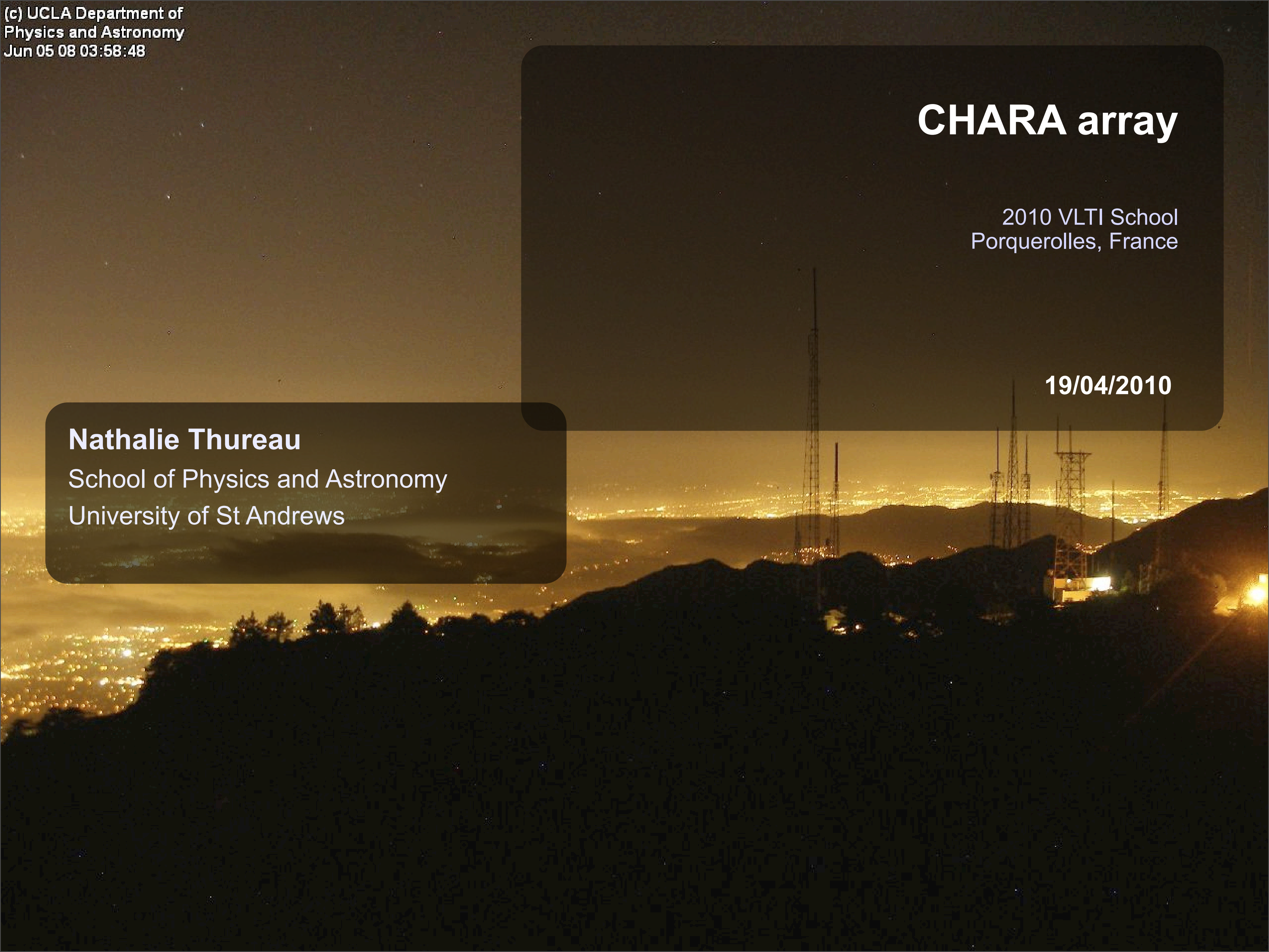


CHARA array

2010 VLTI School
Porquerolles, France

19/04/2010

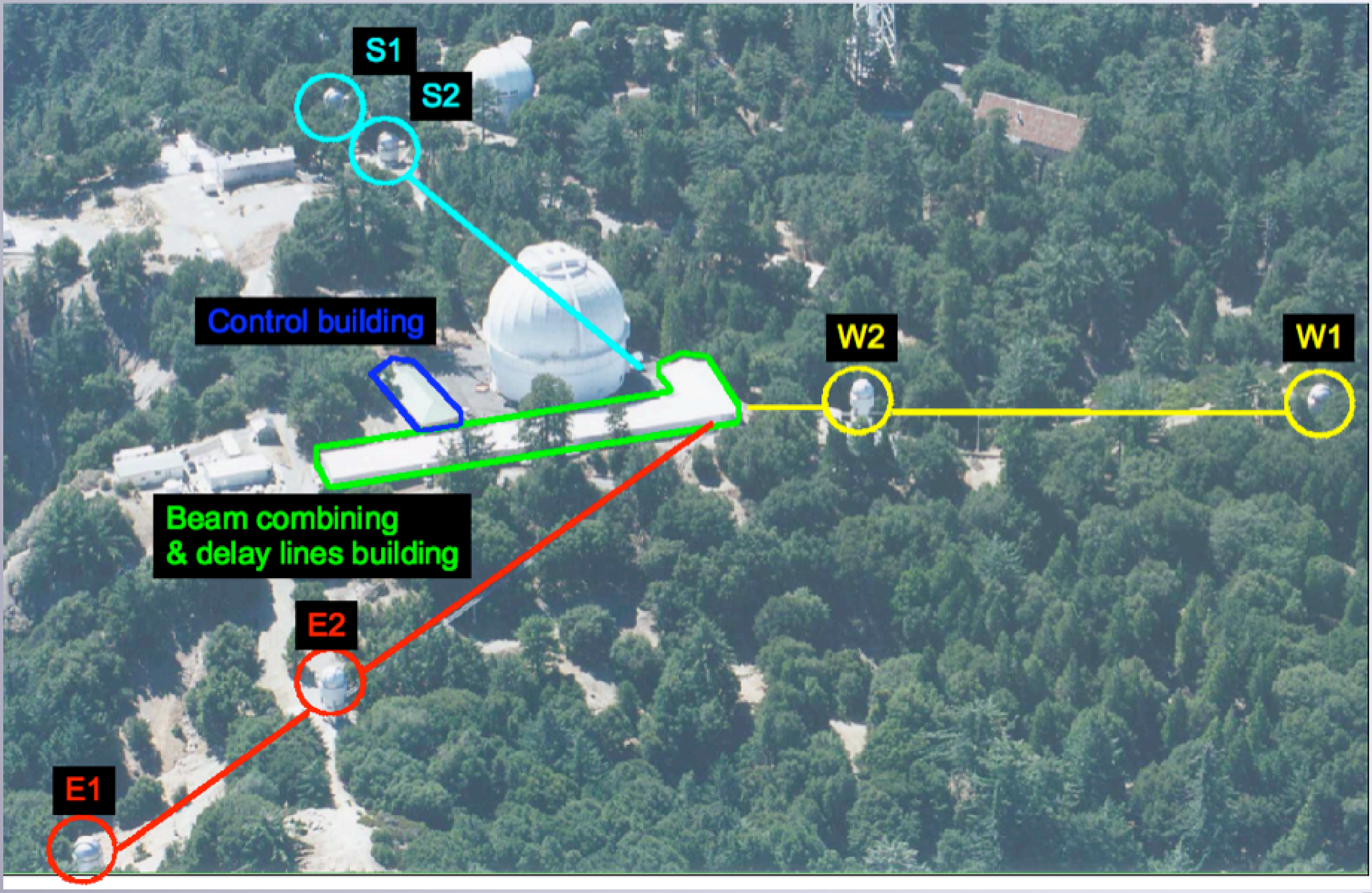
Nathalie Thureau
School of Physics and Astronomy
University of St Andrews

CHARA array and BC's

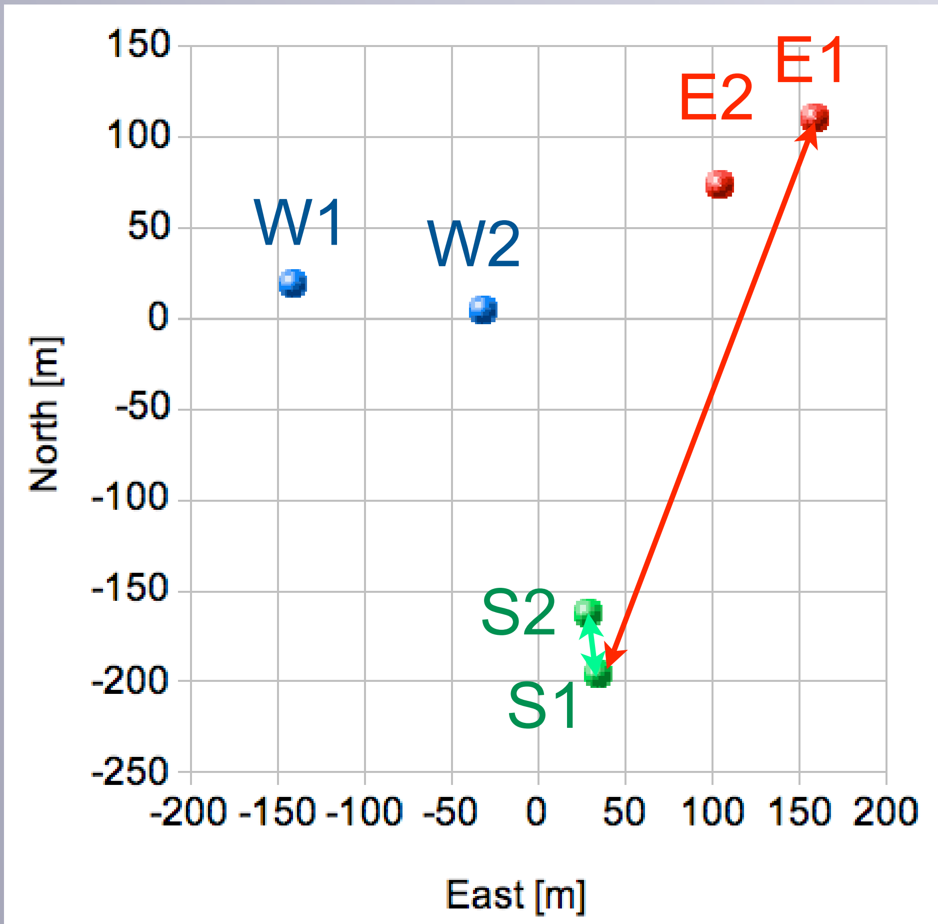
Center for High Angular Resolution Astronomy CHARA

- Operated by Georgia State University
- Mount Wilson, California, USA
- Latitude 34 13 33
- Longitude -118 03 26
- Y-shaped array
- 6 x 1m-telescopes
- Baselines 34-330m

Array overview



CHARA baselines



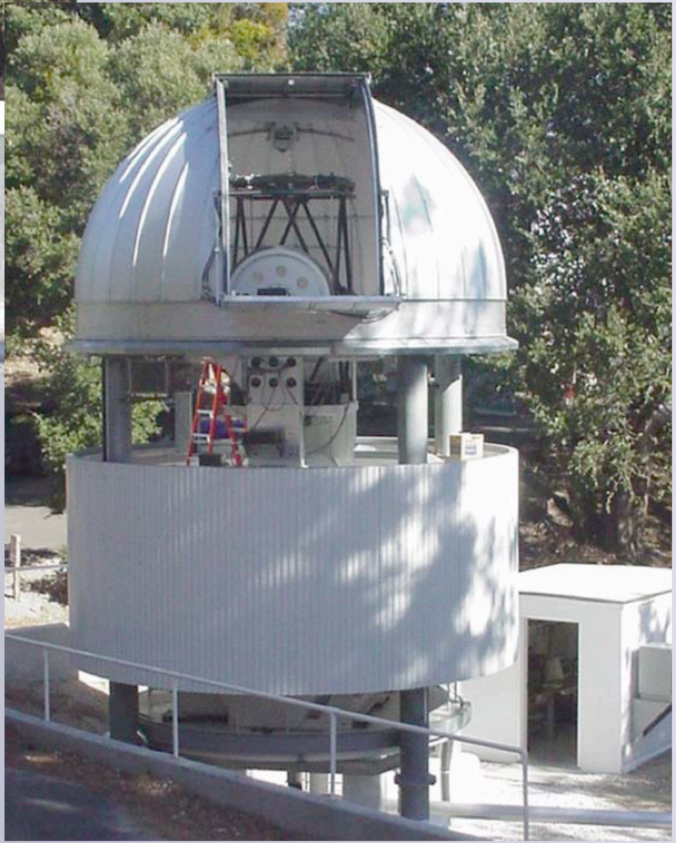
telescopes	east	north	height	baseline
S2-S1	-5.75	33.58	0.64	34.08
E2-E1	-54.97	-36.25	3.08	65.92
W2-W1	105.99	-16.98	11.27	107.93
W2-E2	-139.48	-70.37	3.24	156.26
W2-S2	-63.33	165.76	-0.19	177.45
W2-S1	-69.08	199.35	0.45	210.98
W2-E1	-194.45	-106.62	6.32	221.85
E2-S2	76.15	236.14	3.43	248.13
W1-S2	-169.32	182.74	-11.46	249.39
W1-E2	-245.47	-53.39	-8.03	251.34
W1-S1	-175.07	216.32	-10.82	278.5
E2-S1	70.40	269.72	-2.79	278.77
E1-S2	131.12	272.38	-6.51	302.37
W1-E1	-300.44	-89.64	-4.95	313.57
E1-S1	125.37	305.96	-5.87	330.71

CHARA angular resolution

$$\theta = \frac{\lambda}{B}$$

- B = 330m, θ(λ=0.5μm) = 0.3mas, θ(λ=2.2μm) = 1.4mas
- B = 34m, θ(λ=0.5μm) = 3.0mas, θ(λ=2.2μm) = 13.4mas
- High and low angular resolution equally important for image reconstruction

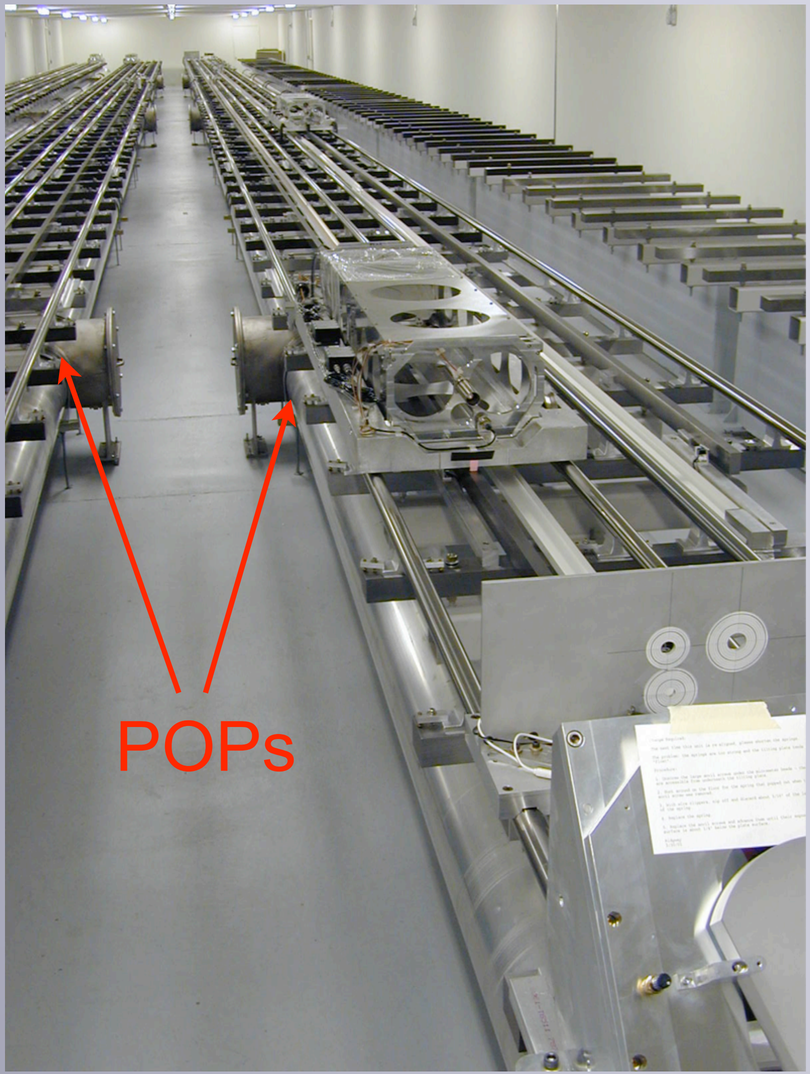
Telescopes



- Alt-Az mount
- Altitude limit 25 degrees
- Tip-tilt M2
- Tracking and tip-tilt correction at 470-800nm (up to V=12)

- Vacuum tubes feed light from each telescope to the central laboratory

Optical path compensation PoPs



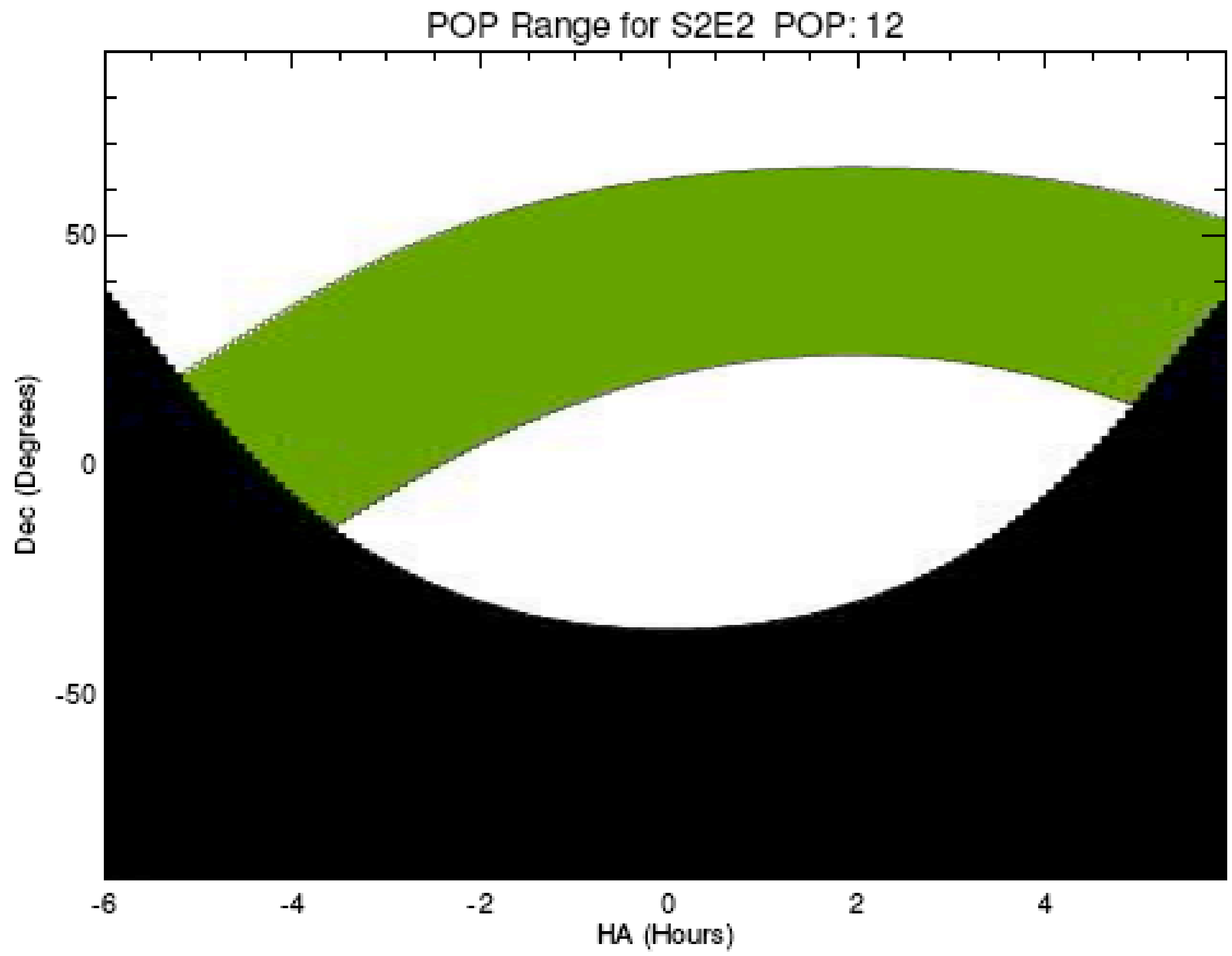
- Fixed delay intervals of 0, 36.6, 73.2, 109.7 and 143.1m
- In the vacuum

Optical path compensation OPLEs

- Continuously variable delay
- Not in the vacuum system
- Cat's eye arrangement
- 46m precision aligned rails
- Tracking RMS <20nm, typical 10nm

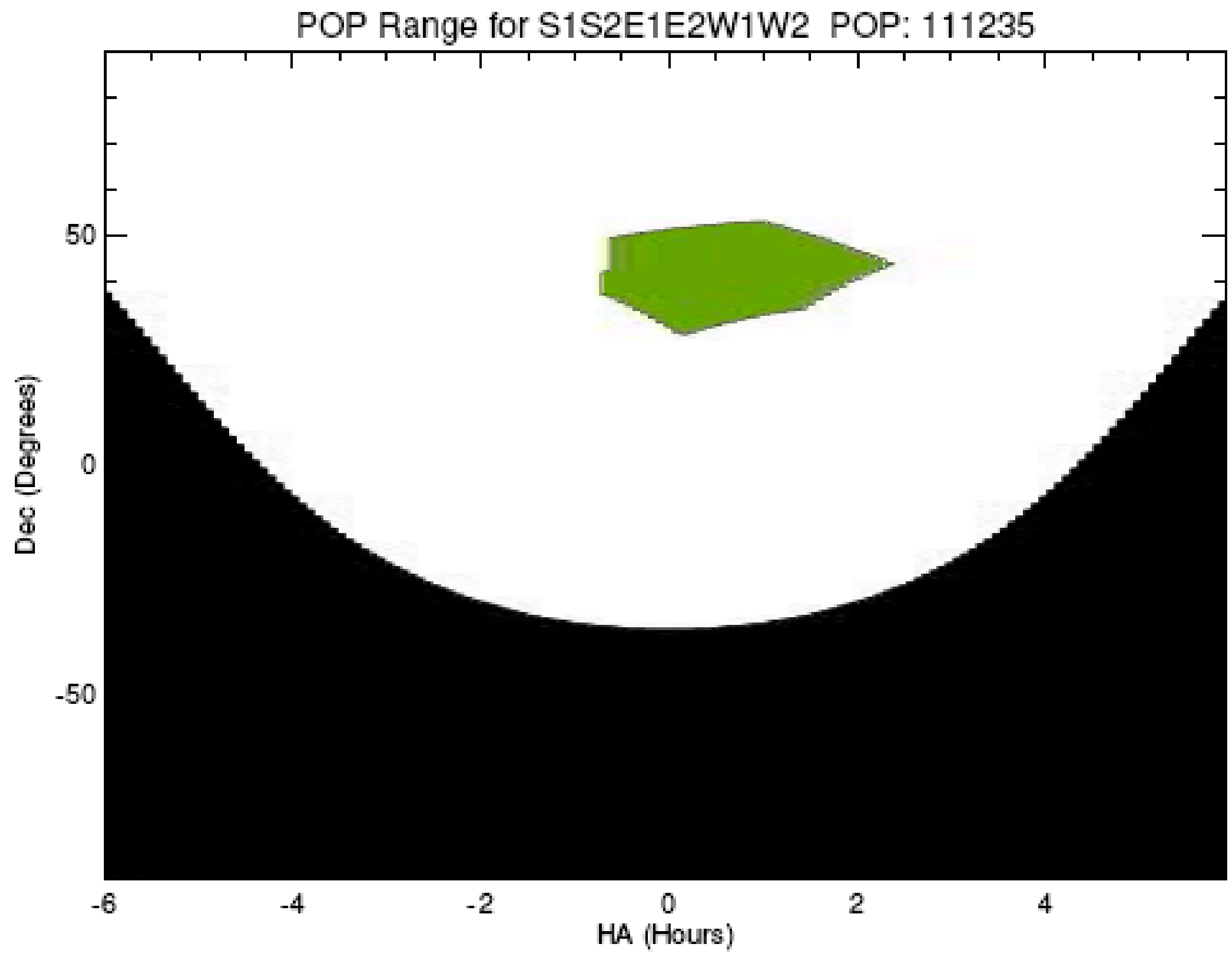
T. Brummelaar, 2003

PoP delay range – 2 telescopes



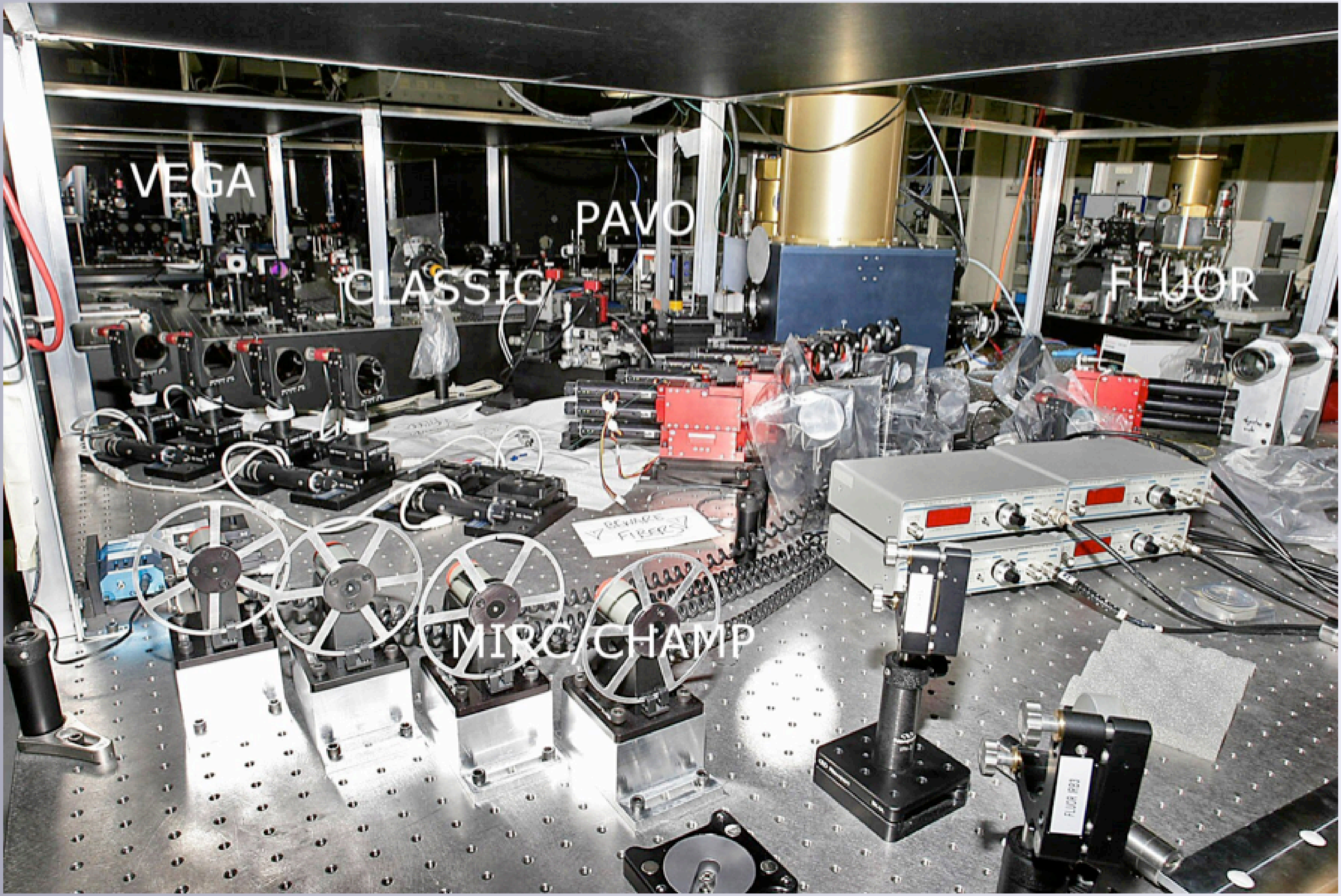
Sky coverage example from M. Zhao

PoP delay range – 6 telescopes



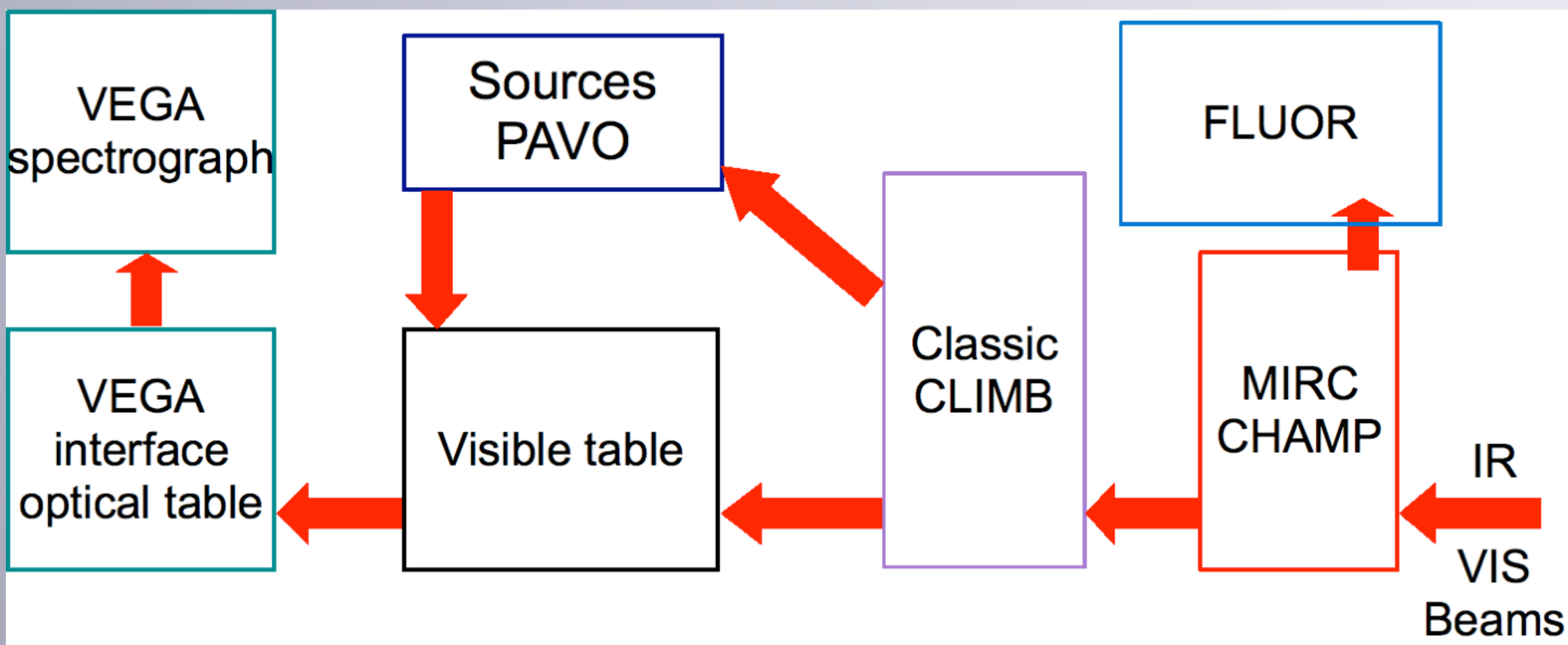
Sky coverage example from M. Zhao

Beam combining laboratory



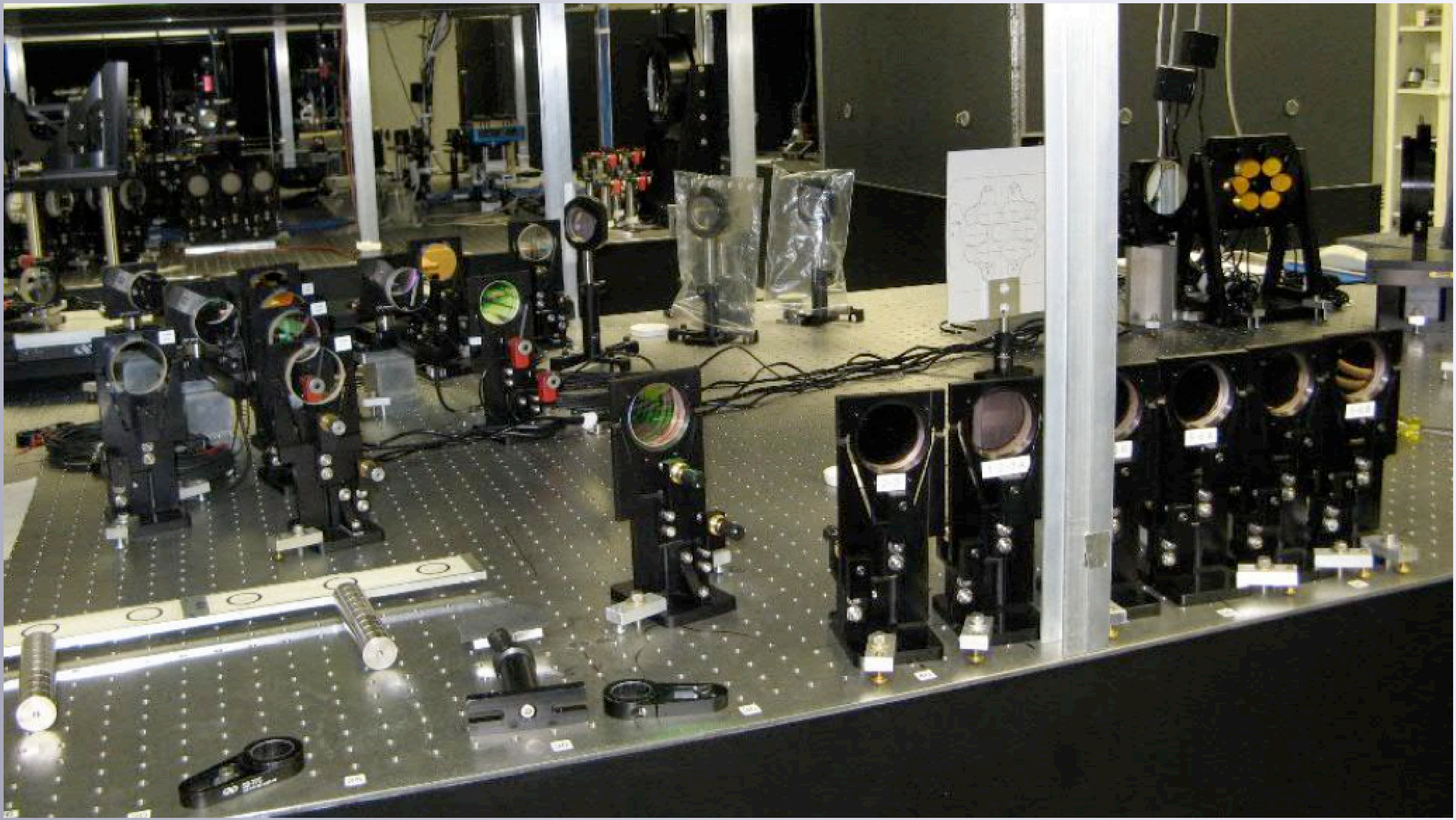
T. Brummelaar, 2003

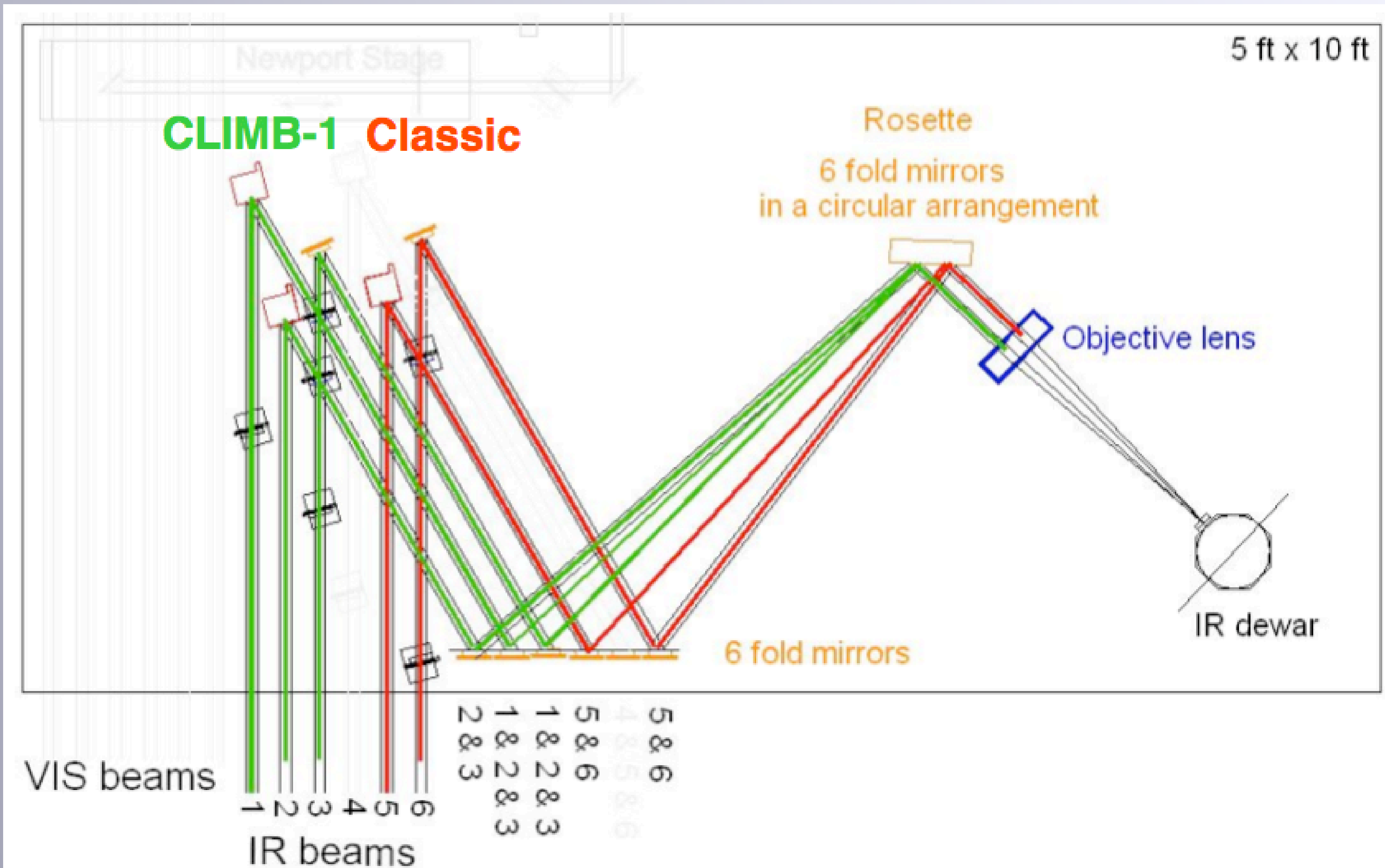
Beam combining laboratory



- Classic
- CLIMB
- FLUOR
- MIRC
- CHAMP
- PAVO
- VEGA

CHARA classic - CLIMB




5 ft x 10 ft
CLIMB-1
Classic
Rosette
6 fold mirrors
in a circular arrangement
Objective lens
IR dewar
6 fold mirrors
VIS beams
1 2 3 4 5 6
IR beams
2 & 3
1 & 2 & 3
1 & 2 & 3
5 & 6
5 & 6

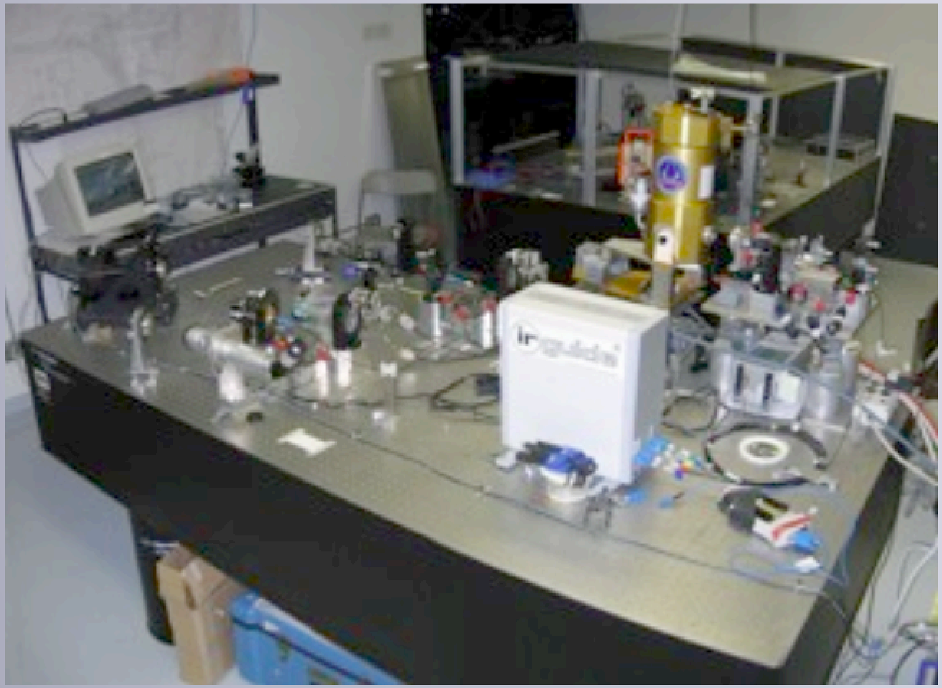
CHARA classic

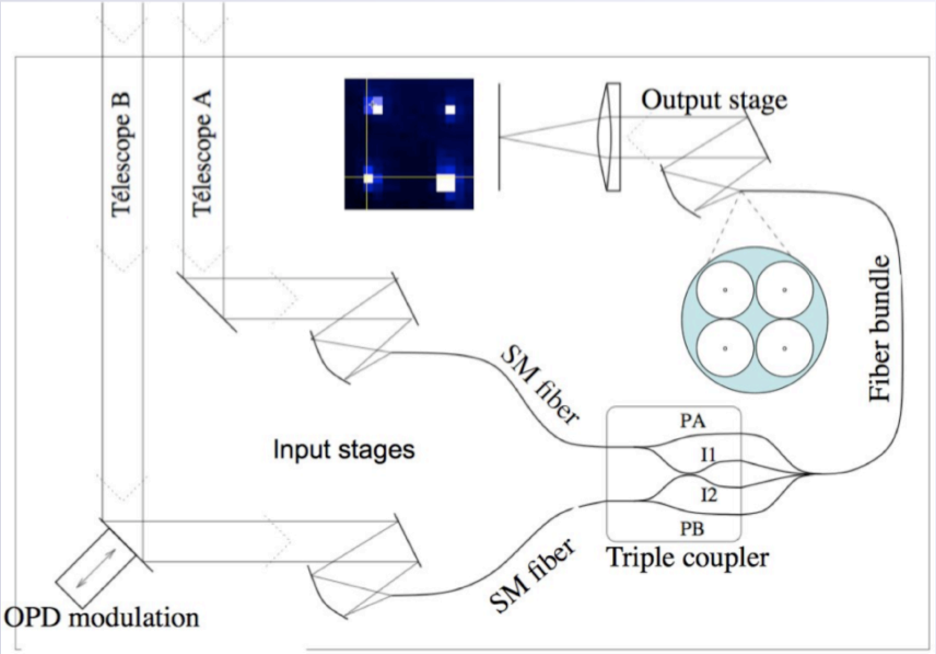
- Two beams
- J,H, K
- Predicted magnitude limit K=8.5
- Current record for finding fringes is K=7.767
- Light detected by Rockwell PICNIC 256x256 array part of NIRO (Near Infra-Red Observer)
- Classic: 2 output beams 1px or 2x2px area

CLIMB
Classic Interferometry on Multiple Baselines

- Three beam combination
- J, H and K operation
- Three visibility amplitude measurement
- One closure phase measurement
- CLIMB-1 currently being tested
- In the future: Dual-CLIMB system
- Both on single target
- One in parallel with one of the other BCs
- Updated NIRO accommodate dual CLIMB 6x1px beams

FLUOR
Fiber Linked Unit for Optical Recombination





FLUOR

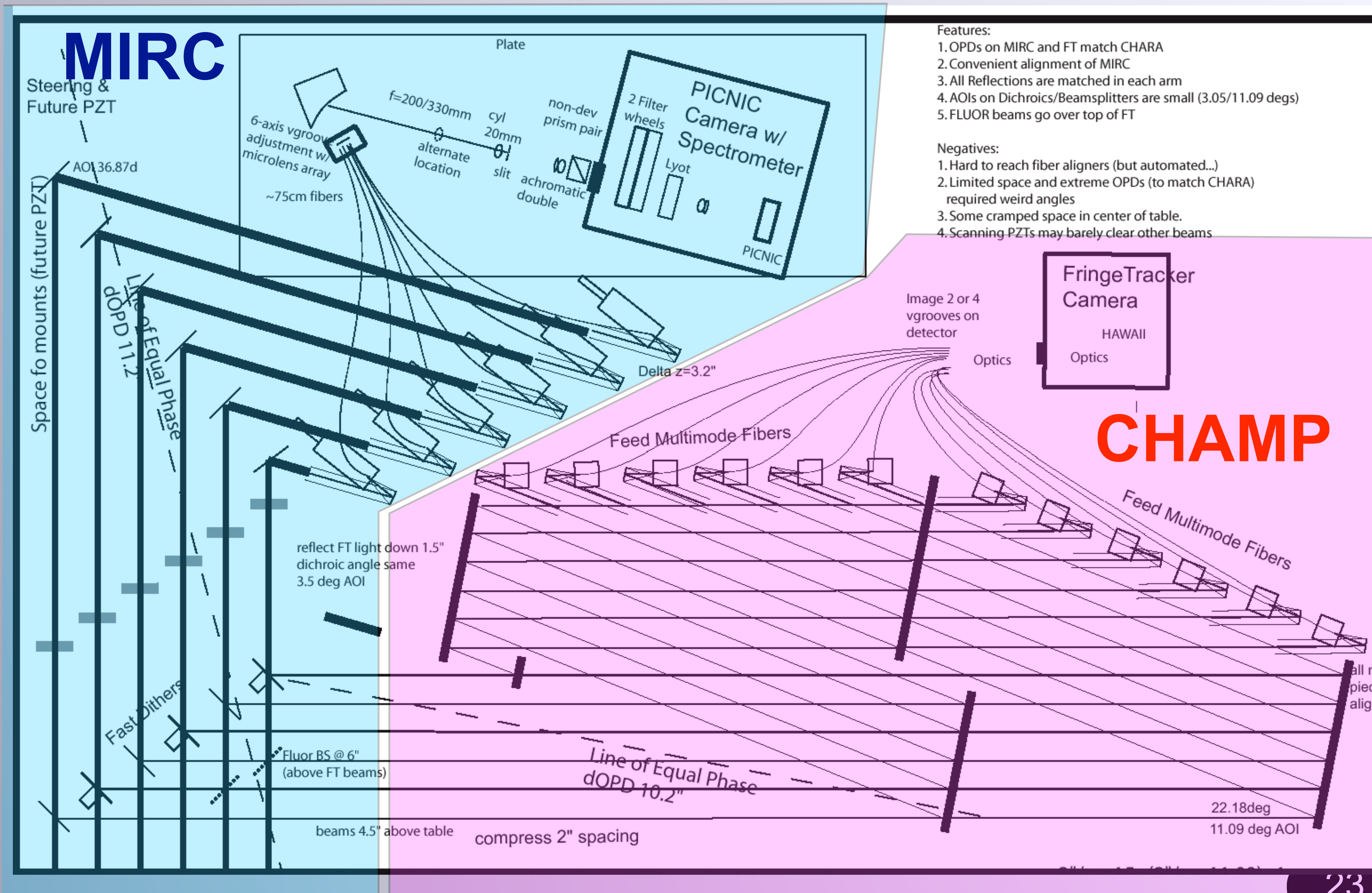
- Single mode fibers combiner
- Demonstrator for fiber spatial filtering for accurate calibration of stellar interferometry data
- Photometry channels calibrate the interferograms against unbalanced intensities
- Works in K-band (2 – 2.4 μm)
- Precision on visibility measurements (<1%)

FLUOR – JOUFLU
Rejuvenation and upgrading of FLUOR

- Increase dynamic from 300 to higher as possible
- Spectral resolution
- Fringe tracking (CHAMP)
- Connect with VEGA
- Simultaneous multicolour observations with VEGA
- Automatisation of alignment procedure
- Remote mode
- New control system

MIRC
Michigan Infra-Red Combiner

MIRC infrared table



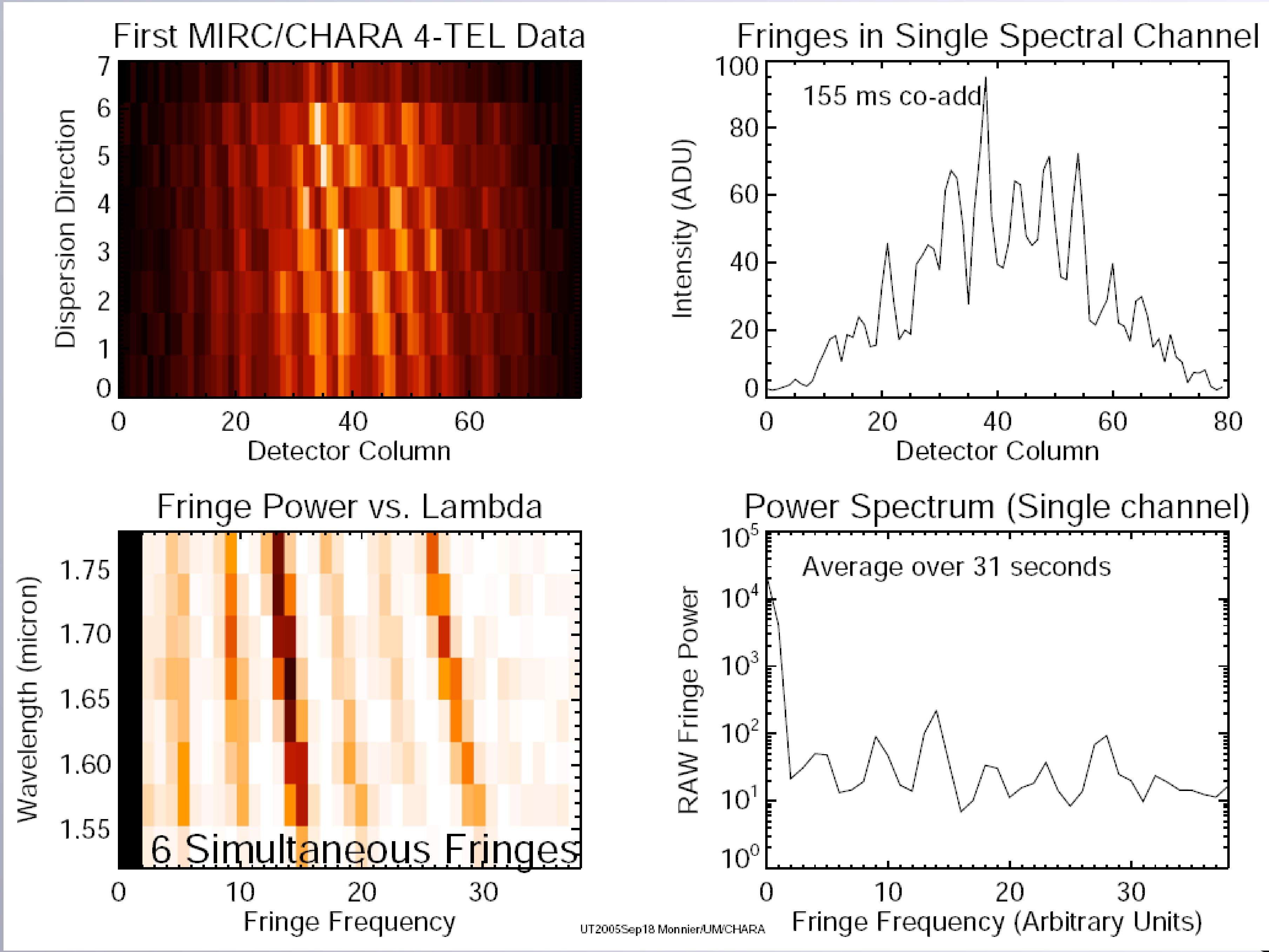
Features:
1. OPDs on MIRC and FT match CHARA
2. Convenient alignment of MIRC
3. All Reflections are matched in each arm
4. AOIs on Dichroics/Beamsplitters are small (3.05/11.09 degs)
5. FLUOR beams go over top of FT

Negatives:
1. Hard to reach fiber aligners (but automated...)
2. Limited space and extreme OPDs (to match CHARA) required weird angles
3. Some cramped space in center of table.
4. Scanning PZTs may barely clear other beams

MIRC

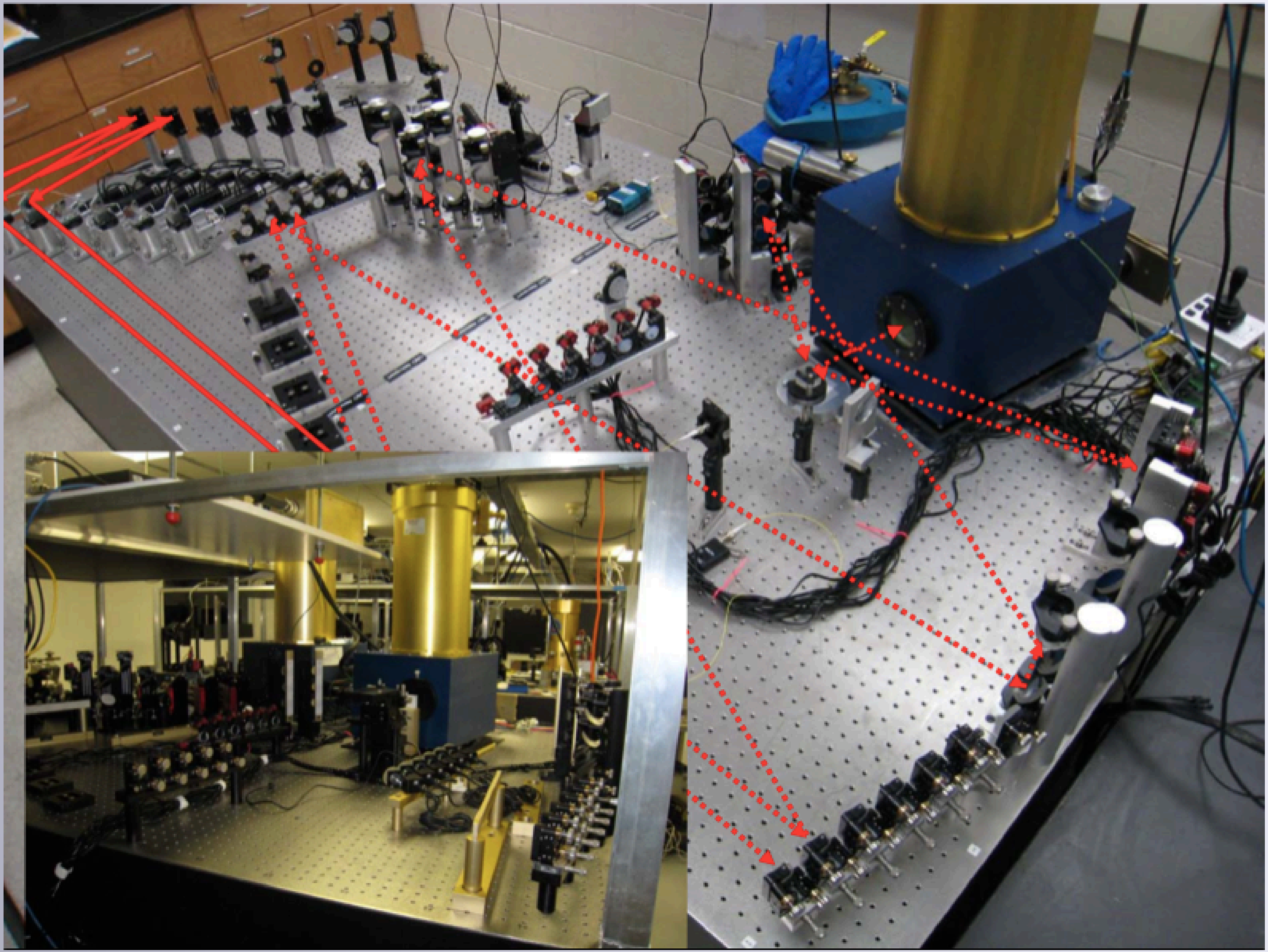
- Combines 4 telescopes at present
- Works at H (1.65 micron) and K (2.2 micron)
- Demonstrated sensitivity: H~ 4.0, K~3.5
- Spectral resolution: R~ 44, 150, or 400
- Calibration: V2 error ~ 10%-20%; CP error ~ 2°-5°(for 6min obs.)
- New Photometric Channels seems to improve V2 error: ~ 5%
- Fringe tracker CHAMP expected to finish September 2010
- MIRC 6-telescope upgrade in 2010-2011

MIRC



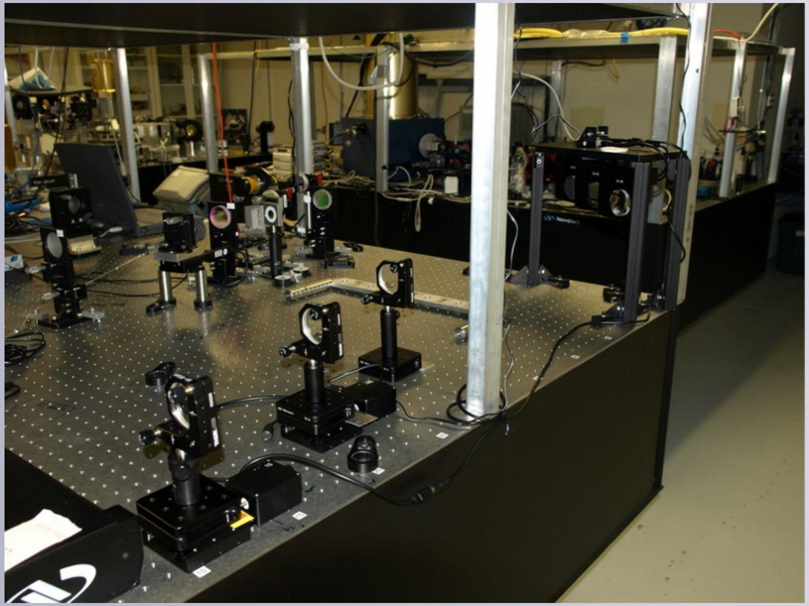
First MIRC/CHARA 4-TEL Data
Dispersion Direction
Detector Column
Fringes in Single Spectral Channel
155 ms co-add
Intensity (ADU)
Detector Column
Fringe Power vs. Lambda
Wavelength (micron)
6 Simultaneous Fringes
Fringe Frequency
Power Spectrum (Single channel)
Average over 31 seconds
RAW Fringe Power
Fringe Frequency (Arbitrary Units)
UT2005Sep18 Monnier/UM/CHARA

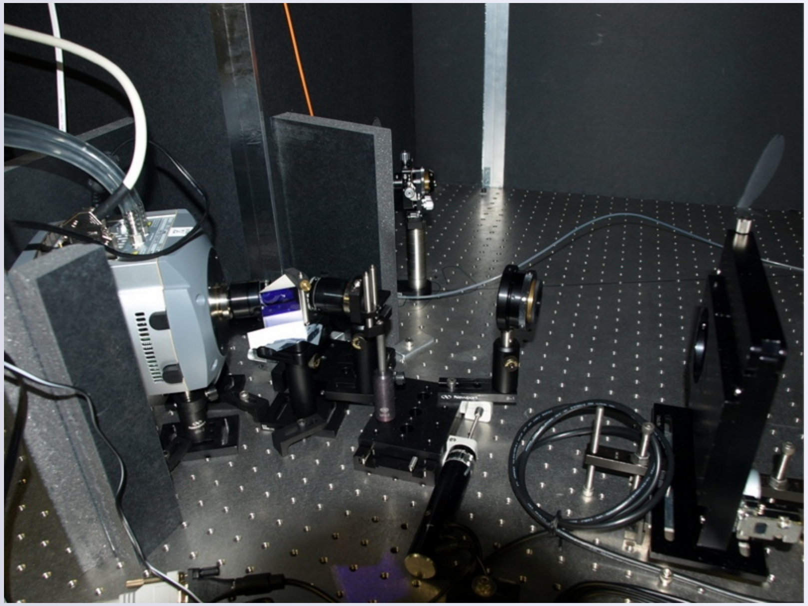
CHAMP
CHARA-Michigan Phasetracker

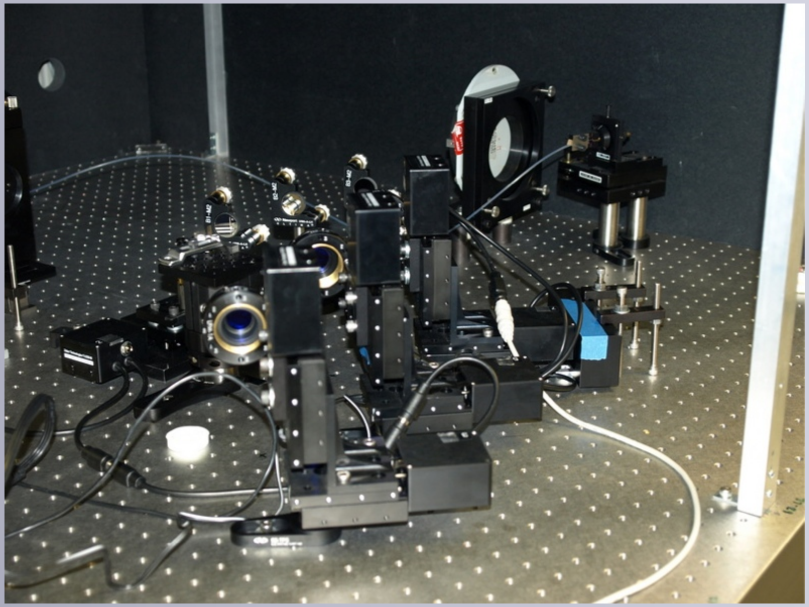


CHAMP

- Will detect and correct pathlength fluctuations
  - “adaptive optics” for an interferometer
  - “freezes” the fringes to allow long integrations
- Operate in J, H, or K (1 to 2.4 microns)
- Separate fringe tracker from science combiners
- New instrument will improve sensitivity x10
  - enable imaging at visible wavelengths
  - extend sensitivity to image Young Stellar Objects
- Optimised for sensitivity: H=7-8
- Fringe phase measured simultaneously on 6 baselines
- up to 500Hz
- Commissioned one baseline in August 2009
- all 6 to be commissioned in summer 2010

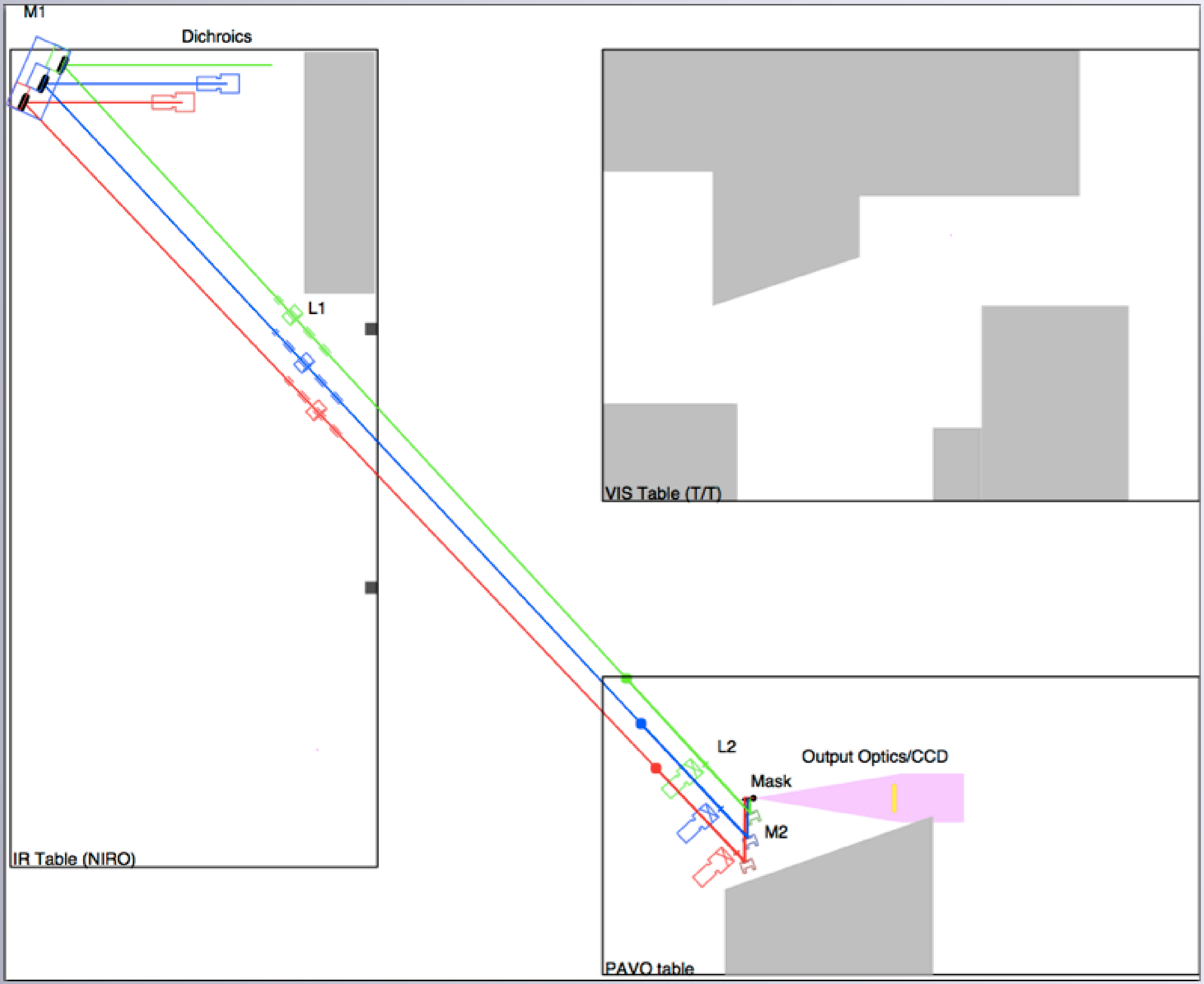






- Relay optics (Classic optical table)
- PAVO optics and detector

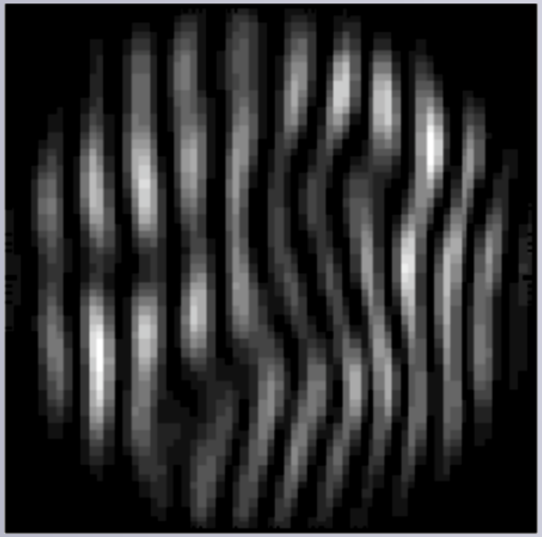
PAVO layout

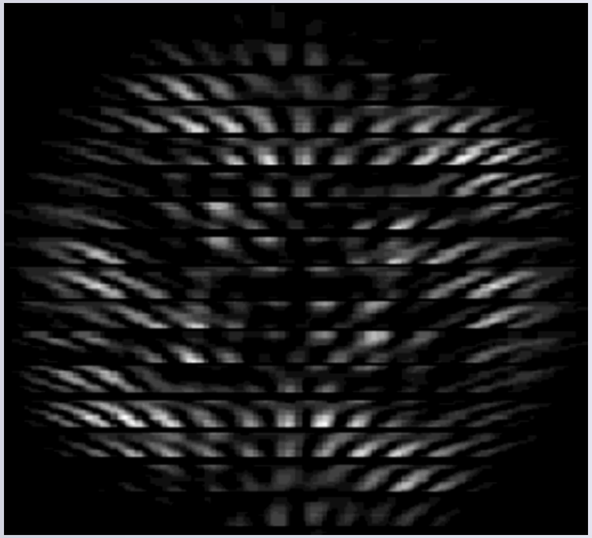


M. Ireland, PAVO wiki

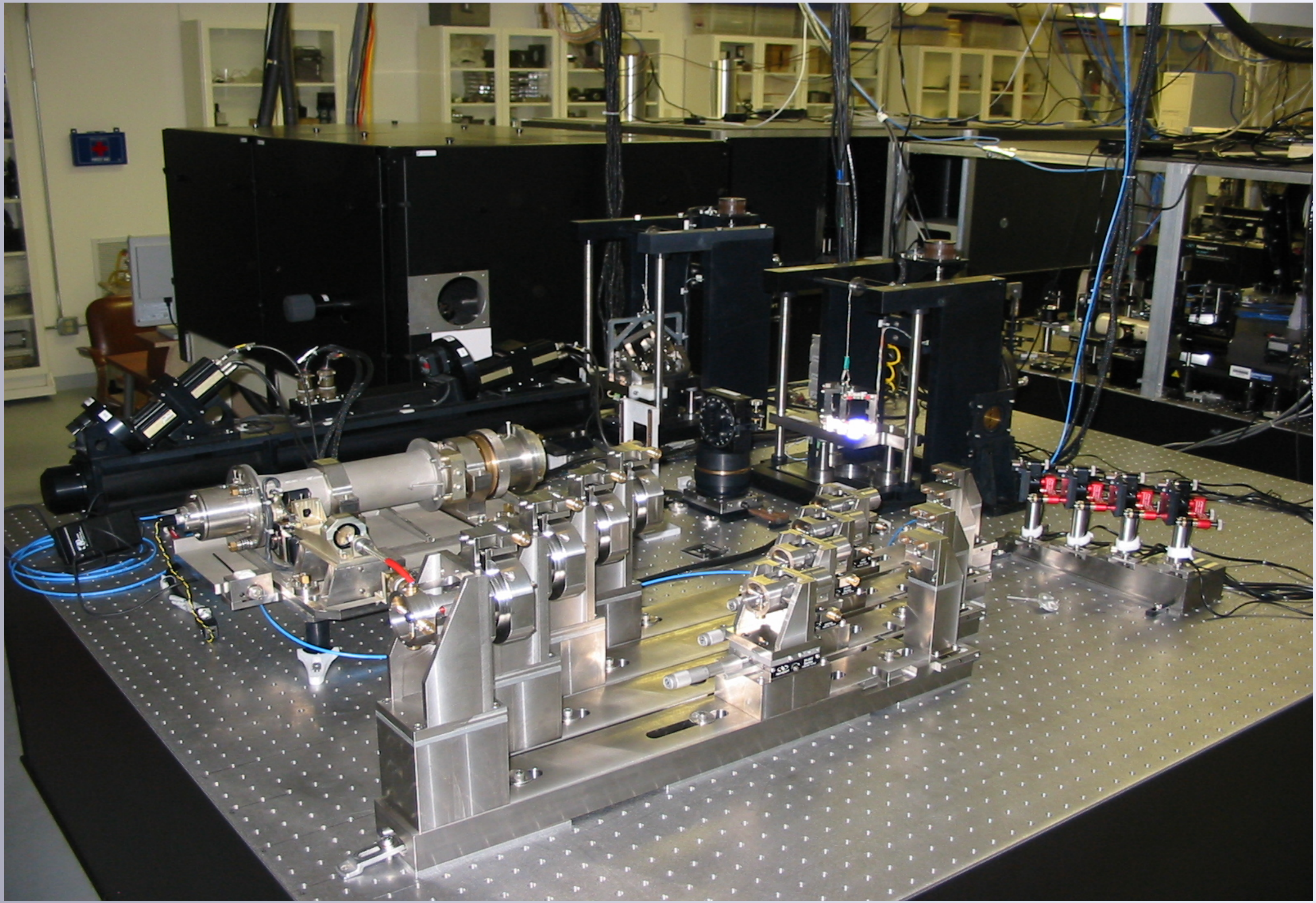
PAVO

- Design for high sensitivity
- 3 beam combiner - V^2 and closure phase measurements
- λ = 620-950nm, R~50
- Pupil-plane fringes
- IFU (Integral Field Unit) turns fringes into data cube = > one image of the fringes at each λ
- Group delay tracking

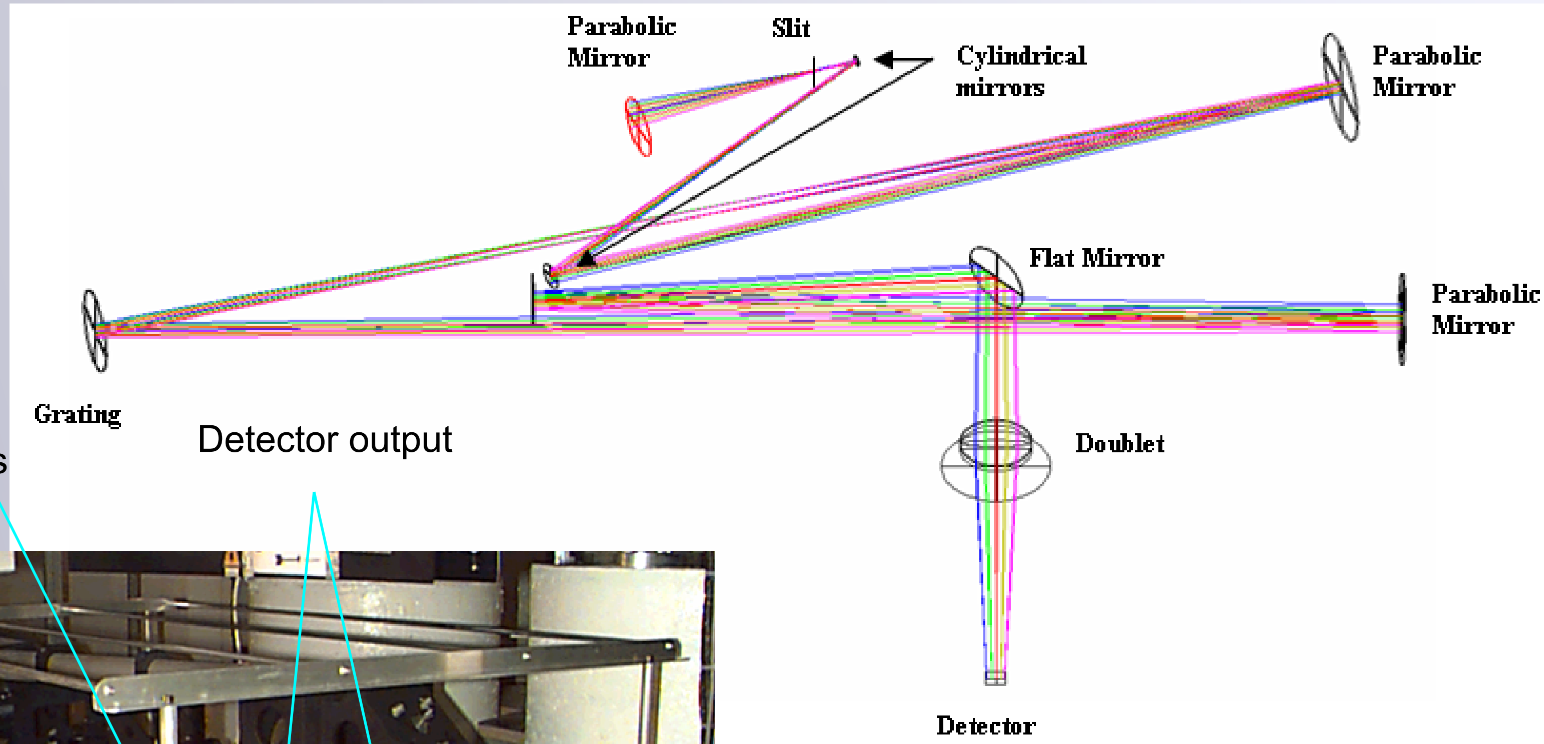


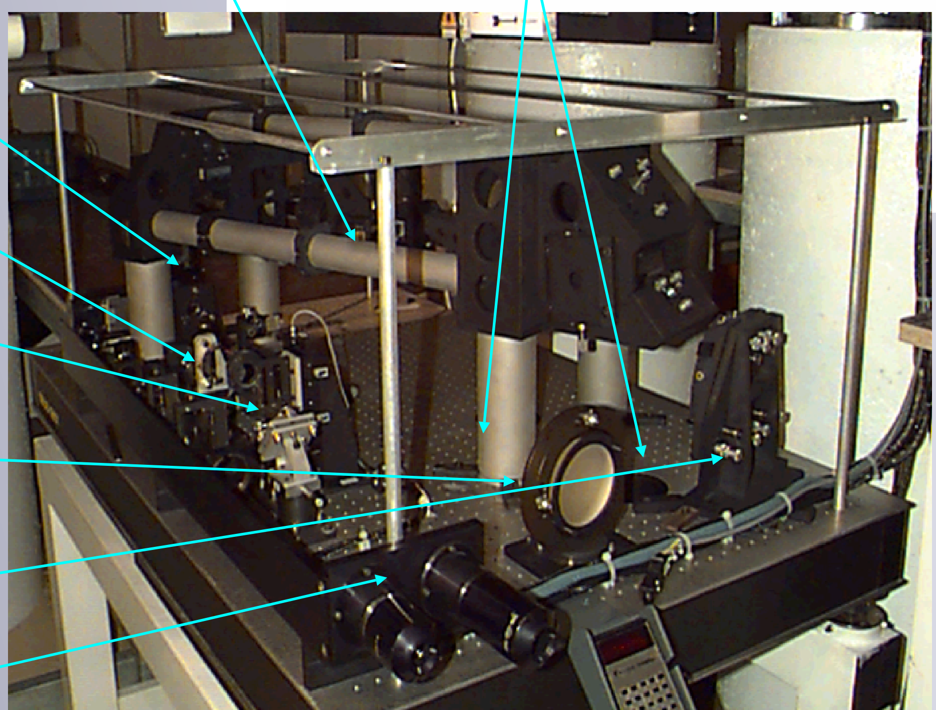


VEGA
Visible spEctroGraph and polArimeter



VEGA spectrograph



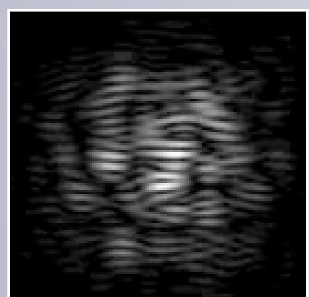


D. Mourard, SPIE 2008

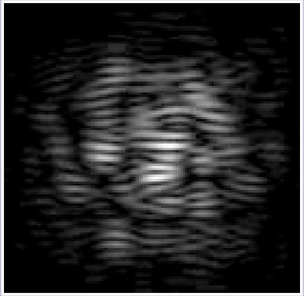
VEGA

- 2 to 4 beam combiner
- 3T/4T modes -> V^2 and closure phase measurements
- two photon counting detectors looking at two different spectral bands simultaneously
- optical design allows simultaneous recording of data, in medium spectral resolution, of the spectral region around Hα with the red detector and around Hβ with the blue detector
- a polarimeter can be placed just before the spectrograph grating

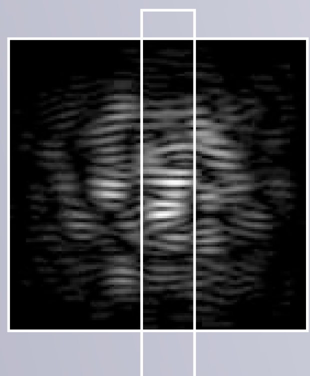
Principle of the VEGA Interferometric Spectrograph



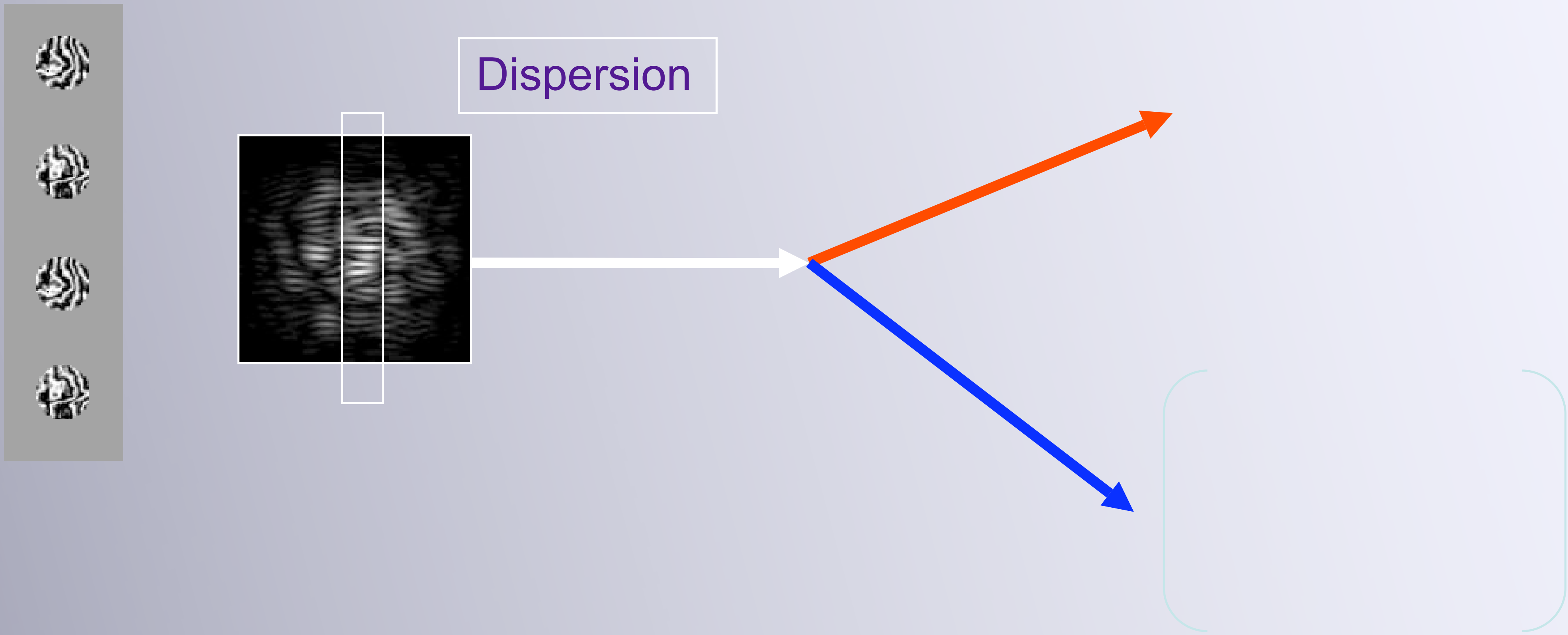
Principle of the VEGA Interferometric Spectrograph



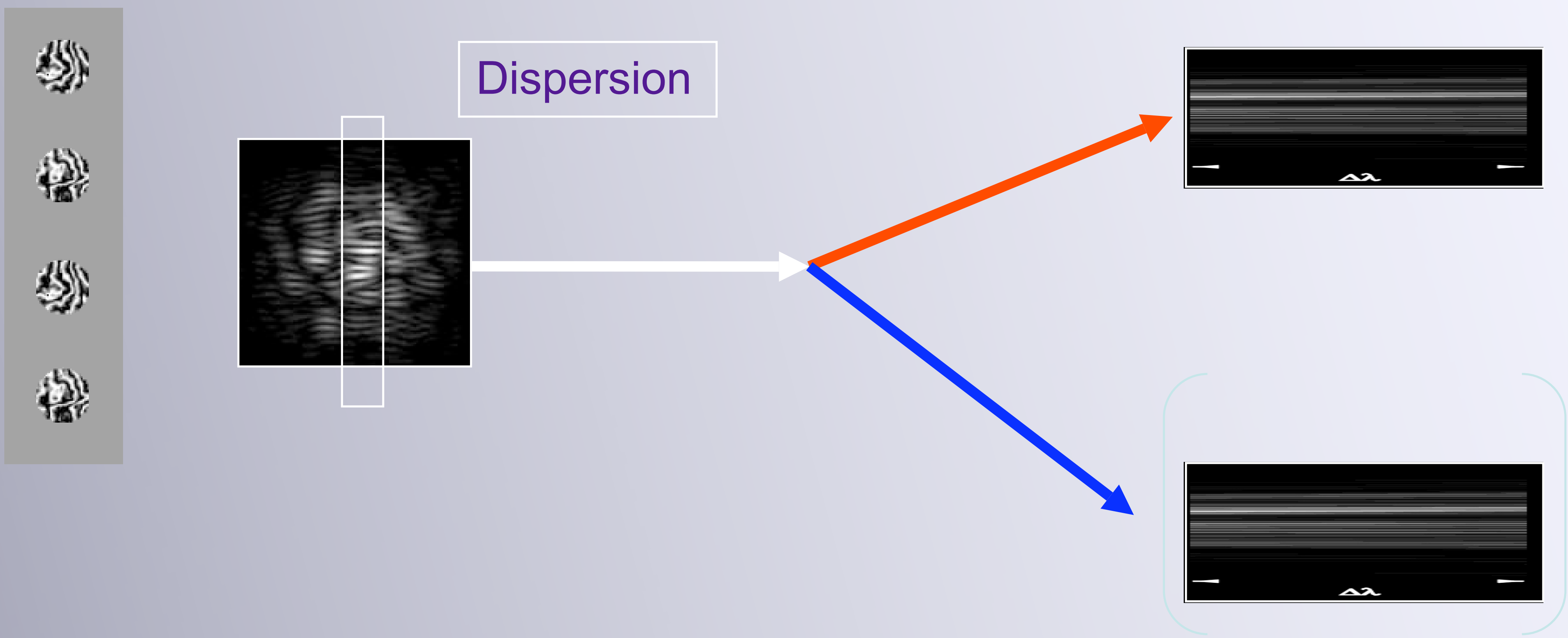
Principle of the VEGA Interferometric Spectrograph



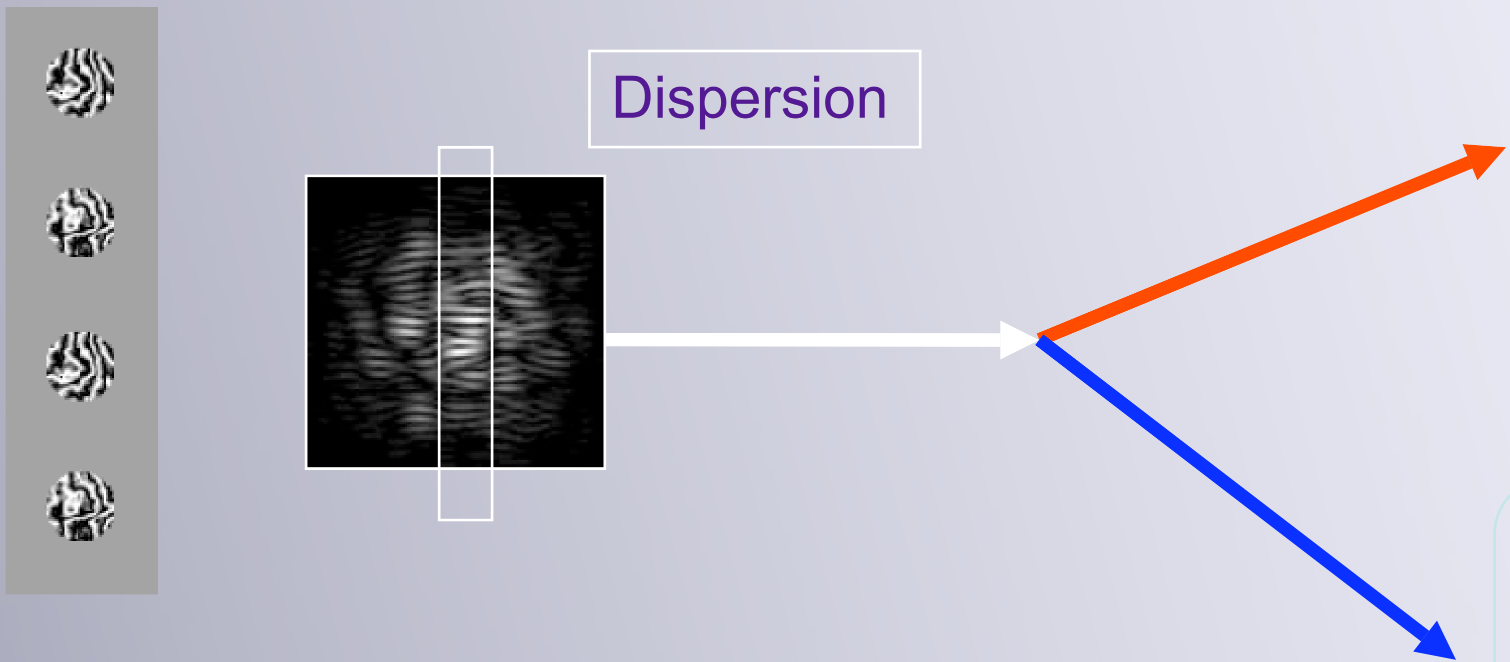
Principle of the VEGA Interferometric Spectrograph



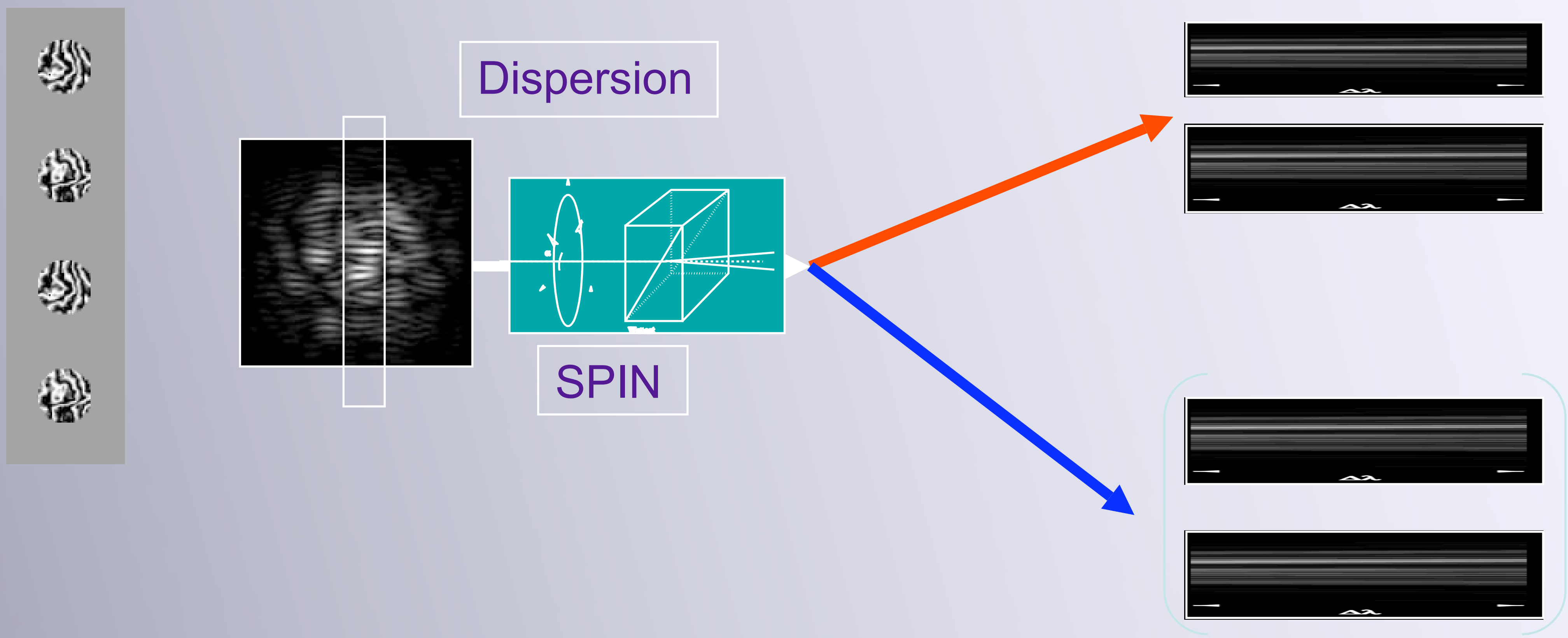
Principle of the VEGA Interferometric Spectrograph



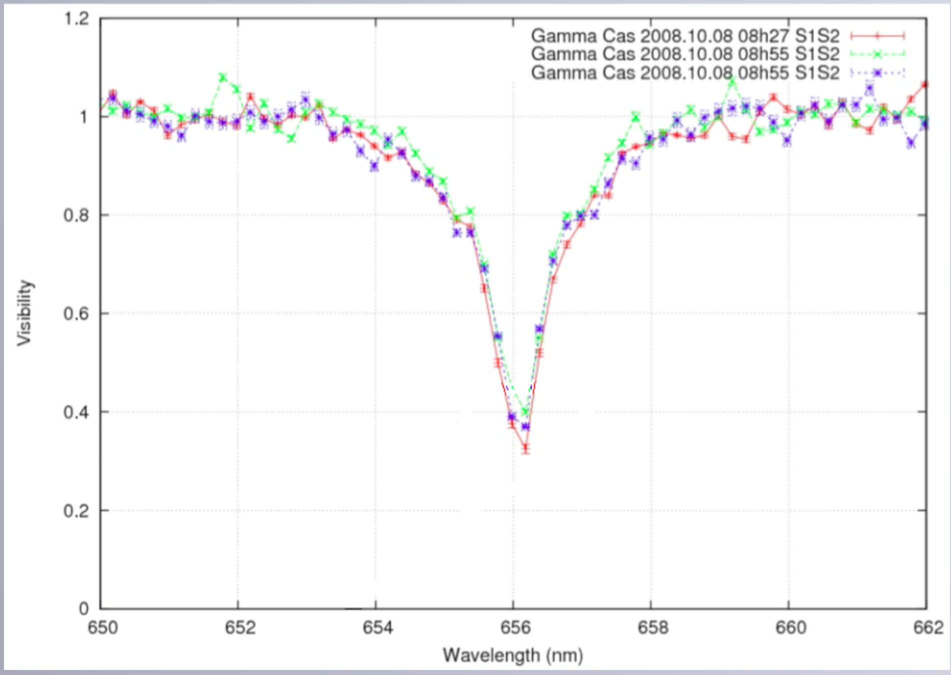
Principle of the VEGA Interferometric Spectrograph

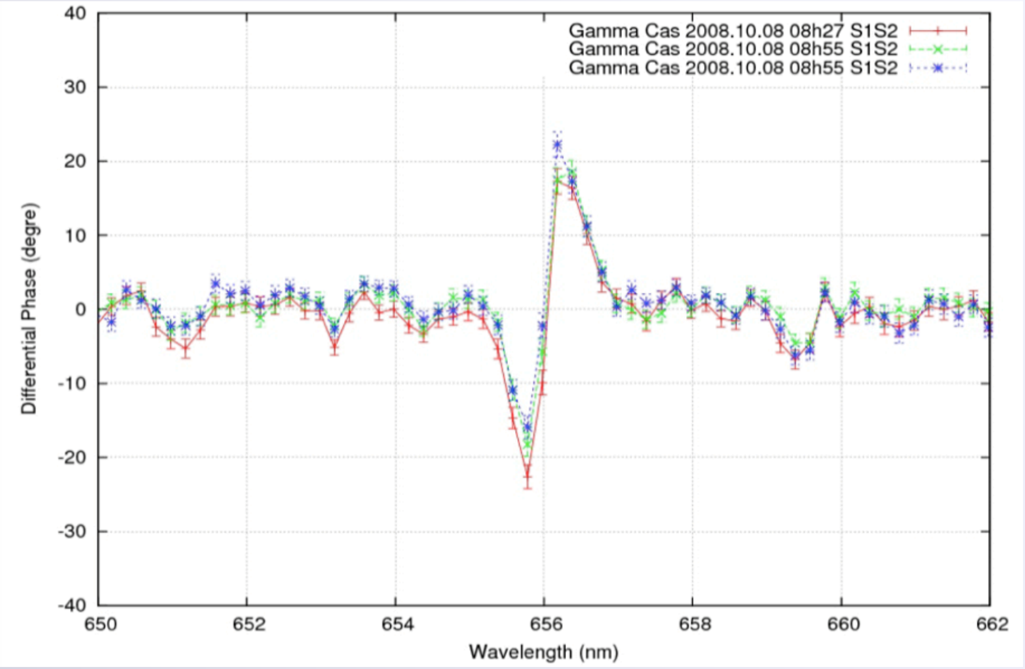


Principle of the VEGA Interferometric Spectrograph



γCas results around the Hα line





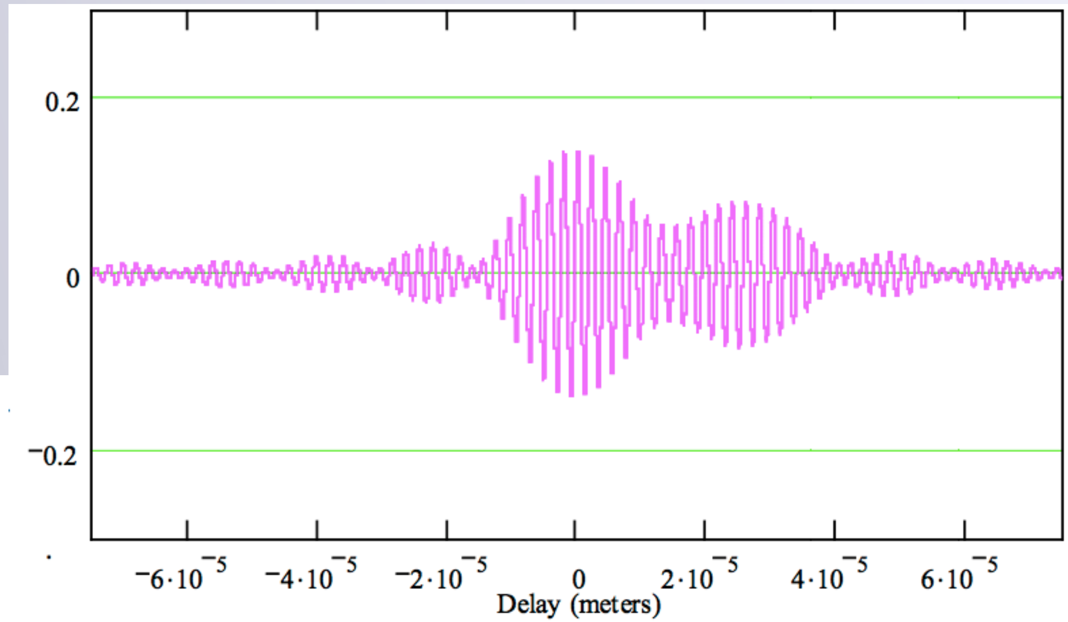
BC's summary

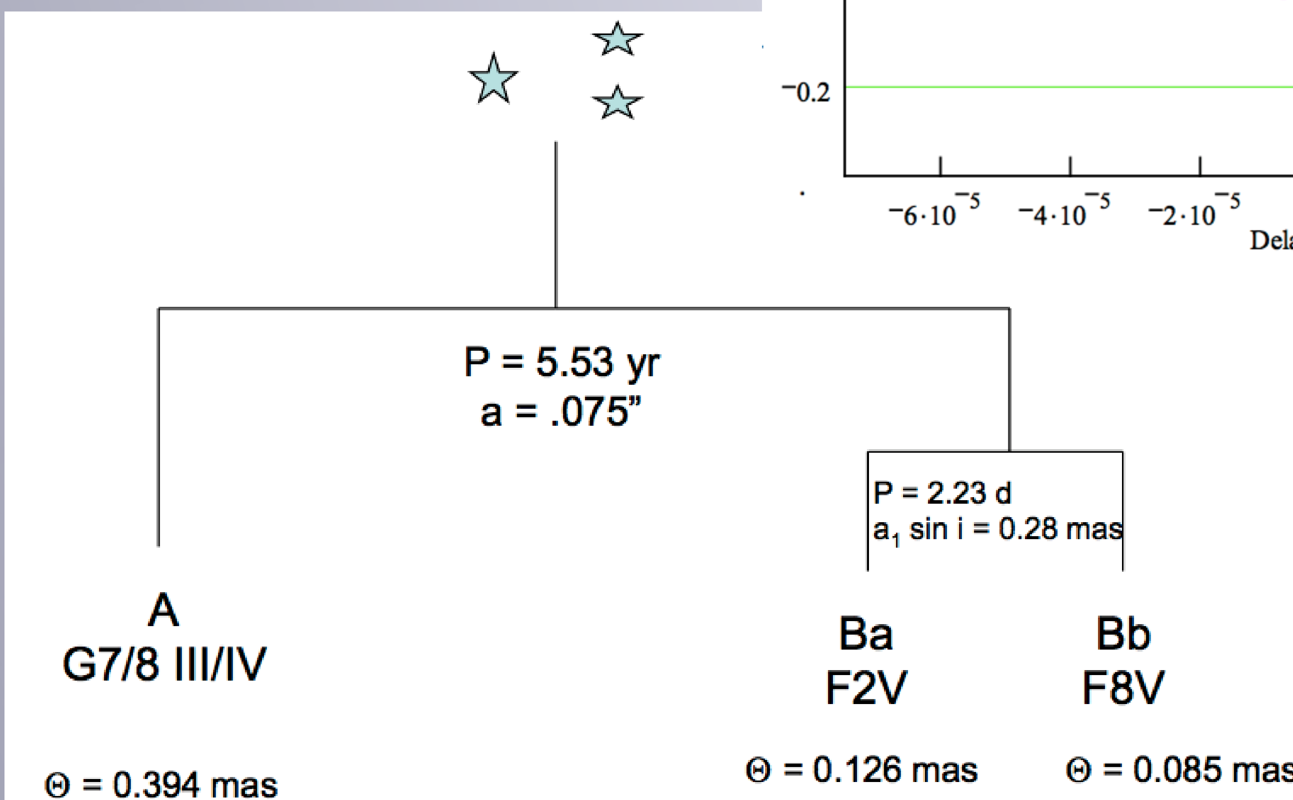
Instruments	Faintest magnitude reached	Wavelength λ [μm]	R (λ/Δλ)	Visibility accuracy	Closure phase Accuracy [°]
Classic	7.5	1.50 - 2.50	N/A	5-10%	N/A
CLIMB	--	1.50 - 2.50	--	--	--
FLUOR	6.0	2.20	N/A	1%	N/A
MIRC	4.5	1.50 - 2.40	40, 150, 400	≳10%	0.1-0.5
PAVO	8.2	0.66 - 0.95	40	2%	--
VEGA	7.5 (LR) 5.5 (HR)	0.45 - 0.90	1700, 6000, 30000	3%	--

CHARA science

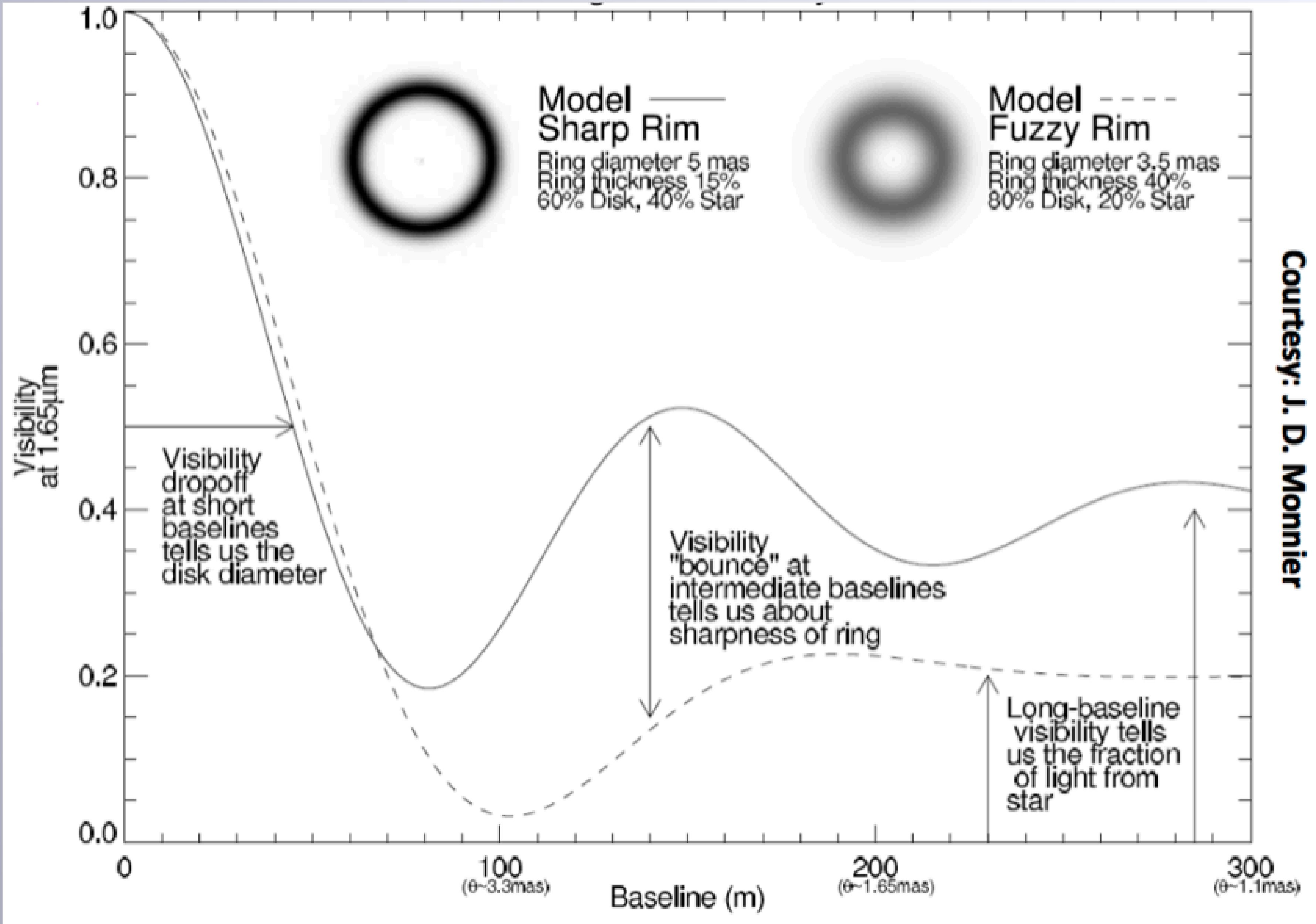
CHARA classic
Separate fringe packet observations

HD 157482 (V819 Her), David O'Brien



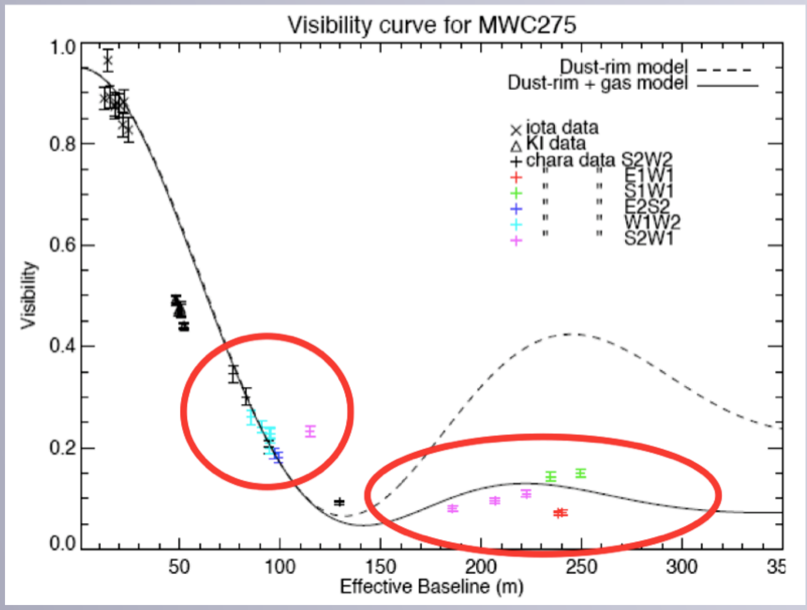


Classic
Young Stellar Objects at CHARA

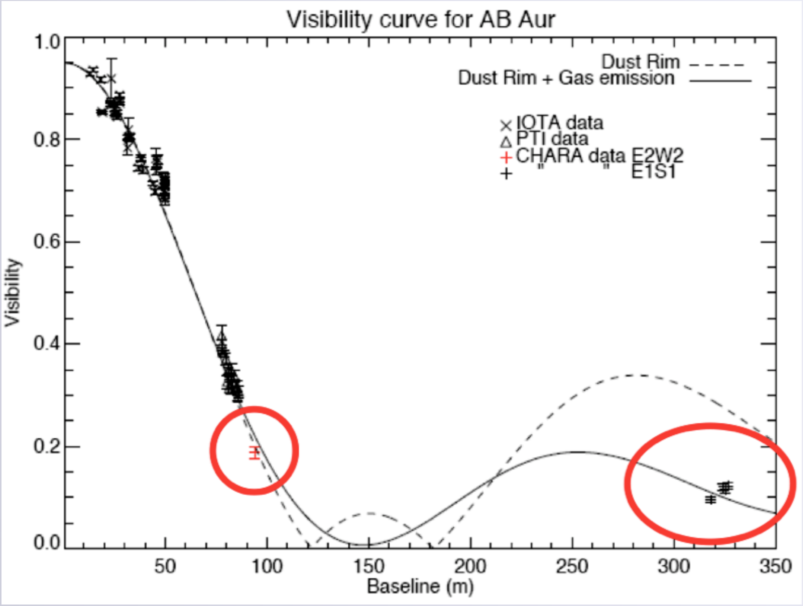


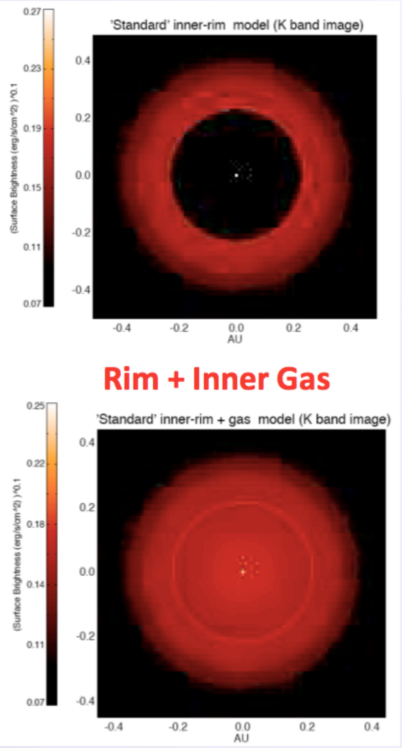
Classic
Young Stellar Objects at CHARA

MWC275: K=4.7, A1 Herbig Ae



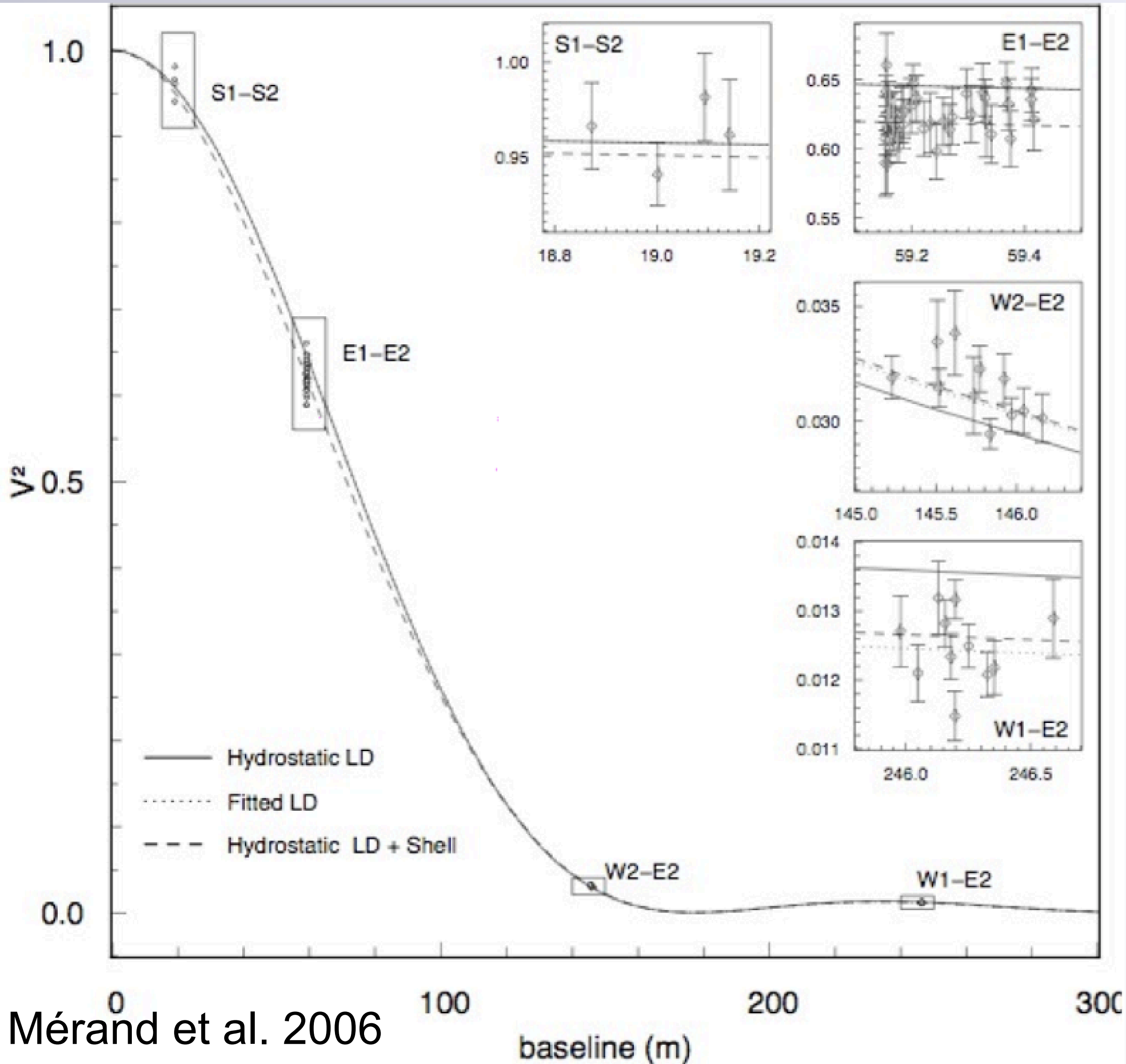
AB Aur: K=4.4, A0 Herbig Ae





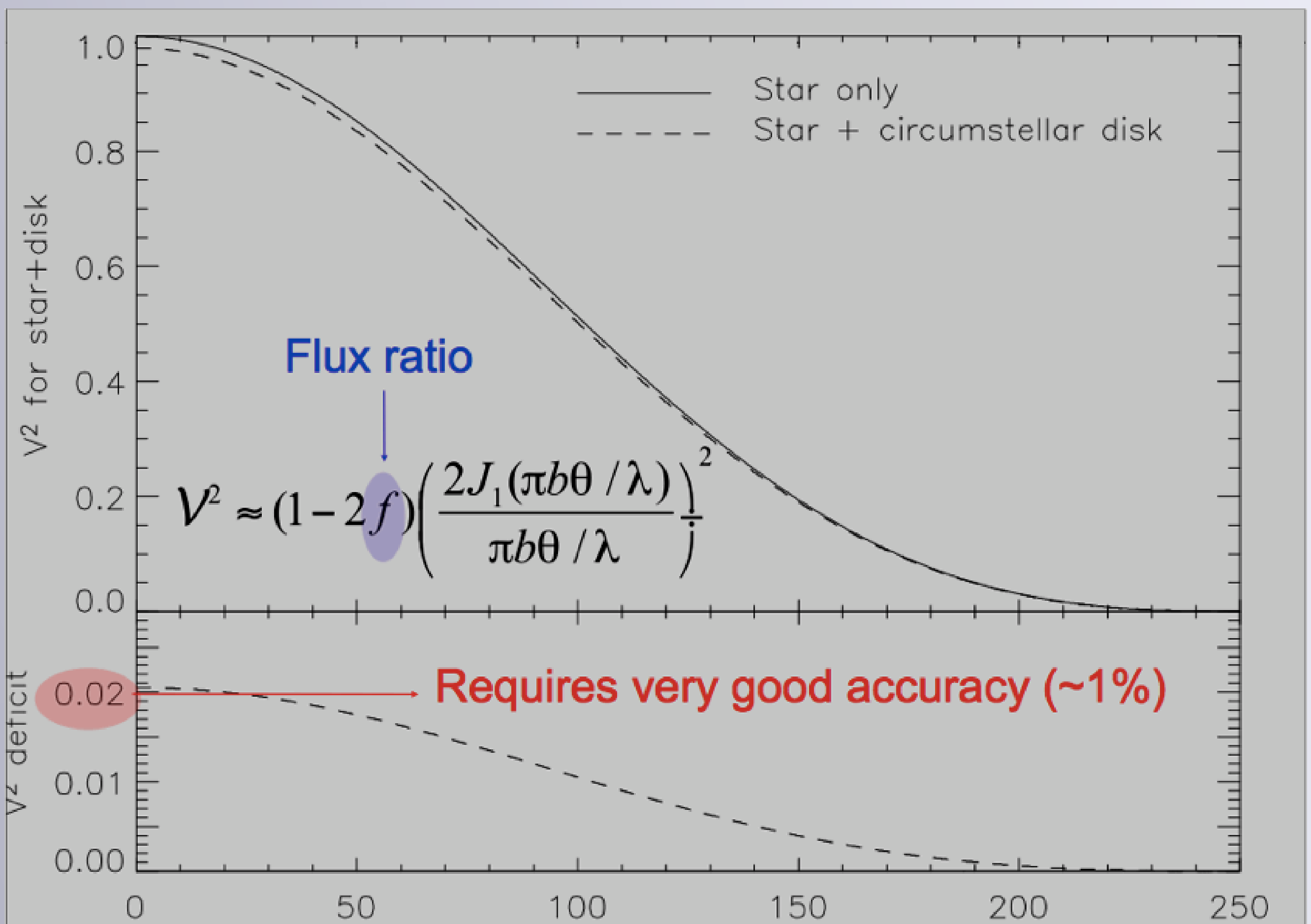
A. Tannirkulam, 2008

Polaris - very low amplitude Cepheid



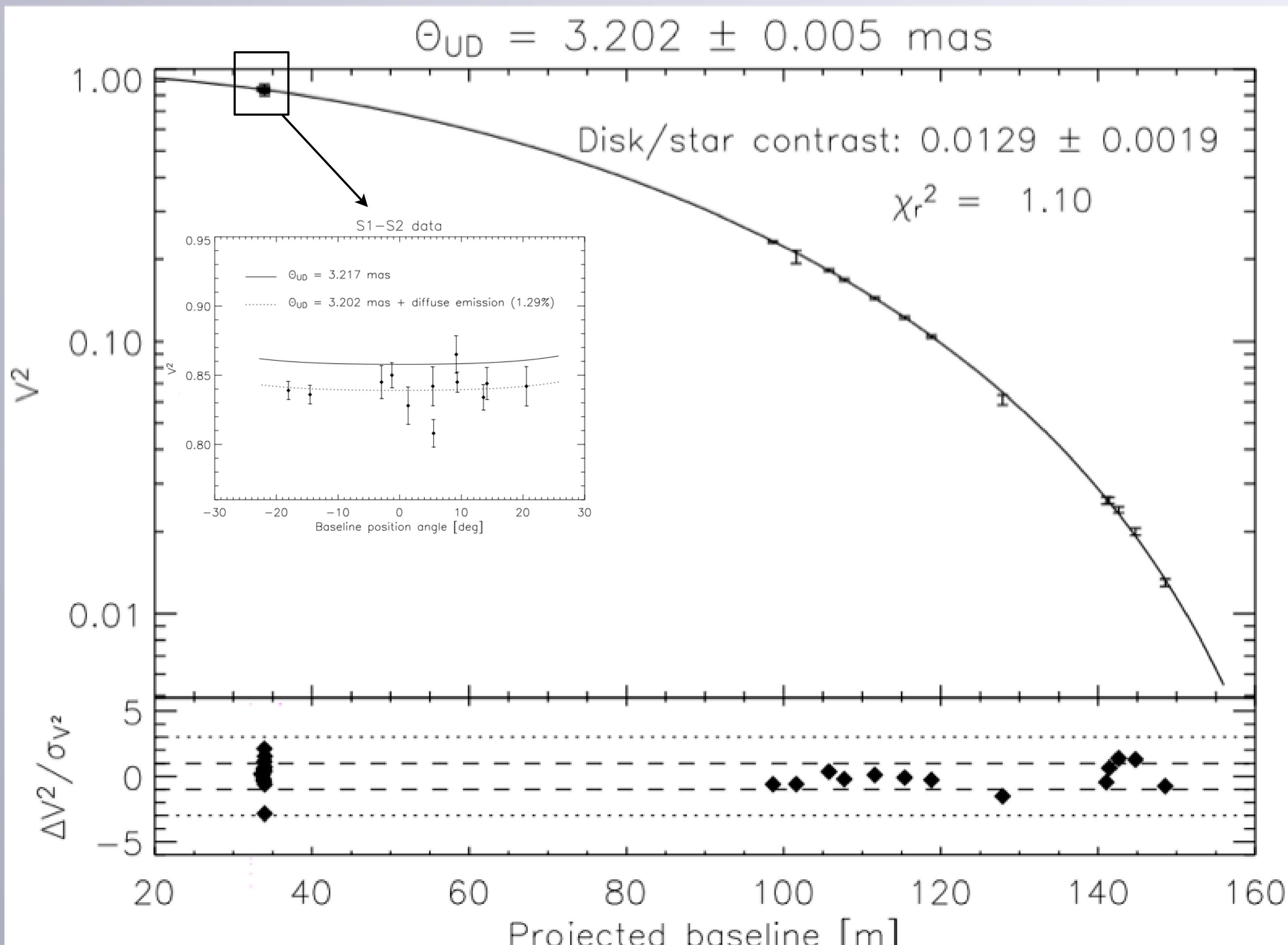
Mérand et al. 2006

- Detection of the hot dust (1000-1500K) in inner debris discs
- Survey of ~40 bright MS stars (K < 4) with known, cold debris discs or not



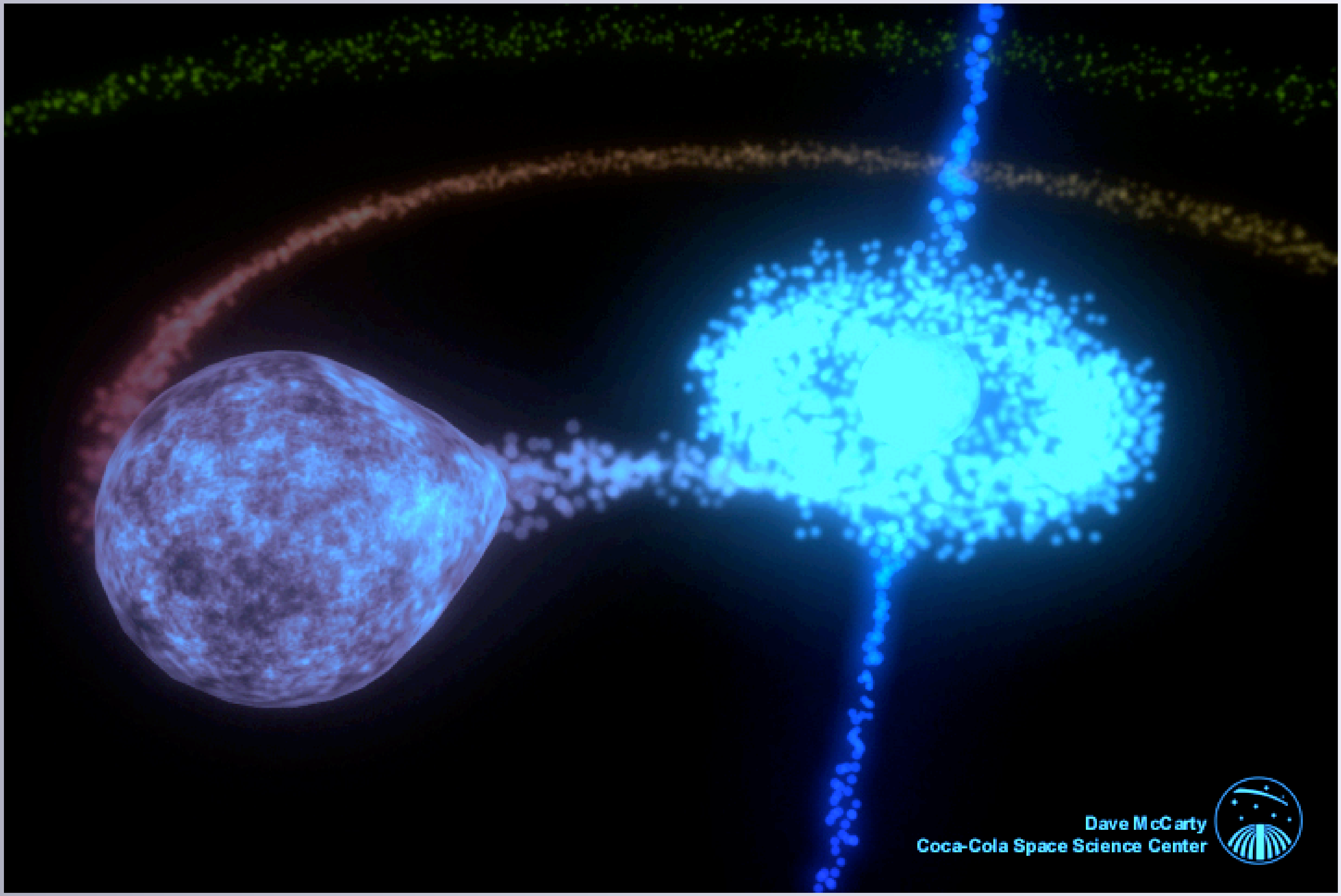
FLUOR
Circumstellar material in the Vega inner system

- Fit of a uniform stellar disk + circumstellar disk



O. Absil, Circumstellar material in the Vega inner system revealed by CHARA/FLUOR, 200

MIRC
The “β Lyrae” system:

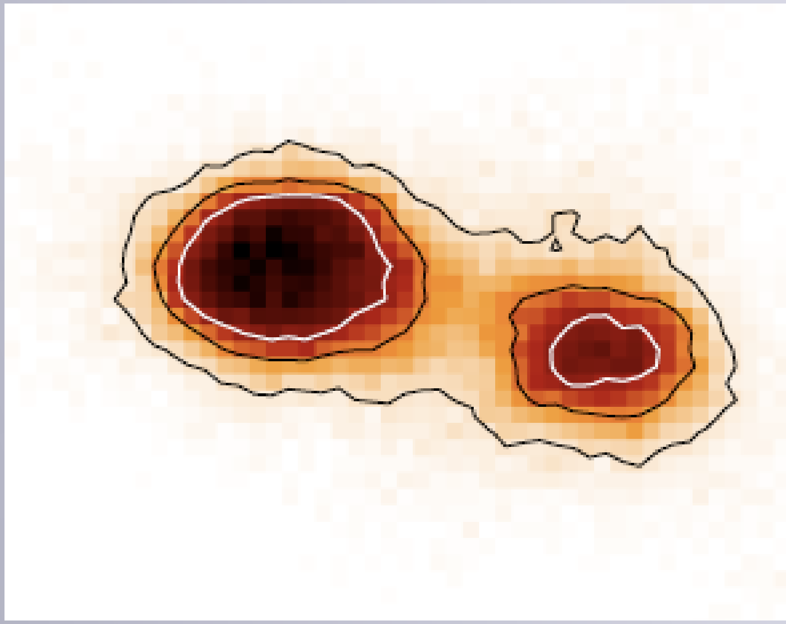


The "β Lyrae" system:

- β Lyrae: interacting and eclipsing binary (period 12.9 days)
- B6-8 II donor + B gainer in a thick disk
- V = 3.52, H = 3.35; distance ~300pc

MIRC
First image of the 12.9-day eclipsing binary β Lyrae

CHARA-MIRC Image



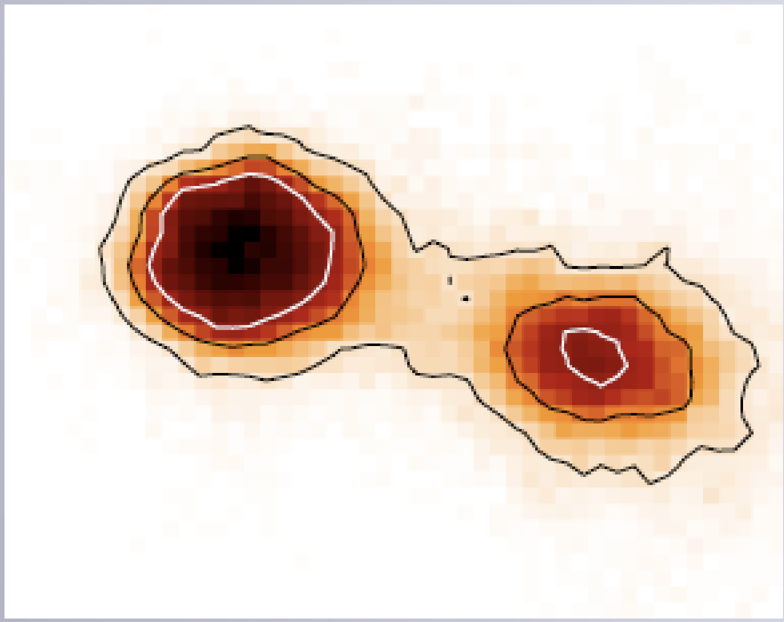
Model

Phase = 0.132

M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

First image of the 12.9-day eclipsing binary β Lyrae

CHARA-MIRC Image



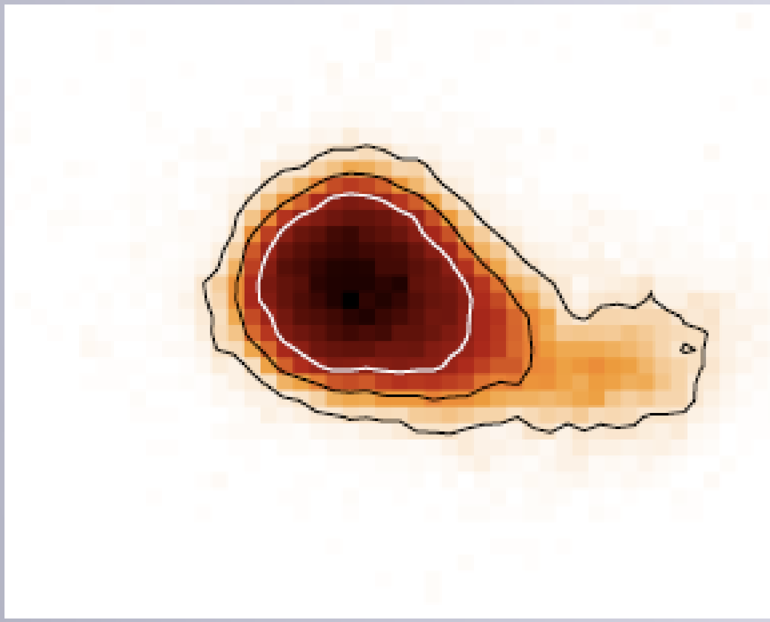
Phase = 0.210

Model

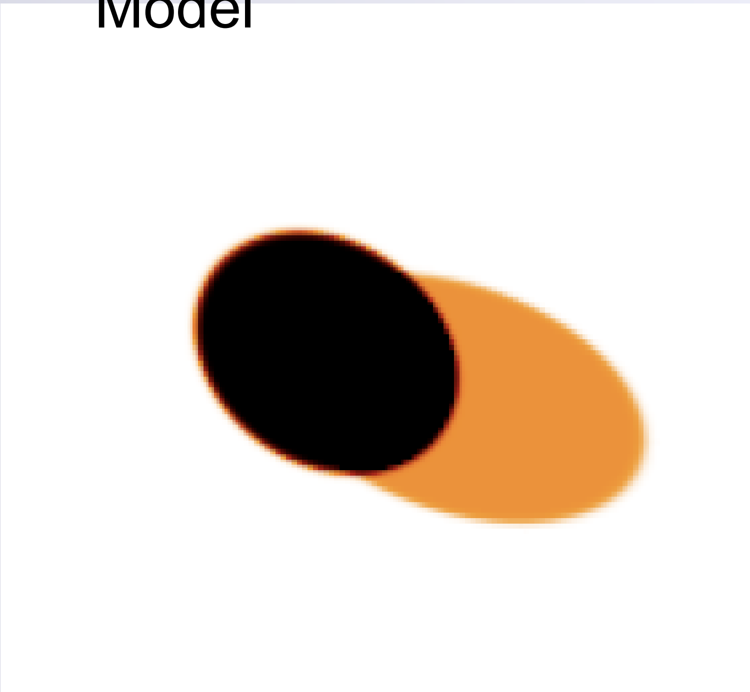
M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

First image of the 12.9-day eclipsing binary β Lyrae

CHARA-MIRC Image



Model

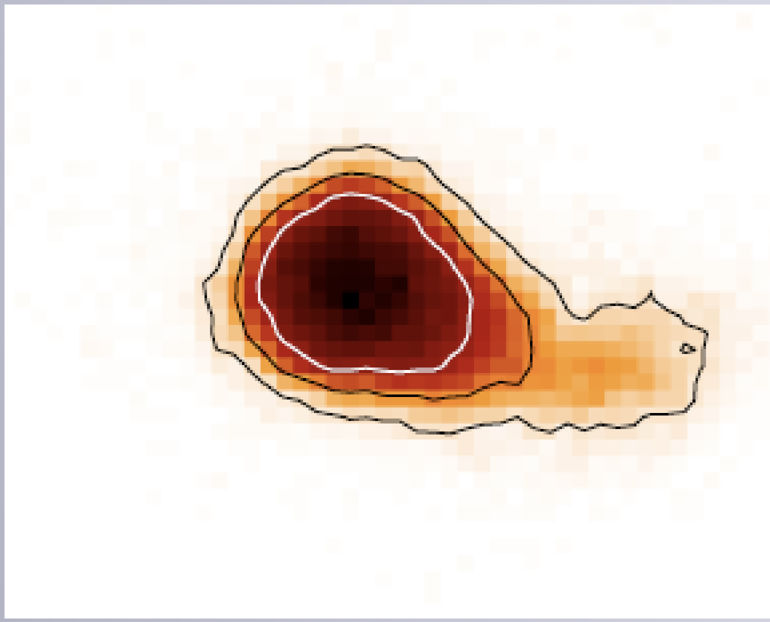


Phase = 0.438

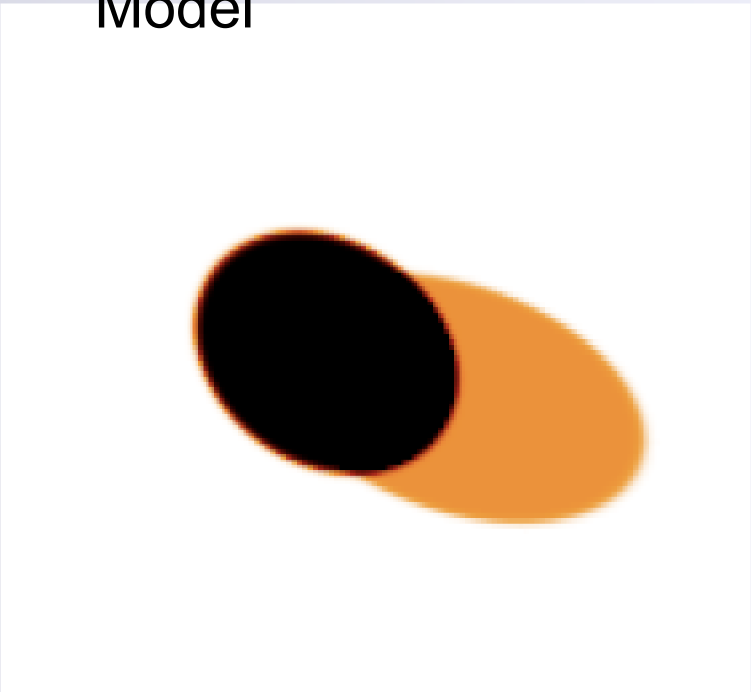
M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

First image of the 12.9-day eclipsing binary β Lyrae

CHARA-MIRC Image



Model

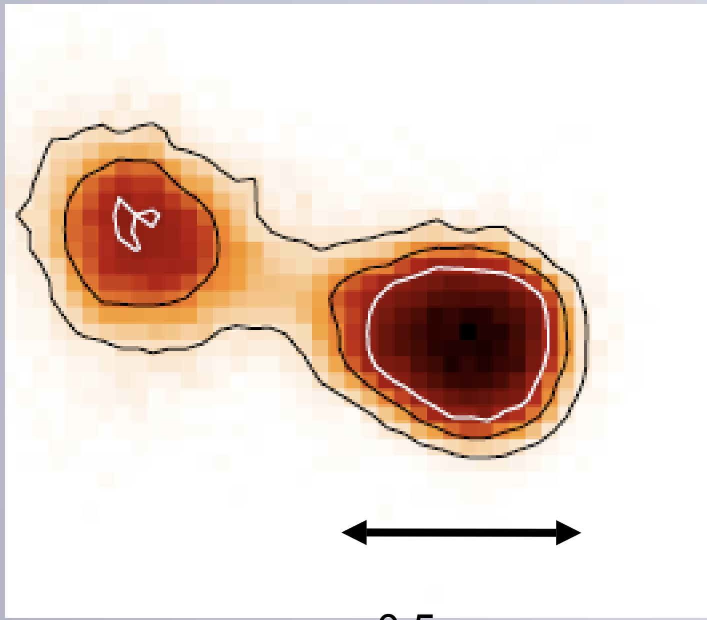


Phase = 0.438

M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

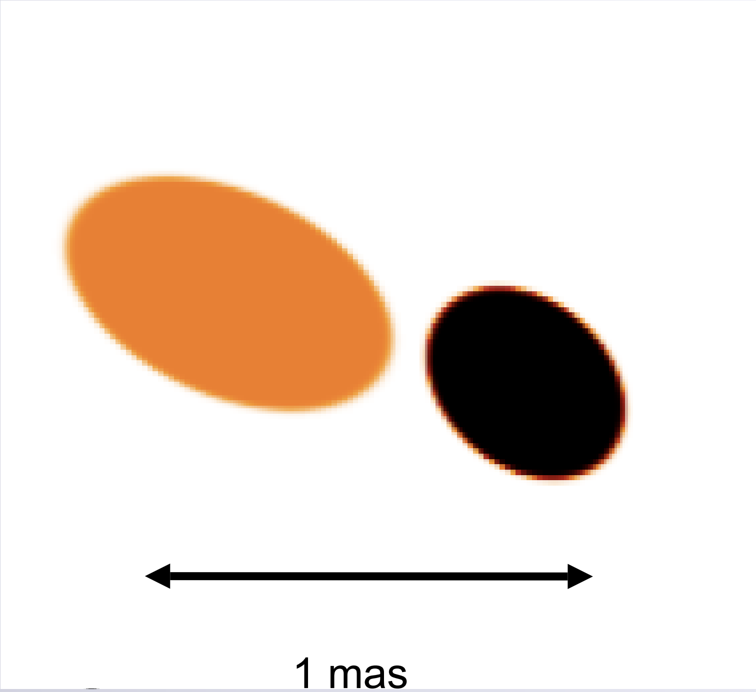
MIRC
First image of the 12.9-day eclipsing binary β Lyrae

CHARA-MIRC Image



0.5 mas

Model



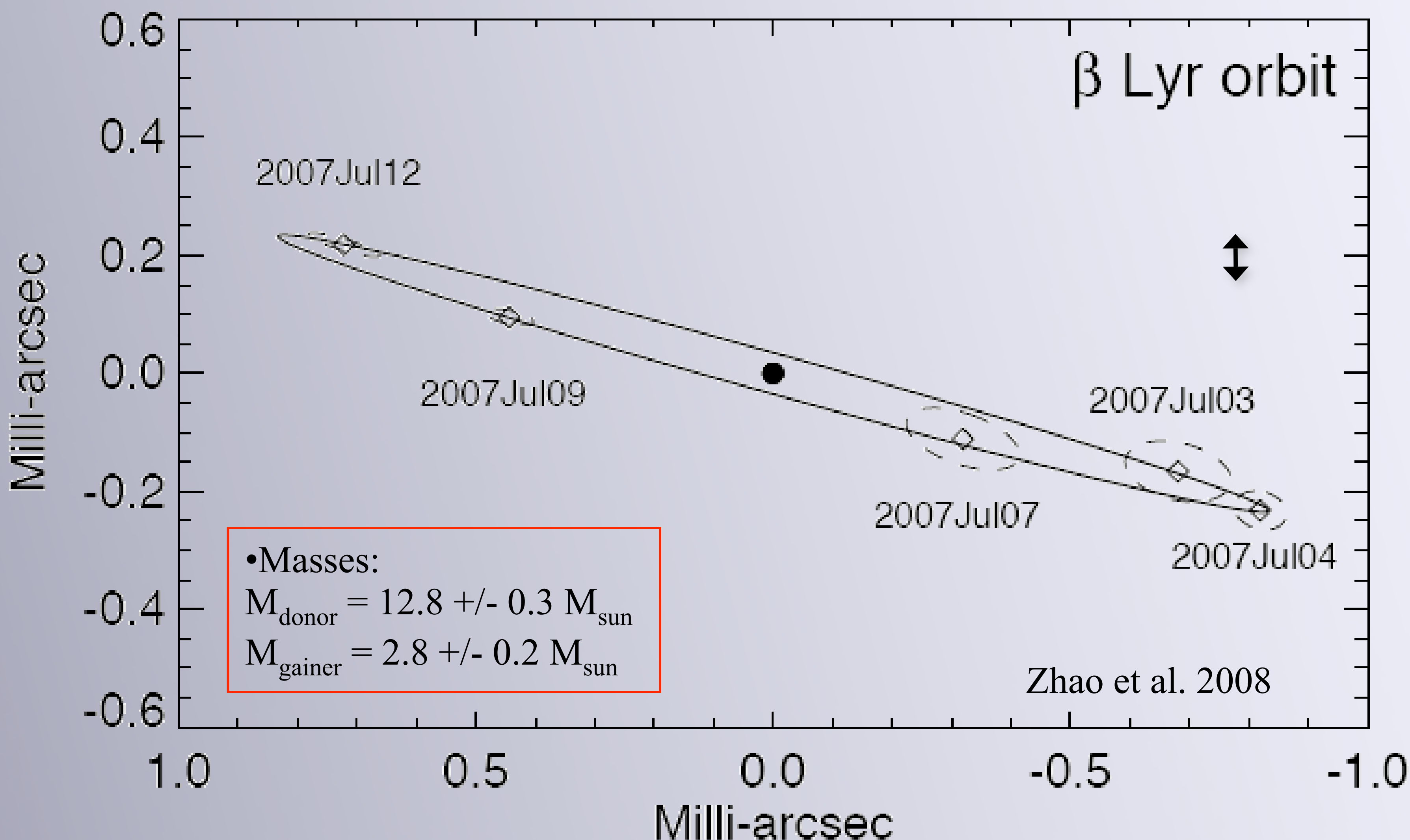
1 mas

Phase = 0.828

Zhao et al. 2008

M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

First astrometric orbit of β Lyrae



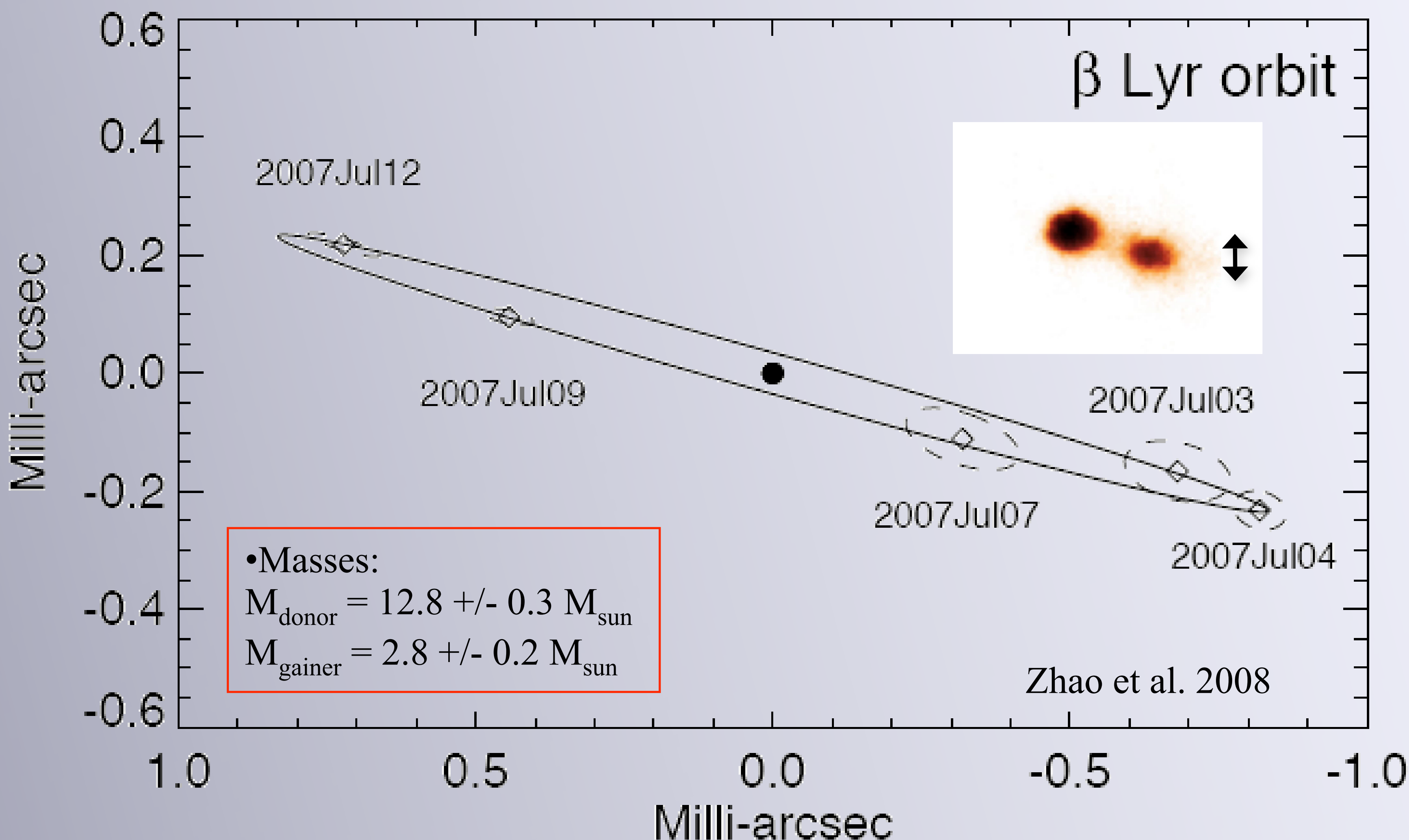
- Masses:

M_{donor} = 12.8 +/- 0.3 M_{sun}

M_{gainer} = 2.8 +/- 0.2 M_{sun}

M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

First astrometric orbit of β Lyrae



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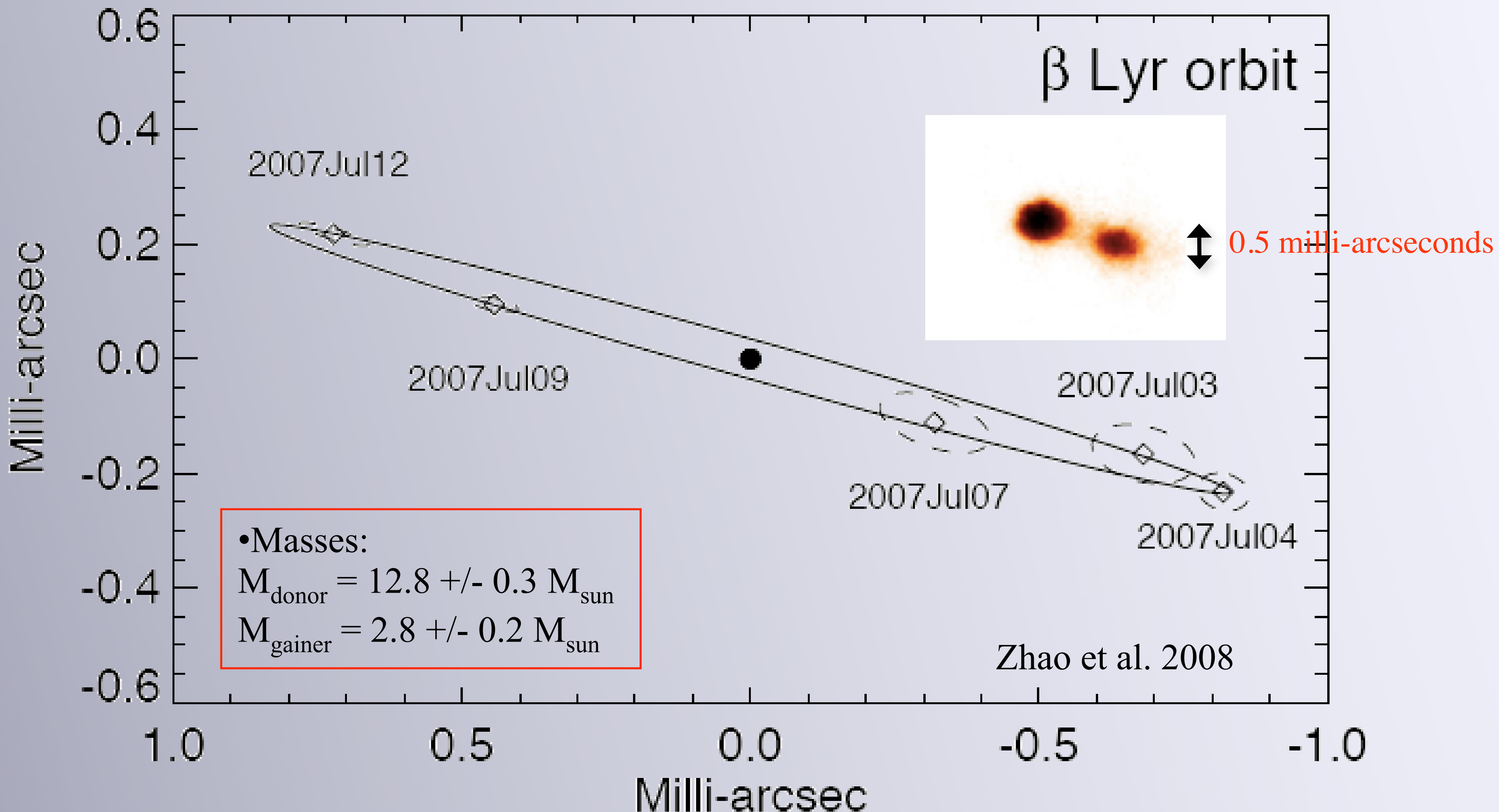
M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

First astrometric orbit of β Lyrae



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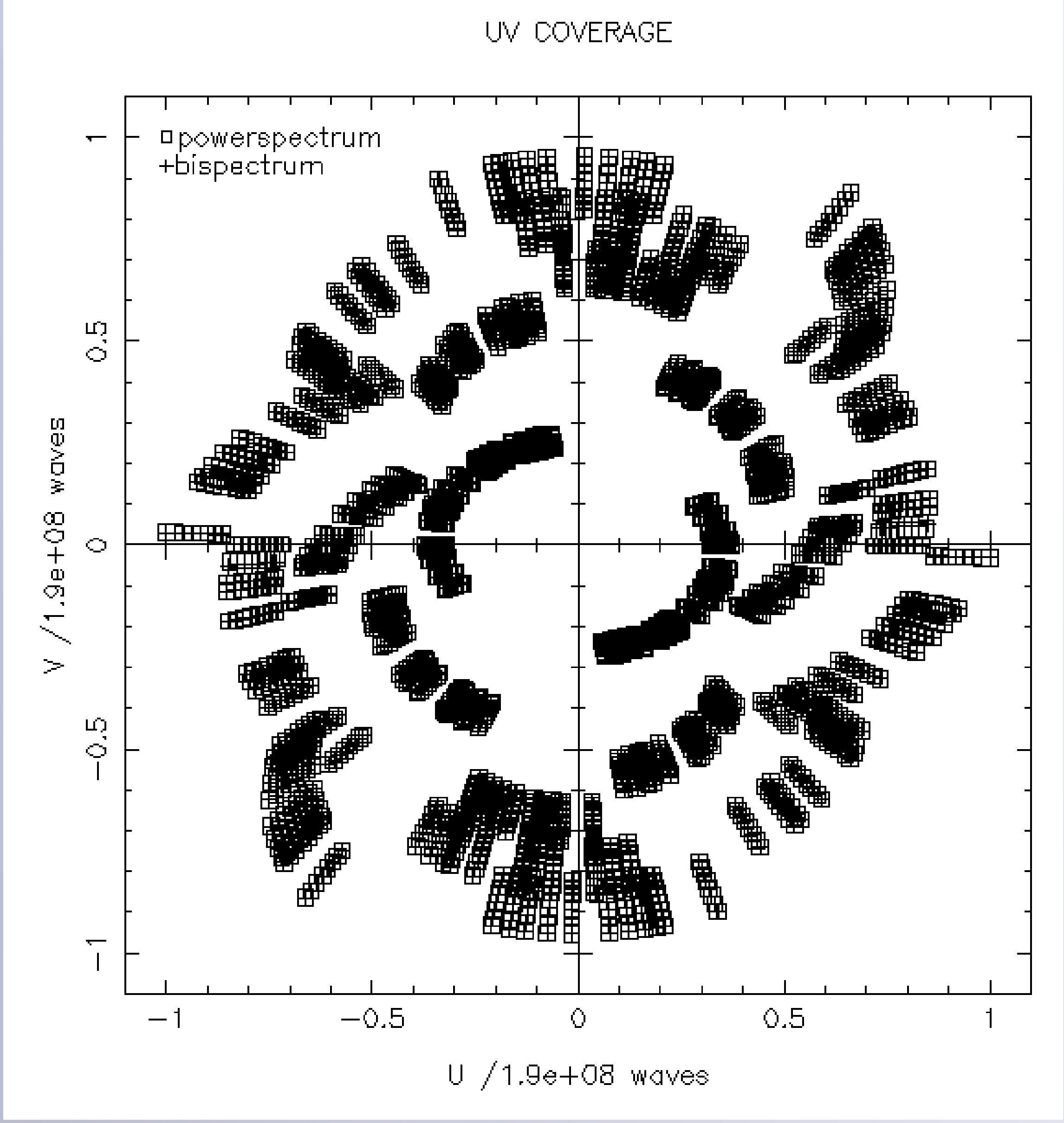
M_{donor} = 12.8 +/- 0.3 M_{sun}

M_{gainer} = 2.8 +/- 0.2 M_{sun}

M. Zhao, First resolved images of the eclipsing and interacting binary β Lyrae, 2008

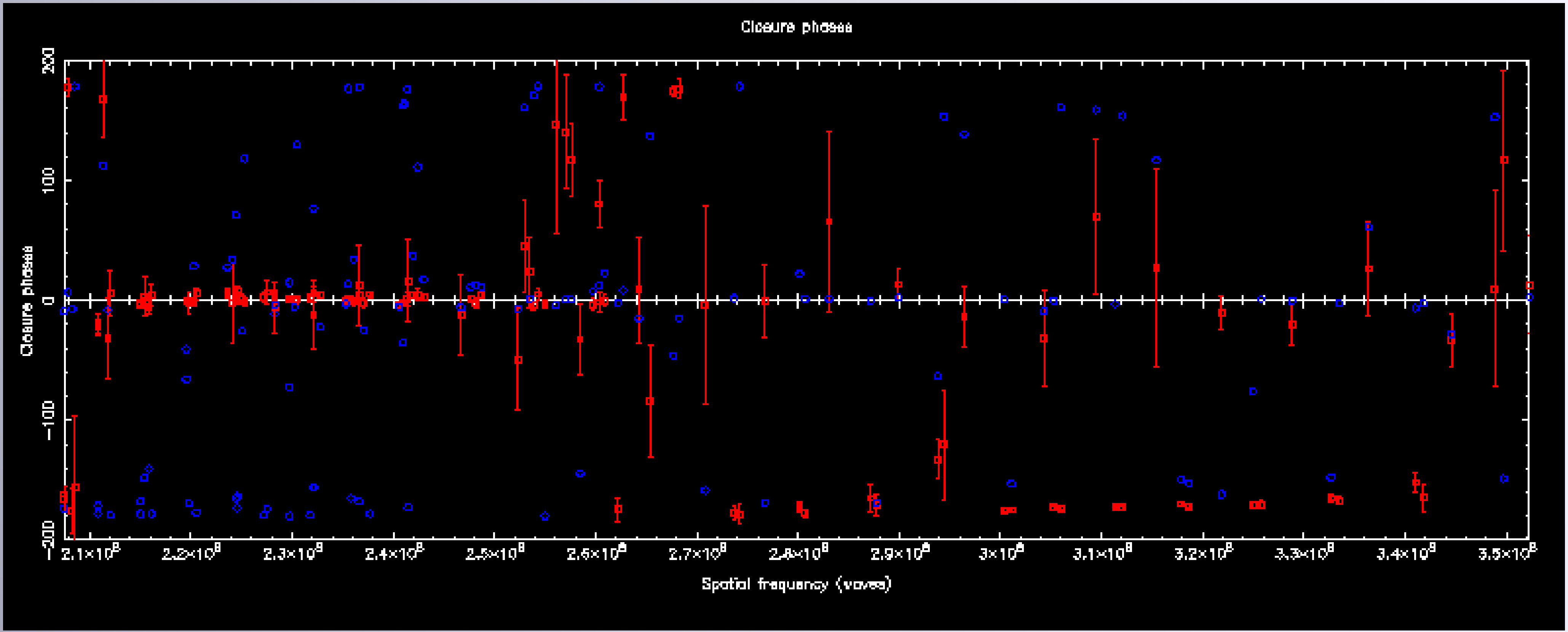
http://spitzer.caltech.edu/news/1036-ssc2010-01-Centuries-Old-Star-Mystery-Coming-to-a-Close

MIRC
uv coverage 2 configs per night (repeated 3 nights)



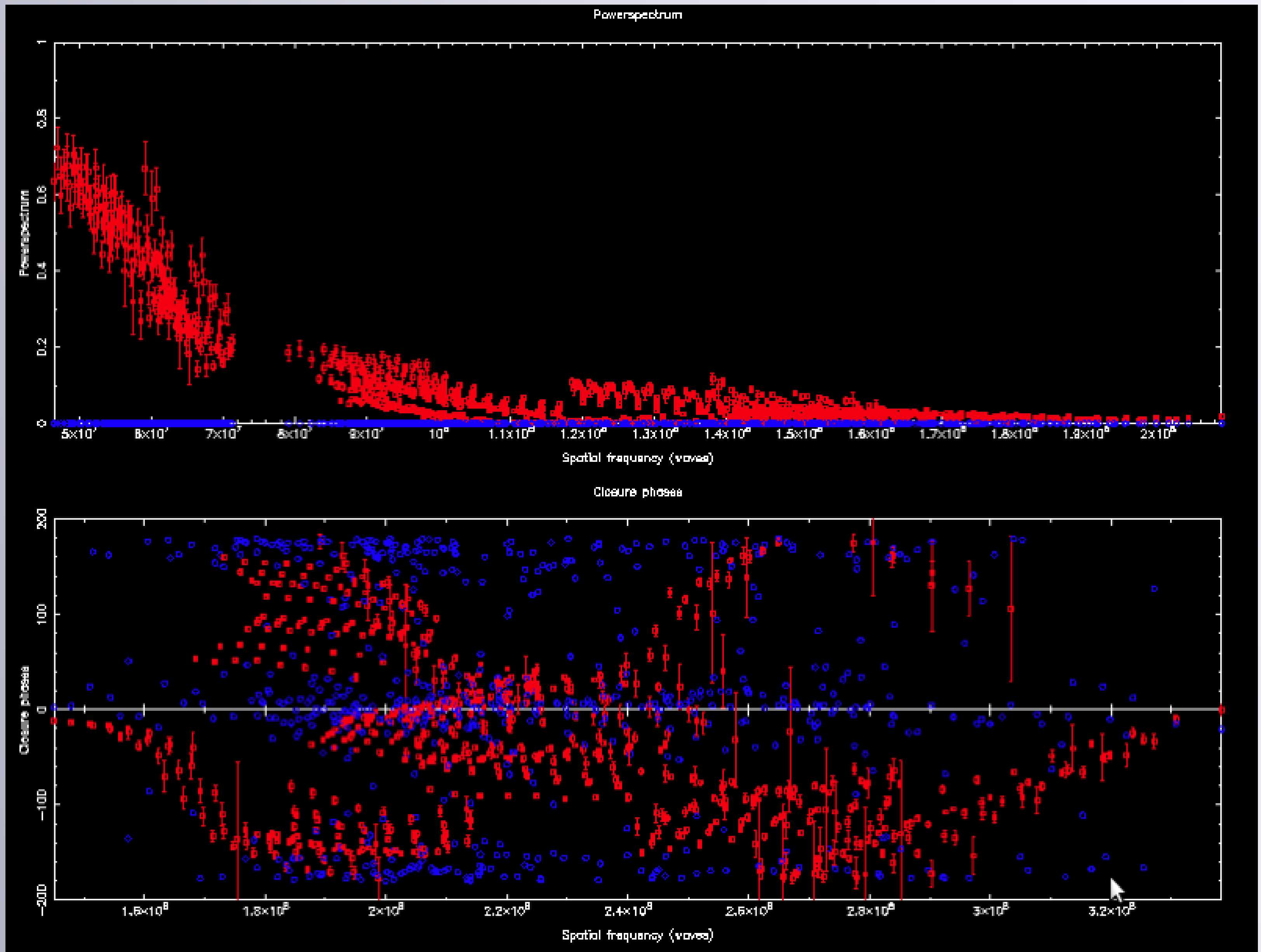
Credits: John Monnier

MIRC
CP pre-eclipse

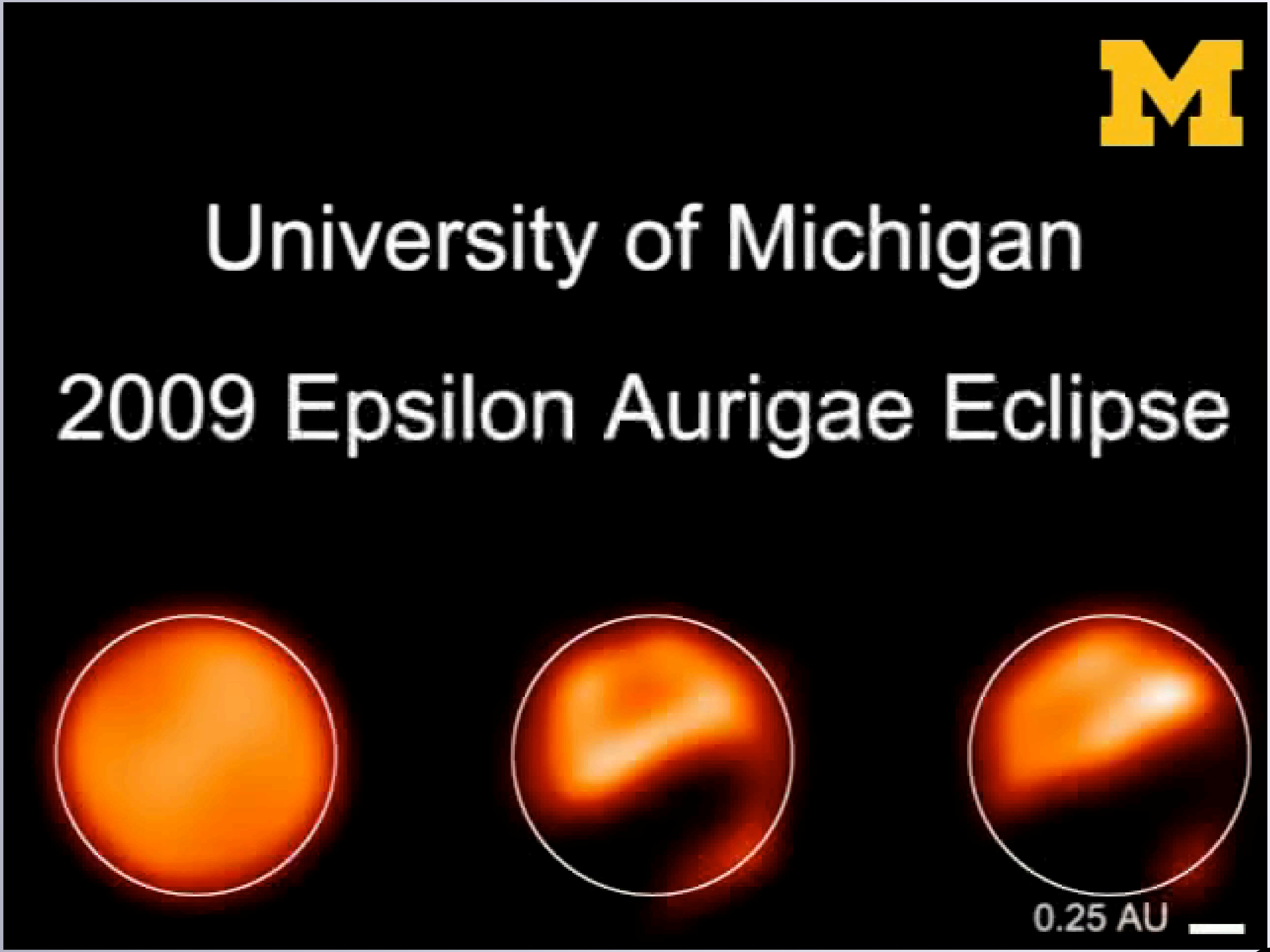


Credits: Brian Kloppenborg

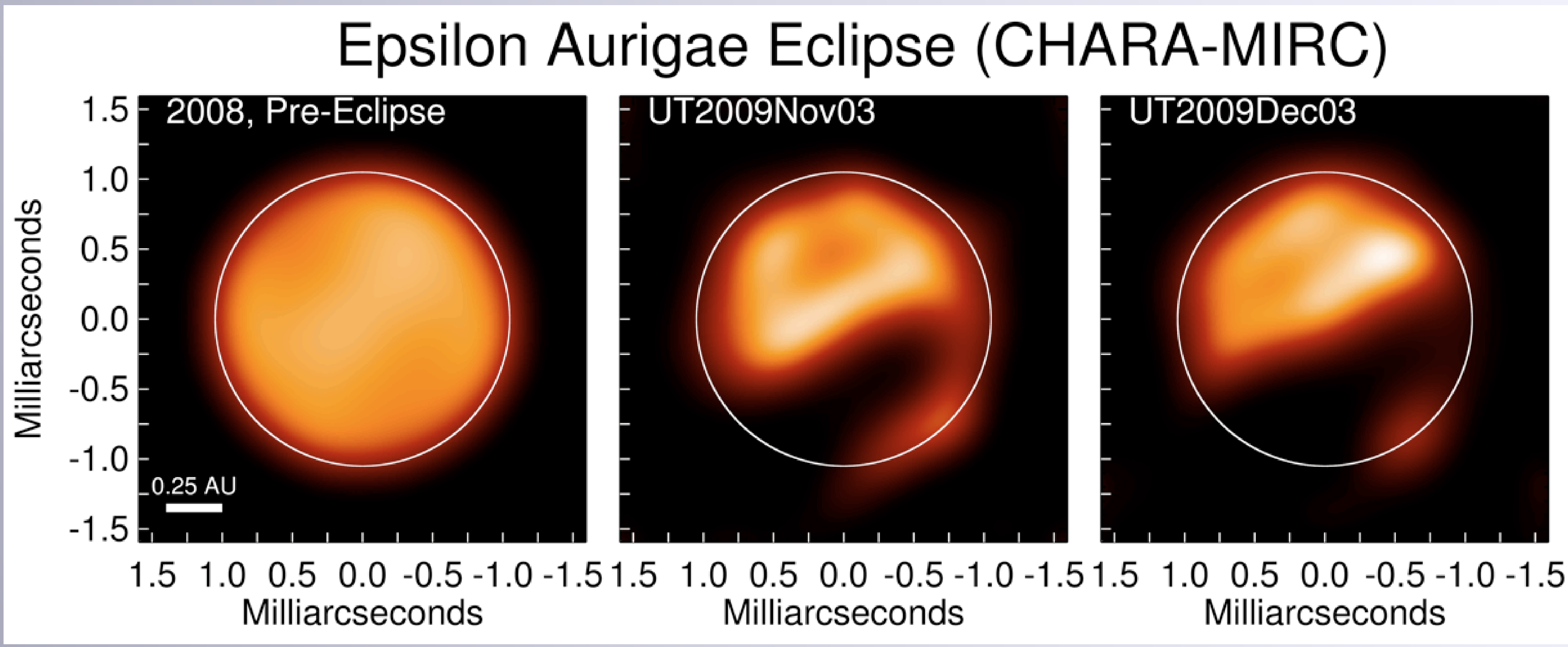
MIRC
Visibility and CP in eclipse



Credits: Brian



Credits: John Monnier



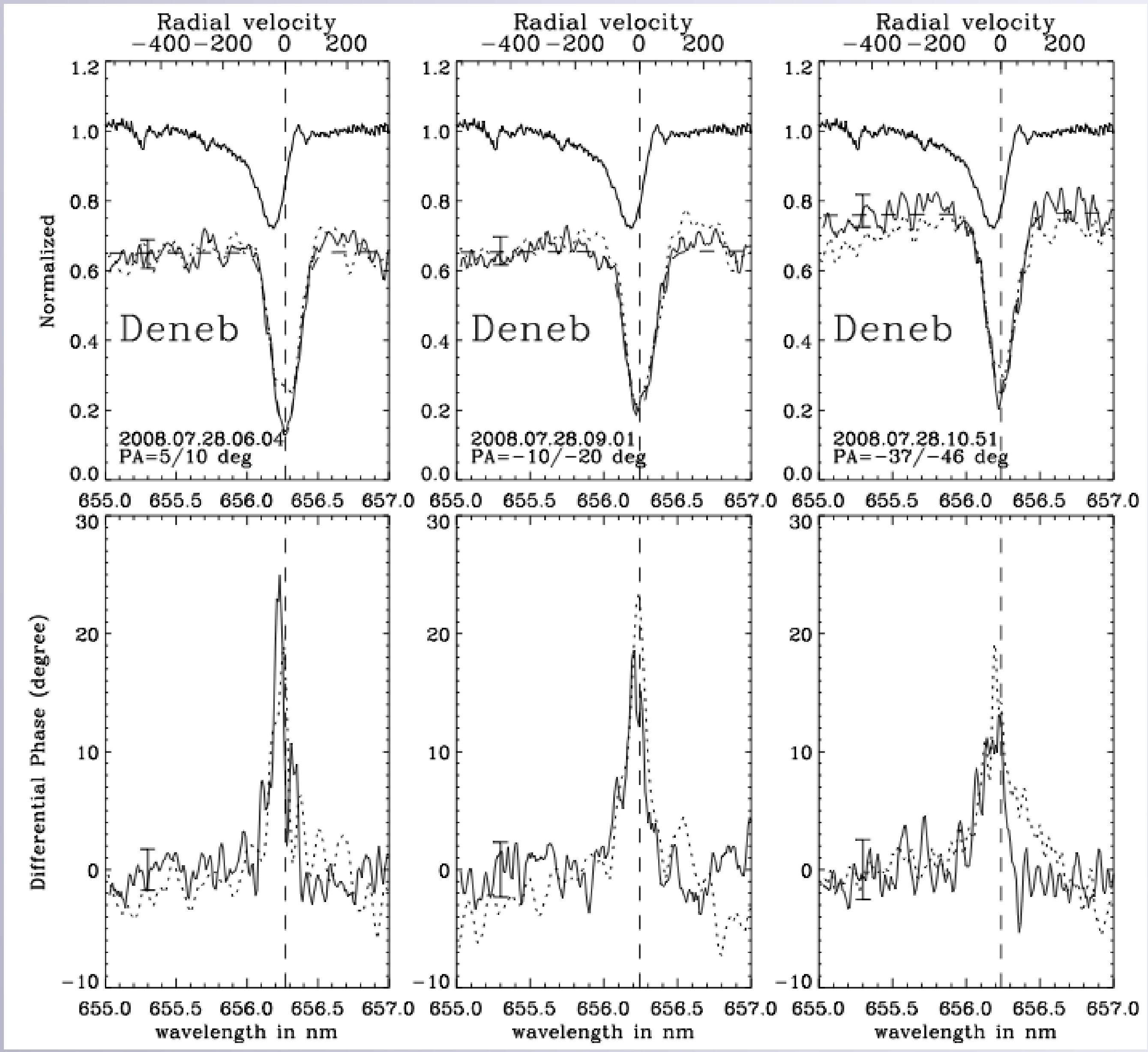
B. Kloppenborg, Infrared images of the transiting disk in the ε Aurigae system, 2010

- Adopting Hipparcos 625 pc distance
  - Semi-major axis ellipse 0.76±0.02 AU
  - Observed motion of disc 0.43±0.08 AU which implies $V = 25.10 \pm 4.65$ km.s^{-1} with respect to the F star
- Using spectroscopic orbit parameters and assuming $i = 88 \pm 2°$ the translational velocity for the F-star is 15.42±0.42 km.s^{-1} relative to the centre of mass
- After subtracting the F-star's motion $V_{disc} = 9.68 \pm 4.67$ km.s^{-1} relative to the centre of mass.

VEGA science

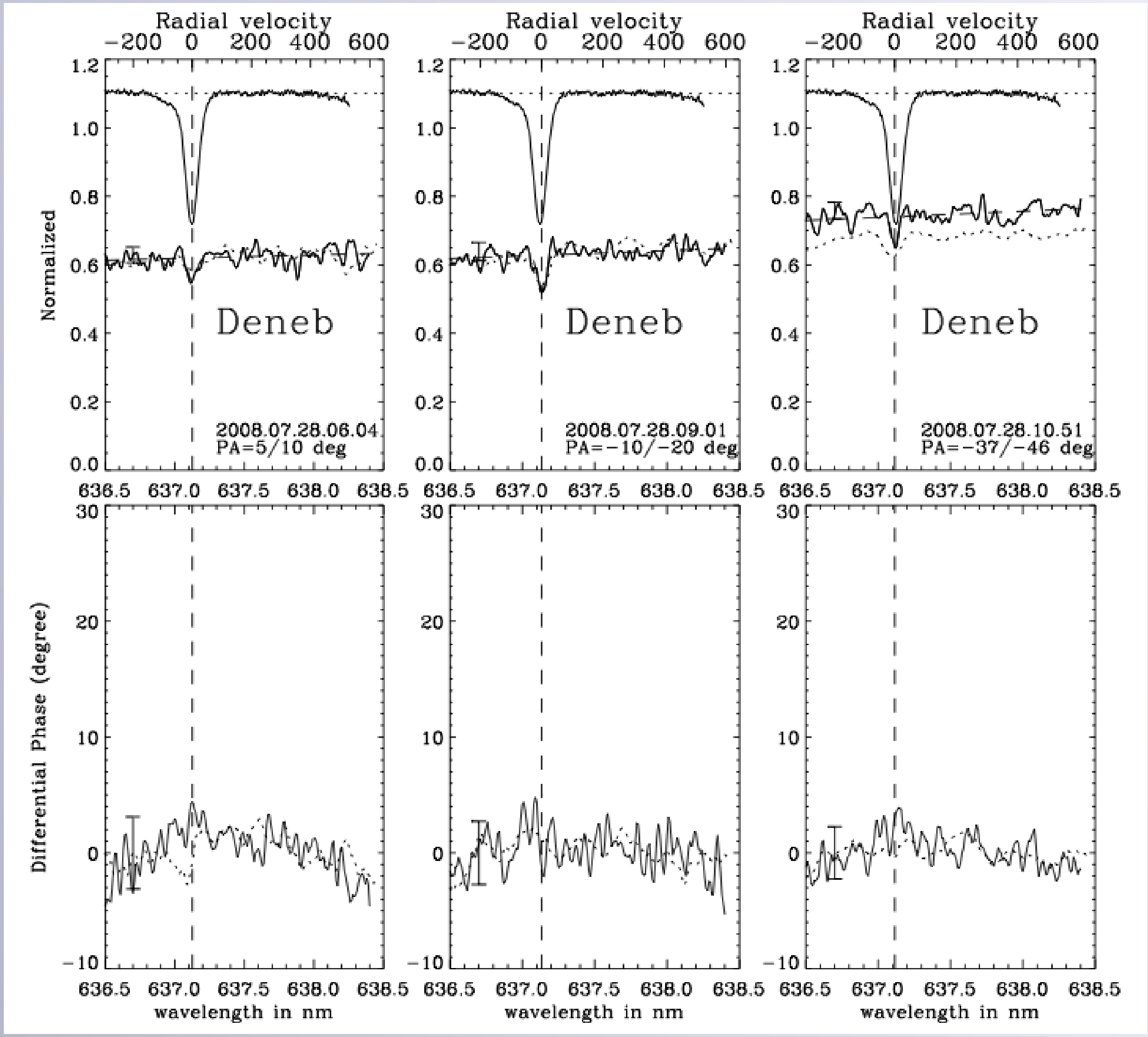
- fundamental stellar parameters
  - angular diameter with VEGA/CHARA with an accuracy is better than 2%
  - distance to cepheids
  - refine the theory of single-star formation and constrain possible scenarios of double star formation
  - geometrical structure of more evolved and interacting binaries such as disks, jets
- stellar activity
  - rotation
  - surface structures
  - polarisation
  - pulsation
- circumstellar environment studies
  - envelope of Be stars
  - closest Wolf Rayet

VEGA
The Hα line forming regions of Deneb



O. Chesneau, **Time, spatial, and spectral resolution of the Hα line-formation region of Deneb and Rigel with the VEGA/CHARA interferometer**

The Hα line forming regions of Deneb



O. Chesneau, **Time, spatial, and spectral resolution of the Hα line-formation region of Deneb and Rigel with the VEGA/CHARA interferometer**

VEGA
The Hα line forming regions of Deneb

- A strong phase signal changing with baseline direction is observed across the Hα line, indicating a significant asymmetry of the line forming region at this time.
- The SiII 6371 line is marginally resolved by VEGA/ CHARA, but no phase signal is observed
- The Hα line forming region appears to be asymmetrical and time variable

Useful links

- http://www.chara.gsu.edu/CHARA/
- http://www.lesia.obspm.fr/astro/interfero/pages/fluor.html
- http://www.astro.lsa.umich.edu/~monnier/Research.html
- http://pavo.wikispaces.com/
- http://www-g.oca.eu/gemini/projets/vega/en/news/index.htm