Discovery of the First Eclipsing Detached Double White Dwarf Binary

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Steinfadt et al. 2010, ApJ, 716, 441
(Steinfadt et al. 2010a)
Kaplan. 2010, ApJ, 717, 108
(Kaplan 2010)

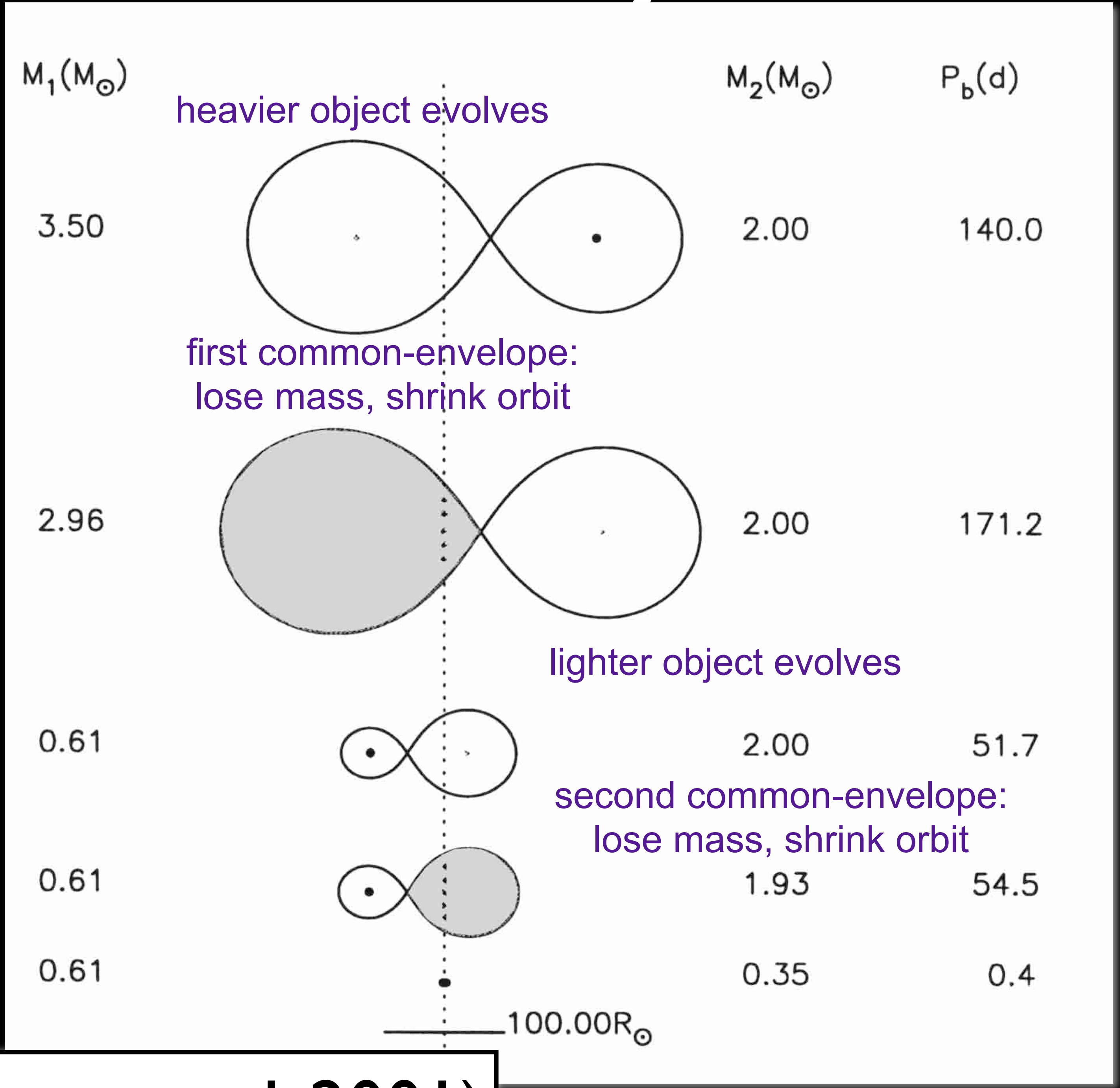
17th European White Dwarf Workshop
Tübingen, Germany - August 16-20, 2010

Punchlines!

- First eclipsing detached double white dwarf! 5.6 hr orbit.
- First (almost) model independent radius measurement of a low mass (<0.2 Msun) helium white dwarf!

He WD formation implies binarity

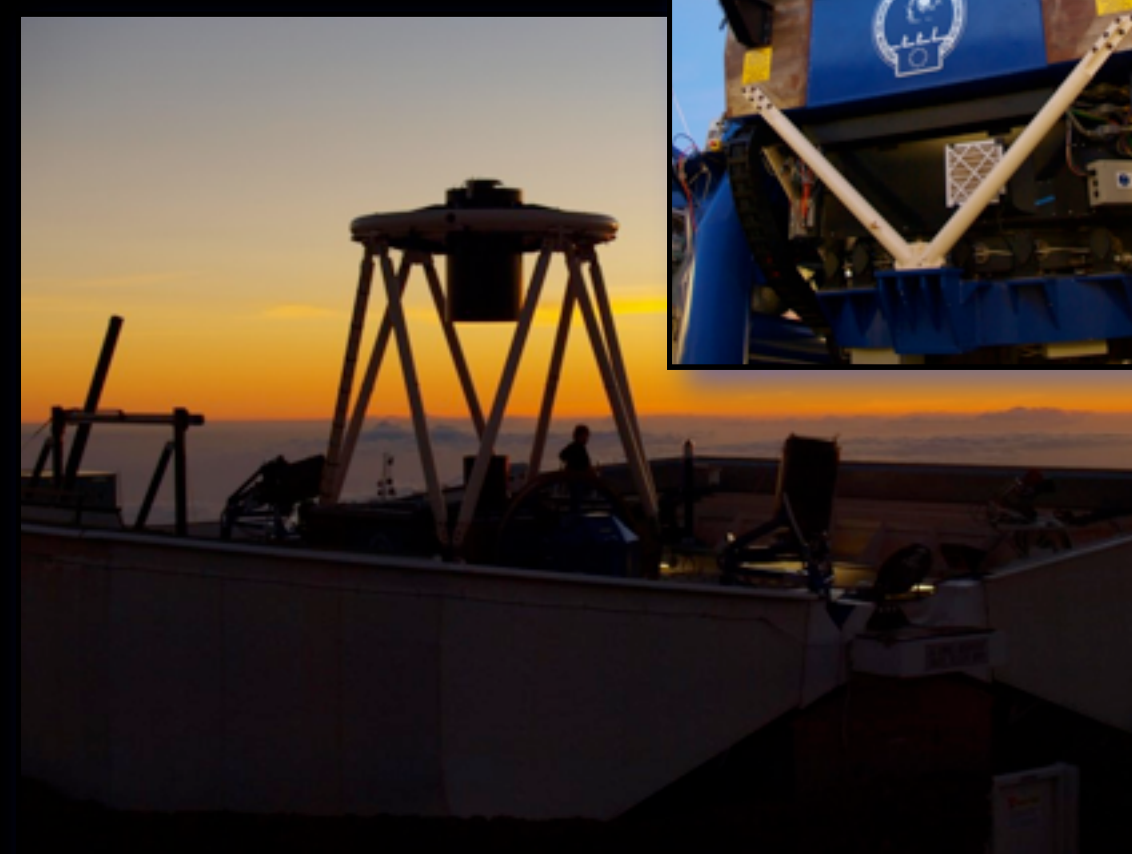
- He WDs $\leq 0.2\ M_{SUN}$ can only be made in binary common envelopes



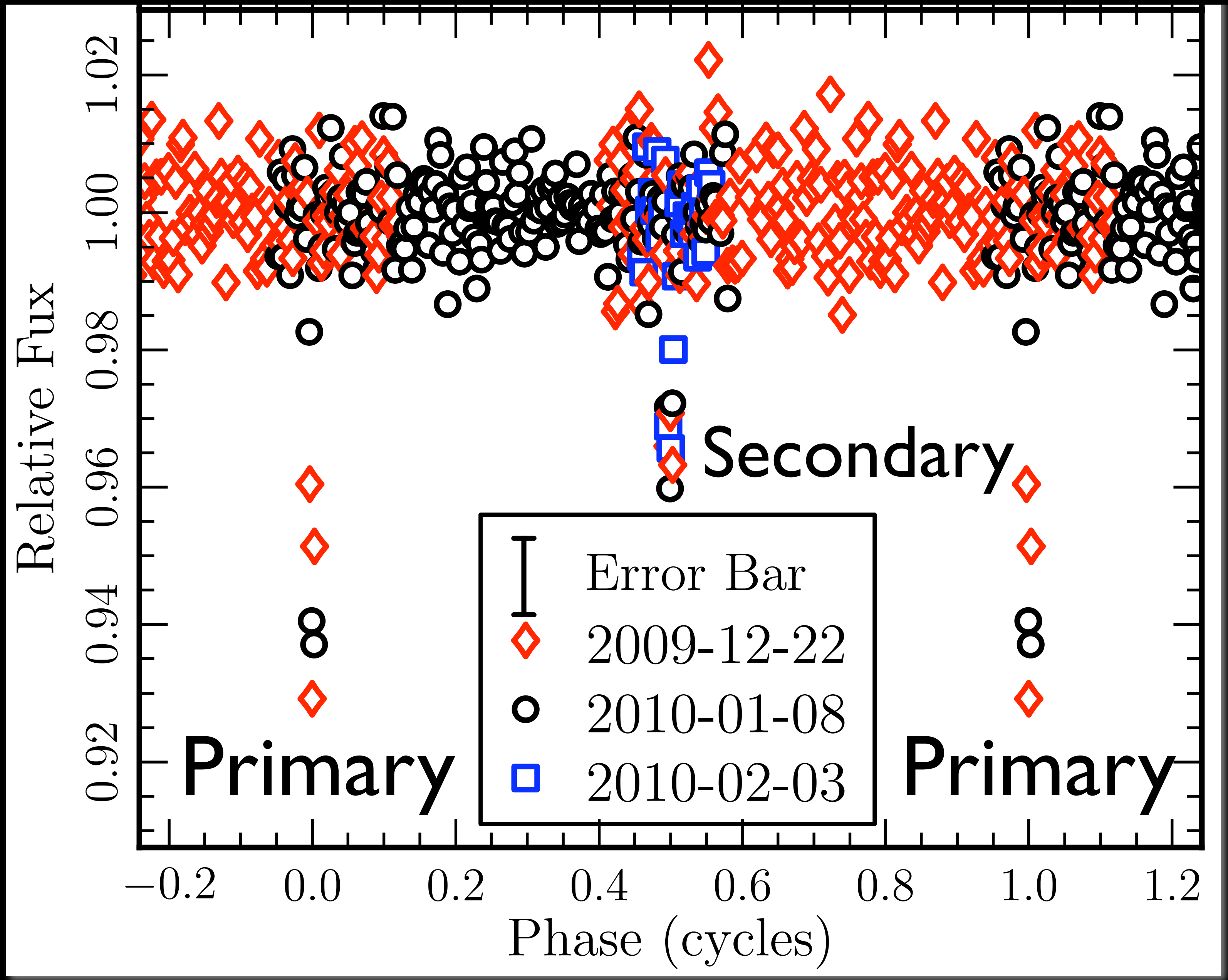
(Marsh et al. 1995, Nelemans et al. 2001)

Observations

- NLTT 11748 was targeted in a search for non-radial g-mode pulsations at 100-1000 second periods
  - None detected at 4 mmag amplitude
- Faulkes Telescope North/ Merope (LCOGT)
  - 2-m Telescope on Haleakala, Hawaii
  - 45 second exposures, 22 second readout
    - 4-5 mmag differential precision
  - Data from 3 nights



We Found Eclipses!



(Steinfadt et al. 2010a)

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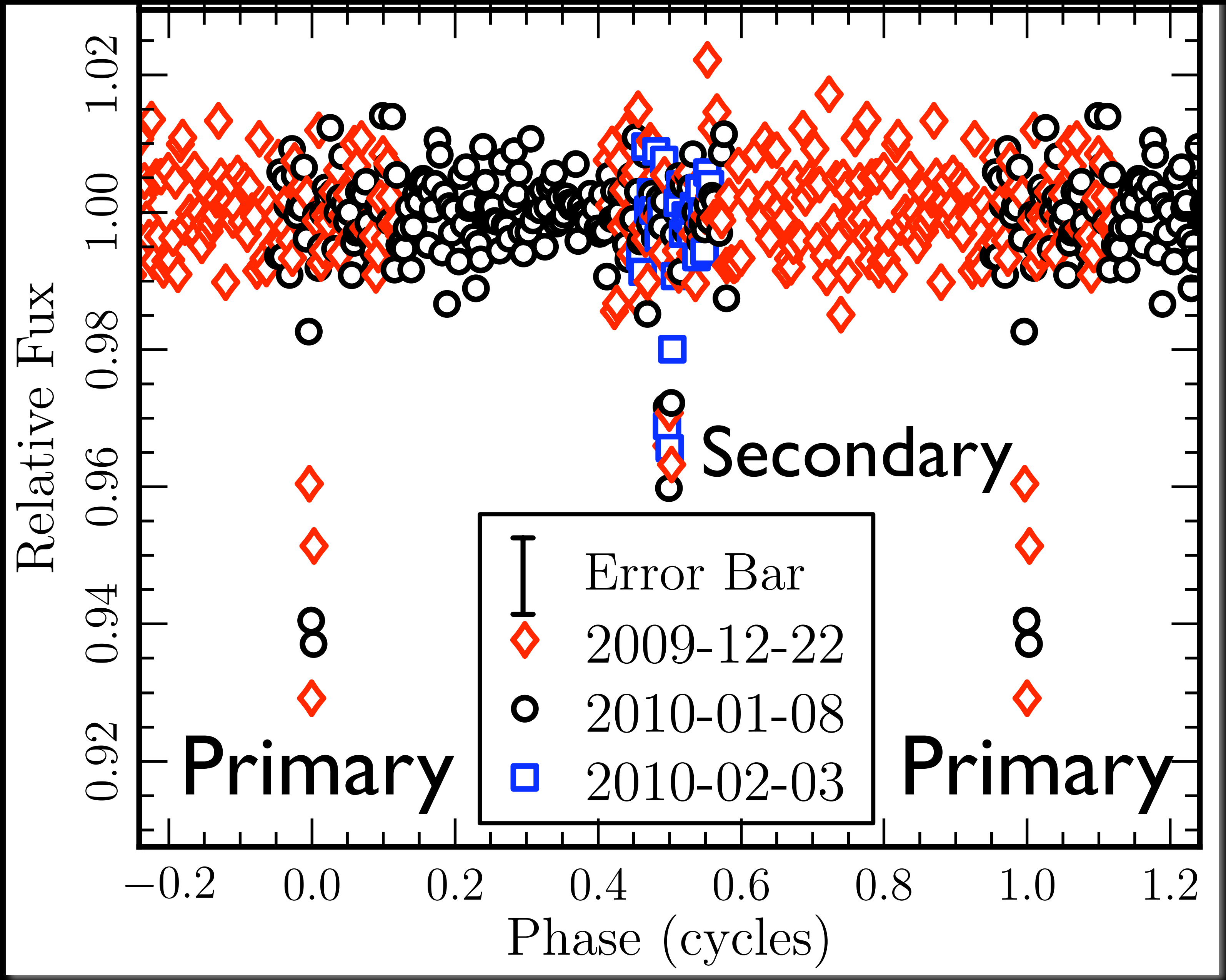
- FTN Photometry
  - 5.6 hr period
  - 3%-6% depth



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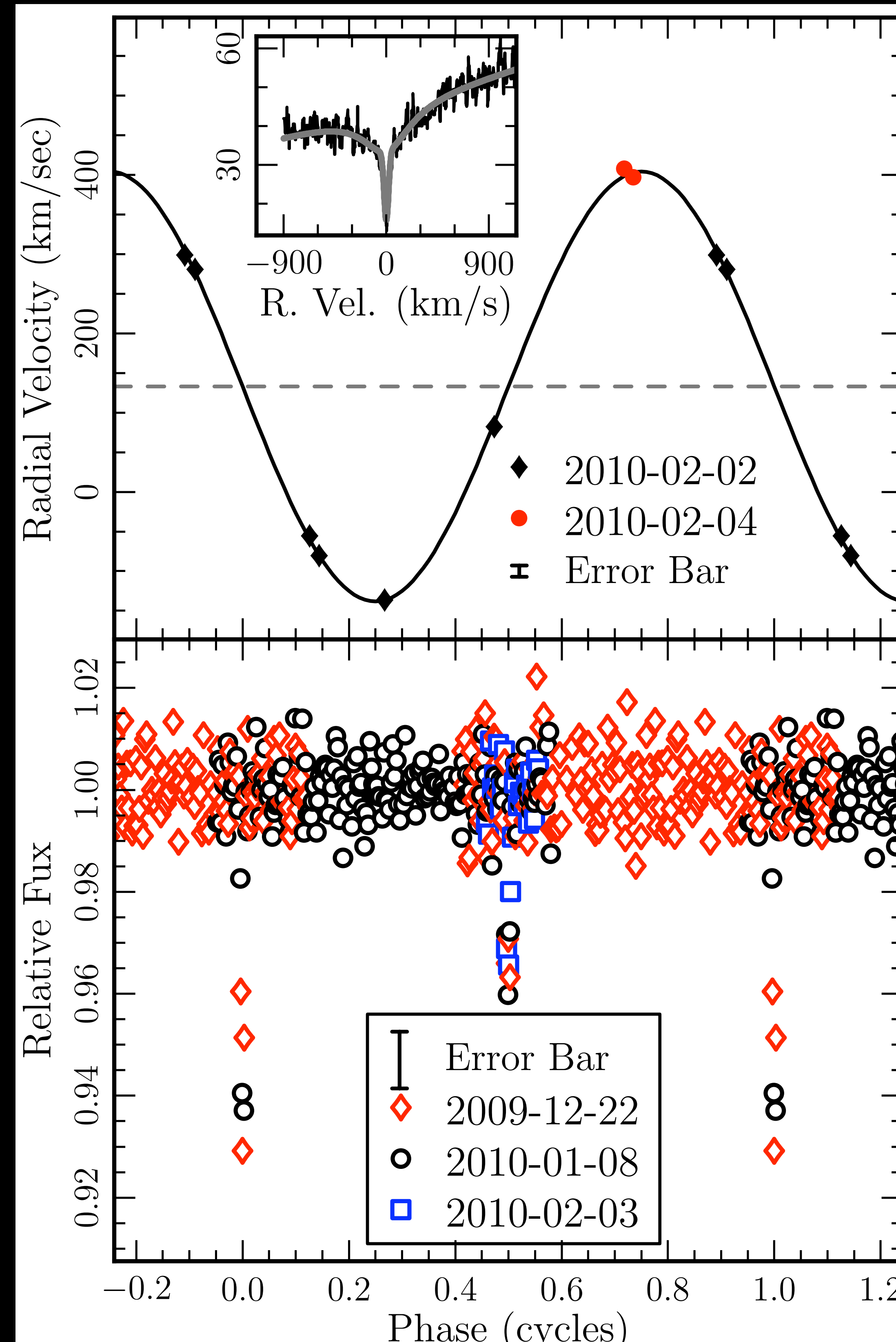
  - K_1=271±3 km/s, circular (ε<0.06)



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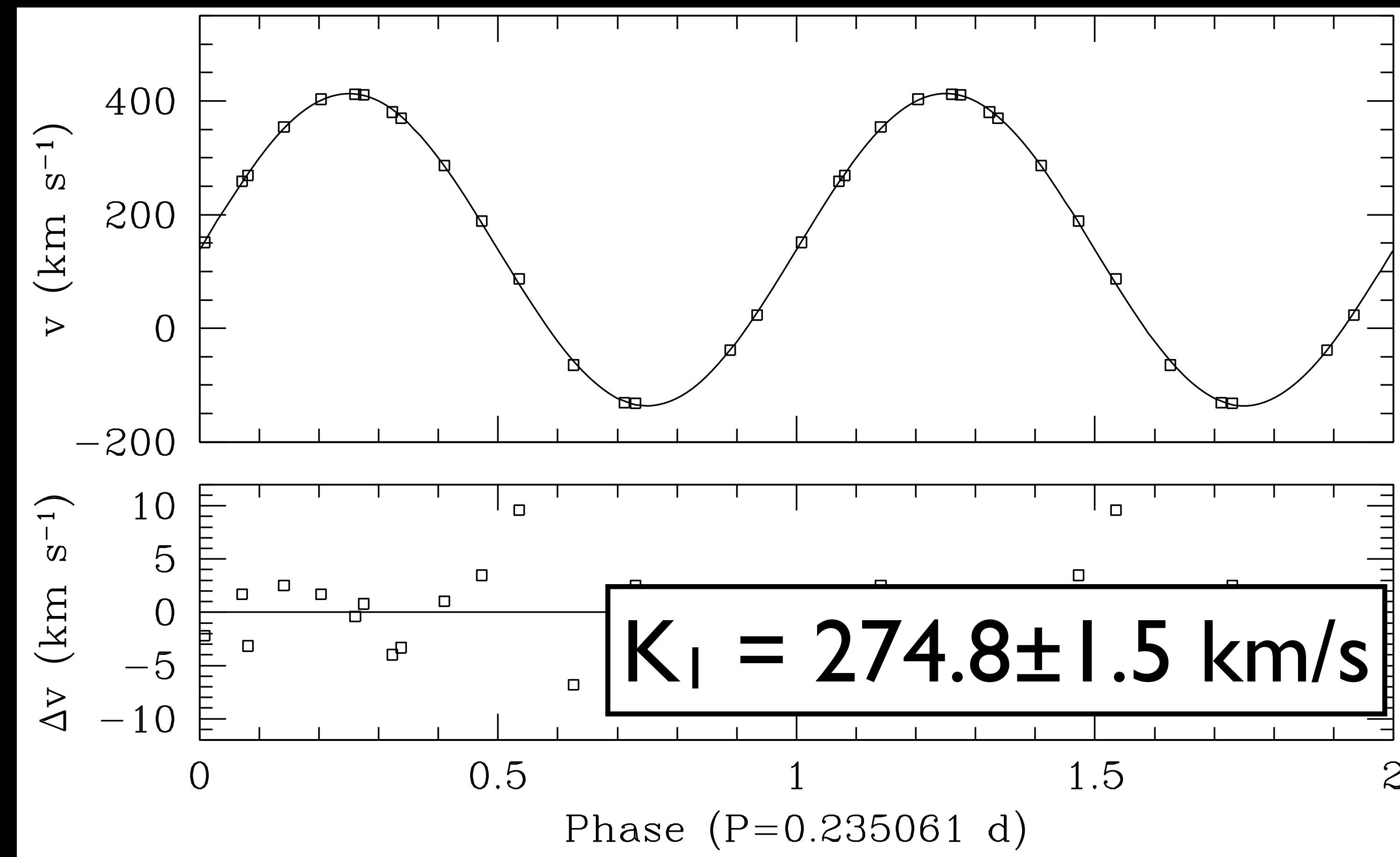
- Confirmed radial velocities by:
  - Kawka et al. 2010 - K_1=274.8±1.5 km/s
  - Kilic et al. 2010 - K_1=273.4±0.5 km/s



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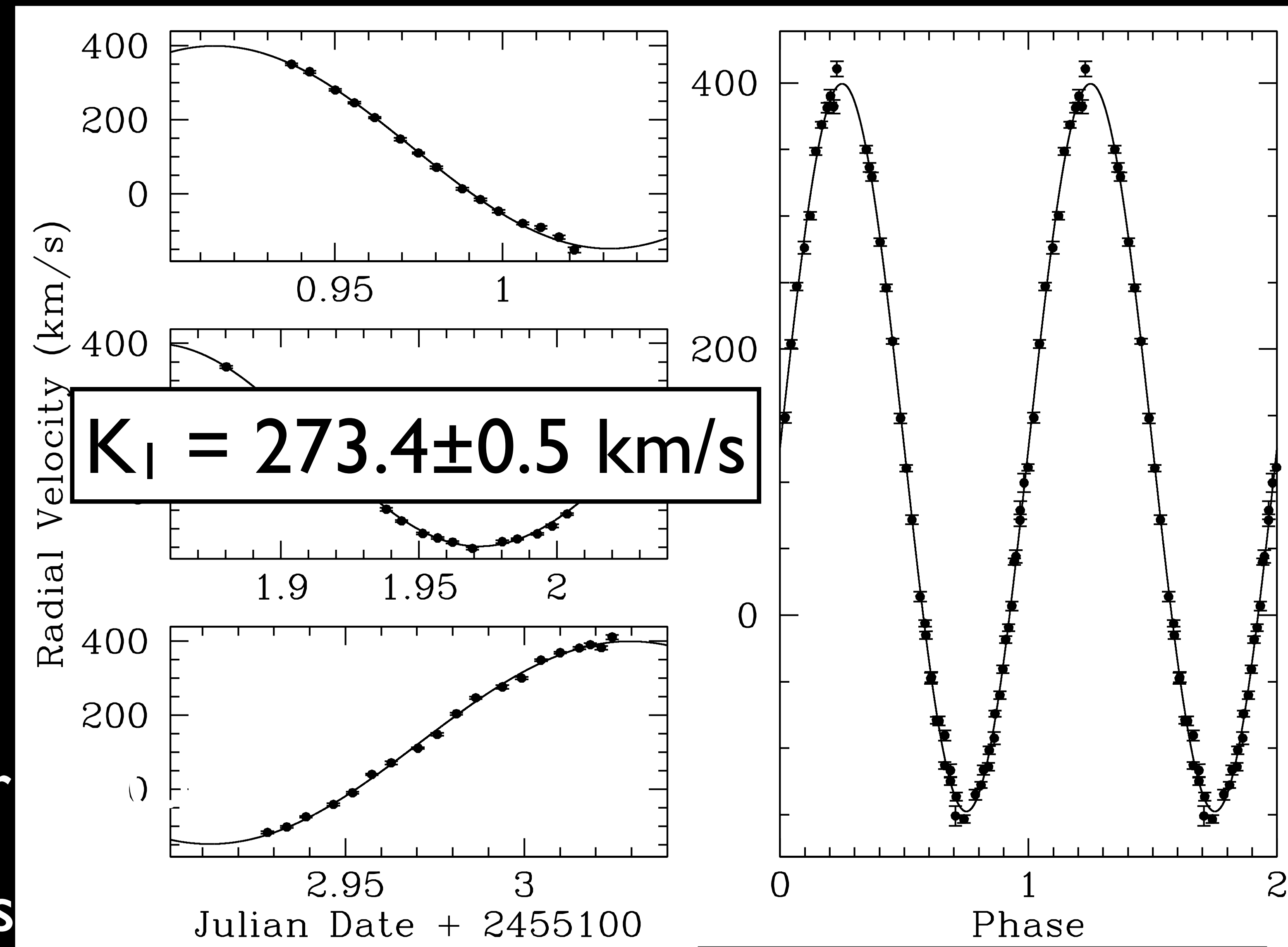
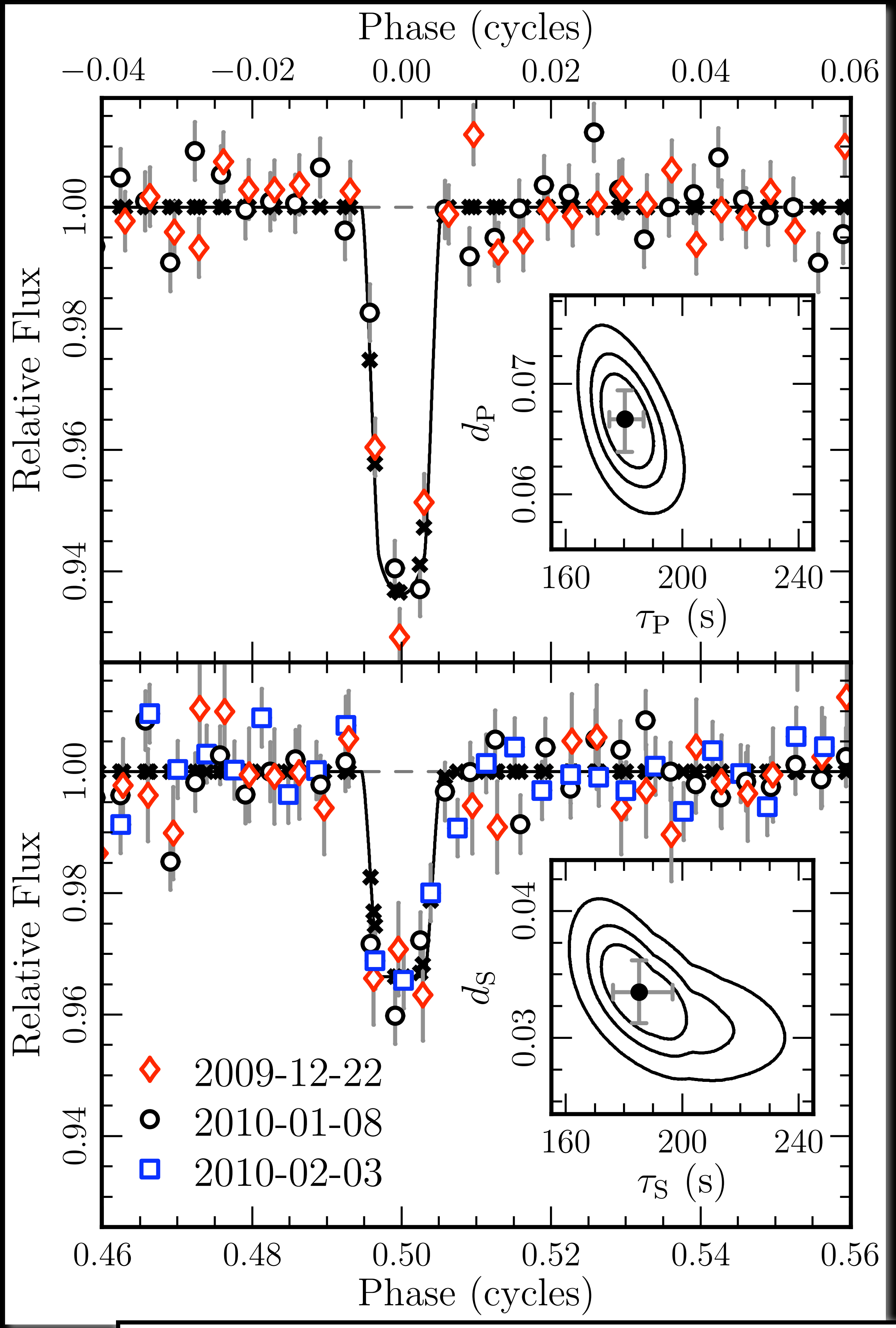


(Kilic et al. 2010)

Results from eclipse modeling

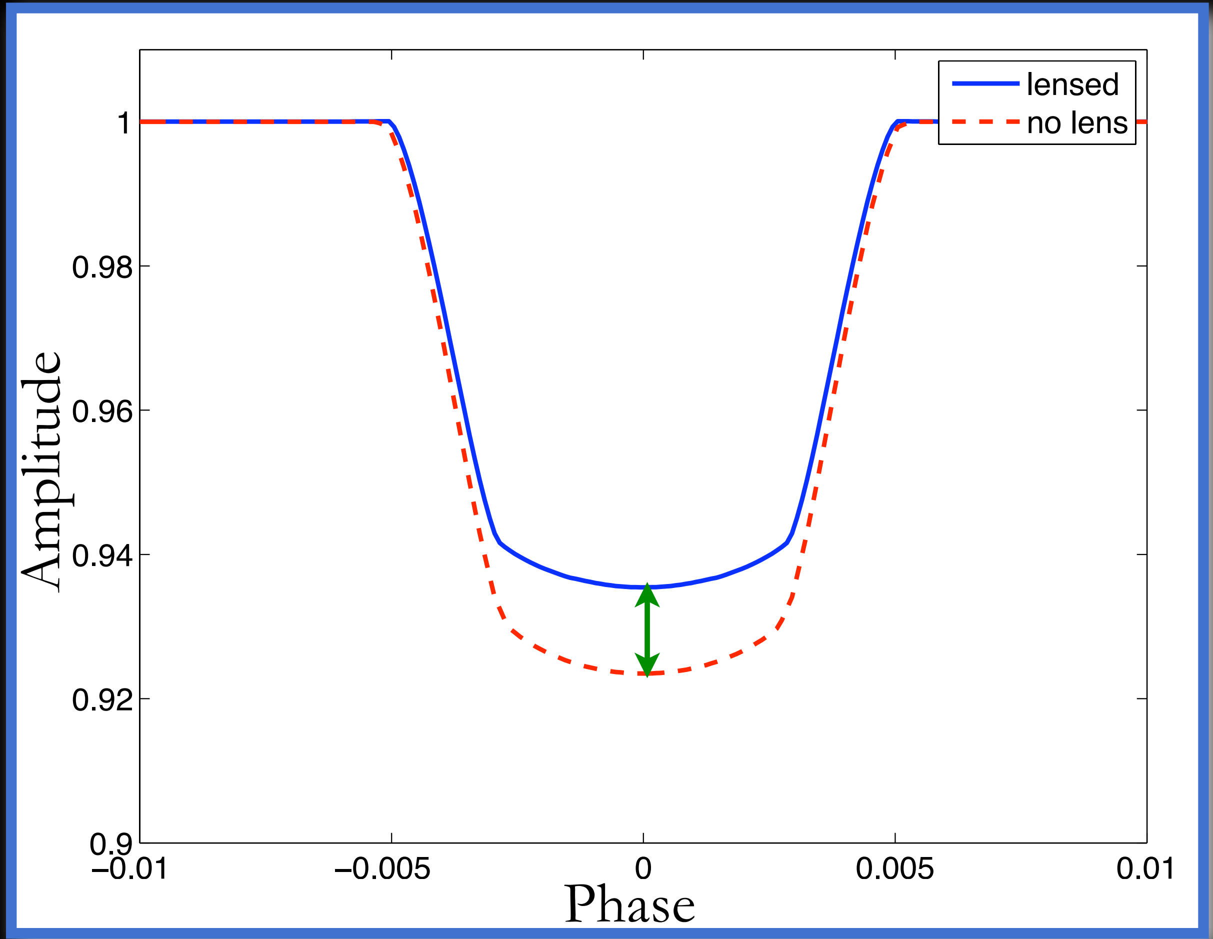
- Parameters: M_1, R_1, (M_2, R_2), P, i (fixed limb-darkening)
- Assumed $R_2(M_2)$ for C/O WD
- Good fits for M_1=0.1-0.2 M_{SUN}
- For M_1=0.15 M_{SUN}:
  - **R_1=0.0406(9) R_{SUN}**
  - M_2=0.71(2) M_{SUN}
    - ➡ a=0.007 AU
    - ➡ R_2=0.0108(2) R_{SUN}
  - i=89.88(11)°
- Secondary eclipse depth gives C/O WD temperature and age ~1.5-3 Gyrs

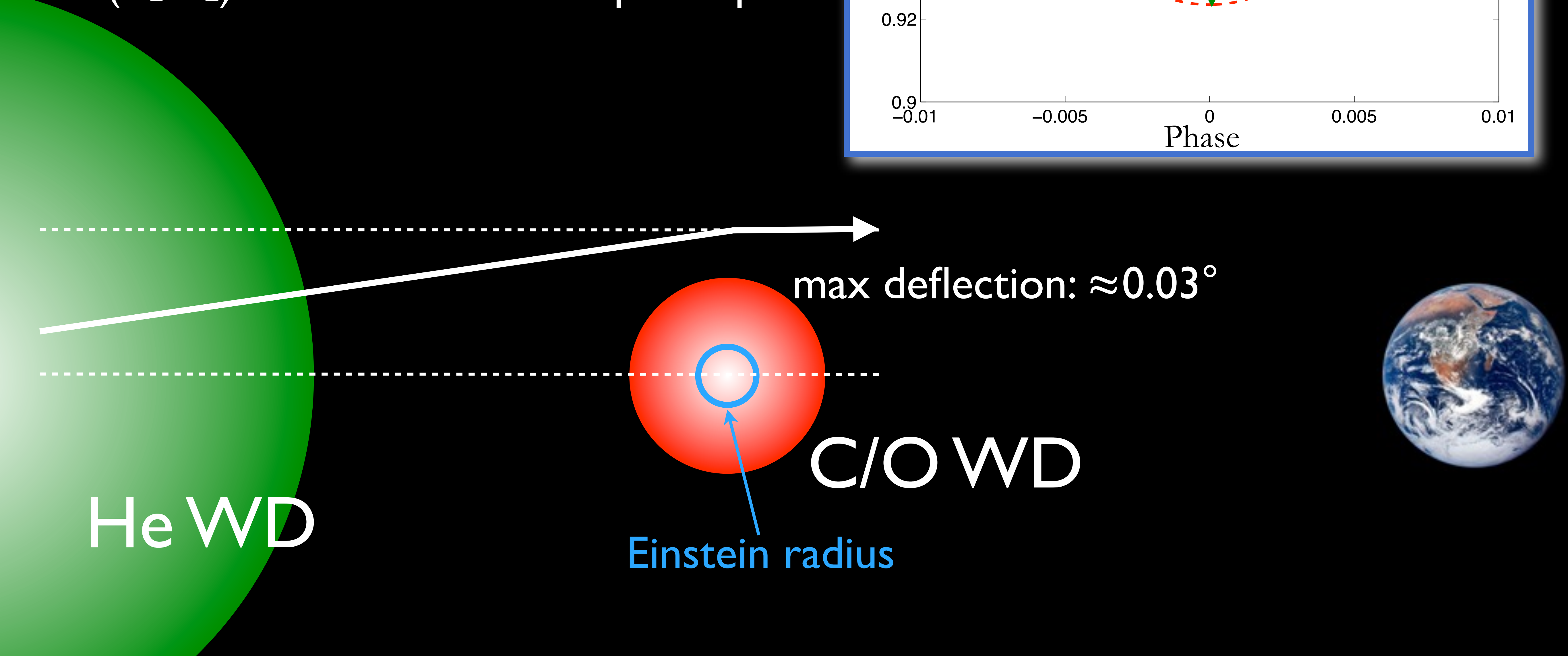


(Steinfadt et al. 2010a)

Lensing by the Massive C/O WD

- Must include effects of microlensing in binary (Maeder '73; Marsh '01; Agol '02)
  - $R_E = \sqrt{(4GM_2 a/c^2)} \approx 0.003\ R_\odot \approx 0.3\ R_2$
- Actual magnitude is $\sim 2(R_E/R_1)^2 \approx 1\%$
- But eclipse is $(R_2/R_1)^2 \approx 6\%$, so lensing is $\sim 2(R_E/R_2)^2 \approx 18\%$ effect on eclipse depth





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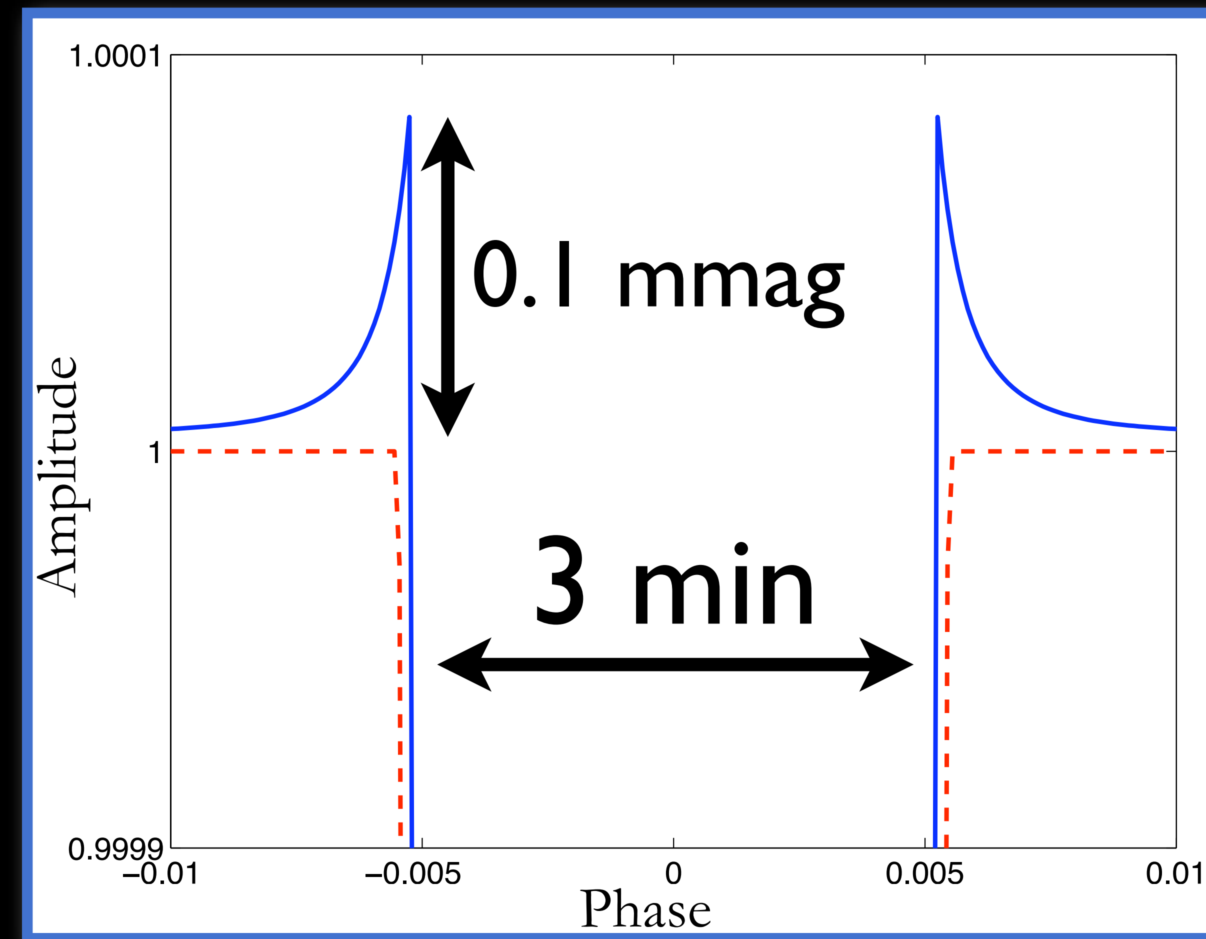
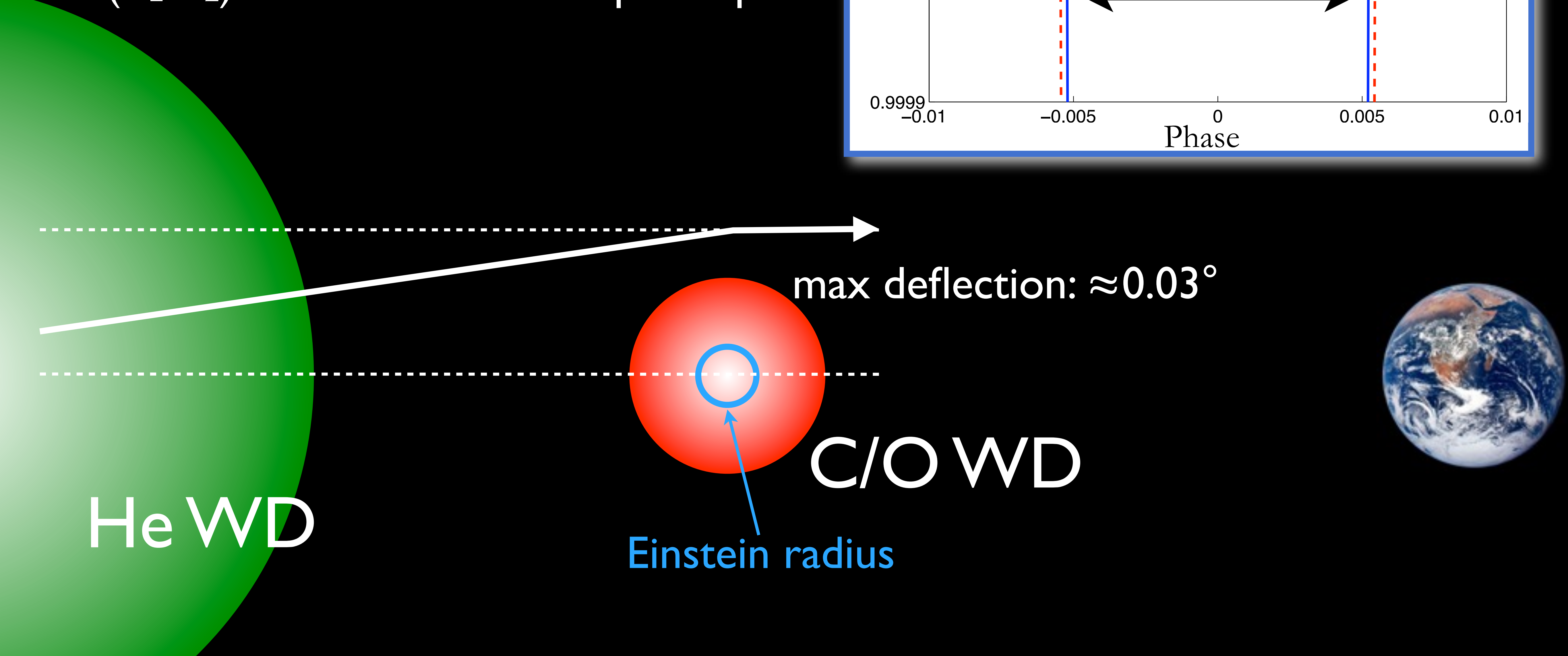
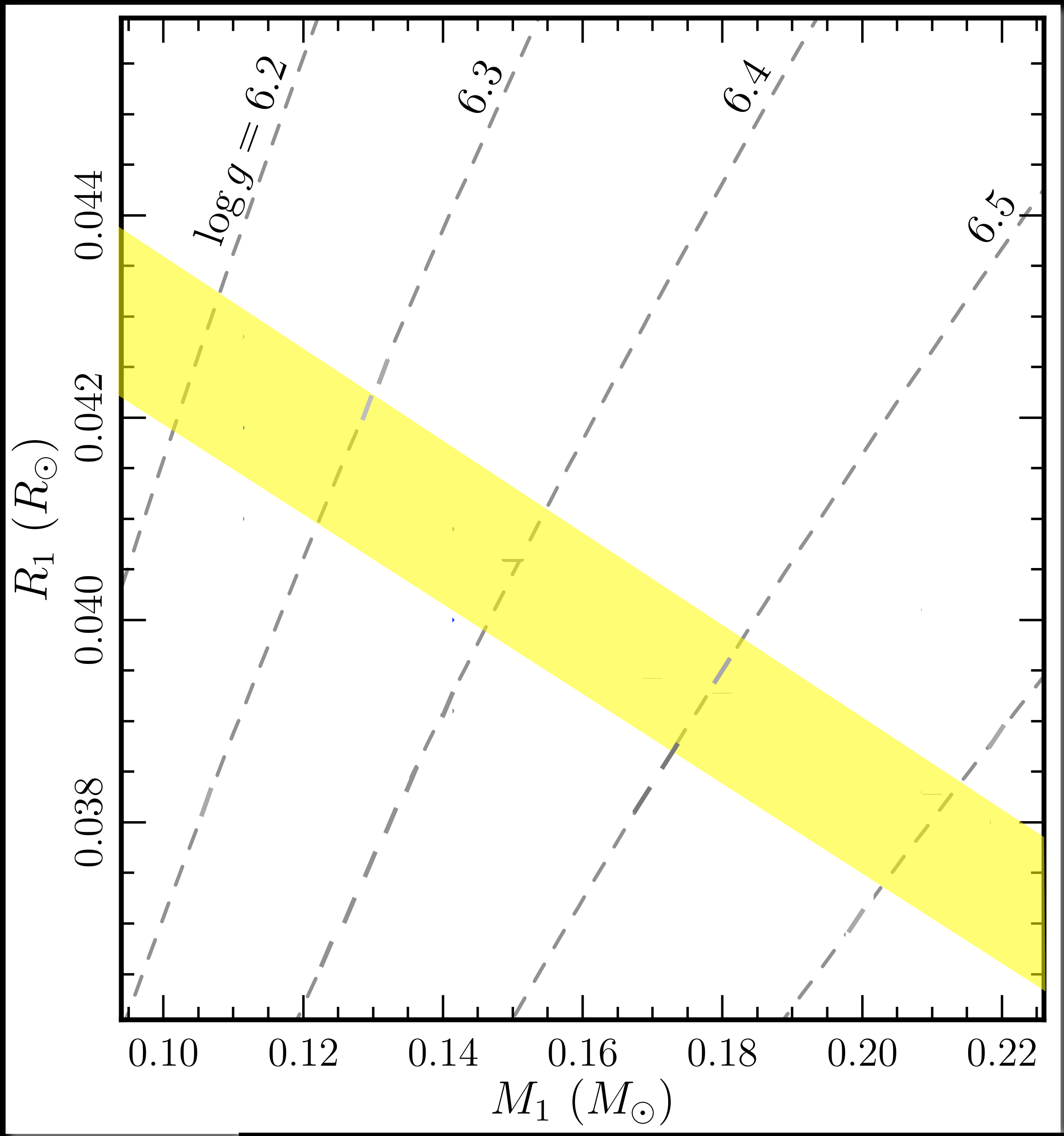




Implications

- Model independent M/R constraints for two WDS
  - Still need to break C/O WD mass function (double lined binary?)
- He WD evolutionary models (Serenelli et al. 2002, Panei et al. 2007) are now constrained



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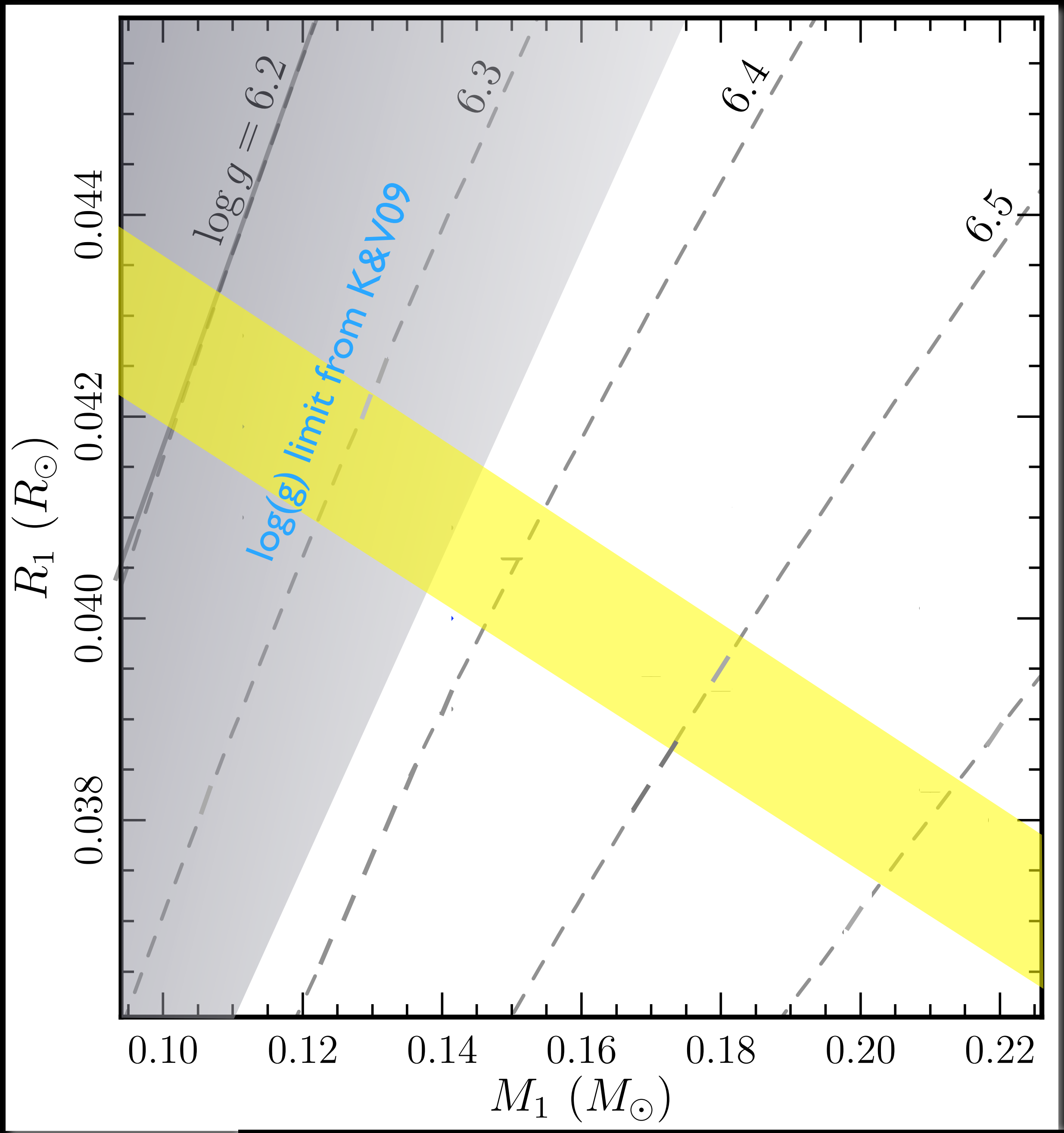

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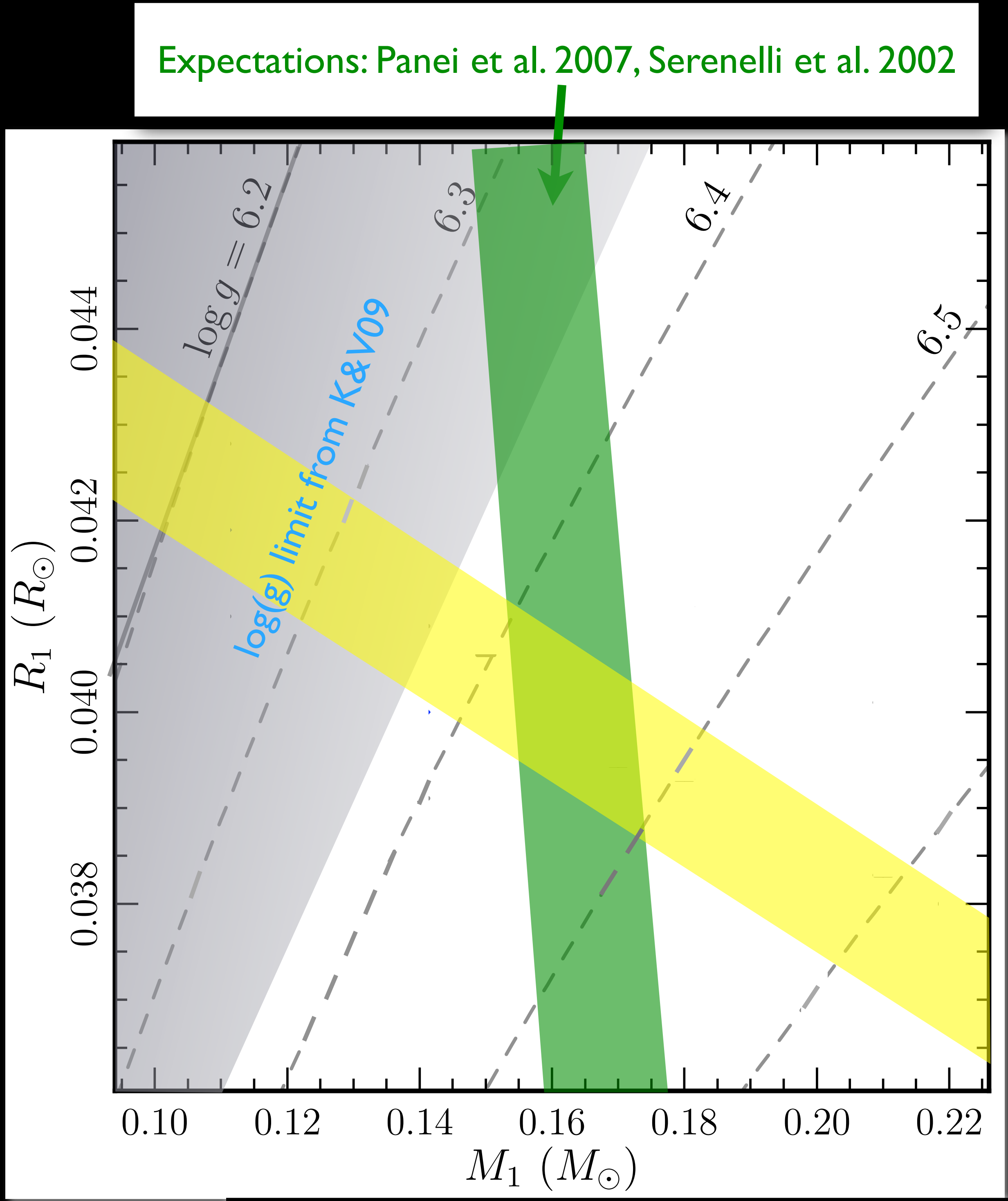

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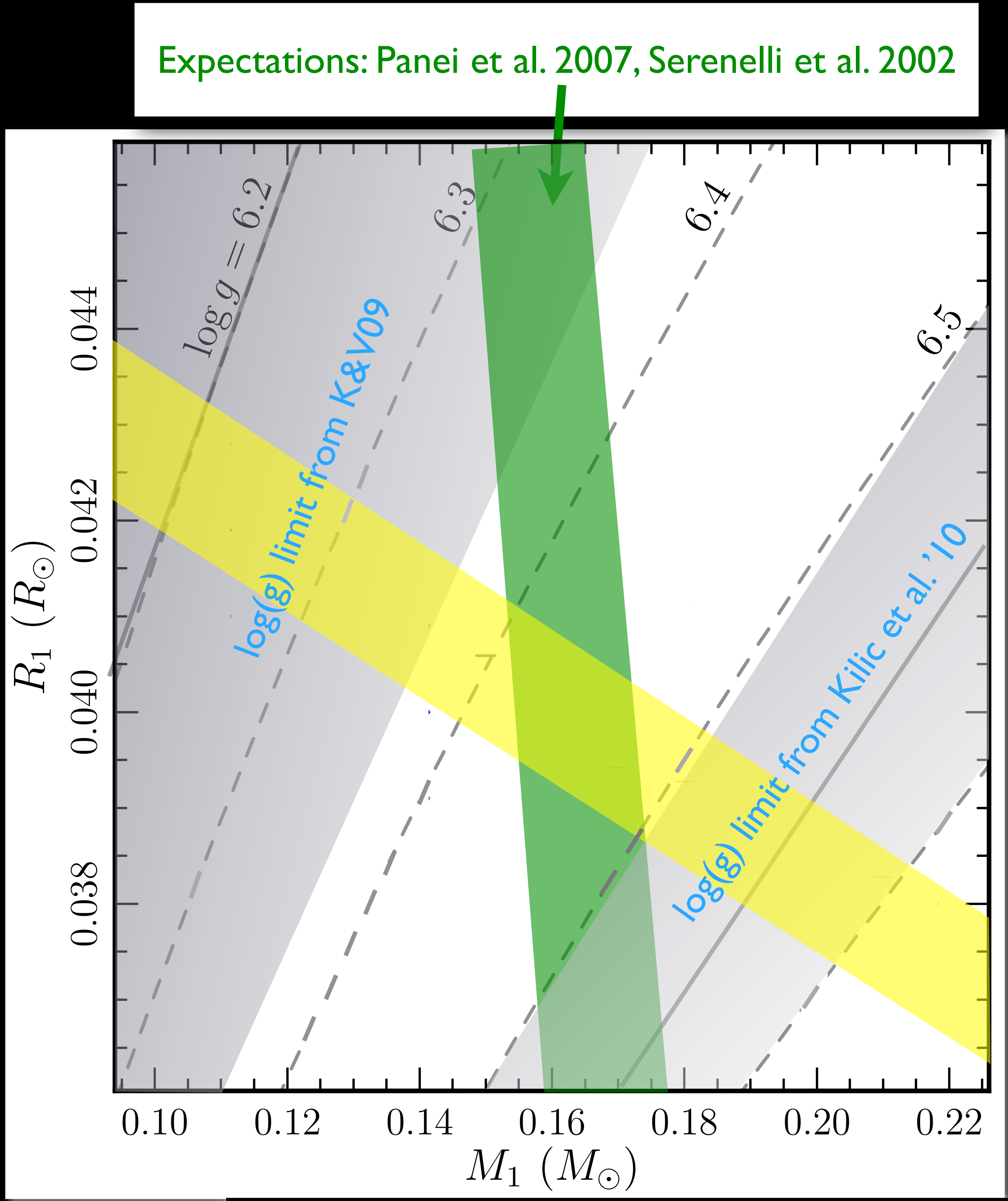

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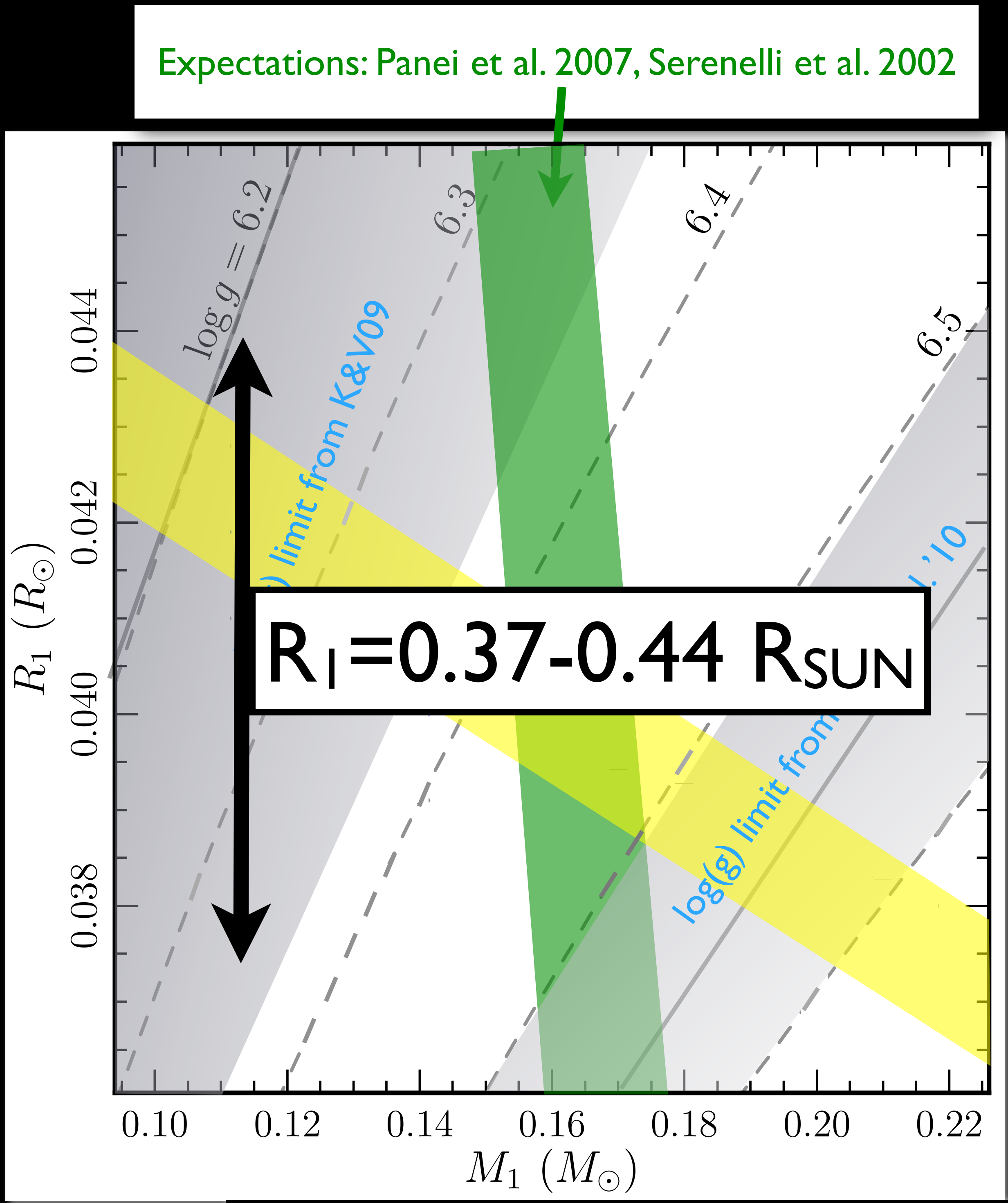

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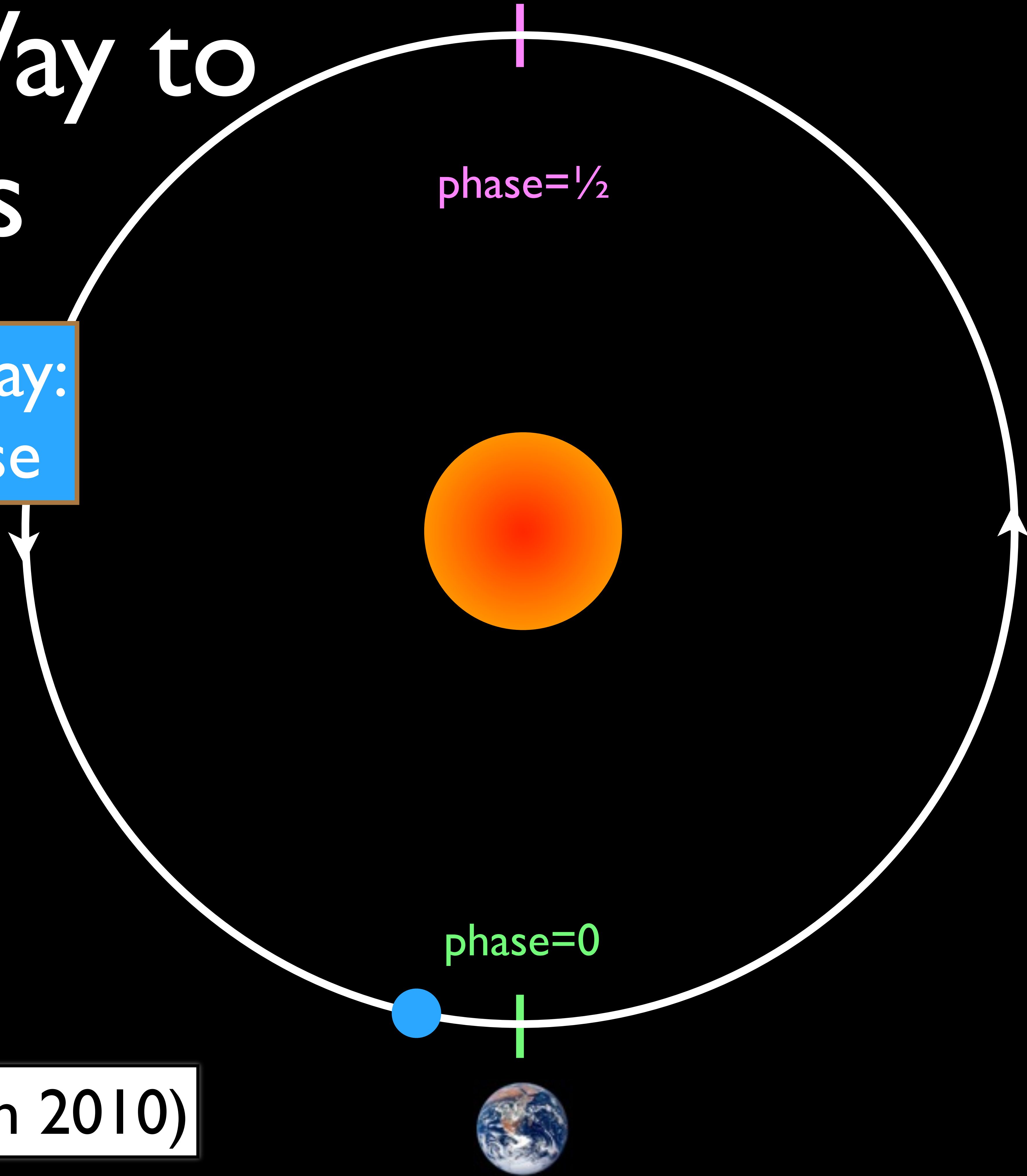
Another Way to Get Masses

Light-Travel Delay:
$q = M_2/M_1 = 0$ case



(Kaplan 2010)

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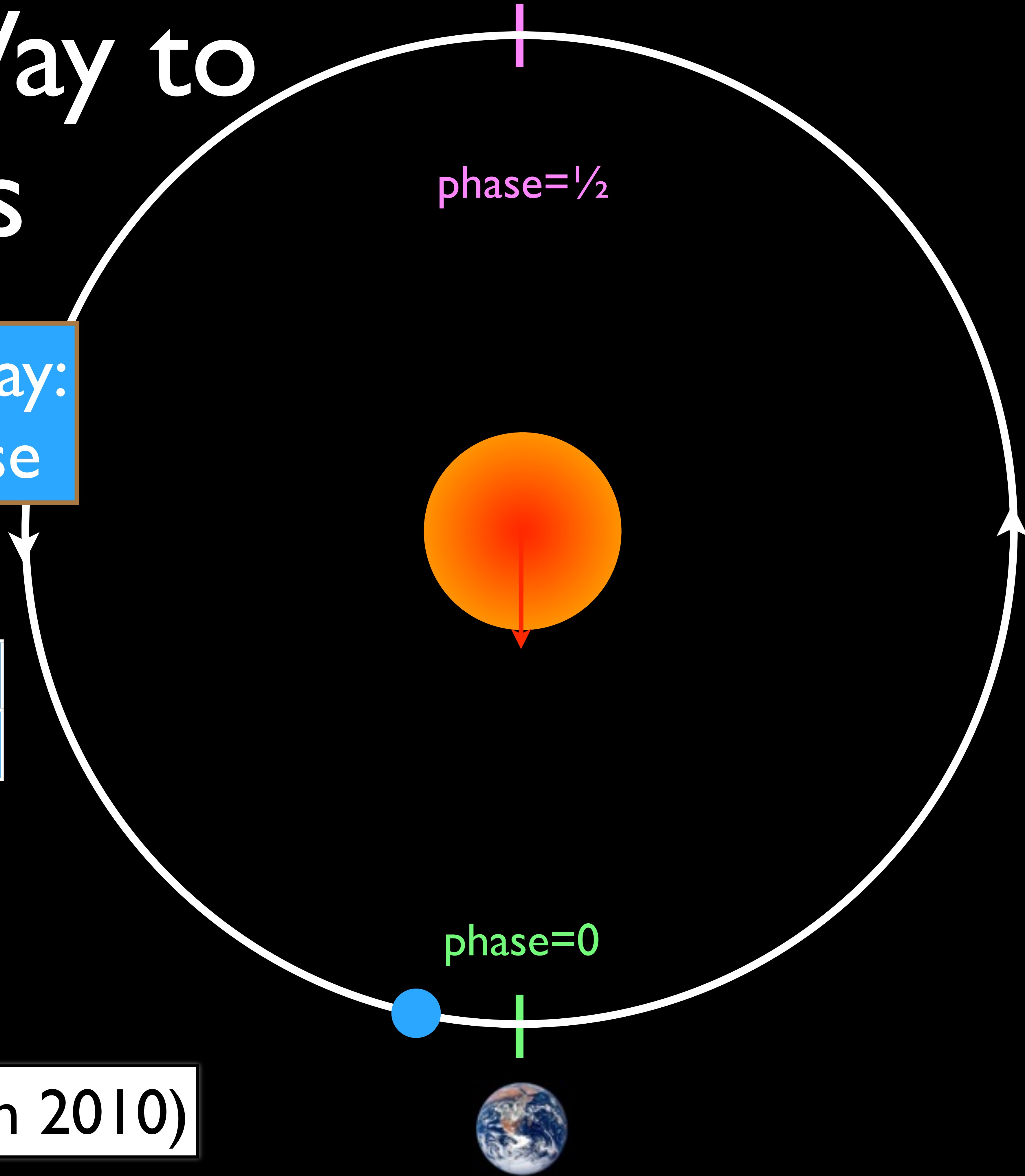
Light-Travel Delay: $q=M_2/M_1=0$ case

phase	action
-a/(Pc)	He WD emits



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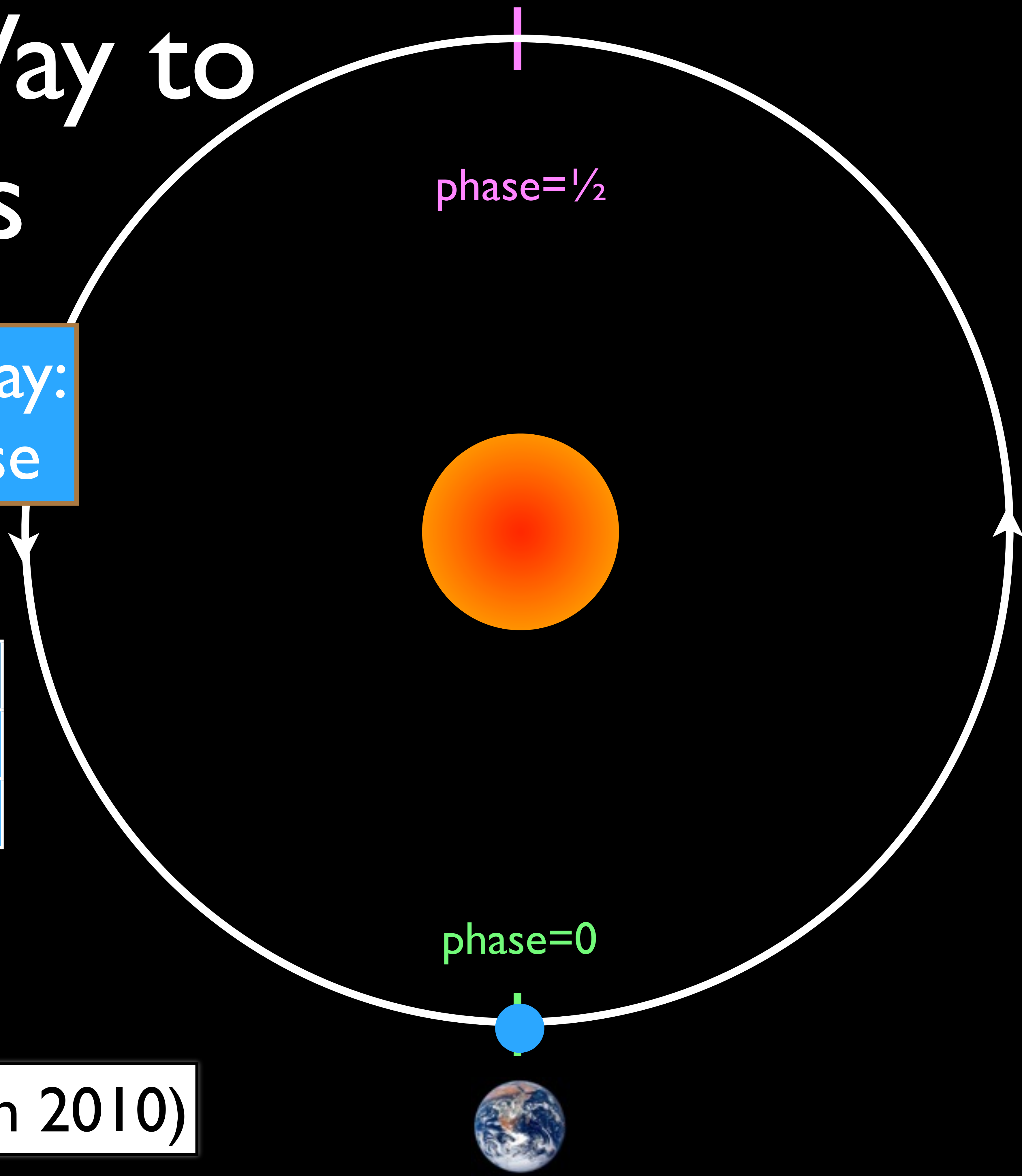

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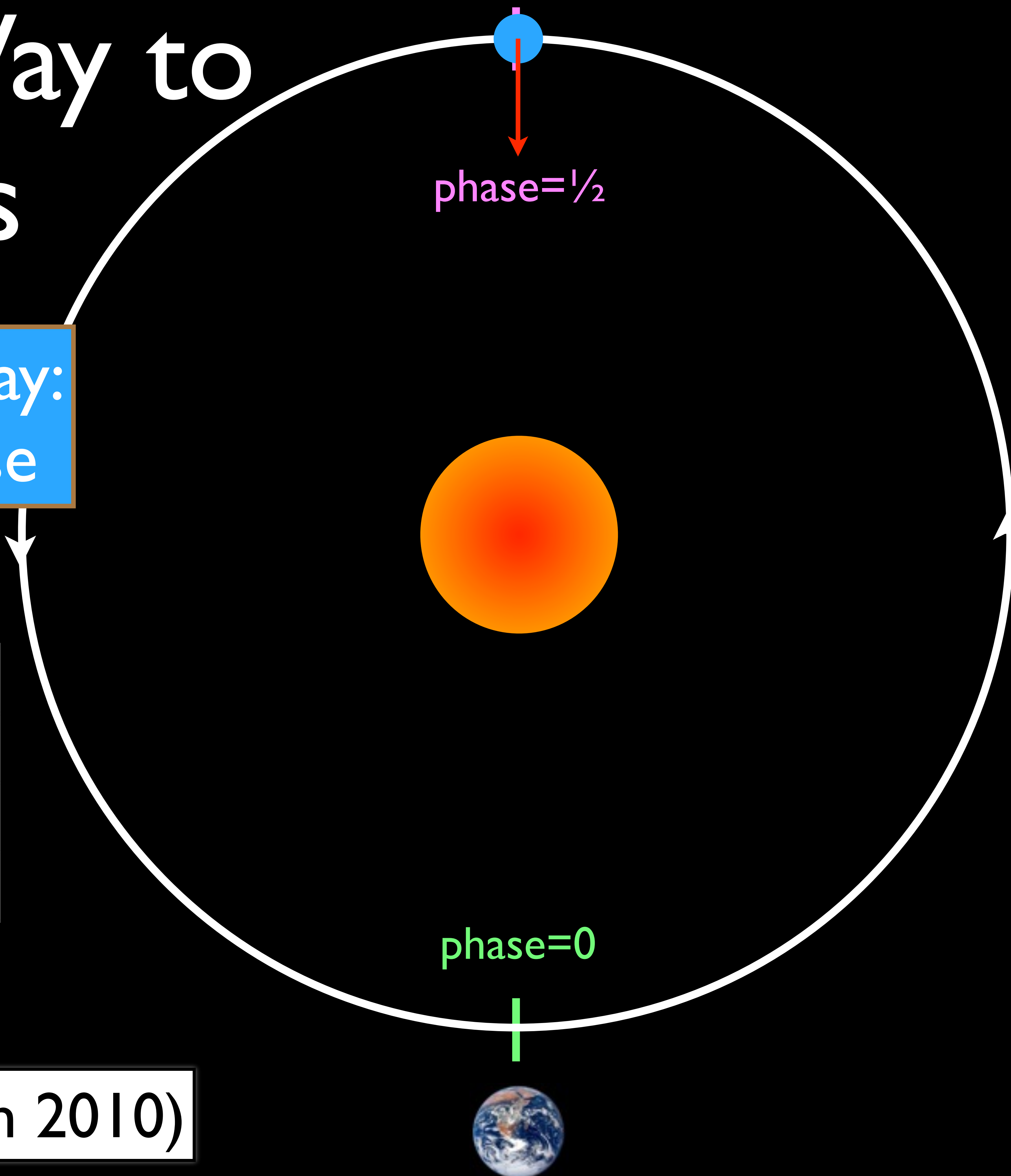

phase	action
-a/(Pc)	He WD emits
0	C/O WD absorbs
½	C/O WD emits

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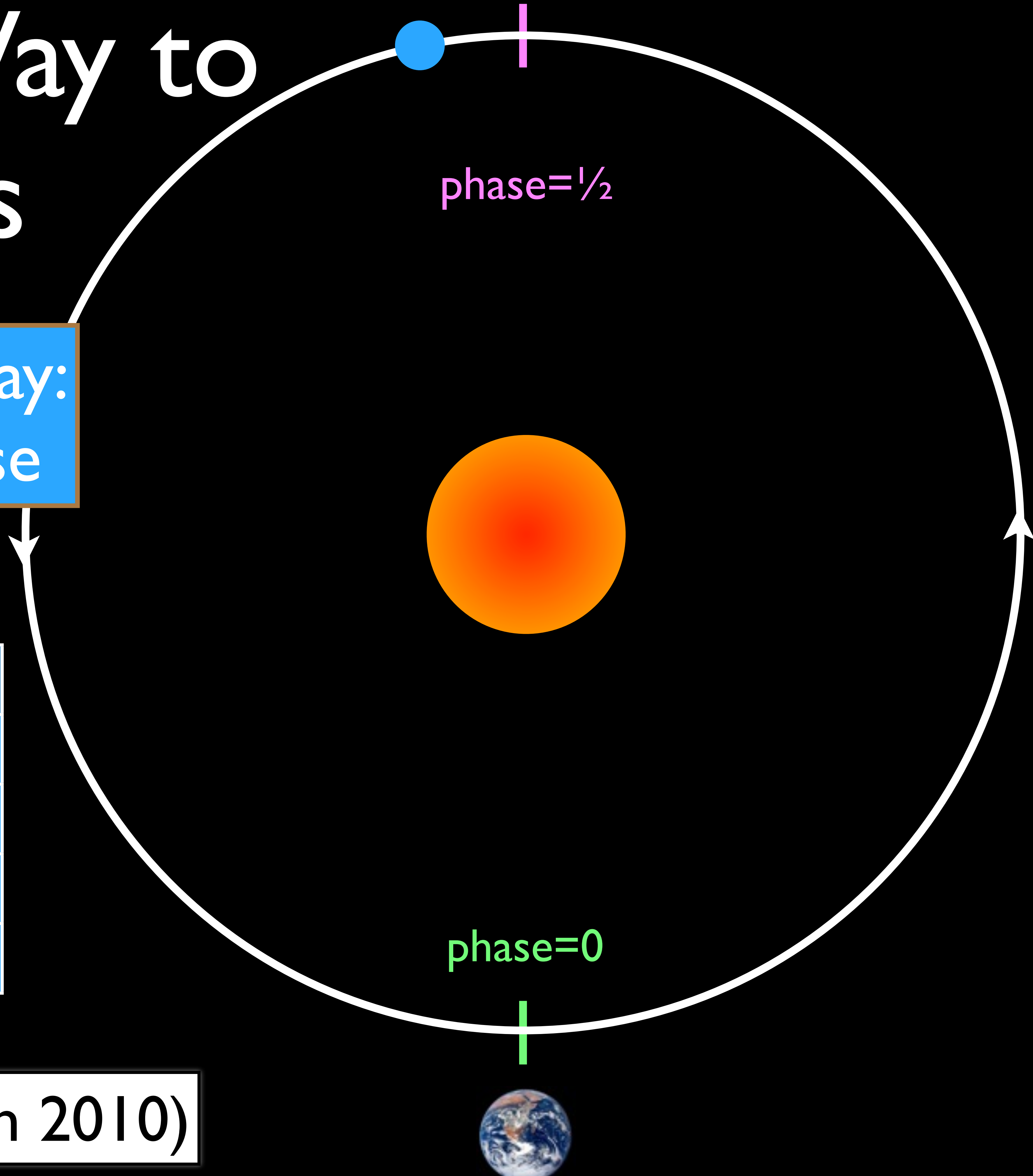

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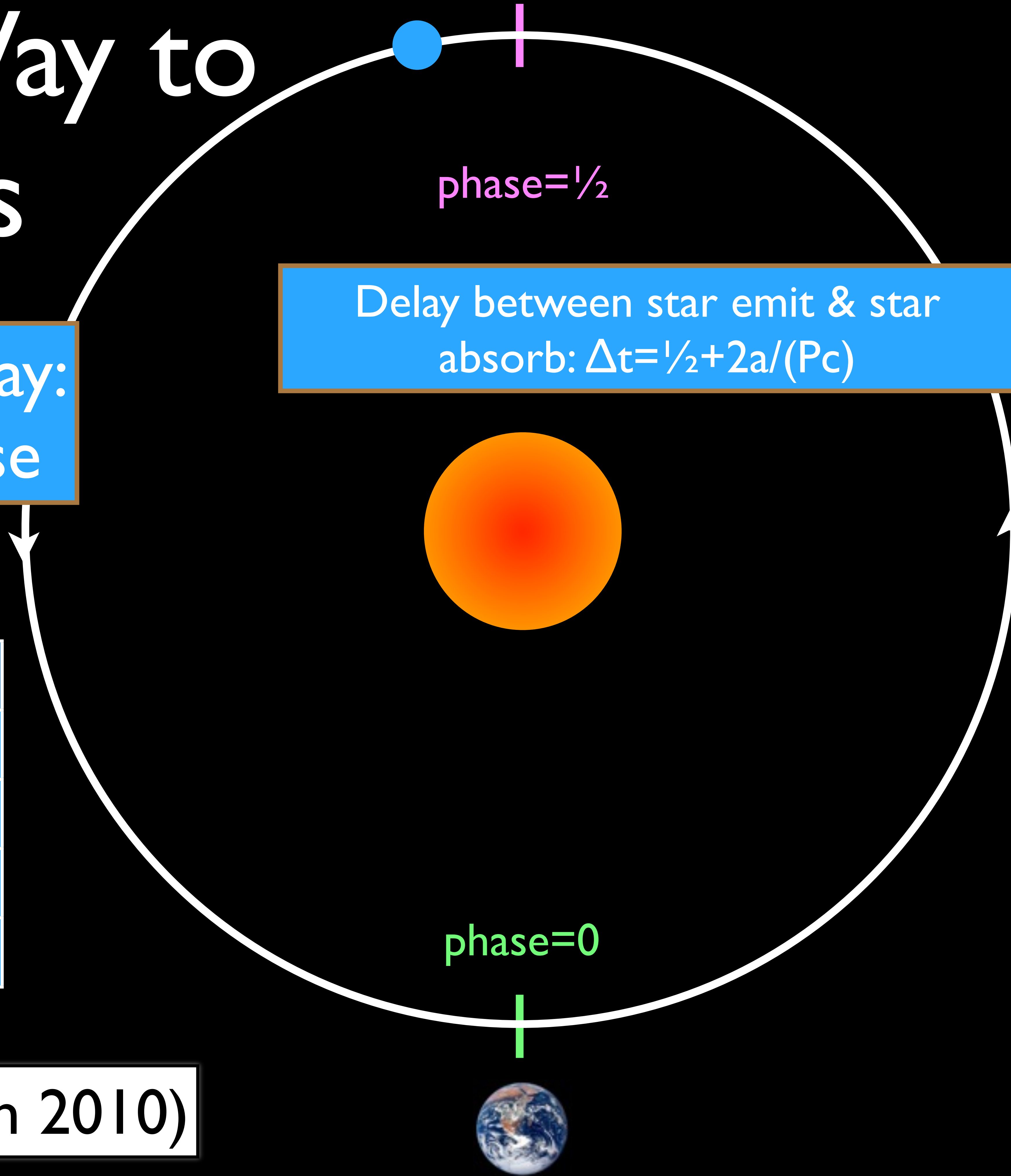
Delay between star emit & star absorb: $\Delta t = ½ + 2a/(Pc)$



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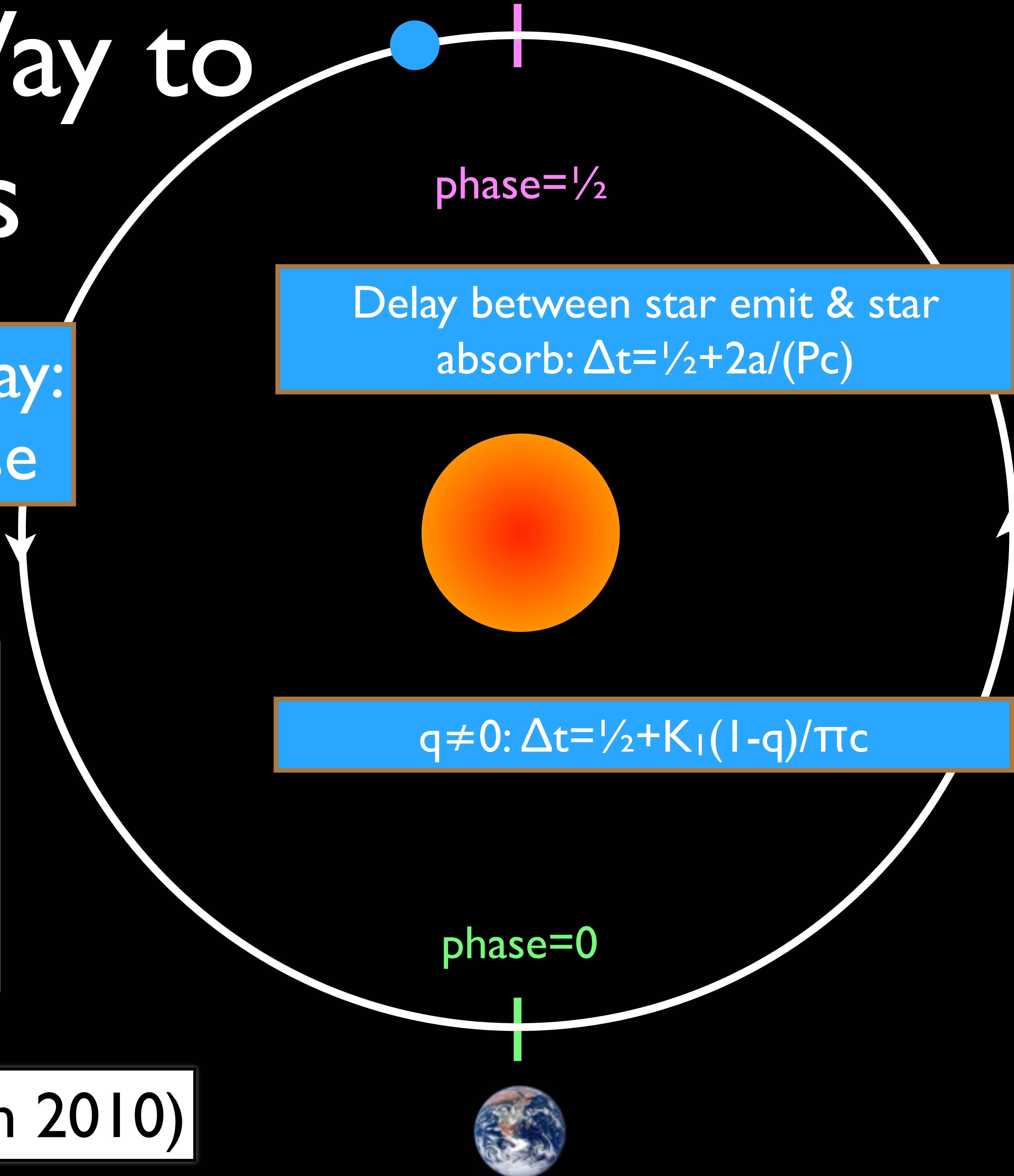

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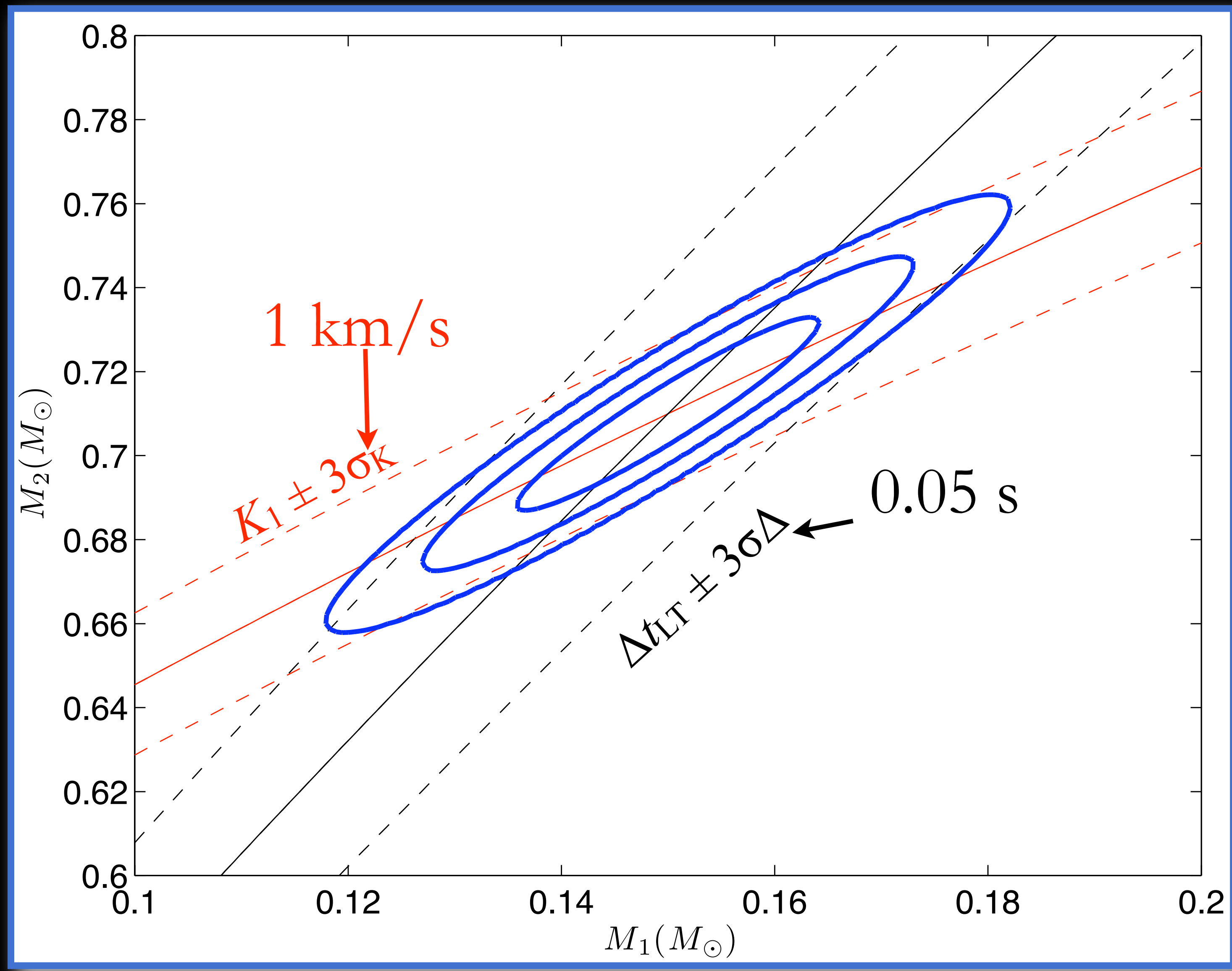
- Light travel delay: ruins phasing between primary/secondary eclipses (Fabrycky 2010)
  - Tells you size of orbit - like Römer delay for pulsars
- **$\Delta t_{LT} = PK_1(1-q)/\pi c = 4.5$s**
- Need high precision: eclipse times to ≲0.1s will constrain masses to ±0.02 M☉
- **But eccentricity ε~10^{-3} gives similar signal: get ε from spectra (& expect circular orbit from CE?)**
- See Kaplan (2010, ApJ, 717, 108)



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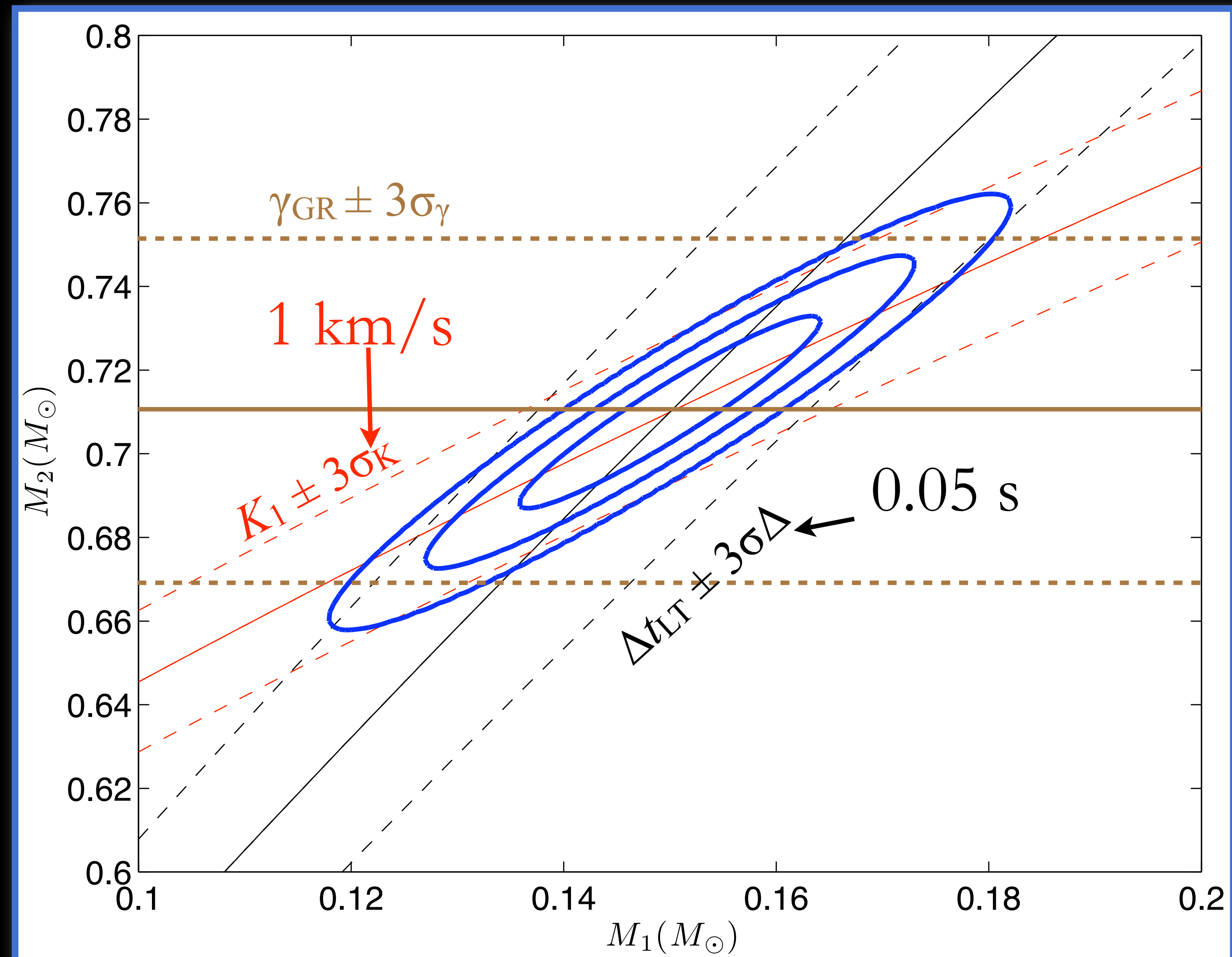

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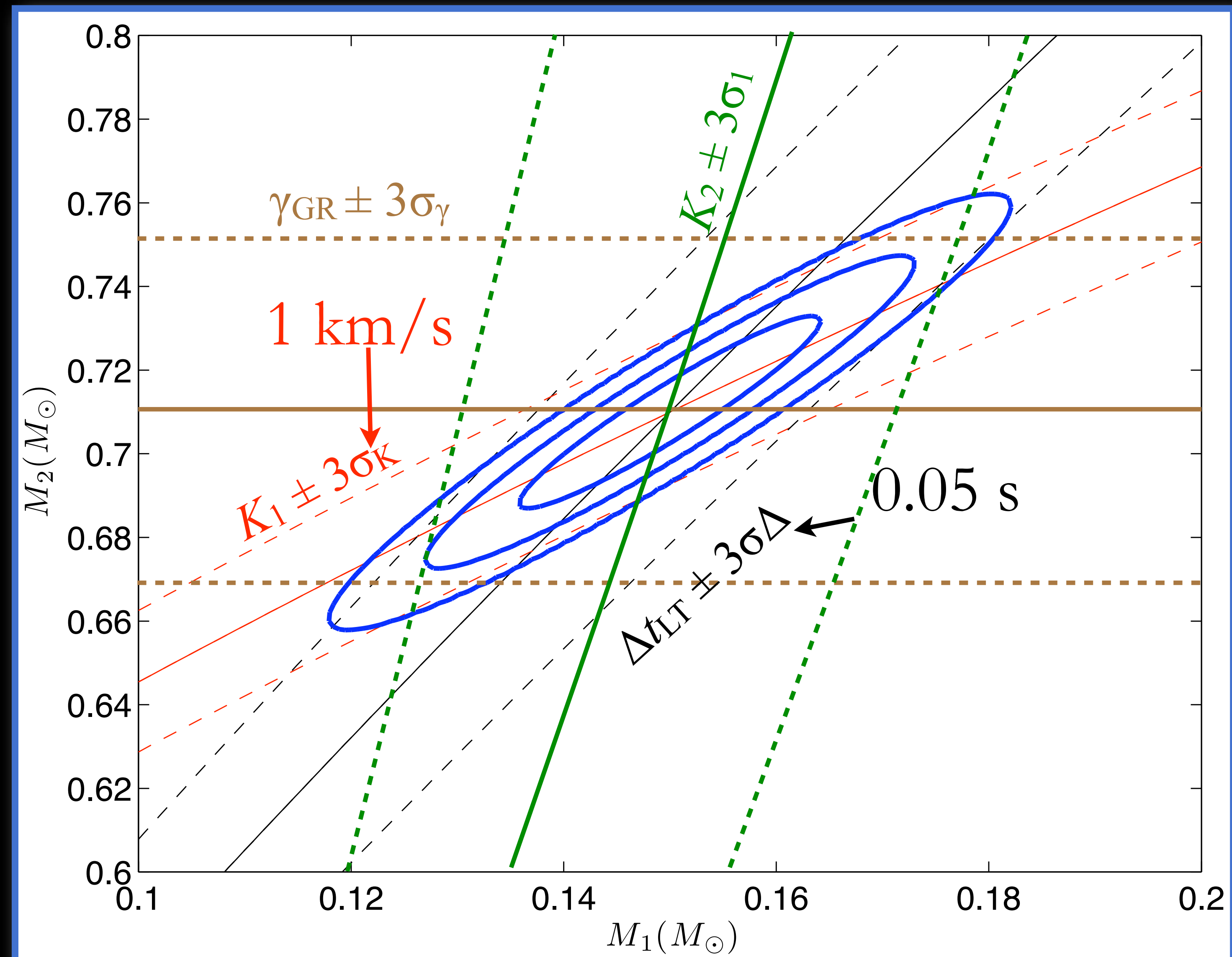

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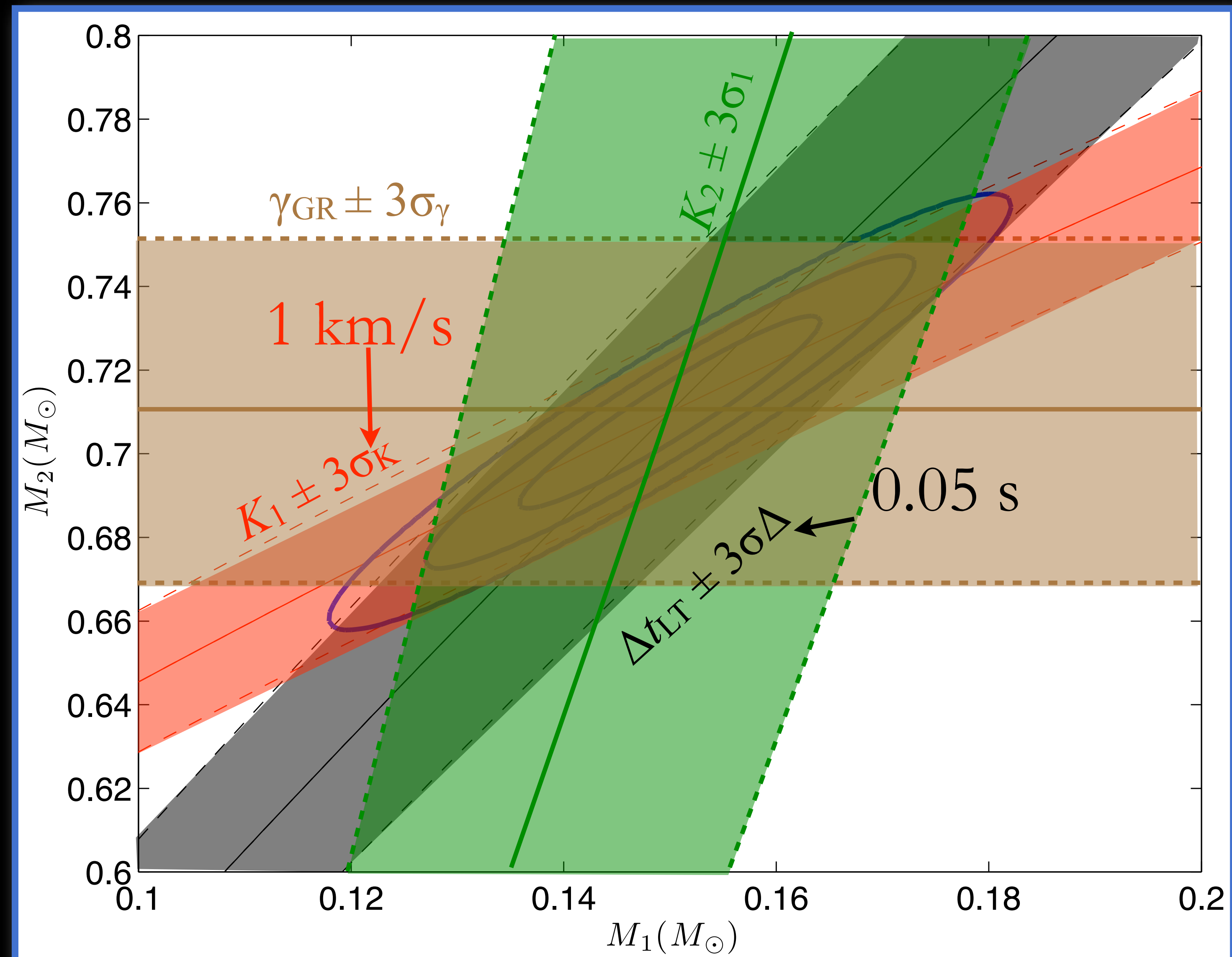
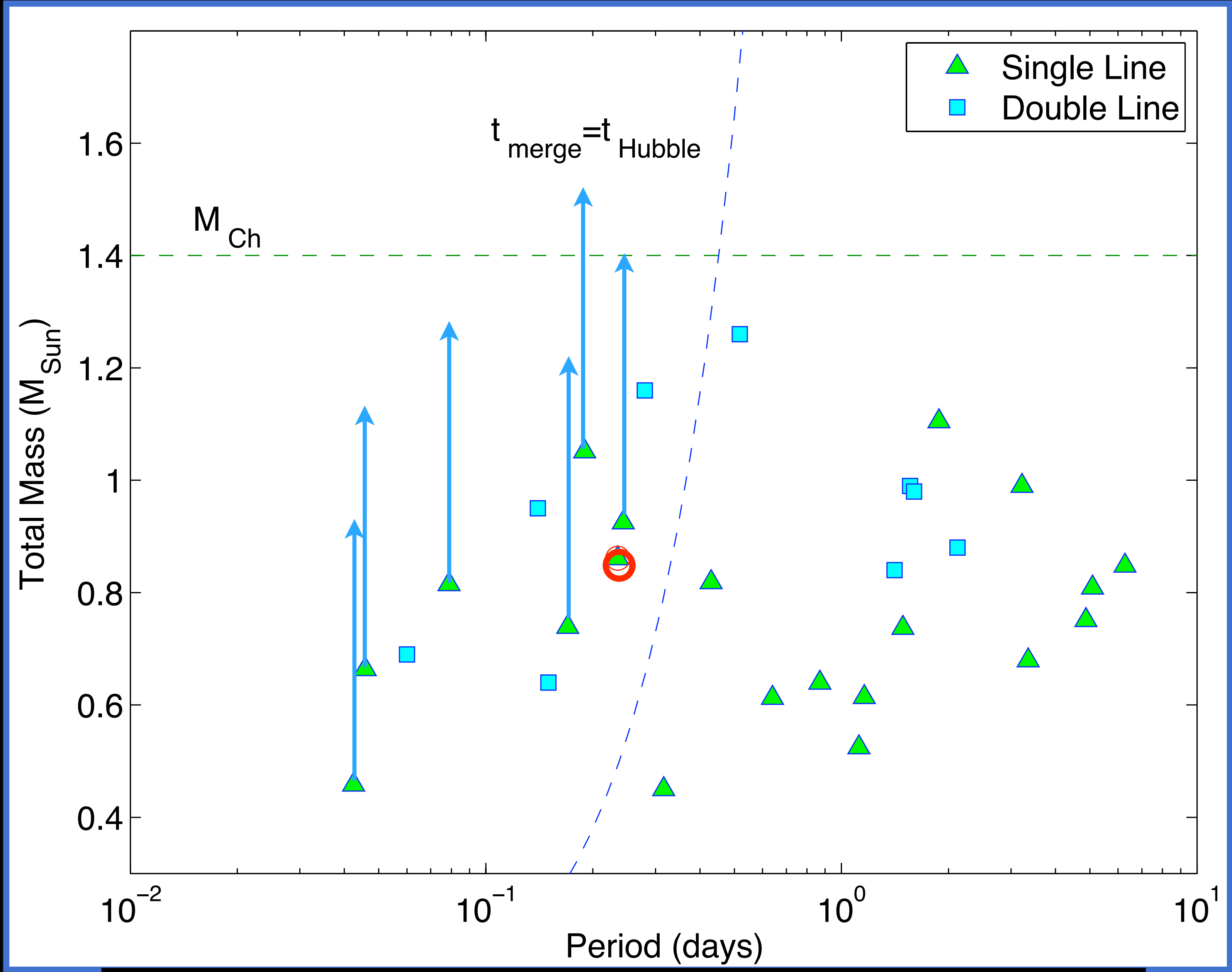


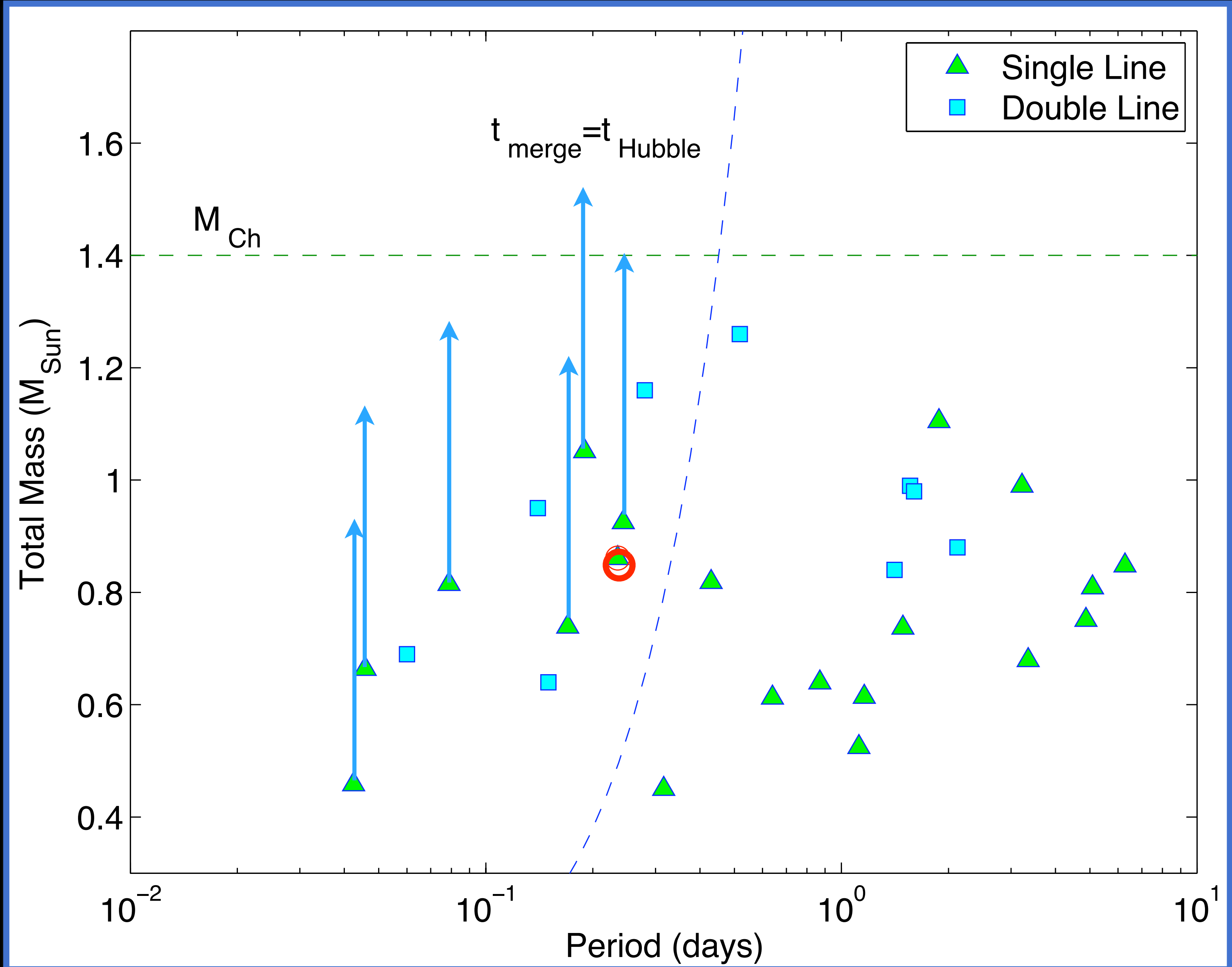
Implications: Binary Evolution



Adapted from Mullally et al. 2009; Nelemans et al. 2005

Implications: Binary Evolution

- Binary contact in ~8 Gyr
- Sub-Chandrasekhar



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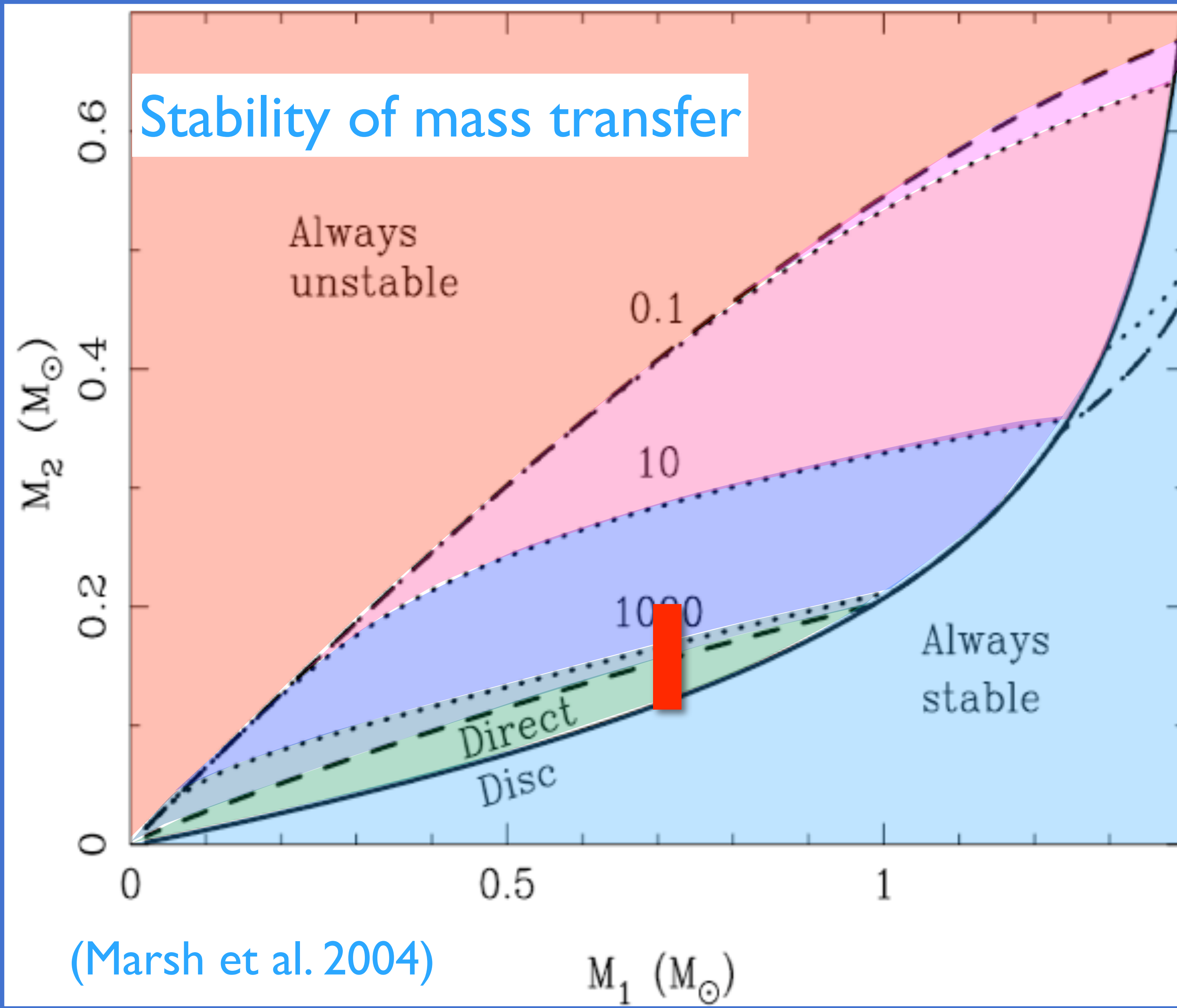
Implications: Binary Evolution

- Binary contact in ~8 Gyr
- Sub-Chandrasekhar
- Stability of mass transfer
  - Definitely stable for $M_1 \approx 0.1$ M_{SUN}
  - Questionable stability for $M_1 > 0.1$ M_{SUN}
    - However, likely stable until at least $M_1 \approx 0.2$ M_{SUN} since R_1 may be ≈50% larger than what Marsh et al. 2004 used (Panei et al. 2007, Steinfadt et al. 2010b)
- Stable transfer → AM CVn
- Unstable transfer → R CrB, other



(Marsh et al. 2004)

Next Steps

- Fast photometry (FTN, WHT/ACAM, NTT/Ultracam, much w/ T. Marsh...)
  - Explore shape of eclipse ingress/egress, constrain limb-darkening, look for color effects
  - Improve ephemeris
  - Ingress/egress last 20s
  - Even faster + more area (ELT, TMT, GMT): lensing signature?
- Slow photometry (FTN, ...)
  - Measure variation over orbit, confirm *K* from Doppler beaming (Maxted et al. '00; Loeb & Gaudi '03; Zucker et al. '07; van Kerkwijk et al. '10)
- IR photometry (Gemini)
  - Precision timing of eclipses
  - measure T_2 by comparing depth of secondary eclipse
- Keck spectroscopy
  - Look over whole orbit, try to find lines from secondary: measure K_2, γ_{GR}!

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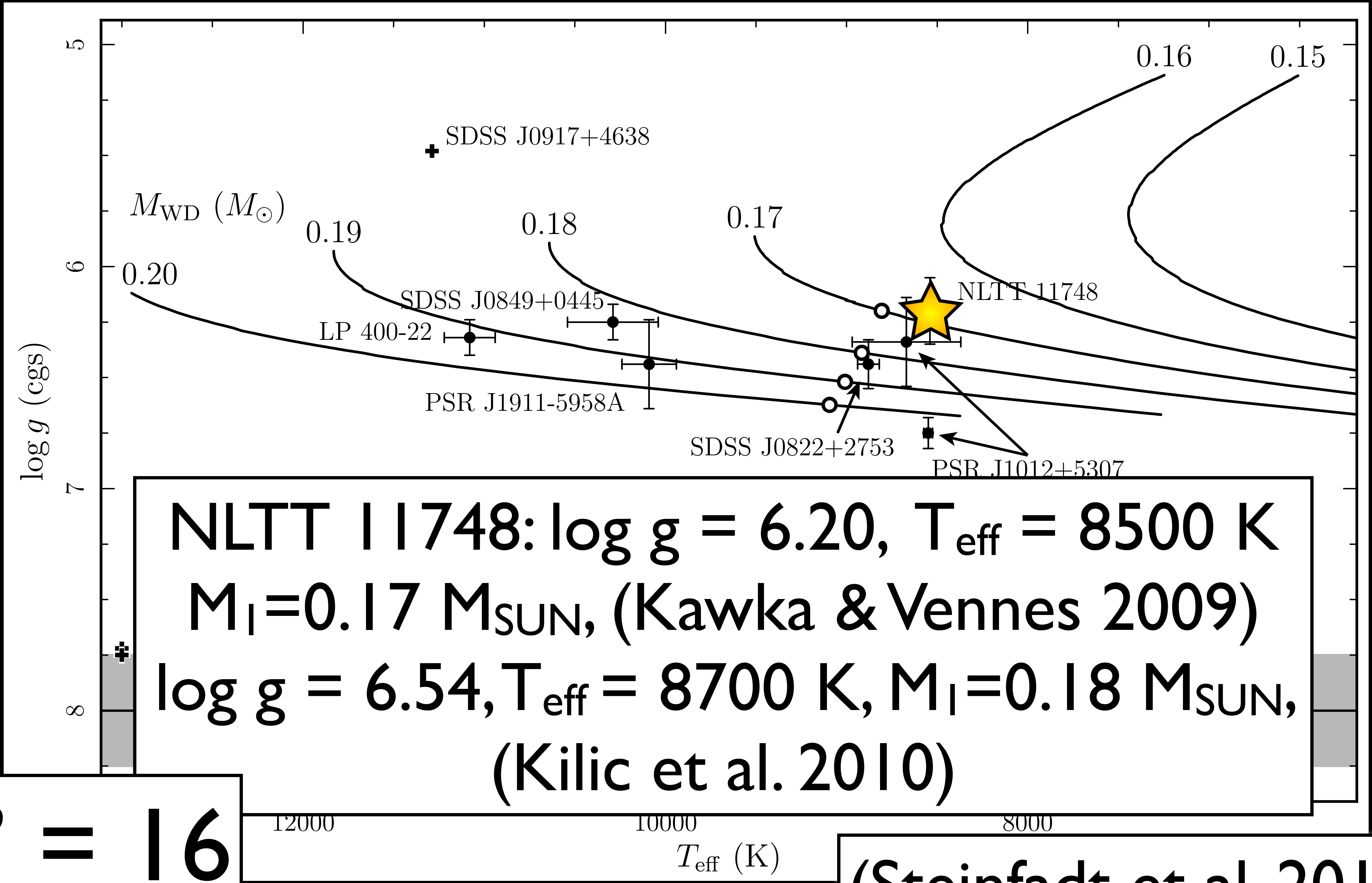
Danke!

- Extra Slides

Searching for the First He-Core Pulsator



NLTT 11748: log g = 6.20, T_{eff} = 8500 K

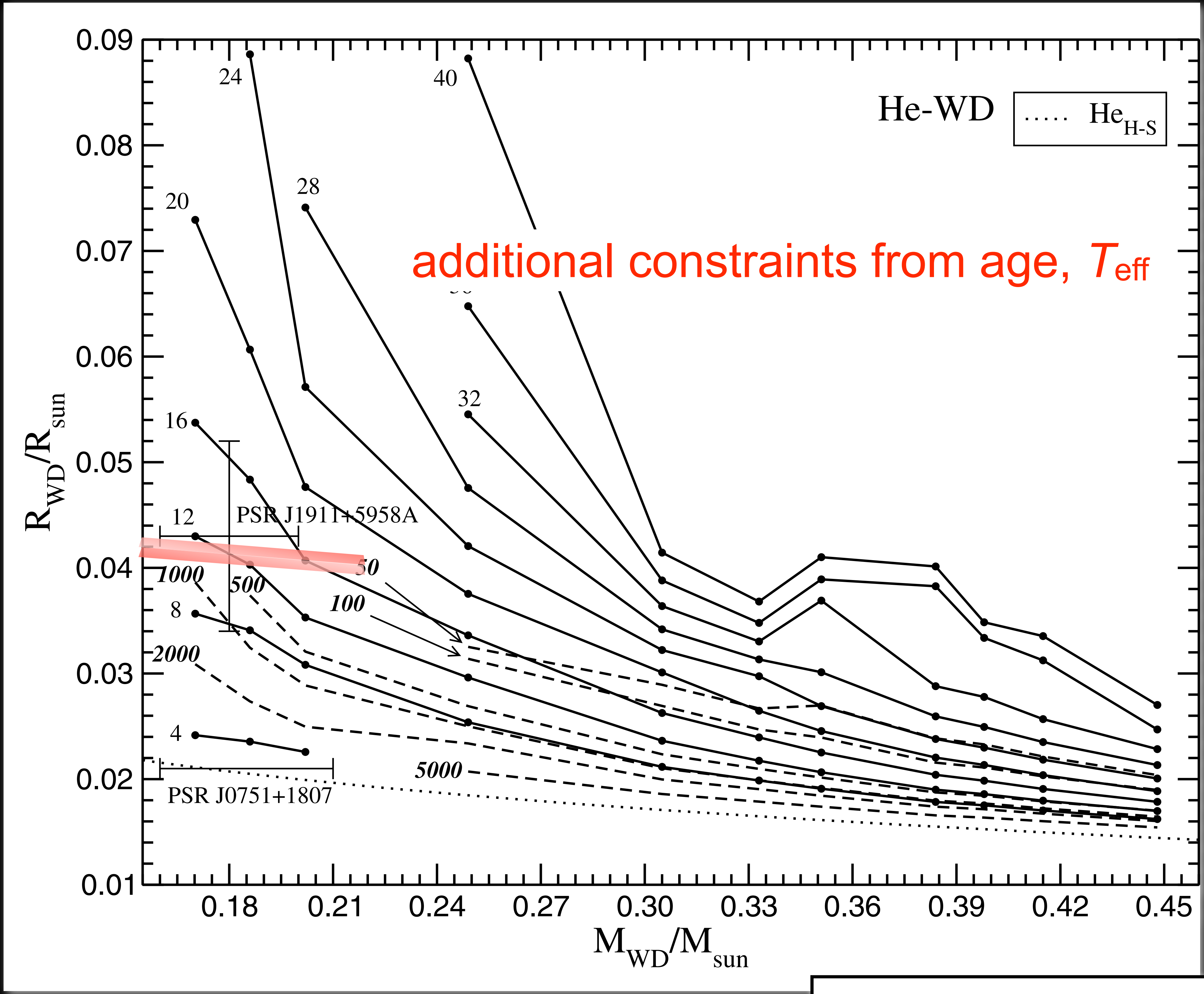
M_1=0.17 M_{SUN}, (Kawka & Vennes 2009)

log g = 6.54, T_{eff} = 8700 K, M_1=0.18 M_{SUN}, (Kilic et al. 2010)

g' = 16

(Steinfadt et al. 2010b)

Mass-Radius



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