The Kavli Institute for Astronomy and Astrophysics at Peking University
北京大学科维理天文与天体物理研究所

# X-Ray Pulse Profile of Scalarized Neutron Stars

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Based on Rui Xu, Yong Gao, and Lijing Shao, arXiv:2007.10080

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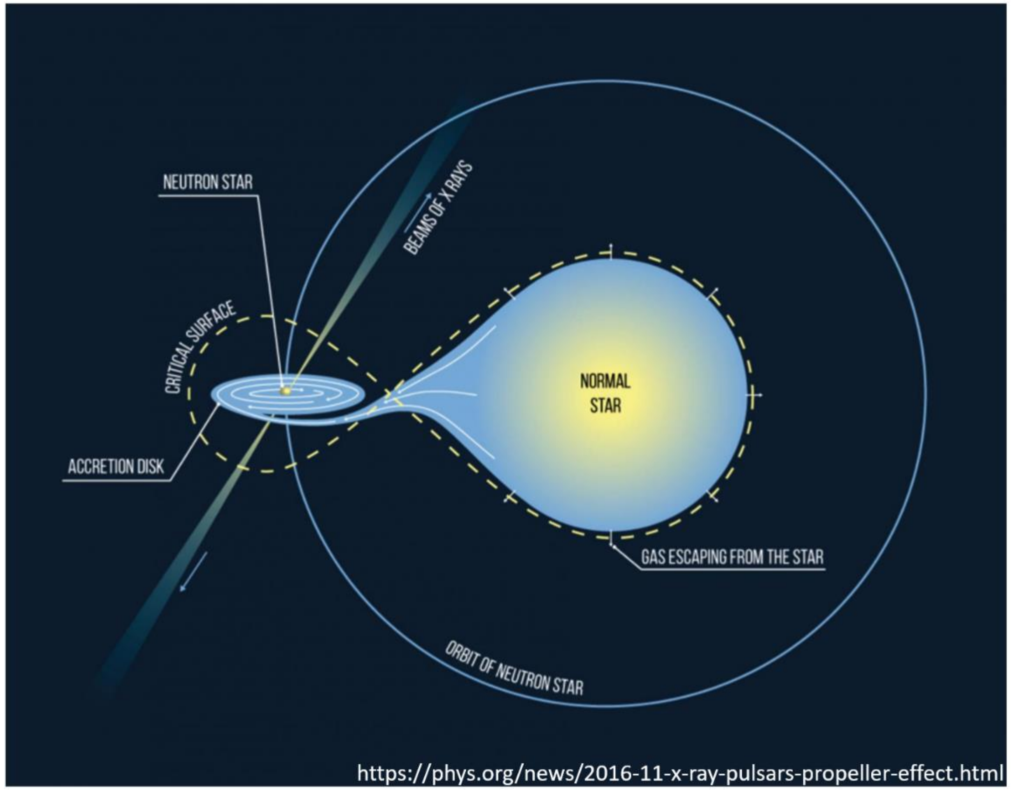
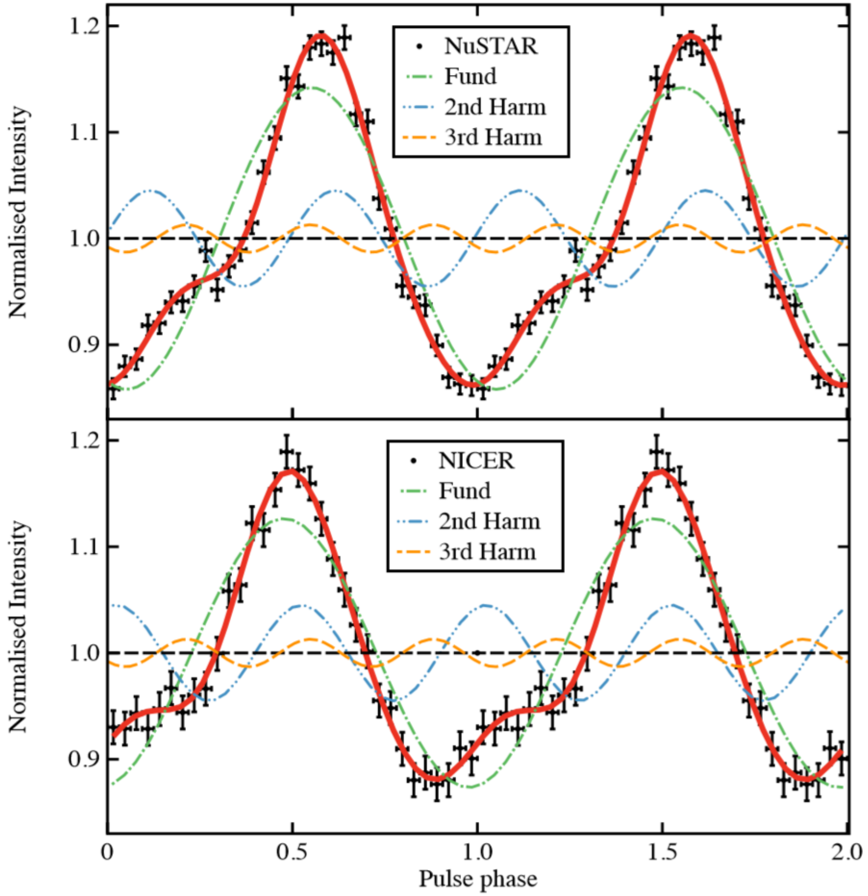
# Outline

- Observed flux from X-ray pulsars
- Spacetime around scalarized neutron stars (NSs)
- Pulse profile of scalarized NSs

# X-ray pulsar

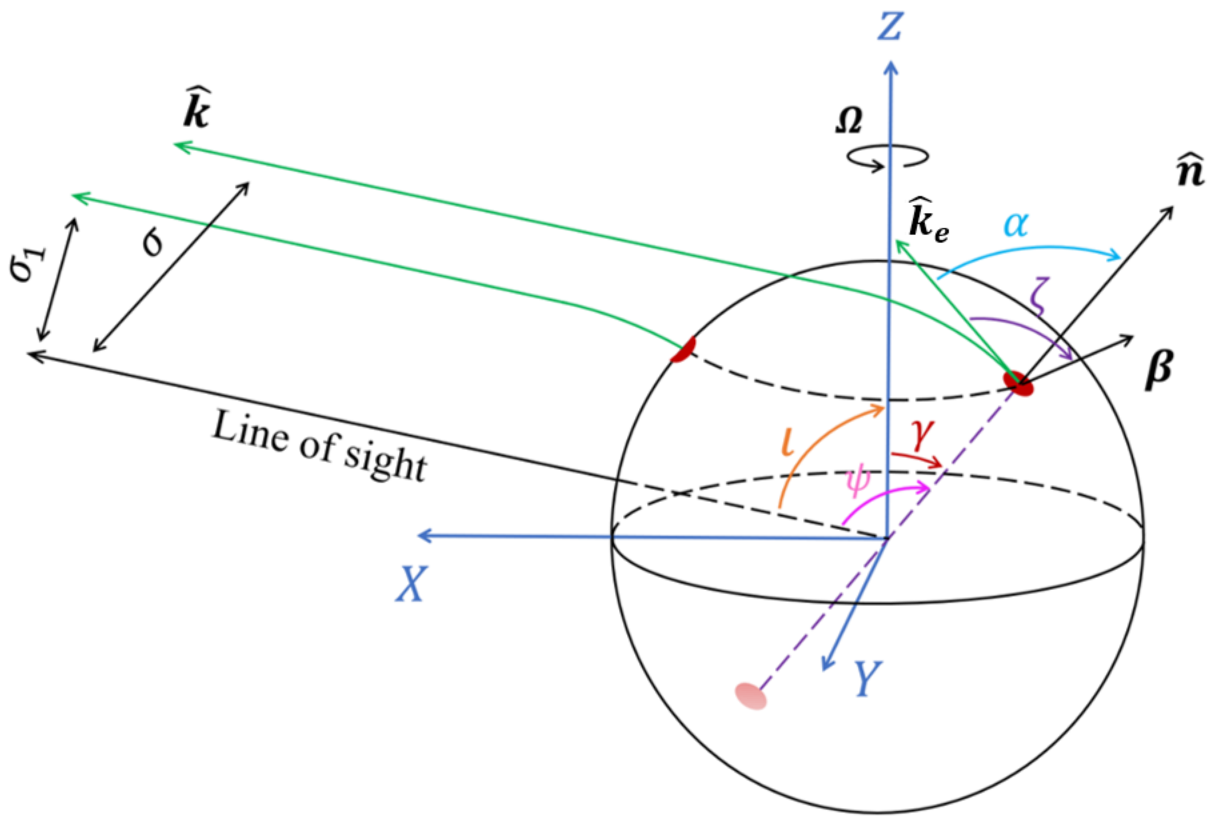



A. Sanna, et al. , A&A 617, L8 (2018)

# Hot spot emission model

- ❖ A pair of small hot spots
- ❖ A far-away observer

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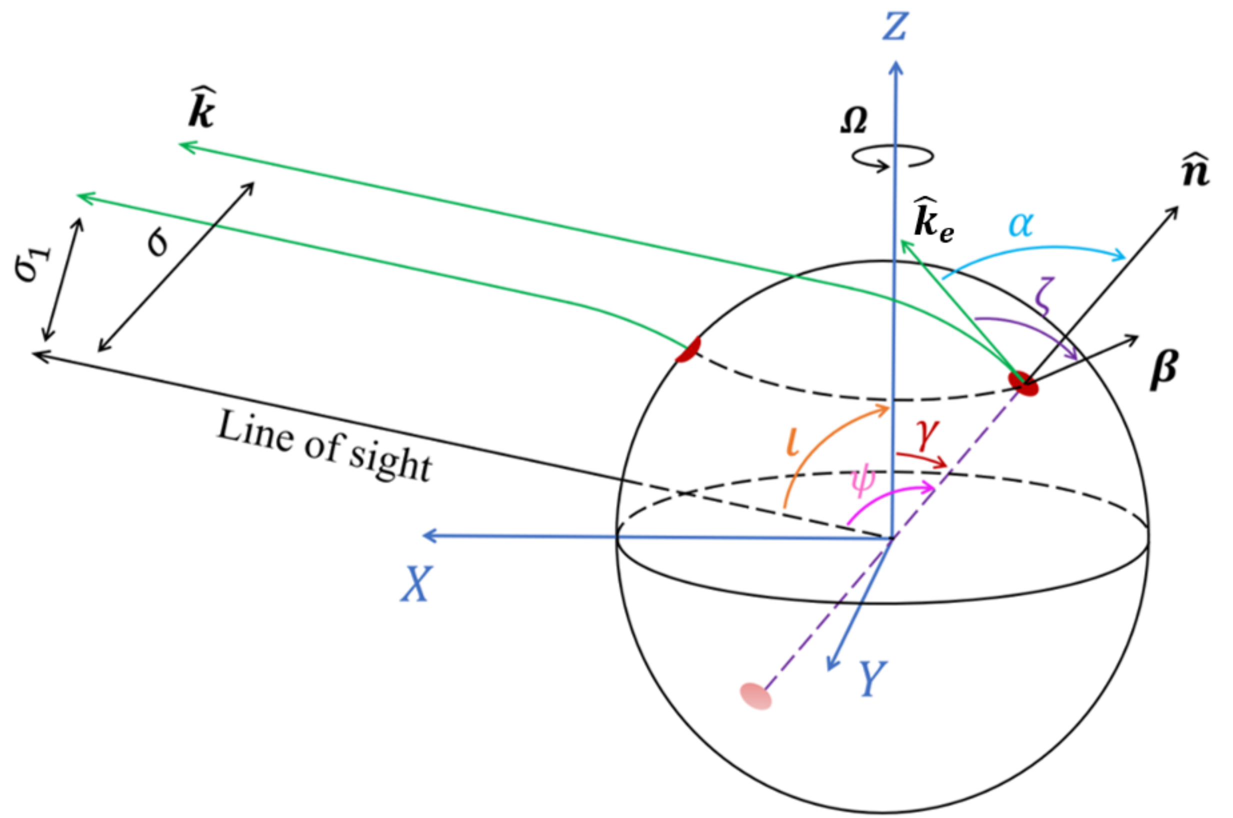
$$dF = I_o(E_o, \widehat{\boldsymbol{k}})dE_o d\Omega = I_o(E_o, \widehat{\boldsymbol{k}})dE_o \frac{\sigma d\sigma d\lambda}{D^2}$$

H. O. Silva, N. Yunes, Phys. Rev. D 99, 044034 (2019)

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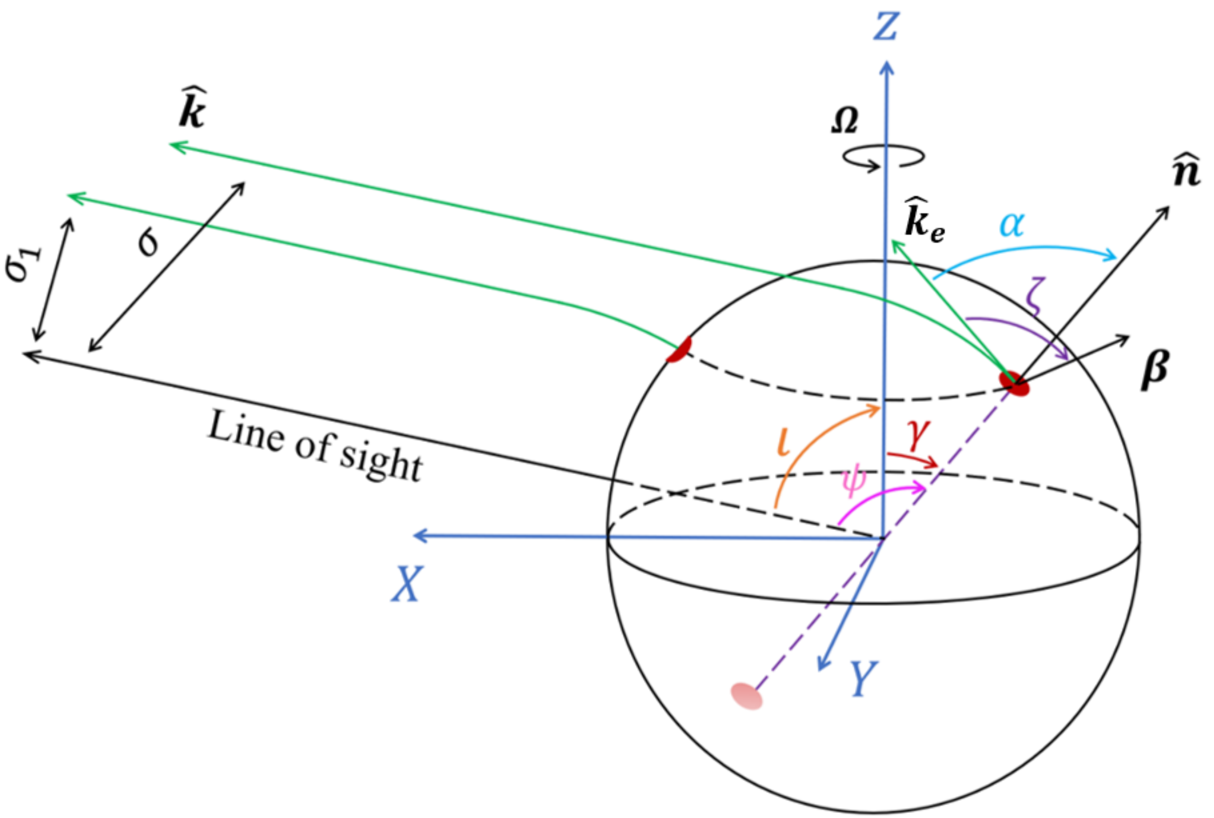


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gravitational redshift ⟶ $I_o/\nu_o^3 = I_e/\nu_e^3$

bending of light ⟶ $d\sigma d\lambda \leftrightarrow dS = R^2 \sin\psi \, d\psi d\lambda$

# Spherical NS

$$ds^2 = -B(r)dt^2 + A(r)dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)$$

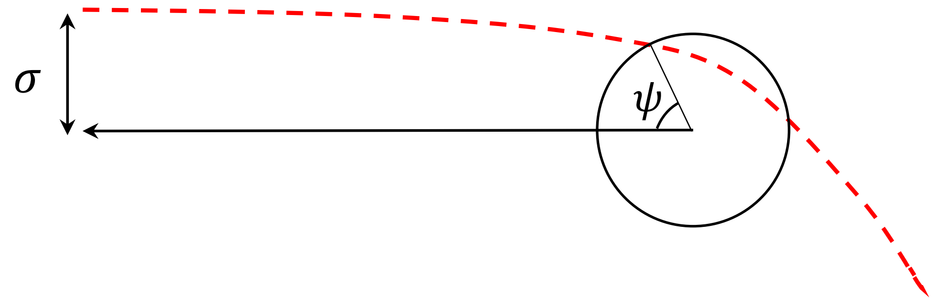
gravitational redshift $$\frac{\nu_o}{\nu_e} = \sqrt{B(R)}$$

bending of light $$\psi = \int_\infty^R \frac{d\theta}{dr} dr = \psi(\sigma)$$

$$\frac{dt}{dp} = \frac{1}{B}$$

$$-B\left(\frac{dt}{dp}\right)^2 + A\left(\frac{dr}{dp}\right)^2 + r^2\left(\frac{d\theta}{dp}\right)^2 = 0$$

$$\frac{d\theta}{dp} = \frac{\sigma}{r^2}$$



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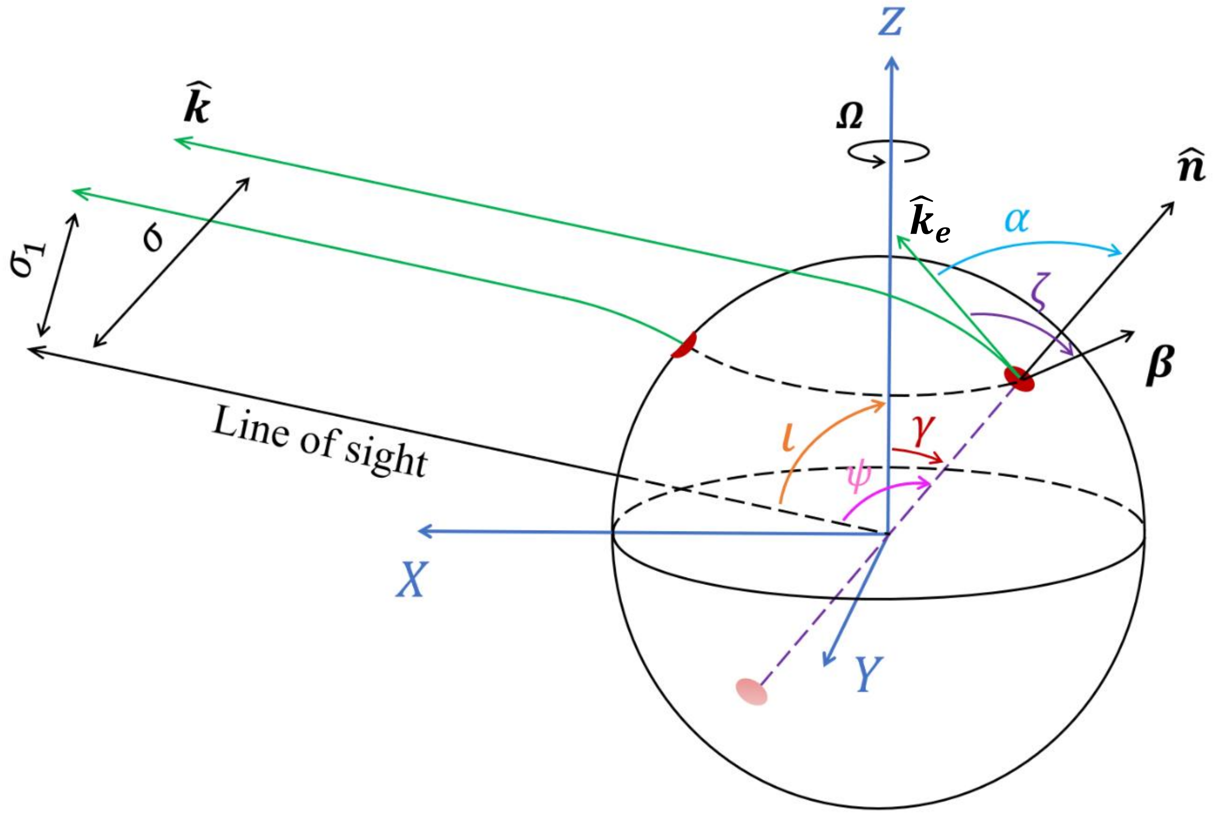
$$= B^2(R) I_e(E_e, \hat{\boldsymbol{k}}_{\boldsymbol{e}})dE_e \frac{\sigma d\sigma}{\sin\psi\, d\psi} \frac{dS}{R^2 D^2}$$

Isotropic radiation: $I_e(E_e, \hat{\boldsymbol{k}}_{\boldsymbol{e}}) = I_e(E_e)$

$$\cos\psi = \cos\iota\cos\gamma + \sin\iota\sin\gamma\cos\Phi$$

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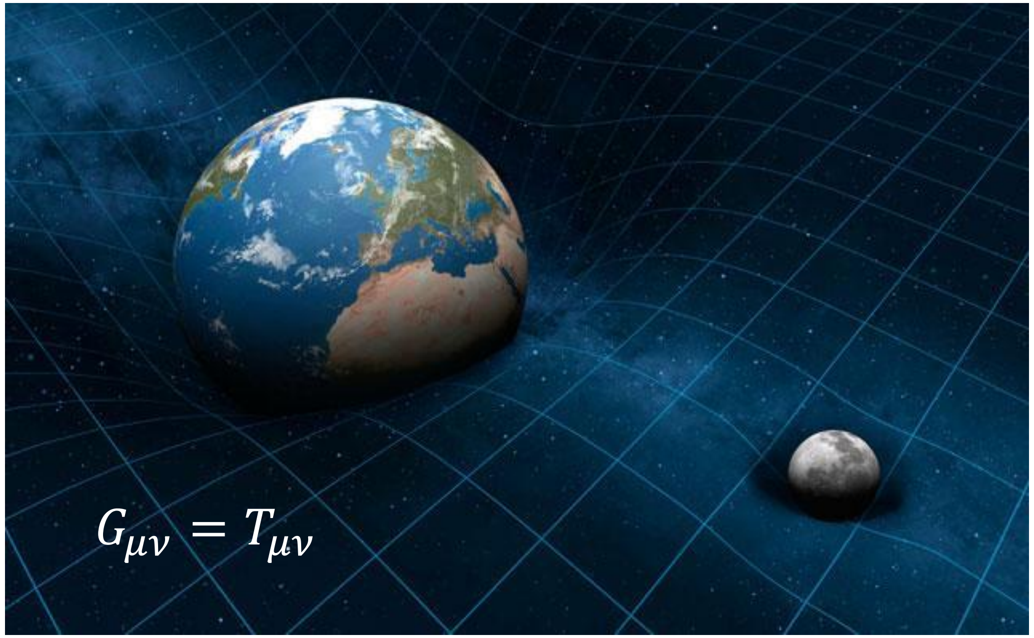


General Relativity (GR): $B(r) = 1 - \frac{r_s}{r}, A(r) = \frac{1}{1 - \frac{r_s}{r}}$

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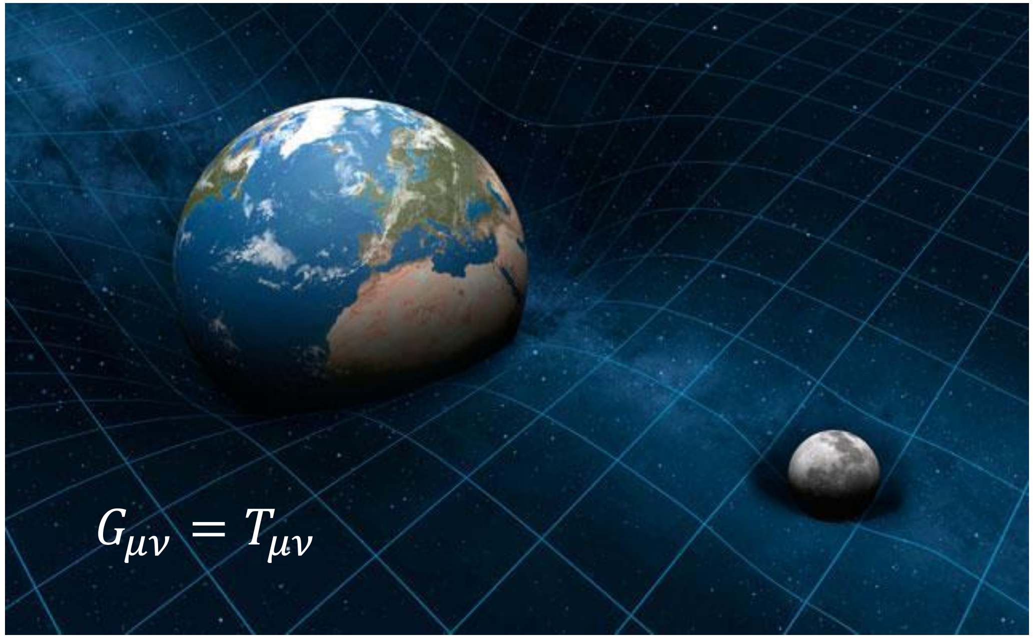


General Relativity (GR): $B(r) = 1 - \frac{r_s}{r}, A(r) = \frac{1}{1 - \frac{r_s}{r}}$

Scalar-tensor theory: $B(r) = ?, A(r) = ?$

- Cosmology: dark energy, inflation
- Quantum gravity

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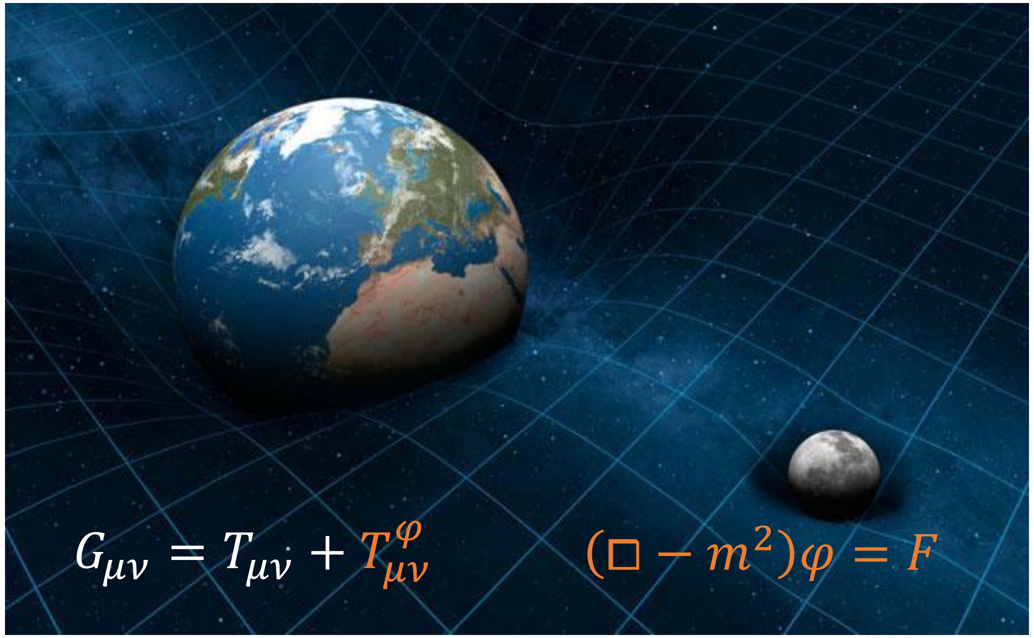


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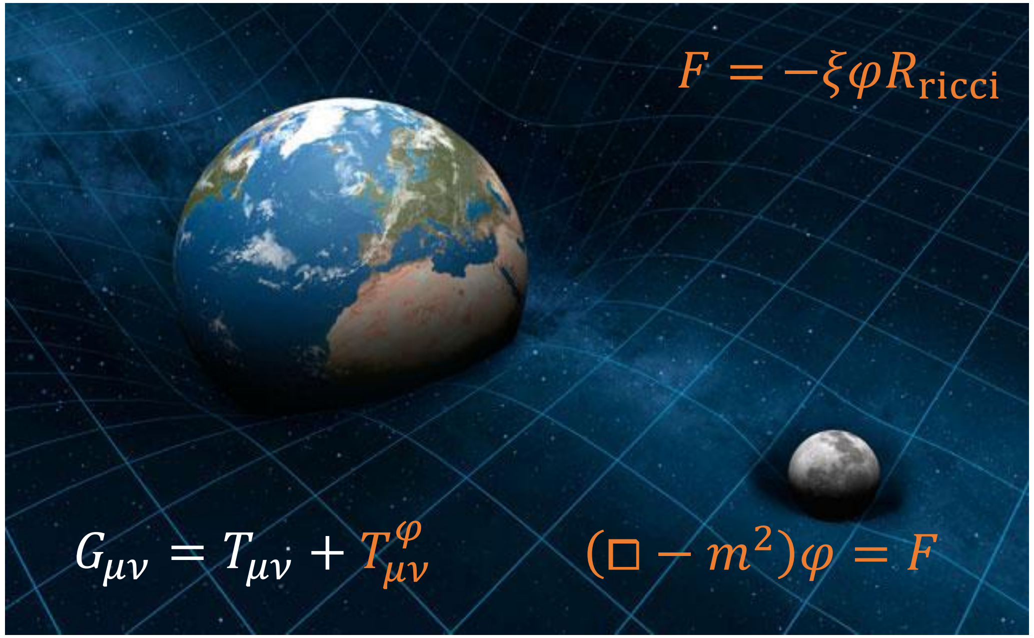


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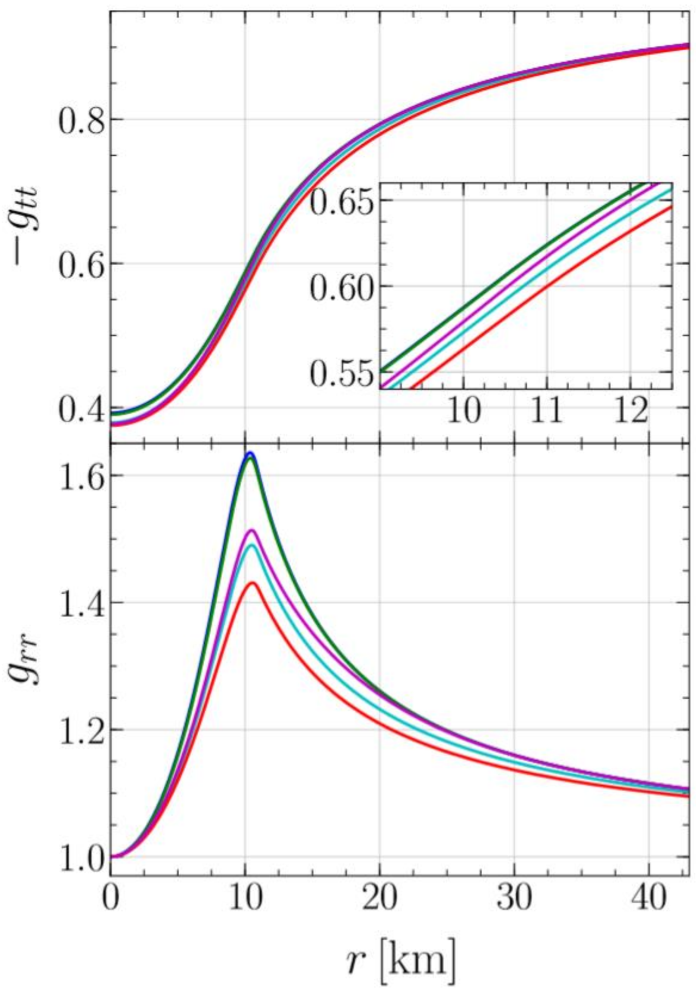
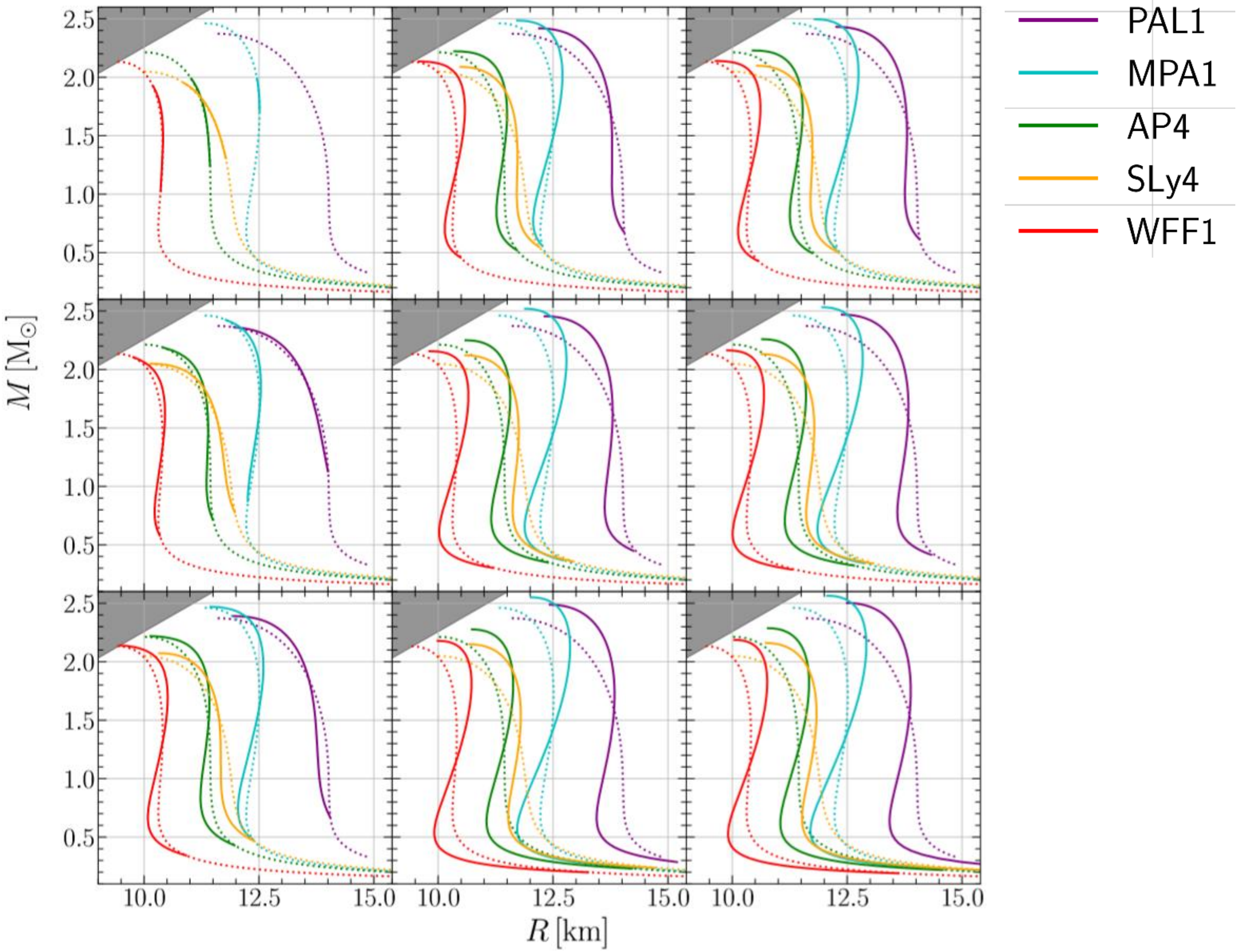
# Spherical NSs in scalar-tensor theory



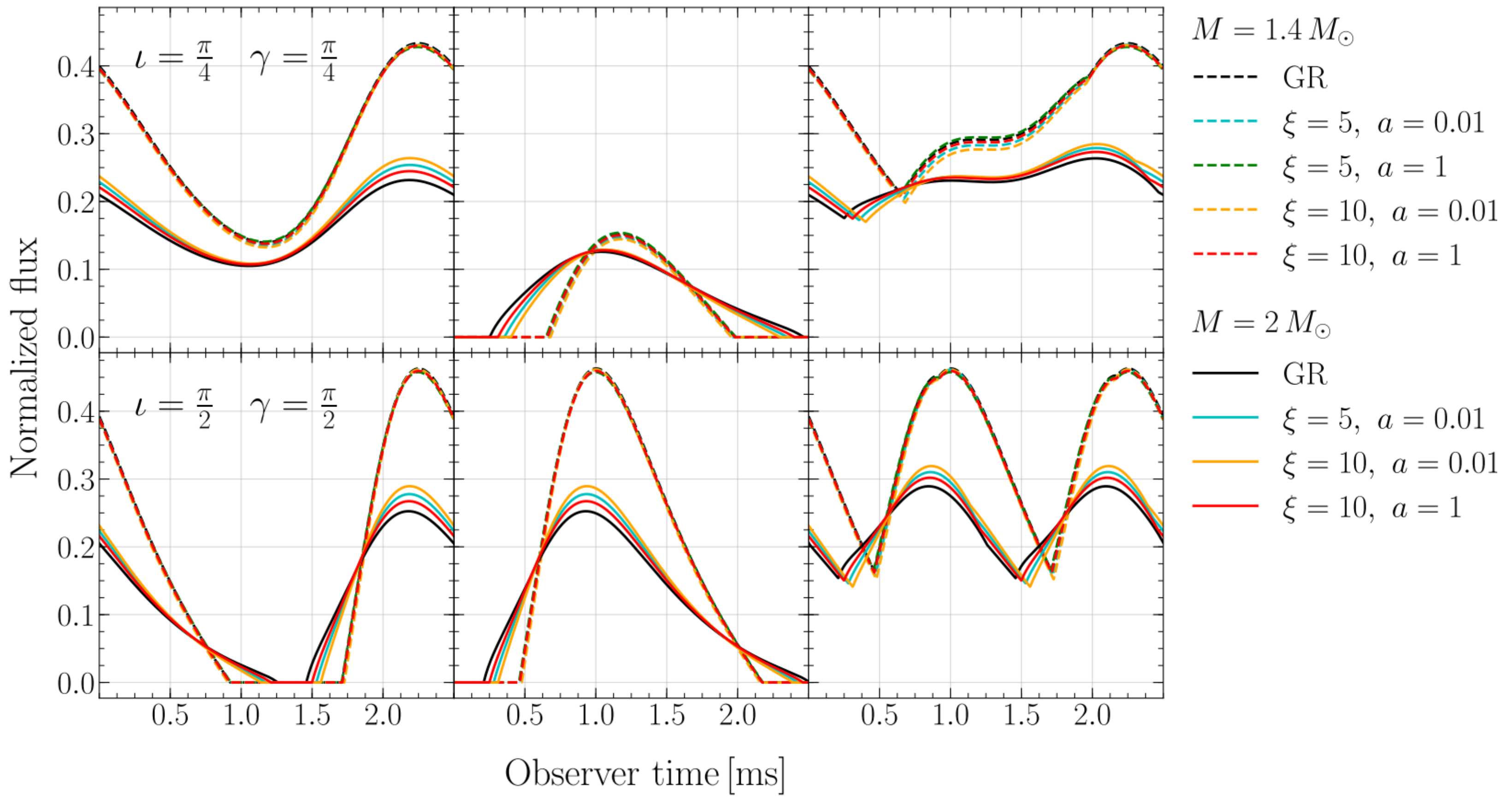



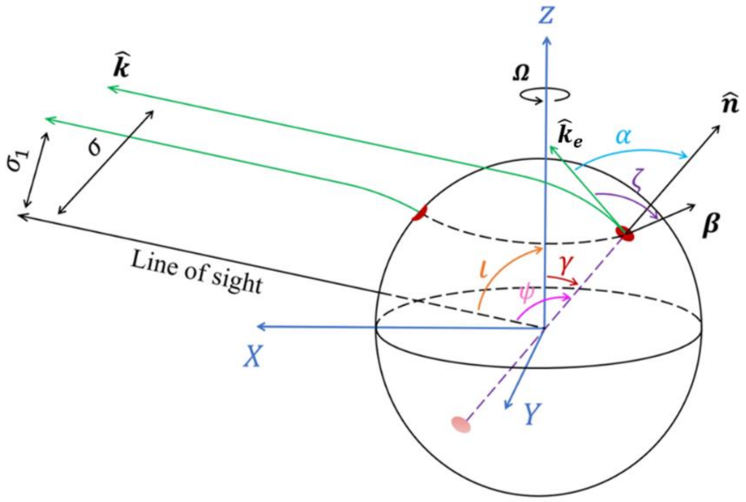
# Pulse profiles

Isotropic radiation

$$dF = B^2(R) I_e(E_e, \hat{\boldsymbol{k}}_e) dE_e \frac{\sigma d\sigma}{\sin\psi \, d\psi} \frac{dS}{R^2 D^2} \propto \frac{\sigma d\sigma}{\sin\psi \, d\psi}$$

$m \approx a \times 1.97 \times 10^{-11}\text{eV}$



# Summary

- X-ray pulse profiles contain information about the spacetime around NSs (gravitational redshift, bending of the light trajectories).

- Scalarized NSs generate spacetime different from the Schwarzschild metric.

- Distinguishing scalarized NSs from those in GR using X-ray pulsar observations is challenging as the differences in the metrics are small for coupling constants of order unity.

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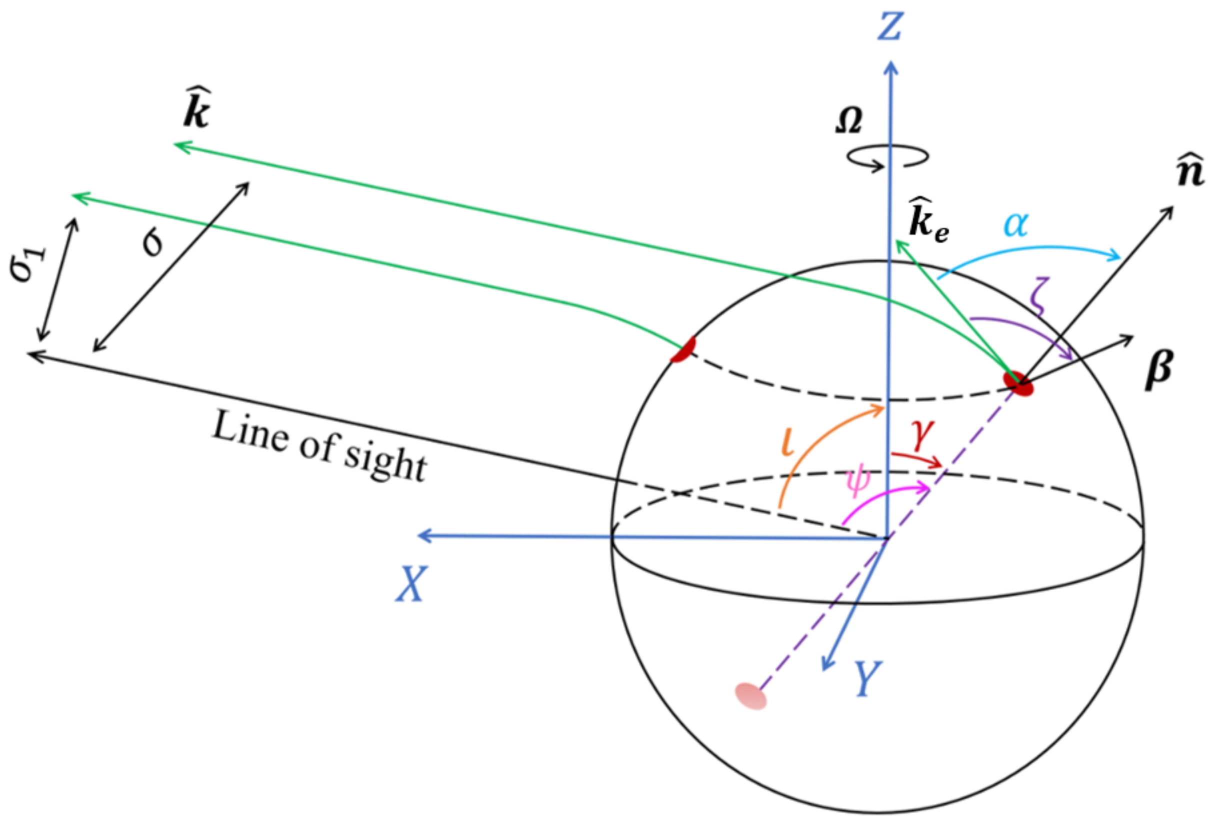
$I_o \leftrightarrow I_e$

$d\sigma d\lambda \leftrightarrow dS$

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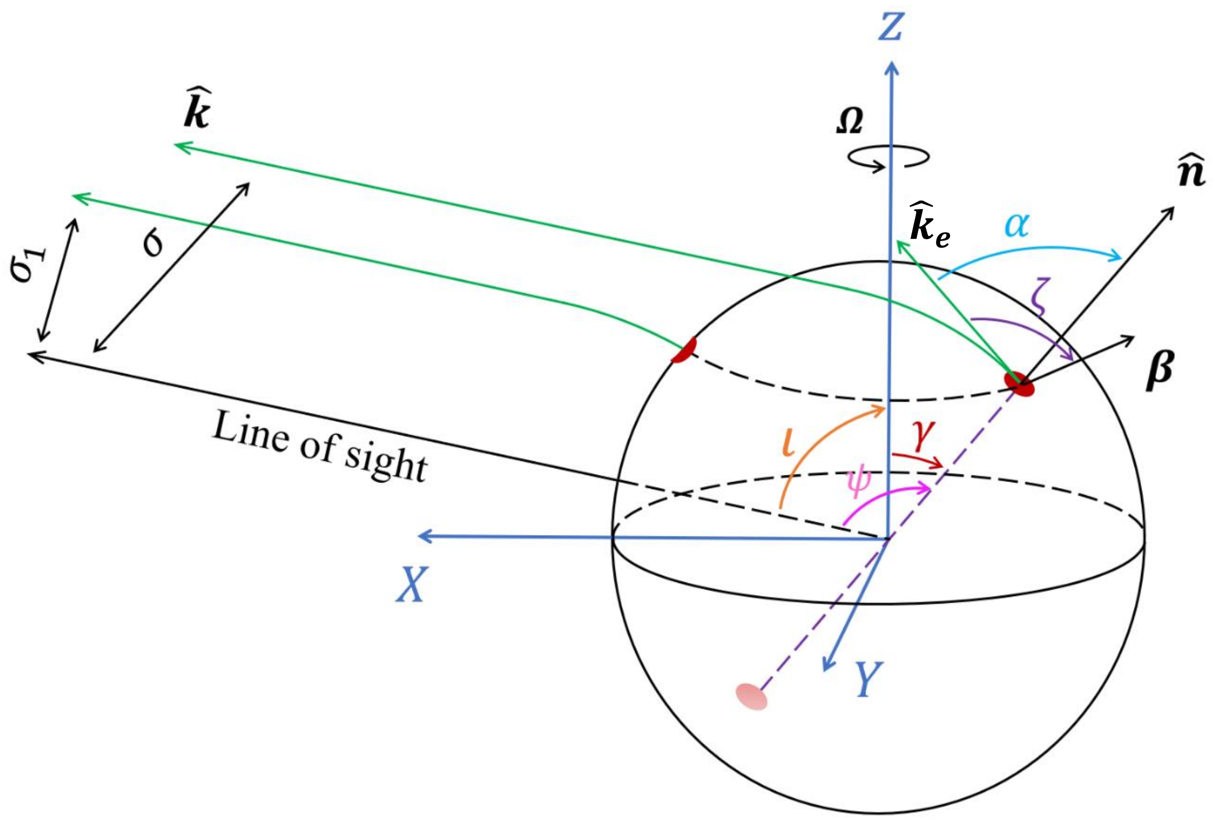


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