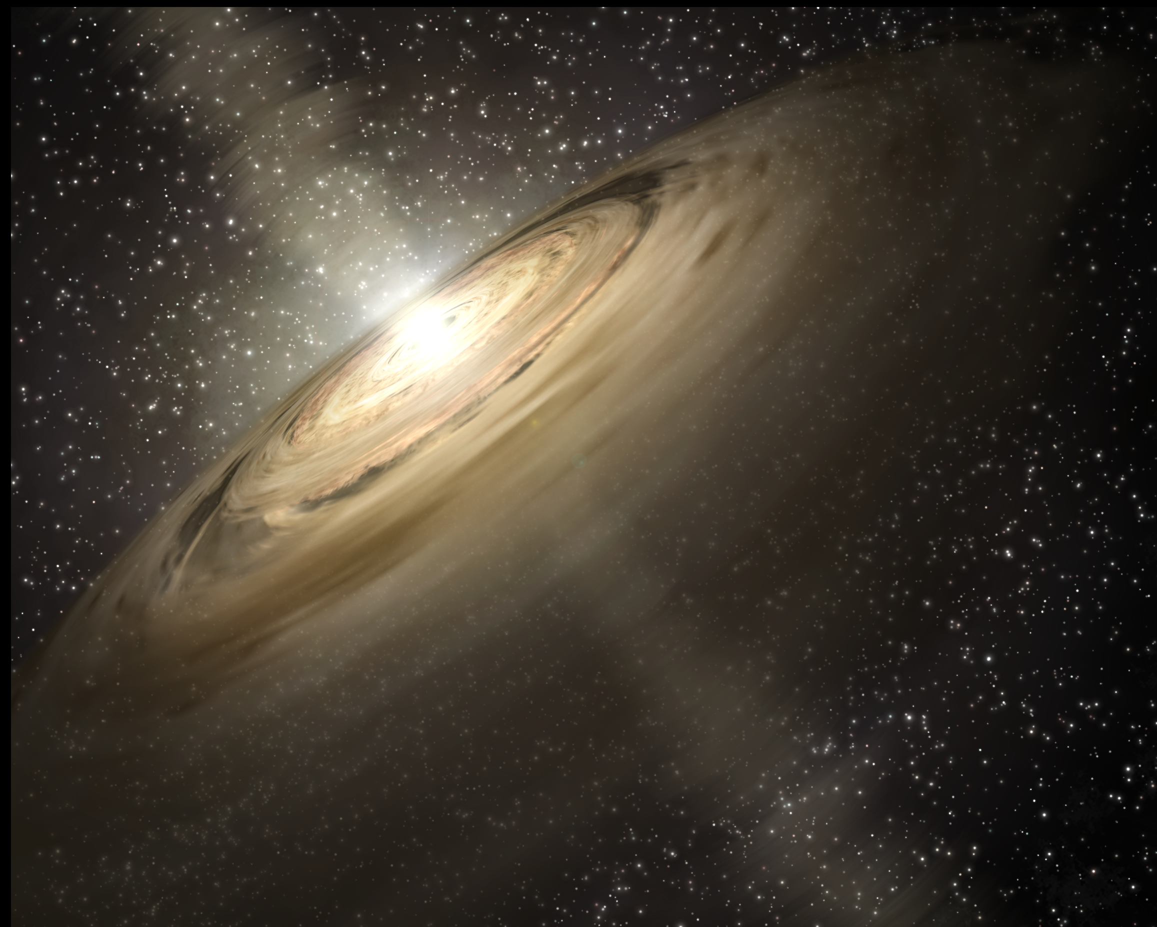
ALMA Observations of the Disk Wind Source AS 205

Keck/VLT

ALMA



2013 ROCKS!

8 April 2013

Geoffrey A. Blake, Division of GPS, Caltech

Transformational Science with ALMA: From Dust to Rocks to Planets

Folks doing the work:

Colette Salyk, Goldberg Fellow, NOAO, Tucson

Klaus Pontoppidan, Hubble Fellow, STScI

Ke (Coco) Zhang, PMA Graduate Student (TW Hya snowline, 2013 ApJ **766**, 100)

Joanna Brown, SMA Fellow, CfA

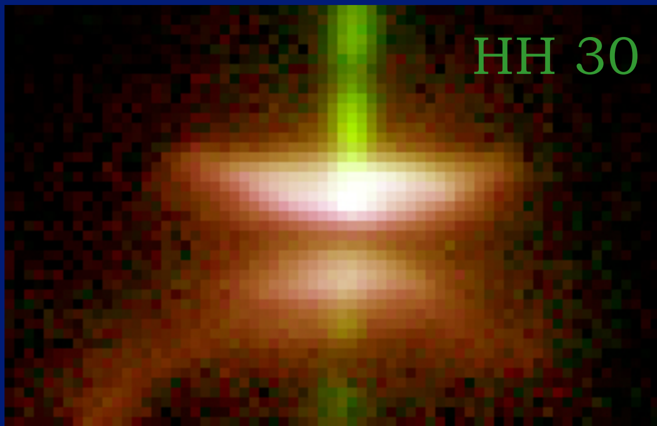
& the Leiden/Garching teams, especially Jeanette Bast and, of course, Ewine van Dishoeck.

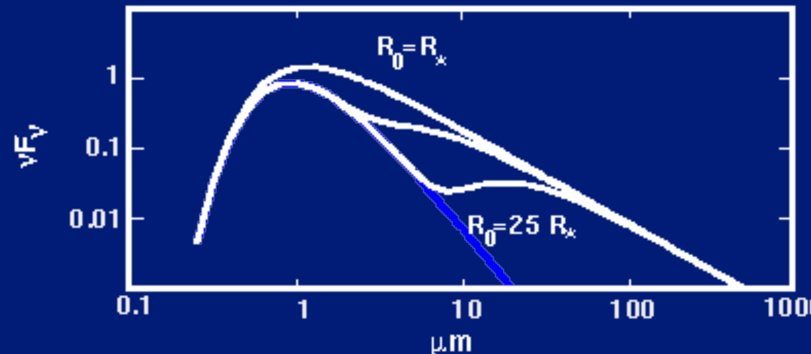
Laplace 1796 – What can the solar system tell us about The formation & evolution of planetary systems?

Key insights:

1. Most of the mass is in the sun.
2. The “major planets” all orbit in the same sense.
3. Small bodies, especially comets, are very different (eccentric, not in one plane).

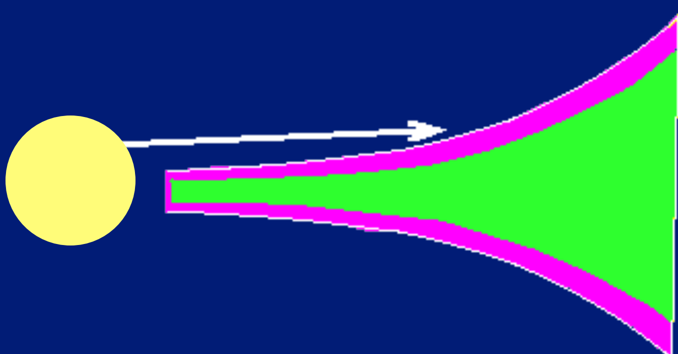
Angular momentum is key. How best to study disks?

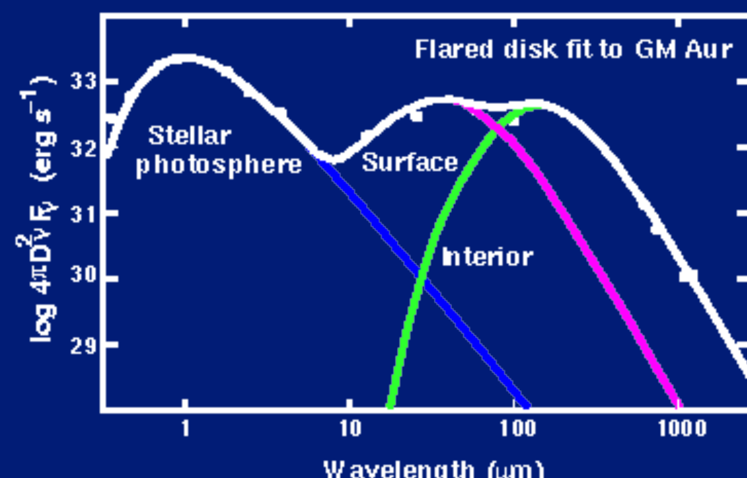




G.J. van Zadelhoff (2002)

← Hotter Colder →





Chiang & Goldreich (1997)

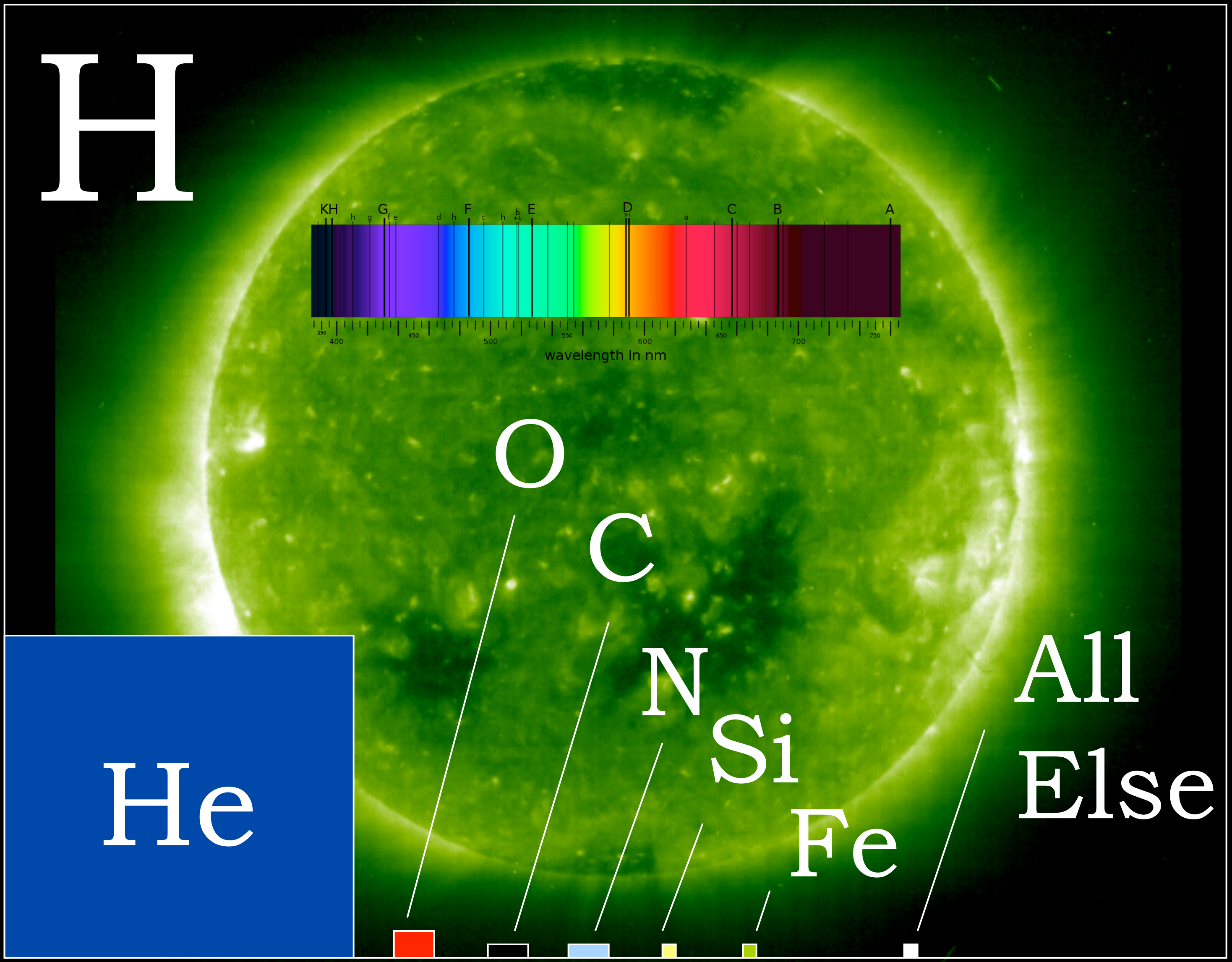
IR ⟹ disk *surface* within several 0.1 – several tens of AU.

(sub)mm ⟹ disk surface at large radii, disk *interior* also.

Need high spatial resolution to break model degeneracies.

The photospheres of stars & disks tell us what they are made of…

The Astronomer's Periodic Table



[O,C] $\sim 10^{-4}$[H]
[N] $\sim 10^{-5}$[H]
[Si,Fe]$\sim 10^{-6}$[H]

H, H_2, He very hard to see.

Dust+Ice/Gas~1%

… and serve as beacons for exoplanet searches.

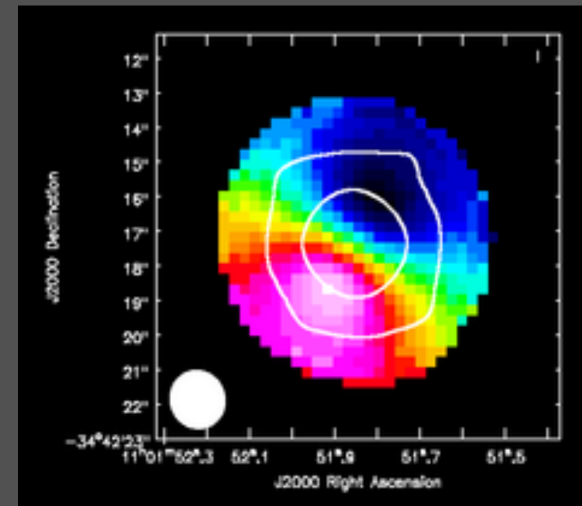
Arrays esp. critical at long wavelengths. ALMA?

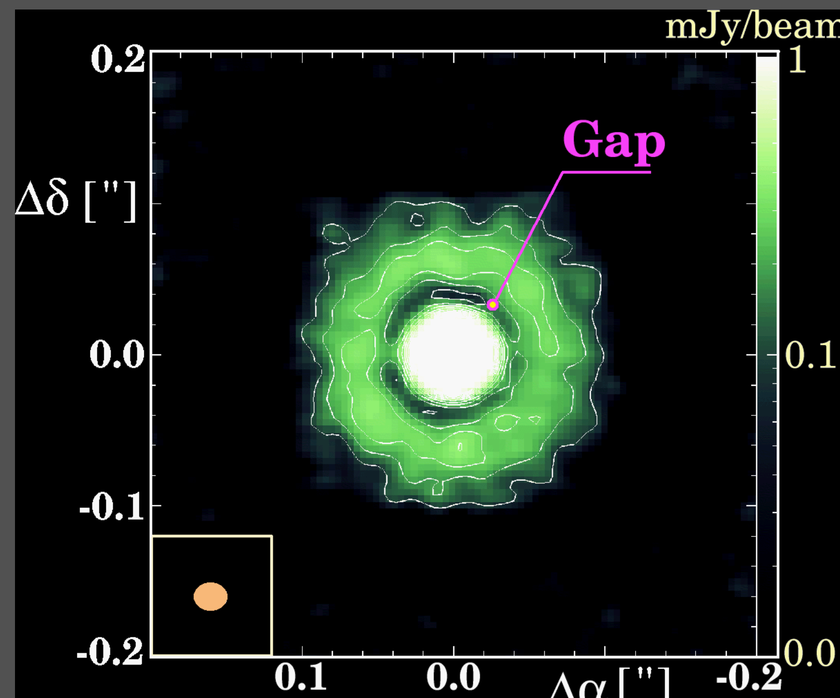
Once completed, ALMA should be able to detect 1 AU wide gaps in its largest configurations via dust imaging, but for 3 AU pixels at 140 pc,

1 km/s in CO 3-2 = 100 K rms in 8 hr

Very difficult to see lines at <5 AU, does the grain emissivity change with radius?

Gas in TW Hya (SV Data)

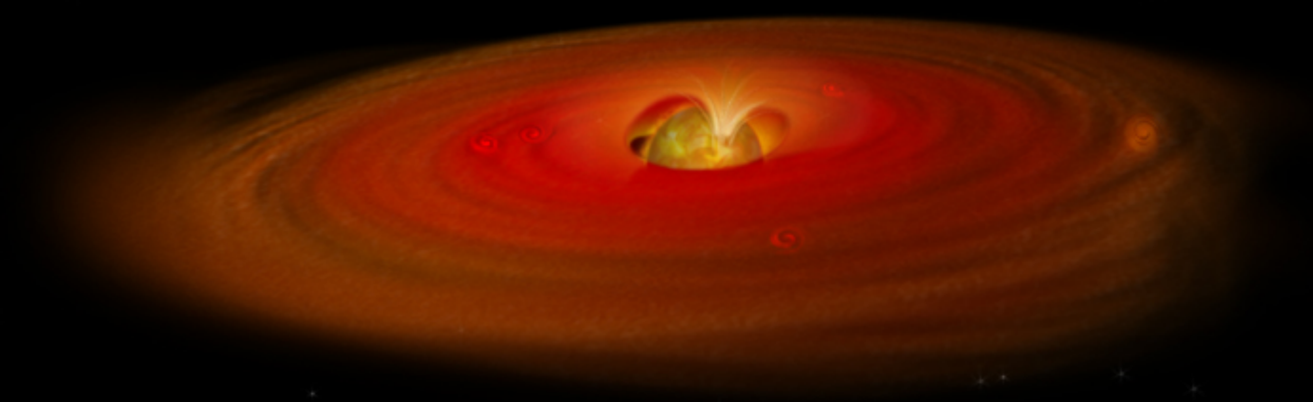




Wolf et al. 2002, ApJ 566, L97.

How can we test disk models with gas tracers @ 0.1-1 AU resolution?

Theory

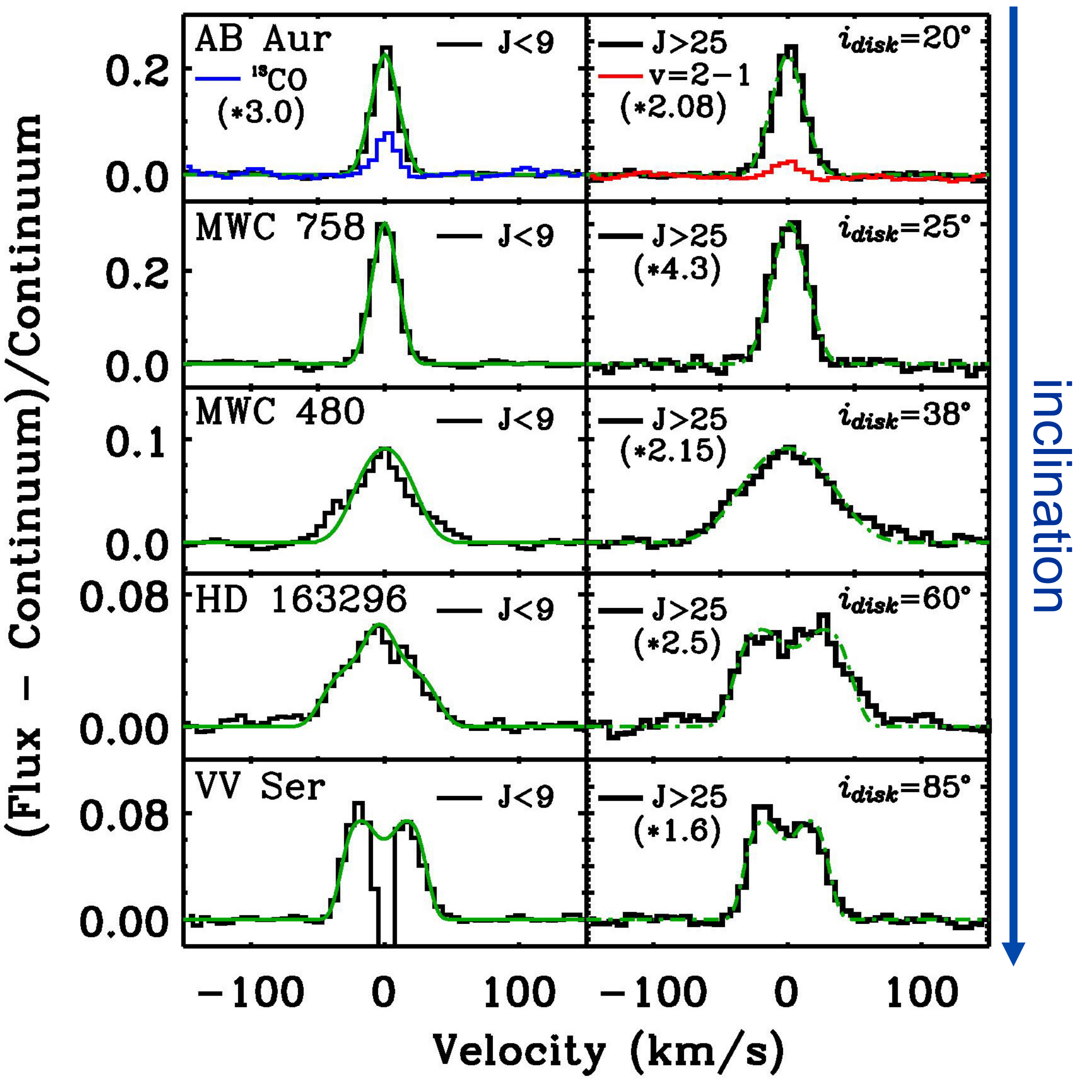


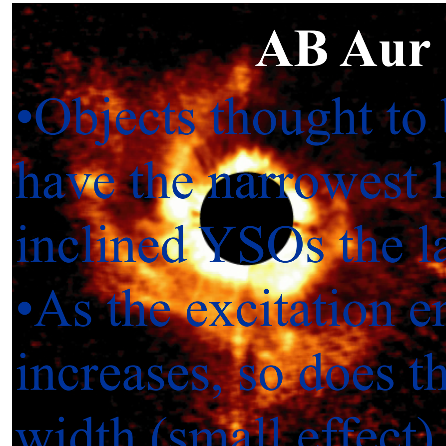
Even w/ALMA, the size scales are too small even for the largest mm-wave arrays. Look where the inner disk is self-luminous, or, IR spectroscopy to the rescue…

Jupiter (5 AU):
$V_{doppler} = 13$ m/s
$V_{orbit} = 13$ km/s

Observation?

Disk Photospheres: CO Line Width Trends

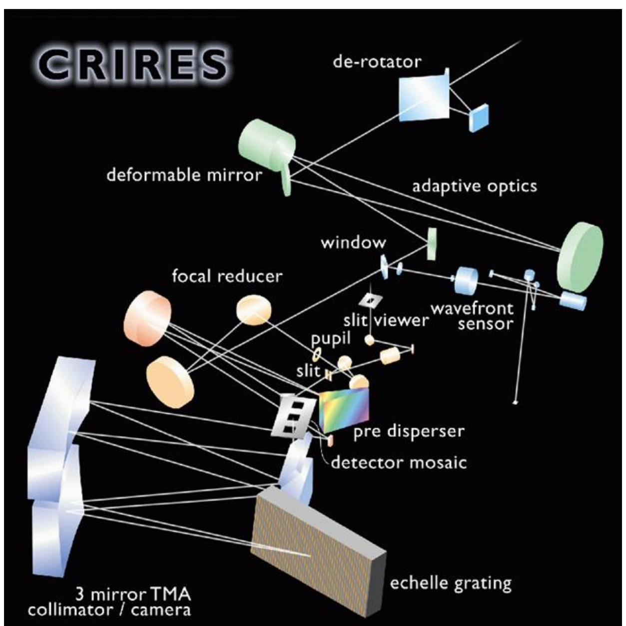




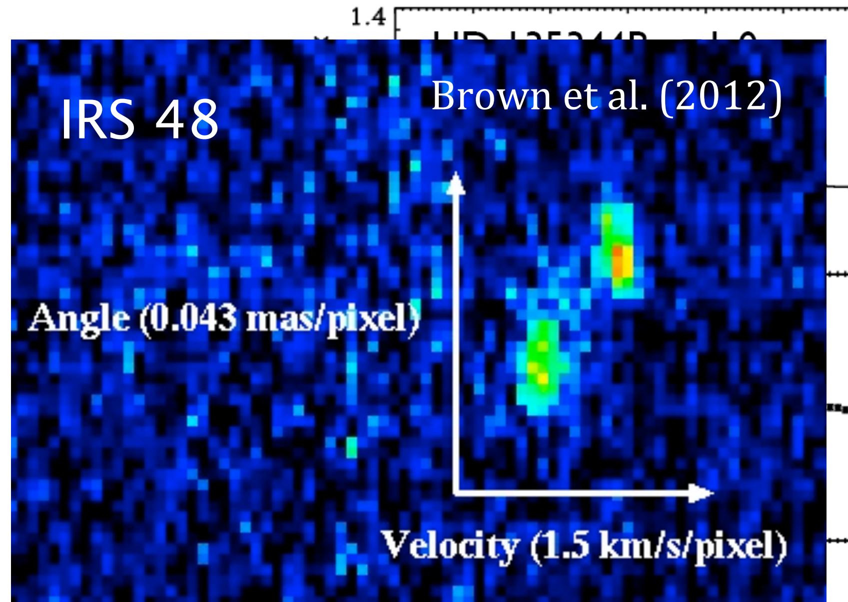
- •Objects thought to be ~face on have the narrowest lines, highly inclined YSOs the largest.
- •As the excitation energy increases, so does the line width (small effect).
- •Consistent with disk emission, radii range from 0.5-5 AU.
- •Low J lines also resonantly scatter 5 μm photons to much larger distances.
- •Asymmetries (VV Ser)?

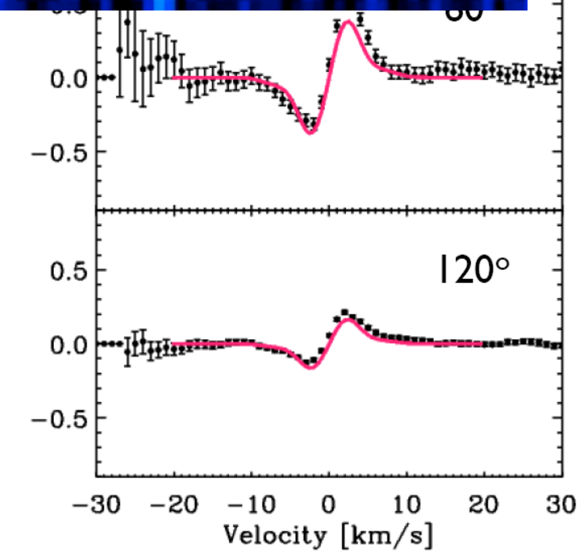
Blake & Boogert 2004, ApJL **606**, L73, Herbig Ae stars (above)
Najita et al. 2003, ApJ **589**, 931 for clasical T Tauri stars

Spectro-Astrometry of Disks with CRIRES, NIRSPEC:



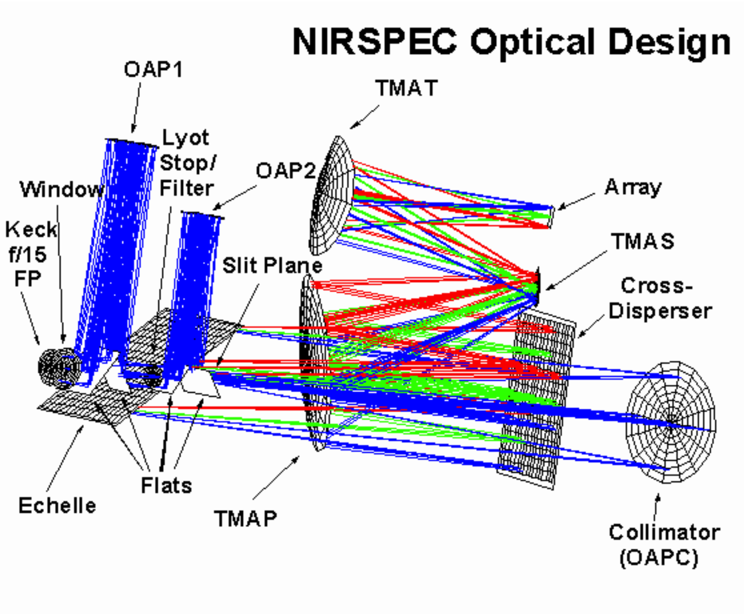
AO-fed echelle

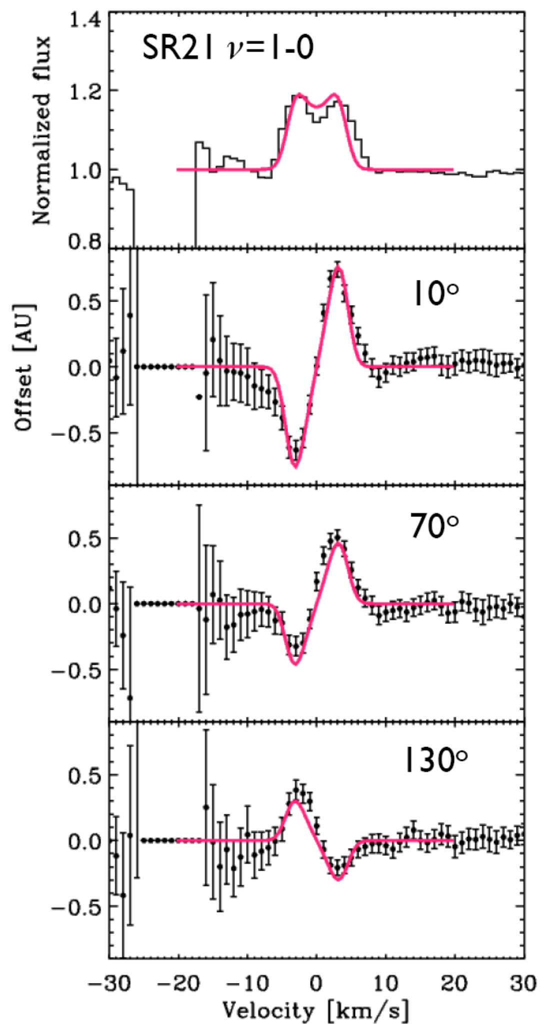




K. Pontoppidan et al. (2008)

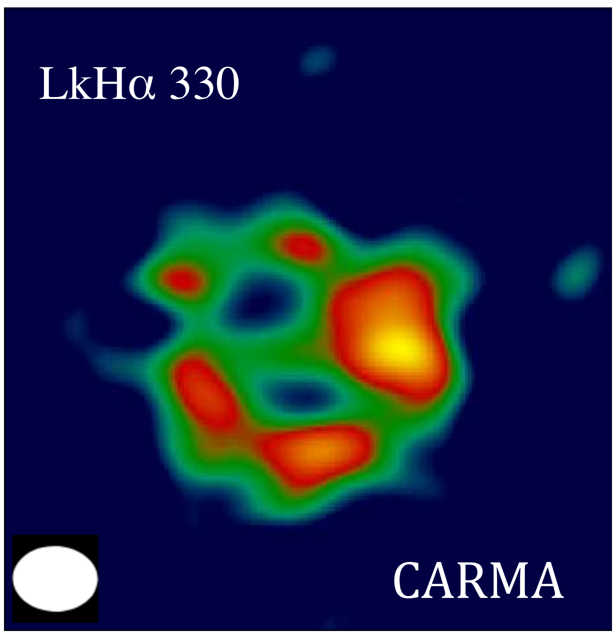
CO Emission from Transitional Disks? S-A.





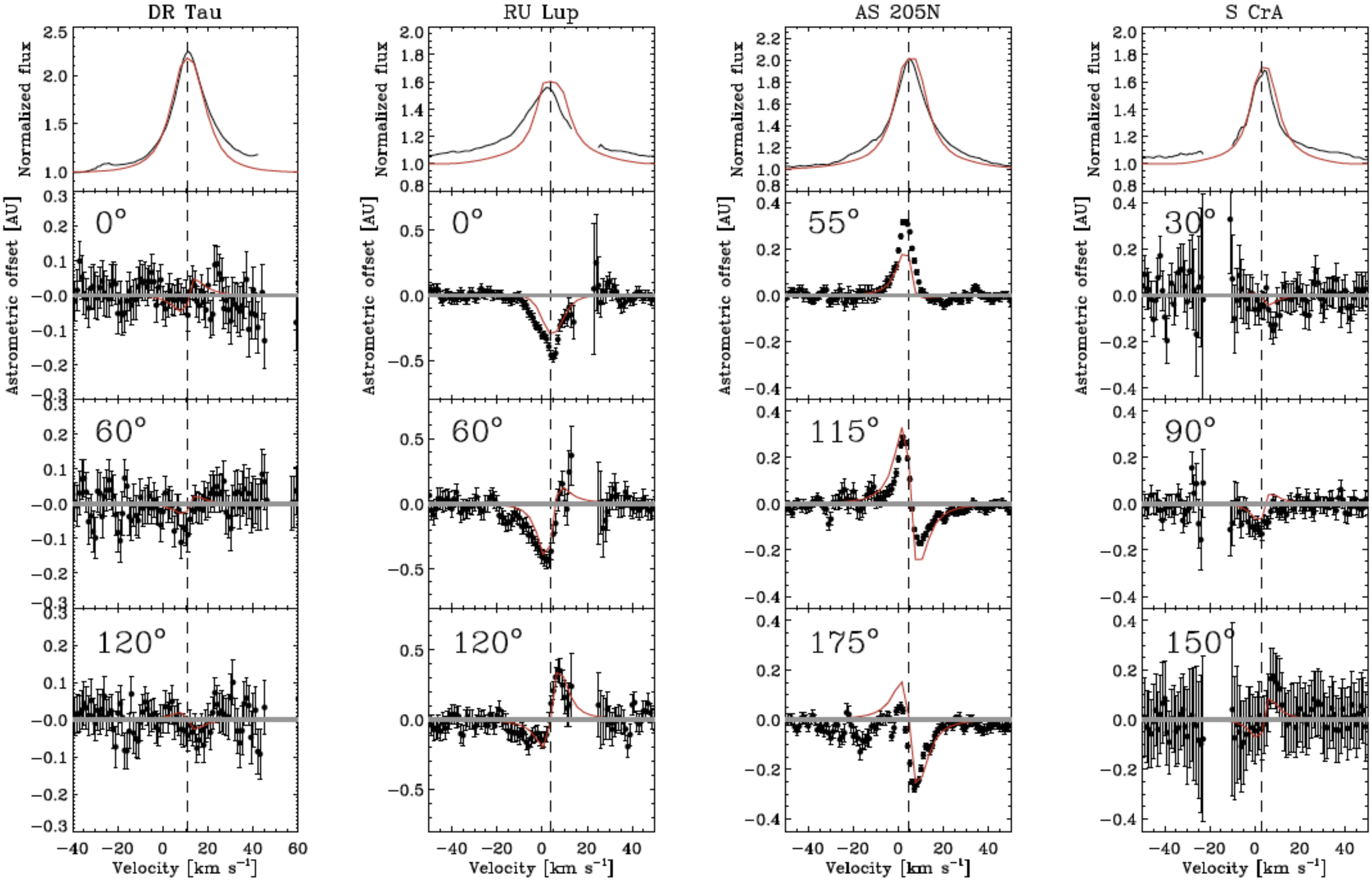
Directly gives emitting radii (typically a few AU), but cannot sense the disk beyond >10 AU (need ALMA).

Better than 0.1 AU precision for both Keck and the VLT.



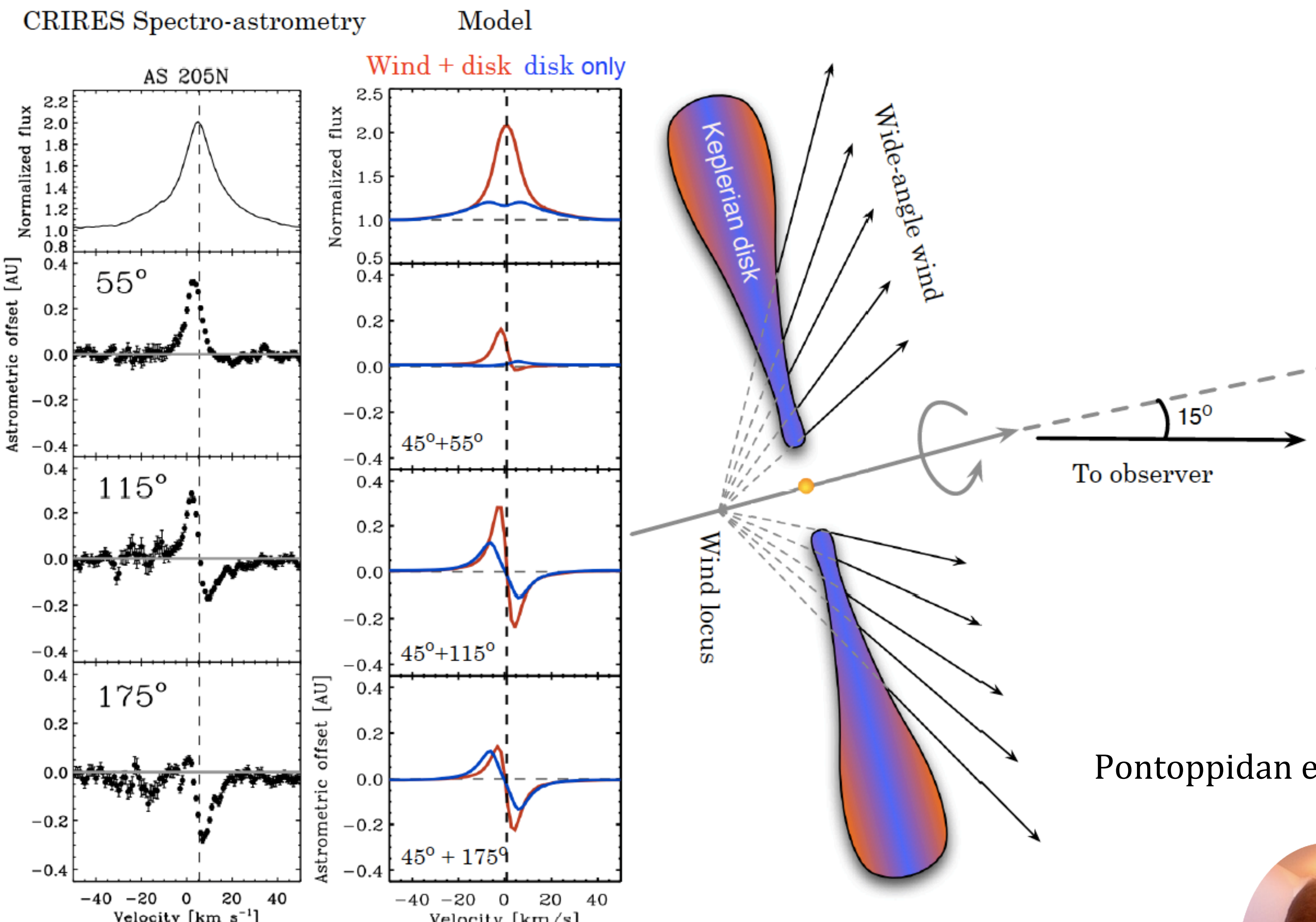
K. Pontoppidan et al. (2008)

Some confusing results:



Some profiles are single peaked even at 3 km/s (Bast et al 2011).

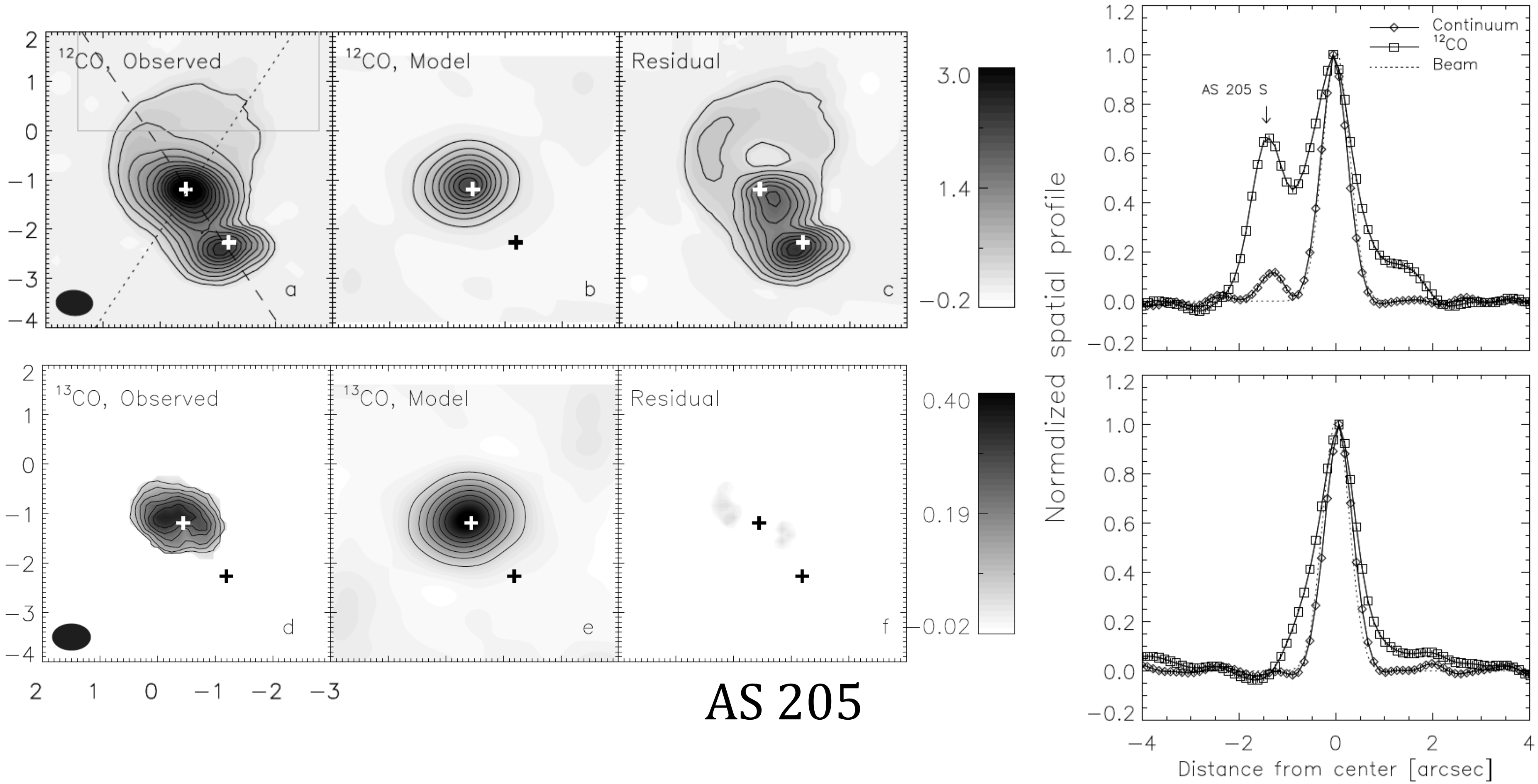
Likely answer? Not just a disk!



Pontoppidan et al. (2011)

Need a *slow*, wide angle, **molecular** wind.
Does this gas escape or re-impact on disk (comets)?

What are the properties & fate of this molecular wind?
Enter ALMA.

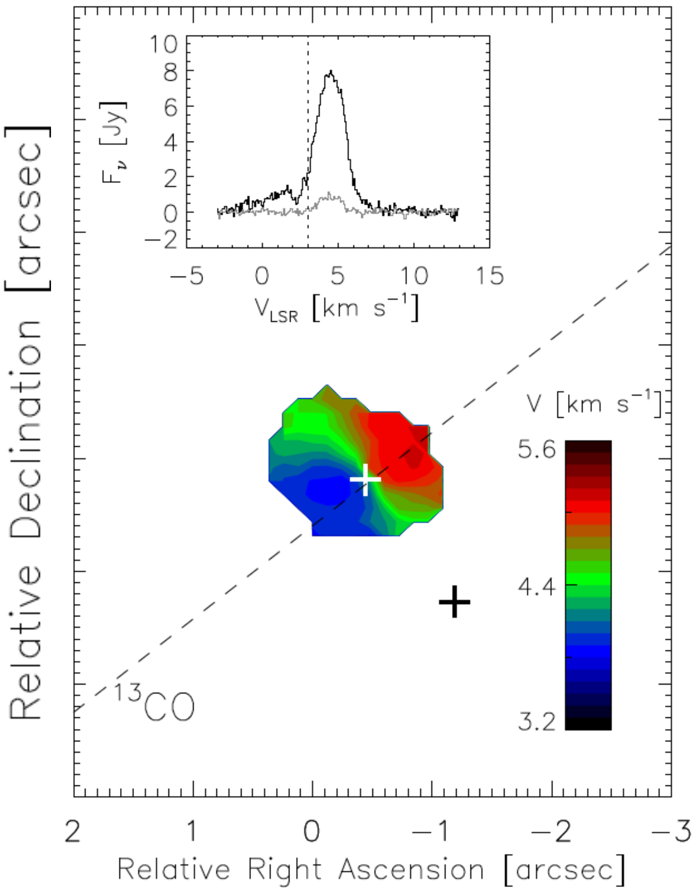


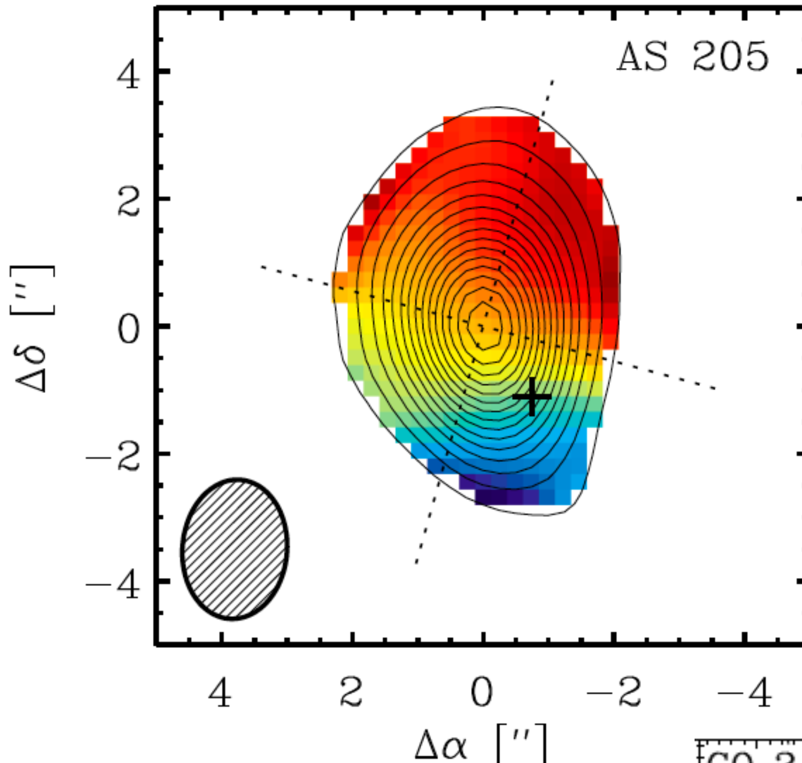
Two Cycle 0 sessions, 31 min. total. CO/^{13}CO/C^{18}O 2-1.

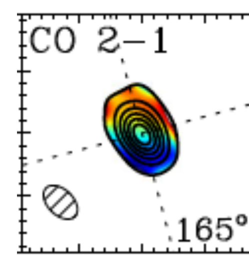
Binary well resolved, all lines nicely detected.

What are the properties & fate of this molecular wind?
Enter ALMA.

AS 205



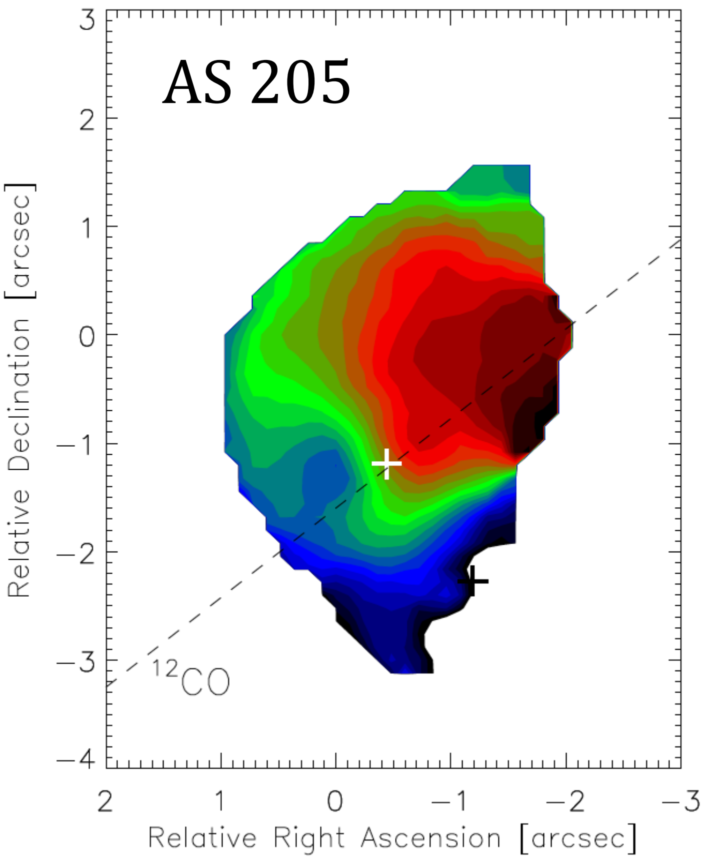


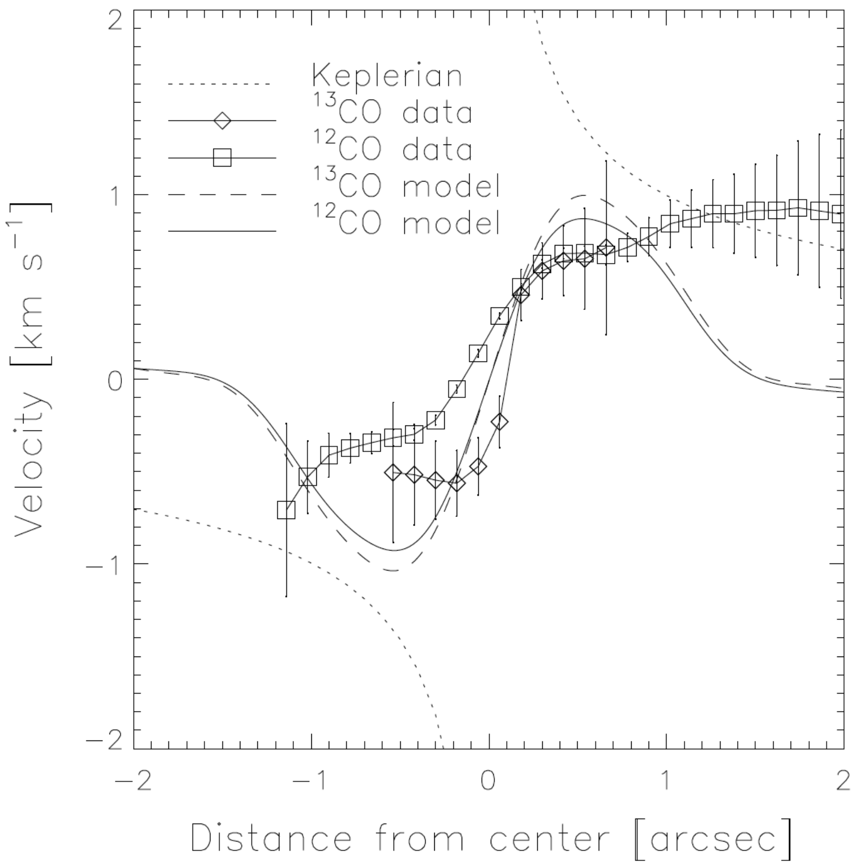


Andrews et al. (2009), ^{12}CO 3-2, see also Oberg et al. (2011).

^{13}CO 2-1 yields a compact velocity pattern around AS 205A that is consistent w/Keplerian rotation.

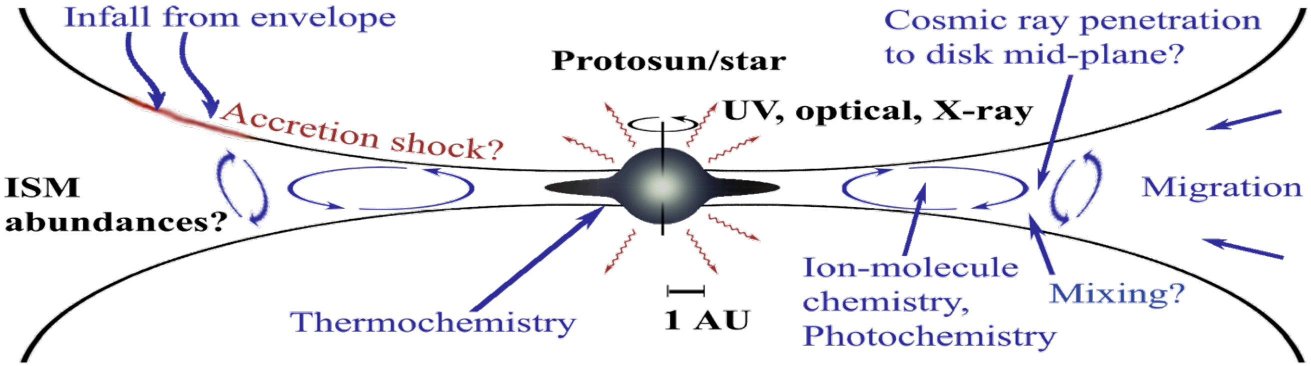
What are the properties & fate of this molecular wind?
Enter ALMA.



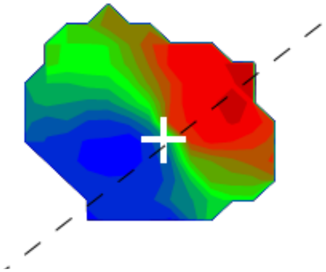


CO 2-1 clearly more extended than ^{13}CO/C^{18}O, patterns not consistent w/a Keplerian field, and as w/some other disks (esp. TW Hya), the gas/dust ratio must increase at large R.

Is there a disk wind in AS 205? Some thoughts.



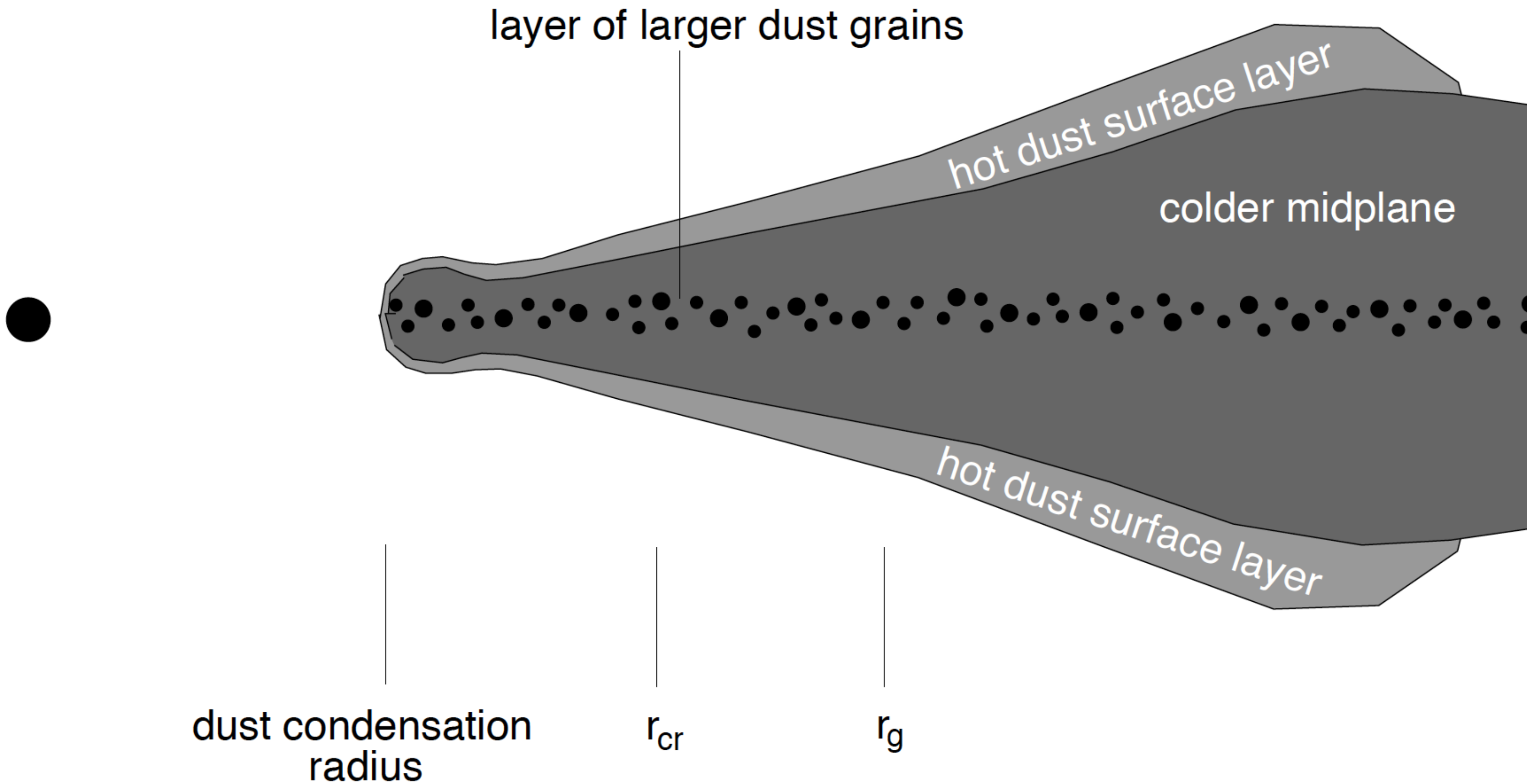
- Gas readily seen @ <0.”5 in disks w/ALMA.
- ^{13}CO Keplerian, but ^{12}CO asymmetric. Comp? Another component? Different gas/dust?
- To constrain this component, ALMA data on several CO transitions/isotopologues needed.
- Are breaks in the gas/dust ratios in disks signatures of disk winds?
- Could the remnant ‘envelopes’ seen around older stars be, in fact, remnant disk winds? Might help explain ISO H_2 detections.



^{13}CO 2-1

At early times, does water aid grain growth? Do small grains remain lofted, ~mm/cm bodies settle quickly?

That is, do we get:



to accelerate planetesimal growth?

If so, the radial location of the snow line is critical!

How does spectro-astrometry work?

- Relative astrometry measures the centroid of a point source image (ΔX, ΔY).
- In long-slit spectra (far right), there is only one spatial centroid, ΔX(n, PA), that is measured for each frequency, slit PA.
- ΔX(n, PA) can be determined to much better precision than the formal PSF width (~100 times better).