Boris Gänsicke

THE UNIVERSITY OF WARWICK

Eclipsing binaries, something different

York 2014
To commemorate the 250th anniversary
of the birth of John Goodricke

John Goodricke

White dwarfs

Cosmology

Eclipsing binaries

Masses and radii

Extra-solar planets

Cataclysmic variables

Life

John Goodricke

White dwarfs

Cosmology

Eclipsing binaries

Masses and radii

Extra-solar planets

Cataclysmic variables

Life

Measuring orbital periods

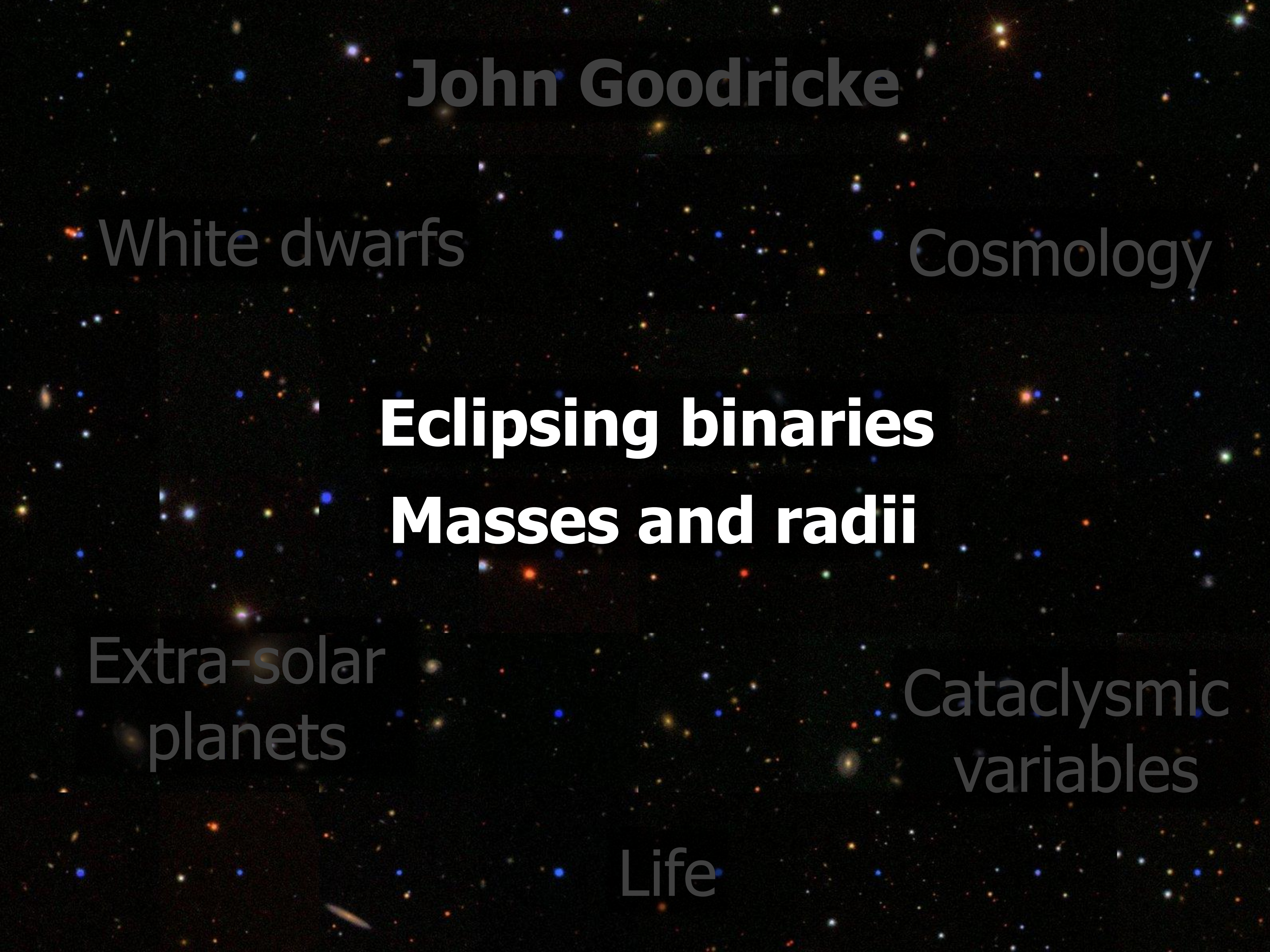
ſingular variation is only about *ſeven hours*. And, ſecondly, it appears alſo, that this variation probably recurs about every *two days and twenty-one hours*. This laſt concluſion will be ren-

Goodricke, 1783, Philosophical Transactions of the Royal Society of London, Volume 73, pp. 474-482

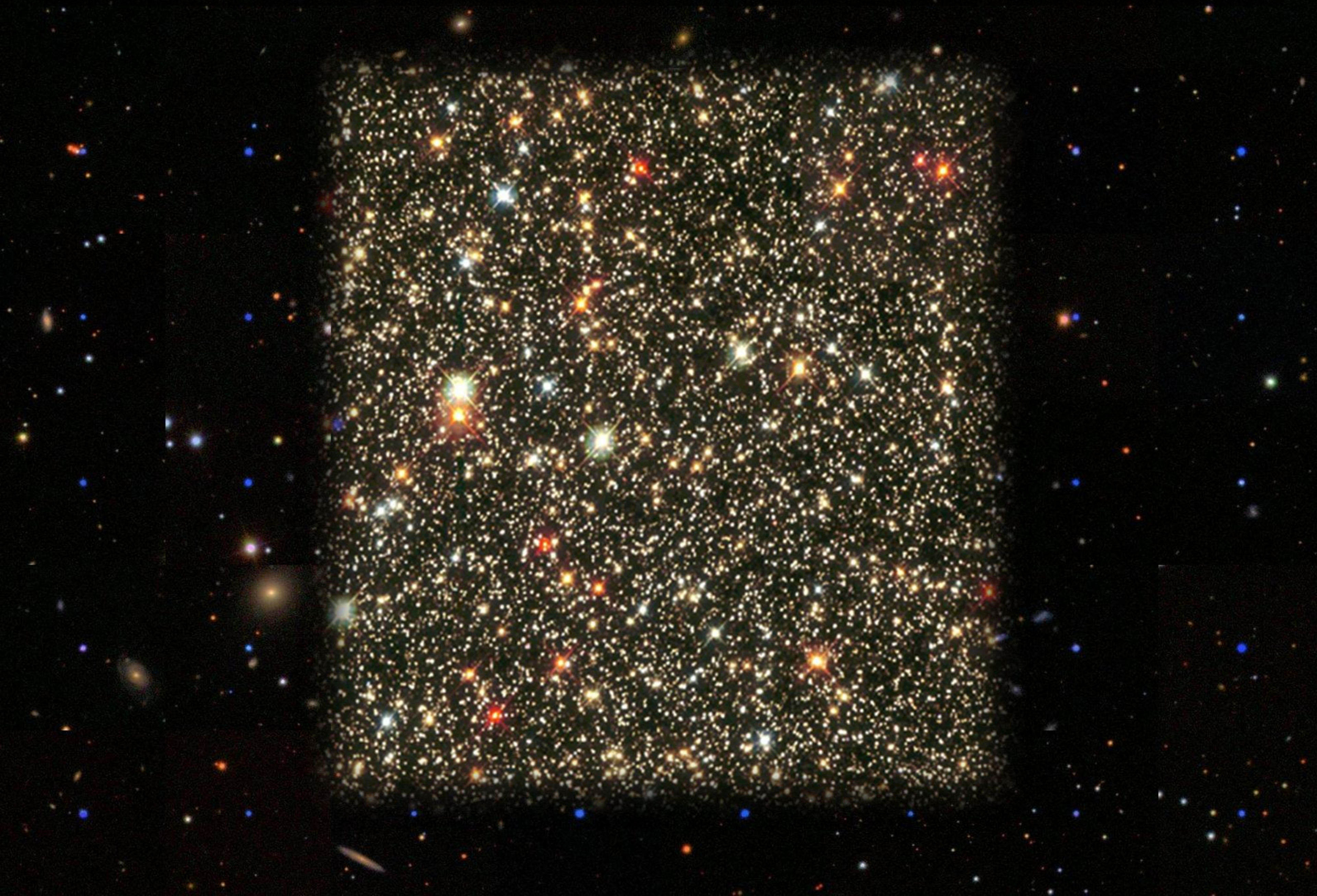
… eclipsing binaries …

If it were not perhaps too early to hazard even a conjecture on the cauſe of this variation, I ſhould imagine it could hardly be accounted for otherwiſe than either by the interpoſition of a large body revolving round Algol, or ſome kind of motion of its own, whereby part of its body, covered with ſpots or ſuch like matter, is periodically turned towards the earth. But the intention of this paper is to communicate facts, not conjectures; and I flatter myſelf that the former are remarkable enough to deſerve the attention and farther inveſtigation of aſtronomers.

Goodricke, 1784, Philosophical Transactions of the Royal Society of London, Volume 74, pp. 287-292


John Goodricke
White dwarfs
Cosmology
Eclipsing binaries
Masses and radii
Extra-solar planets
Cataclysmic variables
Life

Masses and radii of stars



Stellar parameters from eclipsing binaries

Accurate masses and radii of normal stars

J. Andersen

Copenhagen University Observatory, Brorfeldevej 23, DK-4340 Tølløse, Denmark

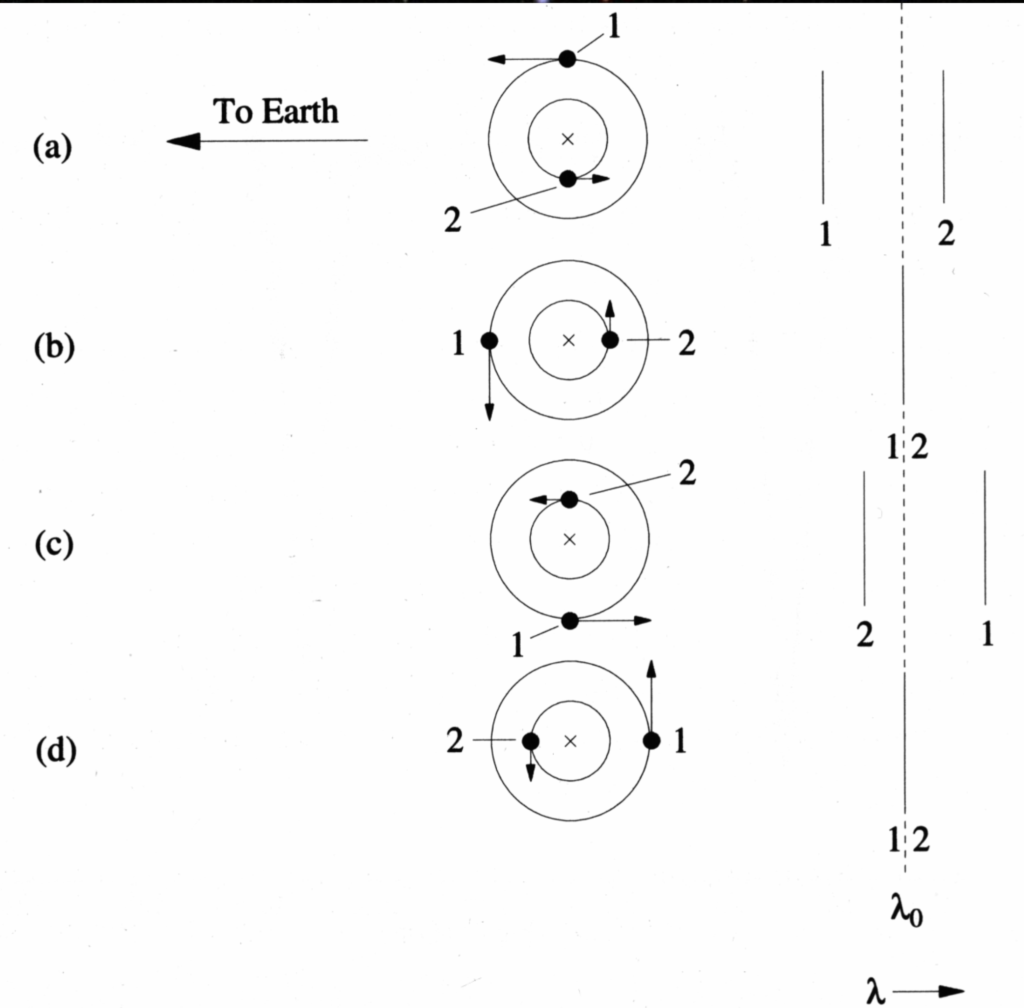
Summary. Binary stars are the main source of fundamental data on stellar masses and radii (M, R). Considerable progress has been made in recent years in the quality and quantity of such data, and stellar masses and radii of high accuracy have led to a number of qualitatively new and interesting results on the properties and evolution of normal stars. This paper reviews the current status of fundamental M and R determinations which (*i*) have errors $\leq 2\%$, the limit for non-trivial results in many applications, and (*ii*) can be presumed valid for single stars. These two conditions limit the discussion to data from *detached, double-lined eclipsing binary systems*.

Andersen 1991, A&ARv 3, 91

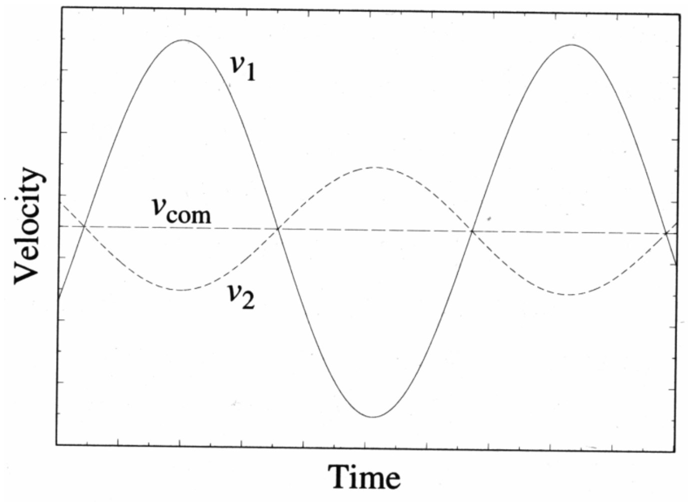
Spectroscopic binaries

Doppler effect:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

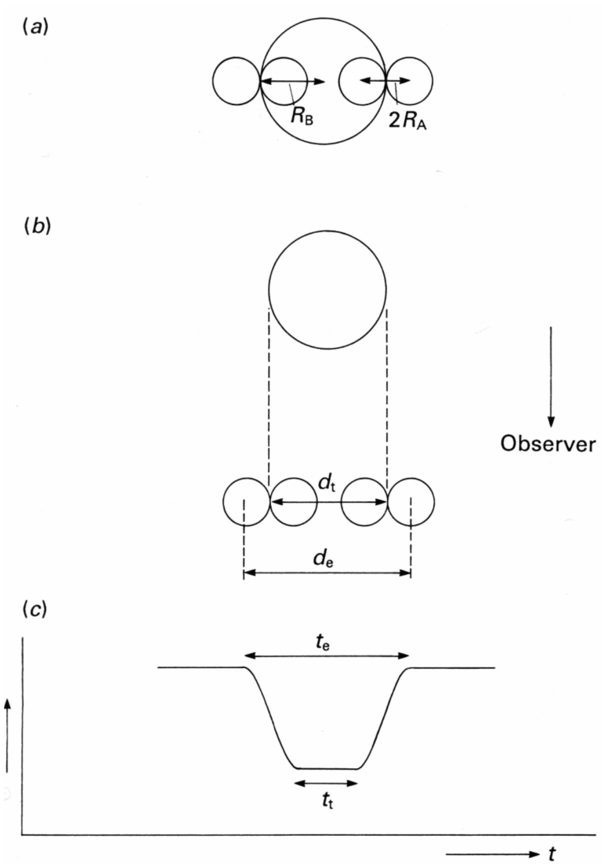


Stellar parameters from eclipsing binaries: A primer



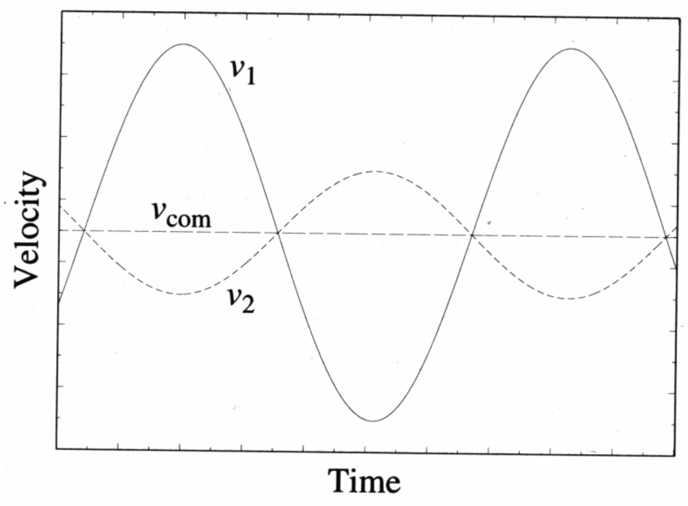
$$\frac{M_1}{M_2} = \frac{v_2}{v_1}$$

$$M_1 + M_2 = \frac{P}{2\pi G}\frac{(v_1+v_2)^3}{\sin^3 i}$$



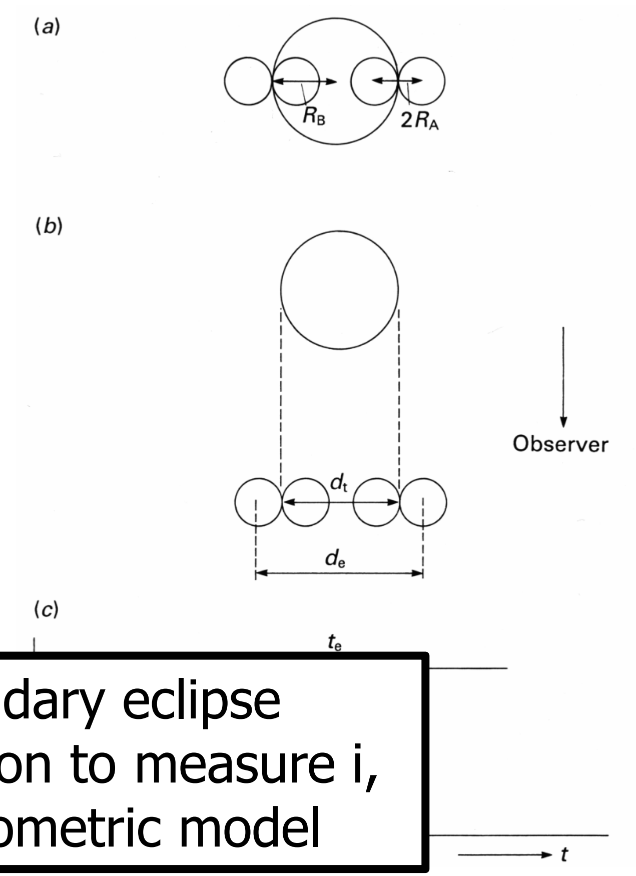
$$R_A = \pi a \frac{t_e - t_t}{2P} \qquad R_B = \pi a \frac{t_e + t_t}{2P}$$

Stellar parameters from eclipsing binaries: A primer



$$\frac{M_1}{M_2} = \frac{v_2}{v_1}$$

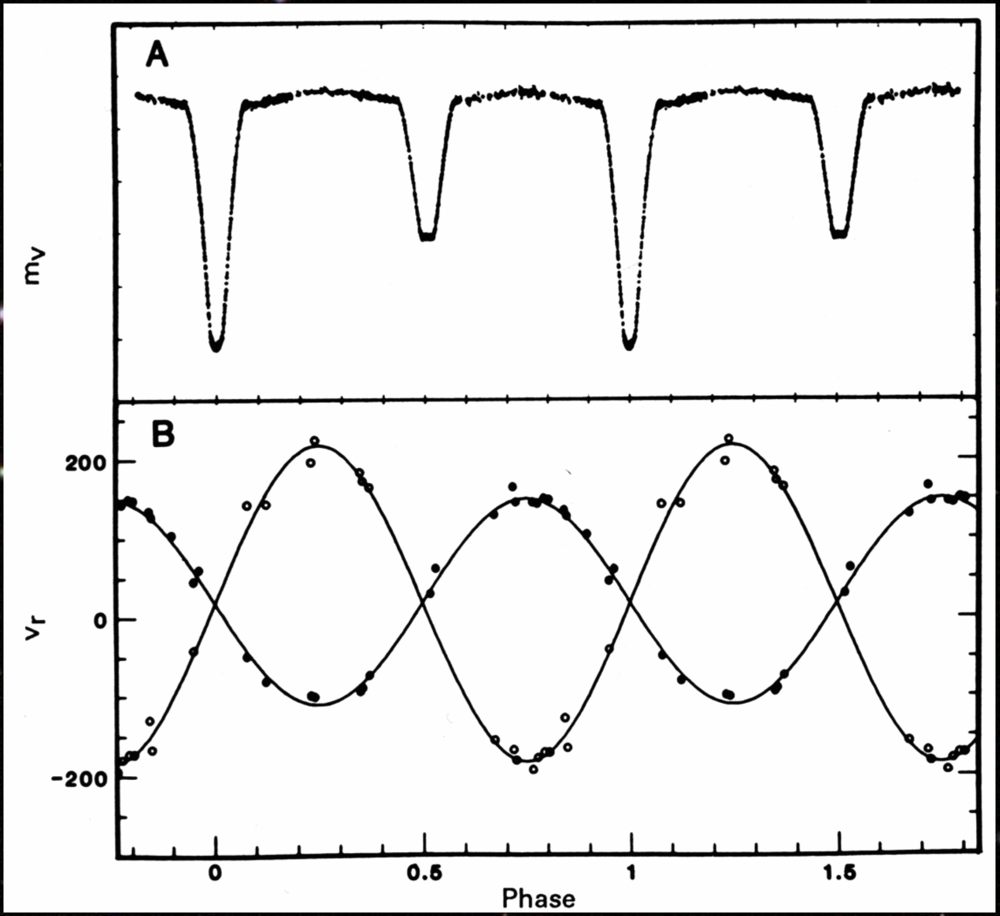
$$M_1 + M_2 = \frac{P}{2\pi G}\frac{(v_1 + v_2)^3}{\sin^3 i}$$



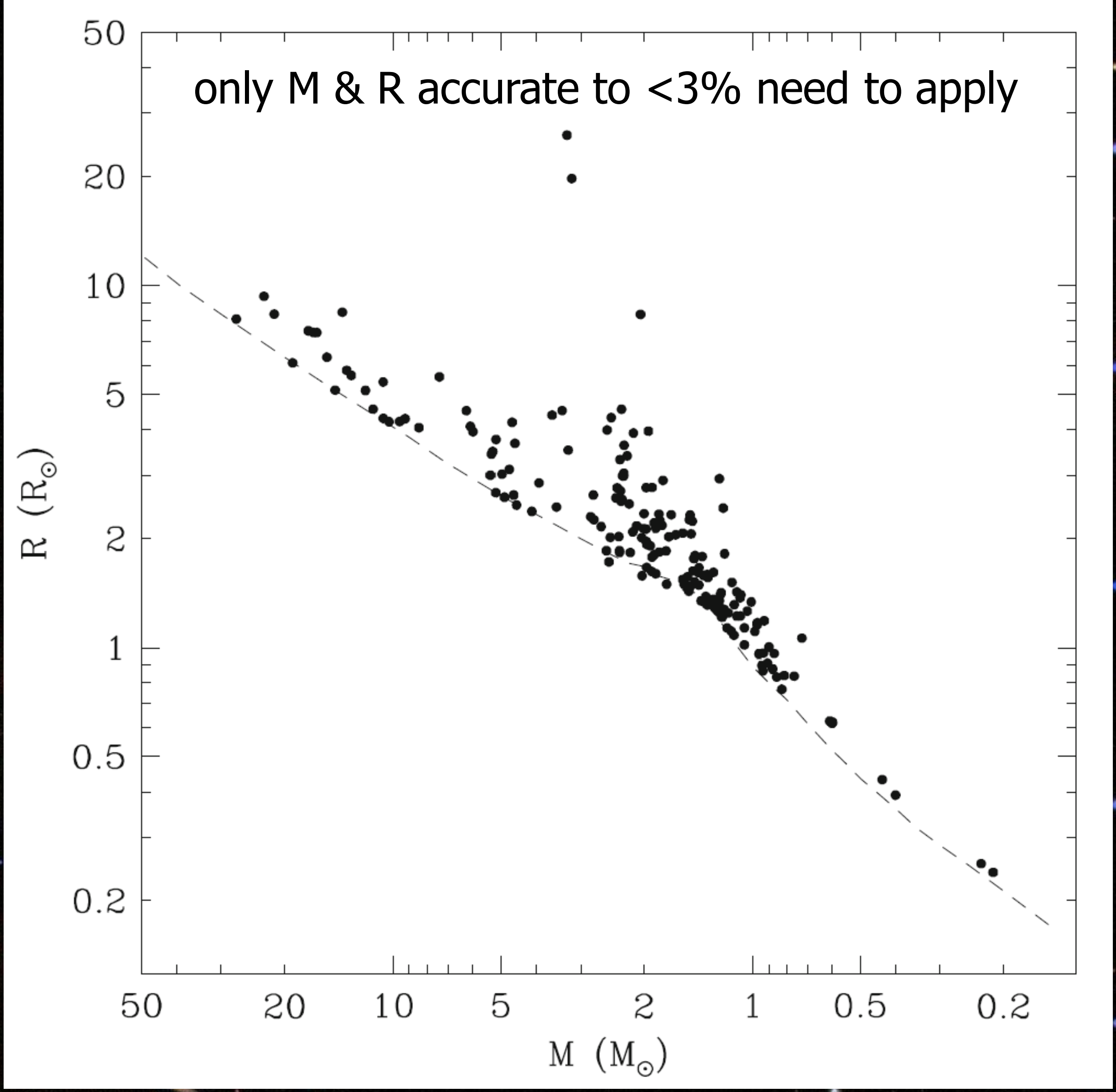
Need primary & secondary eclipse
or ellipsoidal modulation to measure i,
usually using a 3D geometric model

$$R_A = \pi a \frac{t_e - t_t}{2P} \qquad R_B = \pi a \frac{t_e + t_t}{2P}$$

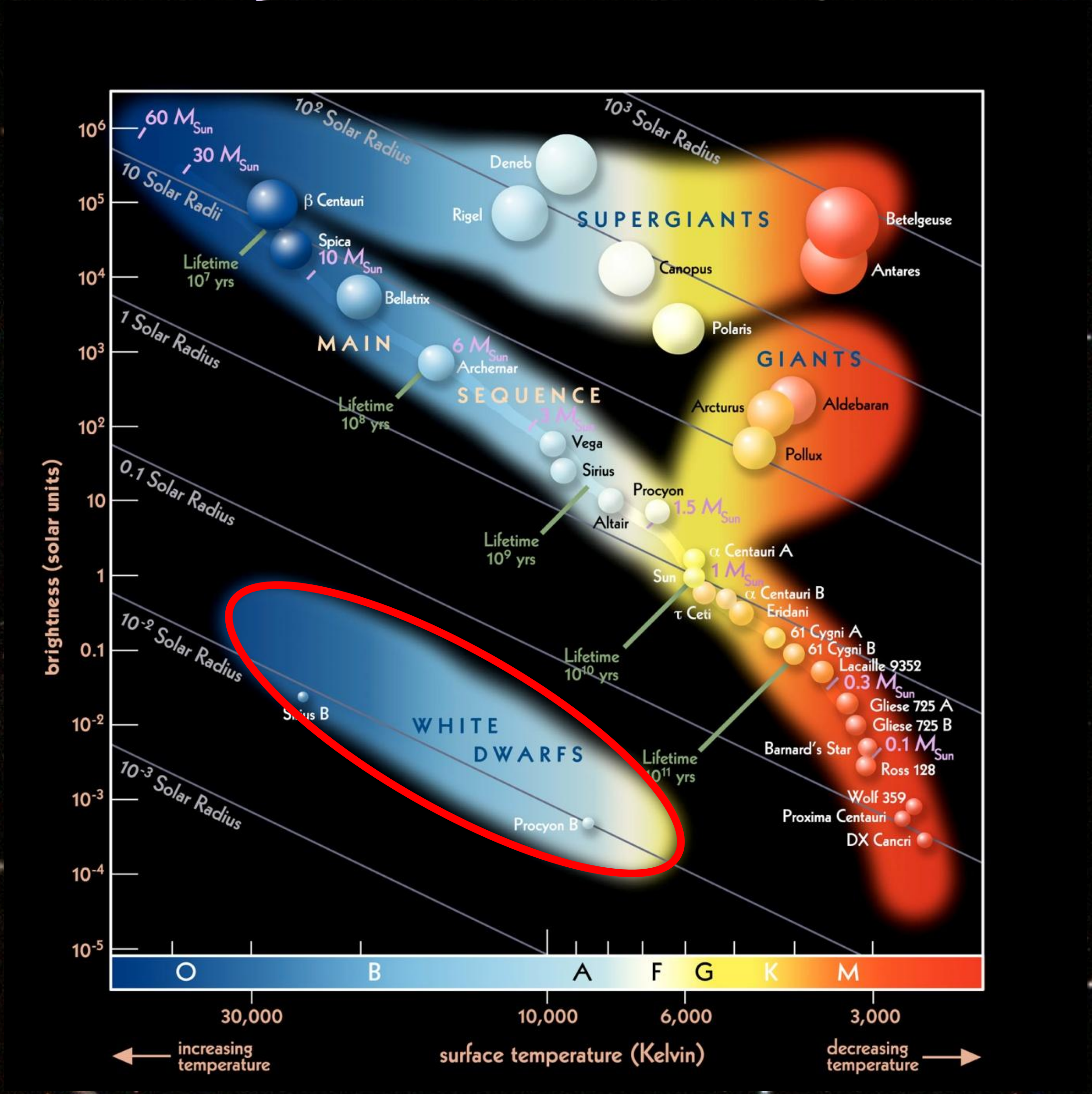
Masses & radii from eclipsing spectroscopic binaries



Masses & radii from eclipsing spectroscopic binaries



The Hertzsprung-Russel diagram



John Goodricke

White dwarfs

Cosmology

Eclipsing binaries

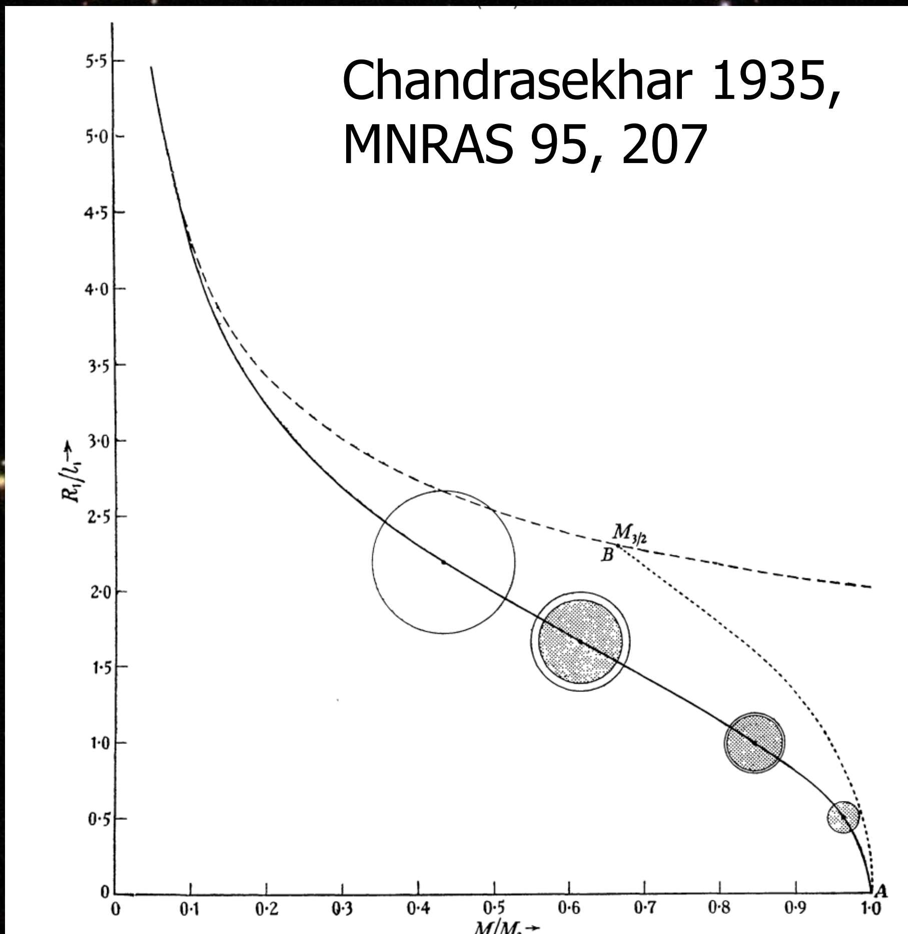
Masses and radii

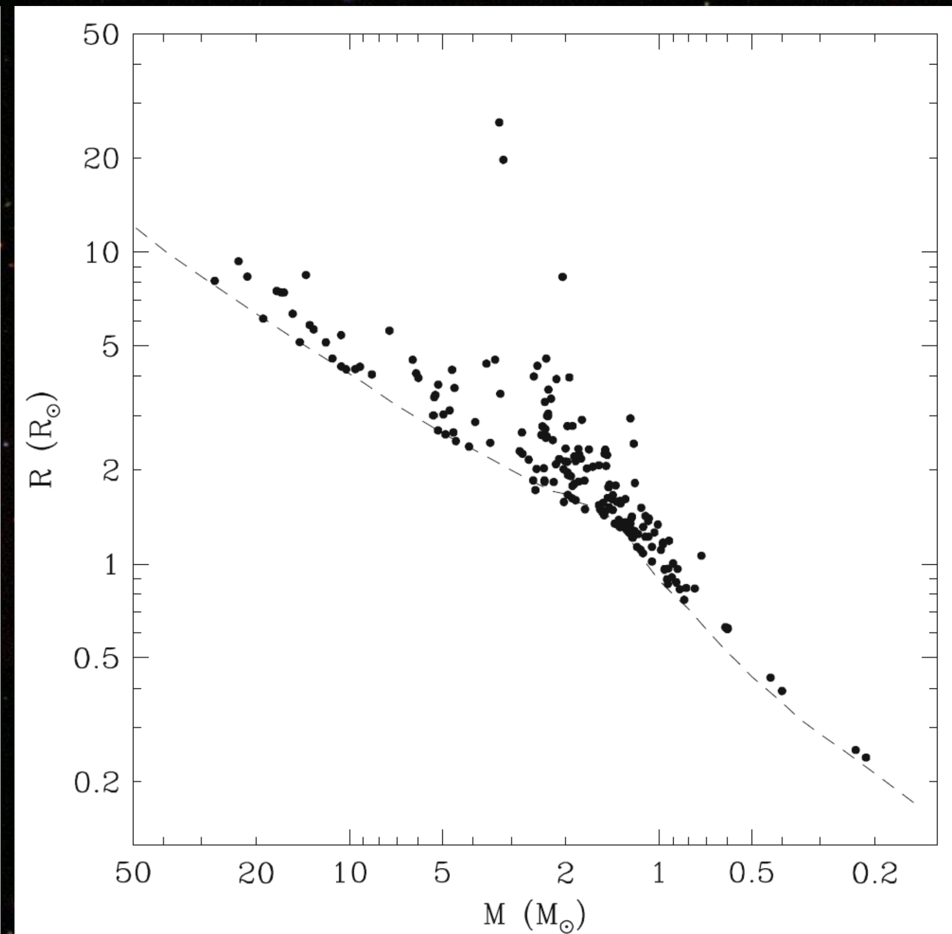
Extra-solar planets

Cataclysmic variables

Life

White dwarfs: electron degenerate stars



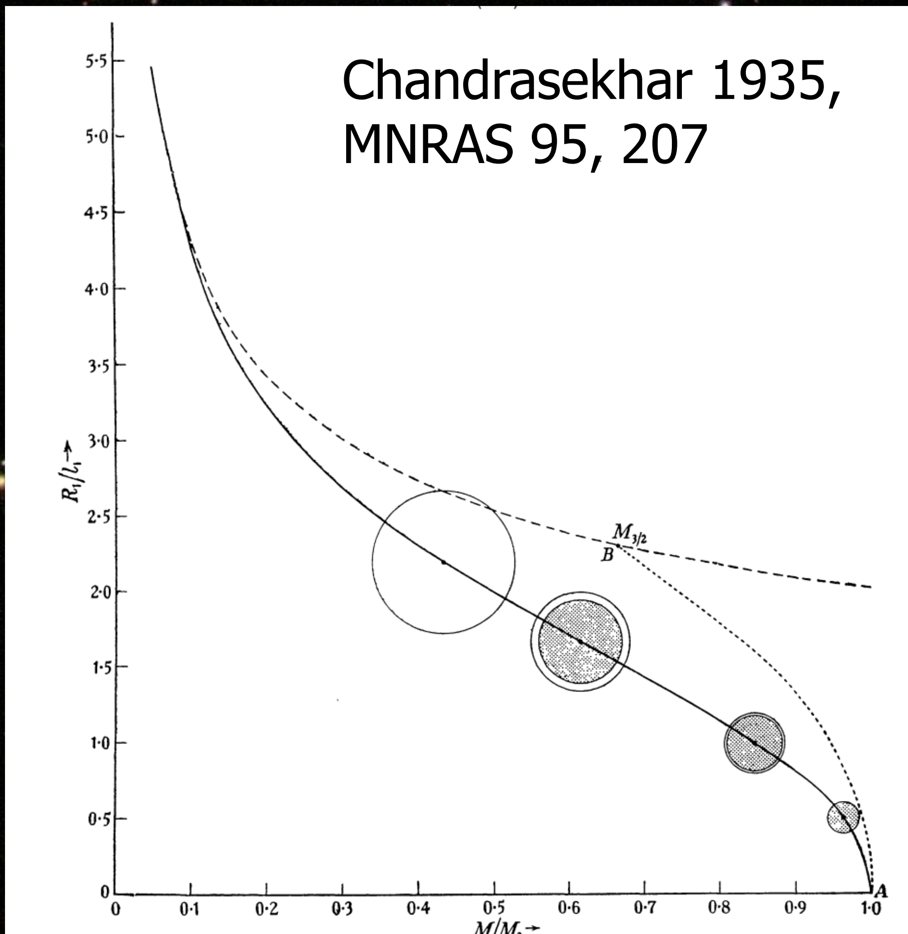


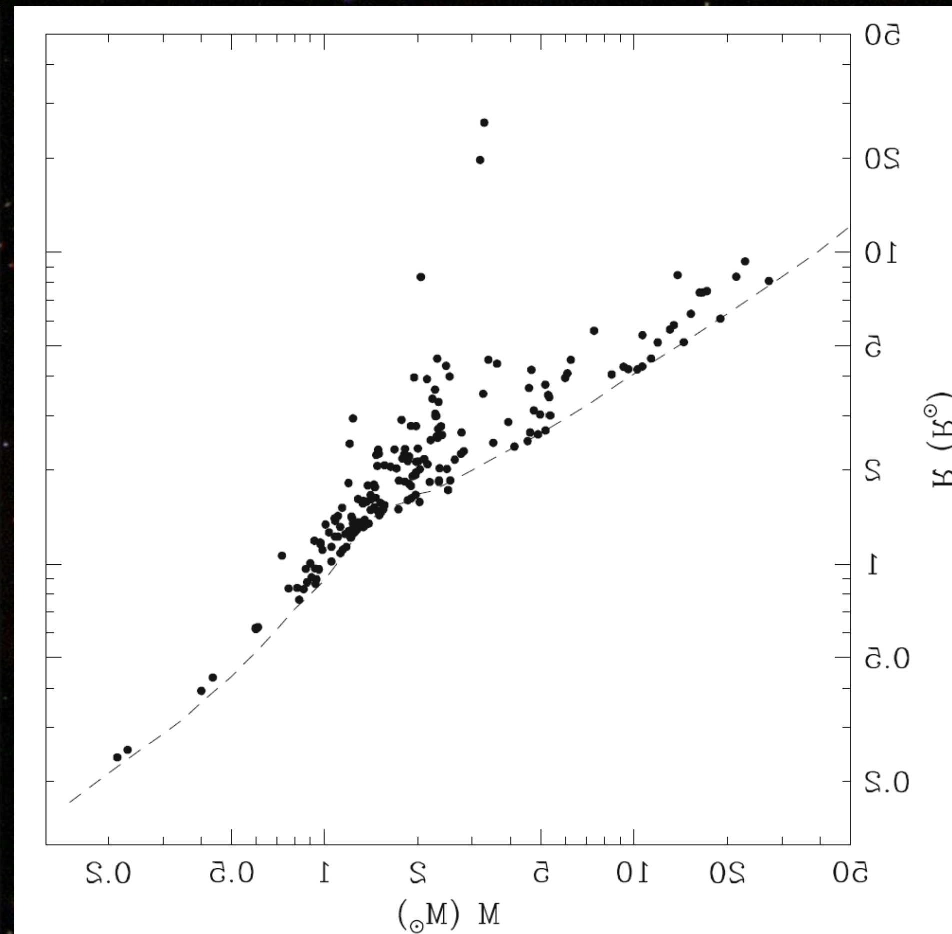
mass

mass

White dwarfs: electron degenerate stars

White dwarfs become *smaller* with increasing mass!





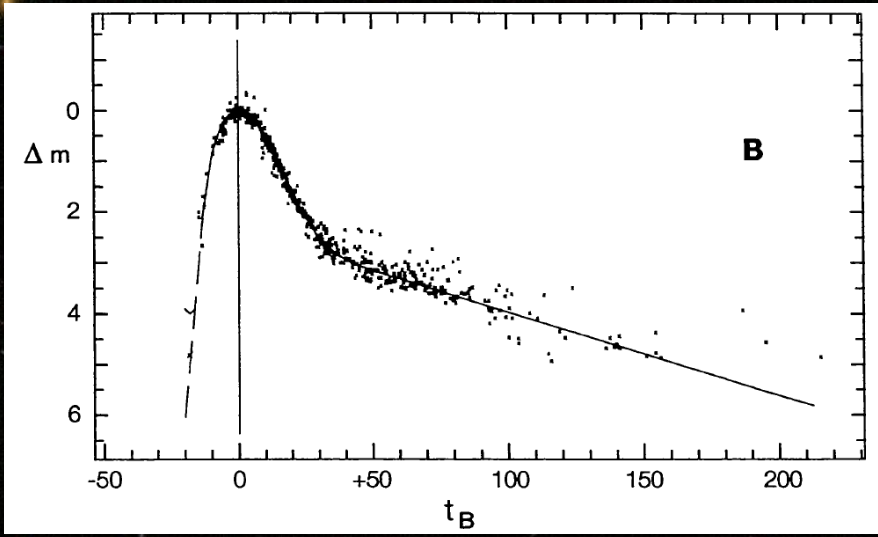
mass

mass

SNIa at Cosmological distances

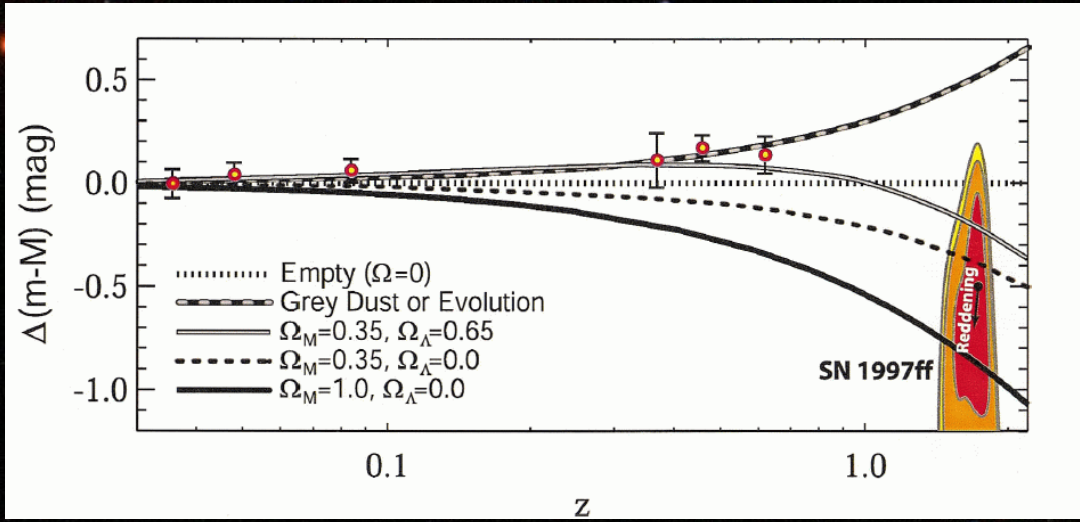
SNIa are *standard candles*

... probing the structure of the entire Universe!

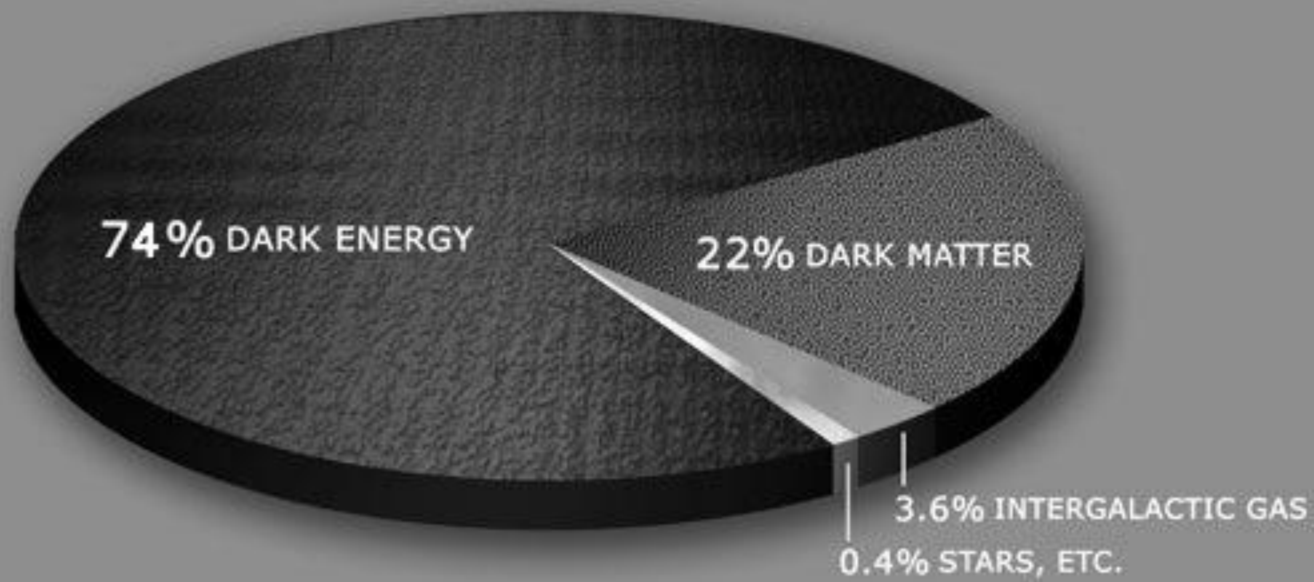


distant SNIa are too bright:

The expansion of the Universe is accelerating



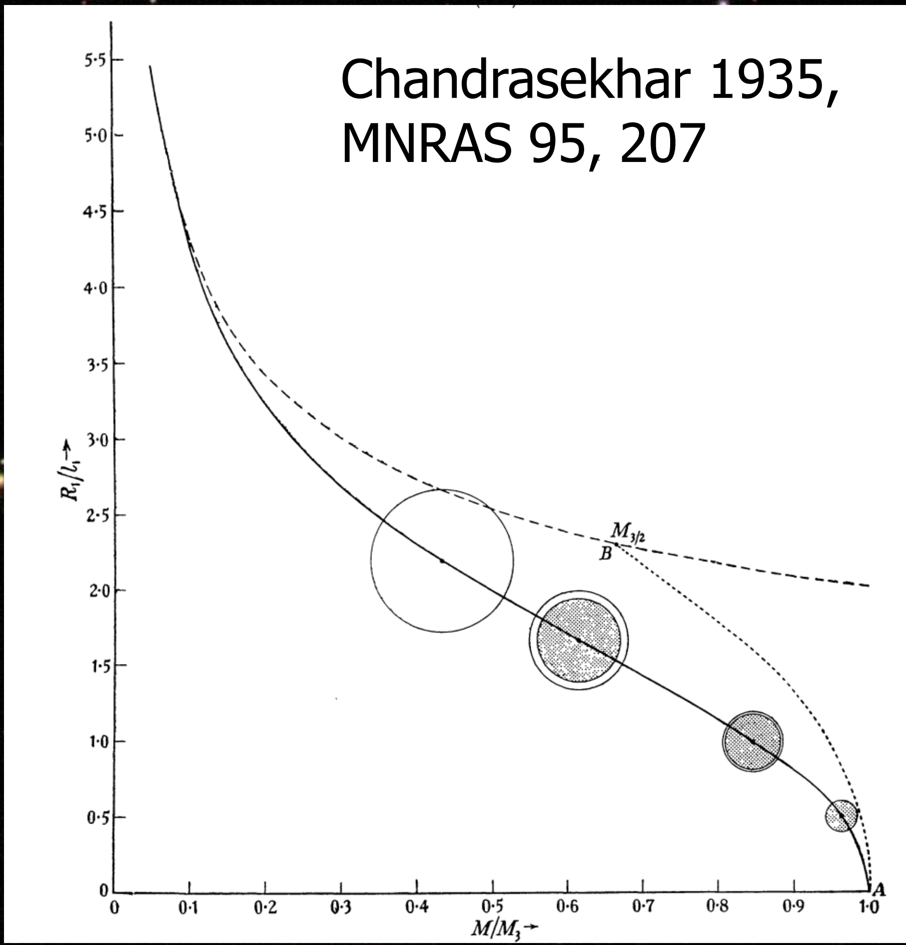
The "composition" of the Universe



2011 Nobel prize in Physics for
Saul Perlmutter, Brian Schmidt & Adam Riess

"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"

White dwarfs: electron degenerate stars, but...

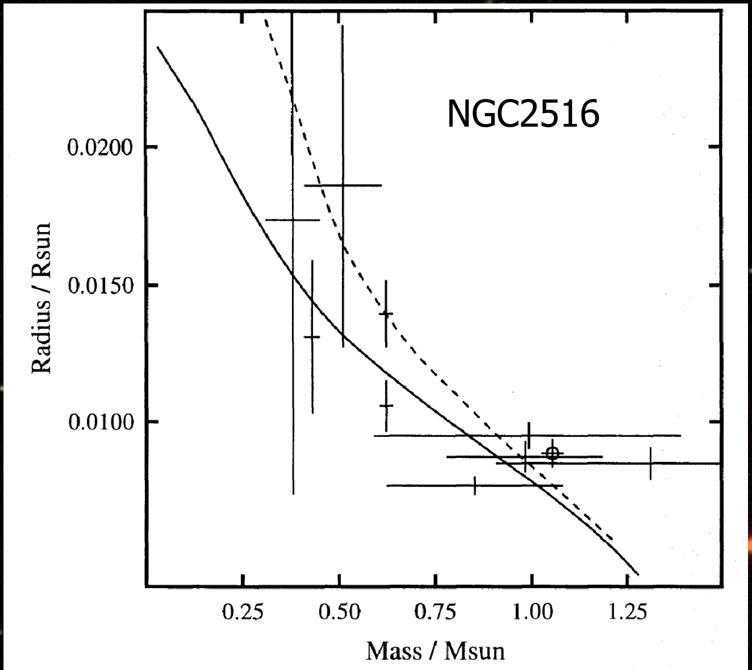


Corrections to the equation of state, core-composition, finite-temperature, He & H envelopes, magnetic fields... See e.g.:

- Hamada & Salpeter 1961, ApJ 134, 971
- Vennes et al. 1995, A&A, 296, 117
- Panei et al. 2000, A&A 353, 970
- Suh & Mathews 2000, ApJ 530, 949
- Althaus et al. 2005, A&A 441, 689

White dwarfs with accurate distances

(e.g. *Hipparcos*, open clusters)



Koester & Reimers 1996, A&A 313, 810

$$L = 4\pi R^2 F = 4\pi d^2 f = 4\pi R^2 \sigma T_{eff}^4$$

$$\left.\begin{array}{l} \dfrac{F}{f} = \dfrac{d^2}{R^2} \\[2ex] g = \dfrac{GM}{R^2} \end{array}\right\} \quad M, R$$

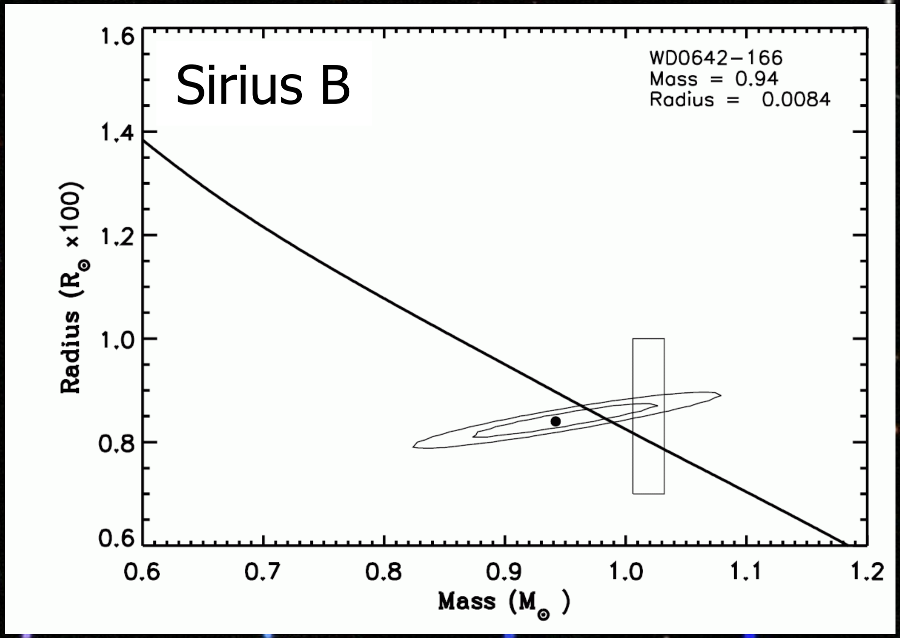
If radial velocity known:

$$v_{GR} = 0.635 (M/M_\odot)/(R/R_\odot)$$

see e.g.: Schmidt 1996, A&A 311, 852; Provencal et al. 1998, ApJ, 494, 759; Casewell et al. 2009, MNRAS 395, 1795

White dwarfs in astrometric binaries

Astrometric orbit, Kepler's 3rd law ⇒ M_{wd}
Spectroscopic surface gravity, GR redshift, "flux scaling factor" ⇒ R_{wd}



$M_{wd} = 0.94 \pm 0.05 M_\odot$

$R_{wd} = 0.0084 \pm 0.0025 R_\odot$

$T_{eff} = 24790 \pm 100K$

see e.g. Barstow et al. 2005, MNRAS 362, 1143; Holberg et al. 2012, AJ 143, 68

V471 Tau – the first eclipsing WD binary

A NEW ECLIPSING BINARY CONTAINING A VERY HOT WHITE DWARF

BURT NELSON

Mount Laguna Observatory

Astronomy Department
San Diego State College

AND

ARTHUR YOUNG*

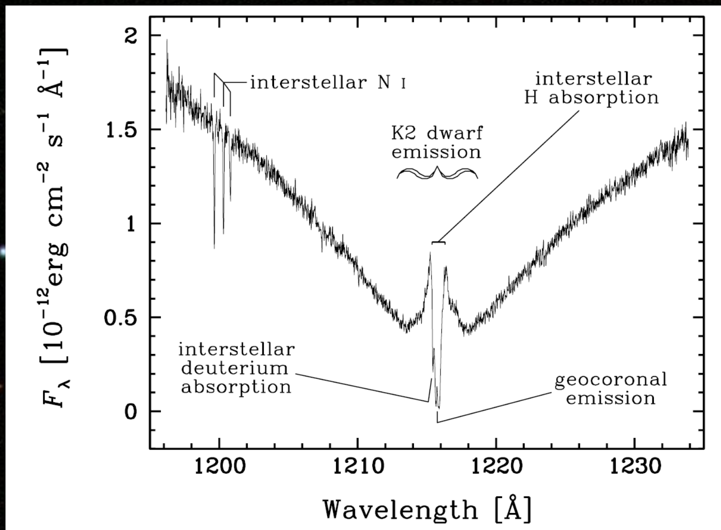
Kitt Peak National Observatory†
Tucson, Arizona

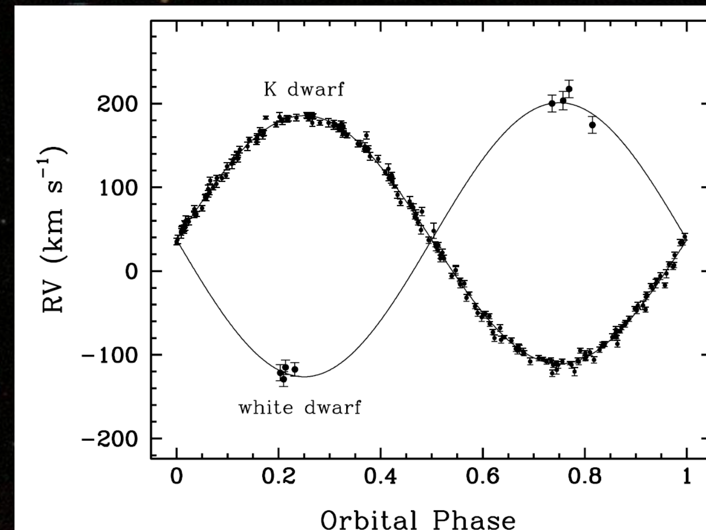
Received March 6, 1970

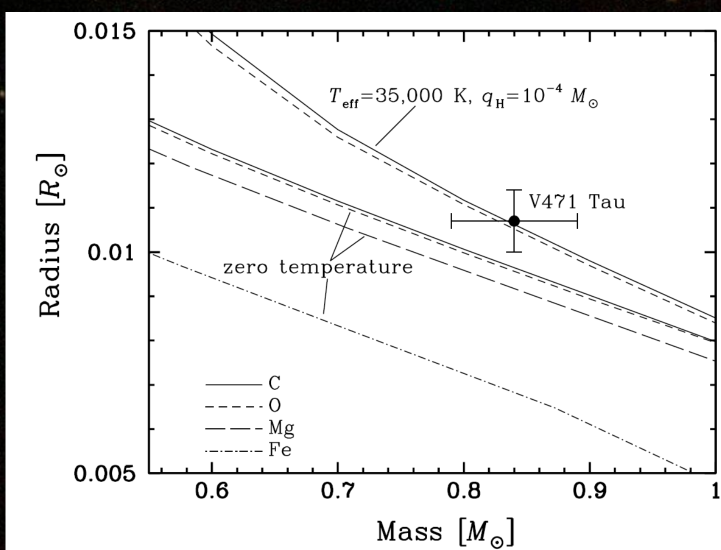
A new eclipsing binary has been discovered in which one of the stars is shown to be a hot white dwarf. The eclipse is total, and considerable fundamental information about white dwarfs appears to be obtainable.

Nelson & Young 1970, PASP 82, 699

... 30 years later ...







$M_{wd} = 0.84 \pm 0.05 M_\odot$

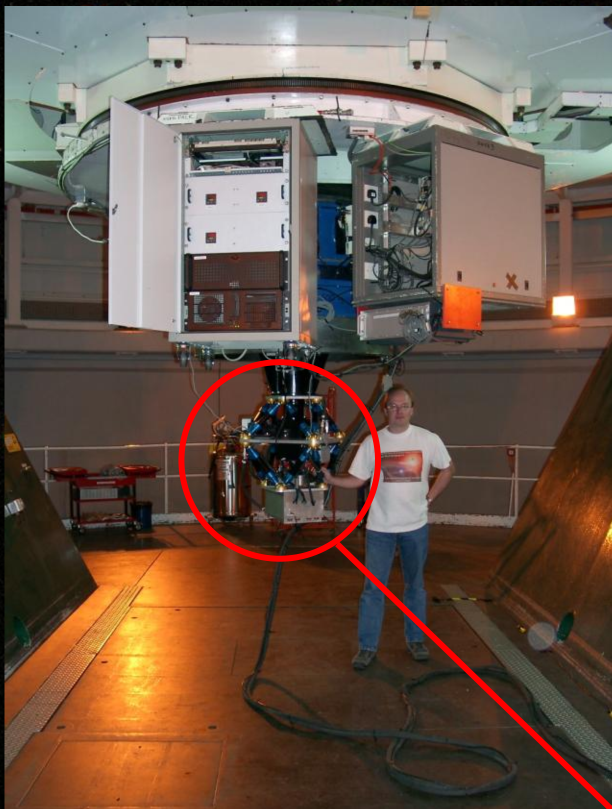
$R_{wd} = 0.0109 \pm 0.0007 R_\odot$

$T_{eff} = 35125 \pm 1275$K

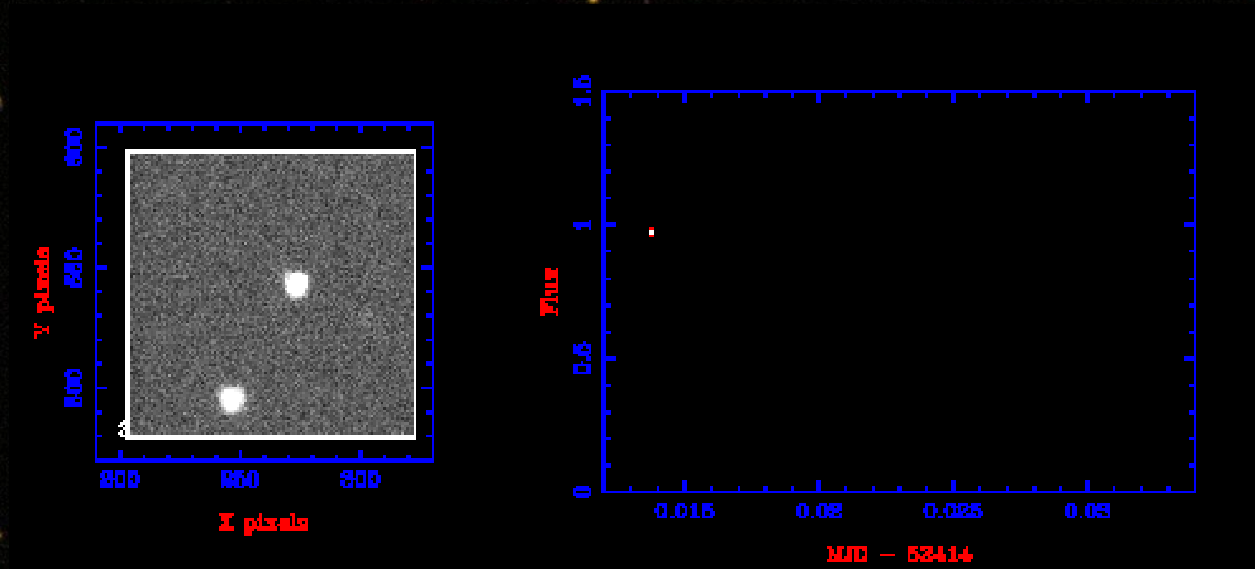
Werner & Rauch 1997, A&A 324, L25

O'Brien et al. 2001, ApJ 563, 971

White dwarfs are *small* → eclipse *very fast*

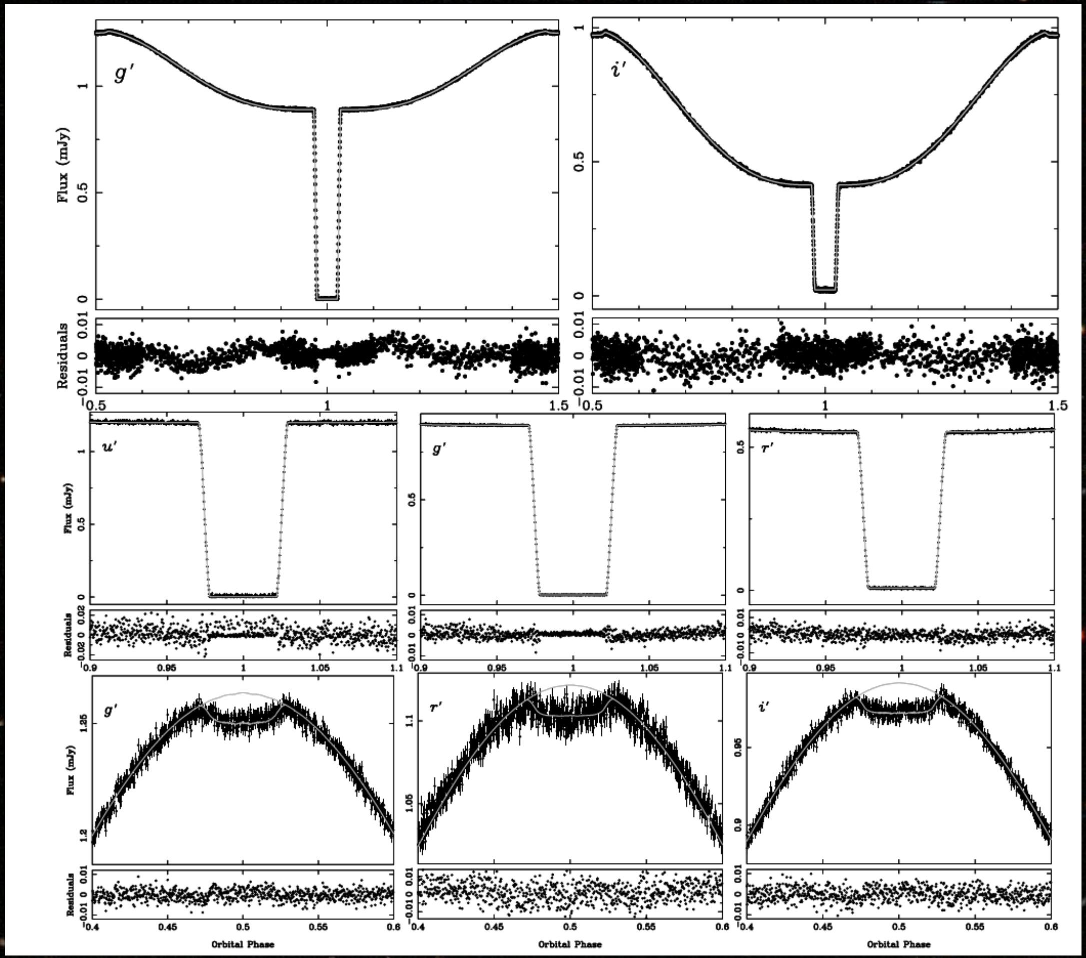


NN Ser: an eclipsing WD+MS binary



ULTRACAM, a triple beam camera, can observe at up to 500Hz
(Tom Marsh, Warwick & Vik Dhillon, Sheffield)

NN Ser: a hot DAO WD + very low mass dM



$M_{wd} = 0.535 \pm 0.012 M_\odot$

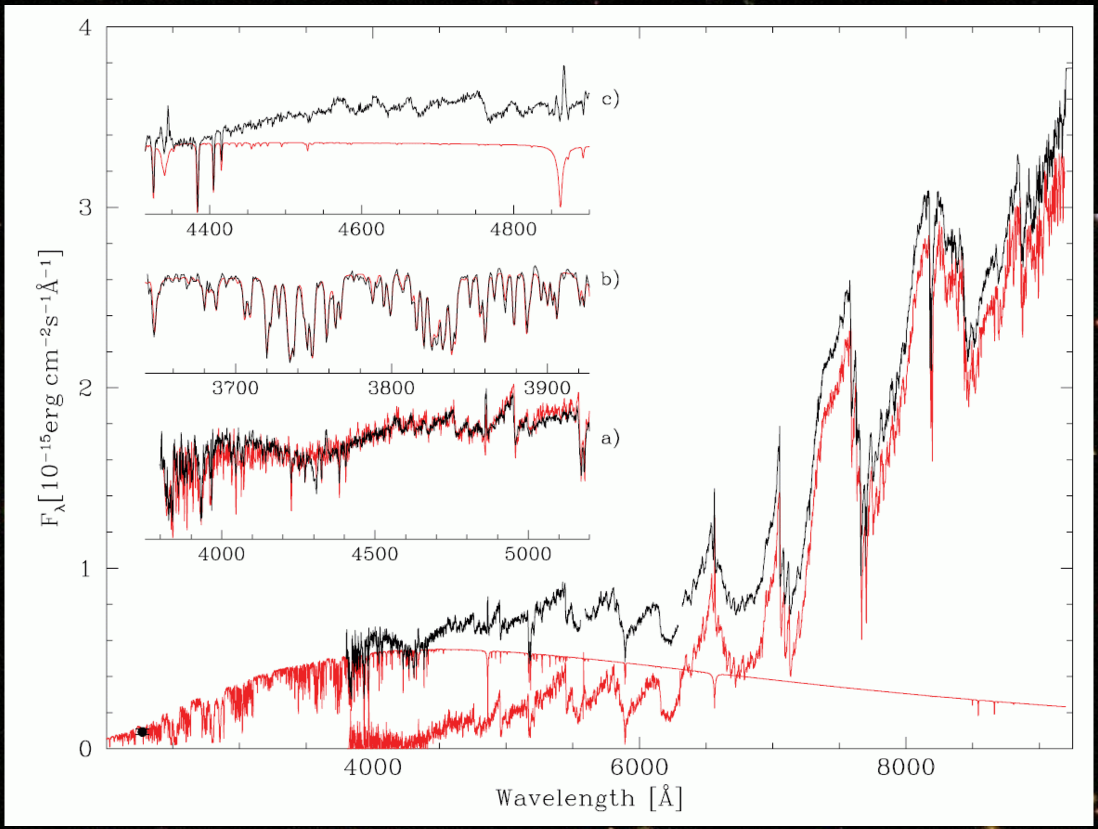
$R_{wd} = 0.0211 \pm 0.0002 R_\odot$

$T_{eff} = 57000 \pm 3000K$

1-2% precision in M, R

Parsons et al. 2010, MNRAS 402, 2591

SDSSJ1210+3347: a cool DZ + dM



M_{wd} = 0.415±0.010M⊙

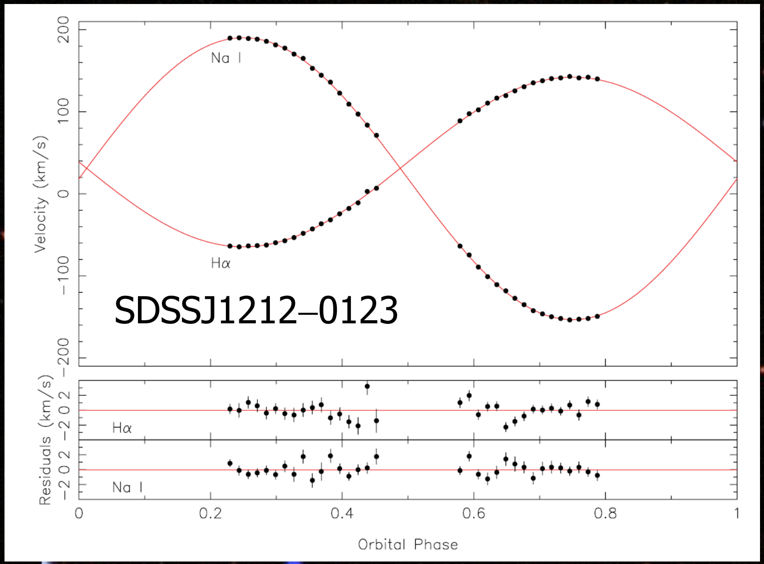
R_{wd} = 0.0157–0.0161R⊙

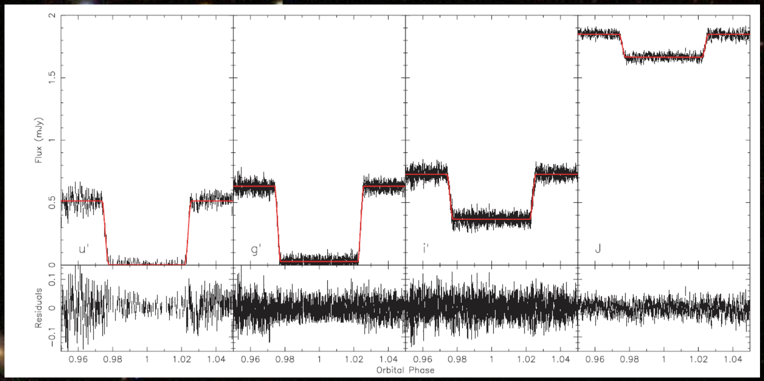
T_{eff} = 6000±200K

... a definite He-core WD ...

Pyrzas et al. 2012, MNRAS 419, 817

GK Vir & SDSSJ1212–0123





SDSSJ1212–0123:

$M_{wd} = 0.439 \pm 0.002 M_\odot$

$R_{wd} = 0.0168 – 0.0003 R_\odot$

$T_{eff} = 17707 \pm 35K$

GK Vir:

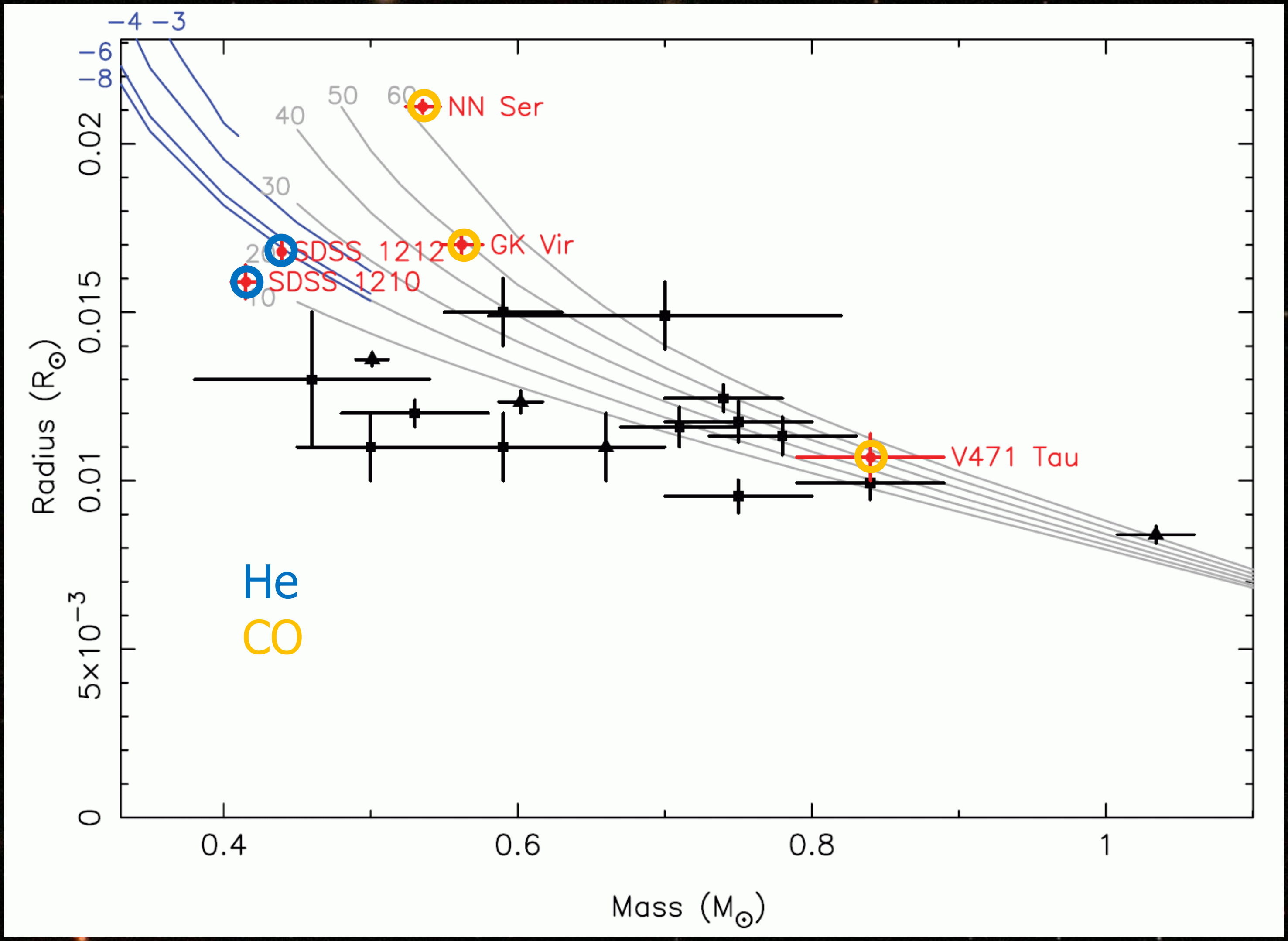
$M_{wd} = 0.564 \pm 0.014 M_\odot$

$R_{wd} = 0.0170 – 0.0004 R_\odot$

$T_{eff} = 55995 \pm 673K$

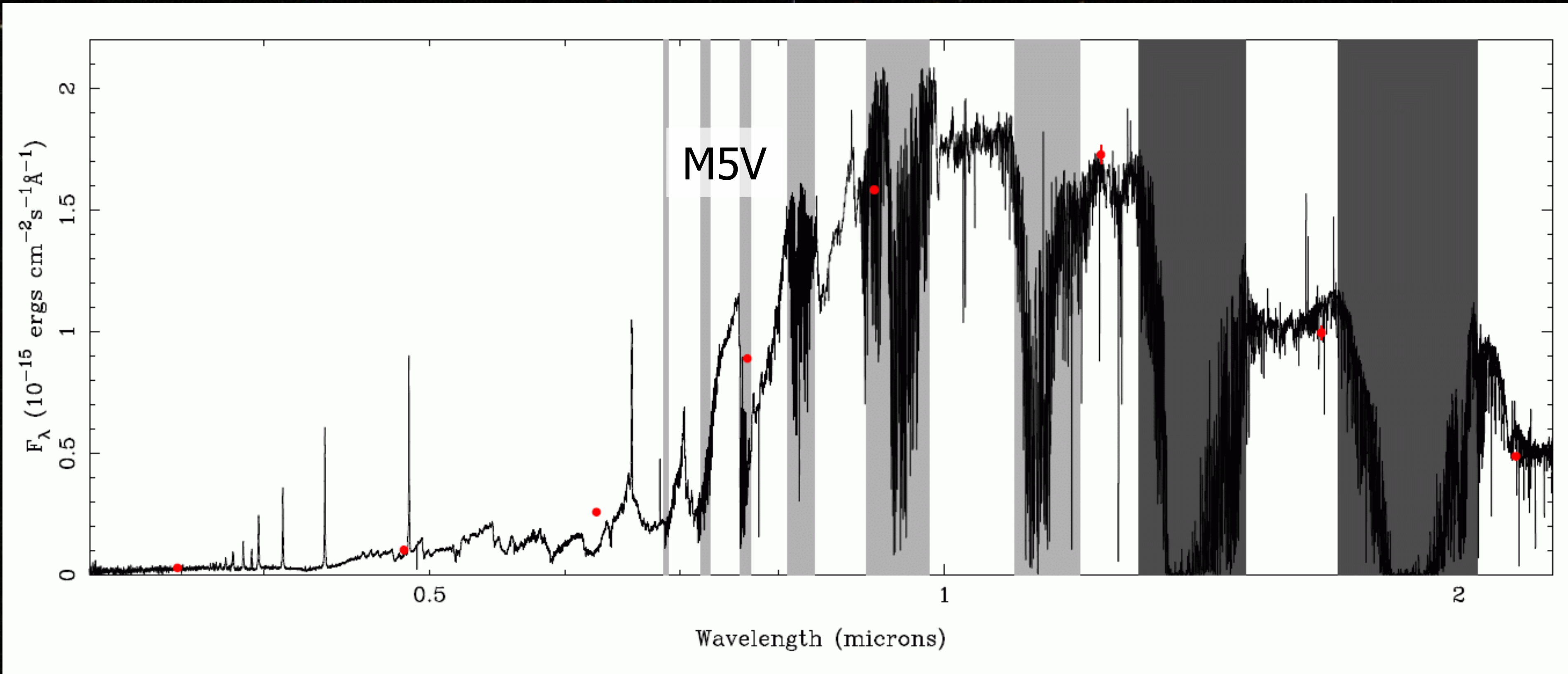
Parsons et al. 2012, MNRAS 420, 3281

A first look at the M-R plane: no surprises so far



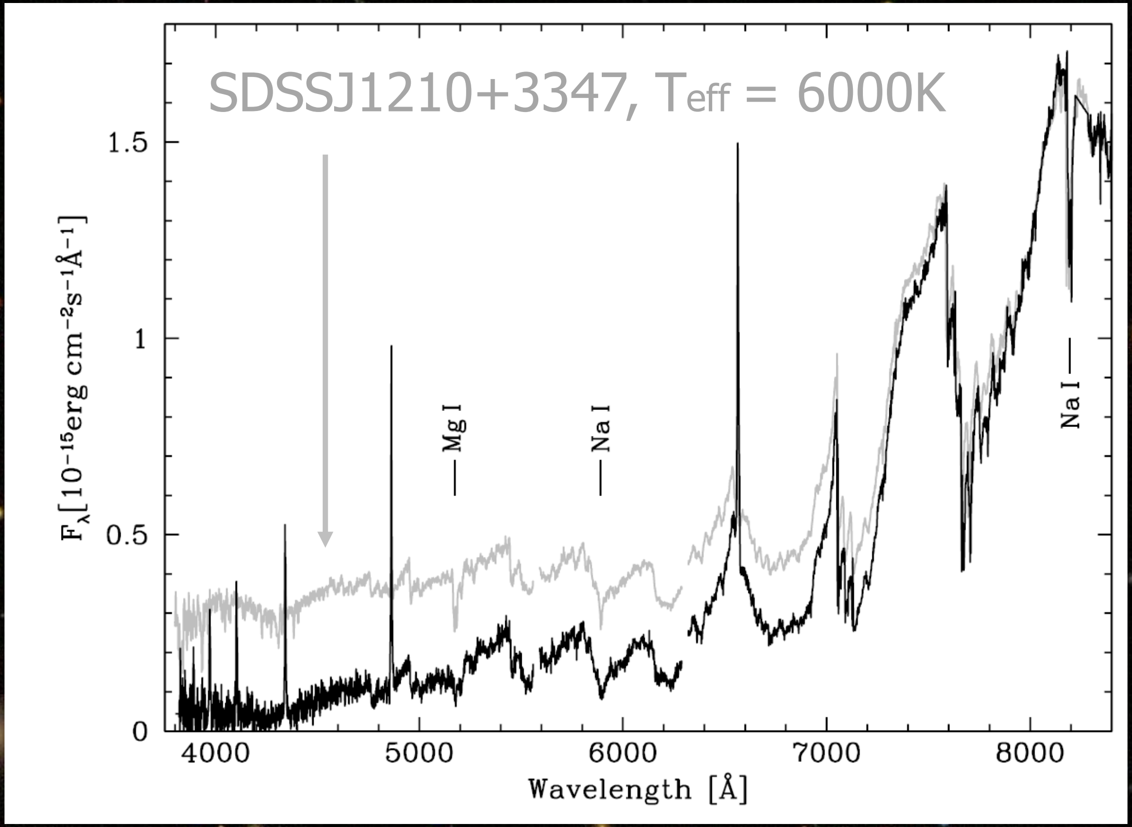
Parsons et al. 2012, MNRAS 420, 3281

SDSSJ0138–0016: an ultracool WD + dM



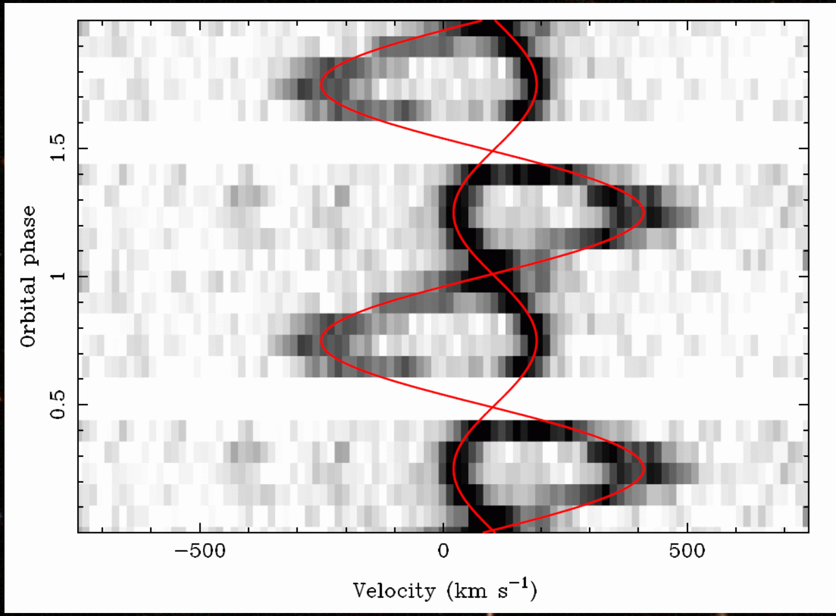
Parsons et al. 2012, MNRAS in press (arXiv:1207.5393)

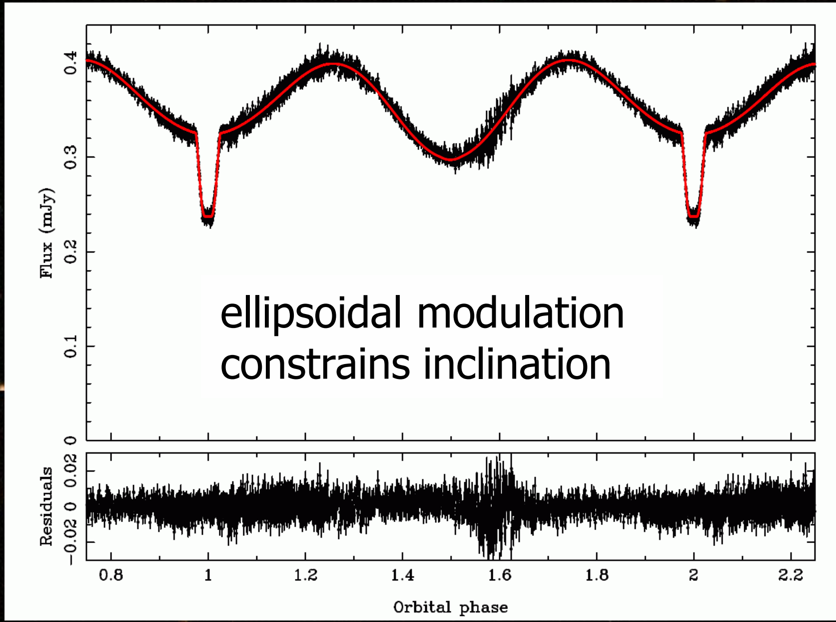
SDSSJ0138–0016: an ultracool WD + dM

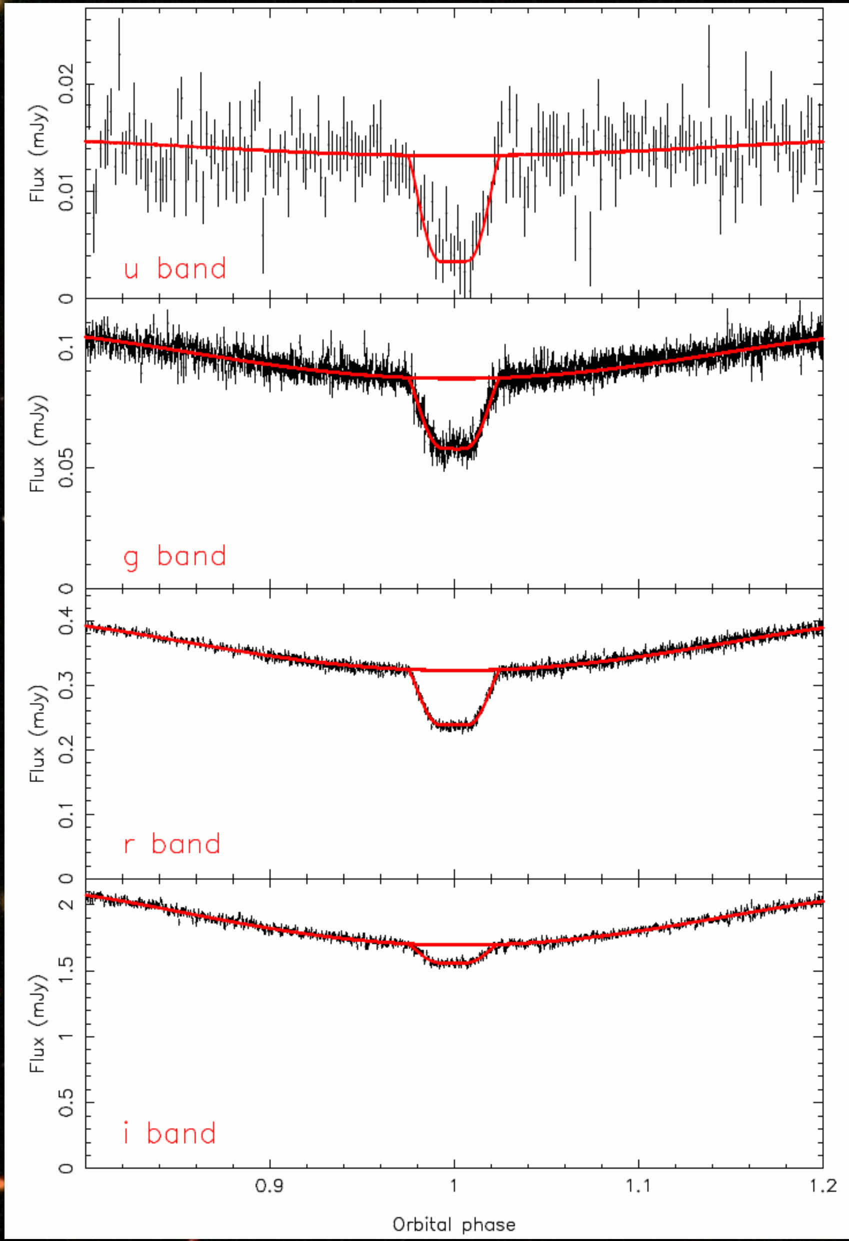


Parsons et al. 2012, MNRAS 426, 1950

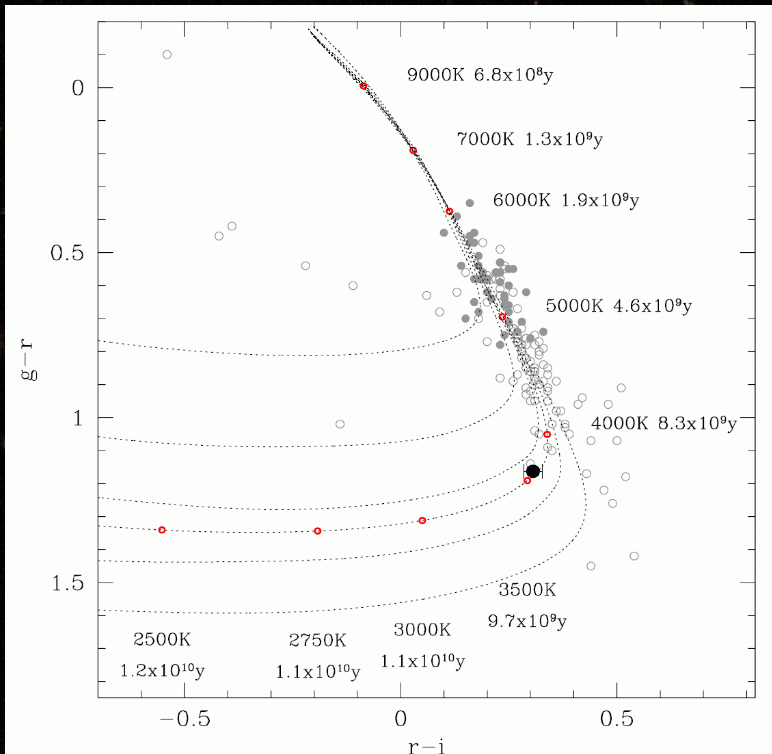
X-Shooter spectroscopy & ULTRACAM photometry







The coolest white dwarf with model-independent M & R



$M_{wd} = 0.529 \pm 0.010 M_\odot$

$R_{wd} = 0.0131 \pm 0.0003 R_\odot$

$T_{eff} = 3570 \pm 100$K

$\Rightarrow$ cooling age: 9.5±0.3Gyr ...

Parsons et al. 2012, MNRAS 426, 1950

John Goodricke

White dwarfs

Cosmology

Eclipsing binaries

Masses and radii

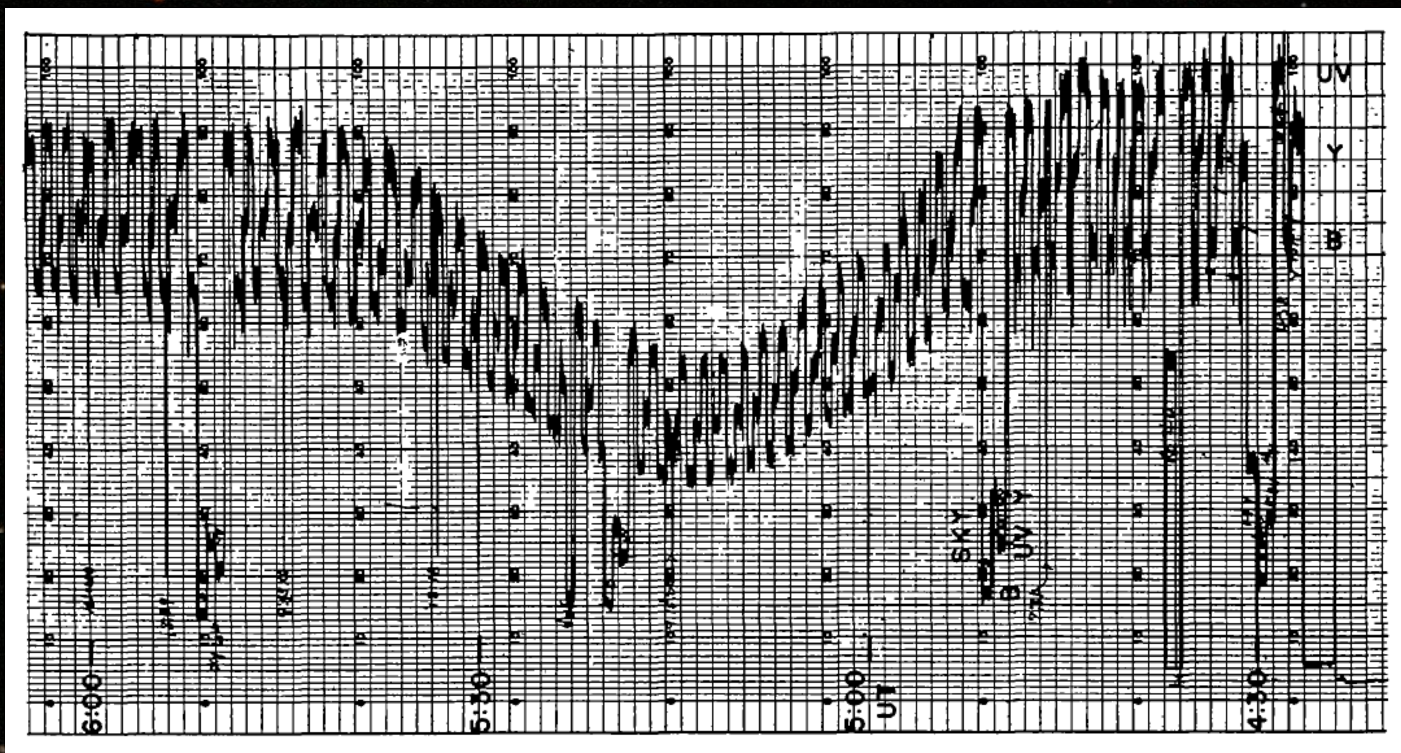
Extra-solar planets

Cataclysmic variables

Life

1950's: Merle Walker & Robert Kraft

Cataclysmic variables are white dwarfs accreting from low-mass companion stars → links to SNIa & gravitational waves



DQ Her

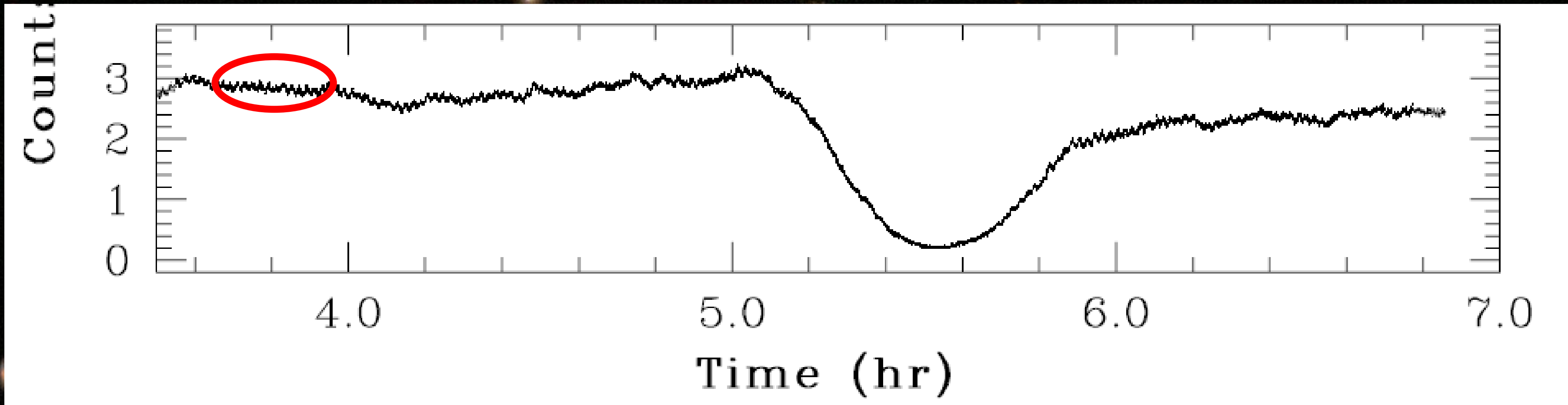
Nova 1934

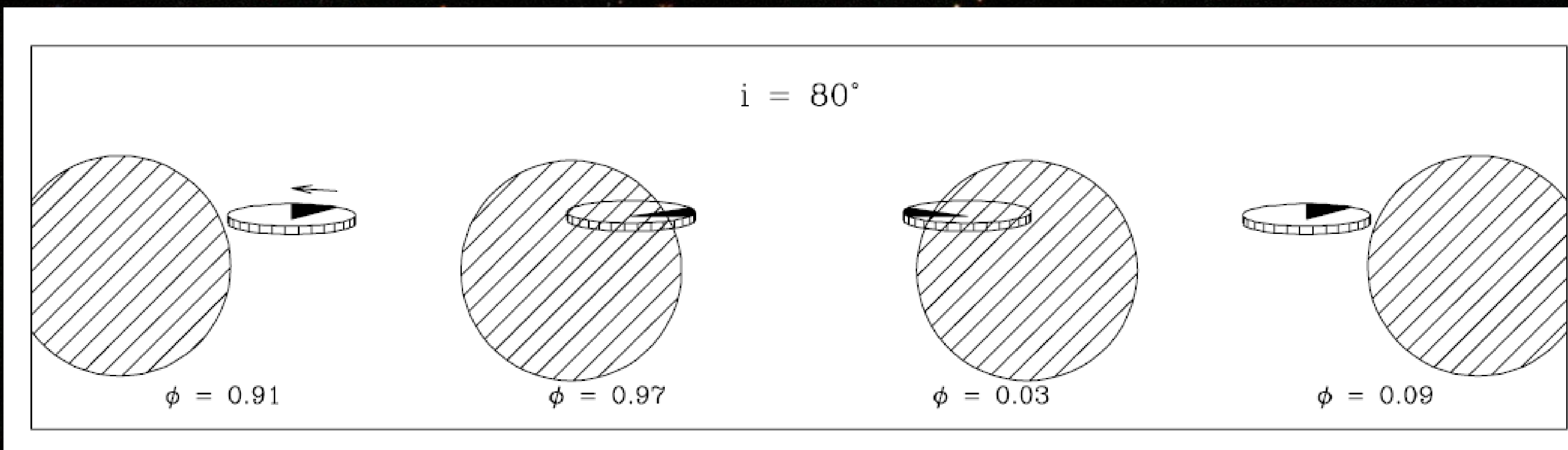
Porb=4.39h

71s variability

Walker, 1954, PASP 66, 230

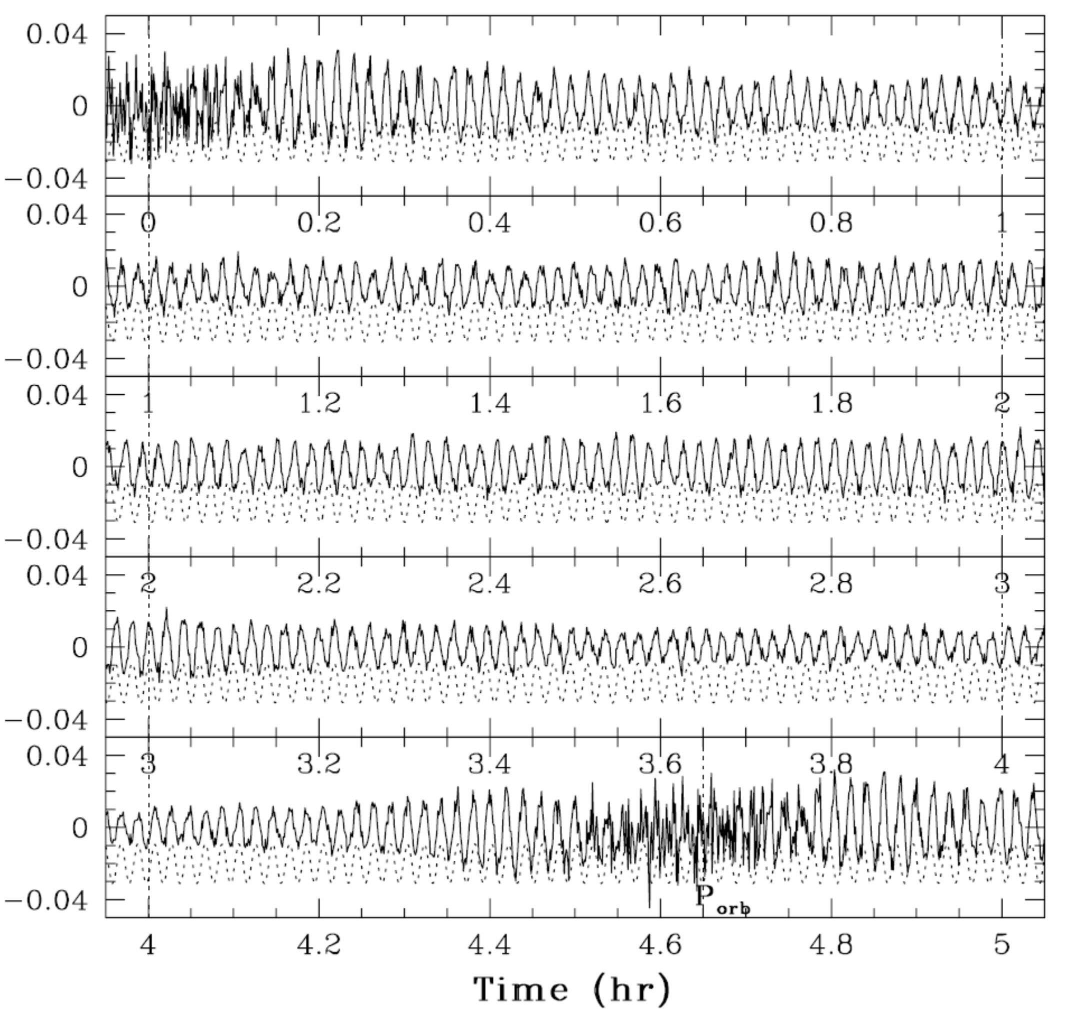
DQ Her, still among the all-time favourites



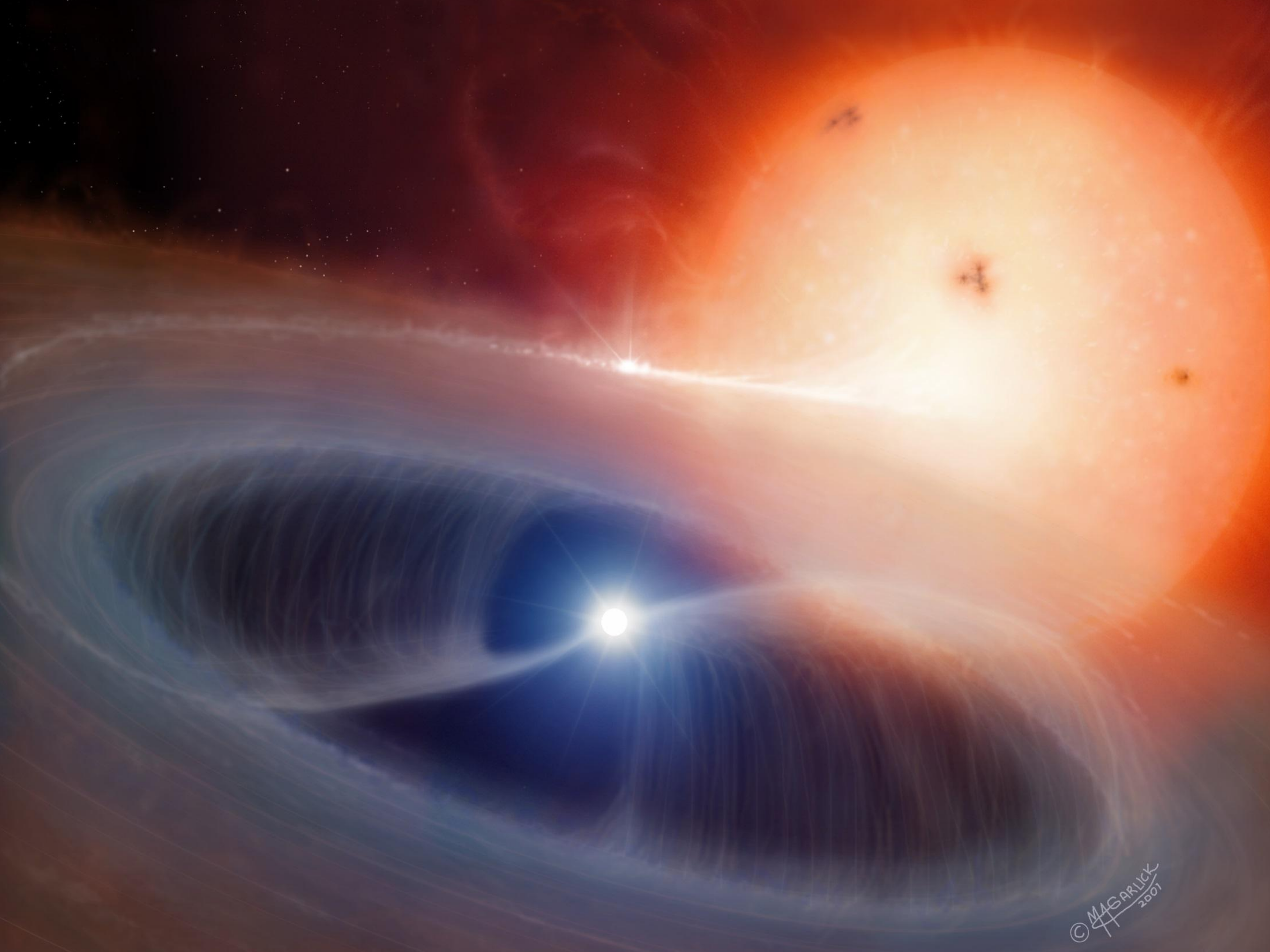


Wood et al. 2005, ApJ 634, 570

… one of the most rapidly rotating white dwarfs …

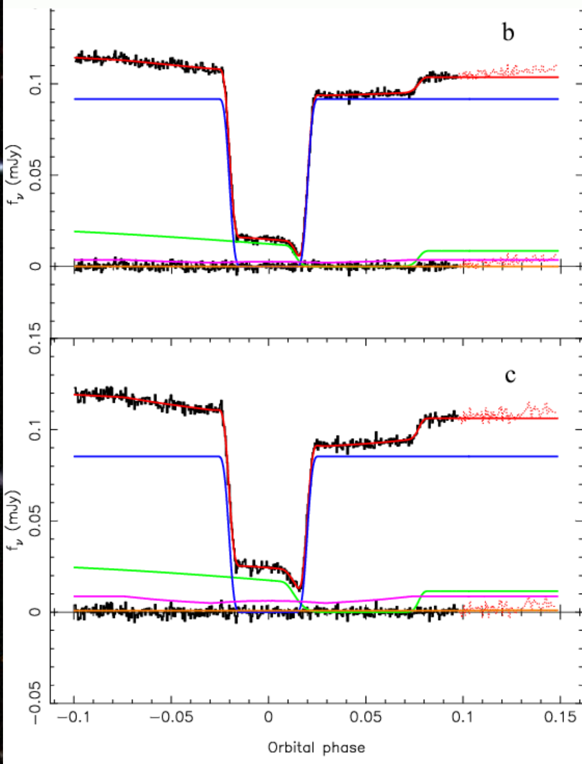


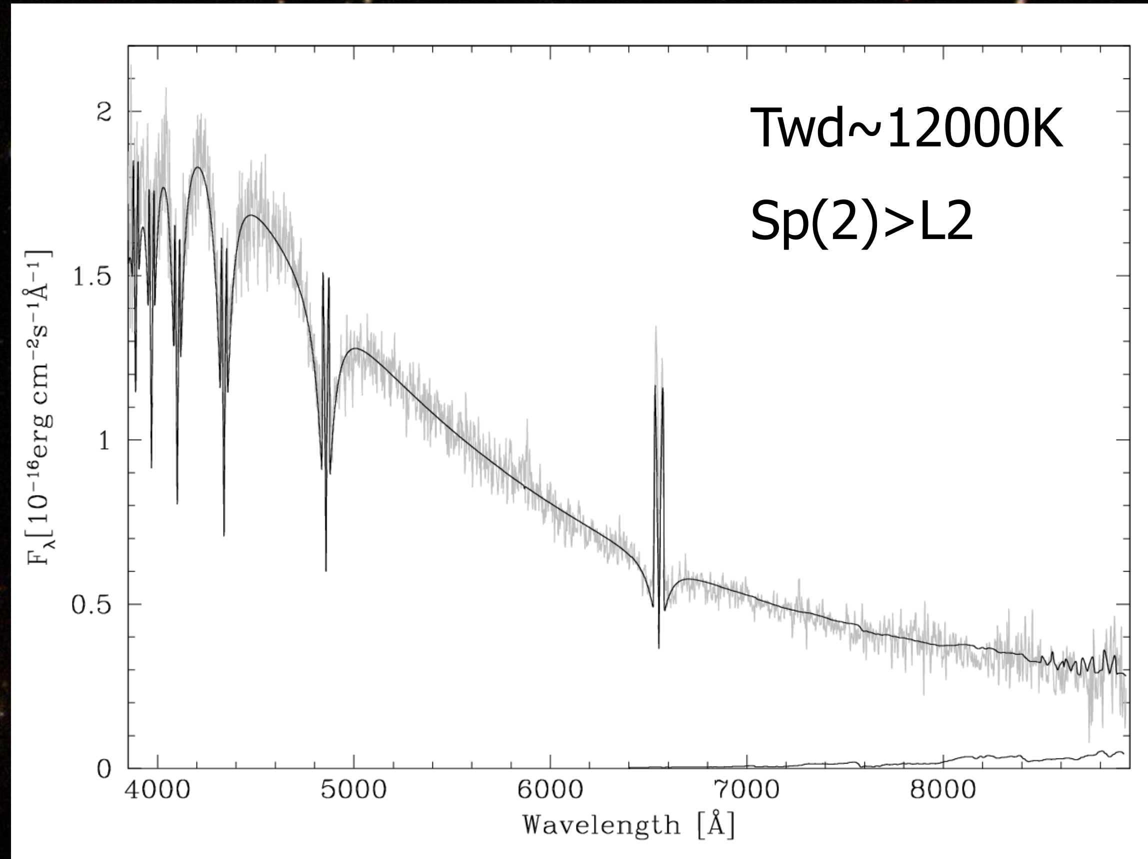
Wood et al. 2005, ApJ 634, 570


©M A GARLICK 2007

SDSS1035+0551: massive WD, light-weight donor

Mass ratio q	0.055 ± 0.002
Inclination i	$83.1° \pm 0.2°$
Orbital separation a	$0.622 \pm 0.003\ R_\odot$
White dwarf mass M_w	$0.94 \pm 0.01\ M_\odot$
White dwarf radius R_w	$0.0087 \pm 0.0001\ R_\odot$
White dwarf temperature T^{eff}_w	$10\,100 \pm 200$ K
Donor star mass M_c	$0.052 \pm 0.002\ M_\odot$
Donor star radius R_c	$0.108 \pm 0.003\ R_\odot$
Disc radius R_d/a	0.362 ± 0.003





VLT spectroscopy: eclipsing, P=82min

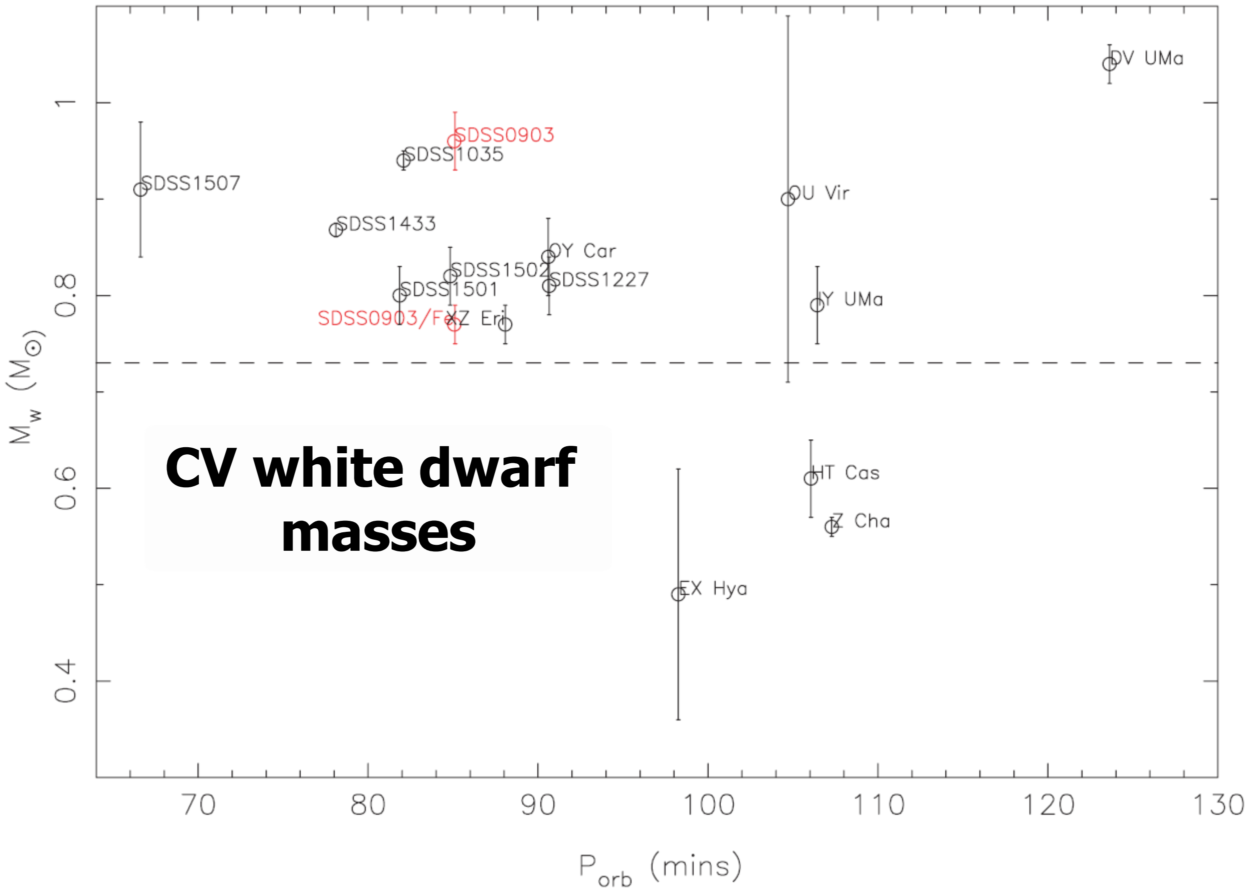
(Southworth et al. 2006, MNRAS 373, 687)

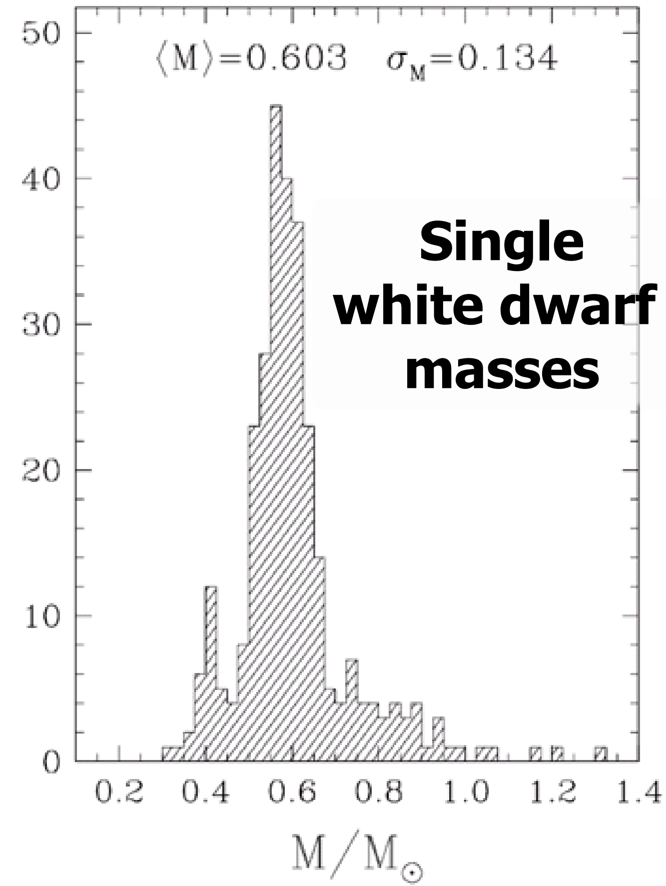
WHT/ULTRACAM photometry: M2=0.055±0.002

(Littlefair et al. 2006, Science 314, 1578)

and many more: Littlefair et al. 2007, MNRAS 381; 2008, MNRAS 388, 1582

What are the masses of white dwarfs in CVs?

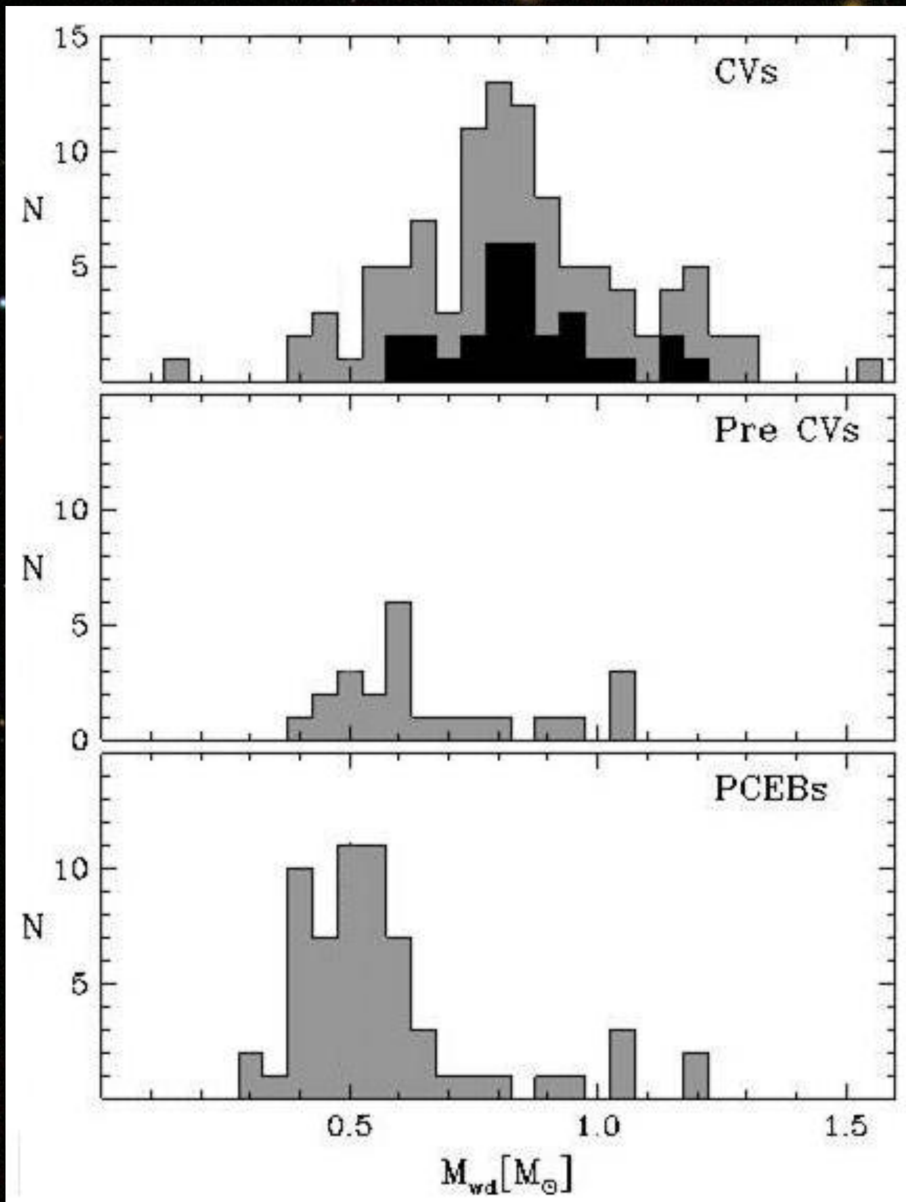




Feline et al. (2004),
Littlefair et al. (2006, 2007, 2008)
Savoury et al. (2011)

Liebert et al. (2005)

CVs versus pre-CVs and PCEBs



$\langle M_{wd} \rangle = 0.83 \pm 0.23\ M_\odot$

$\langle M_{wd} \rangle = 0.67 \pm 0.21\ M_\odot$

$\langle M_{wd} \rangle = 0.58 \pm 0.20\ M_\odot$

$\Rightarrow$ can the white dwarfs in CVs grow in mass !?

John Goodricke

White dwarfs

Cosmology

Eclipsing binaries

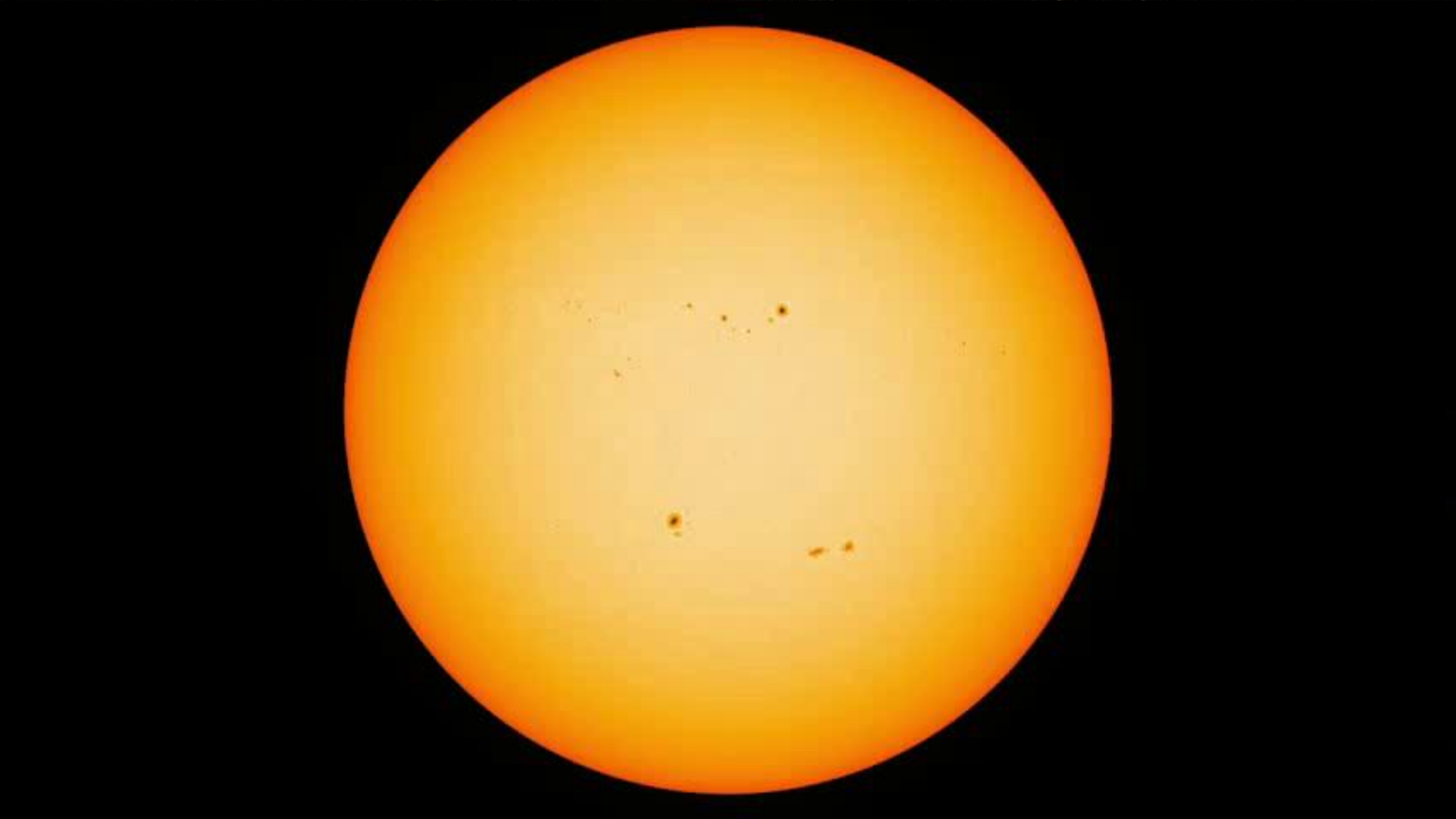
Masses and radii

Extra-solar
planets

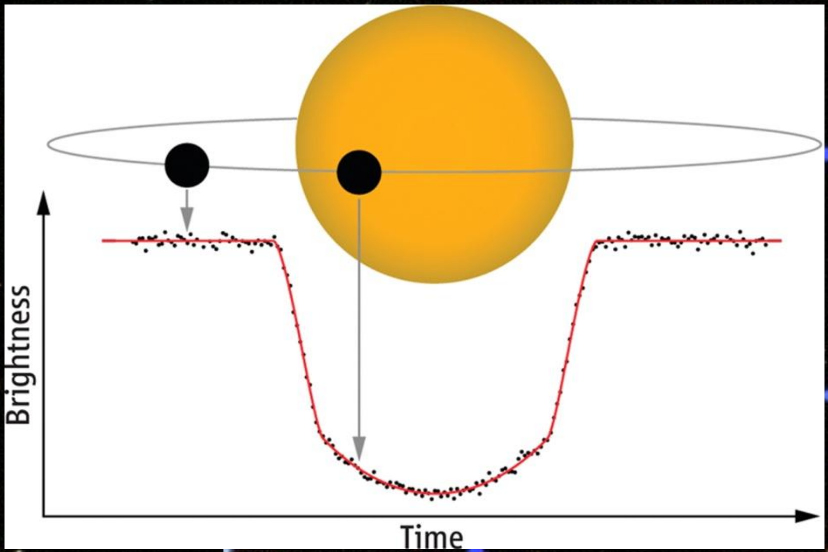
Cataclysmic
variables

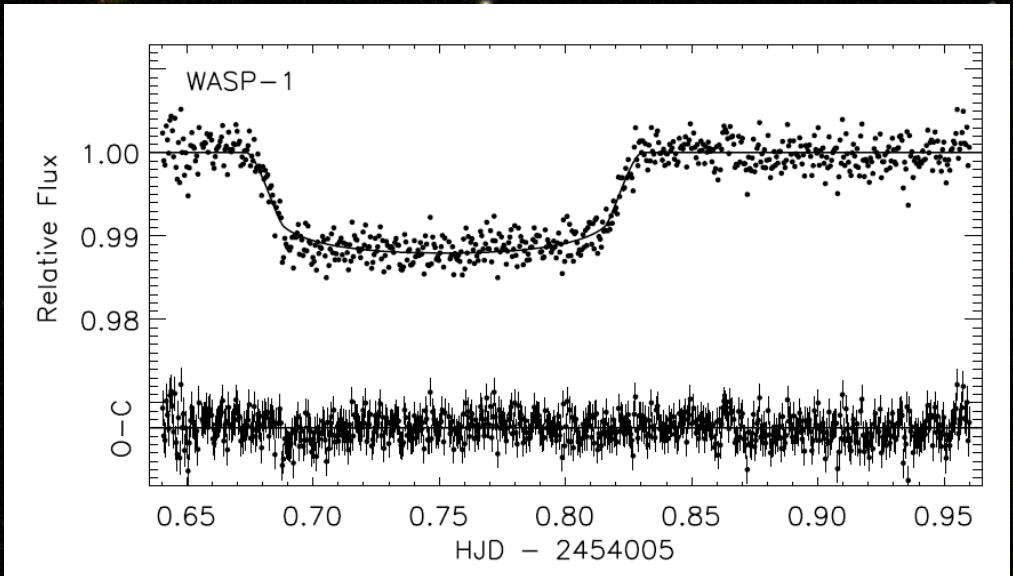
Life

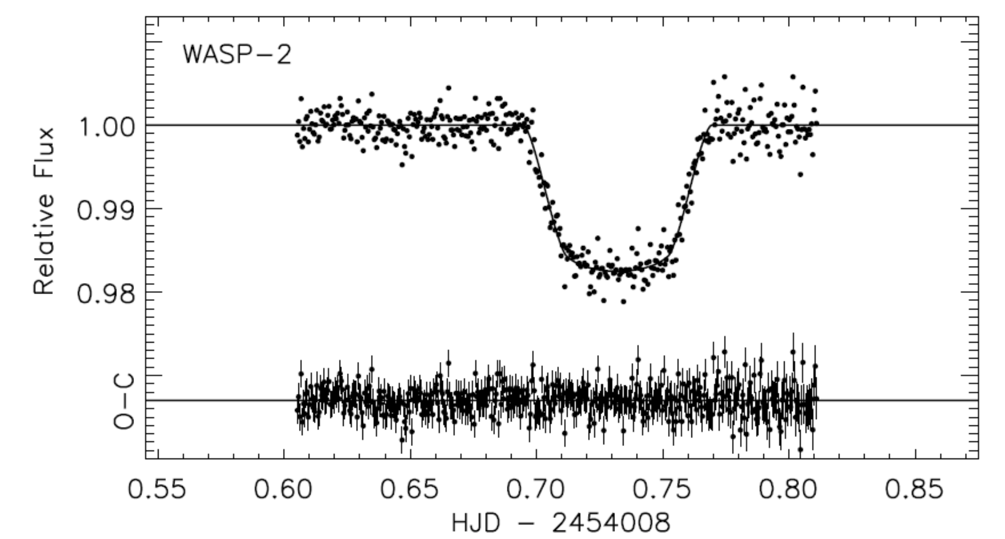
The 2012 transit of Venus observed by SDO



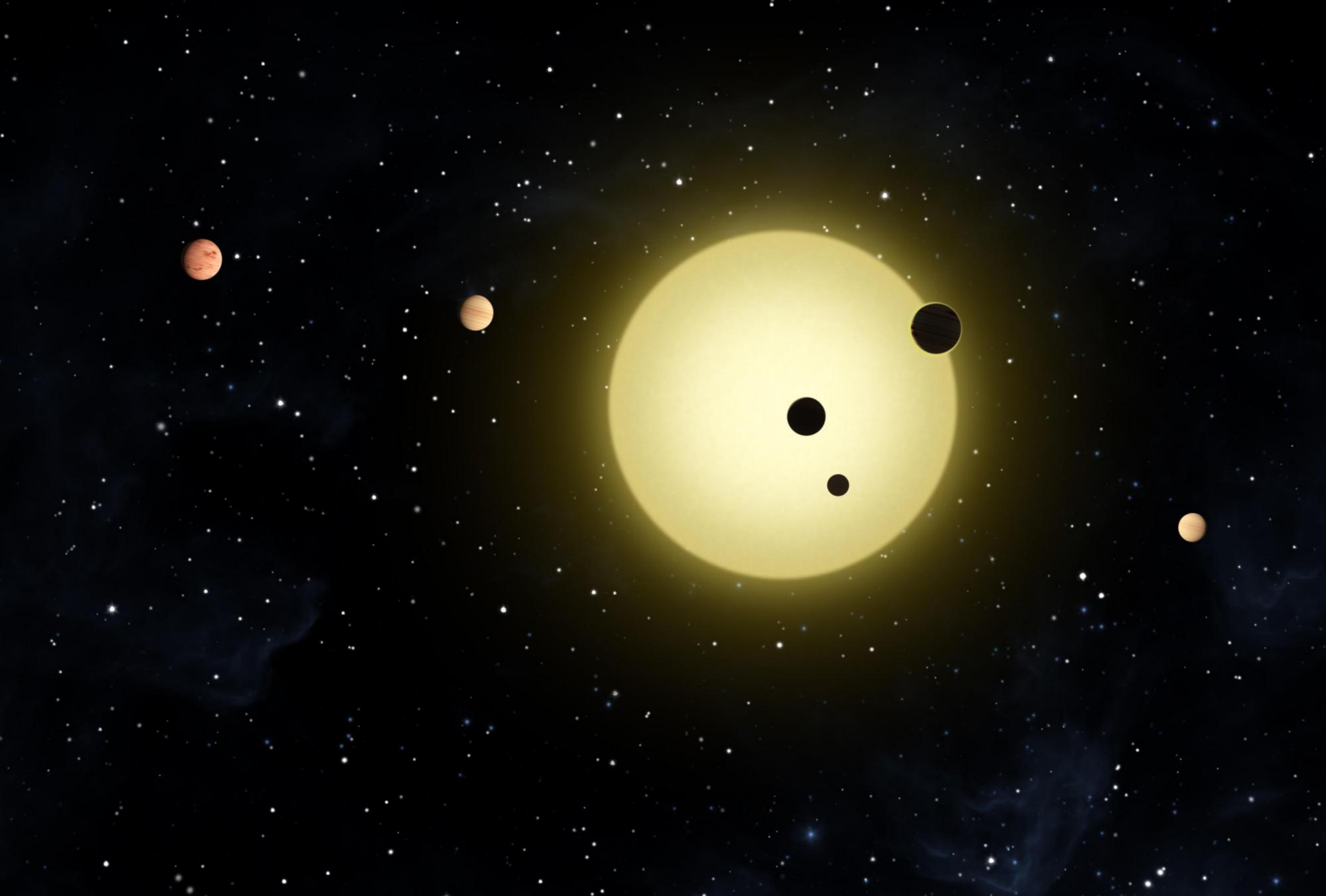
Exo-planets discovered by their transits (eclipses)



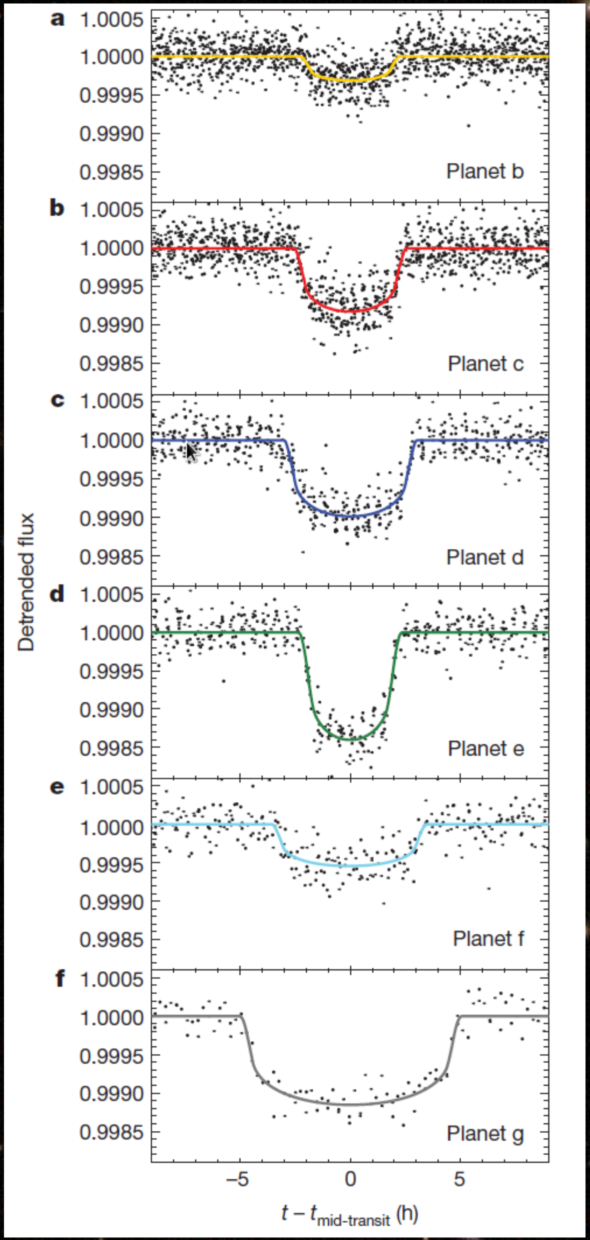


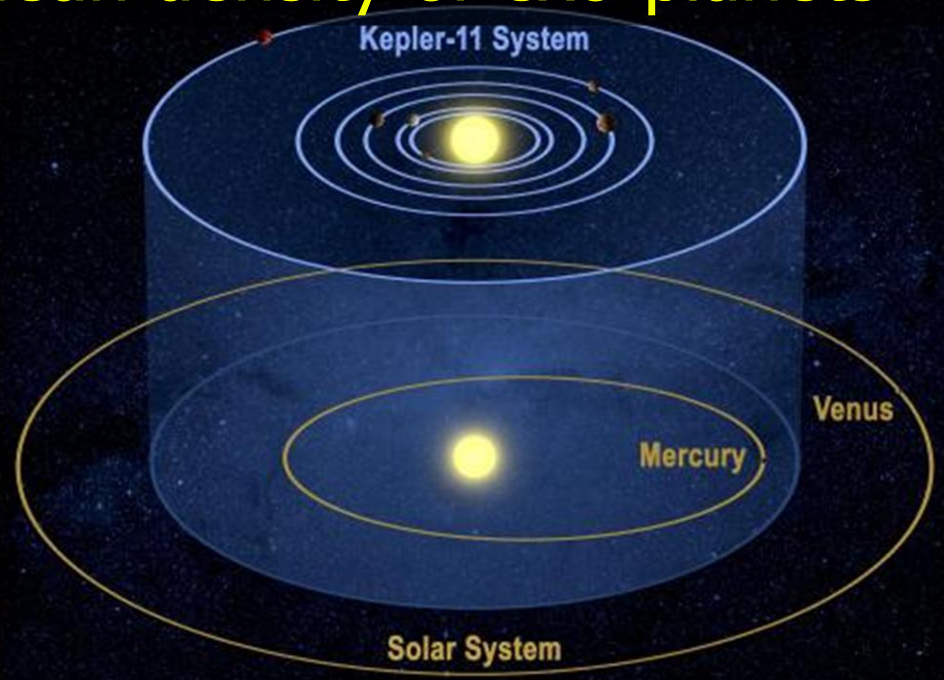


Kepler-11: 6 transiting planets



Estimating the mean density of exo-planets

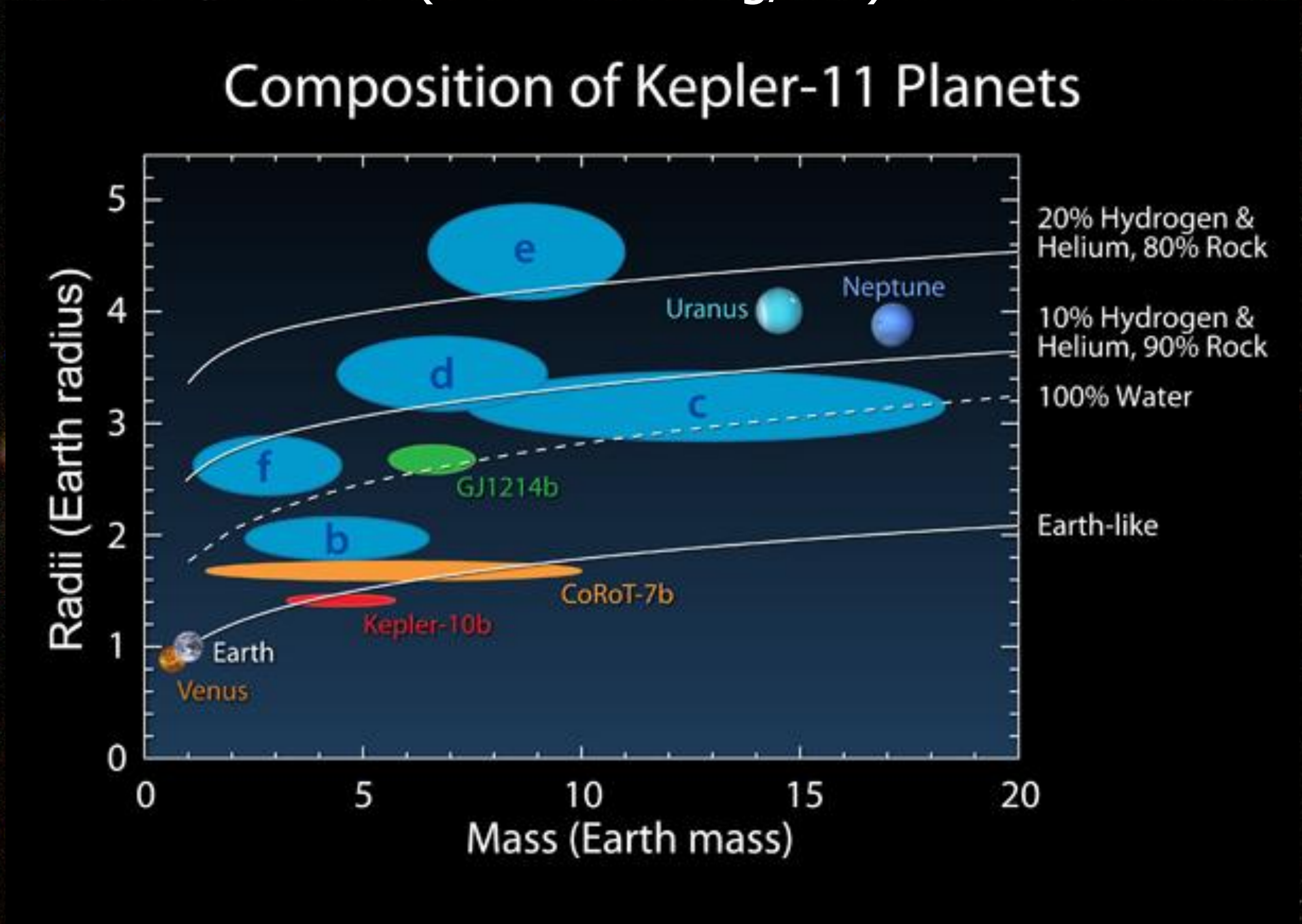




Estimating the mean density of exo-planets

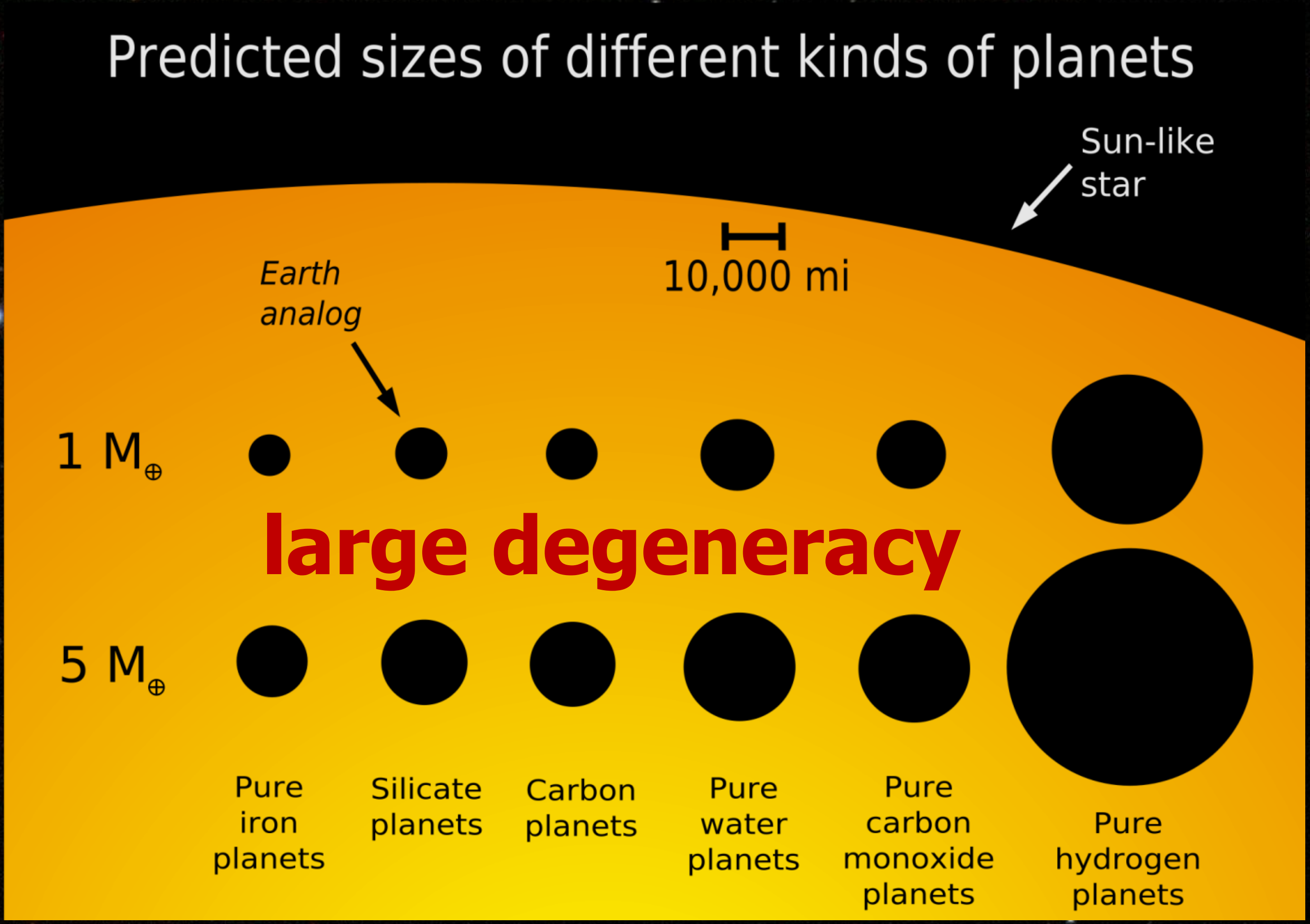
- Transit timing: planet radius ⇒ volume
- Spectroscopy & Kepler's 3rd law: planet mass

e.g. Earth 5500 kg/m^{-3} & Saturn 687 kg/m^{-3}
(water 1000 kg/m^{-3})

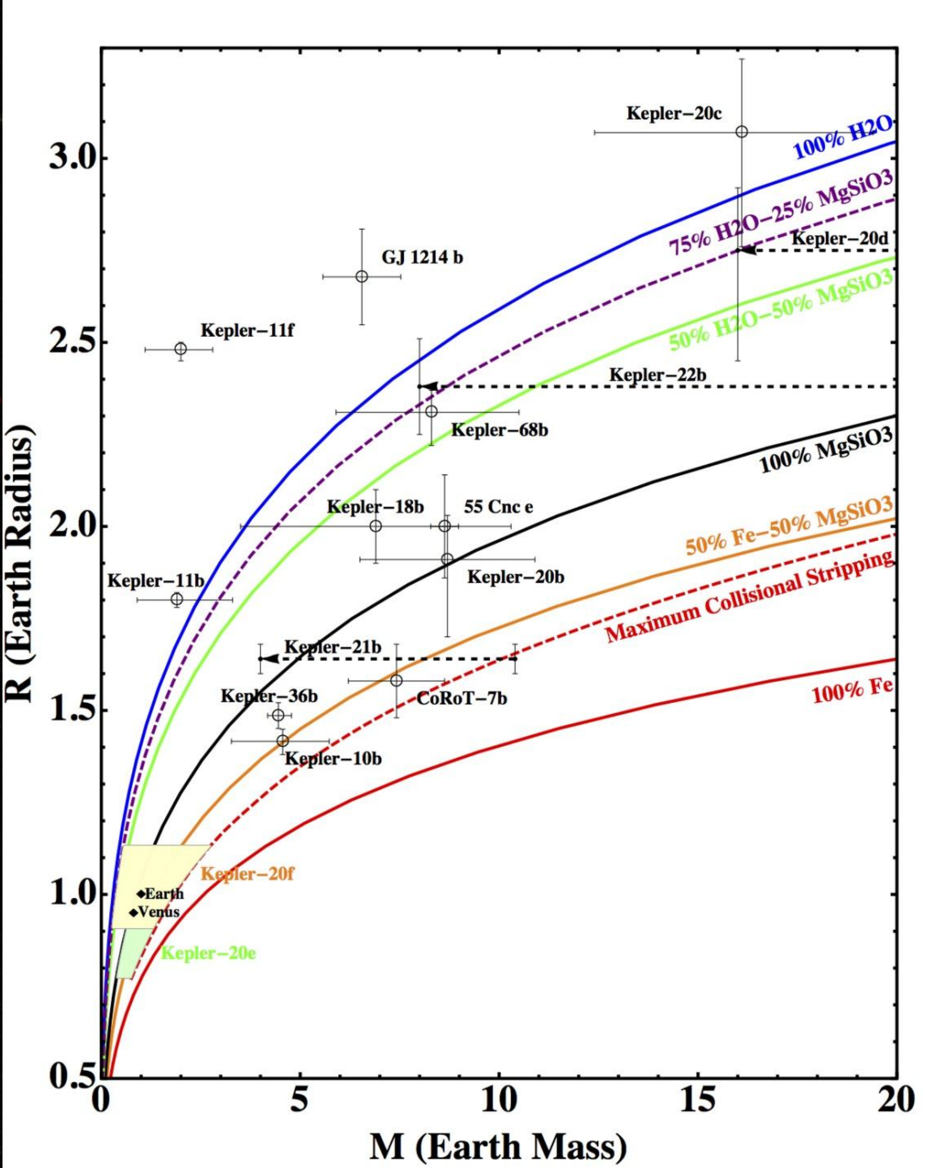


Transiting planets ⇒ M & R ⇒ bulk densities

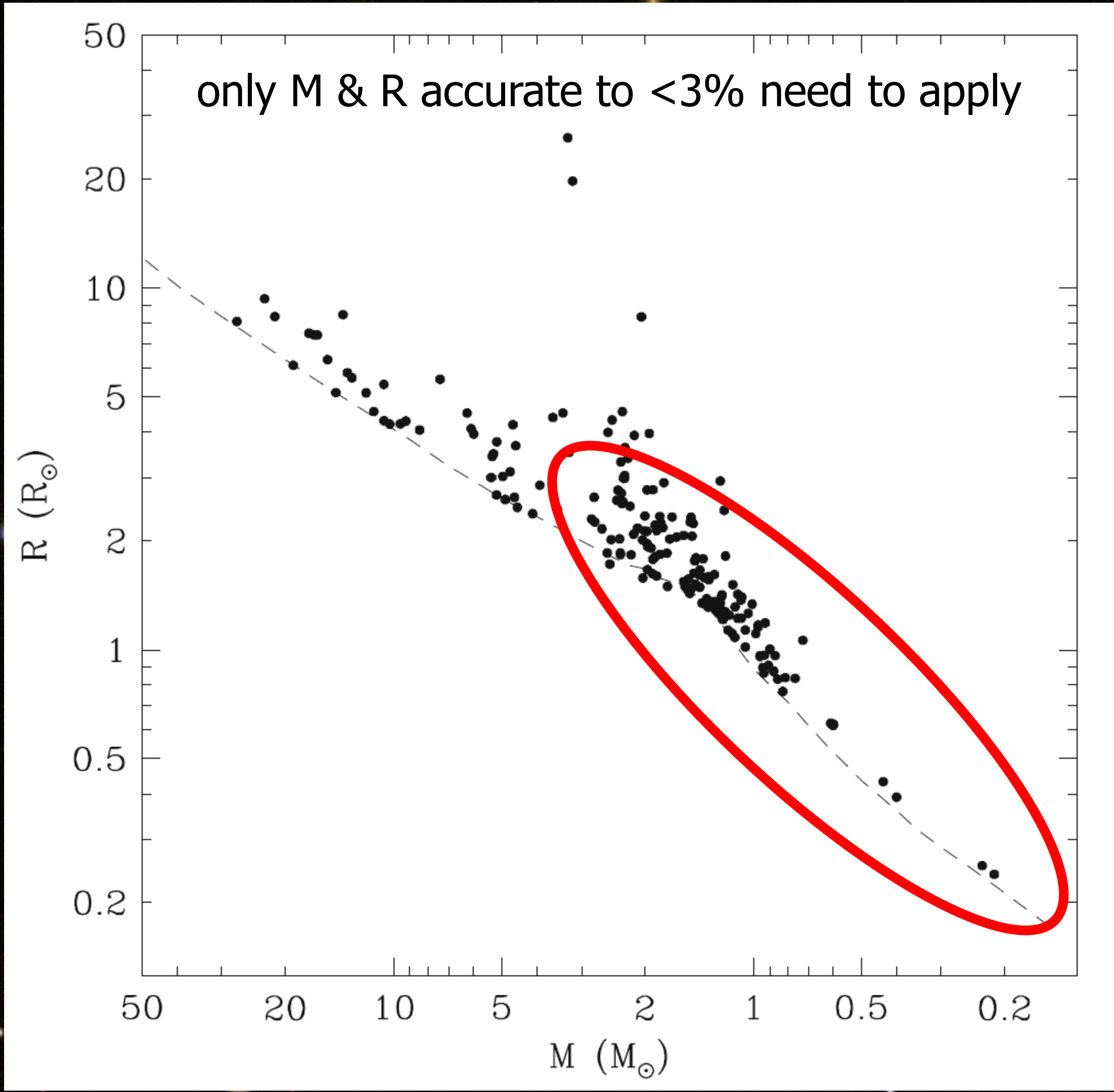
What is the *bulk composition* of exo-planets?



Underlying assumption: **we know Mhost …**

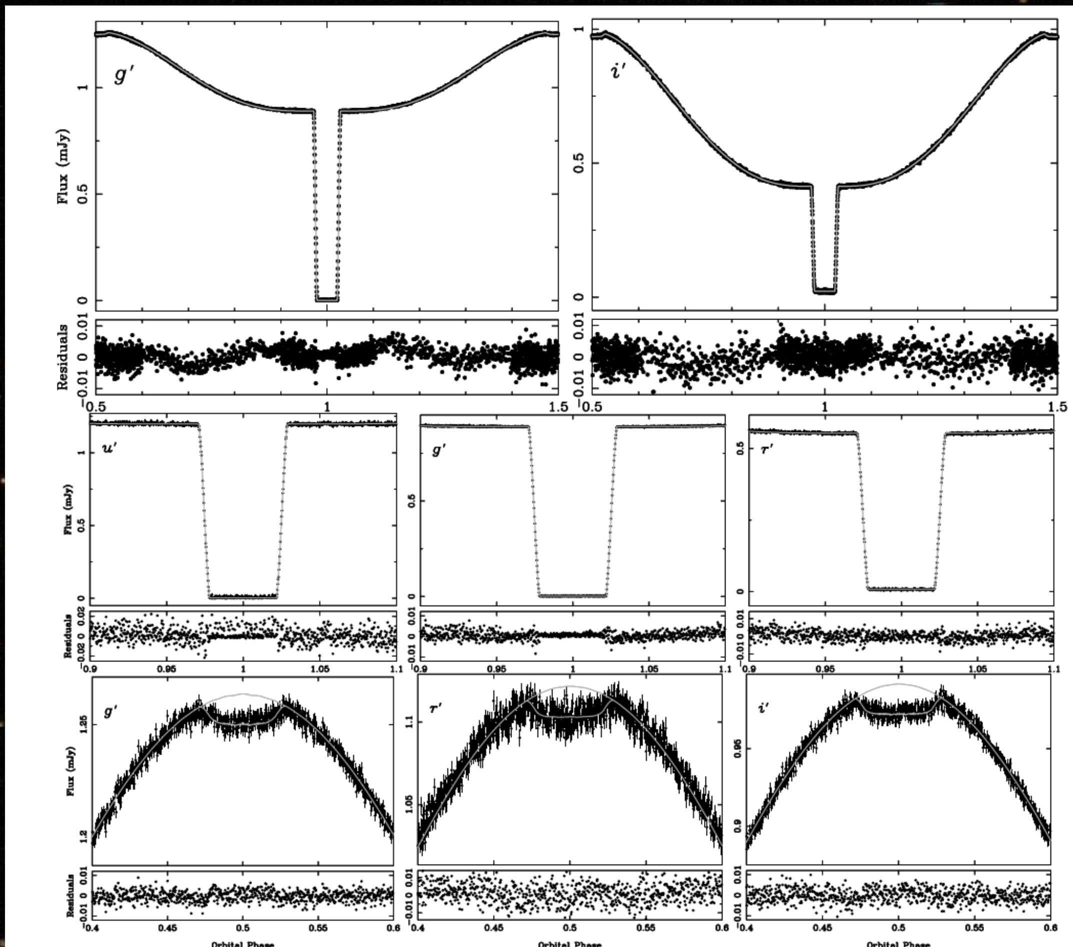


… which we don't always know so well!



… 50% of WD/MS binaries are low mass stars…

NN Ser: a hot DAO WD + very low mass dM



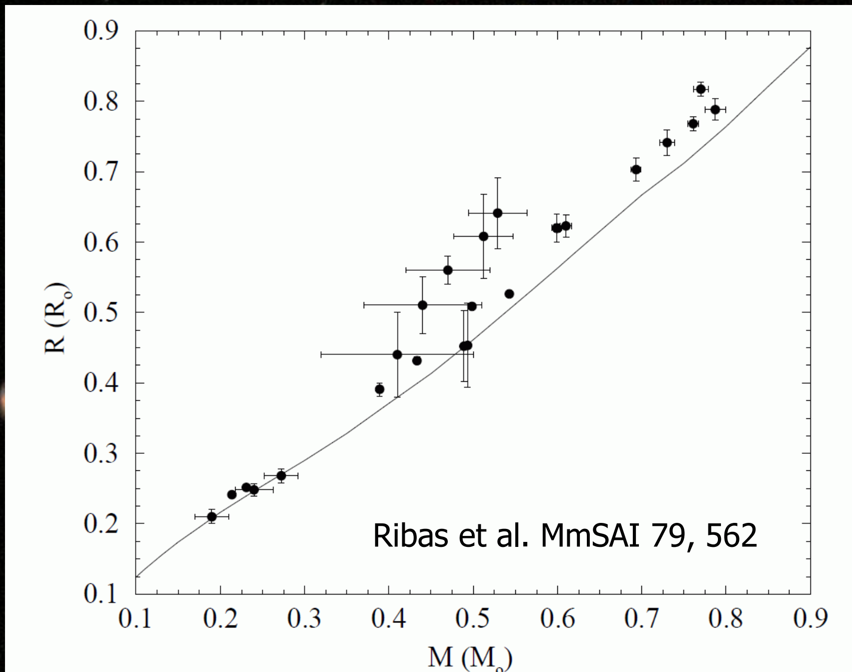
$M_{wd} = 0.111 \pm 0.004 M_{\odot}$

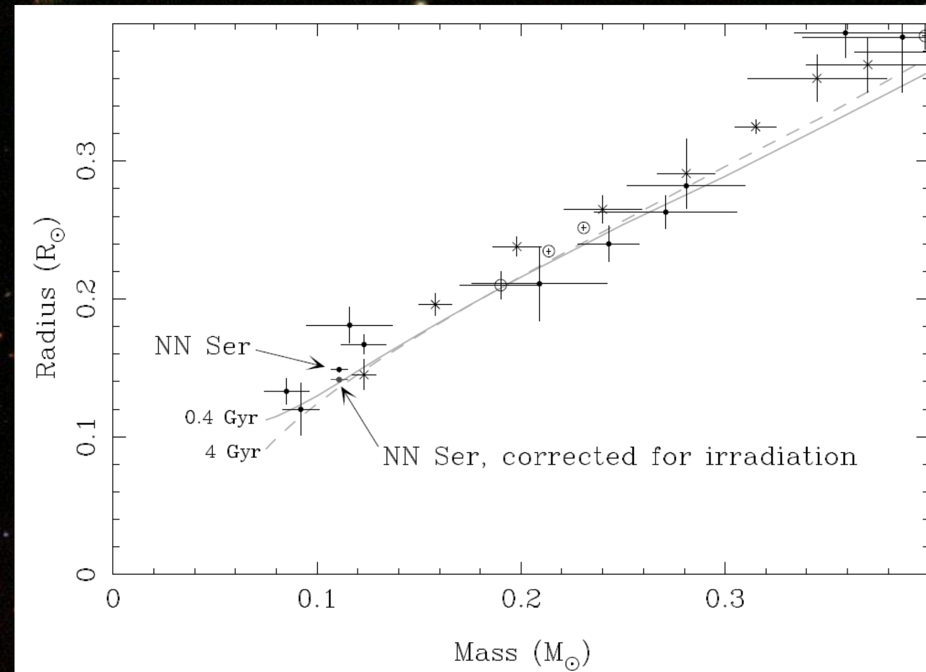
$R_{ms} = 0.149 \pm 0.002 R_{\odot}$

1-2% precision in M, R

Parsons et al. 2010, MNRAS 402, 2591

Constraints on M/R of low mass stars





The best constraints at the lowest masses are from eclipsing WD + MS binaries!

John Goodricke

White dwarfs

Cosmology

Eclipsing binaries

Masses and radii

Extra-solar planets

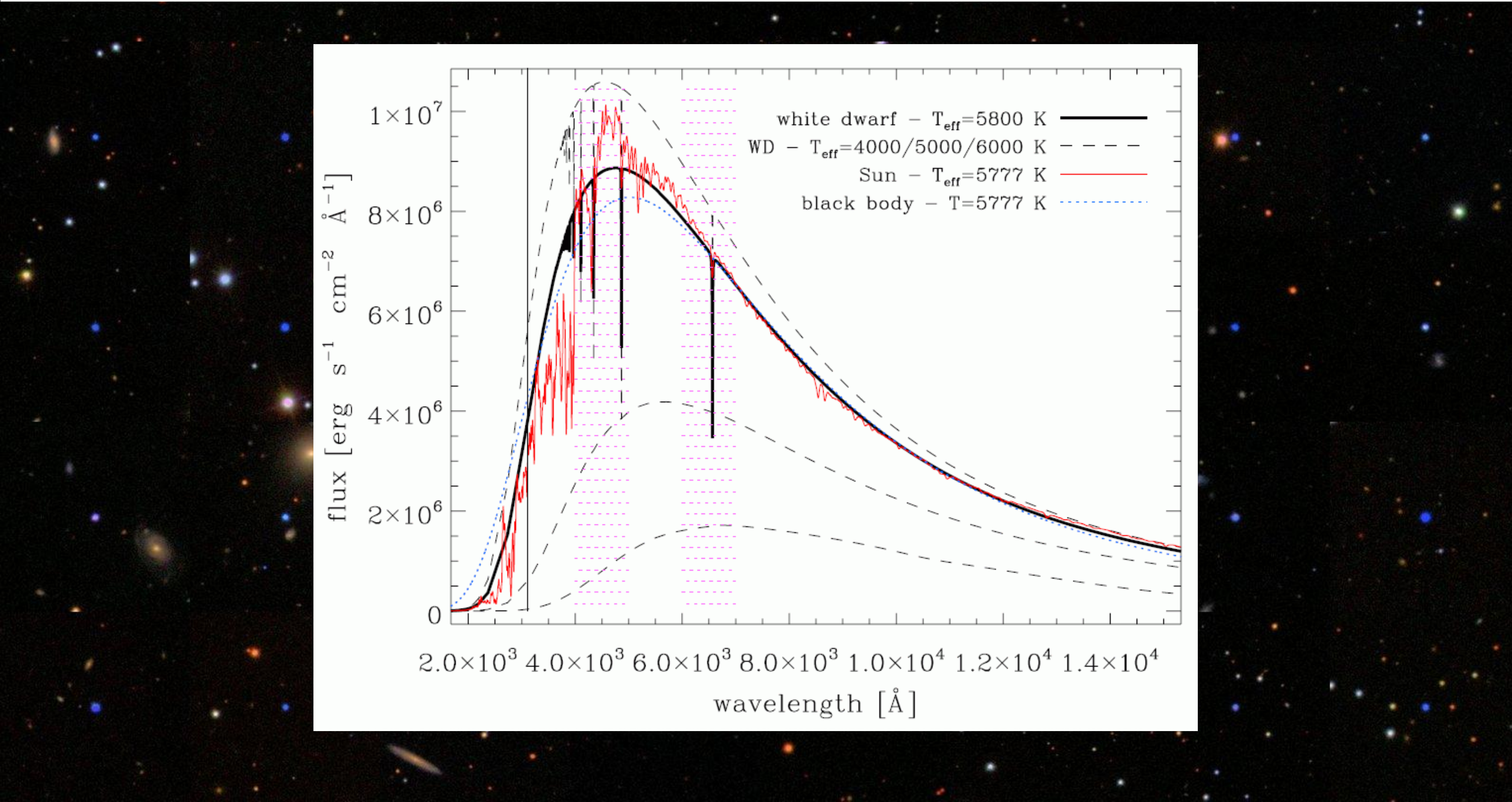
Cataclysmic variables

Life

The Astrophysical Journal Letters, 731:L31 (5pp), 2011 April 20 doi:10.1088/2041-8205/731/2/L31

TRANSIT SURVEYS FOR EARTHS IN THE HABITABLE ZONES OF WHITE DWARFS

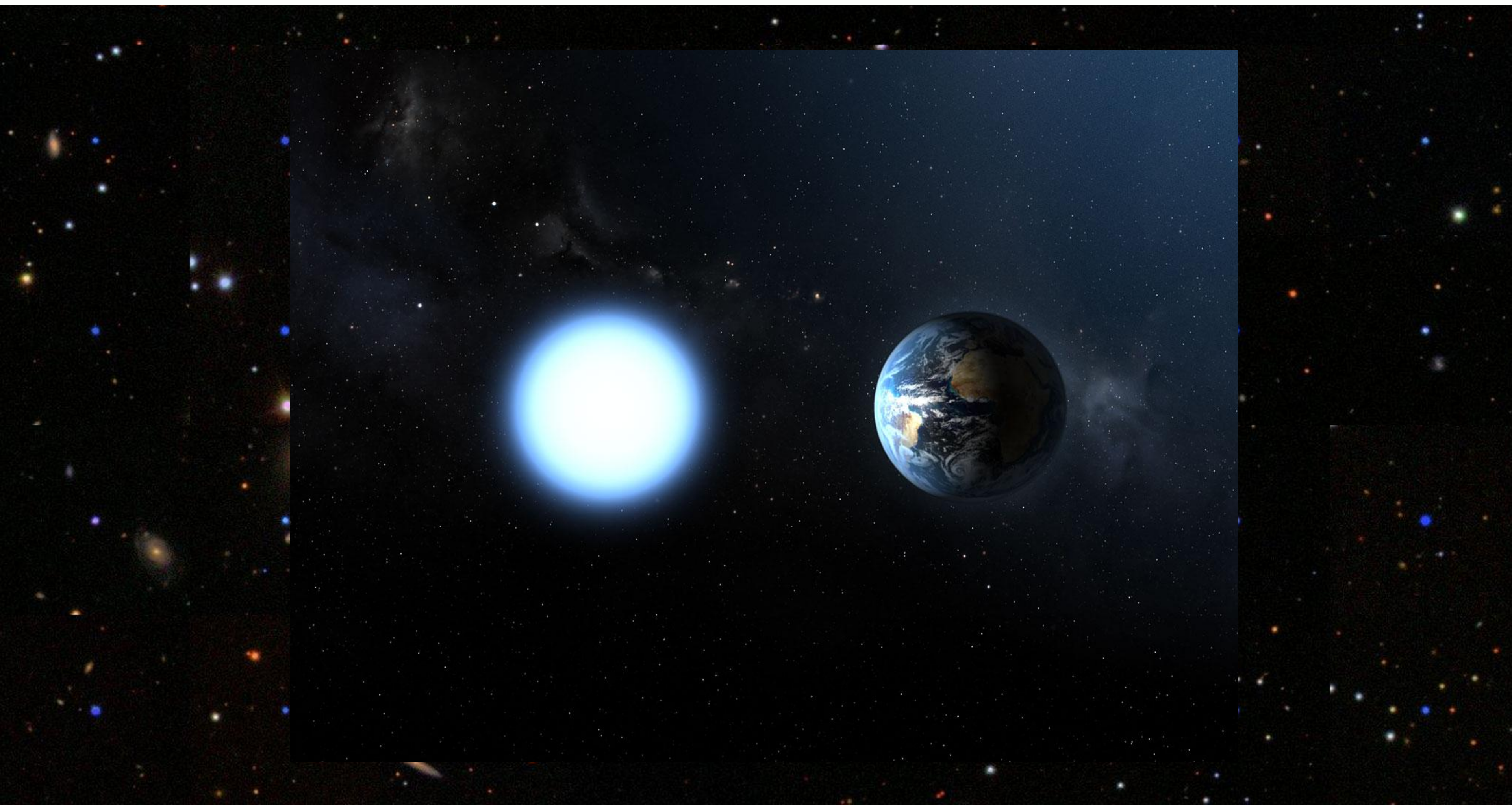
Eric Agol
Department of Astronomy, Box 351580, University of Washington, Seattle, WA 98195, USA; agol@uw.edu
Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA
Received 2010 December 20; accepted 2011 March 9; published 2011 March 29



The Astrophysical Journal Letters, 731:L31 (5pp), 2011 April 20 doi:10.1088/2041-8205/731/2/L31

TRANSIT SURVEYS FOR EARTHS IN THE HABITABLE ZONES OF WHITE DWARFS

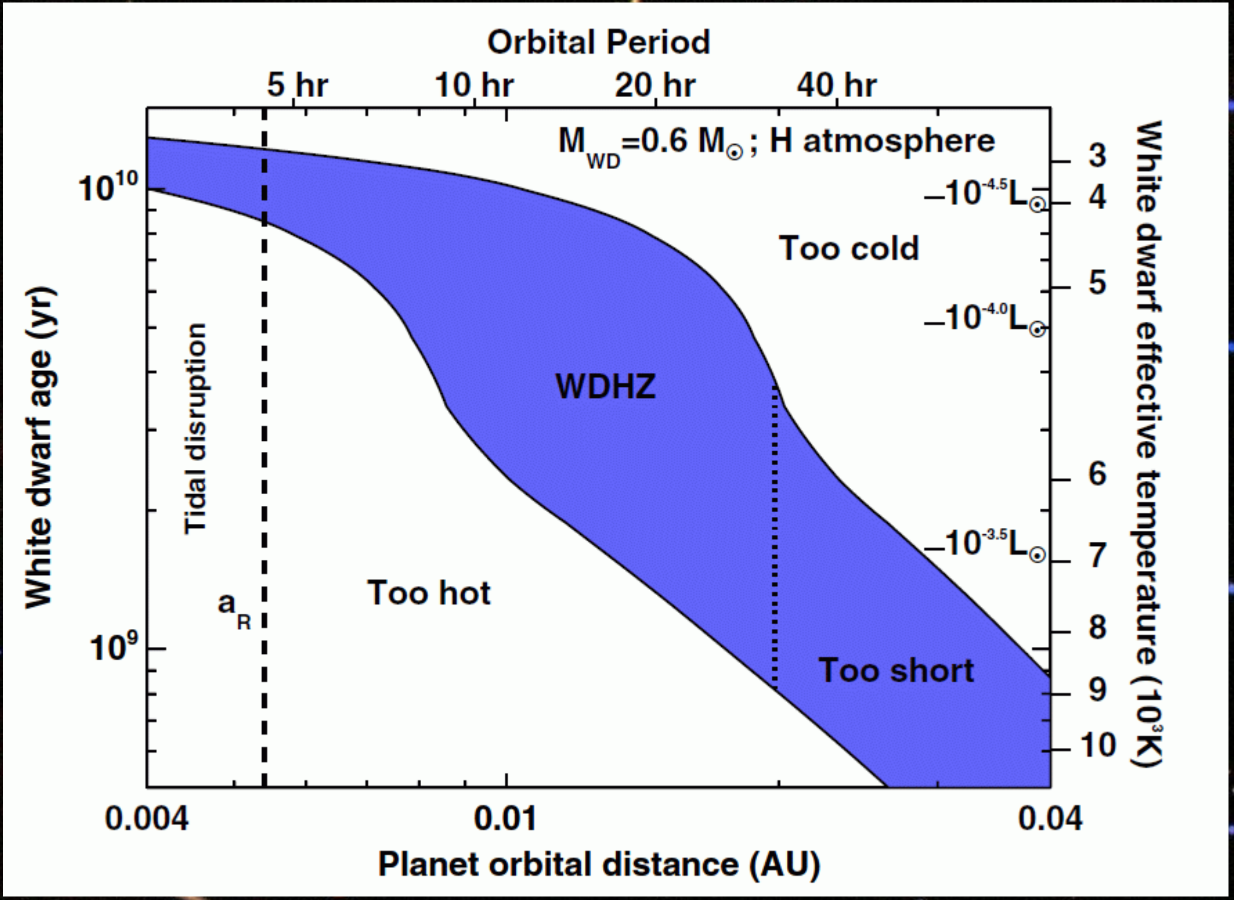
Eric Agol
Department of Astronomy, Box 351580, University of Washington, Seattle, WA 98195, USA; agol@uw.edu
Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA
Received 2010 December 20; accepted 2011 March 9; published 2011 March 29



The Astrophysical Journal Letters, 731:L31 (5pp), 2011 April 20 doi:10.1088/2041-8205/731/2/L31

TRANSIT SURVEYS FOR EARTHS IN THE HABITABLE ZONES OF WHITE DWARFS

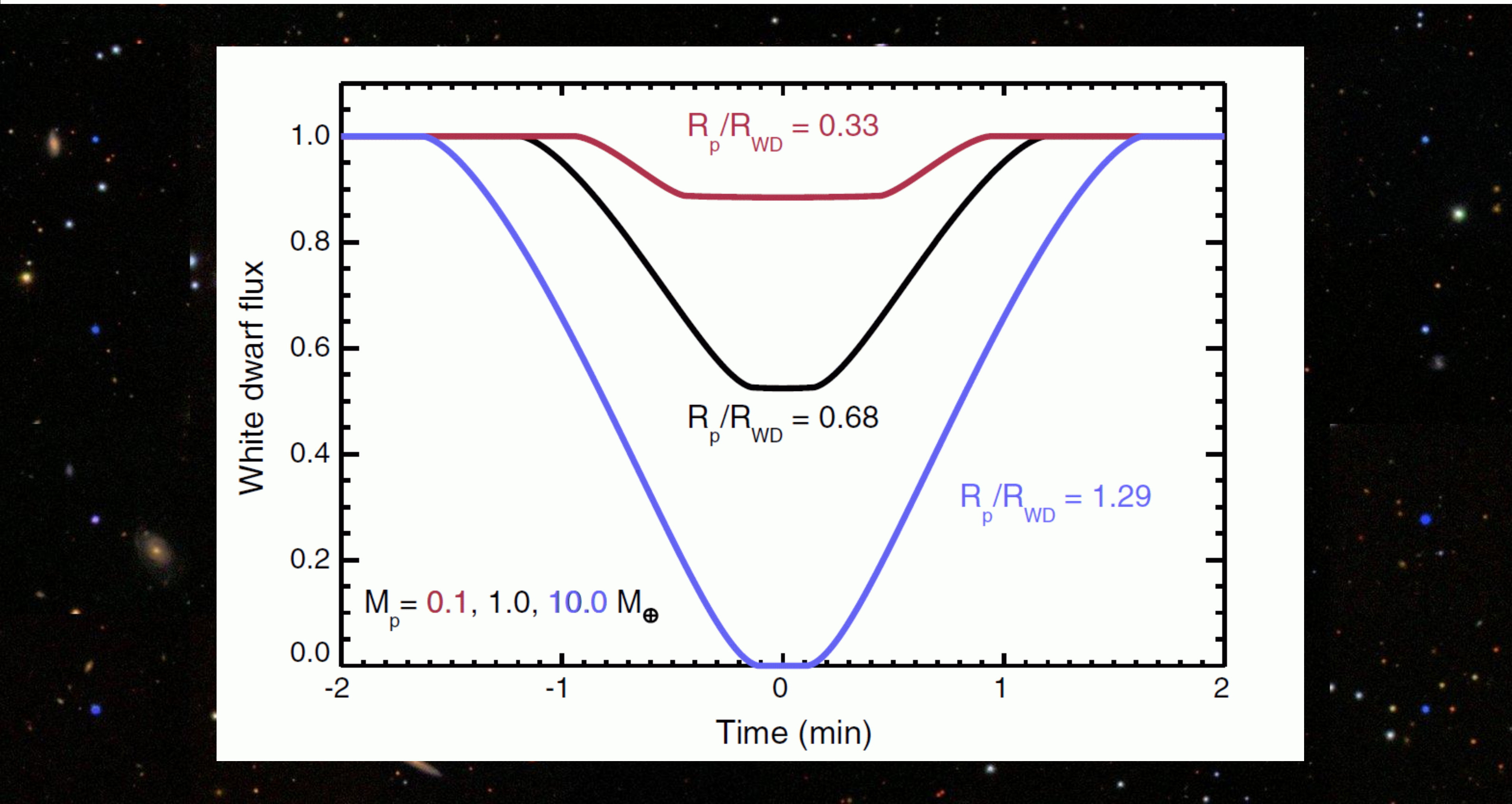
Eric Agol
Department of Astronomy, Box 351580, University of Washington, Seattle, WA 98195, USA; agol@uw.edu
Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA
Received 2010 December 20; accepted 2011 March 9; published 2011 March 29



THE ASTROPHYSICAL JOURNAL LETTERS, 731:L31 (5pp), 2011 April 20 doi:10.1088/2041-8205/731/2/L31

TRANSIT SURVEYS FOR EARTHS IN THE HABITABLE ZONES OF WHITE DWARFS

ERIC AGOL
Department of Astronomy, Box 351580, University of Washington, Seattle, WA 98195, USA; agol@uw.edu
Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA
Received 2010 December 20; accepted 2011 March 9; published 2011 March 29



The discovery of eclipsing binaries has led to many fundamental results in astronomy, and still stimulates forefront science


The end