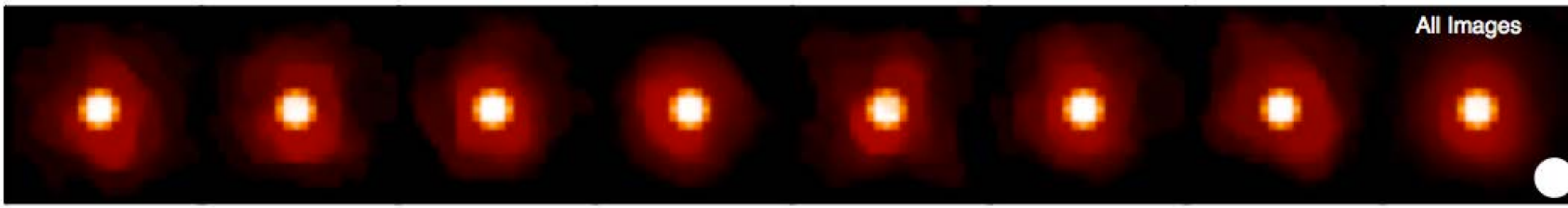
Imaging δ Del Around the 2011 Periastron



X. Che

University of Michigan

Collaborator:

J. Monnier,	University of Michigan
C. Tycner,	Central Michigan University
S. Kraus,	University of Michigan
F. Baron,	University of Michigan

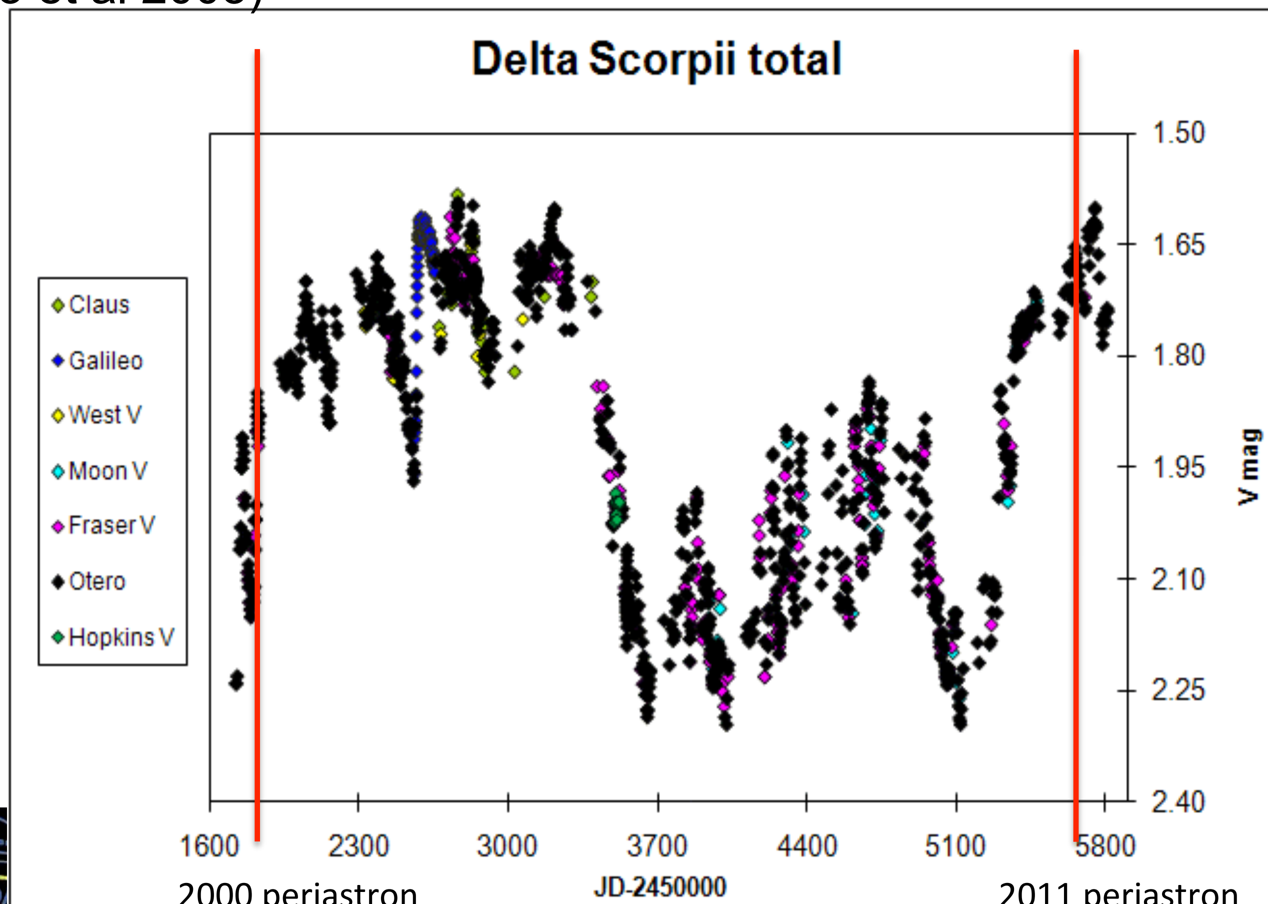
Del Sco: background

- Be binary: B0.5Ve + B2V
- High eccentricity: ~ 0.94
- Period: ~ 10 years
- Periastron was expected around July 6th 2011 (Tycner et al. 2011) when the distance between the primary and secondary will be only a few times of the size of the disk

- ❑Before 2000 periastron:
  - No clear evidence of Be phenomena
- ❑During 2000 periastron:
  - Visible magnitude was increased by 0.4(Otero et al 2001)
  - Strong Hα emission (Fabregat et al. 2000)
- ❑After 2000 periastron:
  - The strength of Hα emission continued to increase (Miroshnichenko et al 2003)

} Disk formation

Del Sco: photometry



Observers: Sebastian Otero, Federico Claus, Brian Fraser, Terry Moon, Jeff Hopkins, Doug West

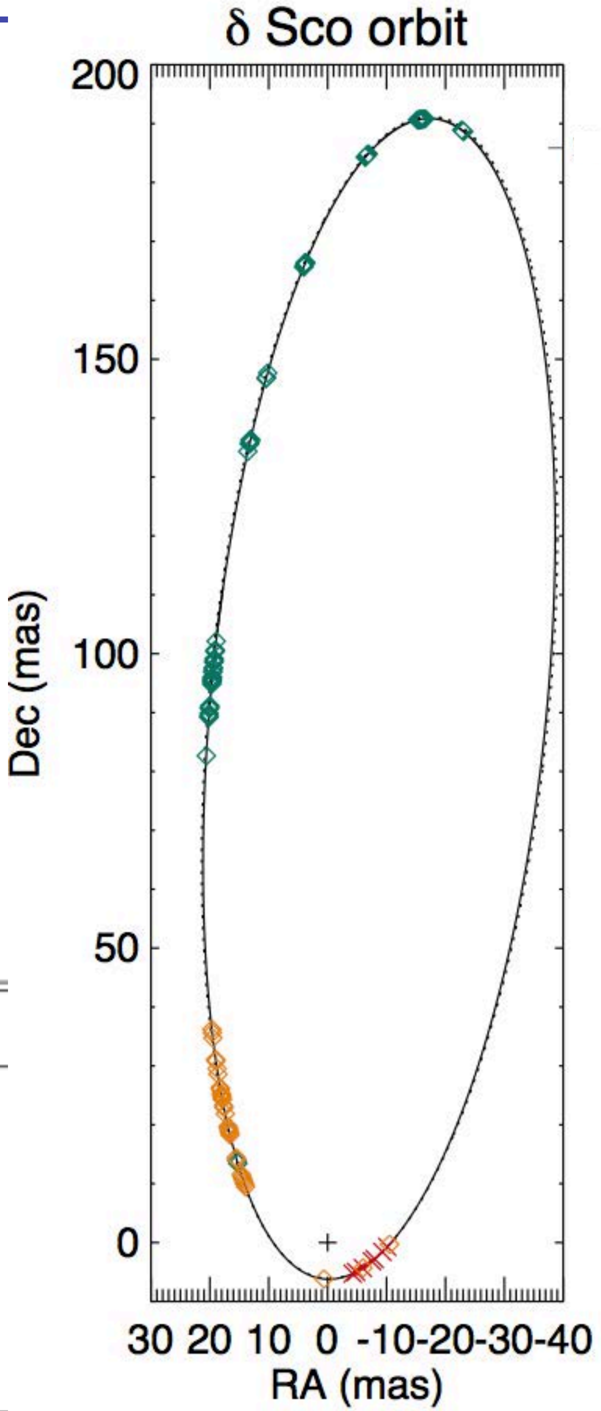
GeorgiaStateUniversity

Observations

- 7 nights of MIRC observation from July 10^{th} to 22^{nd}, only a few days after the predicted periastron. 5-telescope data only. One of the telescopes doesn't have enough delay range because the target is too south.
- 128 astrometric measurements of the binary since last periastron observed at NOI (provided by C. Tycner)

Binary Orbital Parameters

- New orbital parameters from all NOI observation
  - 32 more observations in 2011 from Apr. to Jul.
  - The new calculated periastron date:
    2011 July 03 13:00±4 hours
  - Agrees marginally with 2011 July 06±2 days from Tycner et al 2011



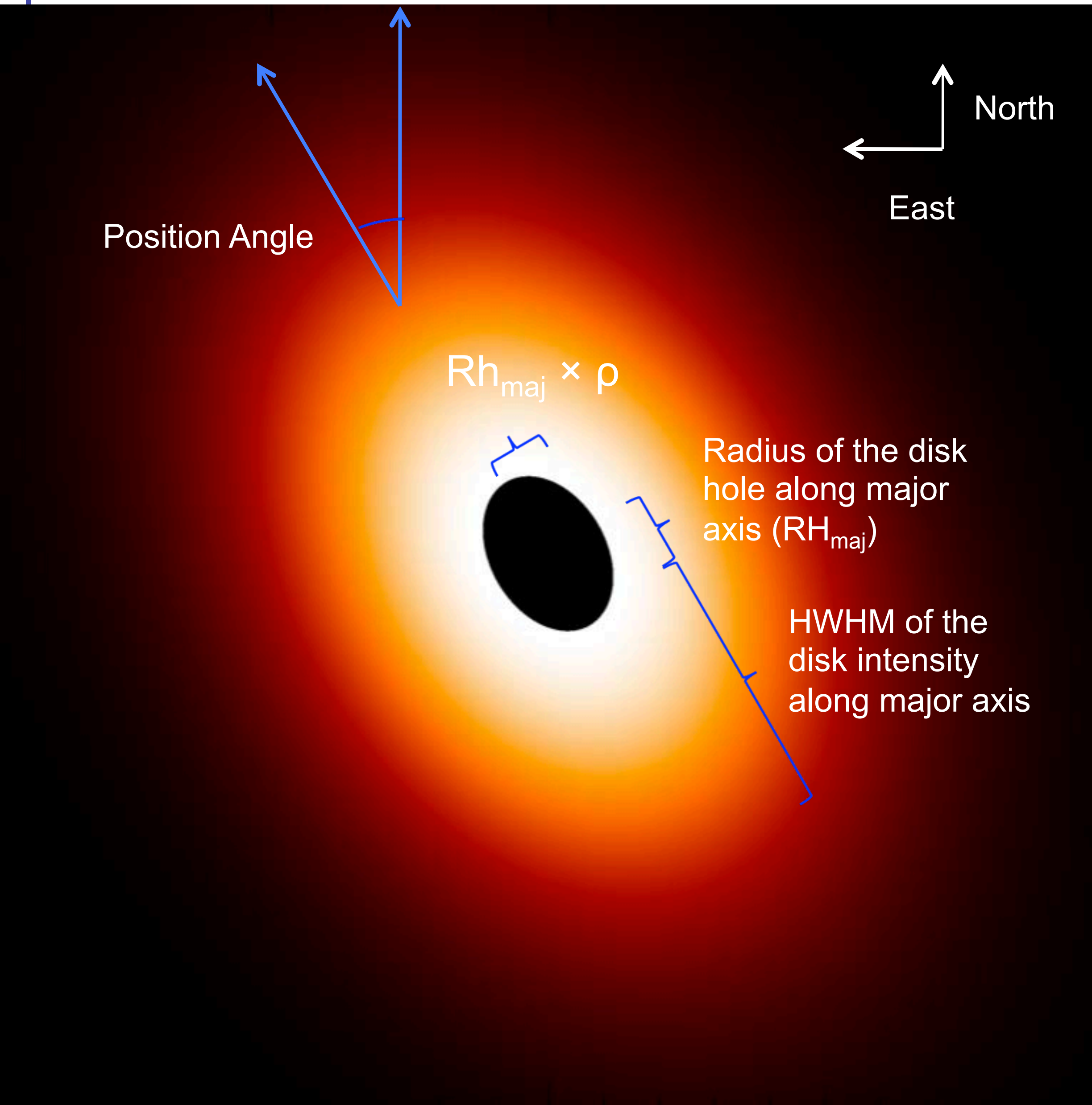
Green: from Tycner et al 2011
Orange: new NOI data
Red: MIRC data in 2011 July

Parameters	Tango et al. (2009)	Tycner et al. (2011)	NOI only (new fit)
a (mas)	98.3 ± 1.2	99.1 ± 0.1	99.04 ± 0.03
i (deg)	38 ± 6	32.9 ± 0.2	32.2 ± 0.3
Ω	175.2 ± 0.6	172.8 ± 0.9	174 ± 1
e	0.9401 ± 0.0002	0.9380 ± 0.0007	0.9389 ± 0.0003
ω	1.9 ± 0.1	2.1 ± 1.1	0.3±0.7
T_0 (MJD[a])	51797.4 ± 0.1	51797.0±0.5	55745.5±0.16
P (days)	3922.7 ± 7.3	3950.8± 1.8	3947.8±0.4

Binary Star Model

- We adopted a rapidly rotating stellar model (Aufdenberg et al 2006) for the primary star with its geometric parameters computed and fixed from observed V band magnitude, effective temperature and vsini.
- The secondary is assumed to be a uniform disk with given diameter.
- The flux ratio of the binary are fixed based on the their size and effective temperature

Disk model



- 2D Gaussian Intensity profile with a hole in the center containing the primary star
- Rh_{maj} is fixed
- ρ is the ratio of the disk hole radii along minor and major axes

Global Model

- Symmetric disk whose properties don't change from night to night
- Secondary following Kepler motion
- Fit the model to both NOI and MIRC data

Parameters	Values from model fitting
Disk	
Flux Fraction	0.717±0.006
Radius of the hole along major axis (RH_{maj}, mas)[b]	0.2213
Ratio of the disk hole radii along minor and major axes (ρ)	0.885 ±0.018
Inferred disk inclination angle (°)	27.9±2.3
PA of major axis (°, East from North)	10.6±3.5
HWHM of major axis (mas)	0.343±0.020
Primary	
Flux fraction	0.1944±0.001
Radius along major axis[b] (mas)	0.2213
Radius along major axis[b] (mas)	0.2142
PA of major axis (°, East from North)	10.6±3.5
Secondary	
Flux fraction	0.0596±0.0012
Radius[b] (mas)	0.1205
Total flux	0.971±0.0068

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Results in 2007 from Millan-Gabet et al 2010

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~ 30%

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FWHM = 1.18±0.16mas

Observatoire de la CÔTE d'AZUR

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PA = 25±29°

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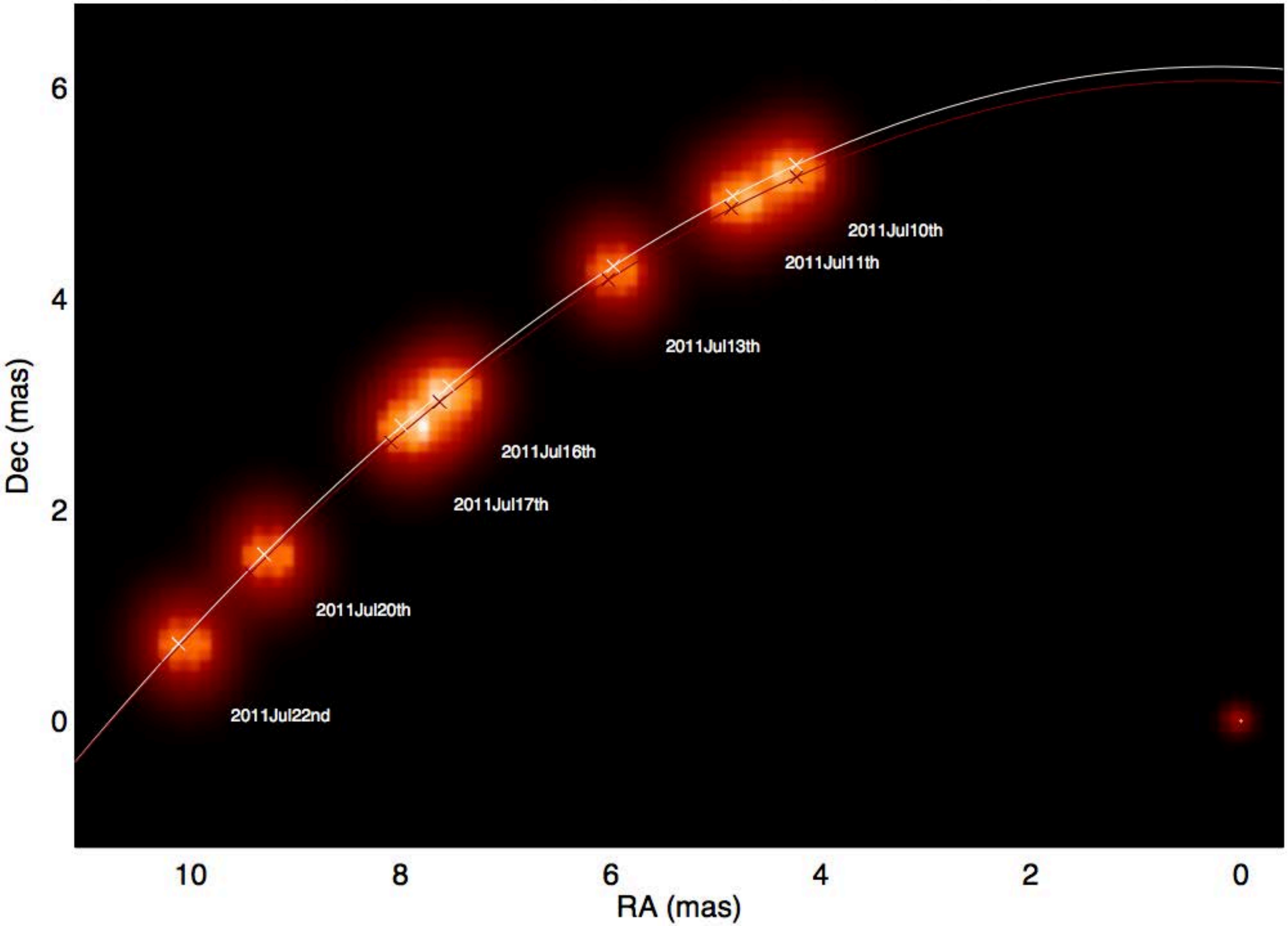
6.3±0.5% on 2011-06-04 from PIONEER/VLTI (Le Bouquin et al 2011)

CHARA/MIRC Observations of Periastron



		10th[a]	11th	13th	16th	17th	20th	22nd
Global Model	Total χ^2	1.82	1.73	1.36	2.22	1.98	1.67	2.38
	Closure Phase χ^2	4.15	3.23	1.91	2.49	3.99	3.68	5.50

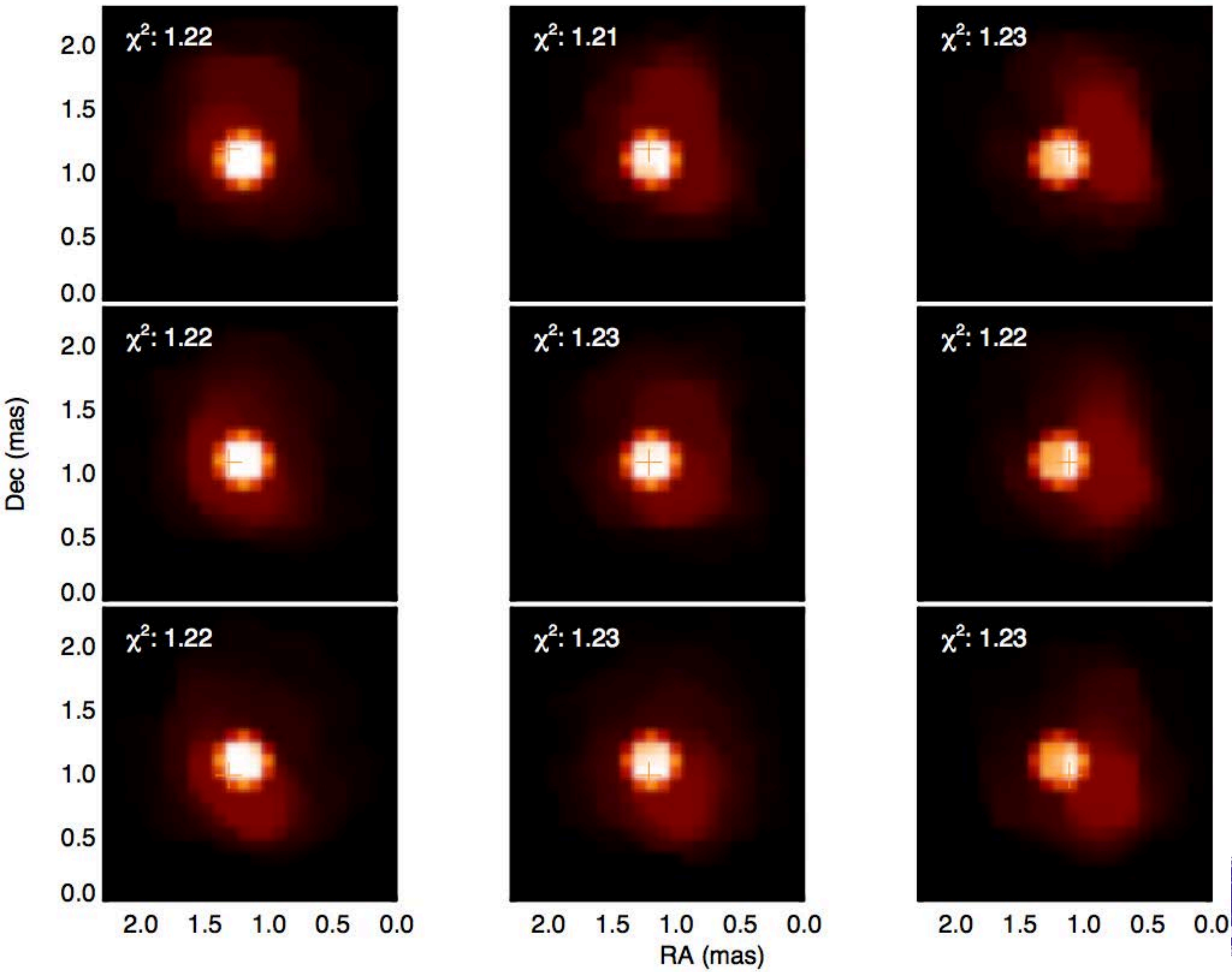
Spotty Disk Model

- Large closure phase χ^2 indicates probable additional asymmetry from the disk
- A bright spot to represent any asymmetry on the disk
- All parameters except those related to the spot are fixed according to the global model fitting.
- Fit the spotty disk model to individual nights independently

		10th$^{(a)}$	11th	13th	16th	17th	20th	22nd
Global Model	Total χ^2	1.82	1.73	1.36	2.22	1.98	1.67	2.38
	Closure Phase χ^2	4.15	3.23	1.91	2.49	3.99	3.68	5.50
Spotty Disk	Total χ^2	0.85	1.14	0.92	1.15	1.56	0.90	1.56
	Closure Phase χ^2	1.24	1.32	1.07	1.96	2.56	1.20	3.20
	Spot flux	0.011±0.001	0.010±0.001	0.026±0.016	0.060±0.003	0.010±0.001	0.012±0.001	0.010±0.001
	Spot PA	290±2	342±4	357±5	261±1	341±3	348±2	331±2
	Spot Distance	0.86±0.07	1.48±0.03	0.49±0.03	1.40±0.02	$\geq$1.50$^{(b)}$	$\geq$1.50$^{(b)}$	1.18±0.04

The spot contribute < 3% (expect 16th which has bad data quality) of total H band flux, indicating a quiescent inner disk during the periastron

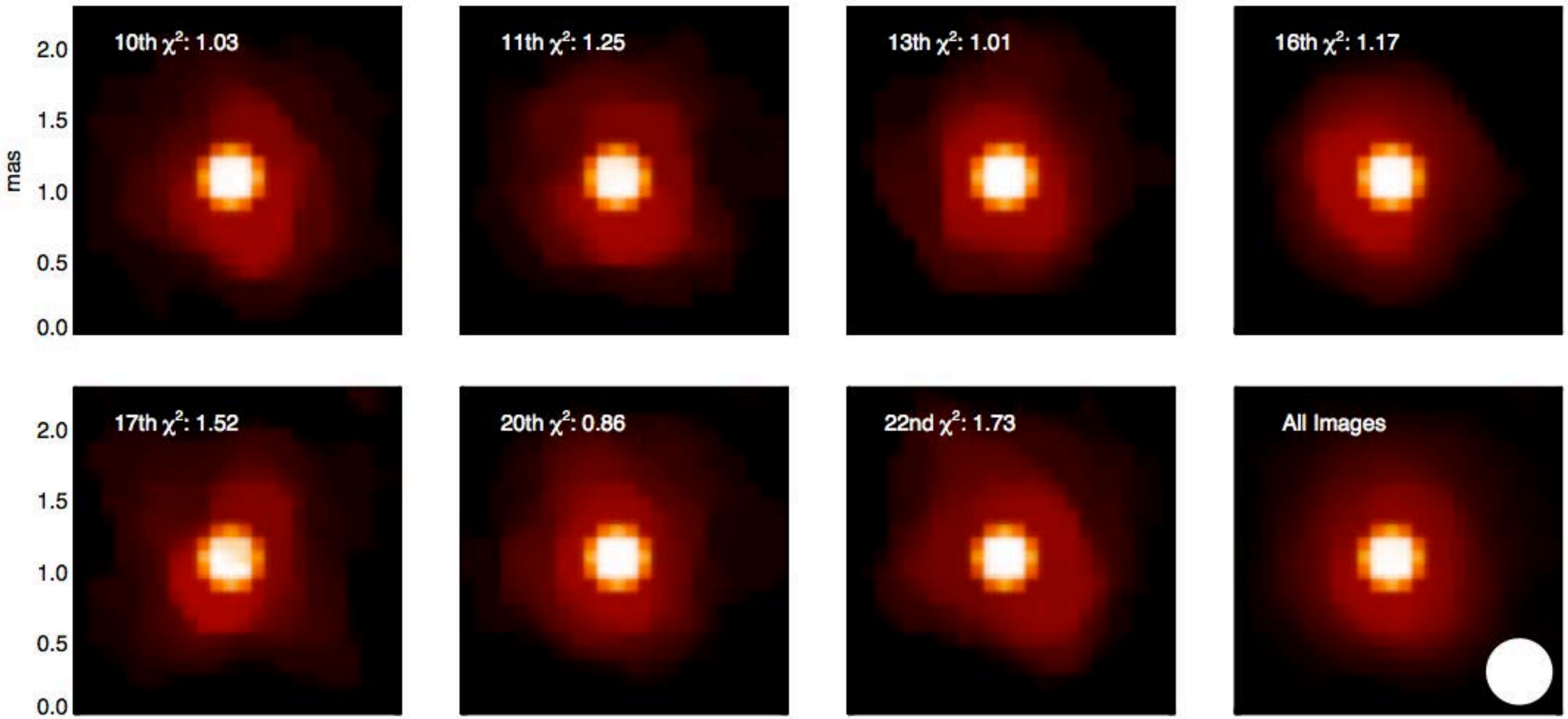
- Degeneracy between the relative position of the secondary and the disk.



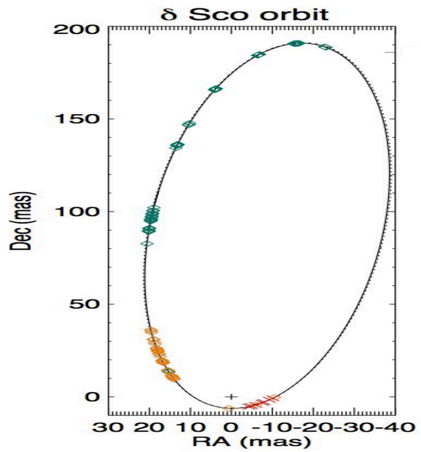
Imaging the disk

Imaging the Disk

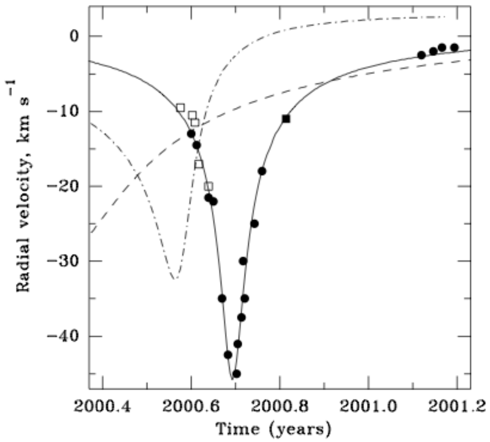
- Secondary position is fixed based on the global model.



Binary Mass Constrain



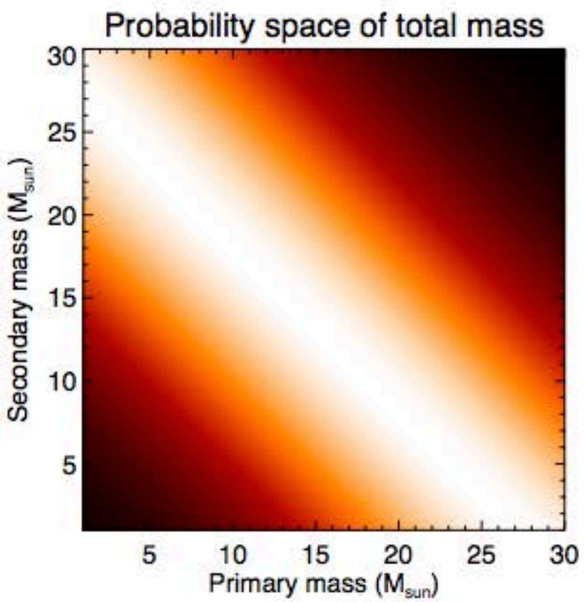
M1 + M2

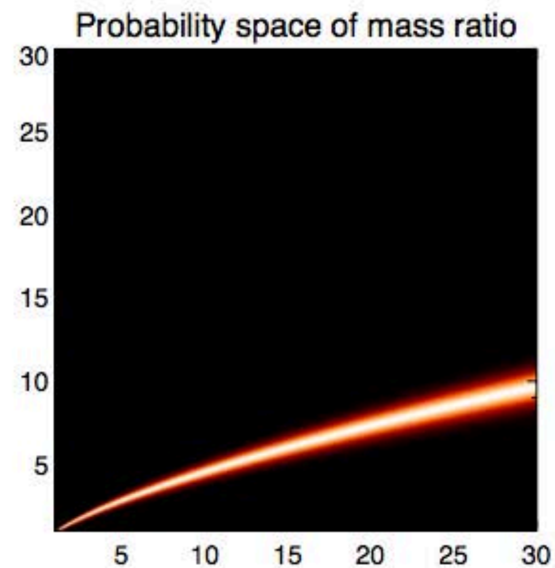


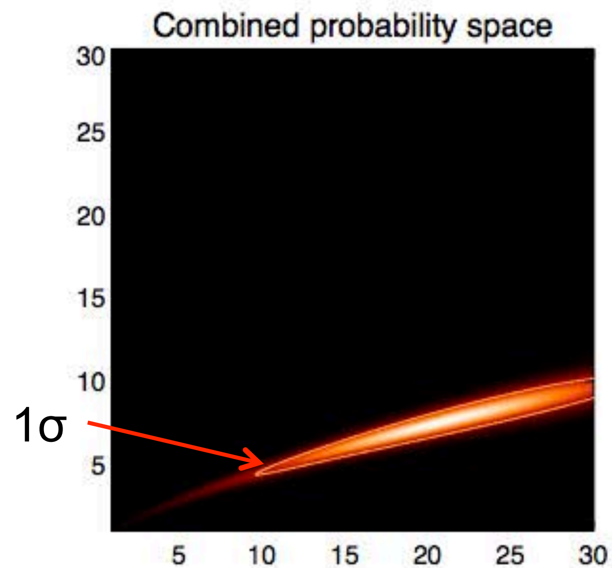
$M2/M1 \times (M1+M2)^{1/3}$

Miroshnichenko et al 2001

The elongated contour is caused by large error bar on parallax

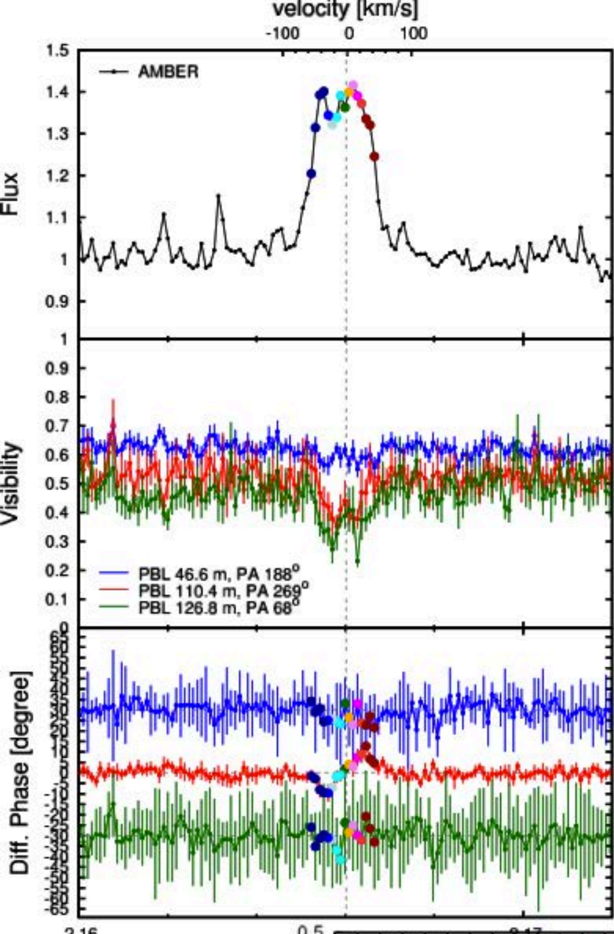


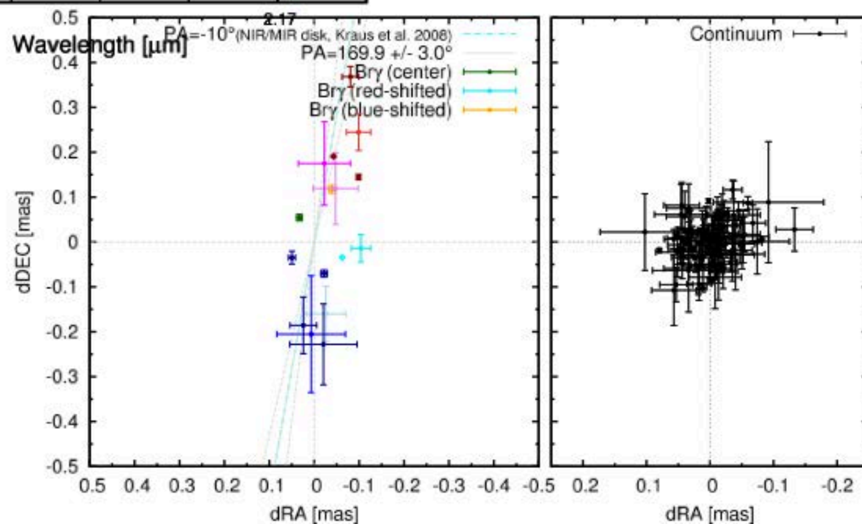


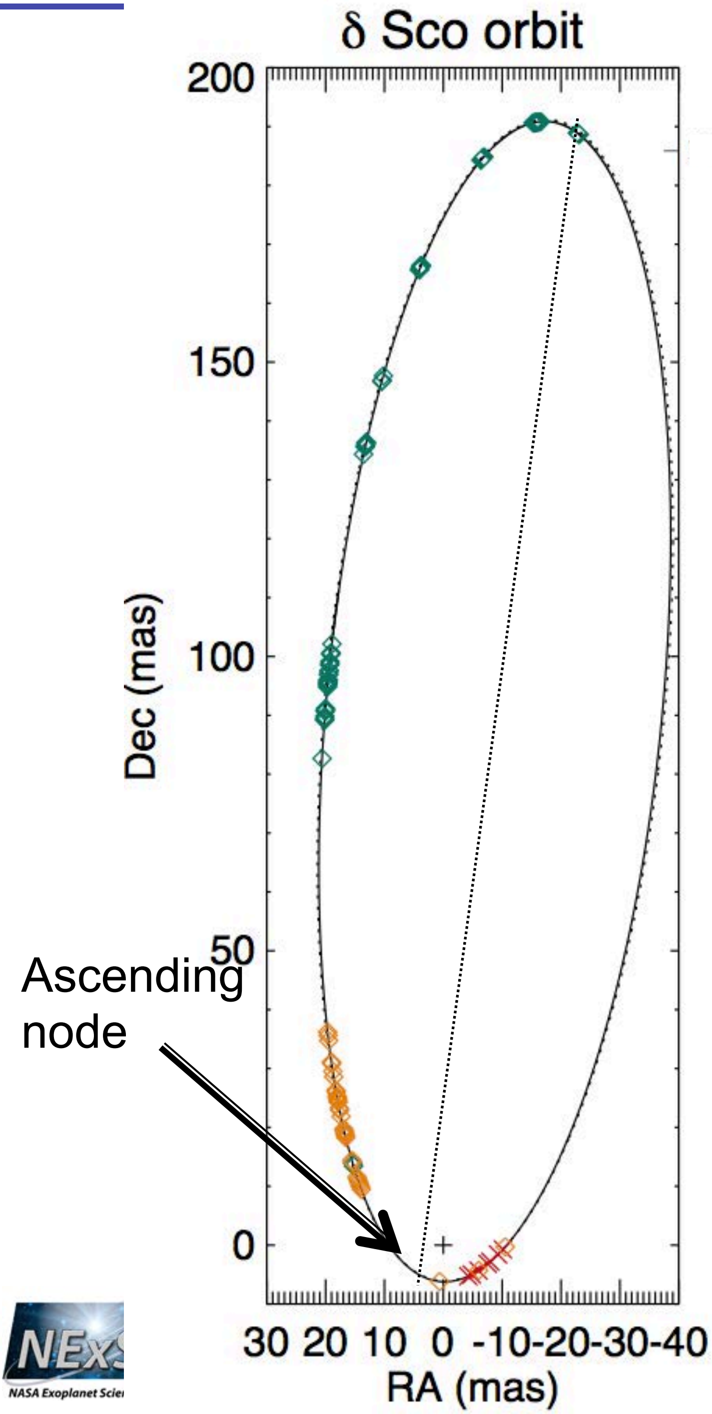


Inclination Angles

- Disk plane inclination angle: 27.9°
- Binary orbital plane inclination angle: 33.97
- From photocenter analysis (Kraus et al 2011) of VLTI/AMBER data, the disk and the secondary is rotating in the opposite direction.
- The mutual angle between the disk plane and orbit plane is either 173 (close to retrograde) or 119 degree, due to the degeneracy in which side of the disk is close to us.


velocity [km/s]
-100 0 100
AMBER
Flux
Visibility
PBL 46.6 m, PA 188°
PBL 110.4 m, PA 269°
PBL 126.8 m, PA 68°
Diff. Phase [degree]
2.16
2.17
Wavelength [µm]


PA=-10° (NIR/MIR disk, Kraus et al. 2008)
PA=169.9 +/- 3.0°
Brγ (center)
Brγ (red-shifted)
Brγ (blue-shifted)
Continuum
dDEC [mas]
dRA [mas]
dRA [mas]


δ Sco orbit
Dec (mas)
RA (mas)
Ascending node

Summary

- Orbital parameters are revised from additional new NOI data, better constrained.
- The disk was mainly symmetry, and didn’t change much during periastron
- The amount of asymmetry is about a few percent of total H band flux, and change from night to night
- Mass constrain is killed by uncertainty of the parallax
- The mutual angle between the orbit and the disk is either 173 or 119 degree

Model for the primary star

Rapidly rotating stellar model
(Aufdenberg et al 2006)

- **Mass**
- Inclination (fixed)
- Rpole
- Omega
- Tpole
- Gravity darkening coeff. (fixed to 0.188, Che et al. 2011)

Fit to

- **Vsini = 157km/s (Glebocki & Gnacinski 2005)**
- Vmag=2.31 before 2000 periastron
- Teff = 27000K (e.g. Carciofi et al 2006)

Check mass on HR diagram

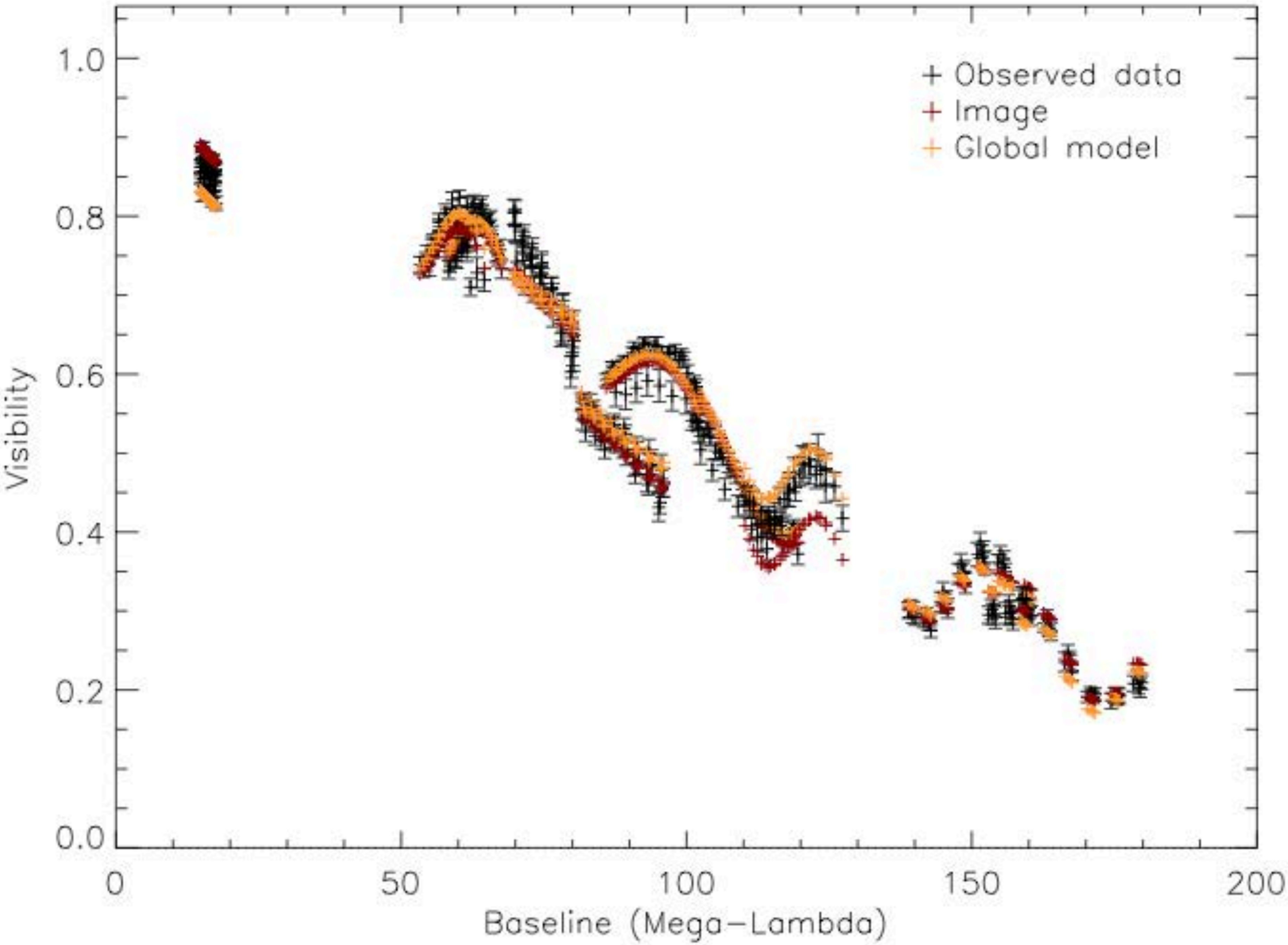
Model for the primary star

Inclination (°)	40	30	25	20	17
Mass ($M_\odot$)	14	14	14	14	13
Ω	0.6599	0.7899	0.8721	0.9555	0.9966
polar radius ($R_\odot$)	6.754	6.450	6.170	5.712	5.193
Polar radius (mas)	0.2095	0.2001	0.1914	0.1772	0.1611
Equatorial radius ($R_\odot$)	7.305	7.322	7.340	7.375	7.440
polar temperature (K)	27907	28274	28639	29310	30307
True luminosity ($L_\odot$)	23590	21869	20316	17935	15767
Apparent luminosity ($L_\odot$)	24807	24915	25042	25272	25625
Nonrotating luminosity ($L_\odot$)	25530	23668	21987	19410	17429
Nonrotating T_{eff}	27755	27870	27976	28181	28485

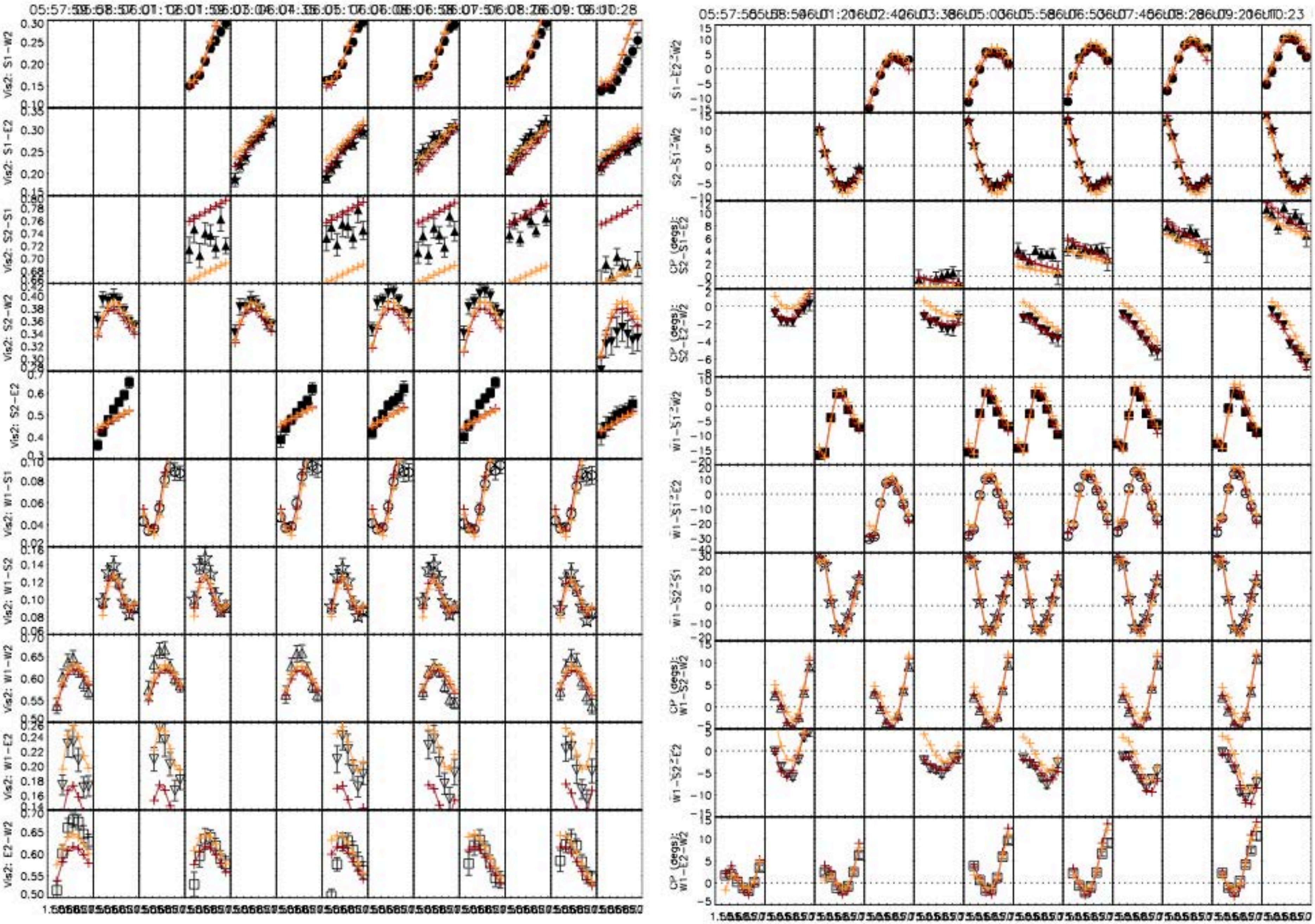
- Adopt inclination=25deg model for the primary, then approximate it with a uniform ellipse
- The secondary is too small to be resolved, using UD=0.241mas based its mass
- In the model, flux ratio between the binary are fixed based on the size and Teff

How much can we trust the spotty model

- The distance of the spot-like asymmetry varies every day probably due to:
  - the model is too simple to reflect the true asymmetry
  - Rotational period about 0.5 – 1.5 days
- The most we can get out of the model is the inner part of the disk is mostly quiescent.
- If there is any, the point-like asymmetry is only about a few percent in H band flux, and probably has nothing to do with periastron passage.
- Supported by photometry observation
- Halonen et al. (2008) find some asymmetry in the Hα line that can not be modeled by an axis-symmetry disk in 2006 away from the periastron



Observed data
Image
Global model
Visibility
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
Baseline (Mega-Lambda)


Vis2: S1-W2
Vis2: S1-E2
Vis2: S2-S1
Vis2: S2-W2
Vis2: S2-E2
Vis2: W1-S1
Vis2: W1-S2
Vis2: W1-W2
Vis2: W1-E2
Vis2: E2-W2
S1-E2-W2
S2-S1-W2
CP (degs): S2-S1-E2
CP (degs): S2-E2-W2
W1-S1-W2
W1-S1-E2
W1-S2-S1
CP (degs): W1-S2-W2
W1-S2-E2
CP (degs): W1-E2-W2

Symmetric Disk Model

- Fit the model with symmetric disk to MIRC data of individual nights independently.

	Ratio to flux of the whole system	Ratio of radii of the disk hole along minor and major axes	Along major axis		
Dates	Disk Flux Fraction	ρ^{a}	HWHM (mas)[b]	PA (°)[c]	Total χ^2
2011Jul10th	0.718±0.008	0.914±0.032	0.342±0.015	27±5	1.5
2011Jul11th	0.760±0.011	0.882±0.032	0.366±0.017	20±3	1.1
2011Jul13th	0.715±0.010	0.855± 0.013	0.365±0.013	-9±5	0.8
2011Jul16th	0.749±0.018	0.919±0.013	0.319±0.014	5±8	0.8
2011Jul17th	0.688±0.007	0.932±0.023	0.314±0.014	11±6	1.9
2011Jul20th	0.694±0.008	0.851±0.027	0.363±0.009	13±5	1.4
2011Jul22nd	0.742±0.005	0.792±0.023	0.426±0.021	33±2	2.4

The disk is stable through MIRC observations!