Variability in Disks; a Signpost for Exoplanets

Thematic Areas (Check all that apply):

☒ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☒ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☐ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☐ (Theme D) A specific concept for a large-scale (∼500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: To gain a full understanding of the exoplanet population and formation processes, they must be studied over the full range of ages, masses and separations. An under-utilized mechanism for detecting and characterizing exoplanets is via temporal variability in circumstellar disks. The timescales of variable illumination of outer disk regions can be linked to planets inside of the nominal inner working angles of ALMA and Ground-based AO, HST and JWST coronagraphs. Rotating shadows have been observed around several disks (e.g. TW Hya) and can be linked to inner disk structures undergoing dynamical interactions with unseen exoplanets. The rotational timescale of this illumination pattern can distinguish between planet and non-planet origins but even the best studied systems are hard to pin down on the timescale of a multi-cycle proposal. The shadowing method is the only way to detect young planets in the inner regions of active circumstellar systems and should be considered within the context of future HST and JWST exoplanet initiatives. One possibility to support these observations is the prioritization of long term monitoring projects with HST and JWST of community-selected disks with shadows, akin to the Outer Planet Atmospheres Legacy (OPAL) project for Solar System objects.

Anticipated Science Objectives: Protoplanetary disks give valuable insight into the initial conditions of planet formation and evolution. Modern instruments can image the structures of disks within several tens of au of the central star, but terrestrial and giant planet formation regions are harder to observe. *Protoplanetary disks that exhibit shadows provide valuable information on structures that exist interior to* $\sim$*10 au* [e.g. 1, 2, 3]. The TW Hya disk shows a well studied shadow using multiple HST/STIS+NICMOS epochs with a period of 15.9 years [4, 5], and consistent with a warp or precessing disk driven by a planet (Figure 1 a, b).

Precessing/misaligned inner disks can explain shadows in at least four other disks [6, 7, 8, 9, 10]. Owen and Lai [11] and Matsakos and Königl [12] show that companions at exterior and interior to disks can generate misalignments and precession sufficient to cause shadows. Nealon et al. [13] show that disk warps raised by Jupiter analog planets cast detectable shadows. The shadow rotation rate and period and the behavior of the shadow's shape vs. wavelength determines whether a shadow is due to a planet, inner accretion structure, or stellar spots.

An example of shadow discrimination is Wolff et al. [14], who found a shadow on the PDS 66 disk over short timescales ($\sim$ 3 months). The shadow interpretation and its location was due to multiple observations across different wavelengths with sufficient cadence to constrain the shadow coherence and timescale (Figure 1 c, d).

Currently the true rate and timescale of shadow evolution is poorly known–thus the need for a) a dedicated campaign to search for planet-driven shadows and b) comprehensive follow-up observations on timescales of 1-20 yr. Prioritization of this science theme will directly constrain planet formation models and impact our understanding of planet migration, mass accretion, and protoplanet architectures.

Urgency: The STIS coronagraph on the Hubble Space Telescope remains the most sensitive instrument for scattered light surface brightness disk detections with the smallest inner working angle. A sample of shadowed disks should be identified soon for longer term follow-up with both HST/JWST.

Risk/Feasibility: Transition disks are easily identified from spectral energy distributions, providing ready targets, and many show variability.

Timeliness: This is an emerging field with community support in modeling and data interpretation. Few disks have been observed more than once or twice.

Cannot be accomplished in the normal GO cycle: This work requires monitoring of the variable illumination pattern across multiple instruments and in some cases over timescales much longer than the multi-cycle timescale; a challenging prospect for a GO proposal.

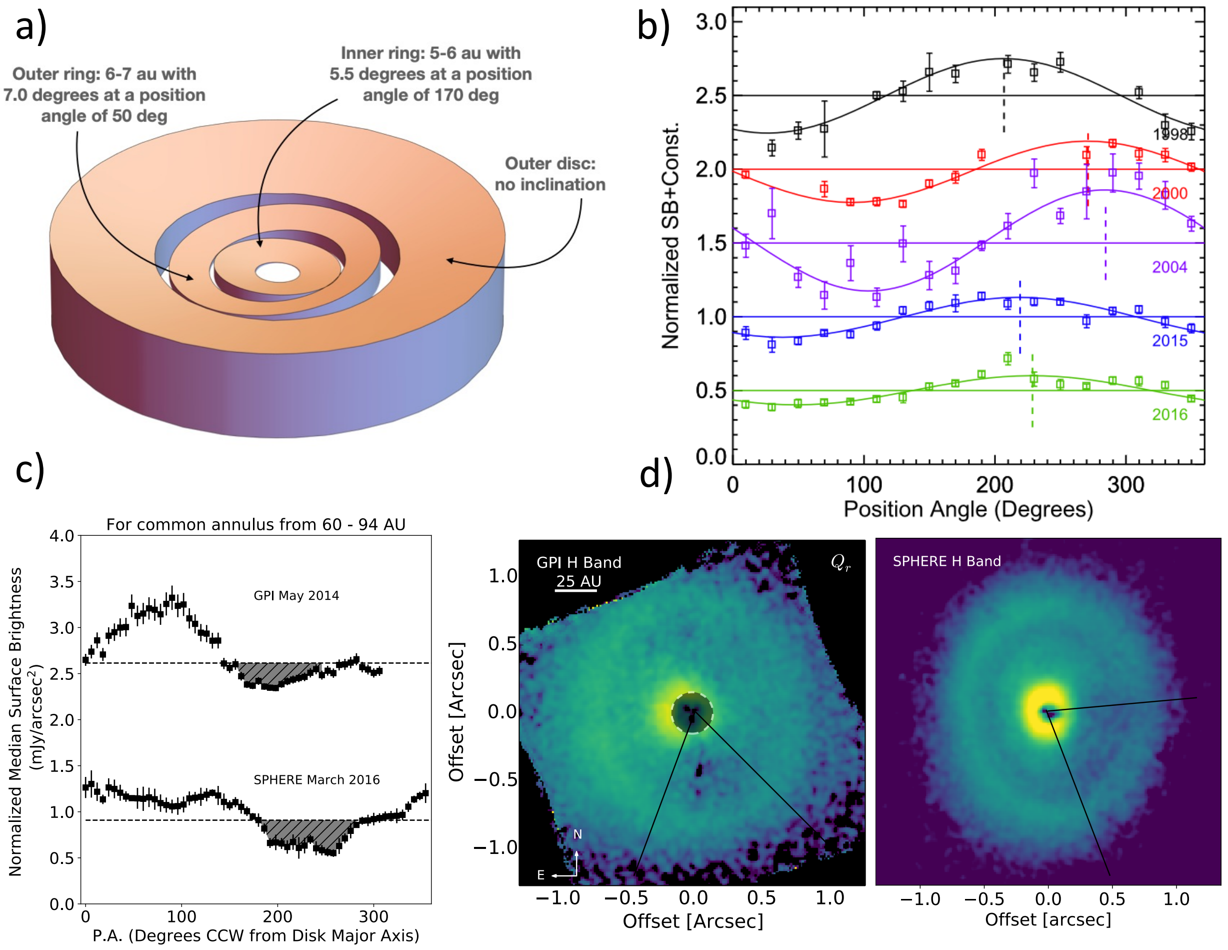

Figure 1: a) Schematic for the misaligned disk model for TW Hya that was found to evolve from casting one shadow to casting two shadows [5] discovered after 20+ years of monitoring. b) Azimuthal profiles from the same orbital distance (98 au) from various epochs of STIS and NICMOS observations of TW Hya, demonstrating the motion of the shadow, consistent with a 15.9 yr period. This implies a physical location of interior to 5.6 au. c) The azimuthal profile for two epochs of polarized intensity data for PDS 66. The shadowed region is shaded. The mean and standard deviation was taken for a common annulus extending from 60-94 au. The motion is consistent with a rotational period for the shadow of ∼22 years (30 degrees over 22 months). With just two images a smaller period for the shadows cannot be ruled out. d) left: H band radial stokes Q image obtained with the Gemini Planet Imager in May 2014 [14]. Right: H band radial stokes Q image obtained with the SPHERE/IRDIS instrument in March 2016 (PI Avenhaus). The outer disk shadow is seen to rotate 30 degrees between the two epochs.

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