The Pleiades Distance Controversy

and Radio Emission from Young to Intermediate-Age Sun-like Main Sequence Stars

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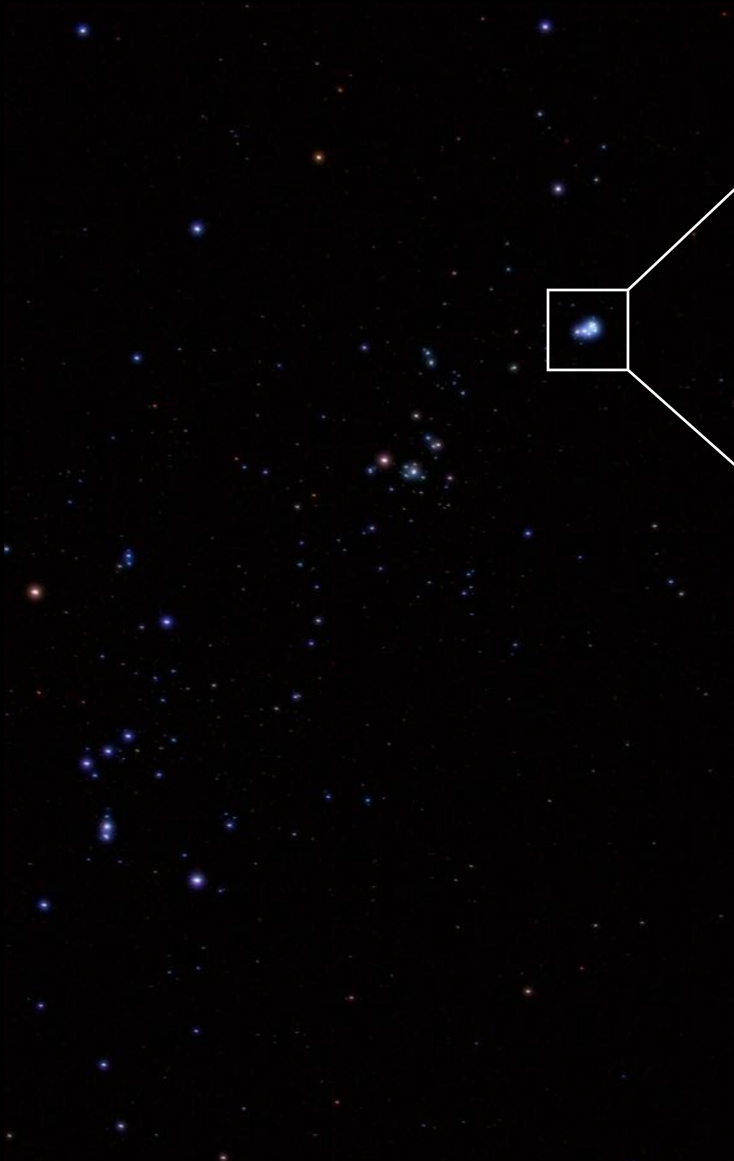
“The distance to the Pleiades can be used as an important first step to calibrate the cosmic distance ladder.” - *Wikipedia*



- Most well studied open cluster in the sky.
- Used to define Zero-Age Main Sequence -> isochronal fitting to derive cluster distances.
- Rotation as a function of age.
- Best defined substellar locus of any cluster.
- etc…

The Pleiades Distance Controversy

Table 1: Pleiades Parallaxes - updated from Soderblom et al. (2005)

Method	π_{abs} (mas)	D (pc)	m−M	Ref.
Hipparcos all-sky	8.45±0.25	118.3±3.5	5.37±0.06	2
Hipparcos new reduction	8.18±0.13	122.2±1.9	5.44±0.03	7
Main-sequence fitting	7.58±0.14	131.9±2.4	5.60±0.04	1
Allegheny Observatory parallaxes	7.64±0.43	130.9±7.4	5.59±0.11	3
Interferometric orbit	7.41±0.11	135.0±2.0	5.65±0.03	4
Dynamical parallax	7.58±0.11	131.9±3.0	5.60±0.05	5
HST FGS parallax of 3 Pleiads	7.43±0.17	134.6±3.1	5.65±0.05	6

References.—(1) Pinsonneault et al. 1998, (2) van Leeuwen 1999, (3) Gatewood et al. 2000, (4) Pan et al. 2004, (5) Munari et al. 2004, (6) Soderblom et al. 2005, (7) van Leeuwen et al. 2007.

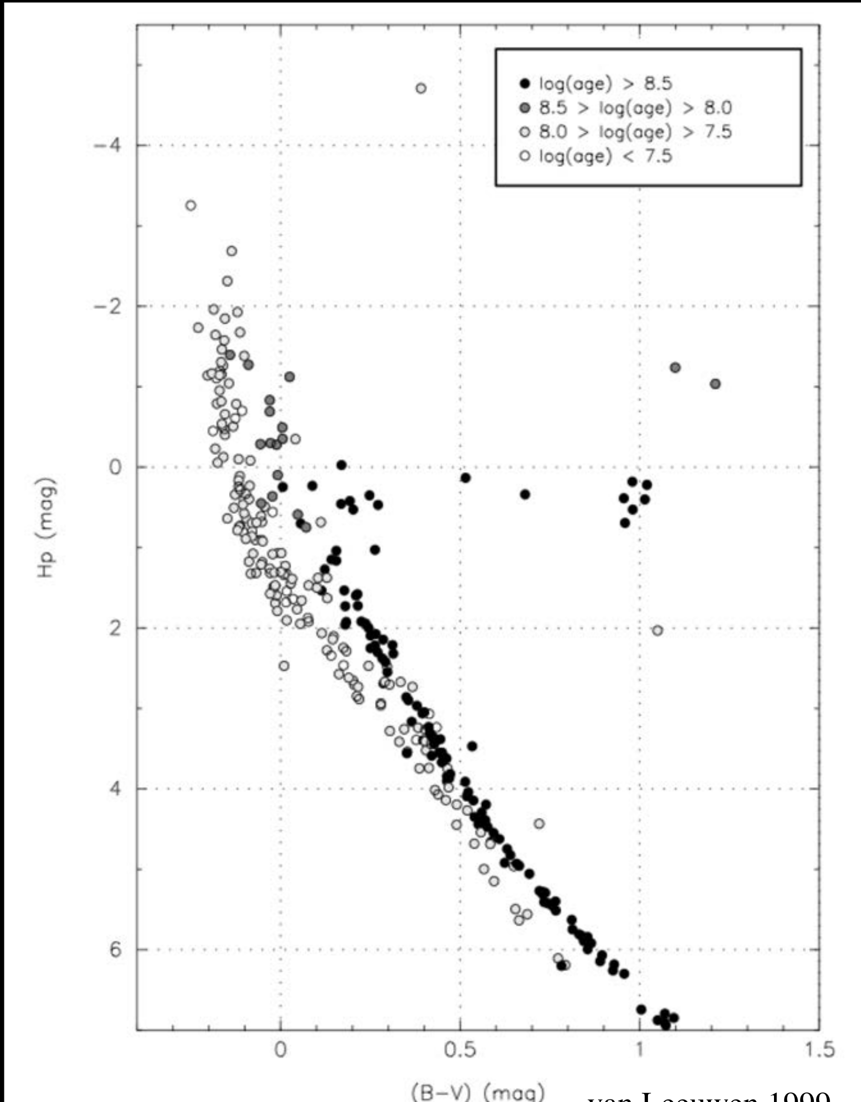
Hipparcos $D_{Pleiades}$ = 122.2±1.9 pc

All others $D_{Pleiades}$ = 133.0±0.9 pc

The Pleiades Distance Controversy

If Hipparcos is correct, then Pleiades and other similarly aged stars are ~0.2 magnitudes fainter than otherwise similar (but older) stars.

- Theoretical models do not accurately describe young stars, calling into question photometric distance estimates and in general our understanding of stellar evolution.



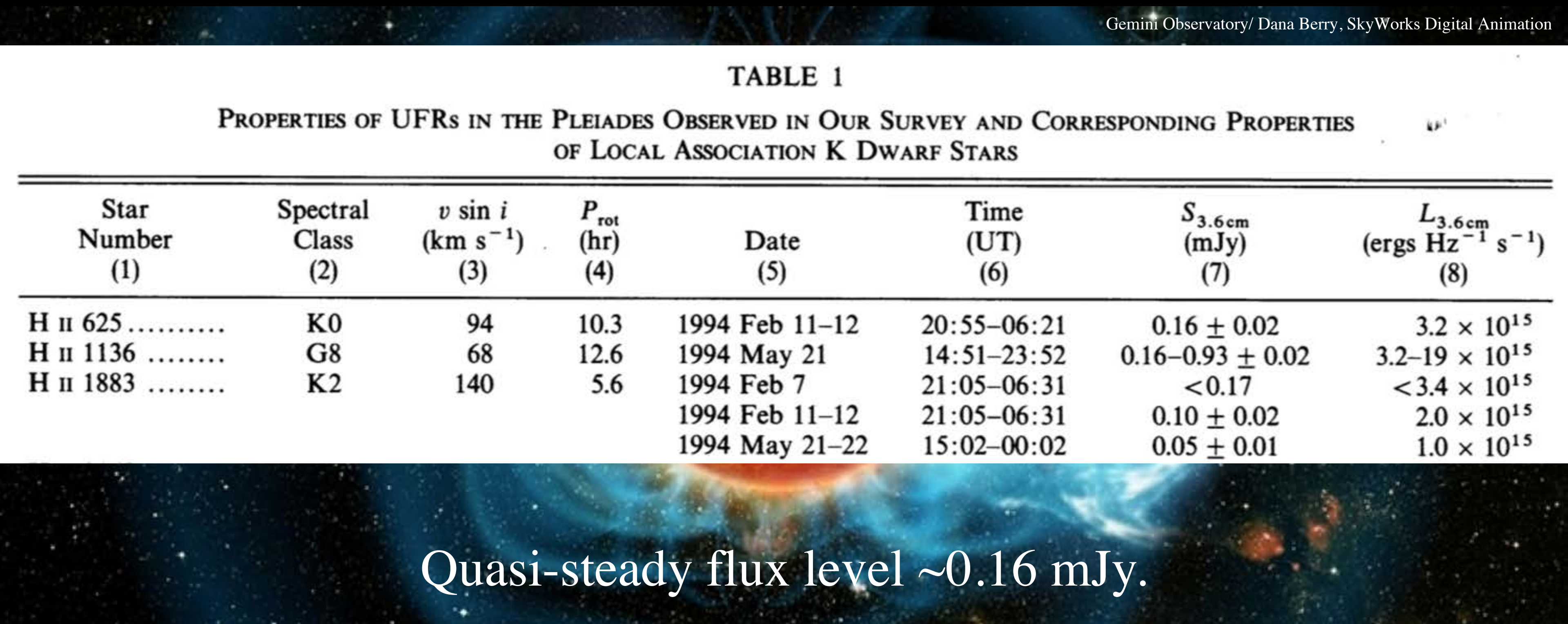
van Leeuwen 1999

VLBI to the rescue!

- Absolute trigonometric parallaxes
- Anchored on the radio reference frame
- $\sigma_{ast} \sim 100\ \mu as$
- ≈1% parallax precision for individual Pleiads

Where are all the radio-loud Pleaids?

A decade of failure leading up to Lim & White (1995):



Gemini Observatory/ Dana Berry, SkyWorks Digital Animation

TABLE 1

PROPERTIES OF UFRs IN THE PLEIADES OBSERVED IN OUR SURVEY AND CORRESPONDING PROPERTIES OF LOCAL ASSOCIATION K DWARF STARS

Star Number (1)	Spectral Class (2)	$v \sin i$ ($km\ s^{-1}$) (3)	P_{rot} (hr) (4)	Date (5)	Time (UT) (6)	$S_{3.6\,cm}$ (mJy) (7)	$L_{3.6\,cm}$ (ergs Hz^{-1} s^{-1}) (8)
H II 625	K0	94	10.3	1994 Feb 11–12	20:55–06:21	0.16 ± 0.02	3.2×10^{15}
H II 1136	G8	68	12.6	1994 May 21	14:51–23:52	$0.16–0.93 \pm 0.02$	$3.2–19 \times 10^{15}$
H II 1883	K2	140	5.6	1994 Feb 7	21:05–06:31	<0.17	$<3.4 \times 10^{15}$
				1994 Feb 11–12	21:05–06:31	0.10 ± 0.02	2.0×10^{15}
				1994 May 21–22	15:02–00:02	0.05 ± 0.01	1.0×10^{15}

Quasi-steady flux level ~0.16 mJy.

VLA and JVLA search for new radio Pleiads

Table 1: VLA Detected Pleiads

Star	$\log(L_X)$ (ergs s^{-1})	B−V	$v\sin i$ (km s^{-1})	Radio Program	Flux (μJy)	Binary?
HII 174	30.19	0.81	28	AM978,JVLA	90-120	Y
HII 253	30.46	0.64	37	AL361	90	N
HII 314	30.28	0.60	38	JVLA	115	N
HII 625	30.19	0.78	94	LW95,JVLA	110-160	Y
HII 1136	30.14	0.72	75	LW95,AL361	110-930	Y
HII 1883	29.67	0.99	140	LW95	50-100	N
HII 2147	30.5	0.76	27	AM978	130-180	Y
HII 2244	29.99	0.99	45	JVLA	60	N
HII 3197	30.14	1.03	33	AM978	90	Y
PELS75	30.1	0.91	56	JVLA	150	Y

X-ray data taken from Stauffer et al. (1994) and Micela et al. (1996,1999).
LW95 = Lim & White (1995).
The binary column indicates whether any hint of binarity is noted in literature studies of the Pleiades (e.g., Mermilliod et al. 1992, Bouvier et al. 1997, and references therein).

VLBI Project BM352

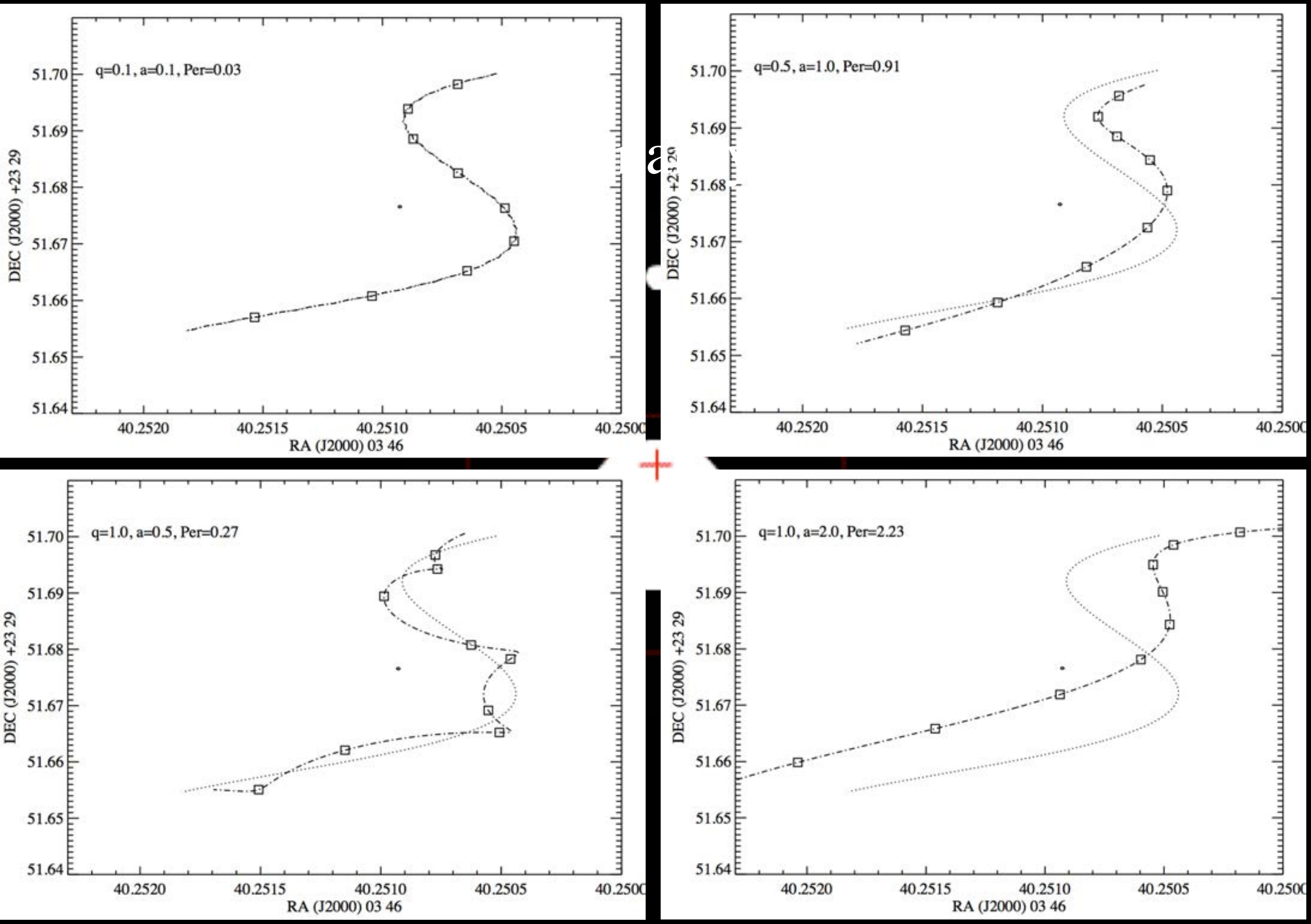
- ~900 hours awarded with the VLBA, Green Bank, Effelsberg, and Arecibo antennas (HSA).

- 5 stars per year for a total program duration of ~2 years.

- 9 epochs per star over a 1 year period.

- One 10 hour track every week for two years!

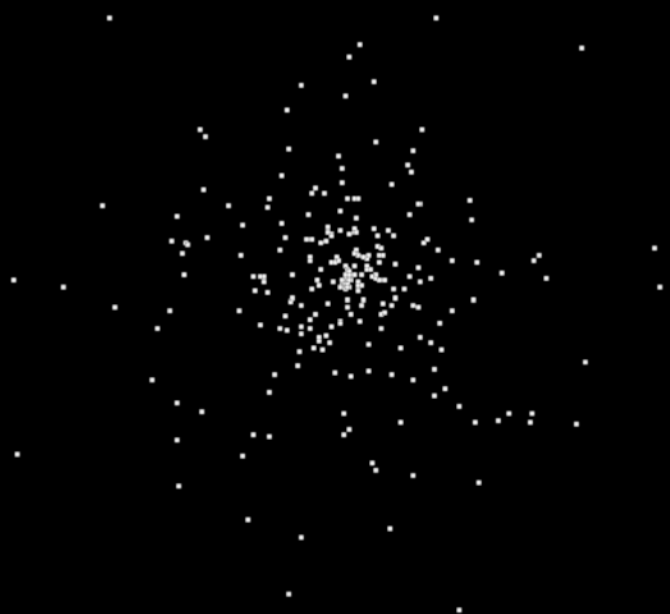
VLBI Project BM352 - Why 9 epochs?

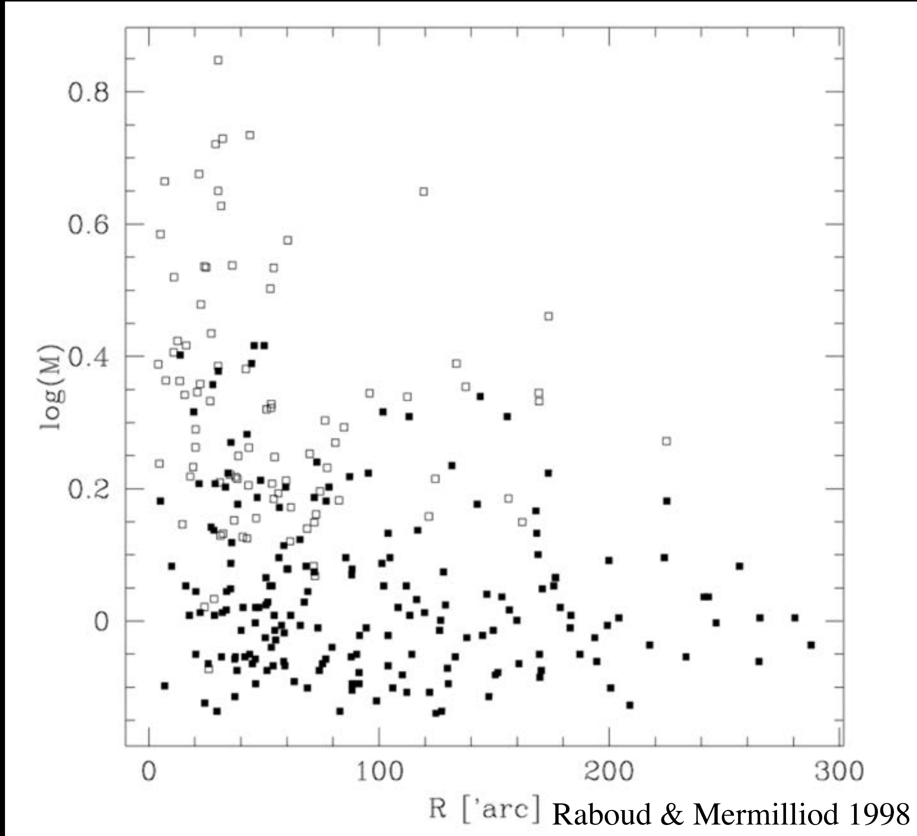


- Periods < 2 yrs ⇒full orbital fits; well matched to observing cadence.
- Periods > 2 yrs ⇒fit motion with acceleration terms as in Loinard et al. (2007).

VLBI Project BM352 - Why 10 stars?

- Cluster depth effects!





Raboud & Mermilliod 1998

Pleiades half-mass and tidal radii of 1.9 (0.88°) and 16 pc (7.4°), respectively (Raboud & Mermilliod 1998).

Preliminary Results - HII 1136

Lim & White (1995)

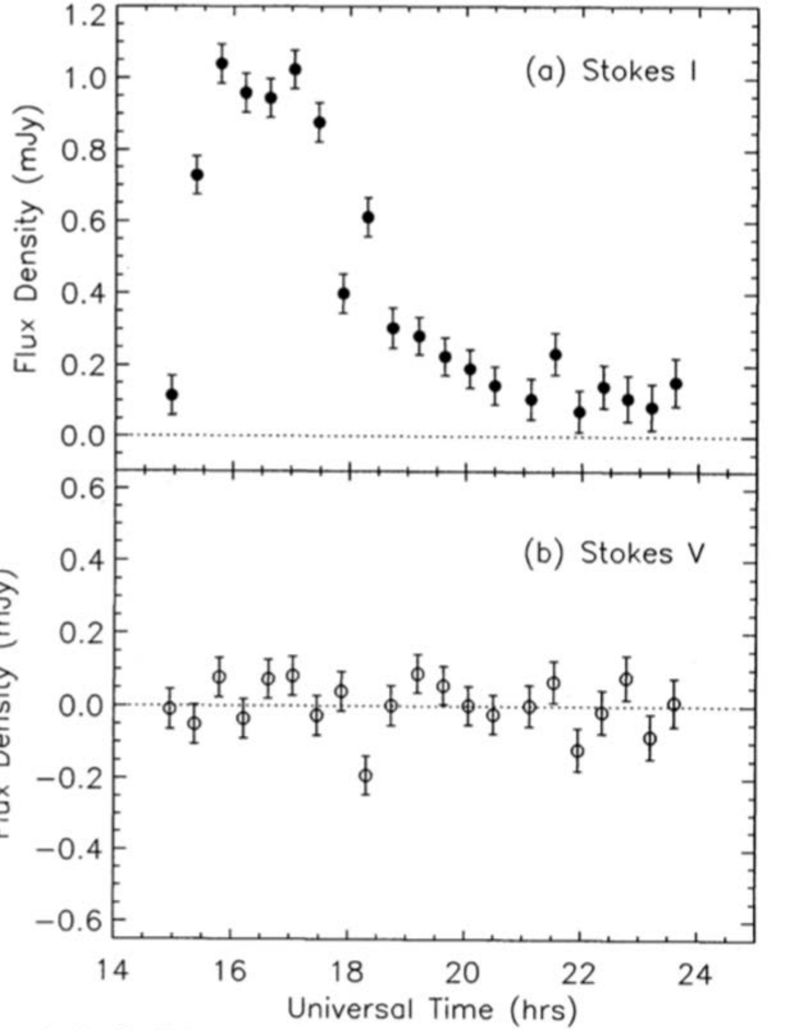
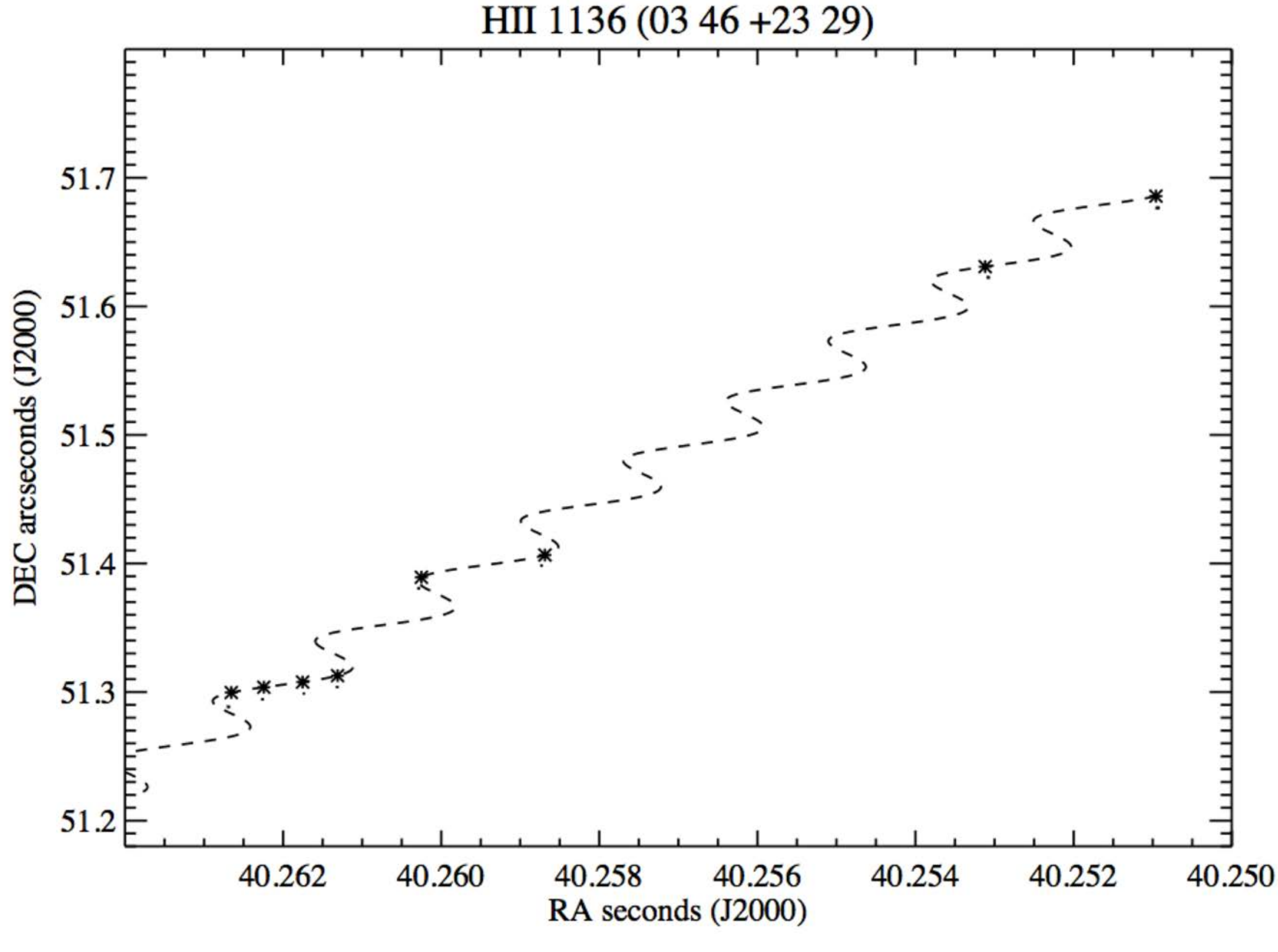
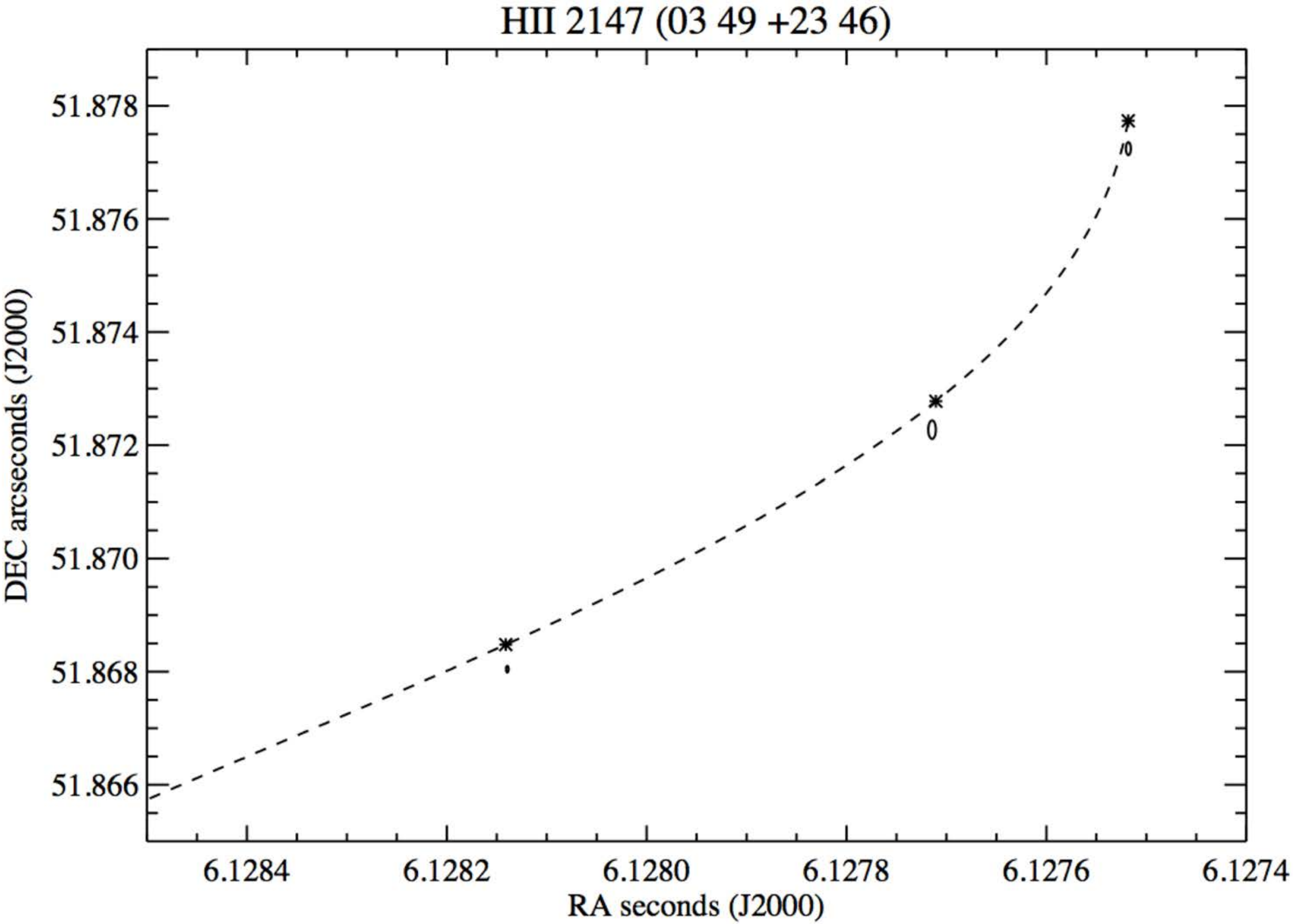


FIG. 1.—Radio light curve of H II 1136 in Stokes *I* and *V*. Each point corresponds to a ~10 minute integration and has an error bar of length ±1 σ.

Most radio-luminous Pleaid detected by Lim & White.

Preliminary Results - HII 1136





HII 2147 (03 49 +23 46)
DEC arcseconds (J2000)
RA seconds (J2000)
51.866
51.868
51.870
51.872
51.874
51.876
51.878
6.1284
6.1282
6.1280
6.1278
6.1276
6.1274

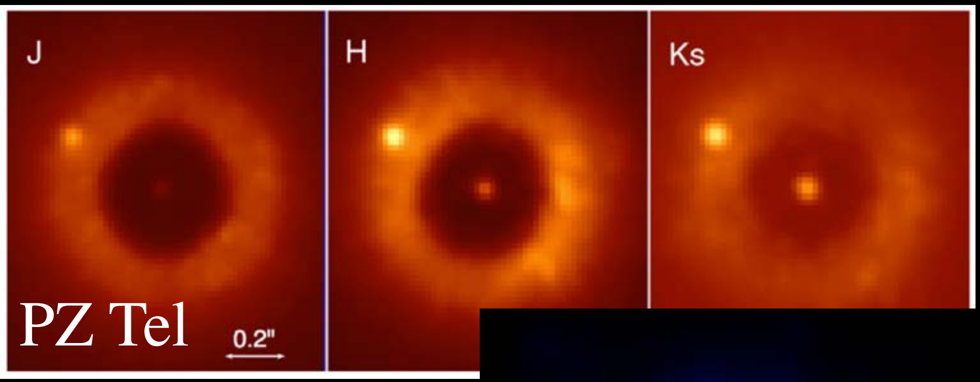
Looking Ahead

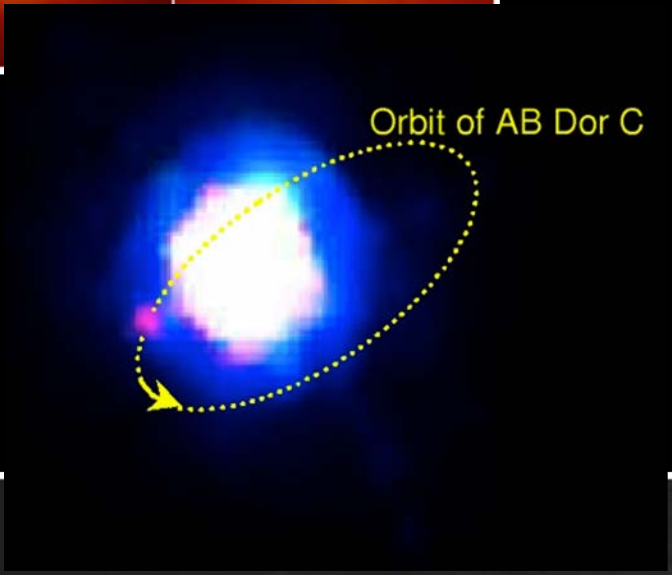
- Complete first year of program and first 5 targets early 2013.

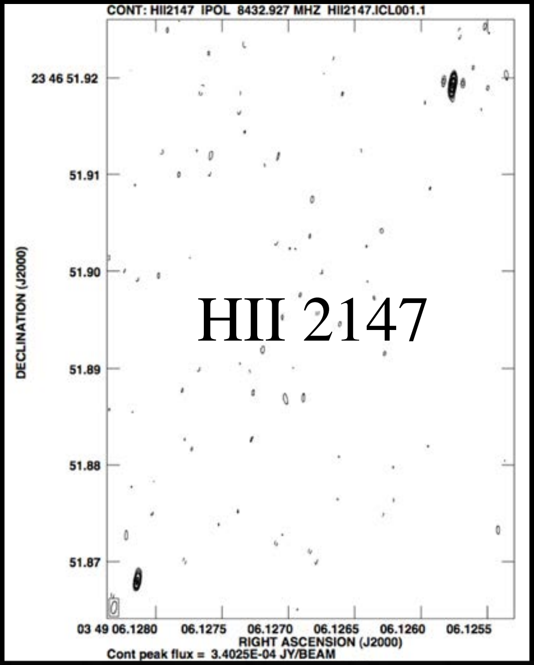
- VLBI slated for major sensitivity upgrade.

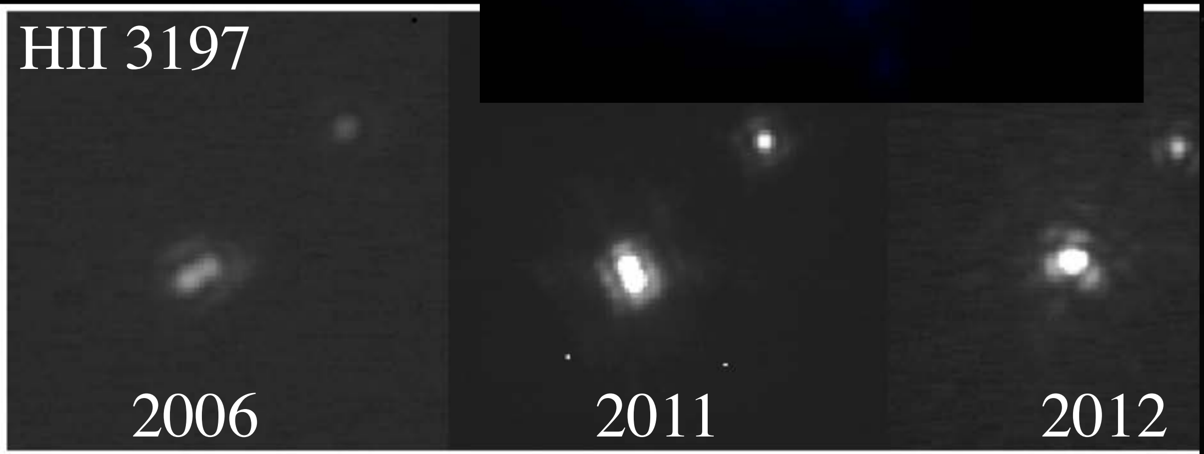
- JVLA should become available as an array element.

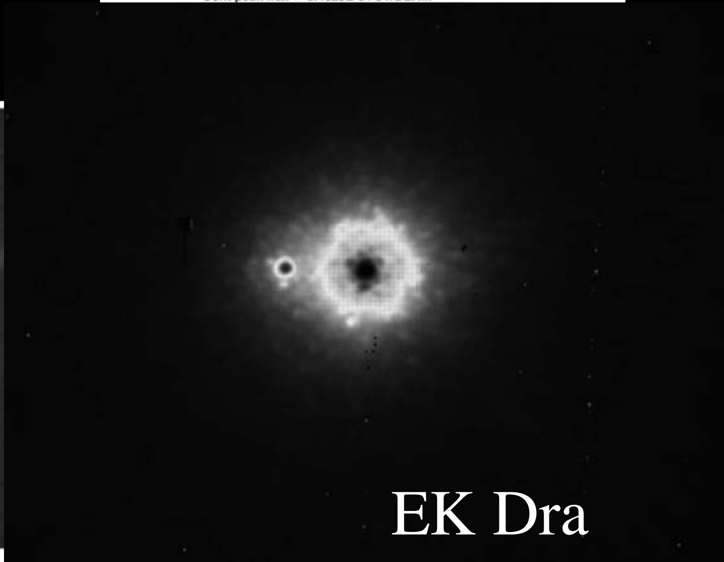
Binarity and Radio-Loud Young Sun-like Stars











Binarity and Radio-Loud Young Sun-like Stars

- Is binarity a necessary component for the most radio-luminous stars (even at young ages)?

- What does this tell us about the evolution of protoplanetary disks and stellar angular momentum?