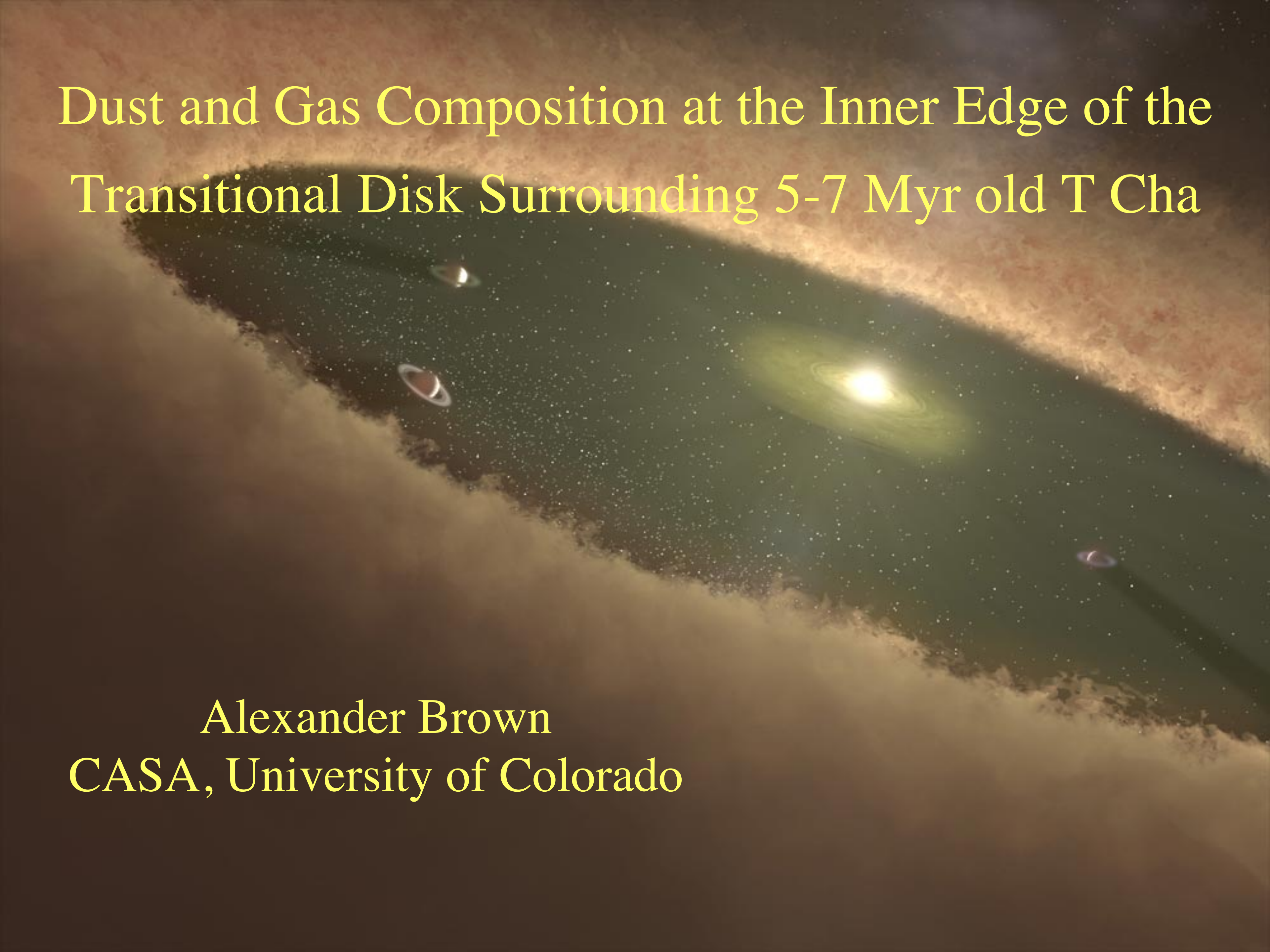
Dust and Gas Composition at the Inner Edge of the Transitional Disk Surrounding 5-7 Myr old T Cha



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Other Team Members:

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Acknowledgments:

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Star of the Show: T Cha

G8 Pre-Main-Sequence Star

Mass = 1.5 solar masses (ALMA outer disk Doppler motions)

Member of Epsilon Cha Association −-- distance = 110 pc [GAIA]

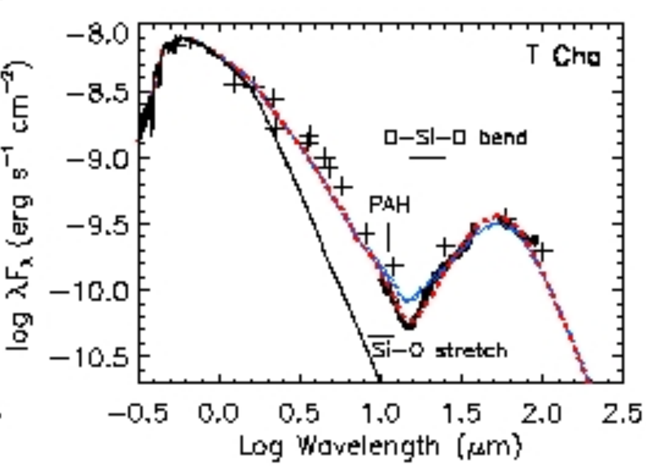
Age ~ 5-7 Myr (unlikely as young as 3 Myr or as old as 10 Myr)
[see Murphy, Lawson, & Bessell 2013, MNRAS, 435, 1325]

Accretion is still on-going − H Balmer alpha, hot FUV lines

Consistent, dramatic, optical variability seen over decades (see Schisano et al. 2009, A&A, 501, 1013) -- this makes proposing for coordinated observations much simpler.

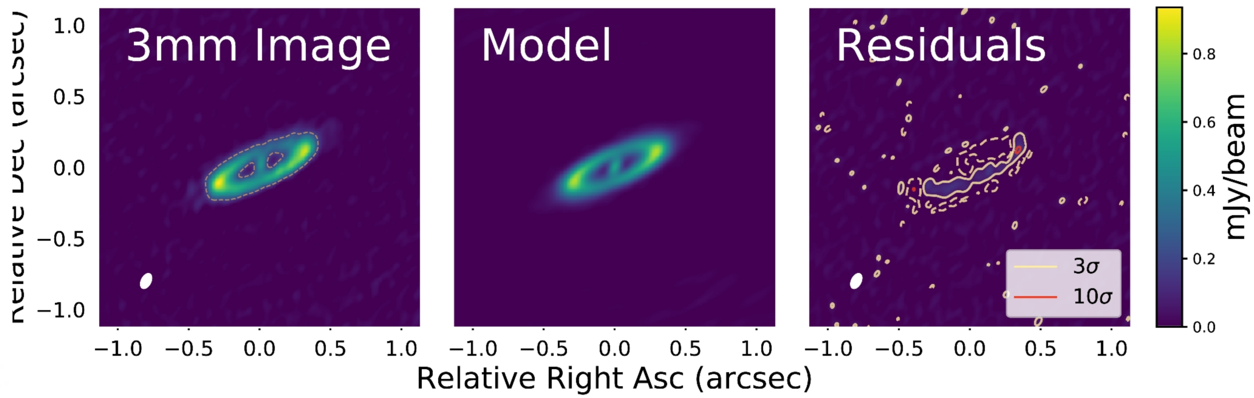
T Cha – Has a Transitional Disk

Spitzer



J. Brown et al. 2007, ApJ, 664, L107

ALMA



(a)

Hendler et al. 2017, MNRAS, 475, L62

Well-developed transitional disk based on both IR/sub-mm SED and ALMA line and continuum imaging. Small inner dust disk at ~0.1-0.2 AU; then a large dust-free gap out to at least 15 AU (or even 25 AU); then a cold, dusty, gas-rich outer disk. ALMA observations do not spatially resolve the inner disk.

Disk Inclination = 67-69° --- so disk periodically obscures the star every few days
The nearest, brightest example of such a dipping transitional disk.

2018 February-March Observing Campaign

With goal of sampling the composition at the inner edge of the inner disk

HST COS/STIS: Three 5 orbit visits (2018 Feb 22, Feb 26, Mar 2)

XMM Newton: Three 25 ksec observations (coordinated with HST)

LCOGT: 35 day monitoring (2018 Feb 10 − Mar 17) − Sloan ugri

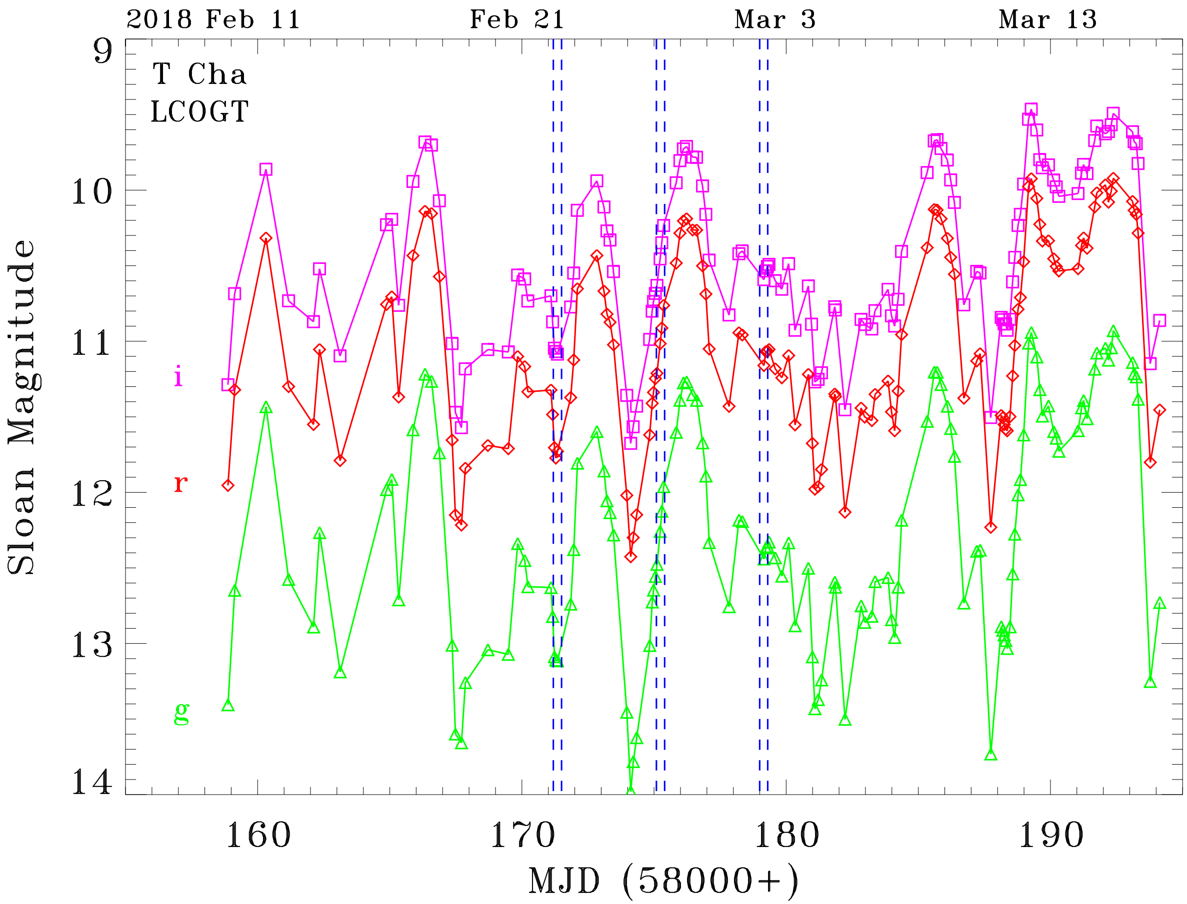
Chile (Cerro Tololo),South Africa (Sutherland), Australia (Siding Spring)

SMARTS: Andicam Photometry, 30 days Johnson BVRI; 20 days JHK

SMARTS: Chiron optical spectroscopy − including Balmer H alpha (R=28,000)

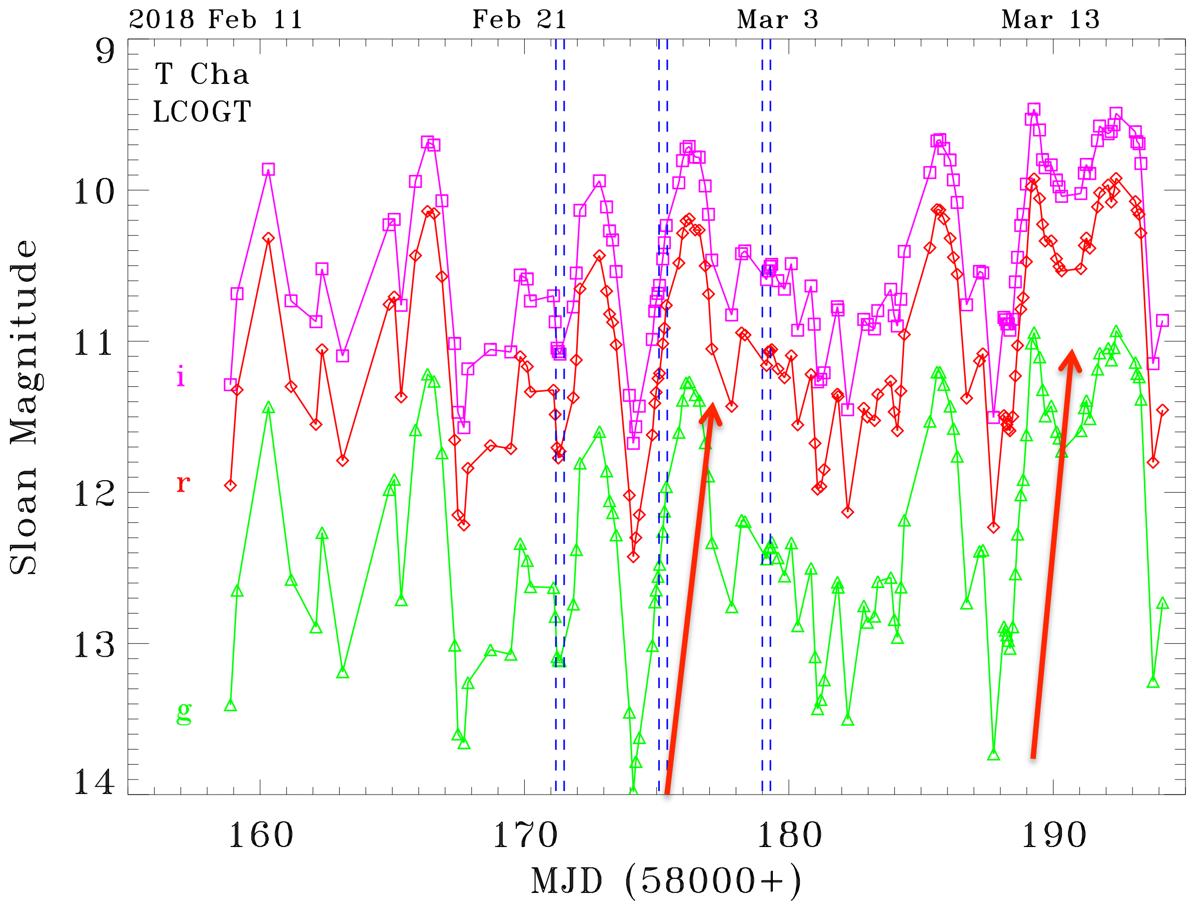
Analysis on-going − much more to do − this talk is a progress report.

LCOGT Light-Curve



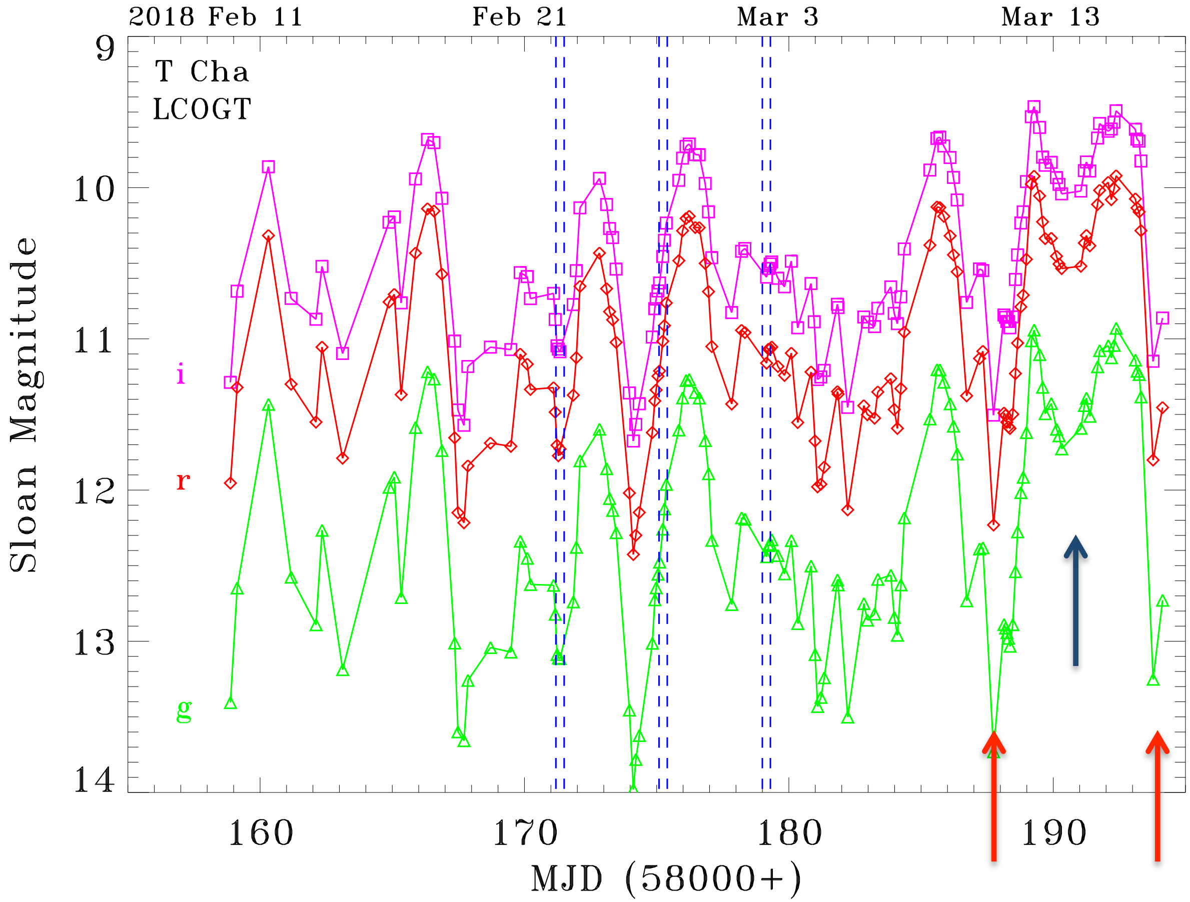
- 35 days monitoring.
- Few hour sampling – need 3 hour cadence or better.
- Consistent variations in all filters.
- Dramatic Variability – note y-axis is 5 magnitudes.

LCOGT Light-Curve



- 35 days monitoring.
- Few hour sampling – need to observe at least every 3 hours or less to follow variations.
- Dramatic Variability.
- 3 magnitude changes in a day.

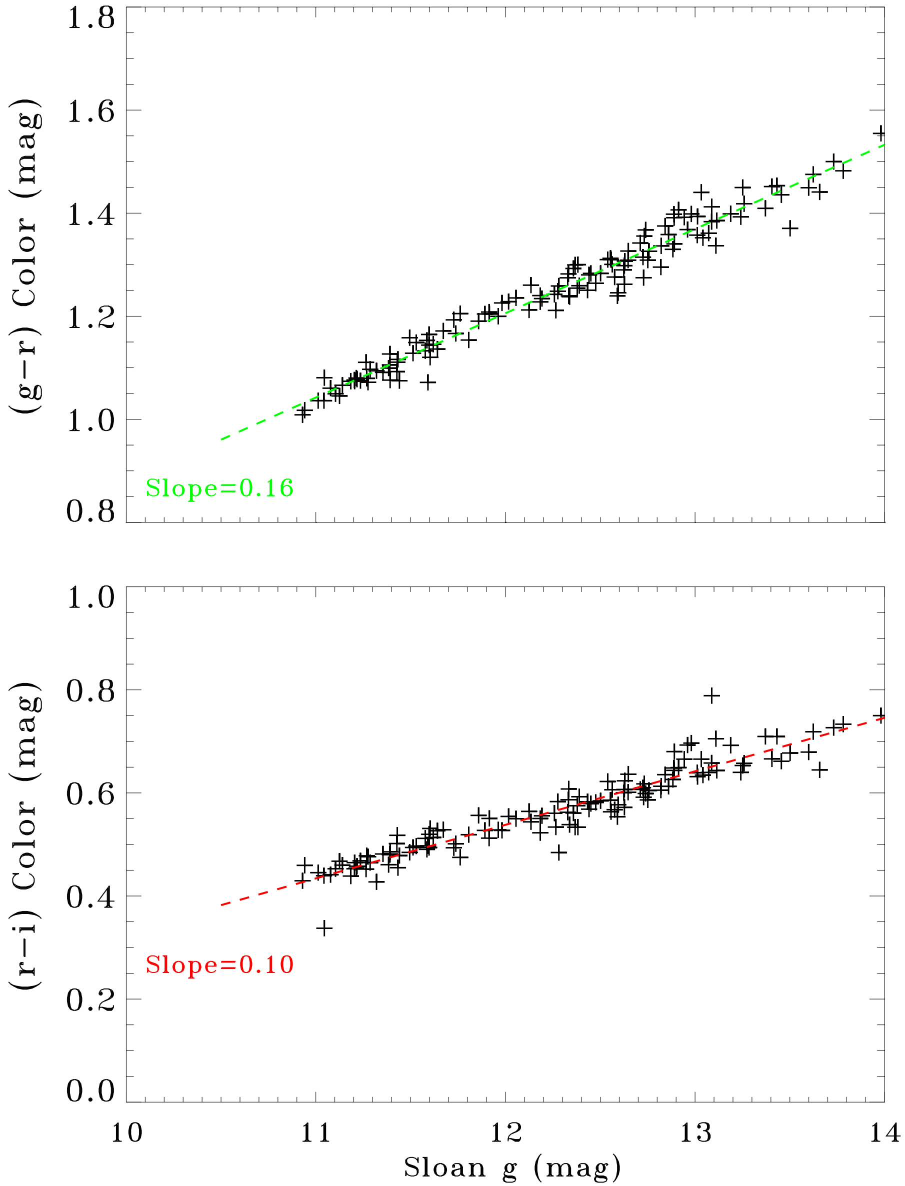
LCOGT Light-Curve



- 35 days monitoring.
- Few hour sampling.
- Dramatic Variability.
- 3 magnitude changes in a day.
- Periodic signal at either 3.25 or 6.5 days. True orbital period is probably the latter.
- Corresponds to 0.08 AU radius.

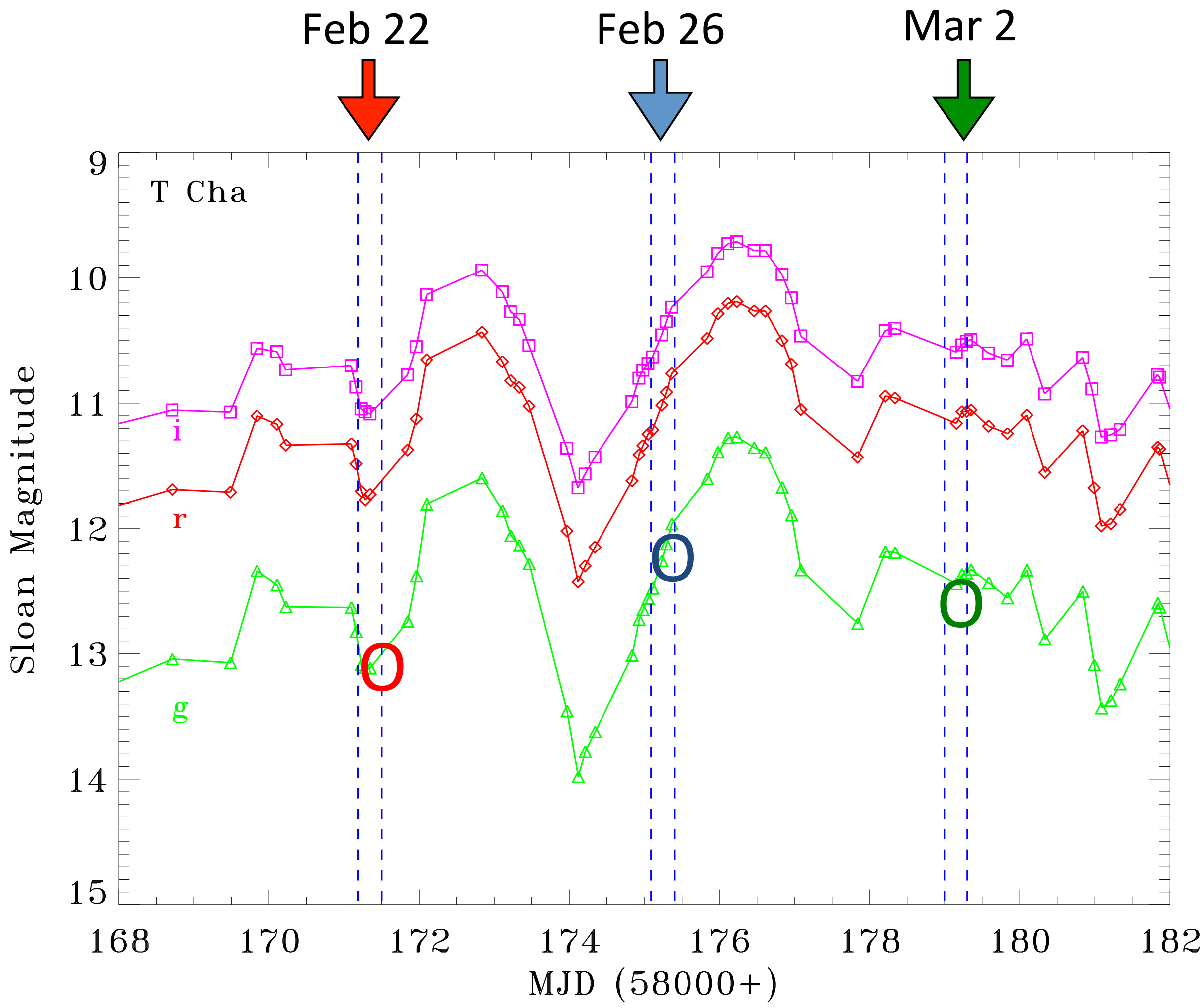
Inner disk -- Spitzer: 0.08-0.2 AU ; VLTI/AMBER: 0.13-0.17 AU; VLTI/MIDI: 0.07-0.11 AU

Variable Dust Obscuration



- Color-Magnitude and Color-Color variations show behavior expected from dust extinction.
- Amplitude of variability increases to shorter wavelengths.
- Near constant absorption depths in near-IR.

HST STIS/COS Observations



HST observations sample three different absorption states.

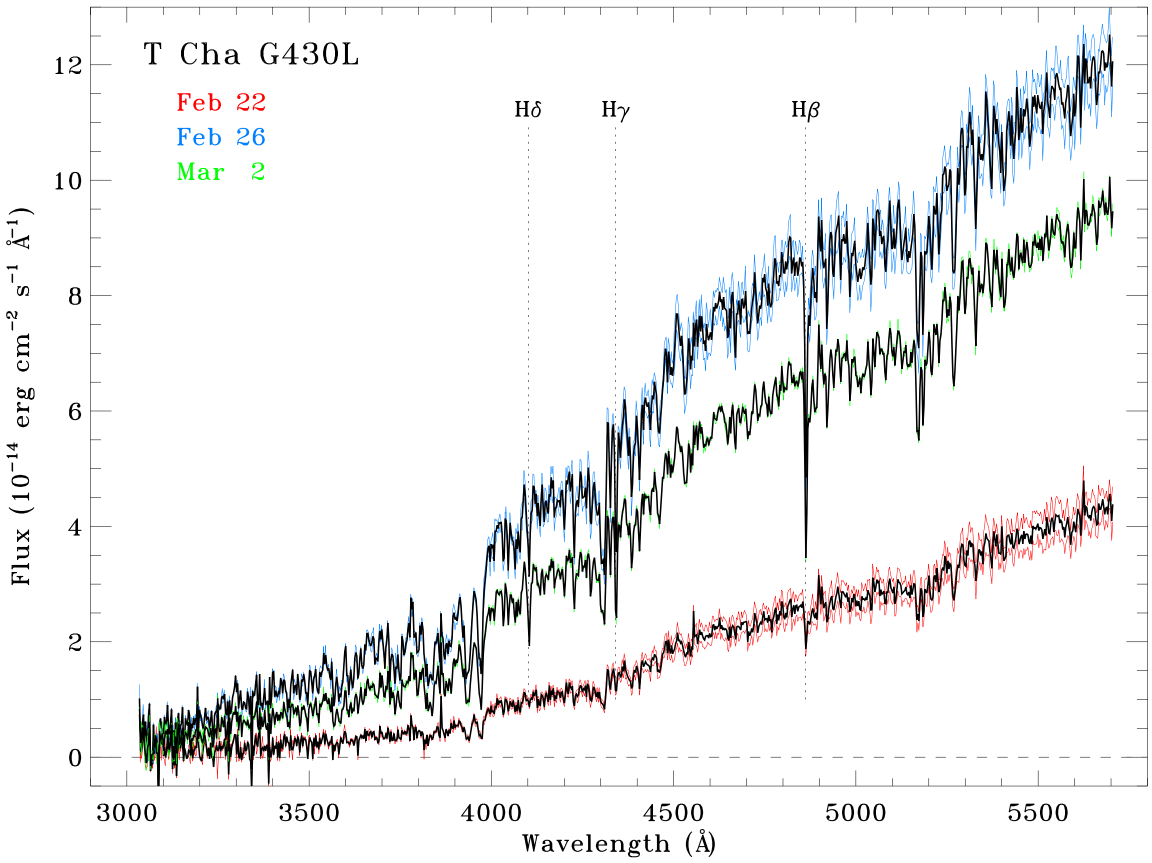
Visit 1 – bottom of small dip.

Visit 2 – rise from big dip.

Visit 3 – plateau (?).

NONE of the observations is at maximum light.

STIS Low-resolution Spectra

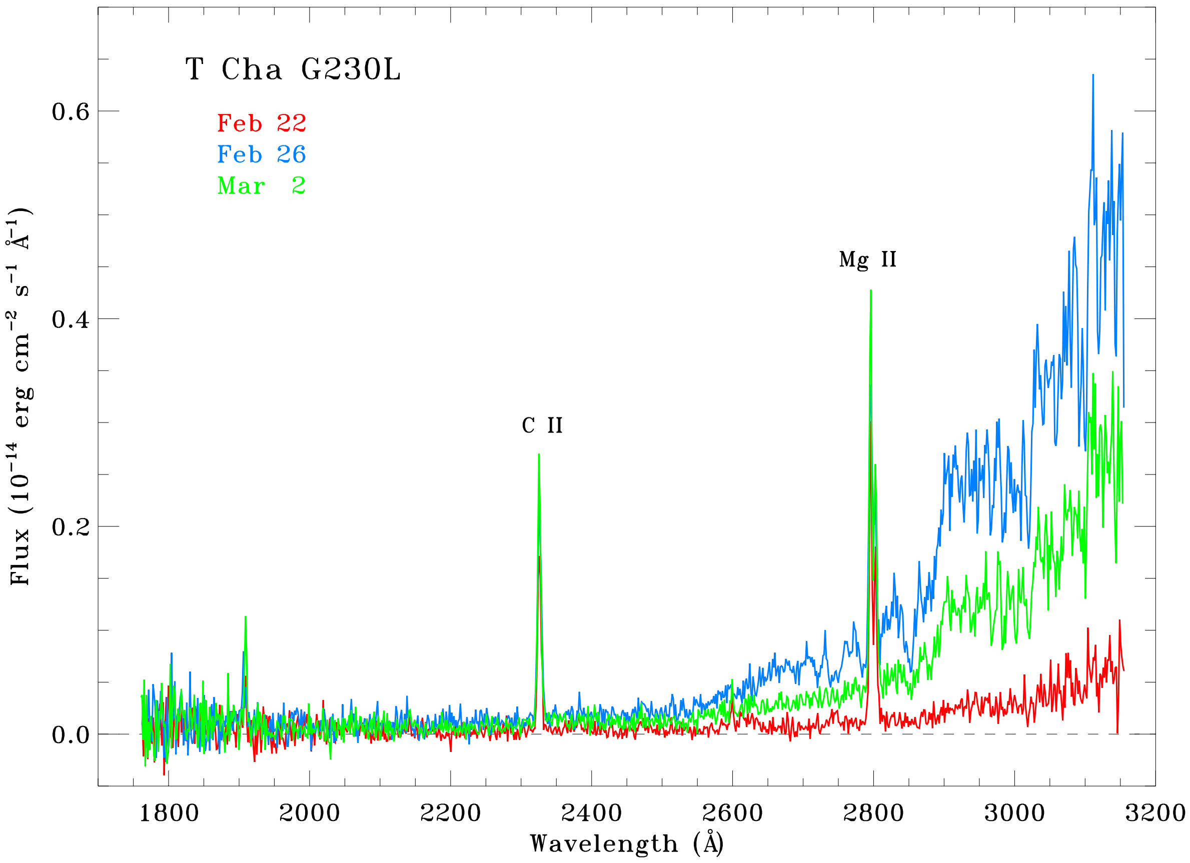


- Measured NUV/Optical SED using G750L, G430L, and G230L gratings.

- Spectra acquired over a single HST orbit.

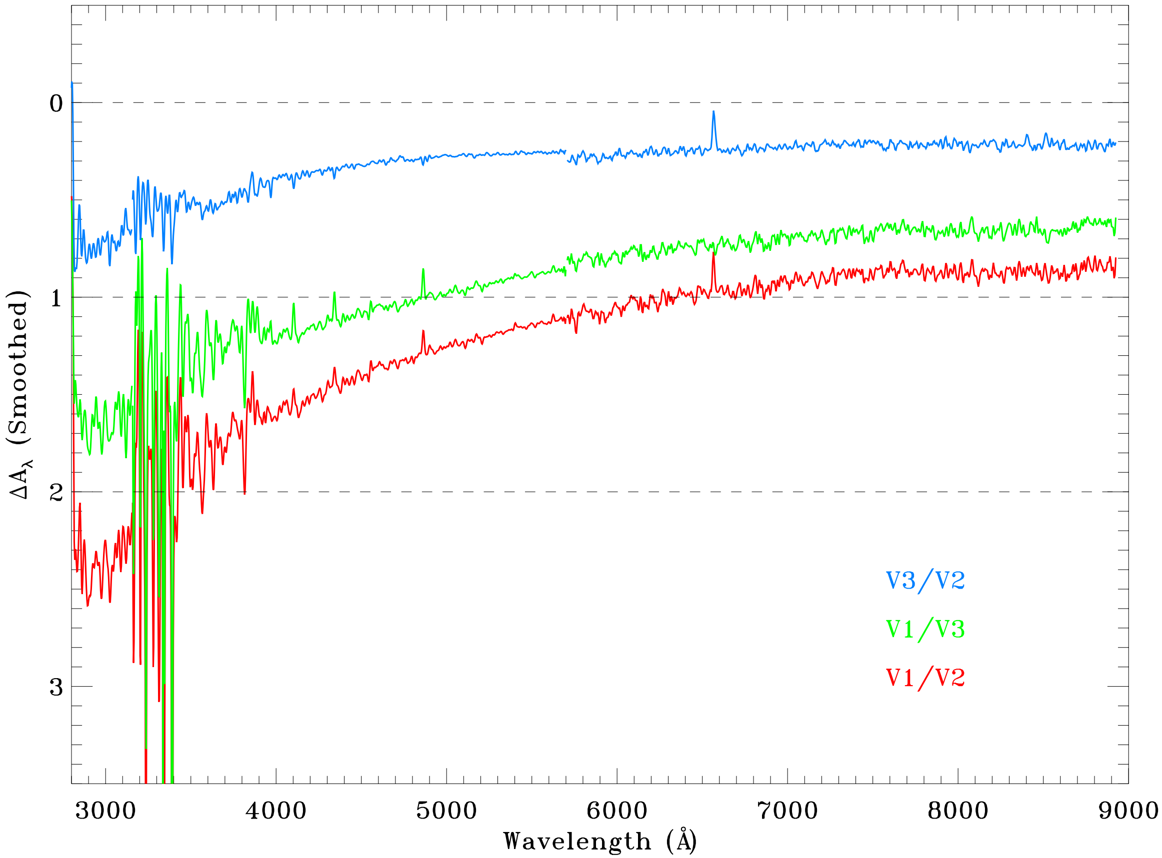
- SEDs changes match the optical photometry.

STIS Low-resolution Spectra



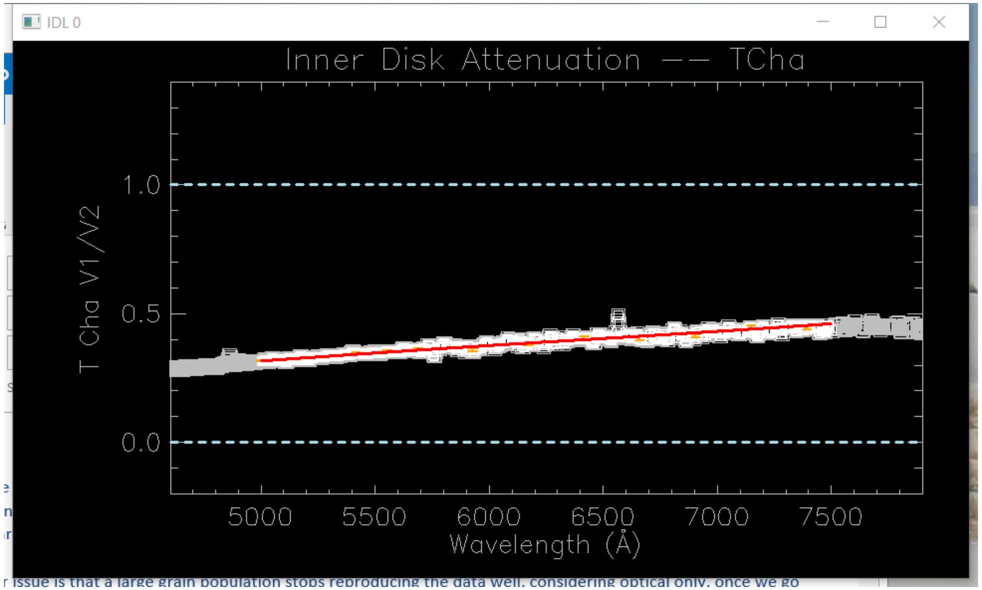
- G230L shows declining continuum
- Strong constant emission in Mg II and CII lines.

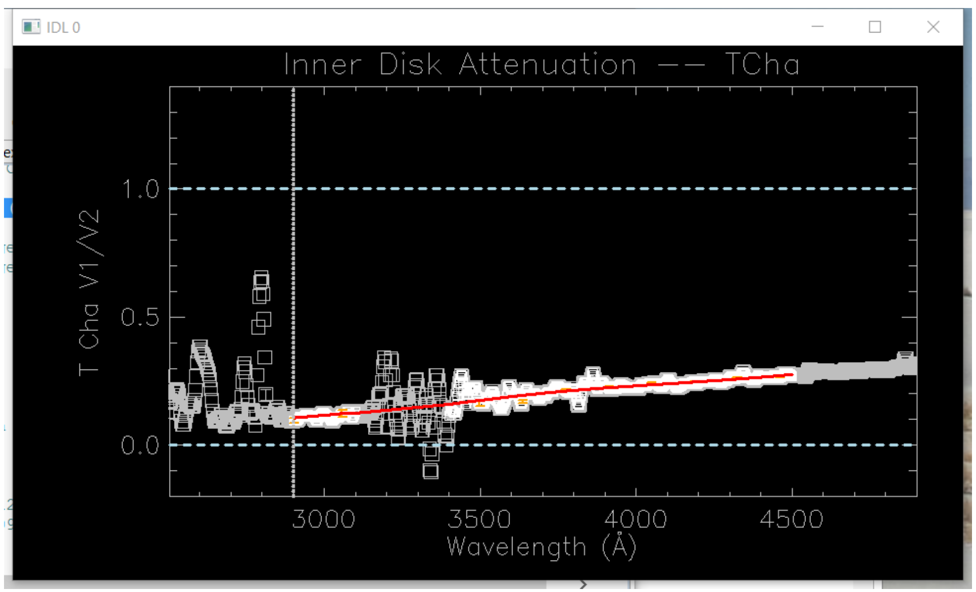
Optical-NUV Differential Absorption



- Dividing the different pairs of spectra shows the extra differential absorption present between the three HST visits.
- Optical absorption is relatively flat.
- NUV absorption is much steeper.

Dust Extinction models





NB: EXTRA ABSORPTION

In optical BOTH BV photometry and STIS SEDs indicate R_V=5-6 – LARGE grains.

Data: V1/V2 -- 5000-7000 A

A_V=1.15, R_V=4.98

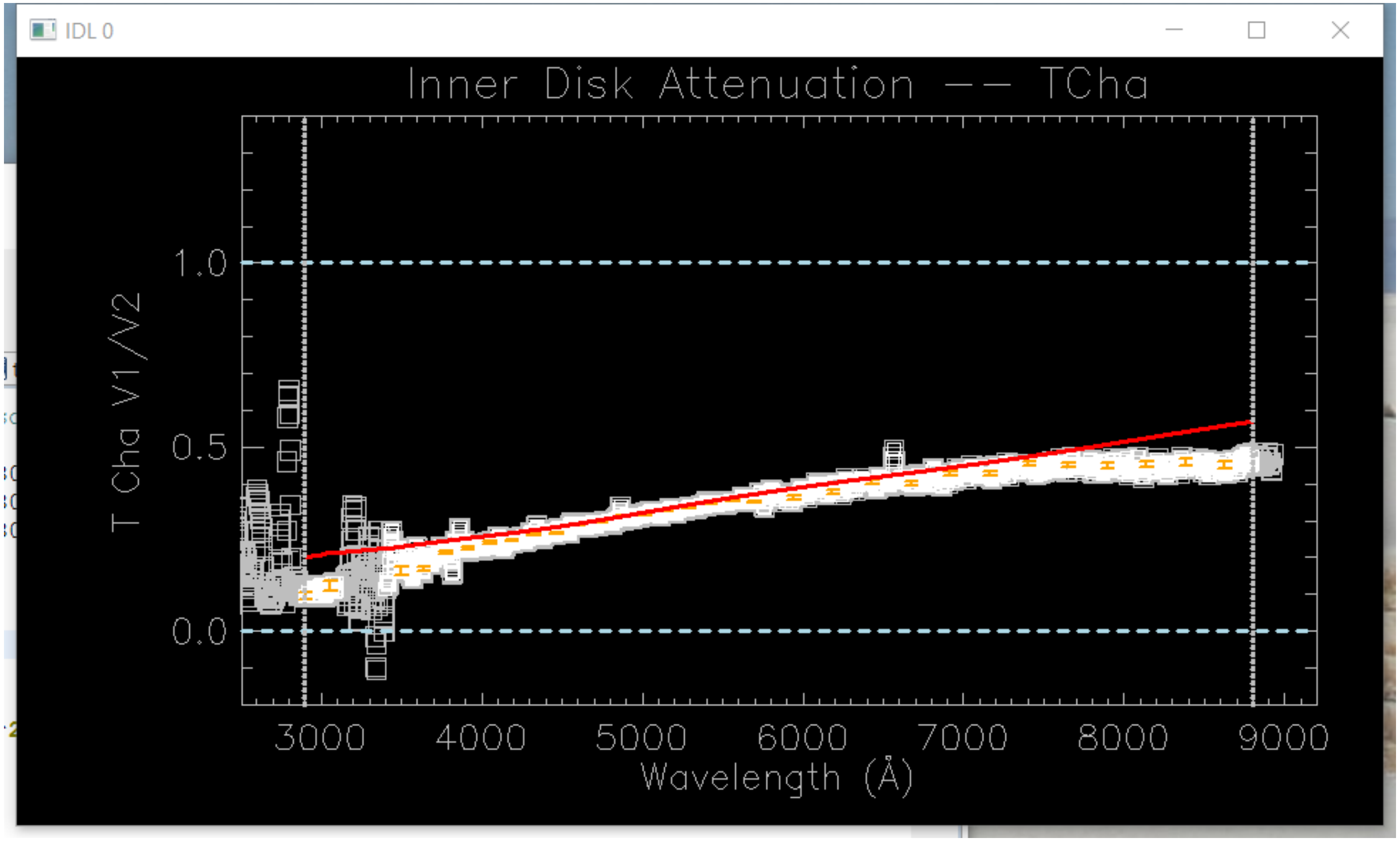
Similar values reported by previous observers.

HOWEVER, the STIS NUV SEDs are only compatible with the presence of SMALL (ISM size) grains --- R_V=2-3

Data: V1/V2 -- 3000-4500 A

A_V=0.97, R_V=2.07

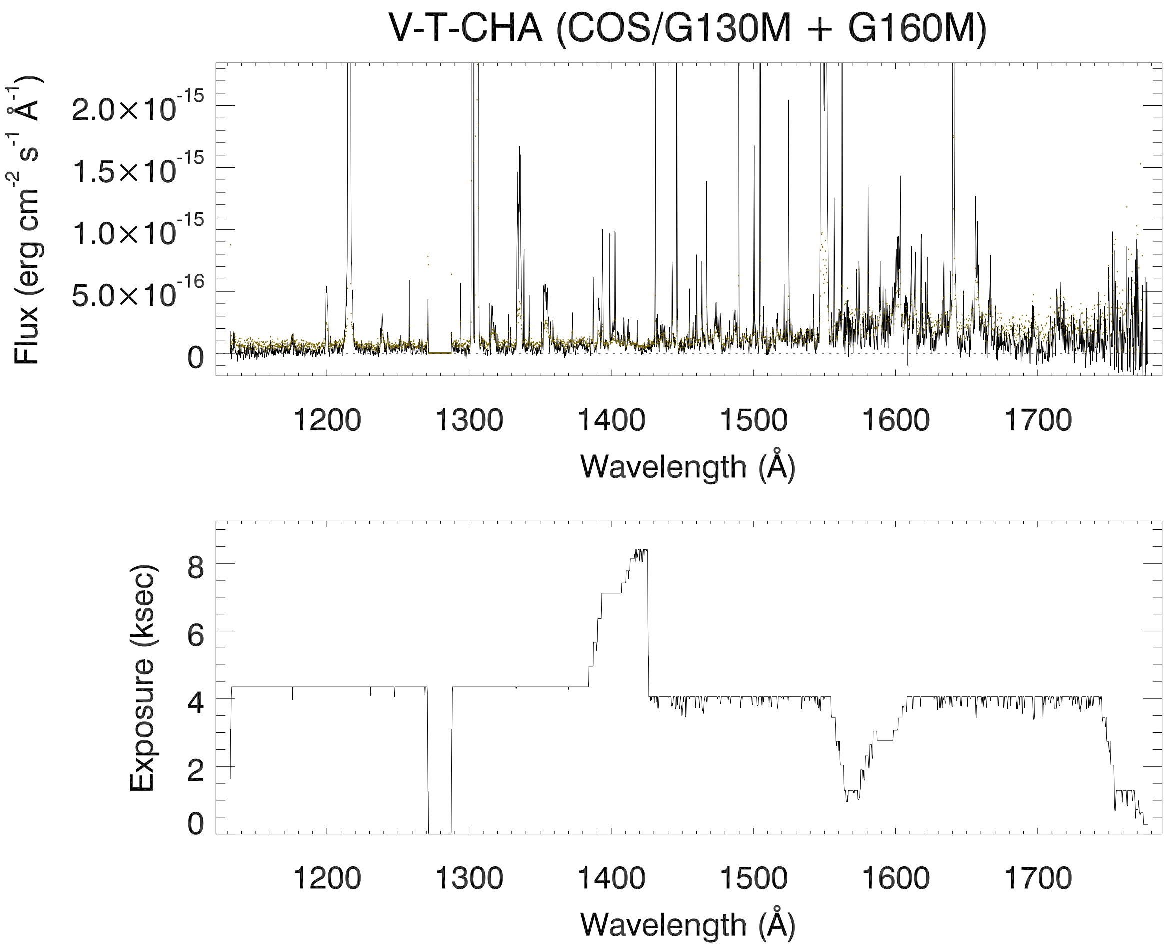
Dust Extinction models



Fitting the full SED: Neither One nor Two component models work well.

Shown: A_V=0.55, R_V=3.14 PLUS A_V=0.56, R_V=5.89 (for 3000-9000 A)

COS Medium-resolution Spectra

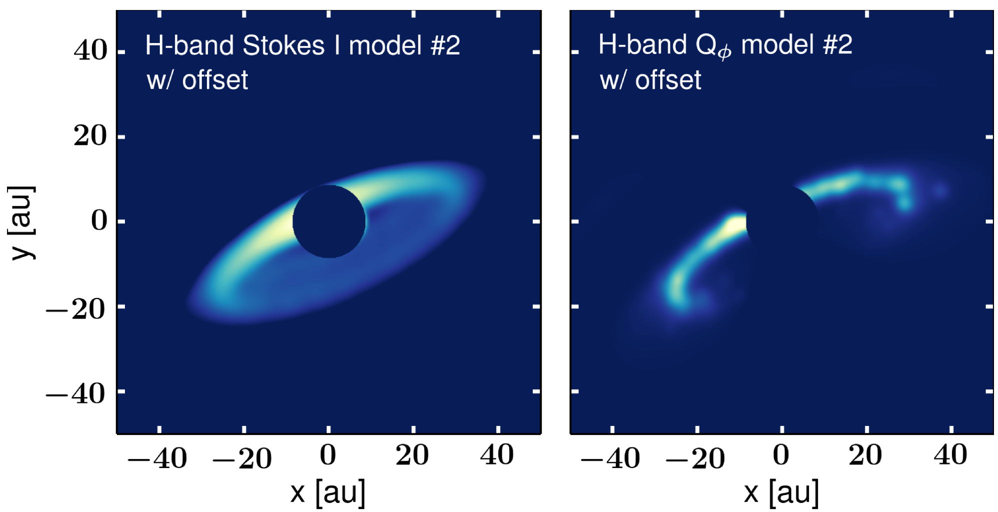


Visit 2
Co-added
COS spectrum

Hot (1500 K–
maybe 2000 K)
molecular gas

- COS G130M/G160M spectra show typical spectrum of a T Tauri star with a warm inner disk.
- Many strong molecular hydrogen emission lines fluoresced by H Lyman alpha.
- Some weak hot emission lines usually generated by accretion.

FUV Viewing Geometry for T Cha

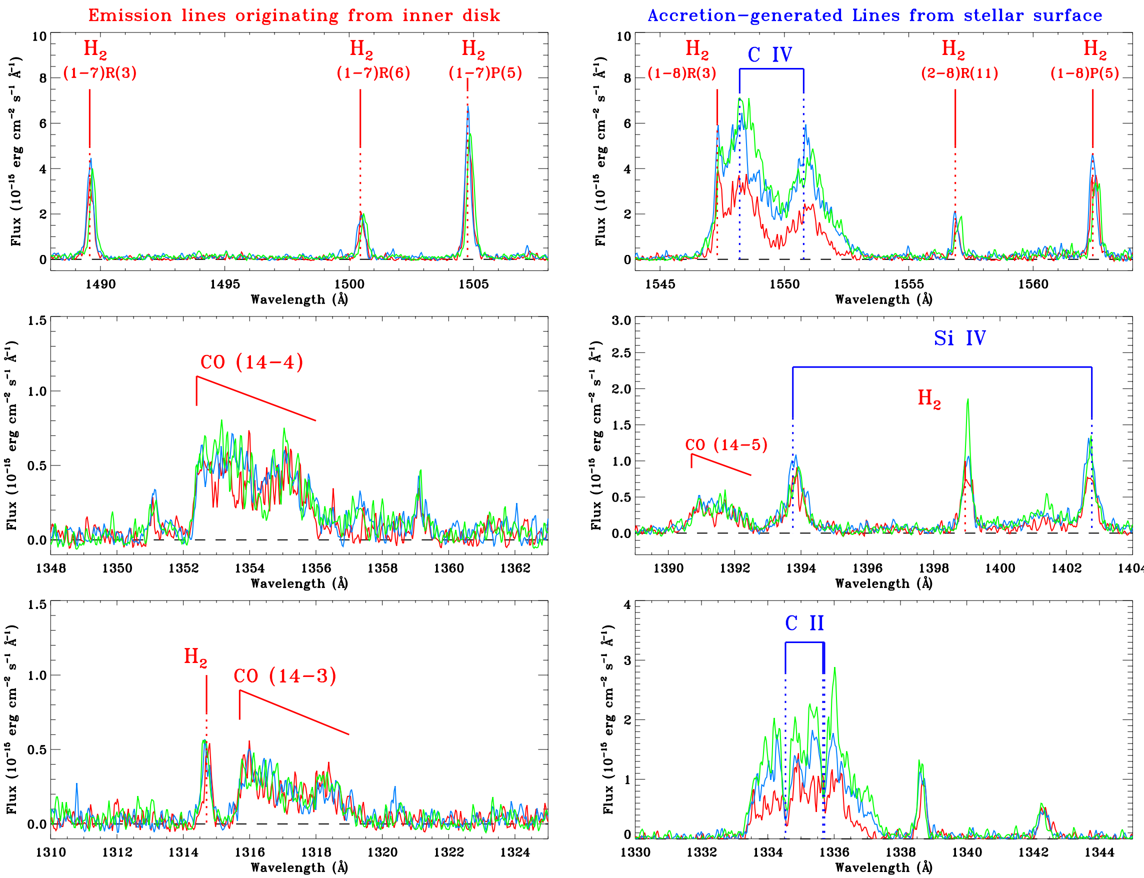


VLT/SPHERE H-band Imaging of T Cha:
Outer Disk NIR Scattered Light Distribution
(Pohl et al. 2017, A&A, 605, A34)

- Outer disk scattered light image. Strong forward scattering from near side of disk.

- In FUV the INNER disk will be a mirror image with the near side obscured but the far inner disk rim visible.

COS Medium-resolution Spectra



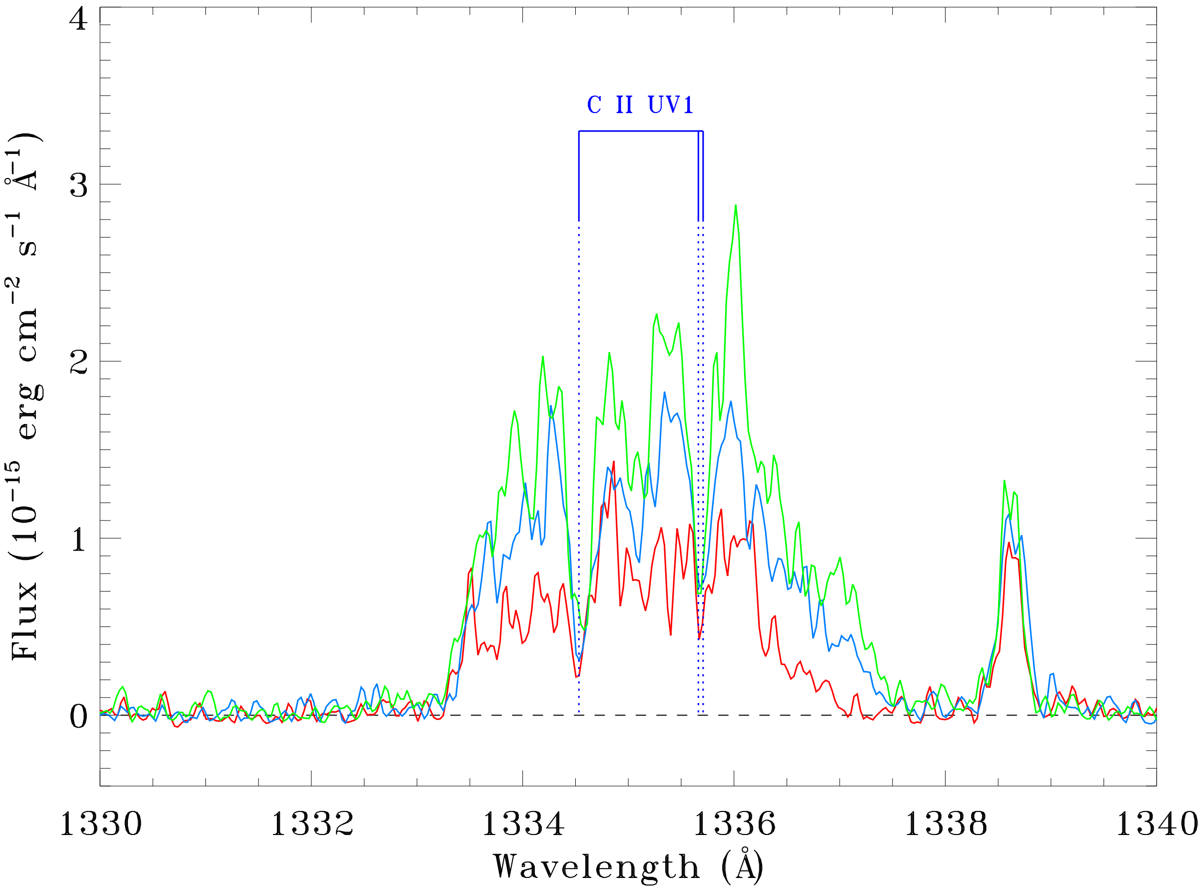
GAS COMPONENT

- Fluoresced molecular hydrogen and CO lines from the inner disk are constant.

- CO stronger than typical.

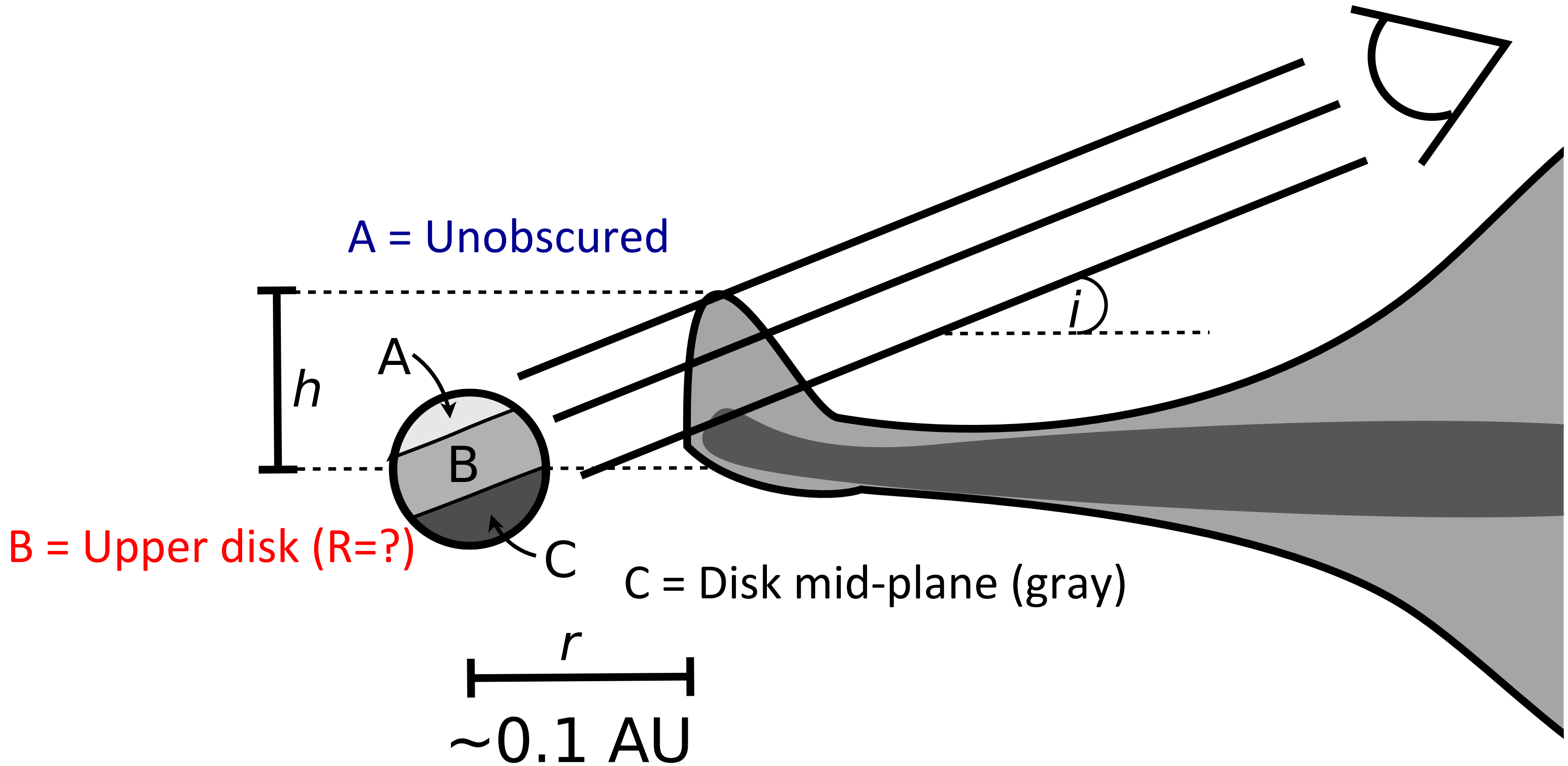
- Hot emission lines (C IV, Si IV, C II) decrease with increasing obscuration BUT not as much as they should if the star is fully covered by the absorbers.

Complex C II 1335A Profiles



- All hot emission lines are VERY broad with wings of individual lines merging.
- C II shows strong absorption at rest velocity in both zero volt ground-state line AND in the excited ground-state lines.
- Reminiscent of carbon-rich variable absorbers seen in some edge-on Herbig Ae/Fe stars.

Viewing Geometry

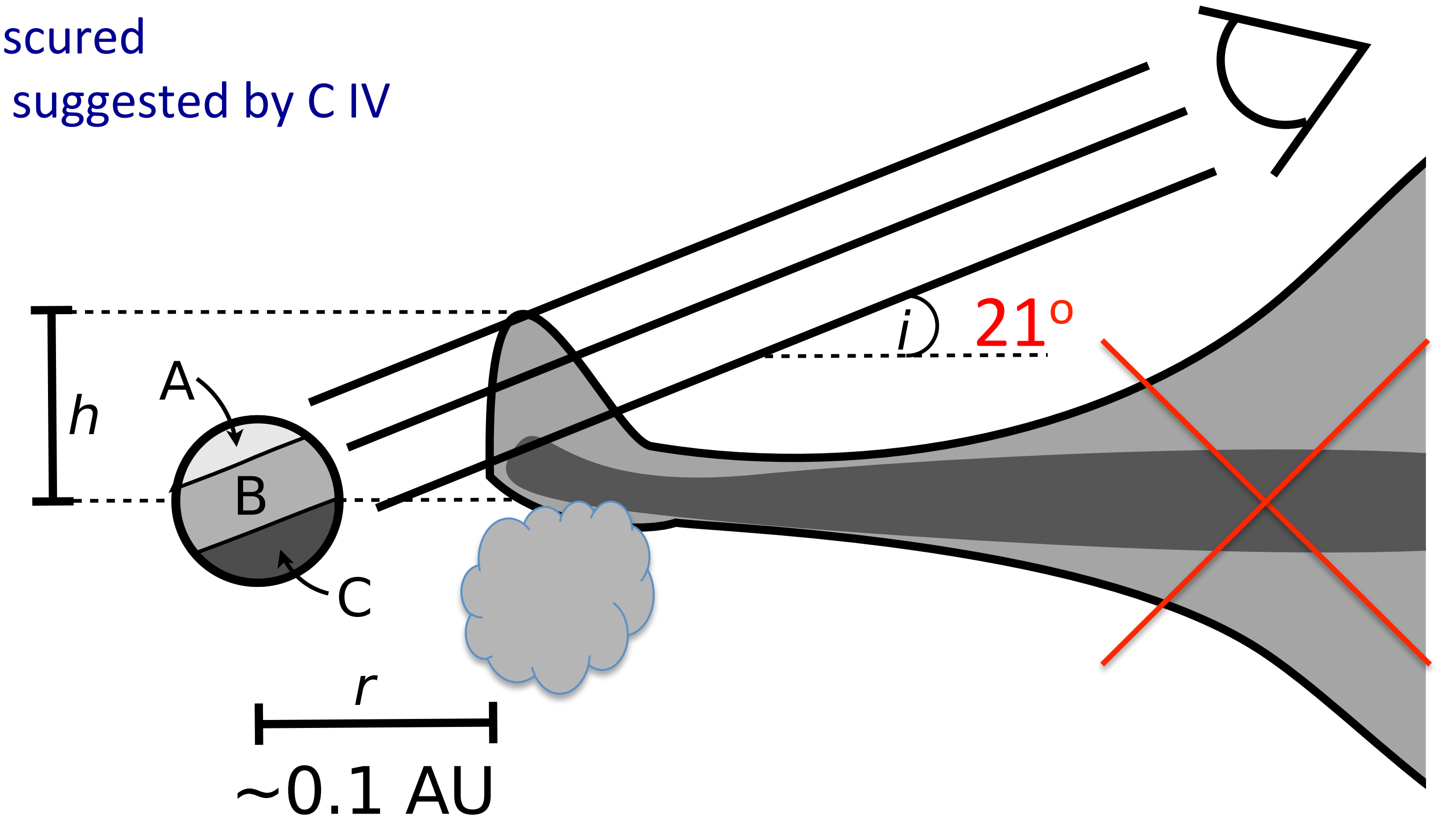


Scenario developed for RW Aur/V354 Mon

Schneider et al. 2018, A&A, 614, A108

Viewing Geometry – T Cha

A = Unobscured
Presence suggested by C IV



B = Upper disk (R=2-3 AND 5-6)

Inner edge of disk is 12 stellar radii from surface.

C = Disk mid-plane (gray)
[Maybe explains longer λ inconsistencies]

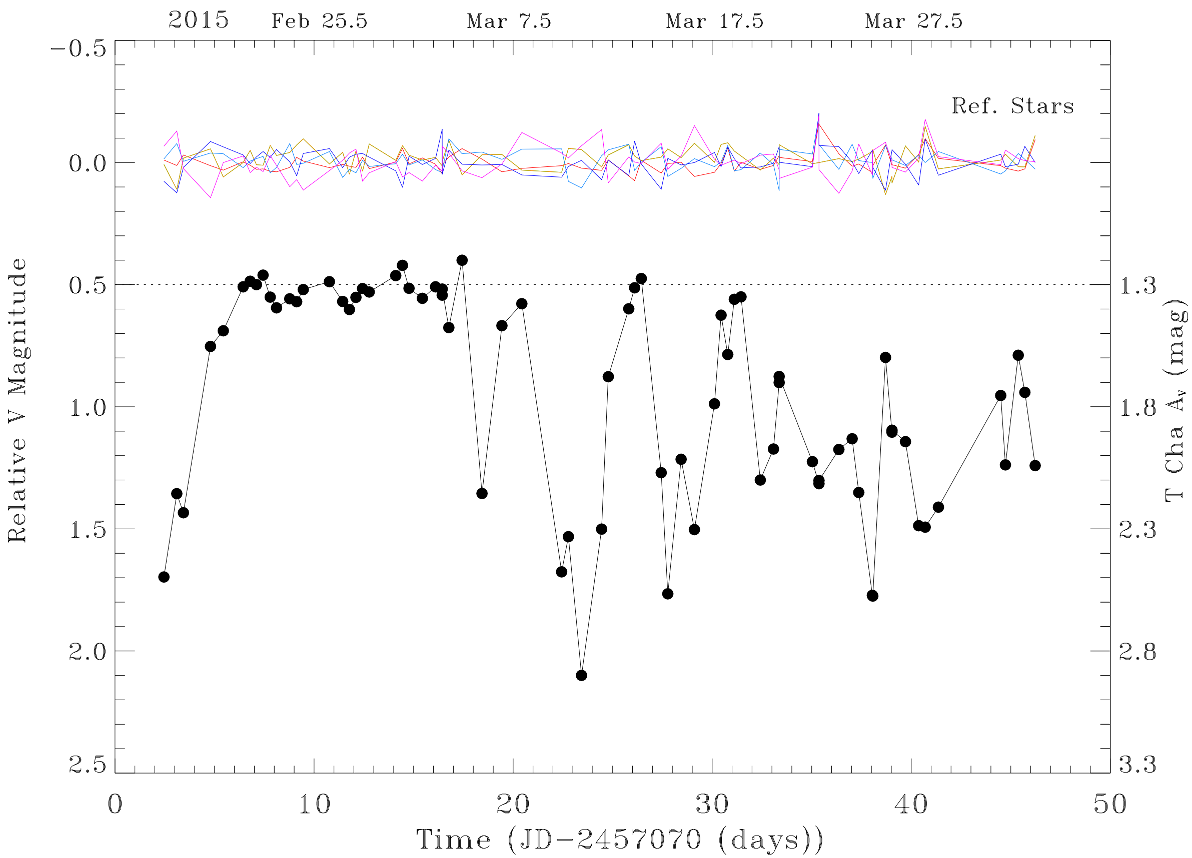
Scenario developed for V354 Mon

Schneider et al. 2018, A&A, 614, A108

Conclusions

- T Cha provides rare opportunity to study inner disk conditions for a transitional disk.
- Rapid large optical absorption events are seen frequently.
- Inner disk obscuration does not cover the star completely.
- Optical/NUV SED shows presence of large and small grains.
- Possibly small grains are a destruction product from large grains.
- Accretion is on-going but is the inner disk being replenished? Would our "large" grains get across the 15 AU gap?

LCOGT – 2015 V Light-curve



- V-band light-curve from 2015 February-March.
- 10 day “flat” signal with no dips.
- Can be combined with 2017 V light-curve (from both g and V) to provide unobscured level.