Black hole radii

Schwarzschild radius:

event horizon of non-spinning BH

$$R_s = \frac{2GM_{BH}}{c^2}$$

Radius of influence:

Kepler speed due to BH = $\sigma_{||}$

depends on l.o.s. kinematics,
so useful in observations

$$R_{infl} = \frac{GM_{BH}}{\sigma_{||}^2(R_{infl})}$$

Dynamical radius:

enclosed galactic mass
(stars, gas, DM, …) = M_{BH}

$$M_{gal}(< R_g) = M_{BH}$$

depends on mass model

orbits with apocenter $<R_g$ are approximately Keplerian

Mass-velocity anisotropy degeneracy

No BH

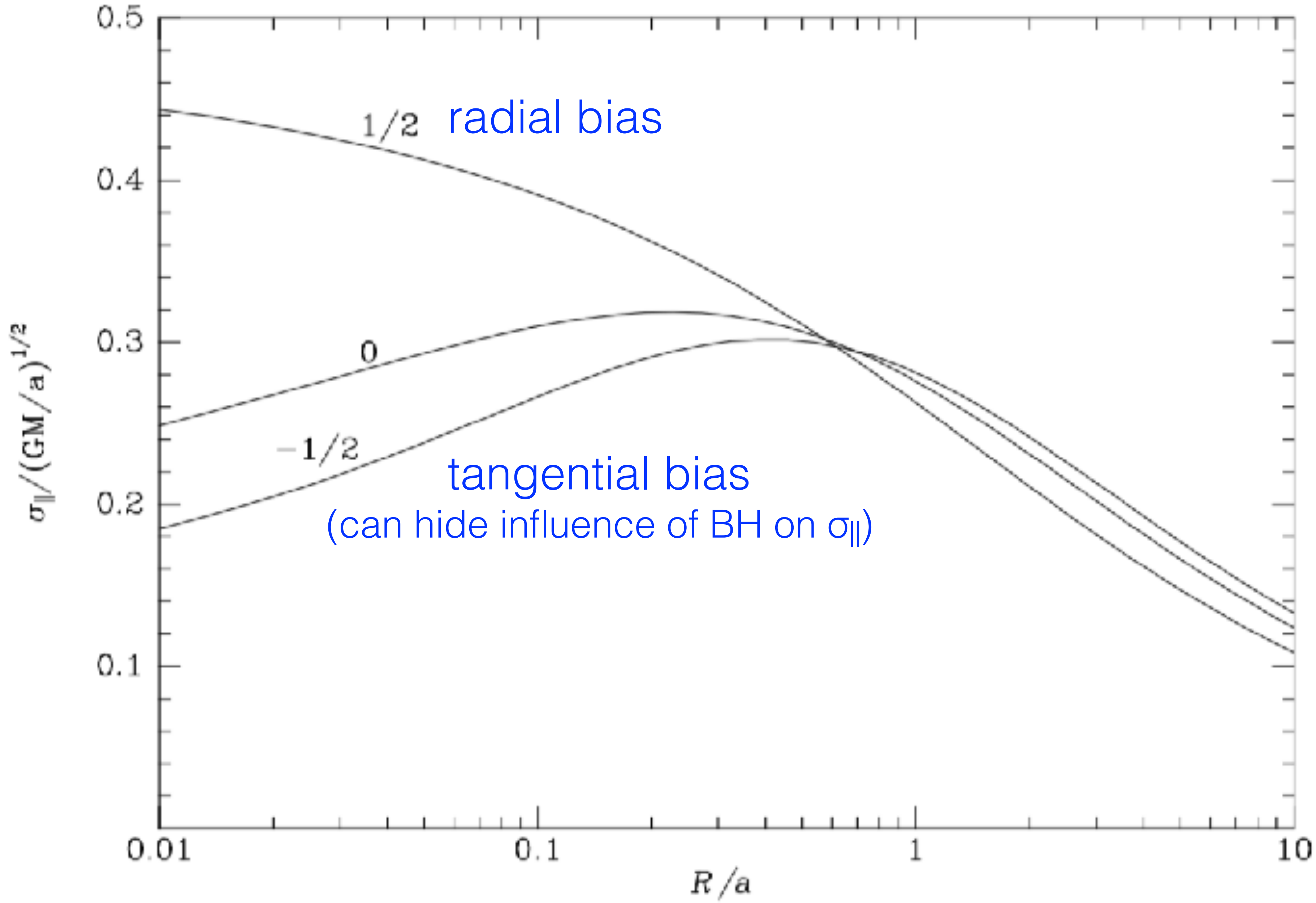


Figure 4.4 Line-of-sight velocity dispersion as a function of projected radius, from spatially identical systems that have different DFs. In each system the density and potential are those of the Hernquist model and the anisotropy parameter β of equation (4.61) is independent of radius. The curves are labeled by the relevant value of β. In the isotropic system, the velocity dispersion falls as one approaches the center (cf. Problem 4.14).

BT2, section 4.3.2 shows how to construct DF with constant anisotropy parameter

With BH

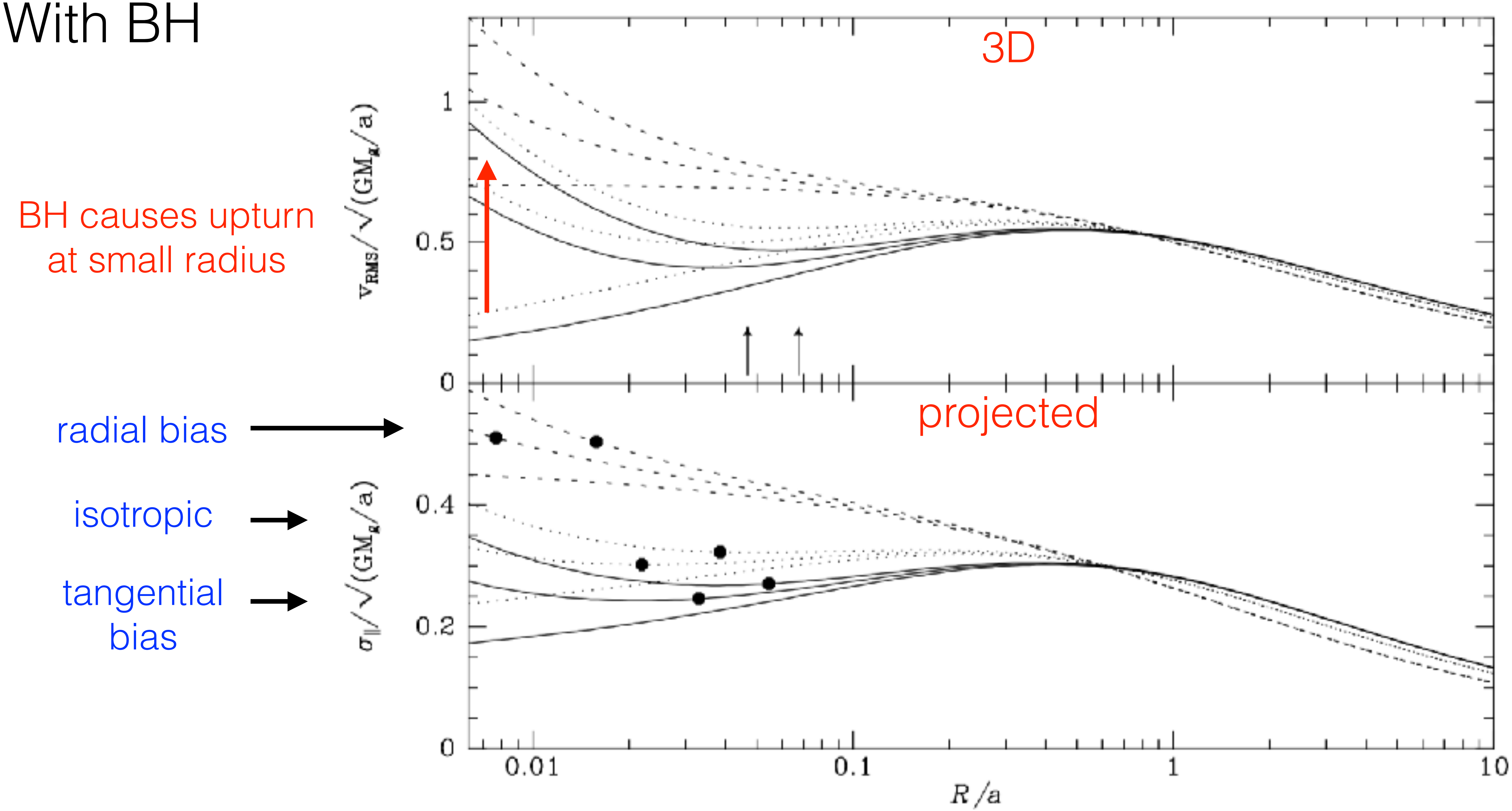


Figure 4.20 Velocity dispersion as a function of radius for three Hernquist models with a central black hole of mass 0, $0.002M_g$, or $0.004M_g$. The bottom panel shows line-of-sight dispersions, the top panel shows the RMS speed as a function of radius. The full curves are for tangential bias ($\beta = -0.5$), the dotted curves are for the isotropic model and the dashed curves are for radial bias ($\beta = 0.5$). The beads mark the radius of influence (eq. 4.220) of the black hole in each model, while the arrows mark the dynamical radius of the black hole, at which the interior mass of the galaxy equals the mass of the black hole.

No BH

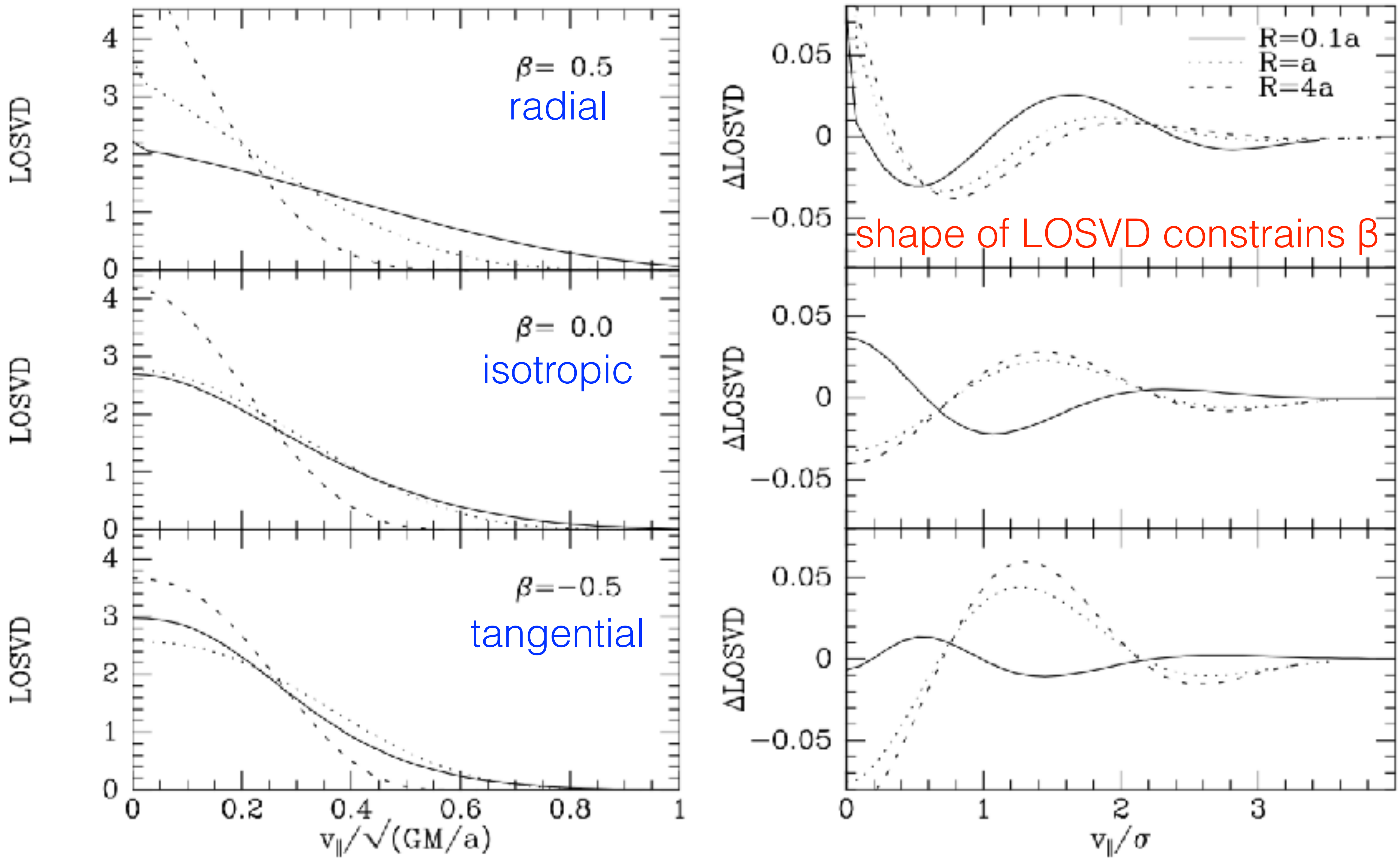


Figure 4.23 Left panels: LOSVDs for the Hernquist models plotted in Figure 4.4. From top to bottom the models have anisotropy parameter $\beta = \frac{1}{2}$, 0 and $-\frac{1}{2}$. In each panel profiles are shown for $R = 0.1a$, a and $4a$. The right panels show the deviations of each LOSVD from the Gaussian that has the same dispersion. From top to bottom the full curves have Gauss–Hermite parameters h_4 (BM §11.1.2) 0.001, 0.024 and 0.002; the dashed curves have $h_4 = 0.038$, -0.022 and -0.057.

using spatially resolved LOSVD, fit for mass distribution and β simultaneously

With and without BH

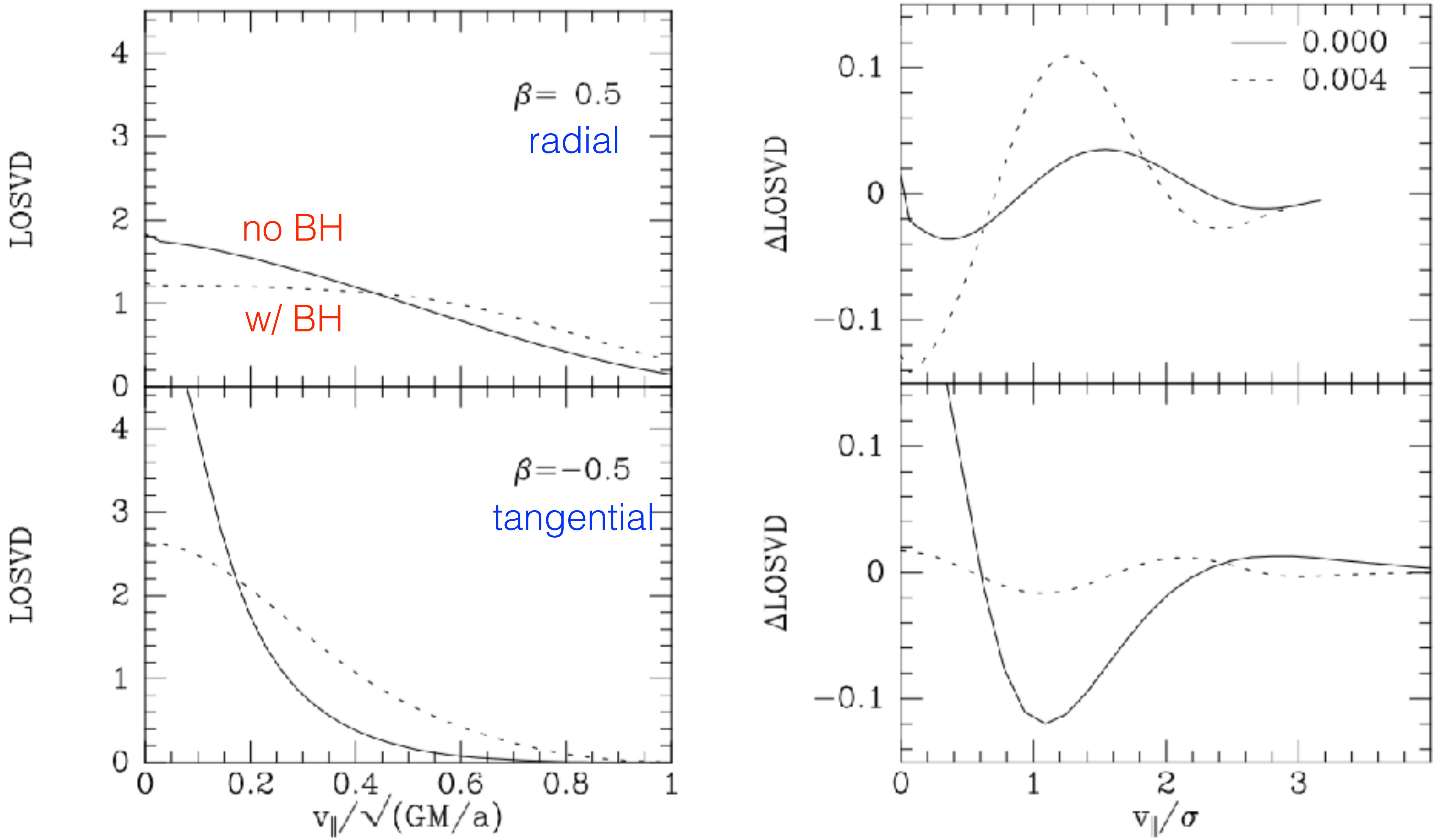
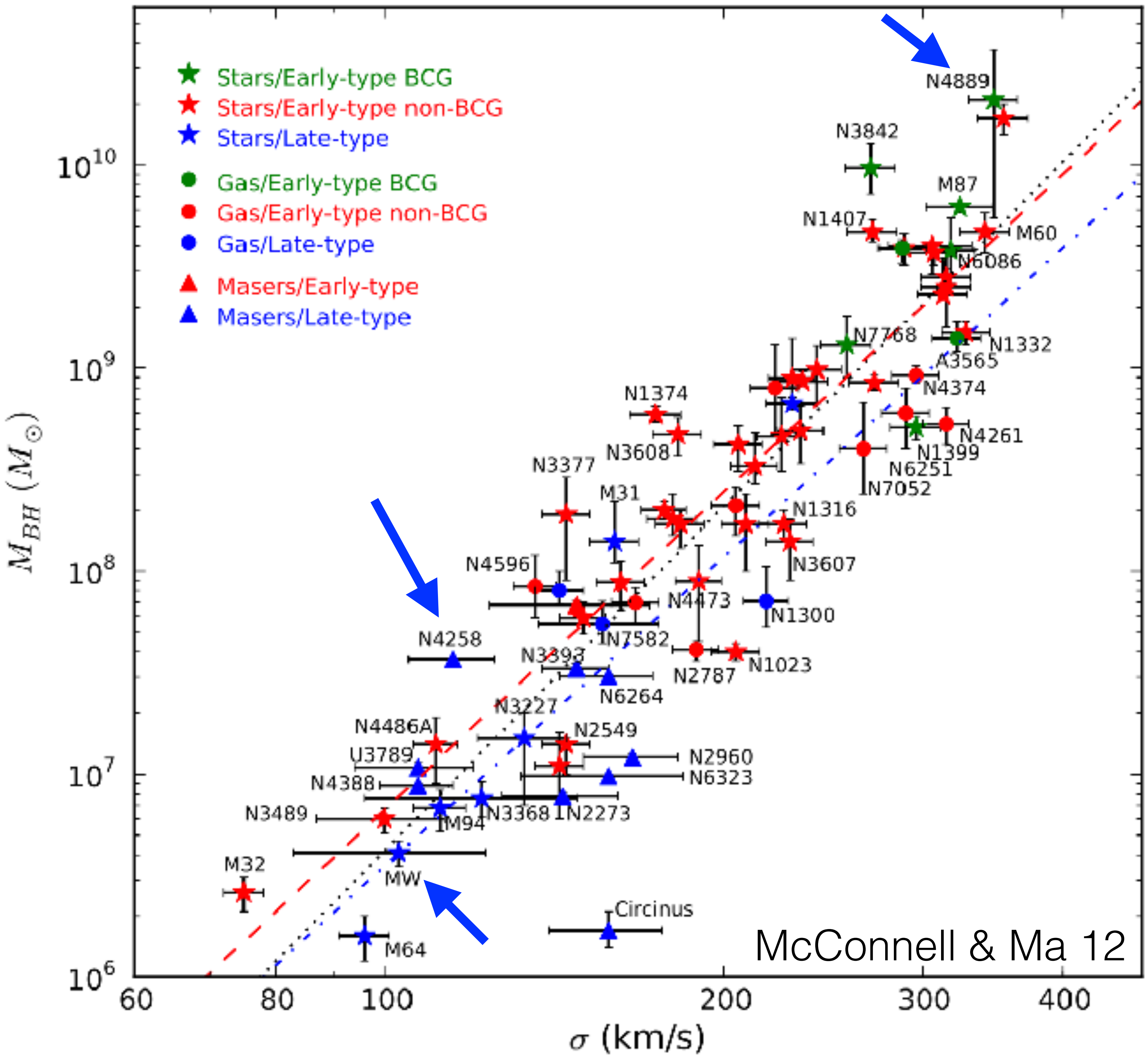


Figure 4.24 LOSVDs along $R = 0.01a$ through a Hernquist model that either does not (full line) or does (dotted curve) contain a black hole. The black-hole mass is a fraction 0.004 of the galaxy mass.

M-σ: black hole mass - stellar bulge velocity dispersion



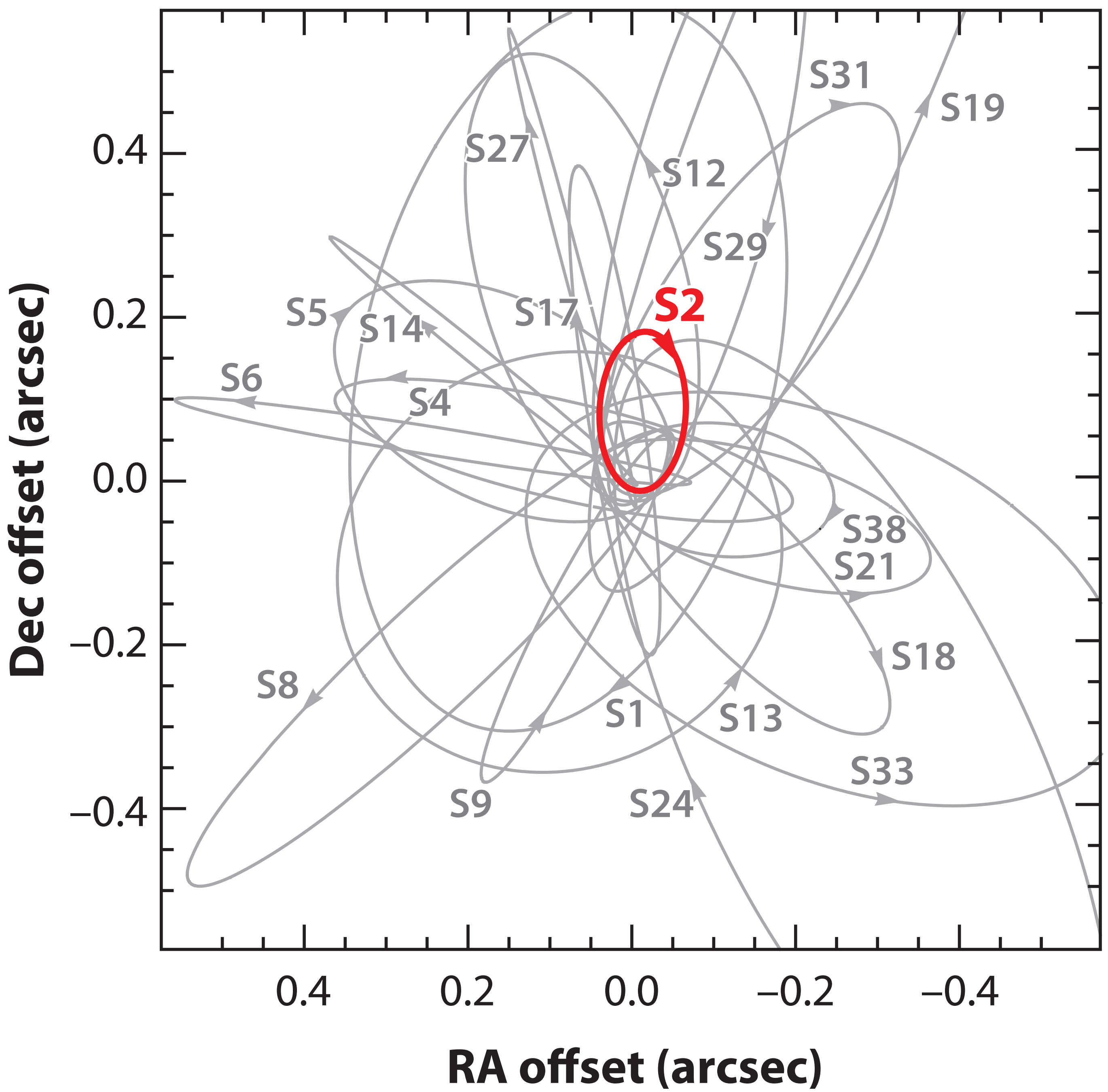
$$\log_{10}(M_\bullet/M_\odot) = 8.32 + 5.64\log_{10}(\sigma/200\,\mathrm{km\,s^{-1}})$$

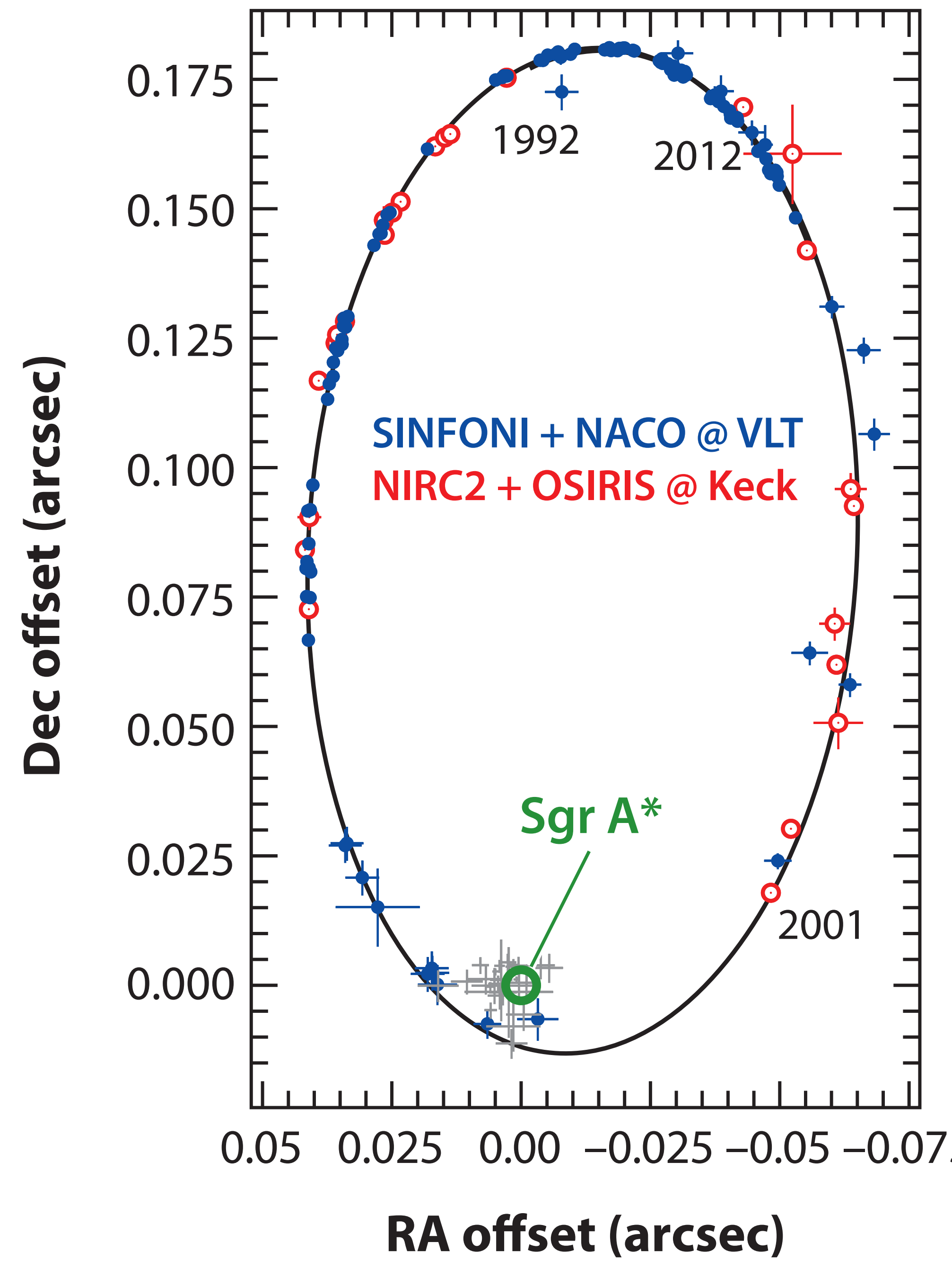
"Magorrian" rel.:

$M_{BH} \sim 0.005\ M_{bulge}$

(Kormendy & Ho 2013)

Sgr A*: directly fit Keplerian orbits to S-stars





$M_\bullet = 4.30 \pm 0.20(\mathrm{stat}) \pm 0.30(\mathrm{sys}) \times 10^6\ M_\odot$

from Kormendy & Ho 2013 review

NGC 4258: accretion disk masers

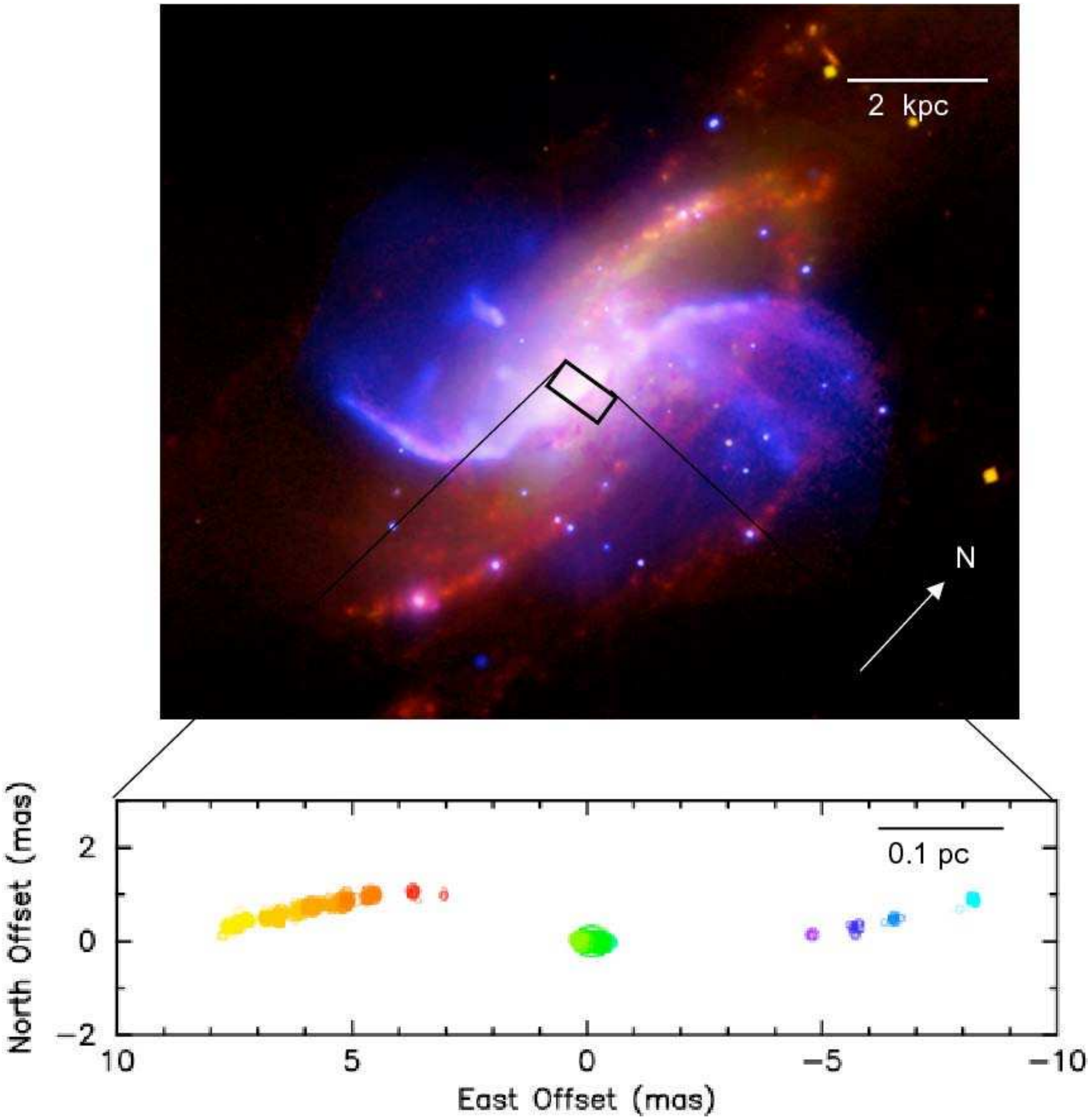


Figure 1. Top: A multiwavelength image (X-ray, Hα, 1.4 GHz radio) of the galaxy NGC 4258, also known as M 106, from data of Yang et al. (2007). This black-and-white rendition does not serve to distinguish the various wavelength regimes very well—see also the color rendition on the cover of this volume. The so-called anomalous arms, seen by their synchrotron emission, have position angles of about −45° and 135°, and exhibit sharp bends about 2 kpc from the nucleus. A large angle between the position angle of the accretion disk and the galaxy was surmised by Oort (1982). Bottom: Image of the maser emission from the central accretion disk of the galaxy from VLBA observations. Note that the overplotting of many maser emission spots makes the disk look much fatter than it actually is. From Argon et al. (2007), reproduced by permission of the AAS.

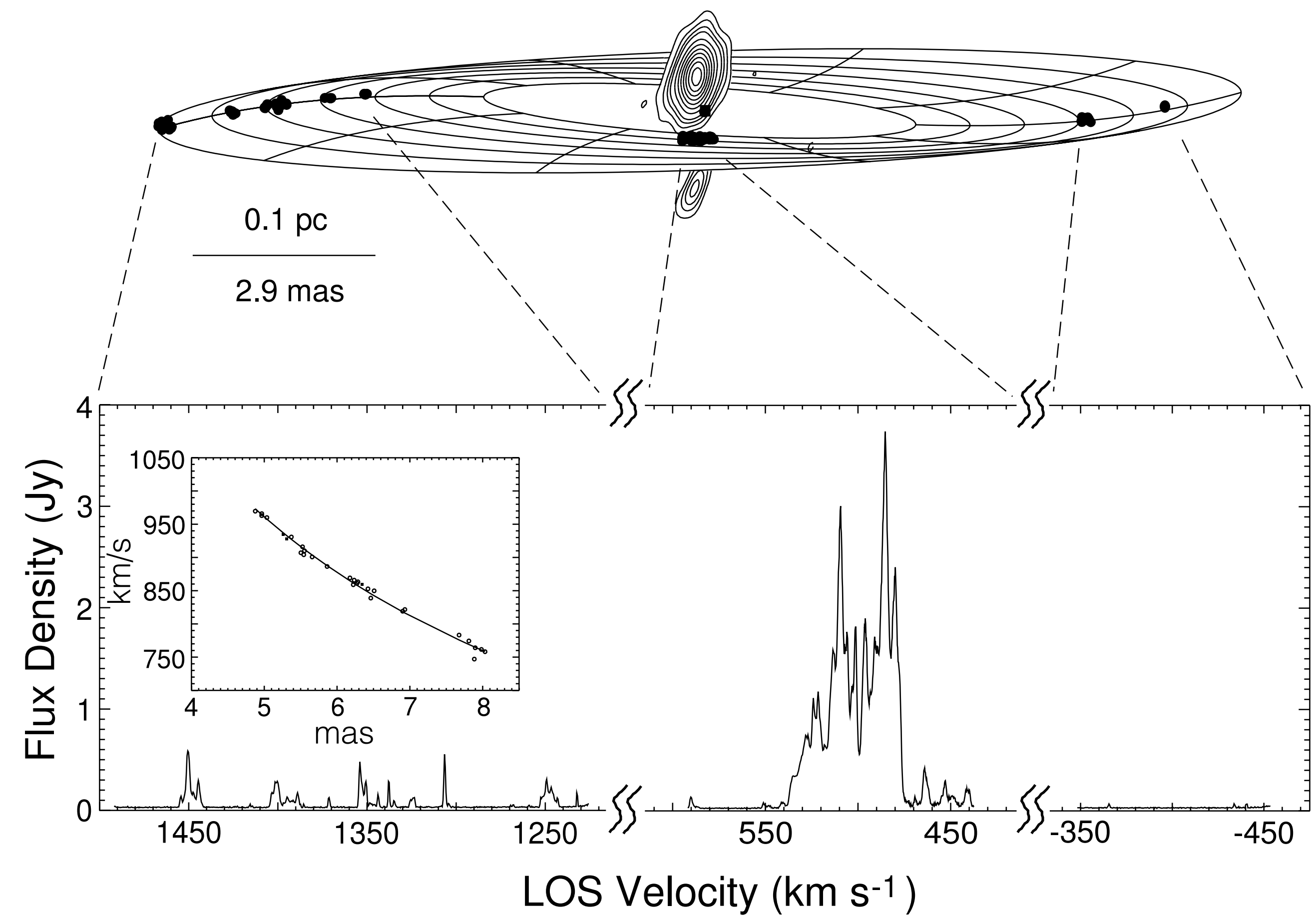


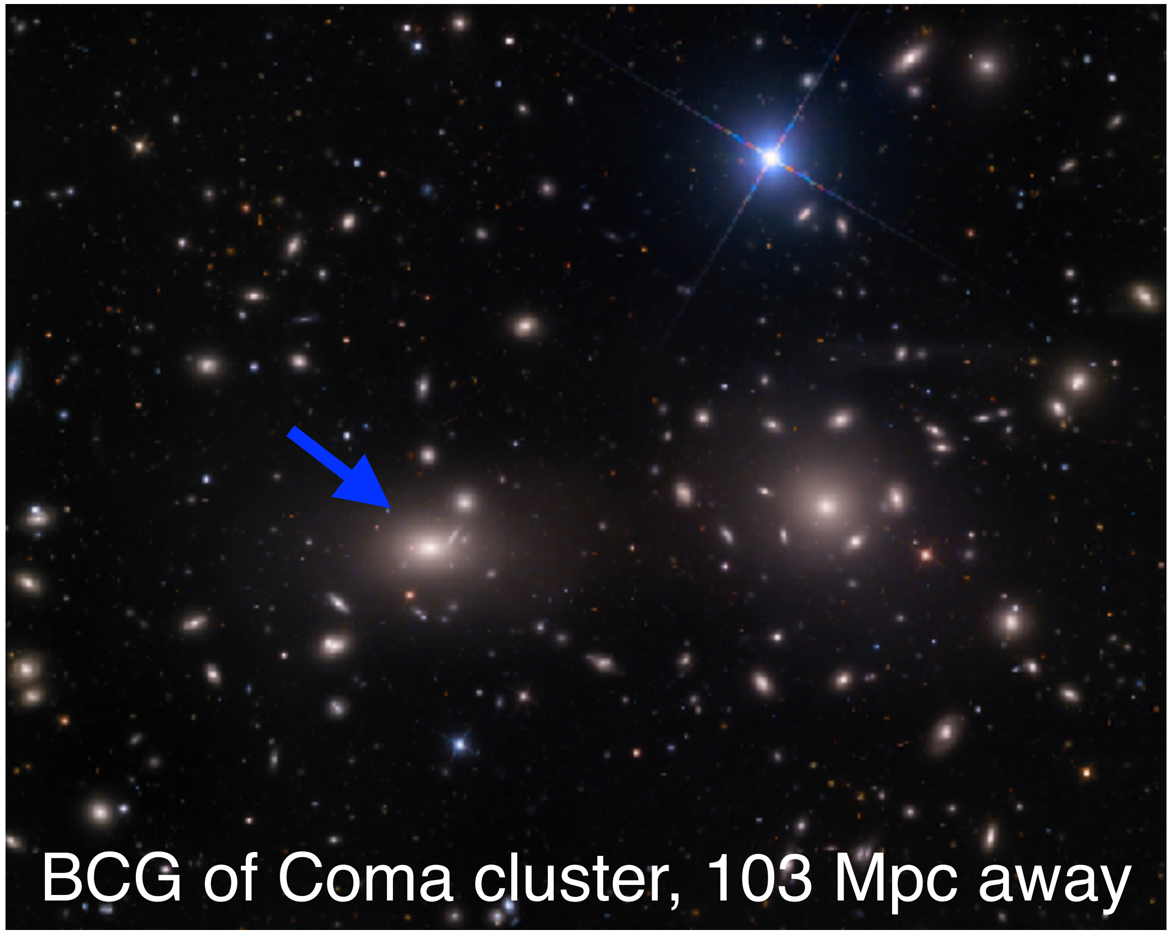
Fig. 1.—*Top:* Warped-disk model with masers and continuum superposed. *Bottom:* Total power spectrum of the NGC 4258 maser, with best-fitting Keplerian rotation curve. Maser data are from VLBA epoch BM36b, and continuum data are from epochs BH25a–c (see Table 1).

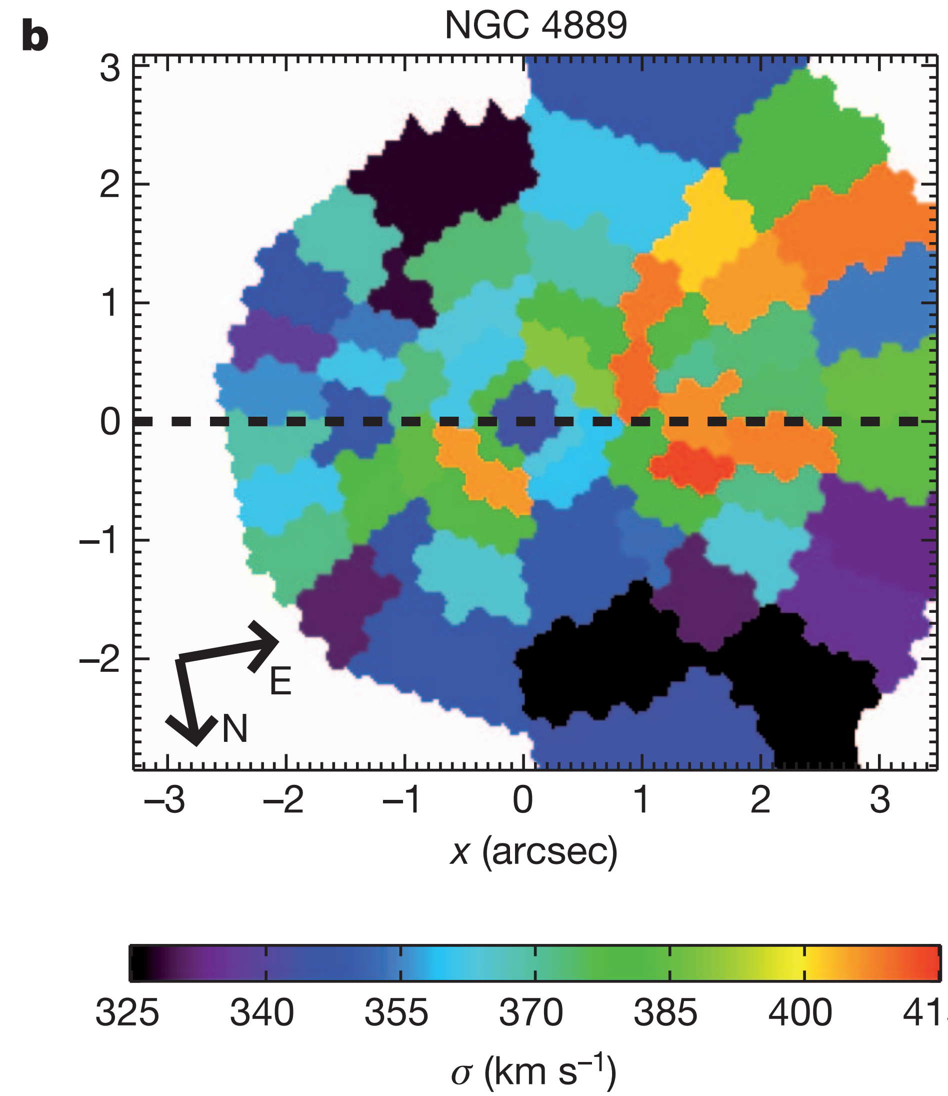
Use Keplerian measurements to check results from stellar dynamics

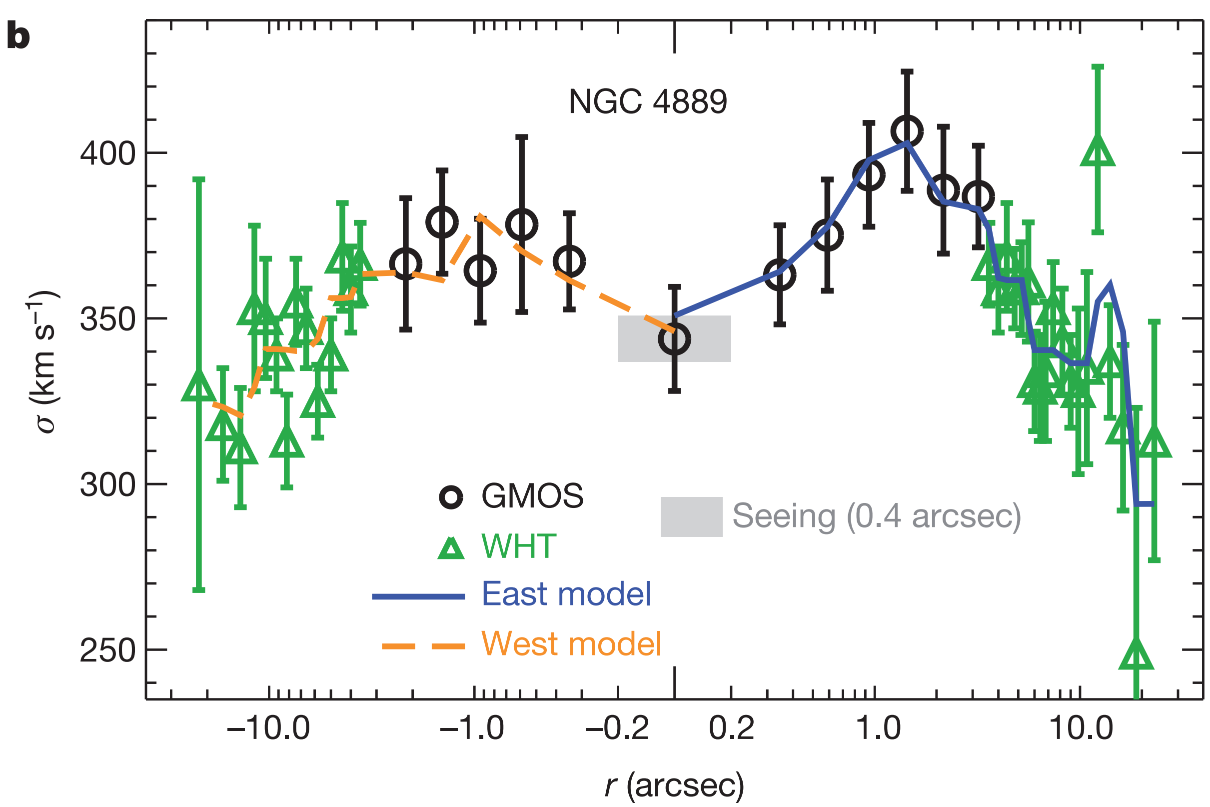
$M_{BH}=3\times10^7\ M_{sun}$

Herrnstein+05, Moran 08

NGC 4889: most massive black hole







Integral field spectroscopy (here with GMOS on Gemini North) gives LOSVD at different positions

$M_{BH}=2.1\times10^{10}$ M_{sun} inferred from orbit modeling even though $\sigma_{||}$ dips at center (tangential bias)

McConnell+11