Black Holes, Big and Small

Impact on Galaxy Formation

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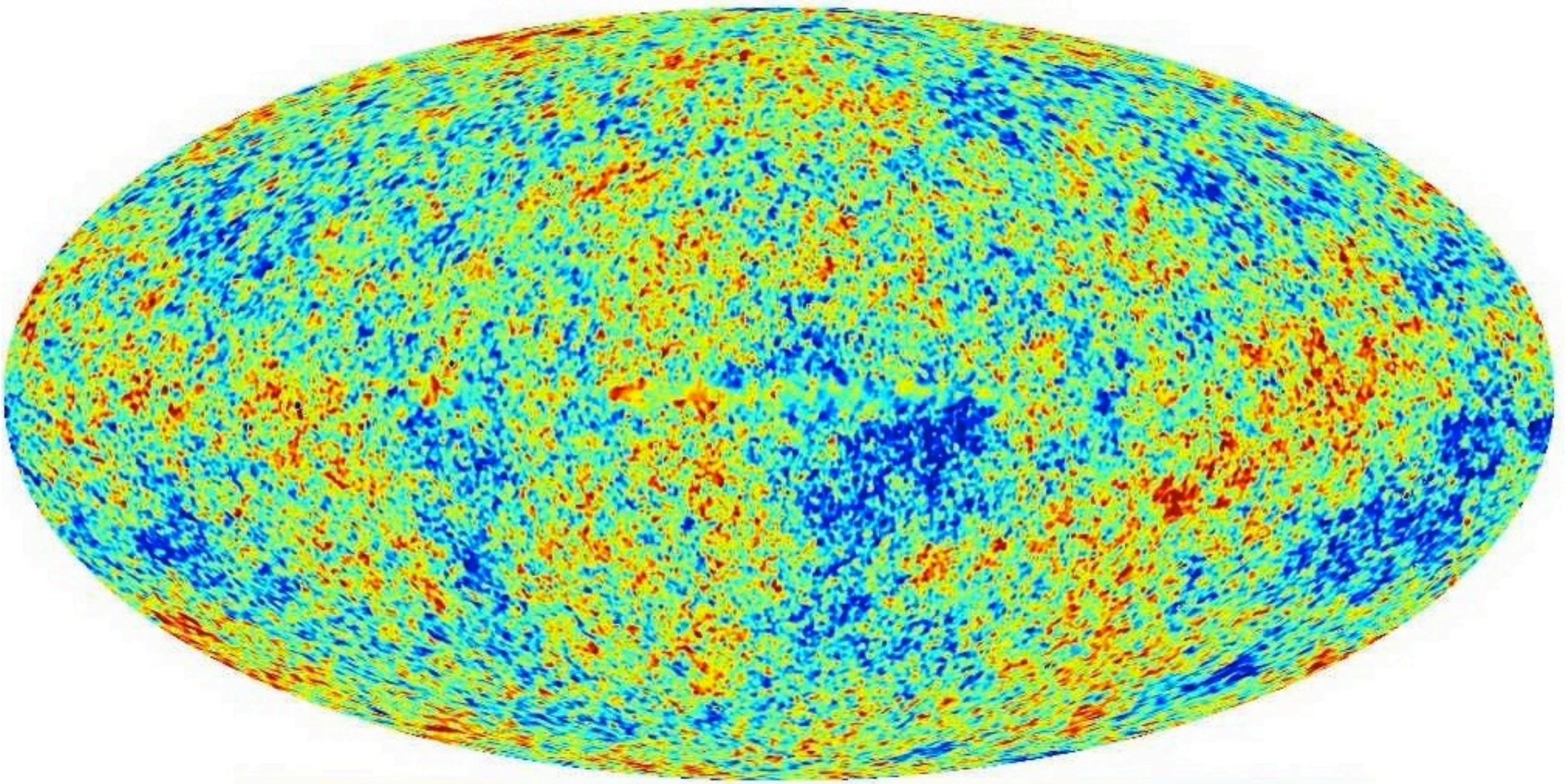
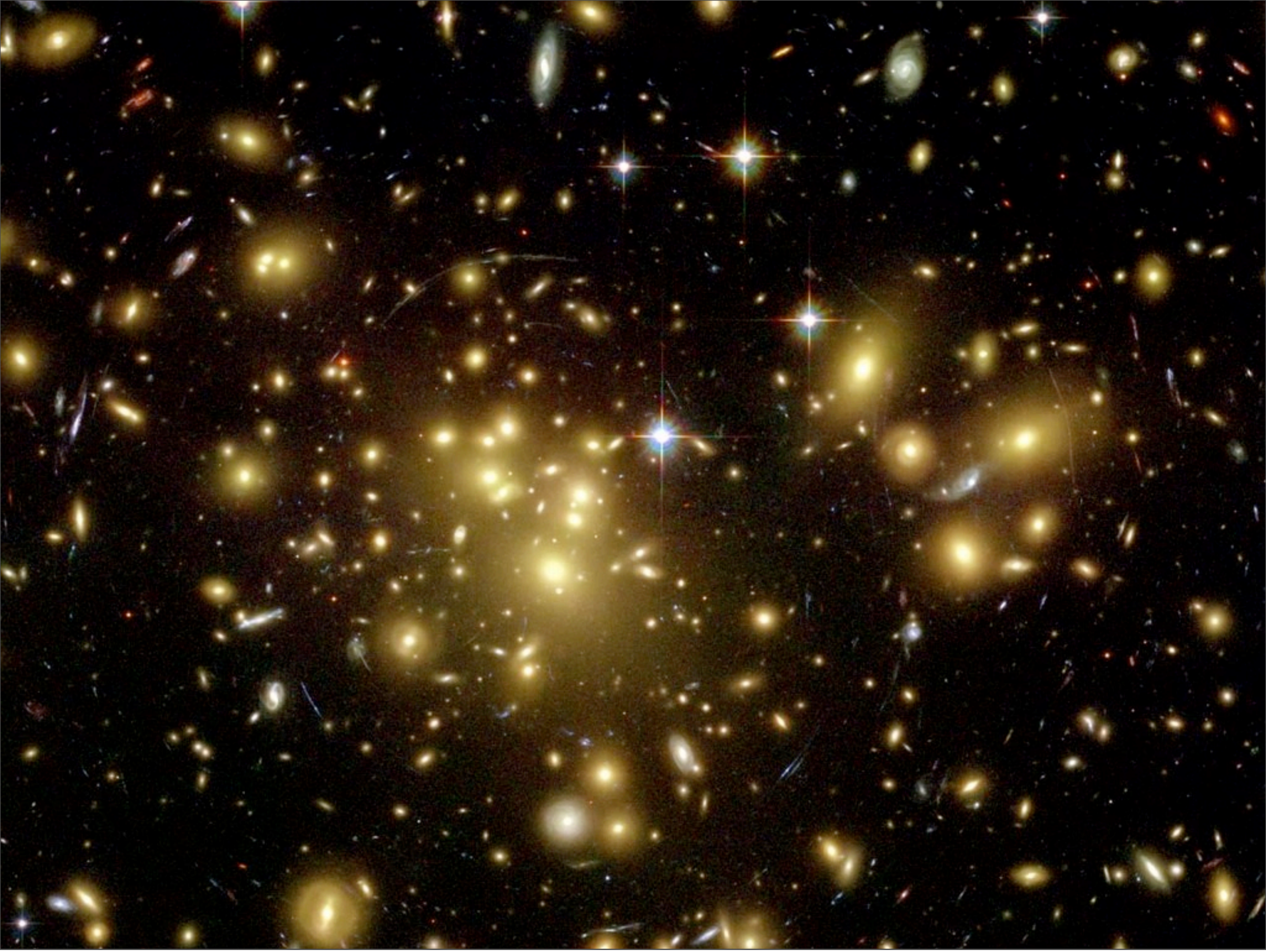


Wednesday, February 26, 14



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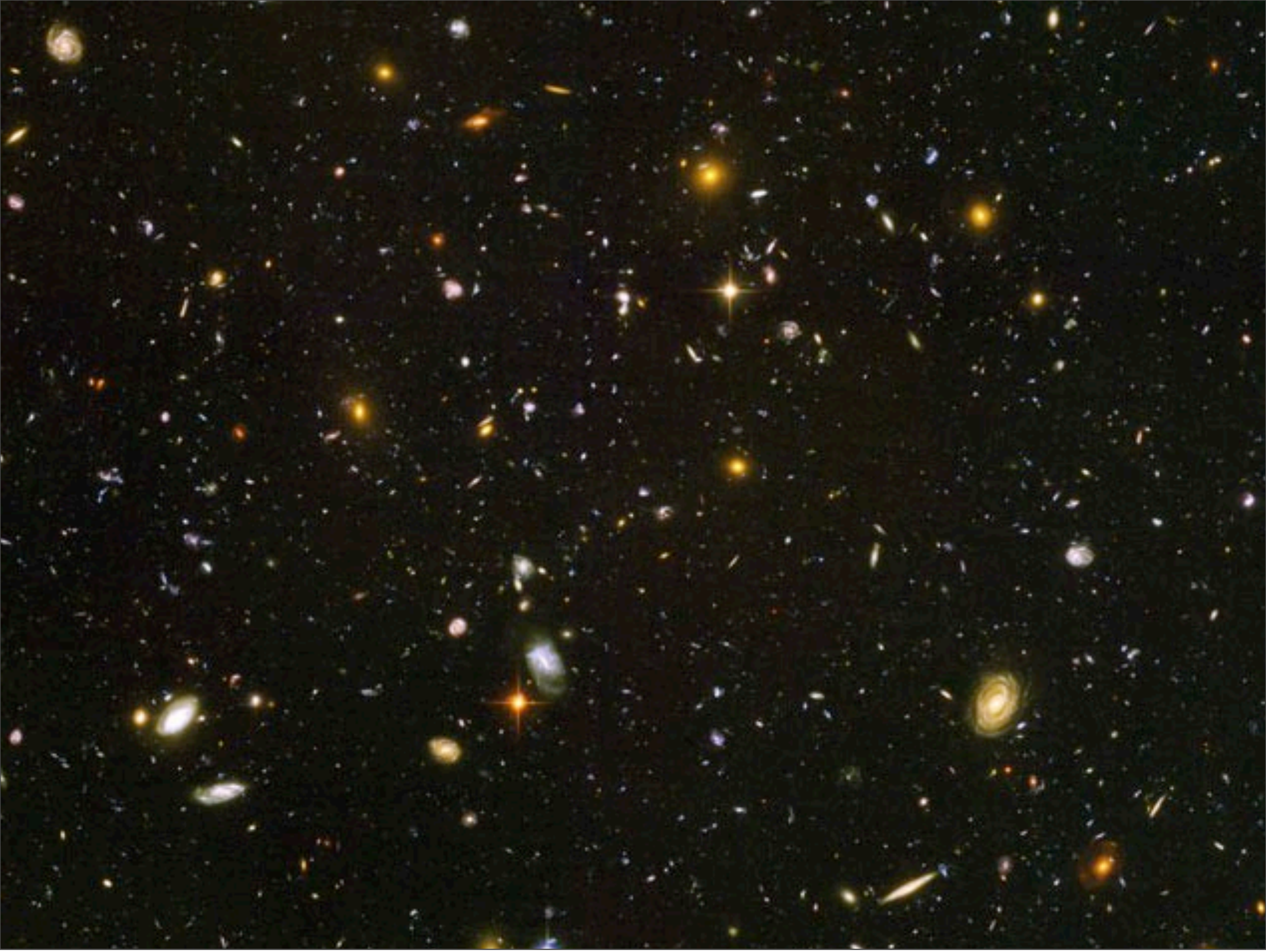

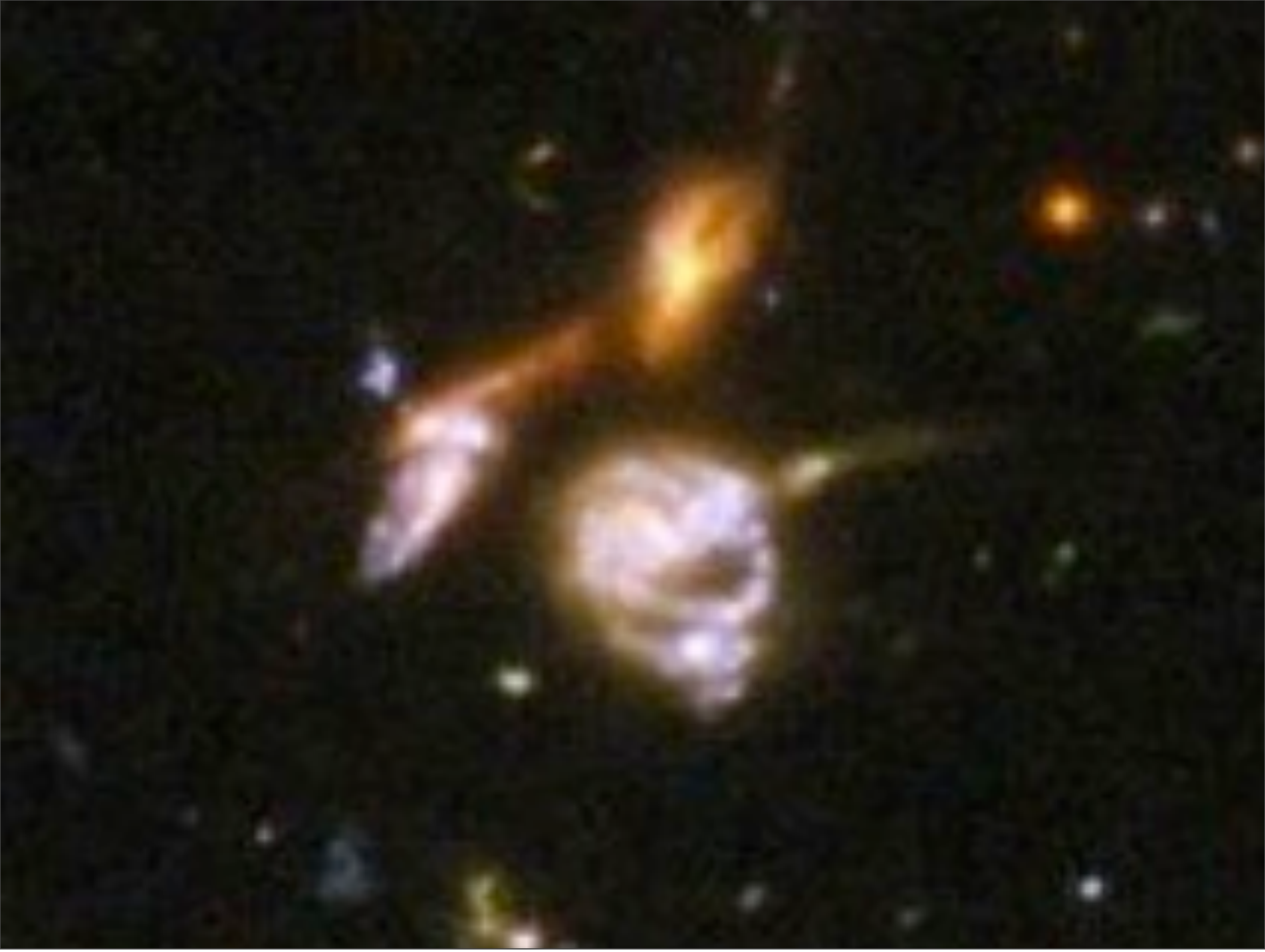

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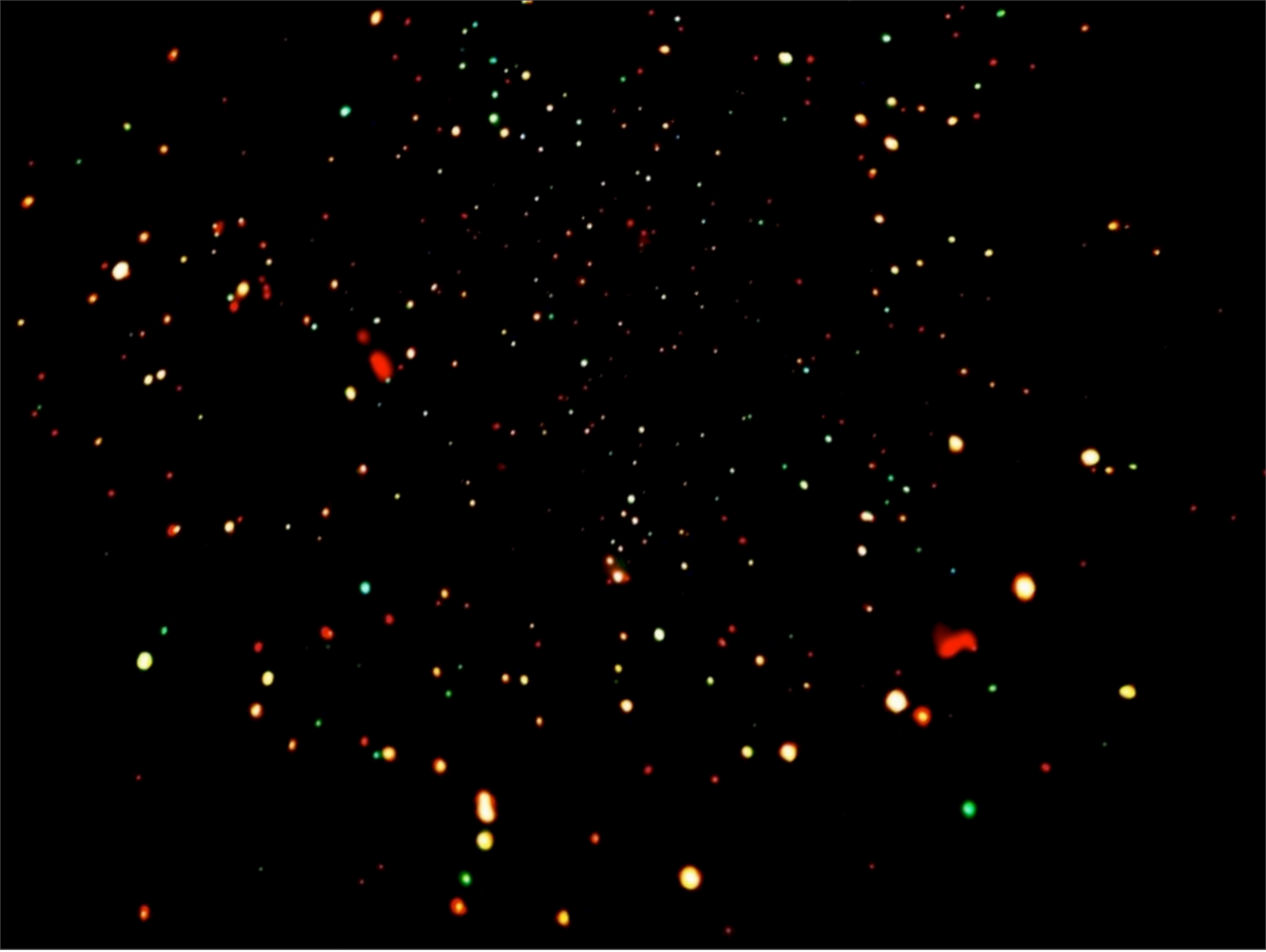
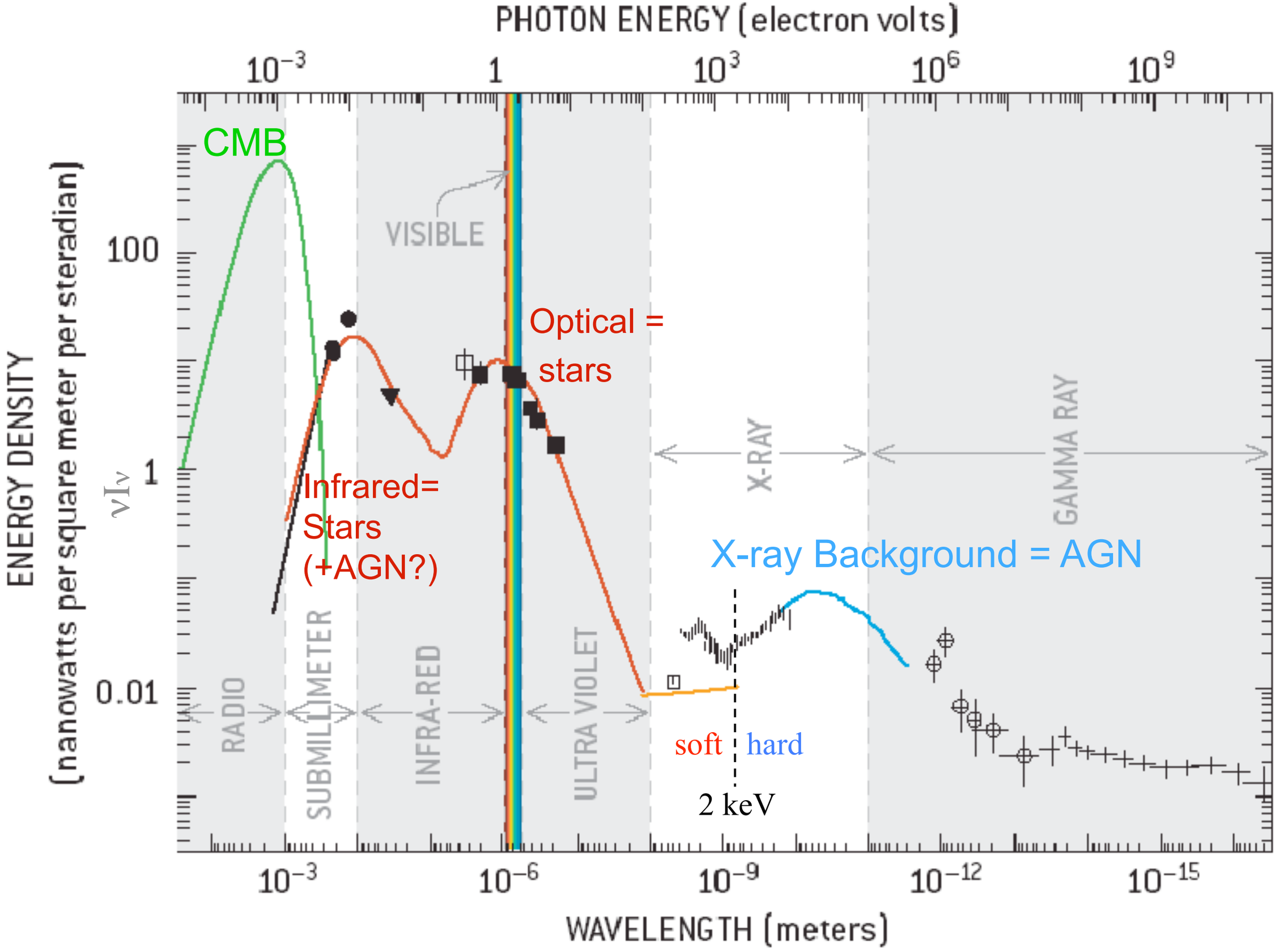
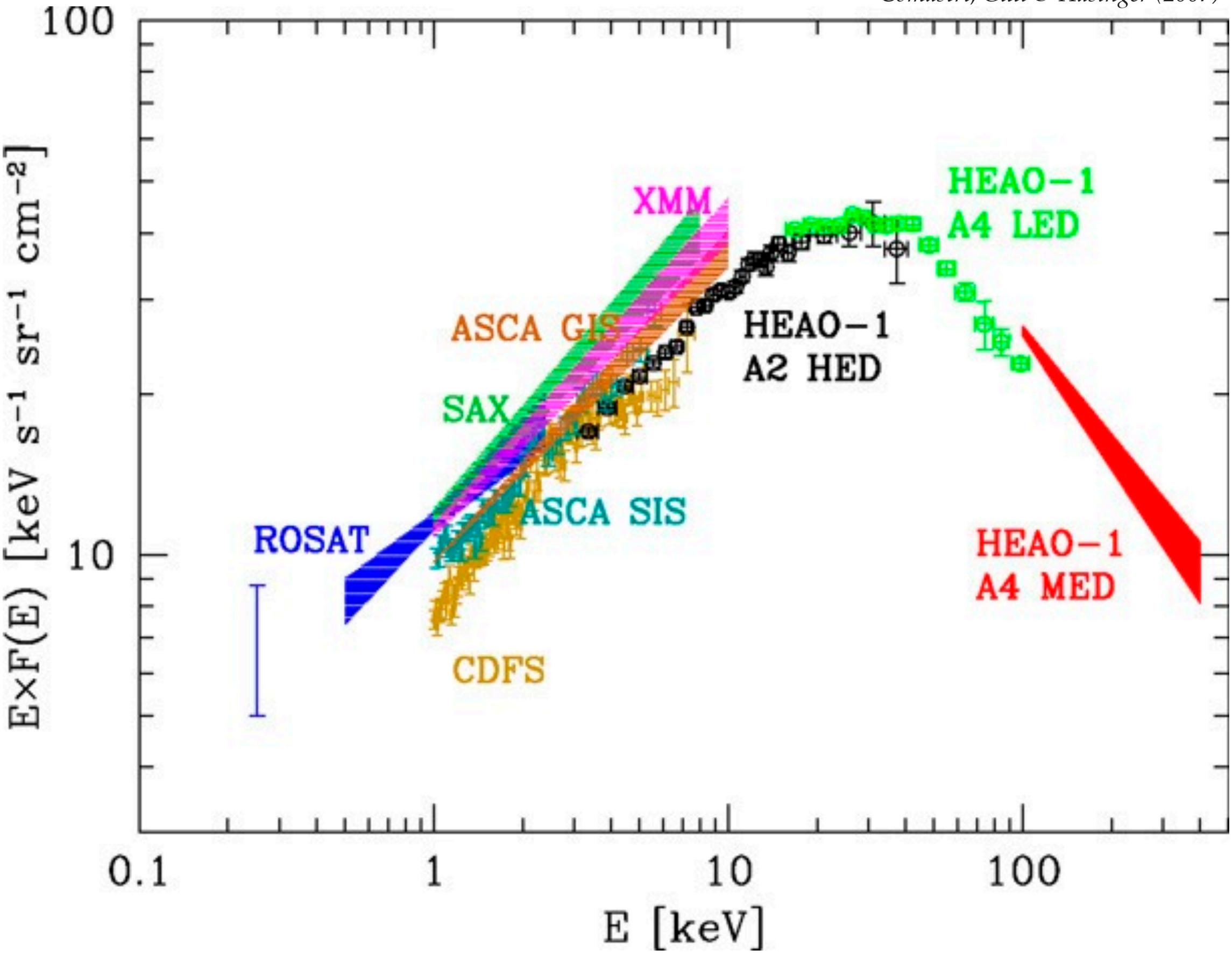
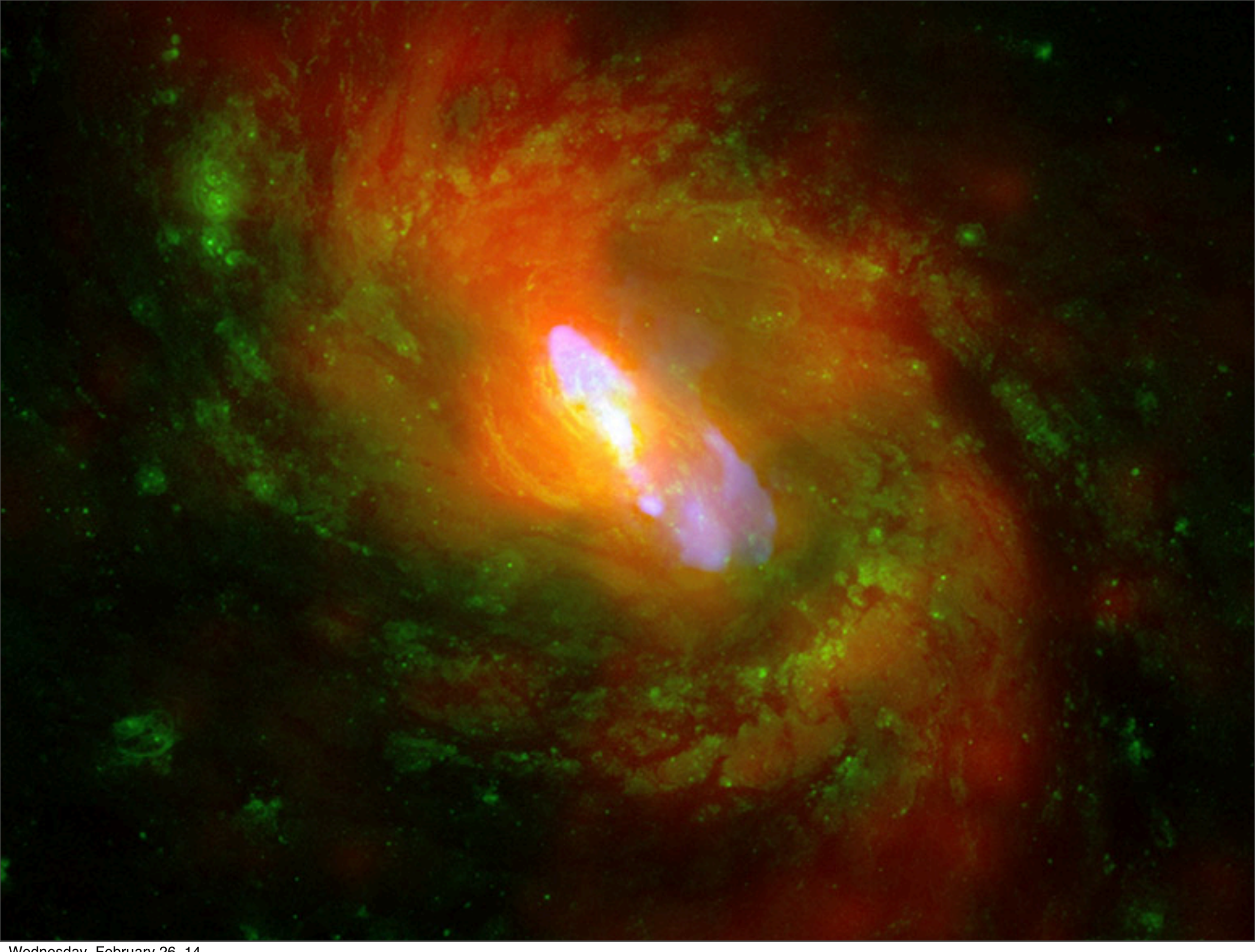
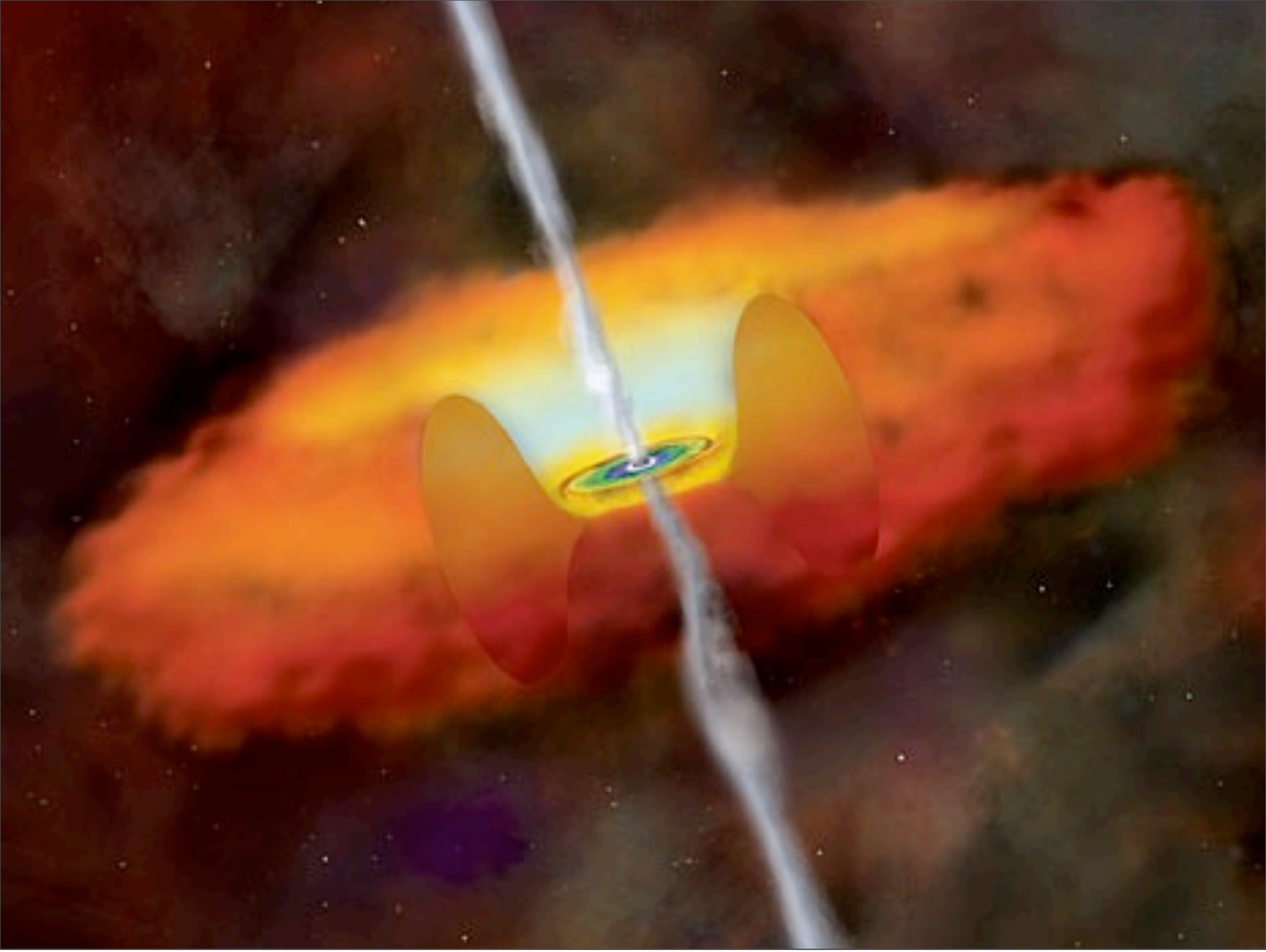



PHOTON ENERGY (electron volts)
10^{-3}
1
10^{3}
10^{6}
10^{9}
CMB
VISIBLE
Optical =
stars
Infrared=
Stars
(+AGN?)
X-RAY
GAMMA RAY
X-ray Background = AGN
soft
hard
2 keV
100
1
0.01
ENERGY DENSITY
(nanowatts per square meter per steradian)
νI_ν
RADIO
SUBMILLIMETER
INFRA-RED
ULTRA VIOLET
10^{-3}
10^{-6}
10^{-9}
10^{-12}
10^{-15}
WAVELENGTH (meters)

Comastri, Gilli & Hasinger (2007)

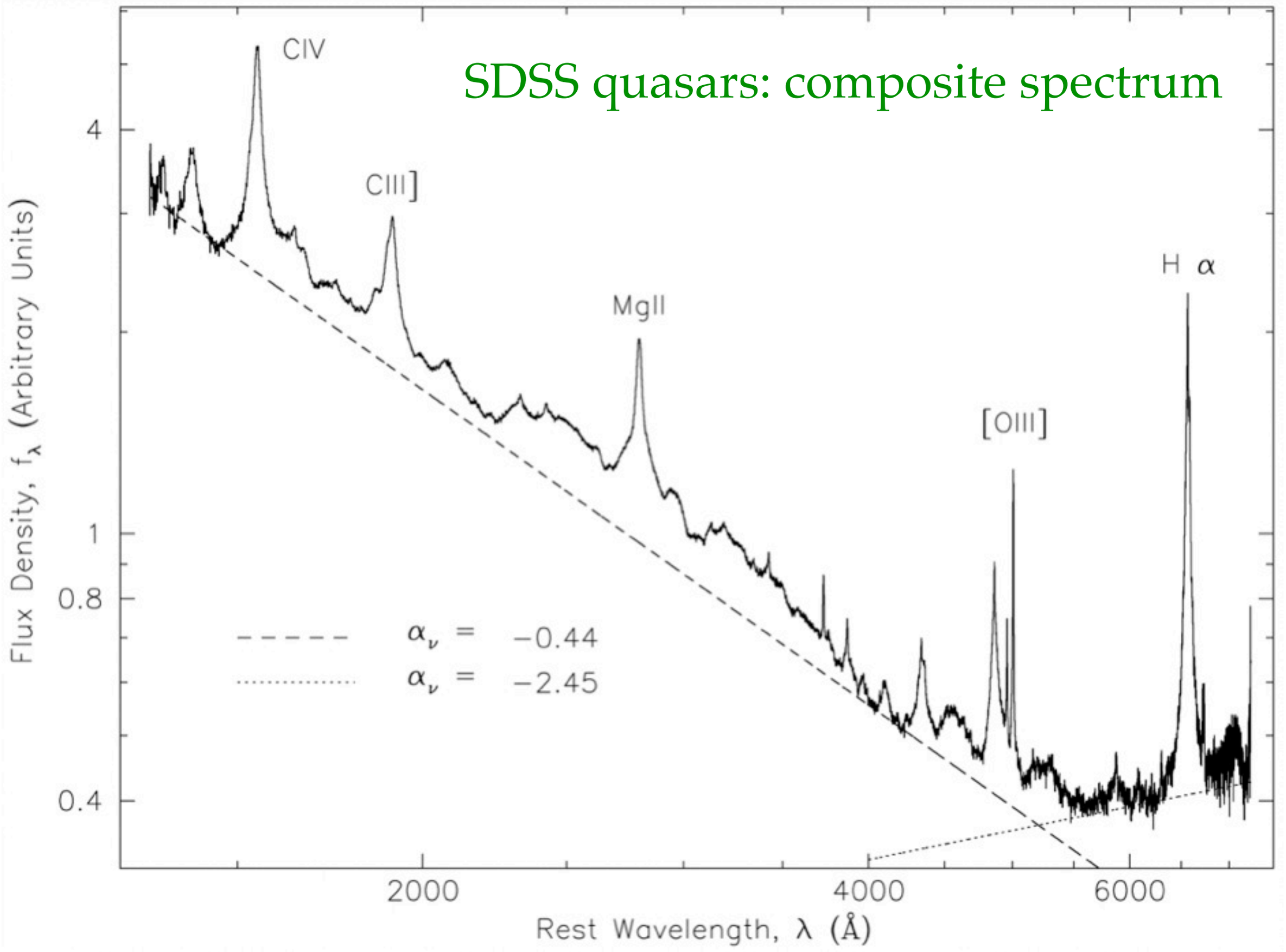




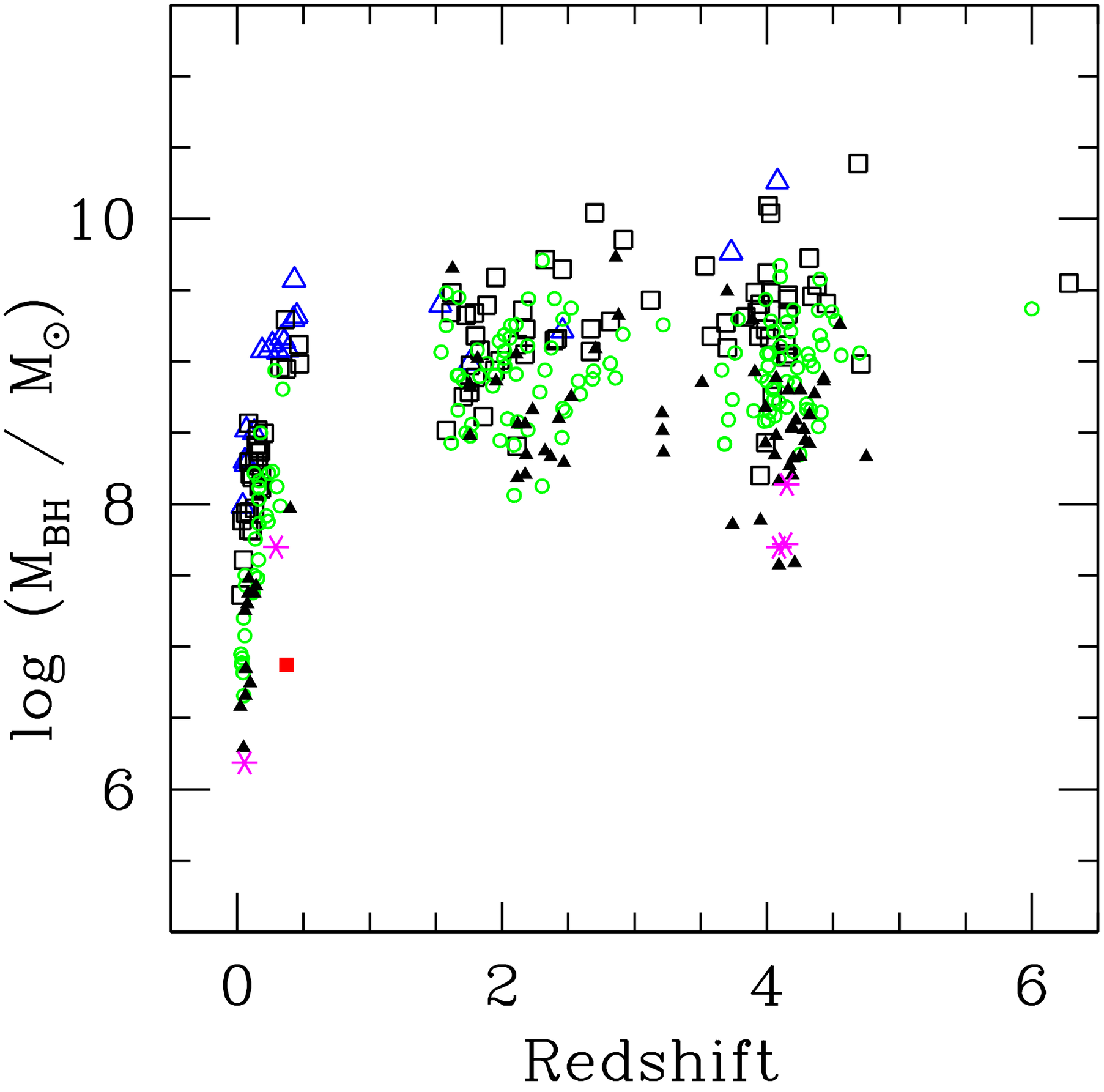


Vanden Berk et al. (2001)

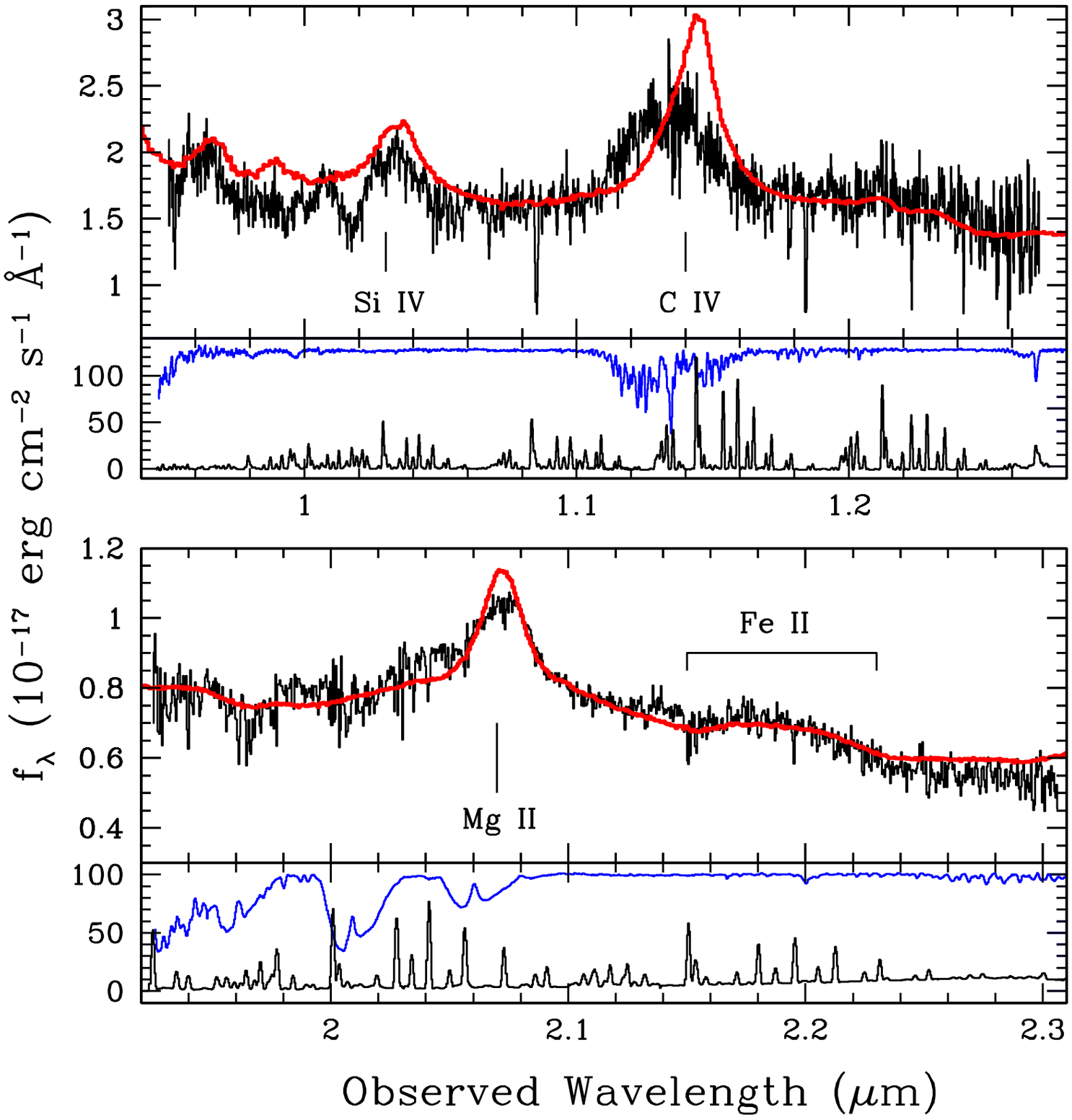
SDSS quasars: composite spectrum

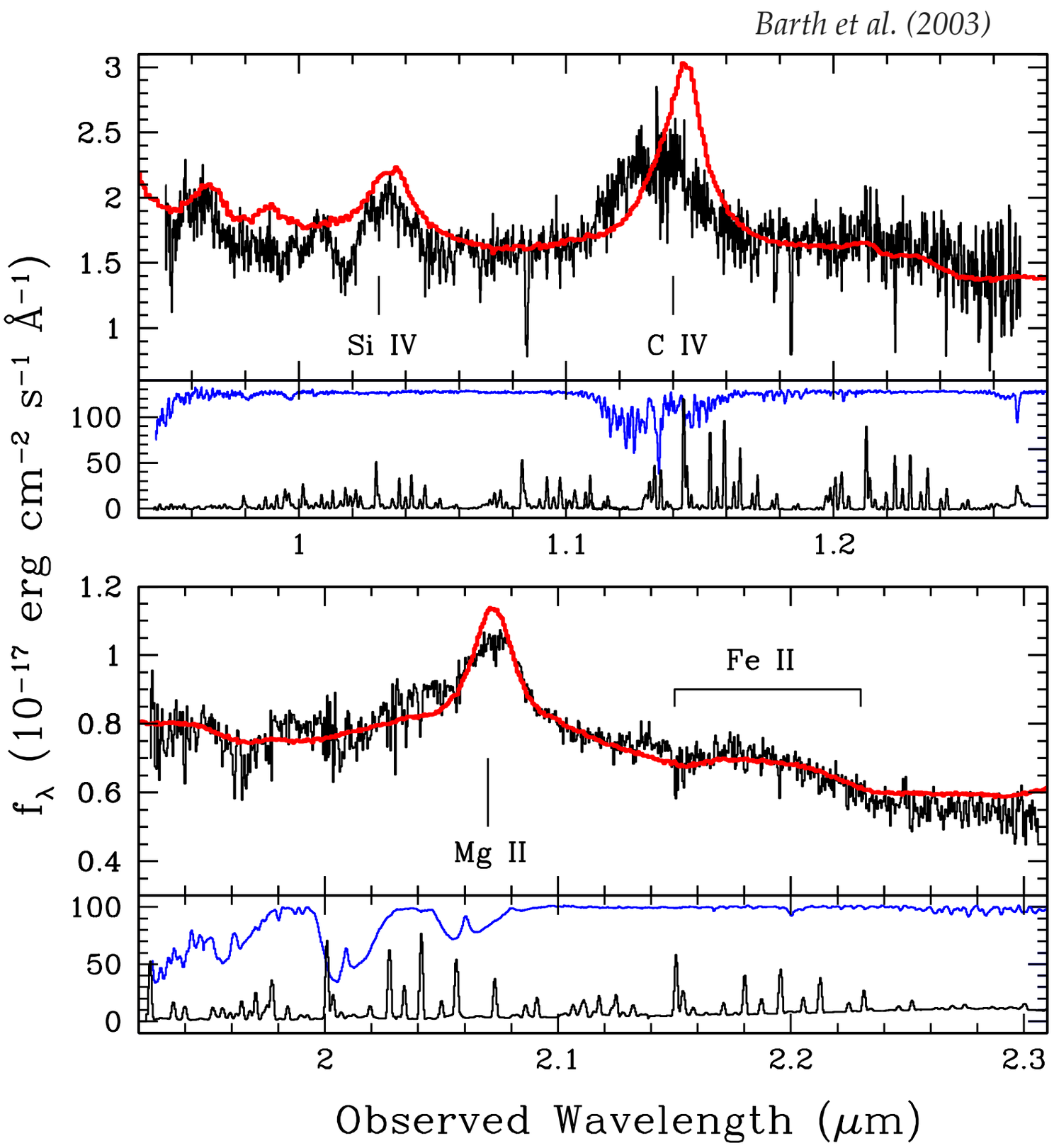


Vestergaard (2004)



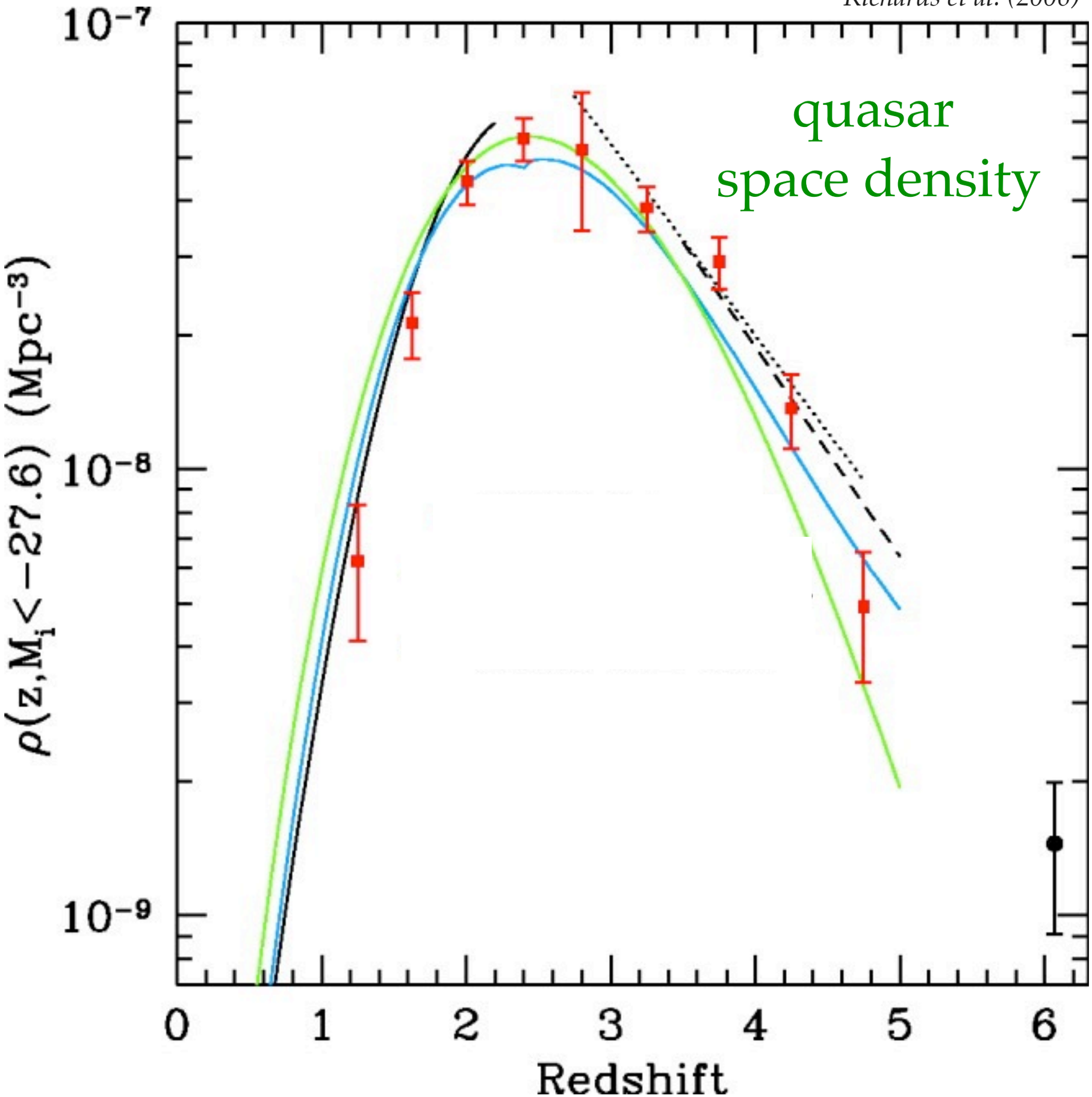
Barth et al. (2003)



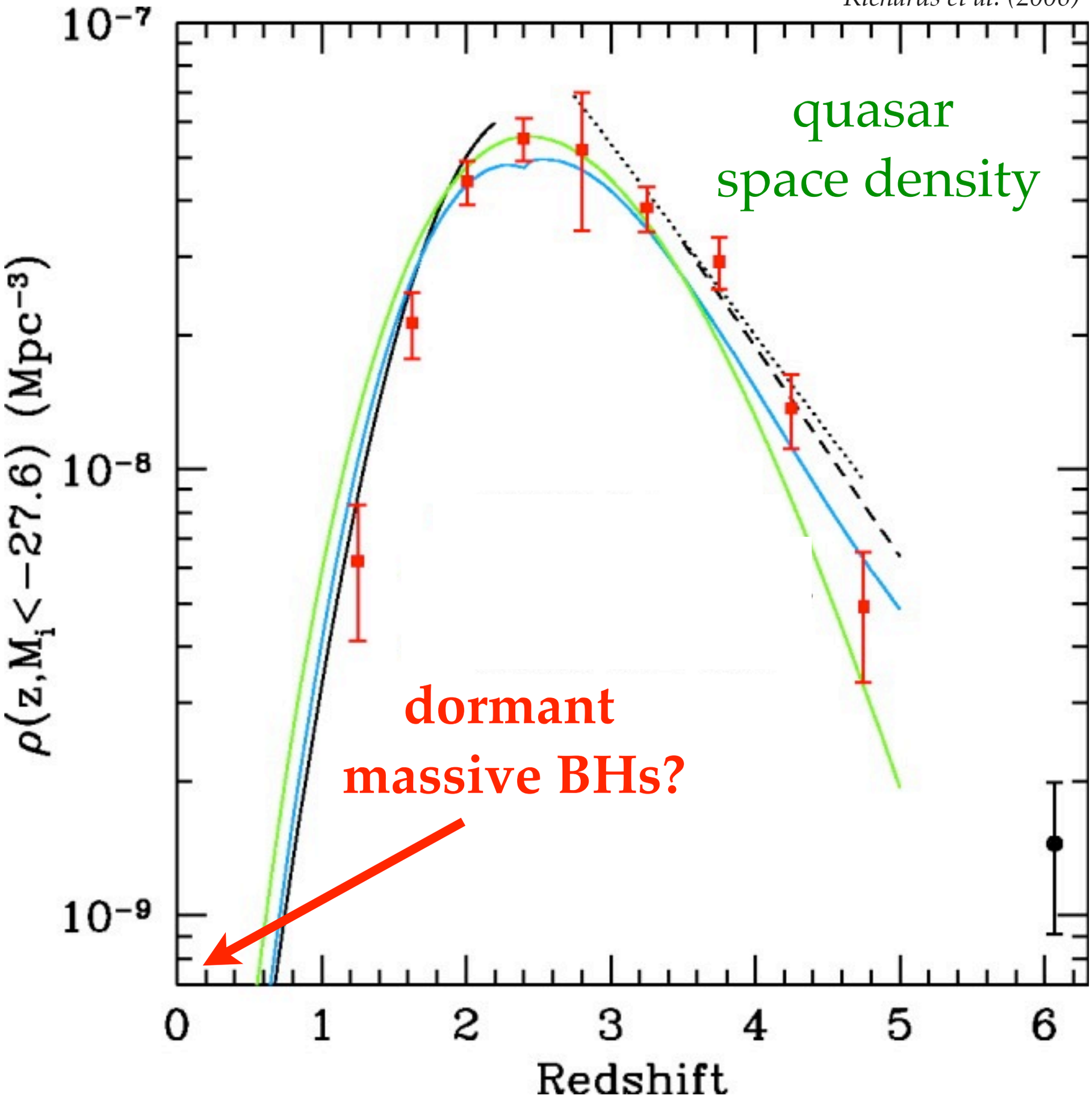


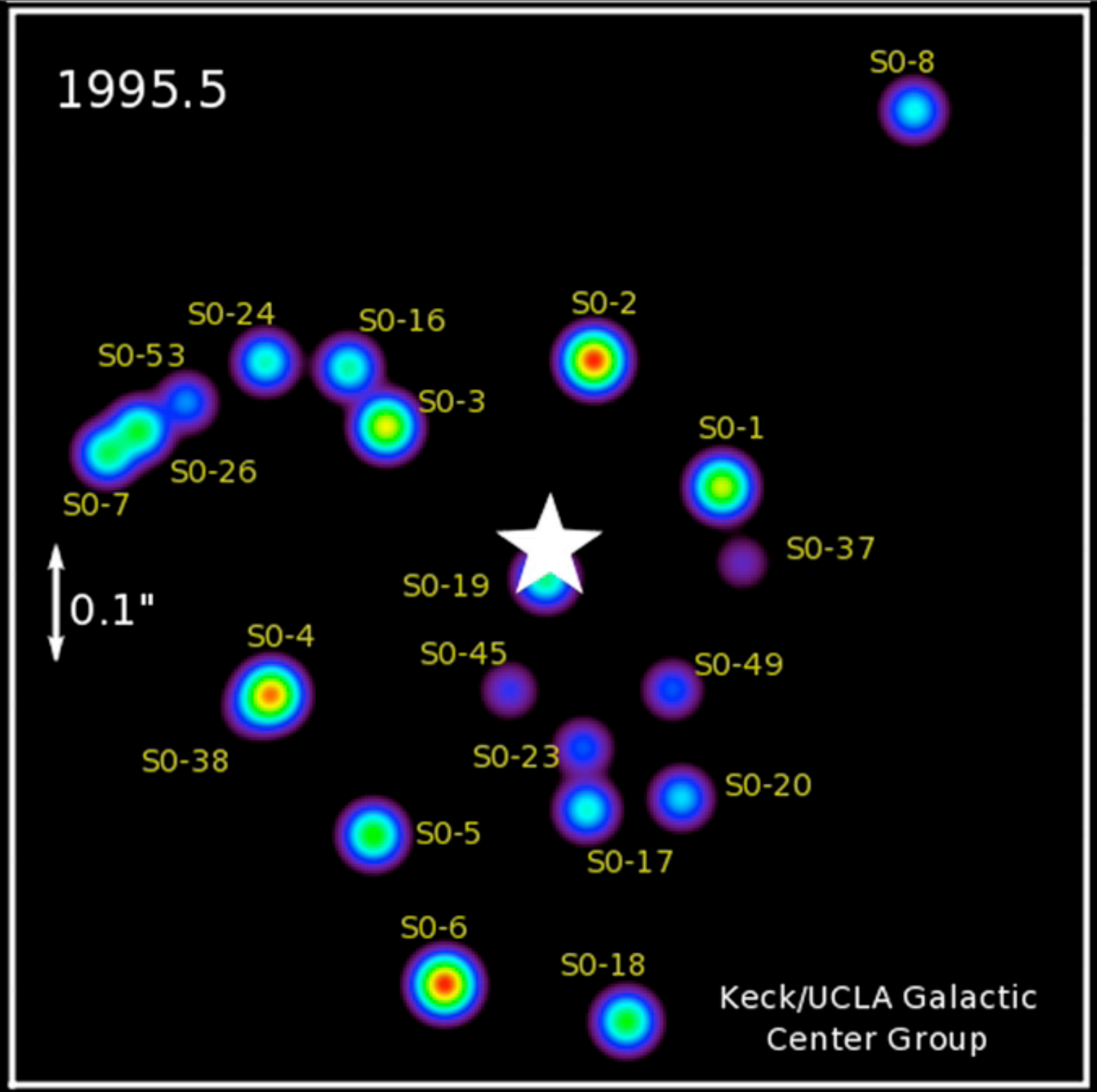
- $M_\bullet = 3 \times 10^9 M_\odot$
- Gas chemical enriched with metals (C, Mg, Si, Fe)
- At $z = 6.42$, age of the Universe only 800 Myr !

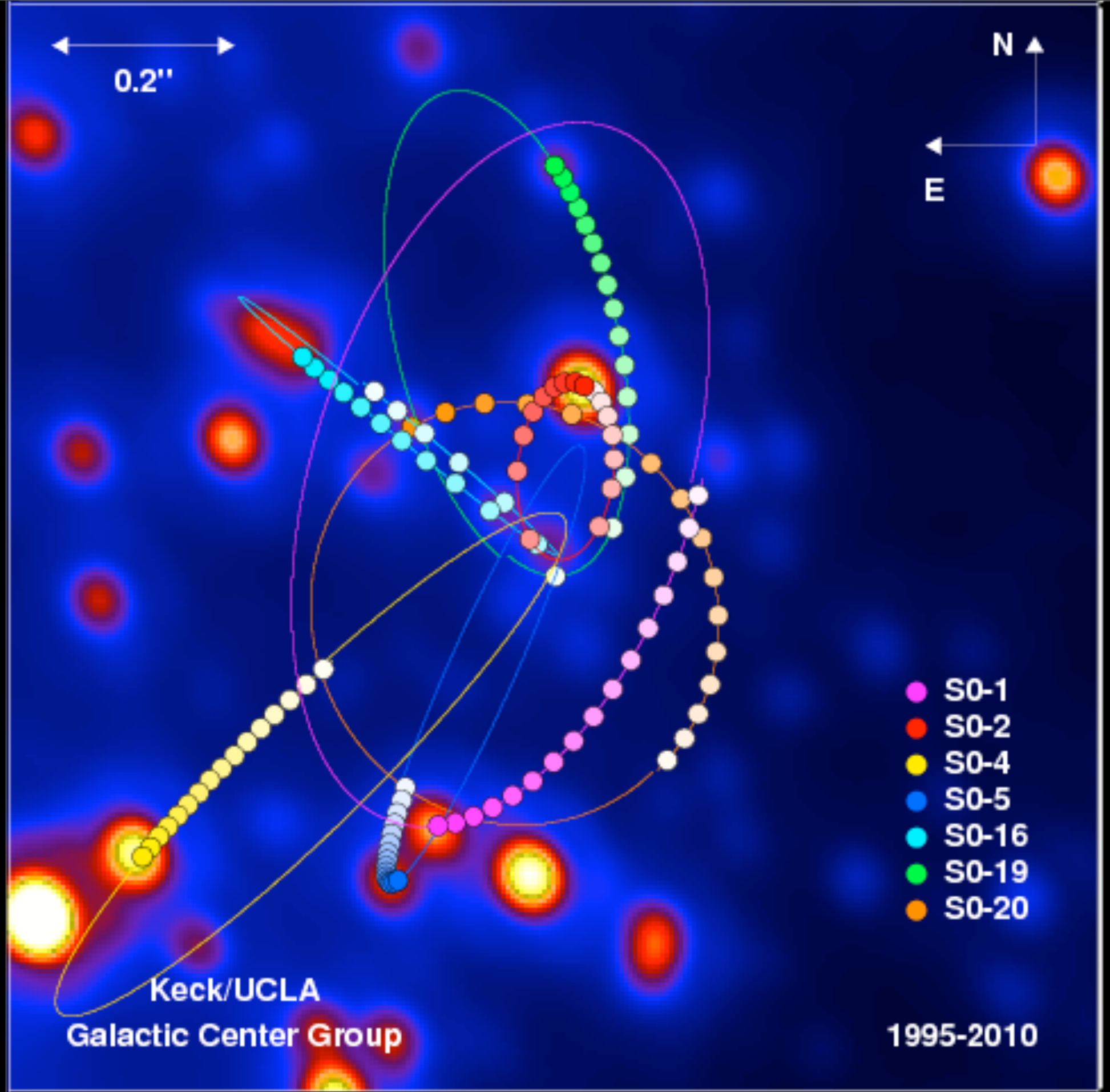
Richards et al. (2006)

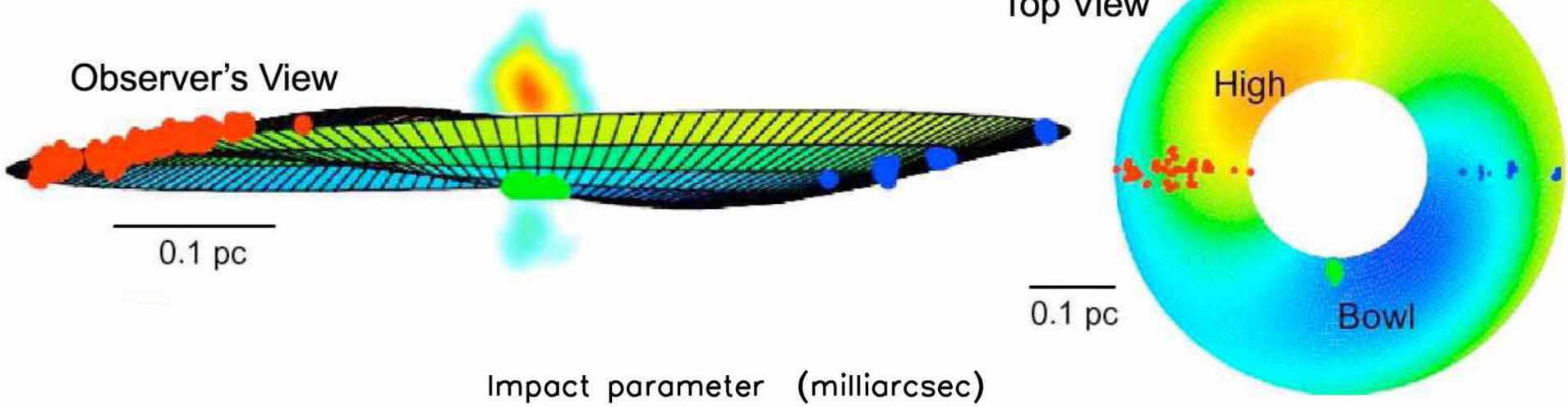


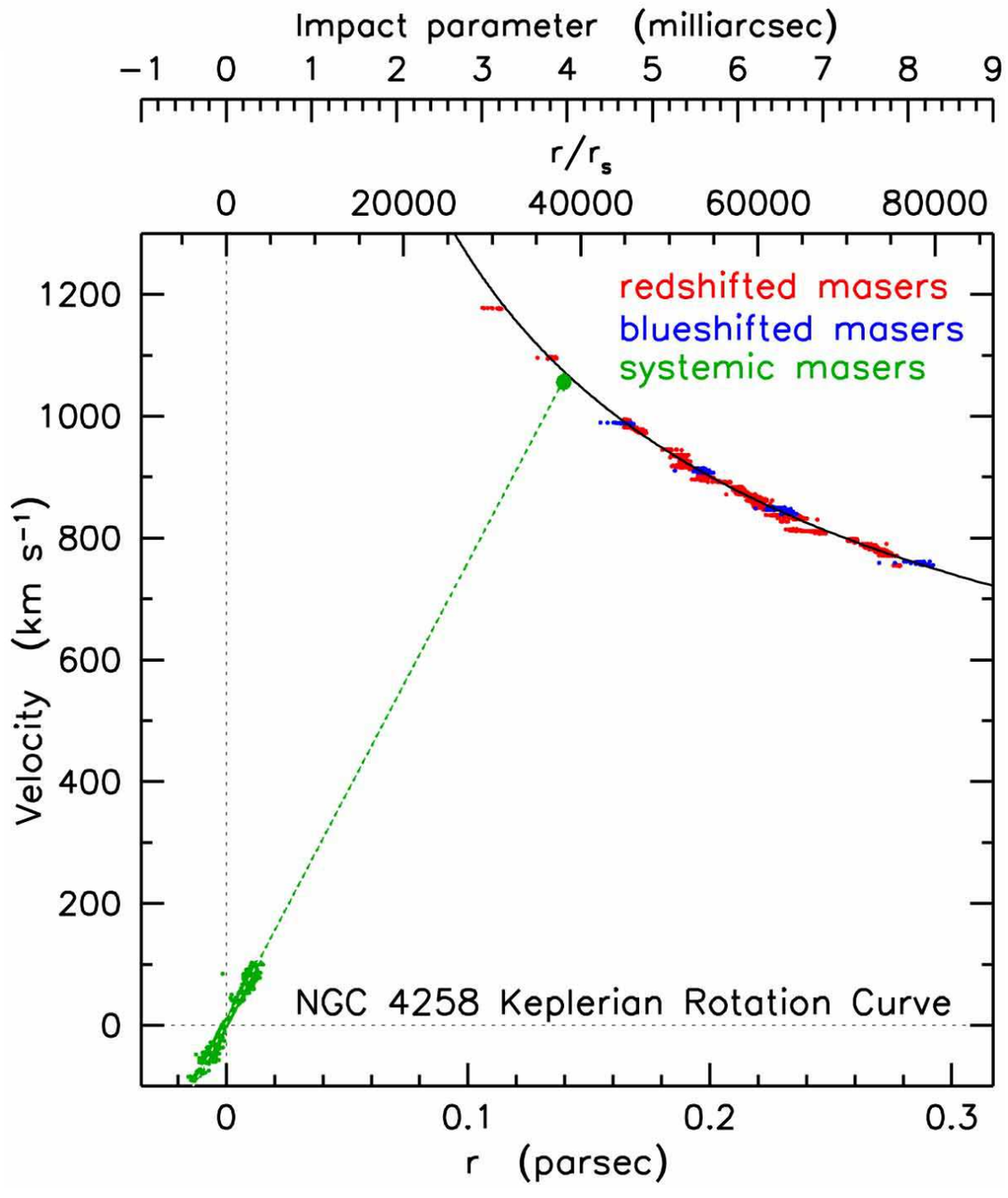
Richards et al. (2006)




1995.5
S0-8
S0-24
S0-16
S0-2
S0-53
S0-3
S0-1
S0-26
S0-7
S0-37
S0-19
0.1"
S0-4
S0-45
S0-49
S0-38
S0-23
S0-20
S0-5
S0-17
S0-6
S0-18
Keck/UCLA Galactic
Center Group

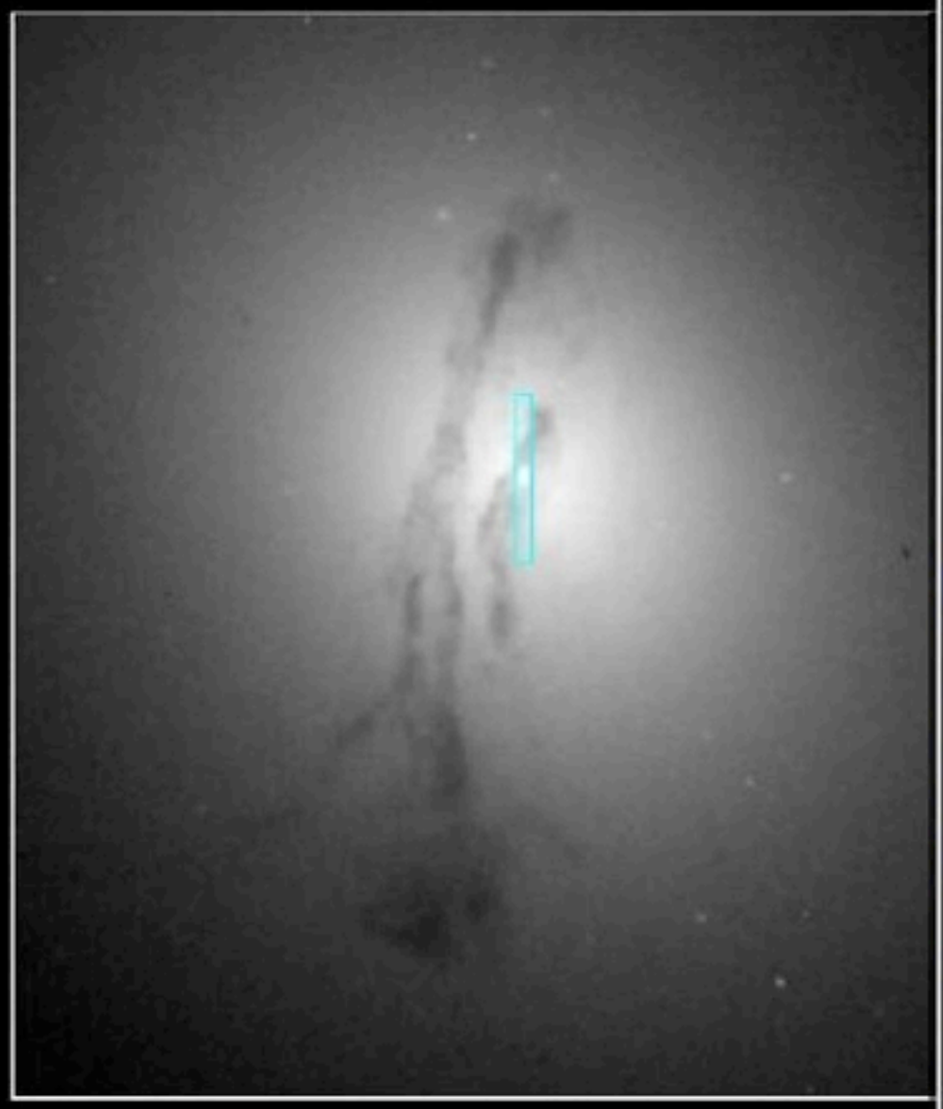

0.2''
N
E
S0-1
S0-2
S0-4
S0-5
S0-16
S0-19
S0-20
Keck/UCLA
Galactic Center Group
1995-2010



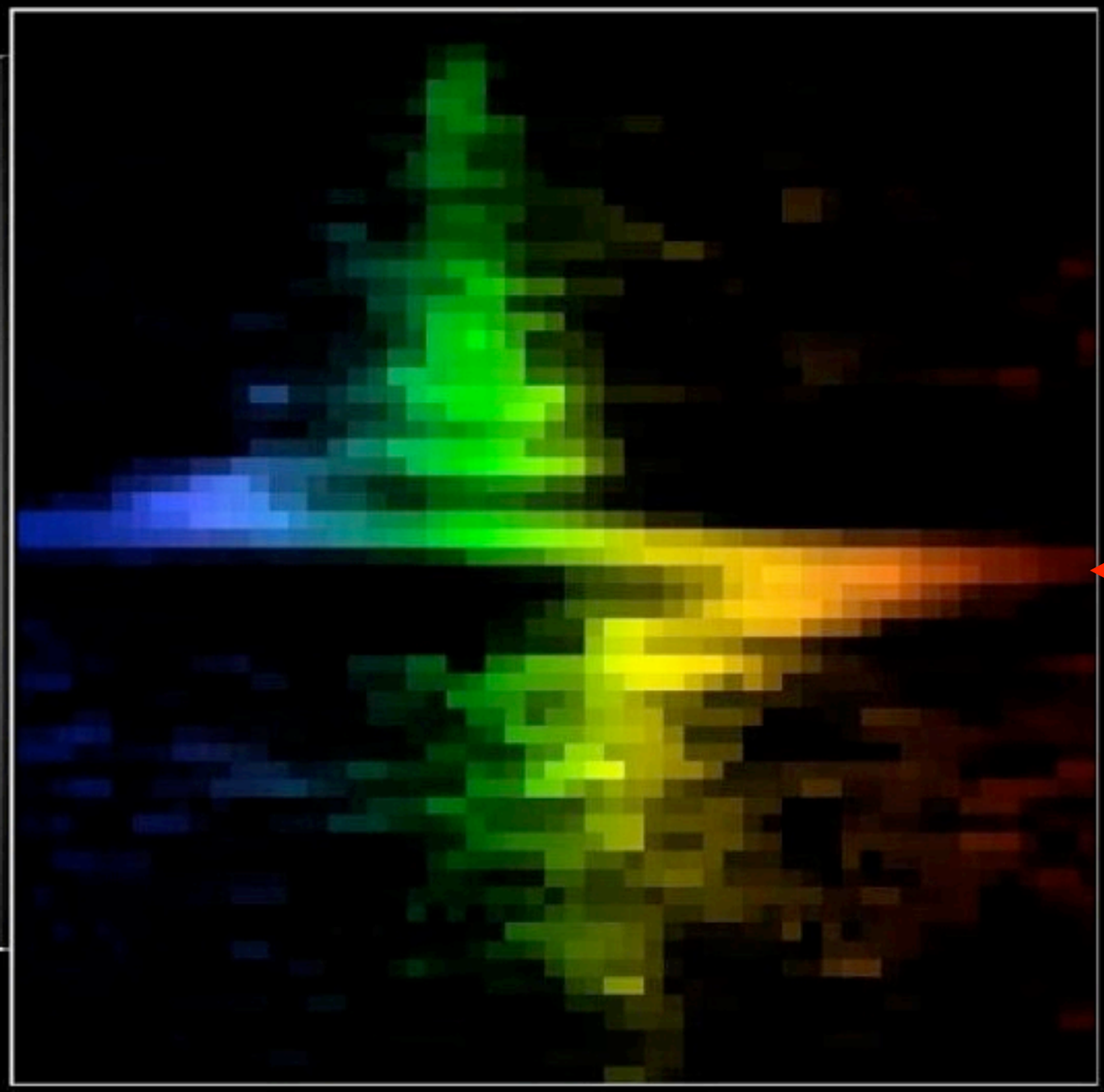


Miyoshi et al. (1995)
Herrnstein et al. (2005)

M84

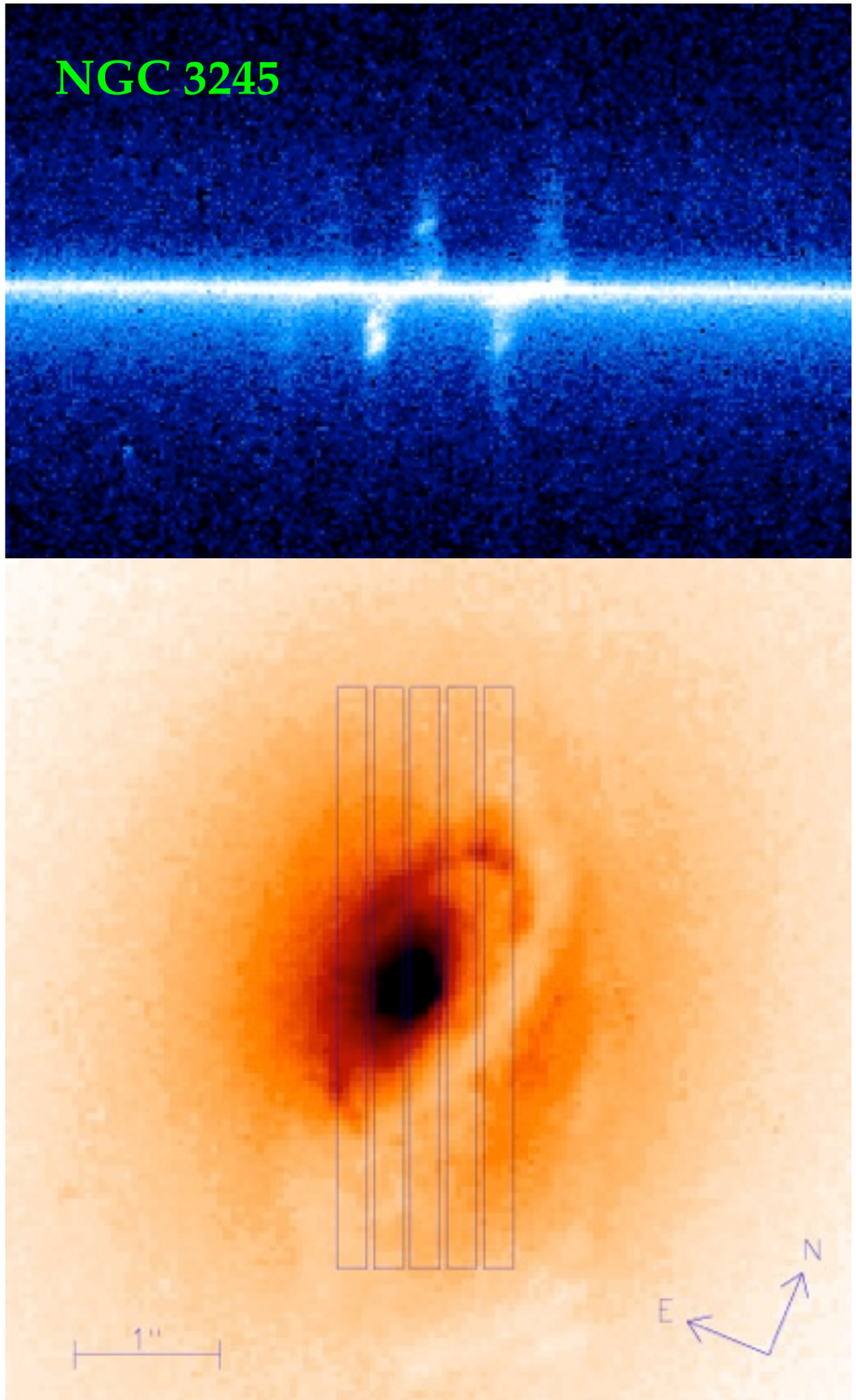


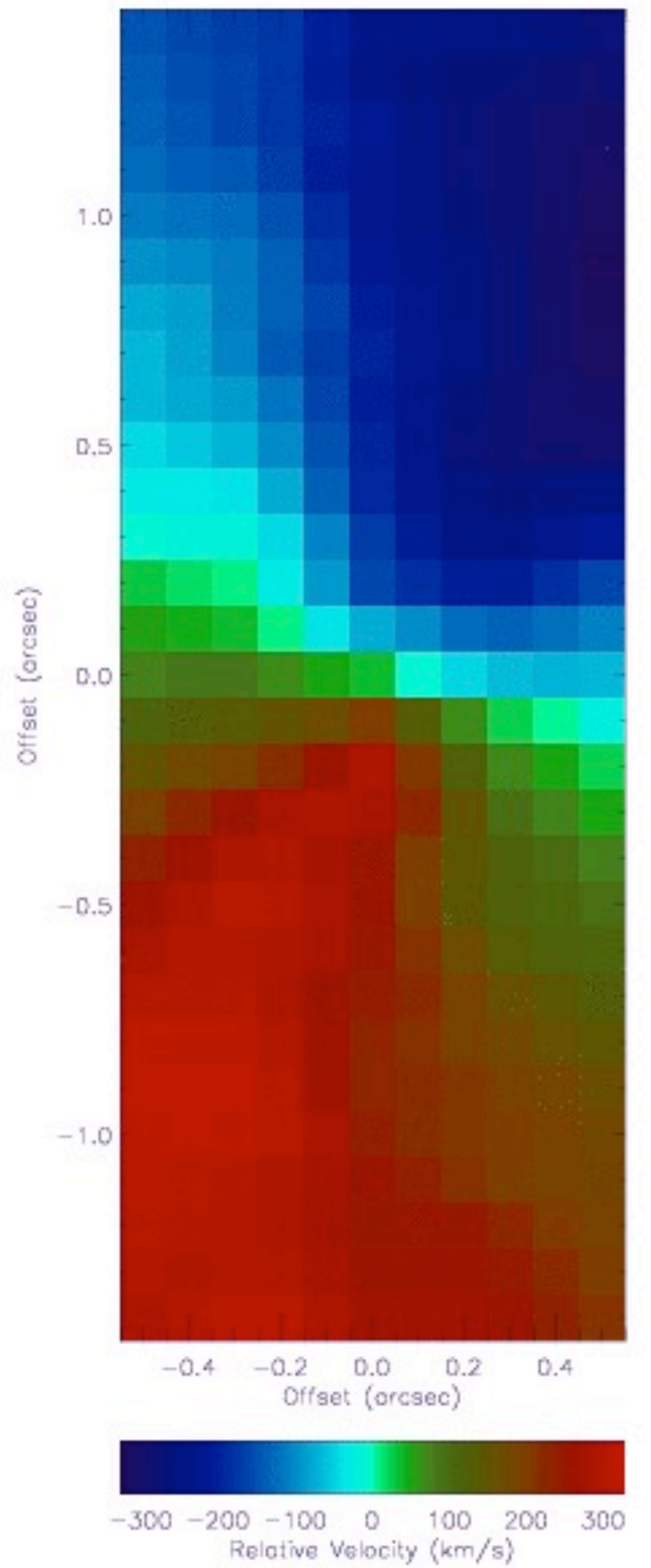
Bower et al. (1998)



distance from the center

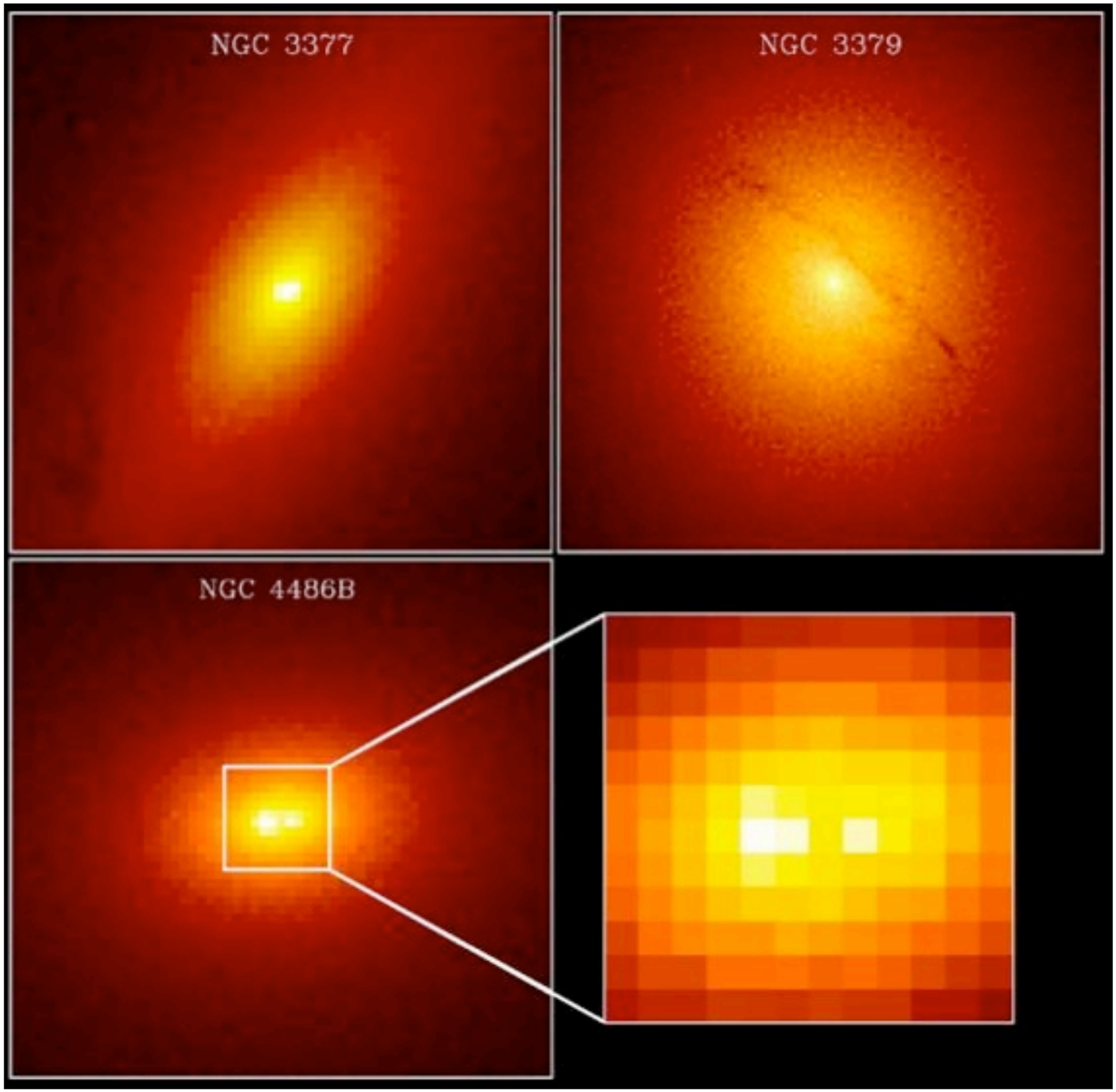
approaching speed of gas clouds receding



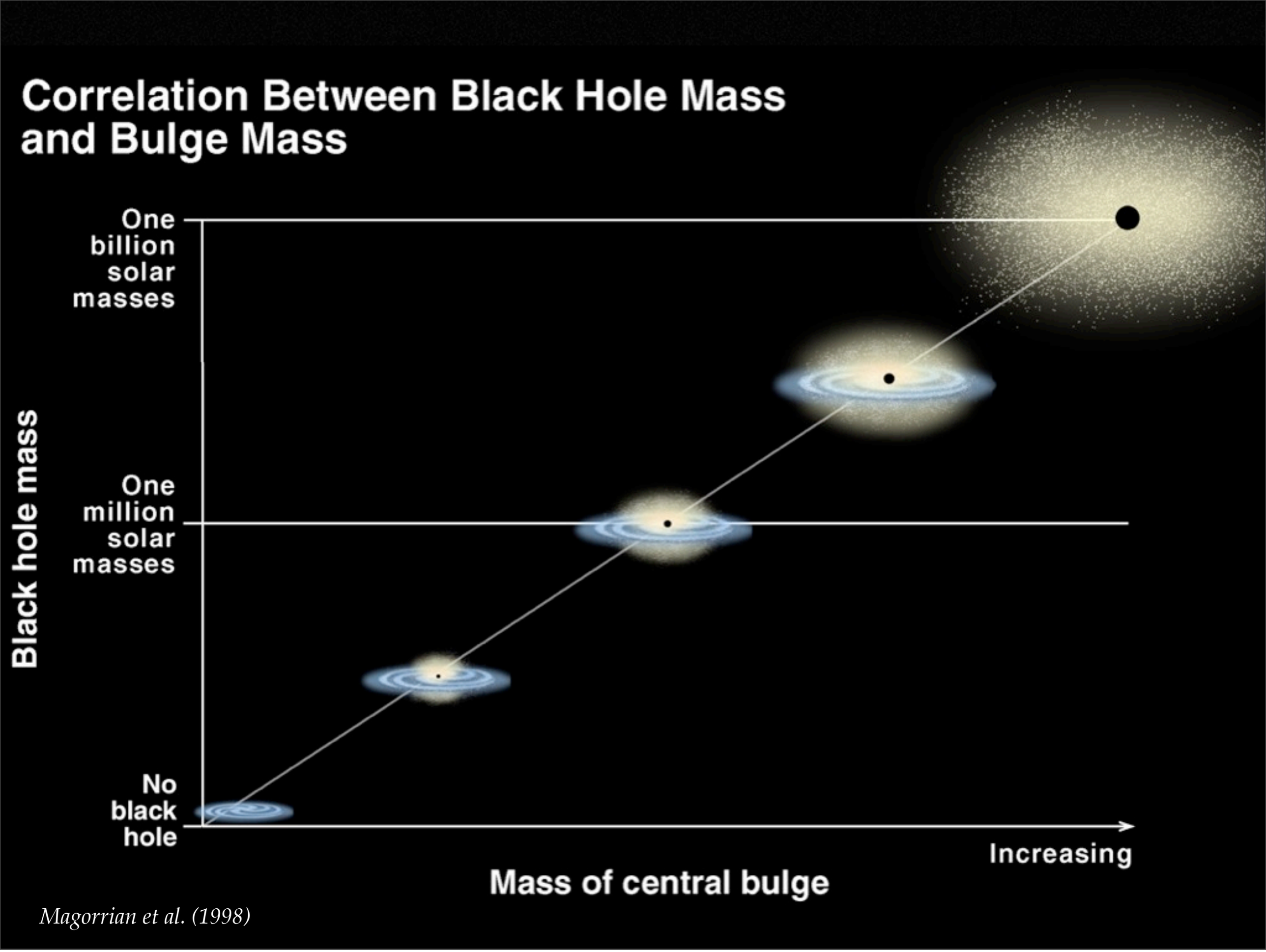


Barth et al. (2001)

The "Nuker" Team

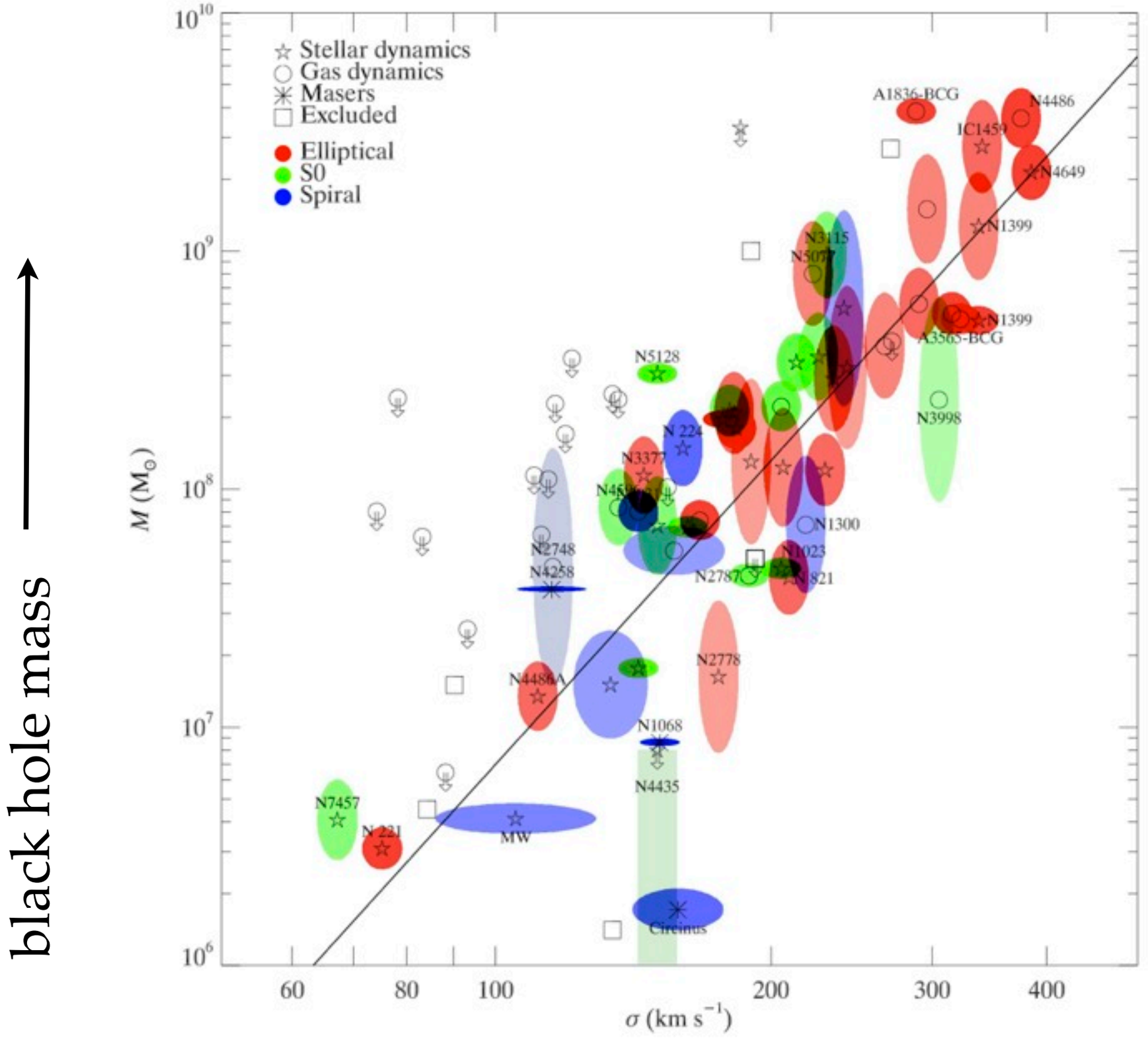


Correlation Between Black Hole Mass and Bulge Mass



Magorrian et al. (1998)

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



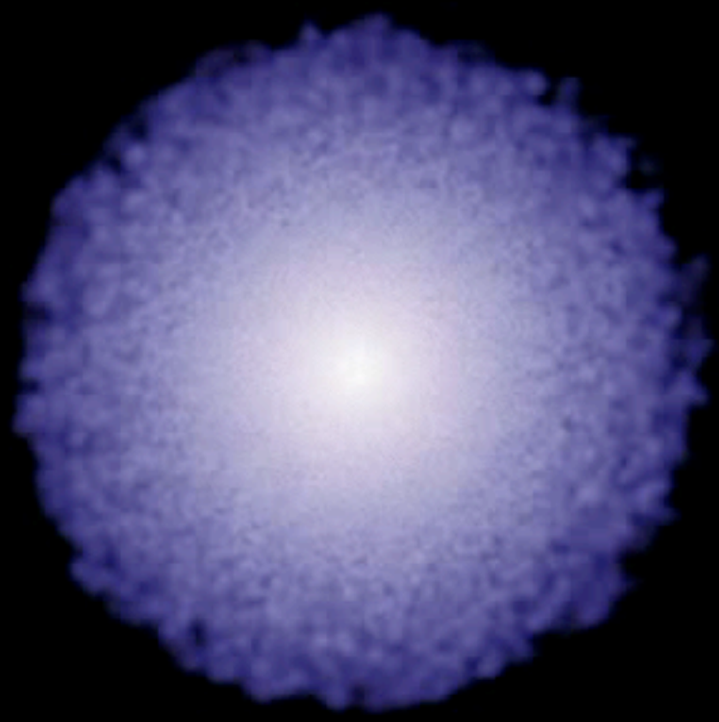
black hole mass

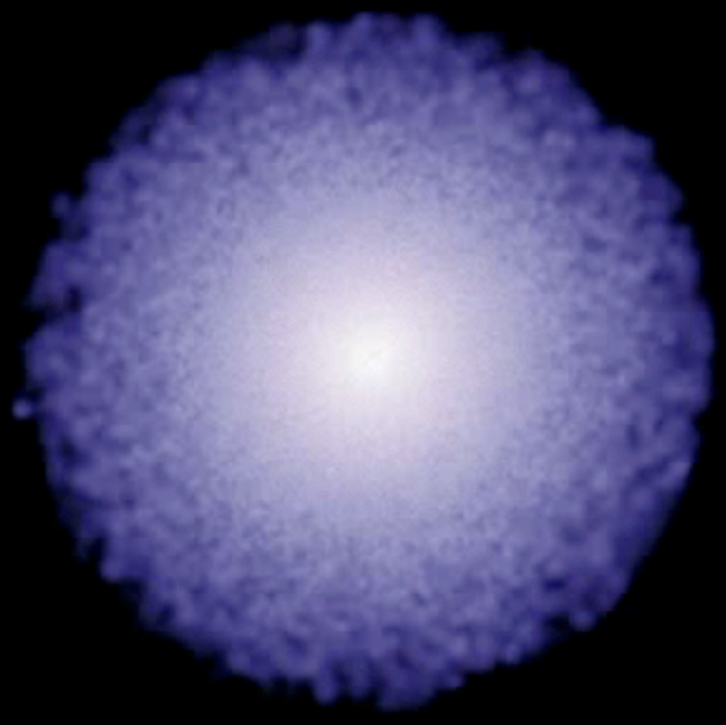
bulge velocity dispersion

Standard "Paradigm"

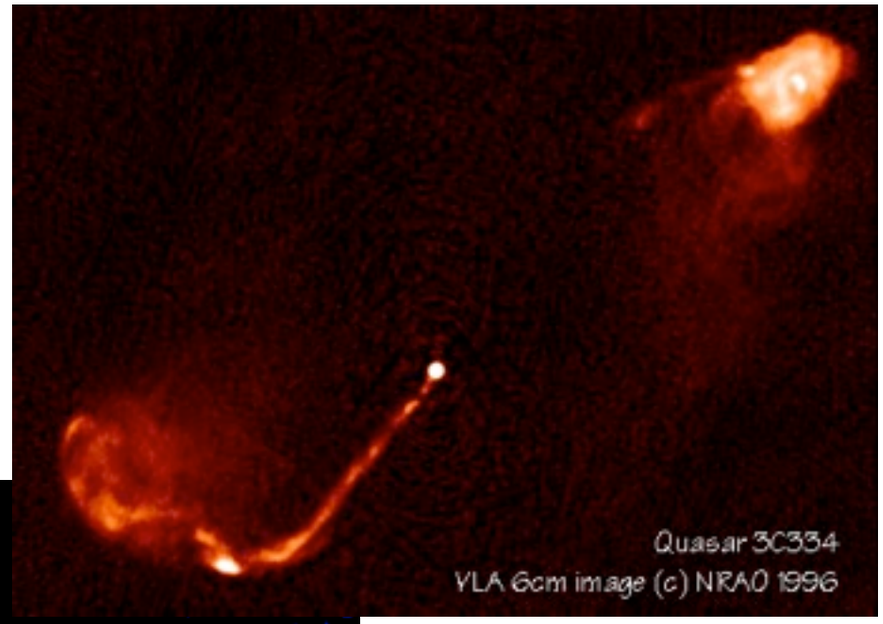
- All bulges contain BHs
- $M_\bullet \sim M_{\rm bulge}^{1.0}$ $\qquad \langle M_\bullet \,/\, M_{\rm bulge} \rangle \sim 0.1\% - 0.2\%$
- $M_\bullet \propto \sigma^4$
- $M_\bullet$–σ relation tighter than $M_\bullet - M_{\rm bulge}$ relation
- No strong dependence on galaxy mass or type
- Mild to strong evolution with redshift
- AGN feedback engineers BH-host correlations

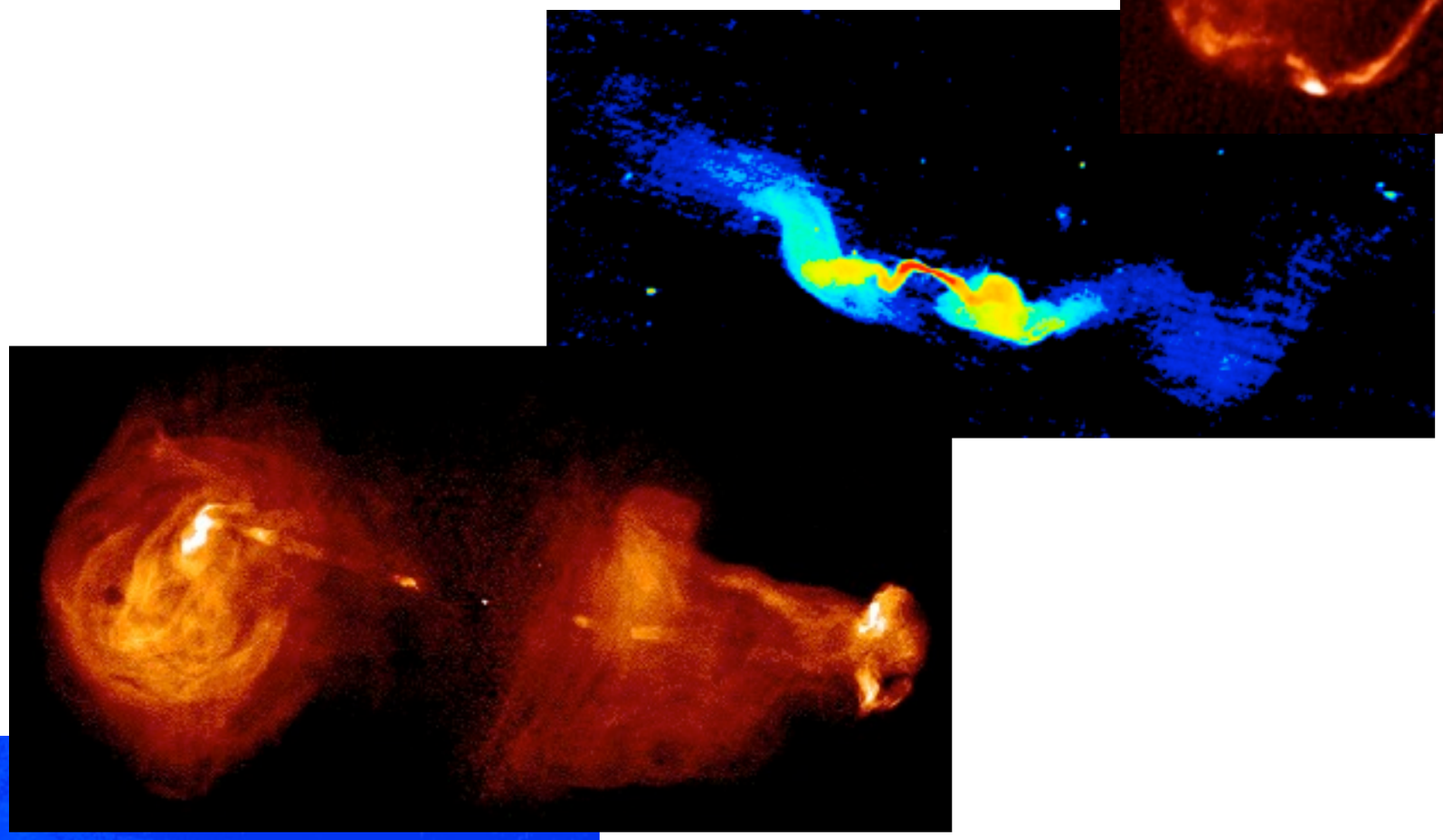
T = 0 Myr

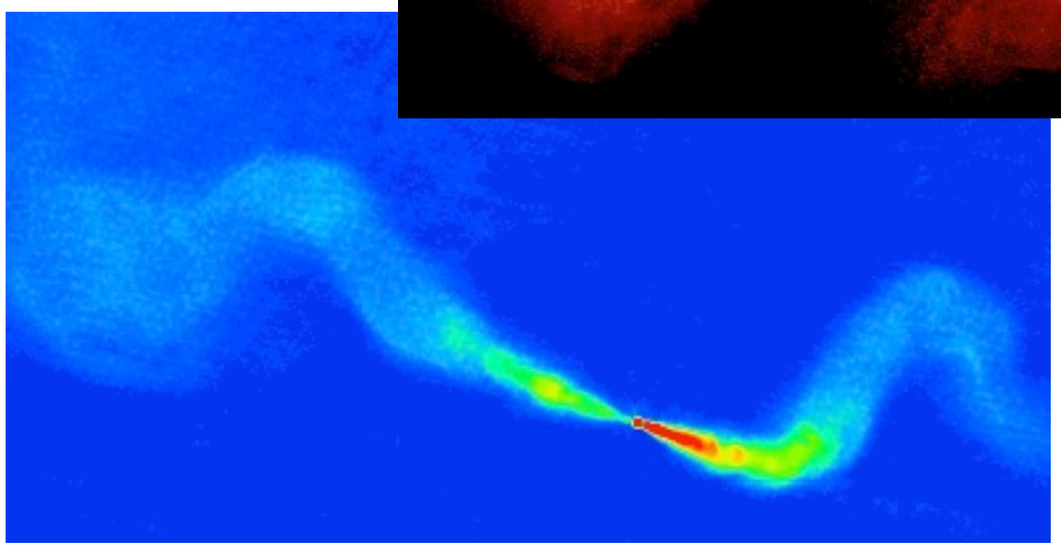




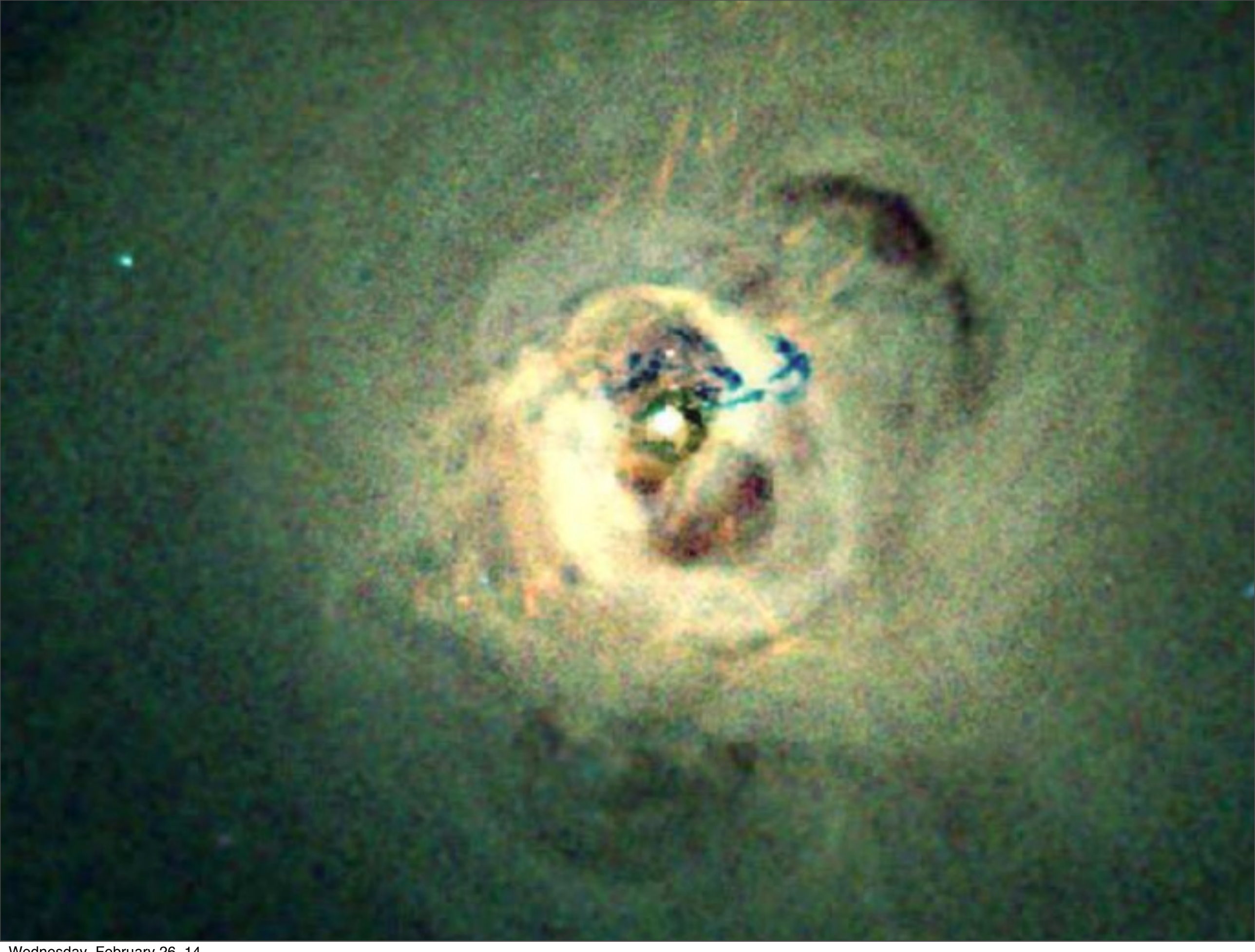
10 kpc/h


Quasar 3C334
VLA 6cm image (c) NRAO 1996

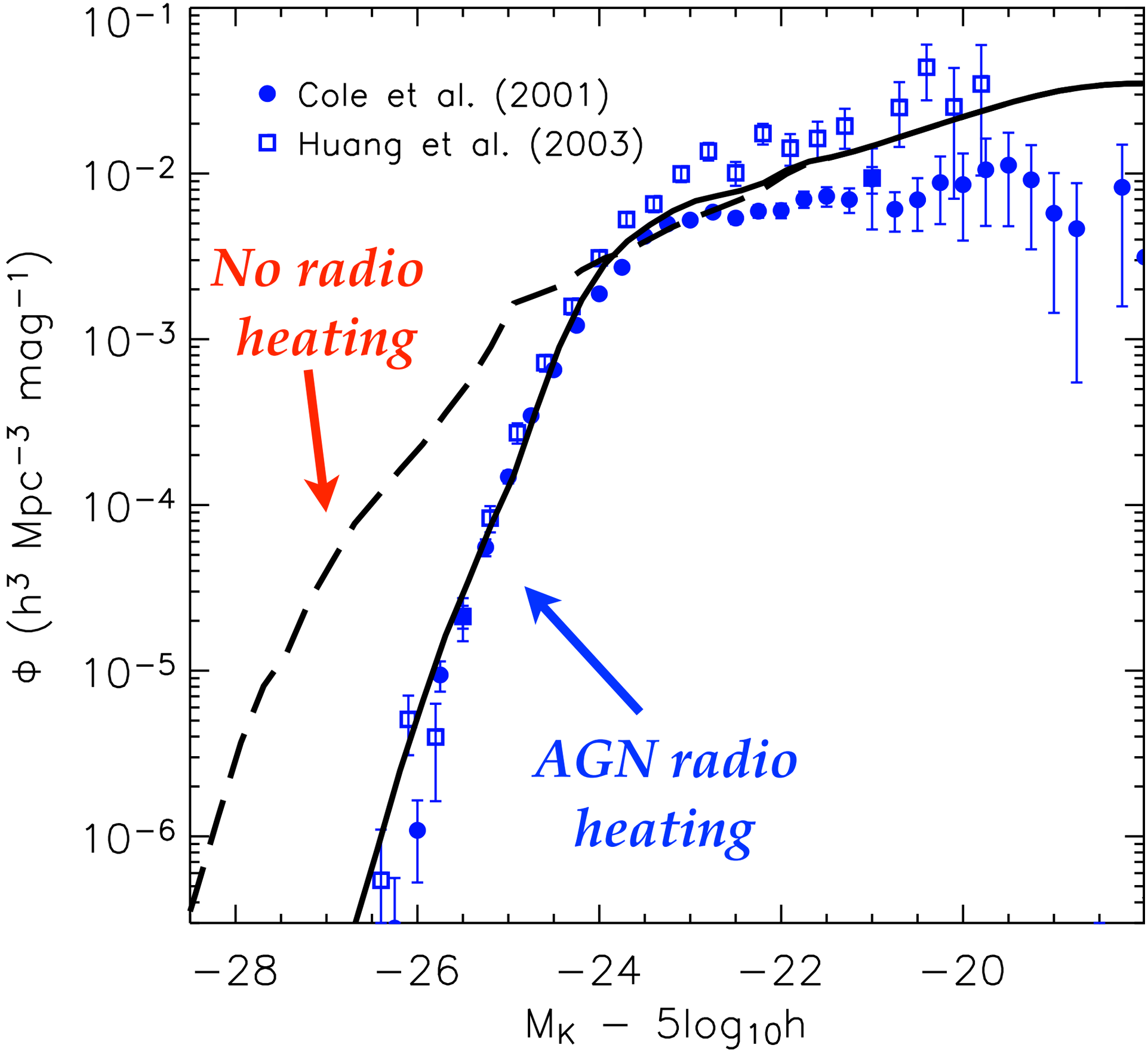




Courtesy of S. Heinz



Crotton et al. (2006)

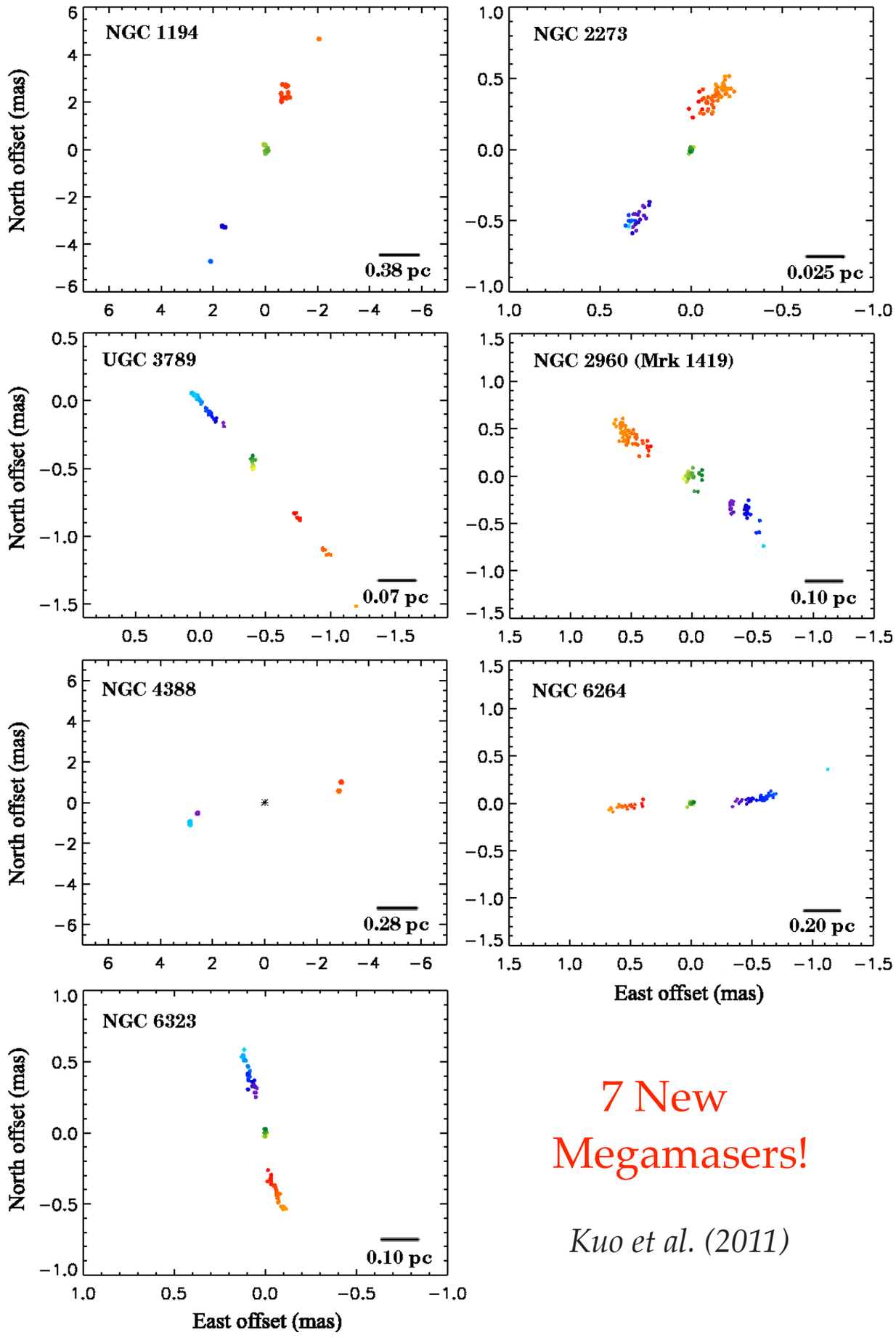


Recent Developments

Ho (2008, ARA&A): *Nuclear Activity in Nearby Galaxies*

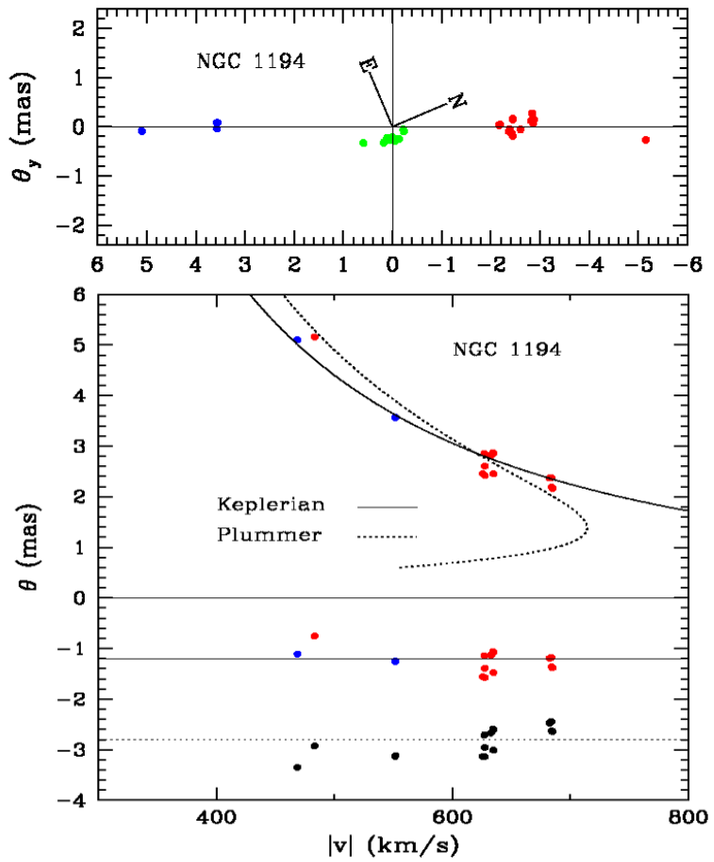
Kormendy & Ho (2013, ARA&A): *Coevolution of Supermassive Black Holes and Galaxies*

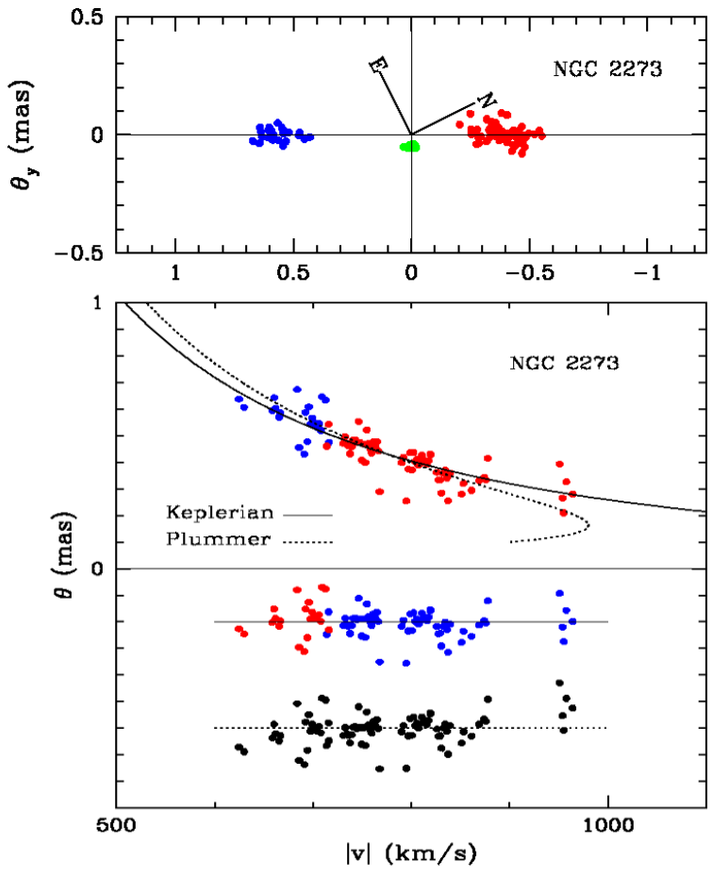

NGC 4889: $M_\bullet = 2 \times 10^{10}\, M_\odot$ *(McConnell et al. 2011)*

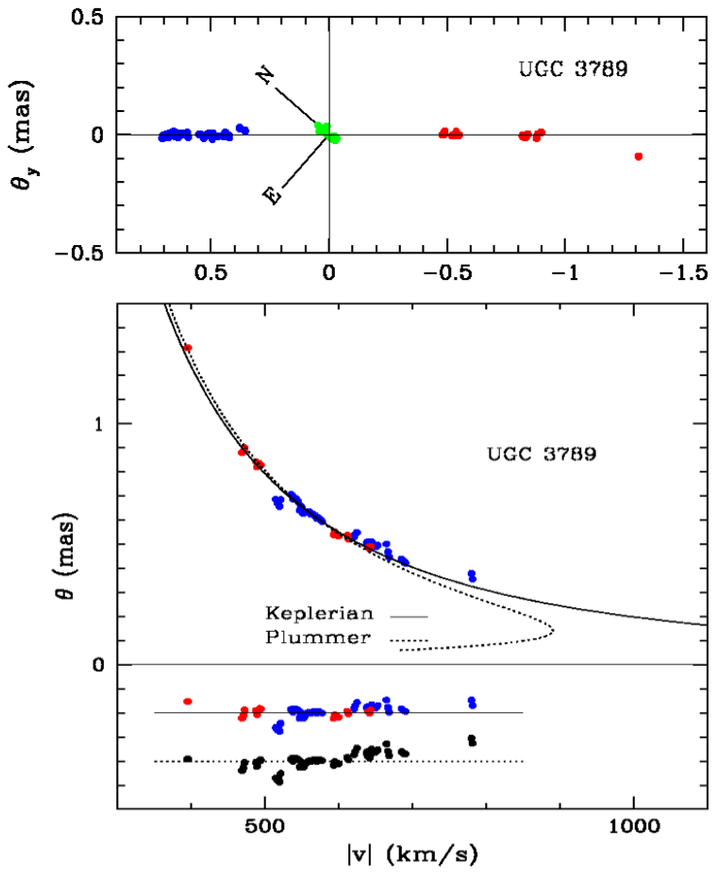


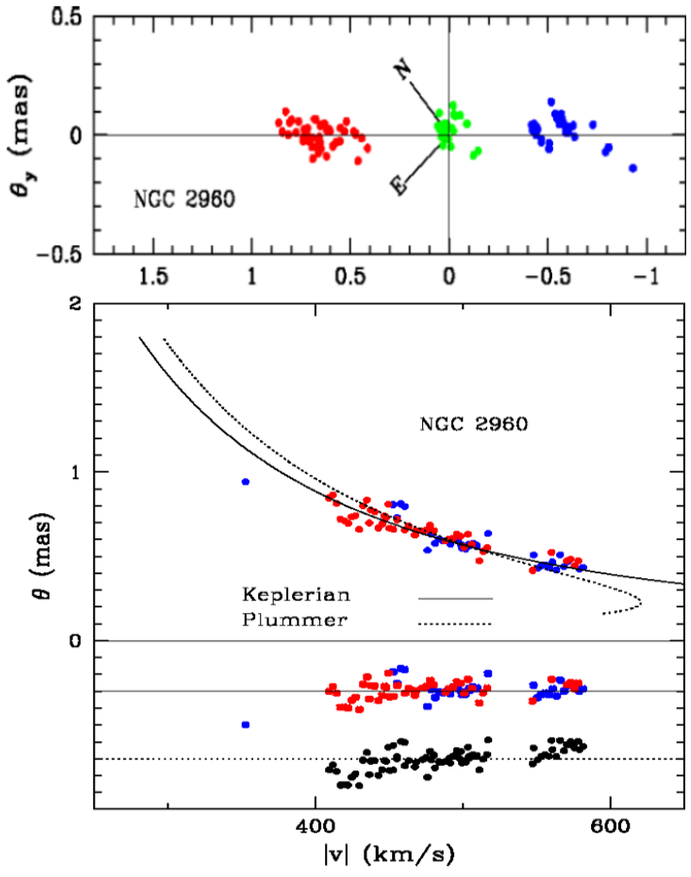
7 New Megamasers!

Kuo et al. (2011)

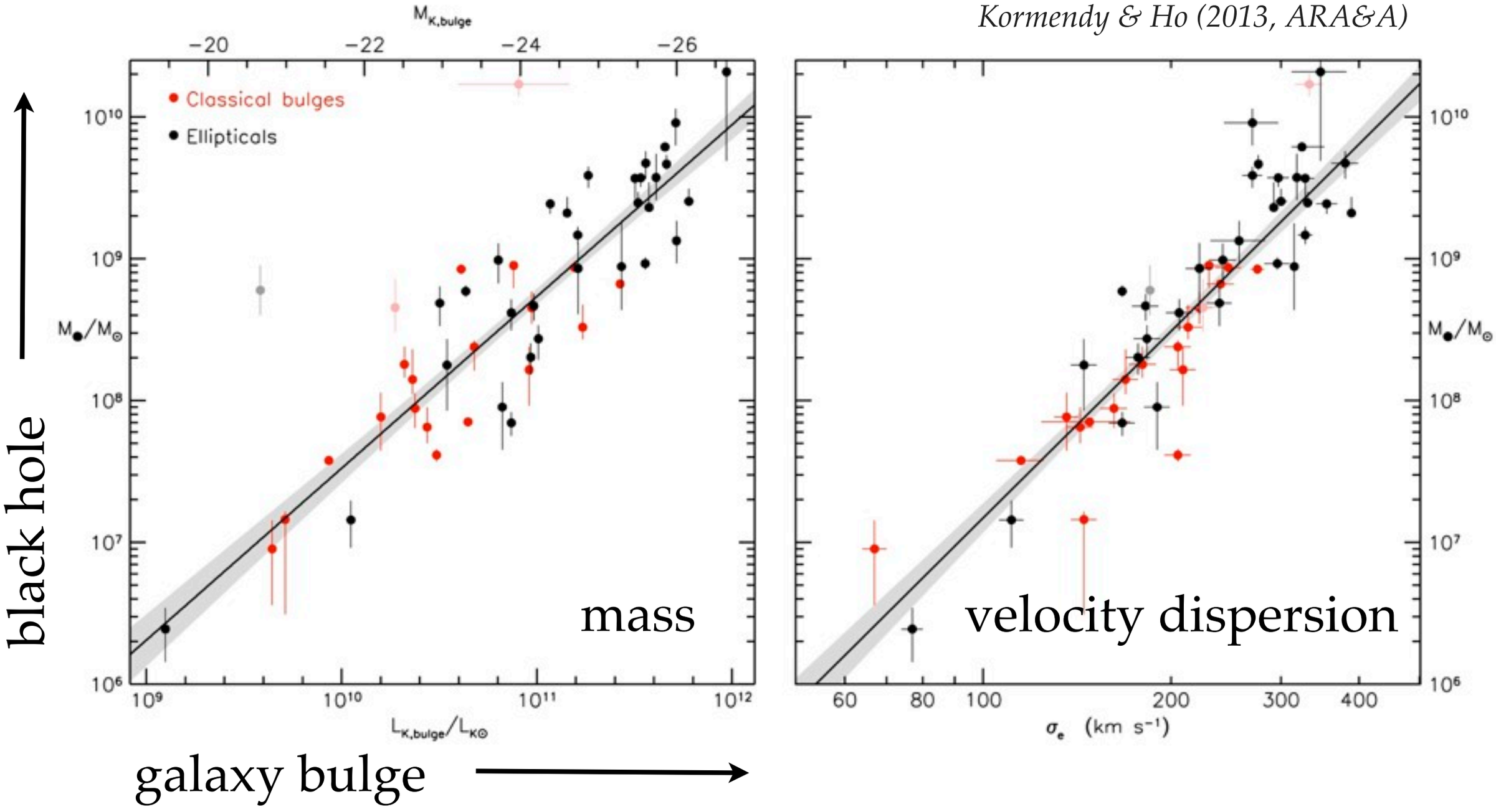

NGC 1194
E
N
θ_y (mas)
NGC 1194
Keplerian
Plummer
θ (mas)
|v| (km/s)


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)

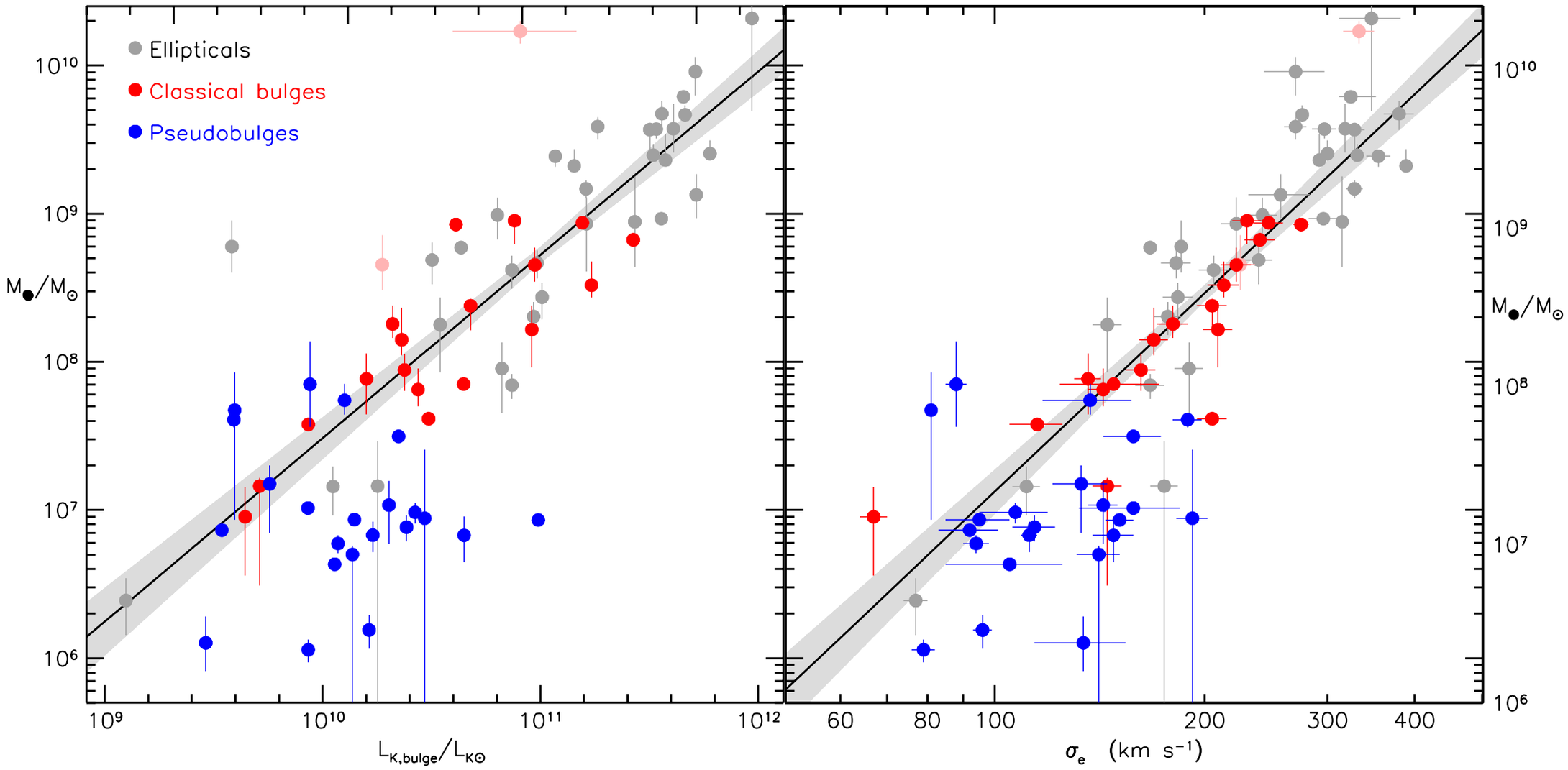
Kormendy & Ho (2013, ARA&A)




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})

$M_\bullet - \sigma$ Relation

$M_\bullet - \sigma$ Relation

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

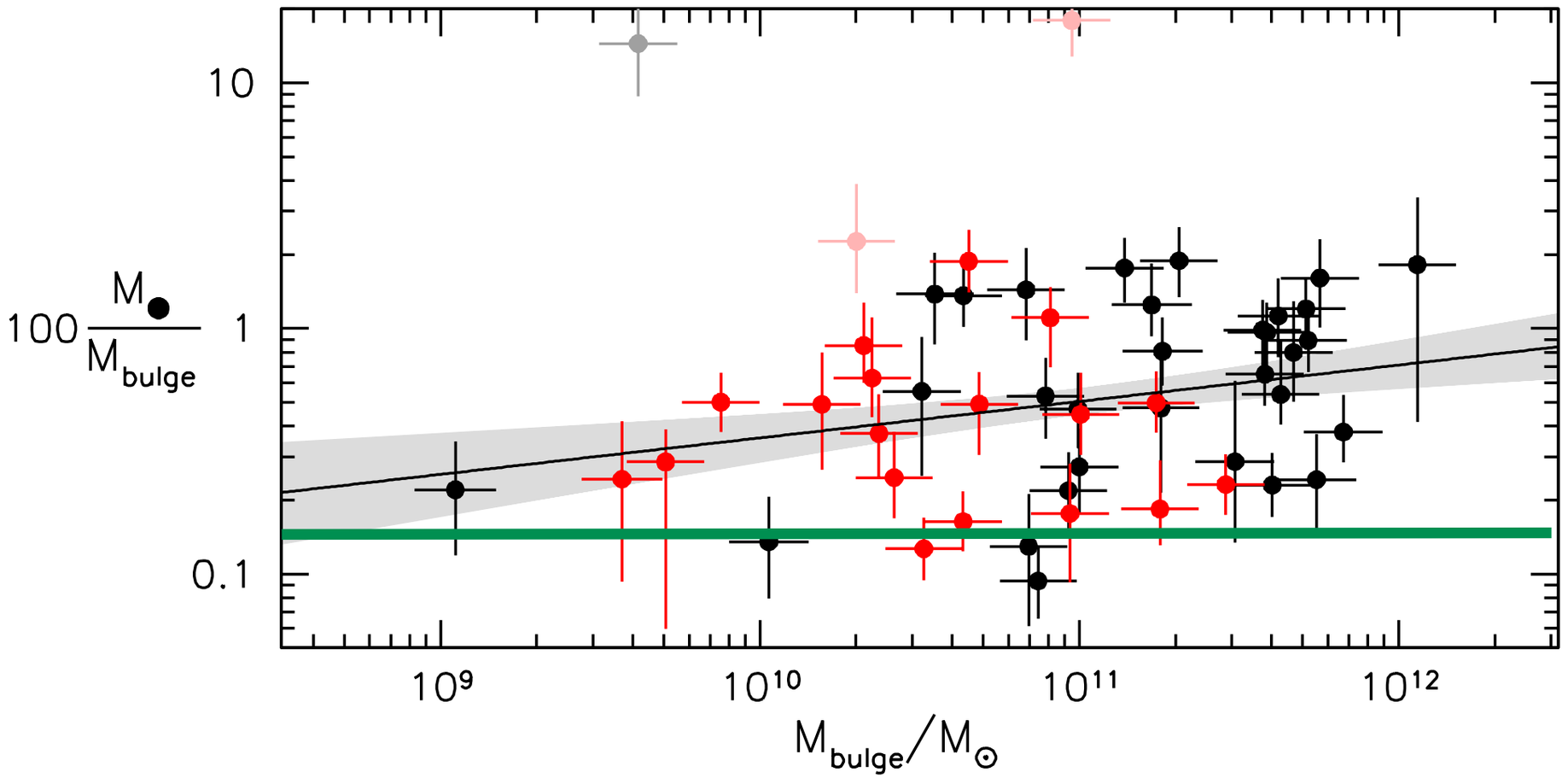
$M_\bullet - M_{\text{bulge}}$ Relation

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

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

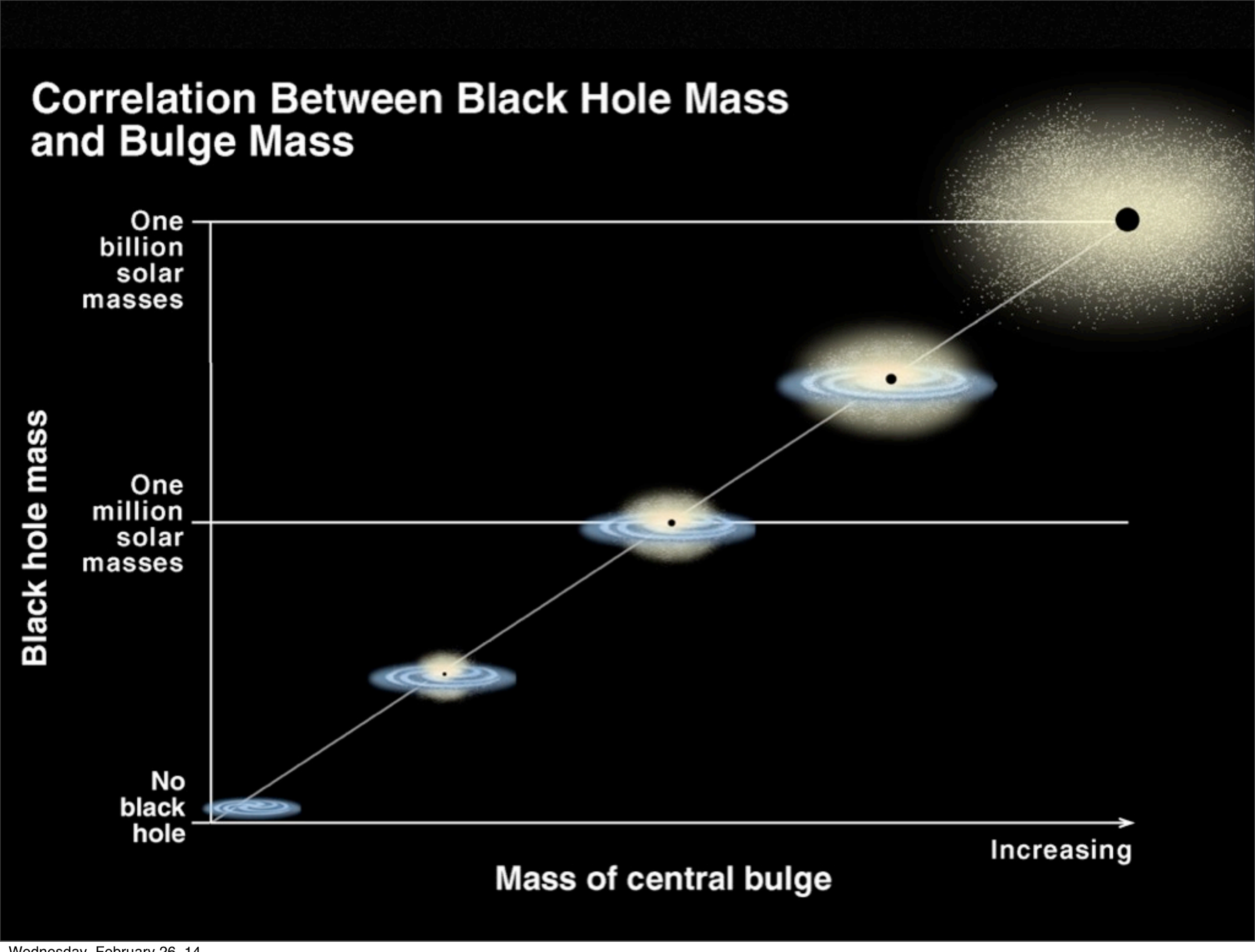
$M_\bullet - M_{\rm bulge}$ Relation

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

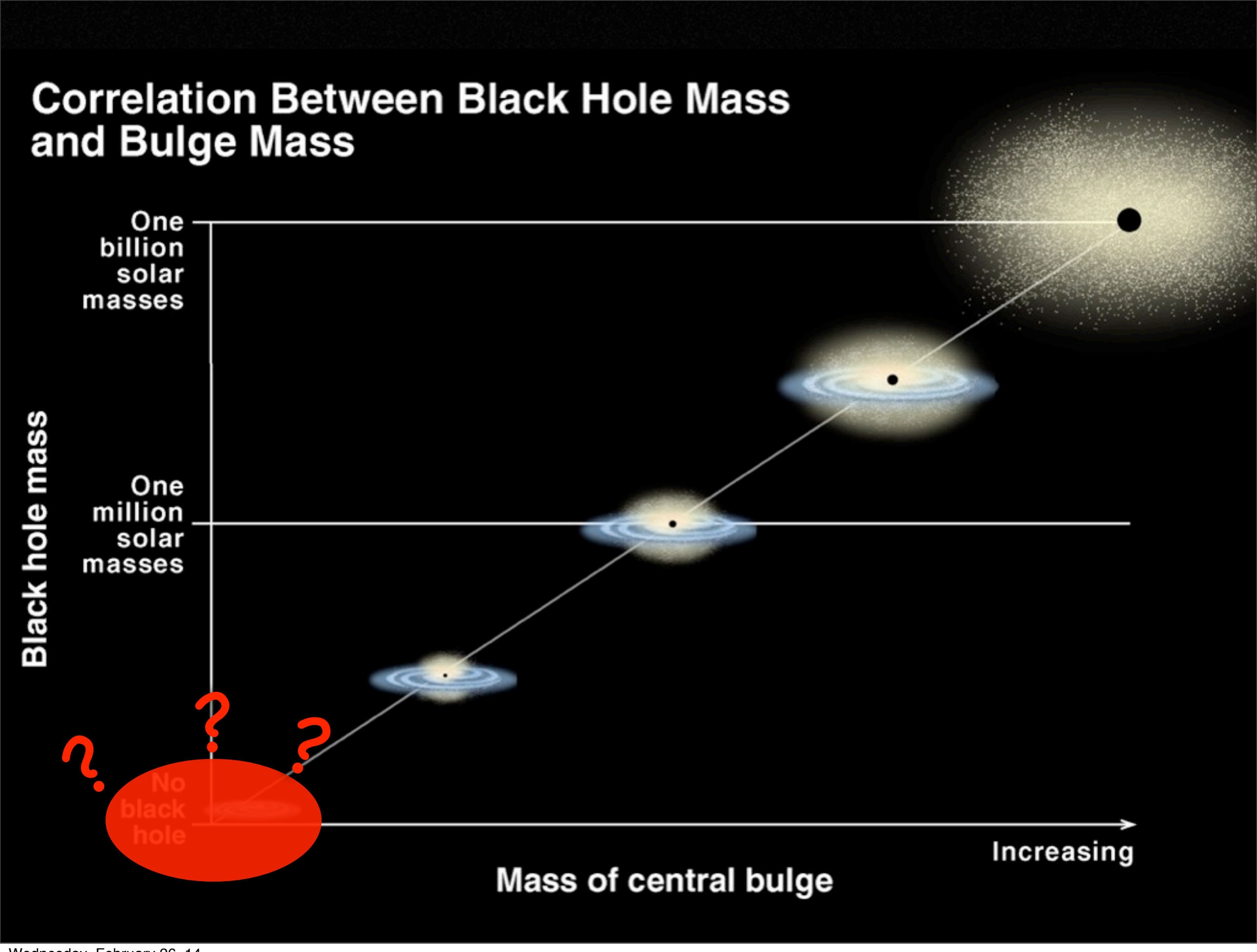


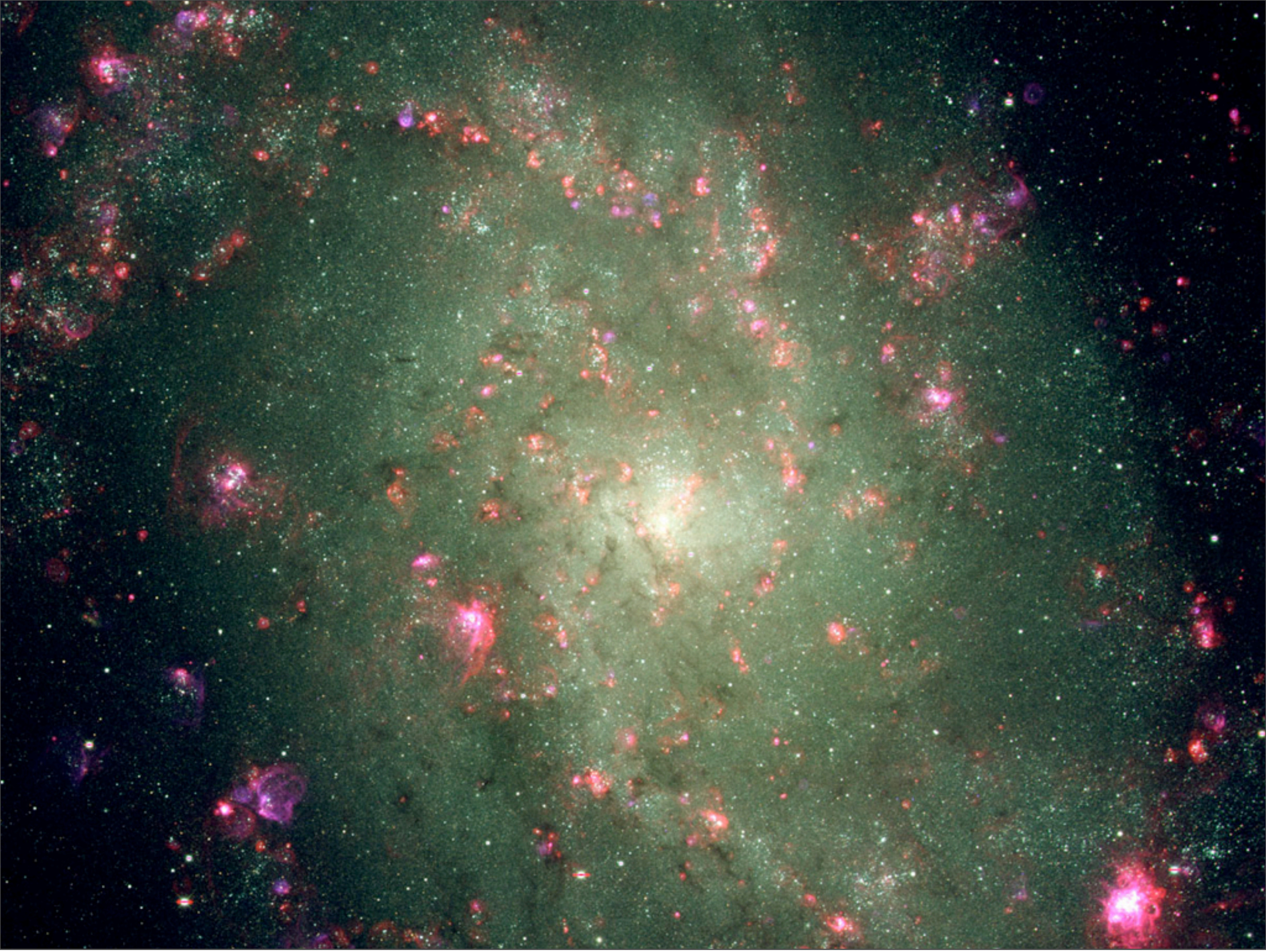
old value

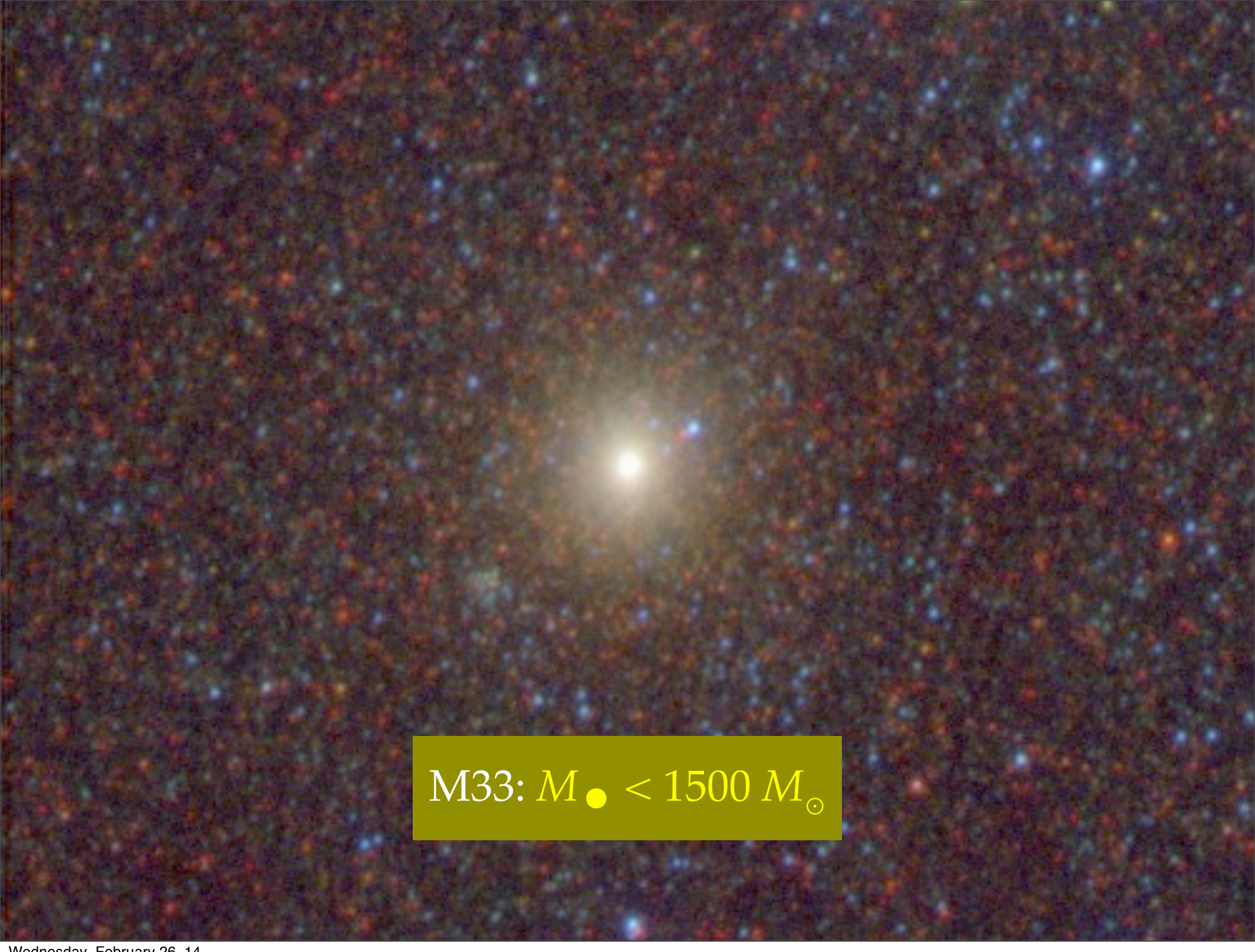
Correlation Between Black Hole Mass and Bulge Mass

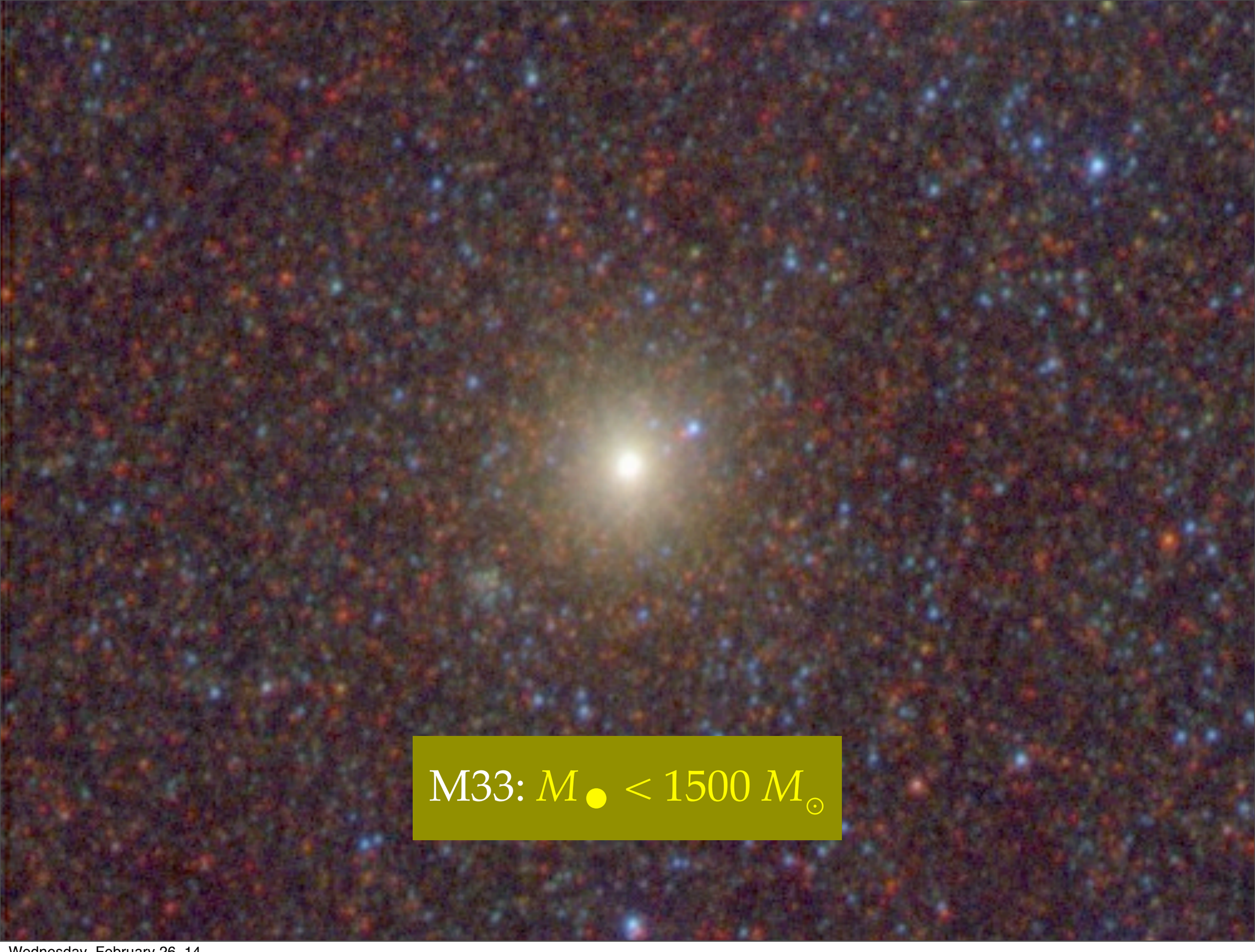


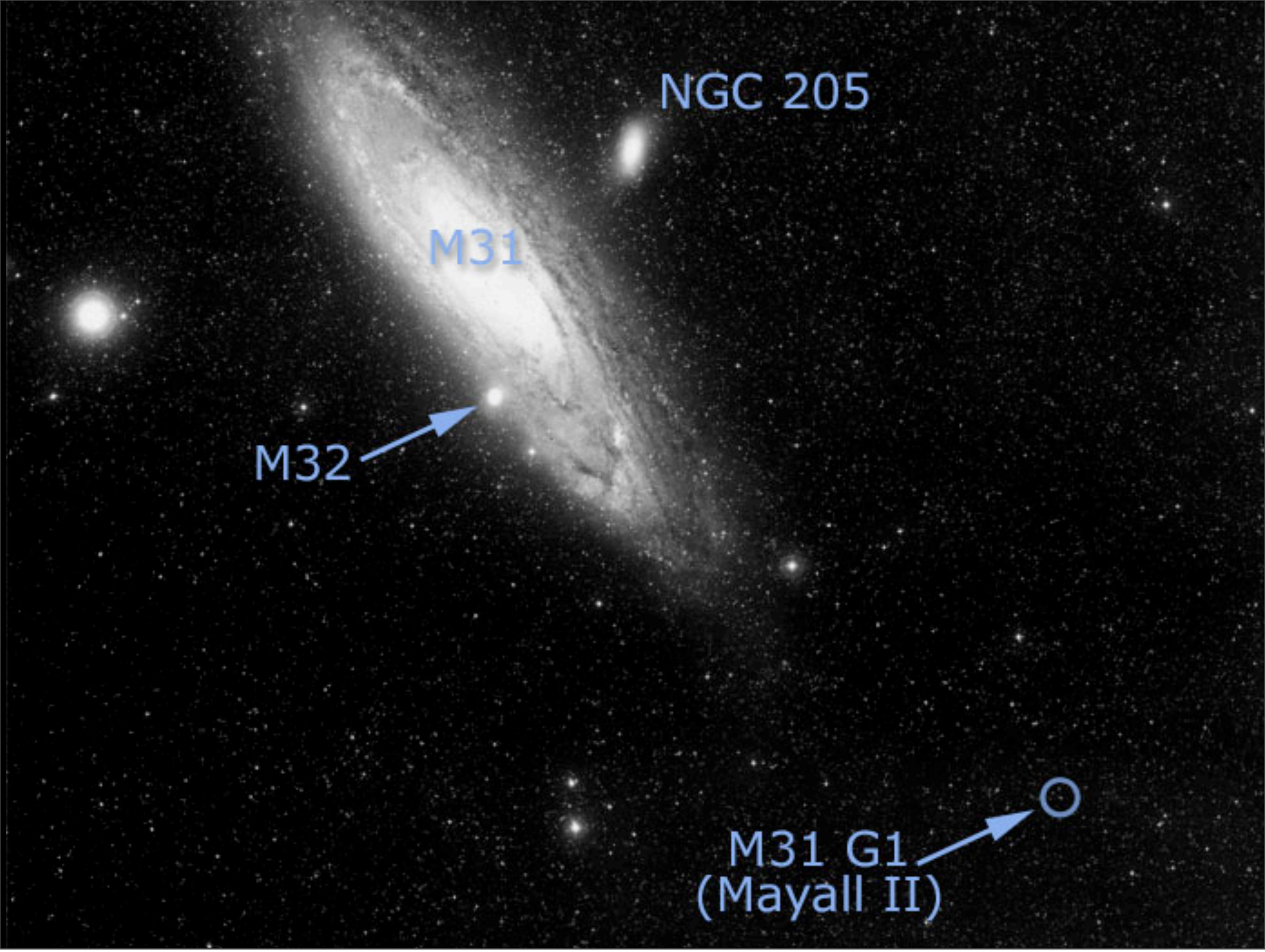
Correlation Between Black Hole Mass and Bulge Mass

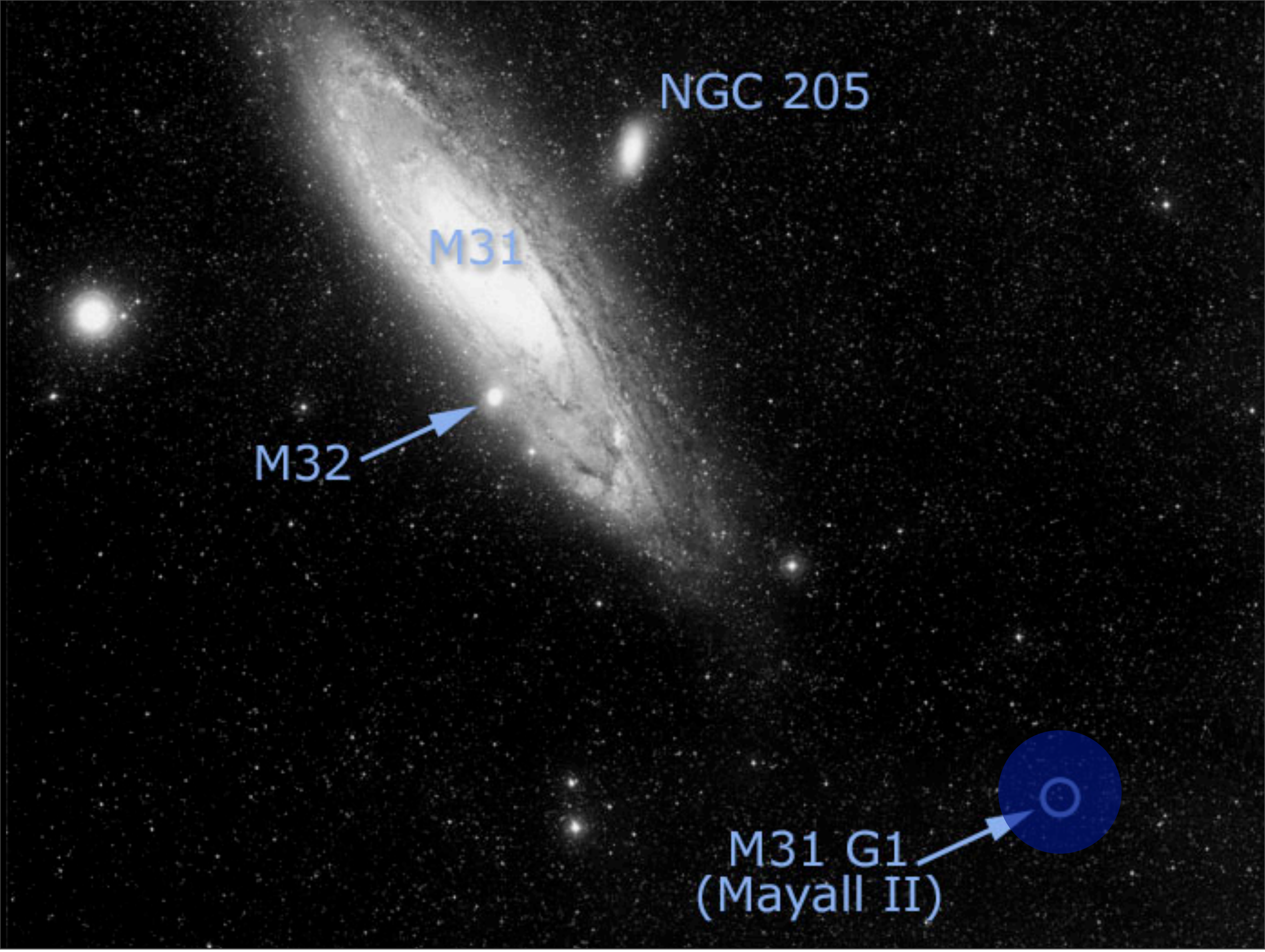


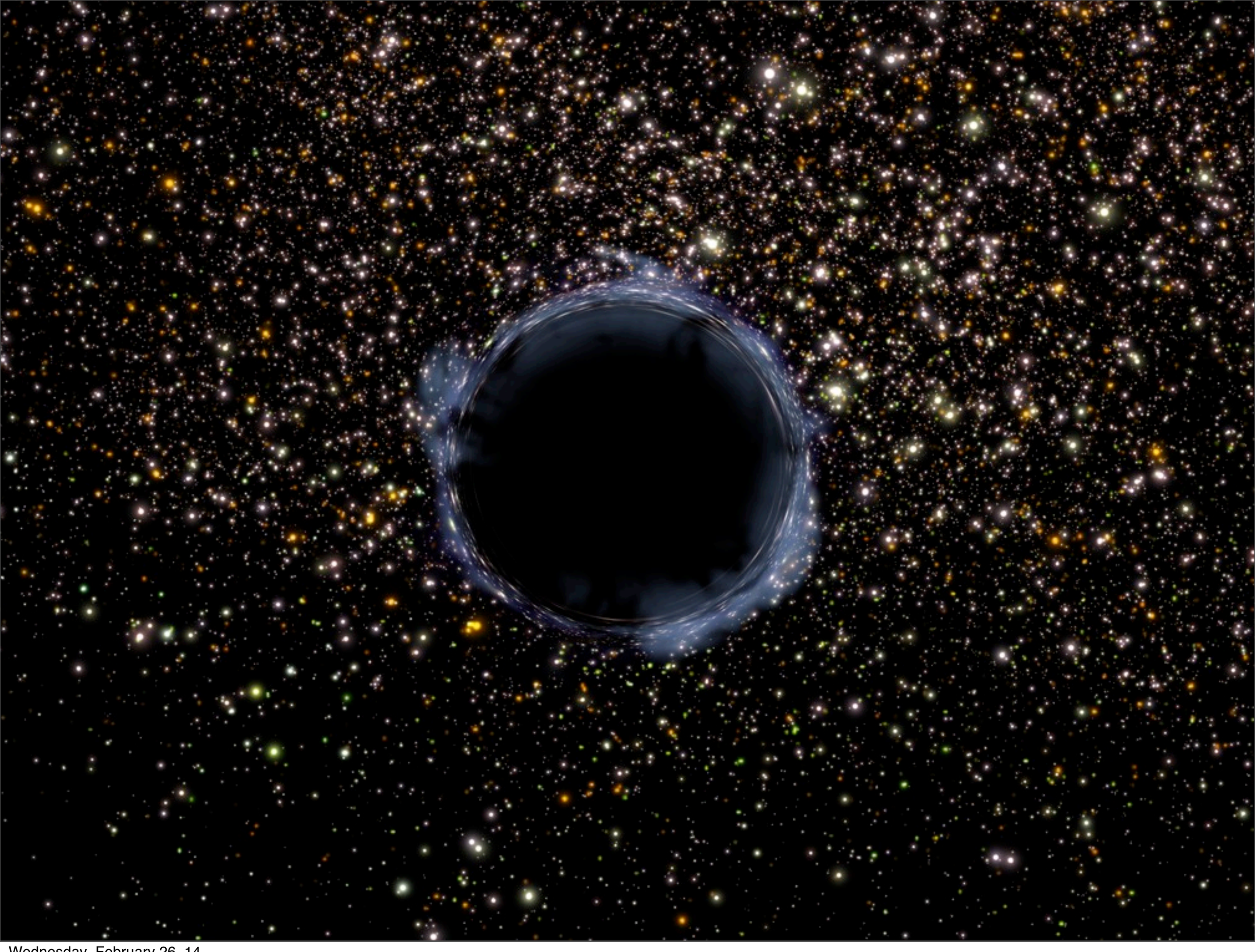



M33: $M_\bullet < 1500\ M_\odot$

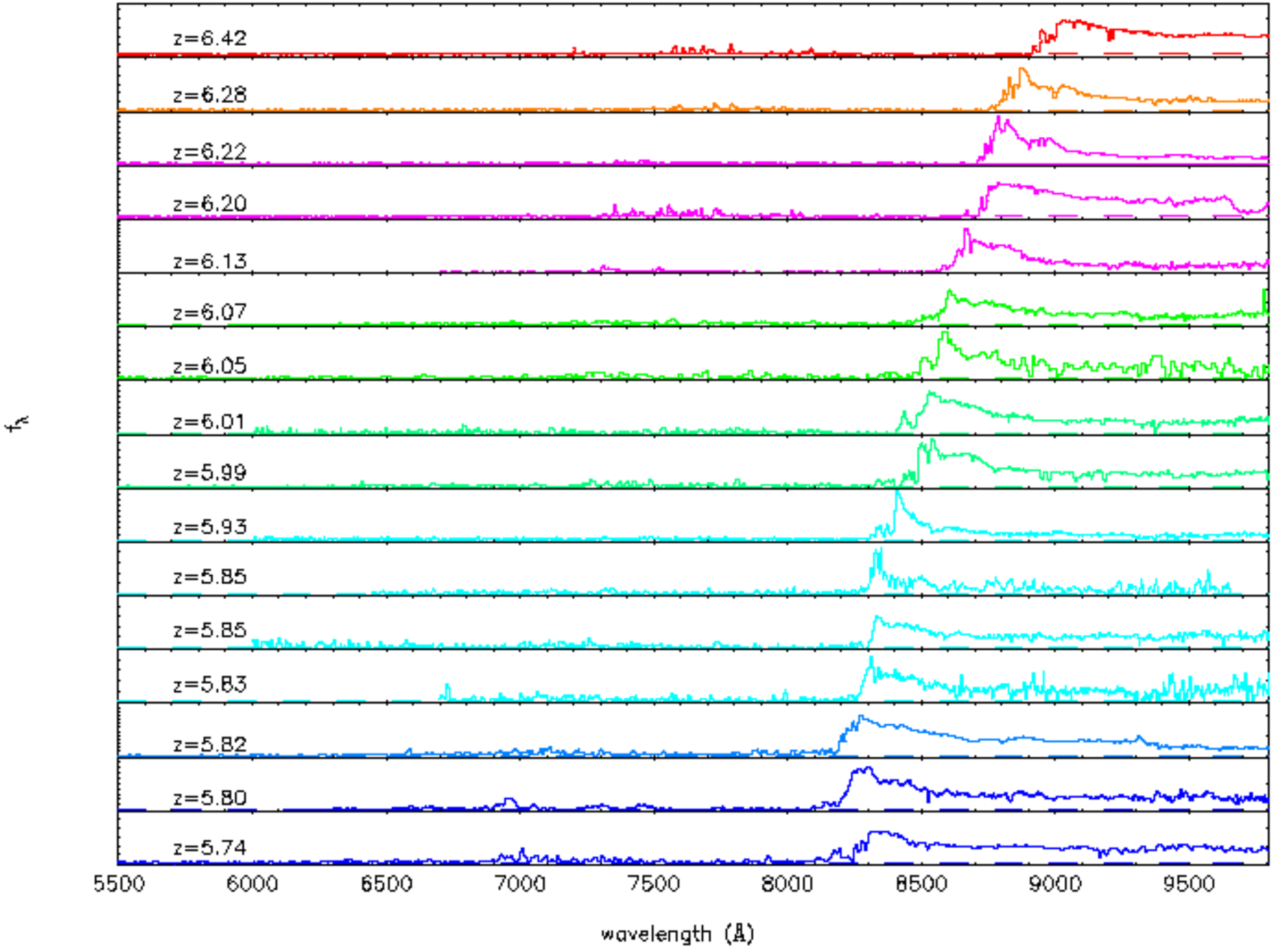

M33: $M_\bullet < 1500\ M_\odot$


NGC 205
M31
M32
M31 G1
(Mayall II)


NGC 205
M31
M32
M31 G1
(Mayall II)




G1: $M_\bullet = 2 \times 10^4\, M_\odot$
Gebhardt, Ho & Rich (2005)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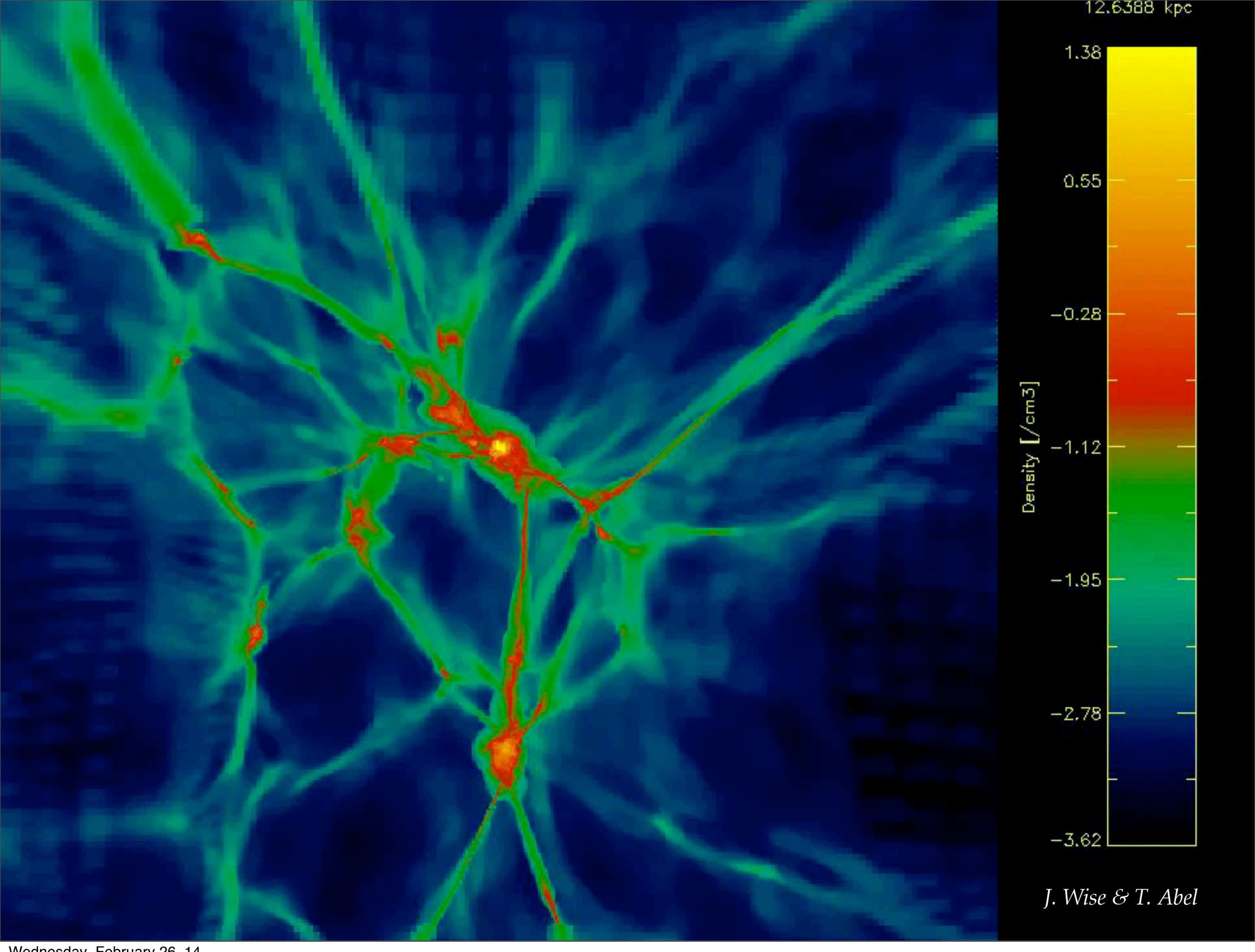
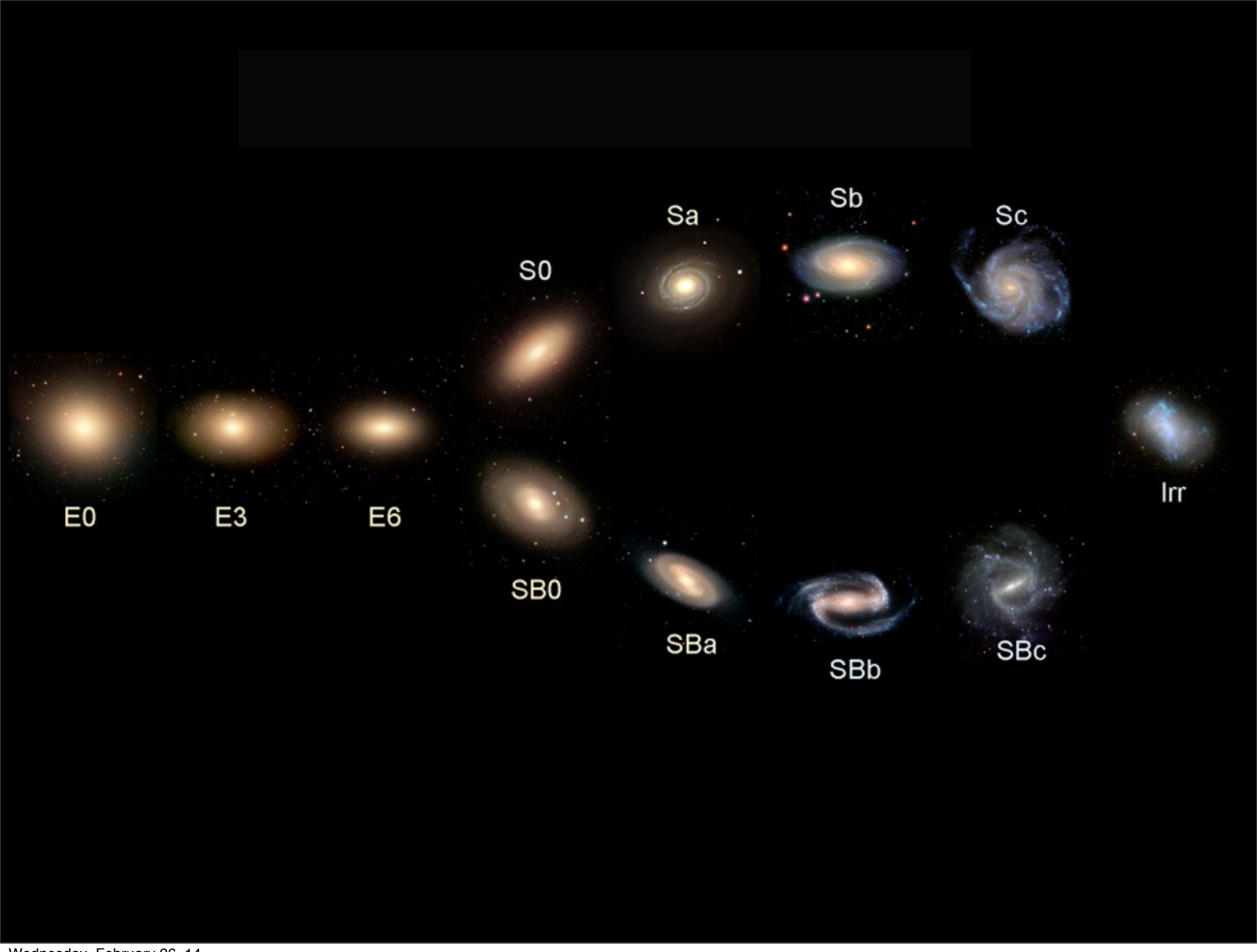
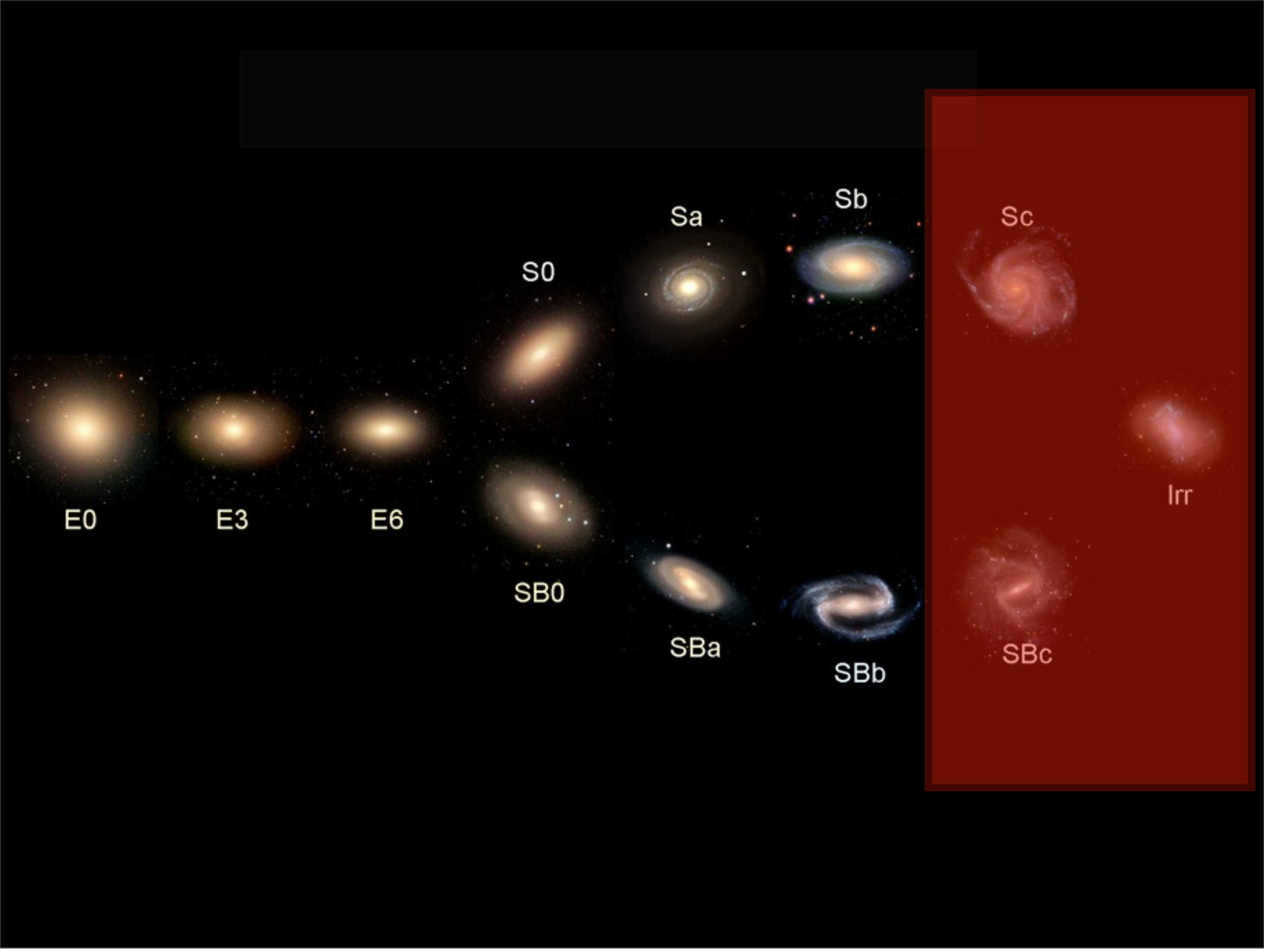
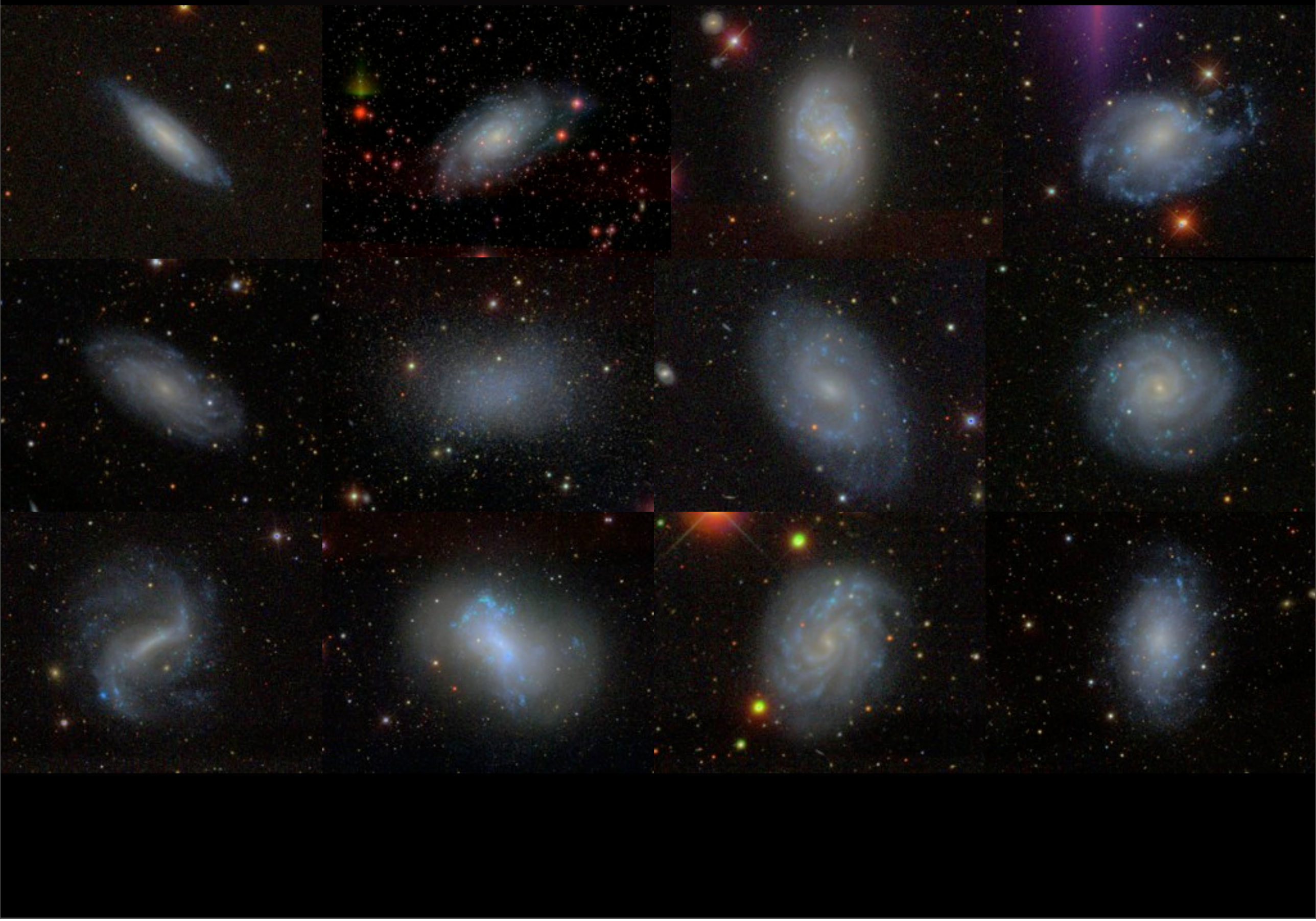
z=6.28
z=6.22
z=6.20
z=6.13
z=6.07
z=6.05
z=6.01
z=5.99
z=5.93
z=5.85
z=5.85
z=5.83
z=5.82
z=5.80
z=5.74
5500
6000
6500
7000
7500
8000
8500
9000
9500
wavelength (Å)


12.6388 kpc
1.38
0.55
−0.28
−1.12
−1.95
−2.78
−3.62
Density [/cm3]
J. Wise & T. Abel

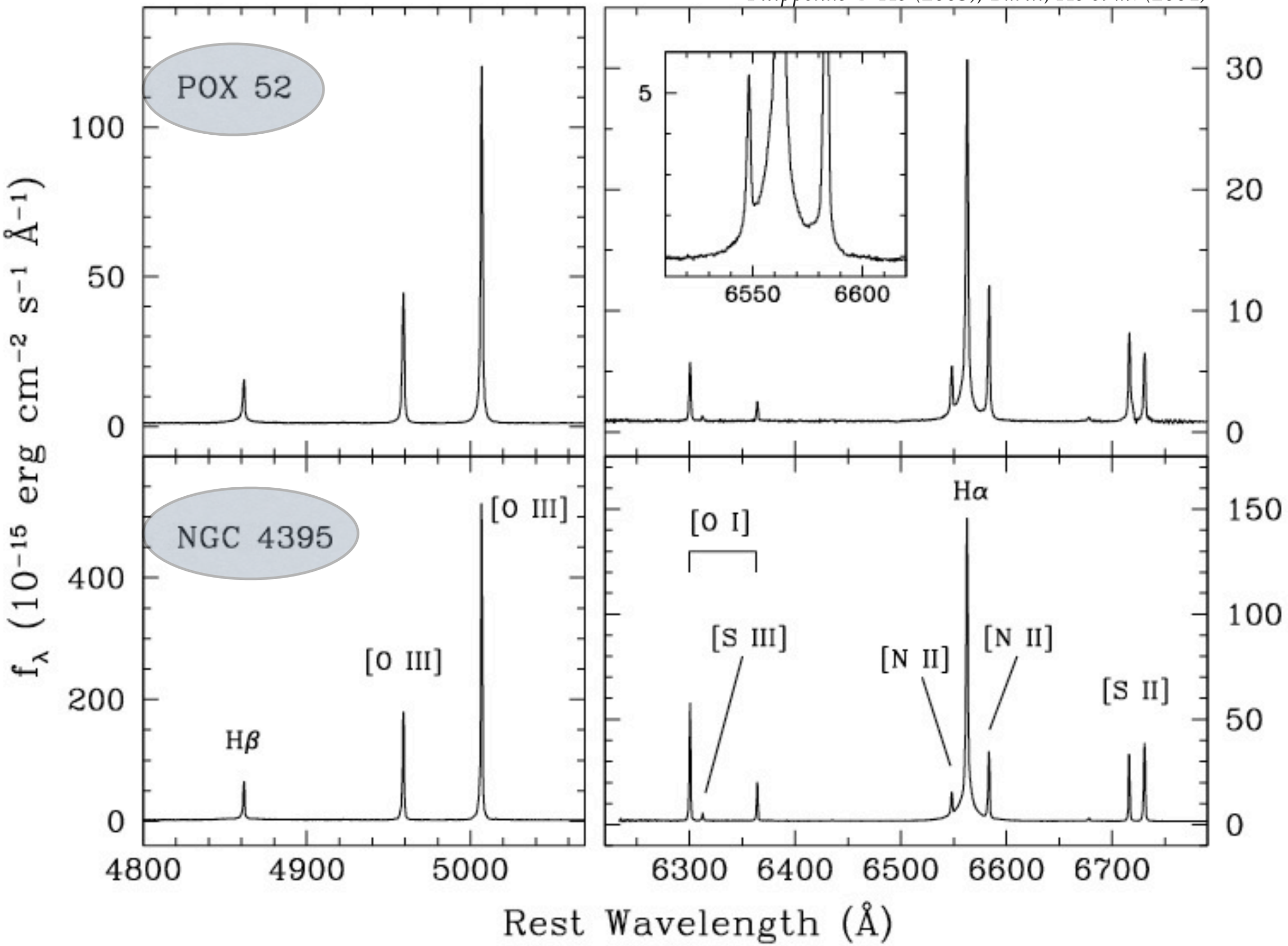

S0
Sa
Sb
Sc
E0
E3
E6
Irr
SB0
SBa
SBb
SBc


E0
E3
E6
S0
Sa
Sb
Sc
Irr
SB0
SBa
SBb
SBc

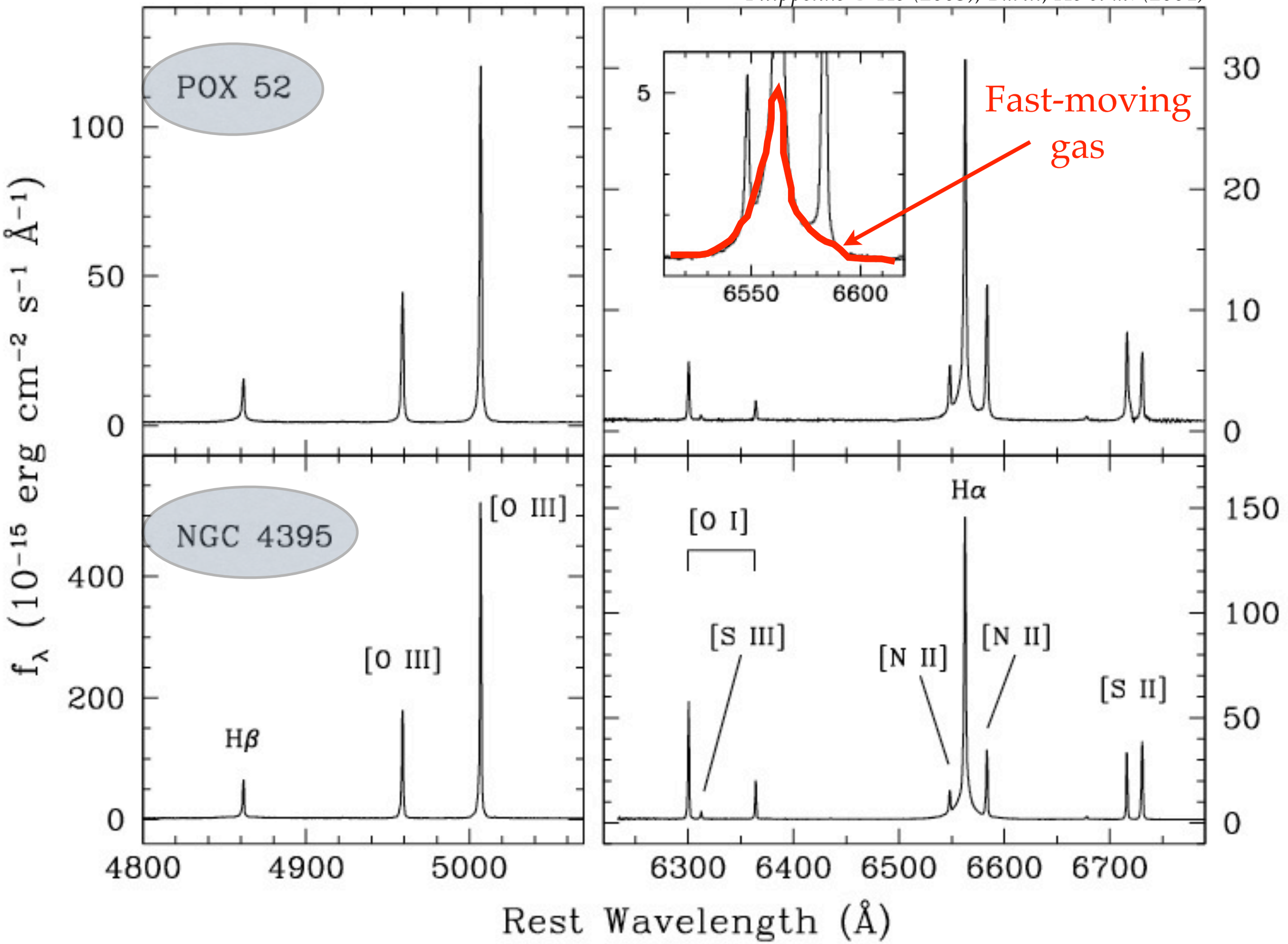



Are there mini-quasars in these "simpler" galaxies?

Filippenko & Ho (2003); Barth, Ho et al. (2004)

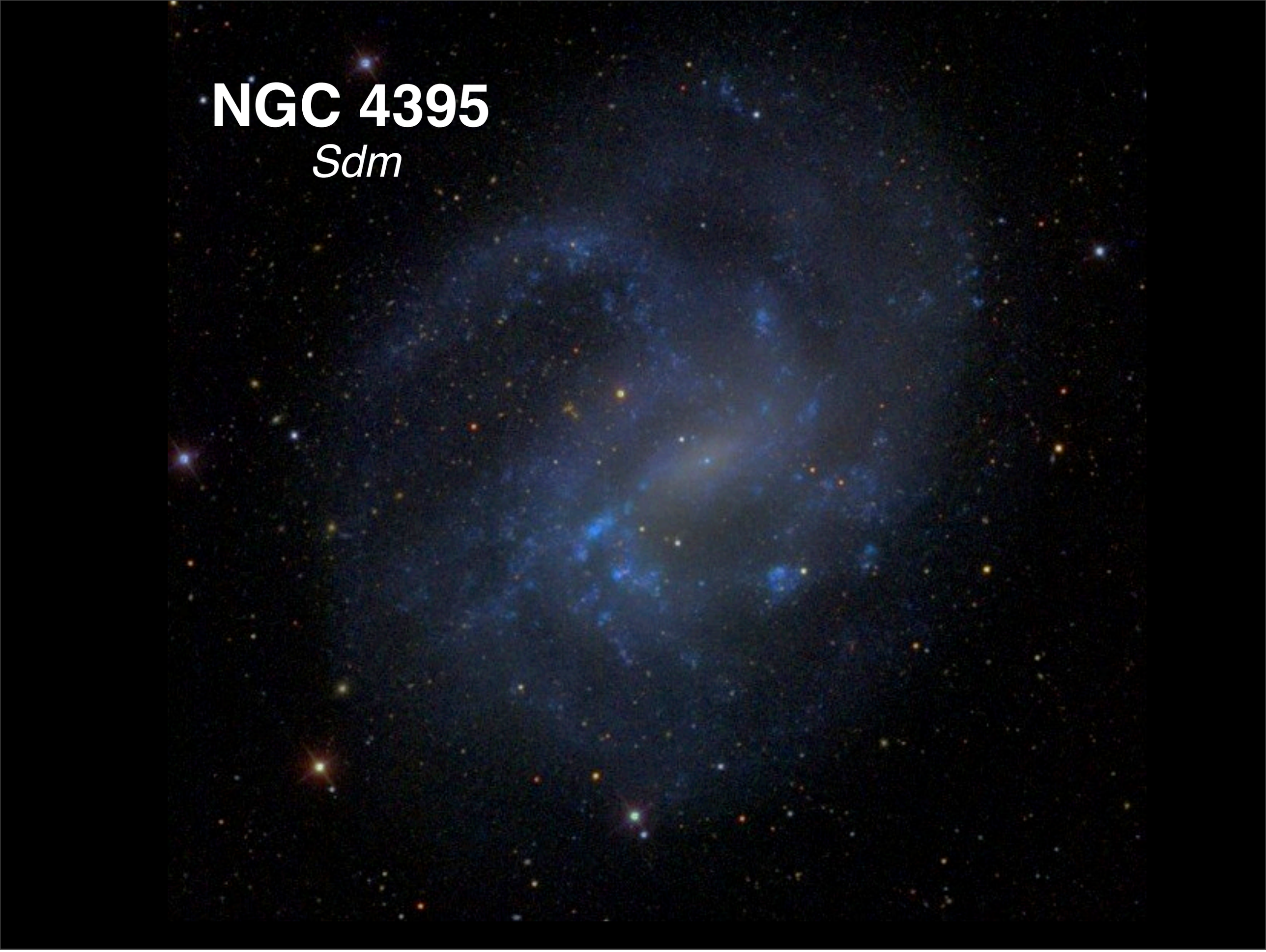


Filippenko & Ho (2003); Barth, Ho et al. (2004)



NGC 4395

Sdm



NGC 4395

Sdm

$M_\bullet = 10^4 - 10^5\ M_\odot$

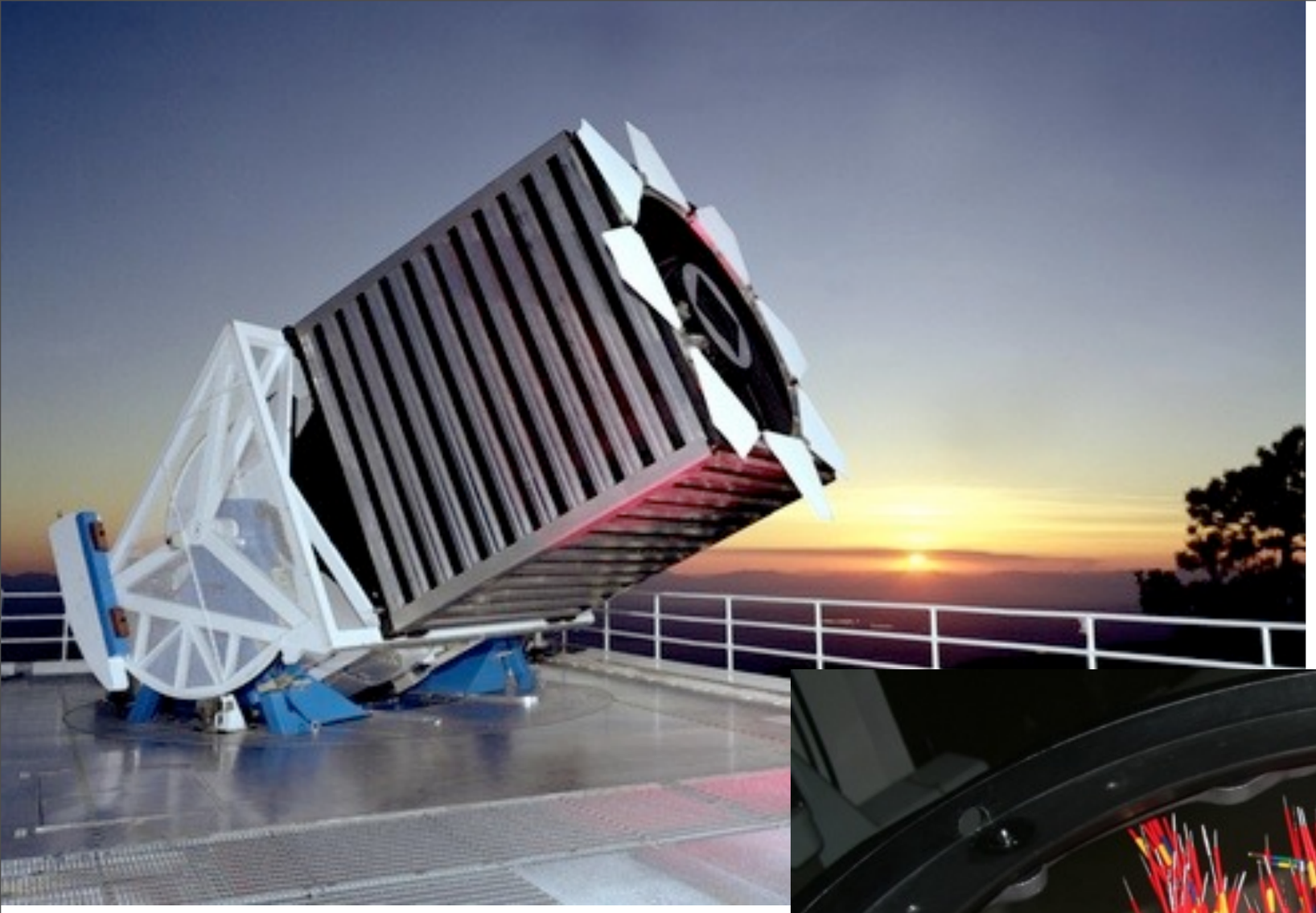
POX 52

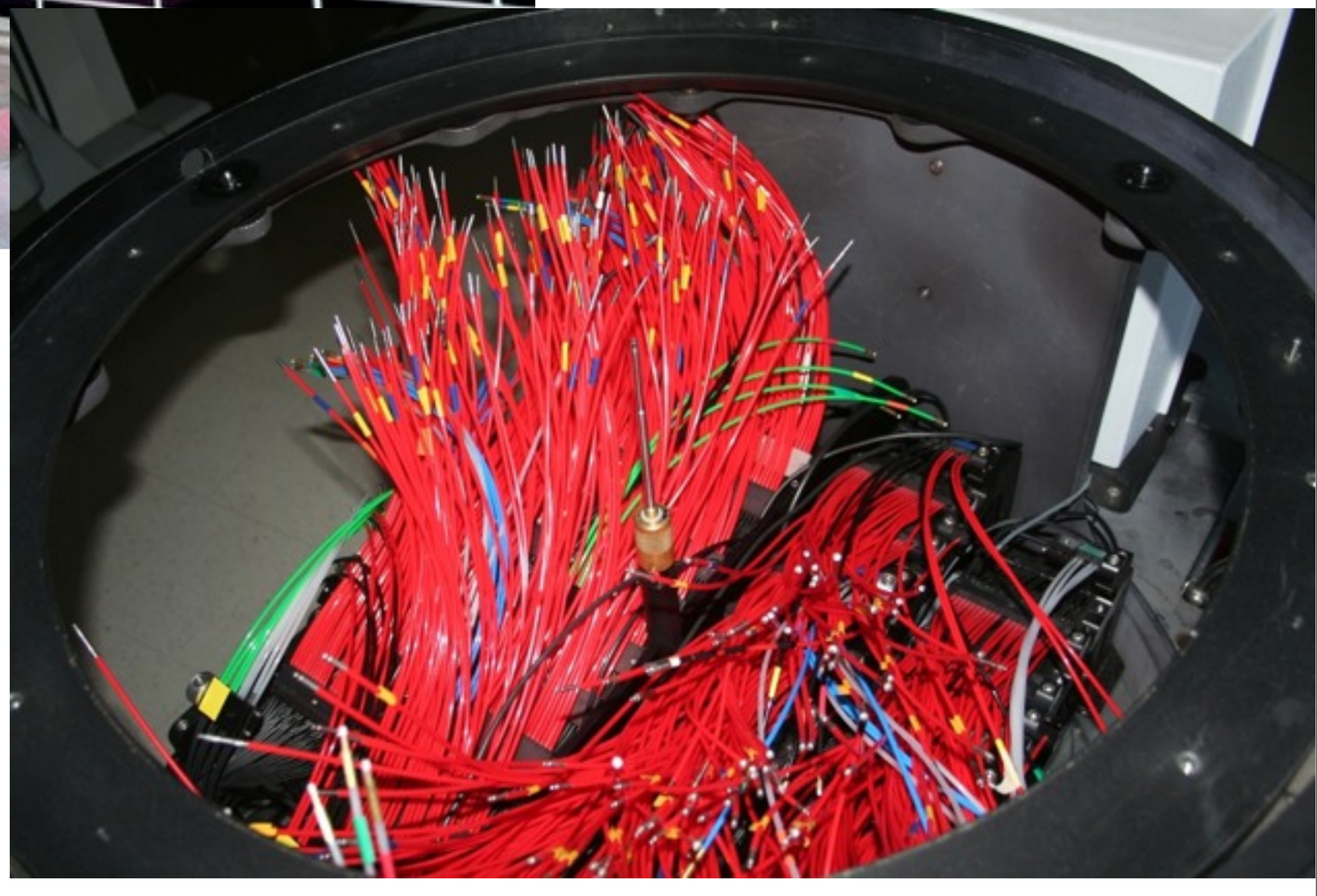
Sph or dE

POX 52

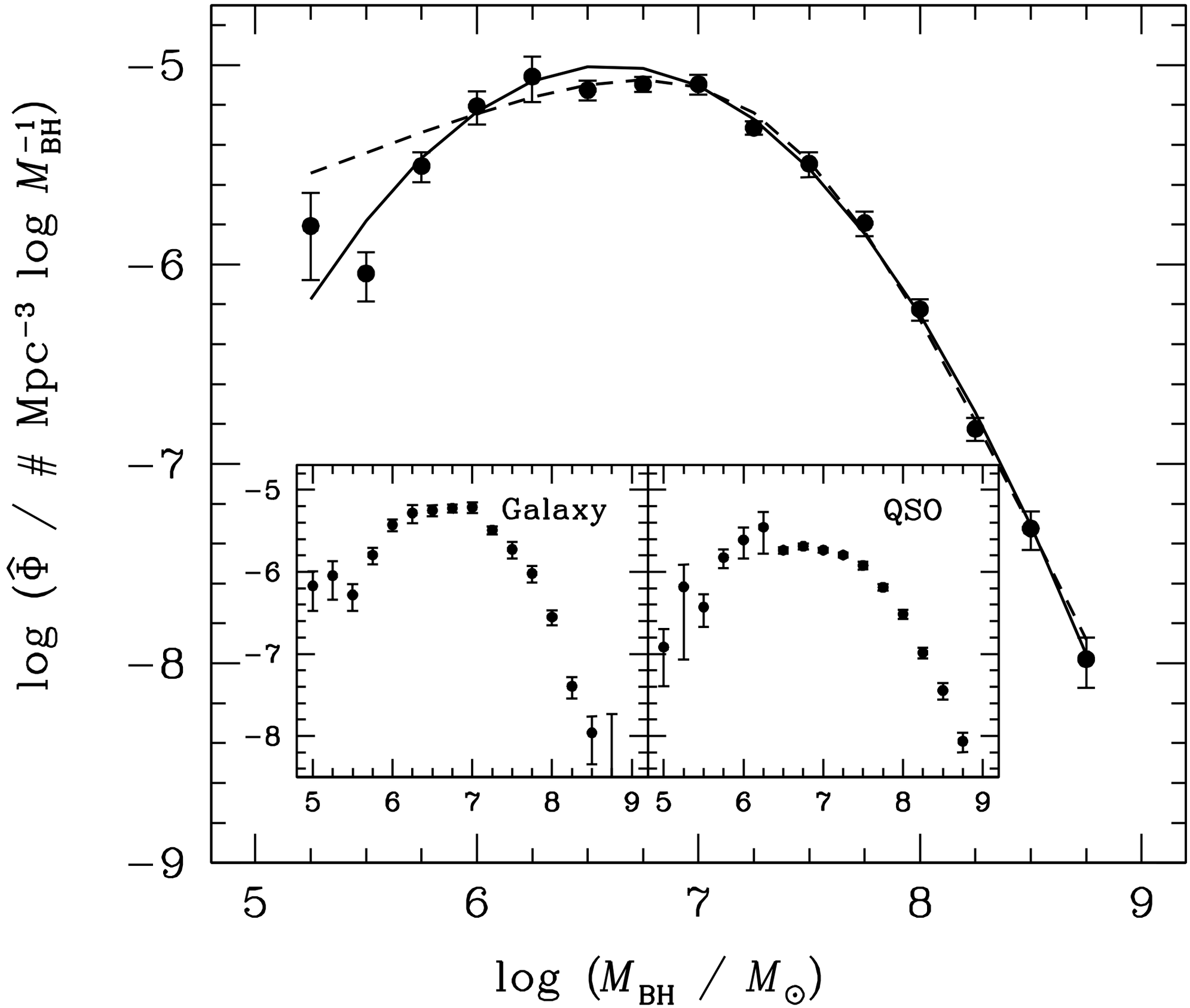
Sph or dE

$M_\bullet = 1.6 \times 10^5\ M_\odot$

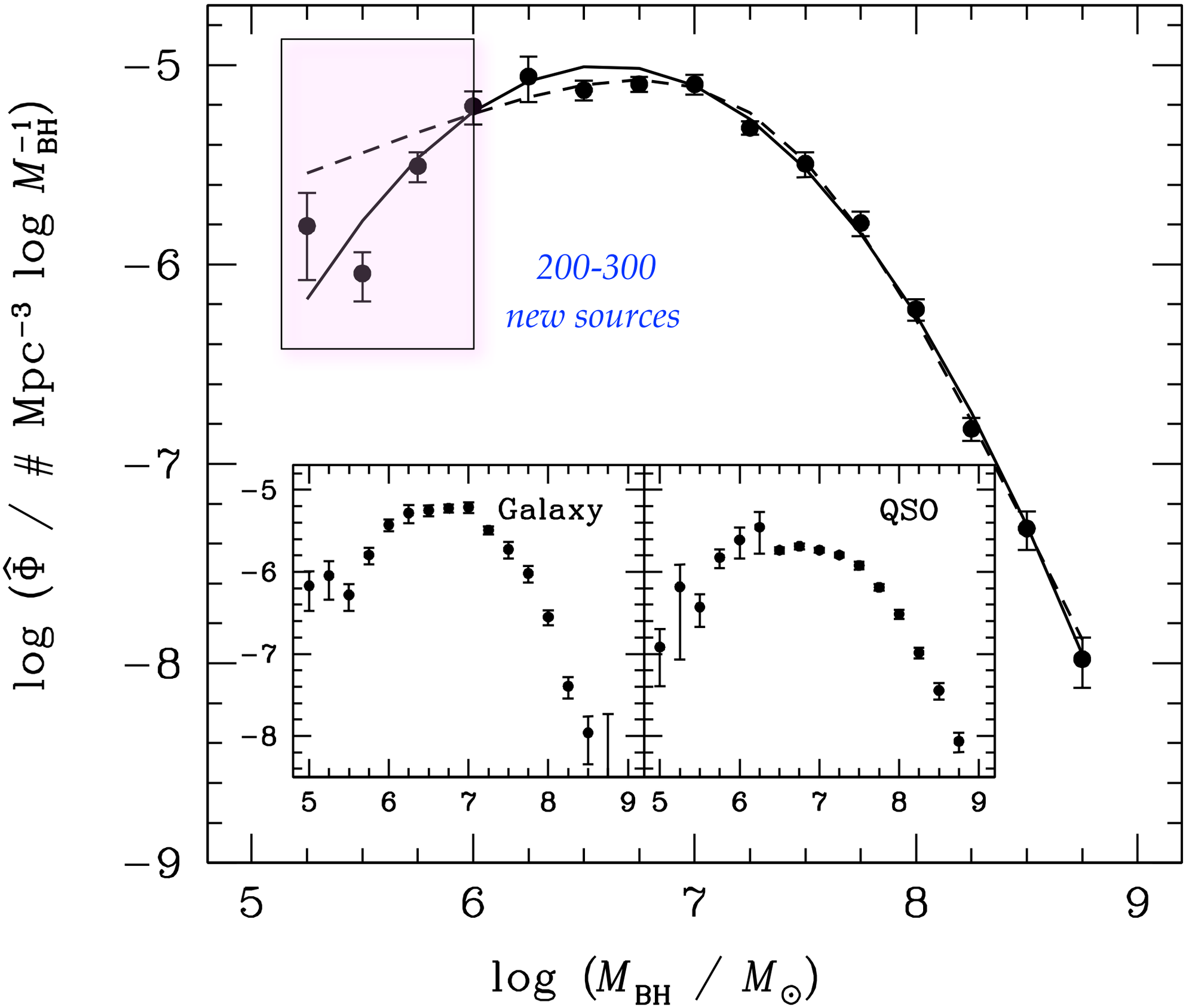




Greene & Ho (2004, 2007); Dong, Ho et al. (2012)

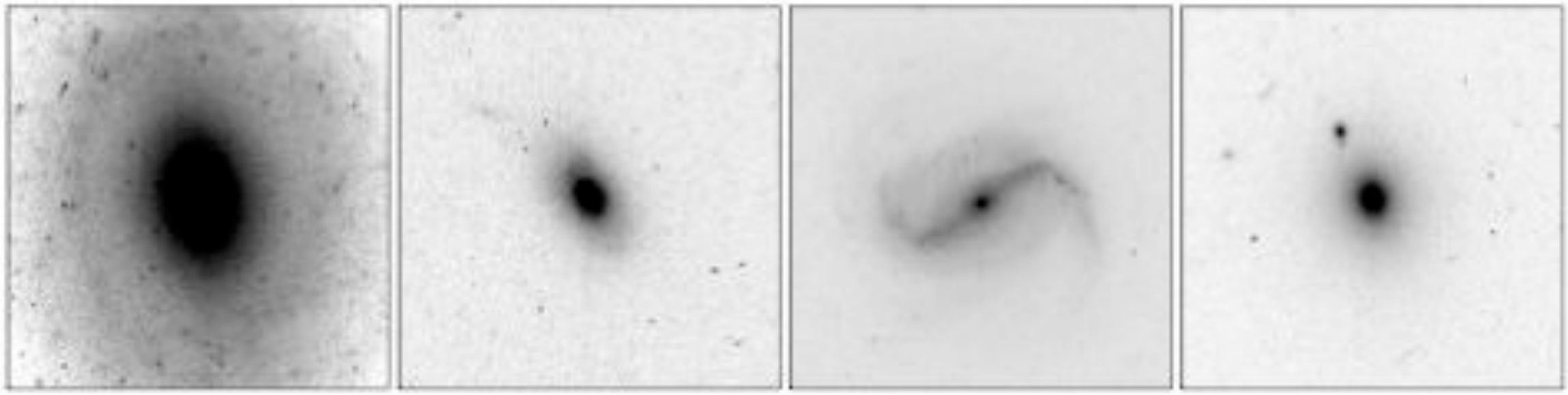


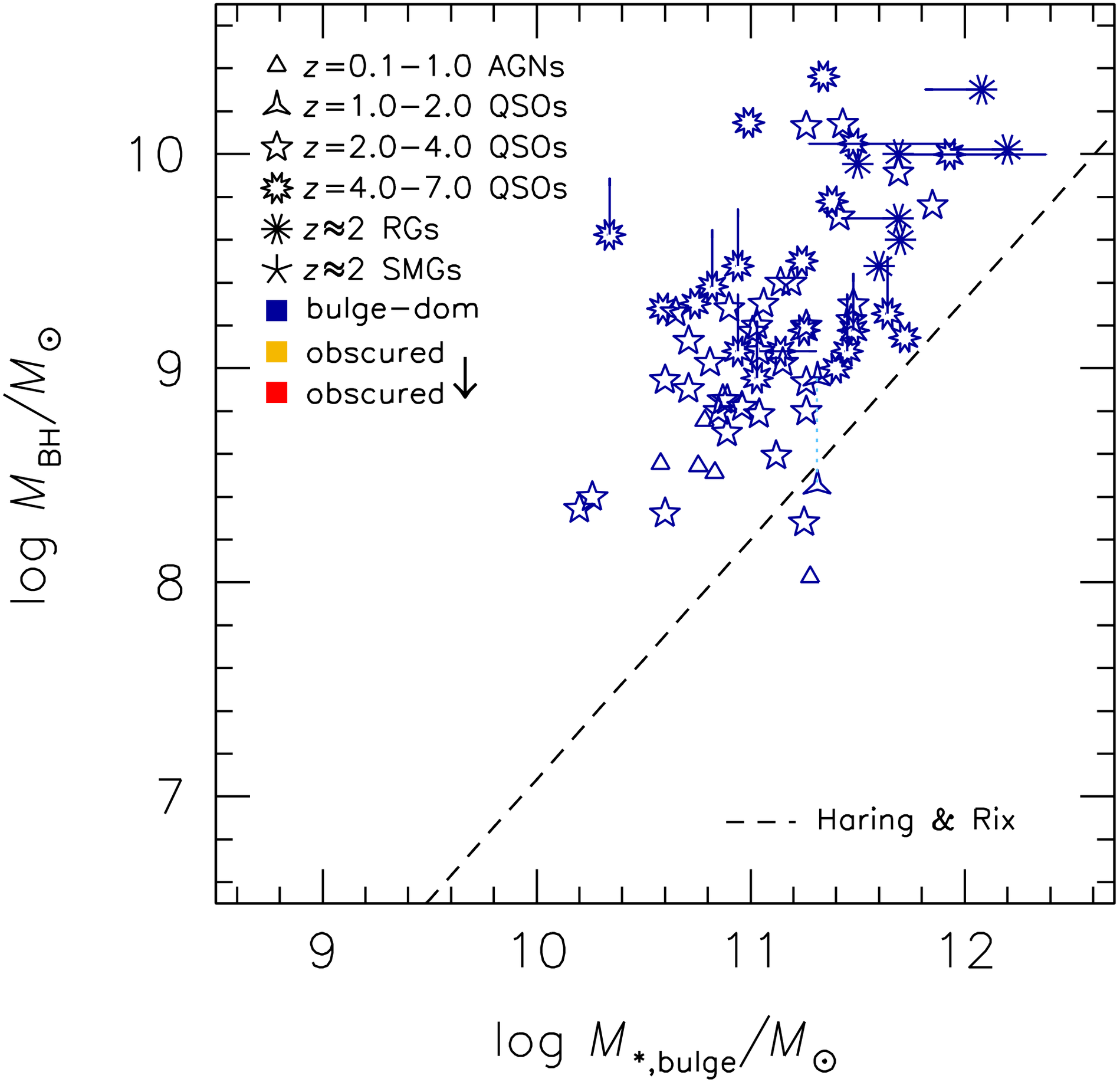
Greene & Ho (2004, 2007); Dong, Ho et al. (2012)



HST / ACS

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

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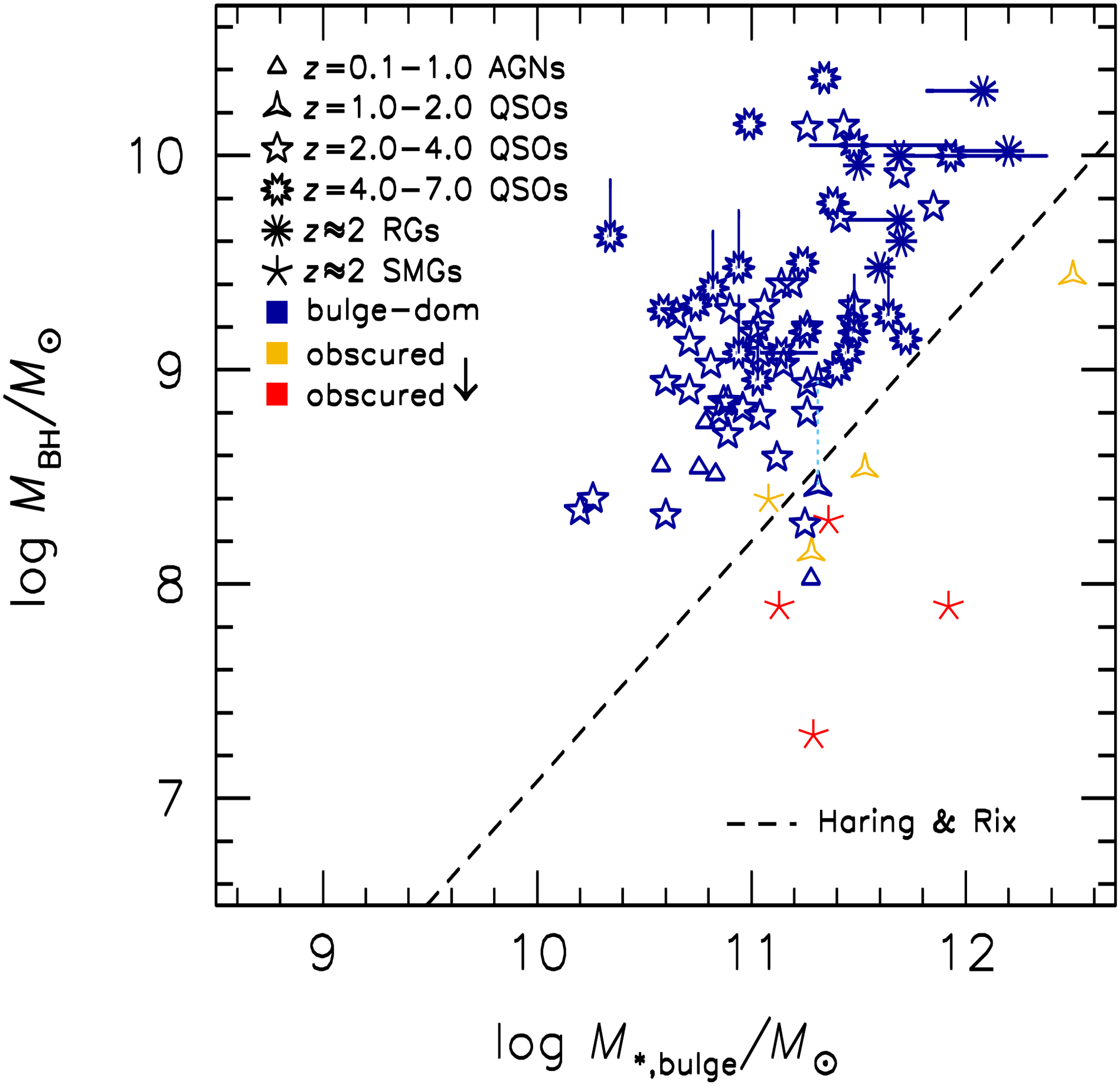
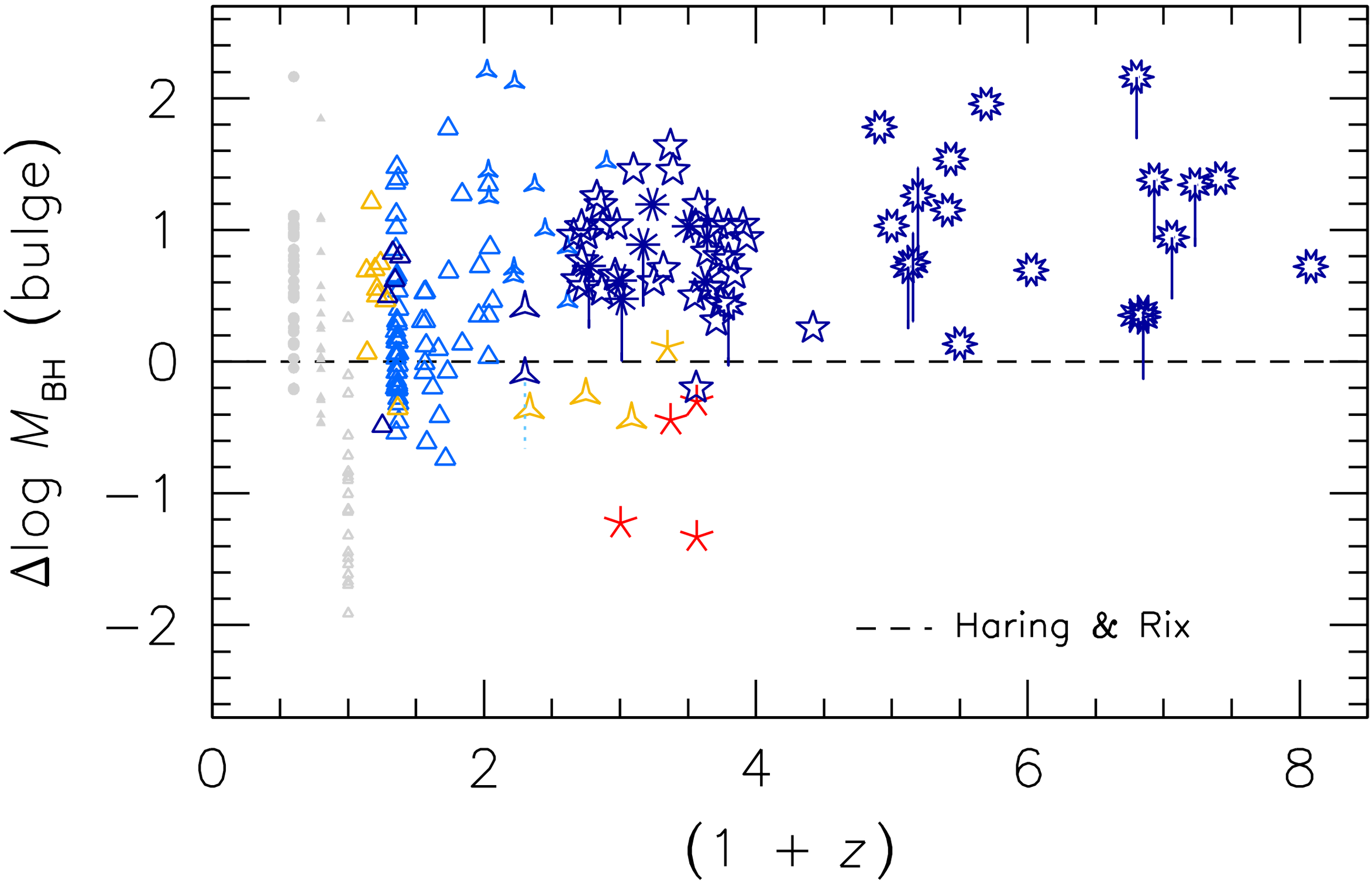
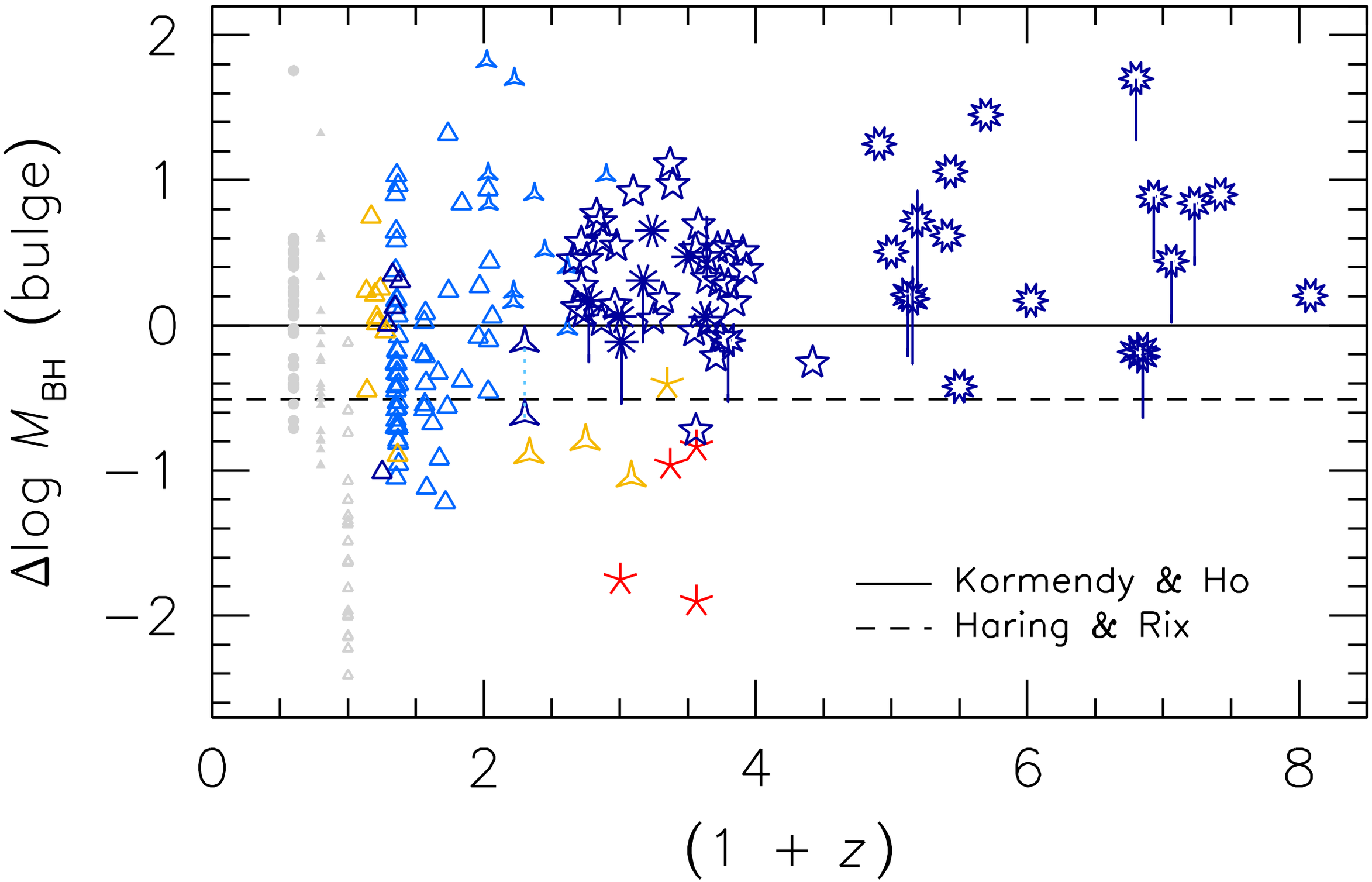
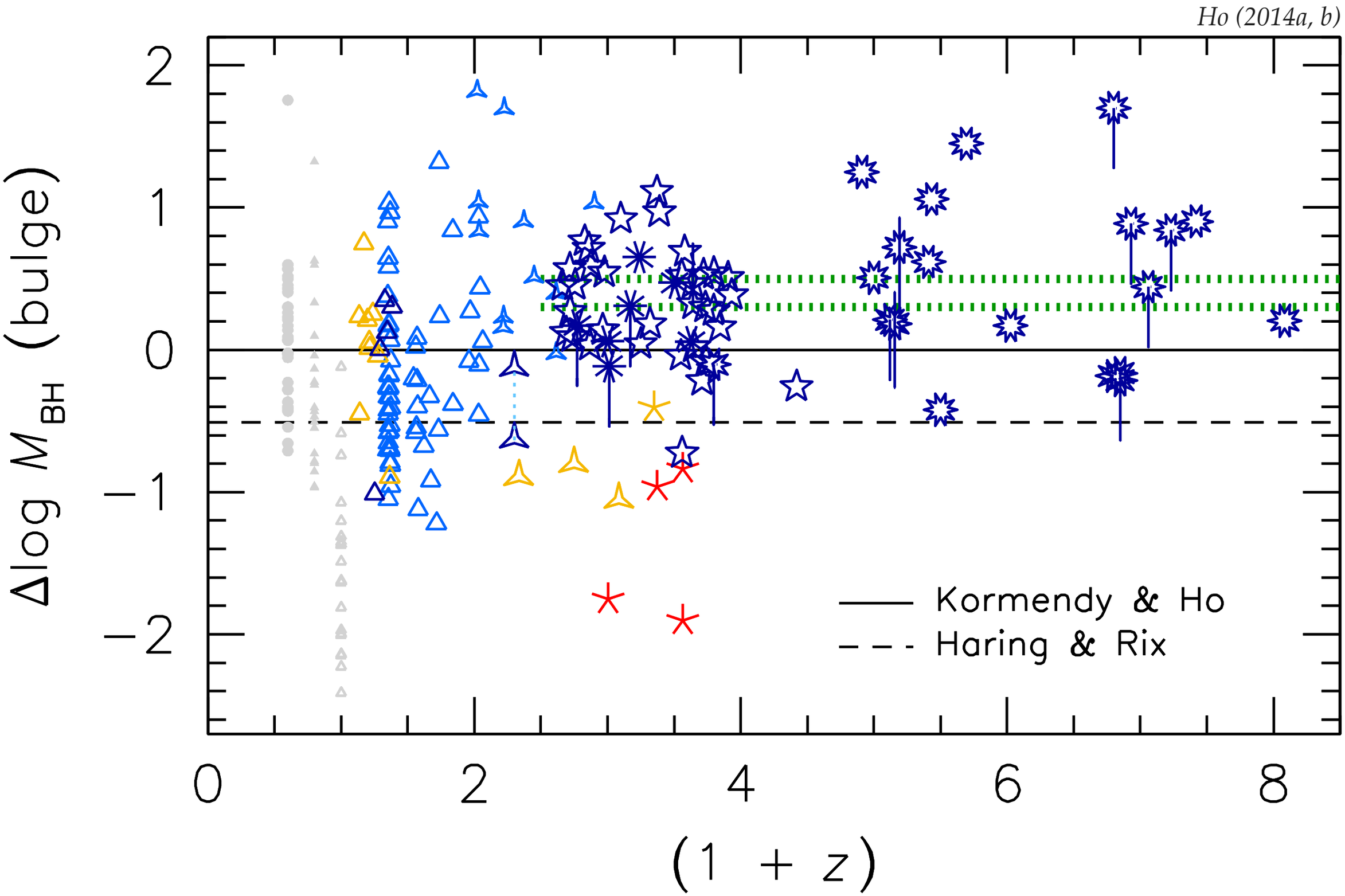
z=1.0−2.0 QSOs
z=2.0−4.0 QSOs
z=4.0−7.0 QSOs
z≈2 RGs
z≈2 SMGs
bulge−dom
obscured
obscured
Haring & Rix
log M_BH/M⊙
log M*,bulge/M⊙
10
9
8
7
9
10
11
12


z=0.1−1.0 AGNs
z=1.0−2.0 QSOs
z=2.0−4.0 QSOs
z=4.0−7.0 QSOs
z≈2 RGs
z≈2 SMGs
bulge−dom
obscured
obscured
Haring & Rix
log M_BH/M⊙
log M*,bulge/M⊙
10
9
8
7
9
10
11
12


$\Delta \log M_{BH}$ (bulge)
2
1
0
−1
−2
0
2
4
6
8
(1 + z)
--- Haring & Rix


2
1
0
−1
−2
Δlog M_{BH} (bulge)
0
2
4
6
8
(1 + z)
Kormendy & Ho
Haring & Rix


Ho (2014a, b)
Δlog M_{BH} (bulge)
2
1
0
−1
−2
0
2
4
6
8
(1 + z)
Kormendy & Ho
Haring & Rix

Recent Updates

- Central BHs detected from 10^4 – $10^{10}\,M_\odot$
- All bulges contain BHs, but not all BHs live in bulges
- $M_\bullet \sim M_{\rm bulge}^{1.2}$ $\qquad$ $\langle M_\bullet \,/\, M_{\rm bulge}\rangle \sim 0.5\%$
- $M_\bullet \propto \sigma^{4.4}$
- $M_\bullet - \sigma$ and $M_\bullet - M_{\rm bulge}$ relations have similar scatter
- Scaling relations only tight for classical bulges and Es
- Scaling relations already in place for high-z QSOs
- Mild evolution only for most massive BHs
- AGN feedback effective only for classical bulges and Es

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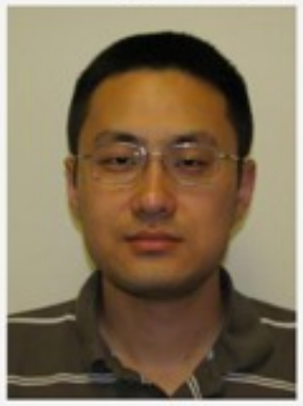
Jiansheng Chen (陈建生)

Richard de Grijs (何锐思)

Subo Dong (东苏勃)



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Gregory J. Herczeg

M.B.N. (Thijs) Kouwenhoven

Kejia Lee (李柯伽)

Lixin Li (李立新)

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Zhuo Li (黎卓)

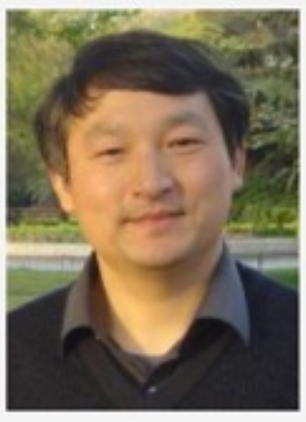
Fukun Liu (刘富坤)

Xiaowei Liu (刘晓为)

Eric Peng (彭逸西)

Rainer Spurzem

Renxin Xu (徐仁新)



Bing Zhang (张冰)

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北京大学科维理天文与天体物理研究所

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Upcoming Events

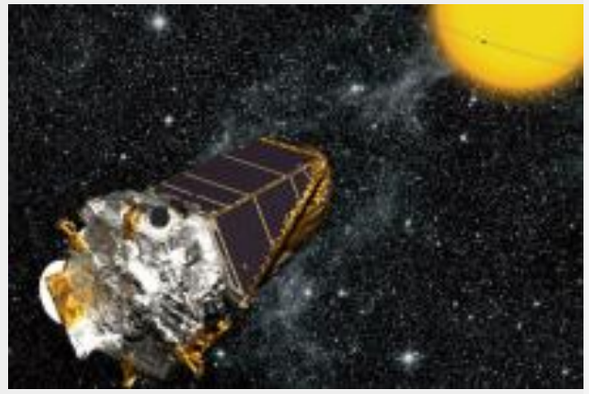
How much cosmological information can be measured?
Speaker: Yinzhe Ma, University of British Columbia
Time: Mon, 2014-01-06 12:00 to 13:00
Location: DoA, Rm 2907

Finding Transiting Exoplanets and Characterizing their Atmospheres: HATSouth and ACCESS
Speaker: Andrés Jordán (PUC)
Time: Thu, 2014-01-09 16:00 to

Featured Science

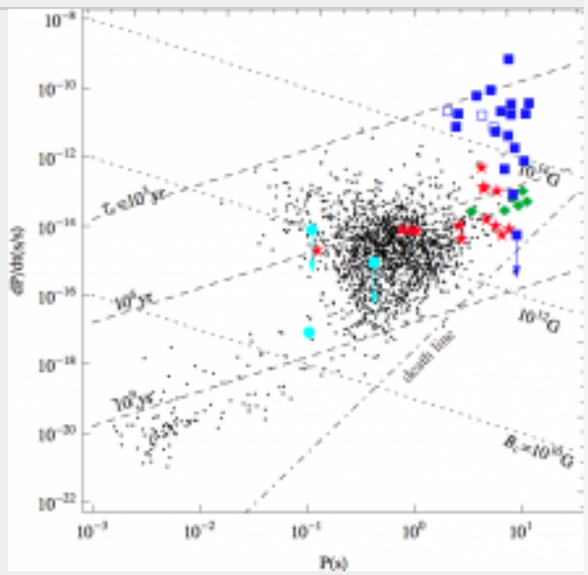
New Patterns in Planet Distributions

Subo Dong (东苏勃) joined the faculty of KIAA in Fall 2013 through the 1000 Talents Program for young researchers (青年千人计划). One of his research interests is to robustly derive the distributions of extrasolar planets in order to find clues on how planet systems form and evolve. In a paper recently published in the Astrophysical Journal (http://arxiv.org/abs/1212.4853), he and Zhaohuan Zhu (Princeton University) determined the distributions of planets down to Earth size and in orbits closer than Venus.



Wind Braking of AXP/SGRs

Anomalous X-ray pulsars (AXPs) and soft gamma-ray repeaters (SGRs) are believed to be magnetars: peculiar neutron stars powered by their super strong magnetic field. Unfortunately, none of the predictions of traditional magnetar models successfully explain their properties. In a recent paper, the group of Prof. Renxin Xu (PKU Department of Astronomy, with joint appointment at the KIAA), in collaboration with Dr. Hao Tong of the Xinjiang Astronomical Observatory, show that a wind braking mechanism in magnetars, where the energy release generates a strong wind, provides a natural understanding of the multiwavelength observational behavior of AXPs and SGRs.



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