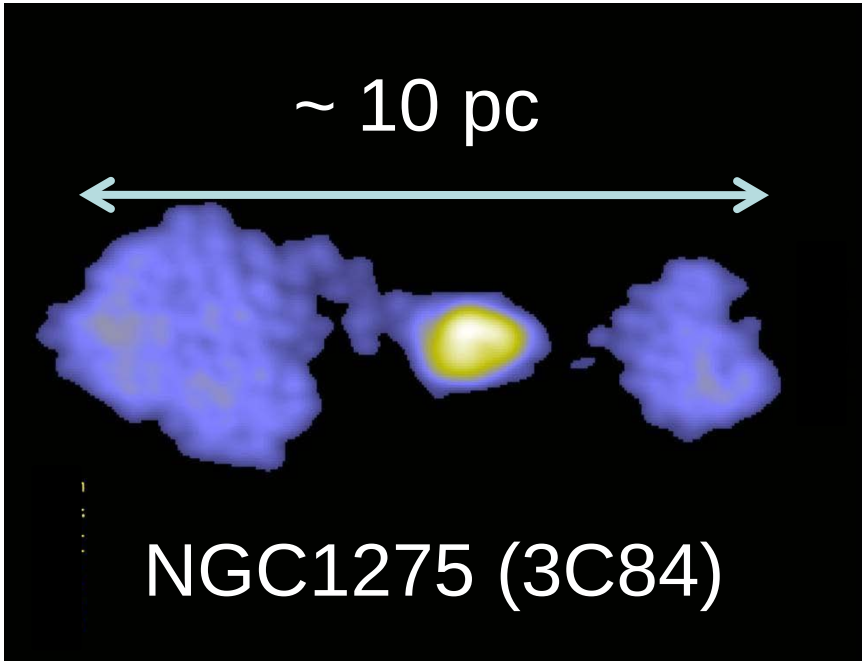
Fate of young radio-loud AGNs
Dead or alive ?



NRAO/AUI/MOJAVE

Nozomu Kawakatu (Univ. of Tsukuba)

ACP seminar @IPMU, 11/03/2010

Contents

- Introduction
- Dynamical evolution of radio galaxies
  - -Theoretical model of cocoon
  - -Fate of young radio galaxies?
- AGN feedback *shortly comment*
- Summary

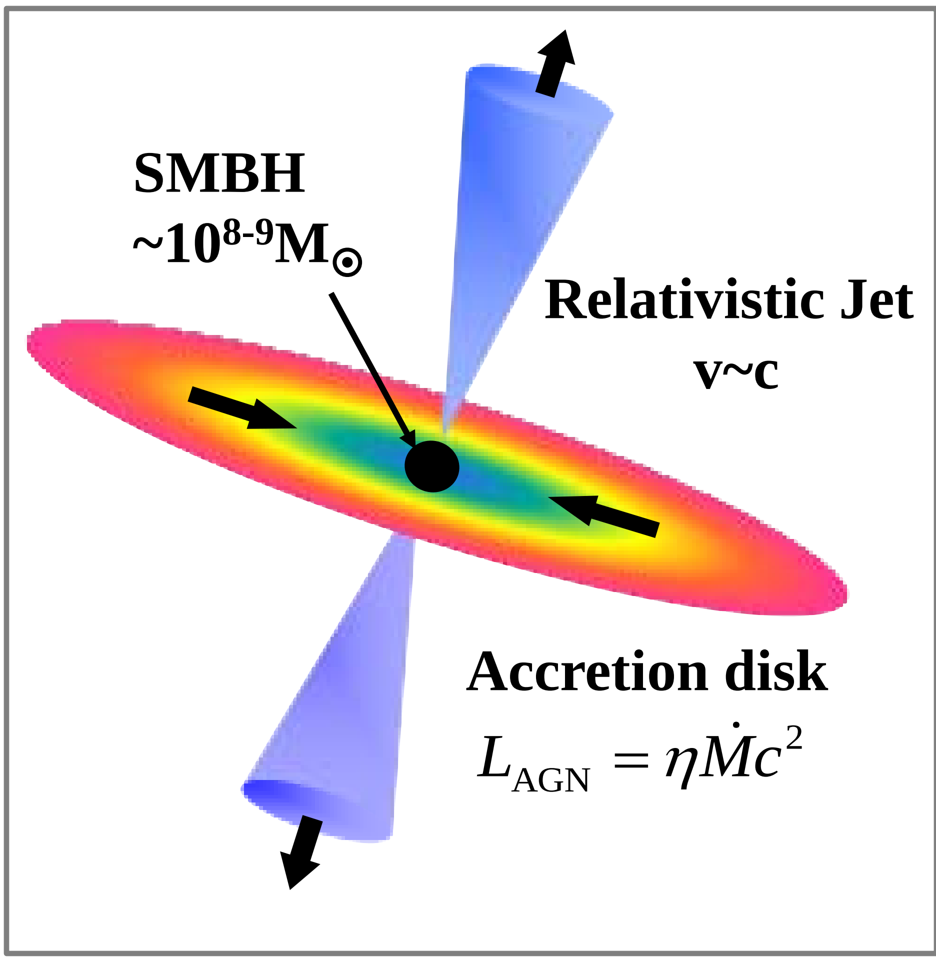
Collaborators

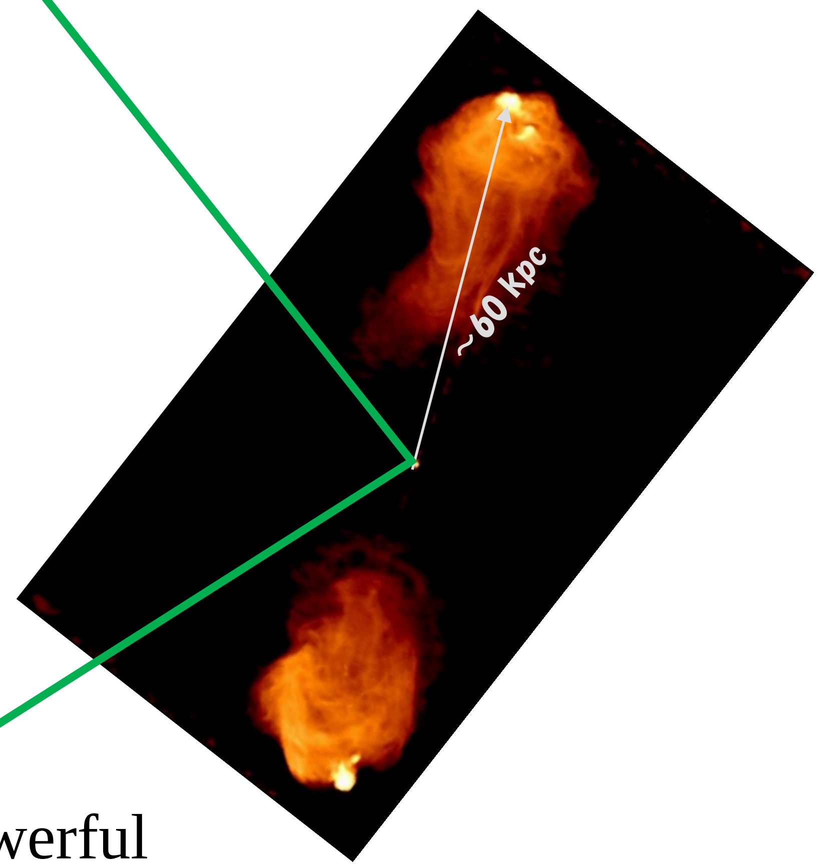
Hiroshi Nagai (NAOJ) and Motoki Kino (NAOJ)

What are Active Galactic Nuclei (AGNs)?

Compact (~ 100 AU) and luminous (~ $10^{46\text{-}47}$ erg/s) objects

cf. typical galaxies 10^{44}erg/s @ kpc

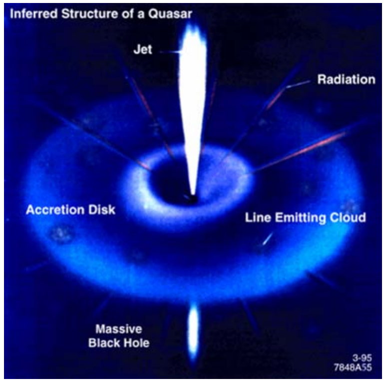




AGN jets: Biggest (〜100kpc) and powerful relativistic plasma fountain in the universe.

Classification of AGNs

SMBH+accretion disk

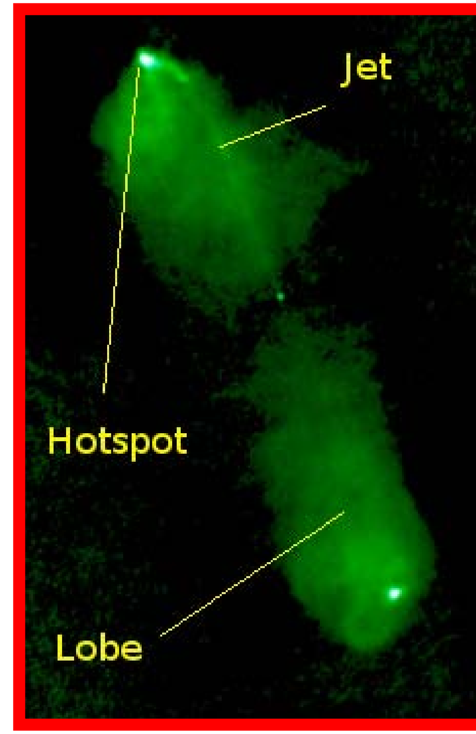


Radio-loud

(relativistic jet)

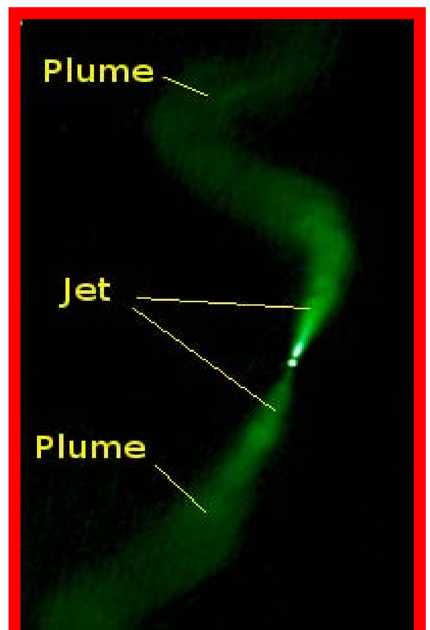
~10 %

High power
~1%



FRII radio galaxy

Low power
~9%



FRI radio galaxy

~90 %

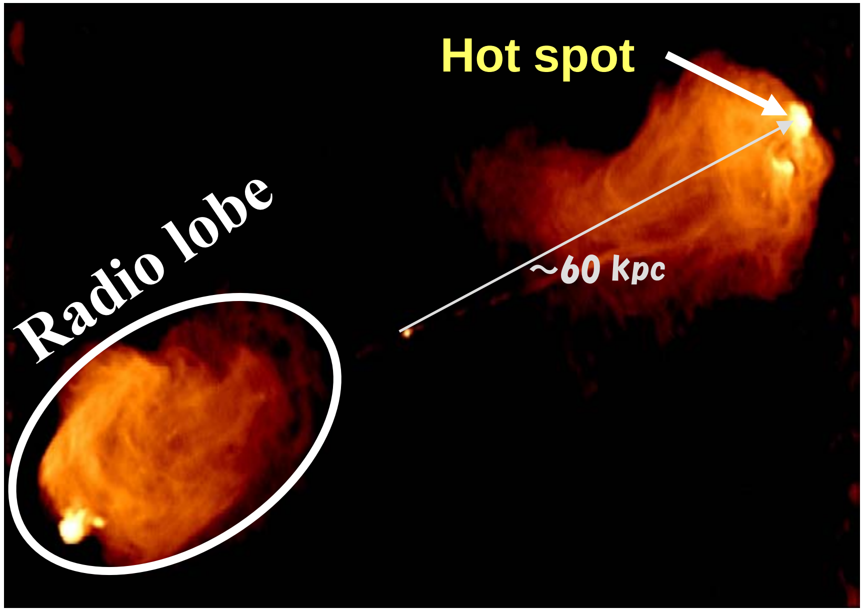
Radio-quit

Seyfert galaxy

Radio-quiet QSOs

~ 100 kpc jet
v
v
Galactic scale

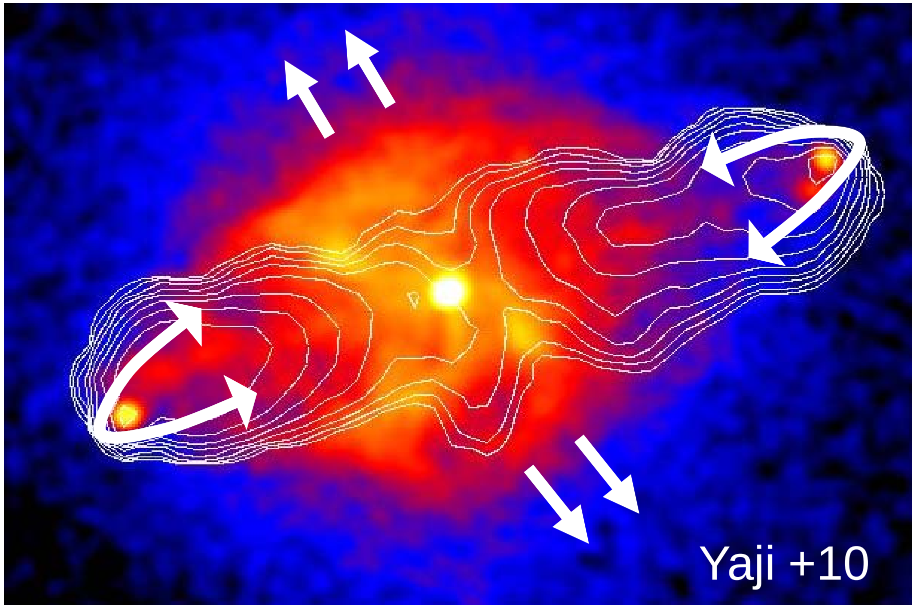
FR II radio galaxies



Cygnus A (VLA 5 GHz)

End points of AGN jets
"Hot spot & radio lobe"

Hot spots=Reverse shock



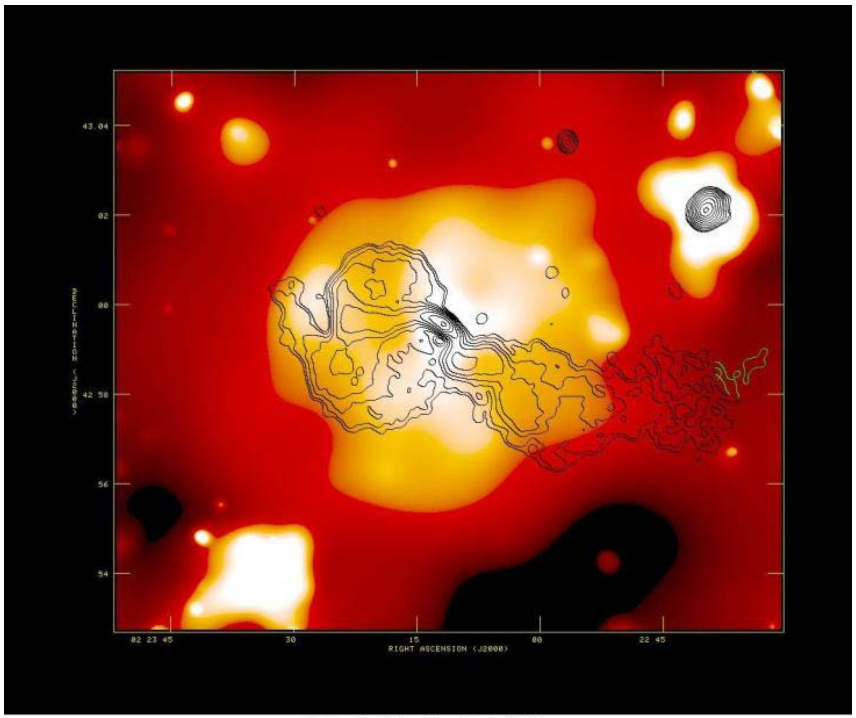
Cygnus A (Chandra+ VLA 0.3 GHz)

Supersonic lobe
@~100 kpc

Cocoon is consist of the shocked plasma escaped from hot spots.

FR I radio galaxies

Subsonic lobe @～100 kpc

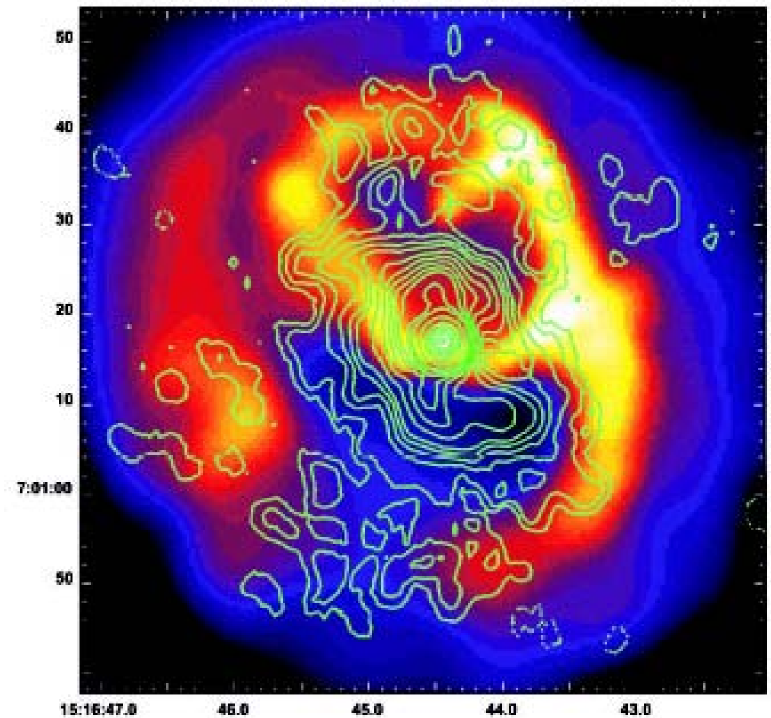


Radio-galaxy/hot-gas interactions in 3C 66B

Image courtesy of J.H. Croston (University of Bristol, UK)

European Space Agency

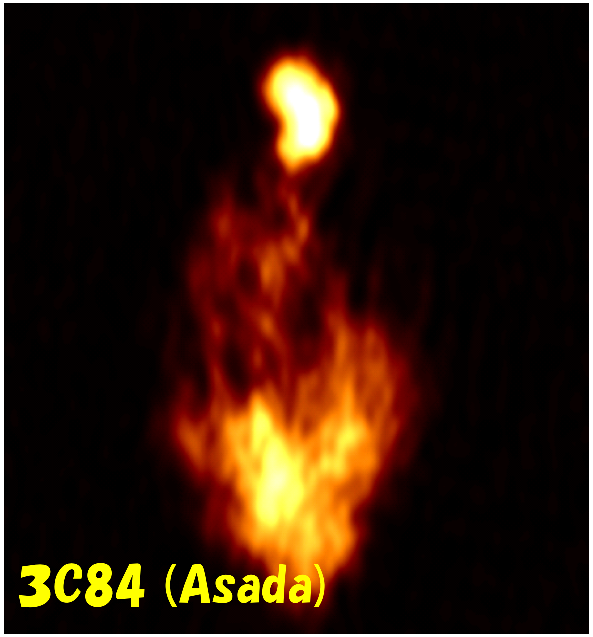
3C66B: Croston et al

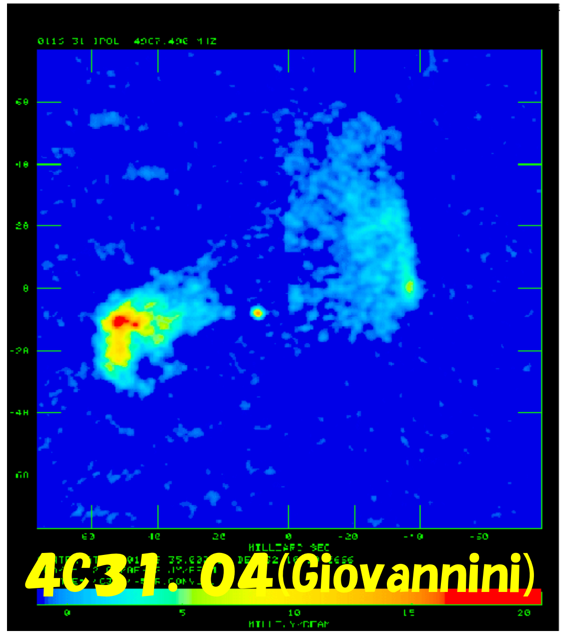


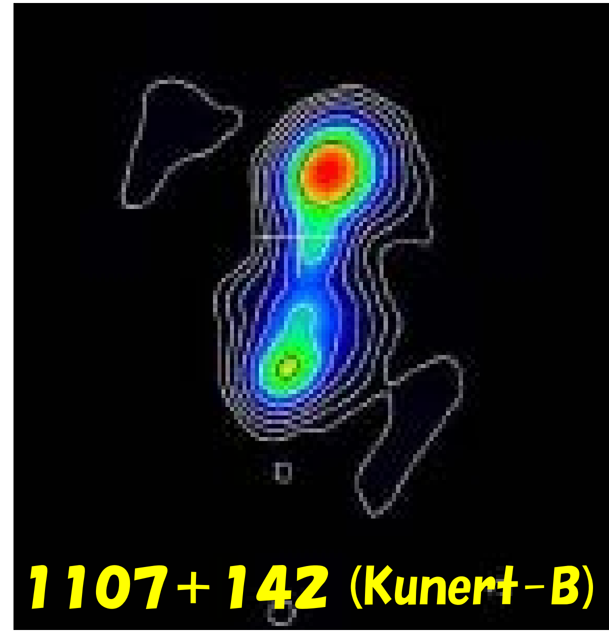
3C317: Blanton et al. 2001

contour :radio color :X-ay

Young Radio galaxies







Size: ~$10^{2\text{-}3}$ pc "Host galaxy scale"

Age: ~$10^{3\text{-}4}$ yrs "Young"

cf. FRIIs an FRIs

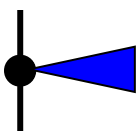
Size: > 100 kpc

Age: $10^{6\text{-}7}$yr

e.g., Owsianik & Conway 1998; Giroletti +03; Polatidis +03; Gugliucci+05;Nagai +06

Jet's scale

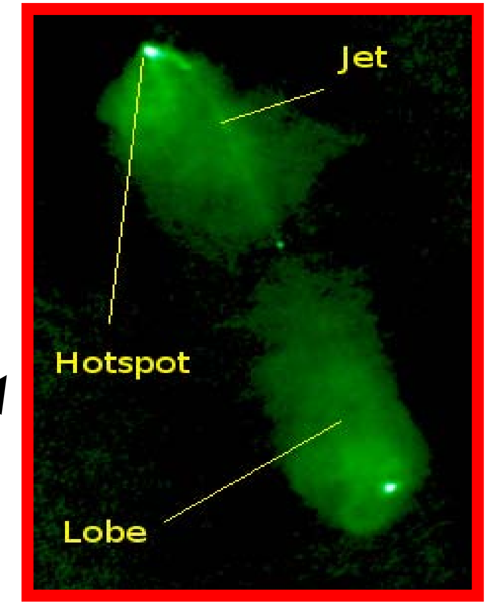
< ~ 1 pc



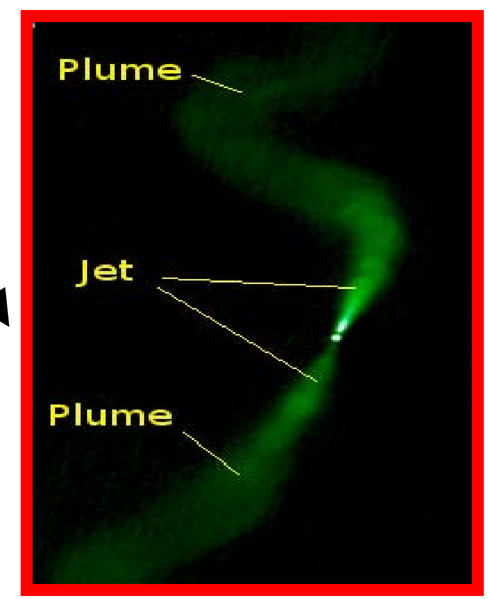
10 pc- 1 kpc

1-10 kpc

> 100 kpc



FRII radio galaxies



FRI radio galaxies

"Young radio galaxies"

Young radio galaxies (RGs)

in a broad astrophysical context

1. **Long term evolution of AGN activity**

   All young RGs evolve into FRIIs ?

   Fate of young RGs: dead or alive ?

Today's talk

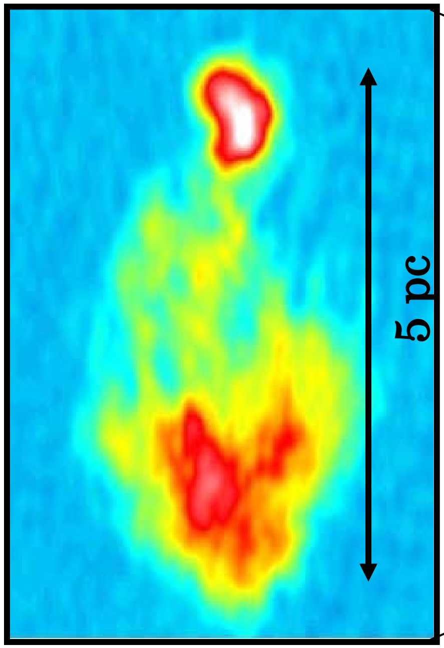
2. **AGN feedback due to AGN jets**

Young RGs provide a direct info. about jet interactions with ISM.

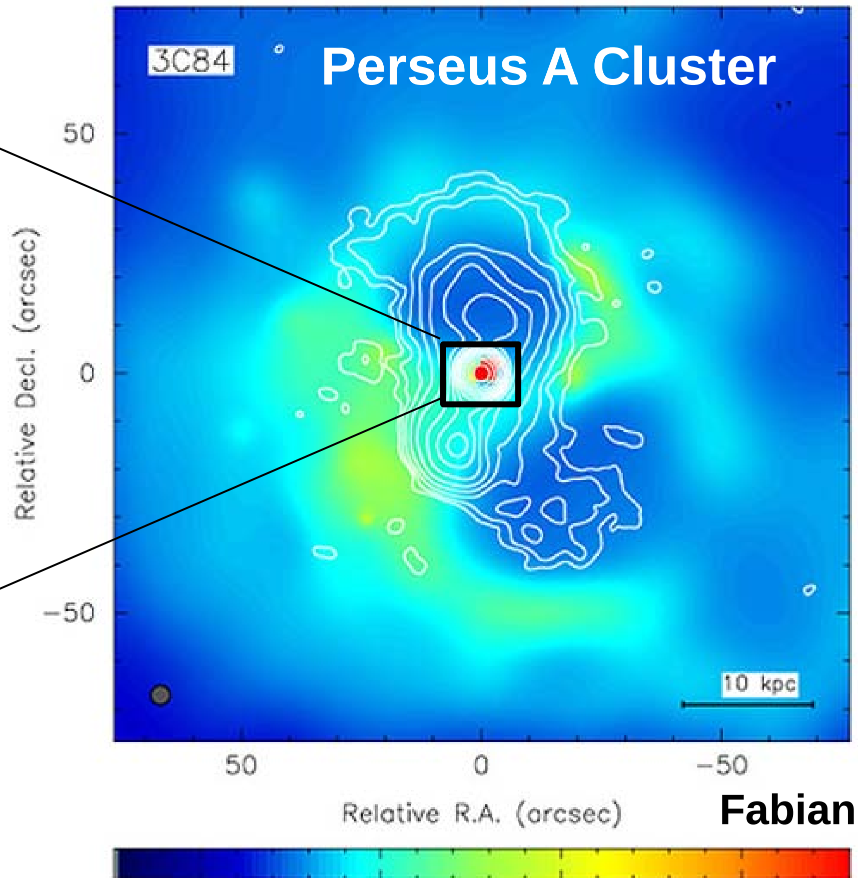
Local Young radio galaxy: NGC1275

- D~ 75 Mpc (Seyfert 2 galaxies)
- Age 50 yrs, advance speed 0.4 c (Asada +06)
- γ-ray detection by Fermi   => Non-thermal activity (Abdo +09)
- Candidate of HECR source ?   (Takami & Horiuchi +10)

High Energy Physics

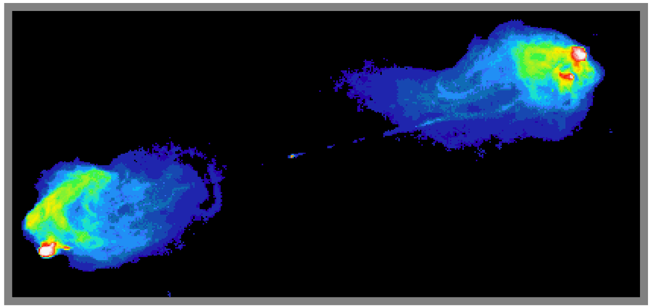


Asada+ 2006

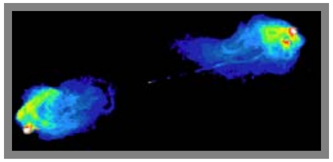


Fabian+ 2002

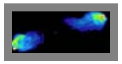
AGN-jet evolution
(Born/Growth/Death; Feedback)



Giant cocoon
(R< 1kpc)



Intermediate cocoon
(1kpc < R < 10 kpc)



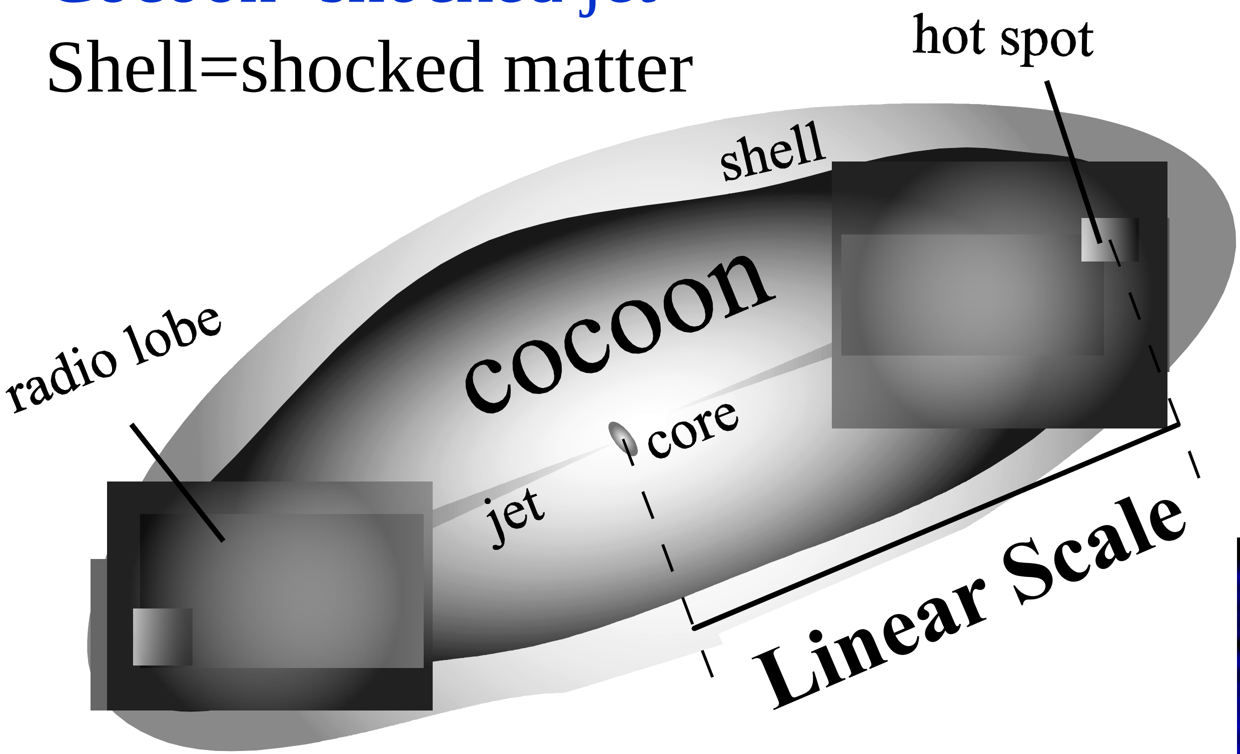
Mini cocoon
(R< 1kpc)

How ?

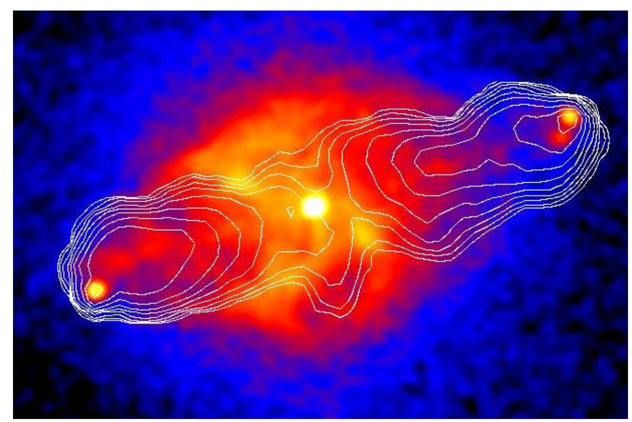
Standard picture of AGN jets

Cocoon=shocked jet

Shell=shocked matter



© Kino



Cocoon formation is inevitable.

A Coevolution model of hot spots and a cocoon

Kino &NK 2005 and NK & Kino 2006, see also Begelman & Cioffi 1989

Eq. of motion (jet axis): $$\frac{L_{\rm j}}{c} = \rho_{\rm a}(l_{\rm h}) v_{\rm h}^2(t) A_{\rm h}(t)$$

Eq. of motion (sideways): $$P_{\rm c}(t) = \rho_{\rm a}(l_{\rm c}) v_{\rm c}^2(t)$$ ***supersonic expansion***

Energy eq. : $$P_{\rm c}(t) V_{\rm c}(t) = 2(\gamma_{\rm c} - 1) L_{\rm j} t$$

$V_c = 4A_c l_h/3$: cocoon volume *P_c: cocoon pressure*

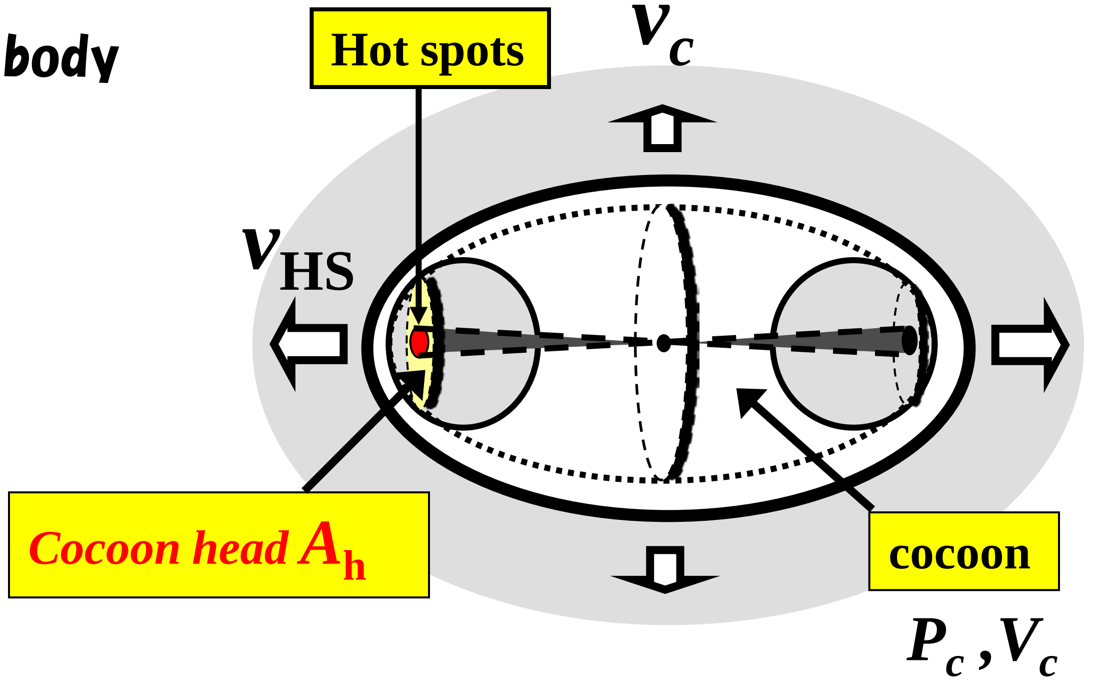
$\gamma_c = 4/3$: specific heat ratio of plasma inside cocoon

- ***cross section of cocoon body***

$$A_{\rm c} \propto t^{-X}$$

- **Mass density profile of ambient medium**

$$\rho_{\rm ext} \propto d^{-\alpha}$$



Analytic model of expanding cocoon

Using a control parameter X describing sideways expand velocity

$$v_c(t) = \bar{v}_c \left(\frac{t}{t_{\rm age}}\right)^{0.5X-1} = \frac{\bar{A}_c^{1/2}}{t_{\rm age}} \mathcal{C}_{vc} \left(\frac{t}{t_{\rm age}}\right)^{0.5X-1}$$

X is tightly constrained by observed shapes

Solutions are as follows;

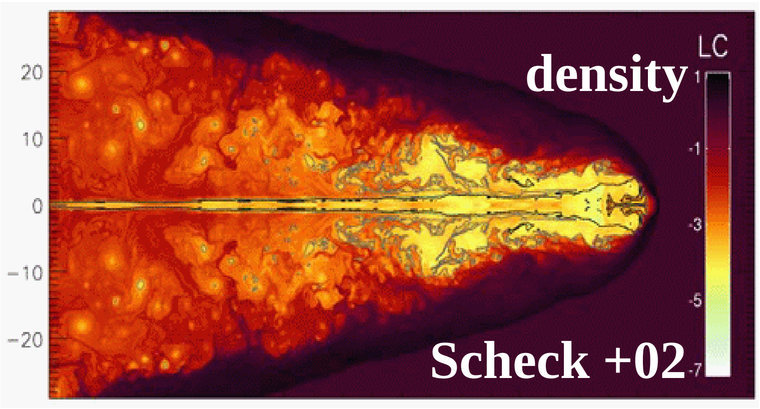
$$\begin{cases} P_c(t, L_j) = \bar{\rho}_a \bar{v}_c^2 \mathcal{C}_{pc} \left(\frac{\bar{v}_c}{v_0}\right)^{-\alpha} \left(\frac{t}{t_{\rm age}}\right)^{X(1-\alpha/2)-2}, \\ v_h(t, L_j) = \frac{L_j}{\bar{\rho}_a \bar{v}_c^2 \bar{A}_c} \mathcal{C}_{vh} \left(\frac{\bar{v}_c}{v_0}\right)^{\alpha} \left(\frac{t}{t_{\rm age}}\right)^{X(-2+0.5\alpha)+2}, \\ A_h(t, L_j) = \frac{L_j}{v_j \bar{\rho}_a \bar{v}_h^2} \mathcal{C}_{Ah} \left(\frac{\bar{v}_h}{v_0}\right)^{\alpha} \left(\frac{t}{t_{\rm age}}\right)^{X(\alpha-2)(-2+0.5\alpha)+3\alpha-4}, \\ n_e(t) \approx 4 \times 10^{-5} \bar{A} n_{-2} \Gamma_{10} \beta_{-2}^2 \left(\frac{t}{10^7 {\rm yr}}\right)^{-2} {\rm cm}^{-3} \end{cases}$$

Let us compare this with numerical simulations!

Comparison with numerical simulations

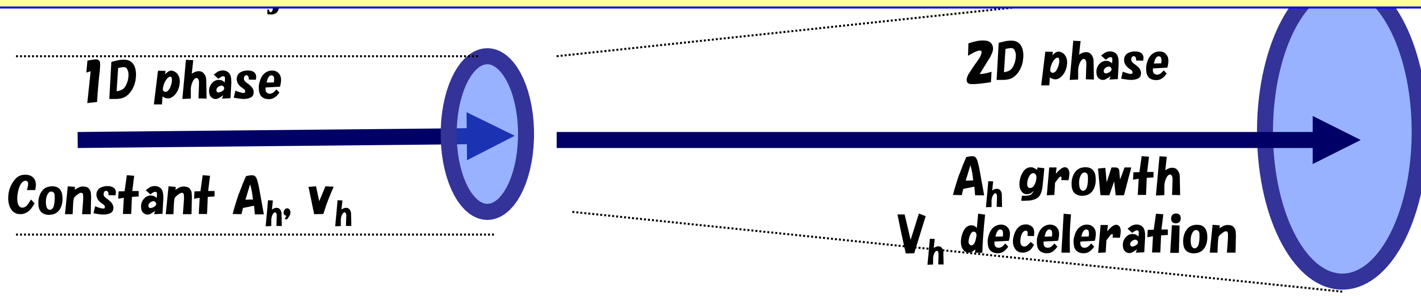
2D relativistic hydro. Simulation in a uniform ambient medium (Scheck +02) and in a declining ambient medium (Perucho & Marti 03).

—	v_{HS}	r_{HS}	P_{HS}
(i) A uniform ambient medium ($\alpha = 0$)[a]			
S02	$t_h^{-0.55}$	$t_h^{0.45}$	$t_h^{-1.1}$
KK06	$t_h^{-0.58}$	$t_h^{0.55}$	$t_h^{-1.1}$
(ii) A declining ambient medium ($\alpha = 1$)[a]			
PM07	$t_h^{-0.11}$	$t_h^{0.78}$	$t_h^{-1.4}$
KK06	$t_h^{-0.11}$	$t_h^{0.67}$	$t_h^{-1.2}$

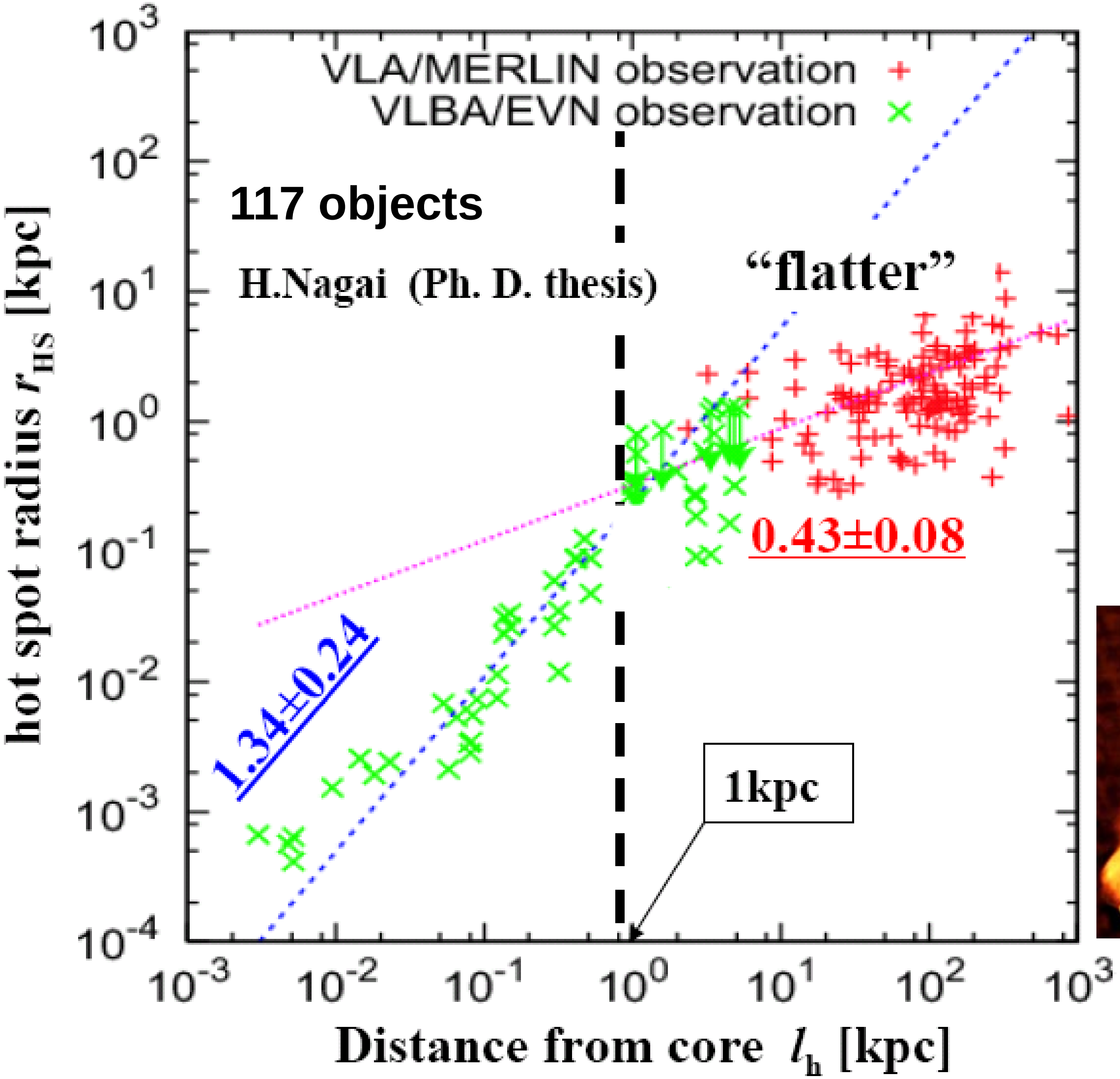


$\alpha = 0$ (flat ambient matter): $X = 1.2$, $\alpha = 1$, $X = 1.4$

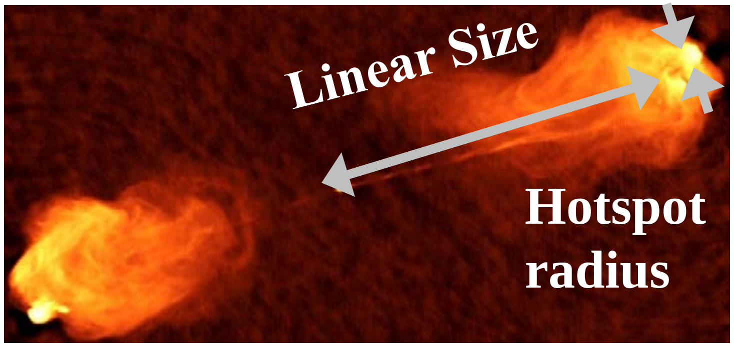
Our model can describe the flow and cocoon behavior very well.



Evolution of hot spot radius

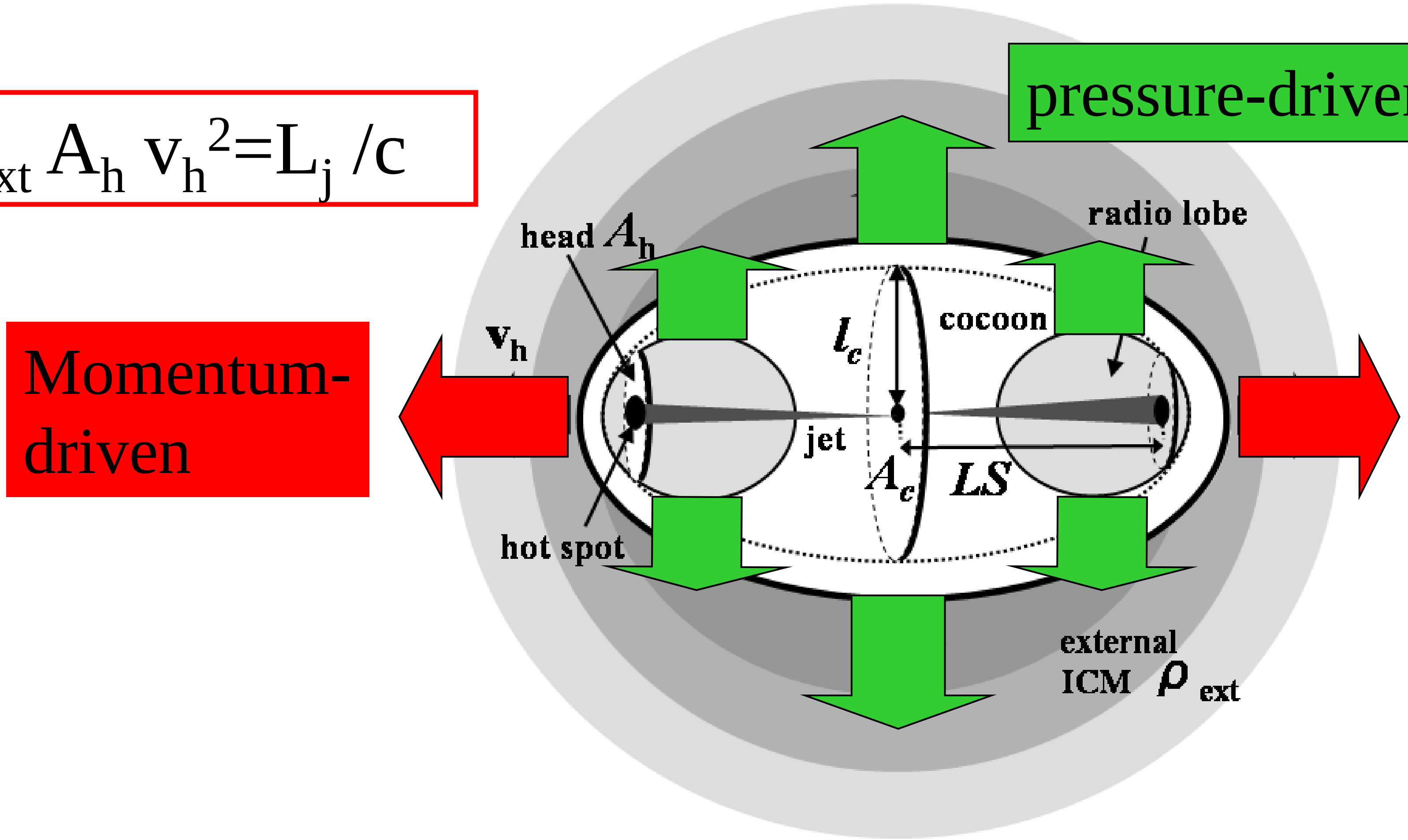


Tight correlation between "hotspot radius" and "Linear size".



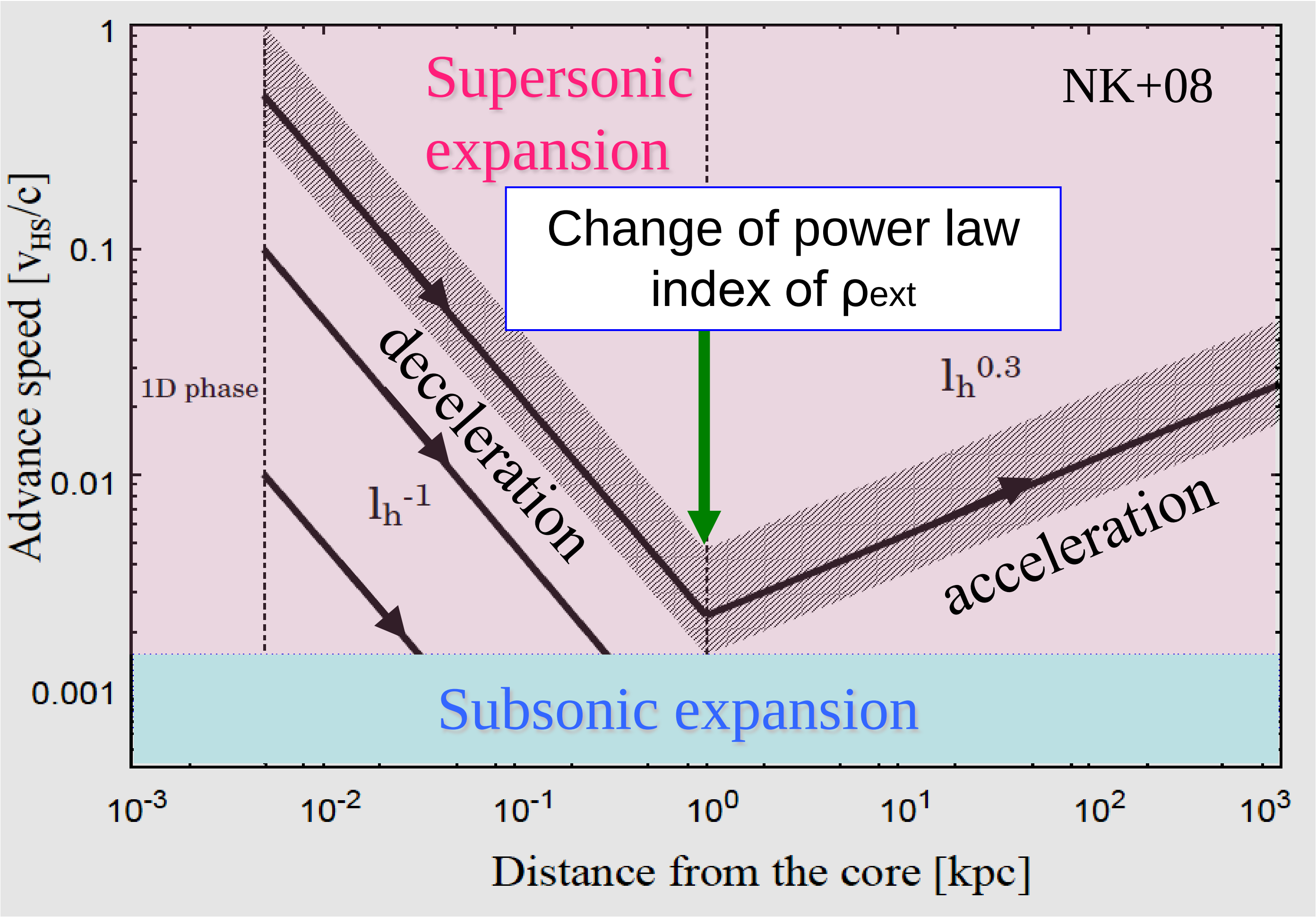
AGN Cocoon model

$\rho_{ext} A_h v_h^2 = L_j / c$



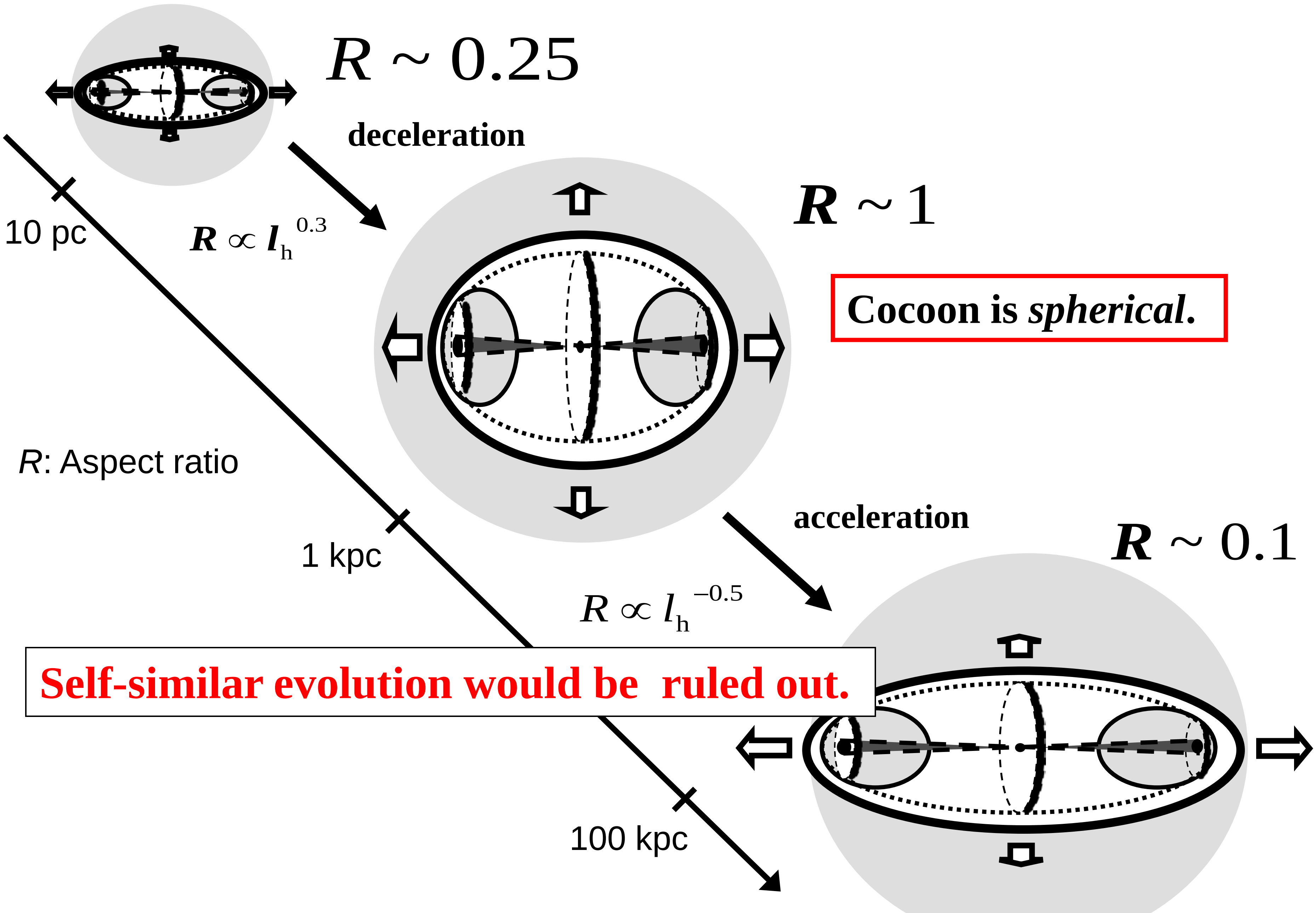
Evolution of advance speed (prediction)

Evolution of hot spot radius (obs.) + Cocoon Model



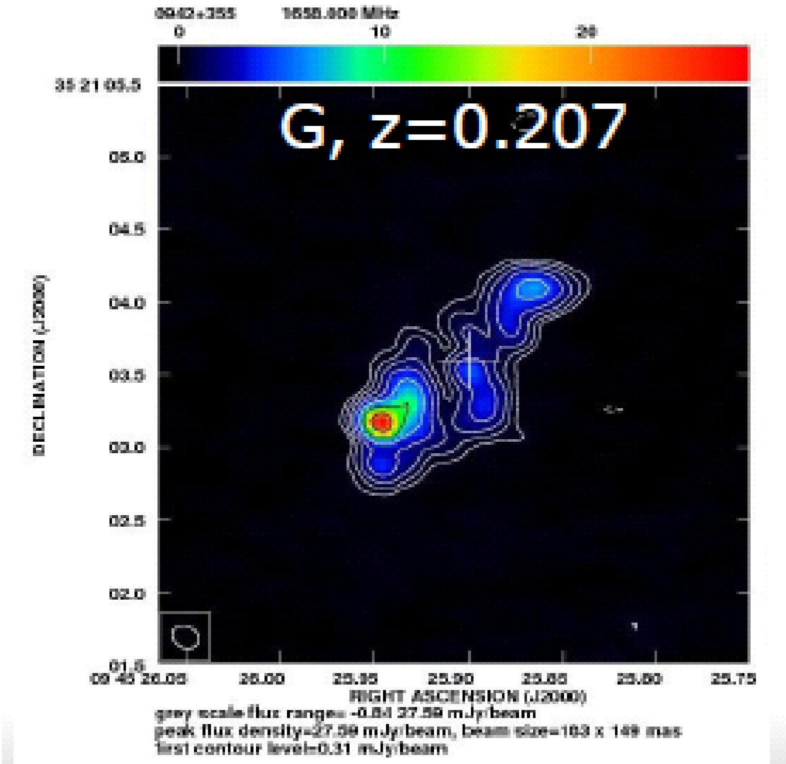
$$T_g = 10^{6-7}\,\mathbf{K}$$

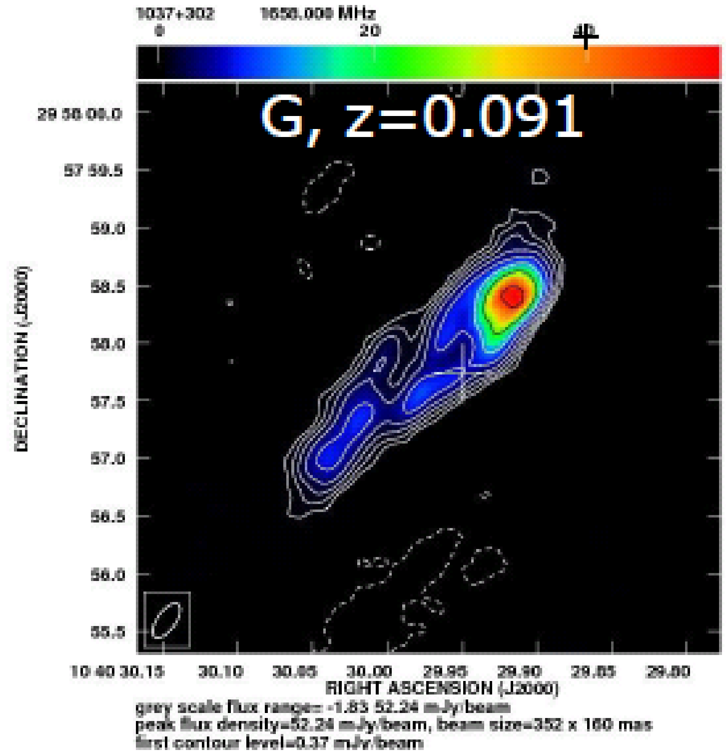
Evolution of cocoon morphology (prediction)



Irregular cocoons: Dying sources?
Intermediate scale (1-10 kpc)

Kunert-B





Previous idea: Jet activities quench => Fade out ?

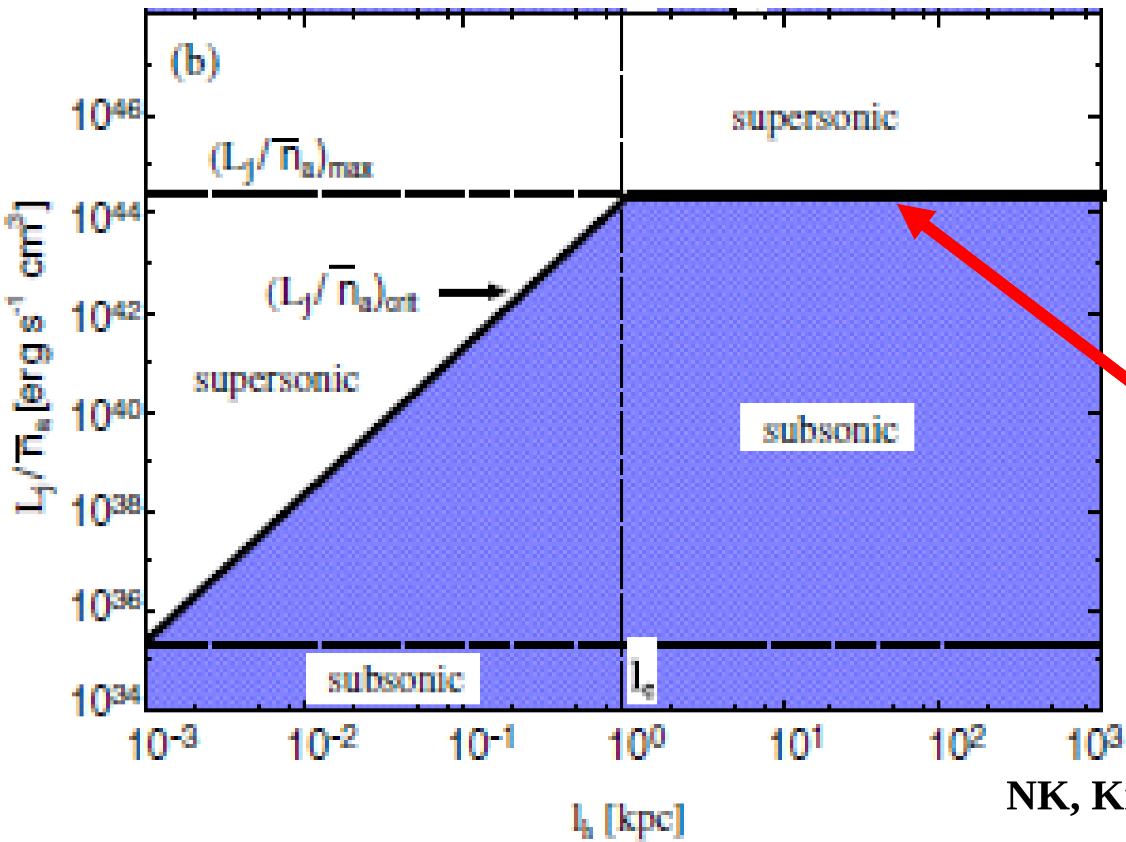
Our interpretation : Subsonic cocoon => Instability ?

Origin of FRI/FRII dichotomy

The condition of the supersonic jet

$$\frac{L_j}{c} = \rho_a A_h v_{HS}^2 = f\pi r_{HS}^2 \rho_a v_{HS}^2 \geq f\pi r_{HS}^2 \rho_a c_S^2 \qquad f \equiv \frac{A_h}{\pi r_{HS}^2}$$

Our results

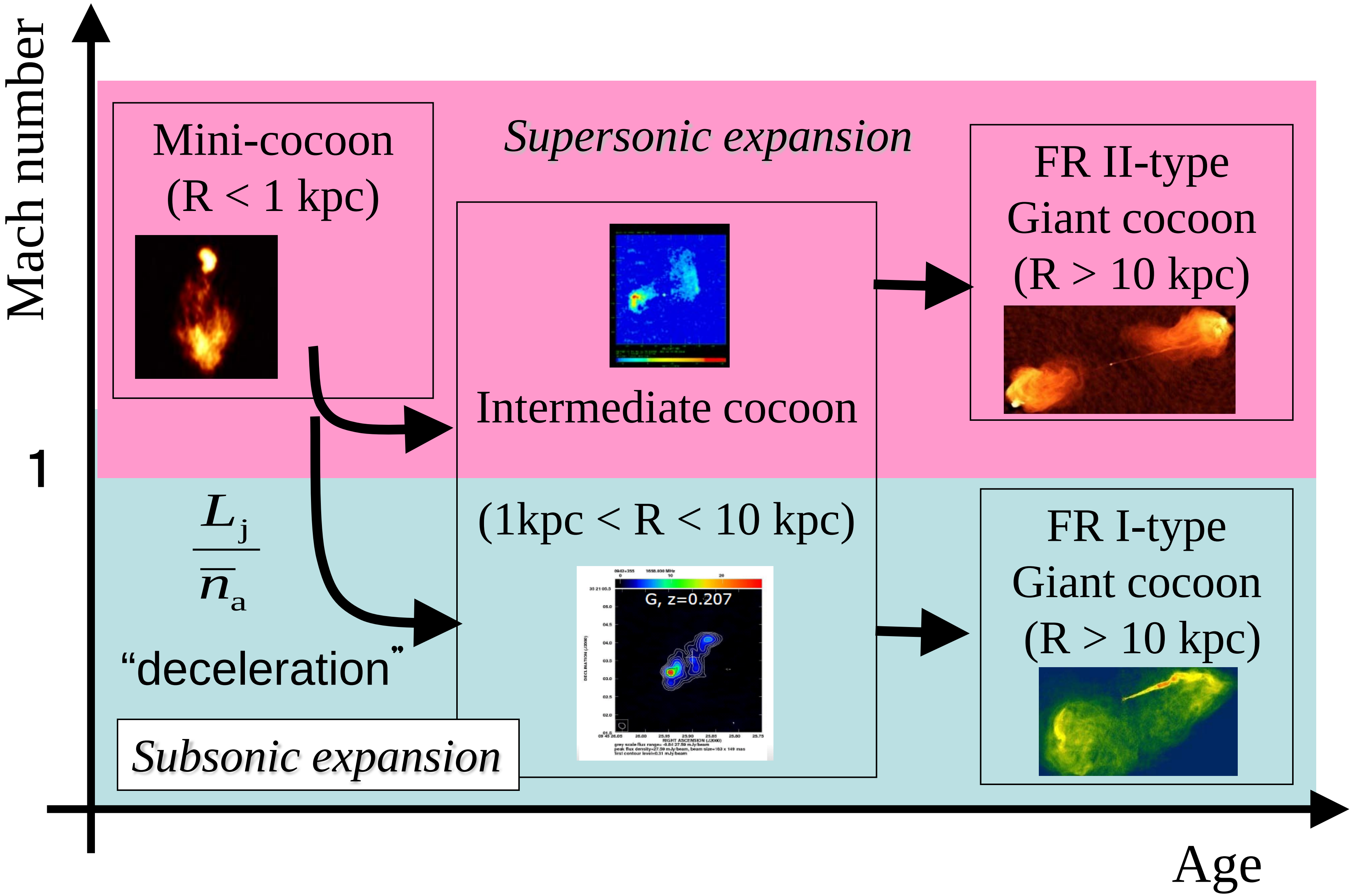


Dividing line between FRIs and FRIIs

$$\left.\frac{L_j}{\bar{n}_a}\right|_{max} \approx f_{10} 10^{44} \,[\mathrm{erg\ s^{-1}\ cm^3}]$$

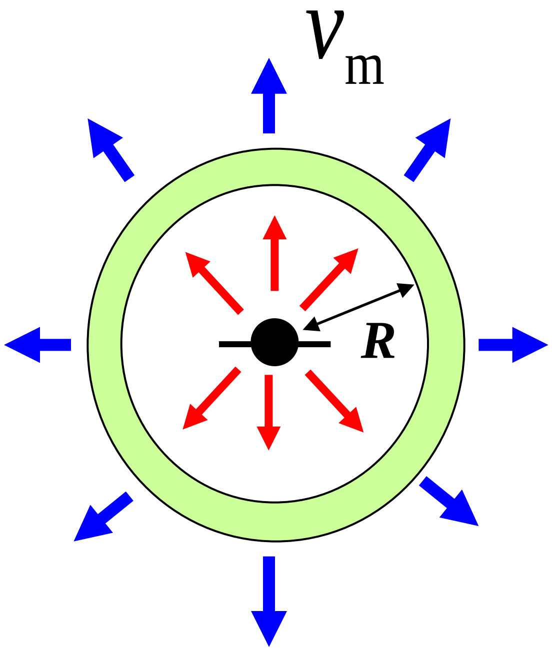
NK, Kino & Nagai 2009

Unified model of AGN cocoon



AGN feedback model (e.g., Silk & Rees 1998)

Scenario: They suggested that AGN feedback quench star formation and regulate the SMBH growth, and consequently the local BH-to-bulge relation can be well reproduced.



Spherical expansion

Eq. of motion

$$\frac{d}{dt}\left[M(R)\dot{R}\right]=\frac{L_j}{c}=\frac{L_{Edd}}{c}$$

$$\rightarrow M(R)\dot{R}=\frac{2f_g\sigma^2 R}{G}\dot{R}=\frac{L_{Edd}}{c}t \quad \left(\because M(R)=\frac{2f_g\sigma^2 R}{G}\right)$$

$$v_m^2=(R/t)^2=\frac{f_g\kappa M_{BH}}{2\pi G}\sigma^{-2} \quad \left(\because L_{Edd}=\frac{4\pi c G M_{BH} c}{\kappa}\right)$$

Constant velocity (singular isothermal : $\rho \propto r^{-2}$)

$$v_m=\sigma \quad \Rightarrow \quad M_{BH}\approx 2\times10^8 f_{g,0.1}\sigma_{200}^4 M_\odot$$

These do not match with our predictions.

Summary

•We predict that the advance speed of hot spots show the deceleration phase (< kpc) and the acceleration phase (> kpc). The deceleration is caused by the growth of cocoon head. ***Thus, the constant velocity model can be ruled out.***

- It is crucial to ***evaluate of v_{HS} of intermediate size cocoon*** **.**

• In this evolution, the cocoon morphology of ～kpc radio source becomes spherical or distorted, while that of young RGs and FRIIs is elongated. ***Thus, self-similar evolution can be ruled out.***

-It is worth examining the evolution of the cocoon shape.

• Only young RGs with $>v_{HS}\sim 0.1c$ can be progenitors of FRIIs.

Most young RGs with $<v_{HS}\sim 0.1c$ may evolve into FRIs.

FRI/FRII dichotomy is determined by the ratio of jet power and the ambient density of ambient matter in host galaxies.

We should reconsider if AGN feedback affect on the evolution host galaxy.