Challenges in Black Hole Mass Measurements

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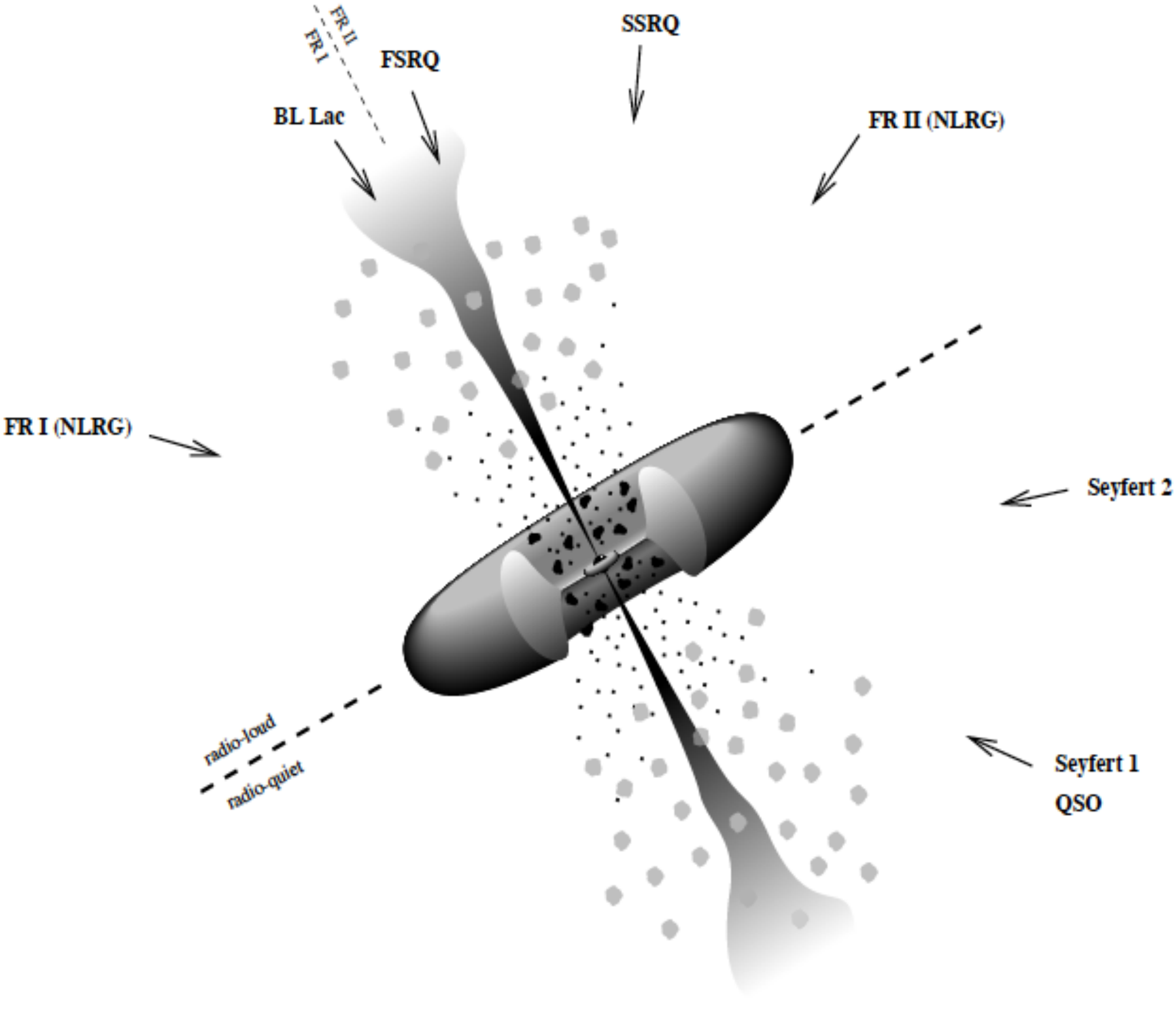
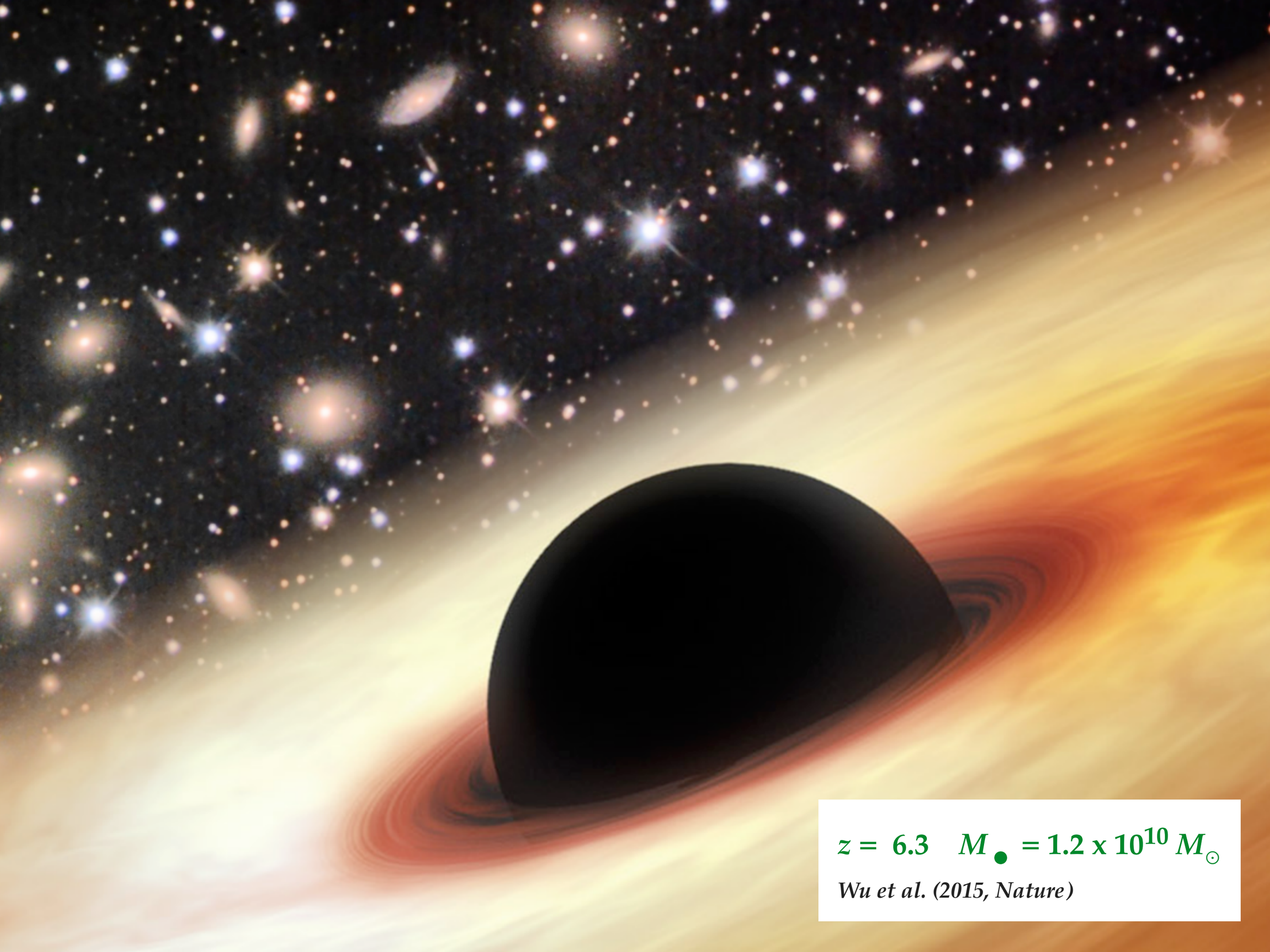
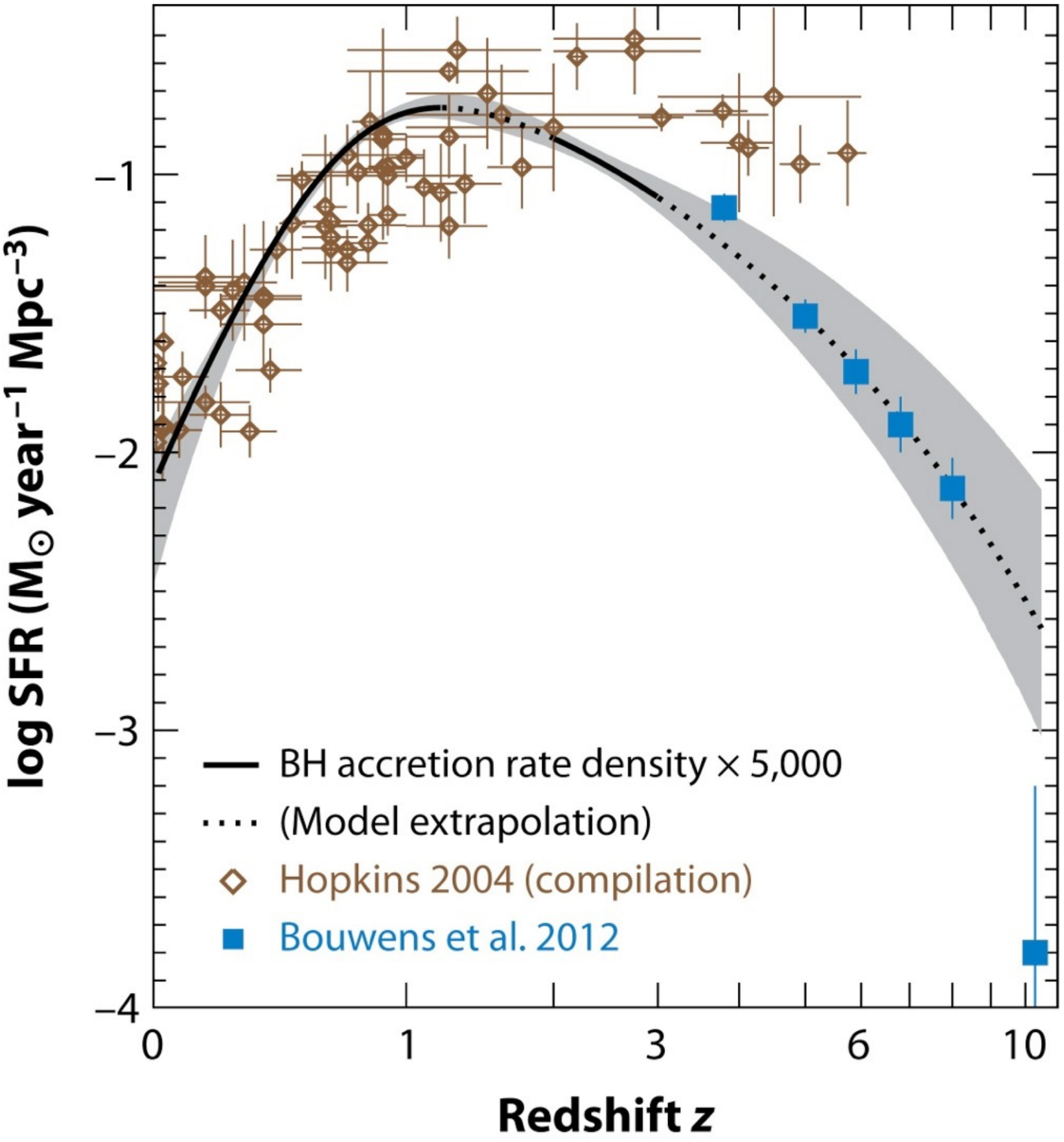
Peking University


FR II
FR I
FSRQ
SSRQ
BL Lac
FR II (NLRG)
FR I (NLRG)
Seyfert 2
radio-loud
radio-quiet
Seyfert 1
QSO



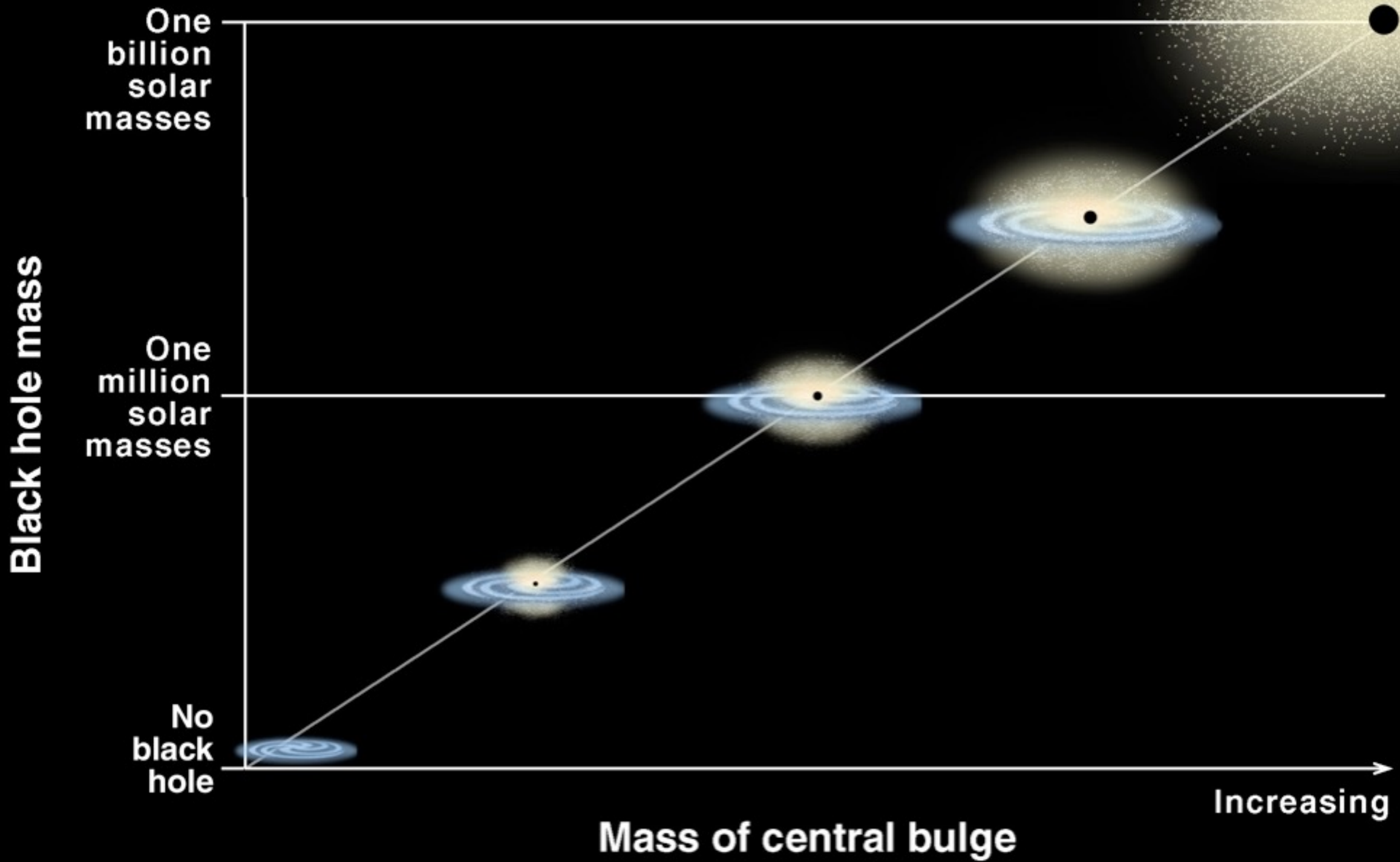
$z = 6.3 \quad M_{\bullet} = 1.2 \times 10^{10} M_{\odot}$

Wu et al. (2015, Nature)

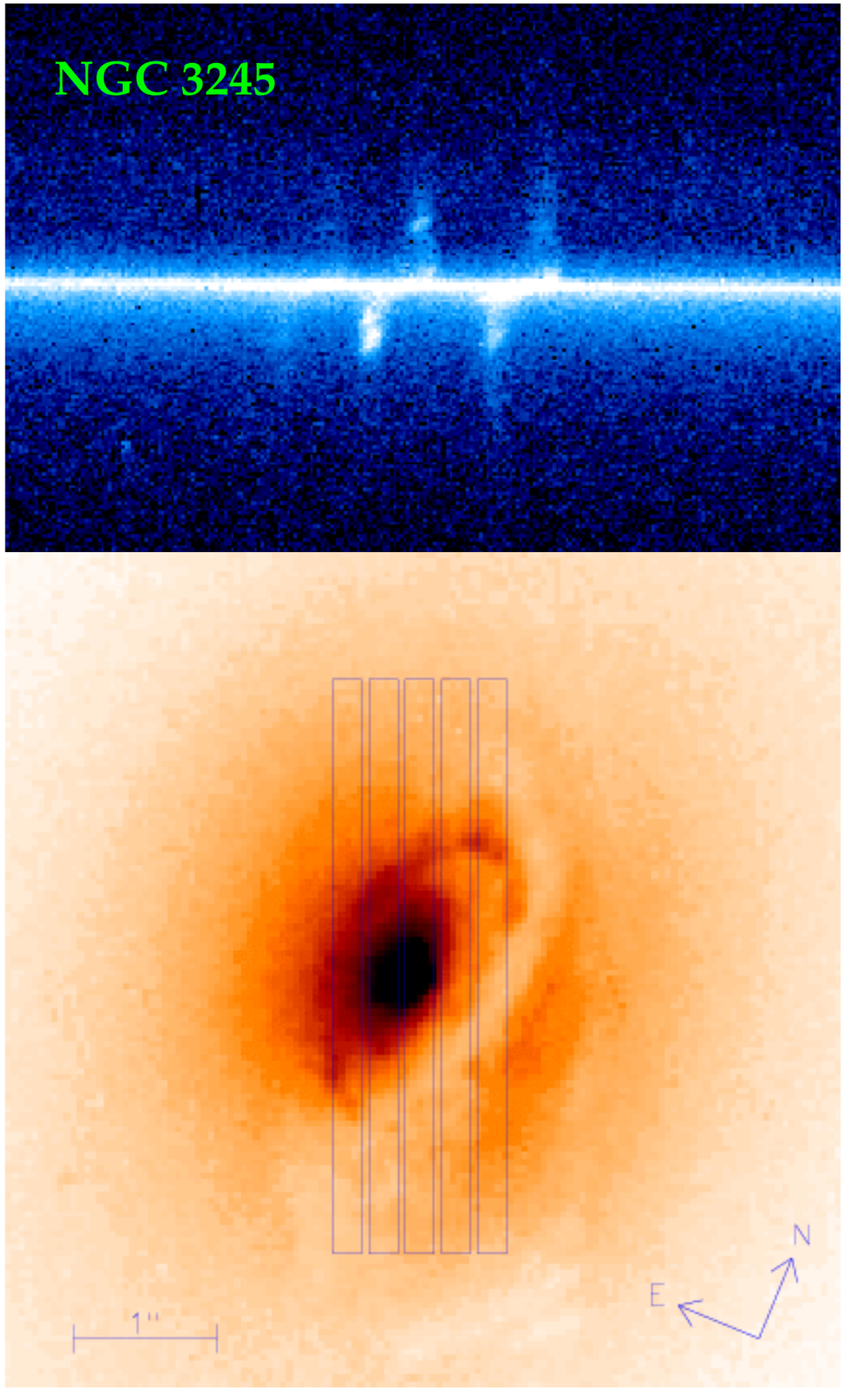


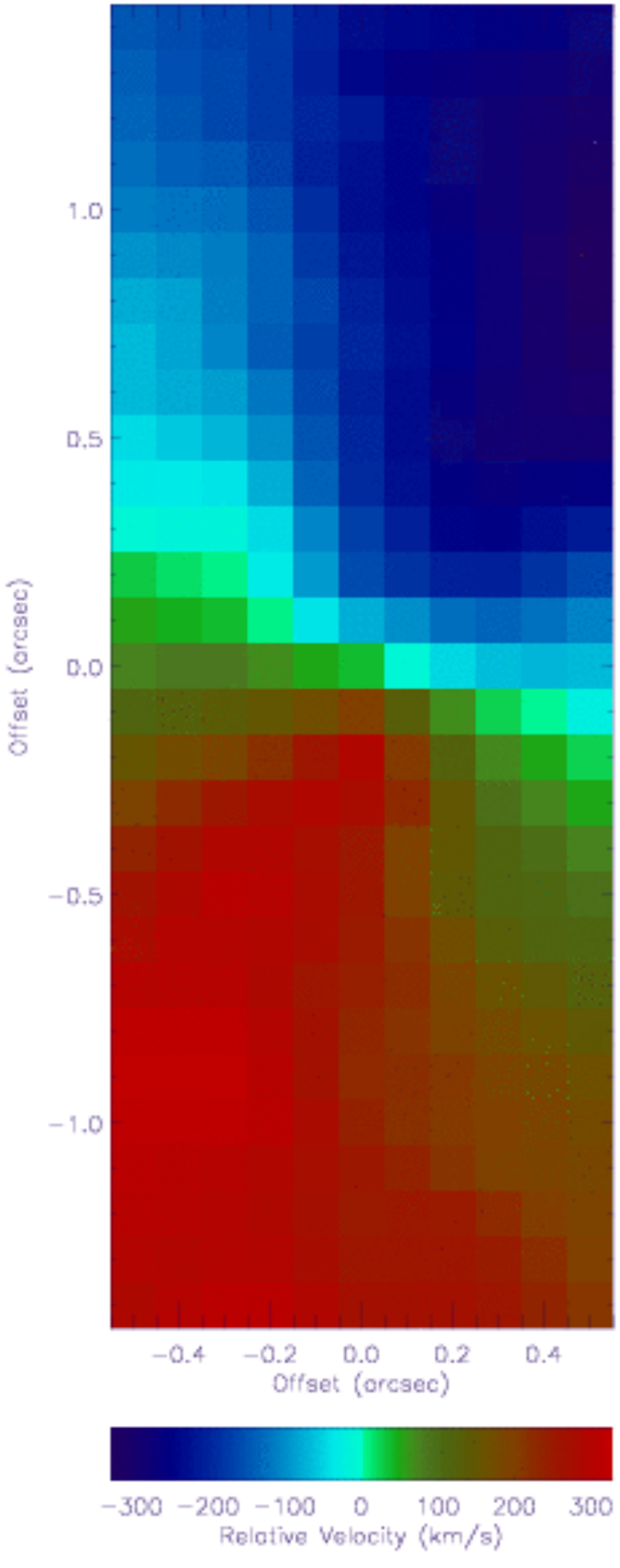
Kormendy & Ho (2013)

Correlation Between Black Hole Mass and Bulge Mass

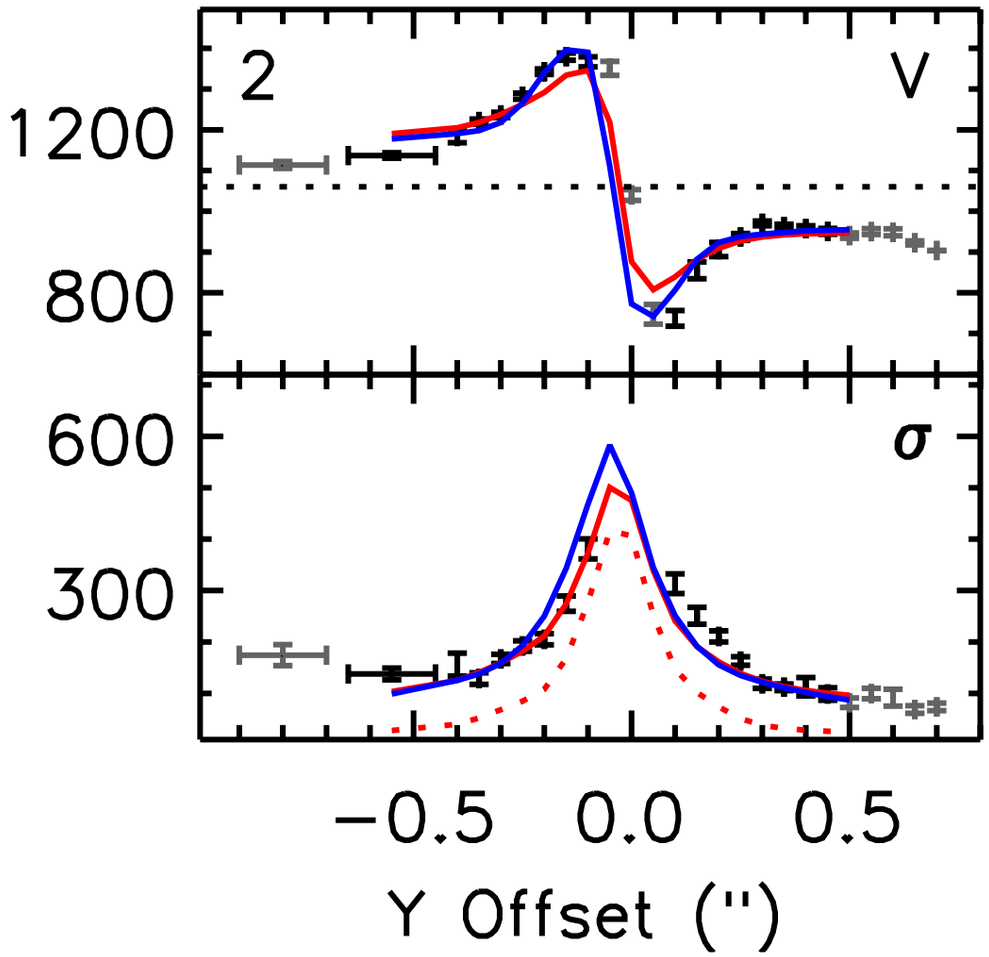


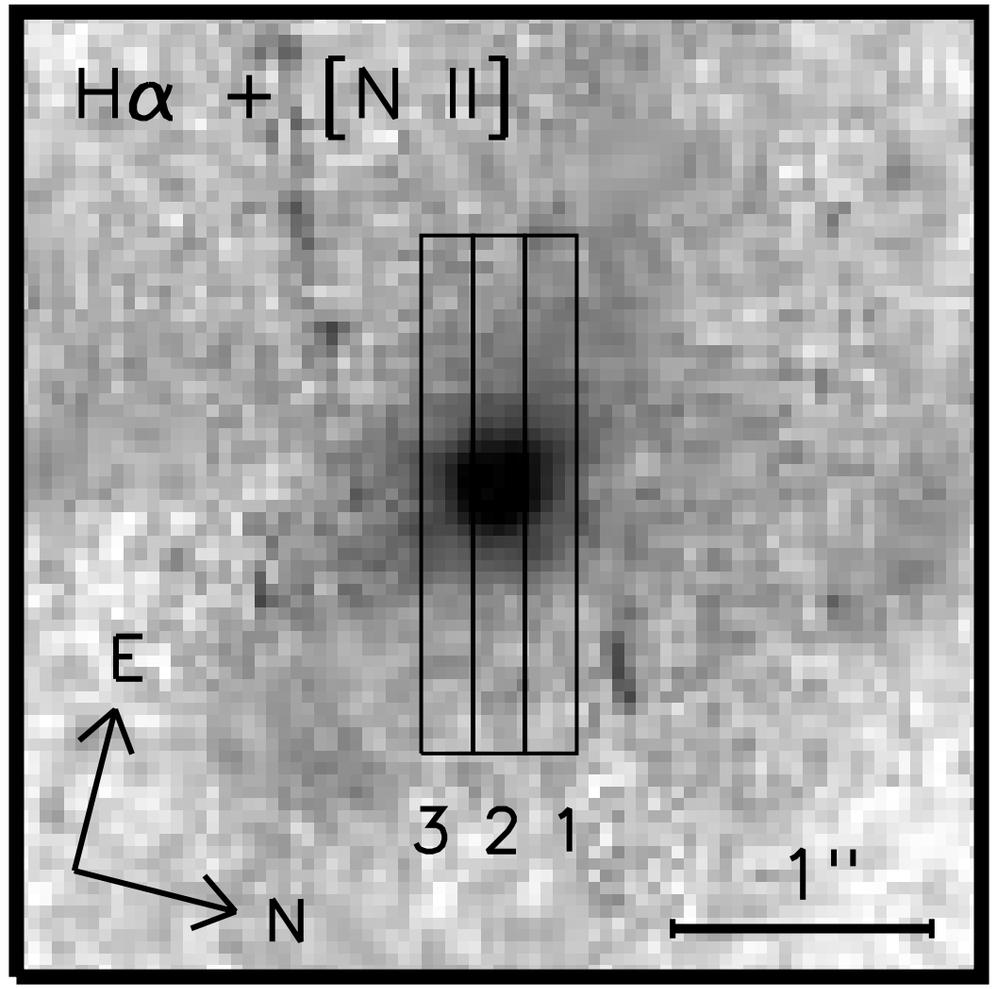
Magorrian et al. (1998)



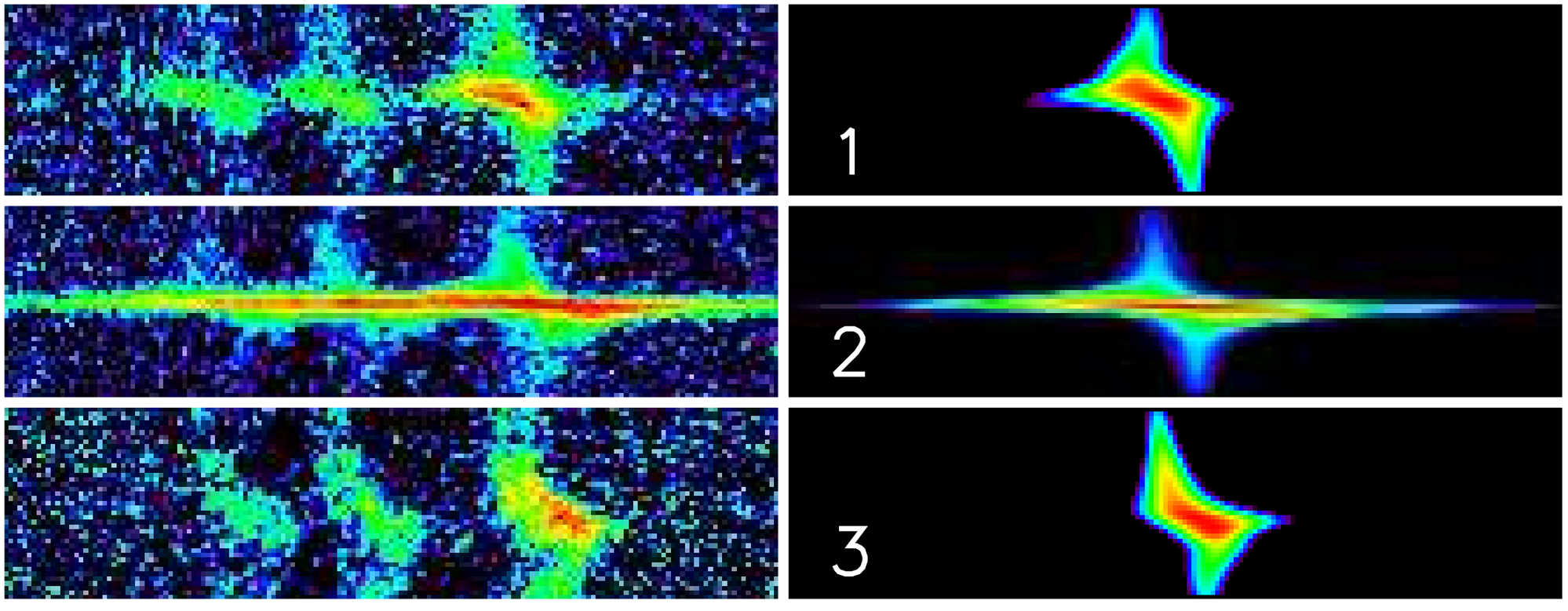


Barth, Ho et al. (2001)

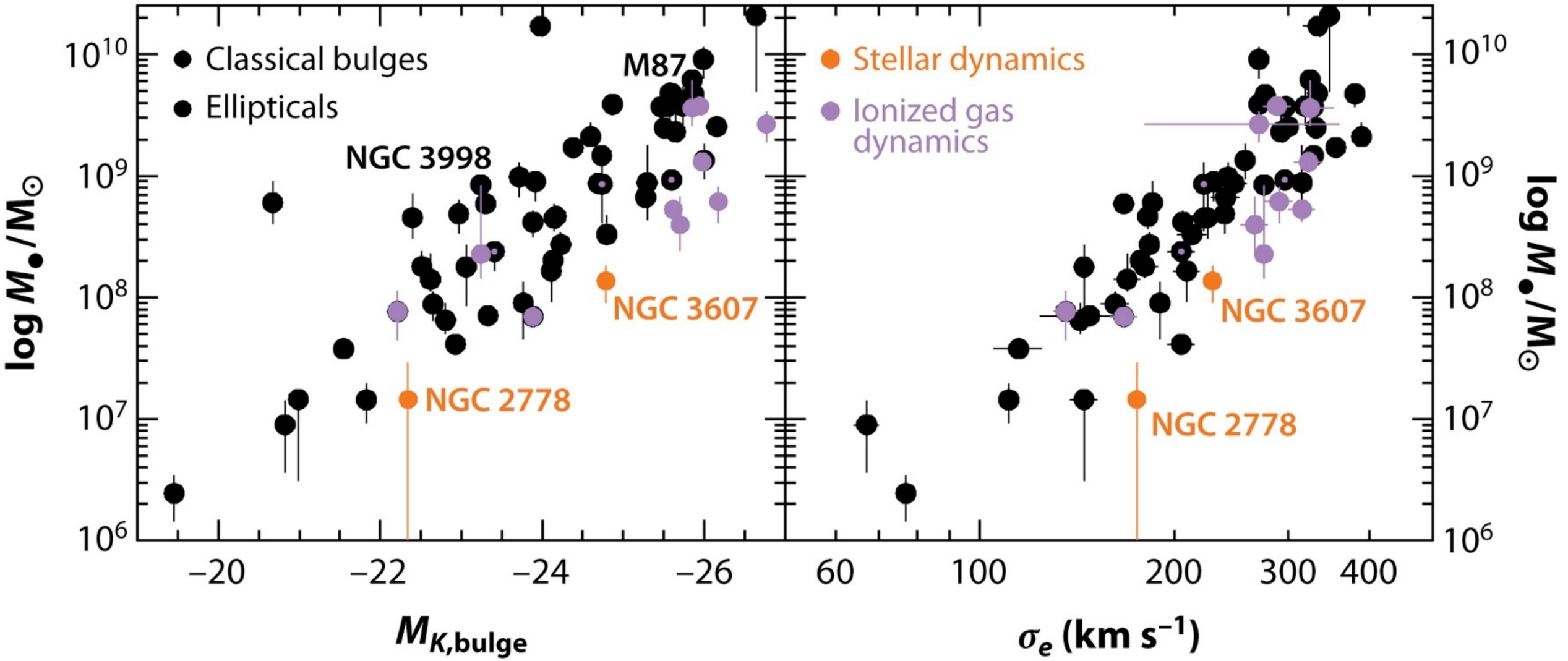




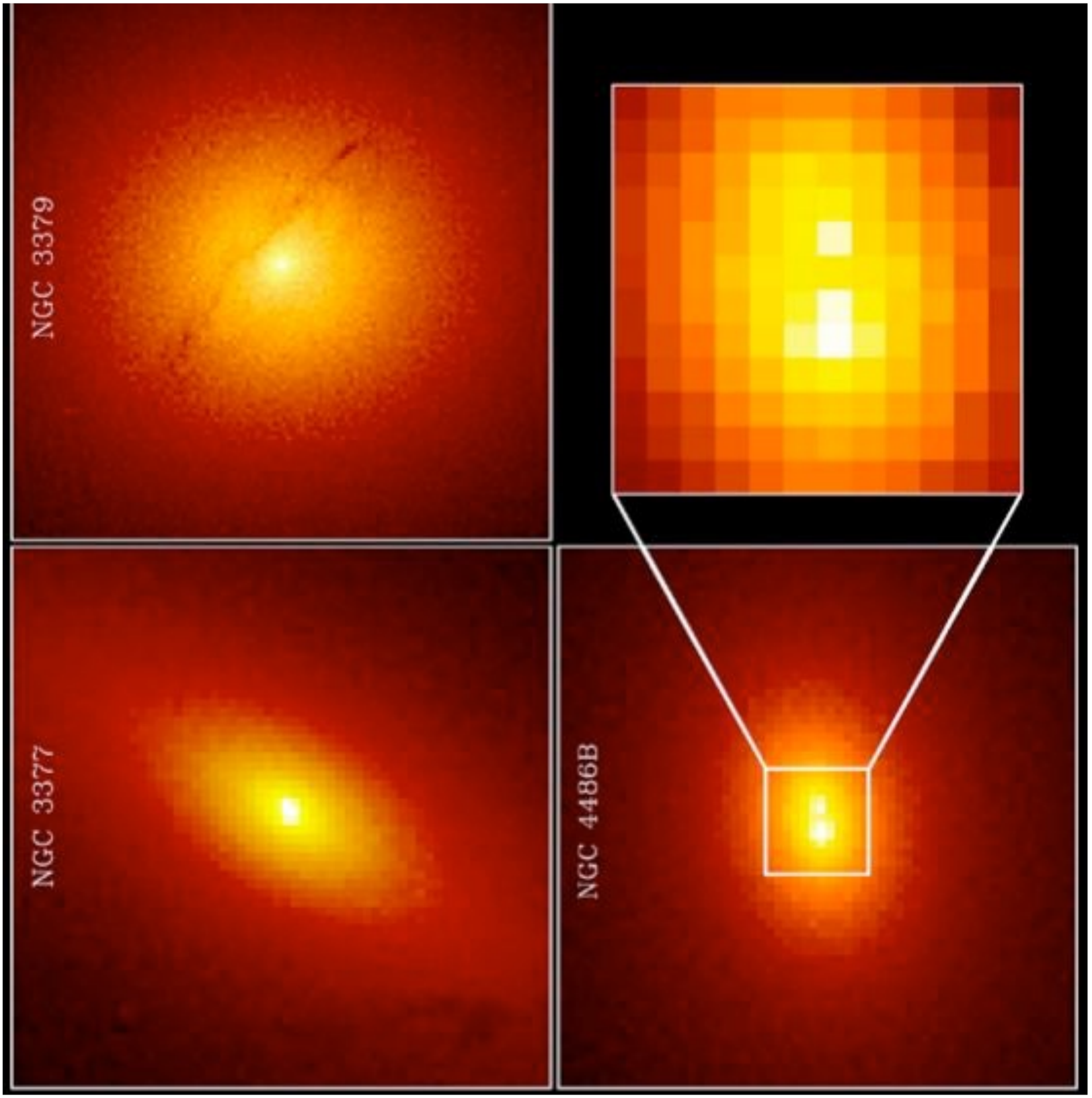
Walsh et al. (2010)



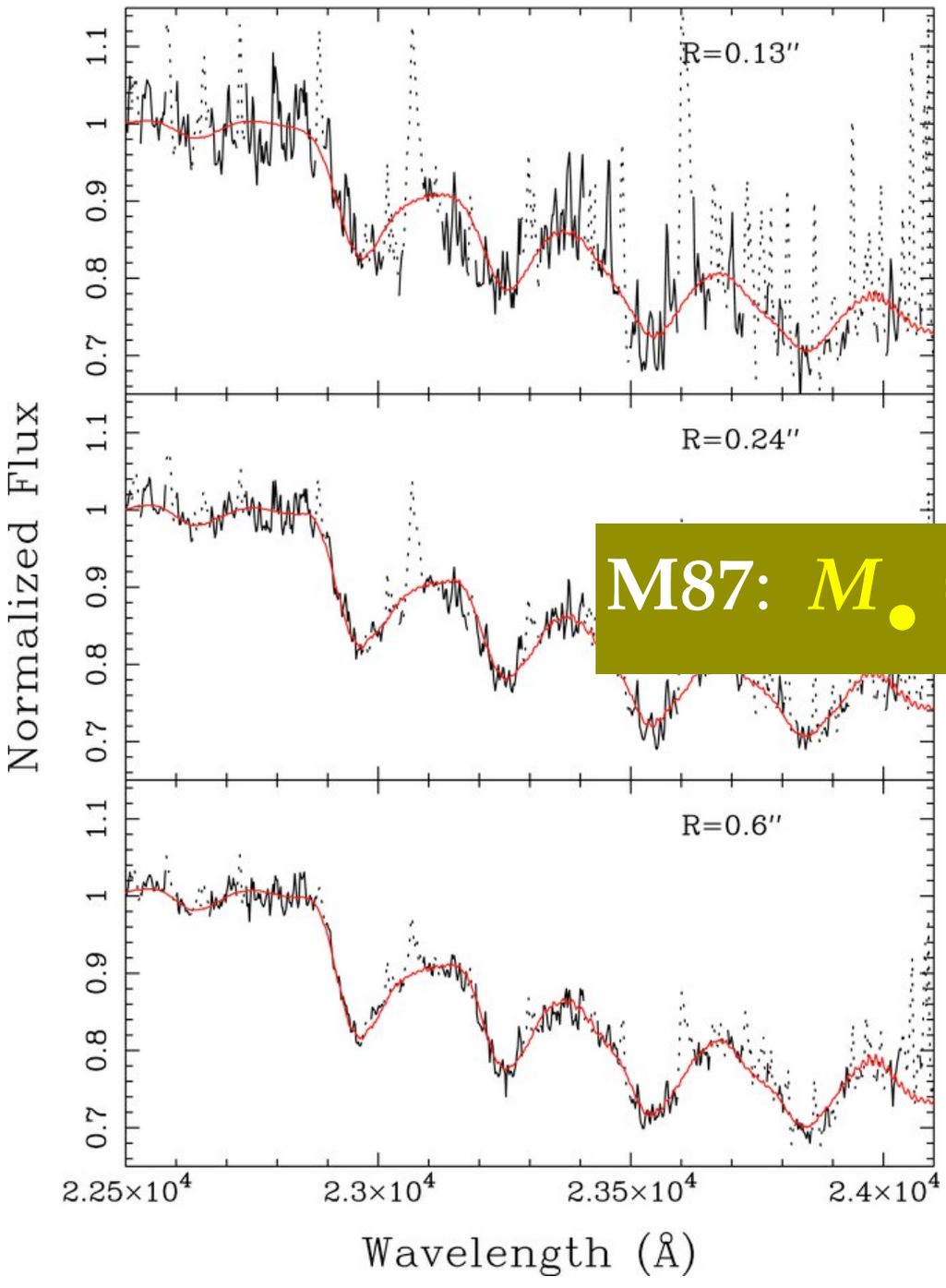
Kormendy & Ho (2013)

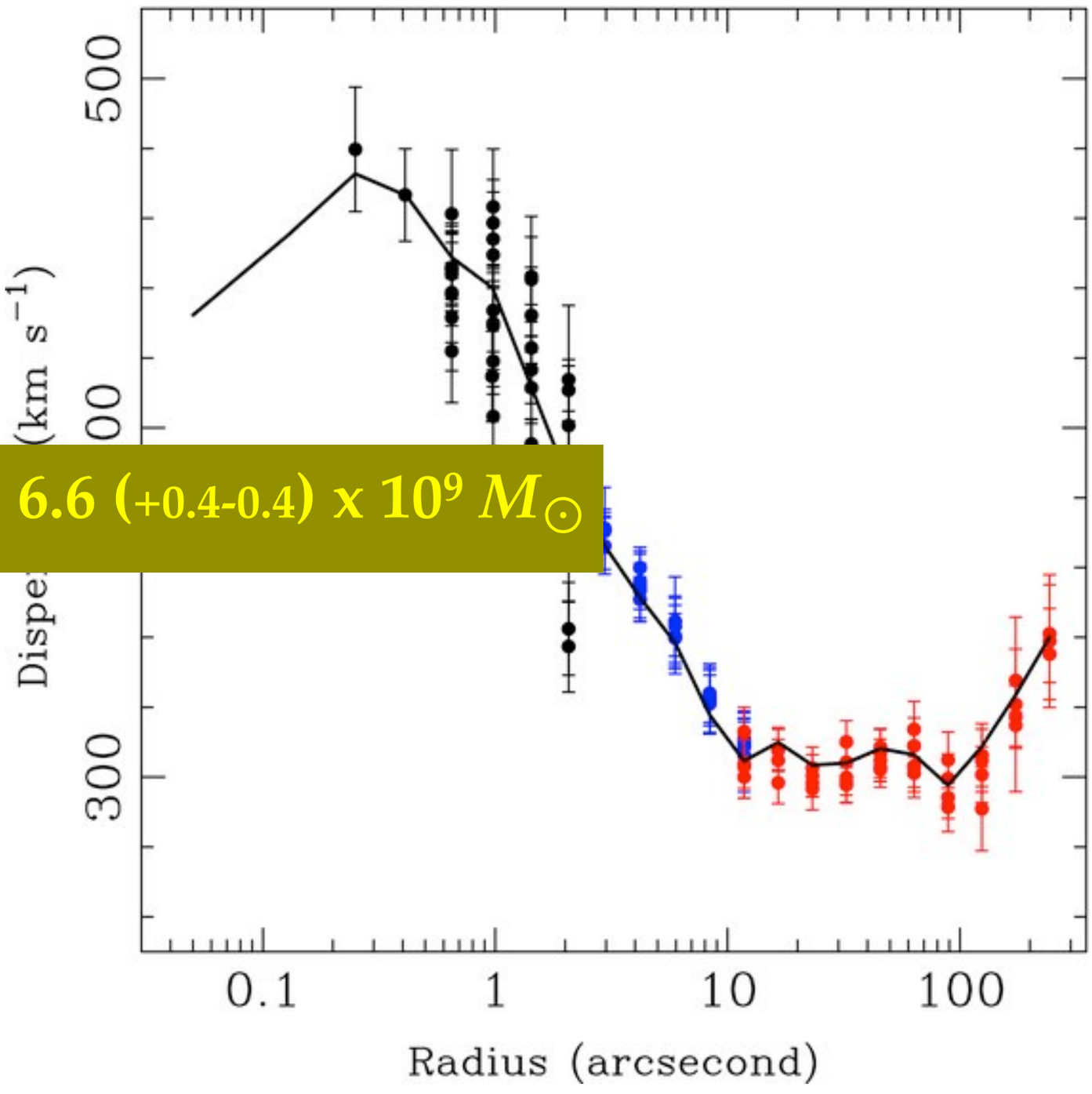


The “Nuker” Team

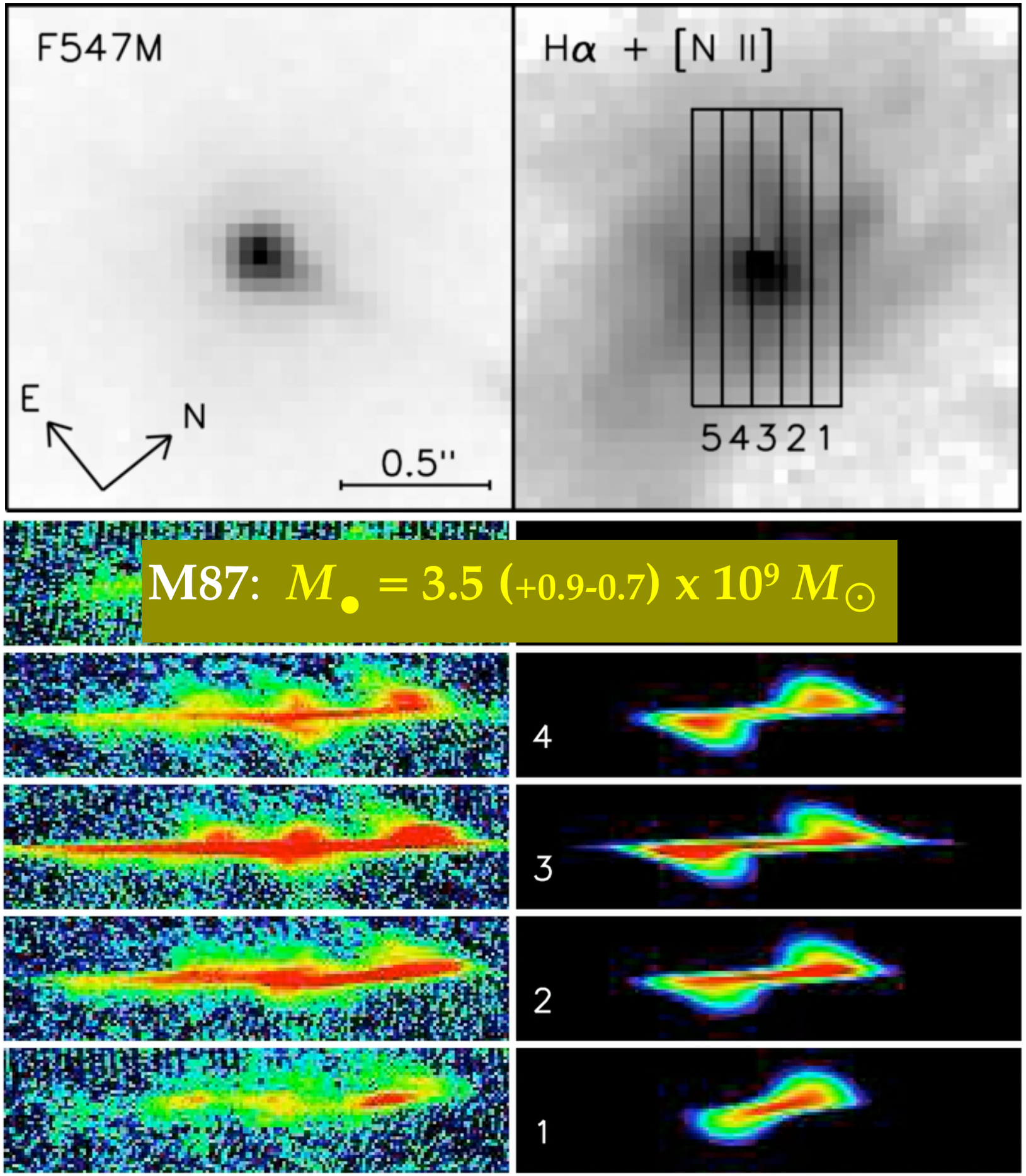


Gebhardt et al. (2011)





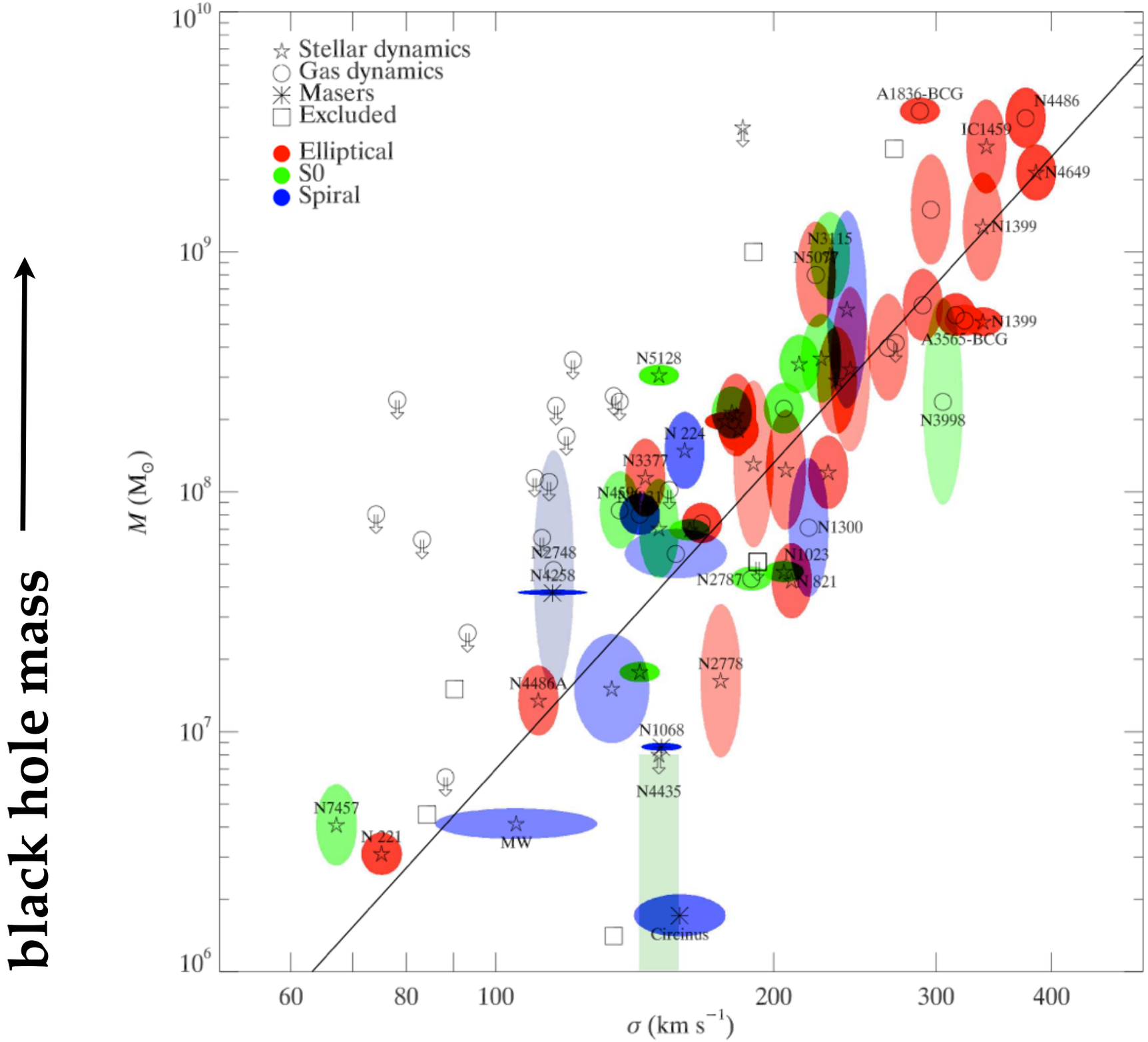
M87: $M_\bullet = 6.6\ (+0.4\text{-}0.4) \times 10^9\ M_\odot$



M87: $M_\bullet = 3.5\ (^{+0.9}_{-0.7}) \times 10^9\ M_\odot$

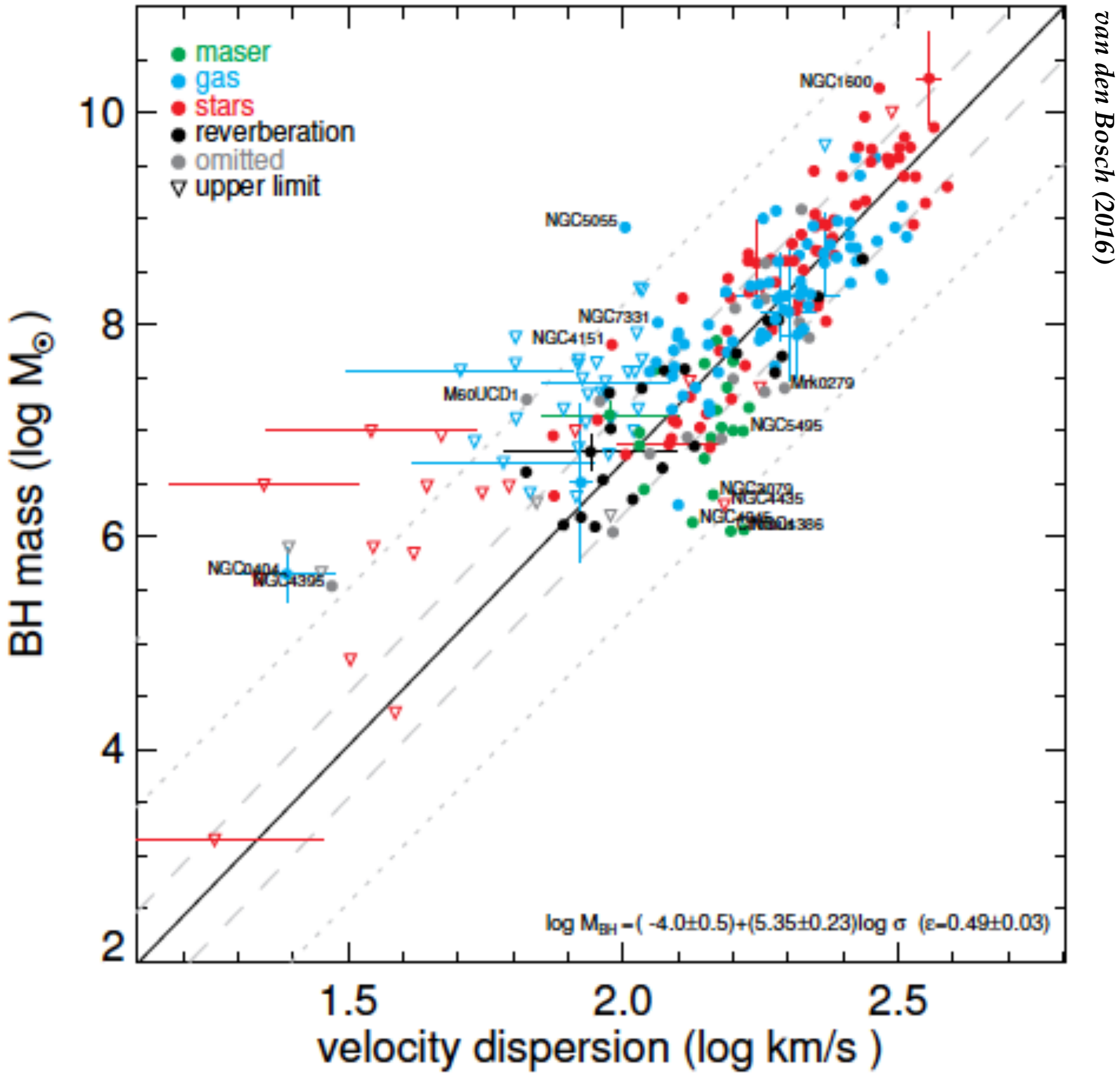
Walsh, Barth, Ho et al. (2013)

Gebhardt et al. (2000); Ferrarese & Merritt (2000); Gültekin et al. (2009)



black hole mass ⟶

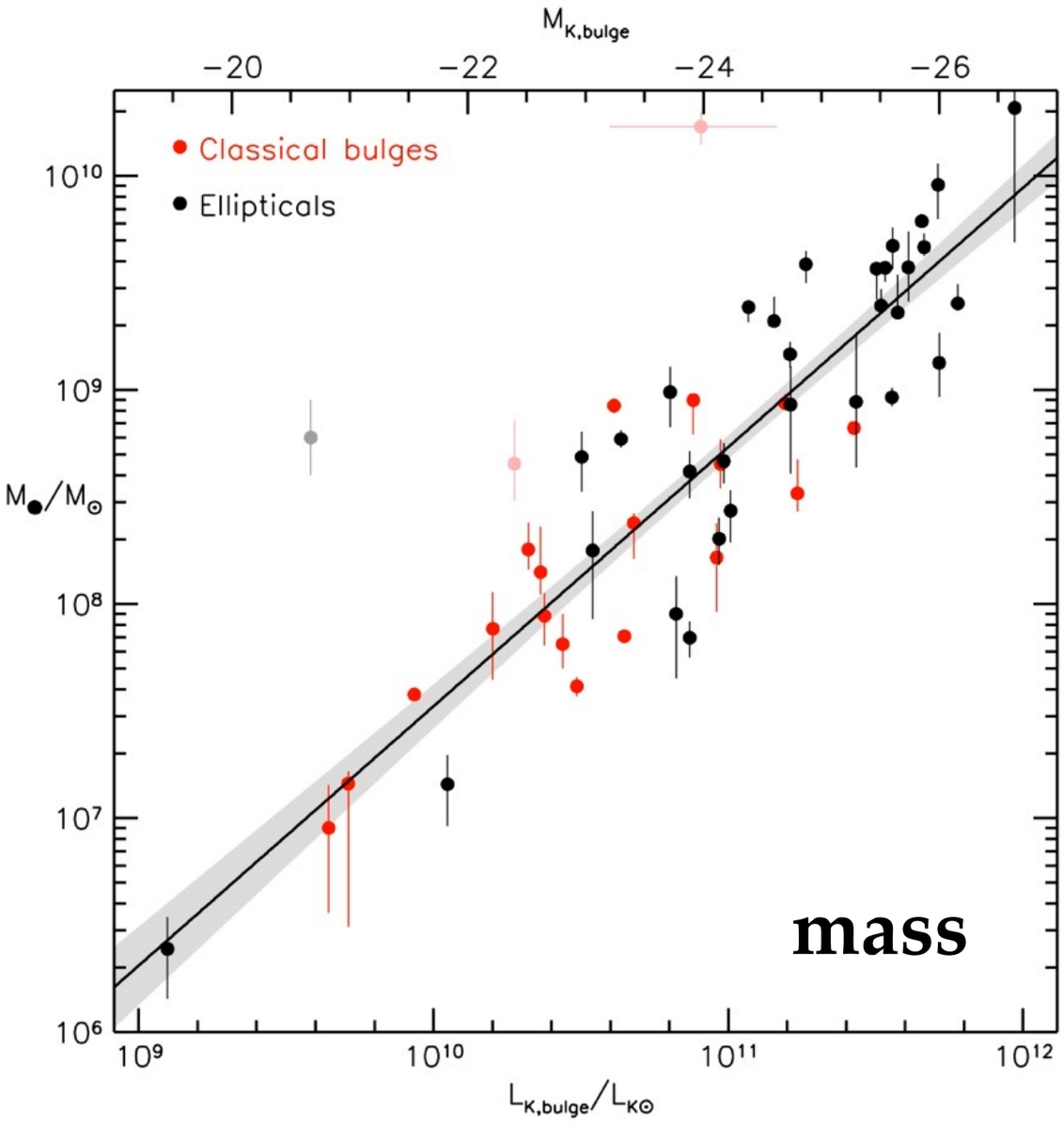
bulge velocity dispersion ⟶

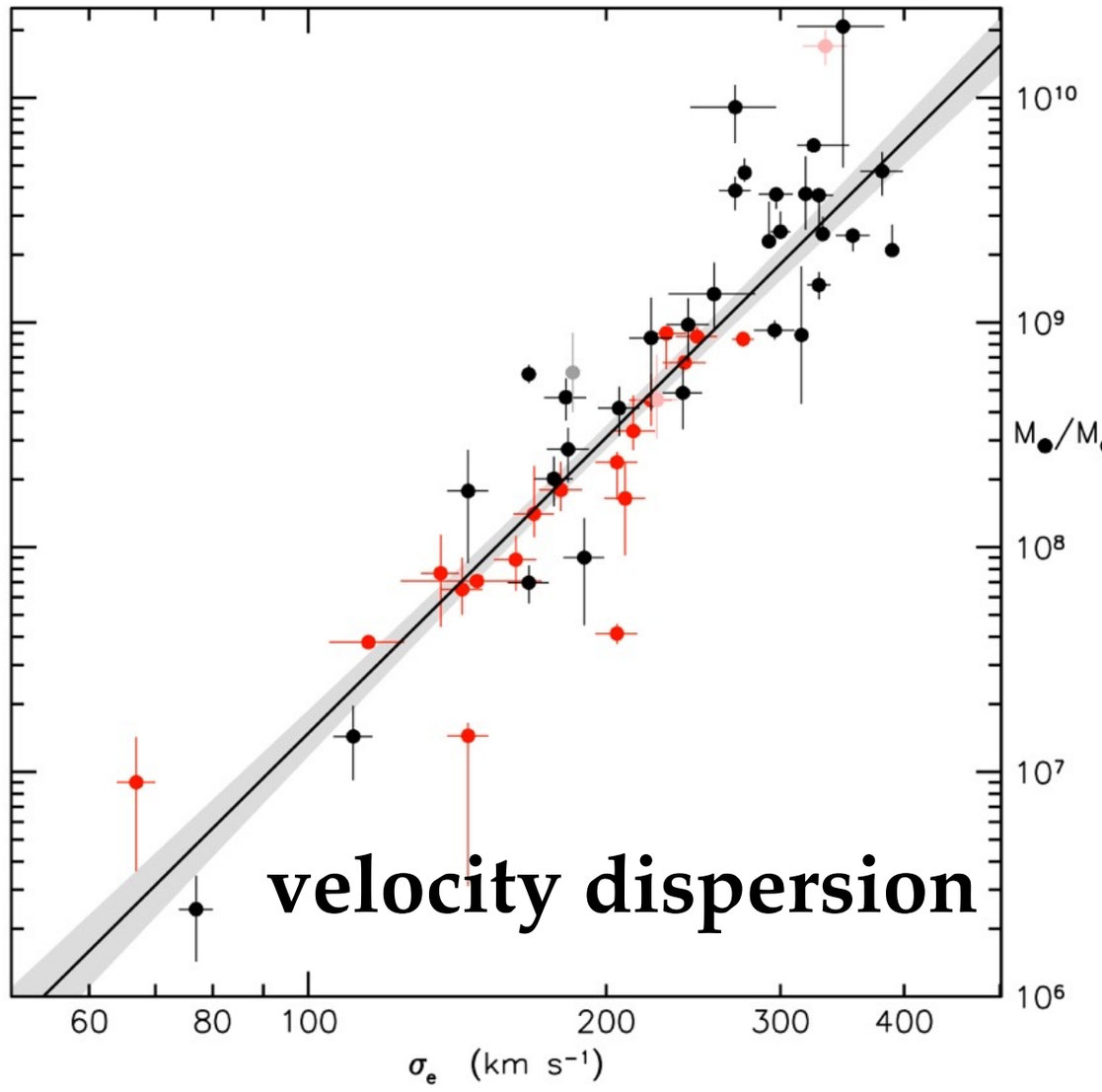


van den Bosch (2016)

Kormendy & Ho (2013, ARA&A)

black hole

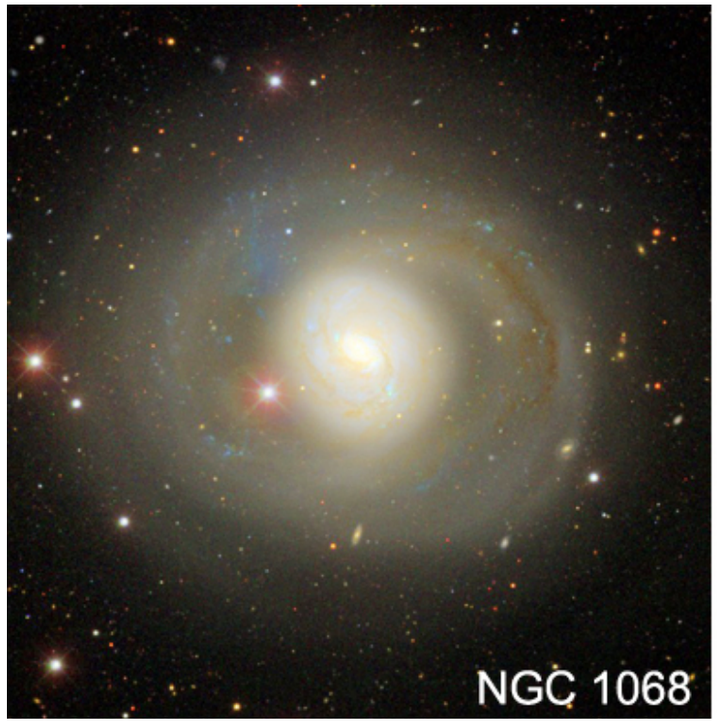


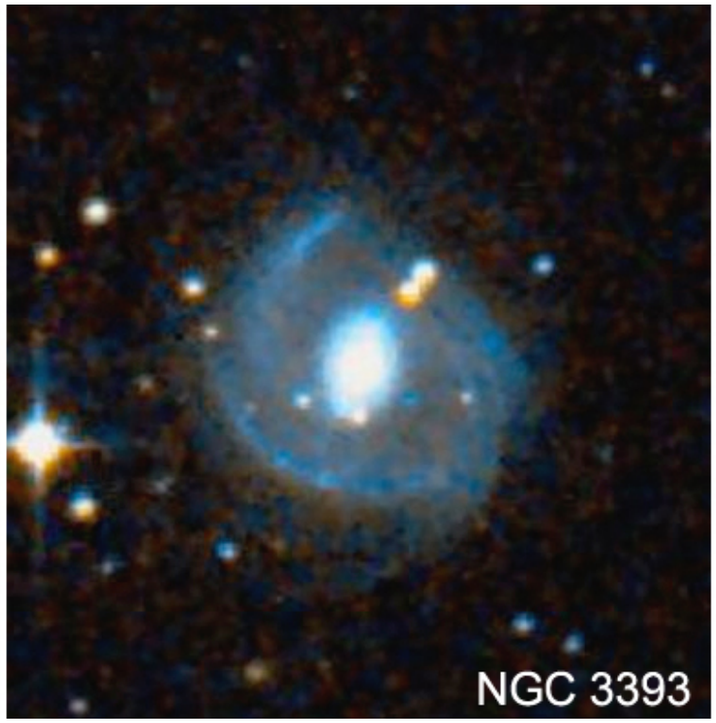


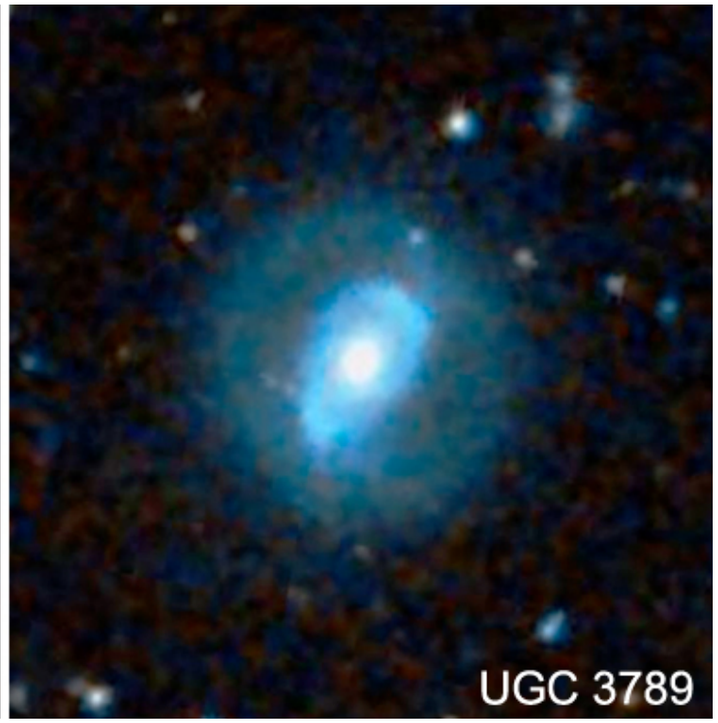
galaxy bulge

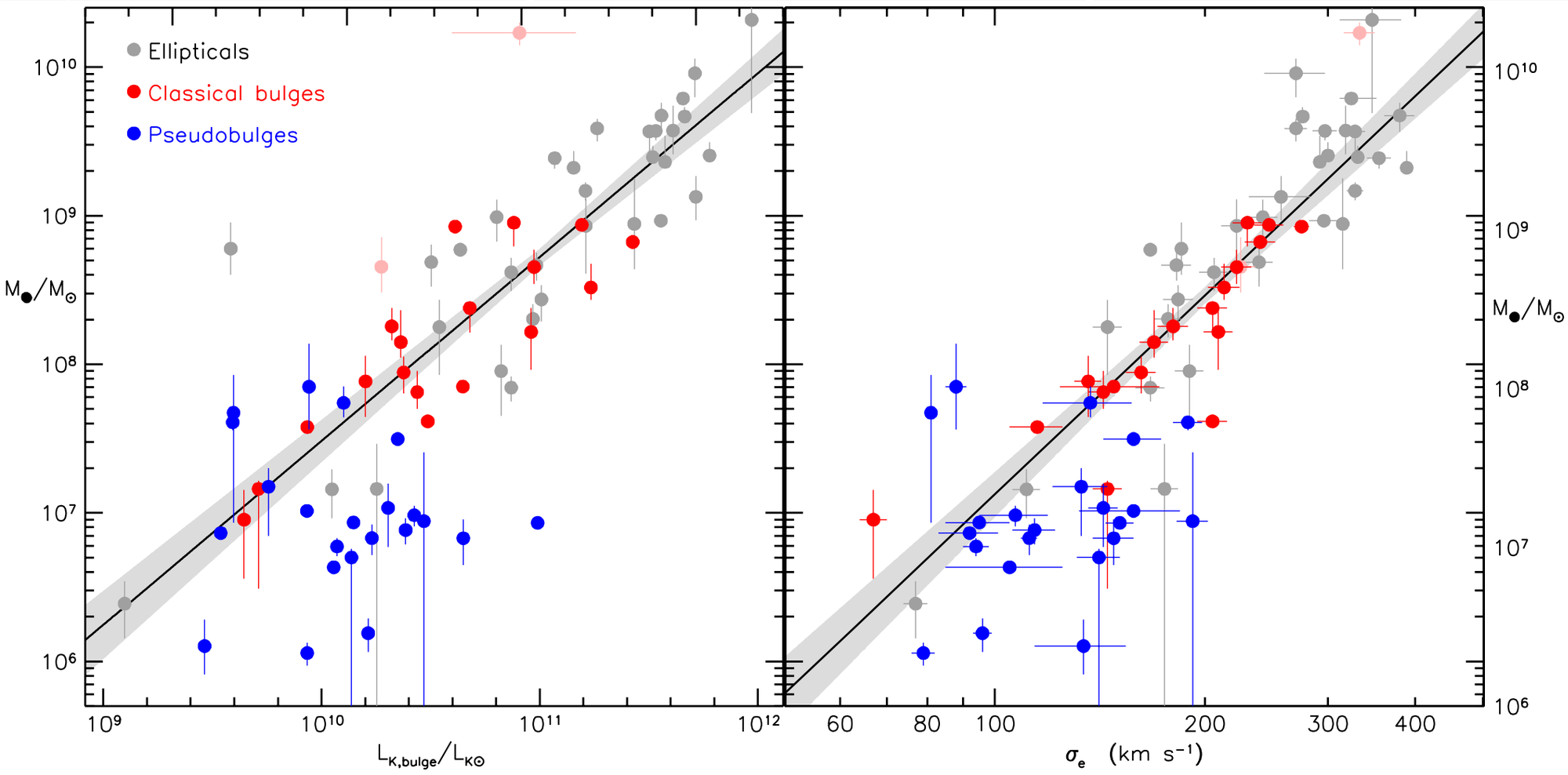
Intrinsic scatter $\varepsilon_0 = 0.29$ dex for both relations

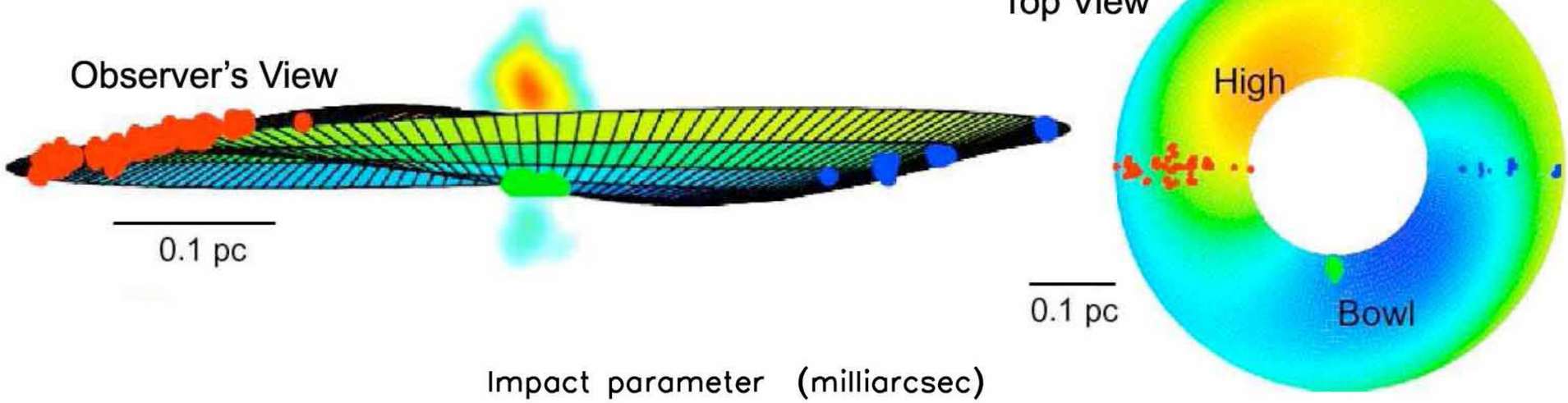
Valid only for ellipticals and classical bulges!

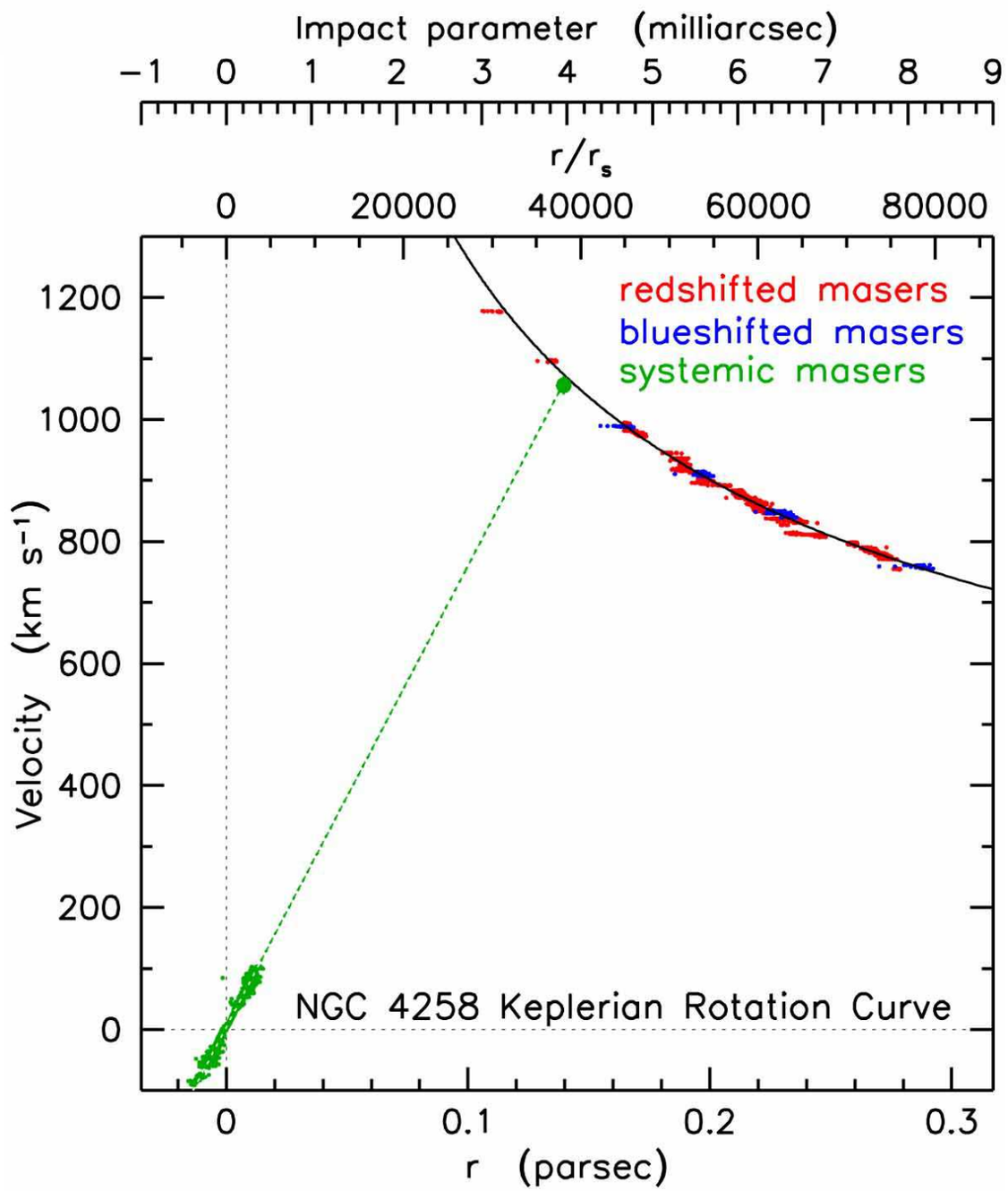

NGC 1068


NGC 3393

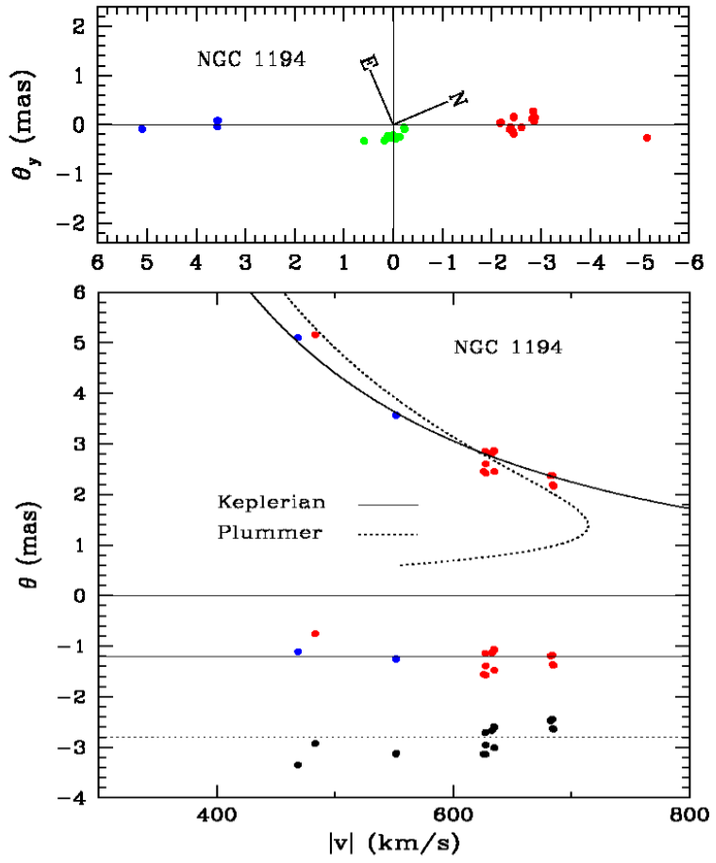

UGC 3789

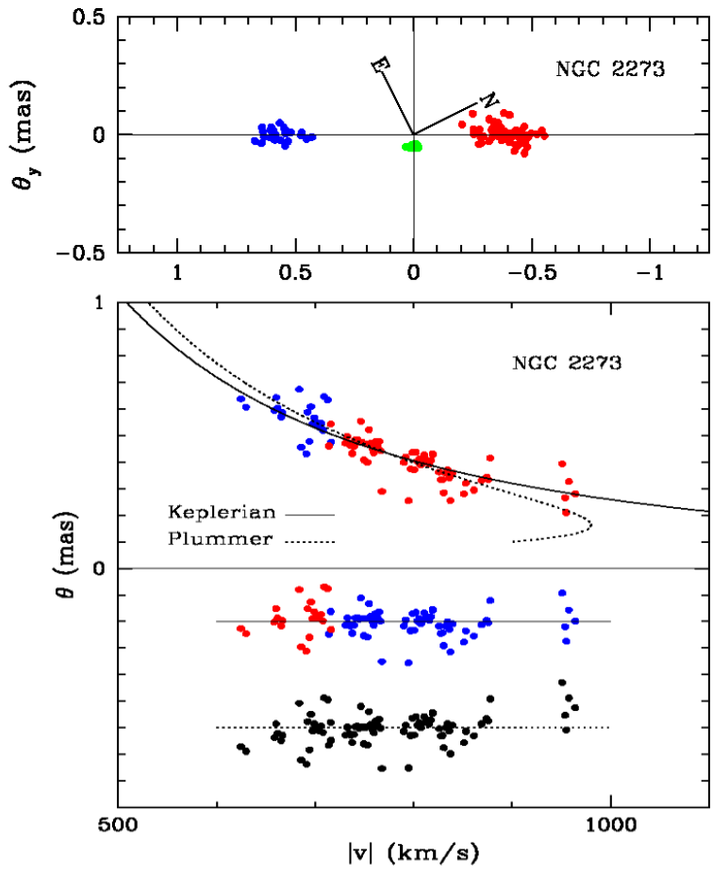

Ellipticals
Classical bulges
Pseudobulges
$M_\bullet/M_\odot$
10^{10}
10^9
10^8
10^7
10^6
10^9
10^{10}
10^{11}
10^{12}
$L_{K,bulge}/L_{K\odot}$
60
80
100
200
300
400
σ_e (km s^{-1})

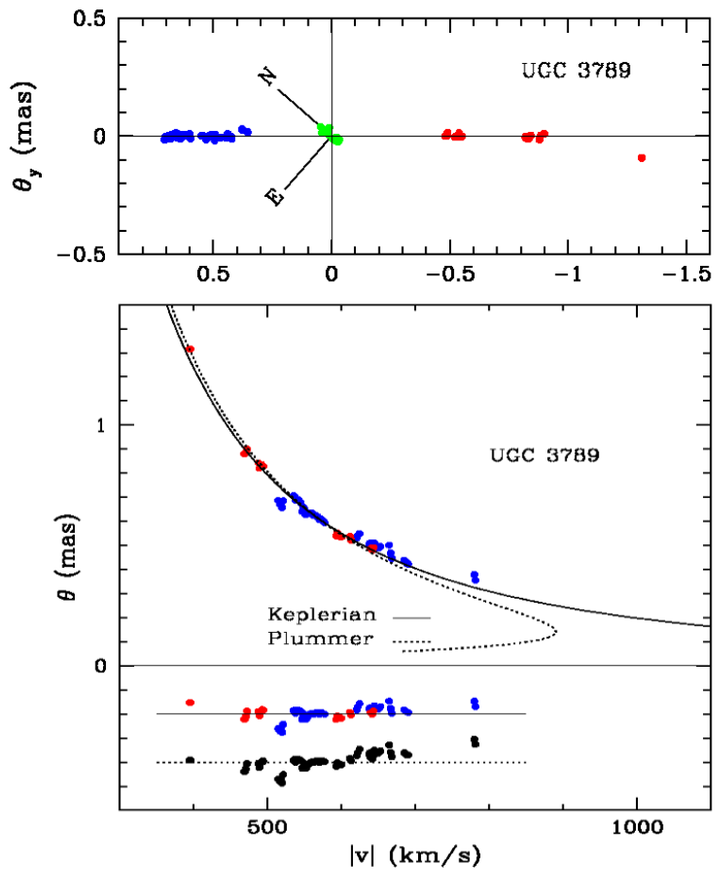


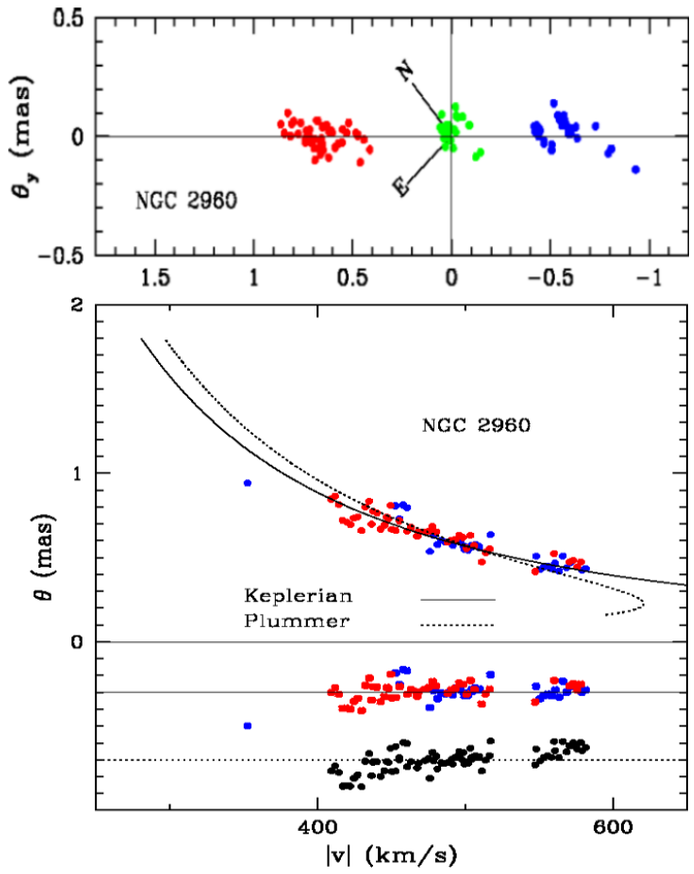


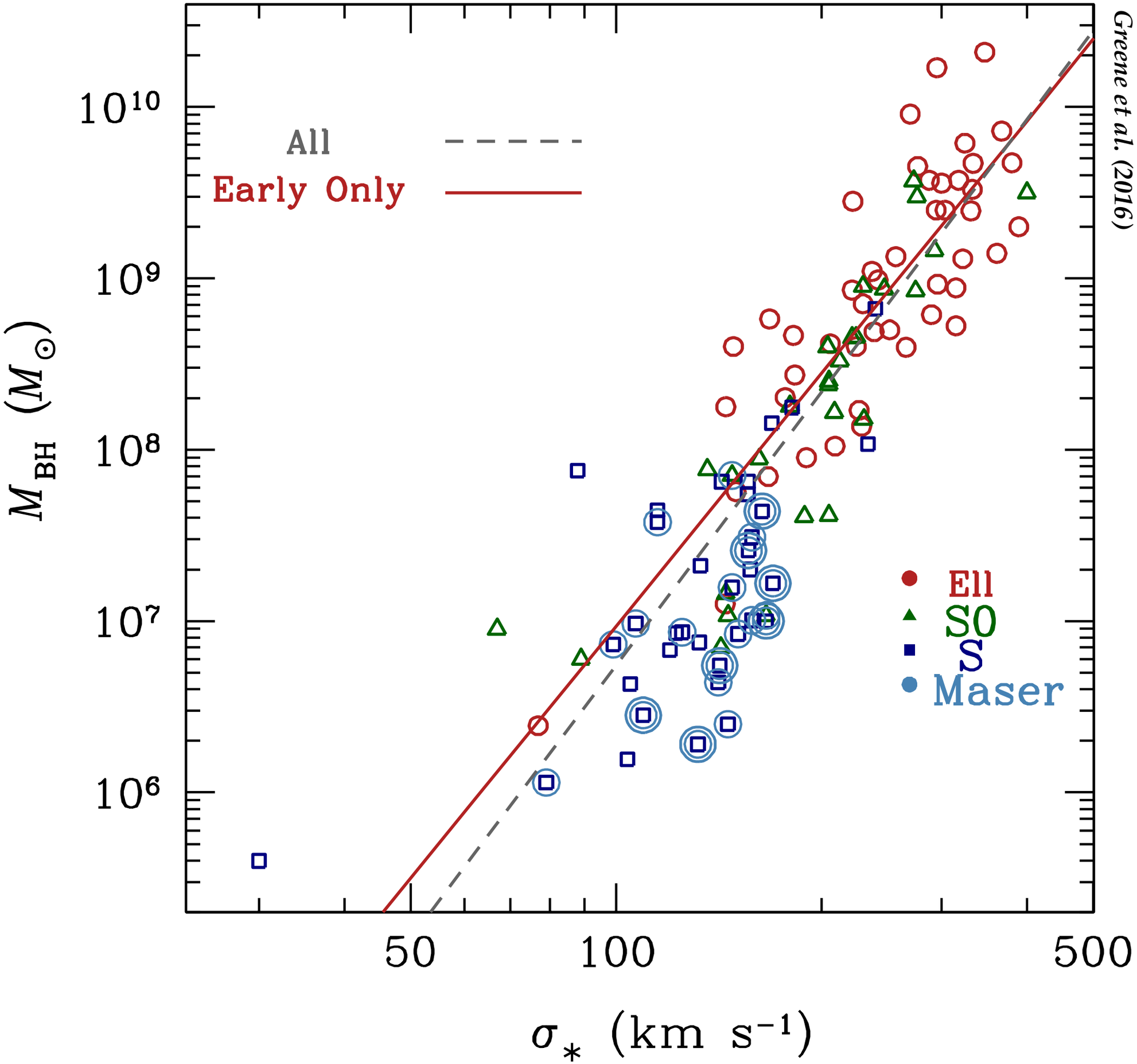
Miyoshi et al. (1995)
Herrnstein et al. (2005)


NGC 1194
E
N
θ_y (mas)
NGC 1194
Keplerian
Plummer
θ (mas)
|v| (km/s)


NGC 2273
E
N
θ_y (mas)
NGC 2273
Keplerian
Plummer
θ (mas)
|v| (km/s)


UGC 3789
N
E
θ_y (mas)
UGC 3789
Keplerian
Plummer
θ (mas)
|v| (km/s)


NGC 2960
N
E
θ_y (mas)
NGC 2960
Keplerian
Plummer
θ (mas)
|v| (km/s)


All
Early Only
Greene et al. (2016)
Ell
S0
S
Maser
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
M_{BH} $(M_\odot)$
50
100
500
σ_* (km s^{-1})

Reverberation Mapping

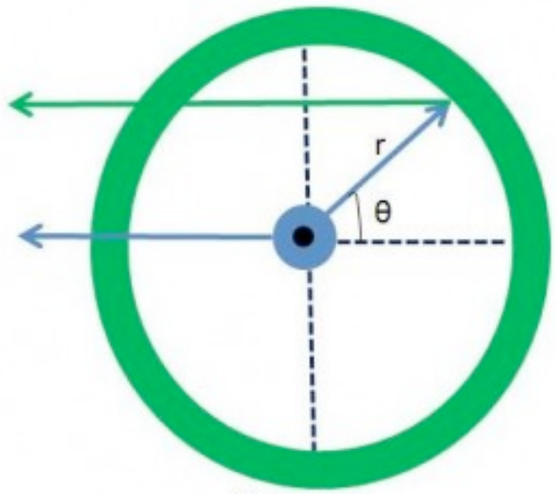
$$M_{\rm BH}({\rm RM}) = f\frac{R(\Delta V)^2}{G}$$

R = **BLR size**

ΔV = **viral velocity**

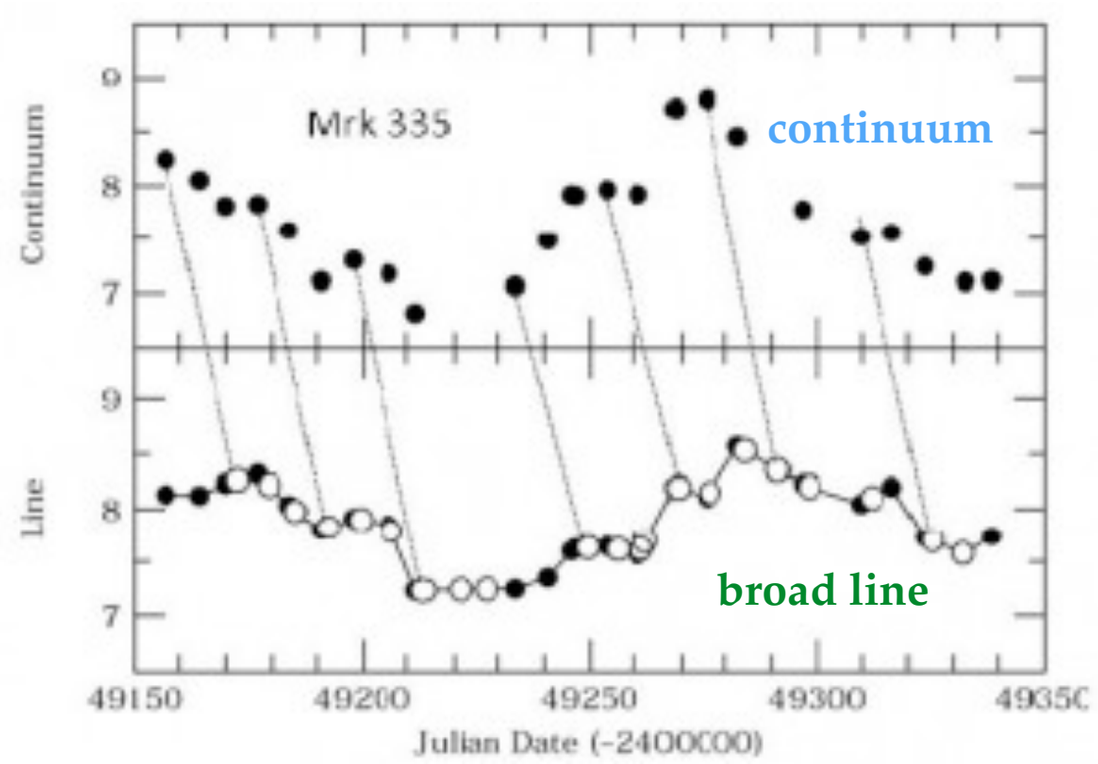
f = **viral factor**

needs external calibration



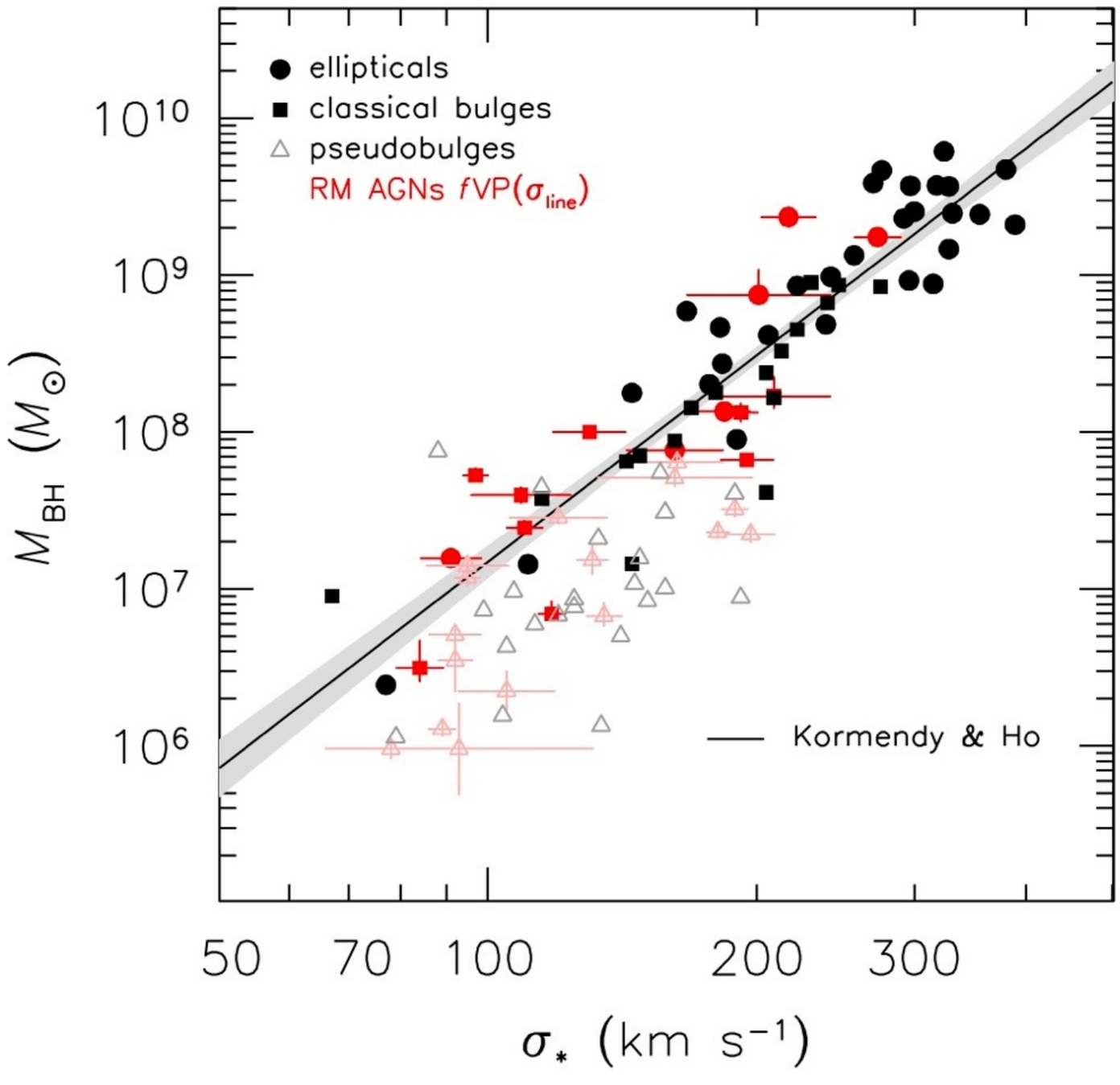
time delay:

$\tau = (1+\cos\theta)\, R/c$



Calibration of *f*-factor

Ho & Kim (2014)



Classical bulges

$f = 6.3 \pm 1.3 \quad \varepsilon_0 = 0.39 \pm 0.07$

Pseudo bulges

$f = 3.2 \pm 0.7 \quad \varepsilon_0 = 0.34 \pm 0.06$

Calibration of Single-Epoch Virial Masses

$$\log M_{\rm BH}({\rm H}\beta) = \log\left[\left(\frac{\rm FWHM({\rm H}\beta}{1000\,{\rm km\,s^{-1}}}\right)^2 \left(\frac{\lambda L_\lambda(5100\,\text{Å})}{10^{44}\,{\rm erg\,s^{-1}}}\right)^{0.533}\right] + a$$

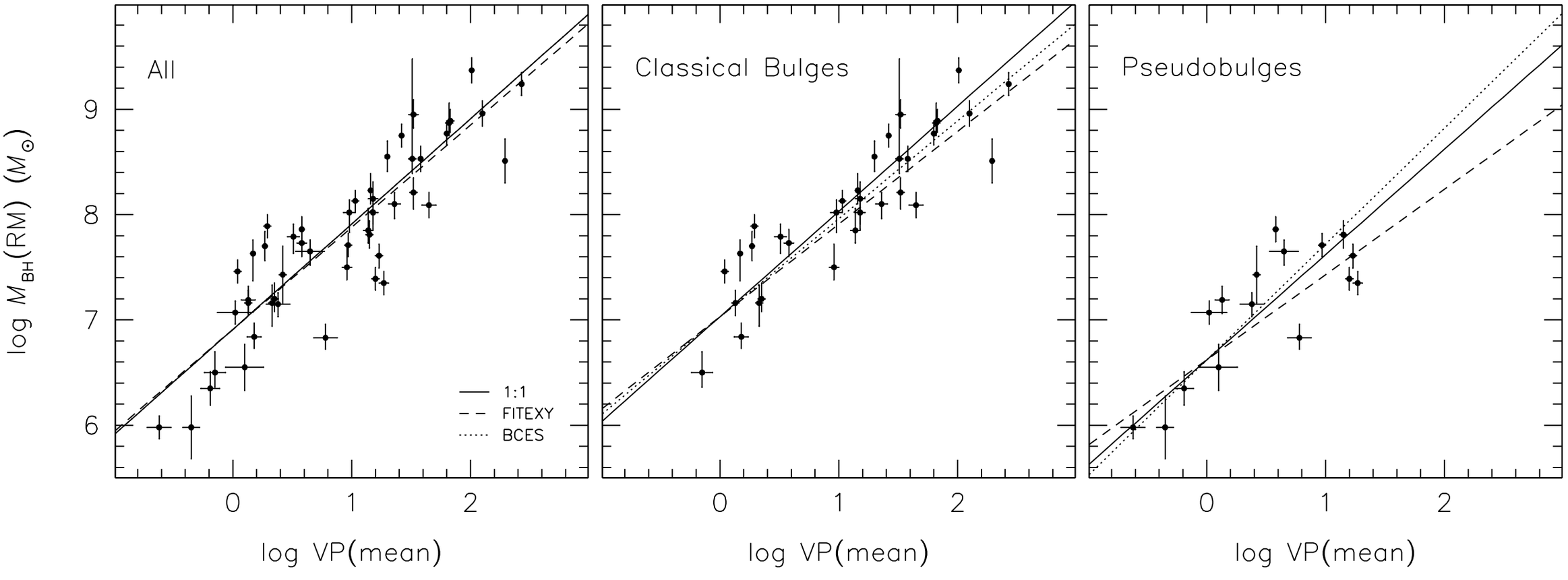
Classical bulges

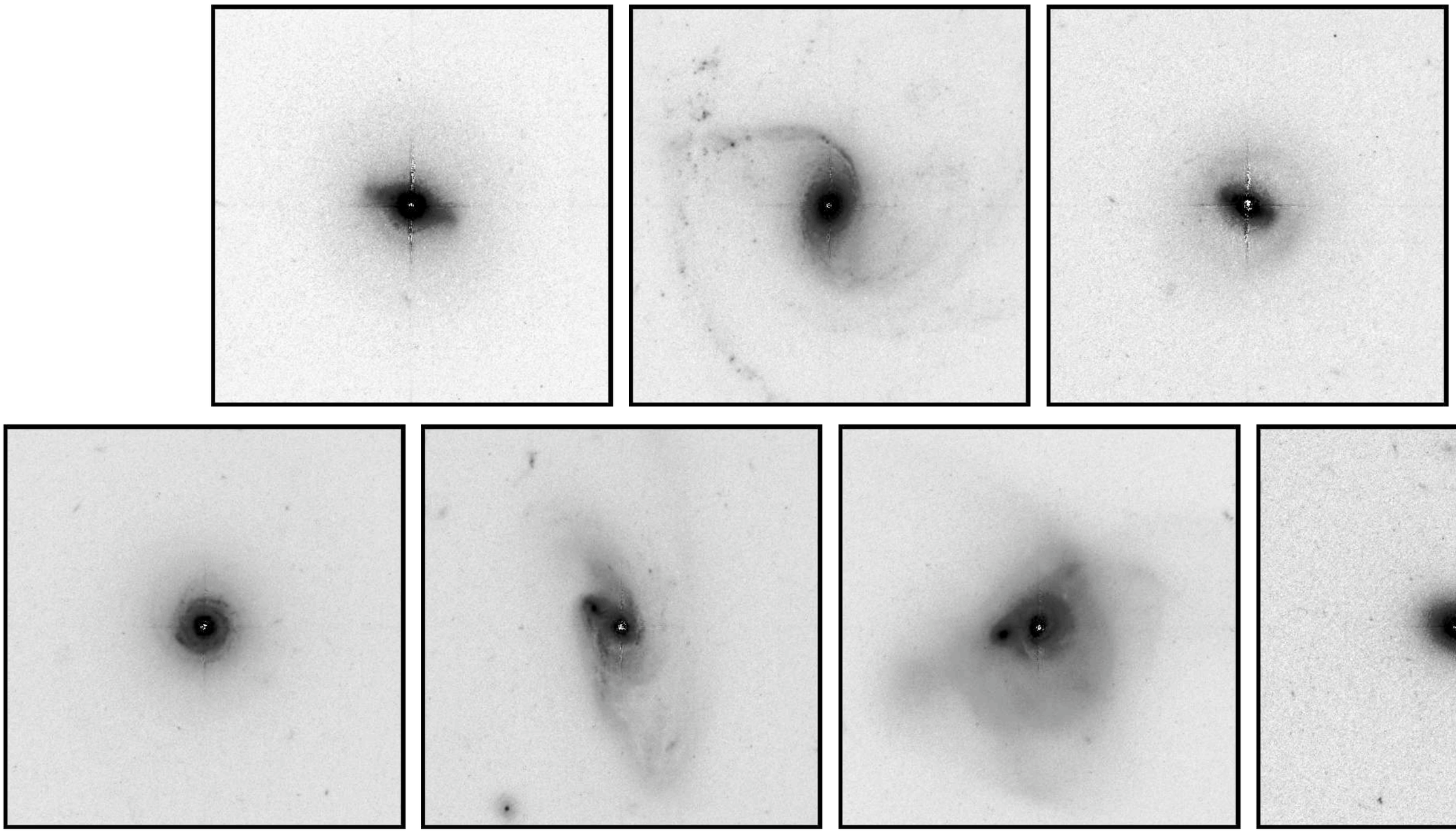
$a = 7.03 \pm 0.02 \quad \varepsilon_0 = 0.32$

Pseudo bulges

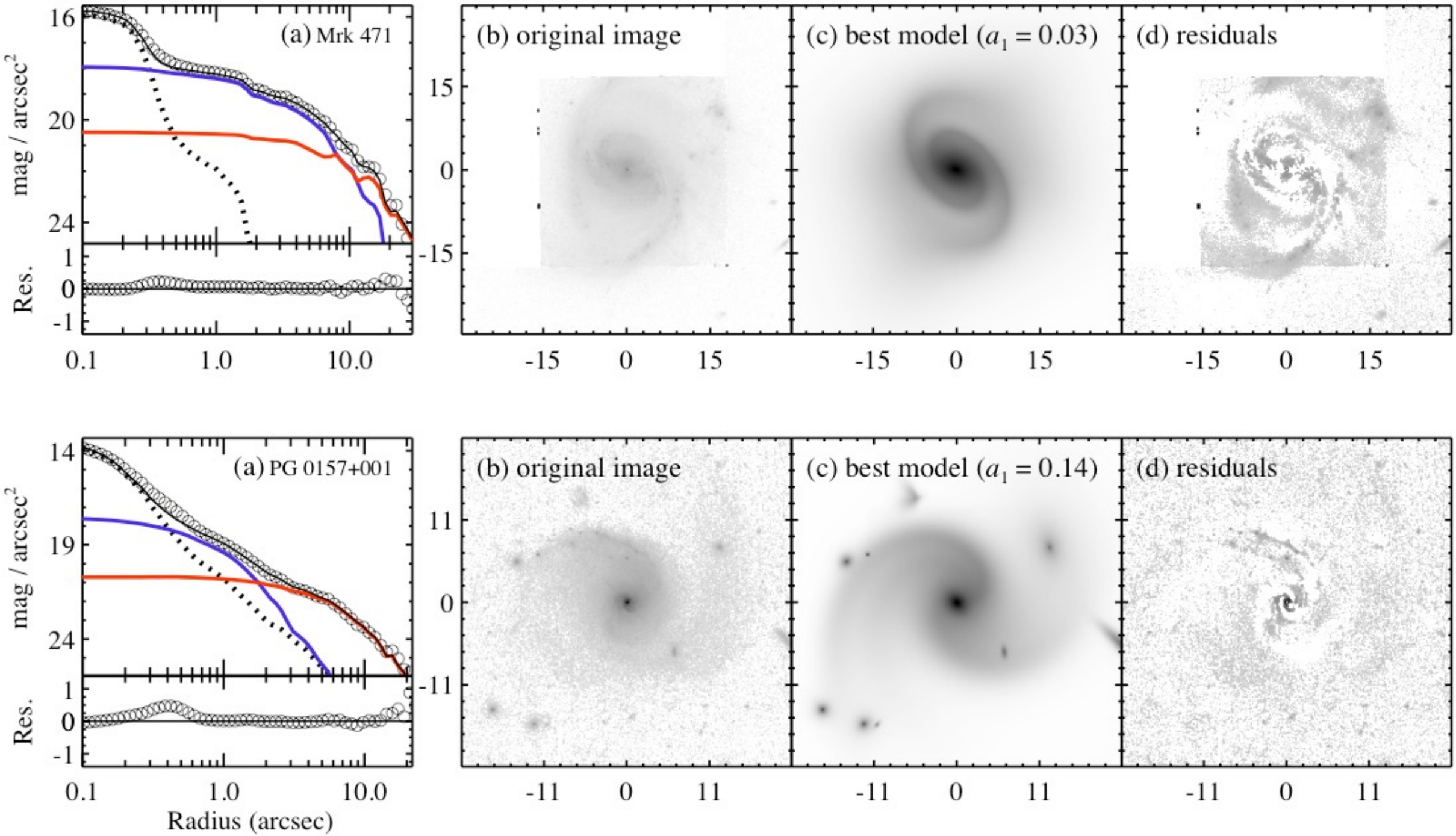
$a = 6.62 \pm 0.04 \quad \varepsilon_0 = 0.38$

Ho & Kim (2015)



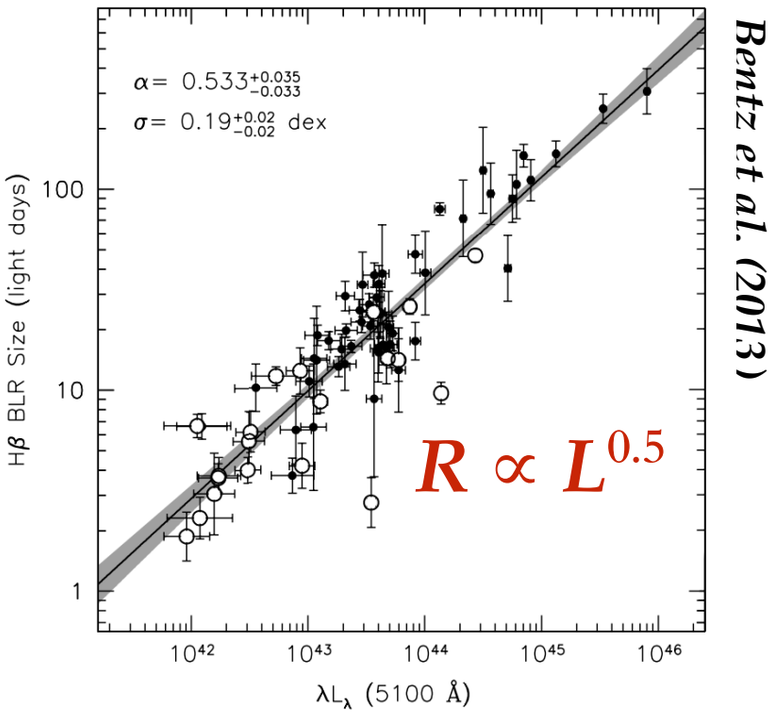


Kim, Ho, et al. (2016)

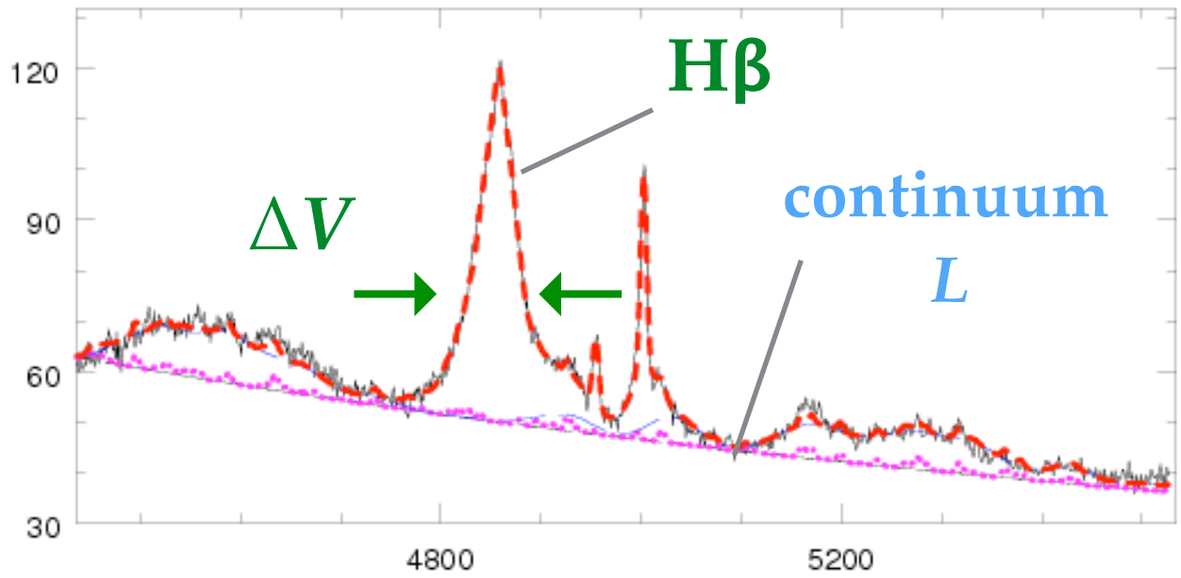


Kim, Ho, et al. (2016)

The Radius-Luminosity Relation

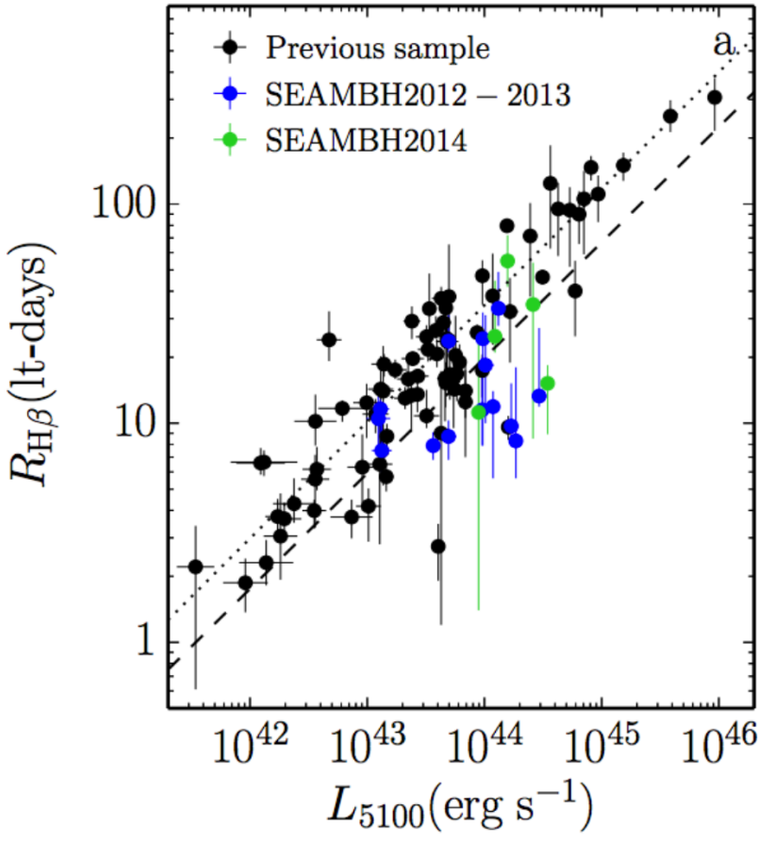


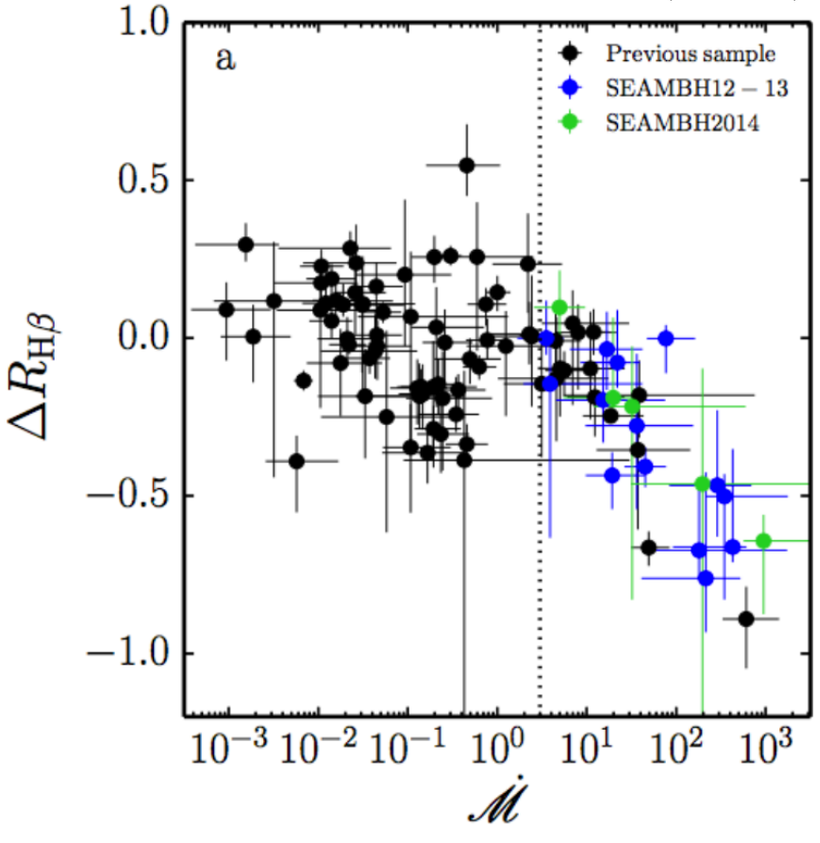
Bentz et al. (2013)

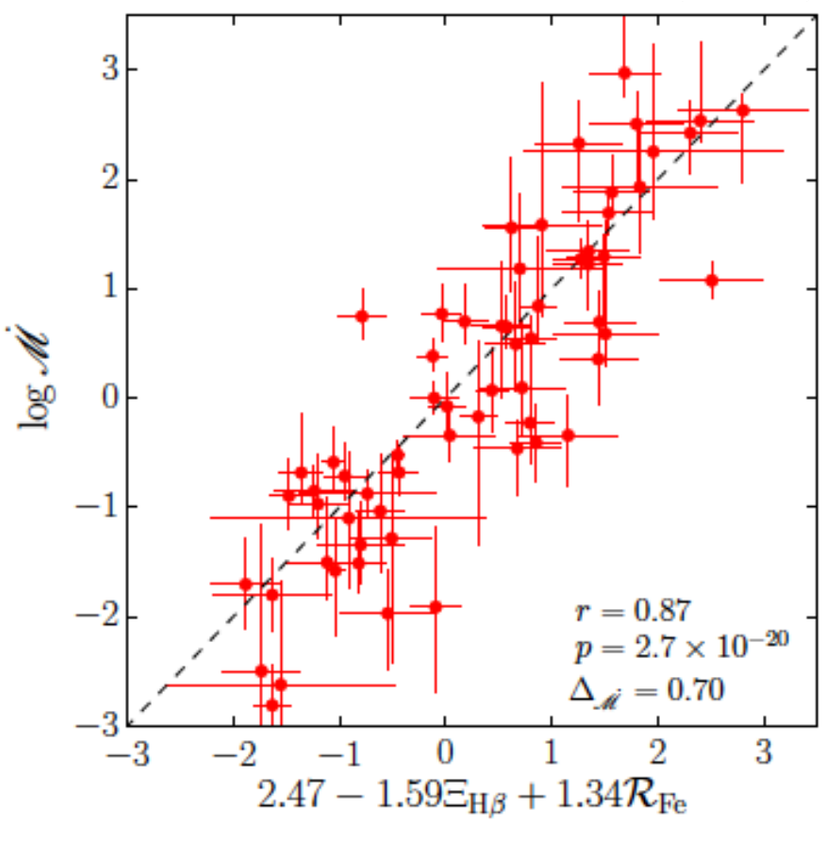


Du et al. (2016b)

Du et al. (2016a)







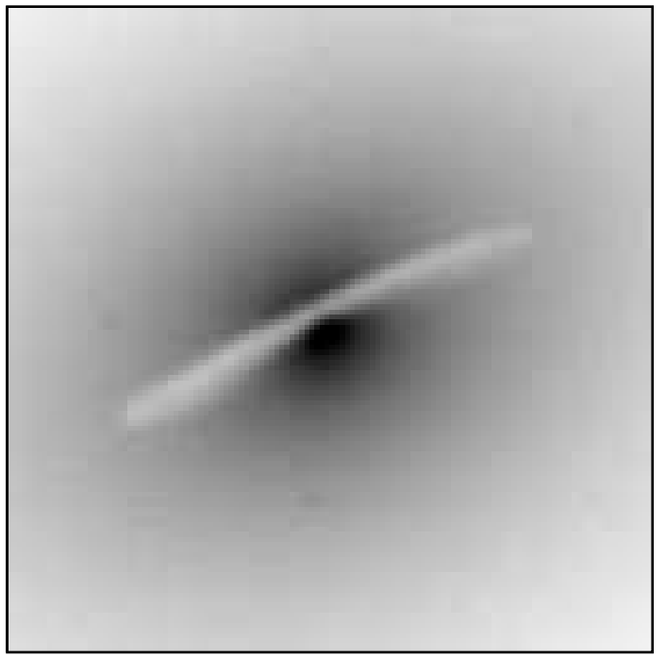
Can we ever get rid of the f-factor?

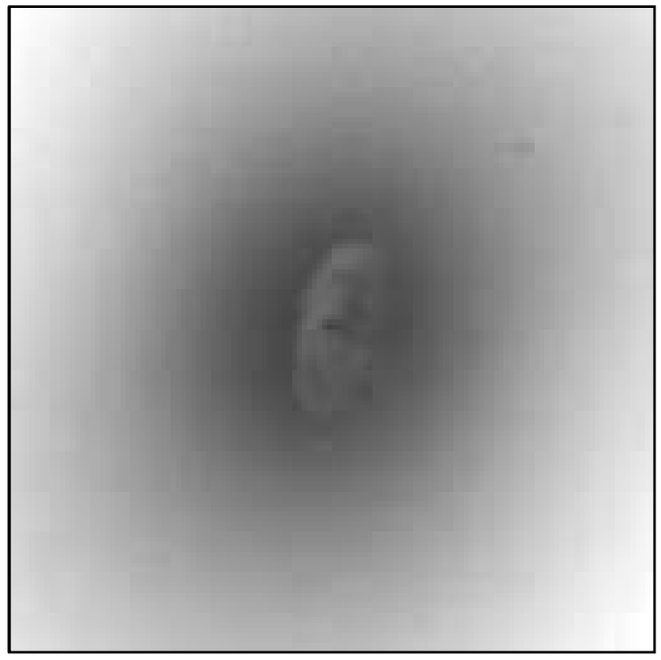
How well can we interpret velocity-delay maps?

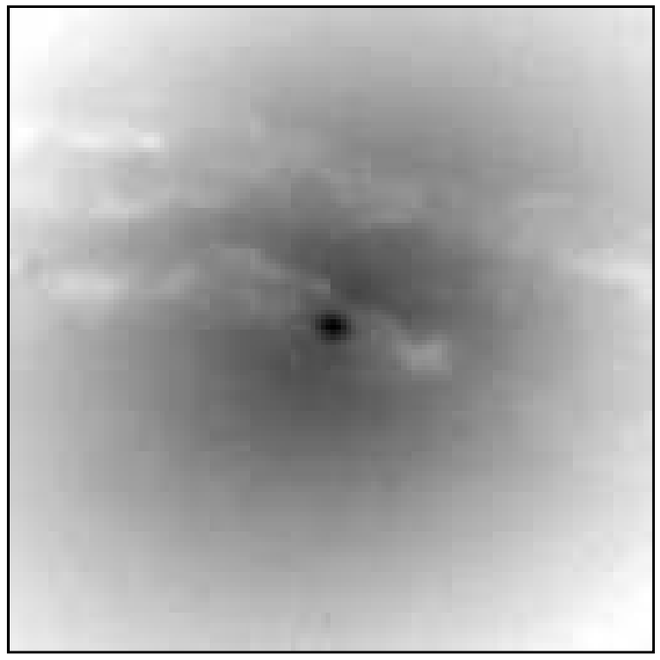
How well can we trust BLR dynamical modeling?

Can we obtain masses better than 0.3-0.5 dex?

A New Strategy Using ALMA

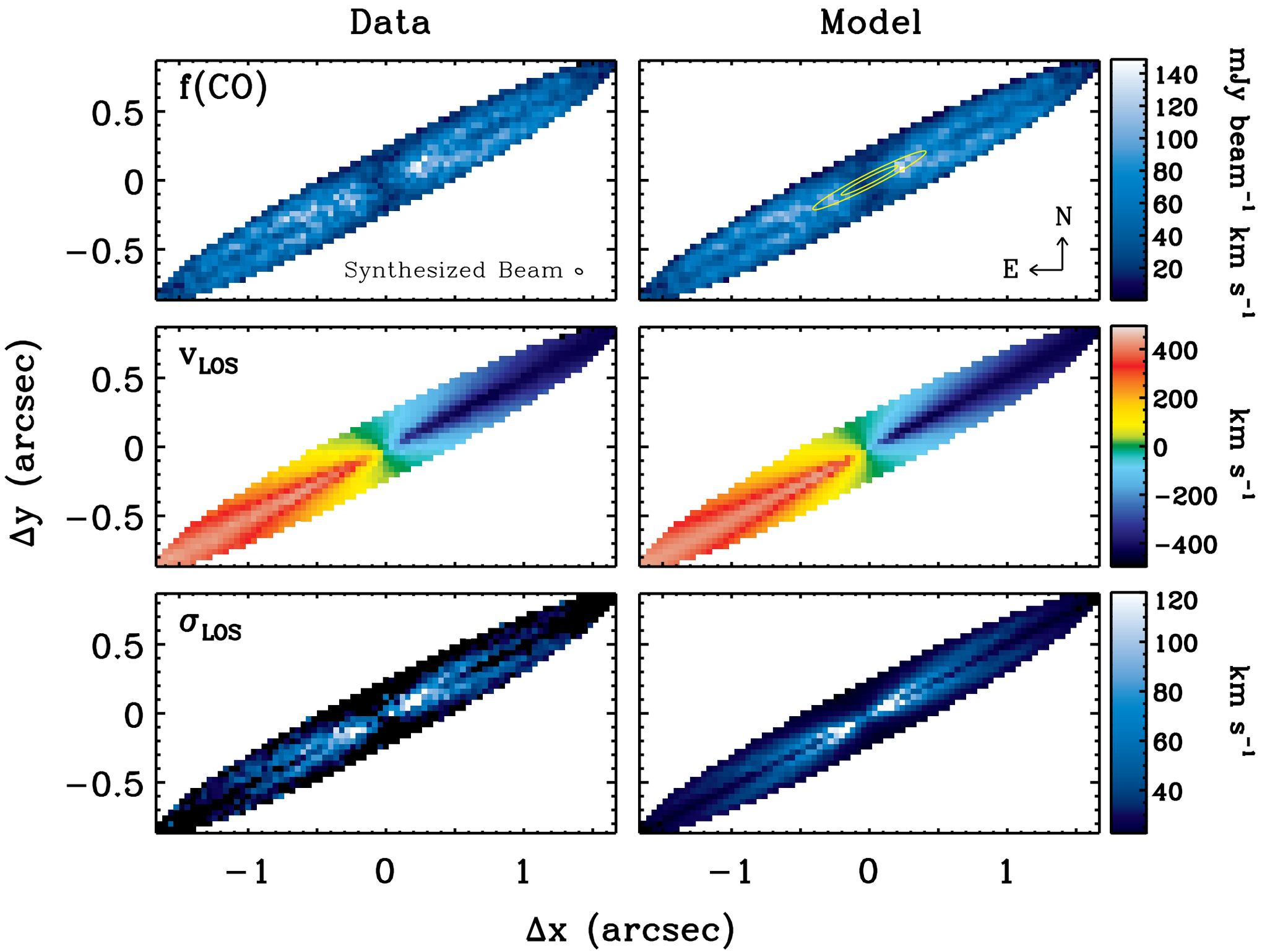


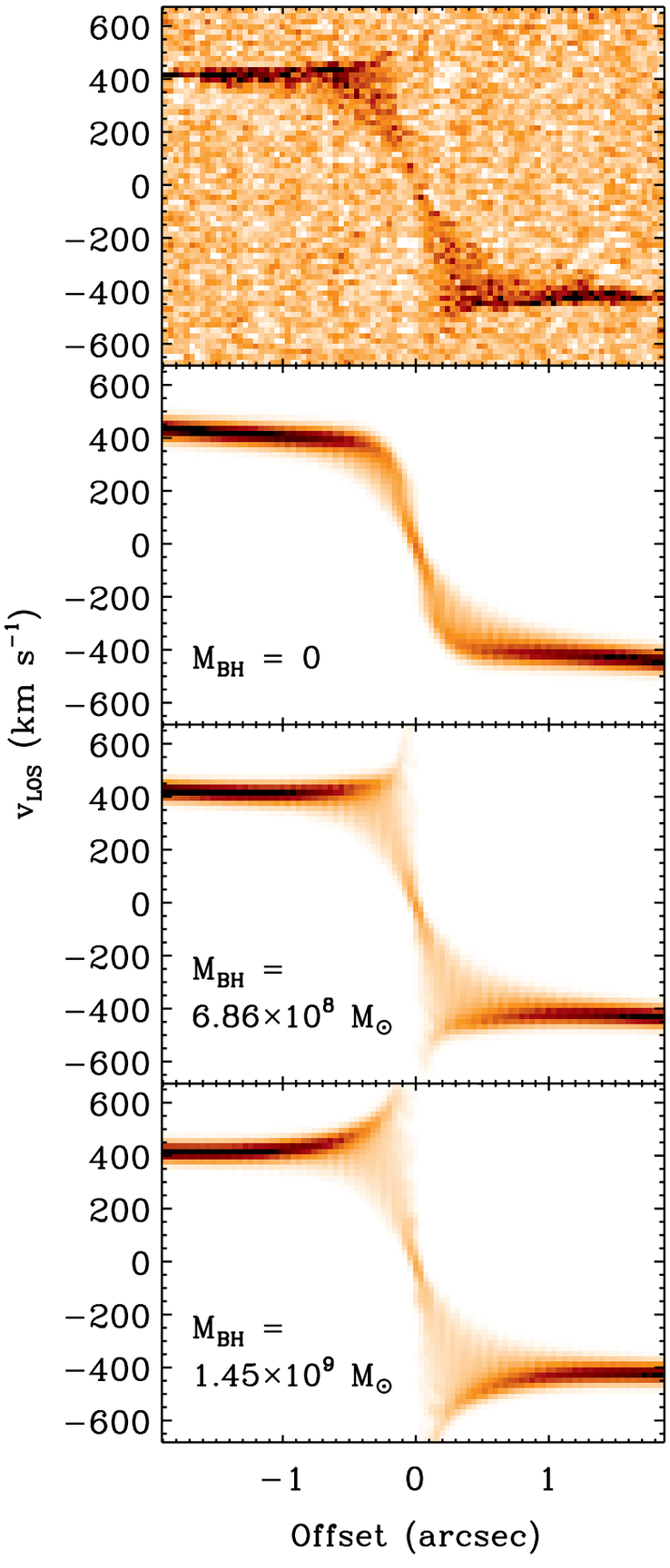


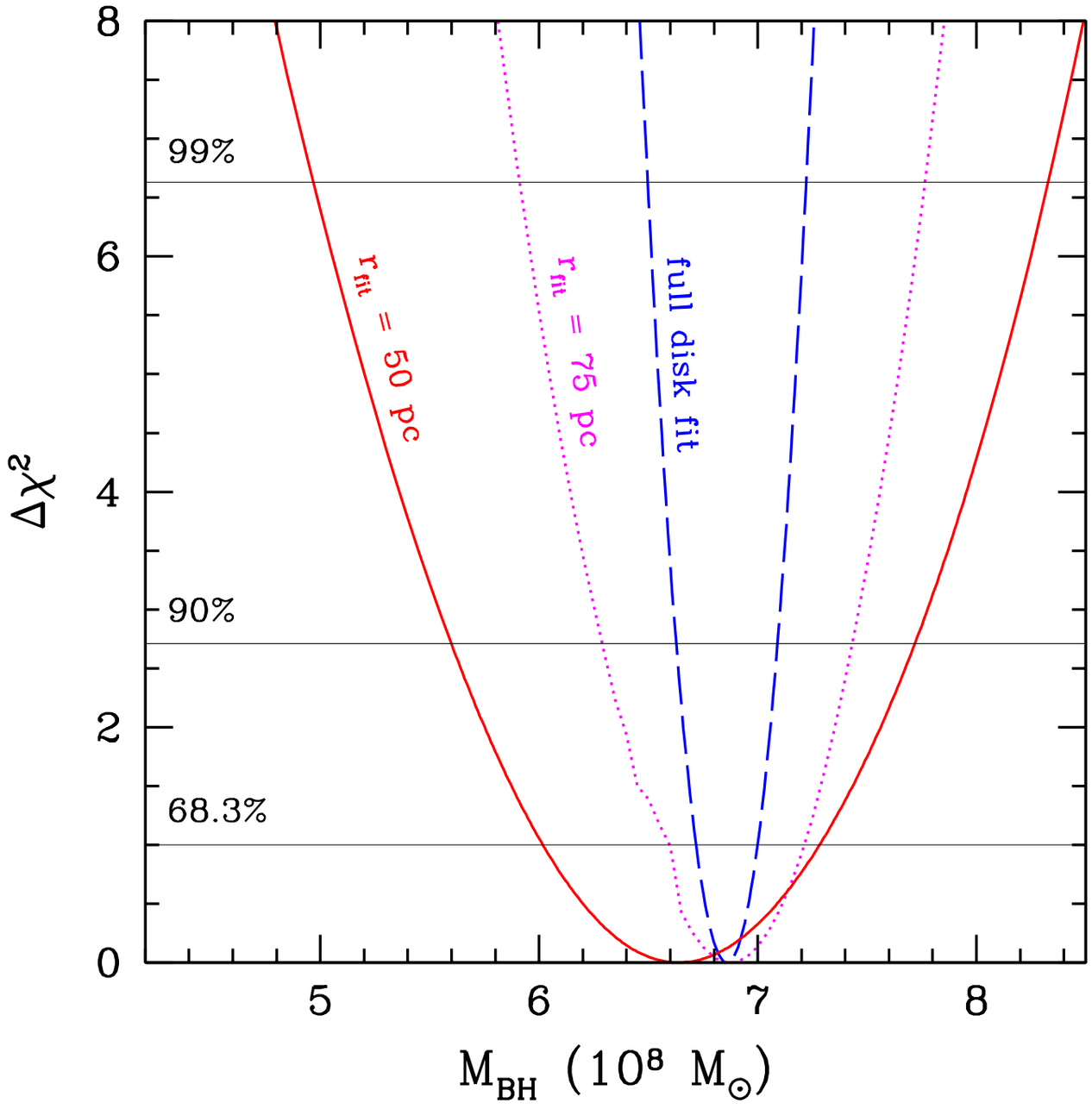


MEASUREMENT OF THE BLACK HOLE MASS IN NGC 1332 FROM ALMA OBSERVATIONS AT 0.044 ARCSECOND RESOLUTION

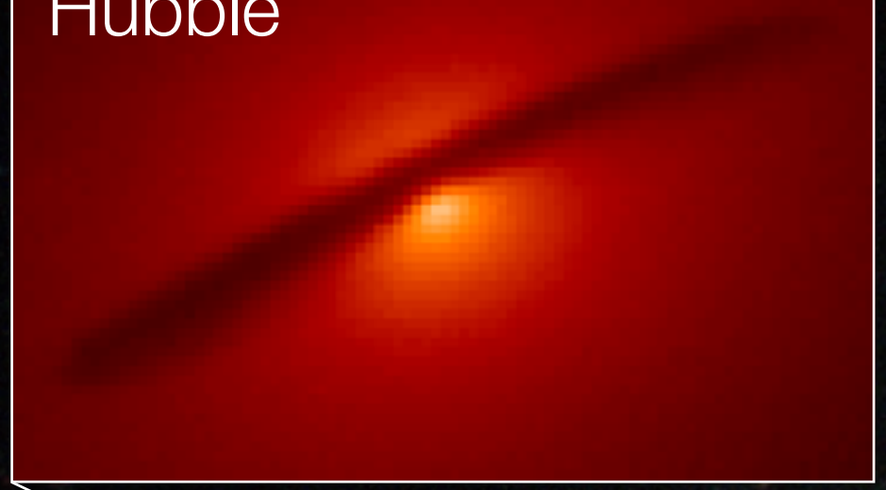
AARON J. BARTH[1], BENJAMIN D. BOIZELLE[1], JEREMY DARLING[2], ANDREW J. BAKER[3], DAVID A. BUOTE[1], LUIS C. HO[4], JONELLE L. WALSH[5]



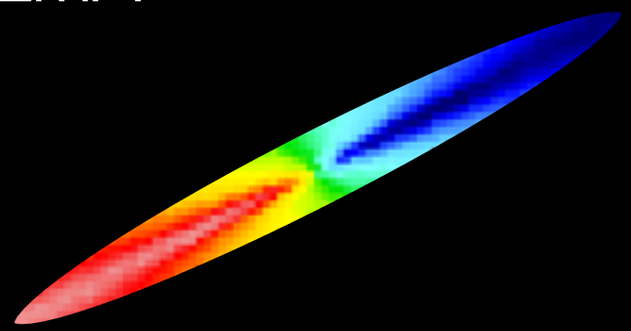

600
400
200
0
−200
−400
−600
v_{LOS} (km s^{-1})
M_{BH} = 0
M_{BH} = 6.86×10^8 $M_\odot$
M_{BH} = 1.45×10^9 $M_\odot$
−1
0
1
Offset (arcsec)


$\Delta\chi^2$
8
6
4
2
0
99%
90%
68.3%
r_{fit} = 50 pc
r_{fit} = 75 pc
full disk fit
5
6
7
8
M_{BH} (10^8 $M_\odot$)

Hubble



ALMA



NGC 1332

ALMA (NRAO/ESO/NAOJ) /
Hubble Space Telescope (NASA/ESA) /
Carnegie-Irvine Galaxy Survey

BHOLE

Black hole–Host Lifecycle Evolution

http://kiaa.pku.edu.cn/bhole

光学红外观测

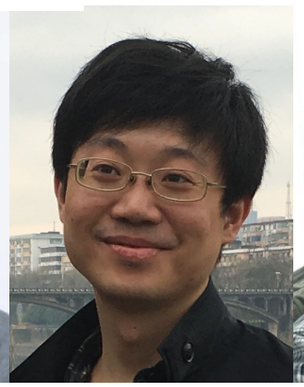

何子山

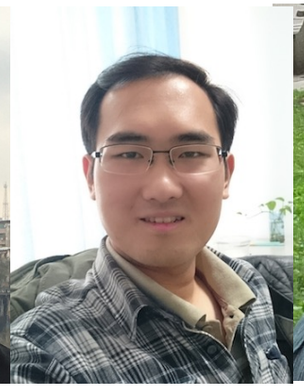

吴学兵


江林华


王建民


李彦荣


胡晨


杜璞

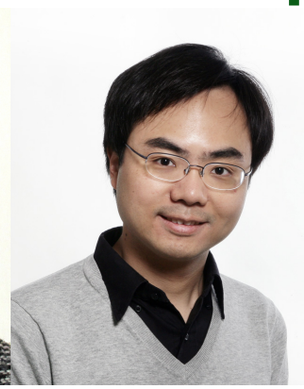

刘桂琳


白金明

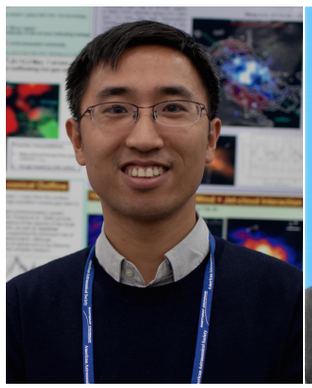
射电观测


吴京文


王然

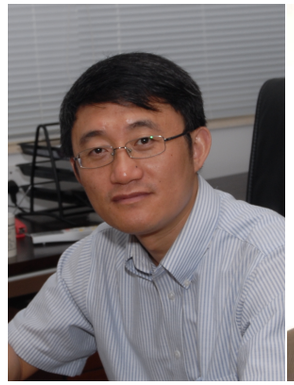

彭影杰

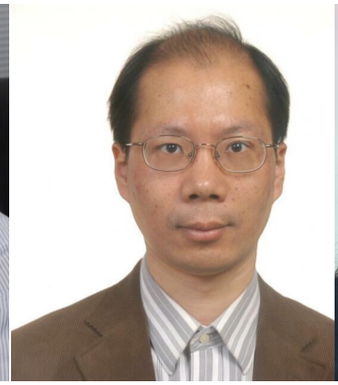
X射线观测


干俊峰

罗斌

理论和数值模拟


袁峰


陆由俊


于清娟

多波段观测： 关学，红外，射电，X射线

观测设备： 国内， 国际，地基， 空间

全面研究方法： 观测， 理论， 数值模拟

宇宙学演化： 低红移，高红移

多尺度： 活动星系核，寄主星系

全面物理过程： 吸积，外流，气体，恒星

BHOLE Postdoc Projects: 10 (2-4 yr) positions

1. *The Stellar Structure of the Host Galaxies of AGNs and Quasars*
2. *The Gas Content and Kinematics of Active Galaxies*
3. *The Spectral Energy Distribution of AGNs*
4. *Numerical Simulation Study of AGN Feedback*
5. *X-ray View of Growing Supermassive Black Holes and Their Connections to the Host Galaxies*
6. *High-Redshift (z>6) Quasars and Their Physical Properties*
7. *Measurements of Black Hole Mass through Reverberation Mapping*
8. *High-resolution Studies of the Interaction between AGNs and Their Host Galaxies*
9. *LAMOST Quasar Survey*
10. *Millimeter and Radio Studies of SMBH-Galaxy Coevolution at High Redshift*
11. *Formation and Evolution of Massive Black Holes*
12. *Tracing Hot DOGs, a Key Stage Connecting Obscured and Unobscured Quasars*
13. *Constraining the Spin and Radiative Efficiency Evolution of Massive Black Holes via Multi-wavelength Observations of AGNs/QSOs*
14. *Observations of Feedback from Luminous Quasars at Different Cosmic Epochs*
15. *AGN Triggering Mechanism and the Impact of AGN Feedback on Star Formation*