Star Formation

With the Jansky VLA and ALMA

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Associated Universities, Inc.

Atacama Large Millimeter/submillimeter Array

Karl G. Jansky Very Large Array

Robert C. Byrd Green Bank Telescope

Very Long Baseline Array

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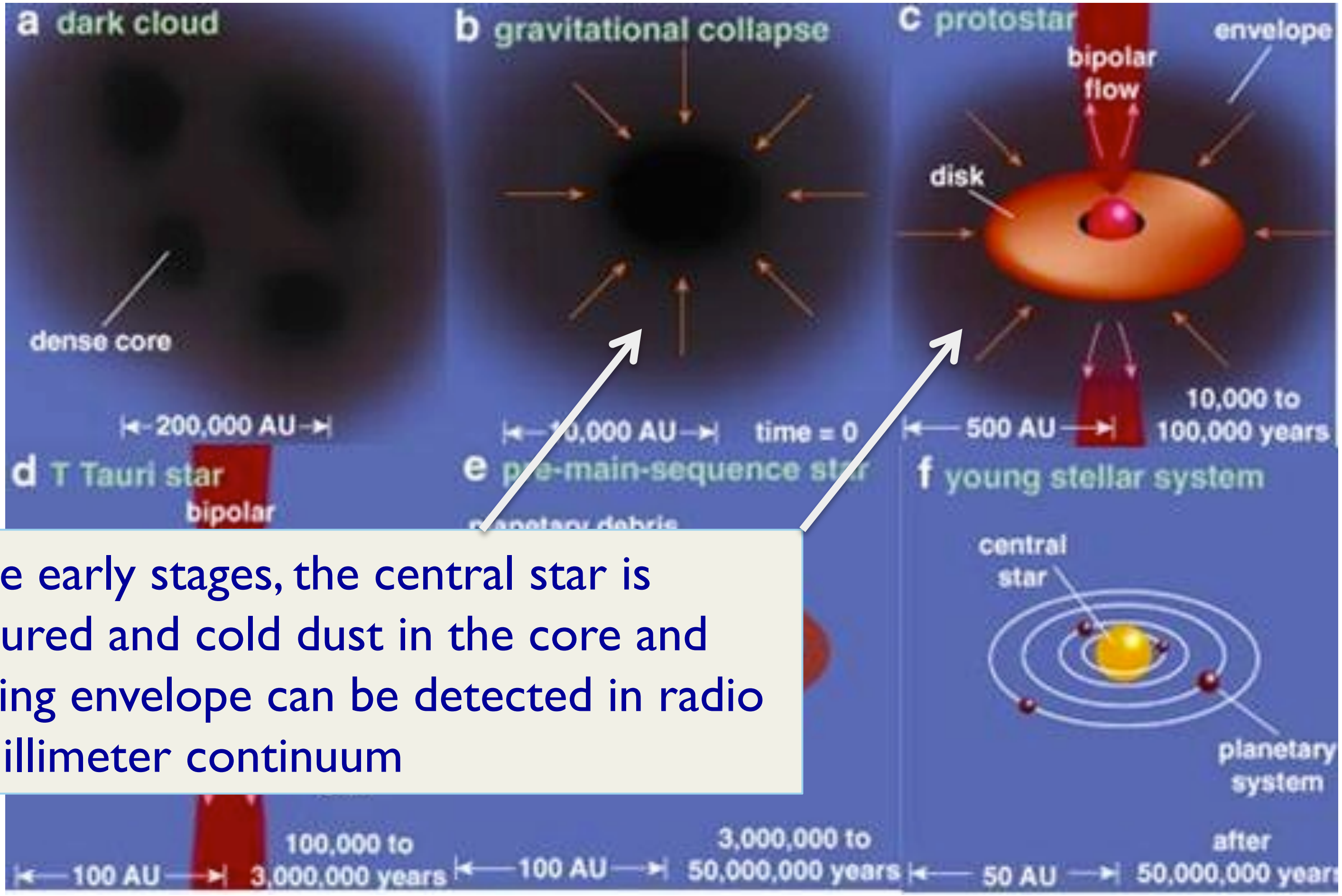
Star formation with the Jansky VLA and ALMA

- The sensitivity and angular resolution of the EVLA and ALMA allow observations of all aspects of star formation
  - Low-mass cores
  - Protoplanetary disks
  - Hot cores
  - High mass protostellar objects
  - HII regions
  - Masers in star-forming regions
  - Jets and outflows
  - Debris disks

Role of radio and sub-mm observations

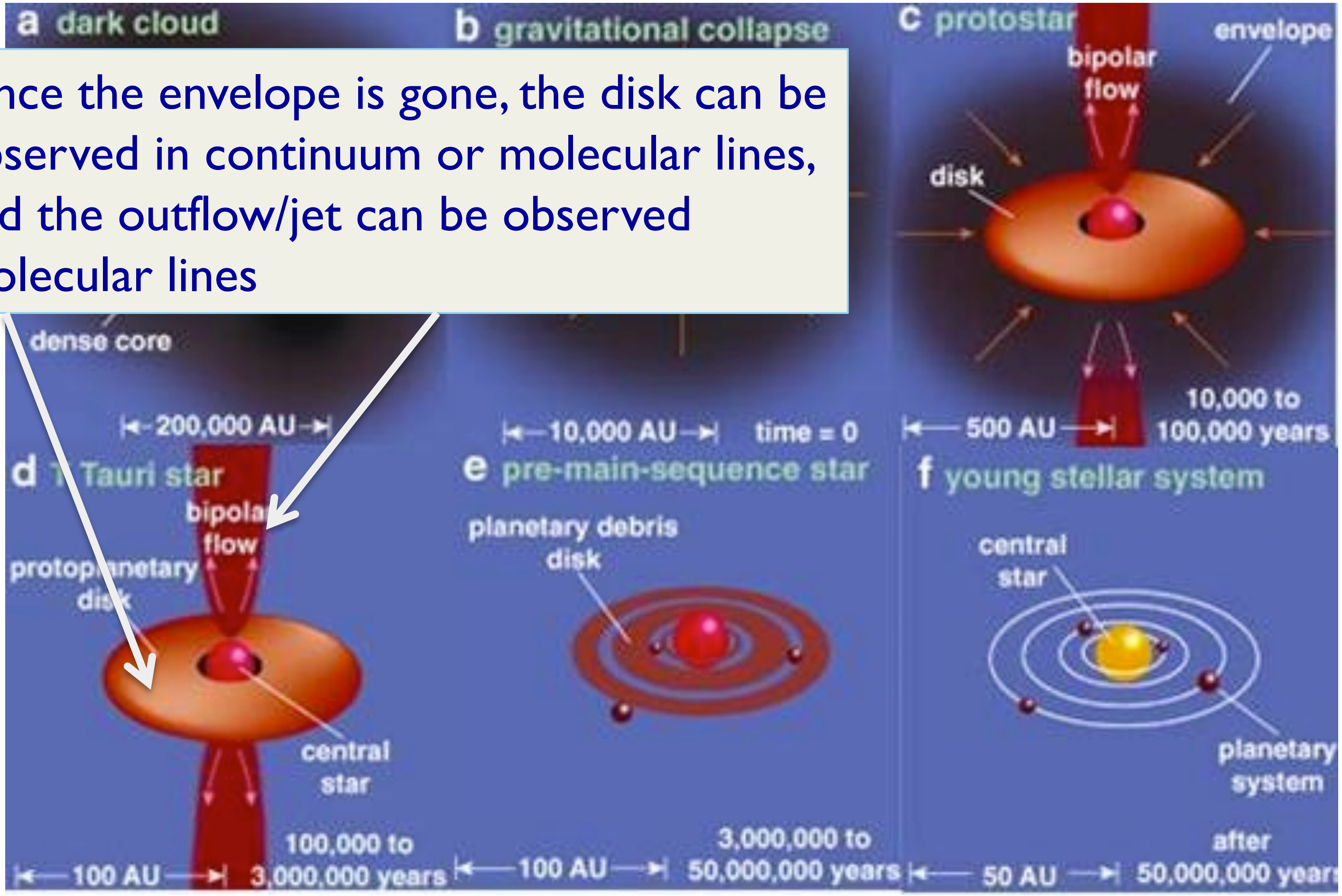


In the early stages, the central star is obscured and cold dust in the core and infalling envelope can be detected in radio to millimeter continuum

Picture from T. Greene

Role of radio and sub-mm observations

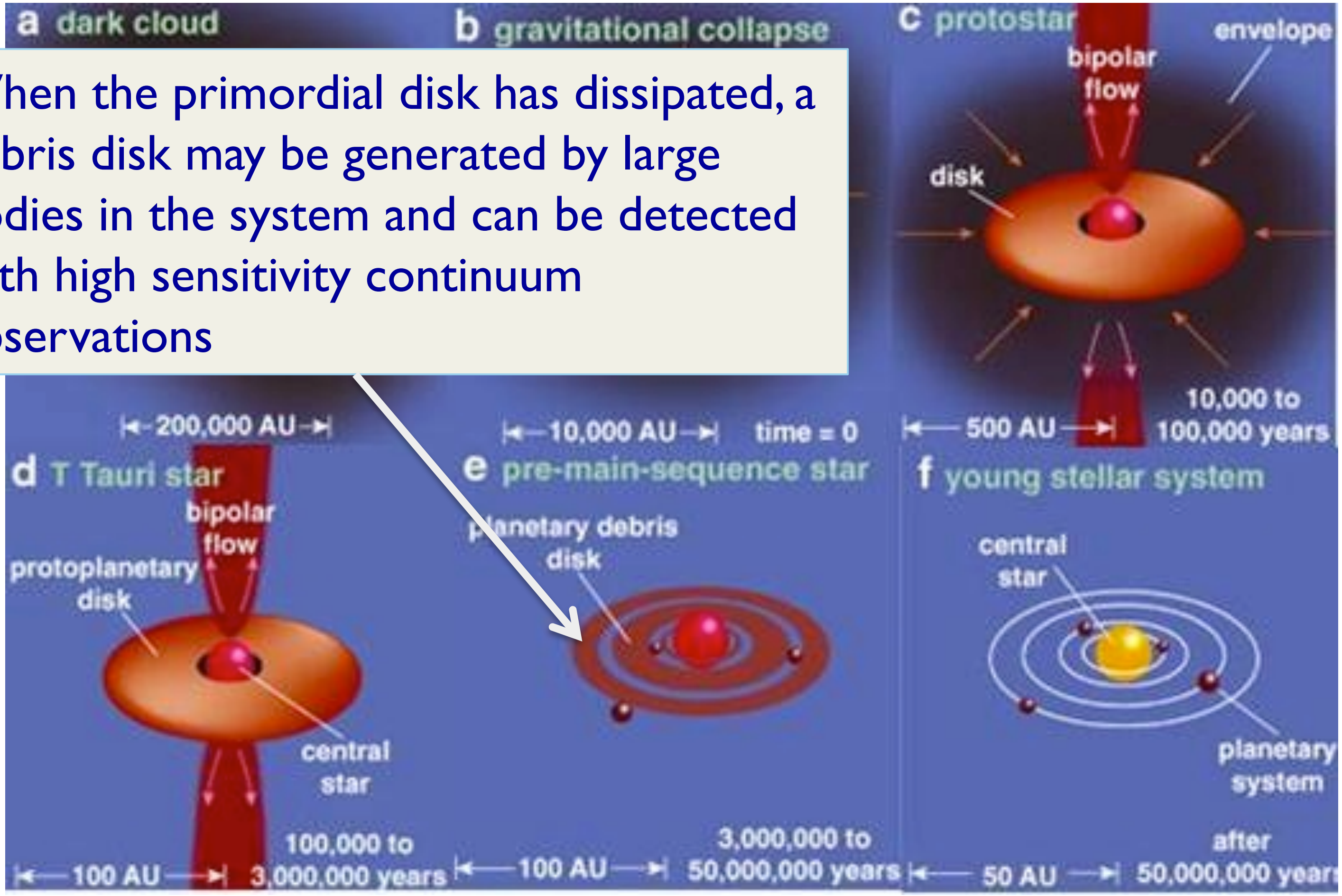
Once the envelope is gone, the disk can be observed in continuum or molecular lines, and the outflow/jet can be observed molecular lines



Picture from T. Greene

Role of radio and sub-mm observations

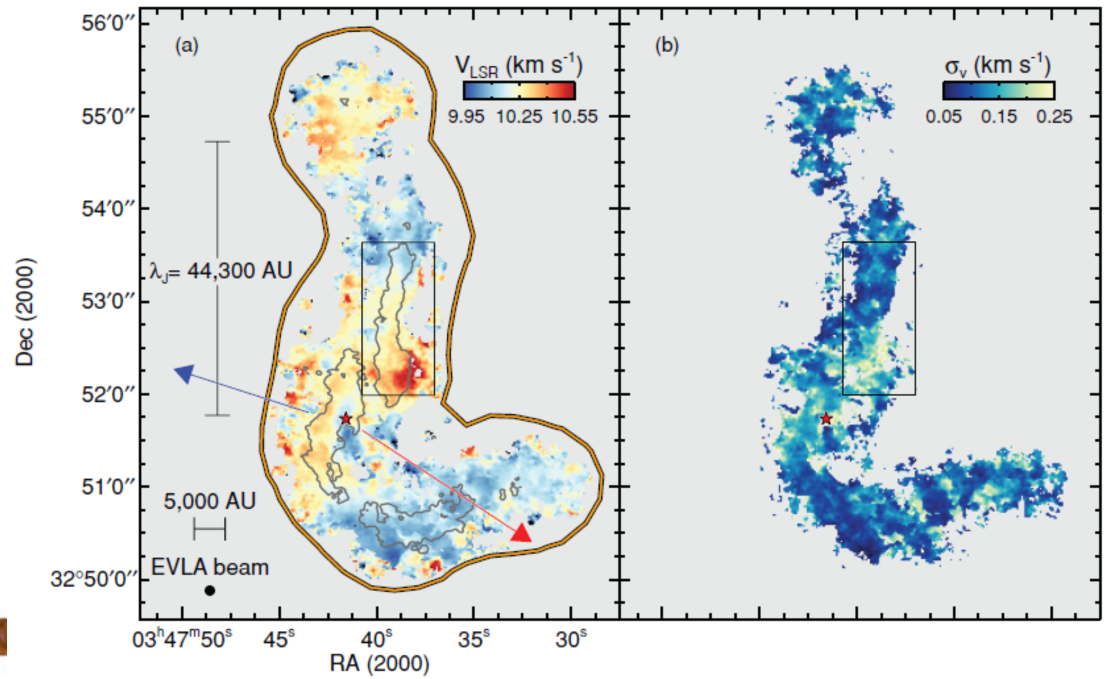
When the primordial disk has dissipated, a debris disk may be generated by large bodies in the system and can be detected with high sensitivity continuum observations



Picture from T. Greene

Molecular cloud structure

- Pineda et al (2011) used VLA to show filaments in B5 have very narrow velocity dispersion in a 6.5 x 8 arcmin
- Velocity profile is consistent with models of an isothermal filament in hydrostatic equilibrium
- These reduced turbulence (low velocity) regions are predicted to be necessary for star formation



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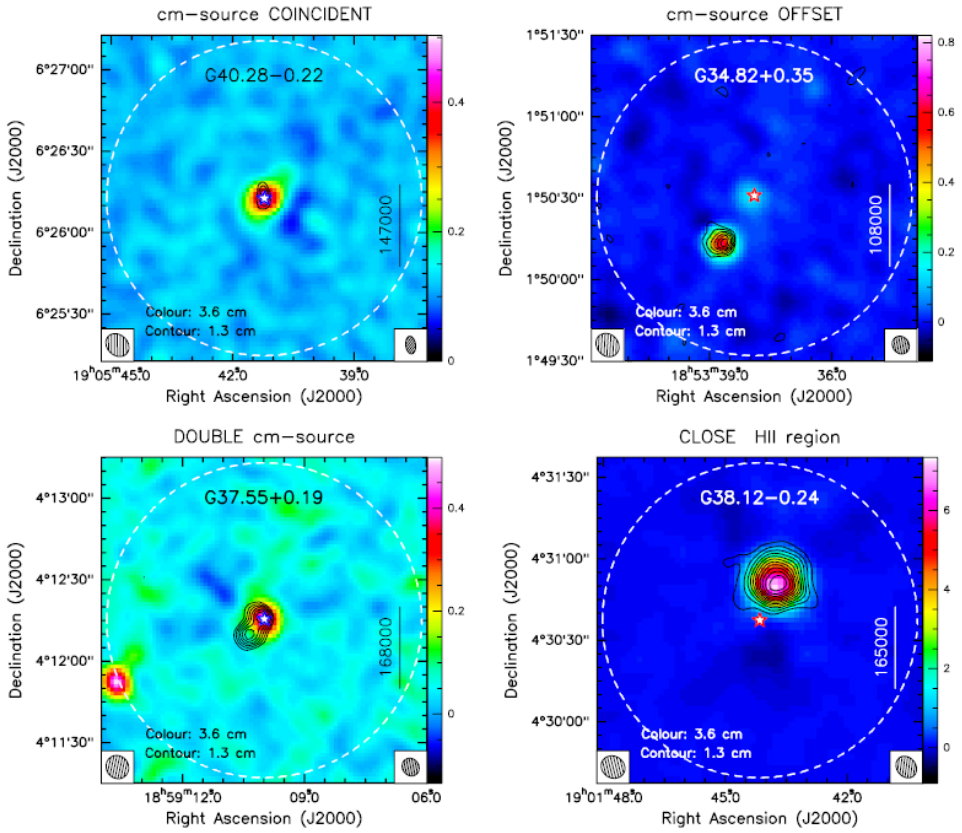
Earliest stages of massive star formation

- Hyper-compact HII regions are thought to be an early evolutionary stage of massive star formation
- This stage is short-lived, so not many are known
- Sanchez-Monge et al. 2011 observed sources identified in a 6.7 MHz methanol survey and found 6 new hyper-compact HII regions



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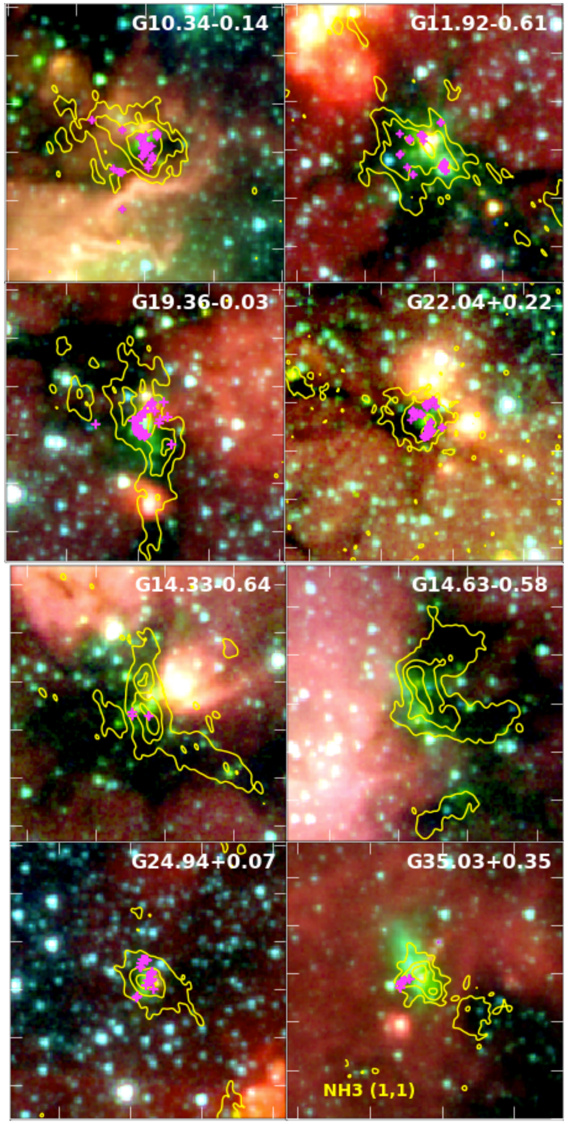
Evolution of high mass protostars

- Survey of high mass protostellar objects spanning 3 orders of magnitude in luminosity by Brogan et al (2011)
- Used expanded EVLA correlator/ receivers to simultaneously observe:
  - NH3 (temperature and density)
  - methanol masers (hot cores)
  - HC5N, HC9N, DC3N (formation history of gas)
  - 2 radio recombination lines (kinematics of ionized gas)
  - Radio continuum

GLIMPSE
3.6 μm
4.5 μm
8.0 μm

+ 44 GHz CH_3OH Masers (Cyganowski et al. 2009)



Resolution 3" = 9000 AU at 3 kpc

120" ≈ 1.7 pc

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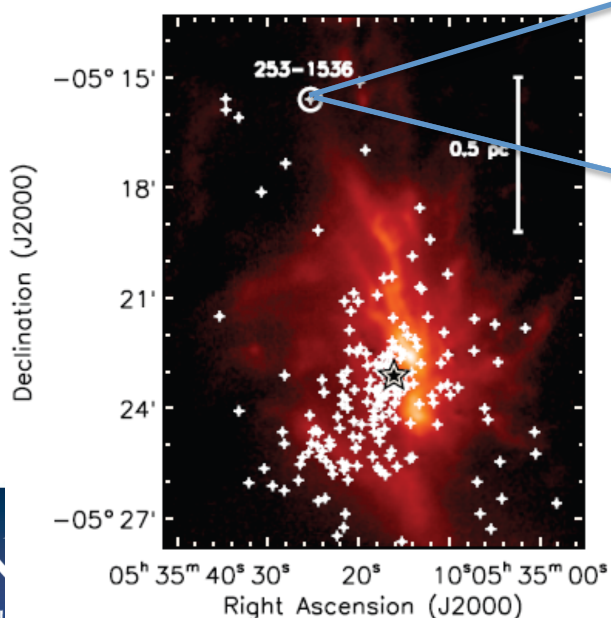
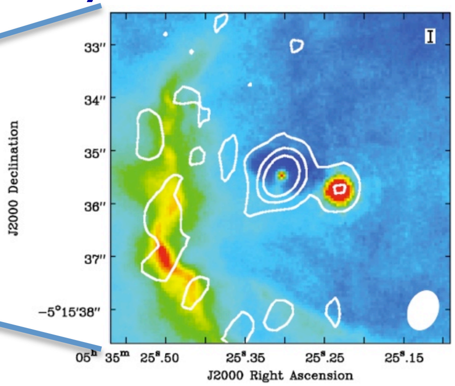
Externally irradiated disks in Orion

- Ricci et al (2011) used the ELVA to observe a binary disk system in Orion
  - Combined EVLA data with data in the submillimeter to derive spectral index
  - The disk with lower density and higher temperature hosts larger grains than the companion disk
    - Opposite of what is predicted by the dust evolution models.

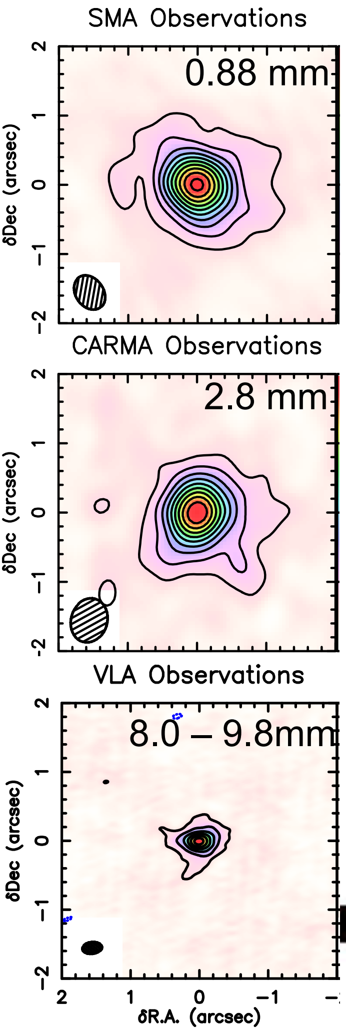


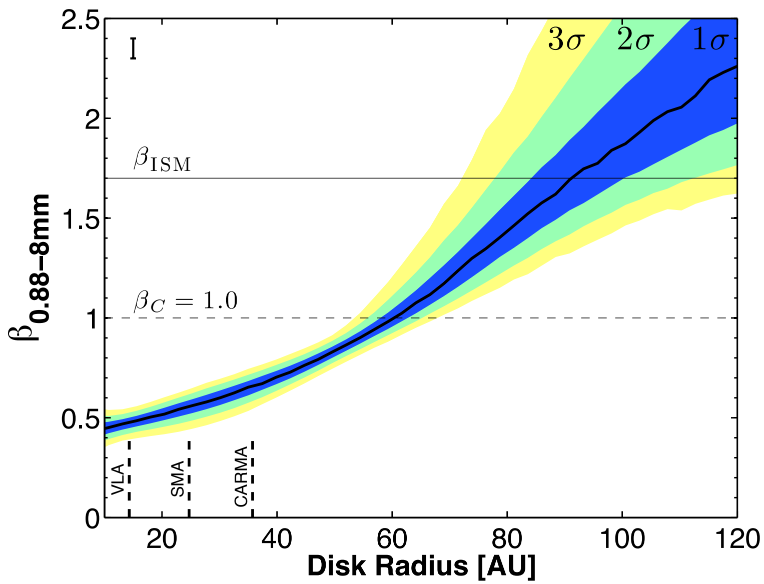


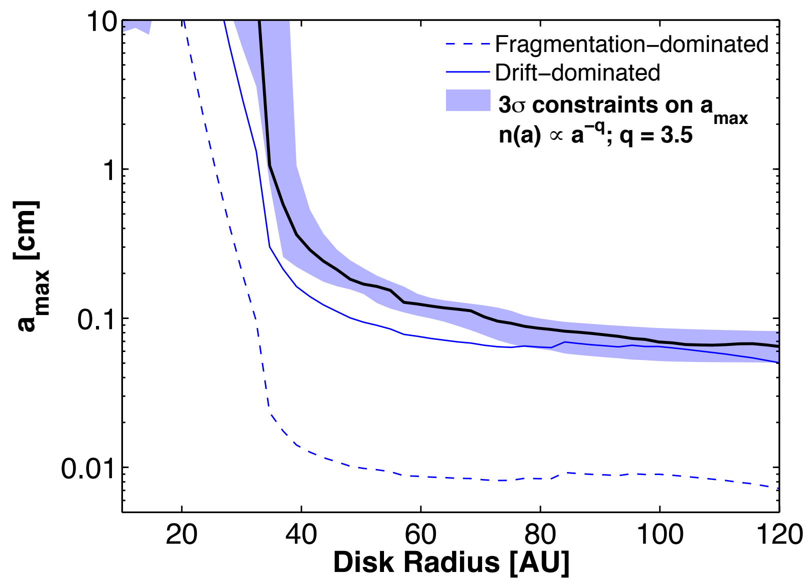
Source	α(0.88-7mm)	R_{out} (AU)	i (°)	β
253-1536a	2.34 ± 0.16	280	55	0.5 ± 0.2
253-1536b	2.30 ± 0.19	40-60	0-50	0.5-1.6

Protoplanetary disks: the case of AS209

- Perez et al (2012) combine submm (SMA)/mm(CARMA)/cm (VLA) observations to measure disk emission spectrum and constrain dust properties
  - Shallow spectral index at small radii is a sign of grain growth (on scales of our own Solar System planets)
  - Outer disk is consistent with interstellar grains

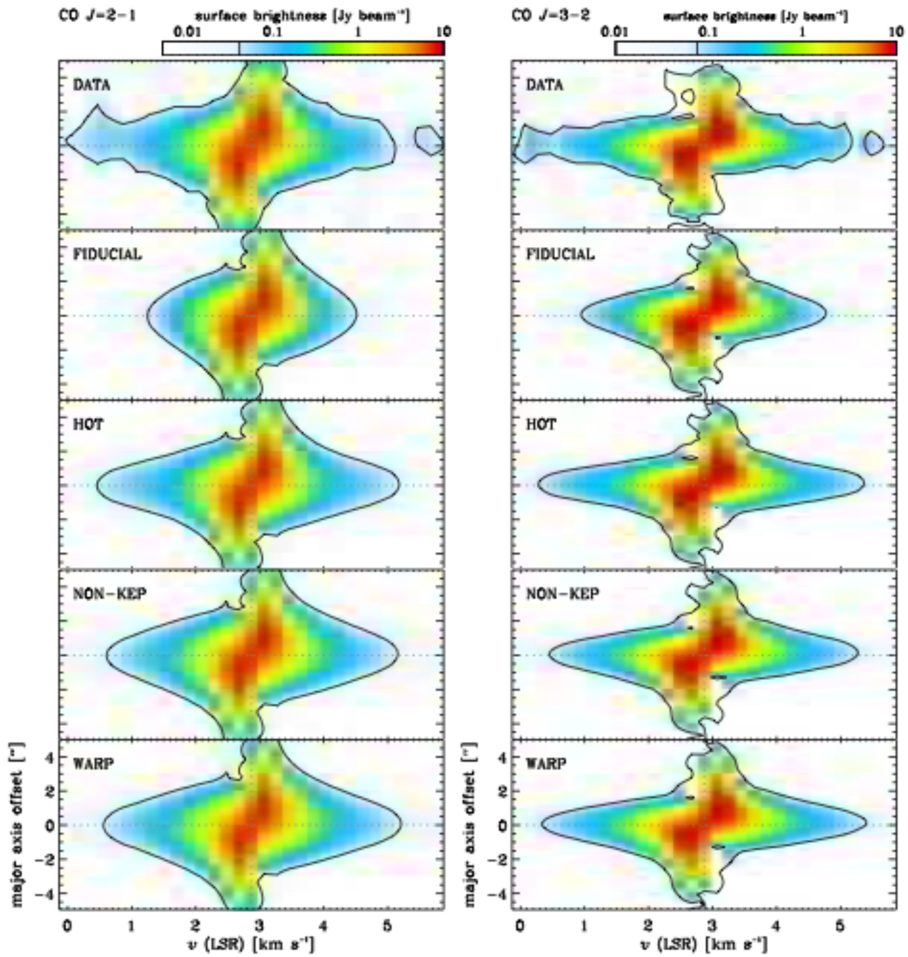






Detailed kinematics

- Rosenfeld et al (2012) use ALMA science verification data to study the details of disk rotation in TW Hya
  - Intensity of high velocity wings at (probes radii of ~2 AU) can not be reproduced with simple disk models
  - Need to alter either:
    - Temperature structure
    - Keplerian velocity field
    - Or include a warp



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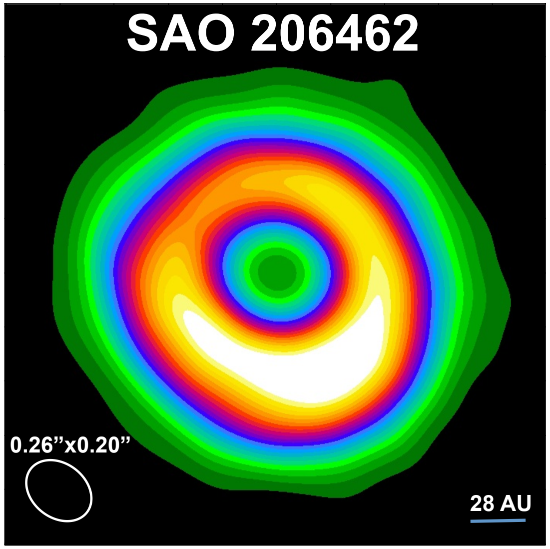
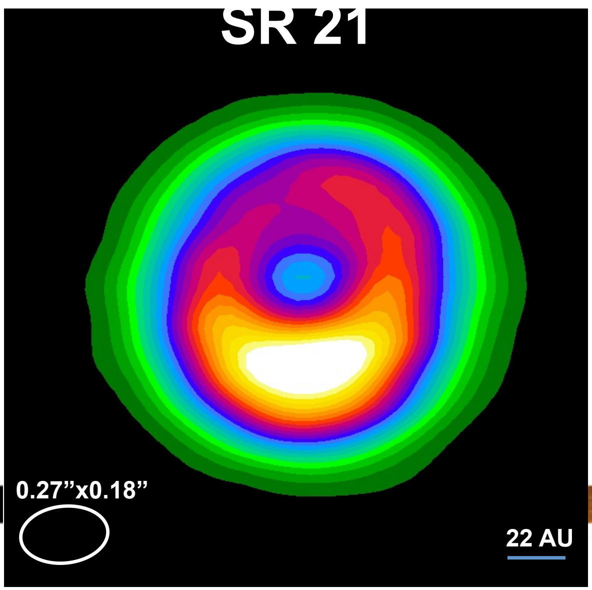
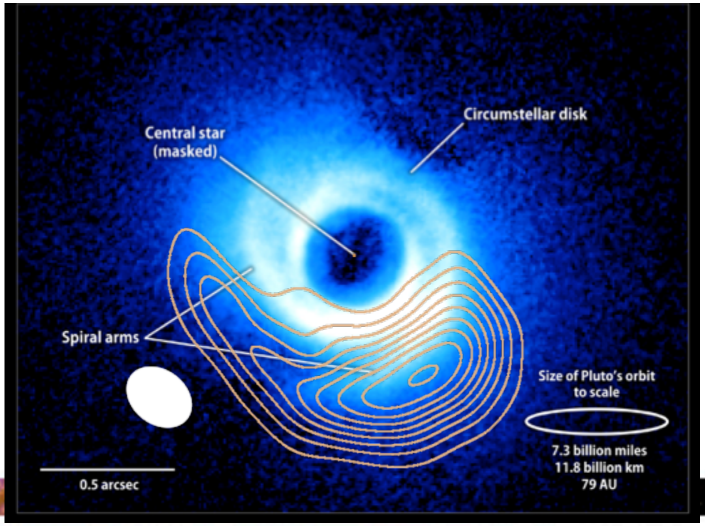
Transition disks: Planets or dissipation?

- Perez et al (2013, in prep) used ALMA band 9 to constrain the sharpness of the cavity and the overall structure of the disk
  - Only 1 spiral arm in SAO 206462 visible in sub-mm
- Detailed images constructed from only 30 minutes of data

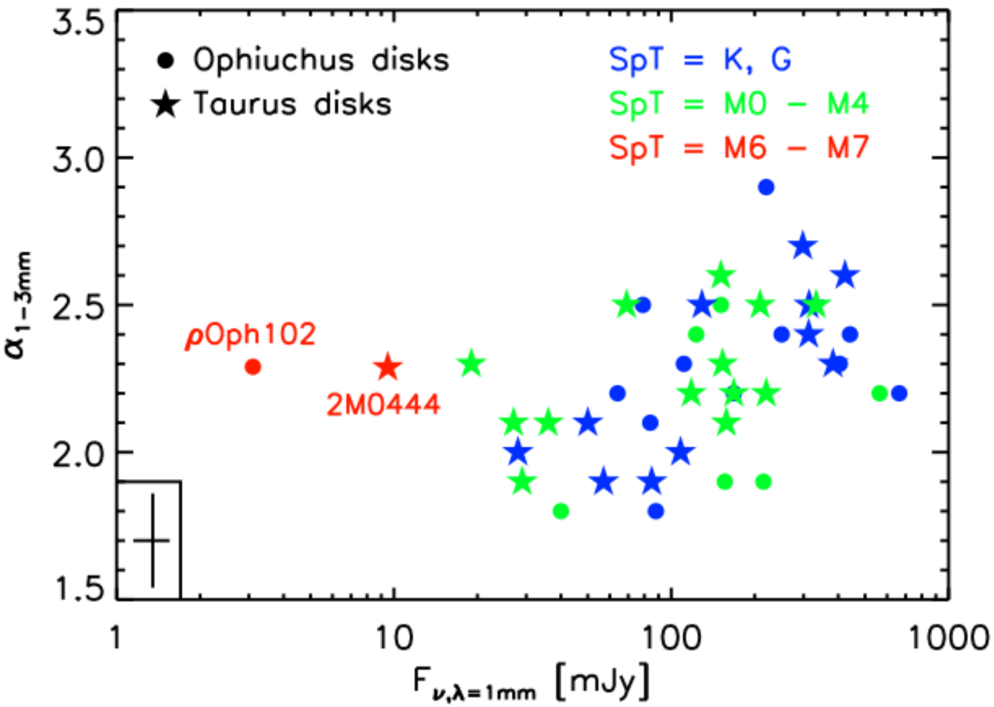




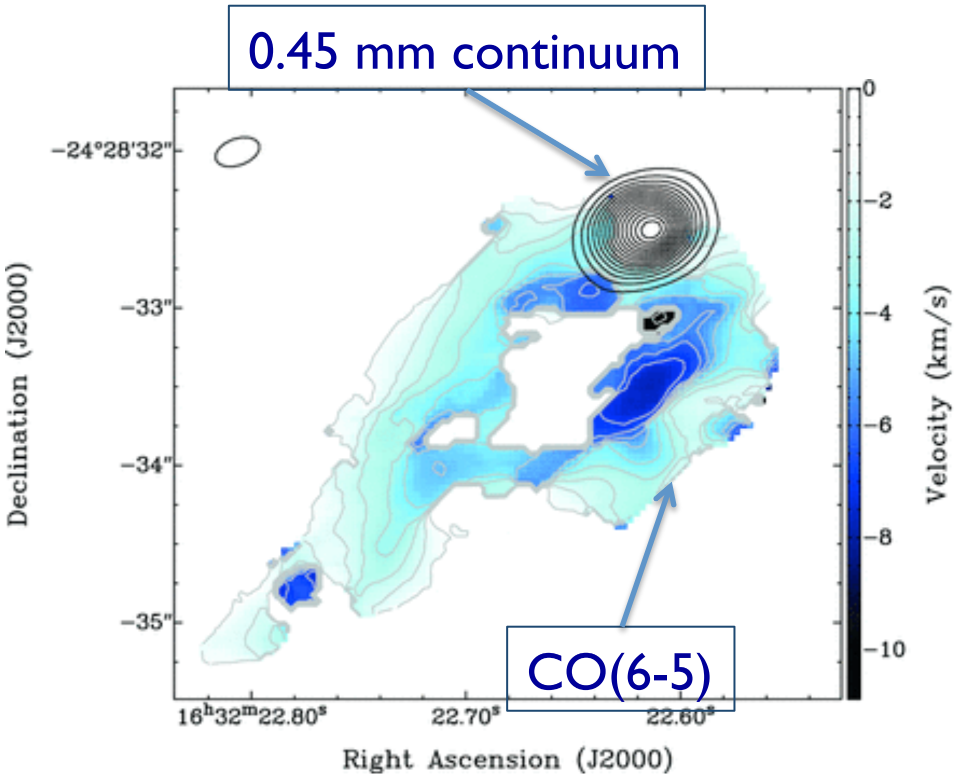


Even brown dwarfs have disks

- Ricci et al (2012) used ALMA observations at 0.89 and 3.2 mm to detect a dust disk around the brown dwarf rho-Oph 102
- Spectral slope suggest mm-sized grains, which means grain growth can occur even in low-density disks
- Molecular gas also detected



Using high excitation molecular lines to probe outflows

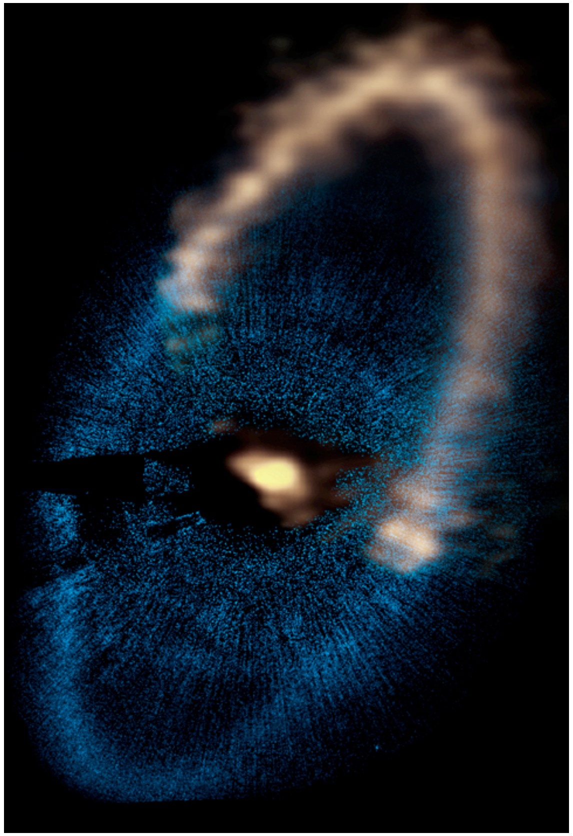


- Loinard et al (2012) combine ALMA and EVLA observations of the young multiple system IRAS 16293-2422
- First detection of outflow driven by source B
- Confirmation that large sclae NE-SW flow is driven by 2A

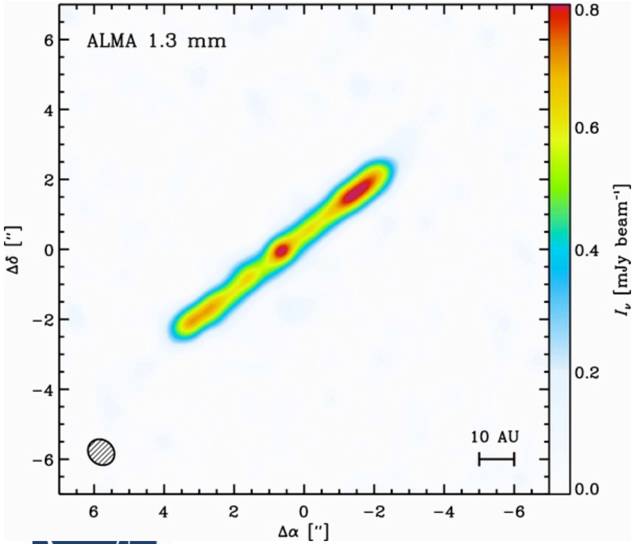
Debris disks: From detection to dynamics with ALMA

- Boley et al (2012) resolve the width of the large grains in a 13-19 AU wide ring around Fomalhaut
- Sheparding by planets is the most likely explanation for the sharp boundaries

Fomalhaut



AU Mic



- MacGregor et al (2012) find two components:
  - Previously known dust belt at 40 AU
  - Unresolved central peak (6 x stellar photosphere)

Summary

- Both the Jansky VLA and ALMA are producing ground-breaking observations in star formation right now
- EVLA
  - The new continuous frequency coverage, wide instantaneous bandwidth and correlator flexibility are allowing simultaneous observations of many transitions at the same time as the continuum
  - See EVLA ApJL special issue (ApJL 739, 2011 September 20) for more results
- ALMA
  - Even in Cycles 0 and 1, the ALMA sensitivity is unprecedented, allowing detection of new objects and the detailed study of objects which had previously only been detected

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