Planetary Systems and Star Formation

Lee Hartmann, University of Michigan

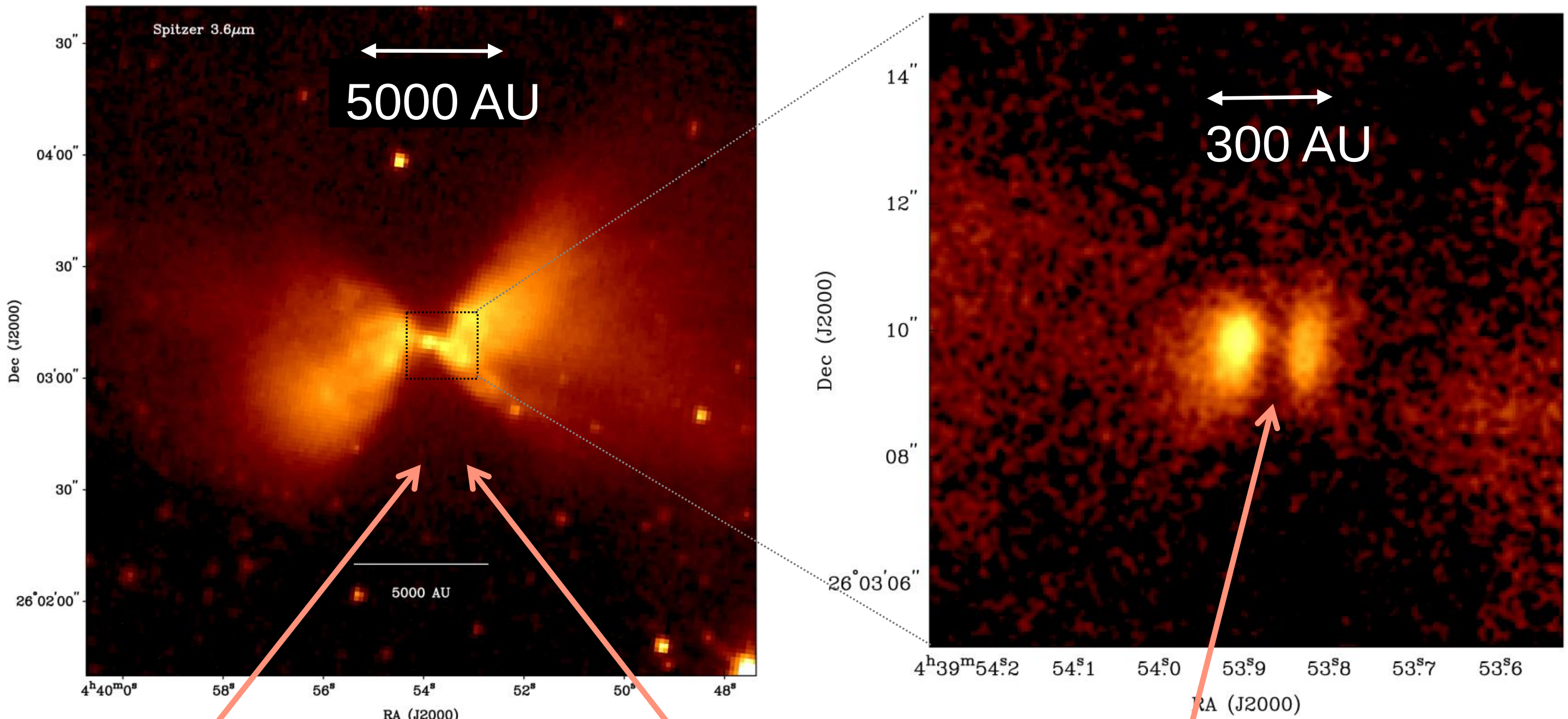
PSF panel discovery areas

- How do stars form?
- How do circumstellar disks evolve and form planetary systems?
- How diverse are planetary systems?
- Do habitable worlds exist around other stars, and can we identify signs of life?
- *special discovery area:* Identification and characterization of nearby habitable exoplanets

- How do stars form? with disks…

Protostar: 3.6μm scattered light (Spitzer)

Gemini 3.8 μm

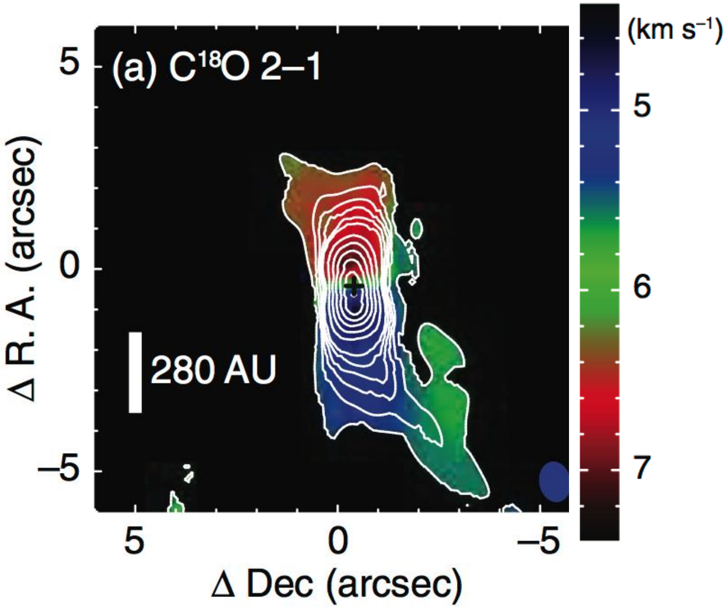


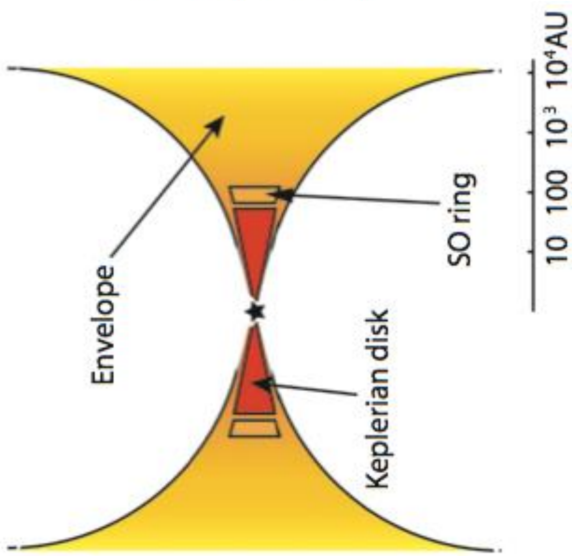
dusty infalling envelope

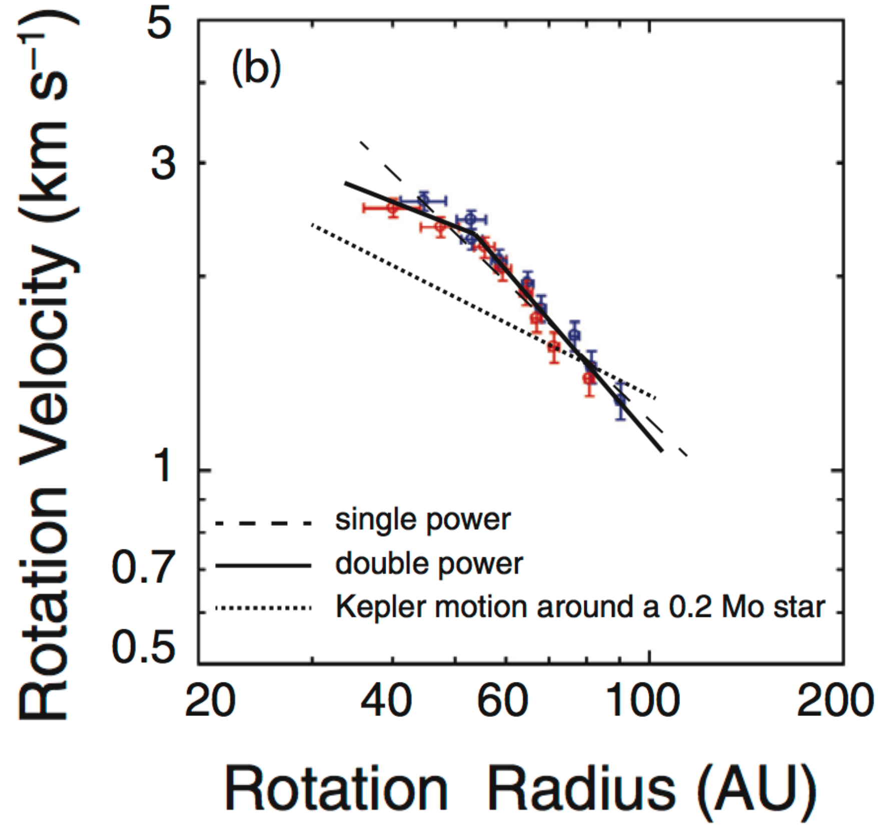
obscured disk midplane

Tobin+10

ALMA!

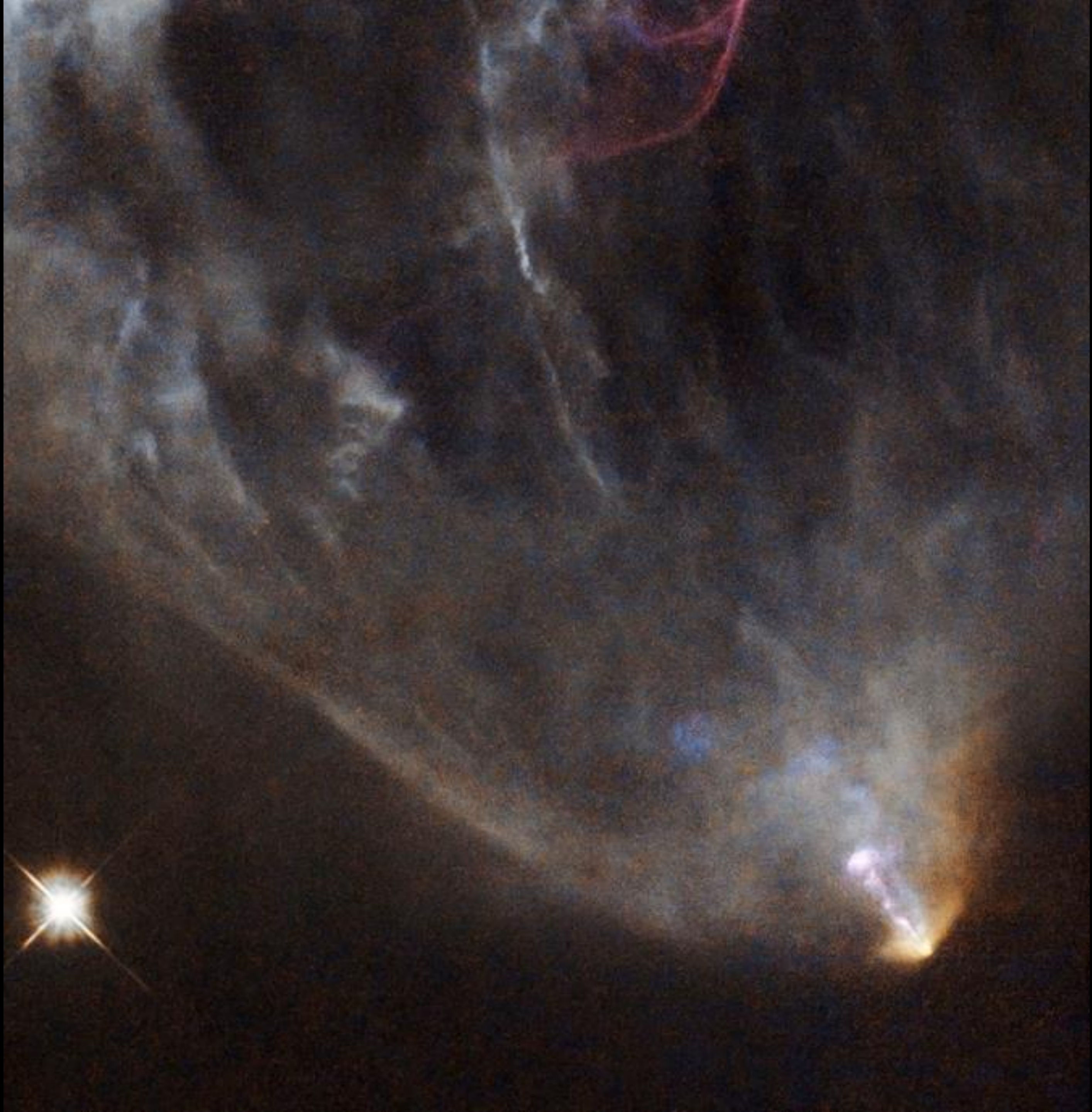






- disk formation
- protostar masses ⇒ evolutionary stages, accretion rates

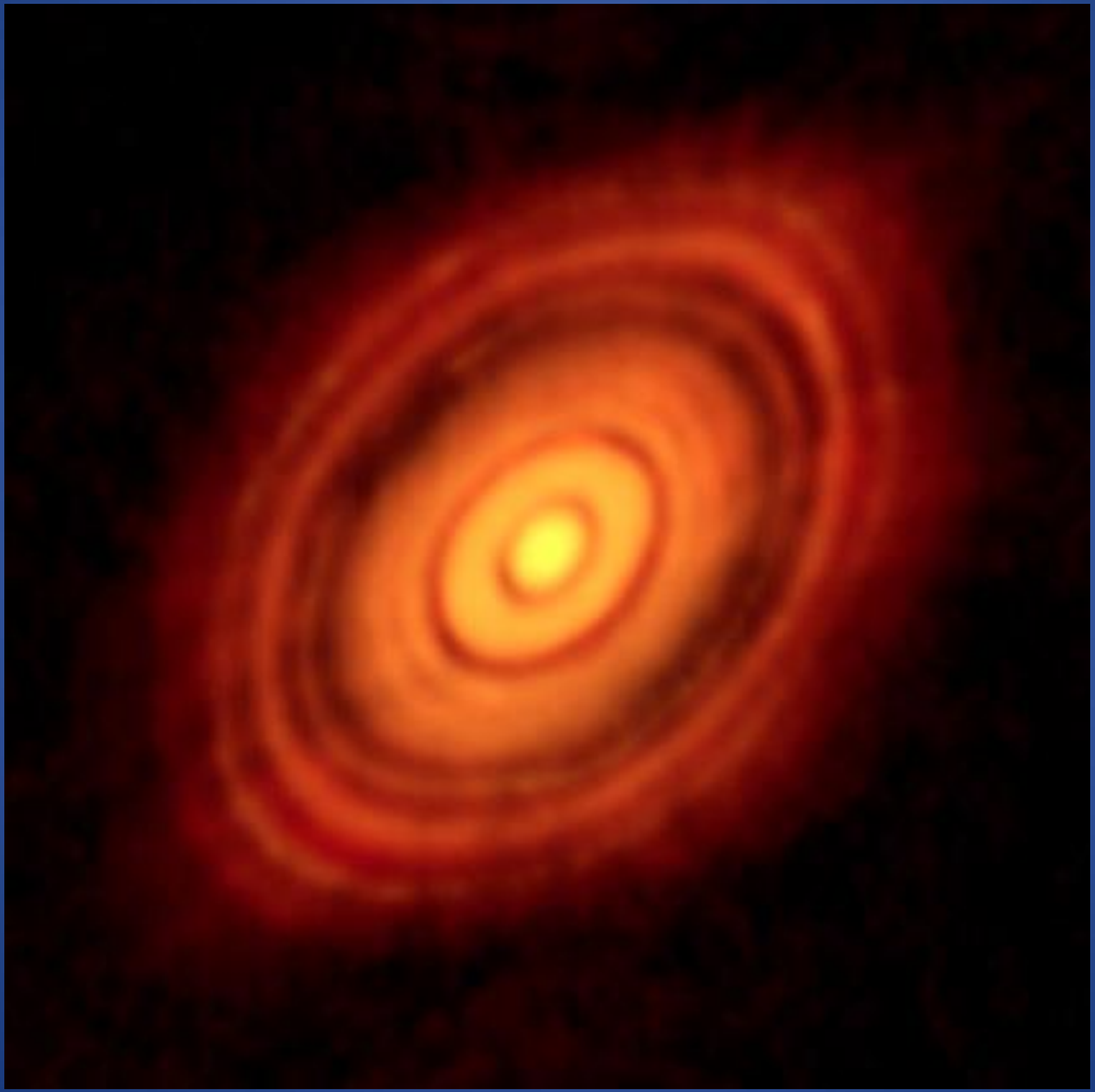
Ohashi+14



ESO

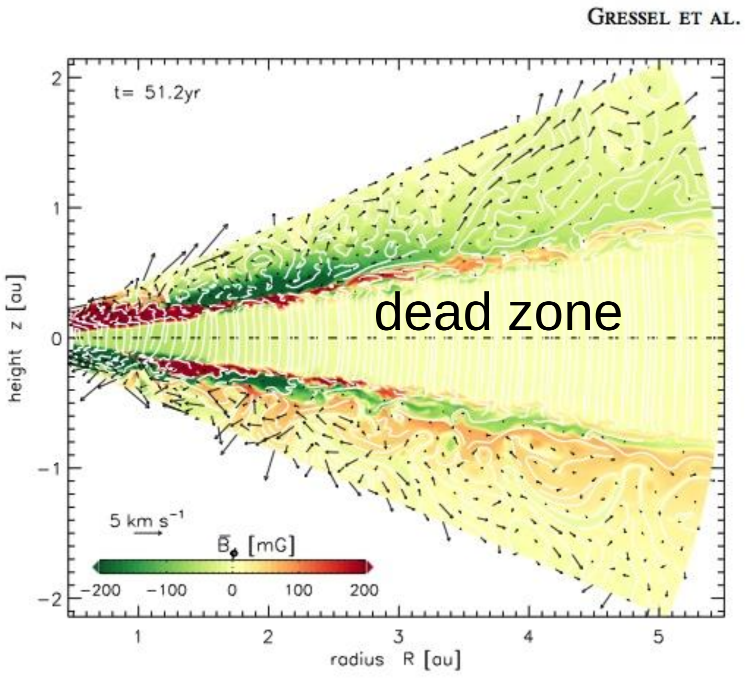
www.eso.org

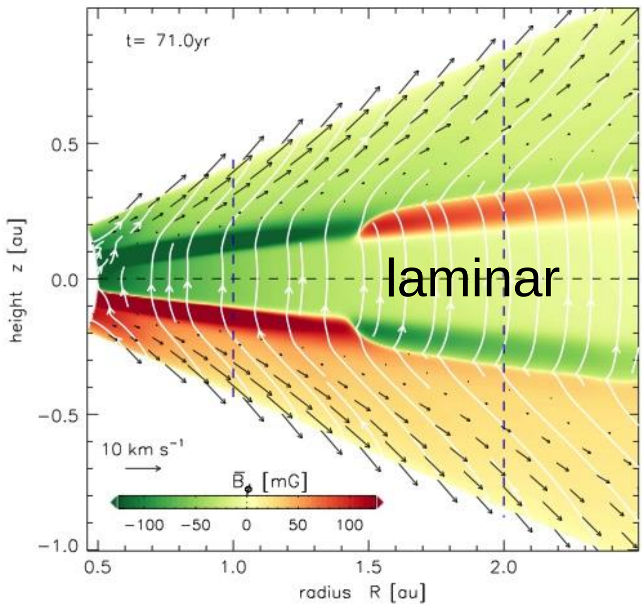
ALMA! HL Tau: planets forming even during infall to disk?



- How do circumstellar disks evolve and form planetary systems?

Theoretical interlude: how do proplanetary disks accrete?





magnetorotational instability (MRI) drives turbulence… but without ambipolar diffusion

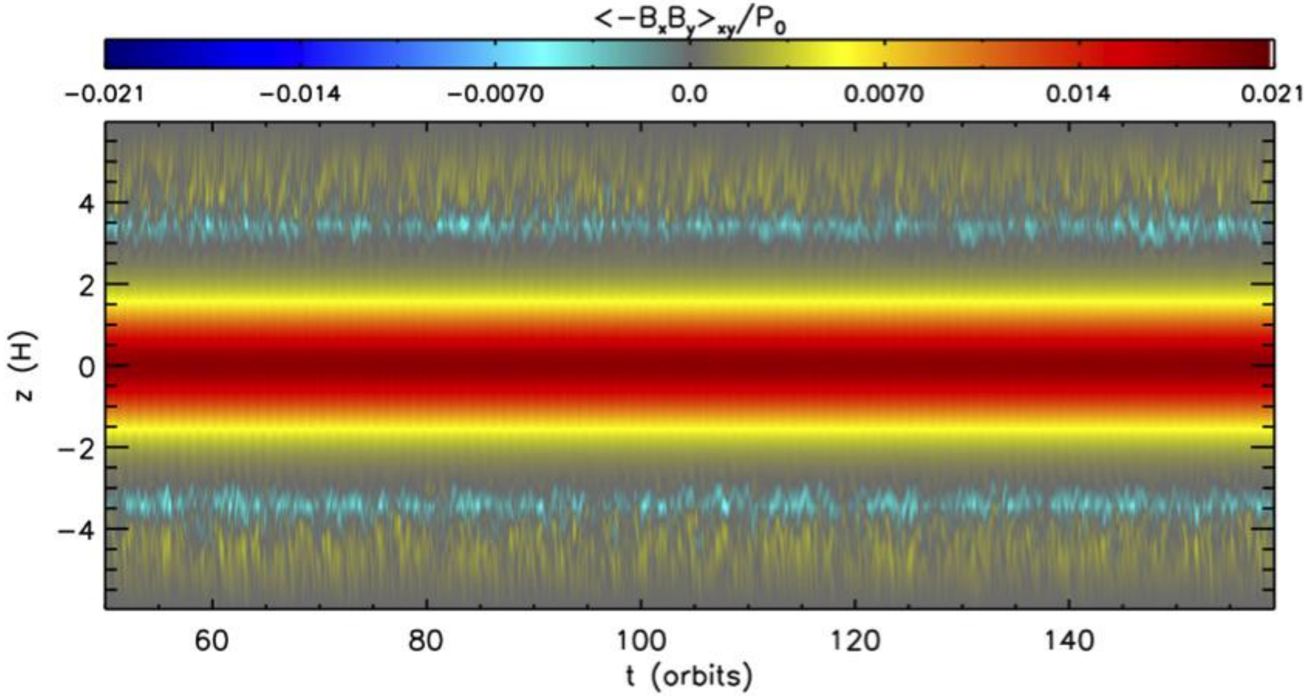
magnetic *disk wind* drives transport with ambipolar diffusion…

Bai, Stone, Gressel, Turner

Hall effect

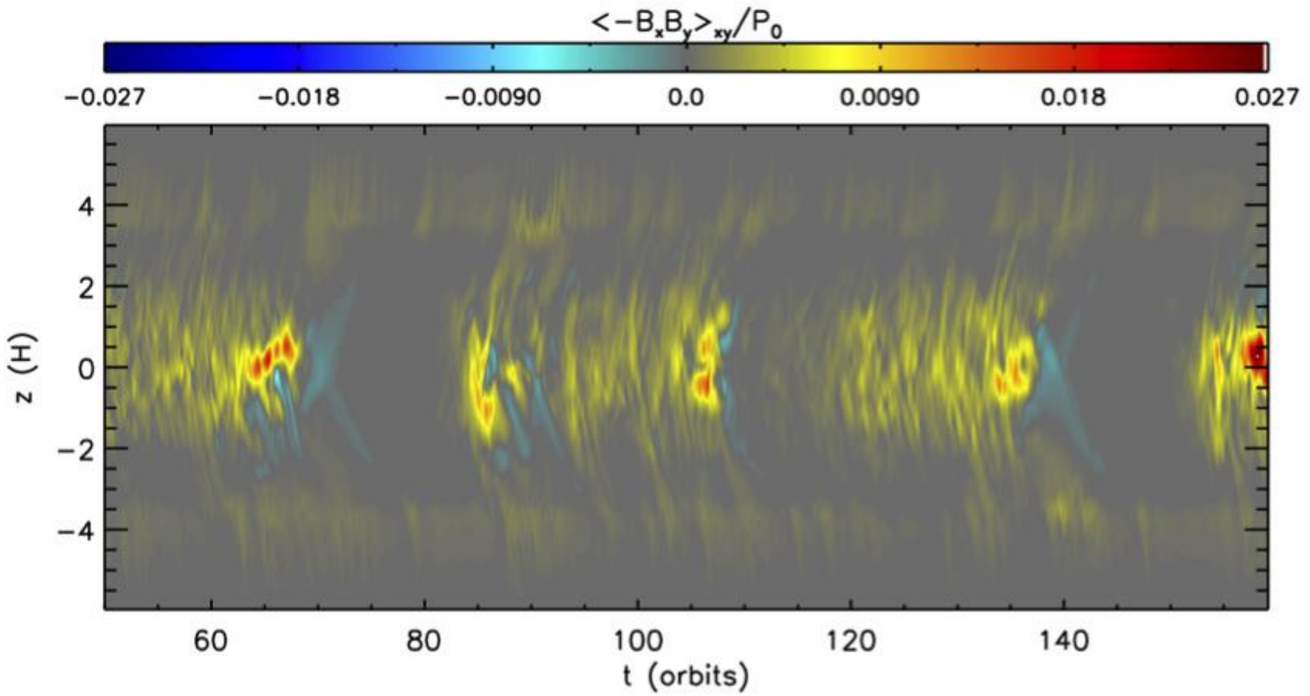
$B \cdot \Omega > 0$;

laminar stress, no turbulence



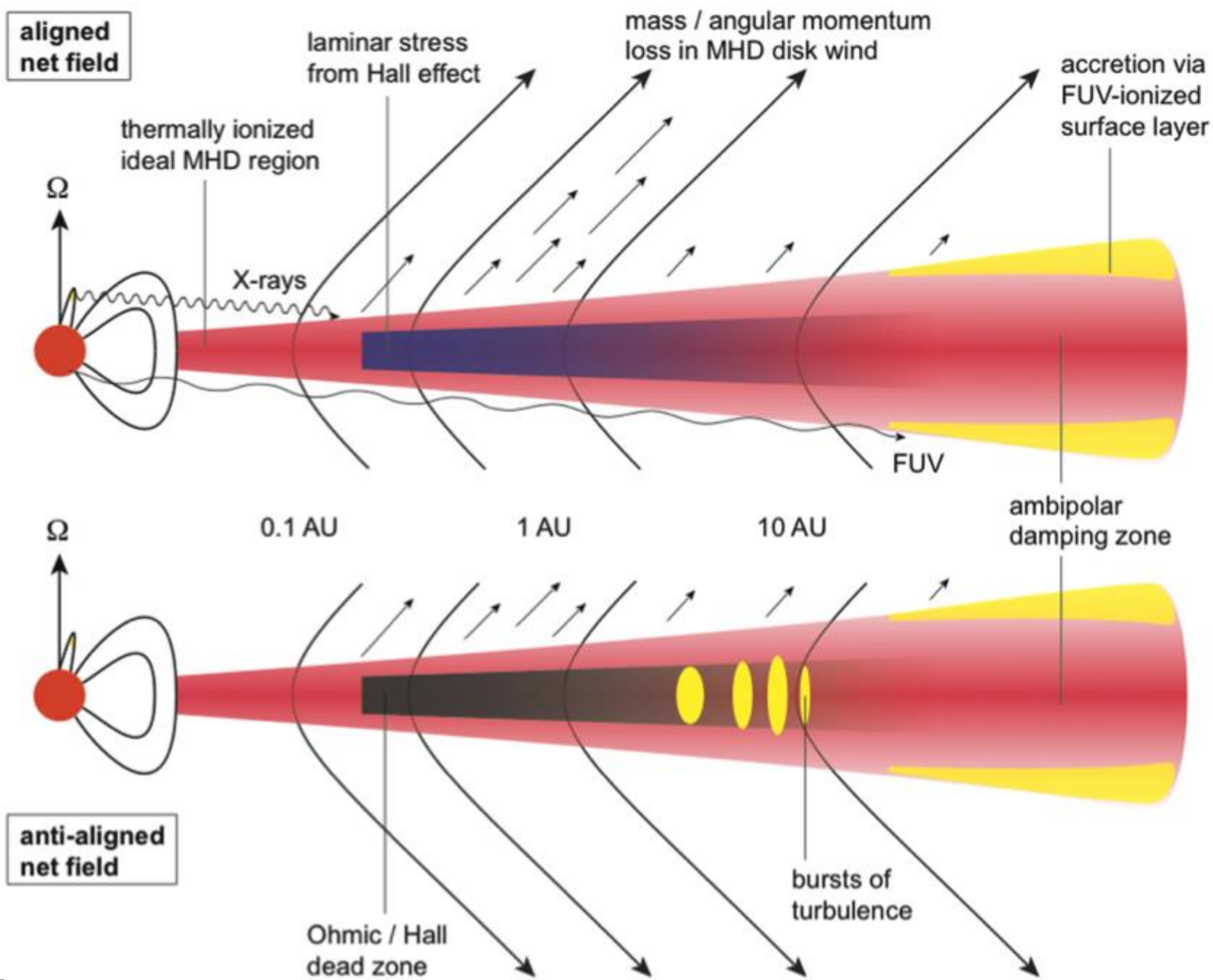
$B \cdot \Omega < 0$;

bursts of turbulence

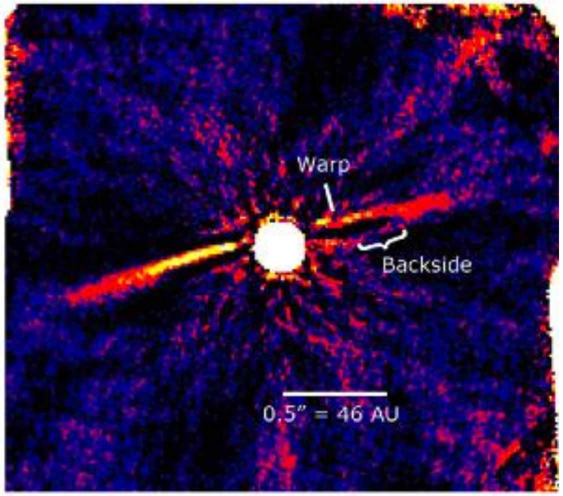


Simon+ 15

Prediction: need more theory + observational tests

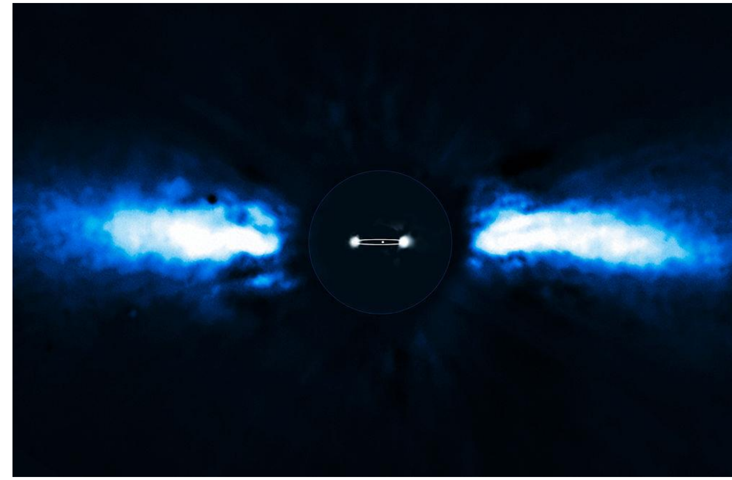


Simon+ 15



Kalas+15

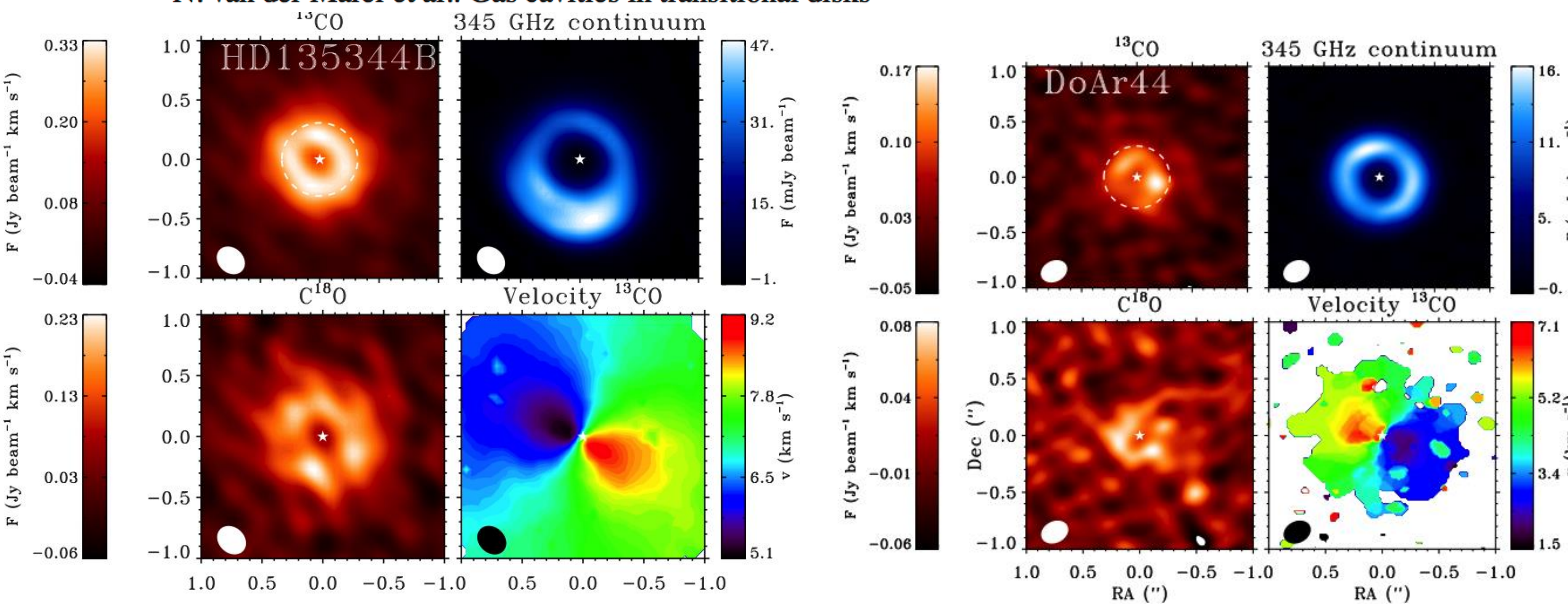
Debris disks and planets…



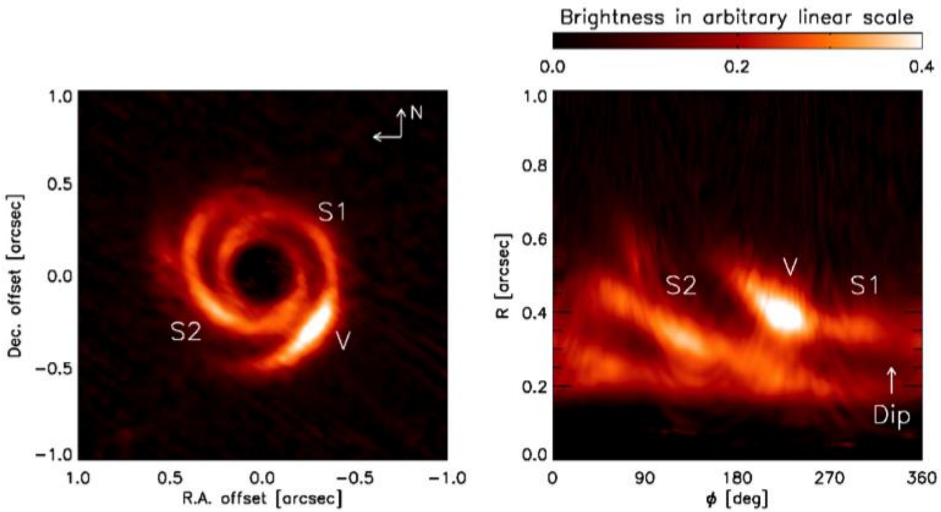
ESO/AM Lagrange

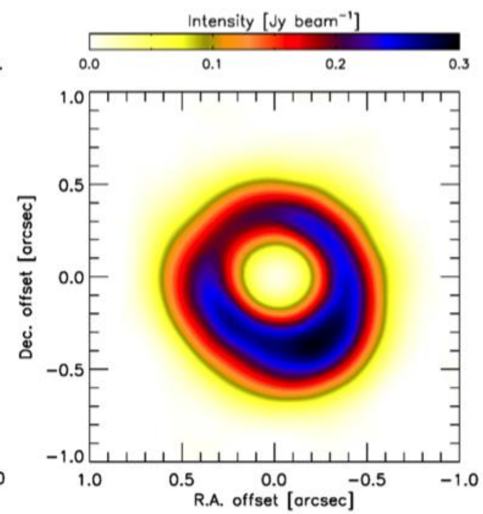
“proto”planetary disks

N. van der Marel et al.: Gas cavities in transitional disks



Concentration of solids in “proto”planetary disks

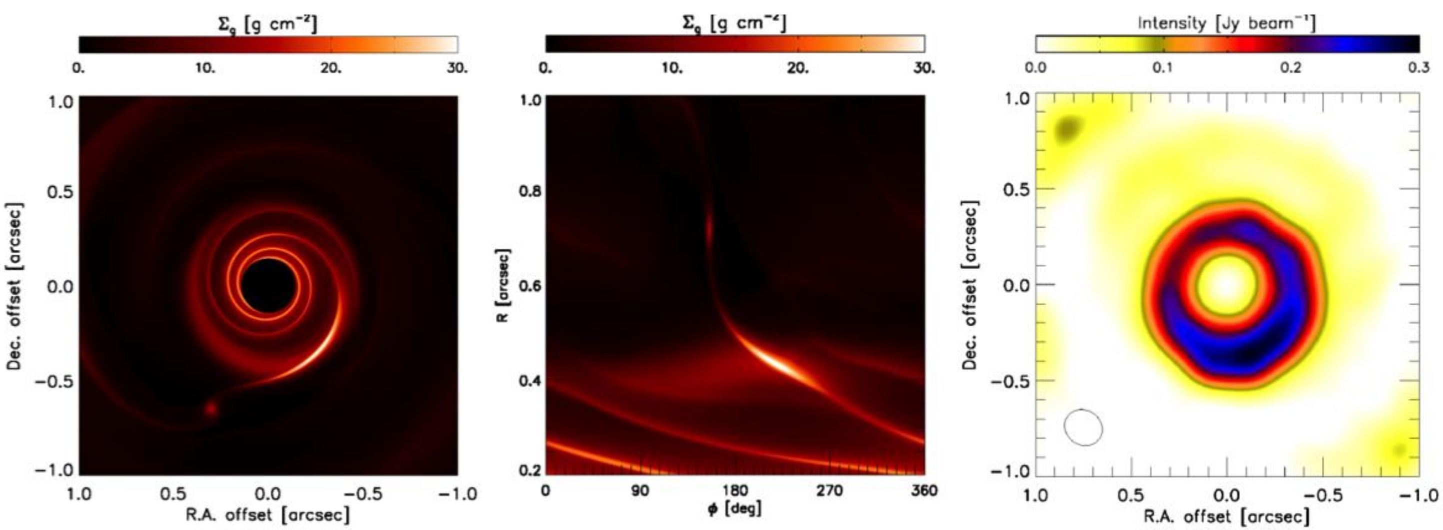




observations

Garufi+13; K_s VLT/NACO

Perez+ 14; ALMA 0.43mm dust



model with dust drift + *vortex*

Bae, Zhu, LH submitted

Sallum + 15; NRM at LBT *and* Hα AO at Magellan of LkCa 15

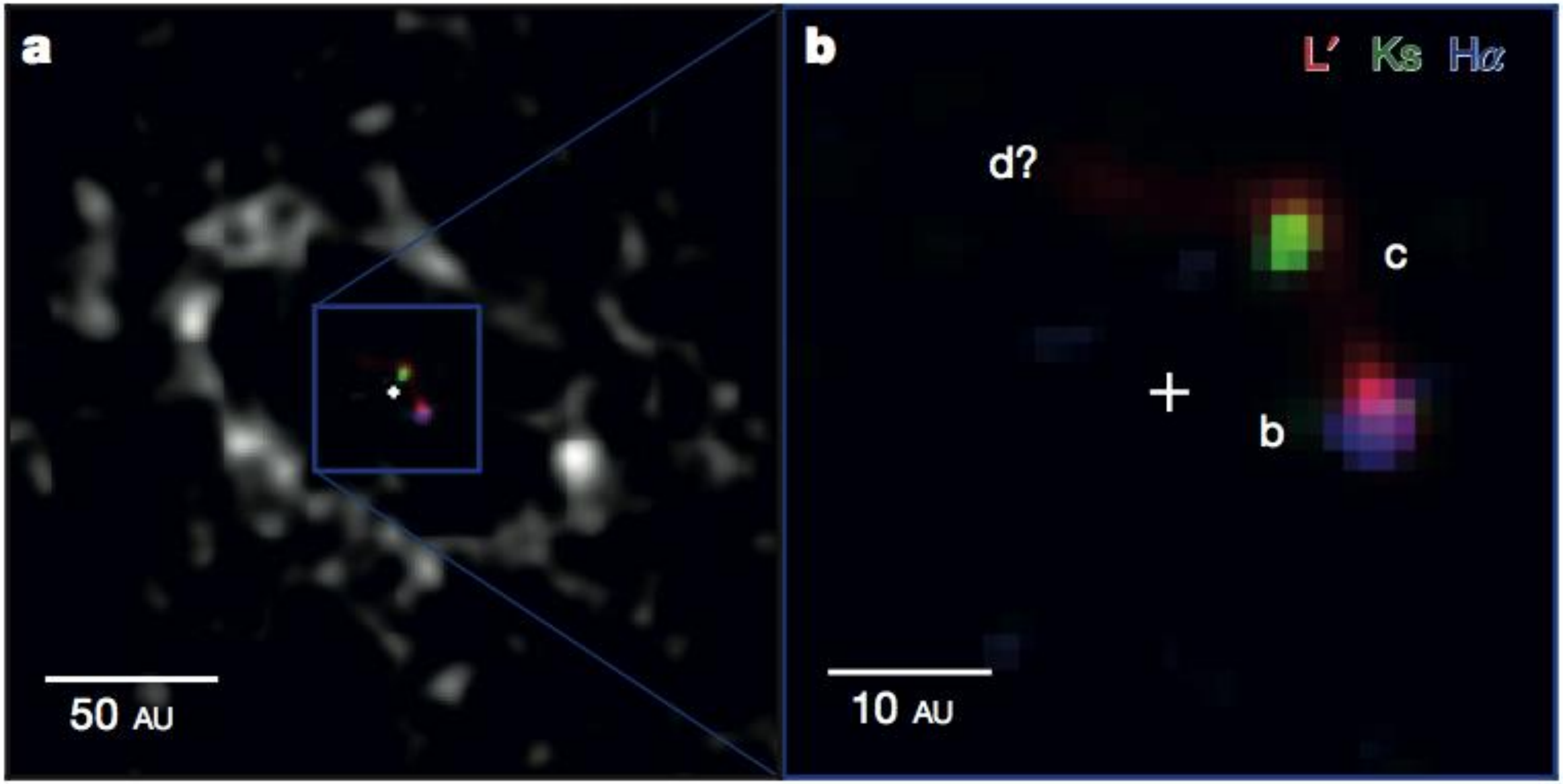


Figure 1 | Composite Hα, Ks, and L′ image. a, The coloured image shows Hα (blue), Ks (green), and L′ (red) detections at the same scale as VLA millimetre observations[29] (greyscale). **b**, Zoomed in composite image of LBT and Magellan observations, with b, c, and d marked.

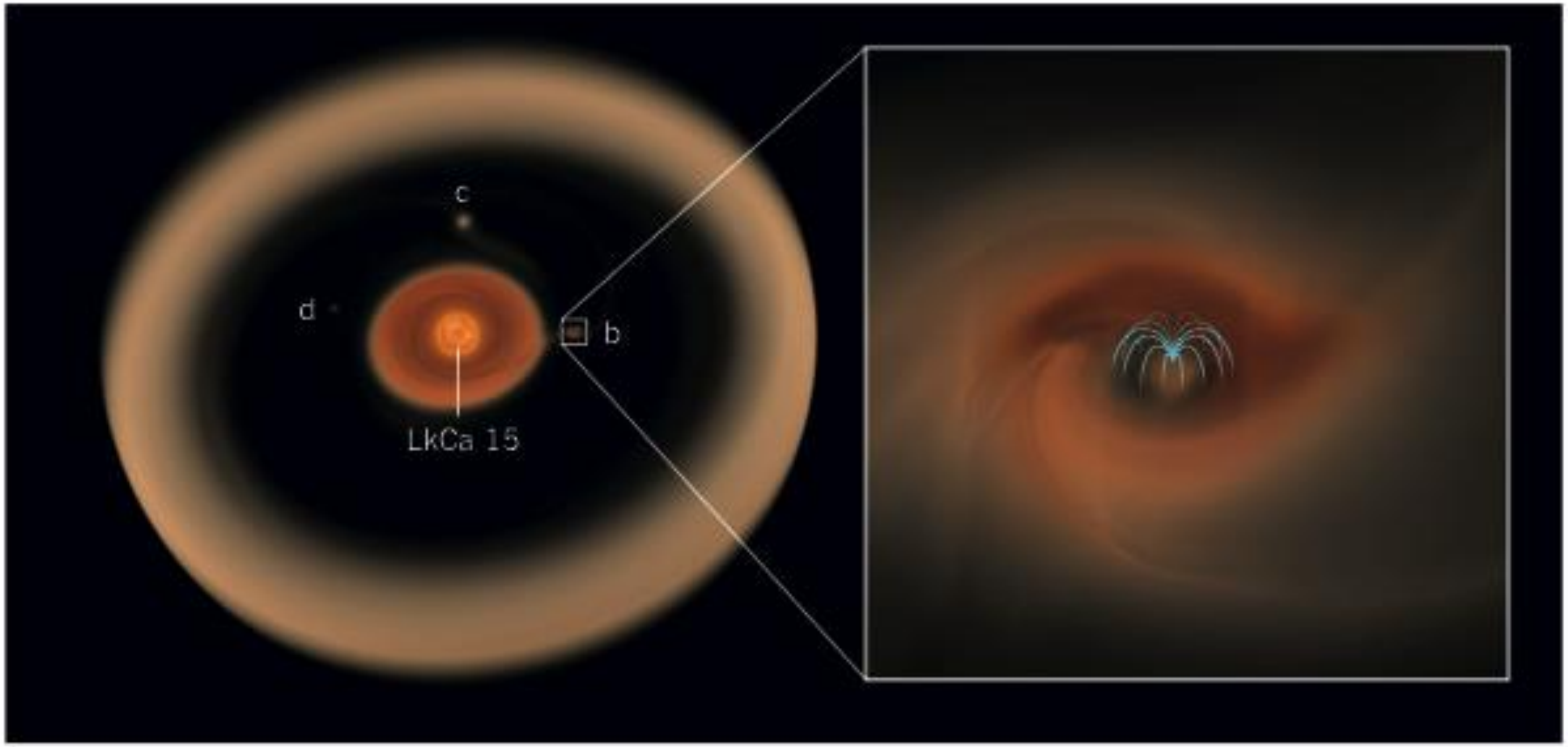


Figure 1 | Circumplanetary-disk discovery. The young star LkCa 15 is surrounded by a disk of dust and gas. Sallum *et al.*[1] report that a young planet (LkCa 15 b) is growing in a gap in that circumstellar disk, and that two other potential young planets (LkCa 15 c and d) also reside within the gap. Disks of dust and gas also form around young planets (inset), providing material for them to grow continuously. When material from a circumplanetary disk follows the magnetic fields of young planets (blue curves) to be accreted onto those planets, it produces light known as Hα photons. The authors report that LkCa 15 b is an Hα emitter. This graphic is based on supercomputer simulations of the gas distribution in the LkCa 15 system; the central star and planets are not shown to scale. (Graphic modified from images provided by Z. Zhu.)

- How do stars/disks form?
- How do disks evolve and form planets?

Progress:

- 8m coronography/scattered light of disks (and planets)
- ALMA (some JVLA, NOEMA coming)
- Numerical simulations with non-ideal MHD

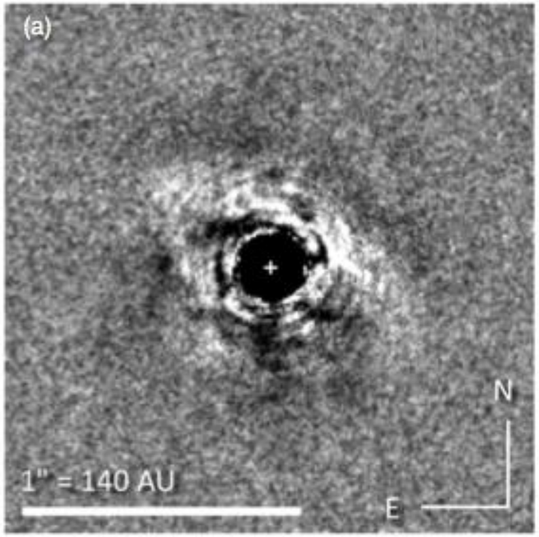
Needed:

- GSMT (stellar IMF; disk structure/followup ALMA results on planet formation)
- Support for computing power to interpret ALMA/8m results

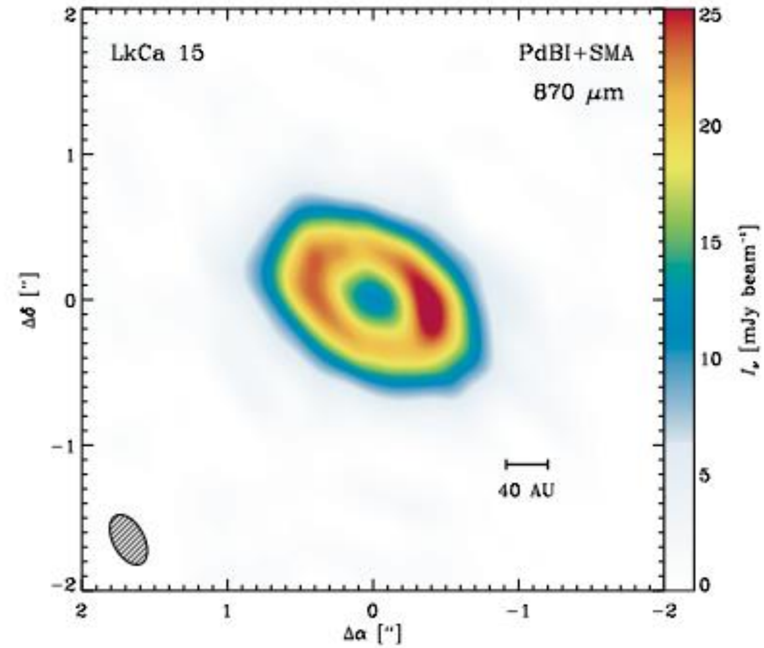
TABLE 4.1 Summary of Conclusions of the Panel on Planetary Systems and Star Formation

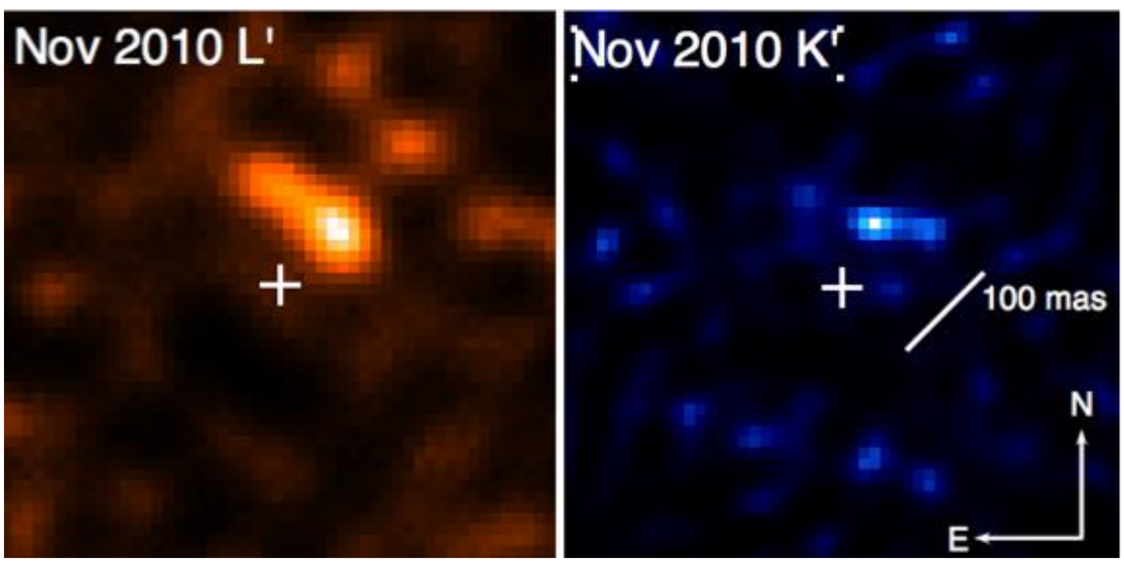
	Question 1: How Do Stars Form?	Question 2: How Do Disks Evolve and Form Planetary Systems?	Question 3: How Diverse Are Planetary Systems?	Question 4: Can We Identify the Telltale Signs of Life on an Exoplanet?	Discovery Area: Identification and Characterization of Nearby Habitable Exoplanets
Facilities expected	EVLA, ALMA, Herschel, SOFIA, JWST, 8- to 10-m telescope with AO	EVLA, ALMA, Herschel, JWST, 8- to 10-m telescope with AO, UV/visible synoptic surveys	1 m sec^{-1} RV surveys and transit follow-up; Kepler, JWST, Spitzer transits; Gaia astrometry	1 m sec^{-1} RV surveys and transit follow-up; Kepler, JWST, Spitzer transits	JWST transiting-exoplanet spectroscopy
New facilities needed	30-m submillimeter telescope; 8- to 10-m telescope with MCAO; GSMT with extreme AO; deep centimeter-wave interferometry on very long baselines	GSMT with extreme AO; near-IR synoptic surveys	0.2 m sec^{-1} RV; microlensing surveys; GSMT with extreme AO	Earth-like planet frequency ($\eta_{\oplus}$); 10-zody limits on exozodies; 0.1-μas astrometry	Census and transit survey, 10^4 nearest M-dwarfs; visible/near-IR RV follow-up
Always needed	Support for theoretical efforts, including high-performance computational resources, and laboratory-molecular astrophysics with an emphasis on far-infrared, submillimeter, and millimeter line identifications, along with chemical studies ranging from surface reactions relevant to cold clouds to processes in planetary atmospheres.				

Thalmann et al. 2010, Subaru coronagraphic H band



Andrews et al. 2011 SMA





Kraus & Ireland 2011 non-redundant aperture masking, NIRC AO on Keck II

Sallum + 15; NRM at LBT + Magellan AO Hα

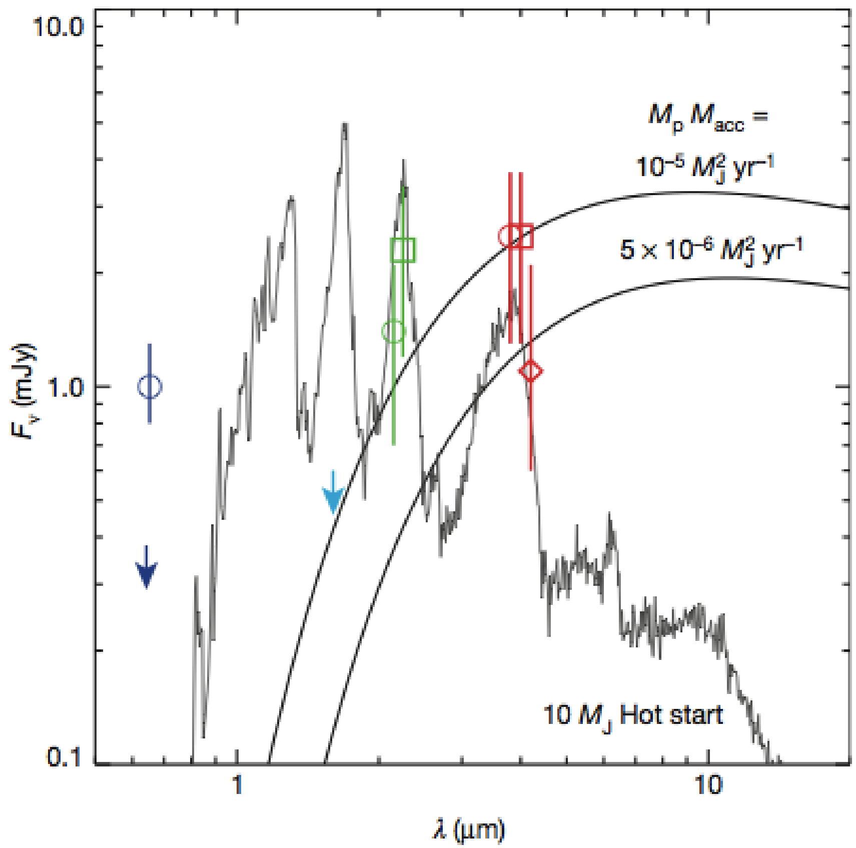


Figure 3 | Spectral energy distributions. Symbols indicate fluxes for LkCa 15 b (circles), c (squares), and d (diamonds), showing Hα (dark blue), Ks (green), and L′ (red). The light and dark blue arrows mark previously-published H-band[9] and 3σ 642 nm upper limits for LkCa 15 b, respectively. The lines show accretion disk and hot-start models. The disk models are simple combinations of blackbody spectra[17], a suitable approximation for the case of a cool ($T < 1{,}500$ K) stellar atmosphere where dust opacity dominates. The $M_p\dot{M}$ calculated from the Hα flux agrees with that inferred from the infrared measurements (see text).