Deformed Disks での波の共鳴励起

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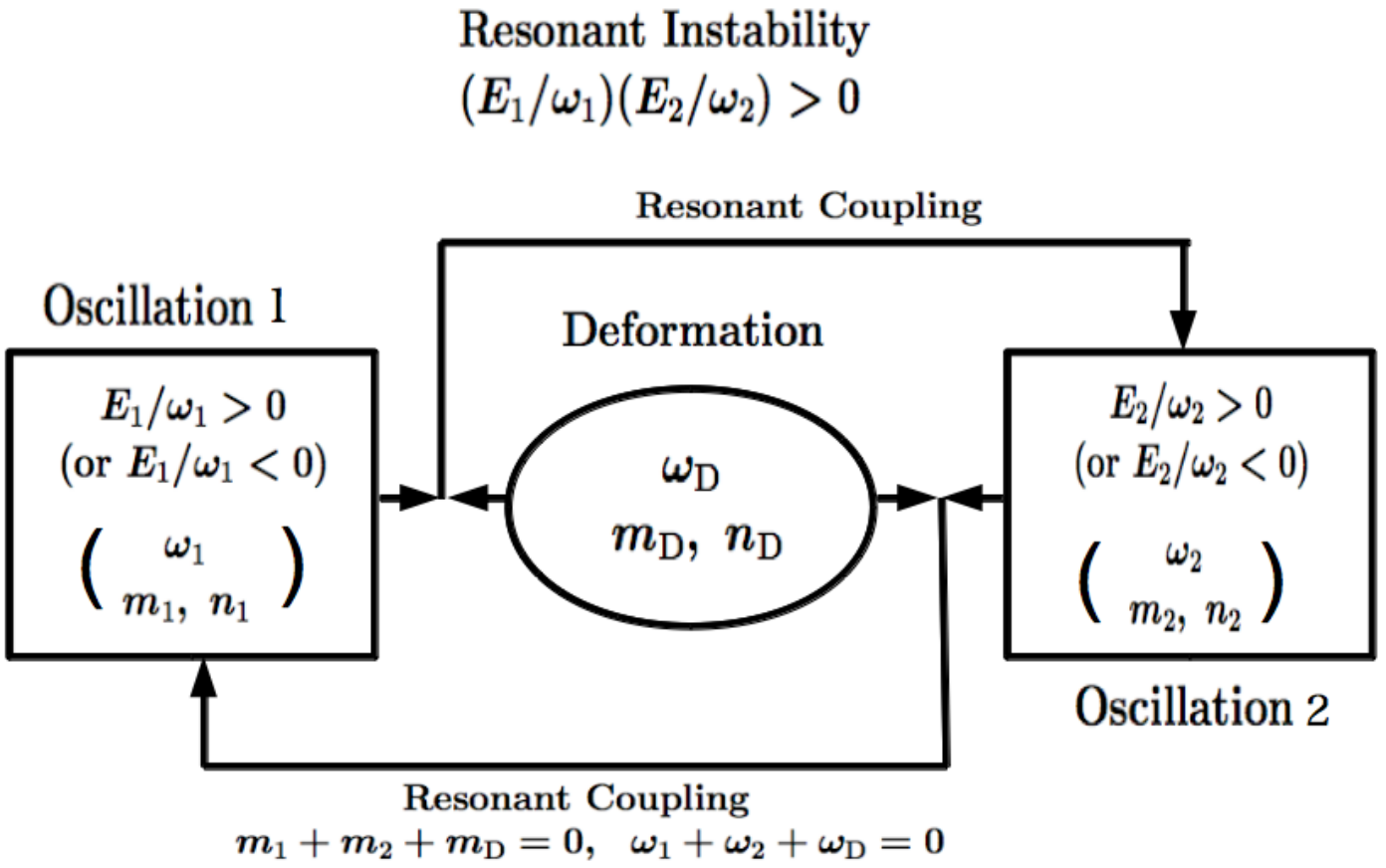

Resonant Instability
$(E_1/\omega_1)(E_2/\omega_2) > 0$
Resonant Coupling
Oscillation 1
$E_1/\omega_1 > 0$
(or $E_1/\omega_1 < 0$)
ω_1
$m_1,\ n_1$
Deformation
ω_D
$m_D,\ n_D$
$E_2/\omega_2 > 0$
(or $E_2/\omega_2 < 0$)
ω_2
$m_2,\ n_2$
Oscillation 2
Resonant Coupling
$m_1 + m_2 + m_D = 0, \quad \omega_1 + \omega_2 + \omega_D = 0$

Applications

1. Dwarf Novae

   Superhumps due to tidal deformation

   1) superhumps

      Eccentric precession mode (one-armed p-mode)

   2) negative superhumps

      Tilt mode (one-armed vertical p-mode)

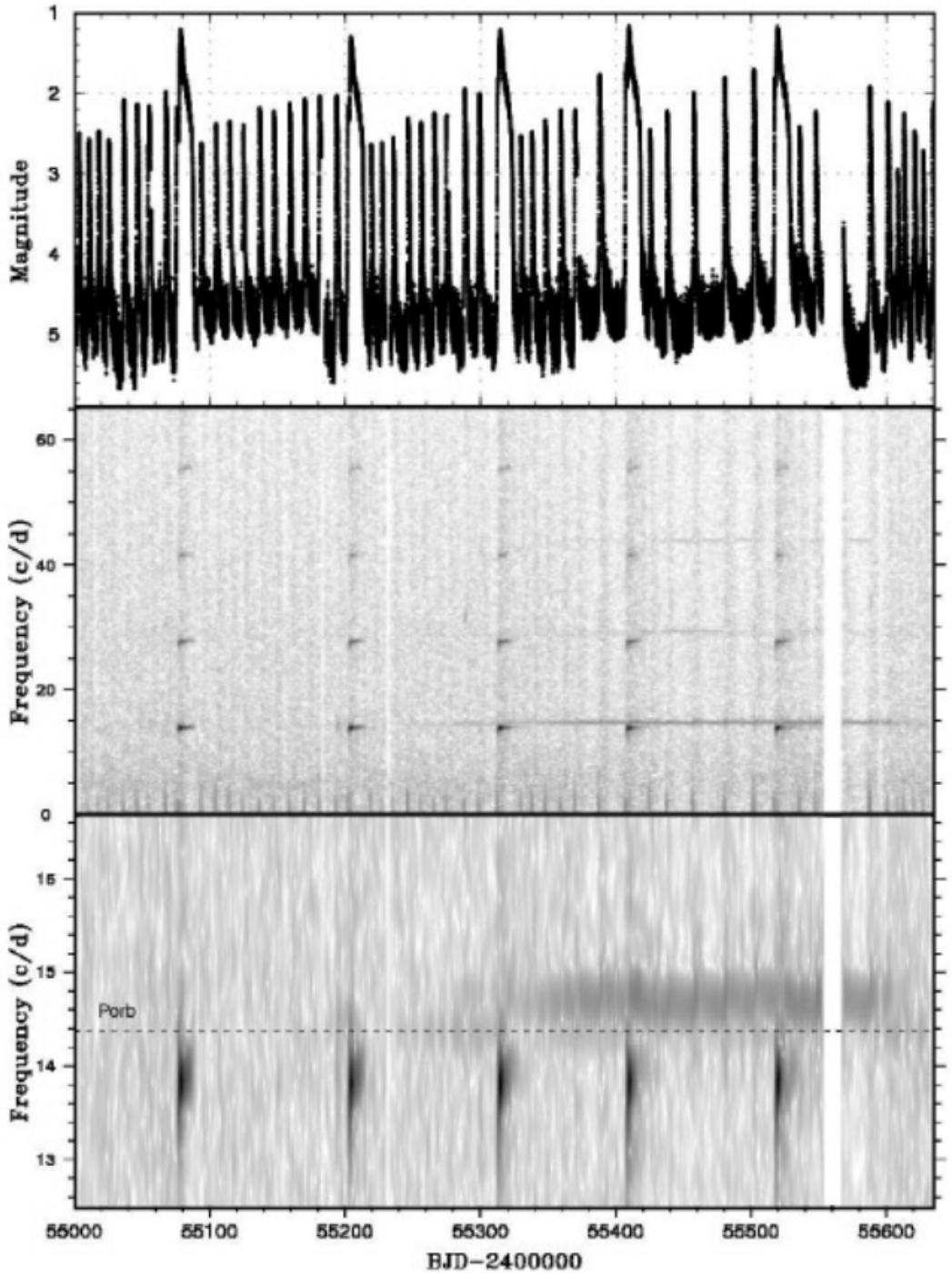
      various stage of evolution

2. KHz QPOs (Neutron-star X-ray binaries)

   Two-armed plane-symmetric deformation
   + two-armed vertical p-mode

3. HF QPOs (Black-hole X-ray binaries)

   Two-armed plane-asymmetric deformation
   + two-armed vertical p-mode


Magnitude
1
2
3
4
5
Frequency (c/d)
60
40
20
0
Frequency (c/d)
16
15
14
13
Porb
55000
55100
55200
55300
55400
55500
55600
BJD−2400000

Superhmp

- slowly prograding eccentric pattern (Osaki 1985)
- 3:1 resonance (Hirose,Osaki 1990, Lubow 1991)
- one-armed p-mode: $(m_1, n_1, \omega_1) = (1, 0, \omega_1)$

$$\omega_1 < \Omega - \kappa, \quad E_1/\omega_1 < 0$$

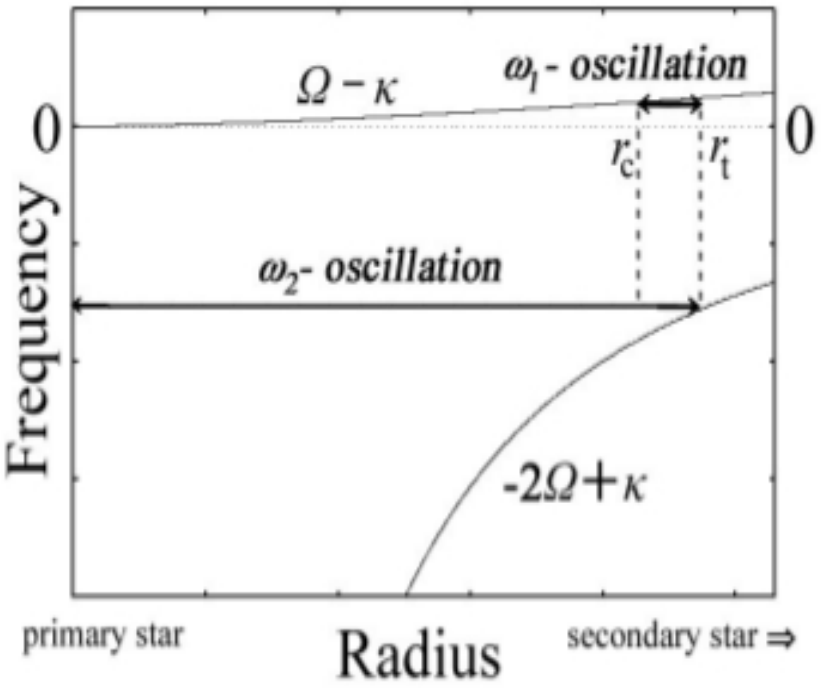
- ω_2-oscillation: $(m_2, n_2, \omega_2) = (2, 0, \omega_2)$ (assume)

$$\omega_2 < 2\Omega - \kappa, \quad E_2/\omega_2 < 0$$

- resonant condition: $m_{\rm D} = -3 \Rightarrow \omega_{\rm D} = -3\Omega_{\rm orb}$

$$\omega_1 + (2\Omega - \kappa)_{r_t} + \omega_{\rm D} = 0$$

$$\Omega_{r_t} = 3\Omega_{\rm orb}$$



Negative superhmp

- ω_1-tilt mode : $(m_1, n_1, \omega_1) = (1, 1, \omega_1)$

$$\omega_1 < \Omega - \Omega_\perp, \quad E_1/\omega_1 < 0$$

- ω_2-oscillation : two-armed vertical p-mode

$$(m_2, n_2, \omega_2) = (2, n_2, \omega_2) \text{ (assume)}$$

$$\omega_2 < 2\Omega - \sqrt{n_2}\Omega_\perp, \quad E_2/\omega_2 < 0$$

- resonant condition:

$$\omega_1 + (m_2\Omega - \sqrt{n_2}\Omega_\perp)_{r_t} + n\Omega_{\rm orb} = 0,$$

where n is defined by $\omega_{\rm D} = n\Omega_{\rm orb}$

$$\Omega_{r_t} = -\frac{n}{m_2 - \sqrt{n_2}}\Omega_{\rm orb} = 0$$

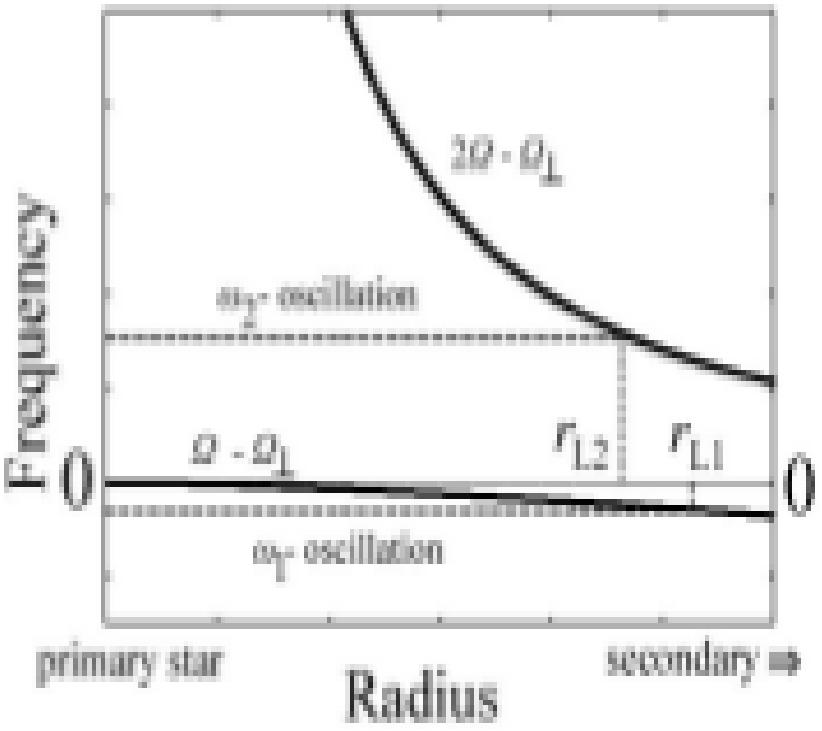
- examples $(m_2, n_2) = (2, 1)$ vertical p-mode

$$\Omega_{r_t} = -n\Omega_{\rm orb}, \quad \omega_{\rm D} = n\Omega_{\rm orb}$$

$n = -3, \quad \Omega_{r_t} \sim 3\Omega_{\rm orb}$ 3:1 resonance

$n = -4, \quad \Omega_{r_t} \sim 4\Omega_{\rm orb}$ 4:1 resonance

Tilt can be excited at certain evolutional stages before disk radius reaches that of 3 : 1 resonance

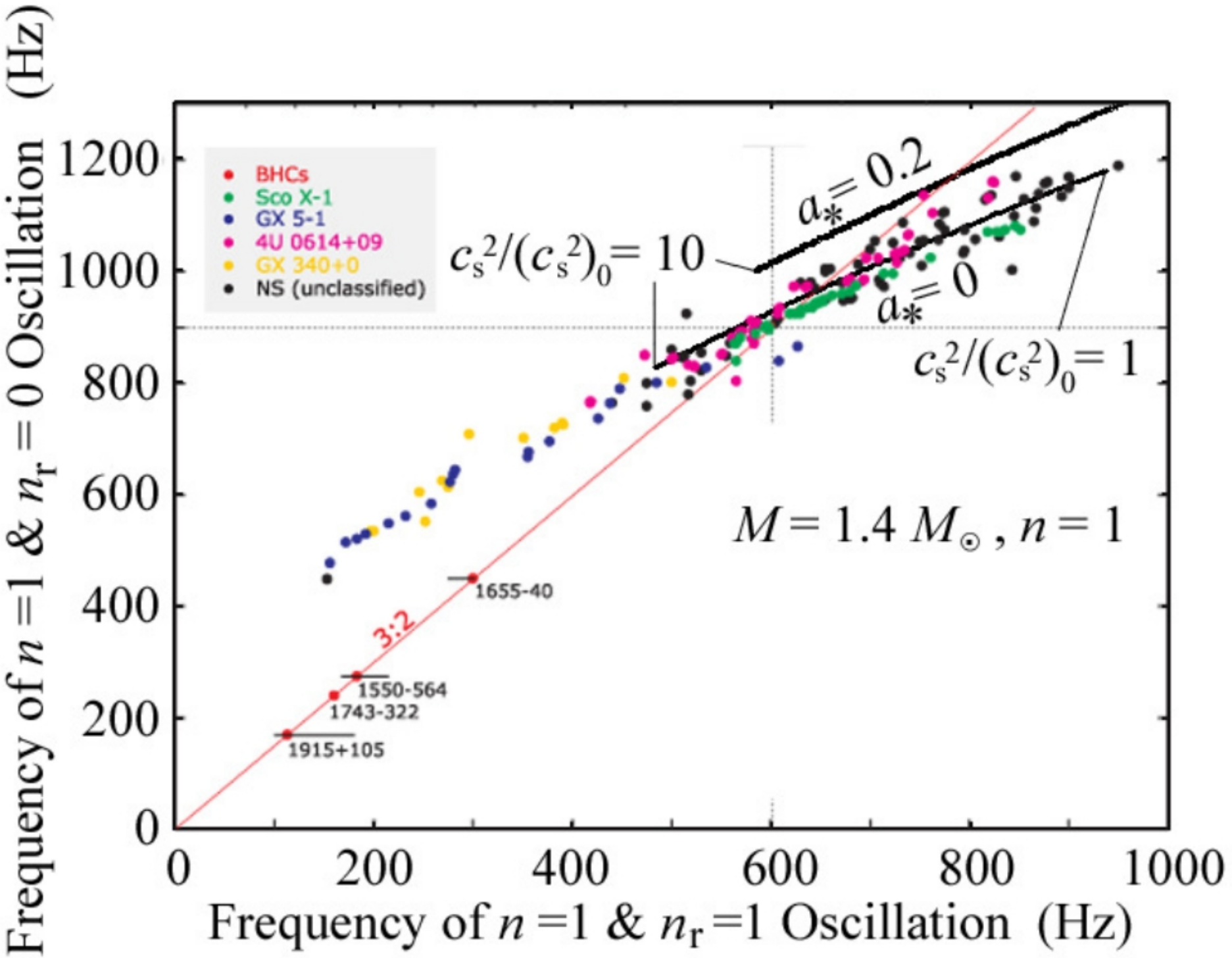


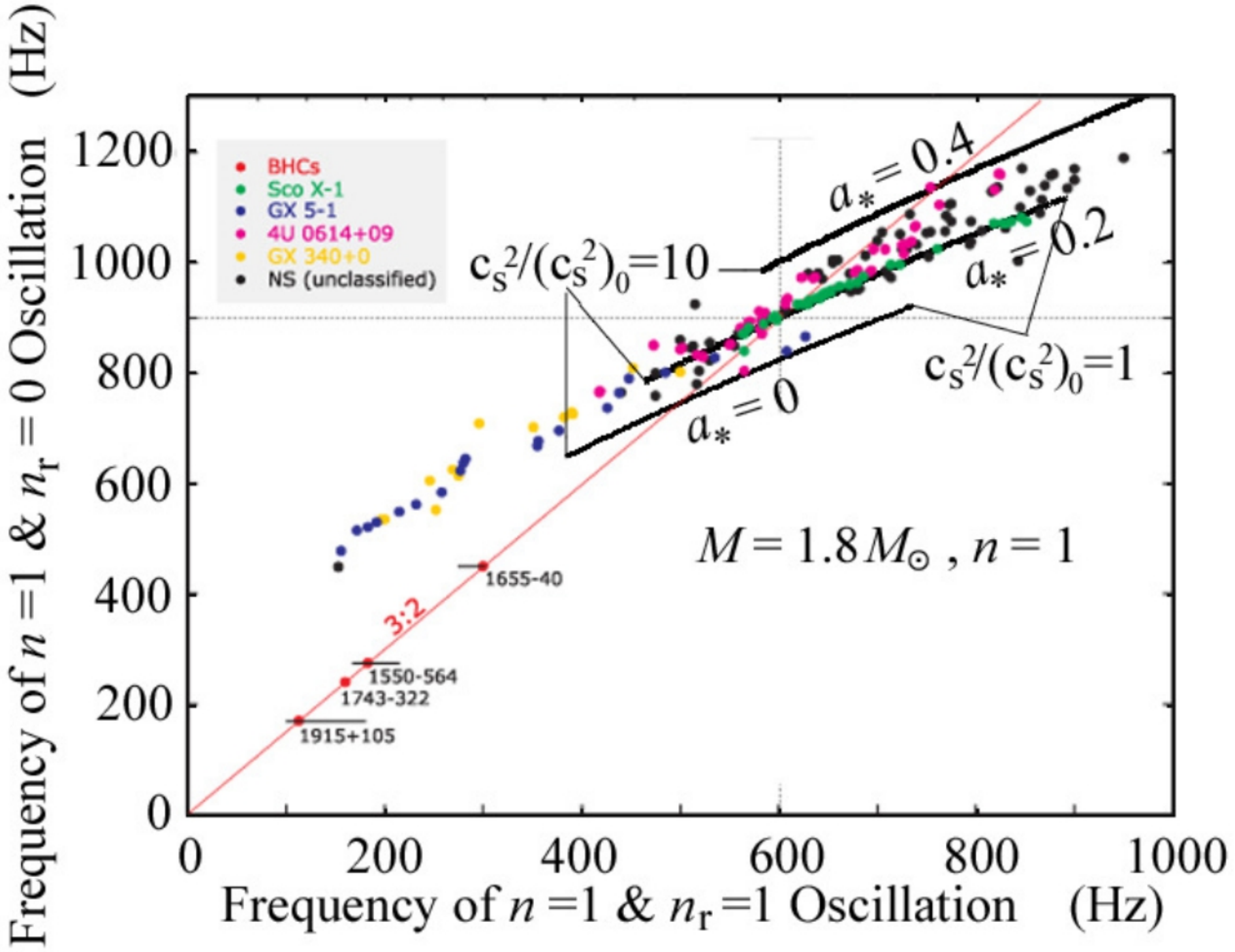
KHz and HF QPOs

課題

- Pair で起こることがある
- KHz QPOs の場合、
  pair の周期は相関をもって変動する。３：２ではない
- HF QPOs の場合
  pair の周期は変動しない。３：２に近い
  特定のdisk 構造のときに起こる(steep power-law state)
  High spin を説明できるものでなければならない
- KHz QPOs と HF QPOs とは異なる振動モードか
- LF QPOs との関係
- 一般に受け入れられているモデルはまだ無い
- コメント

  Two-armed vertical p-modes が比較的良く合う
  そのような modes が deformed disk での wave-wave coupling で励起できるか？


Frequency of n =1 & n_r = 0 Oscillation (Hz)
Frequency of n =1 & n_r =1 Oscillation (Hz)
0
200
400
600
800
1000
1200
BHCs
Sco X-1
GX 5-1
4U 0614+09
GX 340+0
NS (unclassified)
$c_s^2/(c_s^2)_0$= 10
a_*= 0.2
a_*= 0
$c_s^2/(c_s^2)_0$= 1
$M = 1.4\ M_\odot$, $n = 1$
3:2
1655-40
1550-564
1743-322
1915+105


Frequency of n =1 & n_r = 0 Oscillation (Hz)
Frequency of n =1 & n_r =1 Oscillation (Hz)
0
200
400
600
800
1000
1200
BHCs
Sco X-1
GX 5-1
4U 0614+09
GX 340+0
NS (unclassified)
$c_s^2/(c_s^2)_0$=10
$c_s^2/(c_s^2)_0$=1
a_* = 0.4
a_* = 0.2
a_* = 0
$M = 1.8\,M_\odot$, $n = 1$
3:2
1655-40
1550-564
1743-322
1915+105

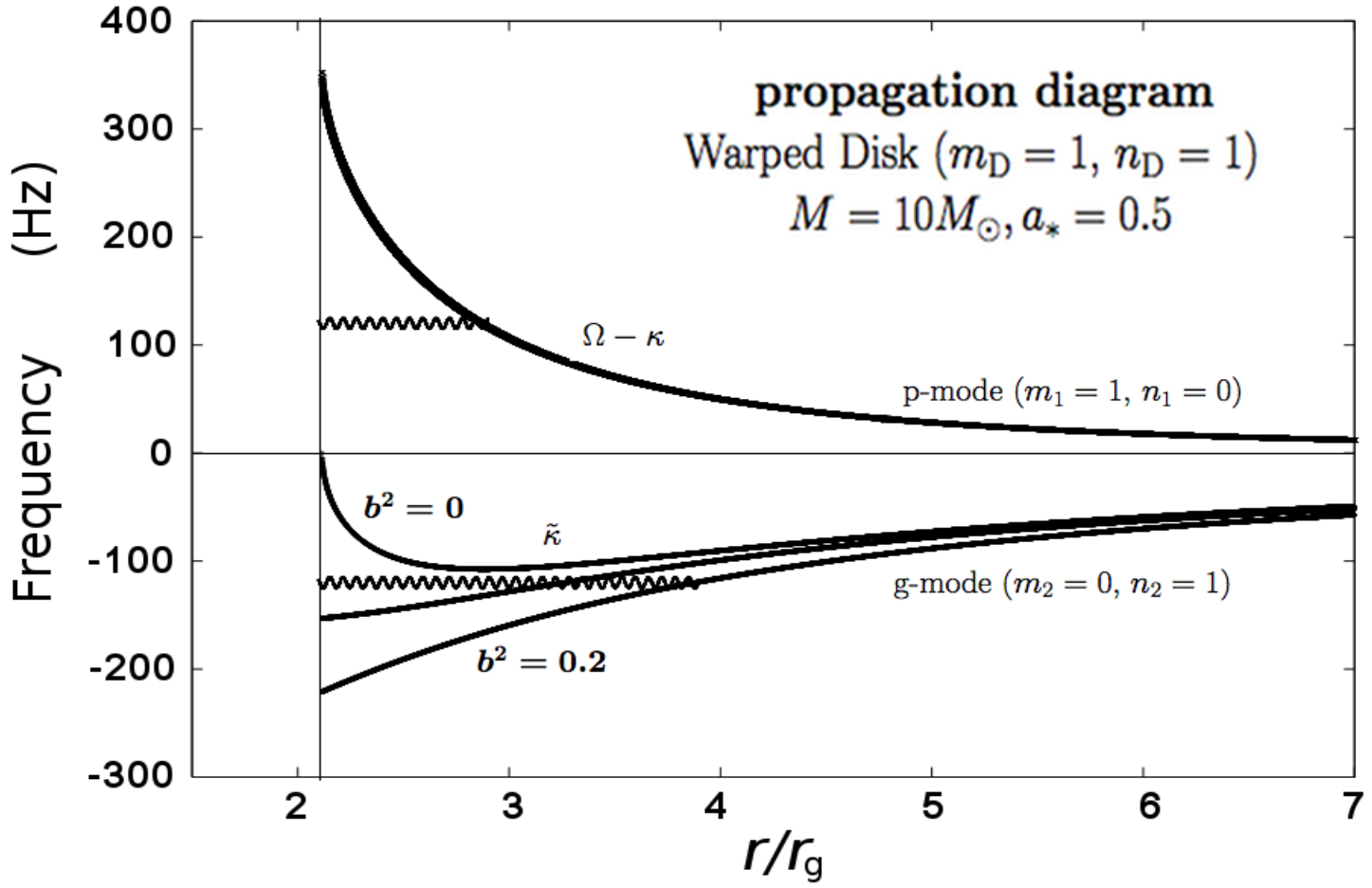
Warped Disks $(m_{\rm D}, n_{\rm D}, \omega_{\rm D}) = (-1, 1, 0)$

- $m_1 = 1$, $n_1 = 0$, $\omega_1 > 0$ (one-armed p-mode)

$$\omega_1 < \Omega - \kappa,\ E_1/\omega_1 < 0$$

- $m_2 = 0$, $n_2 = 1$, $\omega_2 < 0$ (axisymmetric g-mode)

$$\omega_2 > -\kappa,\ E_2/\omega_2 < 0$$



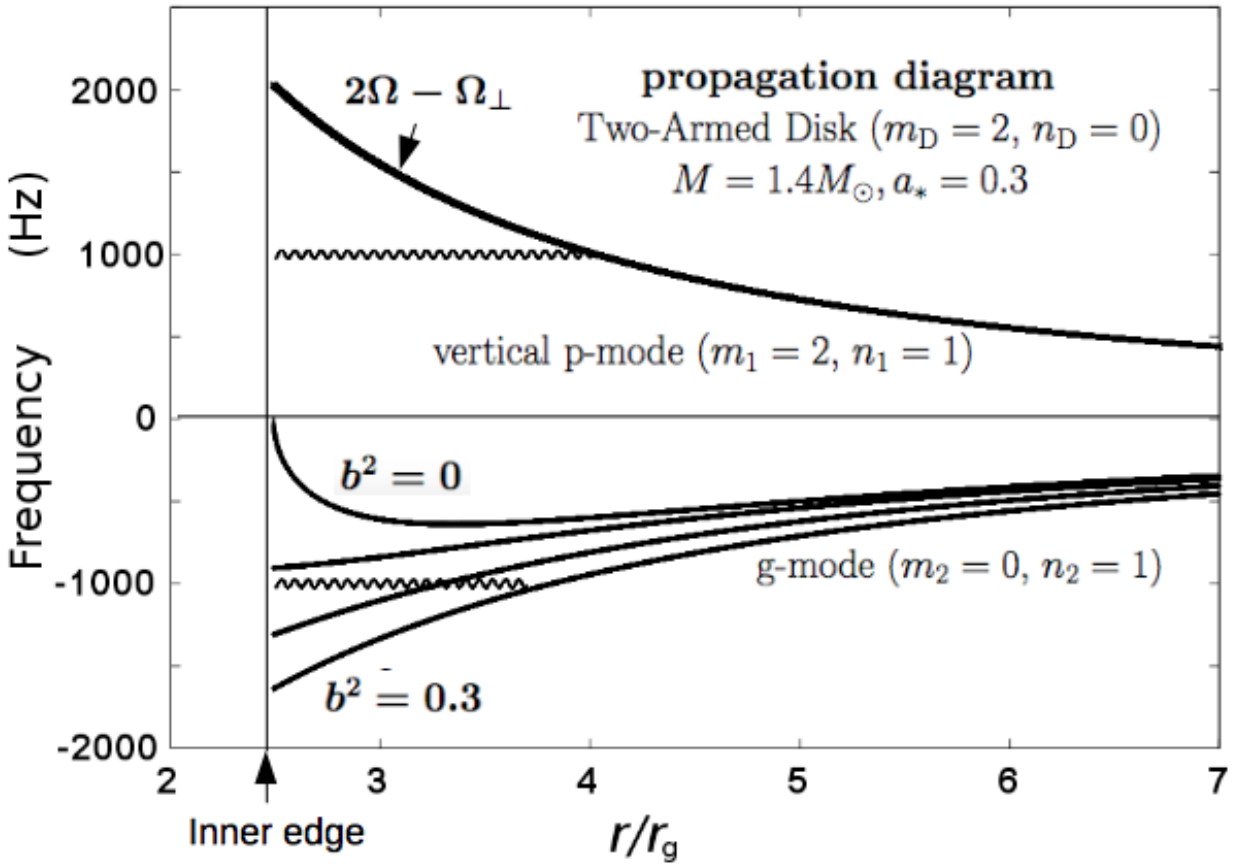
Two-armed Disks $(m_{\rm D}, n_{\rm D}, \omega_{\rm D}) = (-2, 0, 0)$

- $m_1 = 2$, $n_1 = 1$, $\omega_1 > 0$ (vertical p-mode)

$$\omega_1 < 2\Omega - \Omega_\perp, \quad E_1/\omega_1 < 0$$

- $m_2 = 0$, $n_2 = 1$, $\omega_2 < 0$ (axisymmetric g-mode)

$$\omega_2 > -\tilde{\kappa}, \quad E_2/\omega_2 < 0$$



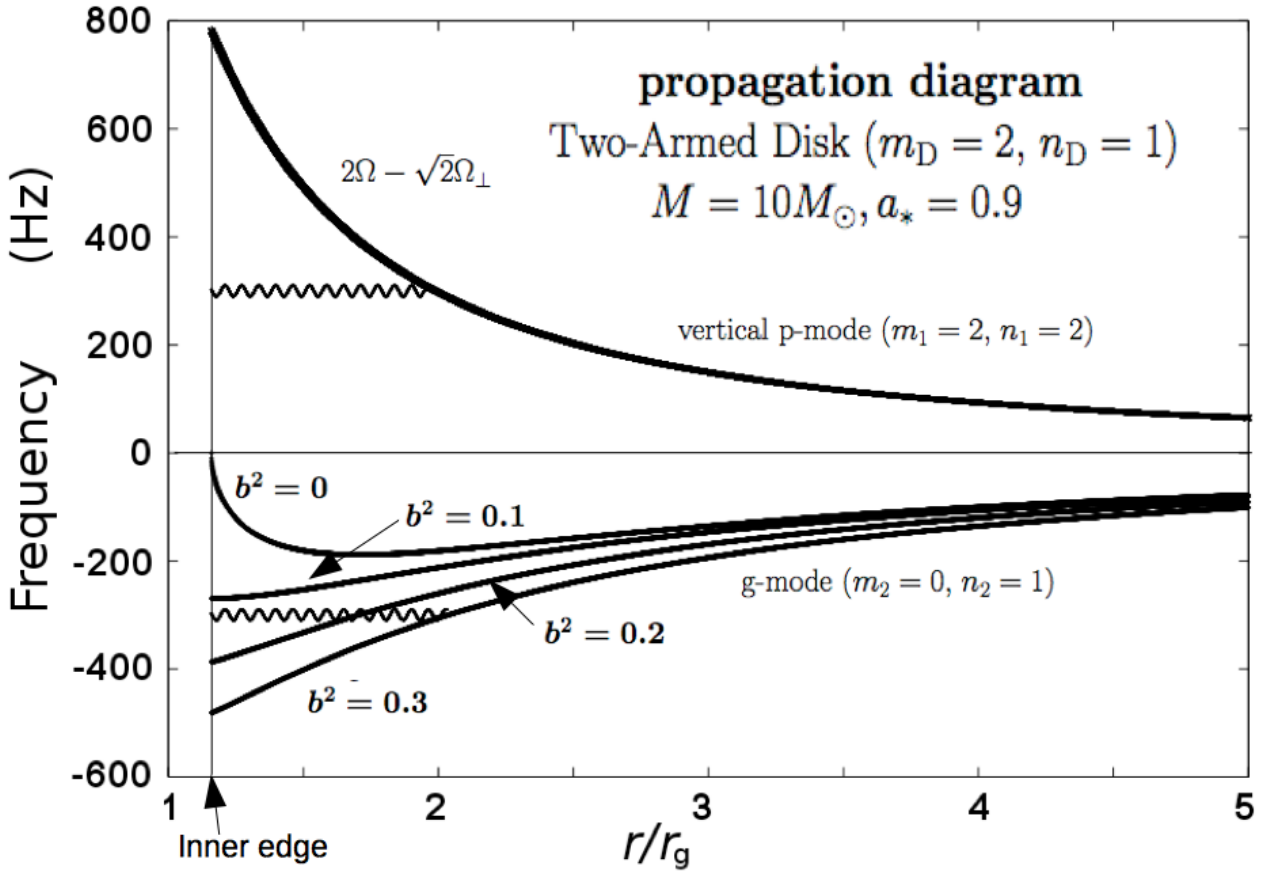
Two-armed Disks $(m_{\rm D}, n_{\rm D}, \omega_{\rm D}) = (-2, 1, 0)$

- $m_1 = 2,\ n_1 = 2,\ \omega_1 > 0$ (vertical p-mode)

$$\omega_1 < 2\Omega - \sqrt{2}\Omega_\perp, \quad E_1/\omega_1 < 0$$

- $m_2 = 0,\ n_2 = 1,\ \omega_2 < 0$ (axisymmetric g-mode)

$$\omega_2 > -\tilde{\kappa}, \quad E_2/\omega_2 < 0$$



Two-armed Disks $(m_{\rm D}, n_{\rm D}, \omega_{\rm D}) = (-2, 2, 0)$

- $m_1 = 2$, $n_1 = 3$, $\omega_1 > 0$ (vertical p-mode)

$$\omega_1 < 2\Omega - \sqrt{3}\Omega_\perp, \quad E_1/\omega_1 < 0$$

- $m_2 = 0$, $n_2 = 1$, $\omega_2 < 0$ (axisymmetric g-mode)

$$\omega_2 > -\tilde{\kappa}, \quad E_2/\omega_2 < 0$$