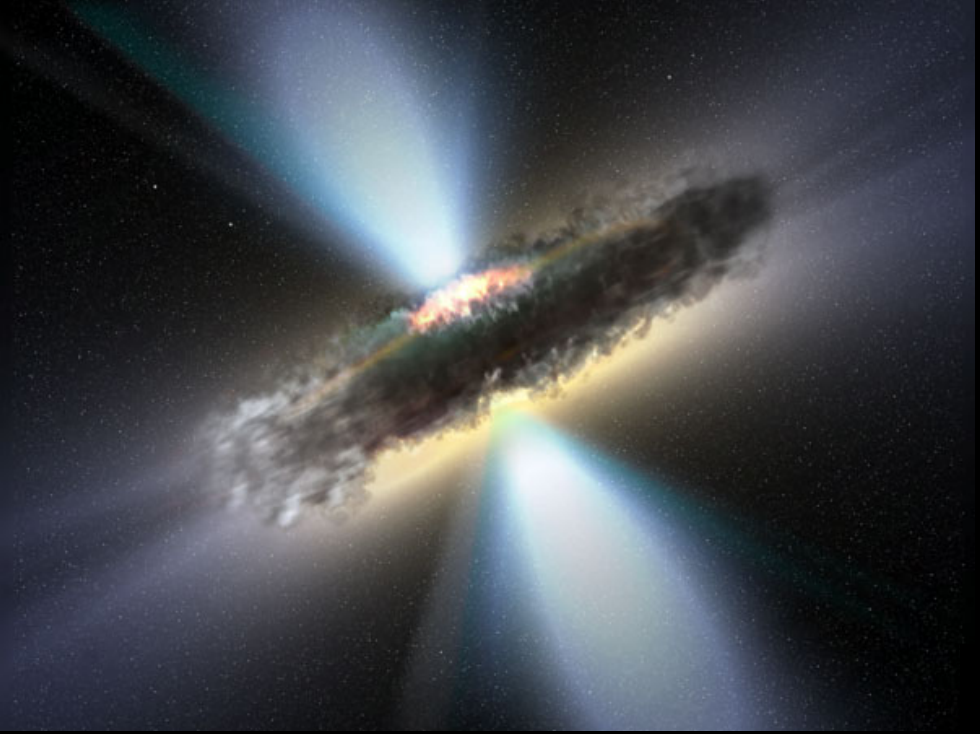
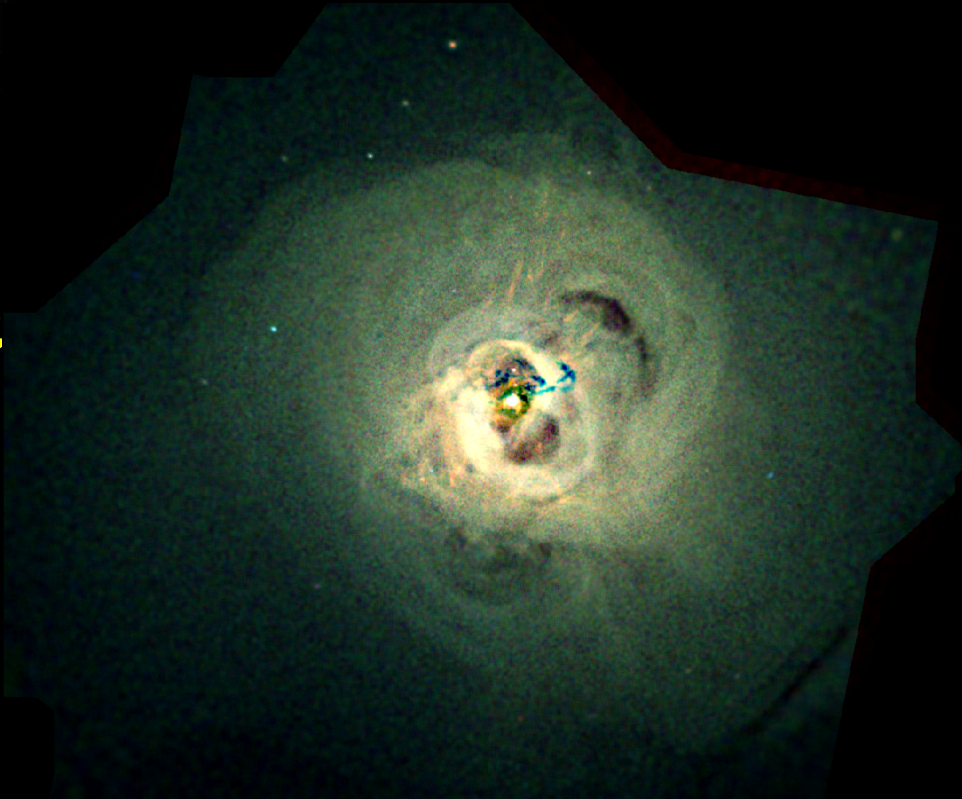


AC Fabian, Cambridge
UK

AGN FEEDBACK
Radiative/Quasar mode
vs Kinetic/Radio mode



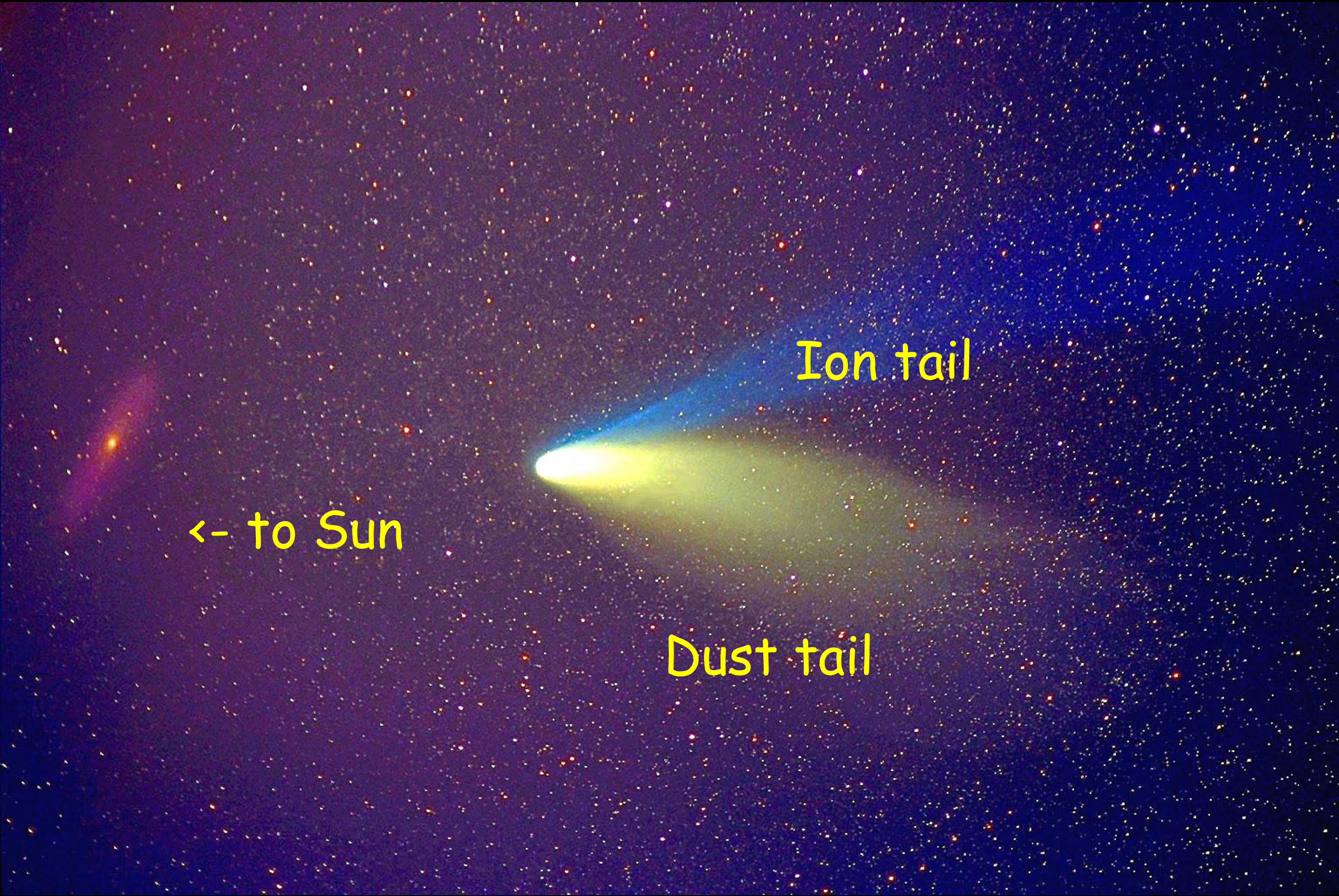
Radiative/quasar mode

Possible effect of central black hole on galaxy

$$E_{BlackHole} > 100 \times E_{Galaxy}$$

Energy released by growth of Black Hole

Gravitational Energy of Host Galaxy



Effects of radiation pressure and winds

Quasar Feedback

- Energy terminates galaxy growth (Silk & Rees 1998; Blandford 1999; Haehnelt+98)

$$M \propto \sigma^5$$

- Momentum : wind (Fabian 99;
  King03,5...)
  radiation pressure (Fabian02, Murray, Quataert, Thompson05; Fabian+09...)

$$M \propto \sigma^4$$

The Eddington limit

$$L_{Edd} = \frac{4\pi G M_{bh} m_p c}{\sigma_T}$$

The effective Eddington limit

$$L_{Edd} = \frac{4\pi G M_{bh} m_p c}{\sigma_T} \qquad L'_{Edd} = \frac{4\pi G M_{gal} m_p c}{\sigma_d}$$

$$\left(\frac{M_{gal}}{M_{bh}} = \frac{\sigma_d}{\sigma_T} = 500 \right)$$

The effective Eddington limit

$$L_{Edd} = \frac{4\pi G M_{bh} m_p c}{\sigma_T} \qquad L'_{Edd} = \frac{4\pi G M_{gal} m_p c}{\sigma_d}$$

$$\left(\frac{M_{gal}}{M_{bh}} = \frac{\sigma_d}{\sigma_T} = 500 \right)$$

Black hole mass fraction set by DUST ?

$$M_{\rm gal} = 2\sigma^2 r/G$$

$$\frac{4\pi G M_{\rm BH} m_{\rm p}}{\sigma_{\rm T}} = \boxed{\frac{L_{\rm Edd}}{c} = \frac{G M_{\rm gal} M_{\rm gas}}{r^2}} = \frac{f G M_{\rm gal}^2}{r^2} = \frac{fG}{r^2}\left(\frac{2\sigma^2 r}{G}\right)^2,$$

$$M_{bh} = \frac{f\sigma^4}{\pi G^2 m_p}\sigma_T$$

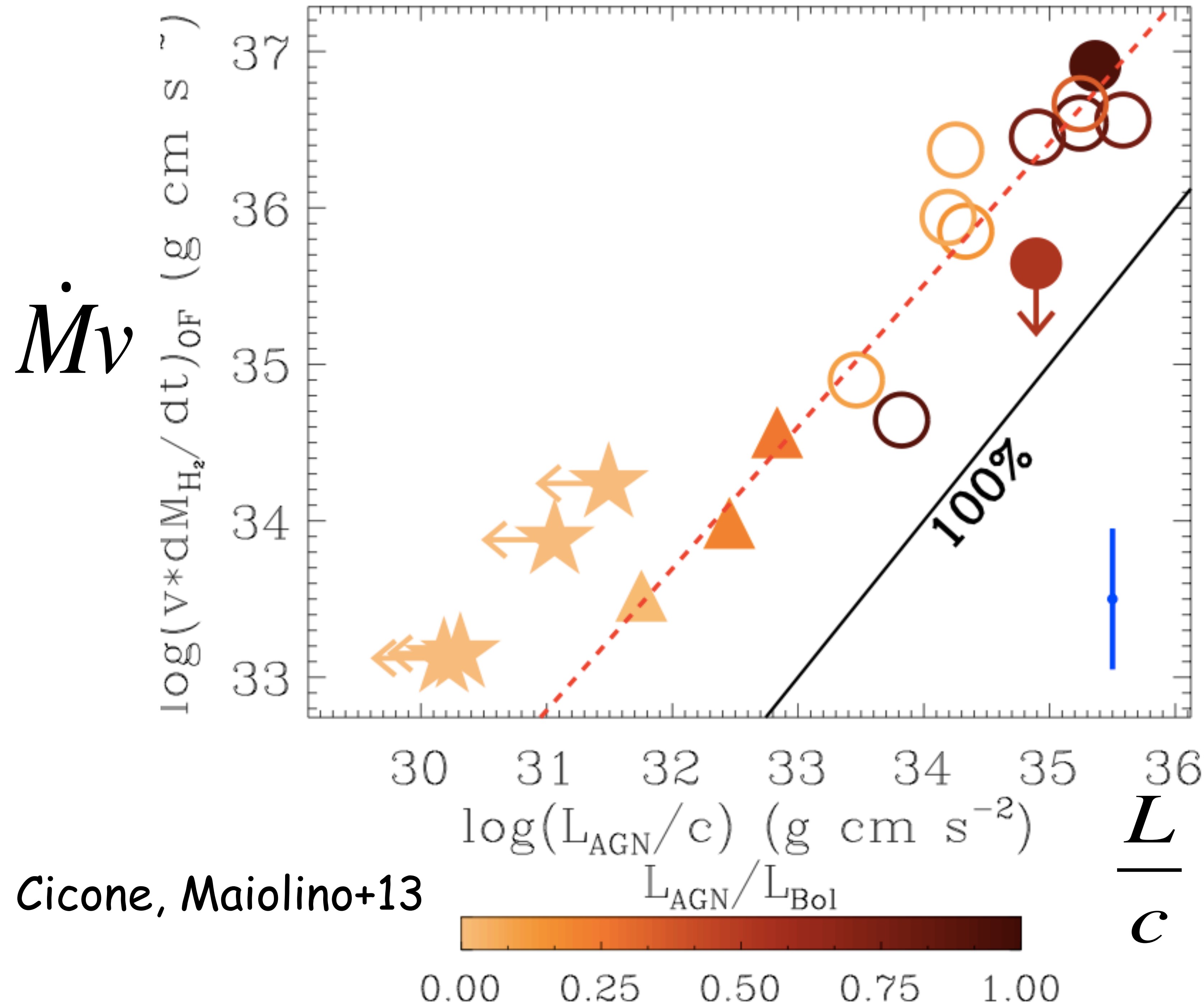
If correct, the basic structure of galaxy bulges is shaped by the effects of radiation pressure on DUST

Fabian12 ARAA 50 455

Does observing $\dot{M}v = 10\frac{L}{c}$

(Sturm, Arav, Tremonti, Cicone)

mean that radiation pressure cannot be the driver??



$\dot{M}v$
$\log(v * dM_{H_2}/dt)_{OF}$ (g cm s^{-2})
37
36
35
34
33
100%
30
31
32
33
34
35
36
$\log(L_{AGN}/c)$ (g cm s^{-2})
$\frac{L}{c}$
Cicone, Maiolino+13
L_{AGN}/L_{Bol}
0.00
0.25
0.50
0.75
1.00

If most gas initially resides within inner 100pc then can easily by optically thick to reprocessed IR. L/c boosted by $(1+\tau_{IR})$.
If τ_{IR} ~ few then can obtain outgoing shell velocity v ~ few σ so

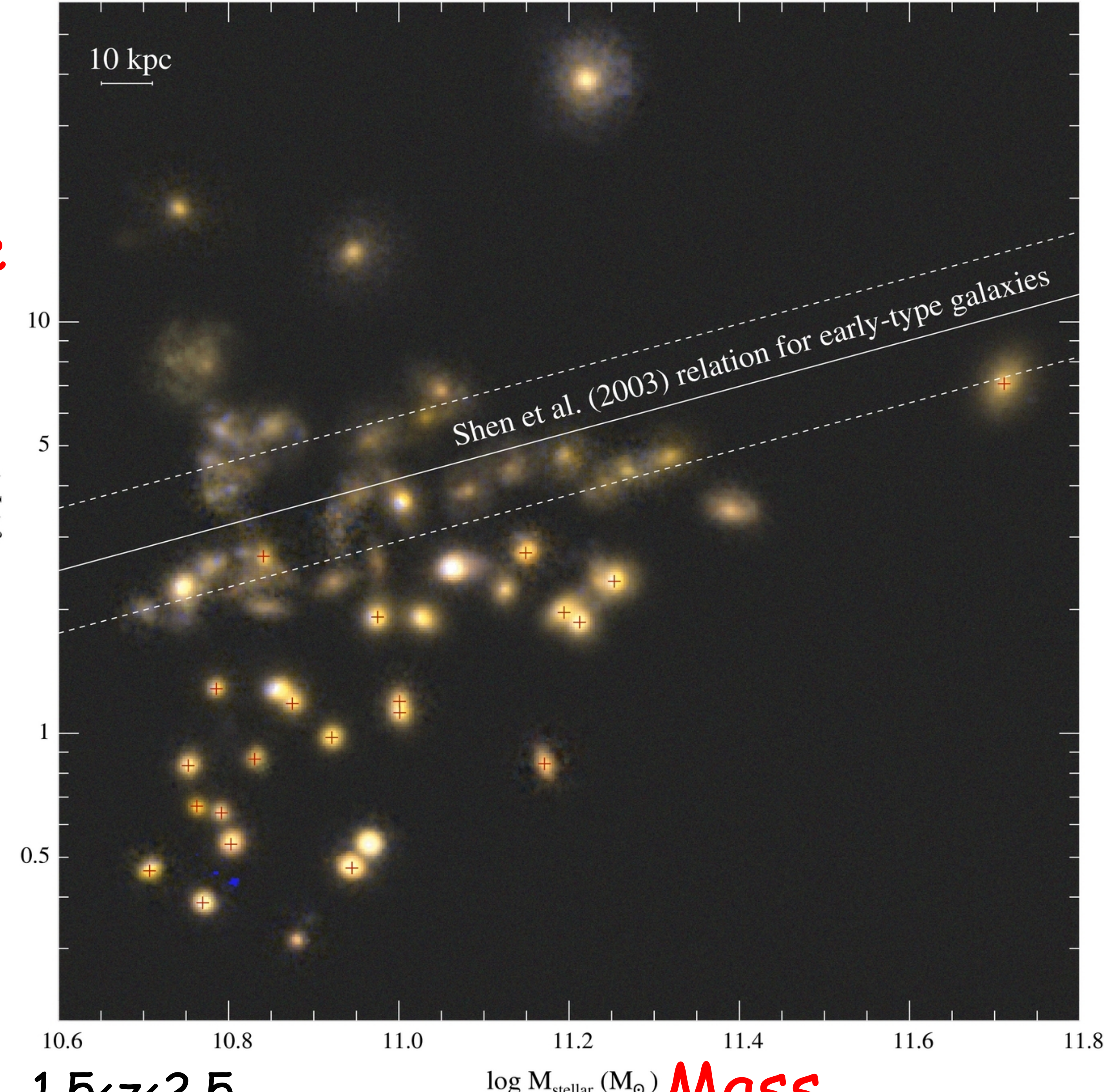
$$\dot{M}v \approx 10\frac{L}{c}$$

Thompson+13 in prep

Szomuru, Franx, Van Dokkum12

Size

Star formation provoked by Feedback?
Ishibashi+
Zubovas+
Silk+

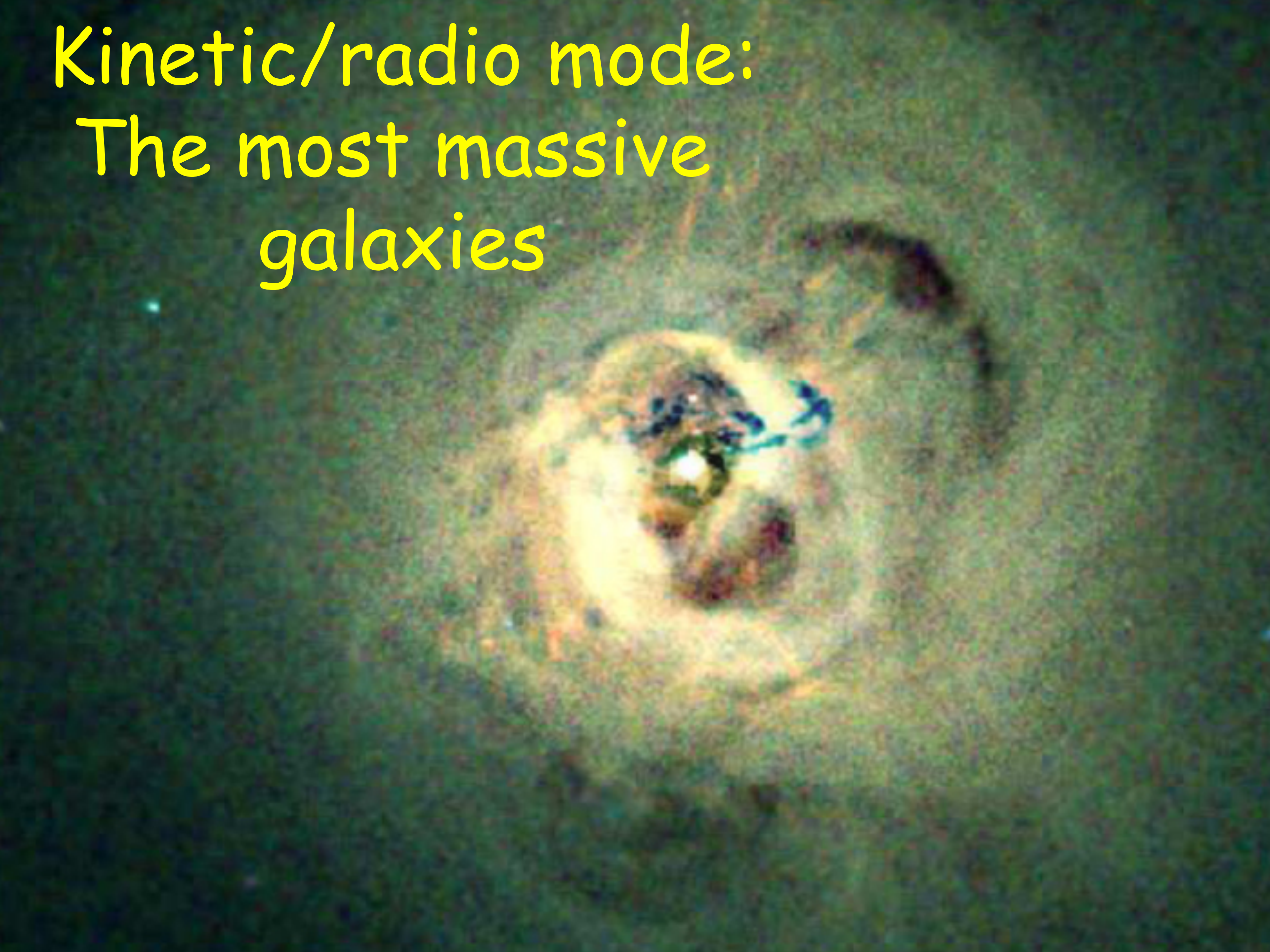


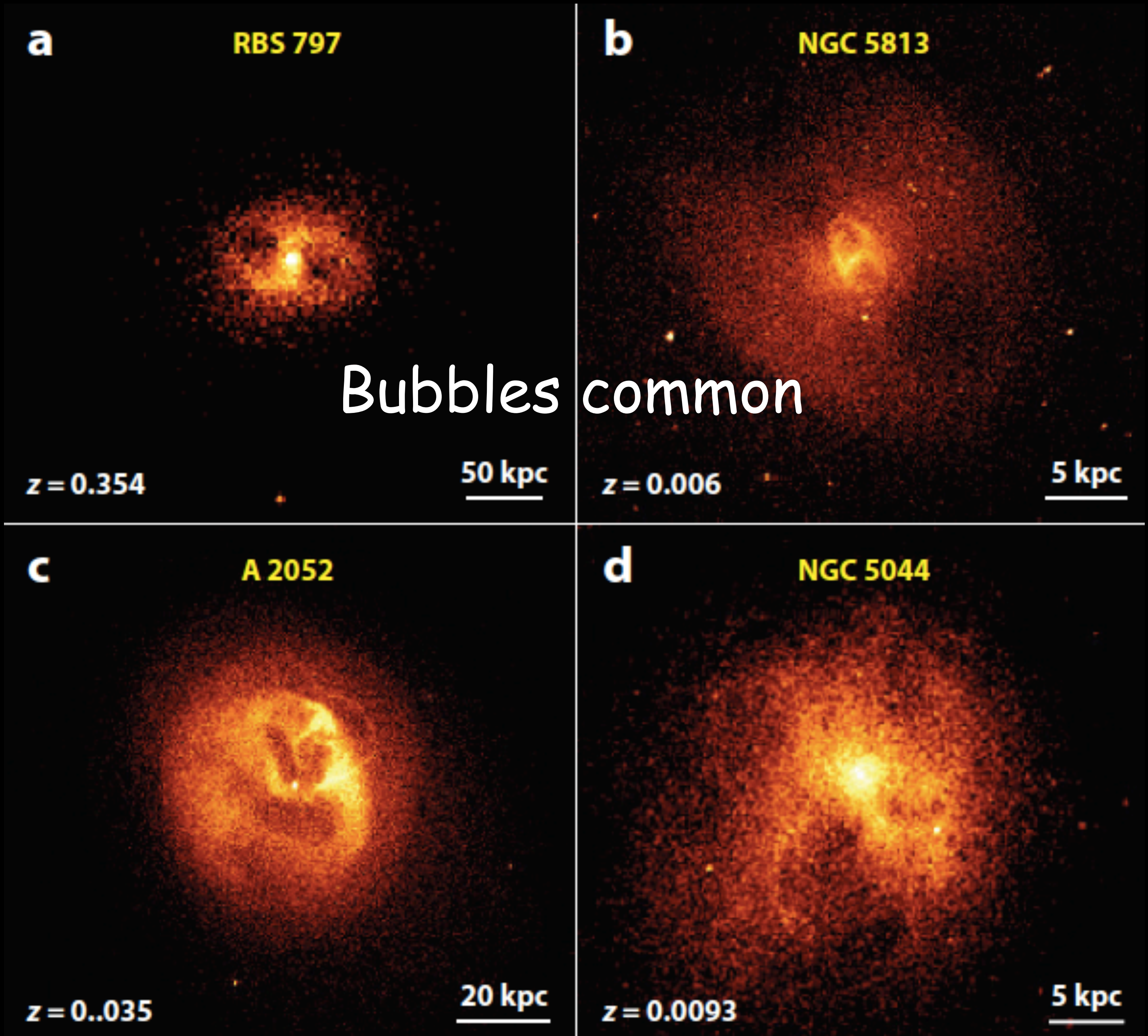
1.5<z<2.5

Mass

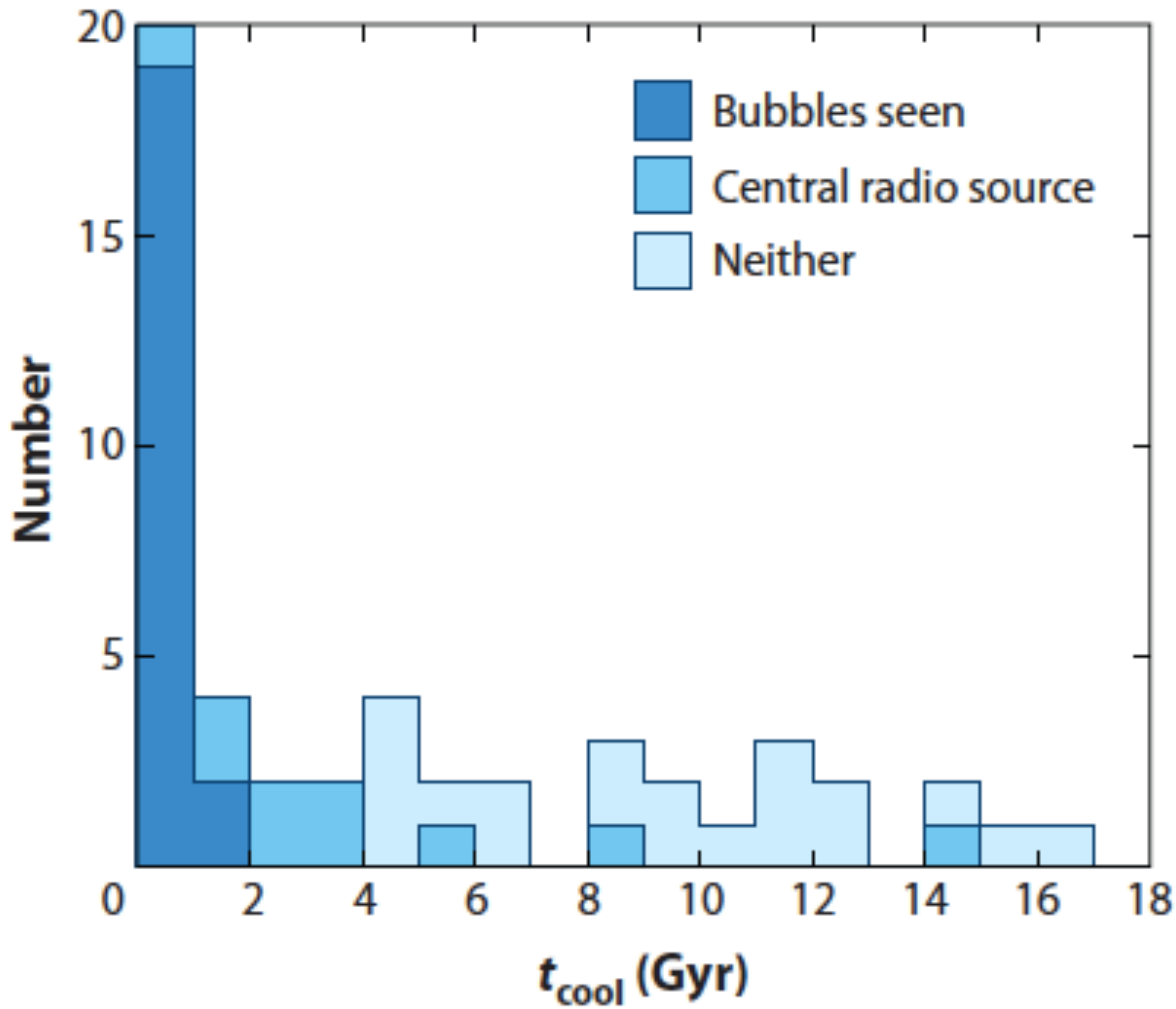

ULAS1234 z=2.5 Banerji+12

Kinetic/radio mode: The most massive galaxies

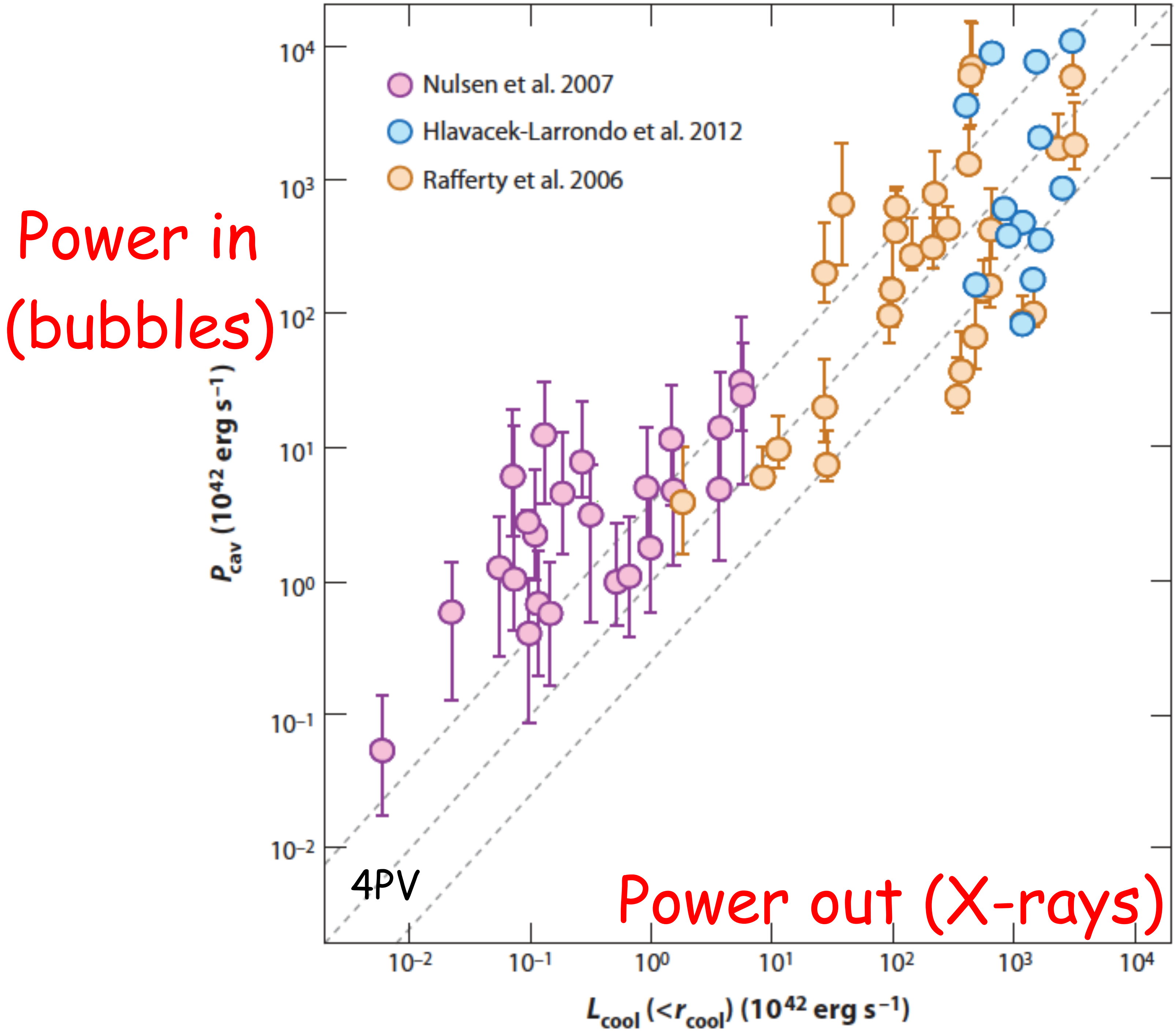



a
RBS 797
z = 0.354
50 kpc
b
NGC 5813
z = 0.006
5 kpc
Bubbles common
c
A 2052
z = 0..035
20 kpc
d
NGC 5044
z = 0.0093
5 kpc

Duty cycle is ~100%



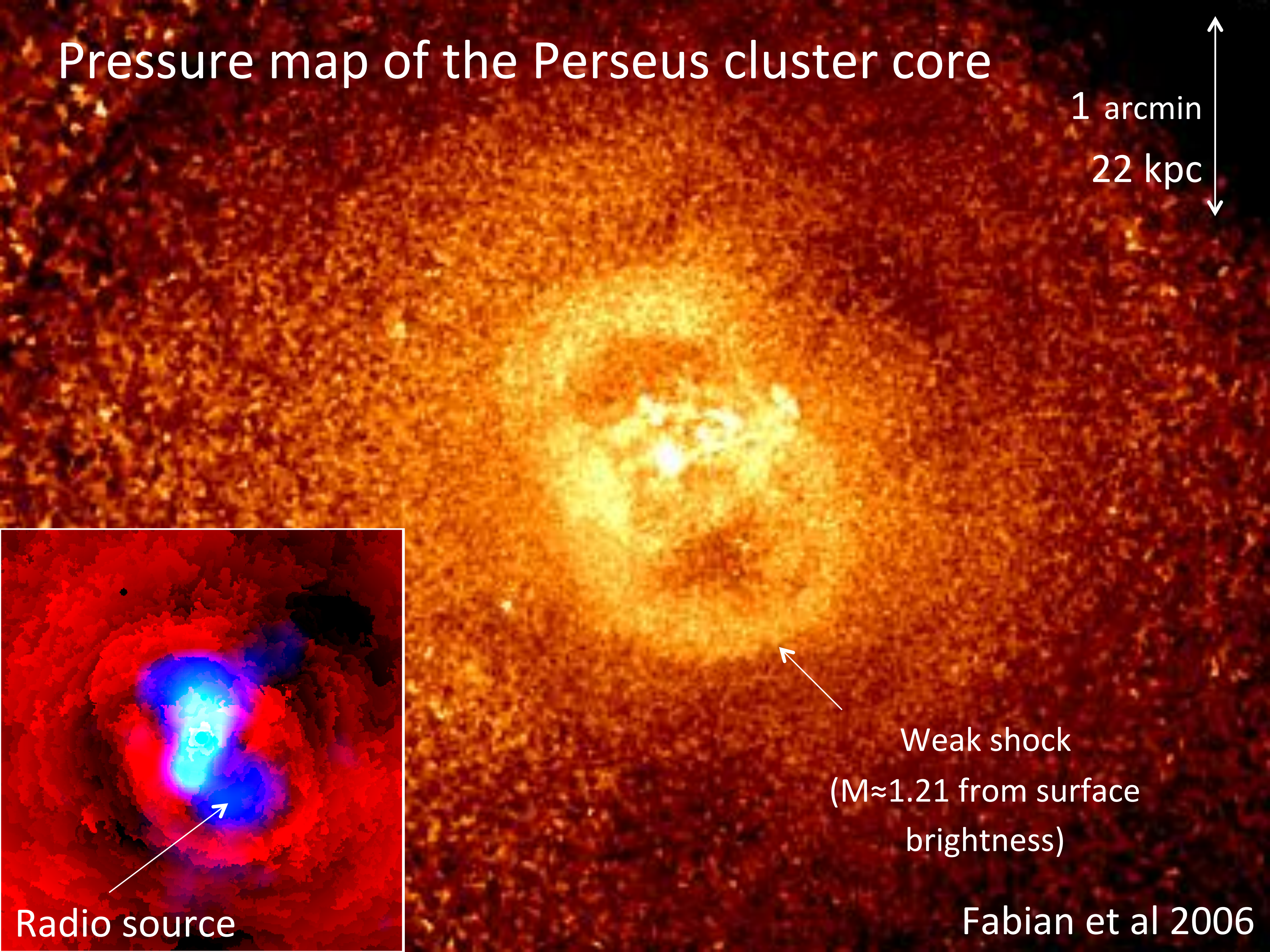
See also Birzan+04, Rafferty+06+08, Dunn+F,06,07

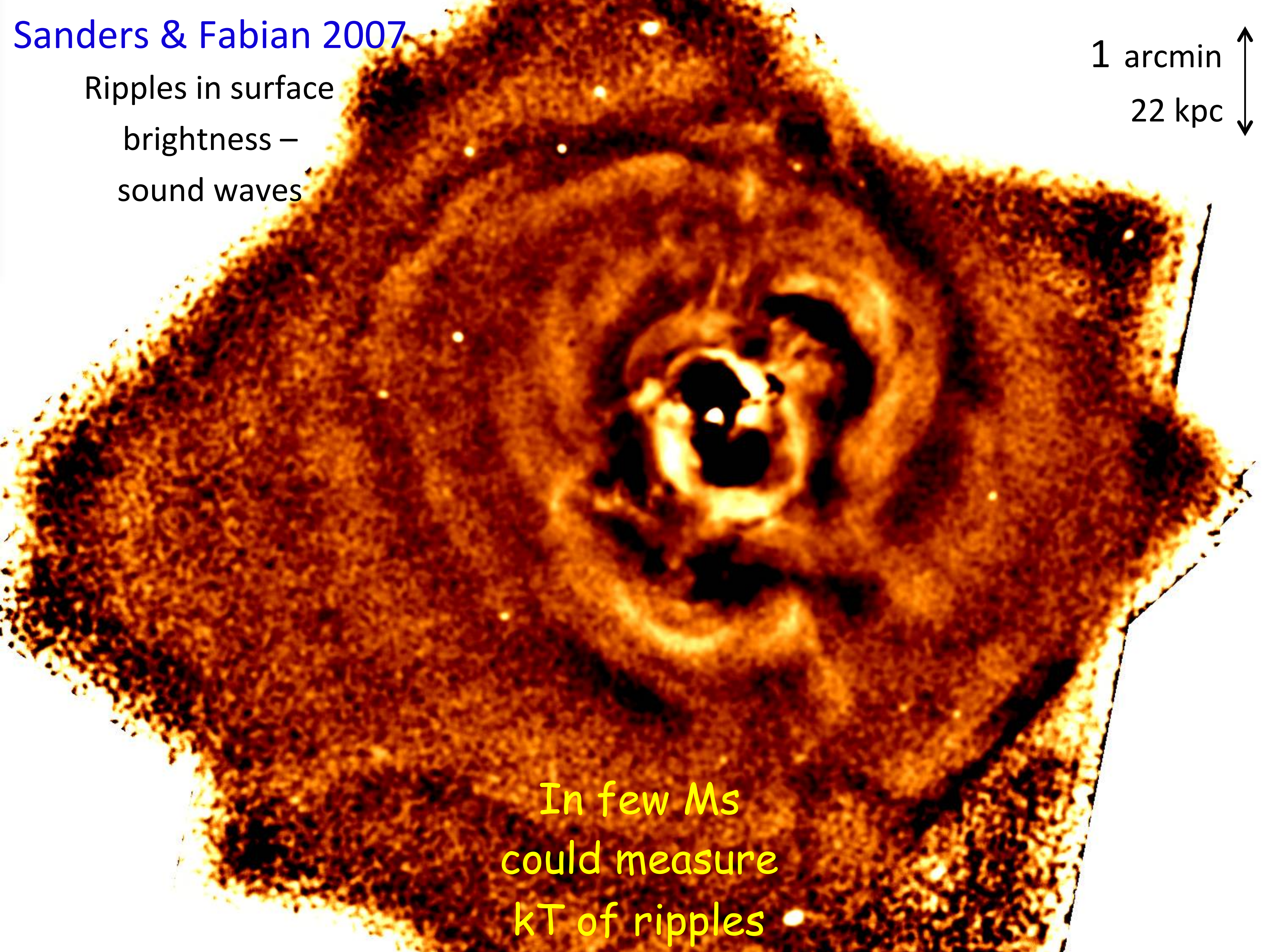


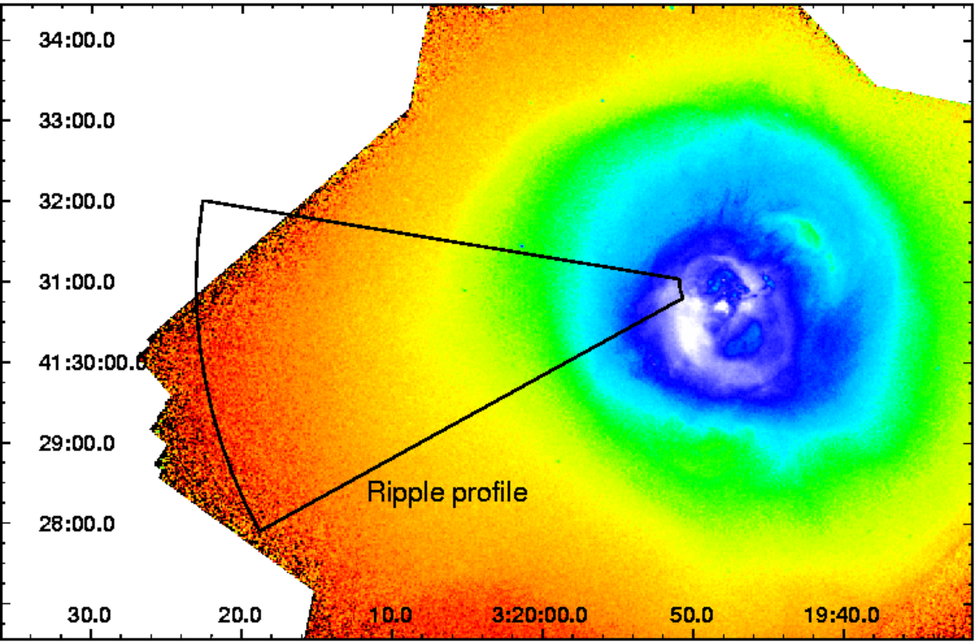
Power in
(bubbles)
Nulsen et al. 2007
Hlavacek-Larrondo et al. 2012
Rafferty et al. 2006
P_{cav} (10^{42} erg s^{-1})
L_{cool} ($<r_{cool}$) (10^{42} erg s^{-1})
4PV
Power out (X-rays)

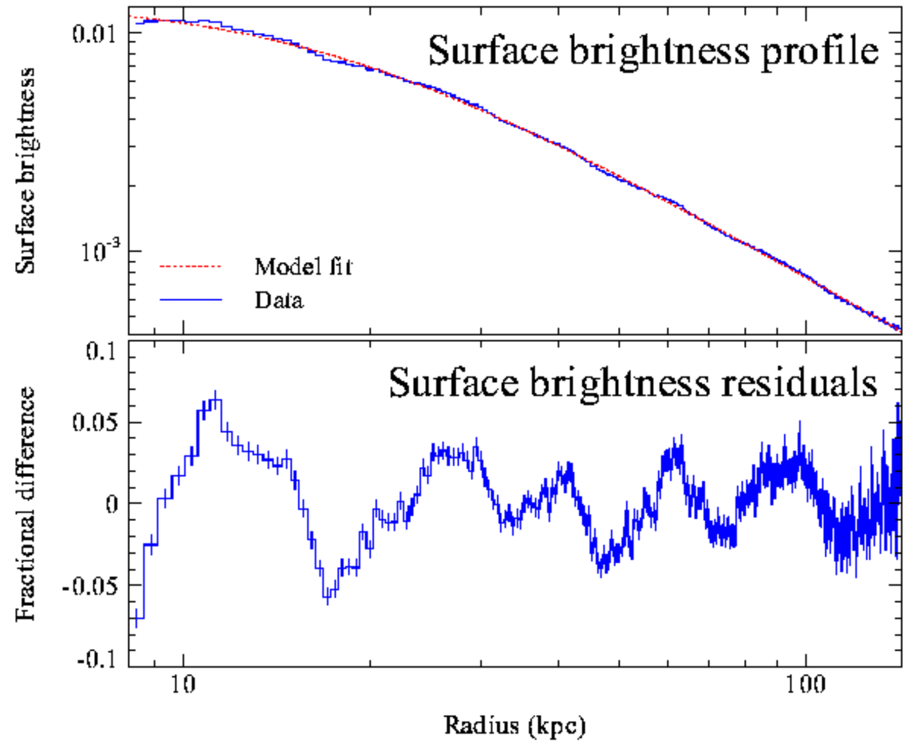
Issues

- Total Energy not an issue.
- How does energy get distributed?
- How close is heating/cooling balance? Feedback too good?
- Observations suggest better than 10% for Gyrs in some objects.
- HOW DOES THE AGN DO THIS?
- How is coolest X-ray gas (ie $T<5.10^6$K with radiative cooling time $\sim 10^7$yr) prevented from cooling?


Pressure map of the Perseus cluster core
1 arcmin
22 kpc
Weak shock
(M≈1.21 from surface
brightness)
Radio source
Fabian et al 2006


Sanders & Fabian 2007
Ripples in surface brightness – sound waves
1 arcmin
22 kpc
In few Ms could measure kT of ripples

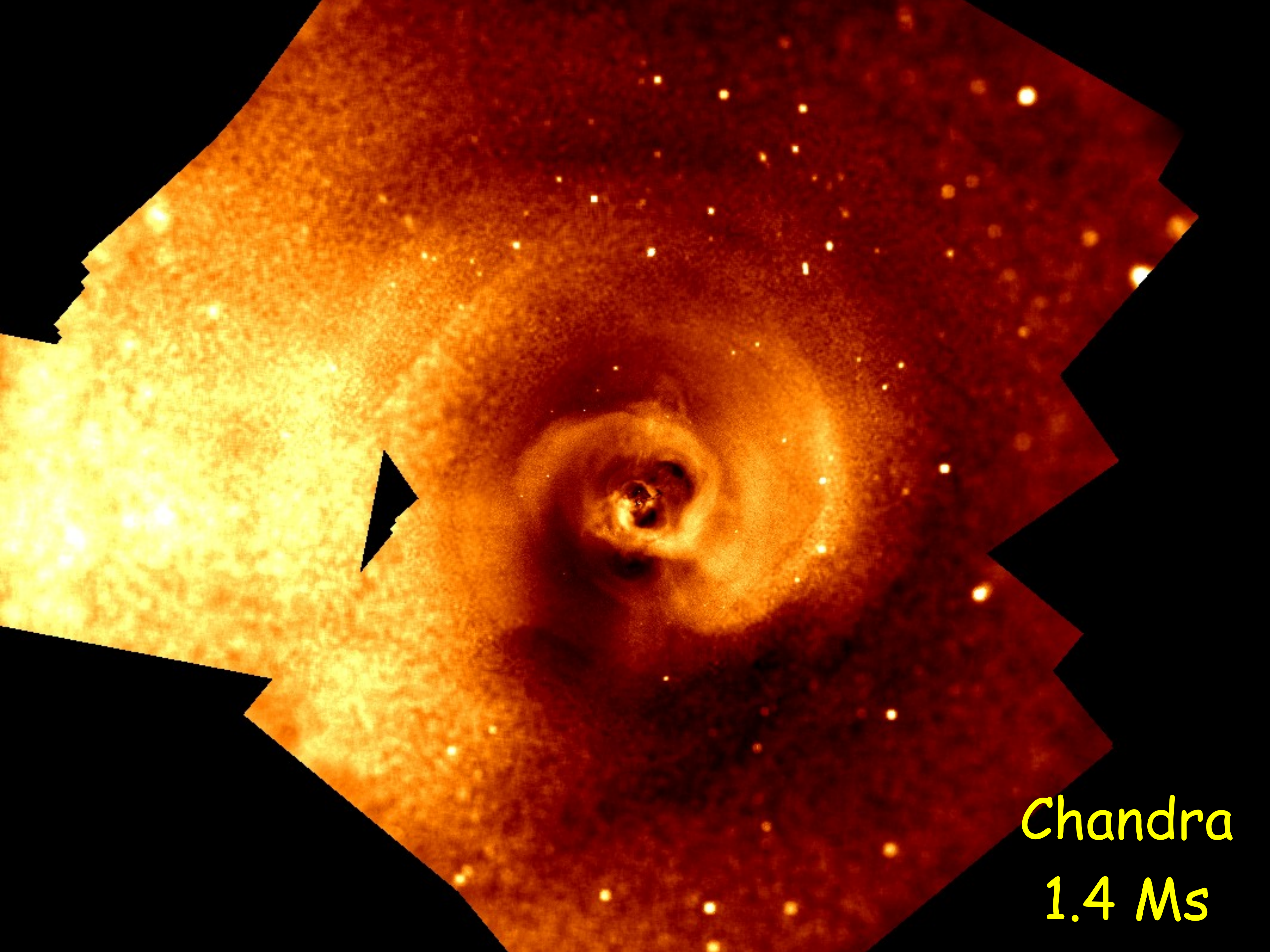




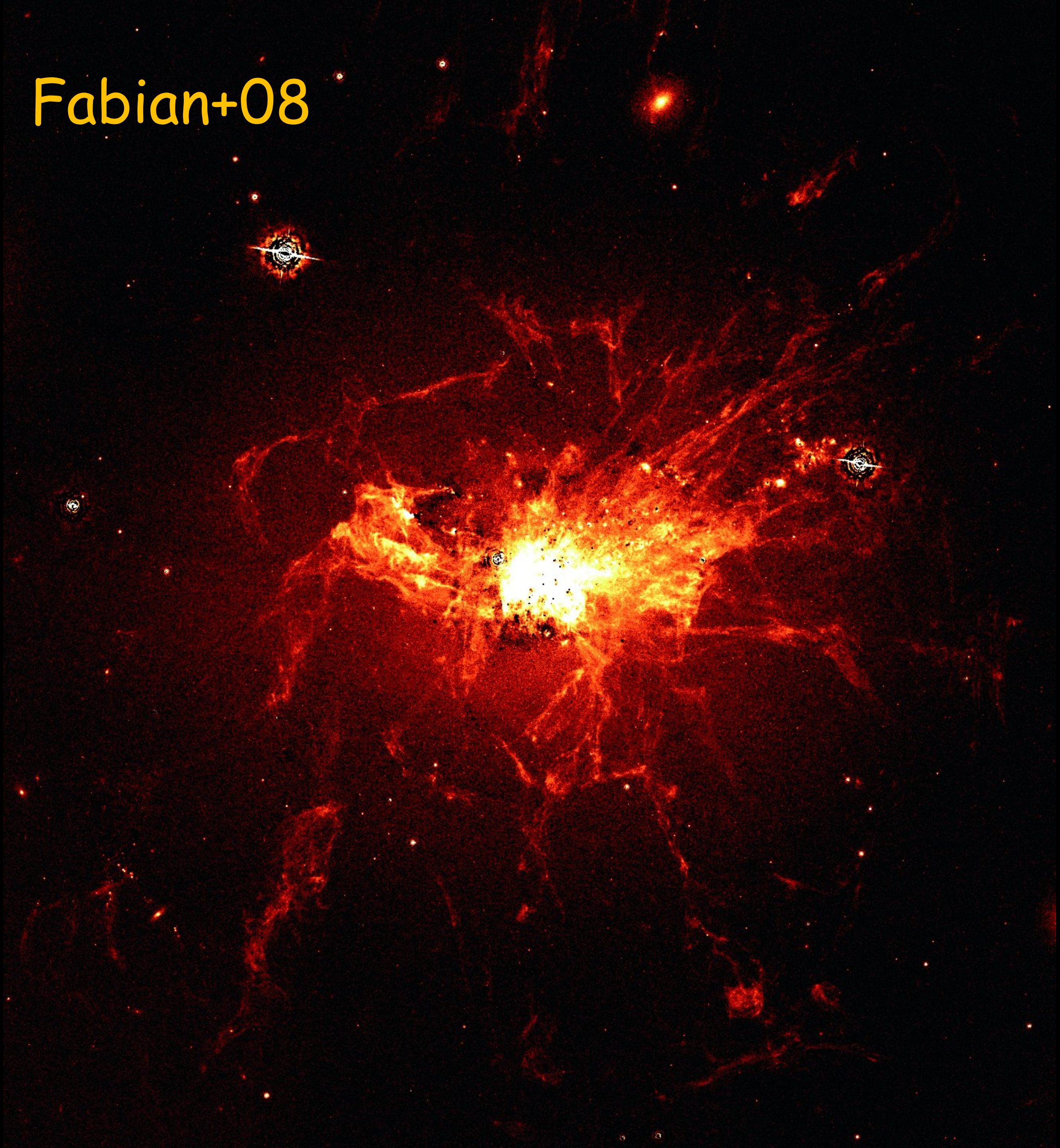
Power in ripples (sound waves) ~ X-ray luminosity within 70 kpc

Also seen in Centaurus, Virgo…

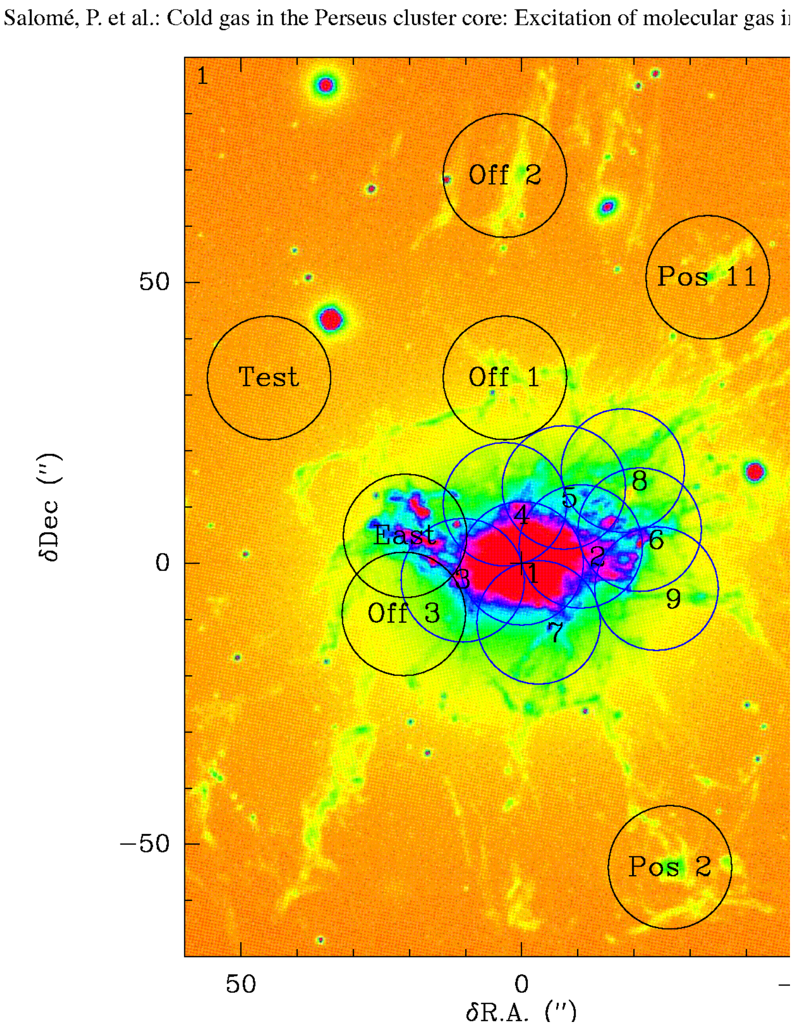
Fabian+03,06, Sanders+, Sijacki+06


Chandra
1.4 Ms

Optical Fabian+08



Salome+08 CO measurements



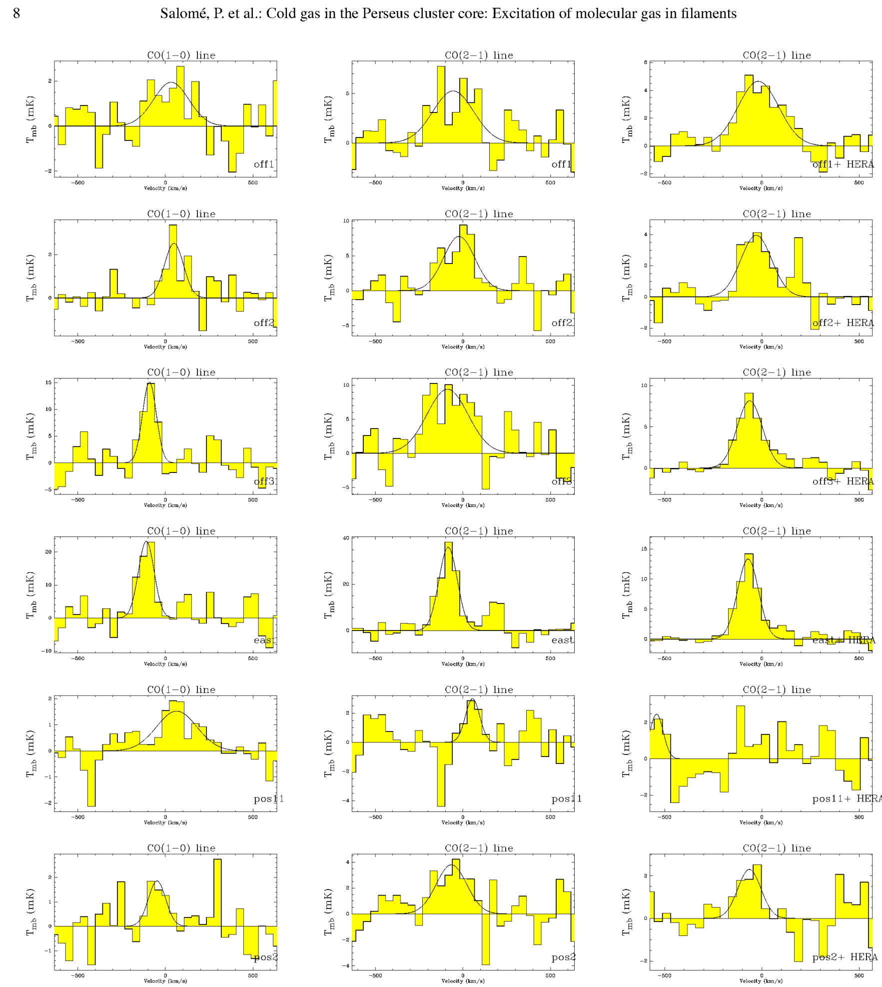
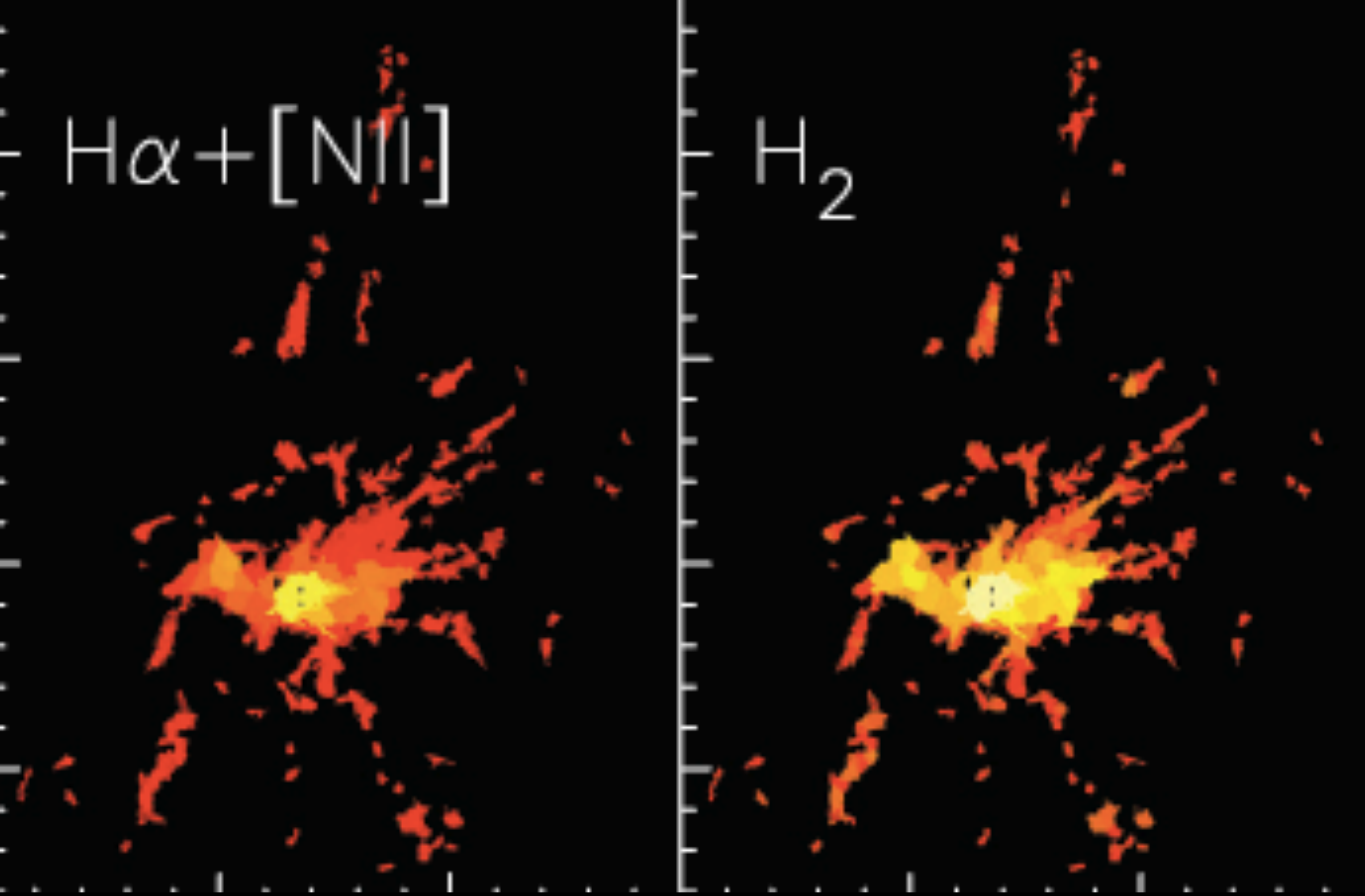


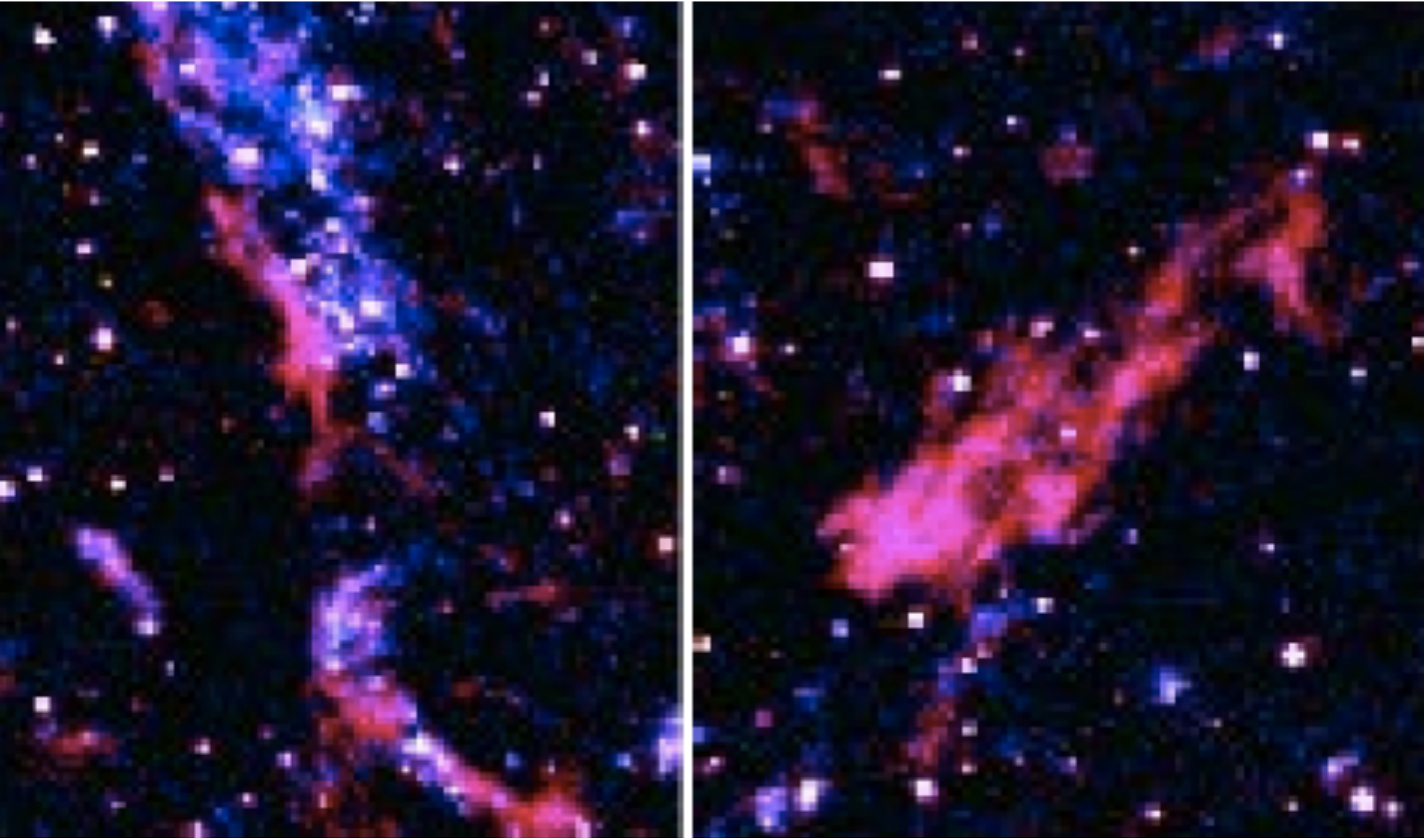
Fig. 2. CO(1–0) and CO(2–1) spectra obtained at all the positions observed as indicated at lower right in each diagram. The channel width is 42 km/s. On the left hand side are the CO(1–0) lines detected with the a100 and b100 receivers. In the middle are the results obtained for the CO(2–1) line with the A230 and B230 receivers. On the right hand side are the CO(2–1) lines computed with both A230 and B230 merged with previous HERA data and smoothed to the 3mm beam size.

Almost 10^{11} Msun of cold gas in Perseus



Lim+12


Spectrum of these filaments is unlike anything in Galaxy,
other than Crab
and due to energetic particles (the hot gas?) Ferland+08/9

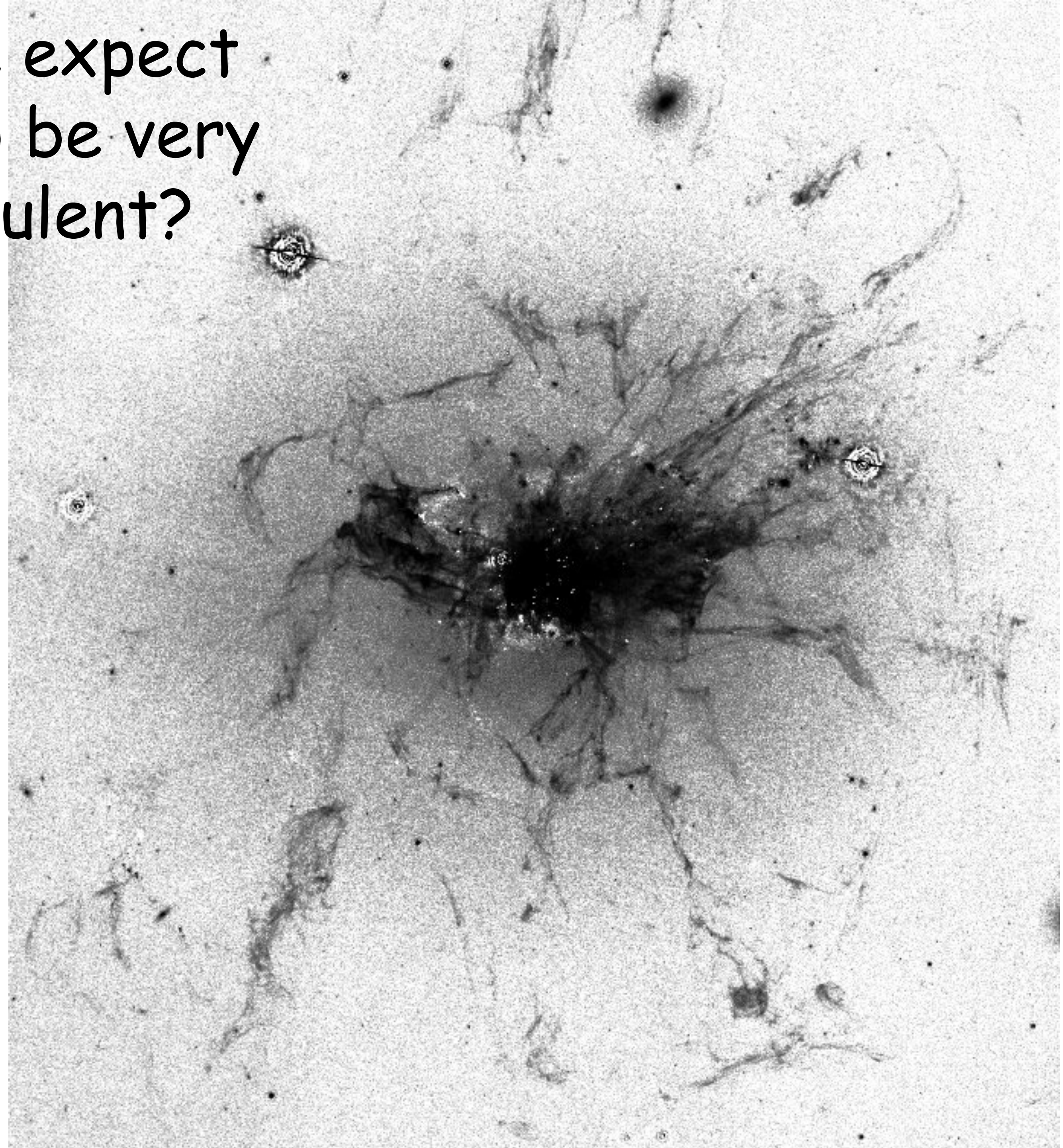


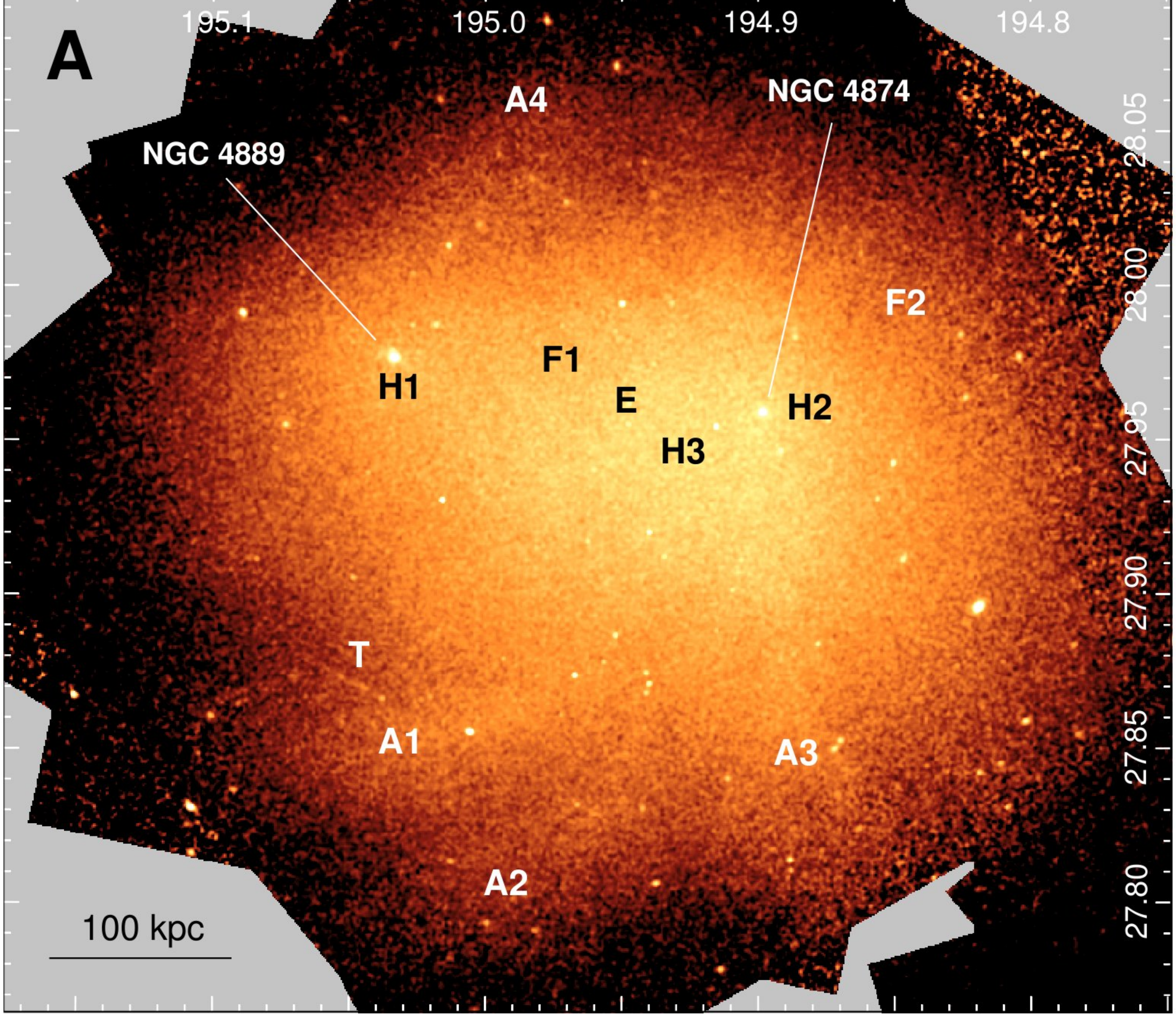
Young stars do not provide ionization in outer filaments

Perseus SFR~20 Msunpyr   Canning+10

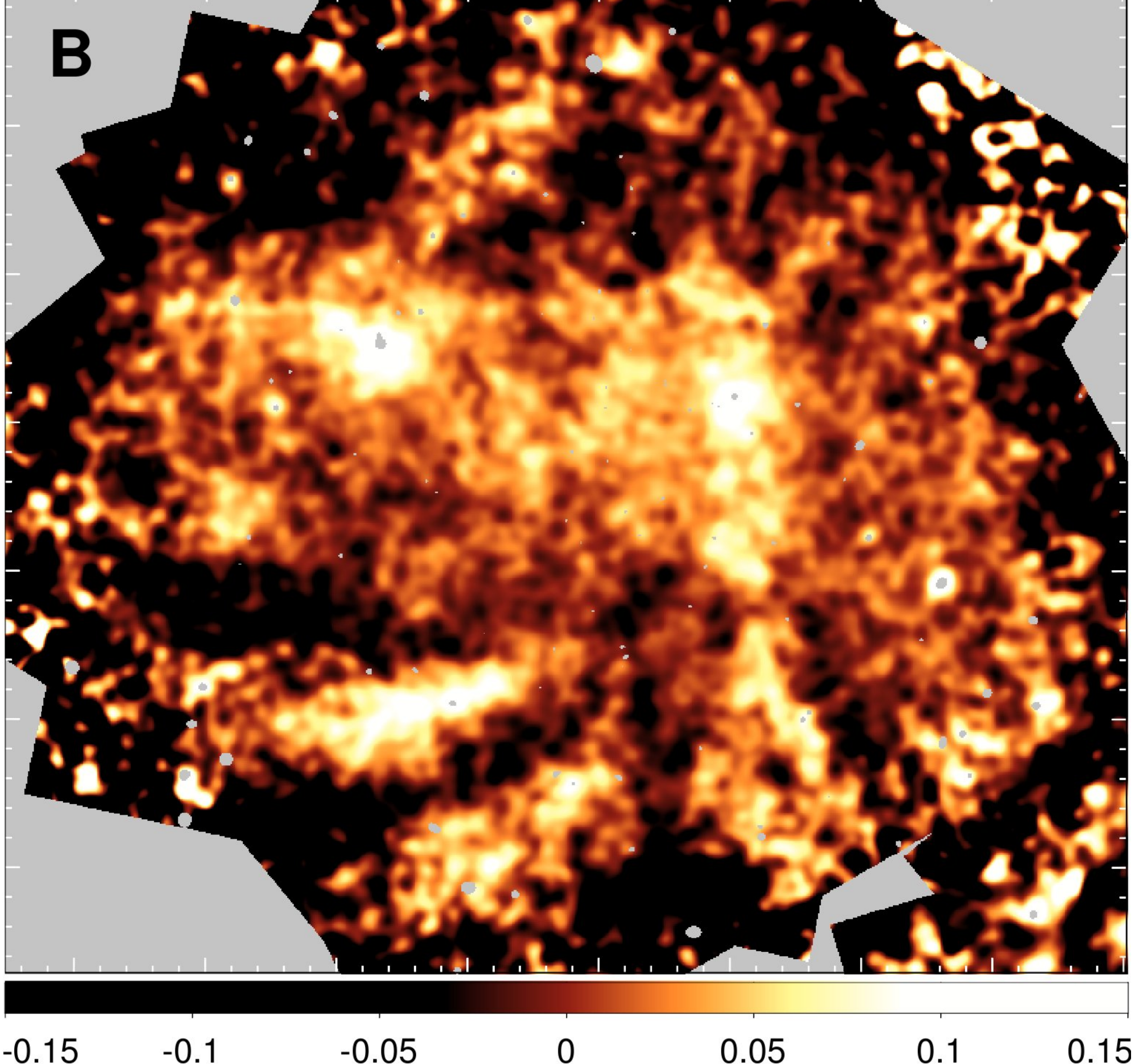
INTERLUDE ON INTRACLUSTER GAS

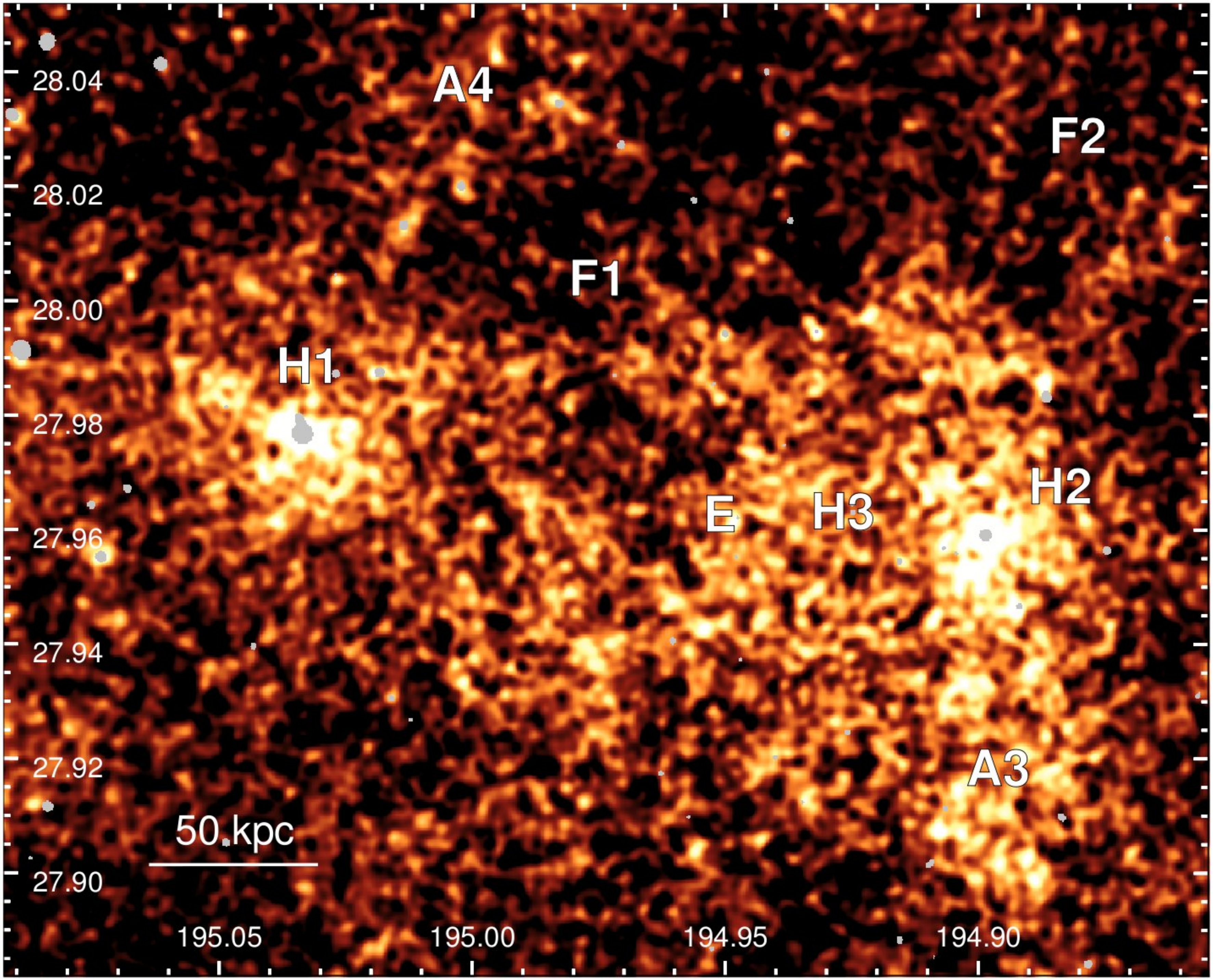
Do we expect this to be very turbulent?





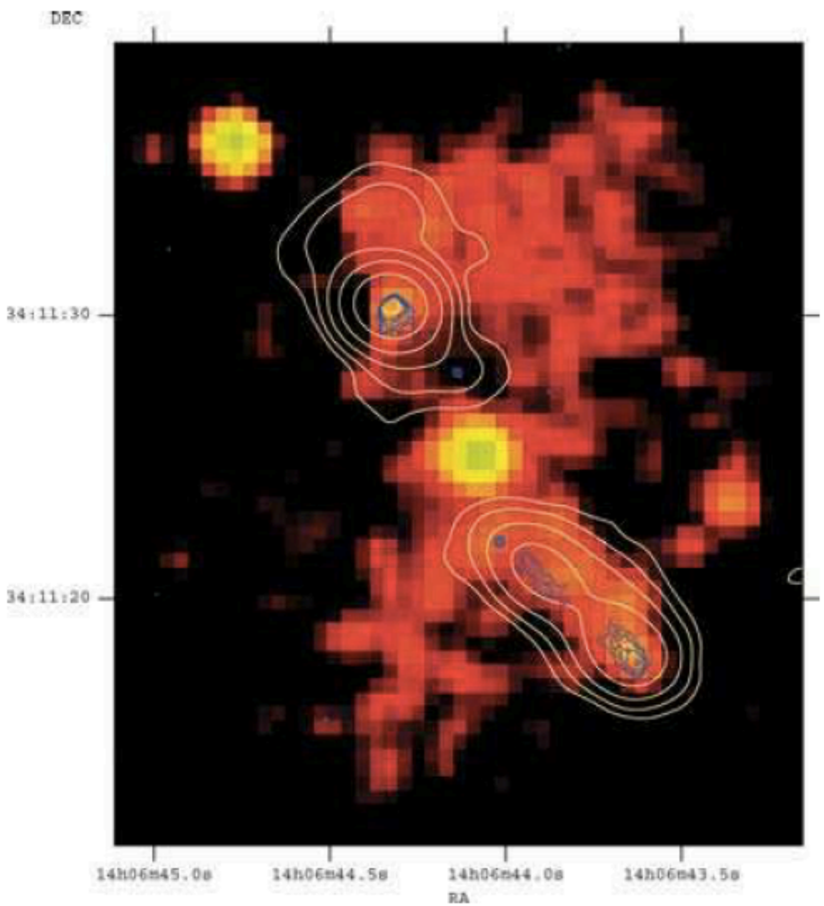
Coma cluster with Chandra - J. Sanders+13

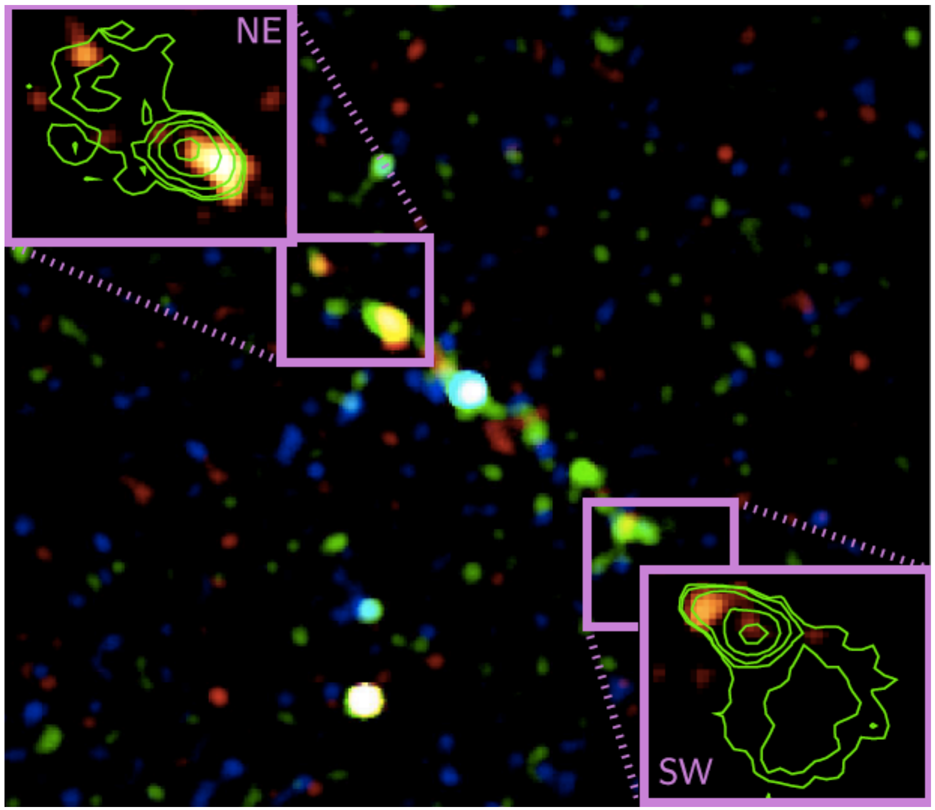

B
-0.15
-0.1
-0.05
0
0.05
0.1
0.15


A4
F2
F1
H1
H2
E
H3
A3
50 kpc
28.04
28.02
28.00
27.98
27.96
27.94
27.92
27.90
195.05
195.00
194.95
194.90

GIANT FRII RADIO GALAXIES

3C294 (z=1.785) and 4C23.56 (z=2.5)

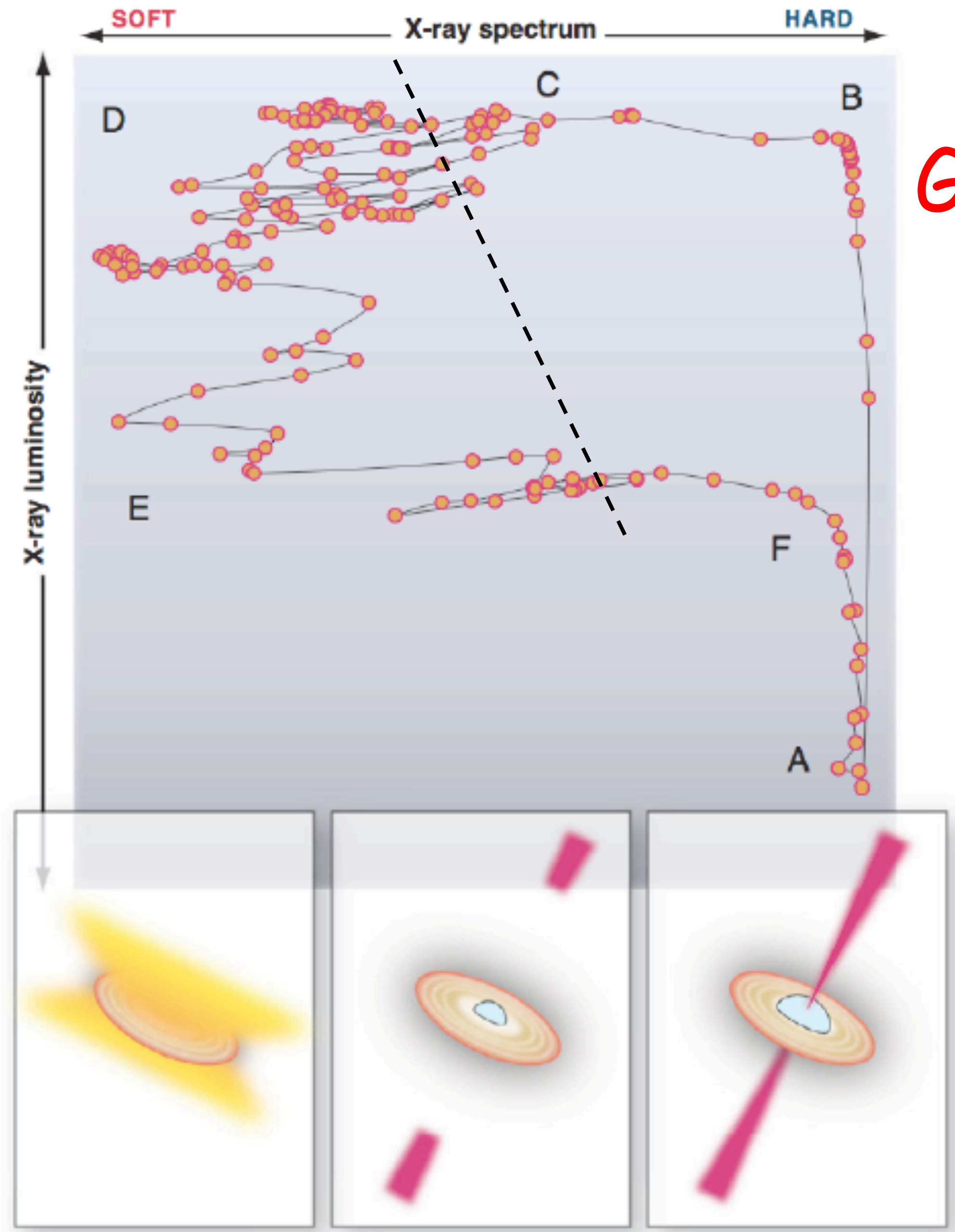




Fabian+03, Erlund+06

Blundell+11

Disc vs corona

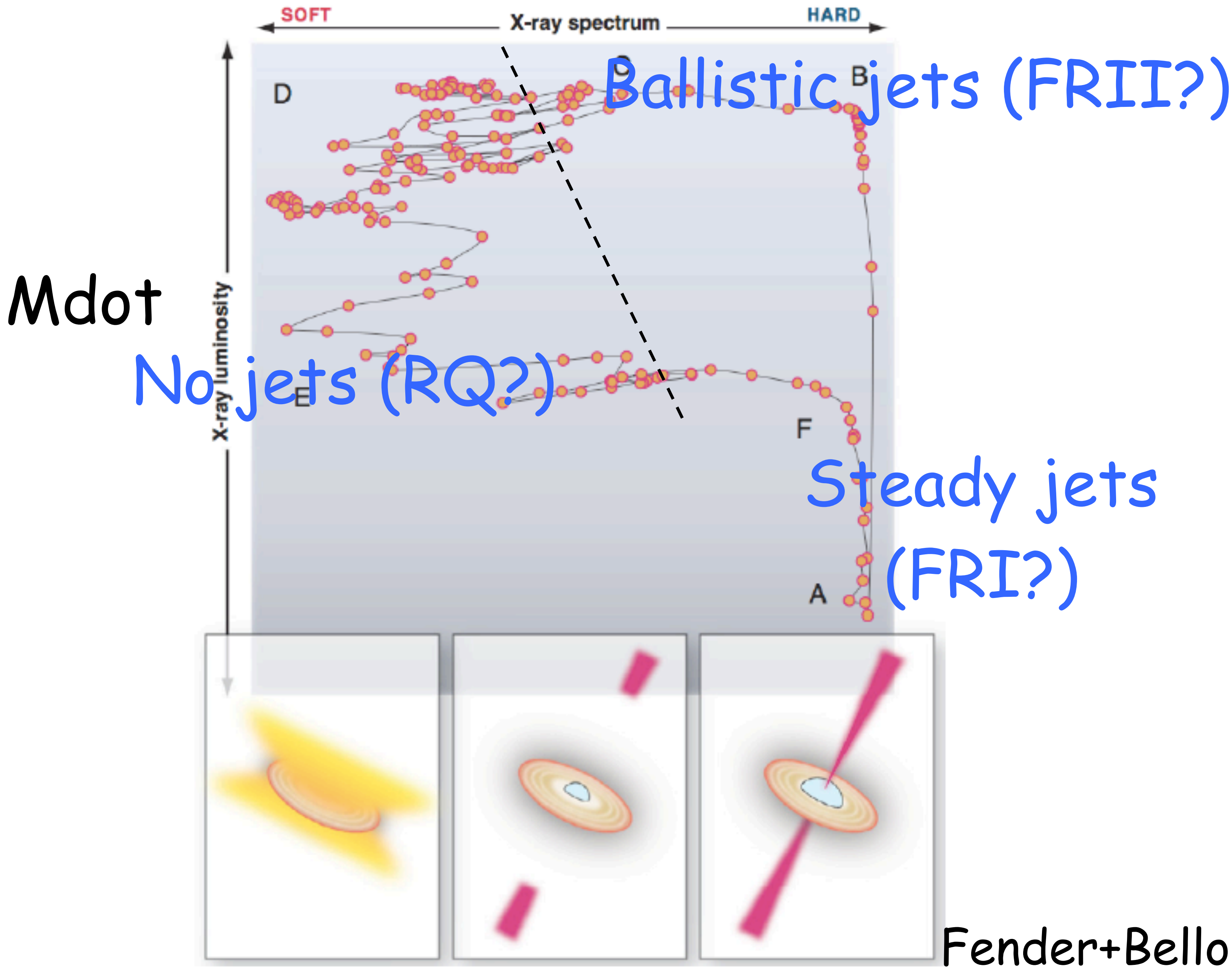


Mdot

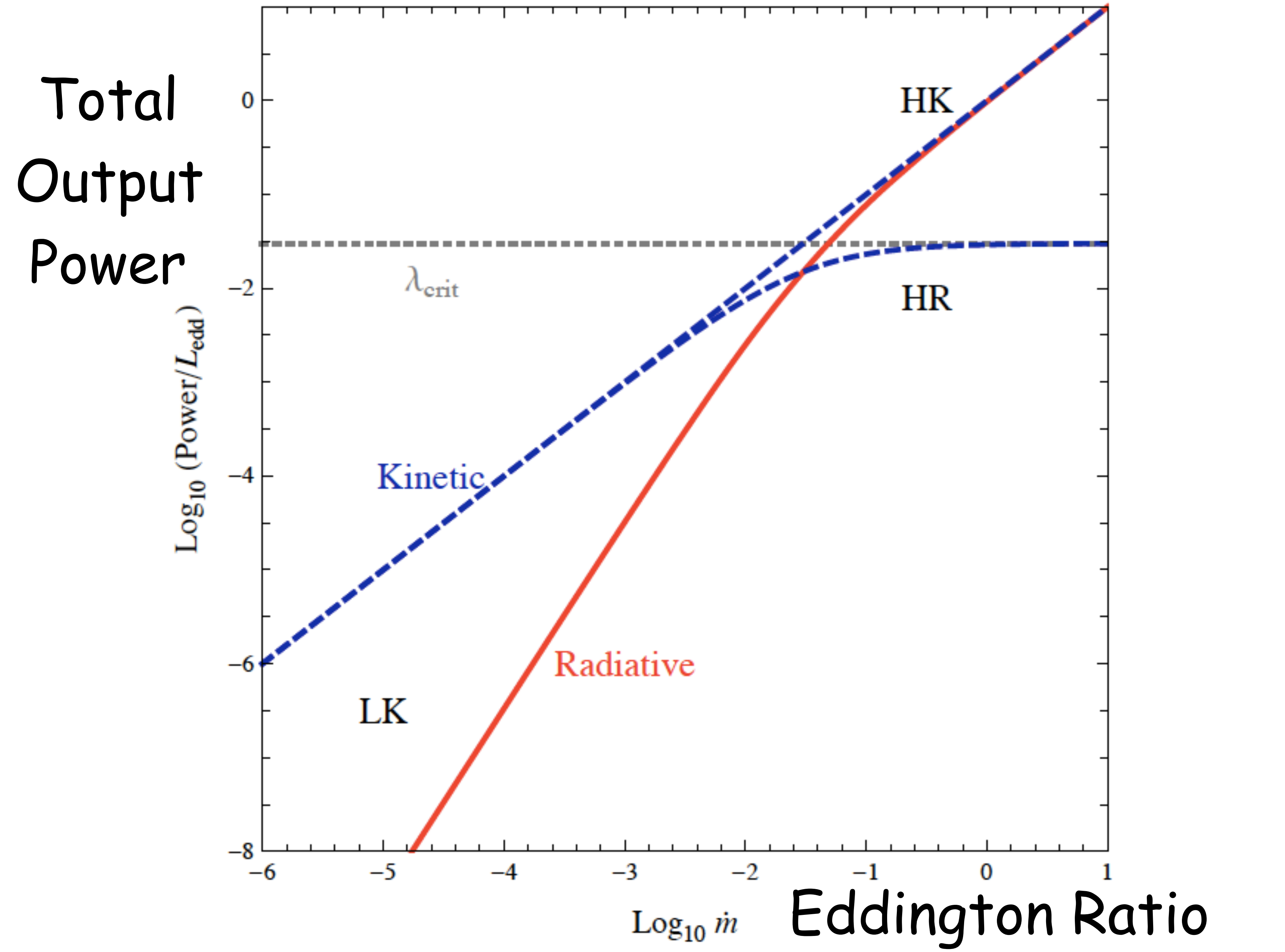
Galactic BHB

Fender+Belloni12

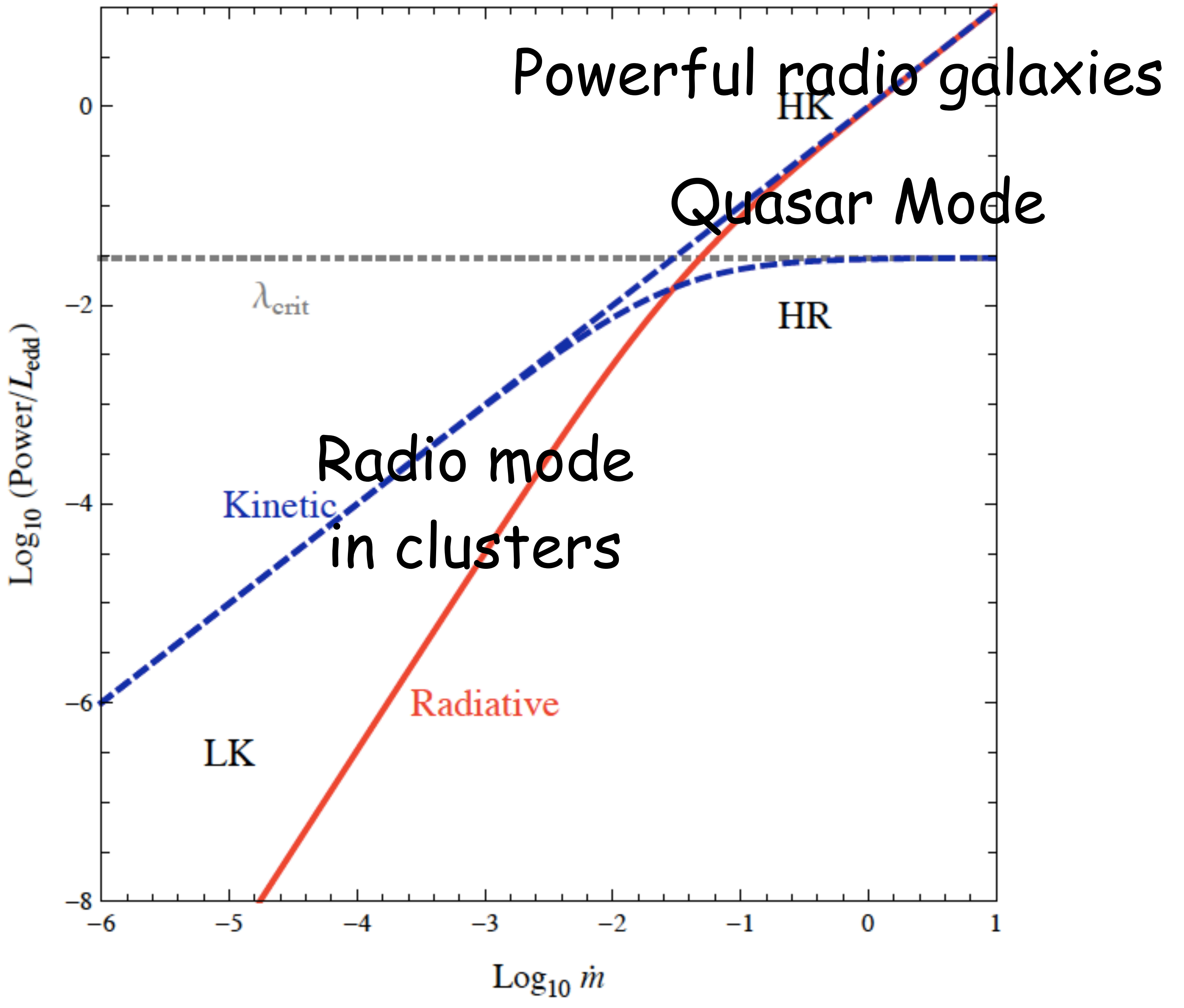
Disc vs corona



Fender+Belloni12



Total Output Power
Log10 (Power/Ledd)
HK
HR
λcrit
Kinetic
Radiative
LK
Log10 ṁ
Eddington Ratio



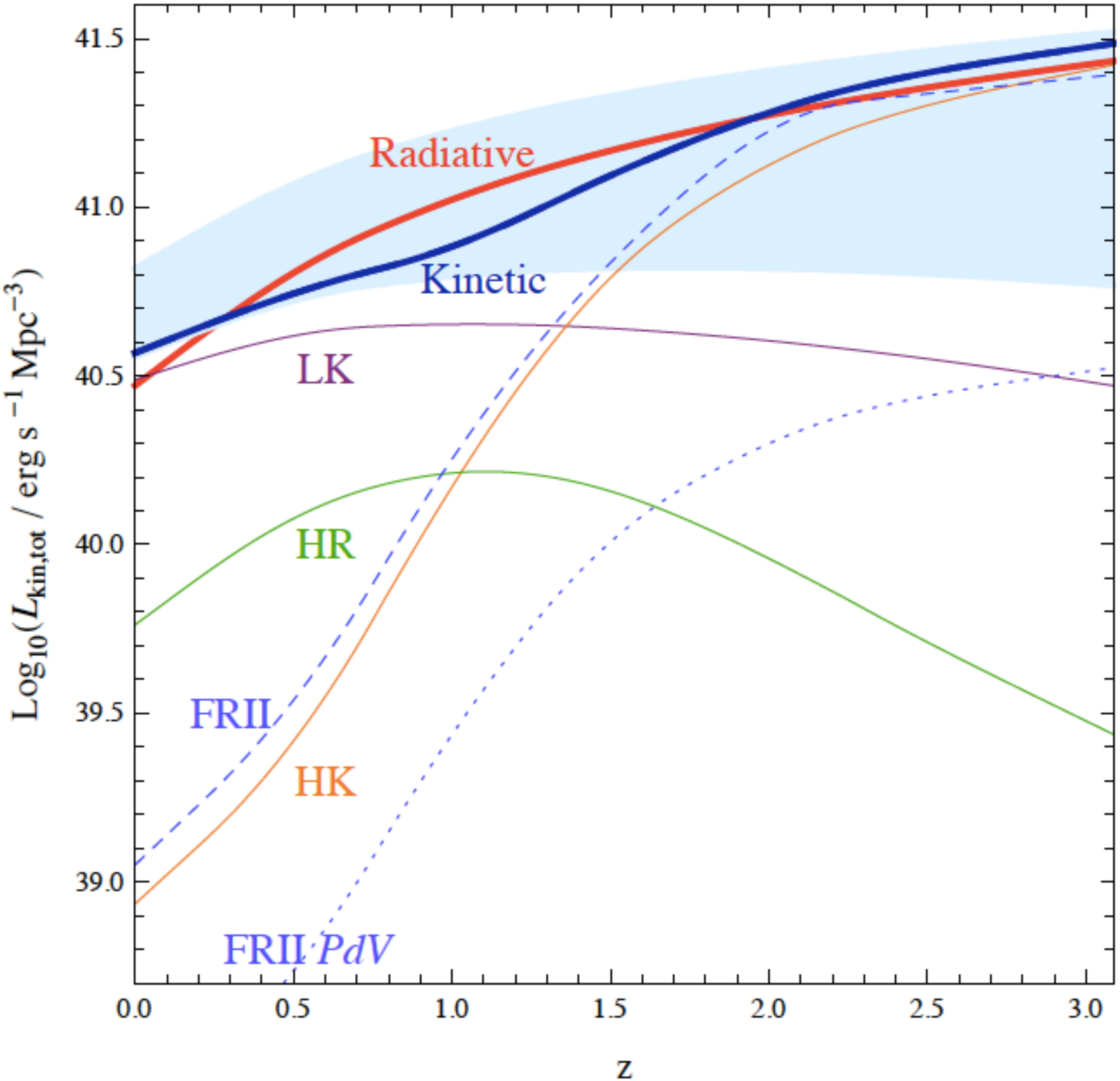
Powerful radio galaxies
HK
Quasar Mode
λ_{crit}
HR
Radio mode
in clusters
Kinetic
Radiative
LK
0
−2
−4
−6
−8
$\log_{10}(\mathrm{Power}/L_{edd})$
−6
−5
−4
−3
−2
−1
0
1
$\log_{10} \dot{m}$

Cosmological growth and feedback from supermassive black holes

P. Mocz[1,2⋆], A.C. Fabian[2⋆] and Katherine M. Blundell[3⋆]
[1]Harvard University, Cambridge, MA 02138, USA
[2]Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK
[3]Astrophysics, University of Oxford, Keble Road, Oxford OX1 3RH, UK

MNRAS 2013

- BH growth following continuity equation
- Attempt to match XLF
- Use RLF in final match
- Determine Kinetic Luminosity Function

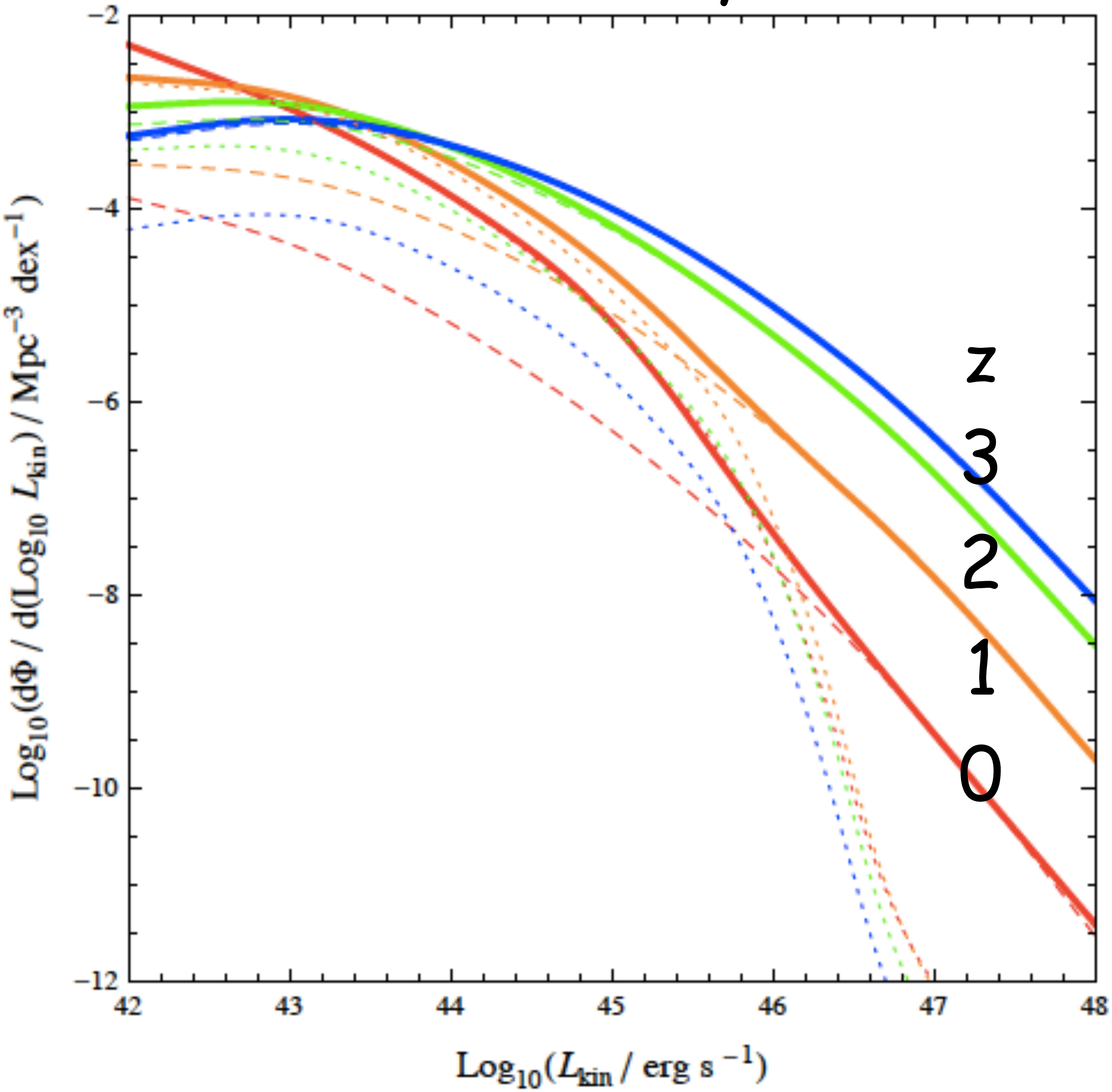


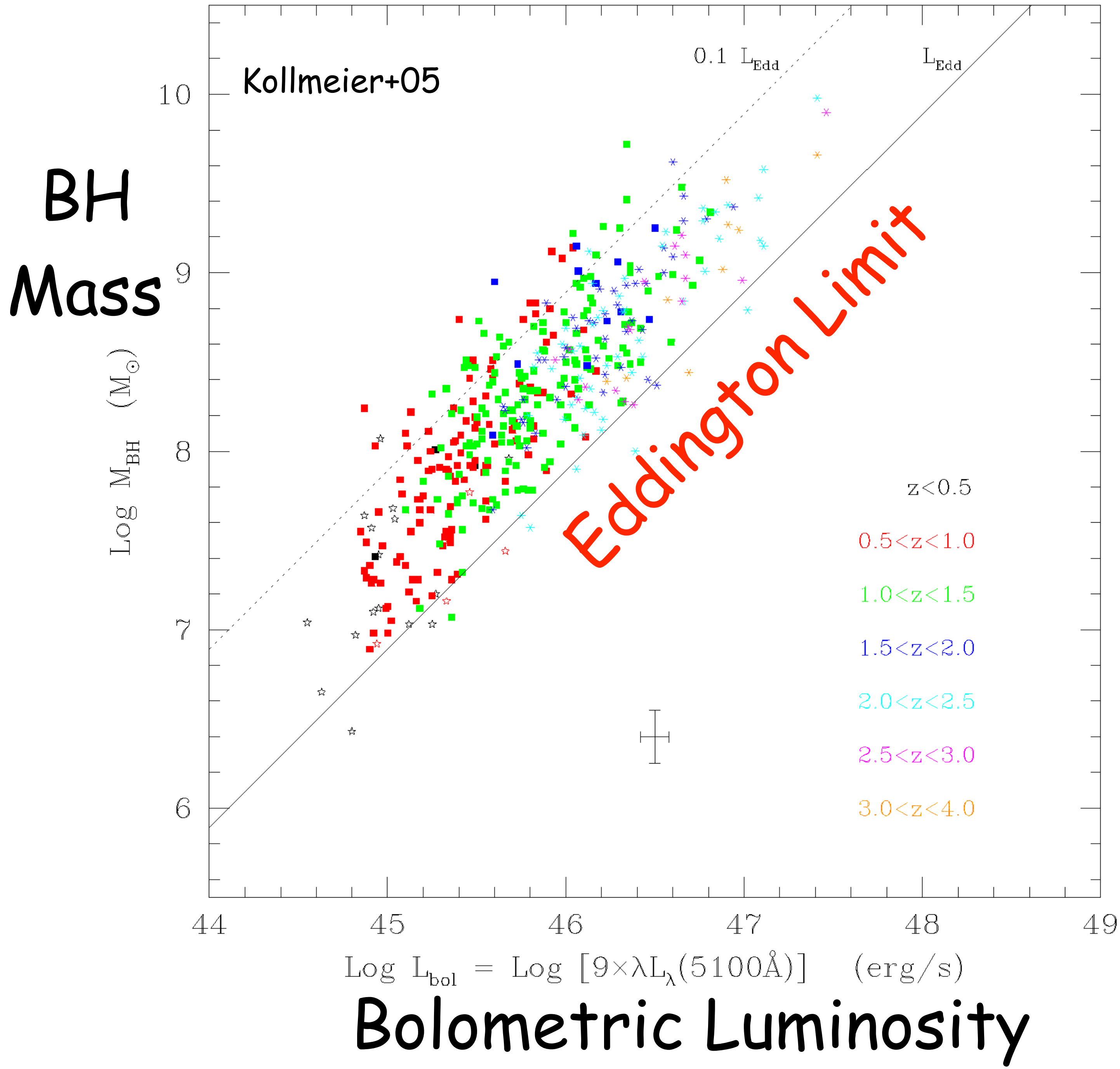
Radiative
Kinetic
LK
HR
FRII
HK
FRII PdV
41.5
41.0
40.5
40.0
39.5
39.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
z
Log10(Lkin,tot / erg s−1 Mpc−3)

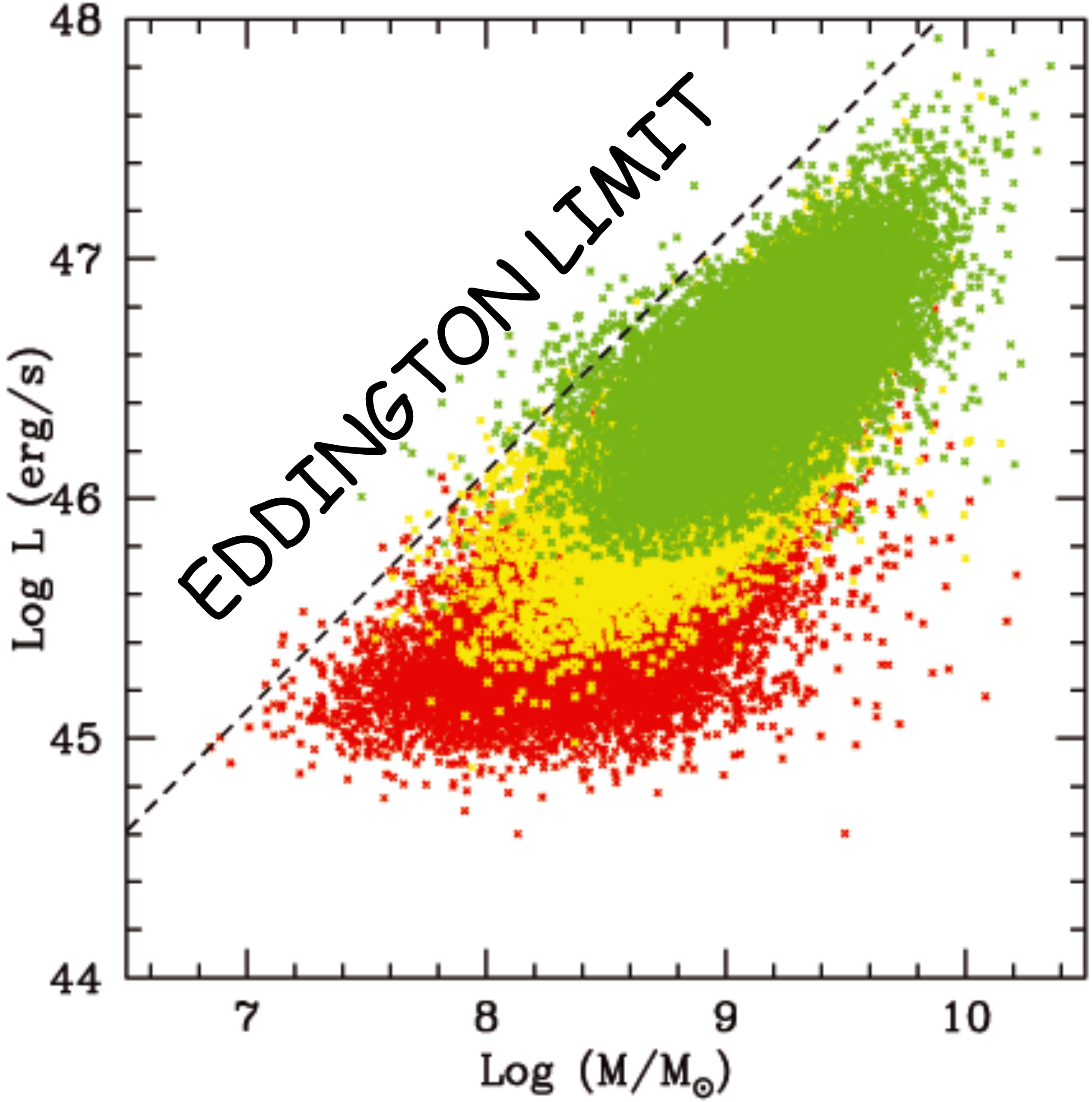
Summary

- Radiation pressure on dust plausible for radiative/quasar mode
- Dust may shape galaxies
- Kinetic/Radio mode in clusters
- Intracluster gas viscosity important
- Giant radio galaxy mode dominates at high z ?

Kinetic Luminosity Function




Kollmeier+05
0.1 L_{Edd}
L_{Edd}
Eddington Limit
BH
Mass
Log M_{BH} ($M_\odot$)
Log L_{bol} = Log [9×λL_λ(5100Å)] (erg/s)
Bolometric Luminosity
z<0.5
0.5<z<1.0
1.0<z<1.5
1.5<z<2.0
2.0<z<2.5
2.5<z<3.0
3.0<z<4.0
10
9
8
7
6
44
45
46
47
48
49



Steinhardt+Elvis10

Energetics of BH vs SB

- Mass of BH ~M/500
- Energy released during growth of BH $E_{BH} \sim 0.1 M_{BH} c^2 \sim 2\times10^{-4} Mc^2$

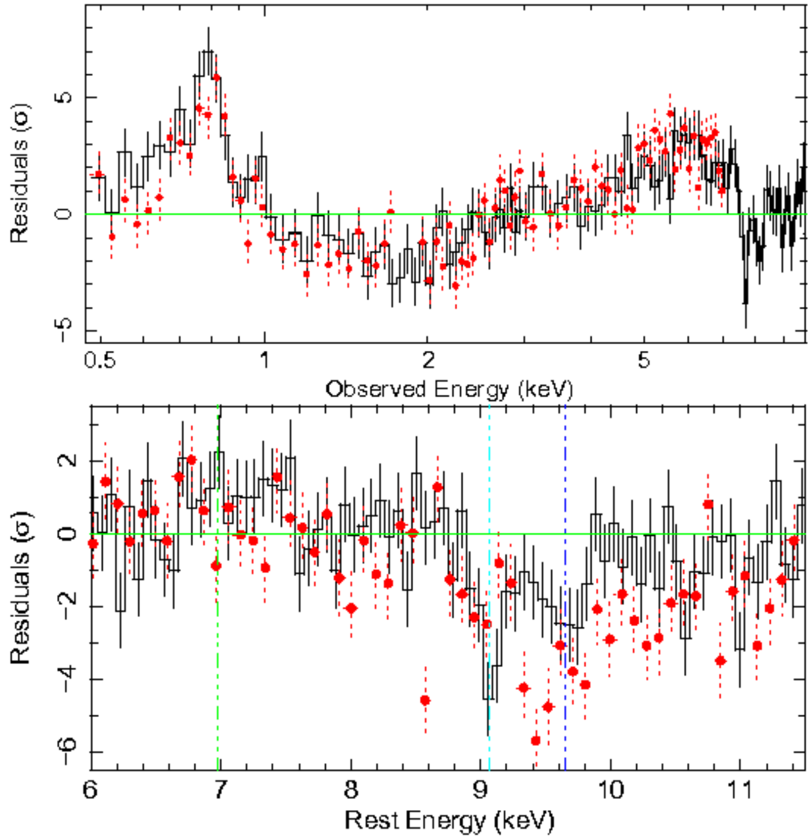
- Energy required to disperse galaxy~Mv^2
- Therefore $E_{BH}/E_{gal} \sim 2\times10^{-4}(v/c)^2$

- Since $v<c/1000$, $E_{BH} \sim 100 E_{gal}$
- Conclude that BH can damage galaxy

- Energy from SNx2~2×10^{-4} Mc^2 also so SB effect similar(modulo energy lost)

PDS456 z=0.184 Reeves+09 Suzaku

Kinetic power ~ 10^{47} erg/s

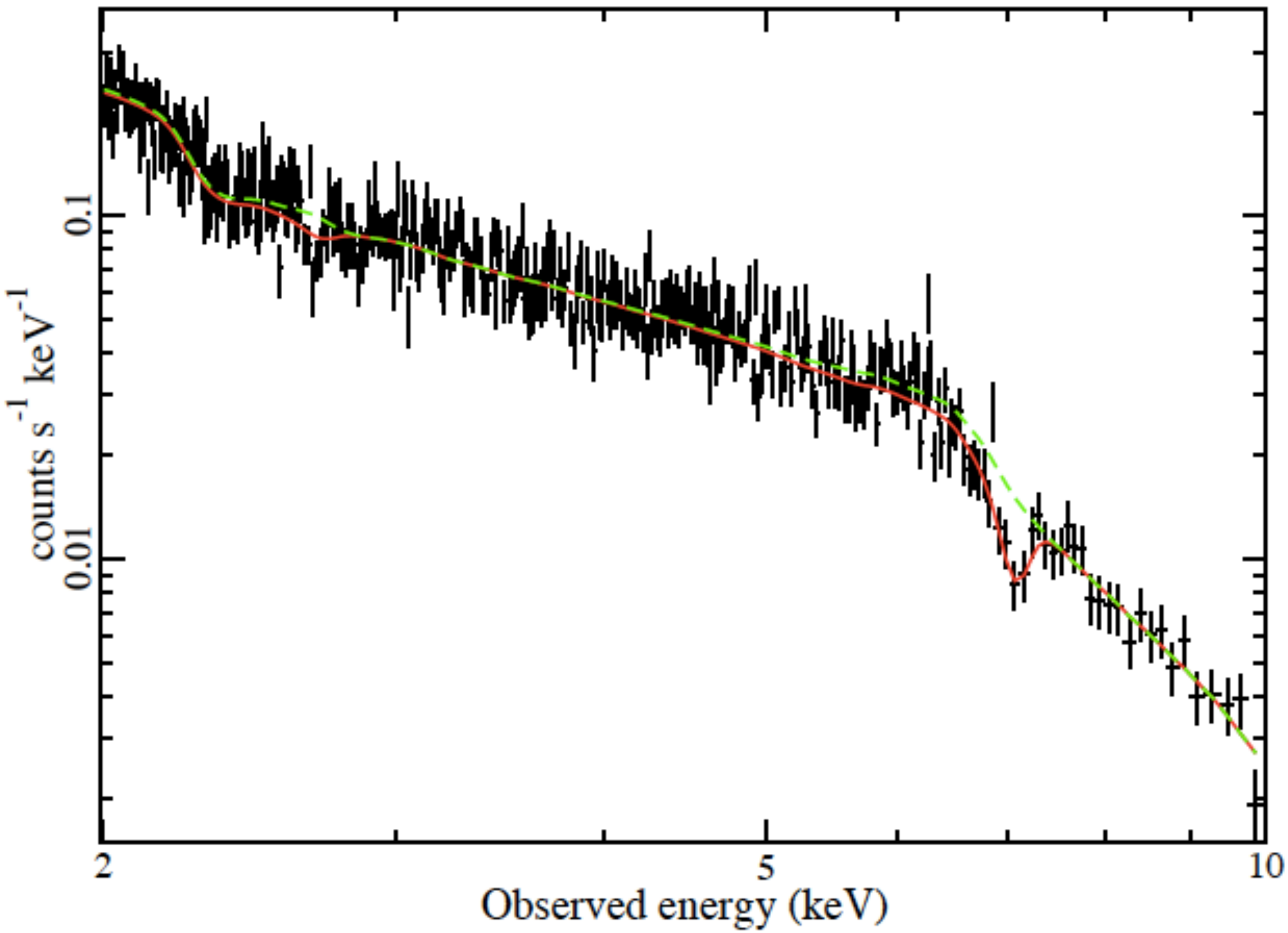


XMM 2001
in red

See Pounds+, Tombesi+ forUFOs

But classic UFO PG1211 can be fit by disc model

Gallo+Fabian13

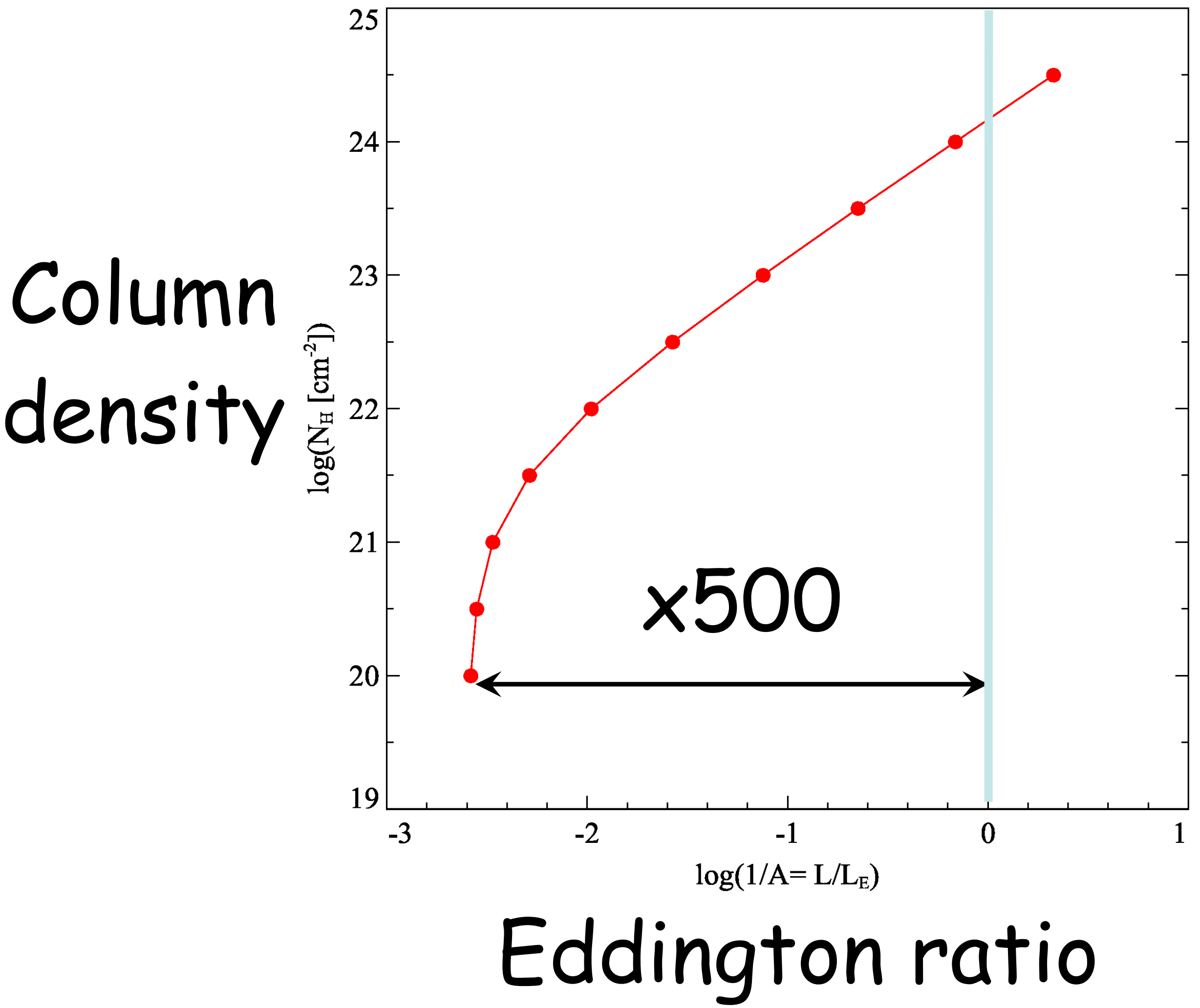


$$E = 5\times10^{-11}Mc^2$$ TNT

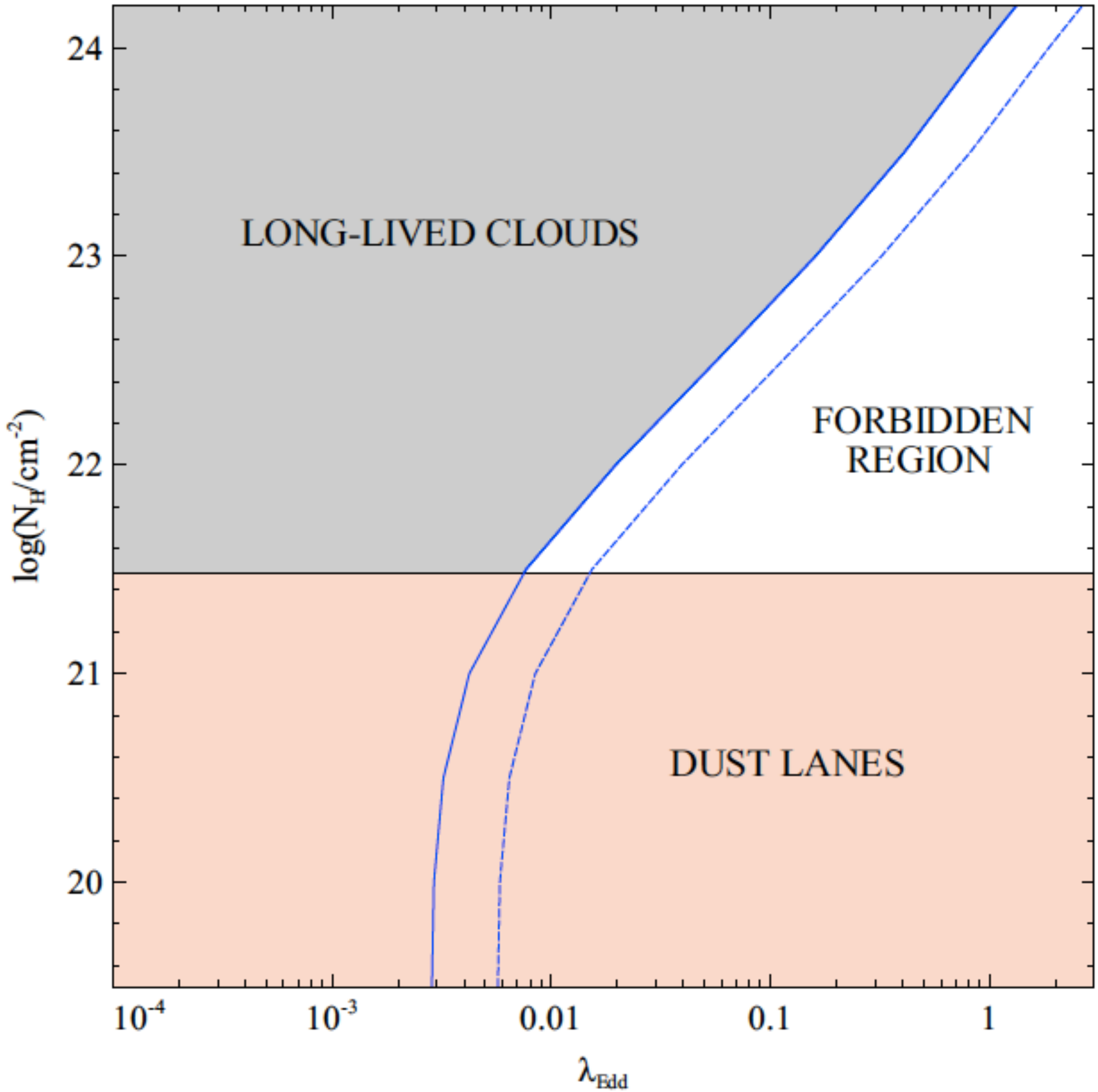
$$E = 0.005Mc^2$$ Nuclear fusion

$$E = 0.1Mc^2$$ Black Hole Accretion

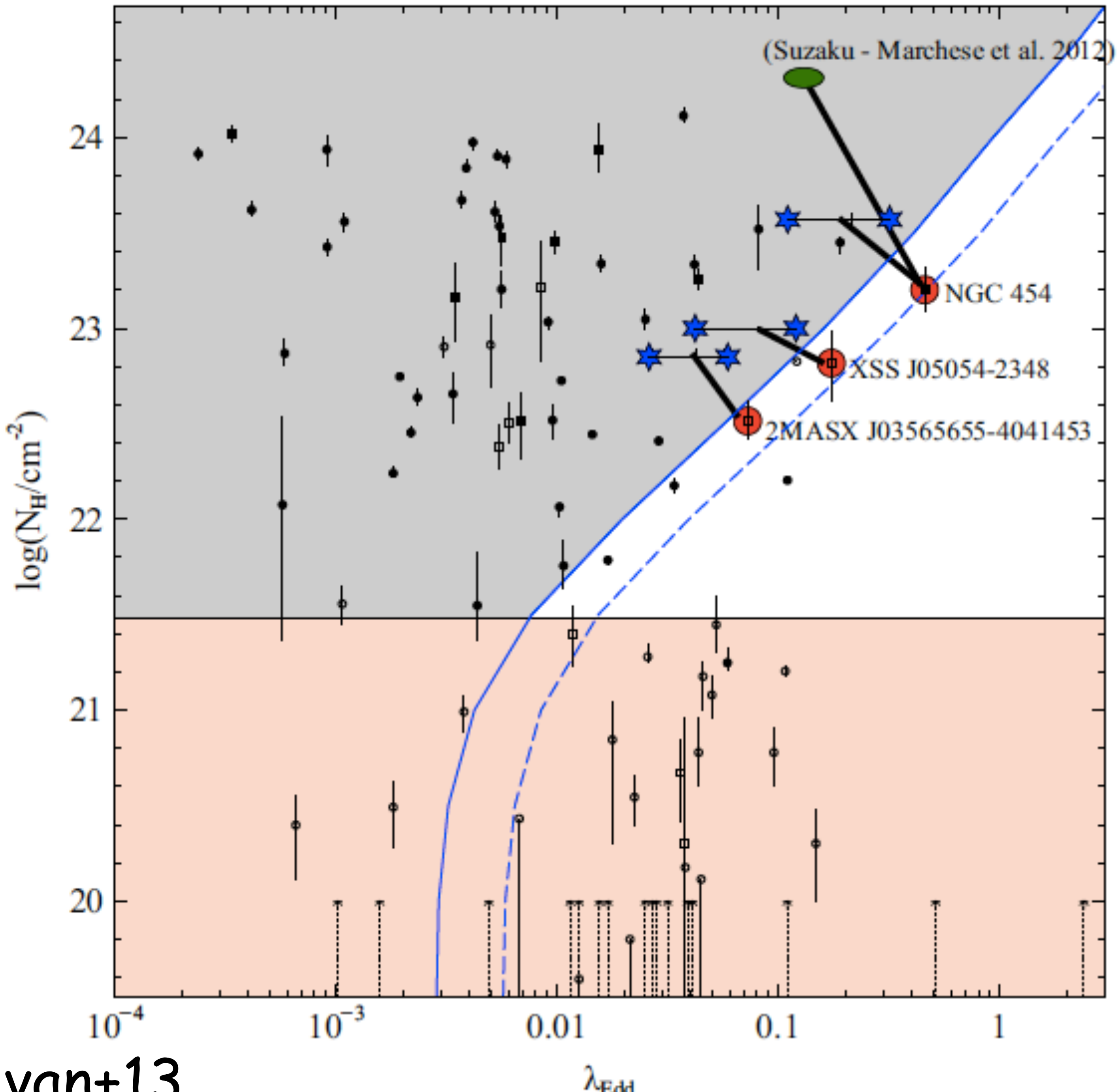
Dusty gas



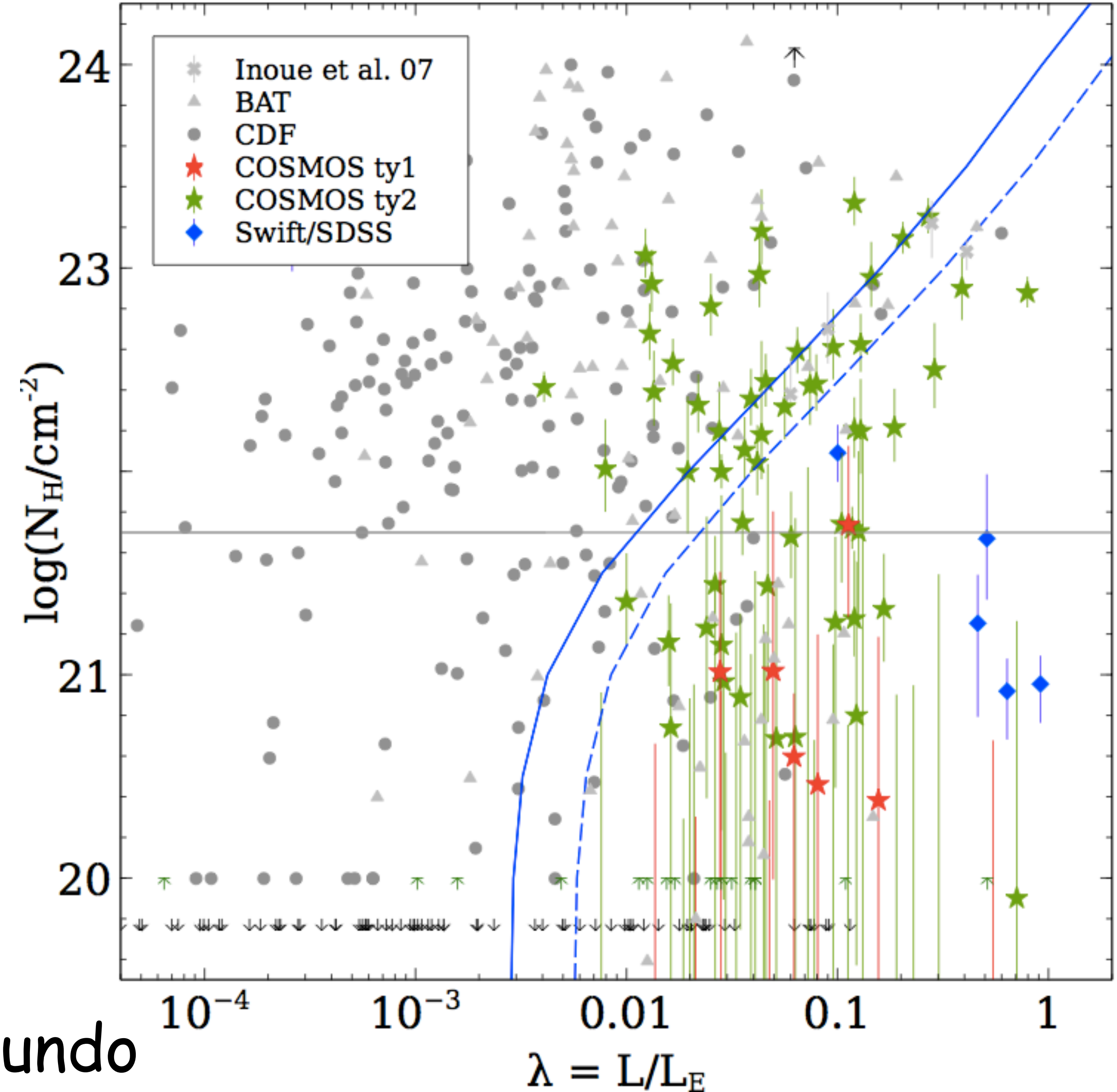
Column density
25
24
23
22
21
20
19
log(N_H [cm^-2])
x500
-3
-2
-1
0
1
log(1/A= L/L_E)
Eddington ratio



LONG-LIVED CLOUDS
FORBIDDEN REGION
DUST LANES
24
23
22
21
20
log(N_H/cm^-2)
10^-4
10^-3
0.01
0.1
1
λ_Edd



Vasudevan+13



Inoue et al. 07
BAT
CDF
COSMOS ty1
COSMOS ty2
Swift/SDSS
24
23
21
20
log(N$_H$/cm^{-2})
10^{-4}
10^{-3}
0.01
0.1
1
λ = L/L$_E$

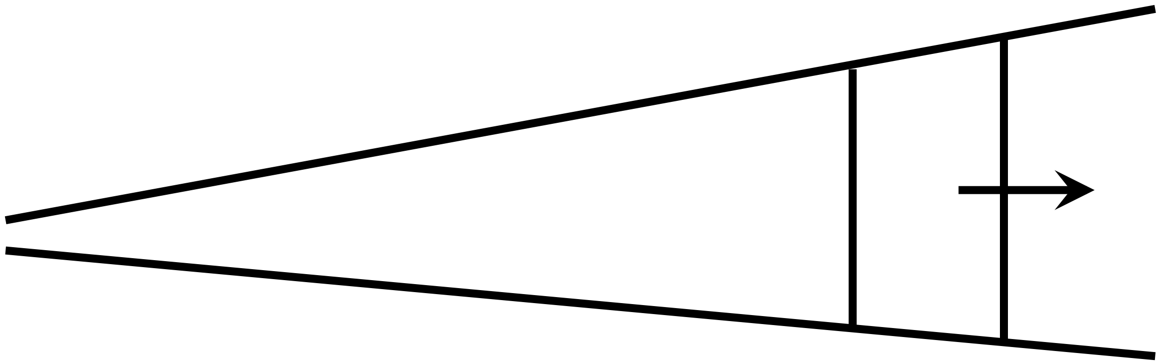
Raimundo

If *gas* in shell occupying only 1/10 radius then has been absorbing flux for long time. Factor ~10 could be appropriate.

Also need to consider work done against gravity.

$$\frac{d}{dt}[M_{\rm g}(r)\dot{r}] = \frac{L}{c} - \frac{GM_{\rm g}(r)M_{\rm DM}(r)}{r^2}$$

e.g.



$\dot{M}$dot$_1$=4 $\pi r^2 \rho v$

$\dot{M}$dot$_2$=M/t=4 $\pi r^2 \Delta r\ \rho/(r/v)$

Ratio=r/Δr

Also L reduced by work done