Simplified Model of Line Profile Variability from Eccentric Orbits of Supermassive Binary Black Hole Systems

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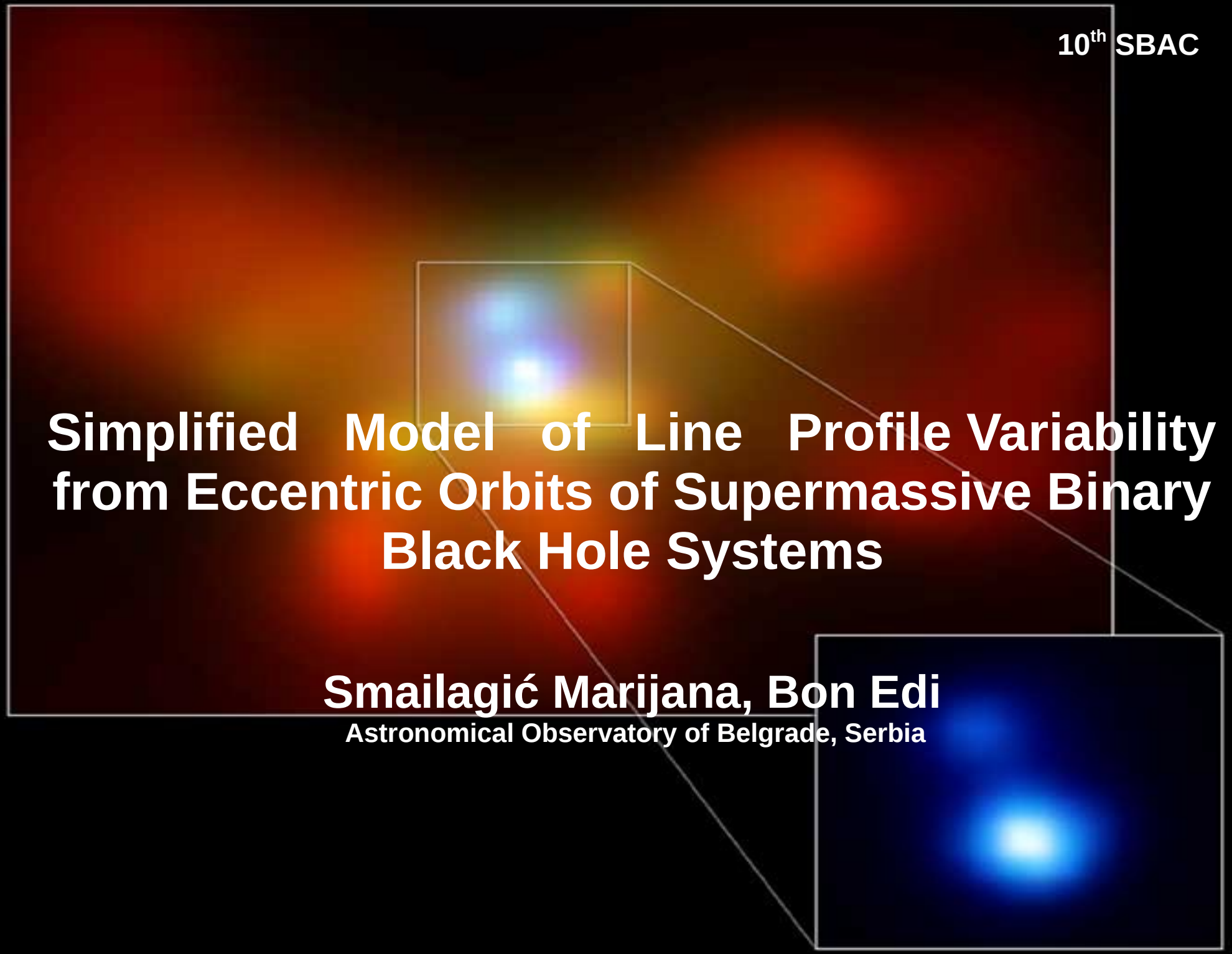


Outline

- Introduction and motivation
- Model
- Results for different parameters
- Conclusions

Introduction and motivation

- **Observational evidence:**

  - or via periodic variability in light curves and line shapes (but often there exist alternative explanations)

- **Simulations:**

  - a number of simulations demonstrated that spiral arms form in binary black hole systems

  - spirals, circumbinary disk, low-density cavity

- **Expectations from models:**

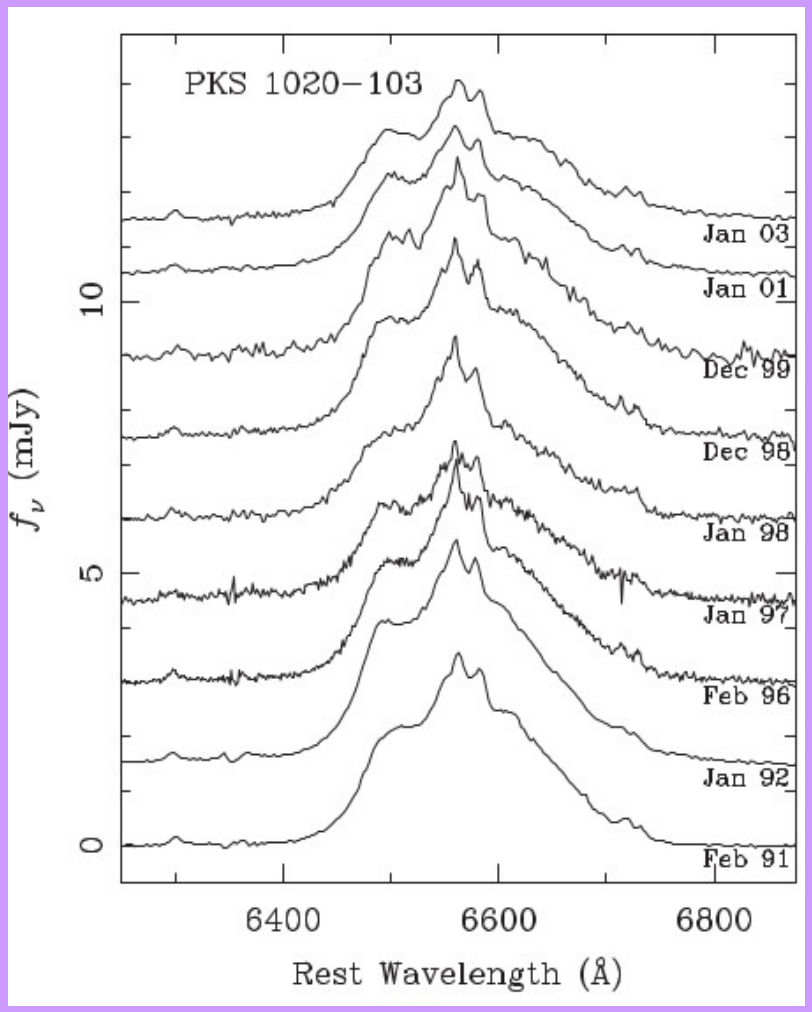
  - it is expected that binary black holes form as a result of mergers between galaxies,

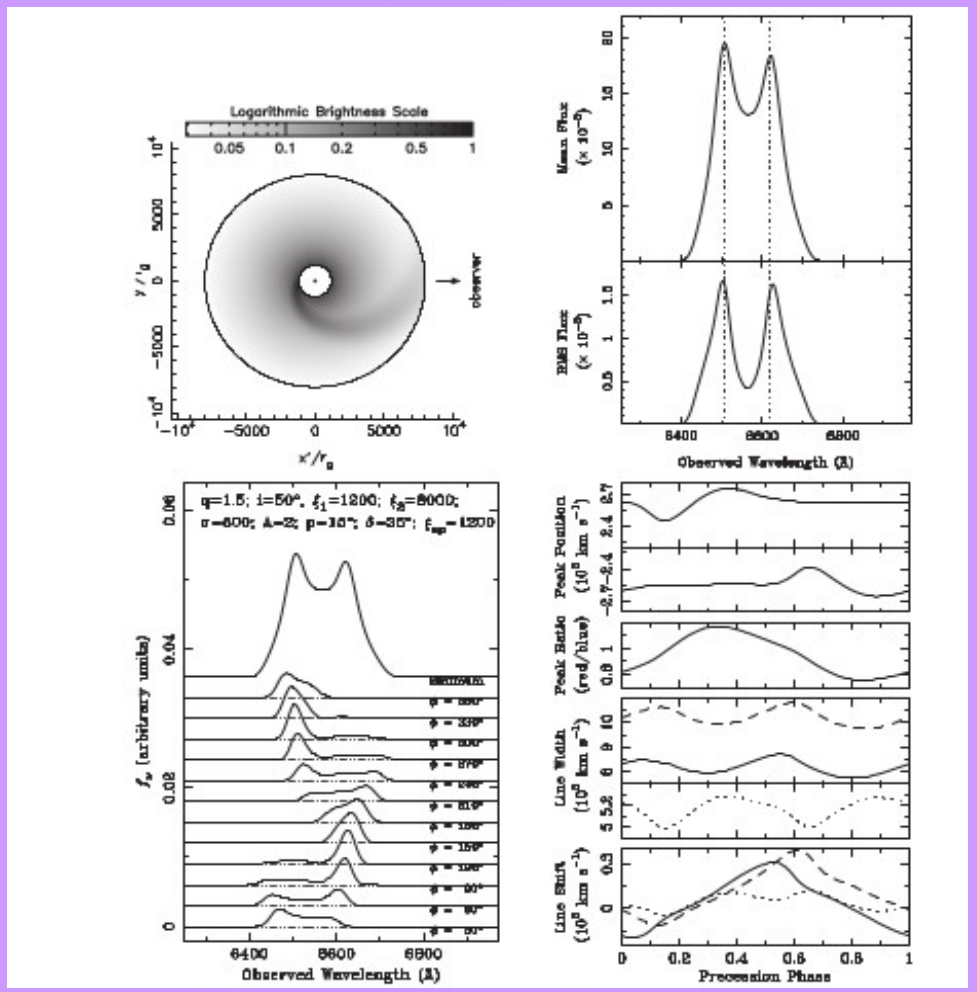
  and that mergers are common in the Universe

Introduction and motivation

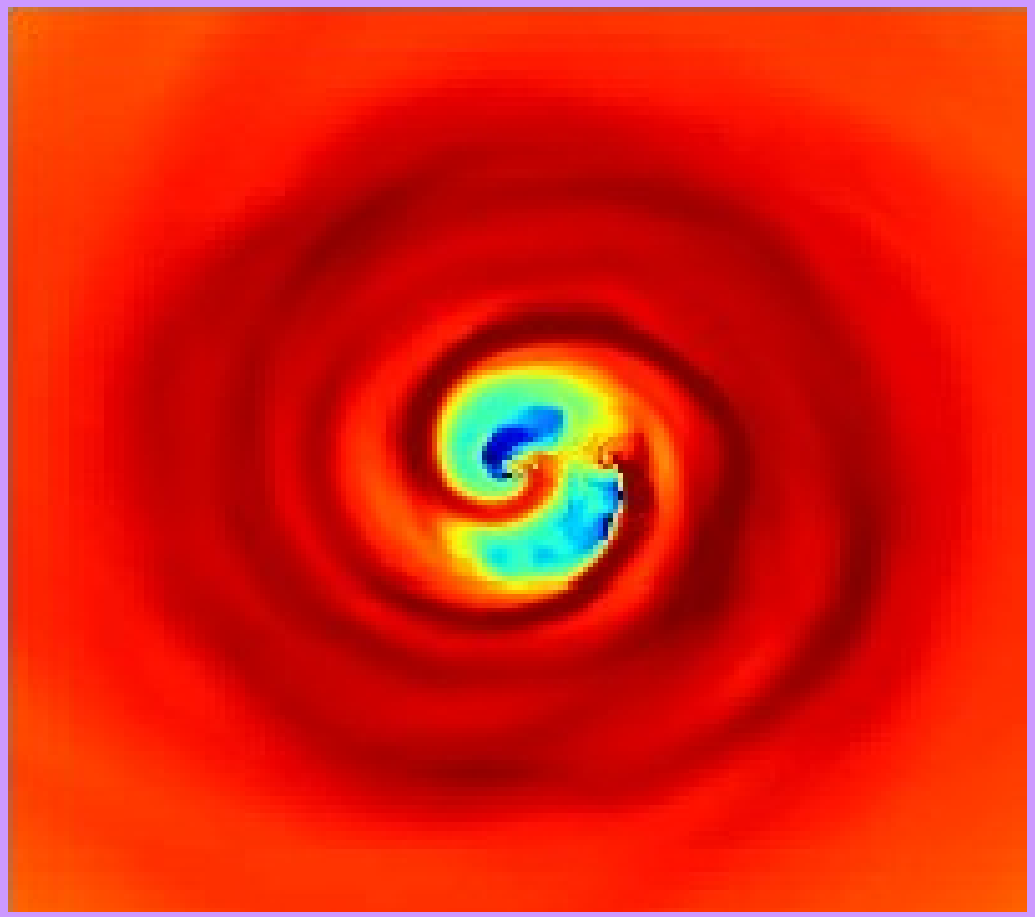
- How to explain variability of active galactic nuclei?

Lewis et al. 2010





Introduction and motivation



- Simulated spirals of gas inflowing into 2 black holes (Gold et al. 2013)

Model

1) BHs

- Masses
M_{tot}, $Q=M_1/M_2$

- Emissivity: $q_{1,2}$

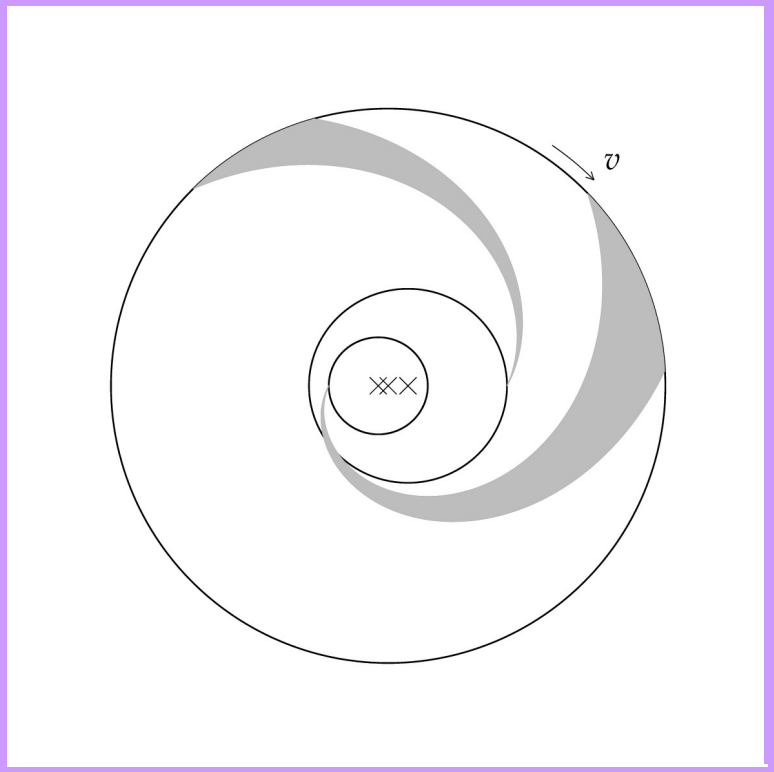
$$\epsilon \sim r_{BH1}^{-q_1} + r_{BH2}^{-q_2},$$

- Orbit: *T, e, w*

3) velocity

- Kepler equations of motion

- plus local turbulences



2) Spirals of gas and CB disk

- geometry of spirals: angle, thickness, (length)

$$R_2 = r_{02} e^{B\varphi}$$

- position of CB disk: *from simulations*

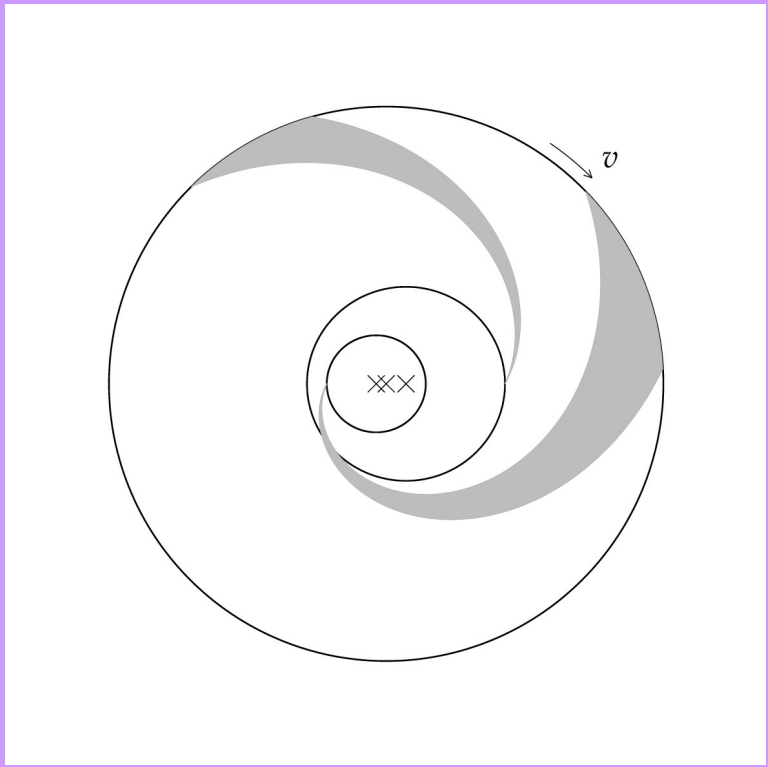
4) Angle of inclination *i*

$$r_{1,2} \sin i = (1.3751 \times 10^4)(1-e^2)^{1/2} K_{1,2} T \ \text{km},$$

$$M_{1,2} \sin i = (1.0361 \times 10^{-7})(1-e^2)^{3/2} (K_1+K_2)^2 K_{2,1} T \ M_\odot$$

$r_{01,02}$ ~ 0.001 - 0.005 pc

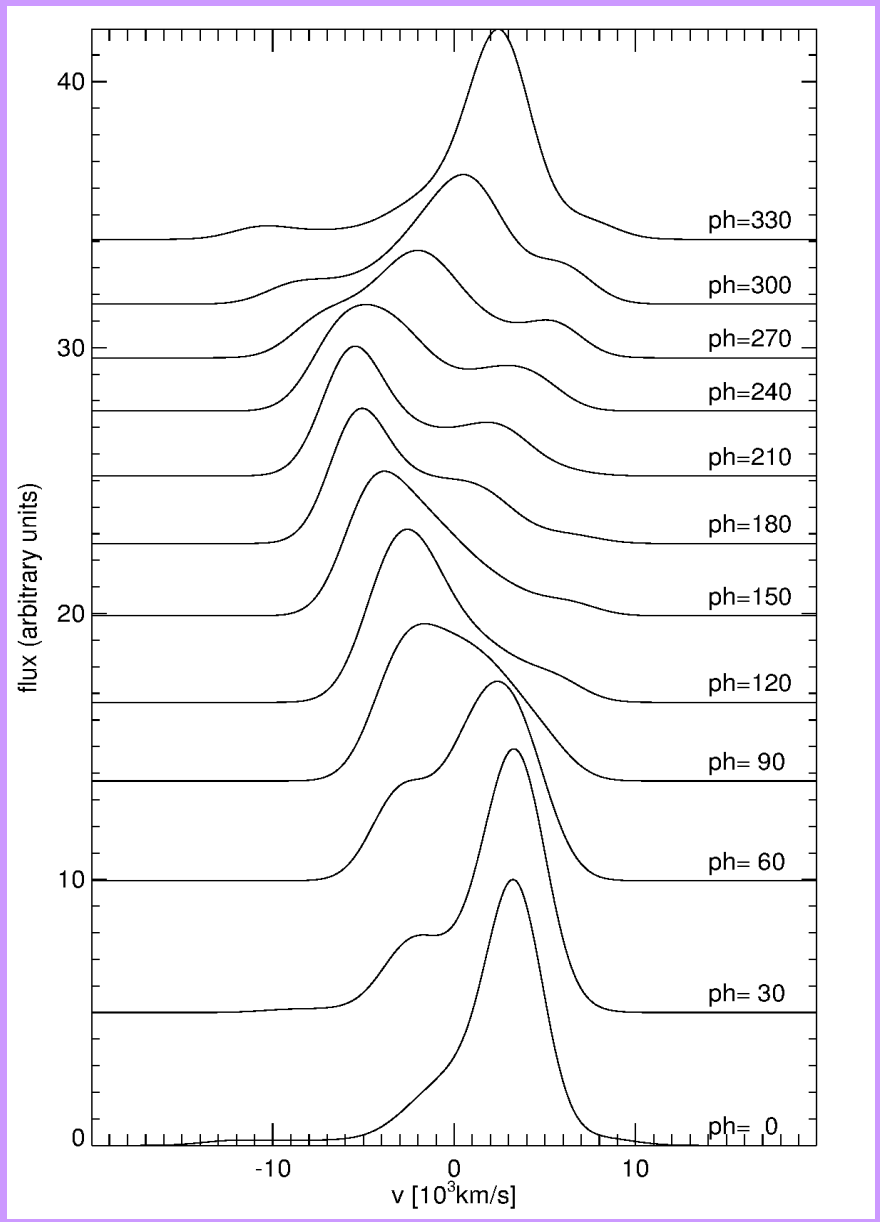
Results



$M = 10^8\, M_{Sun}$ $M_1/M_2 = 0.5$

$e = 0.2$ $w = 0^0$

$T = 15\ yr$ $i = 45^0$



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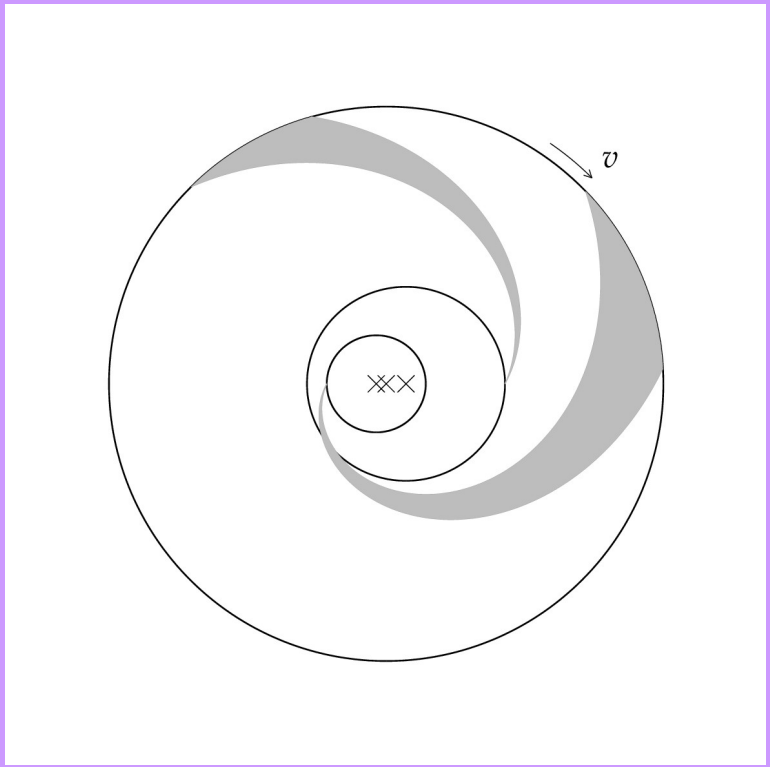

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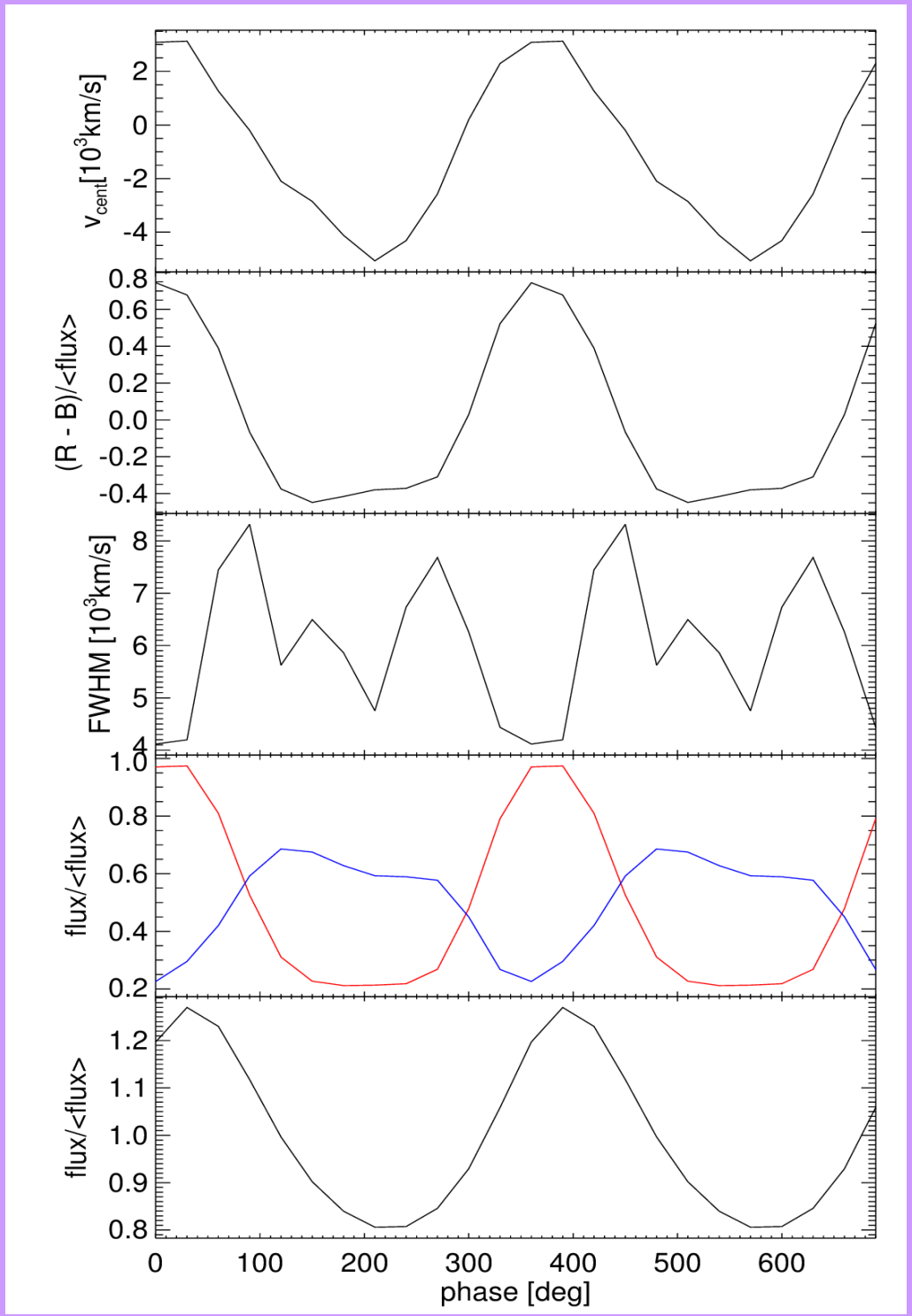

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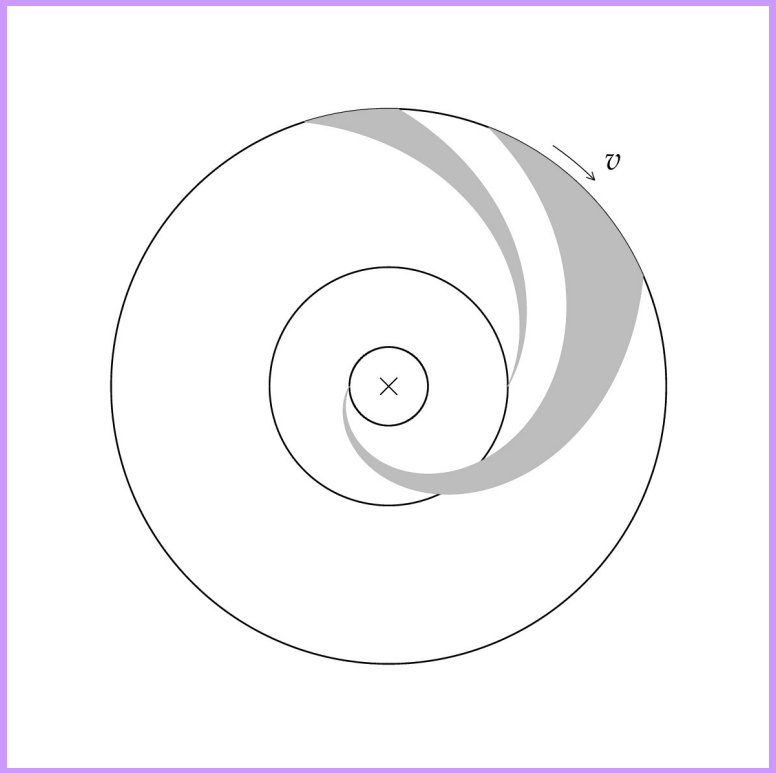

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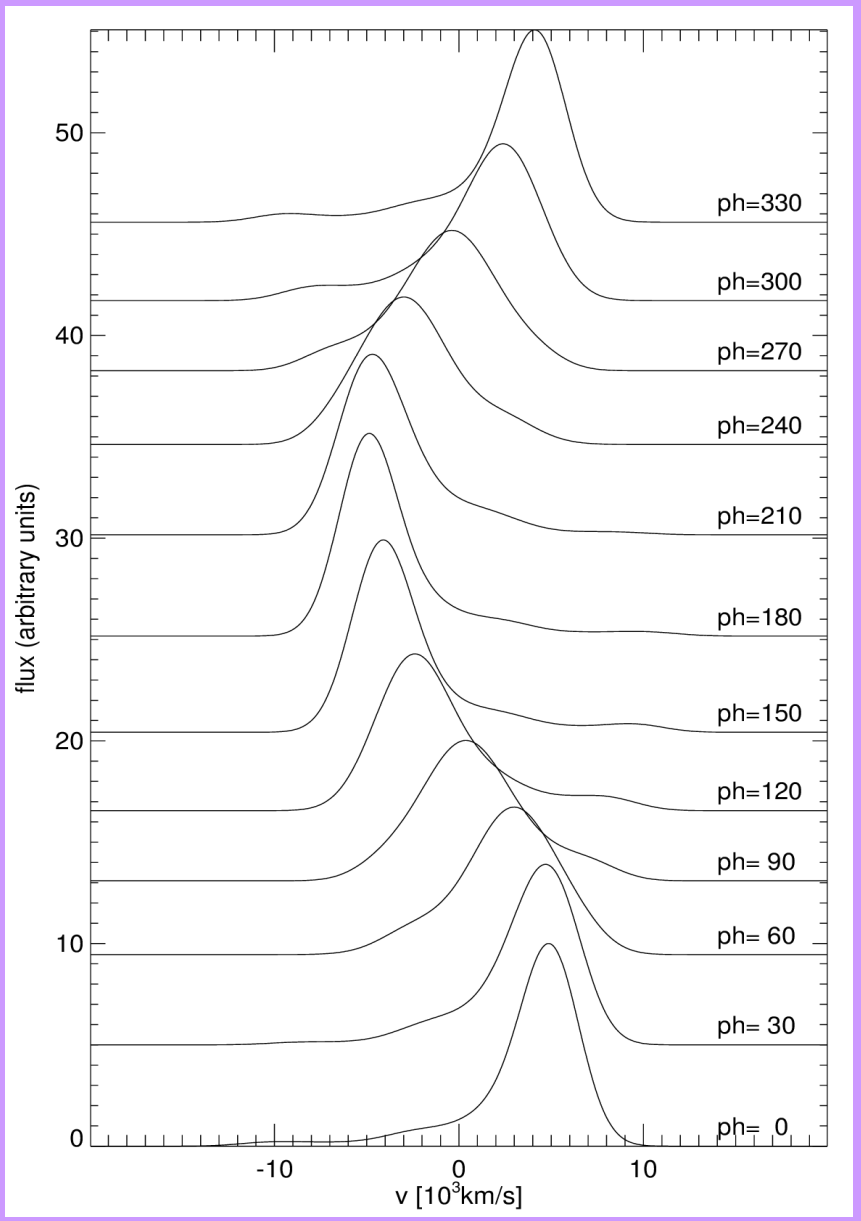

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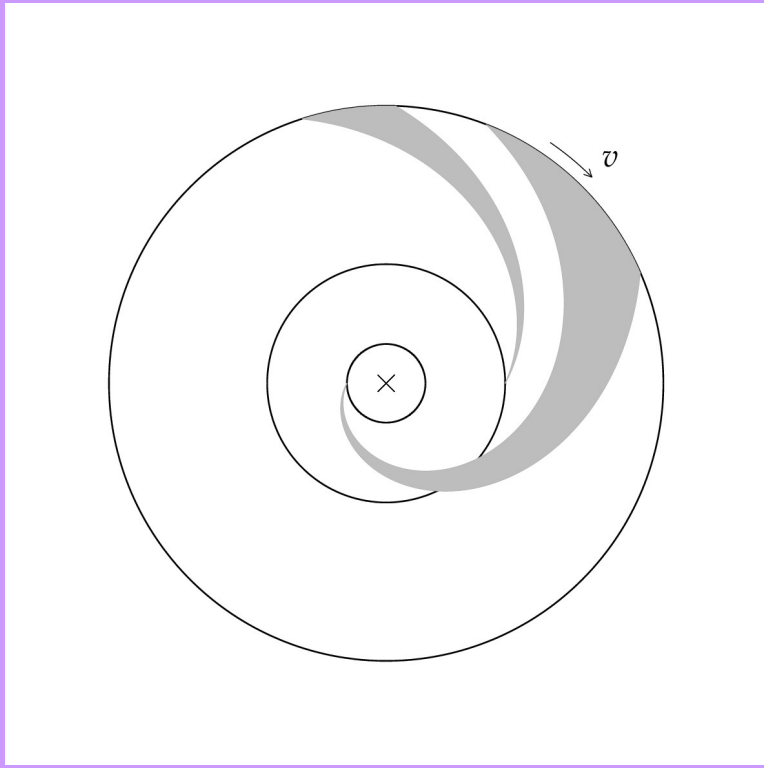

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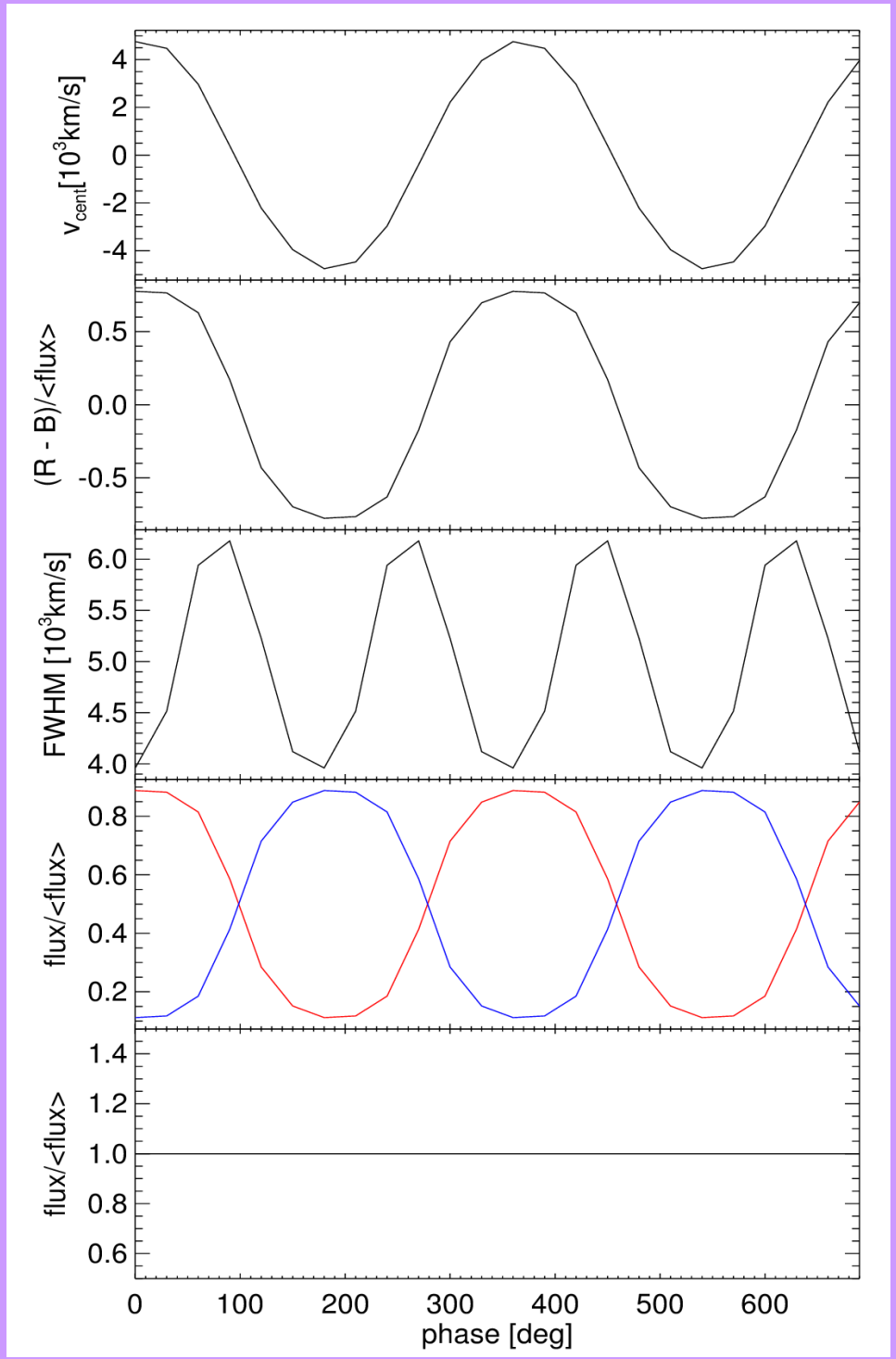

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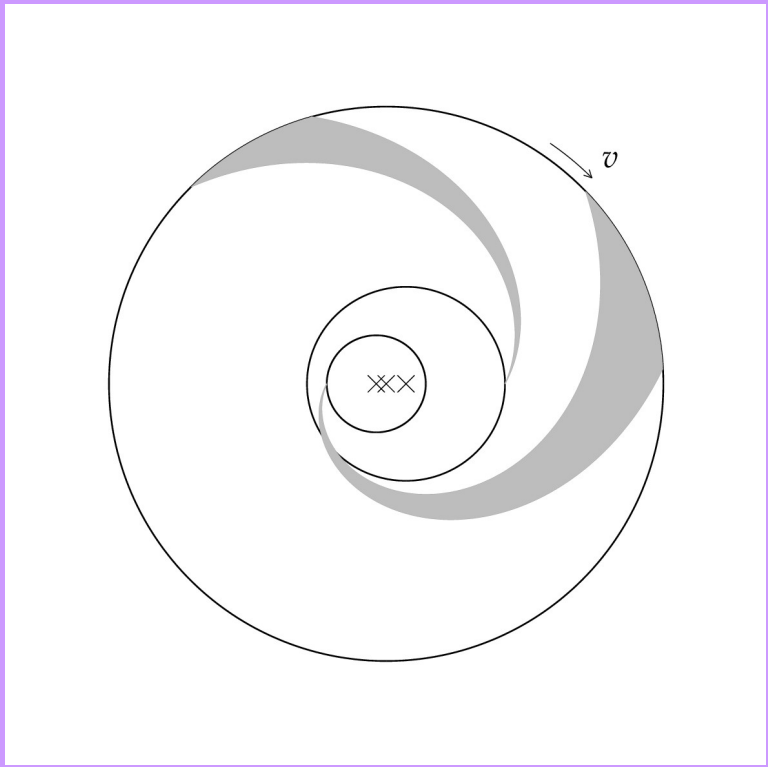

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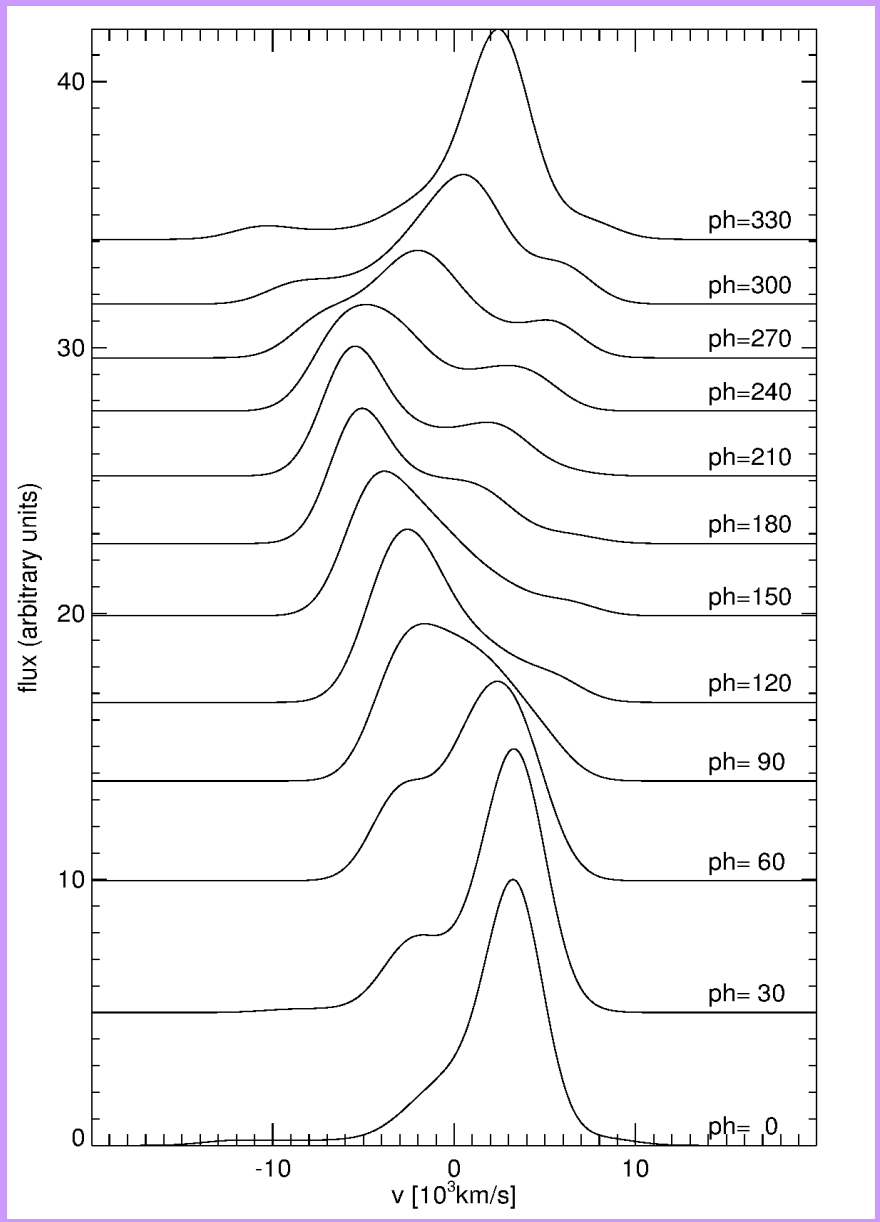

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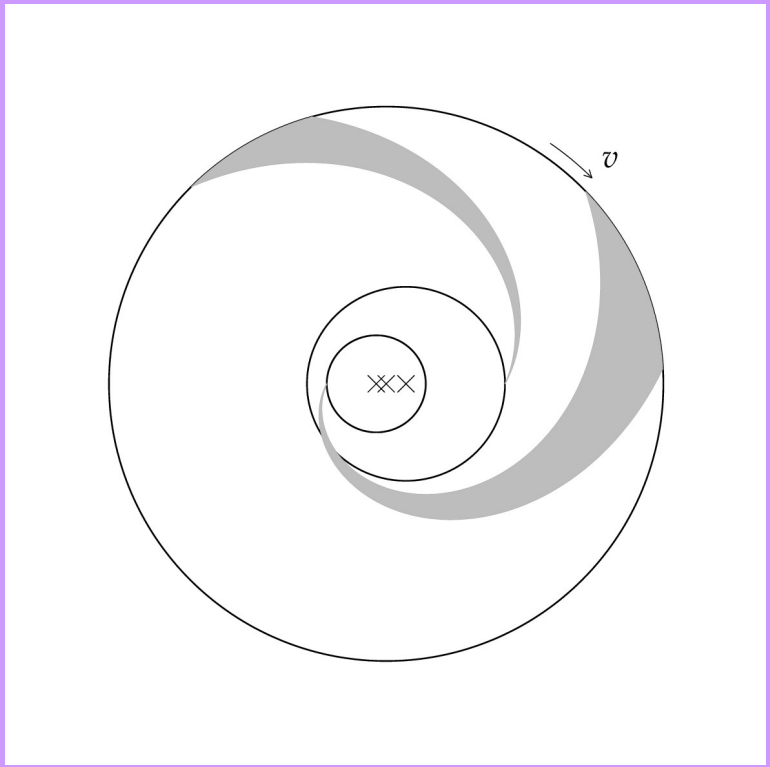

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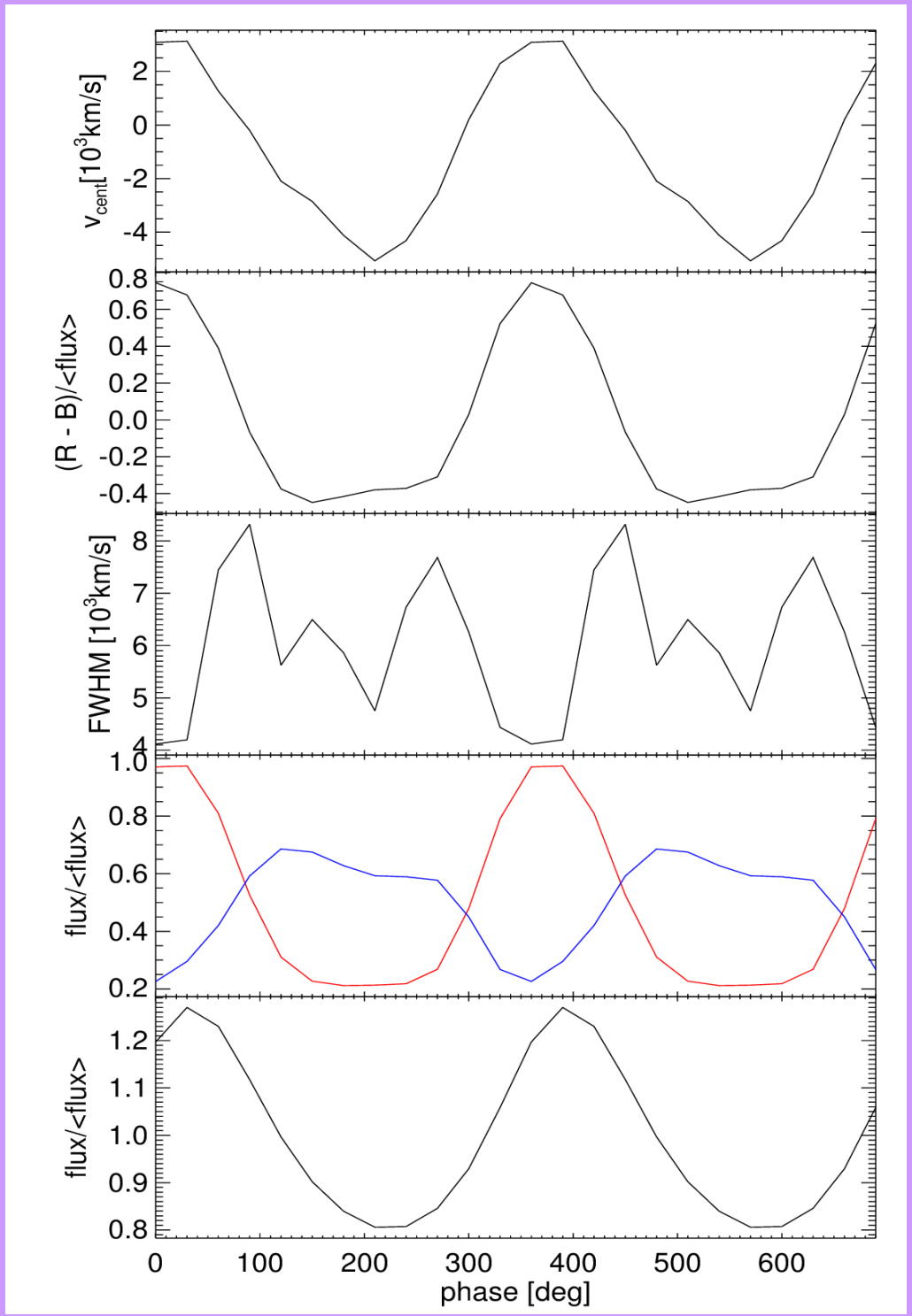

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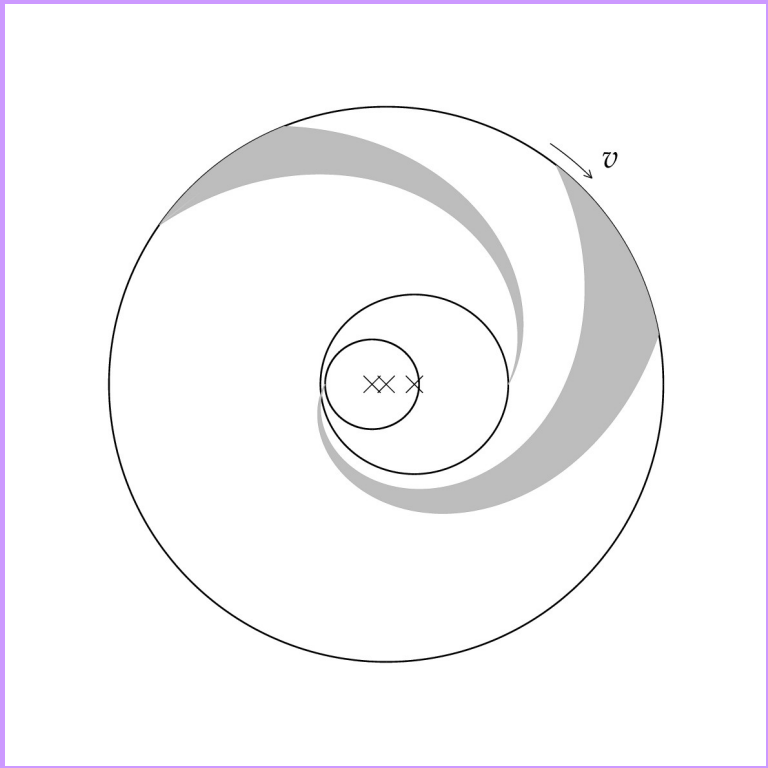

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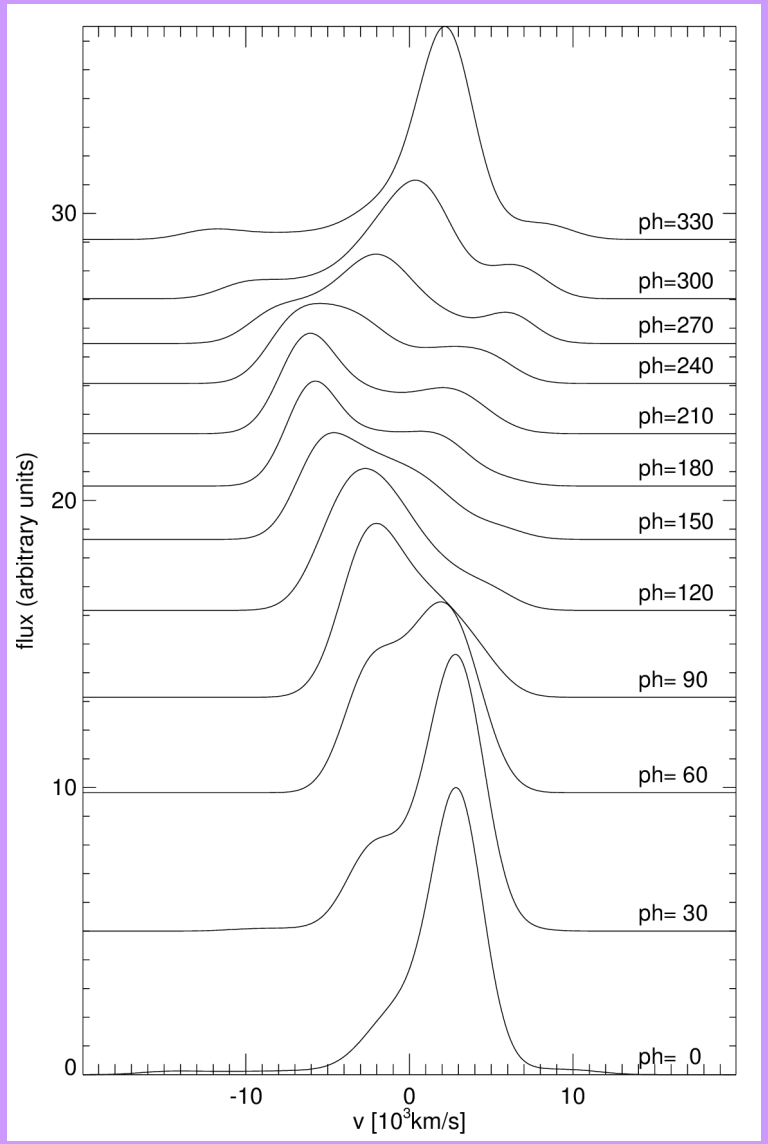

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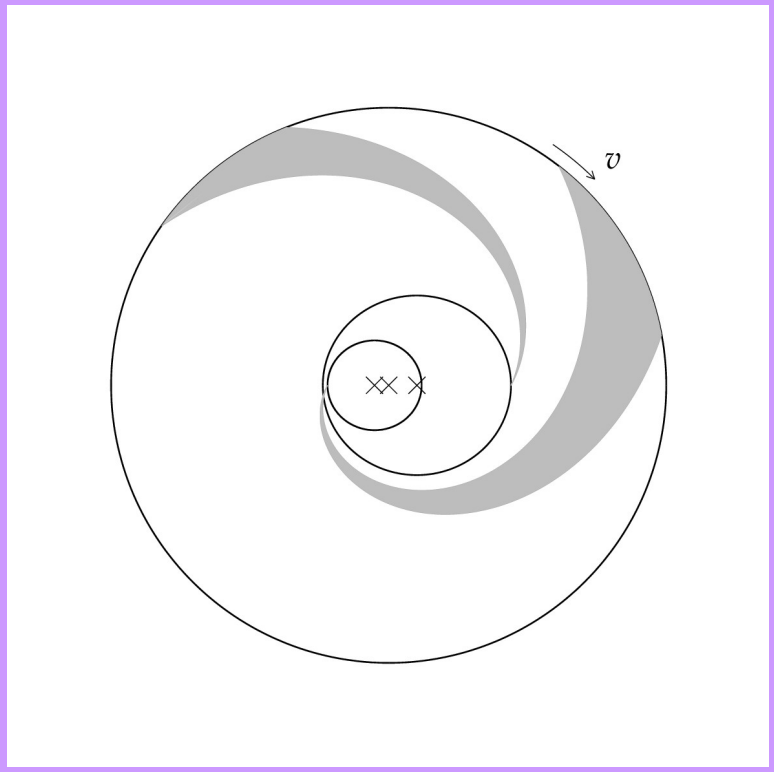

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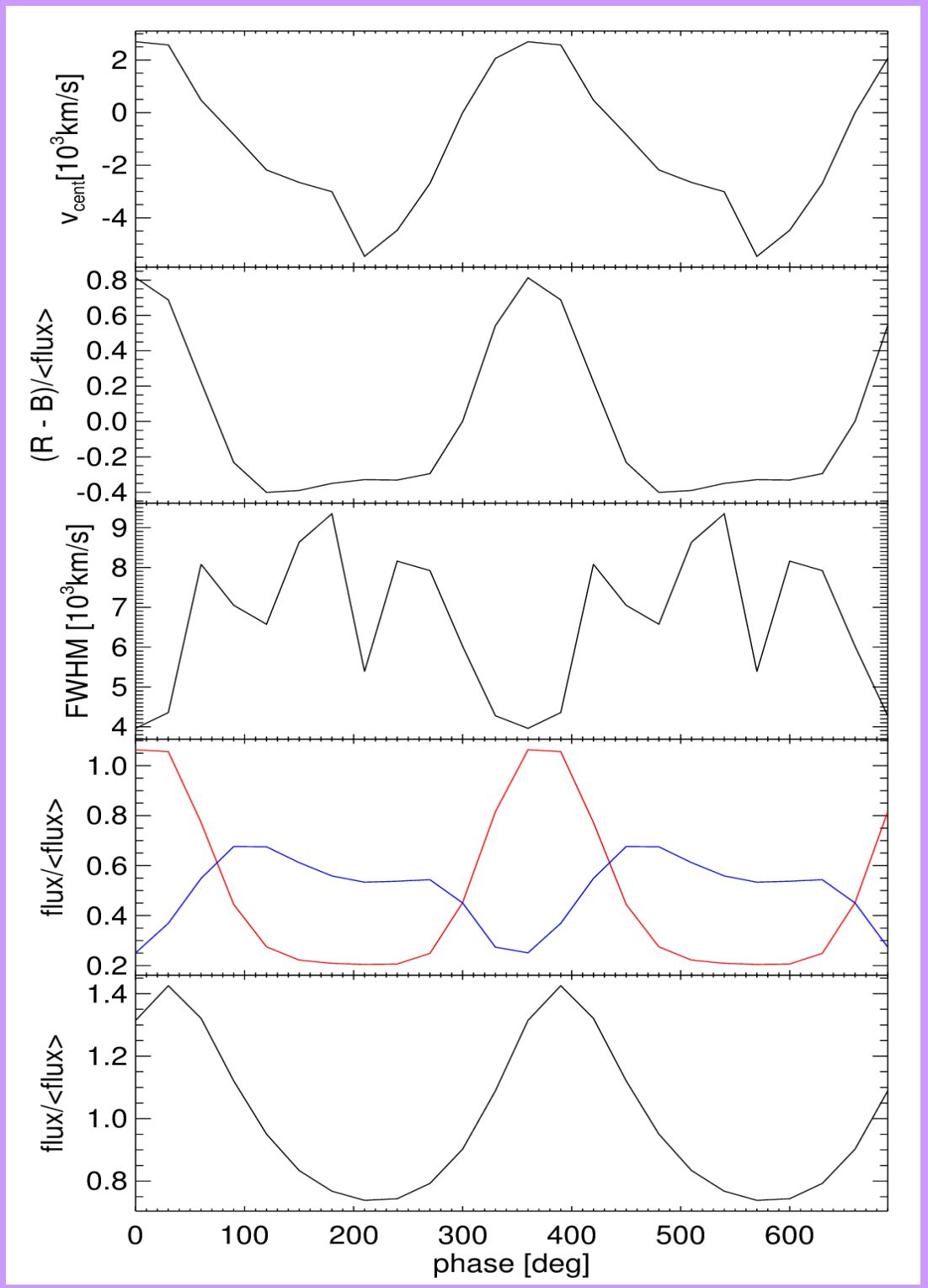
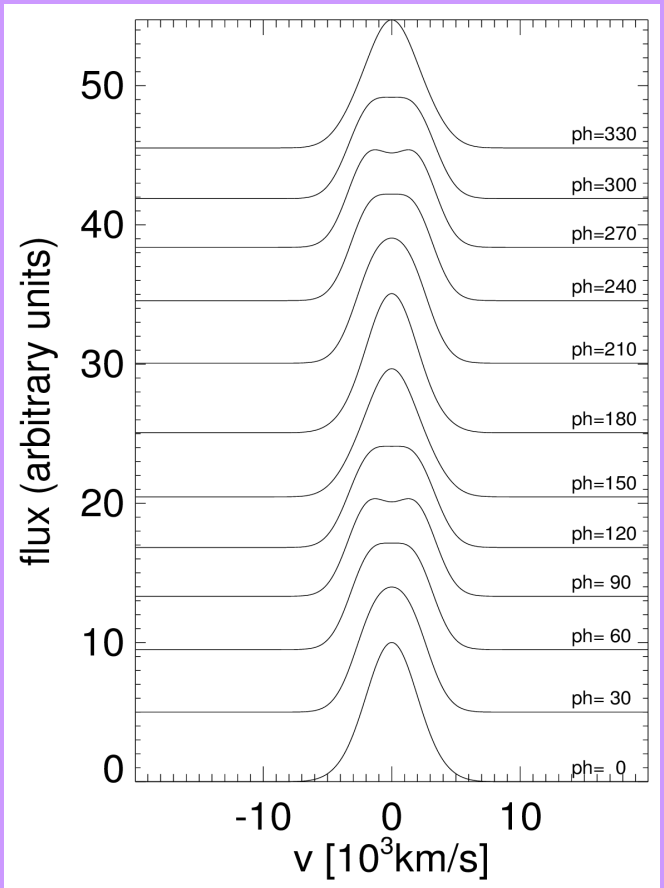
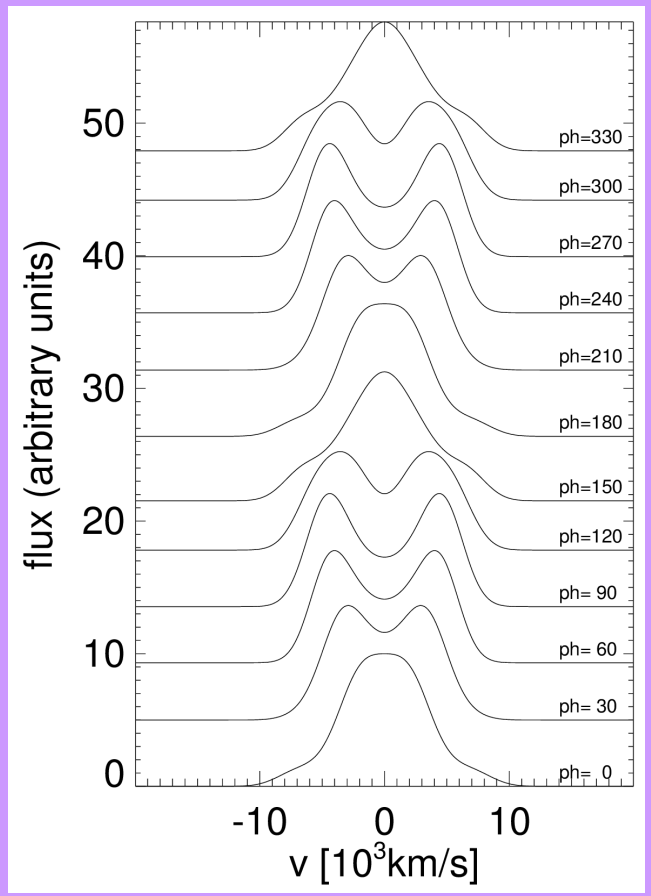


Line profiles for different total masses

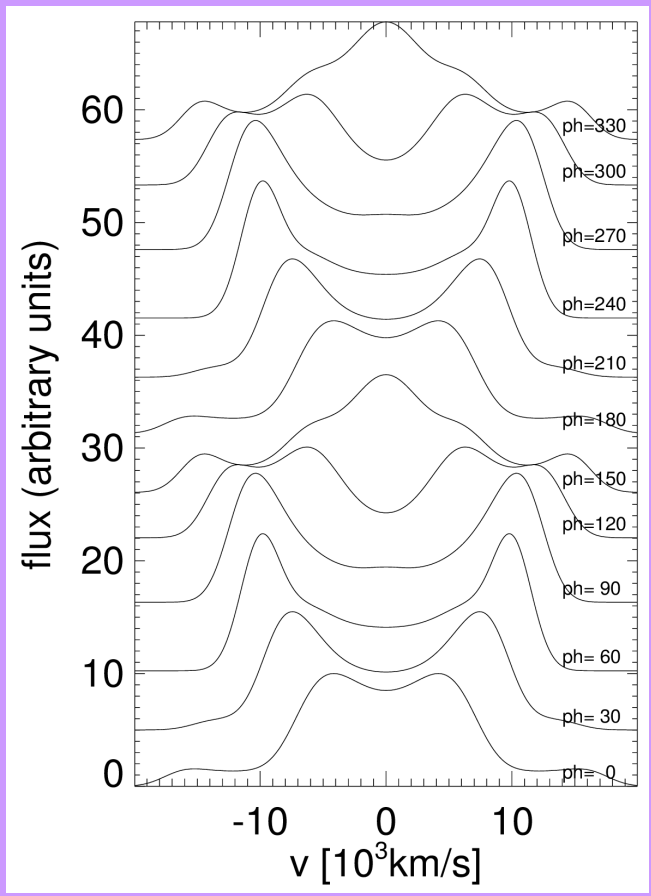
for circular orbits and equal masses



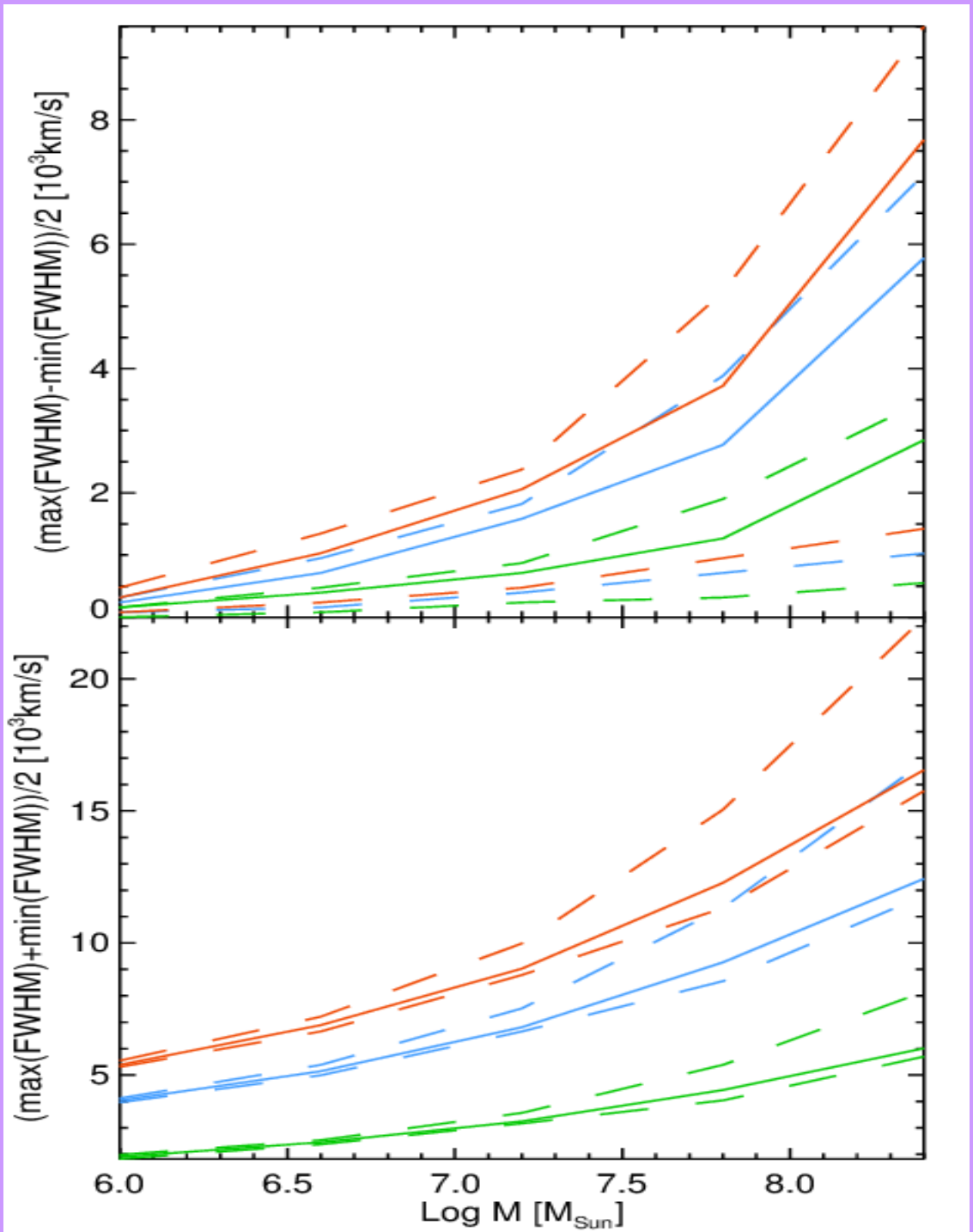
10^7



10^8

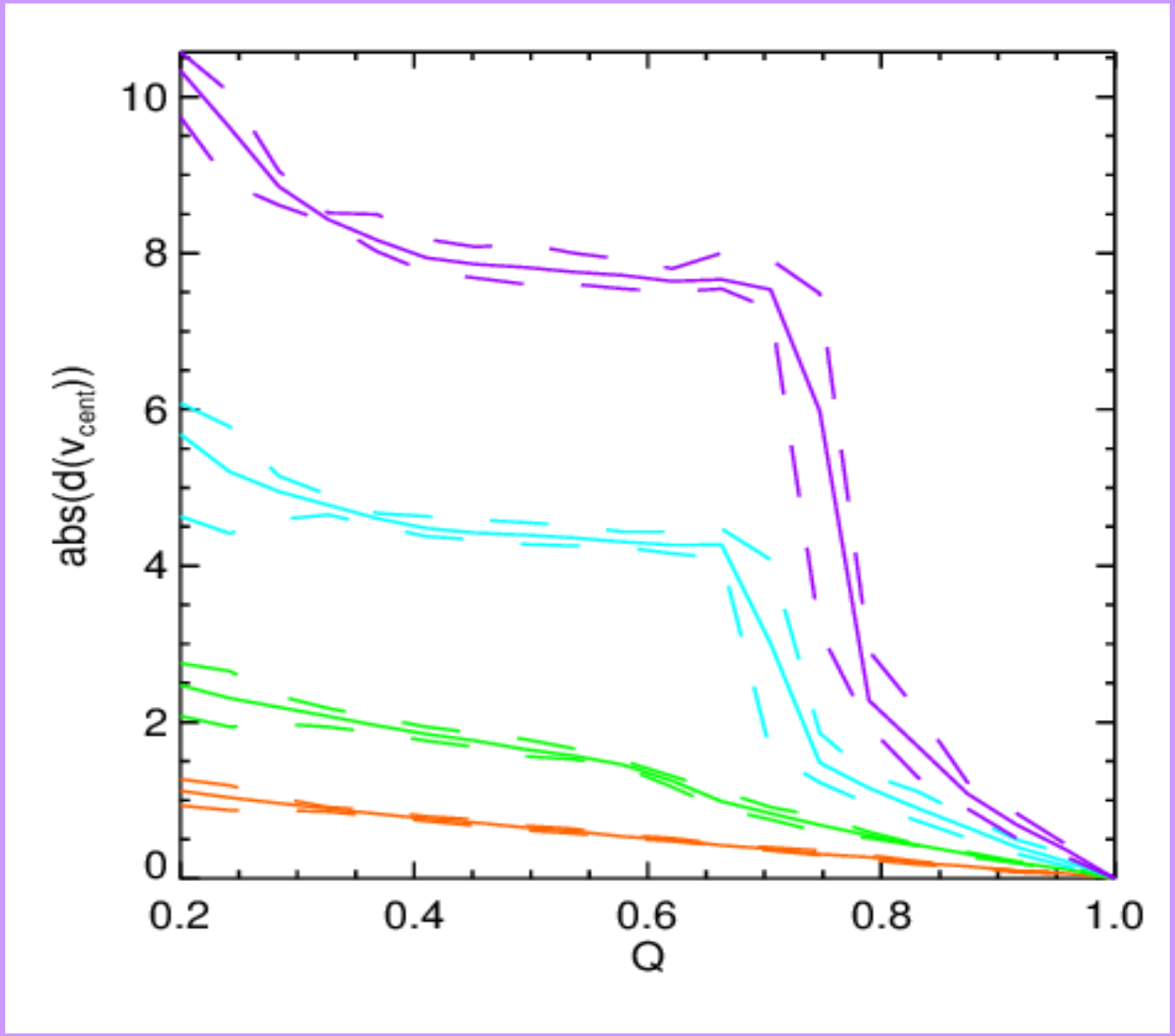


$10^9\ M_{Sun}$

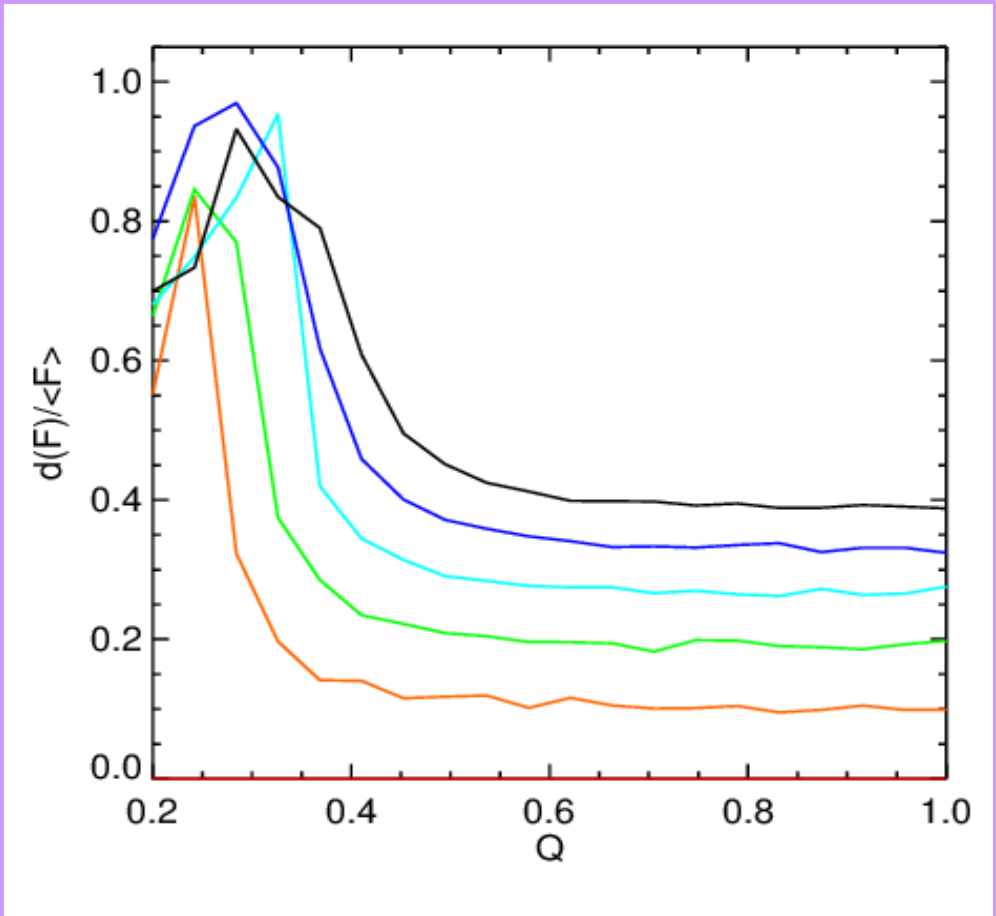


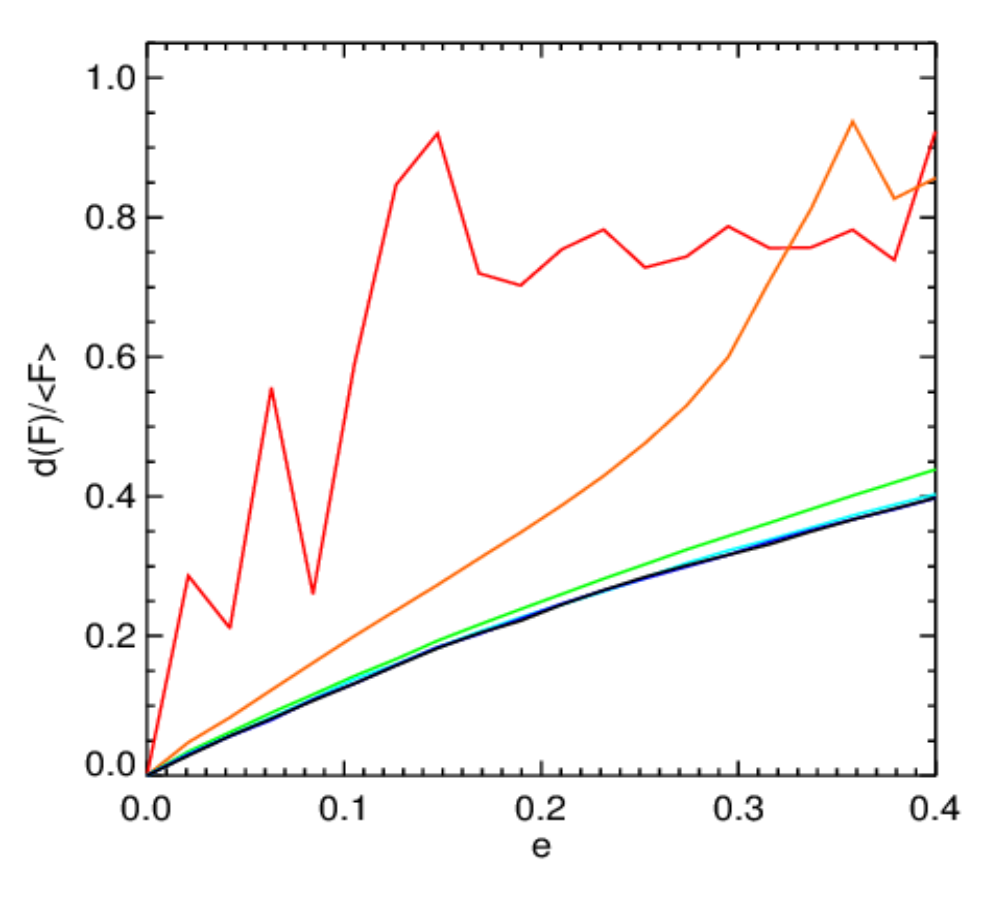
FWHM as a function of mass in black holes

Variability of centroid shift for different mass ratios

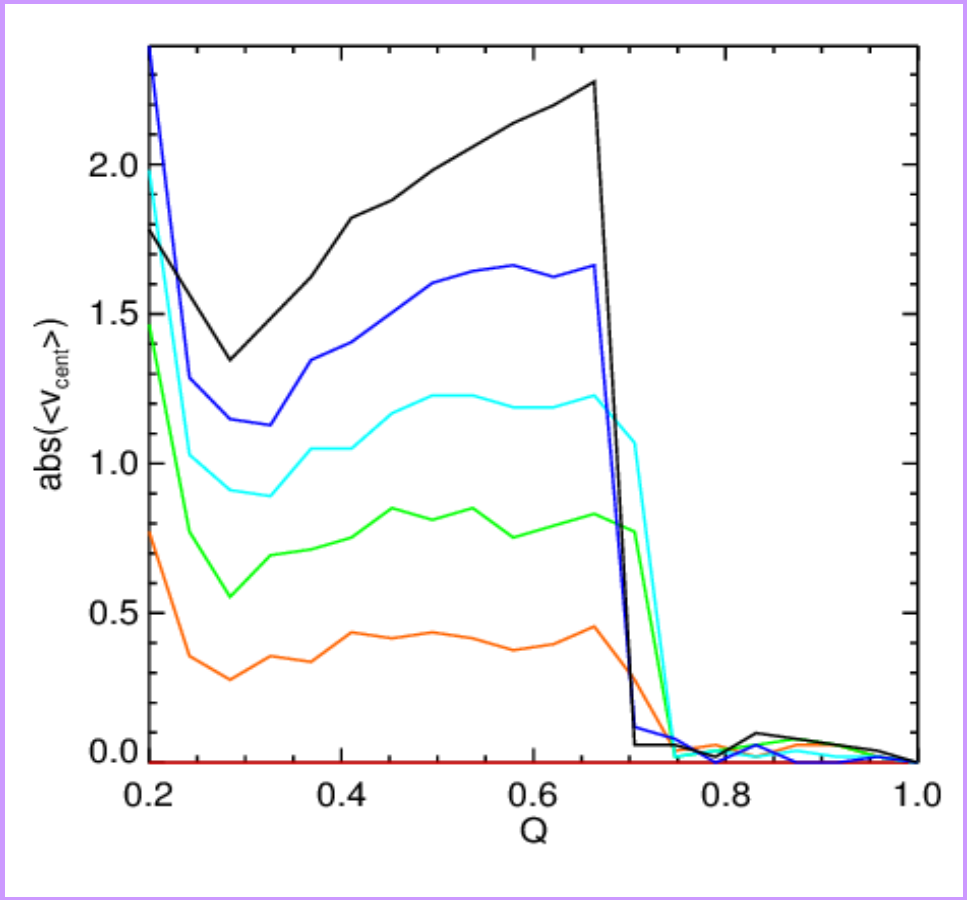


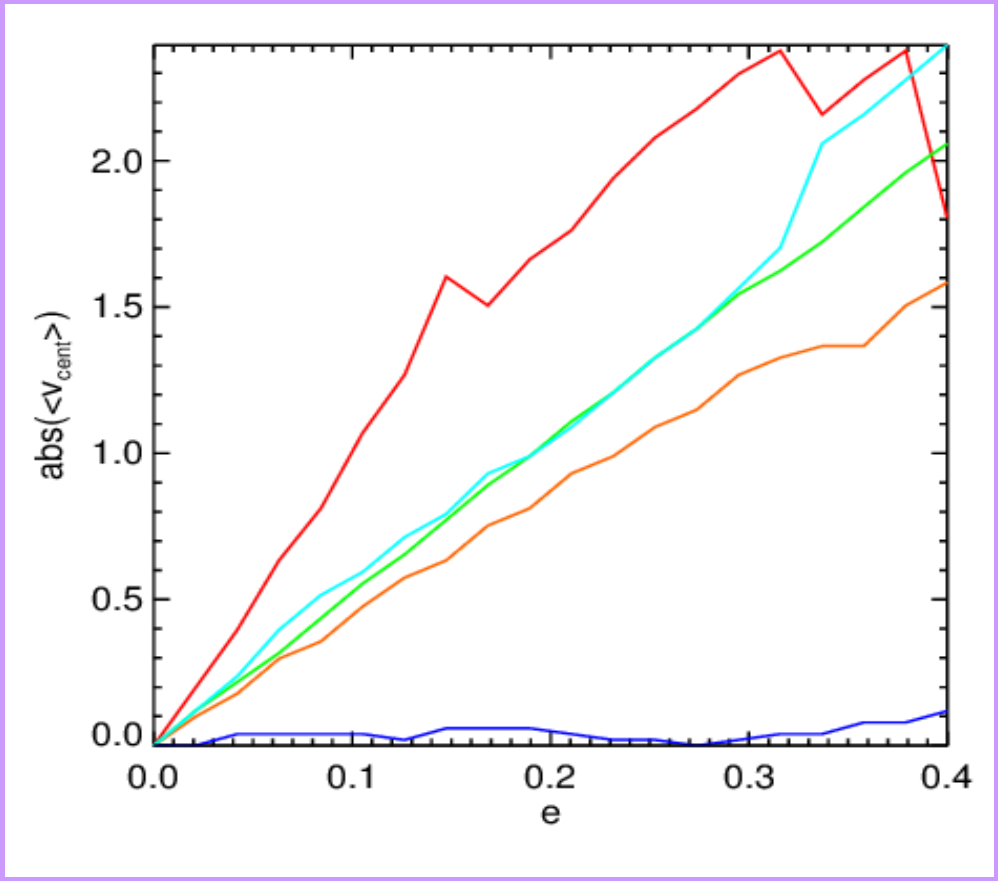
Variability of flux for different mass ratios and eccentricities



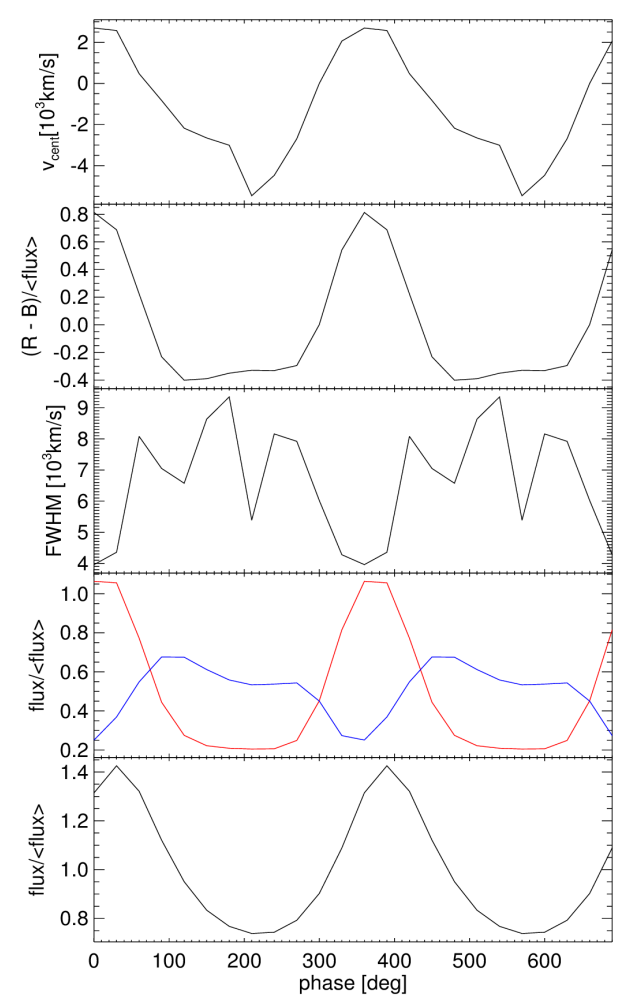


Average centroid velocity for different mass ratios and eccentricities

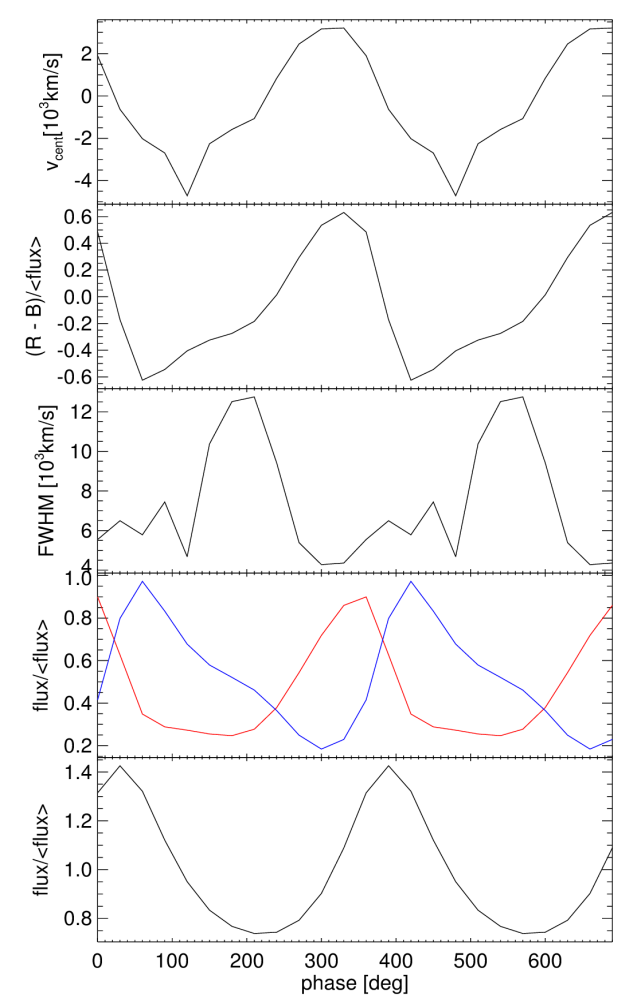




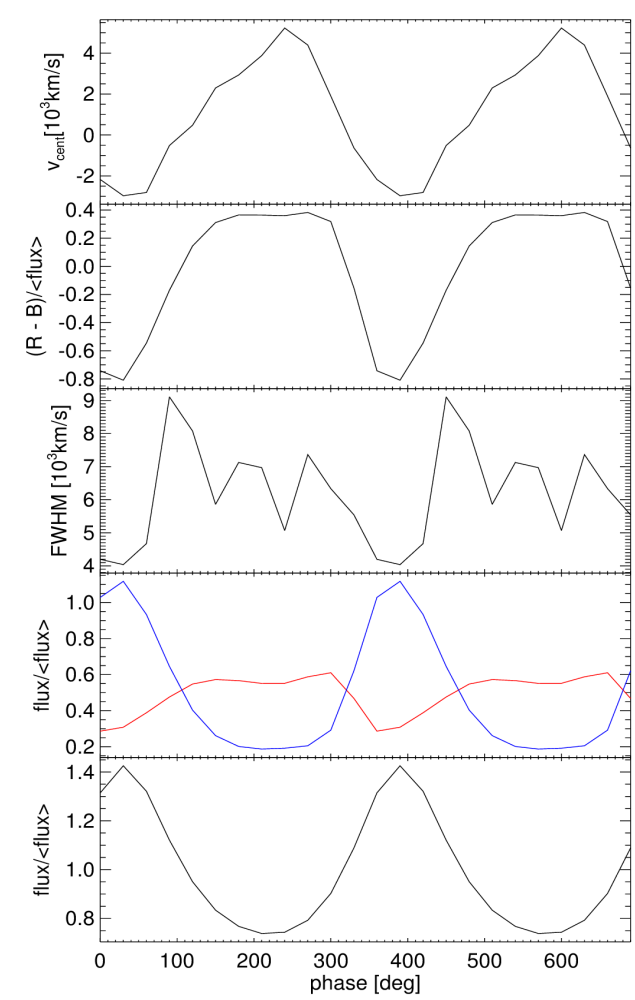
Results for different orientations of orbits



0^0



60^0



150^0

Conclusions

- For equal masses and for circular orbits flux is constant and line profiles are symmetric and not shifted
- More massive BBHs show larger FWHMs and double peaks
- As mass increases, average FWHM and amplitude in FWHM variability increase
- Variability in centroid shift increases when difference between masses of black holes increases, and is almost constant for different eccentricities
- The variability in flux is higher when eccentricities and difference between masses of black holes are higher. For mass ratios Q>0.45, the variability in flux is almost independent on Q.
- Average centroid velocities are higher for more eccentric orbits

- Smailagić & Bon, 2015, JapA, 36, 513 (for circular orbits and equal masses)