EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

# On the inclination dependence of QPO properties

Qingcui, Bu(卜庆翠)

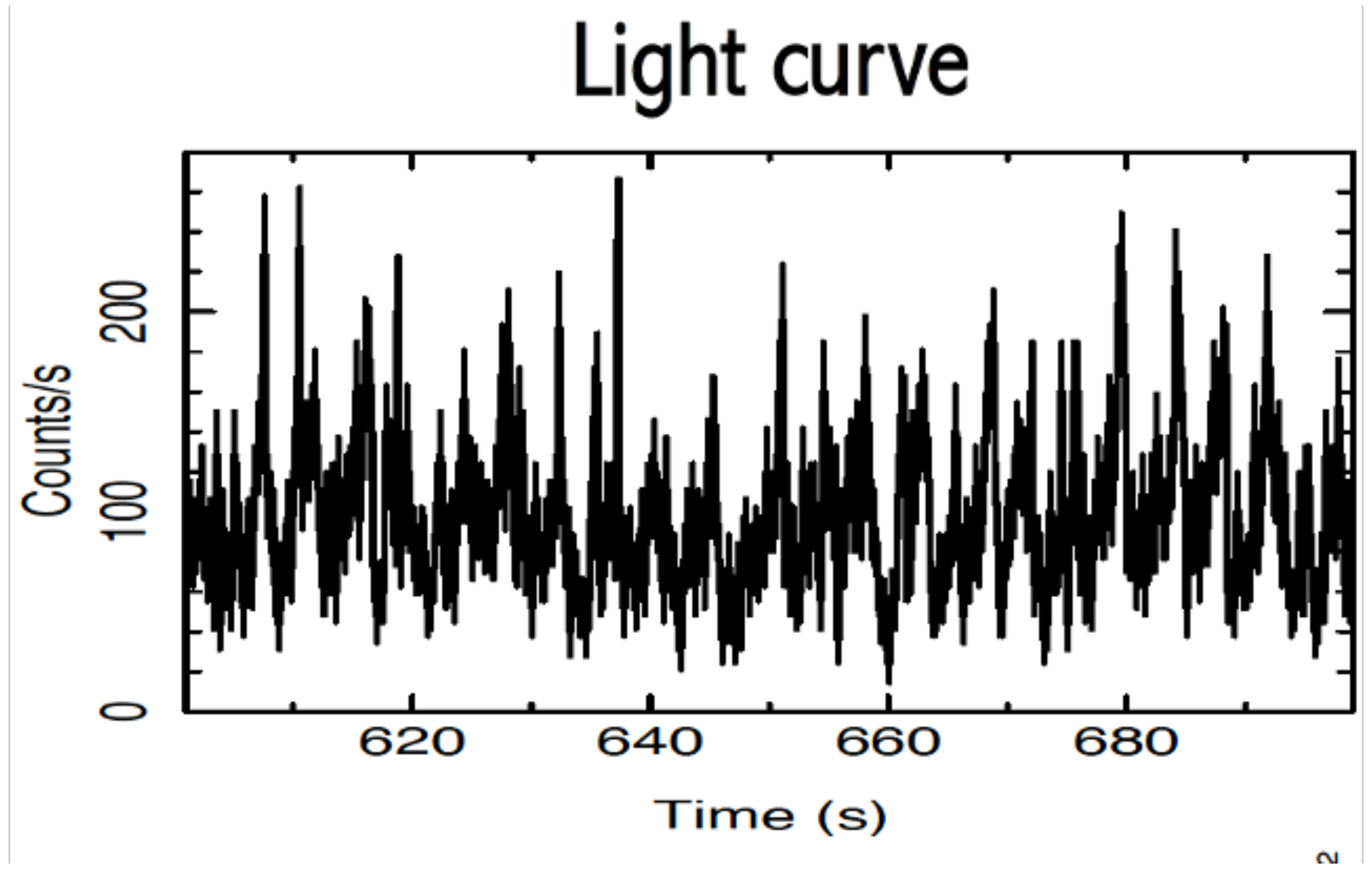
2022-06-15, Beijing

The 60th Anniversary of X-Ray Astronomy: X-ray Astronomy in the Time-domain & Multi-messenger Era

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

# Low frequency QPOs in black hole X-ray binaries

- Quasi-Periodic Oscillations (QPOs) are commonly observed in the X-ray flux
- QPOs are best studied in the Fourier domain
- LFQPOs, centroid frequency is $< \sim 30$ Hz in BHs



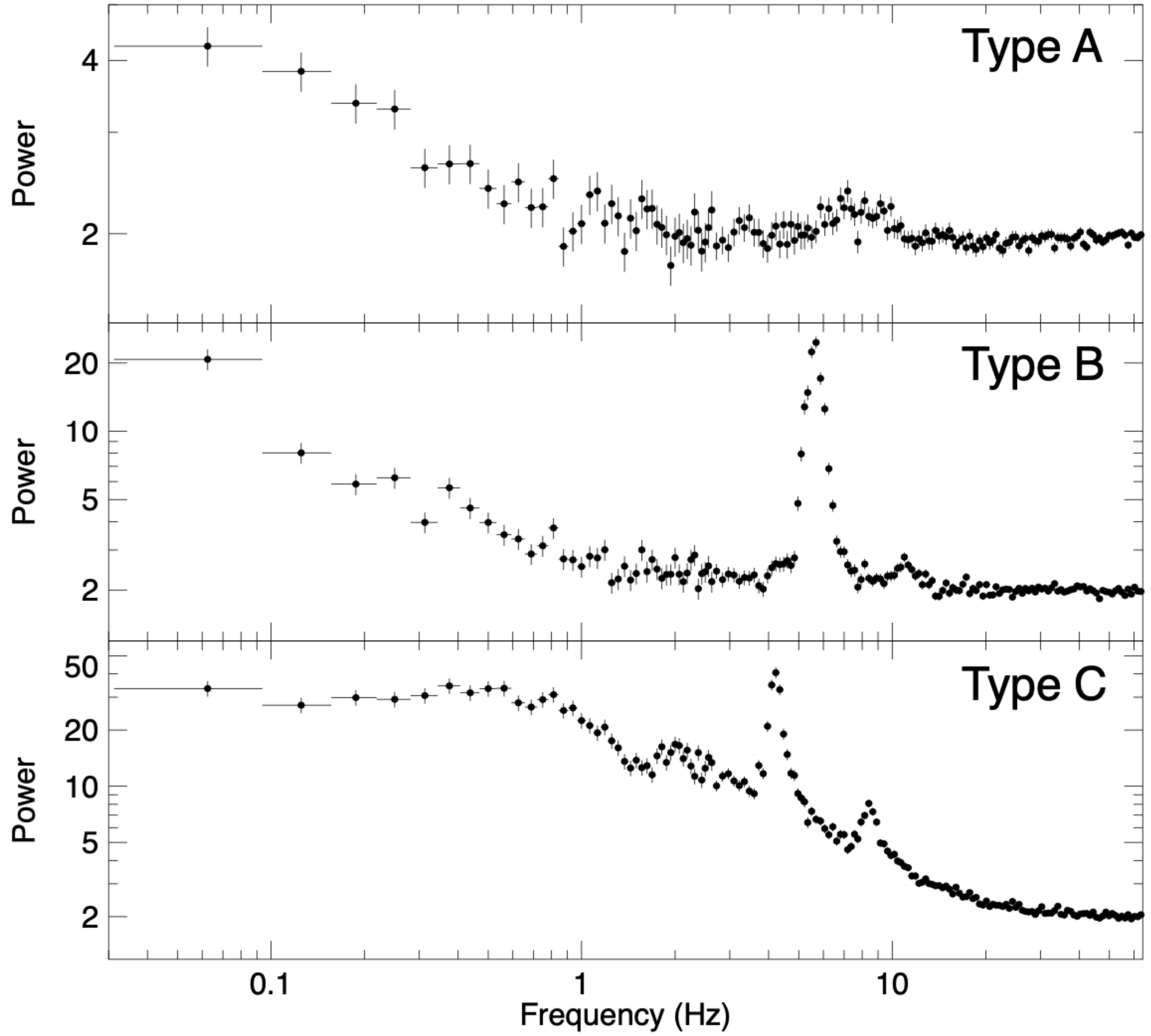
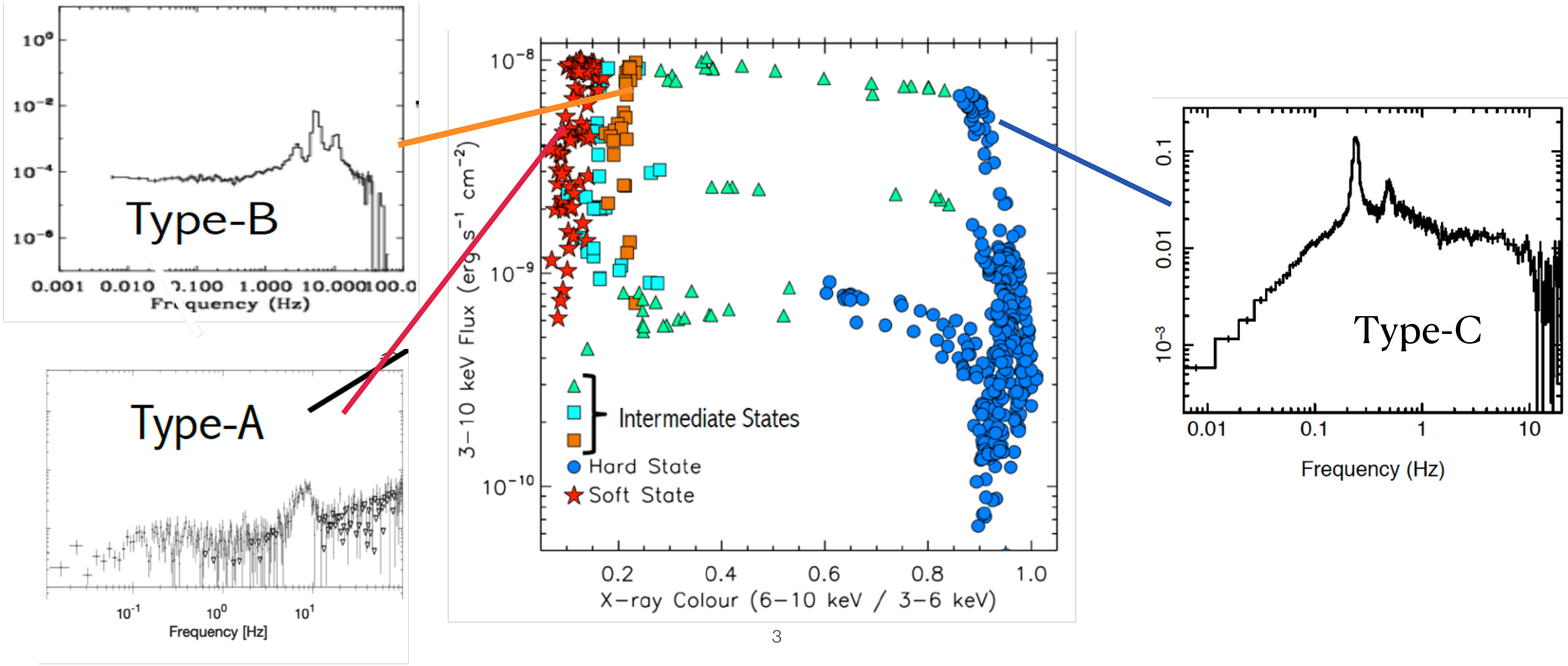




**Fig. 2** Examples of type A, B and C QPOs from our GX 339-4 observations. The contribution of the Poisson noise was not subtracted. Adapted from [115].

Motta, et al. 2011

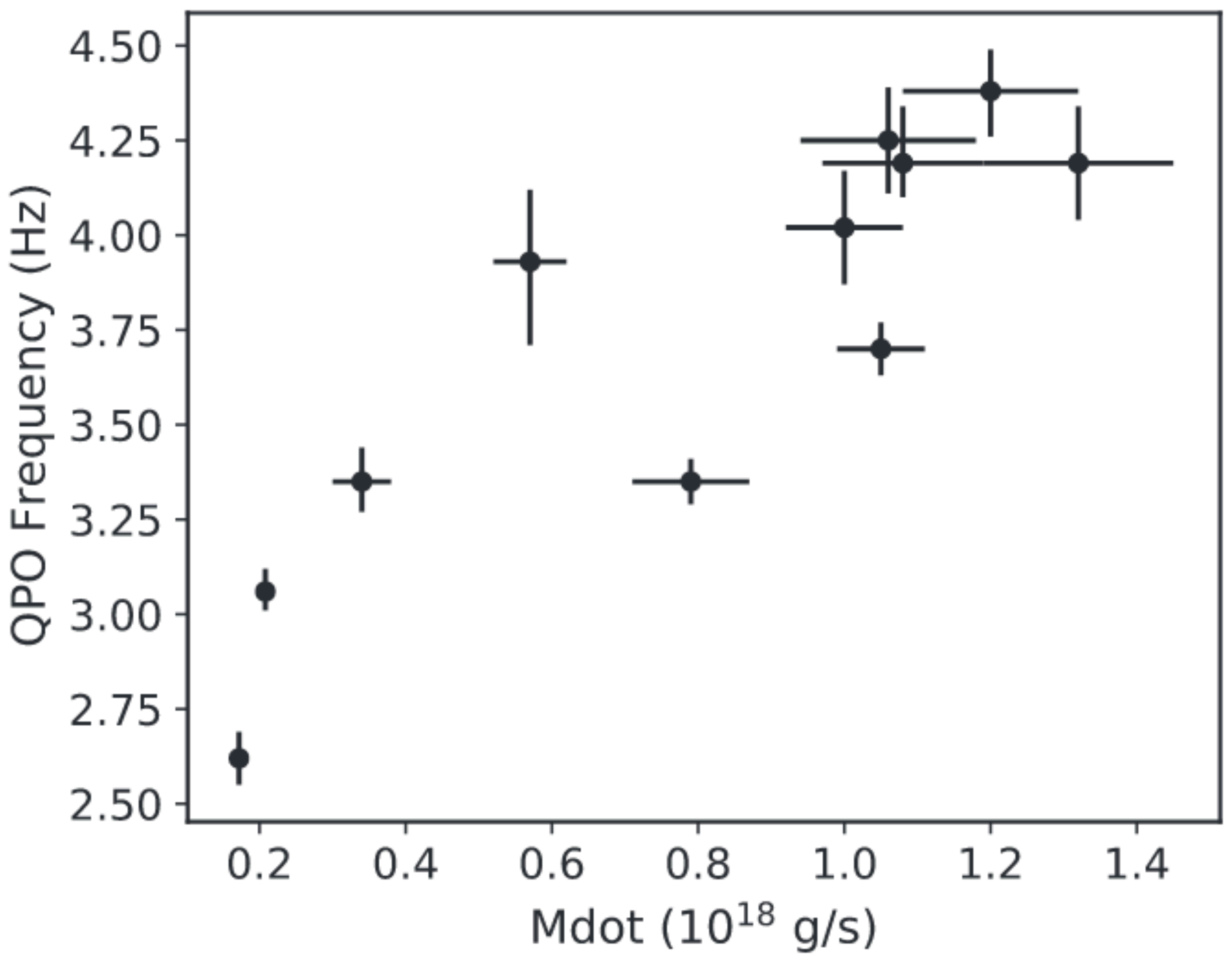
# QPO properties and BH spectral states



EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

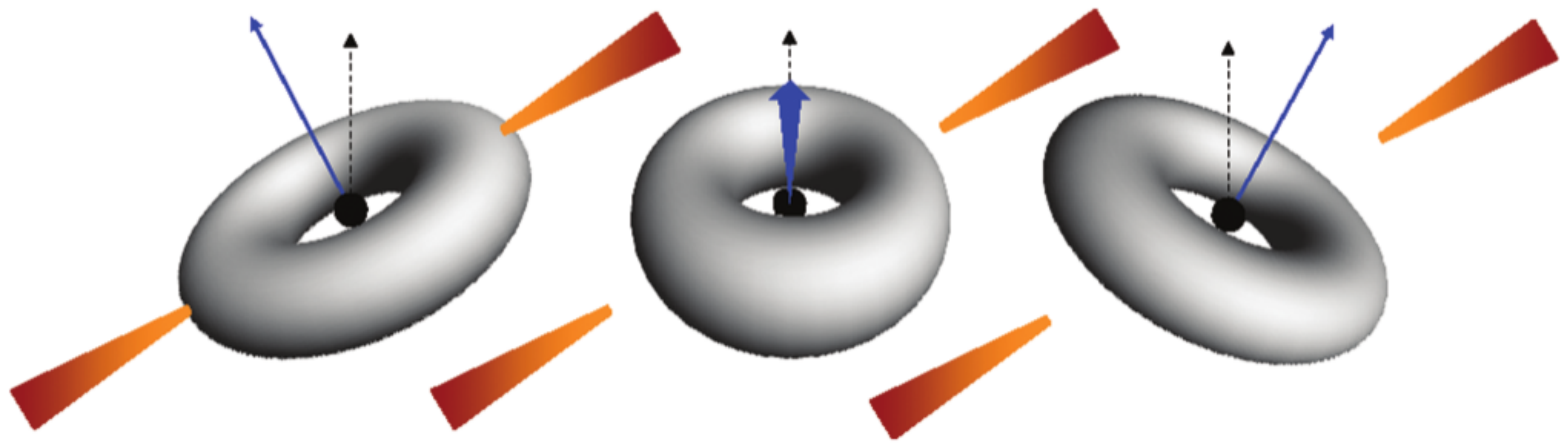
# The ***nature*** of the oscillations

- Geometrical — the shape or size of **something** varies quasi-periodically
- Intrinsic — fundamental property such as pressure or **accretion rate** oscillates in a stable geometry

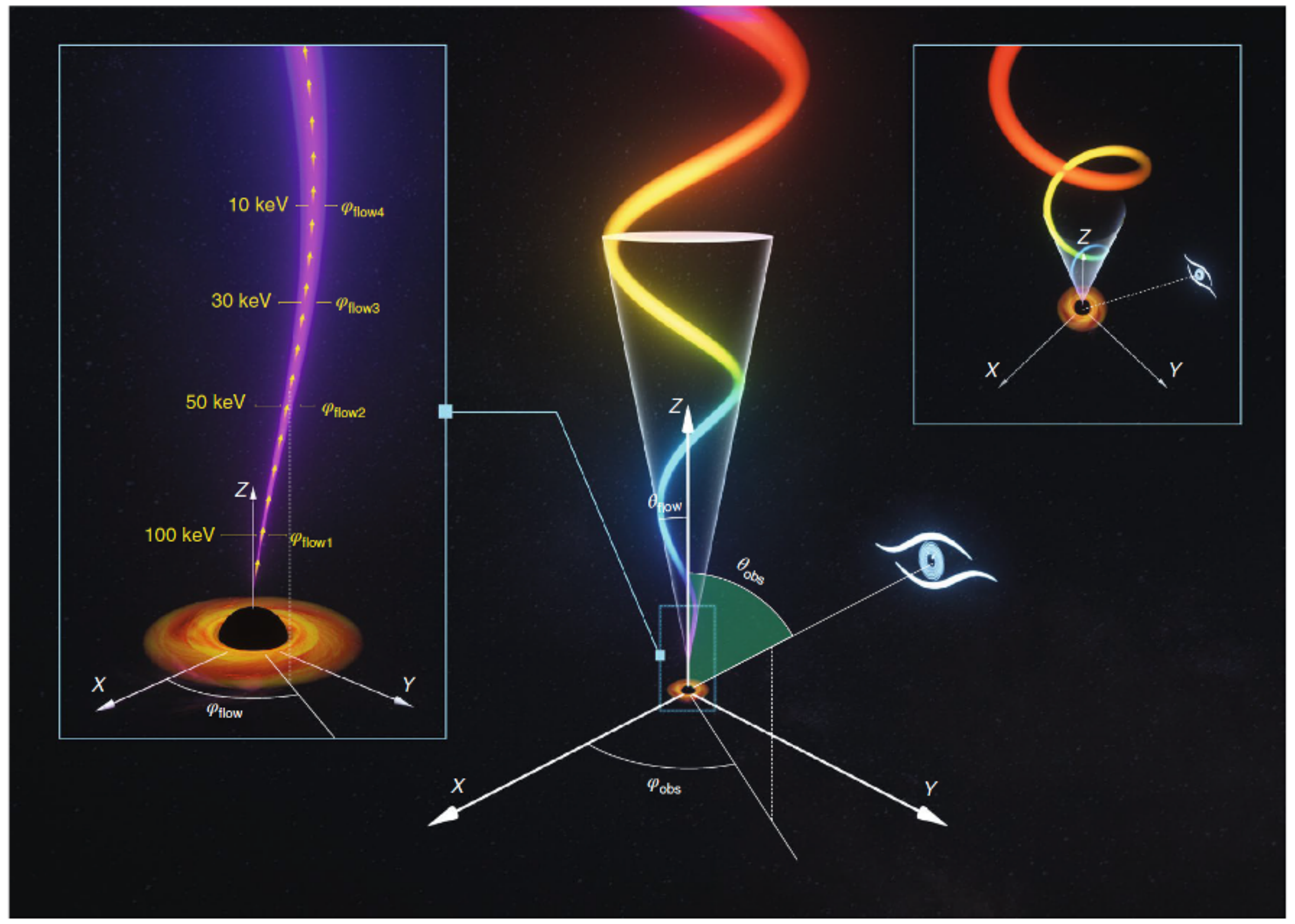



Liu et al. 2021

## LT precession of a hot inner flow or a small-scaled jet



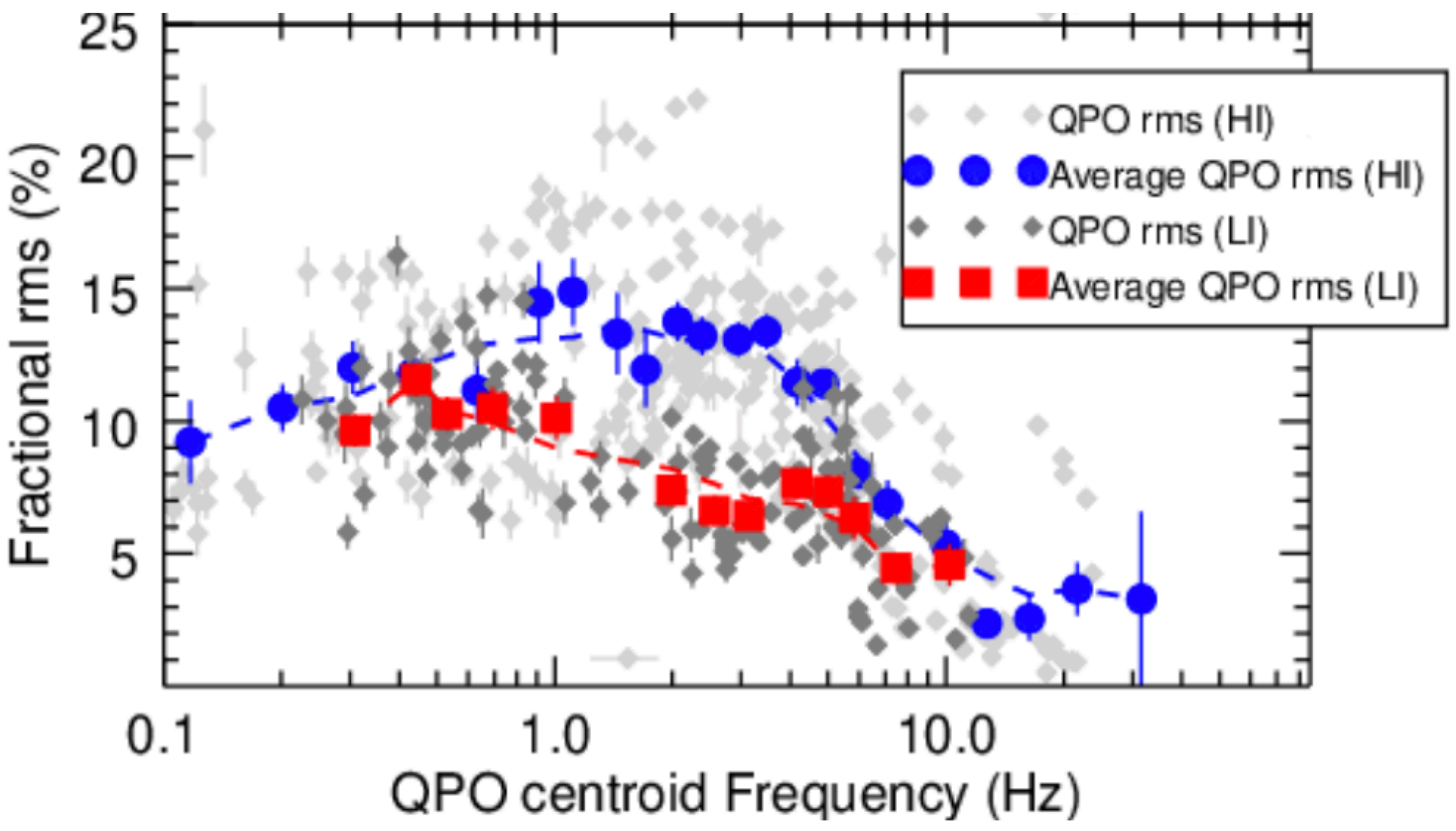
Ingram et al.2009




Ma et al. 2021

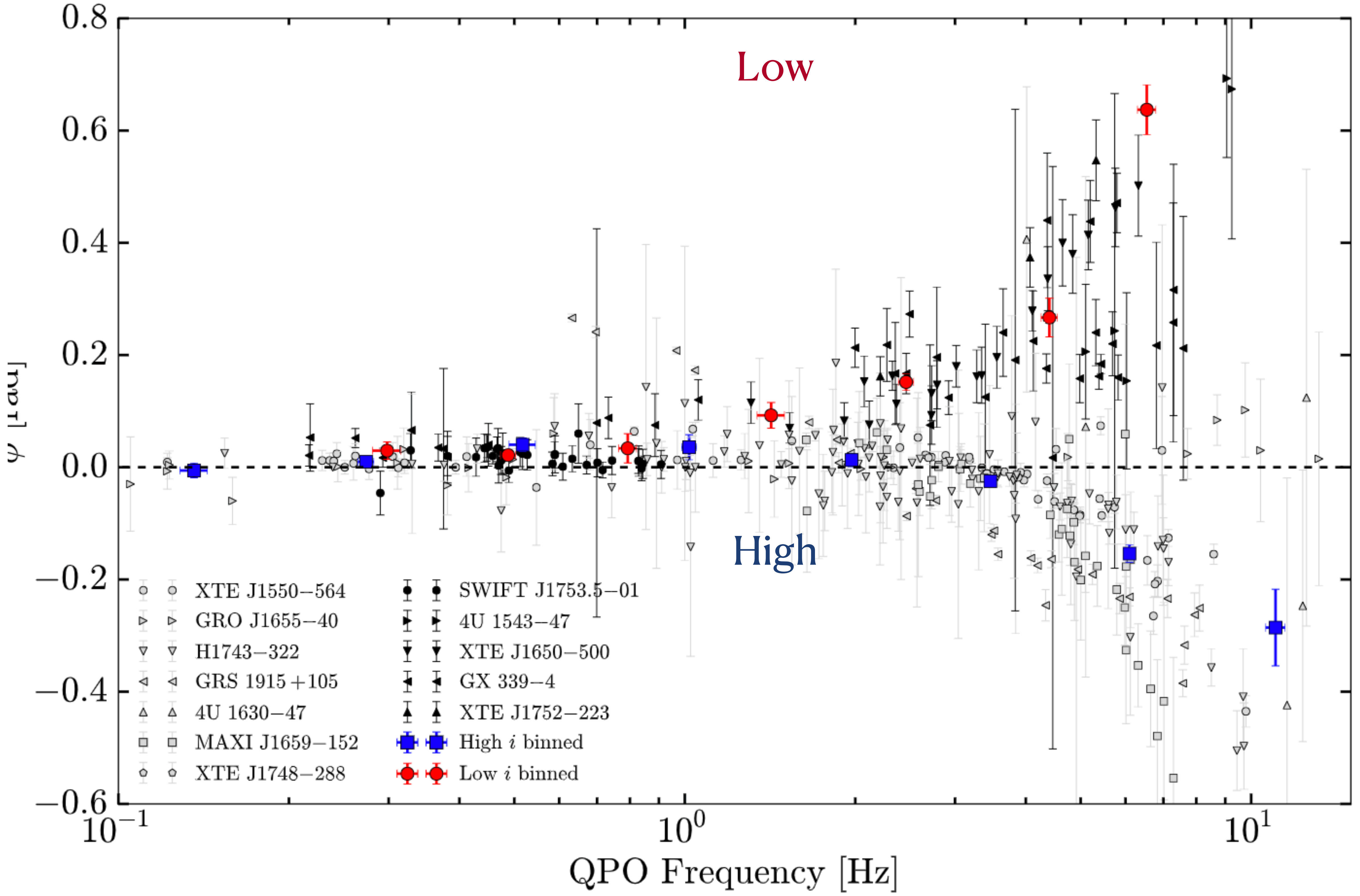
# Inclination dependence of type-C QPO properties

**QPO rms is higher in the high inclination systems**



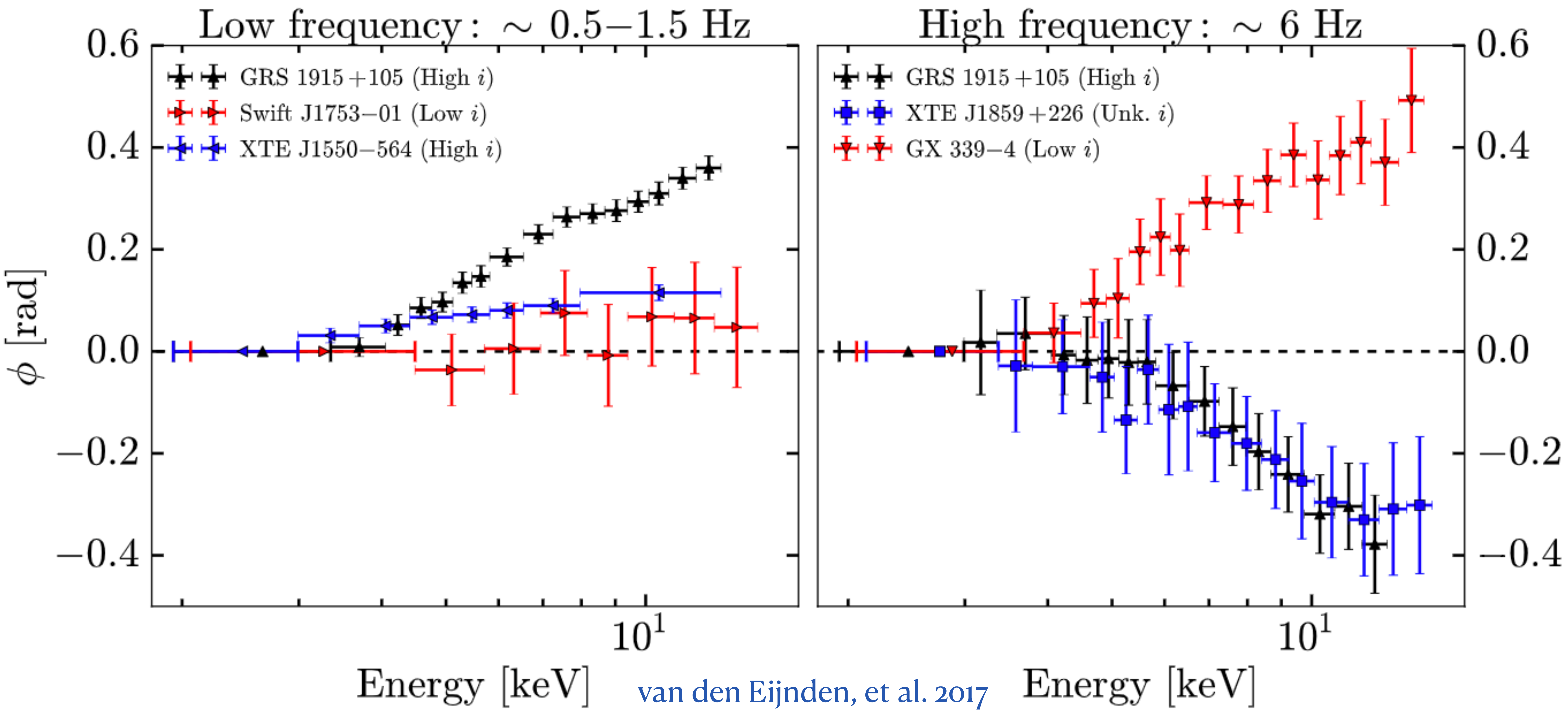

Motta et al.2016

**Hard lags in low inclination systems, soft lags in high inclination systems**




van den Eijnden, et al. 2017

# The inclination dependence on the lag sign

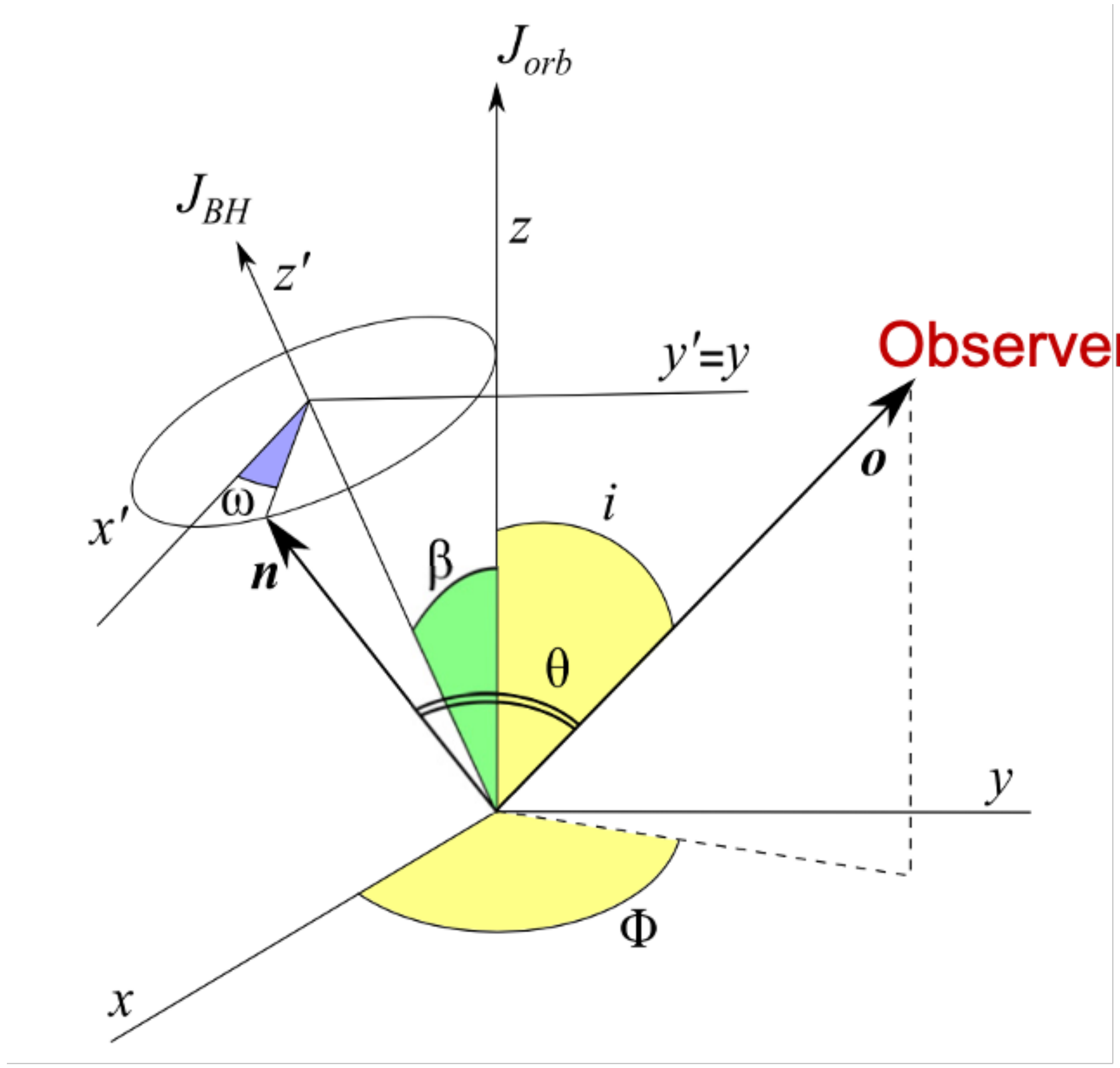


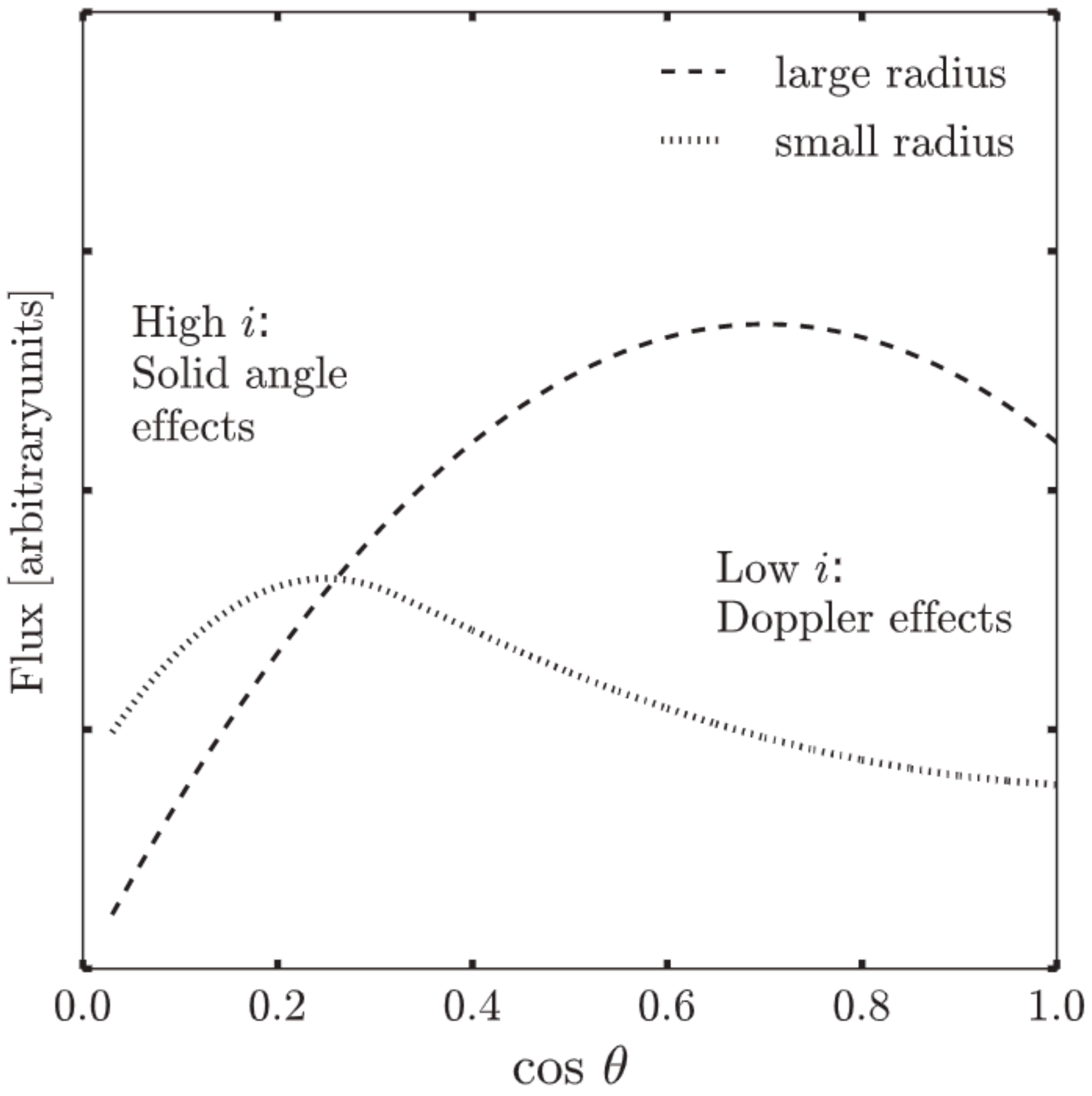

van den Eijnden, et al. 2017

There must be different dominant processes that modulate the observed flux at small radii and large radii

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

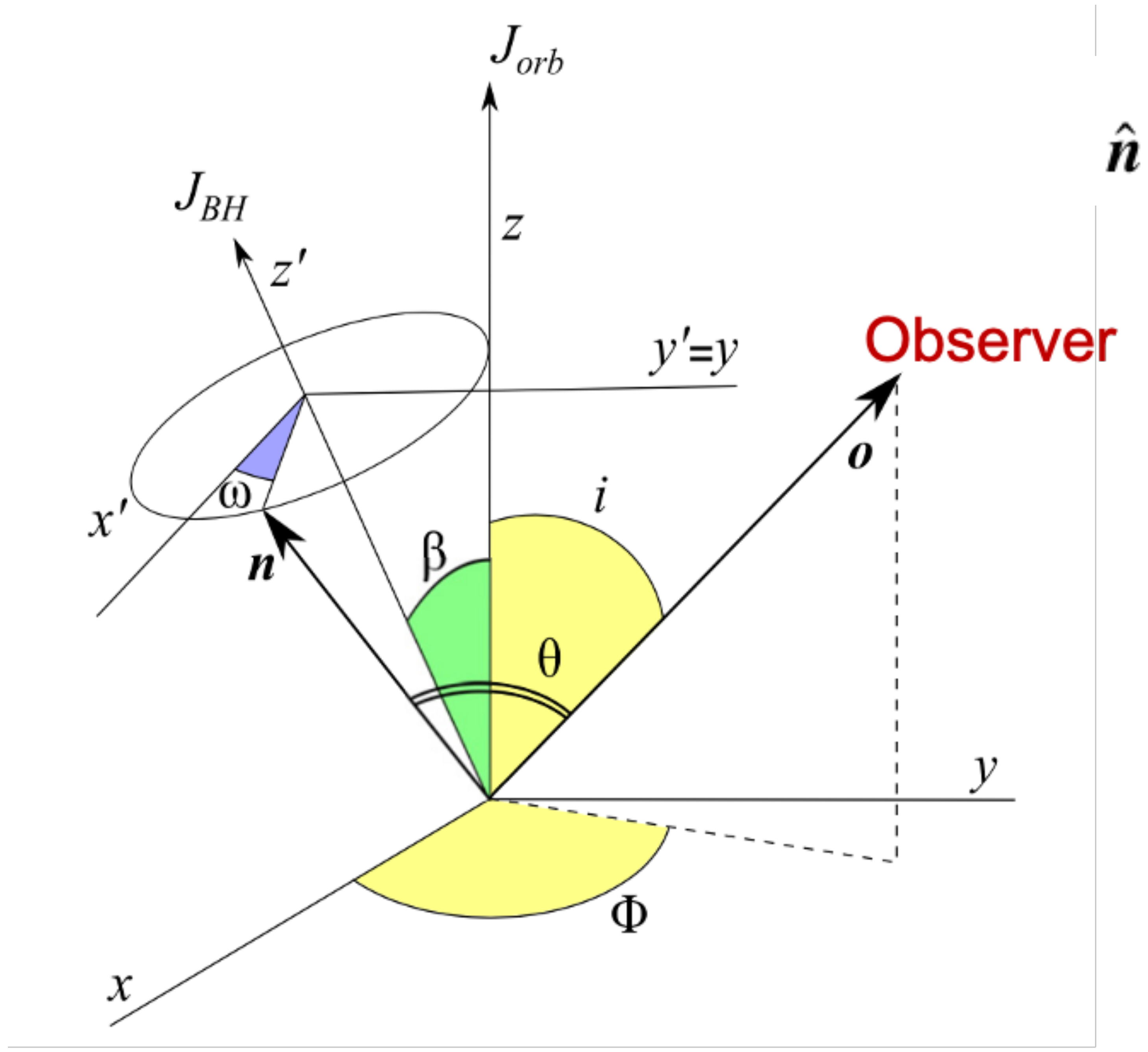
# Assumption:
# The observed flux is modulated by both Doppler effect and solid angle effect



EBERHARD KARLS UNIVERSITÄT TÜBINGEN

# Formalism




$$\hat{\boldsymbol{o}} = (\sin i \cos\Phi, \sin i \sin\Phi, \cos i),$$

Observer

$$\hat{\boldsymbol{n}} = (\sin\beta\cos\beta(1+\cos\omega), \sin\beta\sin\omega, \cos^2\beta - \sin^2\beta\cos\omega).$$

Instantaneous normal to the hot flow/jet

$$\cos\theta = \sin\beta\cos\beta\sin i\cos\Phi\,(1+\cos\omega) + \sin\beta\sin\omega\sin i\sin\Phi + \cos i\,(\cos^2\beta - \sin^2\beta\cos\omega).$$

$$\Omega = \frac{S\cos\theta}{D^2}$$

S is the surface area of the ring at R, D is the distance

$$F = I\Omega = I_E(\delta\sqrt{1 - r_g/r})^{\Gamma-1}]\Omega$$

Γ is the PL index

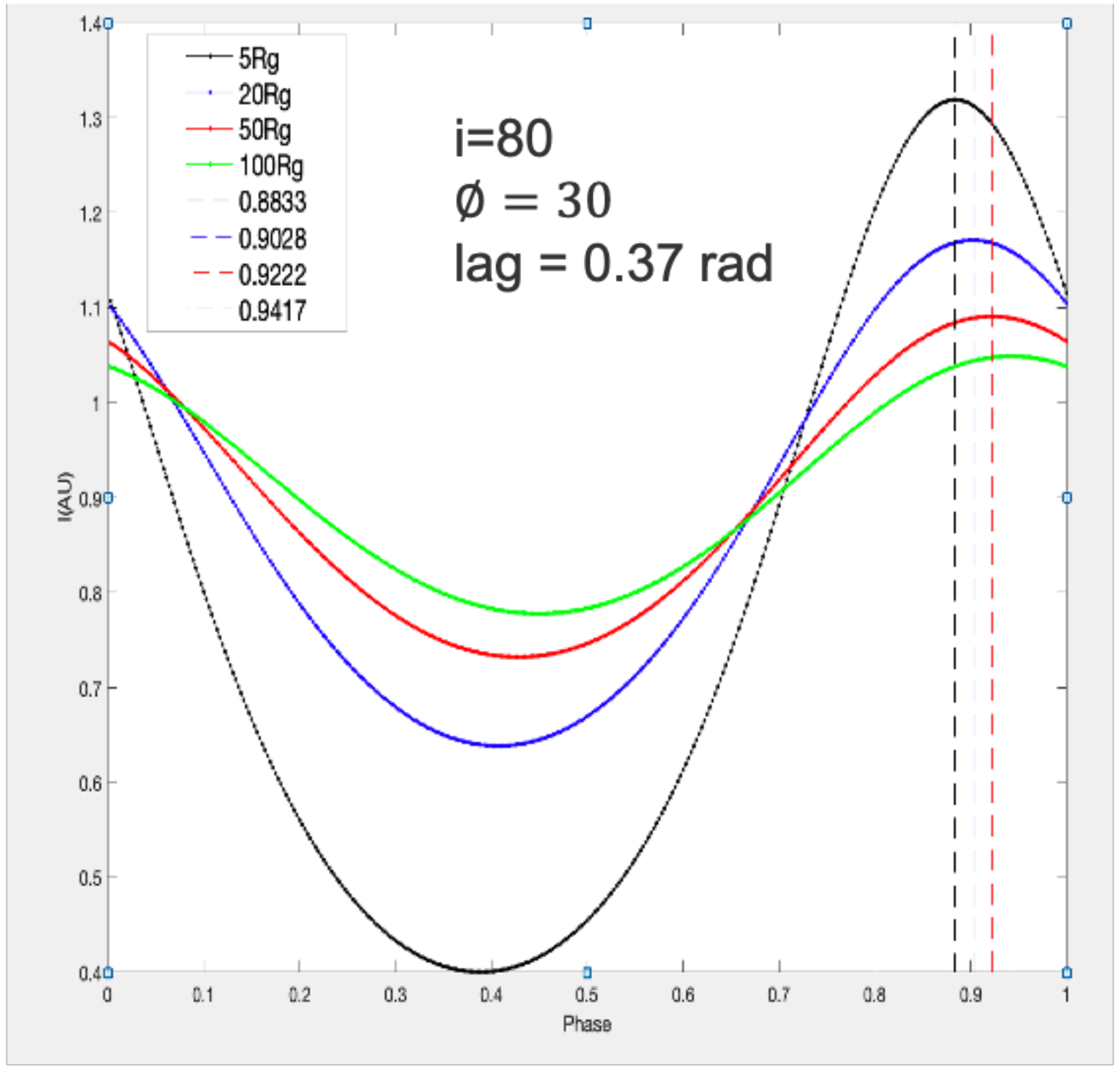
$$\delta = \frac{1}{\gamma(1 - \frac{\hat{v}\,.\,\hat{o}}{c})}$$

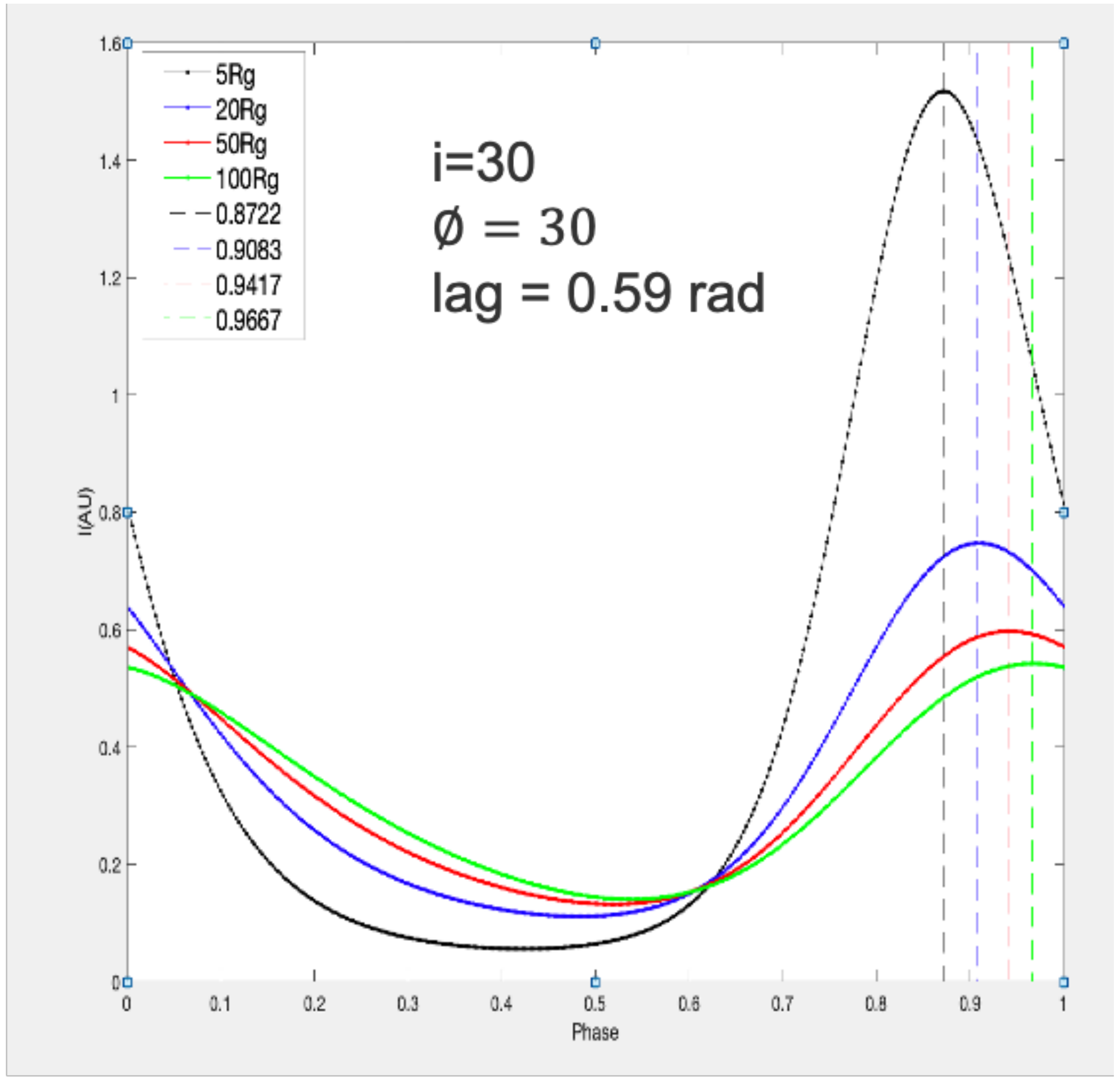
$\gamma$ is the Doppler factor and c is the speed of light



Bu et al. 2022, In prep.

# Simulated flux on different inclination angle

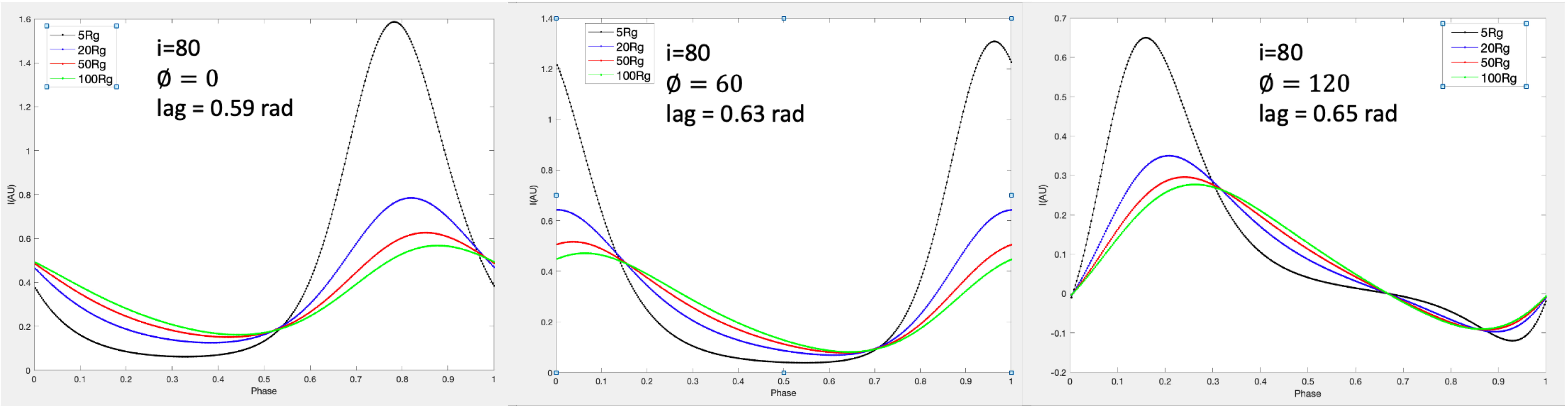


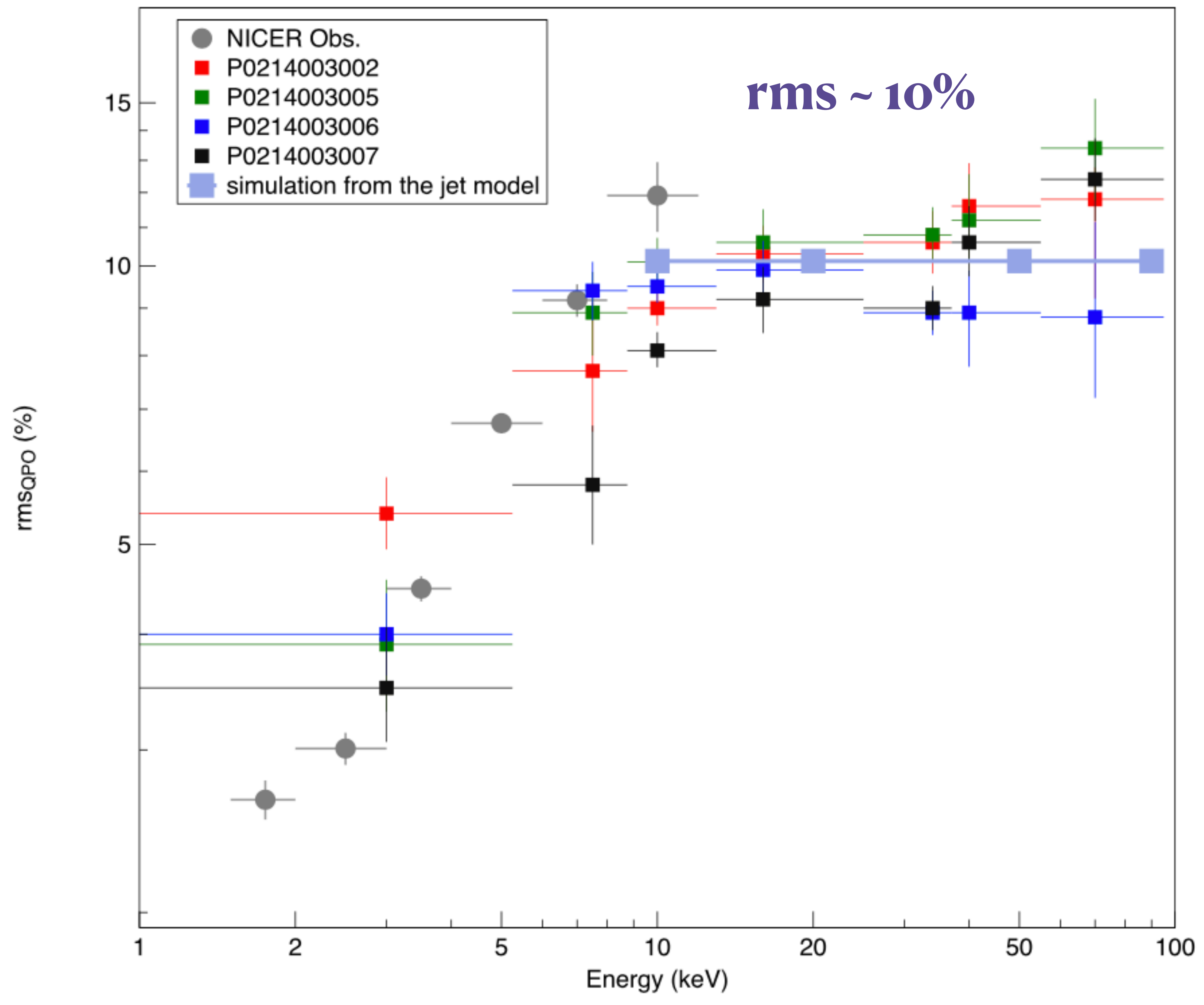
# Simulated flux on different observer's azimuthal angle

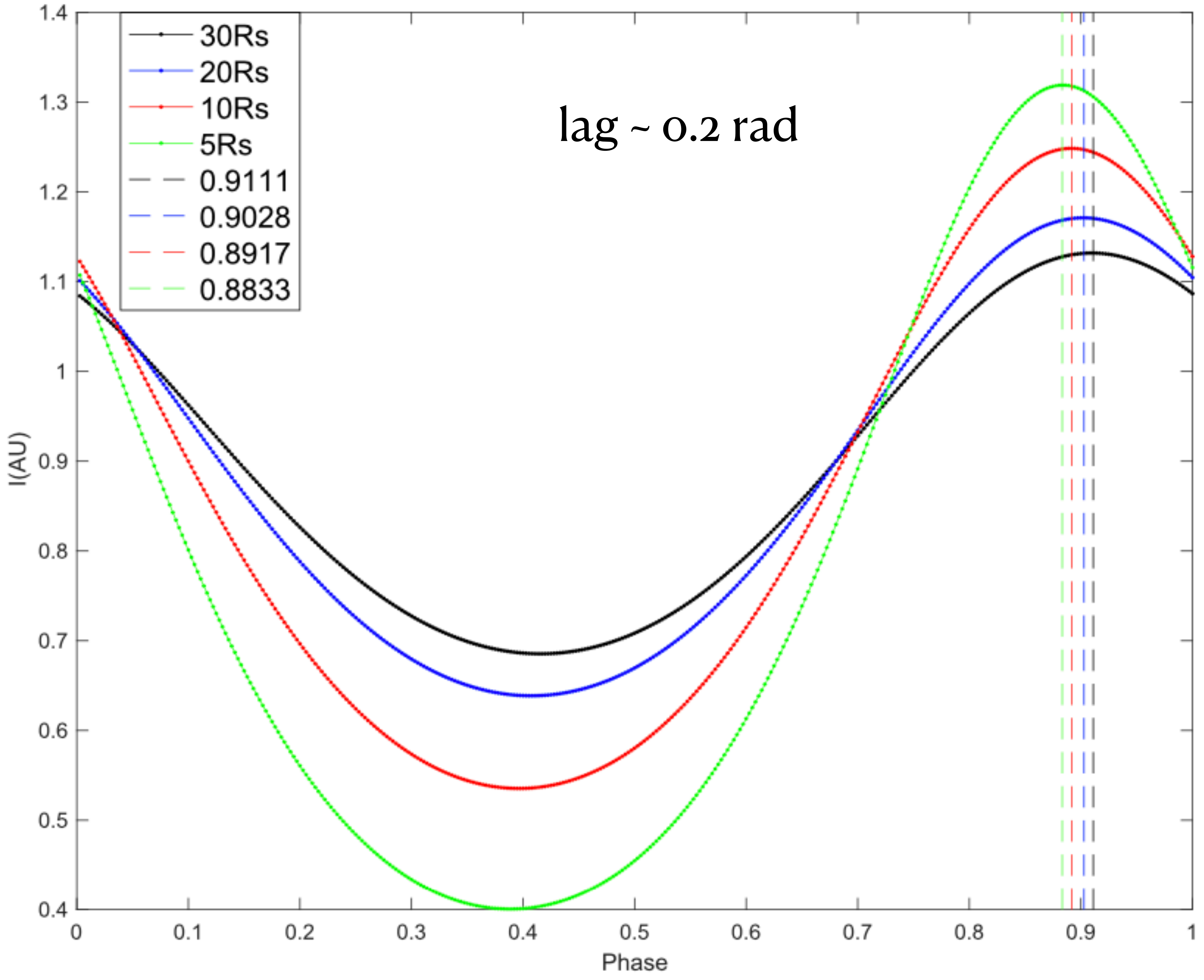

The azimuthal angle has weak effect on the lag in low inclination system

## The azimuthal angle has relatively stronger effect on high inclination system



# Application to MAXI J1631-479




Bu et al. 2021

# Conclusion

- The observed inclination dependence on QPO properties clearly suggest a geometric origin
- The observed flux is modulated by both Doppler effect and solid angle effect
- The lag is a little higher in high inclination system
- The rms is higher in high inclination system
- The solid angle effect become dominant in high inclination system