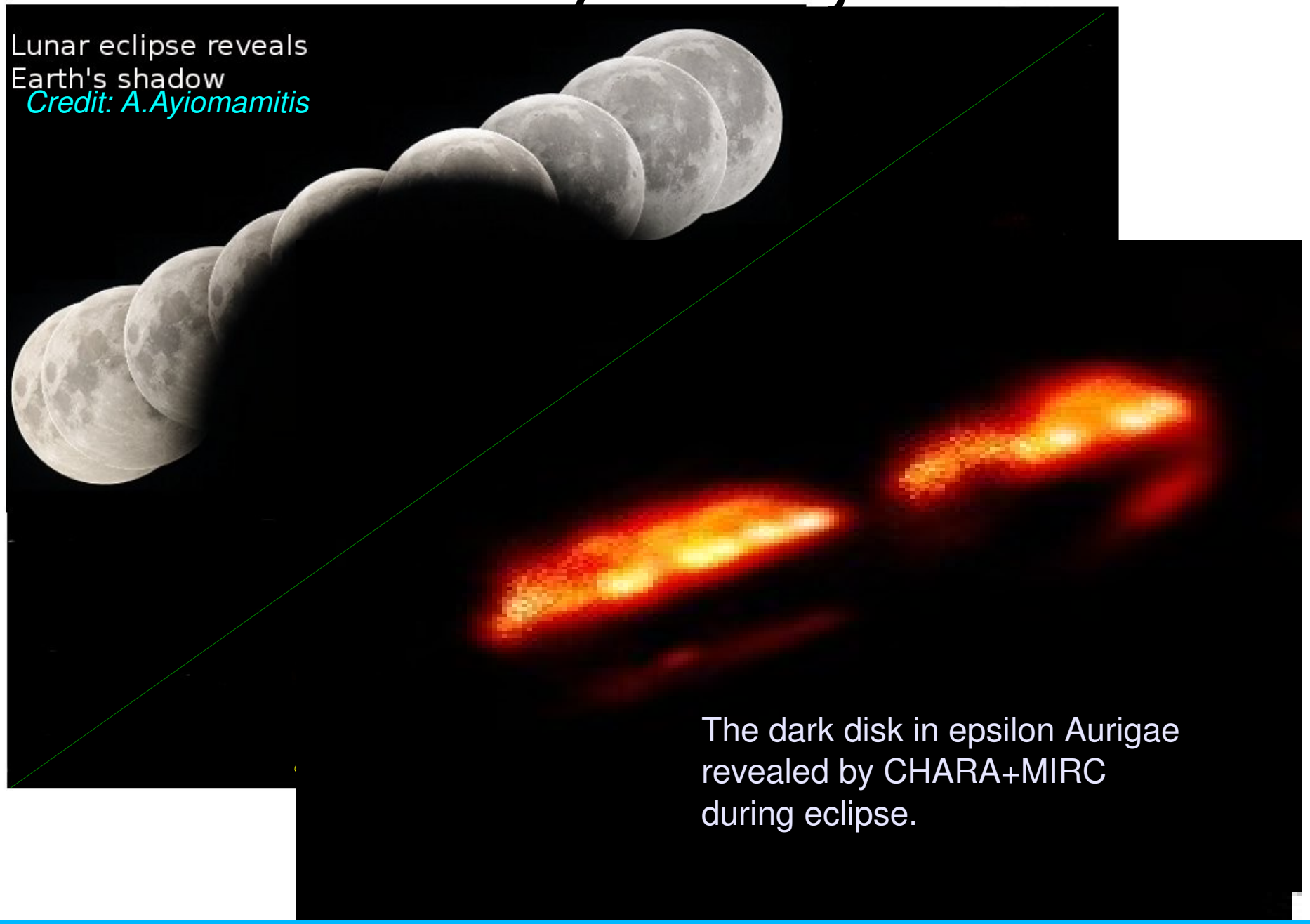
A look inside the disk in the epsilon Aurigae system

Robert Stencel - University of Denver

with gratitude for contributions from:

Brian Kloppenborg, Robin Leadbeater, Michael Sitko, John Rayner, Steve Howell, Don Hoard, Pavel Chadima and the entire CHARA + MIRC science and engineering teams... Thank you!

Today's story...



The dark disk in epsilon Aurigae revealed by CHARA+MIRC during eclipse.

Prep work for eps Aur imaging:

1980s: UV spectroscopy & eclipse campaign

1990s: IR photometry at WIRO & Mel Dyck (IRMA)

2000s: PTI & Michelle Creech-Eakman

2006 IAU Prague, lobbying Hal

2007 Initial PTI diameters, Alexa H. → ApJ

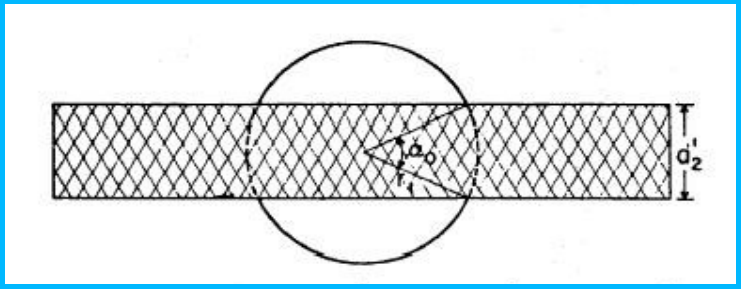
2008 Initial CHARA proposal, Brian K. → Nature

2010-11: current eclipse campaign [UV, Opt, IR, sub-mm*]

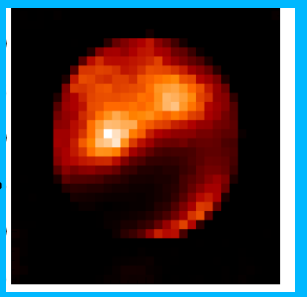
*HSO time awarded, ALMA time requested

GOALS of current work: disk density(r,z), gas/dust ratio, central object, disk age, system evolutionary status

PREDICTION: out of eclipse imaging (MIRC 6T) also will prove to be full of surprises...



← From this... to this →



*MIRC images → improved orbit → timing schematic (Brian's thesis) and context for the spectroscopic results

*Eclipser is asymmetric in almost every diagnostic (ptm & spec)

*IR spectra:

behavior of the H recombination lines → extended nebulosity

mid-eclipse appearance of Helium and CO → strong heating

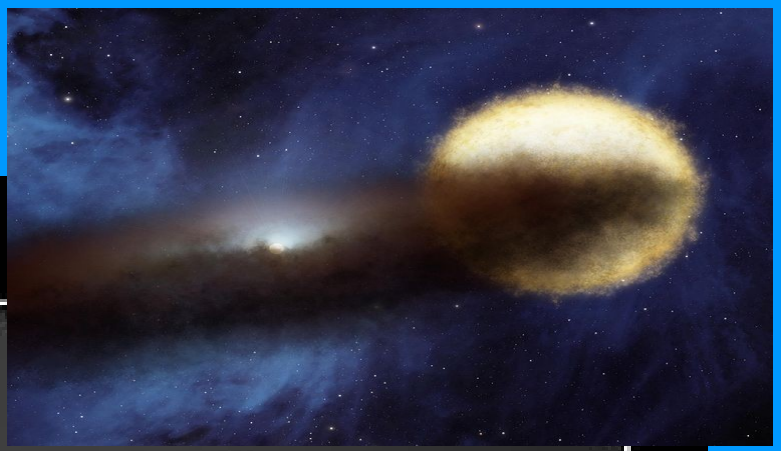
secondary eclipse: differentially heated disk

*UV spectra: sign of accretion on to the central source

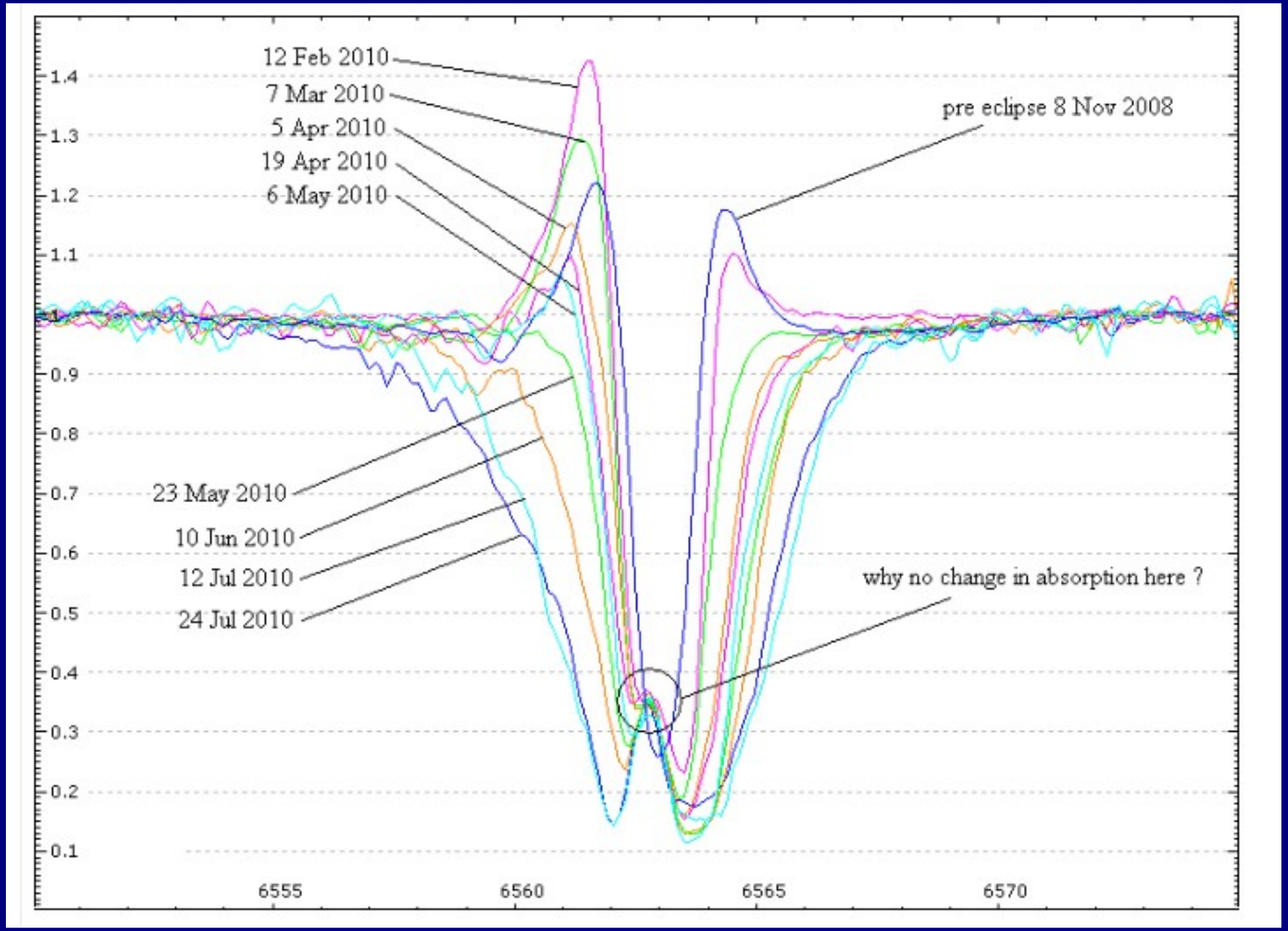
*VEGA data!

*Disk models & implications

Working model from composite SED
(Hoard, Howell &Stencel 2010 ApJ)



SPECTRA: H-alpha – combination of spectra over eclipse...



55060 = 2009 Aug
photometric first contact →

Timeline view:

H-α

(Optically thick)

(and as seen by CHARA+VEGA)

55400 = 2010 Aug
nominal mid-eclipse,
(note asymmetries)

P. Chadima et al.: Spectral and photometric analysis of the eclipsing binary ε Aurigae prior and during the 2009-2010 eclipse

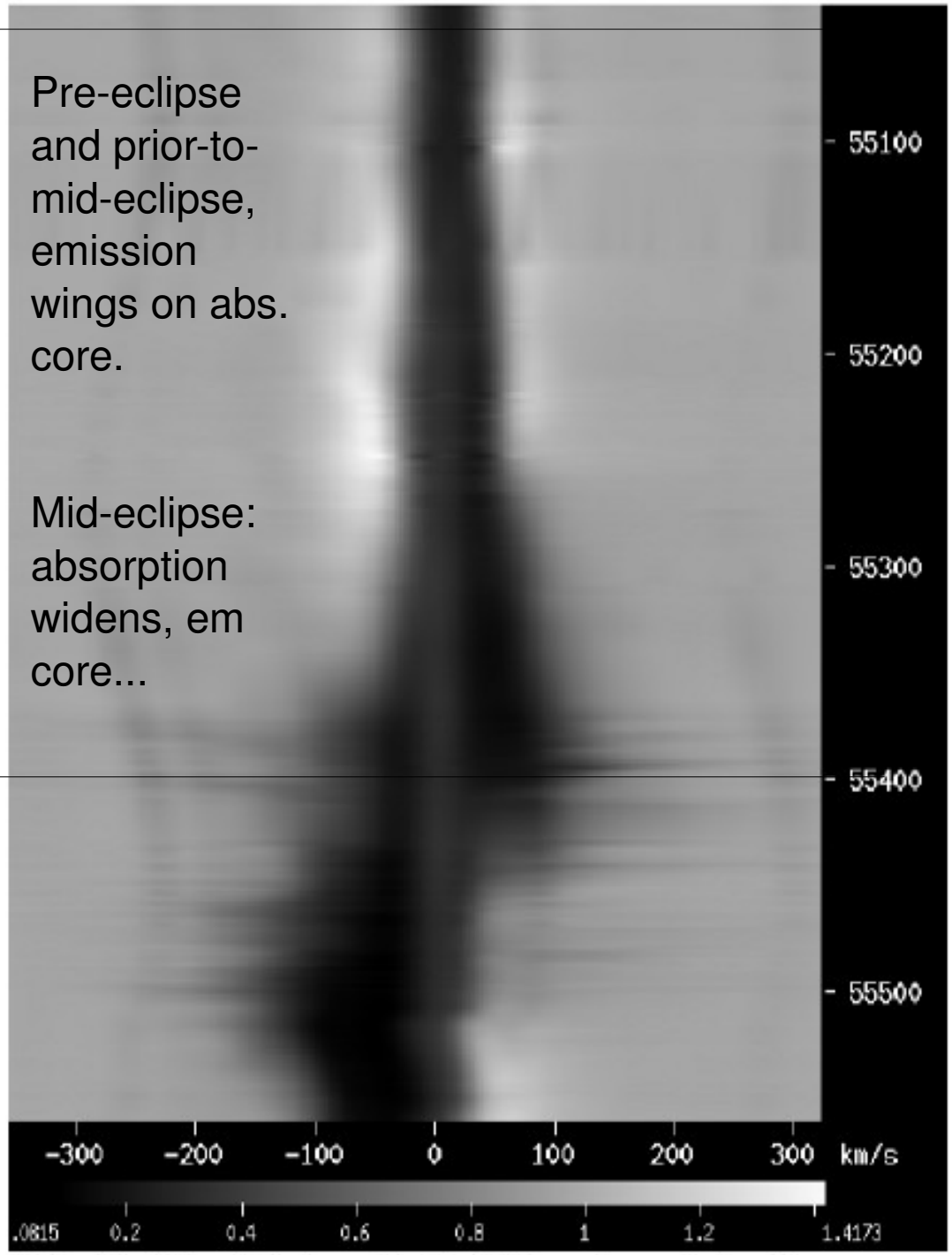
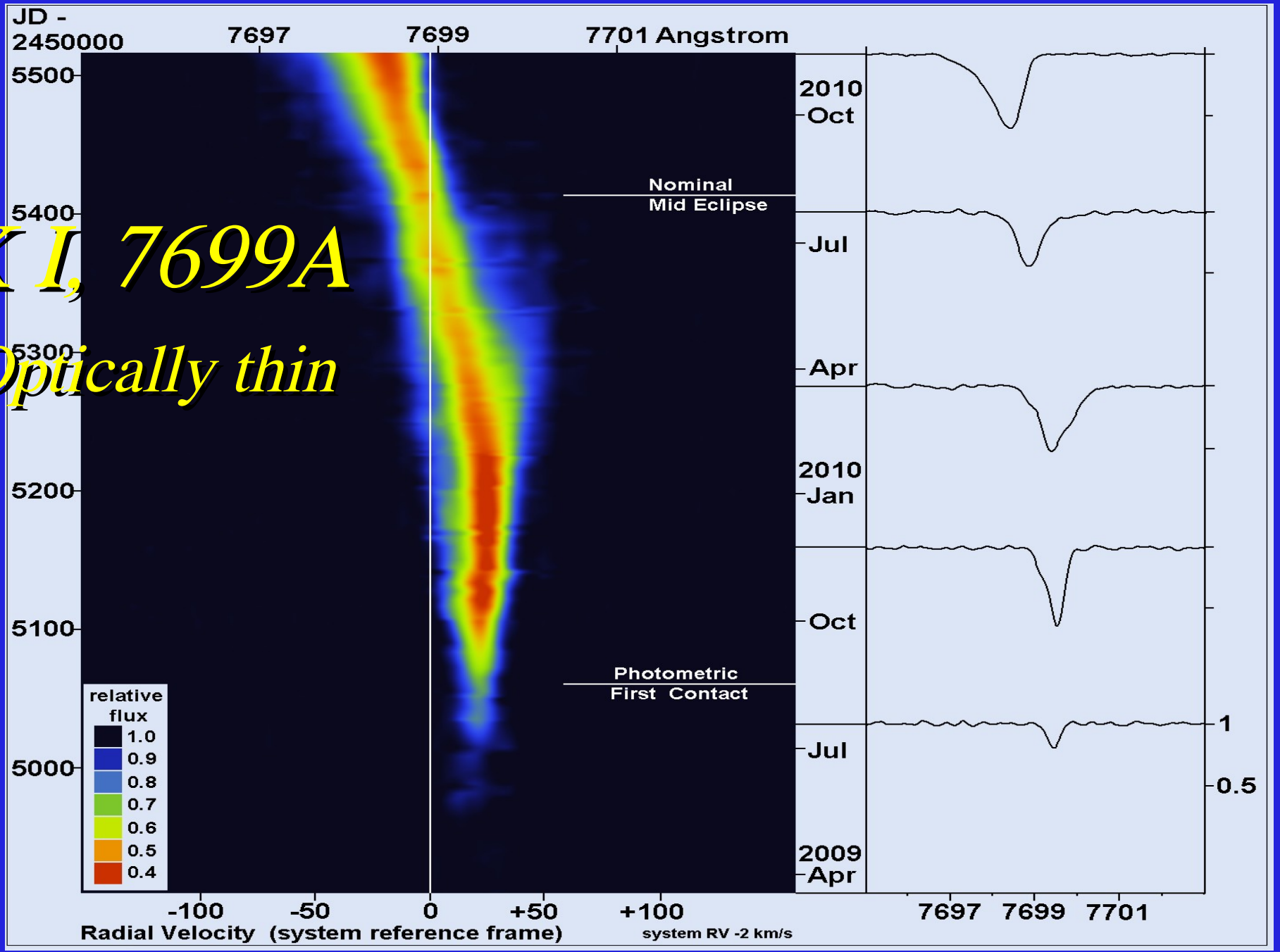


Fig. 3. An evolution of the Hα profile during the current eclipse. Interpolation between spectra was used to get a smooth image.

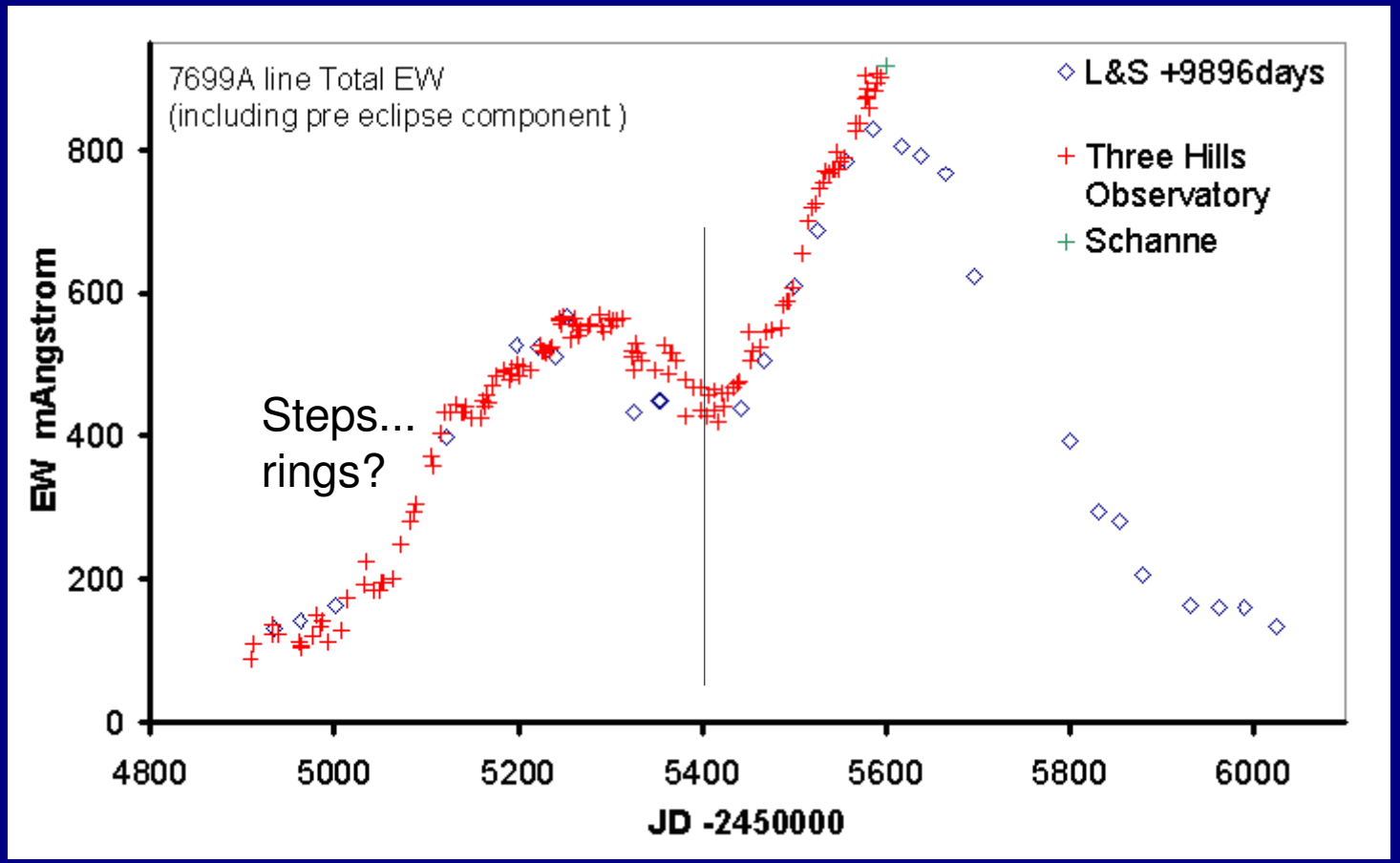
Spectra: optically thin neutral potassium (R.Leadbeater) time going upwards, note rotation curve



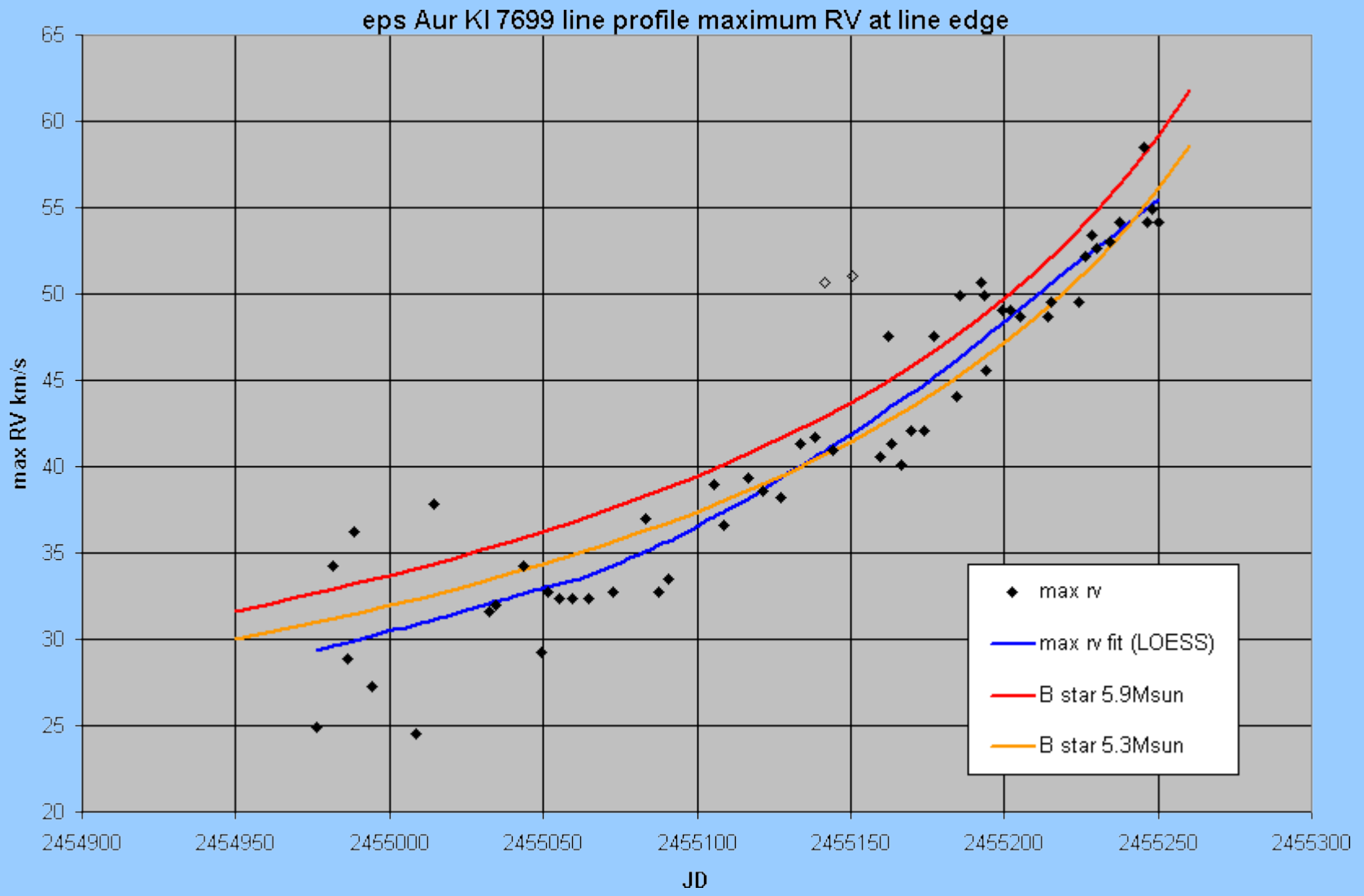
K I, 7699A

Optically thin

Disk tracer: optically thin neutral potassium (R.Leadbeater) note asymmetry around mid-eclipse

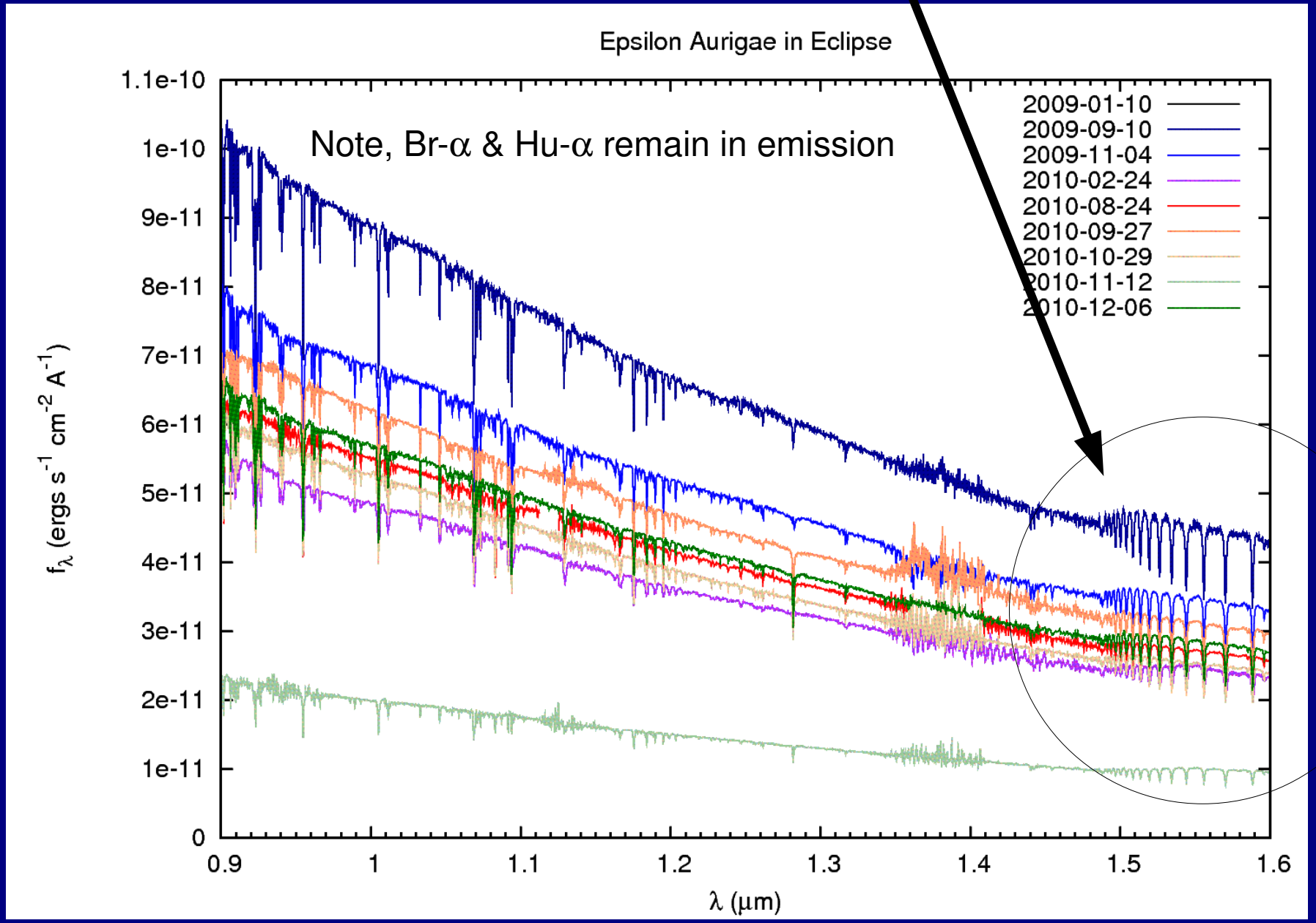


Implication → 5 to 6 Mo star embedded in the disk

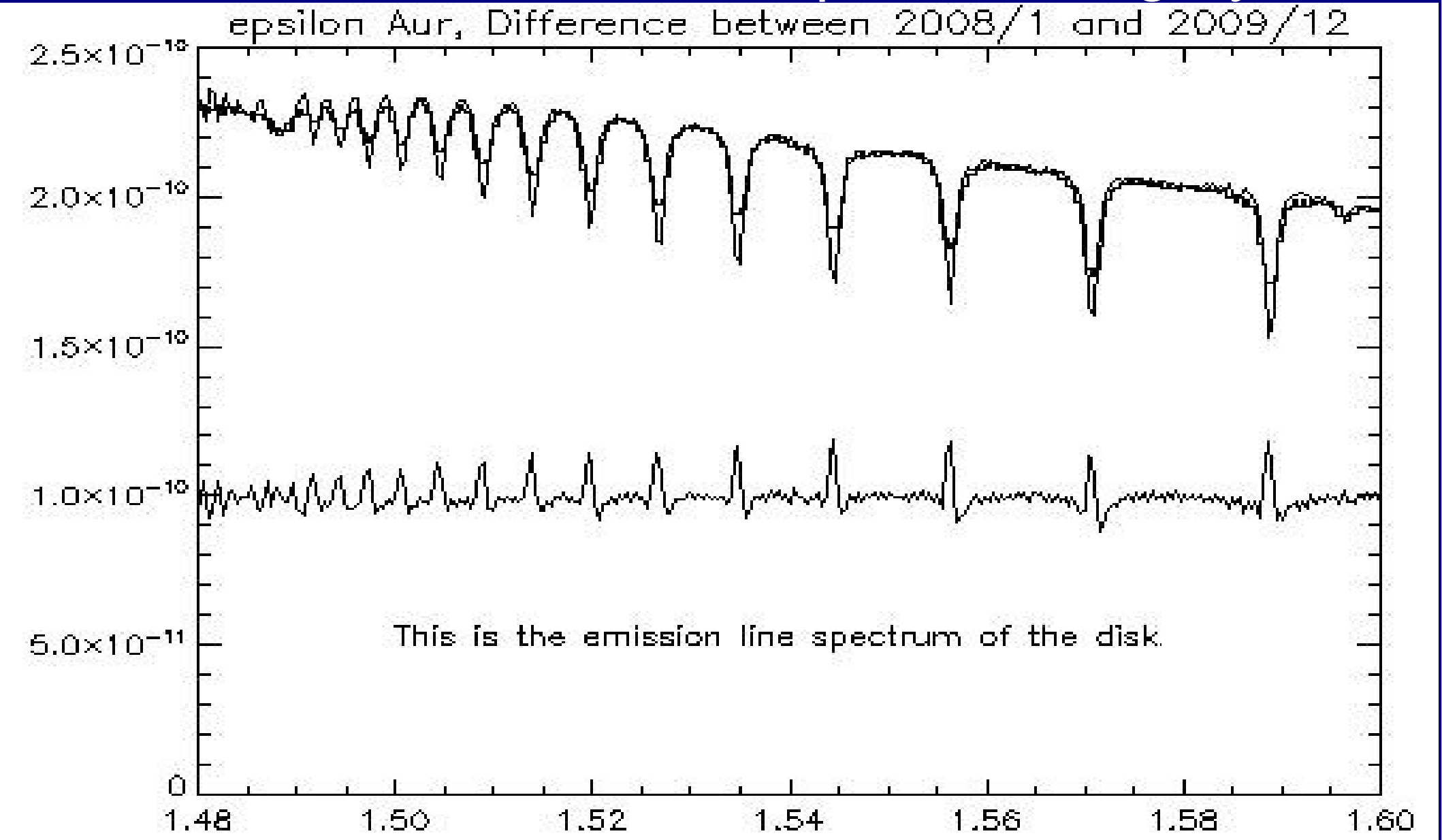


Infrared spectra (IRTF+SpeX)

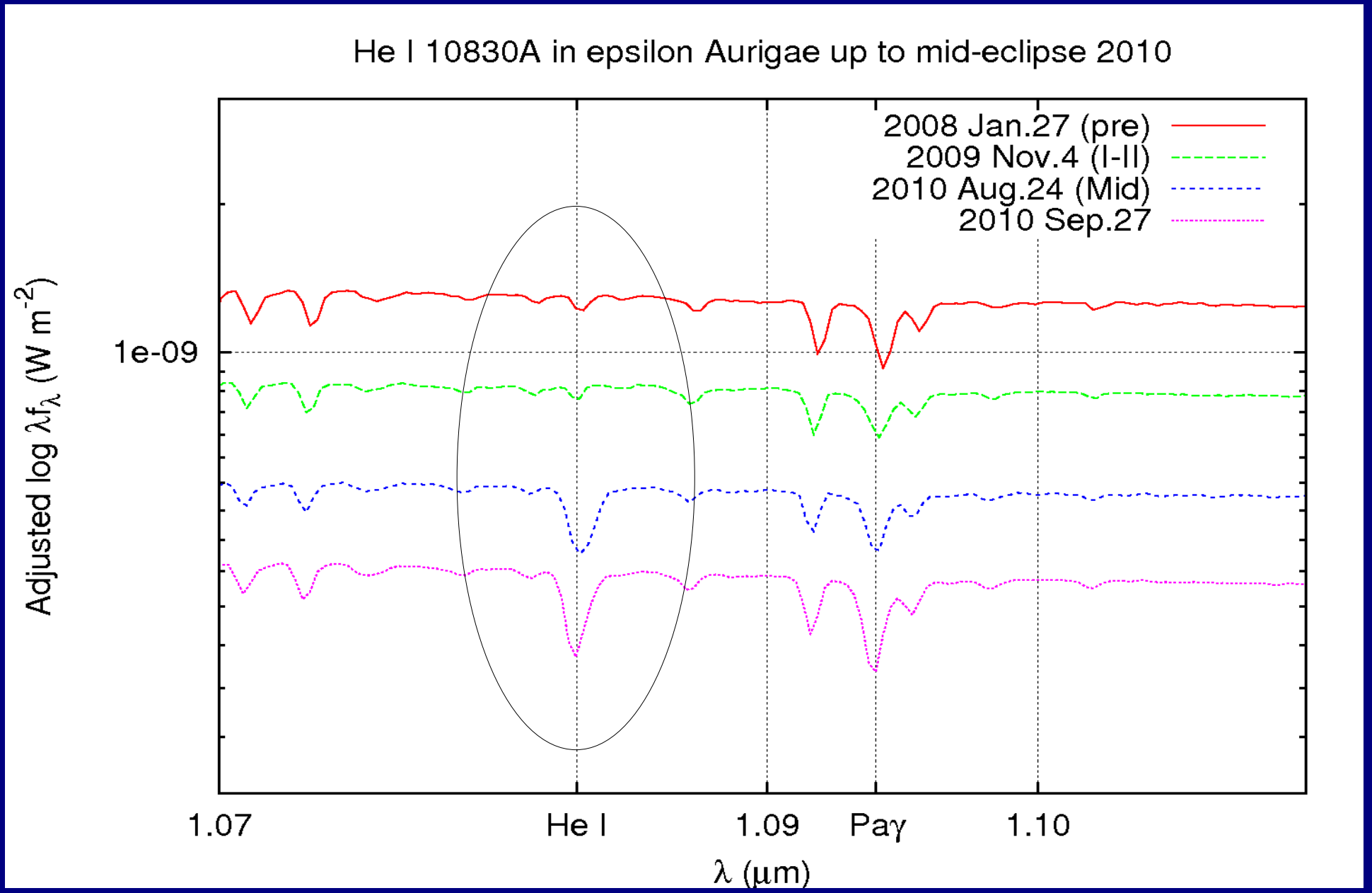
H-recombination lines: Balmer n-2, Paschen n-3, Brackett n-4, Pfund n-5, Humphreys n-6, etc.



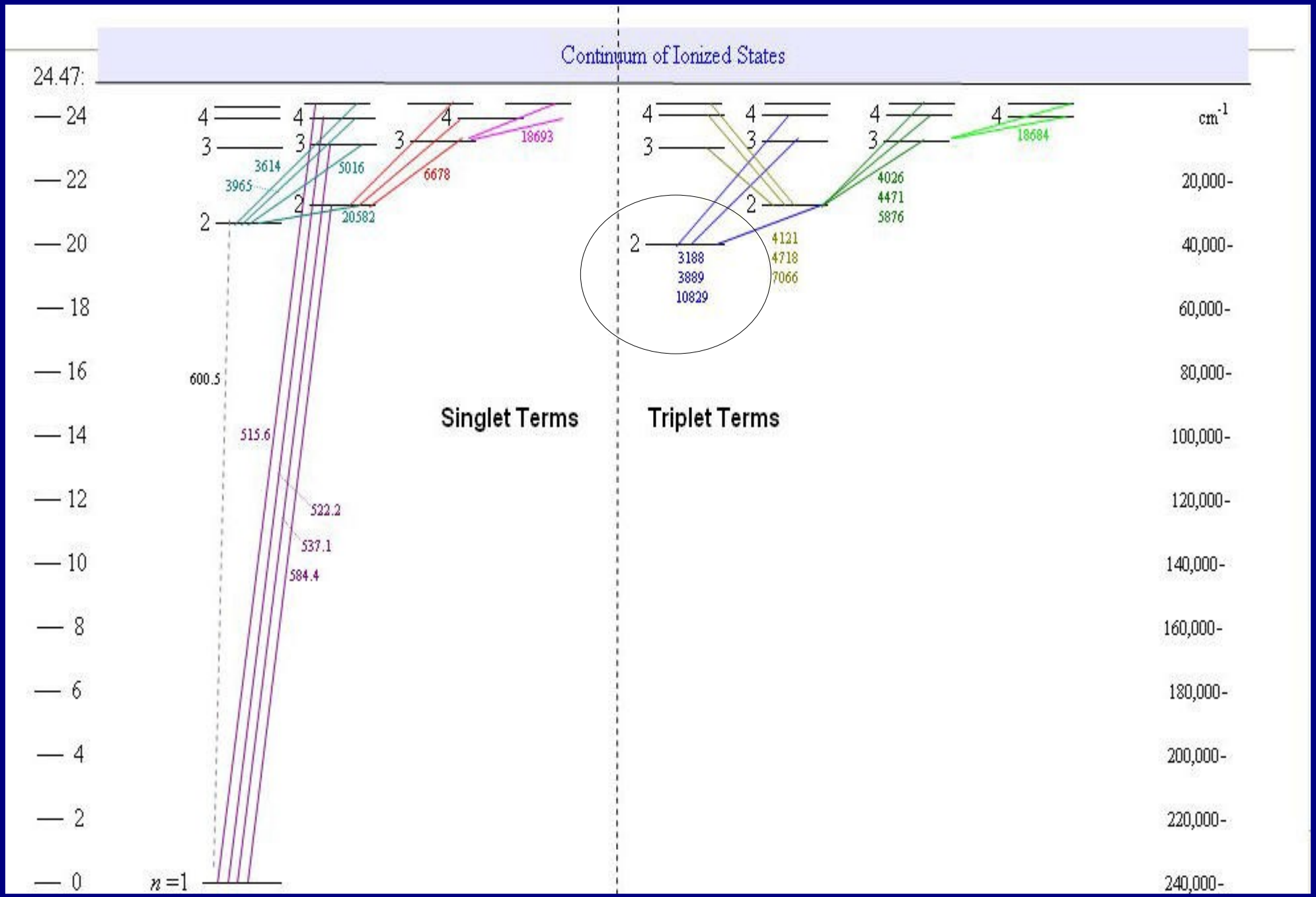
Paschen limit lines: eclipse is not “gray”



More IR surprises: Helium 10830A!

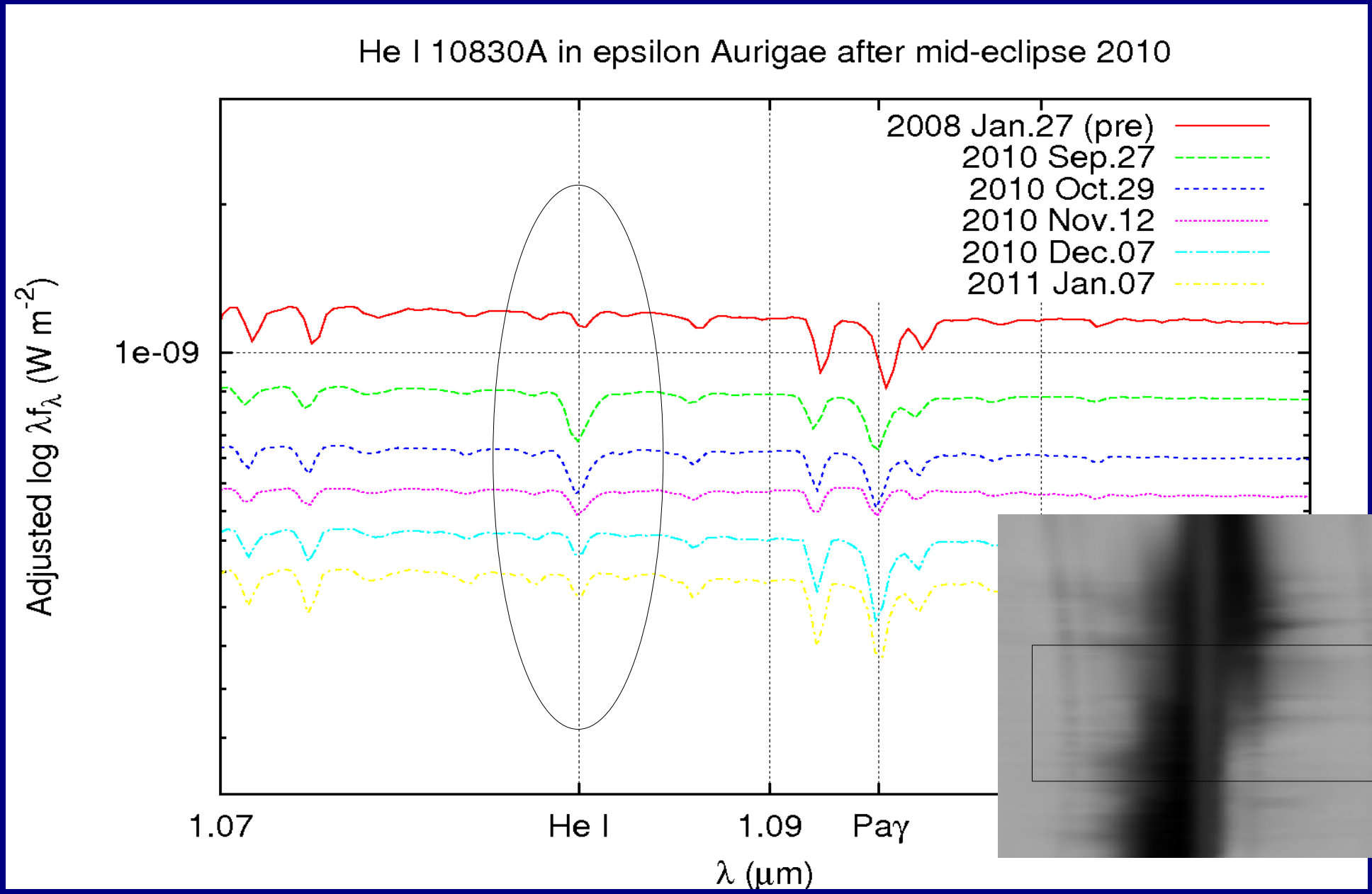


Triplets in neutral helium: 2s-3p = 10830A line @20eV!!!



He I 10830A, ~50,000K!

He 10830A zone crossing time ~90 days @ 20 km/sec ~1AU



Stromgren analysis

Column density: from CO: 3E20 cm^{-2} → n_H ~ 1.5E24 cm^{-2} .

Consistent with lack of soft Xrays, n_H > 1.25E24 cm^{-2} .

Column through 3.8AU radius disk → # density ~ 2.6E10 cm^{-3} .
(similar result to earth mass disk we derived - Nature paper)

Is the duration of He 10830A consistent with a B5V star radiation field ~ Stromgren sphere (central clearing)?

$$R_s = (3/4\pi\alpha)^{1/3} \; N_{uv}^{1/3} \; n_H^{-2/3}.$$

Using: α (He, recomb rate) = 1E-15 cm3/s

n_H = 3E10 /cm3,

N_{fuv}(B0V) = 1.6E46 ph/sec → R_s = 1.3 AU

N_{fuv}(B5V) = 7.0E41 ph/sec → R_s = 0.05AU, too small

Need either hotter than B5V star or lower density... however...

Add accretion!

L_{accr} = G M* Mdot / R*

With Mdot = 1E-6 Mo/yr (1 earth mass/year):

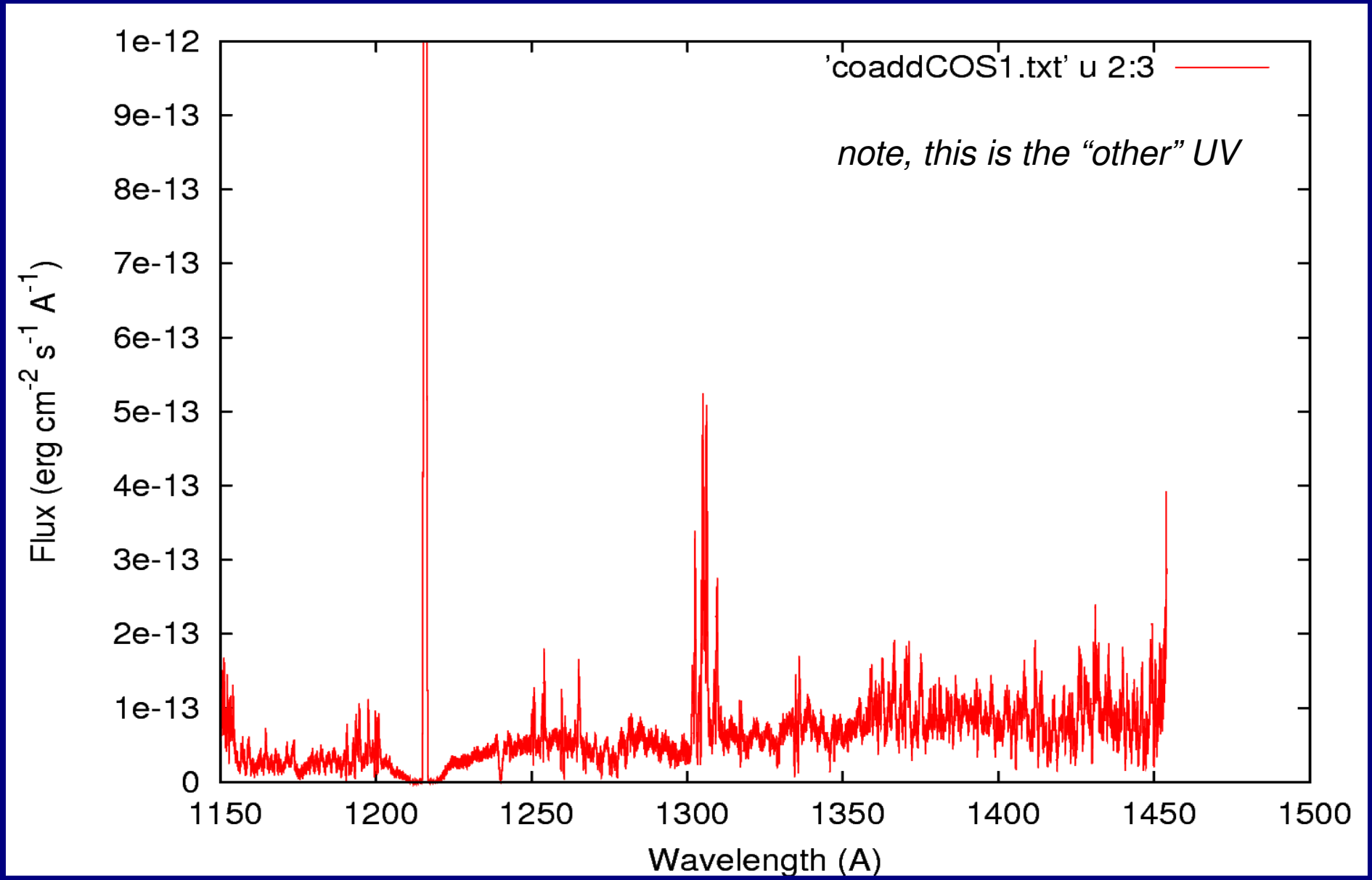
	M/Mo	R/Ro	L_{accr}	photons/s*
B0V:	17	8	2.5E35	6E45
B5V:	6	4	1.7E35	4E45

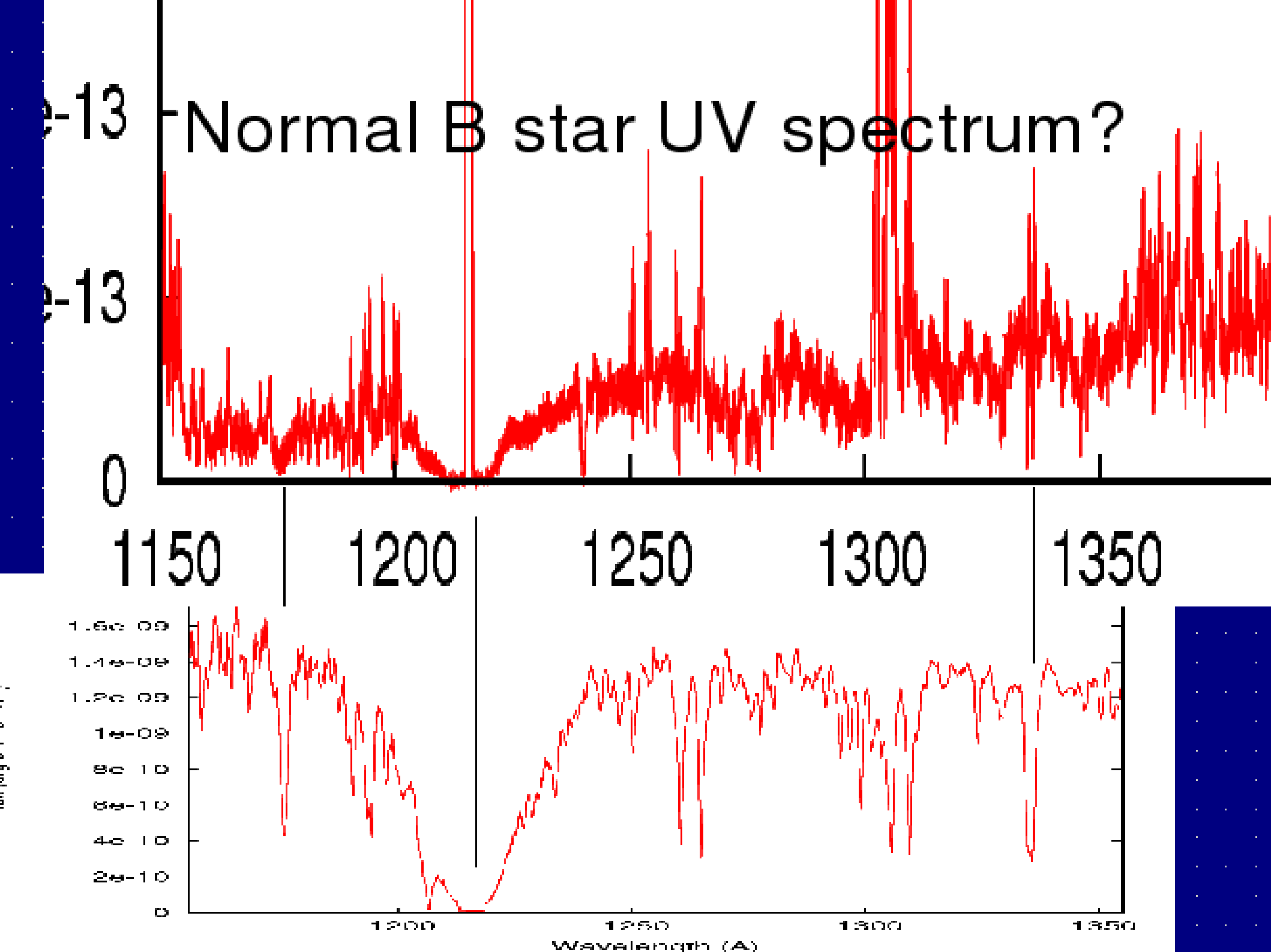
N^*_{fuv}(B0V) = 2.1E46 ph/sec → R_s = 1.6 AU

N^*_{fuv}(B5V) = 4E45 ph/sec → R_s = 0.85 AU - OK

**gain from GPE is ~1E7K, assumed all 505A photons*

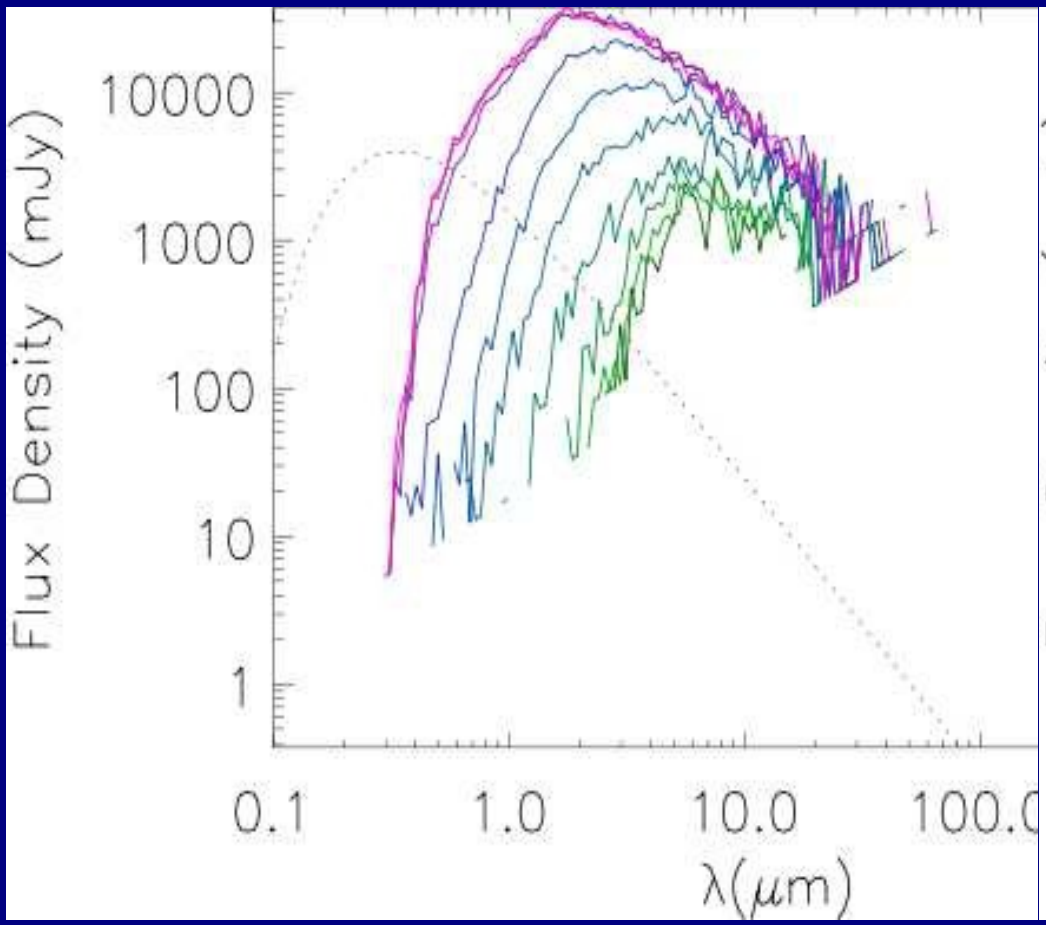
Evidence for accretion: HST-COS (UV) observations (like a symbiotic system?)



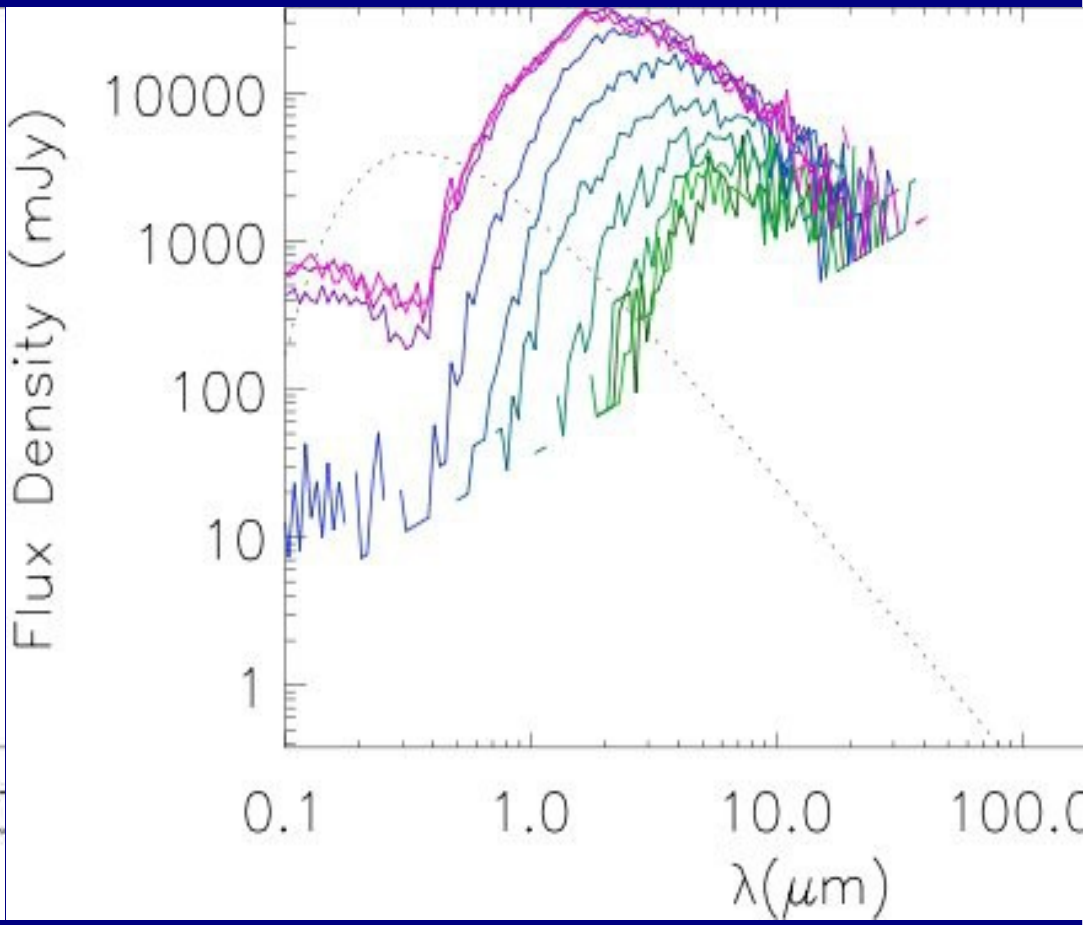

Normal B star UV spectrum?
1150
1200
1250
1300
1350
Wavelength (A)

Evidence for accretion – model calculations by undergrad Naomi Pequette, with B.Whitney disk code

Disk + B star, ZERO accretion (no UV)

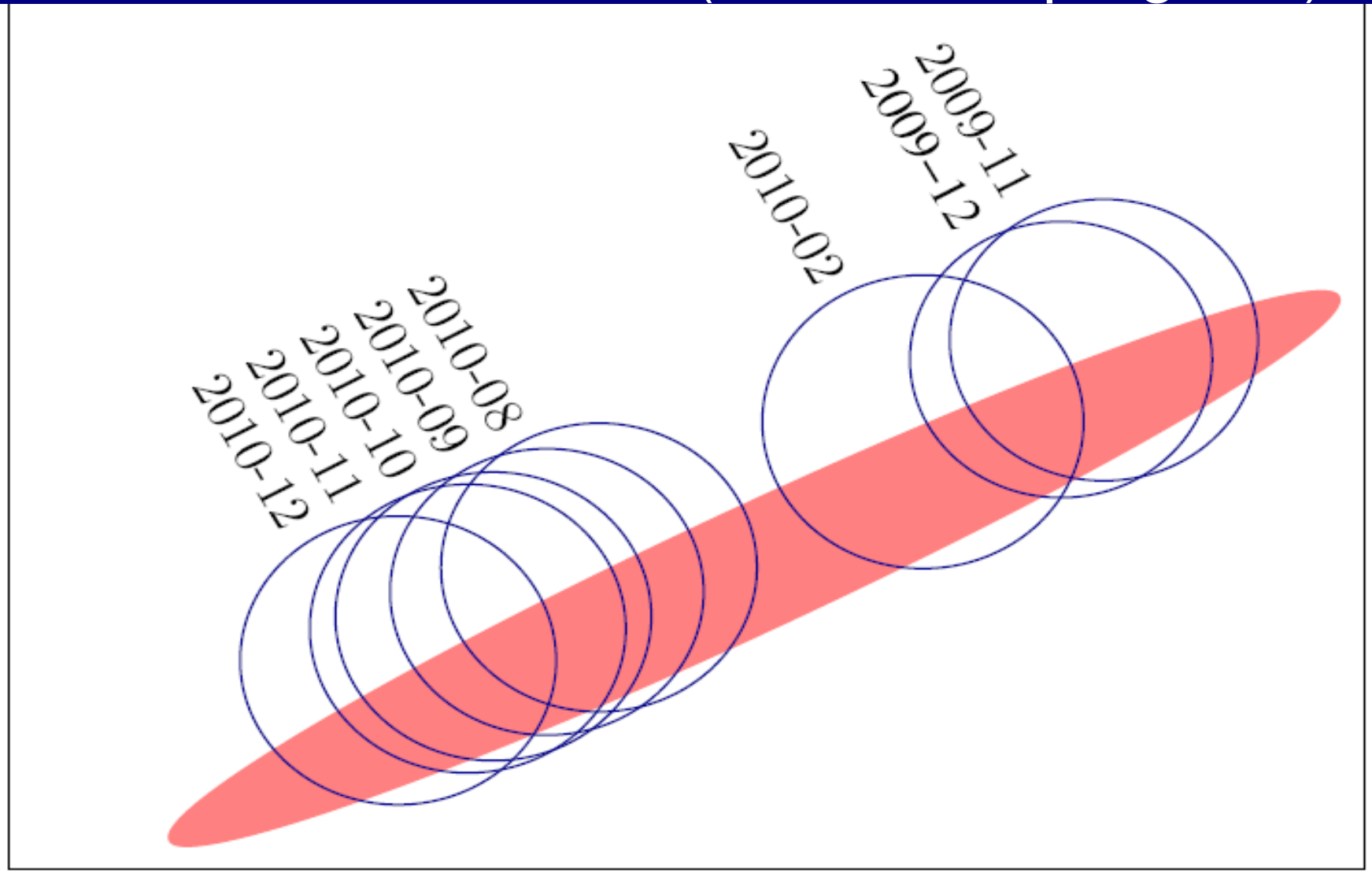


Disk + B star + 2e-6 Mo/yr accretion



Mdot → disk age... if disk gas and fine dust mass is only ~1 M_E, requires replenishment – planetessimal collisions?

Putting it all together: Geometric placement of CHARA Observations (Brian K, in progress)



A schematic diagram showing the elliptical model for the eclipsing object and the position of the F-star in each epoch. The diameter of the F-star is drawn (to scale) according to our model fits. The disk parameters are based on the mid-eclipse thickness and approximate photometric contact times.

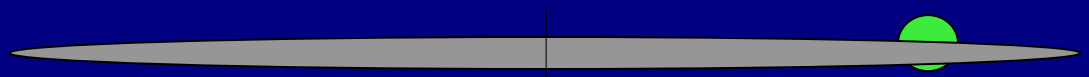
Disk size: 8.AU (V band) x 0.7AU (H band)

F star diam. PTI: 0.67 AU (K band) for assumed dist.

J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

.2009 .2010 | .2011

Ingress **Totality Totality Totality Totality** ***Egress***



Spectroscopic disk signatures (current + past eclipse):

K I 7699A ….ooooooooooooo……..oooOOOOOoooooo……

CO 2.3 um ccccccccccccccccccccccccccc…

H I reduced EW vvvvvvvvvvvvvvvvvvvvvvvvvvvvvv

He I 10830A He He He

plus VEGA/Hα, Ultraviolet and others in progress...

What's next?

Goals:

- Determine the mass of the secondary star → mass ratio
- Determine the evolutionary status of the components in this system
- Determine disk structure and composition. Bonus feature is differential heating of disk exterior due to nearby F star.

Thanks for listening,
and thanks for maintaining CHARA & its instruments!