Fundamental Properties of O- and B-type Stars

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GSU

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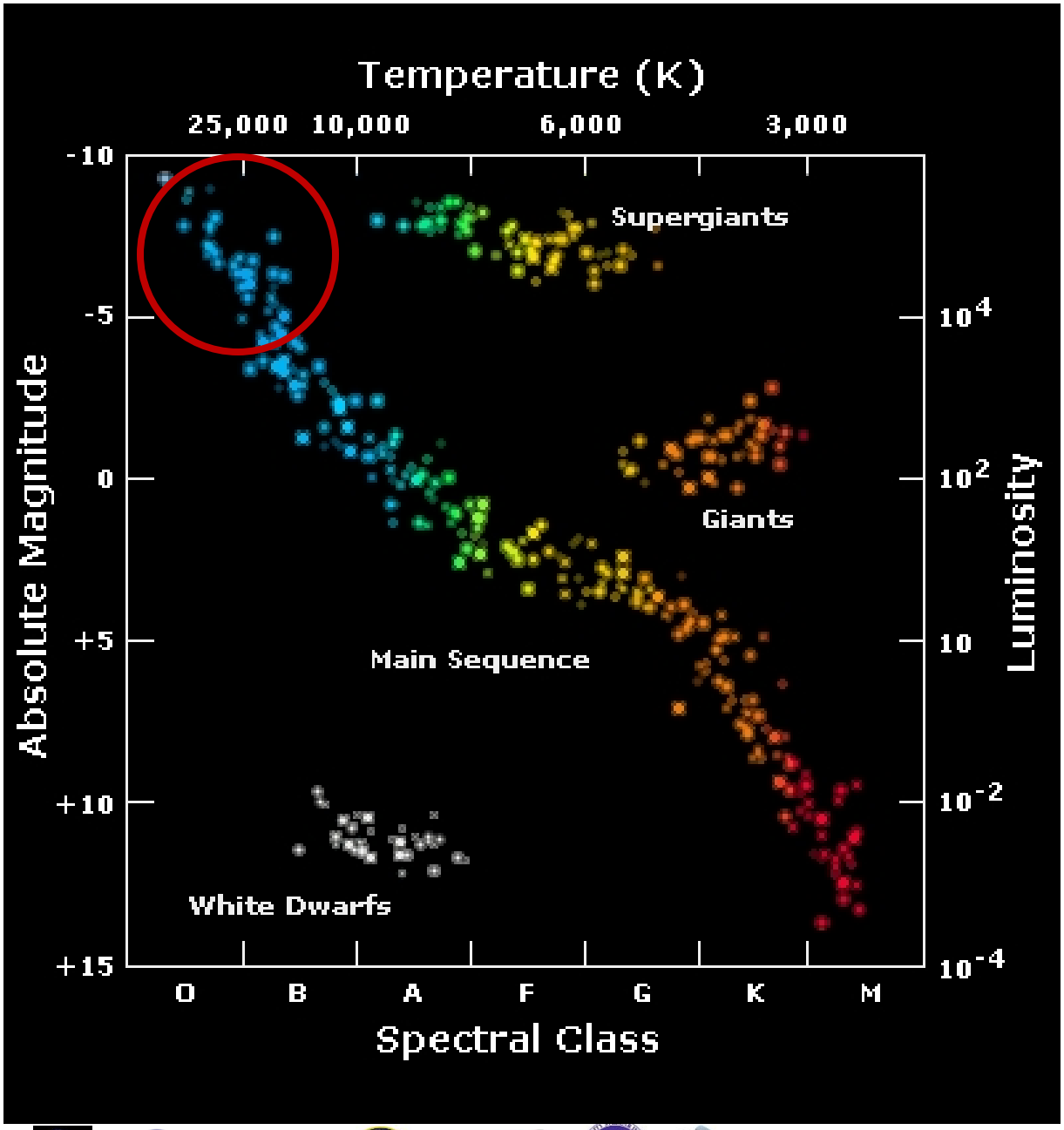
Why do we care?



Hanbury Brown et al. (1974)

4 O stars
16 B stars

Overlap with our sample:

2 O stars
2 B stars

TABLE III

The uniform disc angular diameters, true angular diameters and normalized zero-baseline correlations for 32 stars

1	2	3	4	5	6
B.S.	Name	MK	$C_N \pm \sigma$ (normalized)	$\bar{\theta}_{UD} \pm \sigma$ (10^{-3} seconds of arc)	$\theta_{LD} \pm \sigma$ (10^{-3} seconds of arc)
472	α Eri	‡B3 Vp	0·98 ± 0·05	1·85 ± 0·07	1·92 ± 0·07
1713	β Ori	†B8 Ia	0·98 ± 0·08	2·43 ± 0·05	2·55 ± 0·05
1790	γ Ori	†B2 III	1·03 ± 0·07	0·70 ± 0·04	0·72 ± 0·04
1903	ε Ori	†Bo Ia	0·86 ± 0·07	0·67 ± 0·04	0·69 ± 0·04
1948	ζ Ori	**O9·5 Ib	0·60 ± 0·06	0·47 ± 0·04	0·48 ± 0·04
2004	κ Ori	†Bo·5 Ia	1·18 ± 0·09	0·44 ± 0·03	0·45 ± 0·03
2294	β CMa	*B1 II–III	1·07 ± 0·08	0·50 ± 0·03	0·52 ± 0·03
2326	α Car	Fo Ib–II	0·75 ± 0·22	6·1 ± 0·7	6·6 ± 0·8
2421	γ Gem	**Ao IV	1·17 ± 0·09	1·32 ± 0·09	1·39 ± 0·09
2491	α CMa	A1 V	0·91 ± 0·06	5·60 ± 0·15	5·89 ± 0·16
2618	ε CMa	**B2 II	0·89 ± 0·06	0·77 ± 0·05	0·80 ± 0·05
2693	δ CMa	**F8 Ia	0·93 ± 0·18	3·29 ± 0·46	3·60 ± 0·50
2827	η CMa	†B5 Ia	0·99 ± 0·09	0·72 ± 0·06	0·75 ± 0·06
2943	α CMi	F5 IV–V	0·98 ± 0·10	5·10 ± 0·16	5·50 ± 0·17
3165	ζ Pup	†O5 f	1·04 ± 0·08	0·41 ± 0·03	0·42 ± 0·03
3207	γ^2 Vel	§WC8 + O9 I	—	0·43 ± 0·05	0·44 ± 0·05
3685	β Car	A1 IV	1·01 ± 0·06	1·51 ± 0·07	1·59 ± 0·07
3982	α Leo	**B7 V	1·12 ± 0·07	1·32 ± 0·06	1·37 ± 0·06
4534	β Leo	**A3 V	1·17 ± 0·10	1·25 ± 0·09	1·33 ± 0·10
4662	γ Crv	B8 III	0·97 ± 0·10	0·72 ± 0·06	0·75 ± 0·06
4853	β Cru	‡Bo·5 III	0·88 ± 0·03	0·702 ± 0·022	0·722 ± 0·023
5056	α Vir	*B1 IV	—	0·85 ± 0·04	0·87 ± 0·04
5132	ε Cen	‡B1 III	1·02 ± 0·07	0·47 ± 0·03	0·48 ± 0·03
5953	δ Sco	†Bo·5 IV	0·75 ± 0·07	0·45 ± 0·04	0·46 ± 0·04
6175	ζ Oph	**O9·5 V	1·01 ± 0·12	0·50 ± 0·05	0·51 ± 0·05
6556	α Oph	**A5 III	0·94 ± 0·09	1·53 ± 0·12	1·63 ± 0·13
6879	ε Sgr	Ao V	1·02 ± 0·06	1·37 ± 0·06	1·44 ± 0·06
7001	α Lyr	†Ao V	0·99 ± 0·04	3·08 ± 0·07	3·24 ± 0·07
7557	α Aql	A7 IV, V	0·94 ± 0·06	2·78 ± 0·13	2·98 ± 0·14
7790	α Pav	‡B2·5 V	1·01 ± 0·07	0·77 ± 0·05	0·80 ± 0·05
8425	α Gru	‡B7 IV	1·11 ± 0·08	0·98 ± 0·07	1·02 ± 0·07
8728	α PsA	†A3 V	1·02 ± 0·08	1·98 ± 0·13	2·10 ± 0·14

Our sample

- **Started with: 10 O stars, 189 B stars**
  - **~0 to 5 mag**
  - **In or near galactic plane**

- **Narrowed down to: 10 O stars, 67 B stars**
  - **Use all O stars**
  - **B stars with Hipparcos parallax errors < 10%**
  - **Cluster member**
  - **No Be stars**

Closest O star: zeta Oph (HD 149757) - 140±14 pc
Farthest O star: alpha Cam (HD 30614) - 1900±700 pc

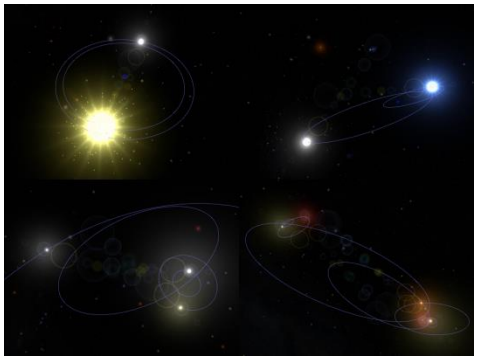
Closest B star: alpha And (HD 358) – 29.8±0.6 pc
Farthest B star: gamma Lyr (HD 176437) - 195±19 pc

8 B stars within 50 pc
37 B stars within 100 pc
30 B stars > 100 pc

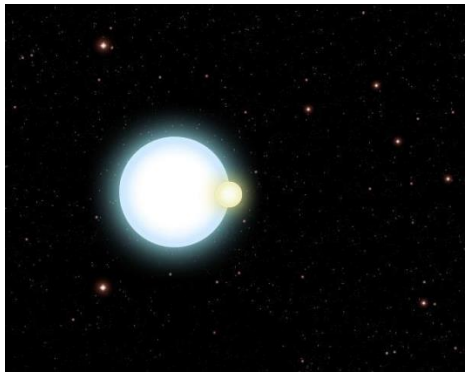
Expected sizes: 0.2 – 1.4 mas

V: 48% IV: 17% III: 27% II: 5% I: 3%

(2)



(3)



(4)

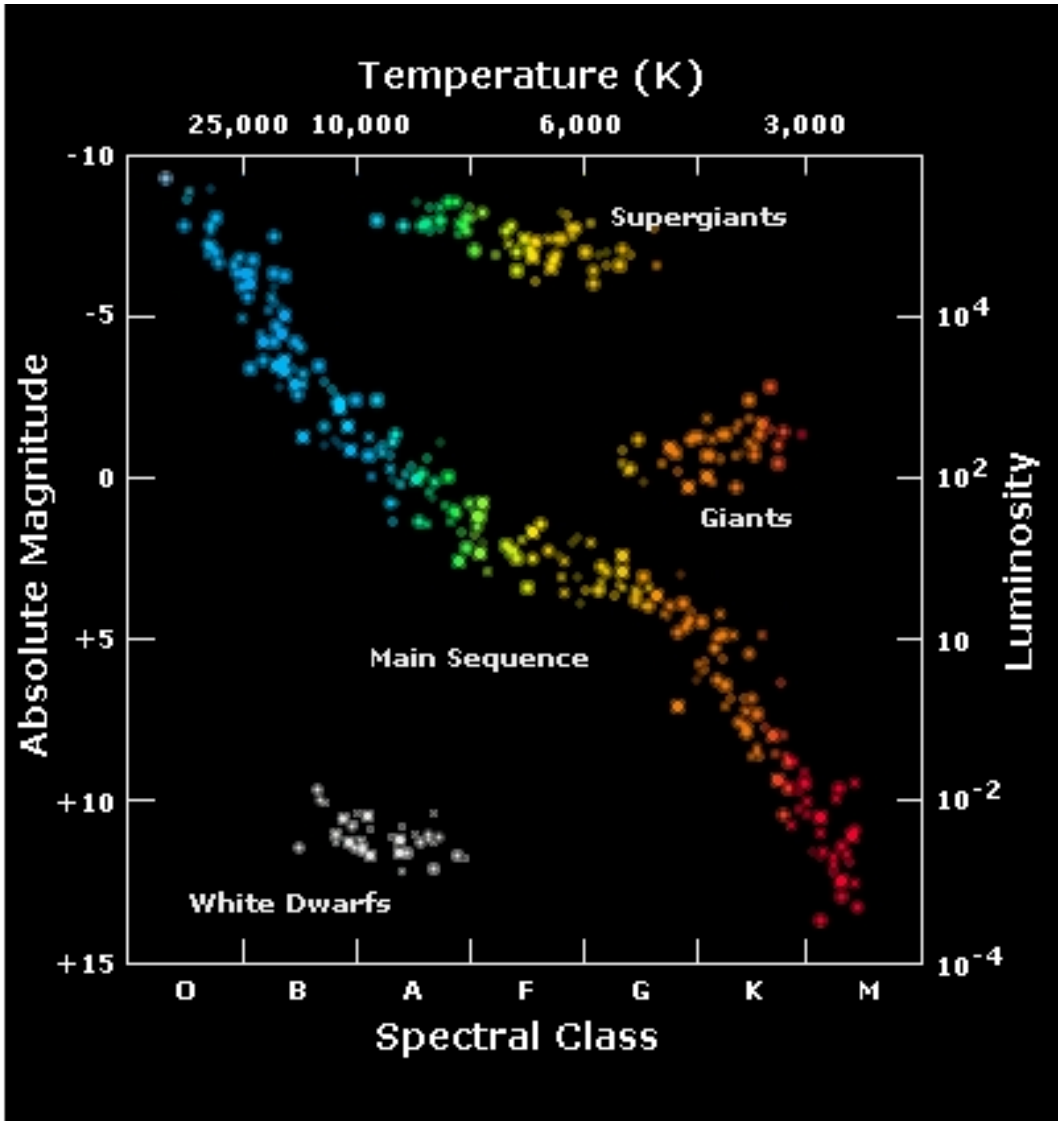
- **Many massive stars are in binary or multiple star systems! (opportunity?)**
- **Not many stars nearby → smaller angular sizes**
- **Working close to resolution limits of CHARA**
- **Good calibrators harder to find**

- **Multiple baseline data important for rotation/shape**
- **10 brackets for each star desired**
- **83% of sample to be observed with PAVO**
- **22% of sample to be observed with CLIMB**

Our Goals

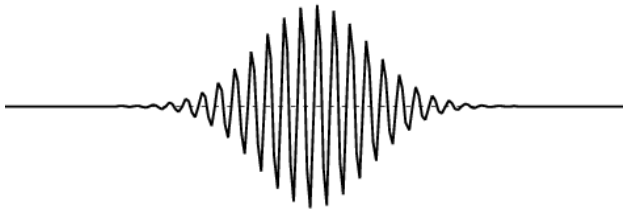
- Radius, temperature, mass, age

- Model dependent!
  - Color and spectra
  - Large errors in luminosity



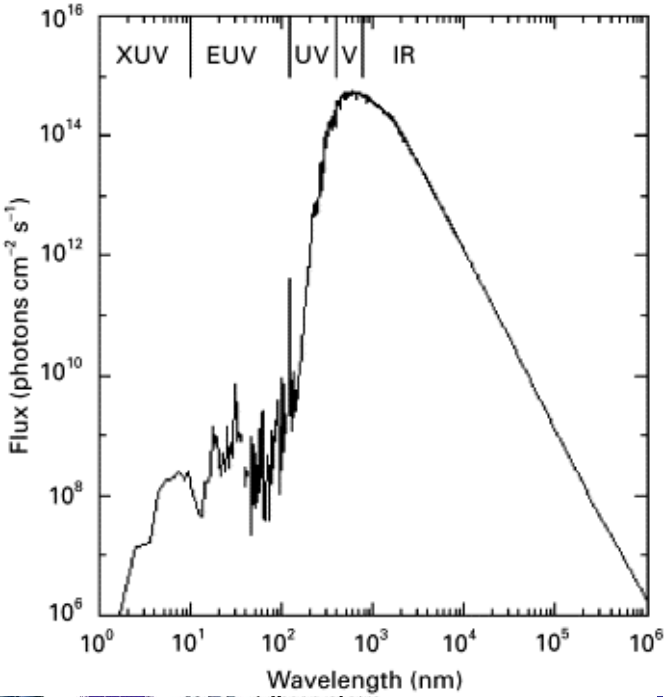
Observationally determined properties

- **Angular size + distance → Radius**
  - **» Interferometry**



- **Integrated flux + angular size → Effective Temperature**
  - **» Spectrophotometry**

$$F_{obs} = \frac{1}{4}\alpha^2 F_{em} \qquad F_{em} = \sigma T_{eff}^4$$

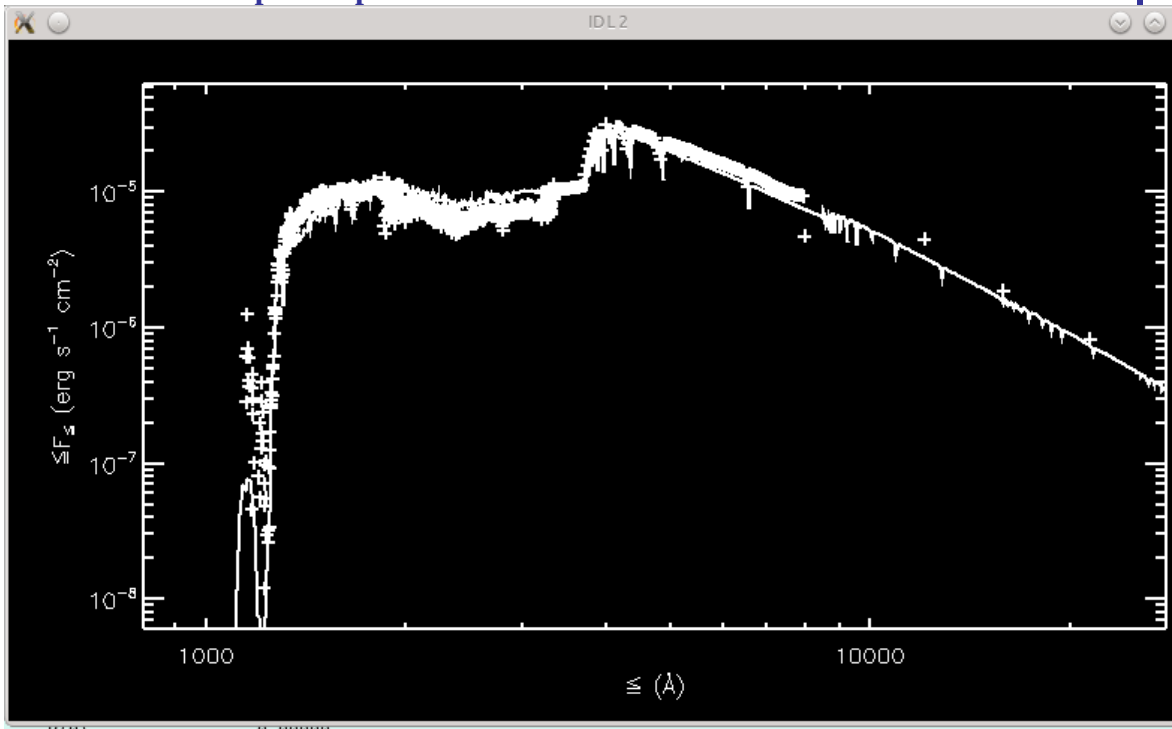


Spectrophotometry:

UV from IUE (1150-3347 Å)

Optical from Burnashev et al., 1985 (3200-8175 Å)

IR from 2MASS (J, H, and K)



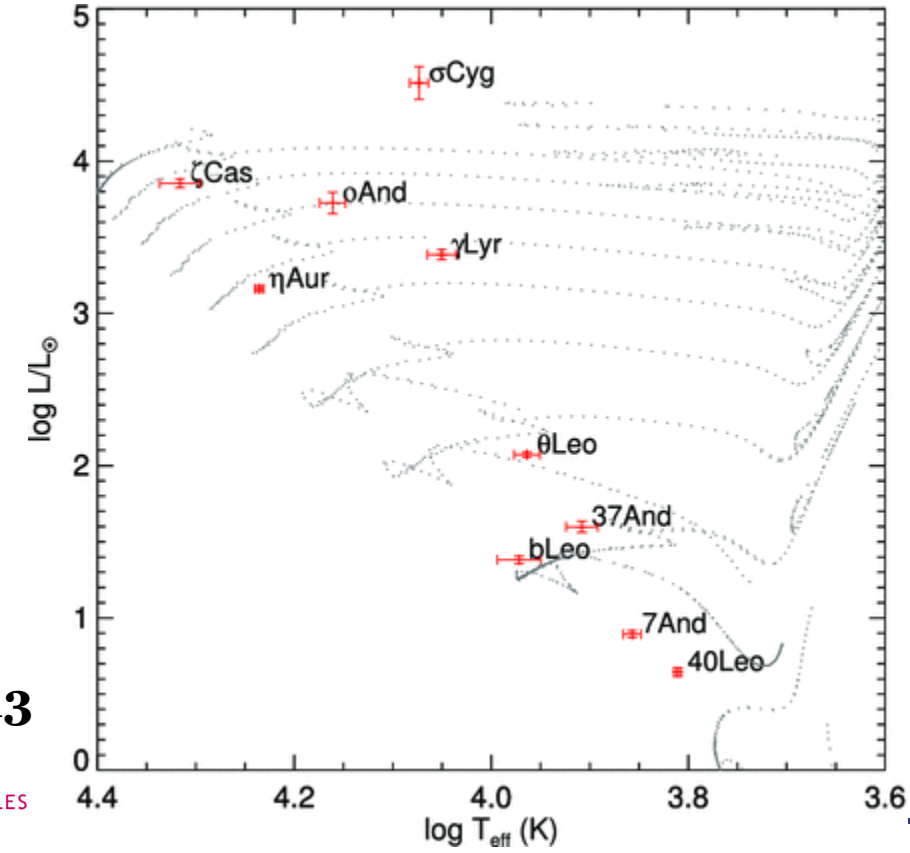

```
    P(0) =              0.00000
    P(1) =              1.56562
Iter     17   CHI-SQUARE =       37540.114          DOF = 1226
    P(0) =              0.00000
    P(1) =              2.51792
Iter     18   CHI-SQUARE =       28870.441          DOF = 1226
    P(0) =              0.00000
    P(1) =              2.85306
Iter     19   CHI-SQUARE =       28837.870          DOF = 1226
    P(0) =              0.00000
    P(1) =              2.87630
Iter     20   CHI-SQUARE =       28837.869          DOF = 1226
    P(0) =              0.00000
    P(1) =              2.87639
Iter     20   CHI-SQUARE =       28837.869          DOF = 1226
    P(0) =              0.00000
    P(1) =              2.87639
 E(B-V) =   0.000 +/- 0.007 (mag)
 R      =  3.1
 theta  =  2.8764 +/- 0.0746 (mas)
Total Flux=   2.6052651e-05
Effective Temperature =       9537.5188
Radius(solar units) =       2.5355837+/-      0.17499250
Luminosity(solar units) =       47.902476
IDL>
```

- **Radius + Temperature → Luminosity**

$$L = 4\pi R^2 \sigma T^4$$

- **Plot L and T on HR diagram**

- **Evolutionary tracks → mass and age**

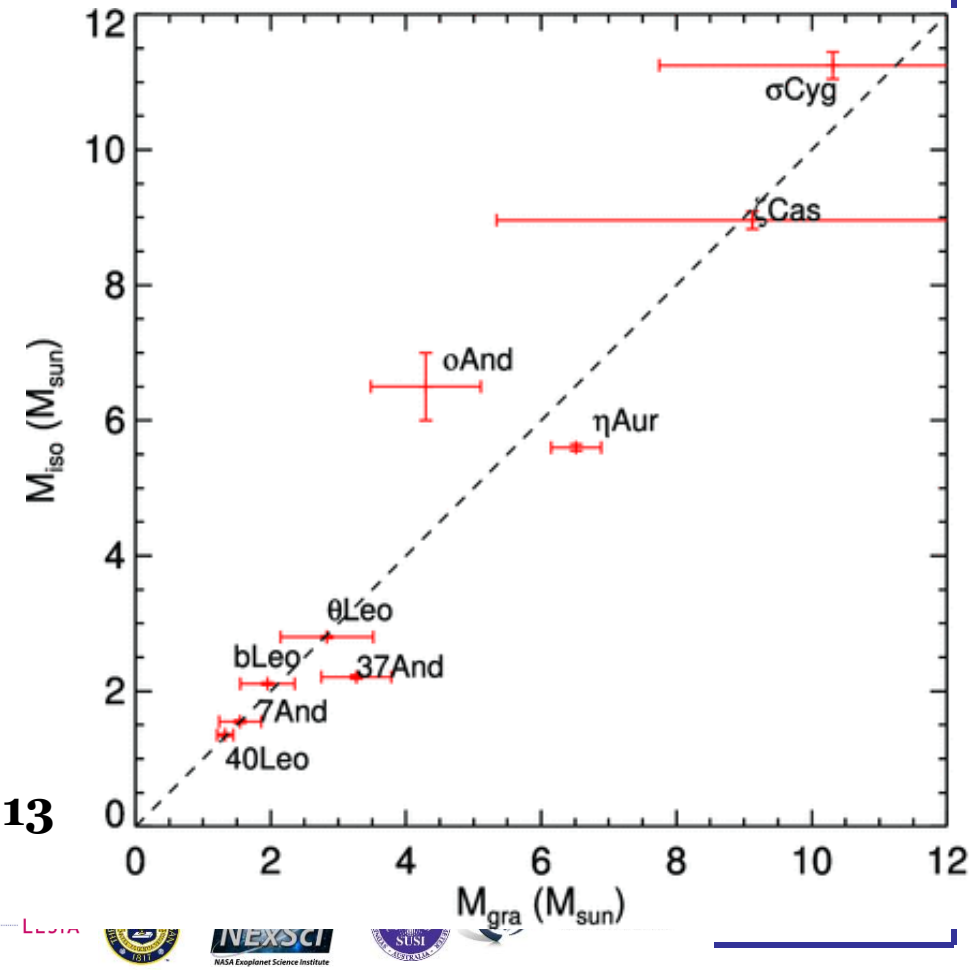


Maestro et al., 2013

Compare to spectroscopy → T_{eff} and log(g)

Log(g) + Radius → another way to get Mass

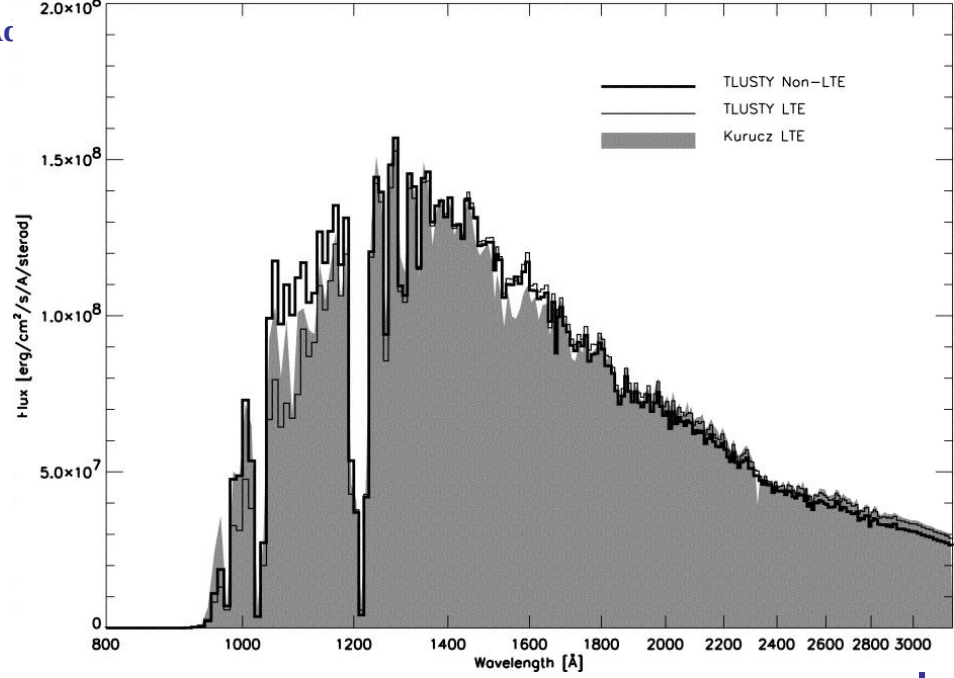
$$g = G\frac{M}{R^2}$$



Maestro et al., 2013

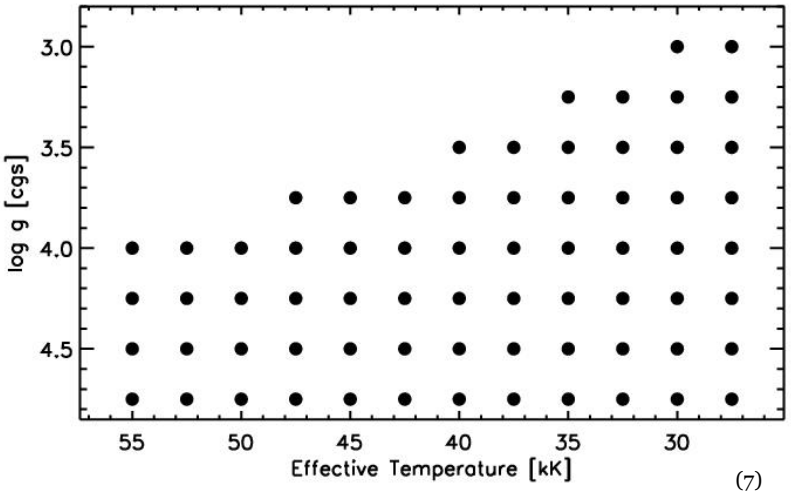
Stellar Atmosphere Models:

Kurucz – 3,000 – 50,000 K



(6)

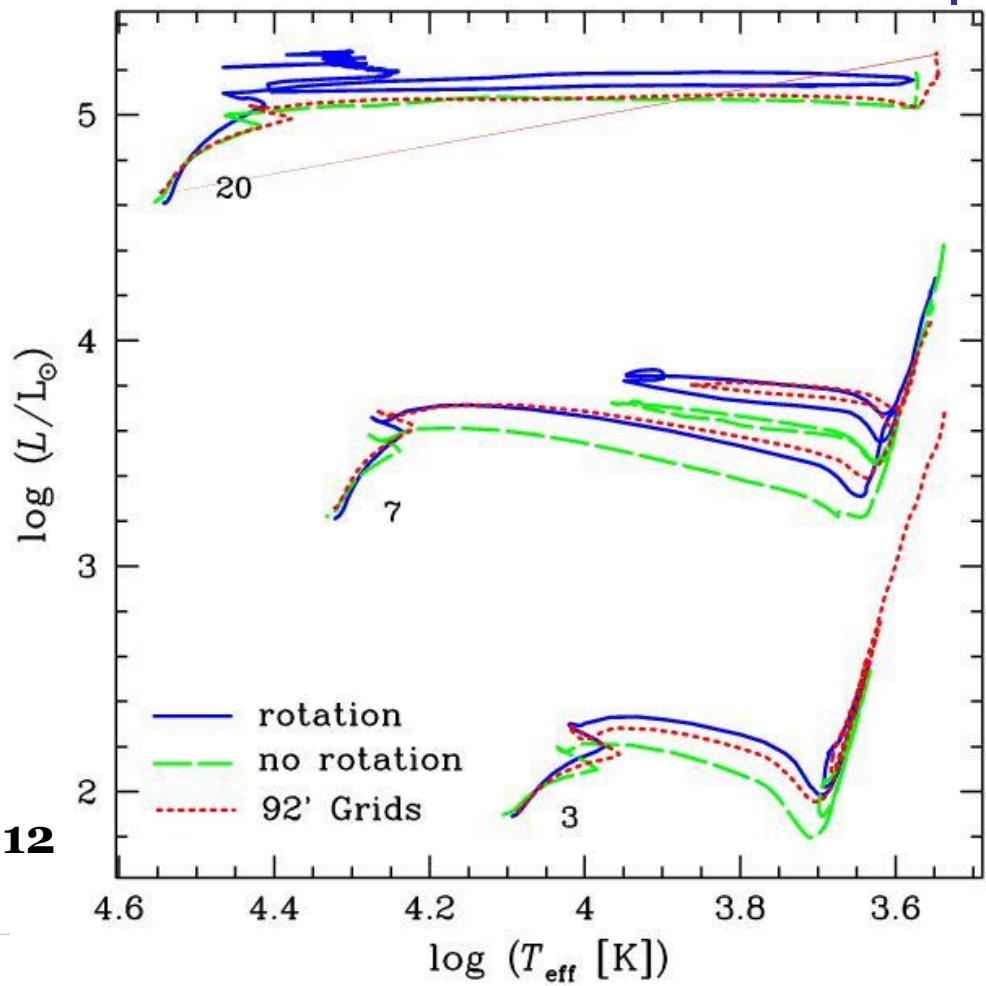
TLUSTY – 15,000 – 55,000 K
NLTE



(7)

Stellar Evolution Models:

Geneva – 0.8 – 120M_0
models with rotation and magnetic fields



Ekstrom et al., 2012

Data and results so far

Nights scheduled: 37
(from 2012-2014)

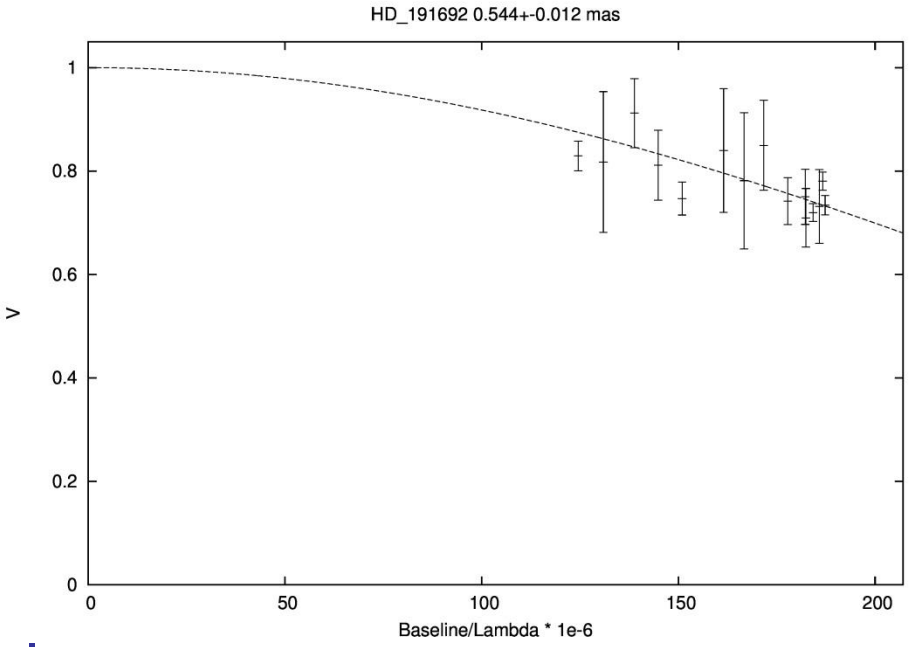
Nights with data: 15

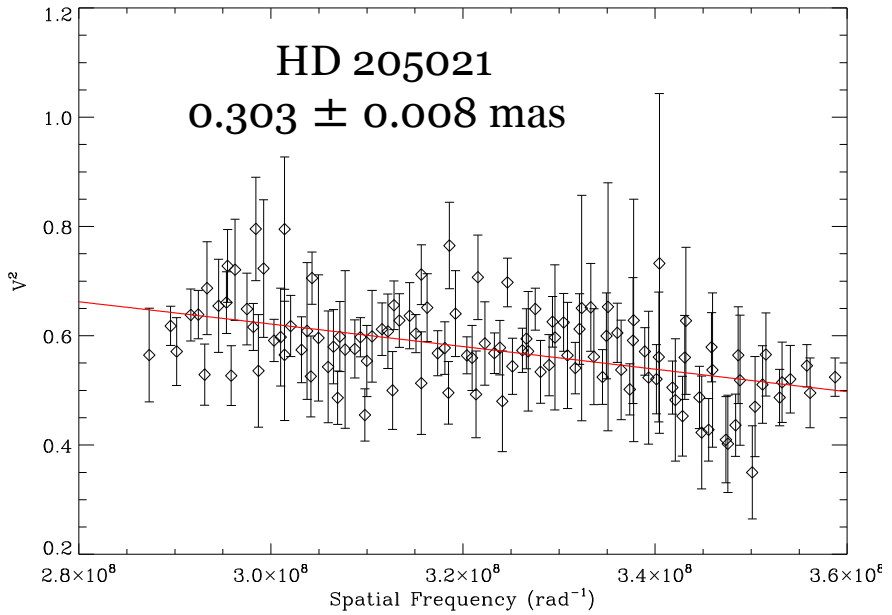
Data on 29 stars

Diameters for 24 stars (2 0 stars – alpha Cam and HD 214680)

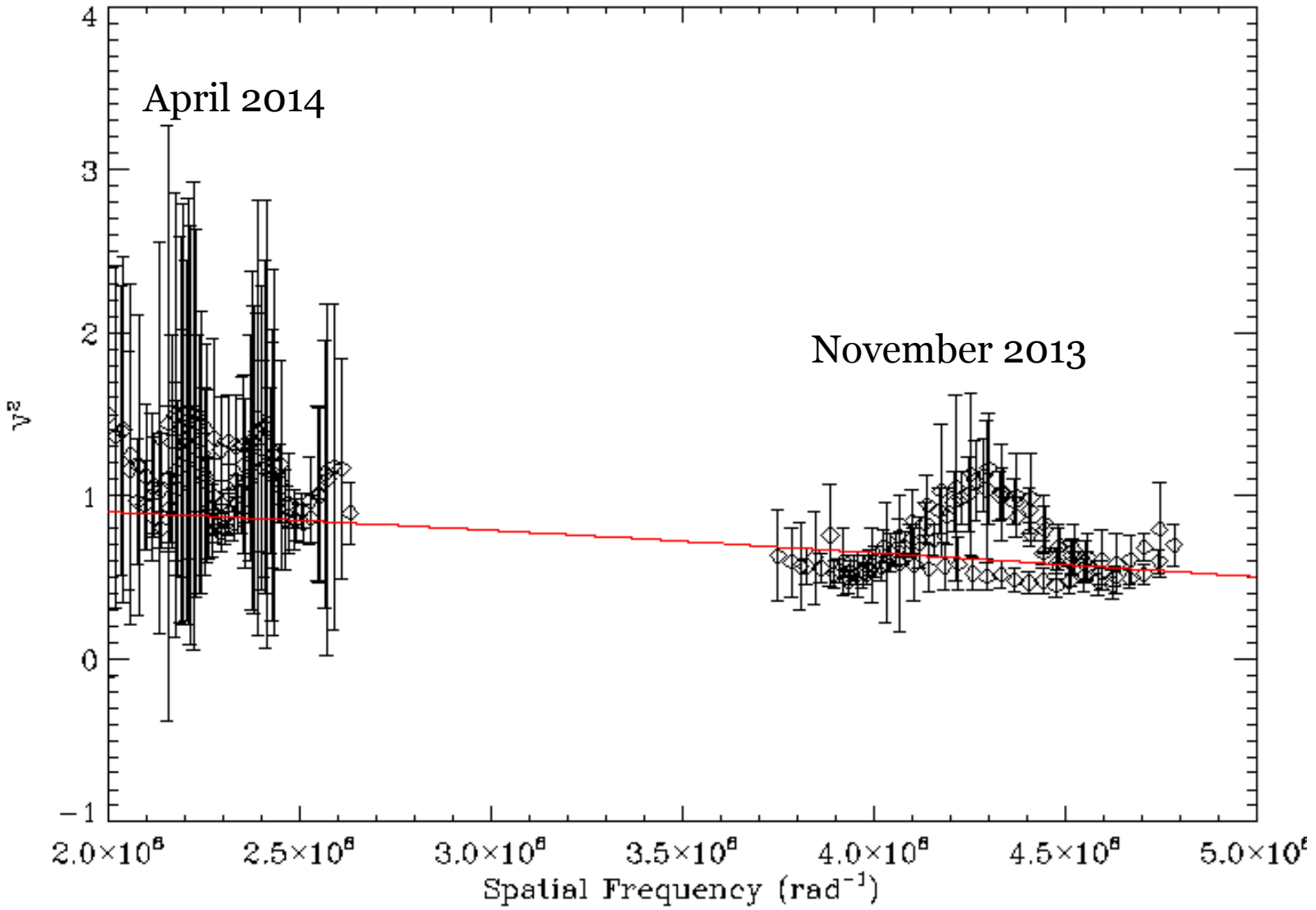
Data fit with standard CLIMB or PAVO pipeline

Use a linear limb darkened fit with limb darkening coefficients taken from Claret et al., 2011





λ Ori

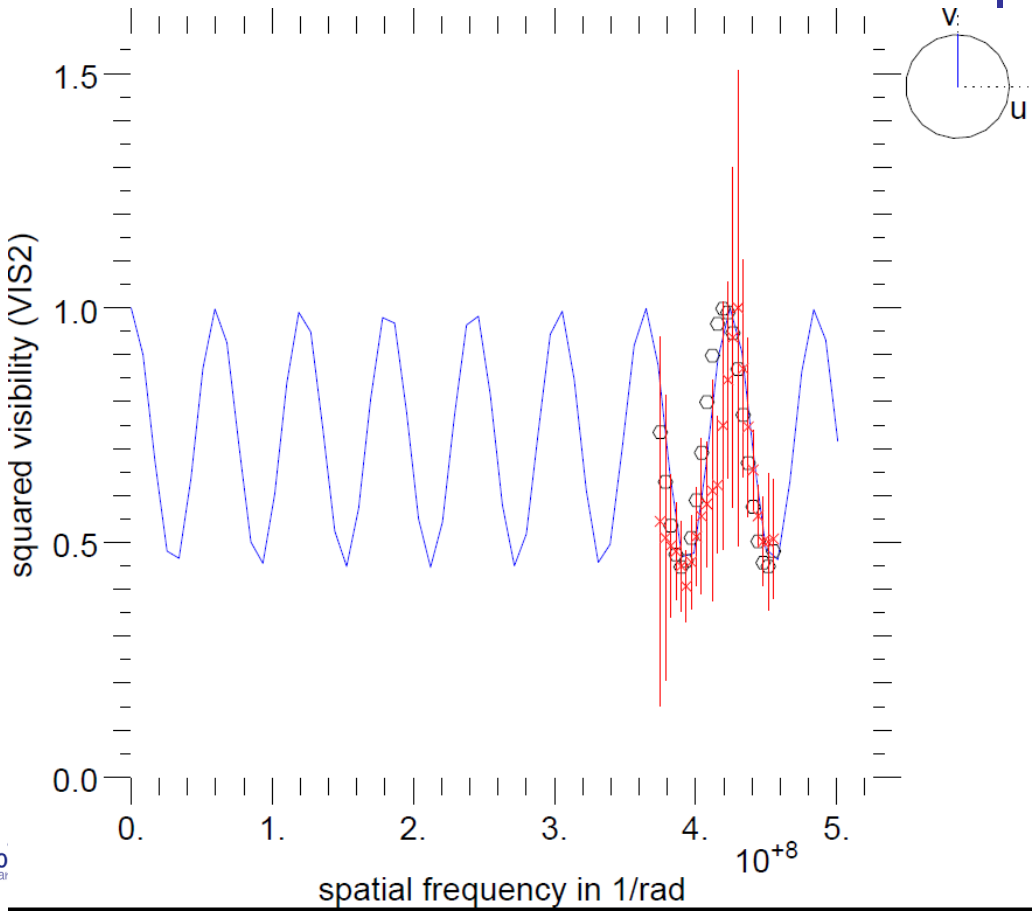

April 2014
November 2013
V²
Spatial Frequency (rad⁻¹)
4
3
2
1
0
−1
2.0×10⁶
2.5×10⁶
3.0×10⁶
3.5×10⁶
4.0×10⁶
4.5×10⁶
5.0×10⁶

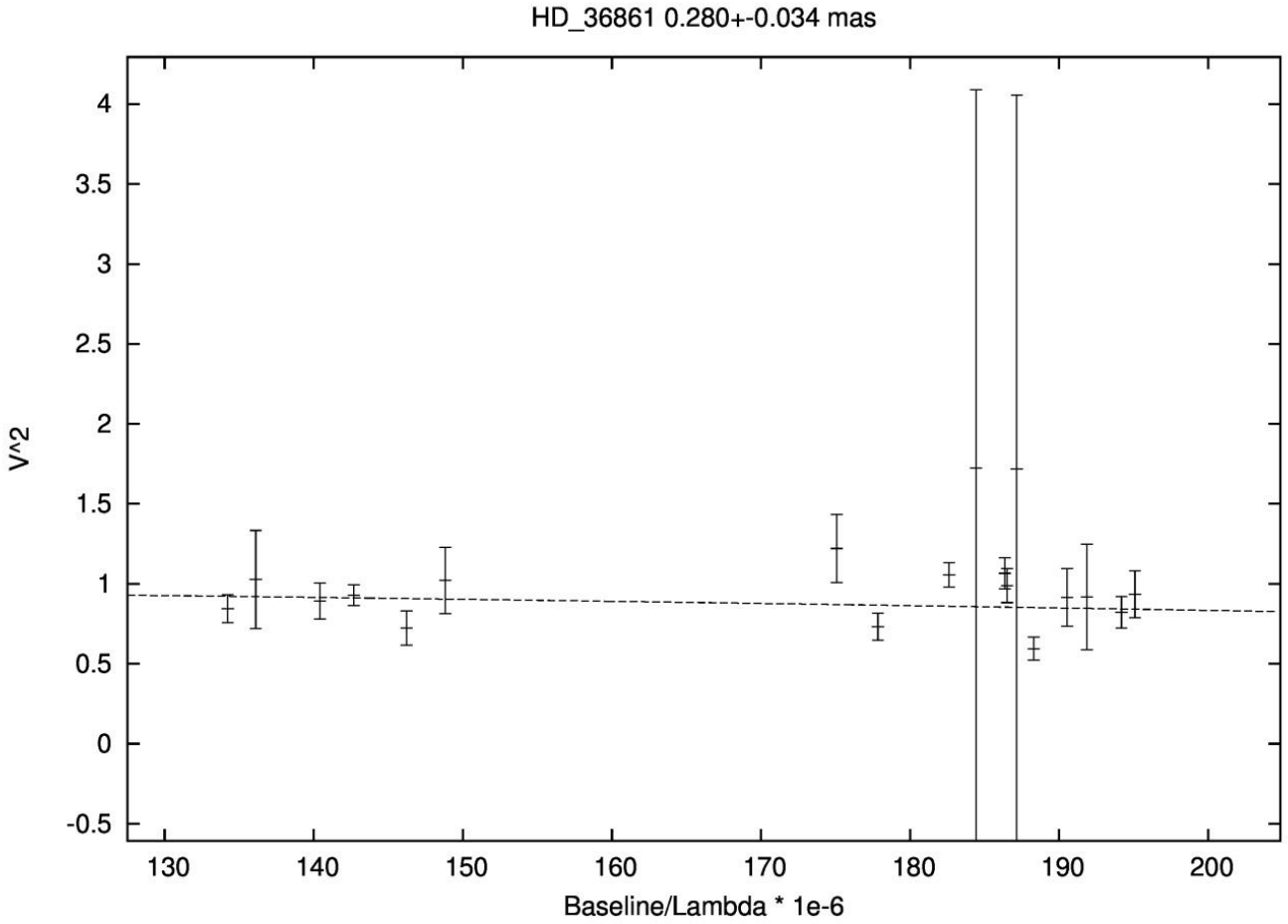
In general: O8III star at 324 pc

assume $23M_0$ and $20M_0$ for companion based on flux ratio of $f_2/f_1=0.8$

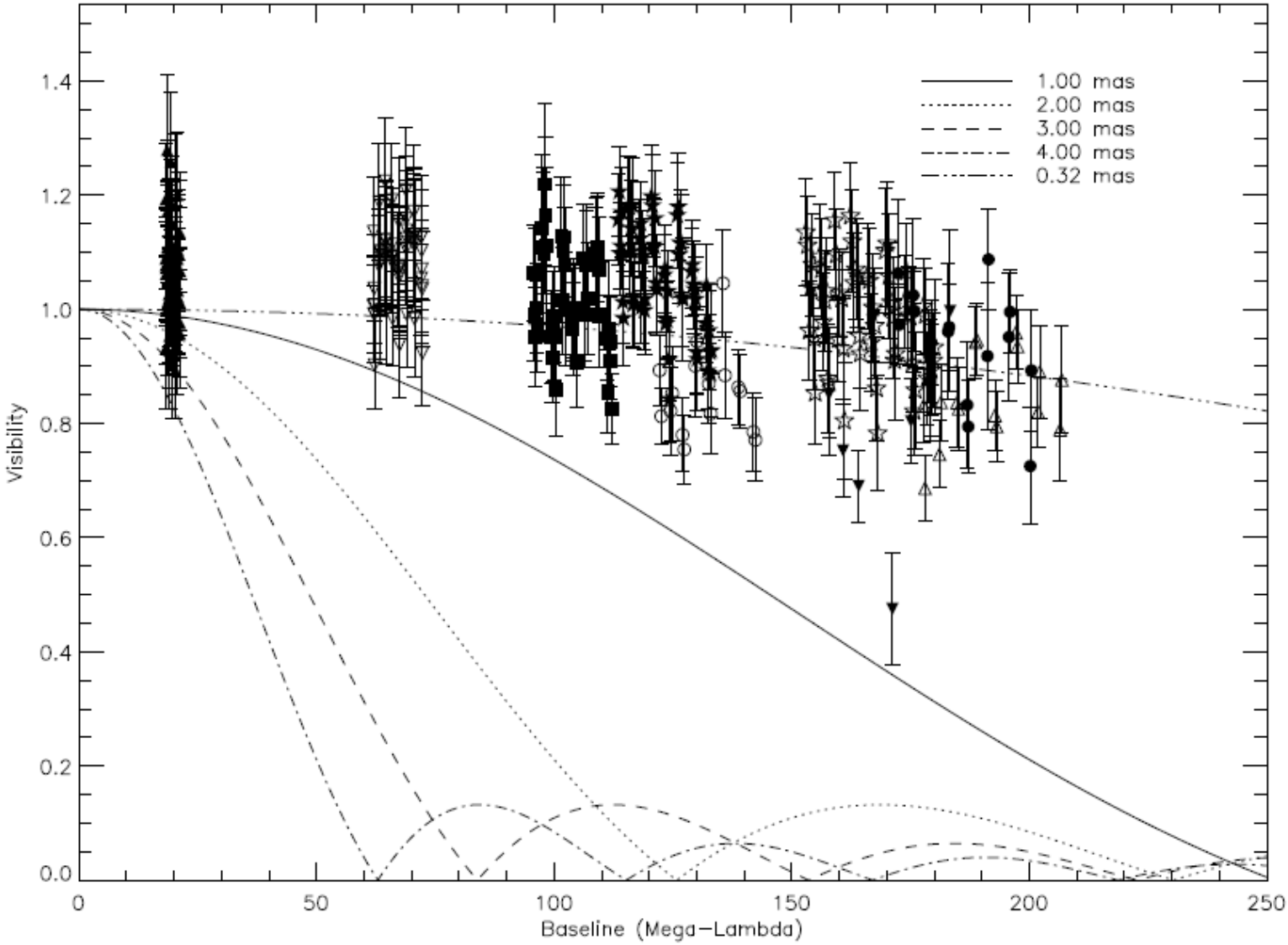
1 - 4 mas
0.32 – 1.3 AU
10 - 83 days

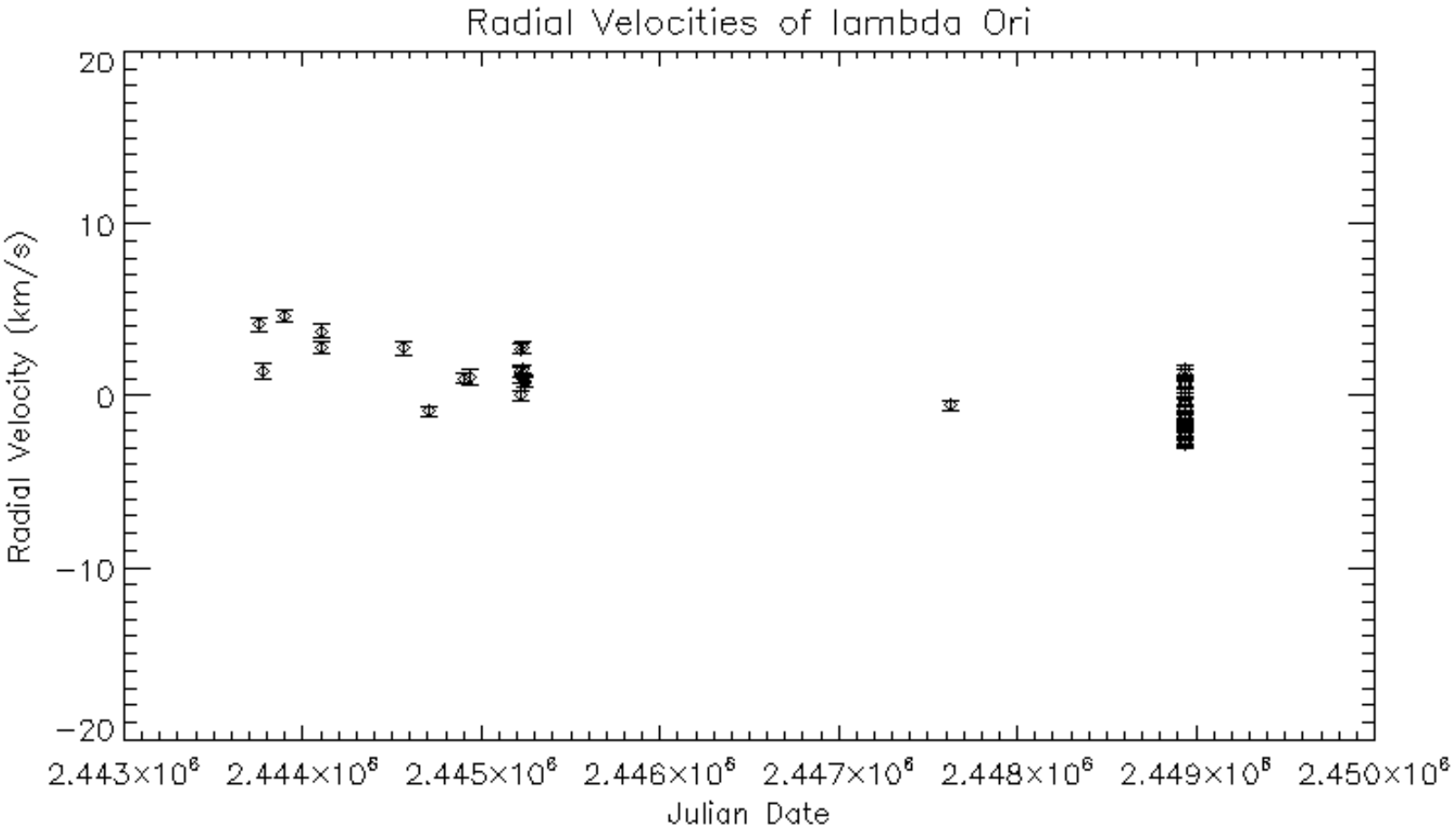
1 bracket fit:
separation = 4 mas
= 1.3 AU
Period = 83 days





Need MIRC data?


1.00 mas
2.00 mas
3.00 mas
4.00 mas
0.32 mas
Visibility
Baseline (Mega−Lambda)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
50
100
150
200
250


Radial Velocities of lambda Ori
Radial Velocity (km/s)
20
10
0
−10
−20
2.443×10^6
2.444×10^6
2.445×10^6
2.446×10^6
2.447×10^6
2.448×10^6
2.449×10^6
2.450×10^6
Julian Date

Future work

- More data!
- Reconcile spectrophotometry fitting size differences
- Be able to fit binaries more reliably (SIMTOI)
- Fit data with one routine to help normalize and understand errors
- Place stars on evolutionary tracks and compare with models


Questions?

Picture Credits

(1) http://sci.esa.int

(2) http://minsex.blogspot.com/2010/11/binary-star-ogle-lmc-cep0227.html

(3) http://www.mpl3d.com/solar.htm

(4) http://www.sciencedaily.com/releases/2010/05/100519092704.htm

(5) Tobiska, W.K. et al., 2000. Journal of Atmospheric and Solar-Terrestrial Physics 62, 1233.

(6) http://iopscience.iop.org/0004-637X/552/1/278/fulltext/52210.fg5.html

(7) http://nova.astro.umd.edu/

(8) http://www.thisissadface.com/2011_05_01_archive.html