classification and statistical properties of radio galaxies with extended morphology at z<0.3

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overview

- Fanaroff & Riley (74)
  - type I (edge-darkened); type II (edge-brightened)
  - dichotomy
- primary goal: origin(s) of different morphology?
  - best way to find distinct populations of radio galaxies (RGs) ⇒ new classification scheme
  - differences in the host galaxy properties and environment
- approach
  - use a simple, continuous parameterization (r_s) of morphology, applied to 1040 uniformly selected RGs
  - study physical properties as a function of r_s: are they bimodal?
  - including optical nuclear emission line properties separates RG populations better
- results
  - 3 types of RGs (with extended, “straight” morphology)
  - accretion rate onto central engine is dominant in determining the morphology; galactic structure/density plays a minor role
  - RG catalog publicly available

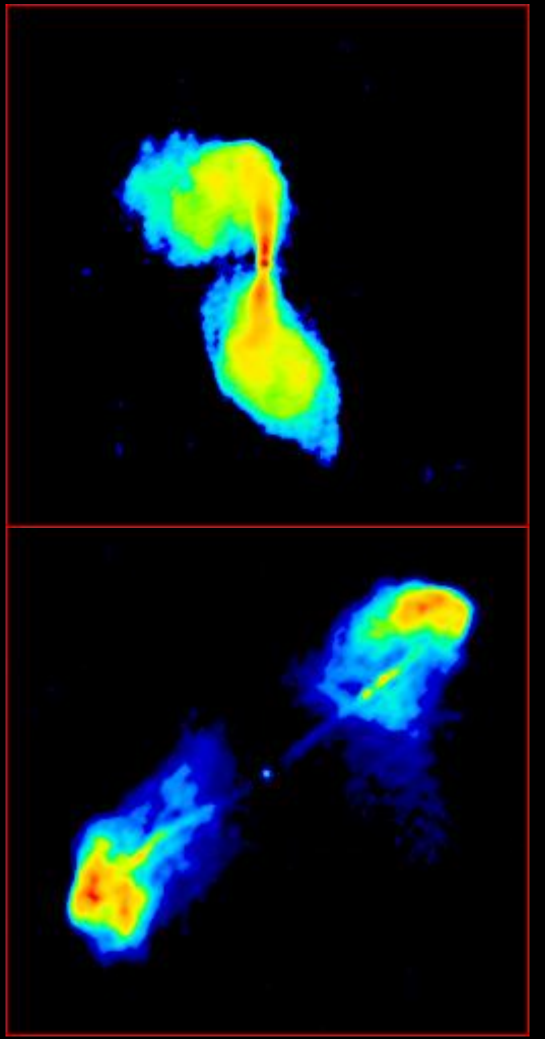


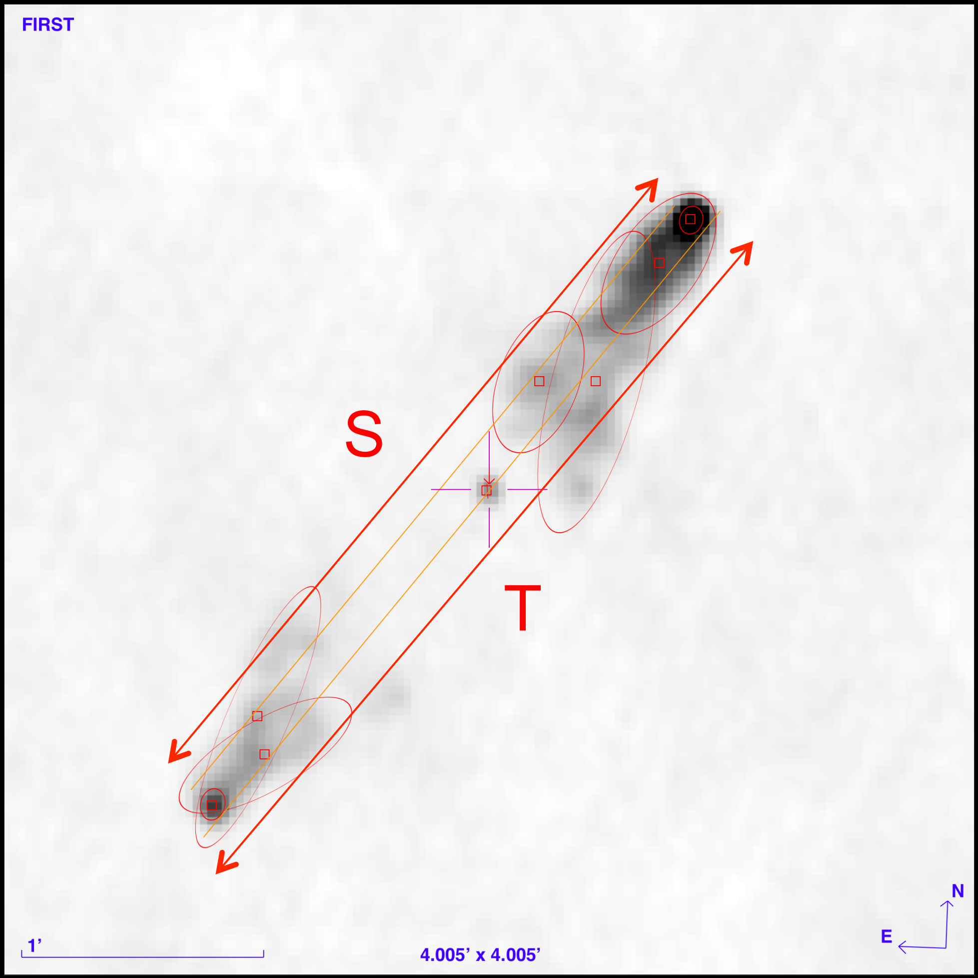
image credit: Leahy, Bridle, Strom

classification schemes and RG sample

- morphology-based scheme (FR, Owen & Laing 89): interactions of the jets with environments
- emission line-based scheme (e.g., Laing+94: HERG vs LERG): accretion processes onto super massive blackhole (SMBH)
- correspondence between FR I/II and HE/LE not perfect: many FR IIs have LE nuclei, while some FR Is are HERG
- a hybrid scheme may work better in revealing distinct populations of RGs
- *classification may be subject to classifiers' experience/preference!*
- cross-matched SDSS DR6 main sample with NVSS and FIRST surveys at 1.4 GHz to generate the largest radio galaxy catalog at z≤0.3 to date: 10,500 RGs stronger than 3 mJy, all brighter than M_* (massive!)
- selection of extended RGs
  - visually inspect all RGs to ensure correct match and fluxes
  - concentrate only on objects with more or less "straight" lobes (ignore wide angle tail and narrow angle tail sources) and large enough to be resolved
  - 1040 RGs satisfy these criteria
  - among the largest, homogeneously selected sample for studying FR I/II dichotomy

an objective classification scheme?

- measure the total size T and the separation between the highest surface brightness (HSB) spots on either side of the host galaxy, S
- use r_s=S/T to trace the RG population continuously
- in the original FR scheme, the two types are separated by r_s=0.5
- class a: lobe-dominated; ~2/3 of all sources
- class b: prominent jet coincide with host; ~1/3 of all sources
- later we will consider adding the OIII emission line as another classification criterion



class a; r_s=0.93

an objective classification scheme?

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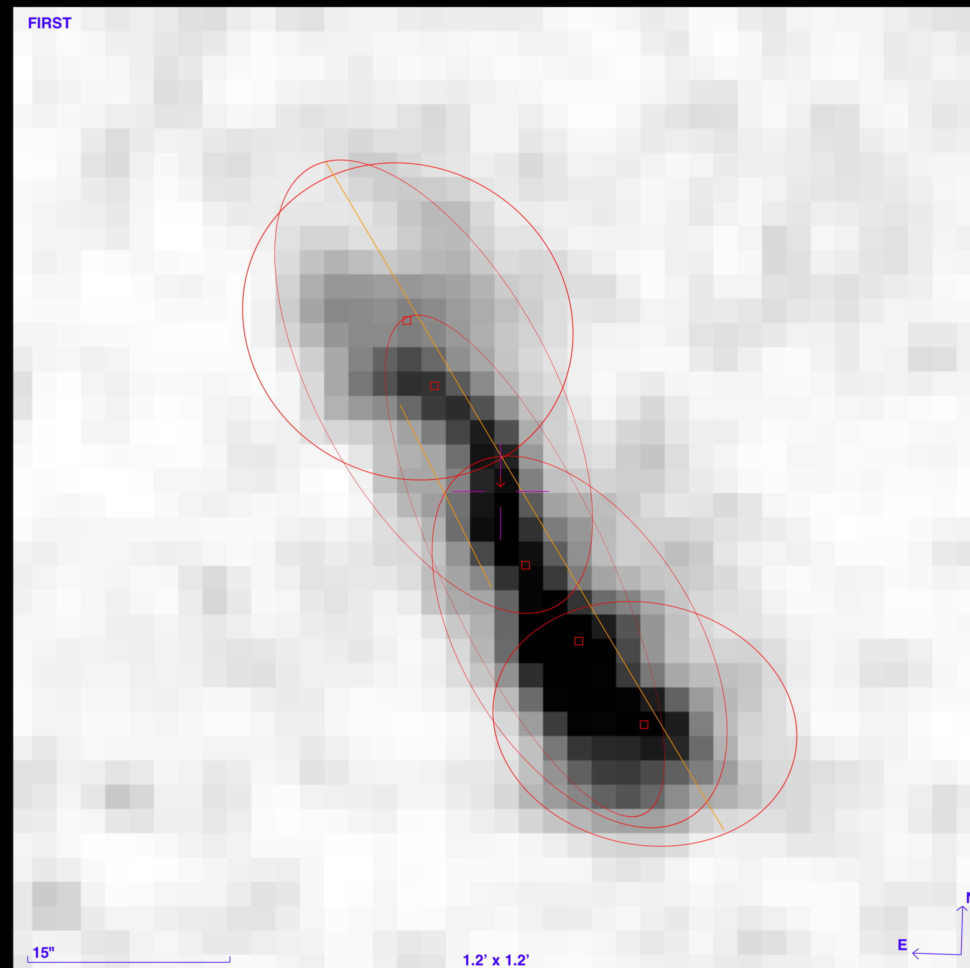
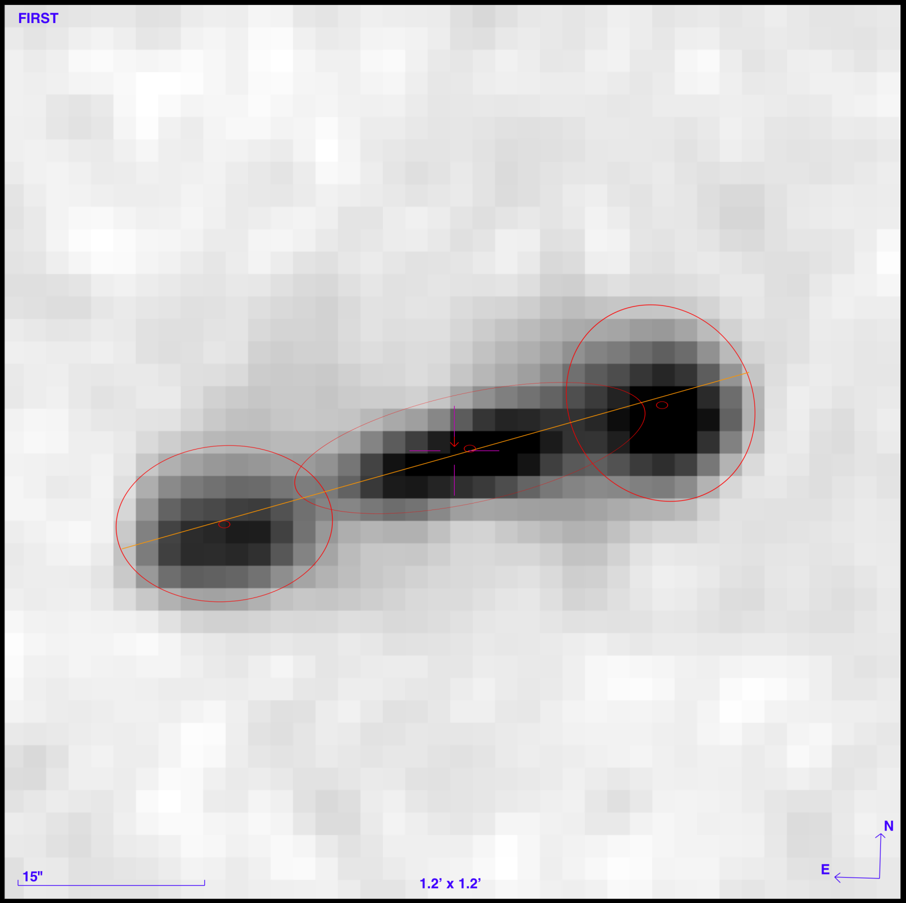
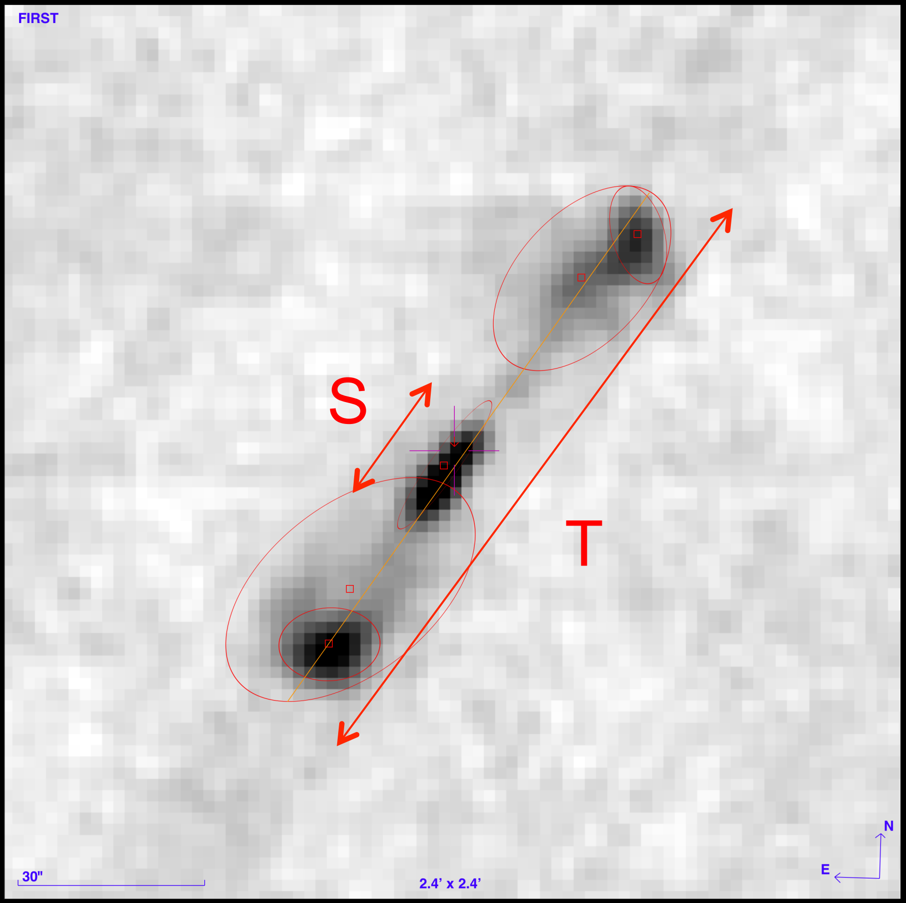


class a; r_s=0.26

an objective classification scheme?



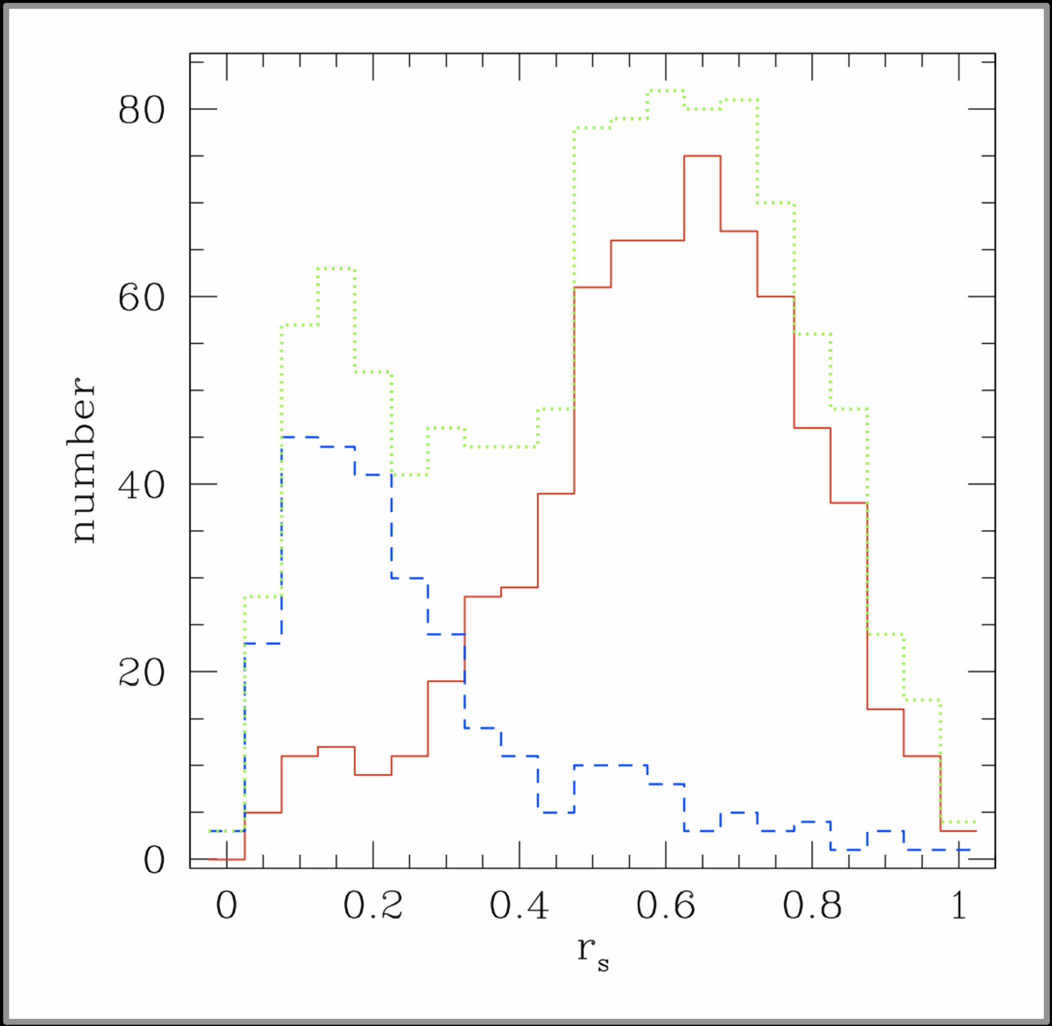
class b; r_s=0.55

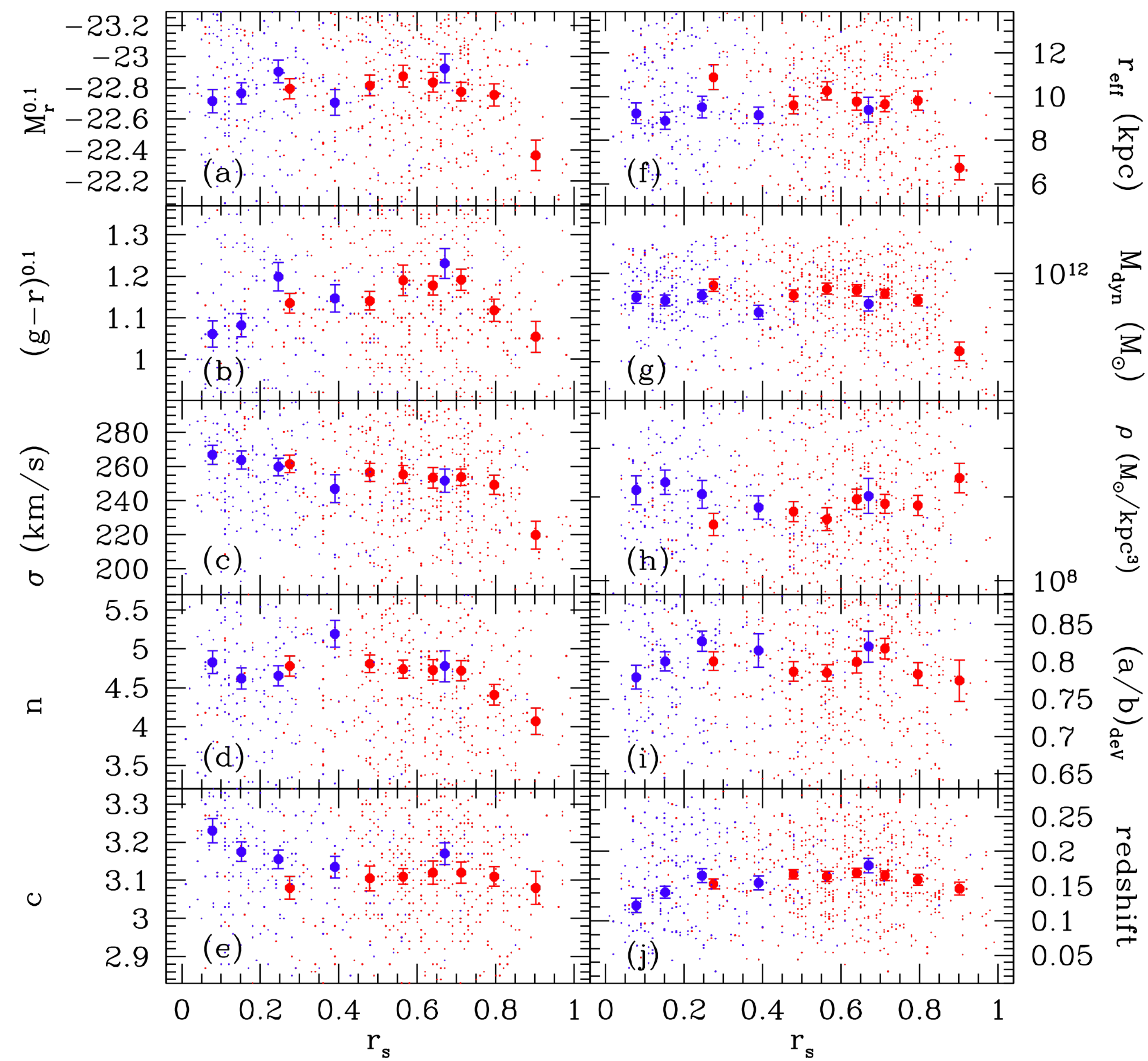


class b; r_s=0.25

distribution of r_s

- two main classes
  - class a: lobe-dominated (red histogram; 64% of extended RGs)
  - class b: prominent jet (blue; 28%)
- identify the two peaks as FR I & II?
- if to stick with FR-like scheme ⇒ division at r_s=0.8 ($a_{0.9}$ vs $a_{<0.8}$+b subsamples)

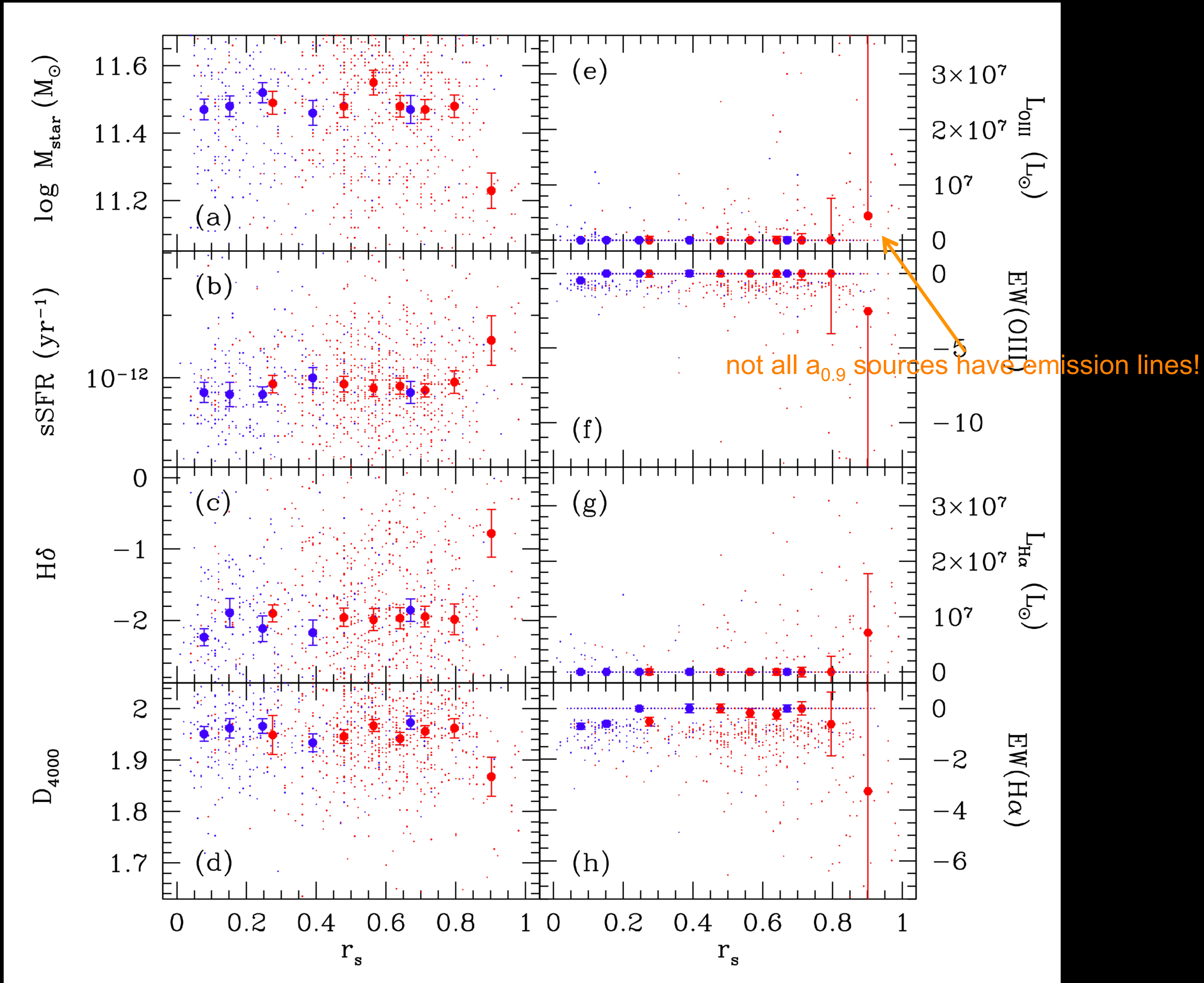




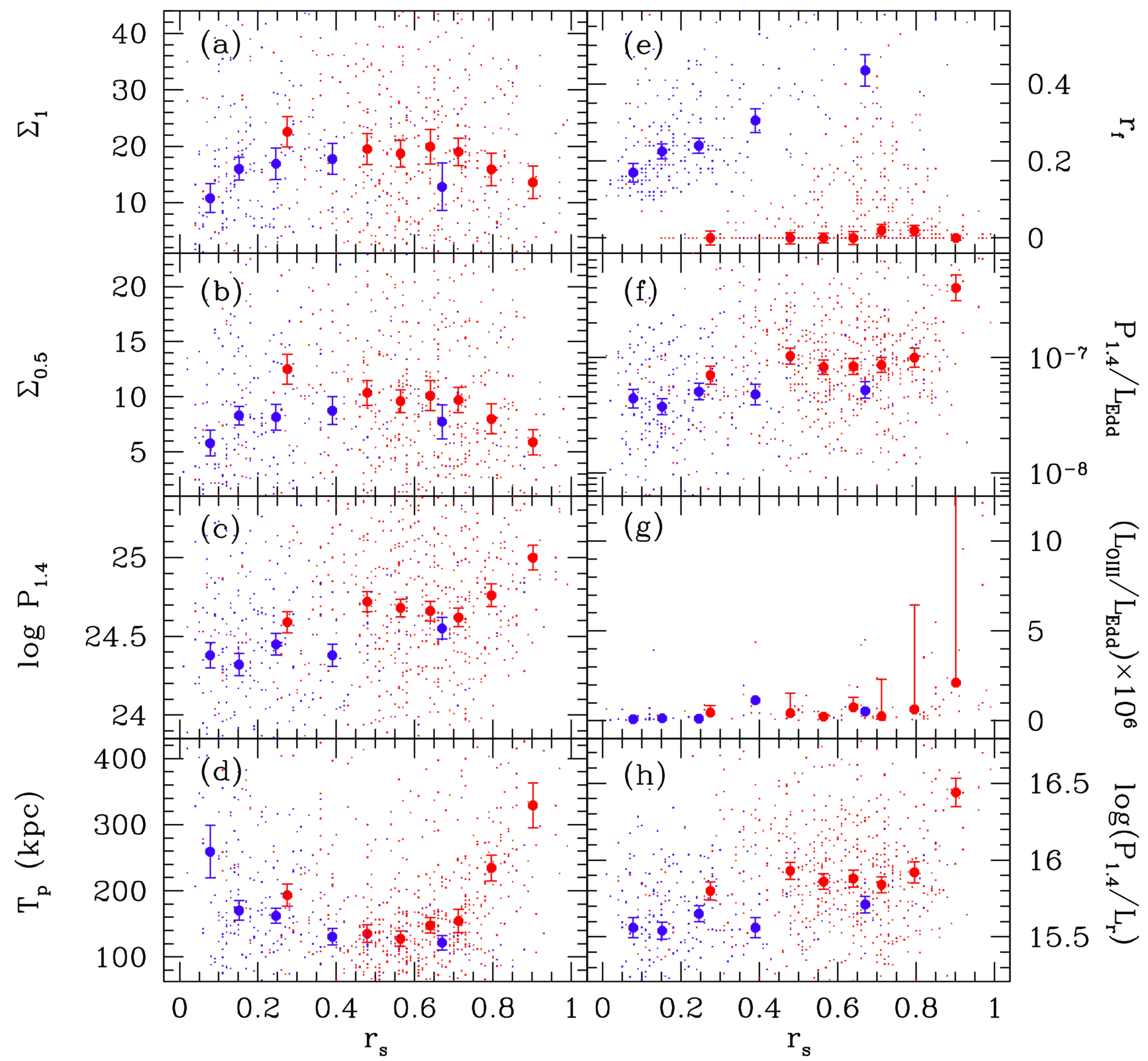
$M_r^{0.1}$
$(g-r)^{0.1}$
σ (km/s)
n
c
r_{eff} (kpc)
M_{dyn} ($M_\odot$)
ρ ($M_\odot$/kpc^3)
$(a/b)_{deV}$
redshift
r_s
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)

trends with r_s

- significant overlap in physical properties of subsamples
- class a objects with highest r_s seem to stand out from the rest (call them $a_{0.9}$ afterwards)
- weak or no trends among the rest of class a (hereafter $a_{<0.8}$), as well as class b
- $a_{0.9}$ vs other RGs
  - least massive, faintest host, smallest in size
- class b vs $a_{<0.8}$
  - slightly more concentrated, smaller in size, lower in total mass



log M_star (M_⊙)
sSFR (yr^-1)
Hδ
D_4000
L_OIII (L_⊙)
EW(OIII)
L_Hα (L_⊙)
EW(Hα)
r_s
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
not all a_0.9 sources have emission lines!

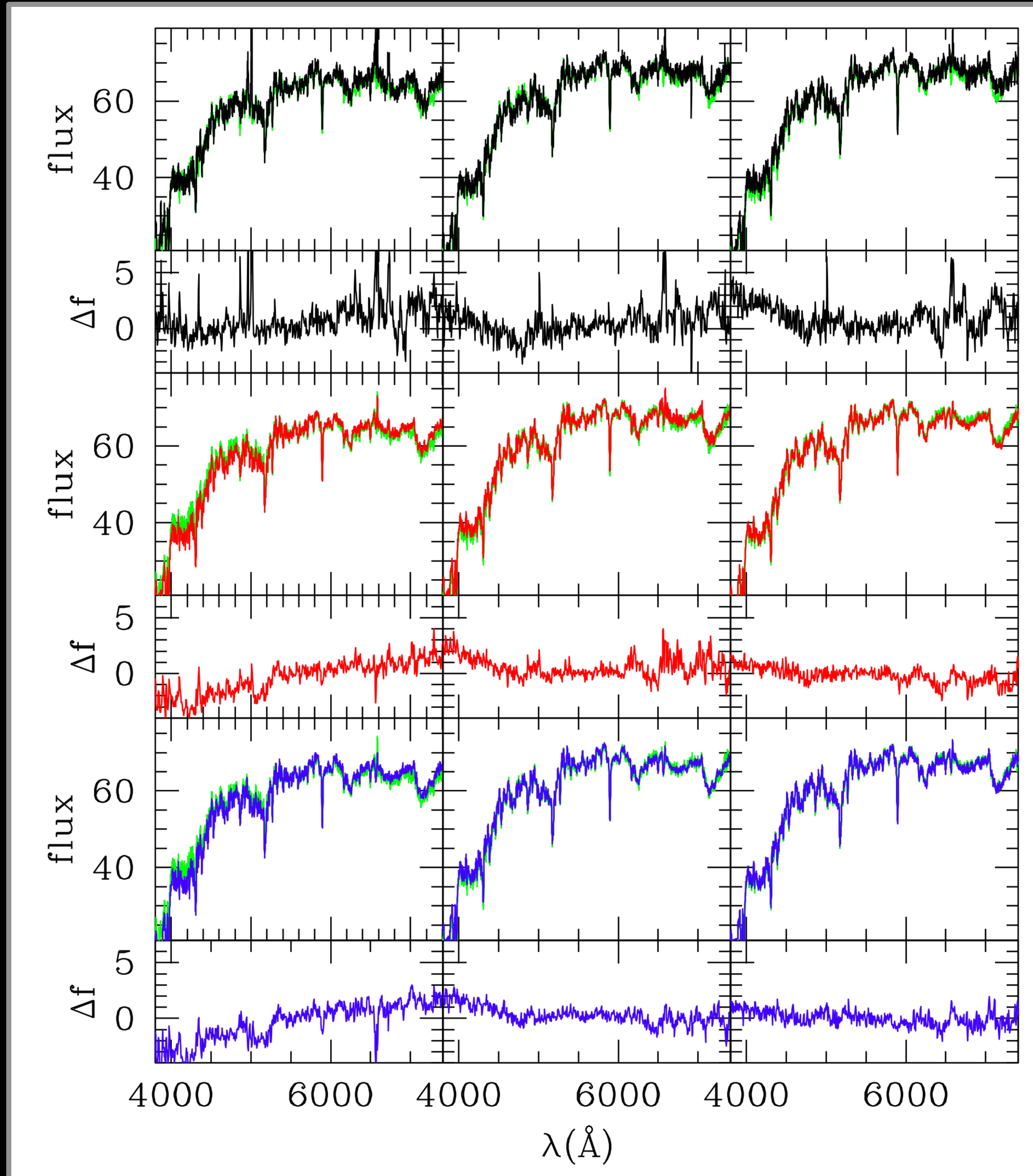

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Σ_1
$\Sigma_{0.5}$
log $P_{1.4}$
T_p (kpc)
r_f
$P_{1.4}/L_{Edd}$
$(L_{OIII}/L_{Edd})\times10^6$
$\log(P_{1.4}/L_r)$
r_s
r_s
0
0.2
0.4
0.6
0.8
1
40
30
20
10
20
15
10
5
25
24.5
24
400
300
200
100
0.4
0.2
0
10^{-7}
10^{-8}
10
5
0
16.5
16
15.5

trends with r_s

- significant overlap in physical properties of subsamples
- class a objects with highest r_s seem to stand out from the rest (call them $a_{0.9}$ afterwards)
- weak or no trends among the rest of class a (hereafter $a_{<0.8}$), as well as class b
- $a_{0.9}$ vs other RGs
  - least massive, faintest host, smallest in size
  - highest sSFR, youngest luminosity weighted stellar age
  - highest line luminosities and accretion rate/Eddington ratio
  - relatively sparse environments
  - highest radio power, largest linear size
- class b vs $a_{<0.8}$
  - slightly more concentrated, smaller in size, lower in total mass
  - slightly lower sSFR
  - less number of neighbors; similar to $a_{0.9}$
  - lowest in radio power and accretion rate/Eddington ratio

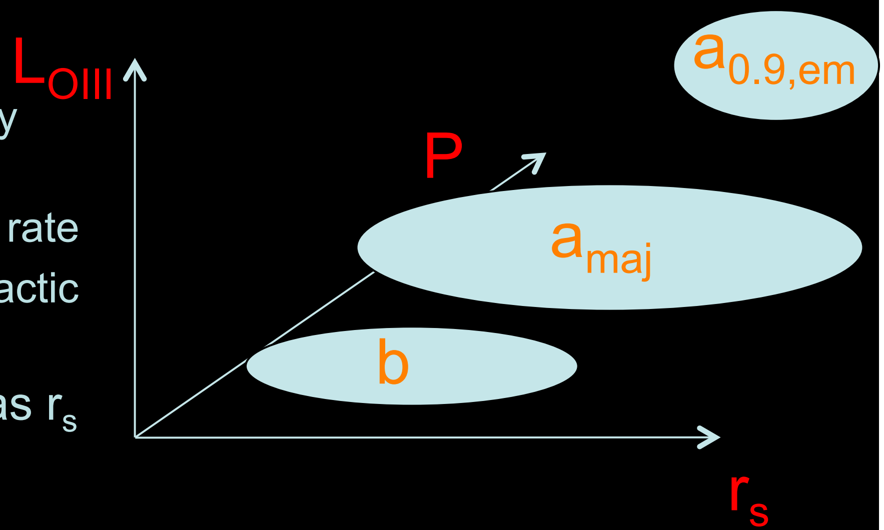
mean spectra

- 3 subsets with similar SMBH mass, dynamical mass and surface density
- 3 SMBH mass bins
- $a_{0.9}$: nucleus becomes less active with increasing mass
- intermediate and high mass $a_{<0.8}$ and b: similar spectra
- lowest mass $a_{<0.8}$ and b: signature of feedback?!



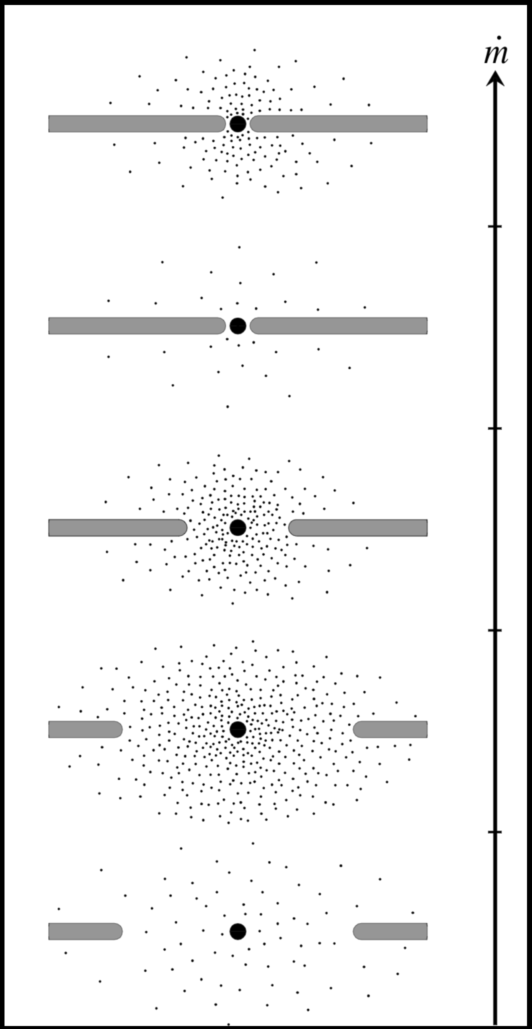
revision of the scheme

- if one is to stick with FR-like, morphology-based scheme
  - $a_{0.9}$ vs $a_{<0.8}$+b
  - large overlap in physical properties among these subsets
- however, 46/85 of $a_{0.9}$ objects have no detectable OIII line
- ~75% of $a_{0.9}$ objects with OIII luminosity>$10^6 L_{sun}$ show “hotspots” at the edge of lobes, while ~2/3 of $a_{0.9}$ objects without OIII line have “weak” HSB spots
  - mechanism that creates the emission lines is physically related to the process responsible for generating the hotspots?
  - it is $a_{0.9}$ objects with OIII line that make this subset stand out
- our “best” scheme
  - $a_{0.9,em}$ (r_s>0.8, L_{OIII}>$10^6 L_{sun}$) – relatively high accretion rate onto SMBH
  - a_{maj} (rest of class a) – lower accretion rate
  - b – low accretion rate, plus dense galactic structure
- simple morphological measure such as r_s has only limited use



origin of different morphologies?

- $a_{0.9,em}$
  - (relatively) higher accretion rate ($L_{OIII}/L_{Edd}>10^{-6}$)
  - accretion mode is the classical thin disk (fed by cold gas?)
  - can generate very well collimated jets; SMBH spin/ magnetic field may/must play some rule
- a_{maj}
  - lower accretion rate
  - probably powered by radiatively inefficient accretion flow (RIAF; fed by stellar mass loss?)
  - jets probably not well collimated
- b
  - lowest accretion rate; powered by RIAF
  - structure of the host galaxy or immediate surrounding probably slows down the jets significantly



Esin et al (97)

some thoughts on feedback

- for $a_{0.9,em}$, the strong jets probably simply punctuate two small holes in the galaxy → not much feedback on the galaxy?!
- the a_{maj} RGs may be the most promising agent for keeping the ICM hot: high probability to be found in cluster center, higher radio power compared to class b, larger cross section of lobes
- for b: the cross section of the jets may be large enough to affect the host galaxy and stop star formation and nuclear activity? (Seyfert/LINER activity in class b is suppressed compared to RQ galaxies of similar mass and SED)

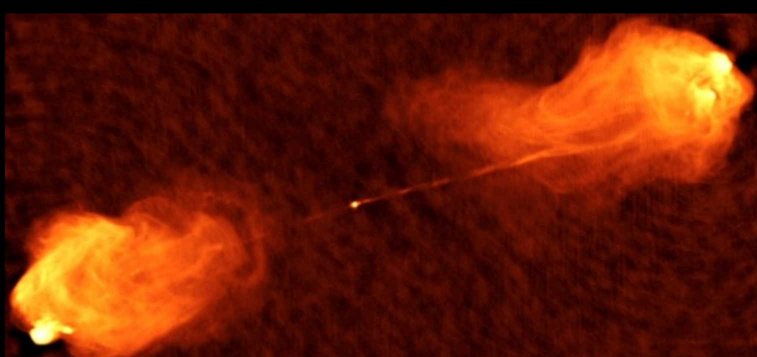
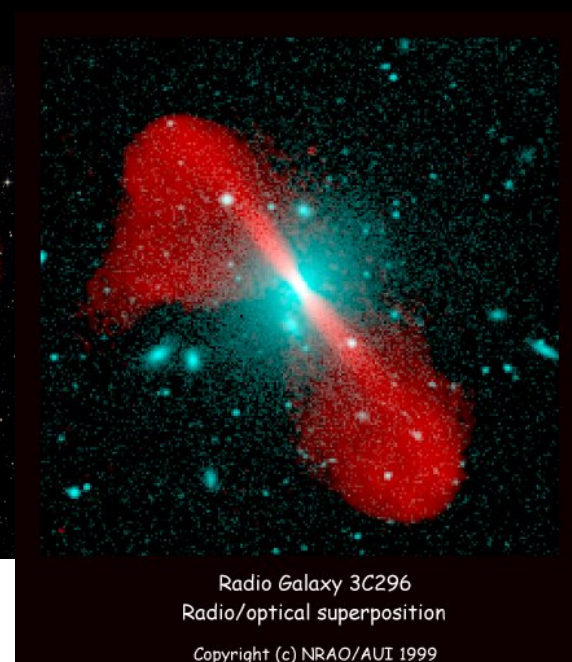
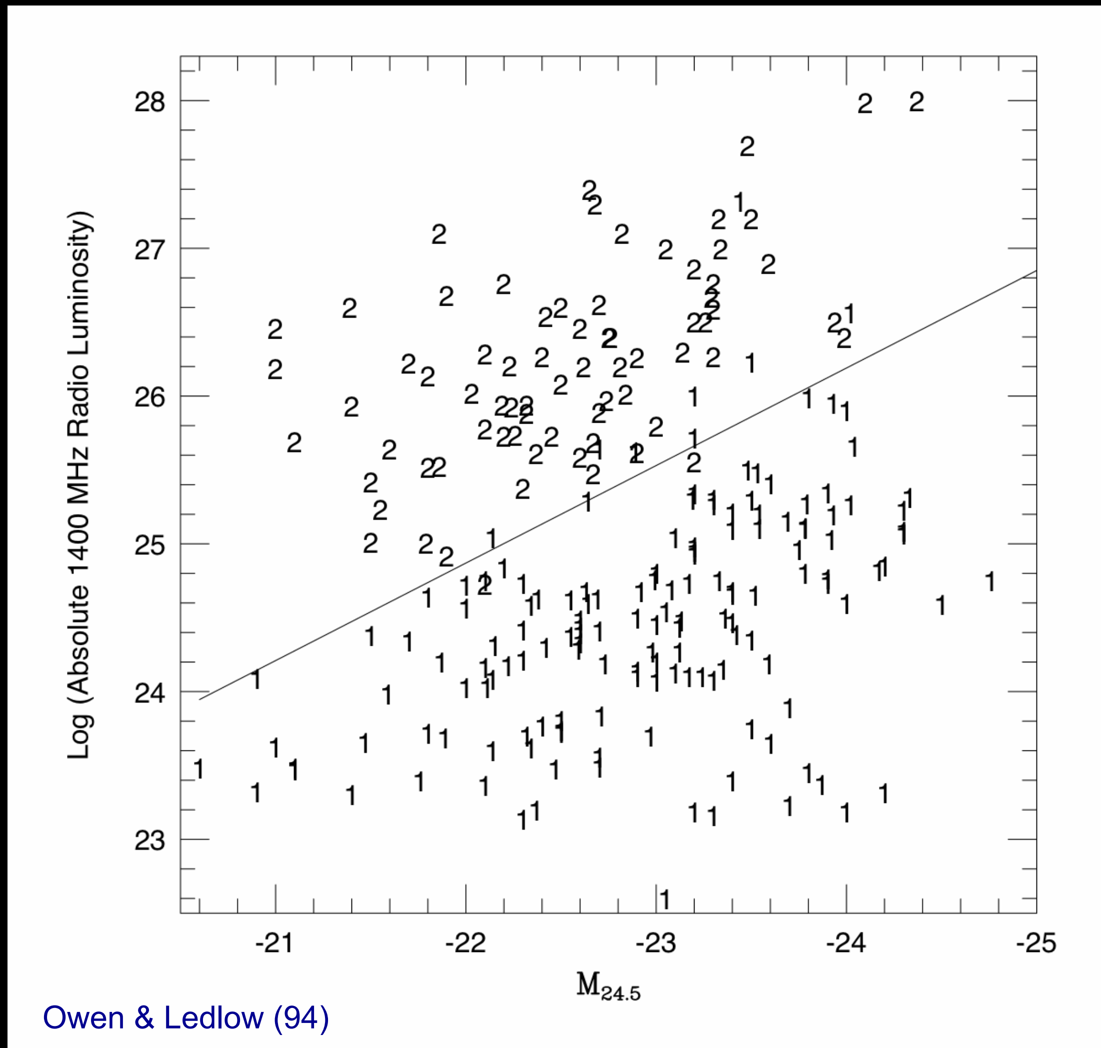


image credit: NRAO



segregation in P-M plane?

- Owen and collaborators found sharp transition from FR I to II as a function of optical luminosity of the hosts



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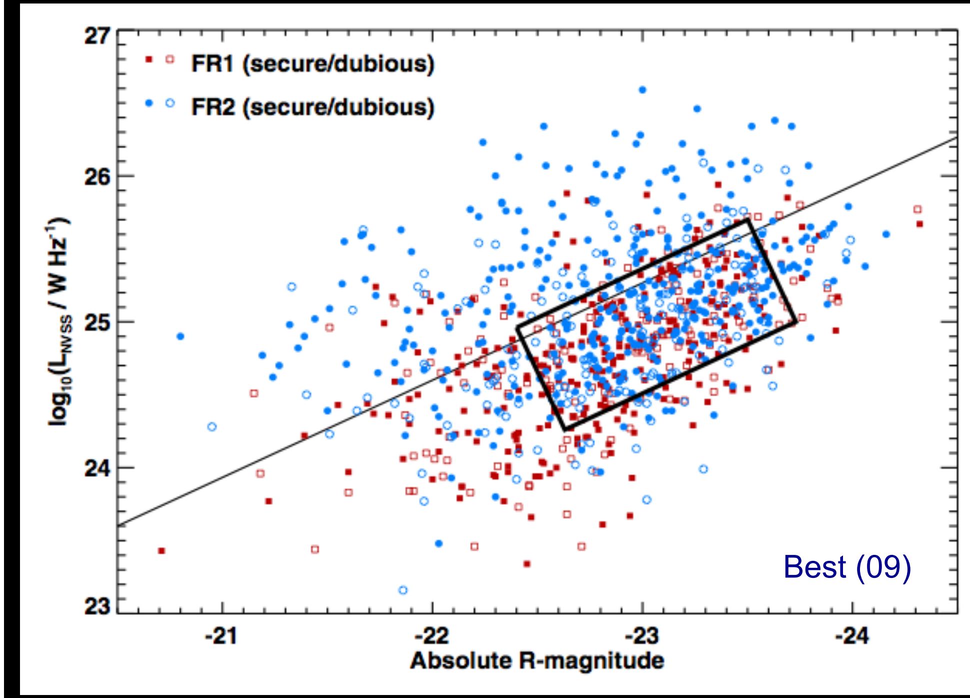

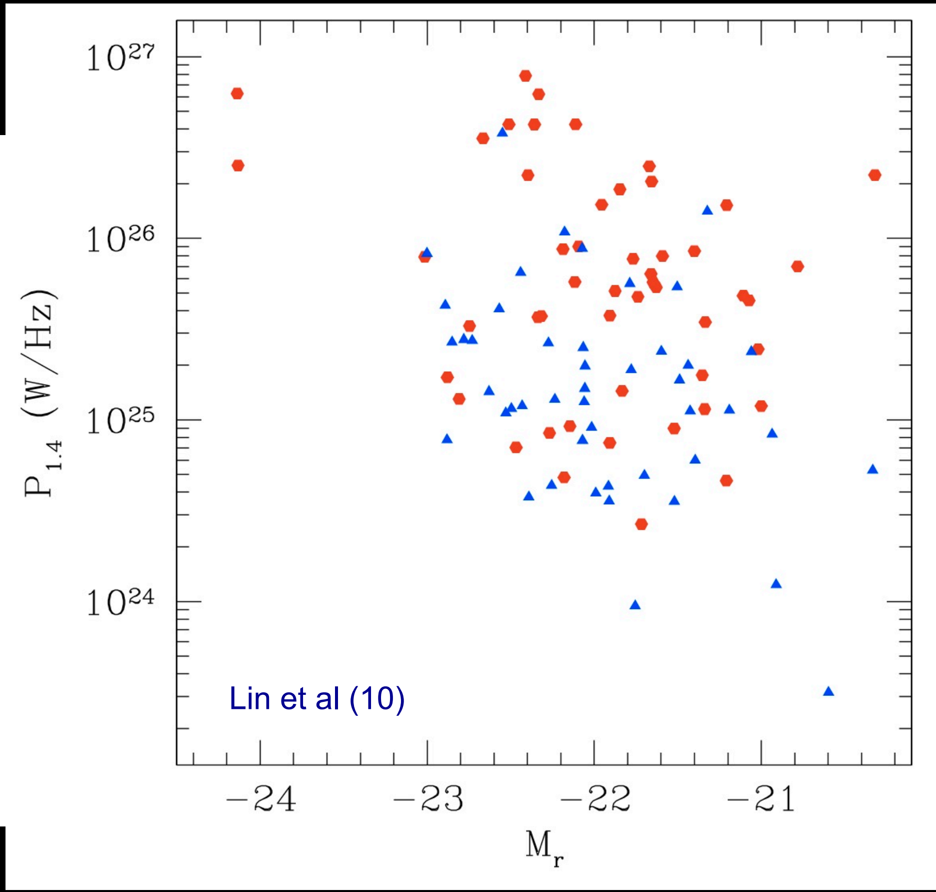

- an independent sample with FR I/II classification (Gendre et al 10)
  - red: FR II; blue: FR I
  - discrepancy due to sample construction?

summary

- simple morphological measure such as r_s has only limited use
- 3 populations of extended RGs with ~straight morphology
  - $a_{0.9,em}$: on average, hosted by lower mass galaxies, live in relatively sparse environments, higher accretion rates onto SMBH
  - a_{maj}: rest of class a, the majority of RGs
  - b: with prominent jet; share similar properties with a_{maj}, but differ in neighbor counts and nuclear emission
- accretion rate onto SMBH may be the primary driver for different populations; galactic structure plays a minor role
- differences in jet-launching mechanism may have implications on feedback at galactic and sub-Mpc scales
  - for $a_{0.9,em}$, the strong jets probably simply punctuate two small holes in the galaxy → not much feedback on the galaxy?!
  - the a_{maj} RGs may be the most promising agent for keeping the ICM hot: high probability to be found in cluster center, higher radio power compared to class b, larger cross section of lobes
  - for b: affect the host galaxy and stop star formation and nuclear activity?