Diagnosing the SEEDS of Planet Formation

John Wisniewski

Department of Astronomy, University of Oklahoma

on behalf of the 100+ member international SEEDS team
OU contributors: Jun Hashimoto, Jamie Lomax, Evan Rich

DoAr–28 polarized intensity
(Rich et al 2014, in prep)
Motivation: distribution of confirmed extra-solar planets

- Radial velocity & transit surveys detect older planets close to their host star.
- Direct imaging surveys can detect younger planets farther from their host stars, including systems in the process of forming.
SEEDS survey

- Strategic Exploration of Exoplanets and Disks with Subaru (SEEDS)
  - PI: M Tamura; co-PIs: T Usuda, H Takami, T Yamada

  - allocated 120 nights over 5 yrs on Subaru telescope
  - uses the HiCIAO coronagraph + AO-188 system at H-band
  - direct, coronagraphic, & (linear) polarimetric observing modes

Survey Goals

1) Perform census of exoplanets in the outer environments of ~250 solar-type (and more massive) stars

2) Spatially resolve ~200 protoplanetary (potentially planet forming) disks

3) Establish a link between disk structure and the presence of exoplanets
SEEDS direct imaging planet survey: results

GJ 758

G9 star, ~8 Gyr old
GJ758B ~ 30-40 MJupiter

Thalmann et al 2009; Janson et al 2011
SEEDS direct imaging planet survey: results

kappa And

B9 star, ~20-200 Myr old
kappa And B ~ 13-50 MJupiter

Carson et al 2013; Bonnefoy et al 2014
GJ 504

G0 star, ~160 Myr old
GJ504B ~ 4 MJupiter
Advantages of (linear) polarimetric imaging

- Polarimetric imaging --> helps suppress light from central star, increasing contrast ratio one can achieve to resolve scattered light from young circumstellar disks
  - Optical/near-IR: traces small, micron-size grains at the disk surface
- Polarization properties (% linear polz) yields information about grain properties, but is difficult to do from the ground
...could also help detect circum-planetary disks

HD 100546

B9 star, ~5-10 Myr old
HD 100546B < 15 MJupiter

see also Rodigas et al (2014)

Currie et al 2014
SEEDS disk results I: confirmed transitional disk gaps

- Transitional disks (defn): exhibit a deficit of near-mid IR flux, interpreted as evidence of an inner disk gap or hole (see e.g. Calvet et al 2005; D’Alessio et al 2005; Espaillat et al 2008)

- SEEDS imagery of LkCa 15 --> confirmed gapped nature of transitional disks in the near-IR

Thalmann et al (2010)
SEEDS disk results II: filled inner gaps

• Some transitional disks with observed sub-mm gaps are “filled-in” in near-IR polarized intensity
  • MWC 758 (Grady et al, 2013)

• see also: SR 21 (Follette et al 2013), SAO 206462 (Muto et al 2013), UX Tau A (Tani et al 2012)
SEEDS disk results III: different gap sizes

- **PDS 70** (Hashimoto et al. 2012, 2014)

  - Gap = 80 AU at 1.3 mm
  - Gap = 65 AU at H-band
SEEDS disk results IV: azimuthal asymmetries

- PDS 70  (Hashimoto et al 2012, 2014)

thermal emission at 1.3 mm  

polarized intensity at H-band
PDS-70 interpretation: planet-induced dust filtration
SEEDS disk results V: spiral arms & planet constraints

SAO 206462: Muto et al 2013
M \sim 0.5 M_{\text{Jupiter}}

MWC 758: Grady et al 2013
M \sim 5 M_{\text{Jupiter}}

AB Aur: Hashimoto et al. 2011; Lomax et al 2014, in prep

\frac{M_{\text{planet}}}{M_{\text{star}}} \sim (\text{pattern amplitude})(h_c)^3
SEEDS disk results VI: variable illumination

MWC 480: Kusakabe et al 2012
SEEDS disk results VI: variable illumination

IR maximum light (shadow cast)  IR minimum light (photons scatter off disk)
Summary

- Polarimetric imaging is paving discovery space in studying how exoplanets form -- via suppressing light from the central protostar

- Science results:
  - Gapped nature of transitional disks confirmed;
  - Differences in radial & azimuthal distribution of dust via multi-wavelength imagery --> sculpting by planets
  - Complex disk morphologies observed --> used to constrain location and mass of forming planets
  - time-variable self-shadowing of outer disks by inner disk
Questions?