不活性ブラックホール連星の探査と理論研究

谷川衝（福井県立大学）

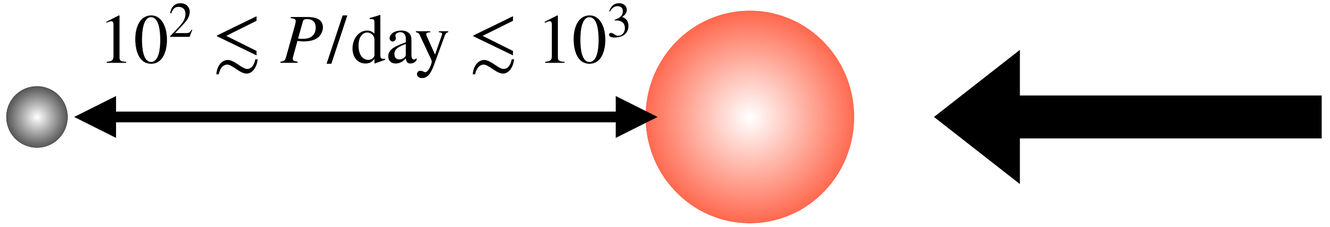
ブラックホール大研究会

～星質量から超巨大ブラックホールまで～

共同研究者：前原裕之，田實晃人（国立天文台），
本田敏志（兵庫県立大学），佐藤文衛（東京工業大学）

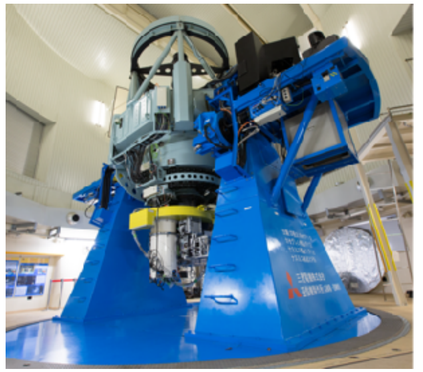
Summary in advance

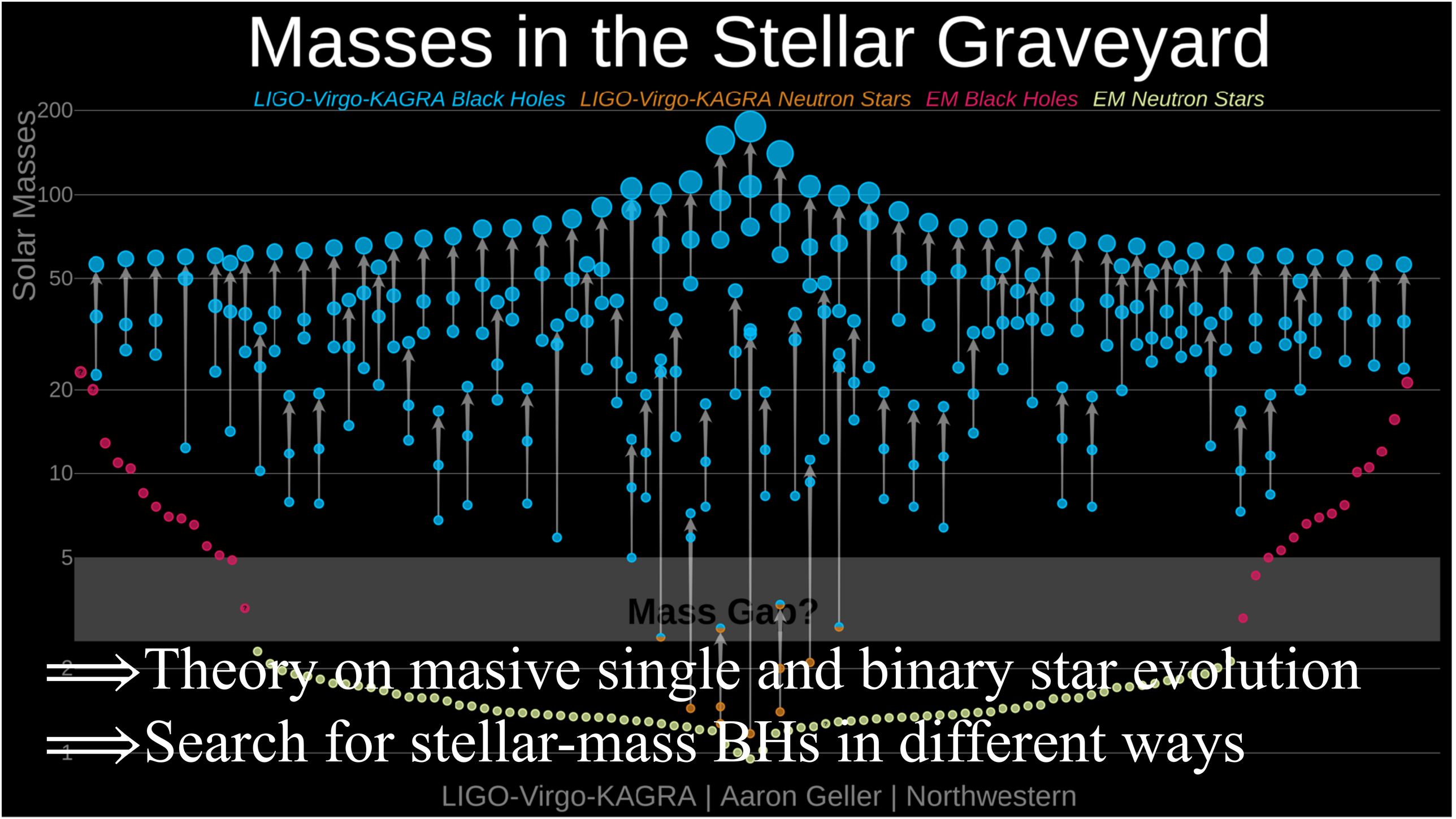
- 重力波による連星BHの発見によりBH探査が活況
- X線で暗い「不活性」なBH連星 （Gaia BH）がGaia DR3から発見 (e.g. Tanikawa et al. 2023, ApJ, 946, 79)
- せいめいGAOES-RV・なゆたMALLSによりGaia BH/NSを探査中



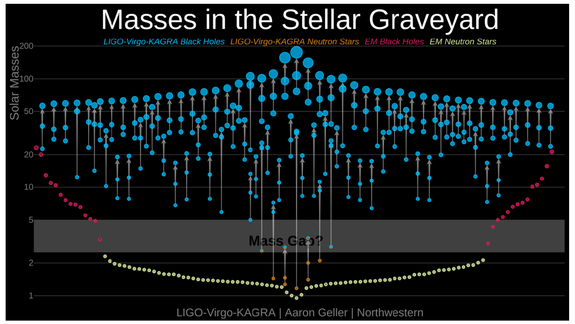
Seimei GAOES-RV

NAYUTA MALLS




Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
EM Black Holes
EM Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
Mass Gap?
⟹Theory on masive single and binary star evolution
⟹Search for stellar-mass BHs in different ways
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

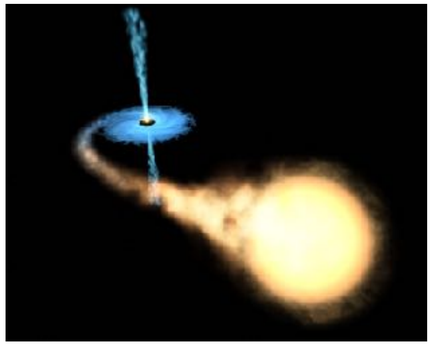
Gravitational wave



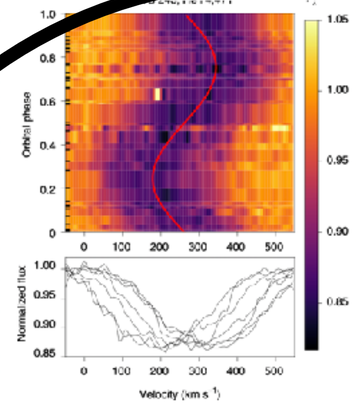
Massive companion ($\gtrsim 8M_\odot$)

Low-mass companion ($\lesssim 8M_\odot$)

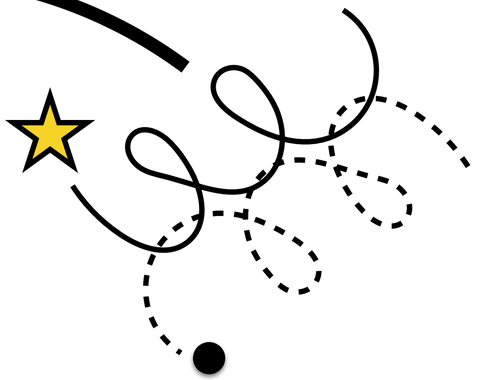
X-ray



No X-ray emission $\Longrightarrow$ Inert

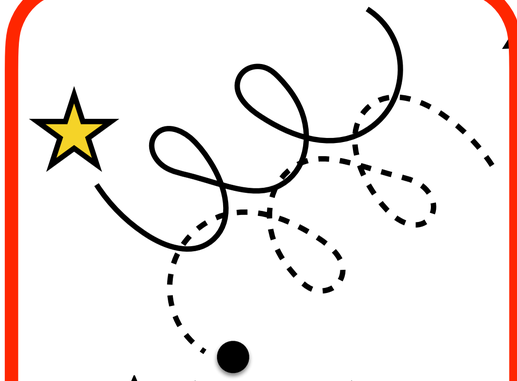


Spectroscopy



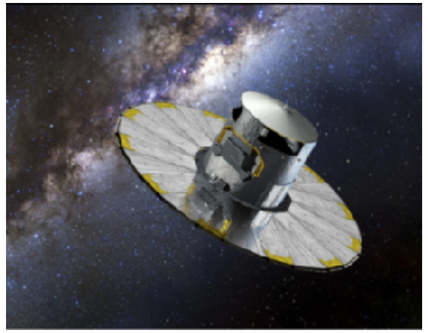
Astrometry

Discovered

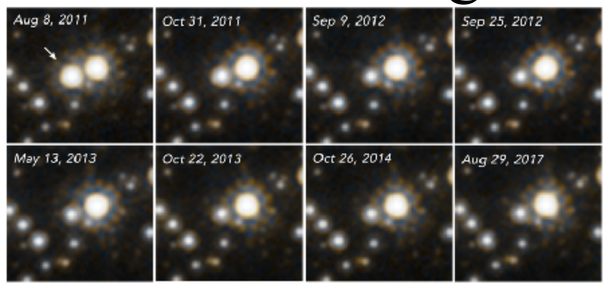


Astrometry

Gaia mission



Microlensing



10^{-1} 1 10 10^2 10^3 10^4 10^∞

Orbital period [day]

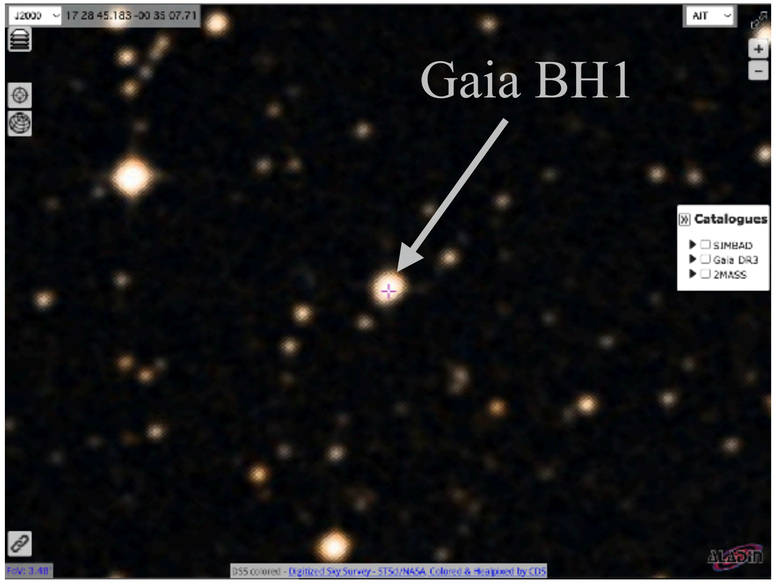
Gaia BH1

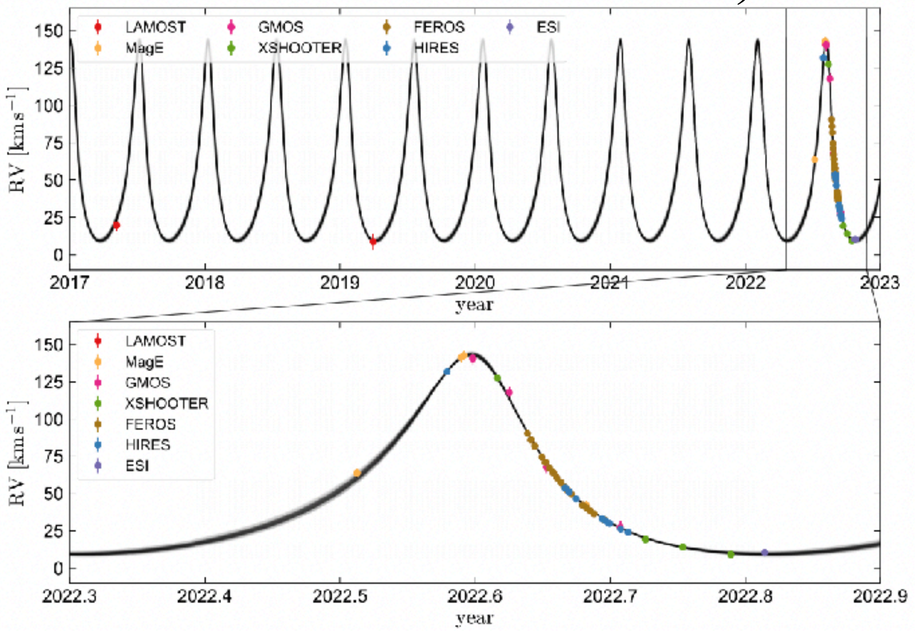
- $M_{\rm BH} = 9.62 M_\odot$
- $M_{\rm comp} = 0.93 M_\odot$
- $P = 185.59$ d
- $a = 1.40$ au
- $e = 0.451$
- [Fe/H] $= -0.2$

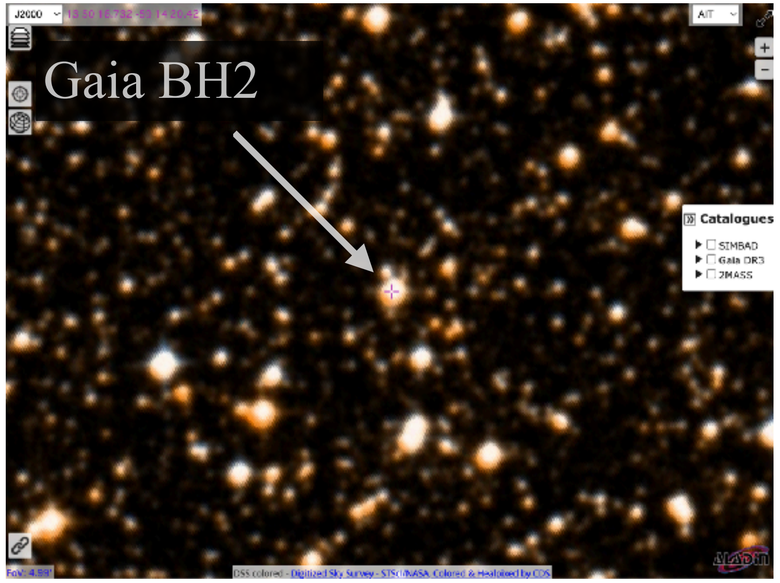
Gaia BH2

- $M_{\rm BH} = 8.94 M_\odot$
- $M_{\rm comp} = 1.07 M_\odot$
- $P = 1276.7$ d
- $a = 4.96$ au
- $e = 0.5176$
- [Fe/H] $= -0.22$

El-Badry et al. (2023; see also Chakrabarti et al. 2023)

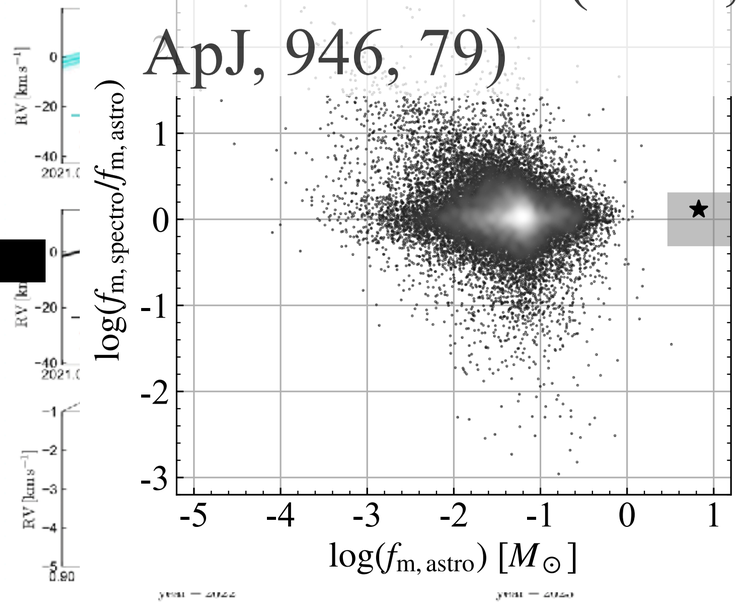


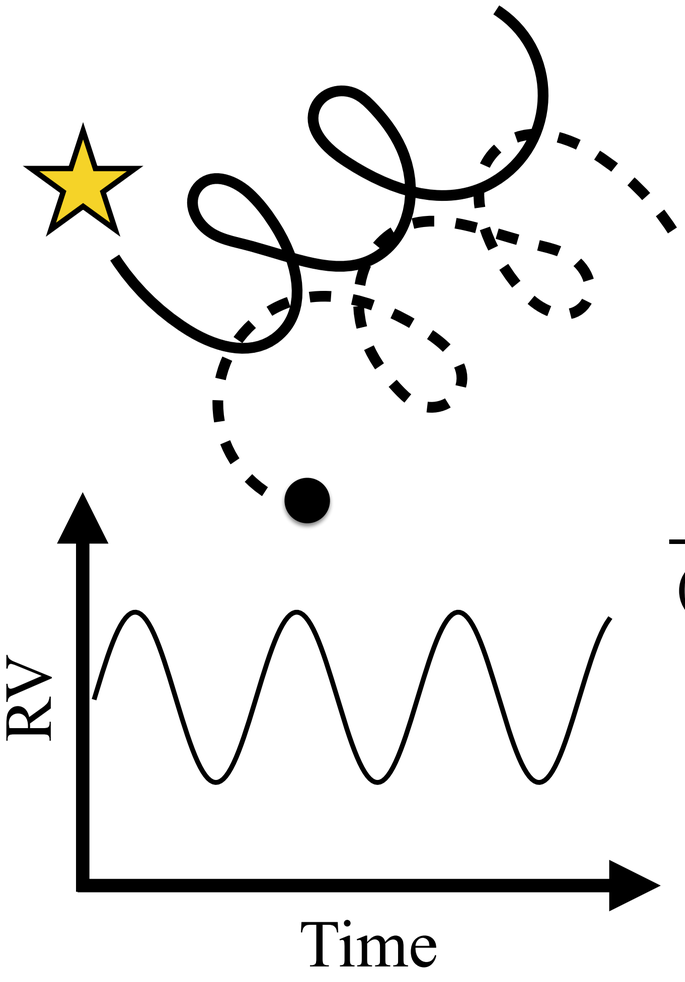




E

Tanikawa et al. (2023, ApJ, 946, 79)





$$\frac{m_2^3}{(m_1+m_2)^2} = 1 \left(\frac{\hat{a}}{\mathrm{mas}}\right)^3 \left(\frac{\varpi}{\mathrm{mas}}\right)^{-3} \left(\frac{P}{\mathrm{yr}}\right)^{-2} [M_\odot]$$

Astrometry

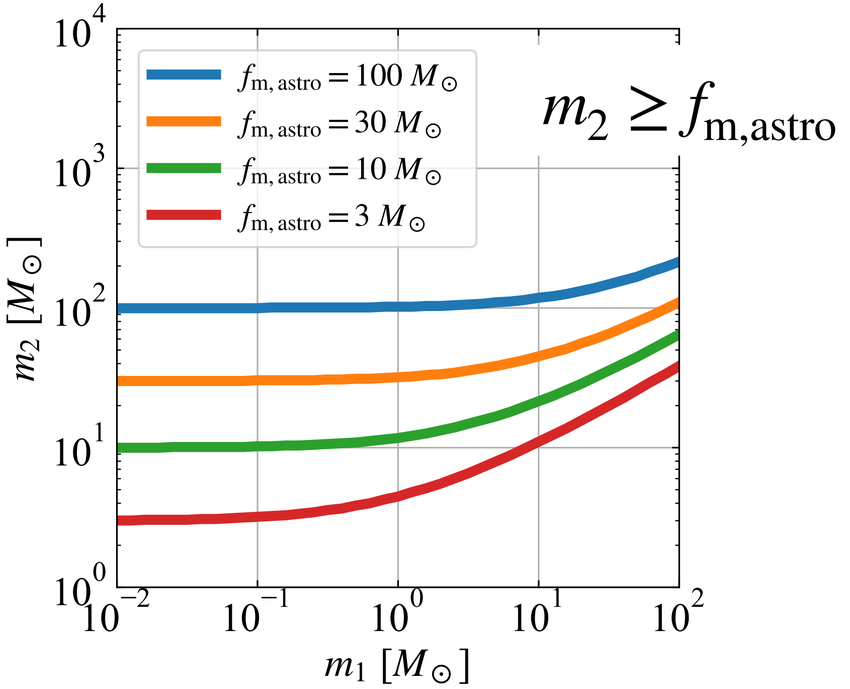
Orbit size Parallax Period

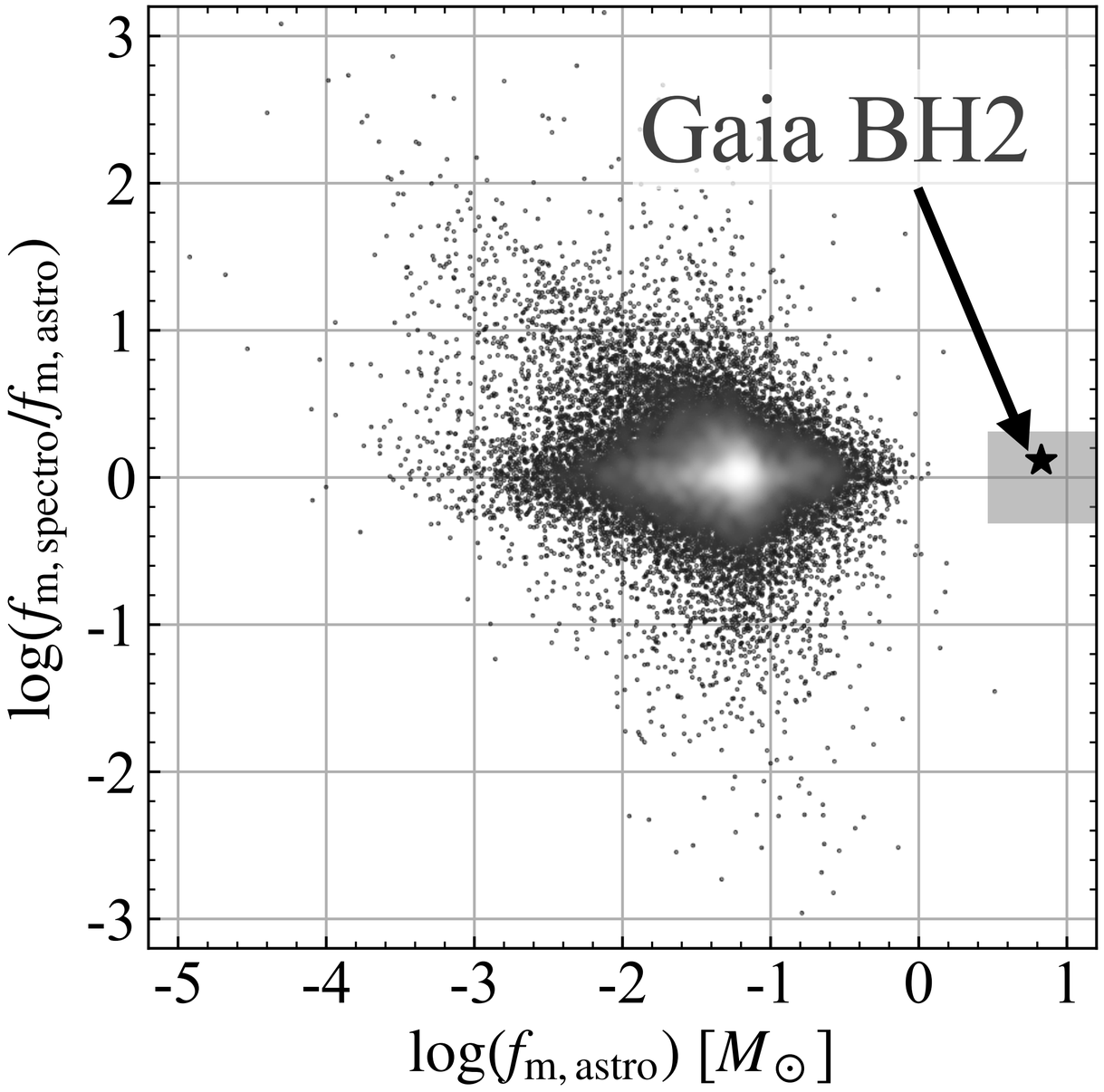
$$\frac{m_2^3}{(m_1+m_2)^2} = 1 \left(\frac{K_1}{30\mathrm{km\ s^{-1}}}\right)^3 \left(\frac{P}{\mathrm{yr}}\right) (1-e^2)^{3/2} \sin^{-3} i\ [M_\odot]$$

RV Semi-amplitude Period Eccentricity Inclination

Spectroscopy

1. $f_{\mathrm{m,astro}} \sim f_{\mathrm{m,spectro}}$
2. $f_{\mathrm{m,astro}} \geq 3M_\odot$



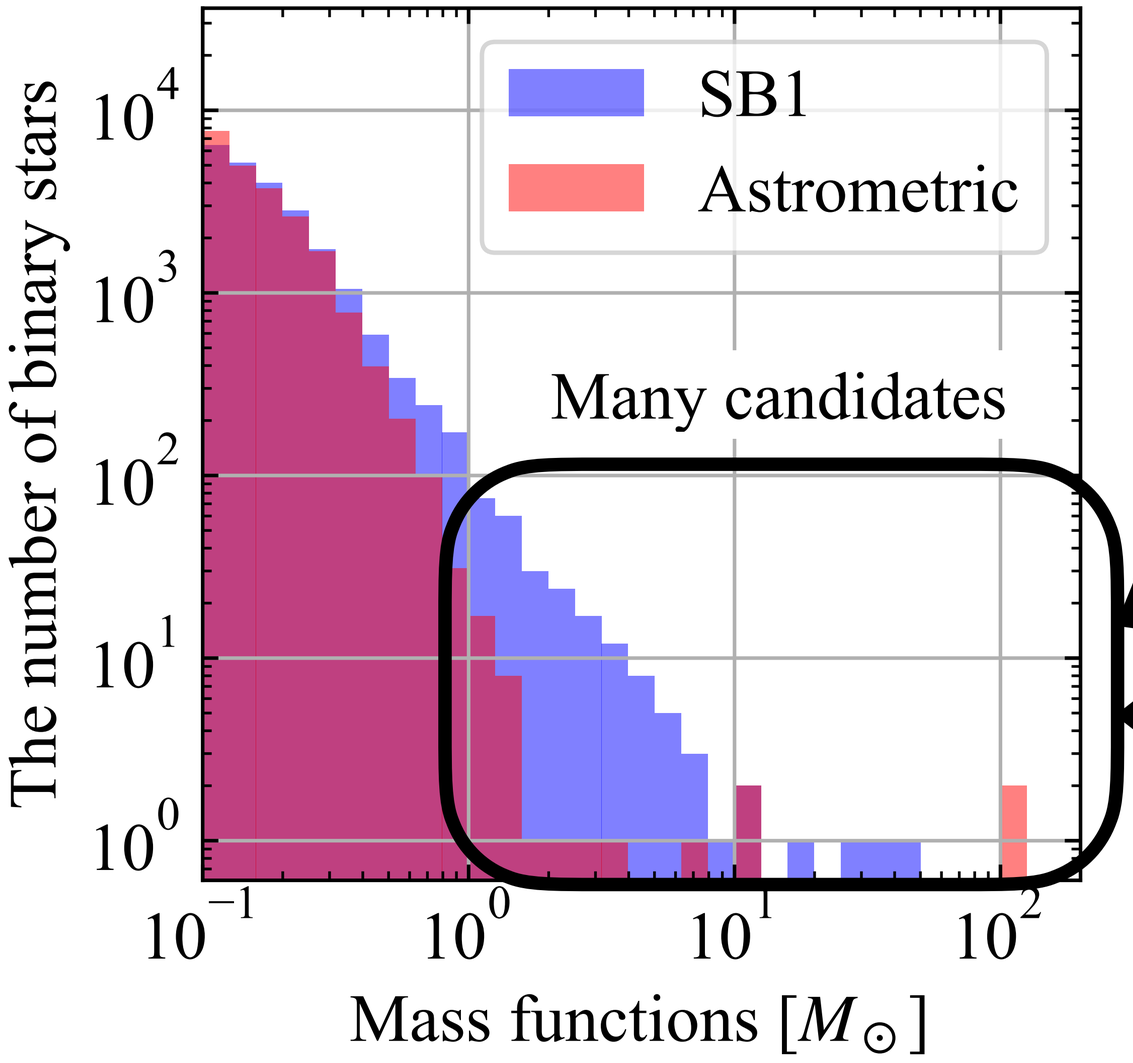


Tanikawa et al. (2023, ApJ, 946, 79)

- Andrews+ (2207.00680)
  - 偽陽性率: N/A (0/0)
  - 偽陰性率: 100% (0/1)
- Shahaf+(2209.00828)
  - 偽陽性率: 75% (3/4)
  - 偽陰性率: 0% (0/1)
- Tanikawa+(2209.05632)
  - 偽陽性率: 0% (0/1)
  - 偽陰性率: 0% (0/1)

We discovered Gaia BH2 not at random.

Another Gaia BHs or “Gaia NSs”

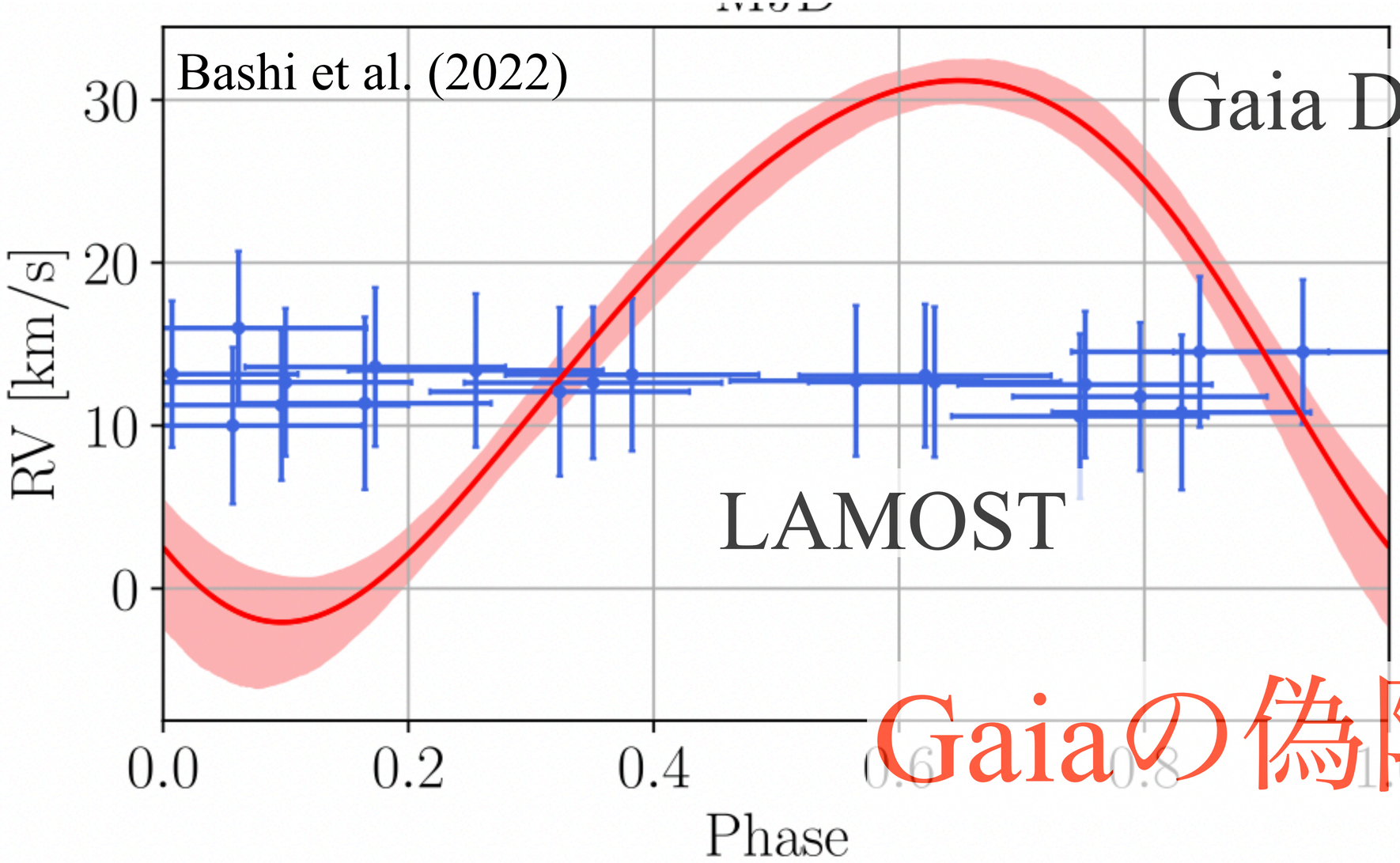


Seimei GAOES-RV

NAYUTA MALLS

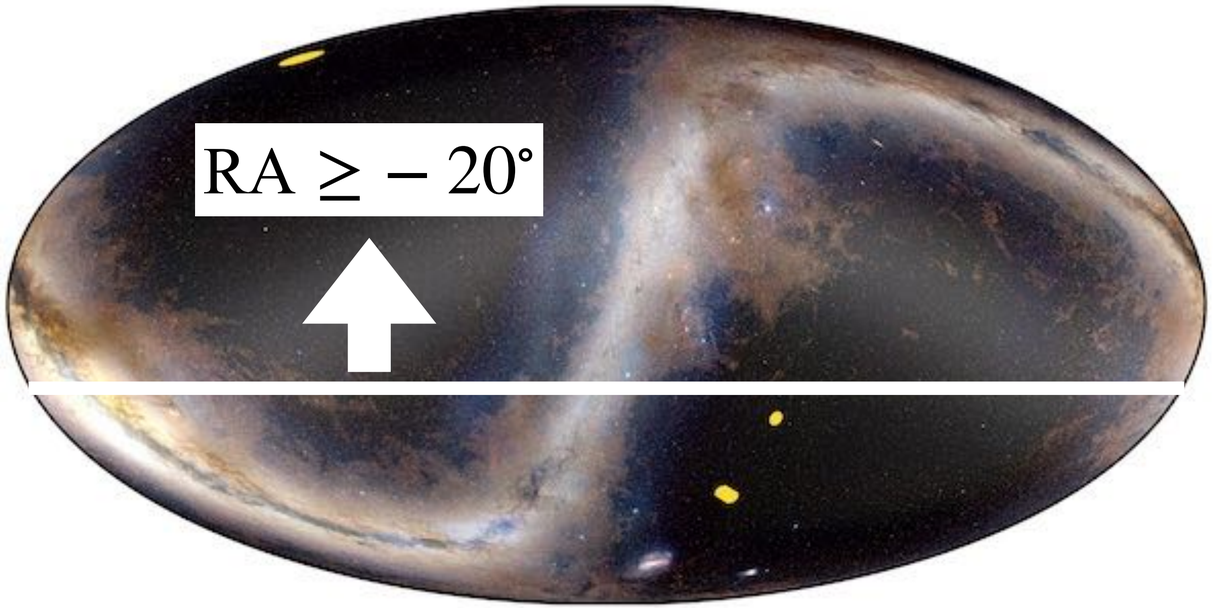
Follow-up RV observations

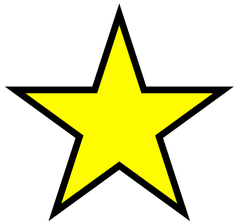
Needs for follow-up observations



Gaiaの偽陽性

Candidate selection



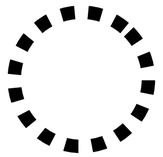


$G_1 \leq 13$ mag

Later than F-type

Not too bright

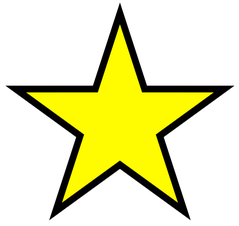
BH/NS candidate



$m_2 \geq 1.35 M_\odot$

$M_{G,1} = -2$

$m_1 \sim 10 M_\odot$



$m_2 = 1.4 M_\odot$

NS: $M_{G,2} \gg M_{G,1}$

MS: $M_{G,2} \sim 3.3$

観測経過

- せいめい望遠鏡GAOES-RV
  - 各夜で複数の候補天体を観測（1天体あたりの時間は1200-1800秒）
  - 2023年8月から14天体（主にG型、K型星）を複数回観測
- なゆた望遠鏡MALLS
  - 有望な天体を週 1 回程度の頻度で観測
  - 2023年10月から5天体を複数回観測

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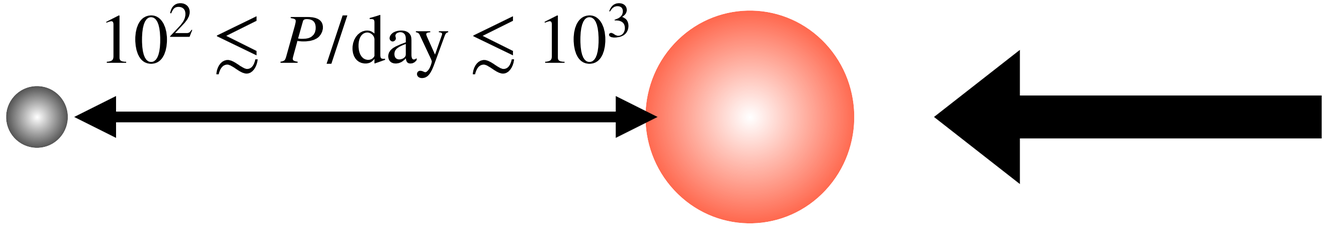

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