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DDE Applications to Eclipsing Binary Stars in Clusters:

A Case Study of DS Andromedae in NGC 752

Presented to a Splinter Meeting of Comms. 26 and 42 (→ C.G1) Honolulu, Hawaii, August 11, 2015

DDE Application to Eclipsing Binary Stars in Clusters:

A Case Study of *DS Andromedae* in NGC 752

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Presented to IAU Comms. 26, 42, C.G1 Splinter Meeting, Aug 11, 2015

Program and Purpose

- WD 2013 version (Wilson 2008; Wilson & Van Hamme 2013), with the *Direct Distance Estimation* (*DDE*) procedure, wherein the
- Distance is determined as a system parameter, ---avoiding the assumption of stellar sphericity and yielding a mean standard error for distance.
- DDE permits calibration of distances of other objects in the clusters in which the analyzed eclipsing binaries are found, with the usually small uncertainty due to relative distances within the cluster.

Previous Direct Distance Estimation Work

- Wilson & Van Hamme (2009): RS Cha, WW Aur, R CMa, RZ Cnc, RZ Cas, AW Uma (but see Slavec Rucinski re concerns about models of this system);
- Wilson et al. (2010): TZ Men, V1130 Tau, TY Pyx, V505 Per, eps CrA, BG Ind, WW Aur;
- Wilson & Raichur (2012): reliability and robustness of DDE. Simultaneously analyze two-component RV curves and absolute physical flux curves for V1143 Cyg, eps CrA & ER Vul, with satisfactory distance checks against Hipparcos parallaxes.

Background to present work

- Systems studied are from our Binaries-in-Clusters program, and previously analyzed with earlier versions of the Wilson-Devinney (WD) light curve modeling program.
- Starting parameters those obtained in fully convergent solutions.
- Previous work: HD 27130 (aka V818 Tau and vB22) in the Hyades (Milone & Schiller 2012, 2014). Although successful the system parameters are uncertain due to only grazing eclipses and variable light curve perturbations from stellar activity. More work is in progress.

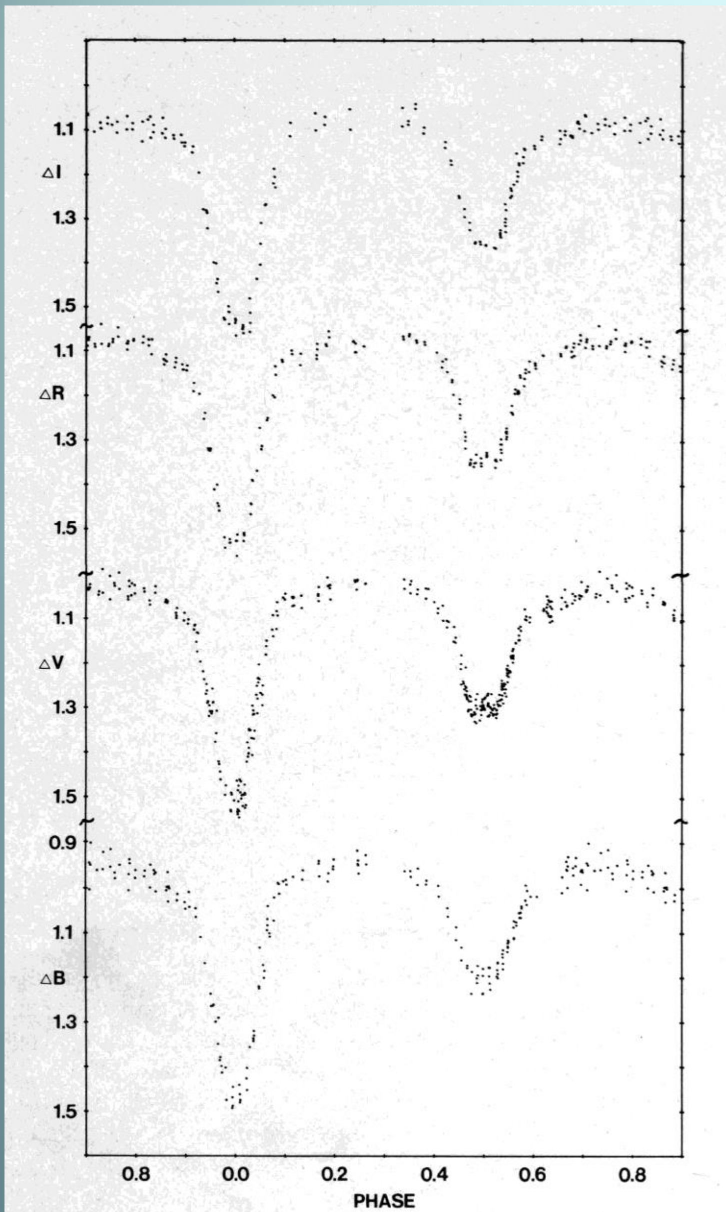
DS Andromedae
= Heinemann 219 in NGC 752

- SB2 total eclipsing system
- Confirmed NGC 752 member
- Primary & secondary eclipses
- 4-passband *calibrated* photometry & DAO RV spectroscopy (Schiller & Milone 1988)
- New RV spectroscopy (Amby 2011)
- Range of A_V and [M/H] reported for NGC 752 (Anthony-Twarog & Twarog 2006 & refs therein)

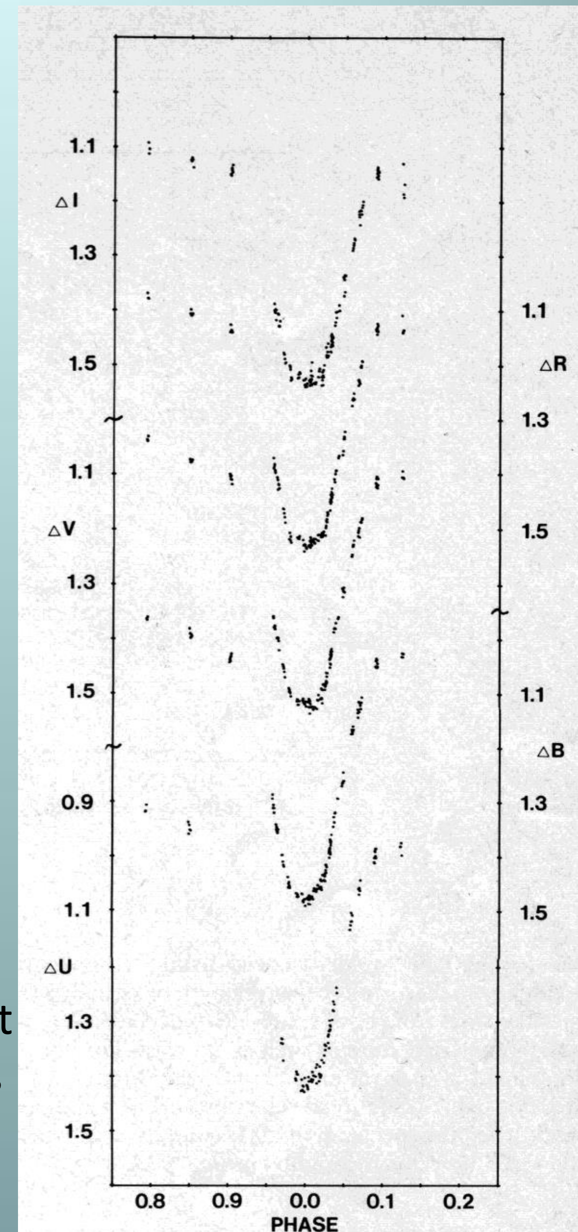
Modeling on DS And Light & RV Curves

- Adjusting one temperature
  (T_1 fixed at 6795, 6775, or 6964 K)
- Adjusting two temperatures
  (T_1 starting at 6775 or 6795 K or higher)
- 2 or 3 Passbands + RVs (S&M 1988, Ambly 2011 or both sets) due to *T-log d* theorem restrictions
- Additional parameters solved simultaneously:
  a; V_{gamma}; i; $T_{[1],2}$; $Omega_{1,2}$; q; t_0; P, log d.
- A_V = 0.075, 0.100, or 0.125 magn fixed
- [M/H] = -0.1, 0 (solar), or +0.1 fixed
- Additional modeling to investigate 3^{rd} light and light curve variability (continuing)

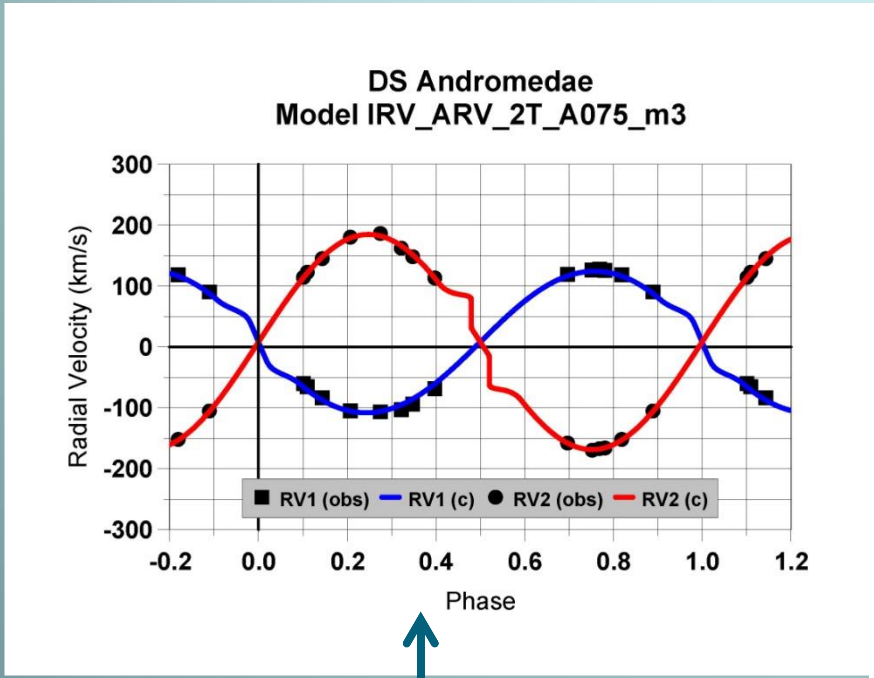
Differential light curves of DS Andromedae



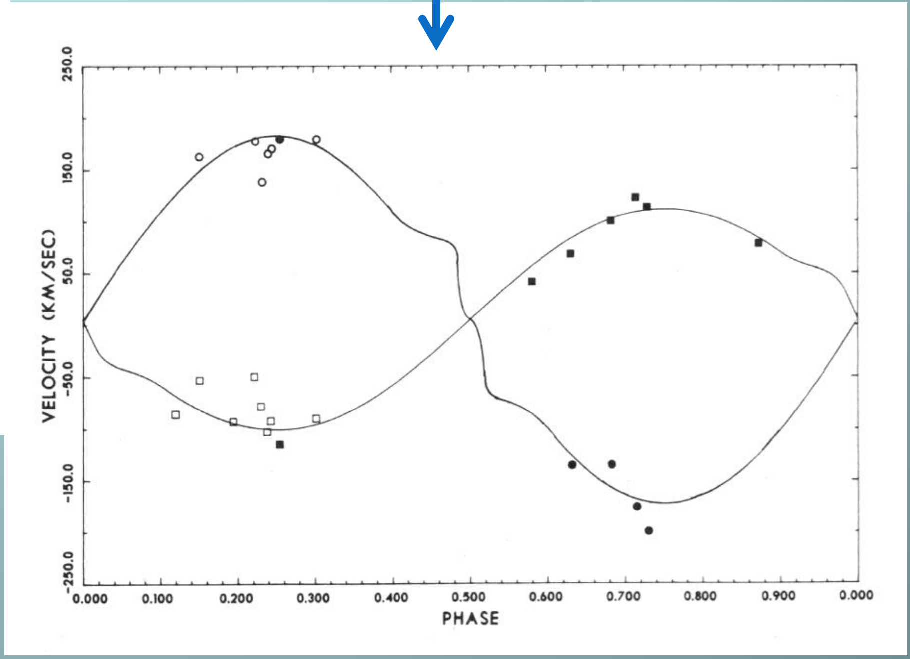
Differential 4-color photo-electric light curves from the RAO obtained with the Rapid Alternate Detection System on the 0.4-m telescope. The data on the right (only the primary minimum is shown) were obtained from 24-in. telescopes of the McDonald and Table Mountain Observatories. The latter were standardized via observations of Landolt standards. The mse of a single RAO diff. datum was 0.015 magn, and that for the MO and TMO was 0.005 magn.. Only the latter data were analyzed in the present work.



DS Andromedae Radial Velocities



S&M 1988 RV from DAO ptg plates and reticon detector.



Th. Amby 2011 RVs from the Nordic Optical Tlescope (fitting from Model 23).

DS And -- Previous WD Analyses

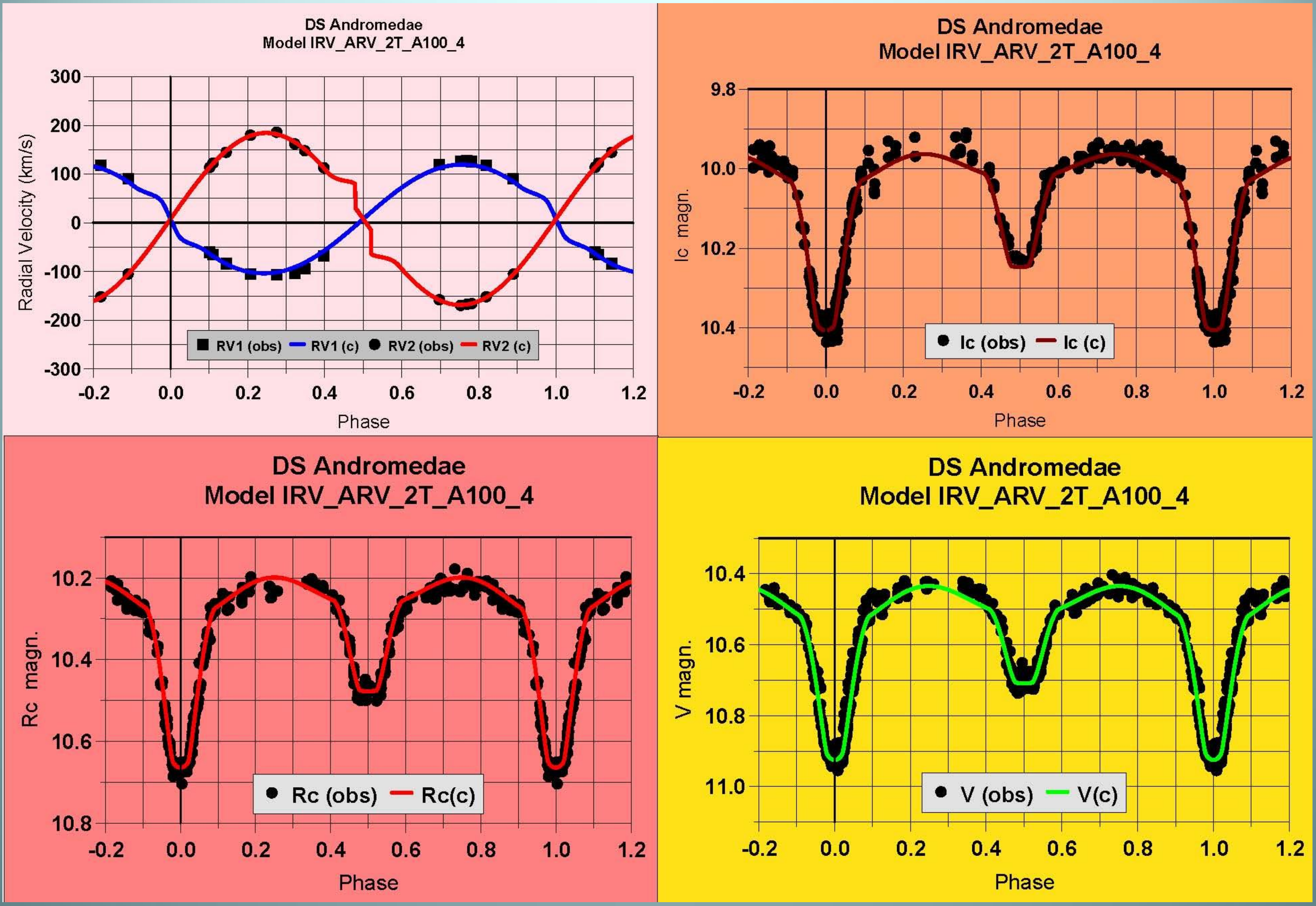
Parameter\ref	S&M 1988 (4-pb, S&M88 RVs)	Amby 2011 (1-pb Amby RVs)	Model 18 (present) (3-PB= IcVB, S&M88 RVs)
a (R_{SUN})	5.77(14)	5.92(10)	5.60(16)
i (degs)	84.3(5)	89.72(2)	85.6(3)
V_{SYS} (km/s)	2.5(20)	8.44(60)	3.1(32)
q = M_2/M_1	0.593(13)	0.680(7)	0.511(20)
P (d)	1.0105187(2)	1.01051870*	1.010522(1)
T_1 (K)	6775[200]**	6775[100]**	7036(4)
T_2 (K)	5997(17)	6144(100)**	5937(17
$Omega_1$	3.40(2)	3.518(3)	3.37(4)
$Omega_2$	4.09(7)	4.652(5)	3.76(11)
Log d (pcs)	2.634(30)	2.665(14)	2.630(12)

* fixed. **T_1 fixed, with est. systematic errors. Other T errors internal

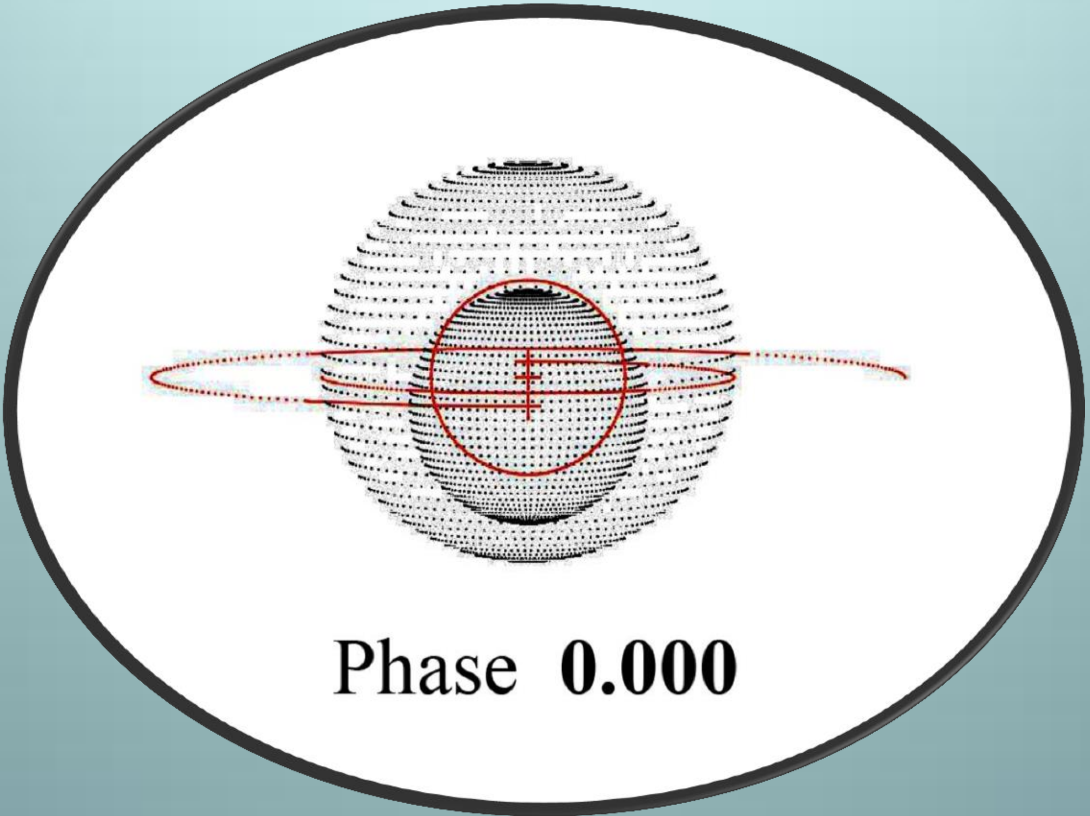
DS And -- Previous WD Analyses
Absolute Parameters

Abs. Param/Suite	S&M88# 4-pb, S&M RVs	Ambly 2011# 1-pb, Ambly RVs	Model 18# 3-pb=IcVB, S&M88 RVs
M_1 (M_{SUN})	1.58(17)	1.63(2)	1.52[4]
M_2 (M_{SUN})	0.94(10)	1.11(2)	0.78 [5]
R_1 (R_{SUN})	2.10(8)	2.15(2)	2.01[2]
R_2 (R_{SUN})	1.19(5)	1.16(1)	1.15[1]
$Mbol_1$	2.34(15)	2.39 (7)	2.38[2]
$Mbol_2$	4.15(19)	4.16(8)	4.33[1]
log g $_1$	[4.21(4)]	3.99(03)	4.02
log g $_2$	[4.24(4)]	4.35(1)	4.21
L_1 (L_{SUN})	[8.7(12)]*	8.8(4)**	8.87**
L_2 (L_{SUN})	1.6(3)*	1.7(1)**	1.47**
$(m-M)_0$ (magn)	8.17(15)	8.30(13)	8.15(6)

*$Mbol_{SUN}$ = 4.69; **$Mbol_{SUN}$ = 4.75; #[M/H] = 0.00; A_V = 0.1


DS Andromedae
Model IRV_ARV_2T_A100_4
Radial Velocity (km/s)
300
200
100
0
-100
-200
-300
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Phase
RV1 (obs)
RV1 (c)
RV2 (obs)
RV2 (c)
DS Andromedae
Model IRV_ARV_2T_A100_4
Ic magn.
9.8
10.0
10.2
10.4
Phase
Ic (obs)
Ic (c)
DS Andromedae
Model IRV_ARV_2T_A100_4
Rc magn.
10.2
10.4
10.6
10.8
Phase
Rc (obs)
Rc(c)
DS Andromedae
Model IRV_ARV_2T_A100_4
V magn.
10.4
10.6
10.8
11.0
Phase
V (obs)
V(c)

DS And via Binary Maker III



Model sets and Distance to DS And

Distance summary, weighted means						
Model	log d	e (log d)	d	e_d	(m-M)o	e_(m-M)
1 (<1b,c,d>)2pb1T(6795)Av(.1)M(0)	2.602	0.001	400	1	8.008	0.003
2 (<2a,b,c>)2pb1T(6775)Av(.1)M(0)	2.595	0.005	393	4	7.973	0.024
3 (<3a,b,c>)2pb1T(6775)Av(.075)M(0)	2.598	0.004	396	4	7.989	0.021
4 (<4a,b,c>)2pb1T(6775)Av(.125)M(0)	2.587	0.006	387	5	7.937	0.028
5 (<5a,b,c>)2pb1T(6964)Av(.100)M(0)	2.626	0.006	422	5	8.129	0.028
6 (<6a,b,c>)2pb1T(6964)Av(.075)M(0)	2.631	0.001	428	1	8.156	0.005
7 (<7a,b,c>)2pb1T(6964)Av(.125)M(0)	2.625	0.004	422	4	8.126	0.020
8 (<8a,b,c>)2pb2T(s6775)Av(.100)M(0)	2.638	0.002	434	2	8.188	0.011
9(<9a,b,c>)2pb2T(s6964)Av(.100)M(0)	2.638	0.002	434	2	8.188	0.011
10(<10a,b,c>)2pb2T(s6964)Av(.075)M(0)	2.637	0.002	434	2	8.186	0.009
11<11a,b,c>)2pb2T(s6964)Av(.125)M(0)	2.638	0.002	435	2	8.190	0.008
12<12b,c,d,e>)3pb2TAv(adjusted)M(0)	2.640	0.005	436	5	8.198	0.024
13<13a,b,c,d>)3pb2TAv(.100)M(0)	2.642	0.001	439	2	8.210	0.007
14<14a,b,c,d>)3pb2TAv(.100)M(+.1)	2.645	0.002	441	2	8.224	0.010
15<15a,b,c,d>)3pb2TAv(.075)M(0)	2.644	0.003	440	3	8.219	0.014
16<16a,b,c,d>)3pb2TAv(.125)M(0)	2.645	0.003	442	3	8.225	0.014
17<17b,c,d>)3pb2TAv(.100)M(-.1)	2.639	0.002	435	2	8.195	0.009
18, 3pb2TAv(.100)M(0)S&MRV	2.630	0.013	427	13	8.151	0.064
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV	2.636	0.004	433	4	8.182	0.019
20, 3pb2TAv(.100)M(-.1)S&MRV	2.627	0.013	423	12	8.133	0.064
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV	2.637	0.005	433	5	8.185	0.025
Weighted mean, models 8-21	**2.640**	**0.001**	**436.4**	**0.8**	**8.199**	**0.004**

Distance summary, weighted means (Amby RV models only)

Model	log d	e (log d)	d	e_d	(m-M)o	e_(m-M)
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV	2.636	0.004	433	4	8.182	0.019
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV	2.637	0.005	433	5	8.185	0.025
22<22a,b,c,d>3pb2T(.075)M(0)ARV	2.638	0.004	435	4	8.191	0.021
23<23a,b,c,d>3pb2T(.075)M(-.1)ARV	2.635	0.005	432	5	8.176	0.026
24<24a,b,c,d>3pb2T(.075)M(+.1)ARV	2.644	0.003	440	3	8.219	0.016
25<25a,b,c,d>3pb2T(125)M(0)ARV	2.642	0.004	439	4	8.211	0.018
26<26a,b,c,d>3pb2T(125)M(-.1)ARV	2.638	0.005	434	5	8.188	0.027
27<27a,b,c,d>3pb2T(125)M(+.1)ARV	2.648	0.003	444	3	8.239	0.014
Weighted mean, models 19,21-27	**2.642**	**0.002**	**438.1**	**1.7**	**8.208**	**0.008**

Distance summary, weighted means (Amby RV models, solar comp., only)

Model	log d	e (log d)	d	e_d	(m-M)o	e_(m-M)
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV	2.636	0.004	433	4	8.182	0.019
22<22a,b,c,d>3pb2T(.075)M(0)ARV	2.638	0.004	435	4	8.191	0.021
25<25a,b,c,d>3pb2T(125)M(0)ARV	2.642	0.004	439	4	8.211	0.018
Weighted mean, models 19,22,25	**2.639**	**0.002**	**435.7**	**2.1**	**8.196**	**0.010**

Distance summary, weighted means (Amby RV models, [M/H]= -0.1, only)

Model	log d	e (log d)	d	e_d	(m-M)o	e_(m-M)
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV	2.637	0.005	433	5	8.185	0.025
23<23a,b,c,d>3pb2T(.075)M(-.1)ARV	2.635	0.005	432	5	8.176	0.026
26<26a,b,c,d>3pb2T(125)M(-.1)ARV	2.638	0.005	434	5	8.188	0.027
Weighted mean, models 21,23,25	**2.637**	**0.001**	**433.1**	**0.9**	**8.183**	**0.005**

Distance summary, weighted means (Amby RV models, [M/H]= +0.1, only)

Model	log d	e (log d)	d	e_d	(m-M)o	e_(m-M)
14<14a,b,c,d>)3pb2TAv(.100)M(+.1)	2.645	0.002	441	2	8.224	0.010
24<24a,b,c,d>3pb2T(.075)M(+.1)ARV	2.644	0.003	440	3	8.219	0.016
27<27a,b,c,d>3pb2T(125)M(+.1)ARV	2.648	0.003	444	3	8.239	0.014
Weighted mean, models 14., 24, 27	**2.645**	**0.001**	**442.0**	**1.3**	**8.227**	**0.006**

Comparison of Adjusted Parameters

Parameter\ref	Model 19 (solar comp,Av=0.1)	Amby 2011 (1-pb Amby RVs)	<Models (9,13,19)> (solar comp, Av=.1)
a (R_{SUN})	5.79(6)	5.92(10)	5.747(4)
i (degs)	84.03(34)	89.72(2)	85.67(8)
V_{SYS} (km/s)	7.95(1)	8.44(60)	7.94(13)
q = M_2/M_1	0.617(17)	0.680(7)	0.551(10)
P (d)	1.01051878(2)	1.01051870*	1.01051878(3)
T_1 (K)	7060(10)	6775[100]**	7047(6)
T_2 (K)	5921(13)	6144(100)**	5928(7)
$Omega_1$	3.54(3)	3.518(3)	3.43(2)
$Omega_2$	4.34(10)	4.652(5)	3.97(5)
Log d (pc)	2.636(4)	…	2.640(2)

* fixed. **T_1 fixed, with est. systematic errors. Other T errors internal

Comparison of Absolute Parameters

Abs. Param/Suite	Model 19# (3-pb, Ambly RVs	Ambly 2011# 1-pb, Ambly RVs	<Models (9,13,19)> (Model 9&13:all RVs)
M_1 (M_{SUN})	1.55(4)	1.63(2)	1.603(2)
M_2 (M_{SUN})	0.94(5)	1.11(2)	0.887(7)
R_1 (R_{SUN})	2.02(2)	2.15(2)	2.044(4)
R_2 (R_{SUN})	1.14(1)	1.16(1)	1.160(6)
$Mbol_1$	2.36(2)	2.39 (7)	2.331(7)
$Mbol_2$	4.37(1)	4.16(8)	4.327(18)
log g $_1$	4.02(4)	3.99(03)	4.022(1)
log g $_2$	4.30(2)	4.35(1)	4.254(4)
L_1 (L_{SUN})	9.06(11)*	8.8(4)*	9.28(10)*
L_2 (L_{SUN})	1.43(2)*	1.7(1)*	1.48(3)*
$(m-M)_0$ (magn)	8.17(15)	8.30(13)	8.20(1)

*$Mbol_{SUN}$ = 4.75; #[M/H] = 0.00, A_V = 0.1

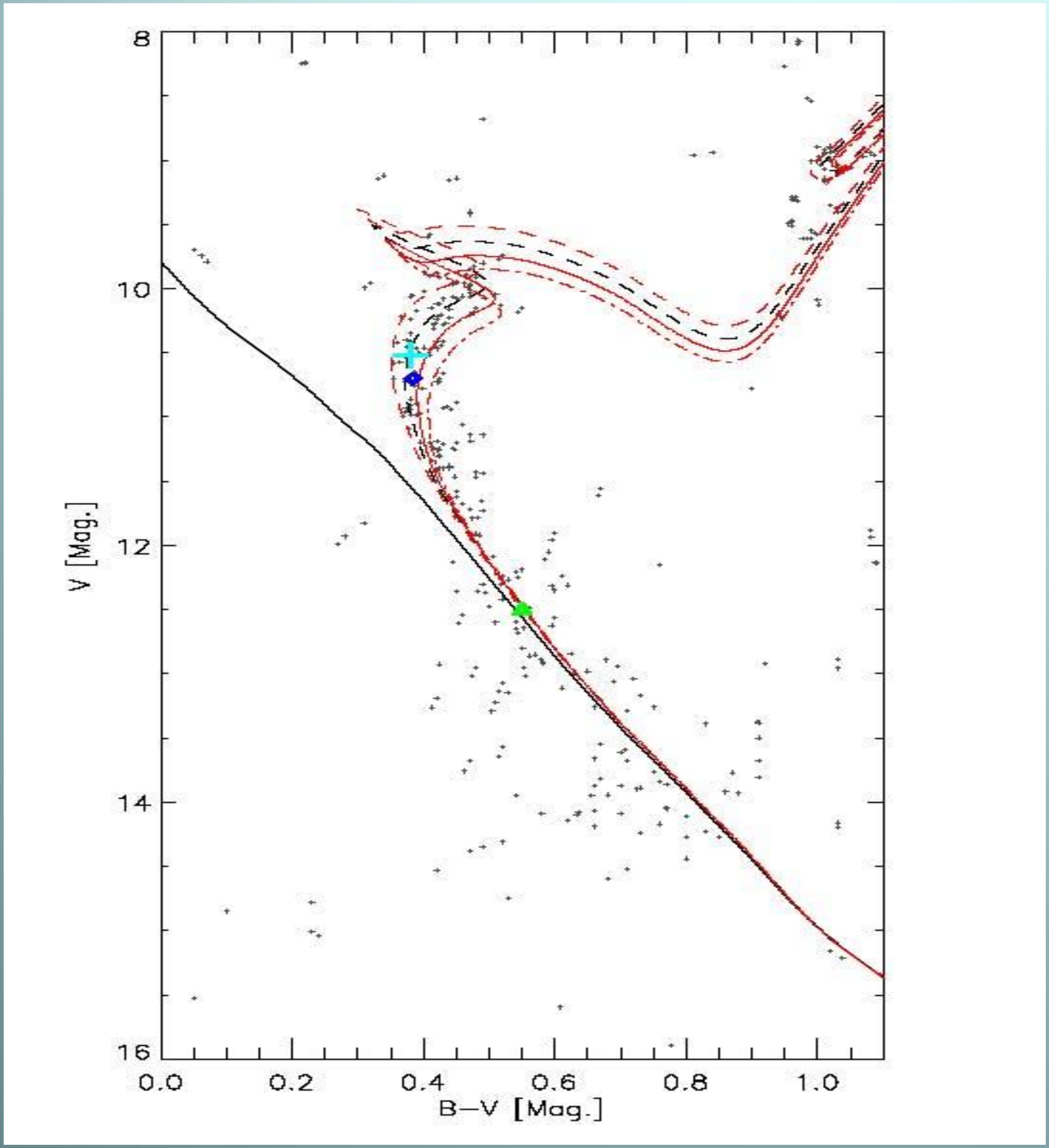
Parameter Weighted Means of all runs: a, V_{sys}, i

Model	**Type**	**<a>**	**e<a>**	**<Vsys>**	**e<Vsys>**	**<i>**	**e<i>**
0, 2pb1T(6795)Av(.1)M(0)	1-T runs	5.442	0.262	-0.0215	0.0606	85.469	0.631
1 (<1b,c,d>)2pb1T(6795)Av(.1)M(0)		5.713	0.029	0.0532	0.0038	85.781	0.132
2 (<2a,b,c>)2pb1T(6775)Av(.1)M(0)		5.747	0.010	0.0600	0.0030	86.084	0.493
3 (<3a,b,c>)2pb1T(6775)Av(.075)M(0)		5.749	0.008	0.0640	0.0013	85.792	0.641
4 (<4a,b,c>)2pb1T(6775)Av(.125)M(0)		5.746	0.008	0.0615	0.0025	86.034	0.596
5 (<5a,b,c>)2pb1T(6964)Av(.100)M(0)		5.670	0.116	0.0502	0.0111	85.622	0.257
6 (<6a,b,c>)2pb1T(6964)Av(.075)M(0)		5.727	0.039	0.0563	0.0076	85.787	0.502
7 (<7a,b,c>)2pb1T(6964)Av(.125)M(0)		5.704	0.012	0.0551	0.0056	85.708	0.371
8 (<8a,b,c>)2pb2T(s6775)Av(.100)M(0)	2-T runs	5.752	0.009	0.0582	0.0038	85.899	0.259
9(<9a,b,c>)2pb2T(s6964)Av(.100)M(0)		5.749	0.011	0.0576	0.0041	85.657	0.230
10(<10a,b,c>)2pb2T(s6964)Av(.075)M(0)		5.754	0.010	0.0581	0.0040	85.669	0.176
11<11a,b,c>)2pb2T(s6964)Av(.125)M(0)		5.748	0.009	0.0569	0.0035	85.848	0.309
12<12b,c,d,e>)3pb2TAv(adjusted)M(0)	3-pb	5.748	0.004	0.0568	0.0039	85.635	0.083
13<13a,b,c,d>)3pb2TAv(.100)M(0)		**5.745**	**0.010**	**0.0535**	**0.0021**	**85.628**	**0.113**
14<14a,b,c,d>)3pb2TAv(.100)M(+.1)		5.748	0.004	0.0558	0.0016	85.635	0.083
15<15a,b,c,d>)3pb2TAv(.075)M(0)		5.748	0.007	0.0554	0.0016	85.654	0.088
16<16a,b,c,d>)3pb2TAv(.125)M(0)		5.749	0.004	0.0560	0.0011	85.652	0.088
17<17b,c,d>)3pb2TAv(.100)M(-.1)		**5.739**	**0.010**	**0.0524**	**0.0029**	**85.707**	**0.116**
18, 3pb2TAv(.100)M(0)S&MRV		5.652	0.073	0.0794	0.0060	85.716	0.340
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV		**5.791**	**0.060**	**0.0795**	**0.0001**	**86.029**	**0.345**
20, 3pb2TAv(.100)M(-.1)S&MRV		5.588	0.158	0.0286	0.0325	85.613	0.315
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV		**5.866**	**0.060**	**0.0800**	**0.0004**	**85.954**	**0.277**
22<22a,b,c>)3pb2TAv(.075)M(0)ARV		**5.849**	**0.066**	**0.0800**	**0.0004**	**86.008**	**0.388**
23<23a,b,c>)3pb2TAv(.075)M(-.1)ARV		**5.792**	**0.074**	**0.0800**	**0.0005**	**85.931**	**0.335**
24<24a,b,c>)3pb2TAv(.075)M(+.1)ARV		5.887	0.043	0.0803	0.0004	85.864	0.006
25<25a,b,c>)3pb2TAv(.125)M(0)ARV		5.889	0.041	0.0805	0.0004	86.045	0.339
26<26a,b,c>)3pb2TAv(.125)M(-.1)ARV		5.882	0.069	0.0804	0.0006	85.908	0.373
27<27a,b,c>)3pb2TAv(.125)M(+.1)ARV		5.914	0.030	0.0808	0.0005	86.115	0.289
Means (all 2-T runs)		**5.779**	**0.018**	**0.066**	**0.003**	**85.808**	**0.037**

Parameter Weighted Means of all runs: $T_{[1],2}$; $Omega_{1,2}$; q

Model	Type	<T1>	e<T1>	<T2>	e<T2>	<Omega1>	<Omega1	<Omega2>	<Omega2	<q>	e<q>
0, 2pb1T(6795)Av(.1)M(0)	1-T runs	6795		5745	40	3.158	0.059	3.191	0.178	0.398	0.038
1 (<1b,c,d>)2pb1T(6795)Av(.1)M(0)		6795		5764	34	3.456	0.008	4.023	0.028	0.557	0.006
2 (<2a,b,c>)2pb1T(6775)Av(.1)M(0)		6775		5763	14	3.484	0.017	4.094	0.049	0.567	0.011
3 (<3a,b,c>)2pb1T(6775)Av(.075)M(0)		6775		5731	8	3.497	0.012	4.133	0.034	0.575	0.008
4 (<4a,b,c>)2pb1T(6775)Av(.125)M(0)		6775		5761	17	3.498	0.012	4.133	0.039	0.573	0.009
5 (<5a,b,c>)2pb1T(6964)Av(.100)M(0)		6964		5913	27	3.385	0.057	3.809	0.180	0.522	0.034
6 (<6a,b,c>)2pb1T(6964)Av(.075)M(0)		6964		5874	11	3.434	0.041	3.975	0.131	0.553	0.026
7 (<7a,b,c>)2pb1T(6964)Av(.125)M(0)		6964		5903	16	3.431	0.039	3.966	0.095	0.551	0.016
8 (<8a,b,c>)2pb2T(s6775)Av(.100)M(0)	**2-T runs**	**7041**	**5**	**5914**	**17**	**3.446**	**0.019**	**4.019**	**0.044**	**0.562**	**0.008**
9(<9a,b,c>)2pb2T(s6964)Av(.100)M(0)		**7041**	**5**	**5913**	**18**	**3.443**	**0.020**	**4.009**	**0.051**	**0.560**	**0.009**
10(<10a,b,c>)2pb2T(s6964)Av(.075)M(0)		6998	4	5879	18	3.445	0.019	4.008	0.050	0.560	0.009
11<11a,b,c>)2pb2T(s6964)Av(.125)M(0)		7084	3	5937	14	3.441	0.016	3.999	0.046	0.563	0.009
12<12b,c,d,e>)3pb2TAv(adjusted)M(0)	3-pb	7691	133	6418	122	3.439	0.019	4.004	0.071	0.560	0.016
13<13a,b,c,d>)3pb2TAv(.100)M(0)		**7058**	**9**	**5937**	**10**	**3.425**	**0.007**	**3.951**	**0.017**	**0.547**	**0.004**
14<14a,b,c,d>)3pb2TAv(.100)M(+.1)		7056	13	5968	13	3.438	0.006	4.001	0.016	0.556	0.004
15<15a,b,c,d>)3pb2TAv(.075)M(0)		7012	12	5938	20	3.435	0.006	3.987	0.027	0.553	0.006
16<16a,b,c,d>)3pb2TAv(.125)M(0)		7099	11	6004	21	3.439	0.003	4.010	0.007	0.558	0.002
17<17b,c,d>)3pb2TAv(.100)M(-.1)		**7047**	**10**	**5928**	**12**	**3.427**	**0.012**	**3.954**	**0.047**	**0.545**	**0.010**
18, 3pb2TAv(.100)M(0)S&MRV		7039	4	5905	17	3.470	0.035	4.095	0.109	0.576	0.020
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV		**7060**	**10**	**5921**	**13**	**3.544**	**0.029**	**4.341**	**0.098**	**0.617**	**0.017**
20, 3pb2TAv(.100)M(-.1)S&MRV		7019	4	5915	17	3.365	0.036	3.745	0.106	0.509	0.020
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV		**7035**	**10**	**5888**	**9**	**3.572**	**0.028**	**4.456**	**0.097**	**0.638**	**0.016**
22<22a,b,c>)3pb2TAv(.075)M(0)ARV		**7018**	**10**	**5885**	**11**	**3.578**	**0.033**	**4.470**	**0.111**	**0.641**	**0.019**
23<23a,b,c>)3pb2TAv(.075)M(-.1)ARV		**6999**	**9**	**5866**	**12**	**3.580**	**0.030**	**4.475**	**0.111**	**0.642**	**0.019**
24<24a,b,c>)3pb2TAv(.075)M(+.1)ARV		7008	14	5916	17	3.587	0.023	4.508	0.073	0.648	0.012
25<25a,b,c>)3pb2TAv(.125)M(0)ARV		7103	10	5944	7	3.569	0.027	4.447	0.076	0.639	0.012
26<26a,b,c>)3pb2TAv(.125)M(-.1)ARV		7081	11	5936	2	3.563	0.040	4.426	0.122	0.637	0.019
27<27a,b,c>)3pb2TAv(.125)M(+.1)ARV		7099	12	5991	12	3.583	0.019	4.507	0.055	0.650	0.008
Mean, all 2-T runs, excl. model 12 for T		**7047**	**8**	**5926**	**8**	**3.490**	**0.016**	**4.171**	**0.054**	**0.588**	**0.010**

DS And: on NGC 752's Color-Magnitude Diagram



The CMD of NGC 752 showing the system (cyan cross) and components (blue diamond and green triangle for stars 1 and 2, resp.), of DS Andromedae.

The Zero-age Main Sequence, isochrones of 1.3, 1.5 and 1.6 Gy (in red), and the 1.4 Gy isochrone (dashed black) are shown also. From Amby (2011).

Means of Absolute Parameters: *M*, *R*

Model / Absolute Parameter	M1	e(M1)	M2	e(M2)	R1	e(R1)	R2	e(R2)
	Msun	Msun	Msun	Msun	Rsun	Rsun	Rsun	Rsun
1 (<1b,c,d>)2pb1T(6795)Av(.1)M(0)	1.595	0.026	0.886	0.012	2.026	0.010	1.150	0.006
2 (<2a,b,c>)2pb1T(6775)Av(.1)M(0)	1.581	0.009	0.910	0.017	2.015	0.005	1.139	0.005
3 (<3a,b,c>)2pb1T(6775)Av(.075)M(0)	1.593	0.008	0.911	0.009	2.020	0.008	1.143	0.005
4 (<4a,b,c>)2pb1T(6775)Av(.125)M(0)	1.586	0.010	0.911	0.011	2.013	0.009	1.137	0.007
5 (<5a,b,c>)2pb1T(6964)Av(.100)M(0)	1.573	0.061	0.813	0.088	2.028	0.026	1.157	0.012
6 (<6a,b,c>)2pb1T(6964)Av(.075)M(0)	1.591	0.010	0.879	0.045	2.035	0.005	1.156	0.002
7 (<7a,b,c>)2pb1T(6964)Av(.125)M(0)	1.608	0.005	0.881	0.027	2.049	0.011	1.163	0.006
8 (<8a,b,c>)2pb2T(s6775)Av(.100)M(0)	**1.604**	**0.001**	**0.902**	**0.013**	**2.043**	**0.007**	**1.162**	**0.004**
9(<9a,b,c>)2pb2T(s6964)Av(.100)M(0)	**1.603**	**0.001**	**0.899**	**0.014**	**2.043**	**0.008**	**1.163**	**0.005**
10(<10a,b,c>)2pb2T(s6964)Av(.075)M(0)	1.607	0.001	0.901	0.014	2.044	0.007	1.164	0.004
11<11a,b,c>)2pb2T(s6964)Av(.125)M(0)	1.602	0.004	0.906	0.015	2.044	0.007	1.164	0.004
12<12b,c,d,e>)3pb2TAv(adjusted)M(0)	1.615	0.004	0.870	0.011	2.042	0.002	1.158	0.001
13<13a,b,c,d>)3pb2TAv(.100)M(0)	**1.613**	**0.005**	**0.882**	**0.008**	**2.046**	**0.004**	**1.163**	**0.005**
14<14a,b,c,d>)3pb2TAv(.100)M(+.1)	1.603	0.002	0.896	0.005	2.044	0.002	1.158	0.002
15<15a,b,c,d>)3pb2TAv(.075)M(0)	1.609	0.008	0.890	0.007	2.044	0.003	1.159	0.003
16<16a,b,c,d>)3pb2TAv(.125)M(0)	1.605	0.004	0.896	0.003	2.046	0.001	1.160	0.002
17<17b,c,d>)3pb2TAv(.100)M(-.1)	1.609	0.010	0.878	0.014	2.041	0.002	1.157	0.001
18, 3pb2TAv(.100)M(0)S&MRV	1.524	0.036	0.780	0.051	2.006	0.018	1.148	0.008
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV	**1.555**	**0.036**	**0.939**	**0.051**	**2.015**	**0.018**	**1.137**	**0.008**
20, 3pb2TAv(.100)M(-.1)S&MRV	1.521	0.044	0.774	0.063	2.005	0.019	1.147	0.006
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV	1.594	0.044	0.994	0.063	2.036	0.019	1.146	0.006
22<22a,b,c>)3pb2TAv(.075)M(0)ARV	**1.570**	**0.044**	**0.961**	**0.062**	**2.022**	**0.020**	**1.140**	**0.008**
23<23a,b,c>)3pb2TAv(.075)M(-.1)ARV	**1.568**	**0.046**	**0.959**	**0.065**	**2.021**	**0.022**	**1.140**	**0.009**
24<24a,b,c>)3pb2TAv(.075)M(+.1)ARV	1.607	0.034	1.016	0.049	2.040	0.015	1.149	0.005
25<25a,b,c>)3pb2TAv(.125)M(0)ARV	1.611	0.033	1.019	0.048	2.040	0.014	1.149	0.005
26<26a,b,c>)3pb2TAv(.125)M(-.1)ARV	1.578	0.063	0.977	0.088	2.025	0.026	1.142	0.010
27<27a,b,c>)3pb2TAv(.125)M(+.1)ARV	1.633	0.023	1.053	0.034	2.054	0.010	1.156	0.003
Means, all 2-T solutions	**1.591**	**0.007**	**0.920**	**0.016**	**2.035**	**0.003**	**1.153**	**0.002**

Means of Absolute Parameters: M_{bol}, log g

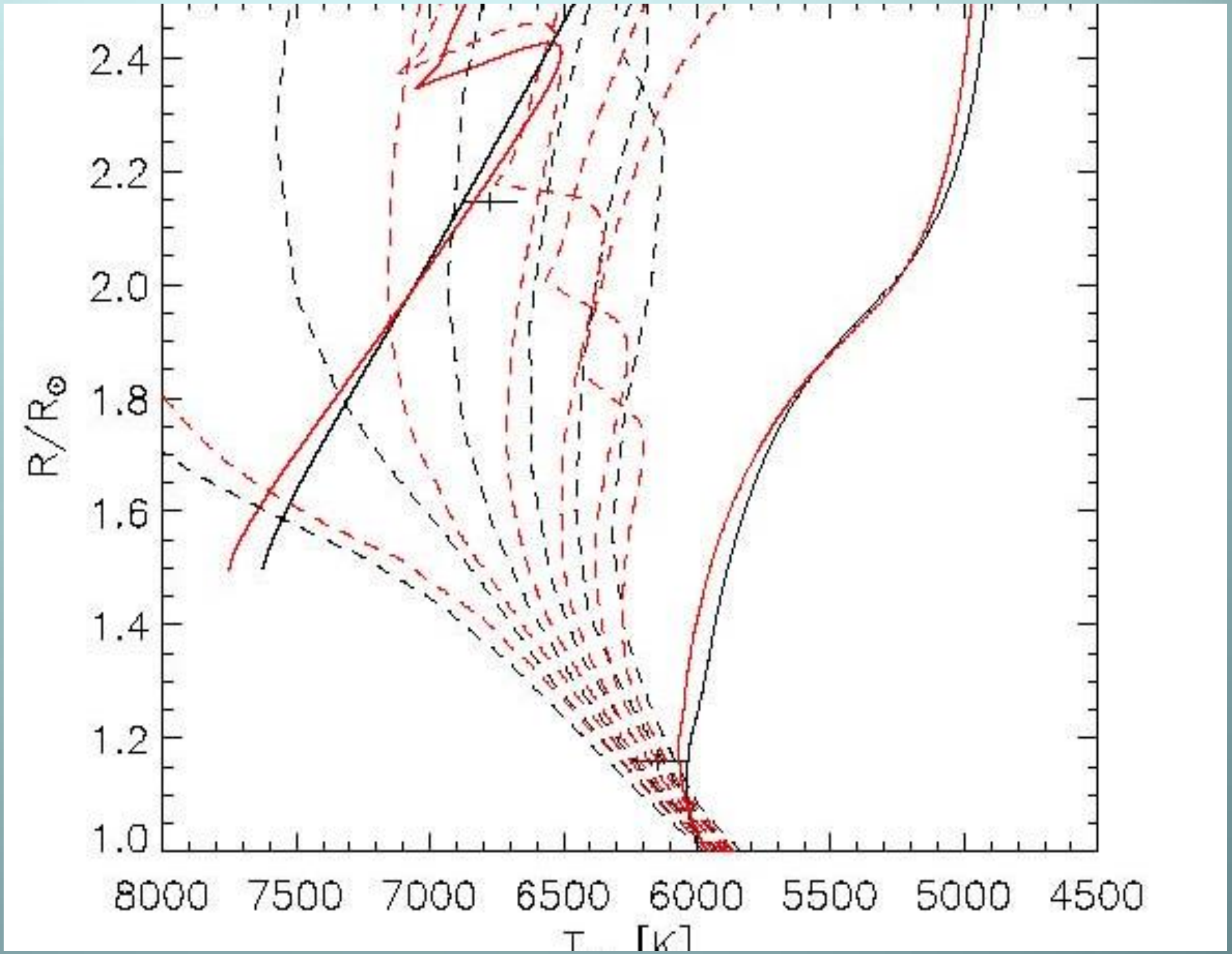
Model / Absolute Parameter	Mbol1	e(Mbol1)	Mbol2	e(Mbol2)	log g1	e(log g1)	log g2	e(log g2)
	magn.	magn.	magn.	magn.	cgs	cgs	cgs	cgs
1 (<1b,c,d>)2pb1T(6795)Av(.1)M(0)	2.510	0.010	4.370	0.056	4.027	0.003	4.263	0.003
2 (<2a,b,c>)2pb1T(6775)Av(.1)M(0)	2.537	0.003	4.483	0.009	4.027	0.003	4.283	0.007
3 (<3a,b,c>)2pb1T(6775)Av(.075)M(0)	2.530	0.010	4.497	0.013	4.030	0.001	4.283	0.003
4 (<4a,b,c>)2pb1T(6775)Av(.125)M(0)	2.540	0.010	4.487	0.012	4.033	0.003	4.287	0.007
5 (<5a,b,c>)2pb1T(6964)Av(.100)M(0)	2.403	0.028	4.327	0.009	4.020	0.006	4.217	0.043
6 (<6a,b,c>)2pb1T(6964)Av(.075)M(0)	2.397	0.003	4.360	0.006	4.023	0.003	4.303	0.028
7 (<7a,b,c>)2pb1T(6964)Av(.125)M(0)	2.380	0.012	4.320	0.015	4.020	0.006	4.250	0.015
8 (<8a,b,c>)2pb2T(s6775)Av(.100)M(0)	**2.340**	**0.012**	**4.330**	**0.017**	**4.023**	**0.003**	**4.263**	**0.009**
9(<9a,b,c>)2pb2T(s6964)Av(.100)M(0)	**2.340**	**0.012**	**4.323**	**0.018**	**4.023**	**0.003**	**4.263**	**0.009**
10(<10a,b,c>)2pb2T(s6964)Av(.075)M(0)	2.367	0.012	4.347	0.015	4.023	0.003	4.257	0.009
11<11a,b,c>)2pb2T(s6964)Av(.125)M(0)	2.317	0.012	4.277	0.015	4.020	0.006	4.263	0.007
12<12b,c,d,e>)3pb2TAv(adjusted)M(0)	1.917	0.015	3.943	0.023	4.023	0.002	4.255	0.010
13<13a,b,c,d>)3pb2TAv(.100)M(0)	**2.325**	**0.006**	**4.308**	**0.009**	**4.023**	**0.002**	**4.253**	**0.002**
14<14a,b,c,d>)3pb2TAv(.100)M(+.1)	2.333	0.009	4.285	0.006	4.020	0.001	4.263	0.003
15<15a,b,c,d>)3pb2TAv(.075)M(0)	2.355	0.009	4.310	0.011	4.023	0.002	4.258	0.005
16<16a,b,c,d>)3pb2TAv(.125)M(0)	2.300	0.007	4.263	0.011	4.020	0.001	4.260	0.000
17<17b,c,d>)3pb2TAv(.100)M(-.1)	2.337	0.007	4.327	0.012	4.023	0.003	4.253	0.009
18, 3pb2TAv(.100)M(0)S&MRV	2.380	0.020	4.330	0.012	4.020	0.004	4.210	0.021
19<19a,b,c,d>3pb2TAv(.100)M(0)ARV	**2.358**	**0.020**	**4.365**	**0.012**	**4.020**	**0.004**	**4.295**	**0.021**
20, 3pb2TAv(.100)M(-.1)S&MRV	2.390	0.029	4.350	0.020	4.020	0.007	4.210	0.023
21<21a,b,c>)3pb2TAv(.100)M(-.1)ARV	2.350	0.029	4.370	0.020	4.023	0.007	4.317	0.023
22<22a,b,c>)3pb2TAv(.075)M(0)ARV	**2.373**	**0.023**	**4.388**	**0.013**	**4.020**	**0.004**	**4.318**	**0.031**
23<23a,b,c>)3pb2TAv(.075)M(-.1)ARV	**2.388**	**0.027**	**4.400**	**0.017**	**4.023**	**0.005**	**4.300**	**0.023**
24<24a,b,c>)3pb2TAv(.075)M(+.1)ARV	2.363	0.019	4.350	0.012	4.023	0.005	4.323	0.018
25<25a,b,c>)3pb2TAv(.125)M(0)ARV	2.303	0.021	4.328	0.011	4.025	0.006	4.323	0.018
26<26a,b,c>)3pb2TAv(.125)M(-.1)ARV	2.330	0.036	4.348	0.019	4.025	0.009	4.310	0.037
27<27a,b,c>)3pb2TAv(.125)M(+.1)ARV	2.293	0.013	4.283	0.007	4.025	0.003	4.333	0.014
Means, all 2-T solutions	**2.323**	**0.022**	**4.311**	**0.021**	**4.022**	**0.000**	**4.276**	**0.008**

DS And: Radius-Temperature Plot

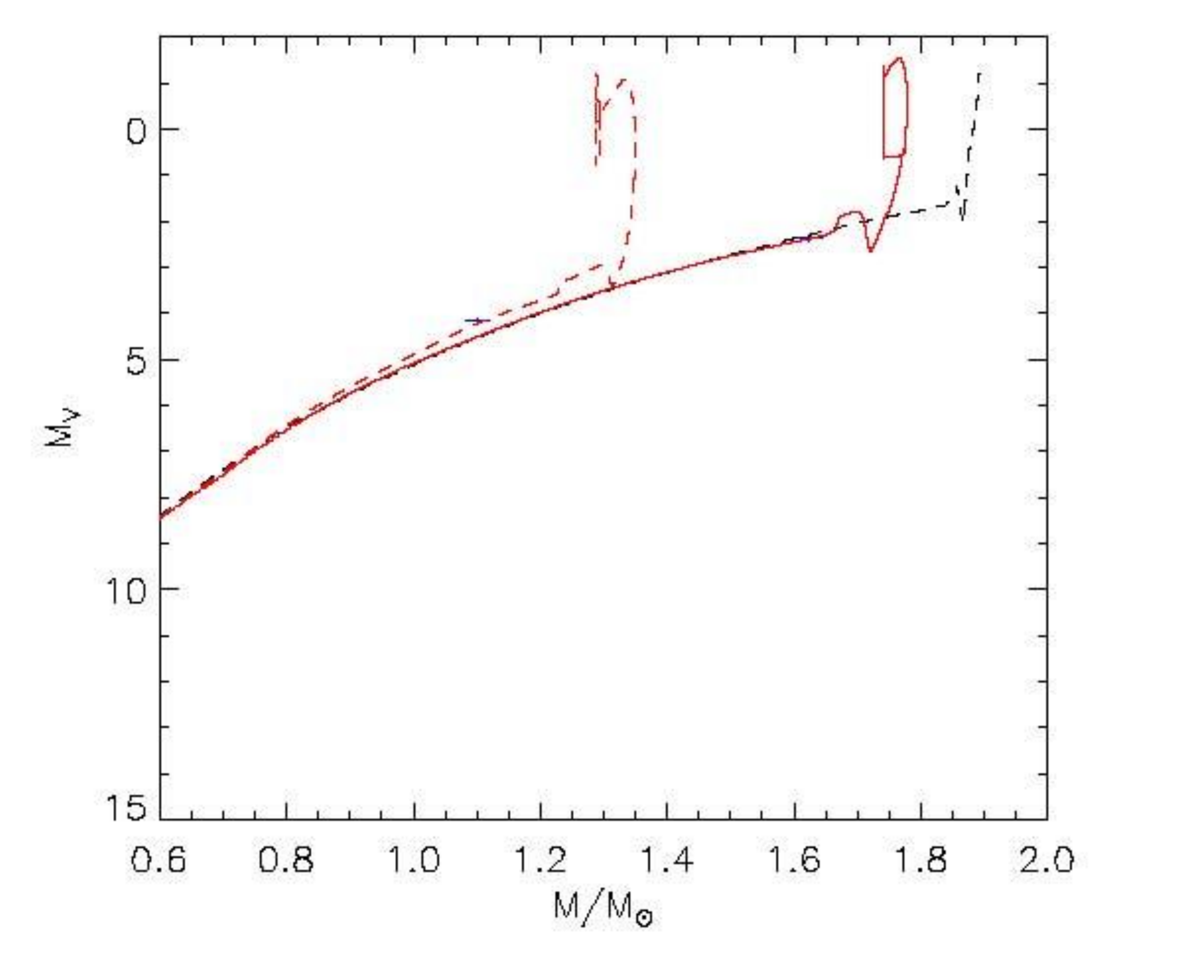
The R-T plot showing approximate locations of stars 1 and 2 superposed on evolutionary tracks (Y2 in black; BaSTI) in red solid curves) and isochrones (dashed curves) corresponding to ages of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 Gy. The Y2 models include overshoot.

From Amby (2011).

Ref to BaSTI: Cassisi et al. (2006);Y2: Spada et al.(2013).



Luminosity vs. Mass Plot



Luminosity vs. Mass Plot showing Stars 1 and 2 superposed on BASTI (red) and Y2 isochrones (black). The solid red and dashed black curves are 1.5 Gy isochrones; the dashed red curve marks a 4.0 Gy isochrone. From Amby (2011), Fig. 6.23

Comments on the DS Andromedae Results

- Effect of different A_V on the parameters is minimal.
- The 2-T solutions tend to have higher Ts than expected from the Flower tables of stellar Ts, colors;
- The 3-pb solutions tend to yield smaller parameter errors than the 2-pb solutions.
- The distance is robust across a range of models.
- Weak dependence of d on [M/H].
- Work continues on the DS And system to explore 3rd light & LC variations, and also on V818 Tau, and on QX And (also in NGC 752).

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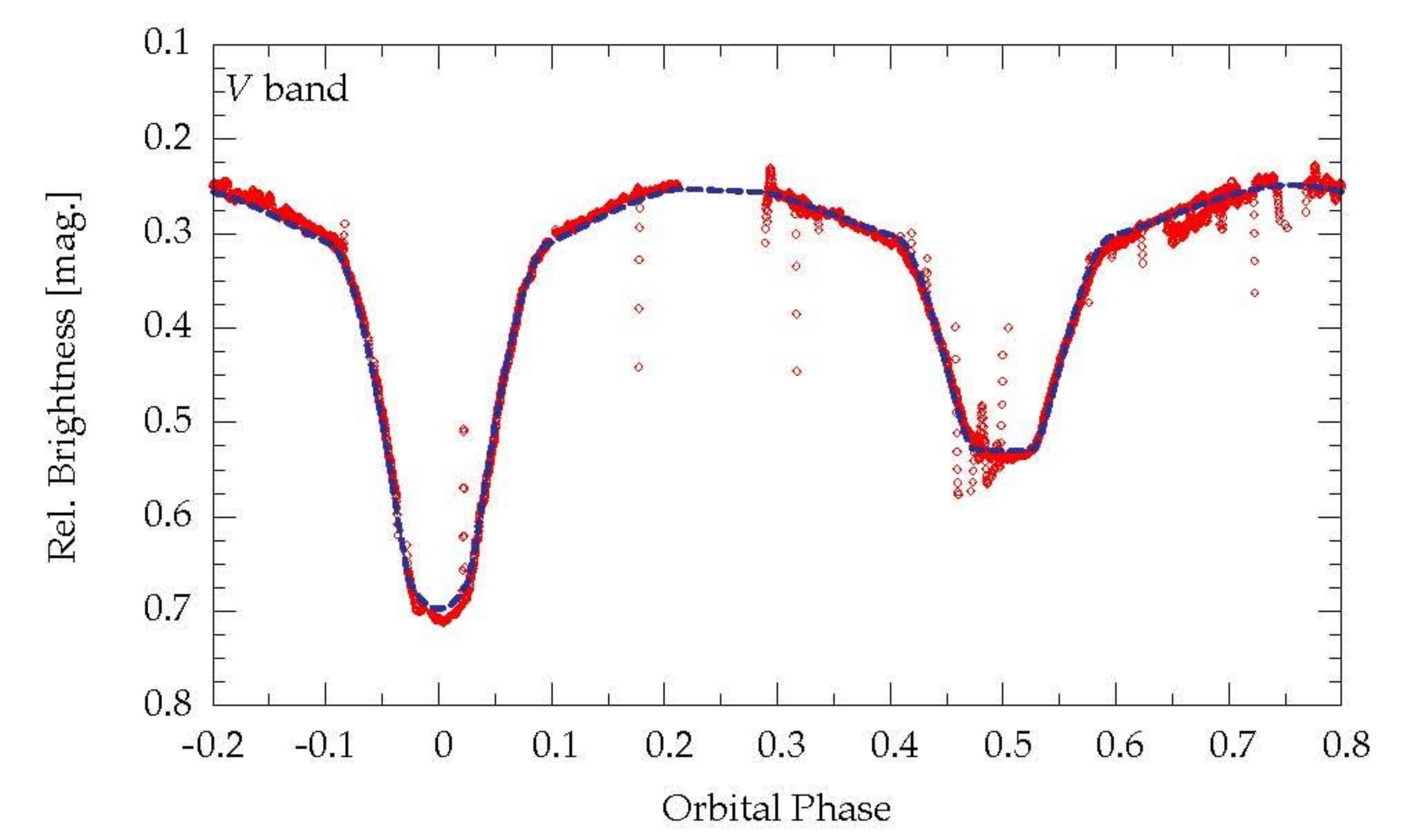
Mahalo nui loa

Spare slides if enough time/questions

Amby (2011) V Keele Light Curve



From Fig. 6.17 of Amby (2011): A smoothed differential V light curve; original data from Keele University. These data were not used in the current analysis.

Comparative RV & LC Adjusted Parameters

Detached, A_V = 0.1, [M/H]= 0 2-pb, 1-T models

Parameter	S&M 1988 (4-pb, S&M RVs)	Model 2 <2-PB, all RVs)>	Model 5 <2pb, all RVs>
a (R_{SUN})	5.77(14)	5.75(1)	5.67(12)
i (degs)	84.3(5)	86.1(5)	85.6(3)
V_{SYS} (km/s)	2.5(20)	6.0(3)	5.0(11)
q = M_2/M_1	0.593(13)	0.567(11)	0.522(34)
t_0 :2436142+	.405(2)	.385(4)	.385(57)
P (d)	1.0105187(2)	1.0105208(4)	1.0105207(8)
T_1 (K)	[6775](200)*	[6775](200:)*	[6965](100:)*
T_2 (K)	5997(17)*	5763(14)*	5913(27)*
$Omega_1$	3.40(2)	3.48(2)	3.38(6)
$Omega_2$	4.09(7)	4.09(5)	3.81(18)

*T_1 fixed, with est. syst. error; T_2 error internal

Comparative RV & LC Adjusted Parameters

Detached, A_V = 0.1, [M/H]= 0, 3=pb Model

Parameter	S&M 1988	<Model 13: 3-PB, all RVs)>
a (R_{SUN})	5.77(14)	5.74(1)
i (degs)	84.3(5)	85.6(1)
V_{SYS} (km/s)	2.5(20)	5.4(2)
$q = M_2/M_1$	0.593(13)	0.547(4)
to :2436142+	0.405(2)	0.396(5)
P (d)	1.0105187(2)	1.0105198(5)
T_1 (K)	6775[200]*	7058(9)
T_2 (K)	5997(17)*	5937(10)
$Omega_1$	3.40(2)	3.43(1)
$Omega_2$	4.09(7)	3.95(2)

*T_1 fixed, with est. syst. error; T_2 error internal

Comparative RV & Light Curve Adjusted Parameters

Parameter	S&M 1987	Model 19 <3-PB, Ambly RVs>
a (Rsun)	5.77(14)	5.79(5)
i (degs)	84.3(5)	86.0(3)
V_{sys} (km/s)	2.5(20)	7.95(1)
$q = M_2/M_1$	0.593(13)	0.617(17)
t_0 :2436142+	0.405(2)	0.4037(3)
P (d)	1.0105187(2)	1.01051878(2)
T_1 (K)	6775[200]*	7060(10)
T_2 (K)	5997(17)*	5921(13)
$Omega_1$	3.40(2)	3.54(3)
$Omega_2$	4.09(7)	4.34(10)

*T_1 fixed, with est. syst. error; T_2 error internal

Comparative Adjusted Parameters

Parameter	S&M 1987	Model 19 <3-PB, Ambly RV)>
L1/(L1+L2) {Ic}	0.823(3)	0.843(2)
“ {Rc}	0.833(4)	0.858(2)
“ {V}	0.846(4)	0.871(1)
“ {B}	0.863(5)	0.898(2)
Log d (pcs)	2.634(30)	2.636(3)
[d, pcs)]	431(30)	432.9(29)
(m-M)	8.17(12)	8.182(15)

Comparative Parameters for 1-T 2-PB, A_V = 0.1, [M/H] = 0 Models

Par./Suite	<Model 5>	<Model 1>	<Model 2>
a (R_{SUN})	5.67(12)	5.71(3)	5.75(1)
i (degs)	85.6(3)	85.8(1)	86.1(5)
V_{Sys} (km/s)	+5.0(11)	+5.3(4)	+6.0(3)
q = M_2/M_1	0.522(34)	0.557(6)	0.567(11)
T_1 (K)	6964*	6795*	6775*
T_2 (K)	5913(27)	5764(34)	5763(14)
$Omega_1$	3.38(6)	3.46(1)	3.48(2)
$Omega_2$	3.81(18)	4.02(3)	4.10(5)
d (pcs)	422(4)	400(1)	393(4)
log d (pcs)	2.63(1)	2.60(01)	2.60(1)

* Fixed

A_V affect on mean DS And Parameters

All RVs, 2-pb, T_1=6775, A_V–range Models

Par./Suite	Model 3 < A_V= 0.075>	Model 2 <A_V= 0.100>	Model 4 <A_V = 0.125>
a (R_{SUN})	5.749(8)	5.477(10)	5.746(8)
i (degs)	85.8(6)	86.0(5)	86.0(6)
V_{SYS} (km/s)	+6.4(1)	+6.0(3)	+6.2(3)
q = M_2/M_1	0.575(8)	0.567(11)	0.573(9)
t_0: 2436142+	.387(2)	.385(4)	.384(4)
P(d) :1.0105...	206(2)	208(4)	208(4)
T_1 (K)	6775*	6775*	6775*
T_2 (K)	5731(8)	5763(14)	5761(17)
$Omega_1$	3.50(1)	3.48(2)	3.50(1)
$Omega_2$	4.13(3)	4.10(4)	4.13(4)
log d (pcs)	2.598(4)	2.595(4)	2.587(6)

* Fixed

Av affect on mean DS And Parameters

2-PB, 1-T (T1= 6964K), all-RVs runs

Par./Suite	6 <0.075>	1<Av= 0.100>	7 <.125>
a (R_{SUN})	5.72(3)	5.67(9)	5.70(1)
i (degs)	85.8(6)	85.6(2)	85.7(3)
V_{Sys} (km/s)	+5.6(6)	+5.0(8)	+5.5(4)
$q = M_2/M_1$	0.553(21)	0.522(26)	0.551(13)
t_0: 2436142+	.3889(57)	.3861(61)	.3897(59)
P(d) :1.0105...	2036(61)	2067(64)	2025(64)
T_1 (K)	6964*	6964*	6964*
T_2 (K)	5874(9)	5913(20)	5903(14)
$Omega_1$	3.434(34)	3.385(44)	3.431(30)
$Omega_2$	3.975(107)	3.809(141)	3.966(76)
d (pcs)	427.7(7)	422.4(44)	394.2(32)
log d (pcs)	2.631(1)	2.626(5)	2.625(3)

A_V affect on mean DS And Parameters
2-PB, 2-T, all-RVs Models

Par./Suite	4 <0.075>	1 <Av= 0.100>	5 <.125>
a (Rsun)	5.754(9)	5.750(9)	5.754(8)
i (degs)	85.67(14)	85.66(15)	85.73(29)
Vs (km/s)	+5.8(3)	+5.8(3)	+5.9(3)
$q = M_2/M_1$	0.560(8)	0.560(8)	0.568(6)
To: 2436142+	.3896(68)	.3899(67)	.3897(65)
P(d) :1.0105...	2030(71)	2067(64)	2027(69)
T_1 (K)	6998(2)	7041(3)	7083(3)
T_2 (K)	5879(13)	5913(20)	5943(12)
$Omega_1$	3.445(15)	3.443(16)	3.450(15)
$Omega_2$	4.008(42)	4.009(42)	4.029(43)
d (pcs)	433.6(14)	434.1(18)	434.7(16)
log d (pcs)	2.6371(14)	2.6376(18)	2.6382(16)

Av affect on mean DS And Parameters
3-PB, 2-T, all-RVs Modeling

Par./Suite	**8 <0.075>**	**9 <Av= 0.100>**	**10 <.125>**
a (Rsun)	5.748(6)	5.750(5)	5.749(4)
i (degs)	85.65(6)	85.64(5)	85.65(6)
V_{SYS} (km/s)	+5.5(1)	+5.6(1)	+5.6(1)
$q = M_2/M_1$	0.553(5)	0.556(2)	0.558(2)
To: 2436142+	.3935(33)	.3941(33)	.3946(32)
P(d) :1.0105...	1972(44)	1981(35)	1984(44)
T_1 (K)	7012(10)	7056(9)	7099(9)
T_2 (K)	5938(18)	5968(18)	6004(19)
$Omega_1$	3.436(6)	3.438(4)	3.439(3)
$Omega_2$	3.987(23)	4.001(13)	4.010(7)
d (pcs)	440(2)	441(2)	442(2)
log d (pcs)	2.643(2)	2.645(2)	2.645(2)

DS And Absolute Parameters

Av = 0.100 assumed

Param/Suite	S&M88	Model 9# 3-pb, 2-T	<3-pb Ambly RV>#
M1 (Msun)	1.58(17)	1.613(5)	1.555(36)
M2 (Msun)	0.94(10)	0.882(8)	0.939(51)
R1 (Rsun)	2.10(8)	2.046(4)	2.015(18)
R2 (Rsun)	1.19(5)	1.163(5)	1.137(8)
Mbol1	2.34(15)	2.325(7)	2.358(20)
Mbol2	4.15(19)	4.308(9)	4.365(12)
log g 1	[4.21(4)]	4.023(3)	4.020(4)
log g 2	[4.24(4)]	4.253(3)	4.295(21)
L1 (Lsun)	[8.7(12)]*	9.55(6)**	9.05(17)**
L2 (Lsun)	1.6(3)*	1.57(2)**	1.43(2)**
(m-M)o	8.17(15)	8.211(6)	8.182(15)

*Mbol_sun = 4.69; **Mbol_sun = 4.75; #[M/H] = 0.000 assumed