Saving protoplanetary disk from stellar flare

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INTRODUCTION

Pre-main sequence (PMS) stars that have short rotation periods of a few days are prone to generate powerful magnetic dipoles (Feigelson & Montmerle 1999). Such a stellar magnetic field is important for facilitating protostellar magnetic accretion and can induce warps in the inner protoplanetary disks (PPDs). In addition, the roots of the field lines are often associated with giant cold/hot spots. The extinction of the warping disk, the presence of spots, and the high-energy magnetic activities cause rich phenomena in the optical/infrared time series (Lin et al. 2021; Cemelijic et al. 2020). It is becoming possible to systematically study their interplay thanks to the monitoring of dedicated space missions. Here we report our case study on the M-type protostar, DM Tau. Based on the optical light curves and the spatial distribution of ionized gas, we decipher how the cold spots may be related to anisotropic X-ray and UV photo-ionization in the PPDs, which is key to understanding the chemical evolution and habitability.

OBSERVATIONS

K2 light curve: K2 high cadence time series observation on DM Tau was acquired during Campaign 13 from March 8 to May 27, 2017.

Optical monitoring: The optical monitoring VRI-bands observations taken by TRTs in early 2019.

JVLA (PI: T. Muto): Two epochs of JVLA observations at 12-18 GHz (Ku band) and one epoch at 8-12 GHz (X band) in 2019 August. The position angle appears to vary in time. (Figure 3)

RESULTS & DISCUSSIONS

Here we present our analysis of DM Tau's Kepler/K2, optical monitor observations, and JVLA data and the relationship between them.

OPTICAL/INFRARED

K2 light curve: DM Tau is a quasi-periodic with 7.36 d periods. (Figure 1)

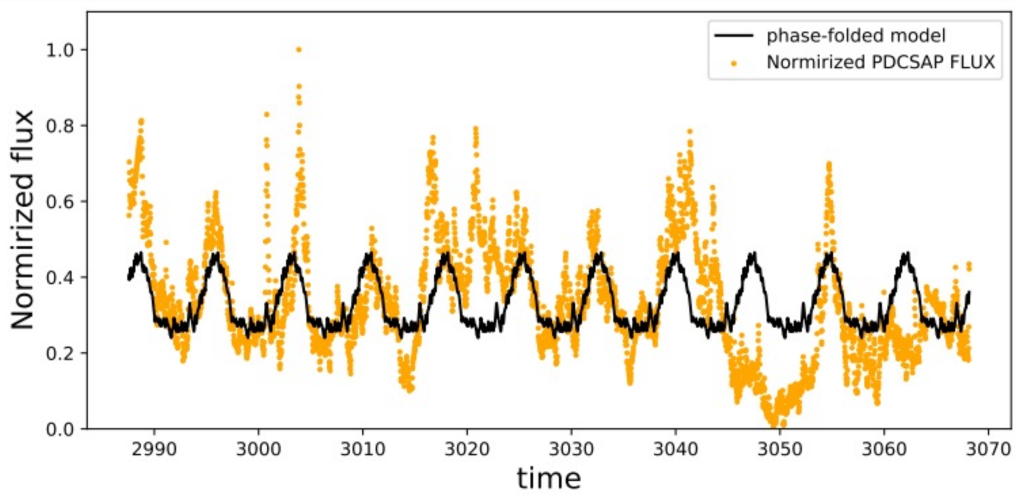
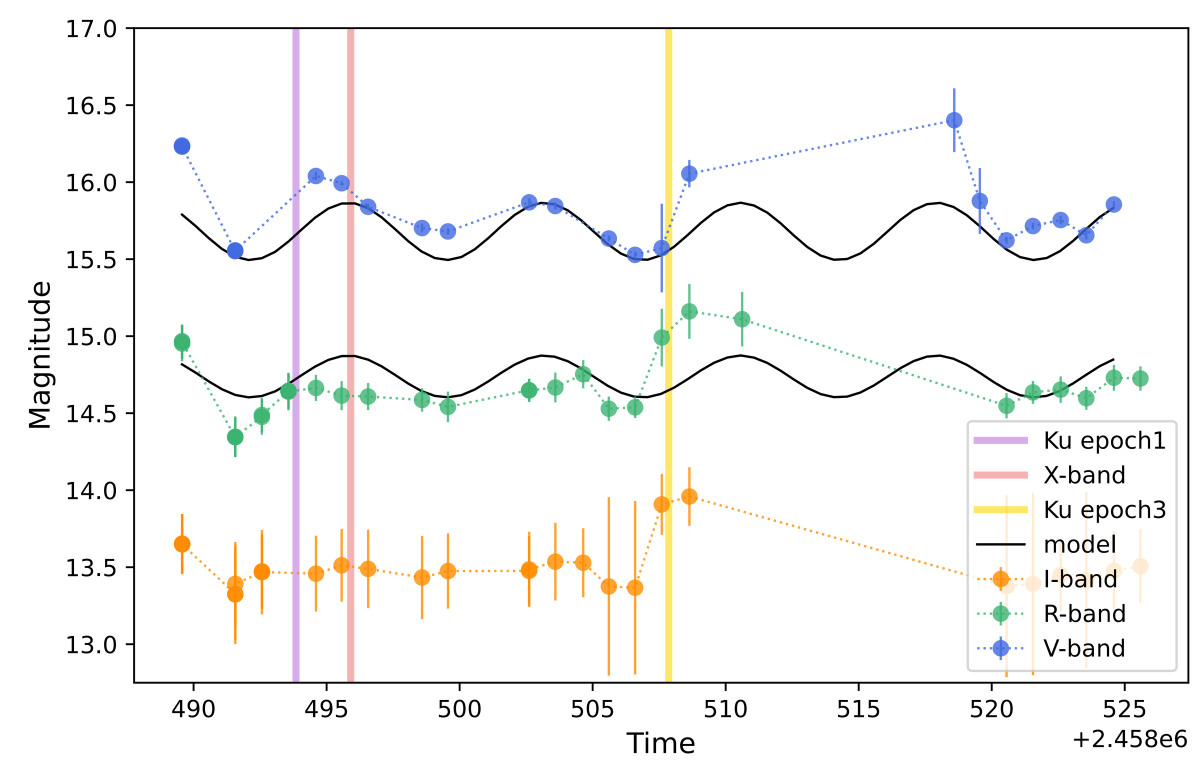


Figure 1

Used for our spot model

Optical monitoring data : Periodic variations are visible in some of the data. Following Boisse et al. (2012), we fitted the data. In our best-fit model, the spot covers ~50% of the stellar surface, spot temperature ~ 3000K, and the spot center at high latitude.



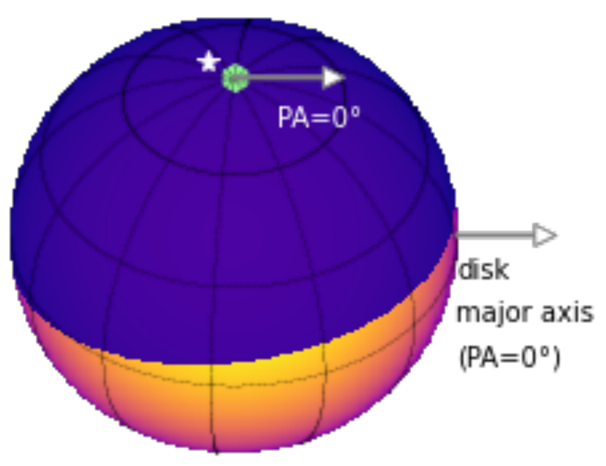


Figure 2. *Top:* A comparison of the magnitudes of the V, R, and I bands monitoring observations with those given by our photospheric model including a stellar spot. *Bottom:* Our spot model. The purple region and orange regions show a spot and a photosphere, respectively.

Spot center(PA) variations

RADIO

JVLA data: Measuring the intensity using various radii (Figure 3, color-coded arcs) for each image.

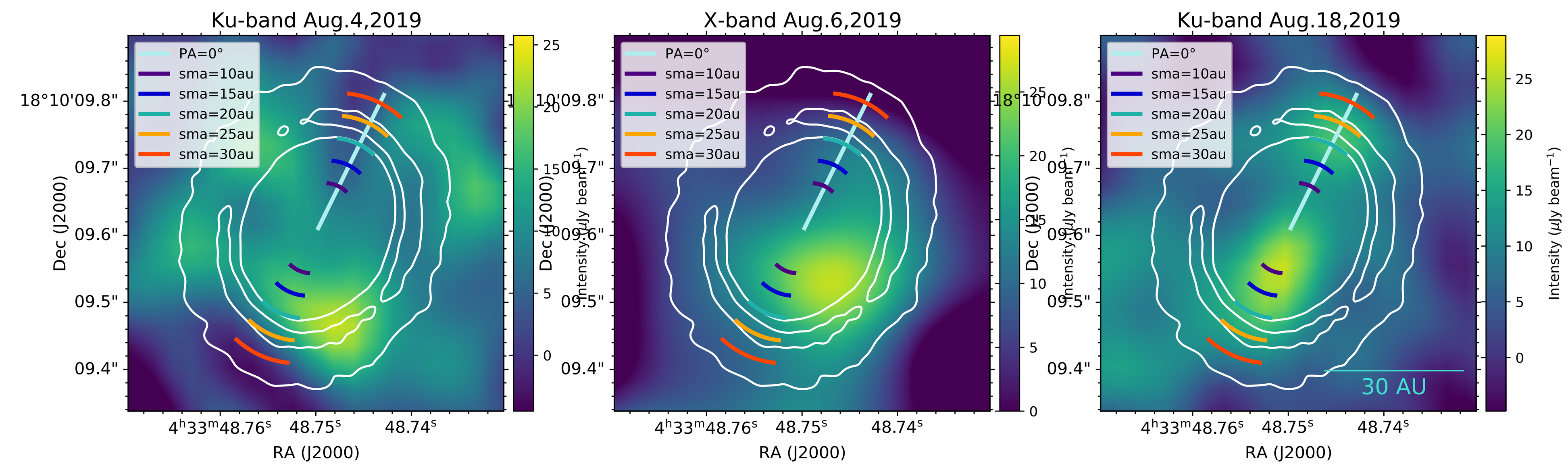
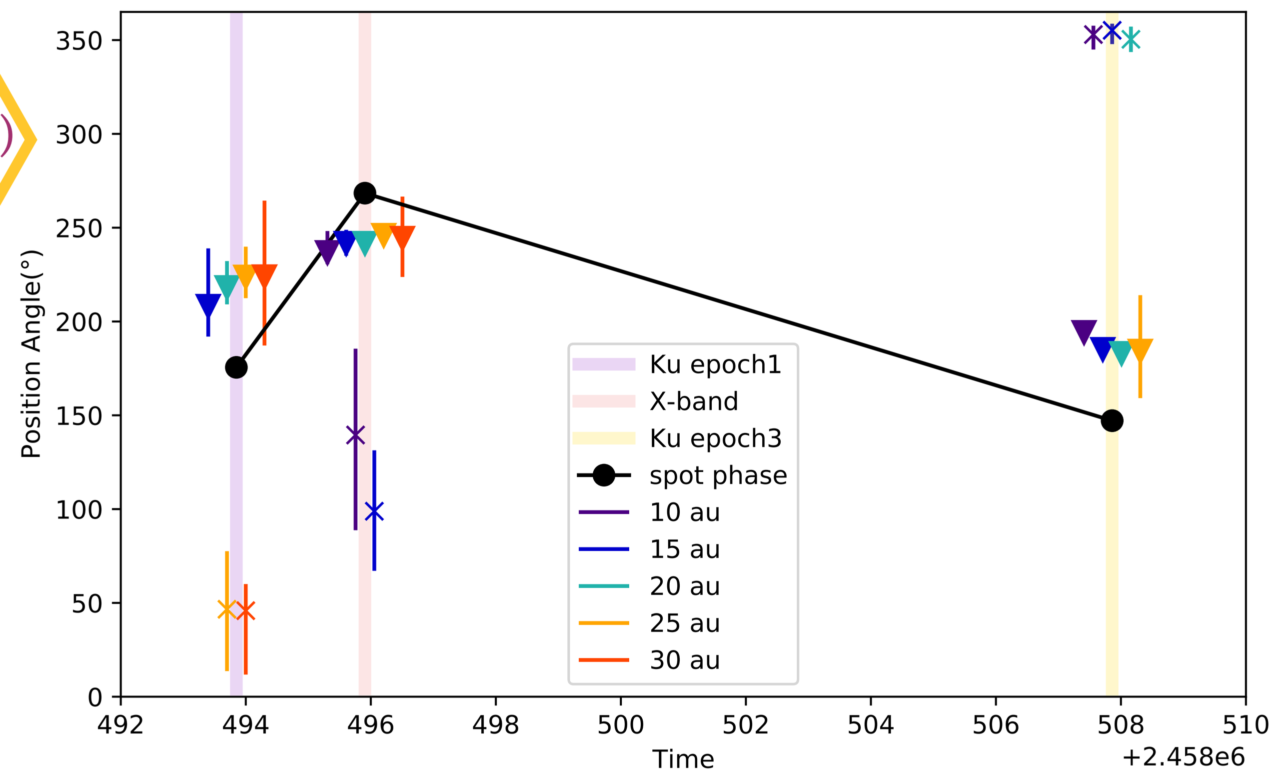


Figure 3. The JVLA images are overplotted with the ALMA 1.3 mm continuum image (Hashimoto et al. 2021).

Peak intensity (PA) variations

COMPARISON

Hypothesis: We hypothesize that the time variations of spot(optical) and radio are related. In other words, the disk is illuminated by beamed X-ray emission emanating from the spot on the host star. We therefore defined the phase of the spot center and compared it to the phase change in the intensity of the JVLA(Figure 4, left).



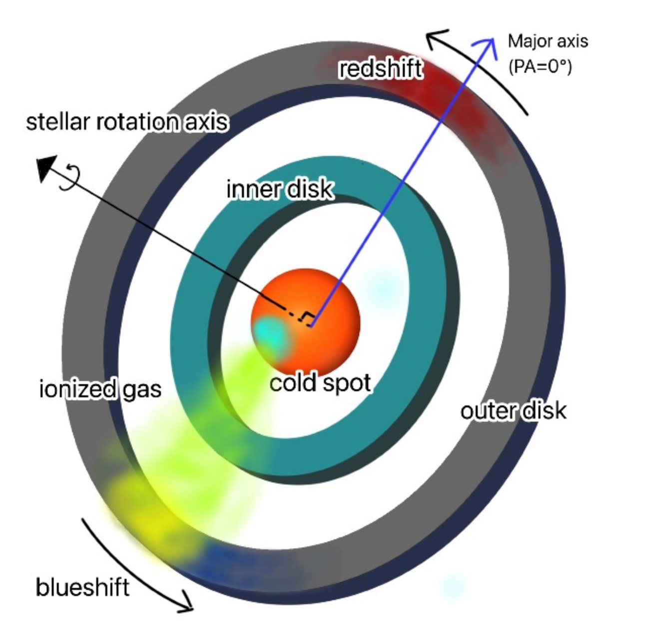


Figure 4. *Left:* The plot compares the mean position angle derived based on the Gaussian fittings to the azimuthal intensity profiles. Downward triangles and closs marks show the brightest and second brightest peaks at each radius, respectively. The black circle indicates the spot phase. *Right:* Schematic model for interpreting the observations on DM Tau.

CONCLUSION

We analyzed the optical, infrared, and radio observational data and identified preliminary correlations in their time variability. Each of the data was observed at different periods. Then, we hypothesize that the X-ray emission from the stellar spot makes the outer disk illuminate and that the radio emission from the disk is time-varying. To confirm the hypothesis, we plan to analyze joint JVLA and XMM-Newton observations data.

This work has been submitted to ApJ (first referee report received). We welcome discussion and are happy to provide a PDF preprint upon request. Our contact information can be obtained via the QR code on this poster.

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