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# Observing Kinematics on AU-scales in B335 with ALMA

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*A&A, 2019, 631, A64:*

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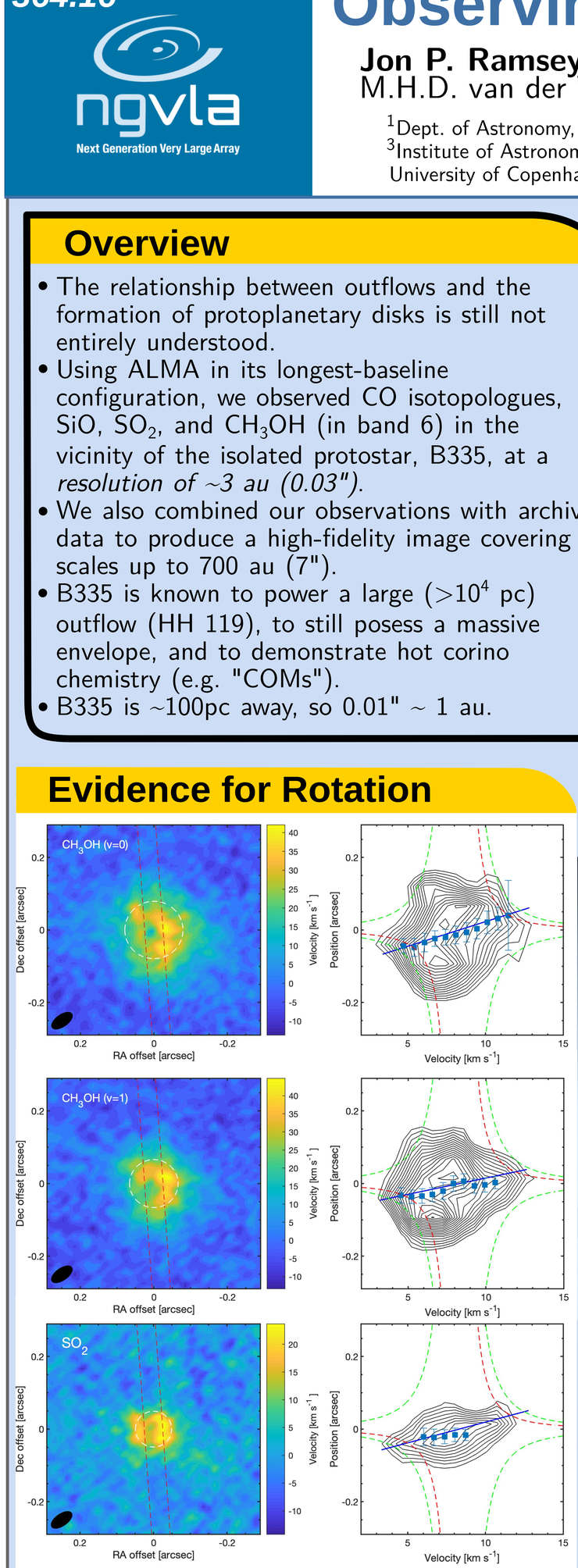
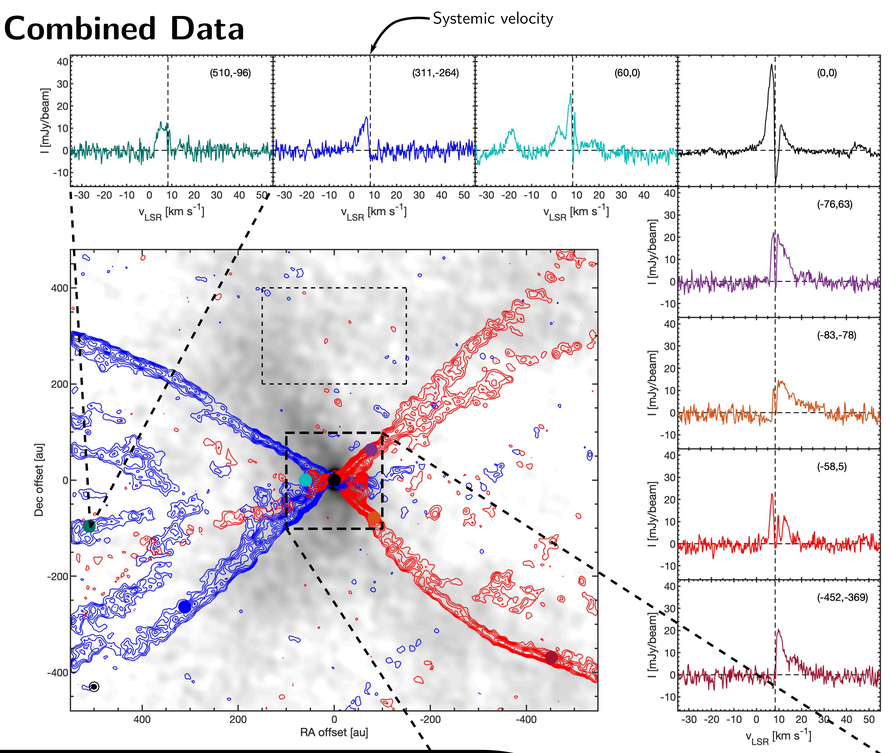
## Overview

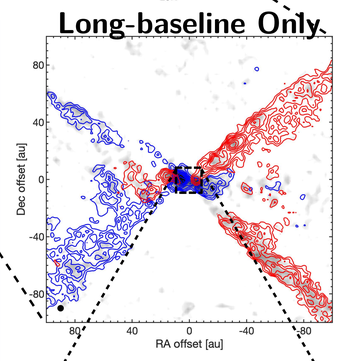
- The relationship between outflows and the formation of protoplanetary disks is still not entirely understood.
- Using ALMA in its longest-baseline configuration, we observed CO isotopologues, SiO, $SO_2$, and $CH_3OH$ (in band 6) in the vicinity of the isolated protostar, B335, at a *resolution of ~3 au (0.03")*.
- We also combined our observations with archival data to produce a high-fidelity image covering scales up to 700 au (7").
- B335 is known to power a large (>$10^4$ pc) outflow (HH 119), to still posess a massive envelope, and to demonstrate hot corino chemistry (e.g. "COMs").
- B335 is ~100pc away, so 0.01" ~ 1 au.

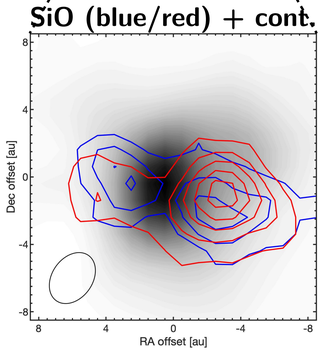
## Evidence for Rotation



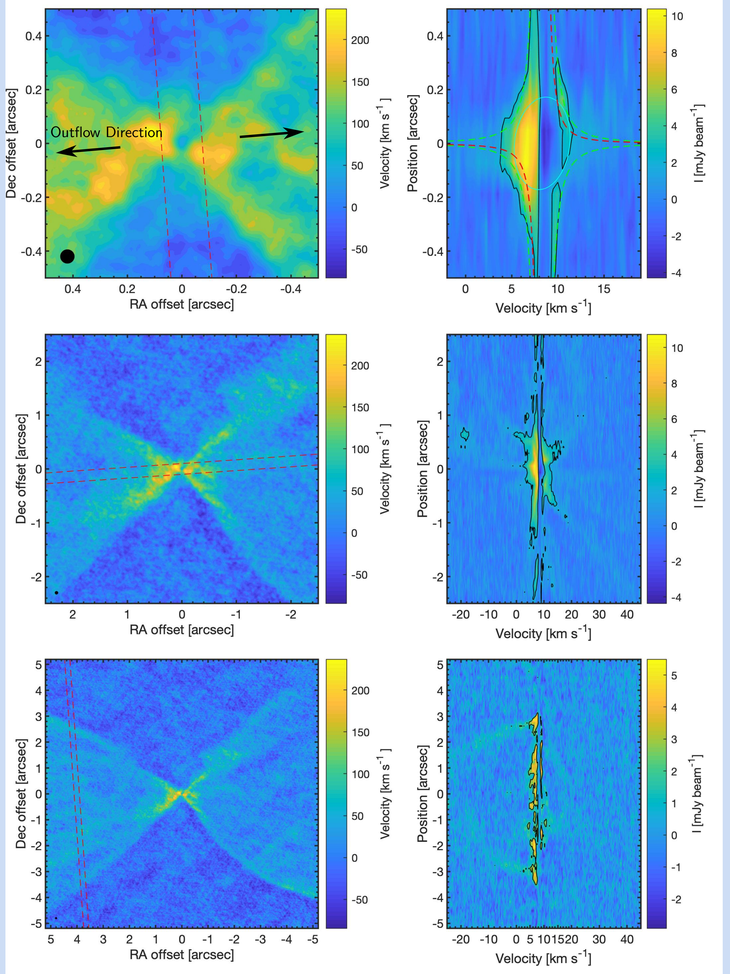

## $^{12}$CO Moment 0 + Continuum




## $^{12}$CO Pos-Vel Diagrams




## Results

- B335 has a large-scale outflow & cavity, but we do not find any significant evidence for a Keplerian disk down to scales of 3 au!
- $CH_3OH$ is detected within 30 au of the cont. peak; SiO also detected close to the peak, but extended along the outflow.
- $CH_3OH$ and $SO_2$ trace a rotating region <16 au in diameter centered on the peak.
- LTE analysis of the $CH_3OH$ lines gives a temp. of 220±20 K and col. density 6.8±0.1 x $10^{18}$ $cm^{-2}$.
- From high-velocity $^{12}$CO features, the outflow launching radius is estimated to be <0.1 au.

## Observational Details

- ALMA Band 6 observations at longest baselines (2017.1.00288.S), including CO isotopologues (2-1), SiO (5-4), and serendipitously $SO_2$ [22(2,20)-22(1,21)], four lines of $CH_3OH$.
- Combined with archival $^{12}$CO data from 2013.1.00879.S (ang. res. ~3") and 2016.1.01552.S (ang. res. ~0.7" & 1.5").
- Multi-scale cleaning (Briggs, robust = 0.5) took ~800 wall-clock hours; a few channels still did not reach desired cleaning threshold of 3 mJy/beam.

## Outstanding Questions

- The region surrounding the cont. peak is optically thick; *what would higher-resolution, longer-wavelength observations reveal?*
- Large, powerful outflows are typically associated with large, Keplerian disks, but no such disk is seen in B335! What's going on?
- B335 is young (≲$10^4$ yr). Are we seeing the *first stages of disk formation*? Or is B335 an example of *magnetic braking in action* (e.g. Yen+ 2018, A&A, 615, A58; Maury+ 2018, MNRAS, 477, 2760)?

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

**Acknowledgements:** This work made use of data from ALMA projects 2013.1.00879.S, 2016.1.01552.S, and 2017.1.00288.S, and data acquired with the APEX telescope. ALMA is a partnership of ESO, NSF and NINS, together with NRC, MOST and ASIAA, and KASI, in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. JPR was supported by the Virginia Initiative on Cosmic Origins (VICO), and by the NSF under grant nos. AST-1910106 and AST-1910675. PB acknowledges support from the Swedish Research Council (VR) through contract 2017-04924.