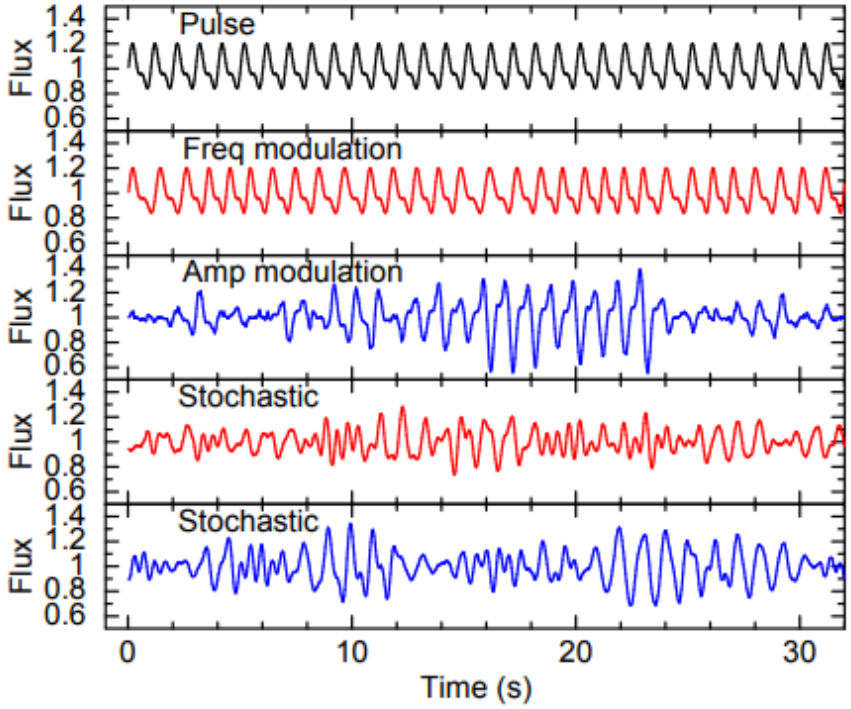
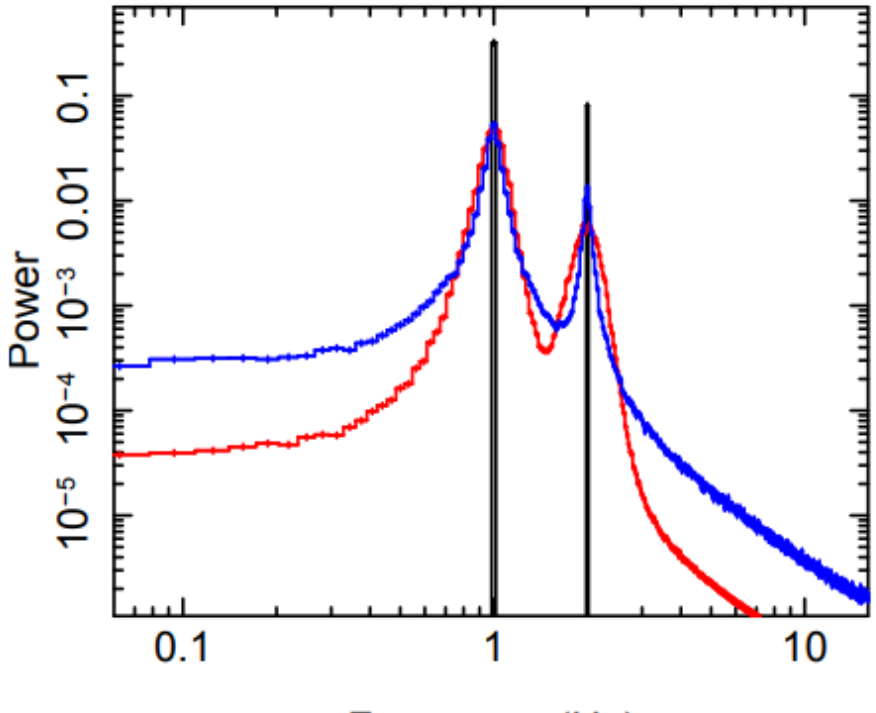
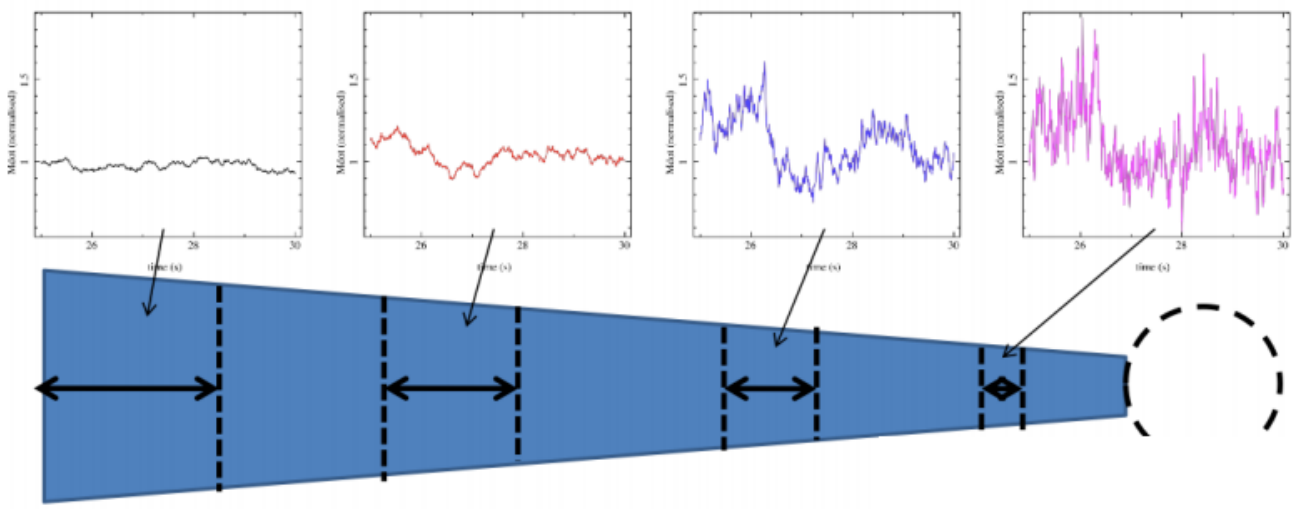
What is a QPO?

In this case we would have a purely periodic function, whose power spectrum would be a sum of delta-functions (i.e. a pulsation). What if we modulate the signal amplitude and frequency?





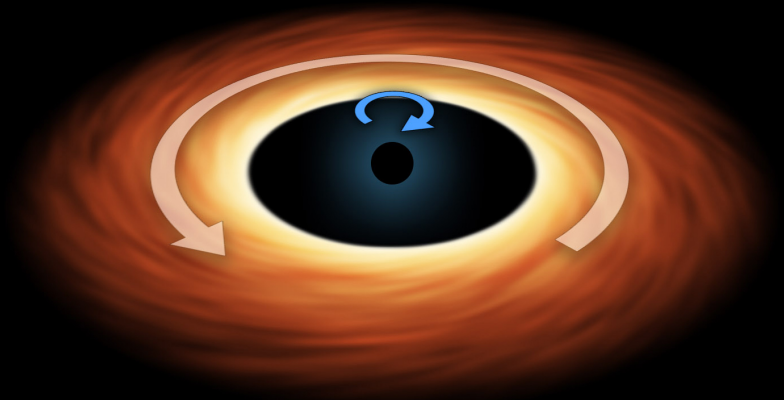
X-Ray Variability: Propagating Fluctuations?



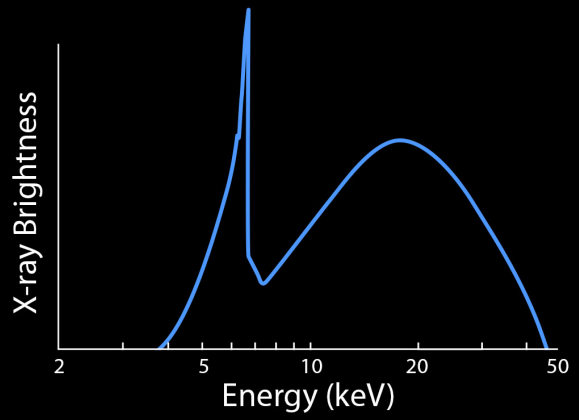
Long times scales produced at large distances (turbulent fluctuations of mass accretion rate ?) and propagate inward on viscous time scale until they reach X-ray emitting region (within 100 R)

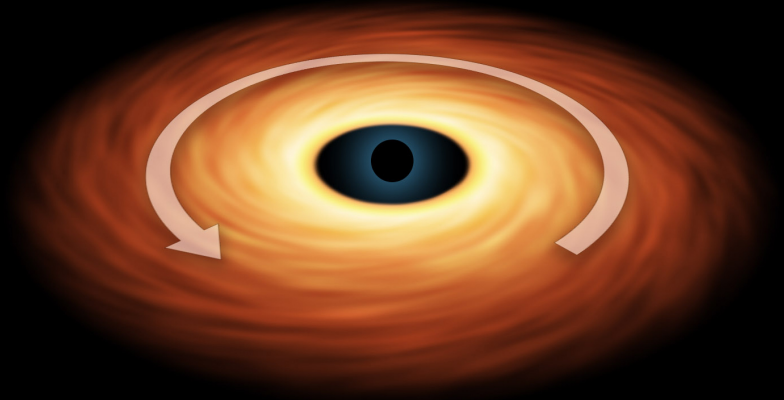
Accretion disks model may produce 1/f noise (Lyubarskii 1997; King et al. 2004; Arevalo & Uttley 2006, Mayer & Pringle 2006, …)

Explains observed rms-flux correlation (Uttley et al. 2005)

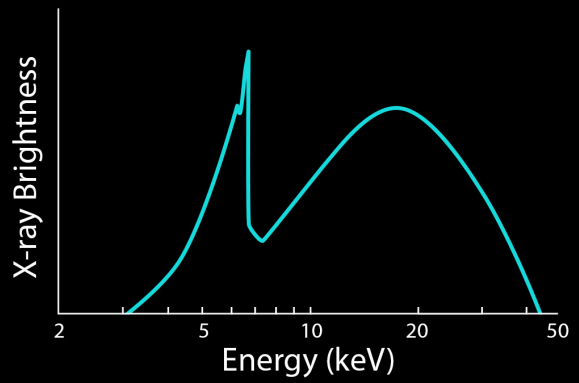


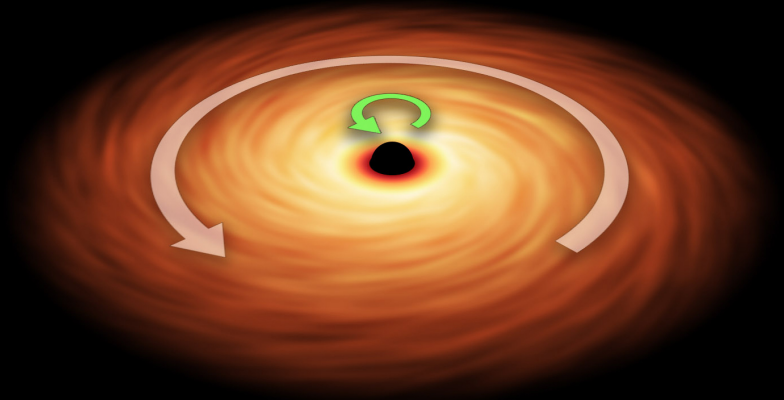
Retrograde Rotation



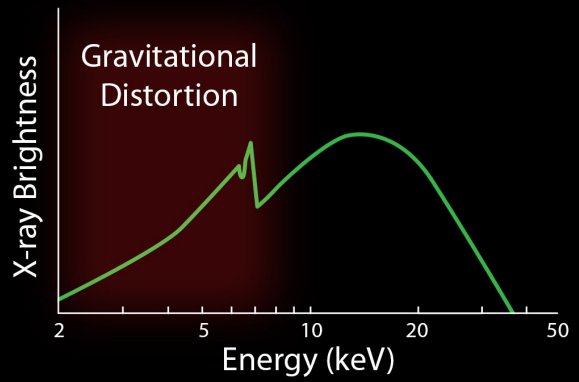


No Black Hole Rotation

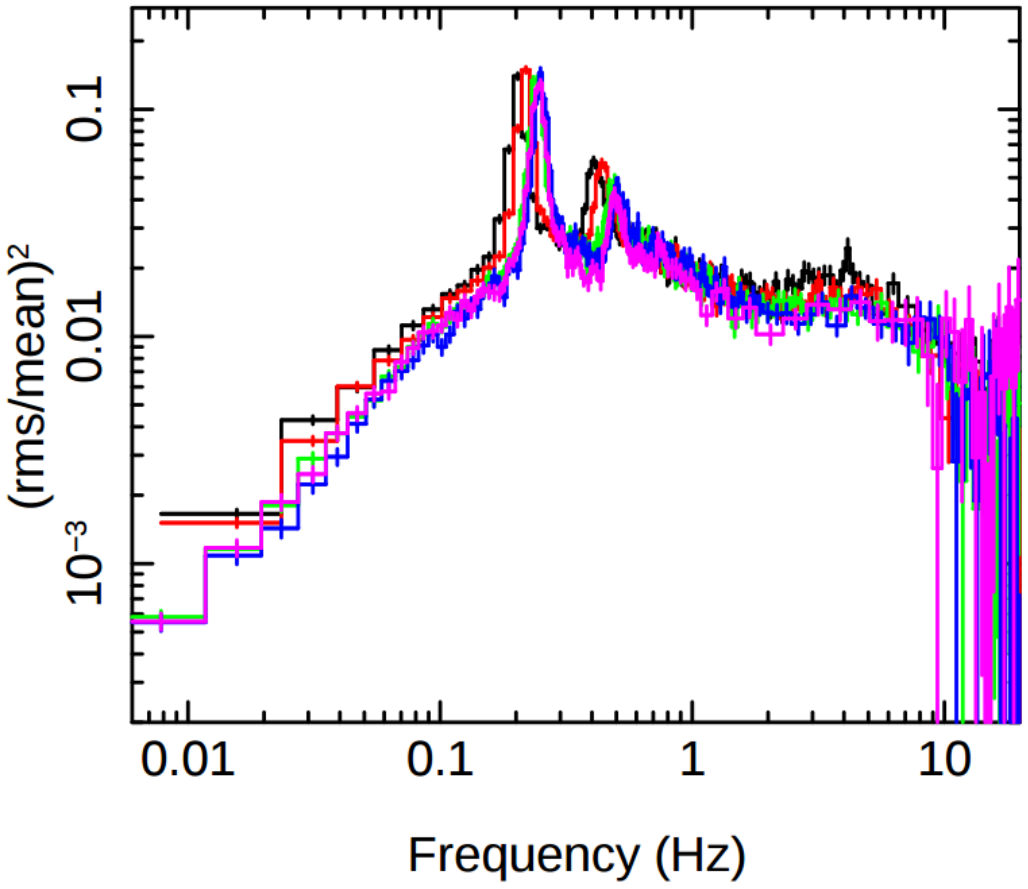




Prograde Rotation



Type-C QPO (Quasi Periodic Oscillation)

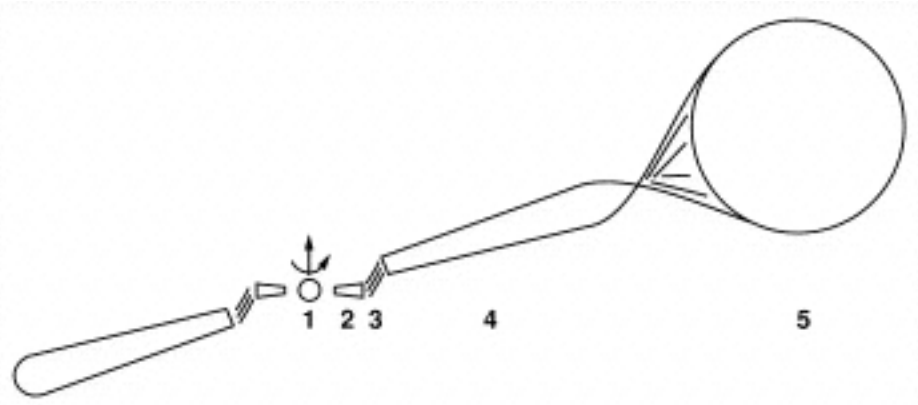


Observed in several Black hole binaries.

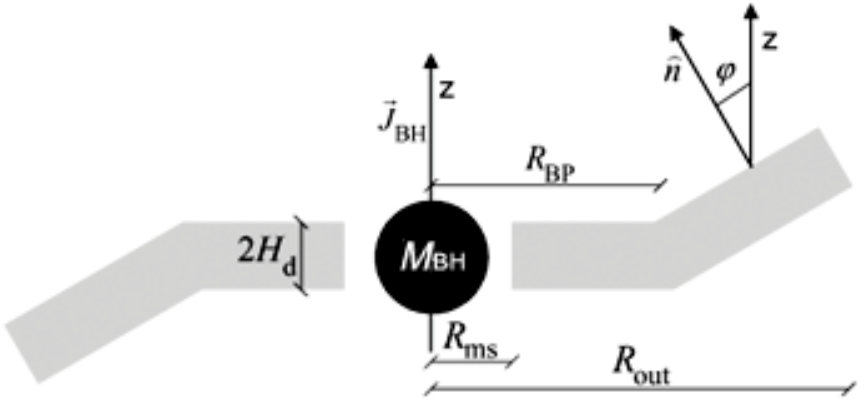
Mysterious origin

0.25 Hz QPO → ~4s modulation

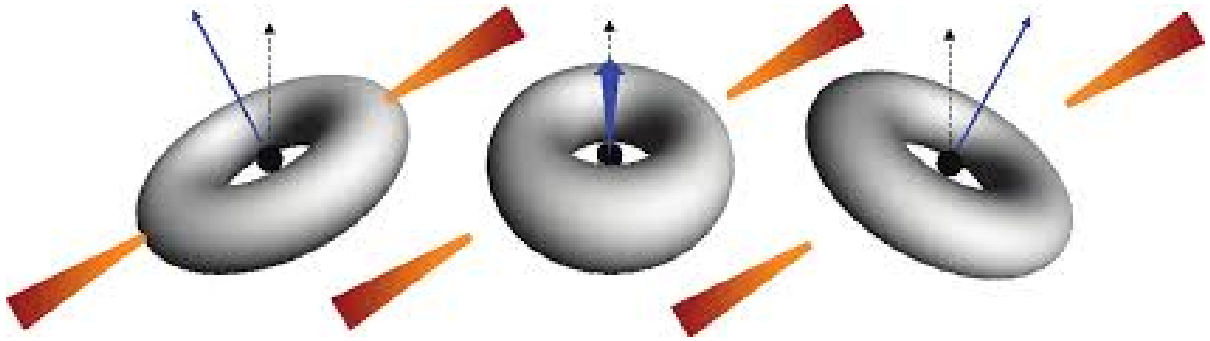
Bardeen-Patterson Effect



Bardeen & Patterson 1975



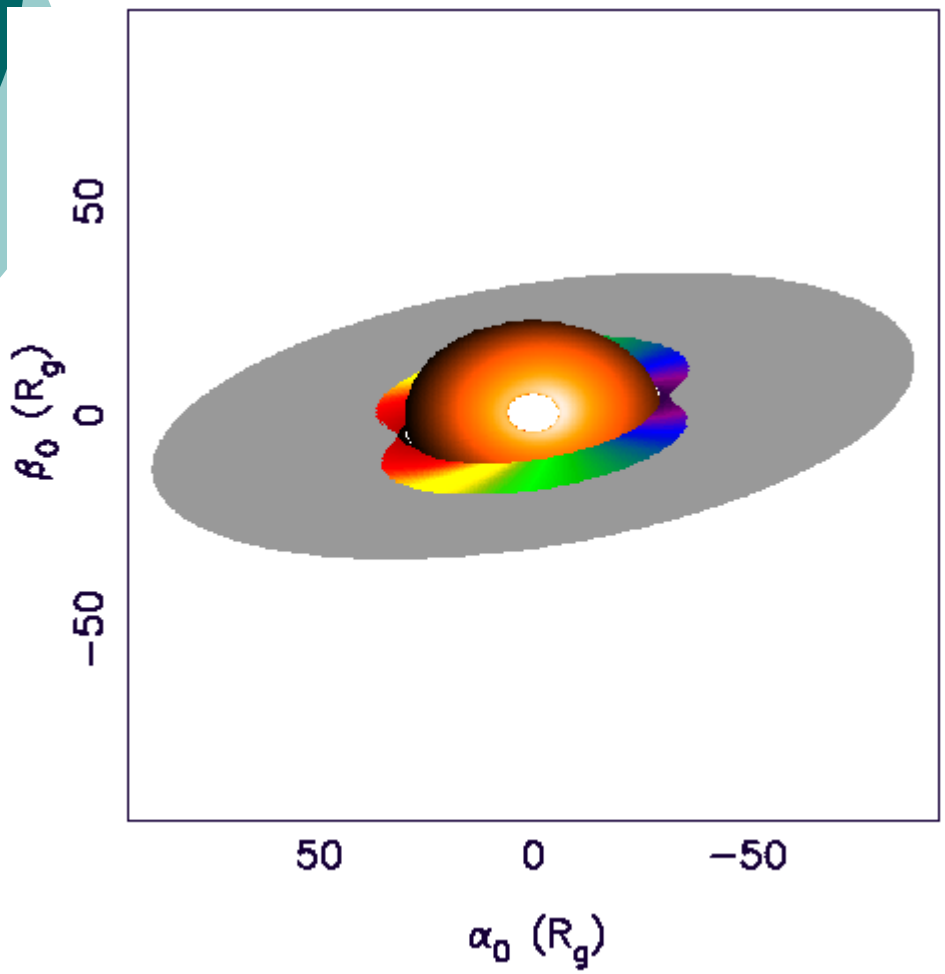
Lense-Thirring Precession

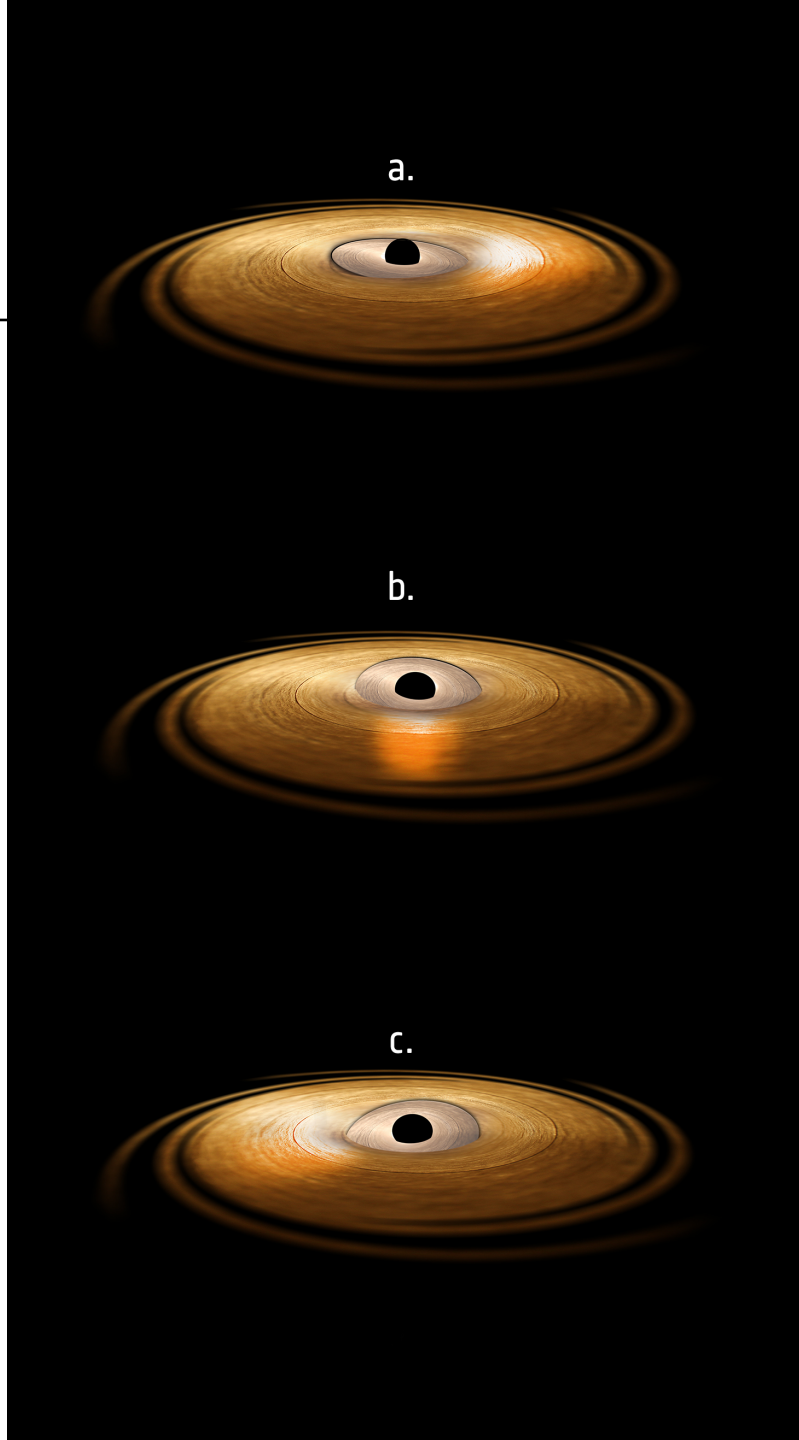


In general relativity, Lense–Thirring precession is a relativistic correction to the precession of a gyroscope near a large rotating mass..

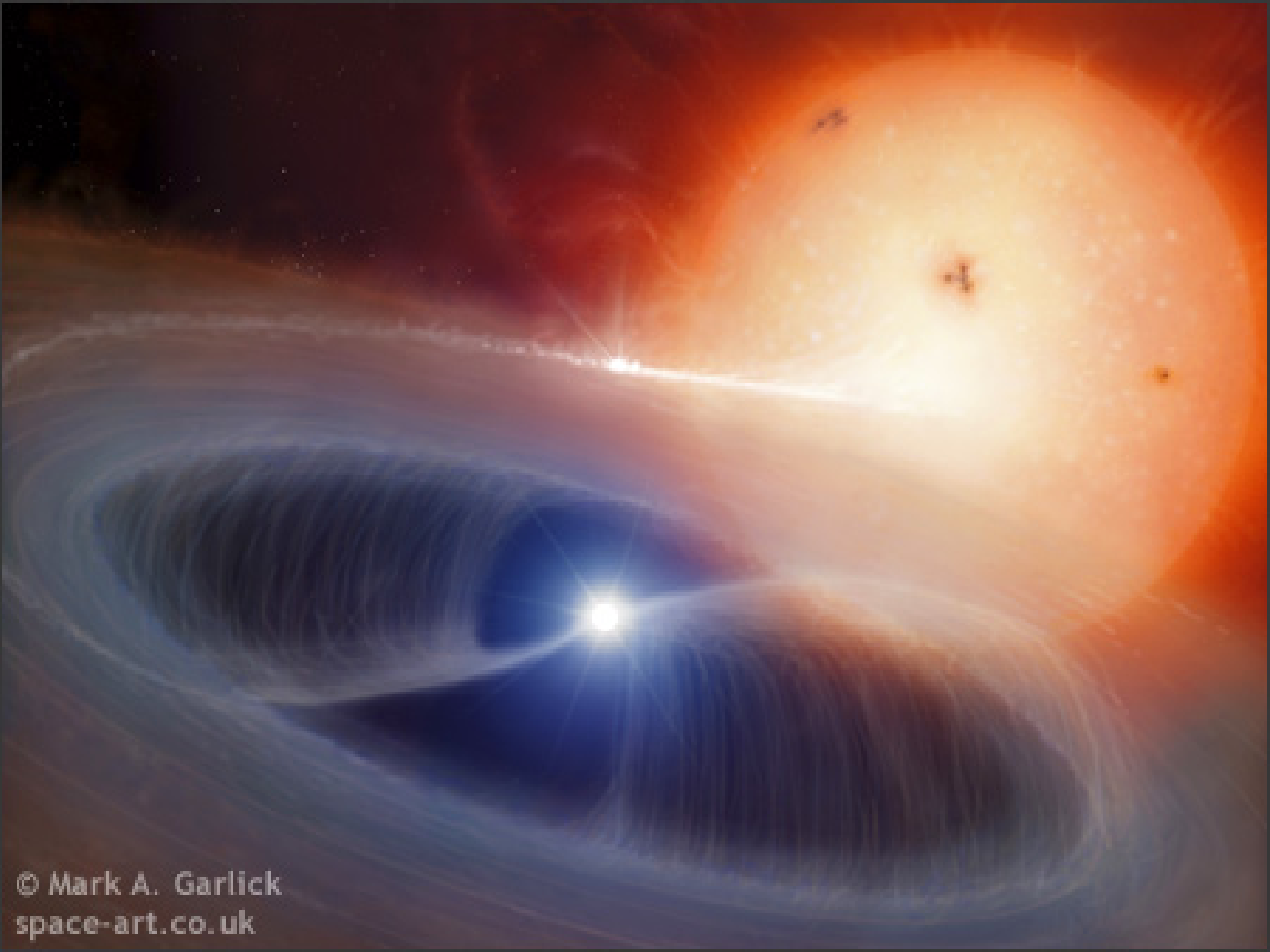
Example Period of Lense-Thirring precession
around Earth ~ 33 Myr
around a 10 Msun Black Hole ~ few seconds

Lense-Thirring Precession around H 1743-322





Ingram et al. 2016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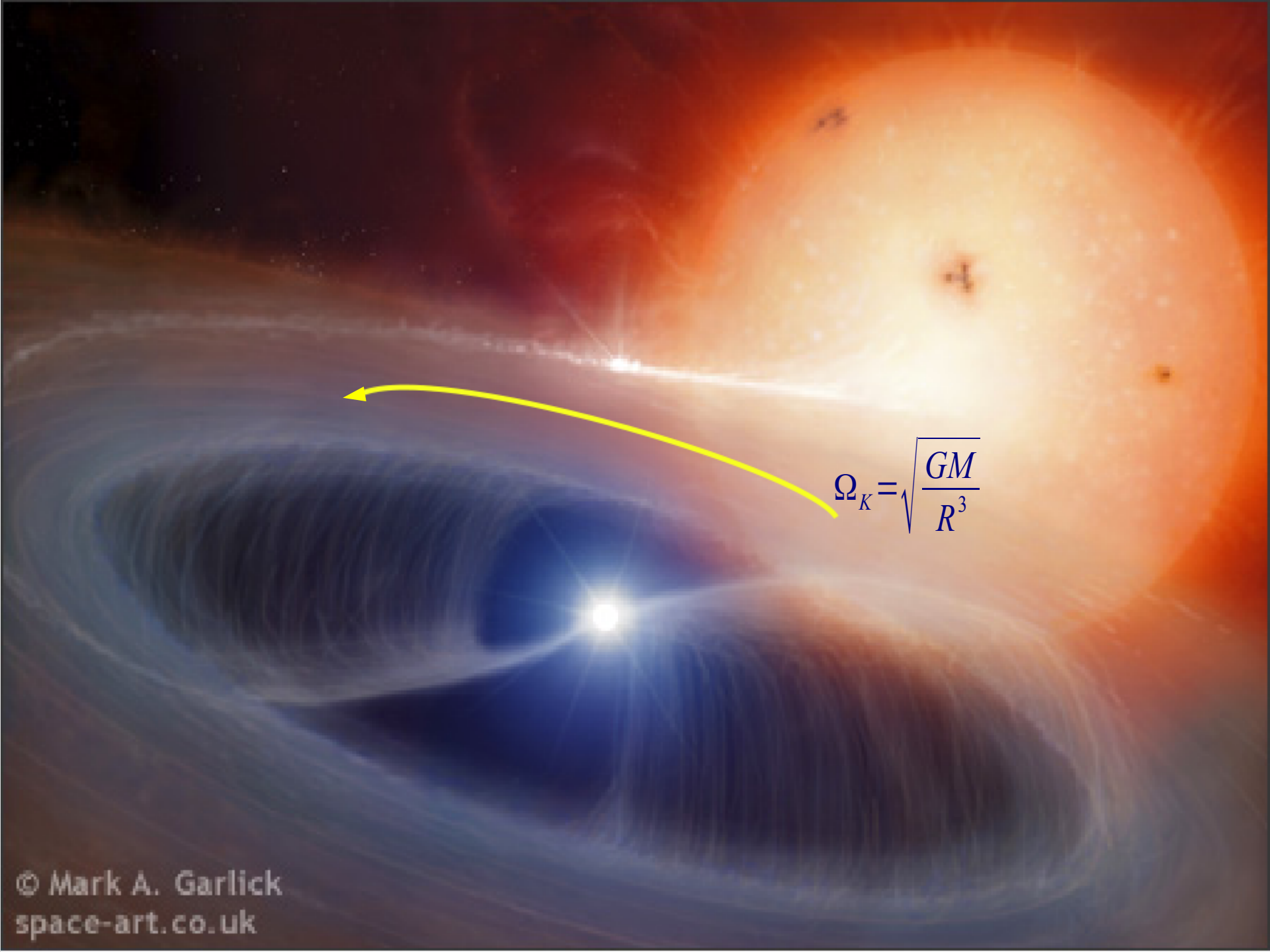
$\Omega_K = \sqrt{\frac{GM}{R^3}}$
© Mark A. Garlick
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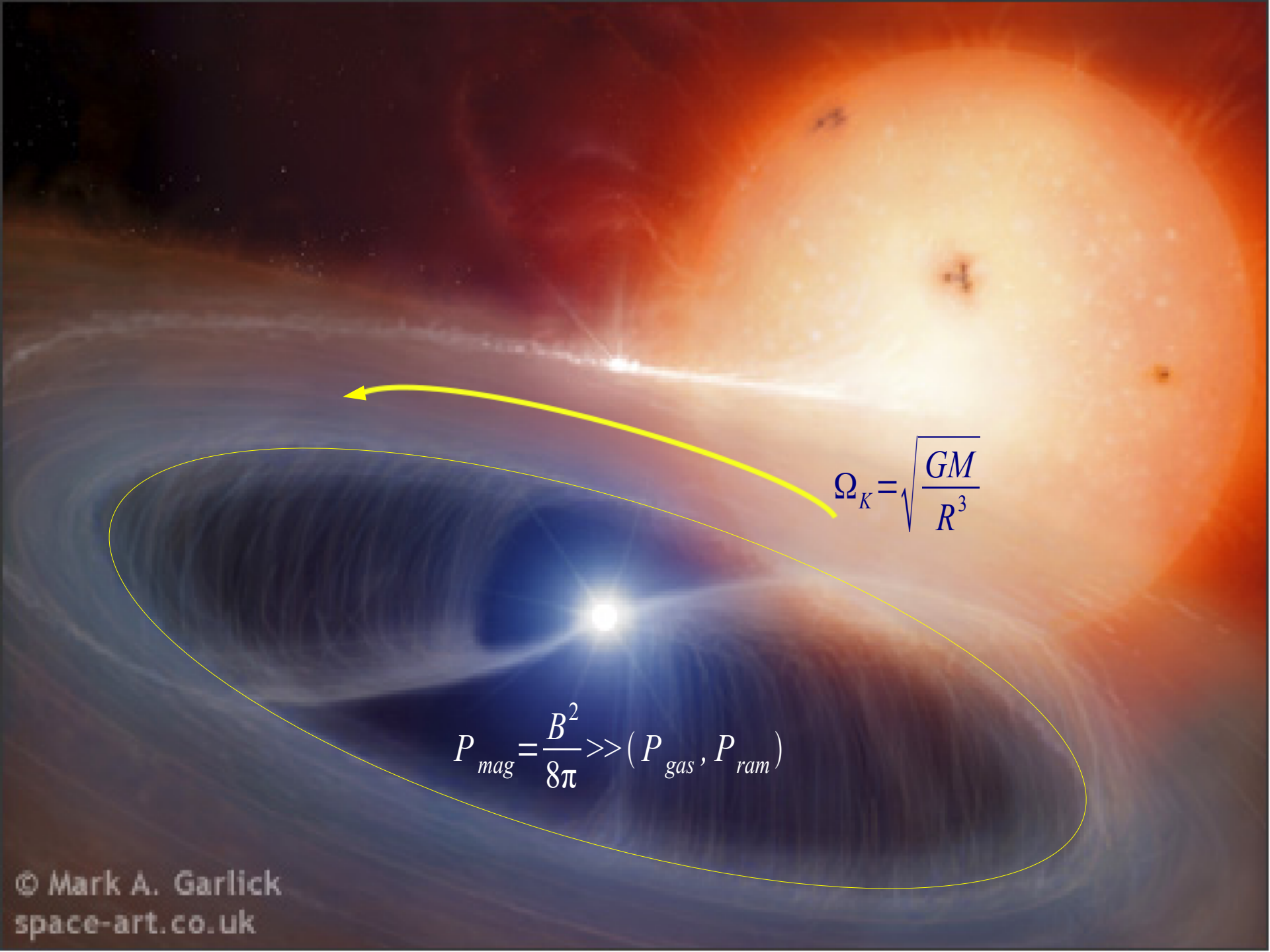
$\Omega_K = \sqrt{\frac{GM}{R^3}}$
$P_{mag} = \frac{B^2}{8\pi} >> (P_{gas}, P_{ram})$
© Mark A. Garlick
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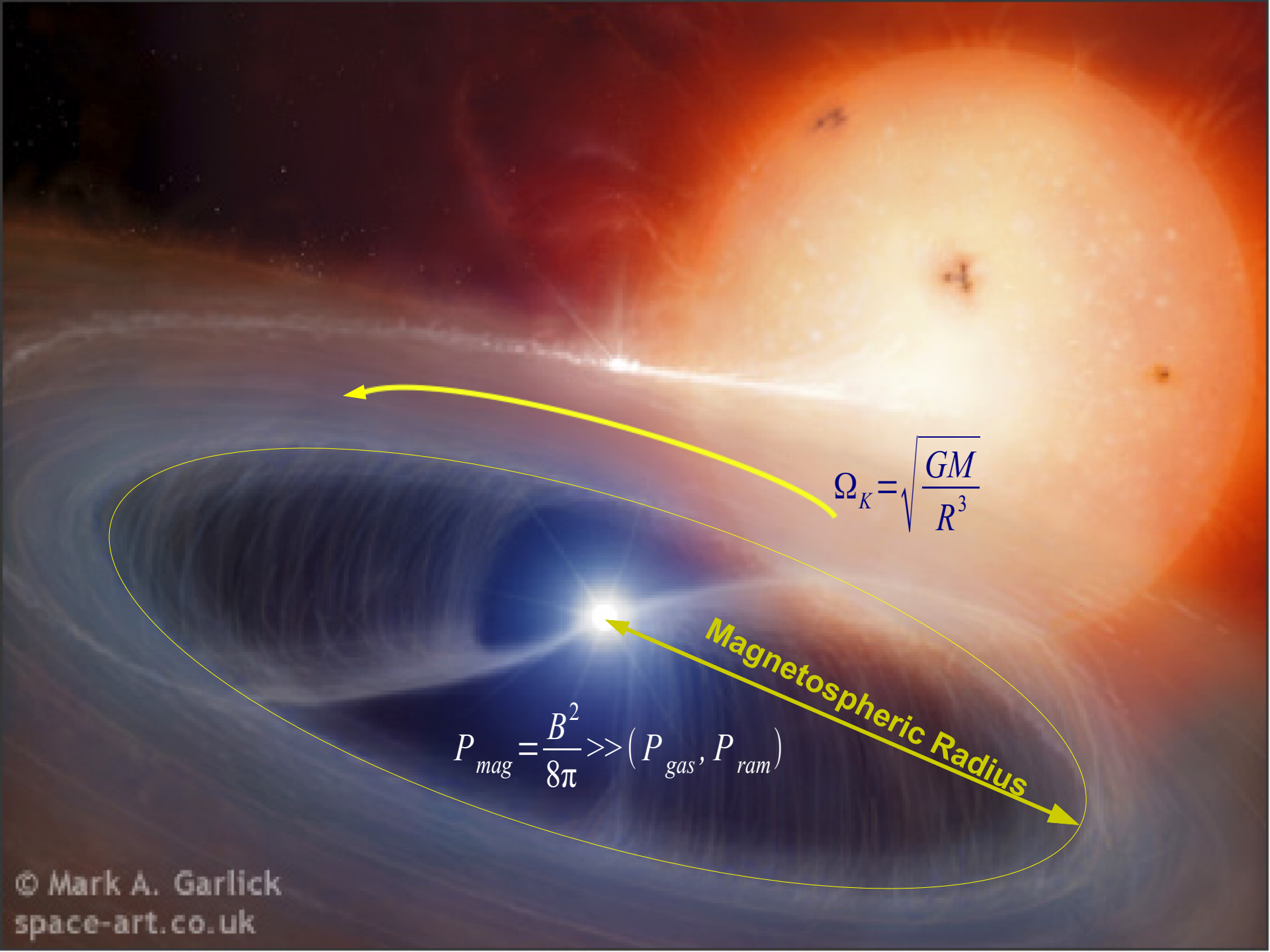
$\Omega_K = \sqrt{\frac{GM}{R^3}}$
Magnetospheric Radius
$P_{mag} = \frac{B^2}{8\pi} >> (P_{gas}, P_{ram})$
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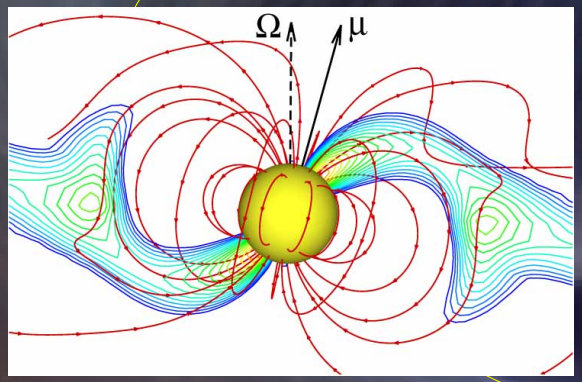


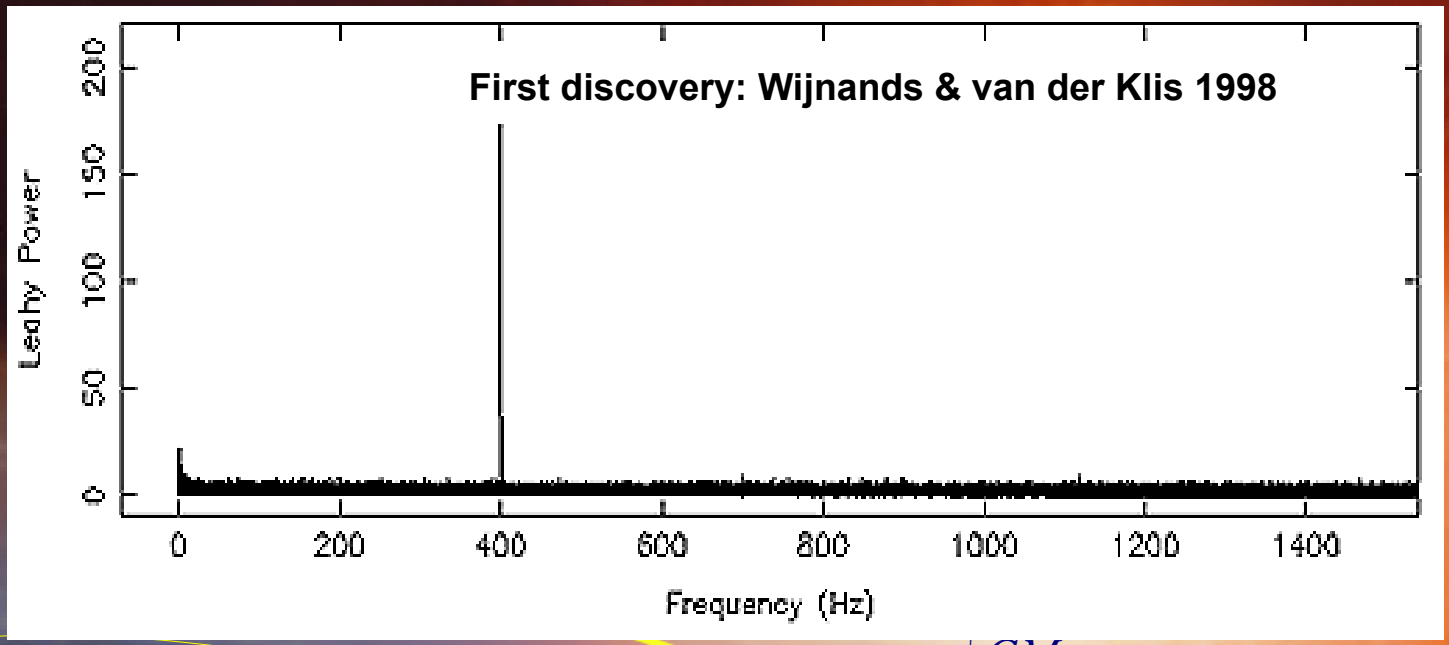
Hot Spots

$$\Omega_K = \sqrt{\frac{GM}{R^3}}$$

Magnetospheric Radius

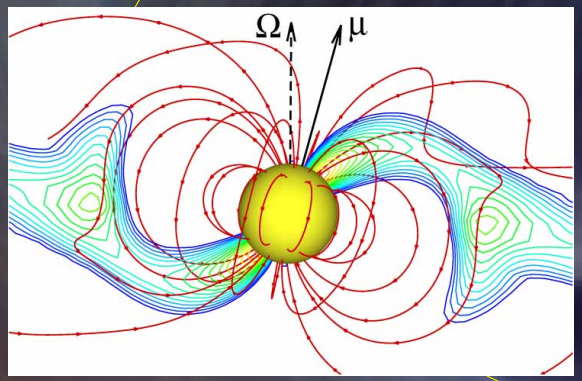
$$P_{mag} = \frac{B^2}{8\pi} >> (P_{gas}, P_{ram})$$

$$\dot{\nu} \propto \dot{M}^{6/7}$$



Hot Spots

$$\Omega_K = \sqrt{\frac{GM}{R^3}}$$



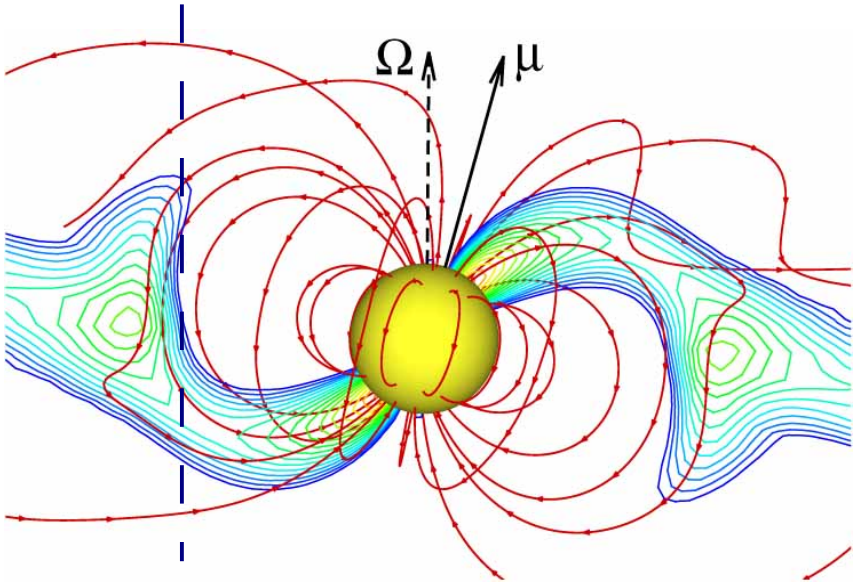
Magnetospheric Radius

$$P_{mag} = \frac{B^2}{8\pi} >> (P_{gas}, P_{ram})$$

$$\dot{\nu} \propto \dot{M}^{6/7}$$

Magnetospheric Accretion

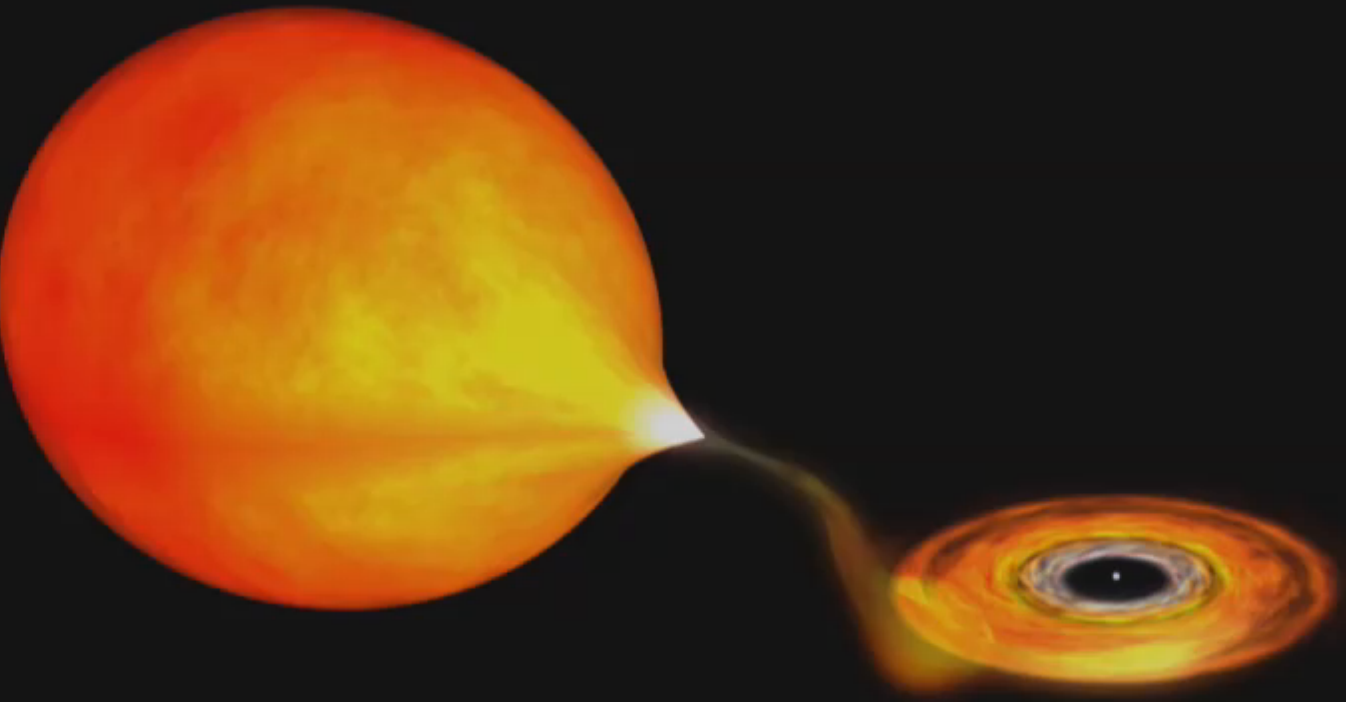
$$N_{acc} \approx \dot{M}\, l(r_m) \approx \dot{M} \sqrt{G M r_m}$$



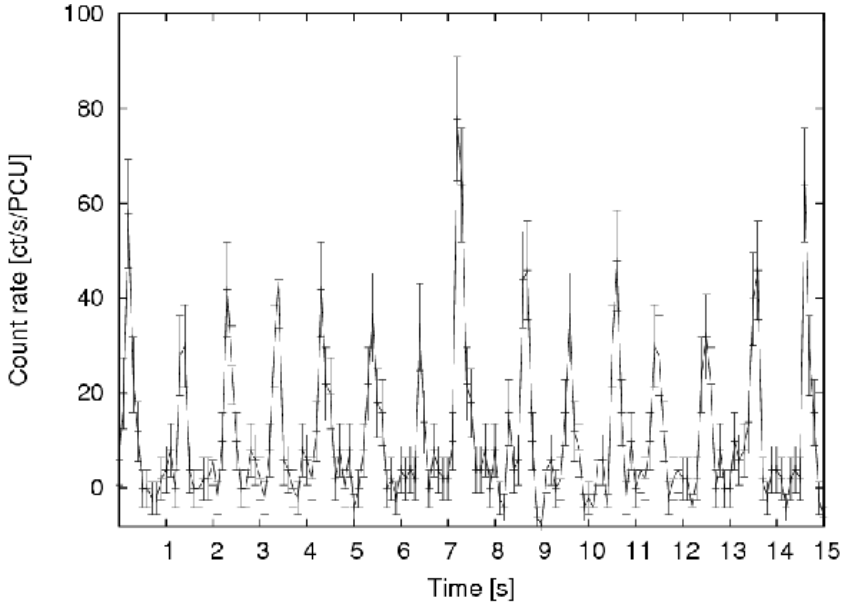
$r_m < r_{co}$ → Accretion is possible. Plasma flows along field lines before landing on the surface.

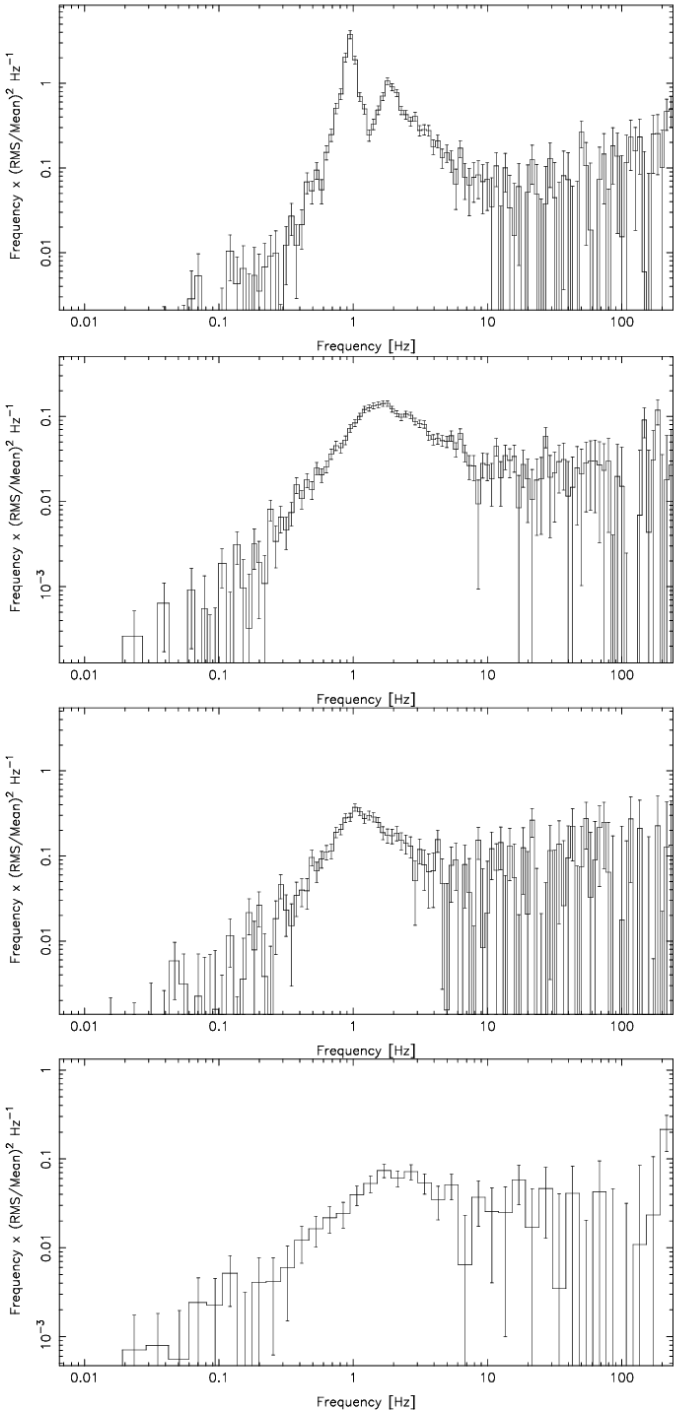
$r_m > r_{co}$ →

- Strong propeller:Accretion is prevented. Plasma is **ejected** by the centrifugal barrier of the magnetic field — Illarionov & Sunyaev '75
- Weak propeller: Material is stopped but **not ejected** from the system — Spruit & Taam '93, Rappaport+ 04, Ustyugova+ '06



1 Hz QPO in Accreting ms Pulsars

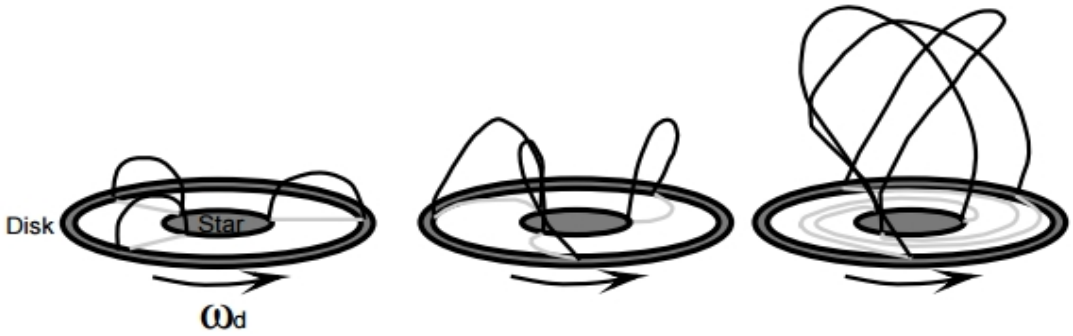




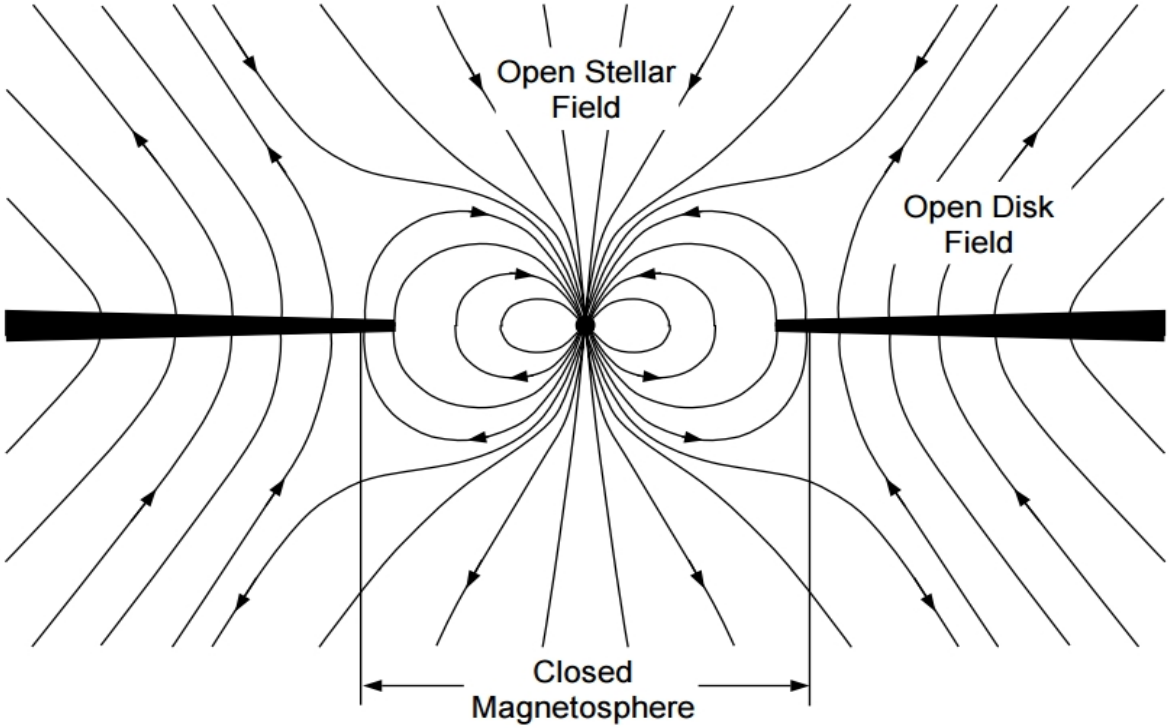
Useful to probe different region of the accretion disk!

Can also help to measure physical characteristics of disk/magnetosphere interaction region (for magnetized neutron stars)

Field inflates almost immediately (ms timescale)



Pulsar field hardly connected at all with the disk.
Field line opening unavoidable



E.g., Aly '85, Lovelace+ '95, Goodson+ '97, D'Angelo & Spruit 2010, Romanova et al. 2008, Patruno et al. 2016

Hydrostatic Equilibrium

with Hydrostatic Equilibrium + EoS you can build a model for your star (and calculate Mass and Radius)

$$m(r) = \int_0^{r'} \rho\, 4\pi r^2\, dr \rightarrow \frac{dm(r)}{dr} = 4\pi r^2 \rho$$

$$\frac{dP}{dr} = \frac{-G\, m(r)\, \rho}{r^2}$$

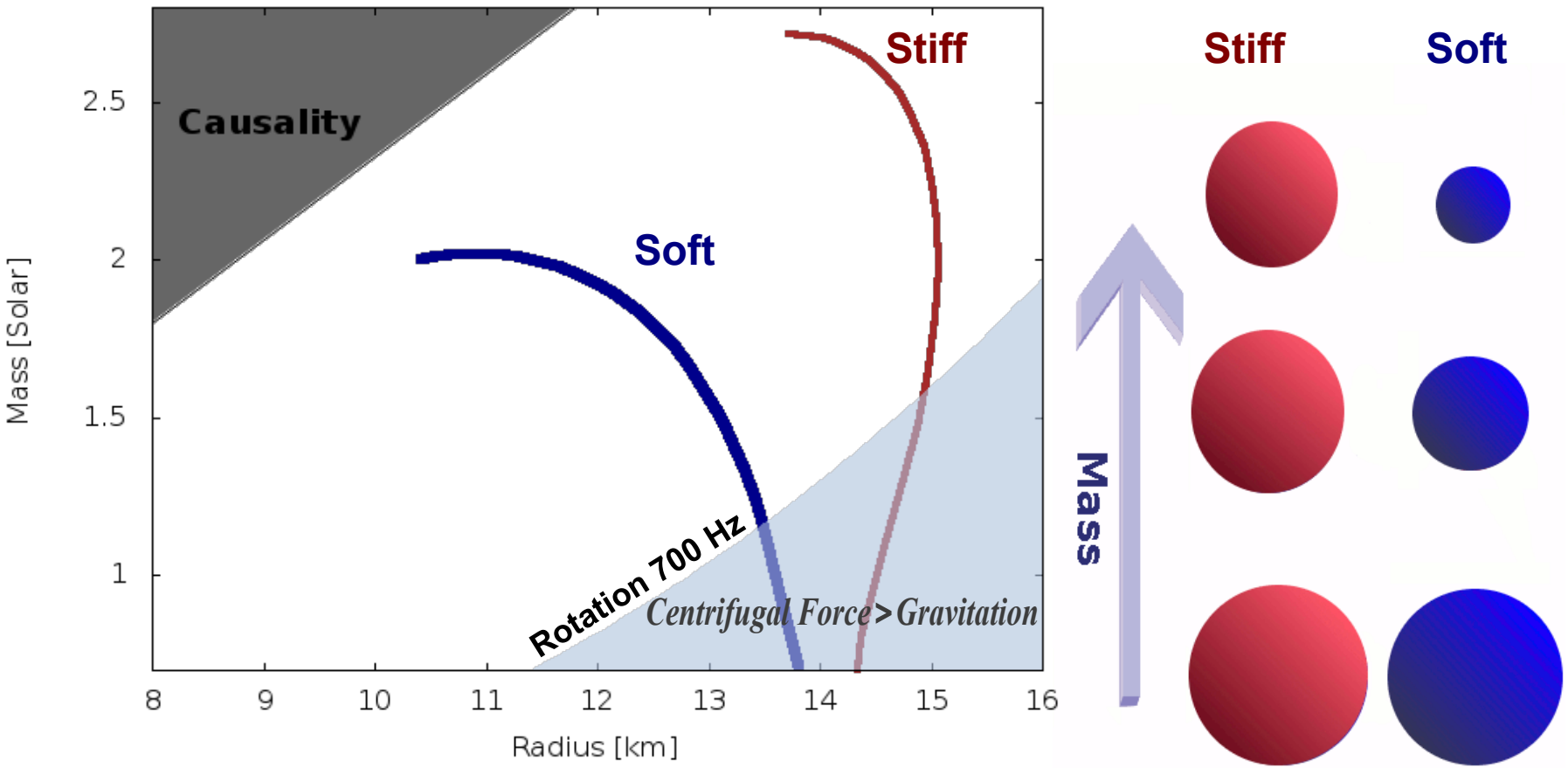
$$\frac{1}{r^2}\frac{d}{dr}\left(\frac{r^2}{\rho}\frac{dP}{dr}\right) = -4\pi G \rho$$

+

Equation of State

Structure of a star (e.g., M-R relation)

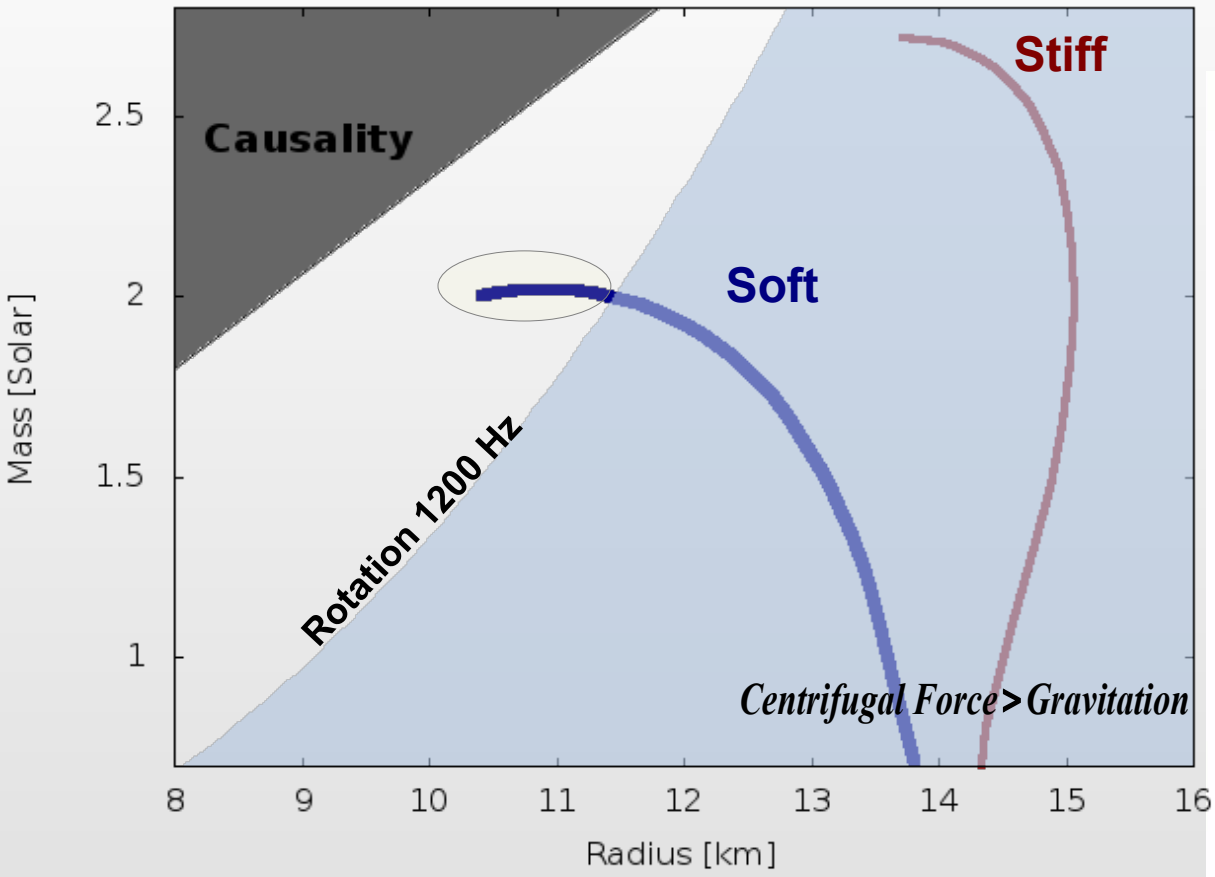
Neutron Stars and Strong Force

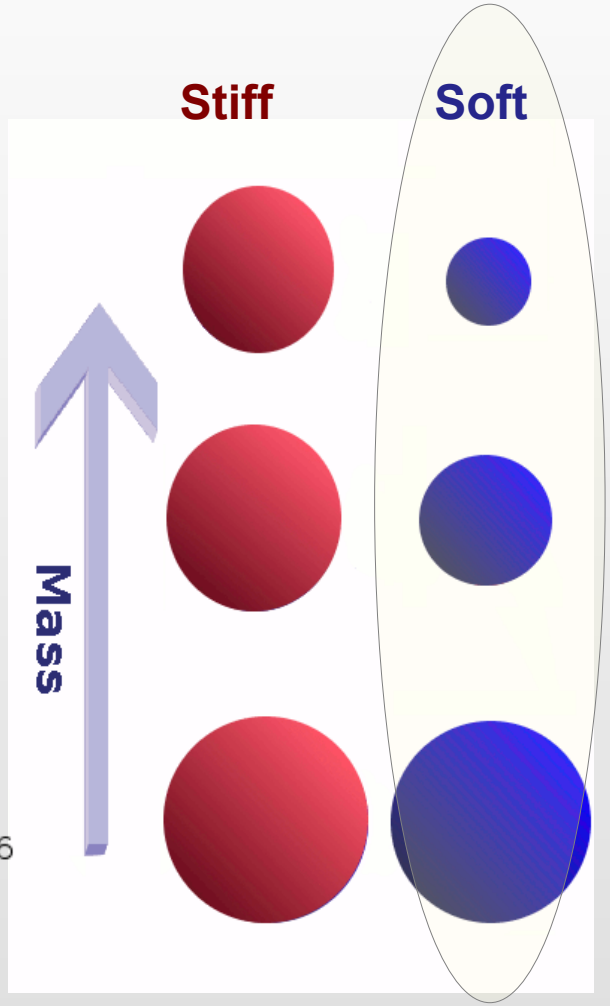


e.g., Lattimer & Prakhash 2011

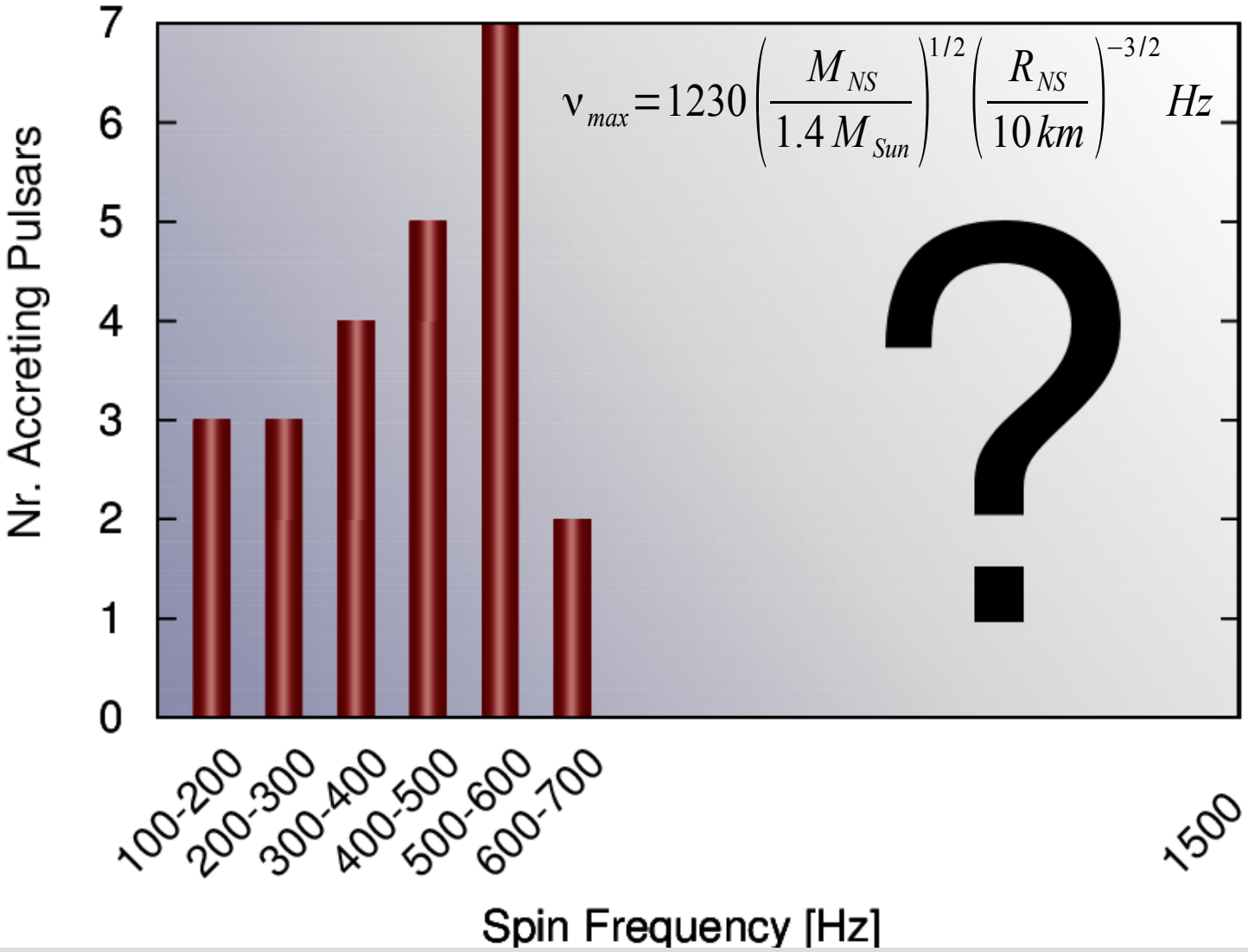
Gravity + EoS → Neutron Star Structure (M-R).
Invert problem: Gravity + M-R → EoS

Neutron Stars and Strong Force





Where are the fastest known pulsar?



Patruno & Watts 2012, Patruno 2010, Chakrabarty et al. 2003