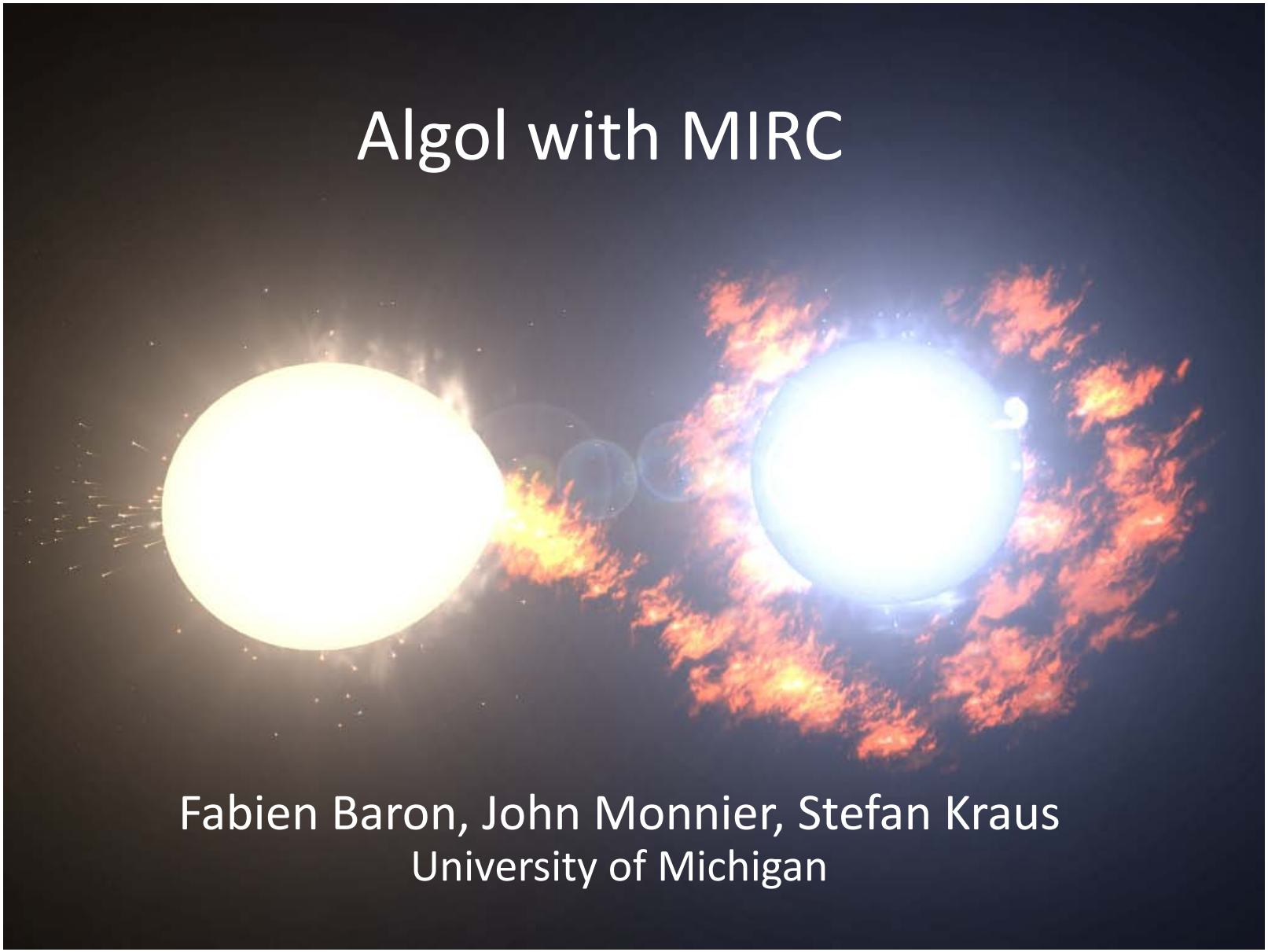

Algol with MIRC
Fabien Baron, John Monnier, Stefan Kraus
University of Michigan

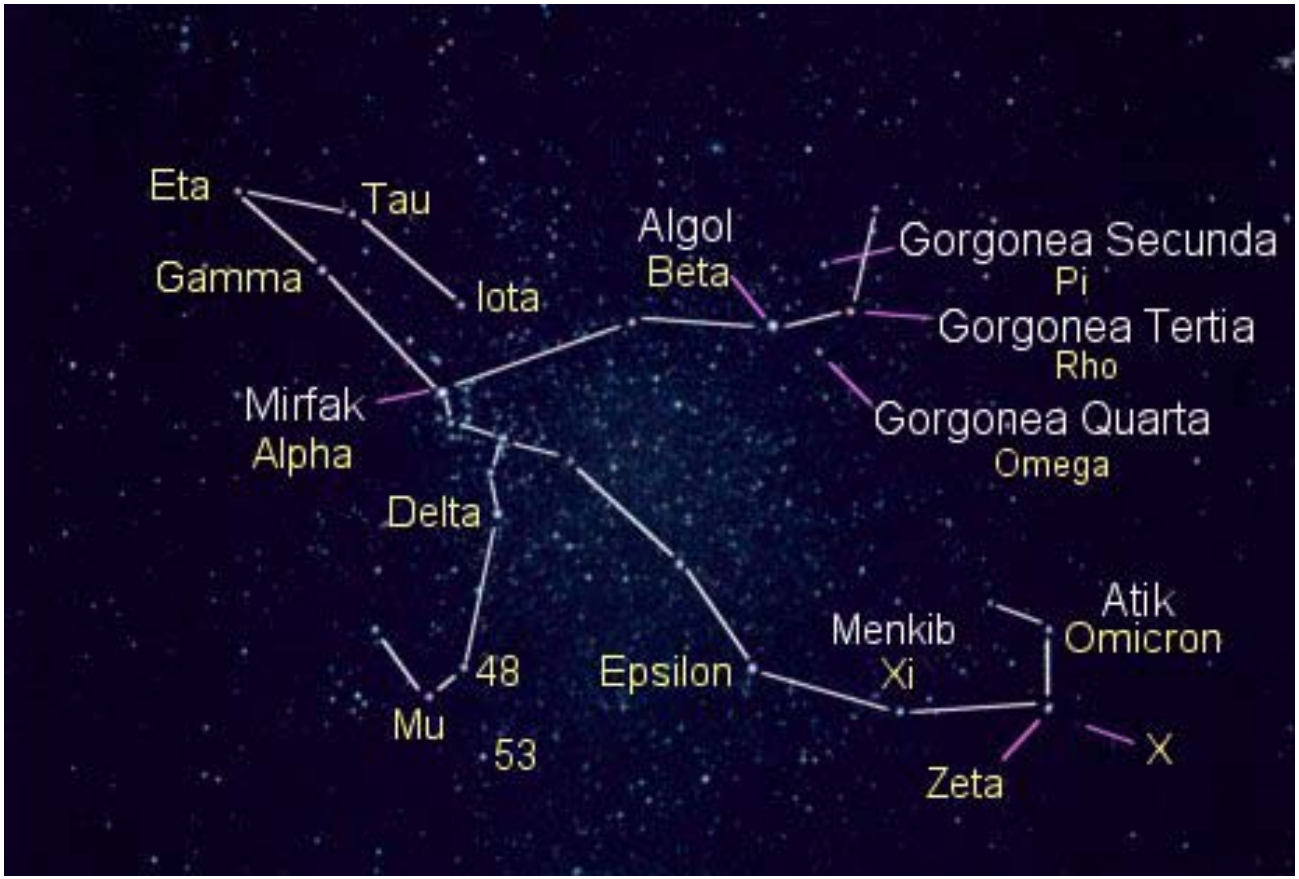
Algol – overview

Algol (Beta Persei), the “Demon Star” or “Blinking Demon”, is derived from the Arabic "Ra's al Ghul" for the Demon's Head.

It’s the "evil eye" of Medusa, changing brightness and color.

Algol is a compact triple-star, d= 92.8 light-years

7.3 million years ago it passed within 9.8 light years, apparent magnitude of -2.5



Algol inner pair A-B

Prototype of Algol-type eclipsing variables.

A: main sequence B8V, 3.8$M_\odot$, 2.9$R_\odot$
B: subgiant K2IV 0.8□$M_\odot$, 3.5$R_\odot$

A-B separated by 1/10 Earth-Sun distance

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

"semi-detached" configuration":
- Algol B fills its Roche Lobe
- Algol A roughly spherical

Circular orbit + synchronous rotation periods

The Algol “paradox”

Normal binary:

the most massive star evolves faster and enters giant phase first

Algol case:

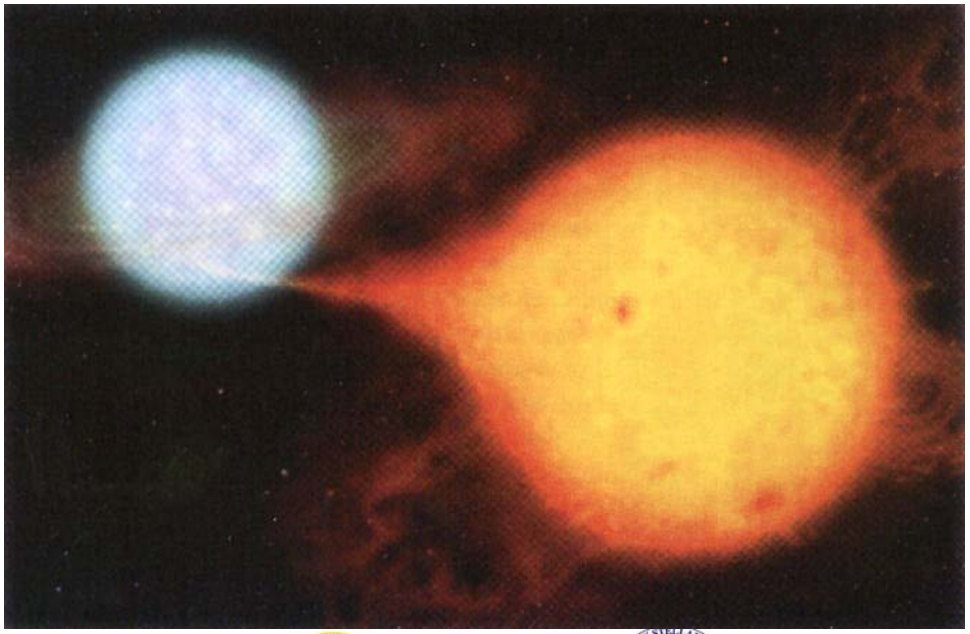
the less massive star, Algol B, is already red giant

the more massive, Algol A, is still within the main sequence

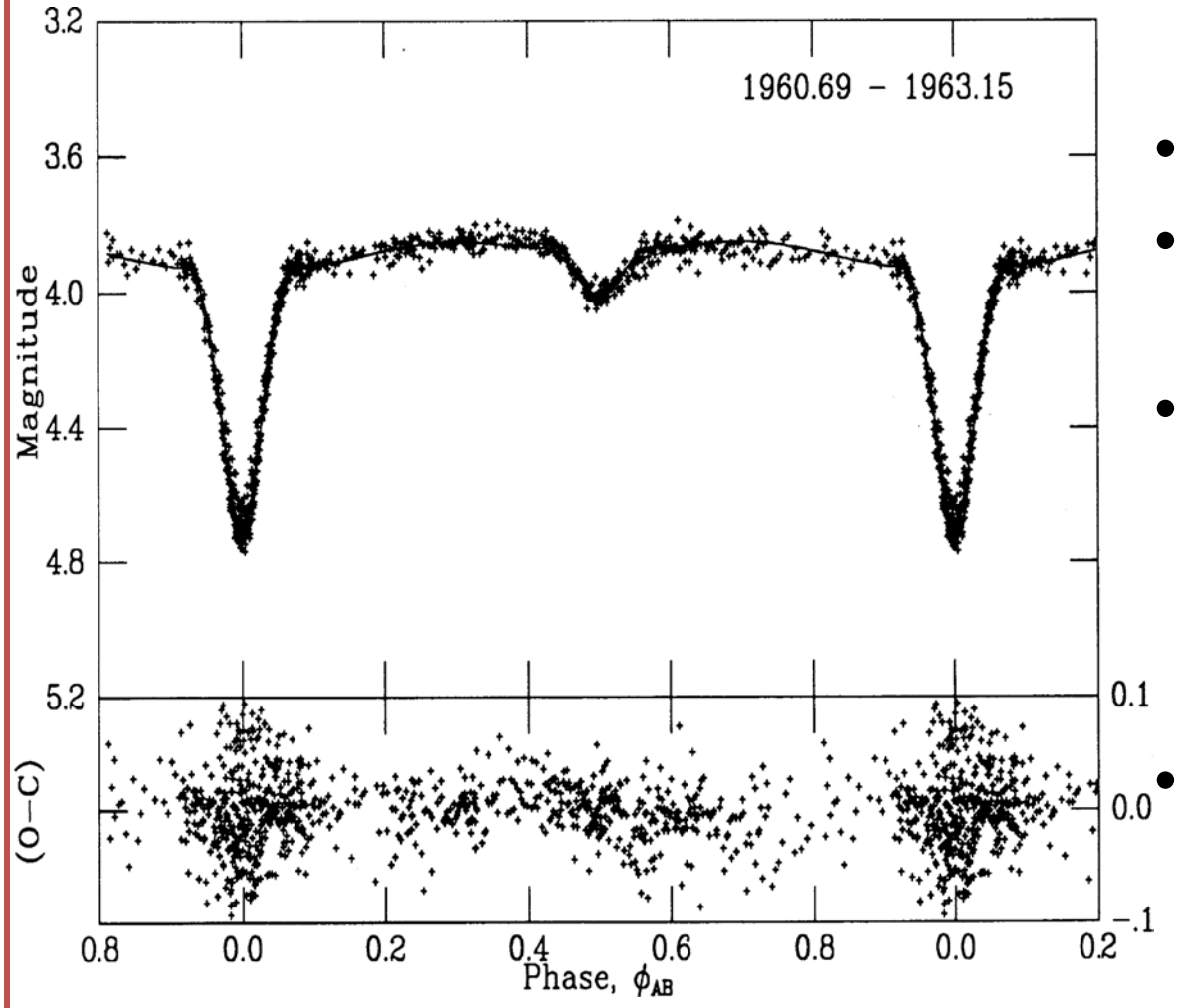
Answer

=

Mass Transfer



Light curve analysis



- Typical light curve
- Potential star spots on Algol B
- Reflection effect
  - B is heated by A radiation, easy computation
  - Negligible effect on A
- Affected by Algol C

Algol A, B and C

	Algol A	Algol B	Algol C
Spectral type	B8V	K2IV	F1IV
Mass ($M_\odot$)	3.8	0.82	1.80
Radius ($R_\odot$)	2.88	3.54	1.67

	Notation	A–B	AB–C
Time of periastron (HJD)	T	2 445 739.0030	2 446 931.4
Period	P	2.87 days	680.05 days
Semimajor axis	a	2.3 mas - 14.1 $R_\odot$	94.61 mas - 582.9 $R_\odot$
Eccentricity	e	0.00	0.225
Inclination	i	82.31°	83.98°
Argument of periastron	ω	-	310.29°
Longitude of the ascending node	Ω	47°	312.26° - 180° !

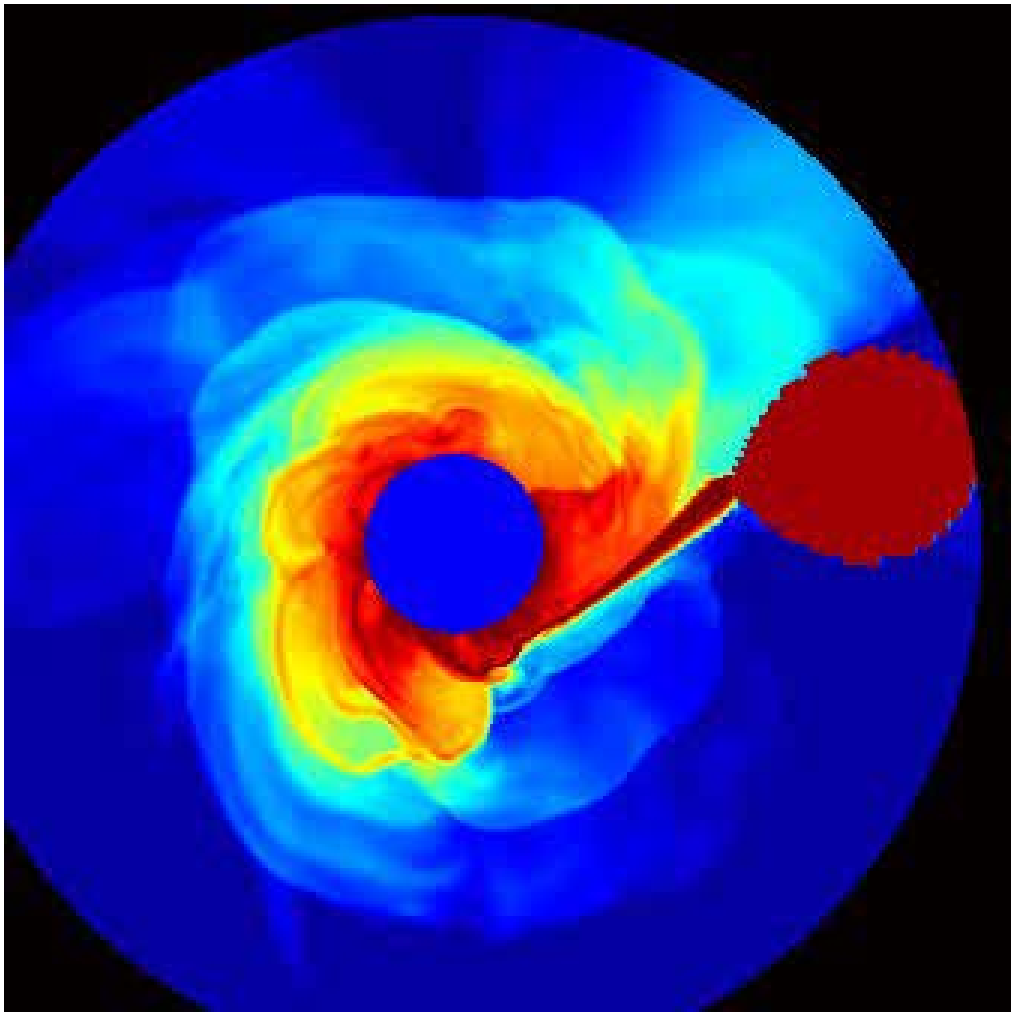
Pan et al. 1993

Potential outflow between A and B

Roche lobe overflow from the companion produces a tidal stream which free falls from the inner Lagrangian point towards the primary under the influence of gravity and the Coriolis force.

Hot/cold spots may also be detected on A and B

Peterson et al., Nature 2010 persistent asymmetric magnetic field structure along A-B



Hydrodynamic simulations of Algol A-B. Blondin et al., ApJ 1995

Algol and interferometry

- Labeyrie 1974
- Soderhjelm 1980, speckle interferometry
  - Coplanarity of A-B and AB-C orbits ?
- McAlister & Hartkoptf 1988
- Pan et al. 1993, with Mark III, AB-C
  - Perpendicular orbits
  - 180 ambiguity corrected on Ω_2… but in the wrong direction
- Czismadia et al. 2009
  - A-B, using CHARA CLASSIC data (~20 points), and VLBI
  - Orbit derived partially from Pan results…
- Zavala/Hummel 2010
  - A-B (marginally resolved) + C, using NPOI + VLBA + Hall Telescope

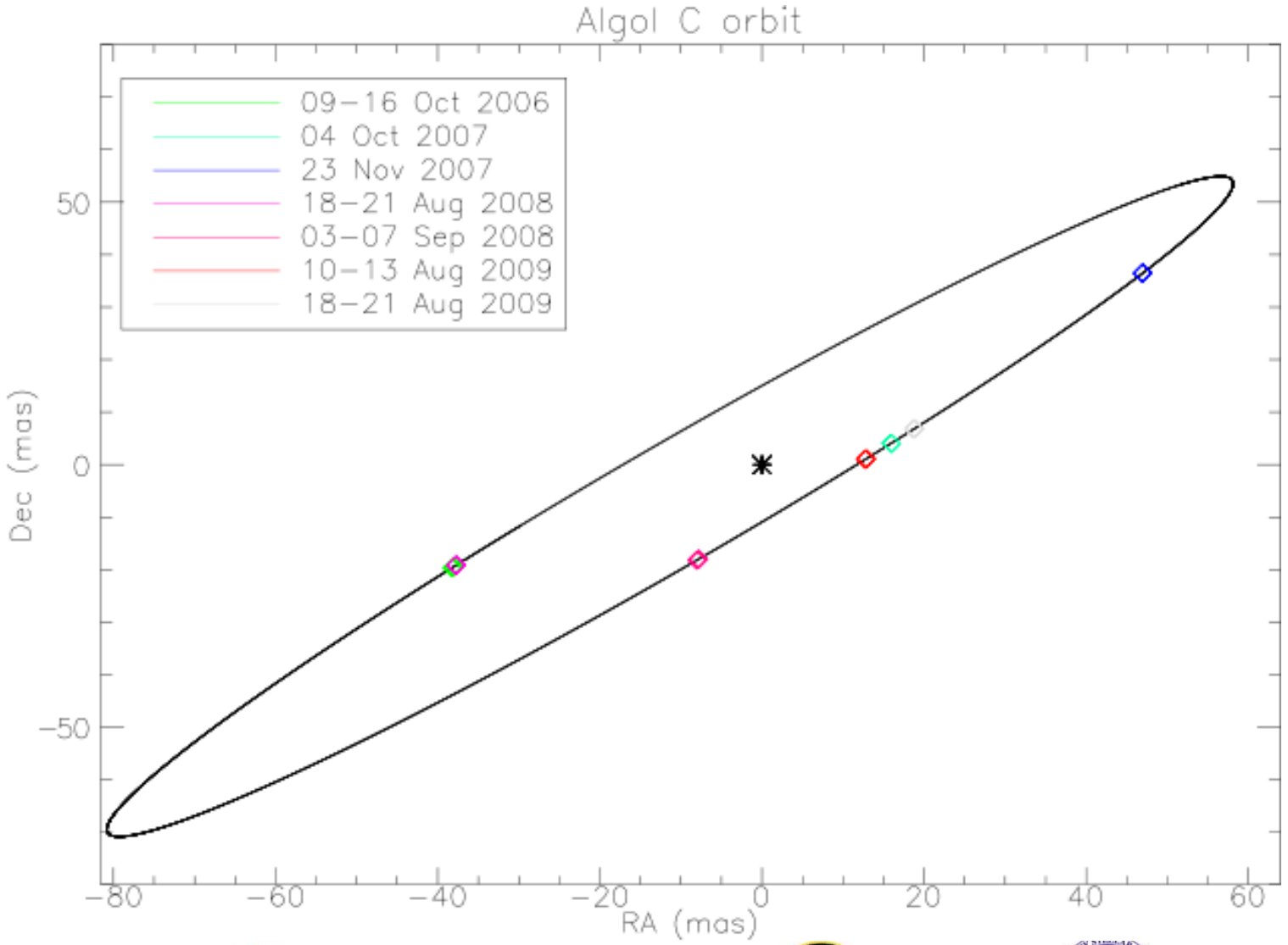
Much confusion about the 180° ambiguity !

MIRC data on Algol - nights

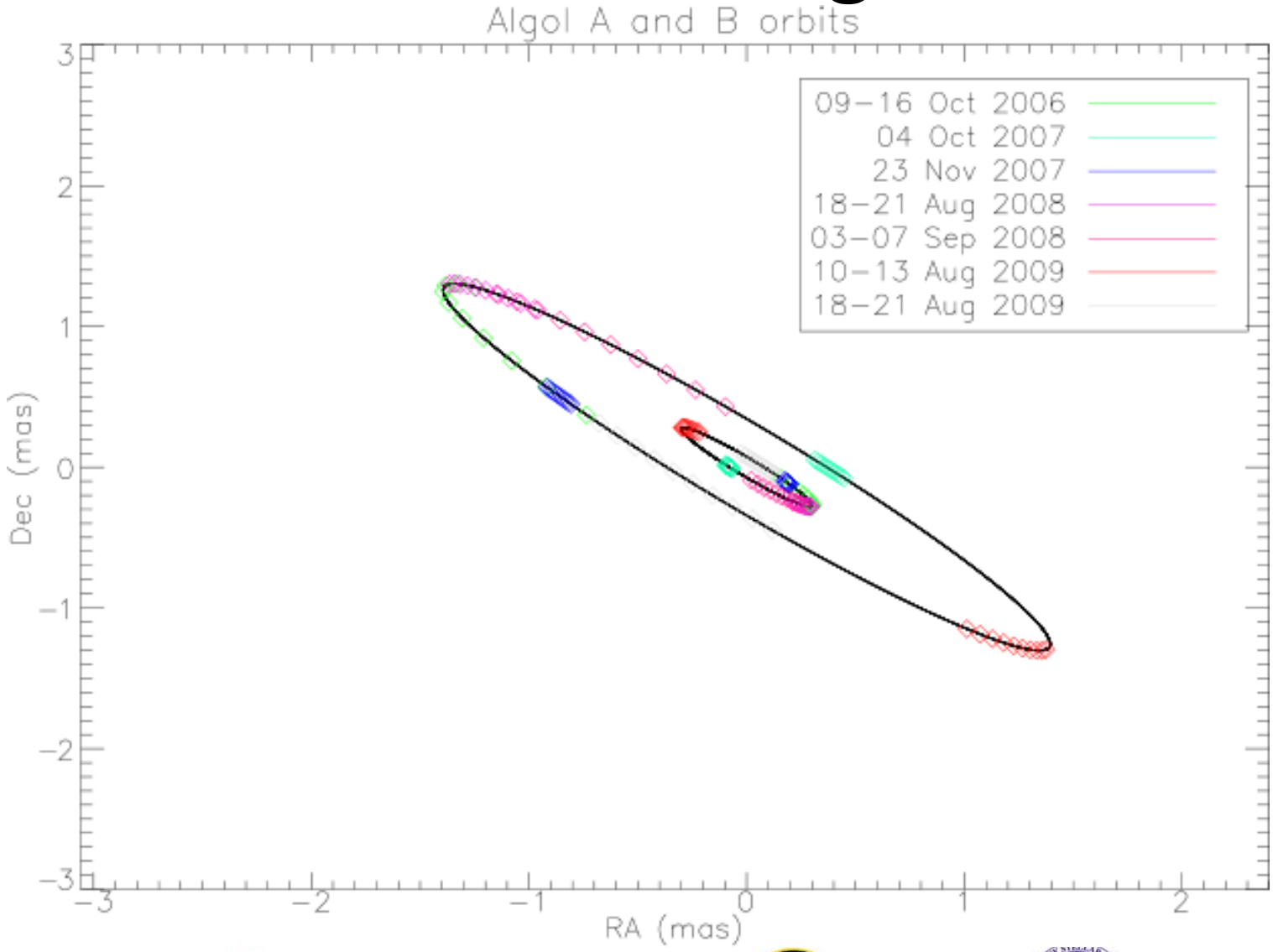
- 22 nights spread over 3 years
  - Thanks to PJ & Chris, JDM, Ming, Etorre, Steve
- Average quality
  - Bad seeing, 3T, Ks grism experiment
- But good uv coverage

UT2006Oct09	S2-E2-W1-W2	
UT2006Oct11	S2-E2-W1-W2	
UT2006Oct12	S2-E2-W1-W2	
UT2006Oct16	S2-E2-W1-W2	3T data
UT2006Oct16	S2-E2-W1-W2	H-band low-, bad seeing
UT2007Oct04	S1-E1-W1-W2	3T data
UT2007Nov23	S1-E1-W1-W2	
UT2008Aug18	S1-E1-W1-W2	
UT2008Aug19	S1-E1-W1-W2	
UT2008Aug20	S1-E1-W1-W2	
UT2008Aug21	S1-E1-W1-W2	
UT2008Sep03	S2-E2-W1-W2	Ks Grism R~500
UT2008Sep06	S2-E2-W1-W2	Ks Grism R~500
UT2008Sep07	S2-E2-W1-W2	Ks Grism R~500
UT2009Aug10	S1-E1-W1-W2	
UT2009Aug11	S1-E1-W1-W2	
UT2009Aug12	S1-E1-W1-W2	
UT2009Aug13	S1-E1-W1-W2	
UT2009Aug18	S1-W1-W2	3T, no E1
UT2009Aug19	S1-E1-W1-W2	
UT2009Aug20	S2-E2-W1-W2	
UT2009Aug21	S2-E2-W1-W2	
UT2009Aug24	S2-E2-W1-W2	Photometric channels

MIRC data on Algol C



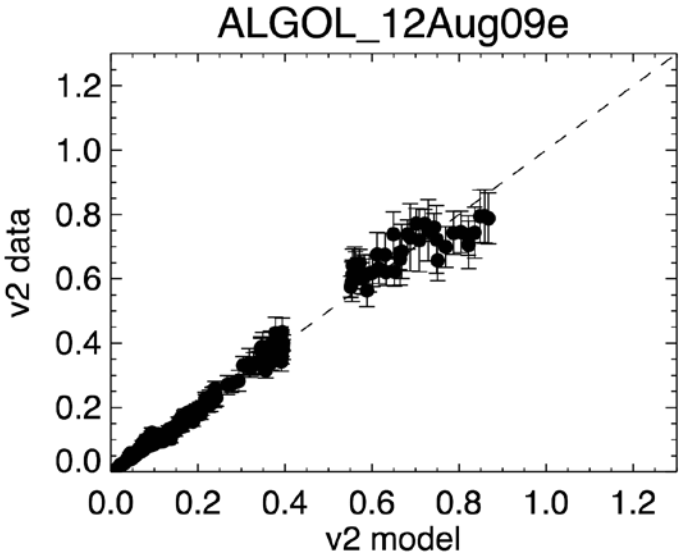
MIRC data on Algol A-B

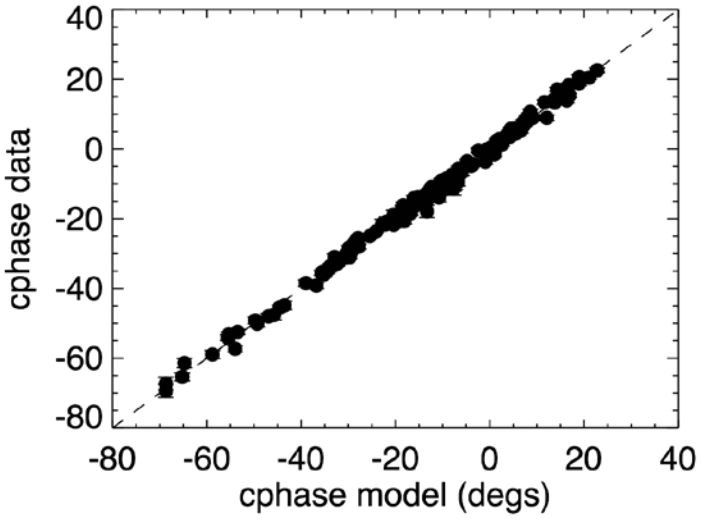


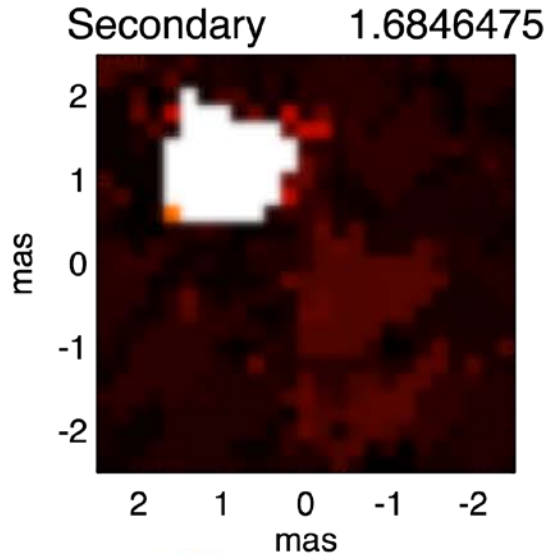
Model fitting - 1

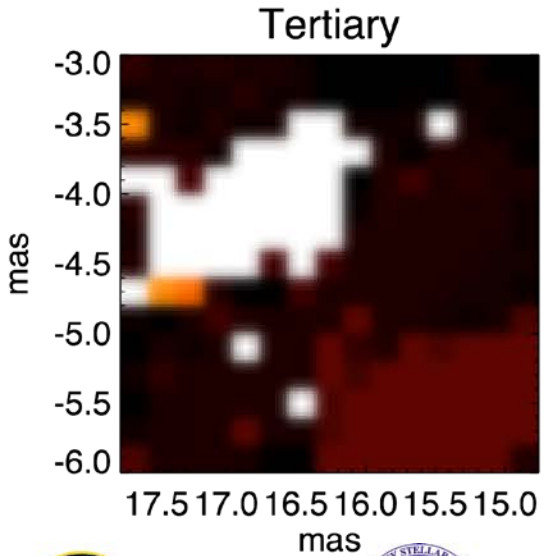
- Night by night approach
  - P(A-B) = 2.87 days, $\Delta\theta$=5°/hour, $\Delta\rho$= few 0.1 mas
  - Algol C does not move much but strong effect on closure phases
- Uniform ellipses (as a first step) relative to Algol A
  - Position (ρ,θ), size, axis ratio, angle, flux ratio
  - Primary can be fixed to circular
  - Bandwidth smearing effect on Algol C, elongated along its θ axis
- High number of dimensions (min 14) + multimodal
  - Combination of grid search with Levenberg
  - Nested sampling (new MCMC technique with Hill Climbing and evidence/model selection implementation)

Model fitting - 2









Model-fitting - 3

	chi2	rho2	PA2	flux2	rho3	PA3	flux3	ud1	ud2	ud3	rat1	rat2	rat3	udpa1	udpa2	udpa3
2009Aug10a	1.56	1.79	-131.38	0.53	15.16	102.06	0.16	0.91	1.13	0.53	1.05	1.23	1.9	-102.06	61.08	-83.02
2009Aug10b	1.94	1.9	-132.65	0.52	15.17	102.13	0.17	0.86	1.09	0.58	1.13	1.45	1.82	-115.69	56.17	101.75
2009Aug11a	2.82	0.6	-72.91	0.83	15.91	102.91	0.36	1.13	0.78	0.35	1.01	1.36	100	0	14.9	-69.47
2009Aug11b	2.86	0.61	-84.39	0.83	15.92	103.18	0.36	1.13	0.75	0.46	1.01	1.48	5.99	0	5.82	109.09
2009Aug12a	1.74	1.71	33.84	0.48	17.19	103.64	0.15	0.89	1.03	0.42	1.01	1.27	8.87	0	28.05	103.64
2009Aug12b	1.71	1.61	34.39	0.39	17.18	103.69	0.18	0.9	1.04	0.7	1.01	1.17	1.6	0	-163.18	103.69
2009Aug12c	3.37	1.53	34.37	0.43	17.21	103.81	0.14	0.92	1.1	0.63	1.01	1.17	1.54	0	27.15	103.81
2009Aug12d	2.04	1.61	33.44	0.42	17.19	103.72	0.18	0.89	1.07	0.65	1.01	1.25	1.8	0	17.24	103.72
2009Aug12e	1.68	1.7	36.05	0.44	17.21	103.72	0.15	0.89	1.01	0.61	1.01	1.3	1.84	0	44.19	103.71
2009Aug13a	7.53	2.12	-132.79	0.44	17.81	107.51	0.16	0.86	1.09	0.57	1.01	1.92	2.49	0	-142.36	107.5
2009Aug13b	4.14	2.02	-137.13	0.55	17.78	107.44	0.2	0.84	1.27	0.67	1.01	1.26	1.91	0	48.05	107.44
2009Aug13c	3.81	2.02	-135.48	0.72	17.77	107.37	0.2	0.81	1.16	0.63	1.01	1.26	2.37	0	58.02	107.37
2009Aug18	4.42	1.35	12.47	1	23.81	108.67	1.92	1.13	1.03	3.08	1.01	2.01	1.87	0	50.7	108.67
2009Aug19a	8.57	2.05	-139.06	0.45	23.32	114.32	0.19	0.91	1.15	0.85	1.01	1.41	1.88	0	40.56	114.32
2009Aug19c	12.07	2.32	122.37	0.33	23.35	114.36	0.12	1.13	1.1	0.77	1.01	54.67	3.8	0	-76.79	114.36
2009Aug20a	3.41	1.51	52.11	0.56	24.38	113.59	0.18	0.86	1.13	0.95	1.01	1.44	1.93	0	44.51	113.59
2009Aug20b	2.82	1.7	50.09	0.63	24.44	113.52	0.19	0.84	1.25	0.81	1.01	1.16	1.92	0	49.3	113.52
2009Aug20c	3.28	1.73	49.35	0.42	24.46	113.51	0.17	0.96	1.1	0.9	1.01	1.34	1.6	0	-124.18	113.51
2009Aug21a	4.5	4.99	-115.06	0.22	25.36	115.09	0.18	0.91	2.25	0.75	1.01	2.79	1.97	0	-129.61	115.09
2009Aug21b	2.95	0.1	-49.99	0.6	25.36	115.06	0.19	0.75	1.81	0.47	1.01	2.03	100	0	101.96	115.06

- Consistant p.a. sizes and fluxes
  - Algol C elongated as expected
  - Eclipse Aug 11 needs more work
- Correct fits, not great on most nights
  - gravity darkening, limb darkening + other effects

Image reconstruction - 1

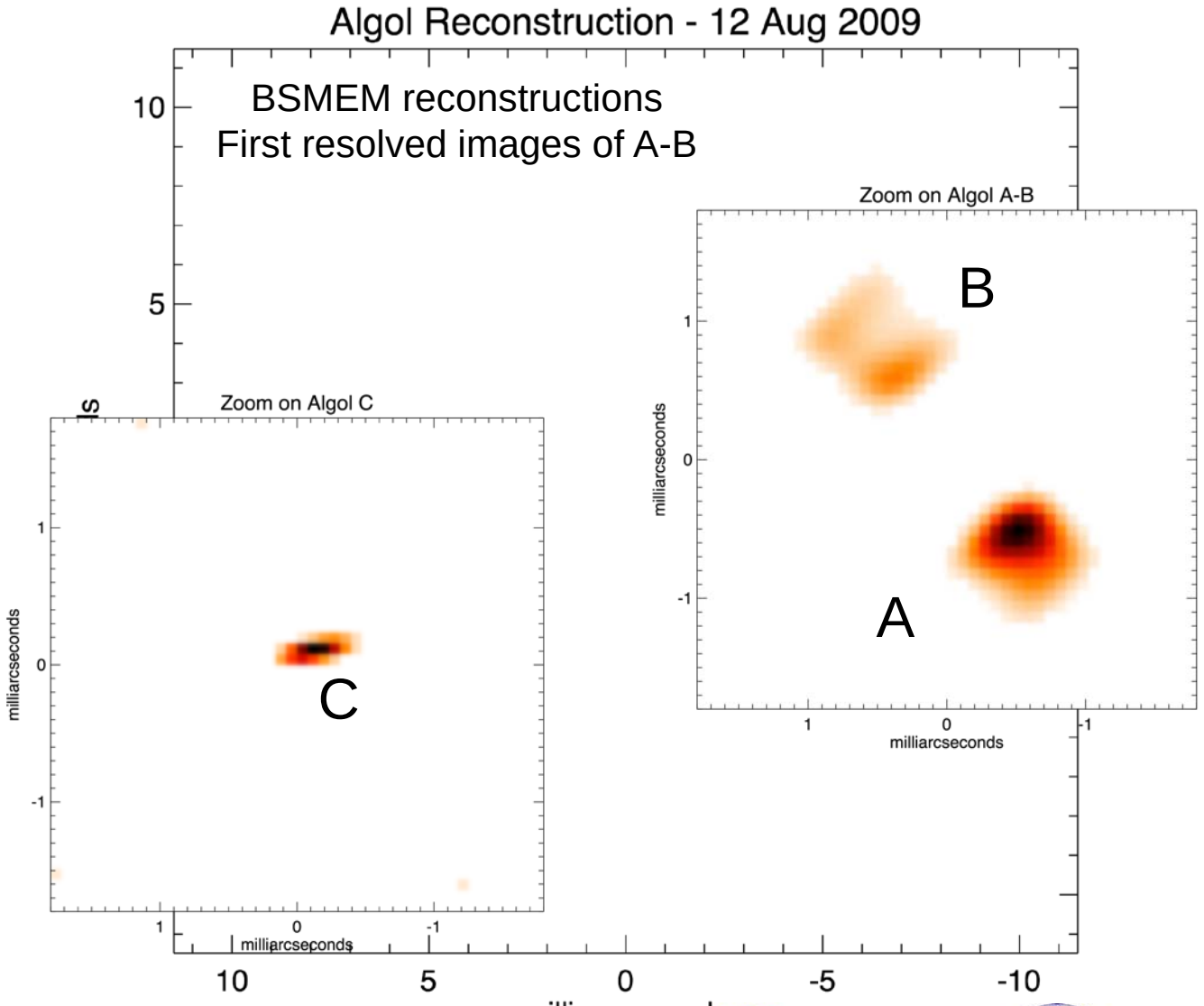
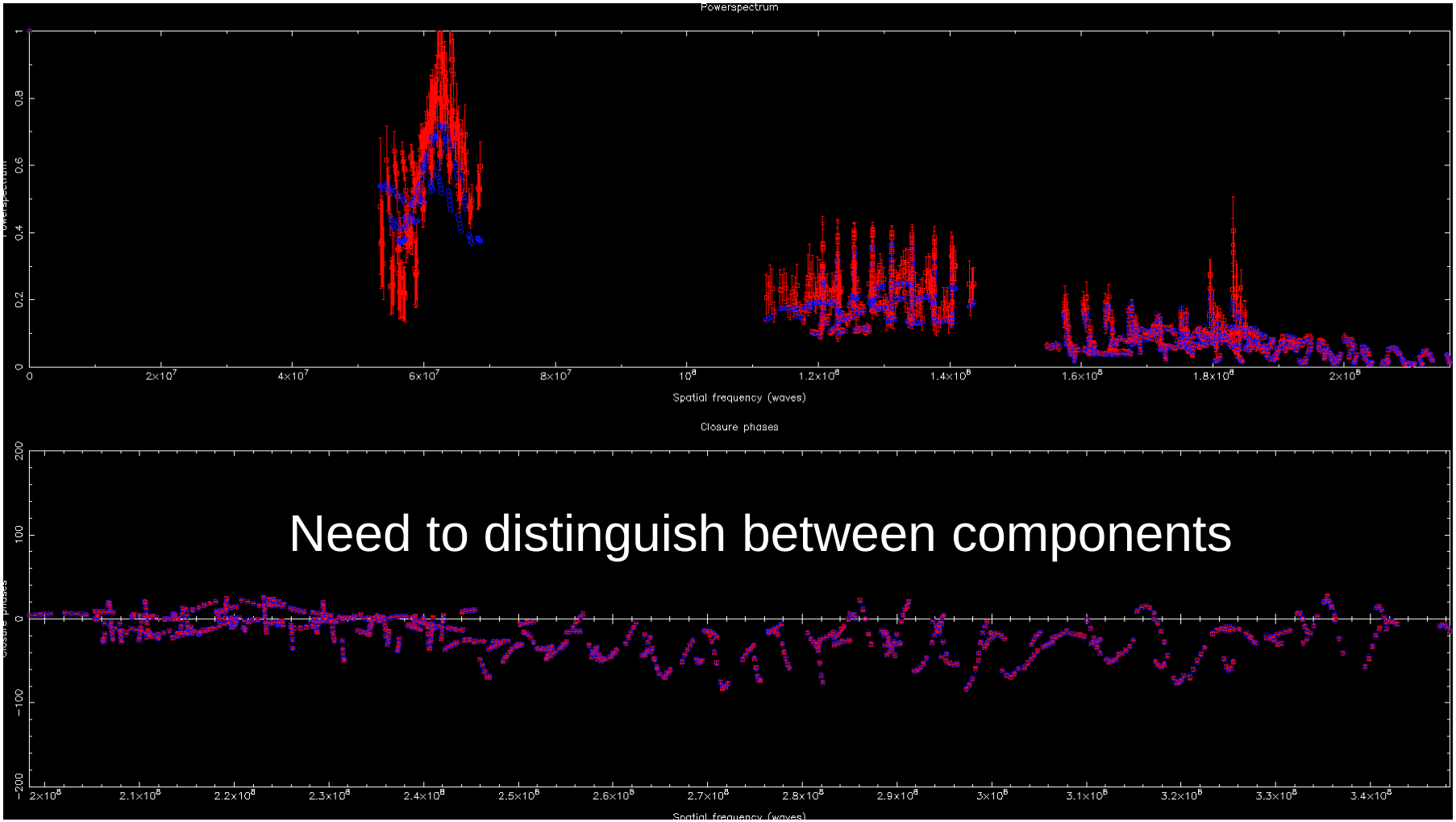


Image reconstruction - 2



Need to distinguish between components

Image reconstruction - 3

- Fluxes, sizes, positions consistent with literature
- Possible detection of the proximity effect
  - Roche lobe filling + binary reflection, TBC
- ☐Difficulties:
  - few nights have enough data/uv coverage
  - those who do suffer from temporal smearing
  - Algol C bandwidth, difficult to correct with BSMEM
  - few “useful” pixels/noise overfitting, bad photometry
- New image reconstruction software to come
  - optimized for low degrees of freedom (new paradigm)
  - simultaneous model fitting/image reconstruction

Orbit fitting and evolution

- Several possibilites
  - from current grid search results: investigated
  - from the image photocenter locations
  - directly from the data, add to current model fitting scheme
    - This adds 7 x 2 - 4 = 10 more parameters
    - More local minimas/degeneracies: nested sampling
- 3D star rotation (shape from model fitting) and Roche lobe parameters as a function of distance
- Preliminary result:
  - Pan/Csimadia A-B orbit easily refined (0.5 mas off/yr)

Conclusion

- Model fitting
  - Non uniform components (limb darkening, gravity darkening, reflection effect), Roche lobe
  - Add modeling of temporal/spectral smearing effect
- Image reconstruction
  - Spot detection at other epochs ?
  - Proximity effect analysis
  - Upcoming image reconstruction software
  - Use of the model fitting results as prior
- Improvement upon current orbit + movie !
- Ks vs H band