Studies of Star and Planet Formation with TEXES on Gemini North

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TEXES

The Texas Echelon Cross Echelle Spectrograph

A cross-dispersed mid-infrared spectrograph

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

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 since 2000

On Gemini North for 27 science nights in 2006-2007

7 refereed papers so far from Gemini observations


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

Why TEXES (why not Spitzer)?

Spectral and spatial resolution of molecular and ionic lines

Spitzer, with R~600, can detect lines if continuum isn't too strong, but cannot separate closely spaced lines or resolve Doppler structure within lines.

Spitzer is much more sensitive to continuum emission than TEXES, especially from extended sources, but is less sensitive to narrow lines from point sources.

Why Gemini (why not IRTF or SOFIA)?

Sensitivity and spatial resolution

TEXES is background photon noise limited with fixed $A\Omega$, so its noise is independent of A_{tel}, but the signal from a point source is proportional to A_{tel}.

TEXES is diffraction limited on Gemini, so its spatial resolution is proportional to D_{tel}.

Star Formation Studies with TEXES on Gemini

7-11 July 2006, 18-27 Nov 2006, 18-31 Oct 2007

GN-2006A-DS-2: Lacy et al., 14 hr

Mid-Infrared Spectroscopy of High-Mass Star Formation Regions

GN-2006A-DS-3: Richter et al., 18 hr

Mid-Infrared Spectroscopy of Protoplanetary Disk Gas

GN-2006B-Q-35: Knez et al., 8 hr (of 20 hr assigned)

Probing Chemistry in Disks through Emission in SiO, C_2H_2 and HCN

GN-2006B-Q-42: Richter et al., 27 hr (of 88 hr assigned)

A Survey for Protoplanetary Disk Gas

GN-2006B-Q-40: Najita et al., 11 hr (of 25 hr assigned)

GN-2007B-C-5: Najita et al., 30 hr

Astrochemistry to Astrobiology: Organic Molecules in a Planet-forming Disk

GN-2007B-C-6: Lacy et al., 15 hr

A Comparative Astrochemical Study of NGC 7538 IRS 1 and 9

GN-2007B-C-7: Carr et al., 20 hr

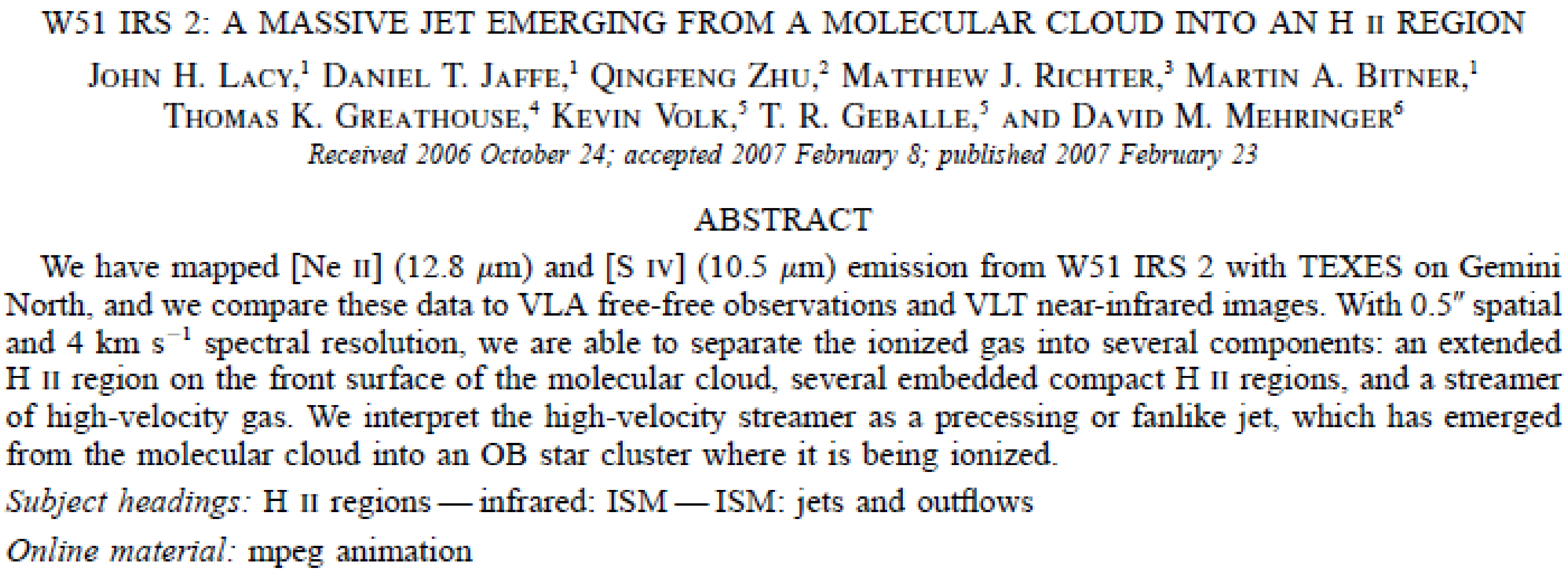
Water in Protoplanetary Disks

GN-2007B-C-9: Bitner et al., 10 hr

Resolving the Location of Protoplanetary Disk Gas in AB Aur

How do high-mass young stars affect their environment?

W51 (IRS 2): Orion scaled up by 10, an OB star cluster on the front side of a molecular cloud, with recent high-mass star formation in the cloud



W51 IRS 2: A MASSIVE JET EMERGING FROM A MOLECULAR CLOUD INTO AN H II REGION

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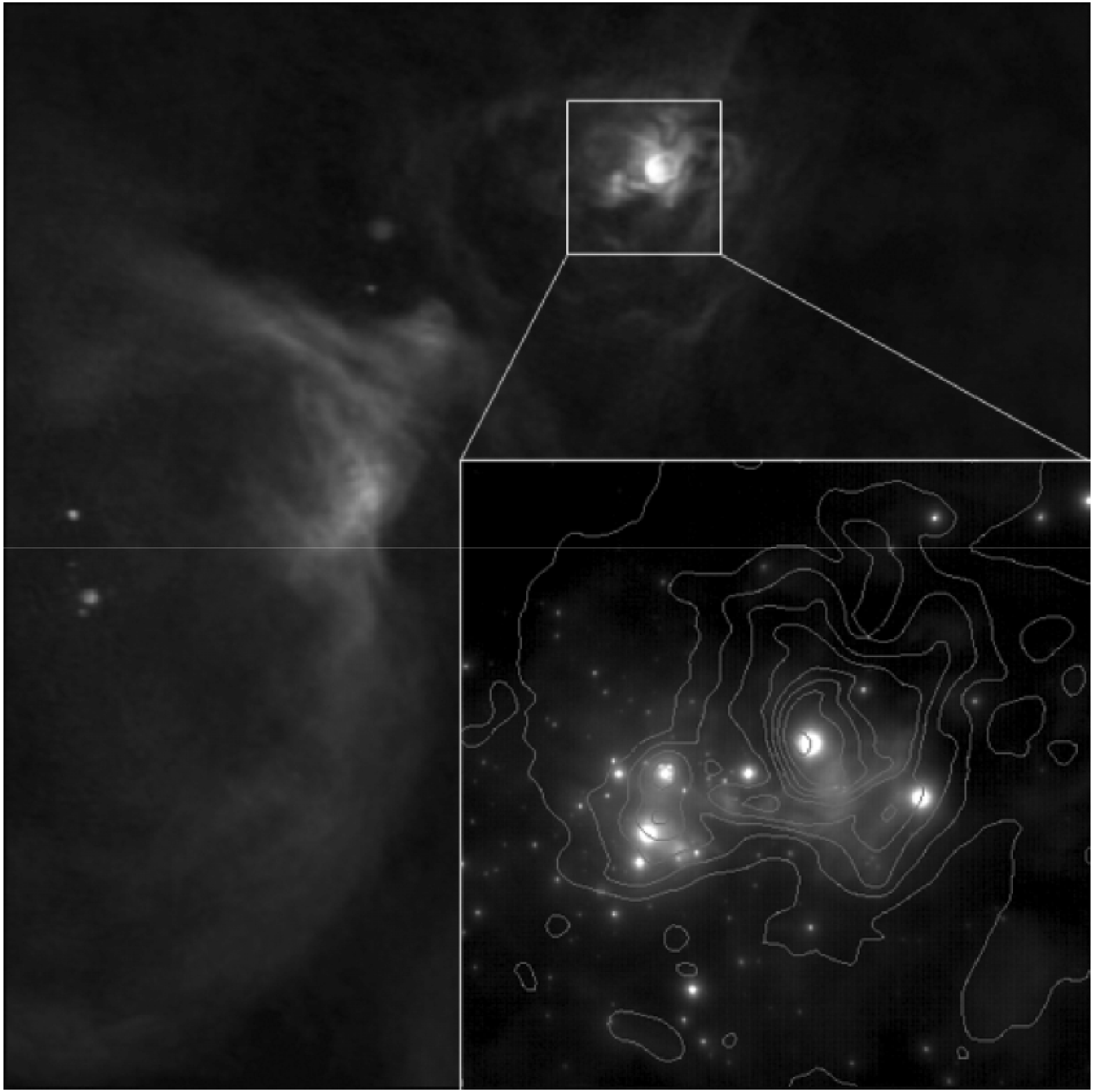
ABSTRACT

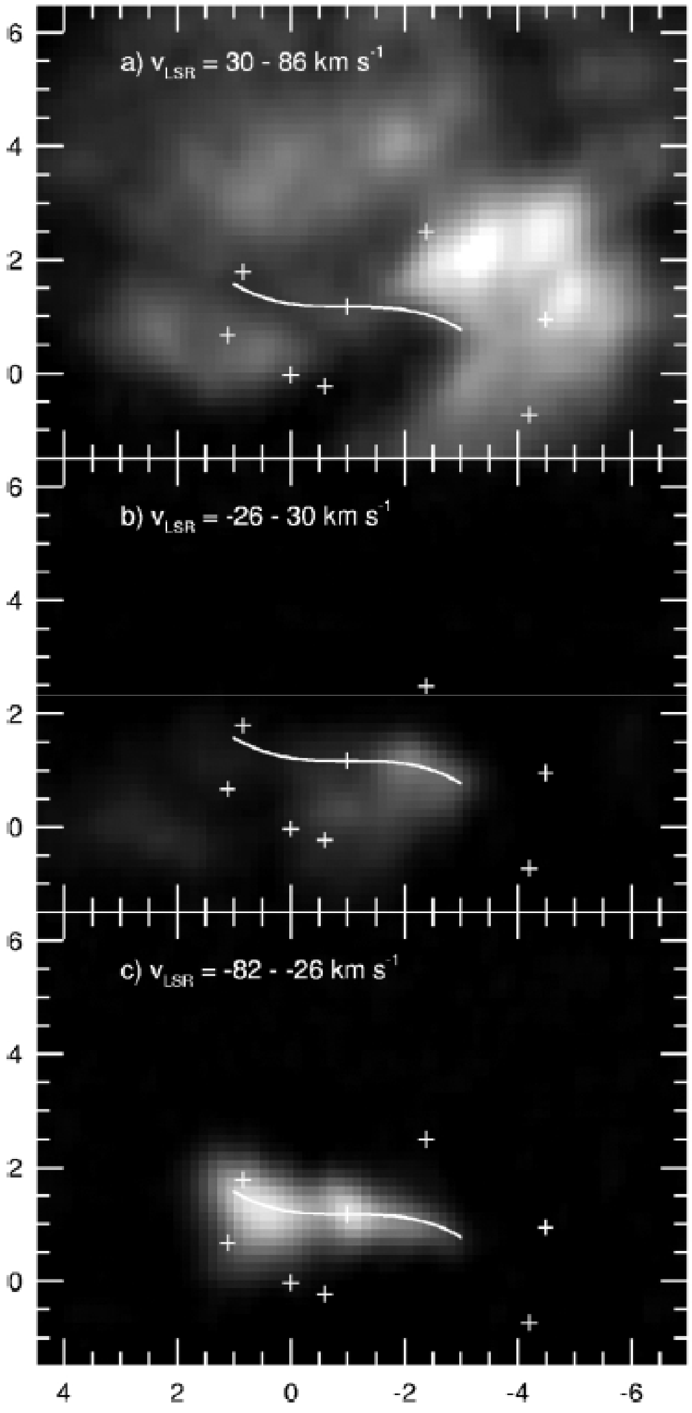
We have mapped [Ne II] (12.8 μm) and [S IV] (10.5 μm) emission from W51 IRS 2 with TEXES on Gemini North, and we compare these data to VLA free-free observations and VLT near-infrared images. With 0.5″ spatial and 4 km s^{-1} spectral resolution, we are able to separate the ionized gas into several components: an extended H II region on the front surface of the molecular cloud, several embedded compact H II regions, and a streamer of high-velocity gas. We interpret the high-velocity streamer as a precessing or fanlike jet, which has emerged from the molecular cloud into an OB star cluster where it is being ionized.

Subject headings: H II regions — infrared: ISM — ISM: jets and outflows

Online material: mpeg animation

W51 IRS2
at 3.6 cm
with VLA
and 1.25 μm
with VLT



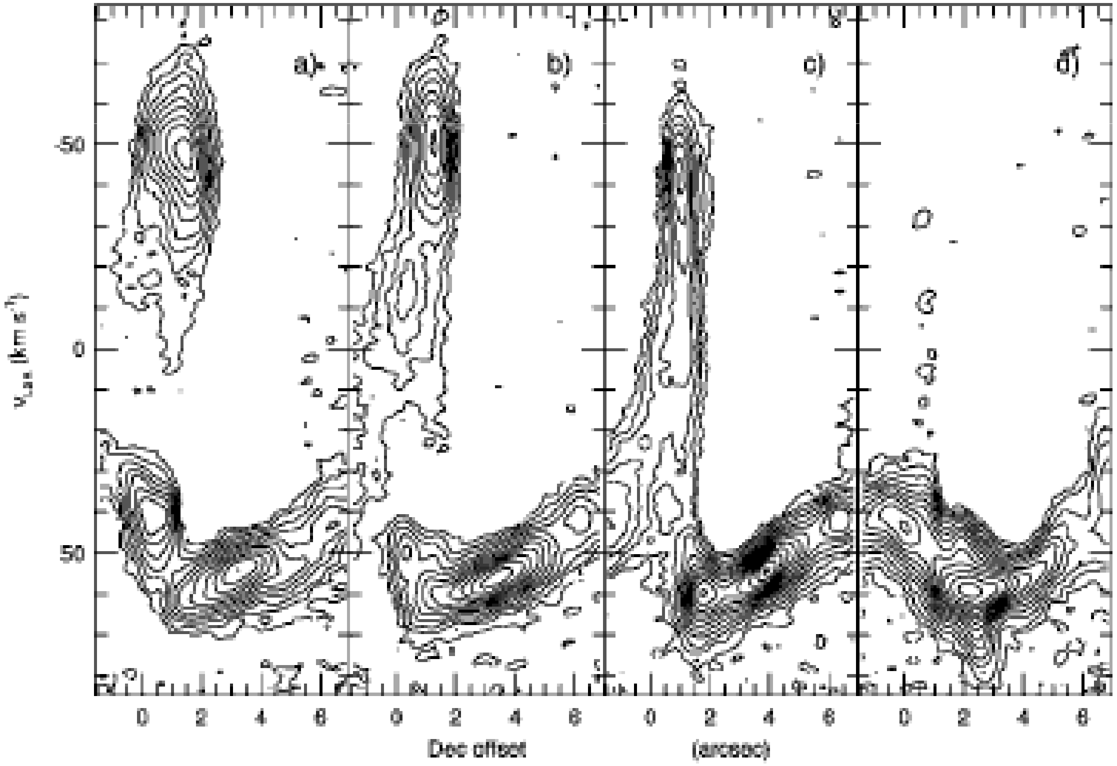


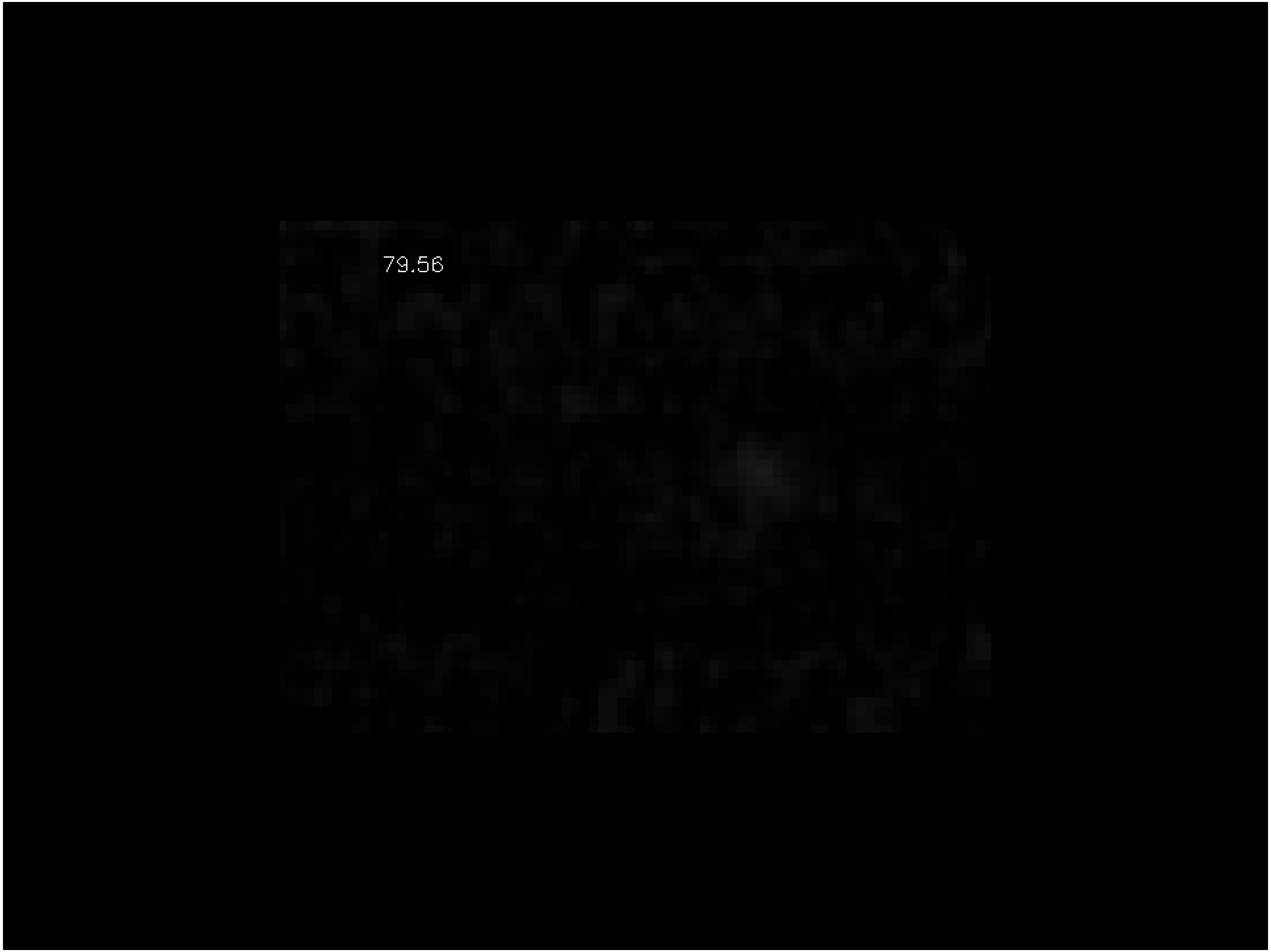
[S IV] maps and PV diagrams

Two flows are seen:

a flow along the surface of a bowl

and a high velocity precessing jet




79.56

A surface flow driven by stellar wind ram pressure

Zhu et al. (2007) found that many compact HII regions have cometary morphologies, caused by compression of the ionized gas by stellar winds, and pressure-driven flow along the resulting shell (not by motion of a star through a molecular cloud).

The extended HII region in W51 IRS2 is a scaled-up version of this kind of a flow.

An ionized jet from a massive young star

Herbig-Haro jets which emerge from molecular clouds can be ionized by radiation from OB stars.

In W51 the jet is much more massive than a HH jet, and the ionized streamer is much more luminous.

How do O stars obtain their masses?

For massive (OB) stars, the time to contract and ignite nuclear fusion is less than the time to accrete their mass.

Forming O stars should approach the main sequence while still accreting, and then evolve upward on the HR diagram, parallel to the main sequence, as they grow.

But other formation mechanisms have been proposed.

It is very hard to find a clear example of an O star in the process of forming.

NGC 7538 IRS1 may be such a star.

NGC 7538
A high-mass star formation complex at 3 kpc

JHK image from
Ojha et al. 2004
with UH 2.2m

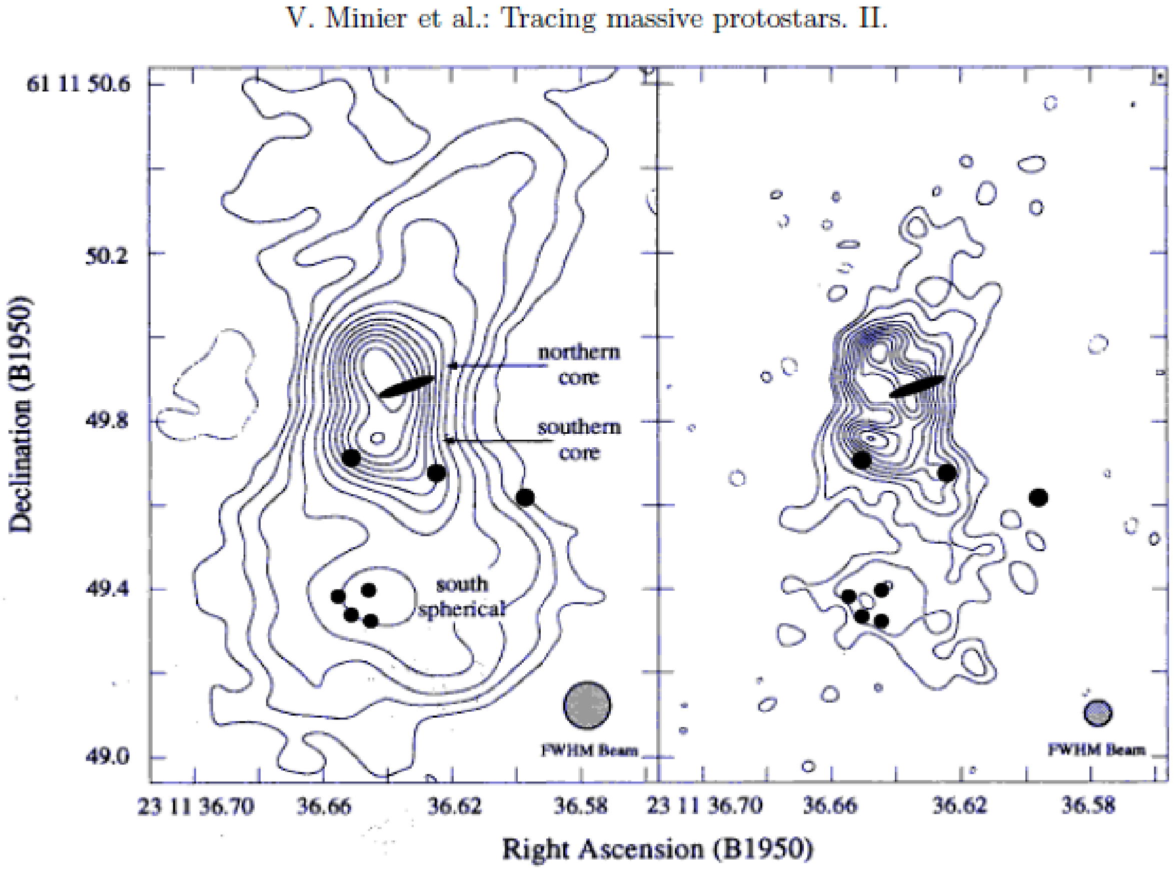
JHK image covering
5’x5’ = 4x4 pc

Minier et al. (2000, 2001) CH_3OH maser peaks on Gaume et al. (1995) f-f continuum map

Minier et al. suggest that the northern maser cluster traces a rotating disk.

Does this disk collimate the molecular outflow from IRS 1?

Or is the disk in the dark lane in the free-free emission?



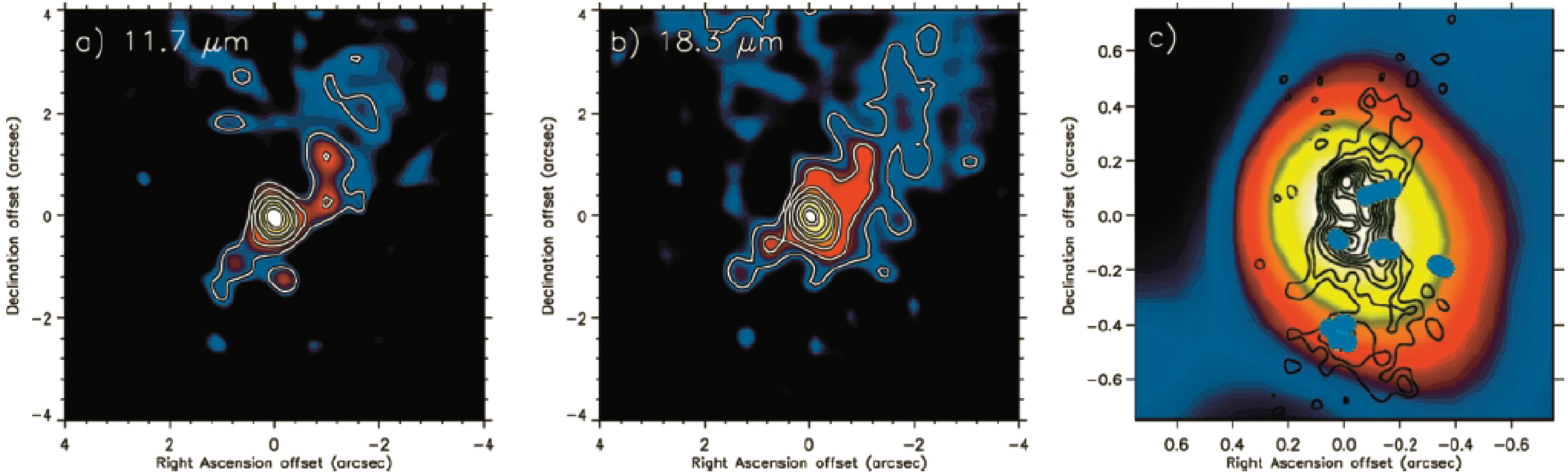
De Buizer & Minier 2005

Imaged IR continuum with Michelle on Gemini

Argue that the emission beyond 1” is in the outflow.

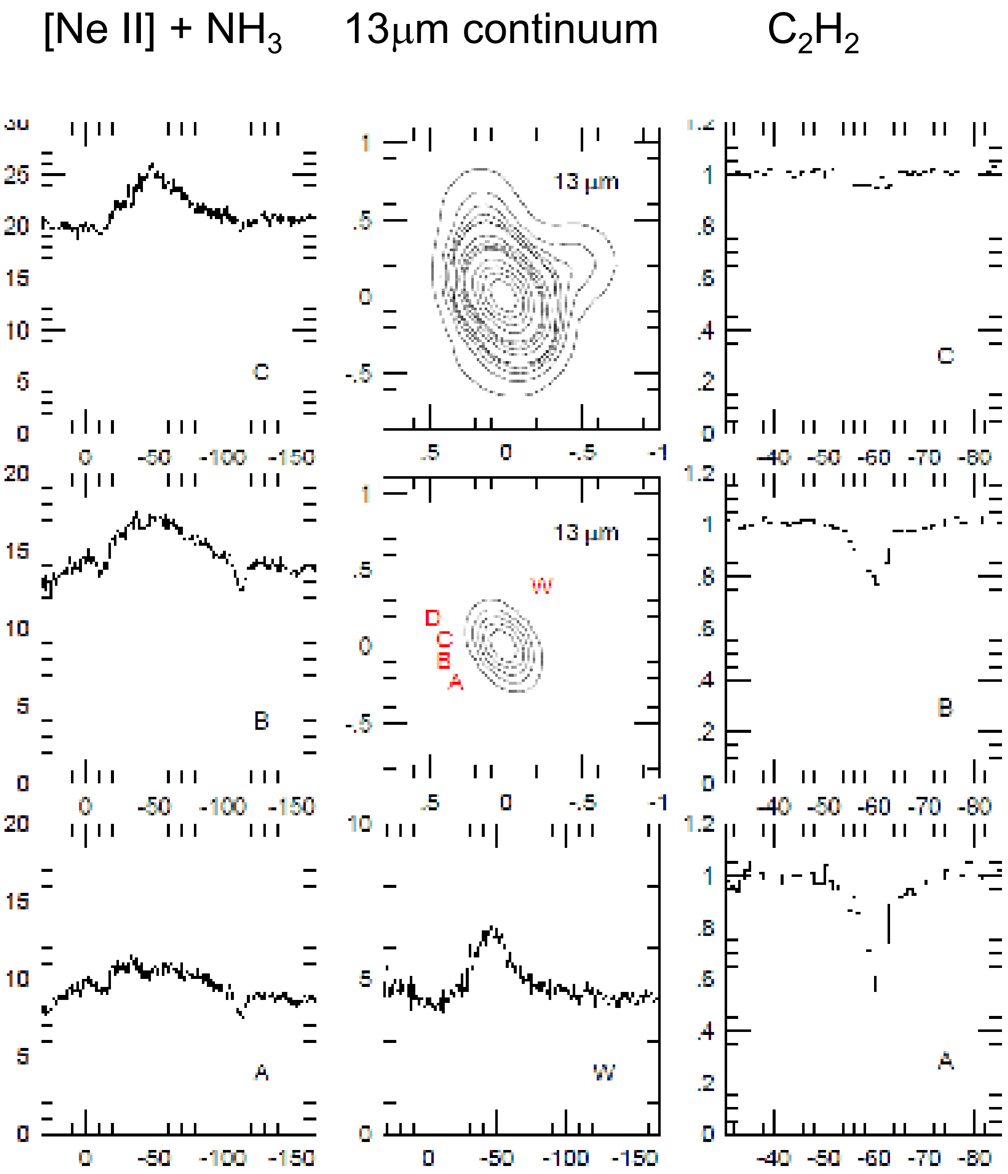
See a NE-SW elongation in inner 0.5” that they suggest is the disk that collimates the outflow.

They think the northern maser group is part of the outflow, not the disk.



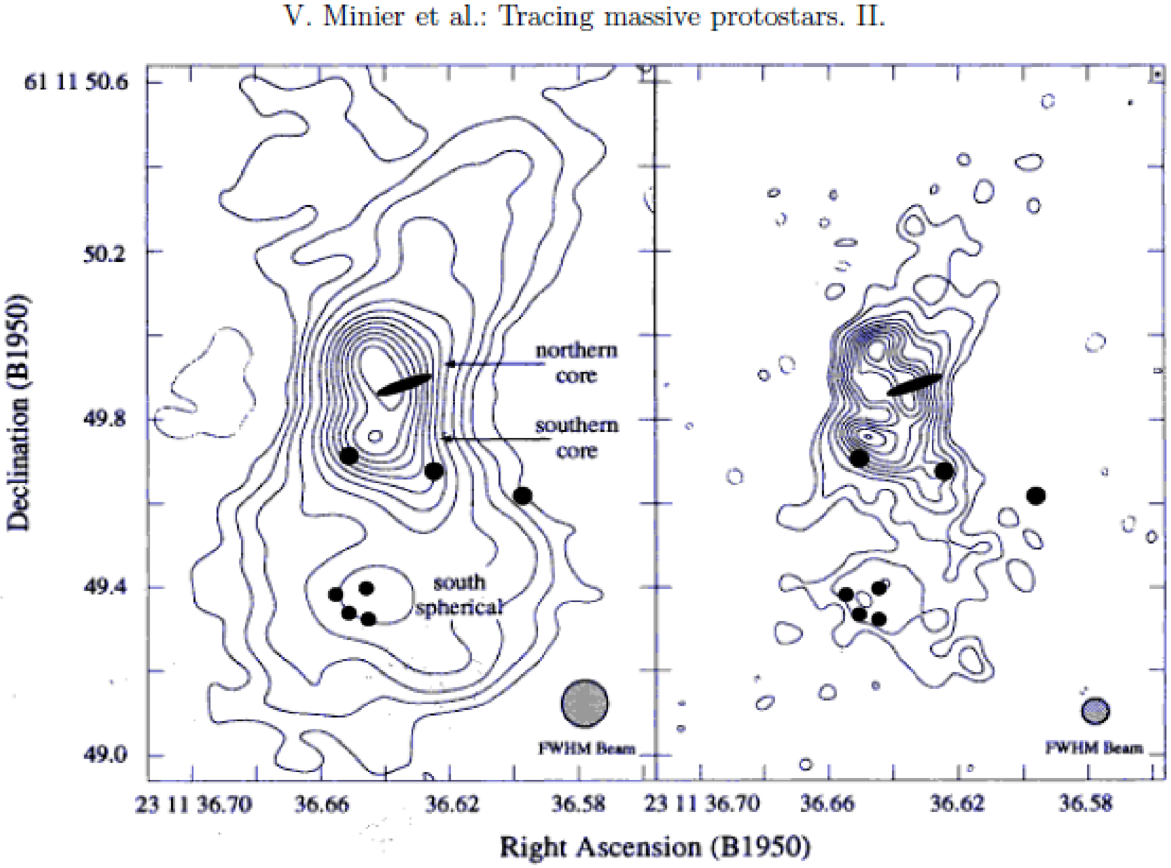
TEXES on Gemini

- The elongated MIR peak is not a disk. It is a blend of two sources.
- The southern source has a broad ionic line and deep molecular absorption.
- It is coincident with the central maser peak.
- The northern source is coincident with the disk-like maser group.



Model based on TEXES observations

- Central maser source is probably dominant luminosity source and source of outflow.
- Broad [Ne II] line may come from the ionized inner disk of an accreting O star.
- The northern maser group may be a disk around a less luminous star or may be due to interaction between a dense clump and the outflow.



V. Minier et al.: Tracing massive protostars. II.

What is the spatial distribution of molecules in the planet-forming region of a protoplanetary disk?

Visible lines probe the accretion onto T-Tauri stars.

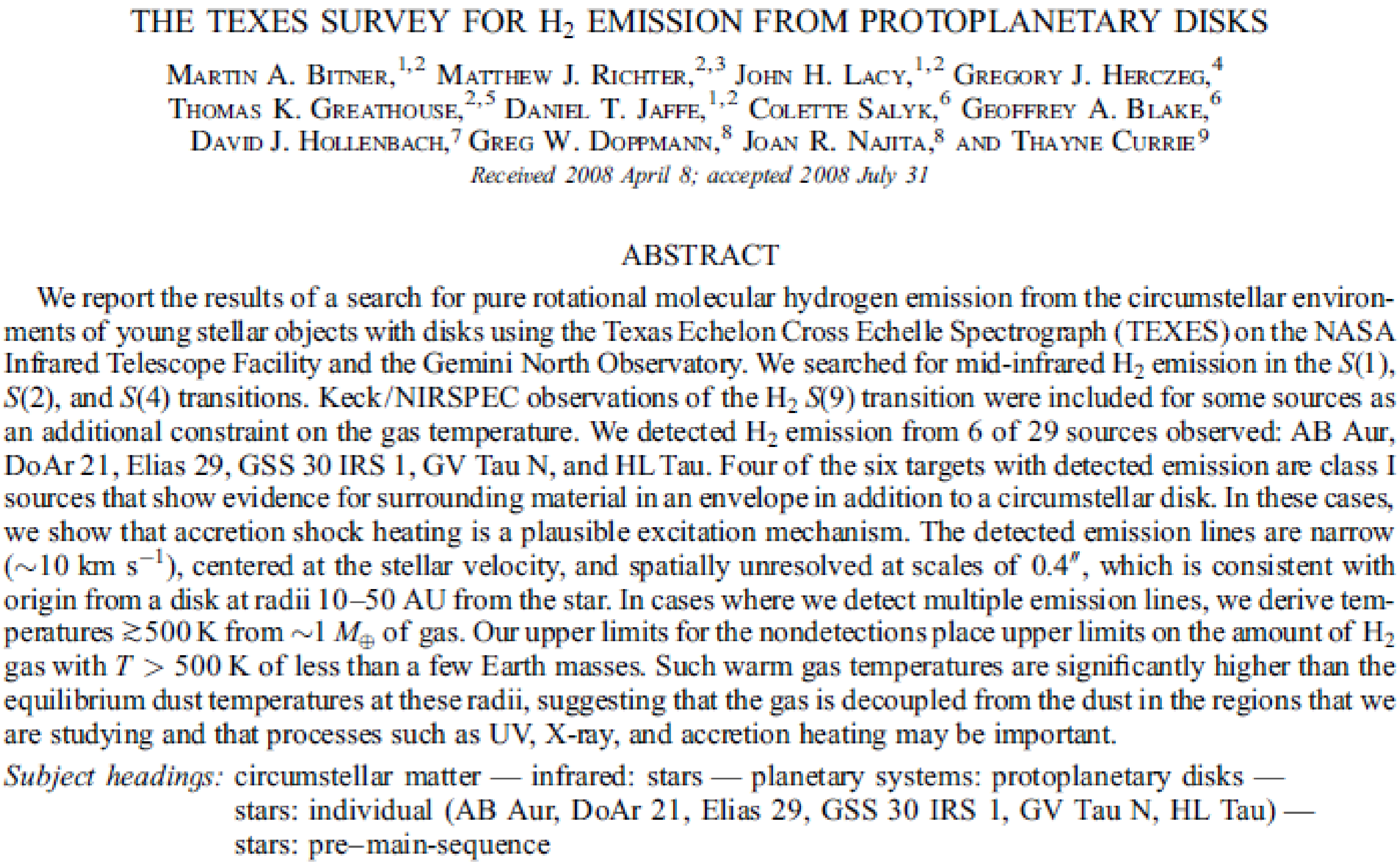
The infrared continuum probes the dust in the disks.

Millimeter lines are dominated by the outer disk.

Infrared lines can probe the gas in the planet-forming regions (0.1-10 AU) of T-Tauri disks.

Line profiles can provide spatial information even if the emission is not spatially resolved since gas close to the star has larger Doppler shifts than gas far from the star.

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

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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

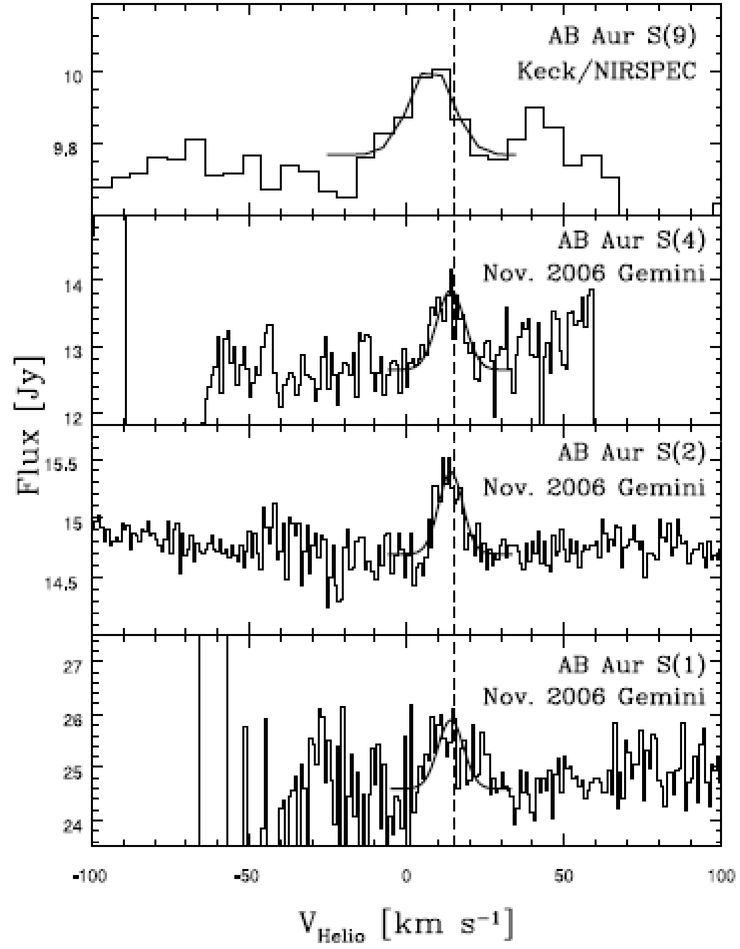


FIG. 1.—AB Aur NIRSPEC/Keck *S*(9) and TEXES/Gemini *S*(4), *S*(2), *S*(1) data from 2006 November observations overplotted with two-component model fit. The dashed line shows the stellar velocity (Thi et al. 2001). The increased noise in the *S*(1) spectrum blueward of the position of the *S*(1) line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

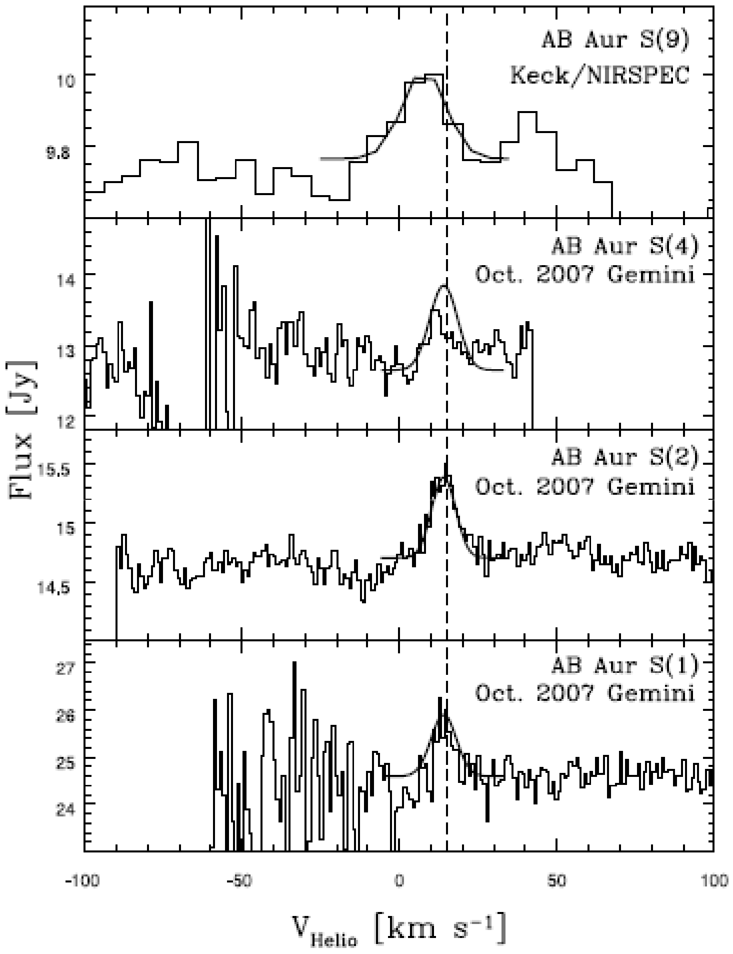


FIG. 2.—AB Aur NIRSPEC/Keck *S*(9) and TEXES/Gemini *S*(4), *S*(2), *S*(1) data from 2007 October observations overplotted with the two-component model fit derived using 2006 November data. The *S*(1) and *S*(2) lines are consistent with our 2006 November observations; however, the *S*(4) line appears 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.

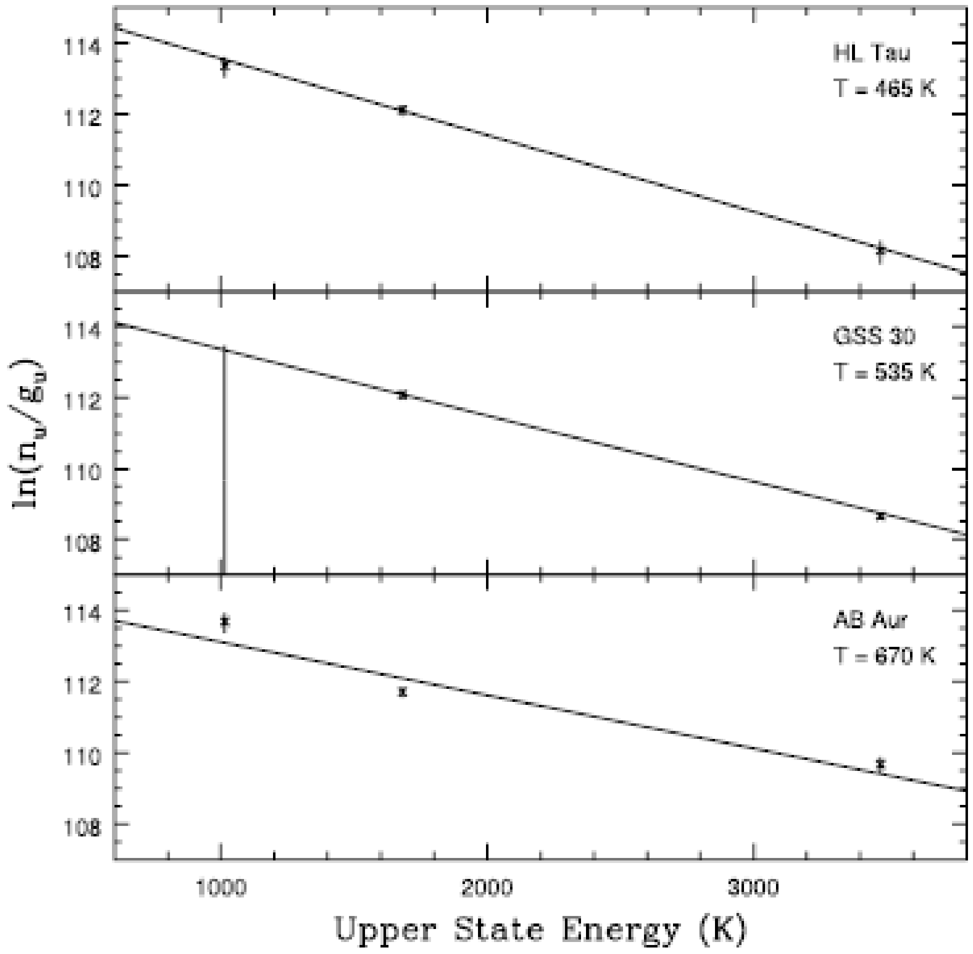
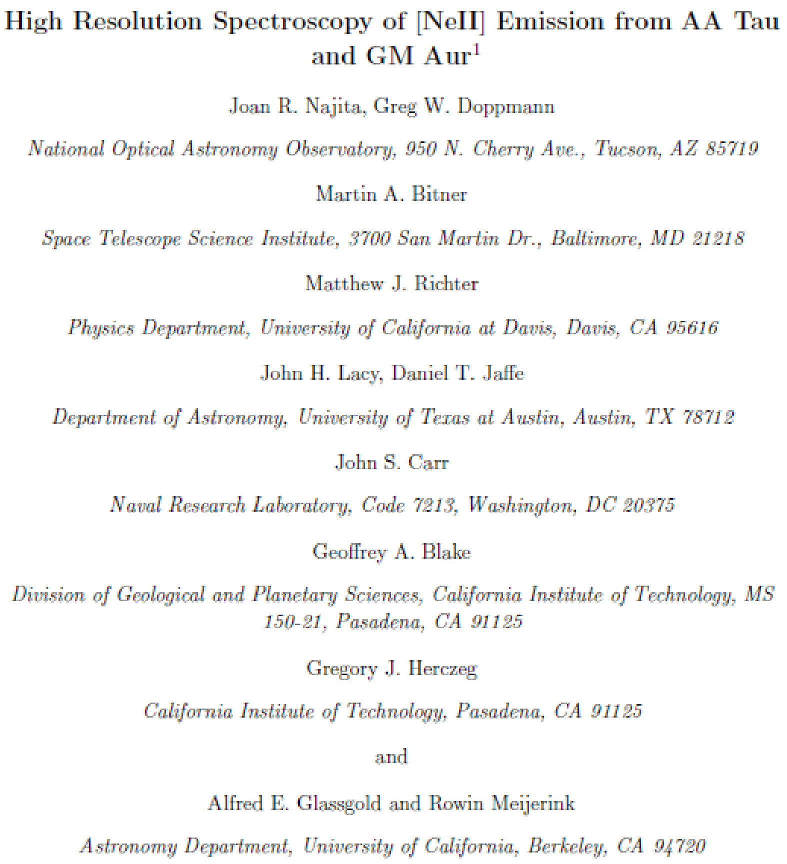


FIG. 8.—Excitation diagrams for the three sources in our sample where we have observations of all three mid-infrared H_2 transitions and detections of at least two. The points are based on Gaussian fits to each of the transitions and are plotted with 1 σ error bars. The overplotted lines show the best-fit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

GN-2006B-Q-40, GN-2007B-C-5: Najita et al.

- Spectra of C_2H_2, HCN, NH_3, and possibly HNCO absorption in the edge-on disk around GV Tau N
- Spectra of [Ne II] emission from the disks around GM Aur and AA Tau



High Resolution Spectroscopy of [NeII] Emission from AA Tau and GM Aur[1]

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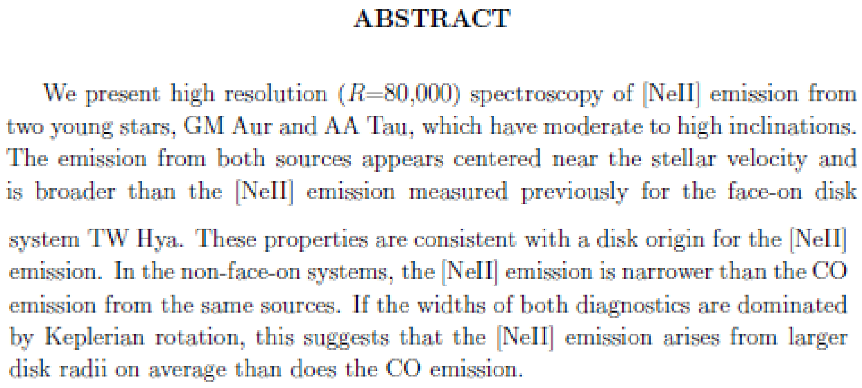
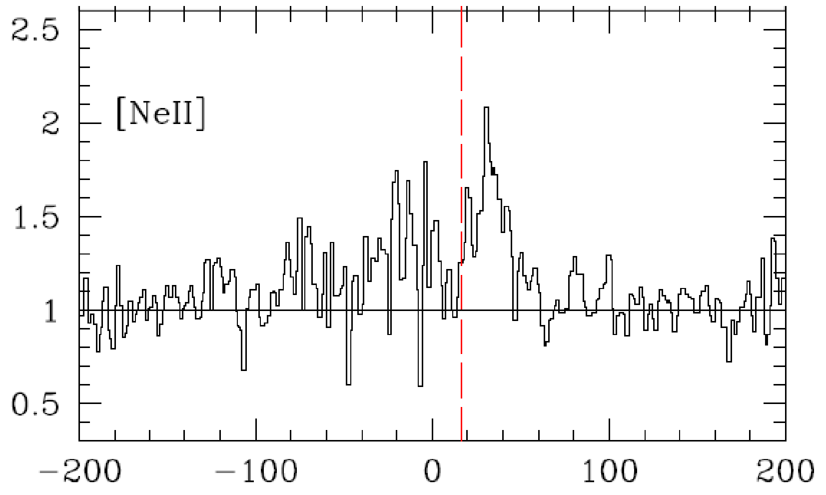


ABSTRACT

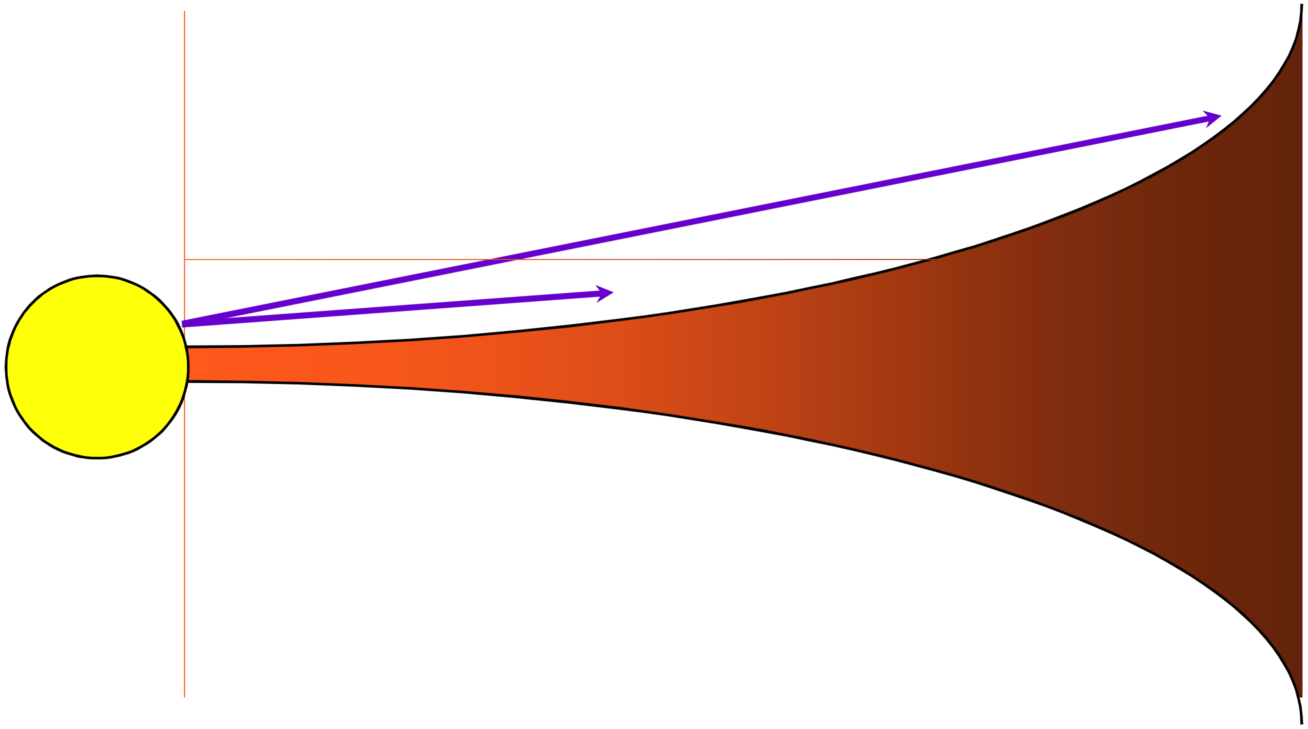
We present high resolution (R=80,000) spectroscopy of [NeII] emission from two young stars, GM Aur and AA Tau, which have moderate to high inclinations. The emission from both sources appears centered near the stellar velocity and is broader than the [NeII] emission measured previously for the face-on disk system TW Hya. These properties are consistent with a disk origin for the [NeII] emission. In the non-face-on systems, the [NeII] emission is narrower than the CO emission from the same sources. If the widths of both diagnostics are dominated by Keplerian rotation, this suggests that the [NeII] emission arises from larger disk radii on average than does the CO emission.



X-ray Irradiated Disks

Detectable [NeII] emission predicted by models

(Glassgold et al. 2007)



X-rays ionize and heat the gas at the disk surface…

[Ne II] vs. CO in AA Tau and GM Aur
Najita et al. (2009)

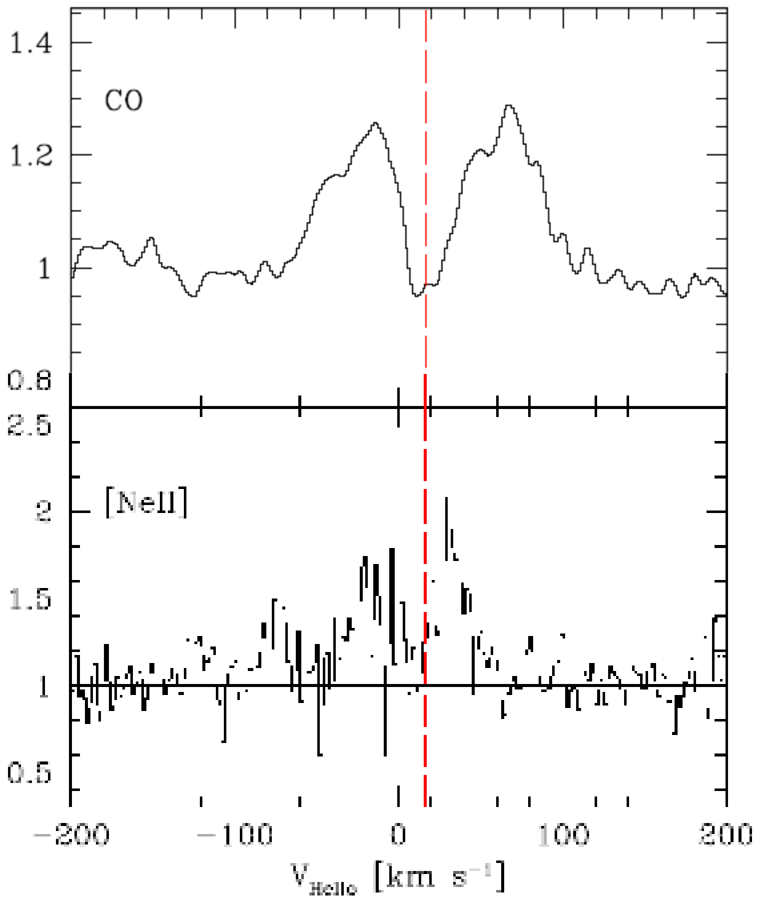


Fig. 3.— *Top:* Average CO emission profile from AA Tau in the 4.9 μm region, normalized to the continuum. The vertical dashed line indicates the stellar velocity (v_{helio} = 16.5 km s^{-1}). In averaging individual CO lines (1–0 P25 through P28), regions of poor telluric correction were excluded from the average. *Bottom:* [NeII] line profile of AA Tau from the combined spectrum shown in Figure 1, normalized to the continuum.

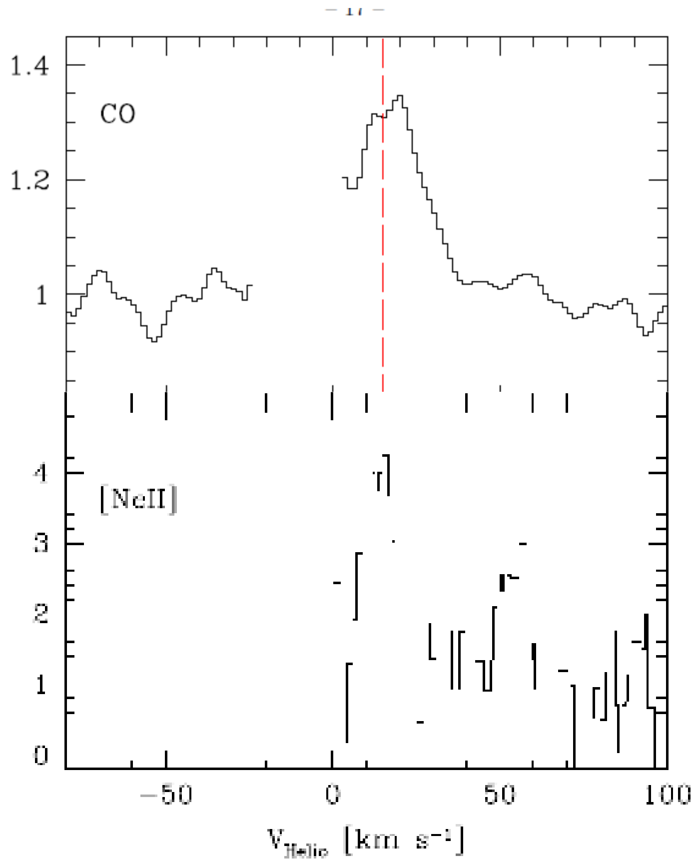
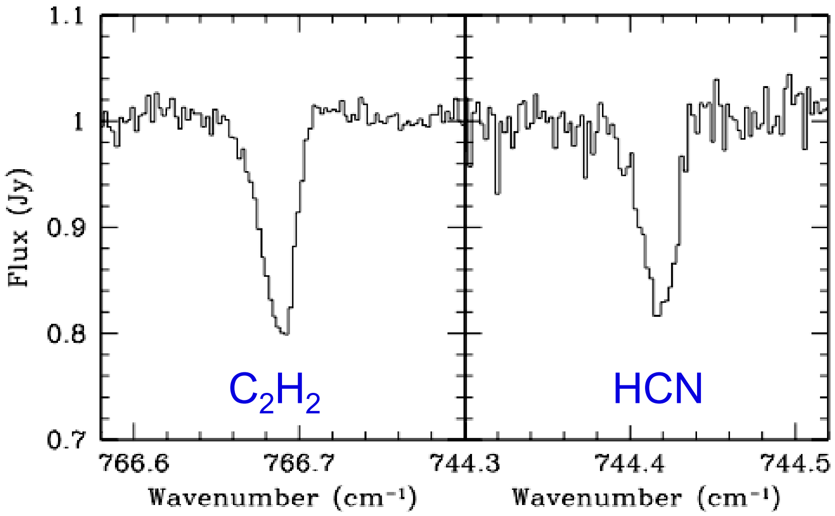


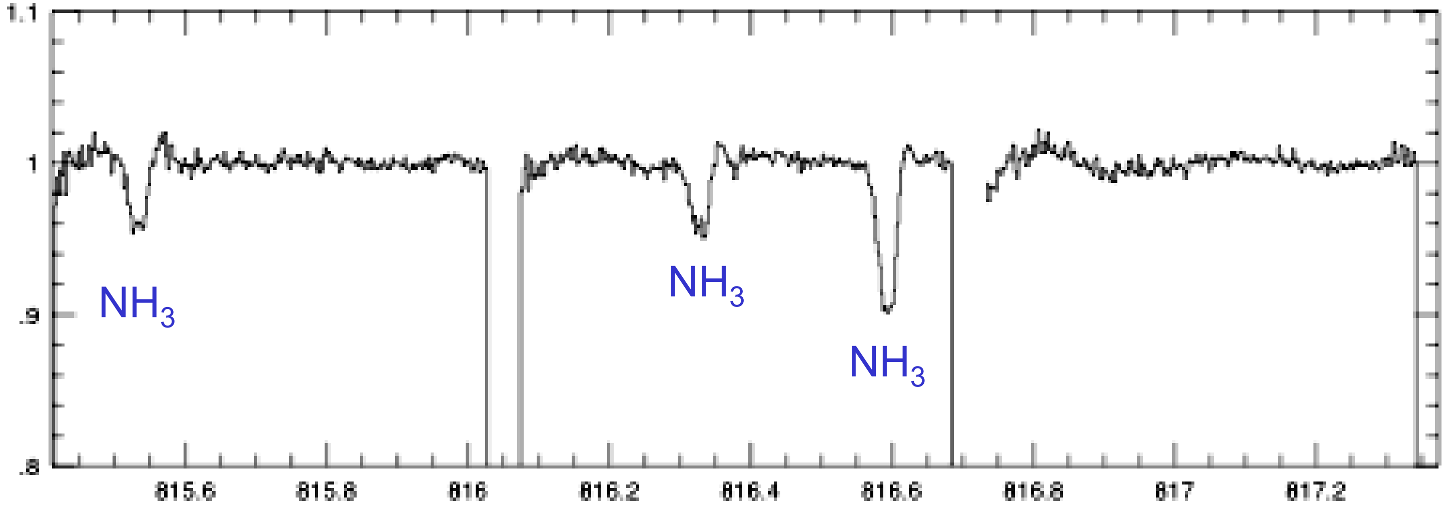
Fig. 4.— *Top:* Average CO emission profile from GM Aur in the 4.7 μm region, normalized to the continuum. The vertical dashed line indicates the stellar velocity (v_{helio} = 14.7 km s^{-1}). In averaging individual CO lines (1–0 P8 through P12), the stellar photospheric contribution to the spectrum was first removed and regions of poor telluric correction were excluded from the average. *Bottom:* [NeII] line profile of GM Aur from the spectrum shown in Figure 2, normalized to the continuum.

GV Tau N: an edge-on disk (Najita et al.)

Lines of C_2H_2, HCN, NH_3, H_2, and possibly HNCO were detected.

Lines are narrow and show both absorption and emission.

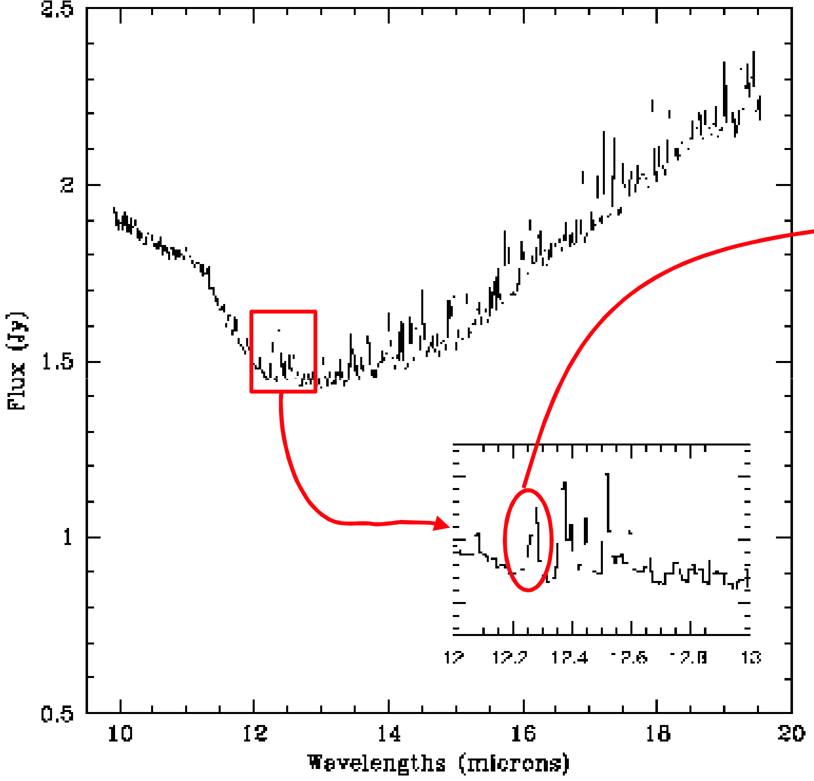




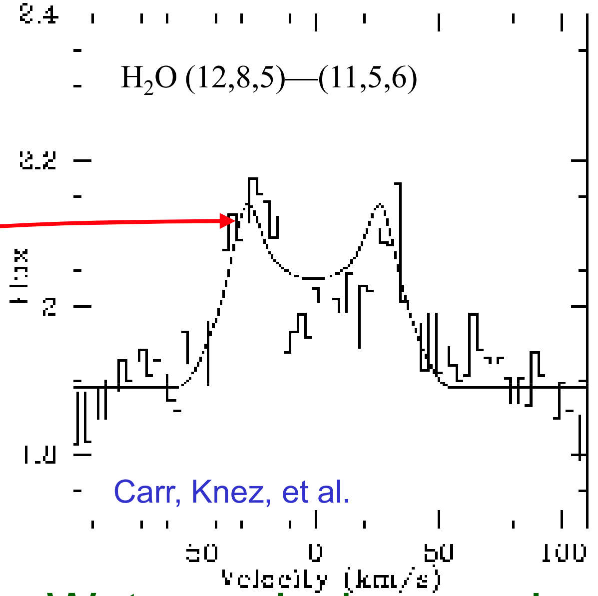
GN-2006B-Q-35: Knez et al., GN-2007B-C-7: Carr et al.

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

Line profiles and gas distribution and excitation

No one source has been observed in all lines, but it appears that there is a pattern in the line widths:

H_2O and CO lines are broadest, indicating that they are formed in the few x 0.1 AU region.

[Ne II] line widths correspond to ~1 AU.

H_2 line widths correspond to ~10 AU.

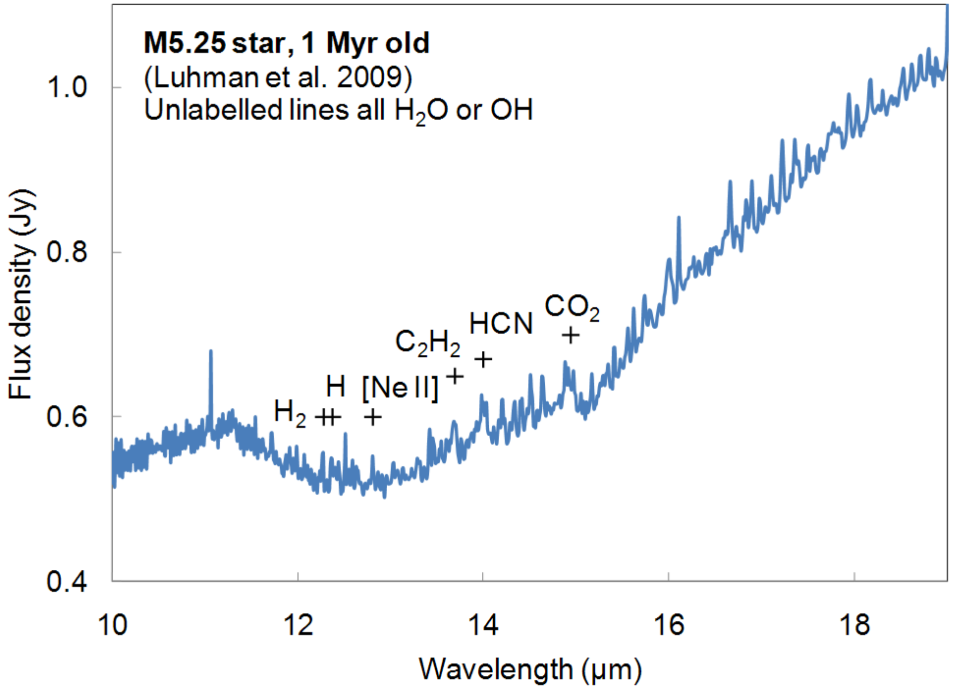
The C_2H_2 and HCN emission lines haven’t been observed at high spectral resolution, but the very narrow absorption lines and temperature like that found for H_2 suggest that these molecules are also found at ~10 AU.

Models are being developed to explain the formation of these lines and the excitation of the molecular gas.

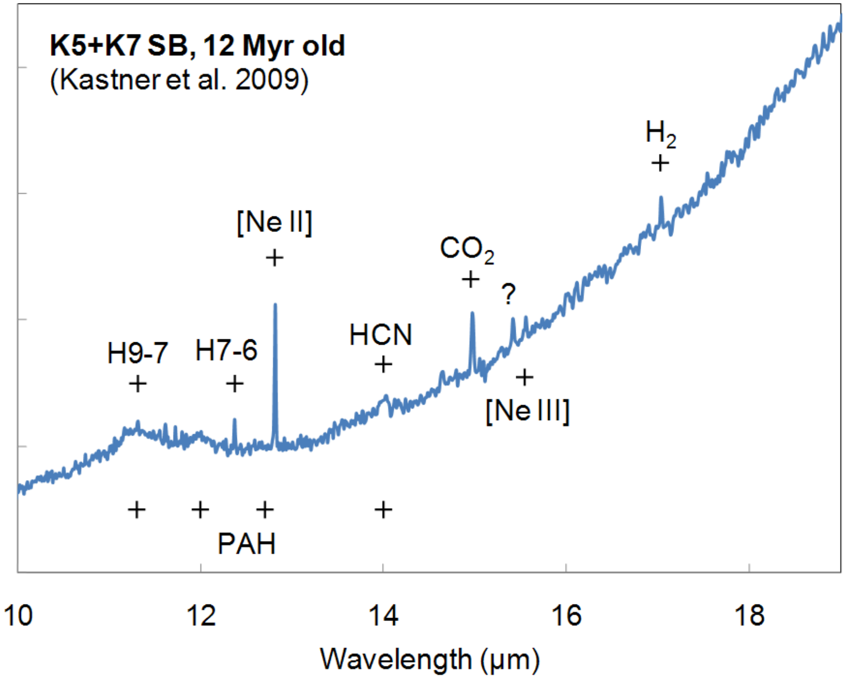
Additional sources of molecular and ionic emission

Spitzer found additional sources with H_2, C_2H_2, HCN, CO_2, H_2O, and ionic emission.

These sources need to be observed at high resolution to determine the location, temperature and abundances these species.



M5.25 star, 1 Myr old
(Luhman et al. 2009)
Unlabelled lines all H_2O or OH



K5+K7 SB, 12 Myr old
(Kastner et al. 2009)

TEXES

TEXES is currently available to the community on the NASA IRTF.

It provides a unique capability for high resolution (R = 30,000-100,000) spectroscopy that will be valuable for Spitzer follow-up.

We hope to make it available again on Gemini, where it has much better sensitivity and angular resolution.