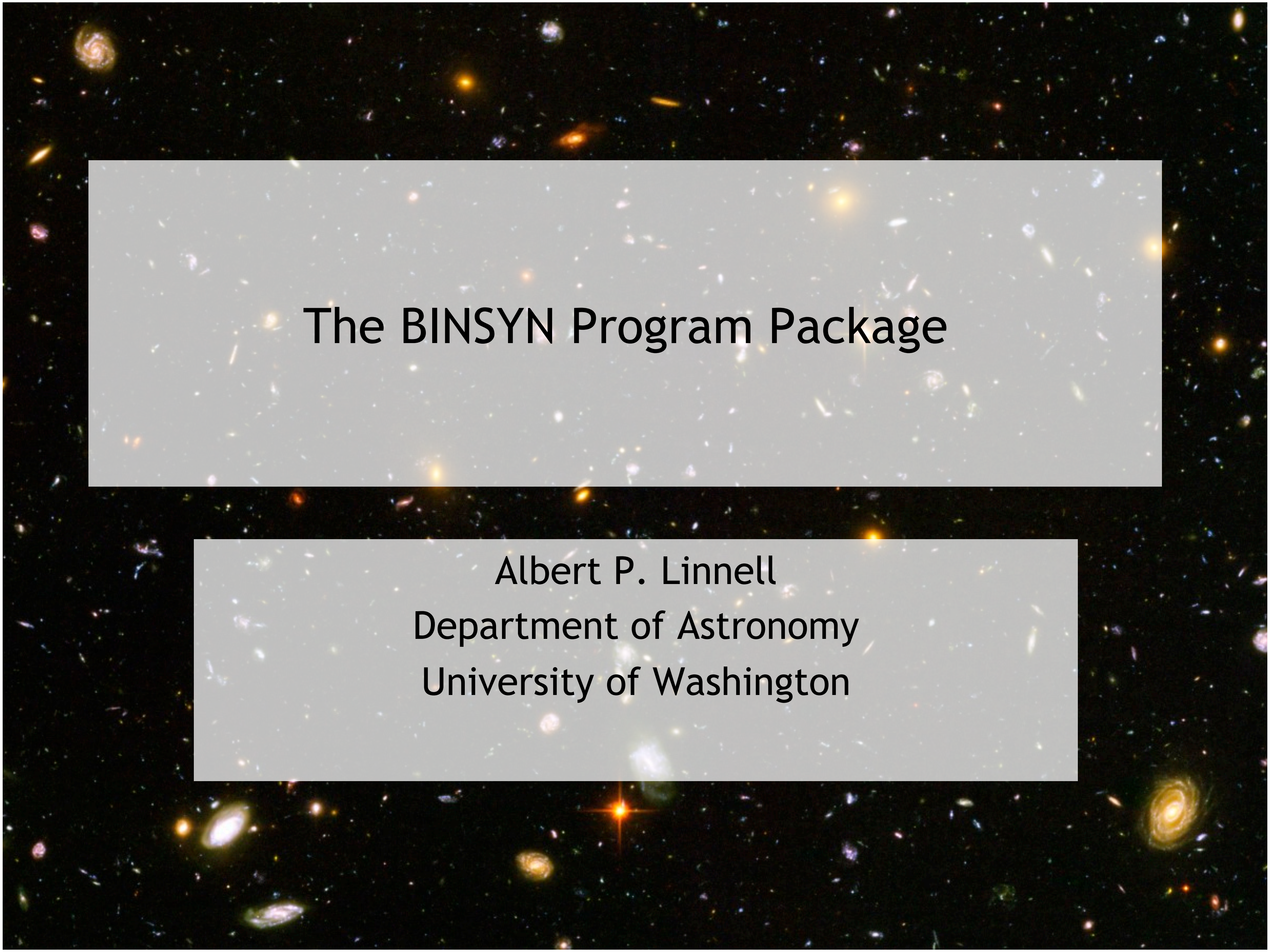

The BINSYN Program Package

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What it is

A program package to simulate binary star systems with or without optically thick accretion disks.

Includes simulation of both photometric and spectroscopic data.

Recent work has been with Cataclysmic Variables.

Useful for EB solutions; will demonstrate.

Spectroscopic capability developed with I. Hubeny.
Uses TLUSTY and Synspec.

Public version under development.

Background

Initial version in 1984, ApJS, 54, 17

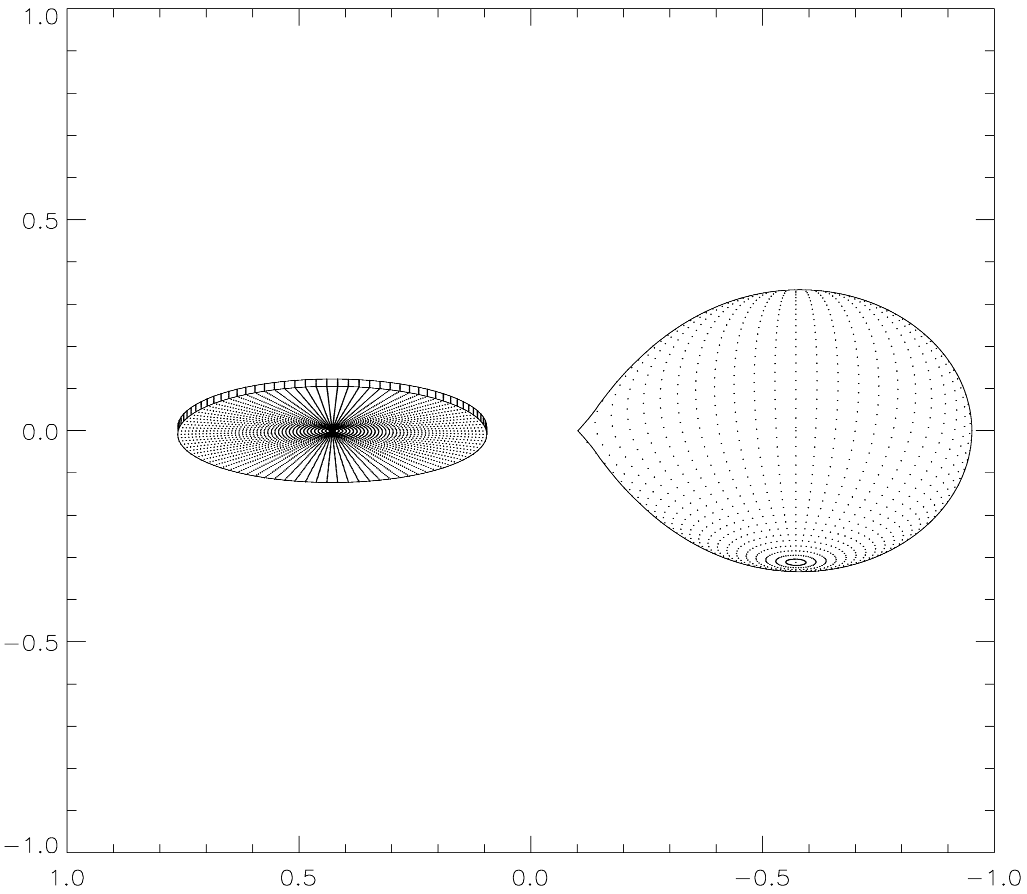
Added differential corrections capability 1989, ApJ, 342, 449

Added spectrum synthesis capability 1994, ApJ, 434, 738
(with I. Hubeny)

Added simulation of accretion disks: 1996, ApJ, 471, 958
(with I. Hubeny)

An accretion disk system

The secondary star fills its Roche lobe.



Some program features

Photosphere representations either by black bodies or synthetic spectra.

Assign absolute flux value to each photosphere segment.

(Either monochromatic (black body) or by wavelength.)

In effect, attach limb darkened, Doppler shifted synthetic spectrum to each photosphere segment (synthetic spectrum option).

Differential corrections light curve optimization on either the black body approximation or the synthetic spectra model.
(EB model.)

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Illustrations of application

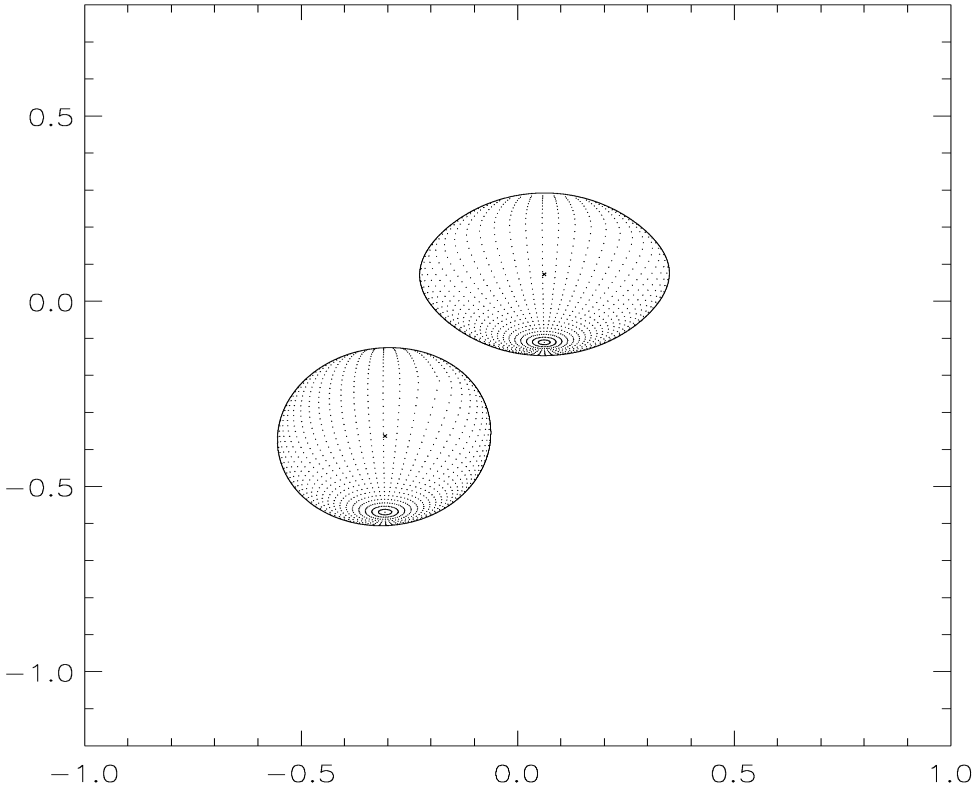
V306 Lacertae

No eclipses, no accretion disk, primary component near critical rotation.

Linnell, et al., 2006, A&A, 455, 1037

V360 Lac at orbital phase 0.44

Note the rotational distortion of the primary component.



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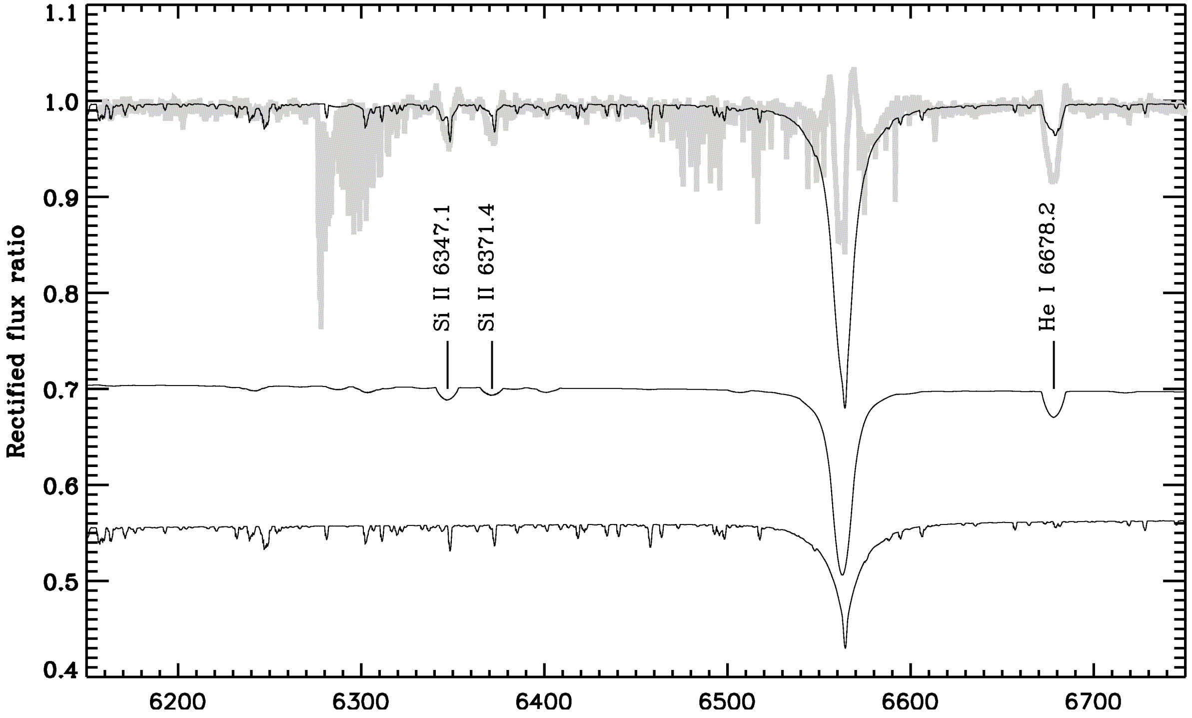
V360 Lac

Note the rotational broadening of the primary component lines in the middle spectrum.



Illustrations of application

WX LMi, a CV system with magnetically-controlled direct impact of the mass transfer stream on the White Dwarf.

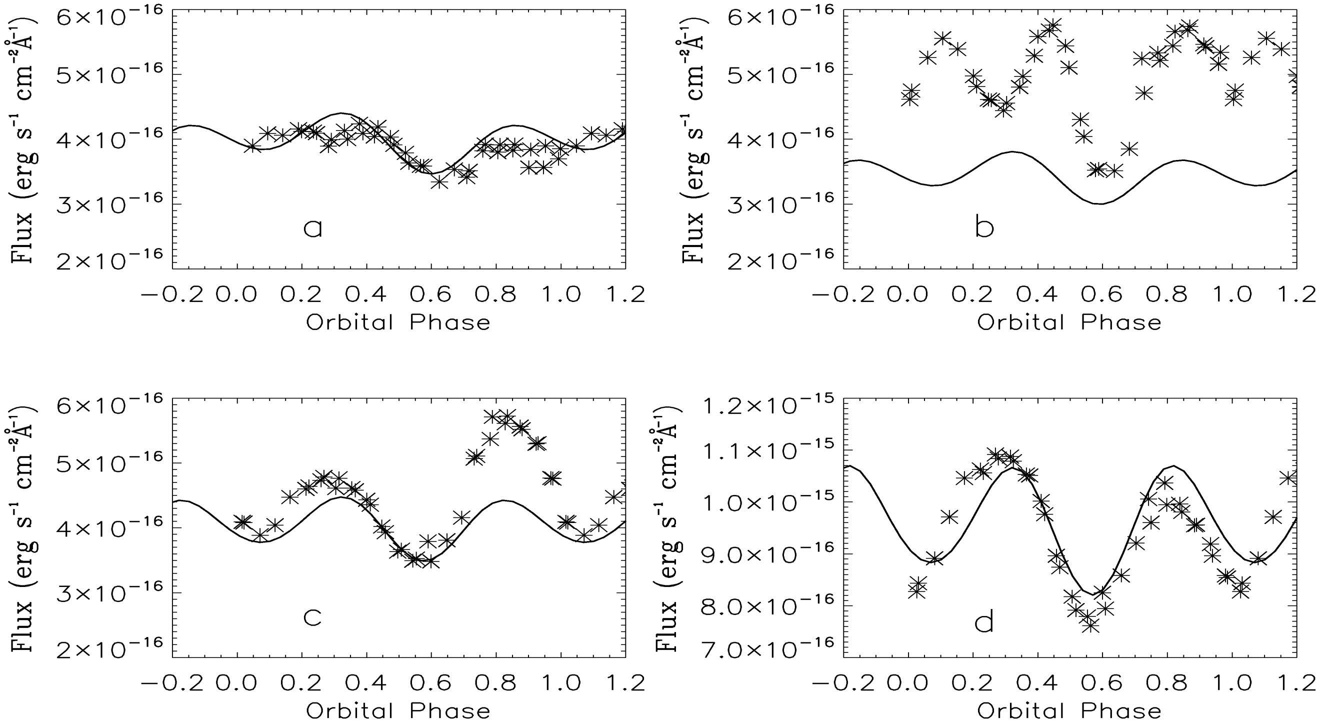
UV and NUV light curves from two hot spots at magnetic poles.

B,V,R,I light curves result from rotation of distorted secondary.

Cyclotron emission contributes significantly.

Linnell, et al., 2010, ApJ, 713, 1183

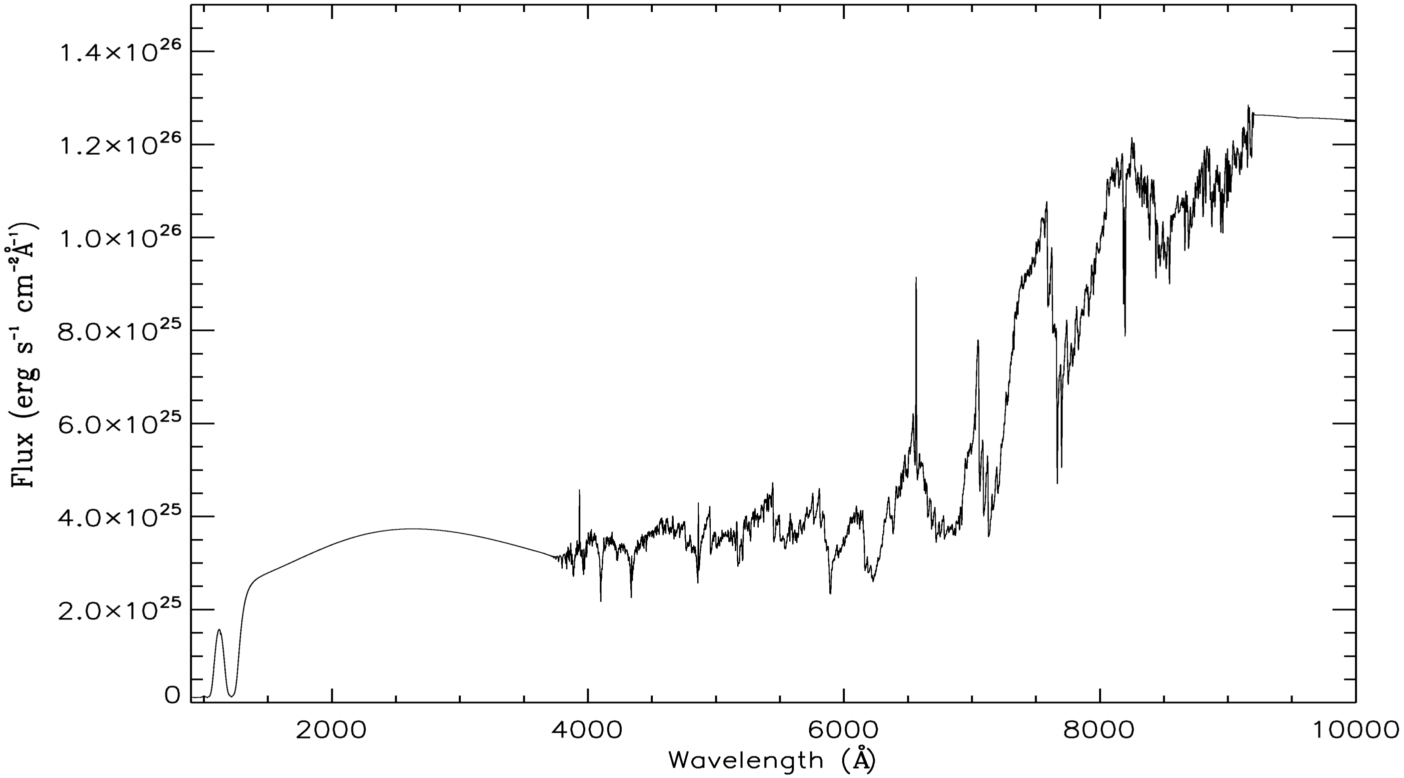
WX LMi synthetic photometry light curves



a= B lt. cve.; b=V lt. cve.; c=R lt. cve.; d=I lt.cve.

The V light curve is strongly affected by cyclotron emission.

WX LMi synthetic spectrum



The 7900K WD spectrum dominates shortward of 4000 A, the 3300K secondary longward (MARCS spectrum).

Revival of EB differential corrections solution.

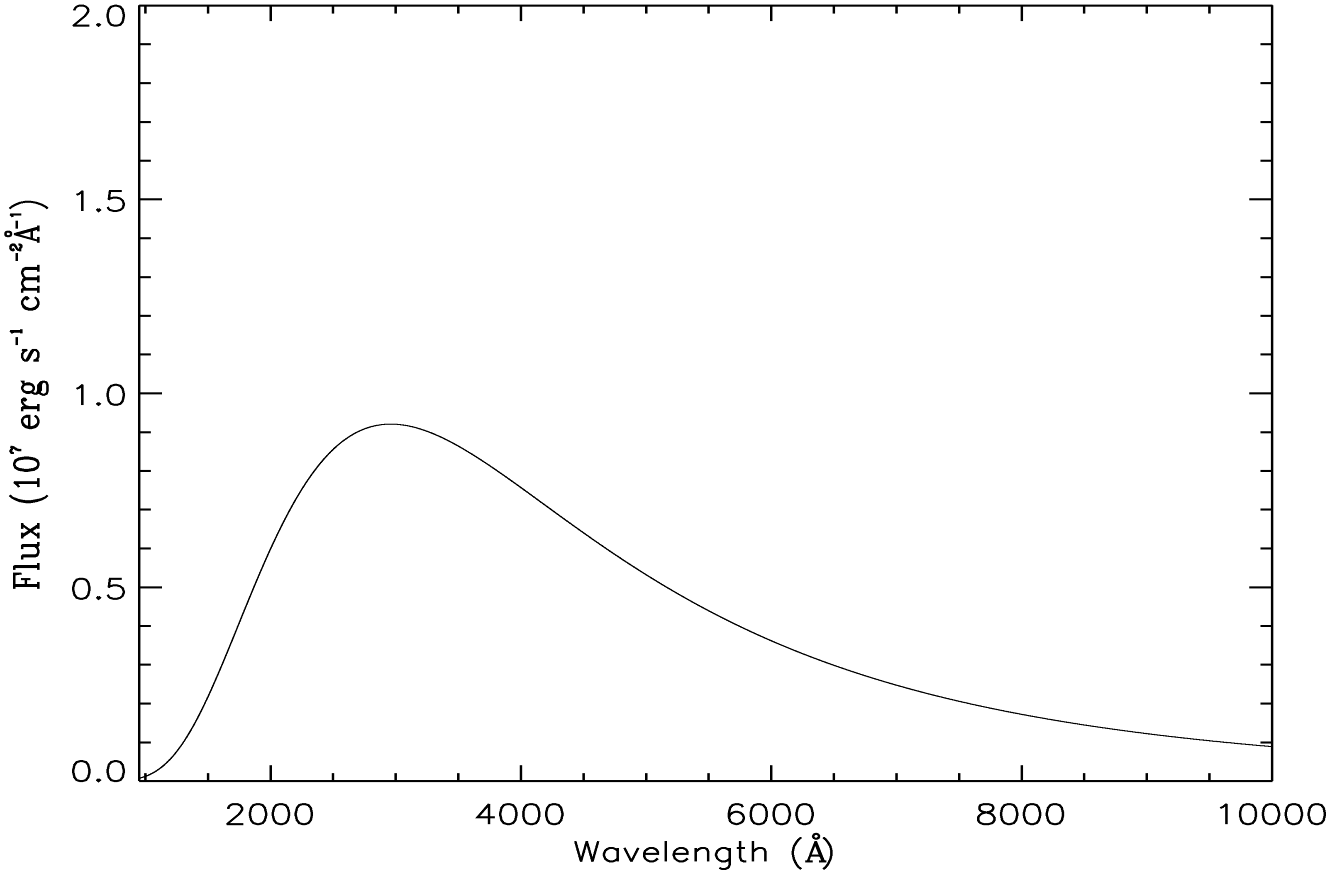
Original version used black body representation.

Poor representation of actual radiation characteristics.

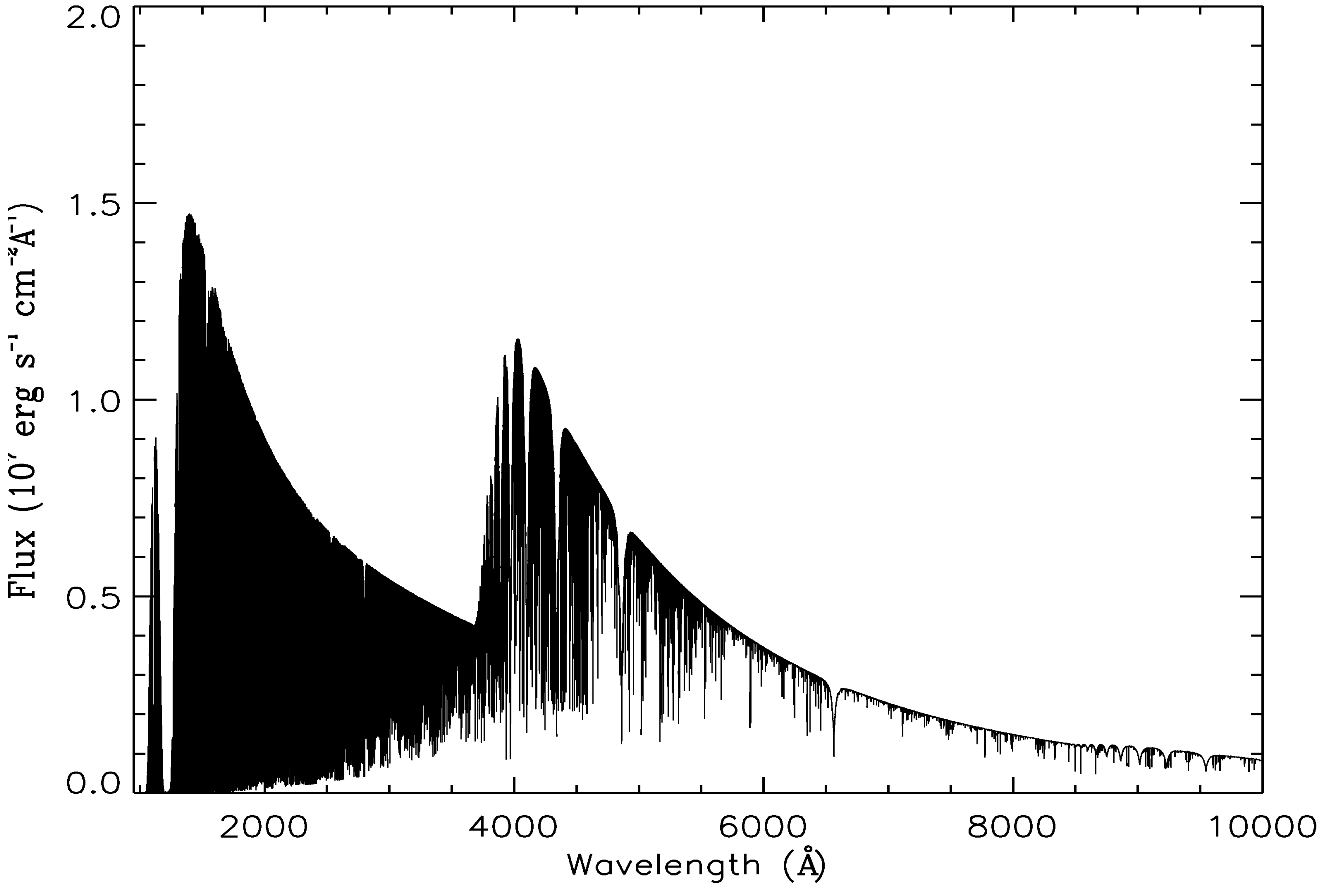
Develop solution procedure based on synthetic spectra.

Test procedure with simulated observational data.

9790 K black body

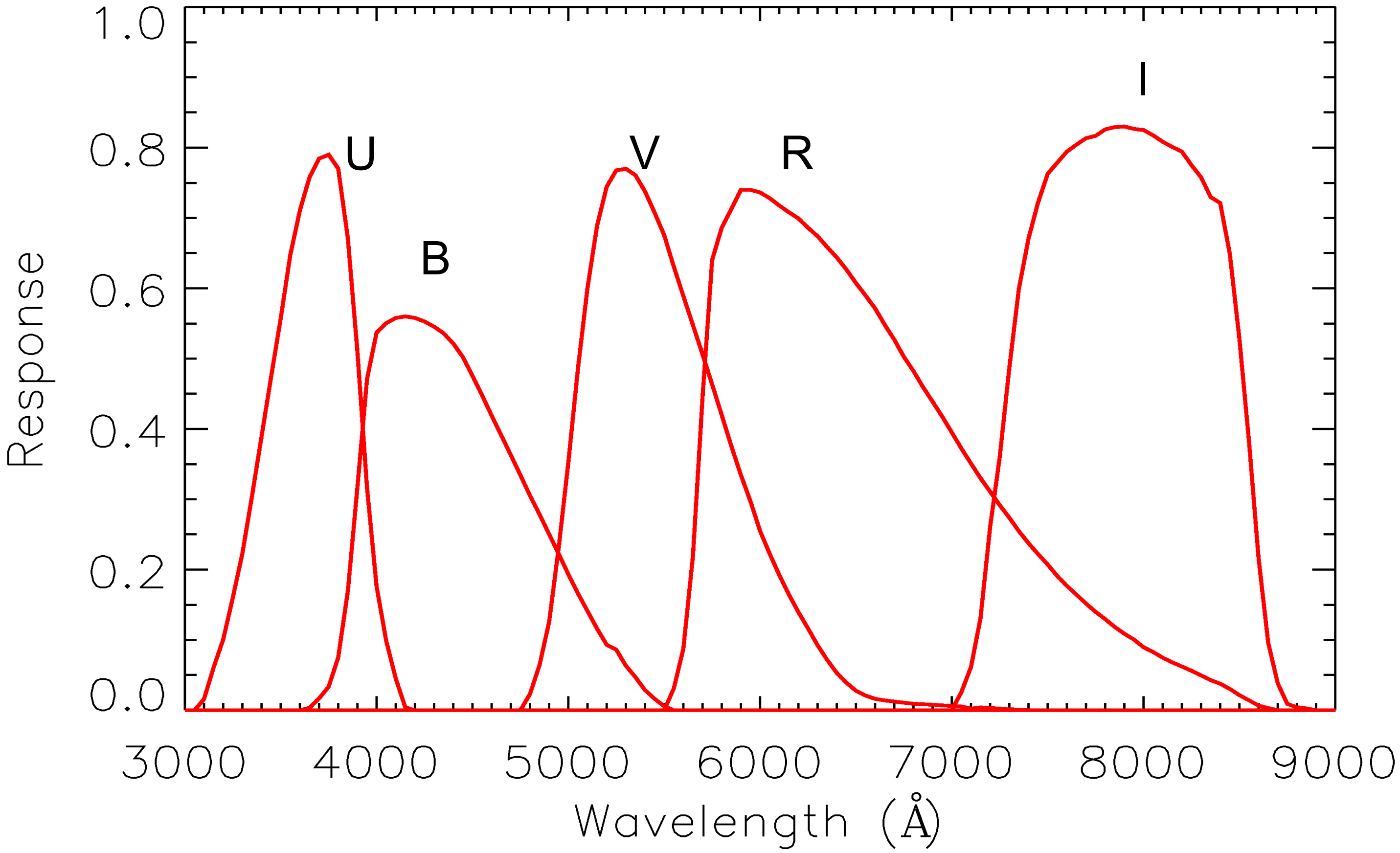


Teff=9750, log g =4.5

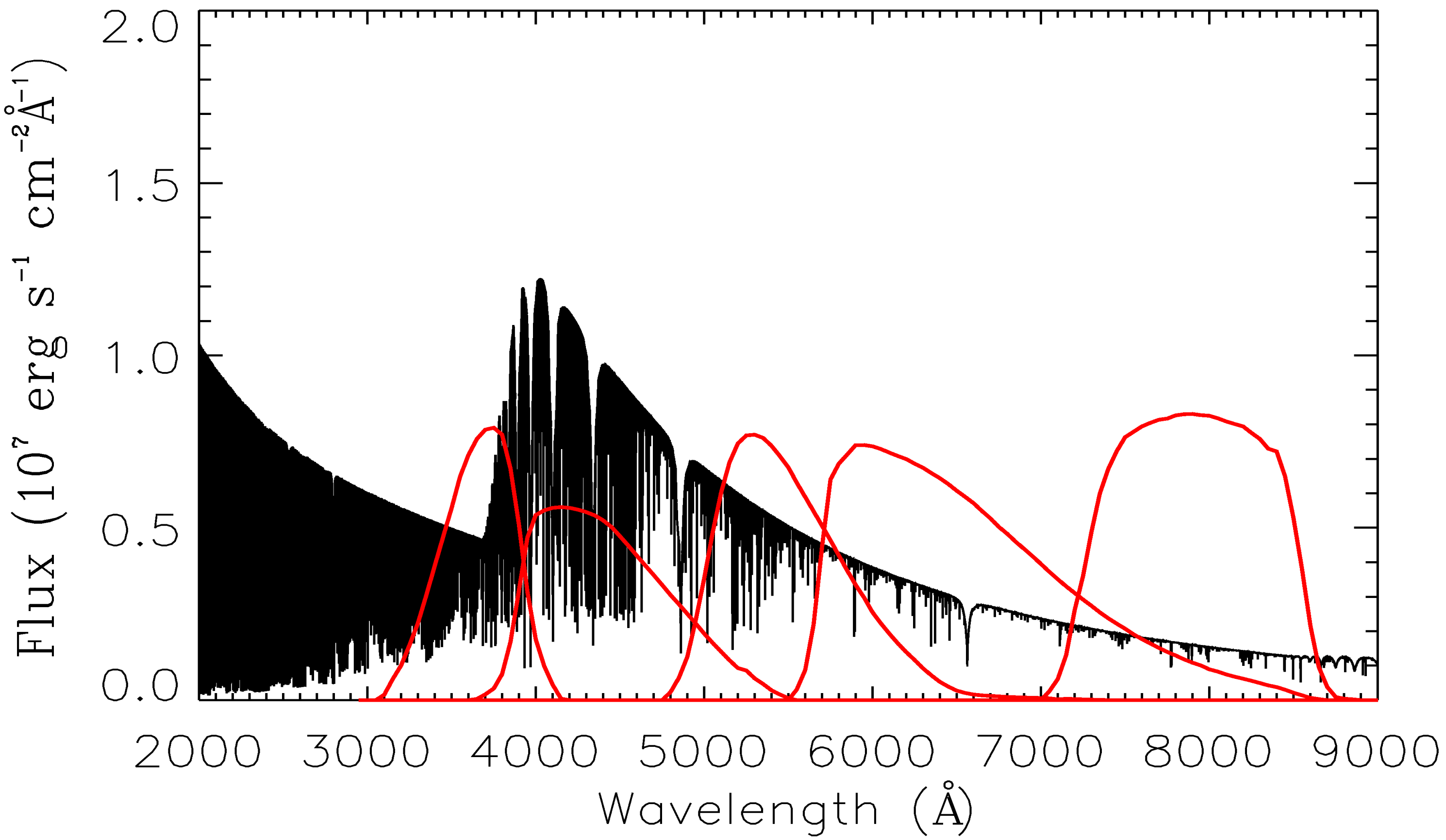


U,B,V,R,I RESPONSE CALIBRATION

Bessell,1976,PASP,88,557



Synthetic photometry illustration



A hypothetical binary system

A0,Teff(pole)=9790K

Ω1=4.4

F5,Teff(pole)=6650K

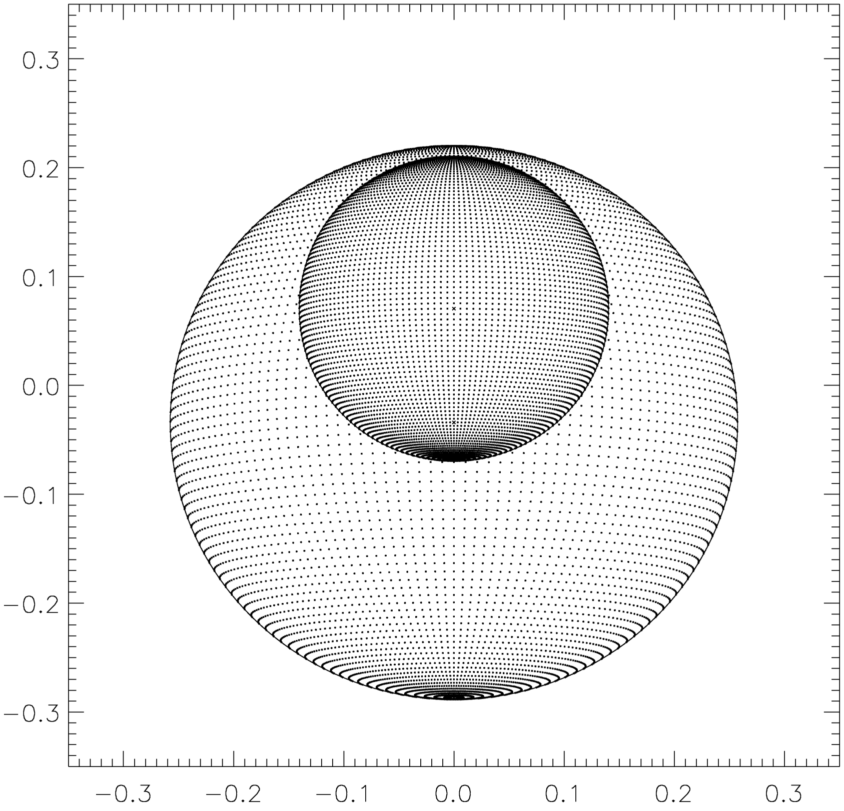
Ω2=4.7

M1=2.9M(sun)

M2=1.4M(sun)
P=1.5 days
i=84 deg.

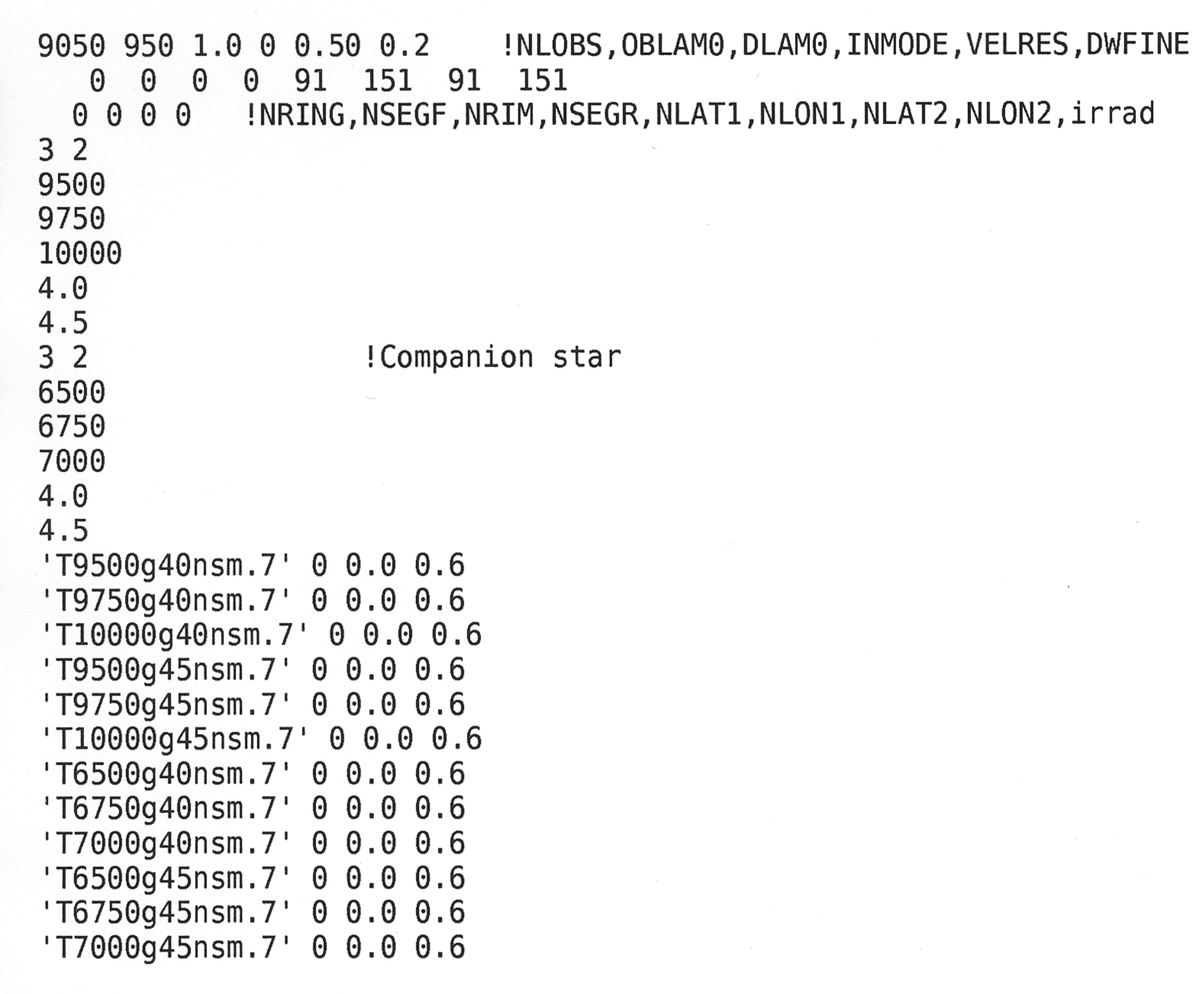
e=0.0

Projected view at phase 0.0



91 colatitudes, 151 longitudes on each component.

Interface to SYNSPEC



```
9050 950 1.0 0 0.50 0.2    !NLOBS,OBLAM0,DLAM0,INMODE,VELRES,DWFINE
   0  0  0  0  91  151  91  151
  0 0 0 0   !NRING,NSEGF,NRIM,NSEGR,NLAT1,NLON1,NLAT2,NLON2,irrad
3 2
9500
9750
10000
4.0
4.5
3 2                 !Companion star
6500
6750
7000
4.0
4.5
'T9500g40nsm.7' 0 0.0 0.6
'T9750g40nsm.7' 0 0.0 0.6
'T10000g40nsm.7' 0 0.0 0.6
'T9500g45nsm.7' 0 0.0 0.6
'T9750g45nsm.7' 0 0.0 0.6
'T10000g45nsm.7' 0 0.0 0.6
'T6500g40nsm.7' 0 0.0 0.6
'T6750g40nsm.7' 0 0.0 0.6
'T7000g40nsm.7' 0 0.0 0.6
'T6500g45nsm.7' 0 0.0 0.6
'T6750g45nsm.7' 0 0.0 0.6
'T7000g45nsm.7' 0 0.0 0.6
```

Generation of model light curves

For each orbital longitude, require 9000 flux values for each of 12 synthetic spectra (1 Angstrom spacing).

Interpolate flux value to each of ~13,000 photospheric segments on each component.

Calculate synthetic system spectrum for 101 orbital longitudes.

Light curve generation, cont.

Why 101 orbital longitudes?

- 10 between pri. min. first contact and second contact.
- 10 between second and third contacts.
- 10 between third and fourth contacts.
- 5 between fourth contact and maximum elongation, etc.

Important stage: have 101 system synthetic spectra stored.

Calculate corresponding synthetic photometry U,B,V,R,I values.

Important point: can switch to other photometric system by substituting alternate calibrated filter pass bands.

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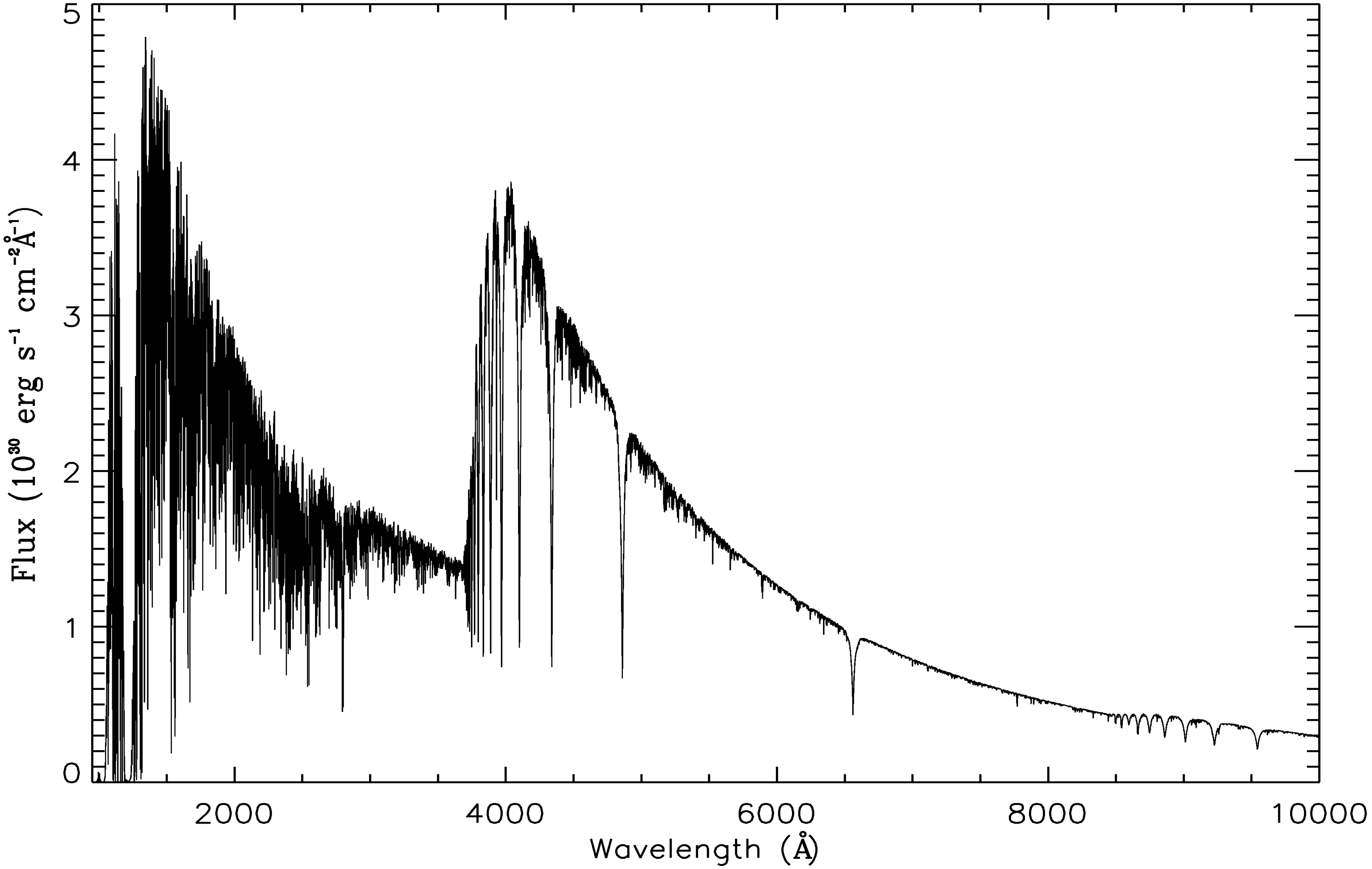
A sample system synthetic spectrum.



Production of “observed” U,B,V,R,I light curves

Generate light curve for specified set of parameters.

By interpolation, produce additional “observations” .

Modulate observations by noise of specified σ.

In separate program, add individual weights.

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“Observed” light curve parameters

2602 observations in each of U,B,V,R,I bands.

Each light curve has observational noise of 0.0001 magnitude.
(Ballpark of CoRoT and Kepler observations.)

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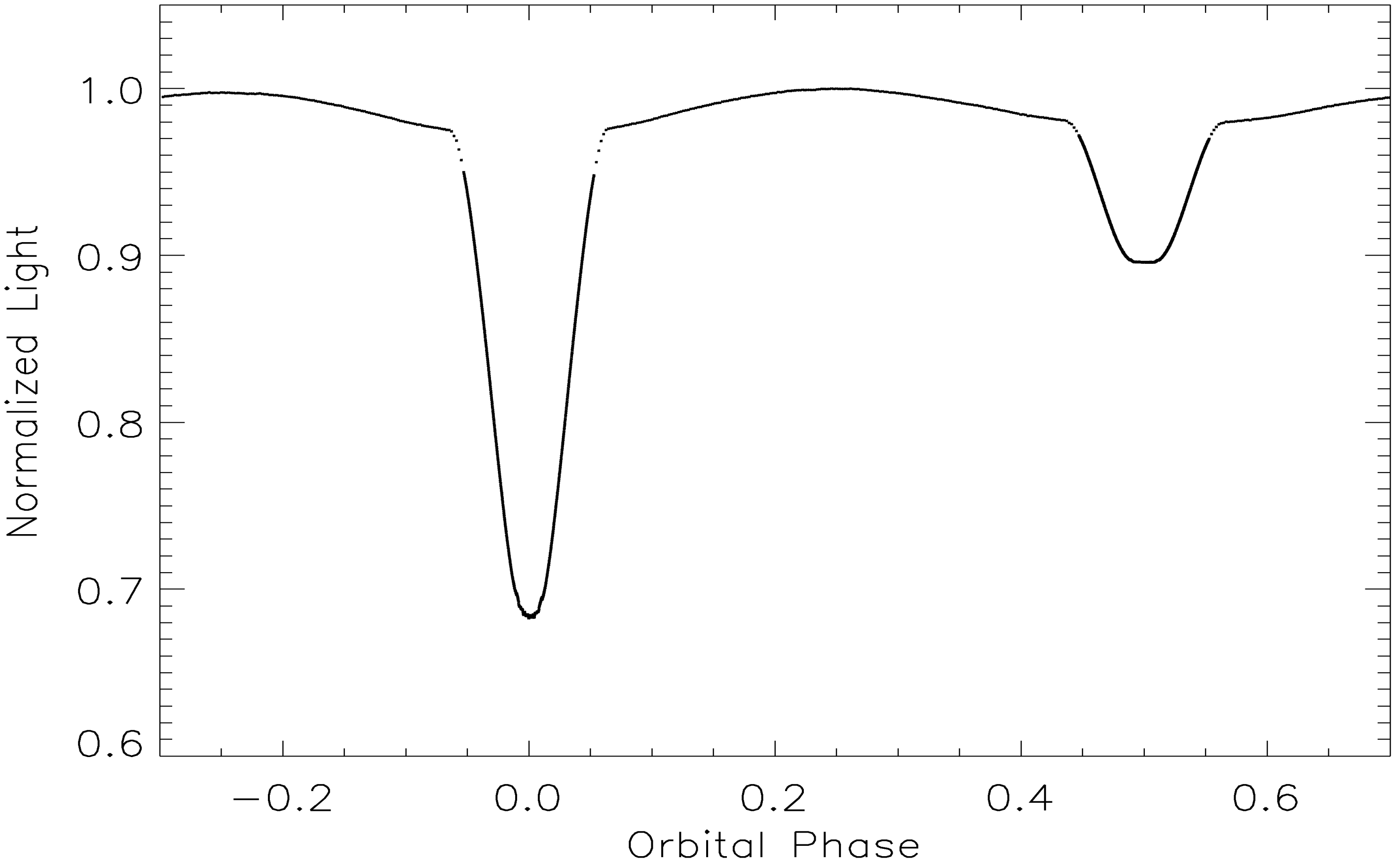
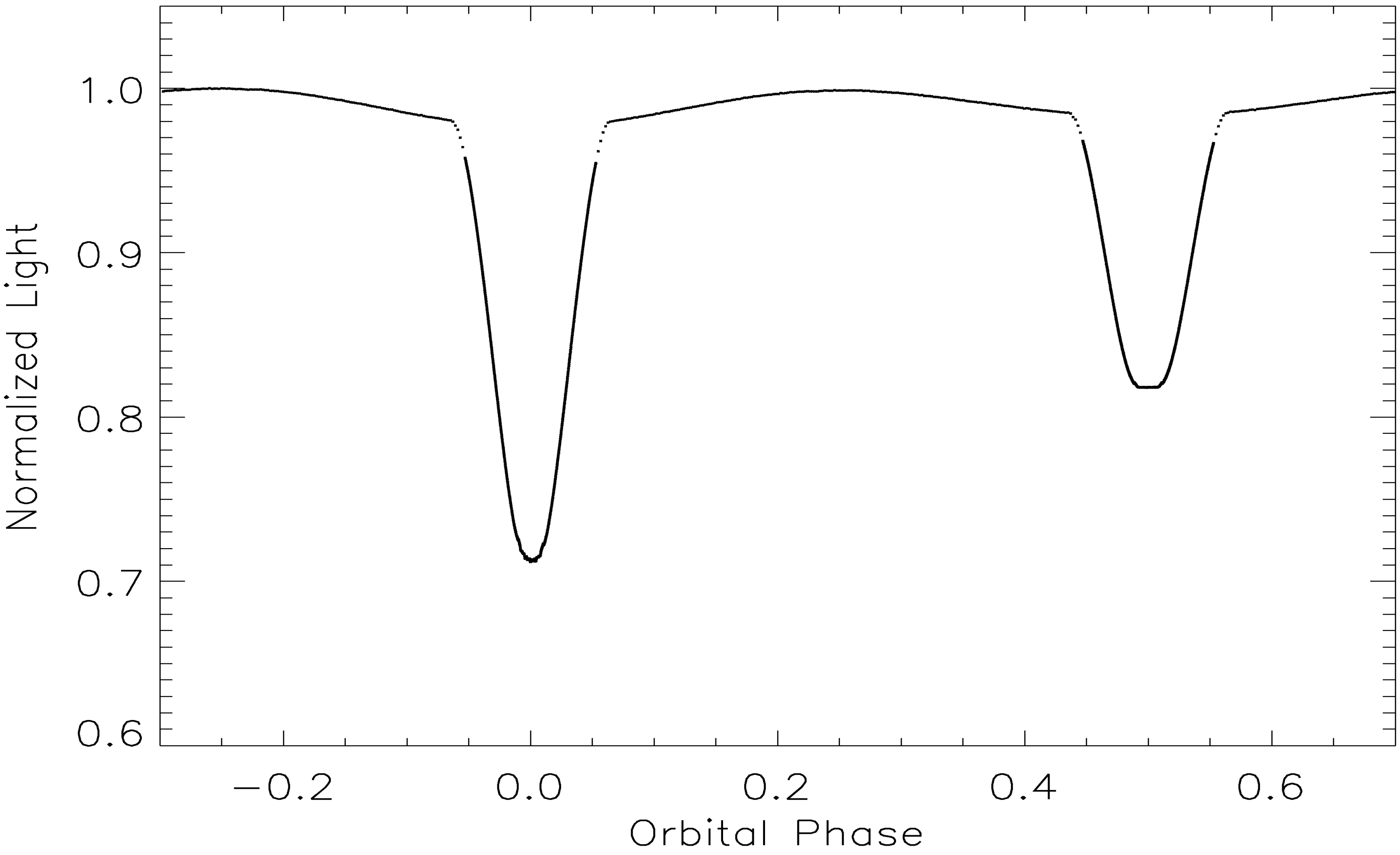
U light curve, simulated data



I light curve, simulated data



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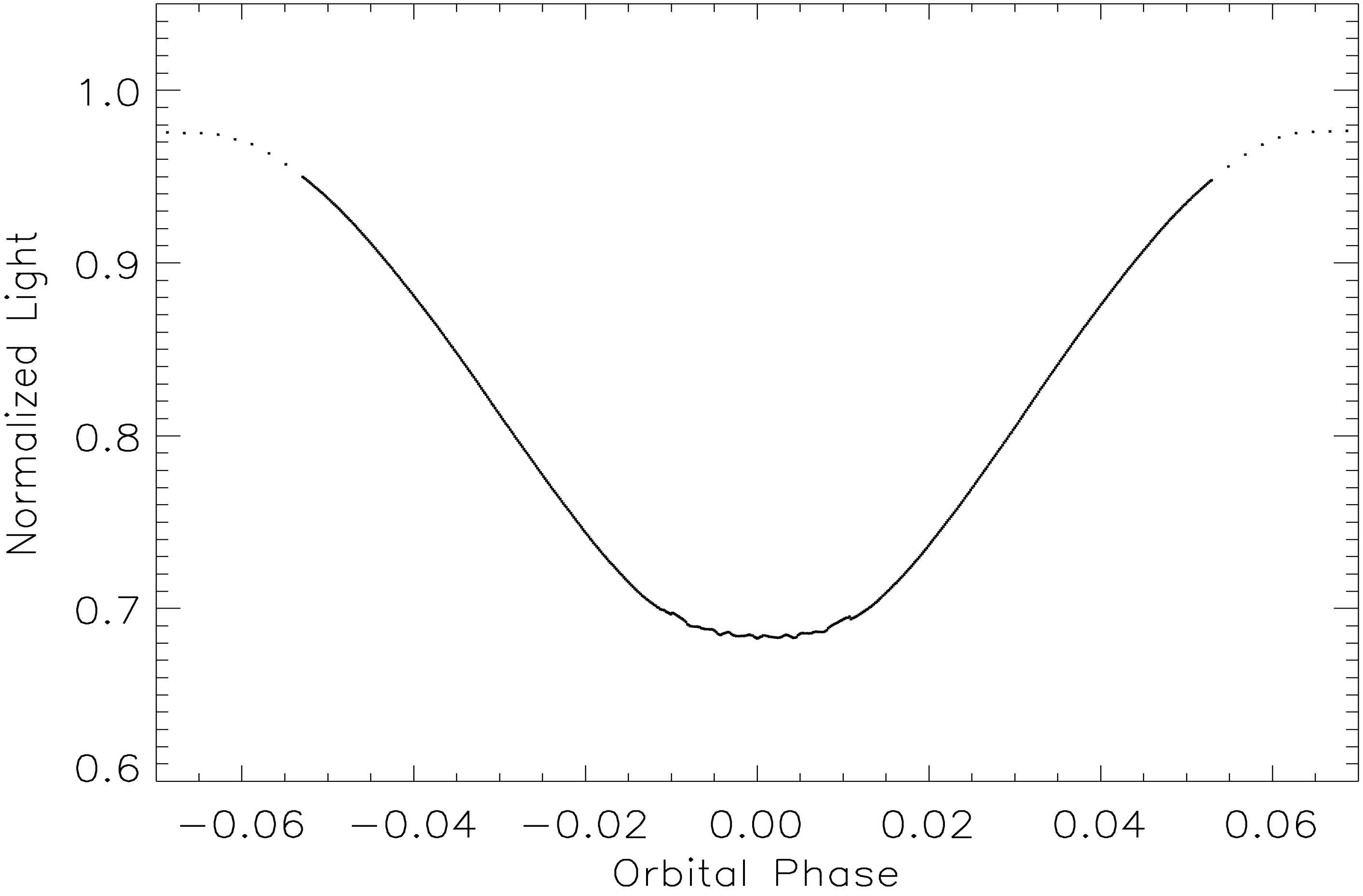
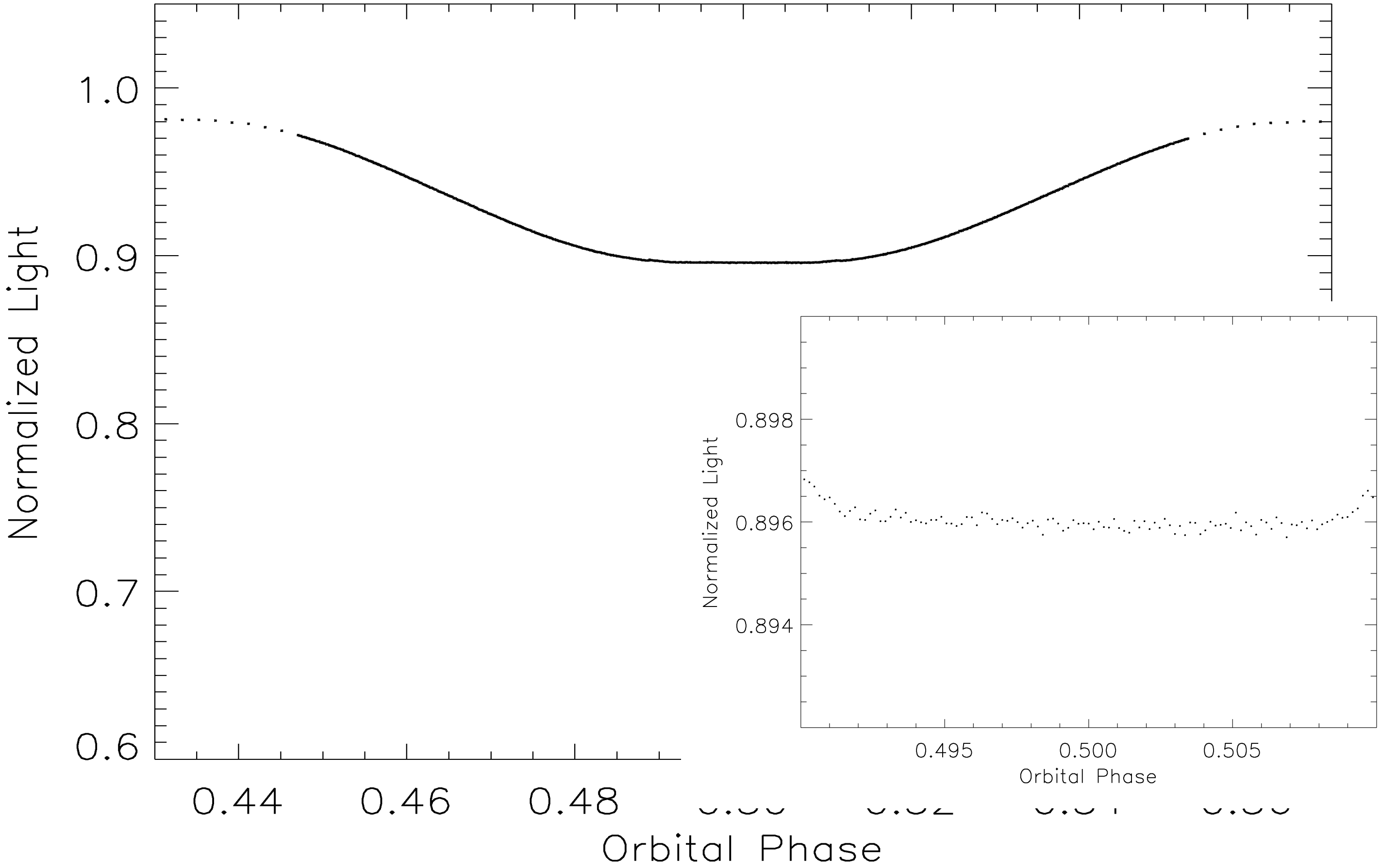
U light curve, primary minimum



U light curve, secondary minimum



Proof of differential corrections, Ω2

Ω2 (true)=4.7

Ω2 (assumed)=4.2

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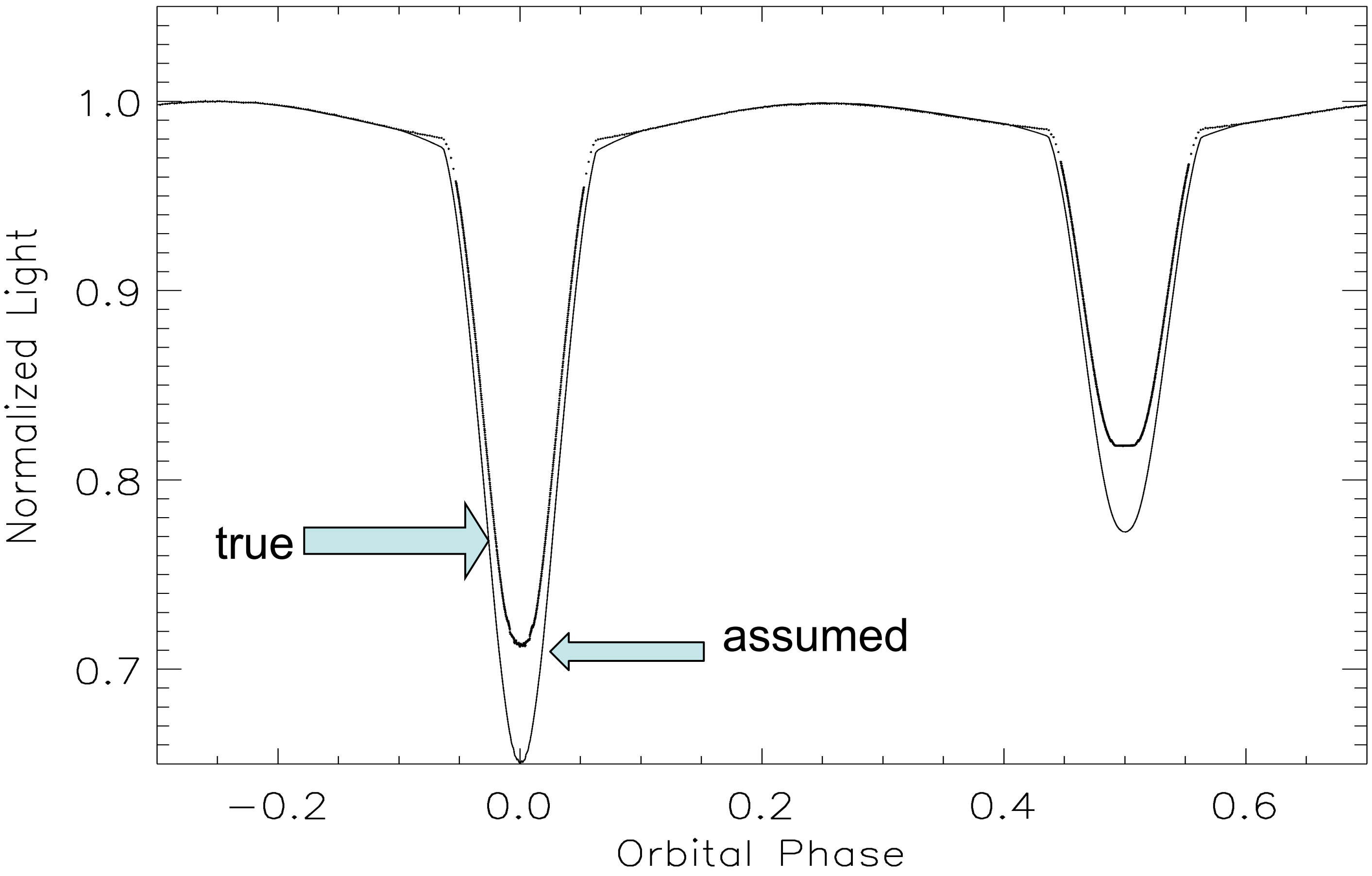
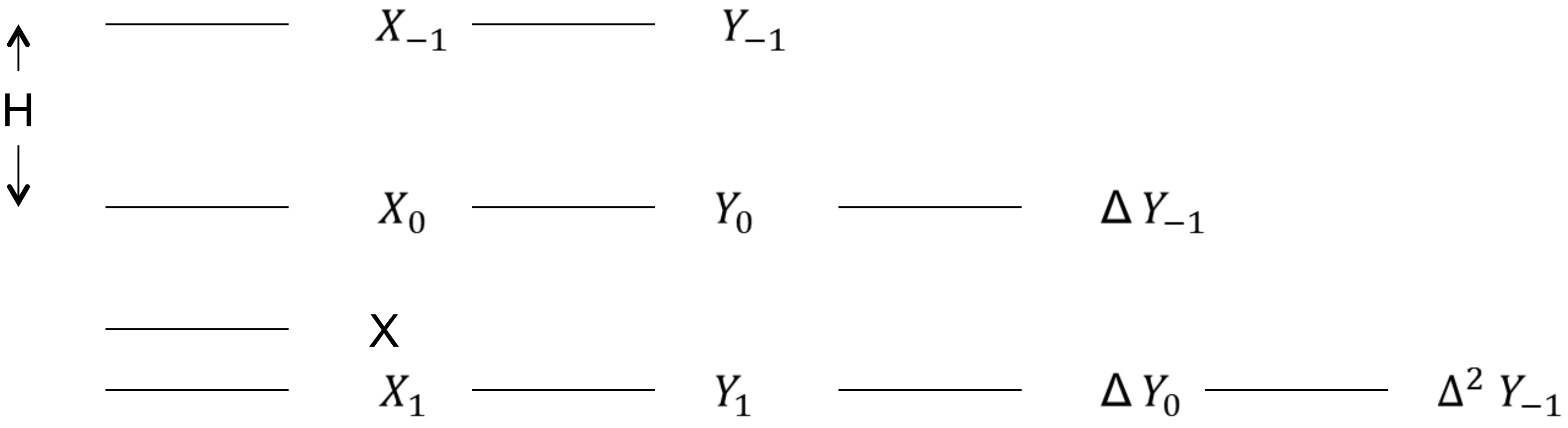
U light curve, true vs. assumed



Derivatives



H

X_{-1} Y_{-1}

X_0 Y_0 $\Delta\, Y_{-1}$

X

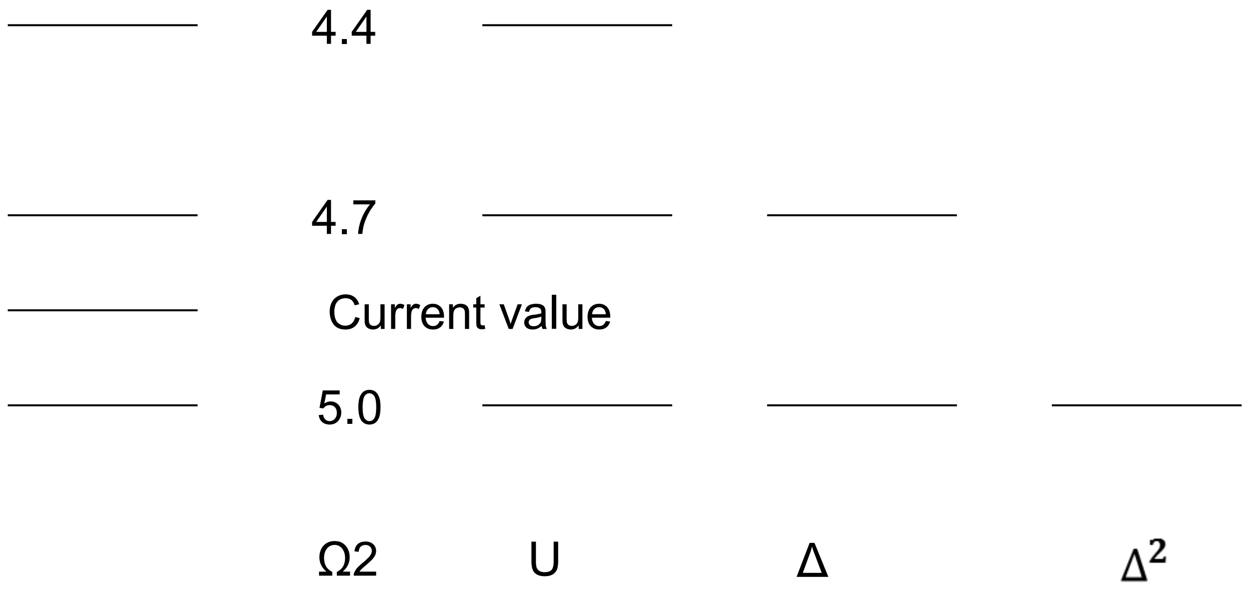
X_1 Y_1 $\Delta\, Y_0$ $\Delta^2\, Y_{-1}$

$$\boldsymbol{u = \frac{x - x_0}{H}}$$

$$\frac{dy}{dx} = \frac{\mathbf{1}}{\boldsymbol{H}}\left[\frac{\Delta \boldsymbol{y}_{-\mathbf{1}} + \Delta \boldsymbol{y}_{\mathbf{0}}}{\mathbf{2}} + \boldsymbol{u}\Delta^{\mathbf{2}}\boldsymbol{y}_{-\mathbf{1}} \quad \ldots\right]$$

Stirling’s equation

Example, Ω2



4.4

4.7

Current value

5.0

Ω2

U

Δ

Δ^2

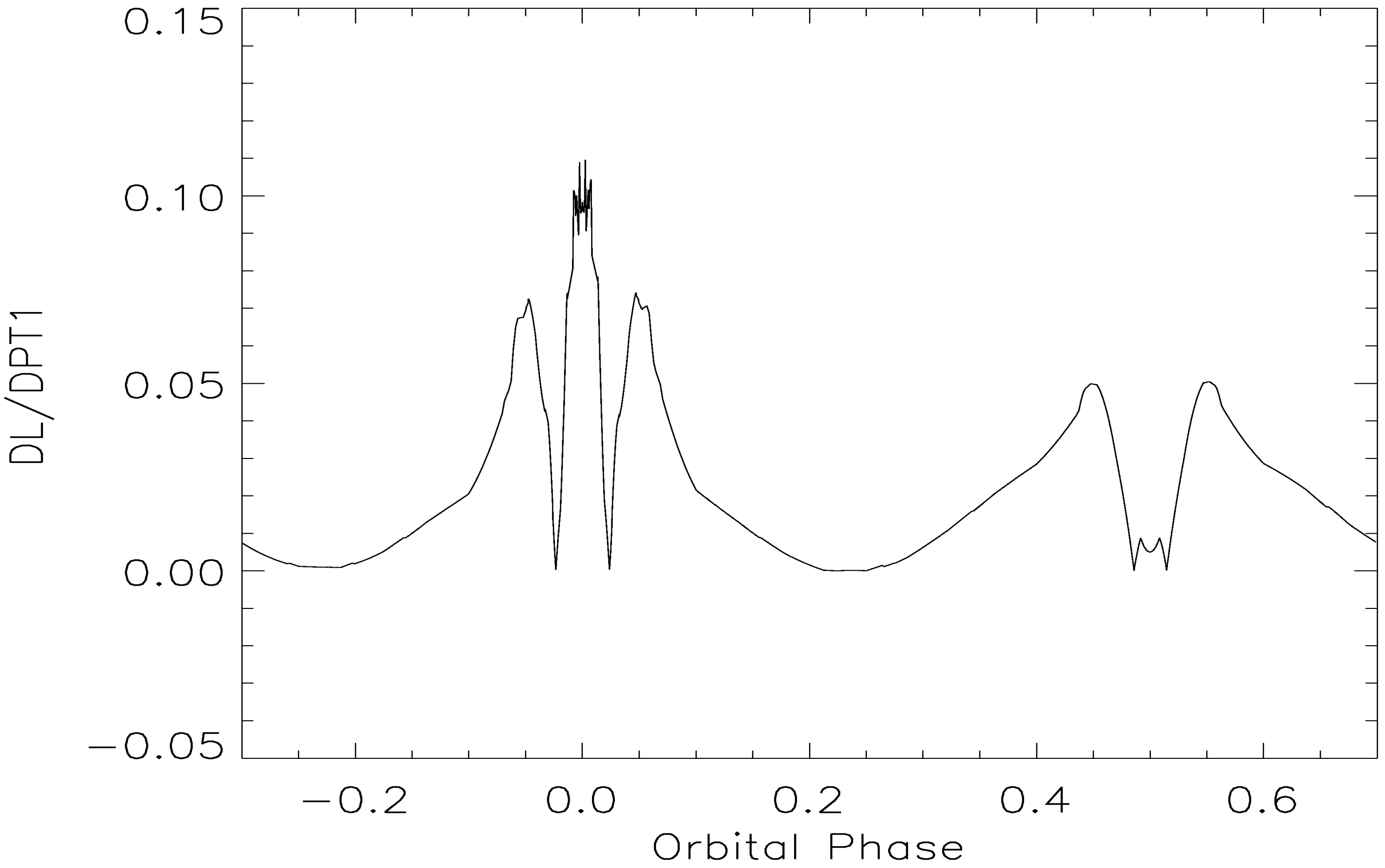
B

V

R

I

Derivative, DL/DPT1



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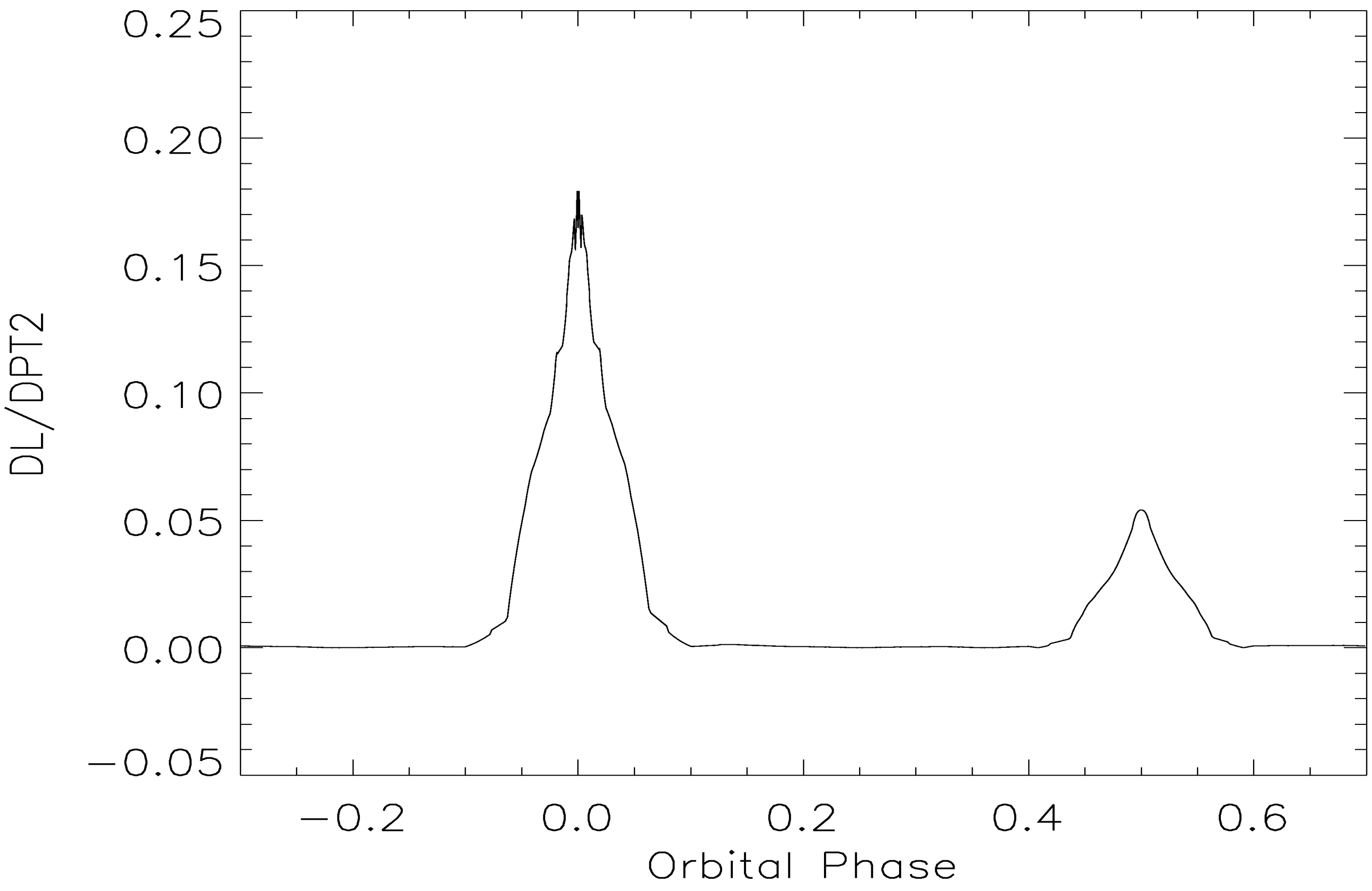
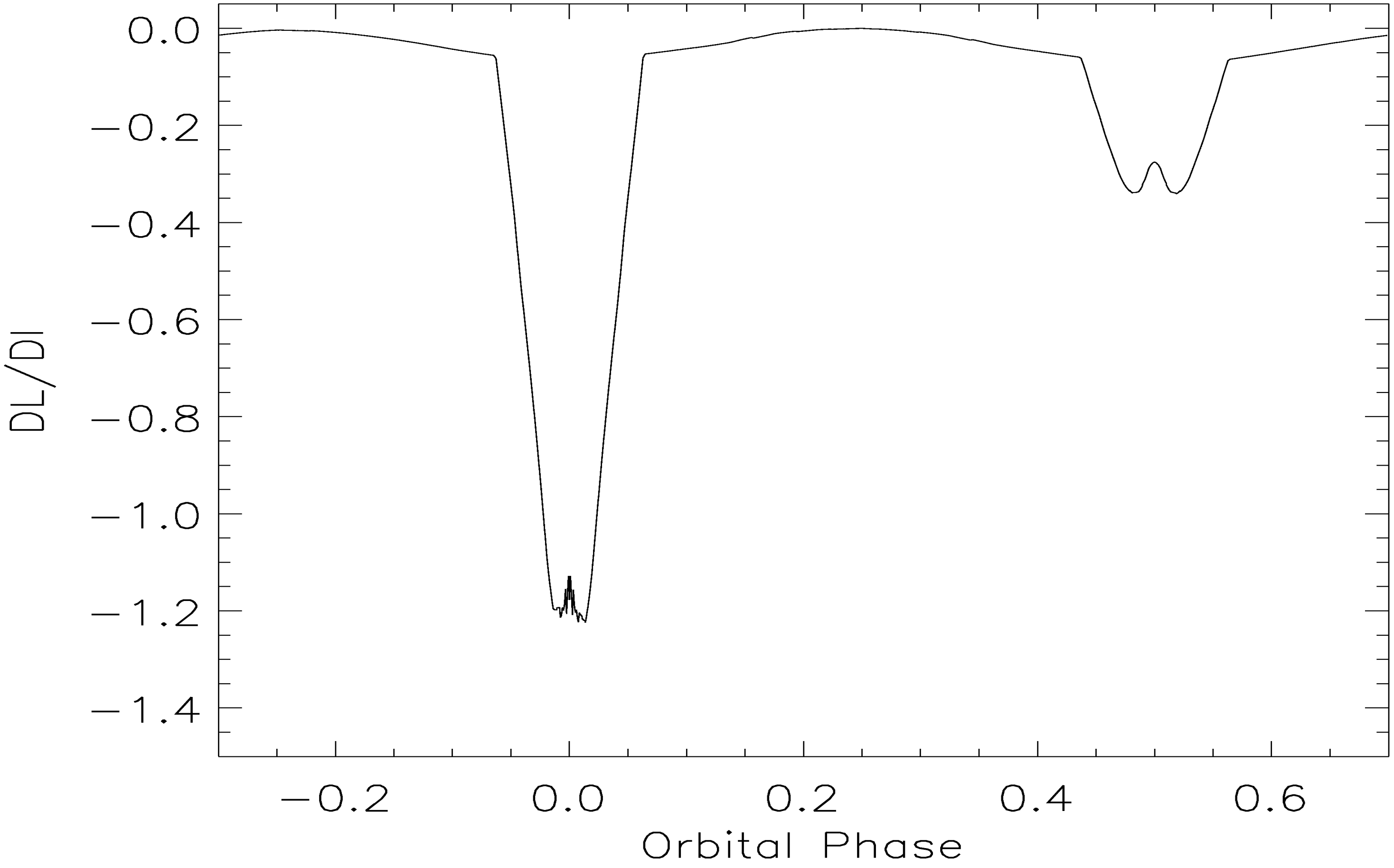
Derivative, DL/DPT2



Derivative, DL/DI



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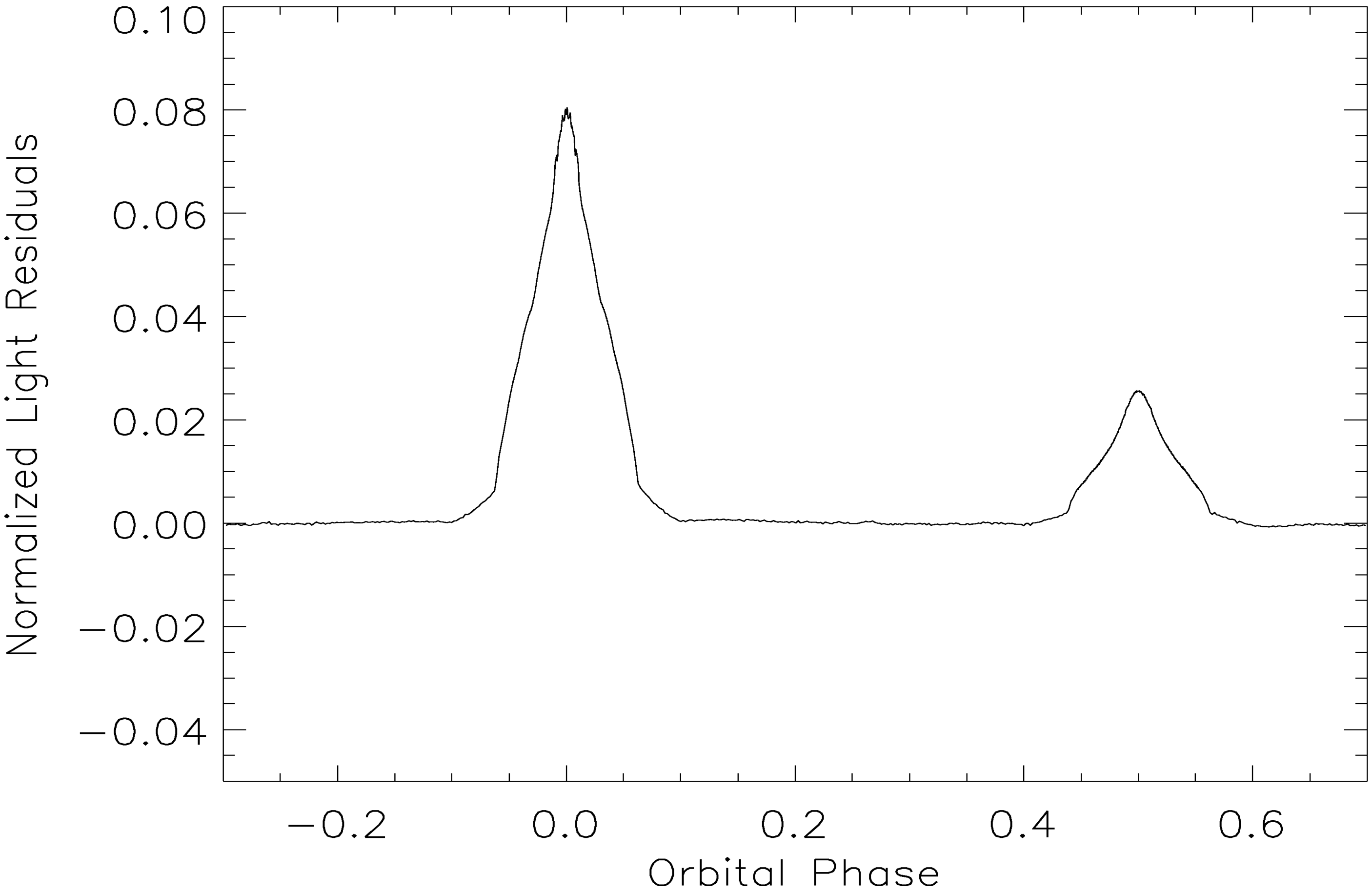
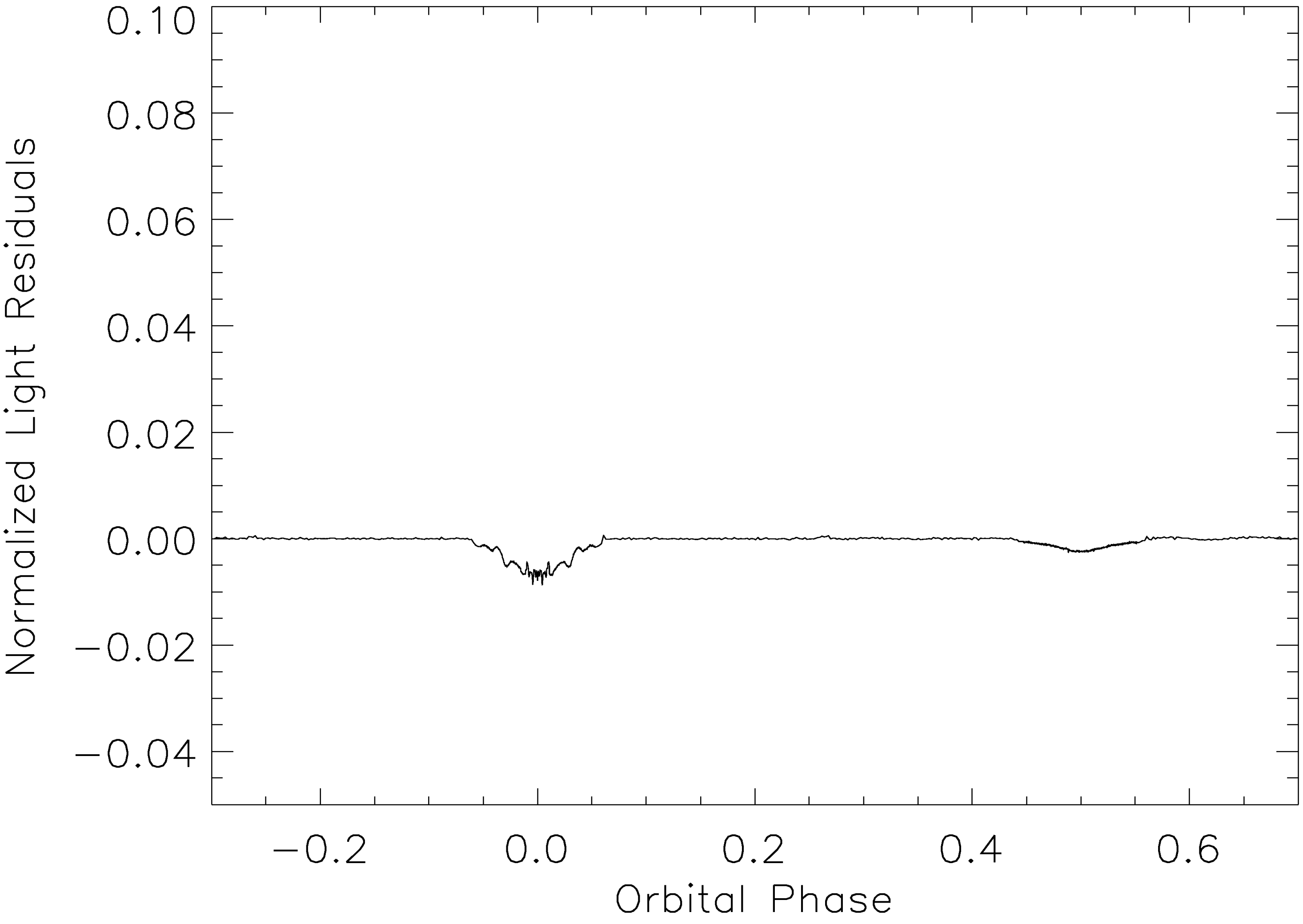
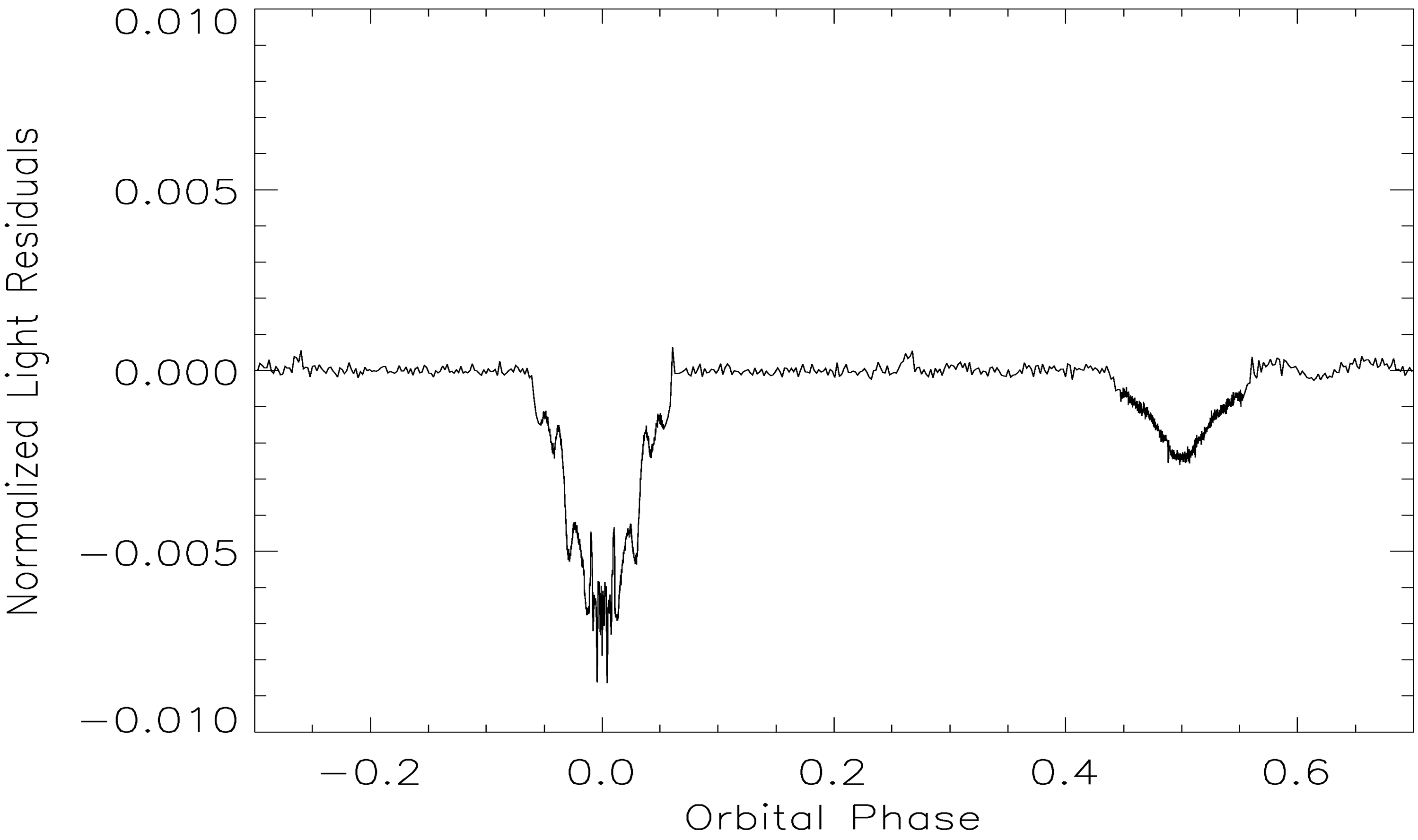
U residuals, initial approximation



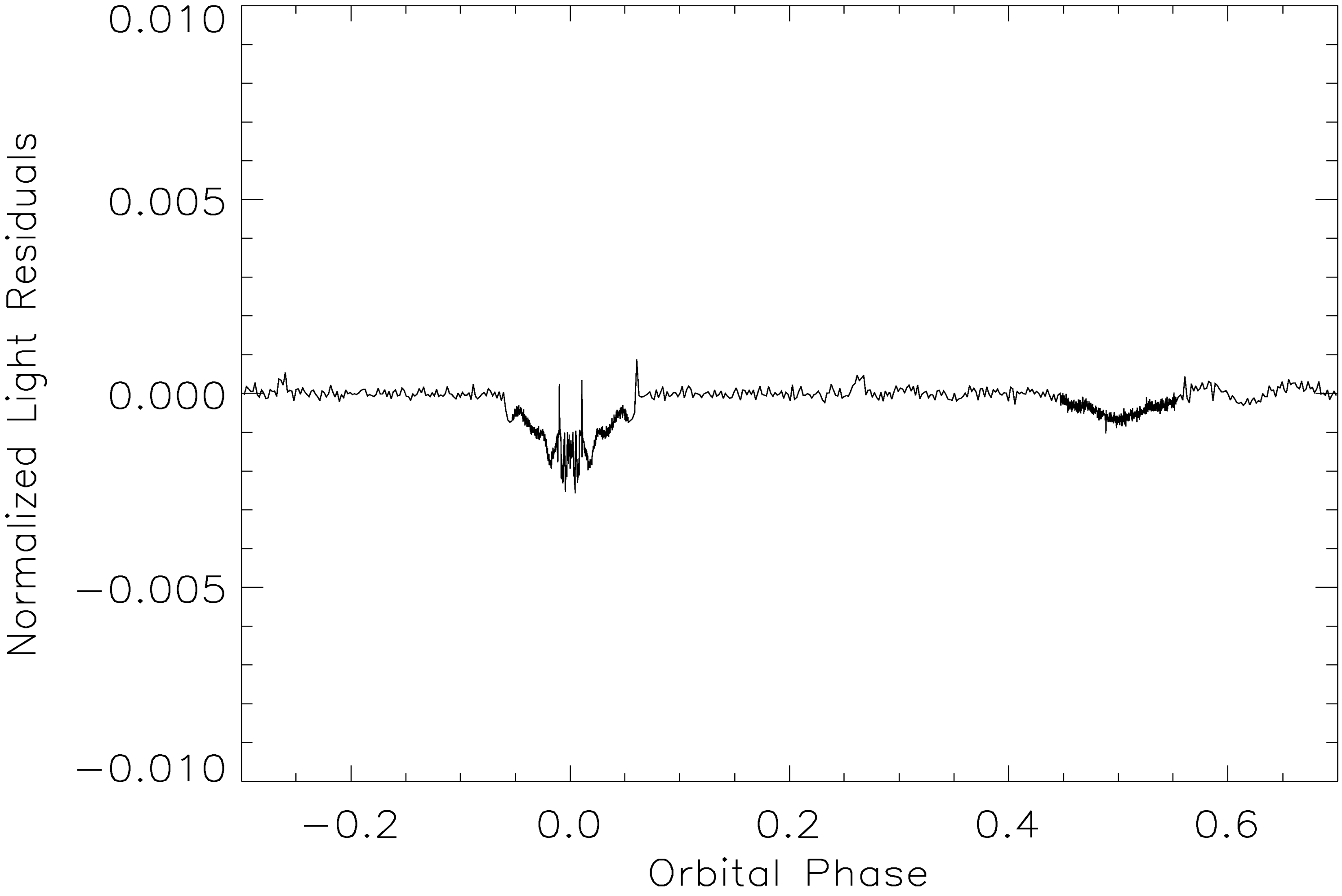
U residuals, iteration #1



U residuals, iteration #1



U residuals, iteration #2



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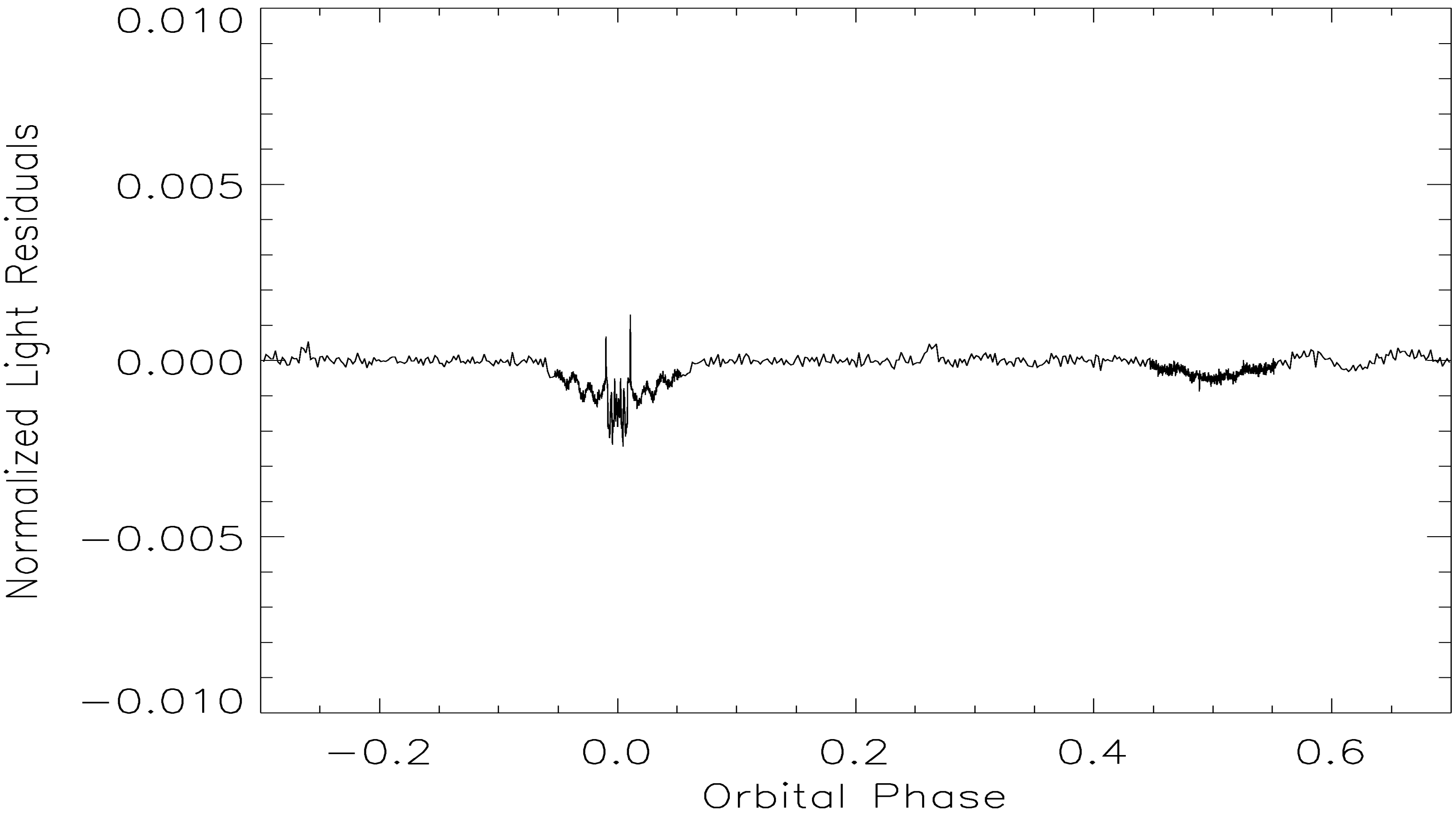
U residuals, iteration #3



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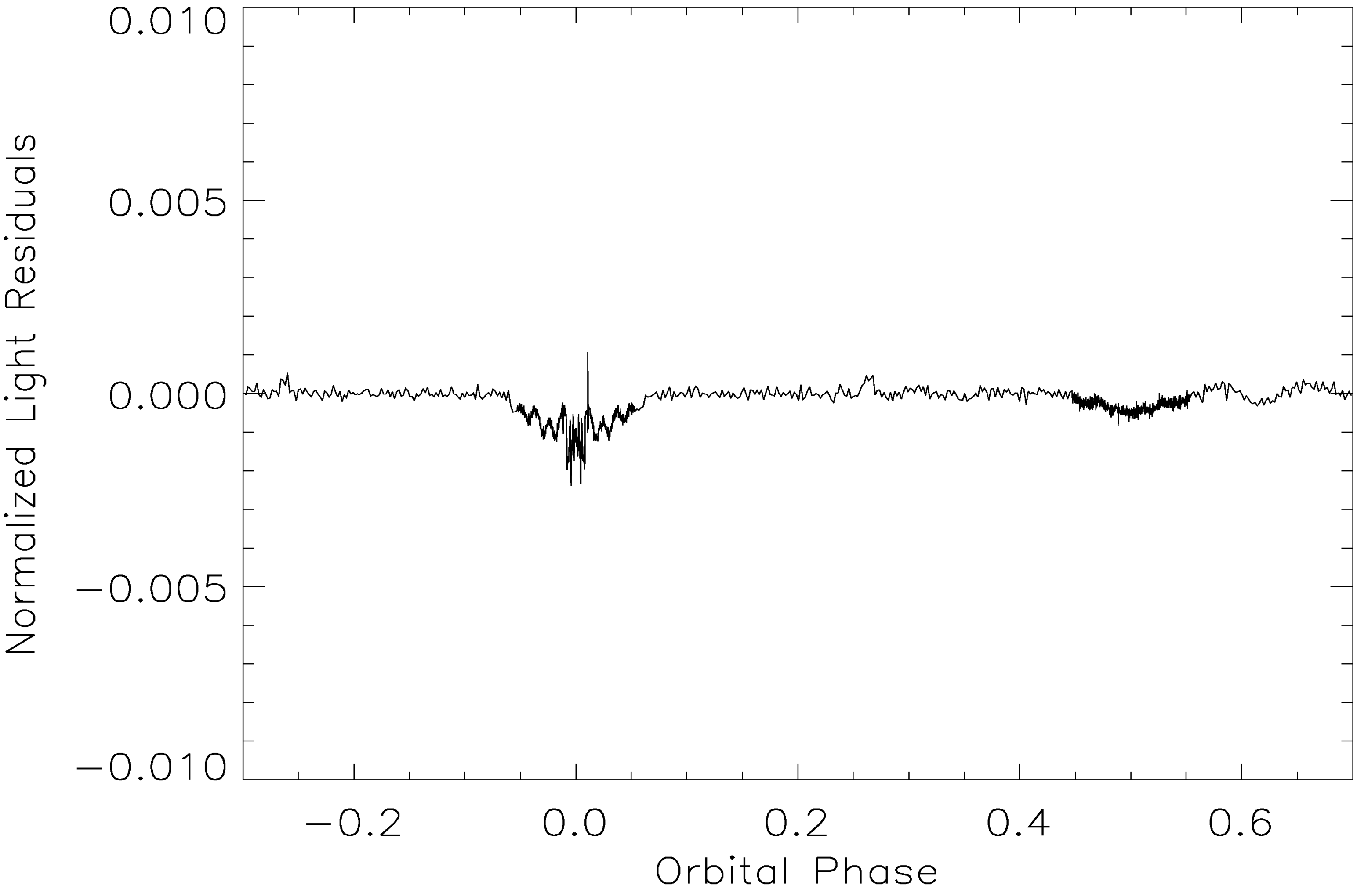
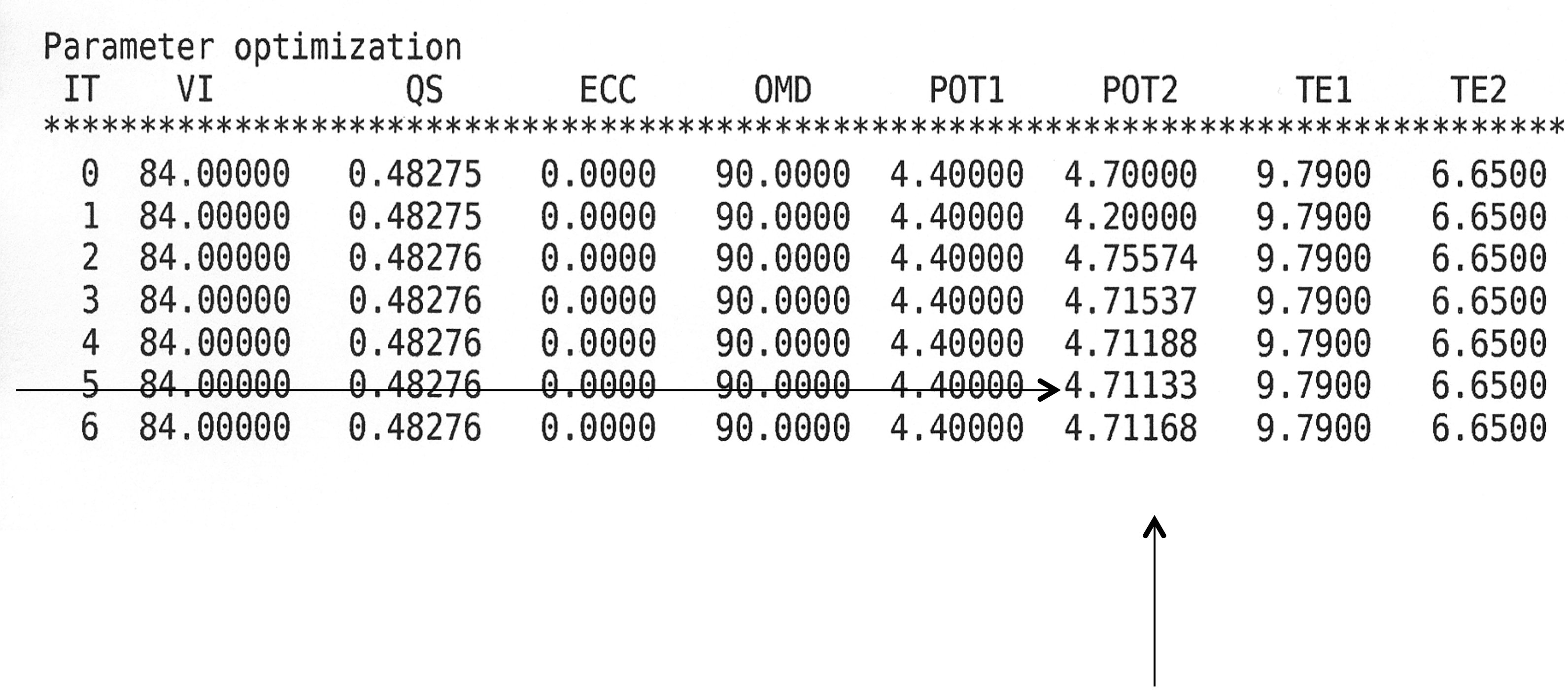
U residuals, iteration #4



Log of optimization



```
Parameter optimization
 IT    VI          QS        ECC       OMD       POT1      POT2       TE1      TE2
********************************************************************************
  0  84.00000   0.48275   0.0000   90.0000  4.40000  4.70000   9.7900   6.6500
  1  84.00000   0.48275   0.0000   90.0000  4.40000  4.20000   9.7900   6.6500
  2  84.00000   0.48276   0.0000   90.0000  4.40000  4.75574   9.7900   6.6500
  3  84.00000   0.48276   0.0000   90.0000  4.40000  4.71537   9.7900   6.6500
  4  84.00000   0.48276   0.0000   90.0000  4.40000  4.71188   9.7900   6.6500
  5  84.00000   0.48276   0.0000   90.0000  4.40000  4.71133   9.7900   6.6500
  6  84.00000   0.48276   0.0000   90.0000  4.40000  4.71168   9.7900   6.6500
```

Evaluation

True value = 4.70000

Calc. value = 4.71133

Difference = 0.01133

Error = 0.3% in 4 iterations

Residuals may be controlled by representational accuracy of components.

Maximum residual ~0.001mag.

Formal solution, Ω1, Ω2, i

i(assumed) = 80 deg.

i(true) = 84 deg.

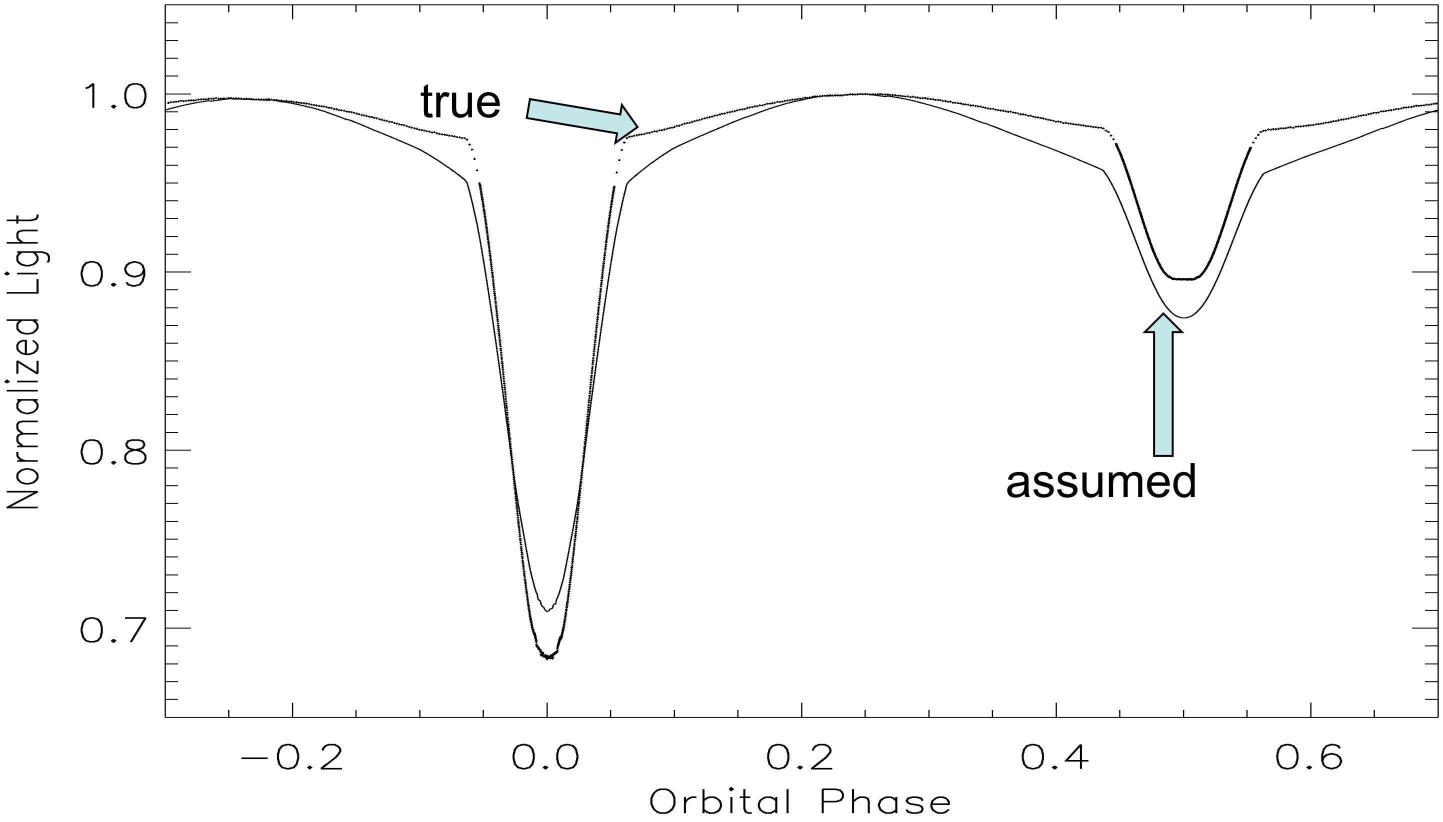
Ω1(assumed) = 4.0

Ω1(true) = 4.4

Ω2(assumed) = 4.2

Ω2(true) = 4.7

U light curve, assumed vs. true



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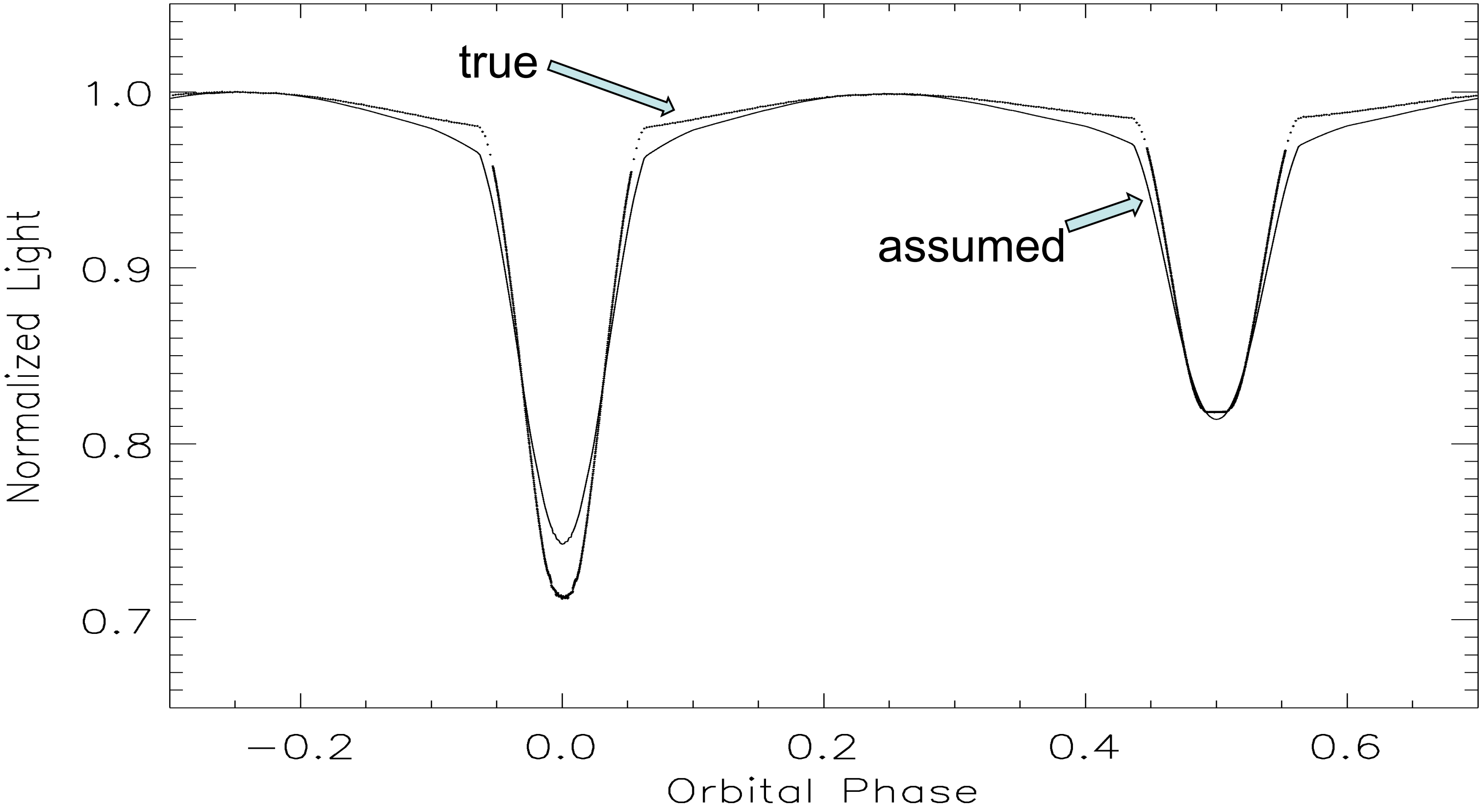
I light curve, assumed vs. true



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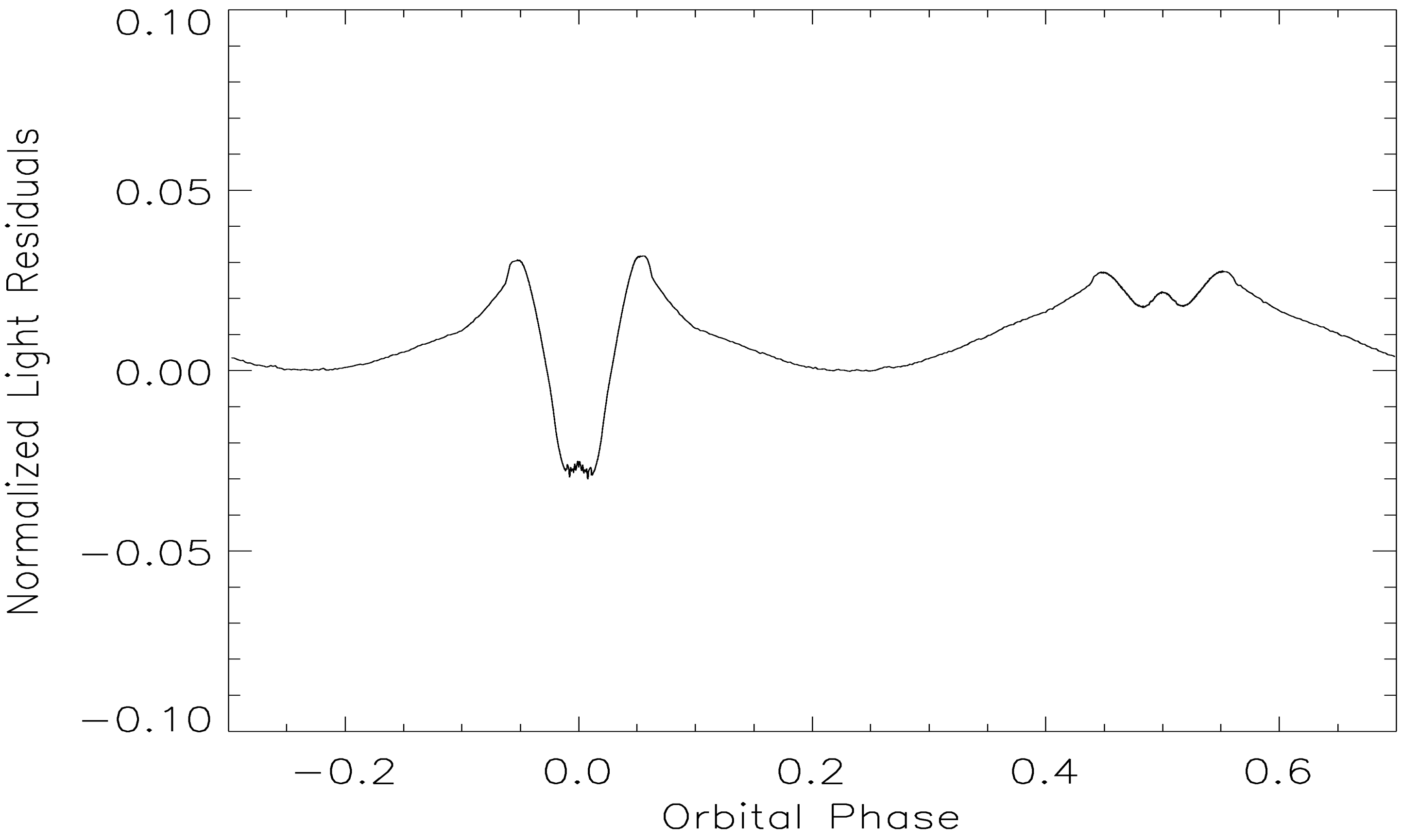
U residuals, starting approximation



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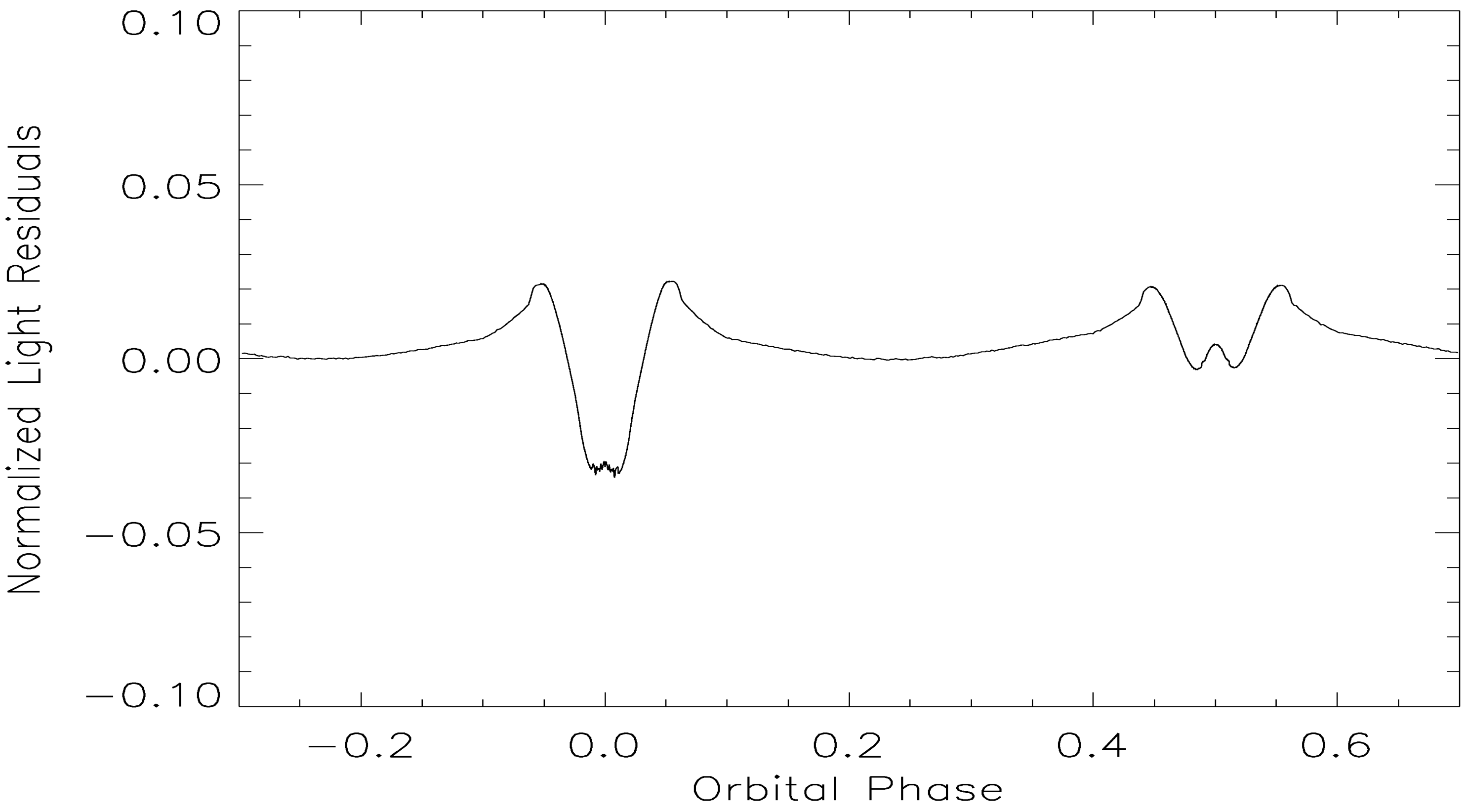
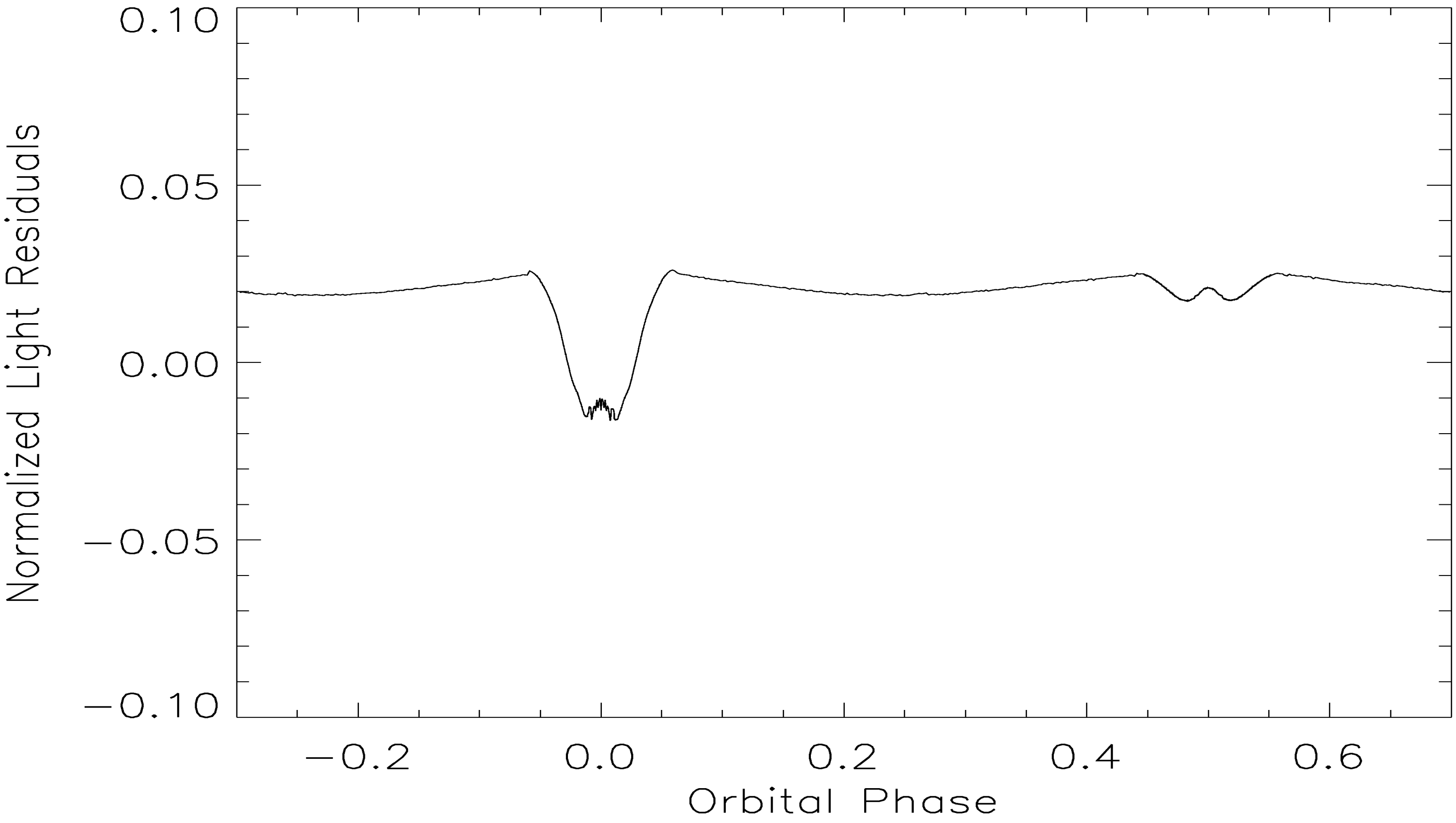
Astronomy

I residuals, starting approximation



U residuals, first iteration



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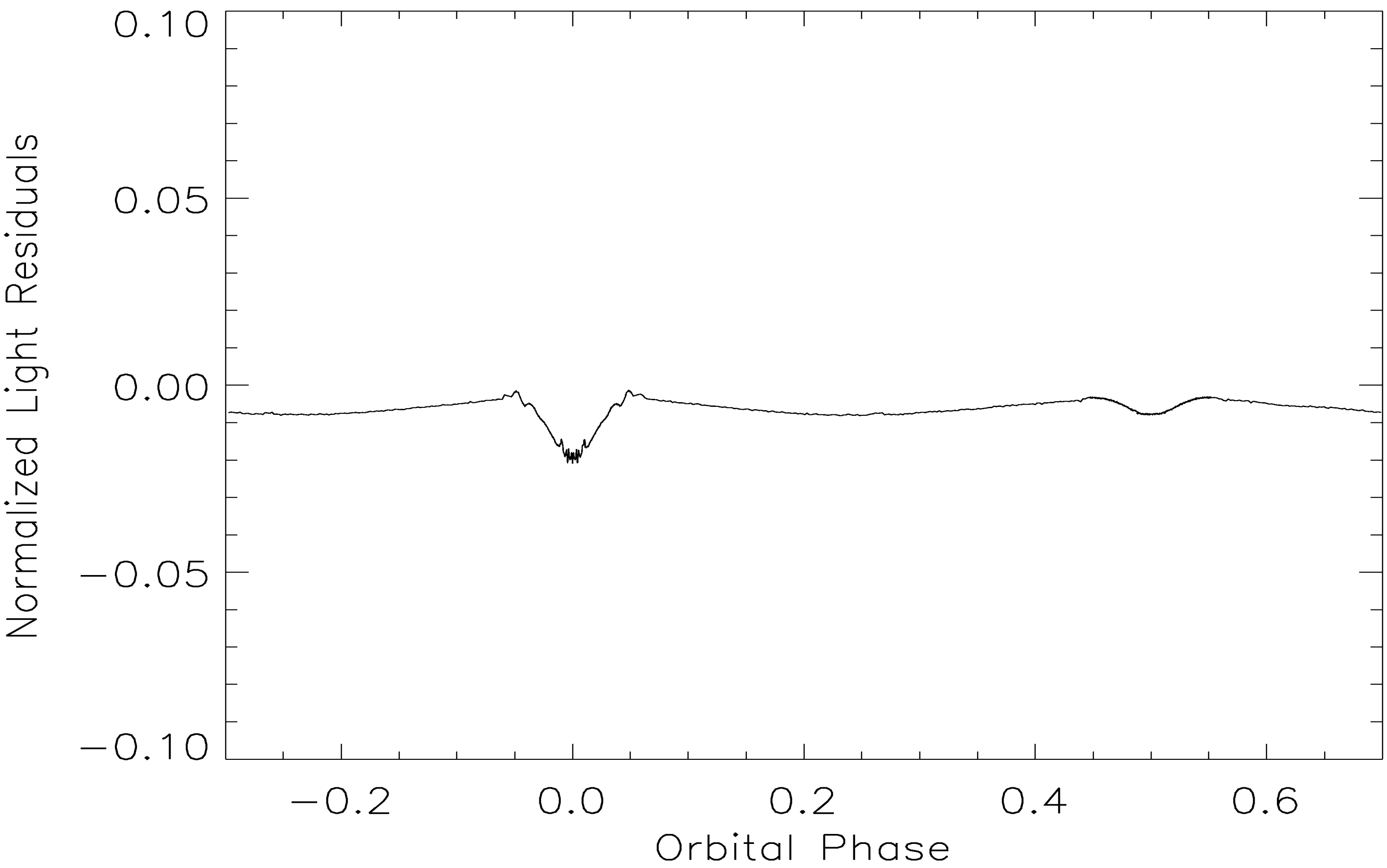
U residuals, second iteration



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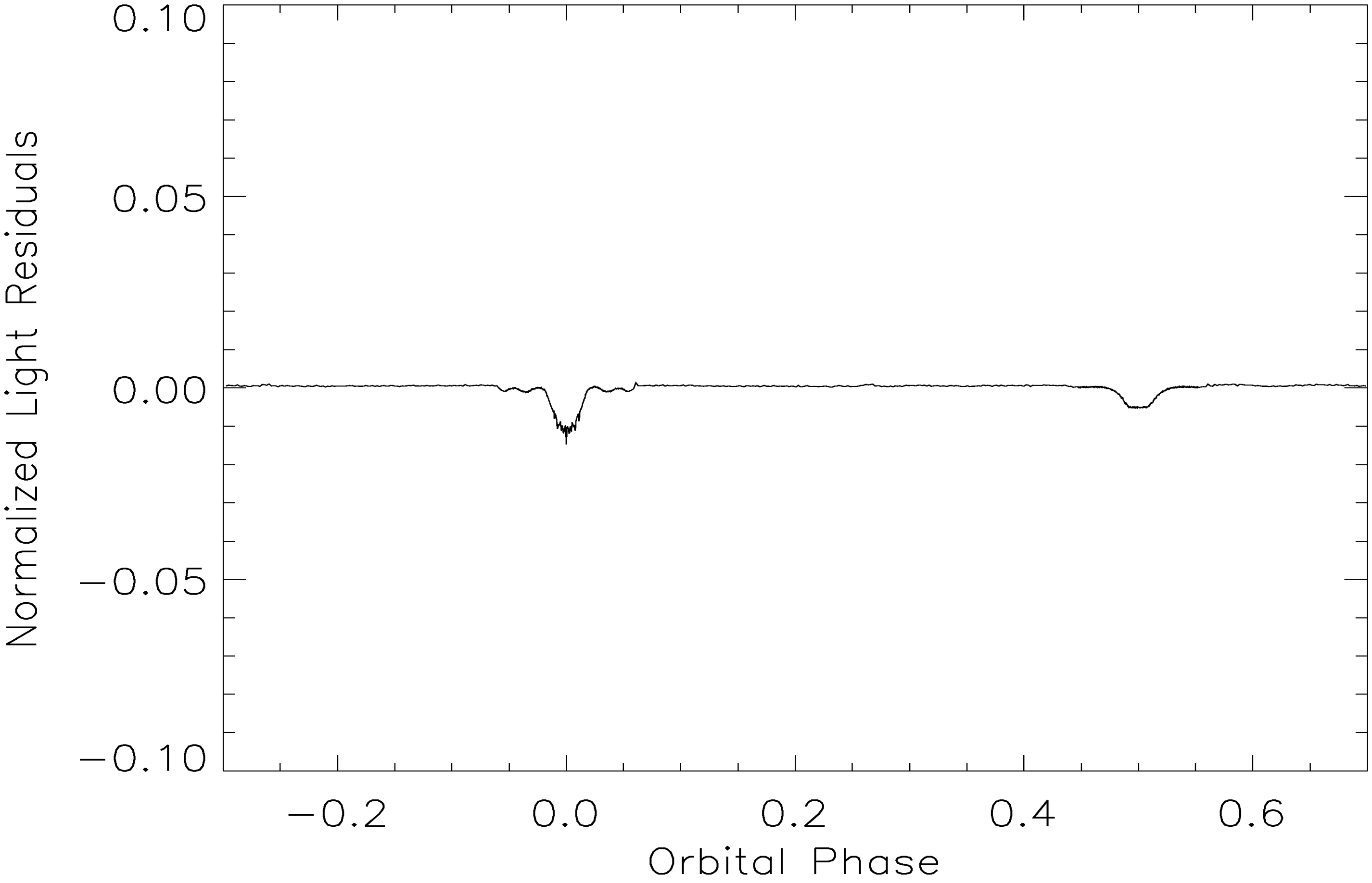
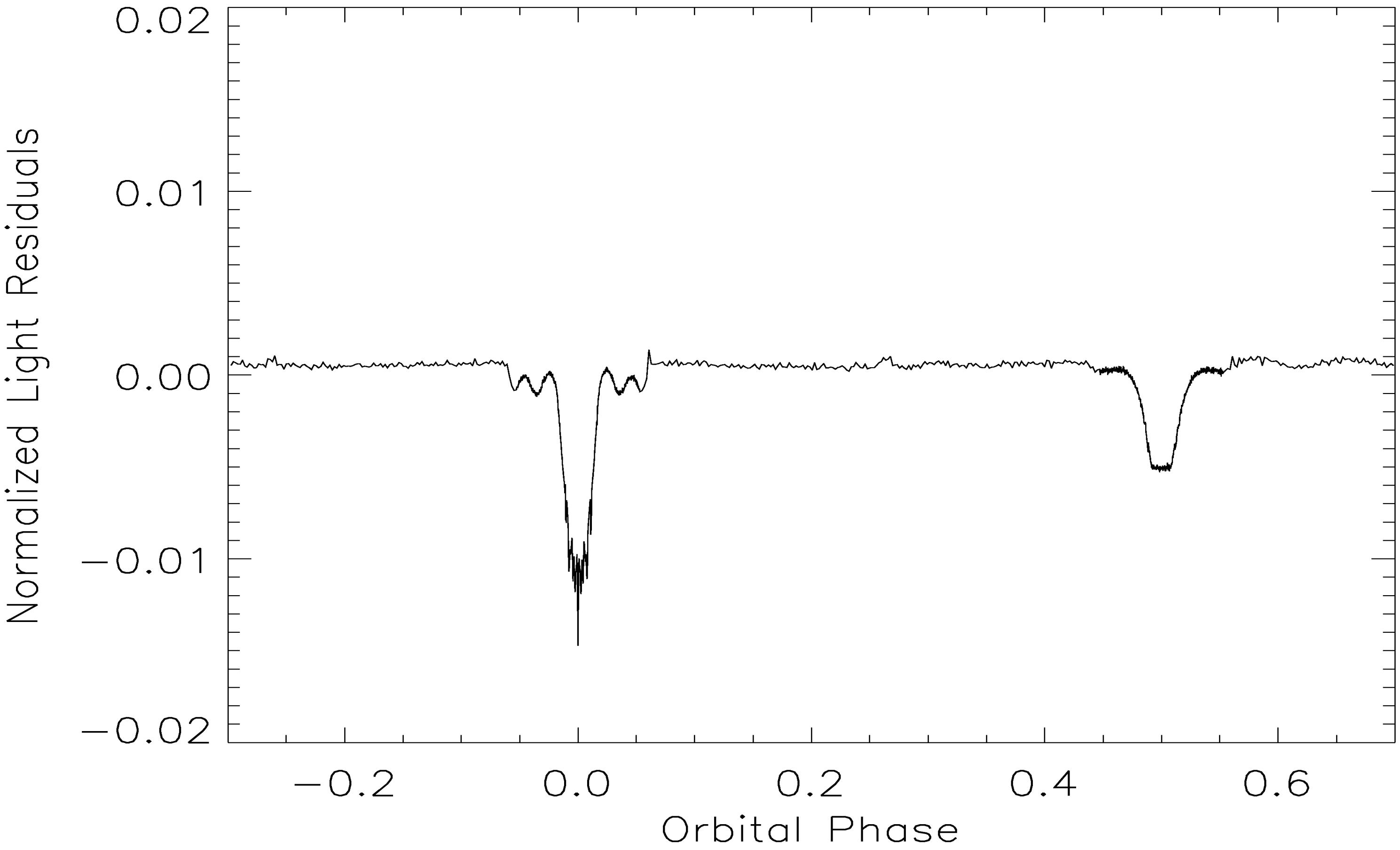
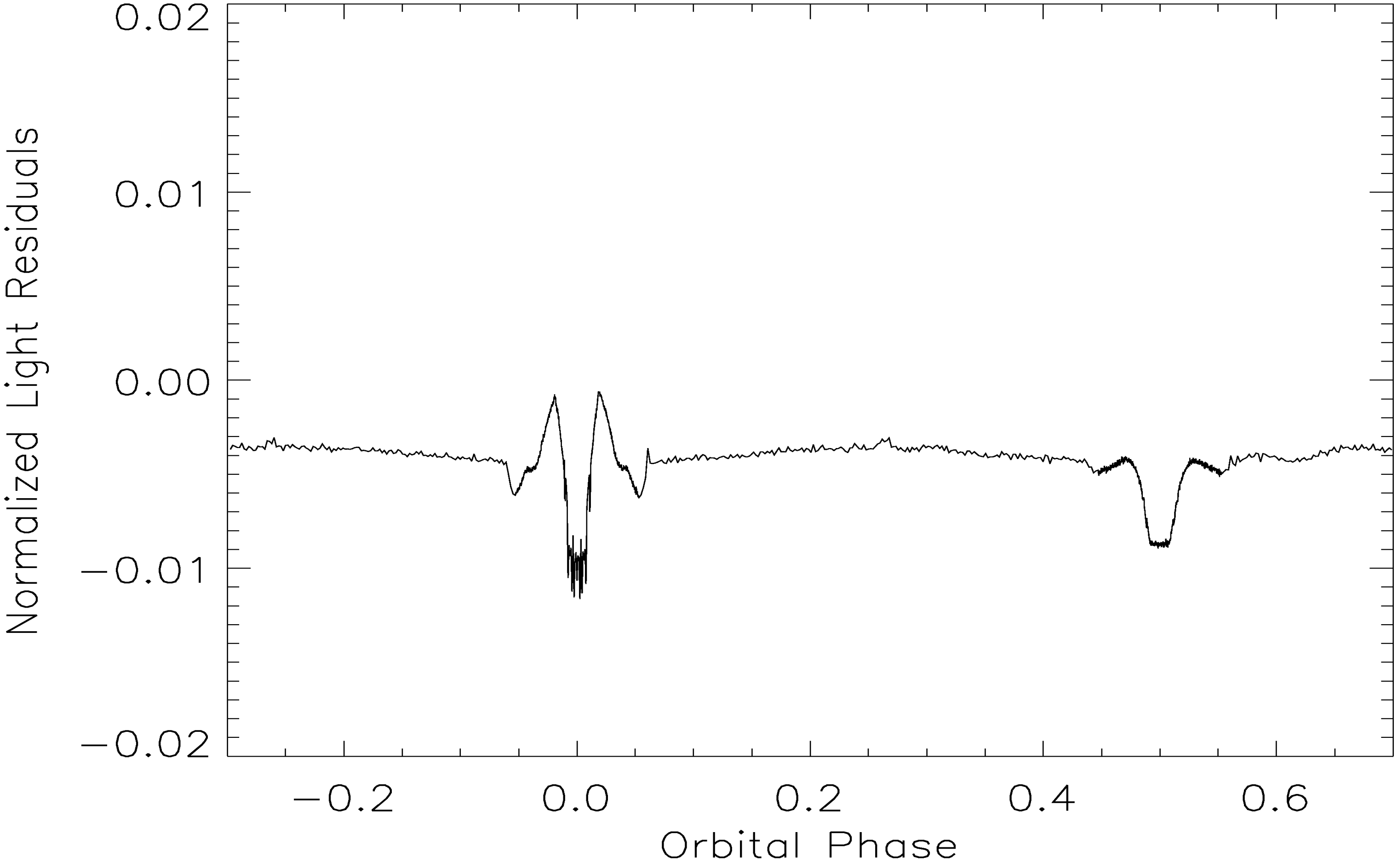
U residuals, third iteration



U residuals, third iteration



U residuals, fourth iteration



Problems !

Solution stalls after third iteration.

Calculated reference light level drifts.

Explanation (?)→ correlations of parameters

Parameters: i, Ω1, Ω2,   table of simple correlation coefficients.

	i	Ω1	Ω2
i	1.000000	0.009530	0.020170
Ω1	0.009530	1.000000	0.011650
Ω2	0.020170	0.011650	1.000000

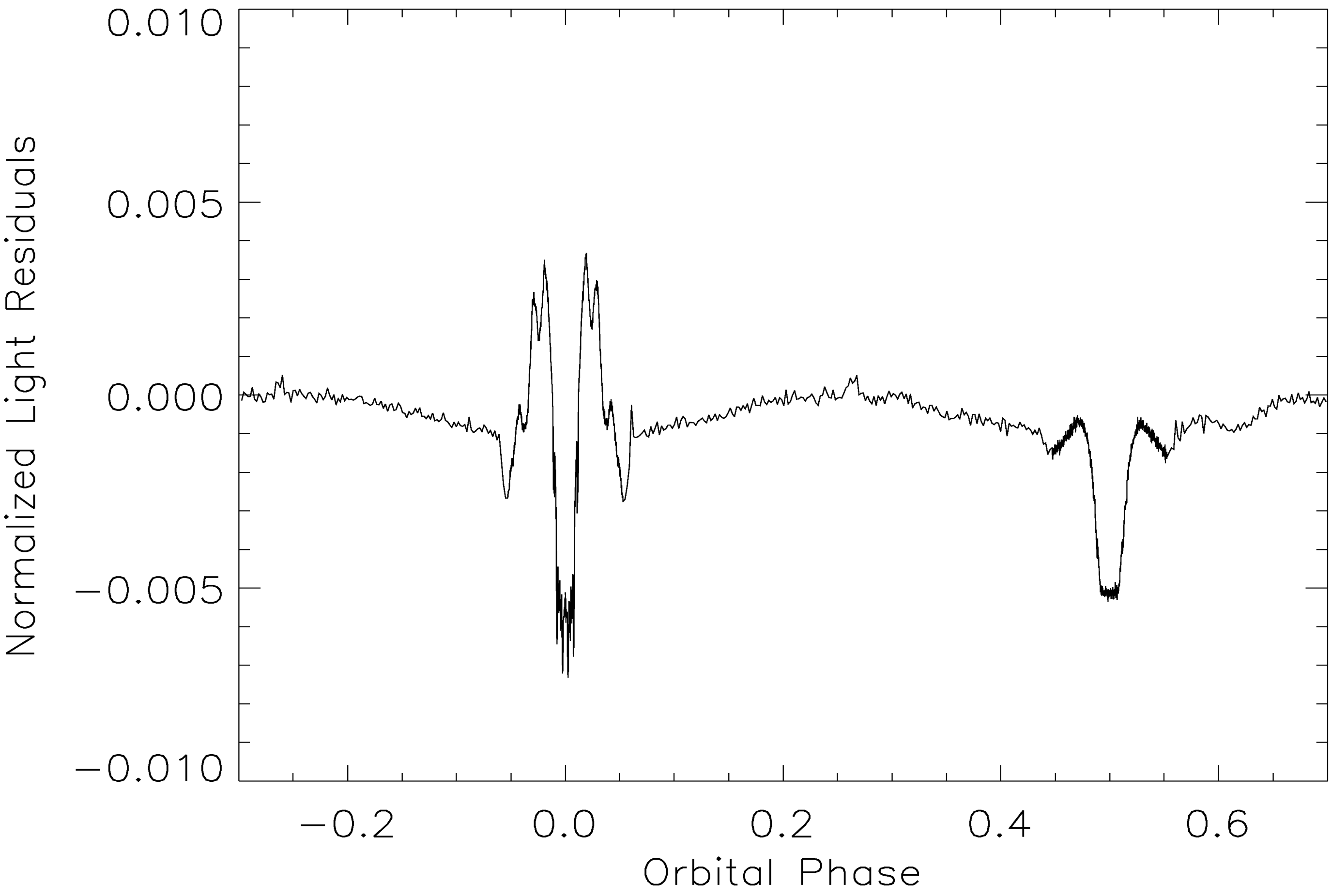
The problem isn’t parameter correlations.

A possible explanation.

The parameter spacing for calculating derivatives is too coarse.

Based on last iteration, reset spacing, recalculate derivatives.

Iteration #1, new derivatives.



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Result, new derivatives.

Little improvement.

Summary

The existing version of BINSYN is useful for spectroscopic studies of binary stars and Cataclysmic Variables.

V360 Lac, WX LMi, others

The upgrade to synthetic photometry currently achieves photometric residuals of ~0.005 mag.

Matches accuracy of ground-based observations.

The next steps.

Produce better grid accuracy.

Have plan, only partly tested.

Expect big improvement in computer time per iteration.

Use closer spacing of orbital phases in primary minimum.

Determine using BB approximation—much faster.

Expect residuals commensurate with CoRoT and Kepler.

That’s It!

THANKS!