Application of the Ghosh and Lamb Accretion Torque Model to the Relation between the Luminosity and Period-derivative of the X-ray Binary Pulsar A 0535+262

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Abstract

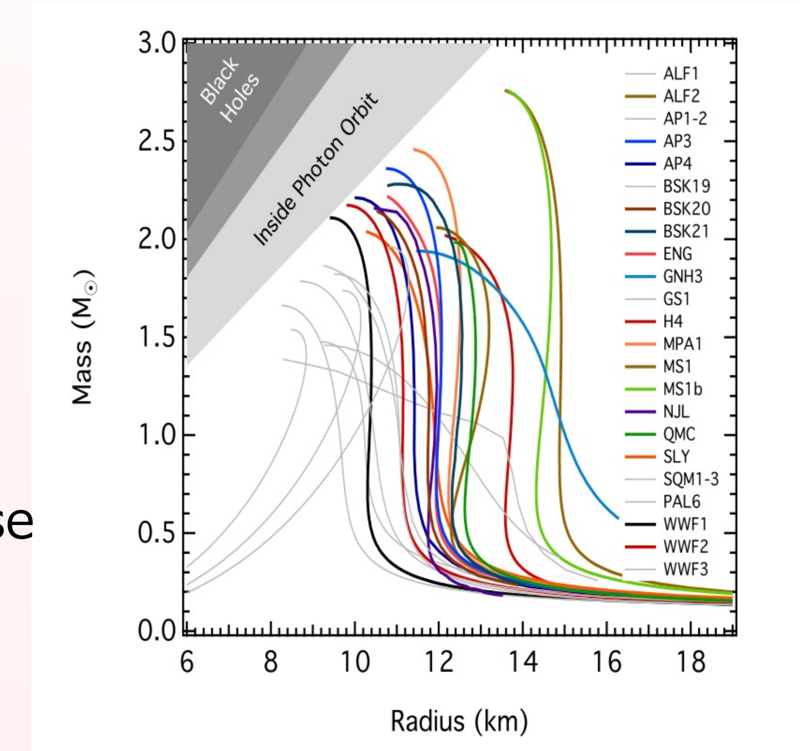
We studied accretion torque induced change in the pulse period derivative of the X-ray binary pulsar A 0535+262 using the long-term light curve from the MAXI/GSC and the time variation of the pulse period from the Fermi/GBM. We found a clear anti-correlation between the bolometric luminosity and the period derivative. We applied the accretion torque model proposed by Ghosh and Lamb (1979) to the observed anti-correlation. This model predicts the relation between the luminosity and the period derivative considering the fundamental parameters of the system including the mass and radius of the neutron star, and hence the application of the model to the data enables us to constrain these parameters. From the A 0535+262 data, we obtained a neutron star mass of 1.1-1.2 solar mass. In this presentation, we will present the details of the analysis and results.

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

- consist of a NS and a companion star
- show X-ray pulsations due to the spin of the neutron star.
- the pulse period changes by angular momentum transfer during mass accretion from the companion star.

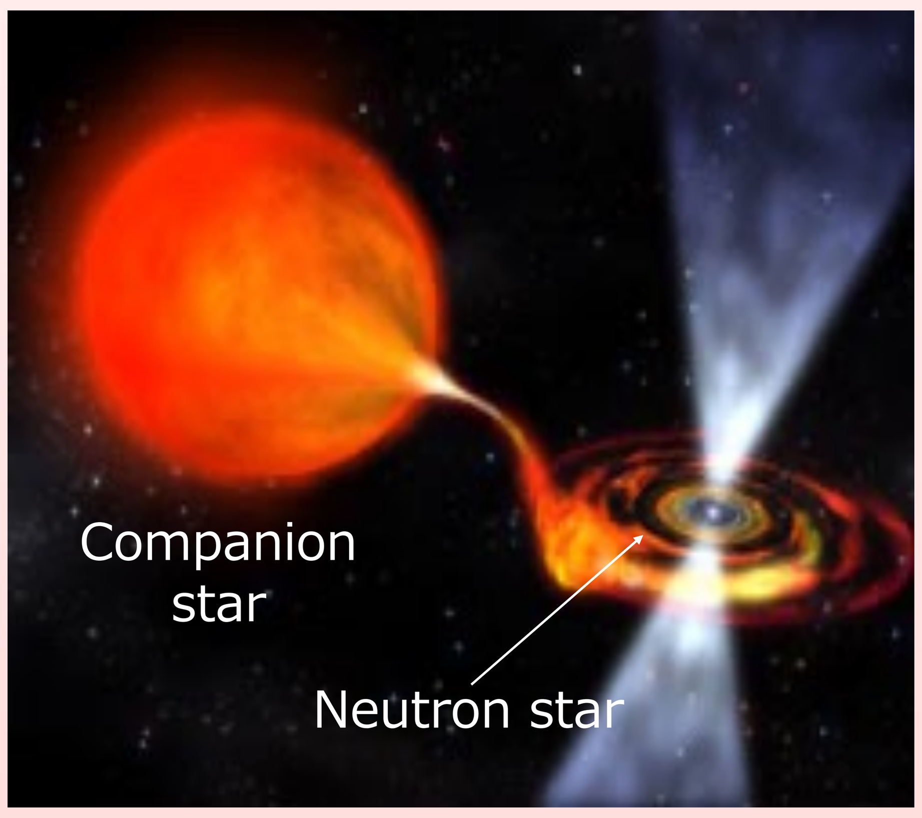
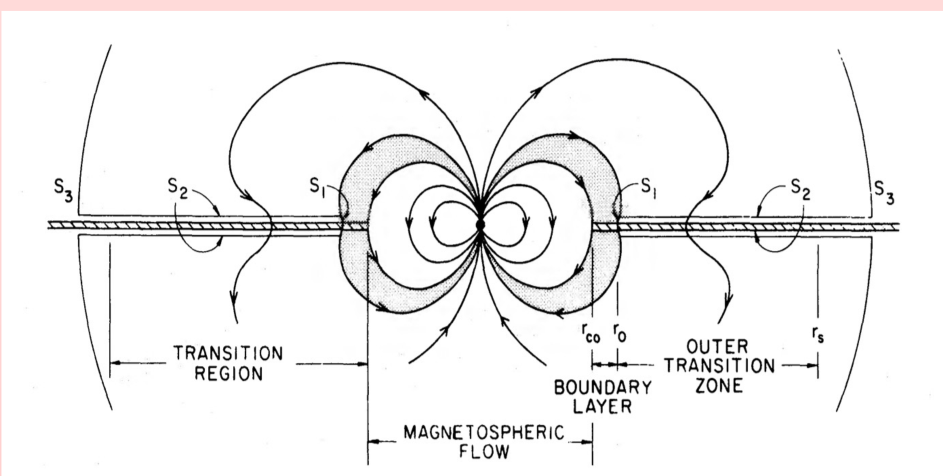


Image of an X-ray binary pulsar

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)

$$\dot{P} = -5.0\times10^{-5}\mu_{30}^{\frac{2}{7}}n(\omega_s)R_6^{\frac{6}{7}}\left(\frac{M}{M_\odot}\right)^{-\frac{3}{7}}I_{45}^{-1}P^2L_{37}^{\frac{6}{7}}\ \mathrm{s\ yr^{-1}}$$

μ_{30}: Magnetic dipole moment in units of $10^{30}\,\mathrm{G\,cm^3}$
R_6: Radius in units of 10^6 cm
I_{45}: Moment of inertia in units of $10^{45}\,\mathrm{g\,cm^2}$
L_{37}: Luminosity in units of $10^{37}\,\mathrm{erg\,s^{-1}}$
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

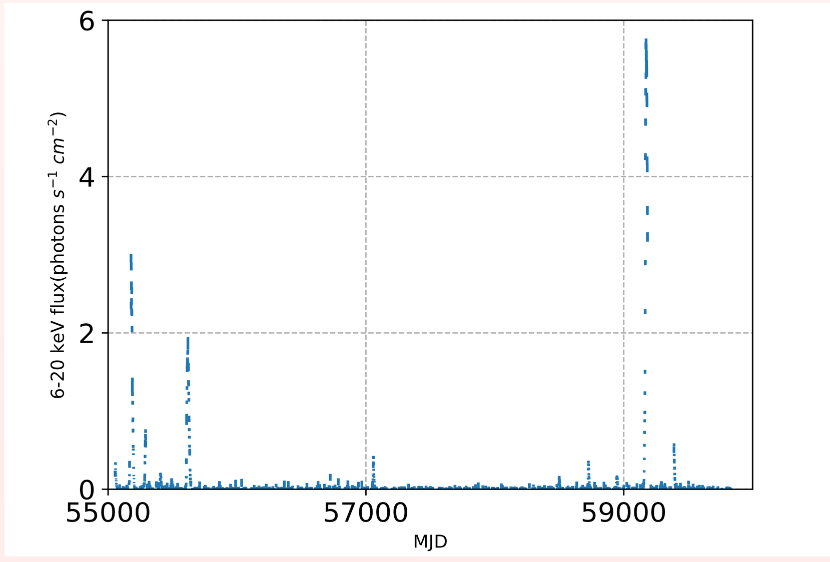
The equation includes physical parameters of an NS, the mass (M) and radius (R) of NSs.

We can estimate M and R of NSs in binary X-ray pulsars using observed correlations between $\dot{P}$ and L.

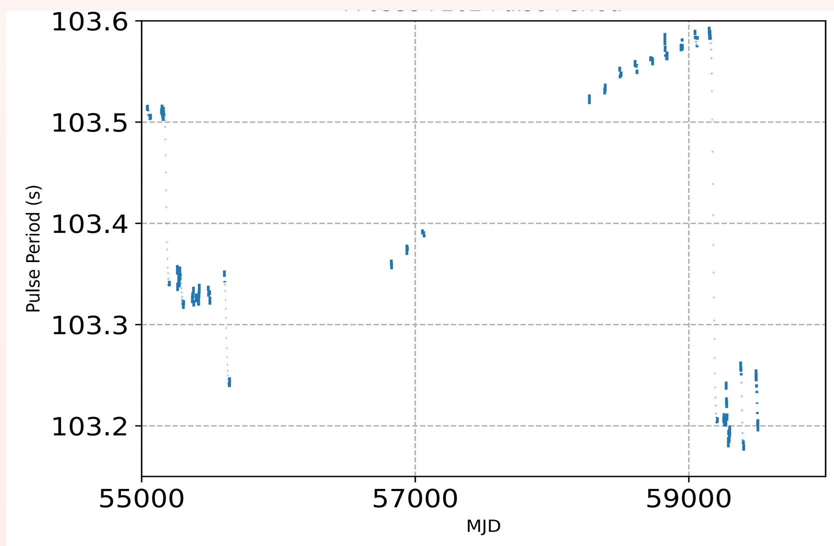
A 0535+262

A galactic binary X-ray pulsar showing X-ray outbursts with large flux changes.
The MAXI/GSC and Fermi/GBM have observed the source over 10 years and provided long-term variation of X-ray flux and pulse period.

Distance : 2.3 ± 0.3 kpc (Gaia Data Release 2)
Magnetic fiend : 4.3 × 10^{12} G (Makishima et al. 1999)



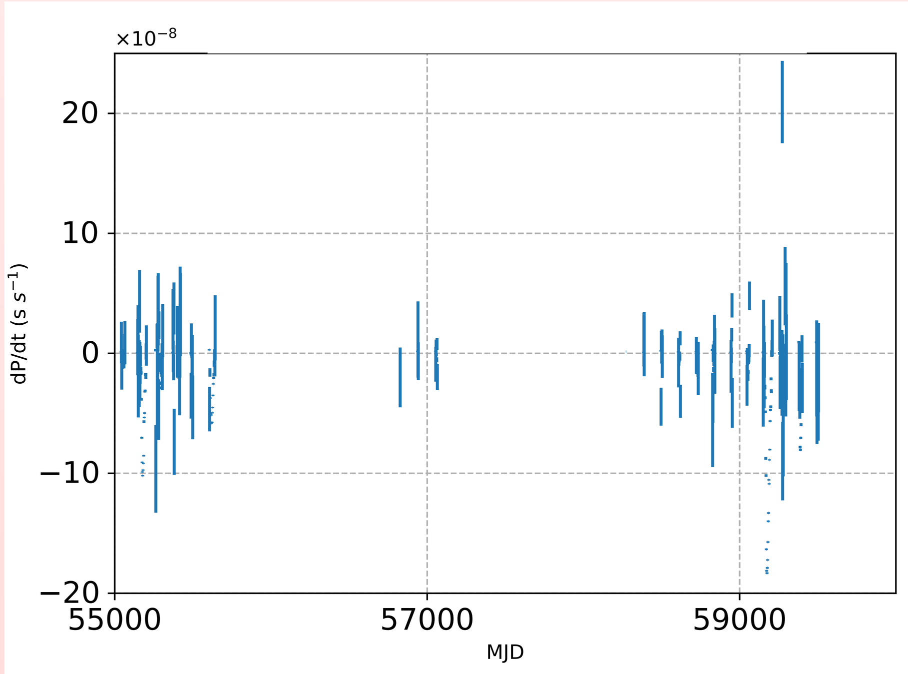
6–20 keV light curve obtained by the MAXI/GSC



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 fitting the time-averaged MAXI/GSC spectrum over the entire observational period with an absorbed cutoff power-law model and extrapolating the best-fit model.

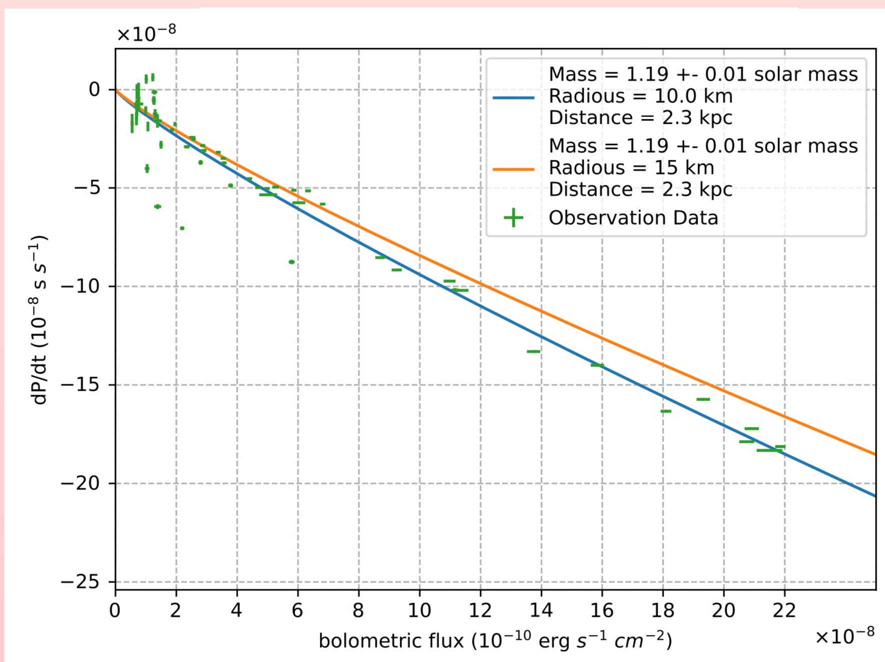


Pulse period derivatives calculated from data obtained with the Fermi/GBM.

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

Ghosh & Lamb model was applied to the bolometric flux vs. $\dot{P}$ data of A 0535+262.

We found constraining M and R simultaneously is difficult, so we fixed R at several different values and estimated M for the individual R values.



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

Estimated mass and radius of the NS in A 0535+262

Radius (km)	10	11	12	13	14	15
Mass ($M_\odot$)	1.19 ± 0.01	1.17 ± 0.01	1.15 ± 0.01	1.14 ± 0.01	1.12 ± 0.01	1.10 ± 0.01

Note. uncertainties in Ghosh and Lamb model (Sugizaki et. al. 2017) are not considered in the above calculations, which will be considered in future calculations.

References

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・Özel, F., & Freire, P., 2016, ARA&A, 54, 401
・Sugizaki, M., Mihara, T., Nakajima, M., & Makishima, K., 2017, PASJ, 69, 100