Panchromatic analysis of a circumstellar disk: the HV Tau C edge-on disk

Gaspard Duchêne (UC Berkeley, gduchene@astro.berkeley.edu)

C. Pinte (Exeter), C. McCabe (IPAC), K. Stapelfeldt (JPL), F. Ménard (LAOG), G. Duvert (LAOG), H. Bouy (IAC), D. Barrado y Navascues (LAEFF), H. Manness (UC Berkeley) , D. Padgett (SSC)

Motivation

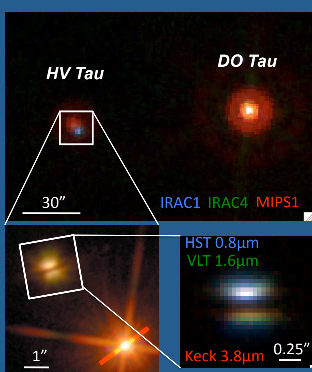
Inferring the physical properties of circumstellar disks (total mass, dust content, …) is generally done by comparing observations and predictions of radiative transfer models. However, single-technique and/or single-wavelength datasets provide only a limited view of a given disk:

- SEDs filters out any spatial information, resulting in large ambiguities;
- Scattered light images only probe the outer surface of the disk;
- Millimeter mapping with interferometers is only sensitive to dust in the disk midplane.

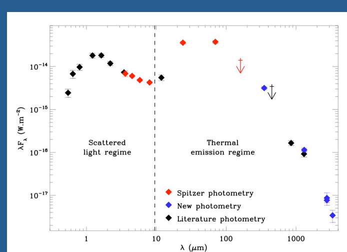
While each of these (and other) observations can provide key information regarding a disk structure and evolutionary status, it is critical to gather and analyze as broad and multi-wavelength a dataset as possible, and to try and reproduce in the context of a single, self-consistent model.

Here, we apply this approach to a well-known circumstellar disk, the edge-on disk surrounding the young T Tauri star HV Tau C, for which we present a slew of new observations.

New observations of HV Tau C



Scattered light images



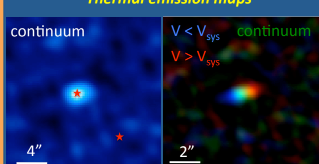
New datasets acquired for this project:

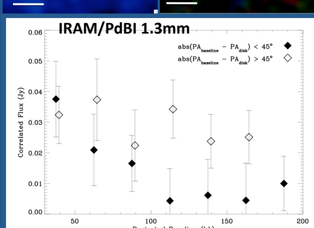
- Adaptive optics imaging from 1 to 5 µm (VLT, Keck)
- 1.3mm mapping at 1" resolution in the continuum and ^{12}CO 2-1 line (IRAM/PdBI)
- Unresolved flux measurements at 350, 1300, 2700 and 3300 µm (CSO, IRAM/PdBI, CARMA)

Empirical results:

- HV Tau AB has negligible emission longwards of 20µm;
- HV Tau C is resolved along its major axis at 1.3mm, with a velocity pattern consistent with Keplerian rotation;
- In the scattered light images, the dark lane shrinks from 0.32" to 0.23" and the flux ratio between nebula drops from ≈4 to ≈2 between 0.8 to 5 µm;
- The slope of the SED in the 2-10µm range is shallow (K-[3.6]=0.8 and K-[8]=2.7), whereas the mid-IR colors are extremely red (e.g., [3.6]-[24]=7.8 and [3.6]-[70]=11.4);
- The slope of the SED in the millimeter regime is shallow (α=3.5±0.3, where $\nu F_\nu \approx \nu^\alpha$).

Thermal emission maps





New flux measurements:

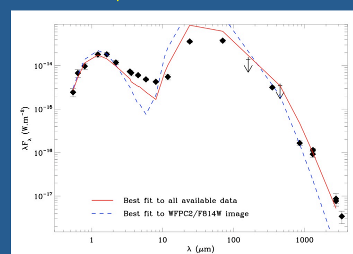
λ (µm)	F_ν (mJy)	Instrument
350	370 ± 30	CSO/SHARC
1300	50 ± 5	IRAM/PdBI
2700	7.1 ± 0.9	IRAM/PdBI
2700	8.0 ± 2.6	CARMA
3300	3.8 ± 1.2	CARMA

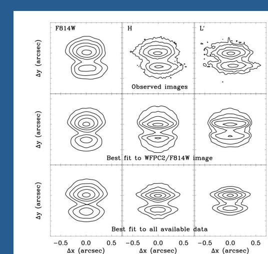
Preliminary results and discussion

The visible wavelength scattered light is best fit with ISM-like dust (a_{max} = 1µm), such a model fails to reproduce the 3.8m image, the near- to mid-IR slope in the SED and the millimeter spectral index. Large grains (a_{max} > 1mm) must be present in HV Tau C, though not at the surface. This may imply the presence of settling/stratification in the disk.

The disk outer radius is likely to be at least R_{out} = 75AU to account for the spatially resolved 1.3mm map. The presence of a time- and wavelength-independent shear-like asymmetry prevents us from obtaining a more precise estimate of the disk outer radius.

There is a best fit for each observation, with major contradictions between them. Inferring global disk properties based on a limited subset of observations yields bias-limited results that are hard to interpret in terms of disk evolution trends.





Radiative transfer modeling

Goals and methods:

We aim at simultaneously reproducing the SED, the 0.8, 1.6 and 3.8 µm scattered light images and the 1.3mm thermal emission map. Each of these observations is sensitive to a distinct dust population and disk region, so this should provide a global picture of the HV Tau C disk.

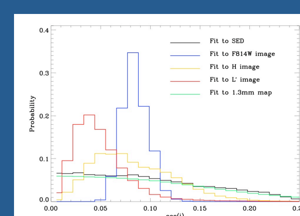
We use the MCFOST (Pinte et al. 2006, A&A, 459, 797) radiative transfer code to produce synthetic "observations" of HV Tau C, which we then compare to observations through χ^2 computation. The physical properties of the disk are determined via a Bayesian inference method, using uniform priors over the entire parameter space.

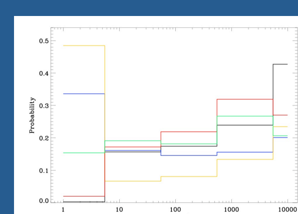
Fixed parameters throughout the analysis:

- D = 140pc
- T_{eff} = 3800 K
- a_{min} = 0.03 µm, p=-3.7 where $N(a) \approx a^p$
- R_{in} = 0.15 AU (T_{max} = 1200-1400K)
- Spherical envelope: $\rho(r) \approx r^{-0.5}$ profile, ISM-like dust and M_{env} =2 10^{-8} $M_\odot$ ($\tau_{0.5\mu m} \approx 1$)

Parameter space explored:

Parameter	Range	Best fit
M_{dust} ($M_\odot$)	10^{-5} .. 10^{-3}	10^{-4}
R_{out} (AU)	50 .. 75	75
H_0 @ 50AU (AU)	4 .. 8	4
β (flaring)	1.05 .. 1.25	1.05
α (surf. dens.)	-1.0 .. 0.5	0.5
a_{max} (µm)	1 .. 10^4	10^4
$R_\star$ ($R_\odot$)	2 .. 3.5	3.
i (°)	0 .. 90	85.3
A_v (mag)	0 .. 5	2.25





1 million models, 50,000 h CPU