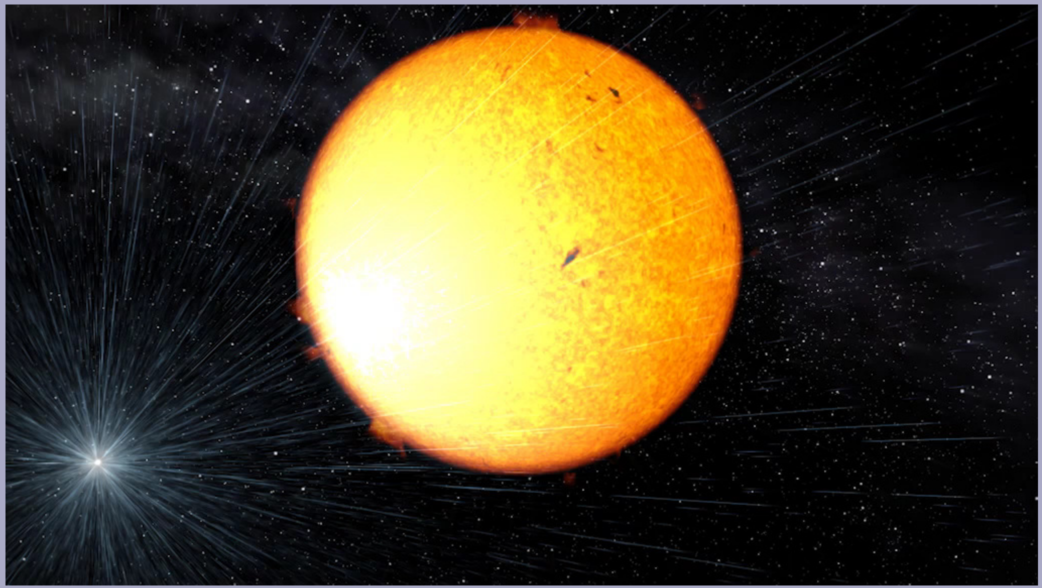
A 2.3 Solar-mass Neutron Star



IAC/Perez-Diaz

Manu Linares (GAA@UPC, Barcelona)
Tariq Shahbaz, Jorge Casares (IAC, Tenerife)

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UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

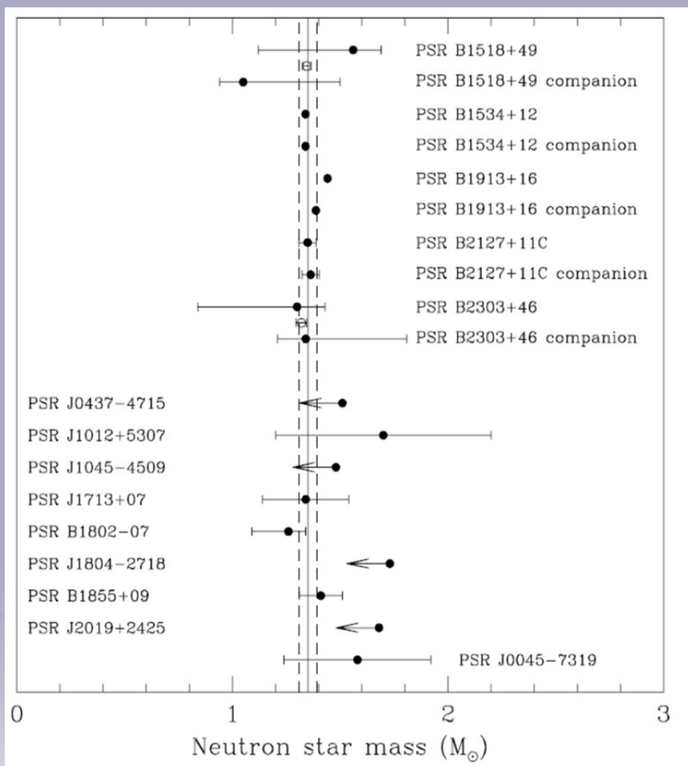
WHAT IS THE MAXIMUM MASS OF A NEUTRON STAR?

Nuclear physics: Set by EoS in the core, where $\rho_{core} > \rho_{nuc}$ (~2 x 10^{14} g/cm^3)

Astronomy: Neutron star mass measurements (binary pulsars)

Neutron Star Mass

Mass Distribution



Thorsett & Chakrabarty (1999, ApJ)

21+5 radio PSRs: 1.35 +/- 0.04 Msun

Demorest/Fonseca 2010-16:

→ 1.93+/-0.02 Msun

(J1614-2230, WD, Porb=8.7 d)

- Antoniadis+ 2013:

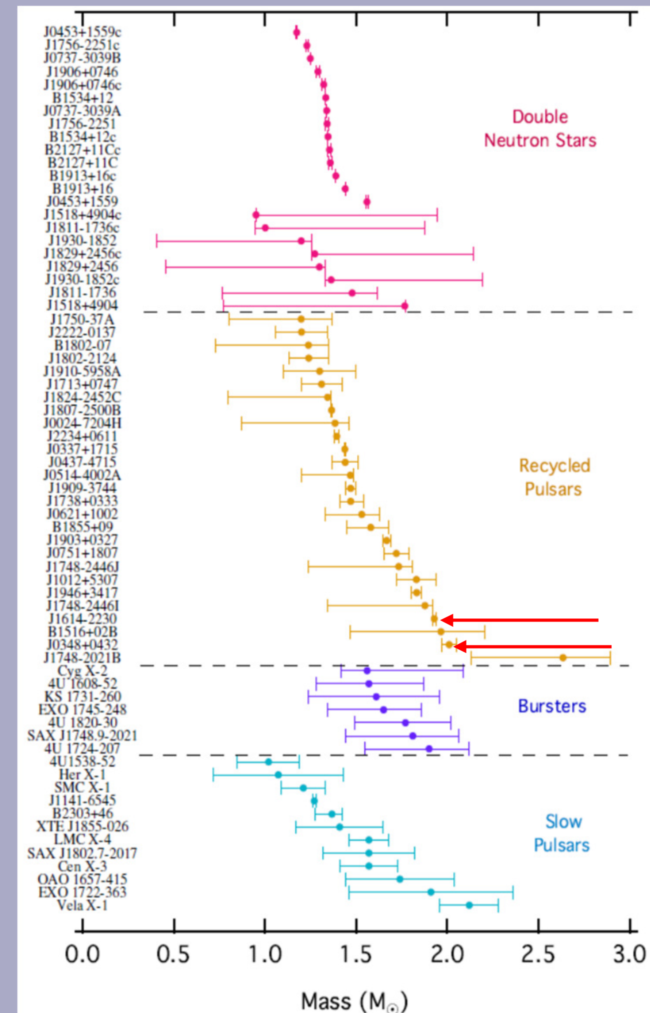
→ 2.01+/-0.04 Msun

(J0348+0432, WD, Porb=2.46 hr)

- van Kerkwijk+ 2011:

2.40+/-0.12 Msun

(B1957+20, BW, P_{orb}=9.2 hr)



Özel & Freire (2016, ARAA)

35-68 NSs in the 1.2-2.0 Msun range

Neutron stars in binaries

What is the maximum neutron star mass?

Bogdanov

Compact binary millisecond pulsars
(blackwidows, BWs; redbacks, RBs):

- Rotation-powered MSP, wind, gamma-rays

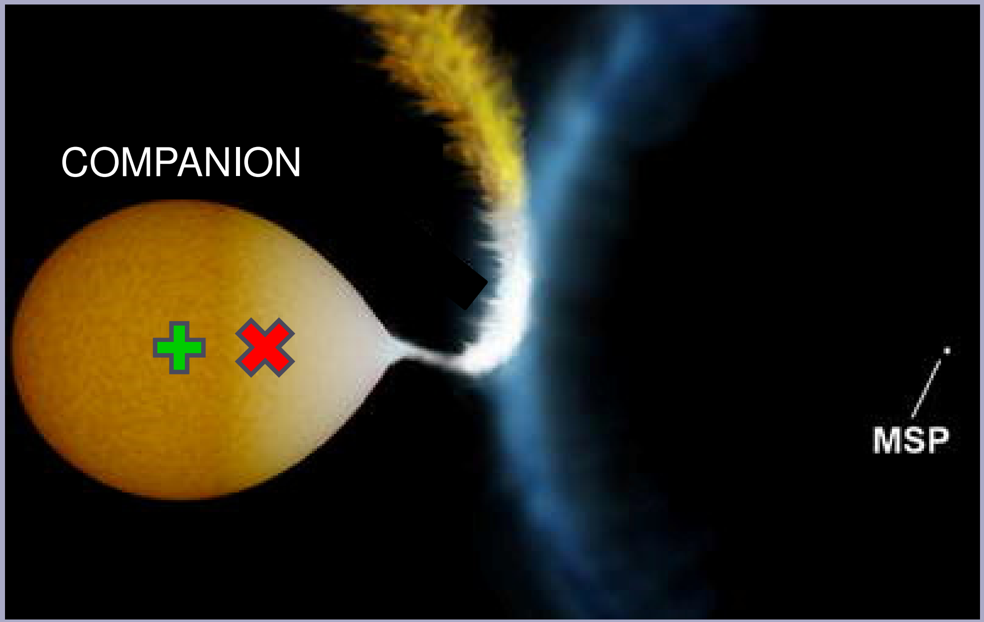
(spin-down luminosity: 10^{34}-10^{35} erg/s)

- Non/semi-degenerate companion star

(low/very-low mass, RBs/BWs: ~0.01-0.5 M_{Sun})

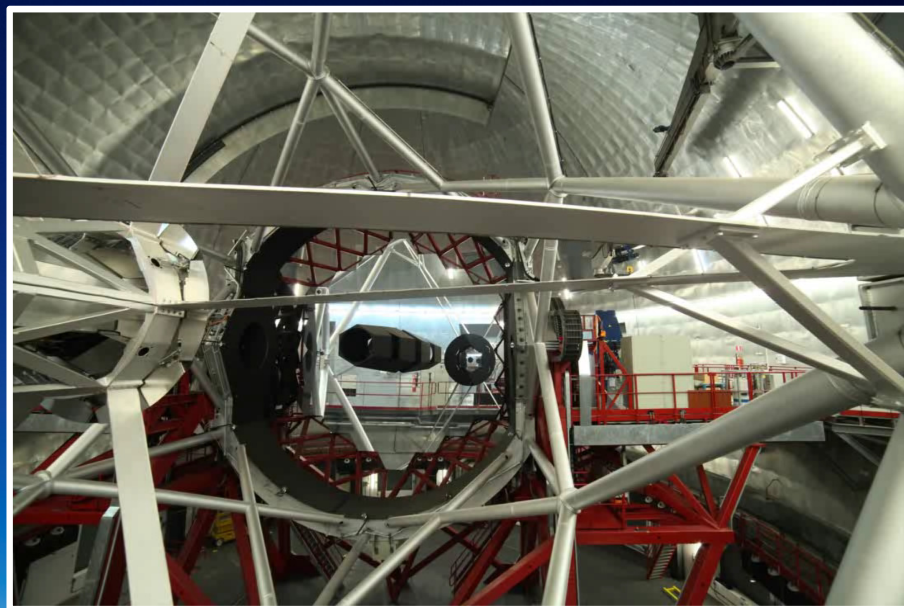
- Compact orbit

(P_{orb} <~ 1 day)



•ACCRETING PAST: INCREASED MASS
(Alpar+ 1982; van Keerkwijk+ 2011, Kaplan+ 2013)

•CLEAN VIEW OF (IRRADIATED) COMPANION
(measure mass: must account for irradiation)



PSR J2215+5135:
4.14 hr orbit
Irradiated MS companion
Massive NS?

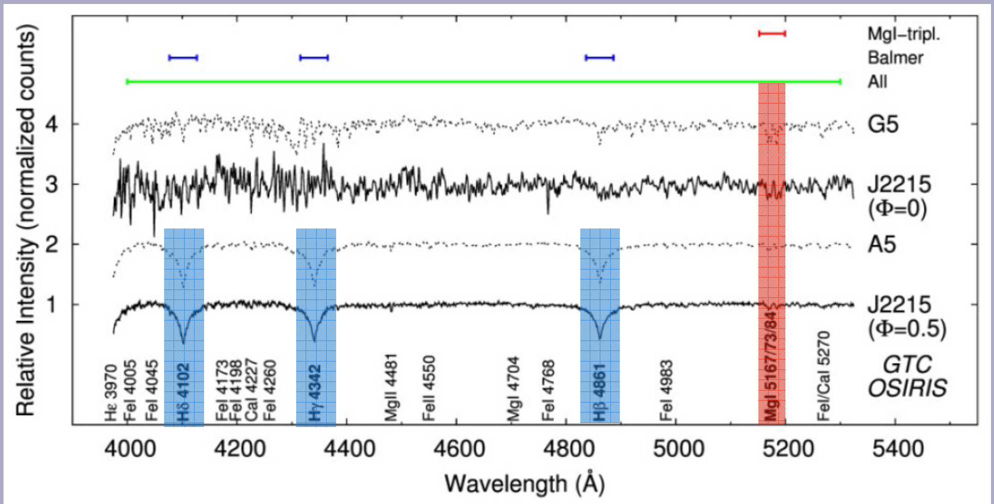
Breton+'13
Schroeder&Halpern'14
Romani+'15,16

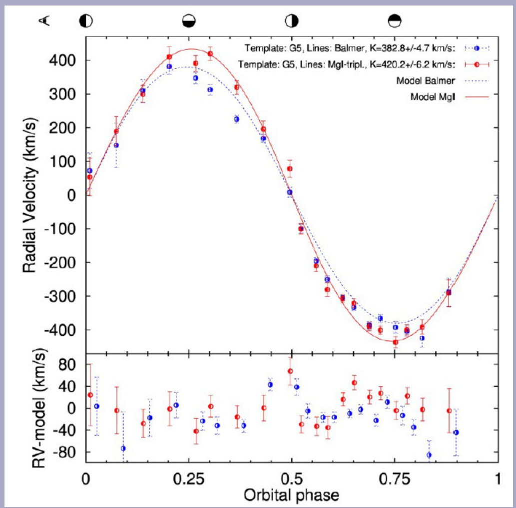
IAC/Rosenberg

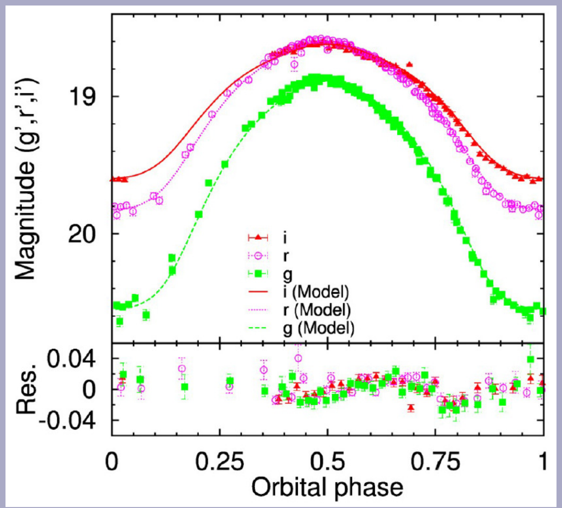
Gran Telescopio CANARIAS (10.4 m)
+WHT, IAC80

A Massive Neutron Star

Dynamical Studies with Irradiation: PSR J2215+5135







T_N=5660 +/- 320 K

T_D =8080 +/- 375 K

K_{Balmer} = 382.8 +/- 4.7 km/s

K_{Mg} = 420.2 +/- 6.2 km/s

K_2 = 412.3 +/- 5.0 km/s

M_{NS} = 2.27 +/- 0.16 M_{Sun}

M_2 = 0.33 +/- 0.03 M_{Sun}

i = 63.9º +/- 2.5º

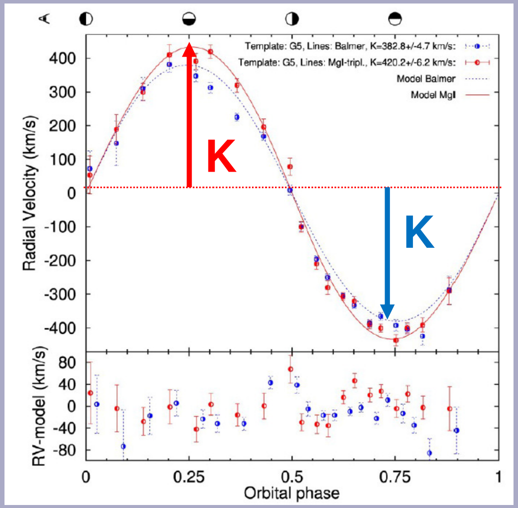
1) Extreme heating by pulsar wind: from G5 (cold/night side) to A5 (hot/day side)!

2) Trace the velocity of both sides using different absorption lines (H vs Mg)

3) Physical model to find inclination and masses (incl. constr. on T_D, T_N and $q = M_2/M_1 = K_2 P_{orb} / 2\pi x_1 c$)

A Massive Neutron Star

Peering into the dark side of the companion



A NEW METHOD TO MEASURE MASS:

'Empirical' K correction, bracket center of mass!

K_{Balmer} = 382.8 +/- 4.7 km/s

K_{Mg} = 420.2 +/- 6.2 km/s

K_2 = 412.3 +/- 5.0 km/s

2) Trace the velocity of both sides using different absorption lines (H vs Mg)

A Massive Neutron Star

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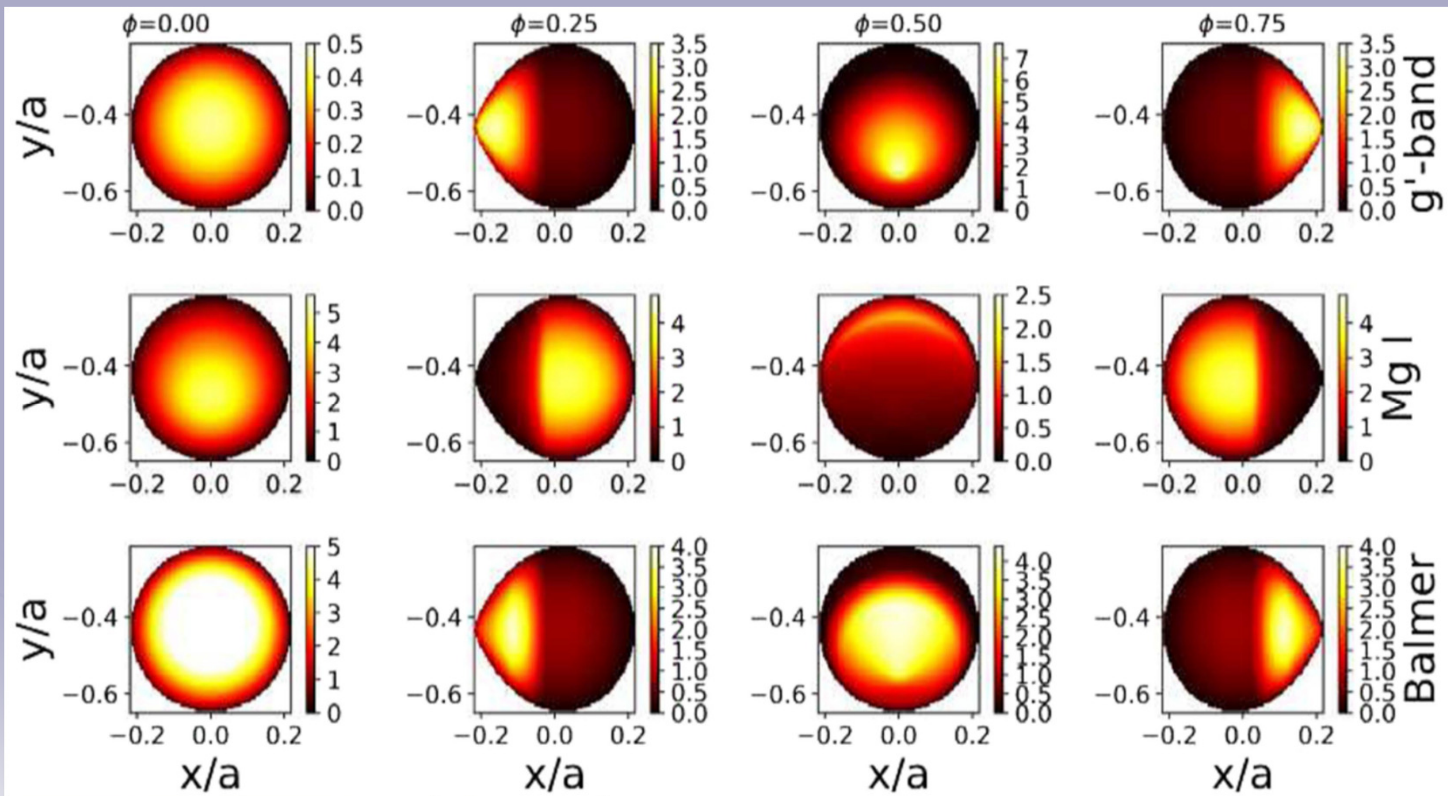

COLD SIDE
inferior
conjunction

ASCENDING
NODE
quadrature

HOT SIDE
superior
conjunction

DESCENDING
NODE
quadrature

K_{Mg}

K_{Balmer}

A NEW METHOD TO MEASURE MASS:

Looking at the irradiated companion star with new eyes.

Magnesium and hydrogen radial velocities carefully modelled, taking into account varying line strength

A Massive Neutron Star

A 2.3 Solar-mass neutron star in PSR J2215+5135

THE ASTROPHYSICAL JOURNAL, 859:54 (14pp), 2018 May 20 https://doi.org/10.3847/1538-4357/aabde6

Peering into the Dark Side: Magnesium Lines Establish a Massive Neutron Star in PSR J2215+5135

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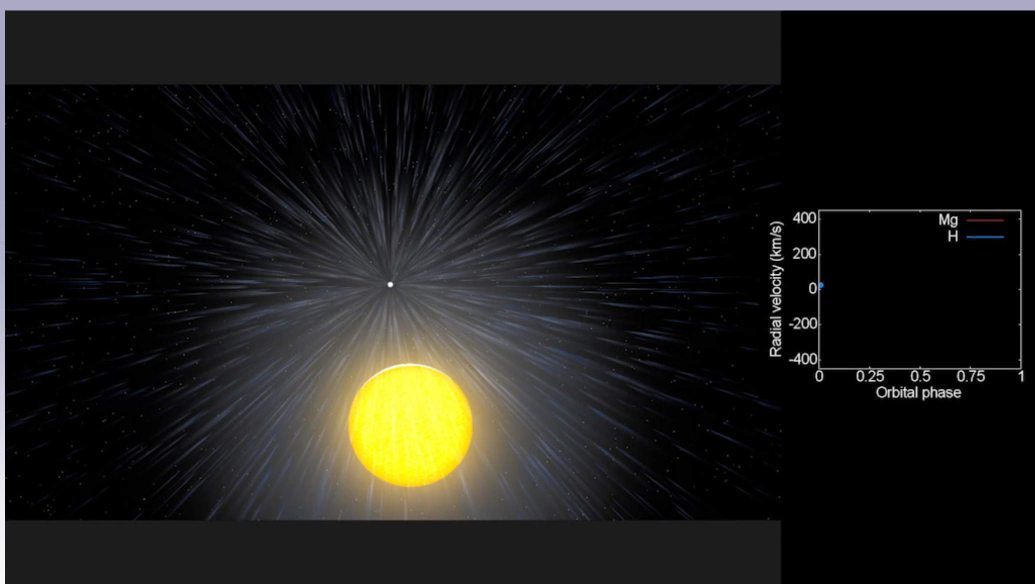
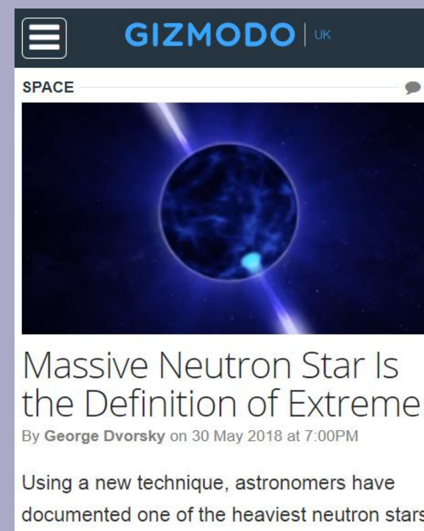


IAC/Perez-Diaz, Hynes

→ **A 2.27 [+0.17-0.15] M_{sun} Neutron Star!**

(Linares, Shahbaz & Casares 2018, ApJ, 859, 54)

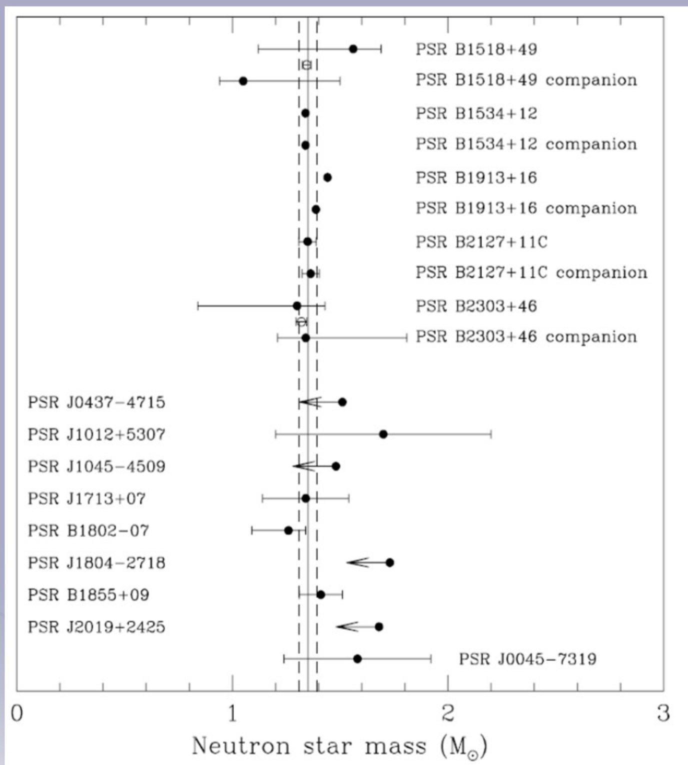


Next:

- **Independent & tighter inclination measurements**
- **Find more (massive?) pulsars (in edge-on orbits?)**

Neutron Star Mass

Mass Distribution



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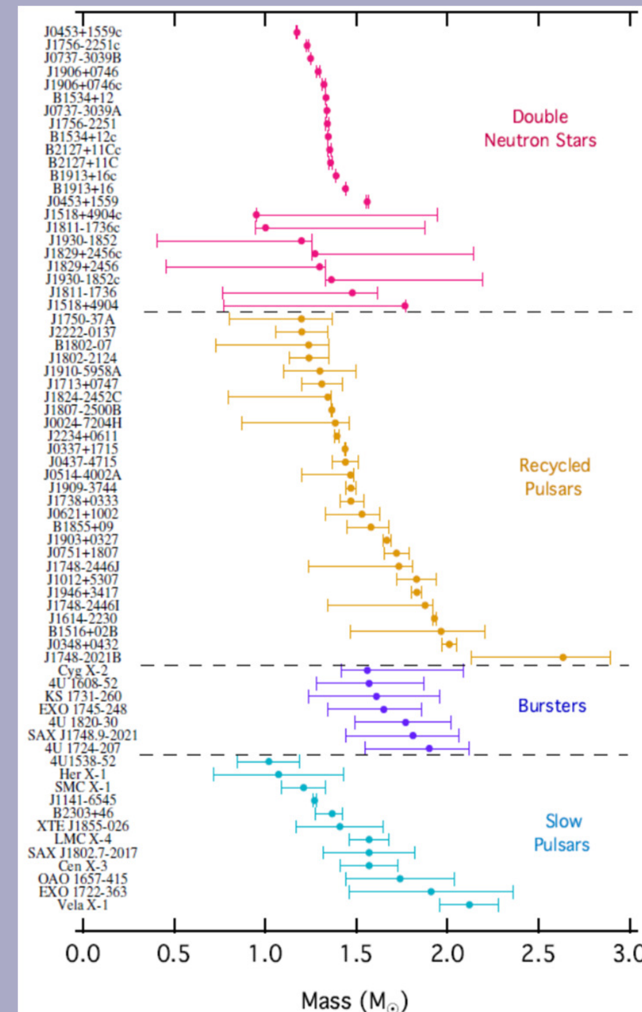

Özel & Freire (2016, ARAA)
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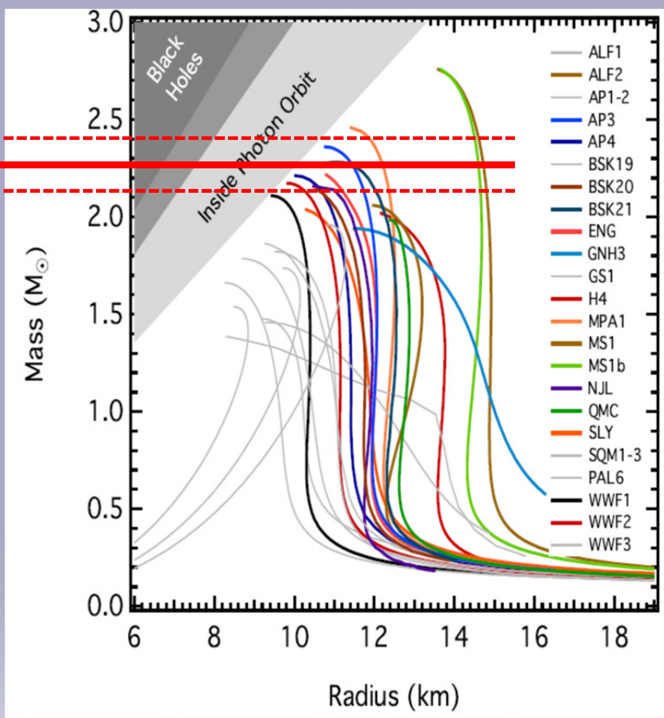
A Massive Neutron Star

Impact on nuclear physics and GW astronomy



Özel & Freire (2016)

EQUATION OF STATE:

Only a 'stiff' EoS can support 2.3 Msun (hyperons or deconfined quarks don't seem able to)

NS MERGERS:

Can they lead to a massive neutron star? (immediate remnant and e.m. emission sensitive to Mtotal / Mmax; e.g. 2.74/2.27 = 1.2)

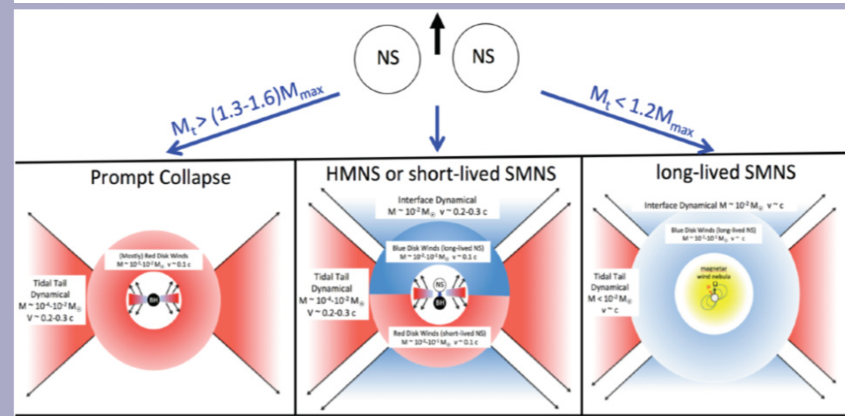
e.g. M_{max}<2.17 (90%)
Margalit & Metzger (2017)

Properties of the binary neutron star merger GW170817

The LIGO Scientific Collaboration, the Virgo Collaboration, B. P. Abbott, R. Abbott, T. D. Abbott, F. Acernese, K. Ackley, C. Adams, T. Adams, P. Addesso, R. X. Adhikari, V. B. Adya, C. Affeldt, B. Agarwal, M. Agathos, K. Agatsuma, N. Aggarwal, O. D. Aguiar, L. Aiello, A. Ain, P. Ajith, B. Allen, G. Allen, A. Allocca, M. A. Aloy, P. A. Altin, A. Amato, A. Ananyeva, S. B. Anderson, W. G. Anderson, S. V. Angelova, S. Antier, S. Appert, K. Arai, M. C. Araya, J. S. Areeda, M. Ar`ene, N. Arnaud, K. G. Arun, S. Ascenzi, G. Ashton, M. Ast, S. M. Aston, P. Astone, D. V. Atallah, F. Aubin, P. Aufmuth, C. Aulbert, K. AultONeal, C. Austin, A. Avila-Alvarez, S. Babak, P. Bacon, F. Badaracco, M. K. M. Bader, S. Bae, P. T. Baker, F. Baldaccini, G. Ballardin, S. W. Ballmer, S. Banagiri, J. C. Barayoga, et al. (1088 additional authors not shown)

(Submitted on 29 May 2018)

On August 17, 2017, the Advanced LIGO and Advanced Virgo gravitational-wave detectors observed a low-mass compact binary inspiral. The initial sky localization of the source of the gravitational-wave signal, GW170817, allowed electromagnetic observatories to identify NGC 4993 as the host galaxy. In this work we improve initial estimates of the binary's properties, including component masses, spins, and tidal parameters, using the known source location, improved modeling, and re-calibrated Virgo data. We extend the range of gravitational-wave frequencies considered down to 23 Hz, compared to 30 Hz in the initial analysis. We also compare results inferred using several signal models, which are more accurate and incorporate additional physical effects as compared to the initial analysis. We improve the localization of the gravitational-wave source to a 90% credible region of $16\ \mathrm{deg}^2$. We find tighter constraints on the masses, spins, and tidal parameters, and continue to find no evidence for non-zero component spins. The component masses are inferred to lie between 1.00 and 1.89 $M_\odot$ when allowing for large component spins, and to lie between 1.16 and 1.60 $M_\odot$ (with a total mass $2.73^{+0.04}_{-0.01}\ M_\odot$) when the spins are restricted to be within the range observed in Galactic binary neutron stars. Under minimal assumptions about the nature of the compact objects, our constraints for the tidal deformability parameter $\tilde{\Lambda}$ are $(0, 630)$ when we allow for large component spins, and 300^{+420}_{-230} (using a 90% highest posterior density interval) when restricting the magnitude of the component spins, ruling out several equation of state models at the 90% credible level. Finally, with LIGO and GEO600 data, we use a Bayesian analysis to place upper limits on the amplitude and spectral energy density of a possible post-merger signal. (Abridged)

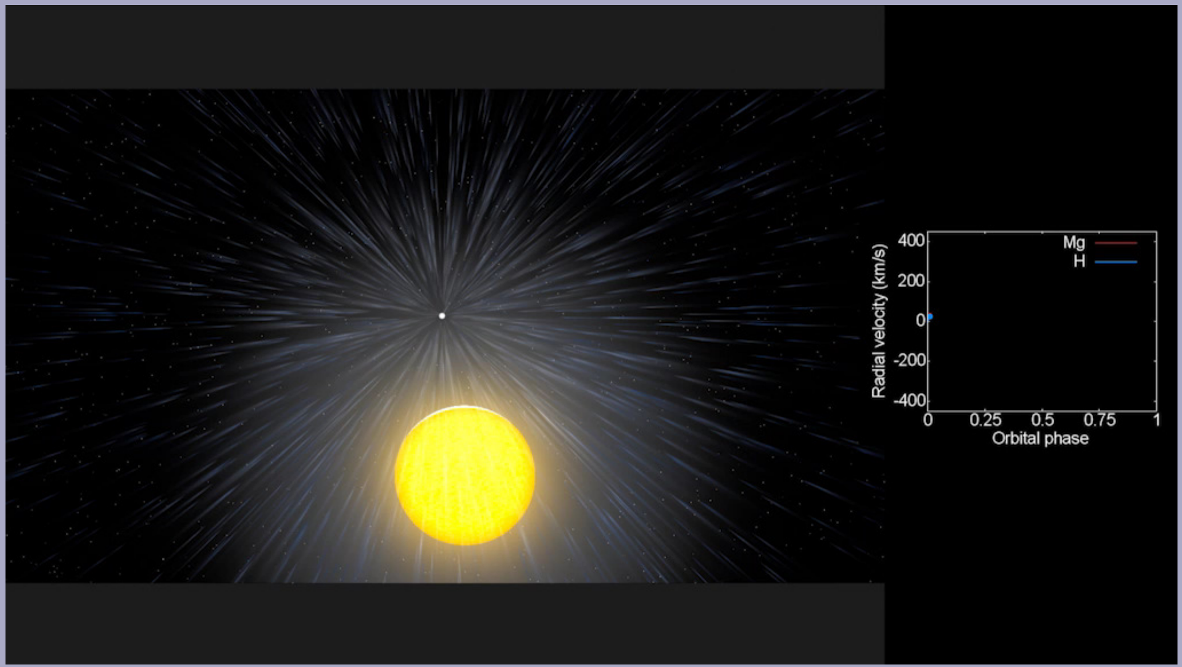


Margalit & Metzger (2017)

Summary

A 2.3 Solar-mass neutron star

- WHERE: PSR J2215+5135
- HOW: GTC, WHT, IAC80, MODELS
- KEY: IRRADIATION
- NEW: EMPIRICAL K CORRECTION
- IMPACT: EoS, GW NS+NS, …
- FUTURE: INDEPENDENT INCLINATION
- FUTURE: MORE (irradiated) SYSTEMS



NS+NS MERGERS:

Can they lead to a long-lived massive neutron star?