Torus oscillations and the 17 minute QPO

(IR flares in Sgr A*)

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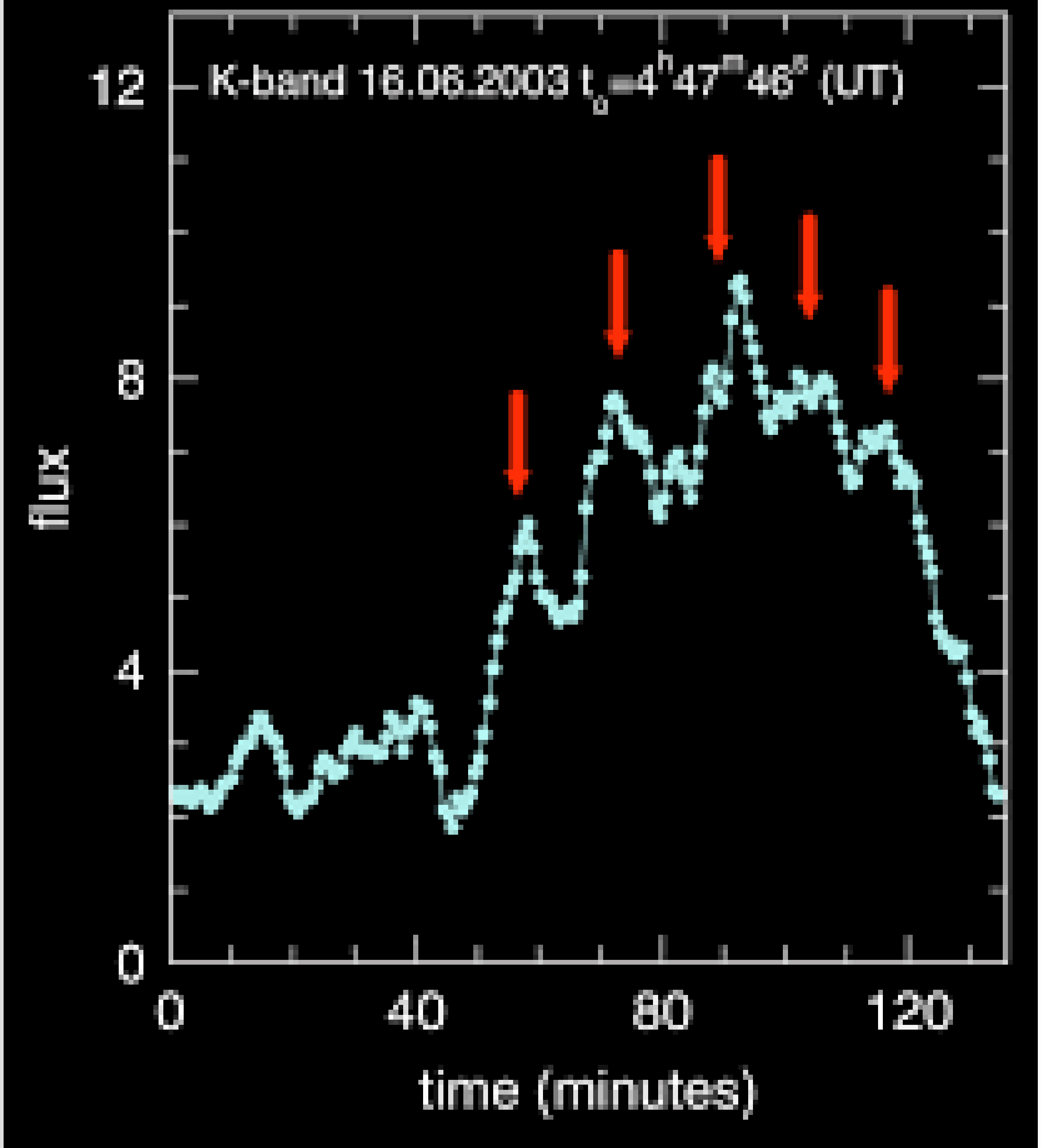
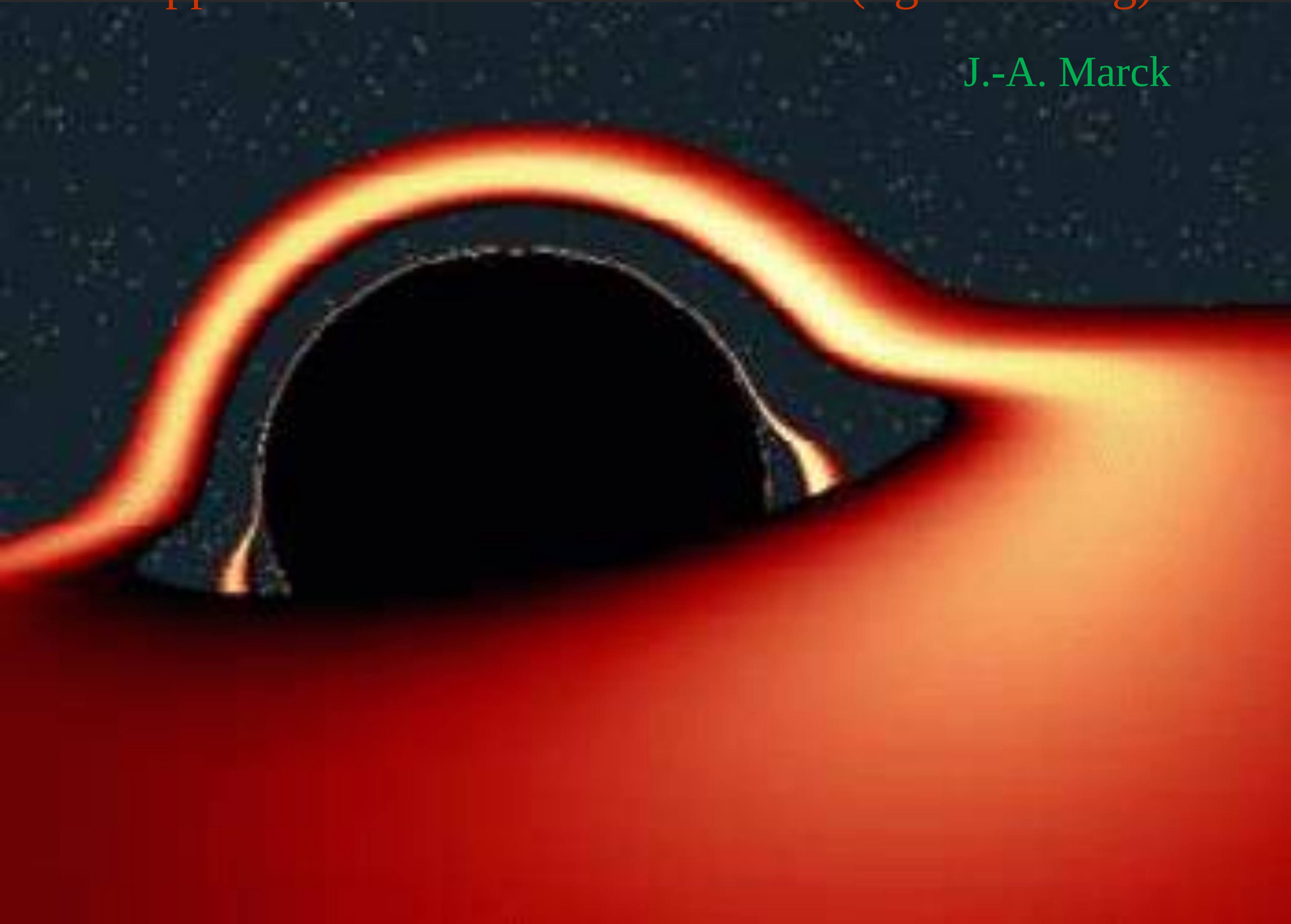
Aspen 2016.02.09

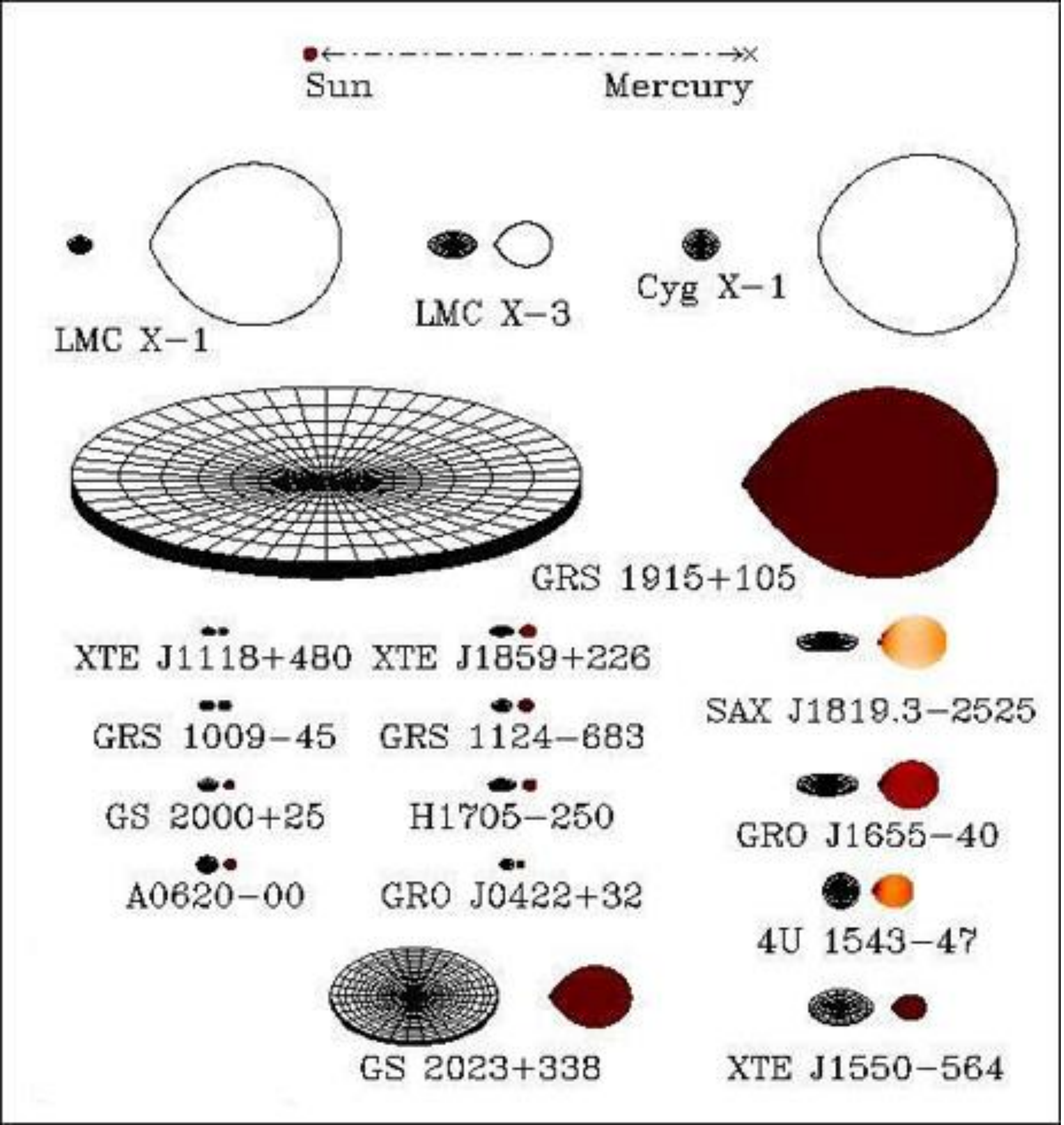
Sgr A*
Genzel et al 2003

17m QPO



Appearance of black hole and disk (light-bending)

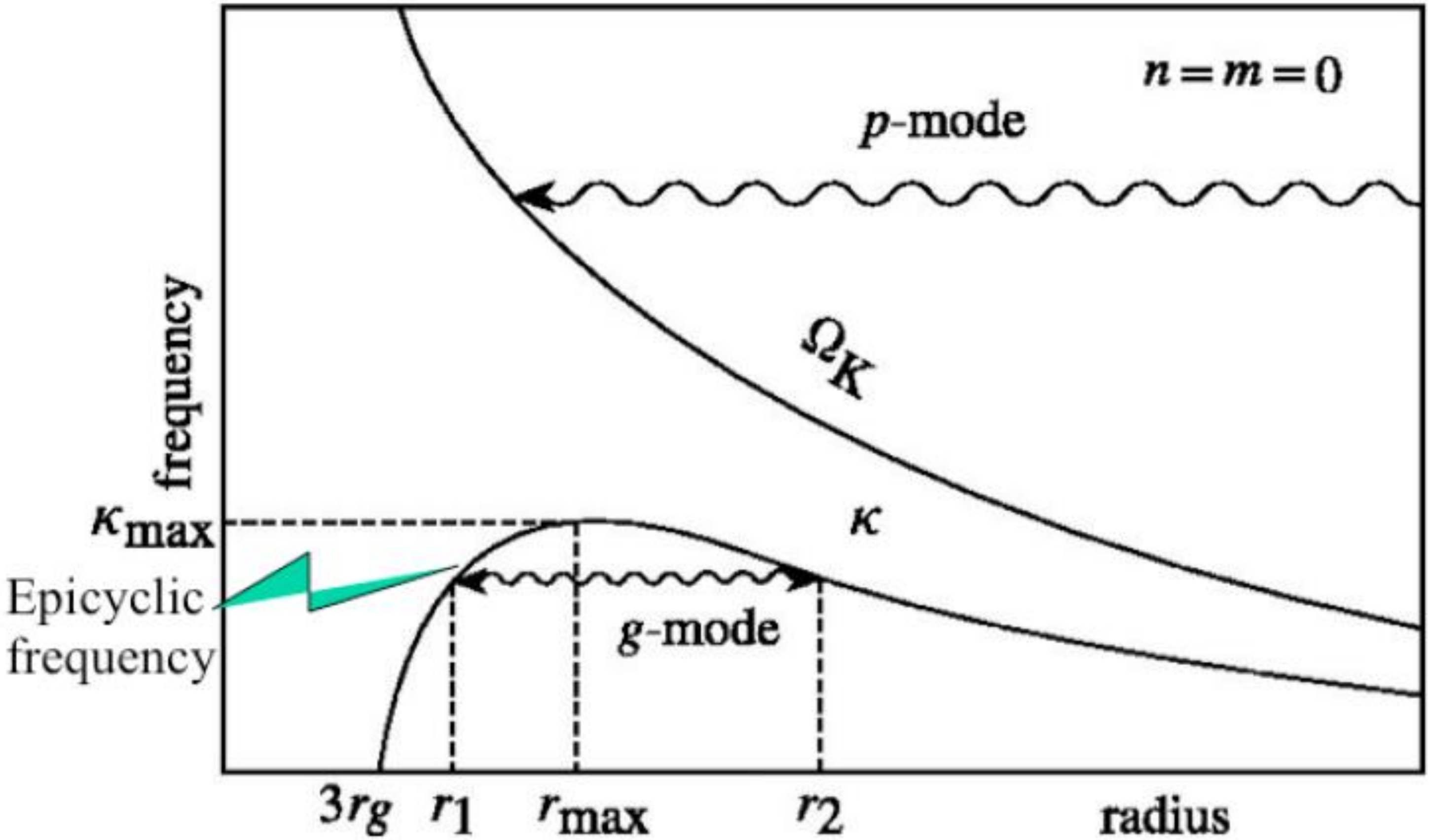




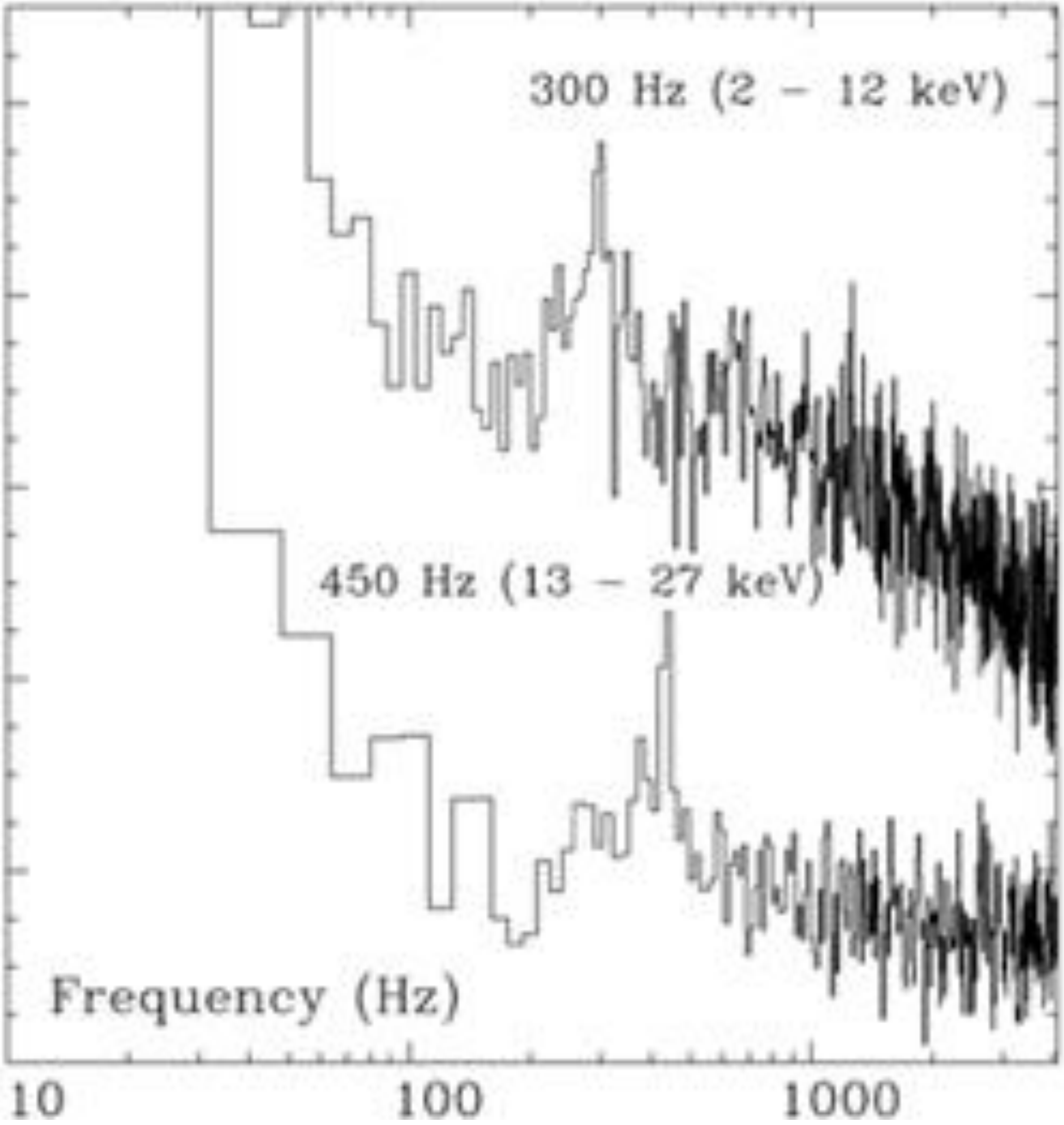
Size of BH binaries

J. Orosz

Okazaki, Atsuo T.; Kato, Shoji; Fukue, Jun: PASJ 39 (1987) 457
Global trapped oscillations of relativistic accretion disks



Kato 2001 $\Downarrow \Rightarrow$ Diskoseismology of Nowak & Wagoner



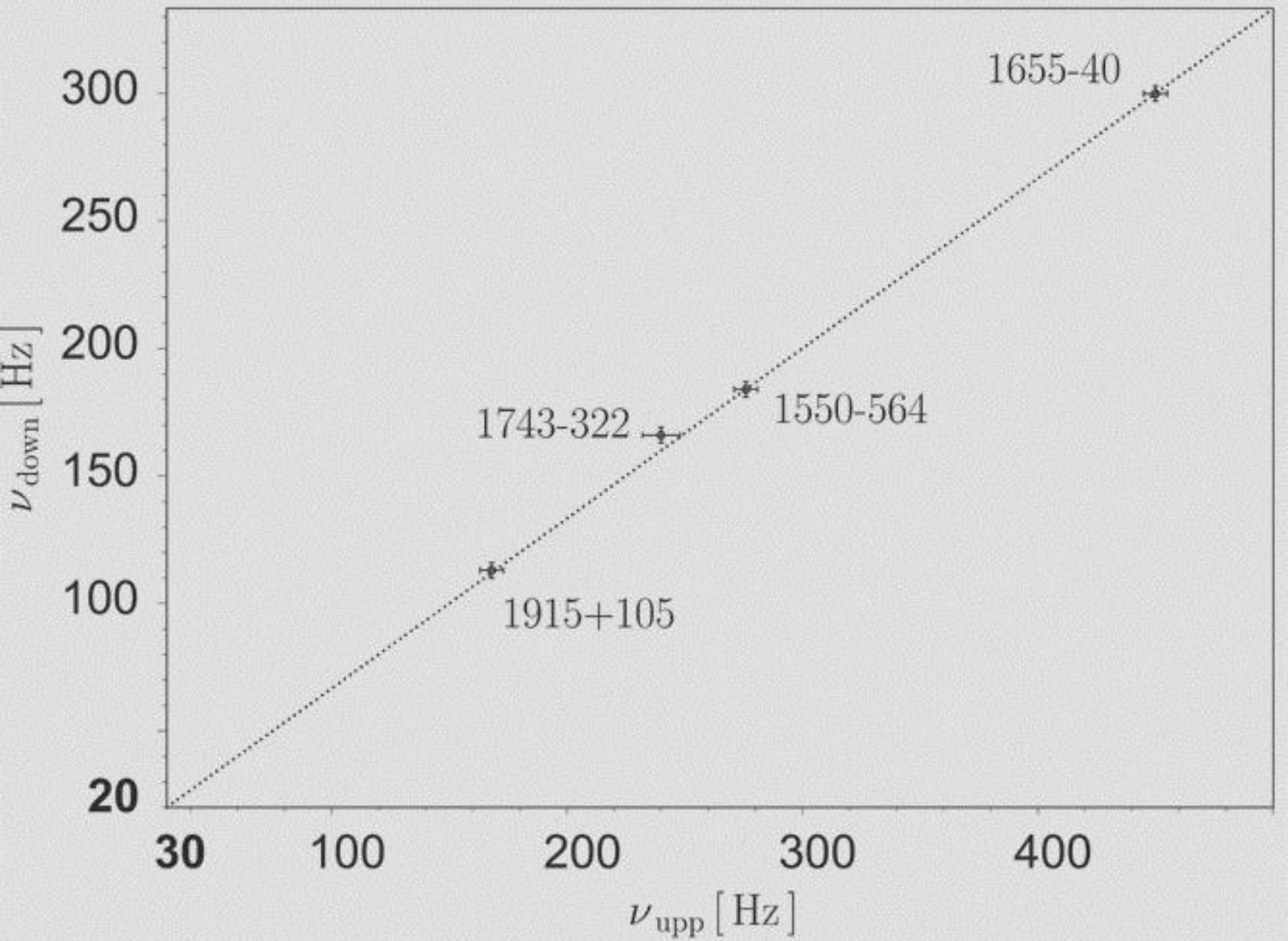
X-ray observations

Black hole
GRO J 1655-40

Strohmayer et al 2001

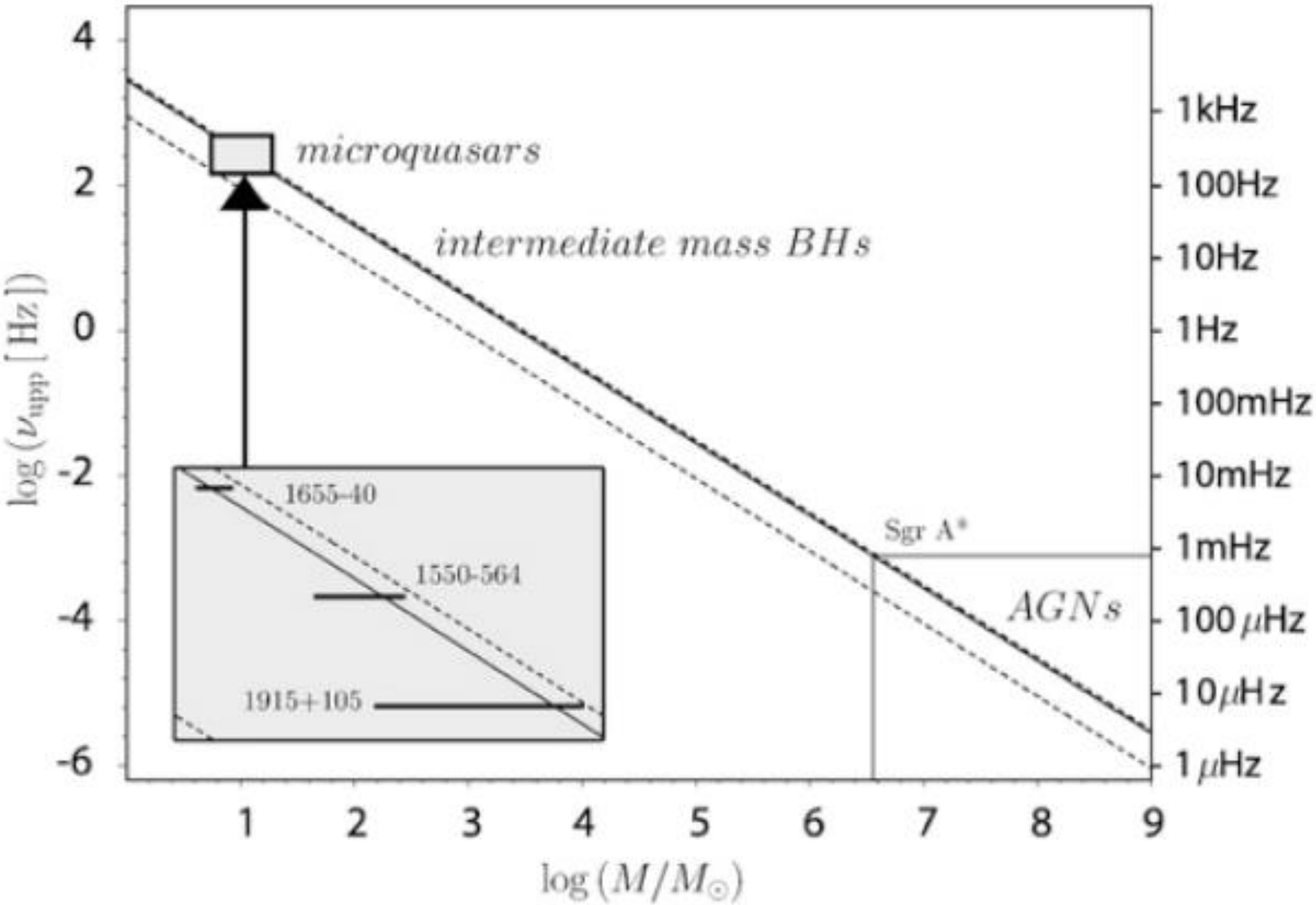
450:300=3:2
Kluźniak & Abramowicz 2001

Twin high-frequency
quasi-periodic oscillations
HF QPOs



1655-40
1743-322
1550-564
1915+105
300
250
200
150
100
20
30
100
200
300
400
$\nu_{\rm down}\,[\rm Hz]$
$\nu_{\rm upp}\,[\rm Hz]$

Abramowicz, Kluźniak, McClintock, Remillard, 2004



←17 minute ?? IR flare
Genzel et al. 2003

In GR, $f \sim 1/M$

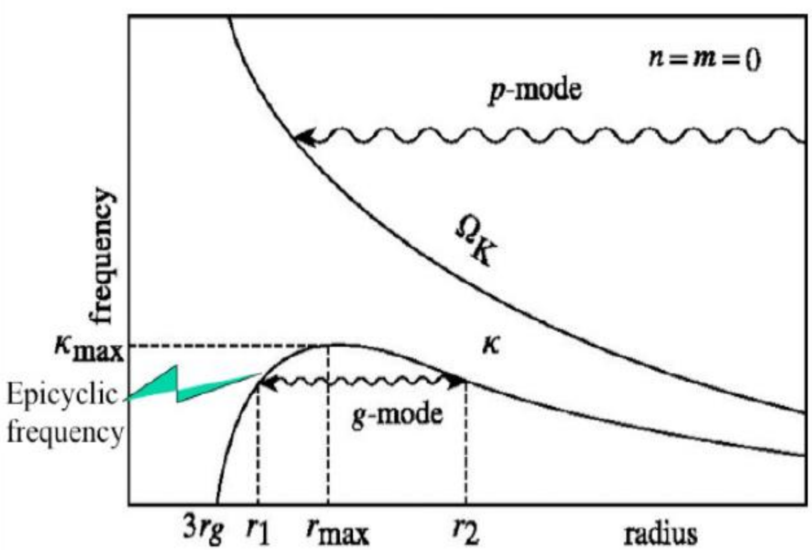
Parametric resonance: Mathieu eq.

$\ddot{U} + \omega_0^2[1 + h\cos(\omega_1 t)]\,U = 0$ e.g., WK 2005

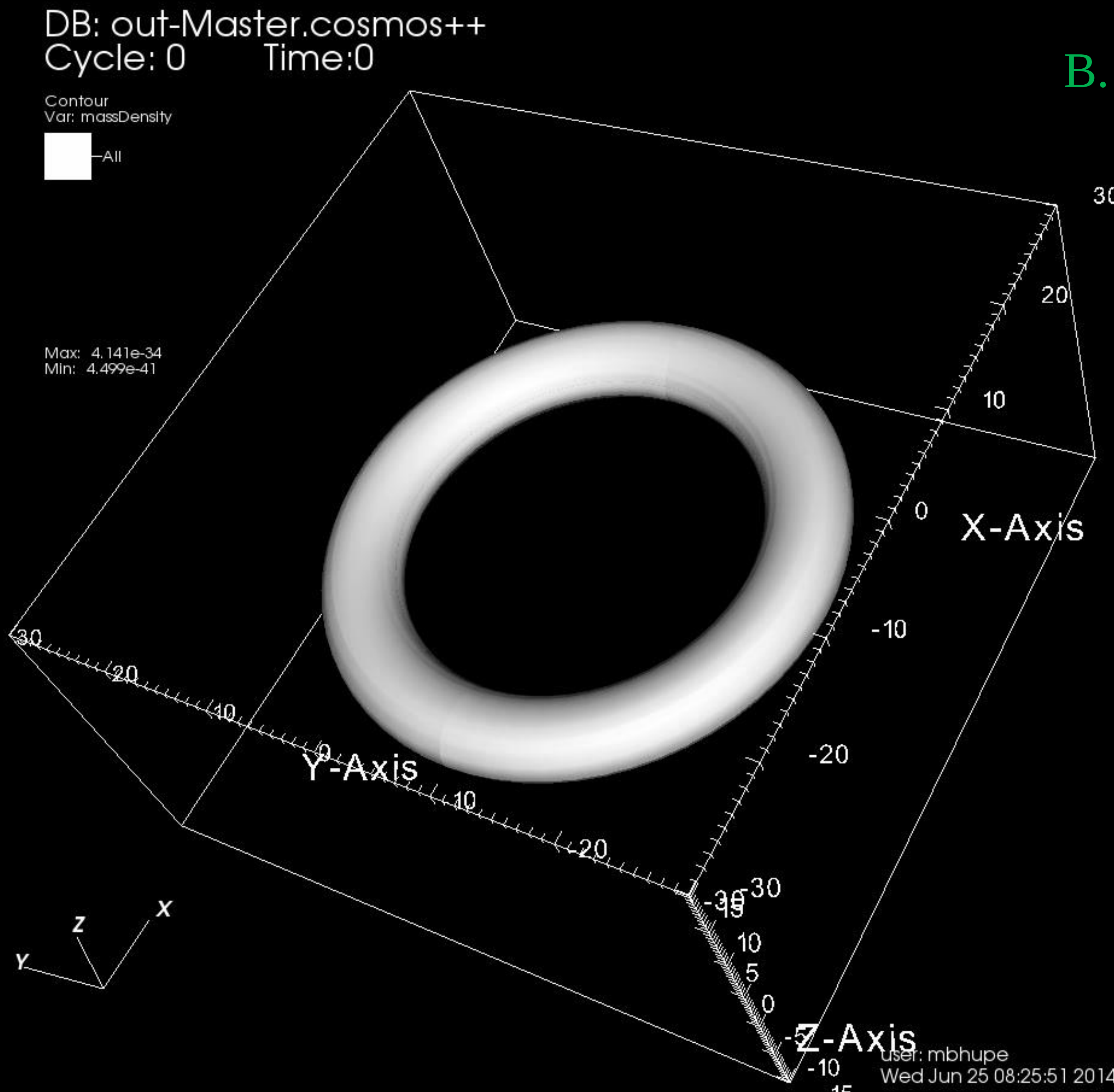
Resonance condition: $\omega_0 = (n/2)\,\omega_1$, $n = 1,2,3\ldots$

Suppose $\omega_1 < \omega_0$ (as true for epicyclic frequencies),

then first possibility $n=3 \Rightarrow$ 3:2 ratio.



Kato 2001 ⇓⇒ Diskoseismology of Nowak & Wagoner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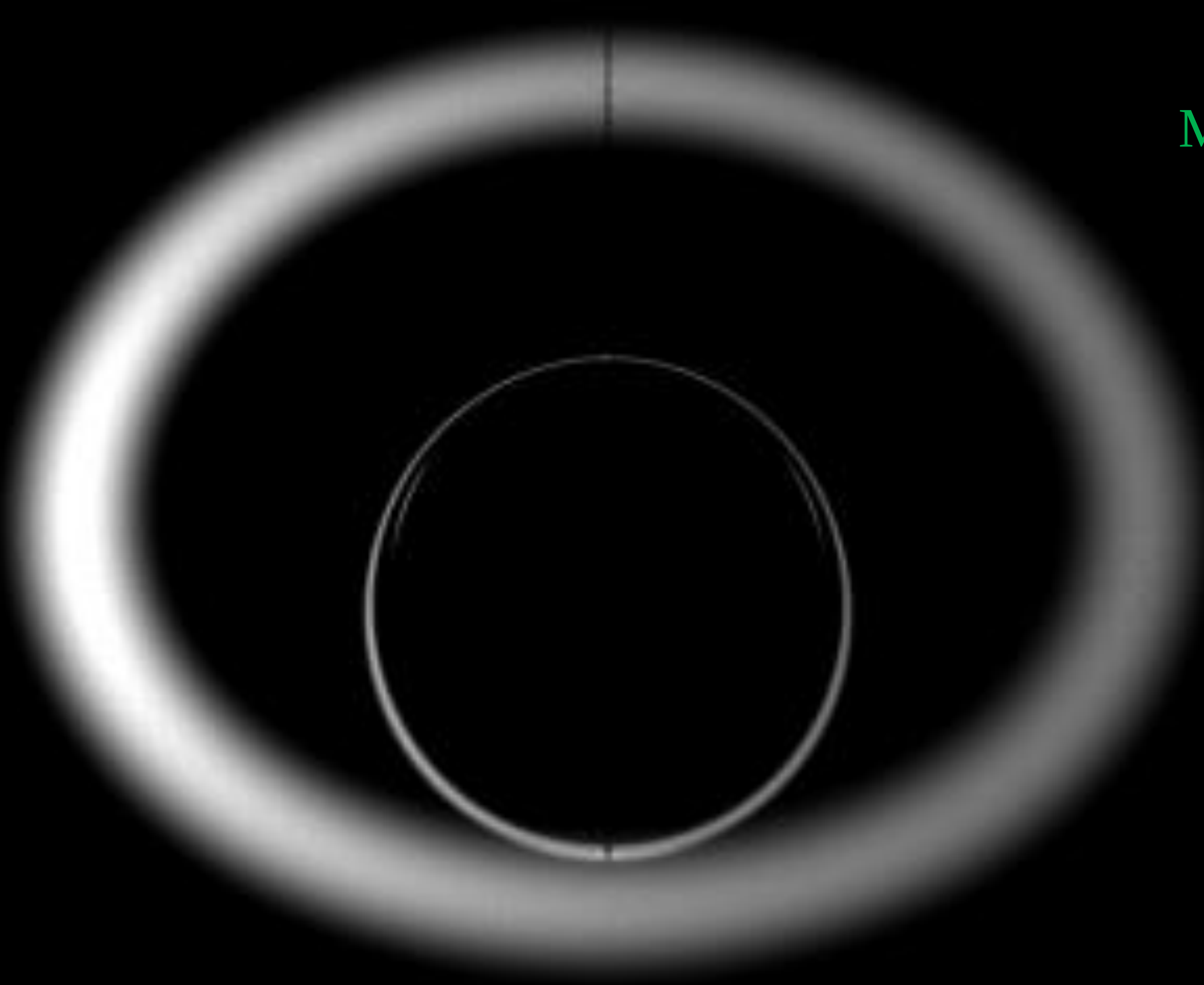
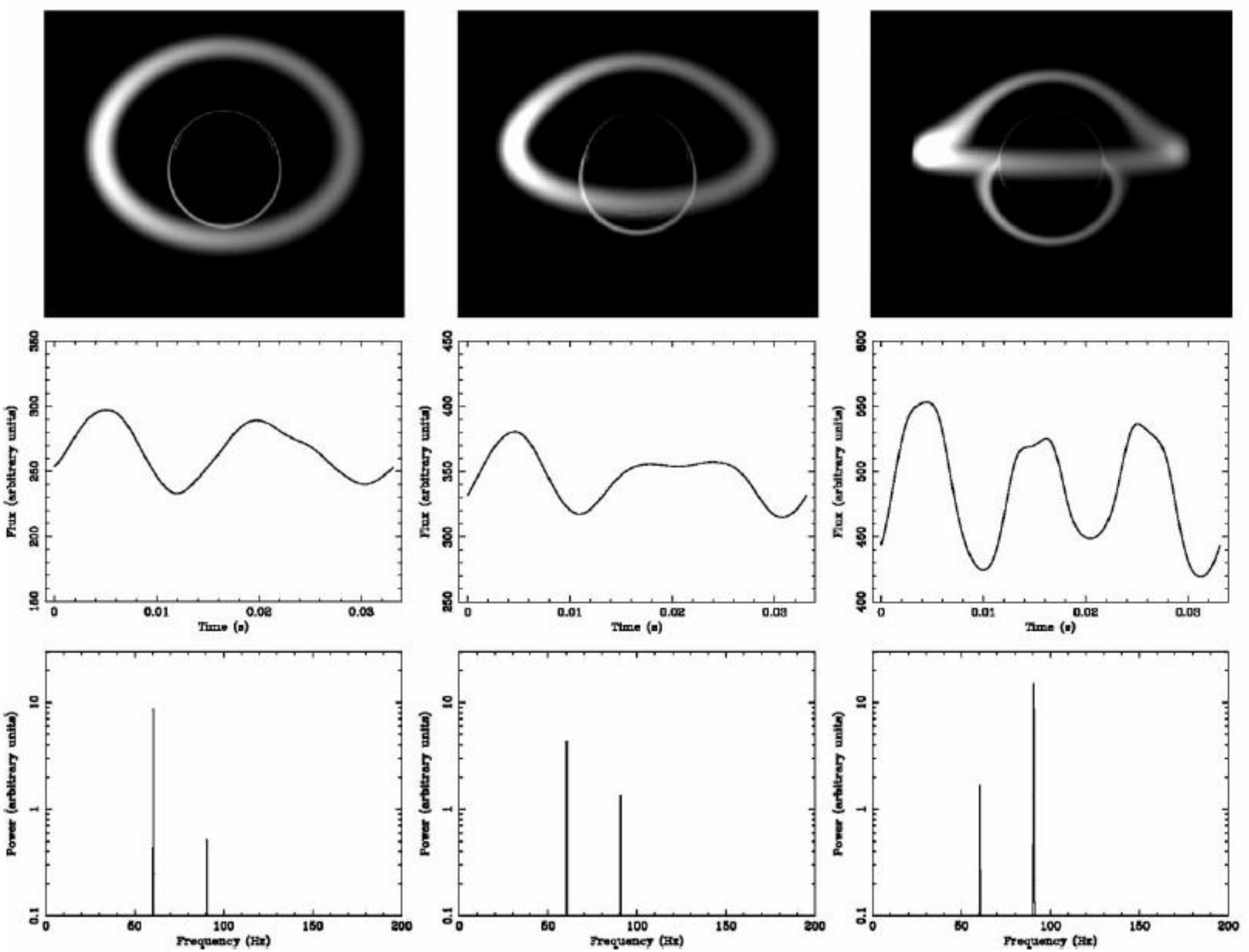
Y-Axis
Z-Axis
user: mbhupe
Wed Jun 25 08:25:51 2014

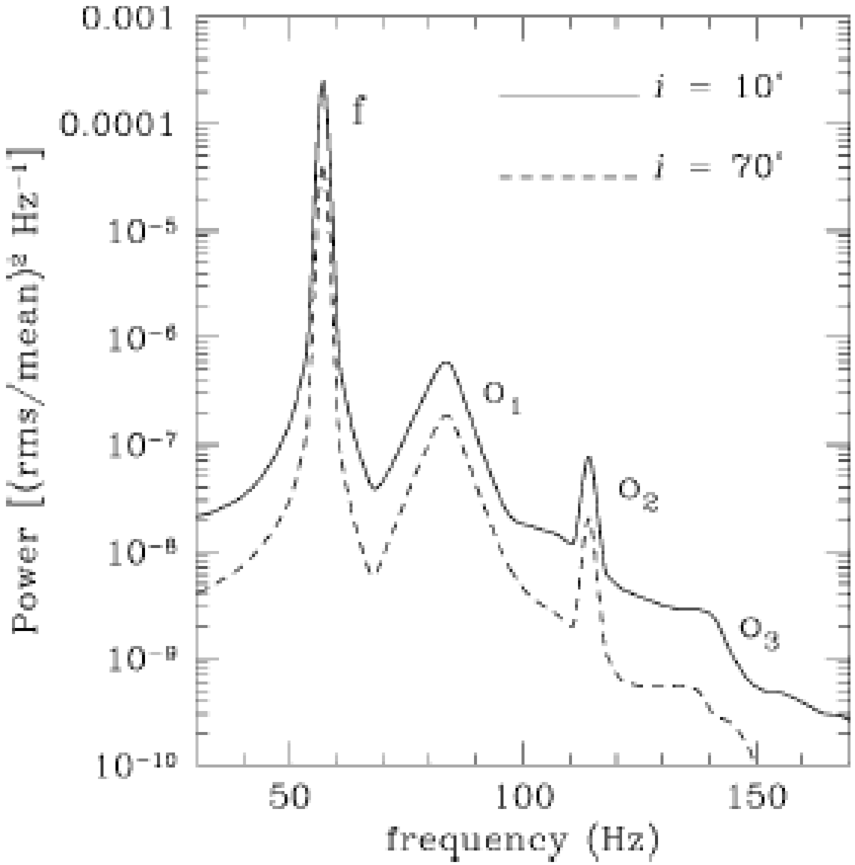
B. Mishra



M. Bursa

Bursa et al. 2004





4. DISCUSSION AND CONCLUSIONS

We have demonstrated a positive correlation between the intrinsic normal-mode oscillations of a pressure-supported torus and the extrinsic X-ray light curves and power spectra as seen by a distant observer. In addition to this being the first ray-tracing calculation exploiting dynamically the results of relativistic hydrodynamics simulations, our investigation confirms the feasibility of the oscillating-torus model as an explanation for the integer ratios seen in high-frequency QPO peaks. The specific parameters of the torus model still require further investigation in order to best fit the QPO data, including a more comprehensive study of black hole mass, spin, and inclination angles.

For the line emission models considered, the variation in the light curve is caused largely by the gravitational redshift of photons coming from different radii as the torus moves in and out of the black hole's potential well. Unlike the relativistic hot-spot model, for the same emission mechanism the oscillating-torus model predicts higher amplitude variations in the light curve for smaller inclination angles, while at higher angles the special relativistic beaming and gravitational lensing counter the gravitational redshift, reducing the variations in flux. On the other hand, the thermal emission model predicts

THE ASTROPHYSICAL JOURNAL, 665:642–653, 2007 August 10

EPICYCLIC OSCILLATIONS OF FLUID BODIES: NEWTONIAN NONSLENDER TORUS

OMER M. BLAES,[1] EVA ŠRÁMKOVÁ,[2] MAREK A. ABRAMOWICZ,[2,3,4] WŁODEK KLUŹNIAK,[4,5] AND ULF TORKELSSON[3]

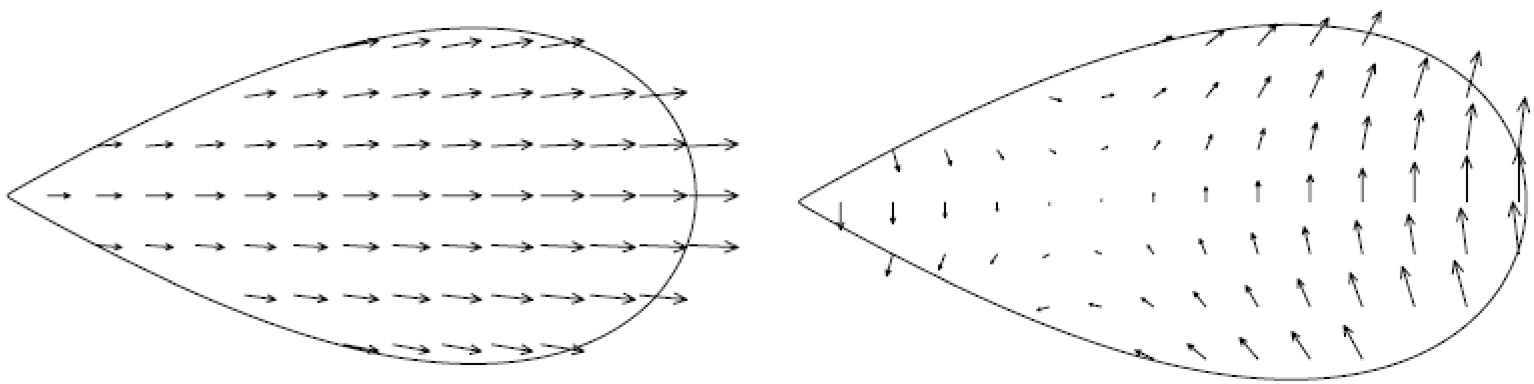
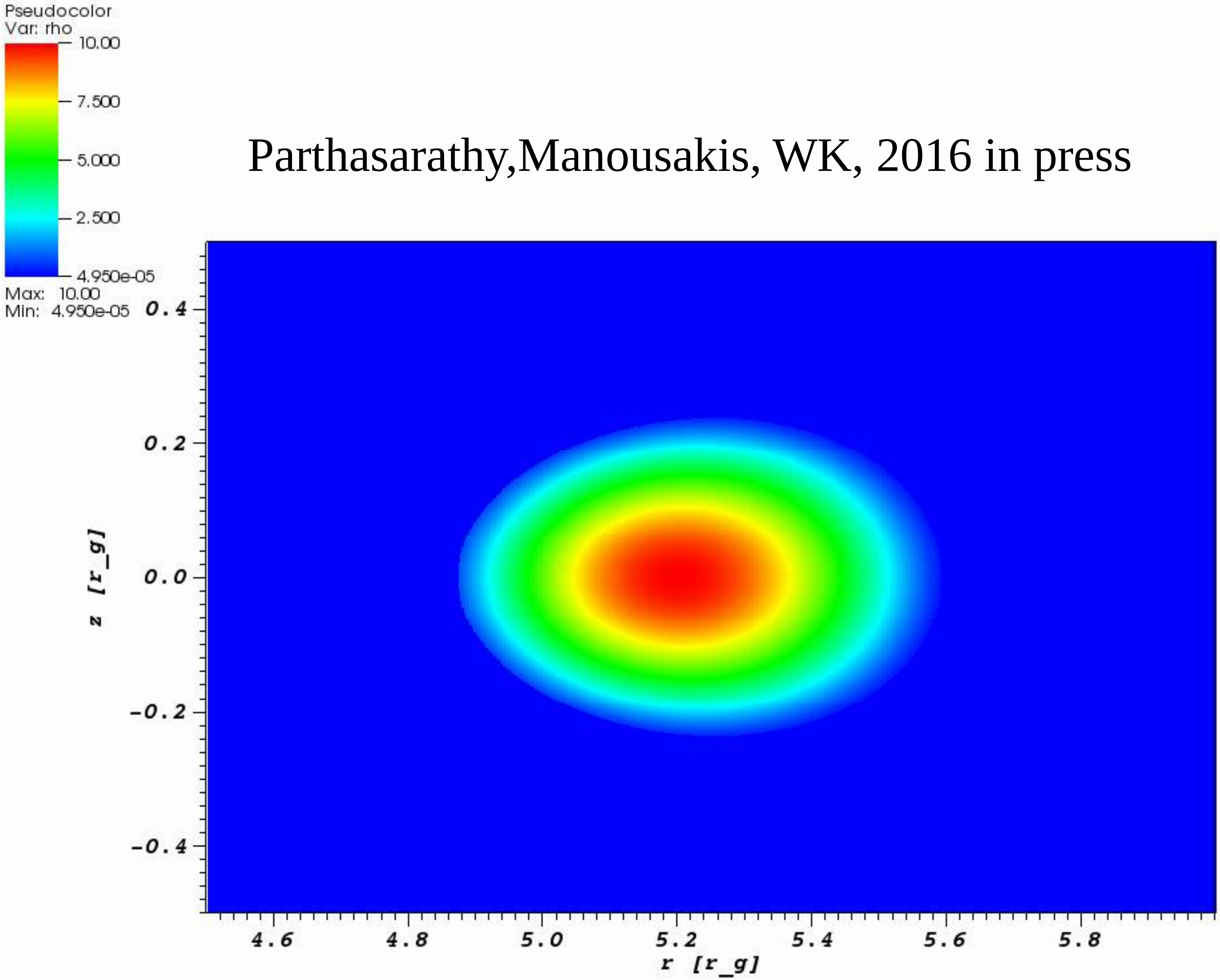
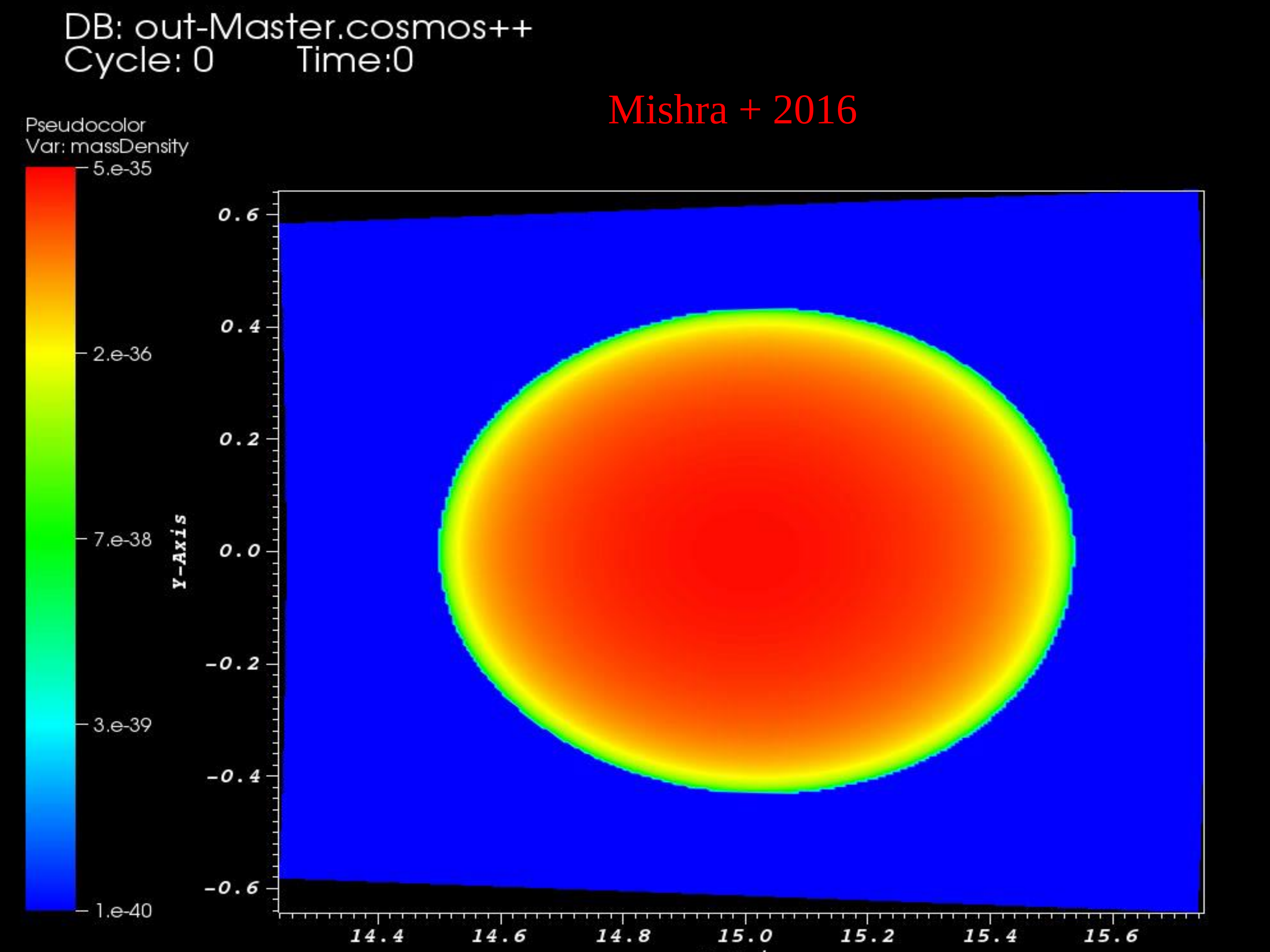


FIG. 5.—Poloidal velocity field for the radial epicyclic mode (*left*) and the vertical epicyclic mode (*right*) of a nonslender $n = 3$ torus with $\beta = 0.134589$ and pressure maximum at $r = 7.293M$ (the same torus illustrated in Fig. 4, *right*).

Parthasarathy,Manousakis, WK, 2016 in press

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Mishra + 2016
Pseudocolor
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2.e-36
7.e-38
3.e-39
1.e-40
Y-Axis
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
14.4
14.6
14.8
15.0
15.2
15.4
15.6

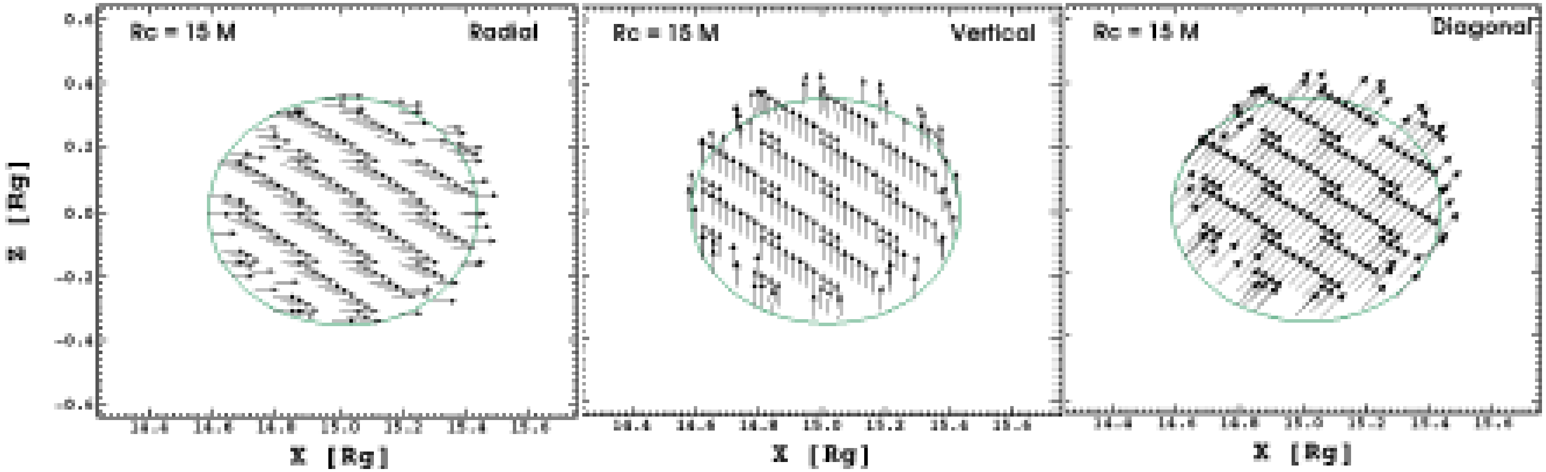
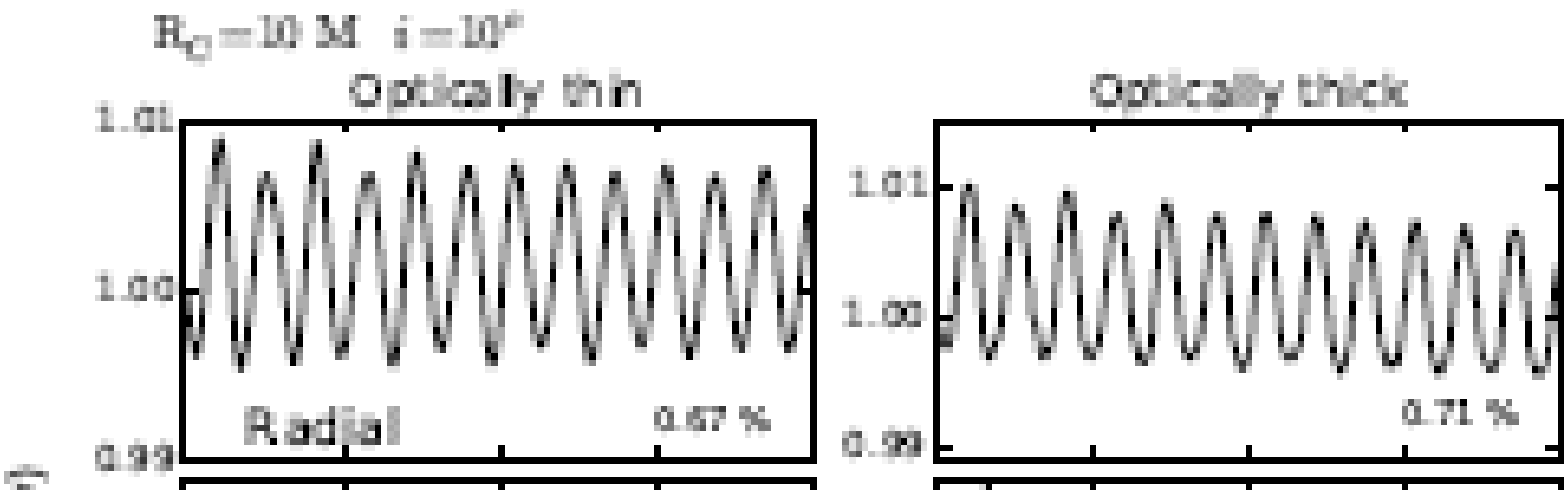
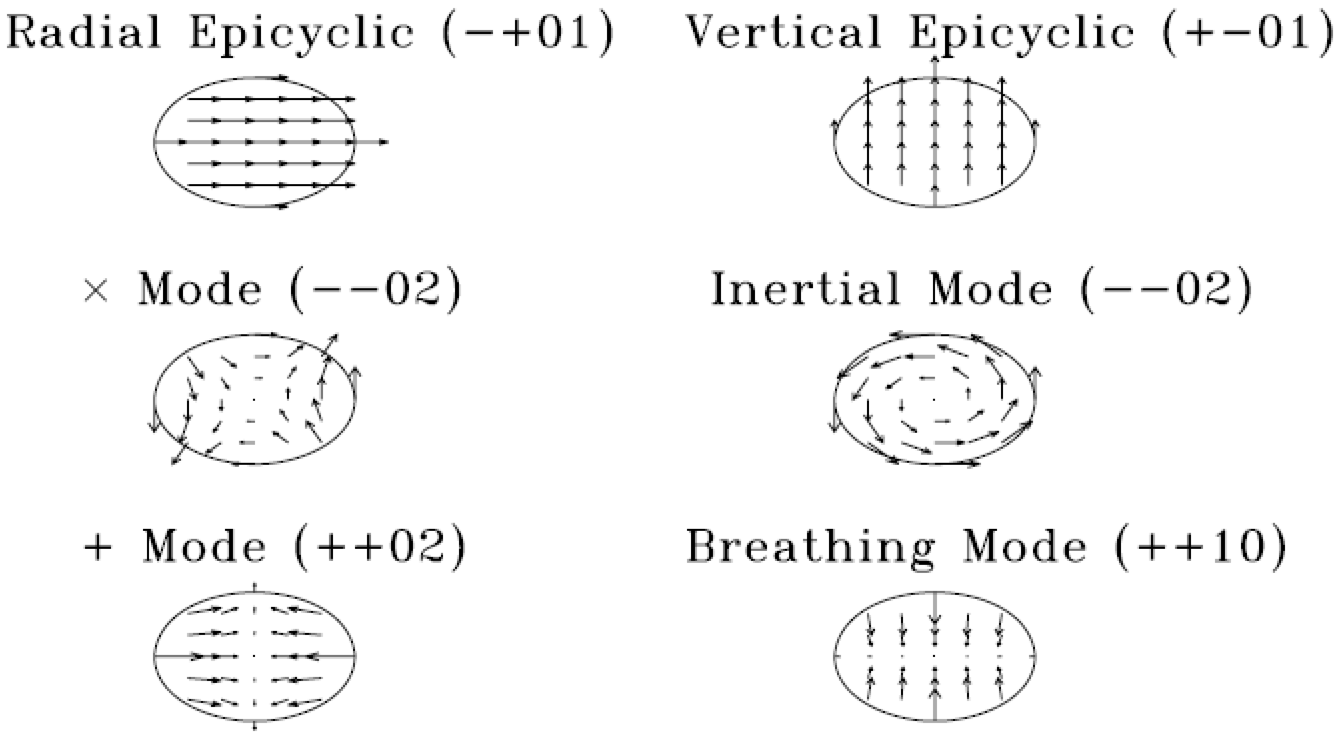


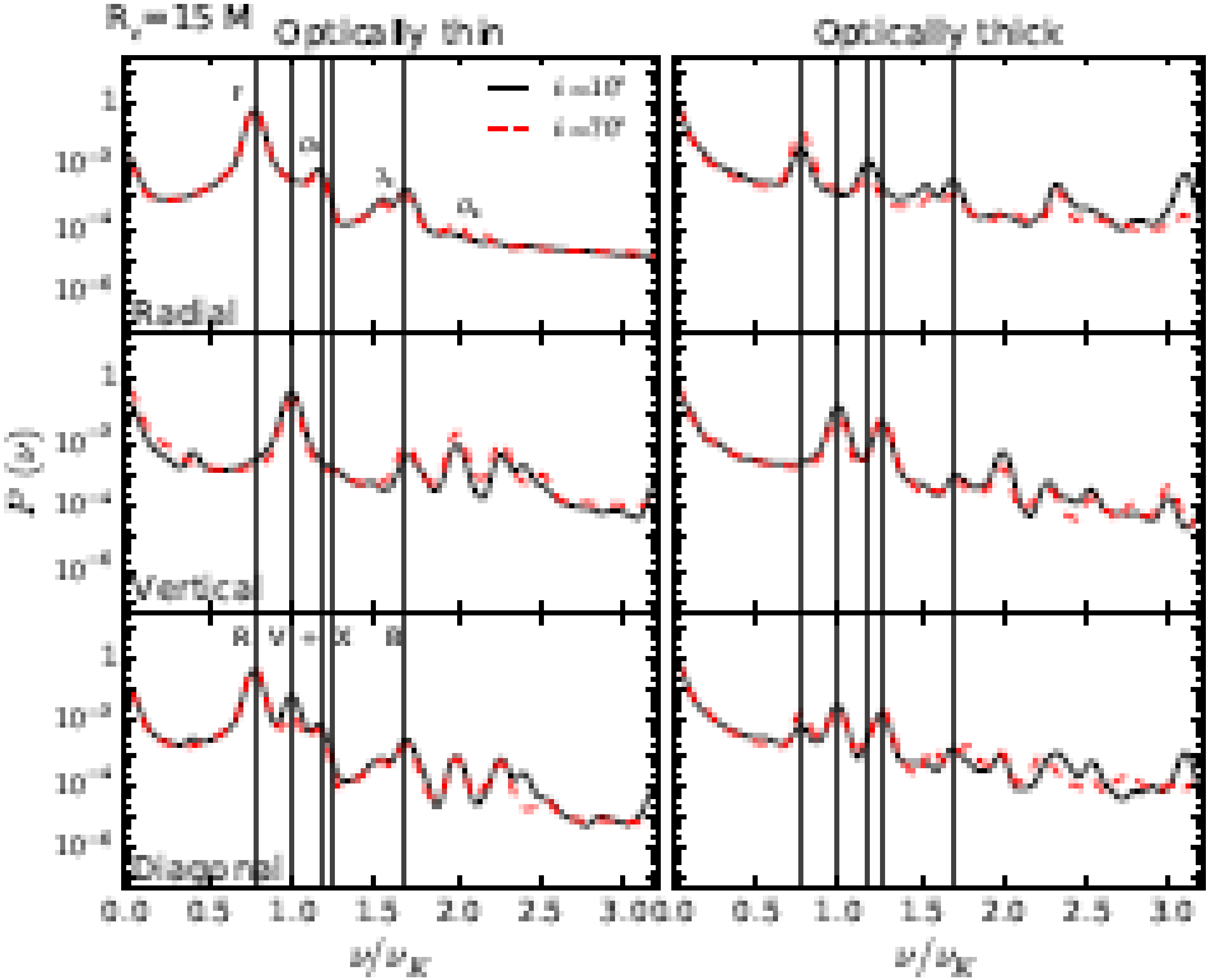
Figure 1. Three initial velocity perturbations to the torus. Plots only present the initial torus with pressure maximum at $R_c = 15M$. The torus setup at $R_c = 10M$ looks qualitatively similar at the corresponding radial position.



Blaes et al 2006



vertical lines: Radial, Vertical, +, X, Breathing



PDS

17 minute QPO likely a counterpart of HF QPO in binary BH
(450 Hz in GRO 1655-40)

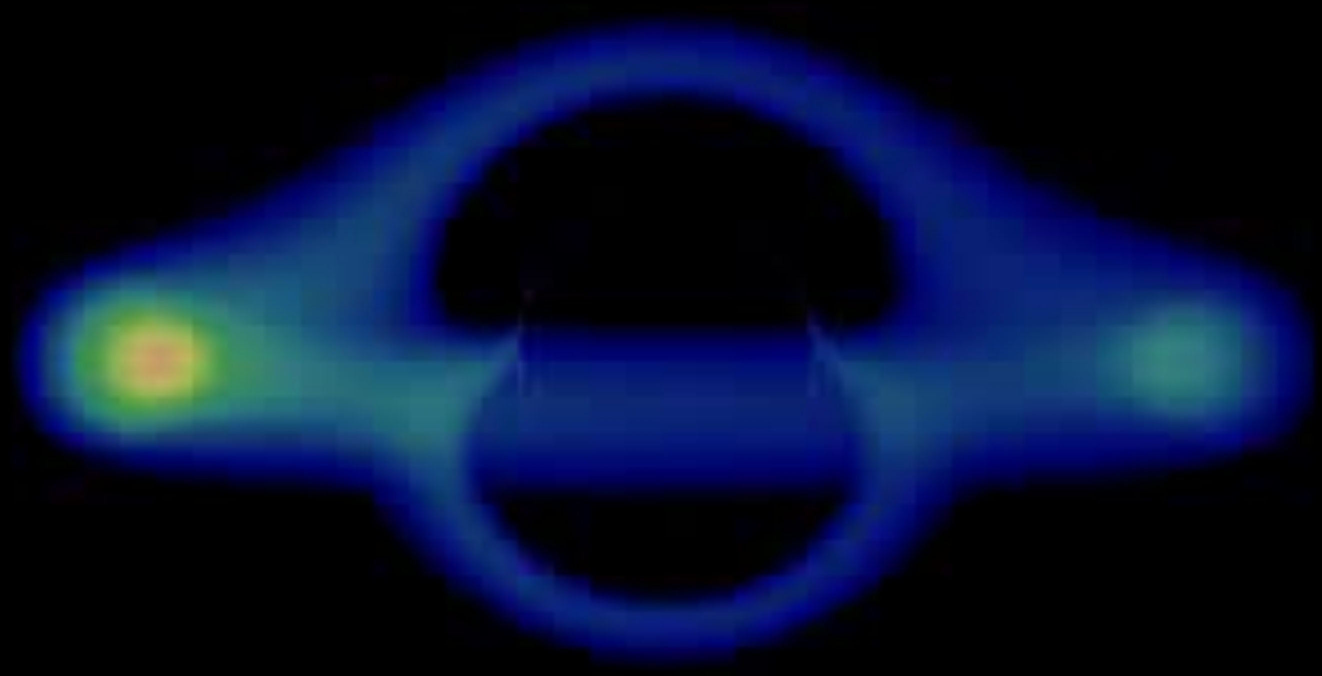
HF QPOs present in PDS of ray-traced GR simulations of tori.
The modes have been identified.

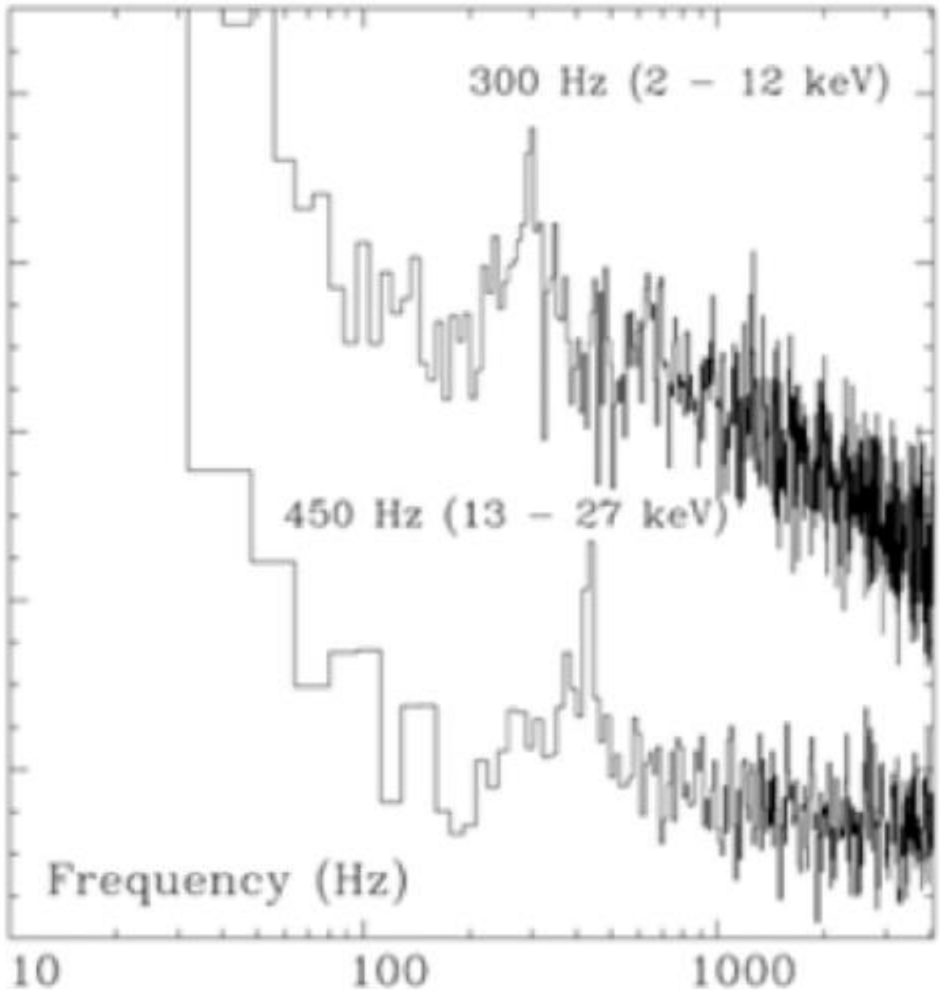
Which modes are present depends on the perturbation type.

Radial perturbations yield two modes (R, +) in ~ 3:2 ratio
Ditto for vertical perturbations (V, B)

but only one pair ever seen in a given binary BH (to date?)

F. Vincent





Abramowicz & Kluźniak 2001, *A precise measurement of BH spin* (A&A):

'We note that the recently discovered 450 Hz frequency in the X-ray flux of the black hole candidate GRO J1655-40 is in a 3:2 ratio to the previously known 300 Hz frequency...'

GRO J 1655-40 X-ray power spectra : discovery of second HFQPO in a BH (Strohmayer 2001).