Imaging Protoplanets from Space: the HALPHA Survey and Beyond

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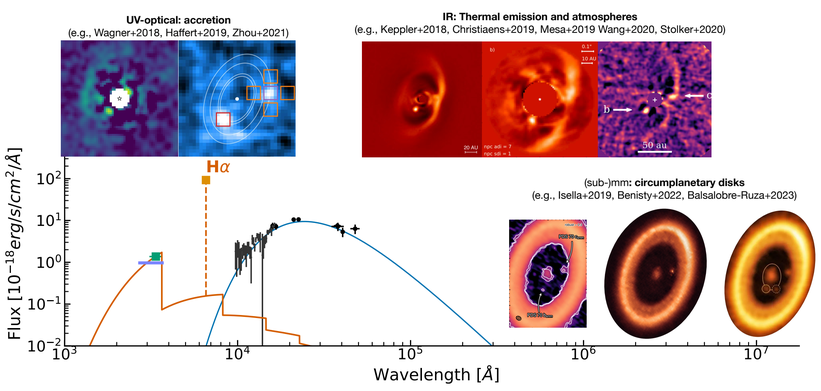
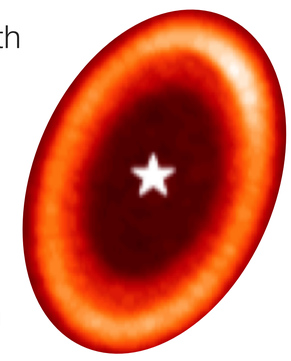
Background and Motivations

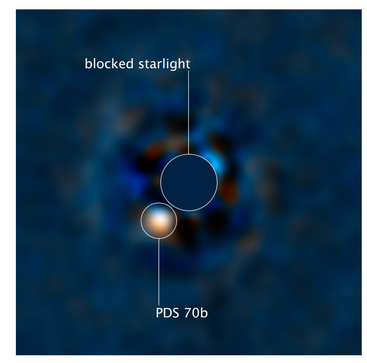
- The discoveries of PDS 70 b and c have provided direct insights into the mass assembly process of giant planets.
- The planets' strong Hα emission and their locations within the protoplanetary disk gaps suggest that imaging transition disks at Hα wavelengths is an effective method for detecting forming planets.
- The Hubble Space Telescope's Wide Field Camera 3 (HST/WFC3) is a powerful planet imager **(Zhou et al. 2021, 2023)**. High-contrast imaging with HST is complementary to ground-based searches.



Survey Design and Observations

- **Targets:** ten transition disks with giant inner cavities. Disks are selected based on ALMA dust continuum images (Francis & van der Marel 2020). Most targets are challenging for ground-based observations.
- **Instruments:** WFC3/UVIS with F656N narrowband Hα filter.
- **Observing strategies:** Two-roll angular differential imaging. Four-point half-pixel dithering was adopted to enhance pixel sampling.
- **Image analysis strategies:** Joint use of angular differential imaging (ADI) and reference star differential imaging (RDI, see Sanghi et al. 2021).
- **HALPHA:** Hubble Accreting Luminous Protoplanets in H-Alpha Survey.

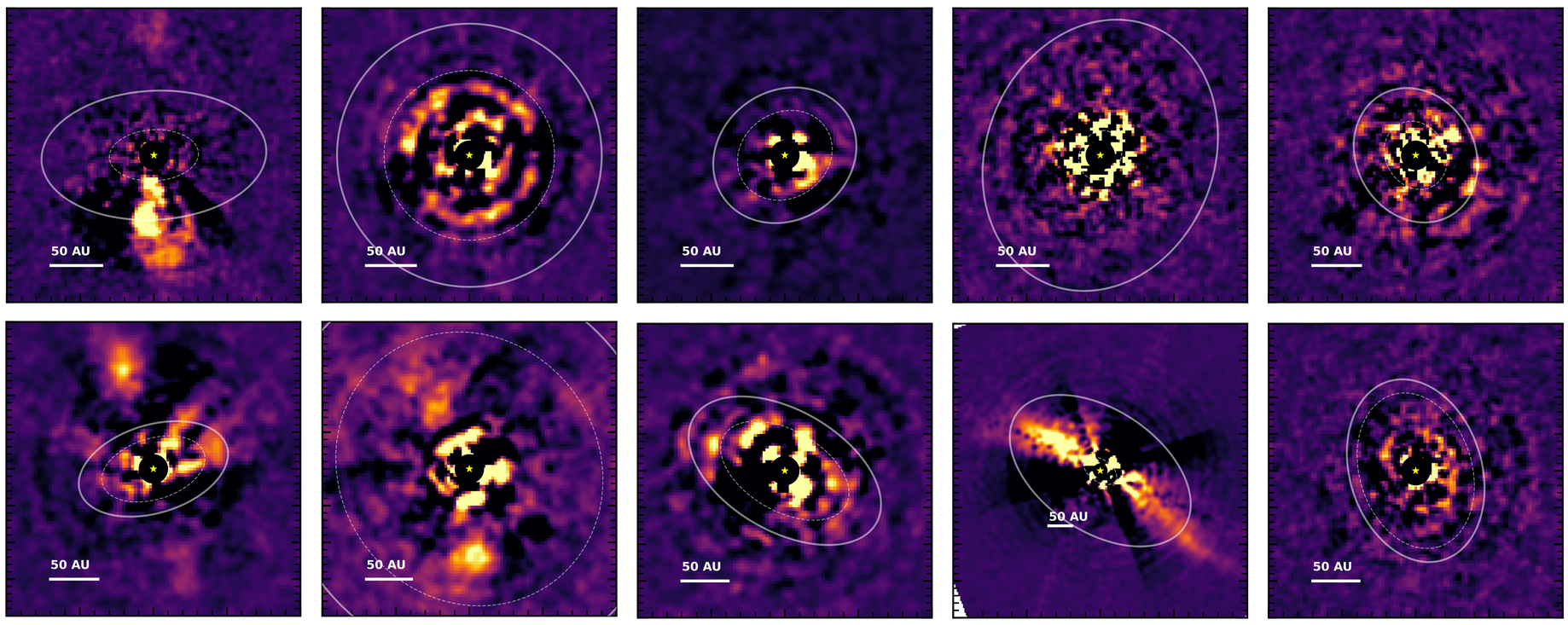




Results and Highlights

A Compilation of Primary-subtracted Hα Images (Zhou et al., in prep)

- RDI results ($1'' \times 1''$ cut-outs) are shown because they best preserve disk structures, although combining ADI and RDI achieves the deepest contrast.
- The gray solid and dashed line indicates the location of the peak brightness and inner edges of the dust continuum emission.
- **The sensitivity of these images is sufficient to detect planets similar to PDS 70 b.** Raw contrasts exceed 8 magnitudes at a separation of 0.2″ and 12 magnitude at 0.5″.

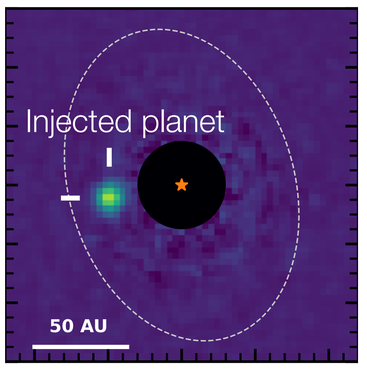


Disks and Outflows: Friends or Foes?

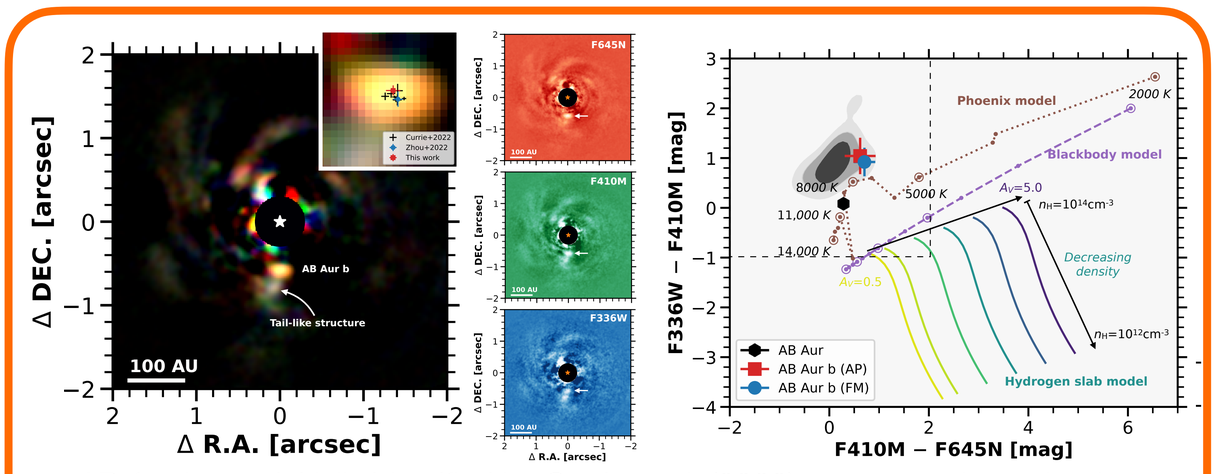
- Most of the images **reveal spatially extended structures.**
- These structures are primarily **scattered light** tracing micron-sized dust. In two cases (left-most column), the images also show outflows perpendicular to the disk planes.
- These detections provide valuable insights into the architecture of protoplanetary disks and the process of star formation..
- They can also act as contaminants, potentially obscuring planetary signals, creates challenges in identifying forming planets.

Where are the Planets?

- Planets like PDS 70 b & c (point-source, accreting, located in the disk cavities) are convincingly detected.
- The right panel illustrates the injection of a fake signal mimicking PDS 70 b into a target that most closely resembles PDS 70 (nearly face-on disk with a clear and large gap).
- The injected planet is confidently recovered; real data do not reveal convincing point sources.
- Potential explanations for non-detections: **disk contamination; extinction by disk material; accretion variability.**



The Curious Case of AB Aur b



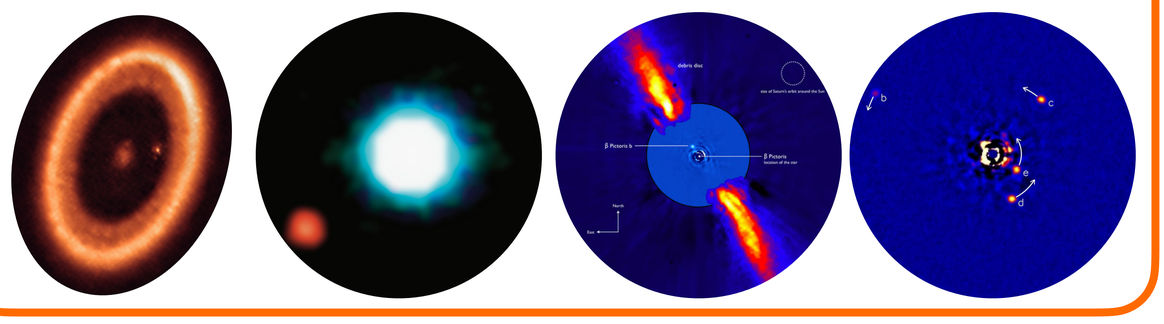
- AB Aur b was initially identified by Currie et al. (2022) as a protoplanet that is possibly formed through gravitational instability.
- Images from the HALPHA survey could not confirm active accretion (Zhou, Sanghi et al. 2022). Also see Paβ observations in the poster by Biddle et al.
- AB Aur b was detected in HST/WFC3 images in UV and optical bandpasses (left) and the **observed colors (right) are consistent with scattered stellar light (Zhou et al. 2023)**.
- New multi-epoch HST/WFC3 Hα observations will further investigate the nature of AB Aur b by studying its temporal variability (Bowler, Zhou, in prep).

Beyond HALPHA: Time-series Imaging

Upcoming Space-based Direct-imaging Monitoring Programs

Program ID	Target	Instrument	Probed Processes
HST 17427	PDS70	WFC3/UVIS	Accretion
JWST 3181	2M1207	NIRSpec/IFU	Accretion; patchy atmosphere
JWST 4758	β Pic	NIRCam	Rotation; atmosphere
JWST 6139	HD8799	NIRCam	Rotation; atmosphere

Upcoming HST and JWST imaging time series will provide new insights into the formation, rotation, and atmospheres of four iconic directly imaged exoplanet systems.



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References: Benisty et al. 2021, ApJL, 916, L2., Biddle et al. 2024, AJ, 167, 172B, Close et al. 2020, AJ, 160, 221, Currie et al. 2022, Nature Astronomy, 6, 751, Francis & Van Der Marel, 2020, ApJ, 892, 111, Sanghi et al. 2022, AJ, 163, 119, Zhou, et al. 2021, AJ, 161, 244, Zhou, Sanghi et al. 2022, ApJL, 934, L13 , Zhou et al. 2023, AJ 166, 220

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