Surface and Circumstellar Structures in Early-Type Interacting Binaries

Geraldine J. Peters
Space Sciences Center & Department of Physics and Astronomy
University of Southern California
Los Angeles, CA 90089-1341

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Objective: To review photospheric and circumstellar features that have been inferred from spectroscopy and photometry that may be detected through interferometry today or in the future.

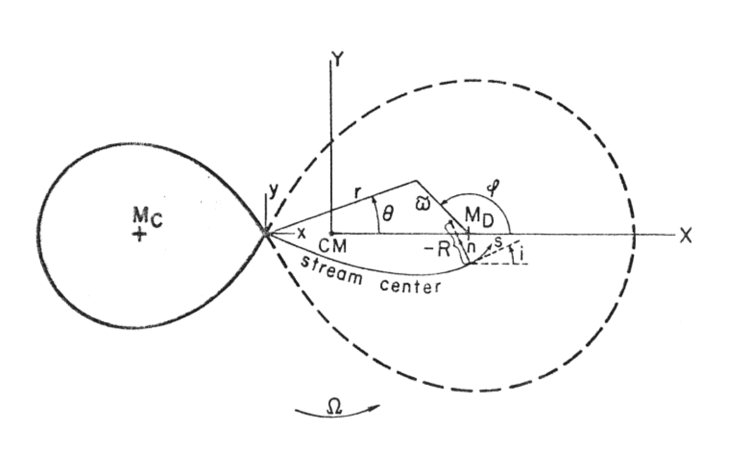
Targets: Algol Systems with B-Type Primaries

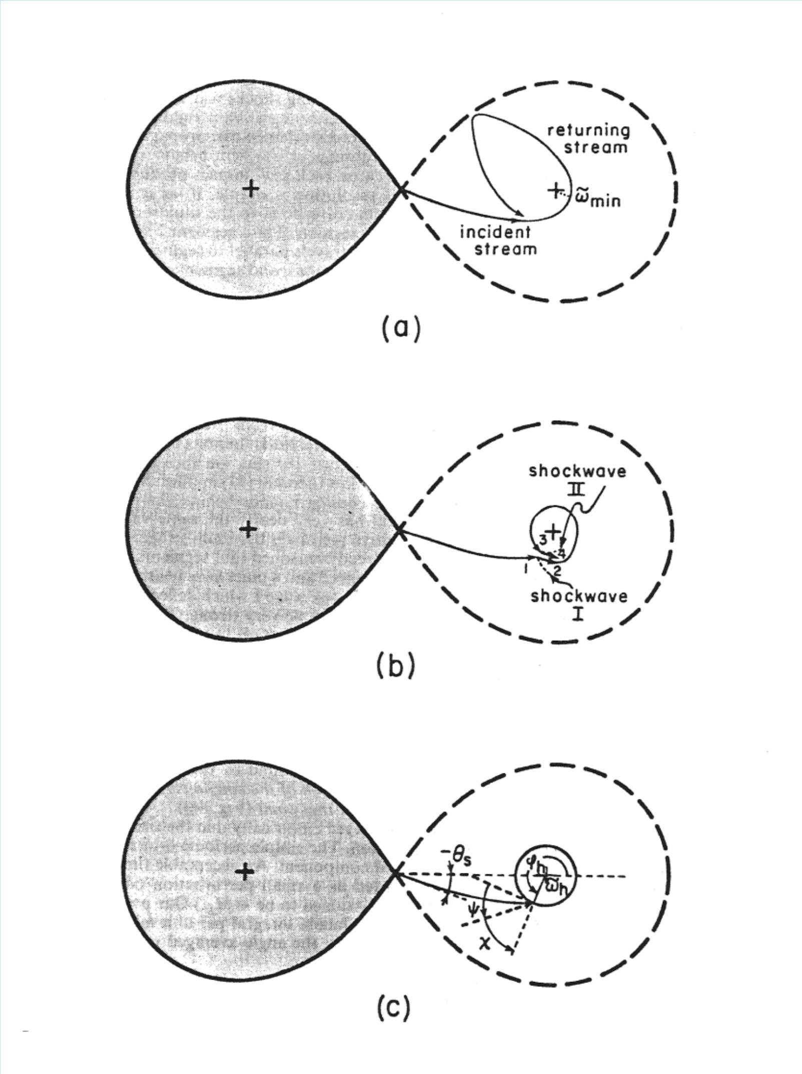
System	Period (d)	Spectral Types	Separation (AU)	Distance (pc)	V (mag)	K (mag)
U Cep	2.49	B7V + G8III-IV	~0.07	253	6.92	6.25
TT Hya	6.95	B9.5e+K1III-IV	~0.10	160	7.31	5.88
V356 Sgr	8.90	B3V + A2II	~0.21	450	6.99	6.65

A *Kepler* target currently way too distant for interferometry

System	Period (d)	Spectral Types	Separation (AU)	Distance (pc)	V (mag)	K (mag)
WX Dra	1.80	A8V + K0 IV	~0.04	……	12.8	11.7

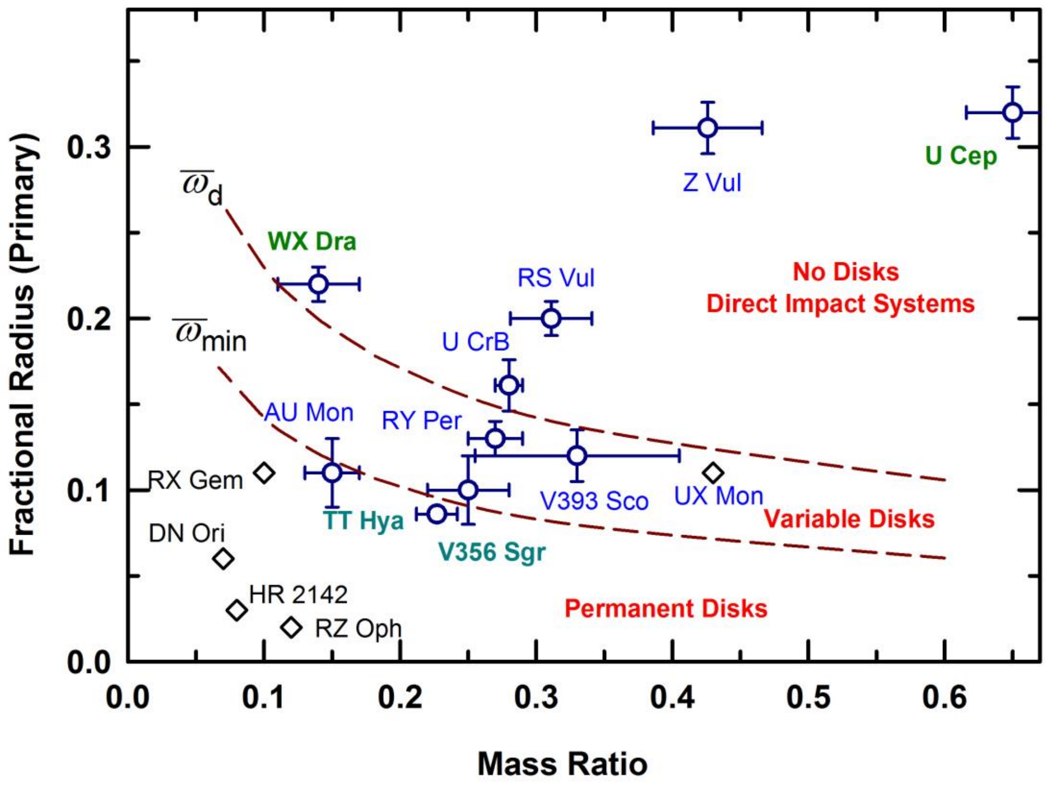
Gas dynamics of Lubow & Shu 1975, ApJ, 198,383



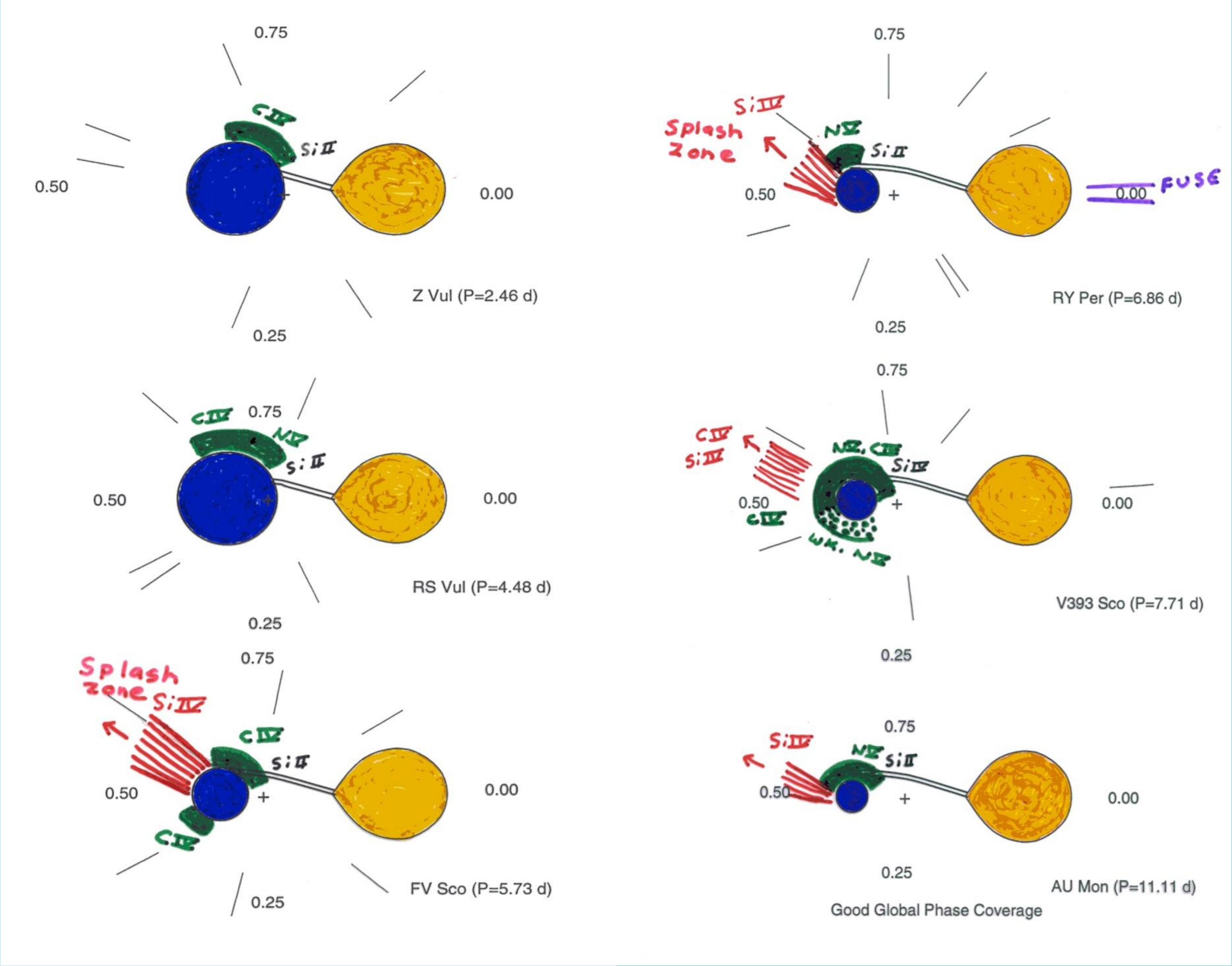


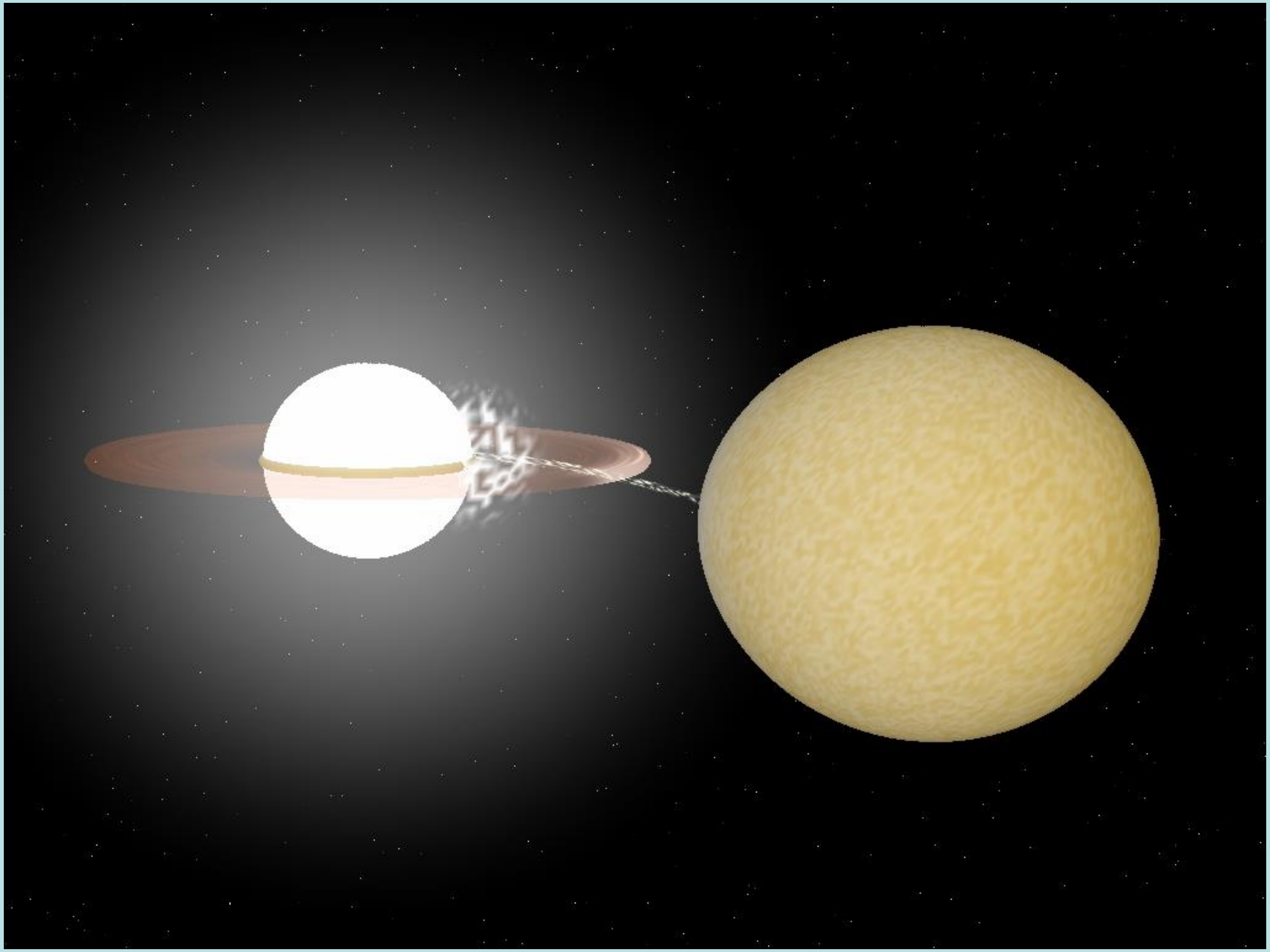
Definition of ϖ_{min} and ϖ_d

The *r* – *q* Diagram



Pictorial Representation of Selected Systems Scaled to Size of Secondary



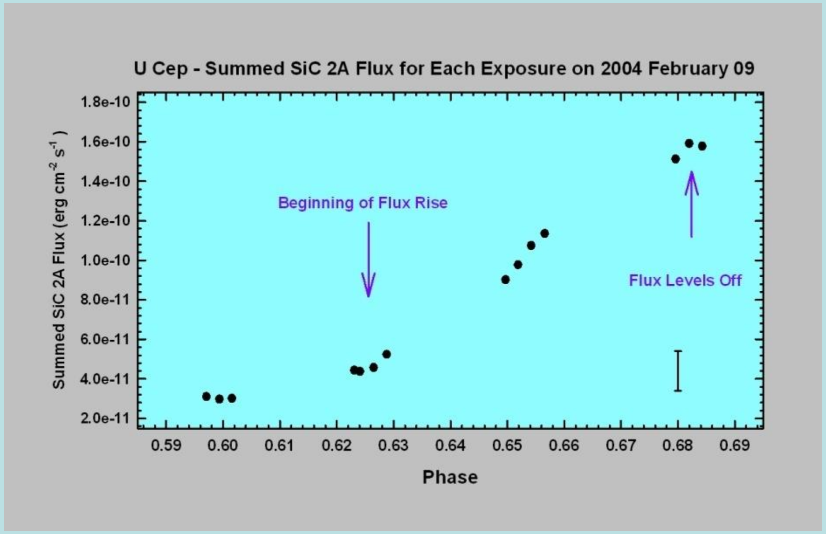


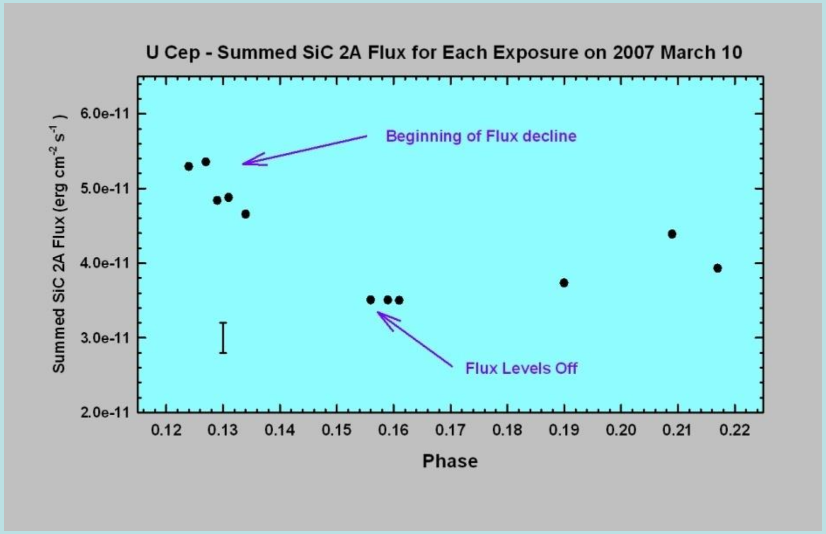
RY Per, P=6.86 d

Parameters from Barai et al. 2004, ApJ, 608, 989

Painting by Rob Hynes, Courtesy of D. Gies

FUSE Observations of U Cep



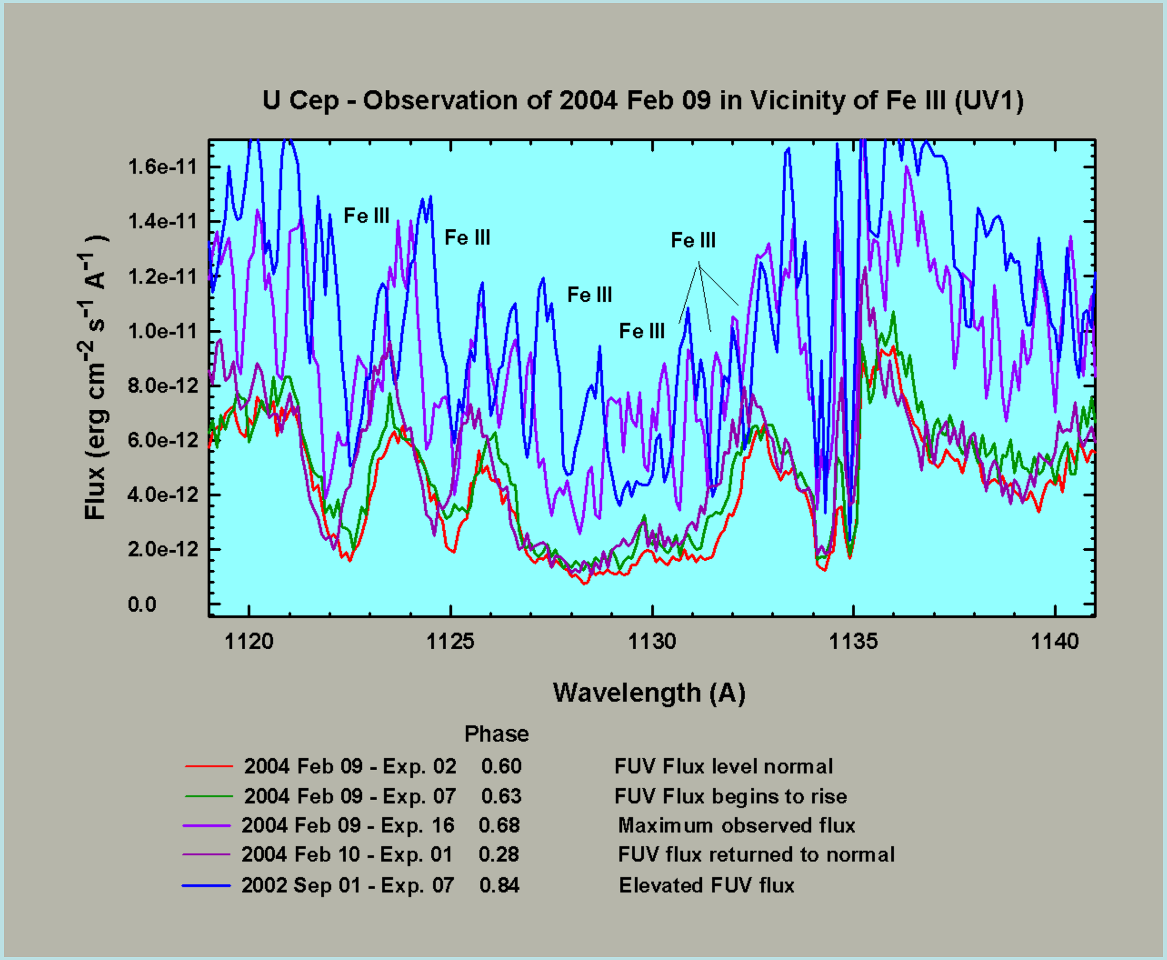


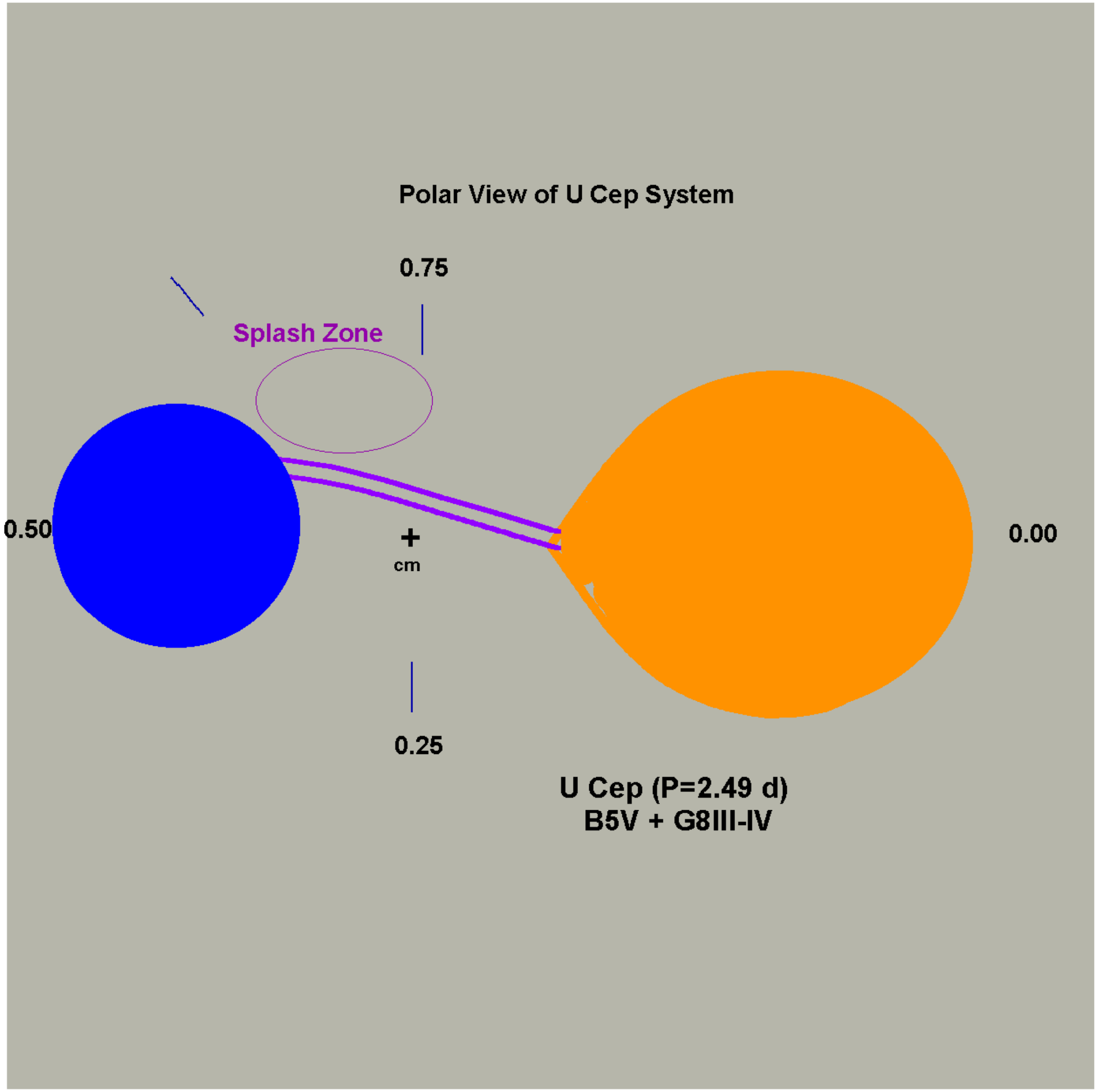
Inferred minimum size of accretion hot spot: 20°

T_e~30,000 K (2 x T_{phot}), Ne~1x10^9 cm^{-3})

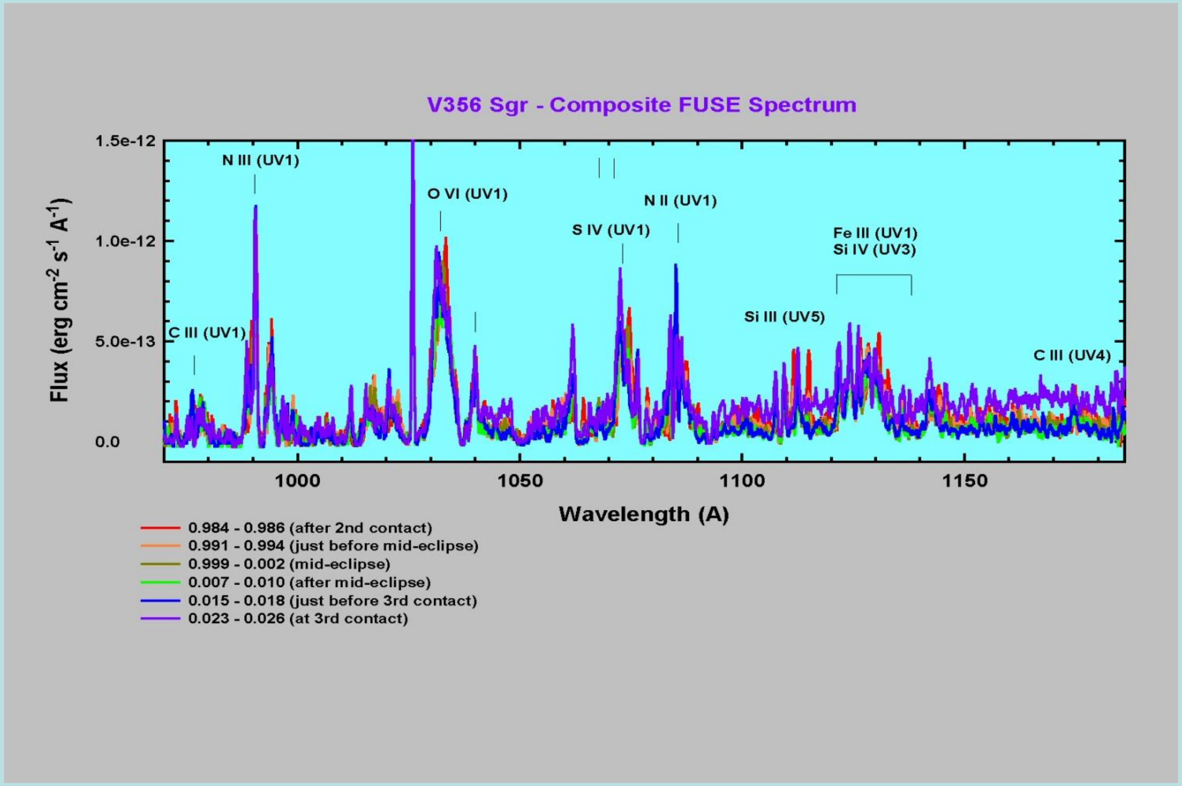
(Peters, G. J., Andersson, B.-G., Ake, T. B., & Sankrit, R. 2017, in prep)

Hot Accretion Spot and Splash Plasma in U Cep

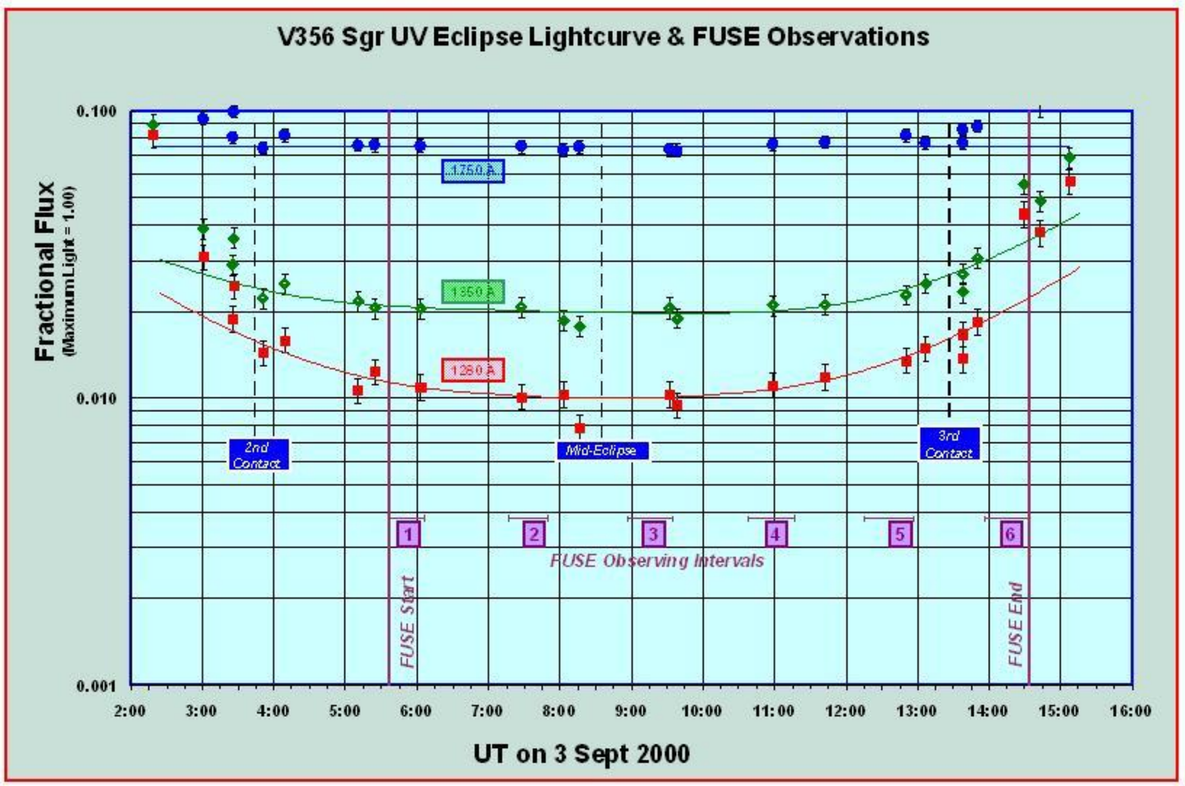


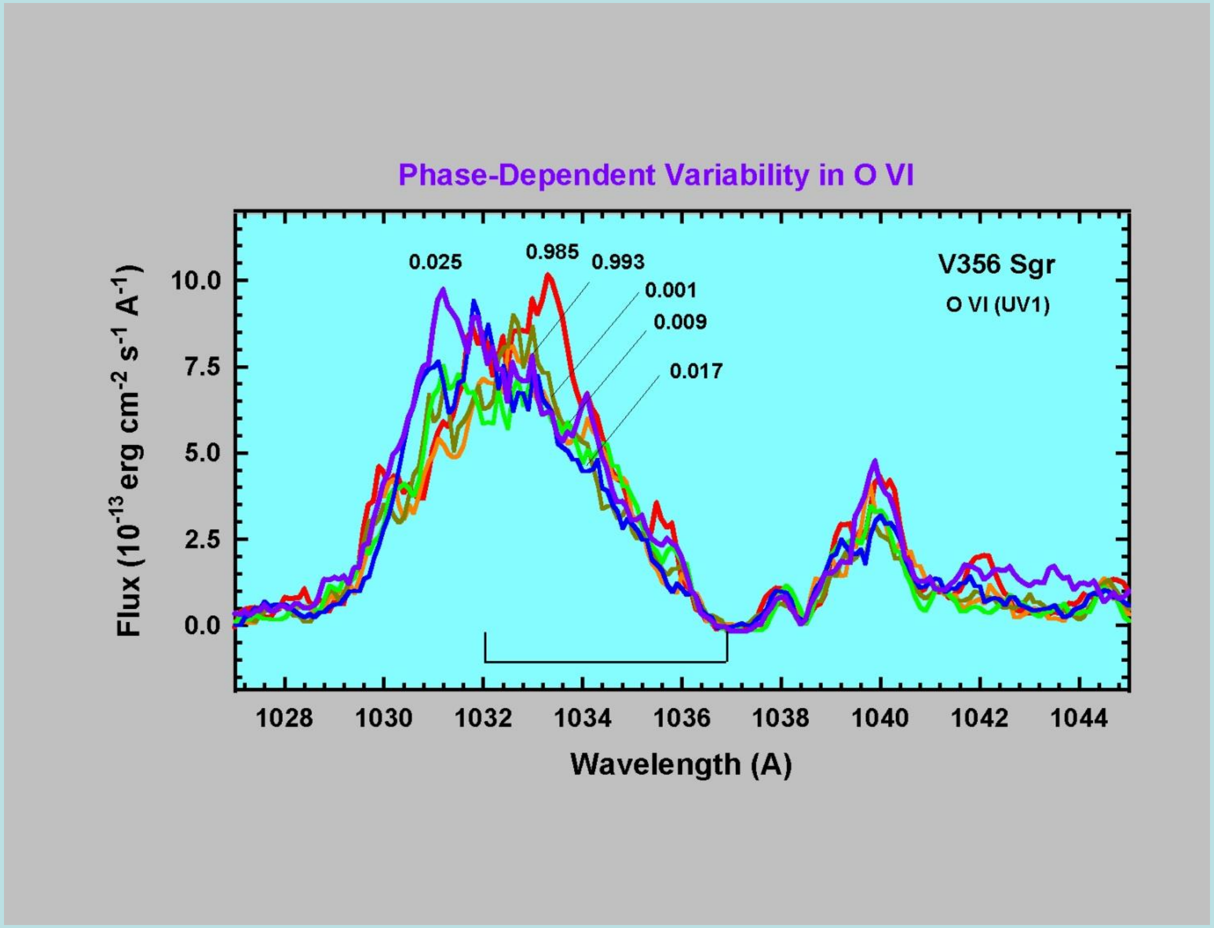

Polar View of U Cep System
0.75
Splash Zone
0.50
+
cm
0.00
0.25
U Cep (P=2.49 d)
B5V + G8III-IV

Eclipse Mapping from *FUSE* Observations Obtained During Totality (Peters, G. J., & Polidan, R. S. 2004, AN, 325, 225)
Stars Observed: V356 Sgr, TT Hya, RY Per

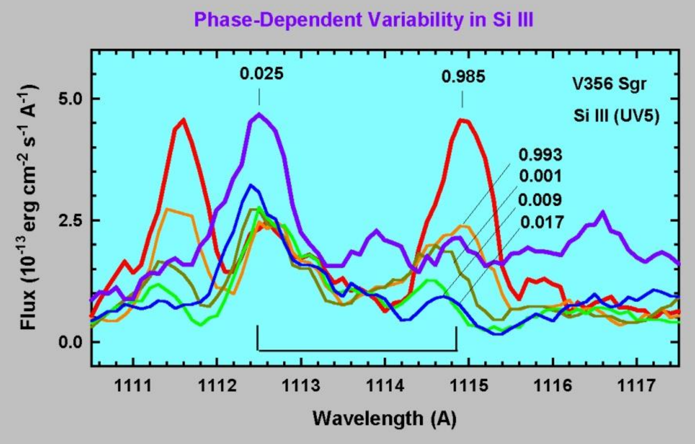


- Strongest emission feature is O VI 1032 A
  - implies presence of 300,000 K plasma
- CS plasma shows evidence of CNO processing


V356 Sgr UV Eclipse Lightcurve & FUSE Observations
Fractional Flux
(Maximum Light = 1.00)
0.100
0.010
0.001
1750 Å
1350 Å
1280 Å
2nd Contact
Mid-Eclipse
3rd Contact
1
2
3
4
5
6
FUSE Observing Intervals
FUSE Start
FUSE End
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
UT on 3 Sept 2000

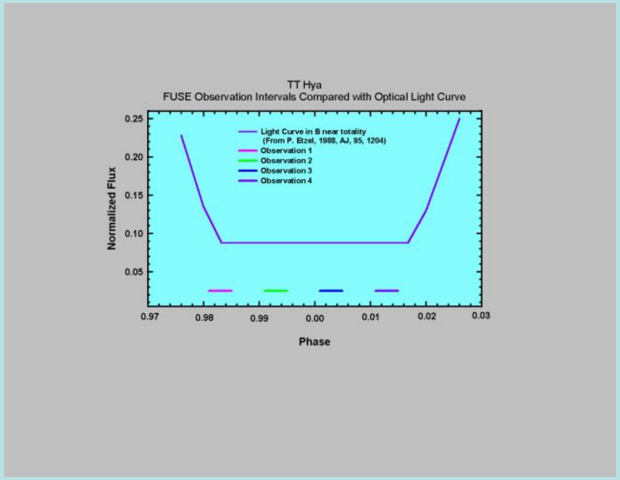


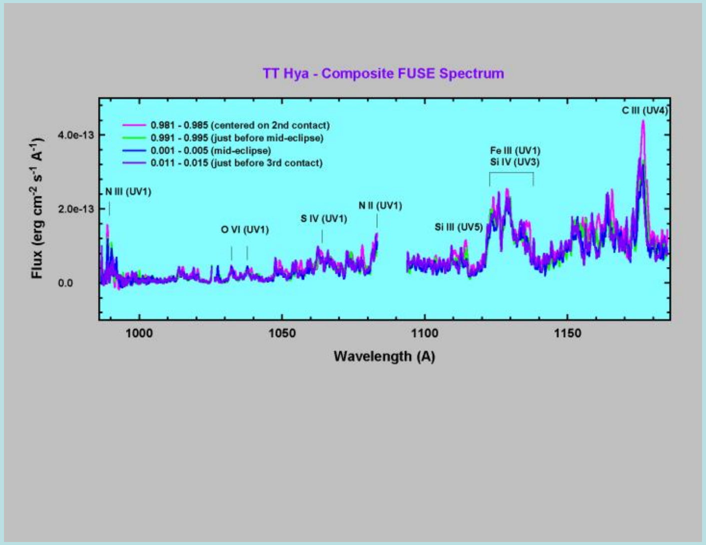
- O VI 1032 displays a FWHM of 1200 km/s
- Feature is a combination of a fixed component that is red-shifted by ~ 200 km/s (plasma above/below orbital plane) and one that displays a V/R variation (source in disk).
- Energy in line: 2 x 10^{32} erg s^{-1}

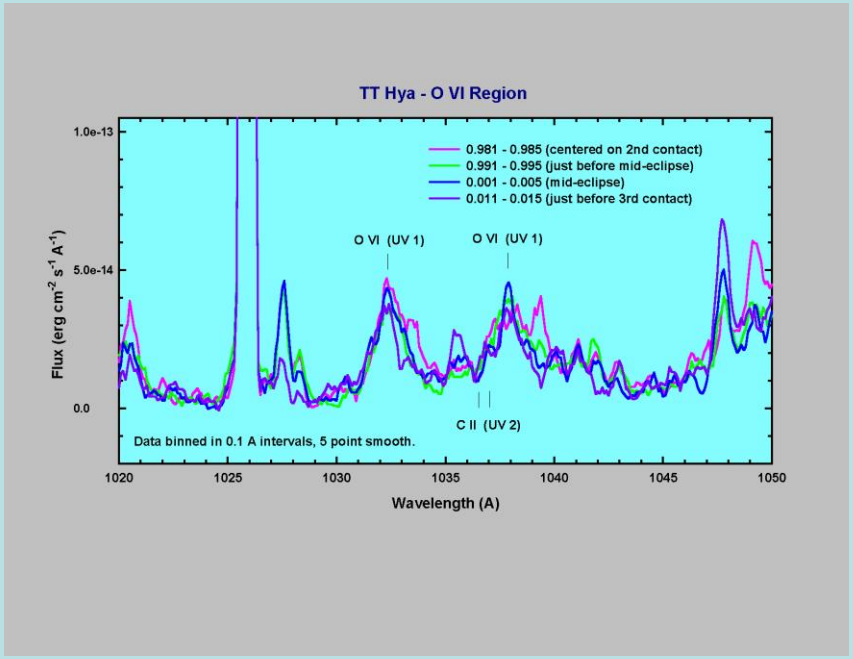


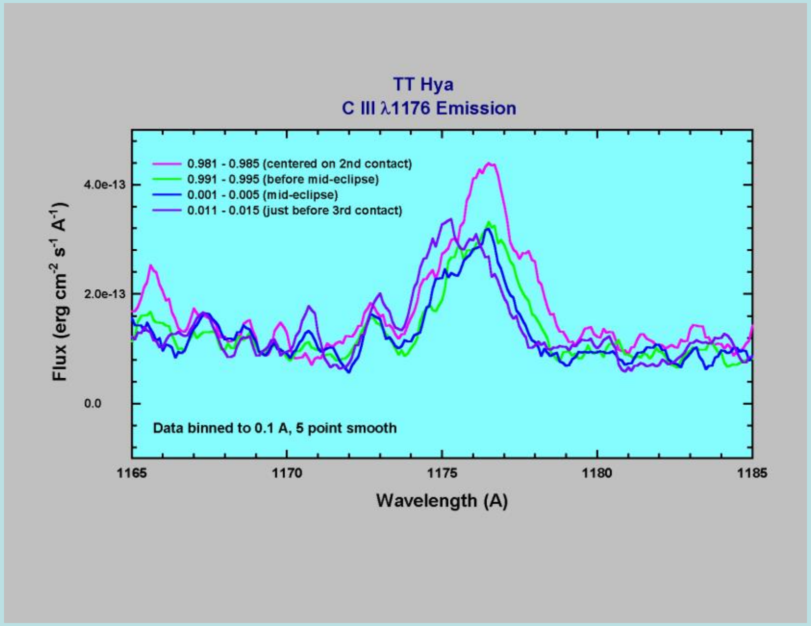
- Emission lines from moderate-ionization species are double-peaked and display classic V/R variability observed in Algol systems throughout eclipse (source in disk)
- Centroid is red-shifted by 150 km/s
- Material concentrated near mass gainer (~0.3R_{star})
- FWHM ~ 2/3 that of O VI feature

TT Hya


TT Hya
FUSE Observation Intervals Compared with Optical Light Curve
Light Curve in B near totality
(From P. Etzel, 1988, AJ, 95, 1204)
Observation 1
Observation 2
Observation 3
Observation 4
Normalized Flux
0.25
0.20
0.15
0.10
0.05
0.97
0.98
0.99
0.00
0.01
0.02
0.03
Phase

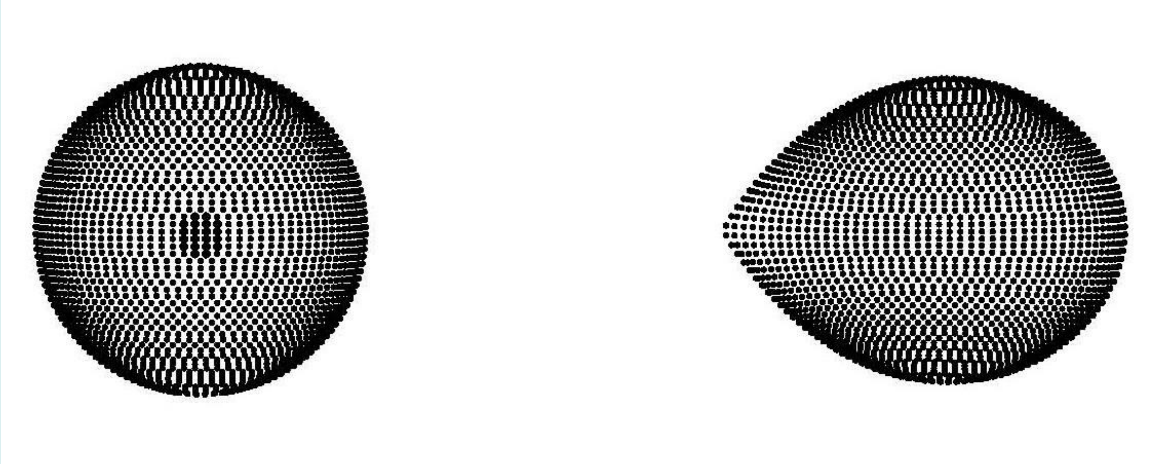

TT Hya - Composite FUSE Spectrum
0.981 - 0.985 (centered on 2nd contact)
0.991 - 0.995 (just before mid-eclipse)
0.001 - 0.005 (mid-eclipse)
0.011 - 0.015 (just before 3rd contact)
N III (UV1)
O VI (UV1)
S IV (UV1)
N II (UV1)
Si III (UV5)
Fe III (UV1)
Si IV (UV3)
C III (UV4)
Flux (erg cm^{-2} s^{-1} A^{-1})
4.0e-13
2.0e-13
0.0
1000
1050
1100
1150
Wavelength (A)


TT Hya - O VI Region
0.981 - 0.985 (centered on 2nd contact)
0.991 - 0.995 (just before mid-eclipse)
0.001 - 0.005 (mid-eclipse)
0.011 - 0.015 (just before 3rd contact)
O VI (UV 1)
O VI (UV 1)
C II (UV 2)
Data binned in 0.1 A intervals, 5 point smooth.
Flux (erg cm^{-2} s^{-1} A^{-1})
1.0e-13
5.0e-14
0.0
1020
1025
1030
1035
1040
1045
1050
Wavelength (A)


TT Hya
C III λ1176 Emission
0.981 - 0.985 (centered on 2nd contact)
0.991 - 0.995 (before mid-eclipse)
0.001 - 0.005 (mid-eclipse)
0.011 - 0.015 (just before 3rd contact)
Data binned to 0.1 A, 5 point smooth
Flux (erg cm^{-2} s^{-1} A^{-1})
4.0e-13
2.0e-13
0.0
1165
1170
1175
1180
1185
Wavelength (A)

Analysis of *Kepler* Observations of WX Draconis

In collaboration with Bob Wilson & Todd Vaccaro



Kepler ID = 10581918

m_{kep} = 12.796

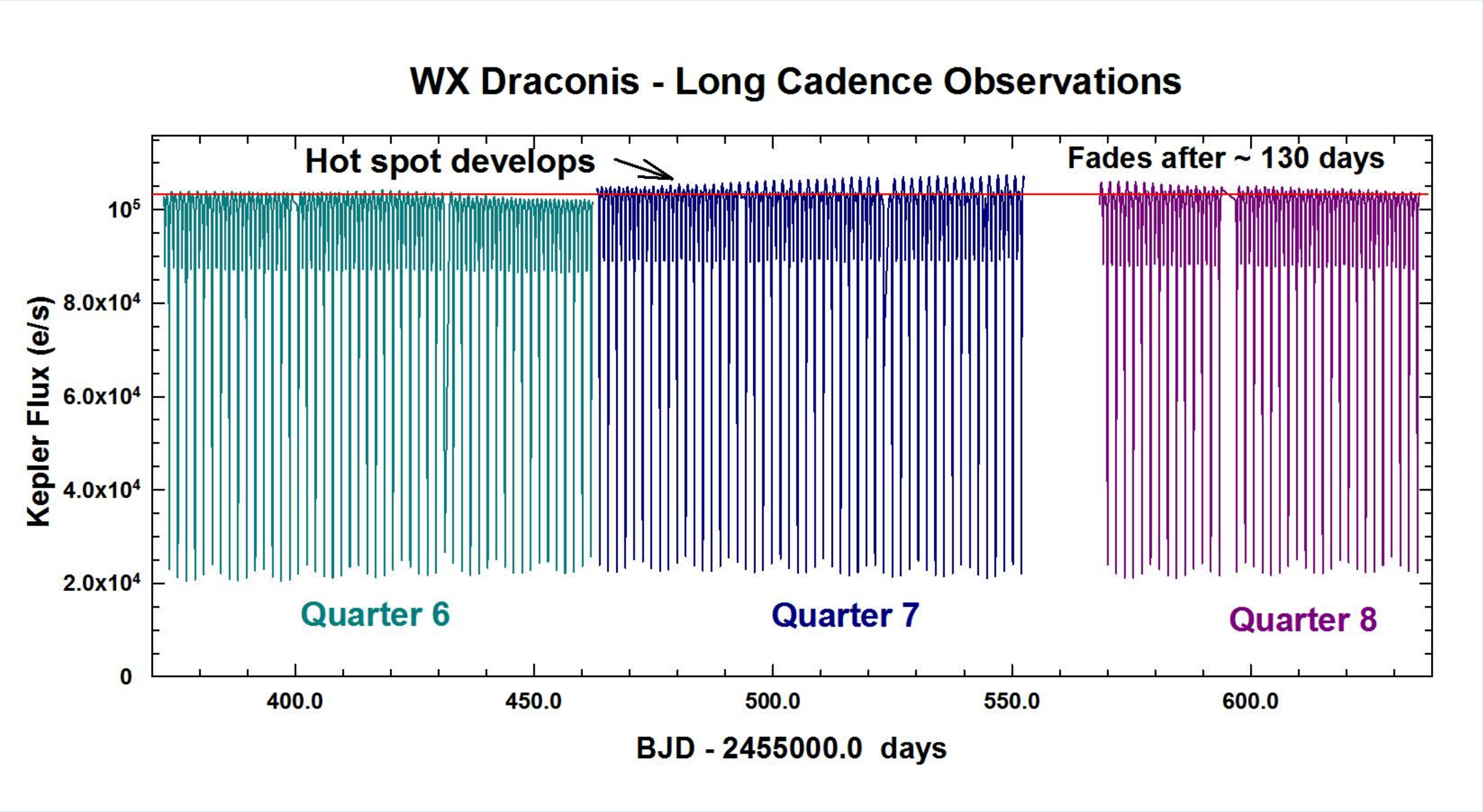
Sp. Types: A8V + K0 IV

P = 1.80^d

Primary is a δ Scuti star

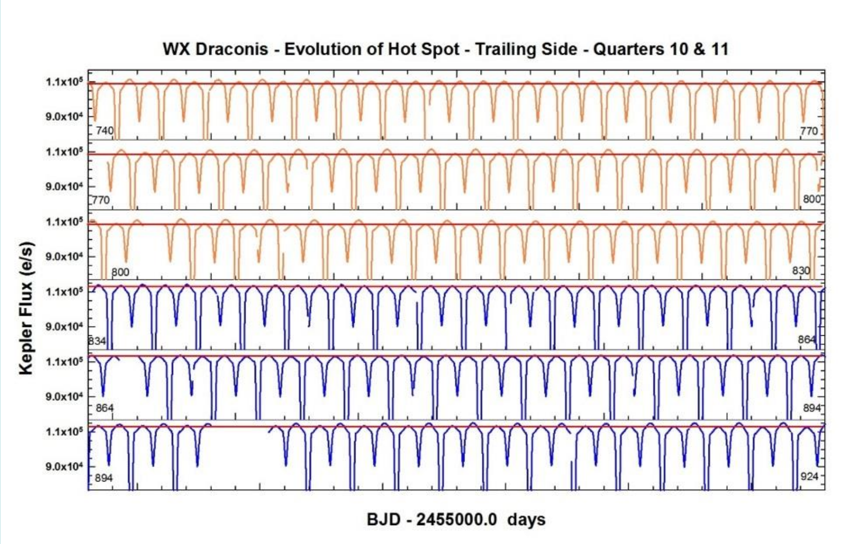
System is an oEA

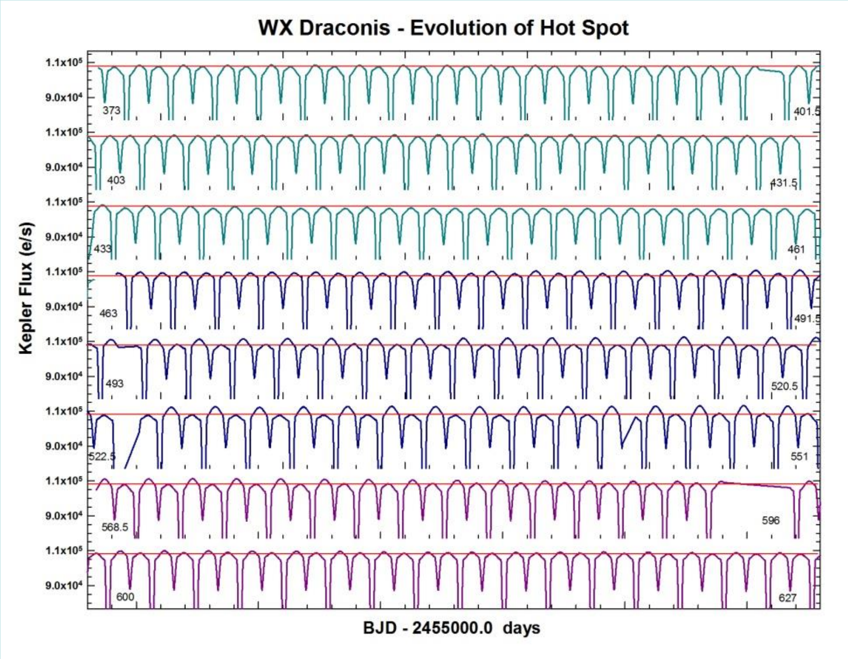
(oscillating EA – Mkrtichian et al. 2007, like AS Eri)


WX Draconis - Long Cadence Observations
Hot spot develops
Fades after ~ 130 days
Kepler Flux (e/s)
10⁵
8.0x10⁴
6.0x10⁴
4.0x10⁴
2.0x10⁴
0
Quarter 6
Quarter 7
Quarter 8
400.0
450.0
500.0
550.0
600.0
BJD - 2455000.0 days

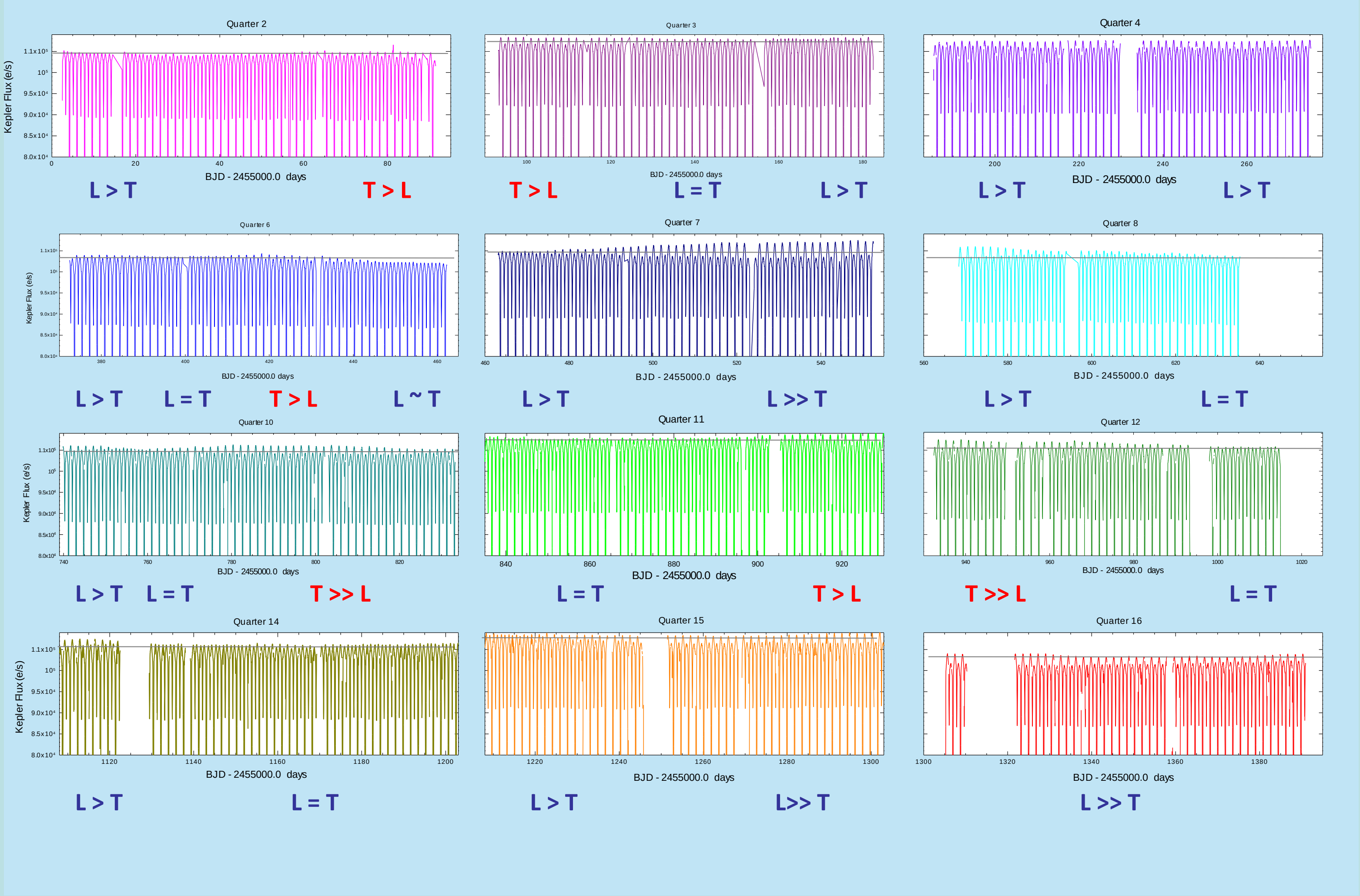
Quarters 10 & 11
T > L

Quarters 6, 7, and 8
L > T





CHARA 2017: Year 13 Science Review – Adaptive Optics and Open Access



ECLIPSING BINARIES WITH ALGOL-LIKE LIGHT CURVES AVAILABLE IN THE *KEPLER* ARCHIVE

Kepler ID	Kepler Mag	Number LC	Number SC	Puls.?	Comments†
2708156	10.67	16	5	no	UZ Lyr,P=1.89d,B9V+G-K1IV:
3241619	12.52	16	1	no	HAT199-30766,P=1.70d
3440230	13.60	15	1	no	P=2.88d
4574310	13.20	13	1	no	HAT199-60342
5294739	13.93	15	2	yes:	V810 Cyg,P=3.73d,A0V:+G6IV
5458880	7.82	12	2	yes	HD 185780,P=3.51d, B0III+?
5774375	13.90	12	0	...	P=1.55d
6205460	12.75	16	5	no:	V461 Lyr,P=3.72d,A2V:+K3IV
6206751	12.14	16	4	yes	HAT199-25863
6852488	13.90	15	1	yes	P=2.17d
7599132	9.39	16	2	no	HD180757, B8.5V+?
8196180	12.81	16	3	yes:	P=3.67d
8552540	10.30	16	3	no	V2277 Cyg
8553788	12.70	16	2	yes	P=1.61d
9101279	13.90	15	1	yes	V1580 Cyg,P=1.81d
9602595	11.88	13	2	no	V995 Cyg,P=3.56d,B8:+G6IV
9899416	10.03	16	4	no	BR Cyg,P=1.33d,A5V+F0V
10206340	11.20	17	12	no	V850 Cyg,P=4.56
10581918	12.80	11	1	yes	WX Dra,P=1.80d,A8V+K0IV:
10736223	13.70	15	0	...	V2290 Cyg, P=1.06d

†From Balona et al. (2011), Malkov et al. (2006), and Pigulski et al. (2009).

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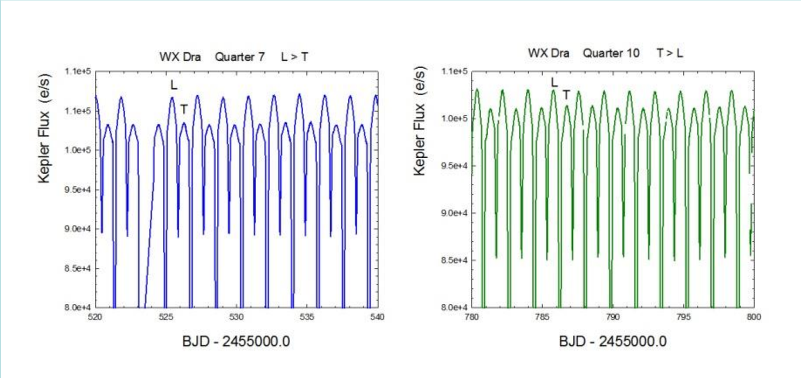
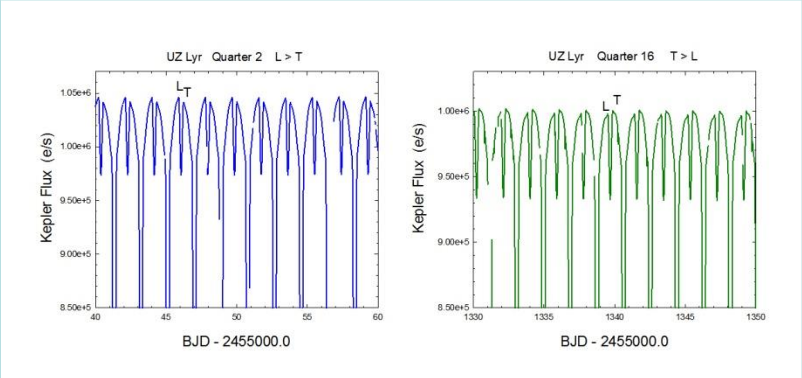
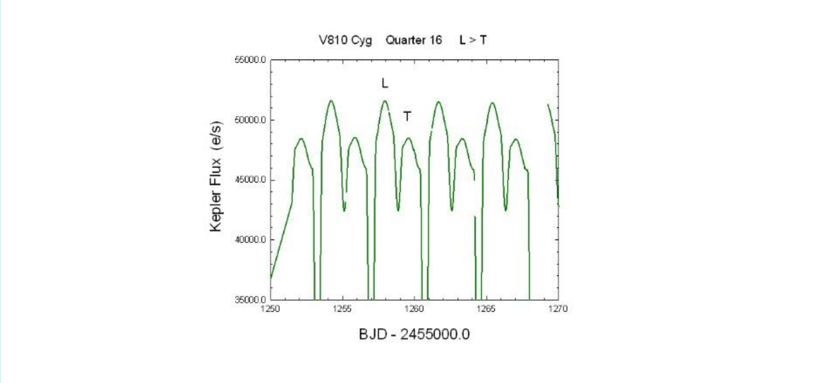
ECLIPSING BINARIES WITH ALGOL-LIKE LIGHT CURVES AVAILABLE IN THE K2 ARCHIVE

K2 ID	Kepler Mag	Campaign	Comments†
202060135	9.3	0	RW Gem, P=2.87 d, B6V+F0IV, total eclipse
202063828	10.5	0	AF Gem, P=1.24 d, A0+G0III-IV, L=T
202064026	11.2	0	BO Gem, P=4.07 d, A2 primary, L=T
202072929	10.5	0	AY Gem, P=3.05 d, A0 primary, L=T
202072971	15.5	0	DV Gem, P=4.40 d, L>T
202072991	10.1	0	V396 Gem, P=2.75 d, L=T
202073003	12.6	0	EF Gem, P=6.10 d, L=T
202073061	14.6	0	V644 Ori, P=2.48 d, L>T
202073064	13.7	0	CP Gem, P=2.40 d, L=T
202073088	14.5	0	V668 Ori, P=2.05 d, T>L var
202073121	15.7	0	HU Gem, P=1.7 d, L=T
202073124	13.4	0	TZ Gem, P=1.68 d, L=T
202073135	11.9	0	BD Gem, P= 1.62 d, L=T
202073270	10.9	0	V392 Ori, P=0.66 d:, A5 primary, L/T var
202083021	16.0	0	KX Gem, P=2.93 d, T>L, total eclipse
201488365	8.81	1	FM Leo, P=3.5 d, L=T
202685083	11.5	2	V867 Sco, P=3.32 d
204399980	8.82	2	V718 Sco, A2 primary
205506785	8.39	2	V1283 Sco, P=1.76 d, A0V+K0III
205982900	10.23	3	BW Aqr, P=6.72 d, L=T
206202136	12.82	3	FW Aqr, P=4.89 d L=T
206260730	11.91	3	XZ Aqr, P=2.06 d, T>L var
206532093	11.56	3	GN Aqr, P=4.41 d, L=T, puls
210786891	11.00	4	SZ Ari, P=1.7 d, T>>L, var
210969614	11.2	4	CF Tau, P=2.8 d, L>T, flaring
211972837	13.5	5	RY Cnc, P=1.1 d, A8III,T>L, puls?
211604396	13.2	5	AB Cnc, P=0.9 d, L>>T, var
211920612	8.4	5	S Cnc, P=9.5 d, B9V+G8-9III-IV, total eclipse, L=T
212841253	10.5	6	V342 Vir, P=0.75 d, A-type primary, L>>T, var
212576383	9.1	6	V338 Vir, P=2.99 d, L=T, var puls
212351048	10.0	6	BD Vir, P=2.55 d, A5+K1IV, total eclipse, T>L

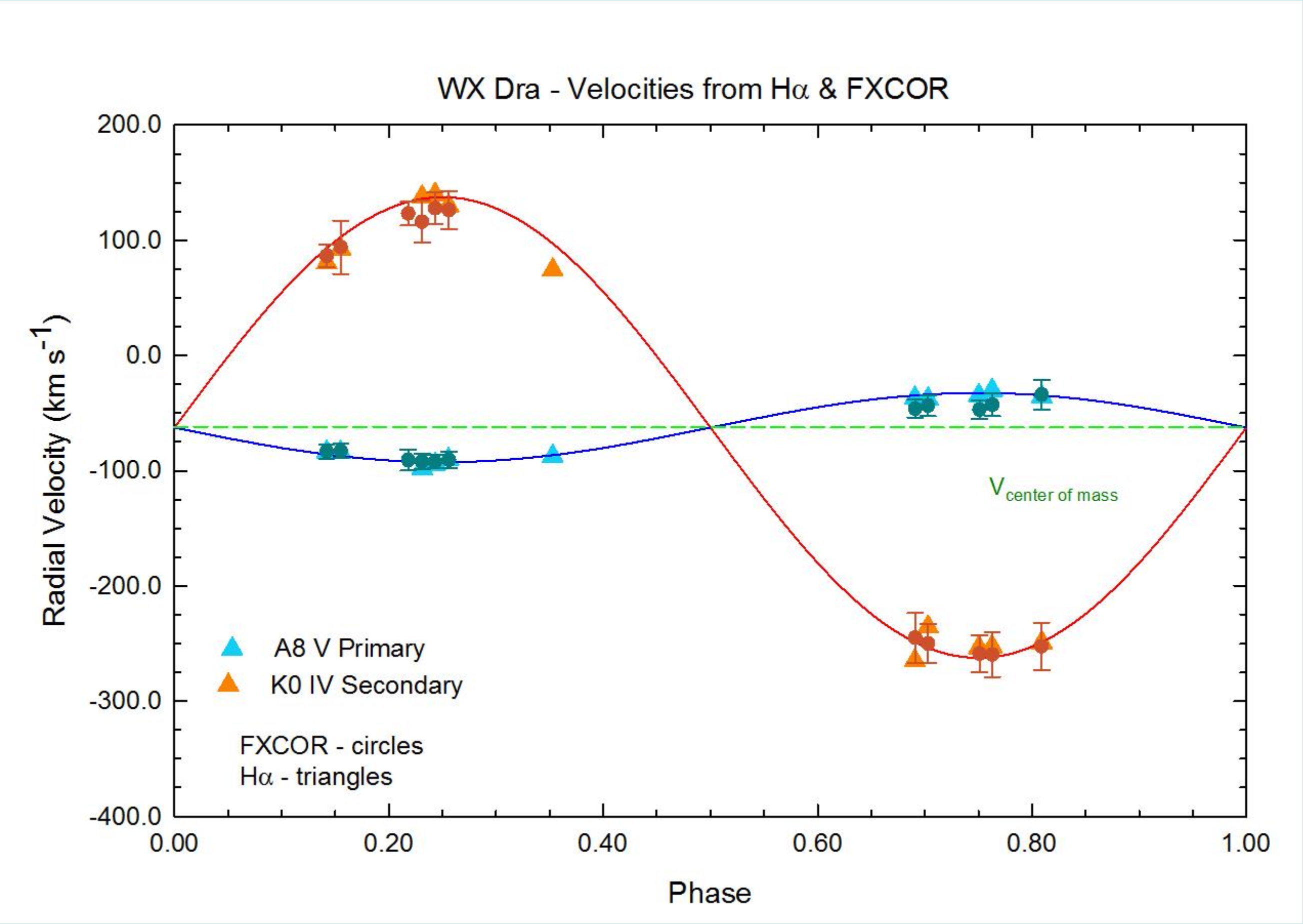

WX Dra Quarter 7 L > T
WX Dra Quarter 10 T > L
L
T
Kepler Flux (e/s)
BJD - 2455000.0


UZ Lyr Quarter 2 L > T
UZ Lyr Quarter 16 T > L
L
T
Kepler Flux (e/s)
BJD - 2455000.0


V810 Cyg Quarter 16 L > T
L
T
Kepler Flux (e/s)
BJD - 2455000.0

Hot or Cool ?

- The light curves are being analyzed with an updated version of the Wilson & Devinney (WD) code (Wilson & Devinney 1971) updated by Wilson (1990, 2008, 2012, 2015).
- Recent additions include major improvements in modeling star spots (Spotted star's light and velocity curves, spot motions due to drift and stellar rotation, and spot growth and decay).
- The analysis can be applied to both accretion hot spots and magnetic cool spots.
- The program gives parameters for times of spot appearance, development, and disappearance.



Spectra from KPNO 4m Echelle spectrograph
Mass ratio ~ 0.14 (almost detached)

Semimajor axis: 7.9 Rsun

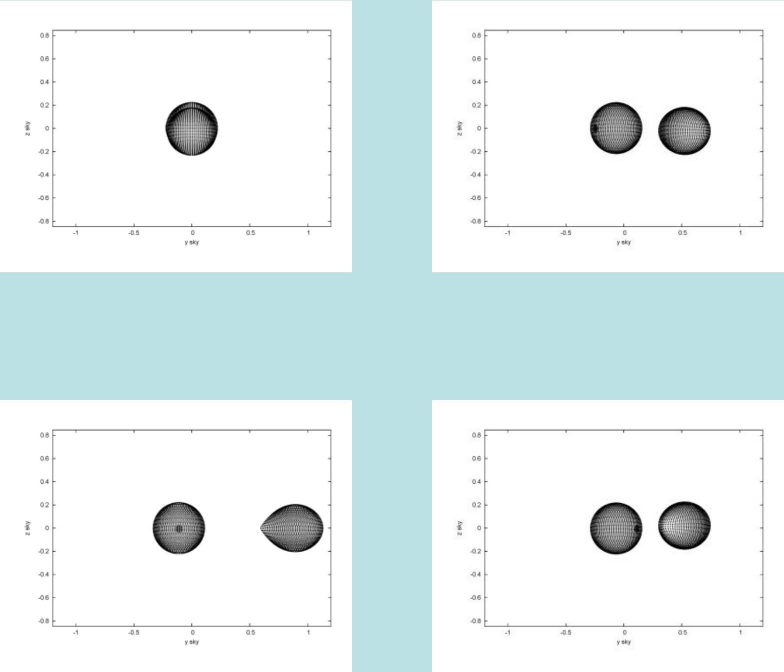
Inclination: 88.25 deg

Spot temperature: 18,000 K

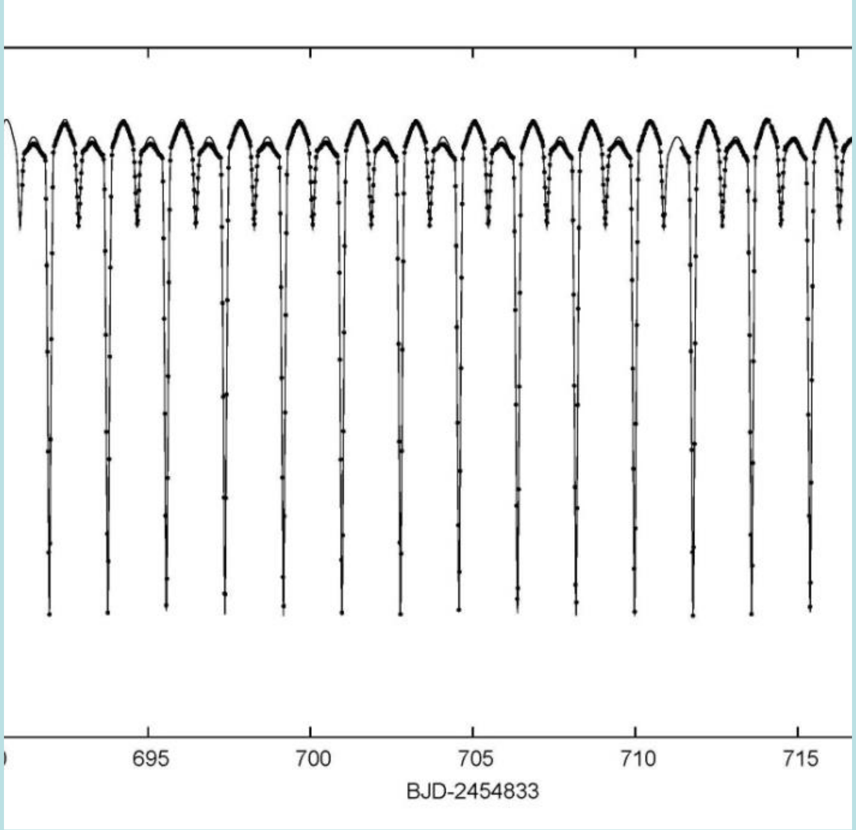
Spot radius: 0.1 rad

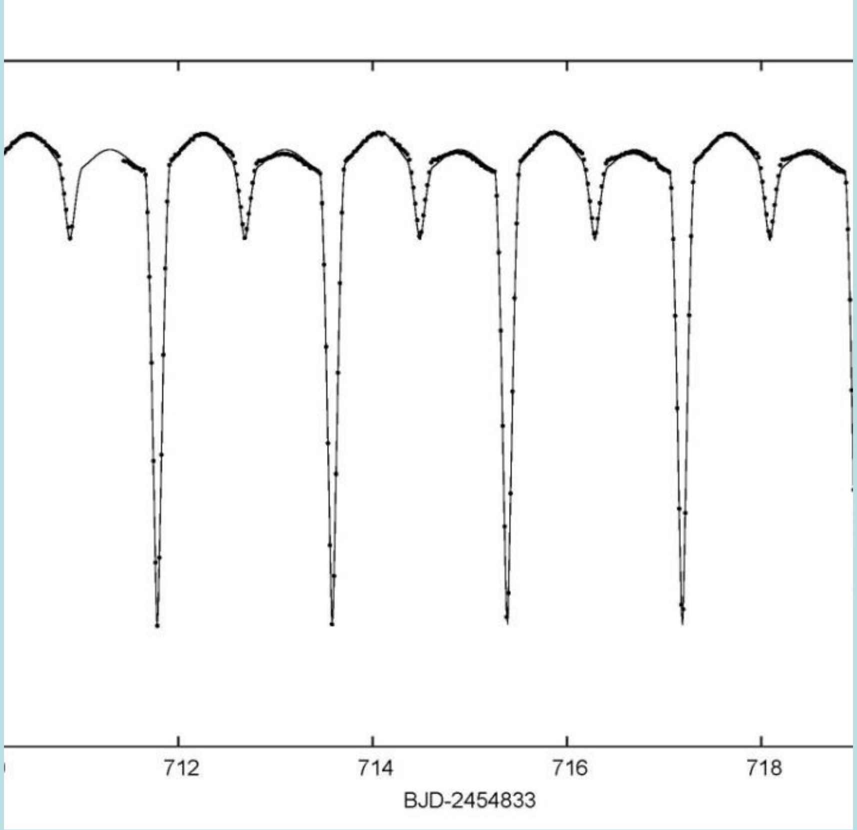
Spot longitude: 4.7 - 5.4 radians

	A8 V star	K0 IV star
T_{phot} :	7800 K	5140 K
Rpole/a:	0.22	0.20
Rside/a:	0.22	0.21
Rback/a:	0.22	0.24



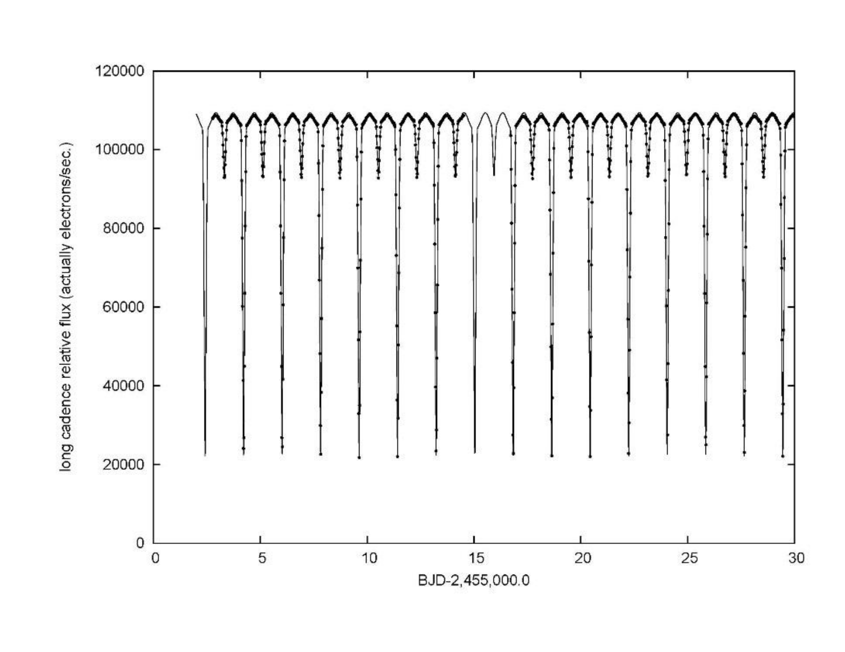
Clockwise from the top left :
Views at phase 0.0, 0.10, 0.25, and 0.45.
The temperature of the spot is about 2.3 Tphot

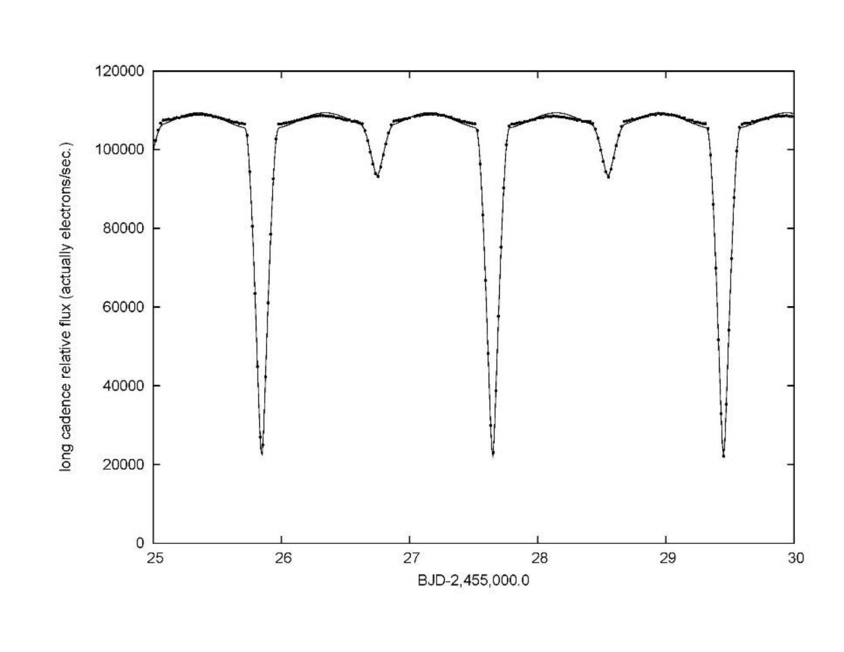




Shoulders of observed light curve too steep compared with model calculation in which the secondary is assumed to fill its Roche lobe.

Is WX Dra Detached ?





Left: Fit to stretch when quadratures were equal
Right: Expansion of plot - Model's quadratures a bit shallow.
If system is detached, hot spot model unlikely.
If L/T variations caused by cool spot, about 40% of the cool star must be covered by black region.

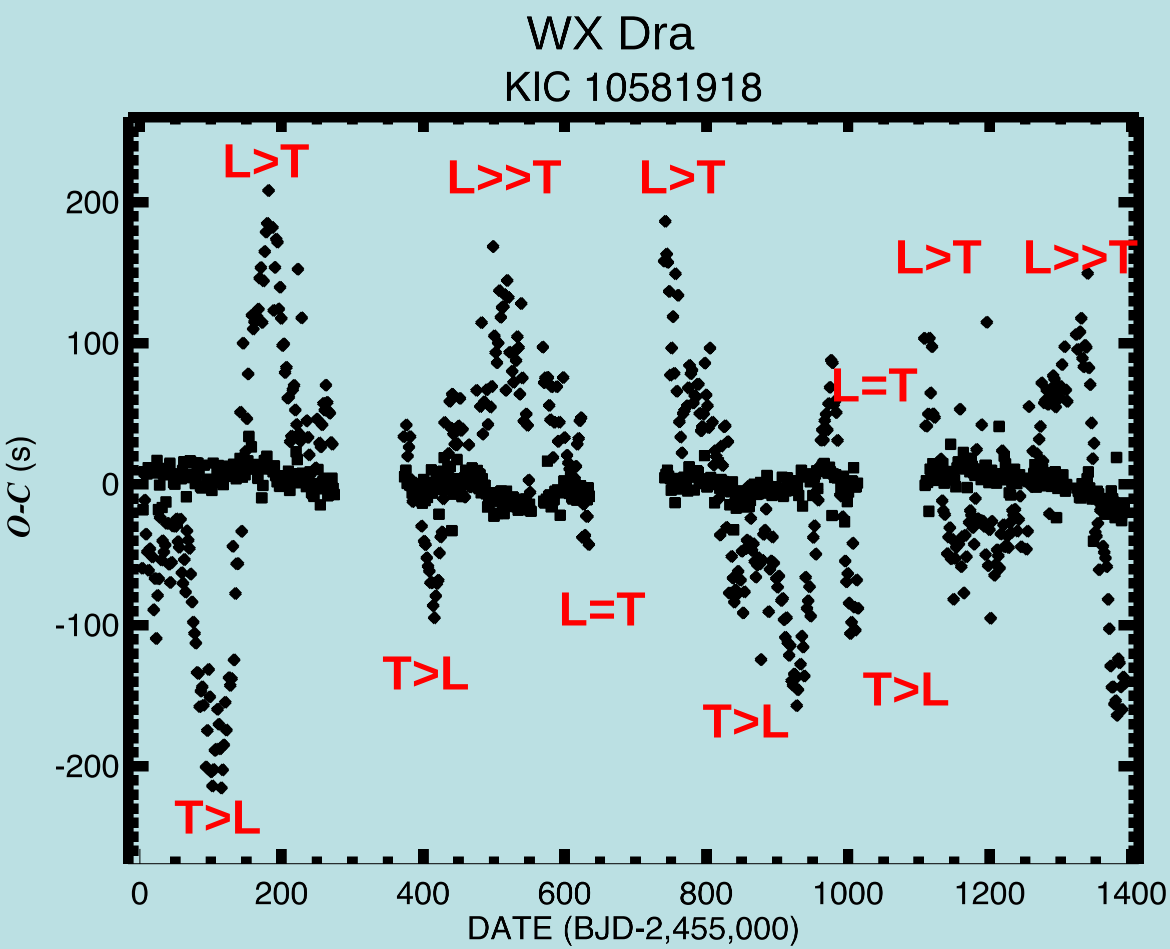
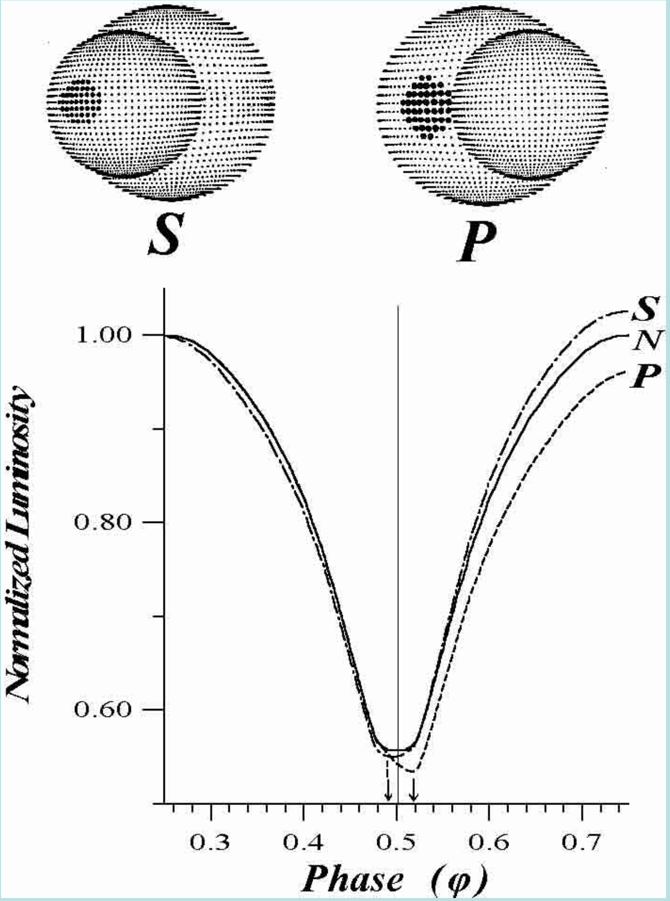
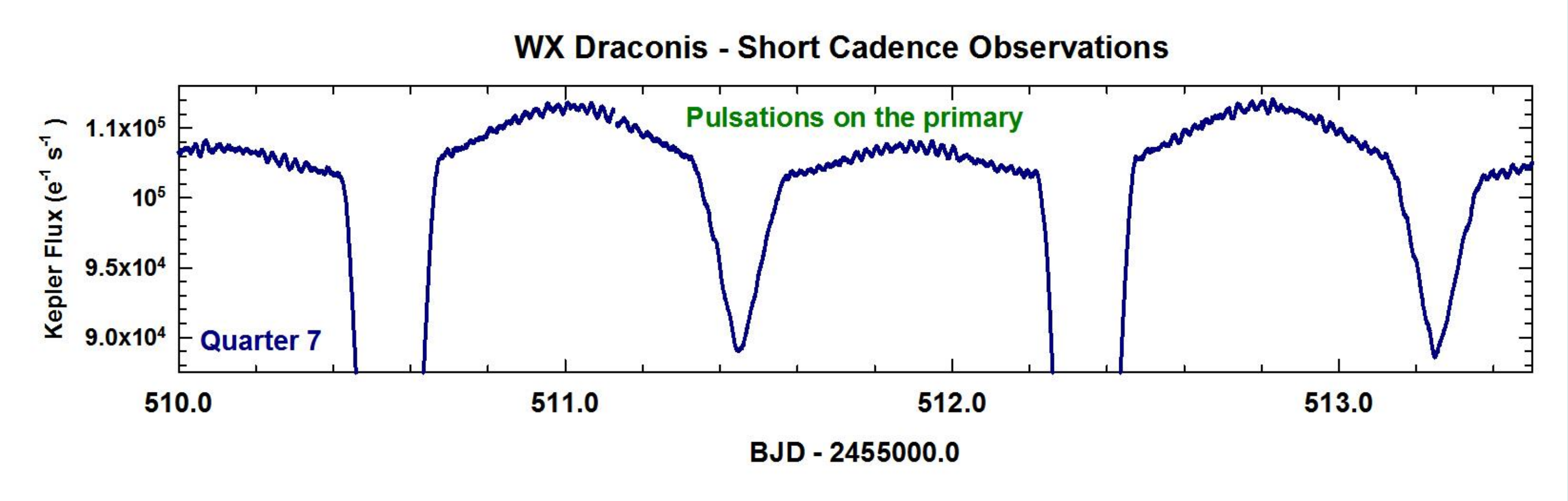


Fig. 1.35.— The observed minus calculated eclipse times relative to a linear ephemeris. The primary and secondary eclipse times are indicated by + and × symbols, respectively.

Gies et al. 2015, ApJ, 150, 178



Kalimeris et al. 2002, A&A, 387,969



- Short cadence observations reveal pulsational behavior
- Dominant period is 40.56 ± 2.87 m.
- Amplitude varies – larger at quadratures
- Maximum continuum light variability is about 2%
- Pulsations associated with the primary as they are observed during secondary eclipse and not at primary eclipse
- Primary is δ Scuti star, similar to KIC 10661783 (Southworth, et al. 2011 (MNRAS, 414, 2413)
- Asteroseismology study is in progress.

Concluding Remarks

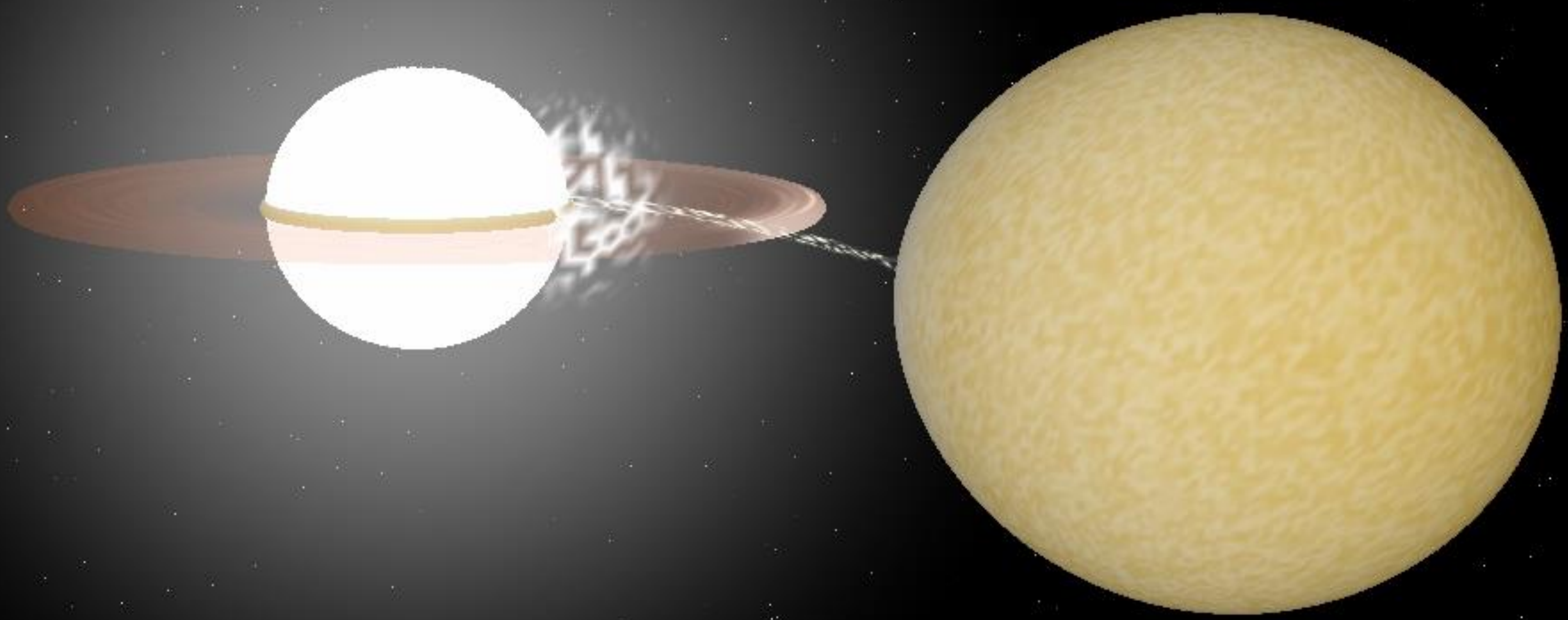
Photospheric and Circumstellar Structures Inferred in Algols that Might be Seen Via Interferometry

- Accretion hot spots on the mass gainer
- Gas stream
- Splash regions
- Large magnetic Cool Spots on mass Loser

A RS CVn phenomenon may be happening in Algols (Reviewed by Richards et al. 2014, ApJ, 795, 160)

Algols are tidally-locked – Mass loser is spun up enhancing magnetic activity – Activity cycles probably exist as in WX Dra.

The magnetic field is frozen-in – carried with the mass flow. This may produce magnetic disks, explain bipolar flows (as in V356 Sgr), and govern the landing spot for the impacting gas stream.



THANK YOU