Measuring the density structure of an accretion hot spot

(Espaillat et al. 2021)

(Published Sep.1. 2021 on Nature)

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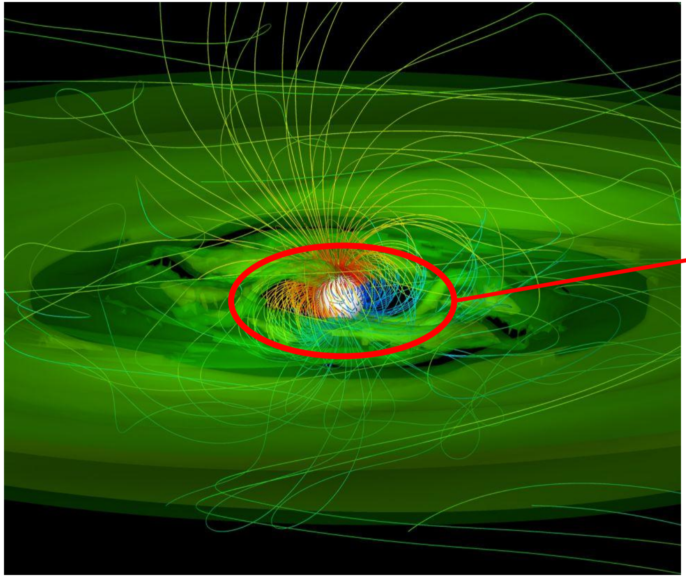
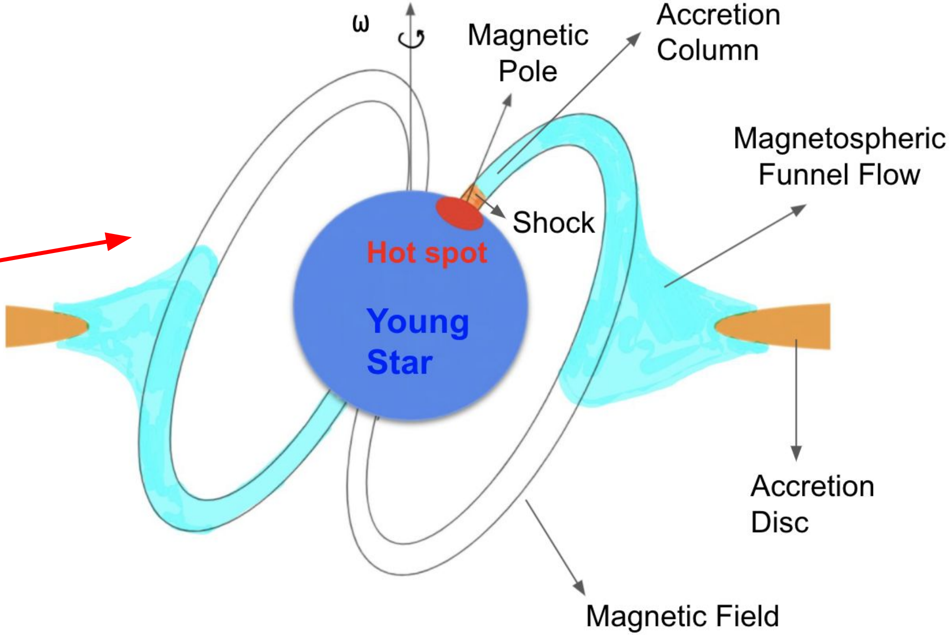
Student Seminar
Dec.3rd.2021

Outline

Accretion Hot Spot



(Image credit: NASA/JPL-Caltech)



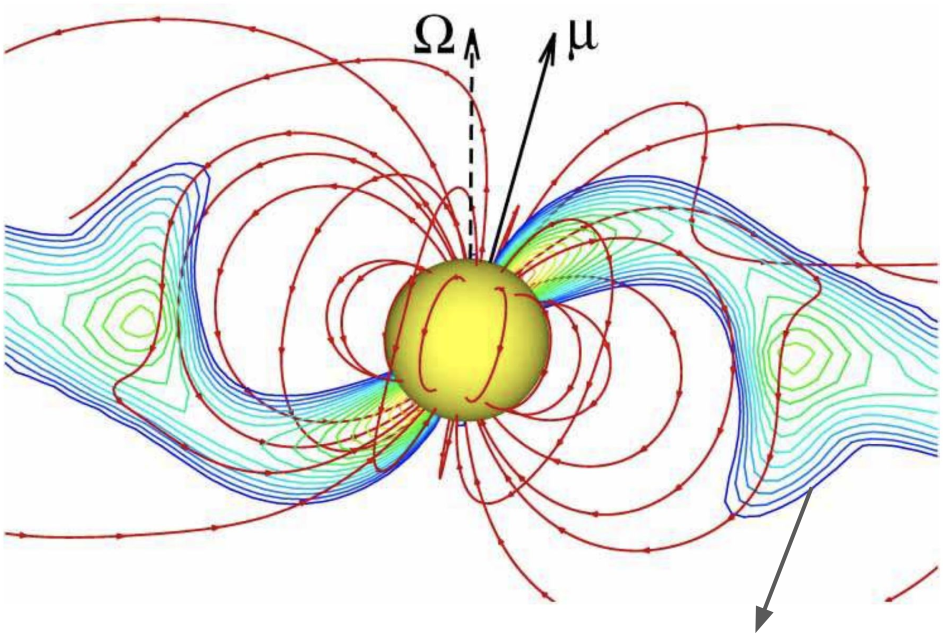
Hot spot is the “footprint” of the accreting material fall onto the stellar surface due to the **magnetic field**.

→ Energy radiated as **shock emission** at the stellar surface.

(Hartmann et al. 2016)

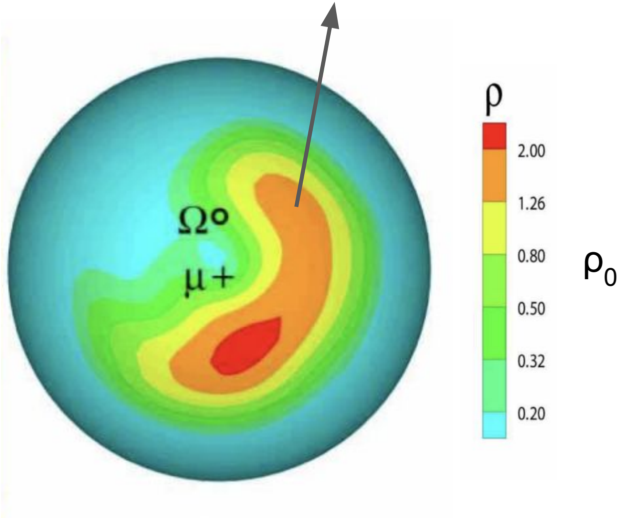
Density Structure

3D MHD Simulation



Funnel Flow

Hot Spot



- Density increases towards the center.
- High density region has smaller coverage of the stellar surface.

(Romanova et al 2004)

Density Structure

Observation

Different Density ⟶ Different Temperature ⟶ Different Wavelength

- **Optical** observation of the hot spot

  Low-energy accretion column

- Large coverage of the hot spot on stellar surface
- Influence of accretion column on the spectra at longer wavelength. (Veiling at 1 μm)

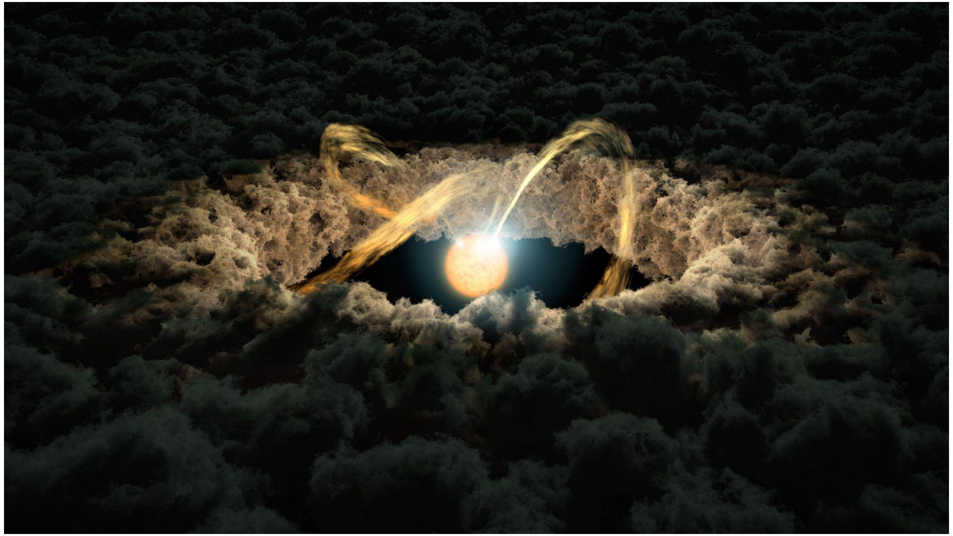
Coexist of the low and high density regions of the hot spot

But NOT radial density gradient

Time lag between peaks of light curve at different wavelength

(Ingleby et al 2013)

GM Aurigae



(Image credit: NASA/JPL-Caltech)

- Accreting magnetized
- Young, pre-main sequence
- Low mass (**sun-like**)
- Cavity --- giant planet formation

Take-home Message

The **time lag** of peaks in the light curves at UV and optical wavelength

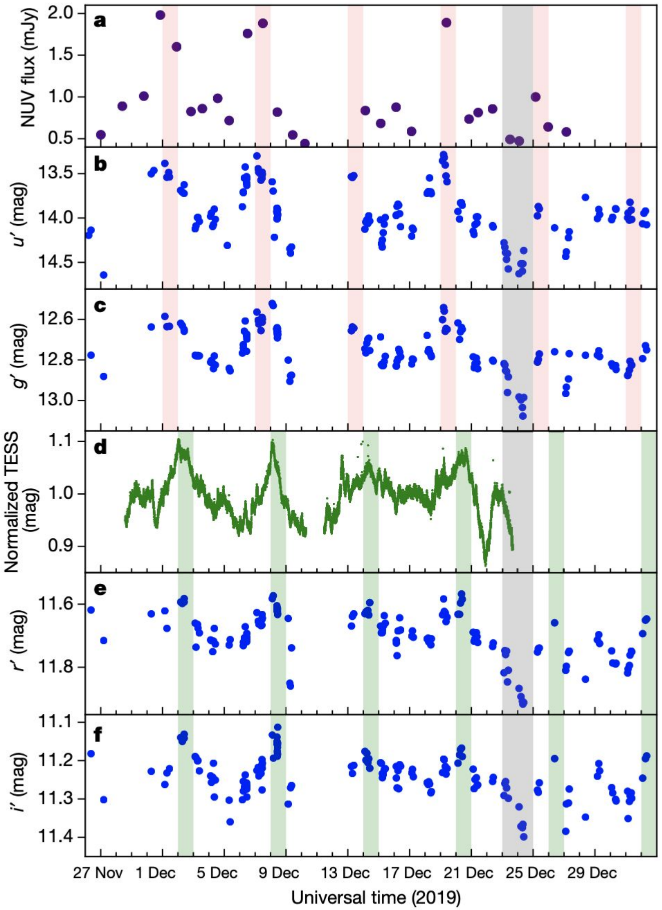
↓

Presence of density gradient in the a hot spot on the stellar surface of an accreting sun-like star.

Observation --- Light Curves

UV (High density)

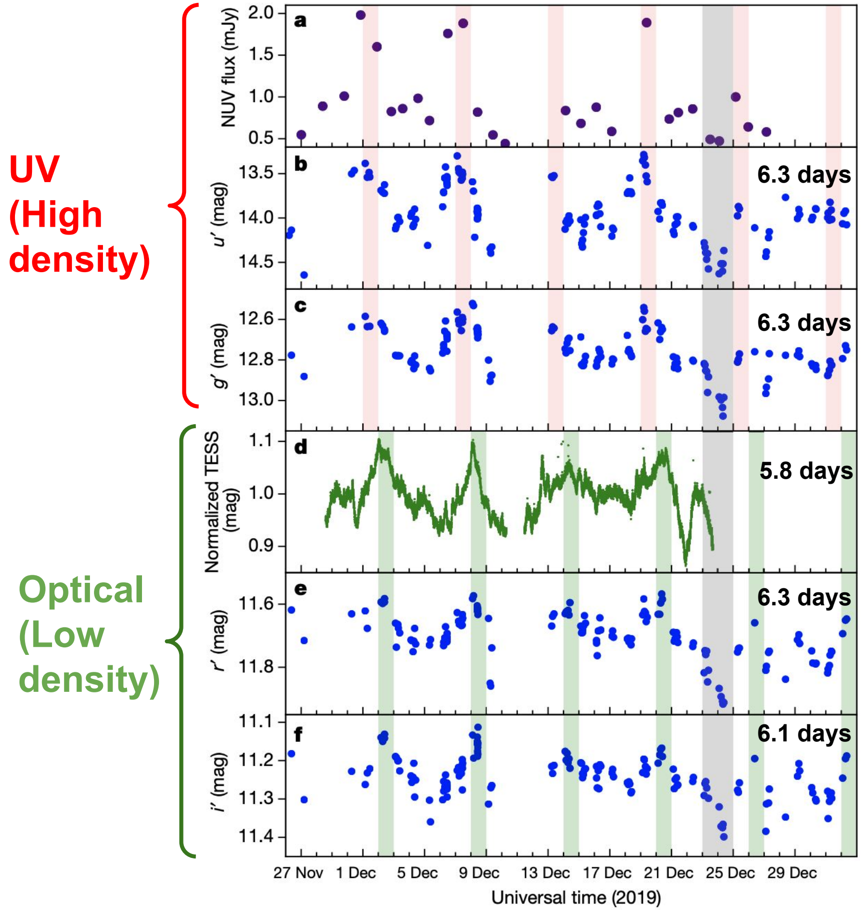
Optical (Low density)



Instrument	Wavelength	Data
Swift	X-ray (1-25 Å) NUV (centered at 2,221 Å)	Light Curve
STIS	NUV-NIR (1,700-10,000 Å)	HST spectra
TESS	Optical (6,000-10,000 Å)	Light Curve
LCOGT	*u’* (3,255-3,825 Å) *g’* (4,020-5,520 Å) *r’* (5,520-6,910 Å) *i’* (6,900-8,190 Å)	Light Curve
CHIRON	Optical (4,082-8,906 Å)	Spectra (Hα profile)

(Espaillat et al. 2021)

Observation --- Light Curves



1. Period of all light curves are rough the same as the stellar rotational period. **Rotational Modulation**

2. **Time lag** between peaks at UV and optical **Density gradient?**

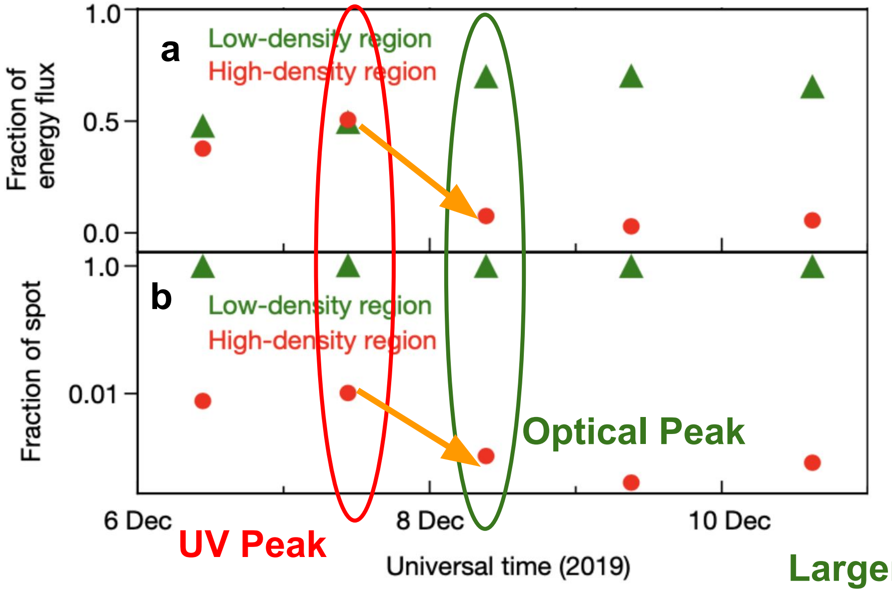
3. The dip in light curves on Dec.23 to 25. **Decrease in accrecton**

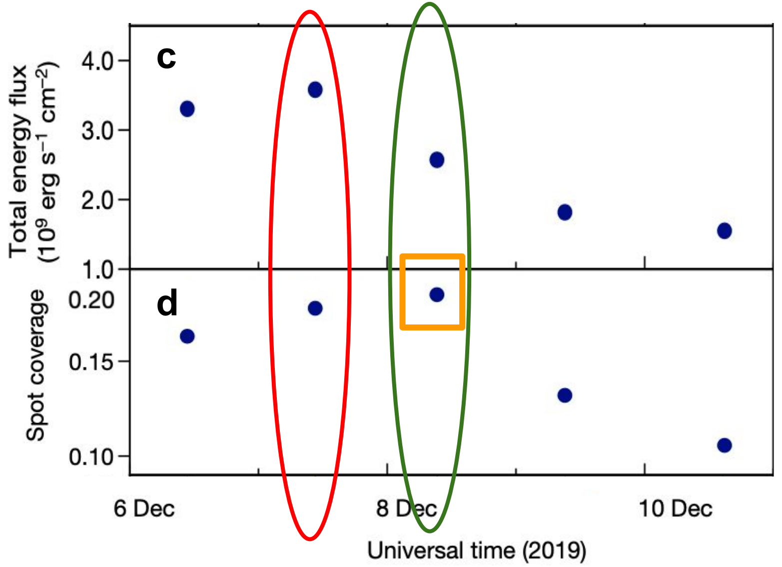
4. Disappearance of peaks at UV after the dip **Density gradient?**

(Espaillat et al. 2021)

Accretion Shock Model

Smaller High-density region dominates the total flux and UV





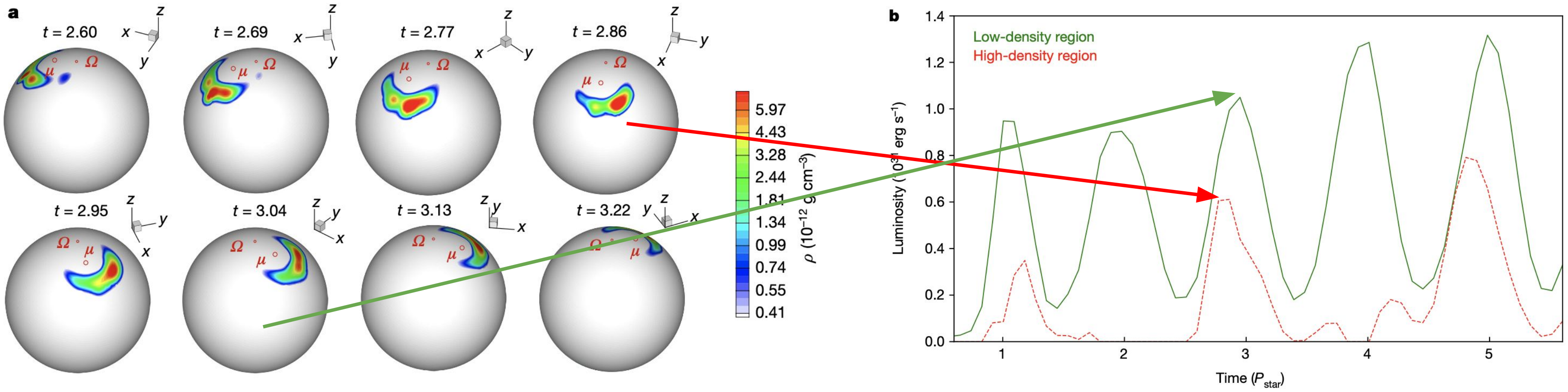
Larger Low-density region dominates the coverage and optical

Time lag is due to that the smaller high-density region of the hot spot is out of view while the larger low-density region is still visible.

A hot spot with density gradient

(Espaillat et al. 2021)

3D MHD Simulation

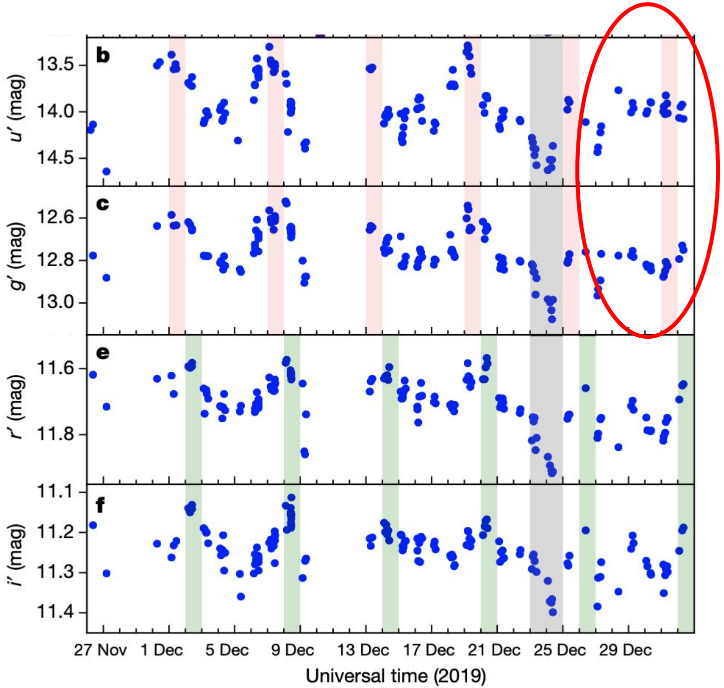


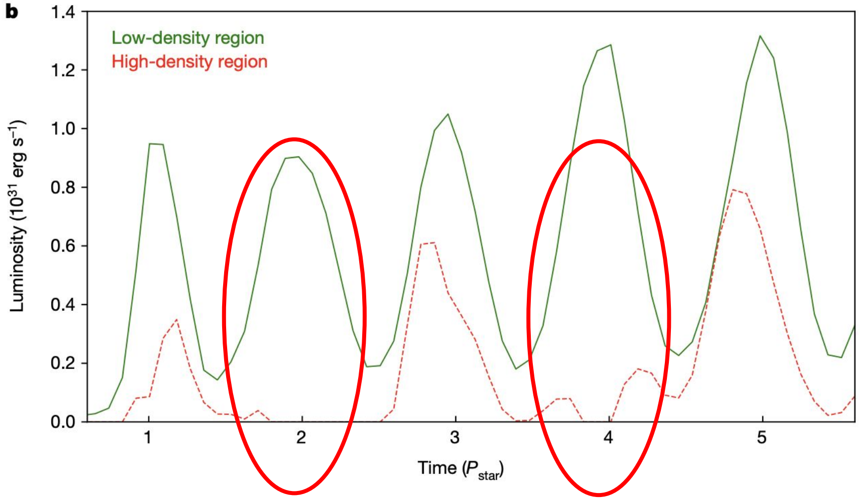
The high-density region rotates out of the view while the most of low-density region is visible and dominates the emission.

→ **Time lag** as observational evidence for density gradient

(Espaillat et al. 2021)

3D MHD Simulation





The difference in rotation of the disk and magnetosphere causes the variation in density distribution which influences the dense part more.

→ **Disappearance of UV peaks** as observational evidence for density gradient

(Espaillat et al. 2021)

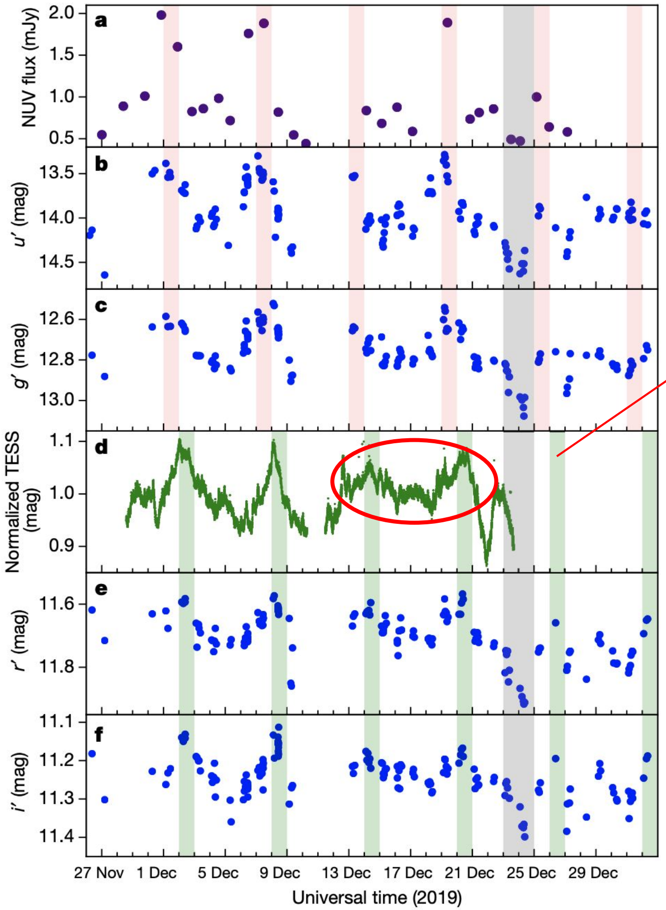
My comments

3,255-3,825 Å

4,020-5,520 Å

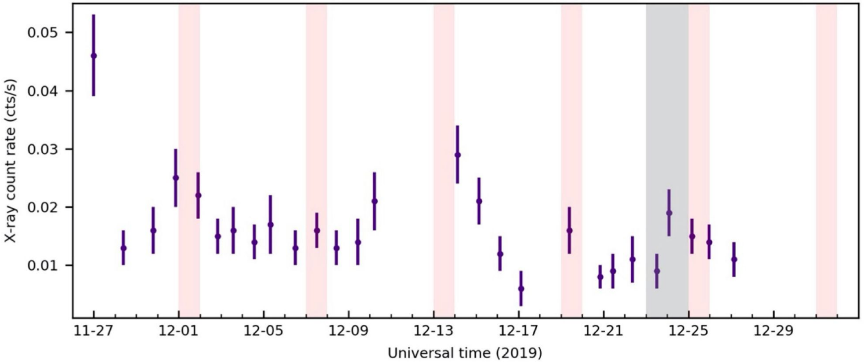
UV?

Optical?



The peaks are not obvious!

X-ray data is not correlated with other data, which does not have the periodic peaks.



(Espaillat et al. 2021)

Summary

- The accretion **hot spot** is the "footprint" of the **accreting material** hitting by the stellar surface due to the **magnetic field**.
- The **time lag** of peaks at UV and optical wavelength caused by the stellar rotation and different coverage of density regions in the hot spot is the **observation evidence of the density gradient**.
- By observations and simulation, the author confirms the theoretical prediction that the hot spot has **increasing density toward the center** while **coverage of the spot is decreasing with density.**

Questions

- Why x-ray emission does not have the same trend as the UV and optical emission?
- How about observing the density gradient with different angle between the rotational axis and magnetic pole?
- Will the similar distribution of the density be observed for other accreting young stars?

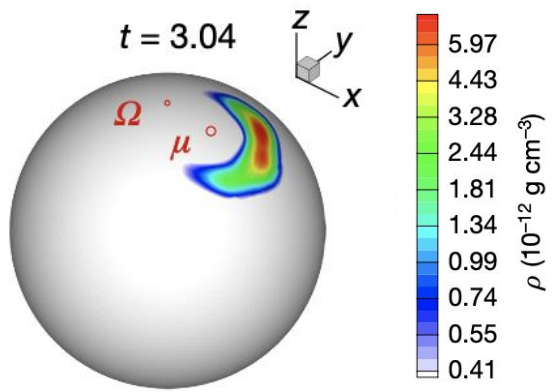
Backup Slides

Significance

Shock Emission
(**Time lag** and disappearance of UV peaks)

Observation & Simulation →

Structure of hot spot
(**Density Gradient**)



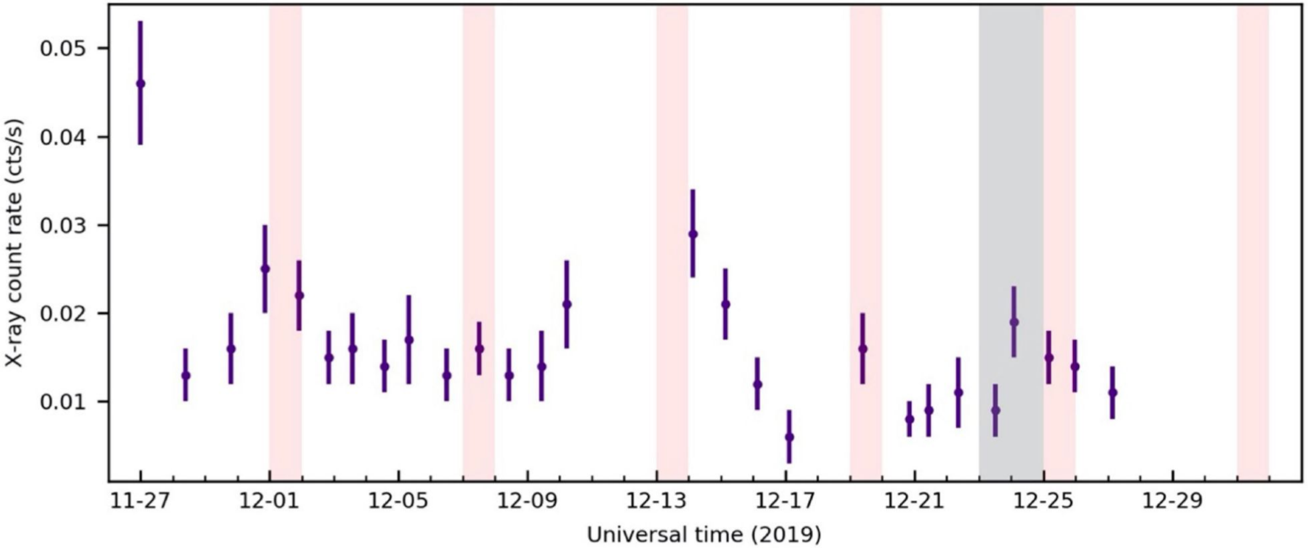
Evolution **Young star**
(How Sun looked like when it is young)

Accretion Modeling

Accretion Mechanism
(which might be applicable to the study of **planet formation**)

(Espaillat et al. 2021)

Swift X-ray Observation



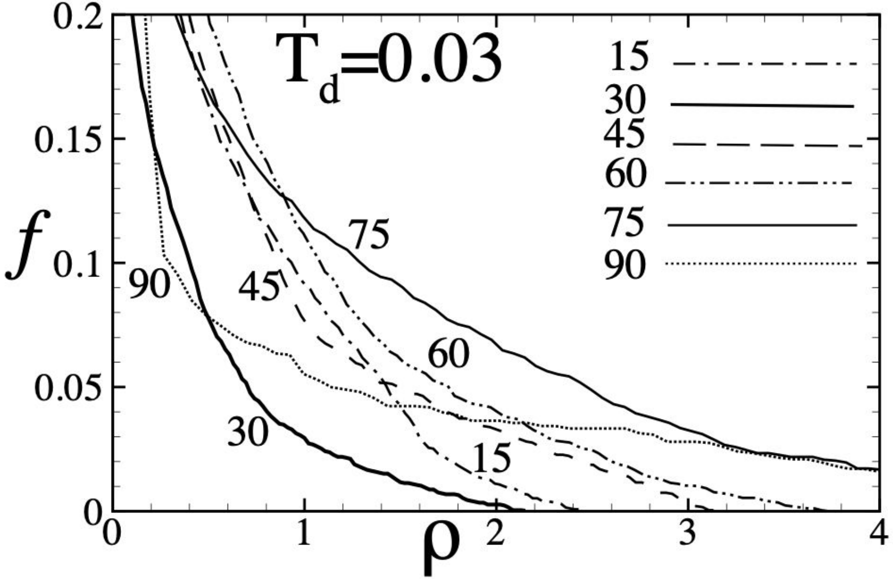
- X-ray corresponds to the very high-density region of the hot spot might be too small to be observed.
- The x-ray emission might not due to the hot spot but the corona or the jet of the accreting star.

(Espaillat et al. 2021)

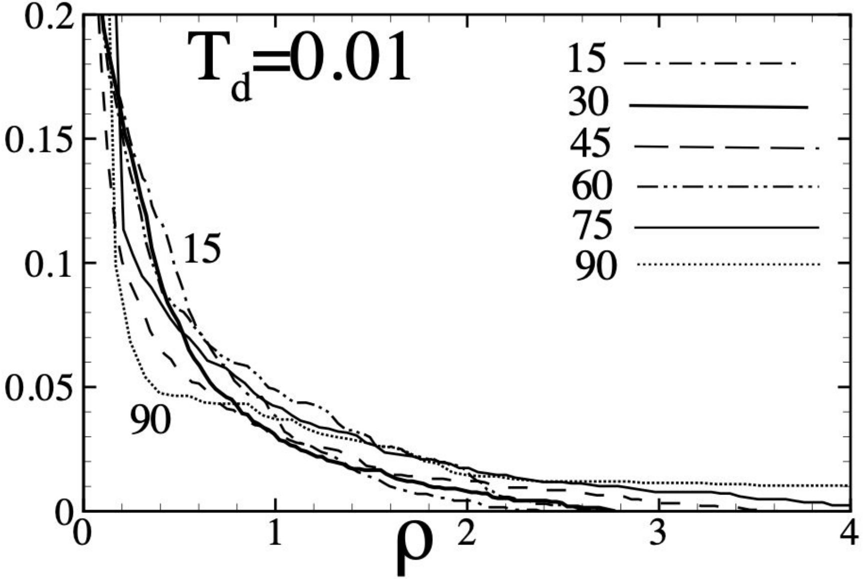
Different Misalignment Angle

Spot Coverage

Warm-disk

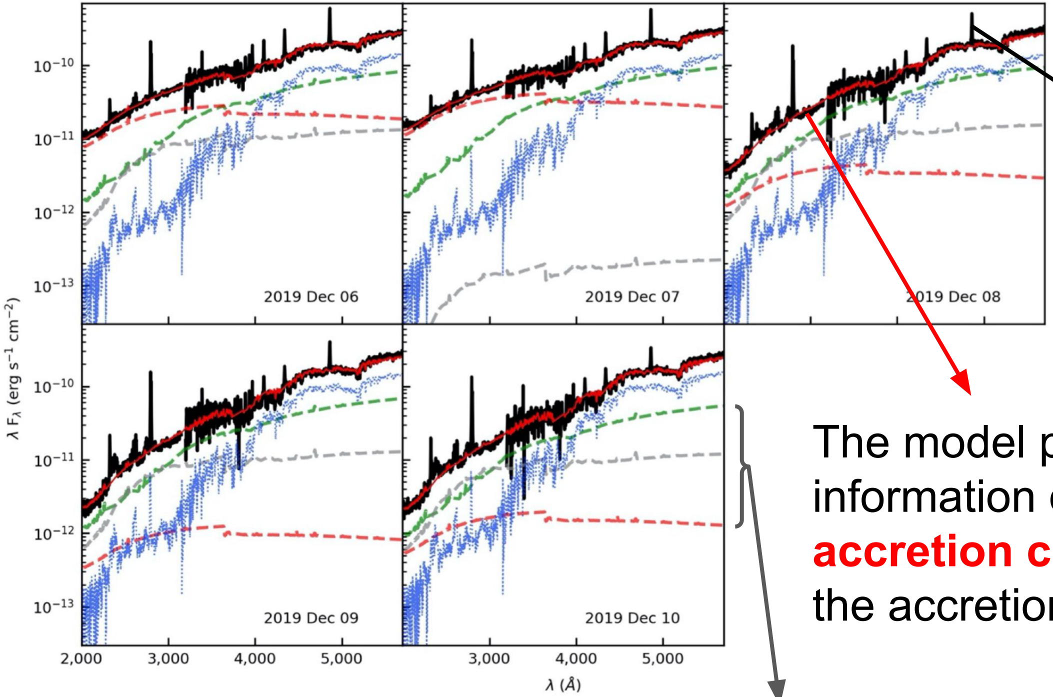


Cold-disk



(Romanova et al 2004)

Accretion Shock Model



Fit with NUV HST spectra

The model provide information of the **accretion column** hence the accretion hot spot.

- Energy Flux (Density)
- Filling parameter (Coverage of hot spot)

The dash lines represent the **three accretion columns** the model consistent that correspond to **different density regions** on the hot spot.

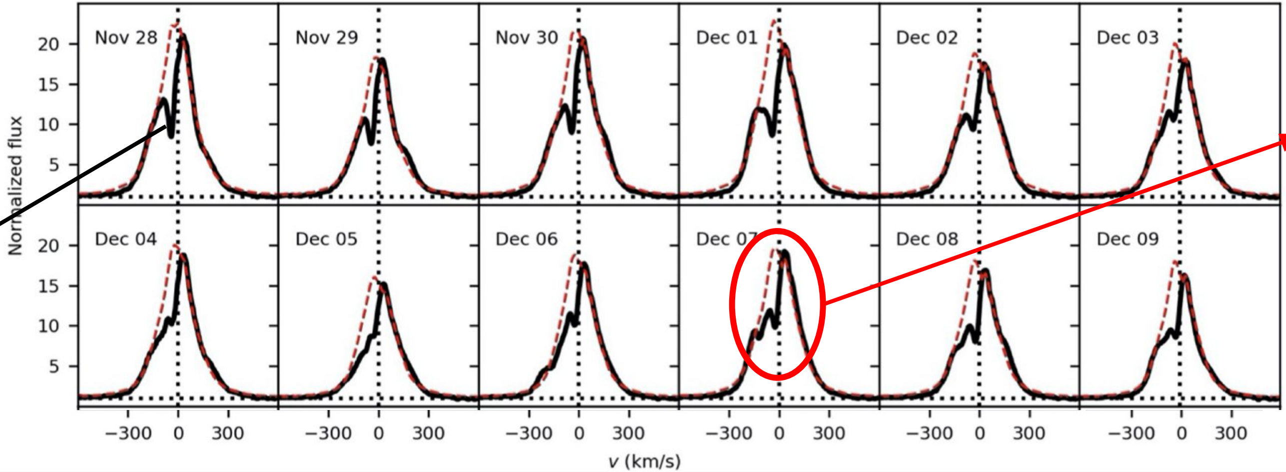
(Espaillat et al. 2021)

(Espaillat et al. 2021)

Accretion Flow Model

Used to get the input parameters (magnetosphere radius) for MHD simulation

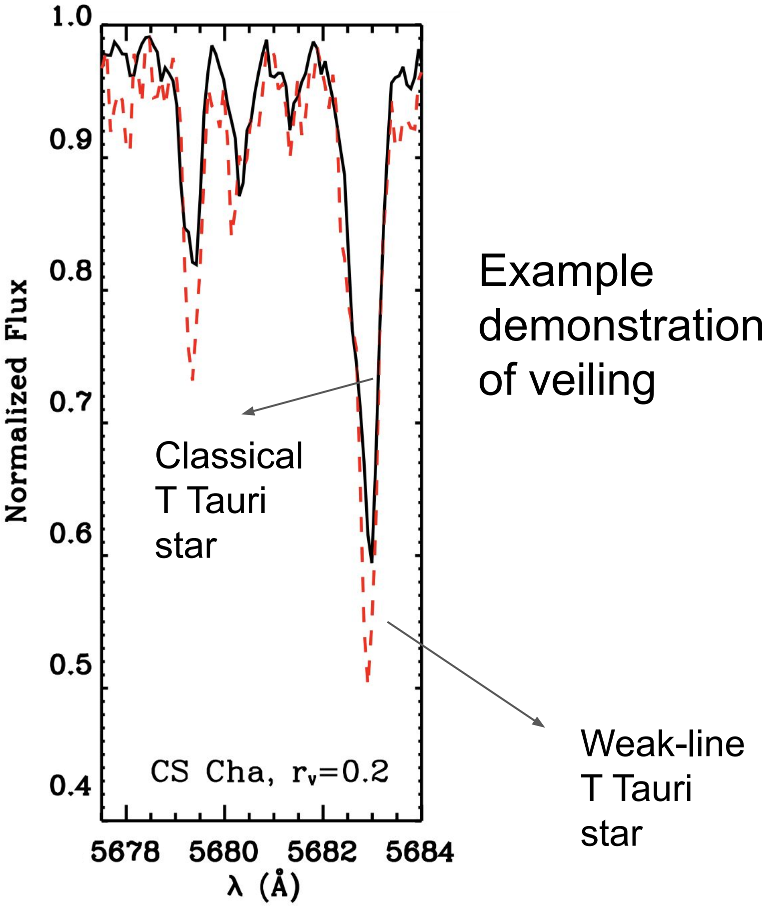
Blue shifted absorption is the evidence of the disc **wind**



Decceleration of flow after high-density emission?

Date (2019 UT)	Accretion rate (10^{-8} M_{sun}/yr)	R_{mag} (R_{star})	W_r (R_{star})	T_{max} (K)	i (°)
12-06	1.4	3.6	0.2	8680	47.1
12-07	1.4	3.7	0.2	8800	49.4
12-08	1.2	3.5	0.2	8870	48.2
12-09	1.1	3.9	0.2	8500	53.9
12-10	1.0	3.8	0.2	8750	61.1
Result used in simulation	1.1	3.8 R_{star}			53°

Veiling at 1 μm



Example demonstration of veiling

- The shock emission **fills in the absorption lines** which makes the lines become shallower than the non-accreting spectrum.
- Such veiling detected at 1 μm but cannot be explained by the single accretion model.
- Ingleby suggested that it is due to **low-energy accretion column**.

(Ingleby et al 2013)