Joint Observation of Protoplanetary Disk with ALMA and Subaru

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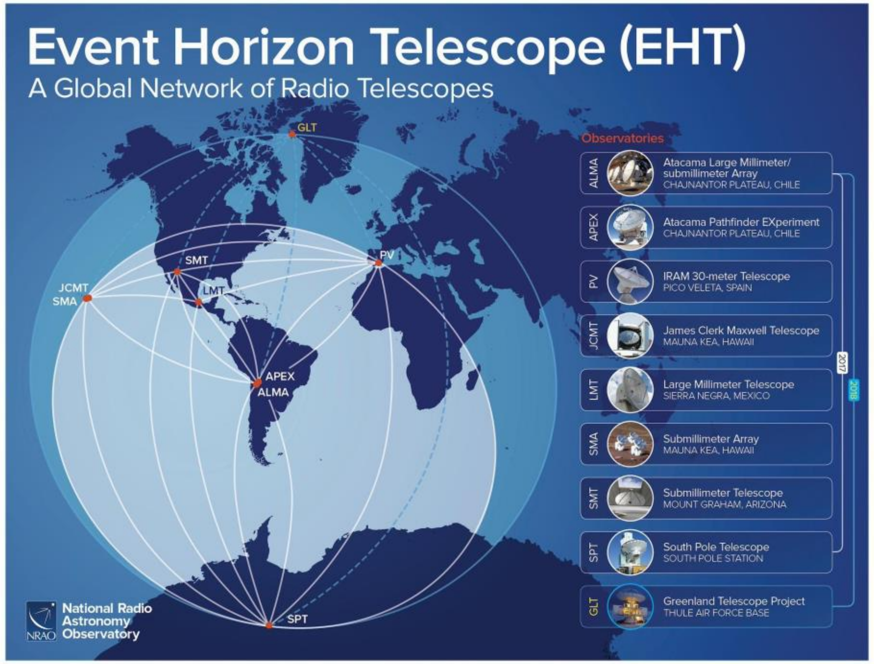
* I was asked to consider science cases for ALMA-Subaru joint proposal.
* If you are interested in Subaru SAC discussions, please visit Subaru SAC minute below (sorry for Japanese...).

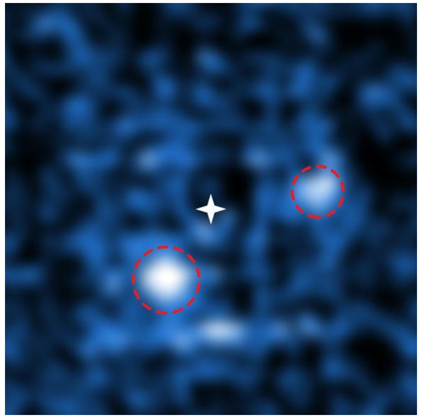
https://www.subarutelescope.org/Science/SACM/SAC2020/20210713.pdf

What is a joint observation ?

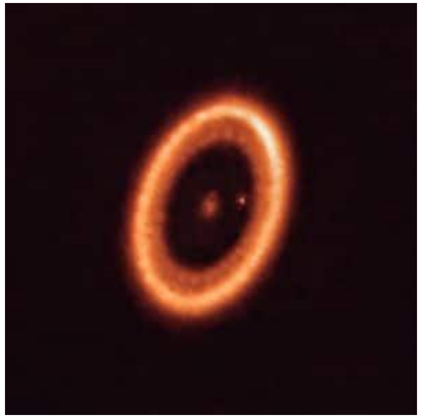
- (Maybe) similar to ALMA-VLBI proposal.
- Require simultaneous obs or obs within one ALMA cycle (i.e., one year).
- Good science case: variability within one year.
- Not suitable science case for joint observation:
  - New exoplanet was found with Subaru !
  - Follow-up observations with ALMA next year !
  - These can be done within current framework...



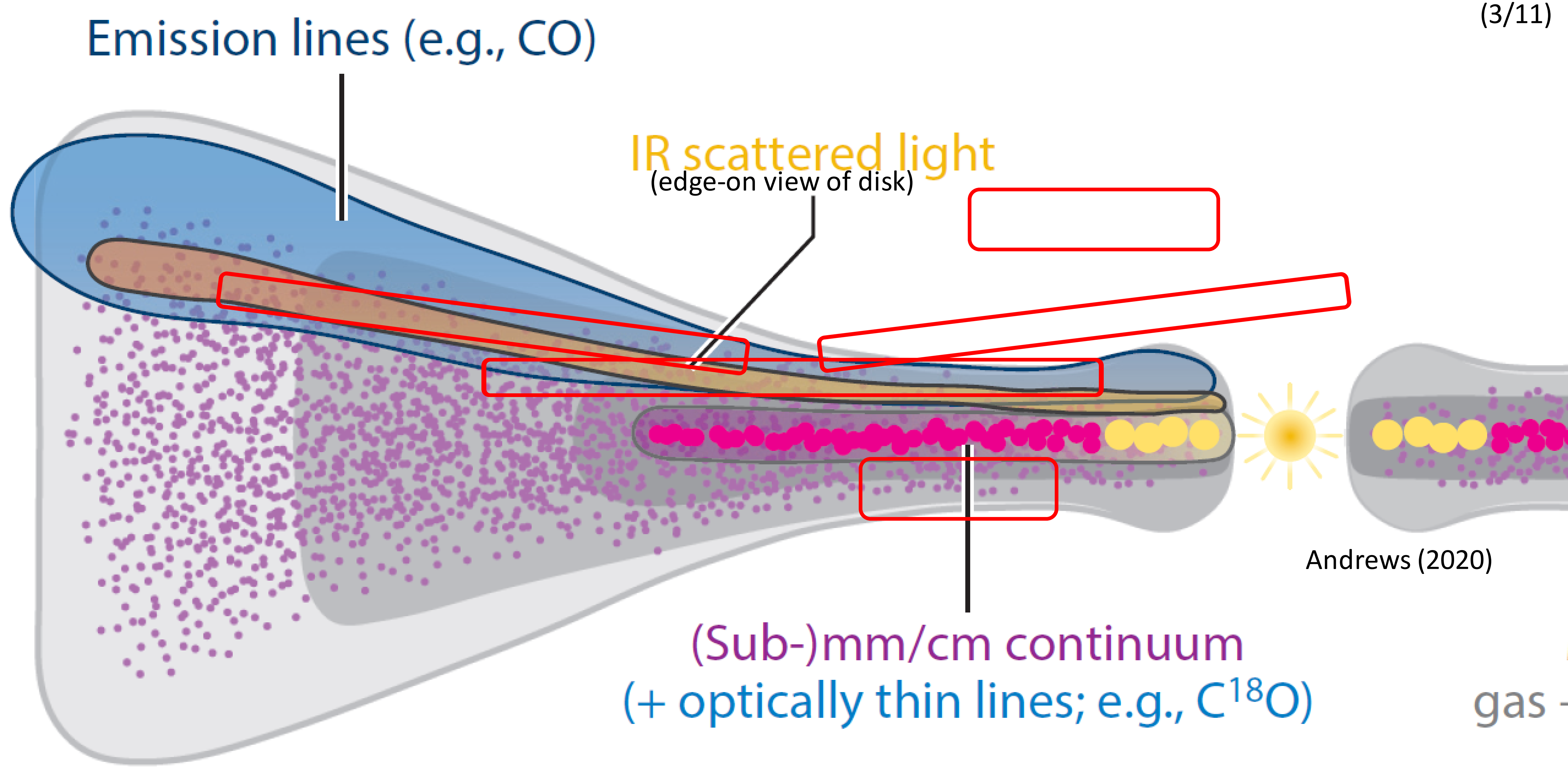
PDS70 planets detected by VLT/SPHERE (Haffert et al. 2019)



Follow-up with ALMA



ALMA dust continuum of PDS 70c (Benisty et al. 2021)

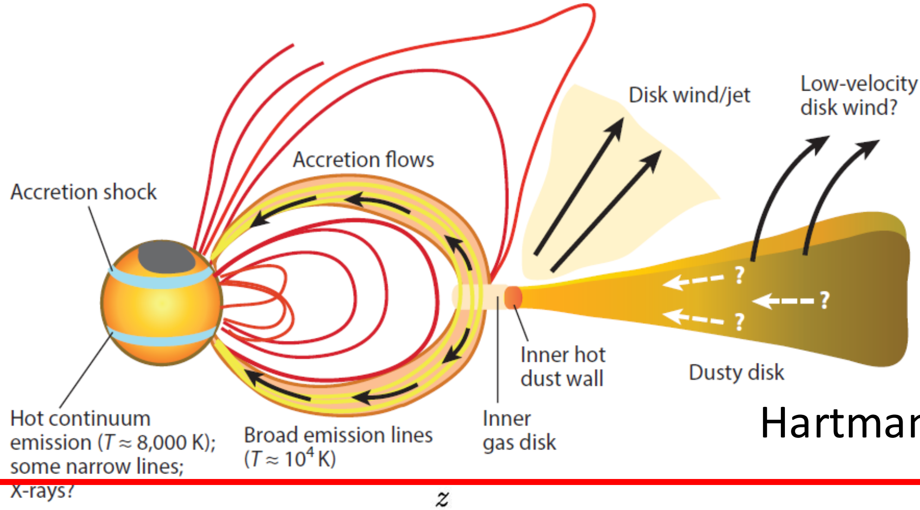


Andrews (2020)

- +optically thick gas (e.g., ^{12}CO)

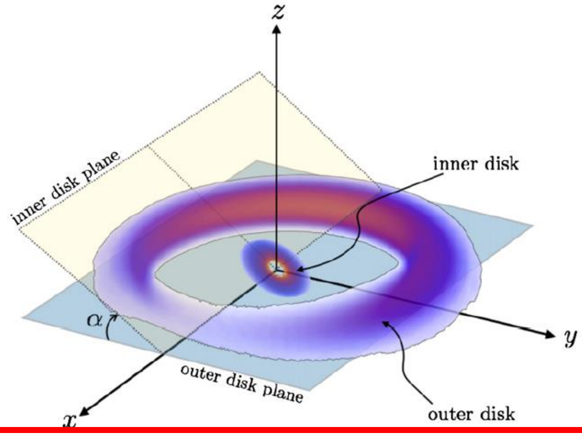
1-yr variability in the field of protoplanetary disk

- Related to the inner disk region at r <1 au, corresponding to dynamical time scale of <1 yr.
  - Accretion onto star/plant



Hartmann et al. (2016)

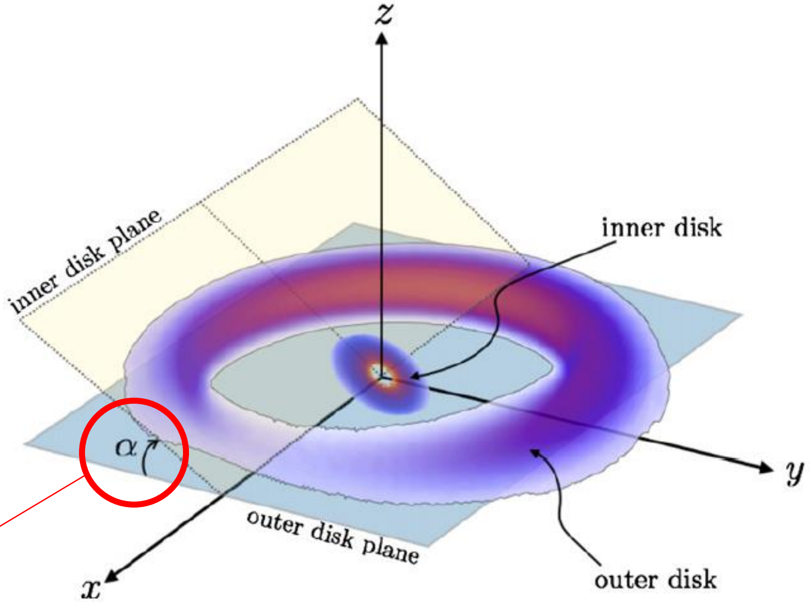
  - Dynamics in inner disks



Marino et al. (2015)

Misaligned inner disks

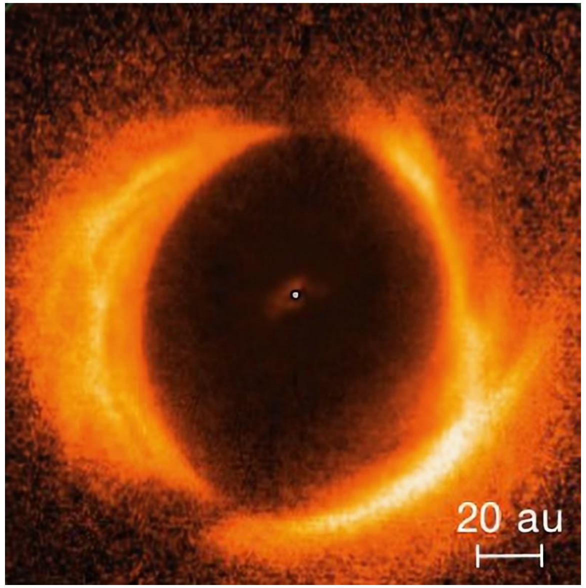
Shadow cast by inner disks in scattered light image



α: misaligned angle between inner and outer disks

Optical image by VLT/SPHERE (α=70 deg)

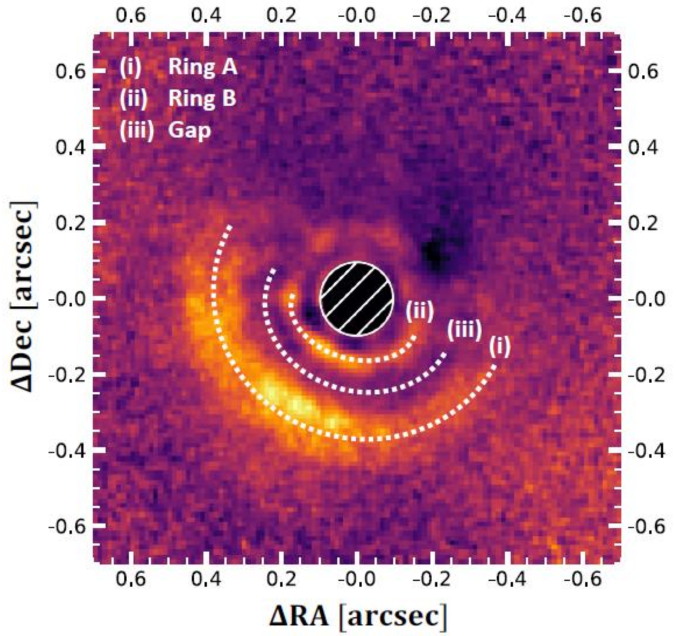
Shadows as two dips



Avenhaus et al. (2017)

NIR image by VLT/SPHERE (α=10 deg)

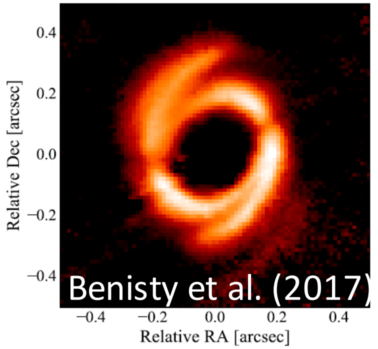
Shadows on half of disk



Bohn et al. (2019)

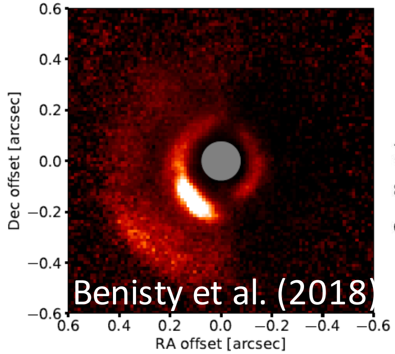
Optical or NIR image gallery of shadows in outer disks

HD 100453



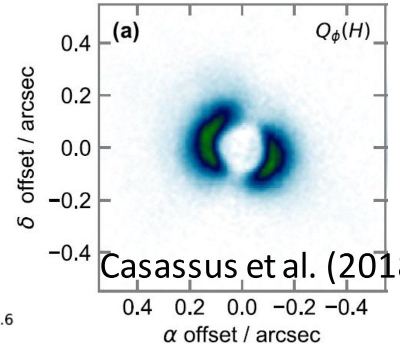
Benisty et al. (2017)

HD 143006



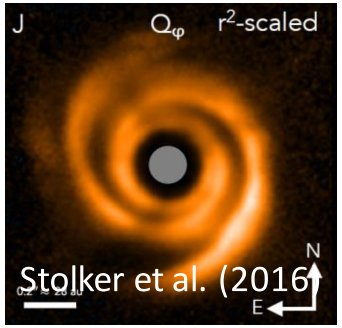
Benisty et al. (2018)

DoAr 44



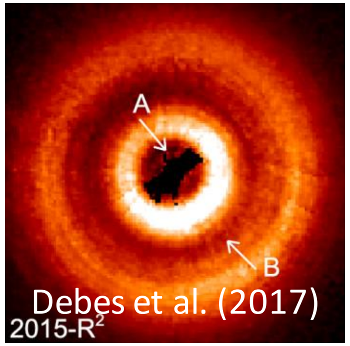
Casassus et al. (2018)

SAO 206462



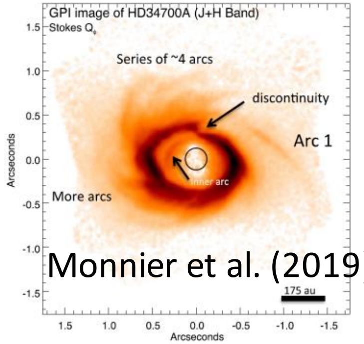
Stolker et al. (2016)

TW Hya



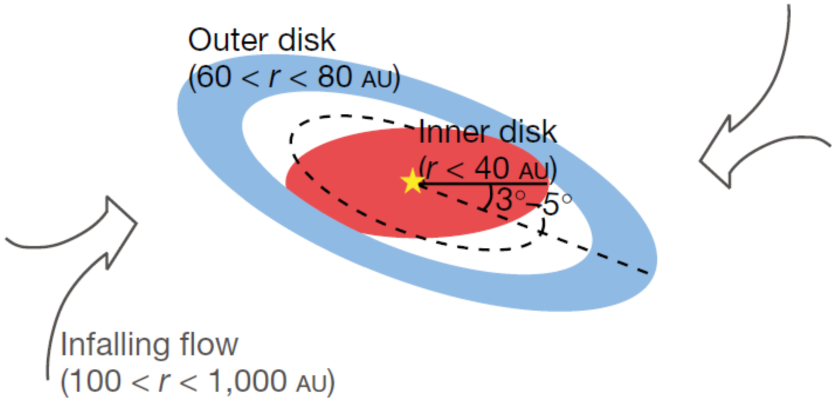
Debes et al. (2017)

HD 34700

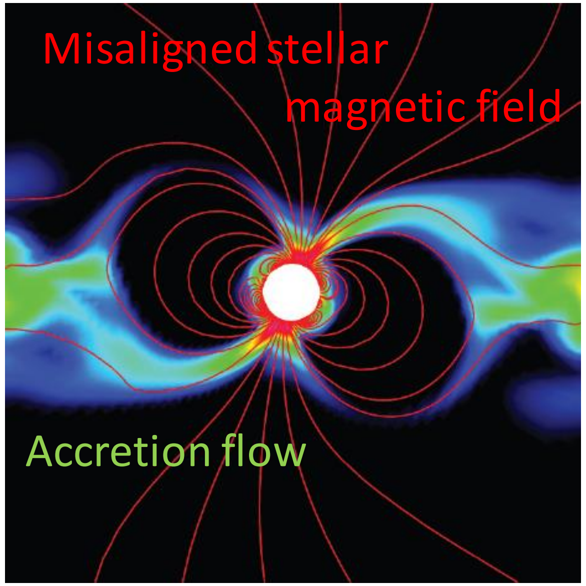


Monnier et al. (2019)

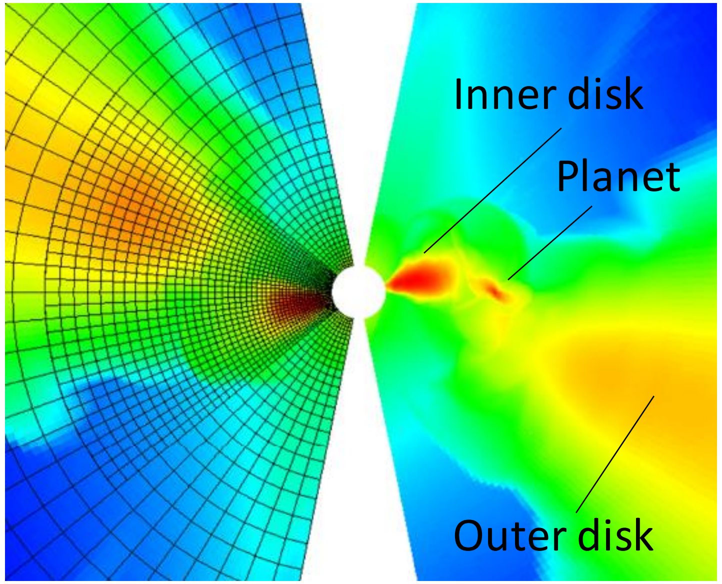
Possible origins of misaligned inner disk



Sakai et al. (2019)



Hartmann et al. (2016)



Zhu et al. (2019)

Anisotropic accretion flow of gas with different rotational axes in younger phase.

Inner disks magnetically warped by misaligned stellar magnetic field with respect to the stellar rotation axis.

A massive planet induces precession of inner and outer disks.

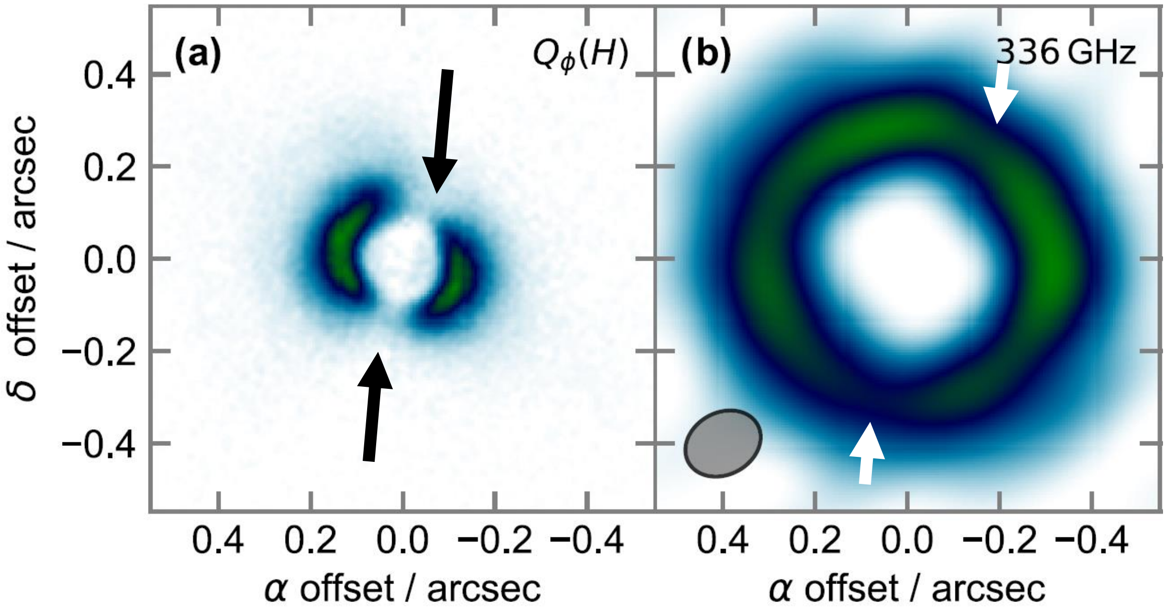
ALMA and NIR observations of disks with dips

Some objects show dips induced by shadows in both ALMA dust continuum and NIR images.

DoAr 44

NIR scattered light image

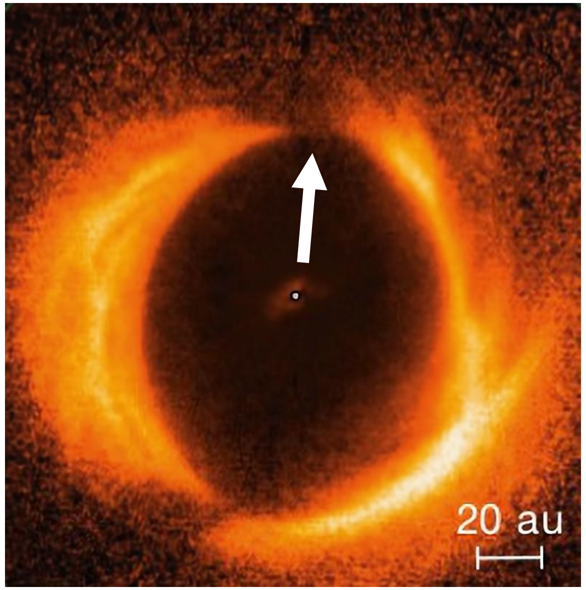
ALMA band 7
dust continuum image



Casassus et al. (2017)

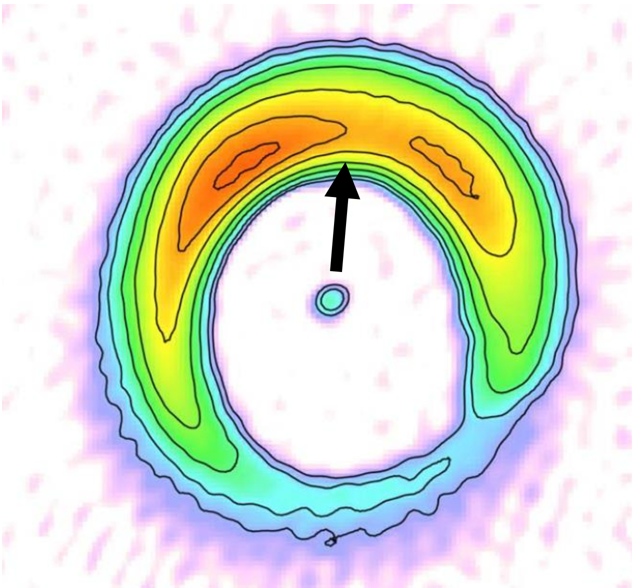
HD 142527

Optical scattered light image



Avenhaus et al. (2017)

ALMA band 7
dust continuum image

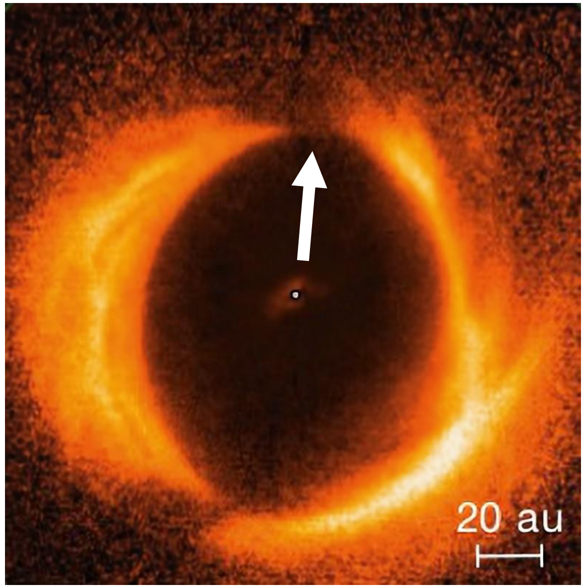


Ohashi et al. (2018)

ALMA traces dust-disk temperature

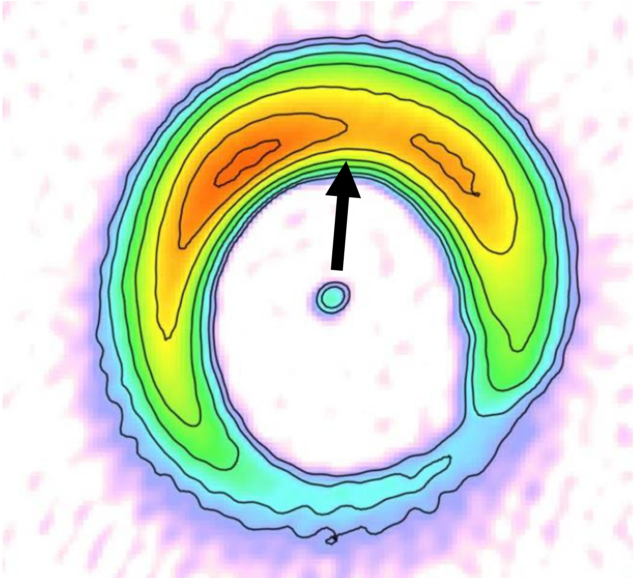
HD 142527

Optical scattered light image



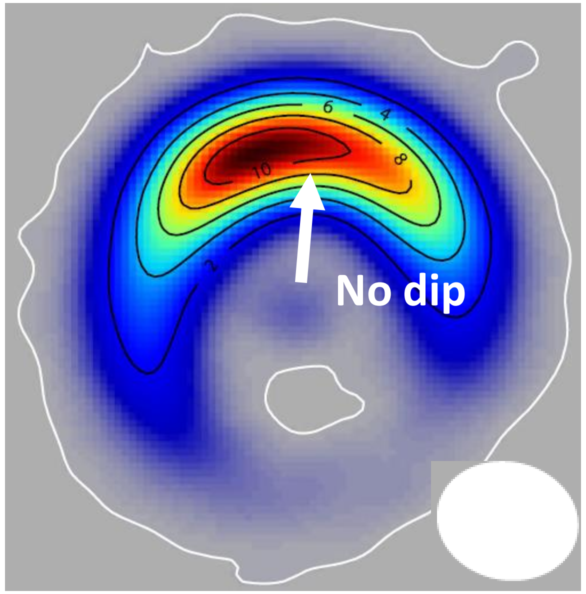
Avenhaus et al. (2017)

ALMA band 7
dust continuum image
(optically thick)



Ohashi et al. (2018)

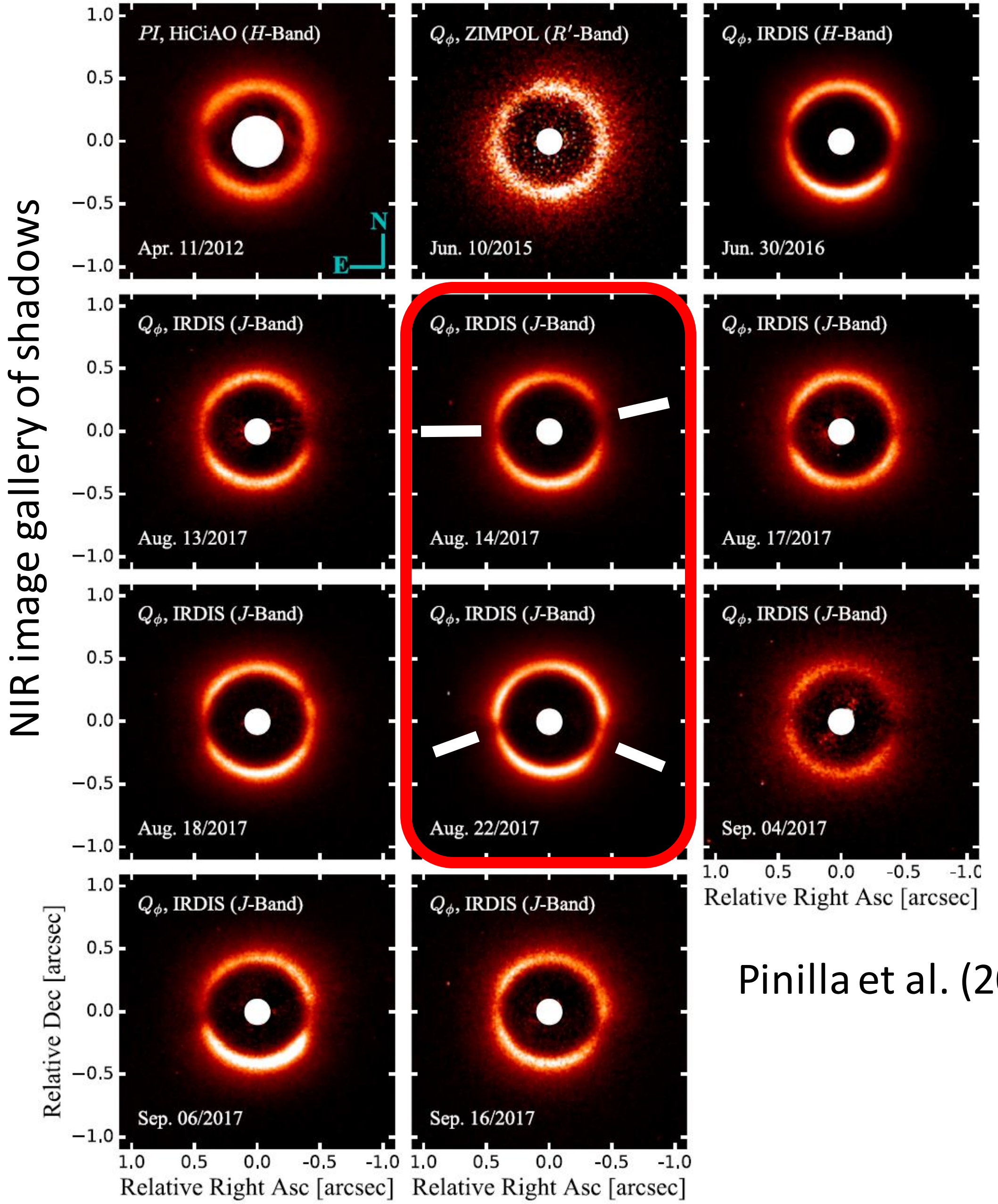
ALMA band 3
dust continuum image
(optically thin)



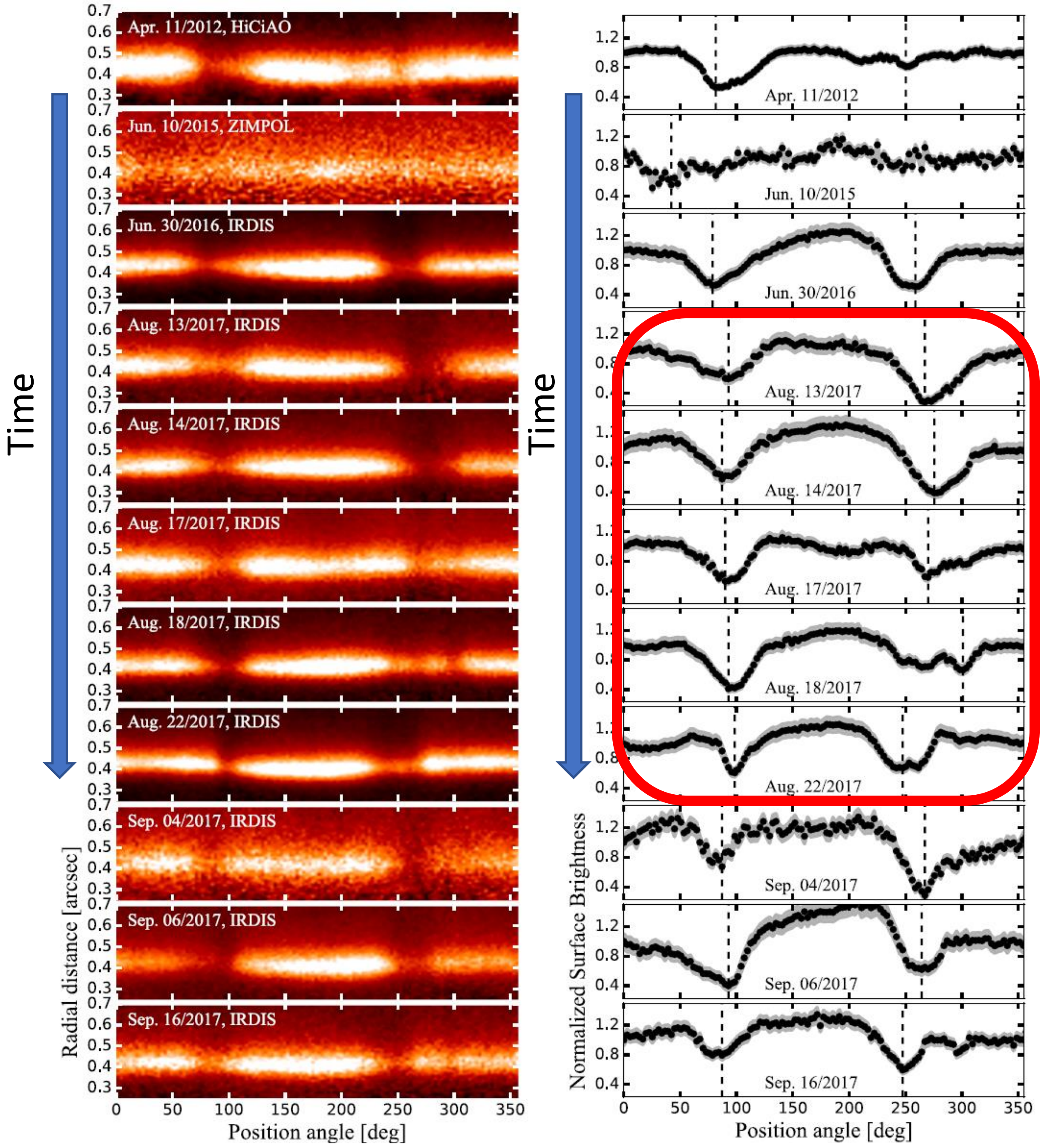
Soon et al. (2019)

- Optical/NIR image traces shadows
- ALMA higher frequency (band 7) traces disk temperature
- ALMA lower frequency (band 3) traces disk surface density

Variable shadows in the J1604 ring



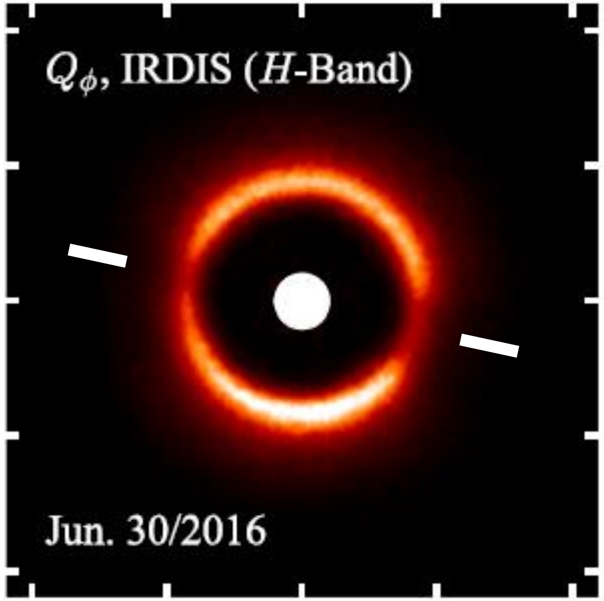
Pinilla et al. (2018)



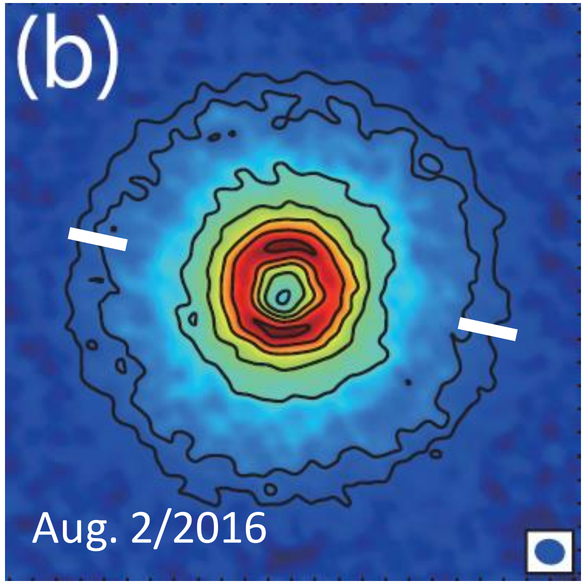
Shadow regions vary with ~1 week.

Comparison in ALMA and NIR images of J1604

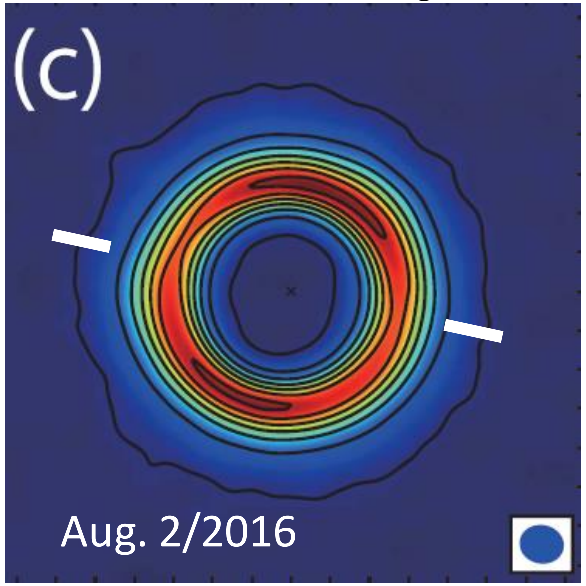
NIR scattered light image



ALMA 12CO(3-2) image



ALMA Band 7
dust continuum image



Pinilla et al. (2018)

Mayama et al. (2018)

- Two dips in NIR, CO gas, and dust continuum images
  - Shadows would affect on temperature in the outer disk
- However, shadows vary within ~1 week.
- To understand effects of shadows on disk temperature, the joint program of ALMA and Subaru is preferable.

Summary (+ my personal opinion)

- **A clear advantage for promoting science with multi-wavelengths**
  - Suitable for science cases: the vicinity of central stars such as mass accretion onto star/planet and dynamics of inner disks at r <1 au from central stars
  - Just follow-up observations with an interval >1-yr is not suitable
- **Possible disadvantage (?)**
  - Reduce observing time of Subaru alone and ALMA alone.
  - Current Subaru allocates maximum 5% of total nights to non-Japanese researchers.
  - If this upper limit is relaxed, Japanese Subaru users (including me) may feel uncomfortable...
  - Hopefully, Subaru SAC keeps the 5% limit even after the joint program starts...