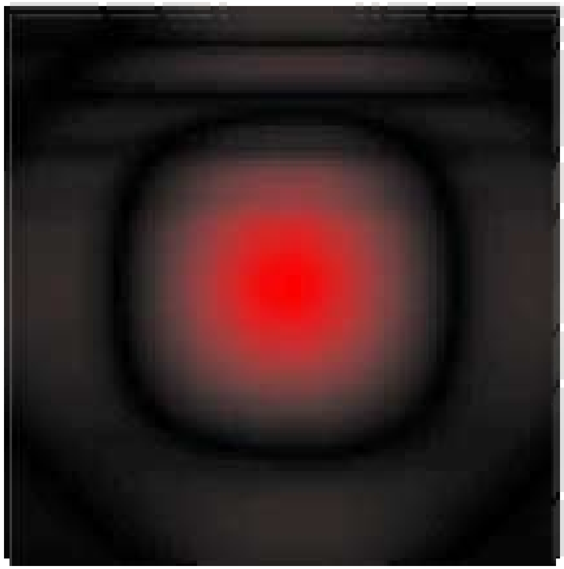
IR Interferometry of stellar sources: Lessons learned and perspectives

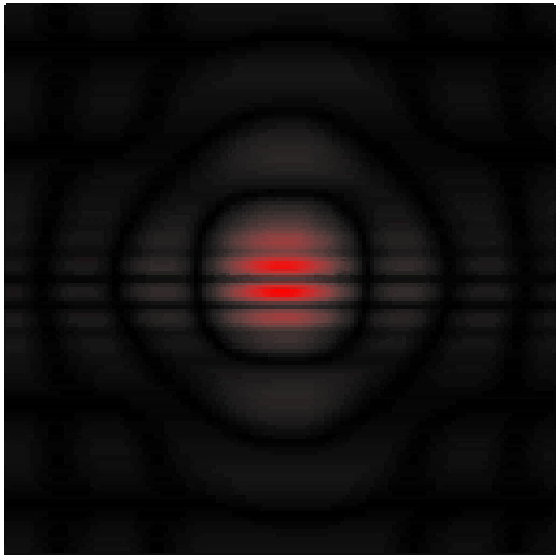
A. Richichi (ESO Garching)

LBT 2002

Bertinoro (Forli'), 7-9 October 2002

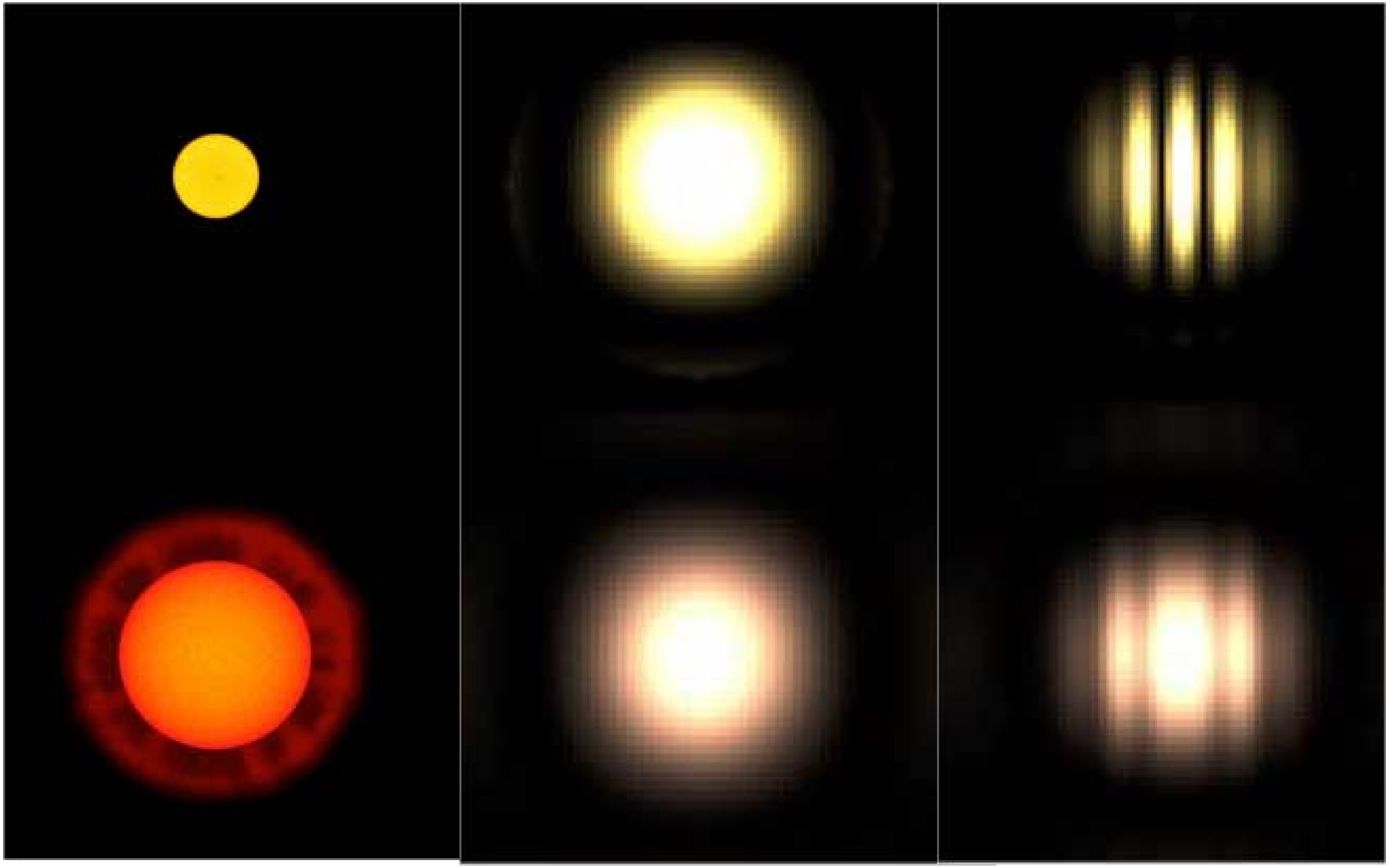
(Michelson) Interferometry at work - I





So now what?

(Michelson) Interferometry at work - II

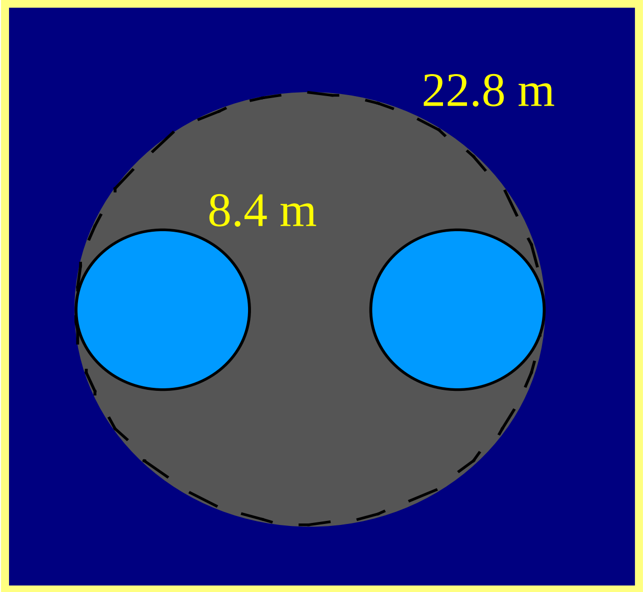


Objects **Single Telescope** **Interf. Fringes**

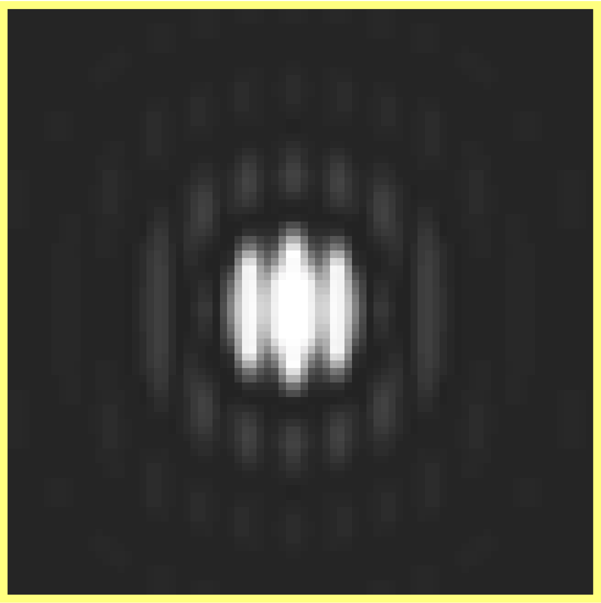
Visibilities

Simulations of some representative cases of single stars and binary systems

(Fizeau) Interferometry at work - I



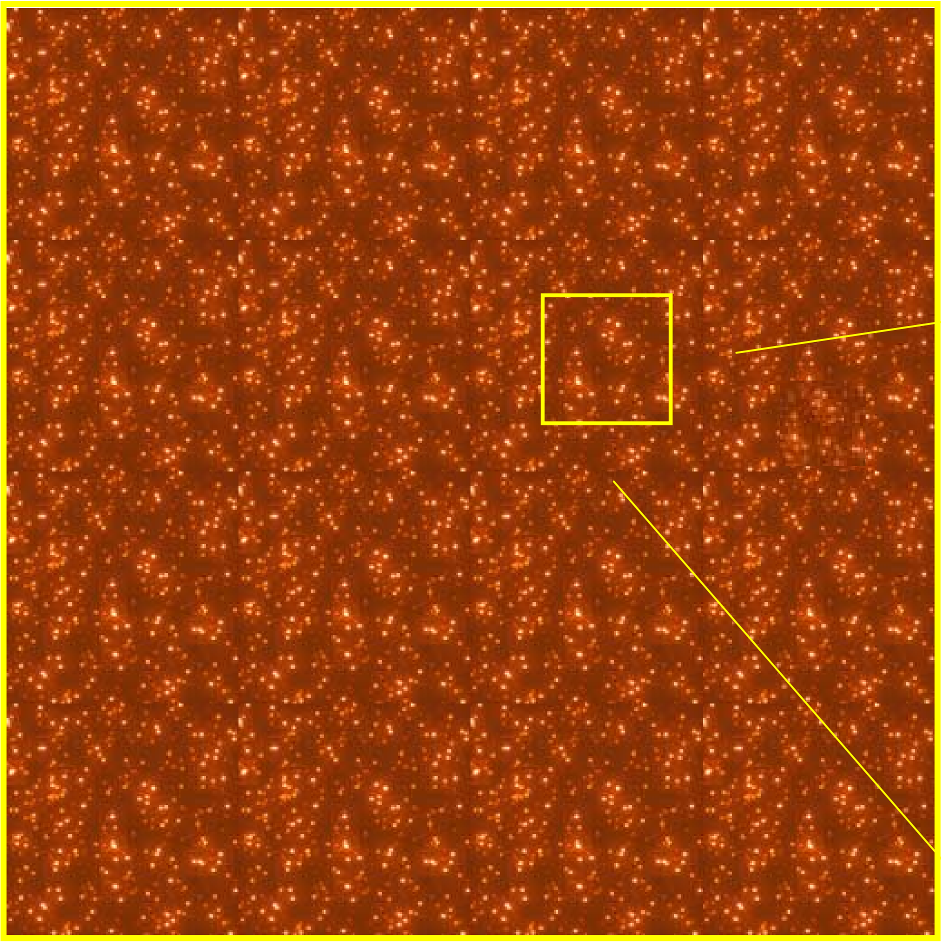
Pupil



PSF

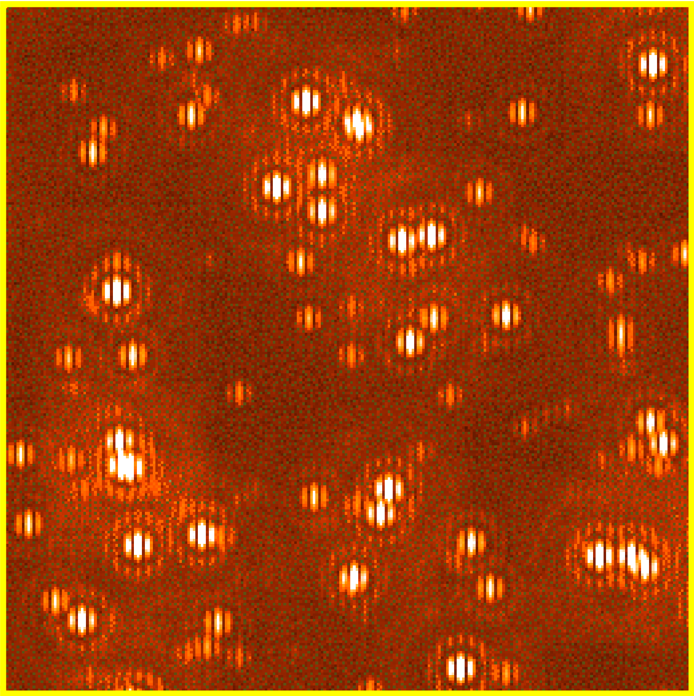
True Imagery

(Fizeau) Interferometry at work - II

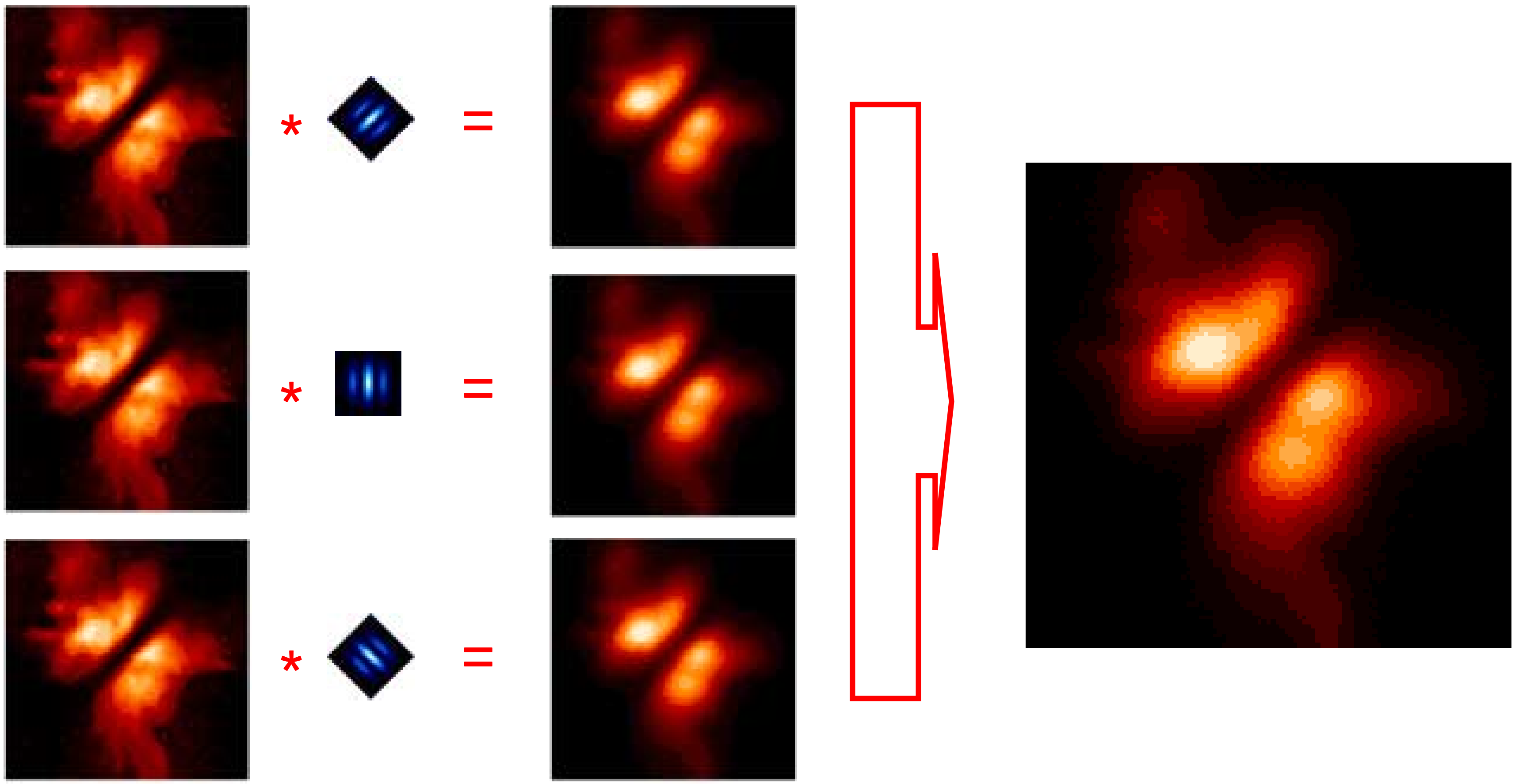


M. Ollivier 2001

2048 x 2048 HAWAII-2
15 x 15 arcsec FOV



Imaging with LBT



Overview of current Interferometers

facility	funding	location	n. of apertures	apertures (m) primary	apertures (m) secondary	baseline max (m)	year of first fringes	wavelength range
CHARA	USA	Mt. Wilson	6	1.0		350	1999	vis
COAST	UK	Cambridge	5	0.4		48	1991	vis
GI2T	F	Calern	2	1.5		65		vis, NIR
IOTA	USA, F	Mt. Hopkins	2-3	0.45		38	1993	VRI, JHKL
ISI	USA	Mt. Wilson	2-3	1.65		75	1988	M
KECK	USA	Mauna Kea	2(4)	10	1.8	85(140)	2001	IR
LBT	USA, D, I	Mt. Graham	2	8.4		23	2005	vis, NIR
MIRA-I.2	J	Tokyo	2	0.30		6	2001	vis
MRO	USA	New Mexico	3	2.4		100	funded	vis, NIR
NPOI	USA	Arizona	3-6	0.35		64	1994	vis, NIR
PTI	USA	Mt. Palomar	3	0.40		110	1995	K
SUSI	AUS	New South Wales	2	0.14		640		B
VLTI	ESO	Paranal	4(4)	8.2	1.8	130(205)	2001	JHK, NQ

The VLT Interferometer

- Four 8.2-m
  Unit Telescopes
  Baselines up to 130m
- Four 1.8-m Auxiliary Telescopes.
  Baselines 8 – 200m
- Field of view: 2 arcsec
- near-IR to MIR (angular resolution 1-20 mas)
- Excellent uv coverage
- Fringe Tracker
- Dual-Feed facility
- Adaptive optics with 60 actuator DM (Strehl >50% in K - Guide Star $m_V < 16$)

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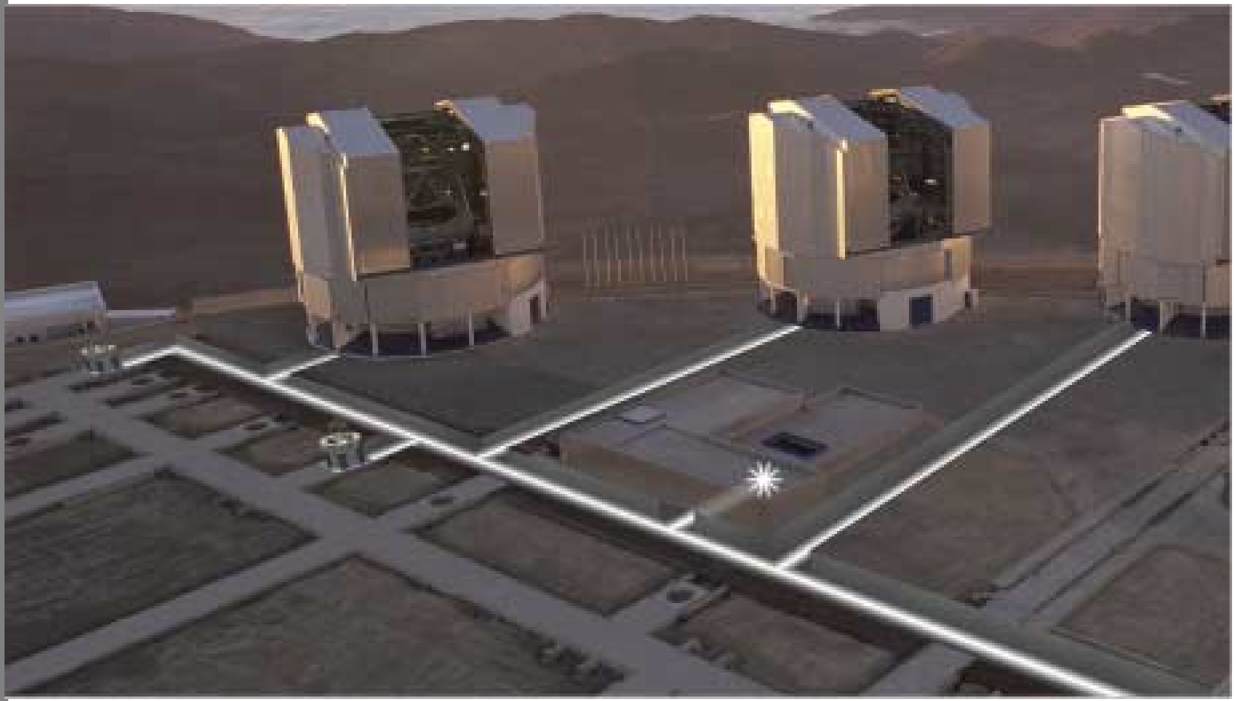
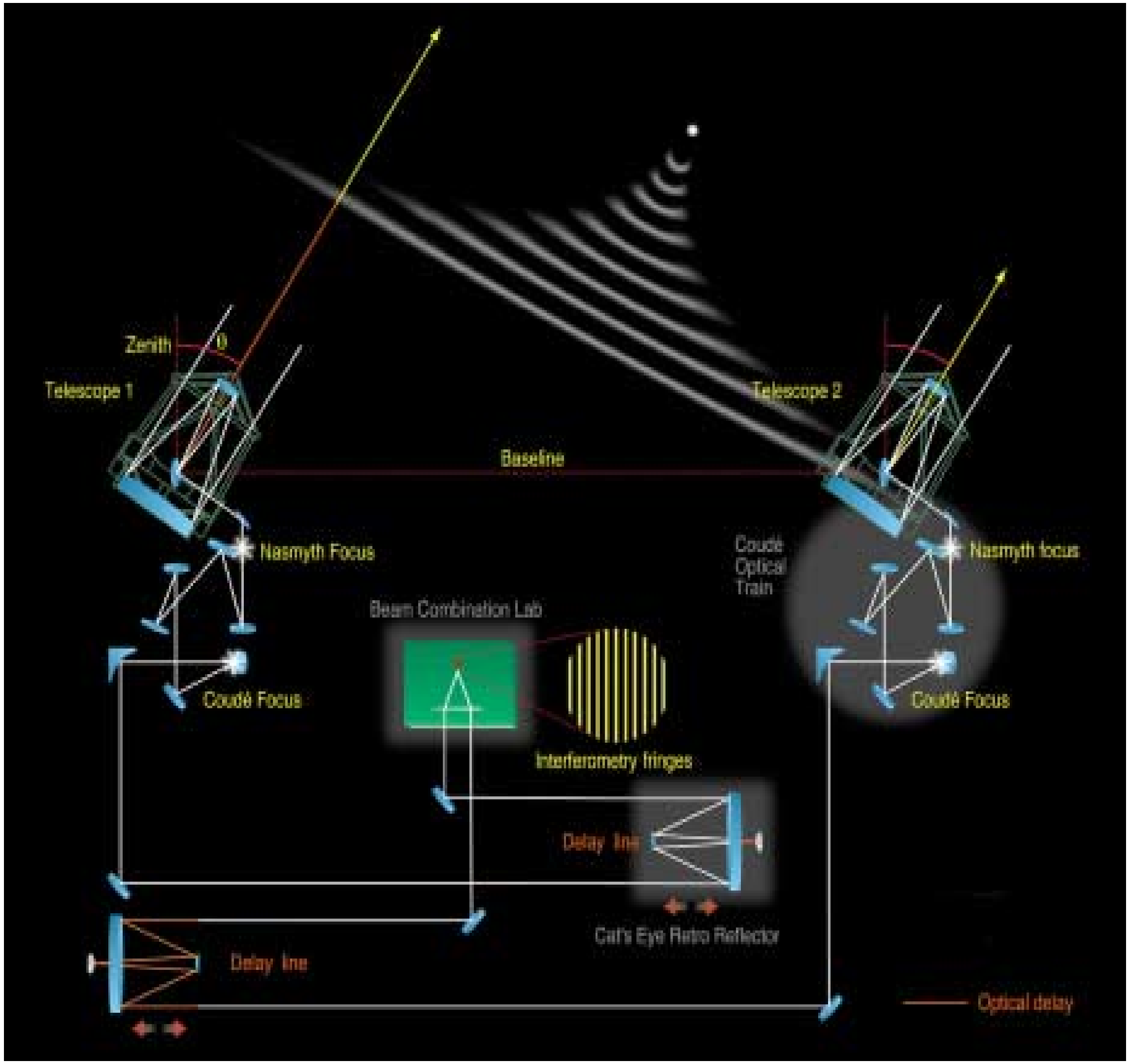
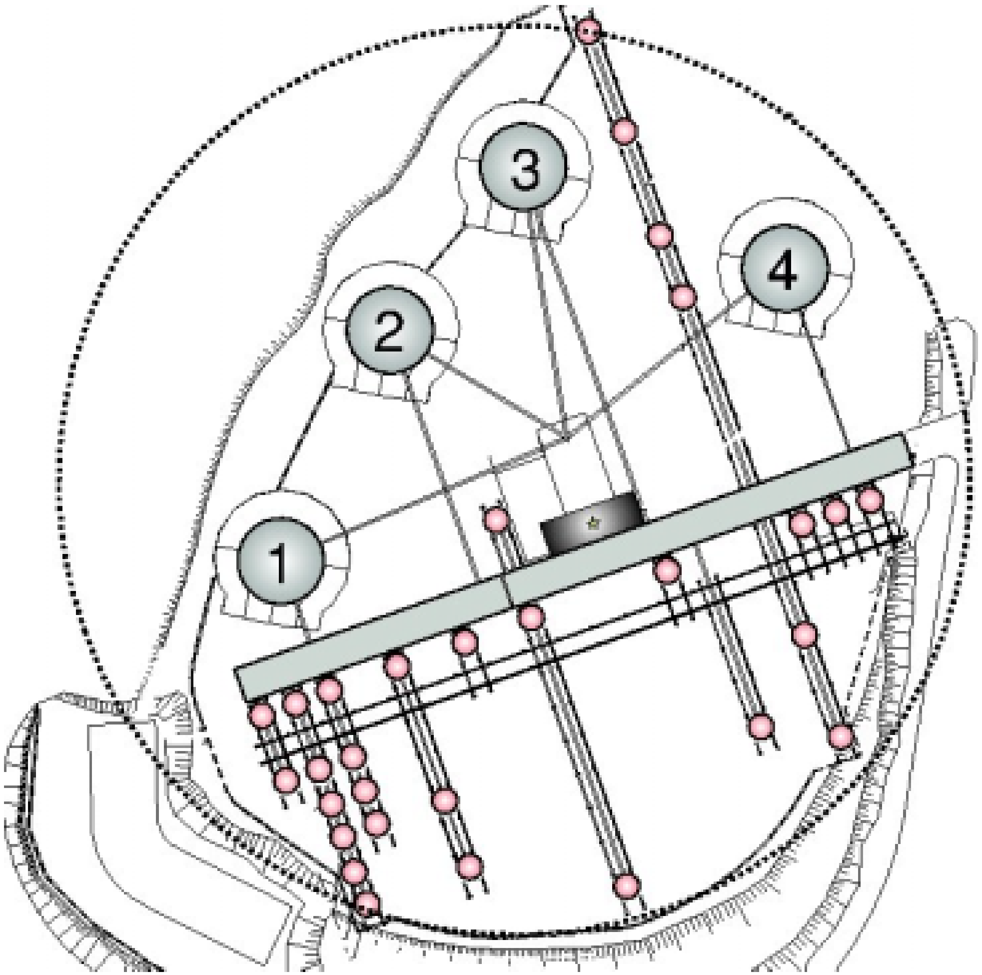


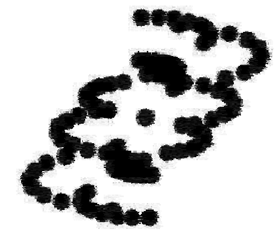
VLTI Scheme



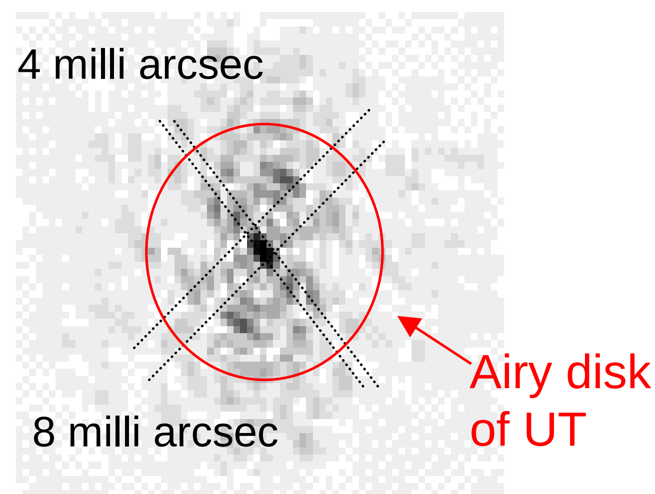
Zenith
θ
Telescope 1
Telescope 2
Baseline
Nasmyth Focus
Nasmyth focus
Coudé Optical Train
Beam Combination Lab
Coudé Focus
Coudé Focus
Interferometry fringes
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

VLTI Main Characteristics





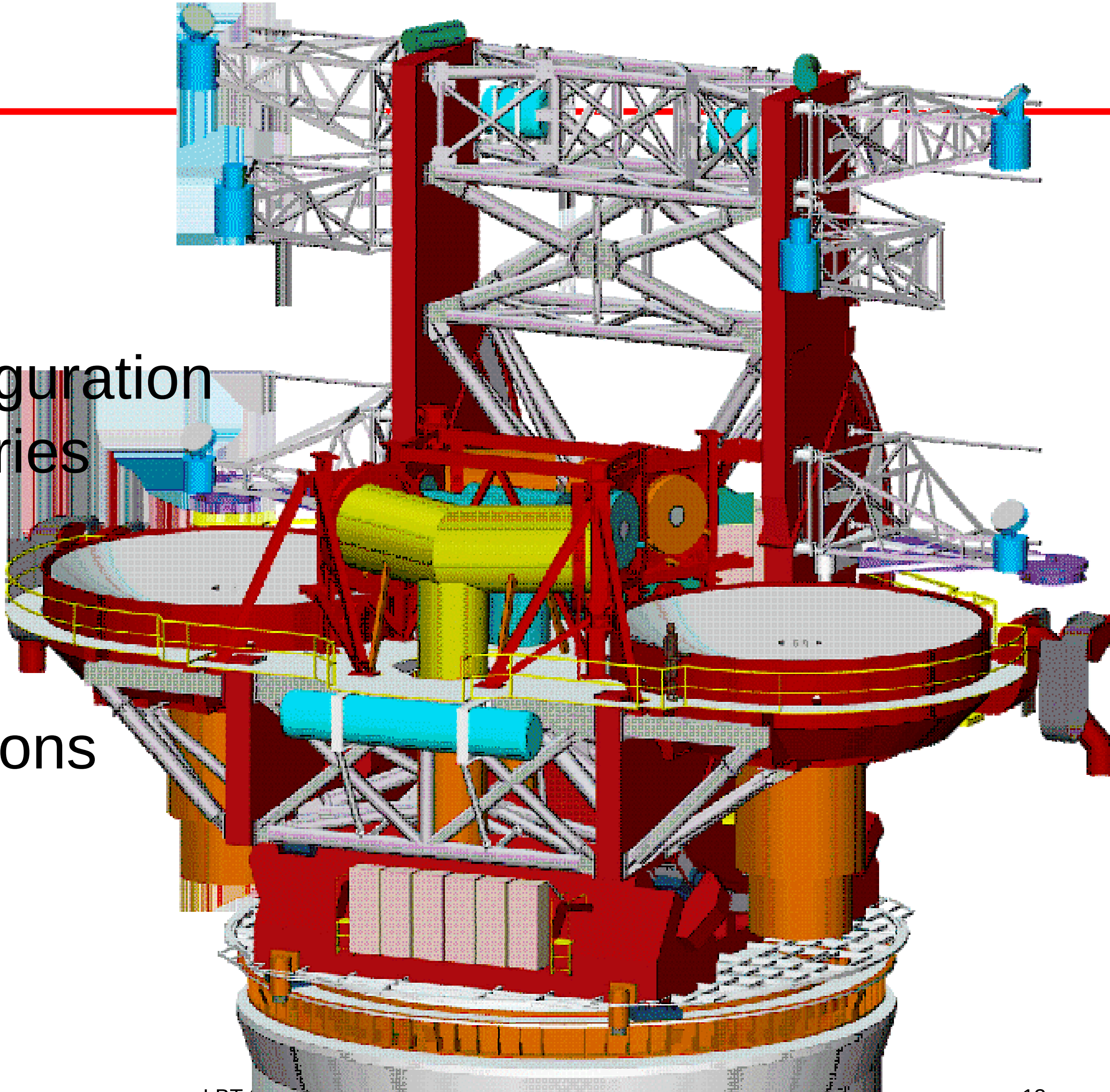
uv coverage after 8 hour observation with all UTs (object at -15^{o})



Resulting PSF is the Fourier transform of the visibilities at λ = 2.2μm (K-band)

The LBT

- 2 x 8.4 m
- flexible configuration
- AO secondaries
- Gregorian



- 10 focal stations
    - 2 prime
    - 2 direct
    - 3 shared

Cannot be avoided: the comparison!

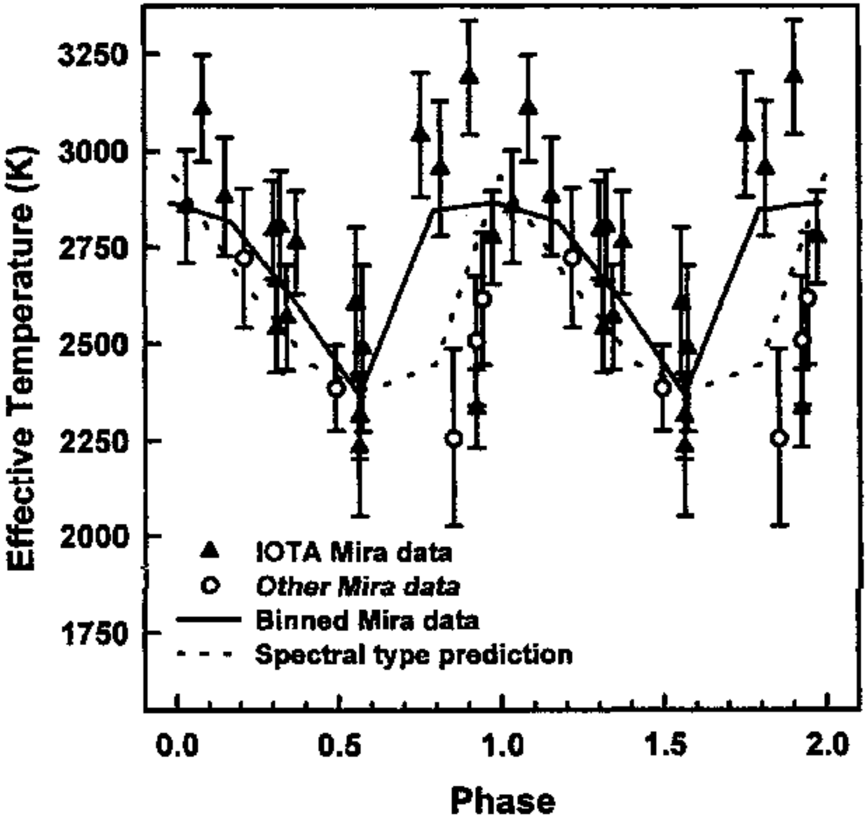
Characteristics	VLTI	LBT
Pointing	2 (more telescopes), delay lines	Single structure
Long Integrations	Declination, baseline, corr. magnitudes	Declination
Imaging	Limited, Airy disk	Yes, 20”-60”
Sensitivity	~210 m^2, 20+ mirrors	~110 m^2, 3+ mirrors
Ang. Resolution	8-205m (0.001” in J)	8-23m (0.009” in J)
Calibrators	Interf. Transfer Function	AO/MCAO ref. stars
Access and Service	Standard ESO frame	TBC

Different characteristics $\Rightarrow$ Different science!

Single stars: fundamental properties

Angular diameters

- Linear Radii (stellar atmospheres)
- Effective Temp (cool stars, <50 K)
- Pulsation (Miras, Cepheids)



Cepheid Stars

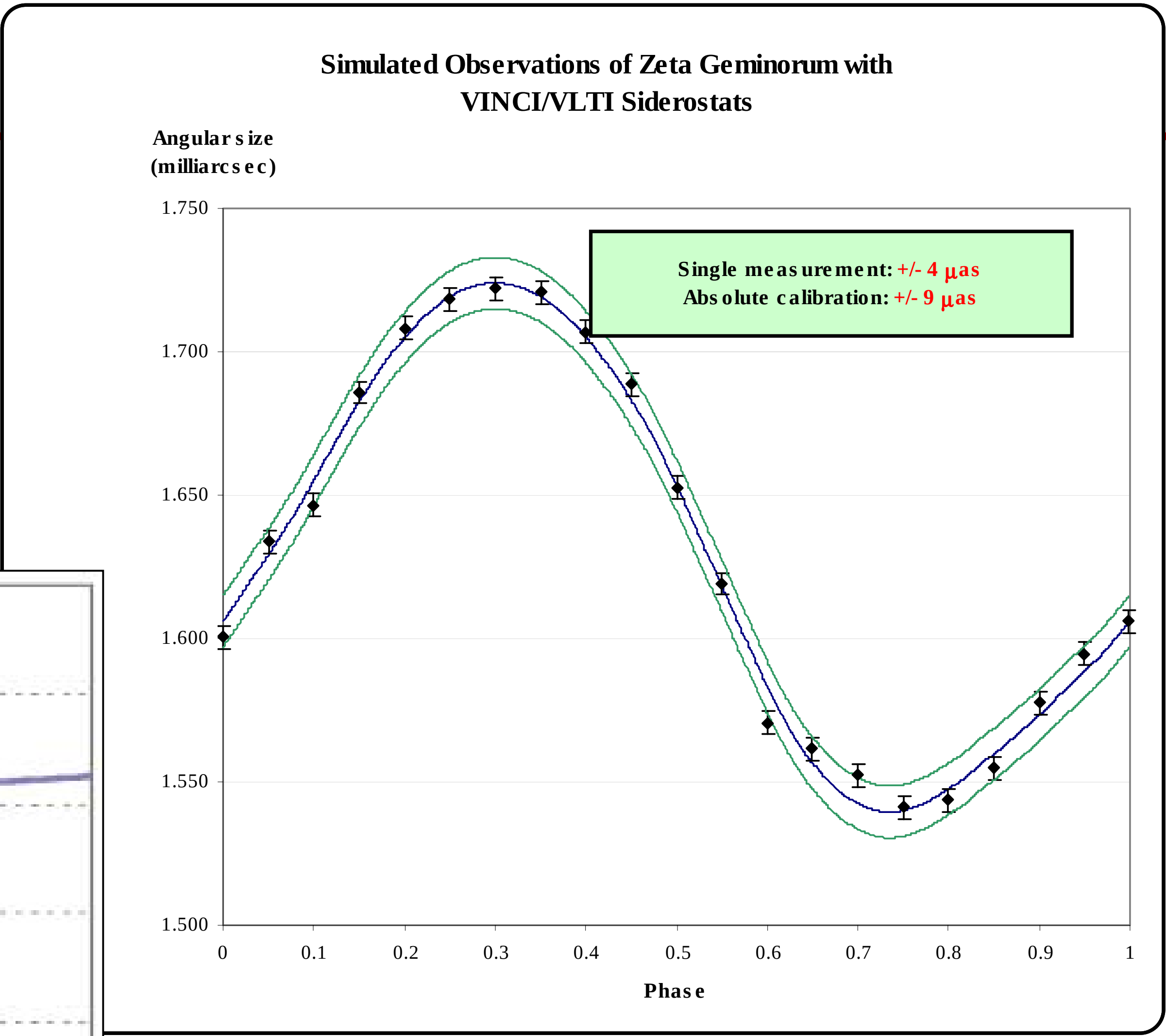
Rationale:

- Period-Luminosity Law
- Standard Candle
- Non-Radial modes?
- Details of pulsation lightcurves not yet completely understood

What modern interferometry can achieve:

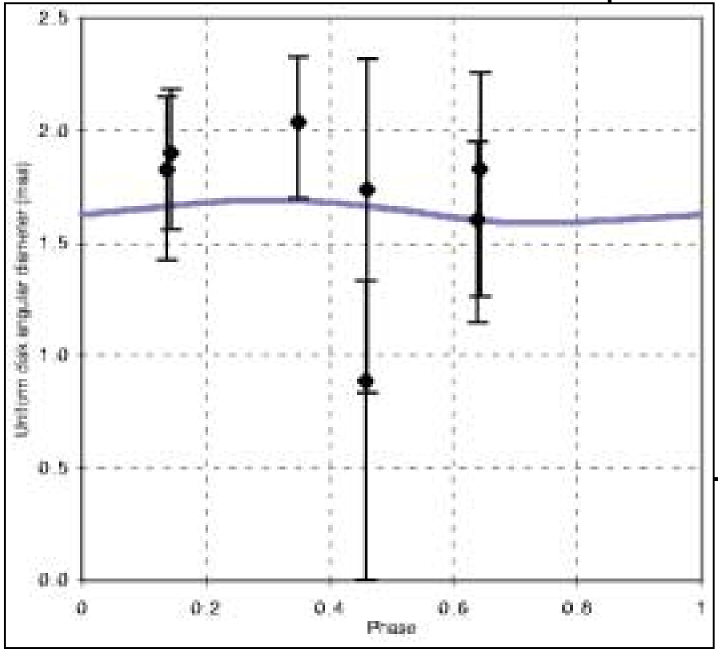
- Measurement of angular diameters, with spectacular improvement over current data
- A priori information available, high efficiency
- Repeated measurements necessary

Zeta Gem



IOTA/Fluor

Kervella et al. (2000)



Simulation by P. Kervella

Single stars: fundamental properties

Angular diameters

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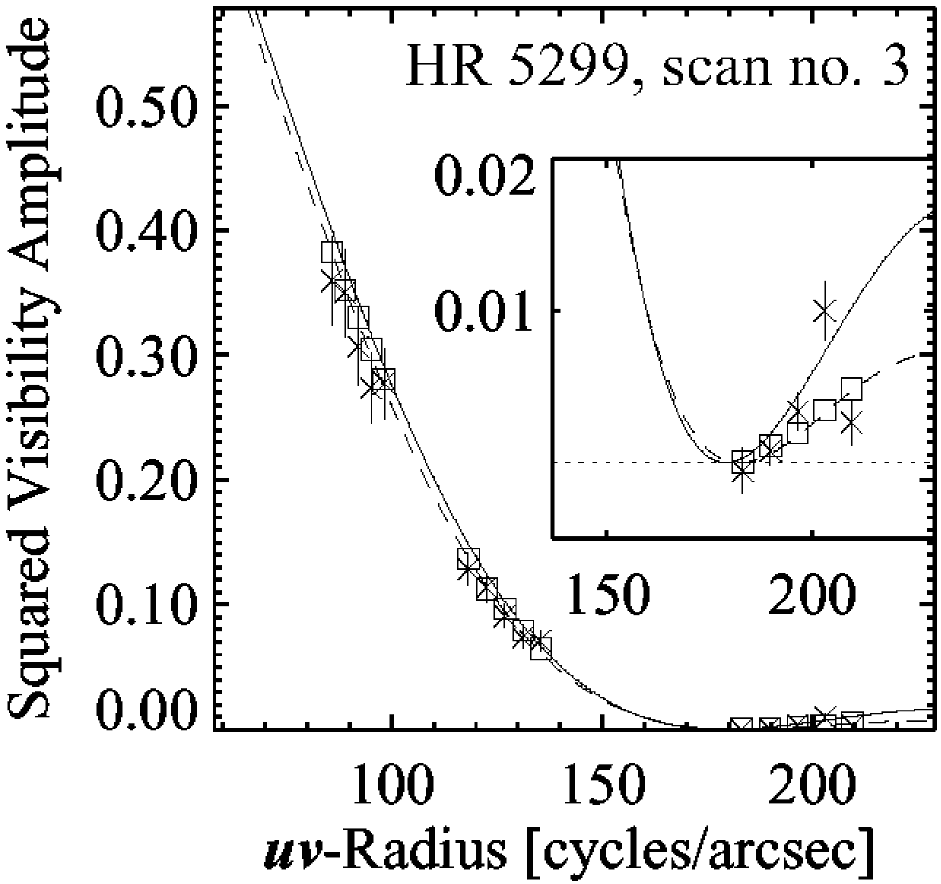
- Pulsation (Miras, Cepheids)
- Limb-Darkening



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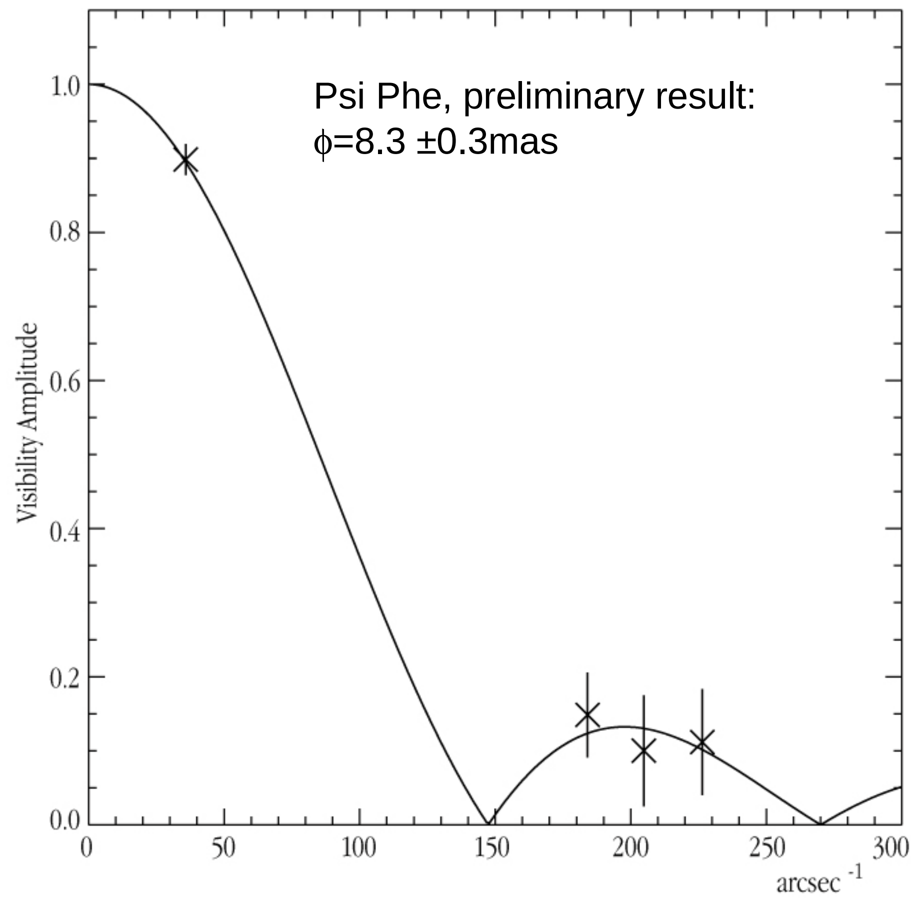


Visibility Curve for Psi Phoenicis
(VLTI + VINCI)

ESO PR Photo 30e/01 (5 November 2001)

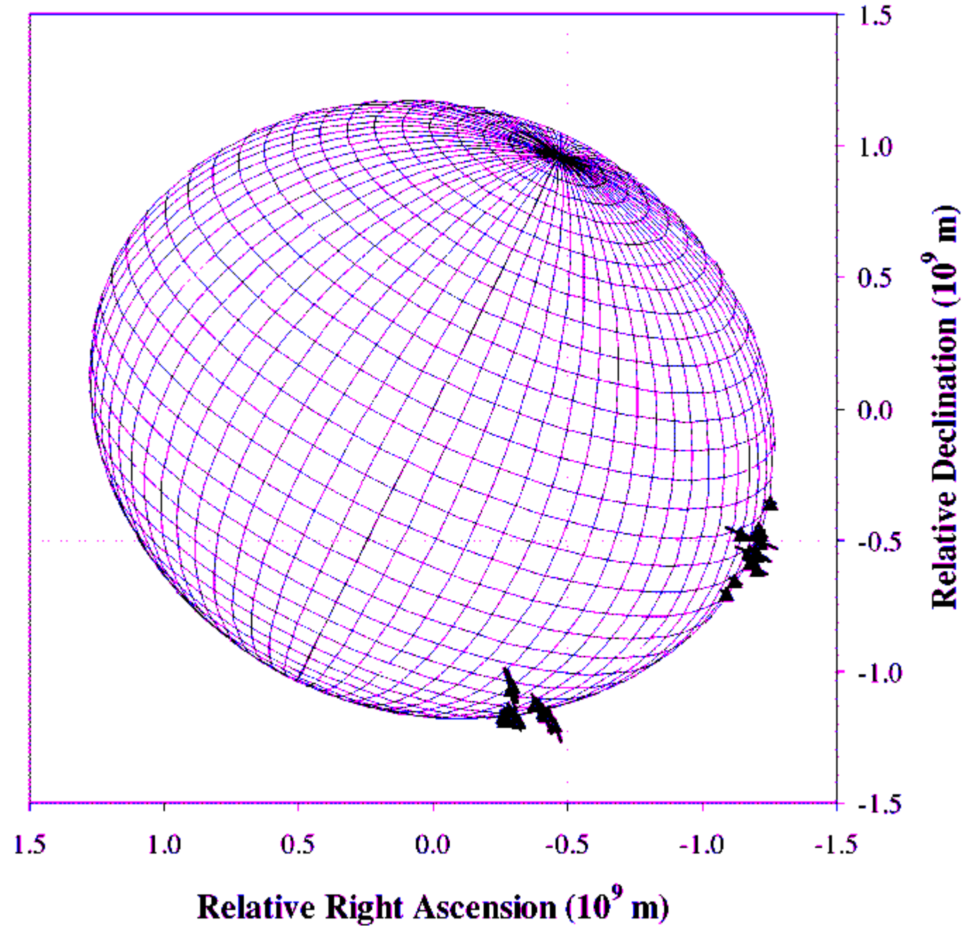
Single stars: fundamental properties

Angular diameters

- Linear Radii (stellar atmospheres)
- Effective Temp (cool stars, <50 K)
- Pulsation (Miras)
- Limb-Darkening
- Asymmetries (fast rotators, envelopes)

Recent detection of 14% equator/pole flattening in Altair (P=10.4hours, V_eq=210 km/s) Van Belle et al. 2002

For a solar analogue, flattening is 0.001%



Single stars: fundamental properties

Angular diameters

- Linear Radii (stellar atmospheres)
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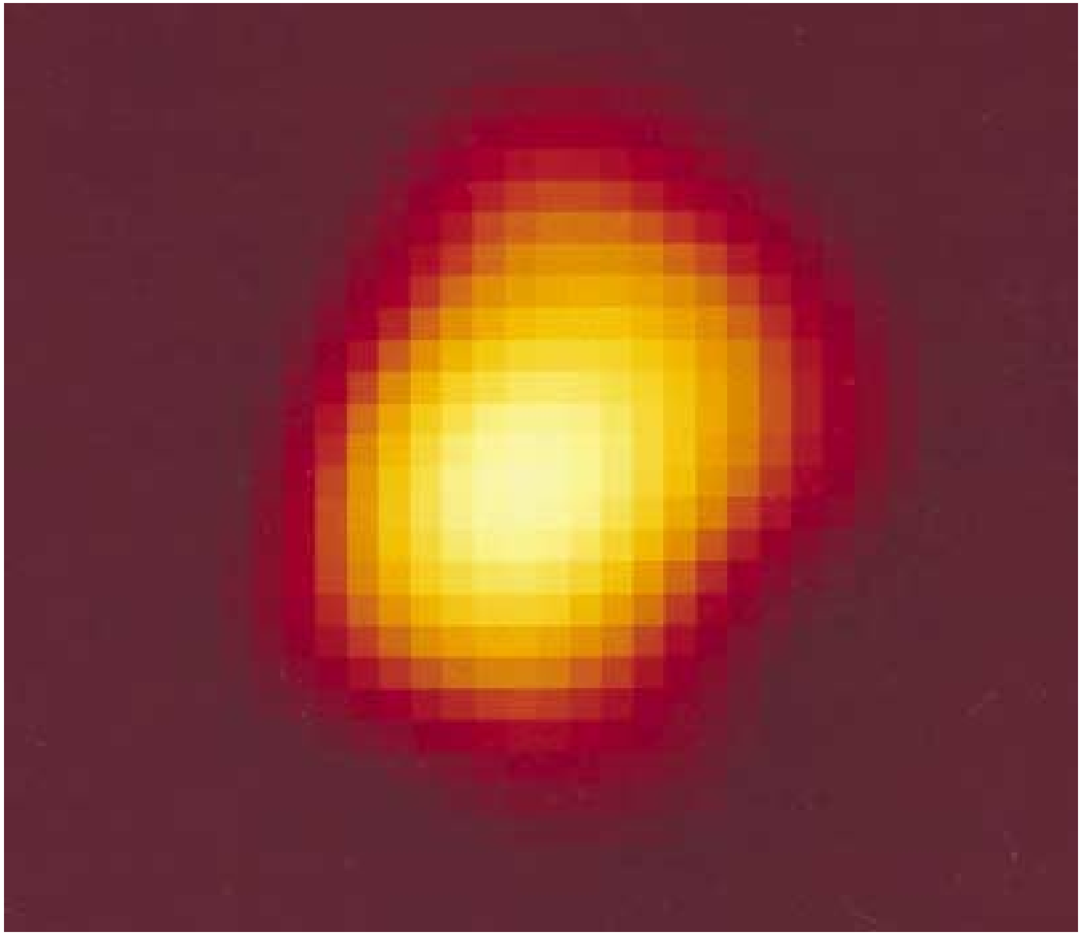
- Asymmetries (fast rotators, envelopes)

In general, these measurements need long baselines

Extended Atmospheres of AGB stars

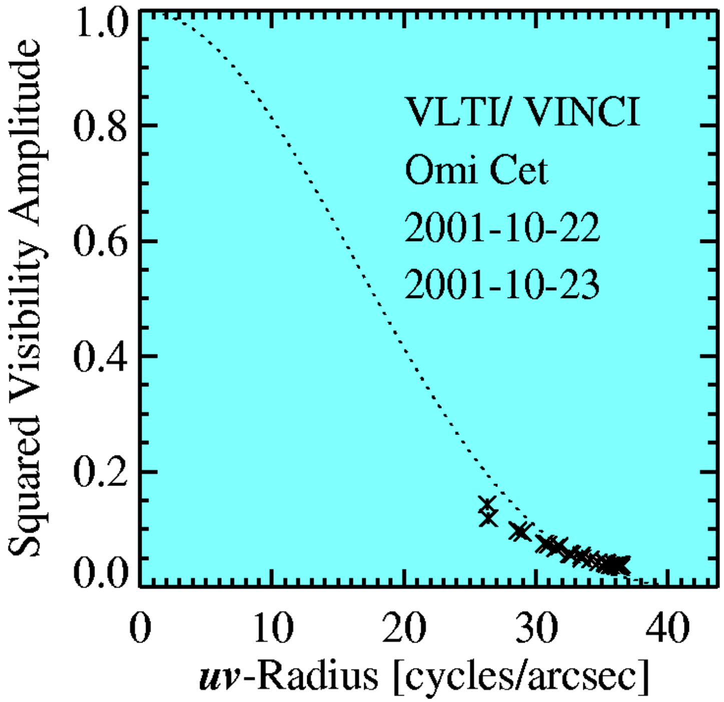
HST observation
of Mira

(Karovska et al. 1997)



Two models for Omi Cet

Uniform disk model

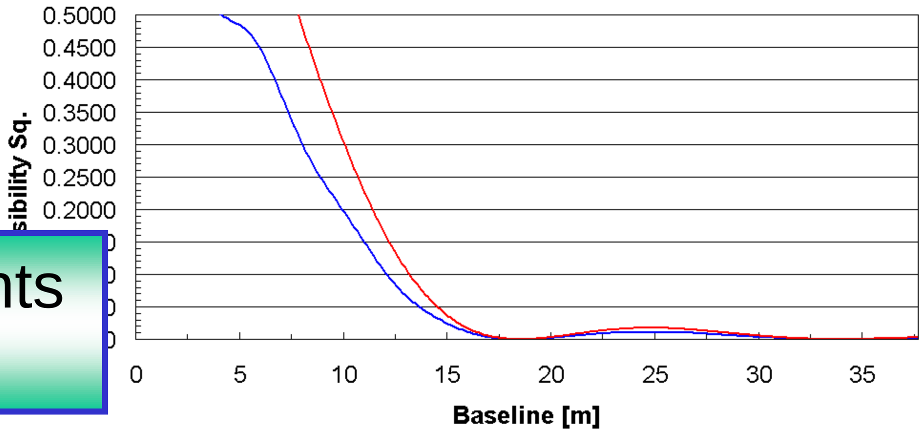


Incompatible with spherical symmetry

Two components model

Could explain Pos. Angle dependance.

Does not rule out possible asymmetries.

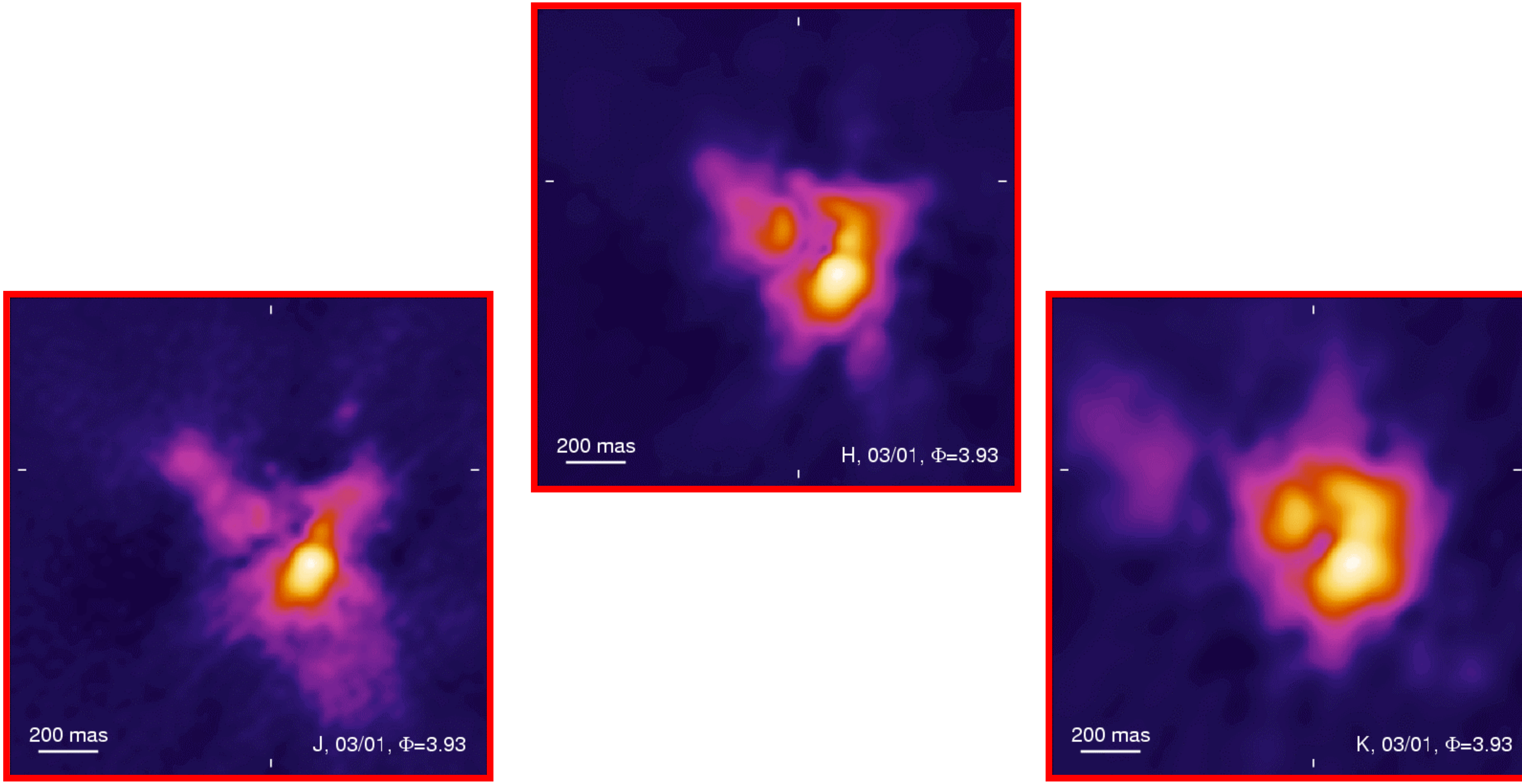


In general, these measurements need imaging capability

Circumstellar Structure

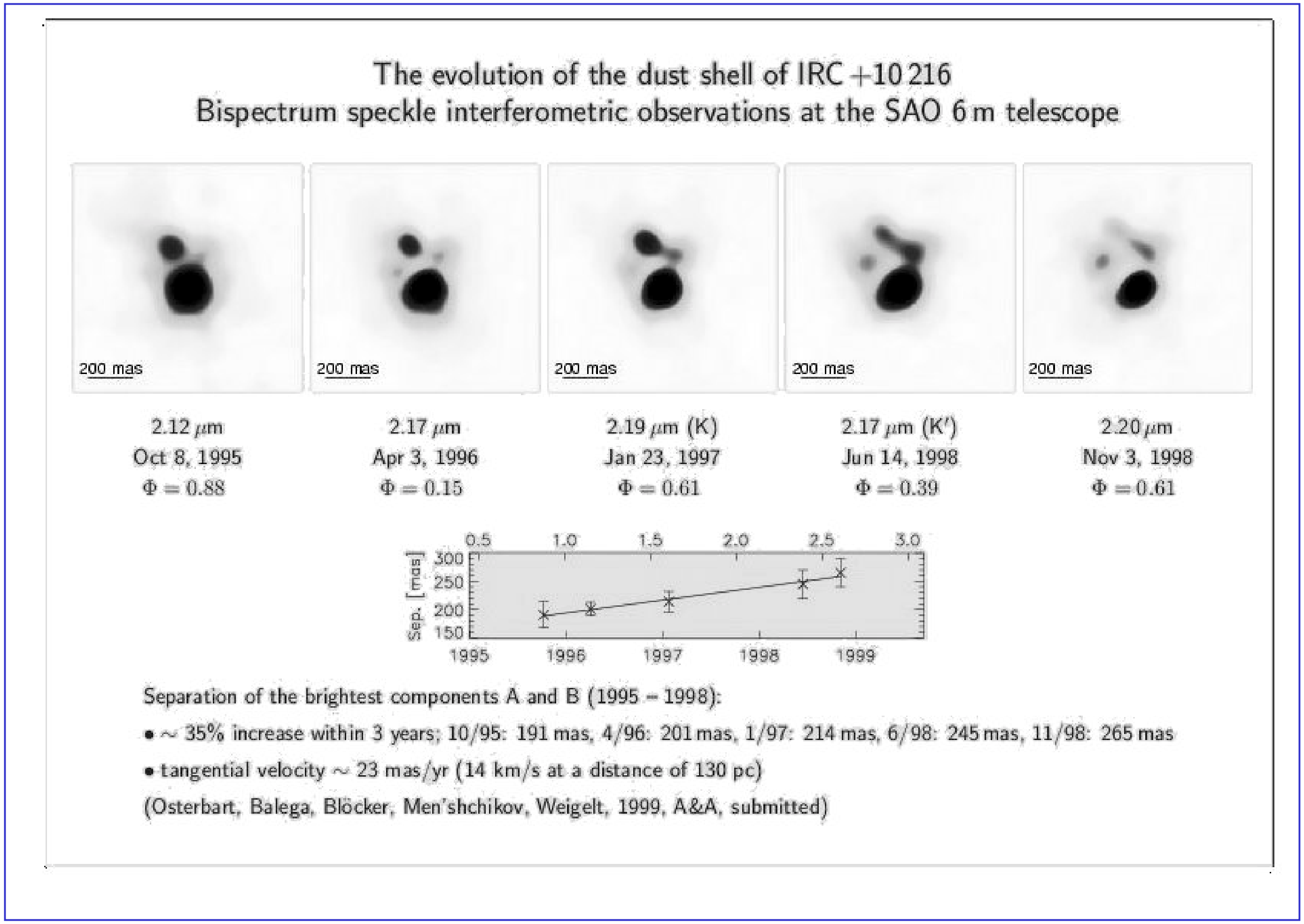
- Close circumstellar shells
- Mass loss
- Close companions, tidal interactions
- Jets and outflows

IRC +10216 - Complexity



Speckle interferometric images (6m tel., Weigelt et al.)

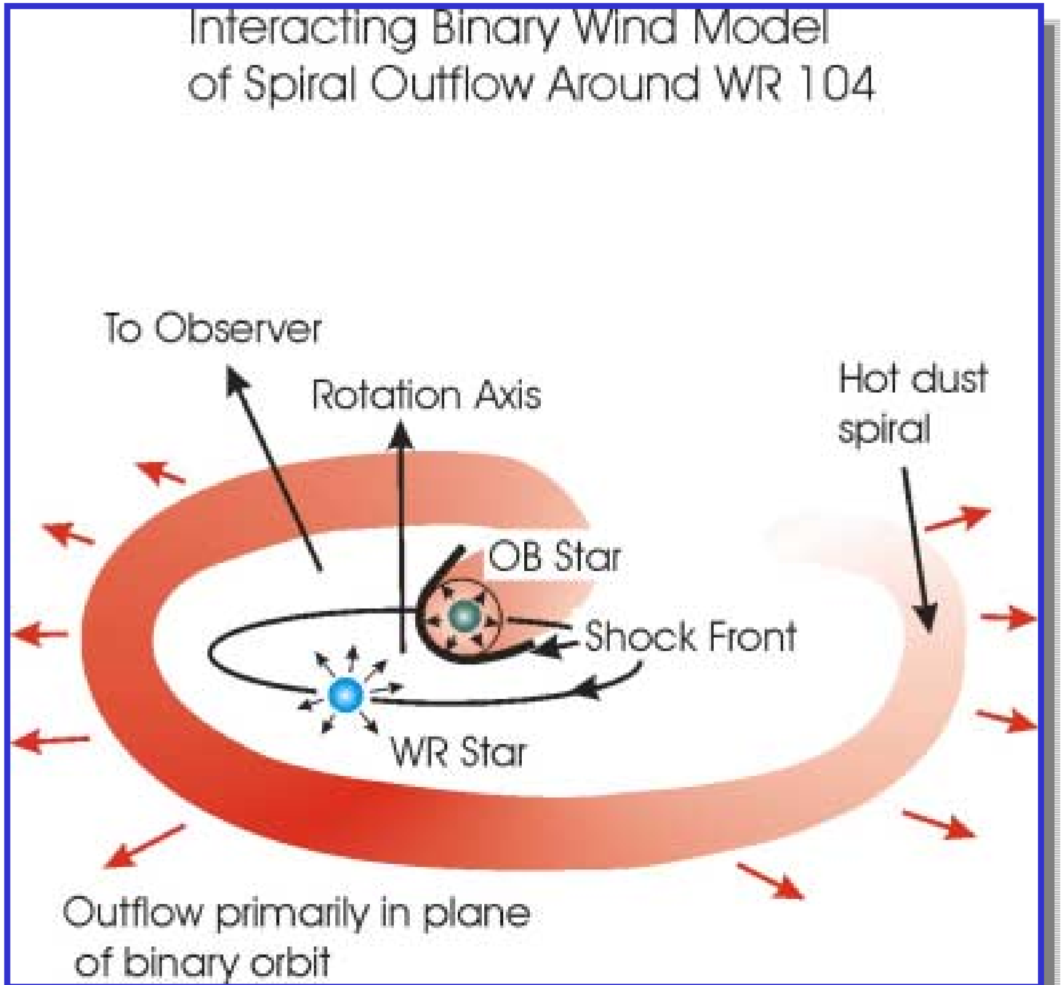
IRC +10216 – Time evolution

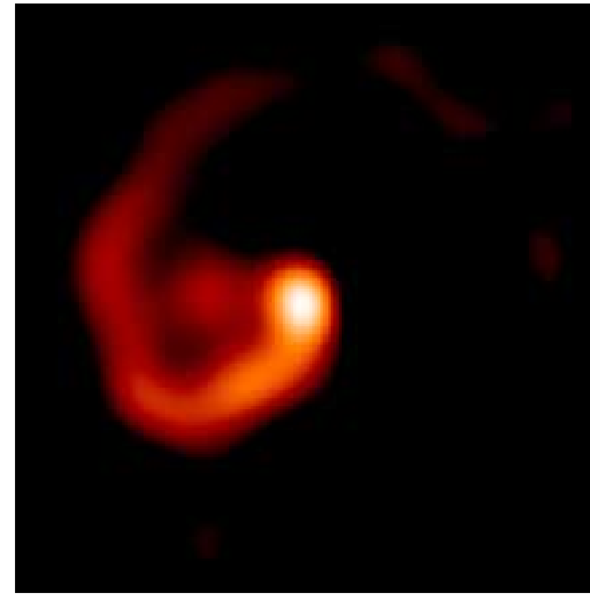


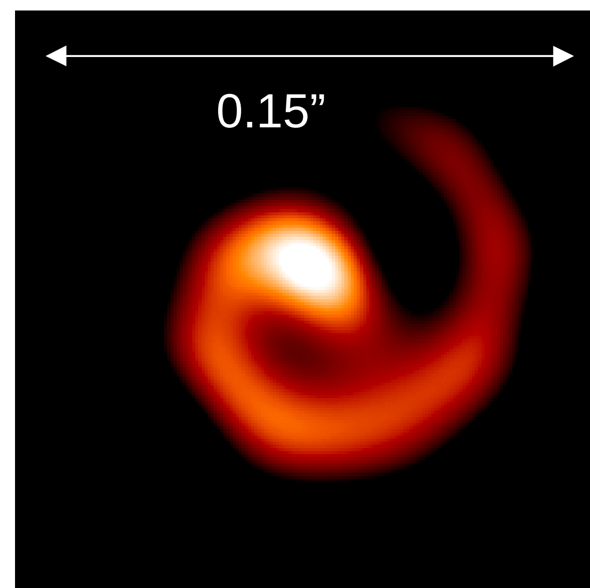
Note: no long-baseline interferometric observations yet!

Spiral Outflows

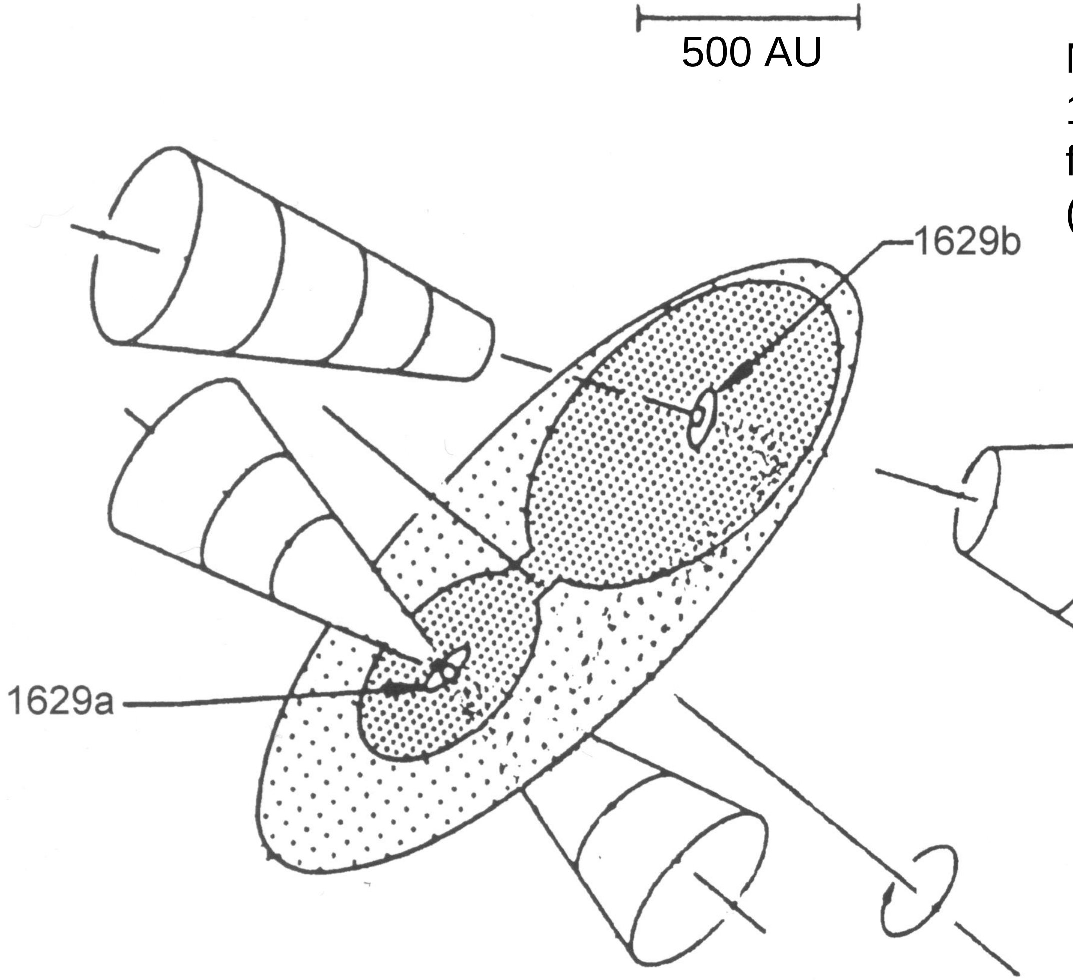
Keck/Speckle masking observations of WR 98A and WR104 (Monnier, Tuthill and coll.)







The environment around YSO



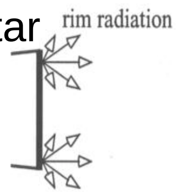
Model for IRAS 16293:1629, adapted from Surdin & Lamzin (2001)

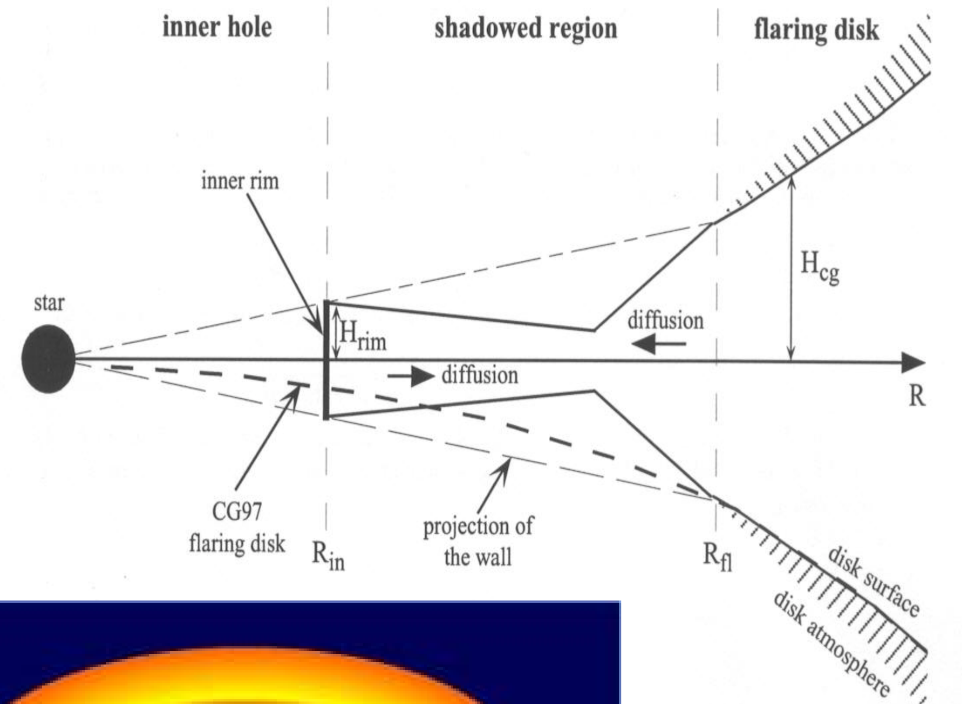
Disks around Herbig AeBe stars

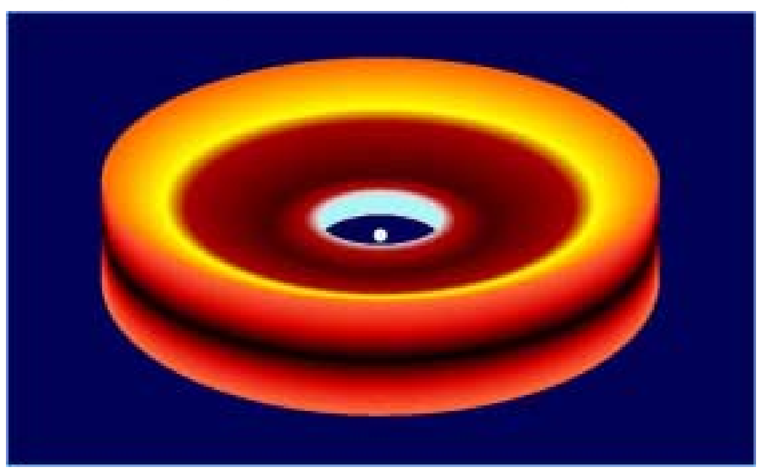
SED can be reproduced by a passive irradiated flaring disk model (Dullemond et al., 2001) determined mainly by:

- m, L, Te and d of star (known)
- total mass and opacity of dust
- R_{in}, R_{out} inner and outer disk radius
- H_{rim}, height of inner wall
- inclination of disk to LOS

VLTI Objective is to test the spatial predictions of the model and to strongly constrain free parameter space

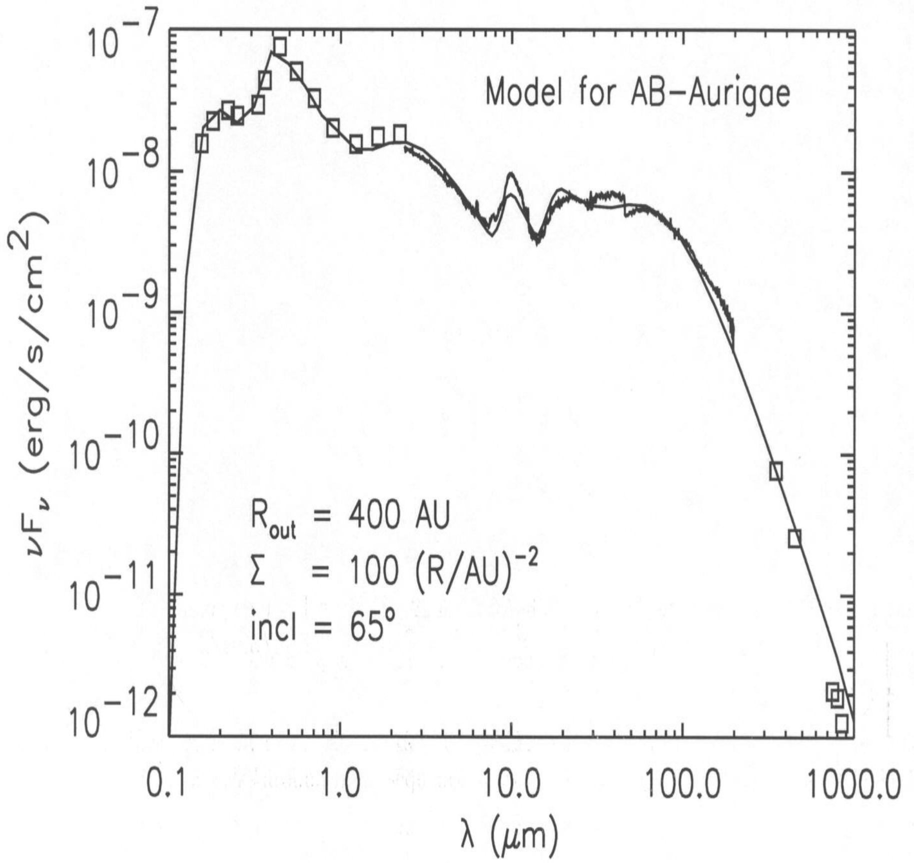






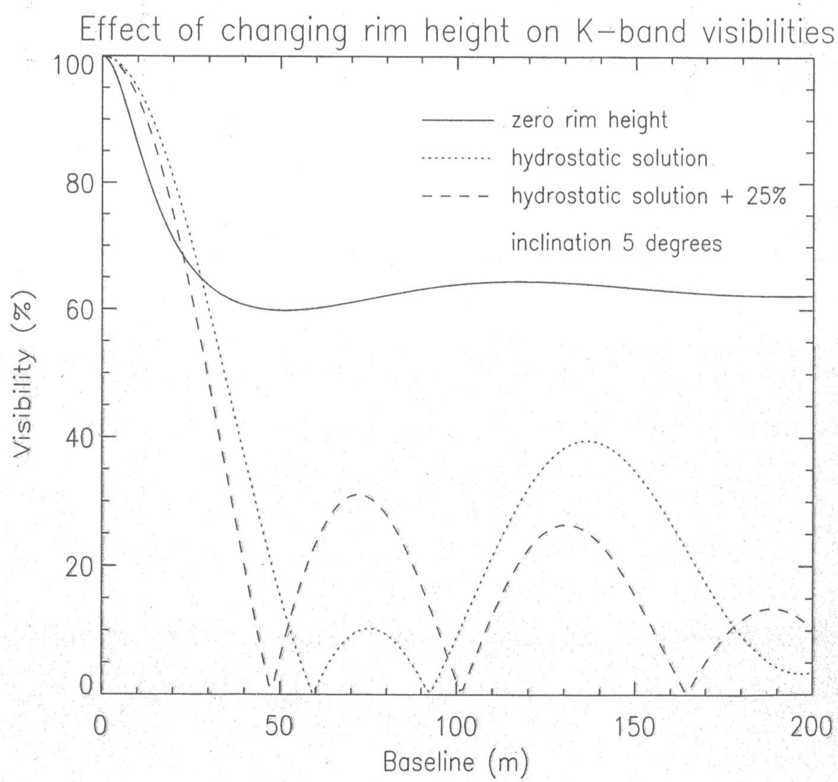
Herbig AeBe stars

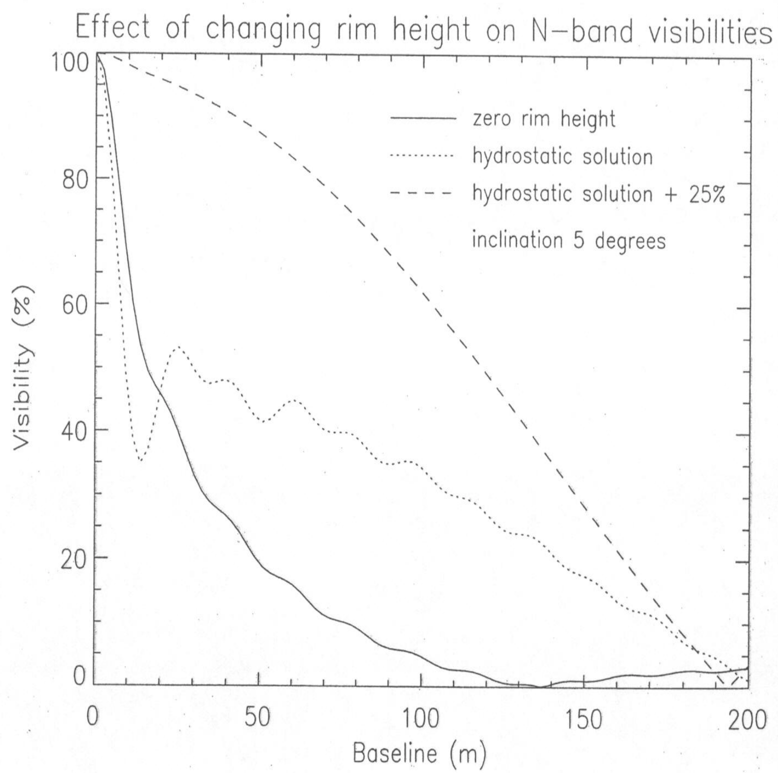
- HAEBEs are young intermediate mass PMS stars
- Ages in the 10^5 and 10^7 yrs range, distances 100-300pc
- Masses in the 2-8 $M_\odot$ range
- Analogue to T Tauris
- Likely progenitors of Vega-like debris disk stars
- Very large IR excess due to CS material in a disk, possible site of planetary formation
- some have mm interferometry sizes of several 100AU (~sec")
- ~1AU in K, 10-20AU in N



slides from R. van Boekel, F. Paresce

Model visibilities and parameters





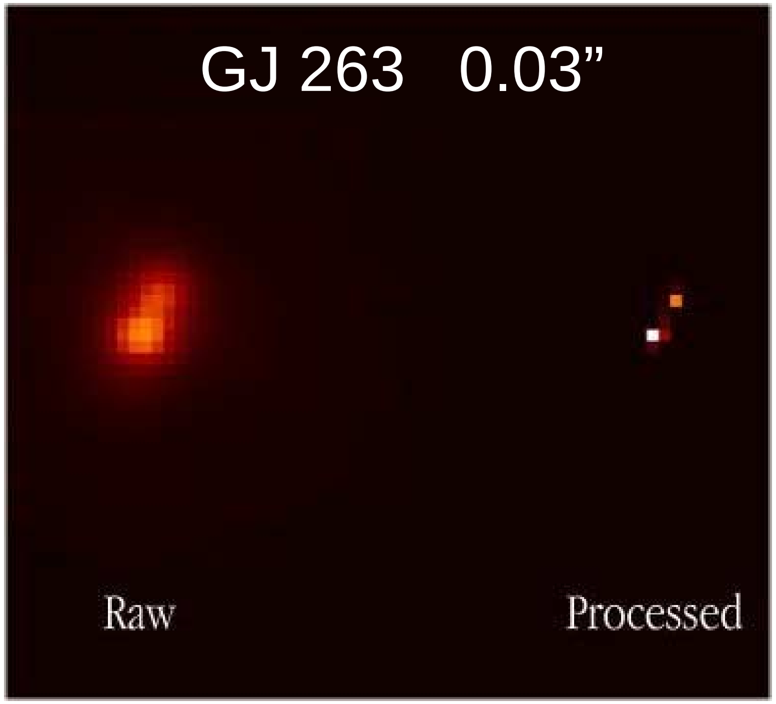
Circumstellar Structure

- Close circumstellar shells
- Mass loss
- Close companions, tidal interactions
- Jets and outflows

In general, these measurements need imaging capability

Double and multiple stars

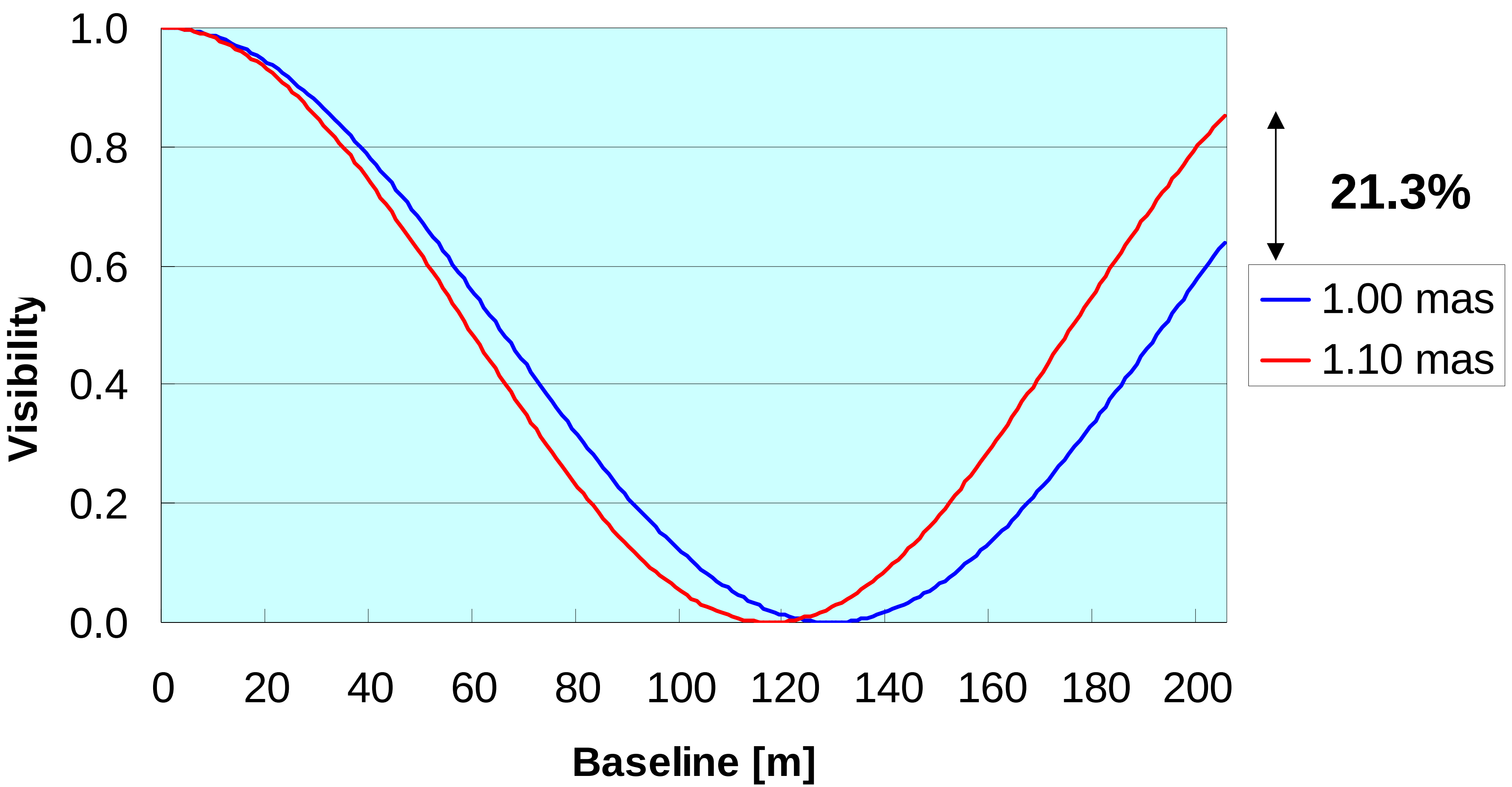
- Direct mass determinations
- Frequency of binary systems (YSO)
- Star formation mechanisms
- Binary/disk connection
- Stellar evolution



NACO/VLT FeII (1.25um)

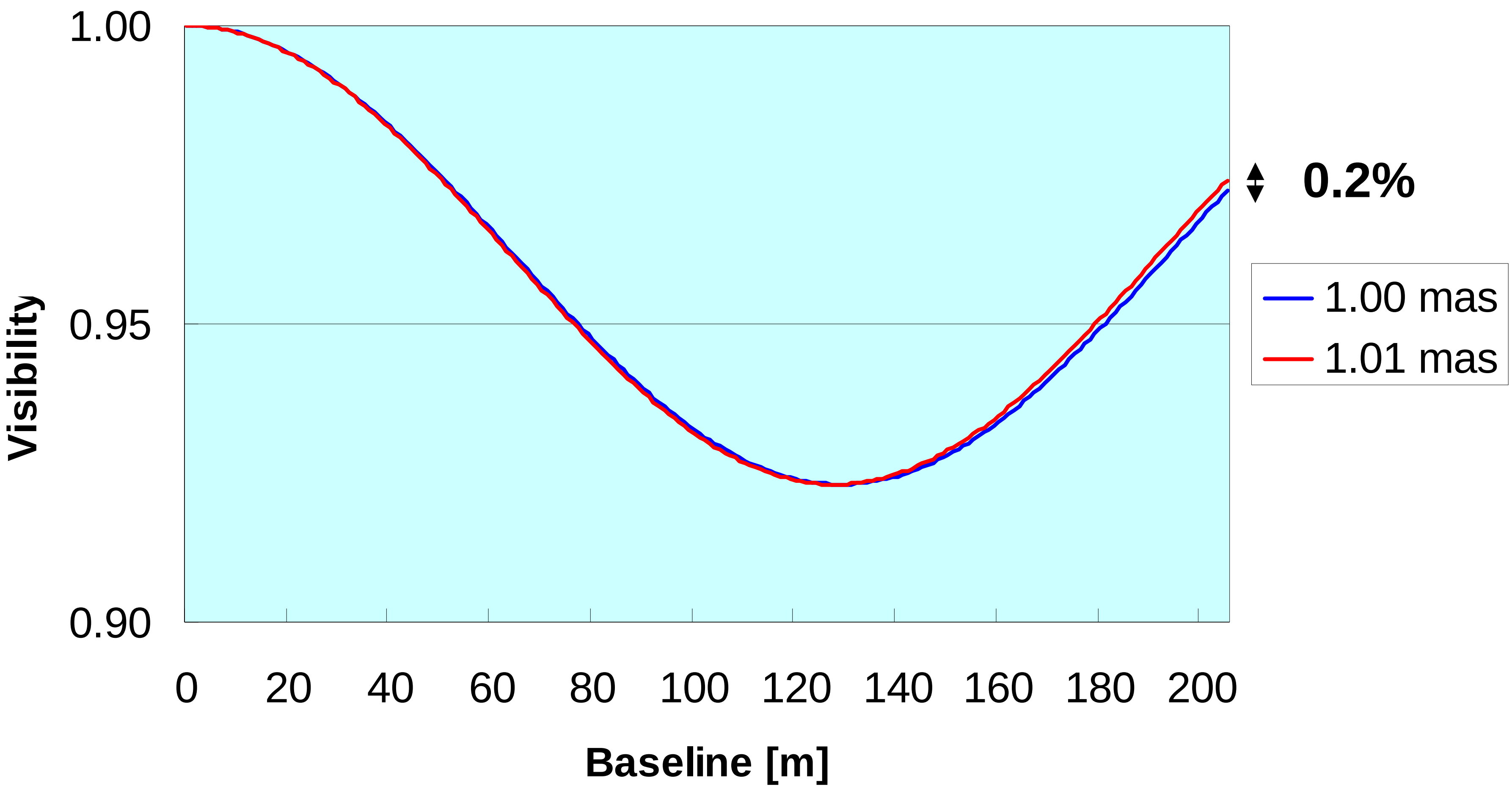
ESO PR 25/2001

Accurate visibilities vs. diffraction limit

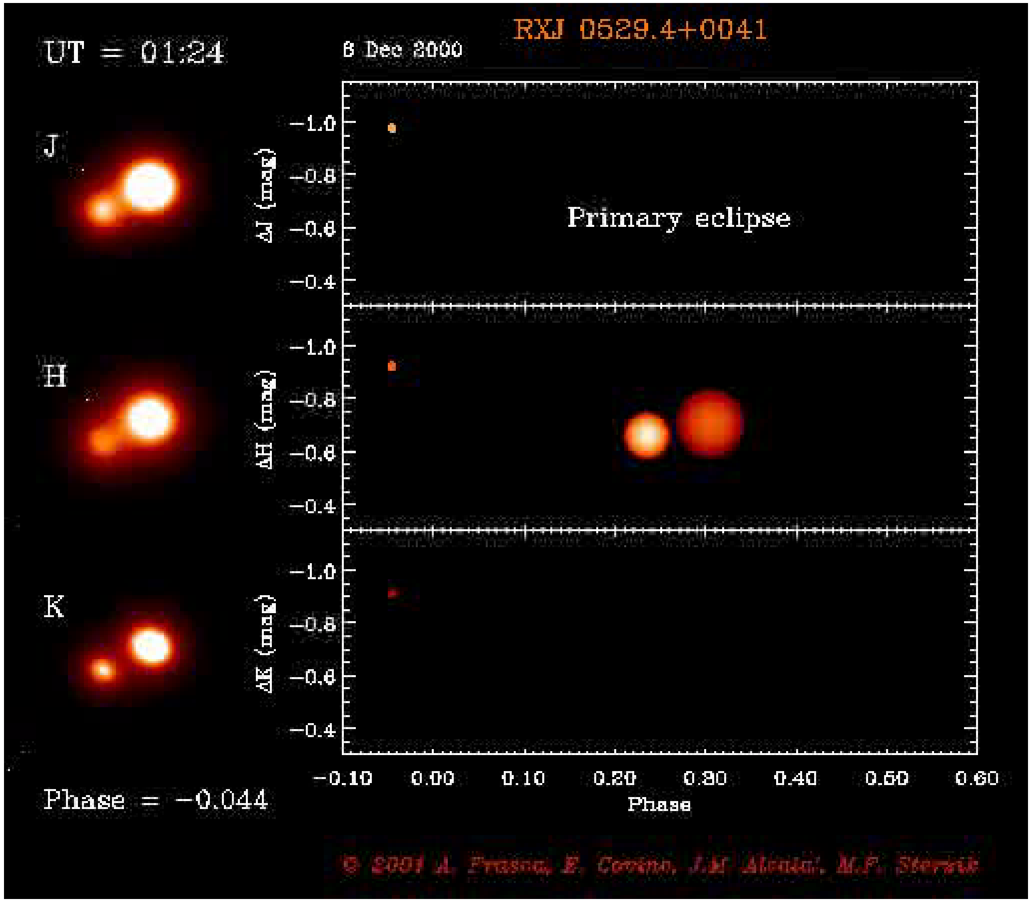


Orbital motions from accurate visibilities

Binary with two point sources, 1:50 Br. Ratio, J band



Eclipsing (young) stars



Eclipsing young binary RXJ 0529.4+0041

ESO PR 22/2001

$M_1=1.3\ M_\odot$

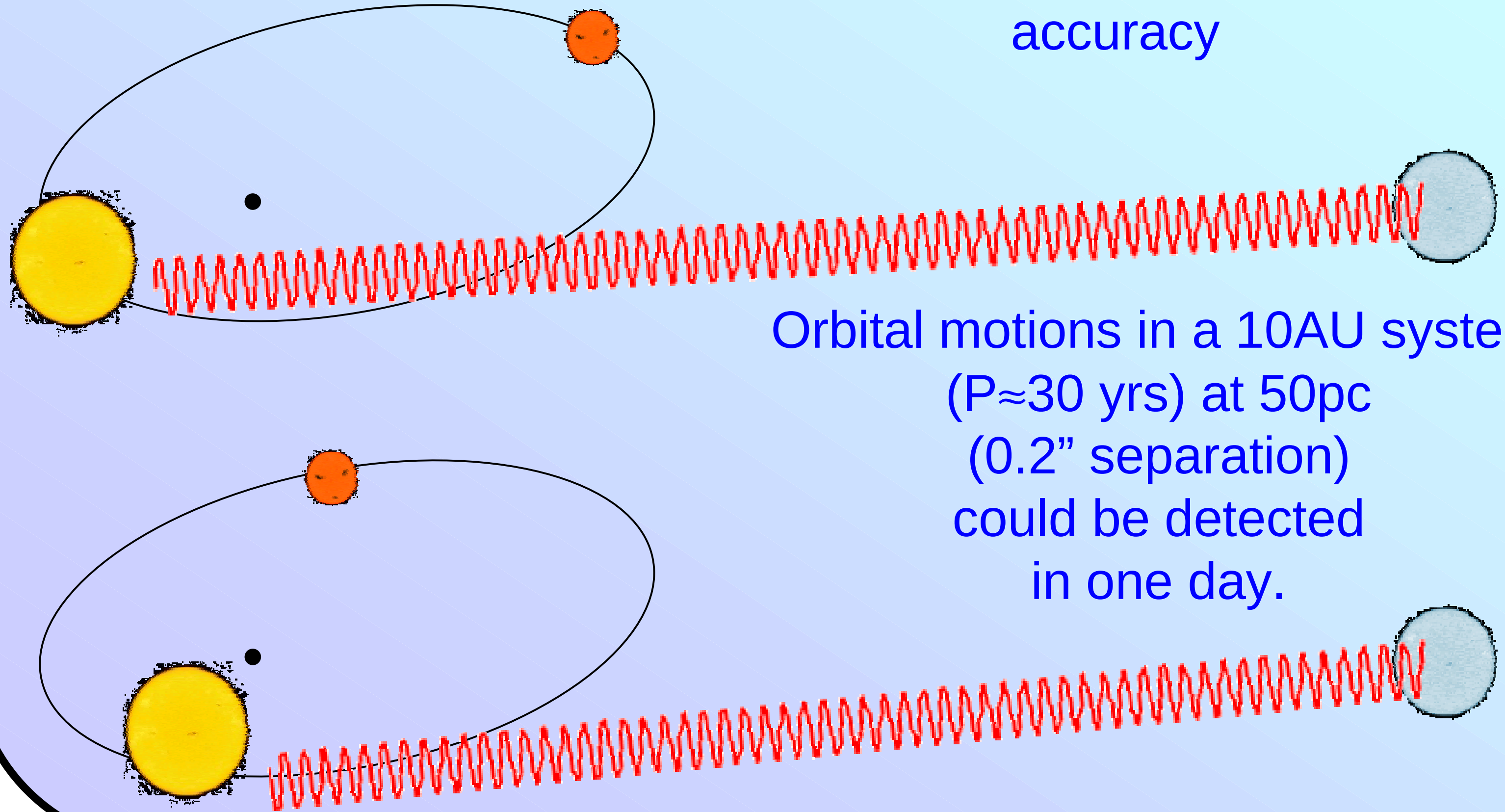
$R_1=1.6\ R_\odot$

$M_2=0.9\ M_\odot$

$R_2=1.2\ R_\odot$

P=3 days

Orbital motions by phase referencing



Narrow-angle astrometry can measure the separation from a distant reference star with 10μas accuracy

Orbital motions in a 10AU system (P≈30 yrs) at 50pc (0.2” separation) could be detected in one day.

Proper motions

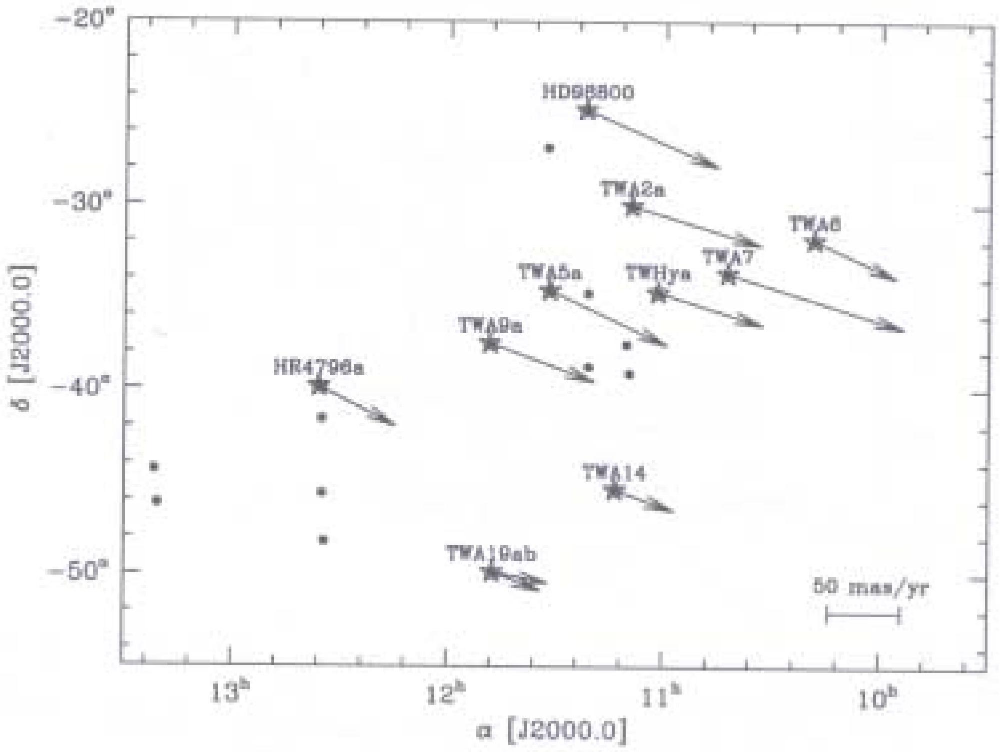


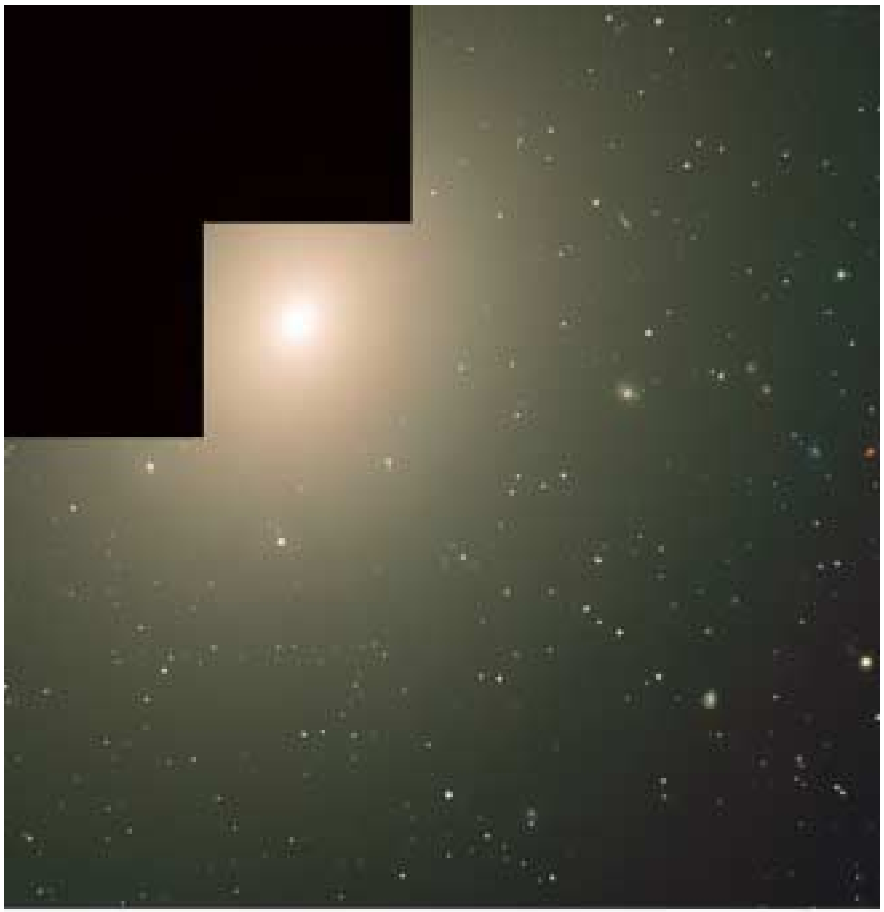
Figure 1. Positions of TW Hya member stars. Proper motions are shown where available from Table 1.

Doppler imaging of the surface of a T Tau star, V410 Tauri.

Adapted from Surdin & Lamzin (2001).

Desirable to model the effects on visibility.

Field of view



The Elliptical Galaxy NGC 4365
(HST/WFPC2 + VLT/ISAAC)

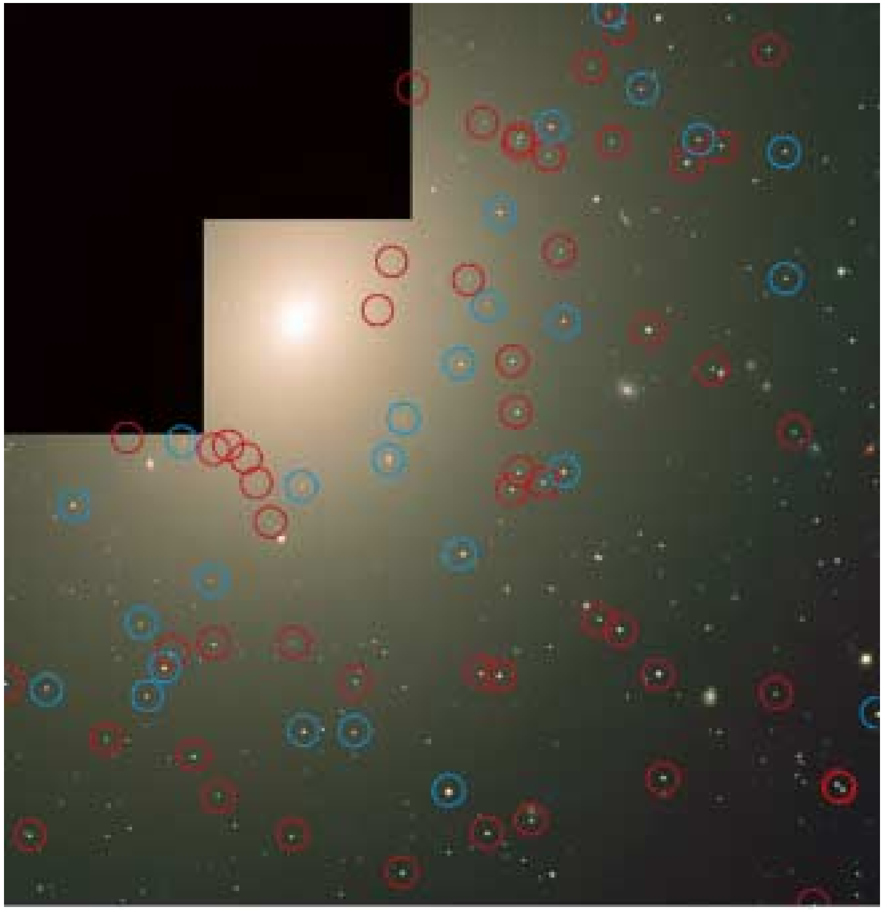
ESO PR Photo 15a/02 (26 June 2002)

© European Southern Observatory

NGC 4365

HST V&I + VLT K

Field of view



Stellar Clusters in NGC 4365
(HST/WFPC2 + VLT/ISAAC)

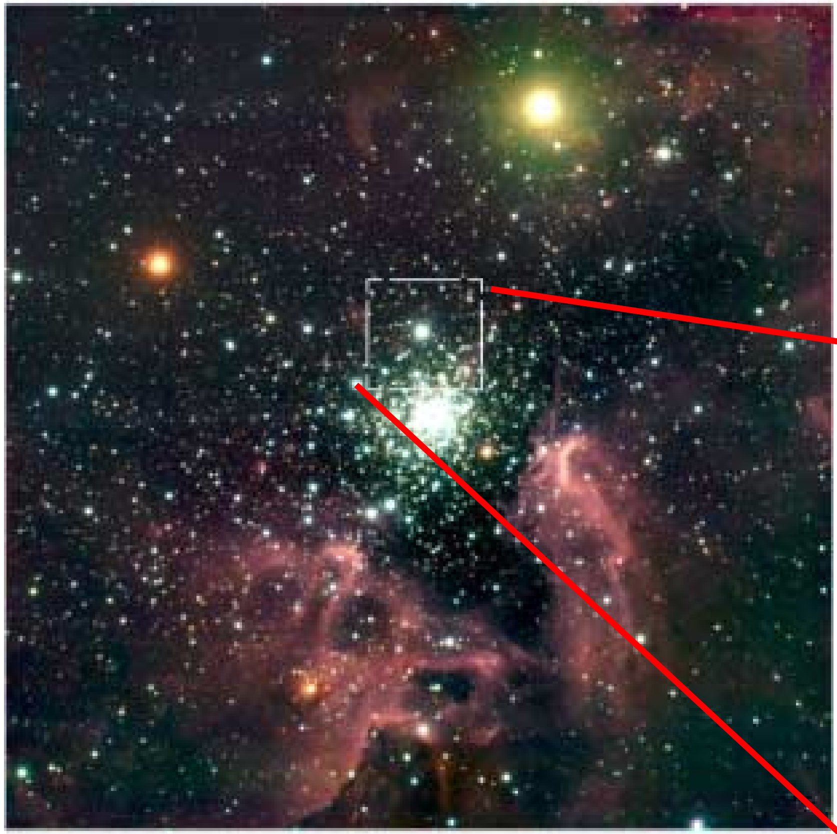
ESO PR Photo 15b/02 (26 June 2002)

NGC 4365

HST V&I + VLT K

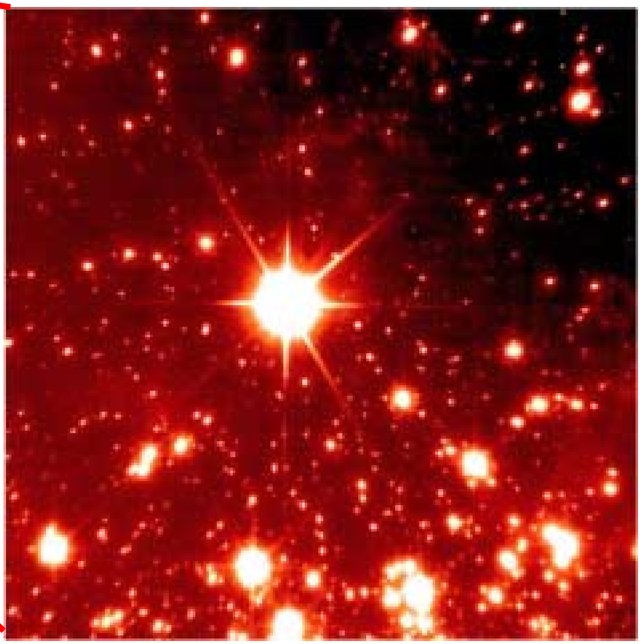
Old and Young stellar clusters

Crowded fields



NACO - VLT+AO - K

27”x27”, 0.07”,SR=56%

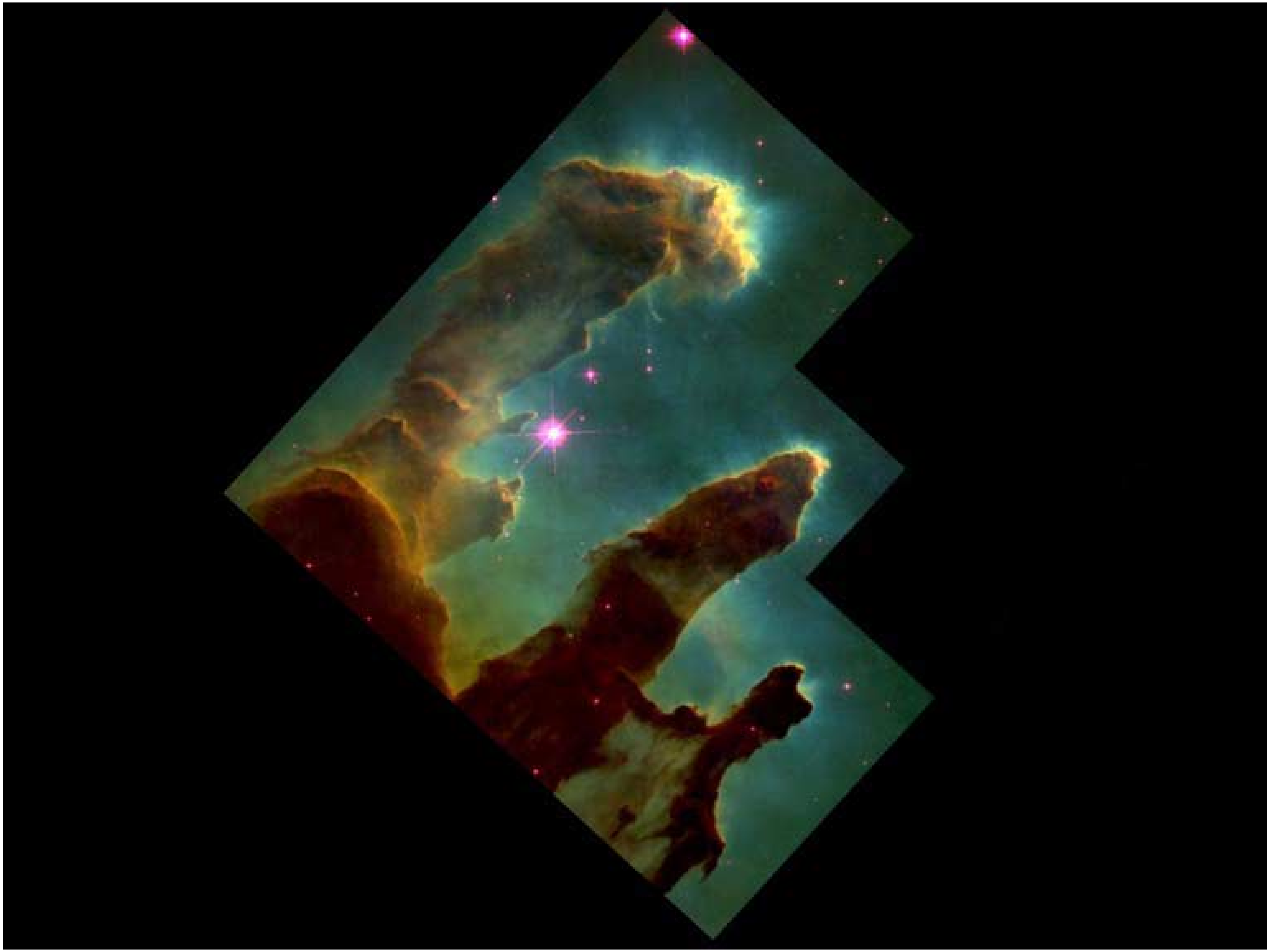


NGC 3603 Starburst Region

VLT ISAAC - 3.4’x3.4’, 0.4” seeing

ESO Press Release 25/01

Wavelength



Instrument Overview - MIDI

MIDI

[D/F/NL;   PI: Heidelberg]

Paranal: November 2002

First Fringes with UTs: December 2002

Mid IR instrument (10–20 μm) , 2-beam, Spectral Resolution: 30-260

Limiting Magnitude   N ~ 4 (1.0Jy, UT with tip/tilt, no fringe-tracker) (0.8 AT)

N ~ 9 (10mJ, with fringe-tracker) (5.8 AT)

Visibility Accuracy 1%-5%

Airy Disk   0.26” (UT), 1.14” (AT)

Diffraction Limit [200m]   0.01”

AMBER overview

AMBER

[F/D/I; PI: Nice]

Paranal: January 2003

First Fringes with UTs (AO): July 2003

Near IR Instrument (1–2.5 μm) , 3-beam combination (closure phase)

Spectral dispersion: ~35, ~1000, ~10000

Limiting Magnitude K =11 (specification, 5σ, 100ms self-tracking)

J=19.5, H=20.2, K=20 (goal, FT, AO, PRIMA, 4 hours)

Visibility Accuracy 1% (specification), 0.01% (goal)

Airy Disk 0.03"/0.06" (UT), 0.14"/0.25" (AT) [J/K band respectively]

Diffraction Limit [200m] 0.001" J, 0.002" K

Conclusions

- The LBT Interferometer is unique in the world.
- It will permit unprecedented modes of observations.
- Ground-breaking (stellar) science on complex objects, surveys, fast evolution phenomena.
- The italian community will have the opportunity to combine observations on the LBT with those at other prime facilities such as the VLTI.
- Access and support for a broad community should be emphasized and planned.