Playing with milliseconds and milliarcseconds at ESO

Vienna, November 23, 2009

A. Richichi (ESO Garching)

ESO Chile

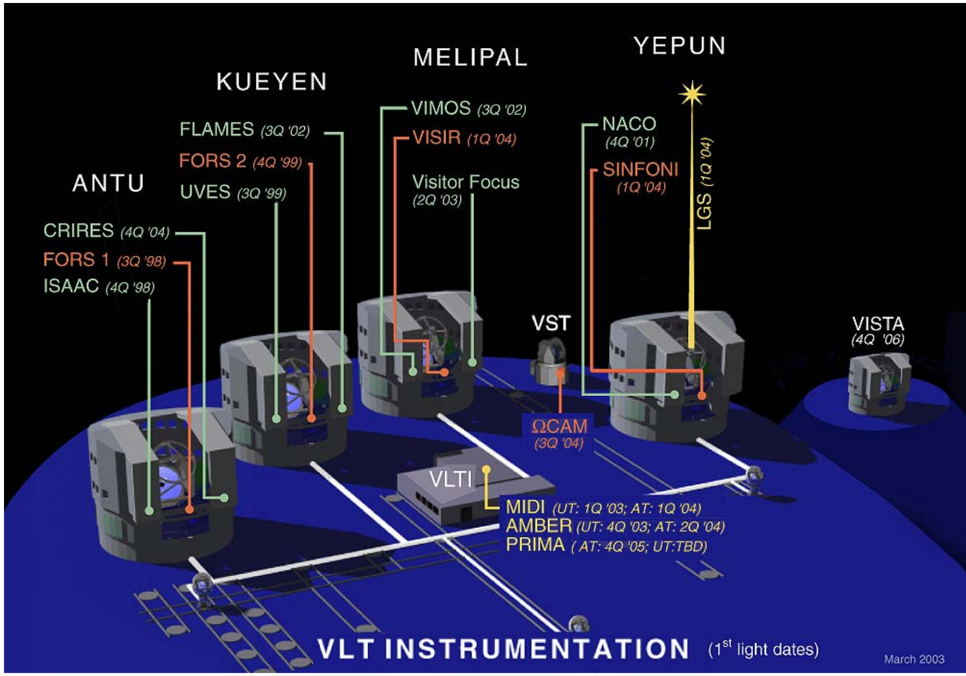
Chajnantor, 5000m

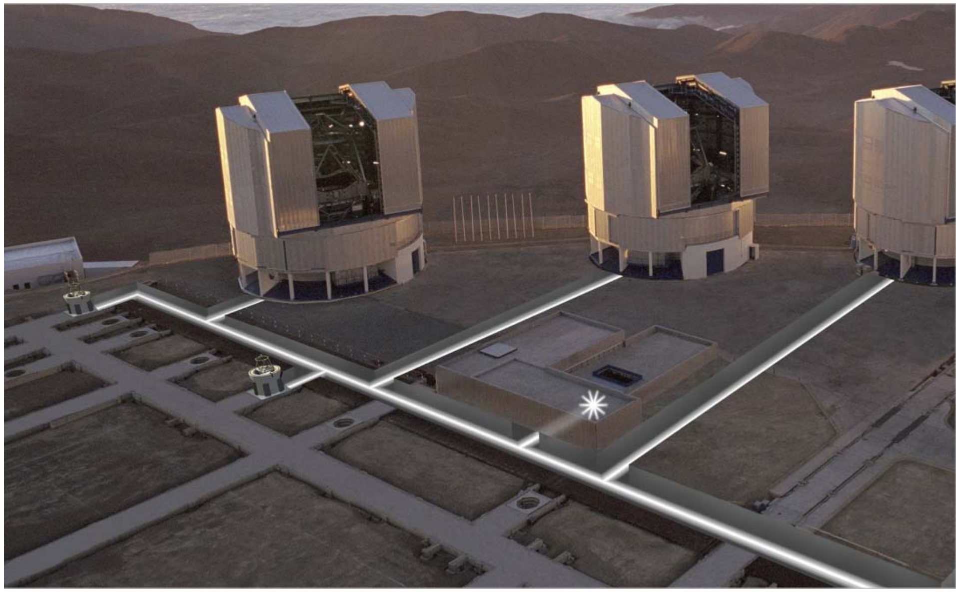
Paranal, 2600m

La Silla, 2400m

Santiago Office

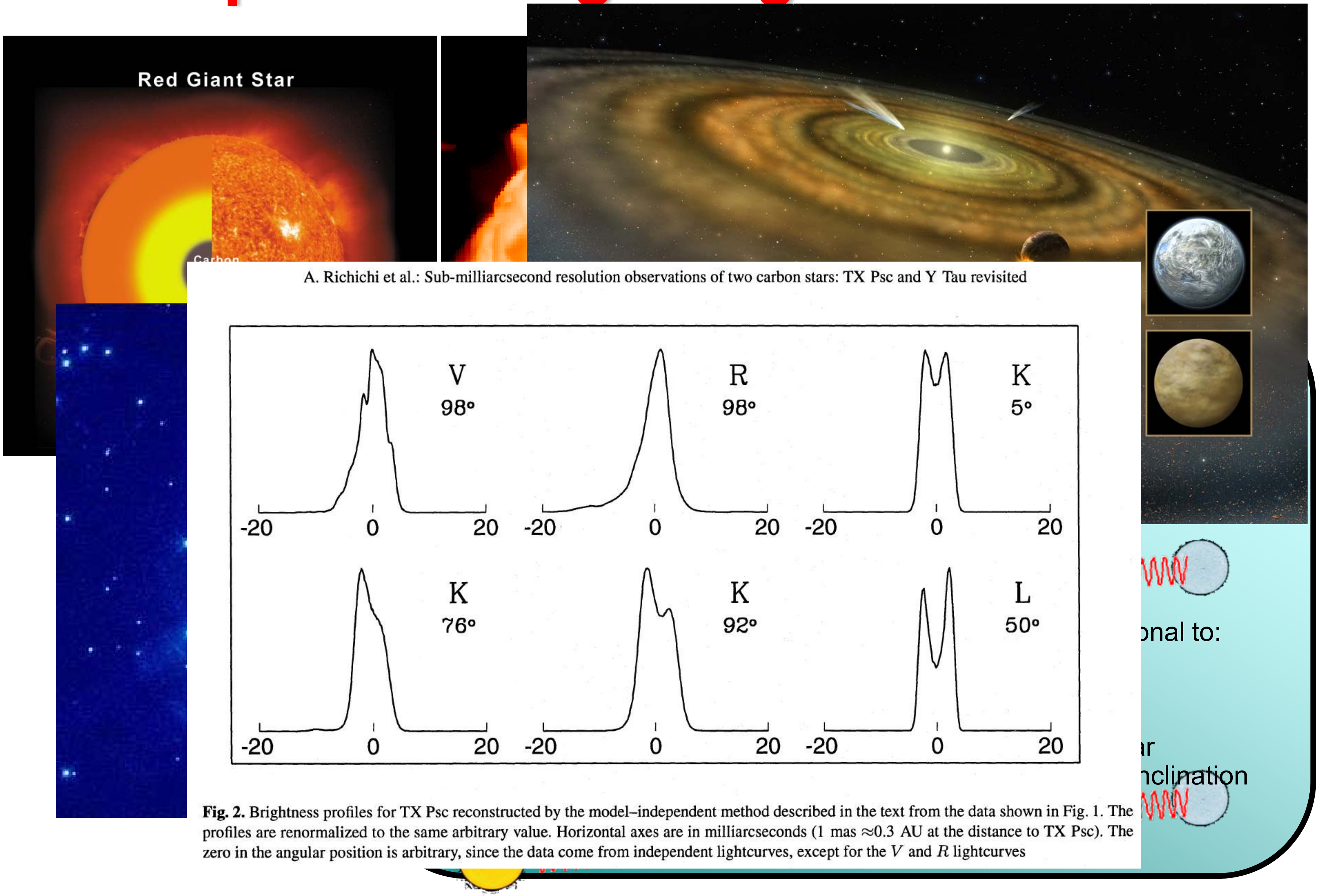
Paranal and its Instruments





Lots of videos and pictures available from the ESO Web site...

The quest for high angular resolution



A. Richichi et al.: Sub-milliarcsecond resolution observations of two carbon stars: TX Psc and Y Tau revisited

Fig. 2. Brightness profiles for TX Psc reconstructed by the model–independent method described in the text from the data shown in Fig. 1. The profiles are renormalized to the same arbitrary value. Horizontal axes are in milliarcseconds (1 mas ≈0.3 AU at the distance to TX Psc). The zero in the angular position is arbitrary, since the data come from independent lightcurves, except for the V and R lightcurves

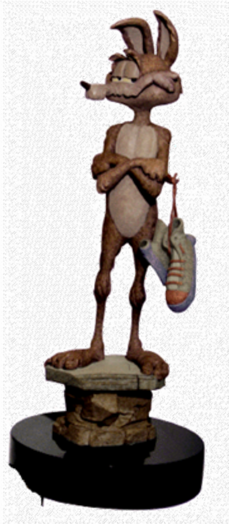
The quest for high time resolution

		Time-scale (now)	Time-scale (ELT era)
Stellar flares and pulsations		Seconds/ Minutes	10-100ms
Stellar surface oscillations	White Dwarfs Neutron Stars	1-1000 μsec	1-1000 μsec 0.1 μsec
Close Binary Systems (accretion and turbulence)	Tomography Eclipse in/egress Disk flickering Correlations (e.g.X & optical)	100ms++ 10ms+ 10ms 50ms	10 ms+ < 1ms < 1ms <1ms
Pulsars	Magnetospheric Thermal	1μsec-100ms 10 ms	nsec(?) <ms
AGN		Minutes	Seconds(?)

Redfern & Ryan
E-ELT Study Report
Marseille 2006

Additional important applications: solar system phenomena, lunar occultations, transits (seconds to milliseconds)

Niche applications: quantum properties of light, single photon experiments... (micro to nanoseconds)



Millisecond: *Observations of Lunar Occultations at the VLT using ISAAC/Aladdin in burst mode*

O. Fors (Barcelona), E. Mason (ESO/Paranal), W.-P. Chen (Taiwan), G. Finger & J. Stegmaier (IR Det Group in Garching)

VISIR
NACO
SOFI
Hawk-I

VLTI
AO

Nanosecond: *Observations with Iqueye at the NTT*

C. Barbieri, G. Naletto, T. Occhipinti, I. Capraro (from various institutes in Padova)

Lunar Occultations

The Moon’s limb acts as a straight diffracting edge

The diffraction phenomenon occurs in “vacuum”, no turbulence effects.

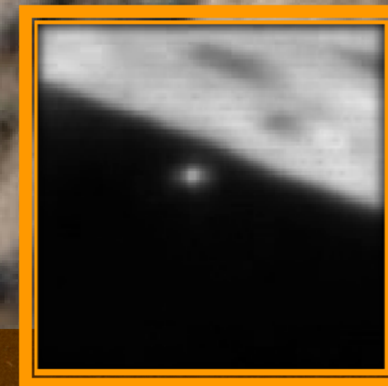
High-angular information is embedded in the diffraction fringes.

Lunar limb irregularities have marginal influence (Fresnel fringes).

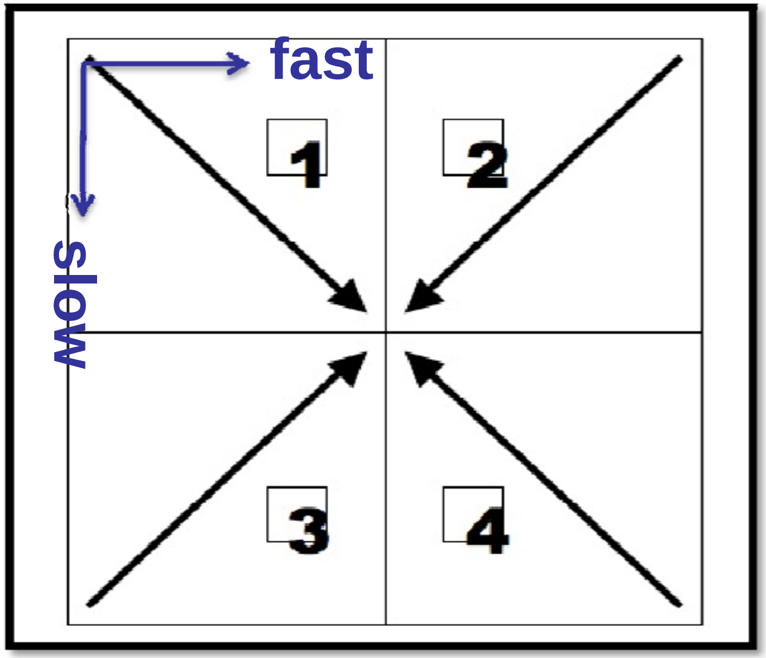
The “resolution” is independent from telescope diameter (but depends on SNR).

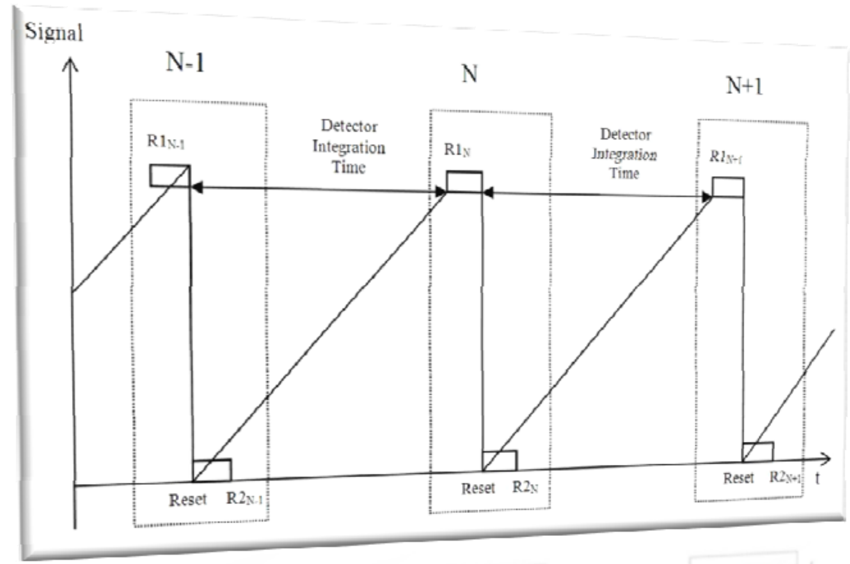
Temporal scales (depending on wavelength and apparent limb velocity) are ~0.1s.

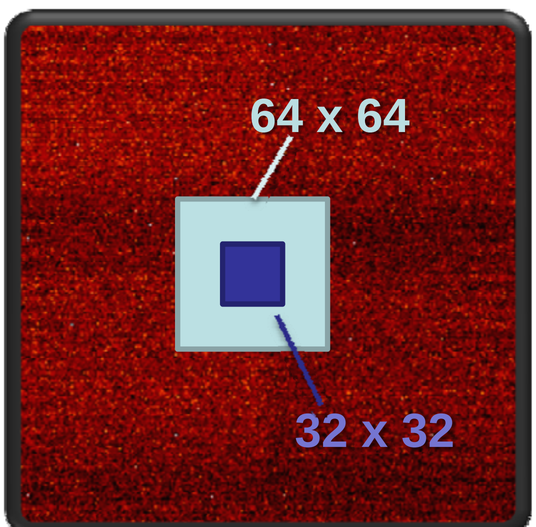
Diffraction patterns of two or more components add linearly.



The ISAAC burst mode



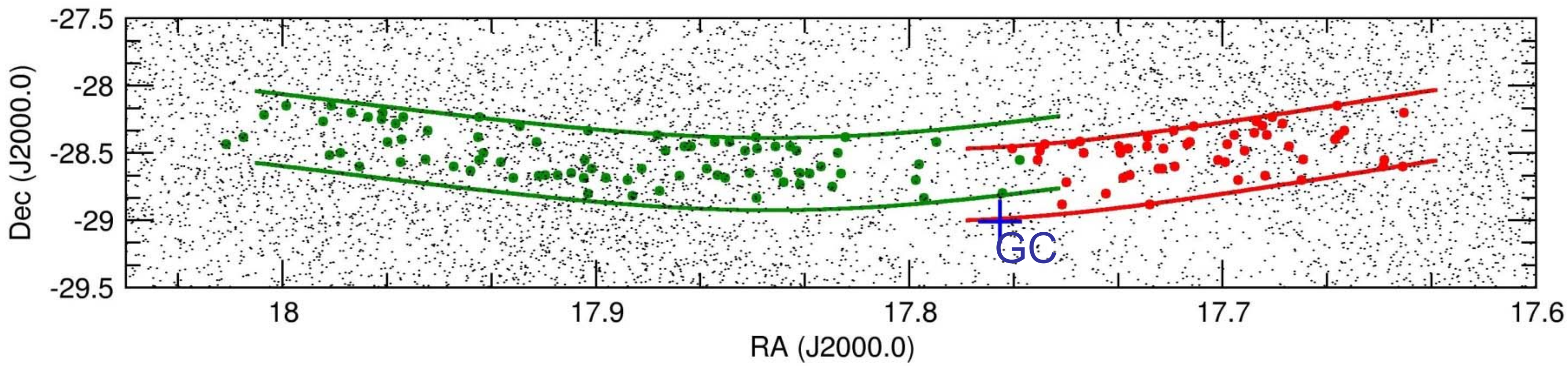




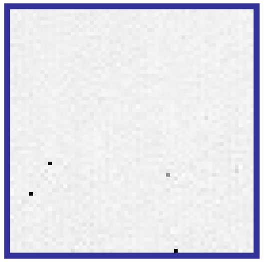
		Burst mode		FastJitter mode	
Window Size [pxs]	Field of View ['']	min DIT [ms]	max NDIT	min DIT [ms]	max NDIT
32x32	4.7x4.7	3.2	16000	12	32000
64x64	9.5x9.5	6.4	16000 *	12	16000
128x128	19x19	14	4000 **	14	4000
256x256	38x38	37	1000 **	37	1000

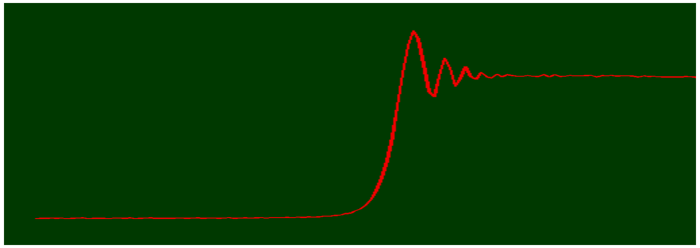
Data cube: Pixel x Pixel x 2 x NDIT

Lunar Appulses to the Galactic Center

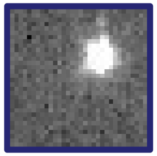


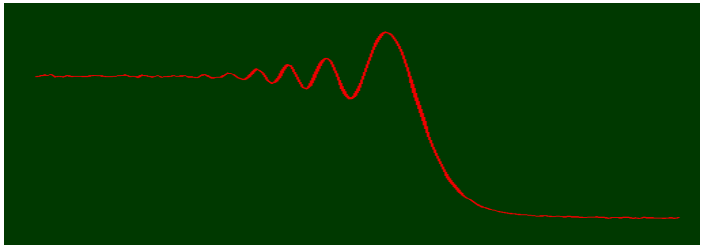
21 March 2006
11” approach to GC 509 events
with K≤7.5 mag ~3 hours
64x64 pix (9.5”), 6.4ms





5-6 August 2006
12’ approach to GC 1188 events
with K≤7.5 mag 7.8 hours
32x32 pix (4.7”), 3.2ms



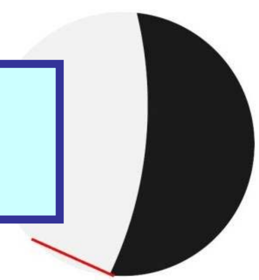


Overview of LO runs

	Mar-06	Aug-06	P80	P81	P83	P83V	Total
Total hours	4.2	8.5	0.3	15	15	9.5	52.5
Type of event	Reap	Disap	Disap	Disap	Disap	Disap	-
Attempted events	51	78	4	125	92	210	560
Successful events	30	72	2	116	New data, not yet evaluated		*>500?*
Diameters	3	1	0	9			13
Binaries/Triples	2	7	0	6			15
Shells/Complex	0	2	0	0			2
Planetary Neb CS	0	1	0	0			1
Masers	2	1	0	0			3

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

By-product: several hundreds of well defined interferometric calibrators!

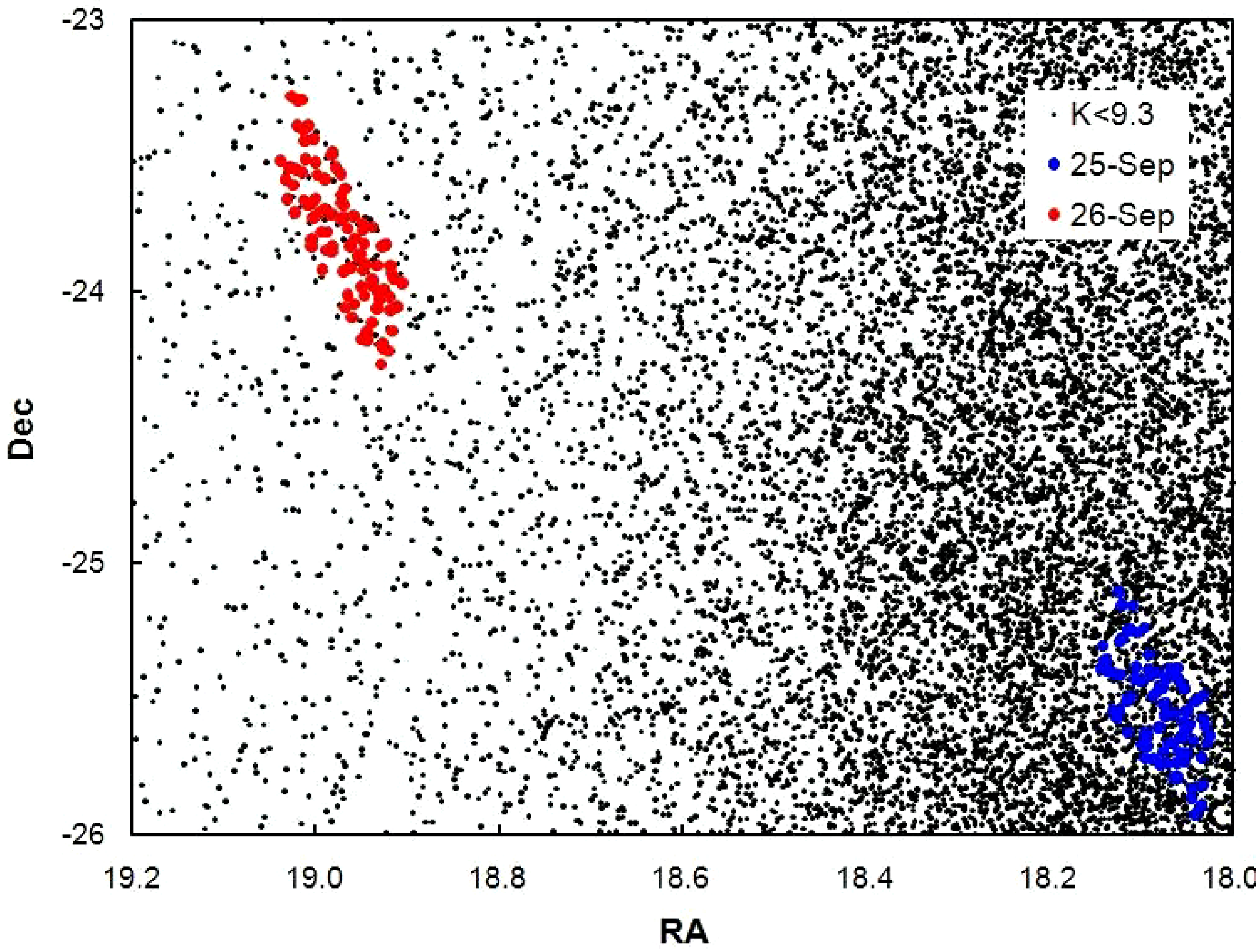


Richichi et al (2008a, 2008b)

This combination of sensitivity and angular resolution cannot be achieved by any other technique in the near-IR.

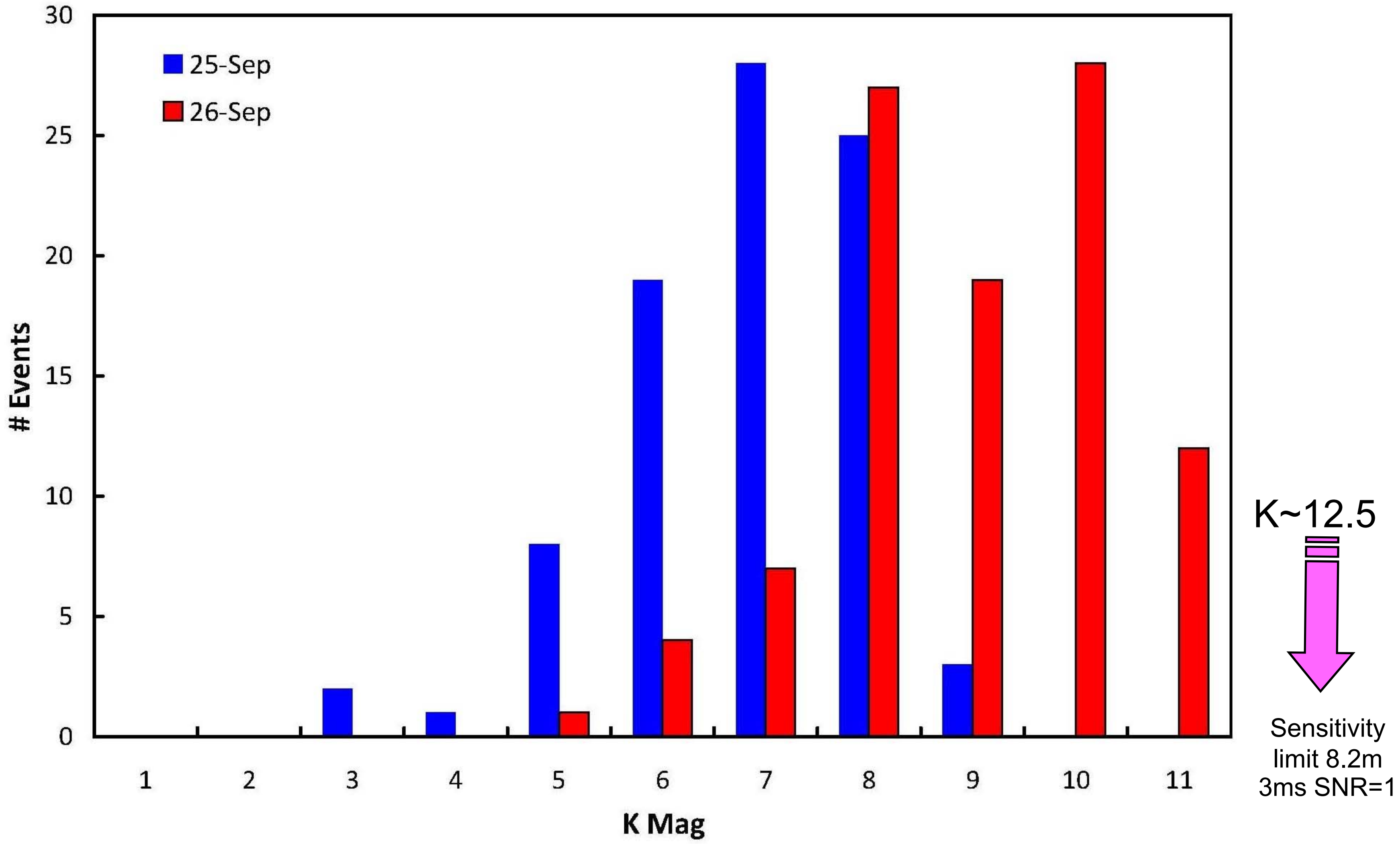
The drawback is that lunar occultations are fixed-time events !

September 2009, Visitor Mode

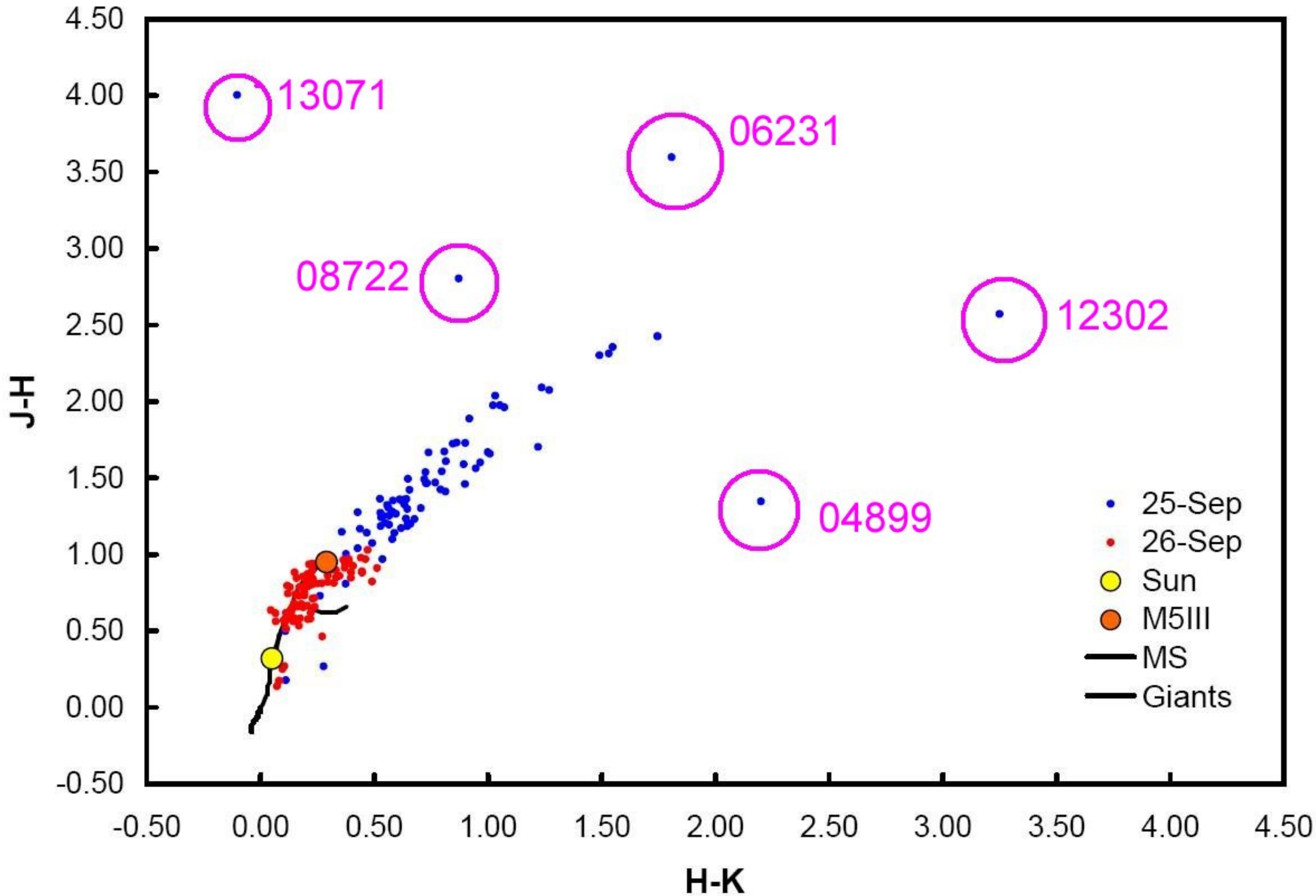


184 LO with positive detections, during two half nights
~80% data analyzed, first report
many binaries; several resolved and extended stars

K magnitudes

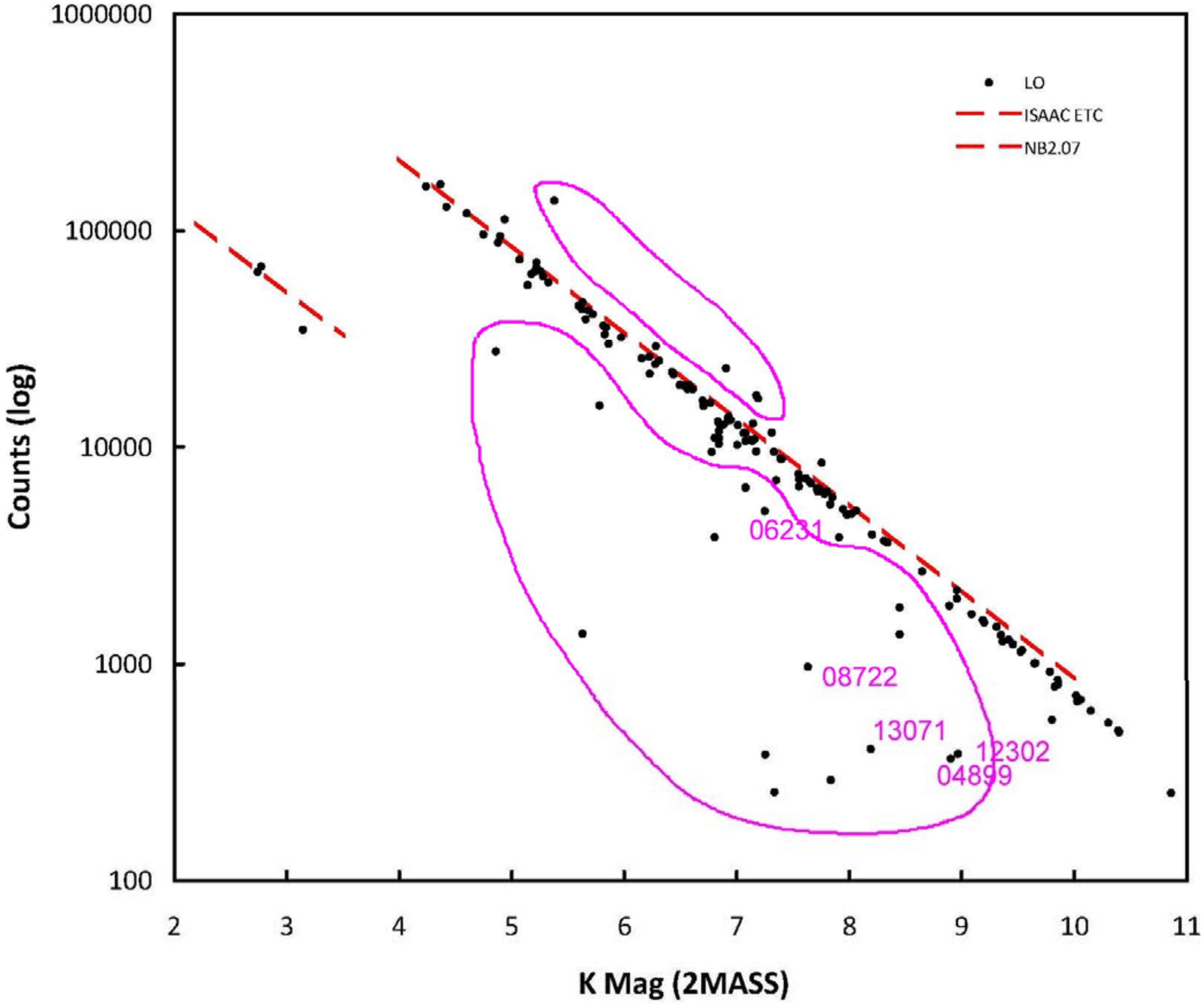


NIR Colors



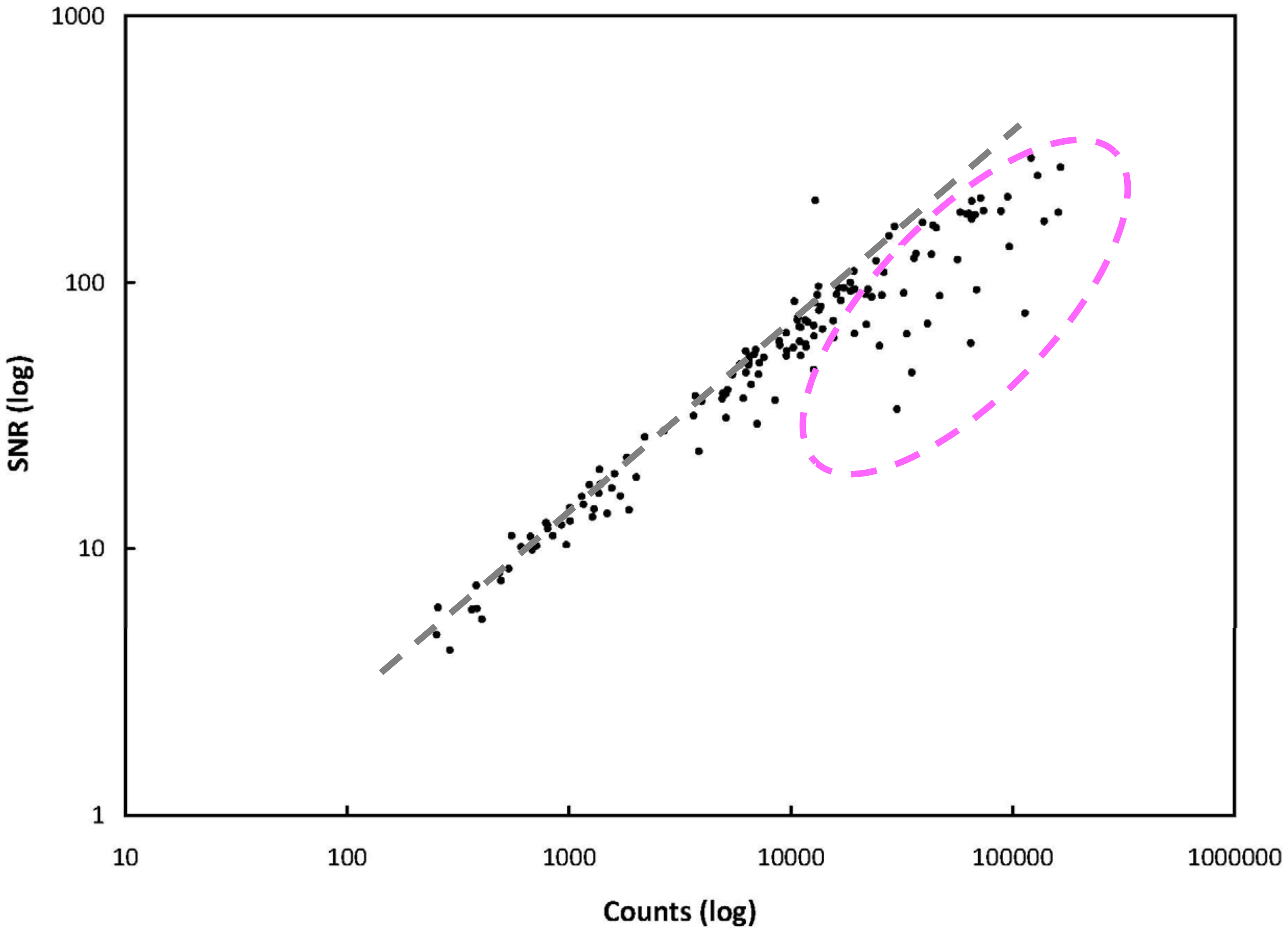
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
J-H
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
H-K
13071
06231
08722
12302
04899
25-Sep
26-Sep
Sun
M5III
MS
Giants

NIR Fluxes



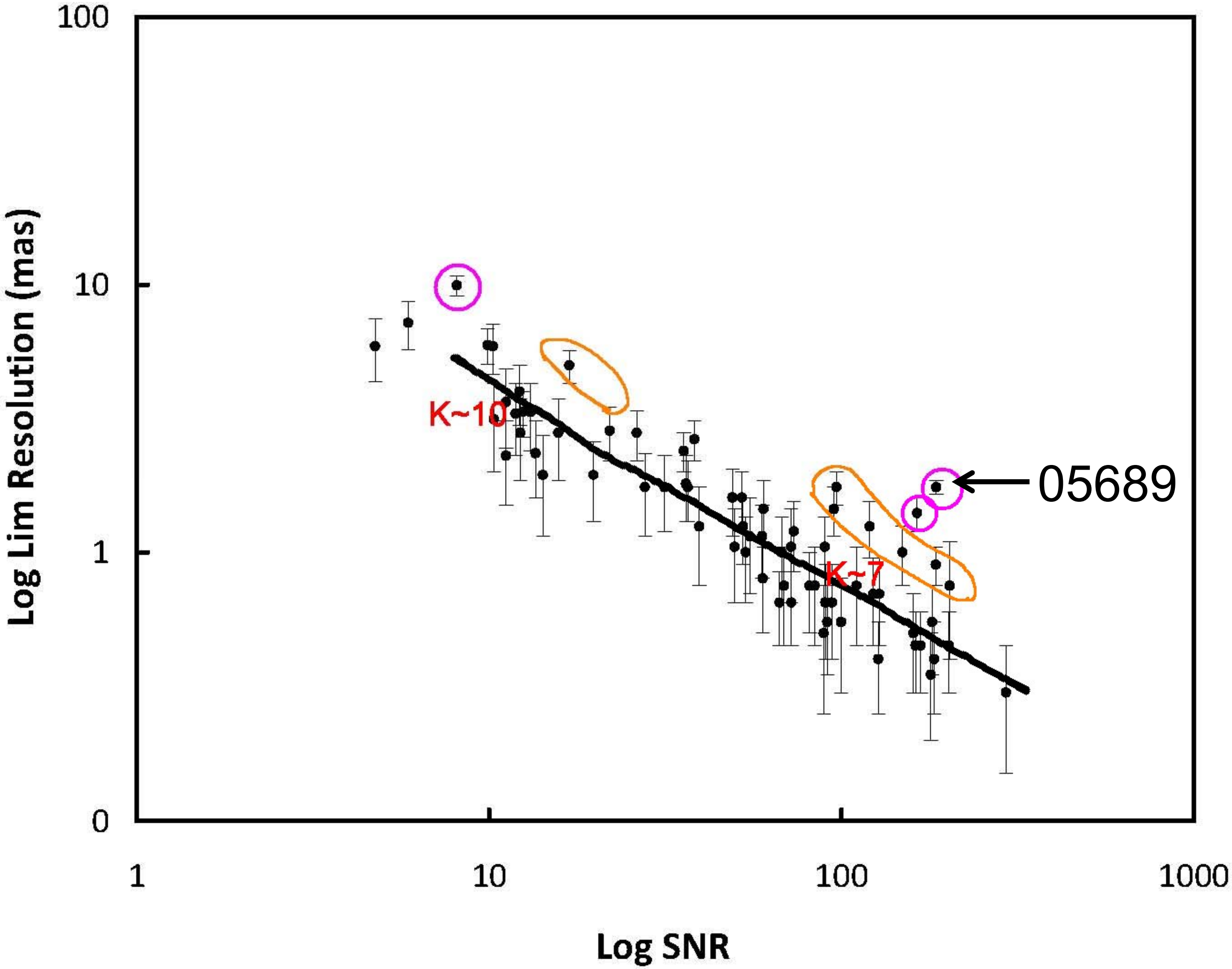
1000000
100000
10000
1000
100
Counts (log)
2
3
4
5
6
7
8
9
10
11
K Mag (2MASS)
LO
ISAAC ETC
NB2.07
06231
08722
13071
12302
04899

SNR



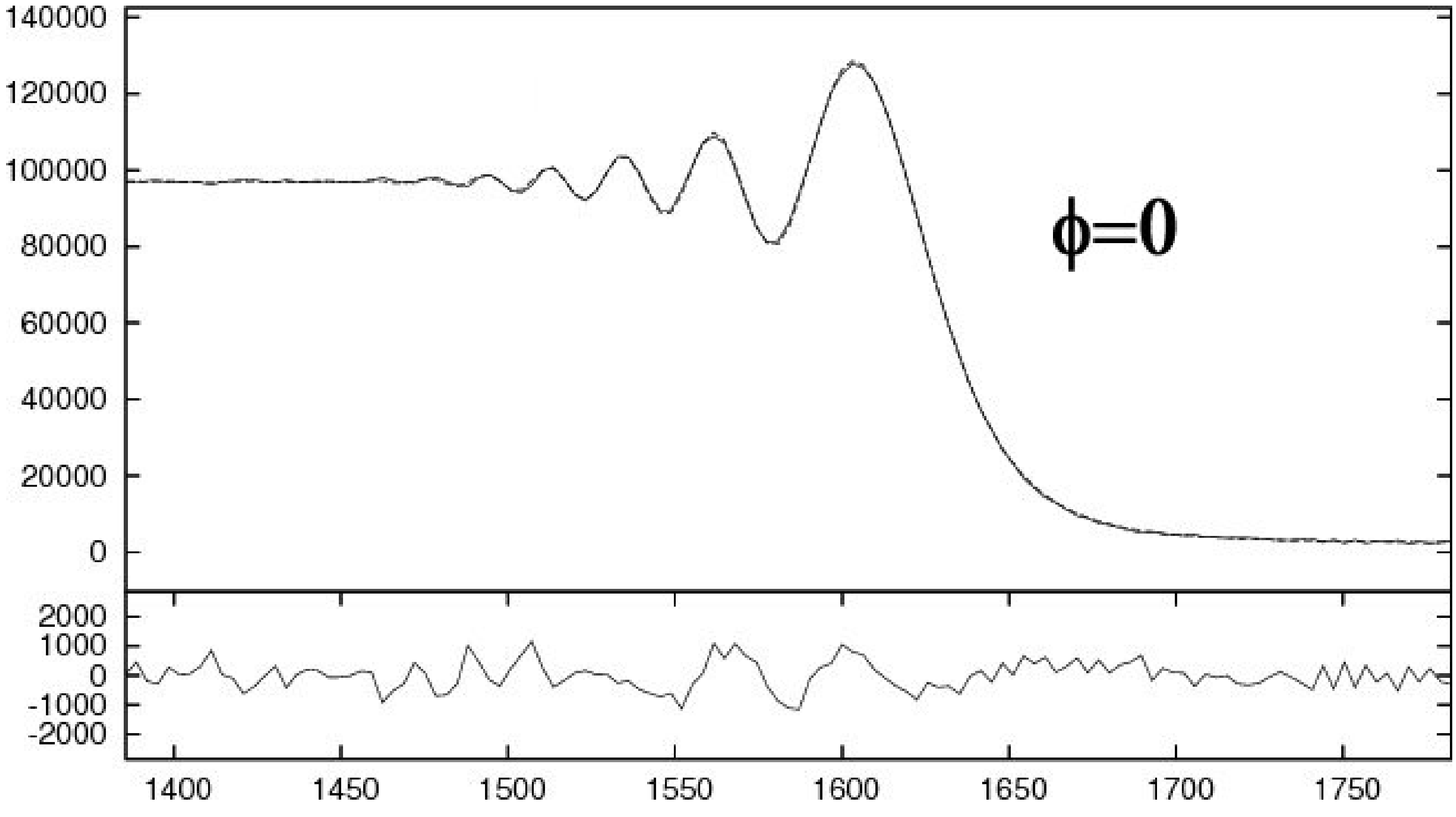
1000
100
10
1
10
100
1000
10000
100000
1000000
SNR (log)
Counts (log)

Limiting Angular Resolution

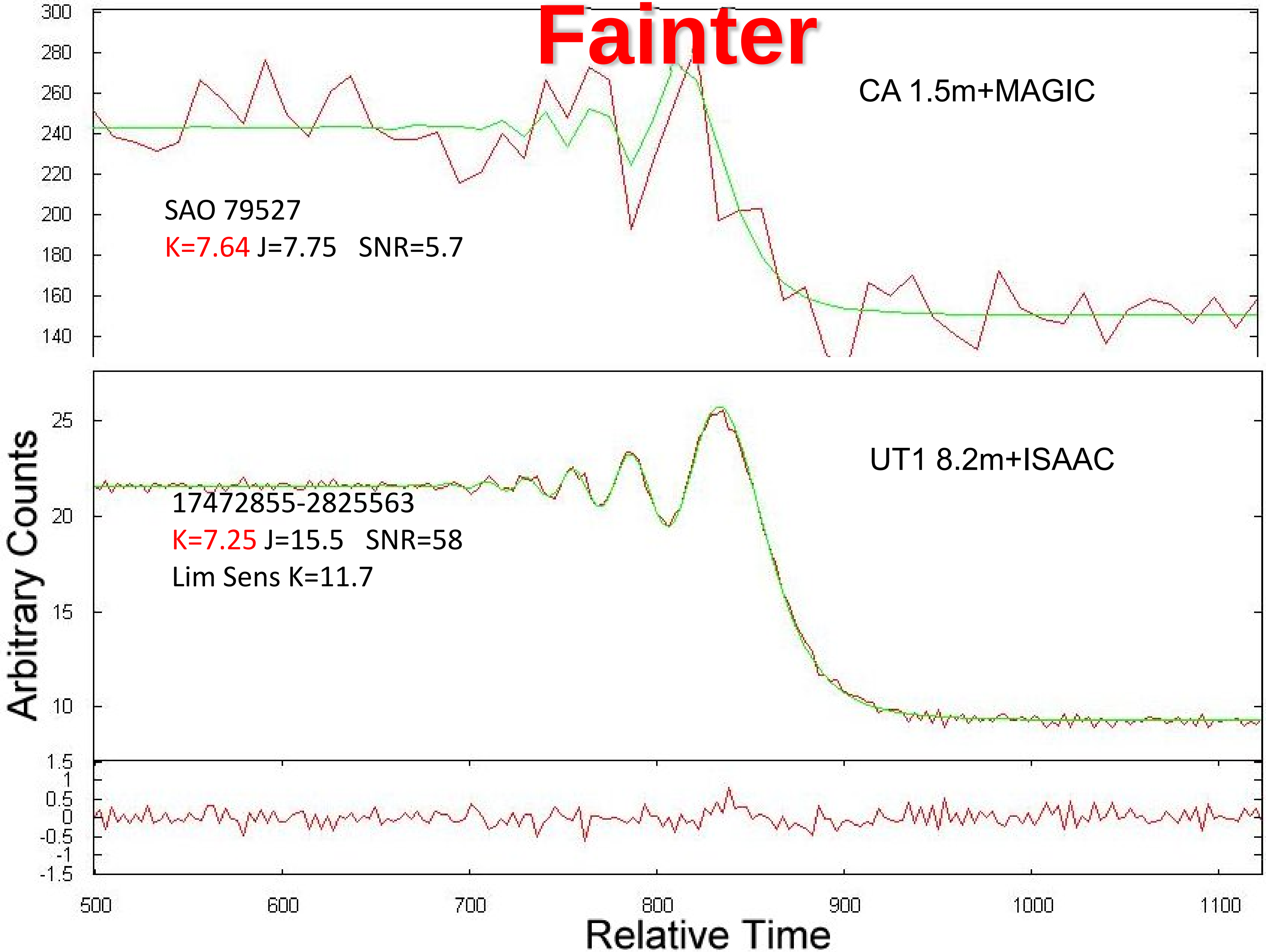


A resolved star (?)

05689 (K=4, SNR=209)

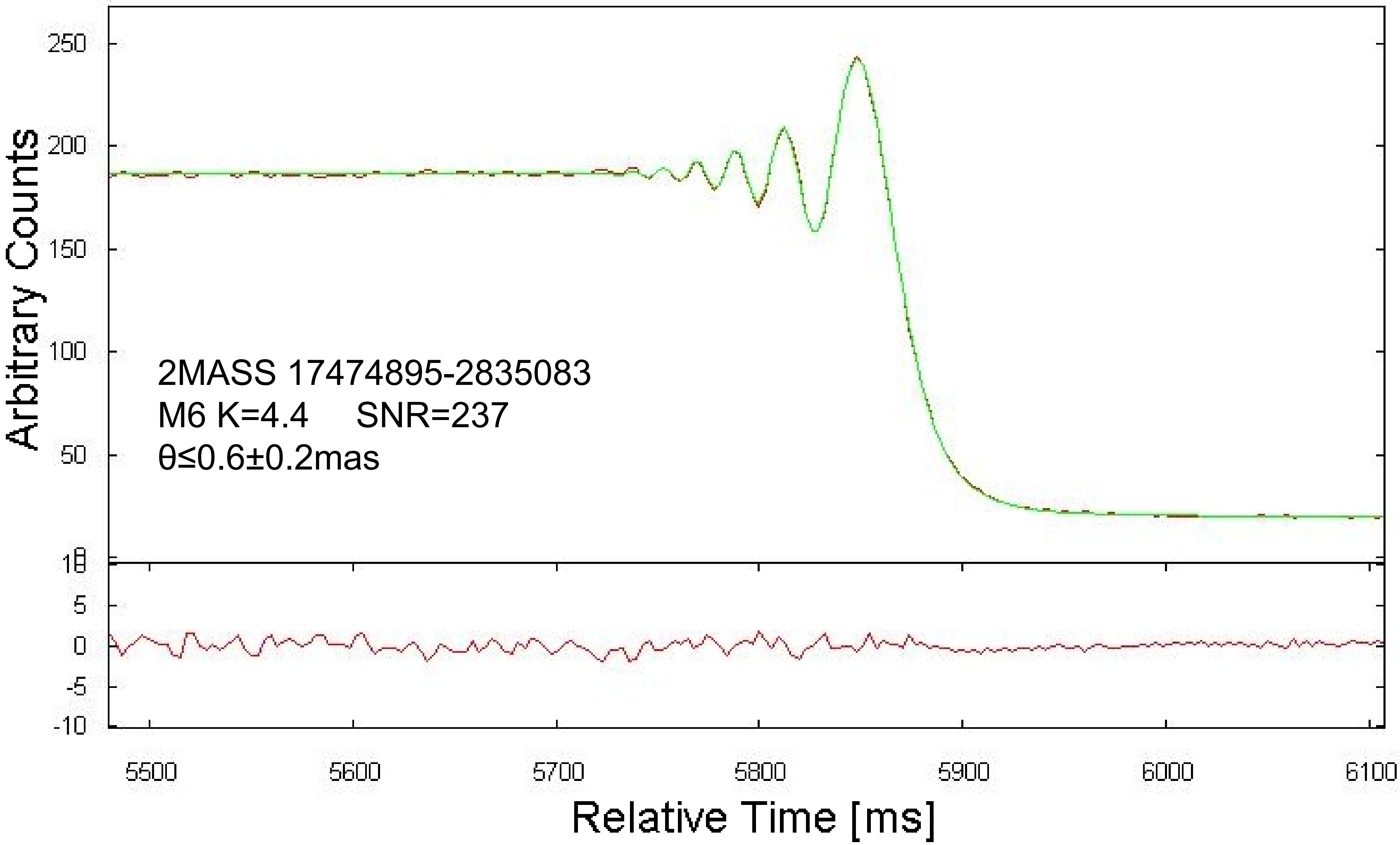


Fainter



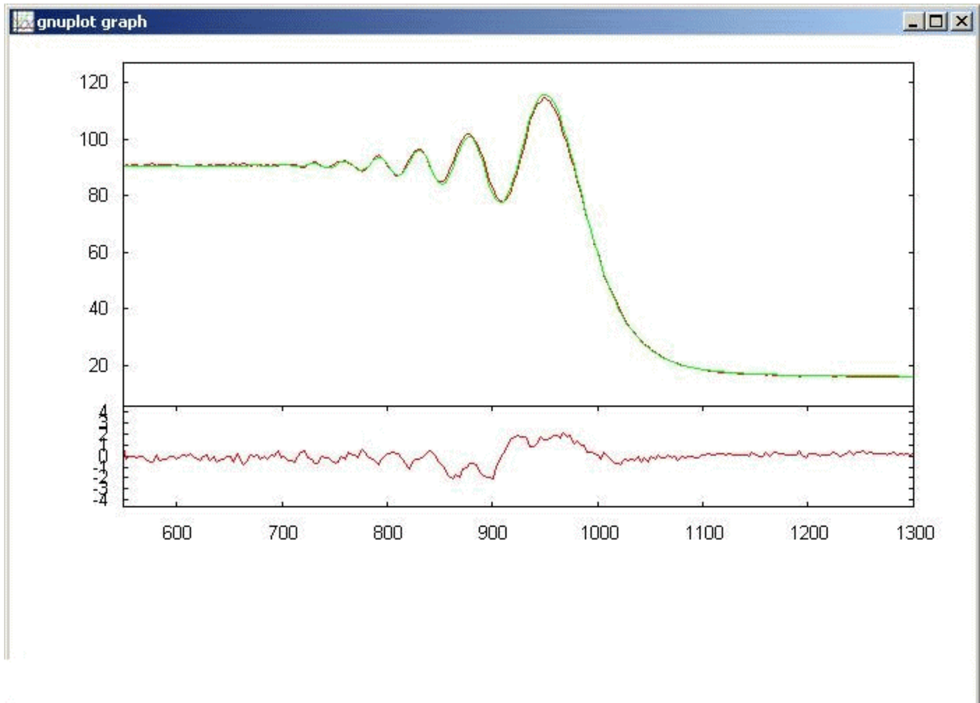
CA 1.5m+MAGIC
SAO 79527
K=7.64 J=7.75 SNR=5.7
UT1 8.2m+ISAAC
17472855-2825563
K=7.25 J=15.5 SNR=58
Lim Sens K=11.7
Arbitrary Counts
Relative Time

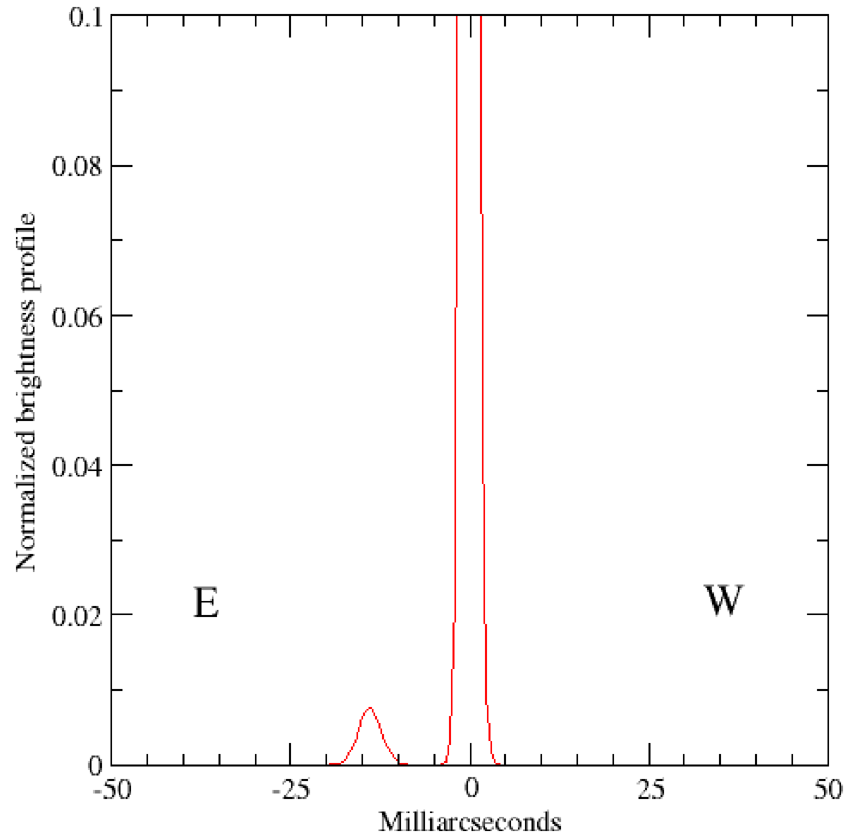
More accurate



Example of a binary star

2MASS17524903-2822586, K=5.21



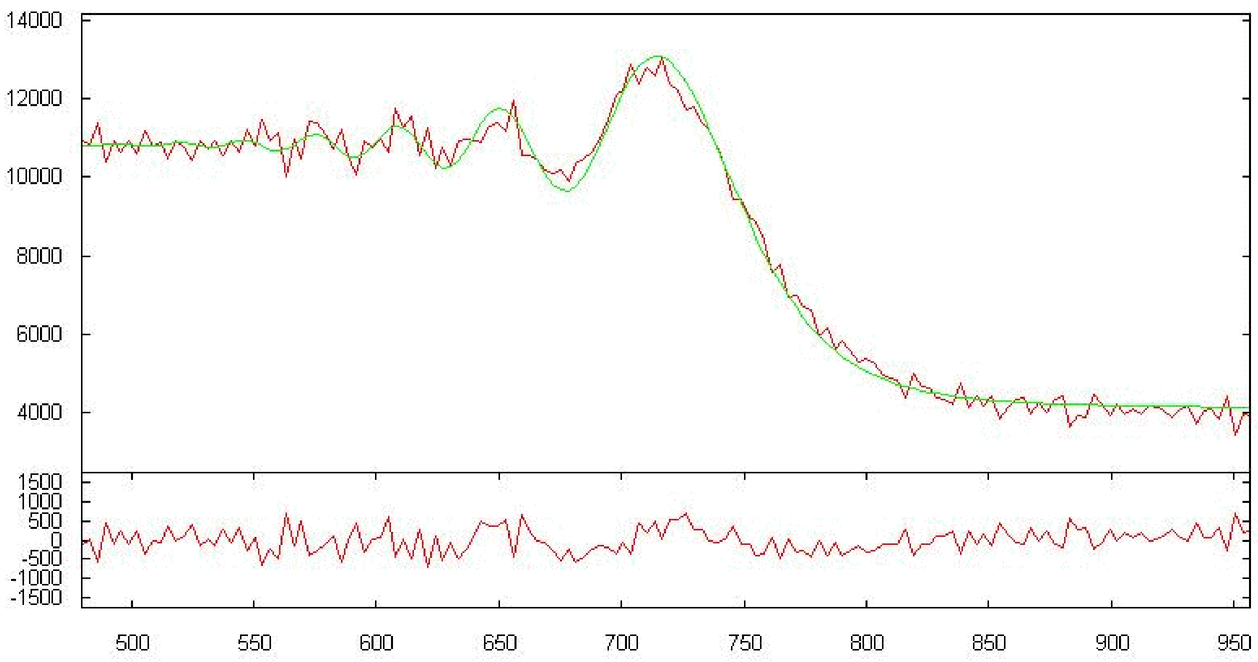


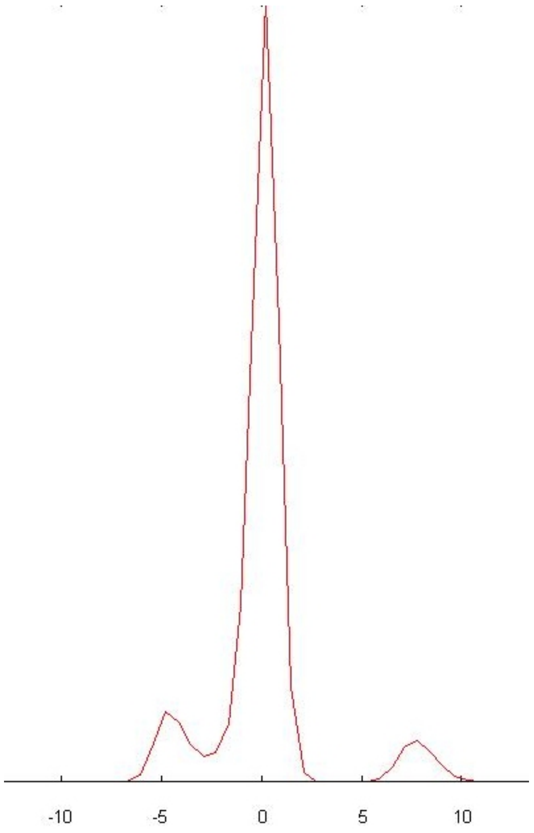
Sep=13.10±2.36 mas

ΔK=3.74±0.09 SNR=186.7

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)

Binary Statistics

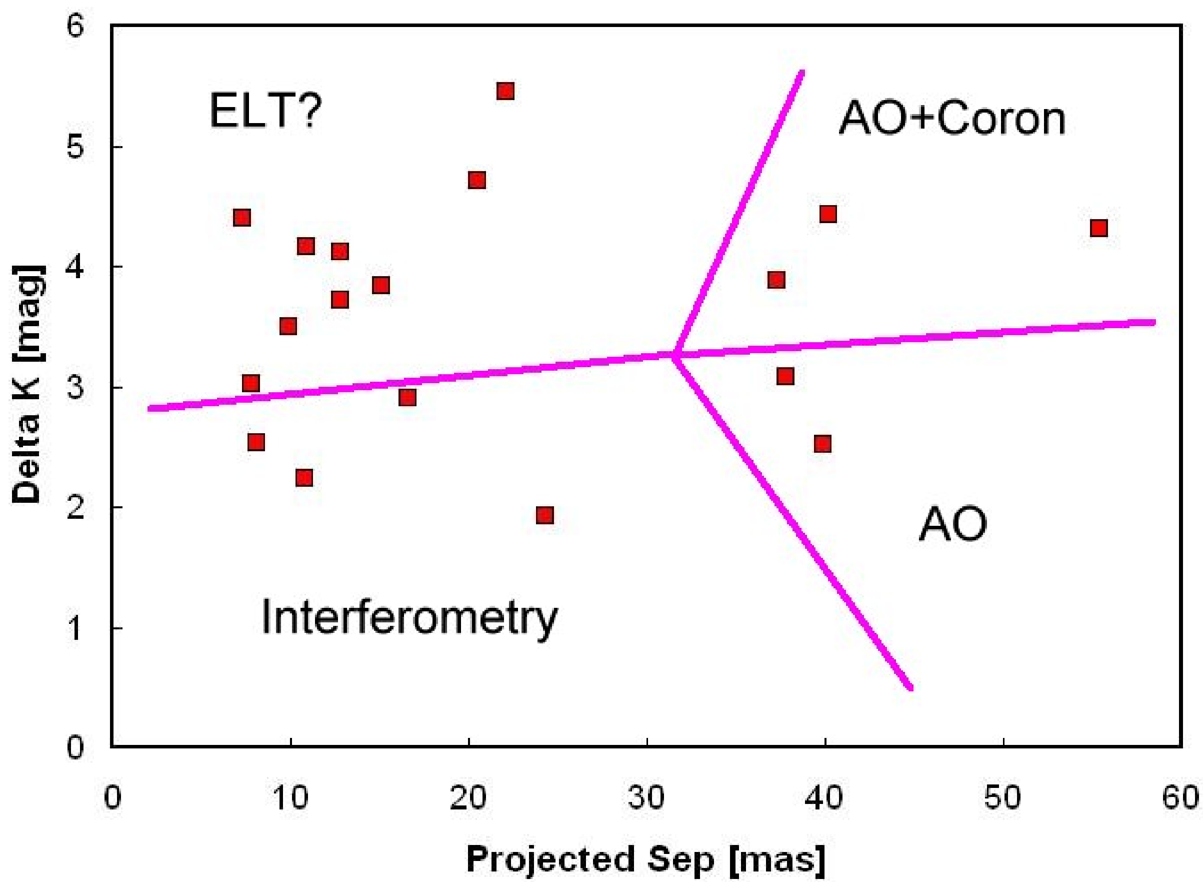
149/184 stars analyzed (similar statistics for the two nights ~12%)

18 binaries of which 5 triples

1 previously known Hipparcos

7 add. suspected binaries (2 triples)

Estimate density of field stars (in progress)

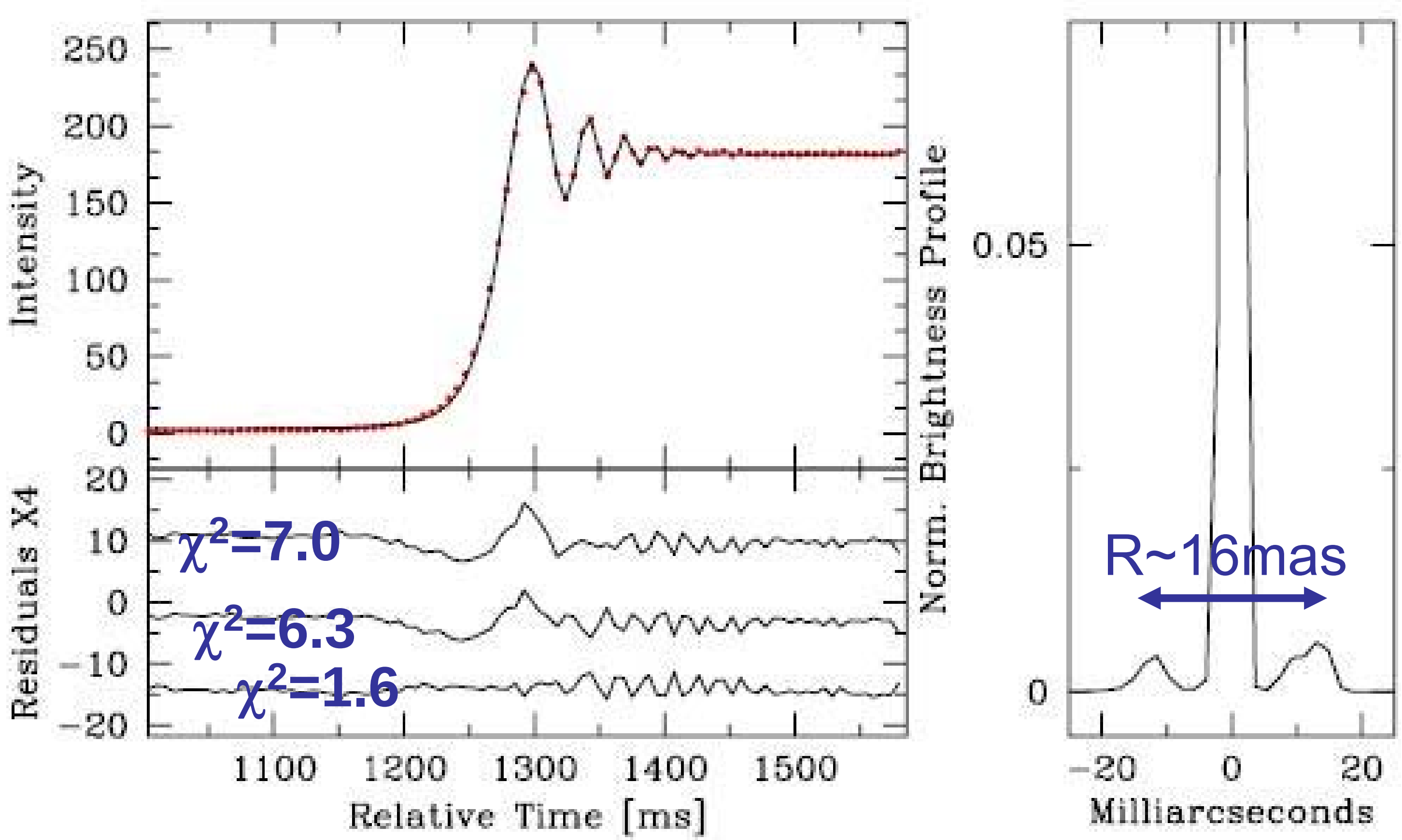


Example of a circumstellar shell

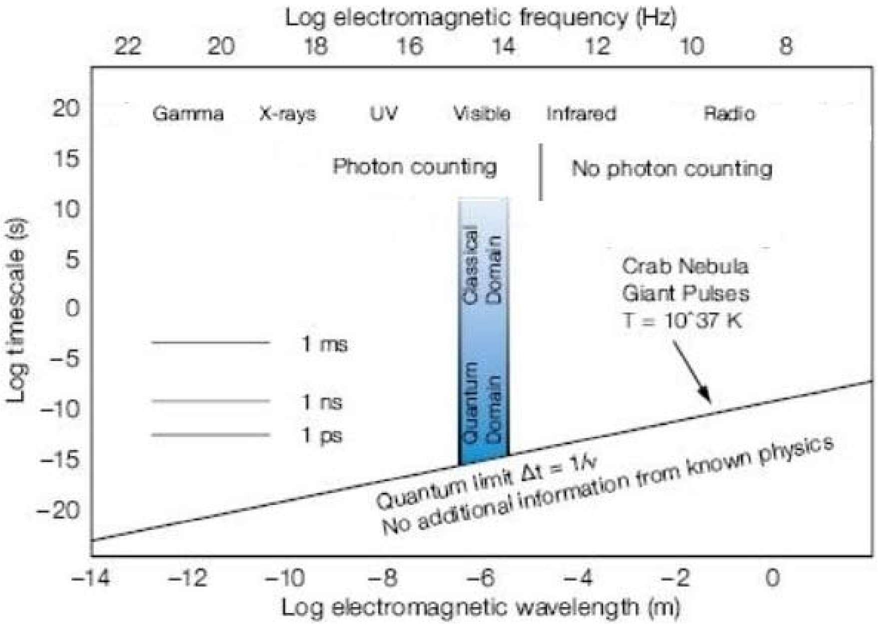
2MASS 17453224-2833429 = ISOGAL-P J174532.3-283338

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



Iqueye: pushing the limits of astrophotonics



Currently 70ns (SPAD dead time), but theoretically capable of 50ps time resolution. Individual photon time-tagging (CERN board). Absolute time via improved GPS (limit 0.5ns/1hr).

Iqueye schematics

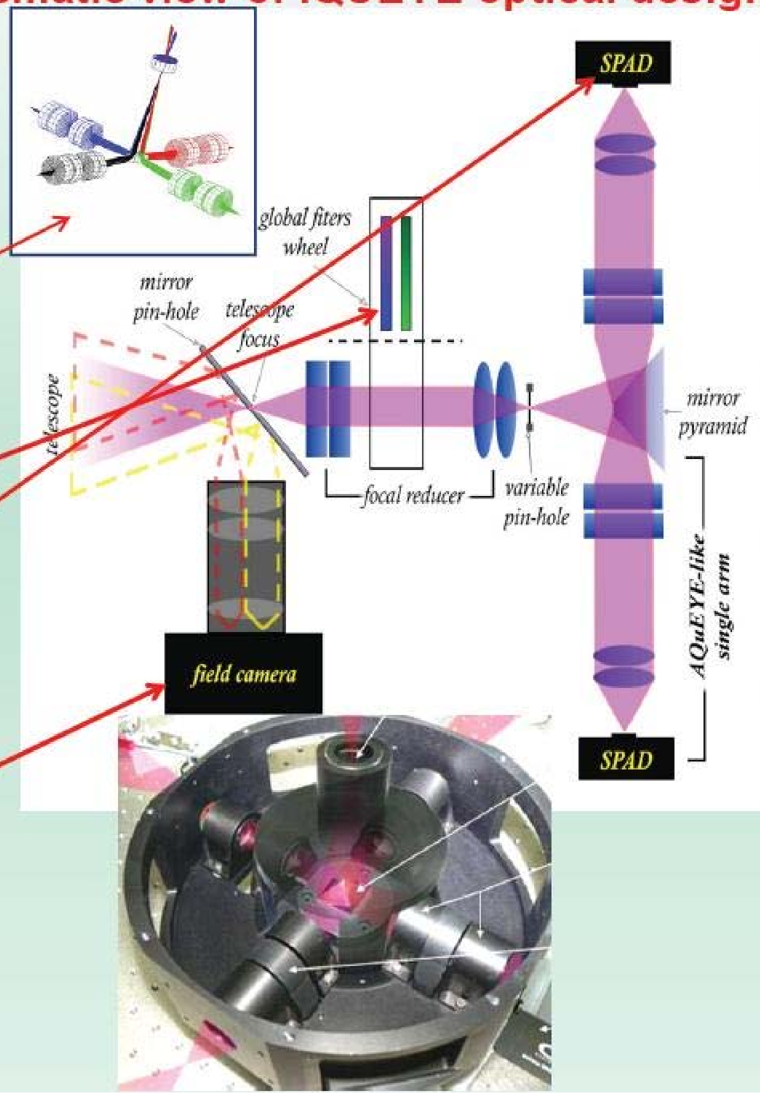
IQUEYE

A PRECURSOR FOR THE NEXT GENERATION HTRA

Iqueye, is a conceptually simple fixed aperture photometer which collects the light within a FoV of just a few arcseconds (selectable from 1” to 6”), splits the telescope light beam in 4 equal parts, and focuses each sub-beam on an independent SPAD.

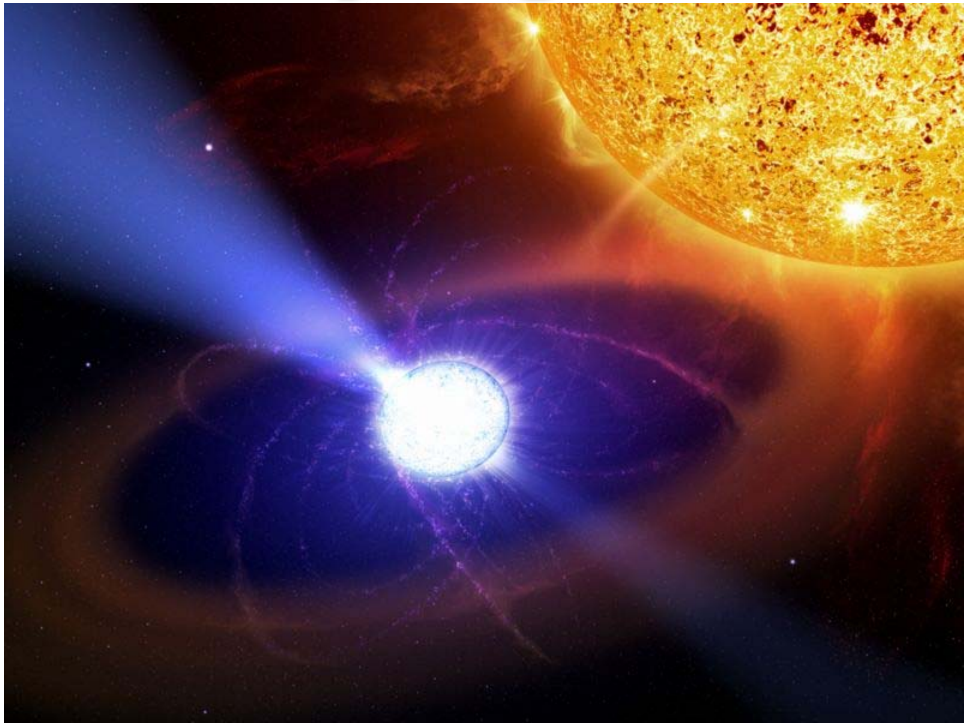
Two wheels allow to insert along the optical path suitable filters and polarizers. Since there is no imaging capability, a field camera visualizes the portion of the sky under investigation.

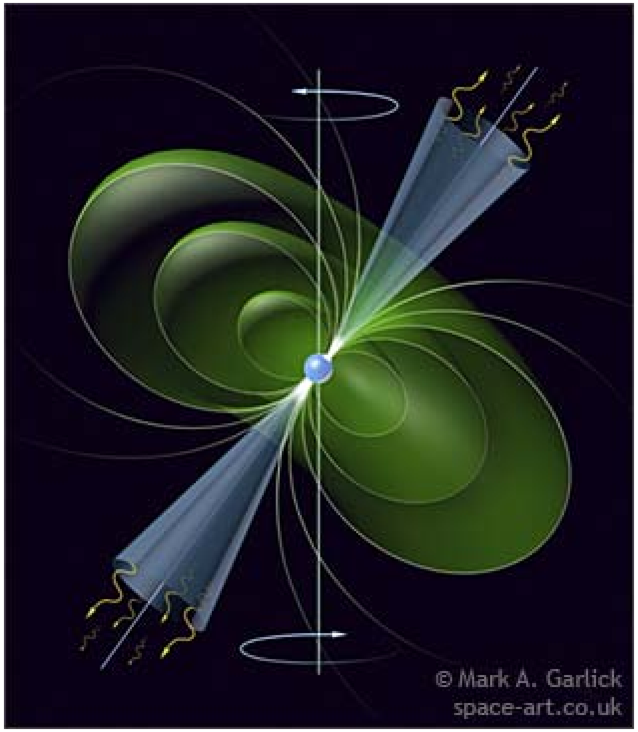
Schematic view of IQUEYE optical design



courtesy G. Bonanno

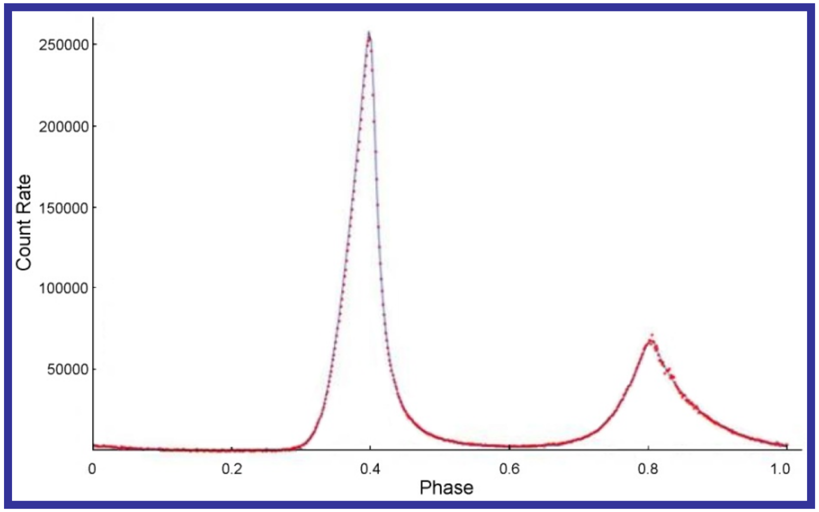
Studying Pulsars with Iqueye



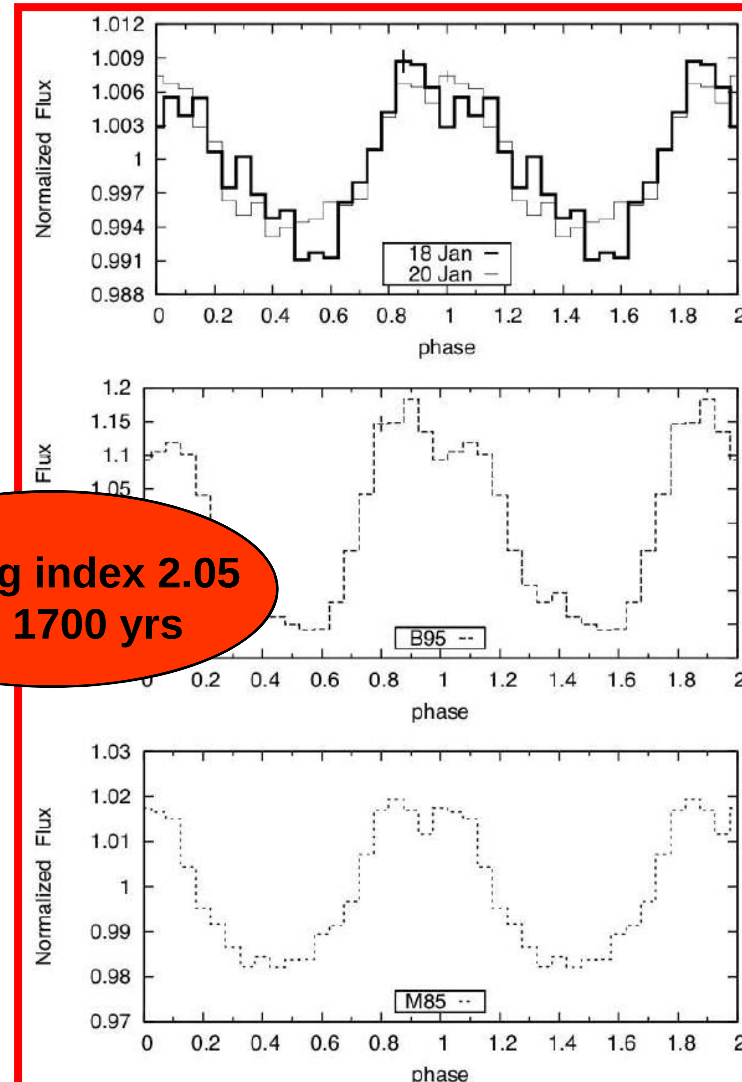


Magnetized, rapidly spinning (few seconds to millisecond) neutron stars. Physical properties and emission mechanisms still not completely understood and not well constrained by observations. Details of light curves of crucial importance.

Studying Pulsars with Iqueye



Crab Nebula, P=33ms
2hrs on 4m telescope
few seconds on 1.8m Asiago+Aqueye
Period agrees with radio to 1ns



Braking index 2.05
Age 1700 yrs

B0540-69 in LMC, V=23mag, P=50.6ms (error 8ns)

Iqueye & NTT (top, Gradari et al submitted)
HST 1995 (middle)
Cerro Tololo 4m (1985)

Wish list

BURST MODE

- Faster data dump! (now ~3min for 20s data)
- Faster read-out (RON often not a concern)
- Improve pixel synchronicity
- bigger pixel scale desirable
- flexibility of window positioning
- avoid bad cosmetics in the subarray

IQUEYE

- reduce SPAD dead time
- improve time base (GALILEO?)
- offer to open time?
- think ahead... E-ELT? (poor image quality ok)