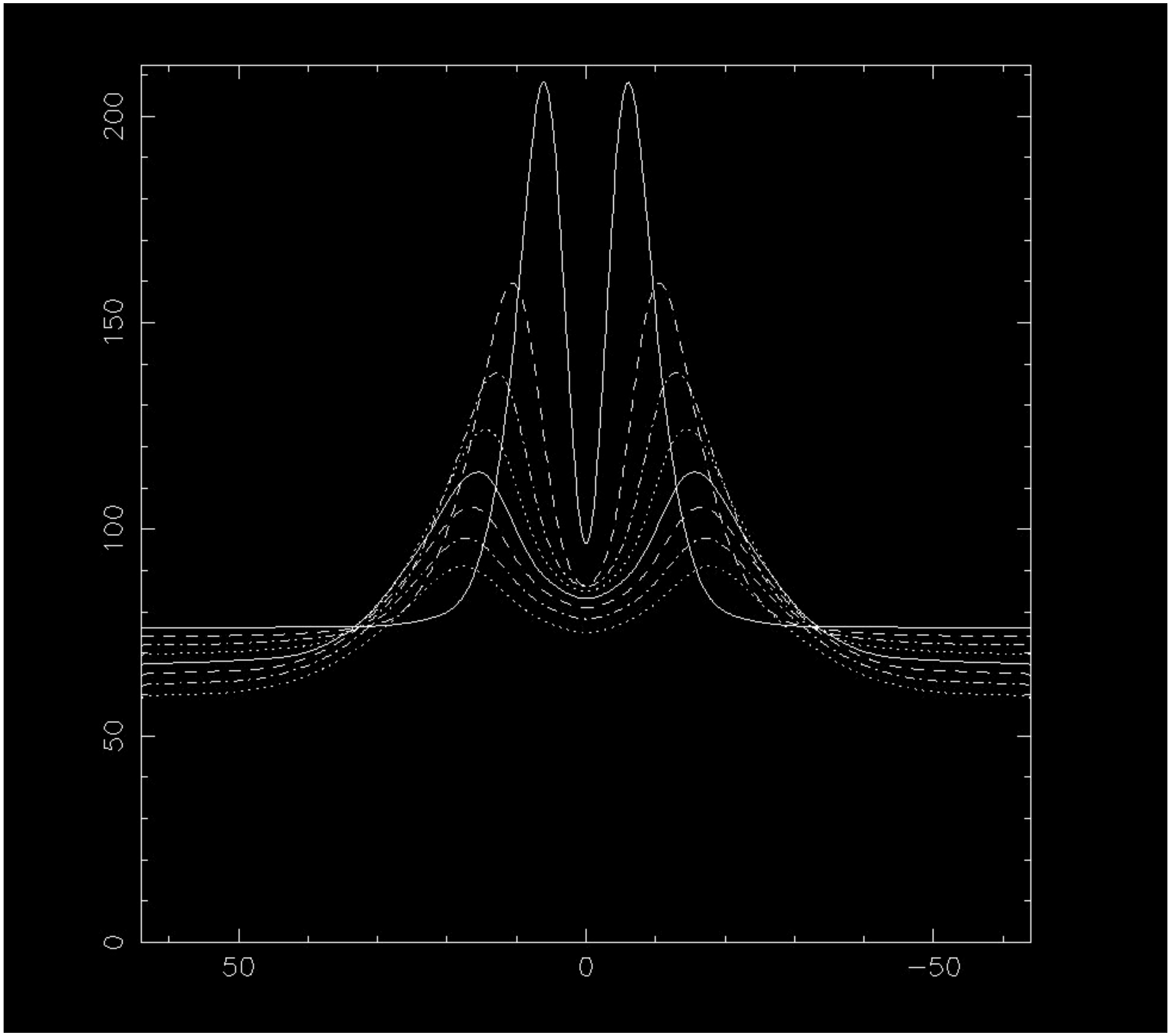
Model dust SEDs



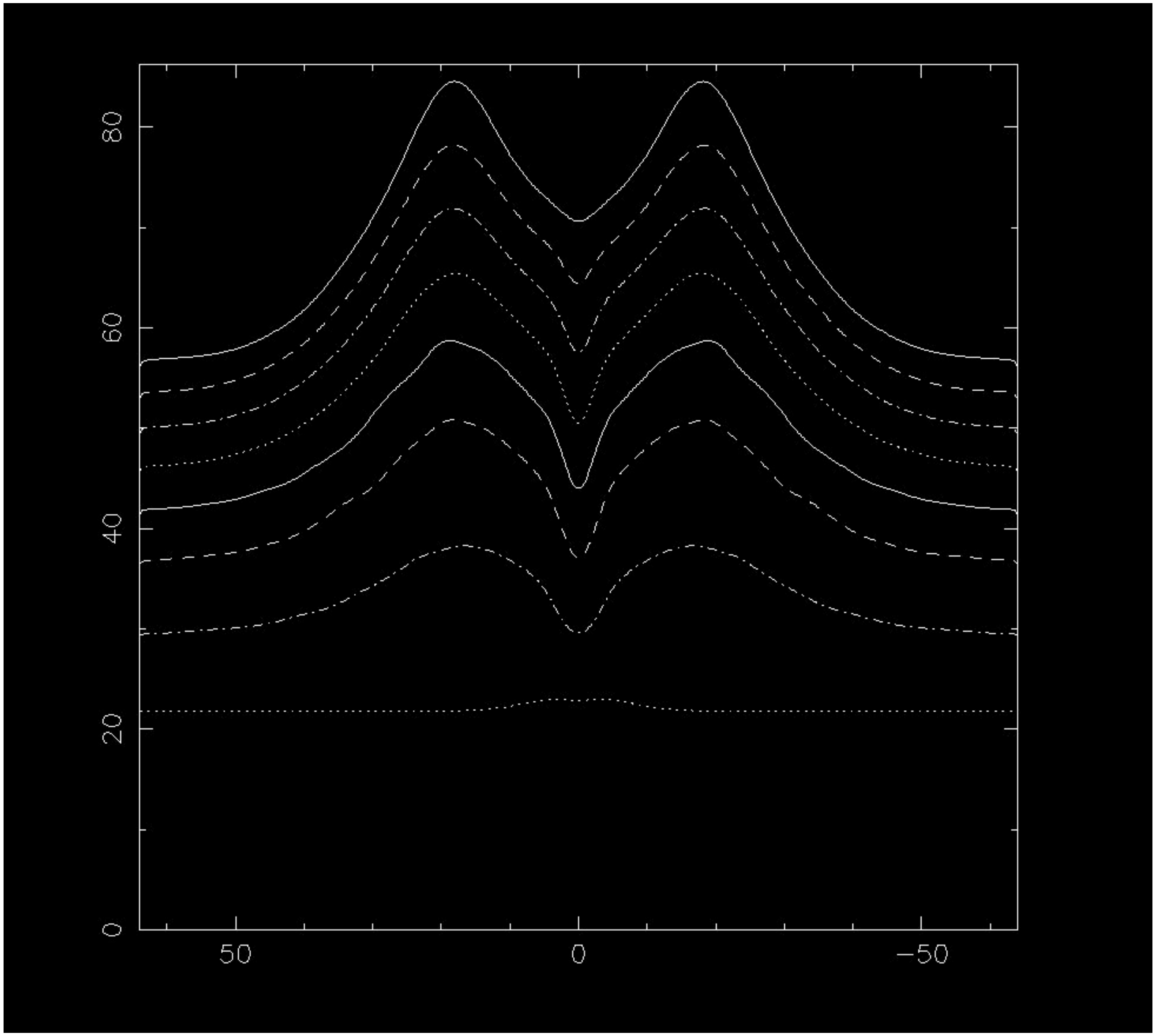
HCN vibrational emission



HCN lines at 14°-58° inclination



HCN lines at 62^o-88^o inclination



Model results

Line profiles depend on inclination and emission radius.

Line fluxes depend very strongly on dust settling.

Lines are almost undetectable if dust and gas are mixed.

Models shown have dust scale heights ½ the gas (hydrostatic equilibrium) scale height.

Observed SEDs have been interpreted to indicate dust settling or grain growth.

To avoid making the lines much stronger than observed, we will probably have to deplete the molecules.