



Imaging Spotted Giant Stars

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and the CHARA collaboration



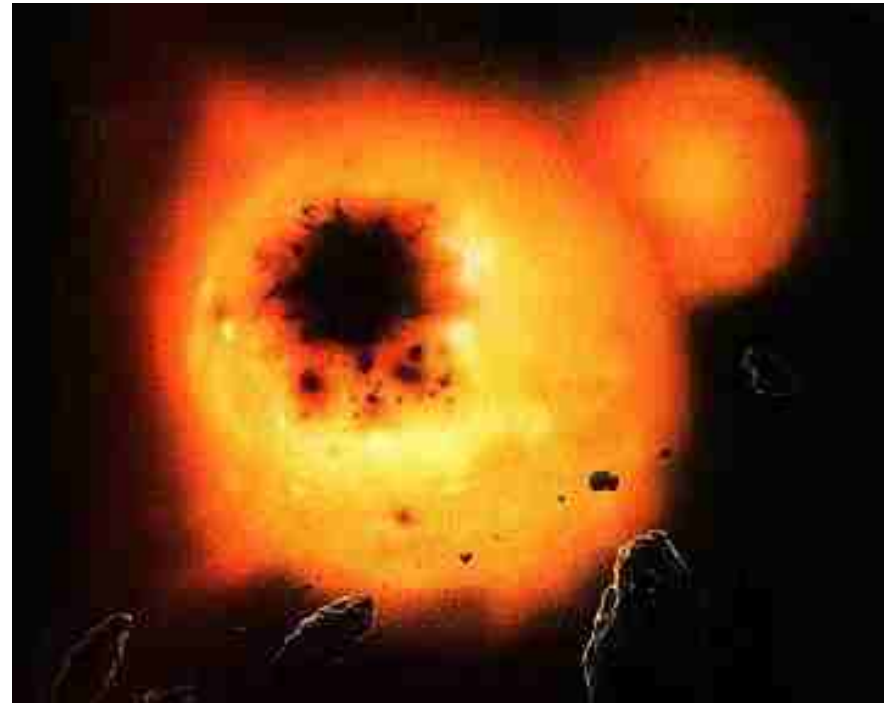
Imaging Spotted Stars with CHARA

- Compare aperture synthesis images with contemporaneous Doppler imaging and light-curve inversion results
- Interferometry from MIRC 6T
- High-resolution spectroscopy from VLT, NOT, STELLA robotic telescope
- Photometry from APT and SMARTS
- Imaging targets: σ Gem and ζ And



RS Canum Venaticorum Stars

- Binary with giant primary and main sequence secondary
- Many with short orbital periods and tidally-locked
- Show Ca II H&K variability
- Many known to have starspots



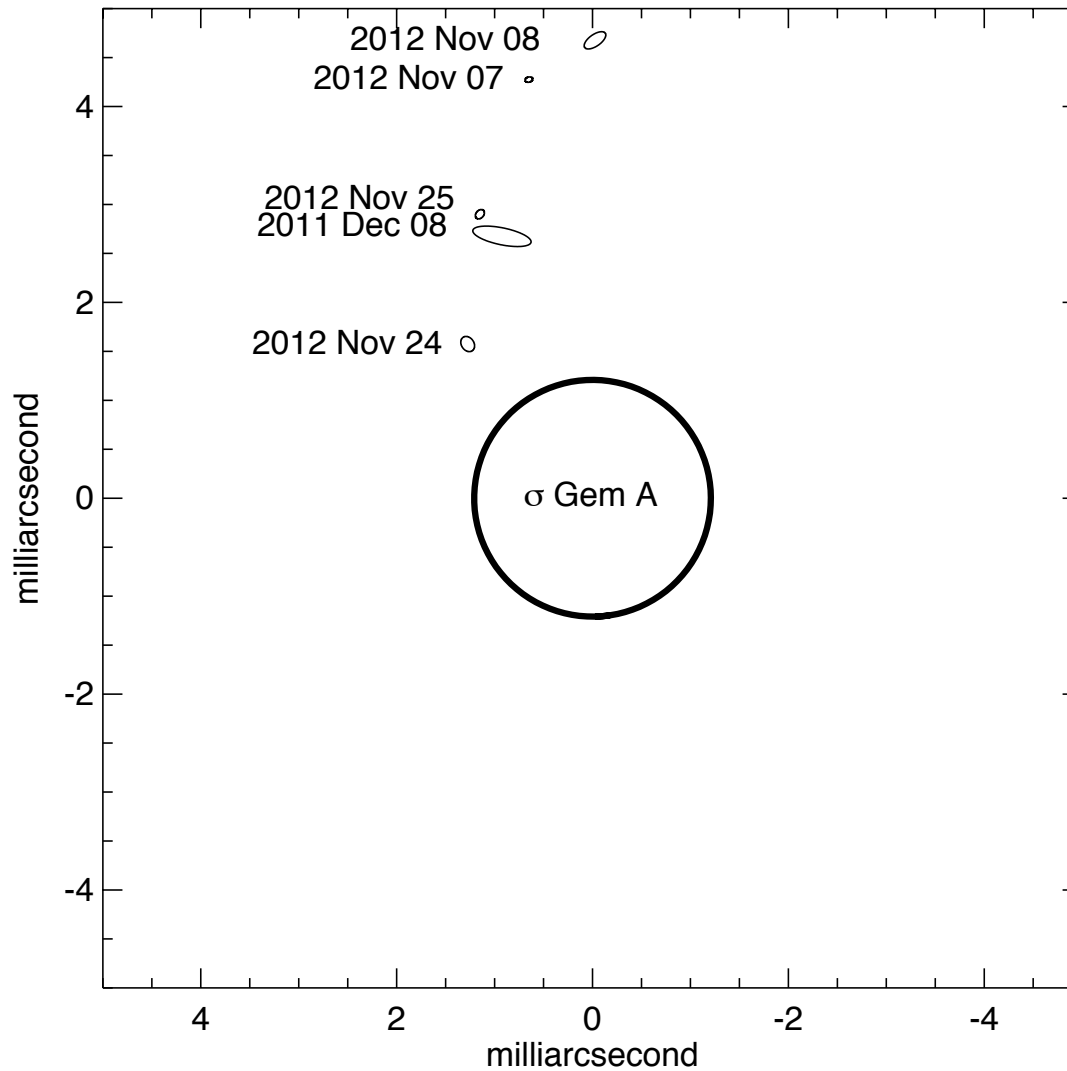


σ Geminorum

- RS CVn binary
 - Undetected companion
 - $T_{\text{eff}} \sim 4530$ K
 - $P_{\text{orb}} \sim P_{\text{rot}} \sim 19.6$ days
 - Known to exhibit starspots
-
- CHARA observations from 2011 and 2012
 - RV data from FLWO and TSU's AST 2003-2015
 - Photometry from TSU's APT 1987-2015



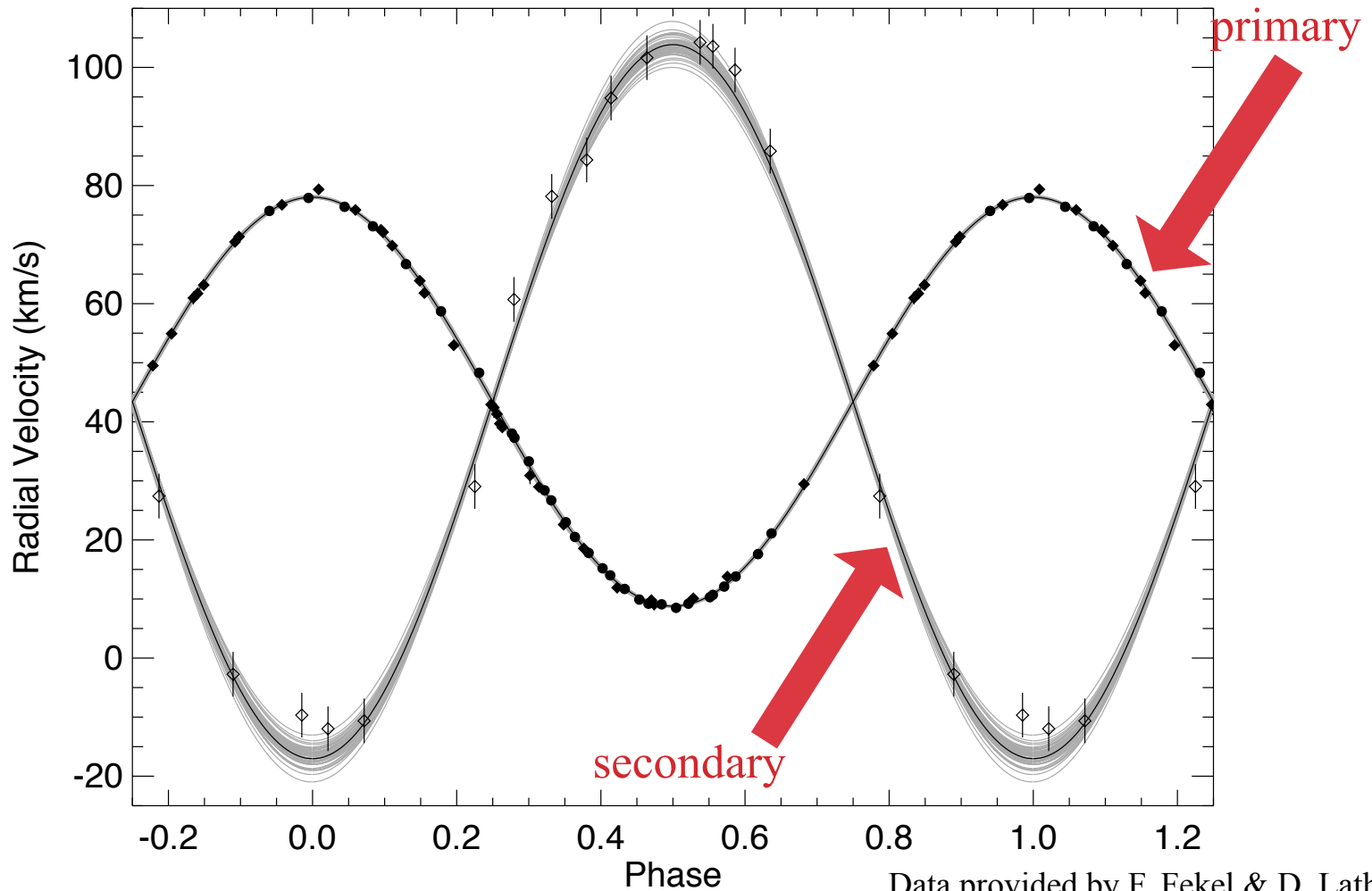
σ Gem Interferometric Detections



Roettenbacher et al. 2015



σ Gem Radial Velocity Curve



Data provided by F. Fekel & D. Latham

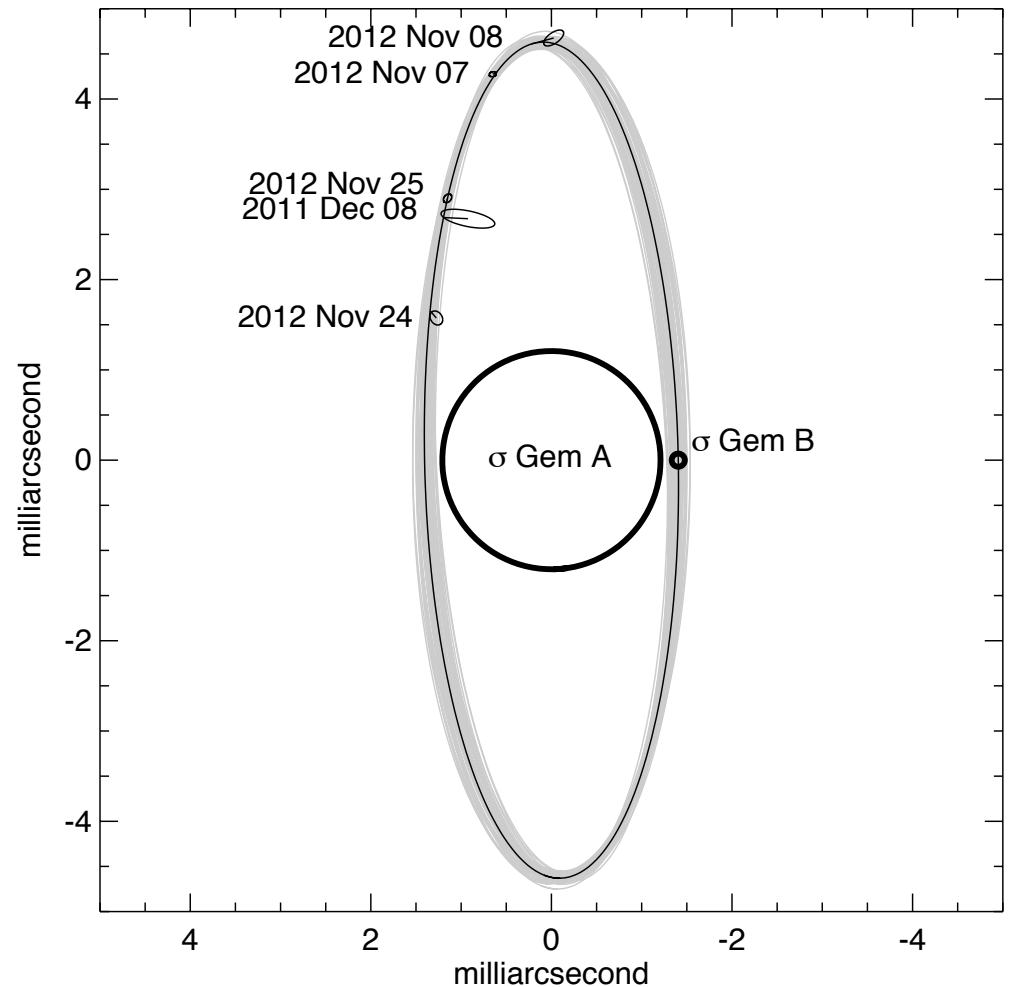
Roettenbacher et al. 2015

$P_{\text{orb}} = 19.6027$ days



σ Gem Orbit

- $a = 4.63 \pm 0.04$ mas
- $e = 0$
- $i = 107.7 \pm 0.8^\circ$
- $P_{\text{orb}} = 19.6027 \pm 0.0005$ d
- $\theta_{\text{UD}} = 2.335 \pm 0.007$ mas
- $R_{\text{A}} = 10.1 \pm 0.4 R_{\odot}$
- $d = 38.8 \pm 0.6$ pc

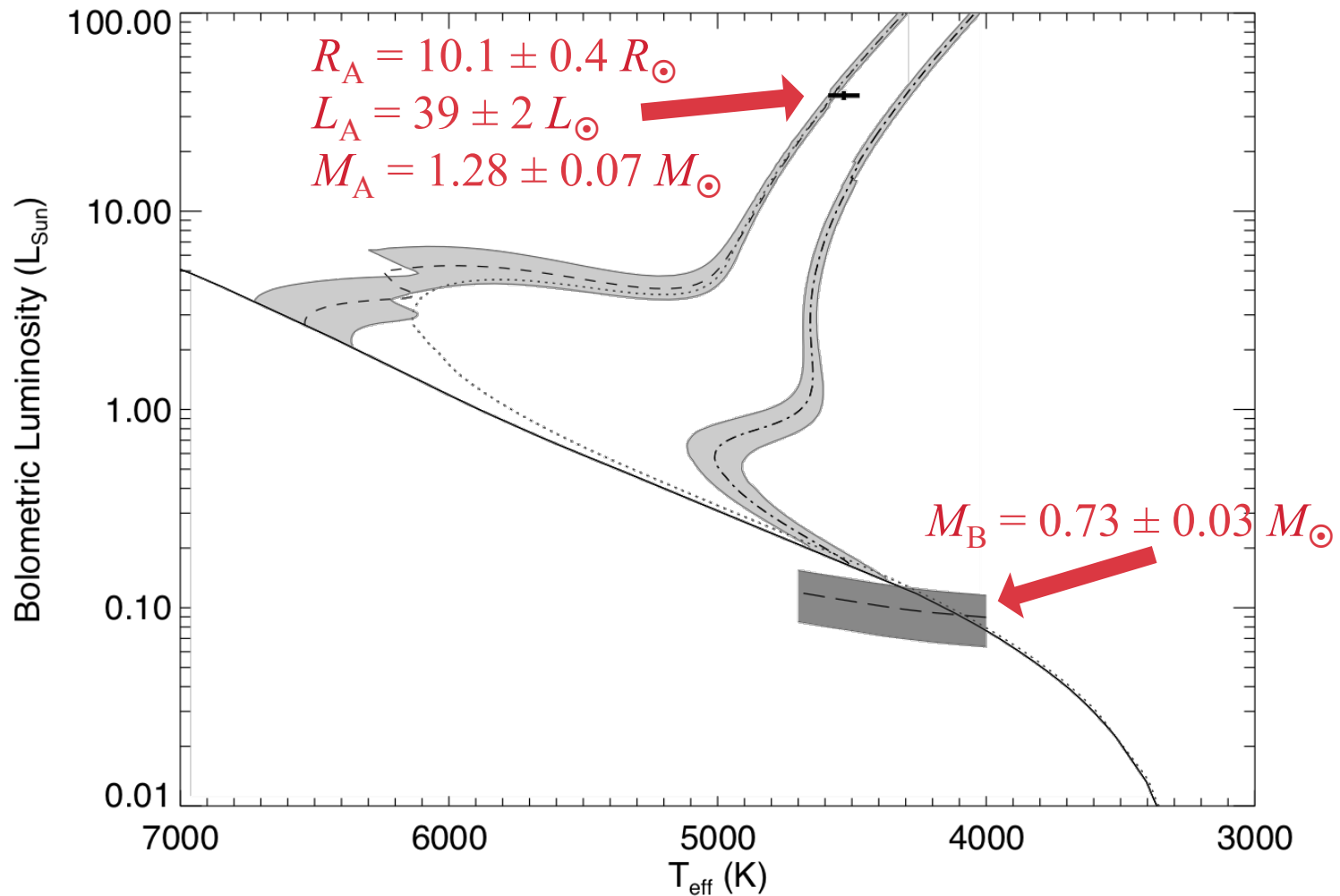


RV data provided by F. Fekel & D. Latham

Roettenbacher et al. 2015



σ Gem H-R Diagram



Roettenbacher et al. 2015

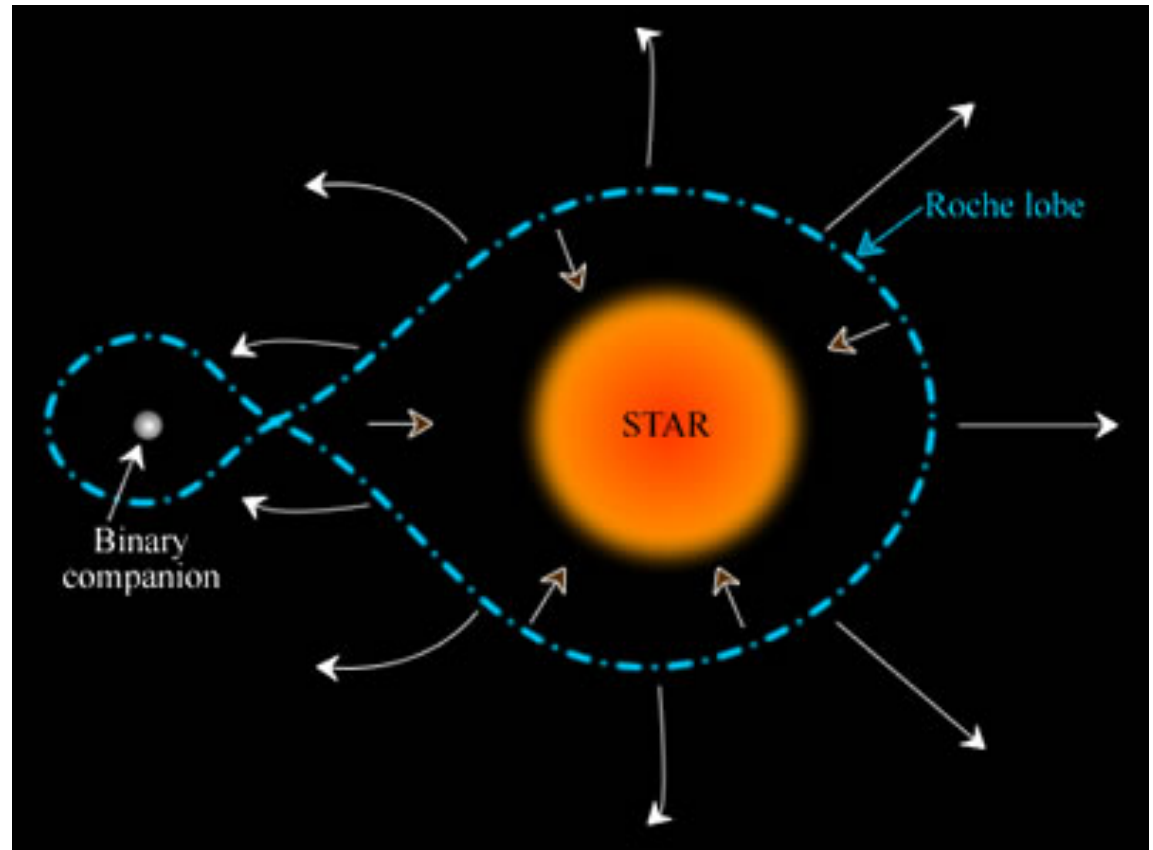


Gravity Darkening

$$T \propto g^{\beta}$$

$\beta = 0.08$
convective stars
(Lucy 1967)

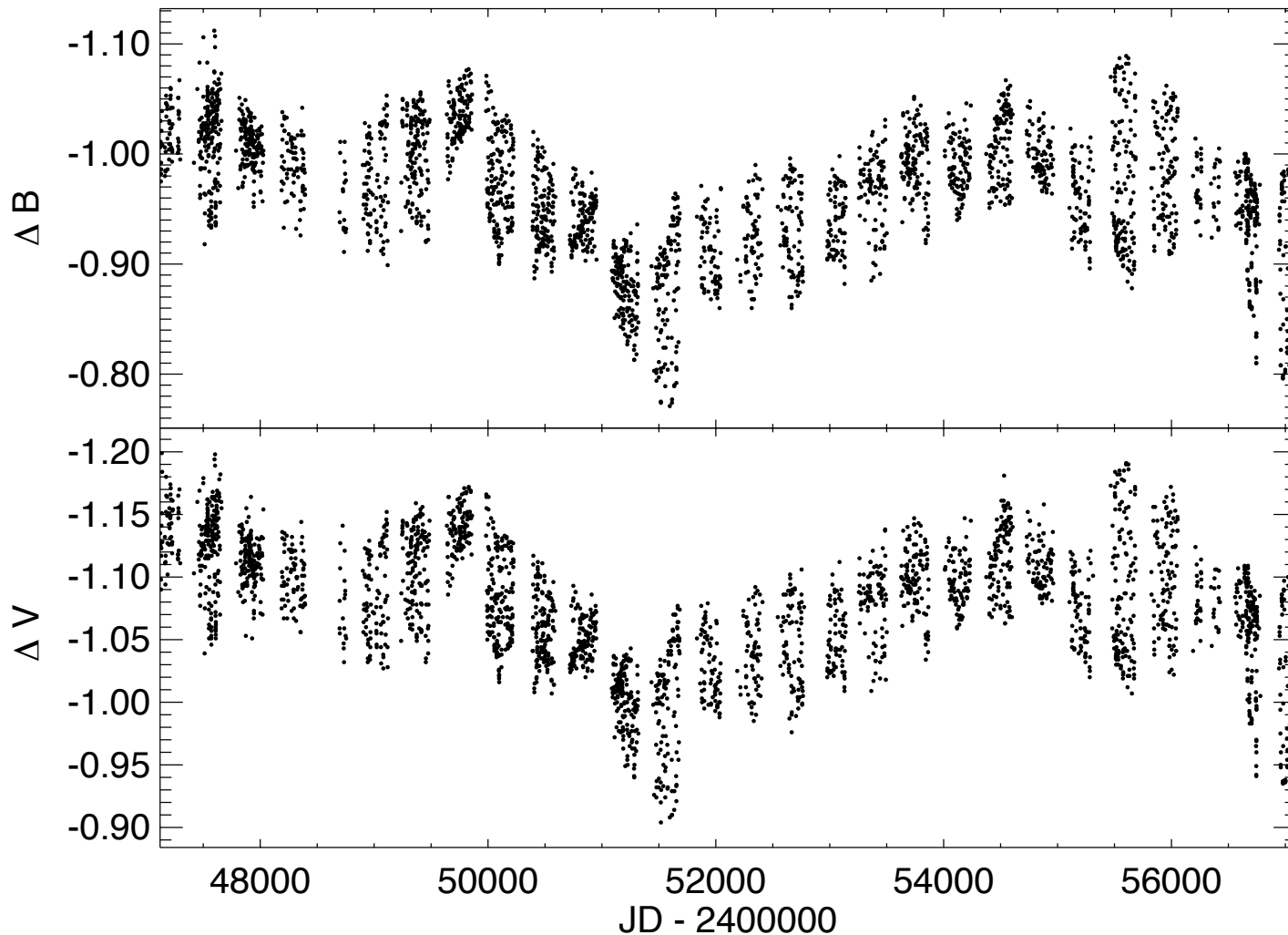
$\beta = 0.25$ radiative
stars
(von Zeipel 1924)



Swinburne University



σ Gem Light Curve

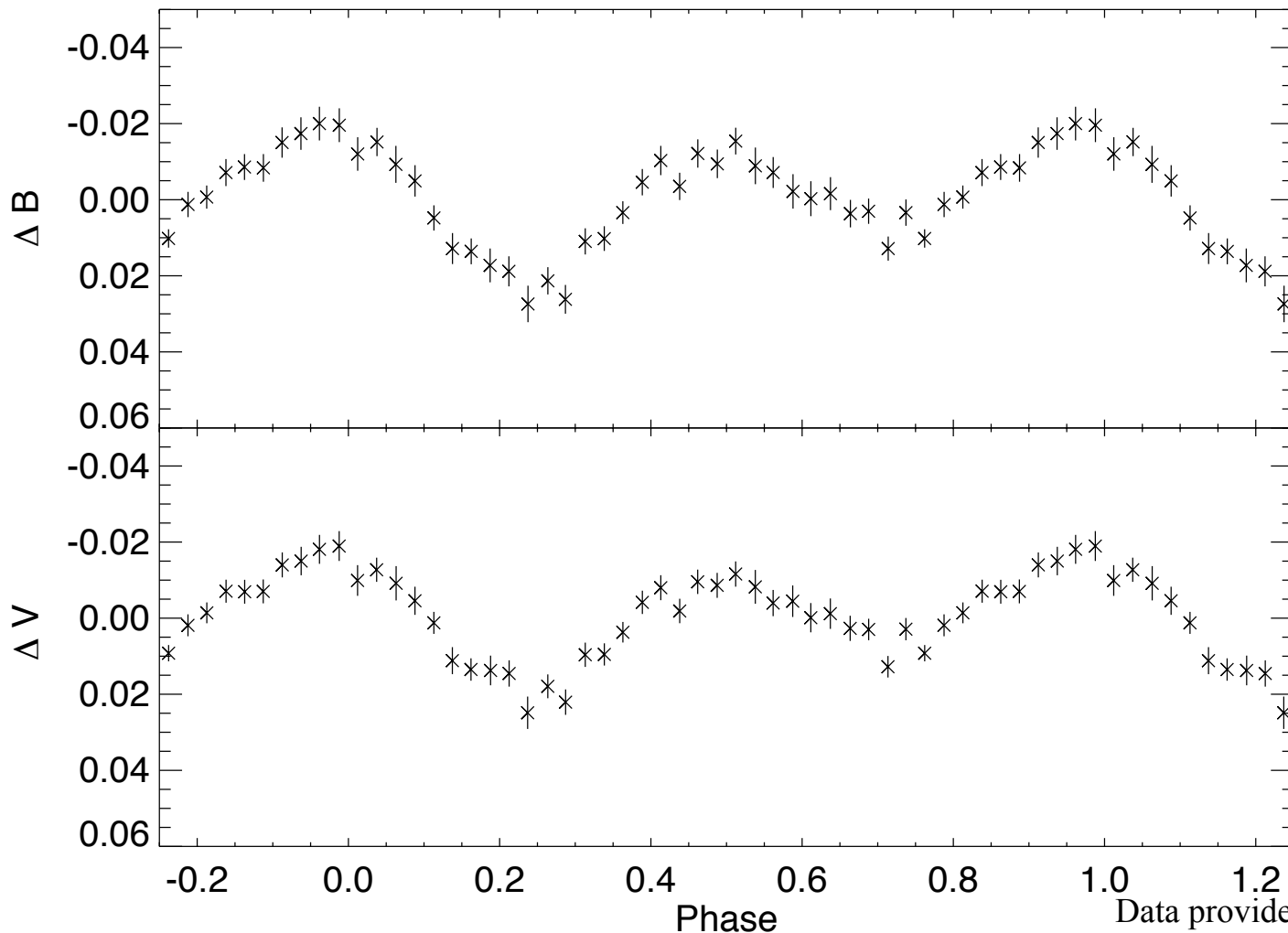


Data provided by G. Henry

Roettenbacher et al. 2015



σ Gem Folded Light Curve



Data provided by G. Henry
Roettenbacher et al. 2015

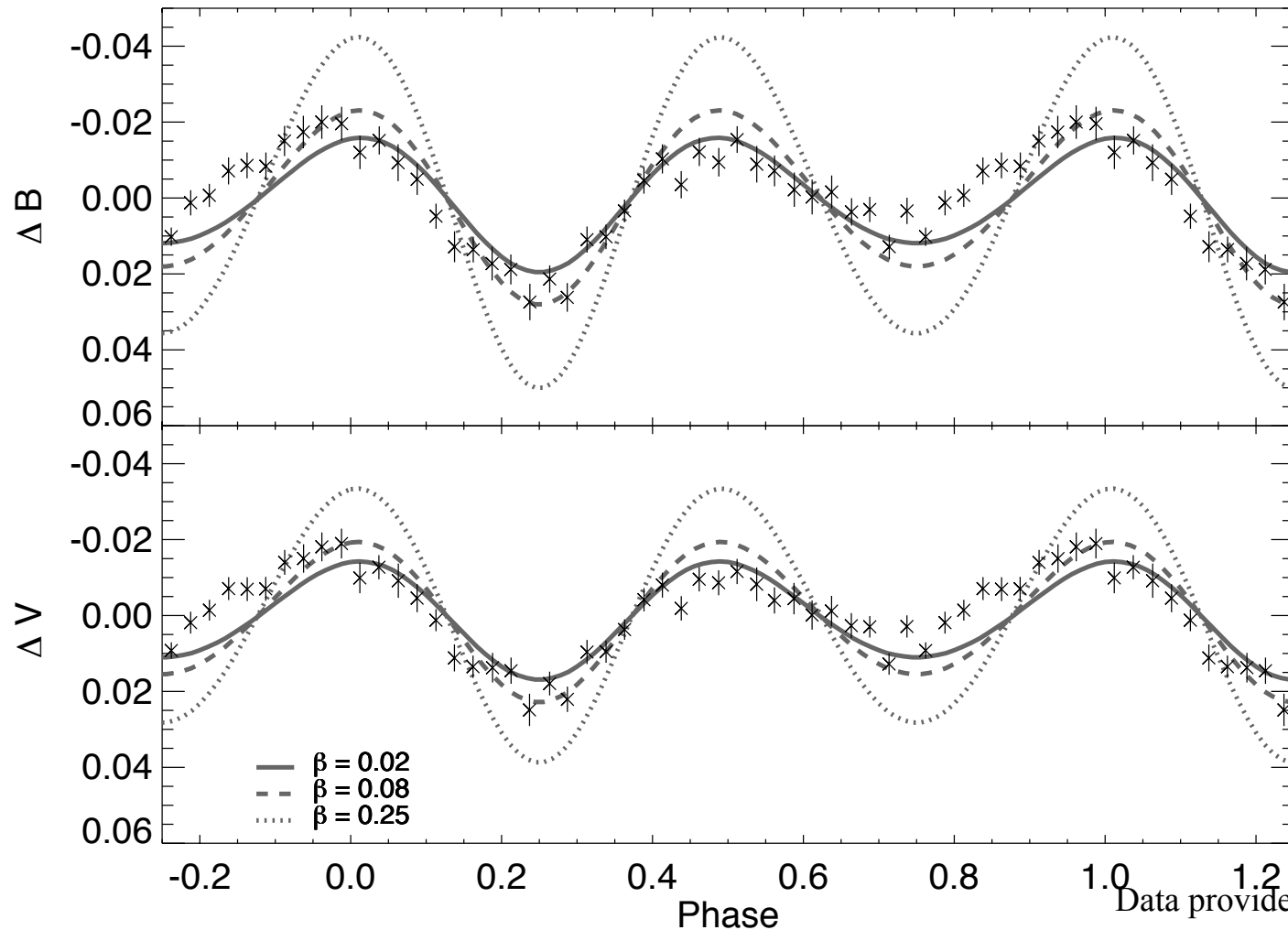
$P_{\text{orb}} = 19.6027$ days



Observatoire
de la COTE d'AZUR



σ Gem Gravity Darkening



Data provided by G. Henry
Roettenbacher et al. 2015

$P_{\text{orb}} = 19.6027$ days



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2011 σ Gem Imaging Comparison

Roettenbacher et al. in prep.



Observatoire de la COTE d'AZUR



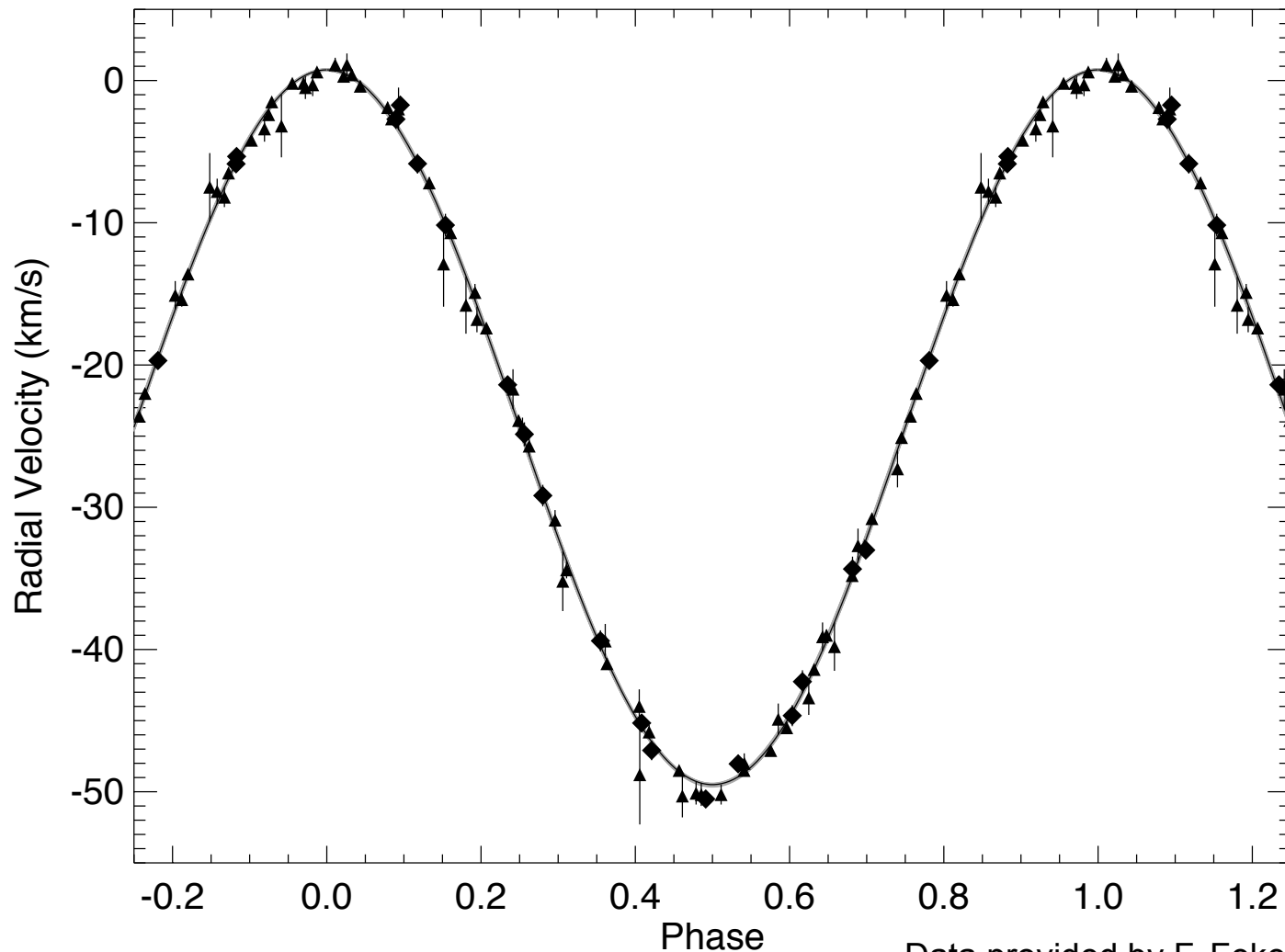
ζ Andromedae

- RS CVn binary
- Undetected companion
- $T_{\text{eff}} \sim 4600$ K
- $P_{\text{orb}} \sim P_{\text{rot}} \sim 17.7$ days
- Known to exhibit starspots
- Ellipsoidally variable

- CHARA observations from 2011 and 2013



ζ And Radial Velocity Curve



Data provided by F. Fekel & D. Latham

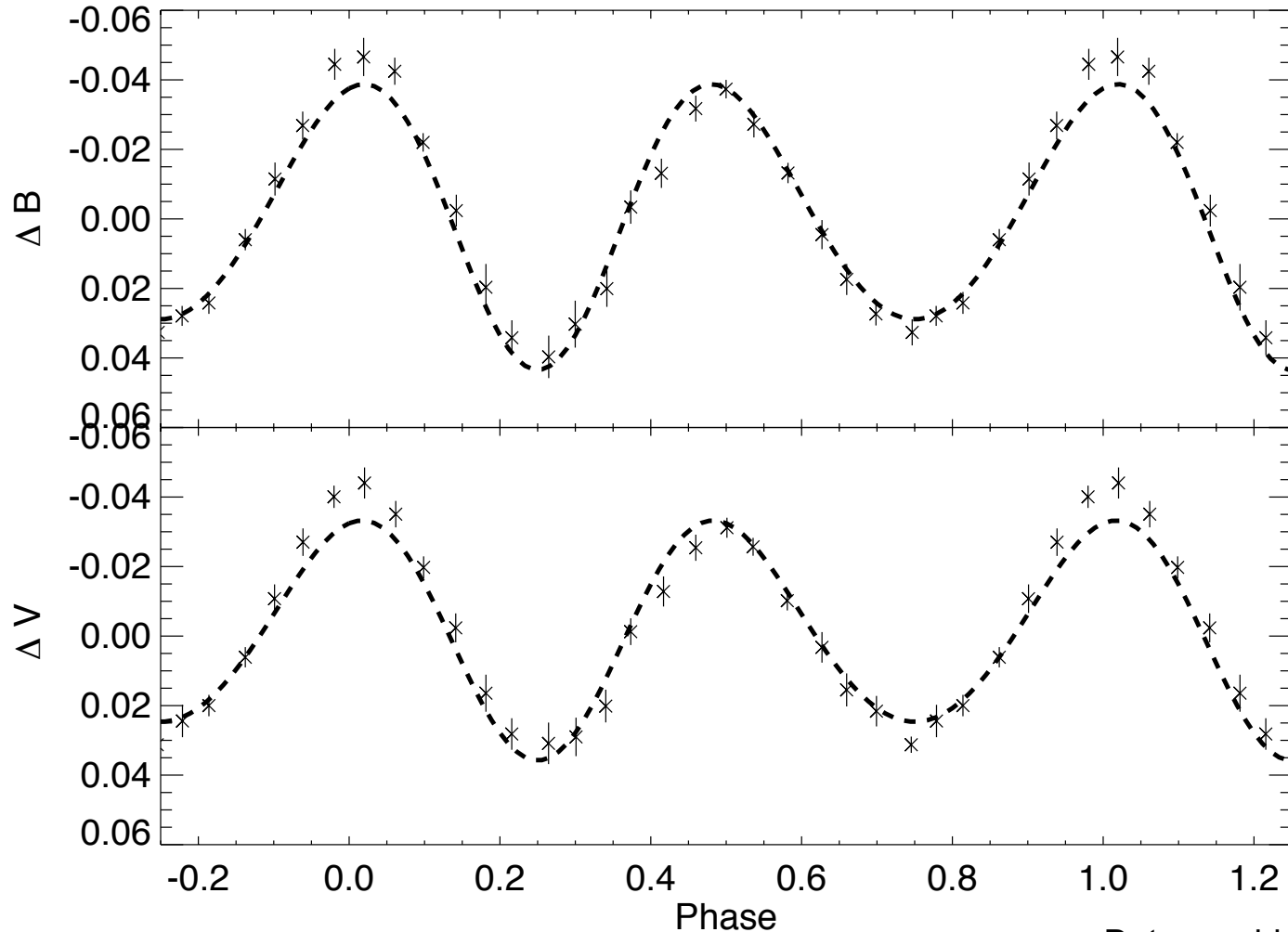
$P_{\text{orb}} = 17.77$ days



Observatoire de la COTE d'AZUR



ζ And Folded Light Curve



Data provided by G. Henry

$P_{\text{orb}} = 17.77$ days



Observatoire de la COTE d'AZUR



2011 ζ And Imaging

Roettenbacher et al. accepted, *Nature*



Observatoire de la COTE d'AZUR



2013 ζ And Imaging

Roettenbacher et al. accepted, *Nature*



Observatoire de la COTE d'AZUR



2013 ζ And Imaging

Roettenbacher et al. accepted, *Nature*



Observatoire de la COTE d'AZUR



2013 ζ And Imaging Comparison

Roettenbacher et al. accepted, *Nature*
Korhonen et al. in prep.





Summary

- Detailed analysis of RS CVns
 - First model-independent measurements of gravity darkening in convective stars
 - Detected previously-unobserved companions, eclipses, and ellipsoidal variations
- Imaged surfaces of RS CVns
 - Confirmed polar spots
 - Detected starspot asymmetries unseen on the Sun