New Light on Symbiotic X-Ray Binaries

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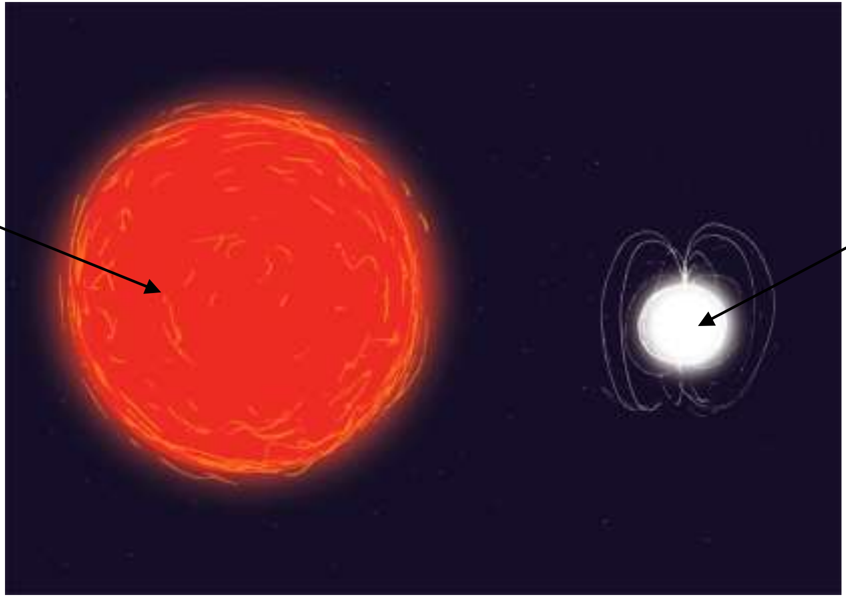
June 3, 2024

Image Credit: NASA

Symbiotic X-ray Binaries

Red Giant (RG)



Wind-Accreting Neutron Star (NS)

Rare class of objects!

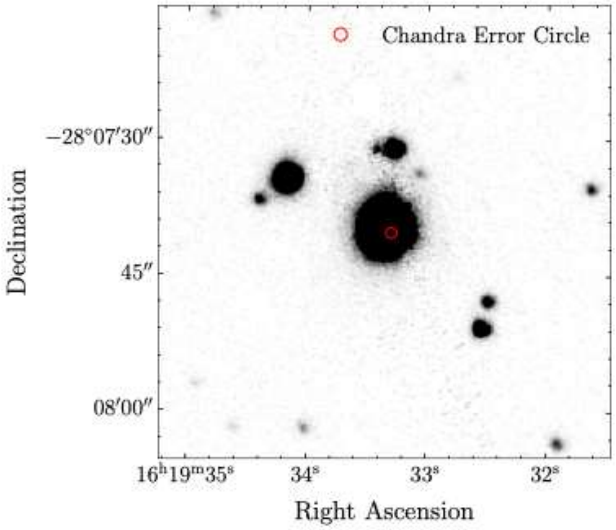
Credit: ESA

Outline

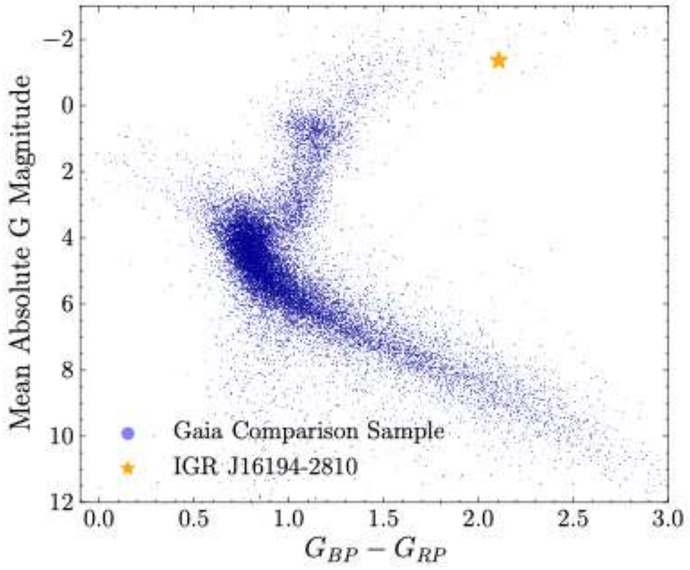
- Characterizing the SyXB IGR J16194-2810
- Formation History and Future Evolution
- Connection to wide main sequence + NS binaries discovered in *Gaia* DR3

IGR J16194-2810

- Discovered by Bird et al. (2006) in the *INTEGRAL* catalog and classified as a SyXB by Masetti et al. (2007)
- Studied extensively in X-ray with *Swift, Chandra, Suzaku, NuSTAR*… but only recently studied in detail in the optical!

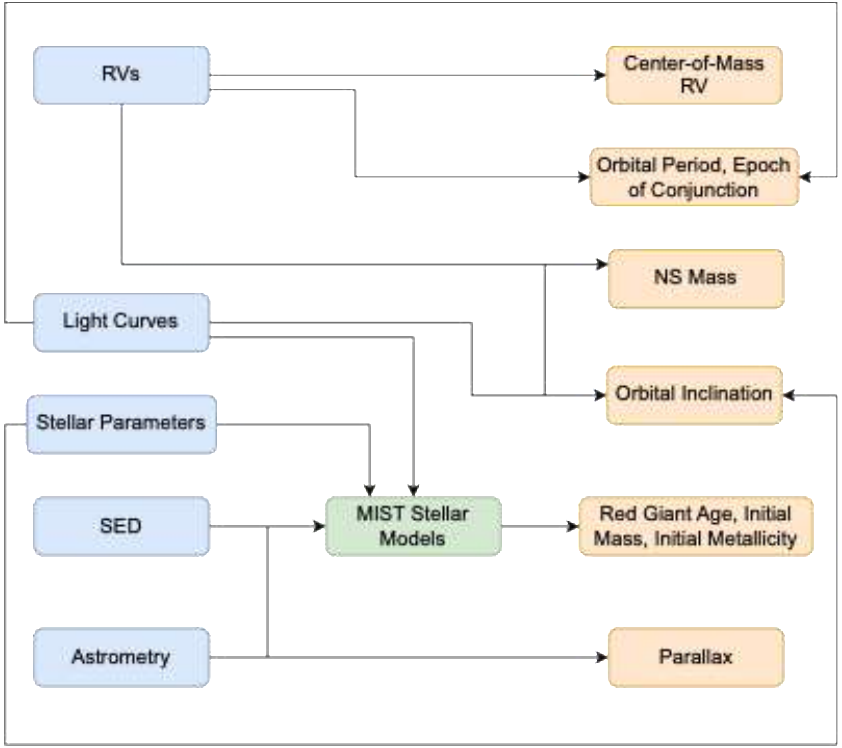


From *Gaia* DR3:
$P(\text{Chance alignment}) < 3 \times 10^{-6}$



Joint Fitting with MCMC

Observed Data



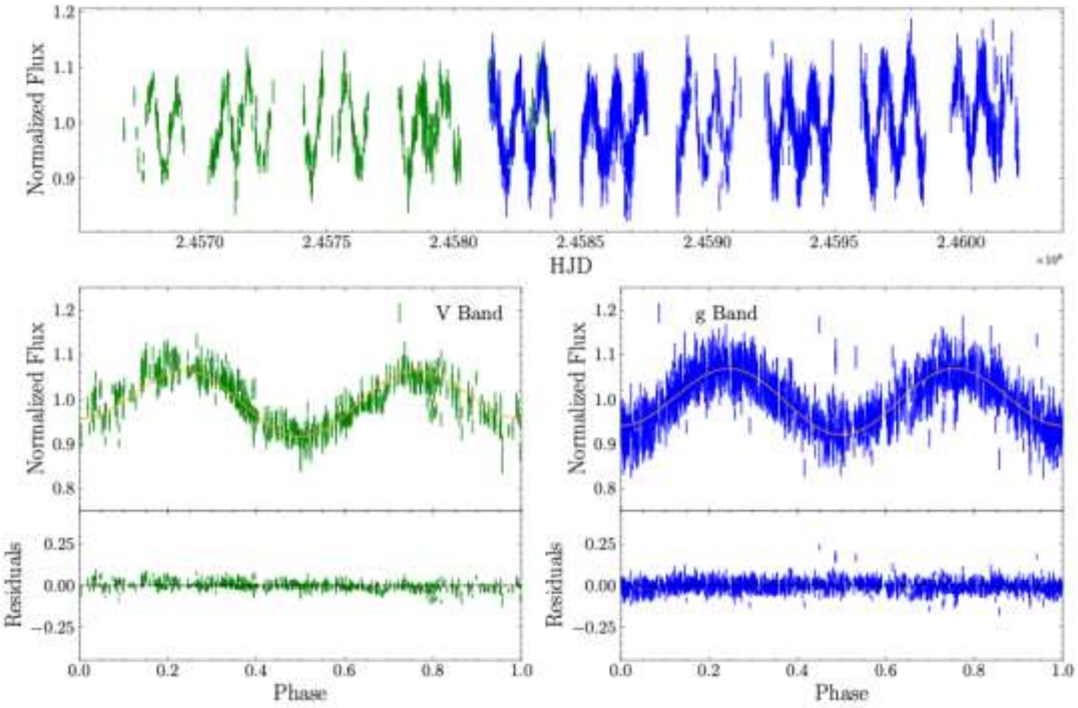
Free Parameters

ASAS-SN Light Curves

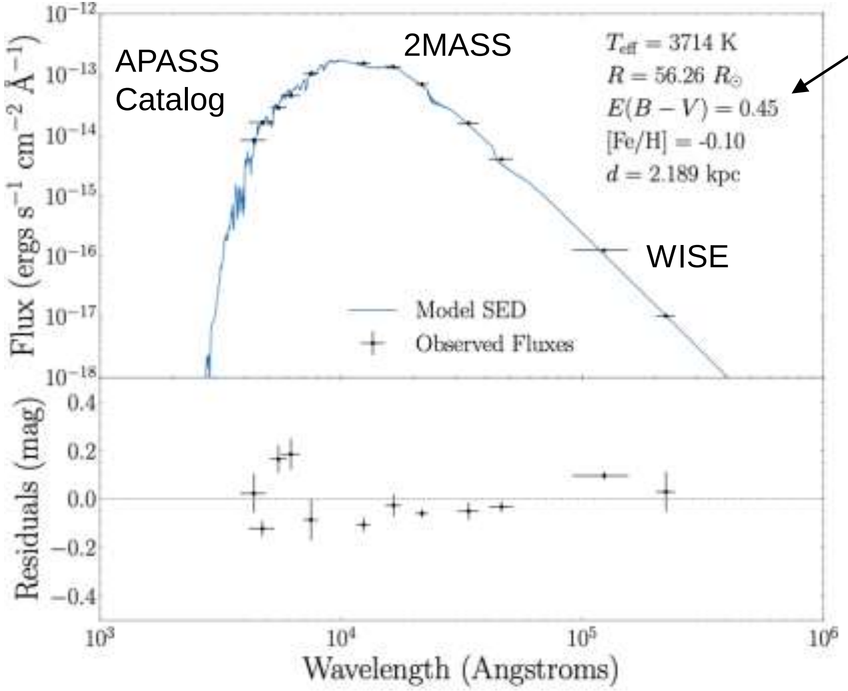
- Clear ellipsoidal modulation with dominant period of ~ 96 days

$$F = \bar{F} + \sum_{i=1}^{2} A_i \cos\left(\frac{2\pi i(t - T_0)}{P}\right)$$

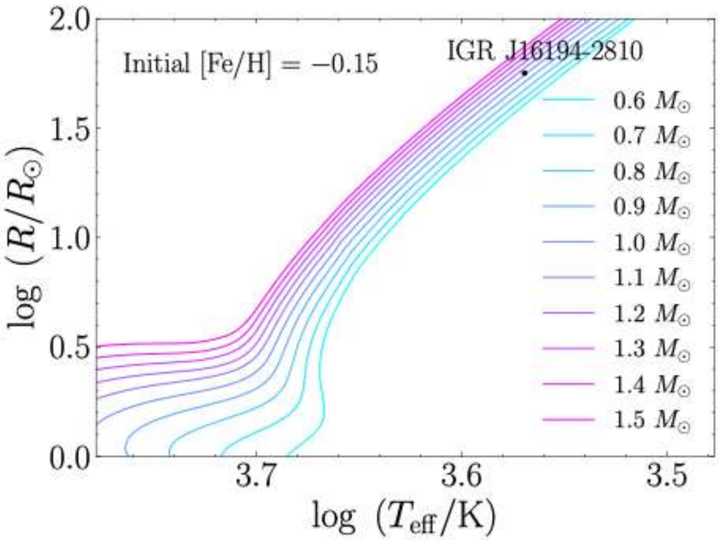
A_2 is the dominant component!



Spectral Energy Distribution



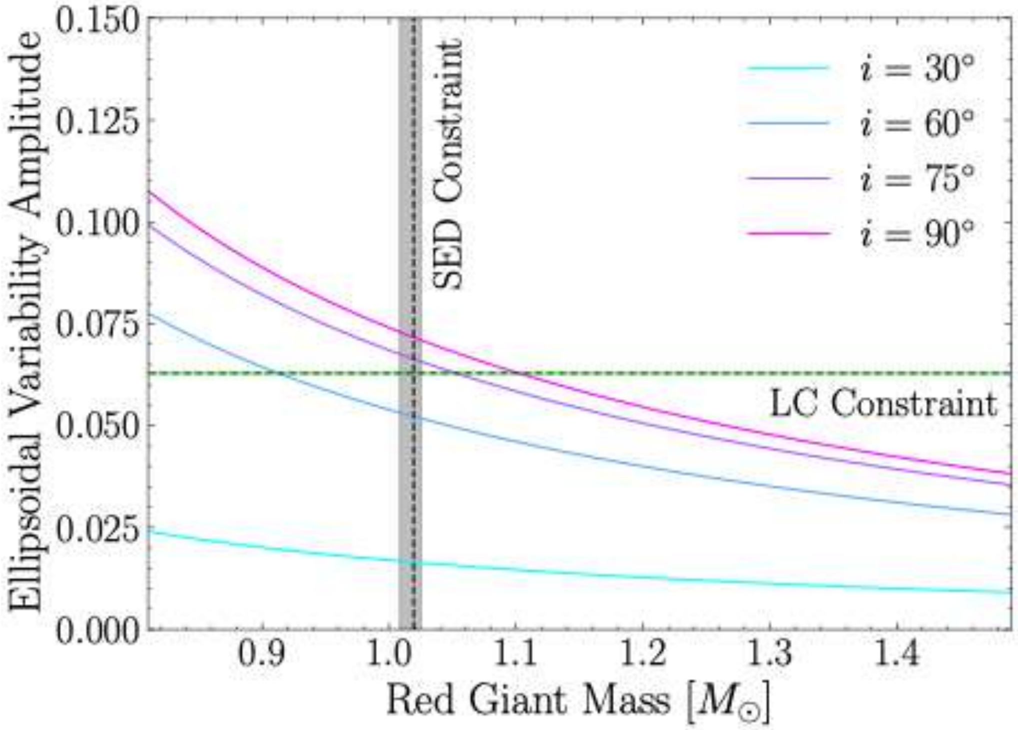
3D Dust Map of Green et al. (2019)
Assume $R_V = 3.1$ for extinction



Model SEDs: `pystellibs`
Synthetic photometry: `pyphot`

Using best-fit $T_{\rm eff}$ and R, MIST models imply an initial mass of $1.0 - 1.1\ M_\odot$ at an initial $[{\rm Fe/H}] = -0.15$

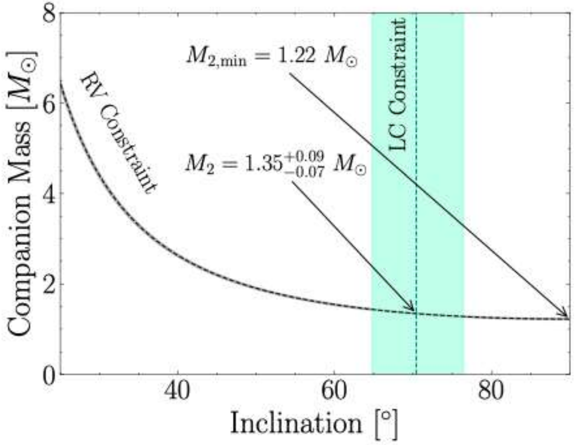
Ellipsoidal Variability

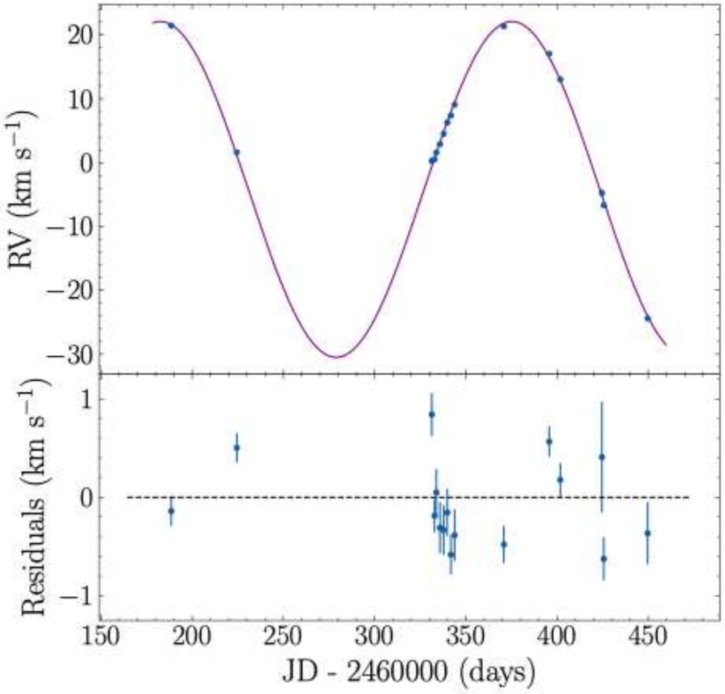


$R_{\rm RG}$ fixed to $56.26\ R_\odot$ (best-fit value from SED)

Radial Velocities

- We observed IGR 1619-2810 16 times with the FEROS spectrograph (R = 50,000 over 350-920 nm)
- We calculate RVs by cross-correlating each order with a model spectrum from the `BOSZ` library (T_{eff} = 3750 K, $\log g$ = 1.5, solar metallicity)



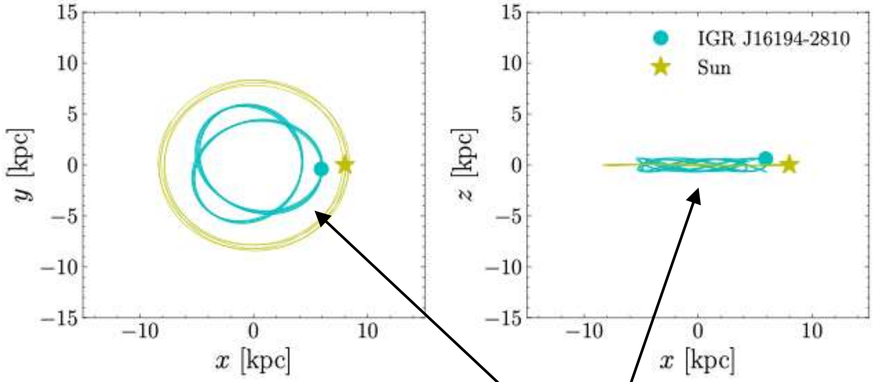


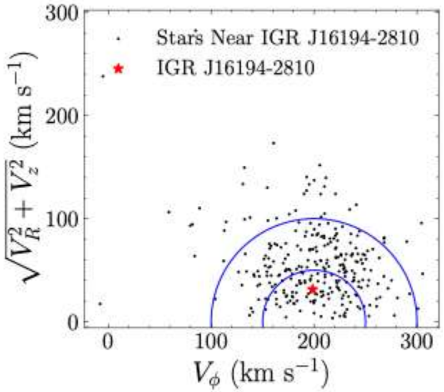
$$\mathrm{RV}(t) = \gamma - K \sin\left(\frac{2\pi(t - T_0)}{P}\right)$$

Galactic Orbit

- We use `galpy` to integrate the galactic orbit back in time by 1 Gyr, using:
    - *Gaia* DR3 proper motions
    - Best-fit parallax and center-of-mass RV
    - Milky Way gravitational potential from `gala`

- From a Toomre diagram, we find the space velocity to be consistent with nearby stars having:
    - Coordinates within 1°
    - Parallaxes within 1 mas
    - Robust Gaia RVs





Less circular, puffier orbit (natal kick?)

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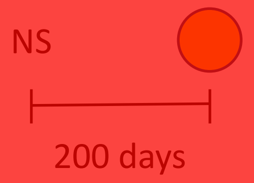
Formation History

- Wide orbits of SyXBs present a challenge for binary evolution modeling
    1. Survived common-envelope evolution (donor-to-accretor mass ratio > 10) without suffering dramatic orbital shrinkage



Formation History

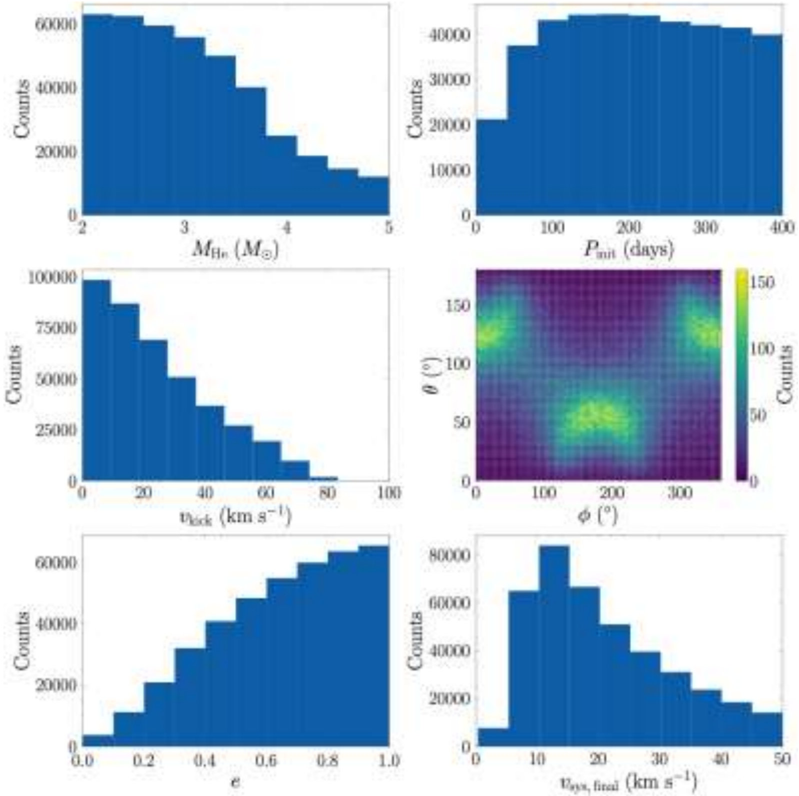
- Wide orbits of SyXBs present a challenge for binary evolution modeling
  2. Natal kick of NS, combined with mass loss from supernova, should unbind the binary

- We simulate 10^7 random orbital configurations and retain bound systems with $\mathrm{P}_{\mathrm{final}} > 193$ days

$$M_{\mathrm{He}} \in [2\ M_\odot, 5\ M_\odot] \quad M_{\mathrm{NS}} = 1.4\ M_\odot \quad M_{\mathrm{RG}} = 1.0\ M_\odot$$

$$v_{\mathrm{kick}} \in [0\ \mathrm{km\ s^{-1}}, 500\ \mathrm{km\ s^{-1}}] \quad P_{\mathrm{init}} \in [0.1\ \mathrm{d}, 400\ \mathrm{d}]$$

$$v_{\mathrm{sys,\ final}} < 50\ \mathrm{km\ s^{-1}}$$



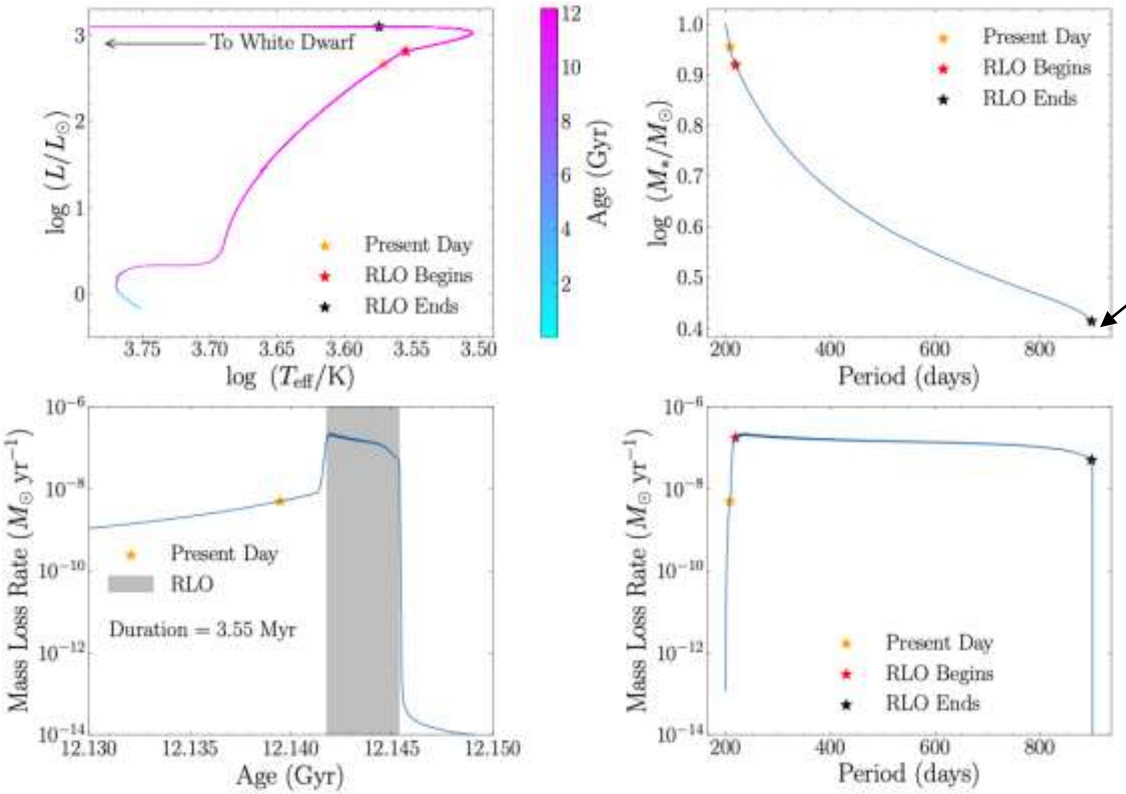
Future Evolution

MESA modeling!

$M_{\mathrm{NS}} = 1.4\ M_\odot$

$M_* = 1.0\ M_\odot$

$P_{\mathrm{init}} = 200$ d



0.4 $M_\odot$ He WD

cf. longest-period WD + MSP binaries

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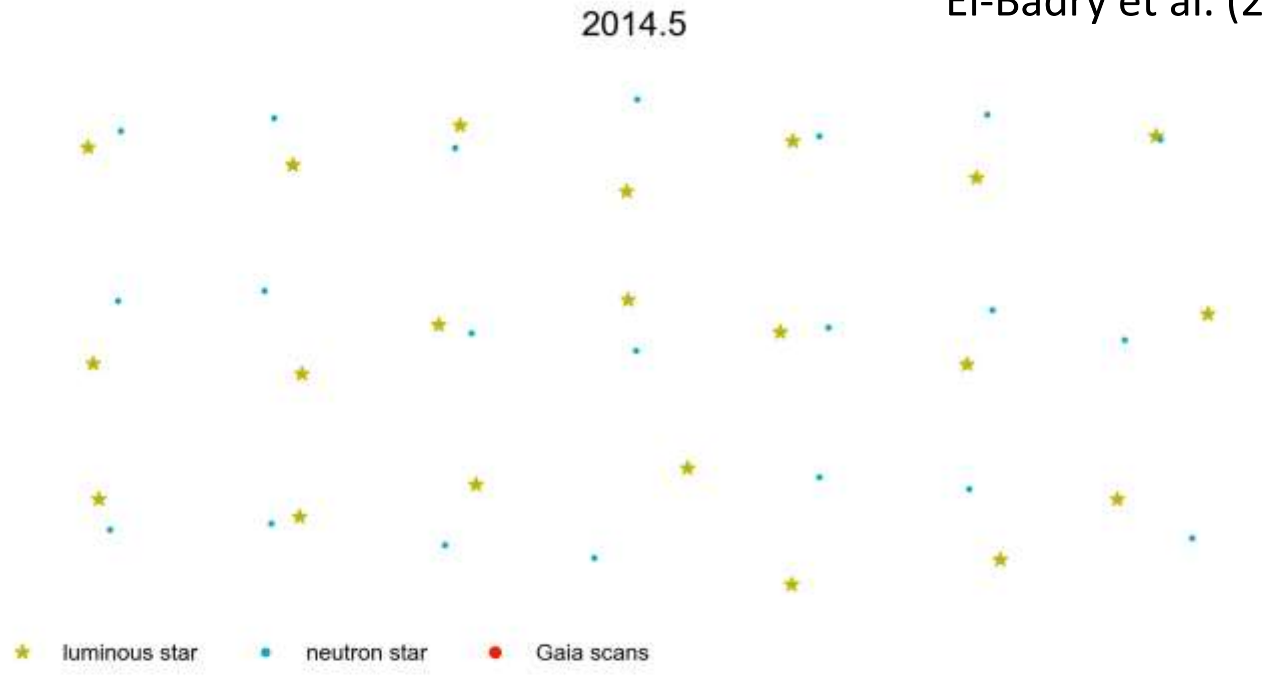
Comparison to *Gaia* NS Population

El-Badry et al. (2024)



Comparison to *Gaia* NS Population

	SyXBs	*Gaia* NS + MS Binaries	Conclusion
Nearest member with $P_{orb} \lesssim 1000$ days	IGR J16194-2810 ($d = 2.1$ kpc)	J2145+2837 ($d = 250$ pc)	SyXB space density 100x lower
Detectable lifetime	About 10 Myr	$3\text{–}10$ Gyr	Comparable birth rates

Thus, most SyXBs are descendants of the wide NS + MS binaries revealed by *Gaia!*

Conclusions

- By jointly fitting the red giant's LC, RVs, and SED, we derive an orbital period of $192.73 \pm 0.01\ \mathrm{days}$ and a companion mass of $1.35^{+0.09}_{-0.07}\ M_{\odot}$, dynamically confirming the NS.
- From simulations of the system's formation history, we find that the majority of would-be SyXBs become unbound during the supernova, and only systems born with relatively weak kicks survive.
- We simulate the binary's future evolution with MESA. Following Roche lobe overflow, the system will end up as a $\sim 0.4\ M_{\odot}$ He WD orbiting the NS in a $\sim 900\ \mathrm{d}$ orbit.
- Since SyXBs are likely the descendants of the wide NS + MS binaries discovered in *Gaia* DR3, IGR J16194-2810 sheds new light on the connection between these rare systems.