The VLA Nascent Disk and Multiplicity Survey (VANDAM) of the Perseus Molecular Cloud: Multiplicity and Disks on < 500 AU scales

John Tobin (PI, Leiden Observatory)

Team: Leslie Looney (Illinois), Zhi-Yun Li (Virginia), Claire Chandler (NRAO), Dominique Segura-Cox (Illinois), Mike Dunham (CfA), Sarah Sadavoy (MPIA), Carl Melis (UCSD), Kaitlin Kratter (Arizona), Laura Perez (NRAO), Robert Harris (Illinois)

Abstract

We present results from a 264-hour Jansky VLA survey of known Class 0 and I protostars (n ~ 80) in the Perseus molecular cloud (d ~ 230 pc). The protostars are being observed at λ = 8 mm, 1 cm in B-array and A-array with best resolutions of 0.25” (~60 AU) and 0.06” (~15 AU) respectively. We are also obtaining A-array observations at λ = 4 cm and 6.5 cm to characterize the free-free emission. This survey is sampling the peak of the field binary separation distribution (~50 AU) toward protostars for the first time. This is the largest and most complete high-resolution millimeter and centimeter-wave survey of protostars, with ultimately uniform resolution and sensitivity. Further characterization of binary formation mechanisms requires molecular line observations. All the multiples separated by < 500 AU are being followed-up with ALMA Cycle 2 observations of 1.3 mm continuum and molecular lines (CO/13CO/C18O) at 0.2” resolution. These data will enable us to determine if there is a rotationally supported disk around the sources, suggesting disk fragmentation origin. Lack of a circumbinary disk would suggest turbulent fragmentation with rapid inward migration.

Key Results

- Discovered 16 previously unknown multiple systems at separations < 500 AU (Figures 1 & 4)
- Resolved nine candidate disks with radii > 20 AU (Figure 3)
- Resolved three multiple systems with separations < 20 AU with apparent circumbinary structures (Figure 4).
- Evidence for a bi-modal separation distribution (Figure 2).
- Bi-modal distribution may suggest multiple formation via core/turbulent fragmentation on larger scales and disk fragmentation on smaller scales.
- Different separation distributions found for Class 0 and Class I protostars (Figure 2)

Multiplicity on < 500 AU Scales

★ - New Multiple

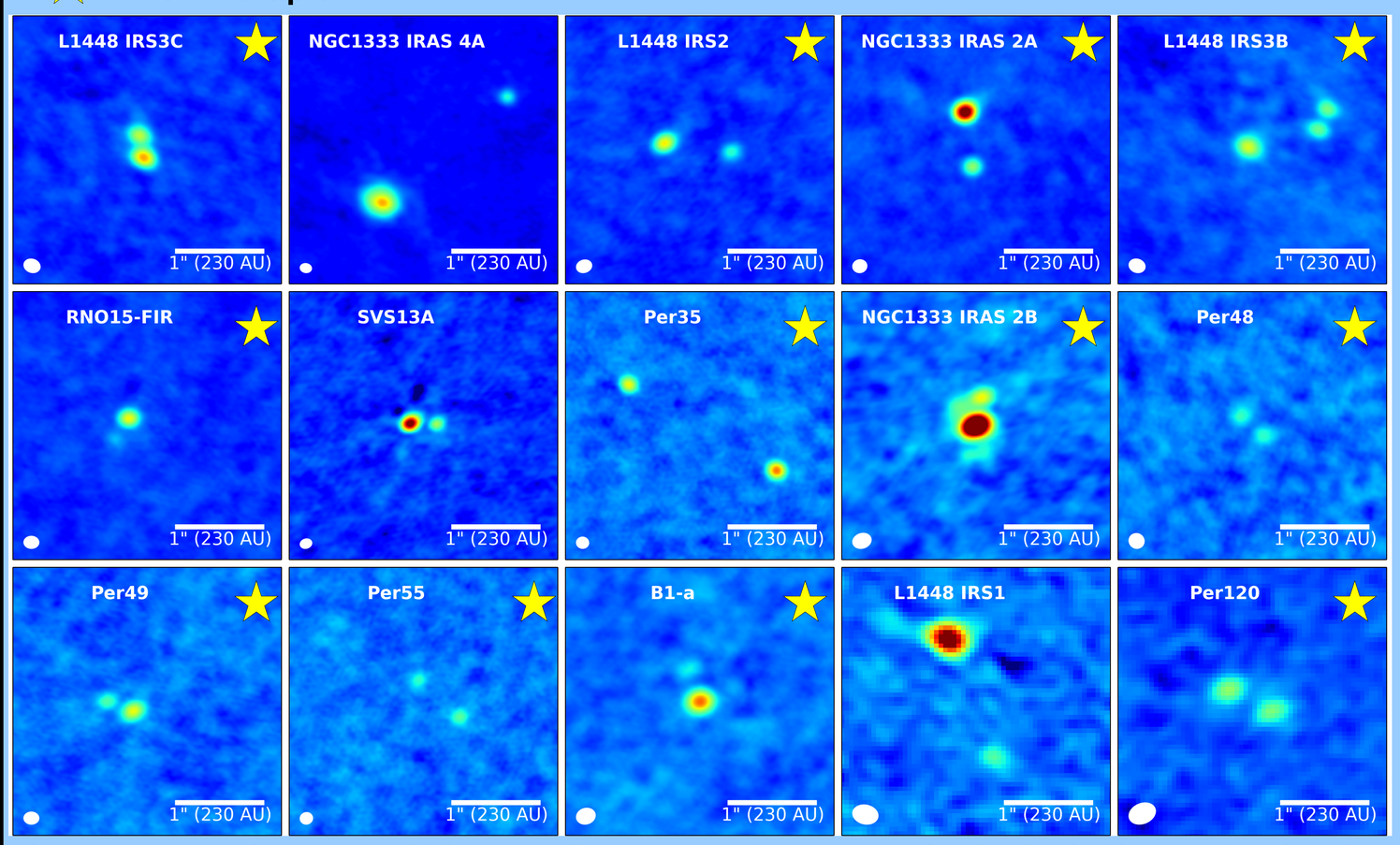

Figure 1: VLA 8 mm images of multiple protostellar systems in the Perseus molecular cloud with separations less than 500 AU. All images are a combination of A and B configuration data with a typical beam size of 0.15” (34.5 AU); L1448 IRS1 and Per120 have only been taken in B configuration thus far and have a beam size of ~0.2”. All images have a typical sensitivity of 9 μJy. Per35 marks the start of the Class I protostars.

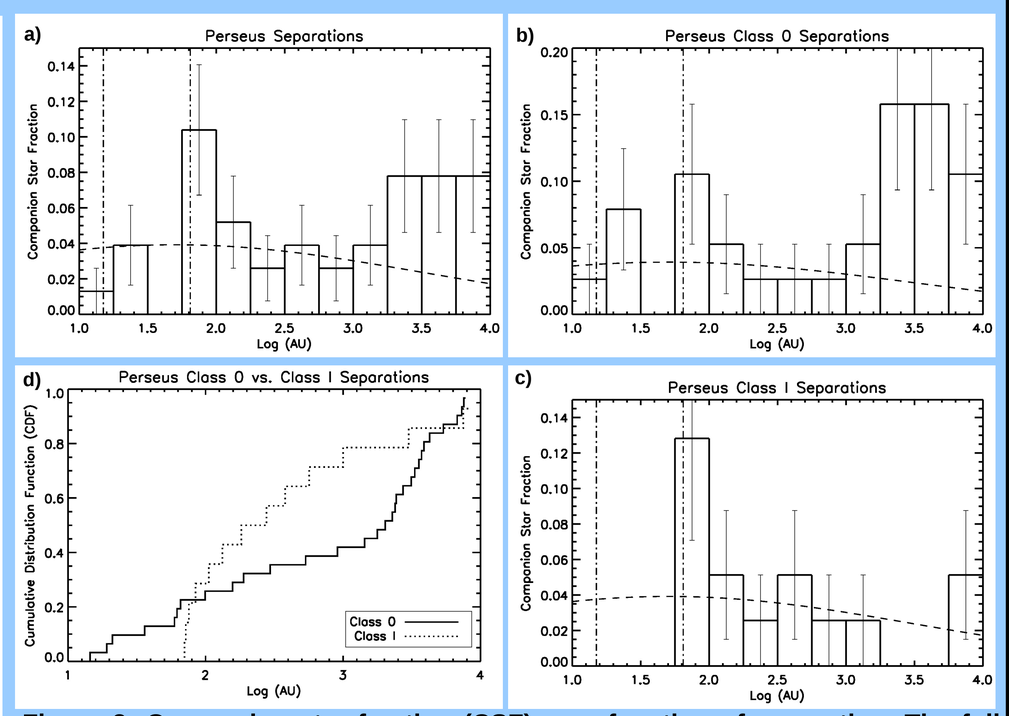

Figure 2: Companion star fraction (CSF) as a function of separation. The full sample is shown in (a), only Class 0 systems are shown in (b), only the Class I systems are shown in (c), and the cumulative distributions of Class 0 and Class I systems are shown in (d). A K-S test reveals that the Class 0 and Class I separation distributions only have a probability of 0.06 to have been drawn from the same distribution. The dashed line is for field solar-type stars (Raghavan et al. 2010). The vertical lines at 1.18 and 1.81 are the resolution limits for A and B configurations, respectively.

The multiplicity fraction (MF) and companion star fraction (CSF), referring to the frequency of multiple systems and the average fraction of companions per system, respectively, are typical diagnostics. The MF and CSF for the Perseus sample (including wider multiples is shown in the table on the right. Approximately half of all Class 0 system are multiple and are more likely to have higher-order multiplicity than Class I systems. Note that Class 0 systems often have a >1000 AU Class I companion; Class 0 – Class I pairs only go into the Class 0 stats.

Multiplicity Statistics

	S :B :T:Q:5:6	MF	CSF
All	38:18:5:2:1:1	0.4	0.66
Class 0	15: 8:4:2:1:1	0.5	1.0
Class I+	23:10:1:0:0:0	0.3	0.35

MF = (B+T+Q+...)/(S+B+T+Q+...)
CSF = (B+2T+3Q+...)/(S+B+T+Q+...)

Candidate Class 0 Disks

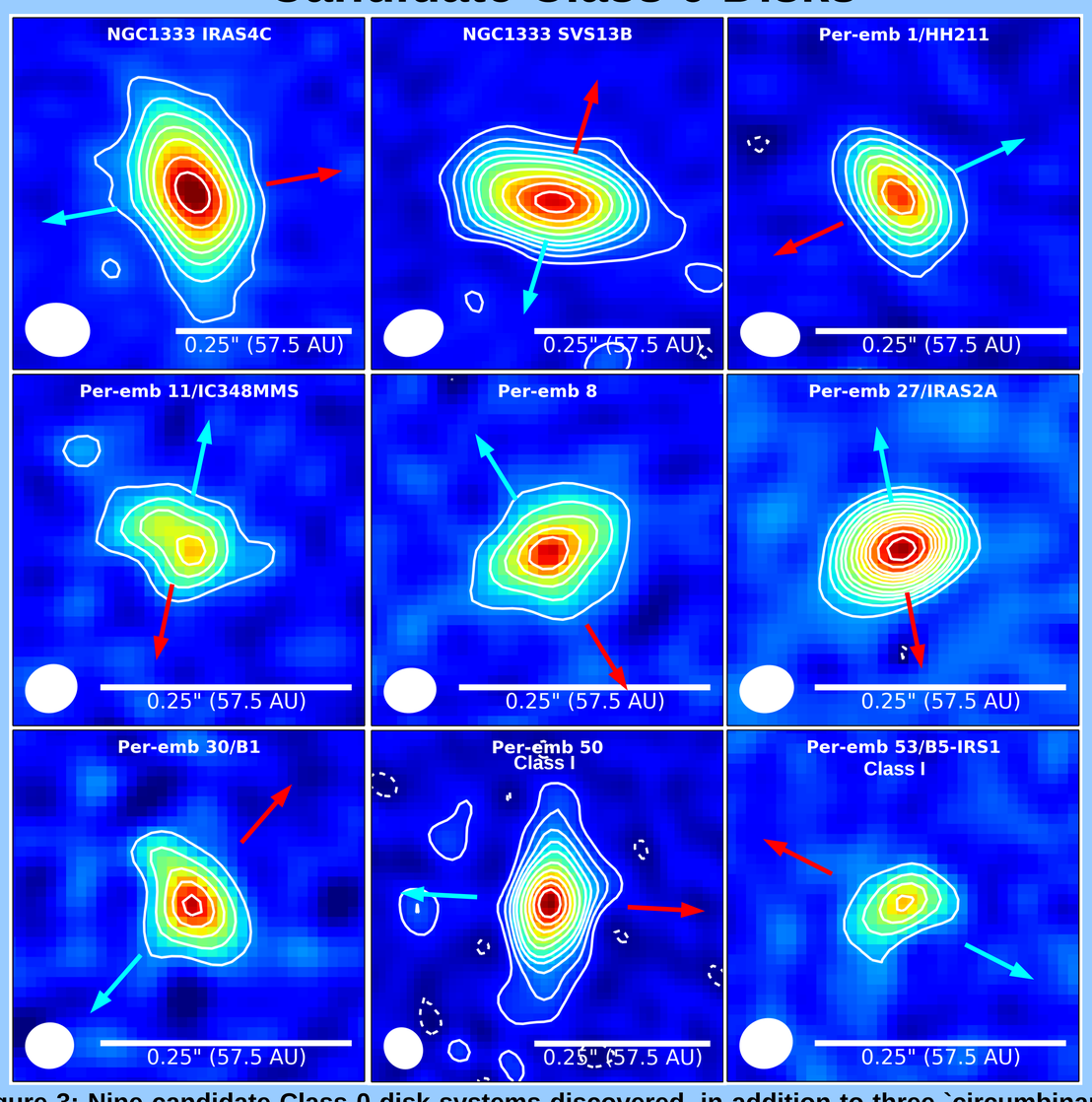

Figure 3: Nine candidate Class 0 disk systems discovered, in addition to three `circumbinary' disk candidates shown in Figure 4. Lee (2009) reported a possible disk toward HH211 and we now resolve the disk on smaller scales, but do not detect the reported binary. Two Class I disk candidates are also shown (Per-emb-50 and B5 IRS1/Per-emb-53).

Multiples Separated by < 50 AU

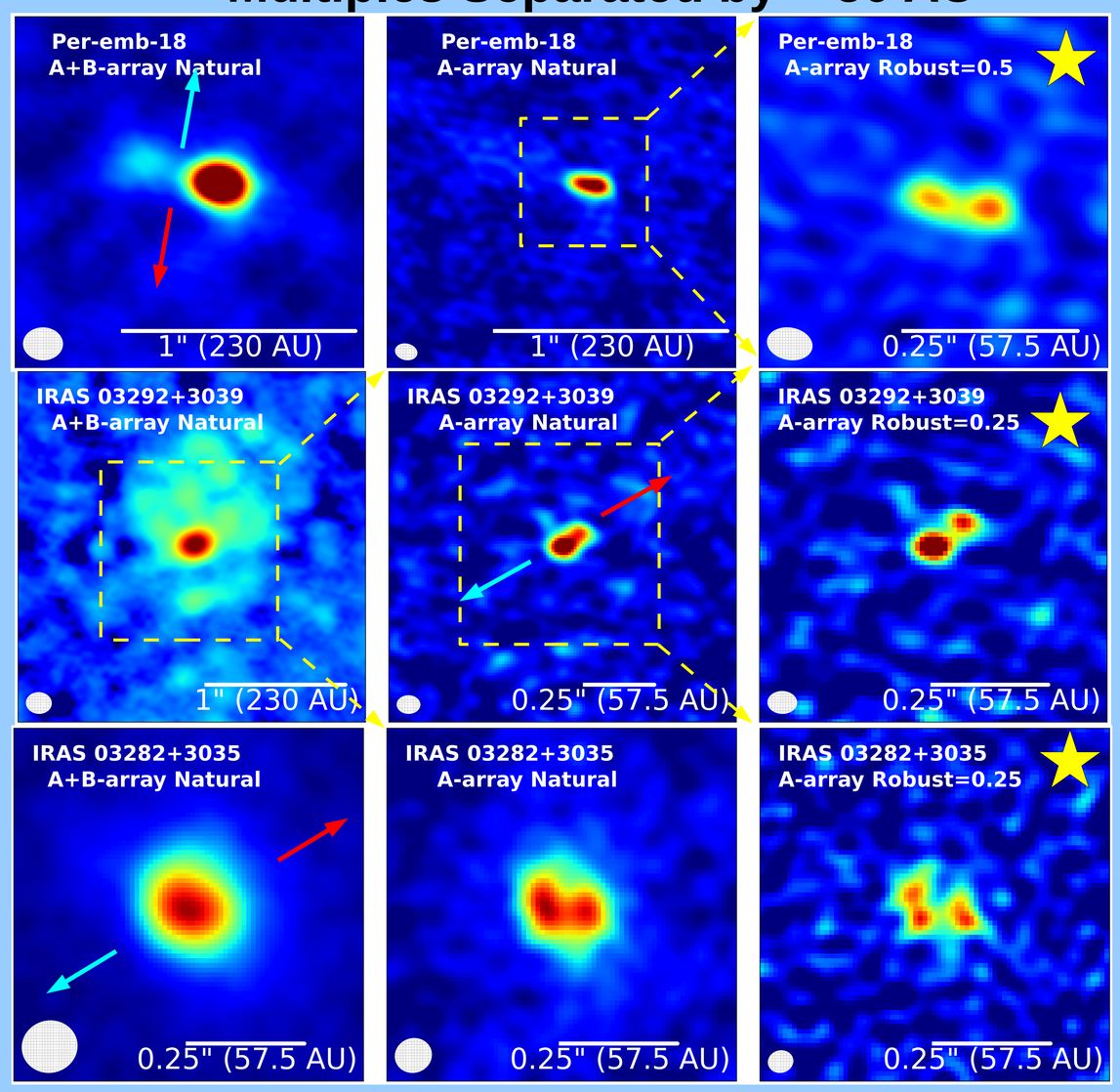

Figure 4: Class 0 systems with companions separated by less that 50 AU discovered with our VLA A-array data. Note the larger-scale dust features in the left images that become resolved in the middle images and reveal the close companions in the right images.