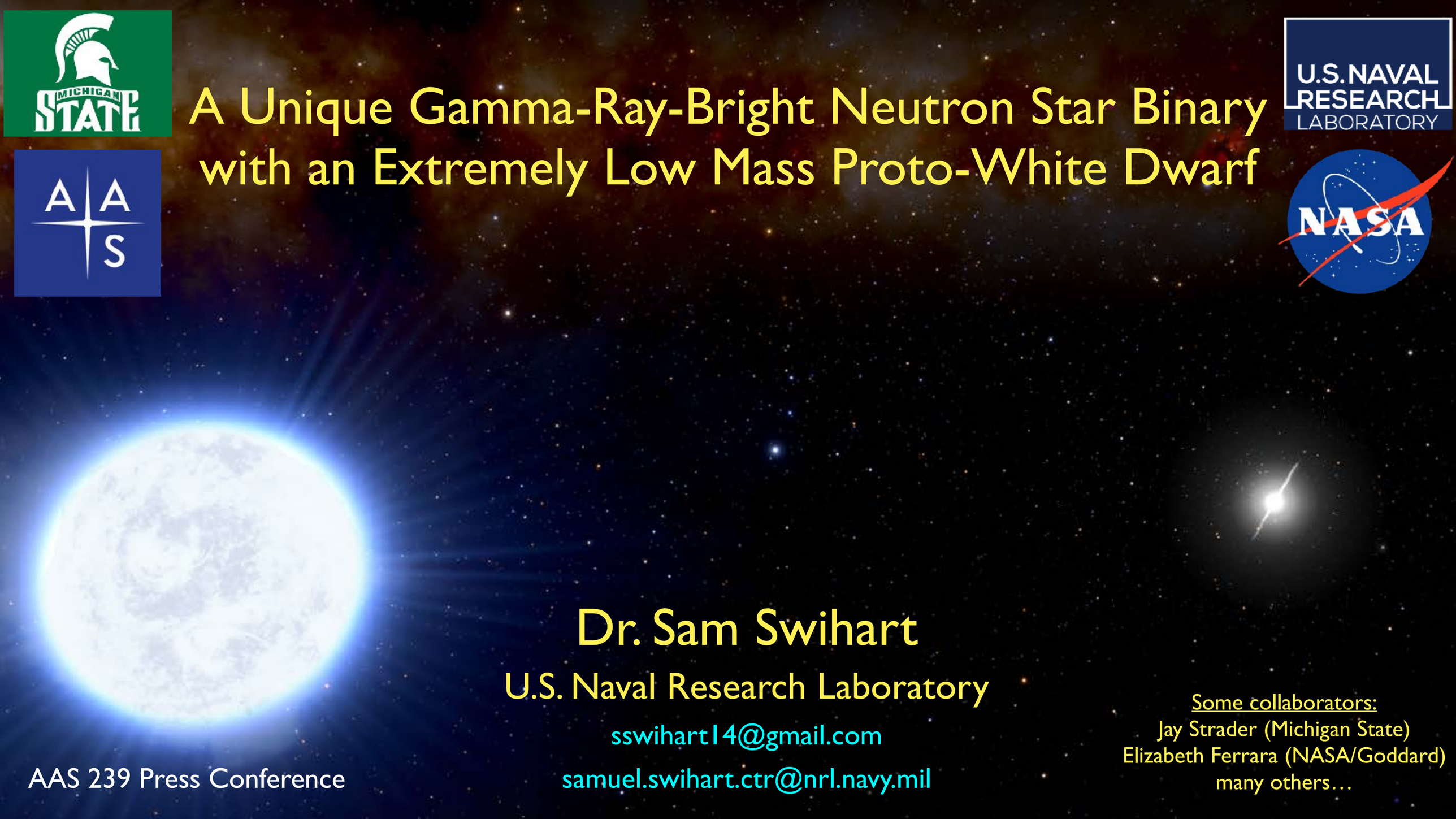
A Unique Gamma-Ray-Bright Neutron Star Binary with an Extremely Low Mass Proto-White Dwarf



Dr. Sam Swihart

U.S. Naval Research Laboratory

sswihart14@gmail.com

samuel.swihart.ctr@nrl.navy.mil

Some collaborators:
Jay Strader (Michigan State)
Elizabeth Ferrara (NASA/Goddard)
many others…

AAS 239 Press Conference

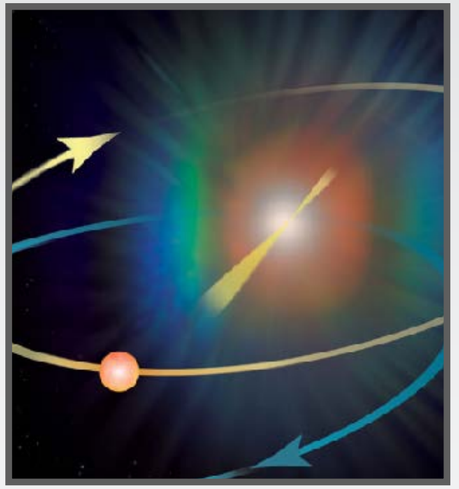
The Millisecond Pulsar (MSP) Recycling Process

Two stars born
in a binary system

The more massive
star evolves quicker…

(live fast, die young)

The Millisecond Pulsar (MSP) Recycling Process



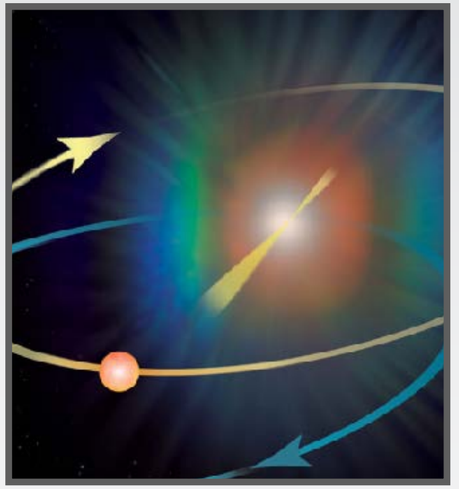
The more massive star goes supernova

Leaves behind a spinning neutron star (pulsar)

like a lighthouse

Pulsar lives "normally"
slowly losing energy over time

The Millisecond Pulsar (MSP) Recycling Process



Companion star expands

Material is accreted onto the neutron star spinning it up to rapid spin periods

Analogy: hitting the side of a basketball to make it spin on your finger

The Millisecond Pulsar (MSP) Recycling Process

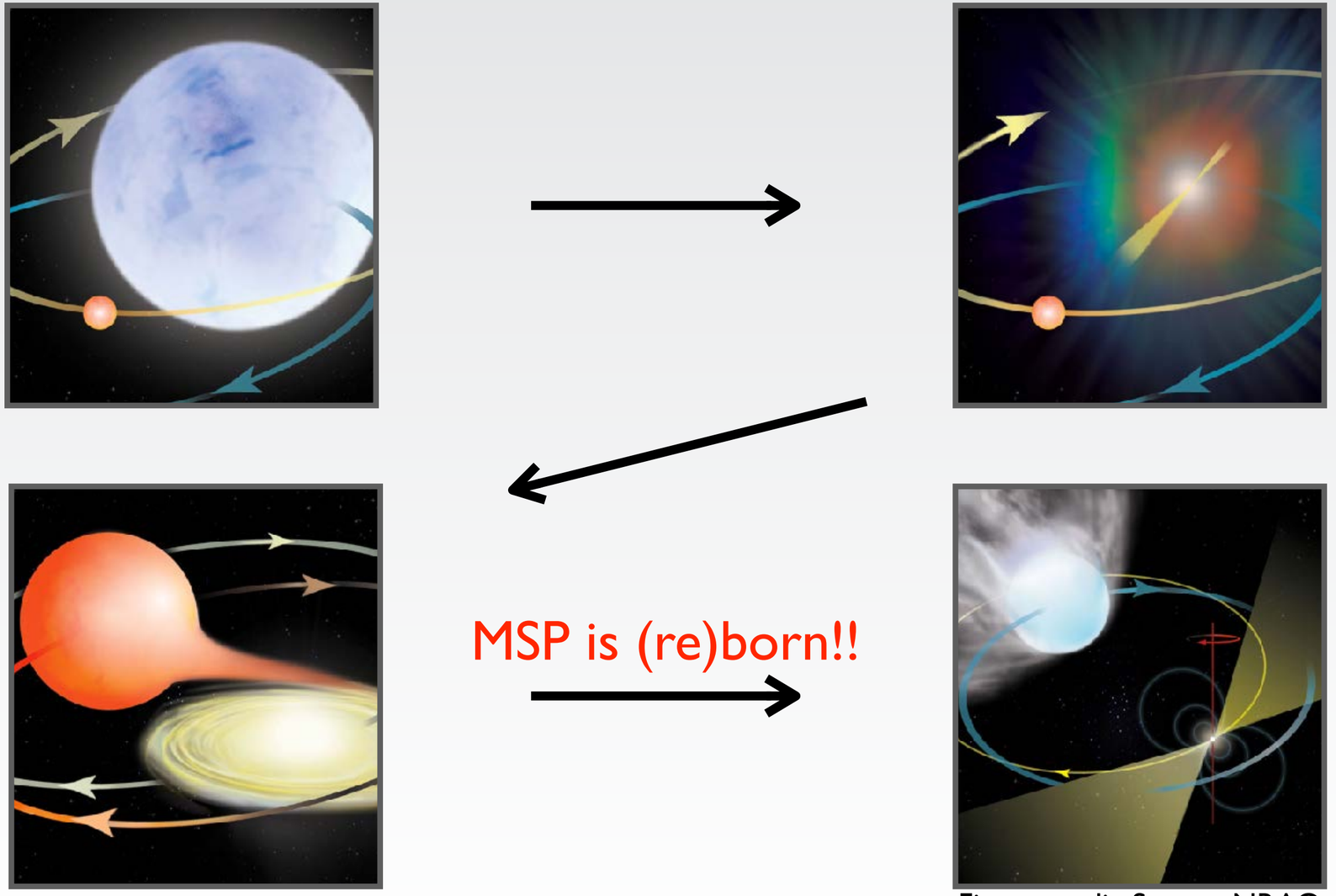
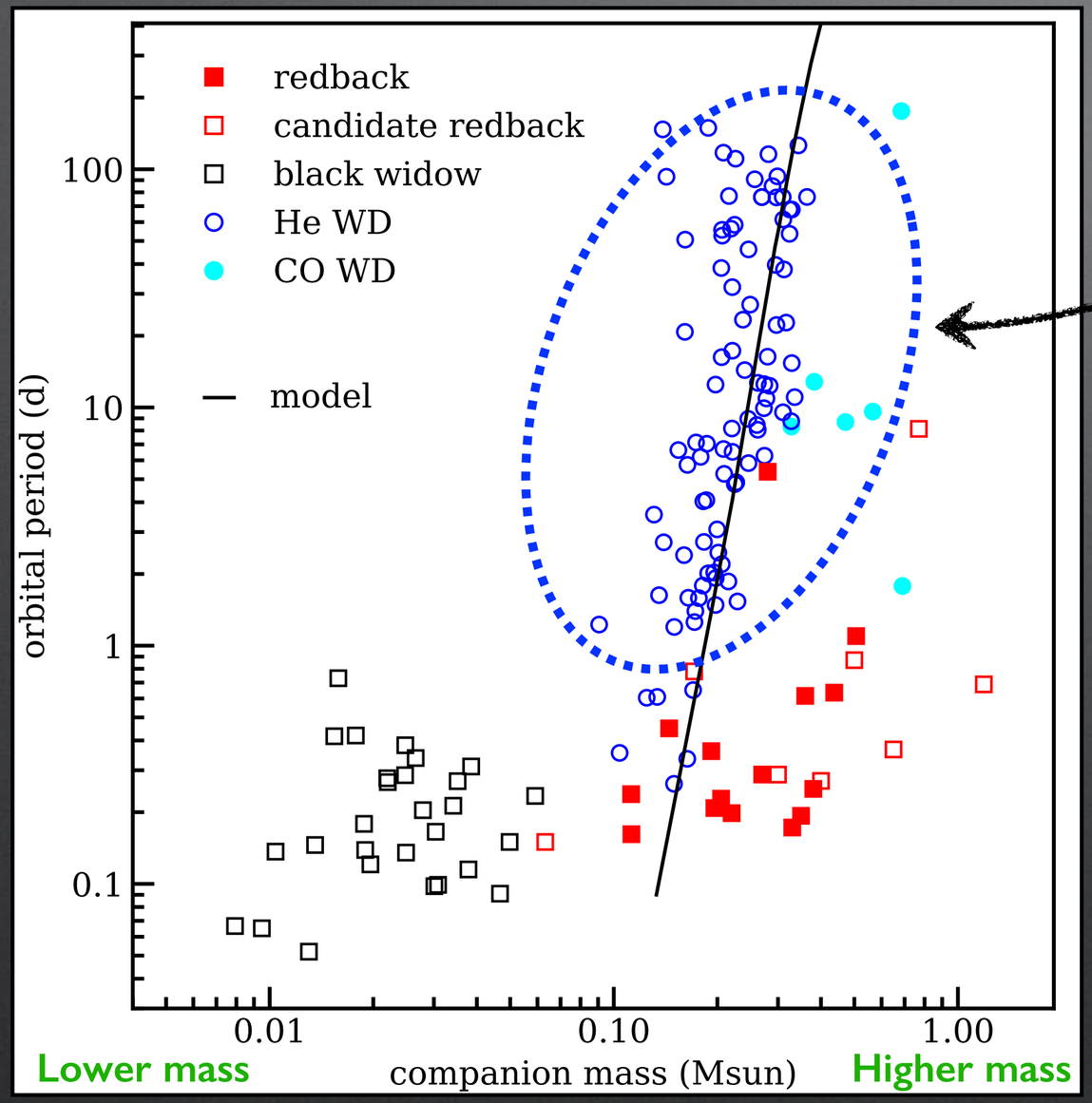


Figure credit: Saxton, NRAO

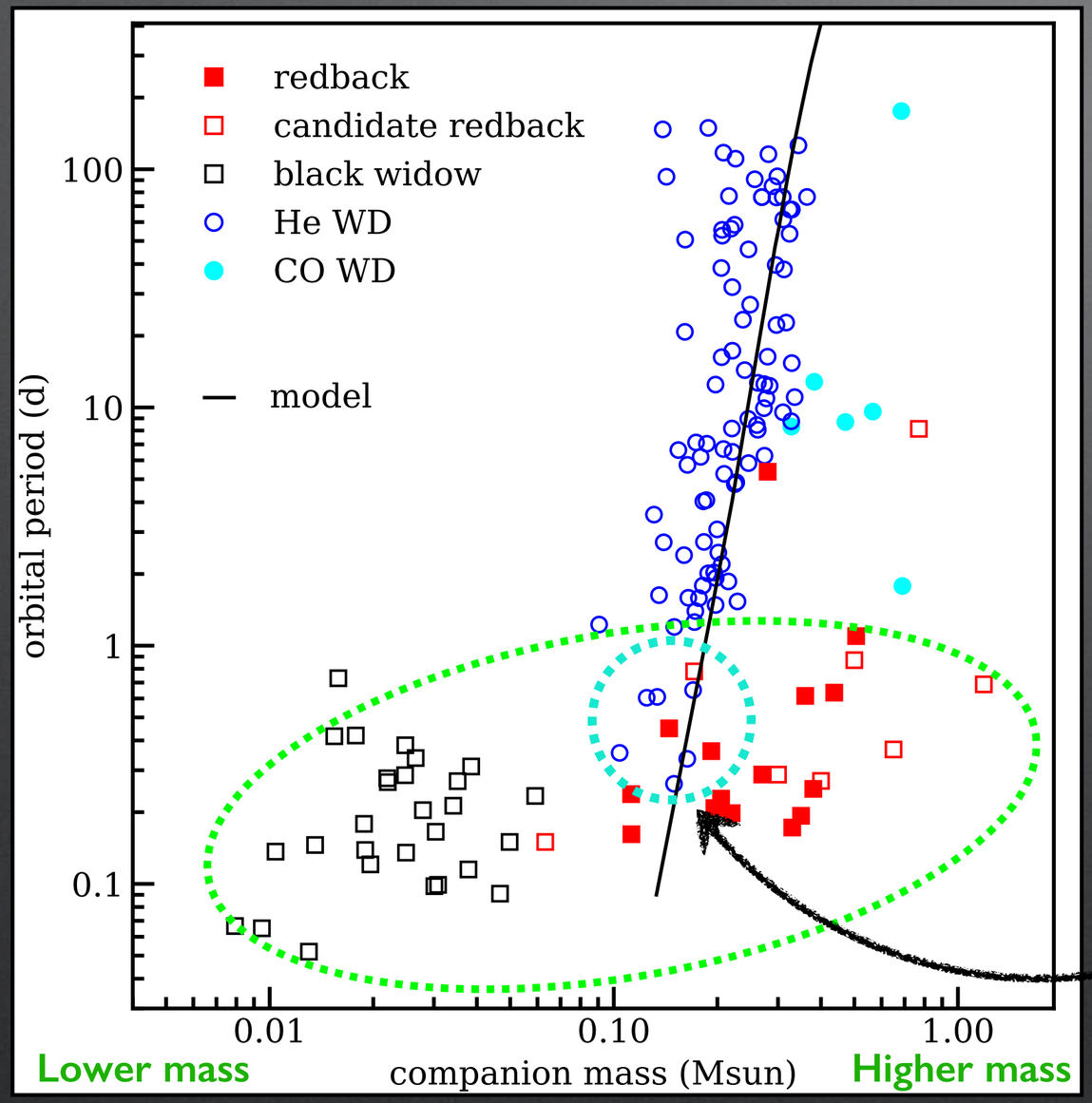
Binary Millisecond Pulsars (2022)



Most known binary MSPs have white dwarf companions in wide orbits

End products of the MSP recycling process

Binary Millisecond Pulsars (2022)

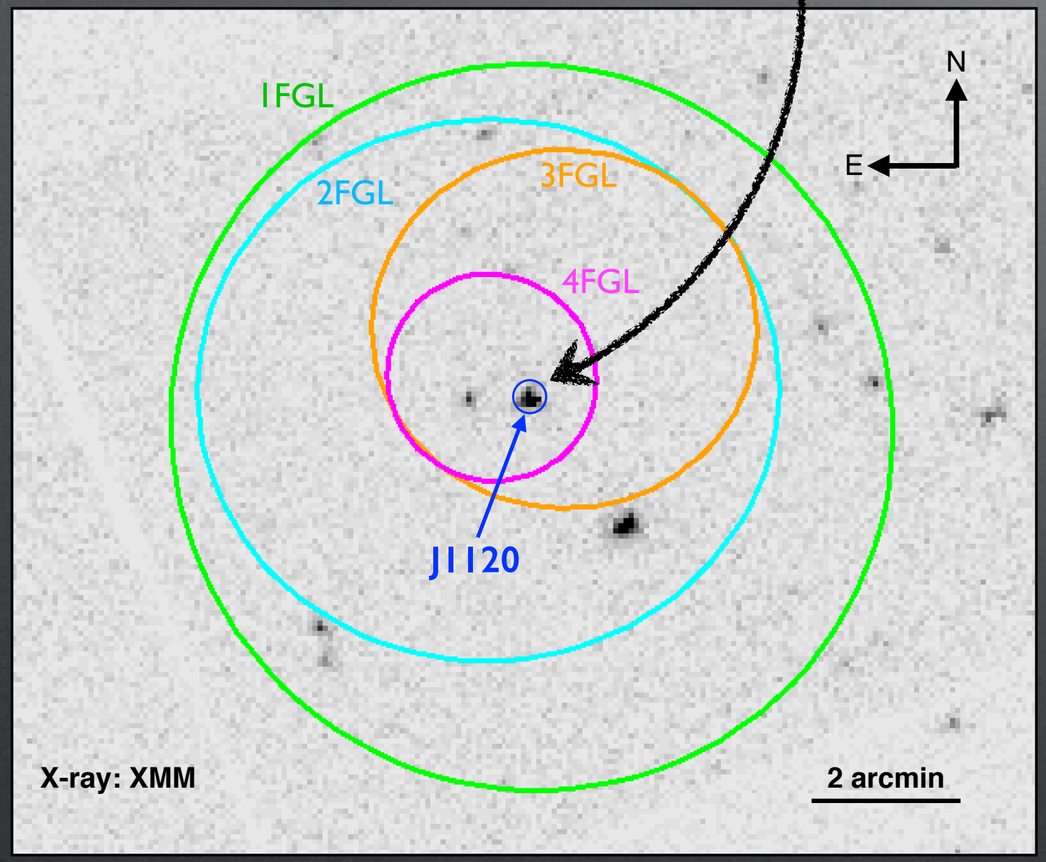


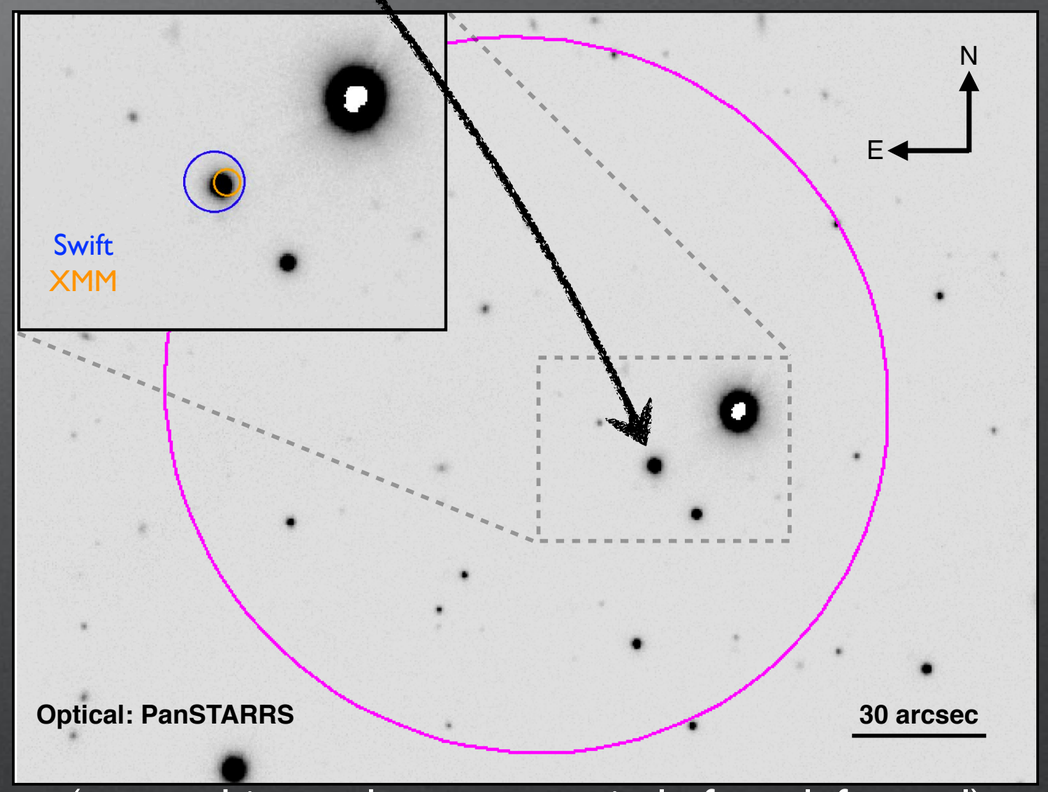
Follow-up of *Fermi* gamma-ray sources has revealed huge numbers of unusual MSPs

- **The "spiders":**
  redbacks & black widows
  (Short period systems where the companion is being "consumed")
- **Extremely-low-mass white dwarfs**

4FGL J1120.0-2204

A bright X-ray source matches to a star with a blue color



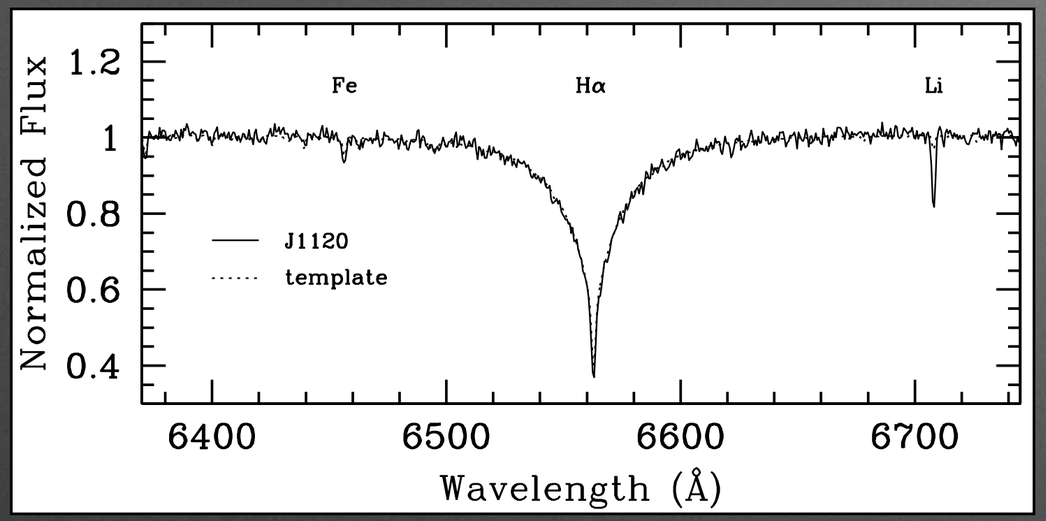


(zoomed-in on the magenta circle from left panel)

So… we have a gamma-ray source that has an X-ray & optical counterpart

Let's figure out what it is!!

Spectroscopy w/ the SOAR telescope reveals a hot object orbiting an unseen companion

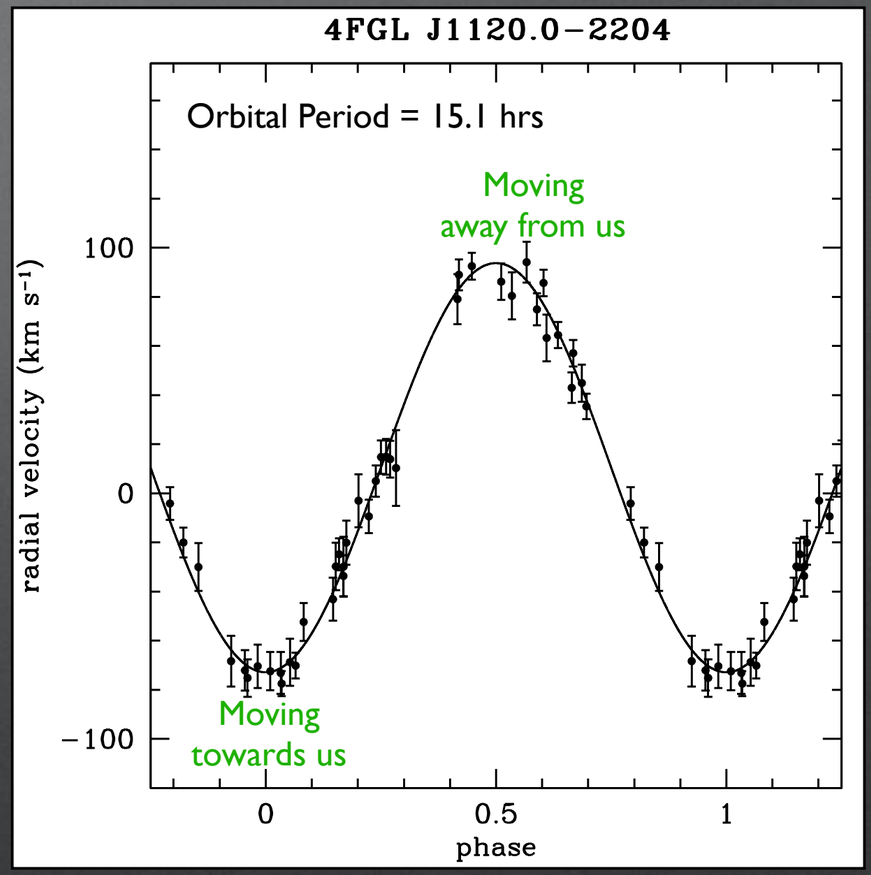


Fitting models to the spectrum gives us the temperature and surface gravity of the companion

T_{eff} = 8500 K (~15,000° F)

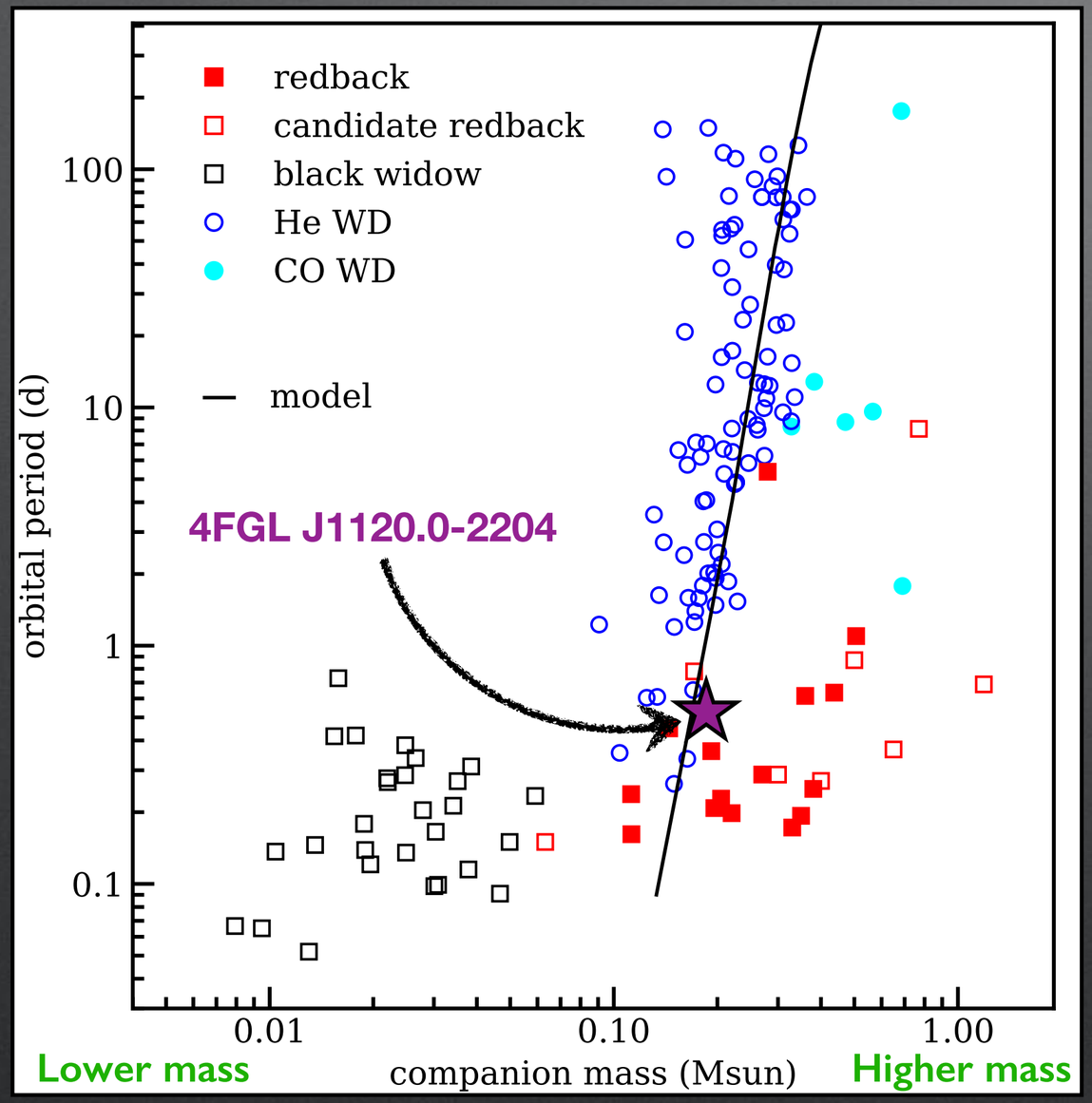
log g ~ 4.6

Hotter and much more dense than the Sun



The radial velocity curve gives us constraints on the MASSES of the neutron star and companion

The companion is a precursor to an extremely-low-mass white dwarf!!



The companion is slowly contracting

↓

A proto-white dwarf with a very low mass due to the accretion process and a radius ~5x larger than "normal" WDs

In ~2 Gyr the companion will have finished contracting, then…

↓

J1120 will look nearly identical to the known MSPs with extremely-low-mass WDs

J1120 is the <u>first</u> system discovered in the penultimate phase of the MSP recycling process!!

Summary & Implications

★ A bright, unidentified *Fermi* gamma-ray source is associated with a X-ray and optical source

★ Optical spectroscopy w/ SOAR telescope shows a warm (~8500 K) companion in a 15-hr orbit around an unseen primary -- likely a neutron star

★ The 0.17 M_{sun} companion is in an intermediate stage, contracting on the way to becoming an extremely-low-mass white dwarf (*i*.e., a pre-ELM white dwarf)

★ Binary evolution models predict that in ~2 Gyr, the properties of the binary will match those of known MSP -- white dwarf binaries with short orbital periods

★ A "missing link" system representing a progenitor to "normal" MSP binaries

Dr. Sam Swihart
U.S. Naval Research Laboratory
sswihart14@gmail.com
samuel.swihart.ctr@nrl.navy.mil

Bonus Slides!

A pre-ELM white dwarf companion

MESA binary evolution models:

Utilize observational constraints on
P_{orb}, log g, Radius, & T_{eff}
to establish feasible evolutionary models

Assuming some initial conditions,
all the model parameters match the
observations at ~8.1 Gyr (blue shaded region)

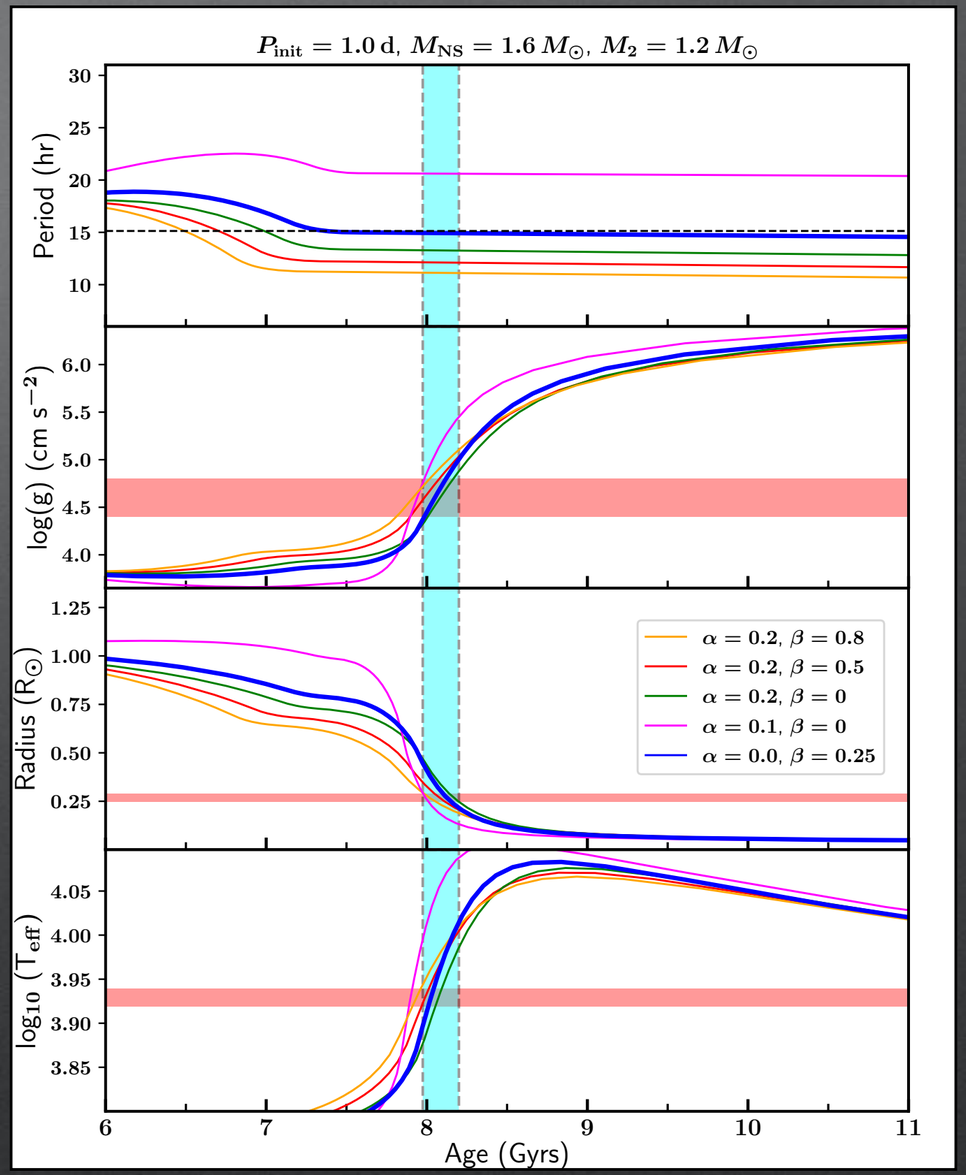
In it's current stage, mass transfer
is completely finished along with the bulk
of the orbital period evolution

↓

The companion is slowly contracting towards
the He-white dwarf cooling sequence

↓

A proto-white dwarf with a very low
mass due to the accretion process and a
radius ~5x larger than "normal" WDs



Companion Size & Lack of Variability

The distance is well-known (~820 pc) from a significant Gaia parallax

Assuming T_{eff} & the extinction-corrected absolute magnitude (M_G=5.85):

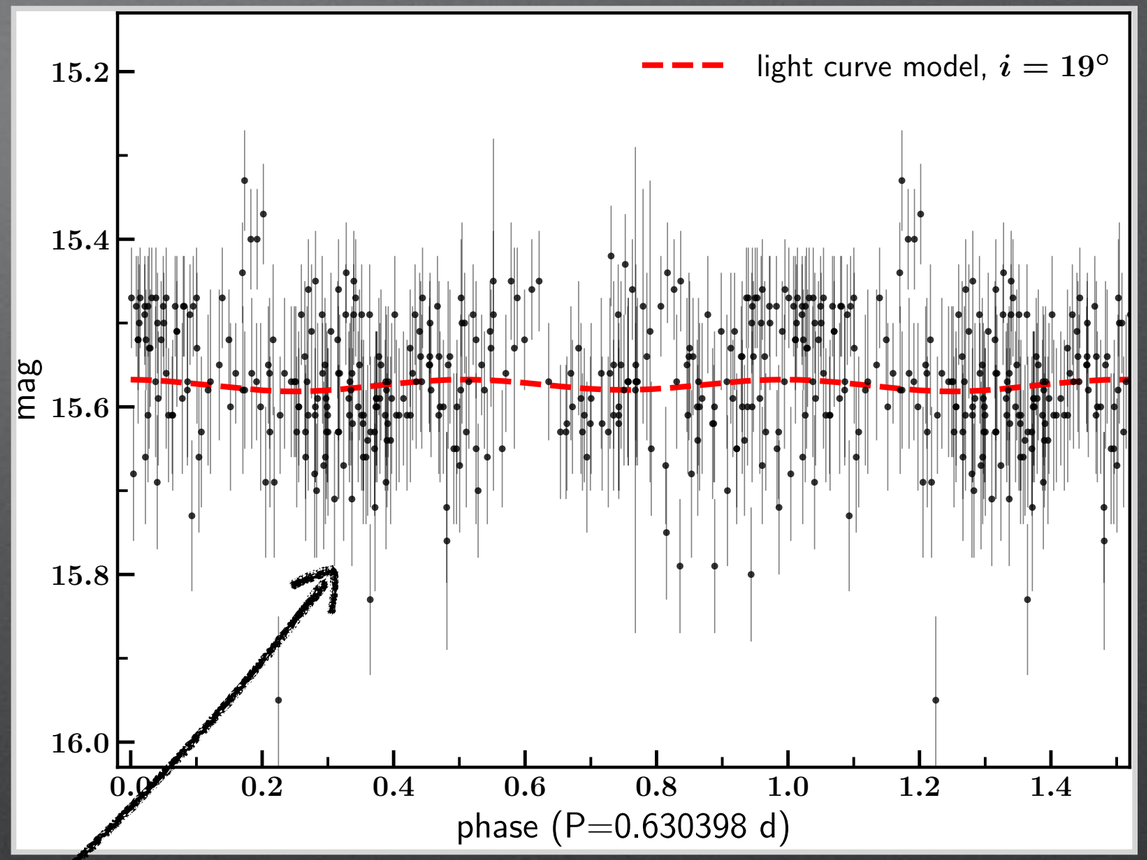
↓

$$R_2 = 0.27 \pm 0.02\, R_\odot$$

This is <45% of the full Roche lobe radius assuming typical NS masses

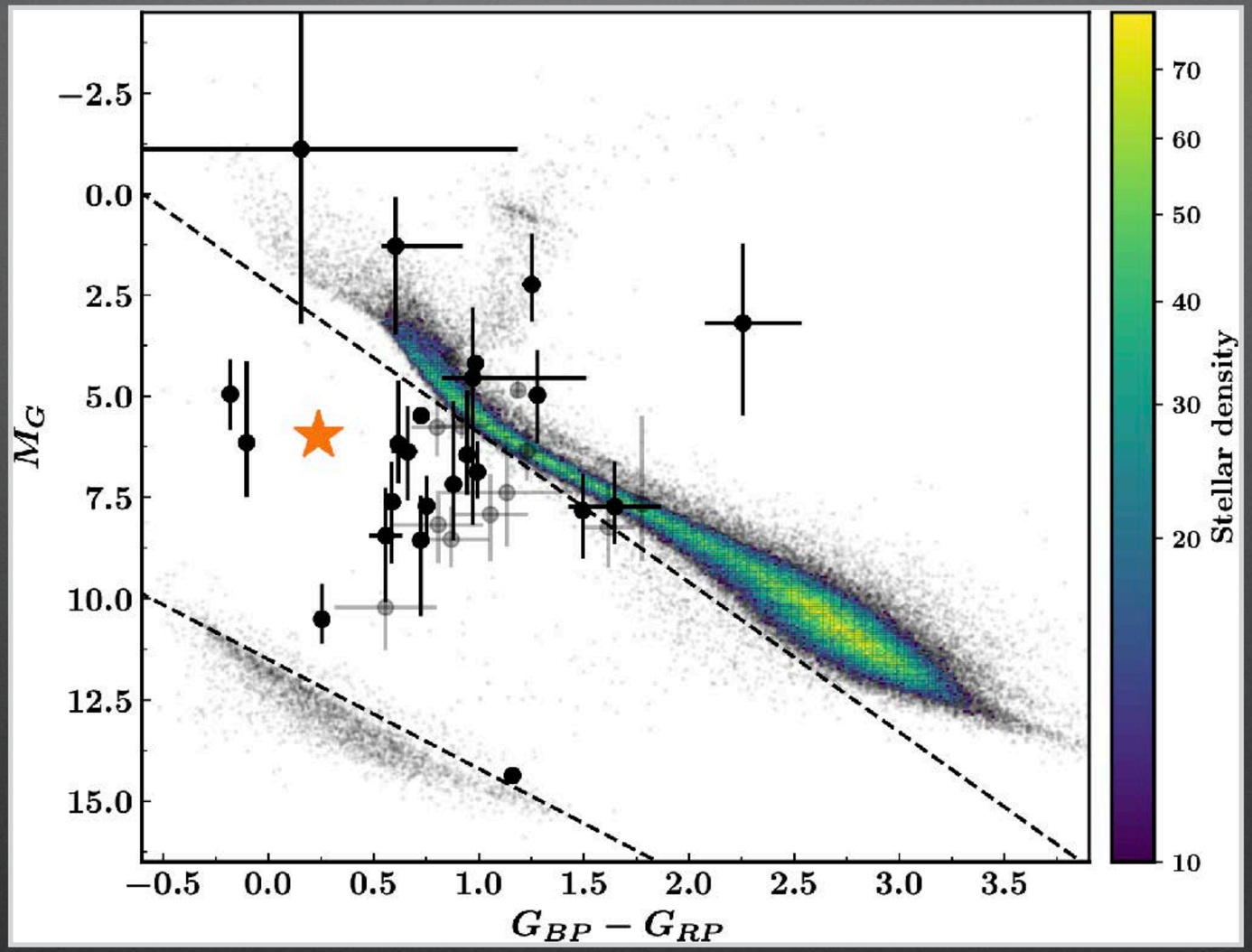
↓

J1120 is strongly UNDERFILLING its Roche lobe!!



Catalina Sky Survey photometry (folded on the binary period) confirms the amplitude of variations from a system with i~19° is much smaller than the scatter in the data

Known companions to MSPs -- J1120 stands out on the color-magnitude diagram



J1120 is much bluer(warmer) than main-sequence stars at a similar brightness & significantly brighter than white dwarfs with comparable colors

Why MSPs…?

- ★ Extremely stable spin periods
- ★ Enabled detection of the first exoplanets
- ★ Ideal laboratories for testing gravitational theories
  - ★ Gravitational waves (mergers, low frequency background, etc.)
- ★ Pulsar-based timescales rival precision of atoms clocks but over much longer baselines
- ★ Window into stellar and binary evolution
- ★ Provide insights into the physics of low-level accretion onto magnetized compact objects
- ★ Known to be high-energy (γ-ray) emitters