Optical Companions to Two MSPs:

1. A Metal-Rich Low-Gravity Companion to the Massive Millisecond Pulsar J1816+4510

2. A He WD Companion to the Pulsar Triple PSR J0337

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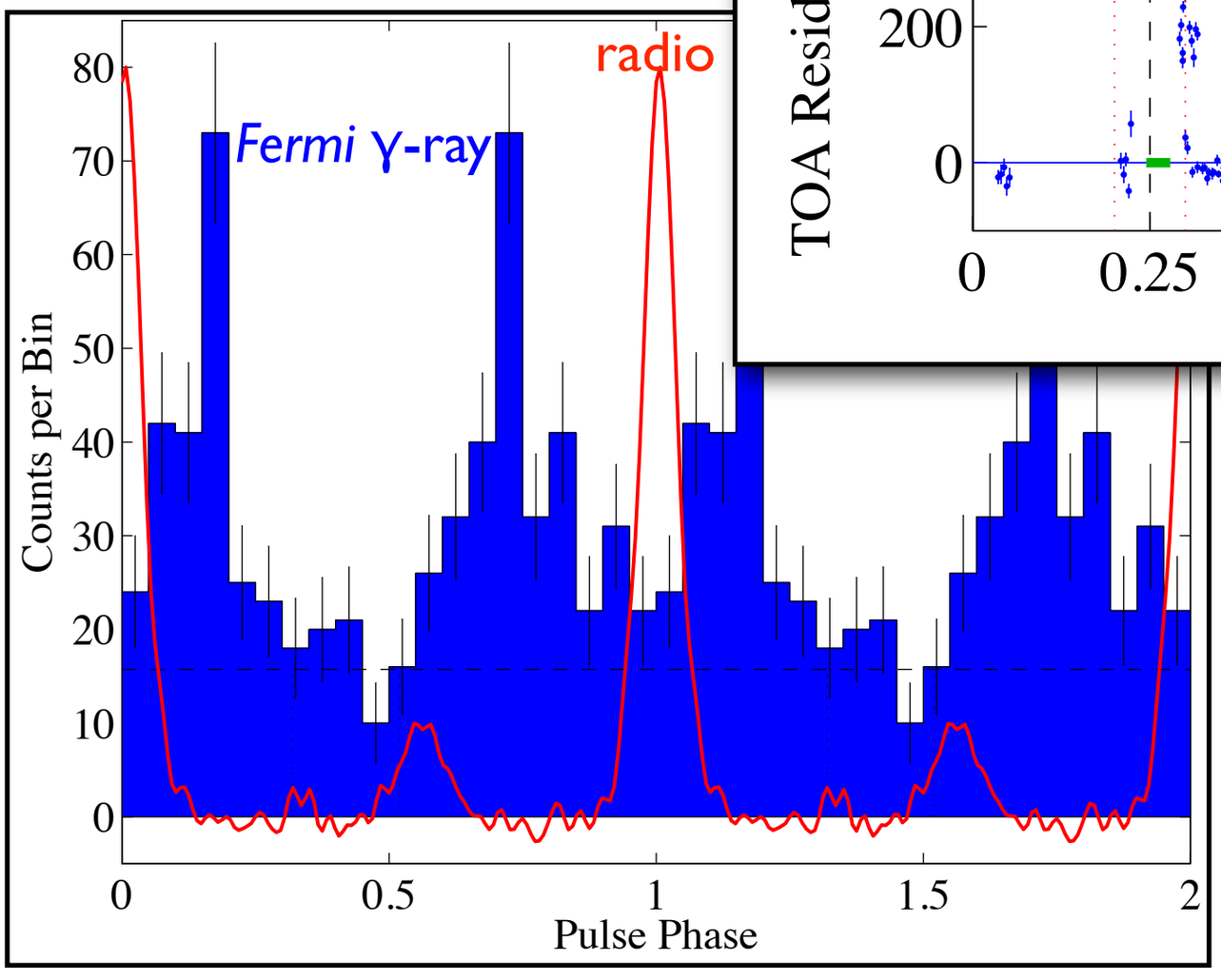
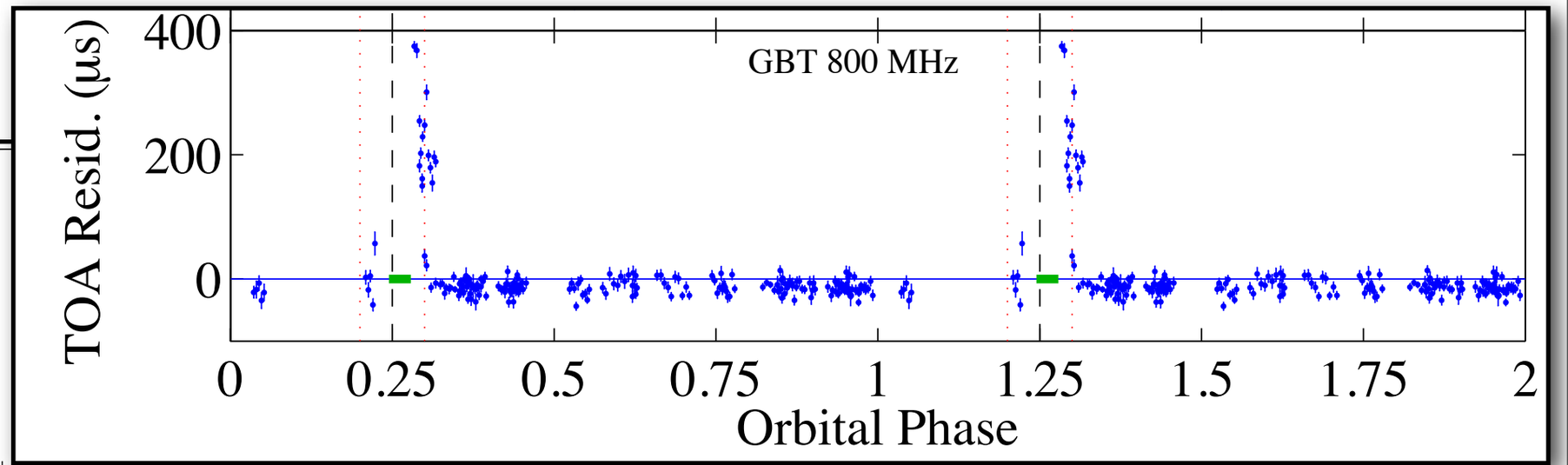
PSR J1816+4510

- 3.2 ms, discovered as part of GBNCC survey (Stovall et al. 2013)
- Orbital period 8.66 hours; companion mass ≳ 0.16 $M_\odot$
- Eclipsed for 10% of orbit, γ-ray pulsations

➡ Looks like black-widow/redback (e.g., Roberts 2011)

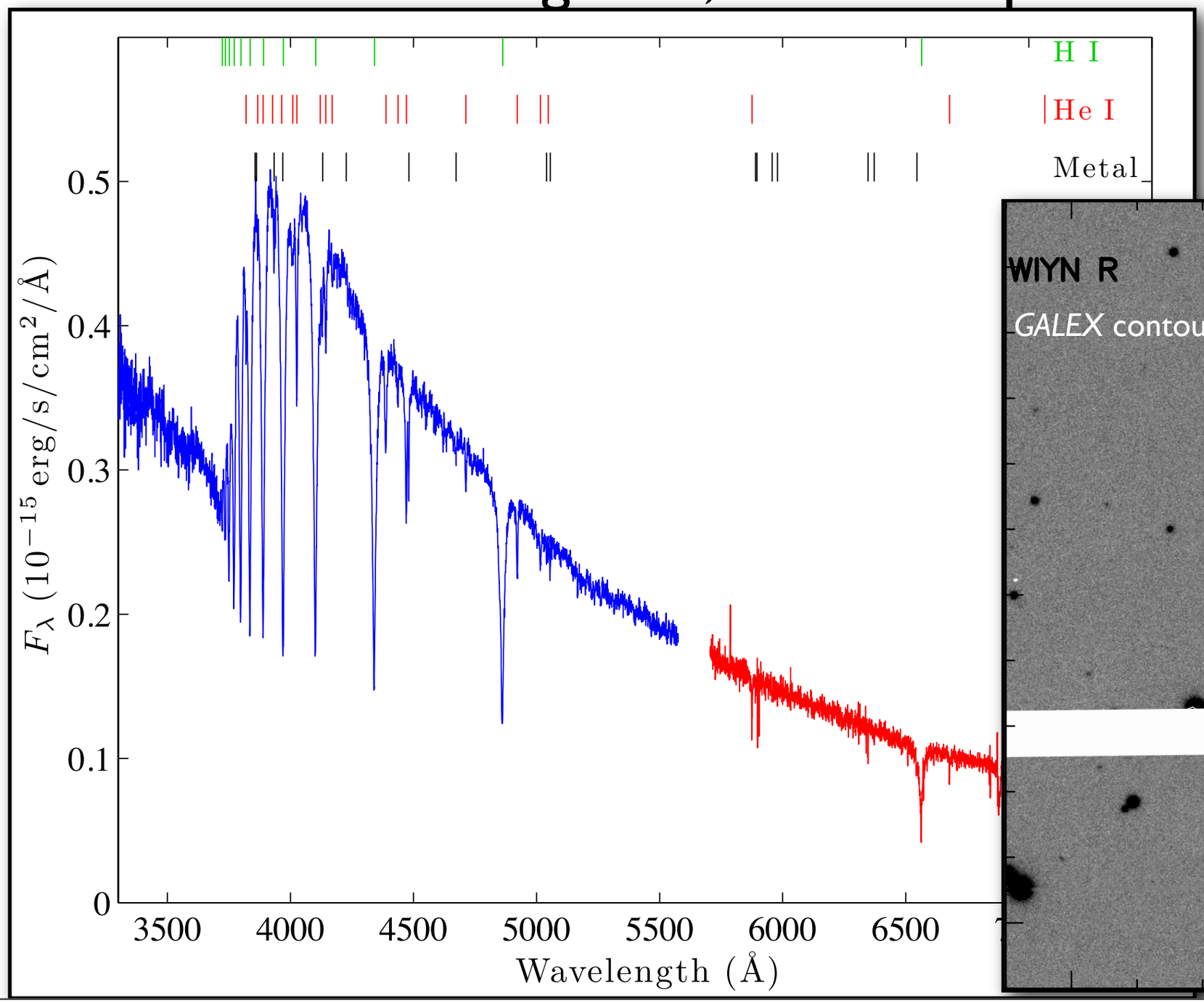


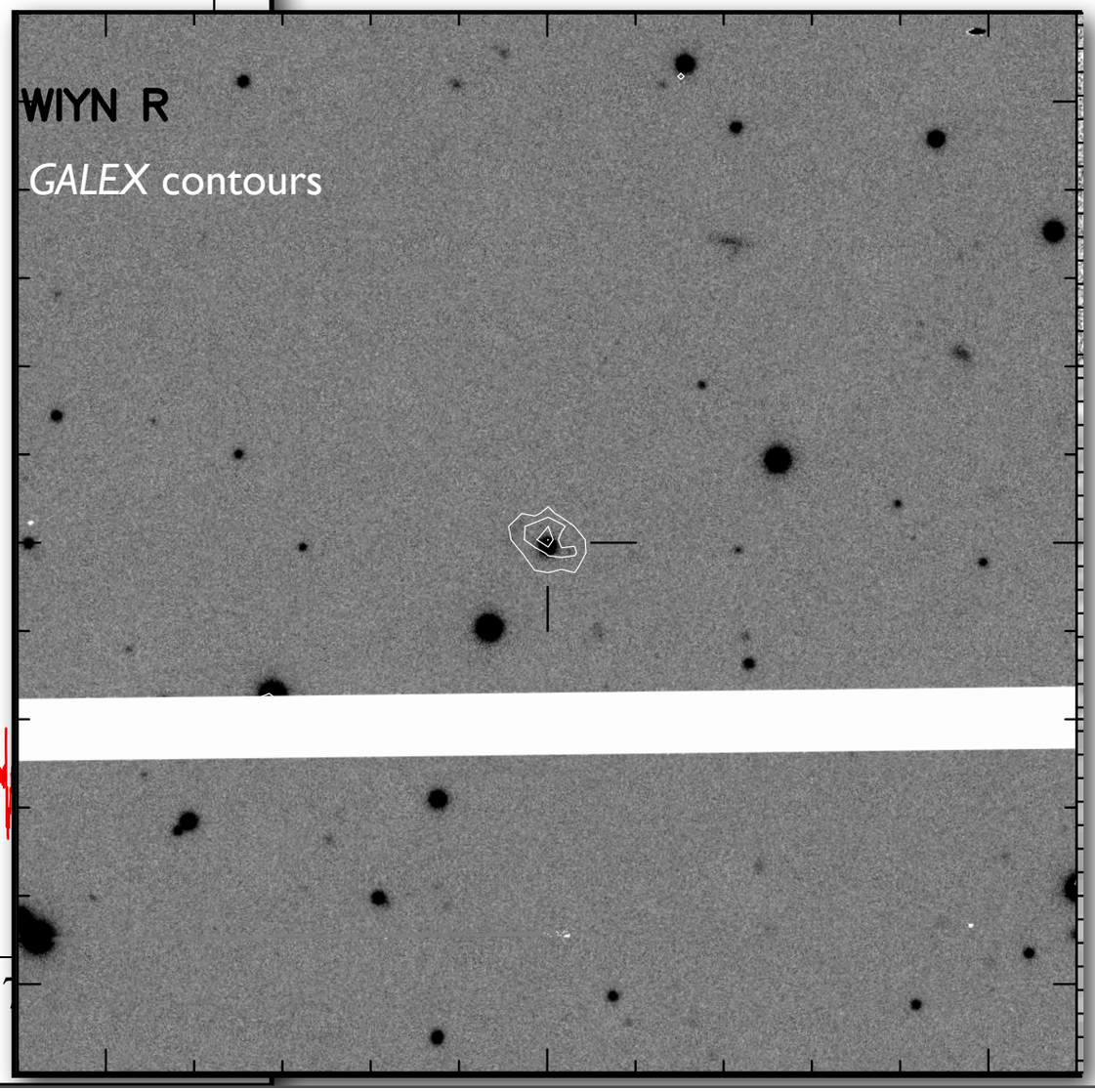


Kaplan et al. 2012, ApJ, 753, 174
Kaplan et al. 2013, ApJ, in press

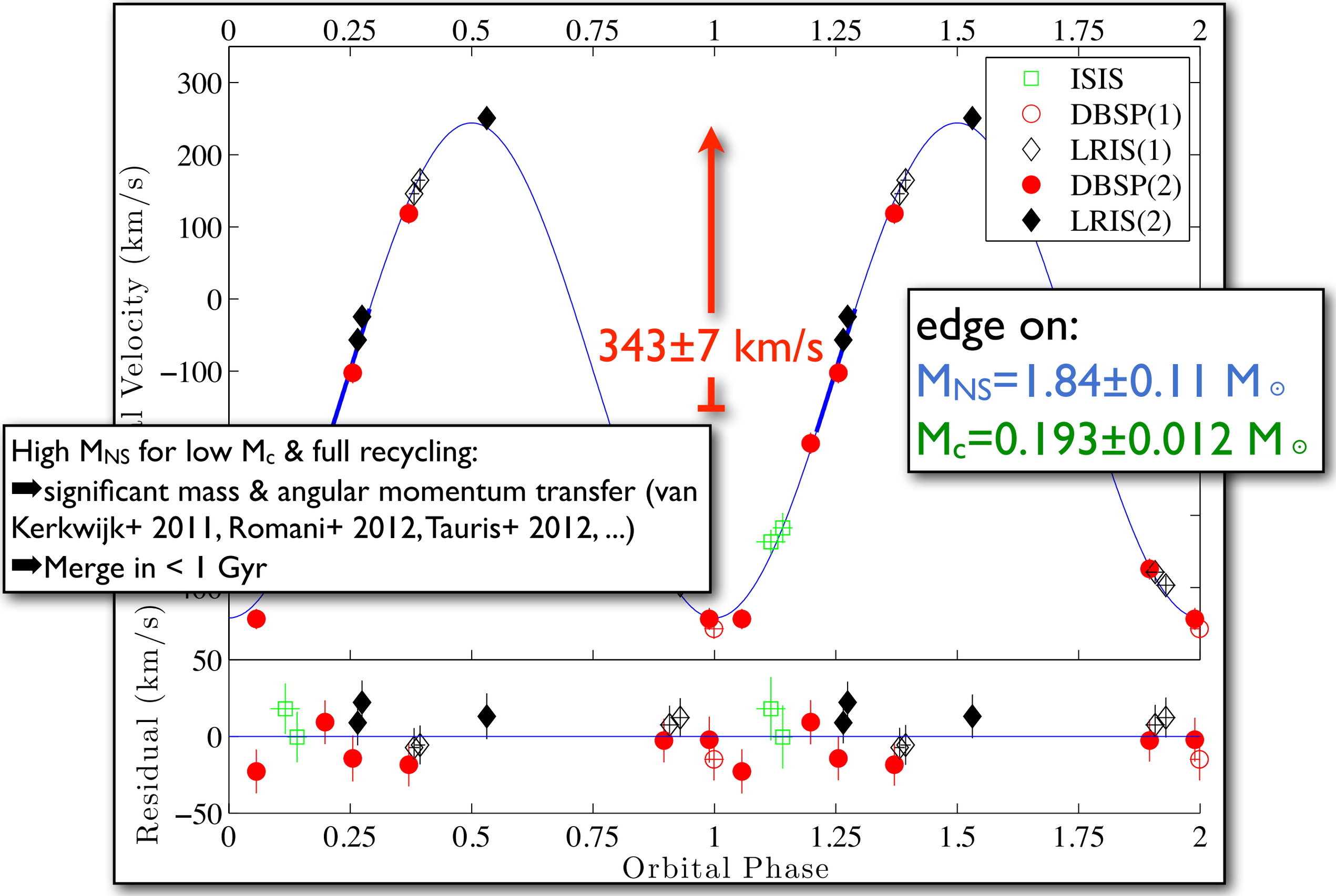
Optical Companion

- Bright (R=18.5) hot ($T \approx 16{,}000$ K) counterpart from archival data
- Spectra: low-gravity ($\log(g) \approx 5.0$), dominated by Balmer lines
  - Also see strong He I, metals → proto-DABZ?





Masses

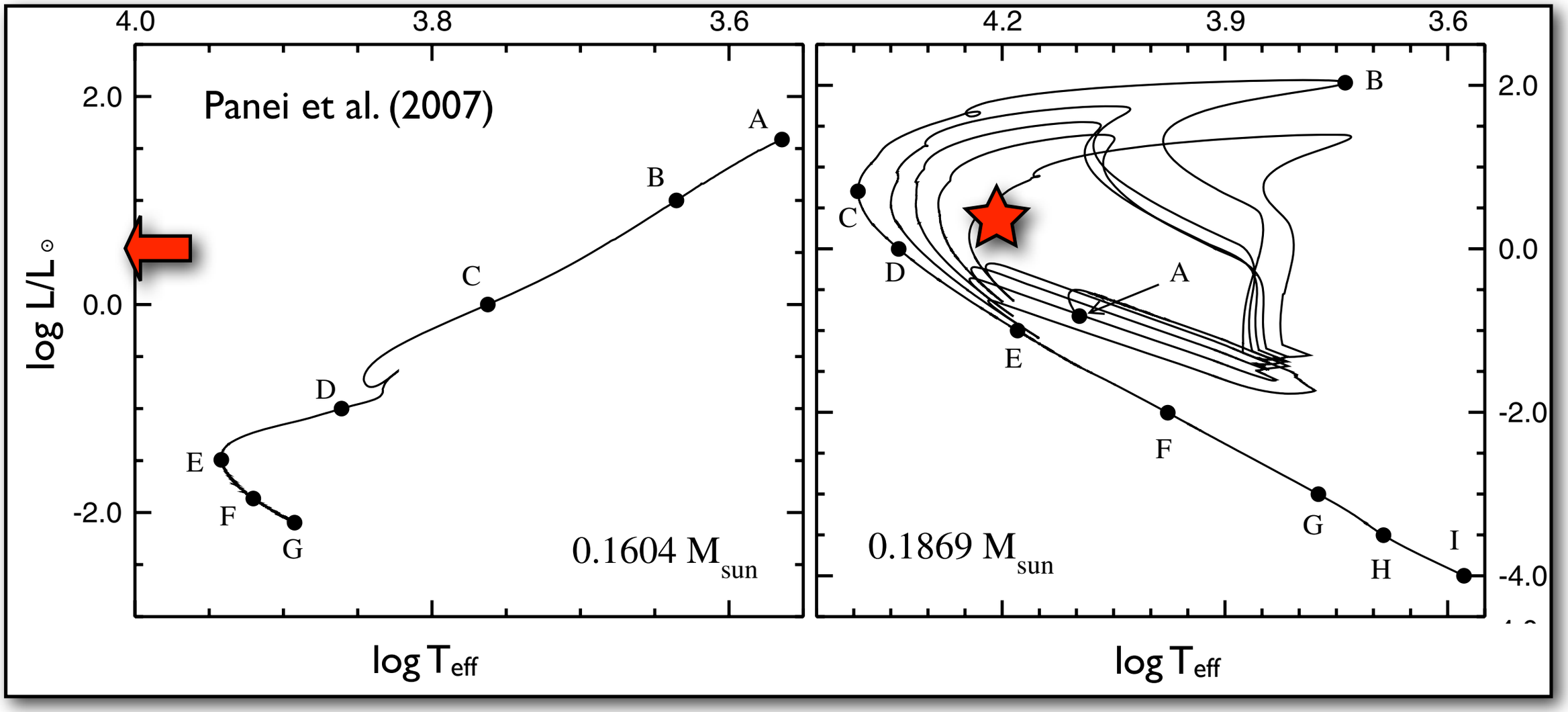

ISIS
DBSP(1)
LRIS(1)
DBSP(2)
LRIS(2)
343±7 km/s
edge on:
M_{NS}=1.84±0.11 $M_\odot$
M_c=0.193±0.012 $M_\odot$
High M_{NS} for low M_c & full recycling:
➡significant mass & angular momentum transfer (van Kerkwijk+ 2011, Romani+ 2012, Tauris+ 2012, ...)
➡Merge in < 1 Gyr
Residual (km/s)
Orbital Phase

Evolution

- Irradiation unlikely to be important: $\dot{E}/4\pi a^2 \sim 3\% \sigma T^4$
- Not like black widow, more like proto-helium core WD
- Possibly coming off cycle of shell flashes

➡ Very early stage in evolution of He-core WD?

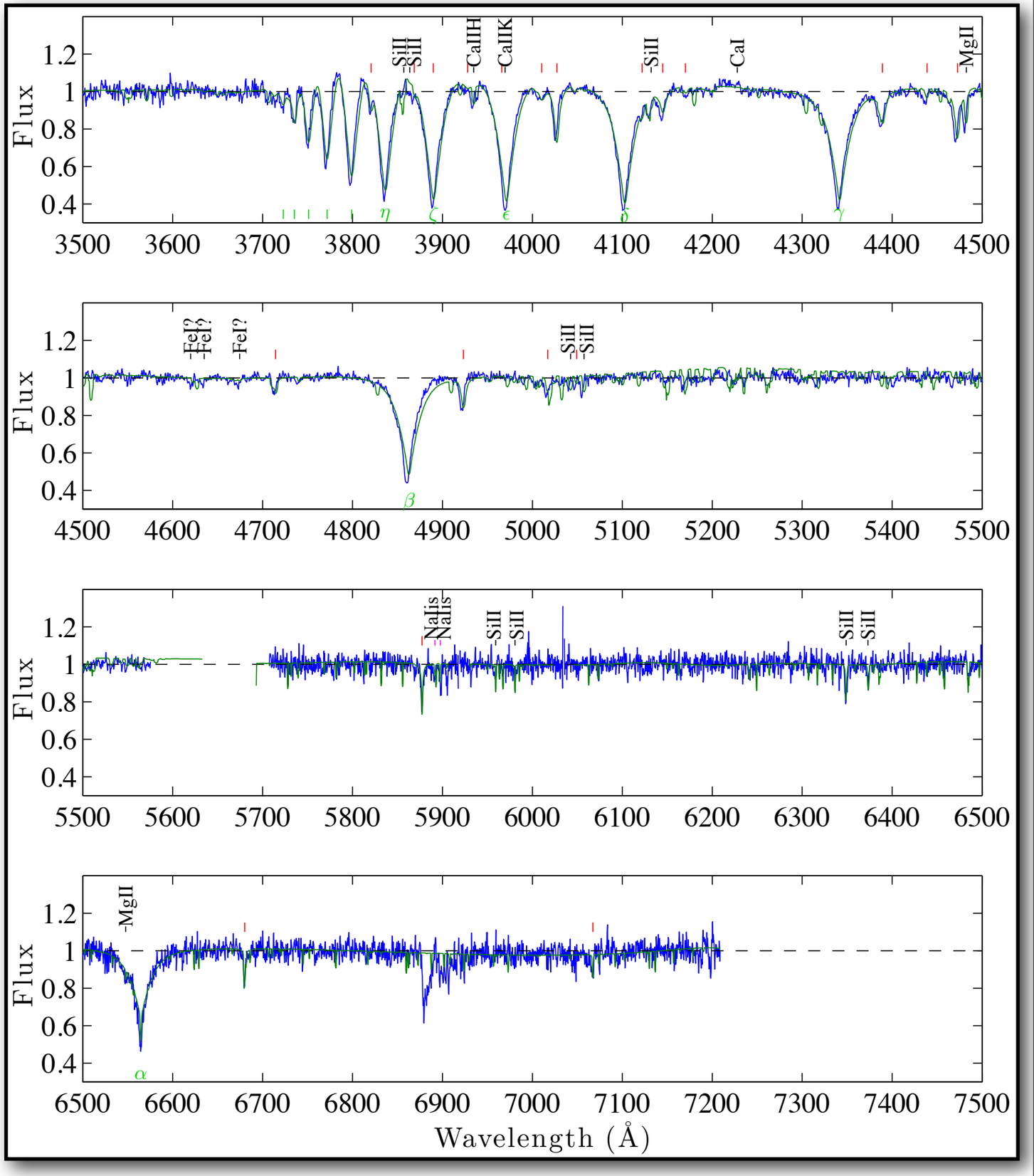
➡ Very recent recyling as well?



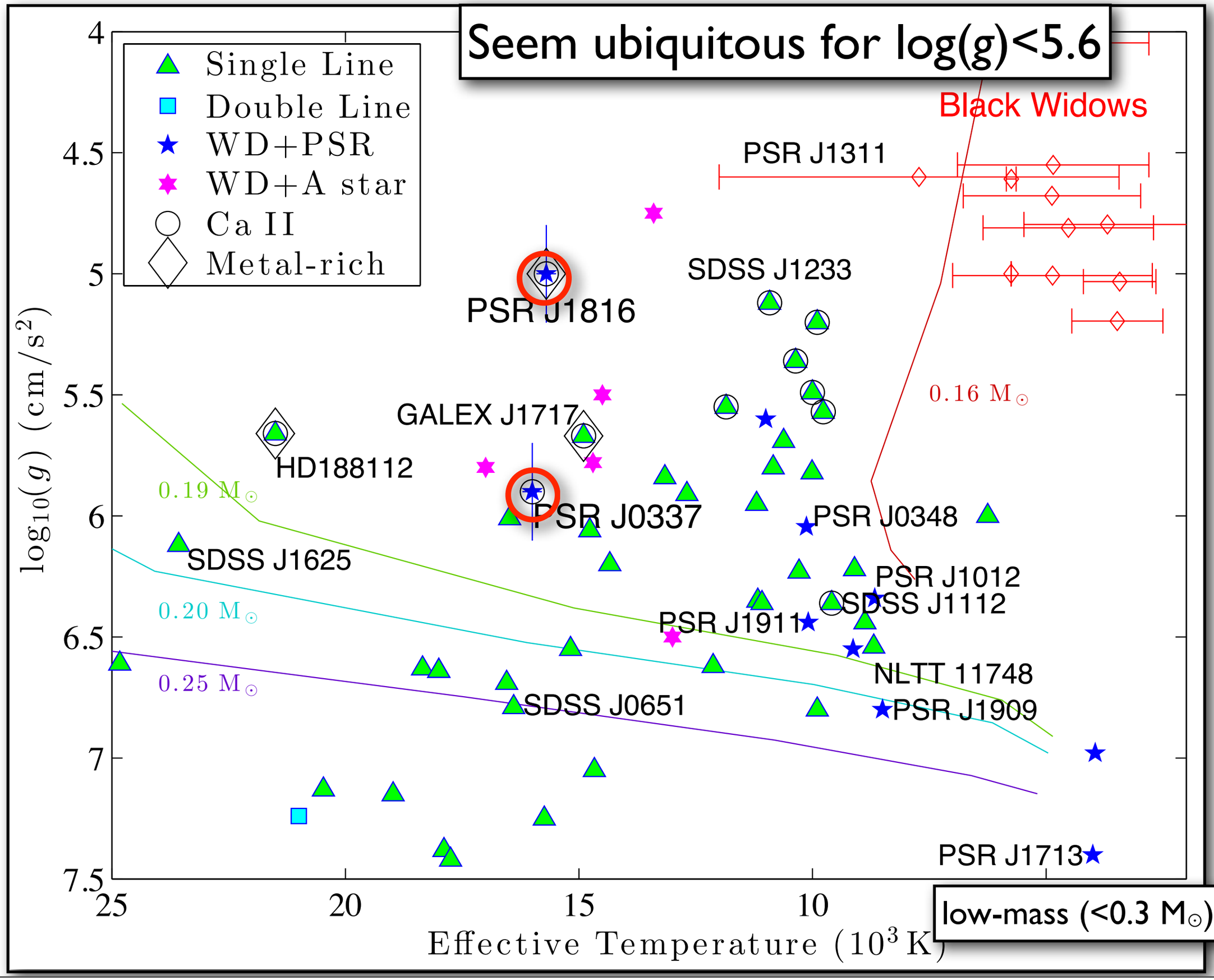
From Panei et al. (2007)

Metals?

- He, Ca, Si, Mg, Fe
  - all at roughly 10x solar abundance (wrt H)
- Accretion unlikely?
  - relativistic wind of pulsar
  - + ionized wind of companion
  - +supersonic velocity
- Dredge-up from shell flash & long sedimentation time?



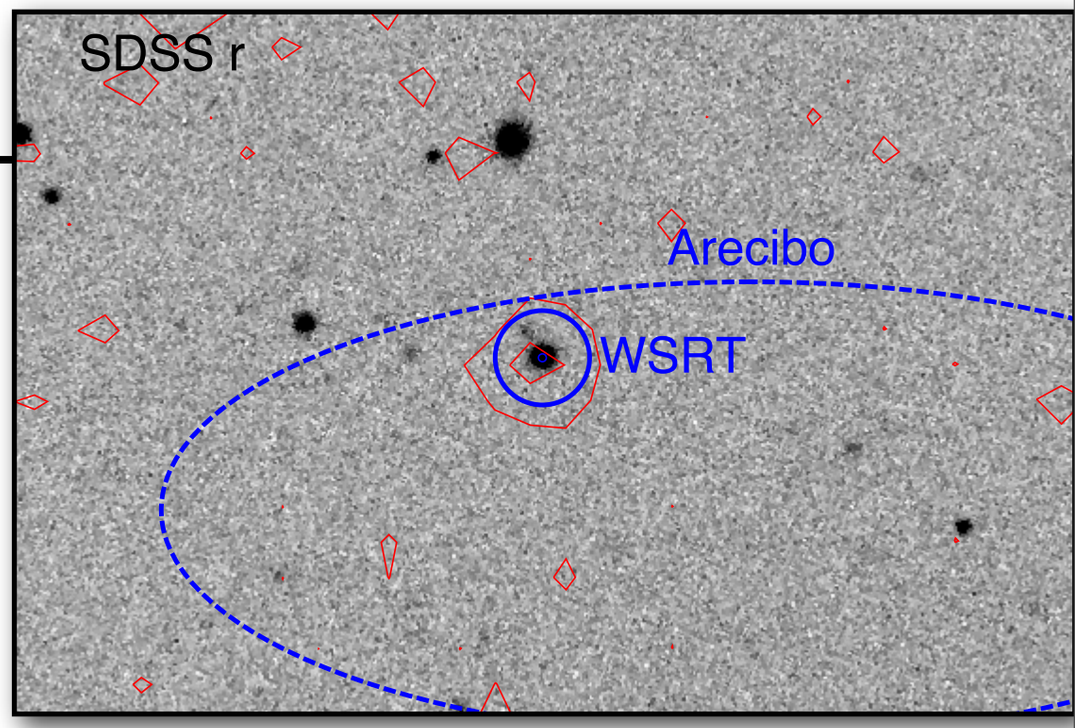
Metals?


Seem ubiquitous for log(g)<5.6
Single Line
Double Line
WD+PSR
WD+A star
Ca II
Metal-rich
Black Widows
PSR J1311
SDSS J1233
PSR J1816
GALEX J1717
HD188112
PSR J0337
PSR J0348
SDSS J1625
PSR J1012
SDSS J1112
PSR J1911
NLTT 11748
SDSS J0651
PSR J1909
PSR J1713
0.16 M⊙
0.19 M⊙
0.20 M⊙
0.25 M⊙
low-mass (<0.3 M⊙) only
log10(g) (cm/s2)
Effective Temperature (10^3 K)
4
4.5
5
5.5
6
6.5
7
7.5
25
20
15
10

Conclusions: J1816

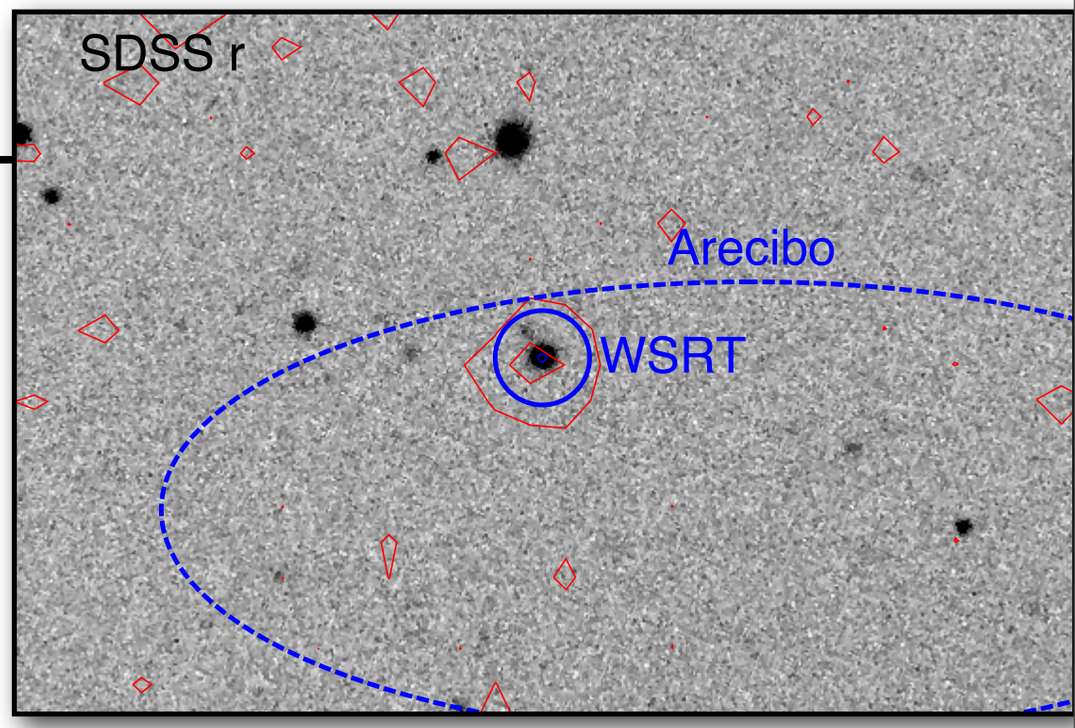
- Massive neutron star & low-mass companion in 8.66 hour orbit
- Evolving into normal MSP-WD system?
- First MSP-WD system with eclipses?
- Origin of metals *not* circumstellar
- Metal lines allow unique probes of the system (rotation, systemic velocity)
- Photometric variability allows additional probes of geometry

PSR J0337



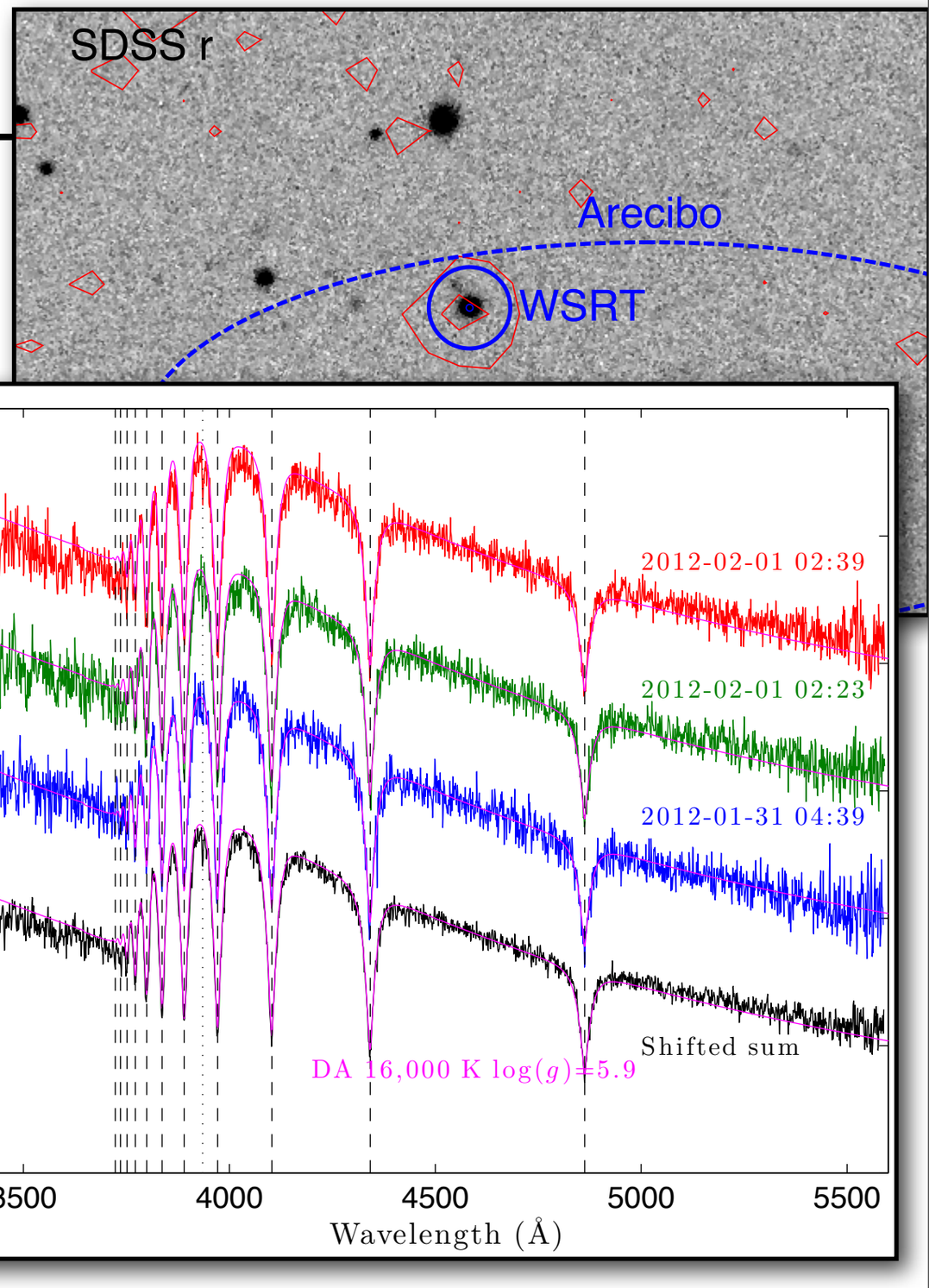
PSR J0337

- Bright (r=18.5) counterpart visible in SDSS, *GALEX*



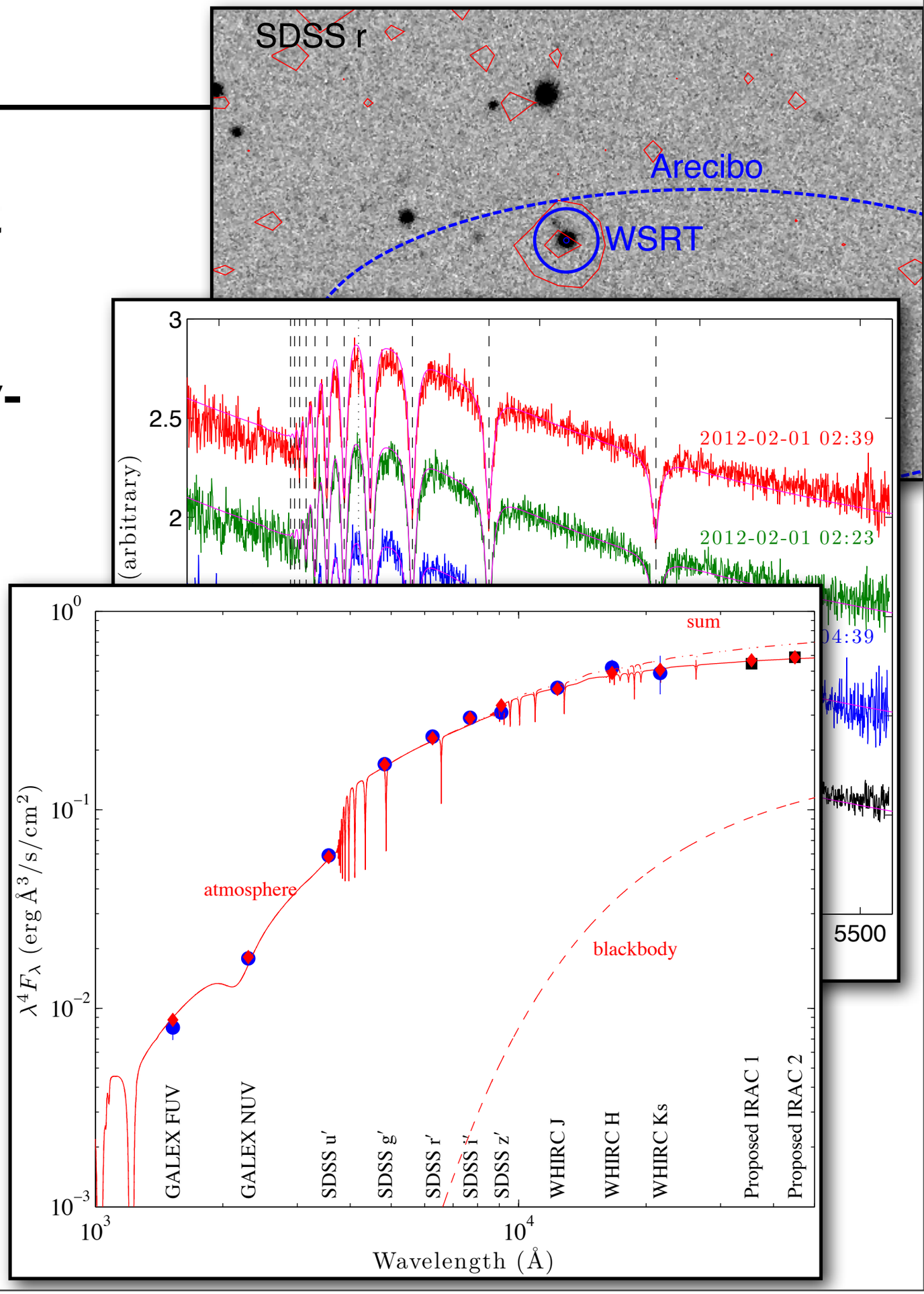
PSR J0337

- Bright (r=18.5) counterpart visible in SDSS, *GALEX*
- Spectra consistent with low-mass He WD (log(g)≈6)



PSR J0337

- Bright (r=18.5) counterpart visible in SDSS, *GALEX*
- Spectra consistent with low-mass He WD (log(g)≈6)
- Inner companion of triple: outer is likely CO WD, but could be late-type M star



Radial Velocities

- 20 observations with Gemini
- Individual precision ~6 km/s
- Mass ratio determined to 1% (preliminary):
  - $M_{psr} \sin^3 i = 0.36(1)\ M_\odot$
  - $M_c \sin^3 i = 0.050(2)\ M_\odot$
  - 1.4 $M_\odot$ for i=39°
  - d=1.2 kpc
- 1σ evidence for 3rd body in RVs
- Better analysis & more data coming