Quiescent SMBHs in elliptical galaxies:

why are they not AGN?

Roberto Soria (CfA)

G Fabbiano, A Baldi, M Elvis, A Siemiginowska (CfA)
A Graham, H Jerjen (ANU)
S Pellegrini (Bologna)

Outline of this talk

We study SMBH X-ray luminosity and gas density
in the nuclear regions of quiescent early-type galaxies

We discuss the mass and power budget

We try to understand why they are faint

Estimating the accretion power

Most SMBHs in the nearby universe are X-ray quiescent

$$P_{acc} = \eta \, \dot{M} \, c^2$$

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

$$L_x = f_x \, \eta_r \, \dot{M} \, c^2$$

observable

$L_x \sim 10^{-8} - 10^{-7} \, L_{Edd}$

Not directly observable
But related to gas available

Model-dependent: ADAF: $\eta_r \ll 0.1$
standard disk: $\eta_r \sim 0.1$

Questions we addressed

Most SMBHs in the nearby universe are X-ray quiescent

$$L_x \sim [\eta_r\,(M, \dot{M})] \times (\dot{M}\,c^2)$$

$\dot{M}$ = *unknown fraction (< 1) of the total gas inflowing into accr. radius*

$$\dot{M} = a\,\dot{M}_t$$ *where a < 1*

Are they faint because:

- -- the (radiative) efficiency is low?
- -- there is little gas available?
- -- only a small fraction of the gas available reaches the BH?

Is there a relation between gas available and luminosity?

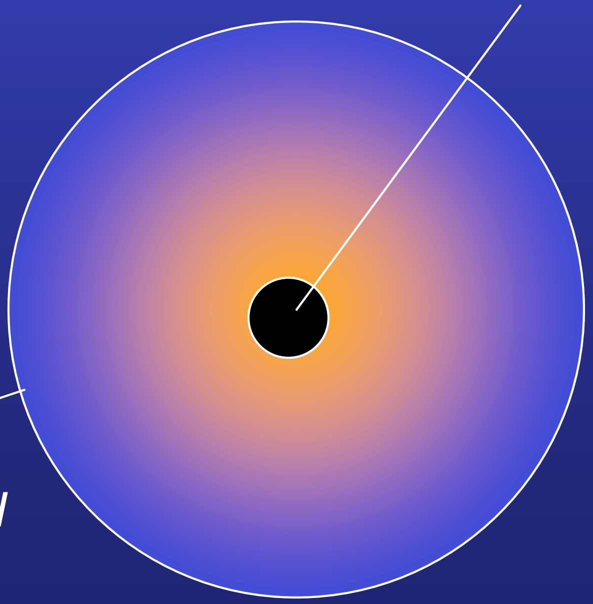
What happens to the gas that does not reach the BH?

What we need to measure

- X-ray luminosity of the SMBH (plus radio if available!)
- Gas density in the nuclear region
- Mass of the SMBH

$\dot{M}_t$ = gas inflowing or injected into the SMBH sphere of influence

$\dot{M}$ = gas actually accreted by the BH



SMBH

Sphere of influence of the SMBH
(r < accretion radius ~ a few pc)

Outline of our study

(Soria et al. 2006a, 2006b)

Sample of quiescent E/S0 galaxies
with dynamic SMBH masses

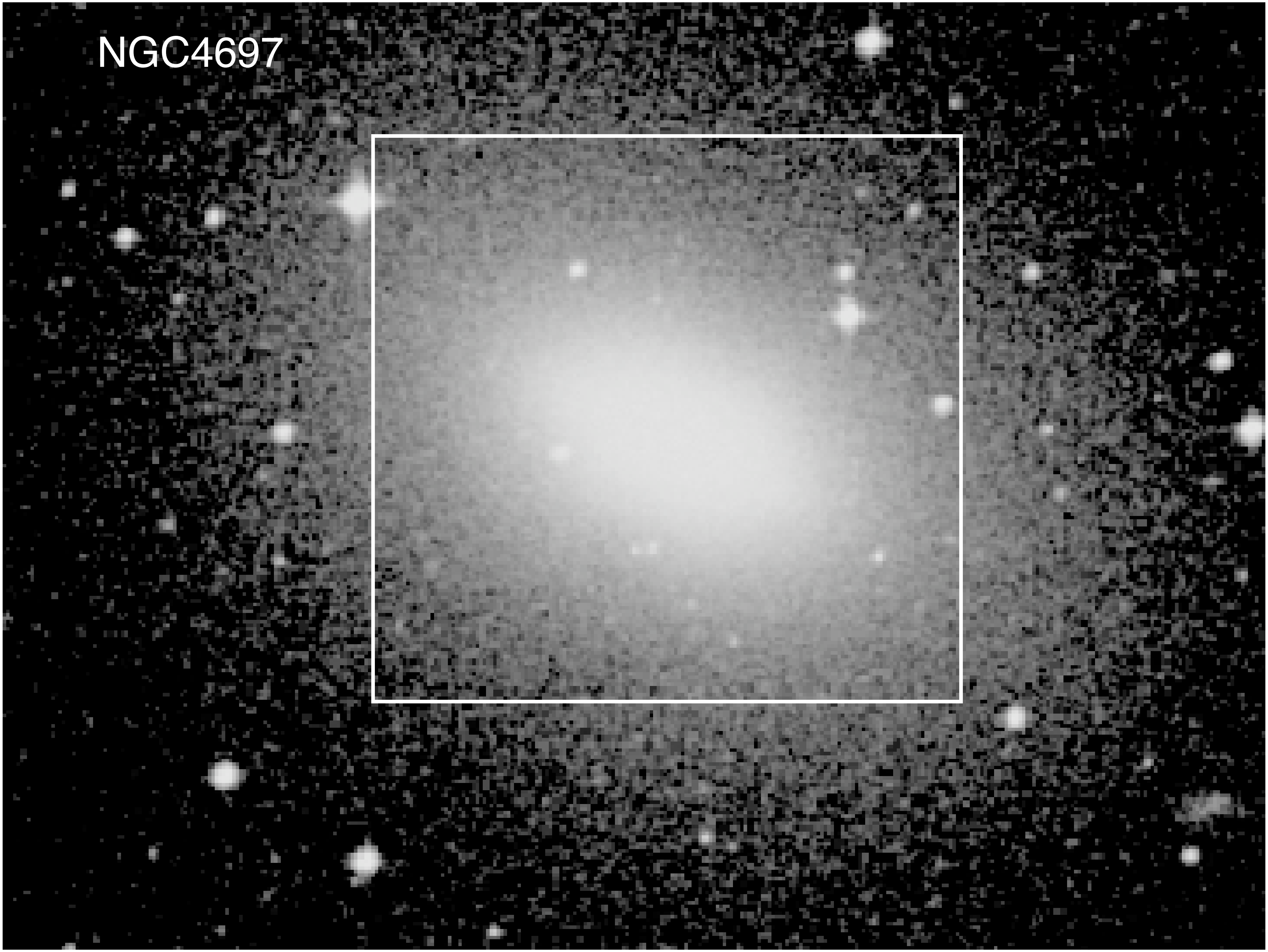
Morphological study of the nuclear X-ray sources
(point-like? extended? jet-like?), with *Chandra*

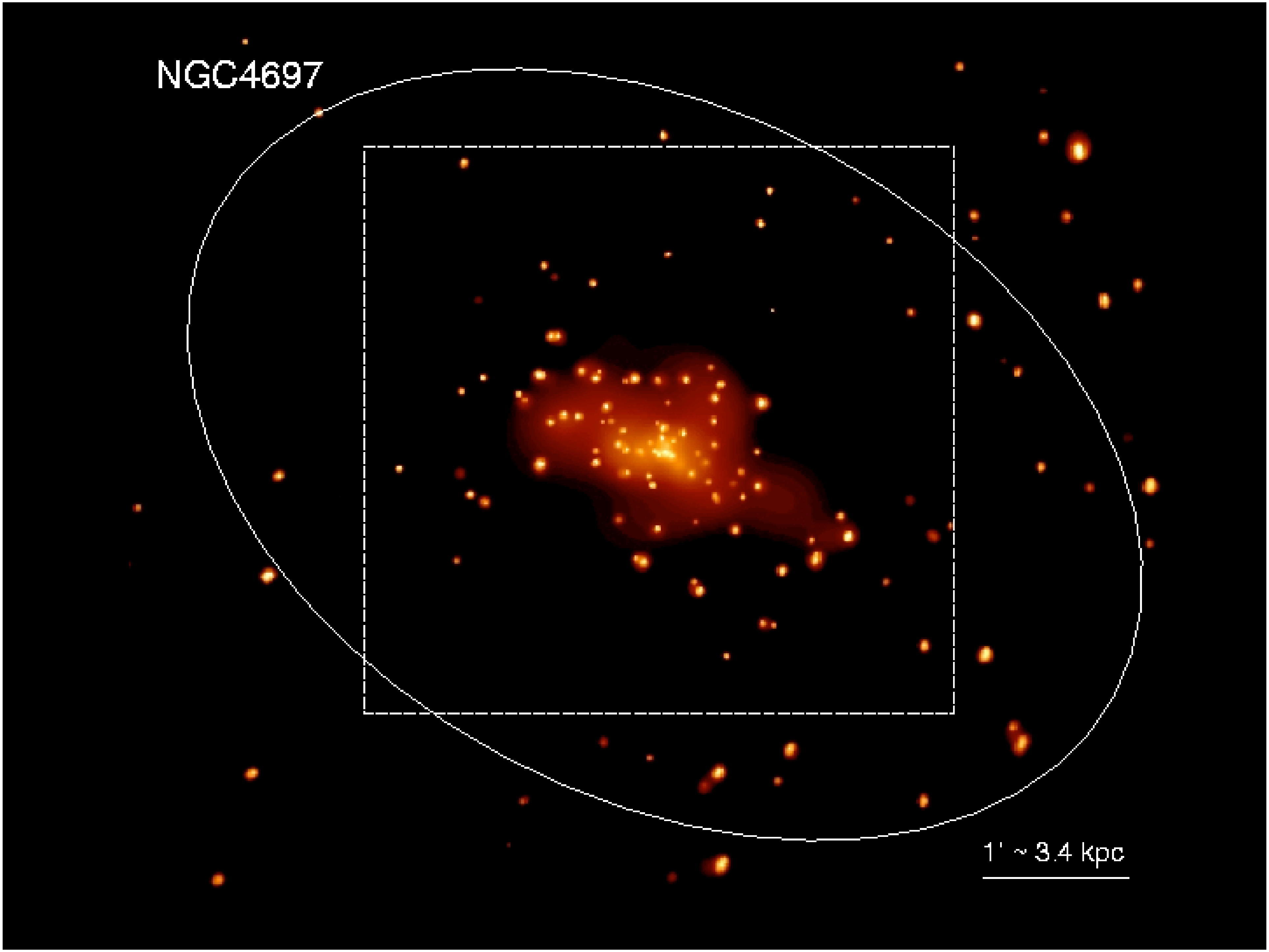
X-ray colors of the nuclear sources
→ consistent with $\Gamma \sim 1.5 -- 2$

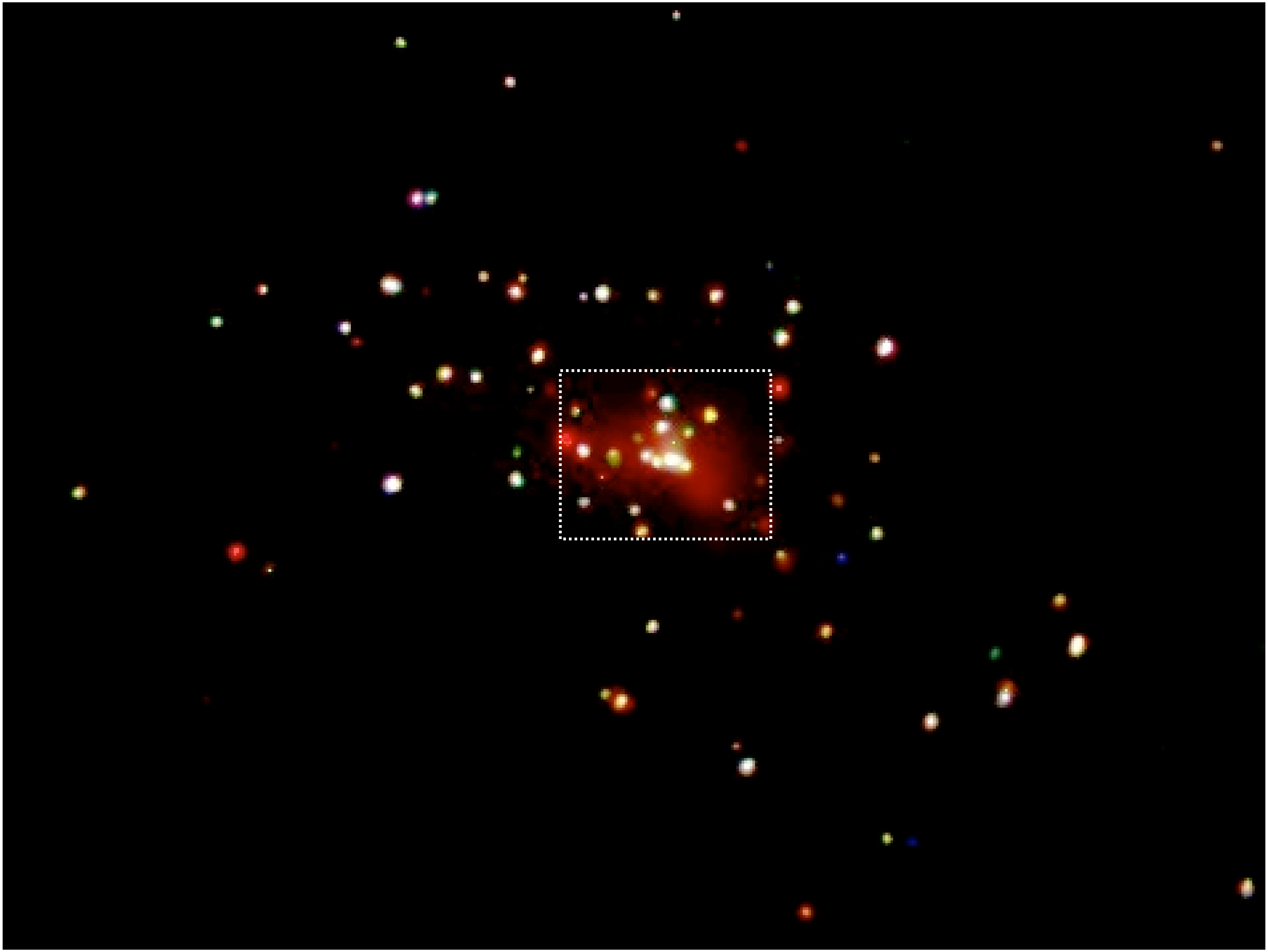
Density of the surrounding hot ISM
Fuel contribution from stellar winds

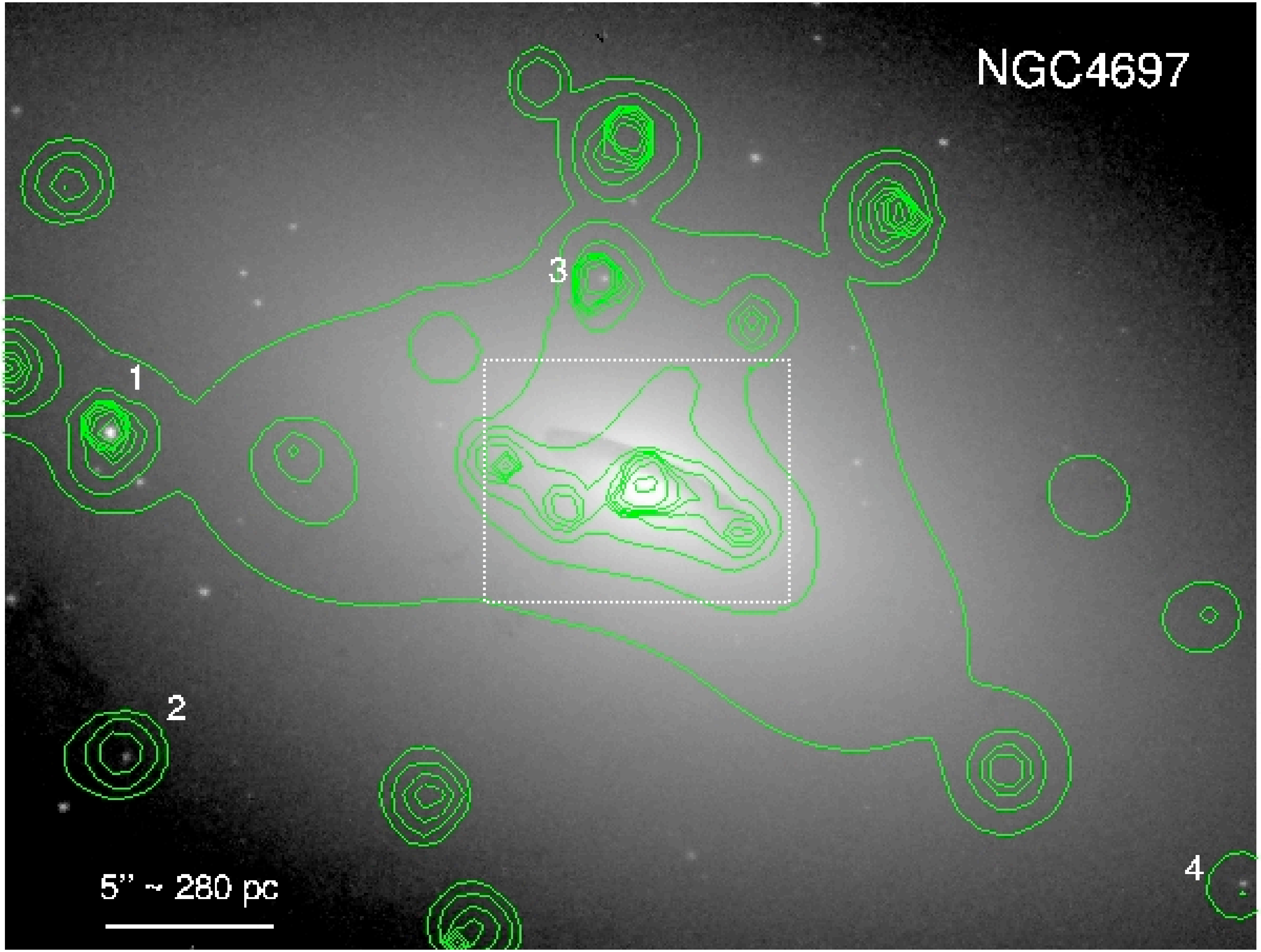
↓

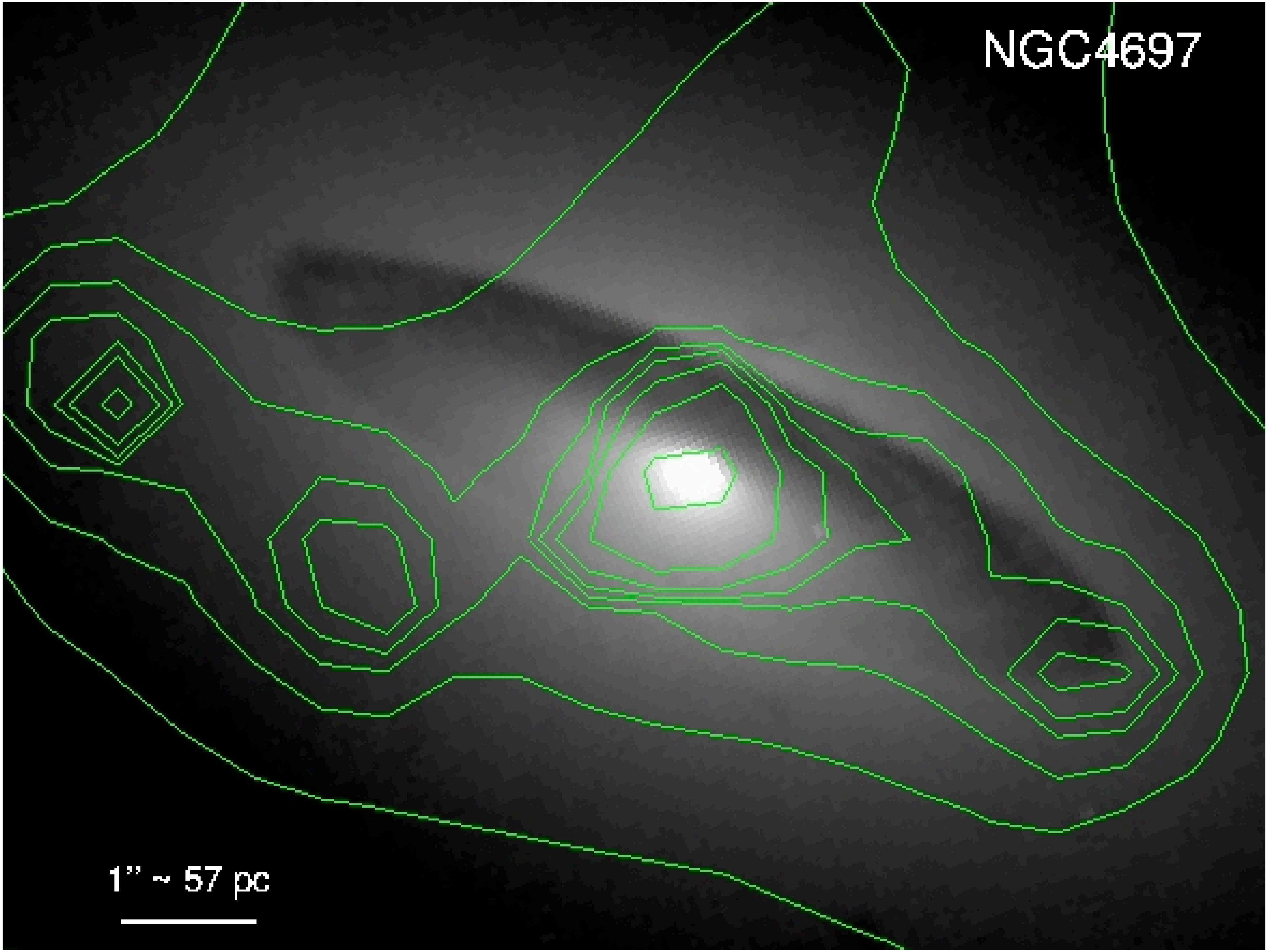
Accretion-power budget
Mass budget

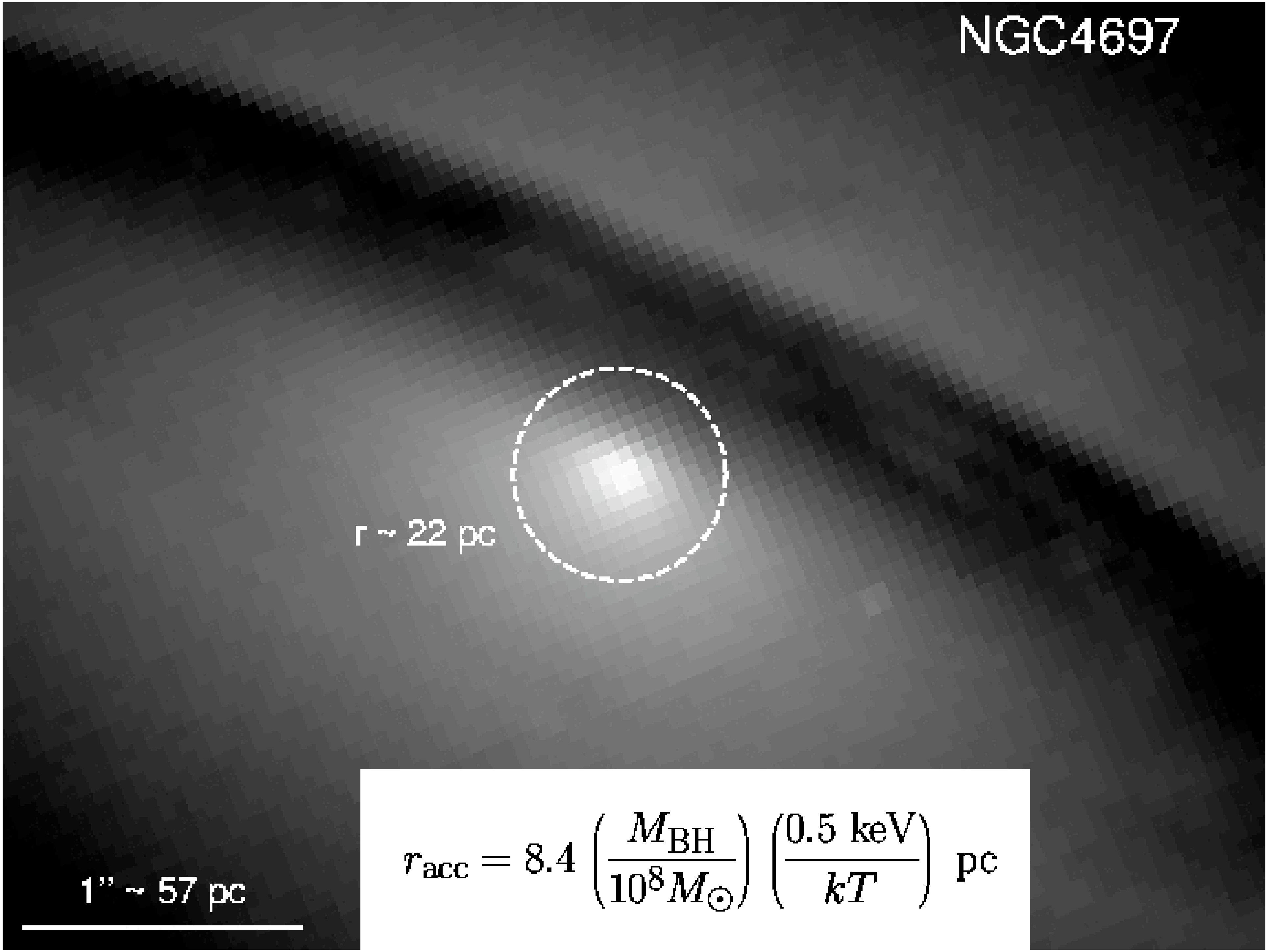

NGC4697

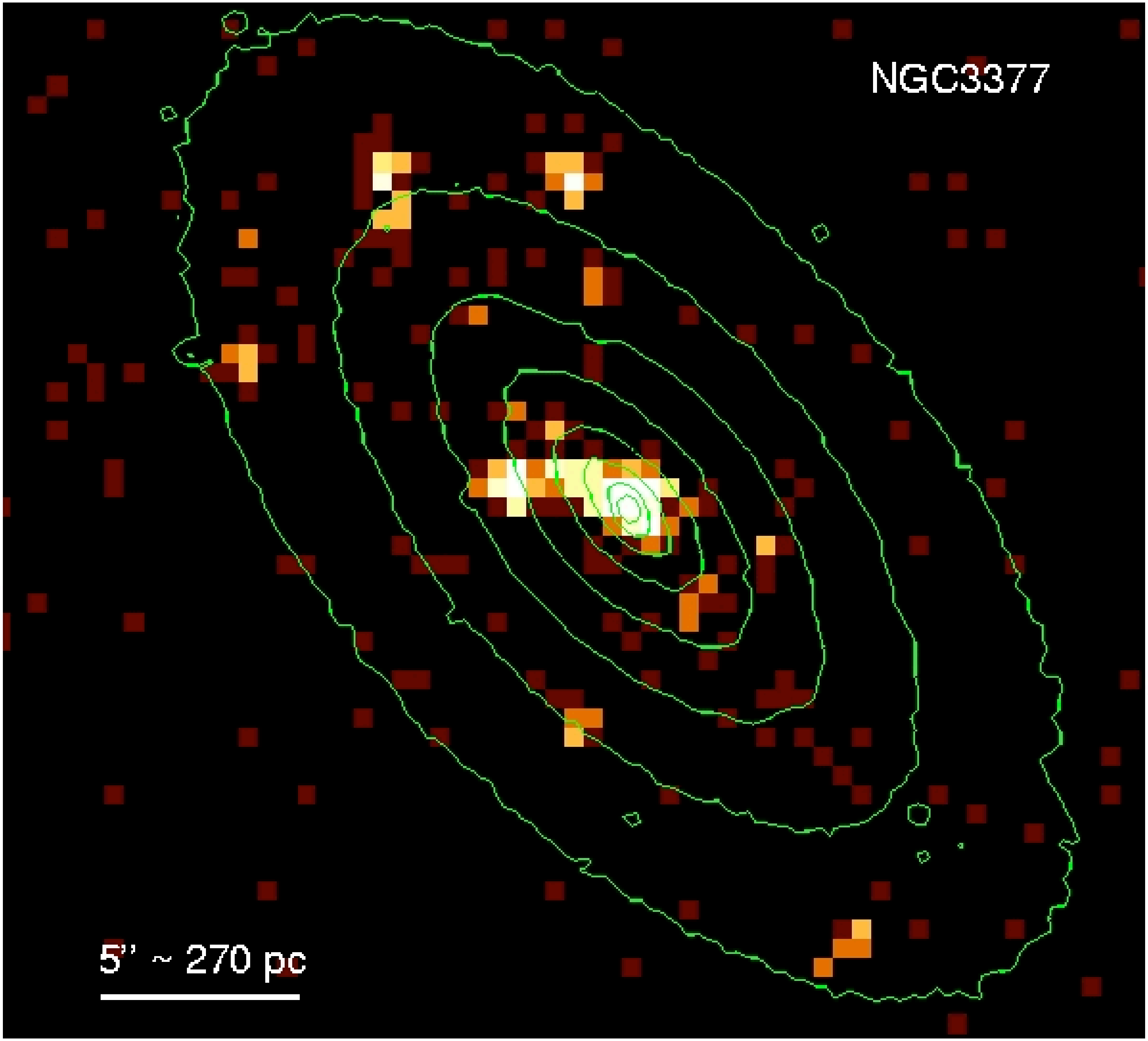

NGC4697
1' ~ 3.4 kpc

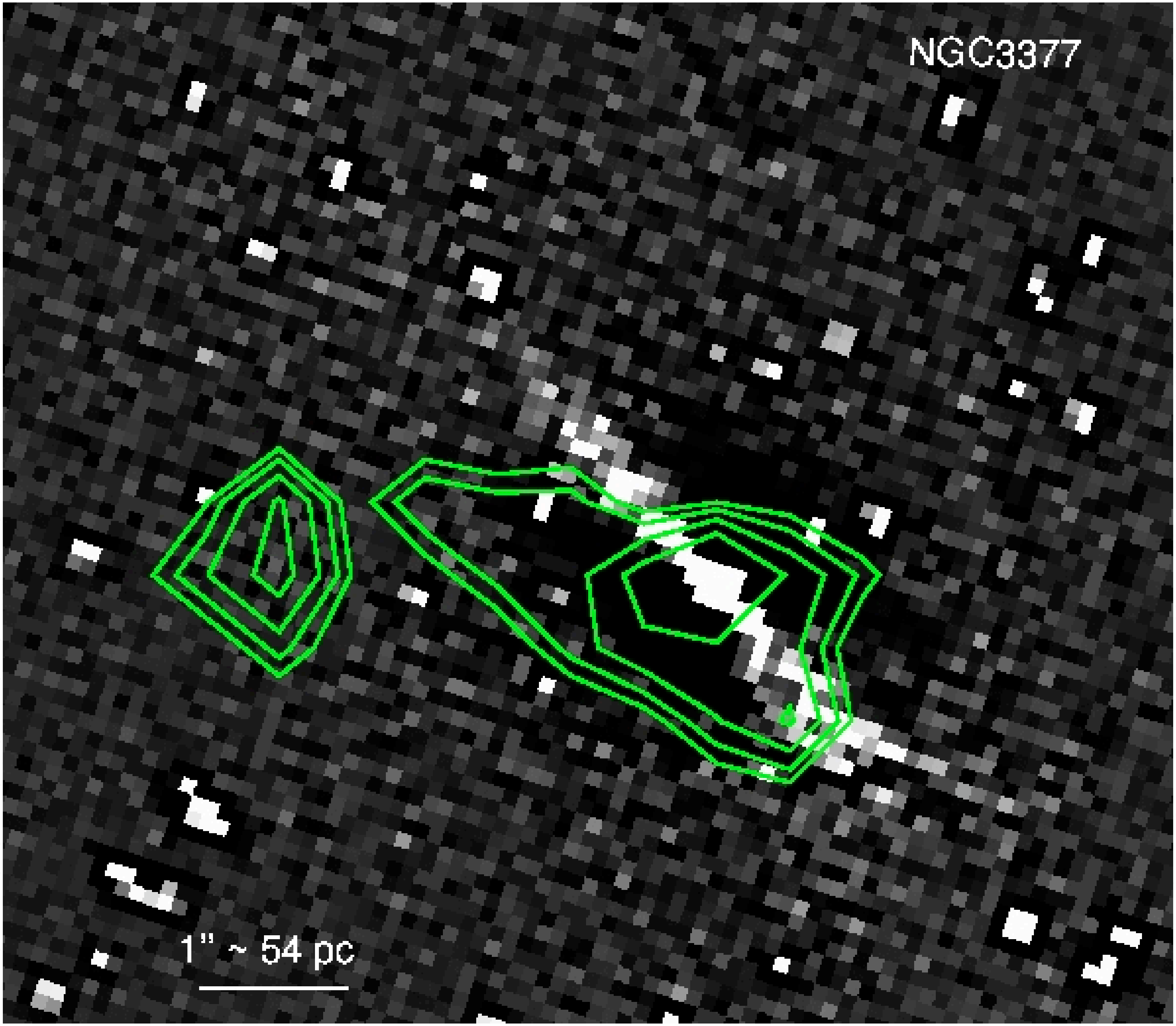


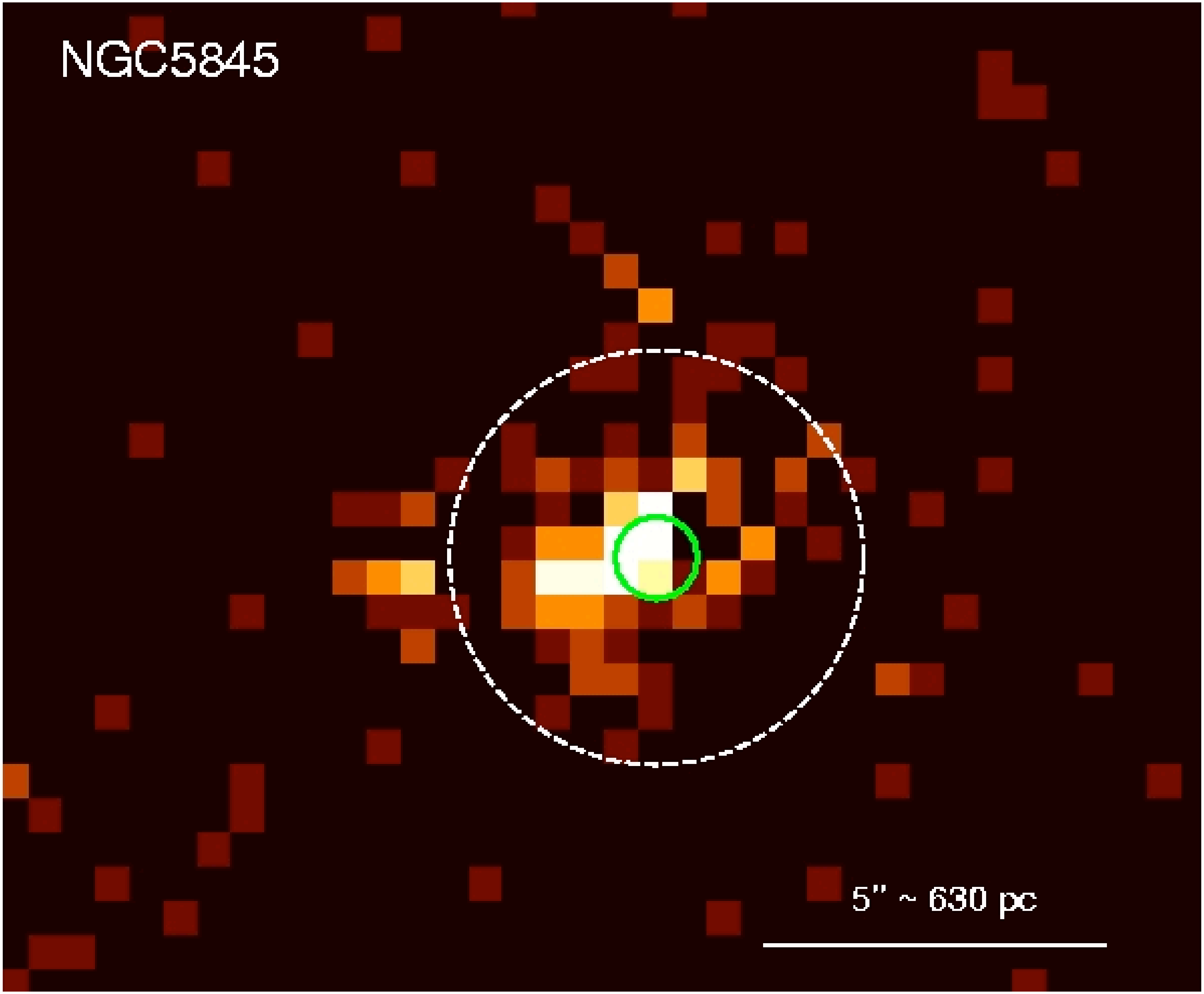

NGC4697
1
2
3
4
5'' ~ 280 pc

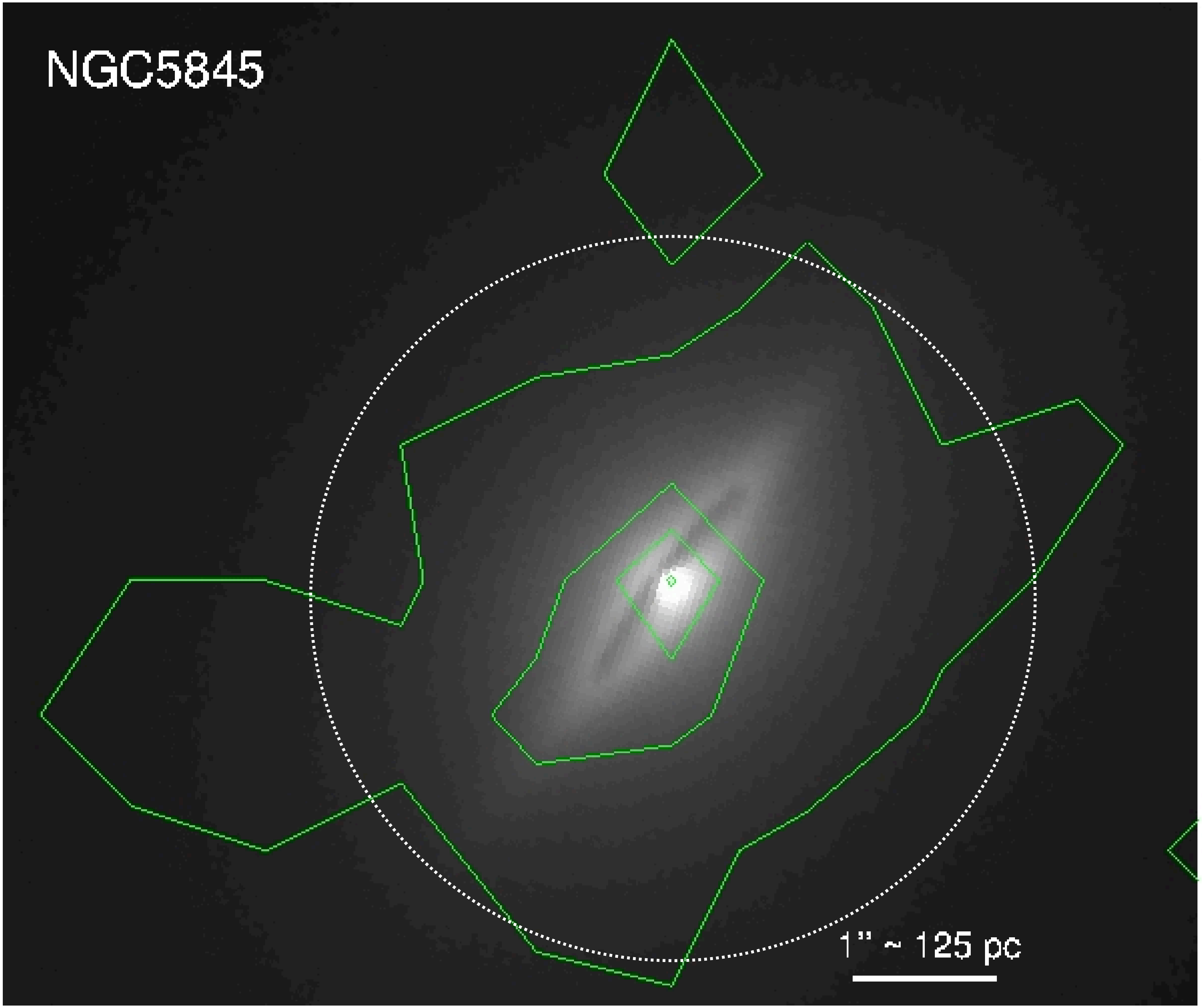

NGC4697
1" ~ 57 pc


NGC4697
r ~ 22 pc
1'' ~ 57 pc
$r_{\rm acc} = 8.4 \left(\frac{M_{\rm BH}}{10^8 M_\odot}\right) \left(\frac{0.5\ {\rm keV}}{kT}\right)\ {\rm pc}$

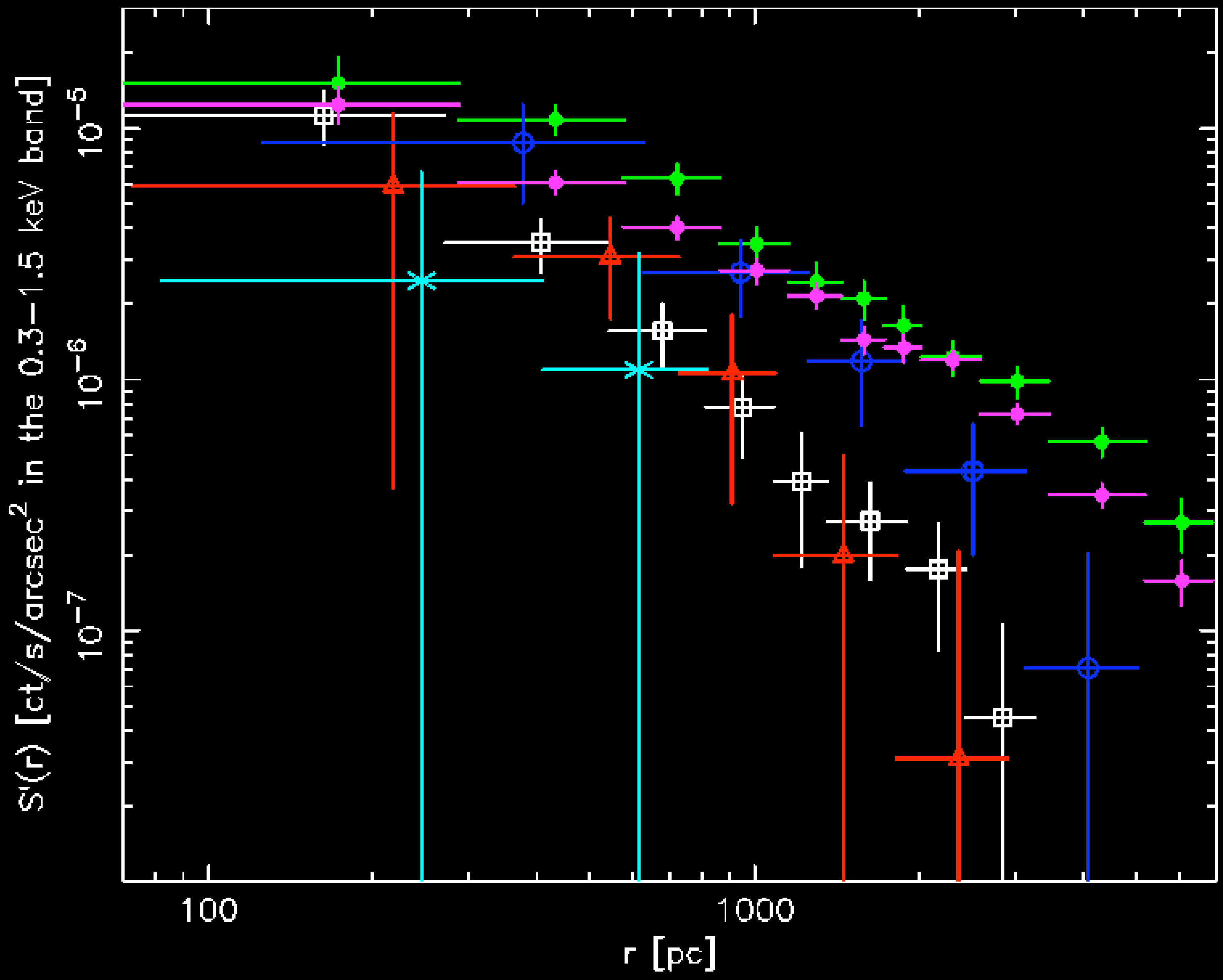

NGC3377
5'' ~ 270 pc


NGC3377
1" ~ 54 pc


NGC5845
5" ~ 630 pc


NGC5845
1" ~ 125 pc

Brightness profiles of the diffuse hot gas



Brightness profiles of the diffuse hot gas

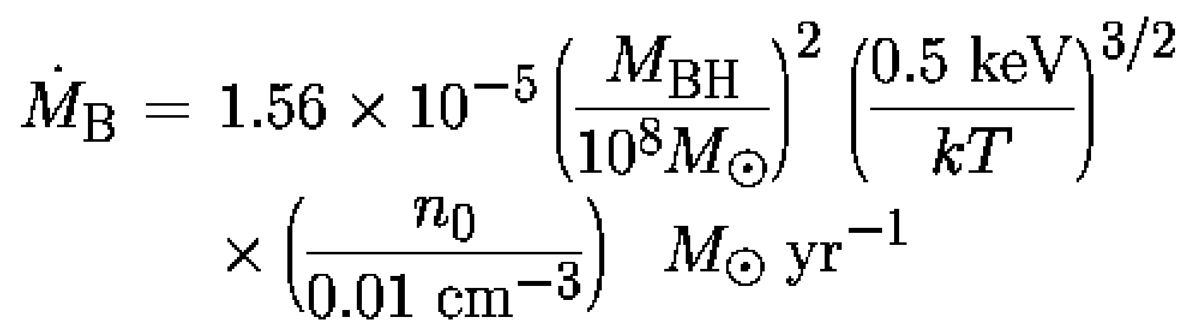
↓

Temperature and density of the hot ISM
inside the accretion radius of the BH

$n_e \sim 0.01 \text{ -- } 0.1\ \mathrm{cm}^{-3}$

↓

Bondi accretion rate



$$\dot{M}_{\mathrm{B}} = 1.56 \times 10^{-5} \left(\frac{M_{\mathrm{BH}}}{10^8 M_\odot}\right)^2 \left(\frac{0.5\ \mathrm{keV}}{kT}\right)^{3/2} \times \left(\frac{n_0}{0.01\ \mathrm{cm}^{-3}}\right) \ M_\odot\ \mathrm{yr}^{-1}$$

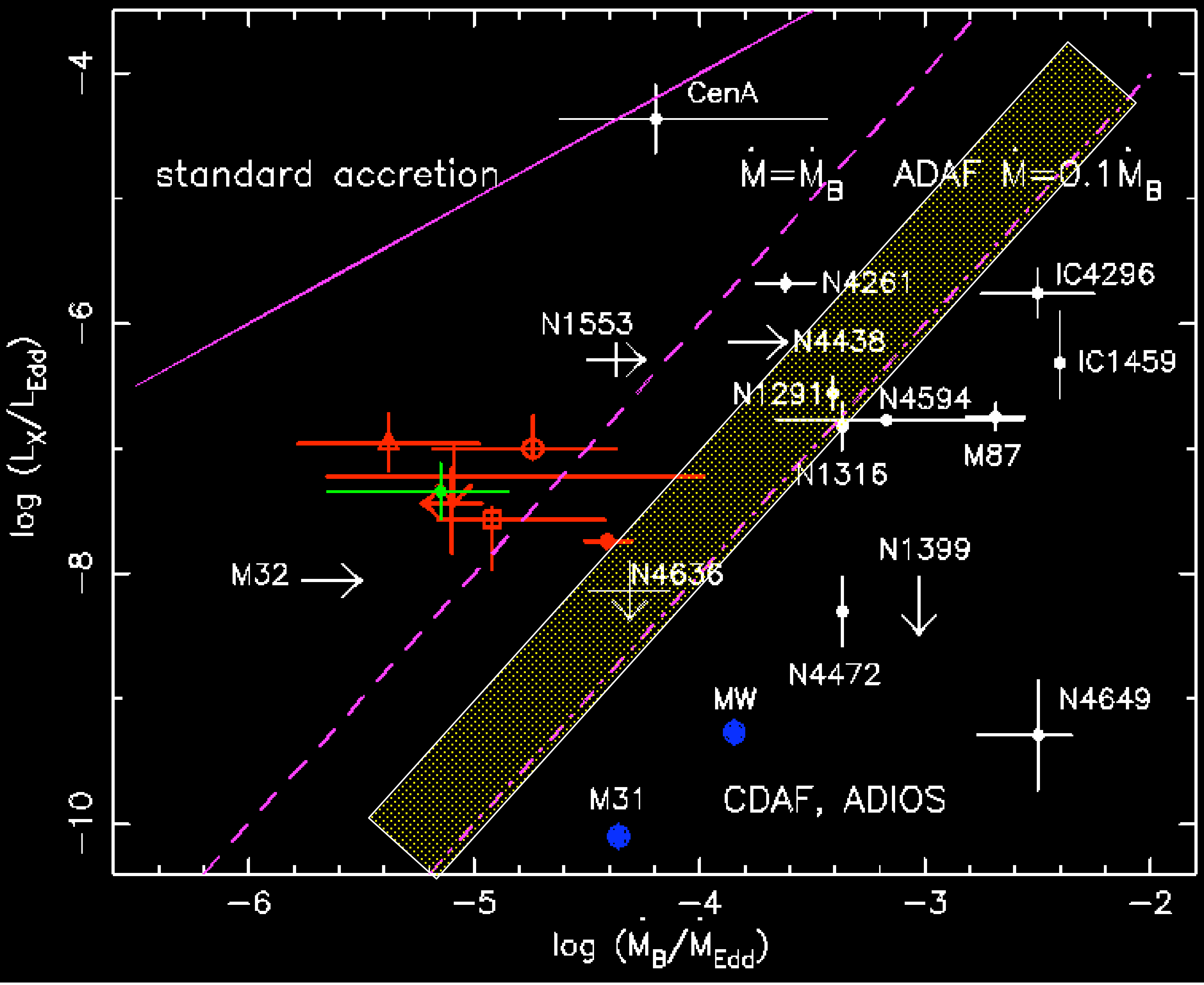
What we need to measure

- V X-ray luminosity of the SMBH
- V Gas density in the nuclear region (hot gas)
- V Mass of the SMBH

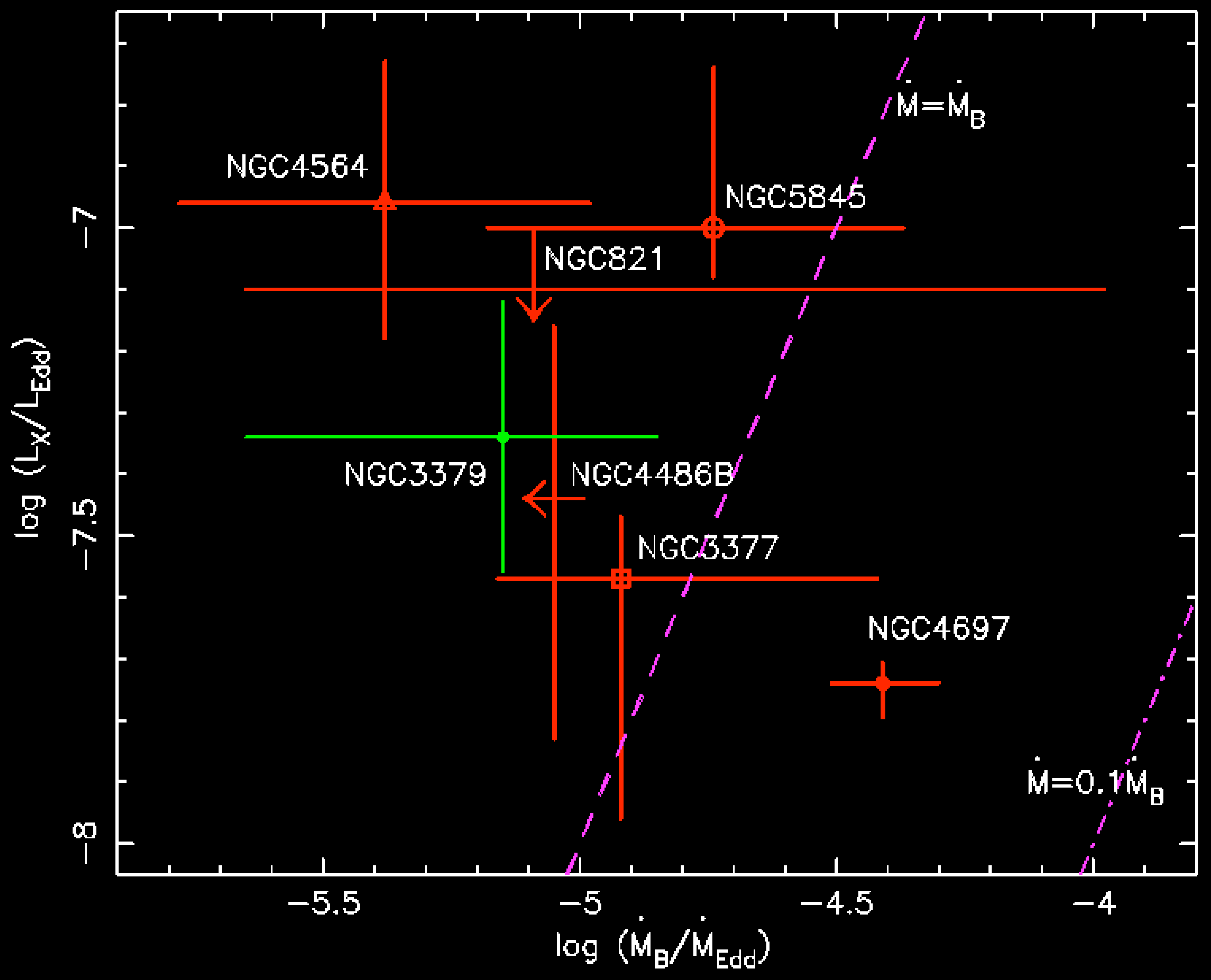
↓

Bondi inflow rate of the hot gas

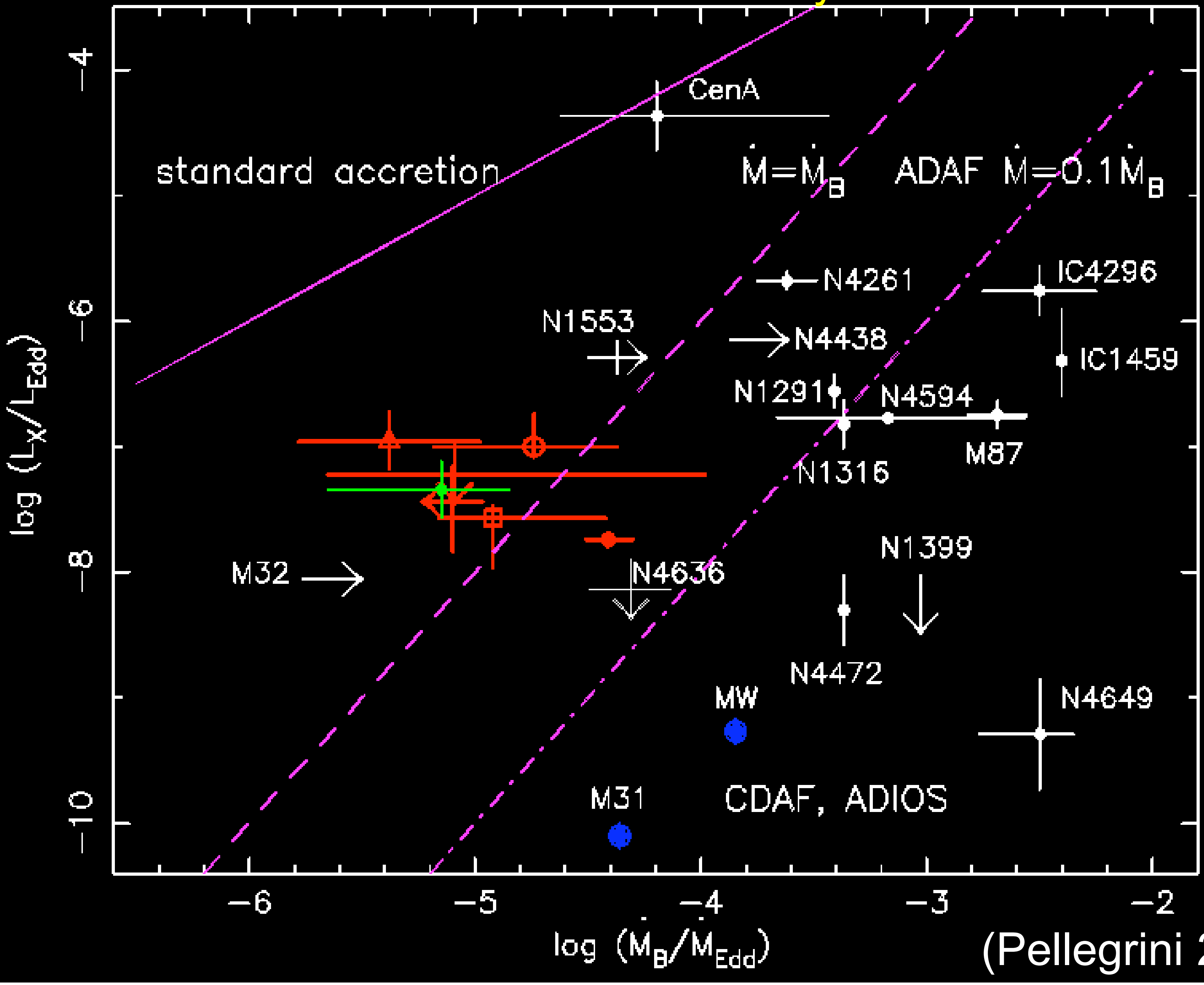
Correlation between X-ray luminosity and Bondi inflow rate?



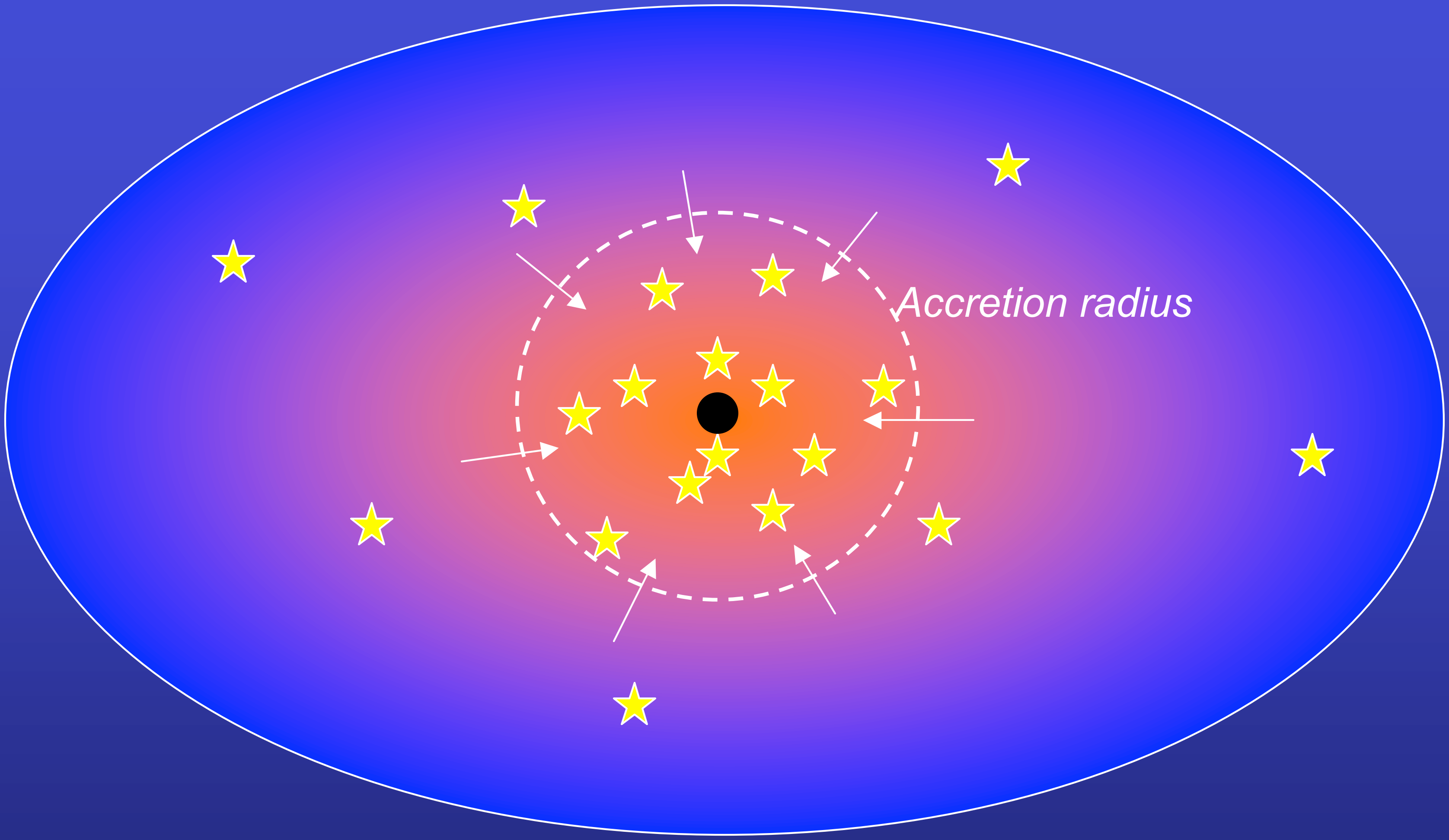
standard accretion
$\dot{M}=\dot{M}_B$
ADAF $\dot{M}=0.1\dot{M}_B$
CenA
N4261
IC4296
N1553
N4438
IC1459
N1291
N4594
M87
N1316
N1399
M32
N4636
N4472
MW
N4649
M31
CDAF, ADIOS
−4
−6
−8
−10
−6
−5
−4
−3
−2
$\log(L_X/L_{Edd})$
$\log(\dot{M}_B/\dot{M}_{Edd})$


NGC4564
NGC5845
NGC821
NGC3379
NGC4486B
NGC3377
NGC4697
$\dot{M}=\dot{M}_B$
$\dot{M}=0.1\dot{M}_B$
log (L_X/L_{Edd})
log ($\dot{M}_B/\dot{M}_{Edd}$)
−7
−7.5
−8
−5.5
−5
−4.5
−4

No correlation between luminosity and Bondi rate



(Pellegrini 2005)



Total gas supply given by:

Bondi inflow of hot gas through the sphere of influence

\+ stellar winds from stars inside the sphere of influence

Optical surface-brightness profiles

Nuker fits from Gebhardt et al 2003; our own Sersic fits (A Graham)

↓

Total B-band luminosity inside accretion radius

↓

Mass-loss rate from stellar population inside r_{acc}

$$\dot{M}_{star} \sim 10^{-4} - 10^{-3}\ M_{sun}/yr$$

Bondi inflow rate of hot gas

$$\dot{M}_{B} \sim 10^{-6} - 10^{-2}\ M_{sun}/yr$$

we can now study the power budget

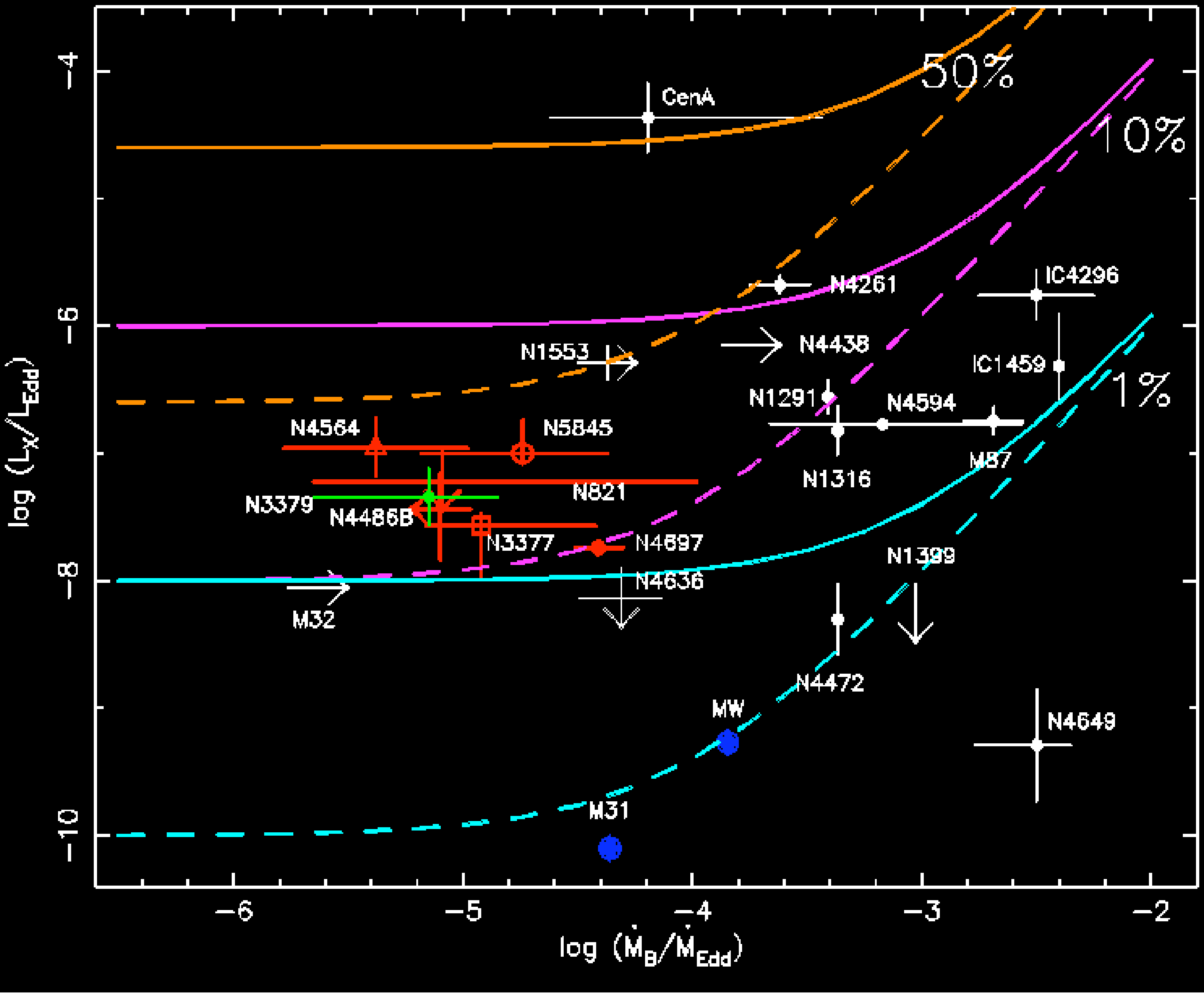
$$P_{acc} = \eta \, \dot{M} \, c^2$$

$$L = \eta_r \, \dot{M} \, c^2$$

$$\dot{M} = a \, (\dot{M}_{star} + \dot{M}_B)$$

From the observed X-ray luminosities,
and assuming "ADAF-like" efficiencies,

$a \sim 1\% \text{ -- } 10\%$


50%
10%
1%
CenA
N4261
IC4296
N4438
N1553
IC1459
N1291
N4594
N4564
N5845
M87
N1316
N821
N3379
N4486B
N3377
N4697
N1399
N4636
M32
N4472
MW
N4649
M31
−4
−6
−8
−10
log (L_X/L_{Edd})
−6
−5
−4
−3
−2
log ($\dot{M}_B/\dot{M}_{Edd}$)

Why is the accretion fraction *a* < 1 ?

Convective motions hamper accretion (CDAF model)?

Most of the gas is removed in outflows (ADIOS model)?

Inflowing gas cannot get rid of angular momentum?

Inflowing gas cools down and forms stars? (Tan & Blackman 2005)

If $\dot{M} < (\dot{M}_{star} + \dot{M}_{B})$*, the gas*
→ is removed by outflows
→ builds up in nucl region

→ Need to solve **mass & power balance**

Mass budget inside the sphere of influence of the BH

$$\underbrace{\dot{M}_a (t)}_{\text{Total gas mass inside the sphere of influence}} = - \underbrace{\dot{M}(t)}_{\text{Accretion rate onto BH}} - \underbrace{\dot{M}_w (t)}_{\text{Outflow rate}} - \underbrace{\dot{M}_{SF}}_{\text{Nuclear SF rate}} + \underbrace{\dot{M}_{star} + \dot{M}_B}_{\text{Sources of gas}}$$

Power budget

$$P_{acc} (t) = \eta \, \dot{M}(t) \, c^2$$

$$(1/2) \, \dot{M}_w (t) \, v_w^2 = k \, P_{acc} (t) \quad \text{with } k < 1$$

SMBH feedback allows a self-regulated outflow

(Recent papers by Ciotti, Ostriker, Pellegrini,…)

$$(1/2)\, \dot{M}_w \, v_w^2 = k\, P_{acc}$$

The power driving the mass outflows
comes from the accretion power ($k < 1$)

For $V_w \sim V_{esc} \sim 500$ km/s

Radiative luminosity >~ power required for mass outflow
even in the ADAF scenario

Total accretion power may be >> needed for slow outflow

Example [toy model]:

Self-regulated outflow + jet scenario

Mass balance

$(\dot{M}_{star} + \dot{M}_B)$

$\rightarrow$ $1/(1+p)$ is accreted ($p \sim 2 - 100$)

$\rightarrow$ $p/(1+p)$ is removed by slow outflows

($v_w \sim v_{esc} \sim 500$ km/s)

Power balance

$(\eta \dot{M} c^2)$

$\rightarrow$ $f_r << 1$ is radiated

$\rightarrow$ $k << 1$ is used to power slow outflow

$\rightarrow$ $(1- f_r - k) \sim 1$ is still available for fast jet

or is advected into the BH

Mass carried by fast jet

CASE 1: RELATIVISTIC JET (*$v_J \sim c$*)

$$P_{acc} = \eta \dot{M} c^2$$

$$P_J = \gamma_J \dot{M}_J c^2 \sim P_{acc}$$

$$\dot{M}_J = (\eta / \gamma_J) \dot{M} \sim (0.01—0.1) \dot{M}$$

$$\sim (0.001—0.01) (\dot{M}_{star} + \dot{M}_B)$$

CASE 2: FAST BUT NON-RELATIVISTIC JET (*$v_J \sim 0.5\, c$*)

$$P_{acc} = \eta \dot{M} c^2$$

$$P_J = (1/2) \dot{M}_J v_J^2 \sim P_{acc}$$

$$\dot{M}_J \sim \dot{M}$$

Summary

Chandra + *HST* study of quiescent SMBHs
with well-determined masses

X-ray properties of the nuclear sources
Density and temperature of the diffuse hot gas
Bondi inflow rate of hot gas
Warm gas from stellar winds

Gas inflow rate towards the BH ~ 10^{-3} M_{sun}/yr
BH accretion rate is only ~ 10^{-5} – 10^{-4} M_{sun}/yr

Slow outflows may remove most of the gas
Fast jets may carry most of the power
Role of feedback (self-regulated outflows)

The end

Work in progress

Why is the accretion fraction only ~ (1—10)% ?
(ang momentum, convection, outflows, mag fields?)

Building a more realistic feedback model
eg, line-driven winds, time delay, hysteresis, …

Steady state or intermittent accretion?

If net gas injection rate is >~ a few 10^{-2} M_{sun}/yr
Bondi accretion rate becomes high enough to allow
for transitions to standard, radiatively efficient accretion

Cycles of low/high states

Simplest scenario: no outflows

Gas builds up

$$\dot{M}_a(t) = -\dot{M}(t) + \dot{M}_{star} + \dot{M}_B - \cancel{\dot{M}_w}(t)$$

$$\downarrow$$

$$M_a(t) = (1-a)\,(\dot{M}_{star} + \dot{M}_B)\,t$$

Cyclic behaviour?

Statistically unlikely for most quiescent galaxies

For asymptotic steady state: outflows must balance injection - accretion

Fine-tuning problem?

$$\dot{M}_a\,(t) = -\,\dot{M}(t) + \dot{M}_{star} + \dot{M}_B - \dot{M}_w\,(t)$$

$$\Big\downarrow$$

Assuming $\dot{M}(t) = b\,M_a\,(t)$

$$M_a \longrightarrow (M_{star} + M_B - M_w)\,/\,b$$

where 1/b ~ viscous timescale ~ 10^4 – 10^6 yr