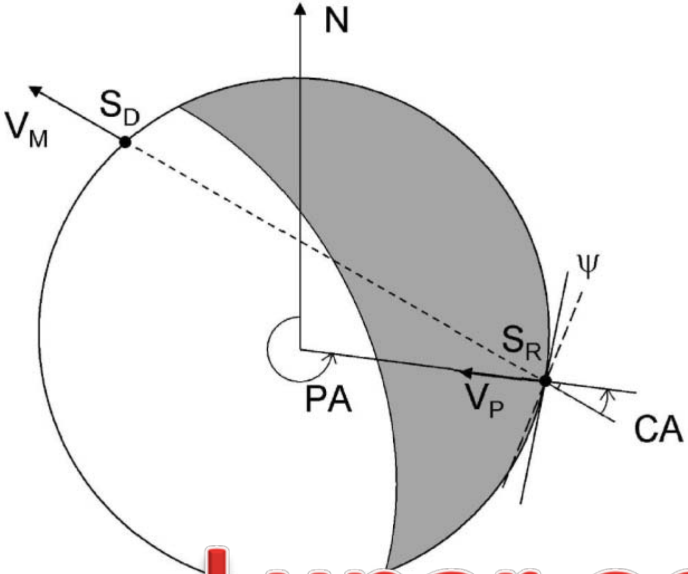
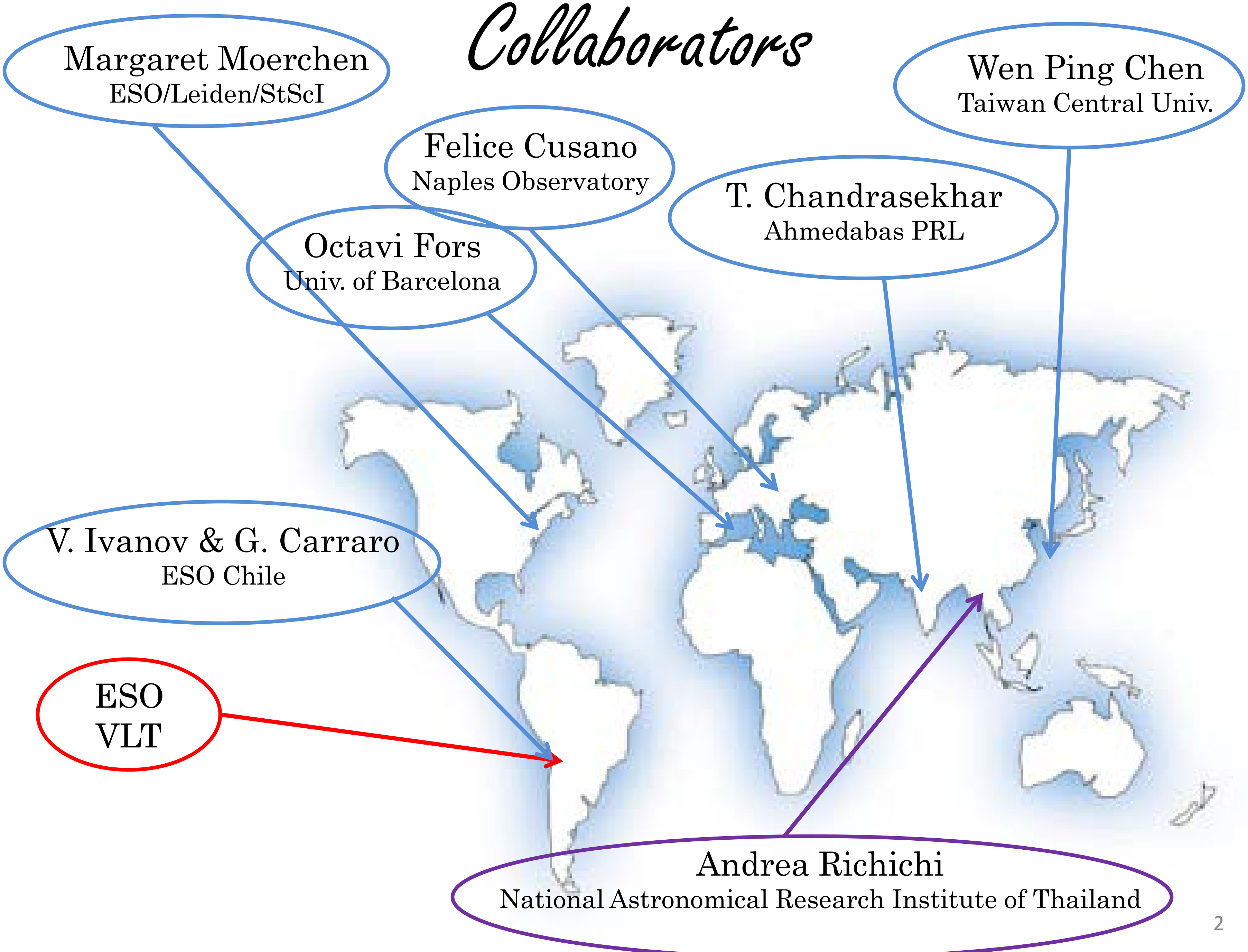
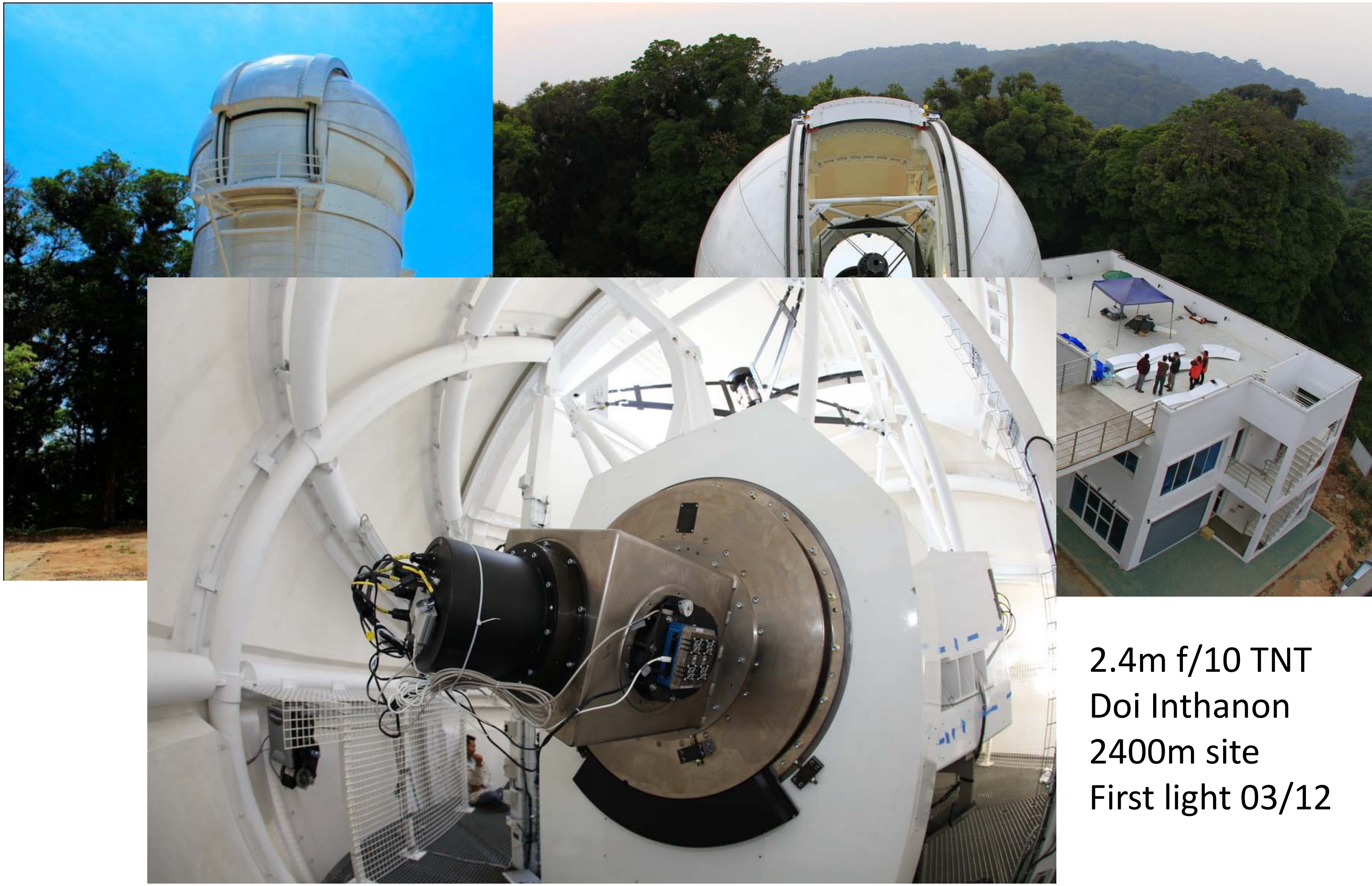


Lunar occultations at the ESO Very Large Telescope

Andrea Richichi (NARIT)
XXXI ESOP, August 25, 2012

Collaborators



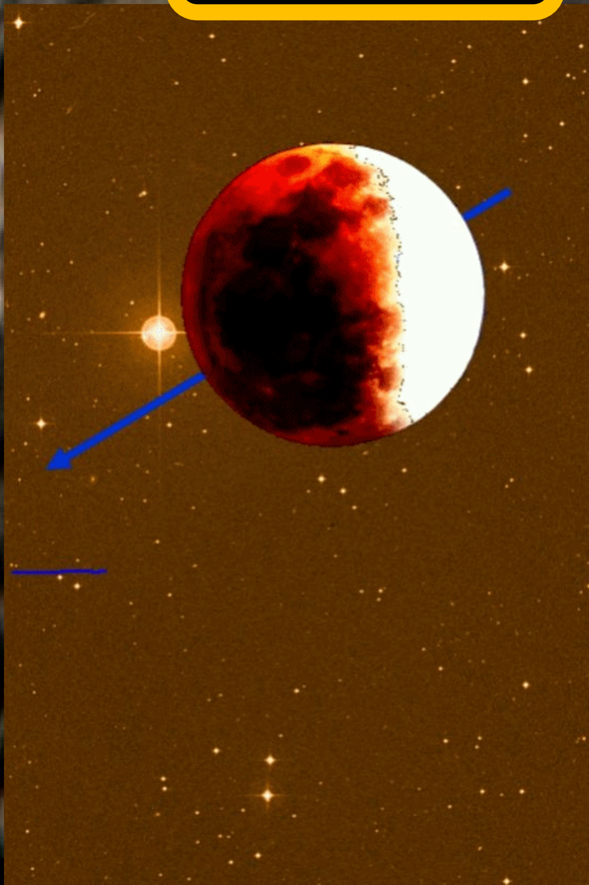


2.4m f/10 TNT
Doi Inthanon
2400m site
First light 03/12

BACK

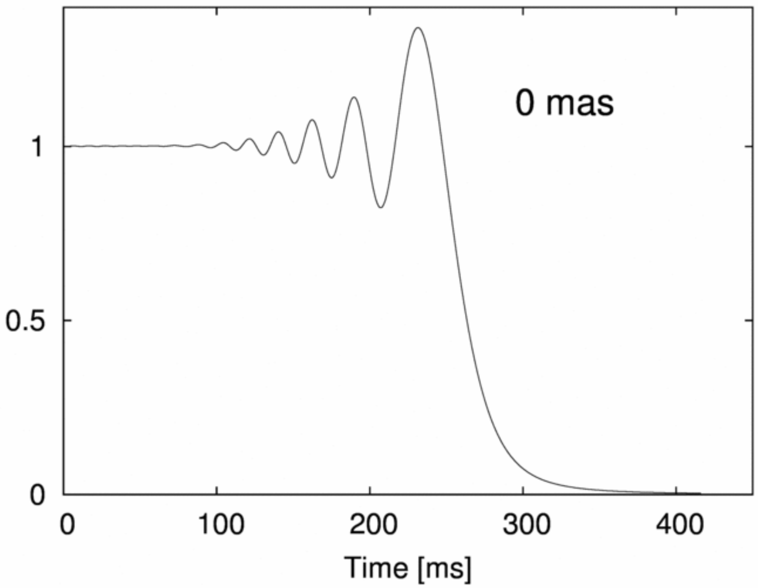
Lunar Occultations

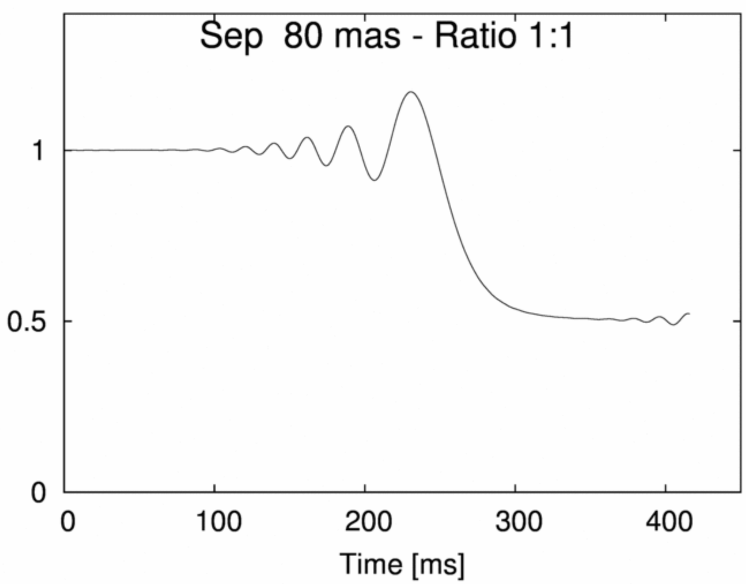
- The Moon's limb acts as a straight diffracting edge
- The diffraction phenomenon occurs in "vacuum", no turbulence effects.
- High-angular information is embedded in the diffraction fringes.
- Lunar limb irregularities have marginal influence (Fresnel fringes).
- The "resolution" is independent from telescope diameter (but depends on SNR).
- Temporal scales (depending on wavelength and apparent limb velocity) are ~0.1s.
- Diffraction patterns of two or more components add linearly.



Measuring Stars with Occultations

Simulations with Ks filter, noiseless, typical lunar rate, source at T=275ms

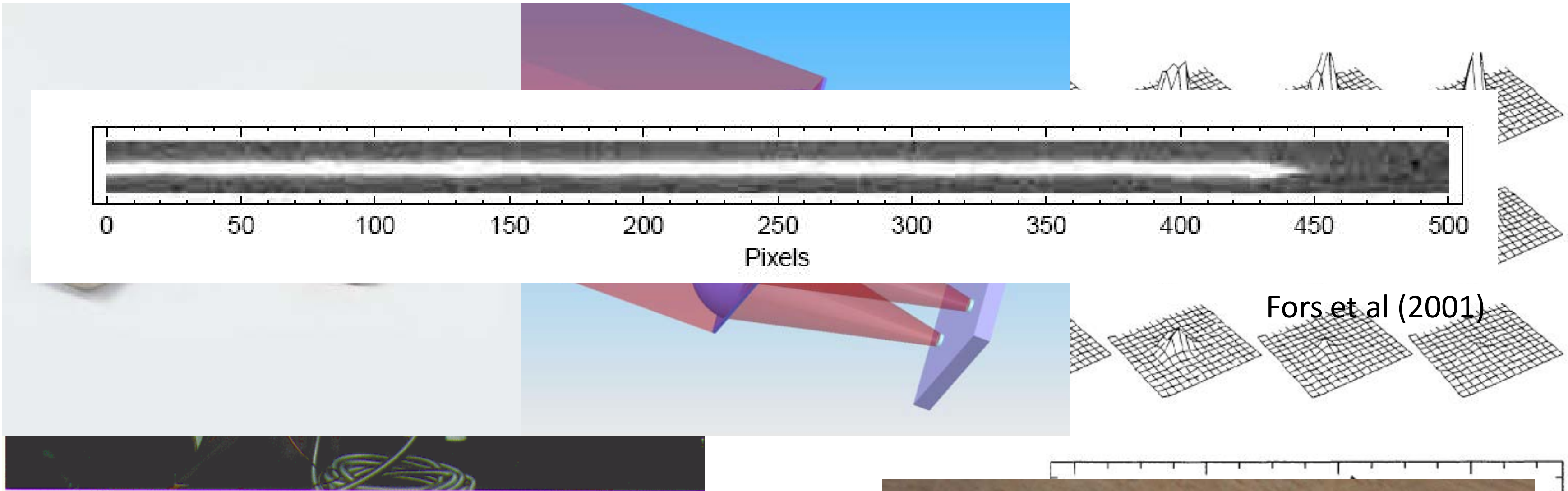




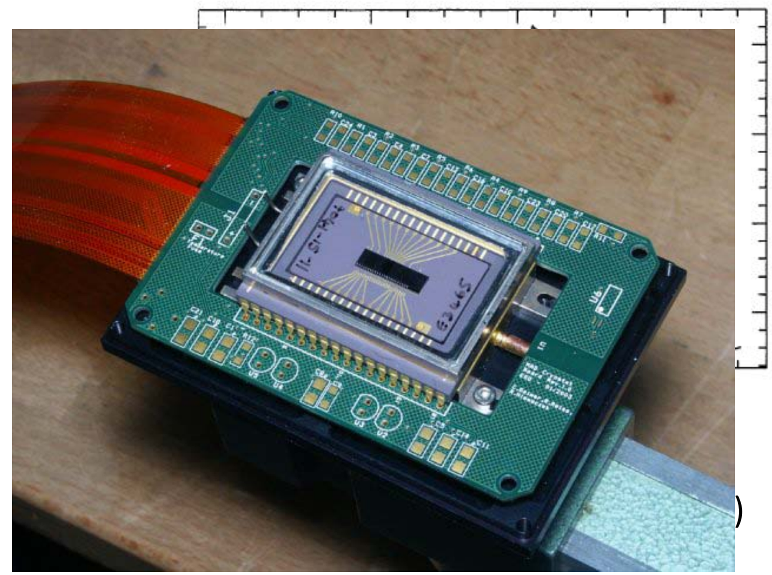
- Signature of diffraction fringes is linked to source size.
- Fringe contrast is maximum for an unresolved source.
- When source size ≈√(λ/D) transition to geometrical optics → size ~ time

- Diffraction patterns of 2 or more sources add linearly
- 1ms time difference ~ 0.5mas angular separation

Instruments & Detectors



- Photometers, photomultipliers, InSb diodes
- APD, SPAD
- CCD (drift scanning)
- NIR Arrays (subwindow)
- Specialized small format arrays (AO)



ESO Chile

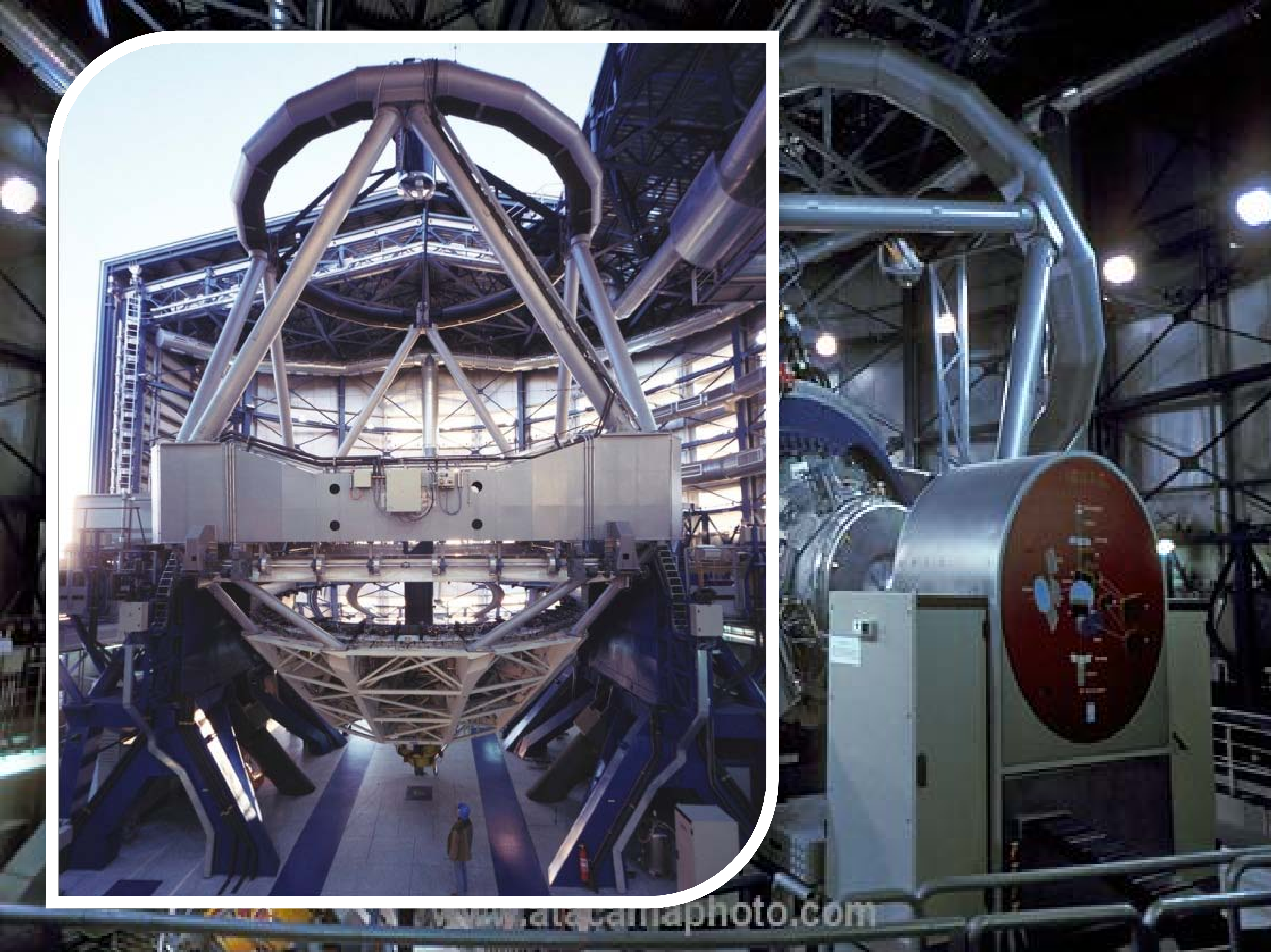
Chajnantor, 5000m

Paranal, 2600m

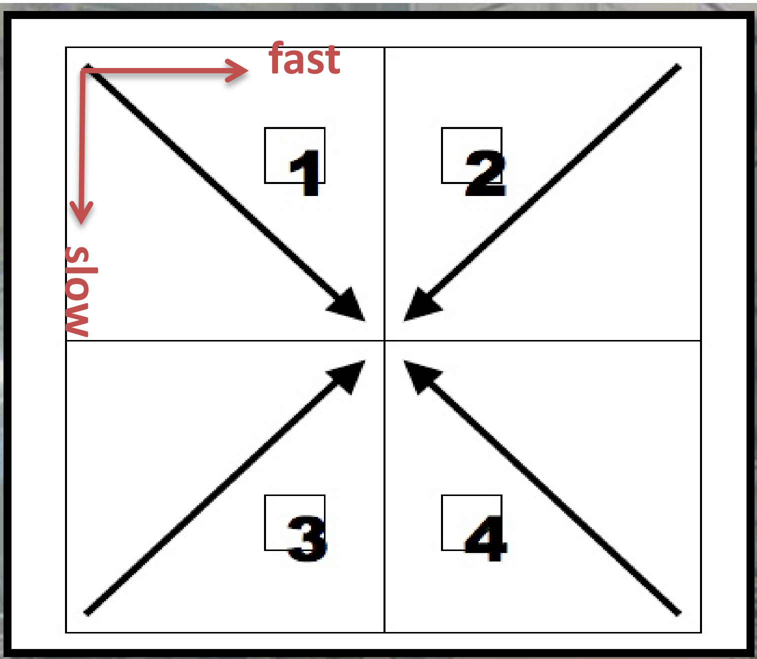
La Silla, 2400m

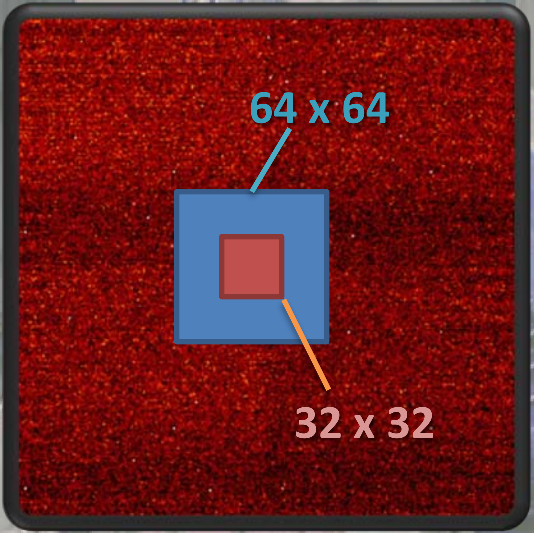
Santiago Office

Paranal


atacamaphoto.com

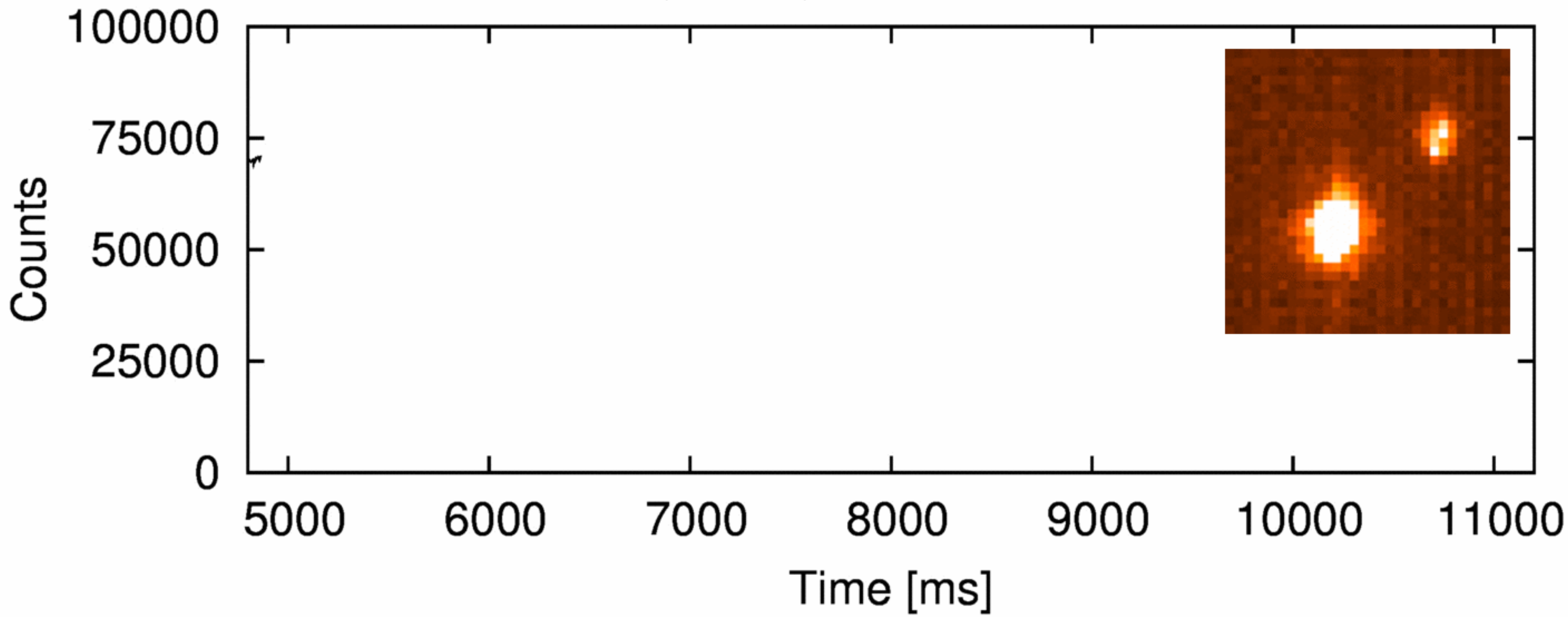
The ISAAC burst mode



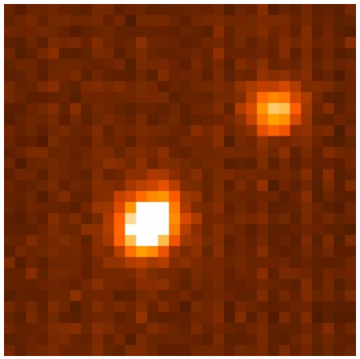


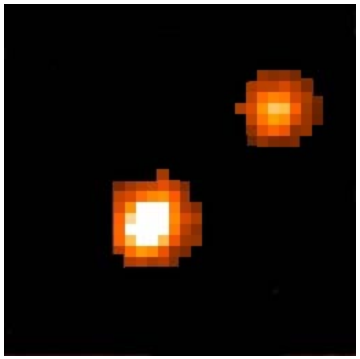
		Burst mode		FastJitter mode	
Window Size [pxs]	Field of View ['']	min DIT [ms]	max NDIT	min DIT [ms]	max NDIT
32x32	4.7x4.7	3.2	16000	12	32000
64x64	9.5x9.5	6.4	16000 *	12	16000
128x128	19x19	14	4000 **	14	4000
256x256	38x38	37	1000 **	37	1000

Extracting Light Curves



- millisecond rates are needed
- Photometers are fast, but collect more of the intense background
- 2-D images allow masking of the background, but arrays are slower



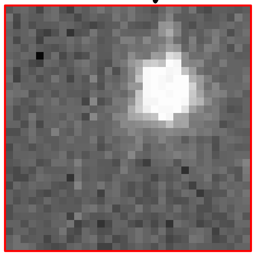


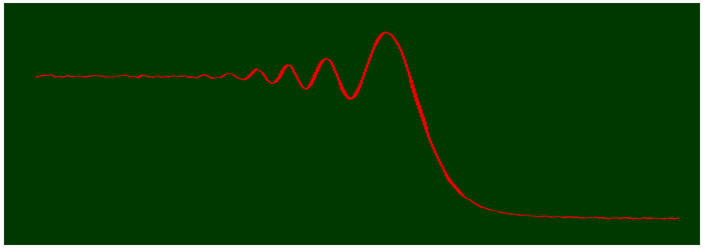
Two Strategies

Visitor Mode

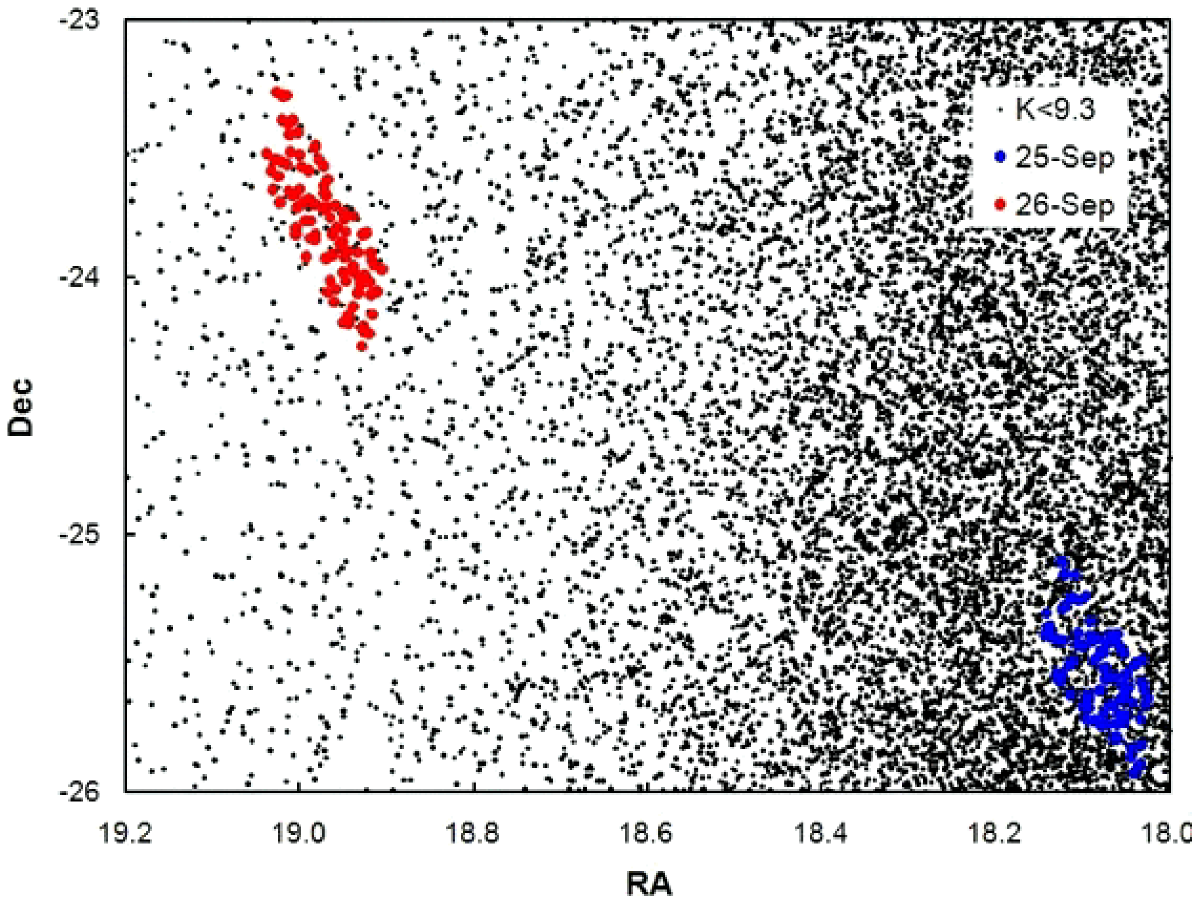
- Presence on Paranal (time consuming, subject to weather)
- Highly effective
- Well suited for special events

LO @ VLT in September 2009





- ISAAC in burst mode, 3.2ms with 32x32
- ~200 events recorded over 2 half-nights
- 184 confirmed LO
- 22 binaries, 5 triples
- 2 ang. diameters
- several extended or complex sources



Two Strategies

Visitor Mode

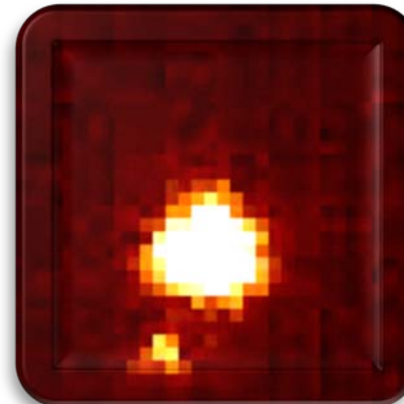
- Presence on Paranal (time consuming, subject to weather)
- Highly effective
- Well suited for special events

Service Mode

- Prepare ~1000 predictions per semester, to fill every ~5min potentially available
- Subject to chance
- Filler for unused time slots

LO @ VLT using ISAAC in burst mode

	Mar-06	Aug-06	P80	P81	P83	P83V	P85V	P85-86	P87v	Total
Total hours	4.2	8.5	0.3	15	15	9.5	4	15		71.5
Type of event	Reap	Disap	Disap	Disap	Disap	Disap	Disap	Disap	Disap	-
Attempted events	51	78	4	125	92	210	49	139		748
Successful events	30	72	3	116	73	184	39	134		651
Diameters	3	1		2		1				7
Binaries/Triples	2	7		13		24				46
Shells/Complex	0	2		1		0				3
Planetary Neb CS	0	1		0		0				1
Masers	2	1		0		1				4
Publication	2008a	2008b		2010		subm				



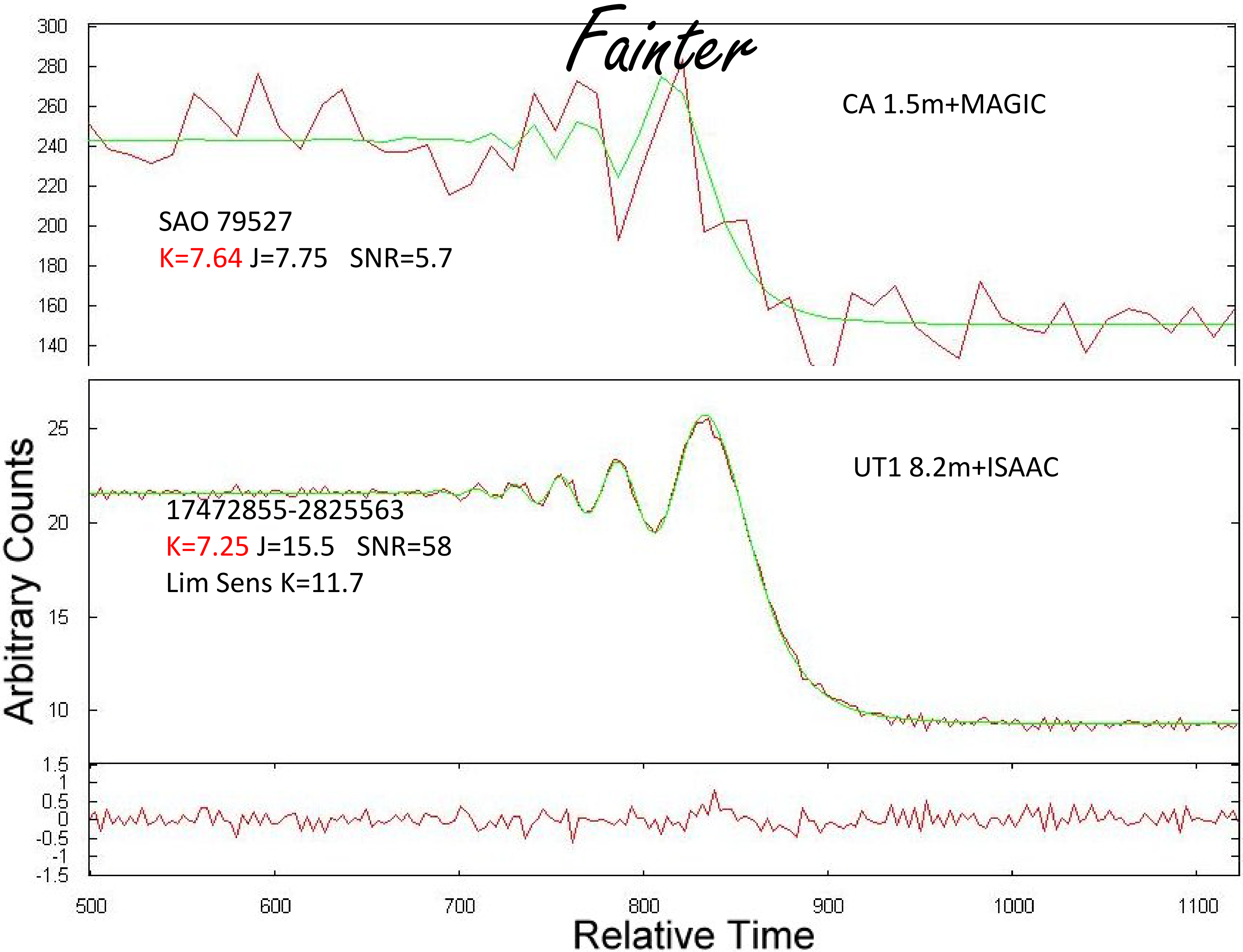
Limiting Sensitivity (SNR=1)	K~12-12.5
Limiting Angular Resolution	0.5-2 mas
Dynamic Range at 0.02"	7-8 mag K

Most powerful combination presently available!

More data obtained in P87-88-89, and start of P90

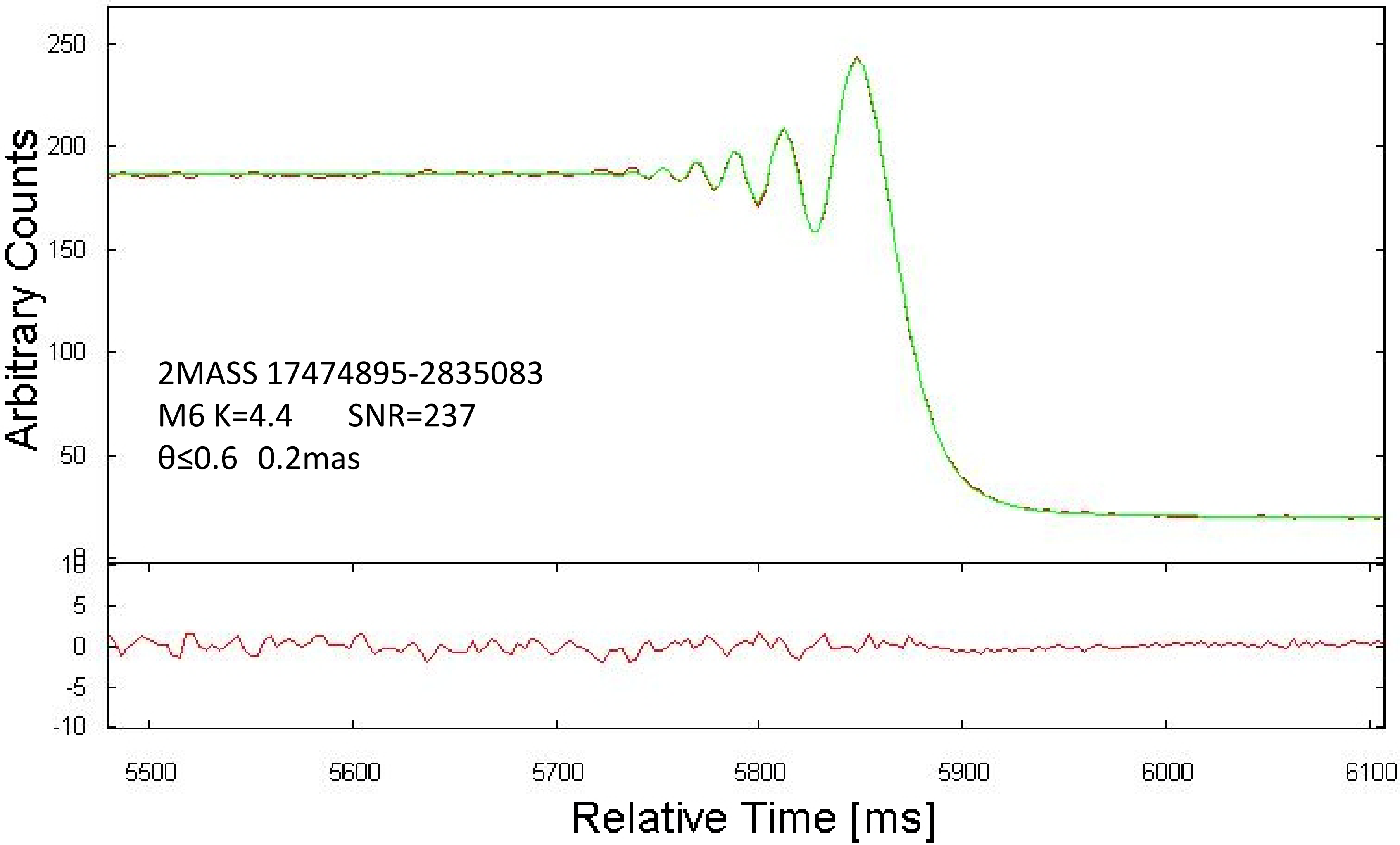
Now database of 984 events available (+34 end July...)

6 refereed paper, 1 under referee, several more in preparation

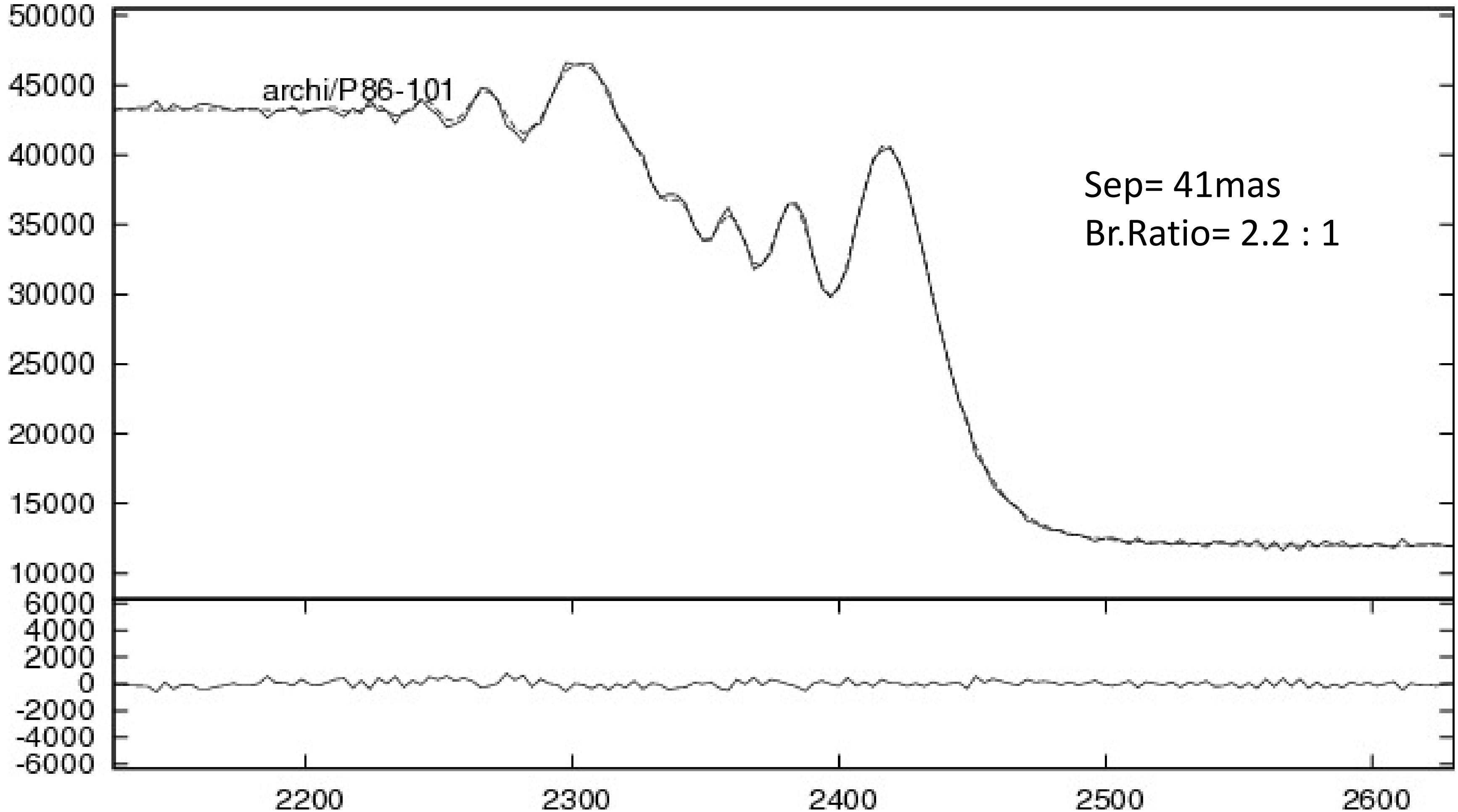


Fainter
CA 1.5m+MAGIC
SAO 79527
K=7.64 J=7.75 SNR=5.7
UT1 8.2m+ISAAC
17472855-2825563
K=7.25 J=15.5 SNR=58
Lim Sens K=11.7
Arbitrary Counts
Relative Time

More accurate

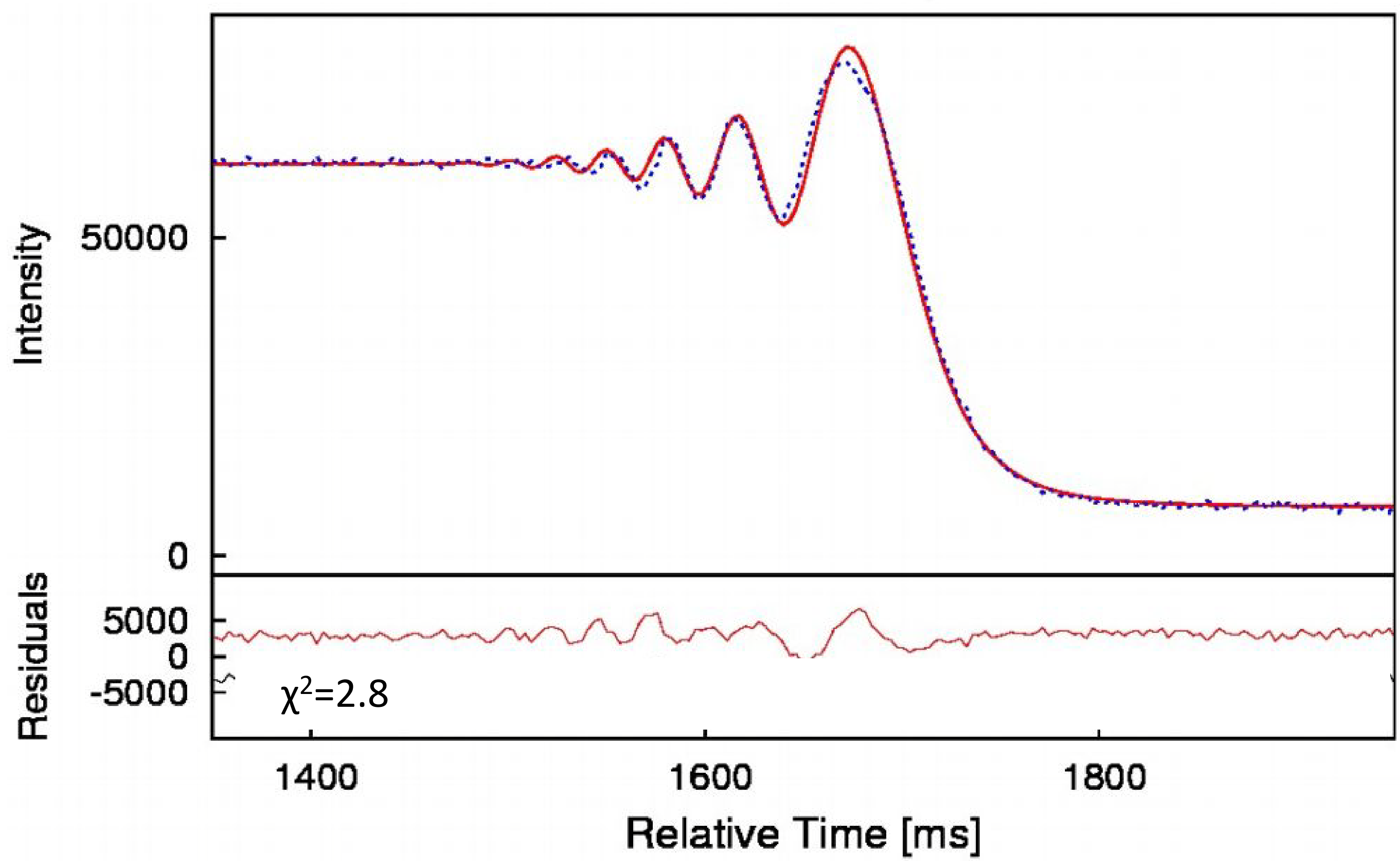


Example of a binary star (easy)



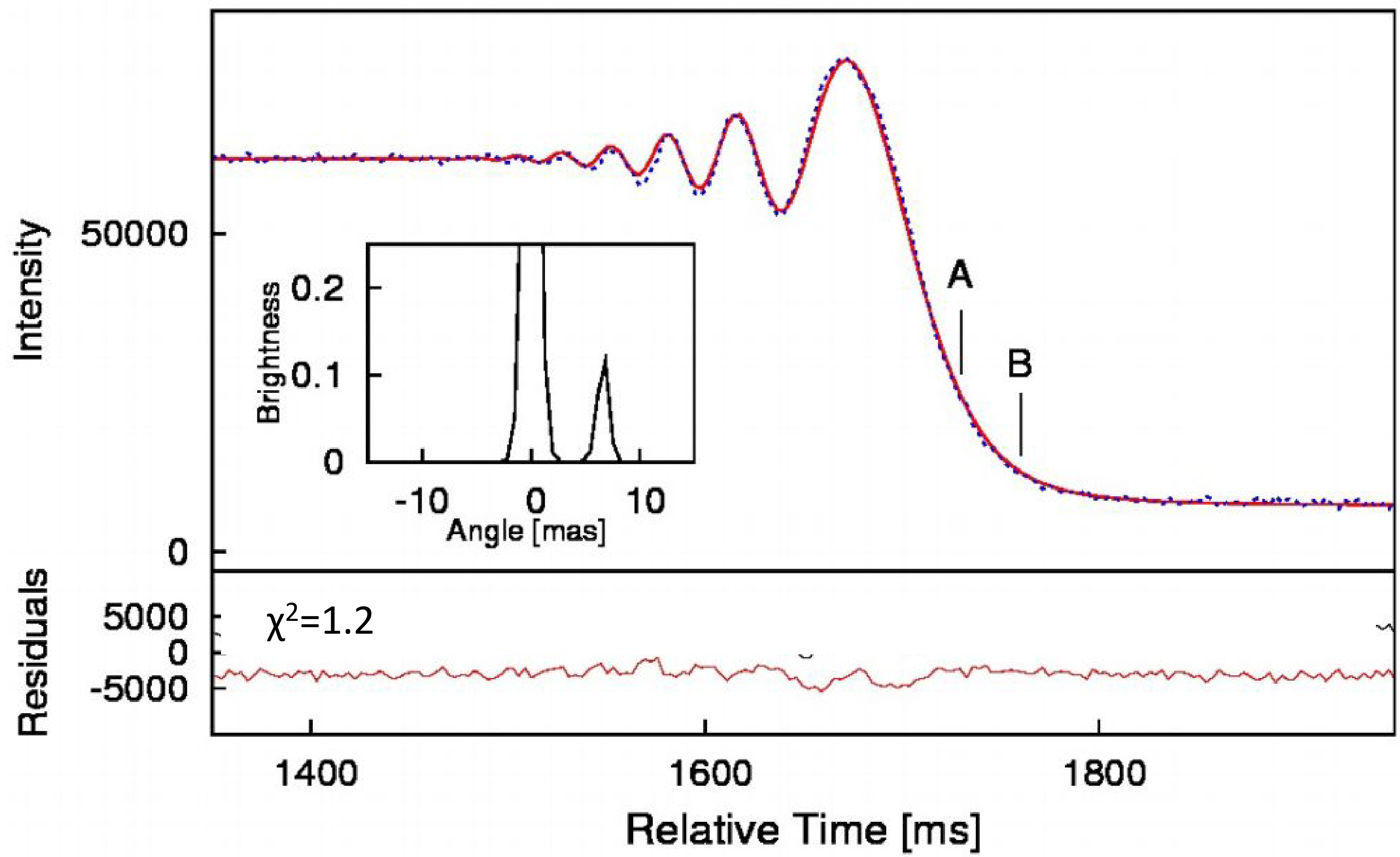
Example of a binary star (harder)

2MASS17073892-2554521, K=5.21



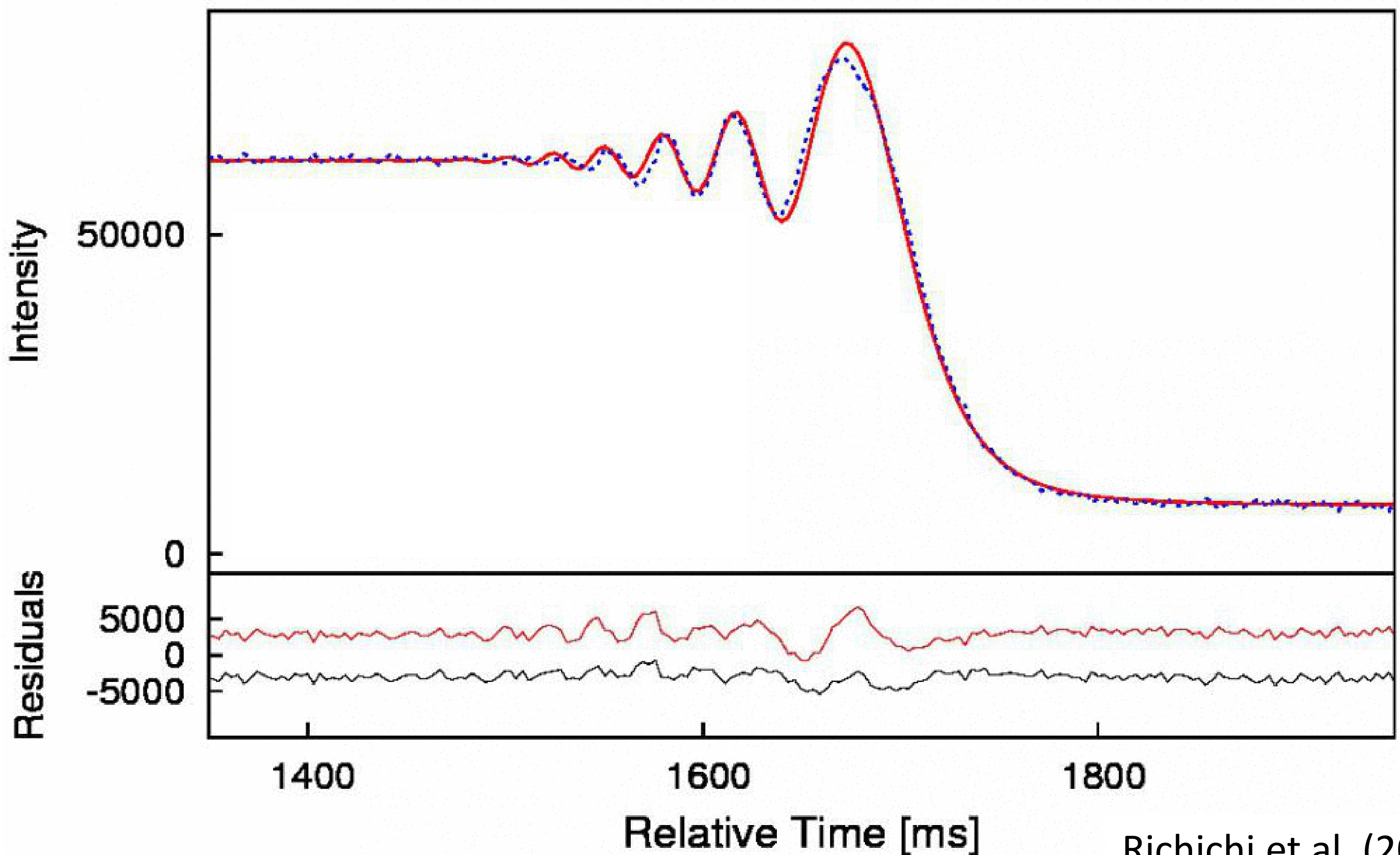
Example of a binary star (harder)

2MASS17073892-2554521, K=5.21



Example of a binary star (harder)

2MASS17073892-2554521, K=5.21

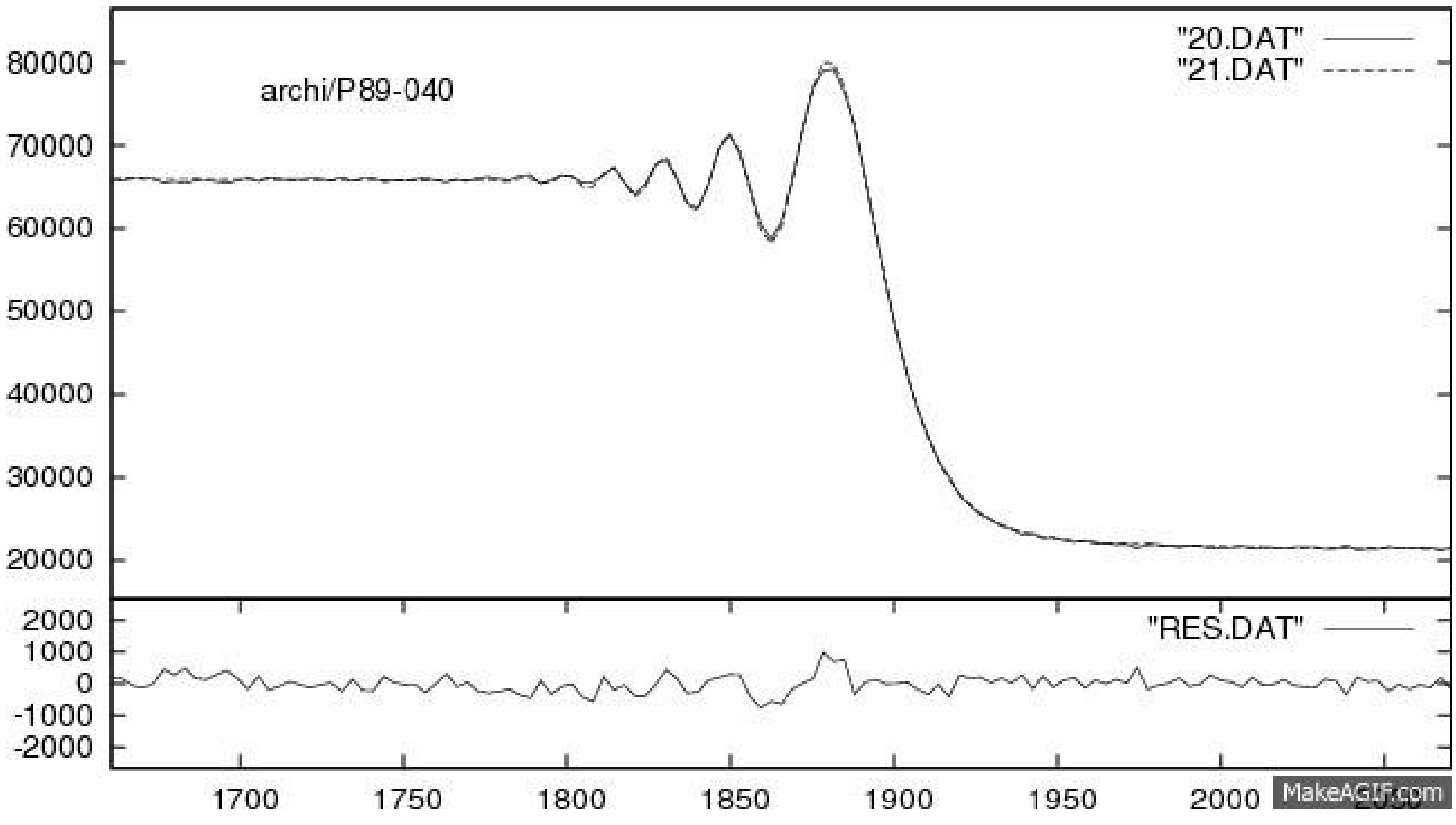


Richichi et al. (2010)

Sep=6.76±0.03 mas K_1=5.6, K_2=7.9

A fresh one (July 2012)

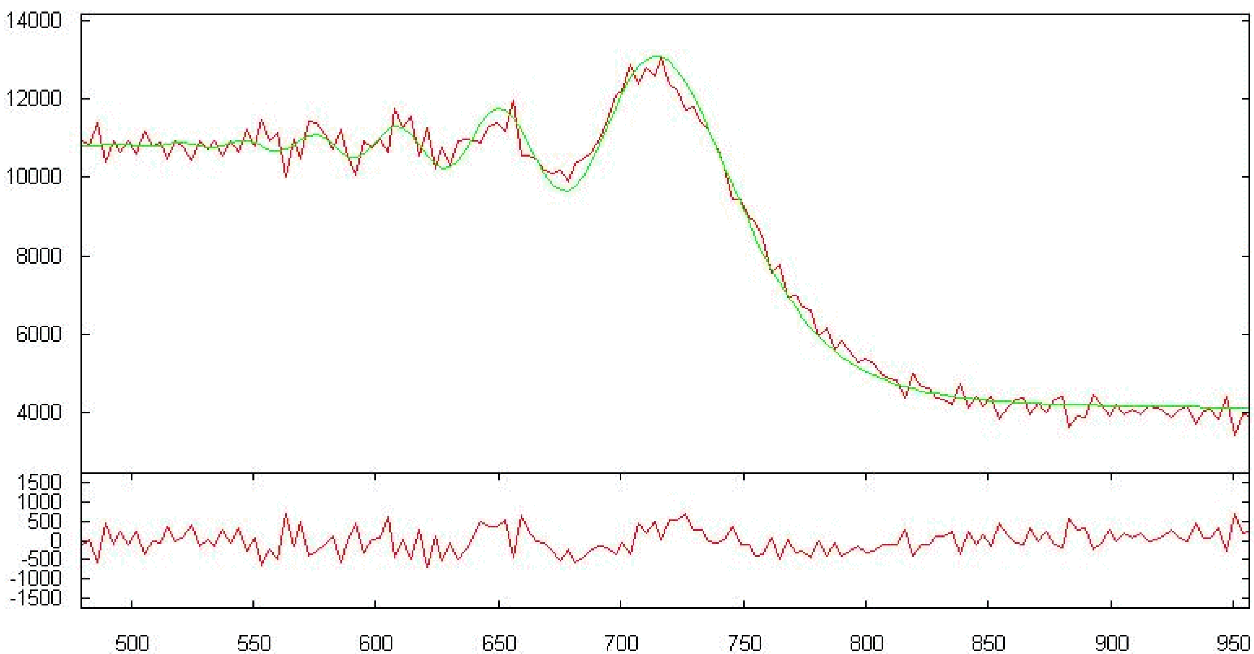
17121145-2134332, K=5.60

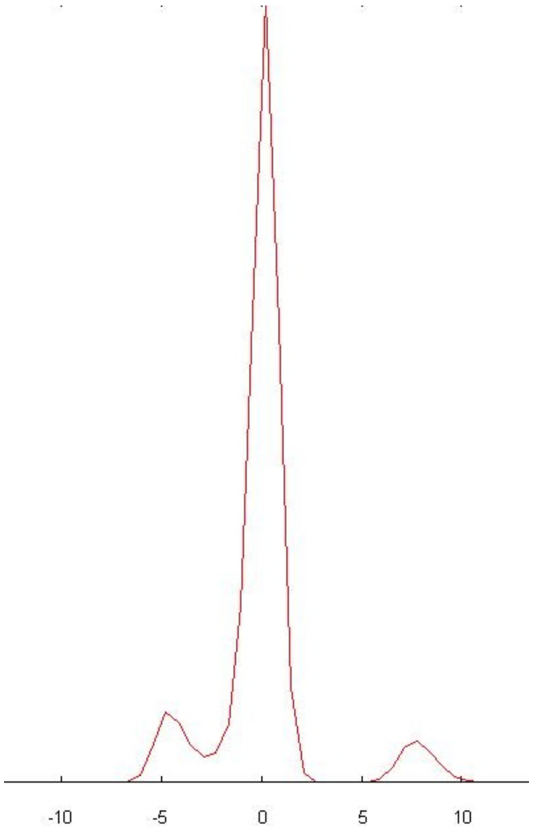


Sep=5.1 mas χ^2=1.6→1.0 ΔK=3.3

Example of a triple star

P83-23 Field star no refs, V=9.3 K=7.8





Pair A-B: Sep=4.1±0.2 mas Pair A-C: Sep=8.4±0.2 mas

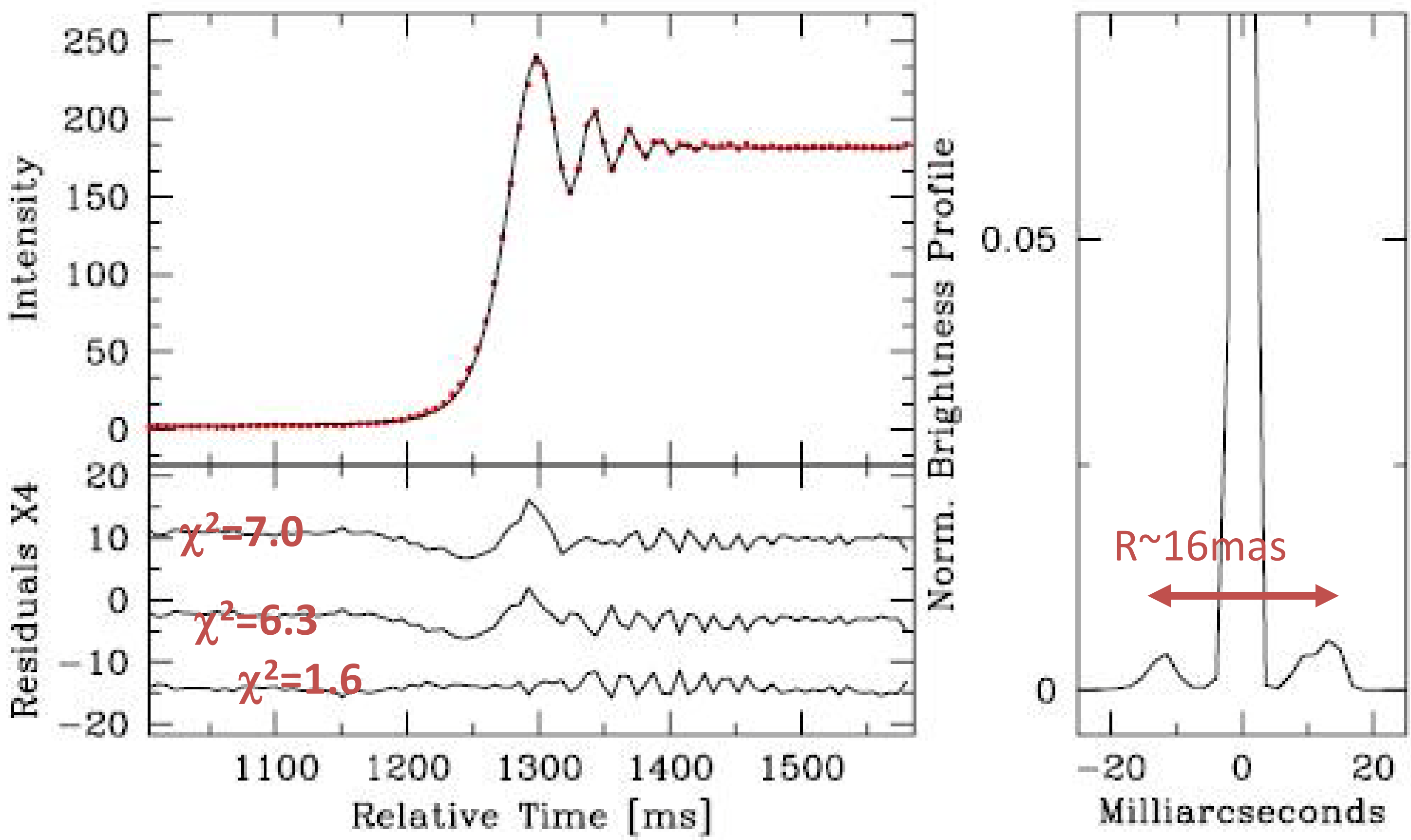
K=8.03, 10.09, 10.41 (±0.02)

Example of a circumstellar shell

2MASS 17453224-2833429 = ISOGAL-P J174532.3-283338

IR source K=5.3, J-K=3.7; no optical cross-ID; SiO Maser

probably fore-GC star ("low" A_K=1.1mag) 1kpc-> shell ~20AU



Conclusions (1)

Lunar occultations at a very large telescope provide a unique combination of high angular resolution and sensitivity

Many new close binaries and resolved sources are being discovered in the near-IR at the VLT

Lunar occultations can also be observed at smaller telescopes, with economical instrumentation

High time resolution opens up a large number of possible research topics, often requiring long time allocations not possible at large telescopes

New Binaries in the Pleiades

A&A 541, A96 (2012)
DOI: 10.1051/0004-6361/201219041

Astronomy & Astrophysics

An investigation of binary stars in the Pleiades with high contrast and spatial resolution★

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3 Department of Physics, National Central University, 300 Jhongda Road, 32001 Jhongli, Taiwan
4 INAF – Osservatorio Astronomico di Bologna, via Ranzani 1, 40127 Bologna, Italy
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6 Observatori Fabra, Camí de l'Observatori s/n, 08035 Barcelona, Spain
7 European Southern Observatory, Casilla 19001, Santiago 19, Chile
8 Leiden Observatory, PO Box 9513, 2300 RA Leiden, The Netherlands
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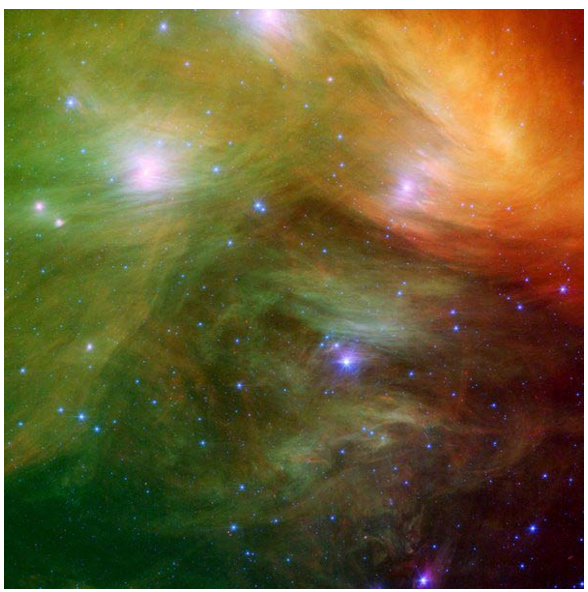
Received 15 February 2012 / Accepted 15 March 2012

The Pleiades Cluster

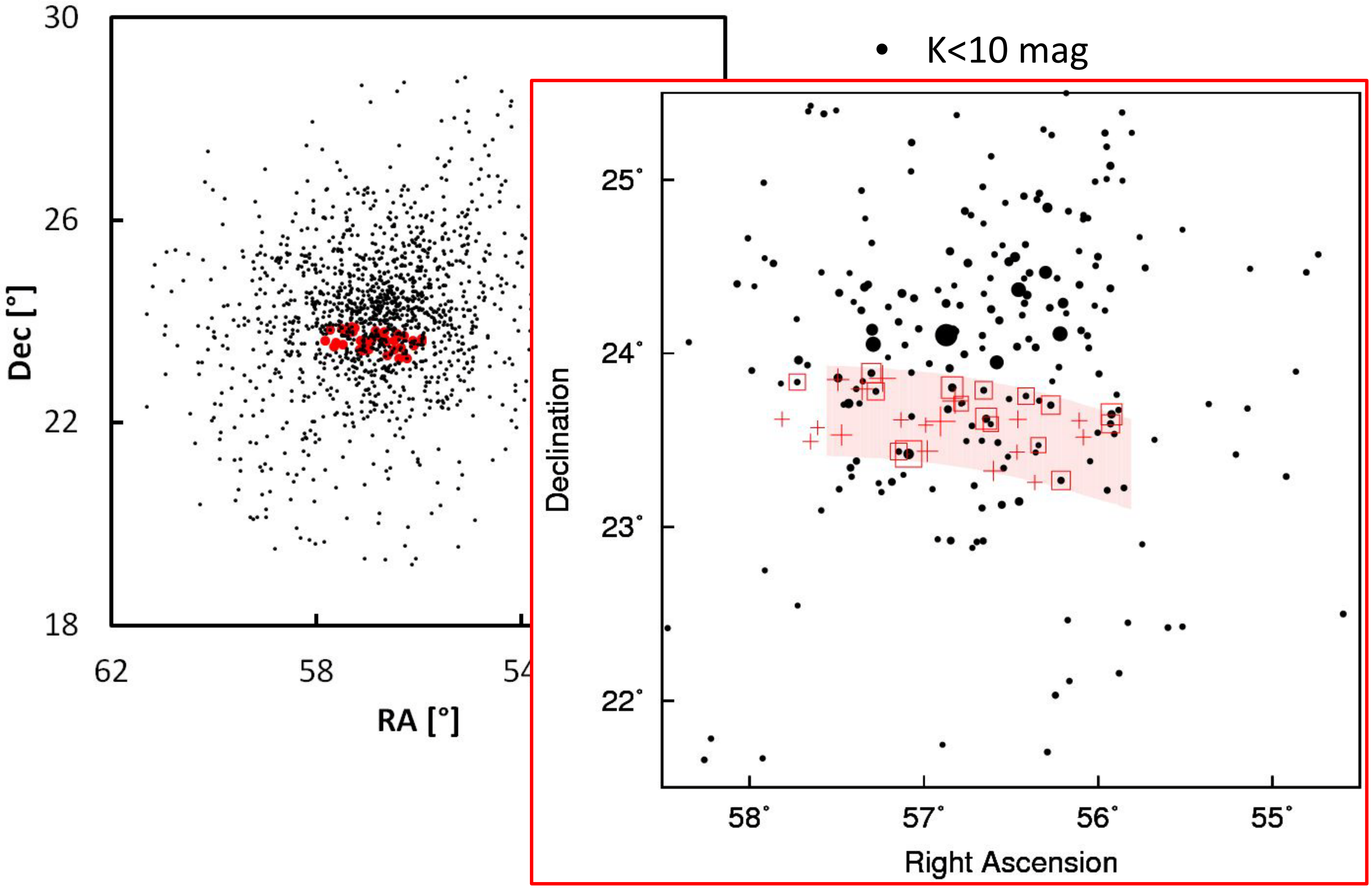


- Bright and outstanding
- Young ~10^8 years, intermediate age
- High proper motions (dissipation)
- Debate over distance (120 vs 135 pc)
- HR (Cosmic distance ladder)
- Broad range of masses (25% BD)
- Nebulosity

- Binarity in (young) clusters and solar-neighbourhood
- No binary excess (?)

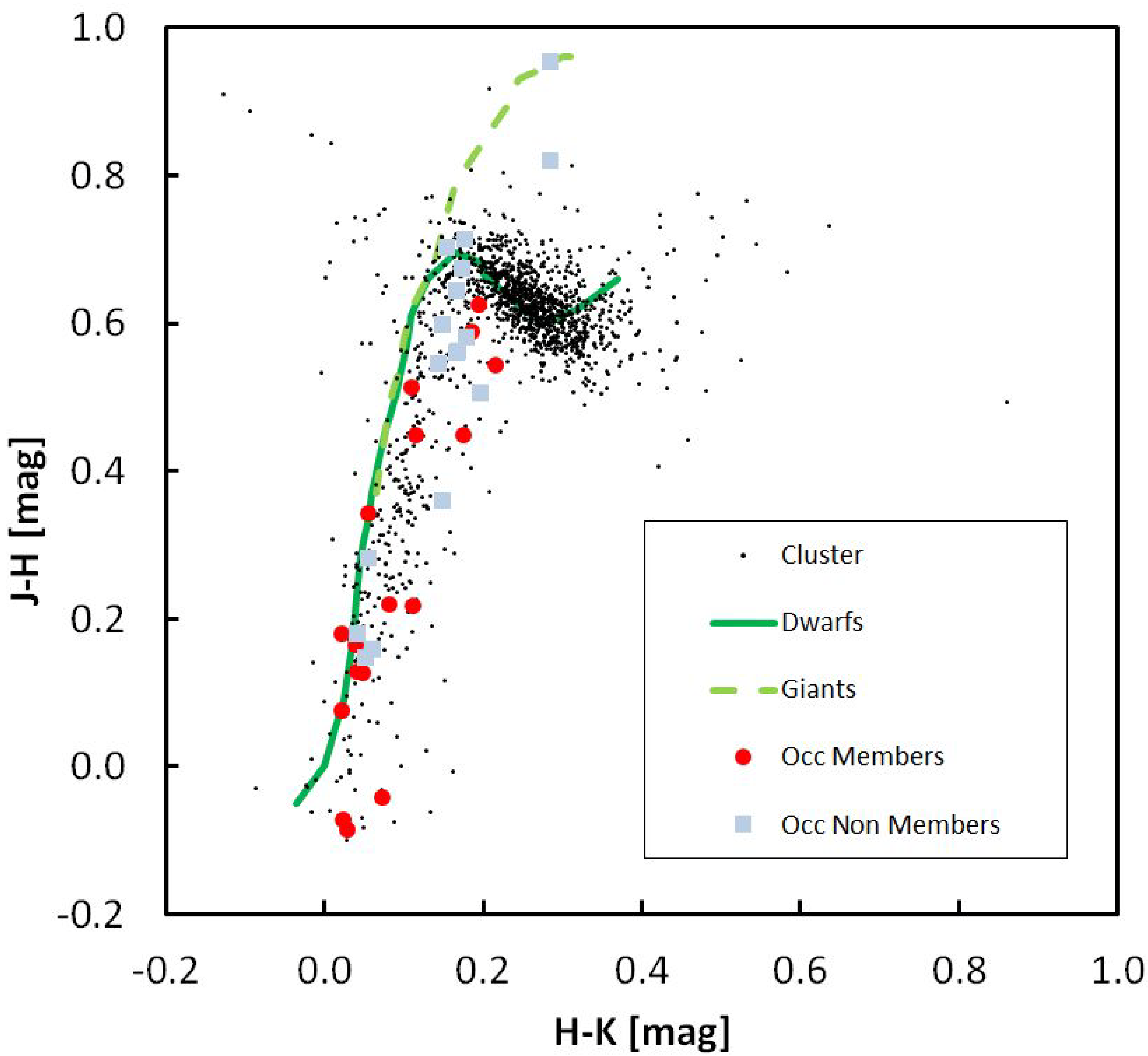
Moon in the Pleiades, December 2010

• K<10 mag



□ members +non-members

Colors



1.0
0.8
0.6
0.4
0.2
0.0
-0.2
J-H [mag]
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
H-K [mag]
Cluster
Dwarfs
Giants
Occ Members
Occ Non Members

Two Samples of Occulted Sources

We can divide the 34 occulted stars (minus one grazing event) into:

- 17 cluster members
- 16 non-members (field stars)

These two subsamples are very similar in spatial location, colors, magnitude and SNR range. Therefore, a comparison of their binary frequencies is justified.

However, these are very small numbers!

Detected Binaries

ID	V (m/ms)	V/V_t-1	$\psi(°)$	PA(°)	CA(°)	SNR	Sep. (mas)	Br. ratio	Magnitudes
P86-38	0.3668	27.3%	8	15	−56	41.8	16.80 ± 0.04	1.378 ± 0.003	$K_1 = 7.62$, $K_2 = 7.97$
P86-43	0.5185	−5.2%	−5	96	22	7.2	176 ± 1	1.652 ± 0.009	$K_1 = 10.12$, $K_2 = 10.67$
P86-46	0.4331	18.3%	8	30	−45	12.7	473.9 ± 0.8	4.42 ± 0.02	$K_1 = 9.23$, $K_2 = 10.84$
P86-51	0.5910	5.3%	11	67	−11	6.3	641.7 ± 0.3	1.352 ± 0.009	$K_1 = 10.50$, $K_2 = 10.83$
P86-61	0.3730	−9.9%	−5	30	−55	202.5	18.5 ± 0.2	92.4 ± 0.8	$K_1 = 5.49$, $K_2 = 10.40$
P86-63	0.2256	−30.8%	−10	15	−70	38.1	22.1 ± 0.8	42.1 ± 0.8	$K_1 = 7.60$, $K_2 = 11.66$
P86-68	0.5420	−2.5%	−2	48	−40	4.5	117.9 ± 0.7	1.08 ± 0.01	$K_1 = 9.77$, $K_2 = 9.85$

Event	Member	Designation	V	J	H	K	Detection
P86-38	370	HD23157	7.95	7.20	7.07	7.03	Known
P86-43		Melotte 22 HII 815	11.94	10.12	9.76	9.61	New
P86-46	559	V1041 Tau	12.26	9.77	9.22	9.01	Known
P86-51	740	FL Tau	13.51	10.72	10.10	9.90	New
P86-61		26 Tau	6.49	5.68	5.53	5.48	Suspected
P86-63	957	HD23863	8.15	7.67	7.60	7.58	New (Triple?)
P86-68	1087	V1176 Tau	11.48	9.68	9.23	9.05	Suspected

The 34 occulted stars included 5 known or suspected spectroscopic binaries, which we did not detect. HD23863 is an exception.

Detected Binaries

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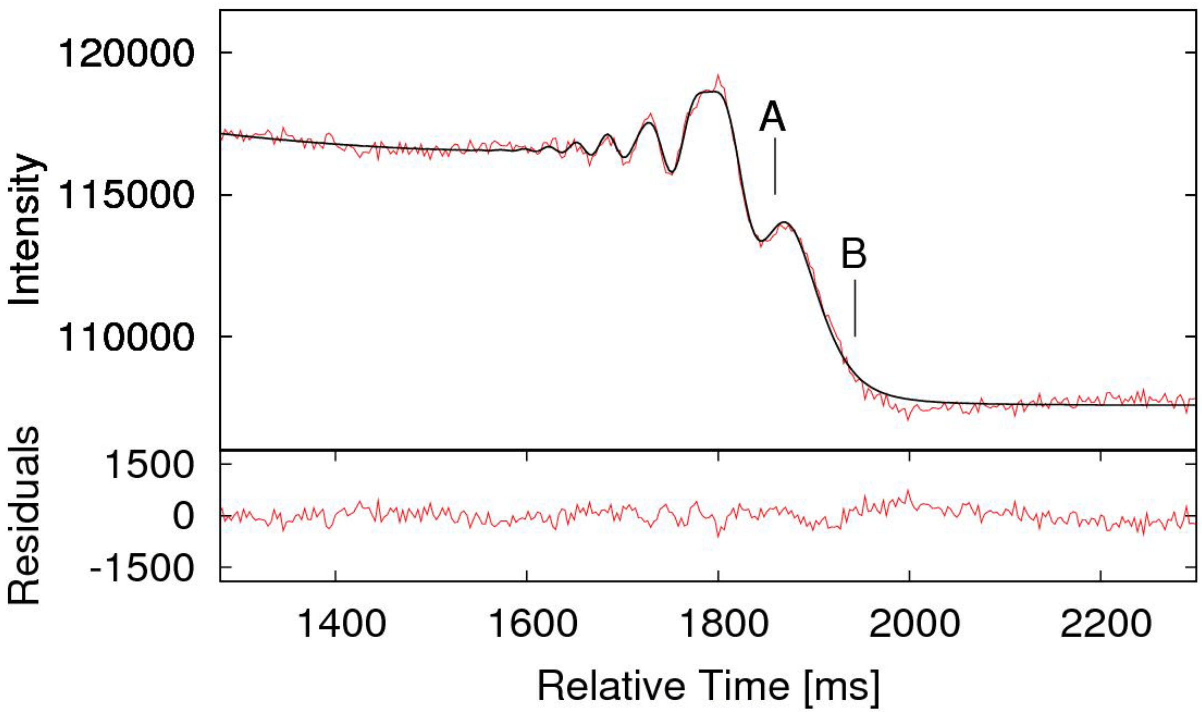

Detected Binaries

ID	V (m/ms)	$V/V_t{-}1$	$\psi(°)$	PA(°)	CA(°)	*SNR*	Sep. (mas)	Br. ratio	Magnitudes
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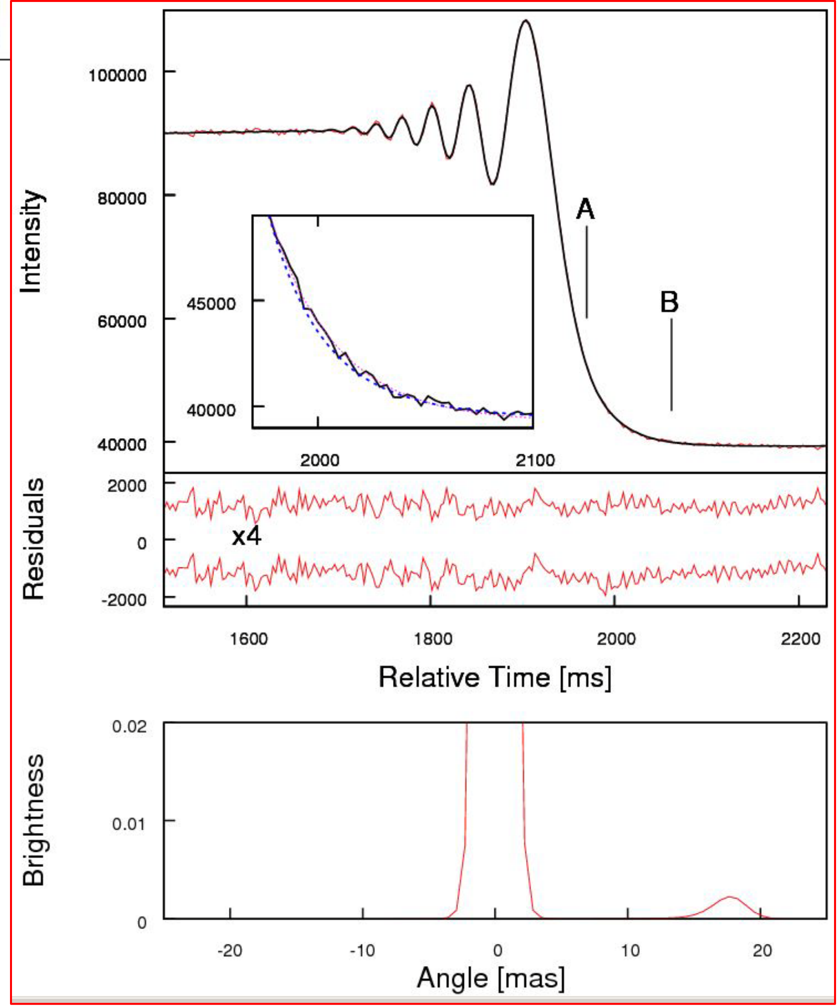
P86-63	0.2256	−30.8%	−10	15	−70	38.1	[illegible]	[illegible]	[illegible]
P86-68	0.5420	−2.5%	−2	48	−40	4.5	[illegible]	[illegible]	[illegible]



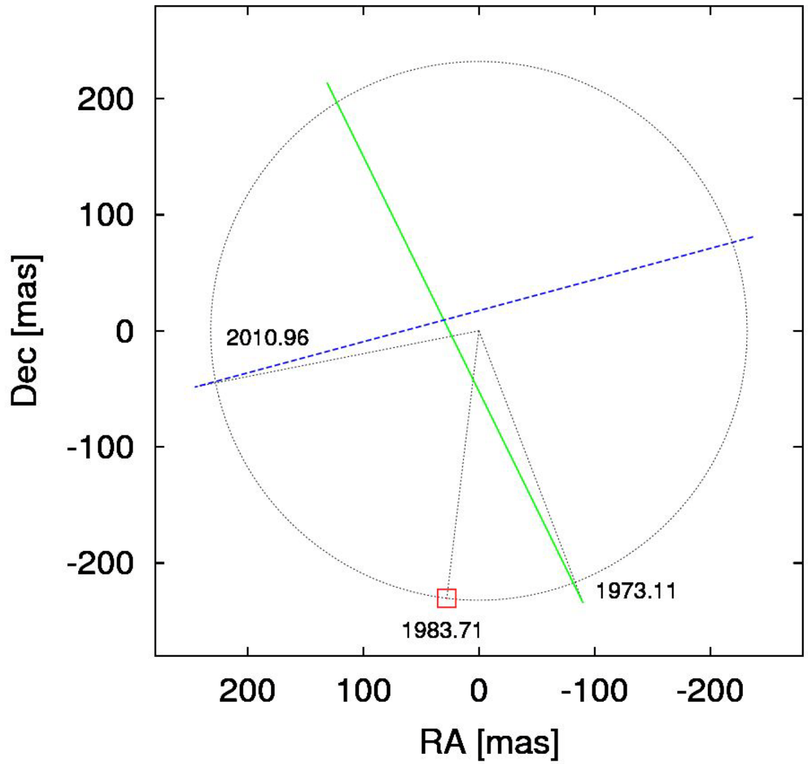
Orbits and Dynamical Masses

Some of the binaries have data spanning back ~40 years, unfortunately very incomplete.

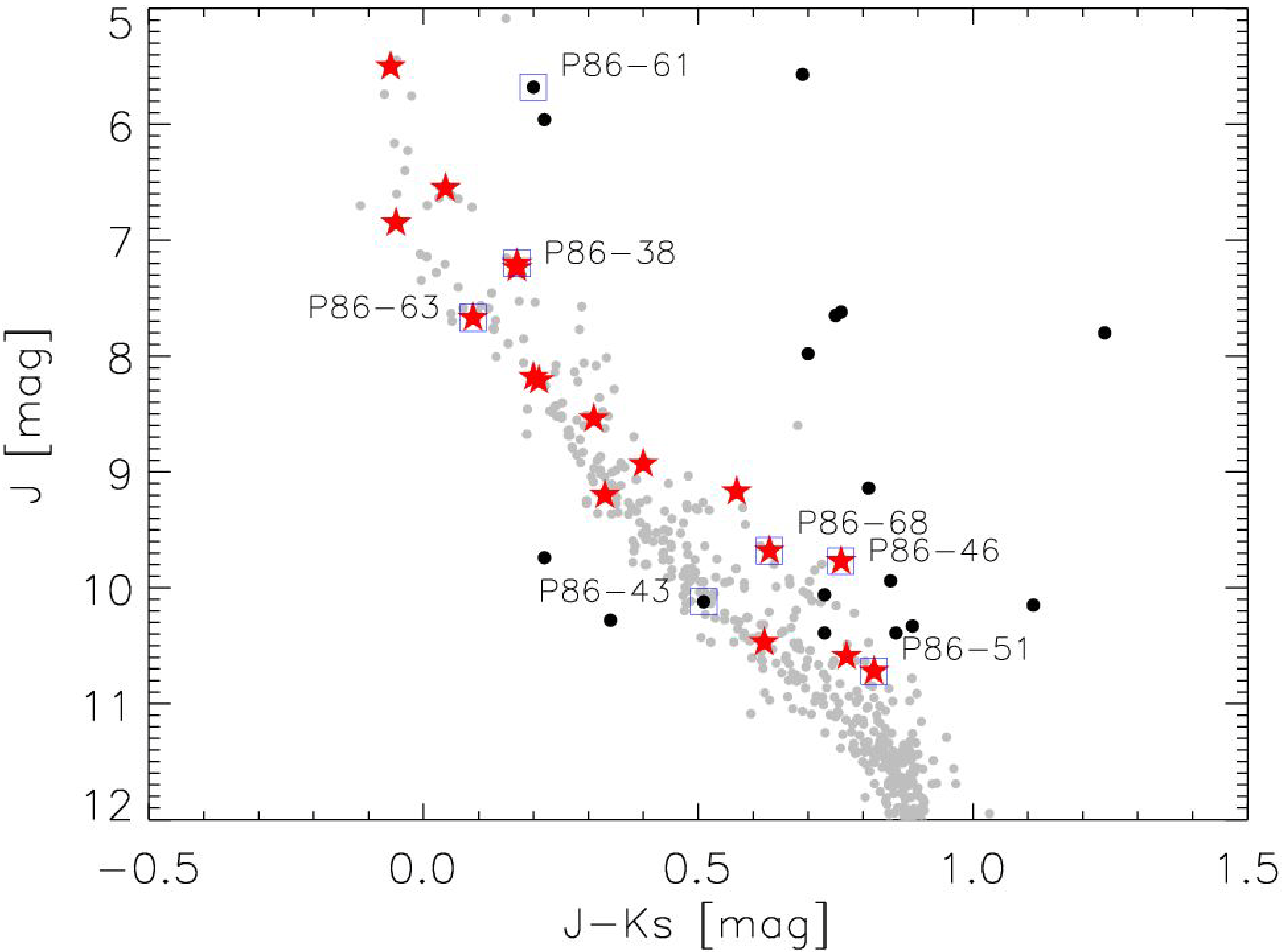
LO measurements provide only projected separations. No general method exists (yet) to combine LO with speckle data.

HD 23157 is an example: 0.23” with $1M_{\odot}$ → P=165 years

High precision AO imaging (and possibly phase referencing) can lead to dynamical masses on short time scales. 6 systems proposed at SUBARU.



Color-Magnitude



Conclusions (2)

- A passage of the Moon over the Pleiades (<4 hours) has been observed, yielding 34 occultation light curves of high quality which have been used to search for binaries
- The occulted stars can be divided into equal and comparable samples of cluster members and non-members
- Seven binaries have been found. Three are new (2M, 1NM), the others are either previously known or suspected. Our new determinations are useful both for orbital parameters and for colors.
- Binaries found: M=5/17, NM=2/16. But... small statistics!
- Binary frequency in the Pleiades... are we still missing some?

http://www.narit.or.th

Thank you!

Grazie!