www.sciencemag.org/cgi/content/full/345/6200/1029/DC1

Supplementary Materials for

A VLBI resolution of the Pleiades distance controversy

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Published 29 August 2014, *Science* **345**, 1029 (2014)
DOI: 10.1126/science.1256101

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Supplementary Text

In this section some comments on the target sample are given and the observations are discussed in detail.

Target Sample

The target systems were selected from lists of well-characterized Pleiades stars and thus there is little doubt that they are members of the cluster. Indeed, the Pleiades proper motion signature is robust and the previously measured optical proper motion values for each system by themselves identify all systems as high probability cluster members (*28*). Inclusion in the VLBI program was determined from an initial radio-imaging survey by our team that targeted rapidly rotating and X-ray luminous Pleiades members (*29* – several other Pleiades members identified by ref. *29* to be radio-loud are currently under investigation with VLBI but do not yet have final results). It is worth noting that none of our target systems are included in the *Hipparcos* Pleiades sample as they are too faint in the optical (visual magnitudes and colors are given for each system in Tables S1-S5).

Summary of the Observations and Datasets

Observations of the four Pleiades star systems were conducted with a very long baseline radio interferometer consisting of the Very Long Baseline Array (VLBA, which consists of 10 identical 25-m antennas in Mauna Kea HI, Brewster WA, Owens Valley CA, Kitt Peak AZ, Pie Town NM, Los Alamos NM, Fort Davis TX, North Liberty IA, Hancock MA, and Saint Croix Virgin Islands), the 100-m Robert C. Byrd Green Bank Telescope in West Virginia, the Effelsberg 100-m Radio Telescope in Bad Münstereifel Germany, and the 300-m William E. Gordon Telescope at Arecibo Observatory in Puerto Rico. Baseline lengths for these antennas range from a minimum of 236 km to a maximum of 10,328 km. It is worth noting that not all 13 stations were available for every epoch and that not every station produced useful data in each epoch. Preliminary observations of one system, HII 1136, began in 2004 and continued through 2010. The main program observations for the sources in Tables S1-S5 began in late 2011 and ended in 2013. Tables S1-S5 list specific observation dates for each system.

Each system was observed in continuum light centered at a frequency of 8.4 GHz (roughly 3.6 cm). During this project the VLBA was undergoing upgrades that enabled wider bandwidth observations, and thus the precise average continuum frequency changed with the bandwidth used. Tables S1-S5 list instrumental setups for each observing epoch. The background quasar J0347+2339 (which has a measured R.A. of 03h47m57.11171s ± 1.3 mas and Decl. of +23°39'55.3248" ± 2.2 mas) served as the main phase-reference source as its typical separation from our Pleiades targets was less than 1° (separations of each target from this reference source are given in Tables S1-S5). Because of the fortuitous placement of J0347+2339 with respect to our target stars, and the intrinsic faintness for most targets, we did not pursue geodetic observations during tracks – geodetic observations often improve astrometric accuracy when using wider separation reference sources (*30*). Observation tracks consisted of scans on bright background quasars that are used to set the instrumental delays and a series of cycles where roughly 1.5 minutes were spent on the target star and roughly 1 minute was spent on the phase-reference source. Although each track was of 10 hours in duration, typically only 4-6 hours of that time were spent on the target source.

Data were recorded on hard disks at each station, then mailed to the Pete V. Domenici Science Operations Center (SOC) in Socorro, NM for correlation. For epochs before 2010.6, a hardware correlator was employed. After that time, correlation was done with the software correlator developed by Deller *et al.* (*31*). Correlated data sets were retrieved from the NRAO data archive service through the world wide web.

Data reduction follows standard phase-referenced radio interferometry practices for very long baseline astrometry datasets. Editing and calibration of each dataset occurrs within the Astronomical Image Processing System (AIPS; *32*) software suite. Earth-orientation parameters for each observation date are obtained from the US Naval Observatory database and applied to the data to correct estimated values utilized by the VLBA correlator. Dispersive delays to incoming radio light caused by free electrons in the Earth's atmosphere are accounted for through the use of an estimate of the electron content of the ionosphere derived from Global Positioning System (GPS) measurements. Amplitude calibration for each antenna is then obtained from measured system temperatures and standard gain curves. Phase corrections due to antenna parallactic angle effects are then applied. Instrumental delays are removed for each antenna and spectral sub-band by fringe fitting a single strong calibration source (typically the quasar J0403+2600). A final, global fringe-fitting pass is made for the main phase-reference source under the assumption that it is point like for all antenna pairs. This final calibration is then applied to the target star scans.

Once calibrated, the target source visibility data are imaged on a spatial grid with pixel size of 110 μas. The map rms noise level obtained is a strong function of which antennas produced useable data in each epoch. These noise levels are listed for each epoch in Tables S1-S5. The variable nature of the emission from the target sources led to numerous epochs with no detections. When detected, the absolute position of the targets is obtained from a two-dimensional Gaussian fitting procedure. Errors associated with these fits are also obtained based on the expected theoretical astrometric performance of an interferometer (*33*). However, systematic errors from uncompensated tropospheric and ionospheric delays also contribute to the uncertainty in source position and their contribution is quantified during the parallax fitting process. It is worth noting that the uncertainties for the absolute positions given in Tables S1-S5 do not include the additional error on the absolute position of the primary phase reference source given previously. However, when performing astrometric fits (to extract parallax and proper motion) it is only the motion of each target relative to the stationary background quasar that needs to be considered.

Table S1.

Observations Summary for HII 174

Separation from J0347+2339 = 1.638°				V_{mag}= 11.6, B_{mag}–V_{mag} color = 0.85				
Observation Date (mid-track)	Band width	Central Frequency	Measured R. A.	R. A. error (one S.D.)	Measured Decl.	Decl. error (one S.D.)	Flux	Map rms noise
Julian Date Years	MHz	GHz	h m s	s	° ‘ “	“	μJy	μJy
2455940.57 2012.0357	128	8432.9	—	—	—	—	—	19
2455982.46 2012.1502	128	8432.9	—	—	—	—	—	19
2456025.34 2012.2673	128	8432.9	—	—	—	—	—	19
2456067.23 2012.3818	128	8432.9	—	—	—	—	—	101
2456109.11 2012.4962	128	8432.9	—	—	—	—	—	33
2456150.99 2012.6106	128	8432.9	03 43 48.3513620	0.0000060	+25 00 15.221939	0.000192	173	24
2456193.91 2012.7279	128	8432.9	03 43 48.3514447	0.0000022	+25 00 15.217191	0.000083	66	16
2456233.77 2012.8368	128	8432.9	03 43 48.3513229	0.0000051	+25 00 15.211728	0.000128	108	19
2456275.66 2012.9513	512	8415.9	—	—	—	—	—	10
2456318.54 2013.0686	512	8415.9	—	—	—	—	—	9
2456360.43 2013.1834	512	8415.9	03 43 48.3511691	0.0000027	+25 00 15.192795	0.000073	72	9
2456403.31 2013.3009	512	8415.9	03 43 48.3515858	0.0000018	+25 00 15.187847	0.000054	141	12
2456451.18 2013.4320	512	8415.9	03 43 48.3521994	0.0000015	+25 00 15.183080	0.000045	190	10

2456487.08 2013.5304	512	8416.2	03 43 48.3525964	0.0000025	+25 00 15.179952	0.000104	90	15
2456528.97 2013.6451	512	8415.9	03 43 48.3528768	0.0000015	+25 00 15.175447	0.000046	96	9

Table S2.
Observations Summary for HII 625

Separation from J0347+2339 = 0.598°				V_{mag}= 12.7, B_{mag}–V_{mag} color = 1.2				
Observation Date (mid-track)	Band width	Central Frequency	Measured R. A.	R. A. error (one S.D.)	Measured Decl.	Decl. error (one S.D.)	Flux	Map rms noise
Julian Date Years	MHz	GHz	h m s	s	° ‘ “	“	μJy	μJy
2455933.59 2012.0167	128	8432.9	—	—	—	—	—	19
2455975.48 2012.1311	128	8432.9	—	—	—	—	—	17
2456018.36 2012.2483	128	8432.9	03 45 21.2035163	0.0000042	+23 43 38.340643	0.000179	111	14
2456060.25 2012.3627	128	8432.9	03 45 21.2039877	0.0000072	+23 43 38.336247	0.000143	346	41
2456102.14 2012.4772	128	8432.9	—	—	—	—	—	18
2456144.01 2012.5916	128	8432.9	03 45 21.2048741	0.0000025	+23 43 38.328707	0.000068	112	14
2456185.93 2012.7061	128	8432.9	03 45 21.2050142	0.0000009	+23 43 38.323798	0.000027	439	16
2456227.79 2012.8205	128	8432.9	03 45 21.2049262	0.0000040	+23 43 38.318108	0.000077	70	14
2456269.68 2012.9349	128	8432.9	—	—	—	—	—	18
2456310.56 2013.0468	128	8432.9	03 45 21.2046021	0.0000093	+23 43 38.305108	0.000249	98	23
2456353.45 2013.1642	128	8432.9	—	—	—	—	—	16
2456396.32 2013.2817	128	8432.9	03 45 21.2050618	0.0000059	+23 43 38.295017	0.000099	110	21
2456445.27 2013.4158	512	8415.9	03 45 21.2056562	0.0000081	+23 43 38.290298	0.000182	94	22

Table S3.

Observations Summary for HII 1136

Separation from J0347+2339 = 0.338°				V_{mag}= 12.2, B_{mag}–V_{mag} color = 1.0				
Observation Date (mid-track)	Band width	Central Frequency	Measured R. A.	R. A. error (one S.D.)	Measured Decl.	Decl. error (one S.D.)	Flux	Map rms noise
Julian Date Years	MHz	GHz	h m s	s	° ‘ “	“	µJy	µJy
2453085.35 2004.2182	64	8421.5	03 46 40.2509284	0.0000048	+23 29 51.676625	0.000138	284	30
2453086.35 2004.2209	64	8421.5	03 46 40.2509467	0.0000056	+23 29 51.676556	0.000203	165	29
2453408.55 2005.1015	64	8421.5	—	—	—	—	—	44
2453456.42 2005.2327	64	8421.5	—	—	—	—	—	41
2453526.21 2005.4239	64	8421.5	03 46 40.2530800	0.0000080	+23 29 51.622538	0.000331	363	34
2453588.05 2005.5933	64	8421.5	—	—	—	—	—	33
2455268.46 2010.1944	128	8432.9	03 46 40.2587312	0.0000026	+23 29 51.398328	0.000094	108	23
2455423.01 2010.6178	128	8432.9	—	—	—	—	—	23
2455429.99 2010.6370	128	8432.9	03 46 40.2602852	0.0000057	+23 29 51.380726	0.000155	93	26
2455606.50 2011.1205	128	8432.9	—	—	—	—	—	20
2455919.64 2011.9785	128	8432.9	—	—	—	—	—	23
2455961.52 2012.0930	128	8432.9	—	—	—	—	—	15
2456003.41 2012.2074	128	8432.9	03 46 40.26131586	0.0000037	+23 29 51.3039153	0.000115	196	15

2456046.29 2012.3246	128	8432.9	03 46 40.26173818	0.0000013	+23 29 51.2988673	0.000050	273	15
2456089.18 2012.4417	128	8432.9	03 46 40.26226048	0.0000041	+23 29 51.2943494	0.000085	259	15
2456130.05 2012.5534	128	8432.9	—	—	—	—	—	15
2456171.95 2012.6679	128	8432.9	03 46 40.2628778	0.0000034	+23 29 51.284851	0.000124	87	15
2456213.82 2012.7823	128	8432.9	03 46 40.2628234	0.0000006	+23 29 51.279617	0.000022	789	15
2456255.71 2012.8967	128	8432.9	03 46 40.2626112	0.0000004	+23 29 51.273089	0.000017	1184	16
2456480.09 2013.5112	128	8432.9	—	—	—	—	—	14
2456521.99 2013.6260	512	8415.9	03 46 40.2640676	0.0000044	+23 29 51.239909	0.000181	48	8

Table S4.

Observations Summary for HII 2147 NW

Separation from J0347+2339 = 0.288°				V_{mag}= 10.9, B_{mag}–V_{mag} color = 0.8 (combined light with HII 2147 SE)				
Observation Date (mid-track)	Band width	Central Frequency	Measured R. A.	R. A. error (one S.D.)	Measured Decl.	Decl. error (one S.D.)	Flux	Map rms noise
Julian Date Years	MHz	GHz	h m s	s	° ‘ “	“	µJy	µJy
2455926.61 2011.9976	128	8432.9	03 49 06.1250154	0.0000039	+23 46 51.934386	0.000270	89	15
2455968.50 2012.1120	128	8432.9	—	—	—	—	—	16
2456010.39 2012.2265	128	8432.9	—	—	—	—	—	15
2456053.27 2012.3436	128	8432.9	03 49 06.12576225	0.0000009	+23 46 51.9192502	0.000045	495	19
2456095.16 2012.4581	128	8432.9	03 49 06.1263090	0.0000036	+23 46 51.915510	0.000161	113	16
2456137.03 2012.5725	128	8432.9	—	—	—	—	—	18
2456178.94 2012.6870	128	8432.9	03 49 06.1269695	0.0000019	+23 46 51.905948	0.000048	364	12
2456221.81 2012.8041	128	8432.9	03 49 06.1269222	0.0000018	+23 46 51.900329	0.000071	148	13
2456304.58 2013.0304	128	8432.9	03 49 06.1266394	0.0000041	+23 46 51.887238	0.000157	135	18
2456346.47 2013.1451	128	8432.9	03 49 06.1267233	0.0000044	+23 46 51.881440	0.000142	156	20
2456388.84 2013.2612	512	8415.9	03 49 06.1270808	0.0000087	+23 46 51.875953	0.000317	43	5
2456472.11 2013.4894	512	8415.9	03 49 06.1281618	0.0000026	+23 46 51.866556	0.000085	33	7

2456515.00 2013.6069	512	8415.9	03 49 06.1285636	0.0000018	+23 46 51.862185	0.000045	184	9
2456556.89 2013.7216	512	8415.9	—	—	—	—	—	19

Table S5.

Observations Summary for HII 2147 SE

Separation from J0347+2339 = 0.288°				V_{mag}= 10.9, B_{mag}–V_{mag} color = 0.8 (combined light with HII 2147 NW)				
Observation Date (mid-track)	Band width	Central Frequency	Measured R. A.	R. A. error (one S.D.)	Measured Decl.	Decl. error (one S.D.)	Flux	Map rms noise
Julian Date	MHz	GHz	h m s	s	° ‘ “	“	μJy	μJy
2455926.61 2011.9976	128	8432.9	—	—	—	—	—	15
2455968.50 2012.1120	128	8432.9	03 49 06.12751797	0.0000025	+23 46 51.8772440	0.000113	173	16
2456010.39 2012.2265	128	8432.9	03 49 06.12771442	0.0000038	+23 46 51.8722728	0.000163	125	15
2456053.27 2012.3436	128	8432.9	03 49 06.12813948	0.0000013	+23 46 51.8680450	0.000056	276	19
2456095.16 2012.4581	128	8432.9	—	—	—	—	—	16
2456137.03 2012.5725	128	8432.9	03 49 06.1289993	0.0000008	+23 46 51.860142	0.000023	791	18
2456178.94 2012.6870	128	8432.9	03 49 06.1291412	0.0000007	+23 46 51.855428	0.000026	534	12
2456221.81 2012.8041	128	8432.9	03 49 06.1290302	0.0000011	+23 46 51.849802	0.000023	1157	13
2456304.58 2013.0304	128	8432.9	03 49 06.1285768	0.0000037	+23 46 51.838635	0.000237	100	18
2456346.47 2013.1451	128	8432.9	03 49 06.1285947	0.0000042	+23 46 51.833105	0.000187	144	19
2456388.84 2013.2612	512	8415.9	03 49 06.1288710	0.0000014	+23 46 51.828353	0.000060	90	5
2456472.11 2013.4894	512	8415.9	03 49 06.1297639	0.0000007	+23 46 51.820971	0.000032	219	7

2456515.00 2013.6069	512	8415.9	03 49 06.1300836	0.0000037	+23 46 51.816703	0.000084	84	9
2456556.89 2013.7216	512	8415.9	03 49 06.1301307	0.0000049	+23 46 51.812418	0.000157	119	19

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