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Characterizing Protoplanetary Disks and Young Exoplanets with VLT/NACO

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Introduction and Motivation

Using high-contrast direct imaging techniques several gas giant planets orbiting young, nearby star have been imaged in the last years. At least some of these stars do not only harbor one (or more) gas giant planets, but also a circumstellar (debris) disk. Interestingly, some of these disks shows geometric or morphological evidence for the orbiting planet. Examples include a) beta Pictoris that shows warps in its disk and and a tilted inner disk (Lagrange et al. 2010); b) Fomalhaut, where the center of the large debris ring does not coincide with the central star (Kalas et al. 2008); and c) LkCa 15, where a young planet candidate was detected inside the large gap of the transition disk (Kraus & Ireland 2012). Turning this around, one may think that circumstellar disks that show string sub-structures close to the star might be good targets to search for (young) planets…

Protoplanetary Disk Imaging

Key collaborators: H. Avenhaus, A. Garufi, E. Buenzli, H. M. Schmid, S. Wolf, C. Dominik.

Technique: To image disks around young Herbig Ae/Be stars with high-spatial resolution, high contrast and small inner working angles (IWA) we use VLT/NACO in polarimetric differential imaging (PDI) mode in the H and K band. By subtracting two simultaneously recorded images from each other that have been taken through linear polarizers with *orthogonal* polarization directions, the light form the central star cancels out –it's largely unpolarized – and the protoplanetary disks are revealed because photons scattered from dust grains on the disk surface are polarized. IWAs around 0.1'' are robustly obtained.

Key Results (see also Fig. 1):

HD100546: The disk rim around ~15 is AU detected; there's a lack of polarized flux detected along the northern direction; the backside of the disk appears brighter in polarized light than the front side (Quanz et al. 2011).

HD169142: Face-on disk with an inner hole (<20 AU), then bright, unresolved disk rim (~25 AU), then annular gap (~40–70 AU), then outer disk out to ~250 AU; brightness asymmetries are seen in disk rim (Quanz et al. 2013b).

HD142527: Large asymmetric and eccentric inner disk hole and no indication for large amount of dust close to the star; several spiral arms; lack of polarization in two locations (Avenhaus et al. in prep.).

SAO206462: Large Inner cavity in disk (<28 AU) followed by bright rim; two main spiral arms plus additional fainter features (Garufi et al. in prep.).

Main conclusion: Disks show huge diversity in structures and geometries.

Main questions: What's creating these structures? Planets? Instabilities?

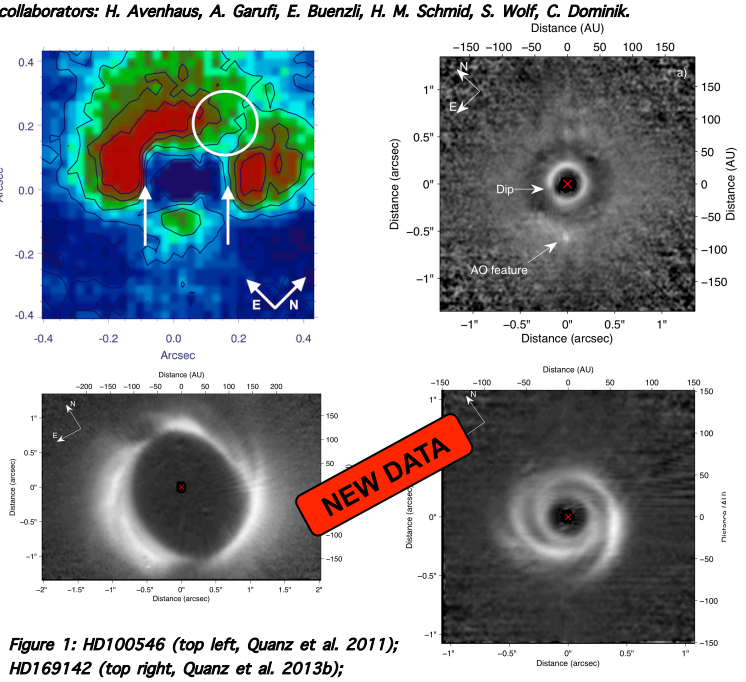

Figure 1: HD100546 (top left, Quanz et al. 2011); HD169142 (top right, Quanz et al. 2013b); HD142527 (lower left, Avenhaus et al. in prep.); SAO206462 (lower right, Garufi et al. in prep.)

Young Exoplanet Imaging

Key collaborators: A. Amara, M. R. Meyer, J. H. Girard, M. Kenworthy, M. Kasper

Technique: The search for (young) exoplanets is done in Angular Differential Imaging (ADI) mode in the L' filter (~3.8 micron) with (or without) the Apodizing Phase Plate (APP) coronagraph at VLT/NACO. Prime targets are disks that show sub-structures possible introduced by planet-disk interaction (see above). The data reduction is done with PynPoint a Principal Component Analysis based software package for high-contrast exoplanet imaging (Amara & Quanz 2012).

Key Results (see also Fig. 2): A protoplanet candidate is detected in the disk around the Herbig Ae/Be star HD100546 (d = 97 pc, age = 5 – 10 Myr, B9Vne; Quanz et al. 2013a). The L-band source is found exactly along the direction where the disk shows a lack of polarized light in the PDI images (see above). The deprojected separation from the central star is ~68 AU and the emission appears slightly extended. The apparent brightness in L' is 13.2±0.4 mag and the minimum luminosity is estimated to be $4 \cdot 10^{-4}$ $L_{\odot}$. Best explanation combining the results from the PDI and the ADI images is gas giant planet in the process of formation.

New data from early 2013 confirm first results. The object is re-detected in L' and newly detected in M' and first astrometric analysis indicates common proper motion with the central star. The emission appears again extended with a clear point source component at least in L'. Images obtained at shorter wavelengths in the Ks filter are currently analyzed, but so far object is not clearly detected. Color and brightness analyses are ongoing.

Main conclusion: A planet might indeed be forming in the HD100546 disk.

Main questions: What's the underlying physics that leads to the formation of such an object? What is the extended component and what's the heating source?

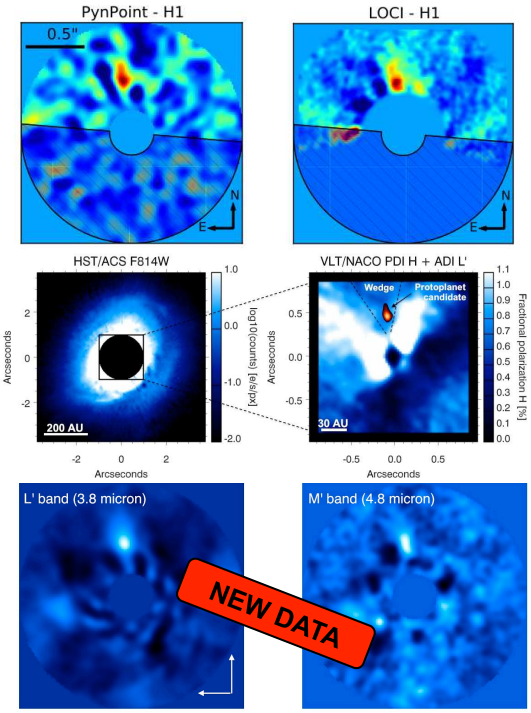

Figure 2 Detection of a protoplanet candidate in the disk around HD100546 at a separation of 68 AU (top and middle row; Quanz et al. 2013a). New data from early 2013 in L' and M' (bottom row). Protoplanet clearly redected in both filters.