UV and Optical Variability of the Young Star T Cha Produced by Inner Disk Obscuration

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Overview: Measuring the inner disk properties of young stars is not easy but inner disk physics and chemistry is important for understanding terrestrial planet formation. One way to isolate the conditions in the innermost disk is by studying systems with inclinations that result in the photosphere being obscured by the inner edge of the disk. We have conducted an extensive multi-spectral-region observing campaign of the young star T Cha to study the gas and dust structure in the terrestrial planet formation zone during the important rapid phase of protoplanetary disk evolution as T Tauri star disks clear and dissipate. To properly sample the changing gas and dust properties requires observations spanning the FUV, NUV, optical, near-IR, and X-ray spectral regions. In this poster we present first results from such an observing campaign and emphasize particularly the optical/NUV variability.

T Cha and its Transitional Disk: The young (7 Myr) 1.5 solar mass T Tauri star T Cha shows dramatic variability. The optical extinction varies by at least 3 magnitudes on few hour time-scales with no obvious periodicity. The obscuration is produced by material at the inner edge of the circumstellar disk and therefore characterizing the absorbing material can reveal important clues regarding the transport of gas and dust within such disks. The inner disk of T Cha is particularly interesting, because T Cha has a transitional disk with a large gap at 0.2-15 AU in the dust disk, based on the mid-IR SED (J. Brown et al., 2007). Near-IR interferometry shows only a narrow ring (0.07-0.11 AU) of warm material close to the star with a large scale height of H/R=0.2 and a much larger gap beyond (Olofsson et al. 2011 and 2013). Both the large-scale gas and dust disks are highly inclined (~67 deg.). Accretion onto the star from the inner disk is on-going. How material moves through the gaps in transitional disks is the subject of great debate and our study should provide important observational input to this topic.

Observations: We have conducted a major multi-spectral-region observing campaign to study the UV/X-ray/optical variability of T Cha.

During 2018 February/March we monitored the optical photometric and spectral variability of T Cha using the LCOGT telescope network (Chile/South Africa/Australia) and the SMARTS telescopes in Chile. SMARTS was used to obtain medium resolution H Balmer alpha spectra and near-IR photometry. These optical data provide a broad context (see Fig. 1) within which to interpret our shorter UV and X-ray observations.

We observed T Cha during 3 coordinated observations (each 5 HST orbits + 25 ksec XMM; on 2018 Feb 22, Feb 26, Mar 2) using the HST COS spectrograph (G160M/G130M/G140L) to measure the FUV (1170–1700 Å) spectrum and STIS G230L/G430L/G750L gratings to record the NUV/optical spectrum.

XMM-Newton was used to measure the corresponding soft X-ray spectra and variability. The soft X-ray emitting regions appear to suffer little disk obscuration. In fact the first visit (faintest in optical) showed the largest X-ray flux due to a factor of 2.5 flare increase during the second half of the observation.

***STATUS – On-going Analysis*:** Our analysis of these data is on-going. We have done initial examinations of all the data but more detailed analysis is definitely required.

a) A comprehensive reduction of the LCOGT data will conducted using standard star field observations that we obtained as part of our campaign – this should provide a larger improved set of comparison stars and allow calibration of the Sloan u filter data. This would then provide 3 colors for grain modeling.
b) Improved binning and treatment of spectral overlap will enable better NUV/optical SED fitting from the STIS and COS spectra. This fitting will include the photometric color-magnitude behavior as a constraint.
c) The COS FUV spectra show both emission features that are mildly variable and others (particularly molecular features) that are constant. By studying which emission vary and which do not, we shall localize the emissions from the stellar surface and those from the extensive unobscured inner disk.
d) Changes in our extensive set of H alpha profiles will be correlated with the optical photometric variability (see Walter et al. poster)

Acknowledgments:

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1. T Cha shows extreme optical variability with frequent dips in brightness on rapid timescales

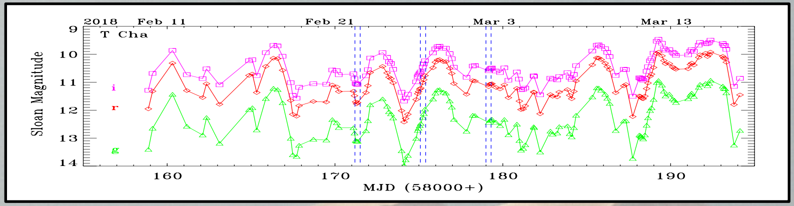
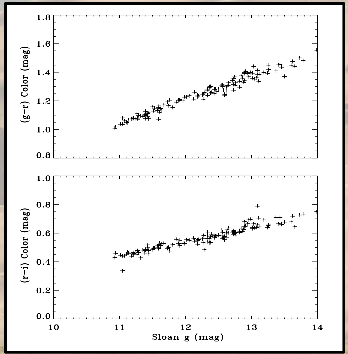


Fig 1 – 35 days of Sloan ugri photometry of T Cha obtained between 2018 Feb 9 and Mar 16 with a planned observing cadence of 1-3 hours. The gri photometry are shown here. Large, extremely rapid variations are seen in all the filters. Changes of 2-3 magnitudes can occur on 1-2 day timescales. The data were reduced by boot-strapping from existing gri photometry of 10 comparison stars in the field. The times when HST/XMM observations were made are indicated by blue dashed lines. The first (Feb 22) visit was during a dip and is the faintest condition observed. The second visit (Feb 26) sampled a rapid rise from a deep minimum and was the brightest observed.

2. The variability is caused by varying absorption of the stellar photosphere by clumps in the inner edge of the circumstellar disk



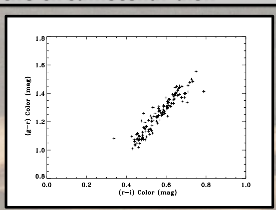


Fig 2 – Color-magnitude and color-color plots of the Sloan photometry for T Cha. While the variability is dramatic, the associated color variations are highly constrained indicating that the absorbers are similar. At the right, the color [(g-r), (r-i)] variations are highly correlated over the full magnitude range. Above, we show the corresponding color-color correlation. These tight correlations indicate that the variability is dominated by variable dust extinction obscuring the stellar photosphere.

3. HST STIS/COS spectra show the corresponding optical/NUV variability

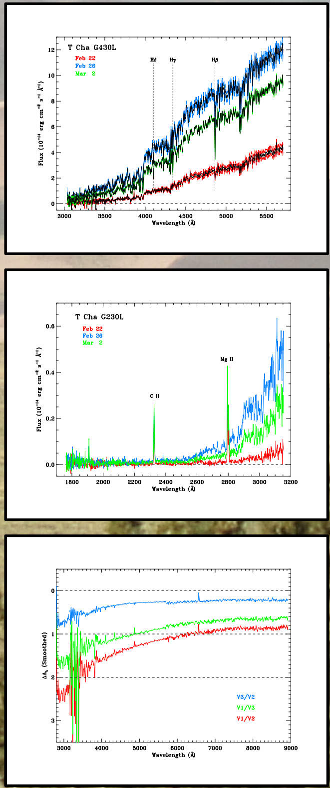


Fig 3 – During the final HST orbit of each visit STIS low-resolution spectra (G230L/G430L/G750L) were used to record the NUV/optical SED. Here we show the G230L[(middle panel] and G430L [upper panel] spectra. T Cha was faintest during the first visit (red curves) and brightest in the second (blue curves). The black curves show the summation of two G430L exposures. Unlike the strong photospheric changes, the Mg II resonance doublet (2800 Å) and C II intersystem multiplet (2325 Å) are essential constant over the three visits. This is also true for many fluorescent molecular hydrogen emission lines and CO bands (observed in the FUV with the COS G160M/G130M gratings) that are emitted from the inner disk itself rather than the stellar photosphere. The differential absorption (in magnitudes) as a function of wavelength is shown in the lower panel.

4. Fitting the HST/STIS SED shows that the inner edge of the disk contains small grains (R<3) that dominate the NUV absorption, while the optical is dominated by much larger (R~5) grains.

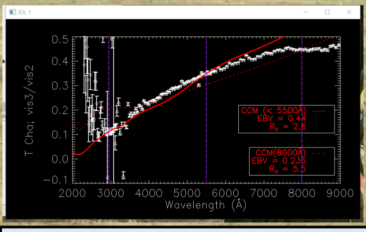


Fig 4 – Changes in the optical/NUV SED can be modeled by comparing the ratio of the Visit 1 spectrum to the bright Visit 2 spectrum and thereby isolating the effects of the additional absorbers. We have initially fitted the differential SED using Cardelli, Clayton, & Mathis (1989) extinction curves characterized by the parameter R_V (the ratio of total to selective extinction at V). No single value of R_V fits the SEDs particularly well, suggesting that a range of grain properties are present. However, the general SED shapes suggest that small grains (with $R_V < 3$ [solid red curves]) are the dominant absorbers in the NUV. Previously, Schisano et al. (2009) suggested $R_V \sim 5.5$, based on optical photometry, and this "large grain" value is clearly a less good fit [dashed red curves] to the SEDs in the NUV but seems to dominate in the optical.

5. COS FUV spectra show constant emission lines from the inner disk and variable hot, accretion-generated, emission lines from the stellar surface

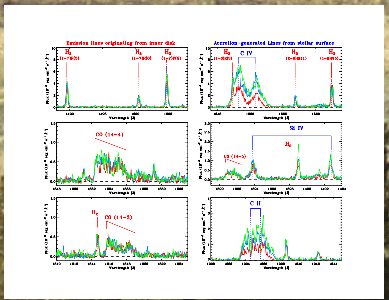


Fig 5 – COS G130M/G160M spectra of T Cha obtained from the three HST visits (color coding as in Fig. 3). Emission lines expected to originate from the warm inner disk edge, such as the H Lyman-alpha-fluoresced H_2 and CO molecular emission are basically constant over all three visits and unaffected by the changing optical absorption. In contrast, emission lines expected to be generated by accretion onto the stellar surface, such as C IV and Si IV, vary considerably with flux decreases of ~2/3 between Visit 2 and Visit 1. The observed changes cannot be simple increases in A_λ , but most likely represent a change in the area of the stellar surface being obscured.