Circumstellar Disks and LBTI+ALES

Eckhart Spalding

Water plays a central role in the planet formation process due to its abundance and its ability to change easily between gas and solid phases in **protoplanetary disks** (~few Myr old). However, the transport of volatiles is observationally very poorly constrained due to the demanding sensitivity and tiny angular sizes involved.

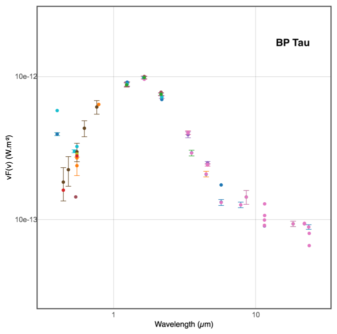

Fig. 1: Example SED of the protoplanetary disk BP Tau. Despite the dense photometric sampling, the SED alone leaves model degeneracies that must be overcome with high-contrast imaging. (VizieR Photometry Viewer)

Debris disks are old (~tens Myr to ~Gyr old), gas-poor late-stage counterparts to protoplanetary disks. They are thought to persist on ~Gyr timescales via collision cascades, but have poorly-constrained grain compositions.

LBT/LBTI is one of the most sensitive platforms in the northern hemisphere for thermal infrared measurements, and its LMIRCam (1.5-5 µm) channel contains a newly-commissioned IFS called ALES, sensitive to 2.8- 4.2 µm at R~15–20 (Skemer et al. 2015). ALES has 50×50 spectrum-generating 'spaxels' across a 1.2″×1.2″ field of view, which is slated to be upgraded to R~40 and 1.8″×1.8″ in summer 2017.

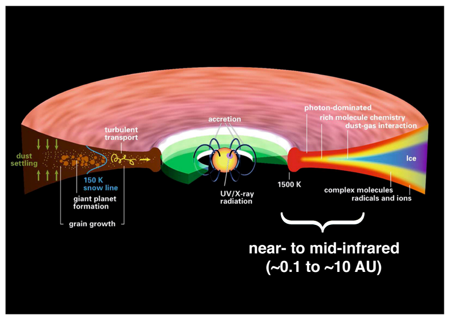

Fig. 2: An illustration of a protoplanetary disk (not to scale) showing the radial dependence of dominant physical processes and the region most relevant to infrared observations. (Adapted from Fig. 2 in Henning et al. 2013.)

ALES is currently the only existing IFS sensitive to the thermal infrared, making it a unique tool for studying circumstellar disks

Within protoplanetary disks, water ice can provide "sticky" ice surfaces which can allow µm- and mm-sized dust to agglomerate (Ros et al. 2013, Gundlach et al. 2014). This helps fill in a gap in size scales in the buildup of planetesimals, where dust grains with sizes on the order of millimeters are too large to combine electrostatically, but too small to combine gravitationally. Time-dependent transport (associated with angular momentum transfer) and the location of the water "ice line" will heavily influence the chemical compositions of forming planetesimals (Marboeuf et al. 2014). The ice line represents a dividing line between orbital radii where gas giants can and cannot form in situ. Due to the build-up of icy material near the ice line, it is also expected to be the preferred orbital radius of gas giant accretion. The ice line's localization will therefore constrain planetary accretion orbits and migration timescales.

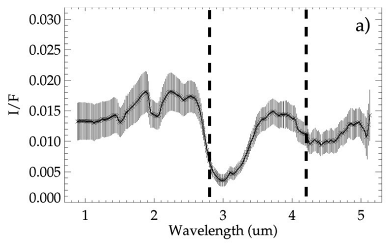

Fig. 3: The reflected over the incident solar intensity on the surface of the Saturnian moon Phoebe, showing the width of the water ice absorption feature centered at ~3 µm. Dashed lines show the sensitivity range of ALES. (Adapted from Fig. 3a of Cassini flyby data in Coradini et al. 2008.)

We have submitted a proposal to put models to the test by using a ro-vibrational transition band from water ice which produces a ~1 µm-wide feature at ~3 µm. With ALES, we hope to resolve the spatial extent of water ice.

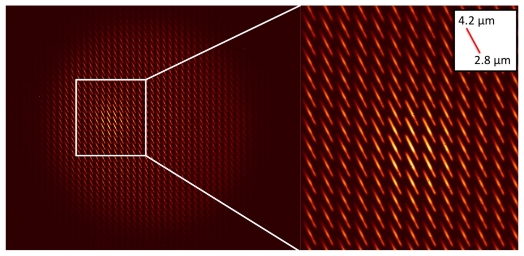

Fig. 4: A raw ALES image and detail of the Loki Patera region of the Jovian moon Io. This illustrates the amount of spectral sampling possible in the current ALES configuration of a ~1″ wide object. (Fig. 7 in Skemer et al. 2015.)

Similarly, water ice would be critical for planet formation in a debris disk, and its detection (or lack thereof) would provide important constraints on debris disk processes. For example, water ice mantles on grains with sizes on the order of microns will be photoevaporated on a timescale of hundreds or thousands of years, meaning that a detection of ice in a debris disk would imply replenishment from ice-carrying planetesimals (Lebreton, 2012). This will have implications for collision rates.

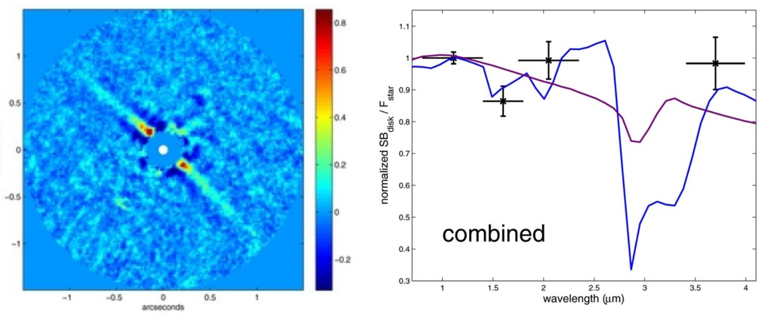

Fig. 5: Left: A reduced L′-band image of HD 32297, in normalized units of detector counts and with the host star masked. (Fig. 1a in Rodigas et al. 2014.) Right: A reflection spectrum of HD 32297, in units of surface brightness relative to the host star. The black data points represent combined values found by taking medians across different orbital distances. Horizontal bars indicate filter widths (not error in x). The blue curve is a pure water ice model, and the purple is a cometary grains model. The pure ice model is a better fit to the data, but the glaring absence of data in the water absorption feature between ~2.5 and 3.5 µm means that variations of models cannot be tested with confidence. (Fig. 8 in Rodigas et al. 2014.)

In addition, mixing ratios of different components of the disk can be constrained with water ice detection. Donaldson et al. 2013 modeled the >25 µm SED of HD 32297 and found that the disk was consistent with a 1:2:3 mixing ratio of silicate, carbon, and water ice grains ranging from single µm to mm. This would suggest grain replenishment by comets. However, closer to the star the original Donaldson model fails badly, and the data is much better fit with a pure water ice grain model.

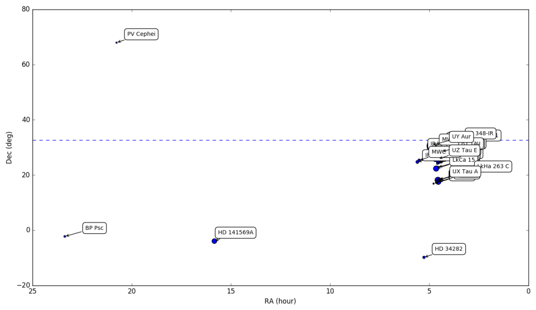

Fig. 5: LBT-accessible protoplanetary disks, with marker size relative to angular size. (The major axis of LkCa 15 is ~9″.) Note the 'Taurus pileup' at RA 4 to 5. (Data from *circumstellardisks.org*, maintained by K. Stapelfeld.)

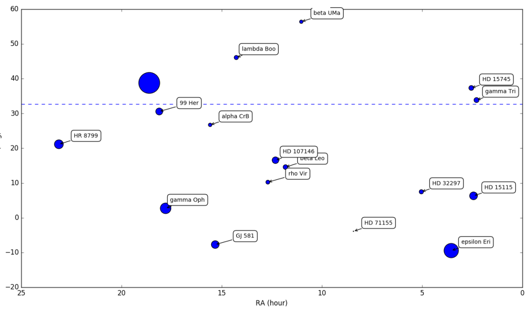

Fig. 6: Same as Fig. 5, for debris disks. (The major axis of eps Eri is ~66″.)

LBTI has submitted a proposal to examine this disk with ALES to resolve a number of questions: Are the grains in HD 32297 truly cometary, but with different mixing ratios? Or does the water ice ratio vary with distance from the star? Or are other parameters like the radial density distribution wrong? Stay tuned!

References:
Coradini et al. 2008. Identification of spectral units on phoebe. *Icarus* 193:233; **Donaldson et al. 2013**. Modeling the HD 32297 debris disk with far-infrared herschel data. *ApJ*, 772:17. **Gundlach et al. 2014**. The stickiness of micrometer-sized water-ice particles. *ApJ* 798:34, 2014; **Henning et al. 2013**. Chemistry in protoplanetary disks. *Chem Rev* 113:9016; **Marboeuf et al. 2014**. From planetesimals to planets: volatile molecules. *A&A*, 570:A36; **Rodigas et al. 2014**. Does the debris disk around HD 32297 contain cometary grains? *ApJ* 783:21; **Ros et al. 2013**. Ice condensation as a planet formation mechanism. *A&A*, 552:A137; **Skemer et al. 2015**. First light with ALES: A 2-5 micron adaptive optics integral field spectrograph for the LBT. *SPIE Optical Engineering+ Applications* 96051D.