



# Yes, CHARA Can Image Cool Starspots, But Can It See Them Move?

*A Case Study of Lambda Andromedae*

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# Committee and Collaborators

## Advisor

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## Committee

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## Special Thanks

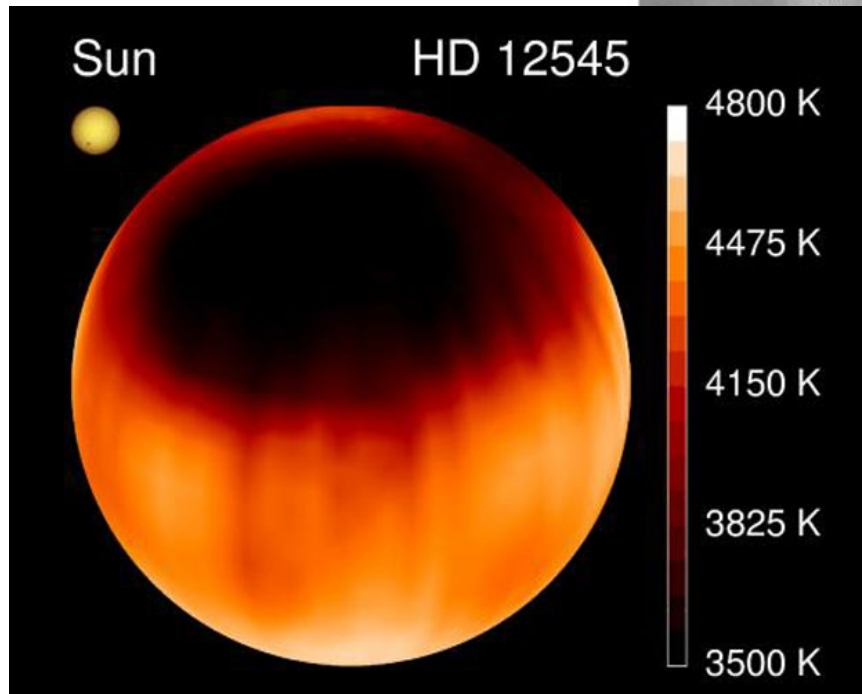
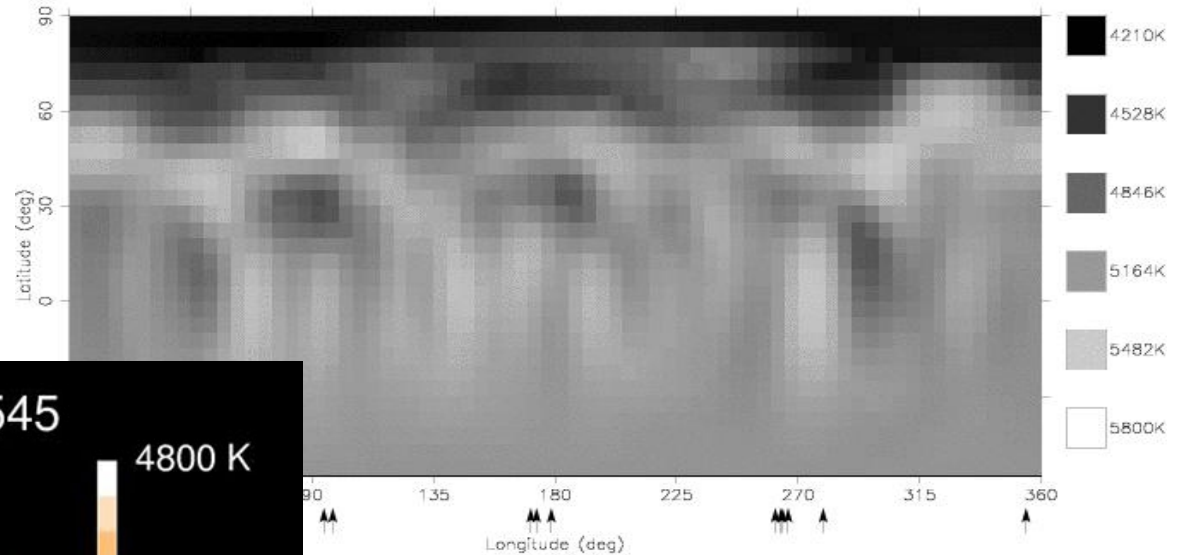
Xiao Che (UM)

Brian Kloppenborg (UD)

The CHARA team

# Goals

HD 171488 average temperature map



Strassmeier 1999



# Goals

- Directly image cool starspots
  - Precisely measure cool starspot properties
- Observe stellar rotation via cool starspot motion
- Develop techniques for imaging other active stars → compare with Doppler maps



1152581 www.fotosearch.com

## “Lambdy Andy”

G8 III

SB1

$\pi = 38.74 \pm 0.68$  mas

**D ~ 25 pc**

$v_{\text{sin}i} = 6.5$  km/s

$P_{\text{phot}} = 54.33$  days

**H mag = 1.501**

**$\Delta V$  mag = 0.22**

$\theta \sim 2.75$  mas

## Henry et al. 1995

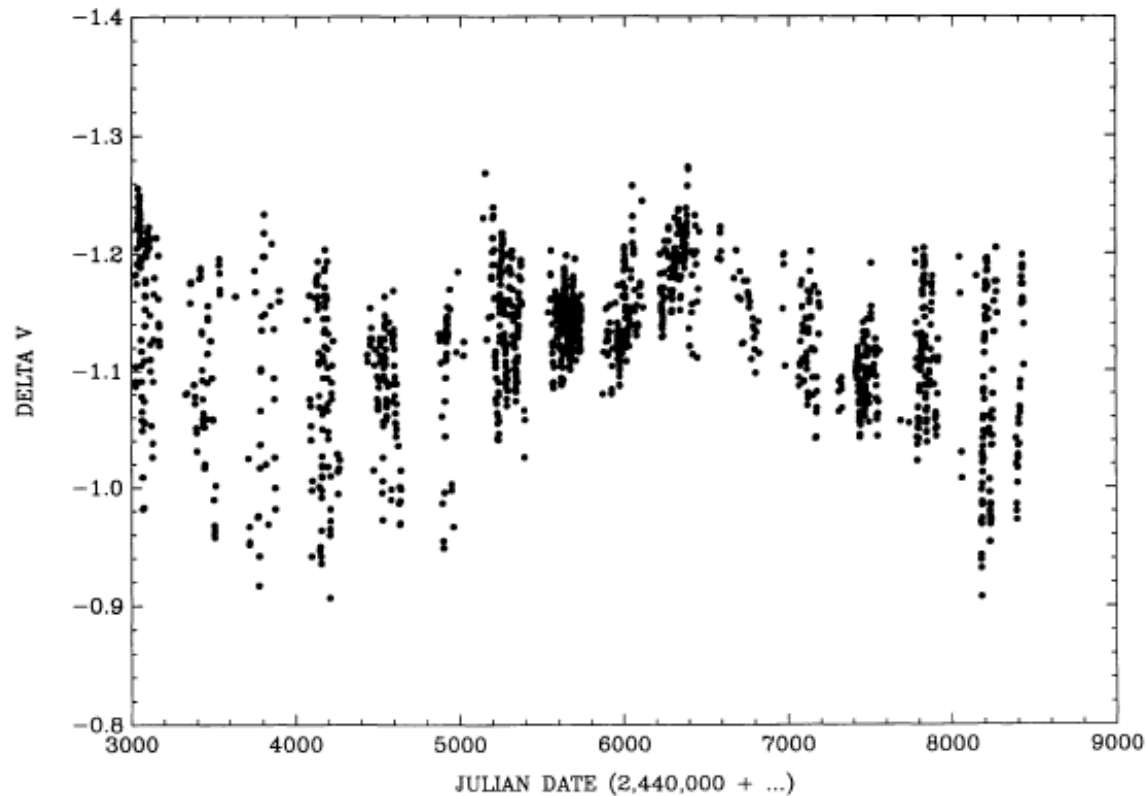
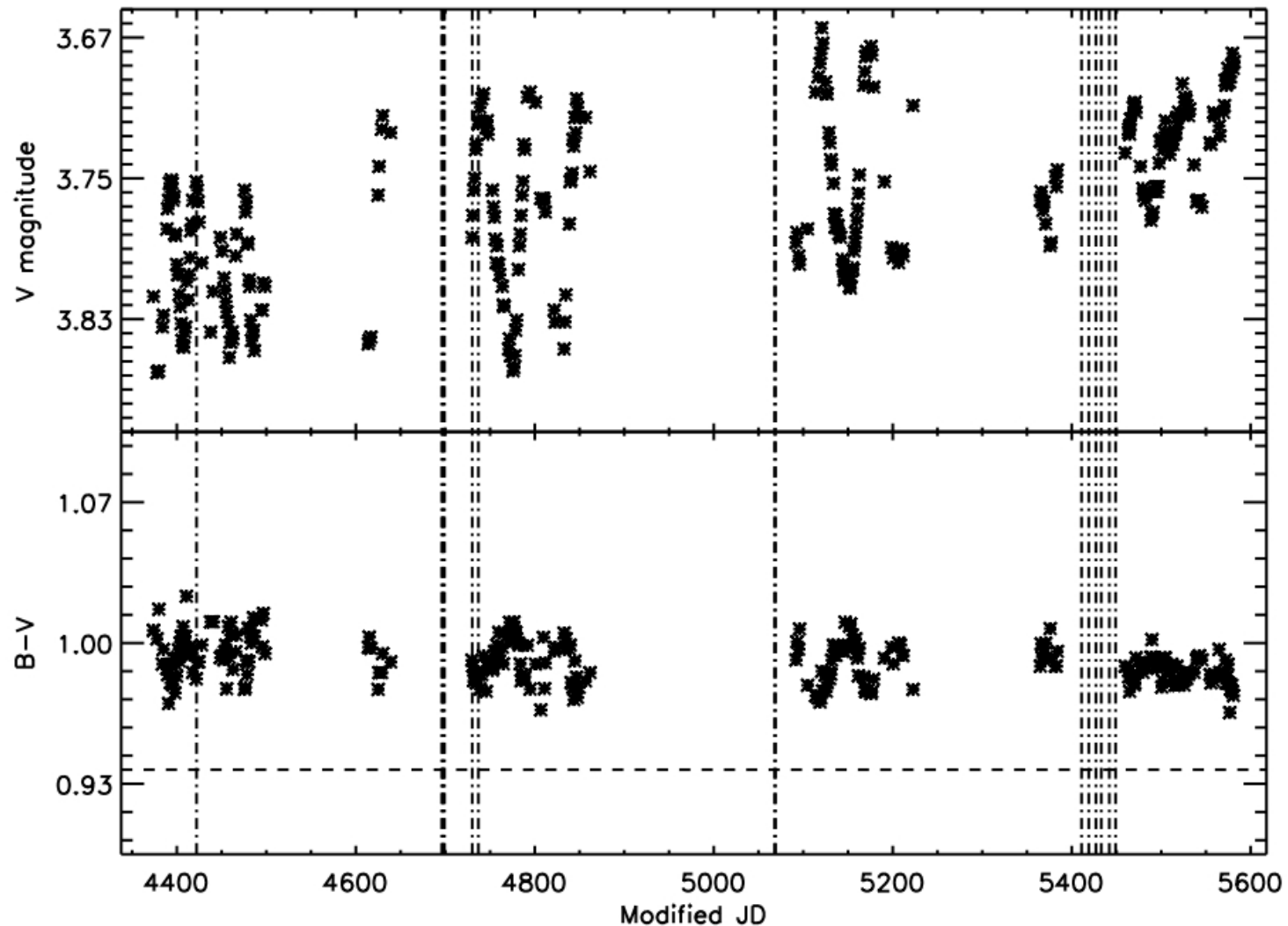


FIG. 2.—1976–1991  $V$  light curve of  $\lambda$  And from the data sources listed in Table 1. Each point is the mean of (usually) three differential observations in the sense of  $\lambda$  And minus  $\Psi$  And. While the 54 day rotation period is difficult to see at this scale, the changing amplitude of the spot wave and the long-term variations in mean magnitude are readily apparent.





# Lam And Light Curve 2007-2011





# CHARA Observations

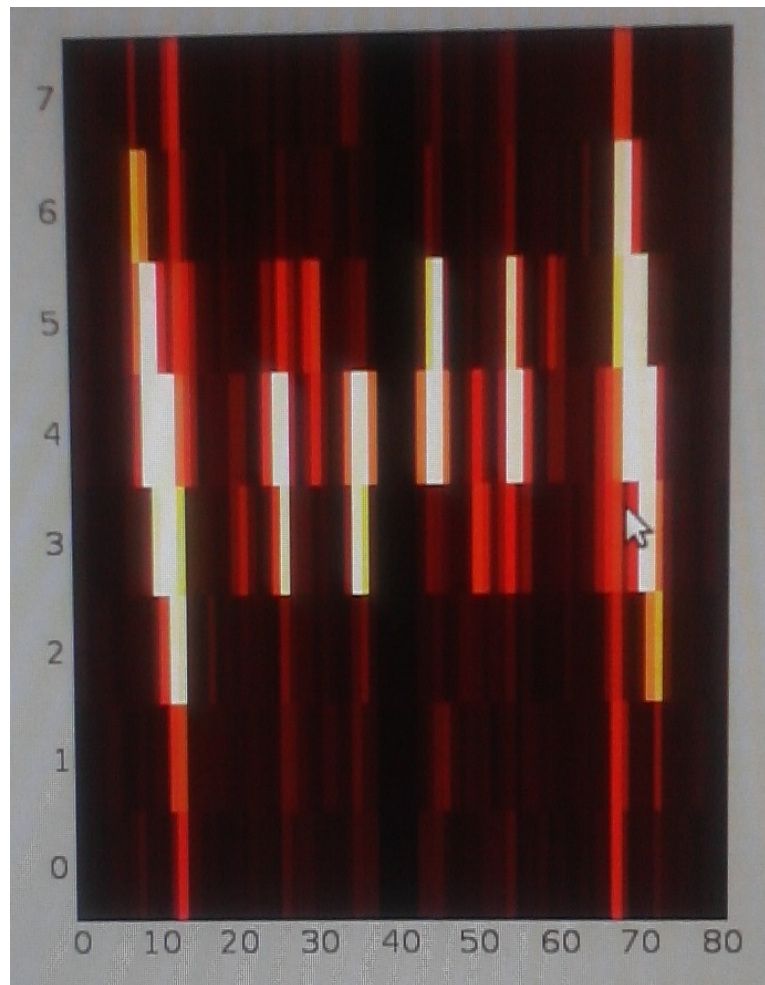
MIRC – H band

$R \sim 40$

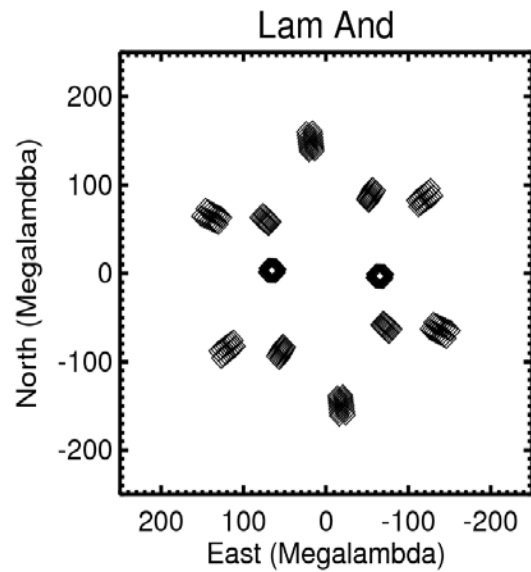
27 epochs

11/17/07 to 10/24/12

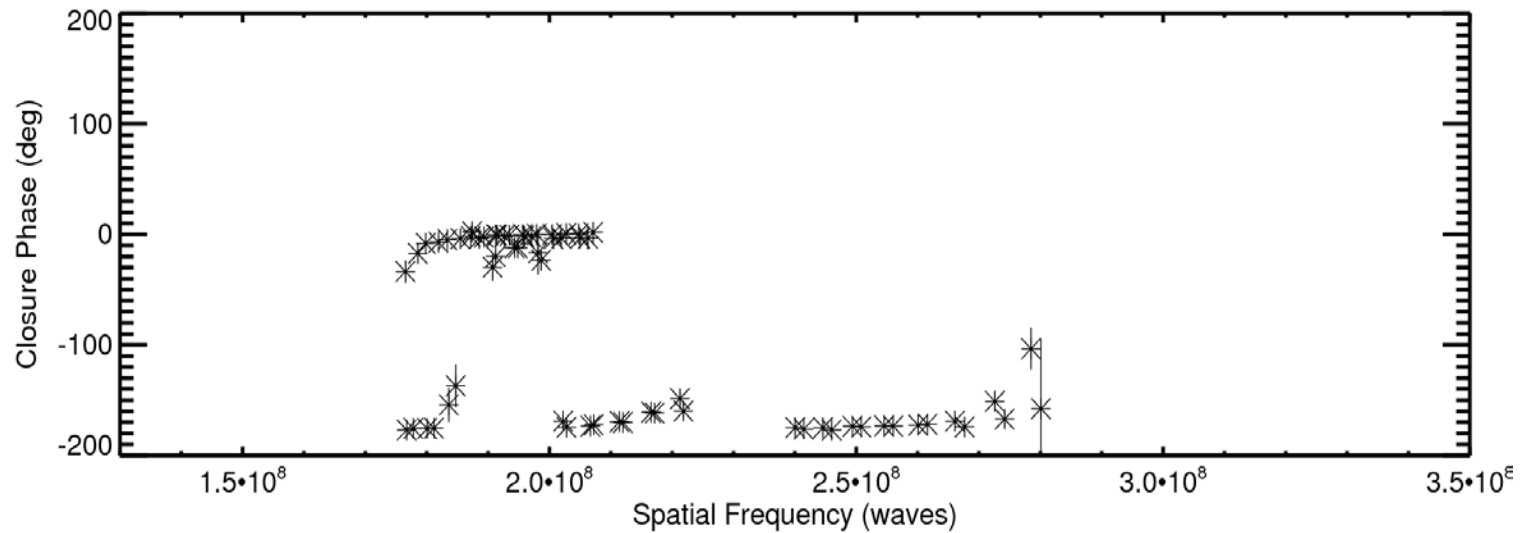
Evolving observing strategy

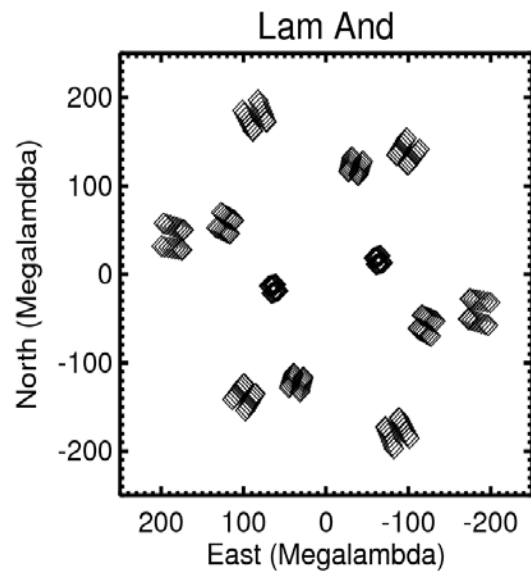




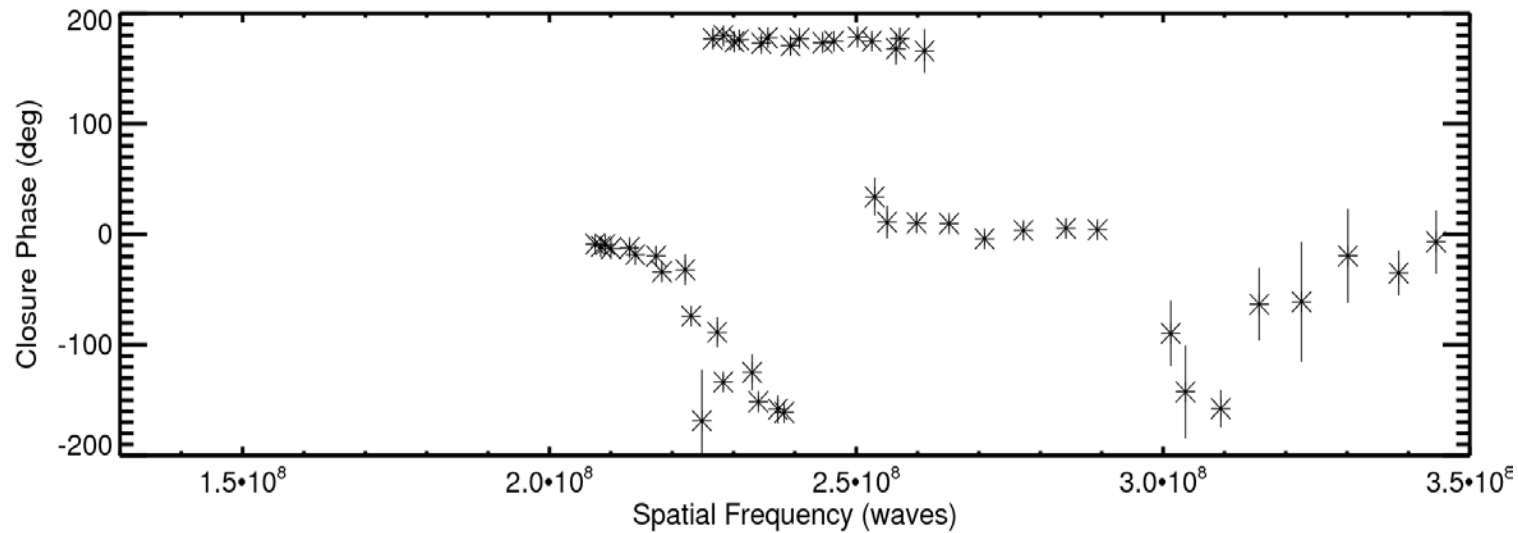


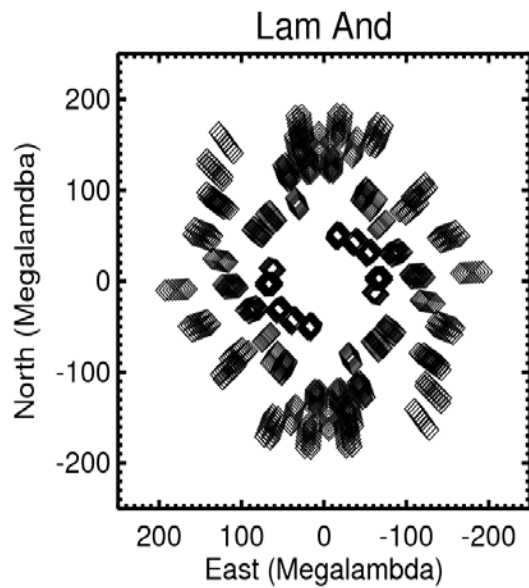
Nov 17<sup>th</sup> , 2007  
S2-E2-W1-W2



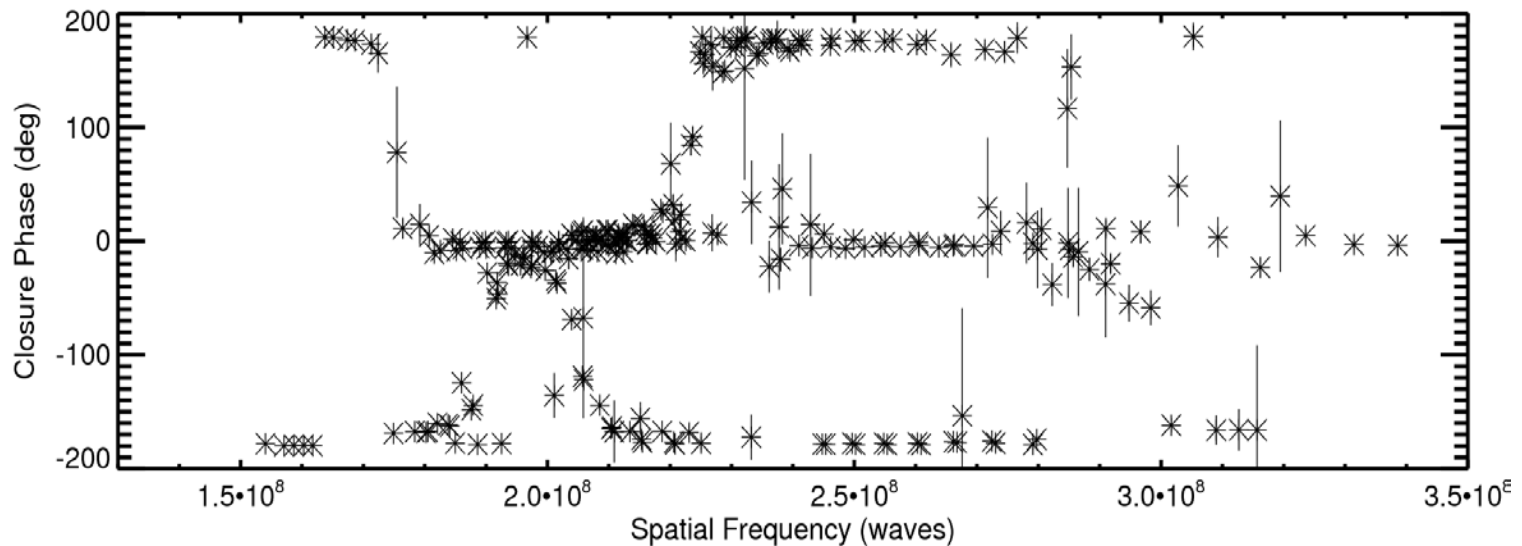


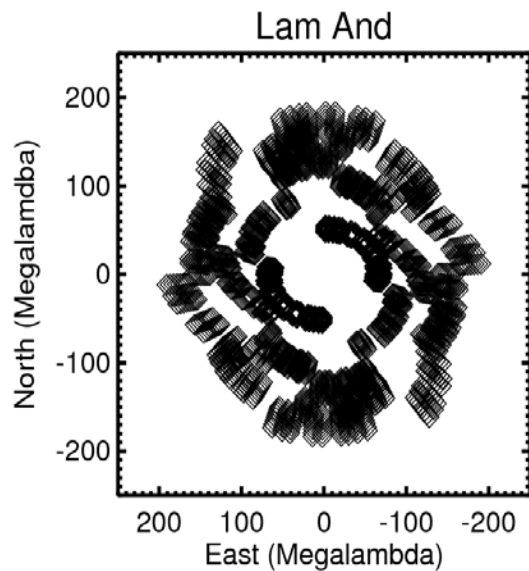
Aug 17<sup>th</sup> , 2008  
S1-E1-W1-W2



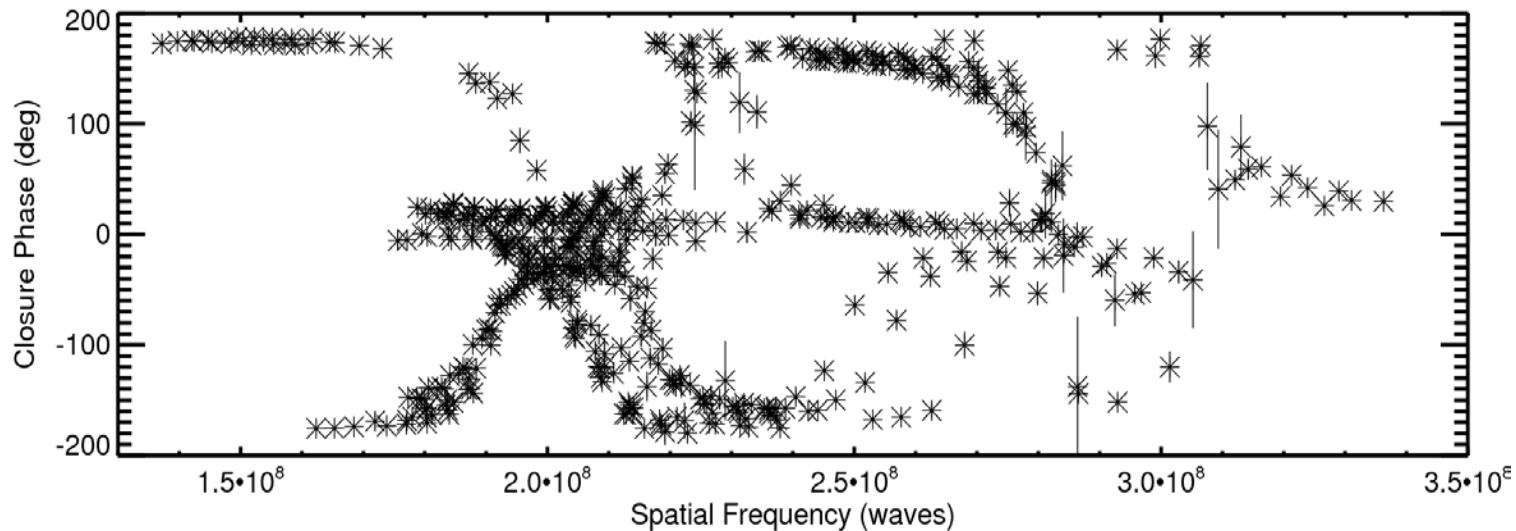


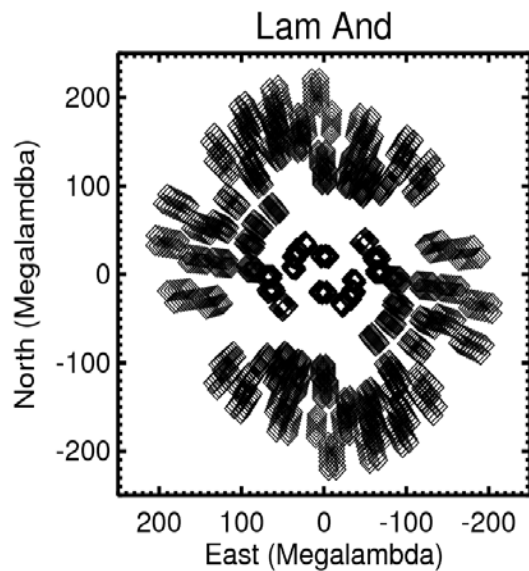
Aug 25<sup>th</sup> , 2009  
S1-E1-W1-W2 &  
S2-E2-W1-W2



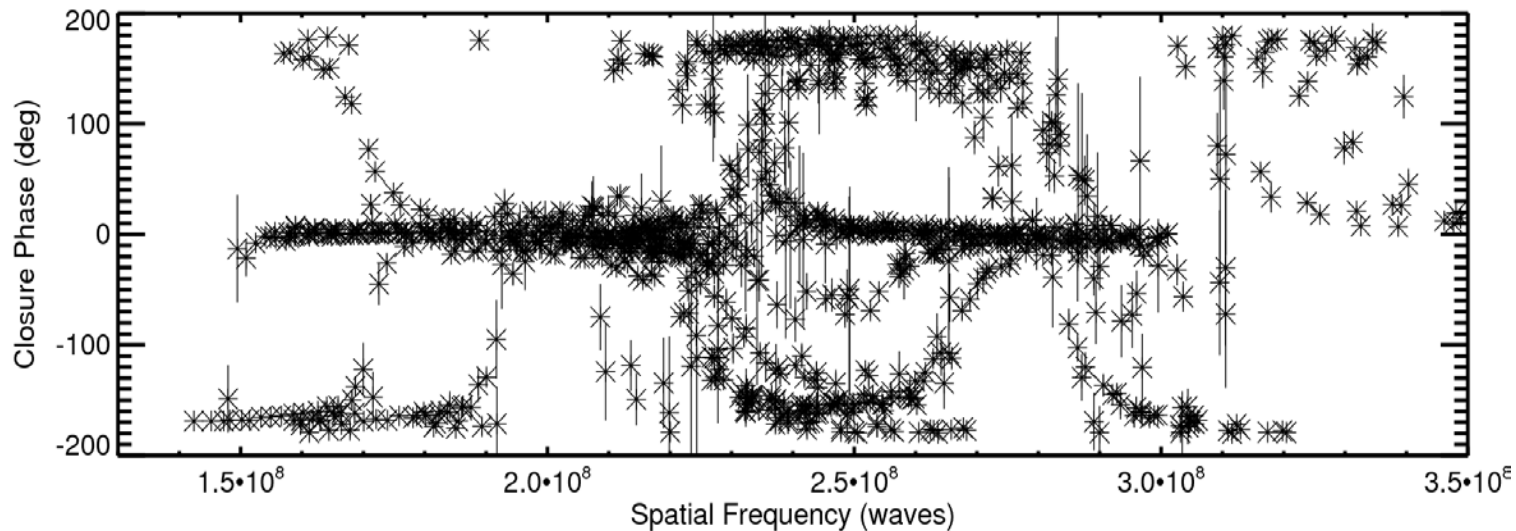


Aug 24<sup>th</sup> & 25<sup>th</sup> , 2010  
S1-E1-W1-W2 &  
S2-E2-W1-W2





Sept 19<sup>th</sup> , 2011  
S1-S2-E1-E2-W1-W2





# Parametric Model & Reconstructions

## MODEL

Power-law limb  
darkening

2 stellar parameters

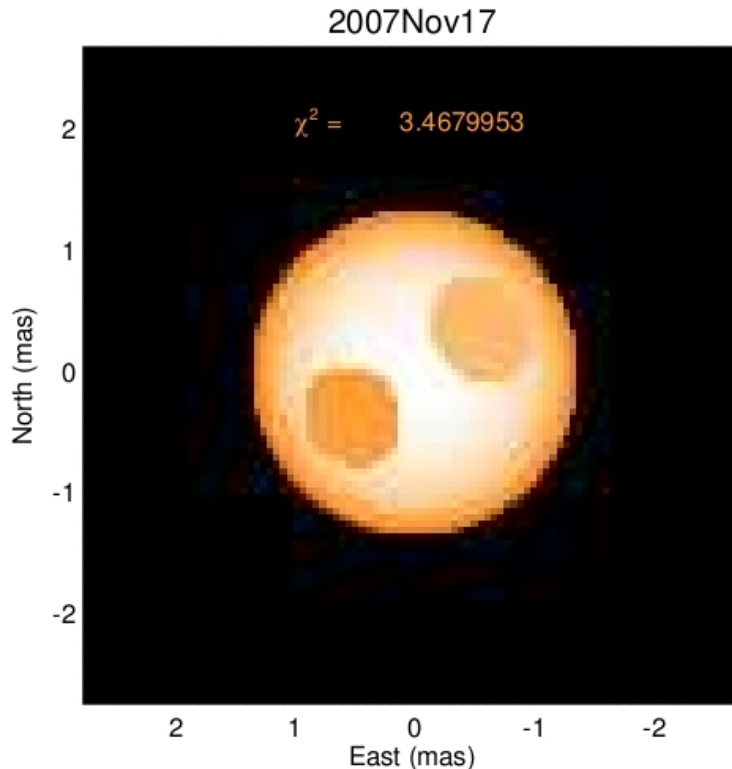
- $\theta, \alpha$

N spot parameters

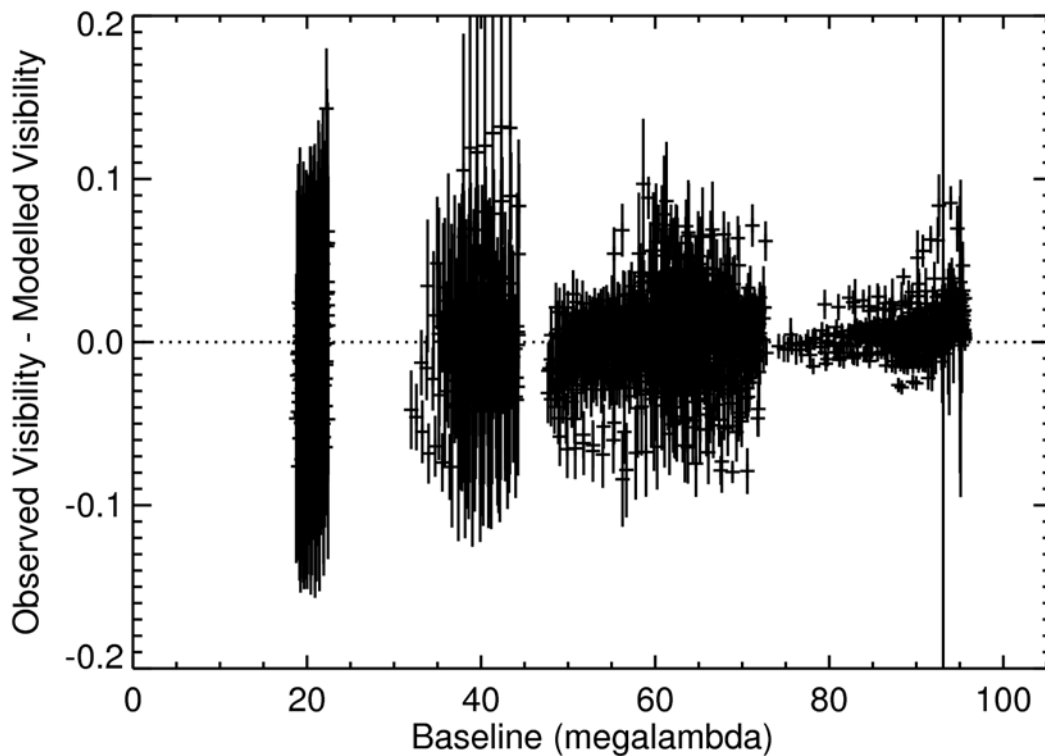
- $(\varphi, b, l, f)$  per spot

Downhill simplex

## MACIM & BSMEM



First find stellar  
diameter and limb  
darkening coefficient  
only using 1<sup>st</sup> lobe  
visibility data



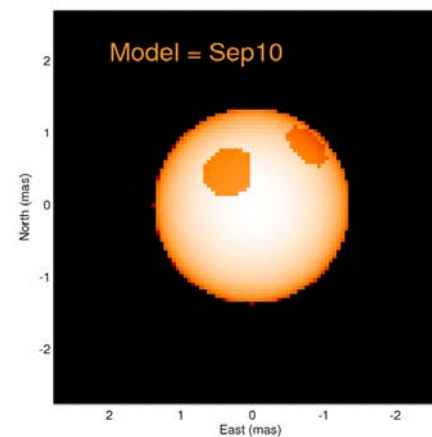
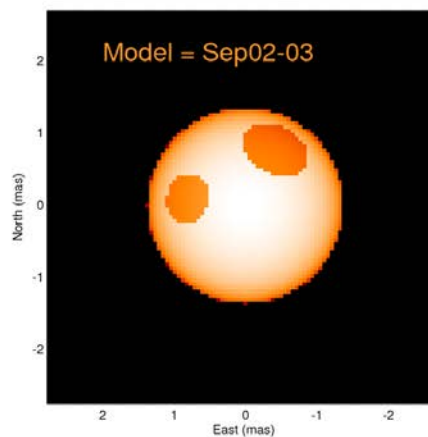
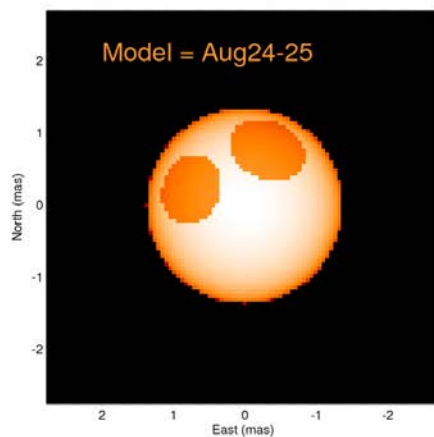
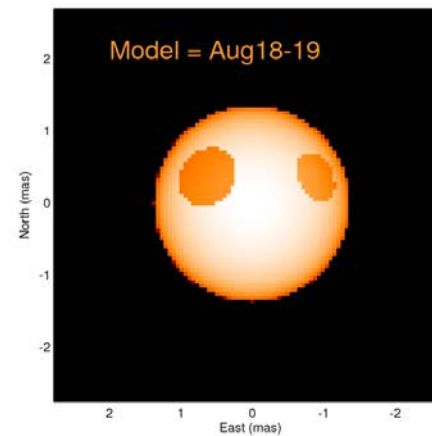
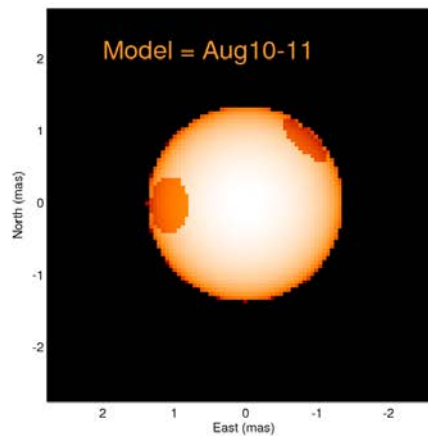
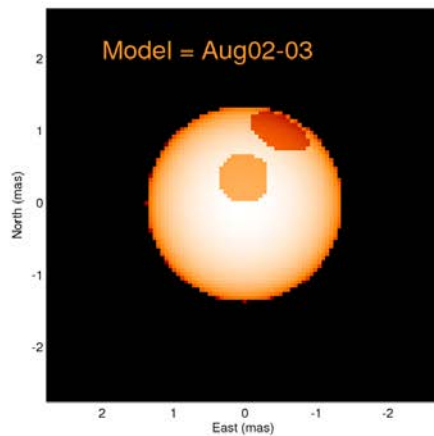
$$\theta: 2.777 \pm 0.027 \text{ (mas)}$$

$$\alpha: 0.241 \pm 0.014$$

$$R_{\text{star}} = 9.64 \pm 0.19 R_{\text{sun}}$$

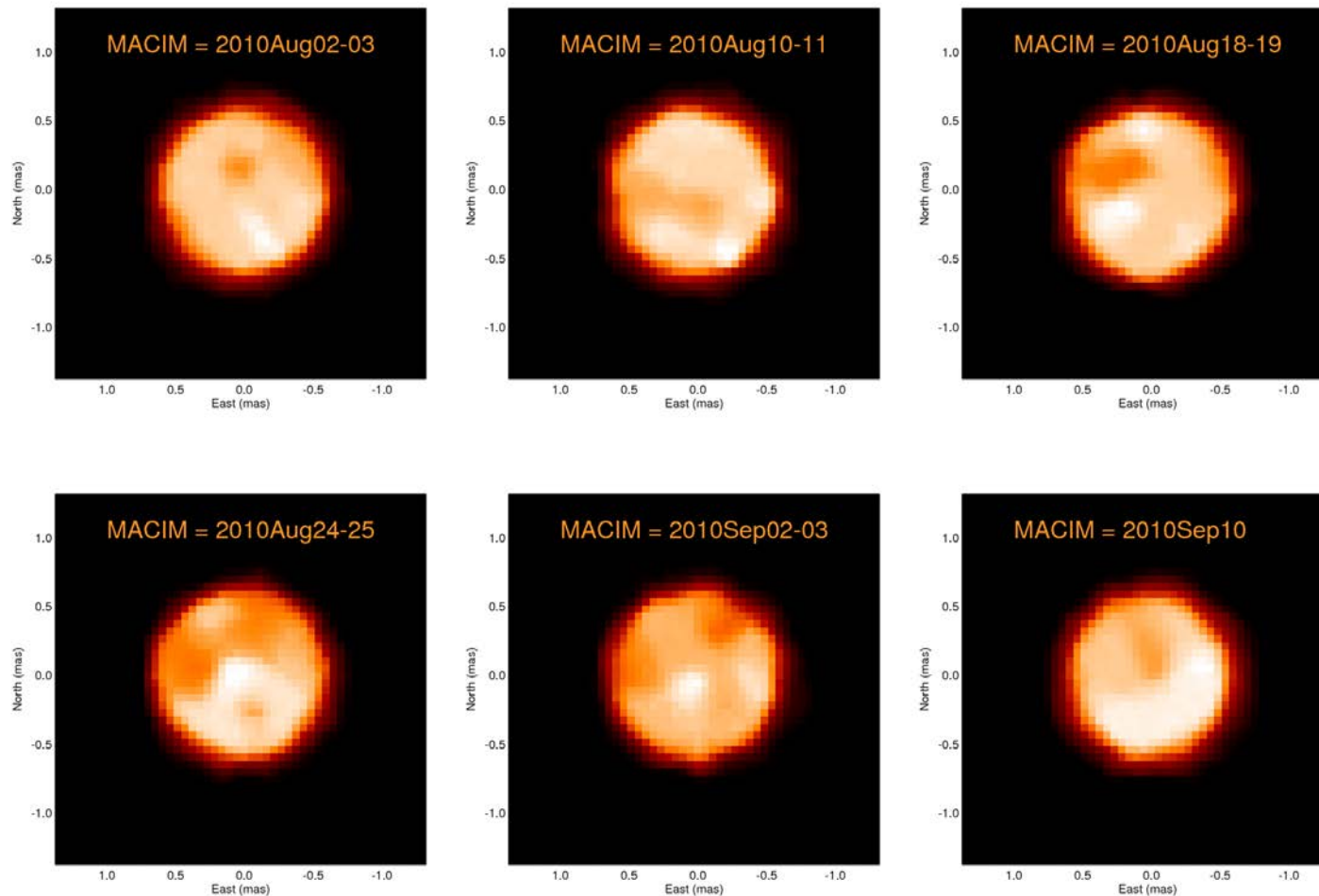


# Observing Cadence: ~ 8 days (15%)



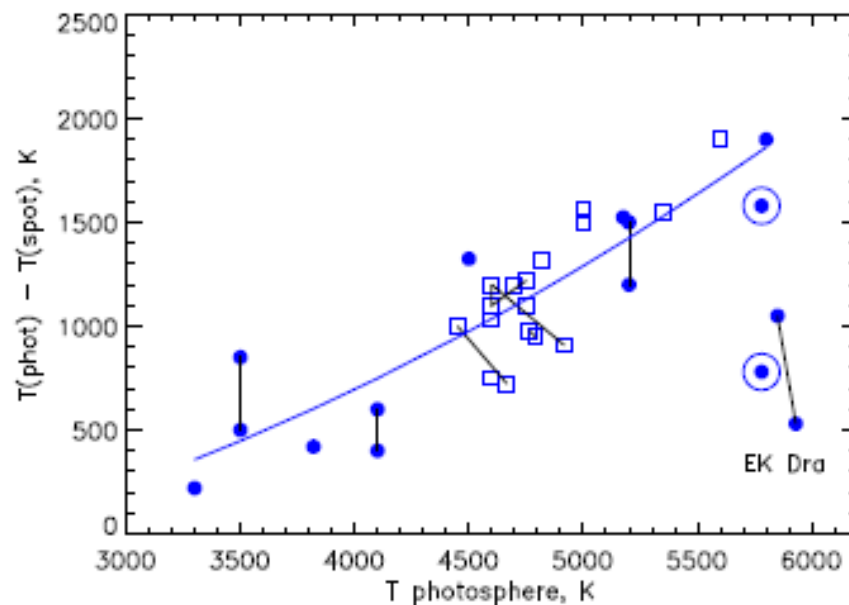


# Observing Cadence: ~ 8 days (15%)



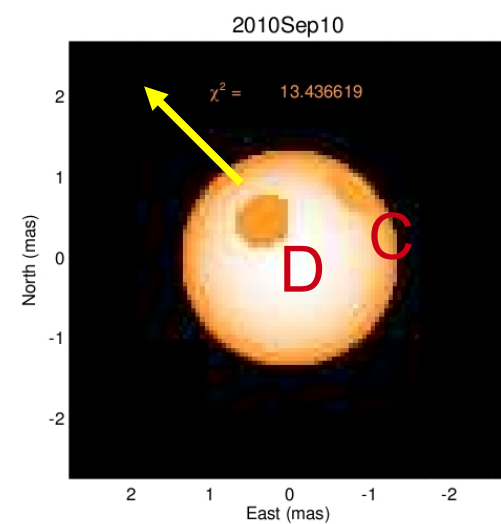
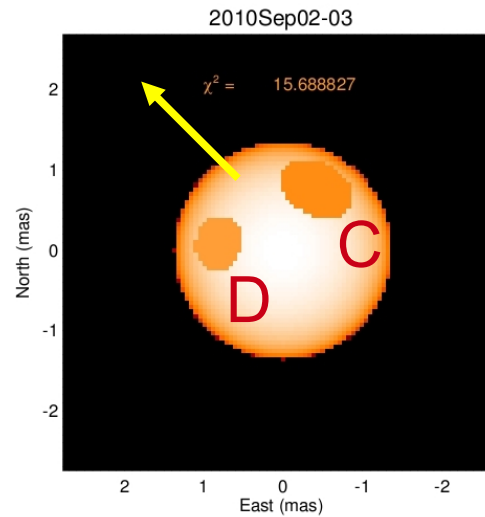
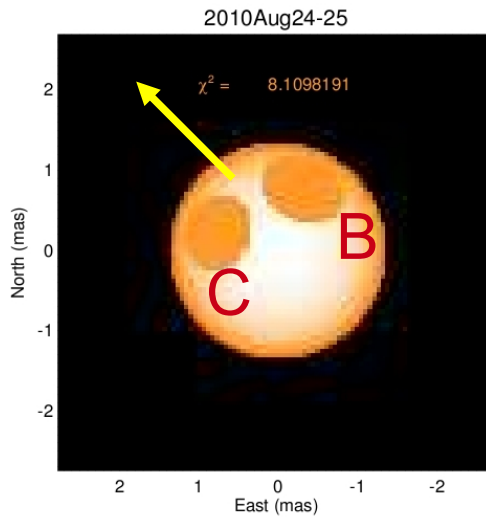
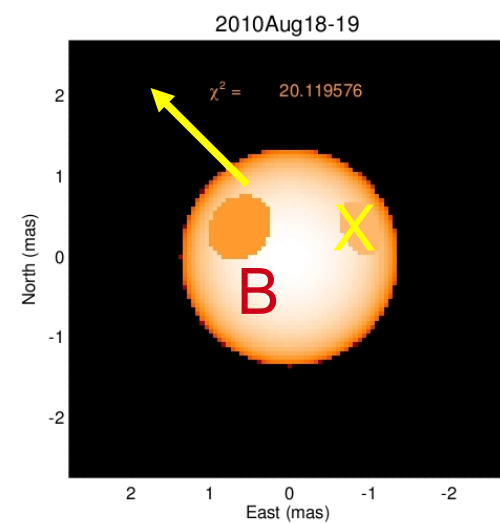
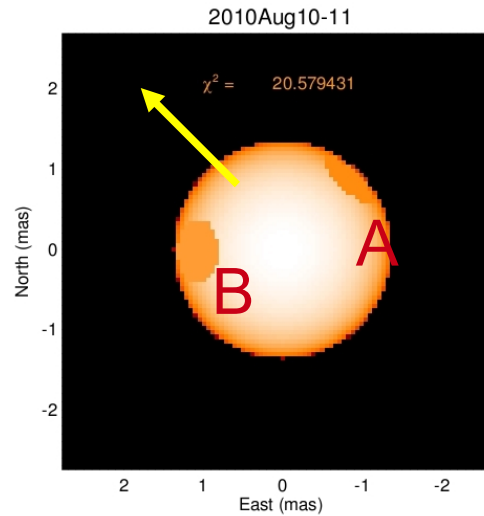
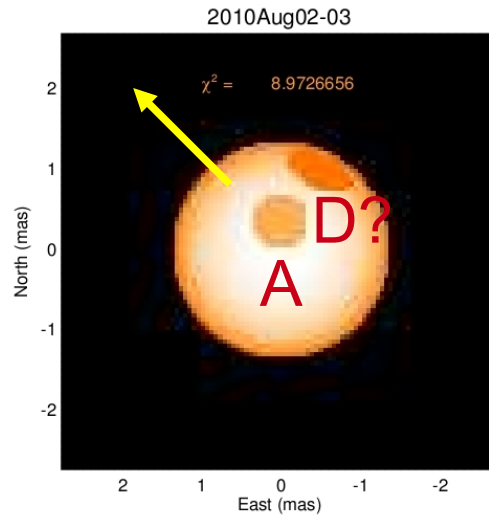
# Are These Spots Real?

- Consistency between models and reconstructions
- Consistent spot parameters
  - $\phi = 0.101 \pm 0.033$
  - $F_{\text{sp}}/F_{\text{ph}} = 0.789 \pm 0.035$
- Starspot temperature consistent with expectations
  - $\Delta T \sim 500 \text{ K}$





# Rotation?

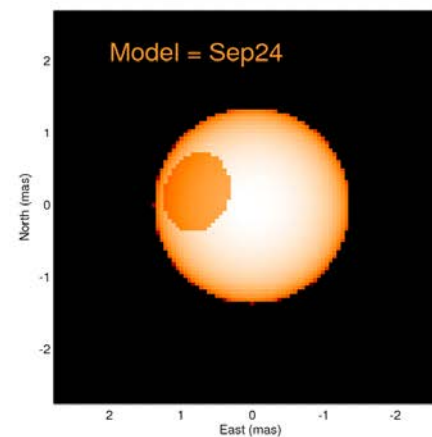
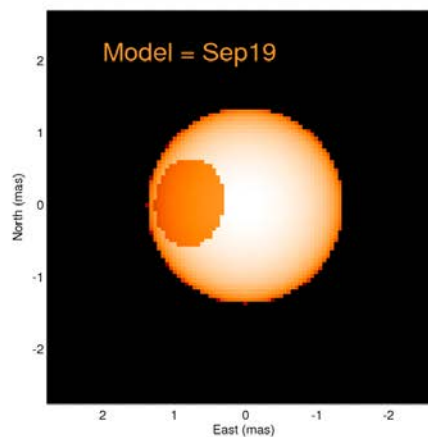
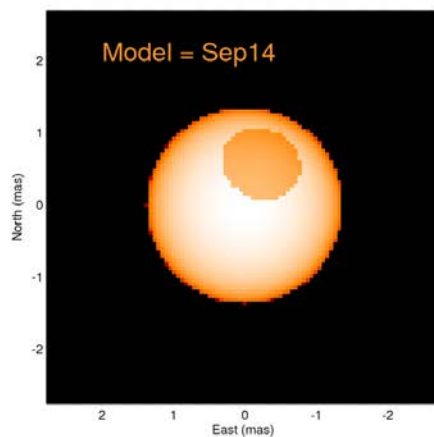
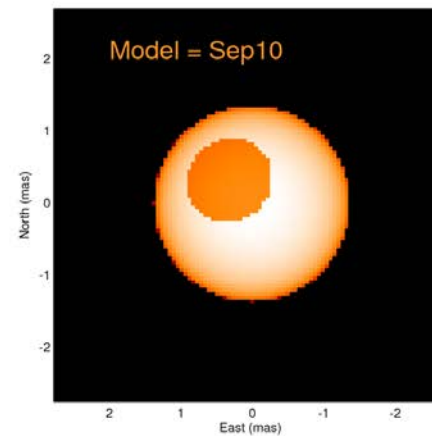
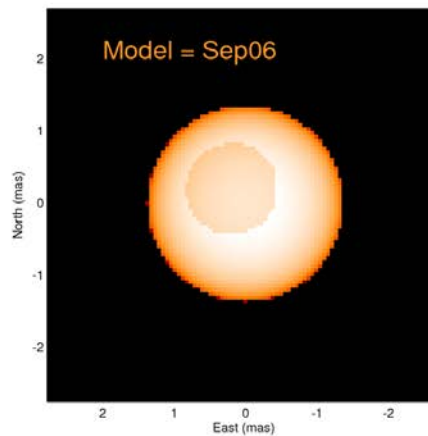
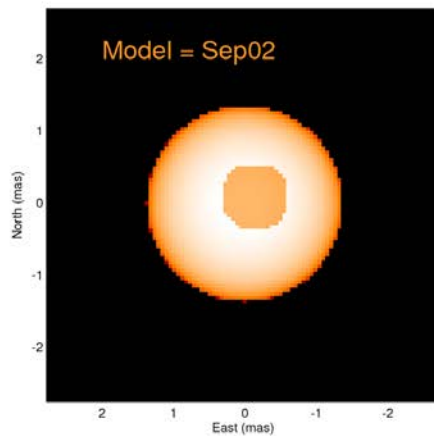




| Spo<br>t | Parameter | 1          | 2      | 3     | Diff         |
|----------|-----------|------------|--------|-------|--------------|
| A        | $\varphi$ | 0.076      | 0.080  | ---   | <b>0.004</b> |
|          | b         | 17.32      | 43.93  | ---   | ---          |
|          | l         | 0.76       | 65.45  | ---   | ---          |
|          | r         | 0.84       | 0.76   | ---   | <b>0.08</b>  |
| B        | $\varphi$ | 0.098      | 0.10   | ---   | <b>0.002</b> |
|          | b         | 0.13       | 18.39  | ---   | ---          |
|          | l         | -<br>51.44 | -27.94 | ---   | ---          |
|          | r         | 0.80       | 0.79   | ---   | <b>0.01</b>  |
| C        | $\varphi$ | 0.14       | 0.14   | 0.06  | <b>0</b>     |
|          | b         | 12.08      | 40.36  | 38.34 | ---          |
|          | l         | -<br>35.65 | 28.96  | 50.19 | ---          |
|          | r         | 0.79       | 0.76   | 0.81  | <b>0.03</b>  |
| D        | $\varphi$ | 0.072      | 0.075  | ---   | <b>0.003</b> |
|          | b         | 5.77       | 22.77  | ---   | ---          |
|          | l         | -          | -15.11 | ---   | ---          |

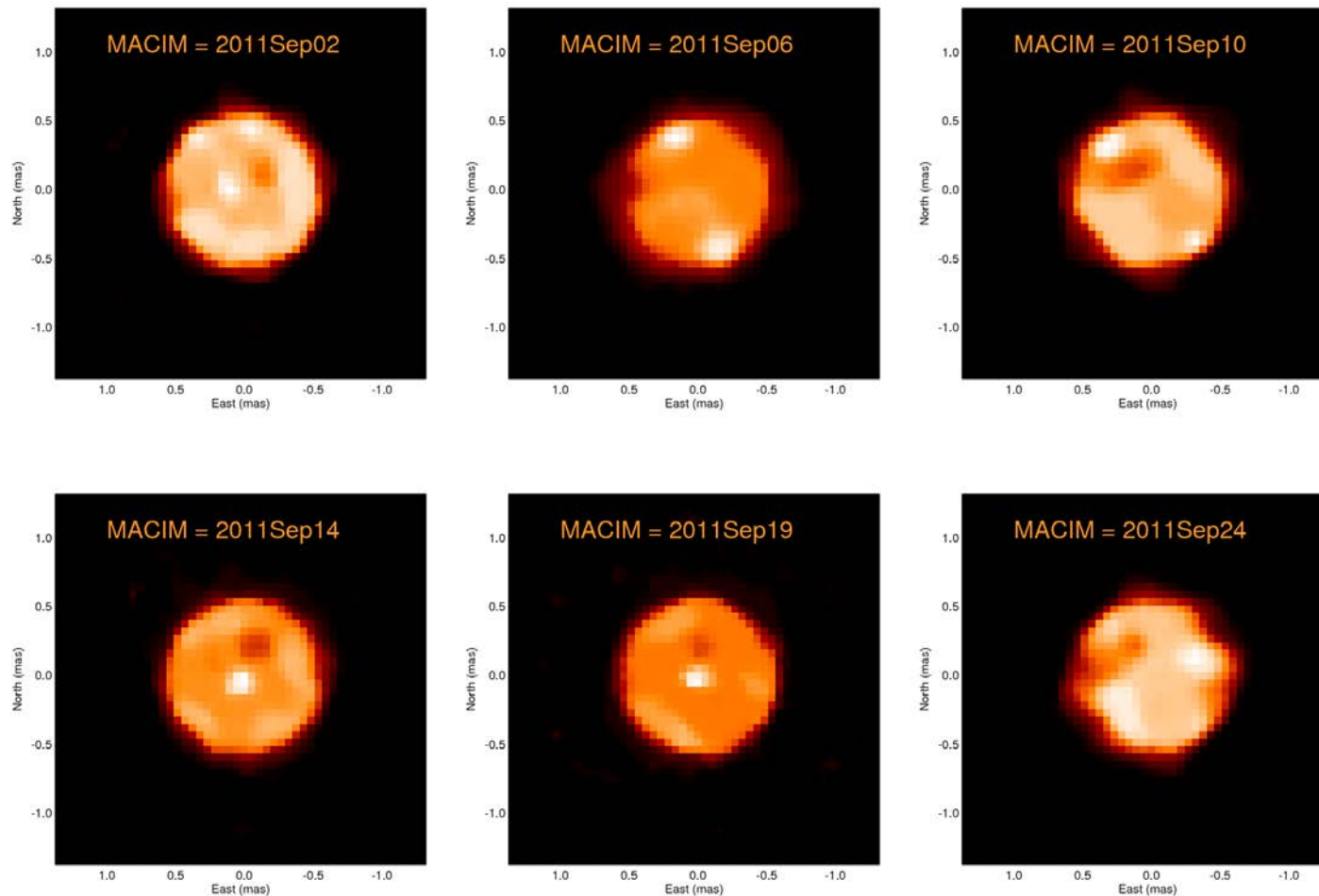


# Observing Cadence: ~ 4 days (7%)

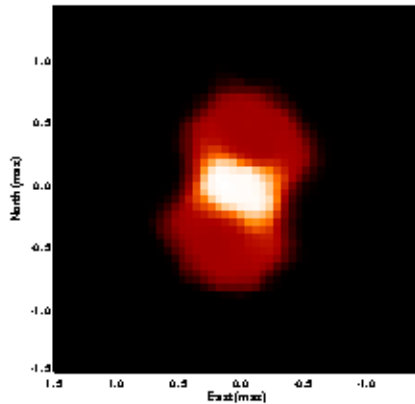




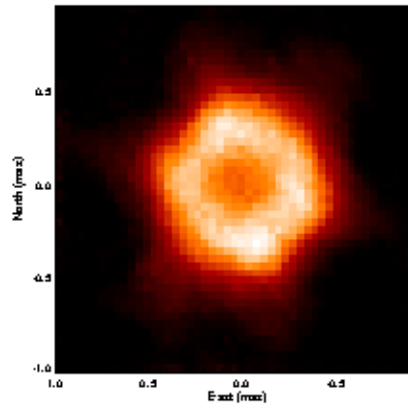
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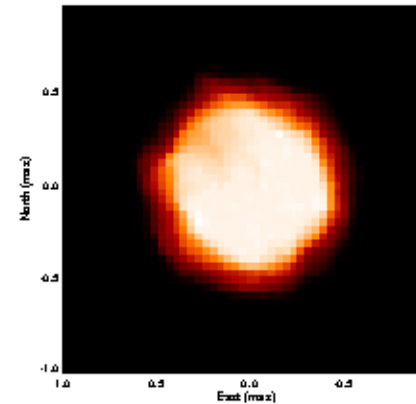
BM 3  
Scale 0.12



BM 3  
Scale 0.08



BM 10  
Scale 0.08



Amoeba solutions  
highly dependent on  
initial positions and  
search scales.

