Application of the Accretion Torque Model to the X-ray Binary Pulsar A 0535+262

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Abstract

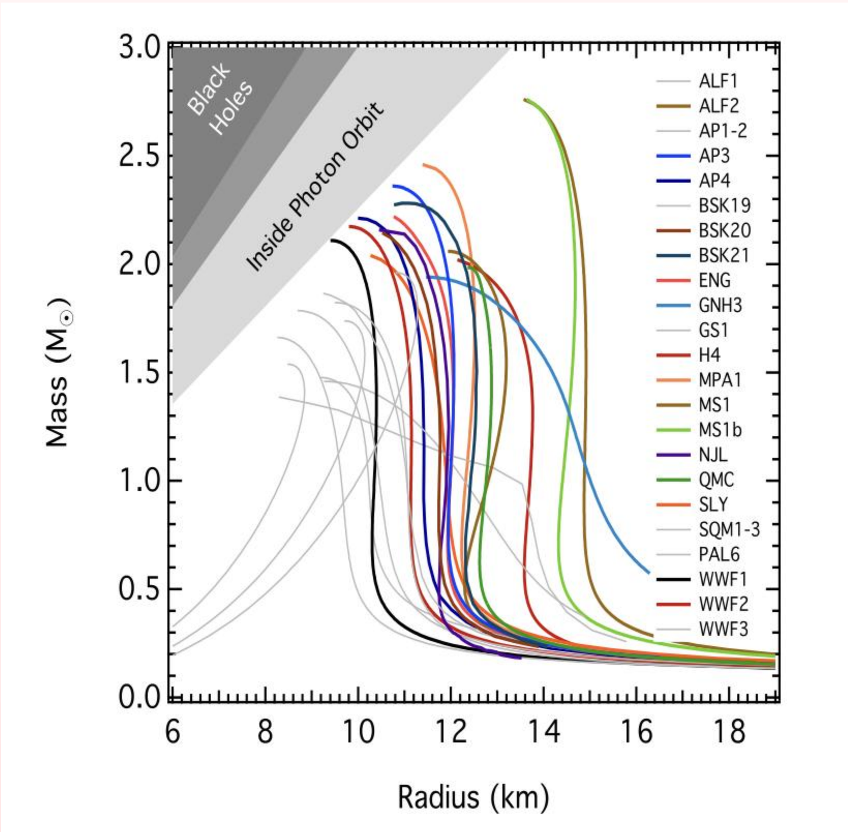
We studied how the neutron star's spin changes with the mass accretion rate in the X-ray binary pulsar A 0535+262. Using the long-term light curve obtained with the MAXI/GSC and the time variation of the pulse period from the Fermi/GBM, we found a clear anti-correlation between the bolometric luminosity and the period derivative. We applied the accretion torque model proposed by Ghosh and Lamb (1979) to the data. This model predicts the relation between the luminosity and the period derivative considering the physical parameters of the neutron star including the mass and radius, so the application of the model to the data enables us to estimate these parameters. We obtained a neutron star mass of 1.1-1.2 solar mass from the A 0535+262 data. In this presentation, we will present the details of the analysis and results and discuss possible uncertainties in the results produced by the model and the data.

Motivation

Neutron star (NS)
Mass : ~1.4 Mo, Radius : ~12 km
=>Extremely high density

To explain the structure of NSs, many theoretical models of the equation of state (EoS) of superdense nuclear matter has been proposed.

We can constrain the EoS models if we can estimate the mass and radius of neutron stars observationally.



Relations between the mass and radius of a neutron star calculated from the proposed EoSs (Özel et al. 2016).

X-ray binary pulsars

An X-ray binary pulsar consists of a NS and a companion star and show X-ray pulsations due to the spin of the NS.

The pulse period changes by angular momentum transfer during mass accretion from the companion star.

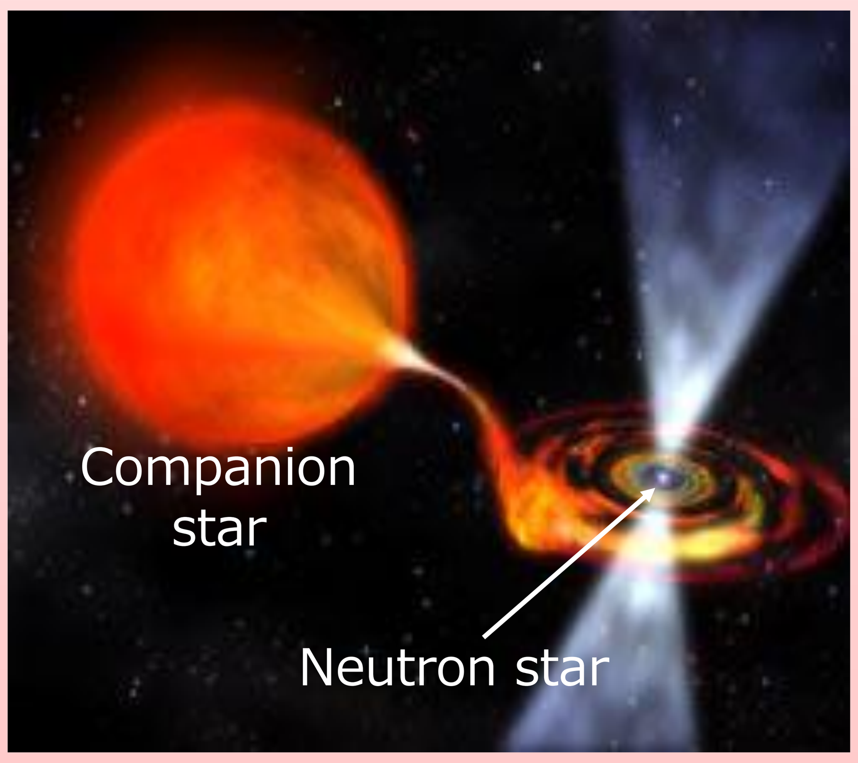
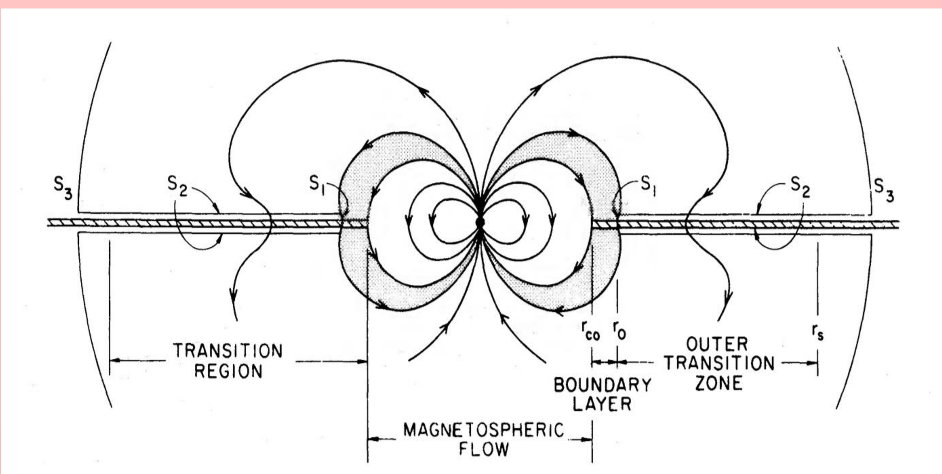


Image of an X-ray binary pulsar.

Accretion torque model

The accretion torque model proposed by Ghosh & Lamb (1979) gives equation between a period derivative $\dot{P}$ and luminosity L.



Edge-on view of the accretion flow (Ghosh & Lamb 1979).

$$\dot{P} = -5.0 \times 10^{-5} \mu_{30}^{\frac{2}{7}} n(\omega_s) R_6^{\frac{6}{7}} \left(\frac{M}{M_\odot}\right)^{-\frac{3}{7}} I_{45}^{-1} P^2 L_{37}^{\frac{6}{7}} \text{ s yr}^{-1}$$

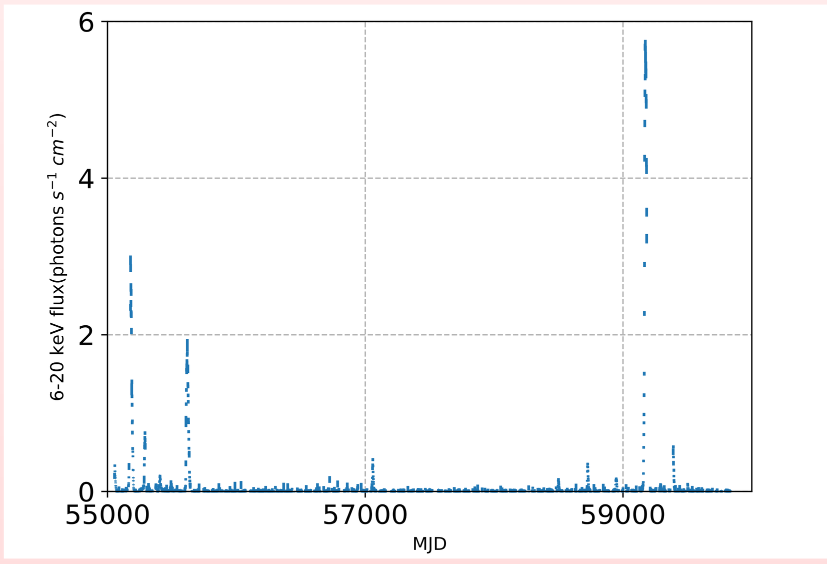
μ_{30}: Magnetic dipole moment in units of 10^{30} G cm^3
R_6: Radius in units of 10^6 cm
I_{45}: Moment of inertia in units of 10^{45} g cm^2
L_{37}: Luminosity in units of 10^{37} erg s^{-1}
ω_s: Ratio of angular velocity of neutron star to accretion gas
$n(\omega_s)$: A dimensionless quantity that is a function of ω_s

The equation includes physical parameters of a NS, such as the mass (M) and radius (R) of the NS.

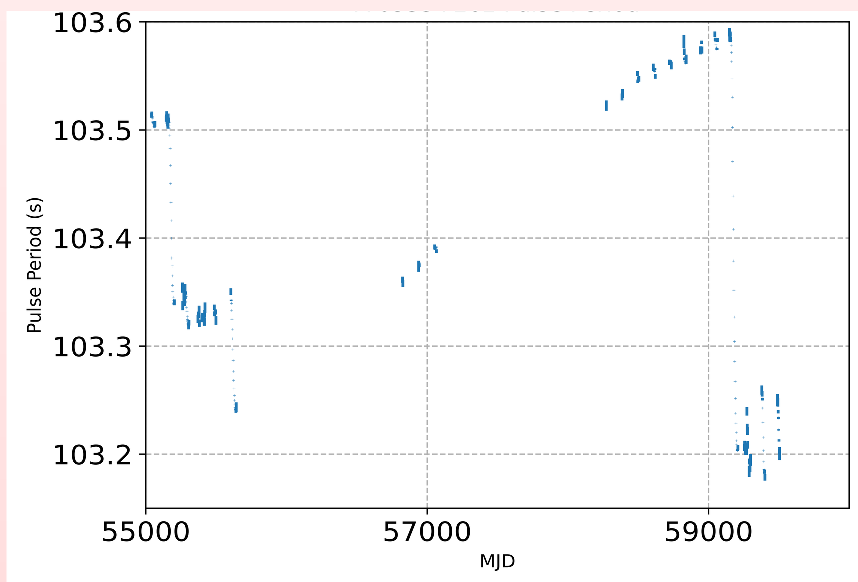
We can estimate the mass and radius of NSs in X-ray binary pulsars using observed correlations ($\dot{P}$ and L).

A 0535+262

A galactic X-ray binary pulsar showing X-ray outbursts with large flux changes.
The MAXI/GSC and Fermi/GBM have been observing the source over 10 years and provided long-term variations of the X-ray flux and pulse periods.
Distance : 2.3 ± 0.3 kpc (Gaia Data Release 2)
Magnetic fiend strength : 4.3 × 10^{12} G (Makishima et al. 1999)



6–20 keV light curve obtained by the MAXI/GSC.

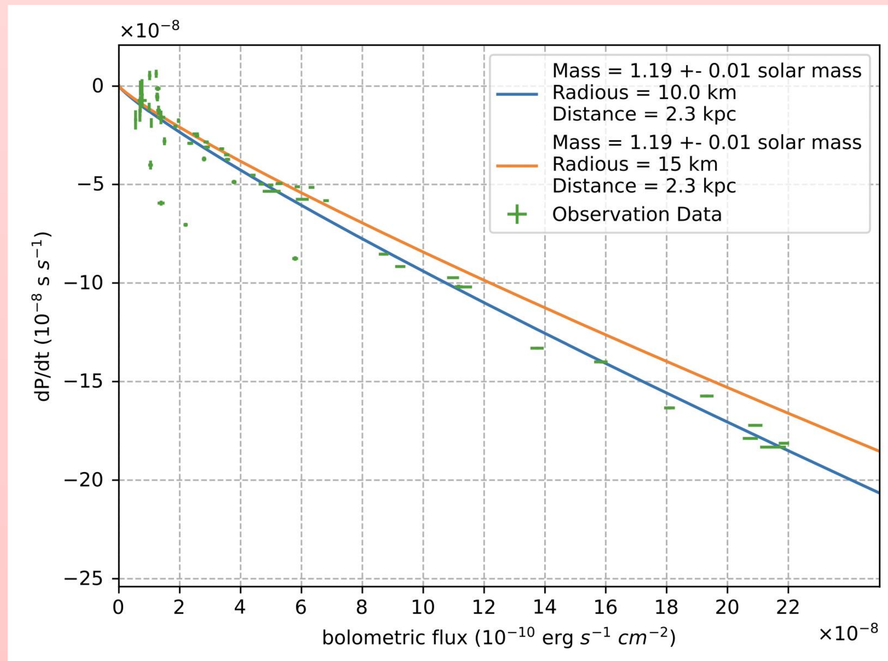


Pulse period obtained by the Fermi/GBM.

Analysis and Results

To apply the Ghosh & Lamb model to the data, we converted the MAXI/GSC 6-20 keV flux to the bolometric flux.
The conversion factor was estimated by the time-averaged MAXI/GSC spectrum over the entire observational period.

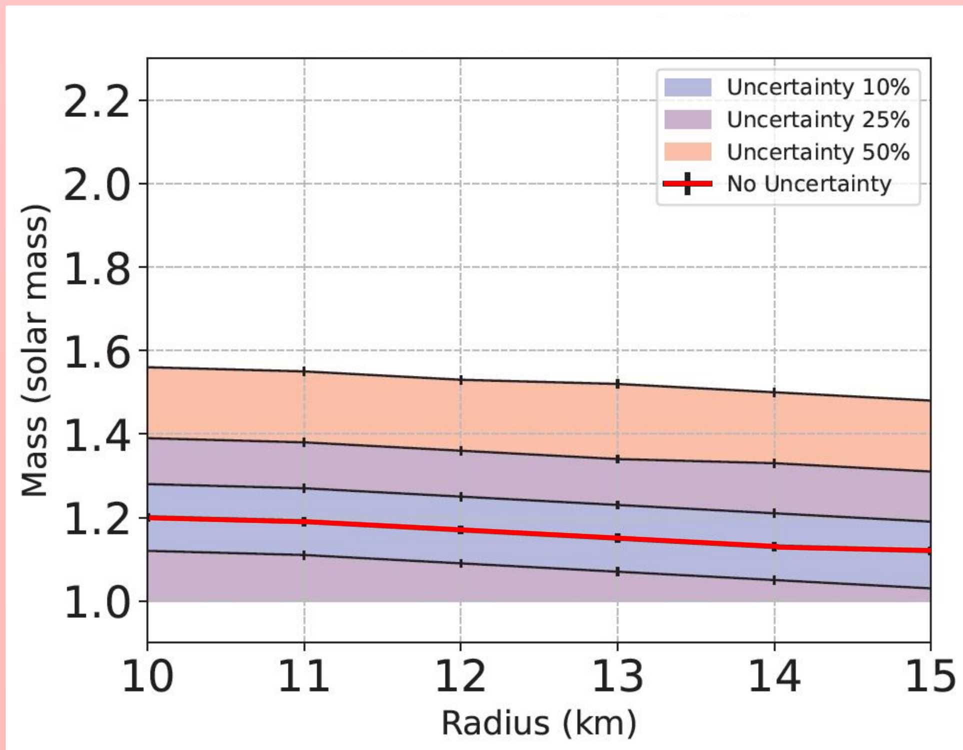
$\dot{P}$ was calculated from two adjacent data points of pulse periods obtained by the Fermi/GBM.



Relation between period derivatives and bolometric flux fitted with the Ghosh & Lamb model.

We applied the Ghosh & Lamb model to the bolometric flux vs. $\dot{P}$ data of A 0535+262, and esitmated a mass and radius of the NS.

We consided the uncertainty in the Ghosh & Lamb model following Sugizaki et al. (2017).



Mass and radius of the NS in A 0535+262 obtained when the Ghosh & Lamb model was assumed to contain 10, 25, and 50 % uncertainties.

The NS in A 0535+262 is likely to have a relatively low mass even if the uncertainty in the model is considered.

References

Ghosh & Lamb (1979), ApJ, 234, 296
Makishima et al. (1999), ApJ, 525, 978
Özel & Freire (2016), ARA&A, 54, 401
Sugizaki et al. (2017), PASJ, 69, 100