Discovery of a localized excess in the millimeter emission of the protoplanetary disk around TW Hya

Tsukagoshi, T., et al., 2019, ApJ, 878, L8

Takashi Tsukagoshi[1] (takashi.tsukagoshi@nao.ac.jp)

T.Muto[2], H.Nomura[1], R.Kawabe[1], K.Kanagawa[3], S.Okuzumi[4], S.Ida[5], C.Walsh[6], T.Millar[7], S.Takahashi[1], J.Hashimoto[8], T.Uyama[9], M.Tamura[3]

1: NAOJ, 2: Kohgakuin Univ., 3: Tokyo Univ. 4: Tokyo Tech. Univ., 5: ELSI, 6: Univ. of Leeds, 7: Queen's Univ. Belfast, 8: Astro Biology Center, 9:Caltech

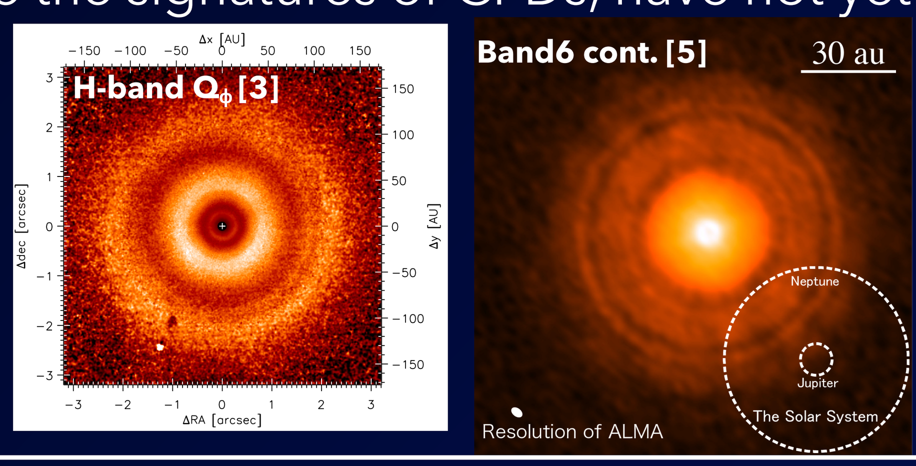
We report the detection of an au-scale excess in dust continuum emission at 233 GHz (1.3 mm in wavelength) in the protoplanetary disk (PPD) around TW Hya, the closest T Tauri star to Earth, revealed through deep 3 au resolution observations with the Atacama Large Millimeter/submillimeter Array (ALMA). Our observations were conducted in 2016 and 2017. With ~200min integration time, the sensitivity was improved by a factor of 3 than that of our previous cycle 3 observations.

The overall structure is axisymmetric, and there are apparent gaps at 25 and 41 au as previously reported. The most remarkable new finding is a few au scale excess emission at the south-west part of the PPD. The excess emission is located at 52 au from the center and is 1.5 times brighter than the surrounding PPD. The extracted emission after subtracting the axisymmetric PPD emission has a size of 4.4x1.0 au and a total flux density of 250 μJy, corresponding to a dust mass of 0.03 earth masses. The identification of the counterpart in the Band7 image implies that the excess emission is situated in the PPD.

Comparing with theoretical predictions, we conclude that the excess emission can be explained by a dust clump accumulated in a small elongated vortex or a massive circumplanetary disk around a Neptune mass forming-planet.

Introduction

- Detection of a substructure related to a forming planet is a promising way to investigate the planet formation process
  - A localized small-scale substructure in PPDs, i.e., Circumplanetary disk (CPD)
- AU-scale substructures, which are expected to be the signatures of CPDs, have not yet been reported at mm/submm wavelengths
  - Recent reports for PDS70[1] and HD100546[2]
- Target: TWHya:
  - Nearest T Tauri star (d=59.5pc; GAIA DR2)
  - K6 star, t_*=10Myr, Face-on (i=7°)
  - Multiple gaps in NIR and submm. [3,4,5]
  - **Small-scale substructure has never been reported**



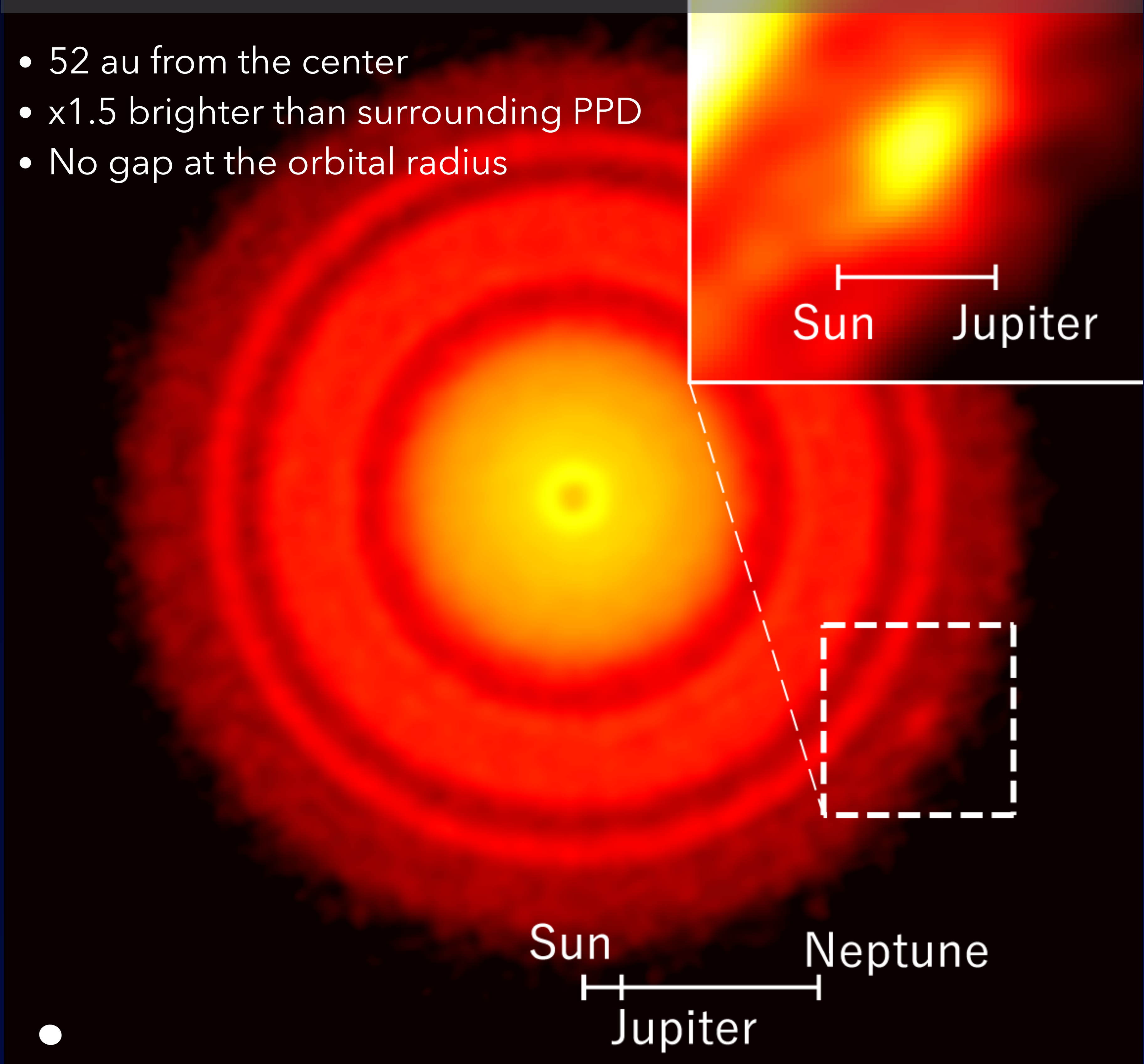
Observations

- May - November 2017
  - Array configuration: C40-5 and C43-8
- Band: Continuum emission at Band6 (1.3mm)
- Resolution: ~45mas (~2.7pc)
- On source integ. time: **~200min.**
- Sensitivity: 9.1 uJy/beam
  - **3times better than TT+2016**

Result: High-sensitivity & high-resolution continuum map at Band6

New finding of an au-scale substructure in the PPD

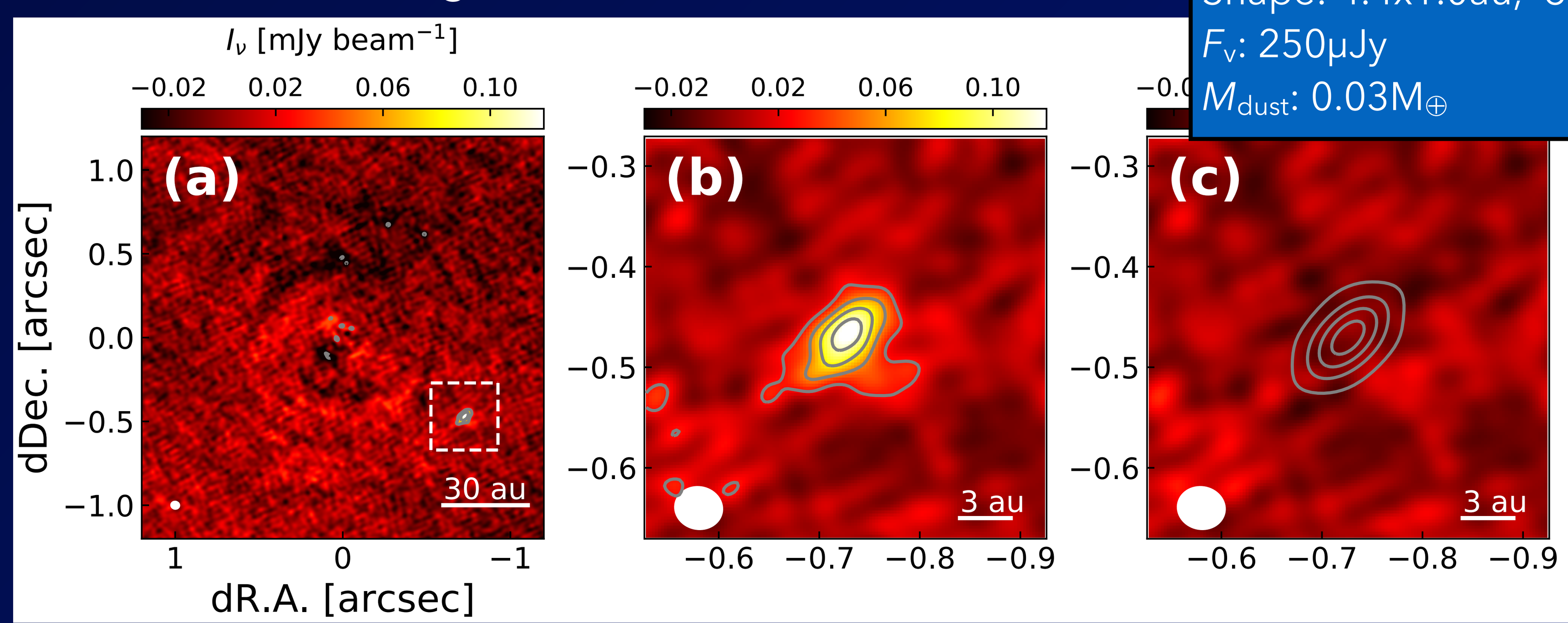
- 52 au from the center
- x1.5 brighter than surrounding PPD
- No gap at the orbital radius



Extraction of the excess emission

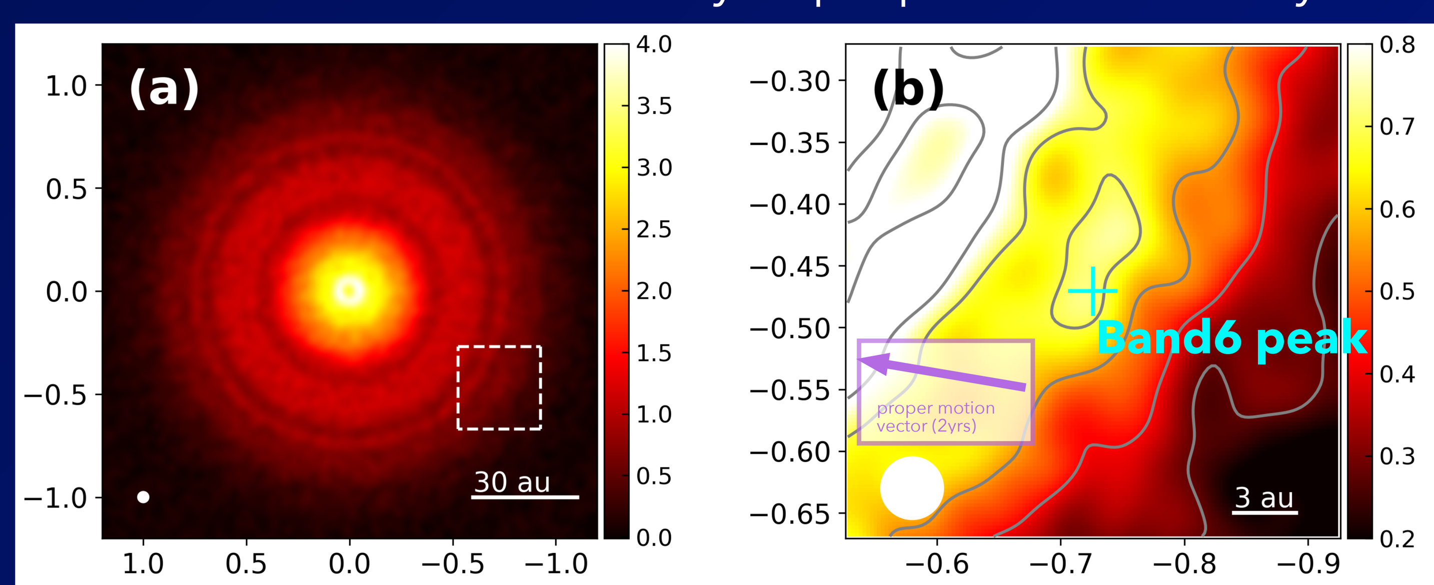
- Subtraction of symmetric emission in the UV plane
- Gaussian fitting to the extracted emission

Shape: 4.4x1.0au, -38.3°
F_ν: 250μJy
M_{dust}: 0.03$M_\oplus$



Excess emission is situated in the PPD

- Band7 image using 8 available archive data taken until 2015
  - Longest baseline configuration [4] is included
- Positional offset is less than the TWHya's proper motion for 2yrs



Discussion: CPD or dust grains trapped in a gas vortex?

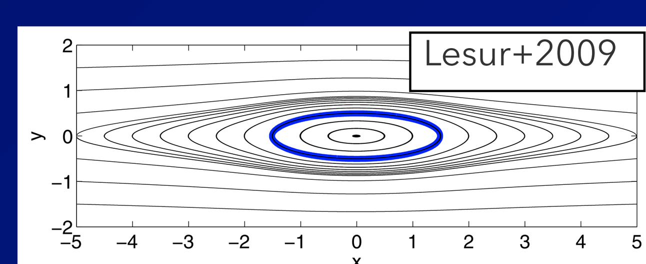
CPD scenario

- Expected planet mass; $M_{\rm pl} \sim M_{\rm Npetune}$

$$r_{\rm excess} \equiv \frac{FWHM_{\rm r}}{2} = \frac{r_{\rm Hill}}{3}$$

- Lower-mass planet agrees with
  - Non-detection at L'-band [6]
    - 1~2M$_J$ at 52au
  - Absence of gap at 52au
    - $M_{\rm pl}/M_* \sim 10^{-5}$ is less than gap opening criterion in gas and dust [7]
- Emission is too bright and elongated
  - If a simple viscous CPD model is adopted [8], the observed 250μJy is difficult to reproduce only with a CPD around a Neptune-mass planet

Small-scale gas vortex scenario



- Aspect ratio of the observed excess emission; **~4**
  => Consistent with theoretical prediction of the shape of stable vortices [e.g., 9]
- Small scale vortex can survive for a long time?
  - Large-scale vortices have long life time, but it is not yet clear for small-scale vortices
  - Theoretical vortices must have size comparable to or less than the local scale height (~5au) and survive for a long time enough to be observed

References

[1] Isella, A. et al., 2019, ApJL, 879, L25, [2] Peréz, S. et al., 2019, arXiv:1906.06305, [3] van Boekel, R. et al., 2017, ApJ, 837, 132, [4] Andrews, S. et al., 2016, ApJL, 820, L40, [5] Tsukagoshi, T. et al., 2016, ApJL, 829, L35, [6] Ruane, G. et al., 2017, AJ, 154, 73, [7] Dipierro, G. et al., 2017, MNRAS, 469, 1932, [8] Zhu, Z. et al., 2016, ApJ, 832, 193, [9] Lesur, G. & Papaloizou, J., 2009, A&A, 498, 1