Supermassive Black Holes

Masses and Accretion Rates

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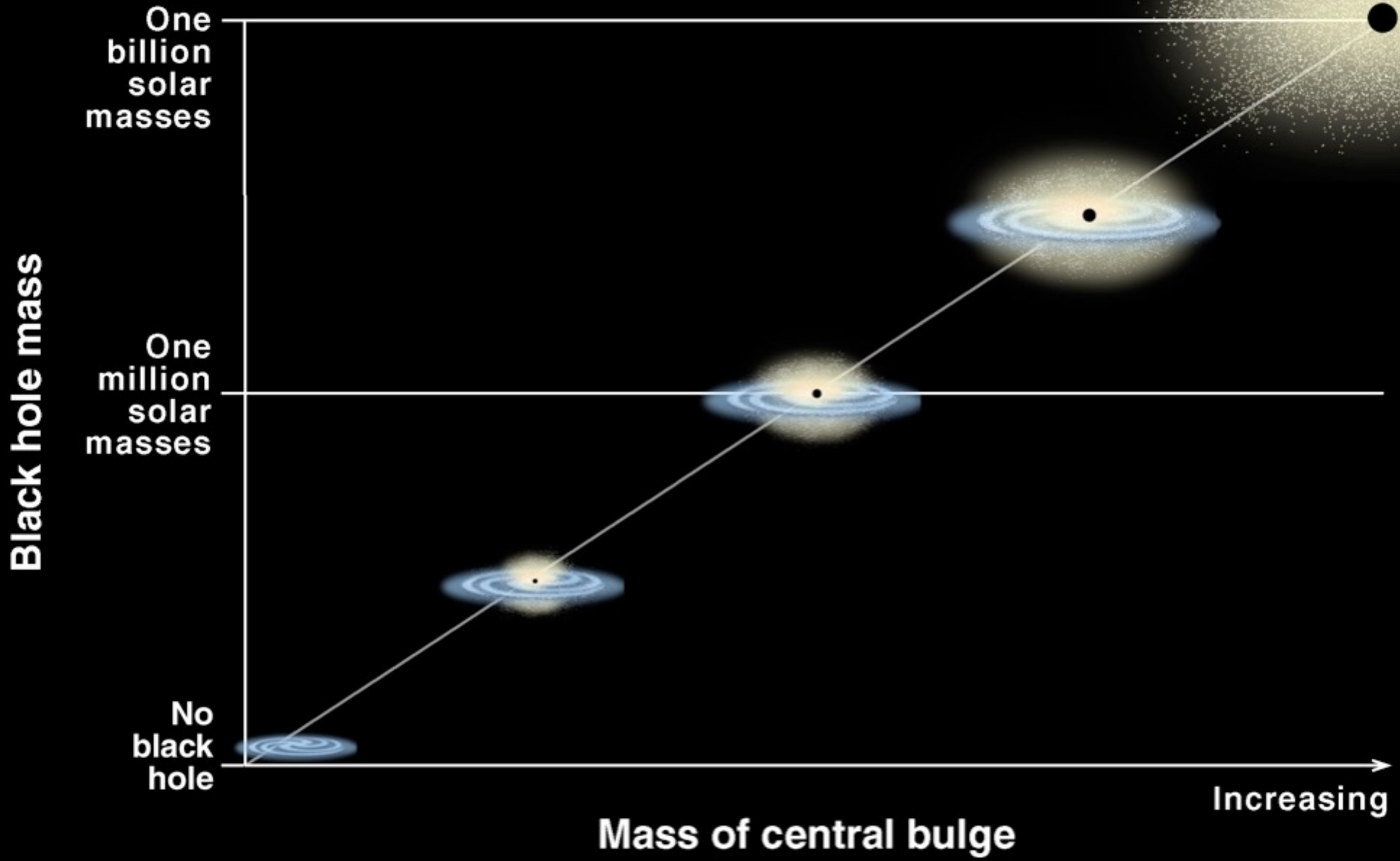
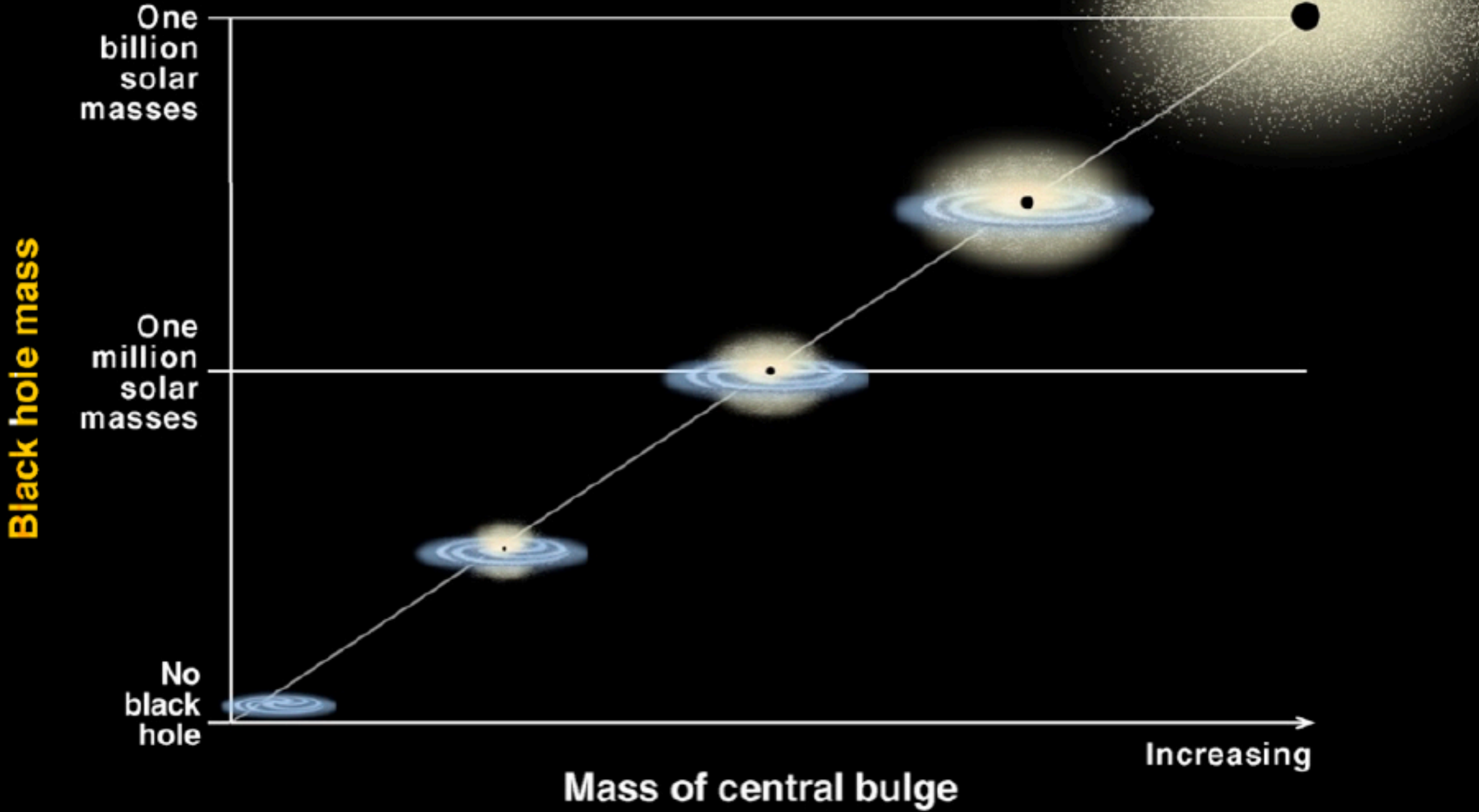
Peking University

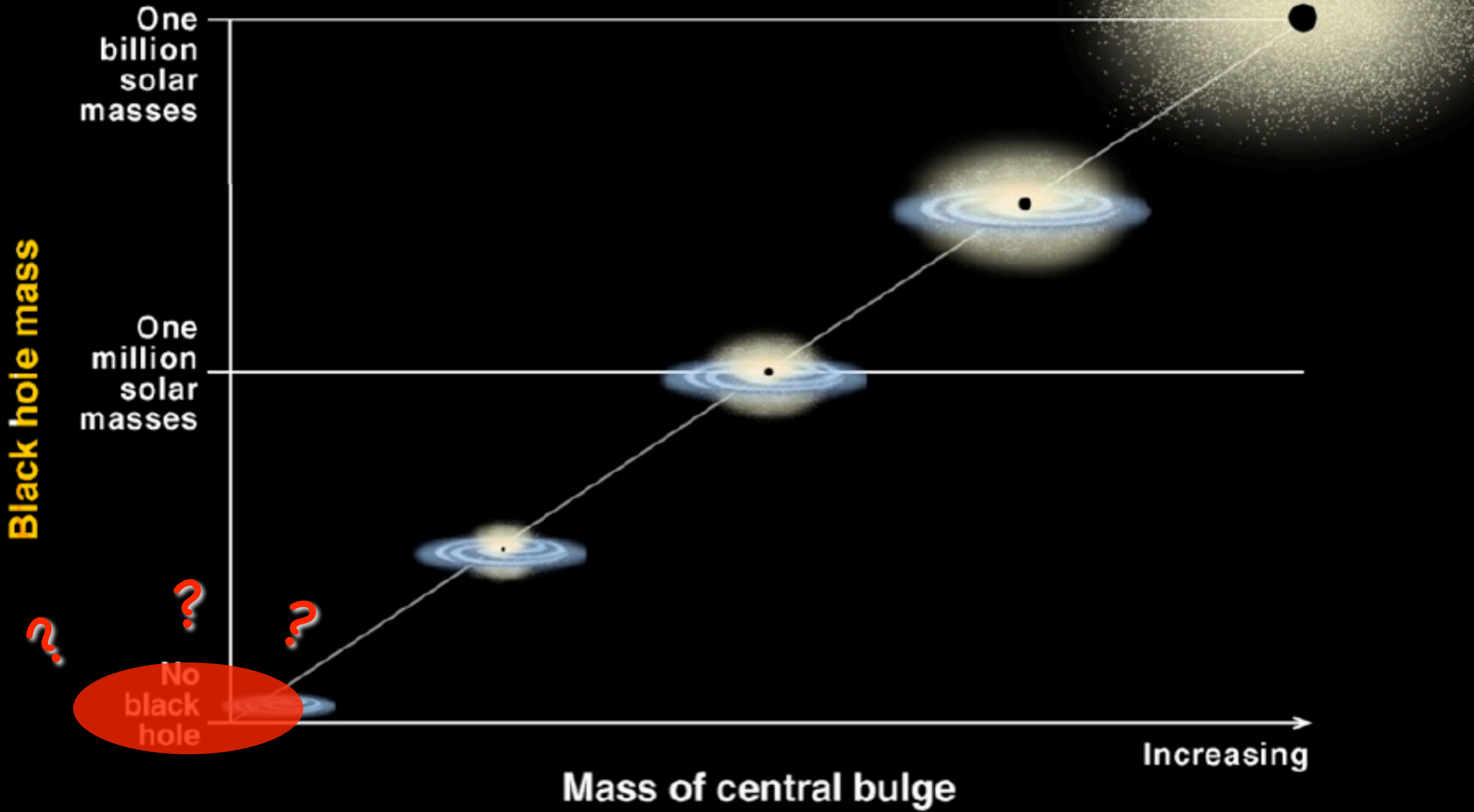
Correlation Between Black Hole Mass and Bulge Mass



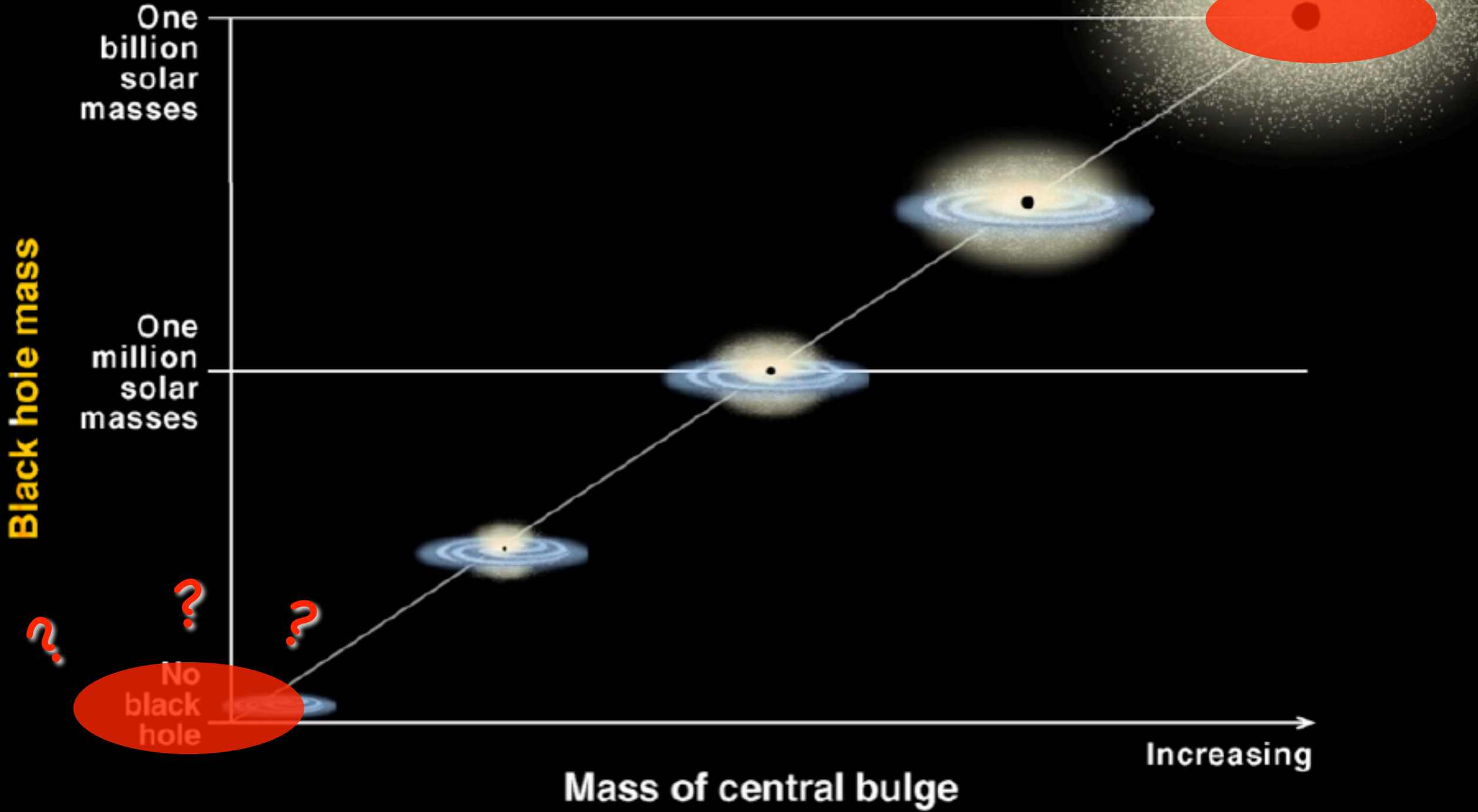
Correlation Between Black Hole Mass and Bulge Mass



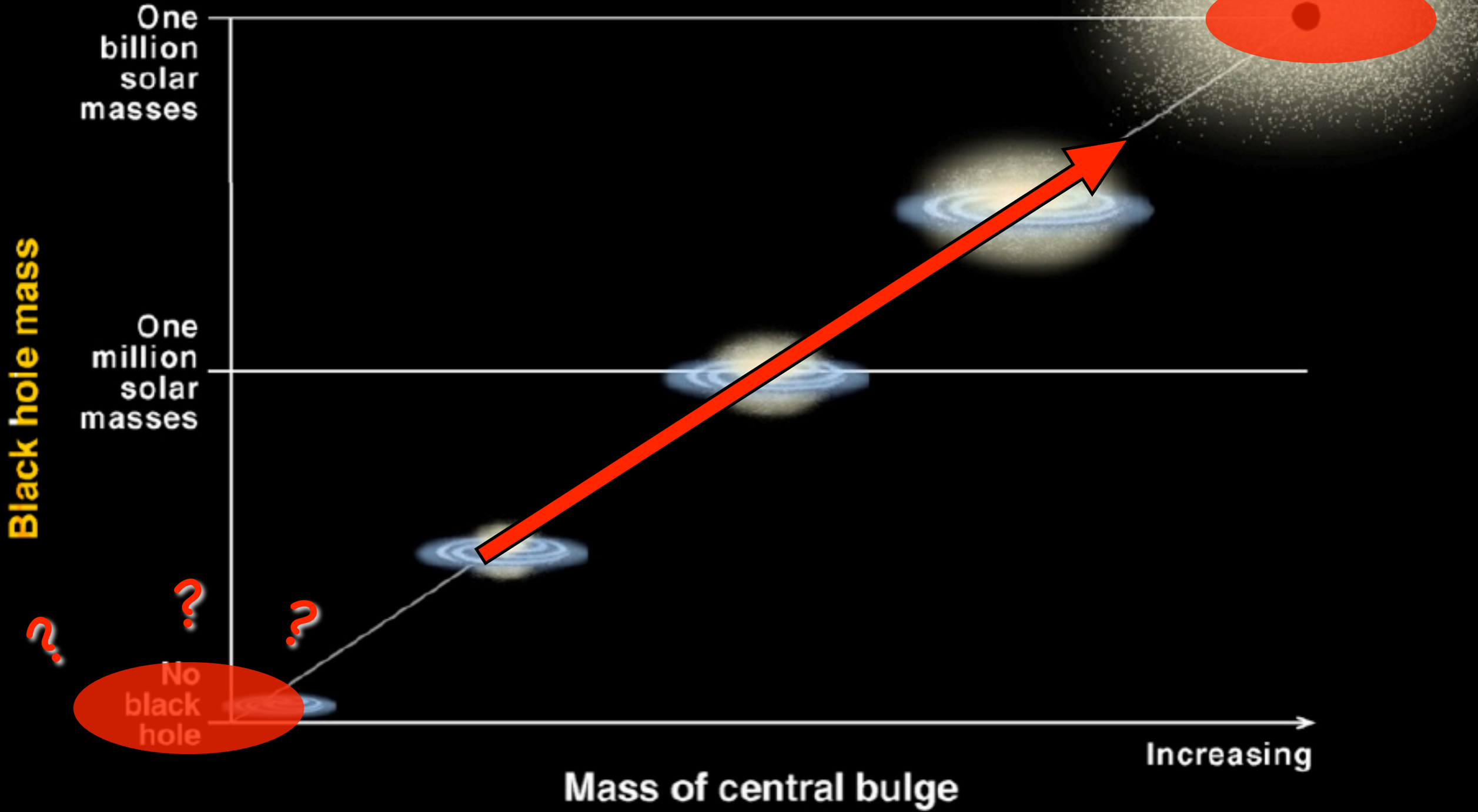
Correlation Between Black Hole Mass and Bulge Mass



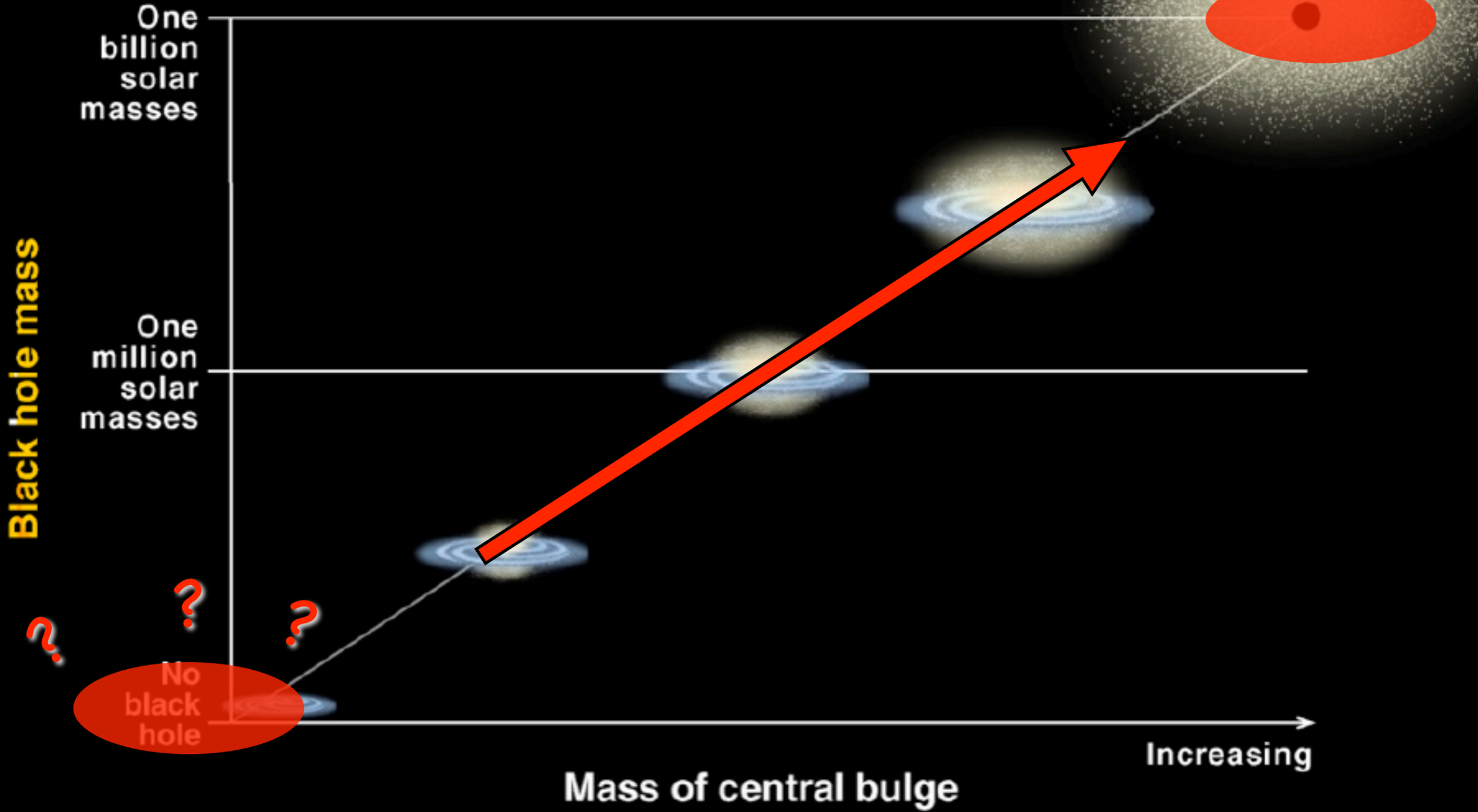
Correlation Between Black Hole Mass and Bulge Mass



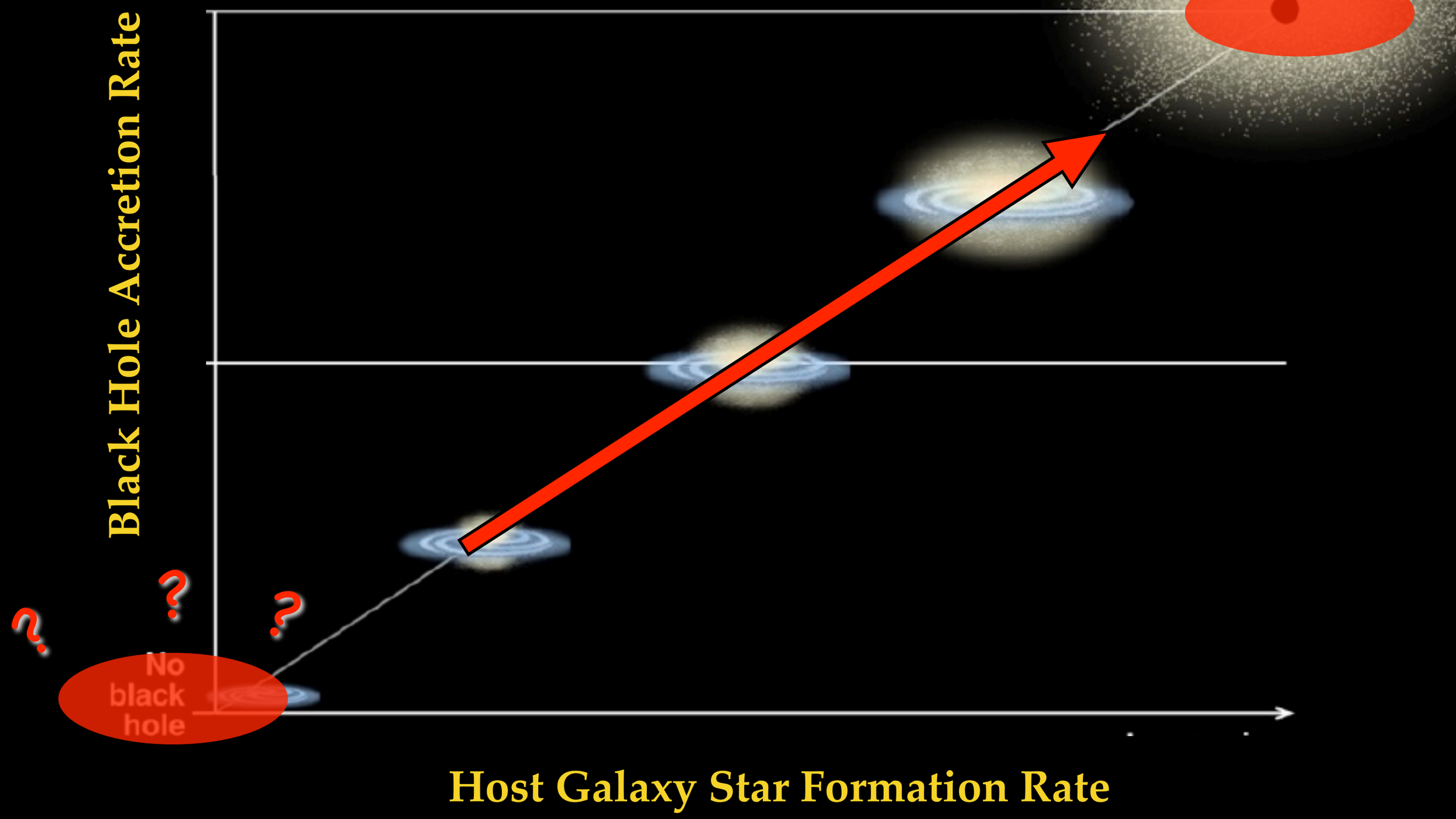
Correlation Between Black Hole Mass and Bulge Mass

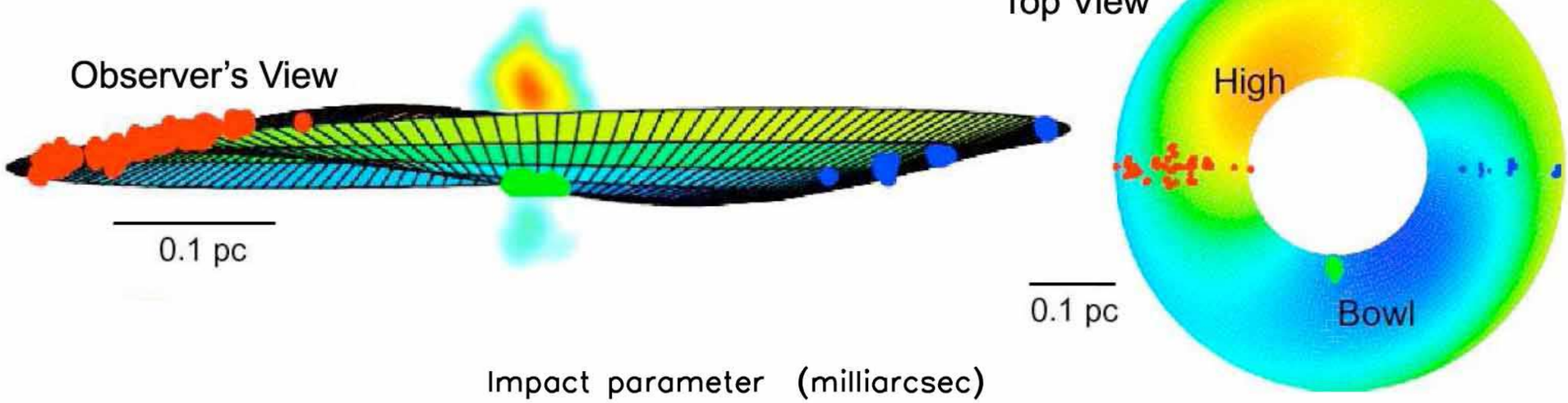


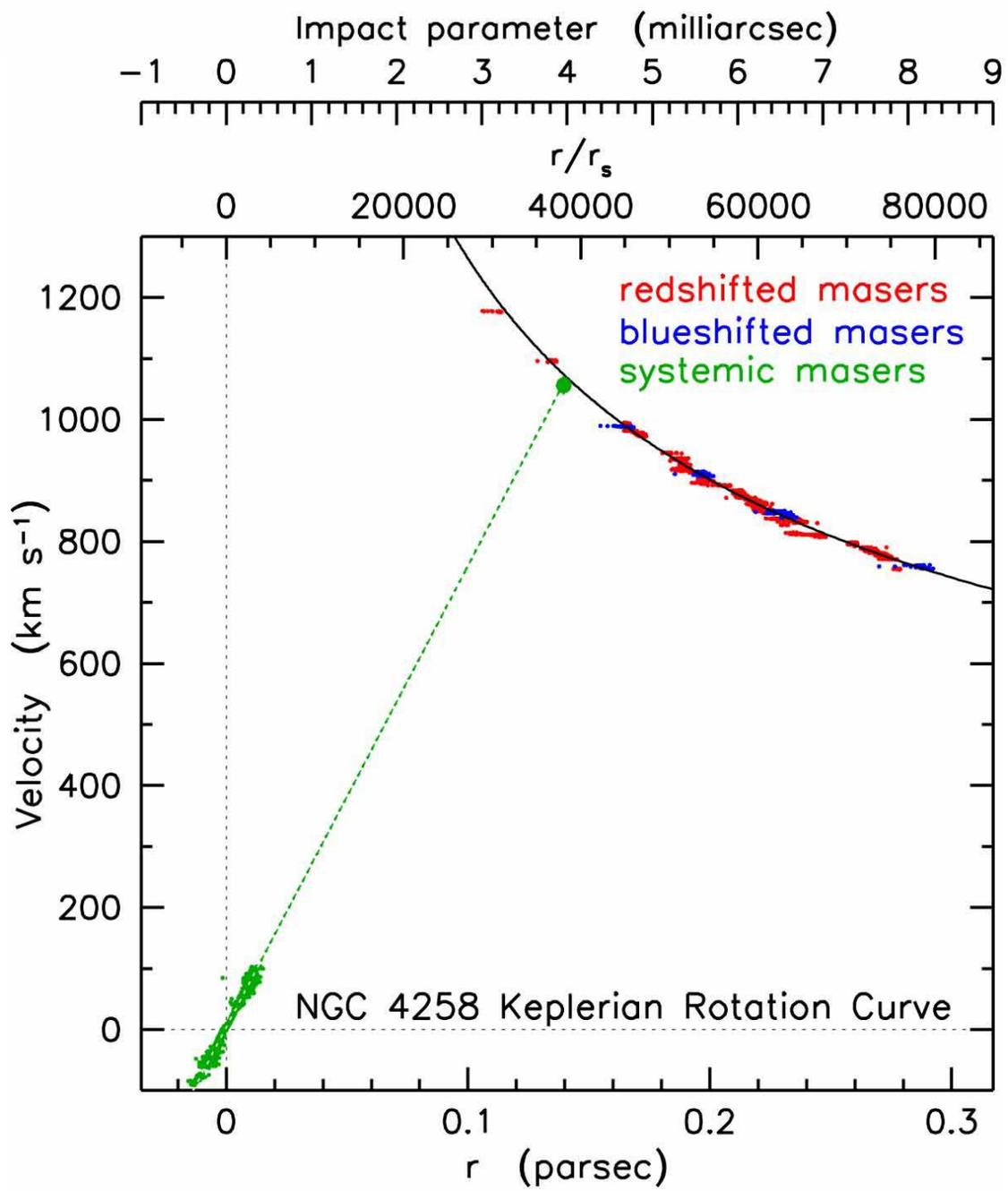
Correlation Between Black Hole Mass and Bulge Mass in Active Galaxies



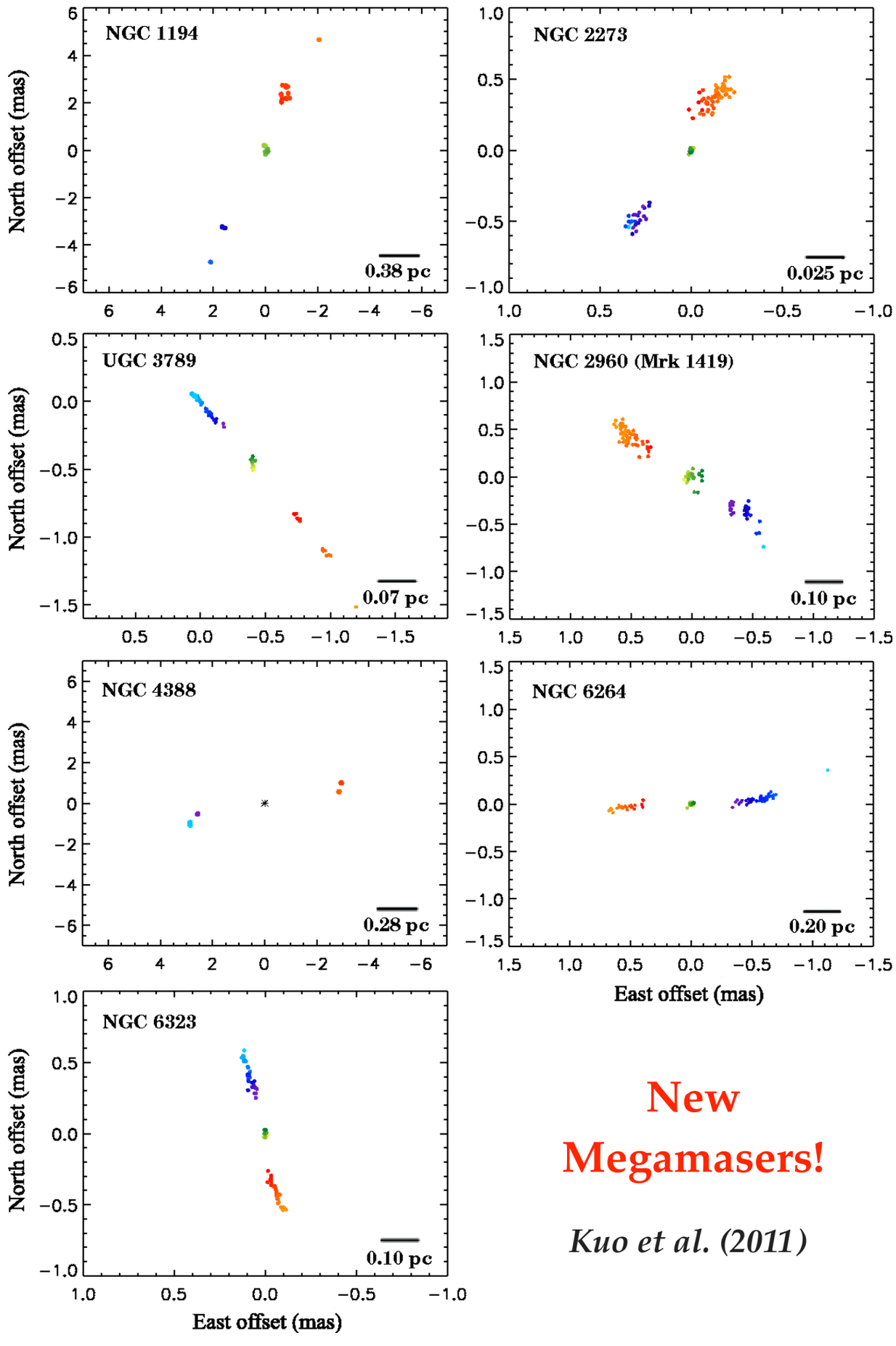
Correlation Between Black Hole Accretion Rate and Host Galaxy Star Formation Rate





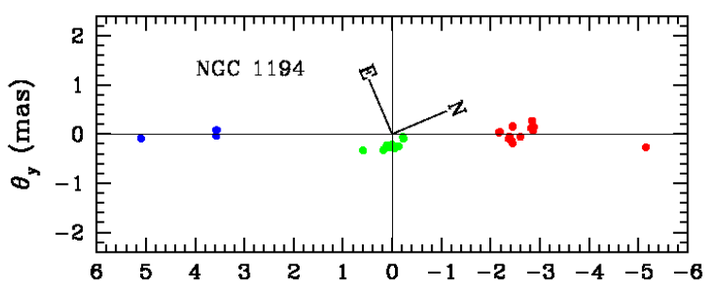


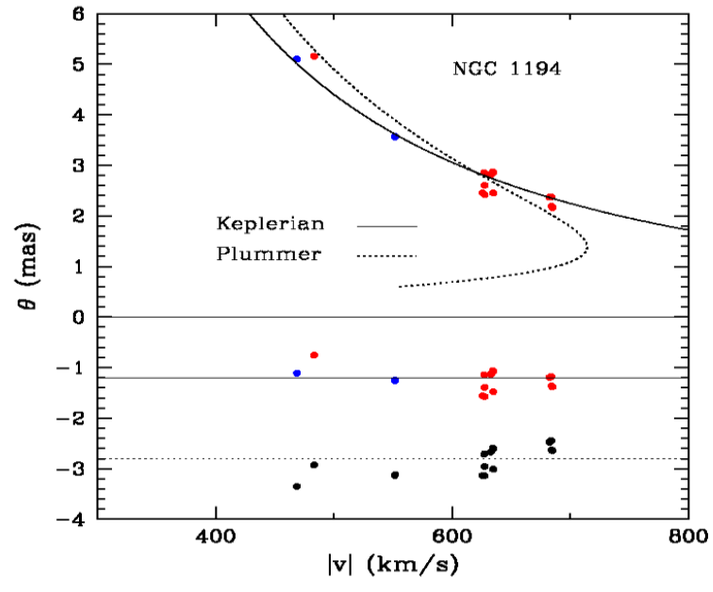
Miyoshi et al. (1995)
Herrnstein et al. (2005)

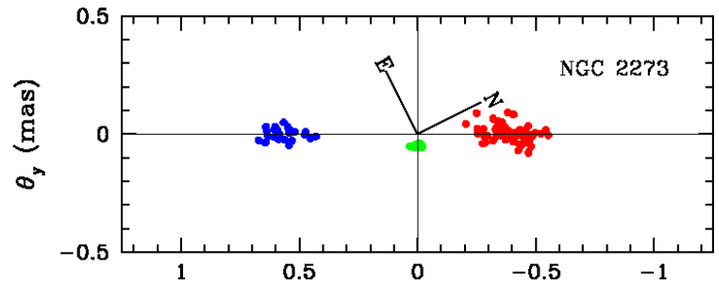


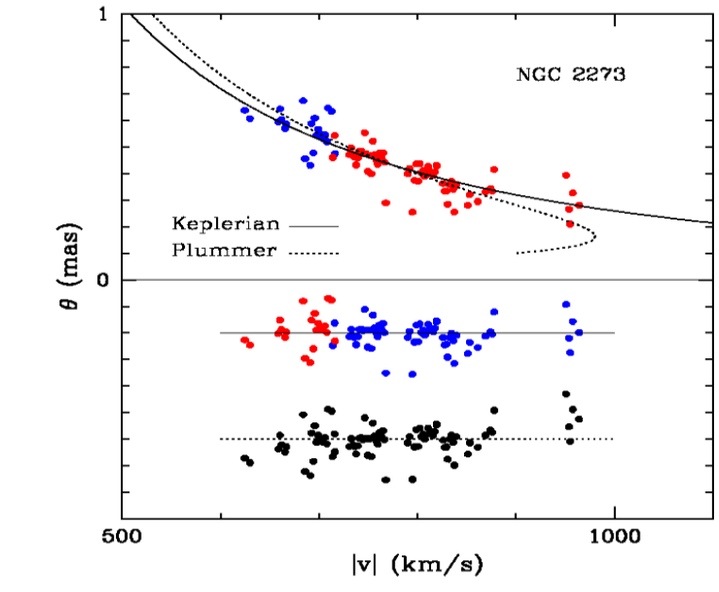
New Megamasers!

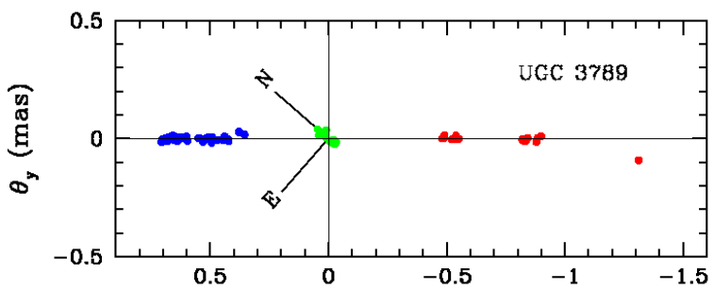
Kuo et al. (2011)

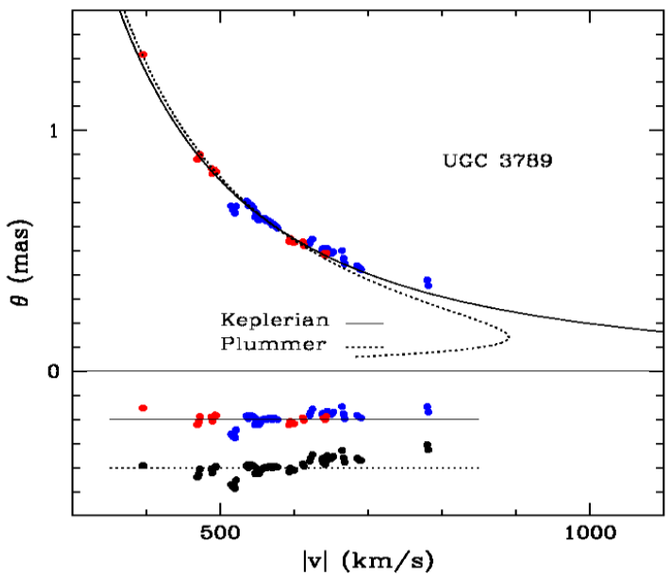

NGC 1194
E
N
θ_y (mas)

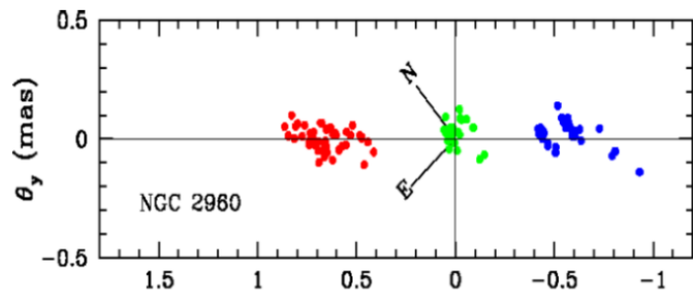

NGC 1194
Keplerian
Plummer
θ (mas)
|v| (km/s)

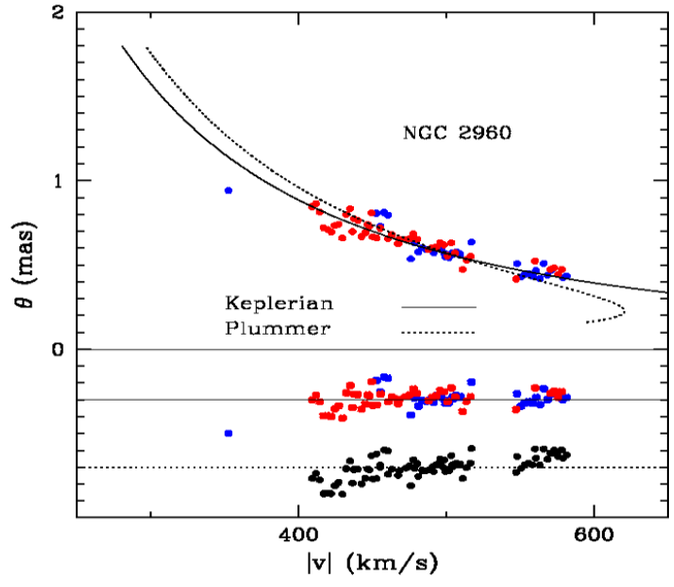

NGC 2273
E
N
θ_y (mas)


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

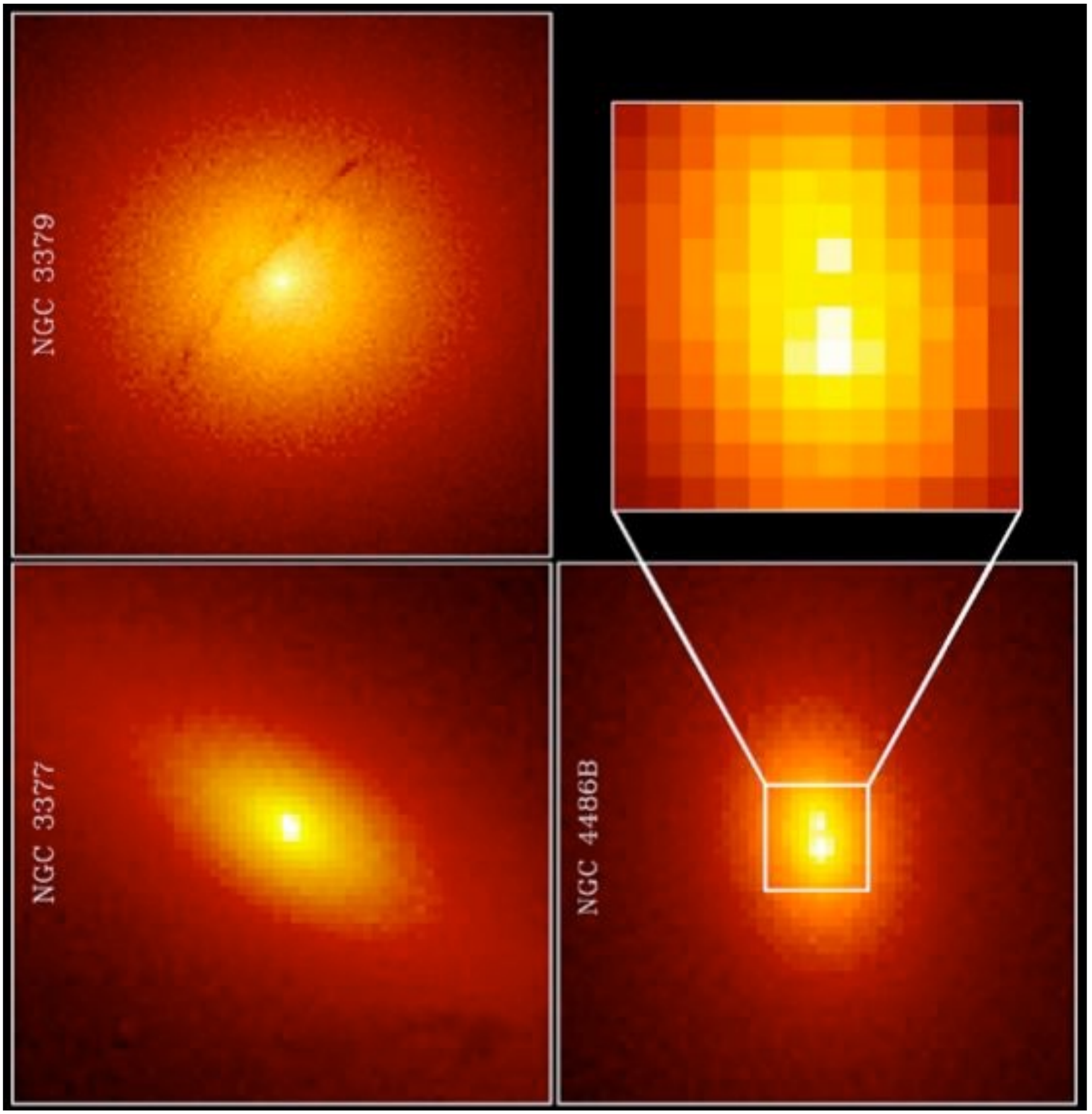

UGC 3789
N
E
θ_y (mas)

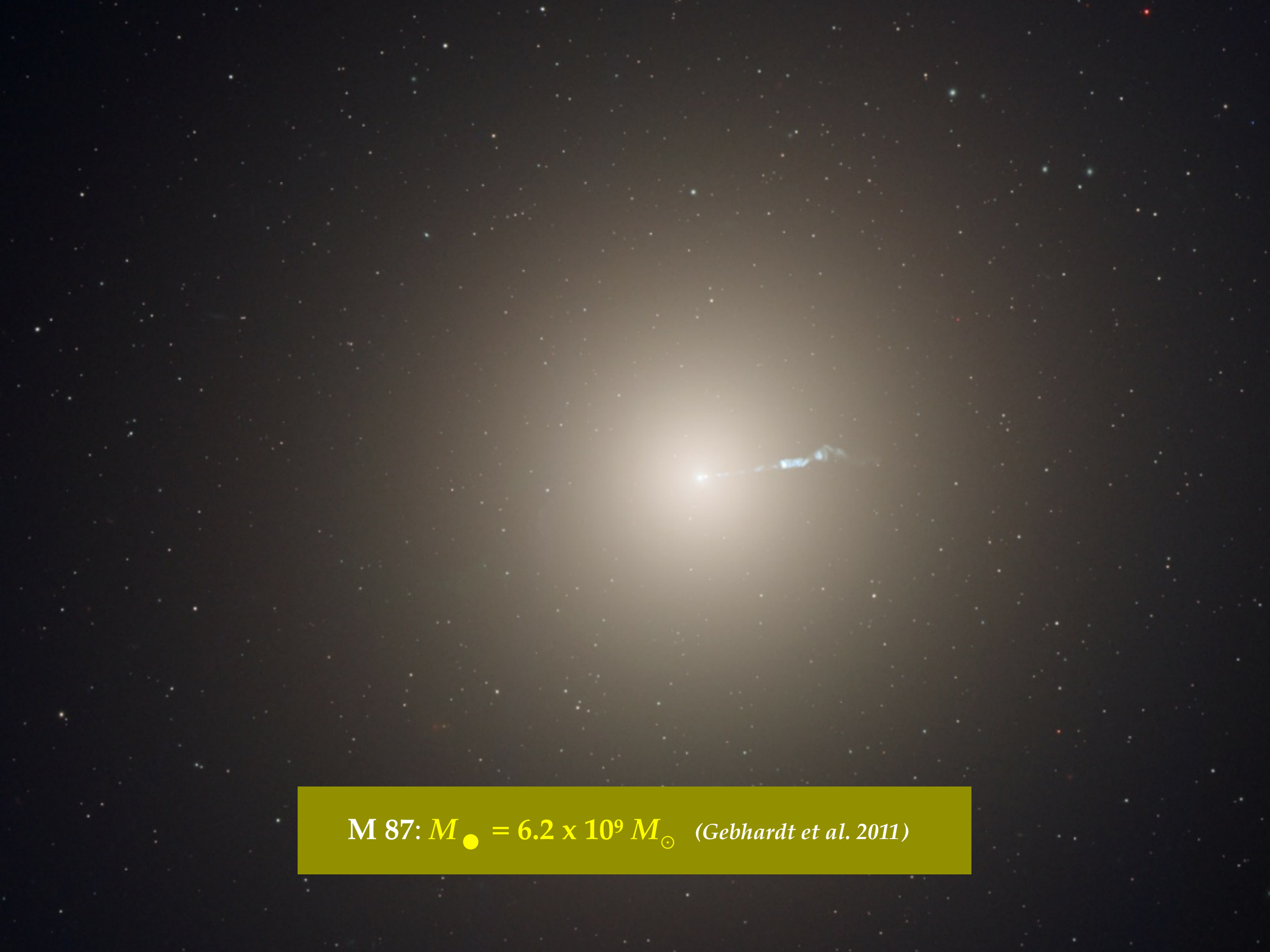

UGC 3789
Keplerian
Plummer
θ (mas)
|v| (km/s)


NGC 2960
N
E
θ_y (mas)


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

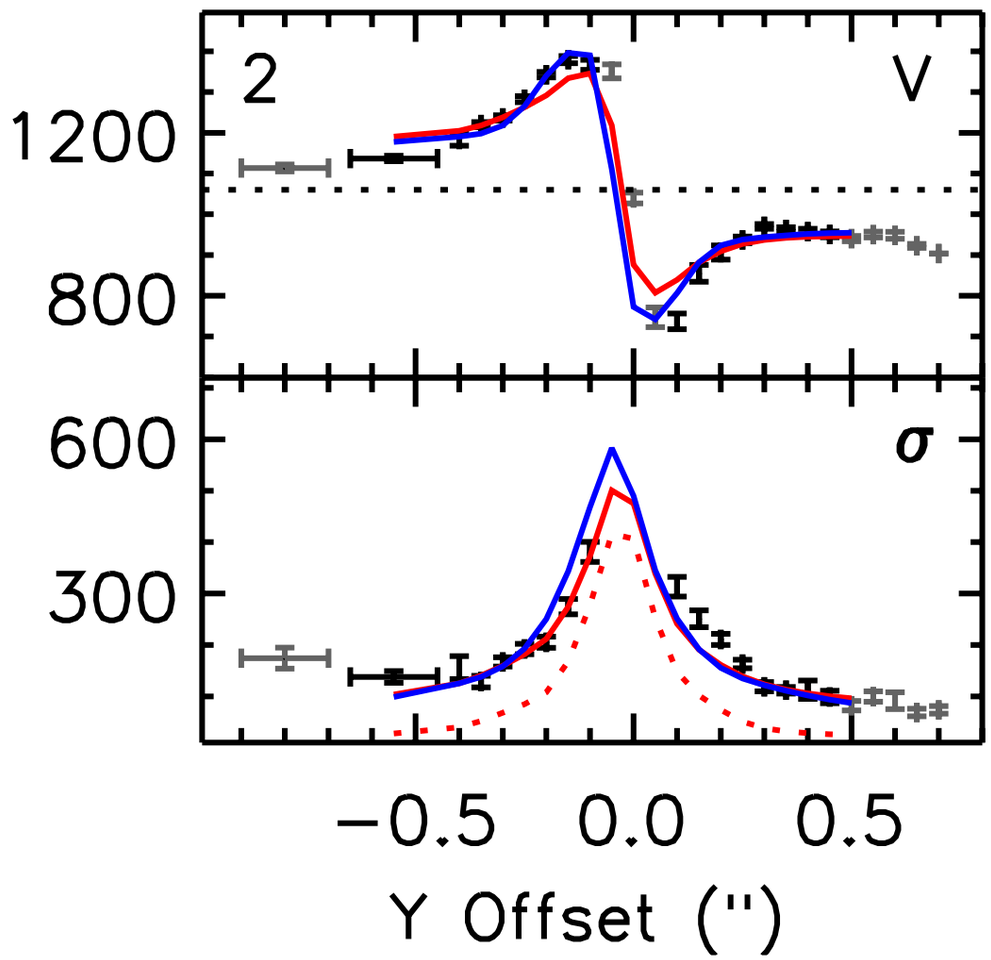
Nuker Team

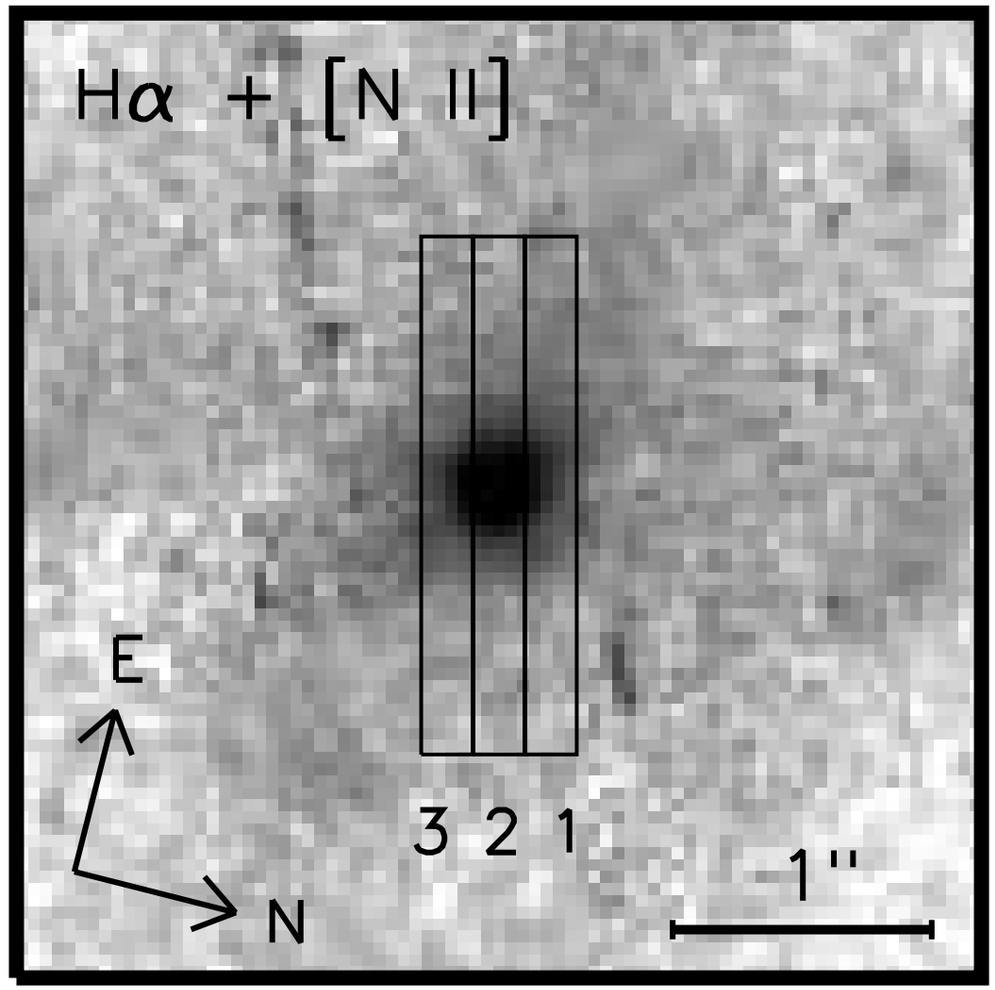


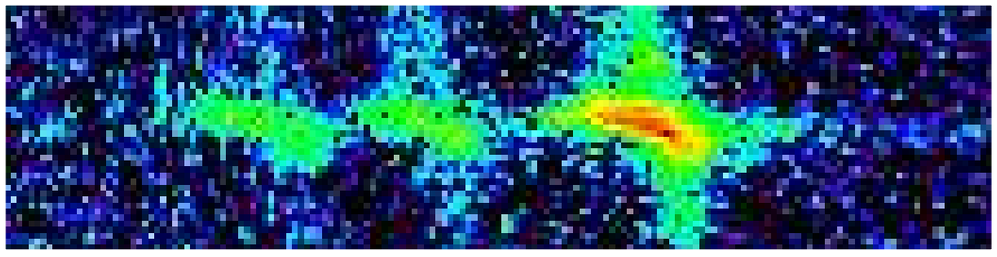


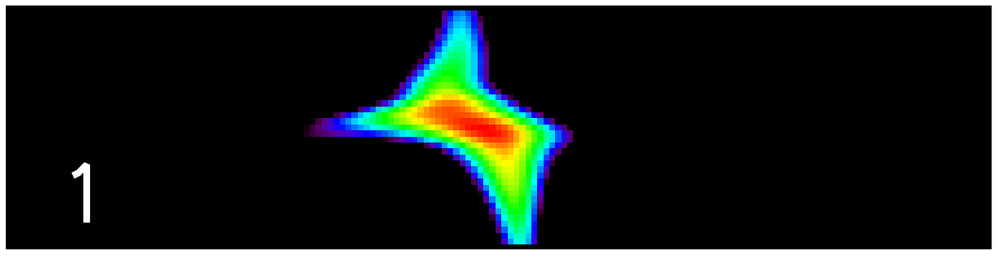
M 87: $M_{\bullet} = 6.2 \times 10^9 M_{\odot}$ *(Gebhardt et al. 2011)*

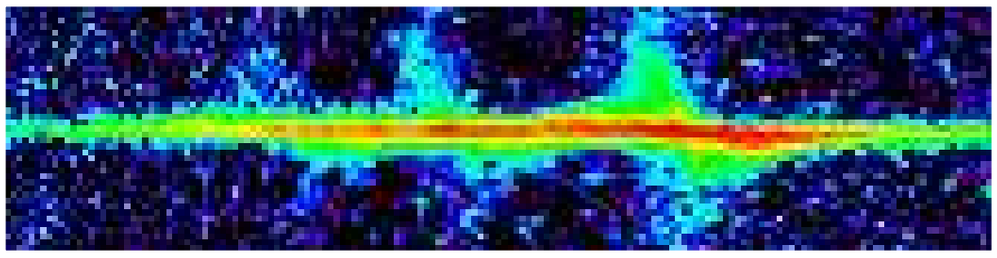
NGC 4889: $M_{\bullet} = 2.1 \times 10^{10}\ M_{\odot}$ *(McConnell et al. 2011)*

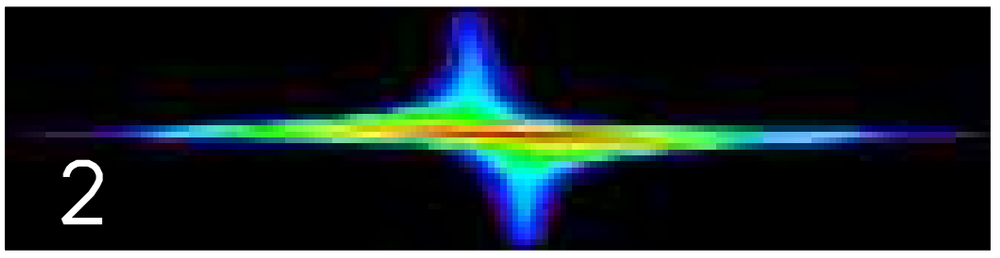

2
V
1200
800
σ
600
300
−0.5
0.0
0.5
Y Offset ('')

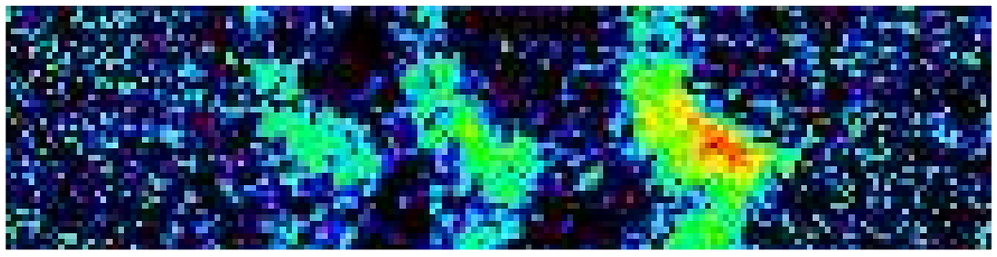

Hα + [N II]
E
N
3 2 1
1''

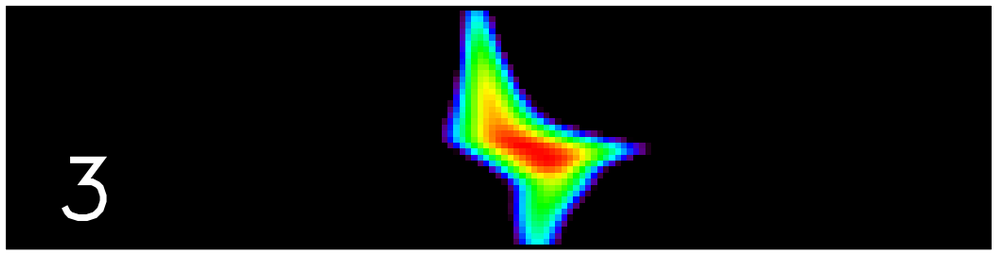



1



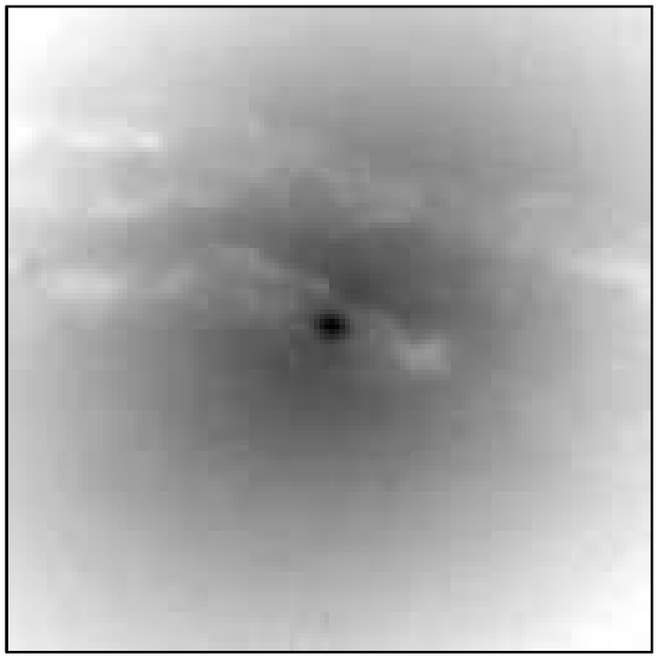

2

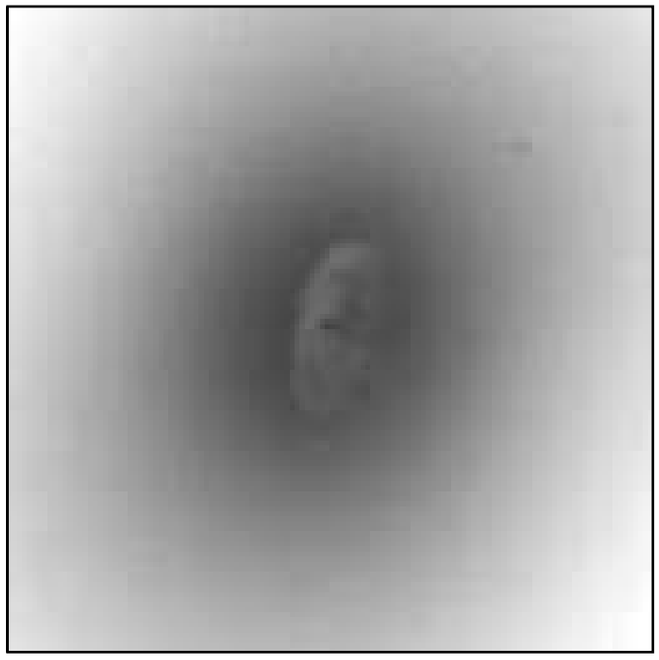


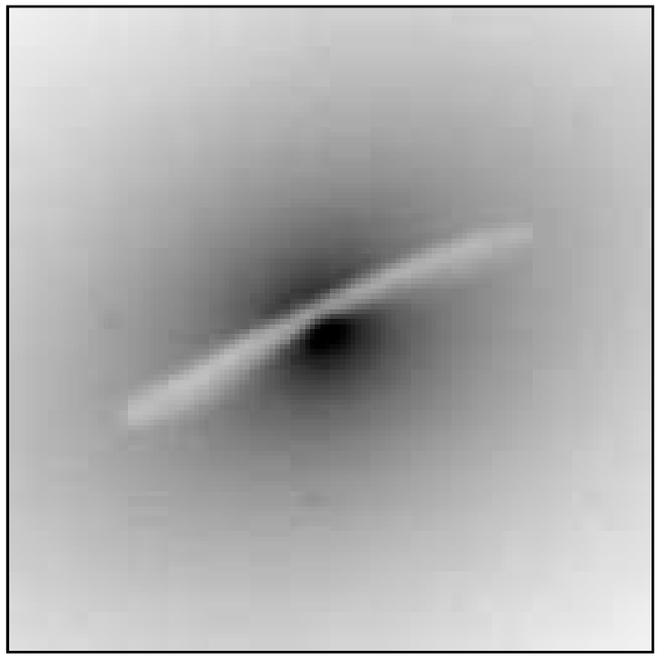

3

High-Accuracy, High-Precision BH Masses with ALMA

Barth, Ho, Baker, Darling

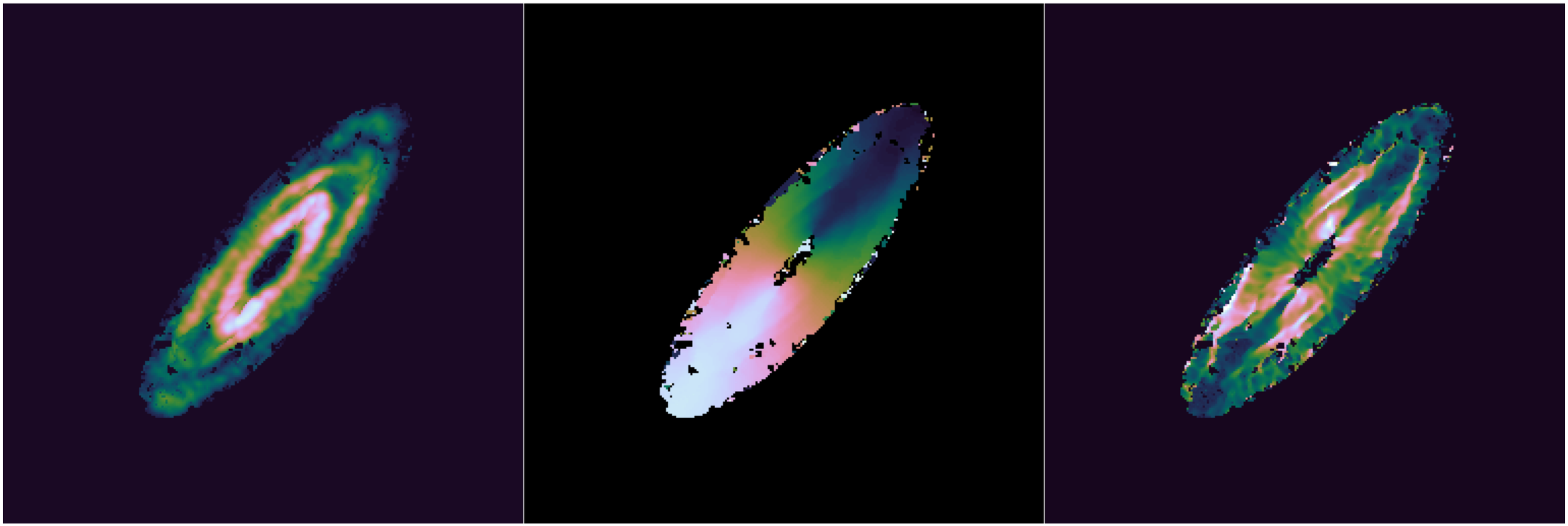






MEASUREMENT OF THE BLACK HOLE MASS IN NGC 1332 FROM ALMA OBSERVATIONS AT 0.044 ARCSECOND RESOLUTION

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]



Data

Model

f(CO)

Synthesized Beam

v_{LOS}

σ_{LOS}

Jy beam^{-1} km s^{-1}

km s^{-1}

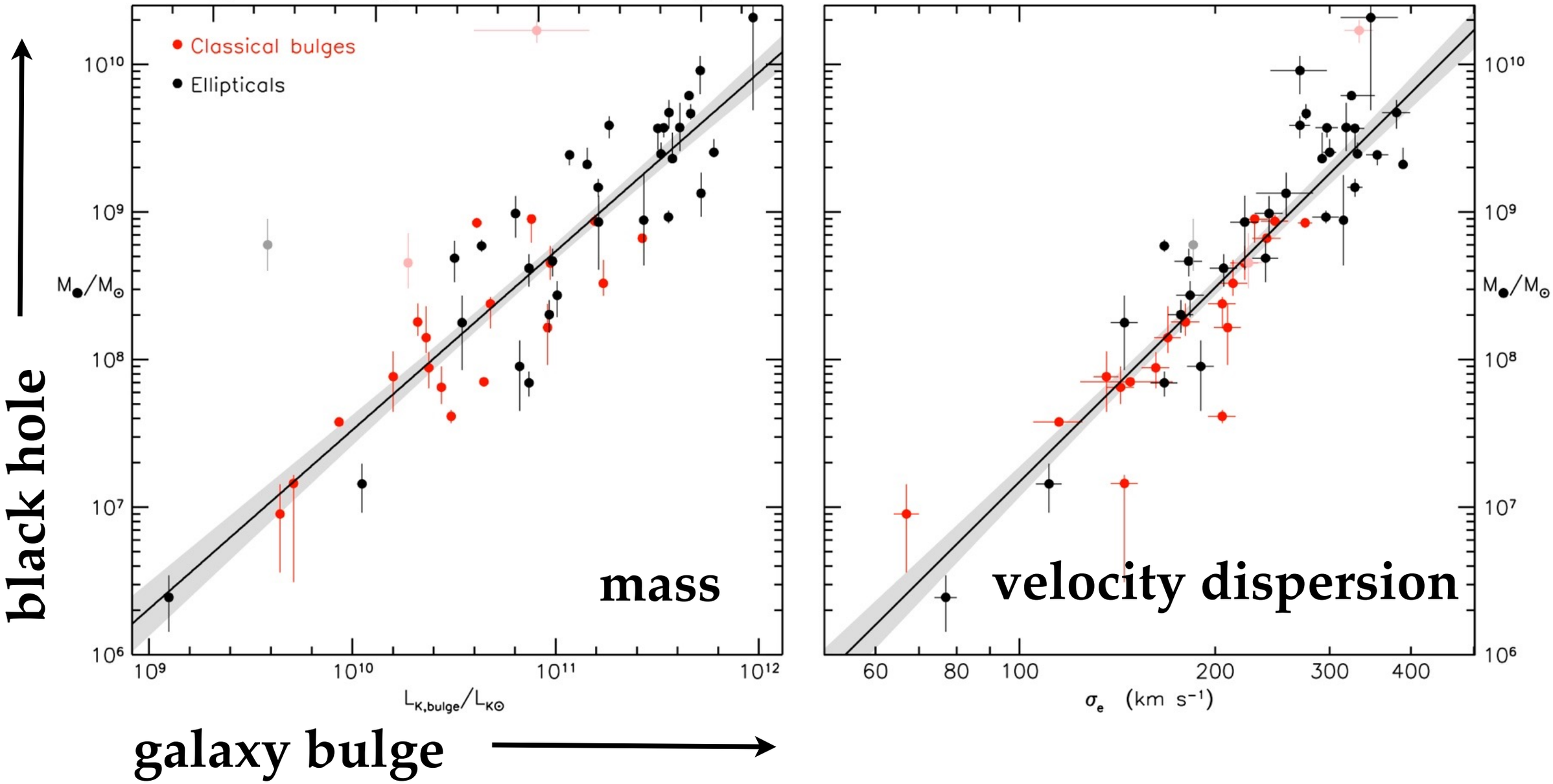
km s^{-1}

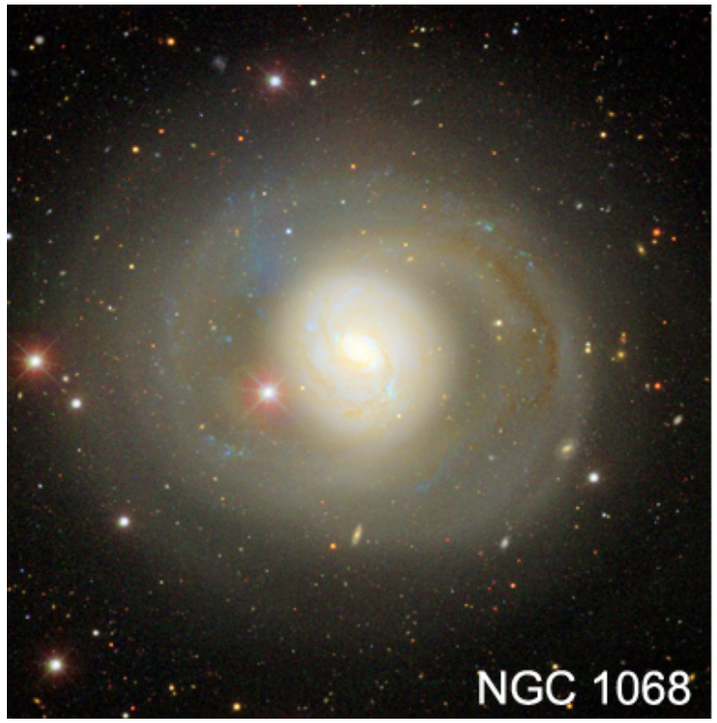
ΔDec (arcsec)

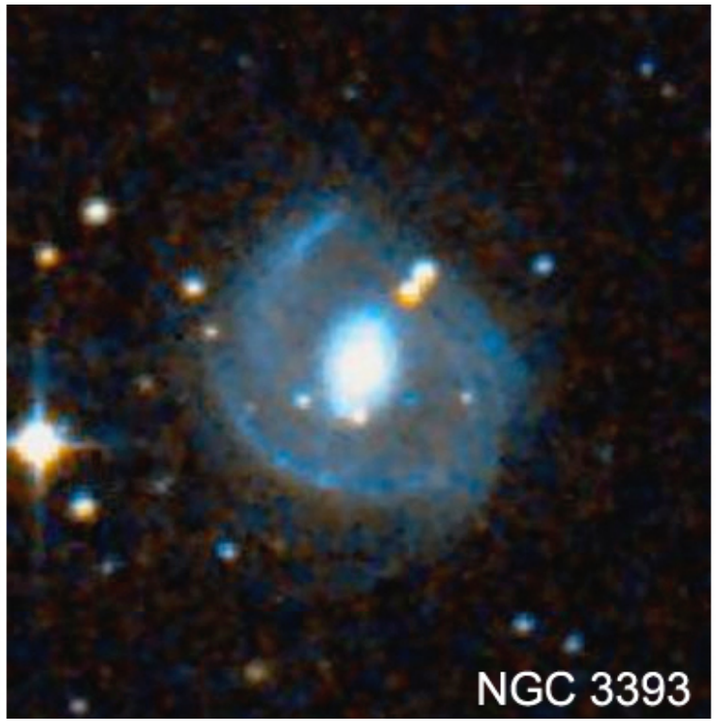
ΔRA (arcsec)

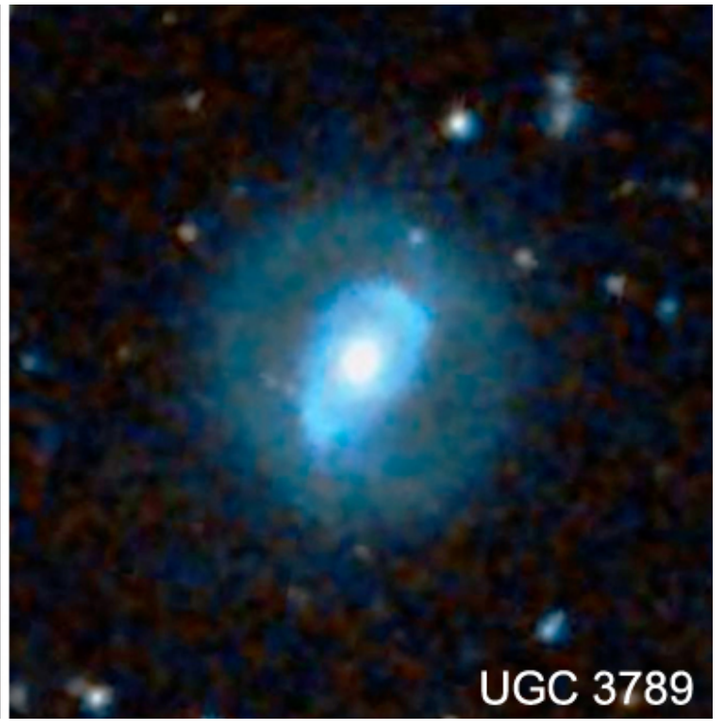
Black Hole - Host Galaxy Scaling Relations

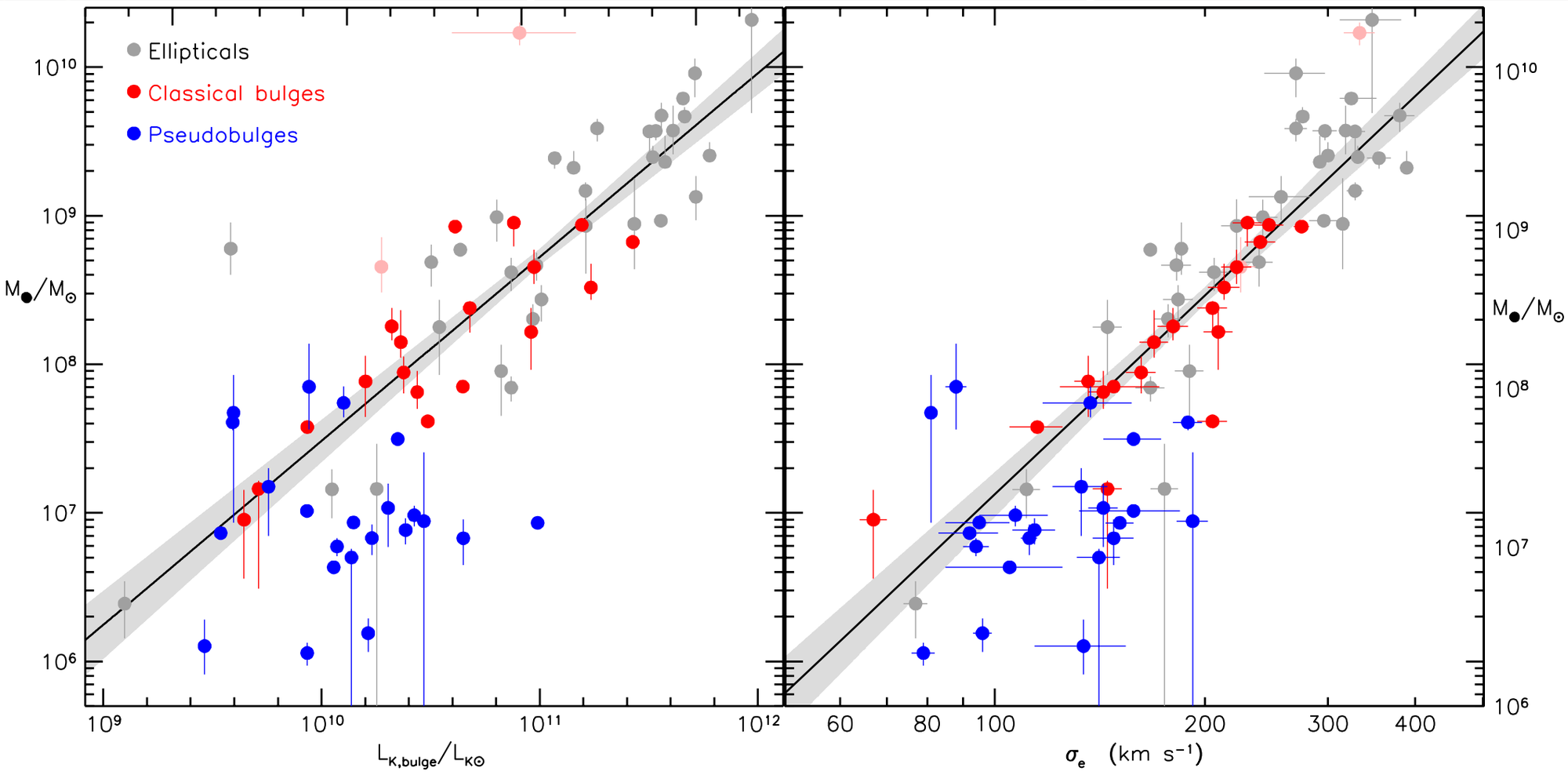
Kormendy & Ho (2013, ARA&A)




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})

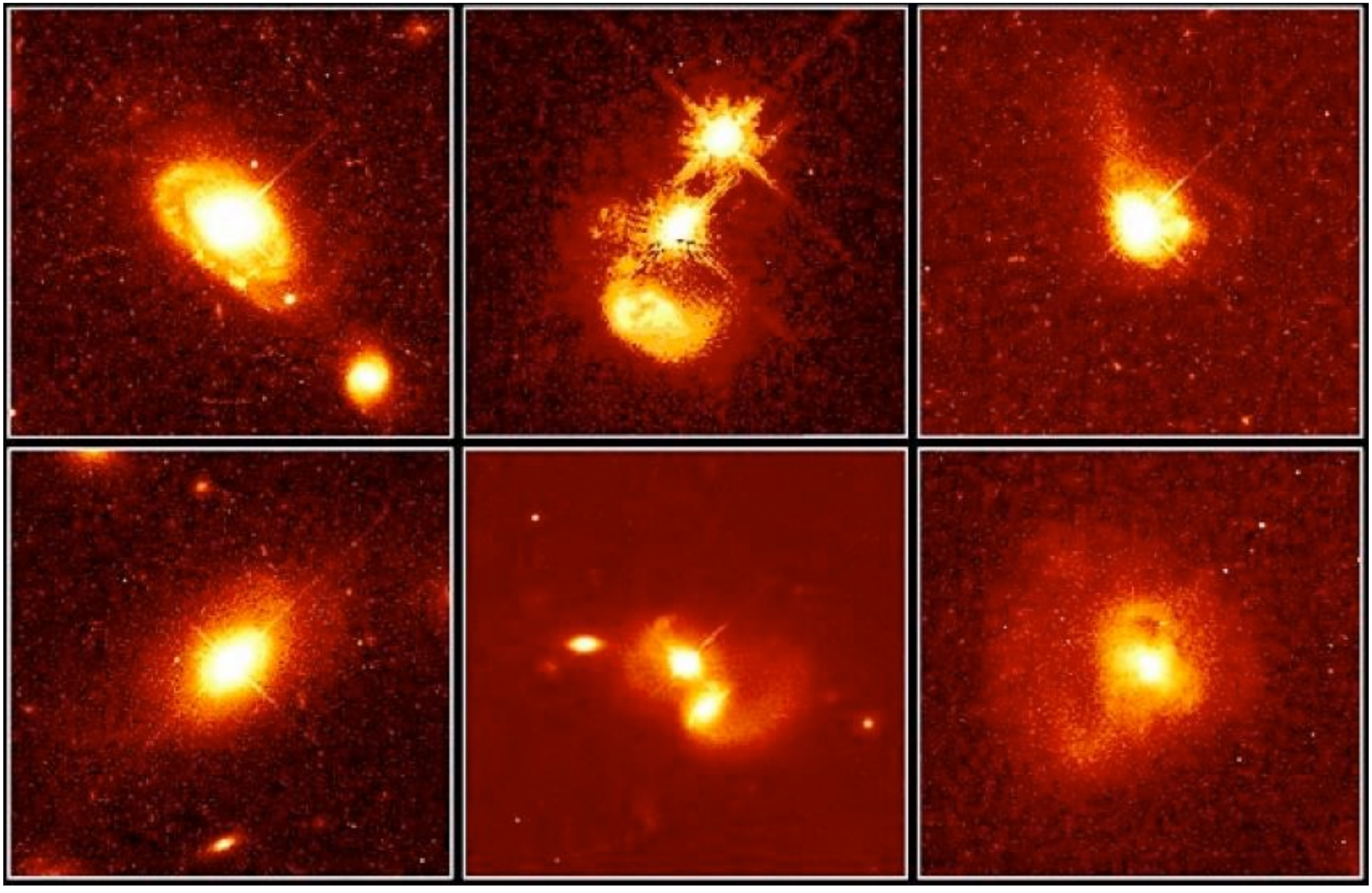
$M_\bullet - M_{\rm bulge}$ Relation

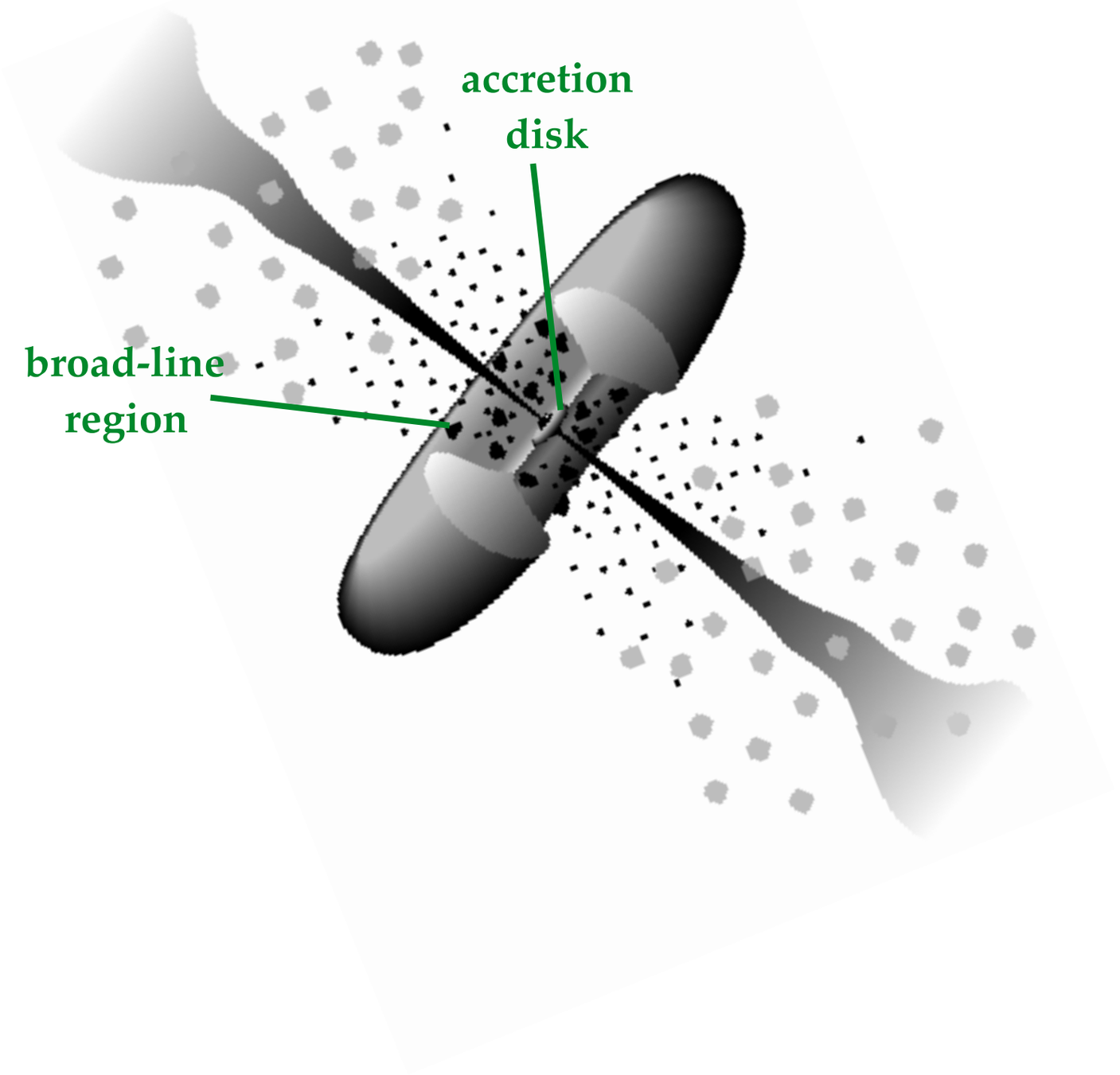
$$\frac{M_\bullet}{10^9\ M_\odot} = \left(0.49^{+0.06}_{-0.05}\right)\left(\frac{M_{\rm bulge}}{10^{11}\ M_\odot}\right)^{1.16\pm0.08} ;\ \text{intrinsic scatter} = 0.29\ \text{dex}.$$

$M_\bullet - \sigma$ Relation

$$\frac{M_\bullet}{10^9\ M_\odot} = \left(0.309^{+0.037}_{-0.033}\right)\left(\frac{\sigma}{200\ \text{km s}^{-1}}\right)^{4.38\pm0.29} \text{intrinsic scatter} = 0.28$$

Black Hole Masses in Active Galaxies

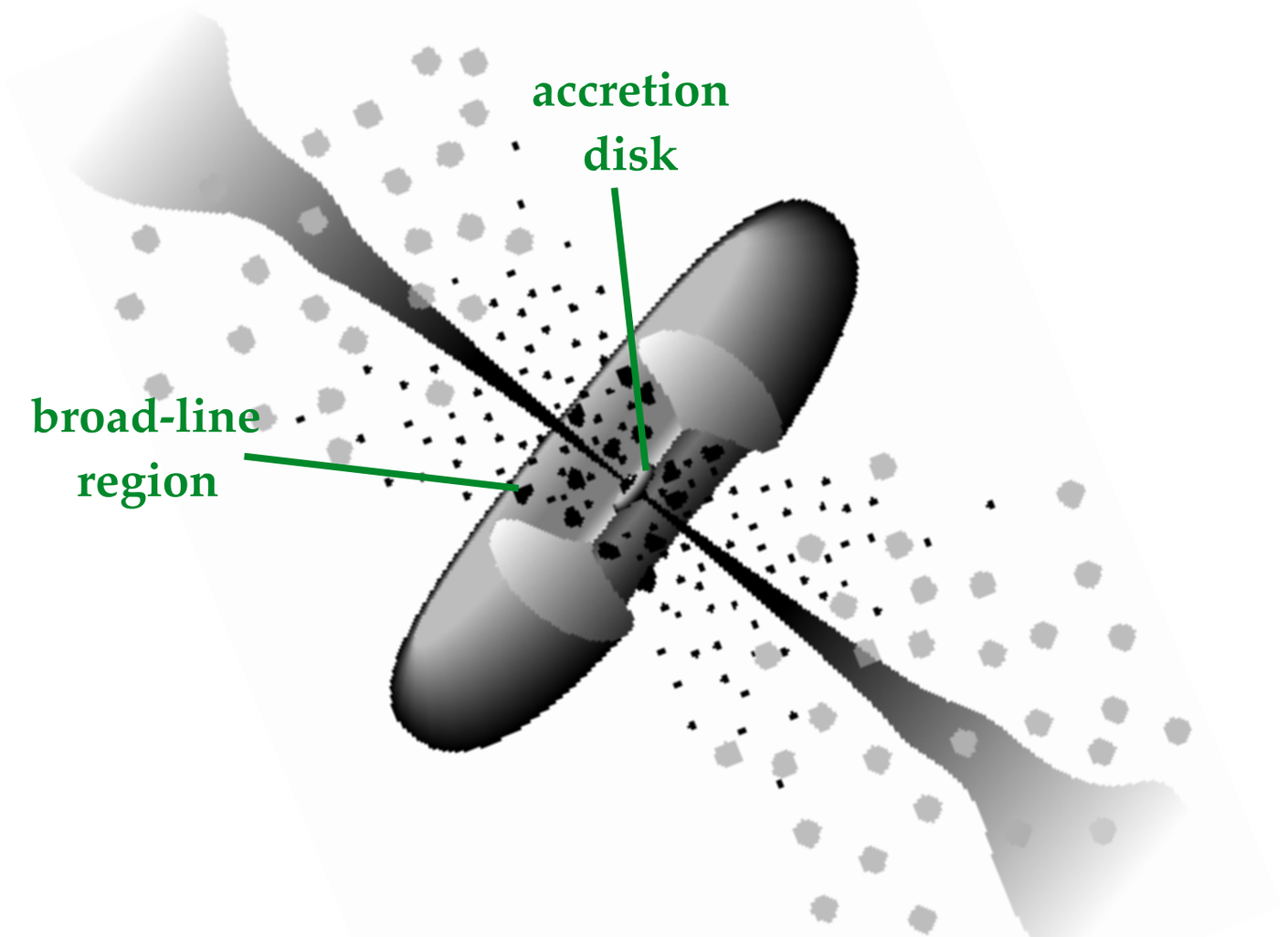




Virial BH Masses for Type 1 AGNs

$$M_{\text{virial}} = f\,RV^2/G$$

- f geometric fudge factor
- R BLR radius
- V BLR velocity dispersion



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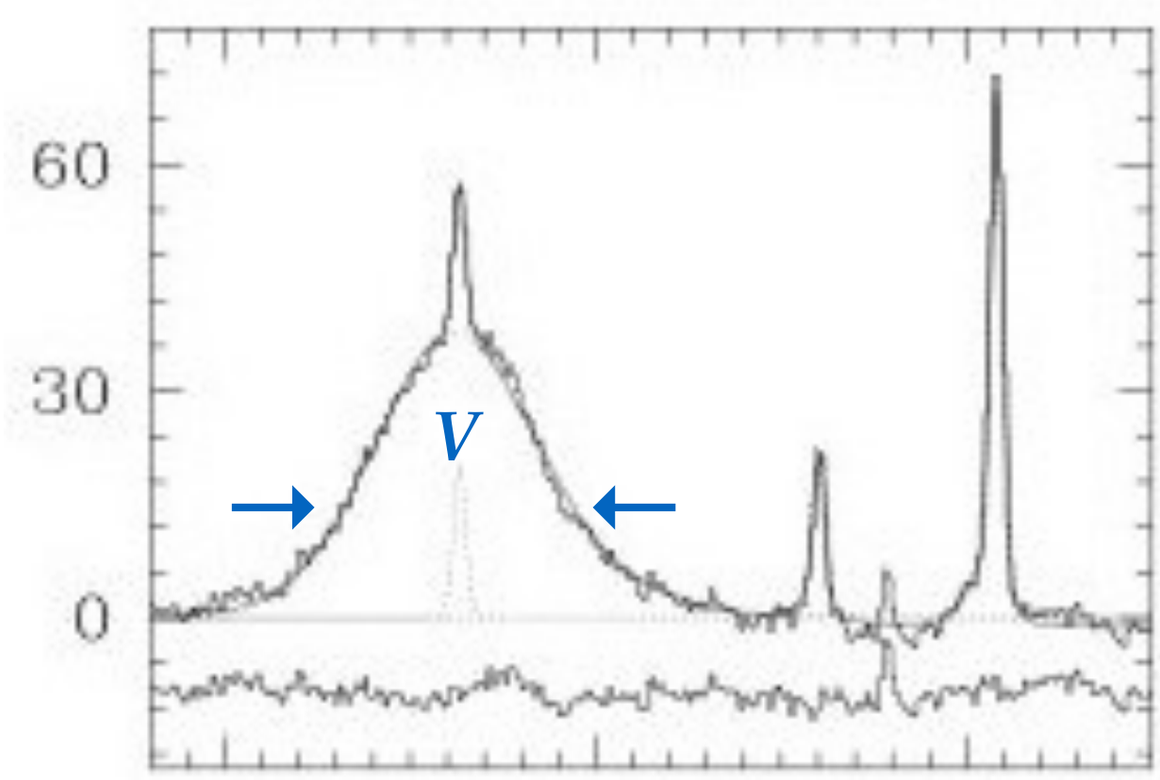

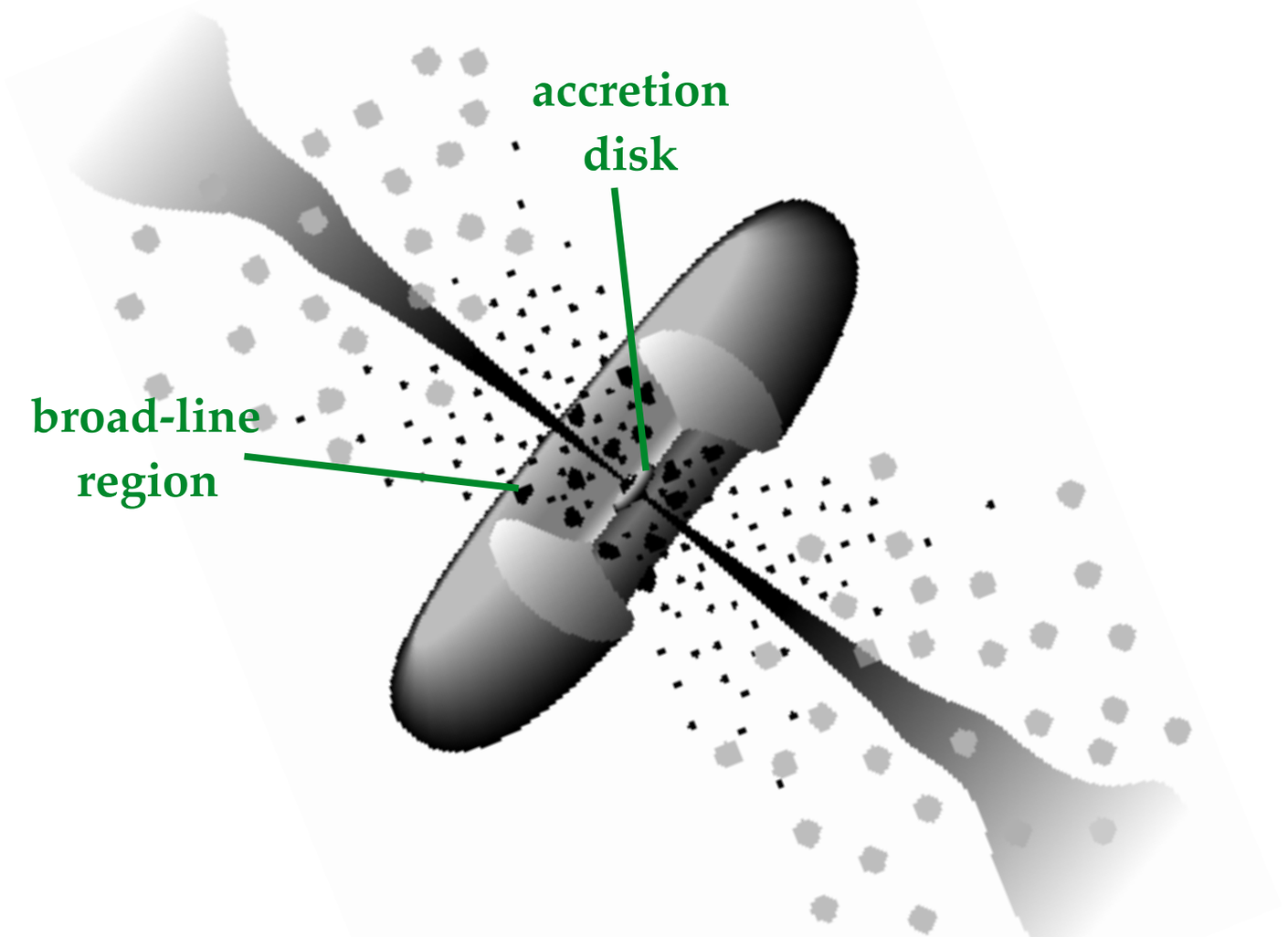

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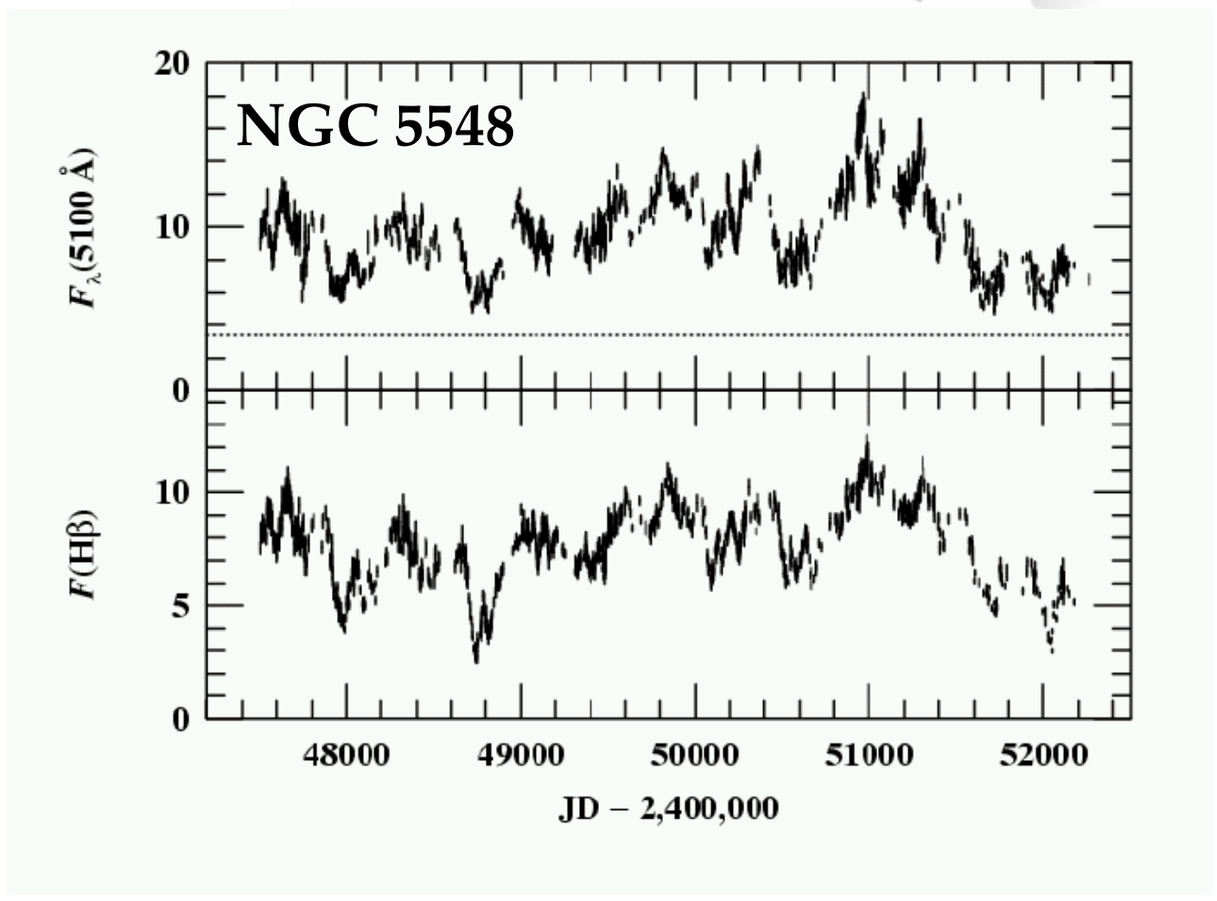

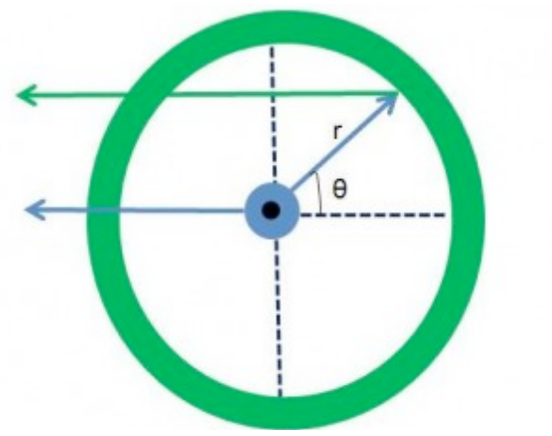

time delay:

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

Virial BH Masses for Type 1 AGNs

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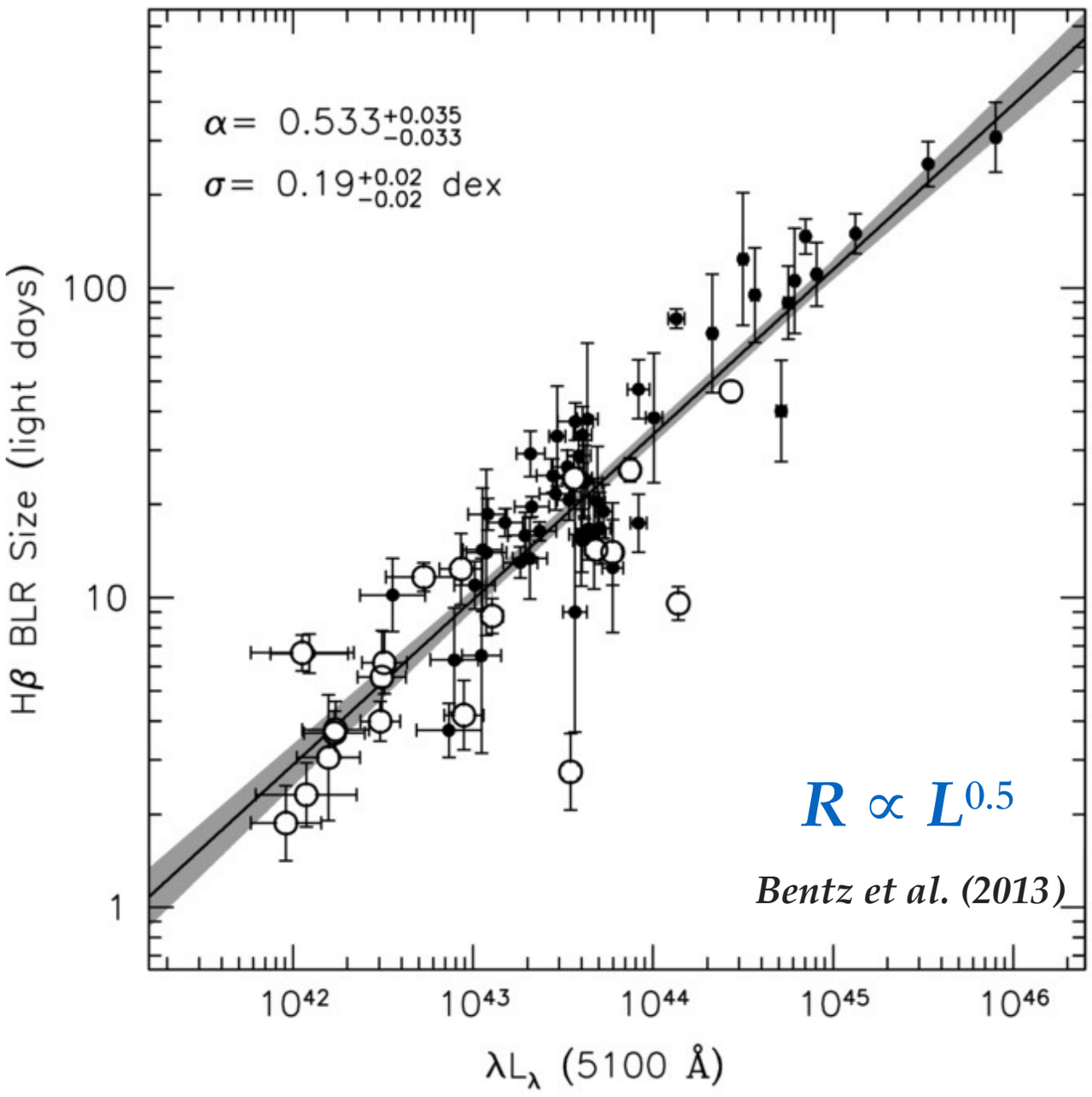
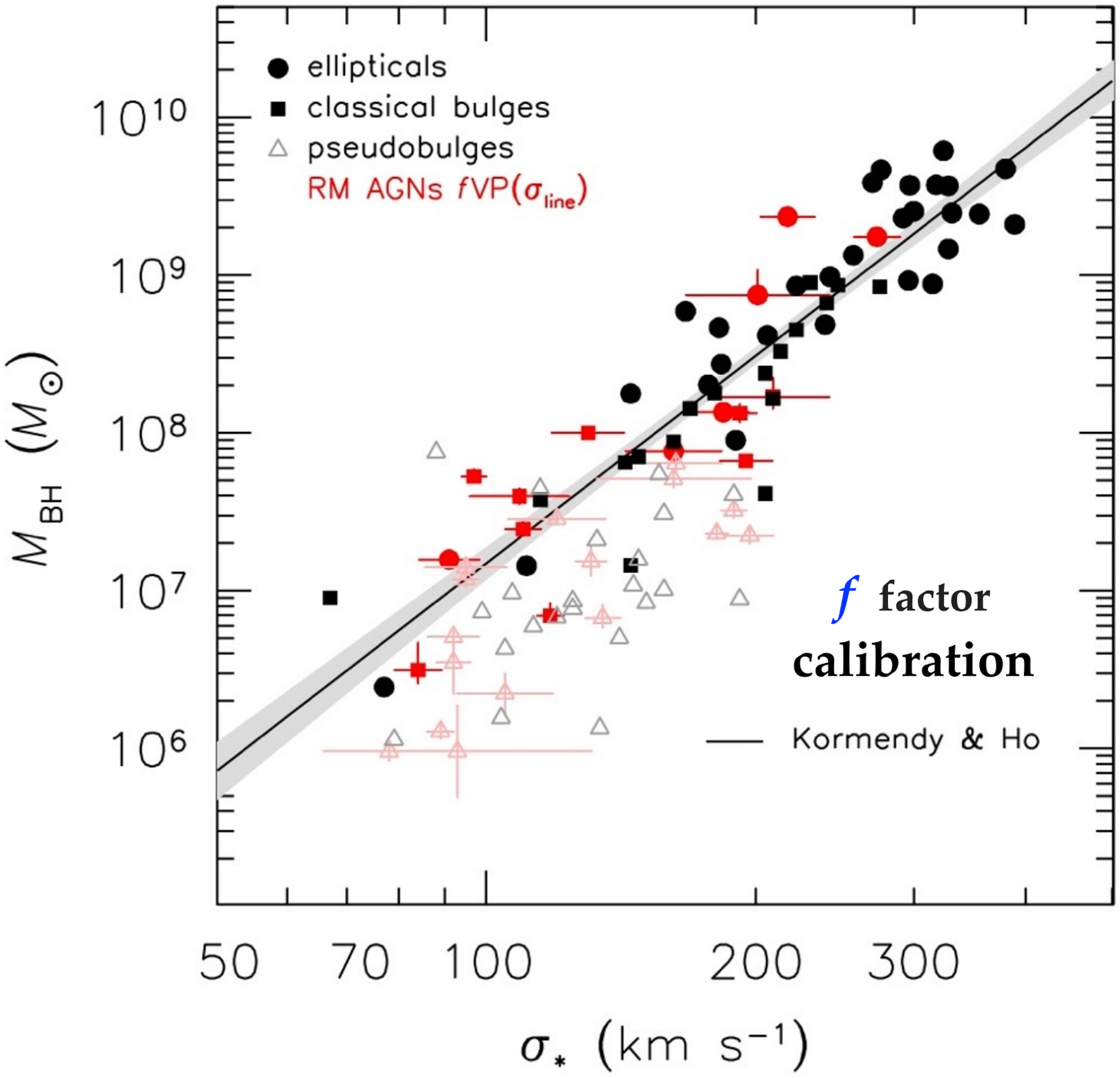
- f geometric fudge factor
- R BLR radius
- V BLR velocity dispersion



Ho & Kim (2014, 2015, 2016)



Virial BH Masses for Type 1 AGNs

$$M_{\rm virial} = f\,RV^2/G$$

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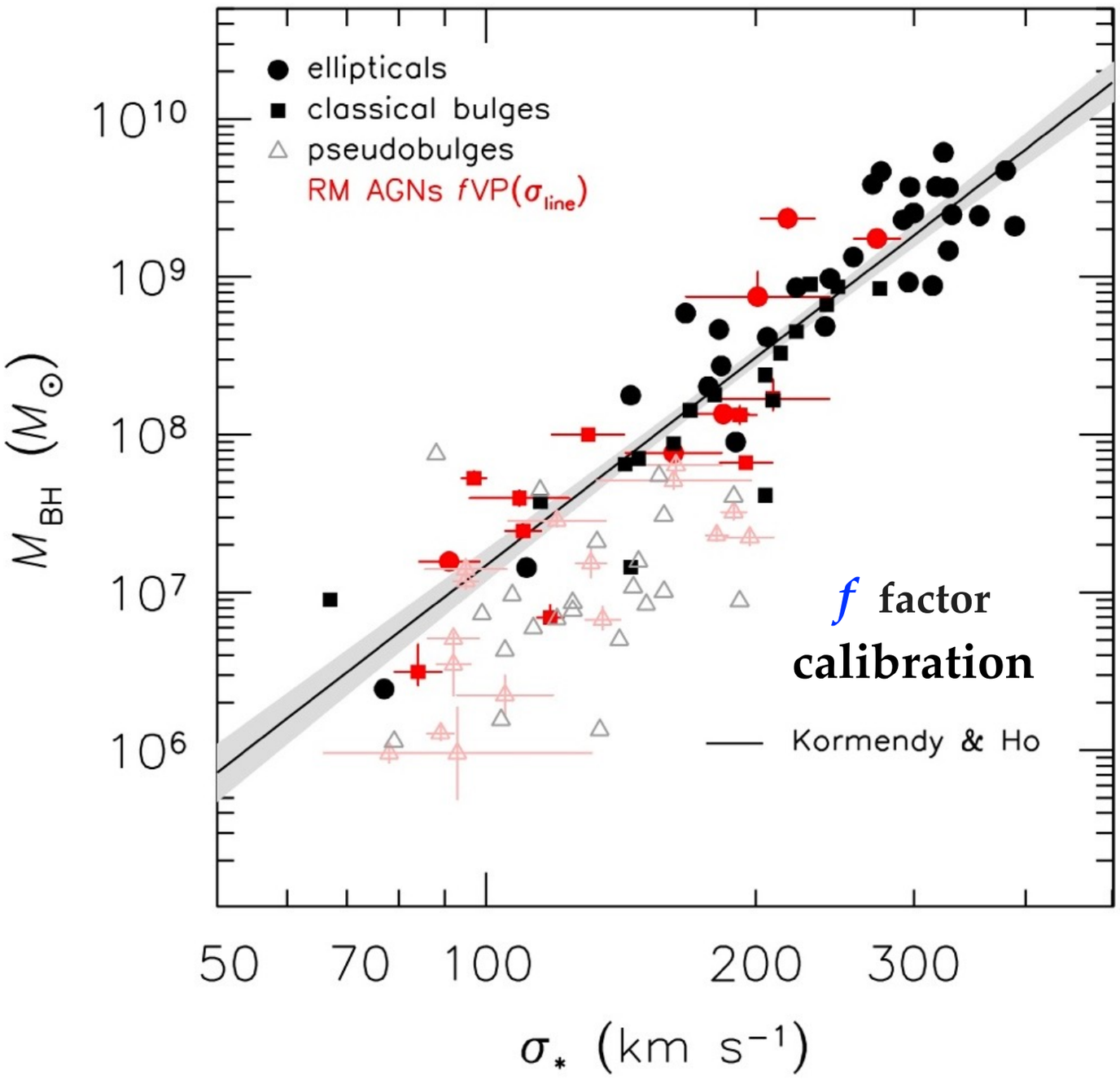
Ho & Kim (2014, 2015, 2016)



Virial BH Masses for Type 1 AGNs

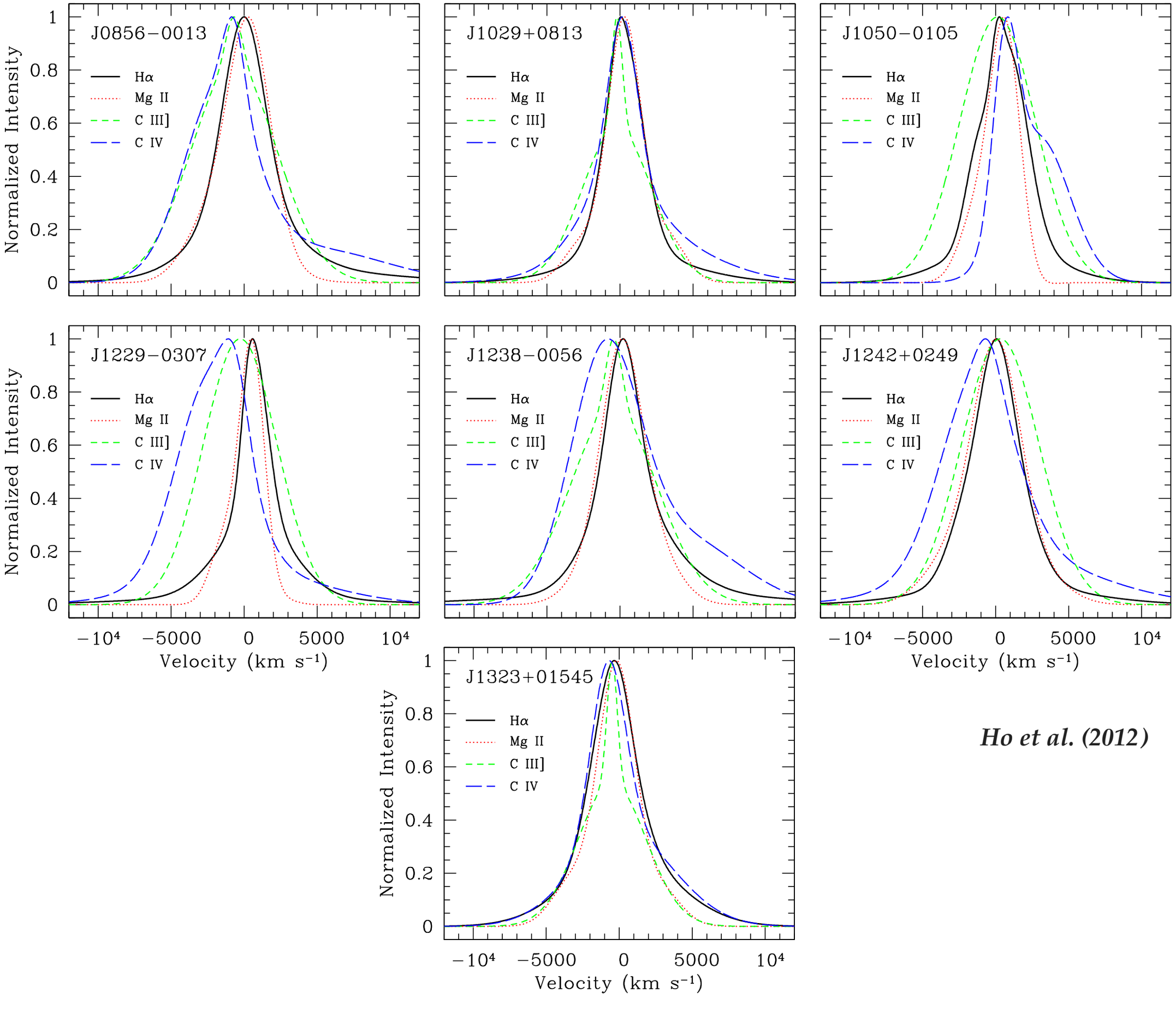
$$M_{\rm virial} = f\,RV^2/G$$

f geometric fudge factor

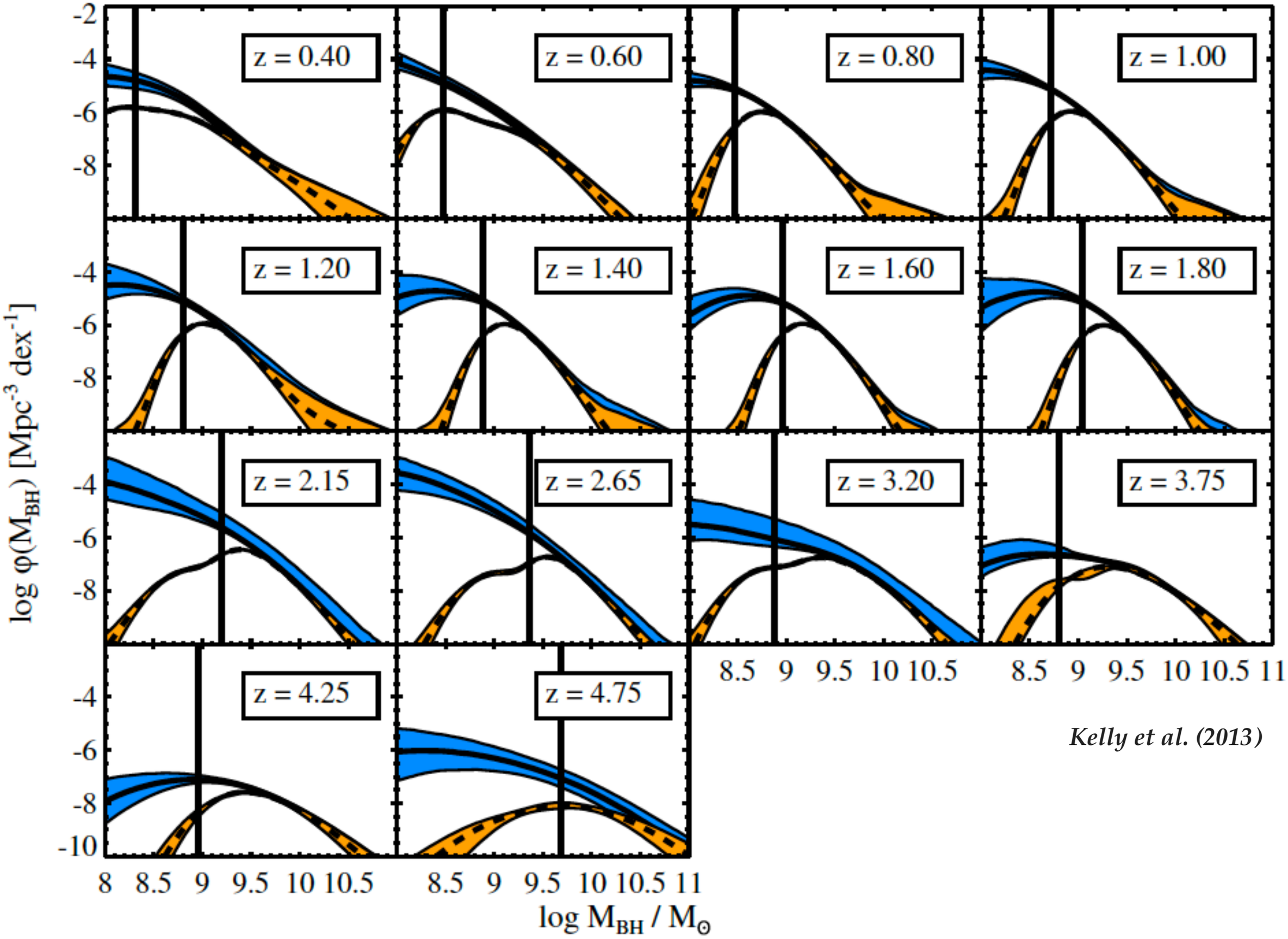
R BLR radius

V BLR velocity dispersion

$M_\bullet$ can be estimated to an accuracy of ~0.3 – 0.5 dex for $z \approx 0 - 7$

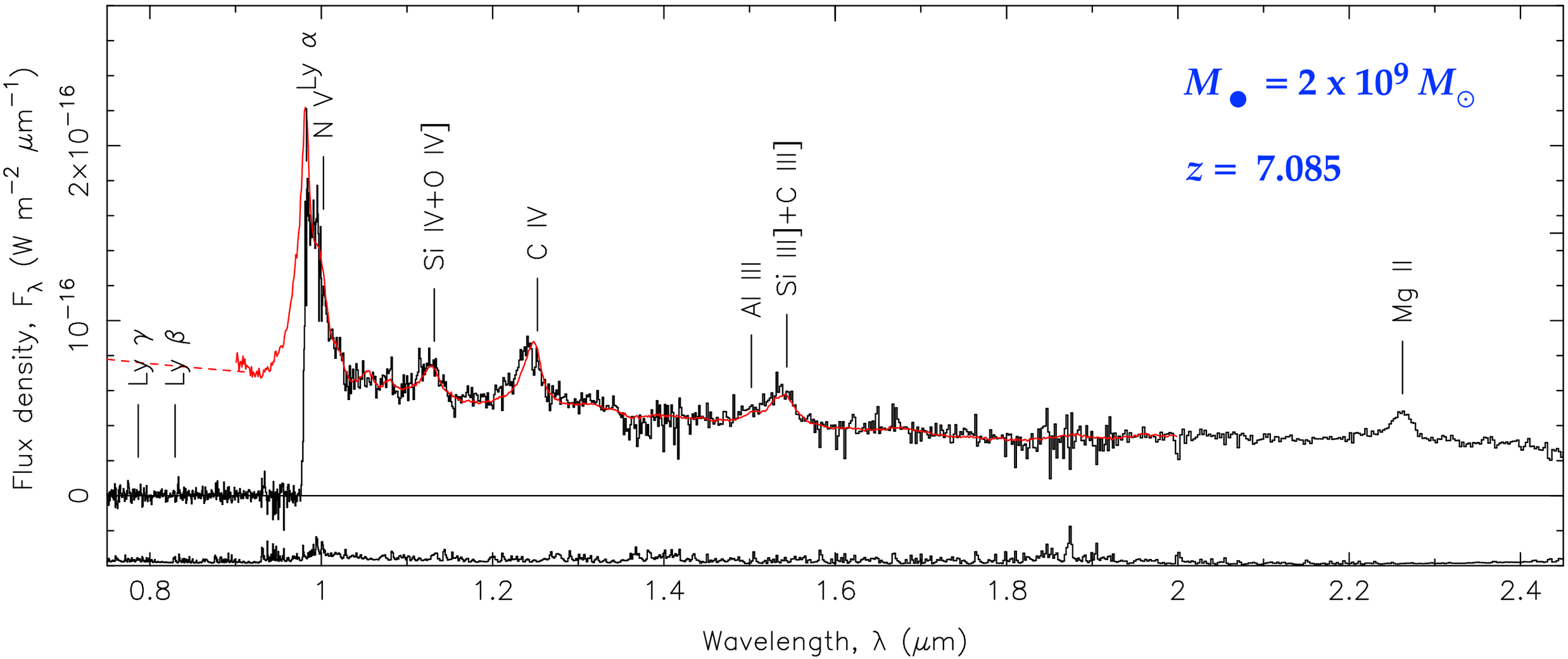

J0856−0013
J1029+0813
J1050−0105
J1229−0307
J1238−0056
J1242+0249
J1323+01545
Hα
Mg II
C III]
C IV
Normalized Intensity
Velocity (km s⁻¹)
0
0.2
0.4
0.6
0.8
1
−10⁴
−5000
5000
10⁴

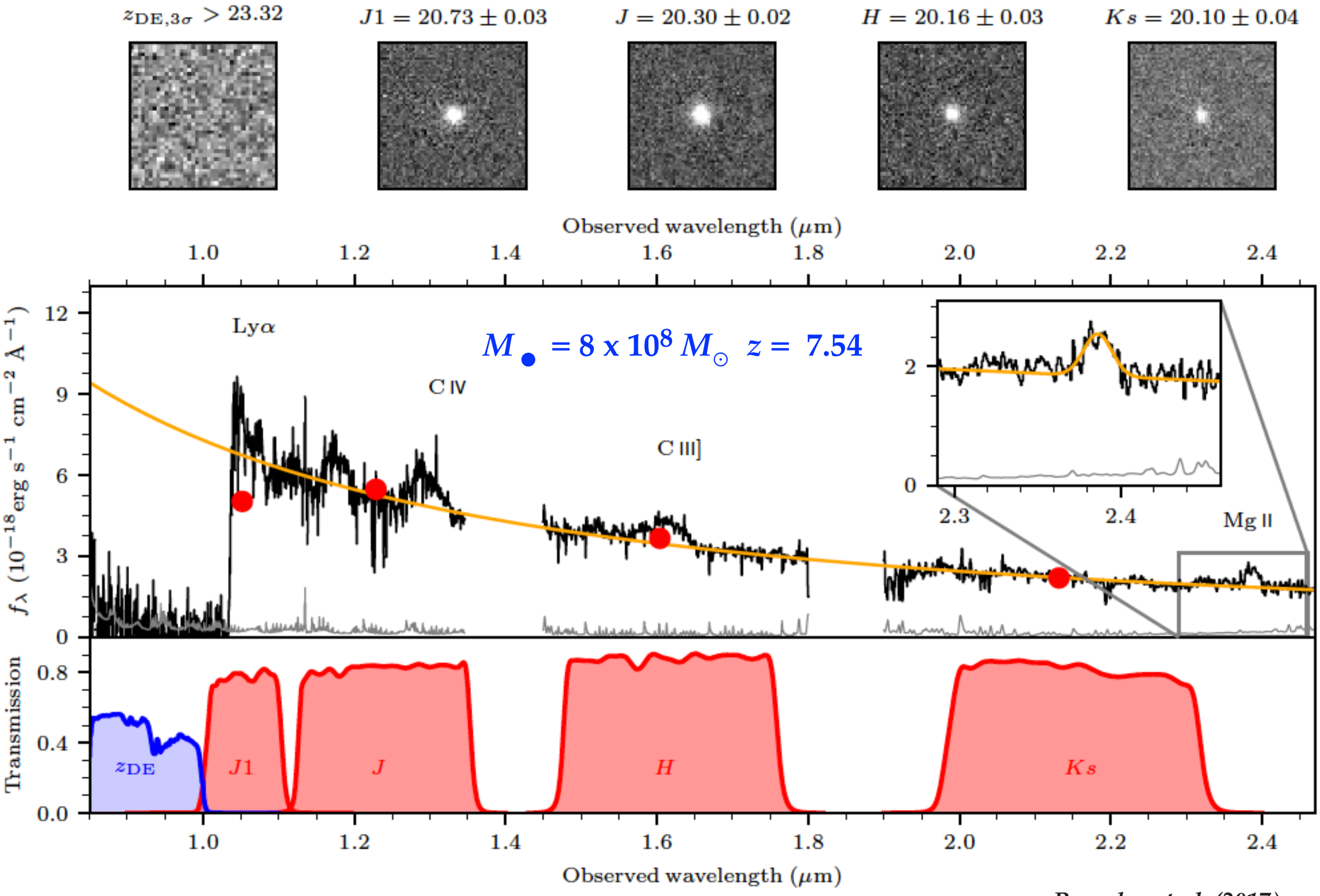
Ho et al. (2012)



Kelly et al. (2013)

Mortlock et al. (2011)

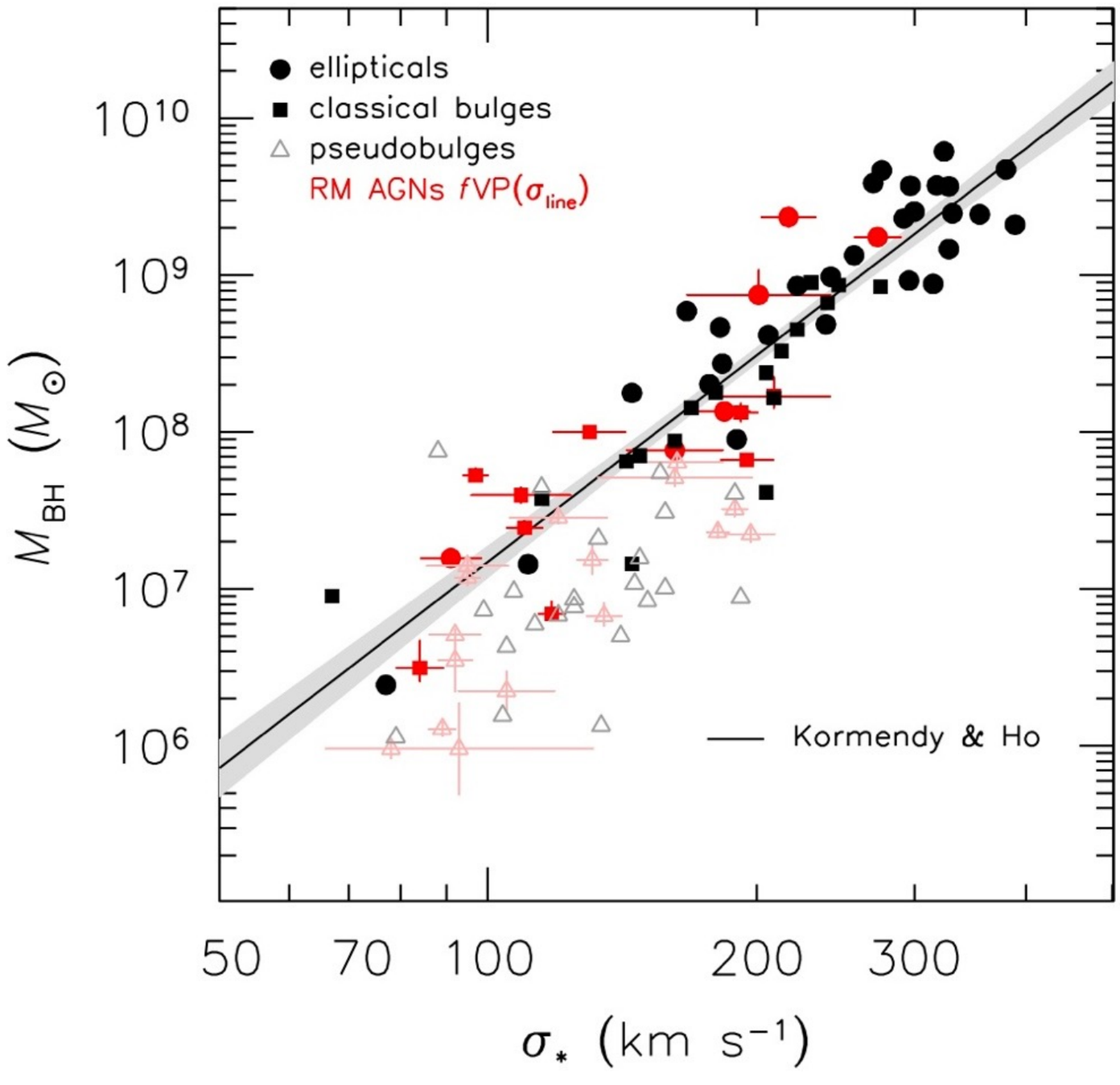




Banados et al. (2017)

Calibration of *f*-factor

Ho & Kim (2014)

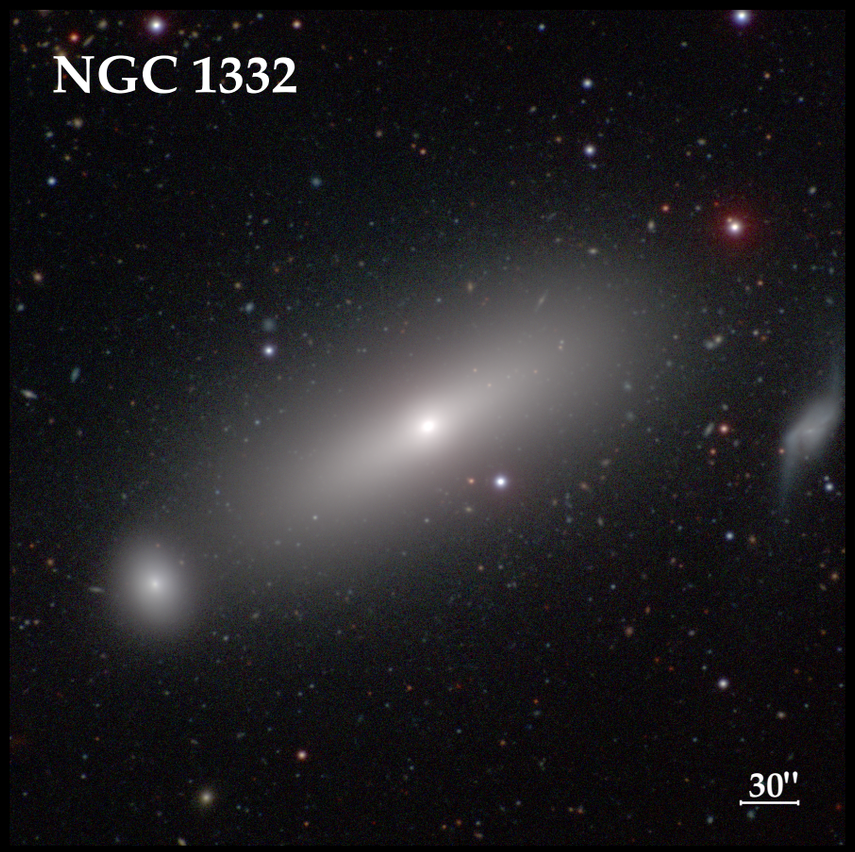


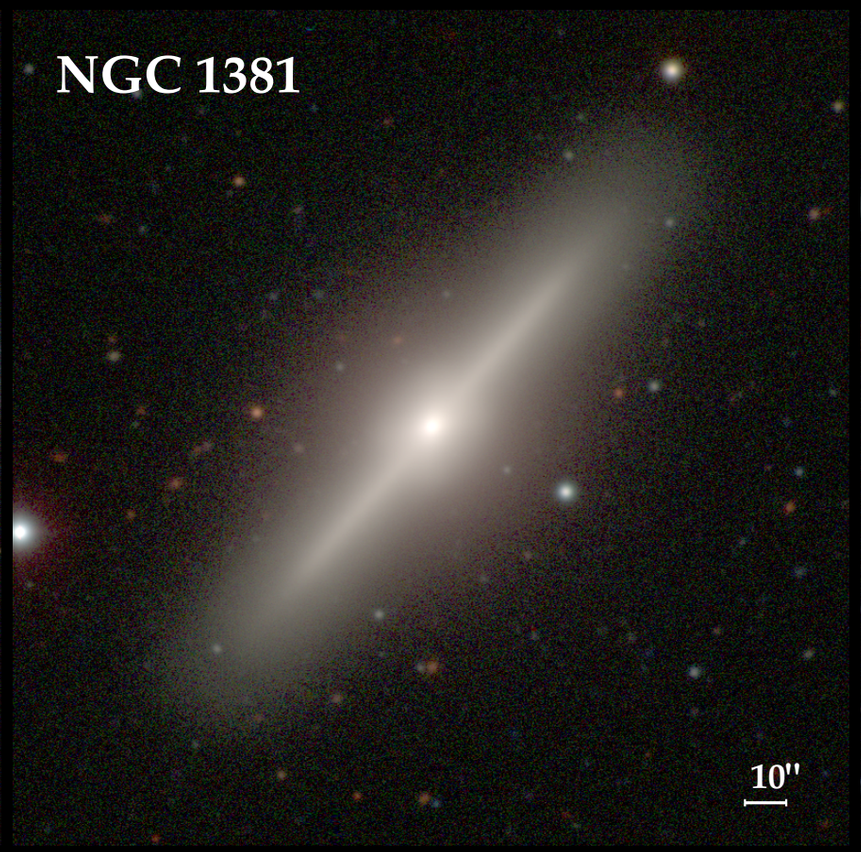
Classical bulges

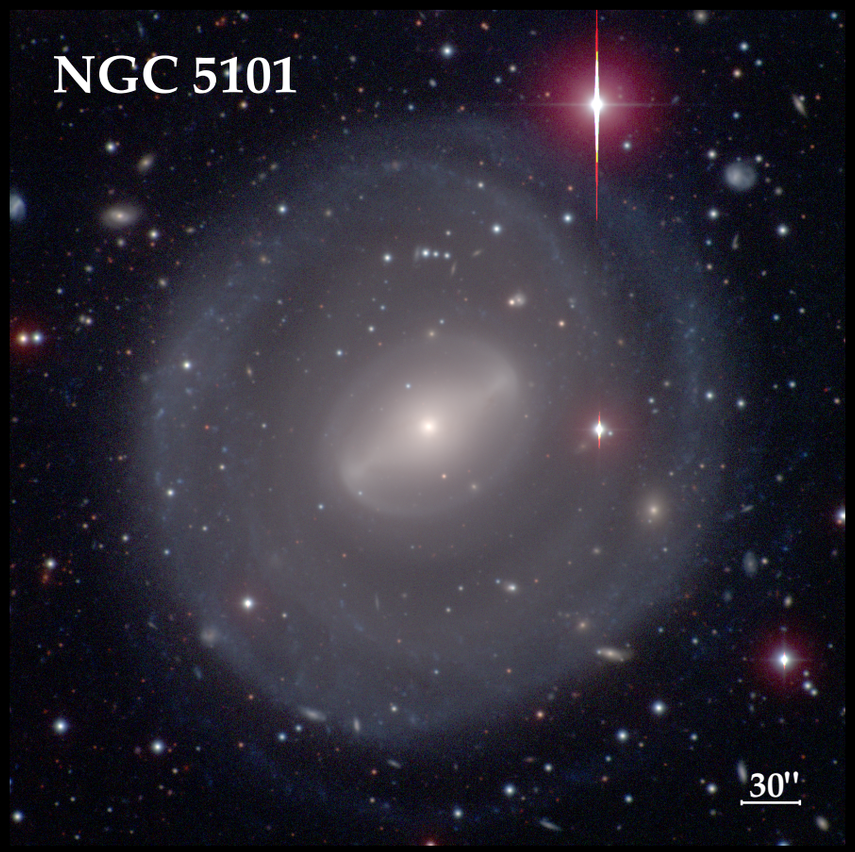
$f = 6.3 \pm 1.3 \quad \varepsilon_0 = 0.39 \pm 0.07$

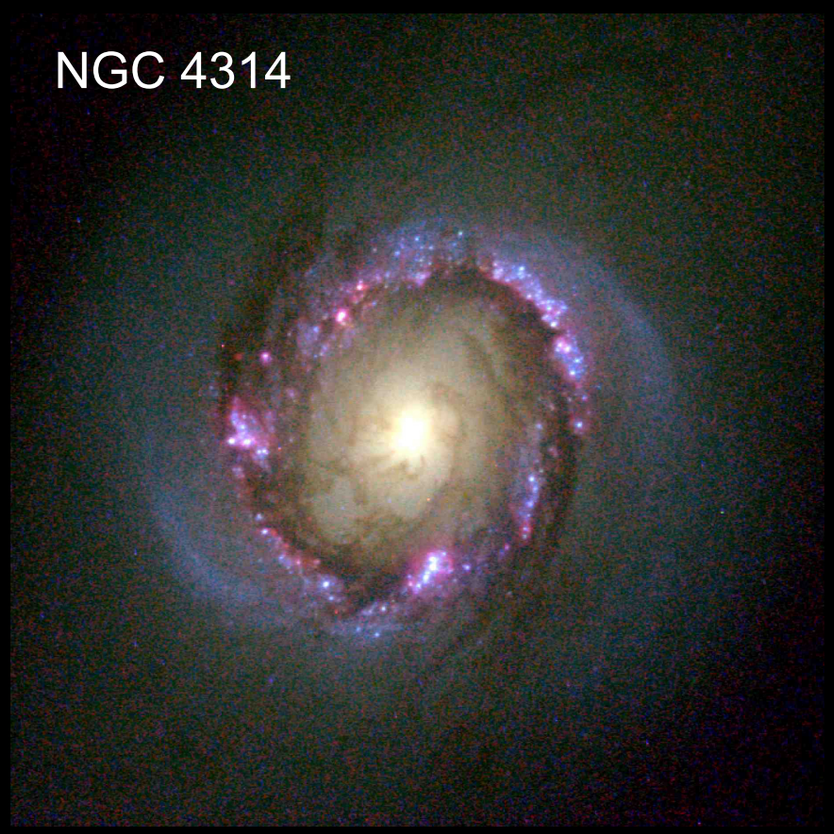
Pseudo bulges

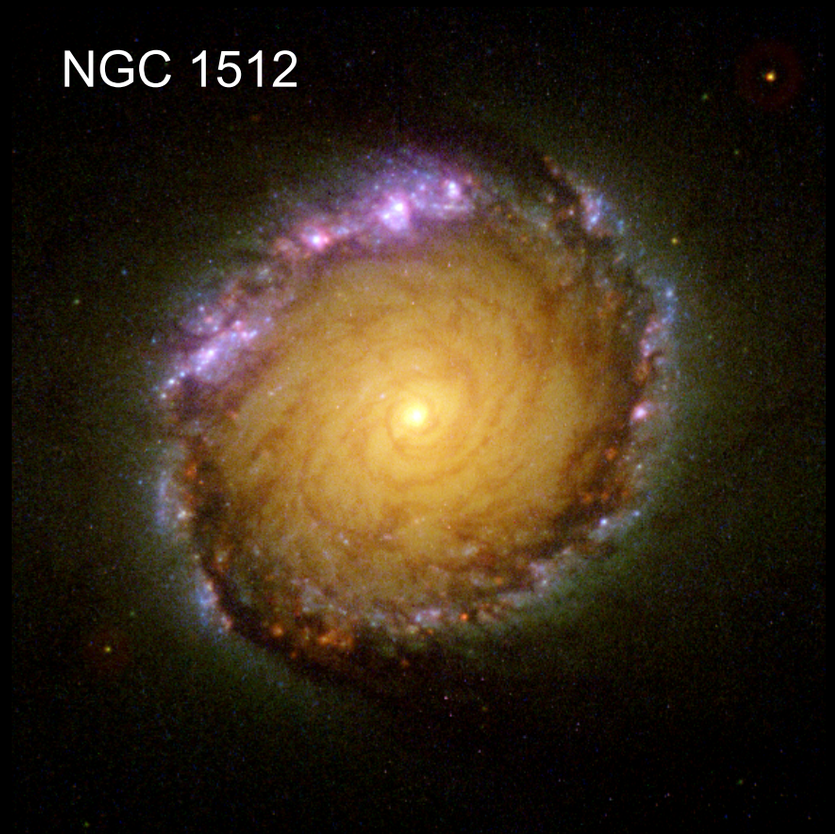
$f = 3.2 \pm 0.7 \quad \varepsilon_0 = 0.34 \pm 0.06$


NGC 1332
30''


NGC 1381
10''


NGC 5101
30''


NGC 4314


NGC 1512


NGC 6782

Calibration of Single-Epoch Virial Masses

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

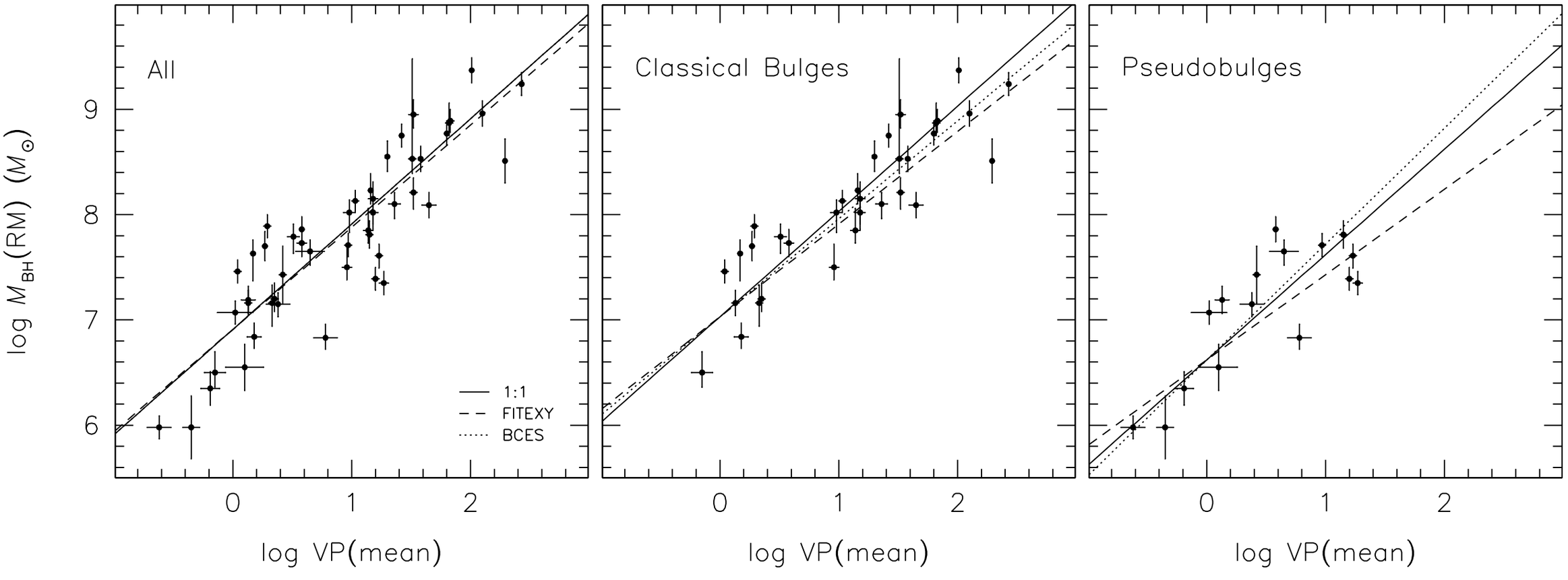
Classical bulges

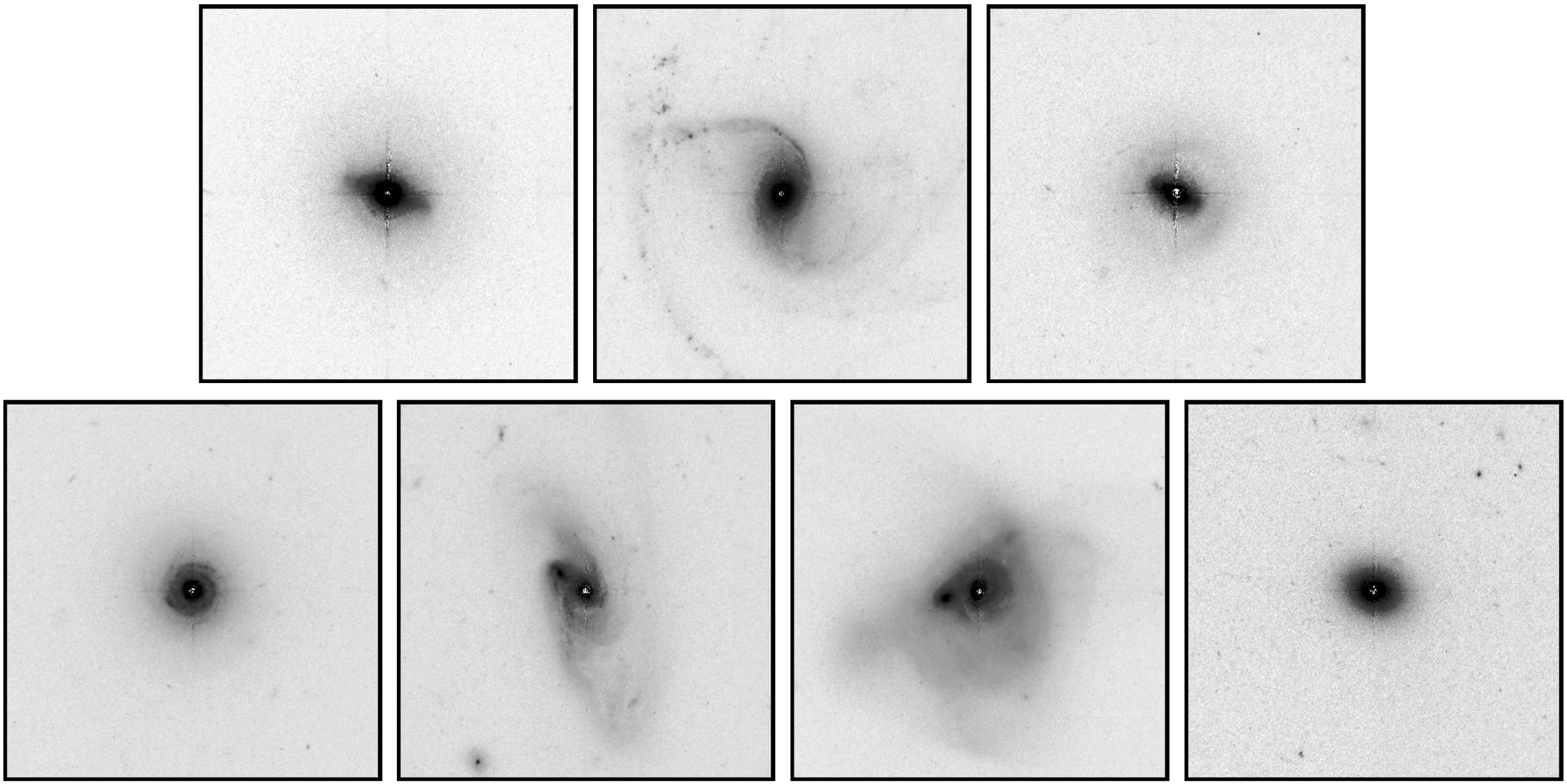
$a = 7.03 \pm 0.02 \quad \varepsilon_0 = 0.32$

Pseudo bulges

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

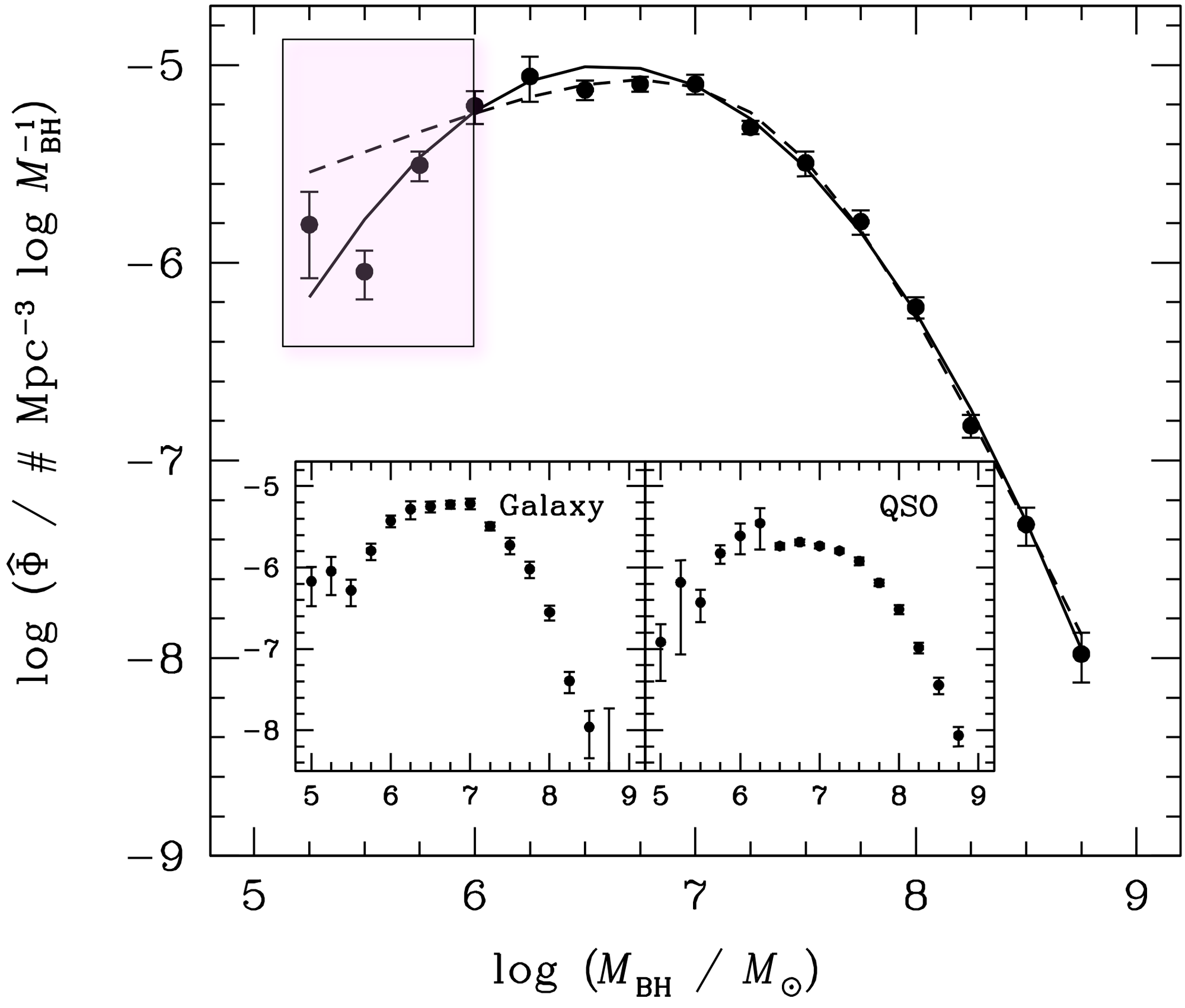
Ho & Kim (2015)





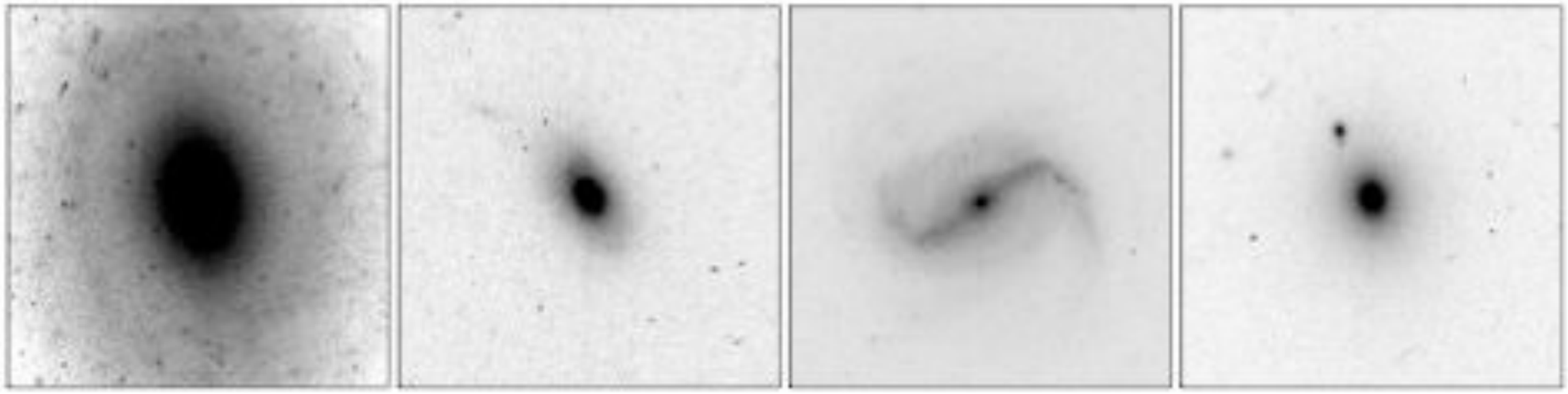
Kim, Ho, et al. (2017)

Greene & Ho (2004, 2007a,b); Dong, Ho et al. (2012)



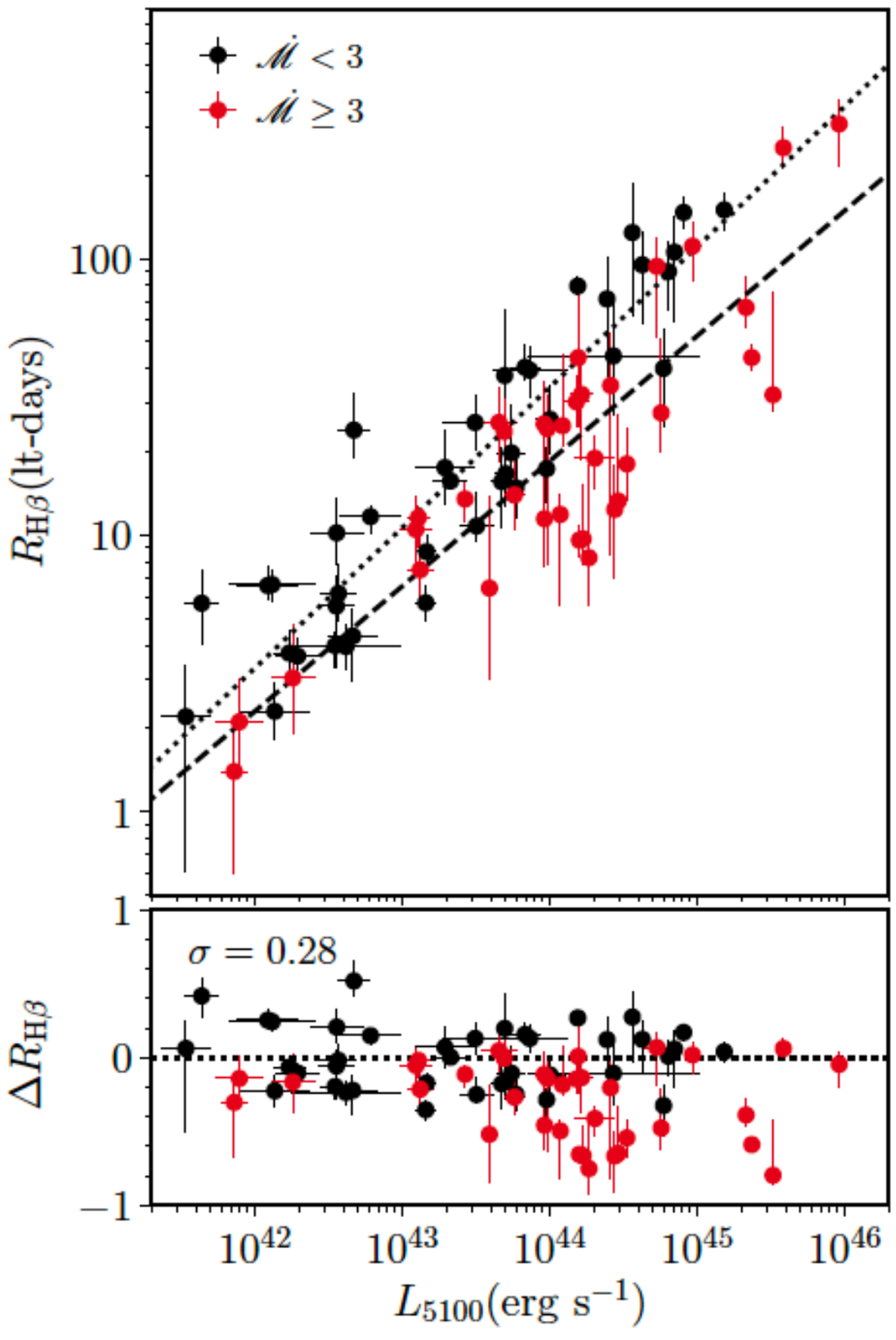
HST/ACS

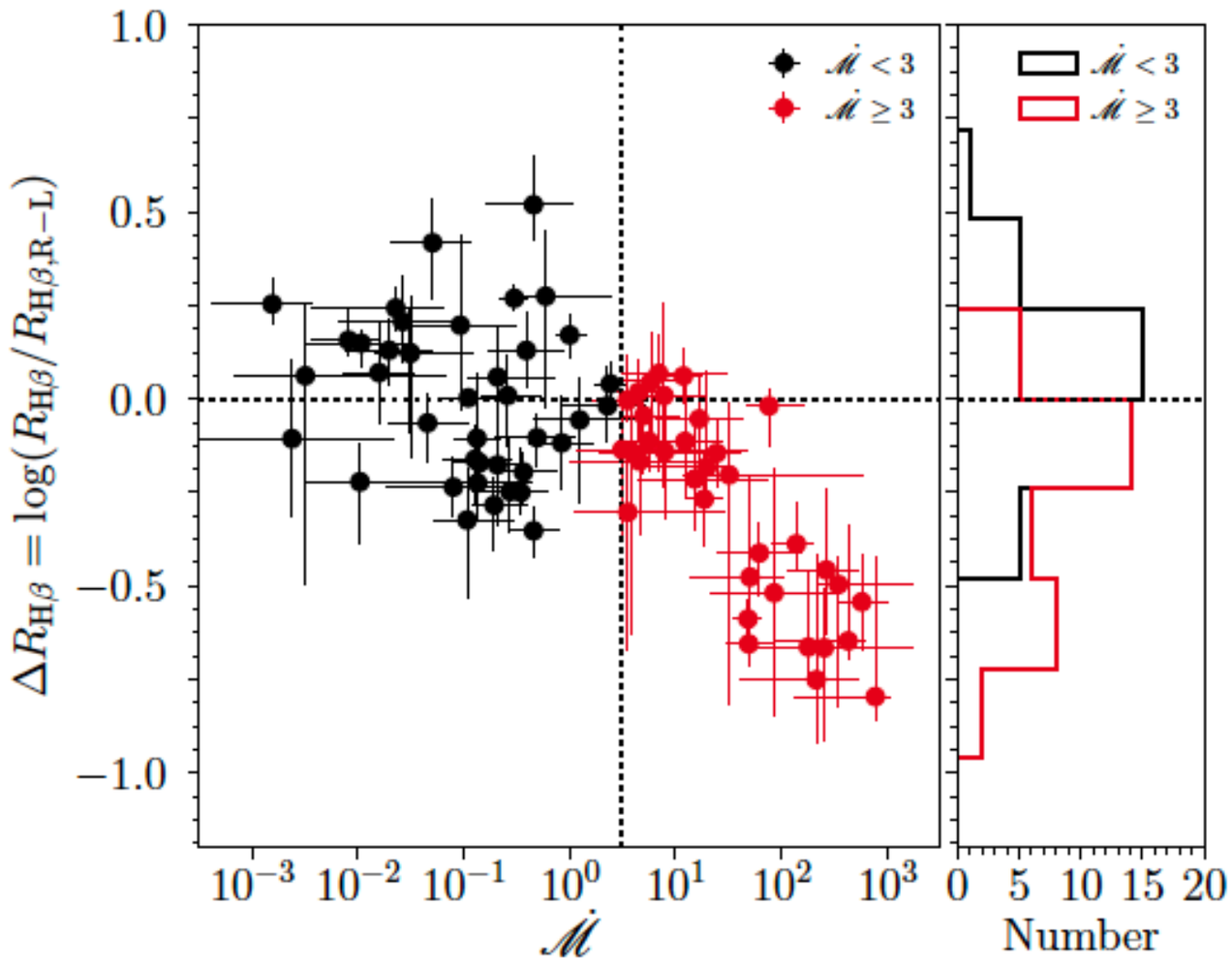
Greene, Ho & Barth (2008); Jiang, Greene & Ho (2011a, b)



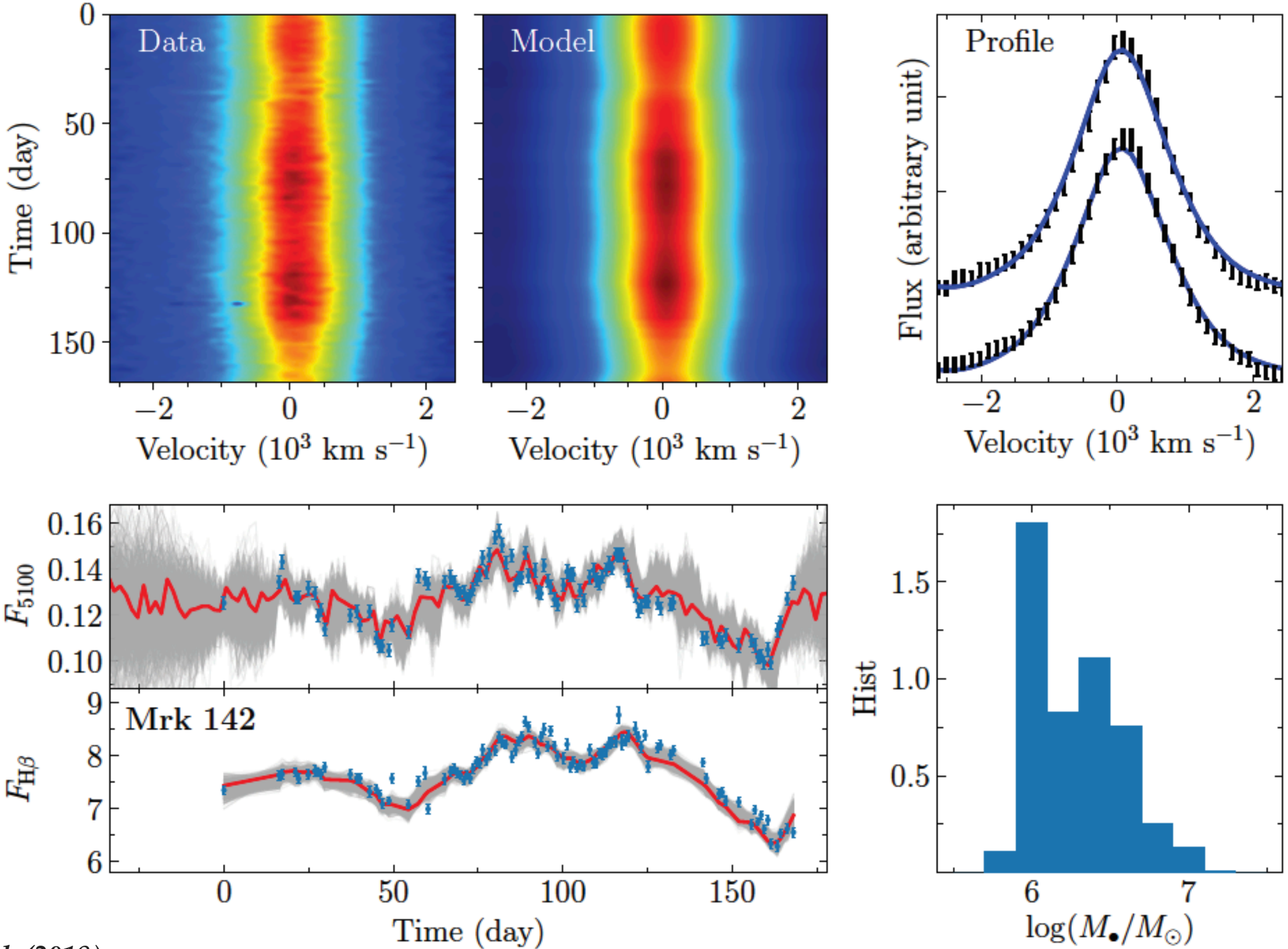
A Revised BLR Size-Luminosity Relation

Du et al. (2016, 2018)





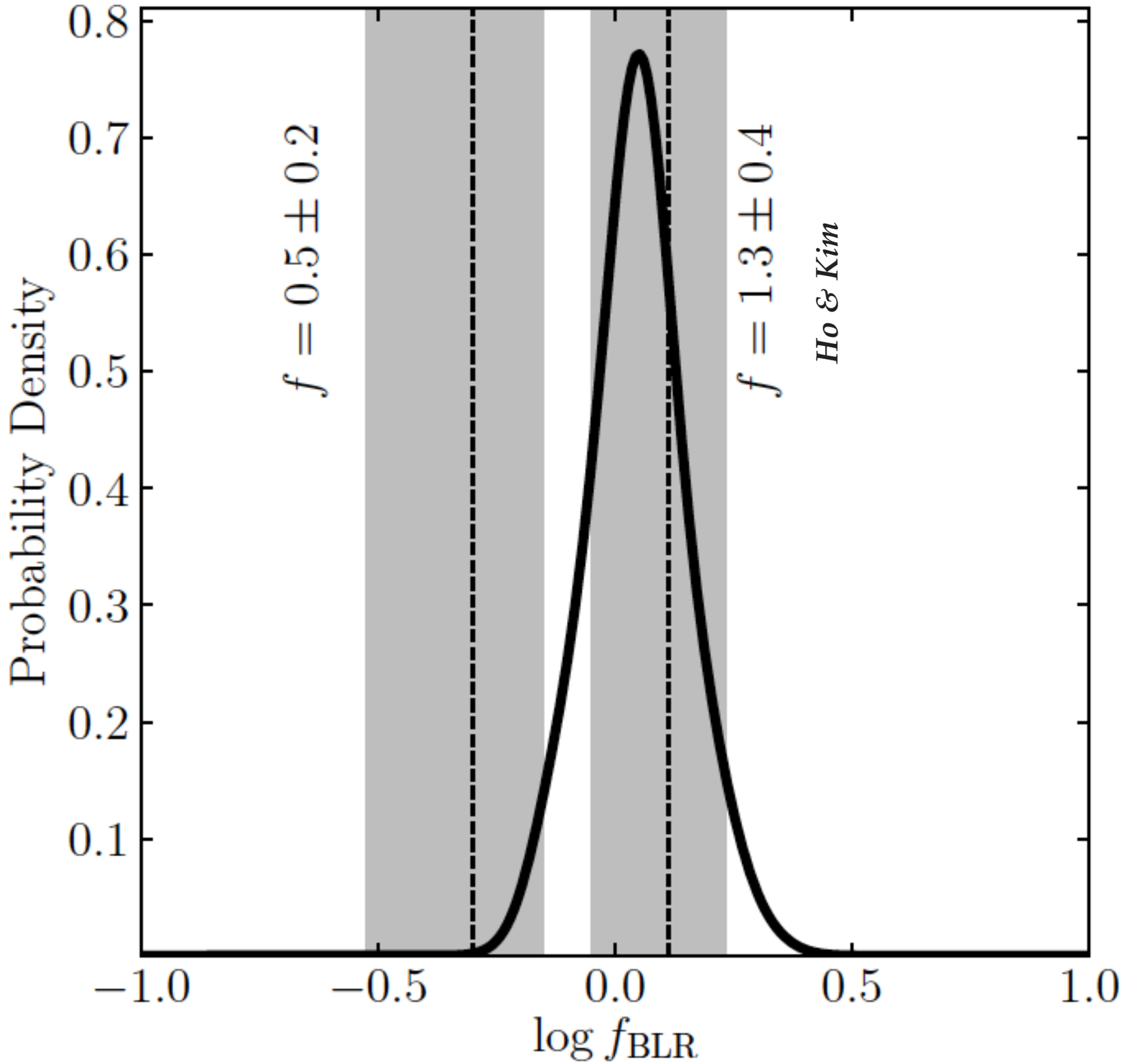
Can we ever do better than factor of 2-3?



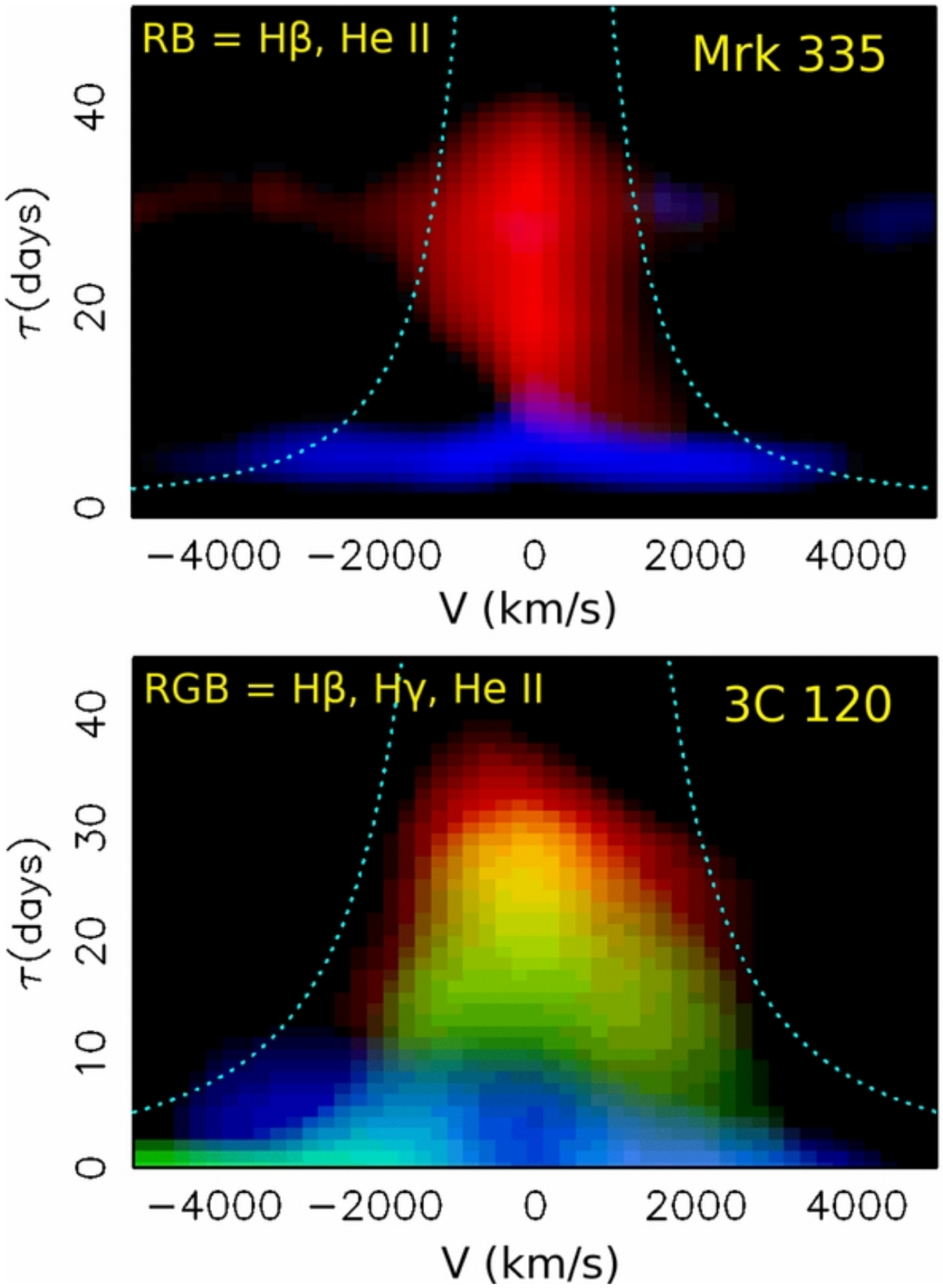
Li et al. (2018)

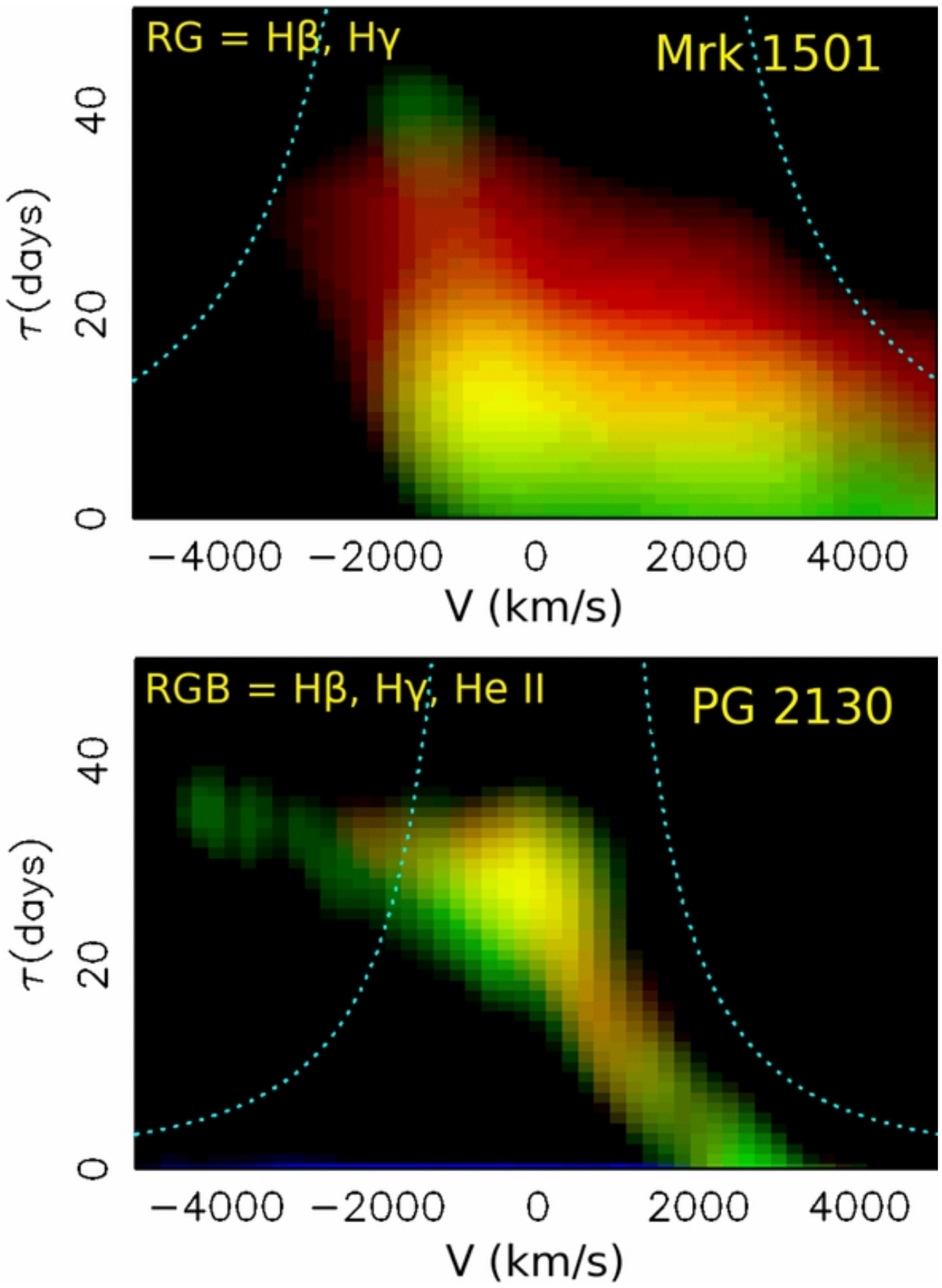
Can we ever do better than factor of 2-3?

Li et al. (2018)

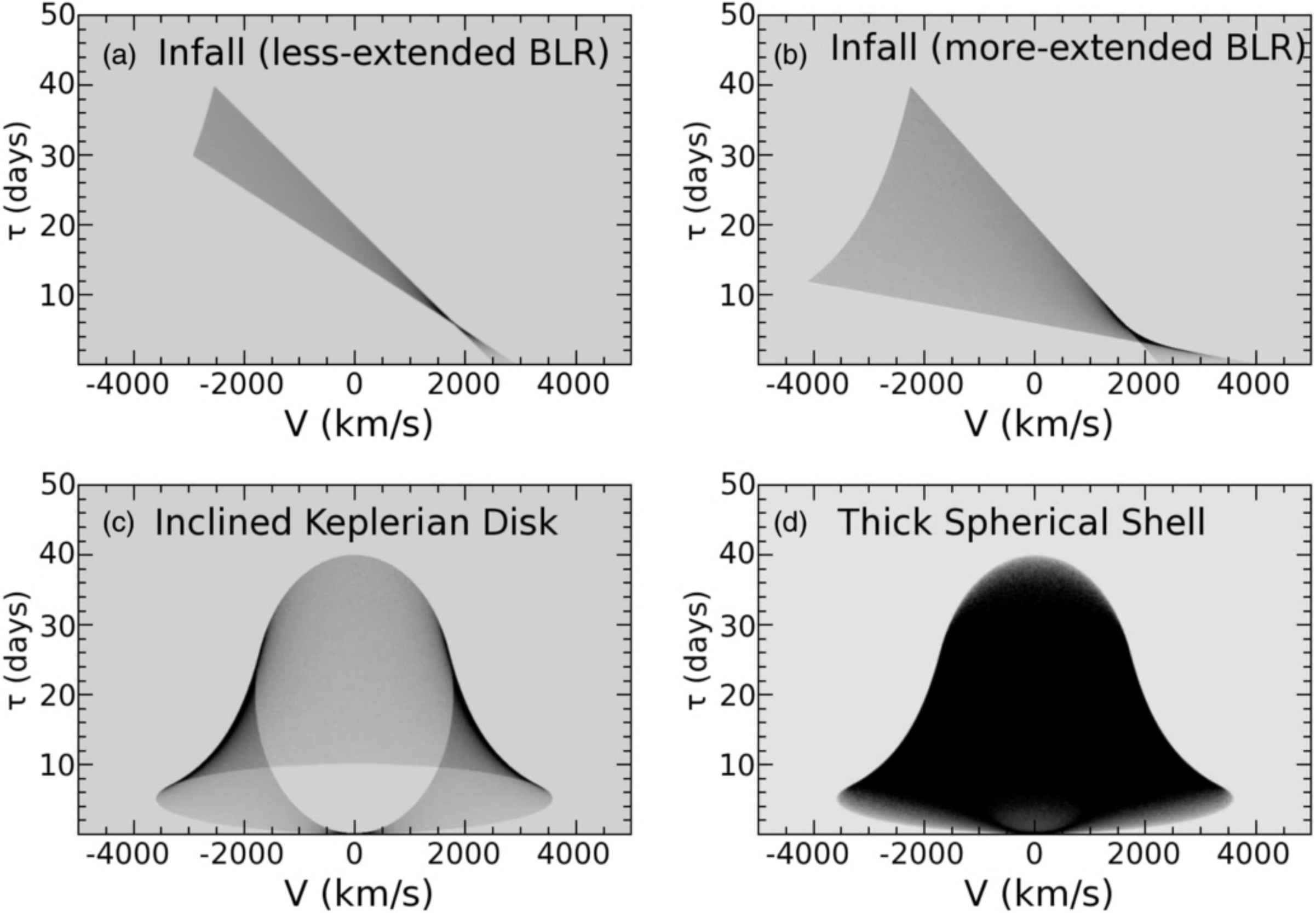


Grier et al. (2013)

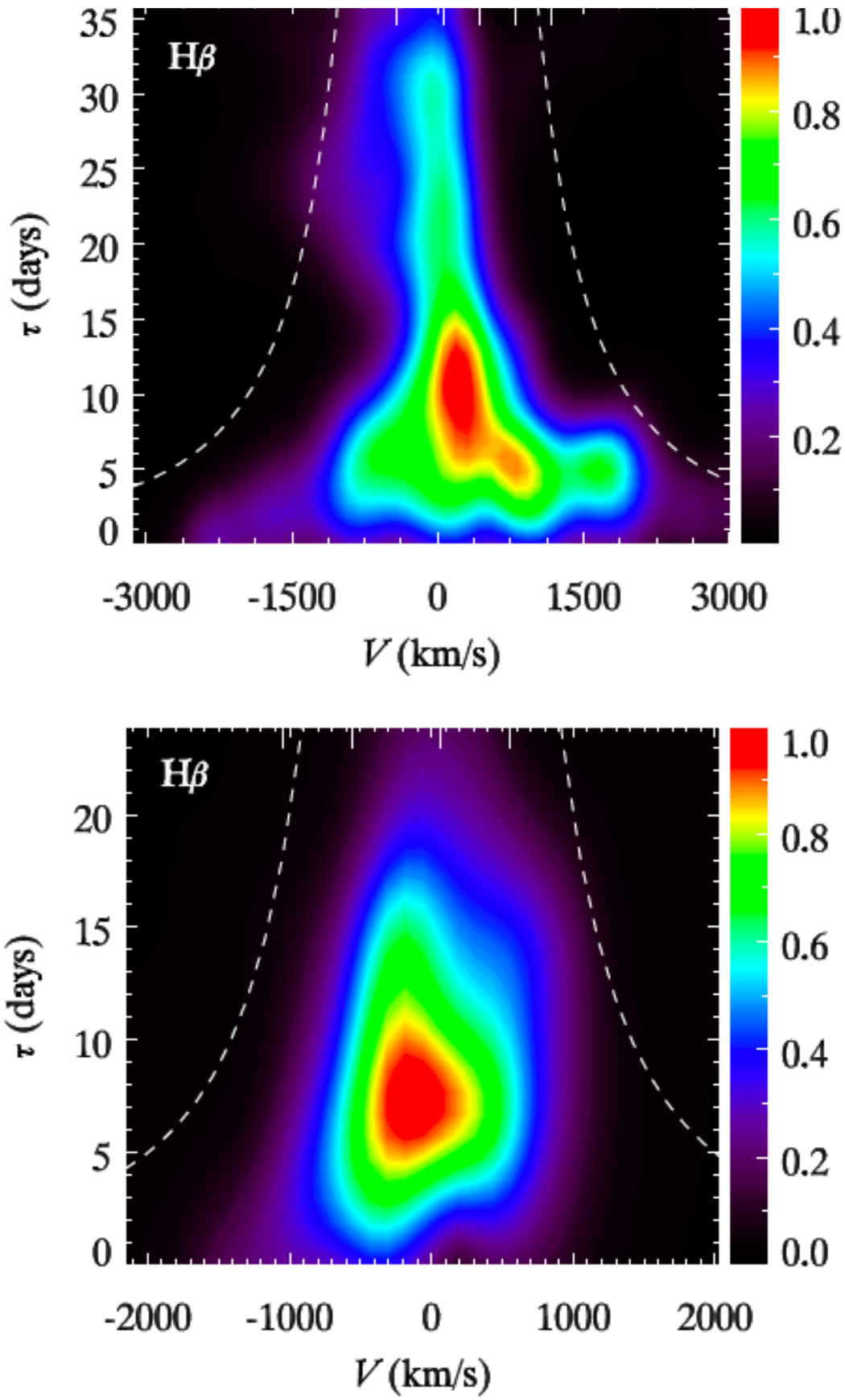


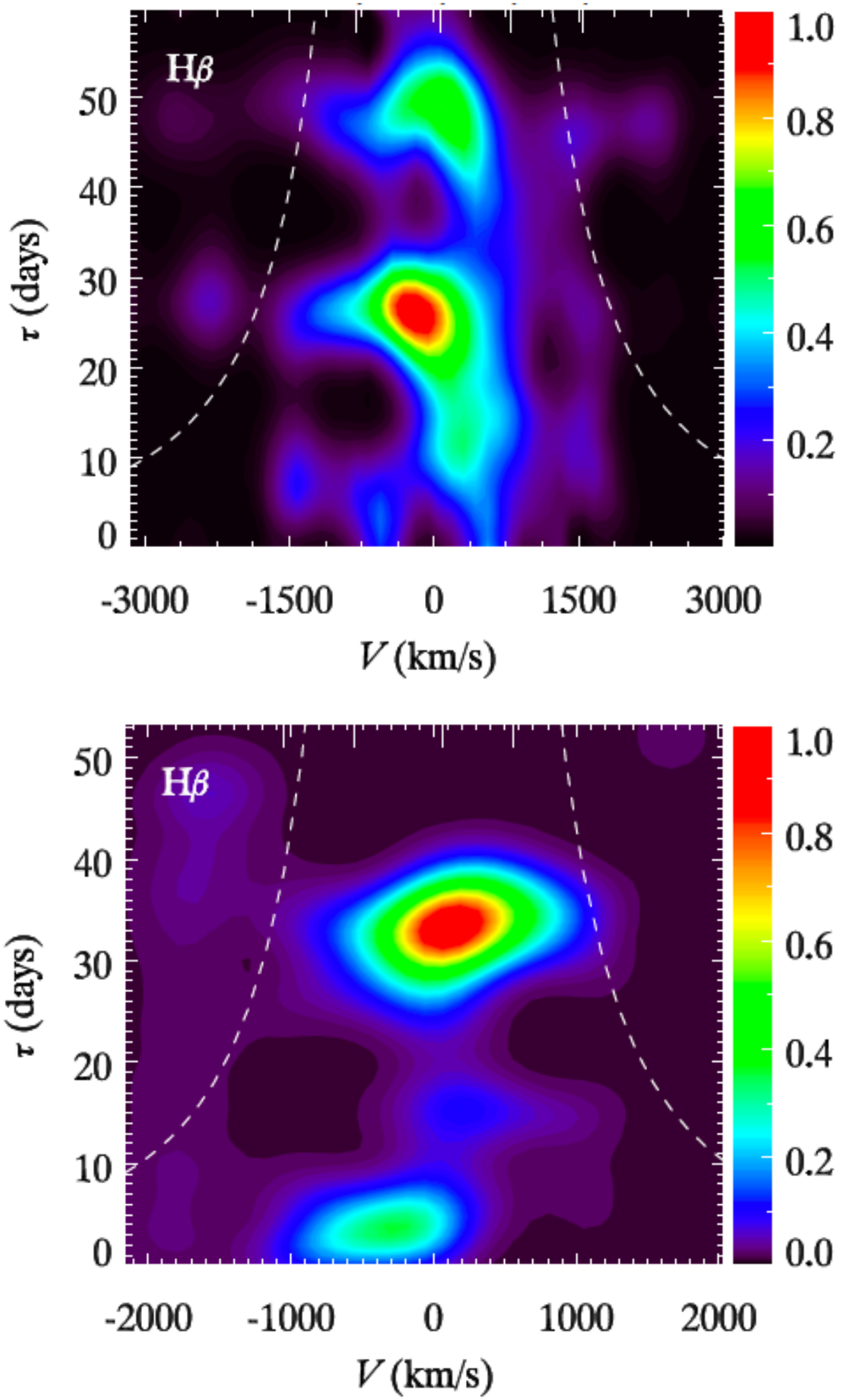


Grier et al. (2013)

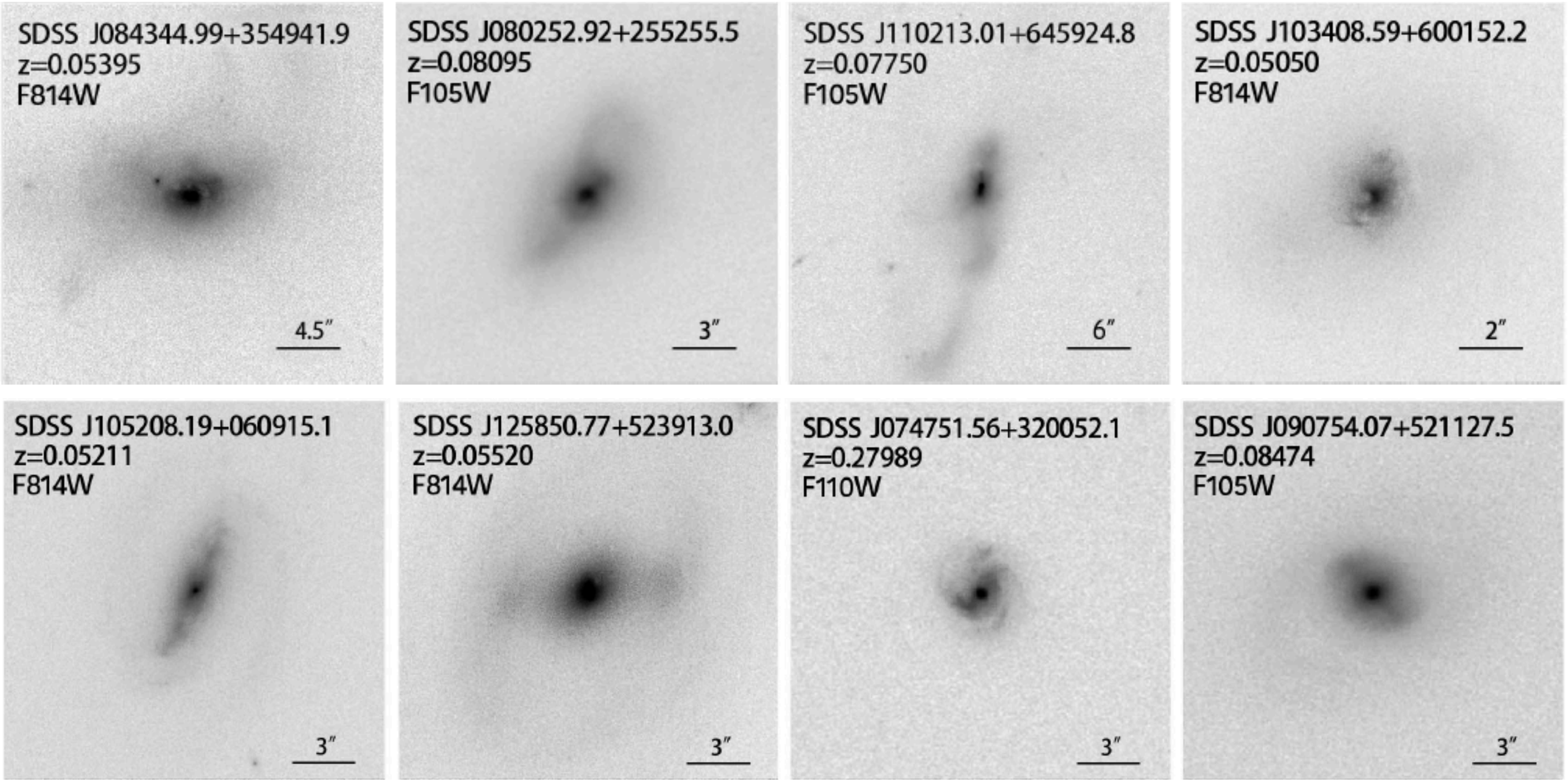


Xiao et al. (2018)





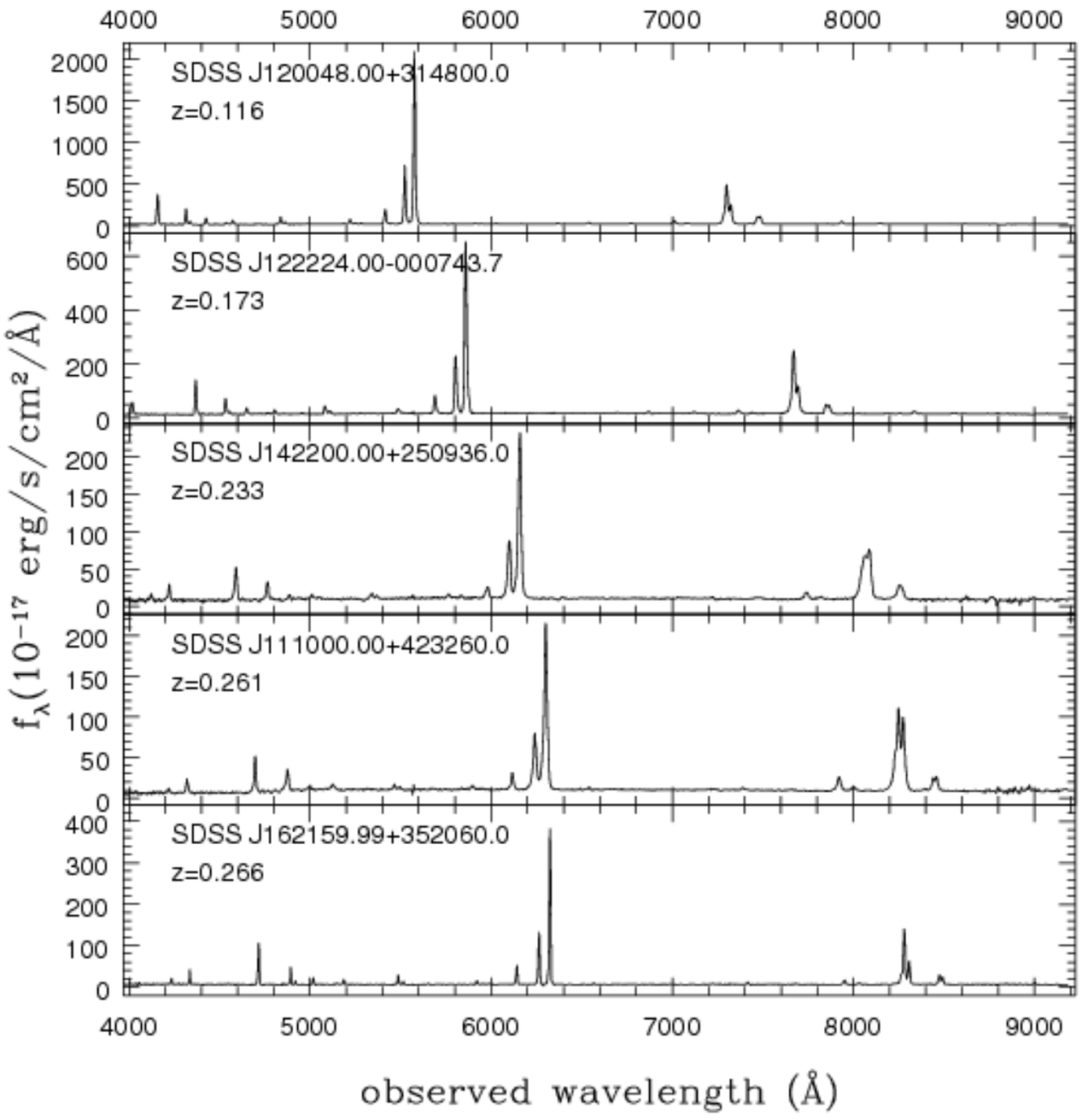
What about Type 2 AGNs?

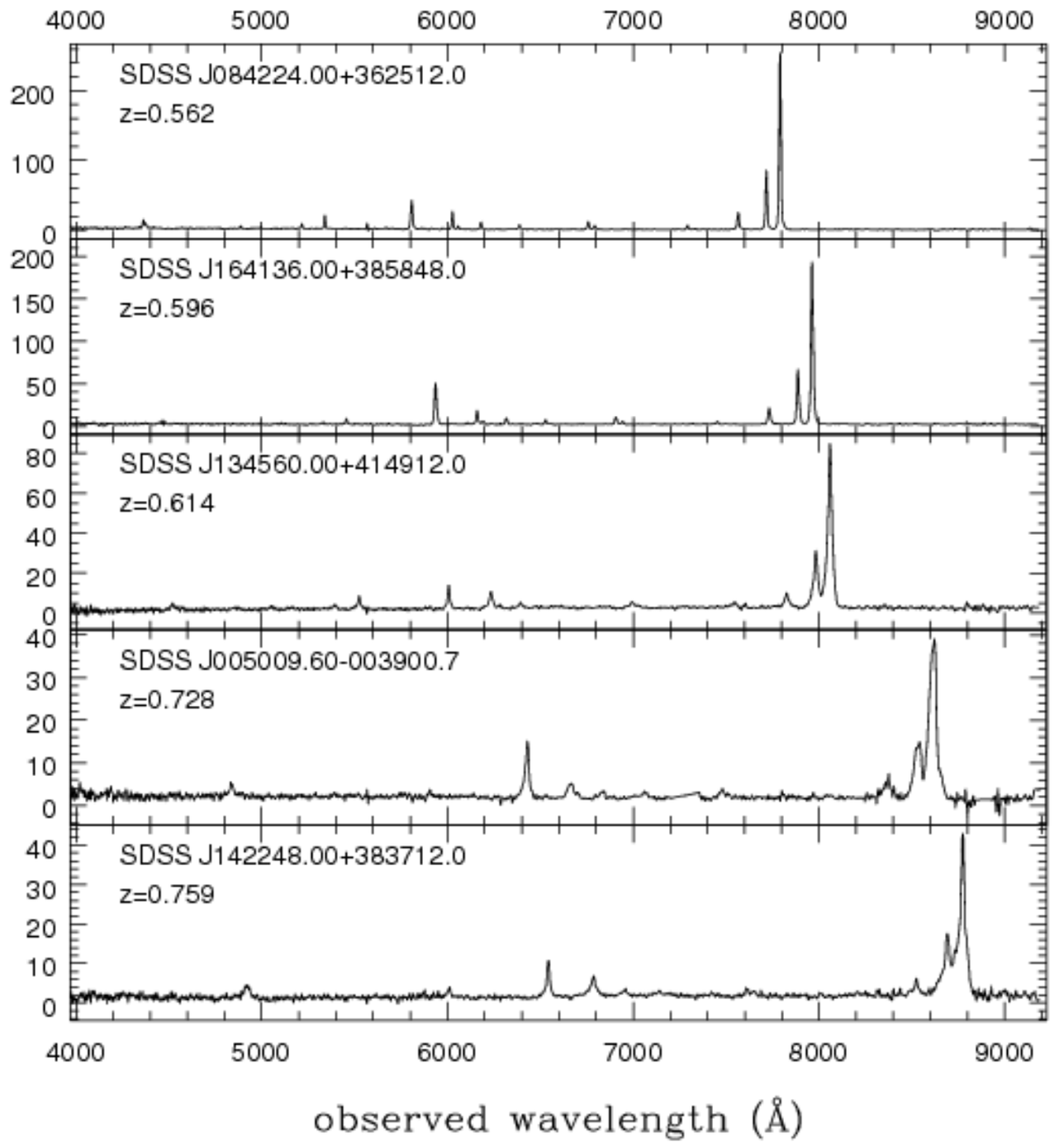


Zhao, Ho et al. (2018)

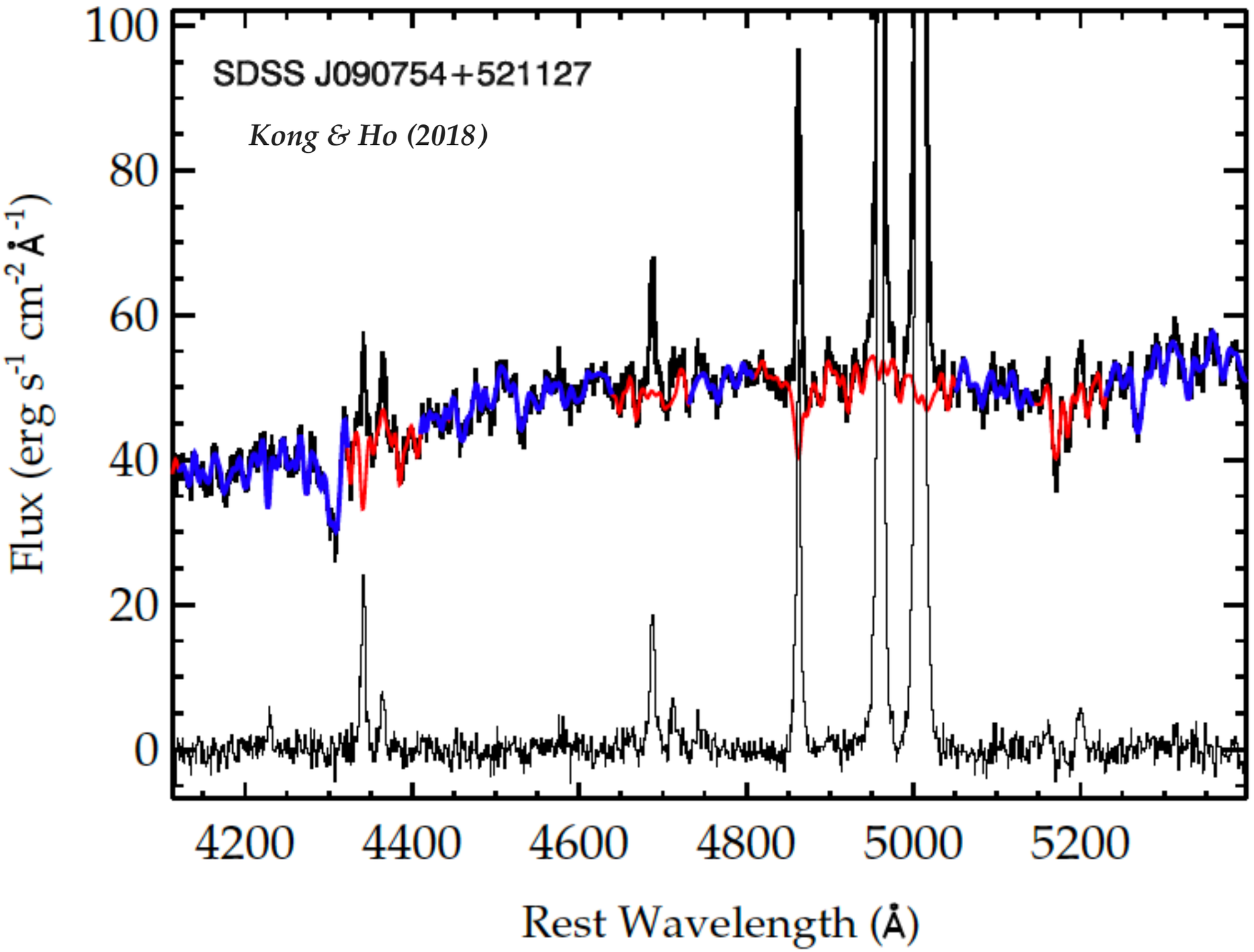
What about Type 2 AGNs?

Kong & Ho (2018)

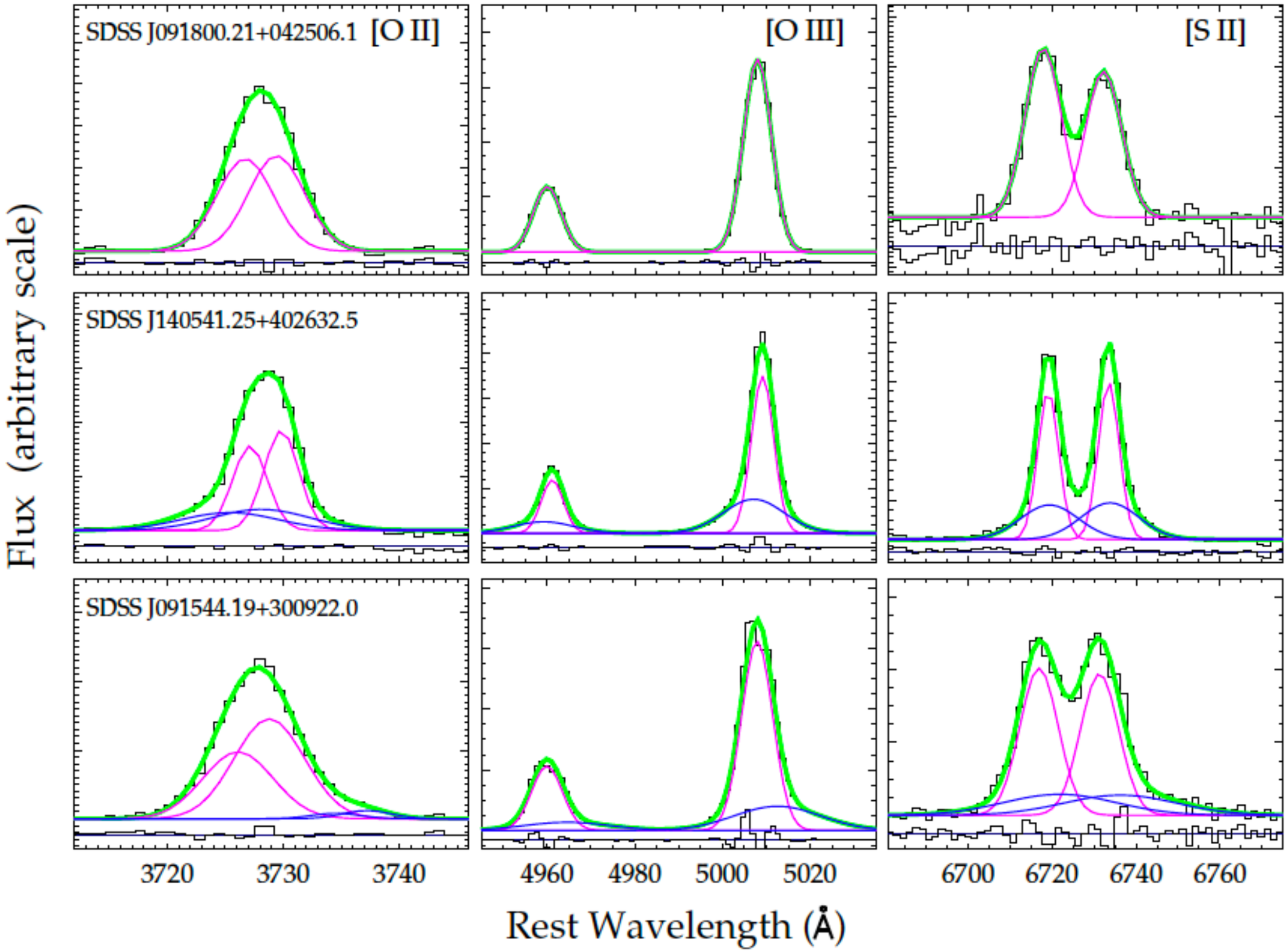




What about Type 2 AGNs?

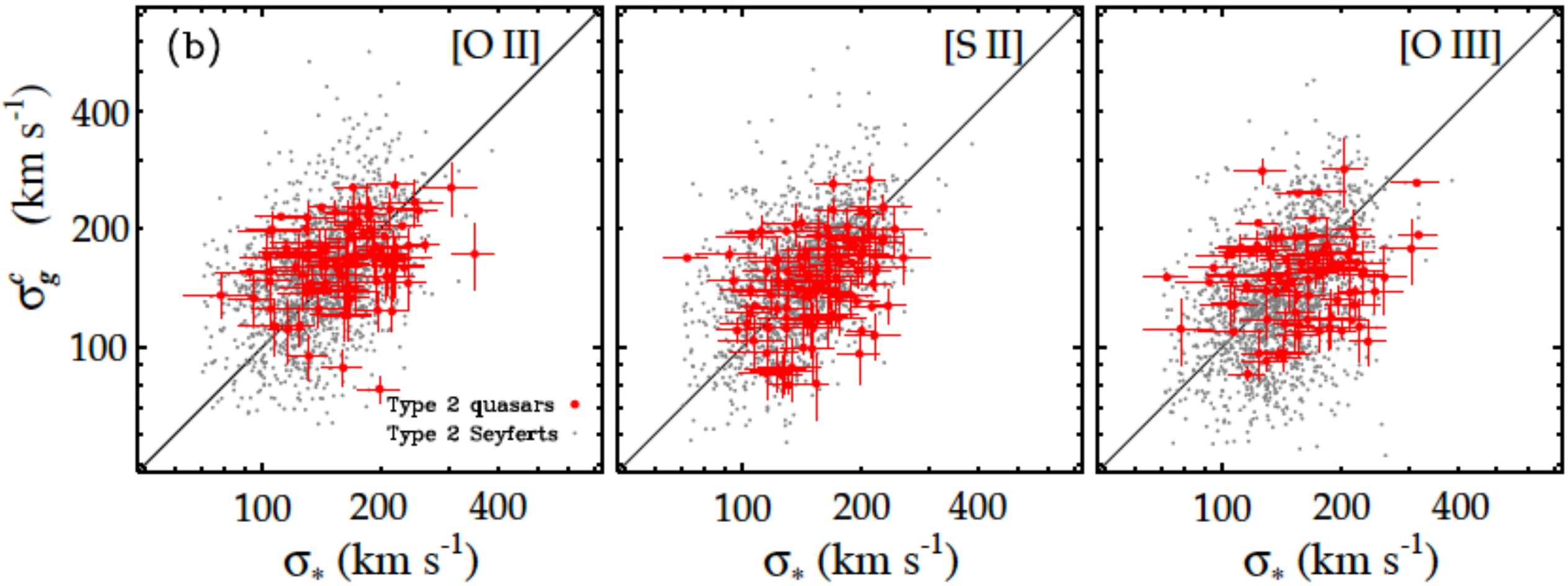


What about Type 2 AGNs?



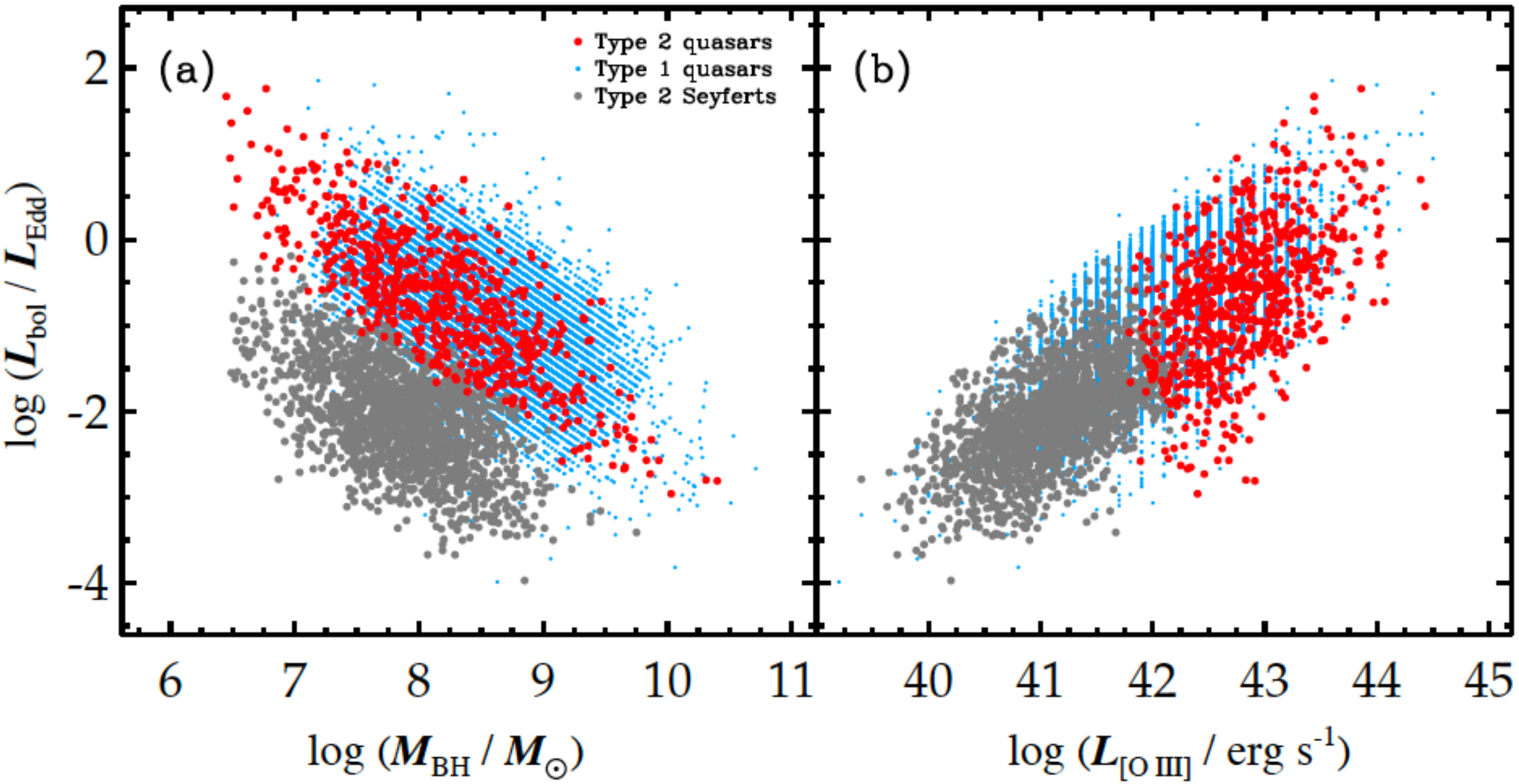
What about Type 2 AGNs?

Kong & Ho (2018)



What about Type 2 AGNs?

Kong & Ho (2018)

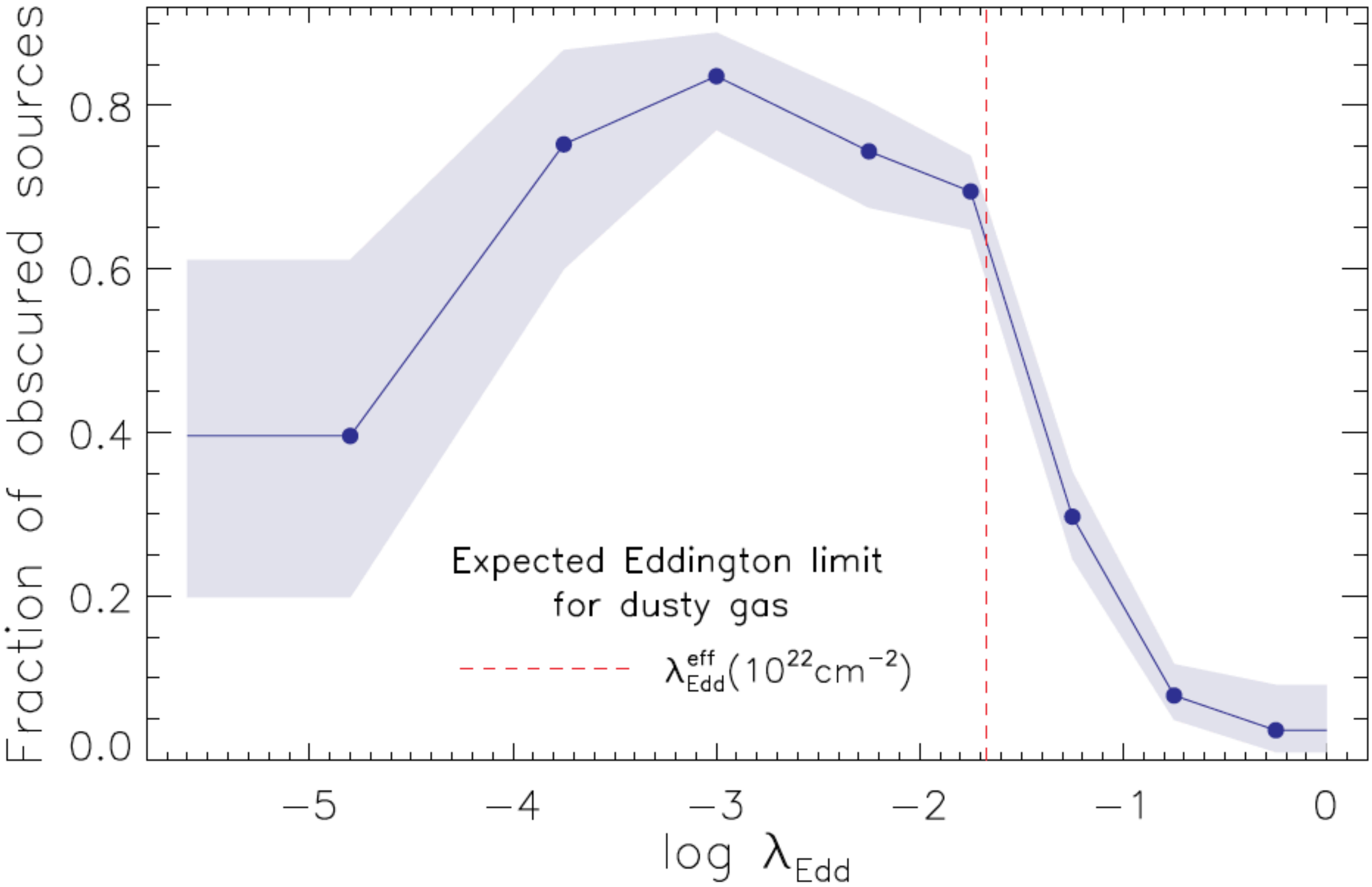


Eddington Ratio

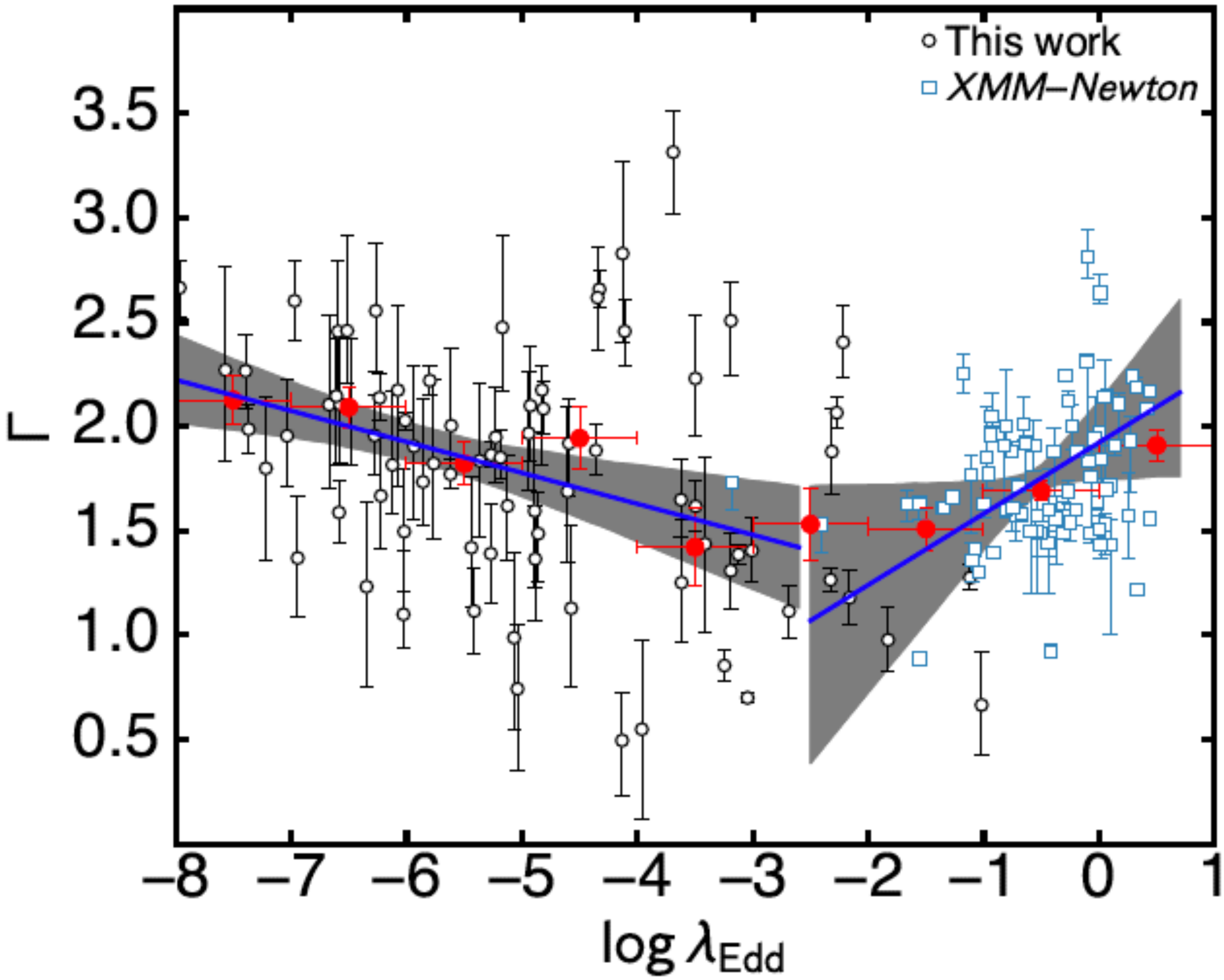
Rules Everything !

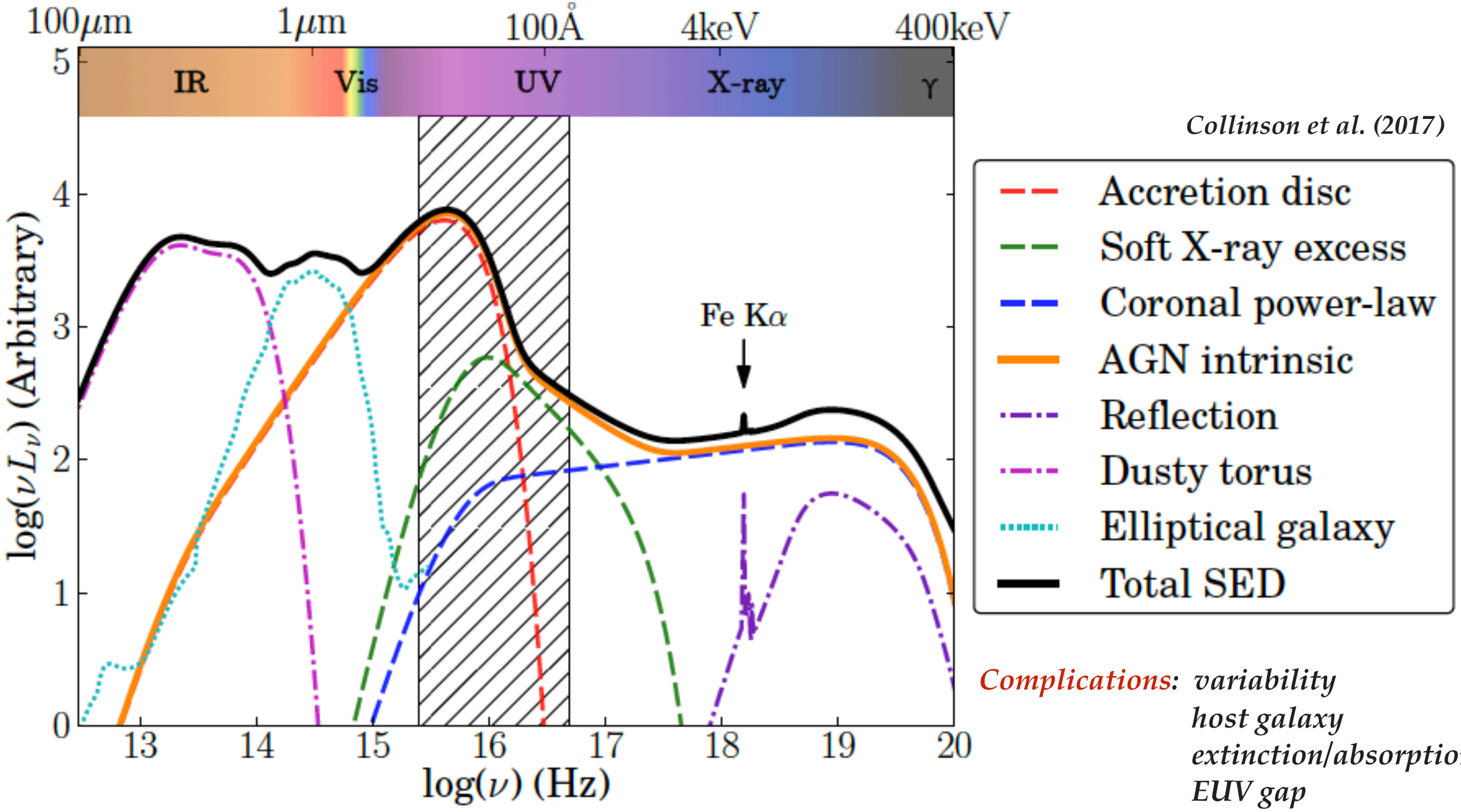
L/LEdd

Ricci et al. (2017)



She, Ho & Feng (2018)

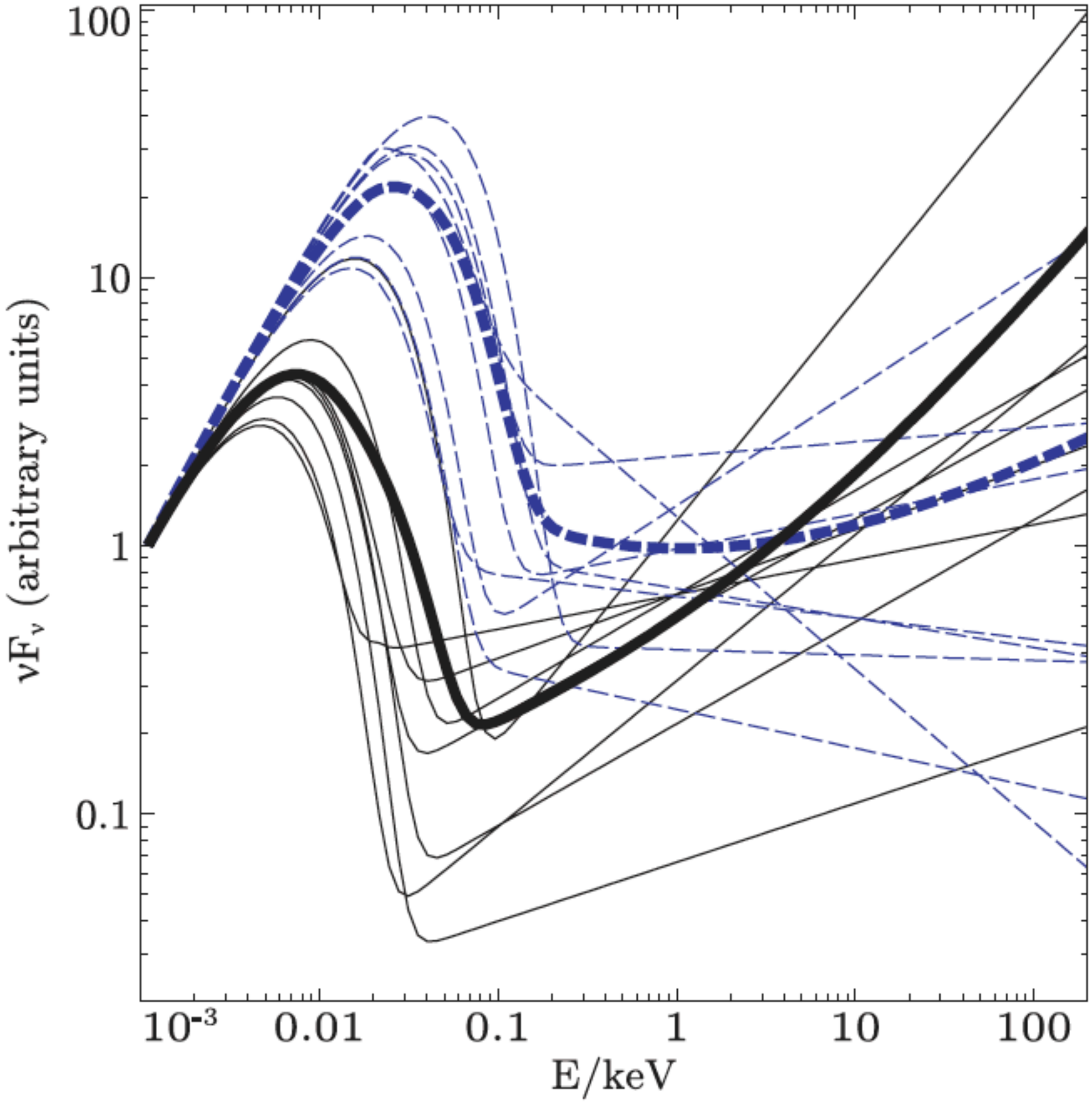




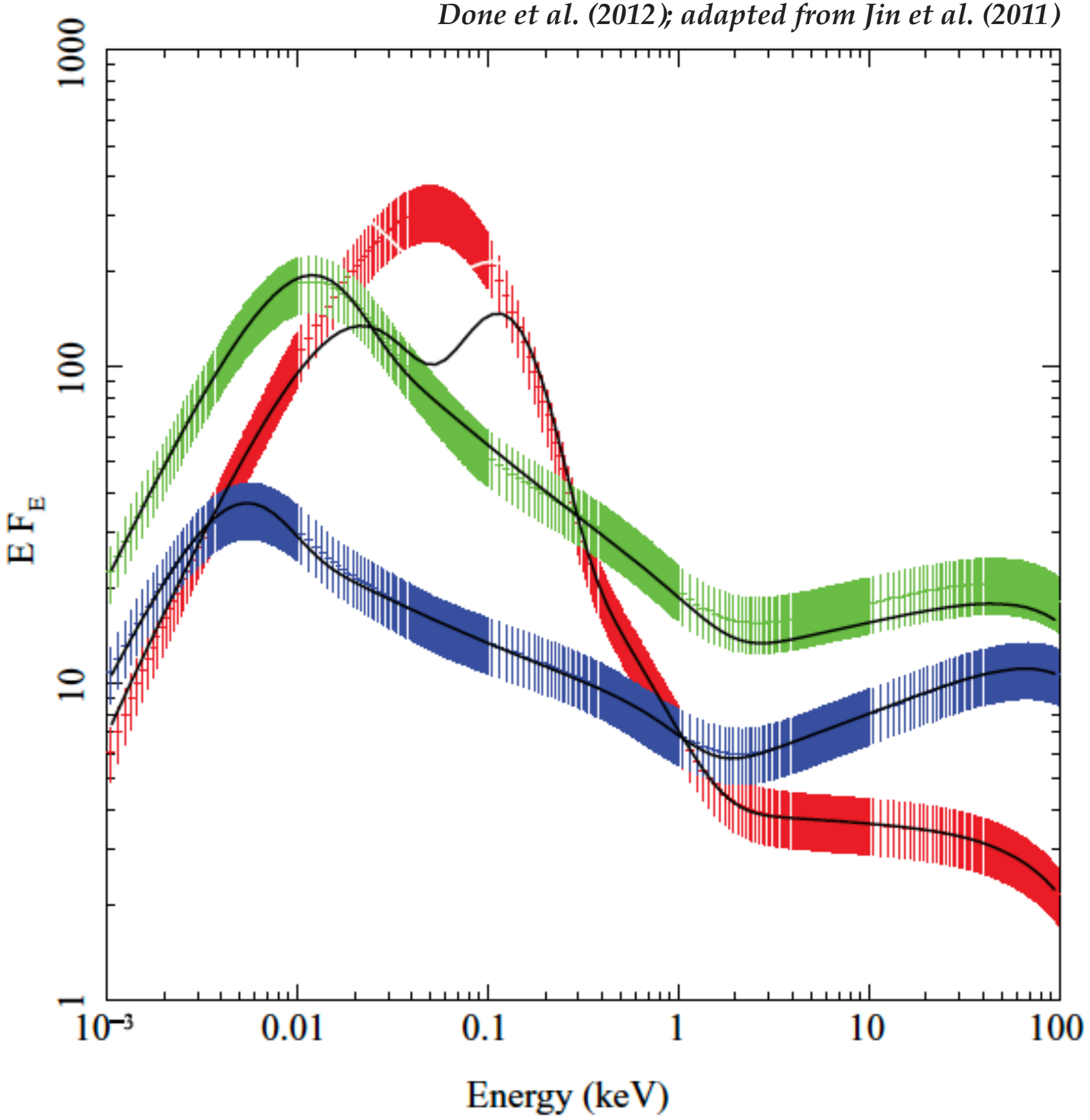
Collinson et al. (2017)

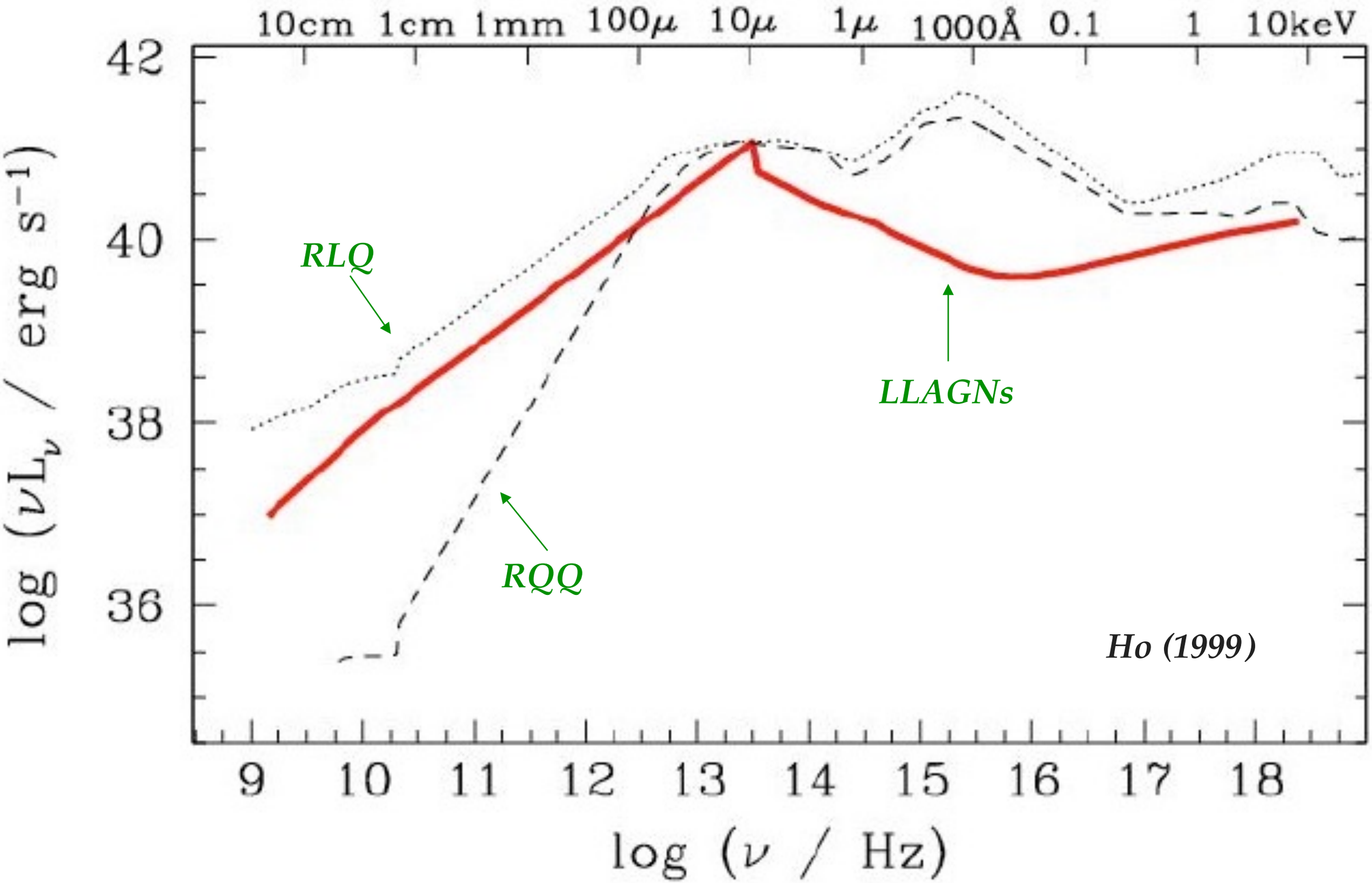
Complications: *variability*
host galaxy
extinction/absorption
EUV gap
spectral diversity

Vasudevan & Fabian (2007)

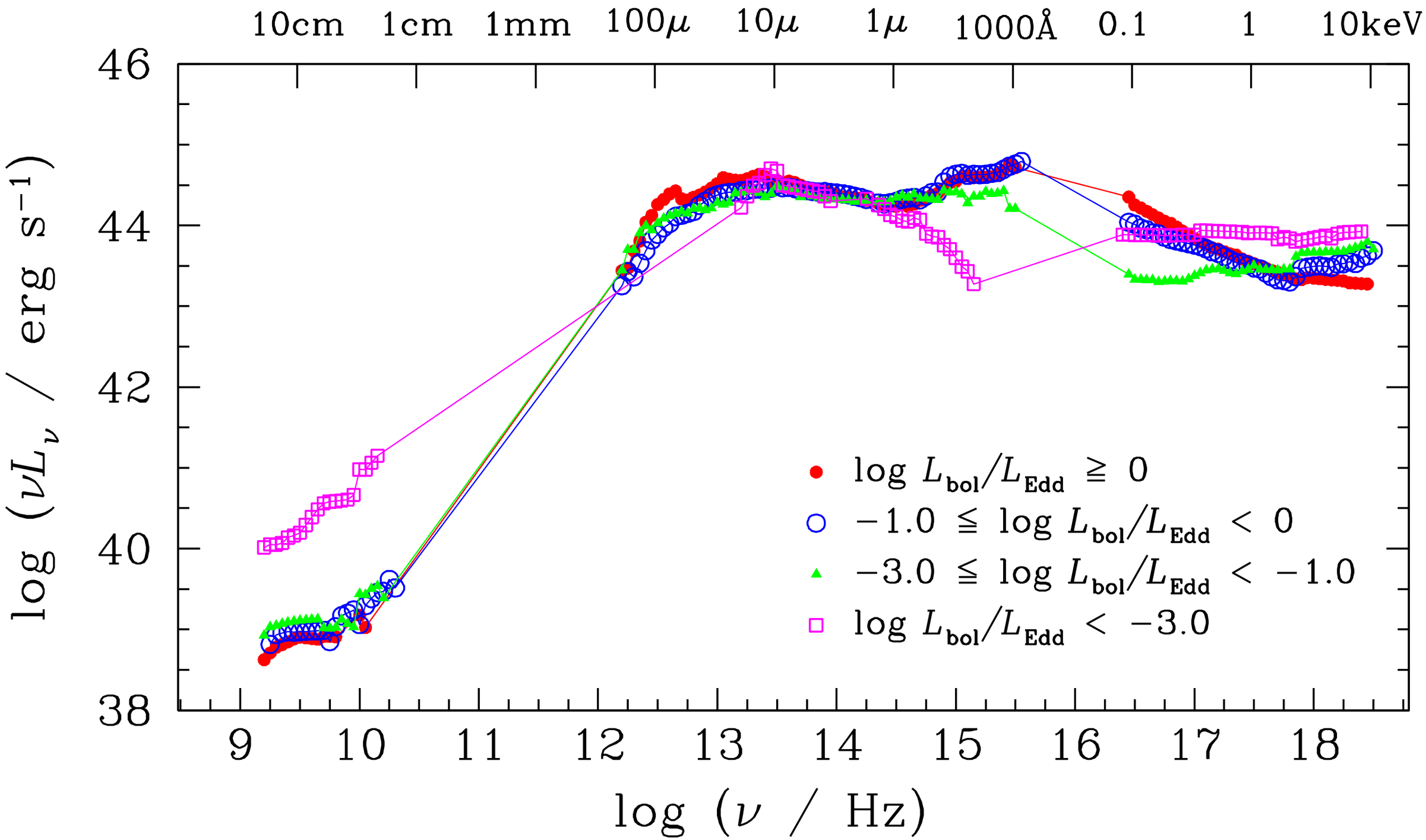


Done et al. (2012); adapted from Jin et al. (2011)




10cm
1cm
1mm
100μ
10μ
1μ
1000Å
0.1
1
10keV
42
40
38
36
log (νL_ν / erg s^-1)
RLQ
LLAGNs
RQQ
Ho (1999)
9
10
11
12
13
14
15
16
17
18
log (ν / Hz)

Ho (2004, 2008)


10cm
1cm
1mm
100μ
10μ
1μ
1000Å
0.1
1
10keV
46
44
42
40
38
log (νL_ν / erg s^-1)
9
10
11
12
13
14
15
16
17
18
log (ν / Hz)
log L_bol/L_Edd ≧ 0
−1.0 ≦ log L_bol/L_Edd < 0
−3.0 ≦ log L_bol/L_Edd < −1.0
log L_bol/L_Edd < −3.0

Bolometric Corrections

$$L_{\mathrm{bol}} = \kappa_{\mathrm{x}}\ L_{\mathrm{x}}$$

x = 5100 Ang

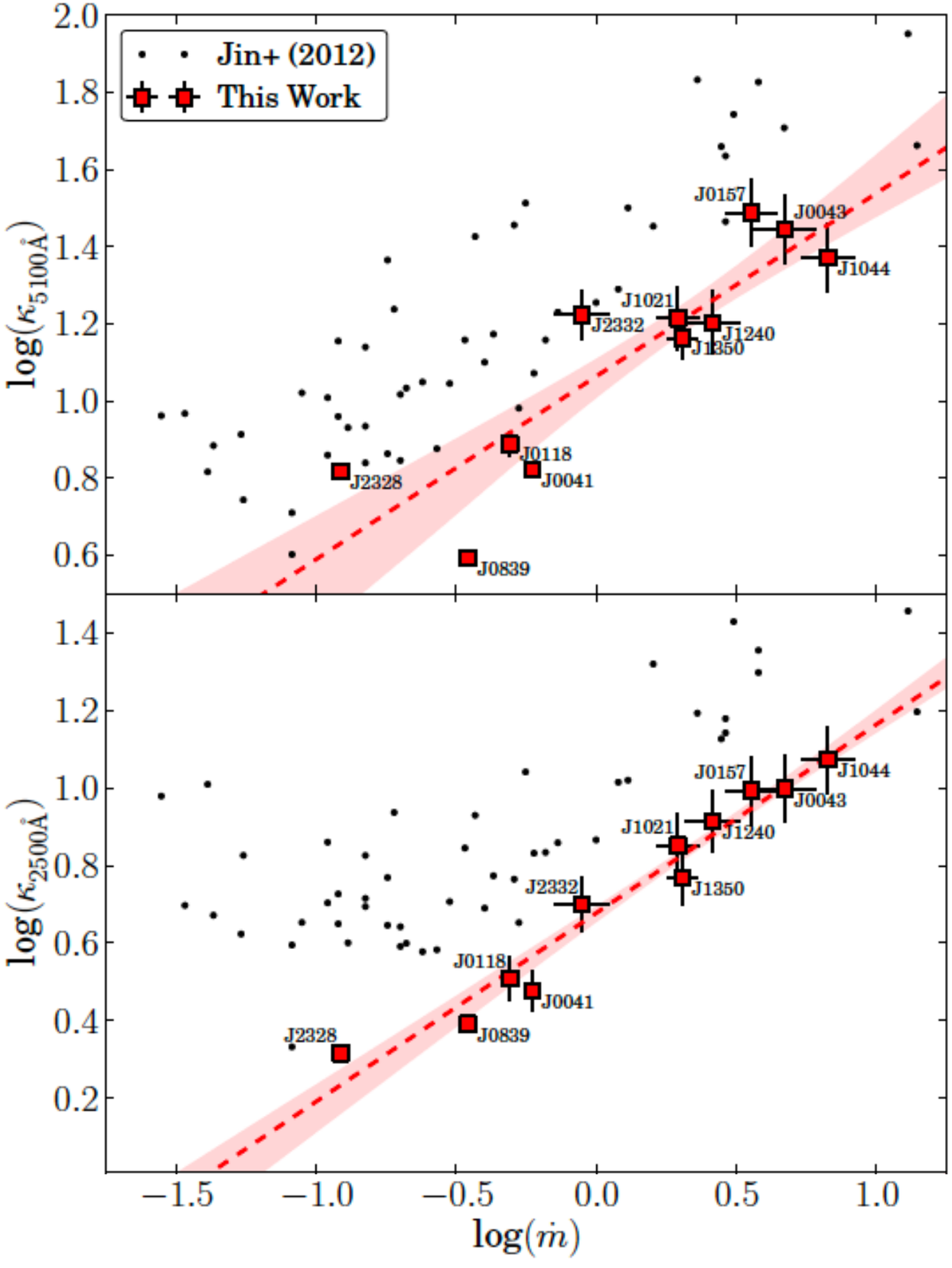
2–10 keV

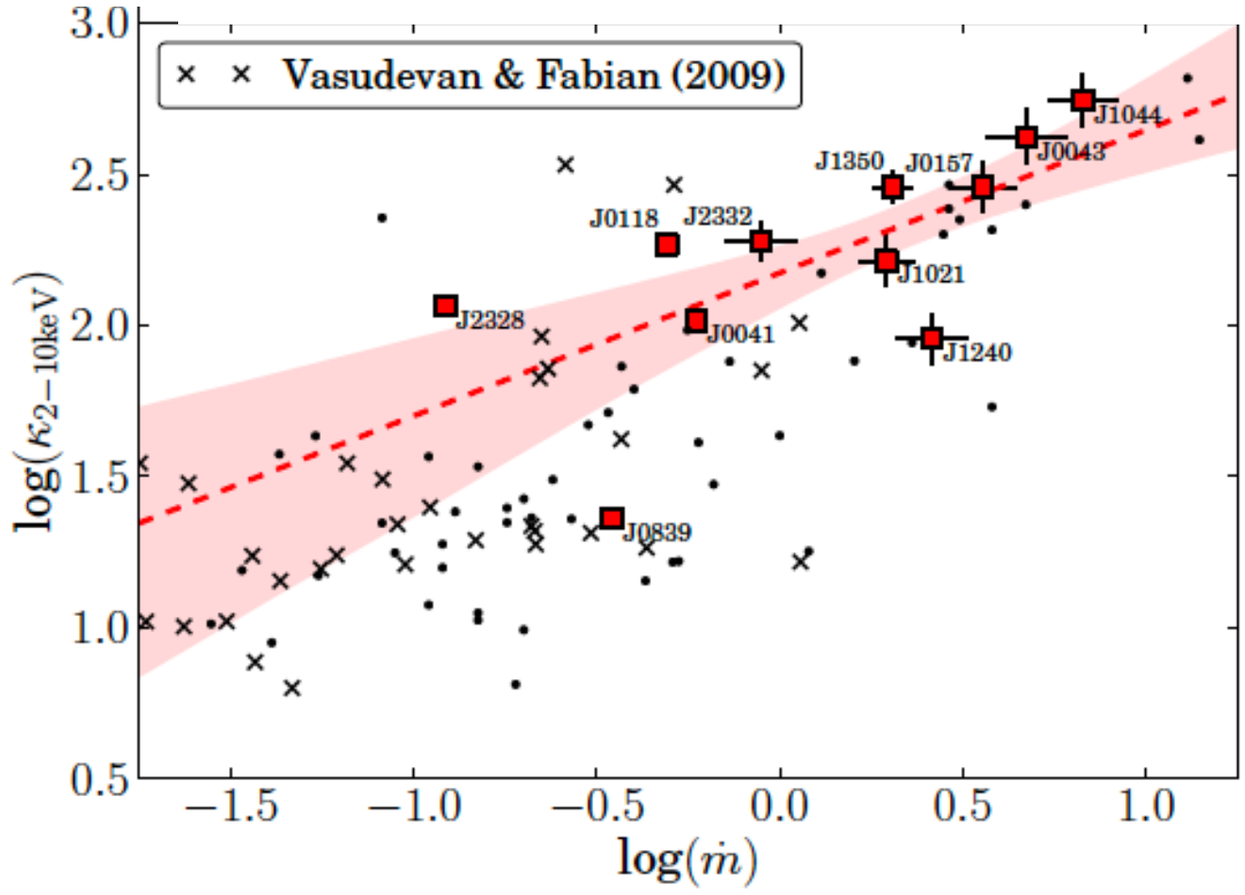
[O III] 5007

etc …

κ_{x} ***is not a constant !***

Collinson et al. (2017)



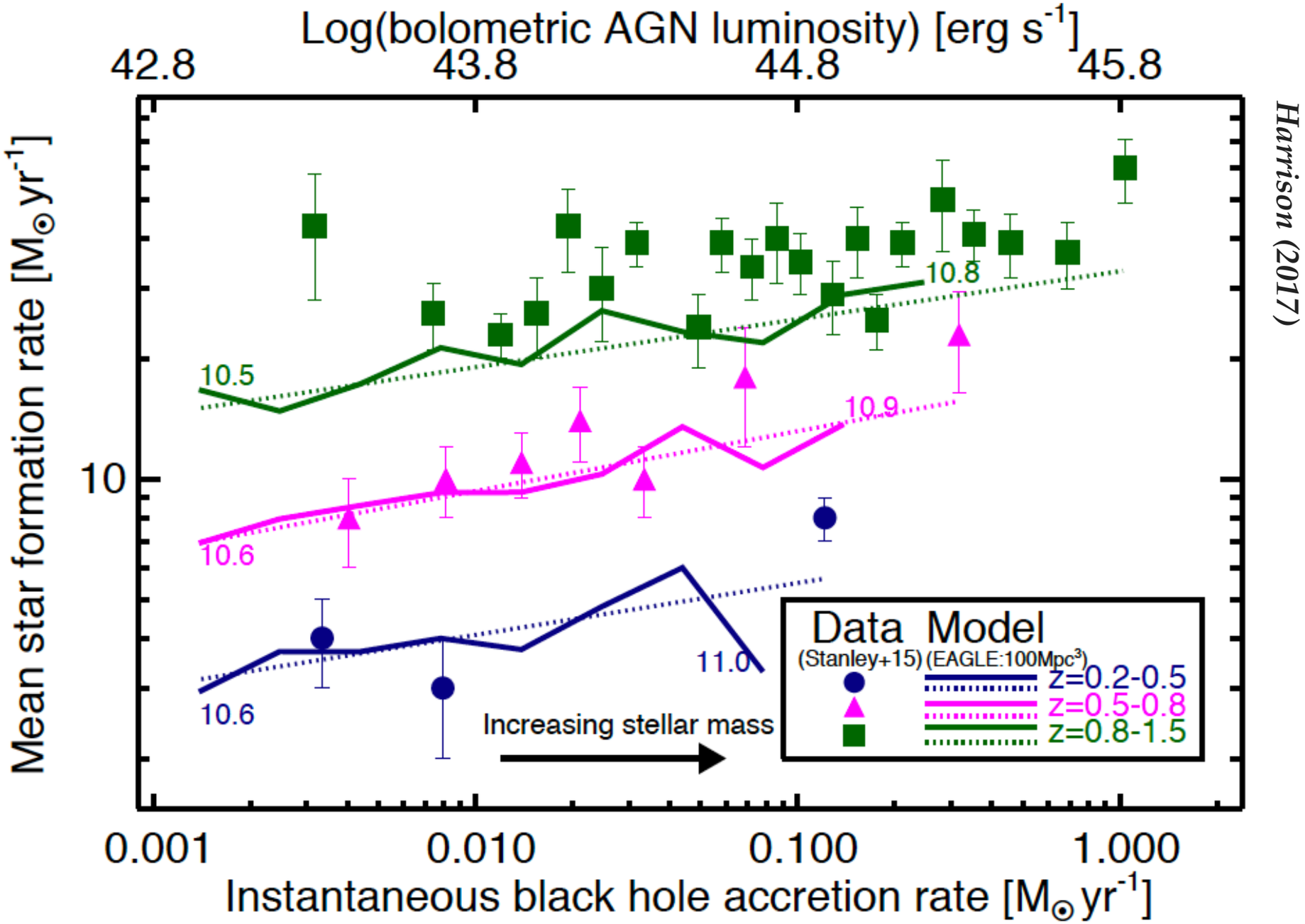


Mass Accretion Rates

$$L_{\rm bol} = \eta \, \dot{M} \, c^2$$

Mass Accretion Rates

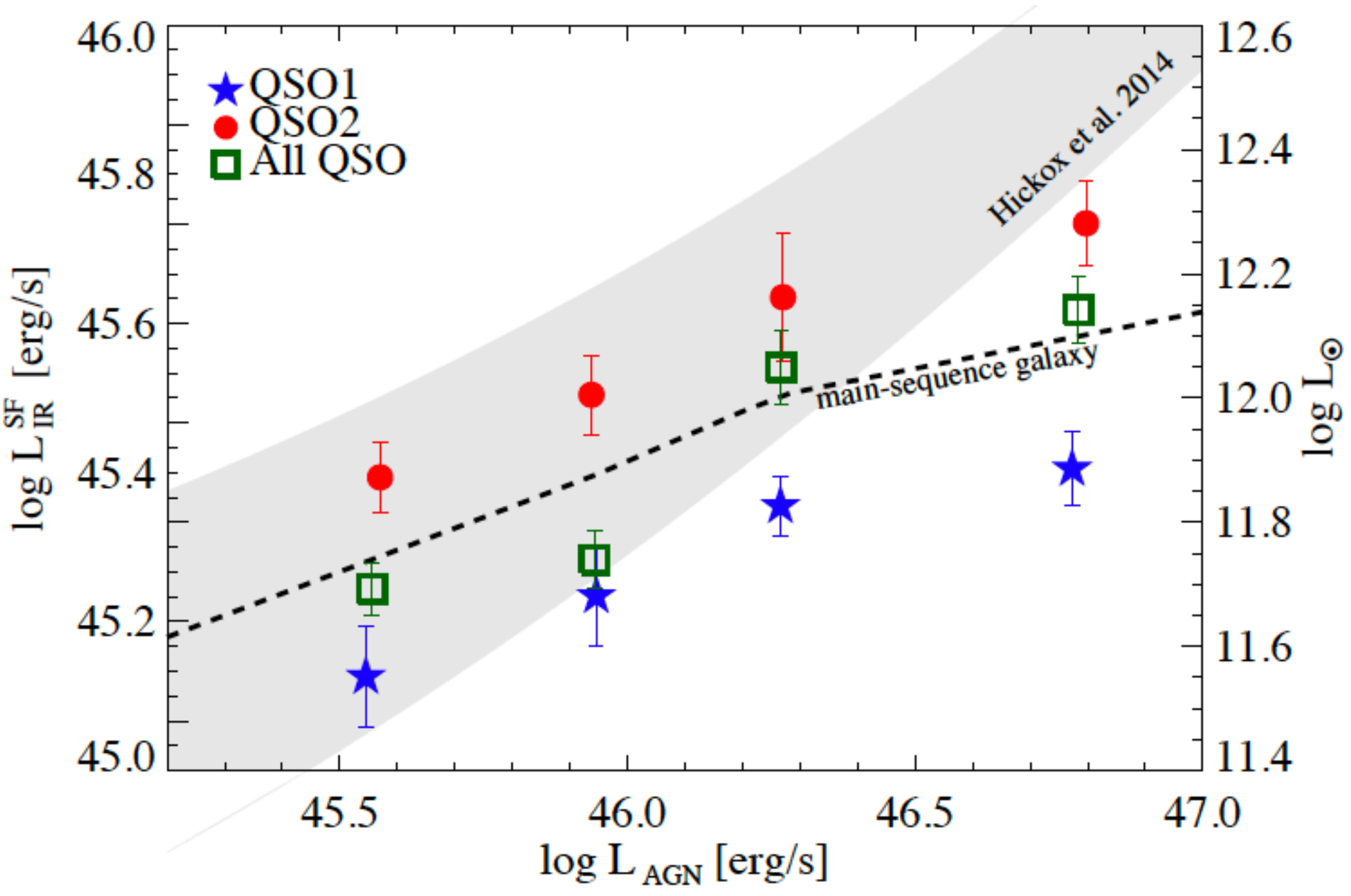
$$L_{\mathrm{bol}} = \eta \, \dot{M} \, c^2$$



Mass Accretion Rates

$$L_{\rm bol} = \eta \, \dot{M} \, c^2$$

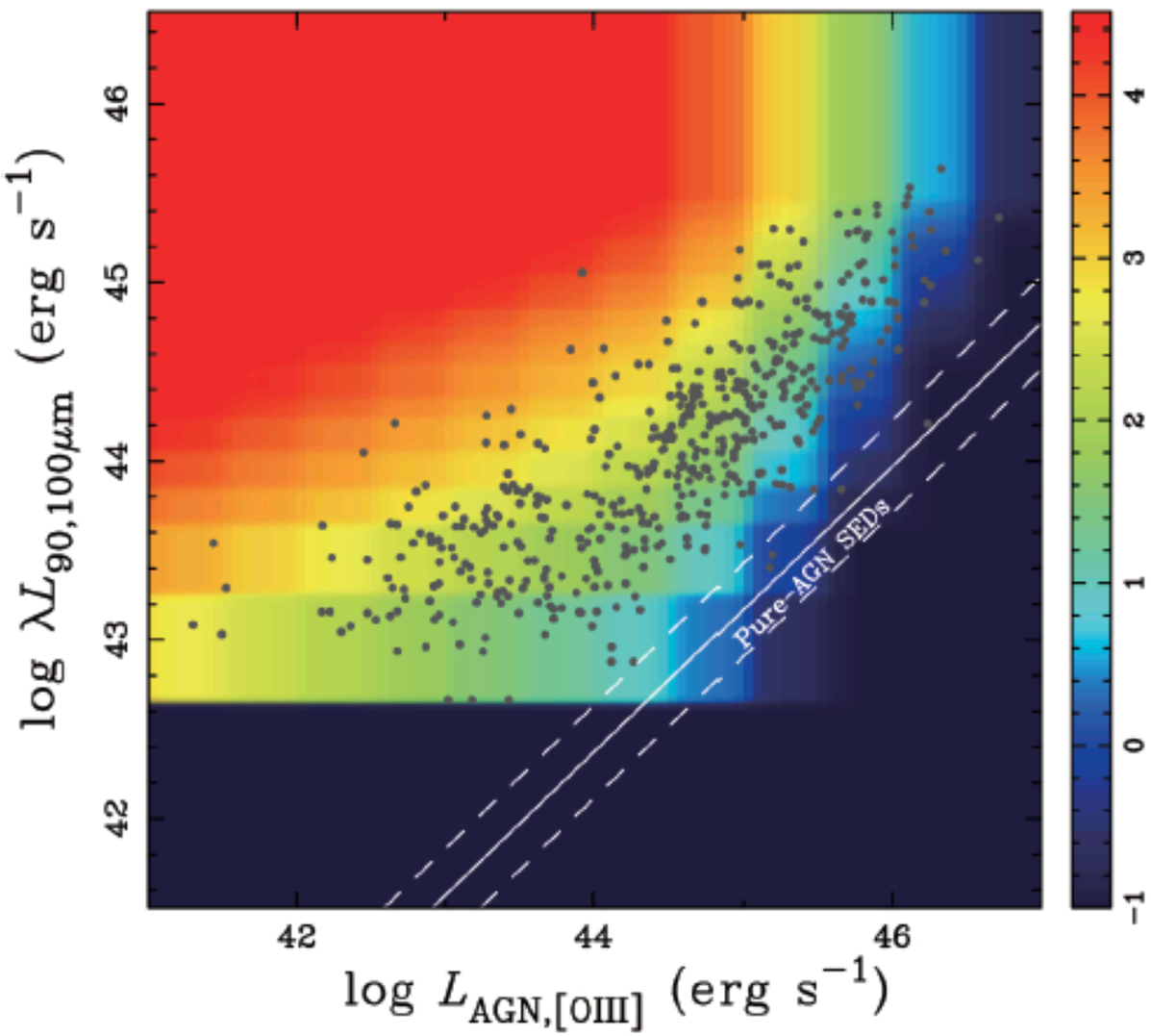
Chen et al. (2014)

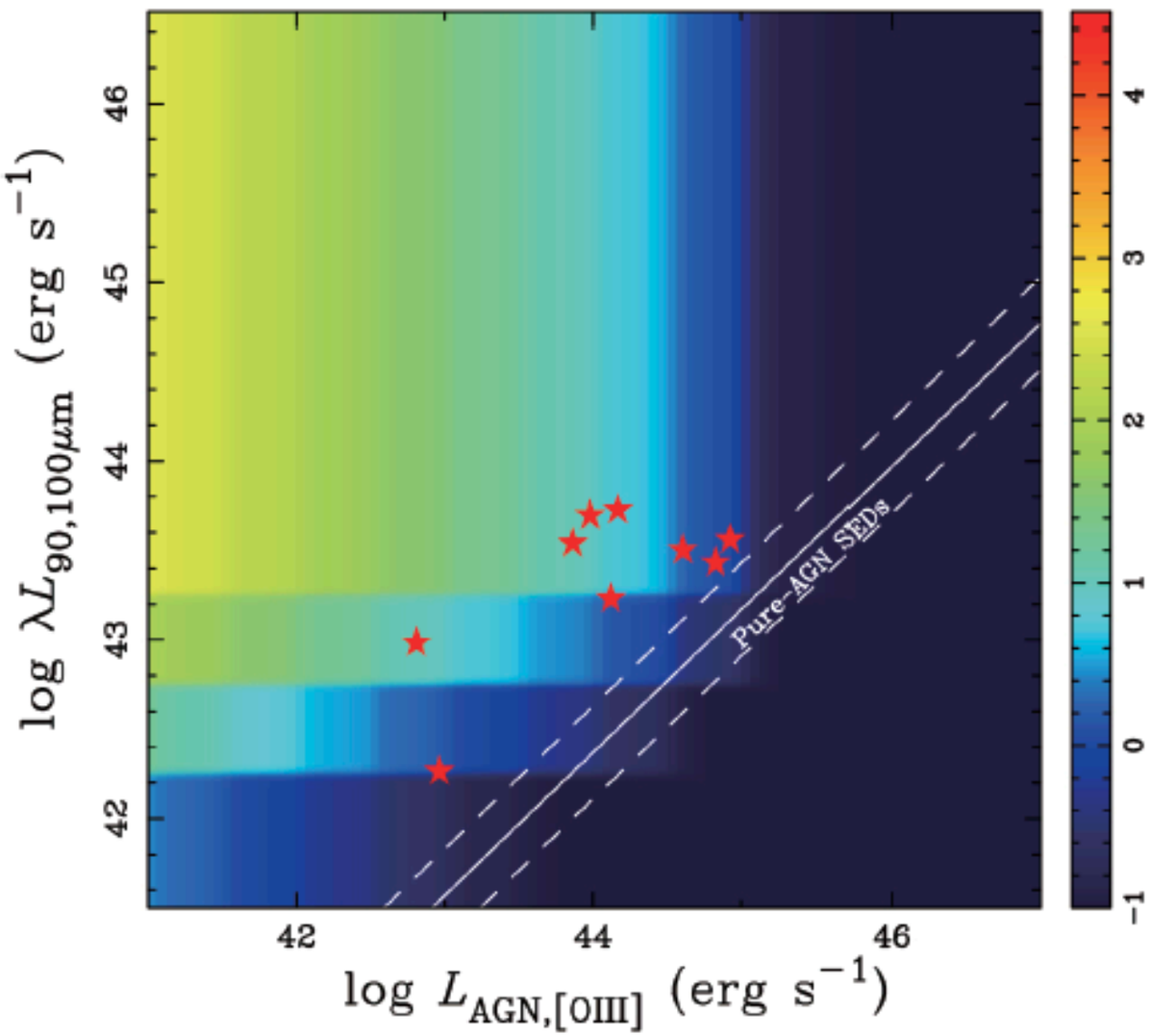


Mass Accretion Rates

$$L_{\rm bol} = \eta \, \dot{M} \, c^2$$

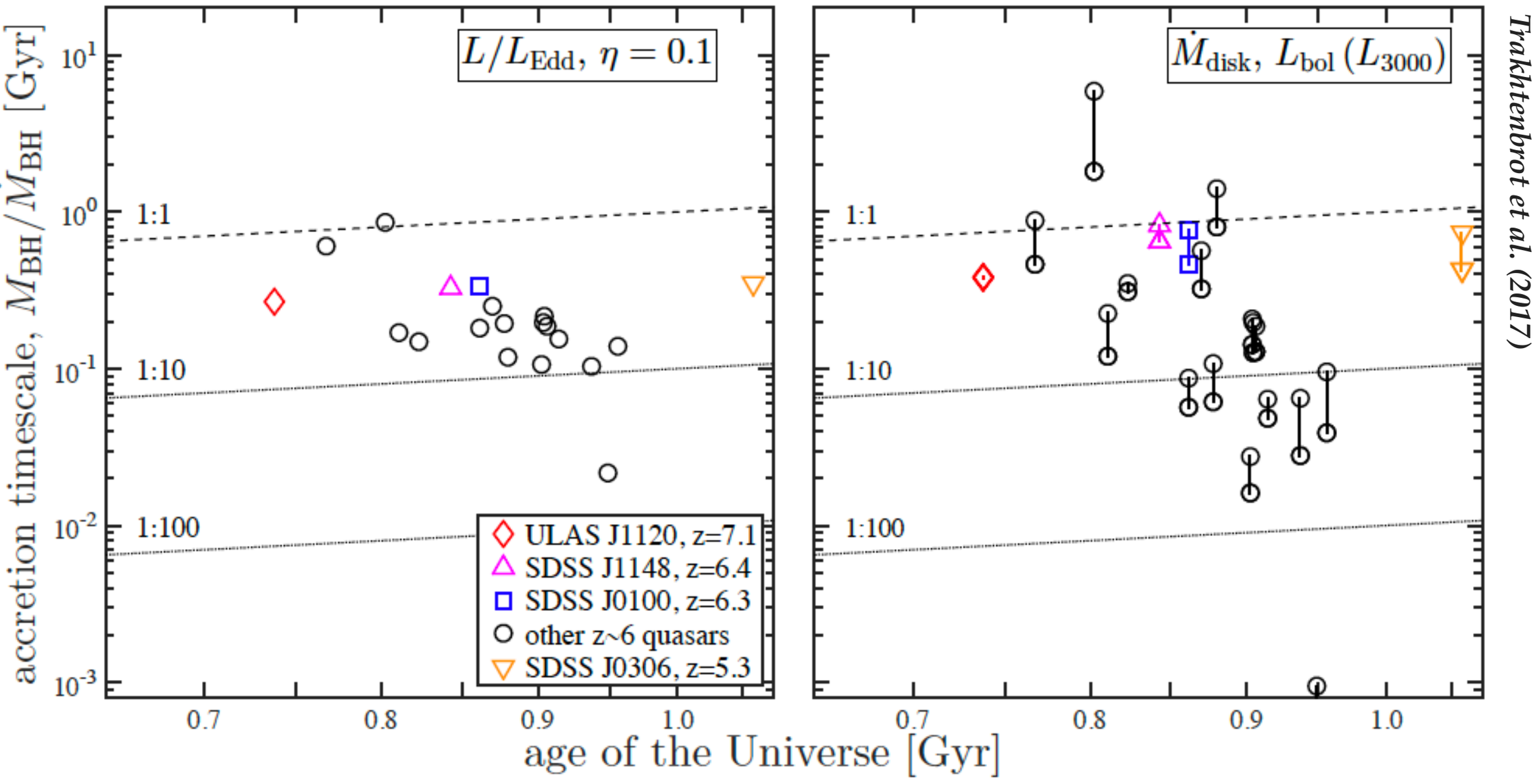
Matsuoka et al. (2015)





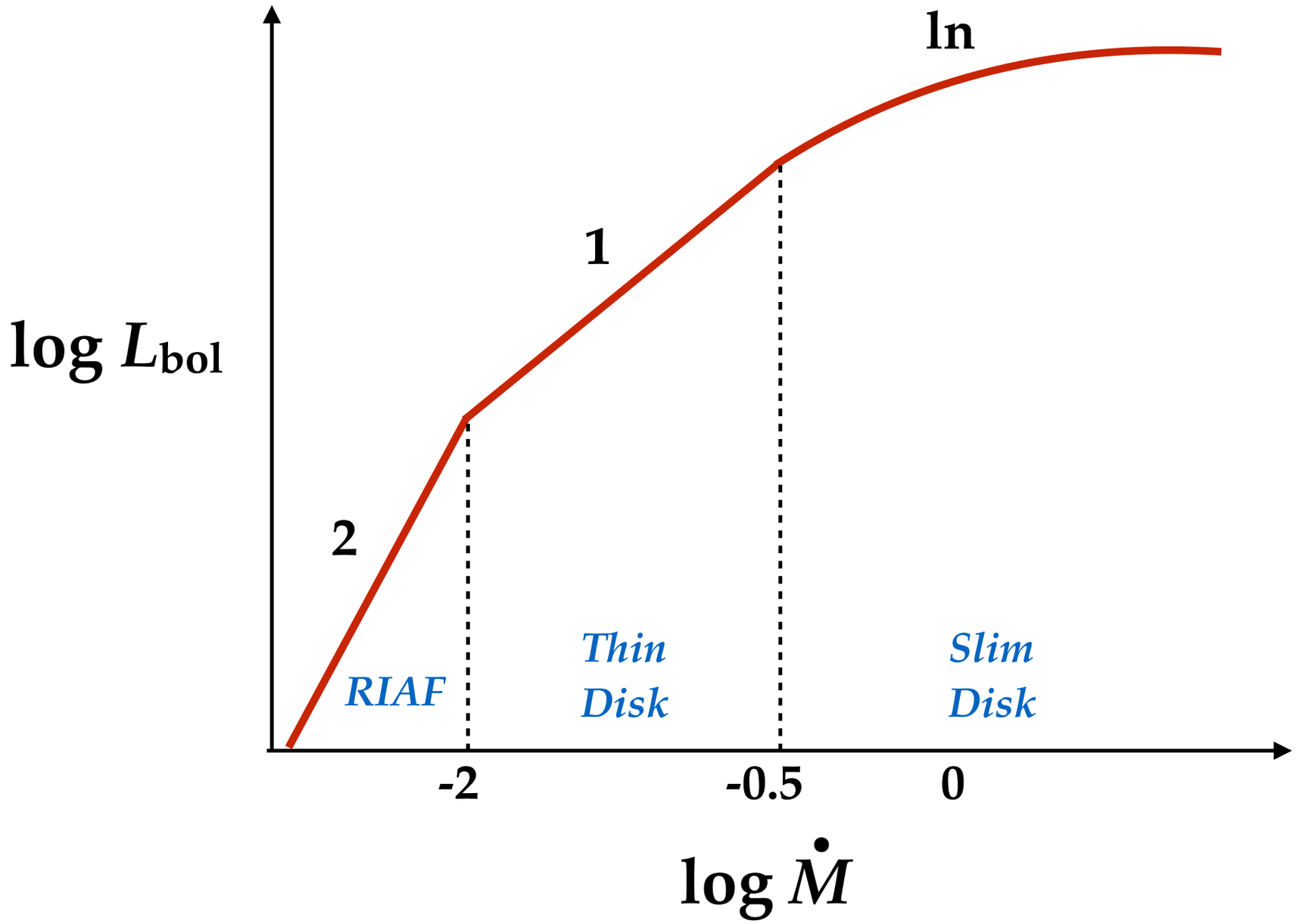
Mass Accretion Rates

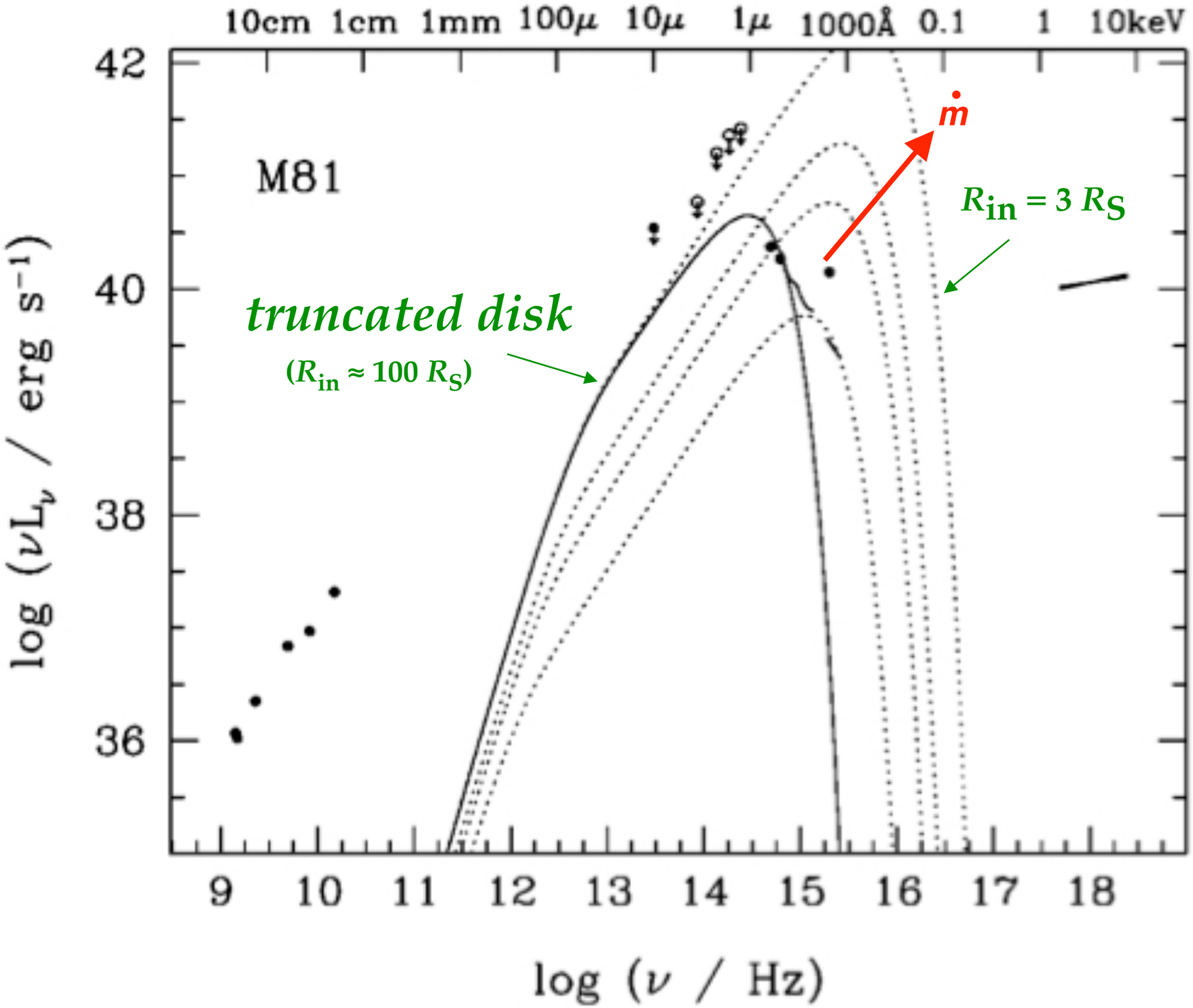
$$L_{\rm bol} = \eta \, \dot{M} \, c^2$$

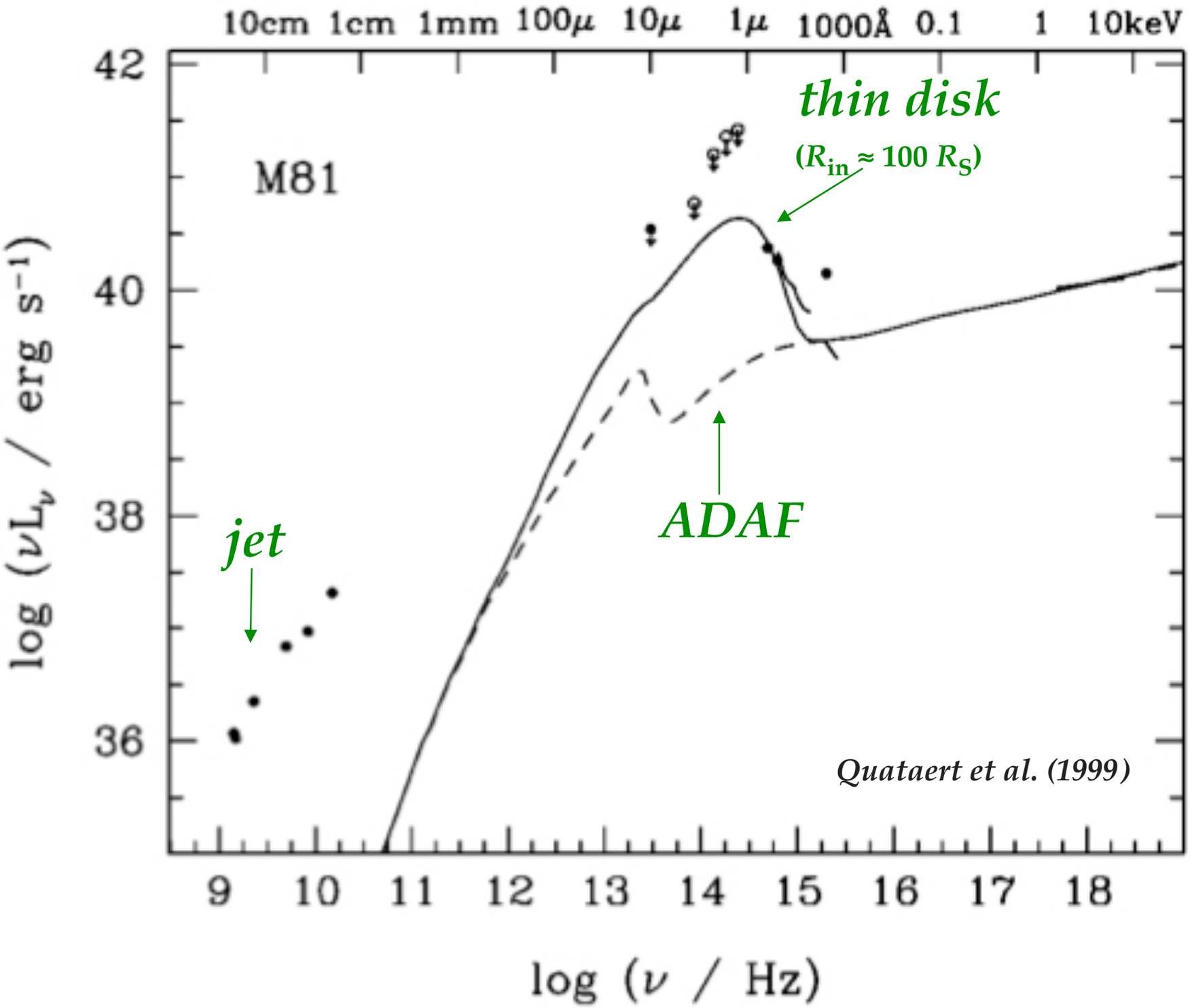


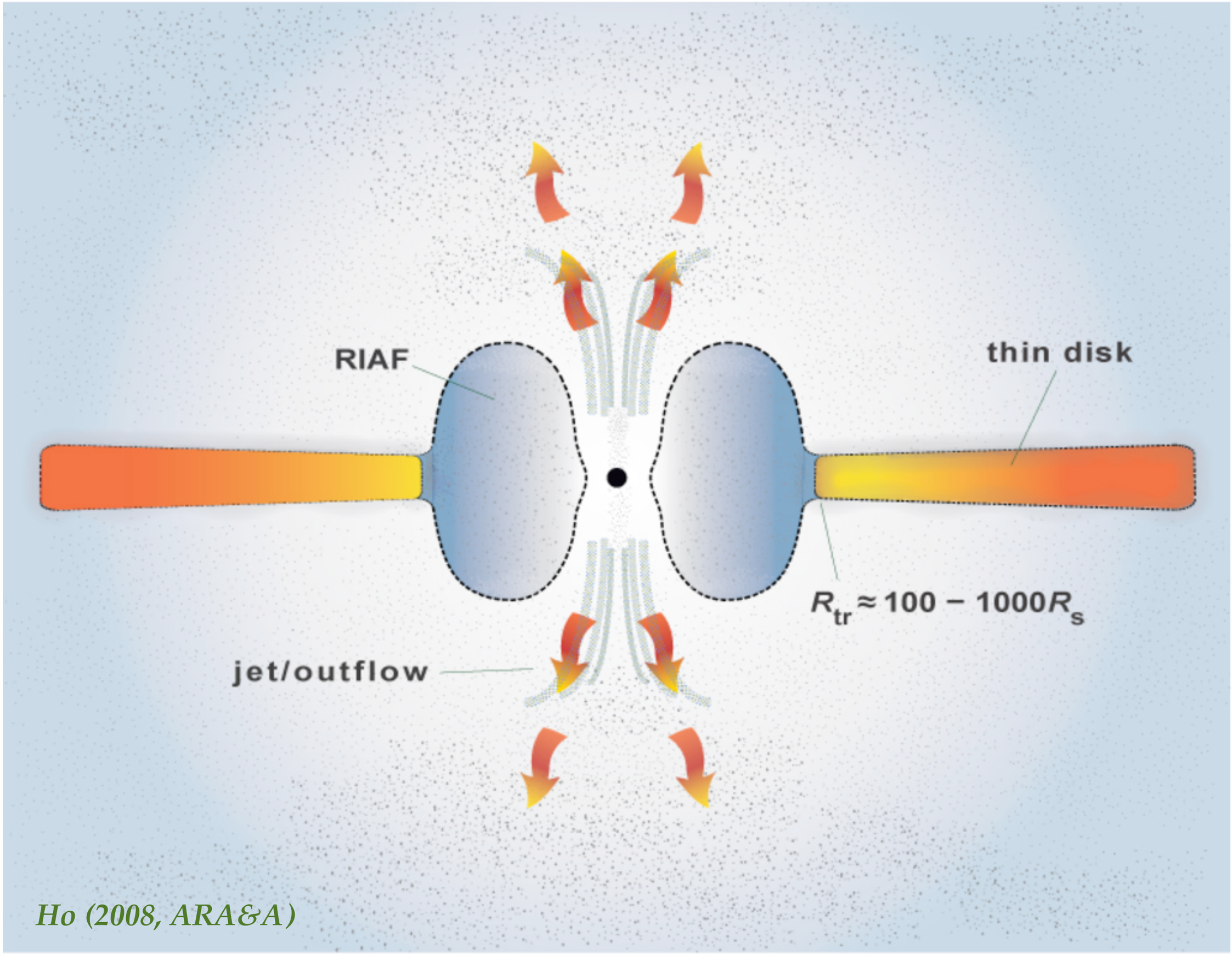
Mass Accretion Rates

$$L_{\rm bol} = \eta \, \dot{M} \, c^2$$

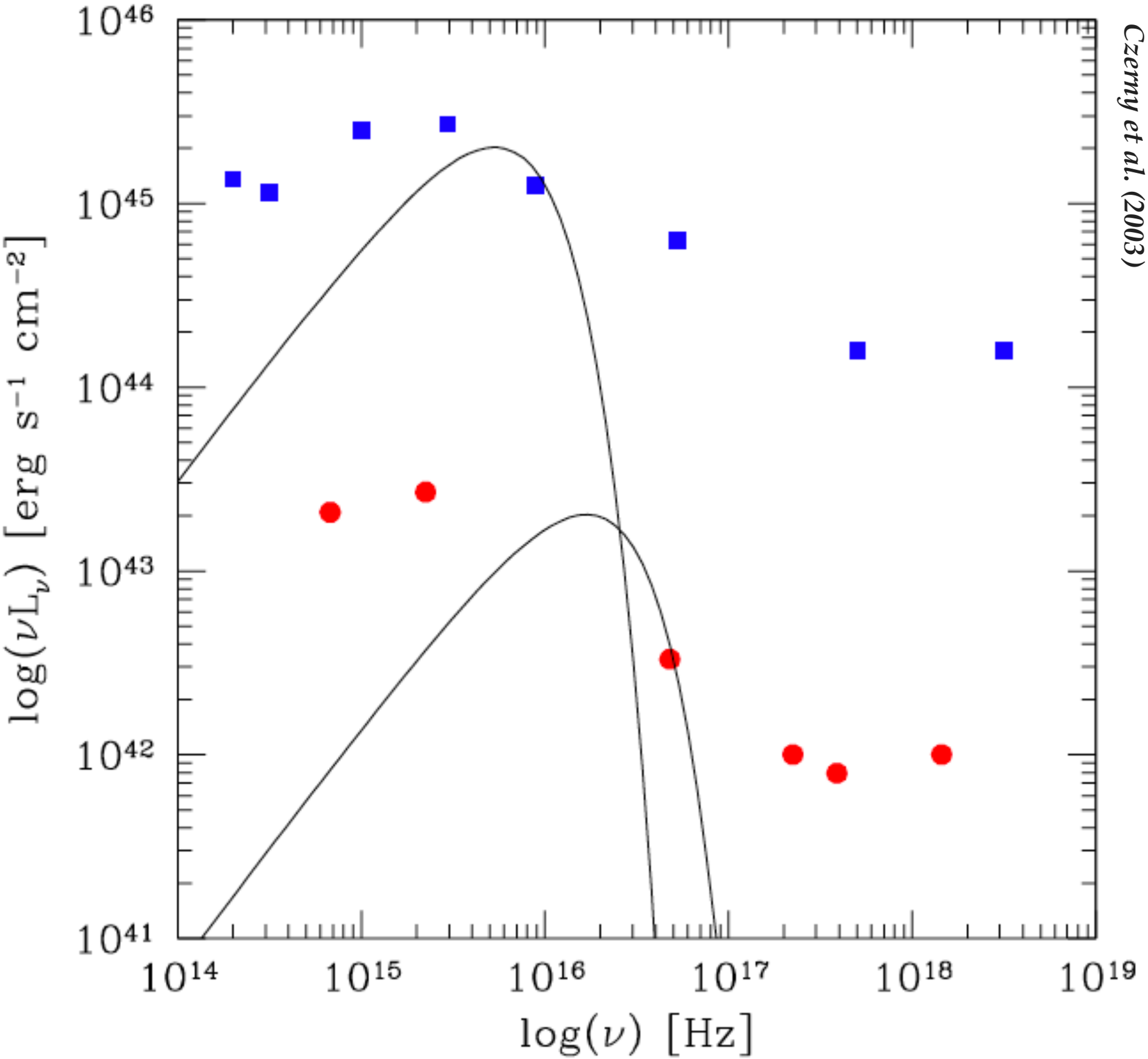



10cm
1cm
1mm
100μ
10μ
1μ
1000Å
0.1
1
10keV
M81
truncated disk
($R_{in} \approx 100\ R_S$)
$\dot{m}$
$R_{in} = 3\ R_S$
log (νL_ν / erg s^{-1})
log (ν / Hz)
42
40
38
36
9
10
11
12
13
14
15
16
17
18

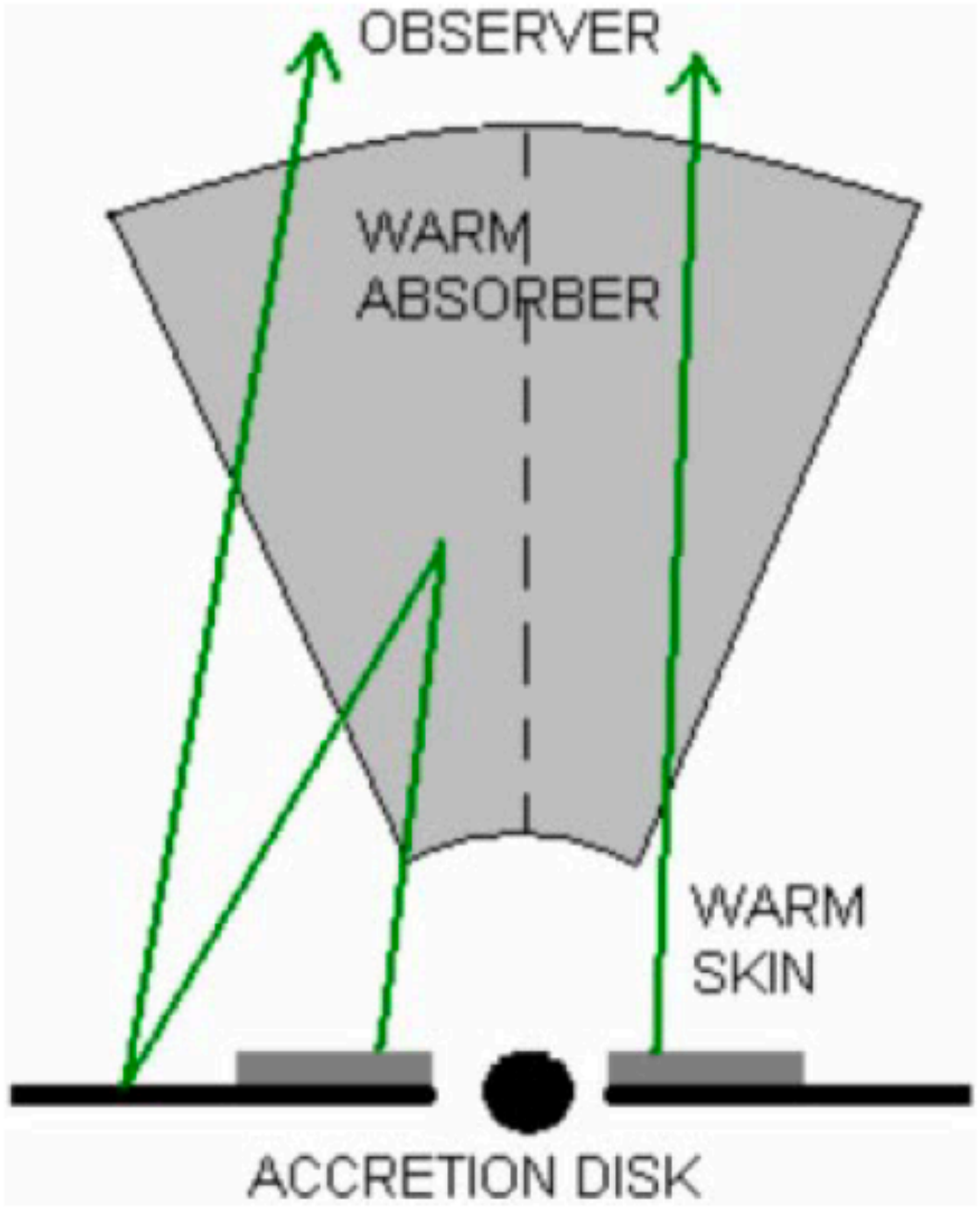

10cm 1cm 1mm 100μ 10μ 1μ 1000Å 0.1 1 10keV
M81
thin disk
($R_{in} \approx 100\ R_S$)
ADAF
jet
Quataert et al. (1999)
log (νL_ν / erg s^{-1})
log (ν / Hz)
42
40
38
36
9 10 11 12 13 14 15 16 17 18

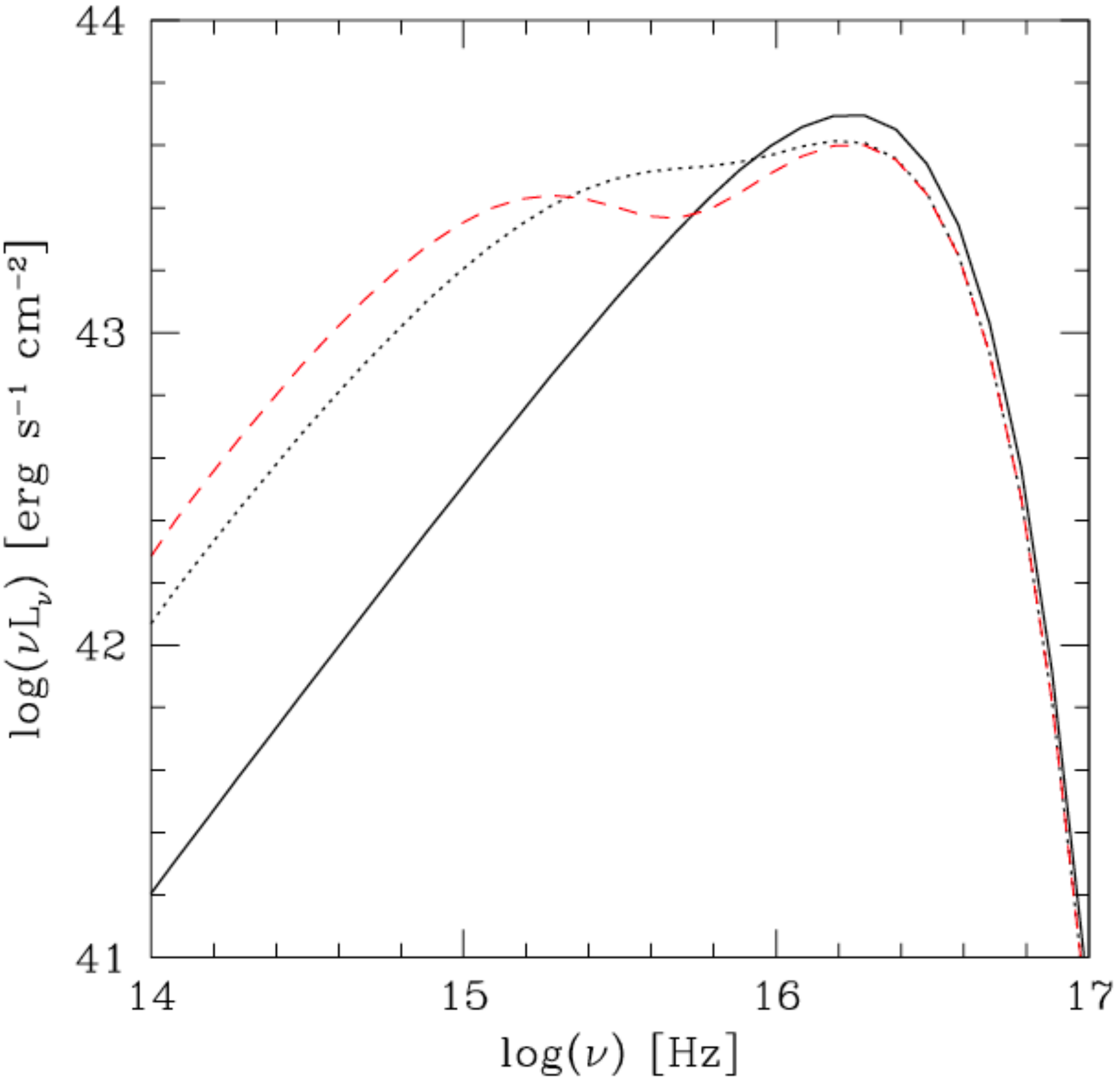


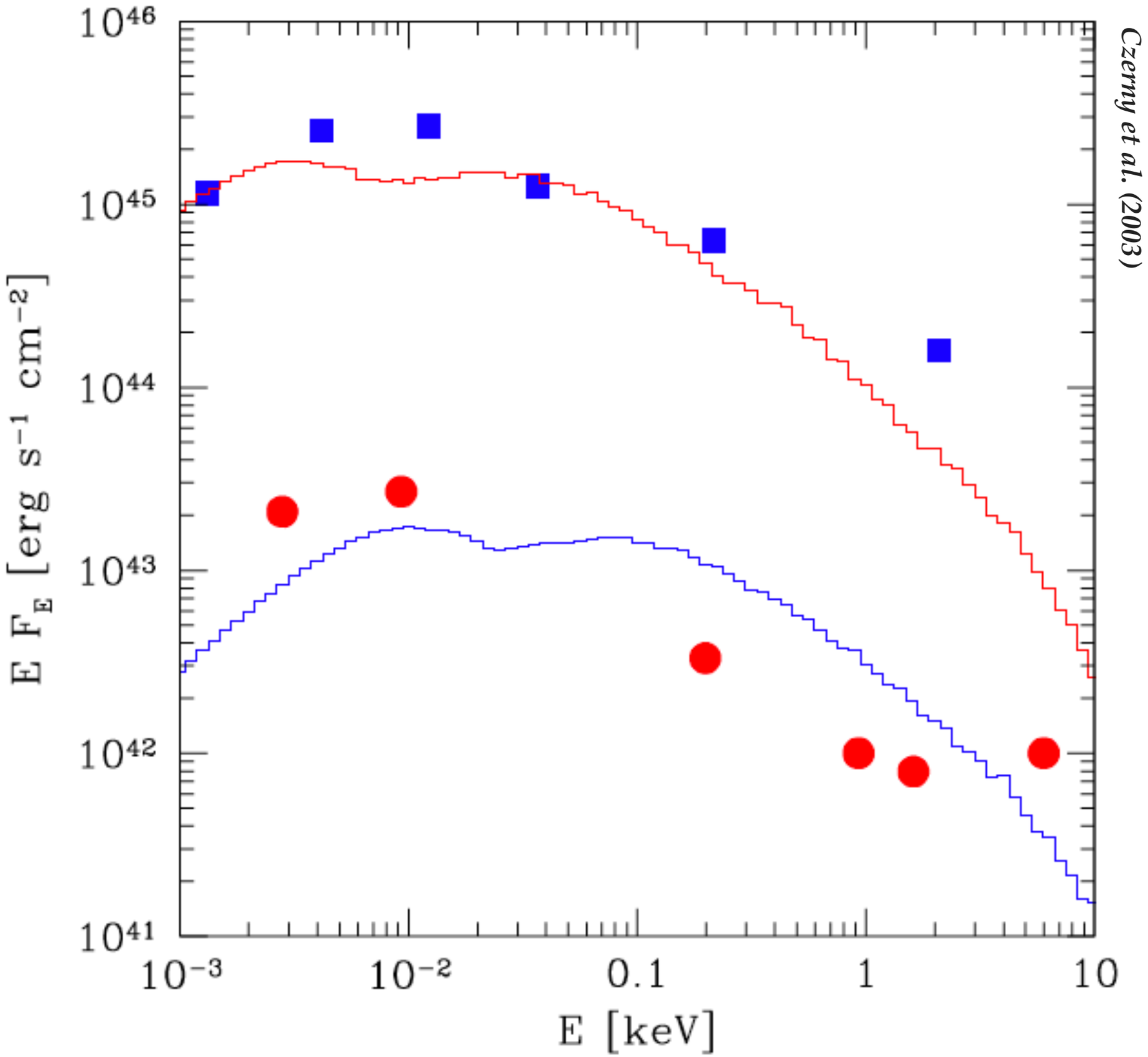
Ho (2008, ARA&A)



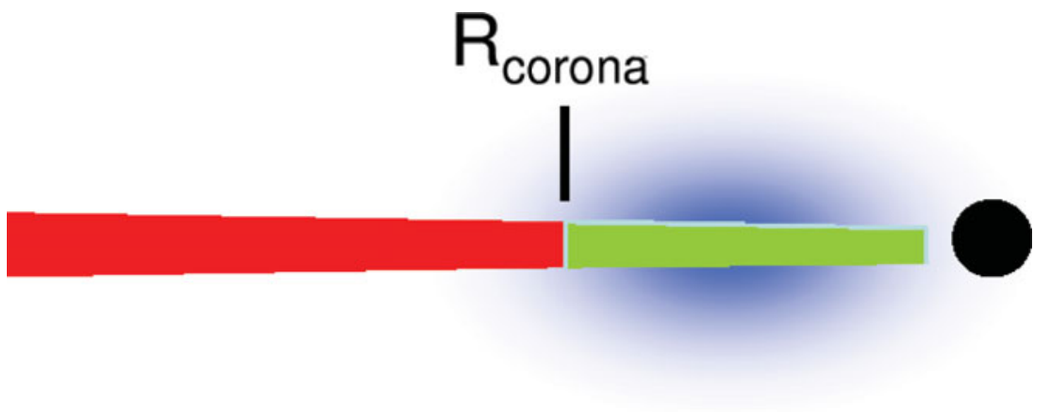
Czerny et al. (2003)

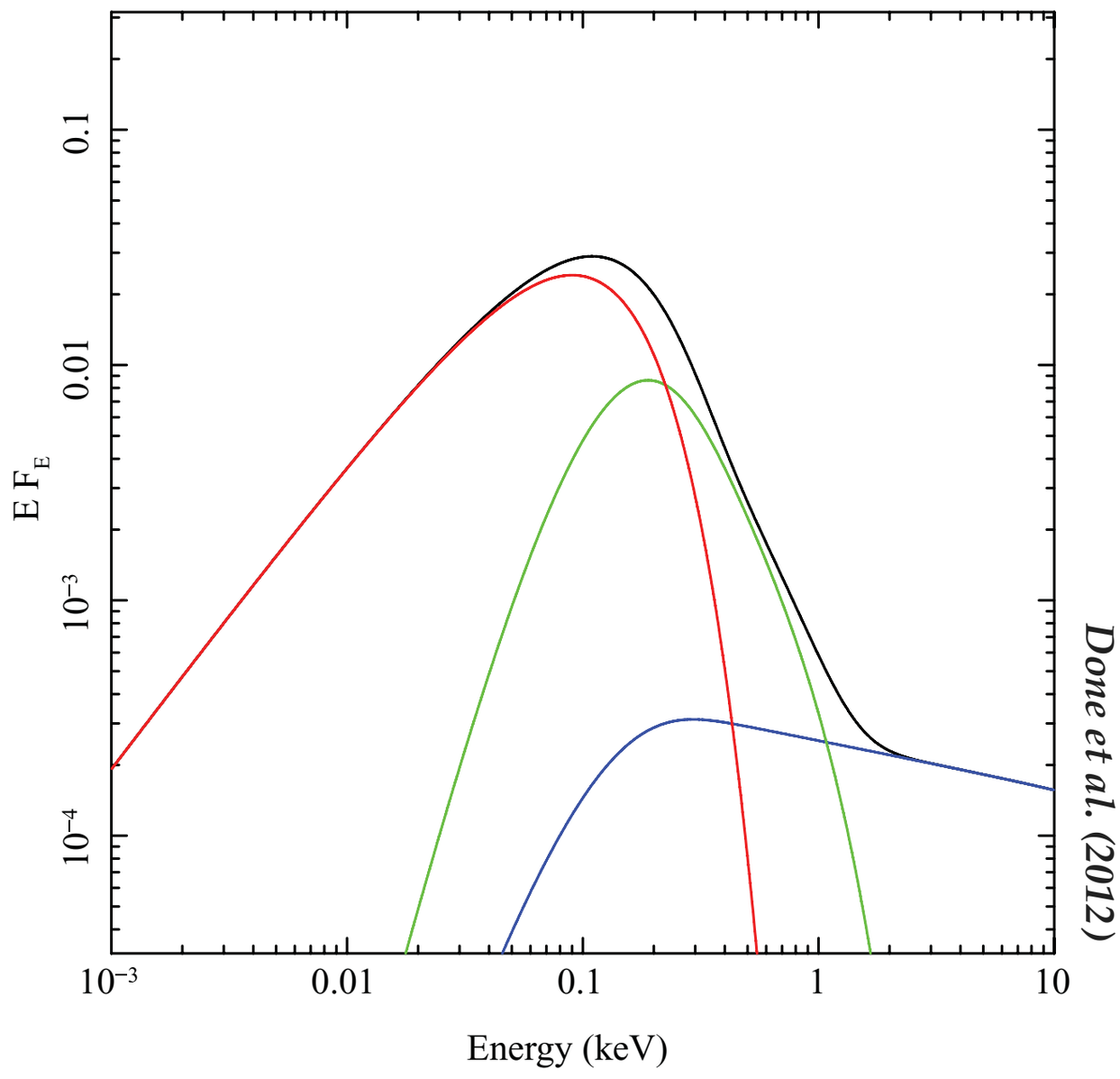

OBSERVER
WARM
ABSORBER
WARM
SKIN
ACCRETION DISK


44
43
42
41
14
15
16
17
log(ν) [Hz]
log(νL_ν) [erg s^-1 cm^-2]

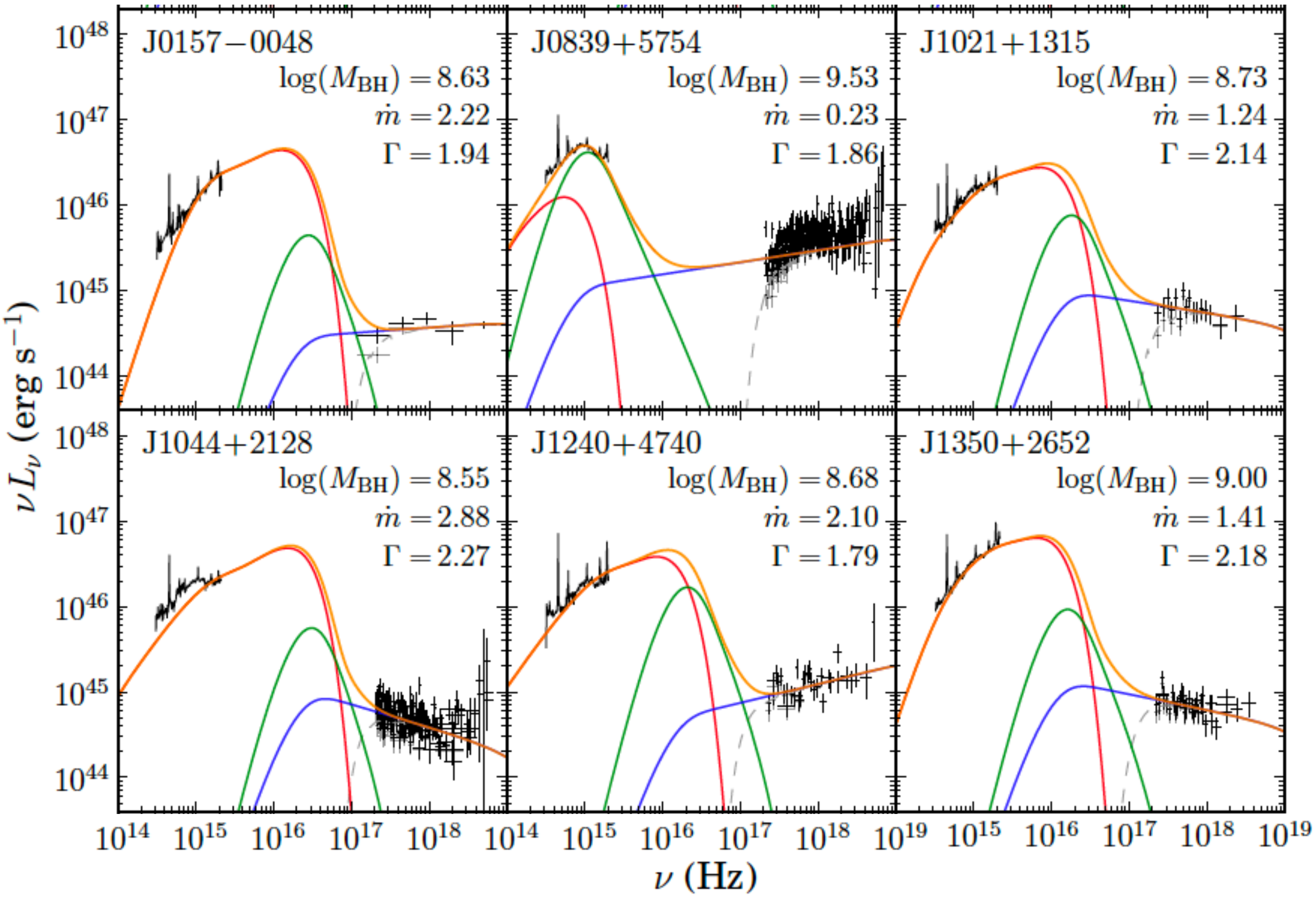


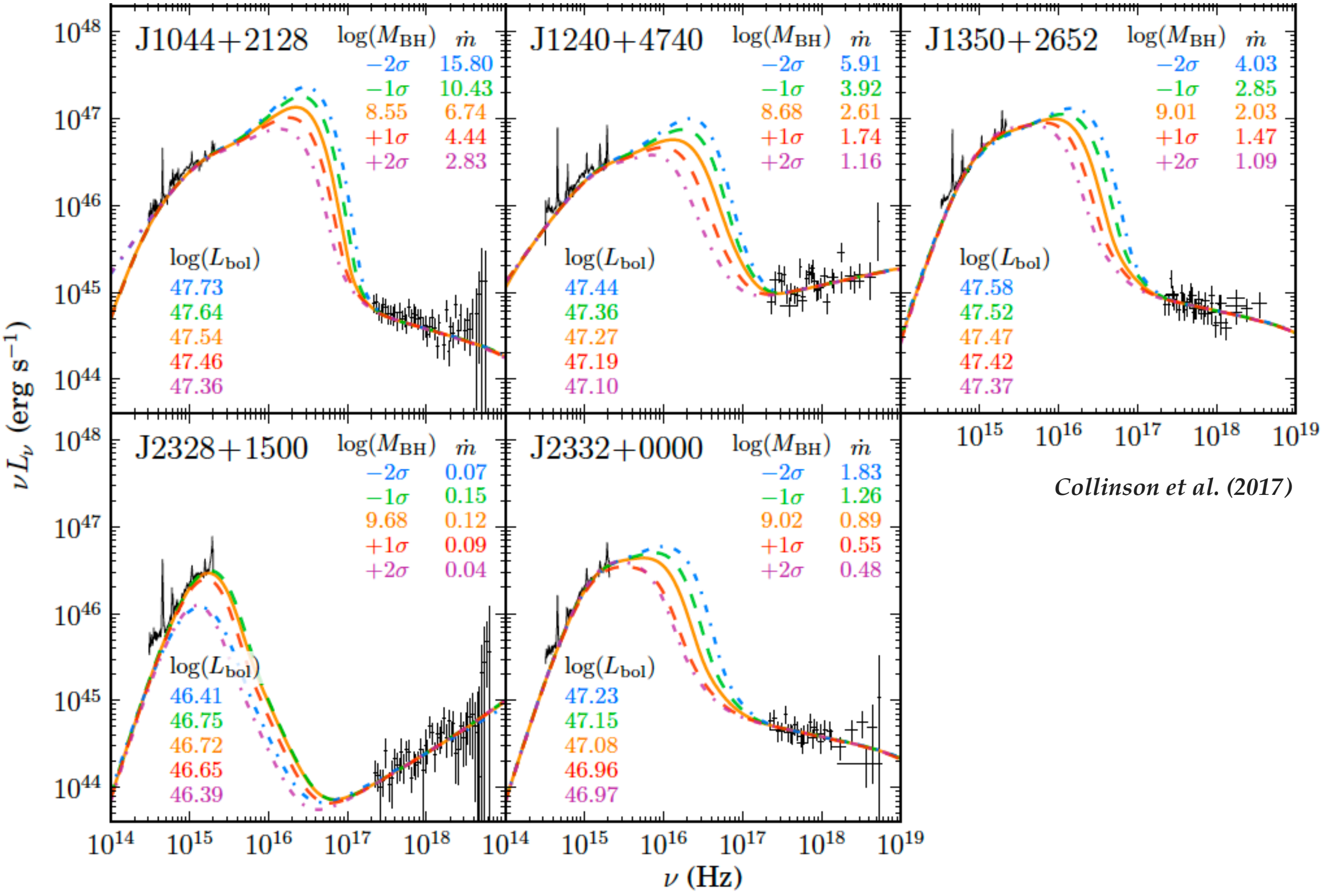
Czerny et al. (2003)


R corona


0.1
0.01
10^{-3}
10^{-4}
E F$_E$
10^{-3}
0.01
0.1
1
10
Energy (keV)
Done et al. (2012)

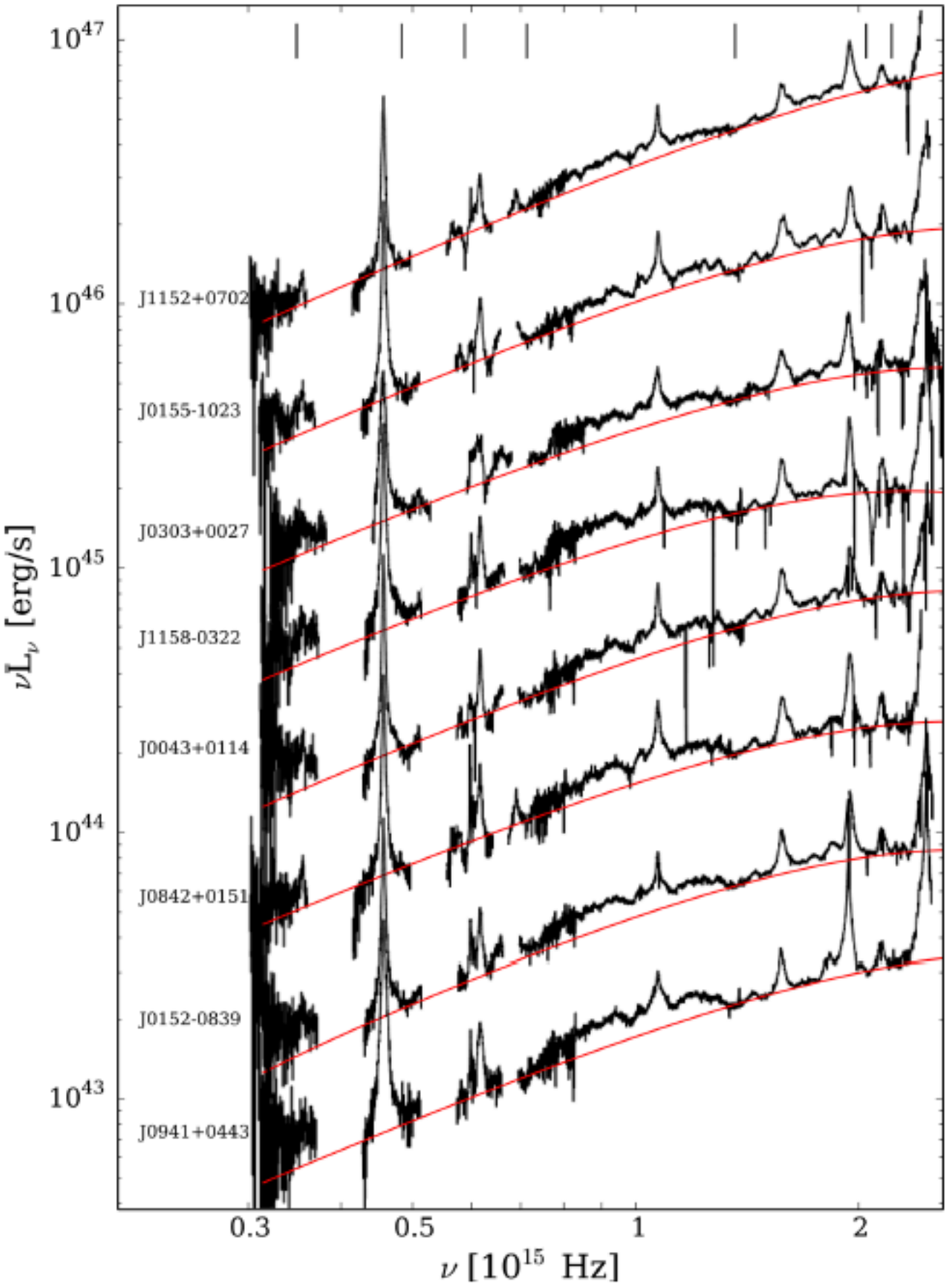
Collinson et al. (2015)



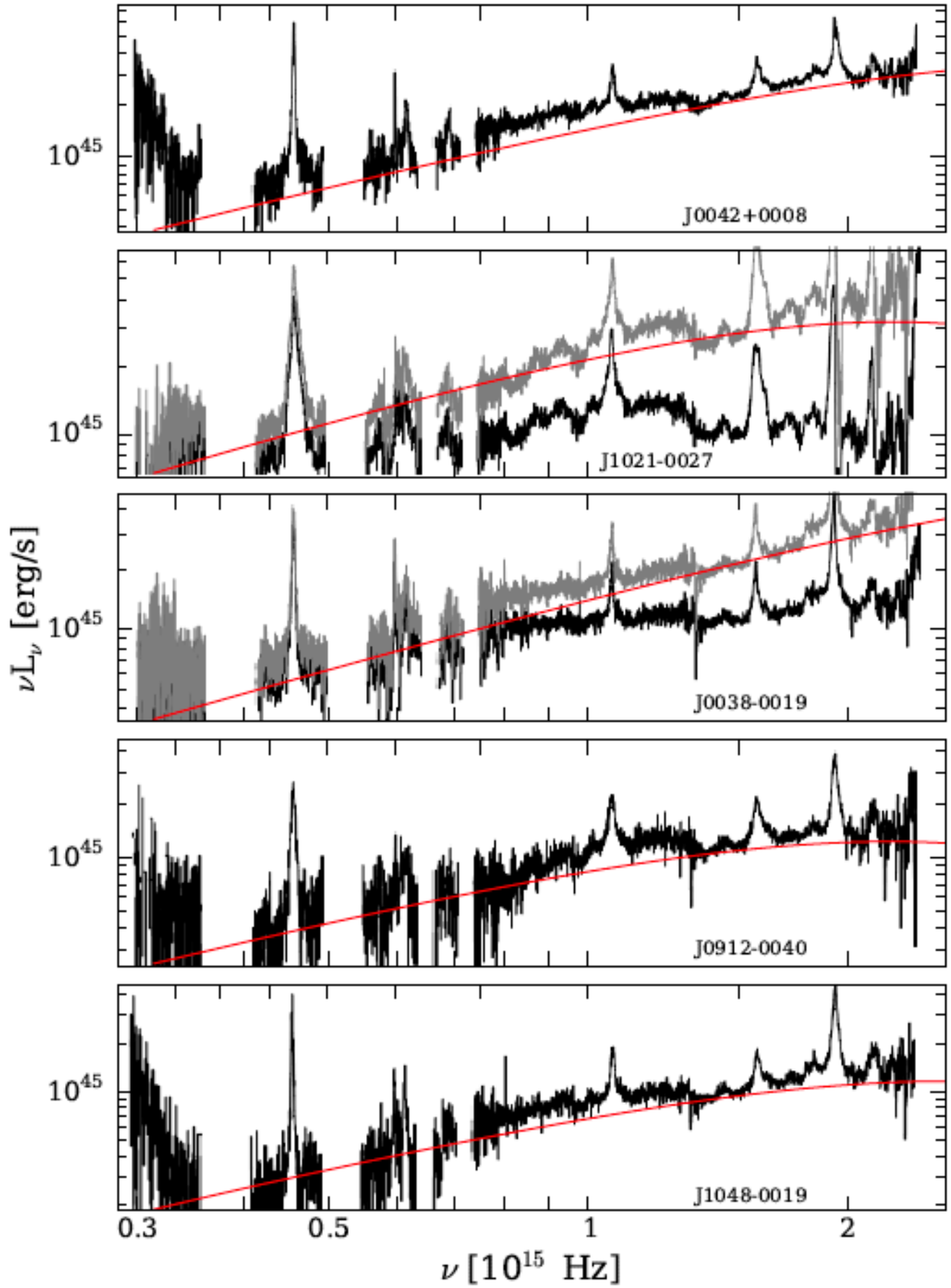


Collinson et al. (2017)

Capellupo et al. (2015)



Capellupo et al. (2016)



Tweaking

reddening

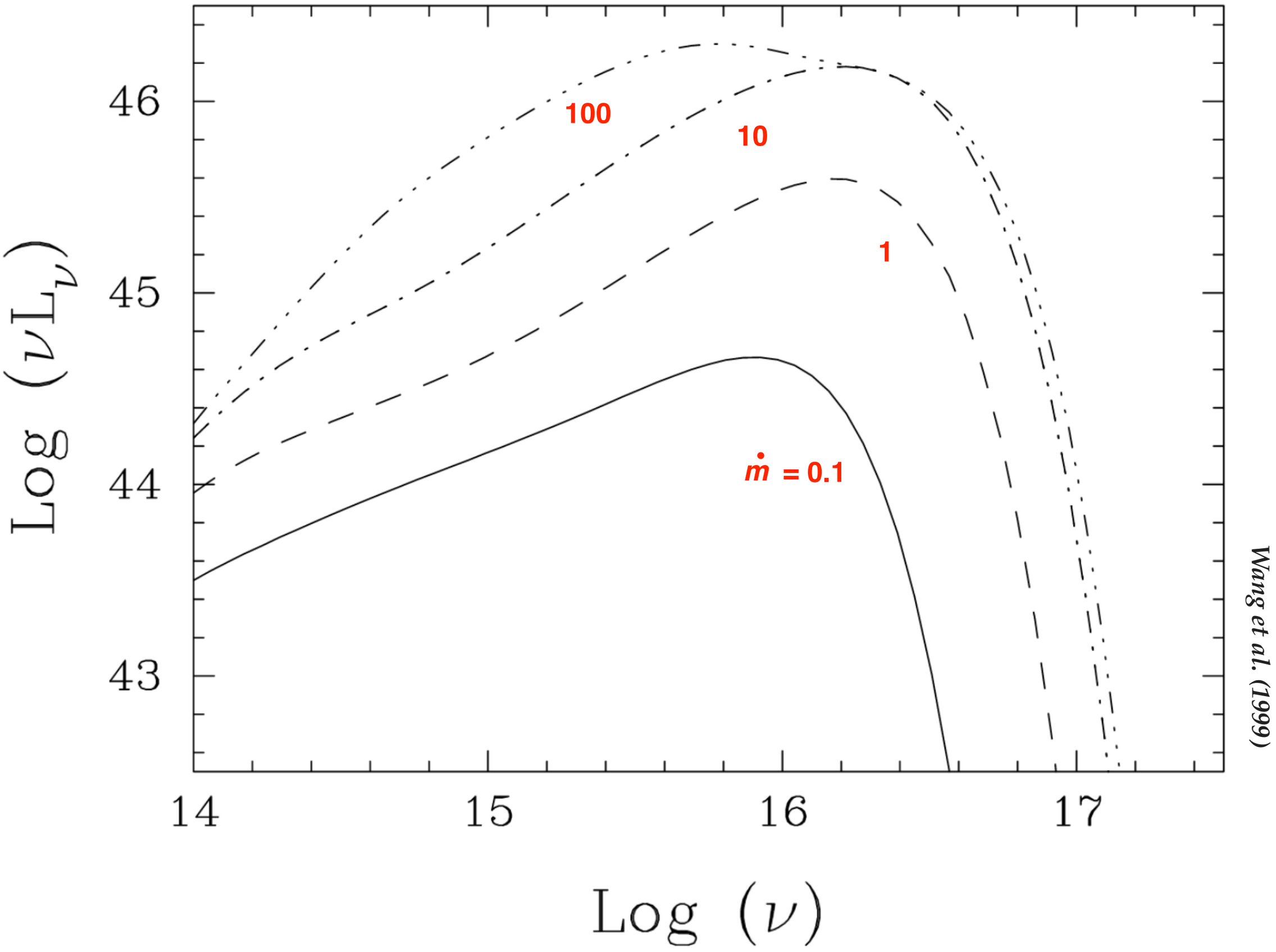
host galaxy

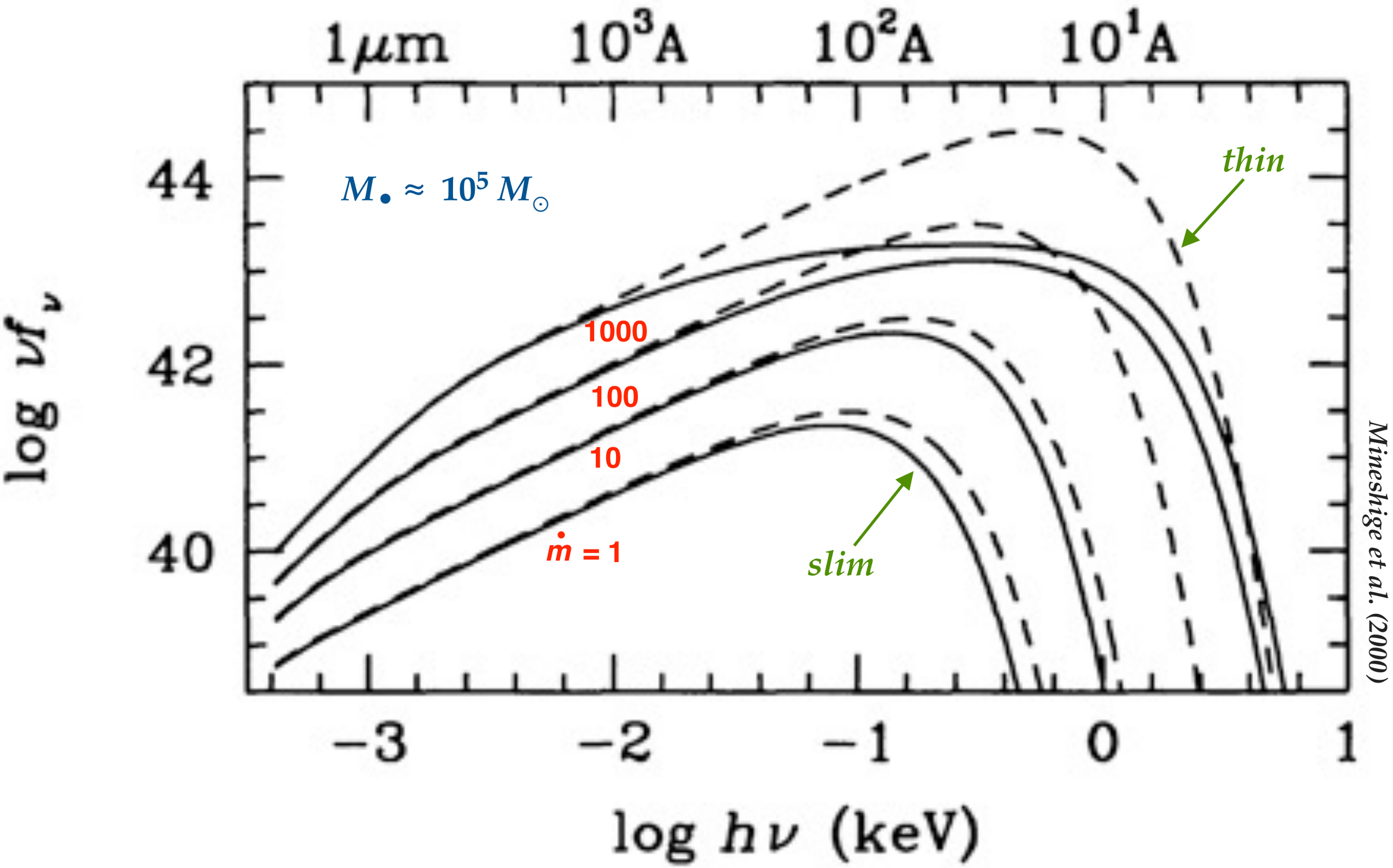
“wind”

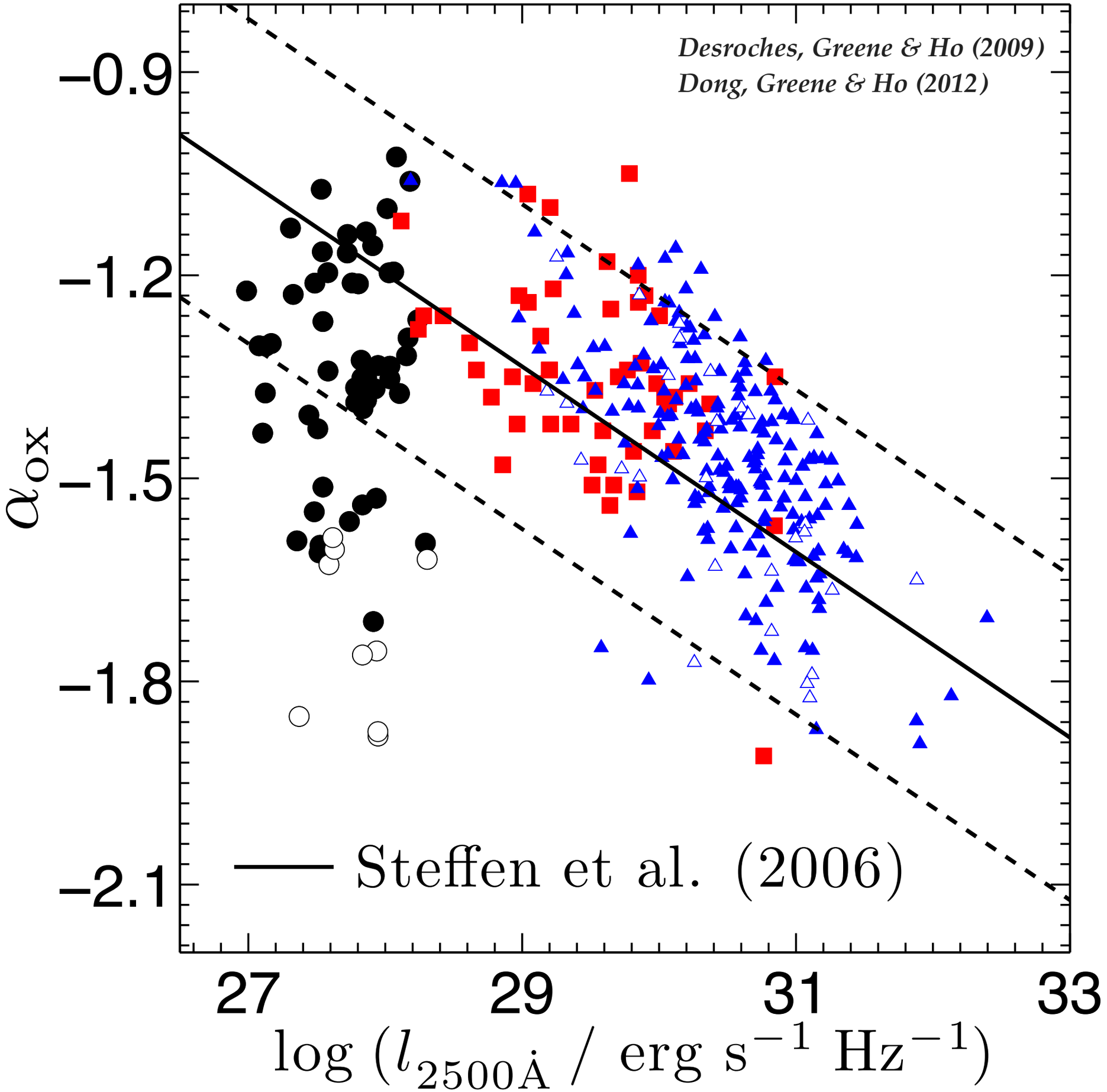
inclination

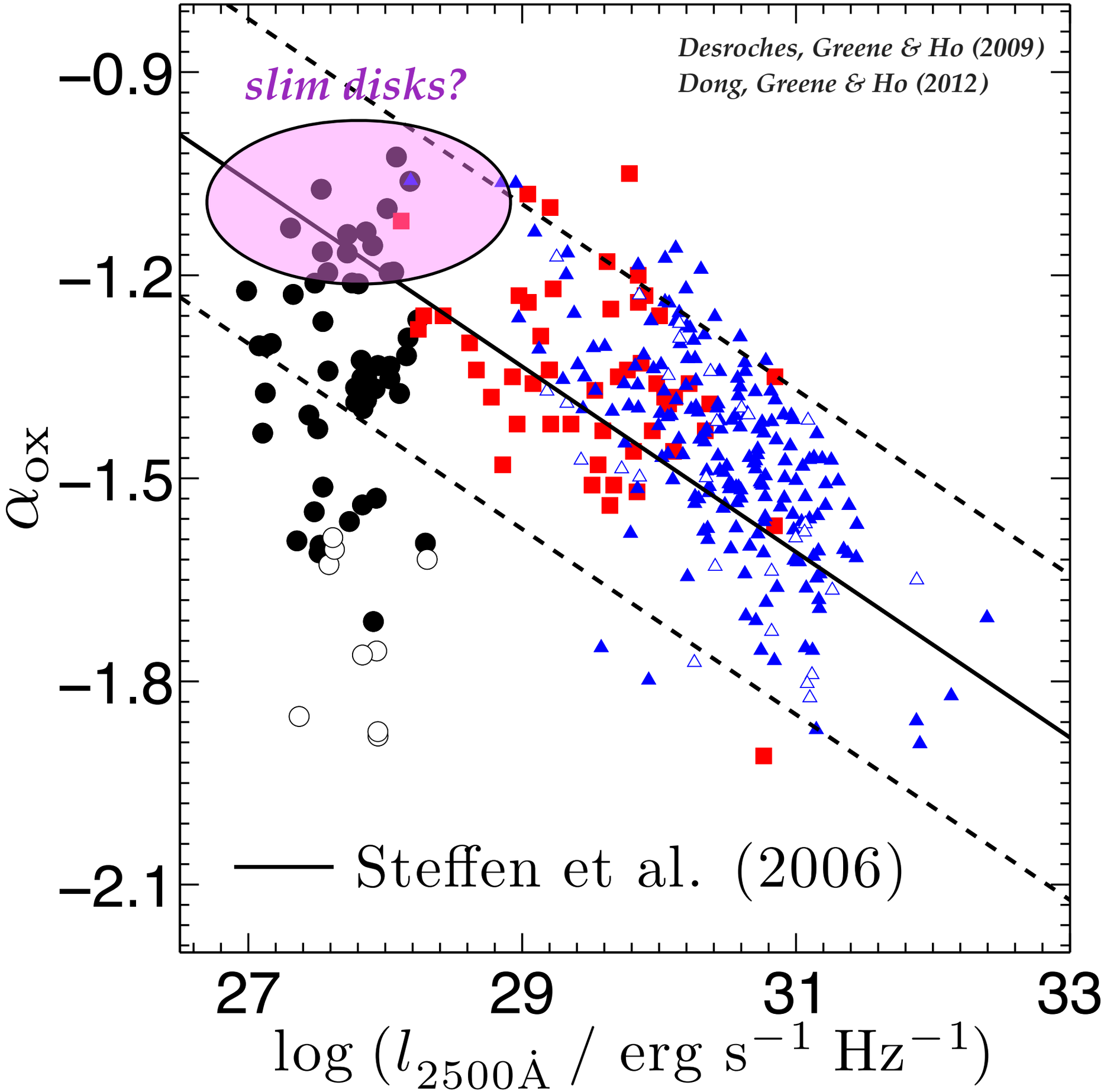
spin

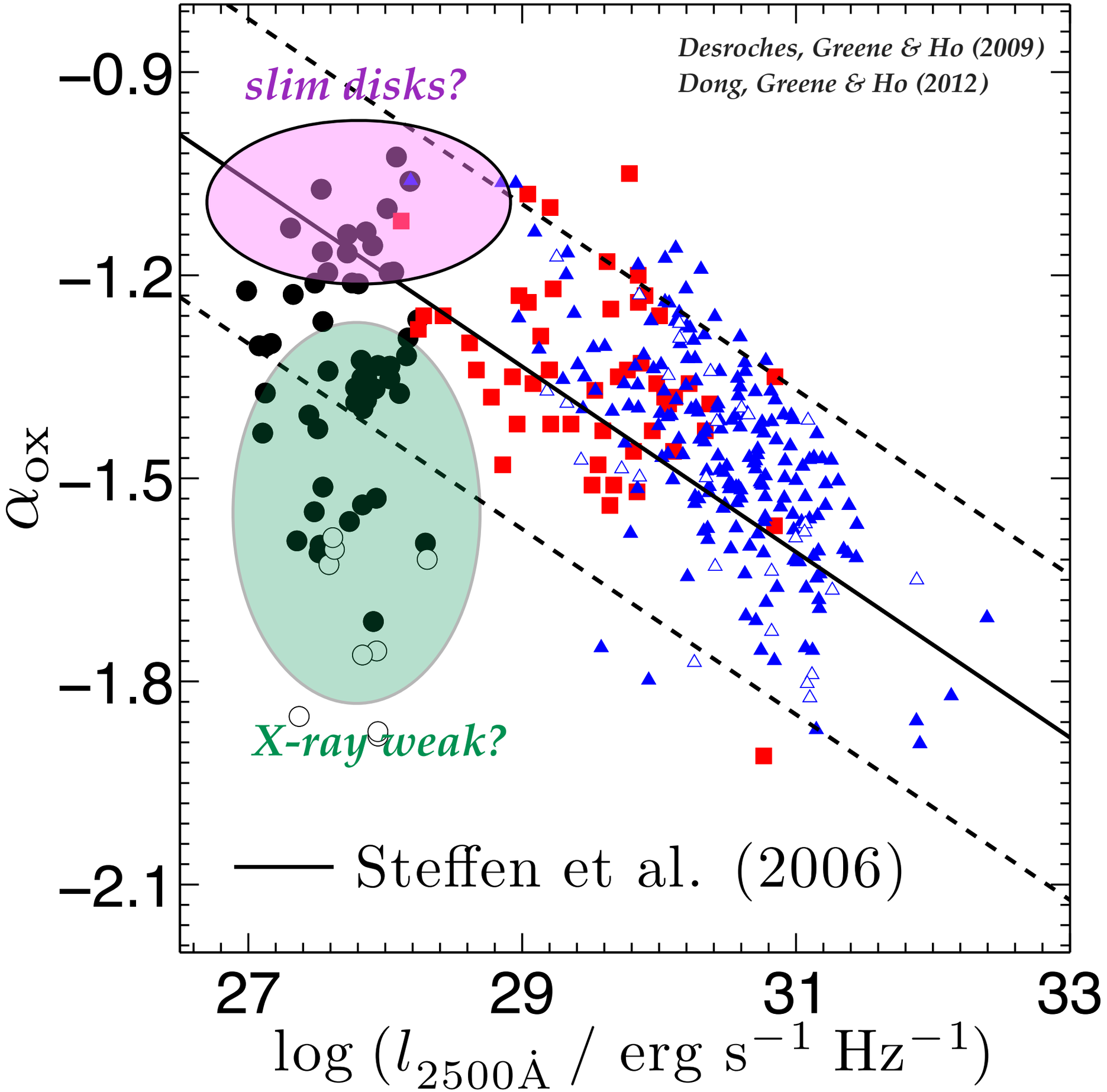

Tweaking
adening
host galaxy
"wind"
inclination
pin


100
10
1
$\dot{m}$ = 0.1
46
45
44
43
14
15
16
17
Log (νL_ν)
Log (ν)
Wang et al. (1999)


1μm
10³A
10²A
10¹A
44
42
40
log νf_ν
M• ≈ 10⁵ M⊙
thin
1000
100
10
ṁ = 1
slim
−3
−2
−1
0
1
log hν (keV)
Mineshige et al. (2000)

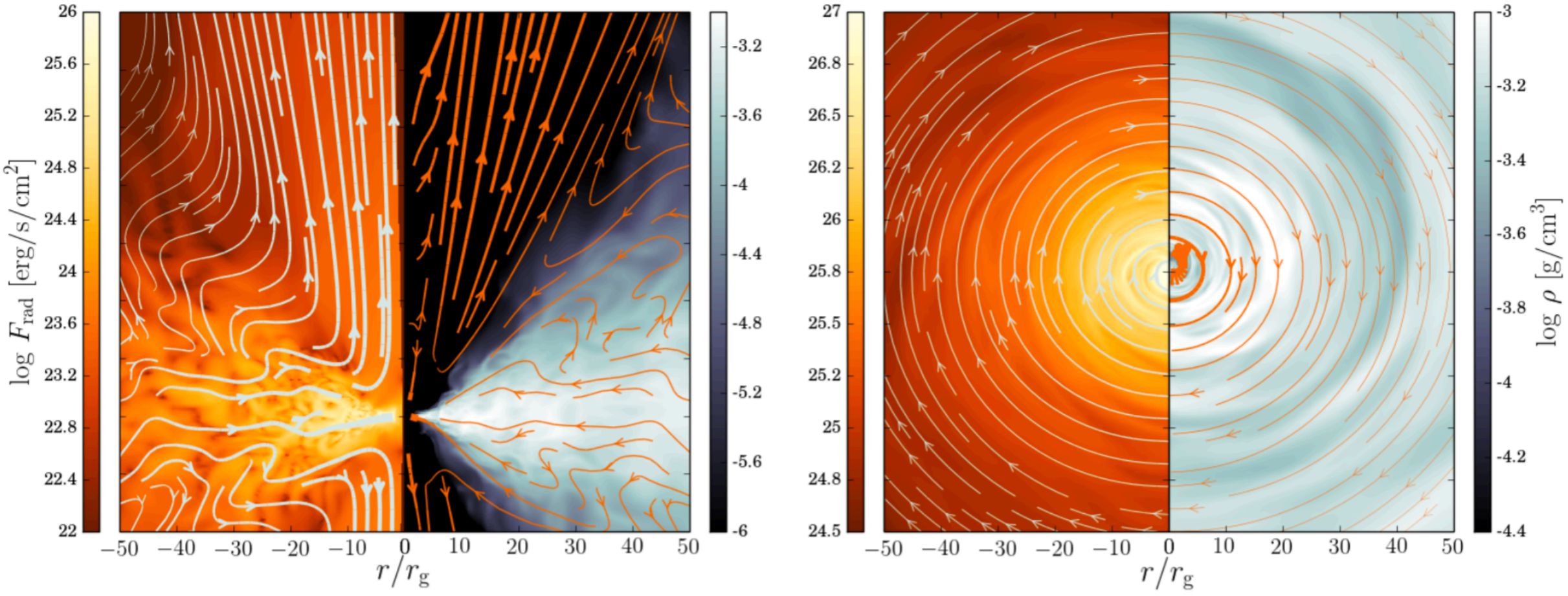

Desroches, Greene & Ho (2009)
Dong, Greene & Ho (2012)
−0.9
−1.2
−1.5
−1.8
−2.1
α_{ox}
Steffen et al. (2006)
27
29
31
33
$\log\,(l_{2500\text{Å}}\,/\,\mathrm{erg\ s^{-1}\ Hz^{-1}})$


slim disks?
Desroches, Greene & Ho (2009)
Dong, Greene & Ho (2012)
−0.9
−1.2
−1.5
−1.8
−2.1
α_{ox}
Steffen et al. (2006)
27
29
31
33
$\log\,(l_{2500\text{Å}}\,/\,\mathrm{erg\ s^{-1}\ Hz^{-1}})$

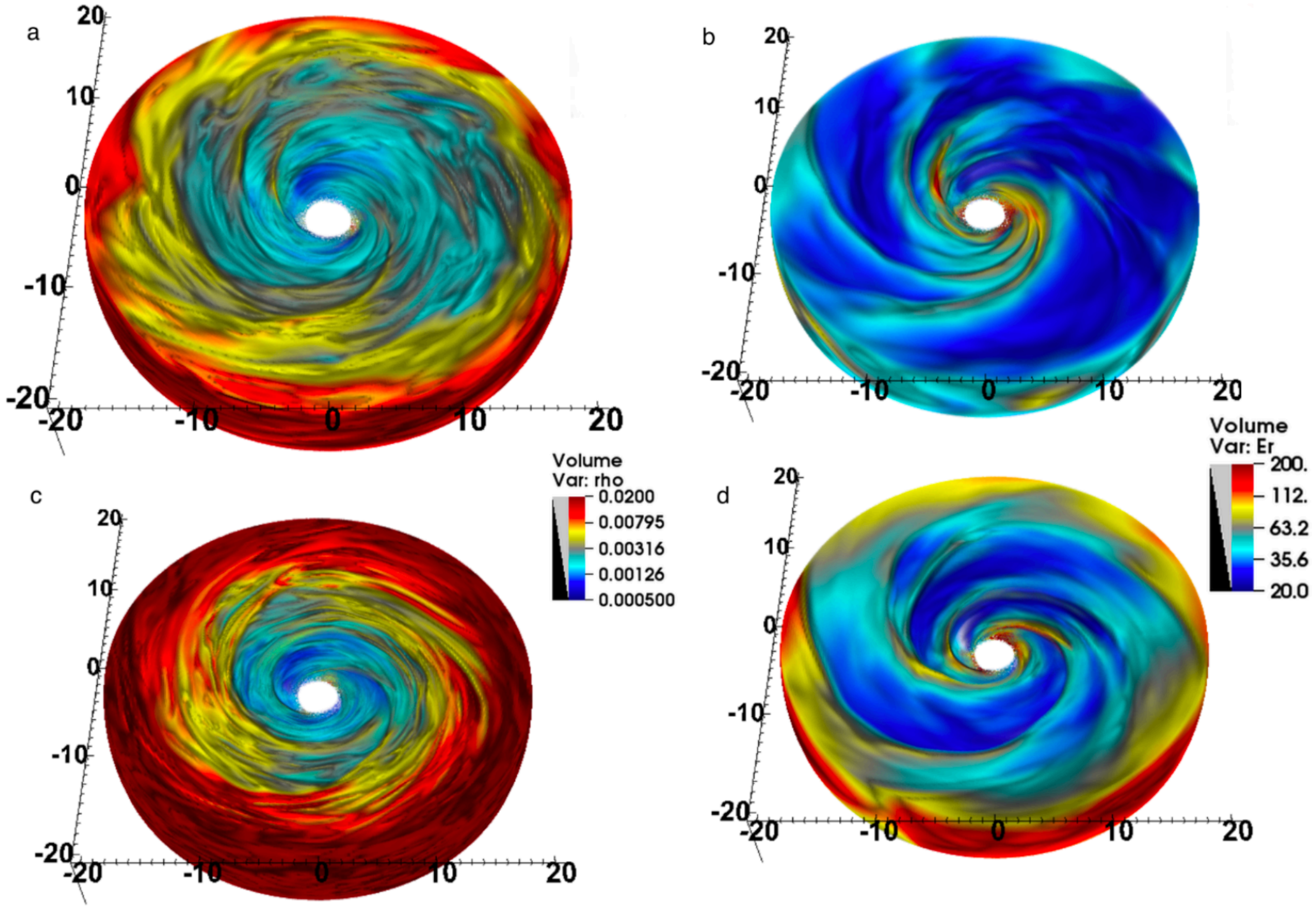

Desroches, Greene & Ho (2009)
Dong, Greene & Ho (2012)
slim disks?
X-ray weak?
Steffen et al. (2006)
−0.9
−1.2
−1.5
−1.8
−2.1
α_{ox}
27
29
31
33
$\log\,(l_{2500\text{Å}}\,/\,\mathrm{erg\ s^{-1}\ Hz^{-1}})$

poloidal plane

equatorial plane



Sadowski & Narayan (2016)



Jiang, Stone & Davis (2017)

Jiang, Stone & Davis (2017)

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