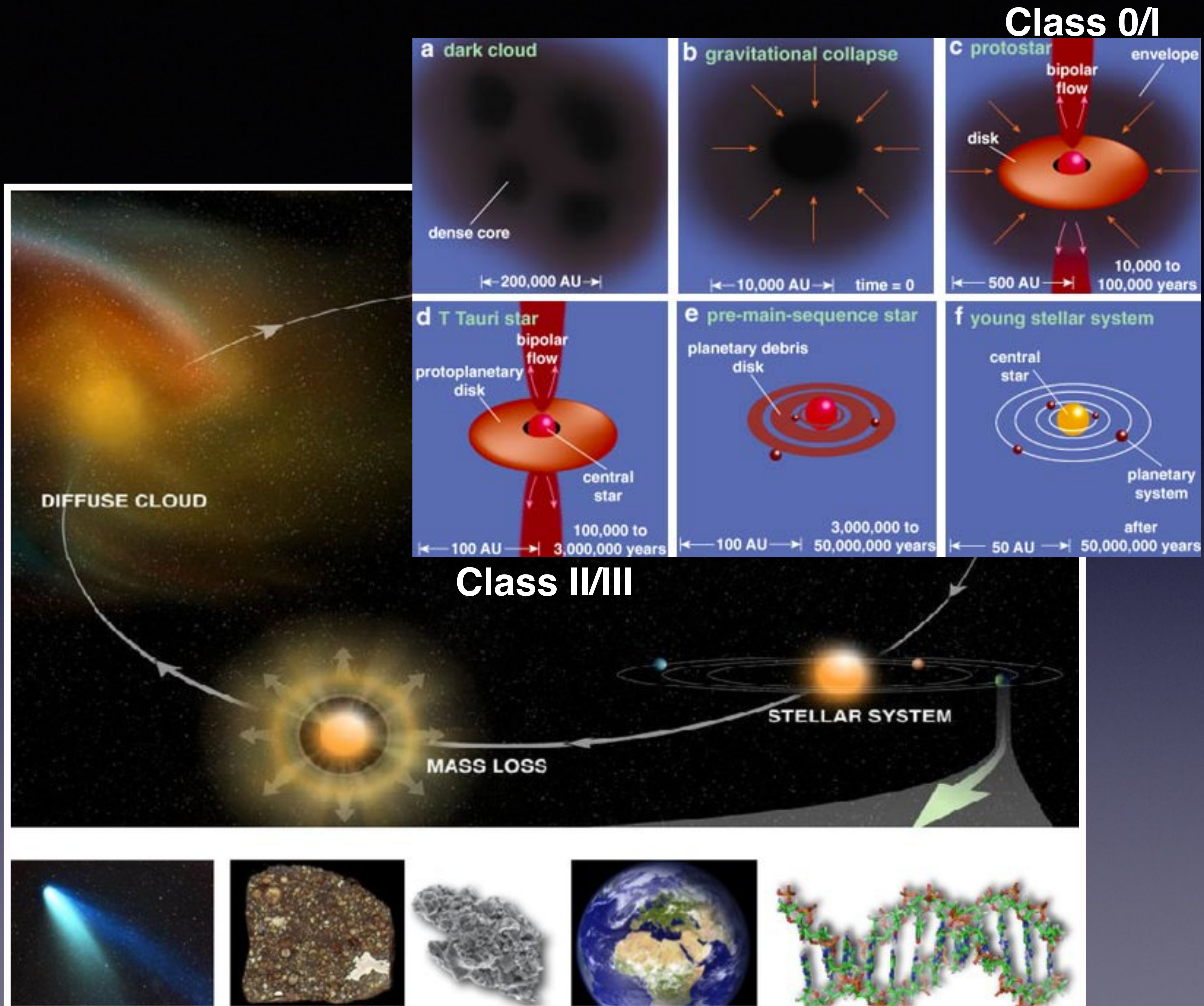
ALMA Science Cases with our Galaxy

Town hall meeting for ALMA Cycle 4
2016 March 28

Woojin Kwon

- 916 refereed articles (ADS) with “ALMA” in abstracts, as of 3/28/2016

- Array sciences: relatively compact structures!



Class 0/I
a dark cloud
dense core
200,000 AU
b gravitational collapse
10,000 AU
time = 0
c protostar
bipolar flow
envelope
disk
500 AU
10,000 to 100,000 years
d T Tauri star
bipolar flow
protoplanetary disk
central star
100 AU
100,000 to 3,000,000 years
e pre-main-sequence star
planetary debris disk
100 AU
3,000,000 to 50,000,000 years
f young stellar system
central star
planetary system
50 AU
after 50,000,000 years
Class II/III
DIFFUSE CLOUD
STELLAR SYSTEM
MASS LOSS

- Cases in ALMA primer
  1. Protoplanetary disks
  2. Magnetic fields
  3. Evolved stars
  4. Asteroid 3 Juno
- Solar objects
- Evolved stars
- Young stellar objects

Science Cases in ALMA primer

1. Multi-wavelength Continuum Survey of Protostellar Disks in Ophiuchus

- Science goals: evolution of protostellar disks
- Method: dust properties based on SED
- Targets: 6 Class II YSOs in Ophiuchus MC (d~125 pc)

Observation design

- Receivers: Bands 3, 4, 6, 7, 8, 9, 10
  (98, 145, 233, 344, 405, 679, 869 GHz)

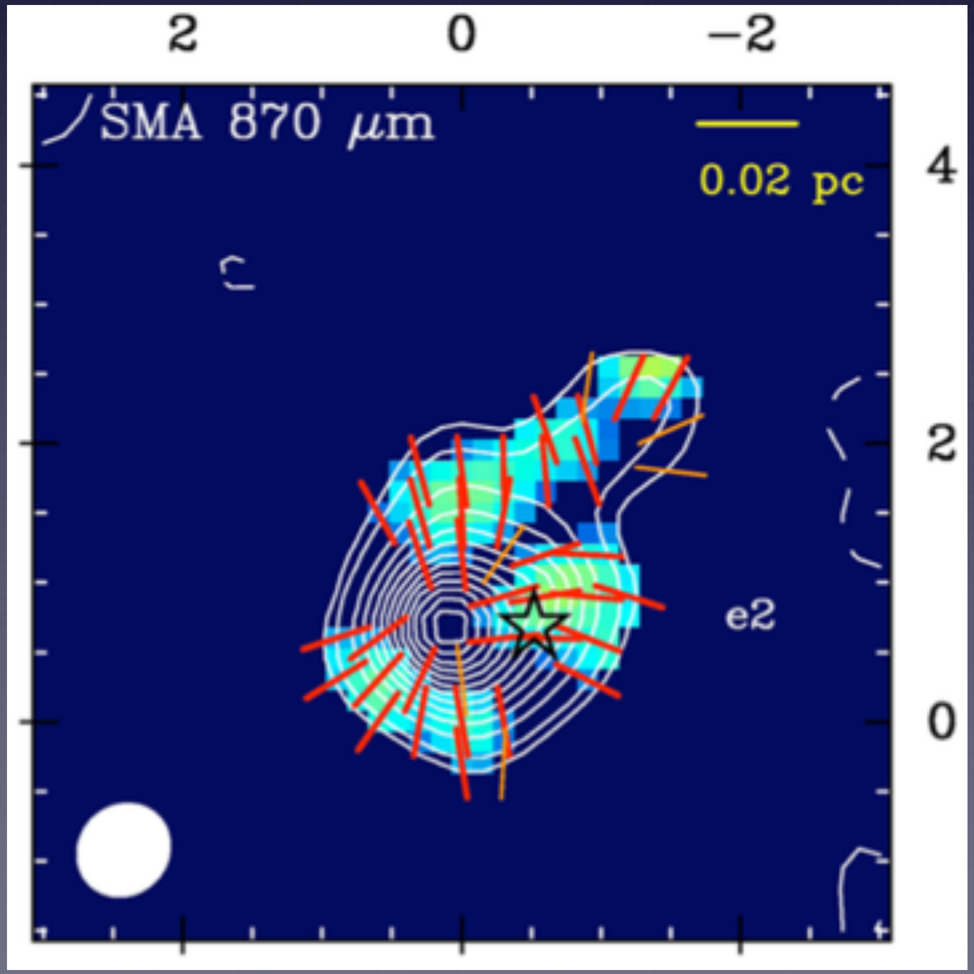
- Angular resolution (LAS): 0.4'' (2'')
  e.g., 100 AU disks = 0.8'' at 125 pc of Oph MC

- Sensitivity:
  0.019, 0.043, 0.11, 0.24, 0.34, 0.94, 1.54 mJy/beam
  e.g., 0.01 $M_\odot$, 20 K, typical opacity, 125 pc
  detect 3 beam size disk, edges ~ 10% of the peak

- Target time (36 main array antennas)
  26 min, 6.6 min, 1.2 min, 47 sec, 1.5 min, 3.3 min, 7.2 min

2. Dust Polarization and Magnetic Fields in Star Forming Clouds

- Science goals: magnetic field effects at thermal Jeans-length scales
- Method: dust polarization
- Targets: W51 e2 (d~7 kpc)



Ya-Wen Tang et al. 2009

Observation design

- Receivers: Band 7 (343 GHz)
  highest sensitivity to polarized dust emission

- Angular resolution (LAS): 0.2'' (0.8'')
  thermal Jeans length scale 1400 AU at 7 kpc => 0.2''
  core size => 0.8''

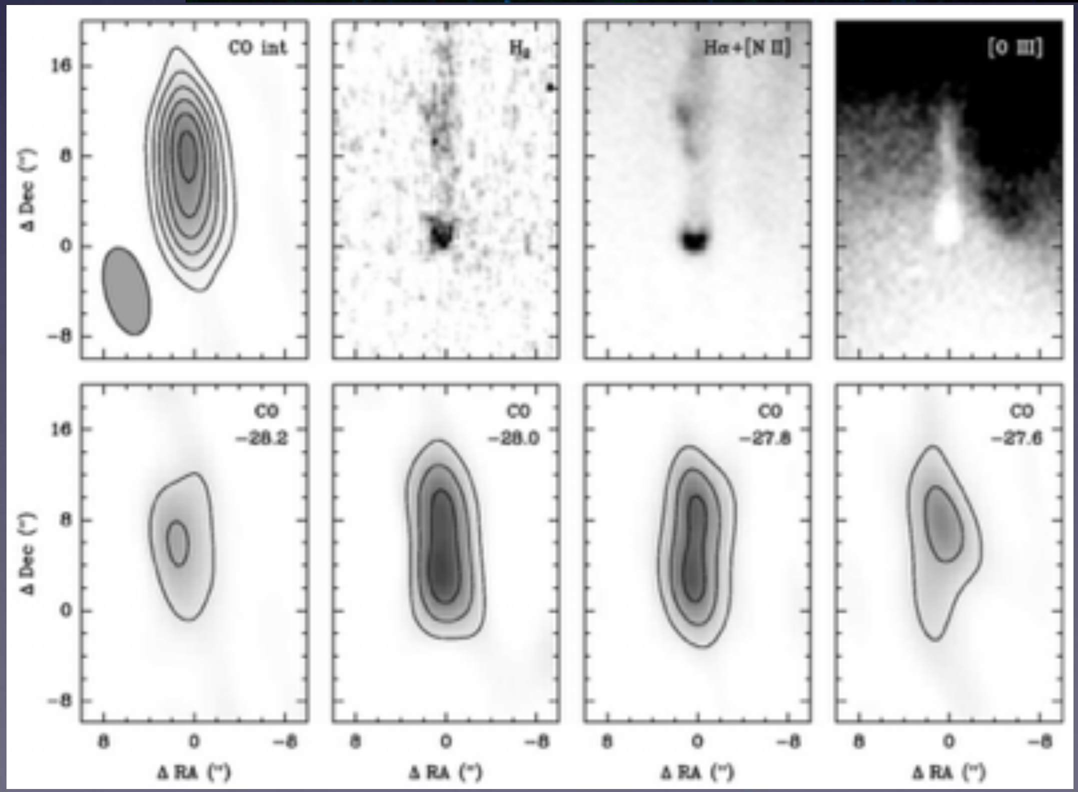
- Sensitivity: 100 μJy/beam
  flux 9.3 Jy over 0.8''
  9.3 Jy / 16 beams = 0.6 Jy/beam
  1% polarization => ~6 mJy/beam, so 60σ detection

- Target time: 4.5 min but 3 hours requested
  for sufficient parallactic angle coverage

3. Observing Molecular Gas in a Planetary Nebula

- Science goals: physical processes that created the nebulae, origin of tiny clumps (windswept, photo-evaporating, or shadowing?)
- Method: map the structure of molecular gas in a Planetary Nebula
- Targets: Helix Nebula thousands of small (< 1''), dense ($n \sim 10^5$ cm^{-3}), quiescent ($\Delta V < 1$ km/s), and faint ($T_A^* < 5$ K) clumps slowly evaporating in the radiation field of the central white dwarf
  Huggins et al. 2002

Spitzer Space Telescope



Huggins et al. 2002 PdBI

Observation design

- Receivers: CO 2-1 in Band 6 (230.538 GHz)
- Angular resolution (LAS): 0.3'' (1'')
  10x10 better than previous studies (~3'') => 0.3''
  fragmentation scale => ~1''
- Mosaic required: Helix (diameter~25')
  (primary beam~27'' => roughly 7500 pointings)
  one pointing each SE and NW of the nebula
- Spectral resolution: 234 MHz bandwidth, 0.183 km/s resolution
- Sensitivity: 0.5 K, moderate sensitivity for bright Helix Nebula fragments
- Observation time: 3.4 hours to reach 0.5 K in 0.18 km/s, including overheads
  two positions => ~7 hours

4. Continuum High Resolution Imaging of the Asteroid 3 Juno

- Science goals: T distribution, regolith thickness and composition
- Method: observe at 1.3 mm continuum over time for rotational period and 3D shape as well
- Targets: Asteroid 3 Juno

Observation design

- Receivers: Band 6 (233 GHz)

- Angular resolution (LAS): 0.032'' (0.17'')
  near-IR + modeling: Juno ~ 240 km
  5 beams => ~46 km resolution (32 mas at 1.97 AU)
  Max. Recoverable Scale 0.34'' of the configuration > 0.17''

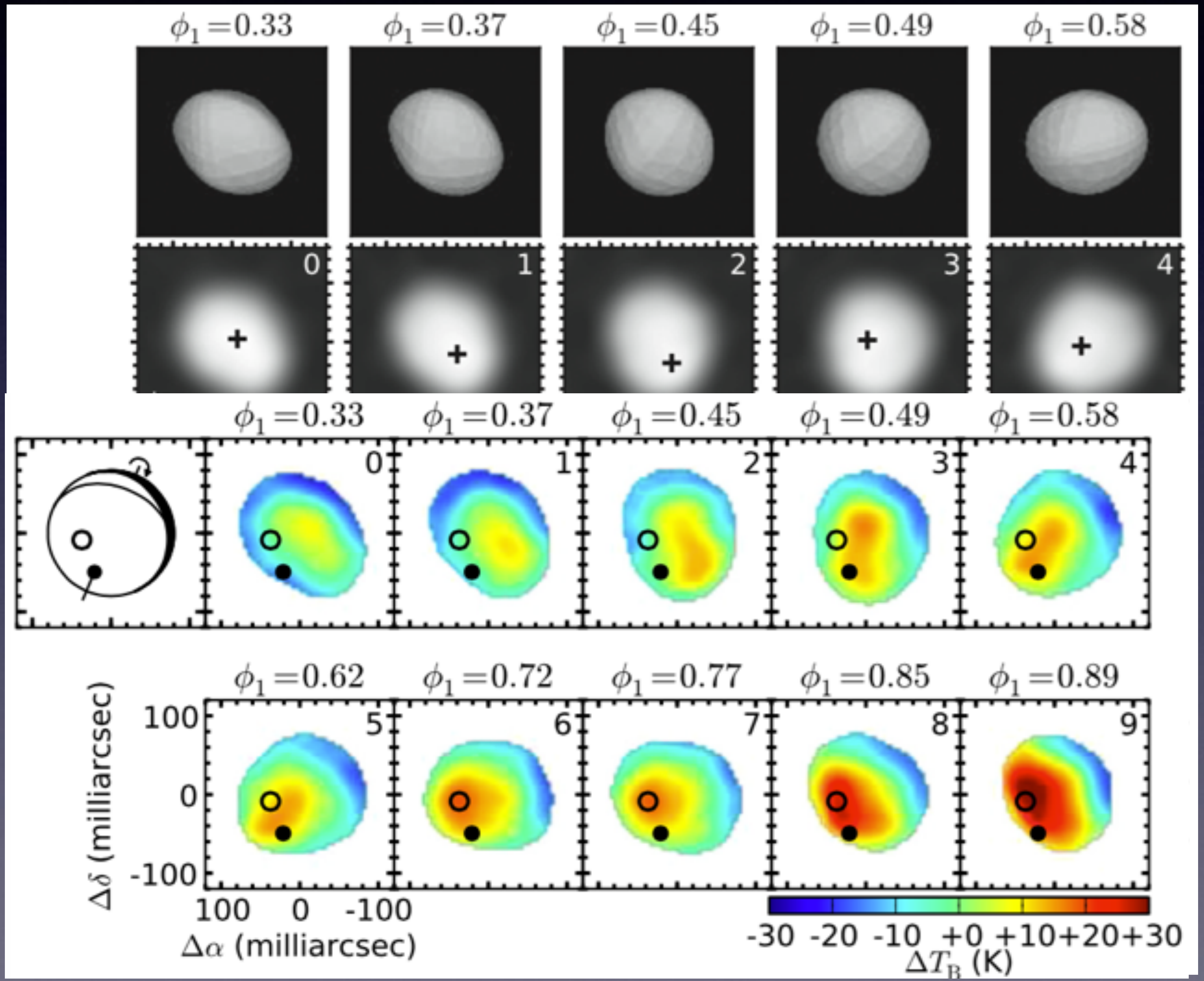
- Sensitivity: 0.1 mJy/beam
  flux 240 mJy at 250 GHz
  240 mJy/25 beams = 9.6 mJy/beam, 100σ detection

- Observation time:
  2 min for 0.1 mJy/beam (dual pol, 7.5 GHz bandwidth, 40 antennas)
  20 min including overheads
  more than 10 times observations (cf. Juno's rotation P ~ 7.2 hours)

Science Cases using ALMA

Solar Objects: Asteroid 3 Juno

- One of the long-baseline campaign data sets
  ALMA partnership et al. 2015
- Angular resolution: 0.042''
- 1.3 mm continuum
  DAMIT models
- Results:
  - consistency between models and data
  - crater in images 6-7
  subsolar points?



ALMA partnership et al. 2015

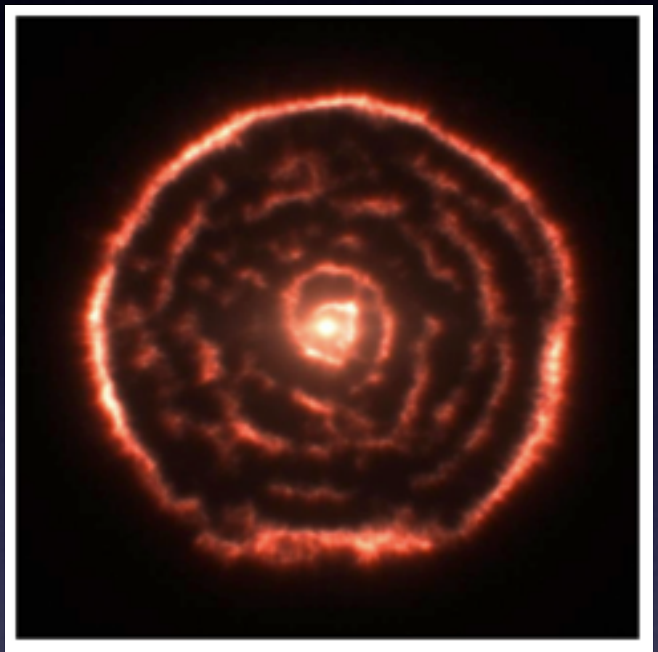
Evolved Stars: R Sculptors

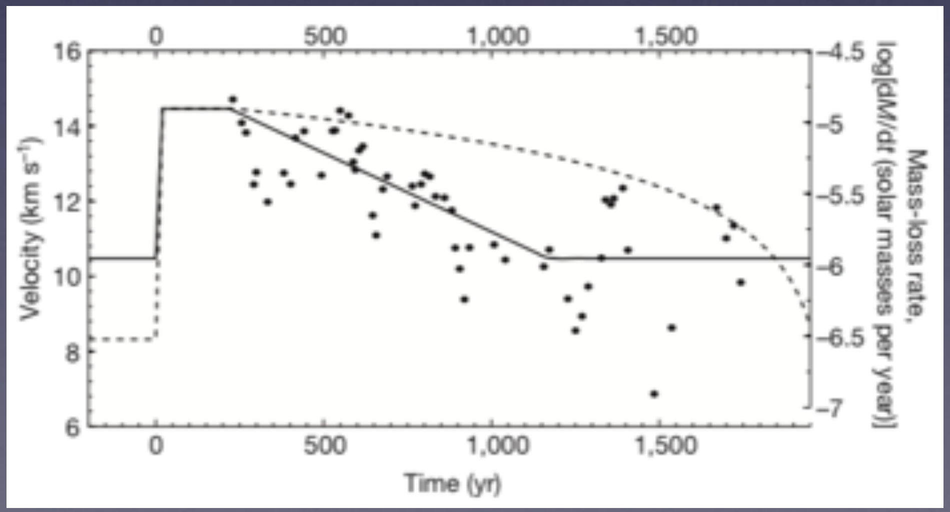
- Unexpectedly large mass loss during the thermal pulse cycle of the red giant star R Sculptors
  Maercker et al. 2012 Nature

- Timescales and mass-loss properties during and after a thermal pulse determining lifetime of asymptotic giant branch and amount of elements returned

- ALMA cycle 0 observations:
  CO 3-2 (345 GHz)
  angular resolution of 1.3''

- Binary system <= spiral shell structure
  200 year lasting thermal pulse, 1800 years ago
  30 times higher mass-loss rate during the pulse
  (mass-loss ~ $3x10^{-3}$ $M_{\odot}$, 3 times more mass than previously thought)

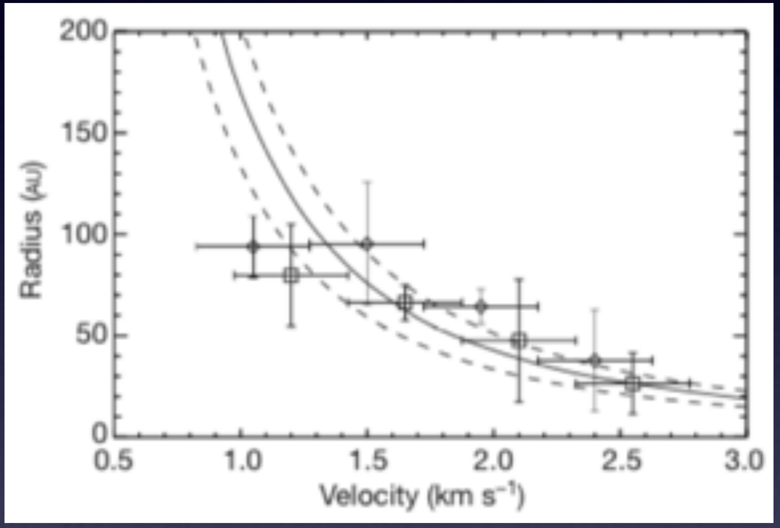


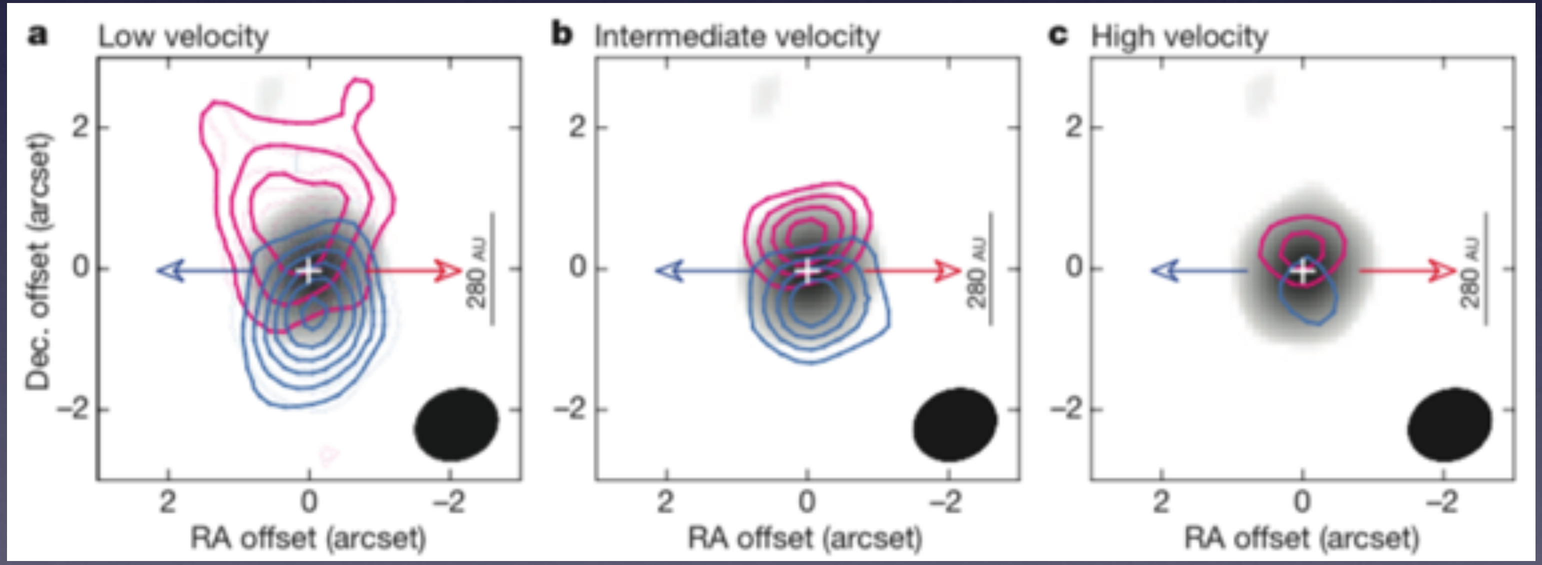


Circumstellar disks of Class 0 YSOs

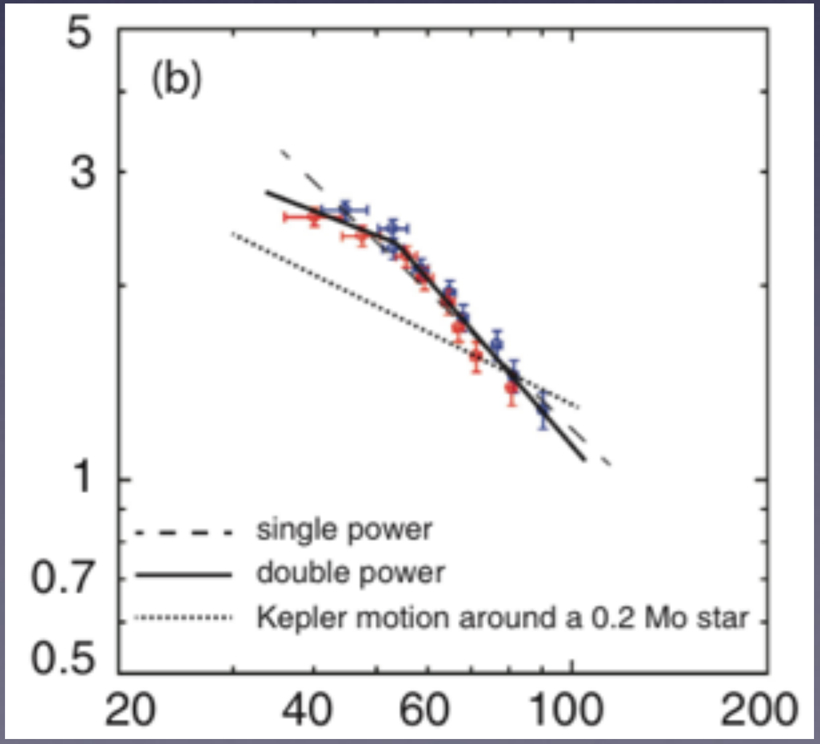
- L1527
  Taurus MC (d~140 pc)
  CARMA (SMA): ^{13}CO, 1.0''
  ALMA: $C^{18}O$, 0.7'', 0.17 km/s

Tobin et al. 2012, Nature



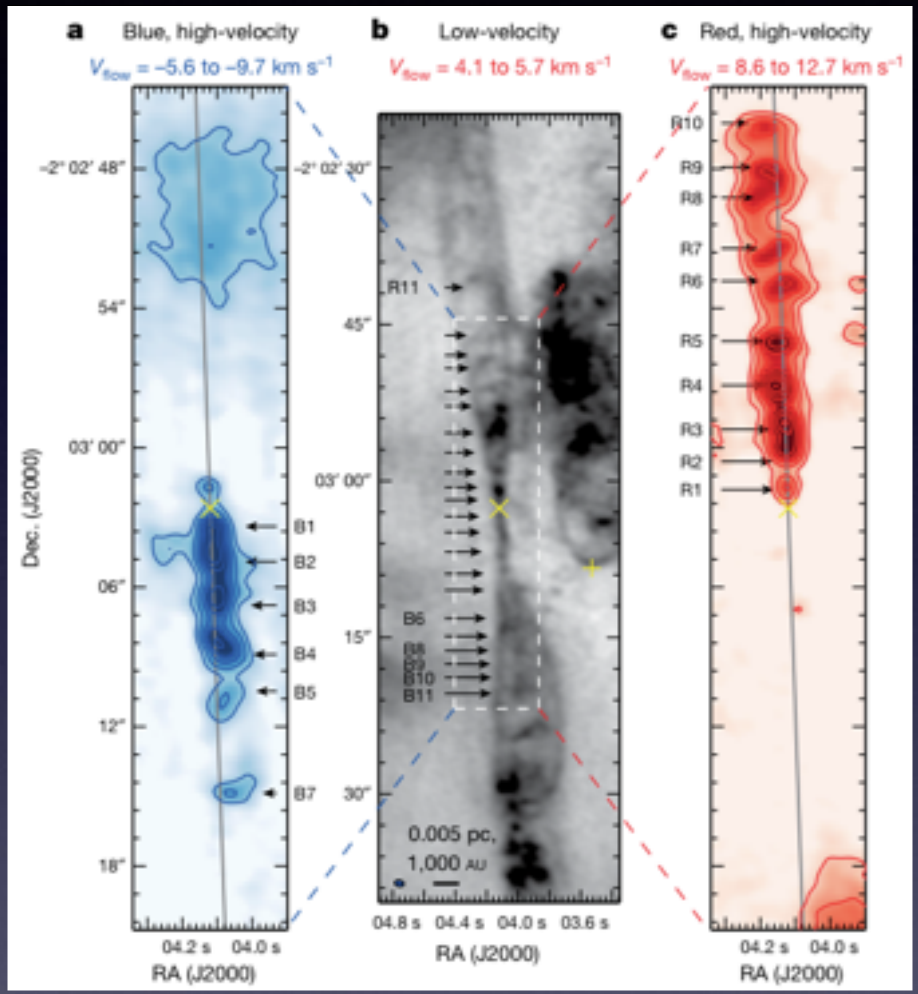


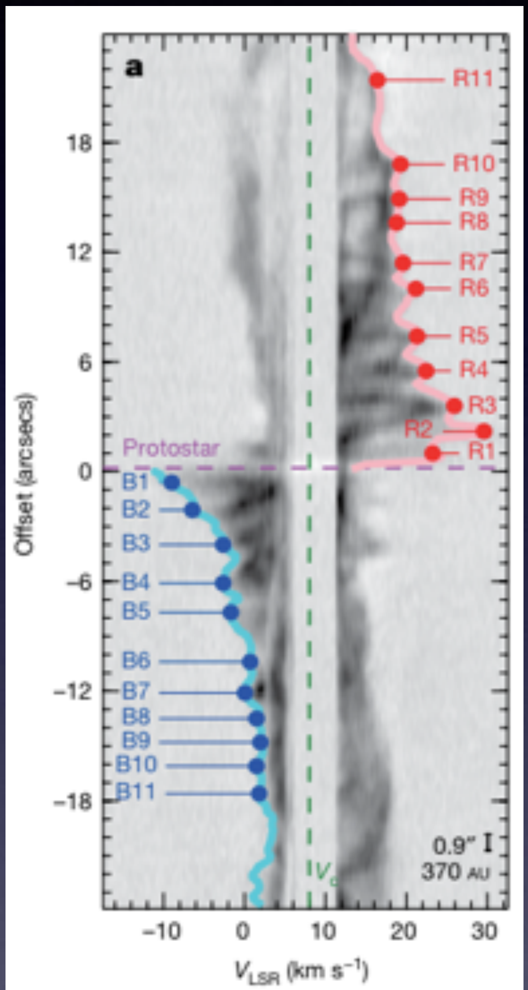
Ohashi et al. 2014

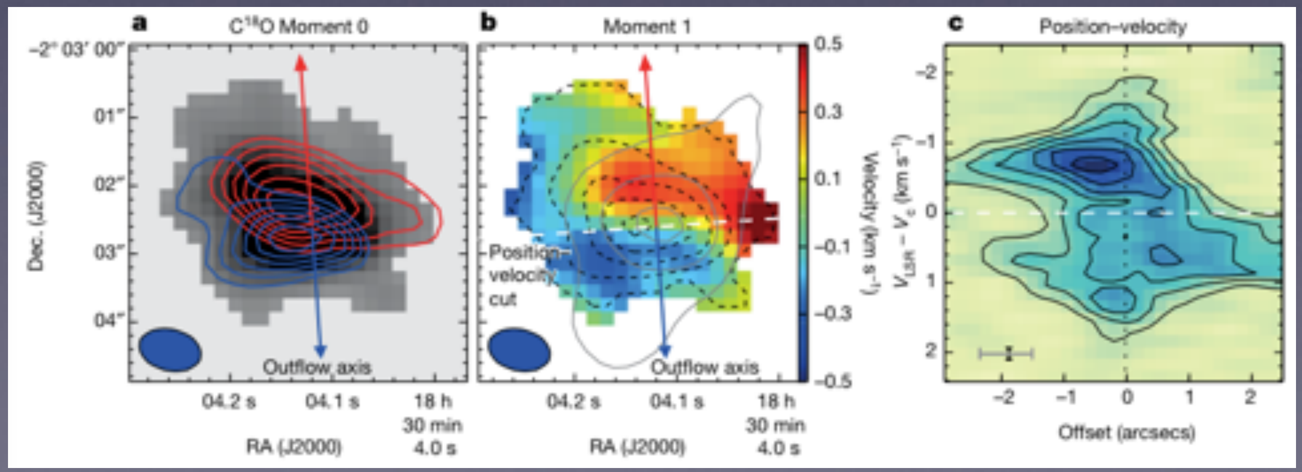


Class 0 YSOs: Bipolar Outflow & Disk

- Episodic outflow events
  Plunkett et al. 2015, Nature
- CARMA-7 (Class 0 YSO) in Serpens South (415 pc)
  0.9''
  CO 2-1, (^{13}CO), C^{18}O
- clumpy CO emission => episodic ejection
- slow-down jet-entrained material and/or intrinsically variable ejections
- "Keplerian rotating disk"?

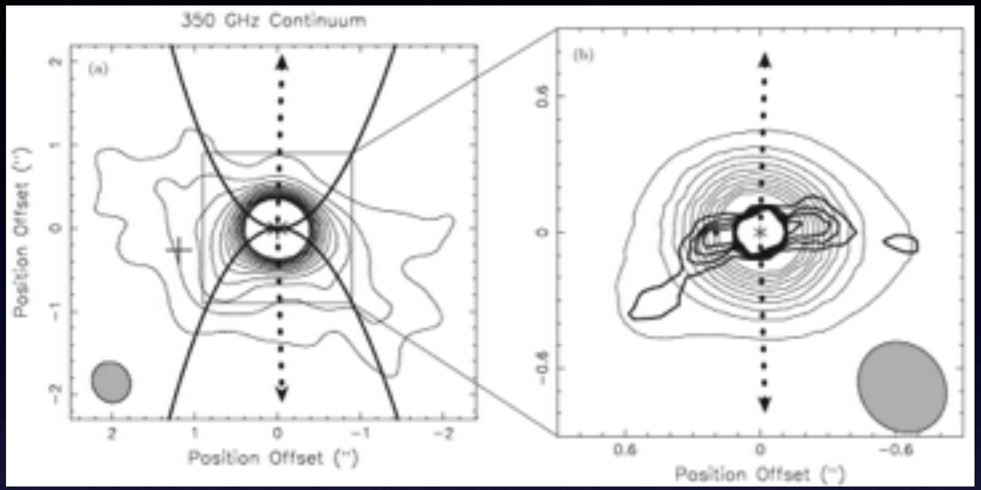






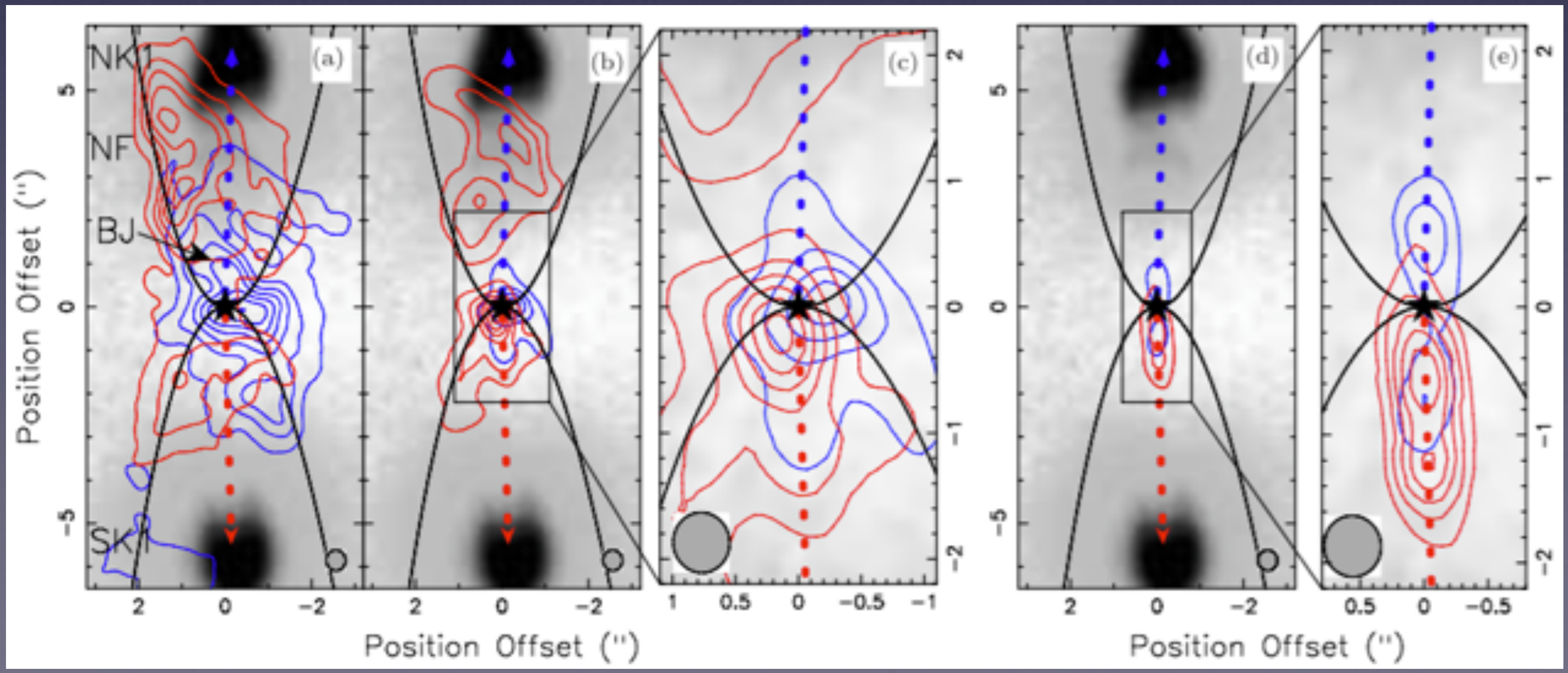
Class 0 YSOs: Bipolar Outflow & Disk

- HH212 (Class 0 YSO, 400 pc)
  Chin-Fei Lee et al. 2014
- angular resolution ~ 0.4''
  350 GHz continuum, HCO^+ 4-3



> 120 kλ, clean comp.

- Flattened envelope and compact disk in continuum
  Infalling envelope, rotating disk in HCO^+ (Keplerian?)
  $|V_{off}|$ < 1 km/s, (1 km/s, 2 km/s), (2 km/s, 3 km/s)

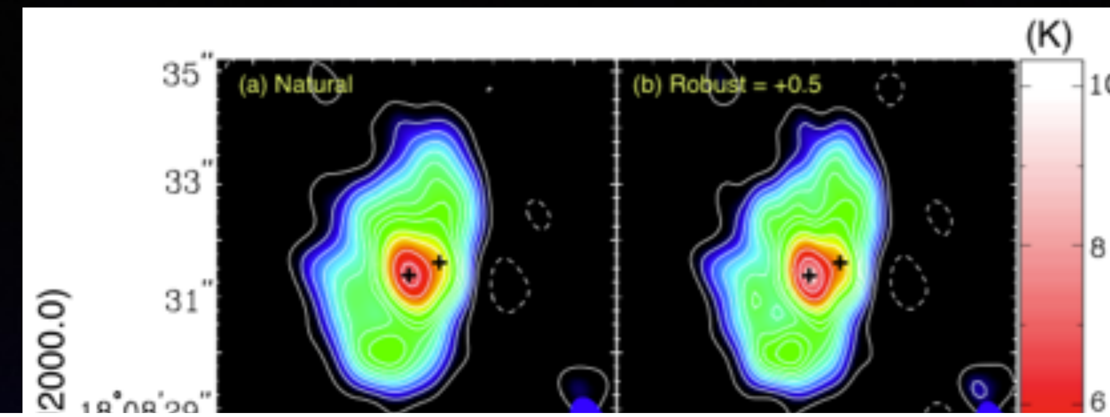


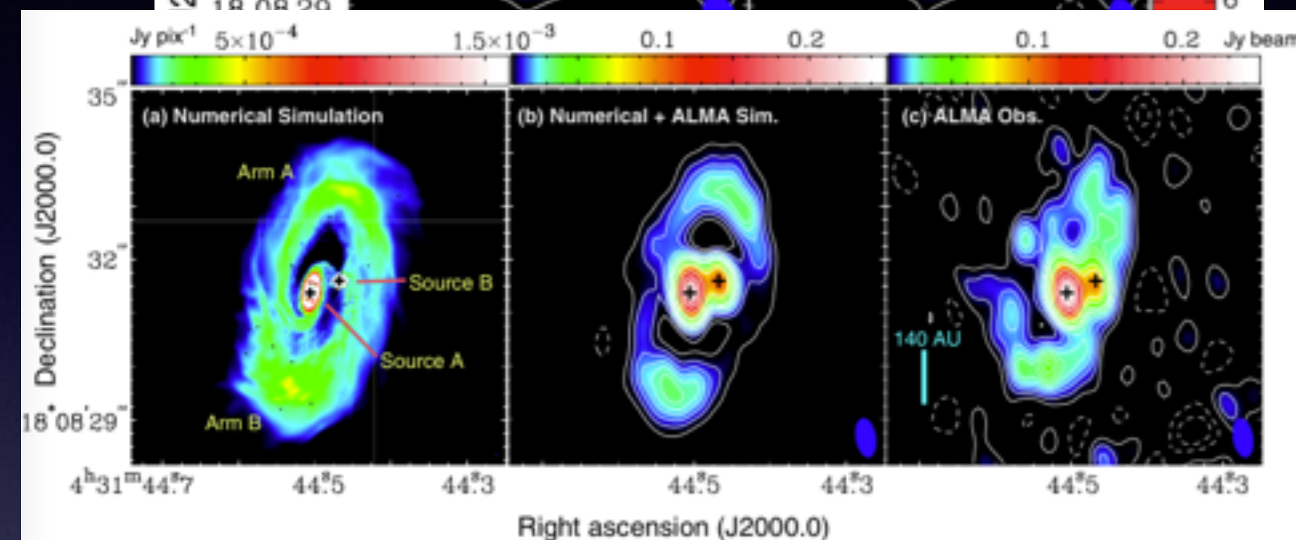
Class I Binary System

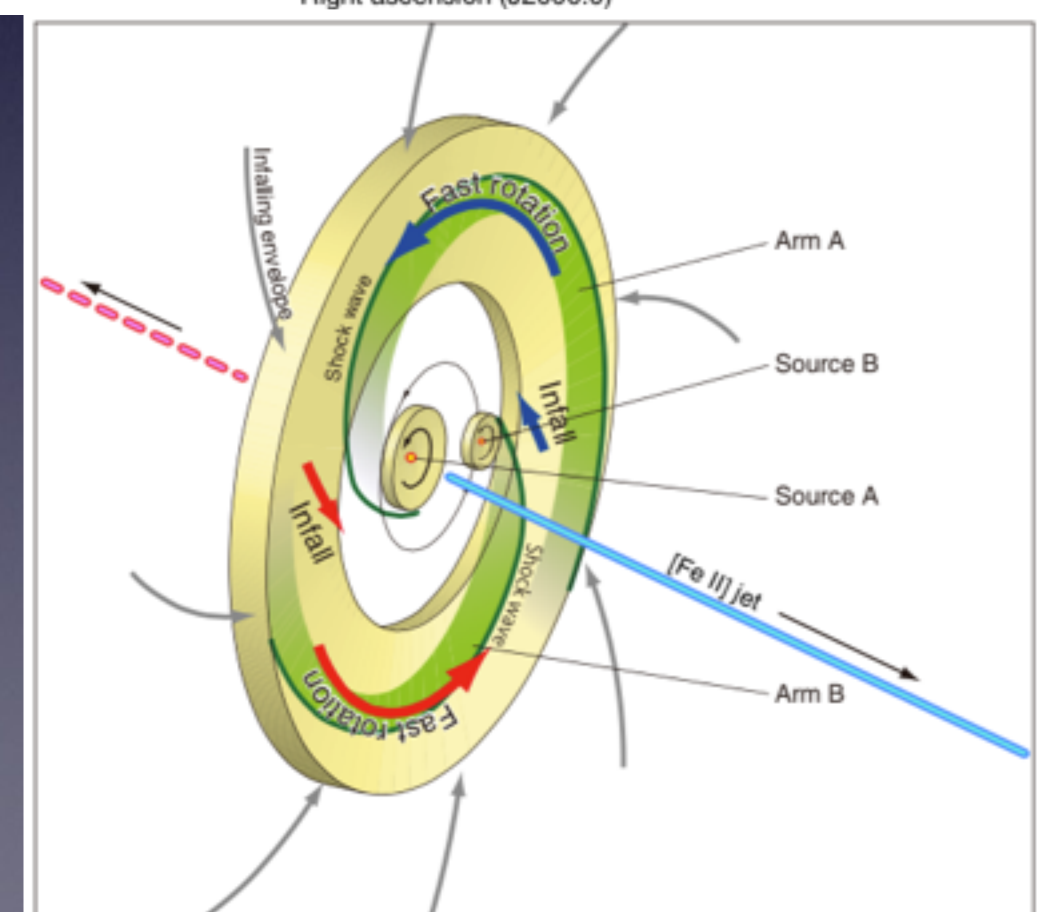
- L1551 NE
  Takakuwa et al. 2014

- Observations
  - 0.9 mm continuum, $C^{18}O$ 3-2, ^{13}CO
  - Angular resolution up to 0.36''
  - 1.6 times higher resolution, 6 times higher sensitivity than previous SMA data

- Results:
  - circumstellar disks, circumbinary disk
  - Keplerian rotation of circumbinary disk
  - infalling gas motion

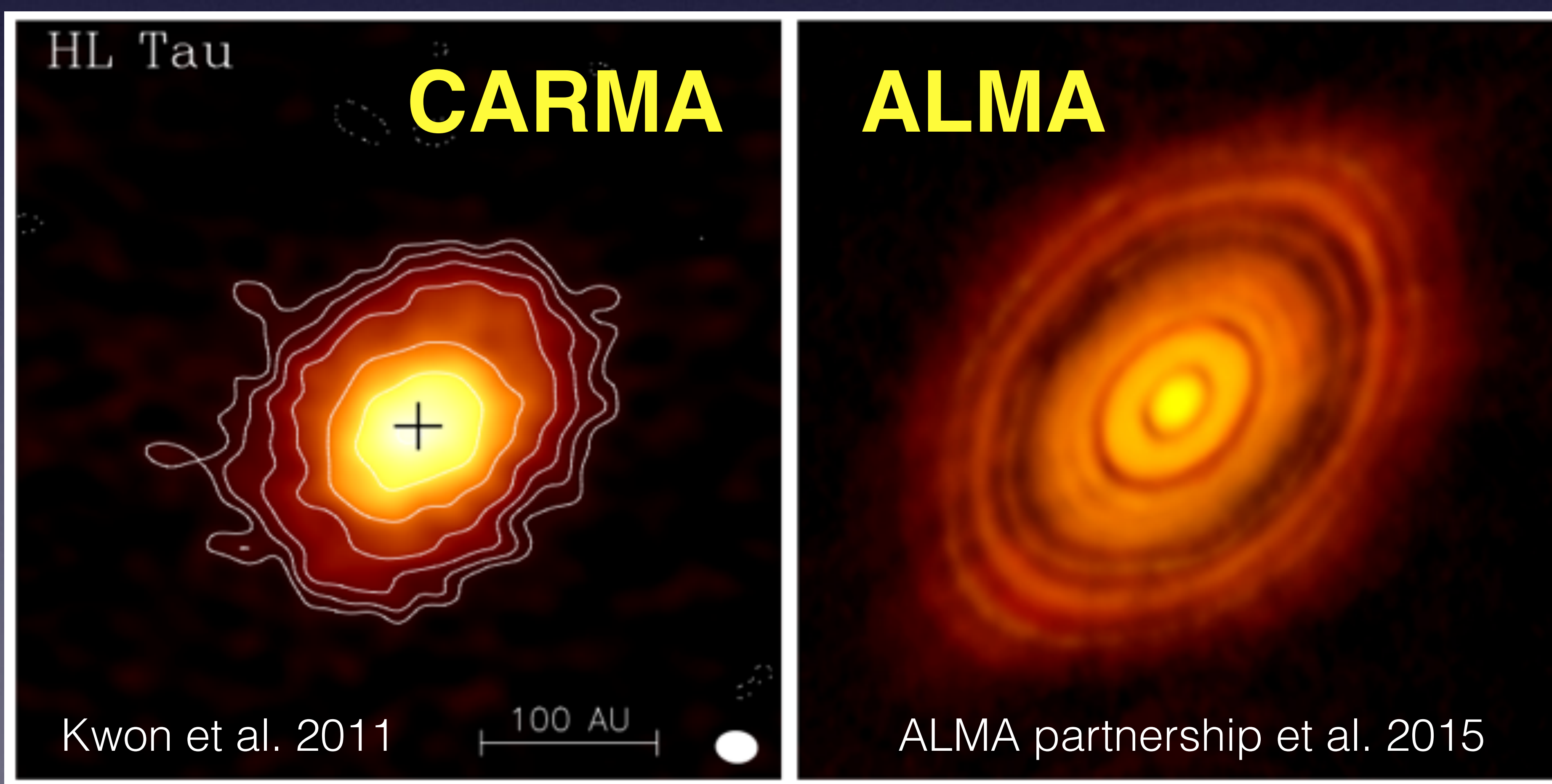


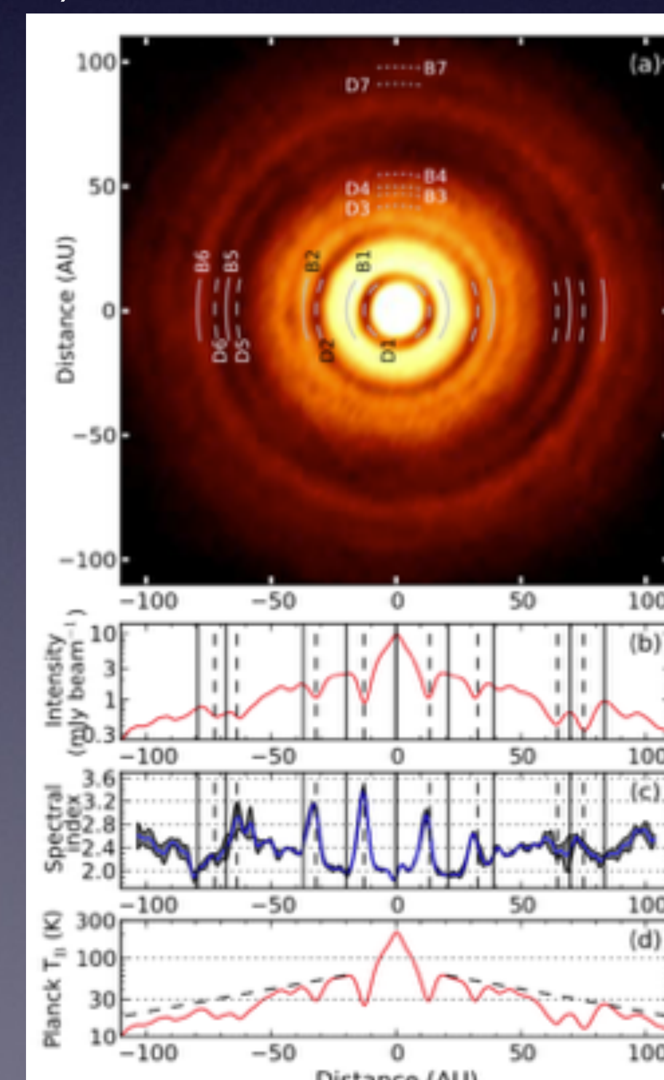




Protoplanetary disks: HL Tau

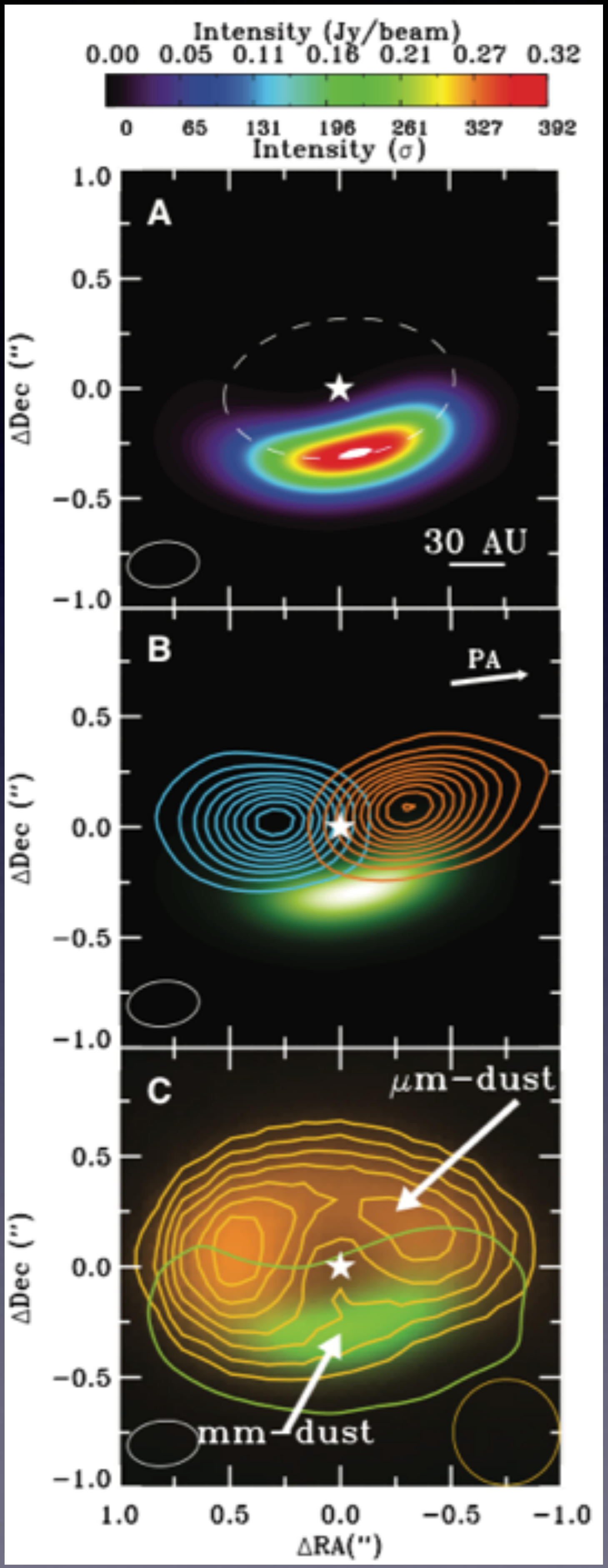
- ALMA Partnership et al. 2015
- Bands 3, 6, 7 (102, 233, 344 GHz) continuum
- Angular resolution: up to 0.02”
- Flat disk, 7 bright and dark rings, grain properties, 1.3 $M_\odot$ (HCO^+)





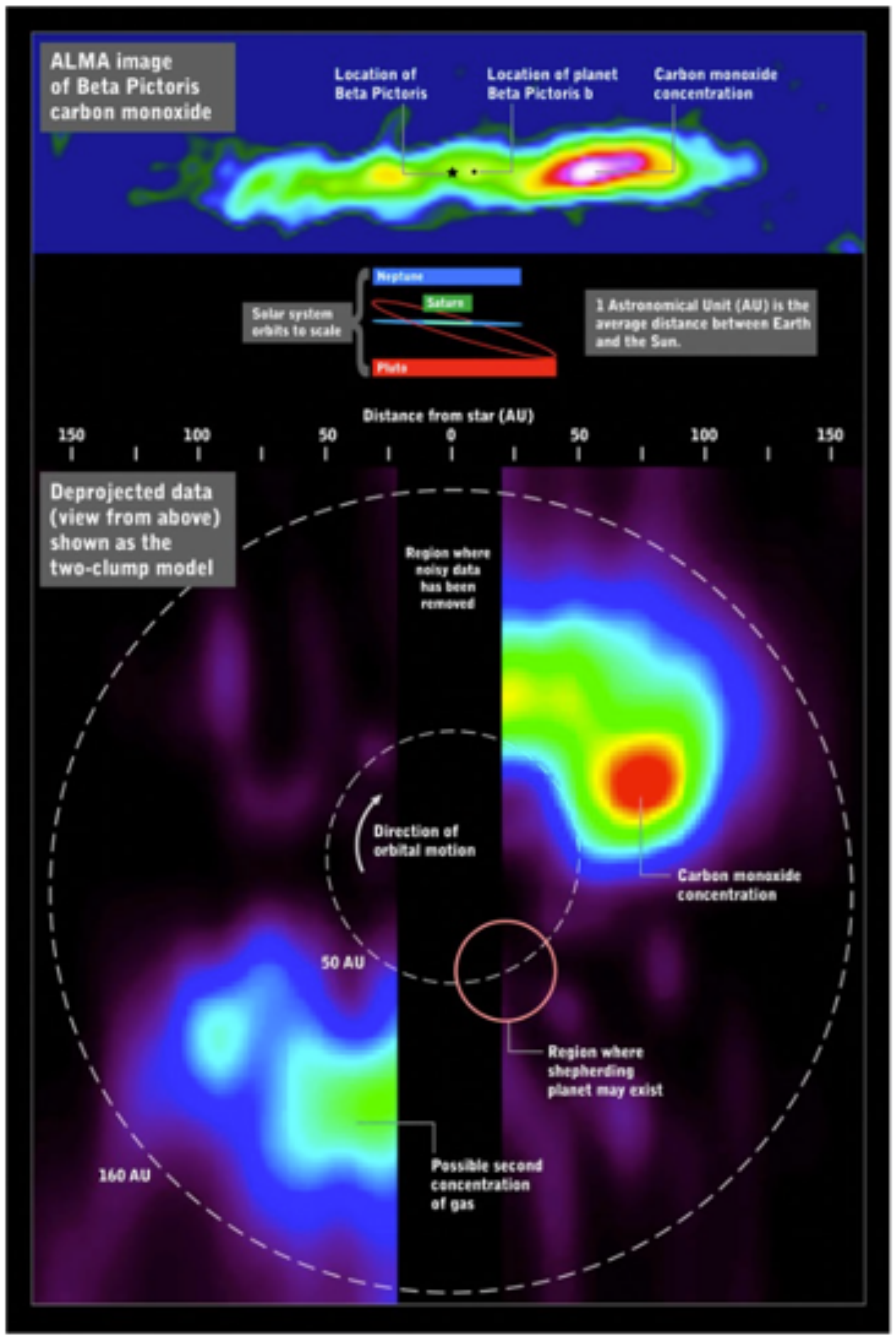
Protoplanetary disks

- A Major Asymmetric Dust Trap in a Transition Disk
- Van der Marel et al. 2013, Science
  147 citations so far
- Oph IRS 48 (d ~ 120 pc)
- 0.44 mm (685 GHz, Band 9) continuum, CO 6-5
  0.32”x0.21”
  VLT 18.7 μm emission



Debris disks

- Dent et al. 2014, Science
- β Pictoris (d ~ 19.44 pc)
  edge-on debris disk,
  infalling comets at a few AU from the star,
  a massive planet at ~10 AU,
  atomic gas out to ~300 AU
- ALMA observations
  870 μm continuum, CO 3-2
  0.6'' (12 AU)
- CO photodissociation timescale in the unshielded outer disk (by UV photons of ISM)
  ~ 120 years << 600 year orbital period at 85 AU
  => CO must be continuously replenished at ~$1.4\text{x}10^{18}$ kg/yr
- Photodesorption can't explain the amount.
  => planetesimal collisions trapped in resonances by a outward migrating planet or
  => a recent collision of ~Mars mass



Conclusions

- Unprecedented, highest angular resolution AND sensitivity at (sub)mm wavelengths

- Excellent image fidelity

- Want to study small structures (< 5”) at (sub)mm
=> (sub)mm arrays (e.g., ALMA, ALMA ACA, SMA, NOEMA)
And need a high sensitivity
=> **ALMA!!!**