

# The Spitzer View of FR-I Radio Galaxies

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# Radio Galaxies

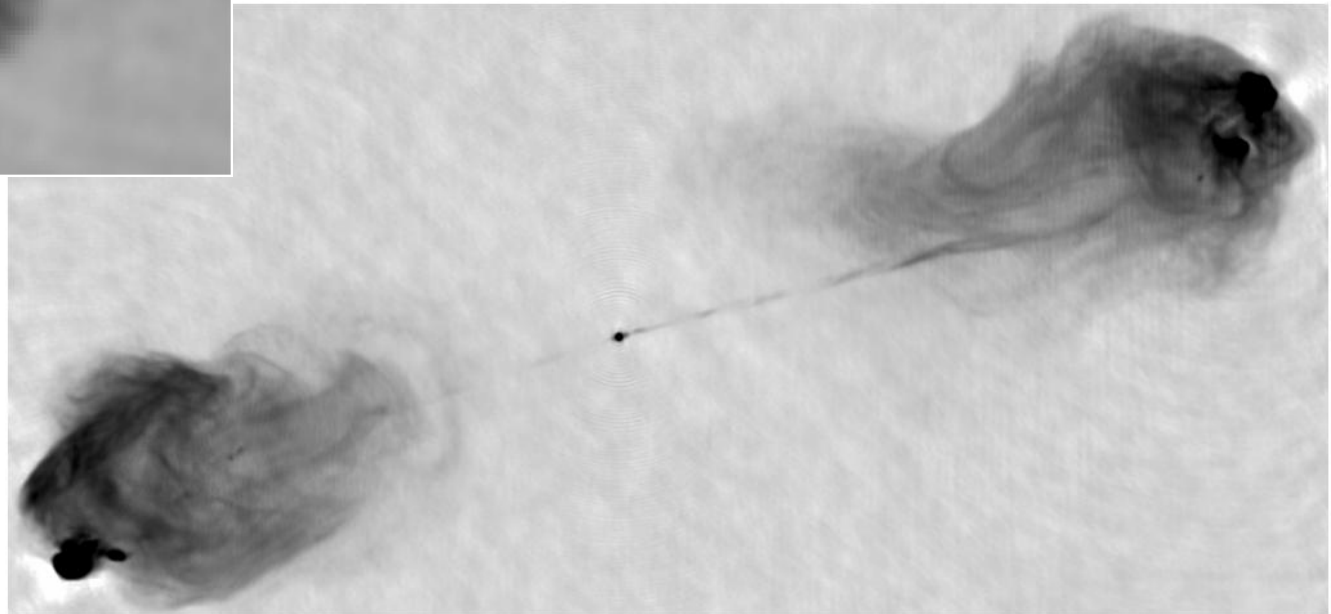
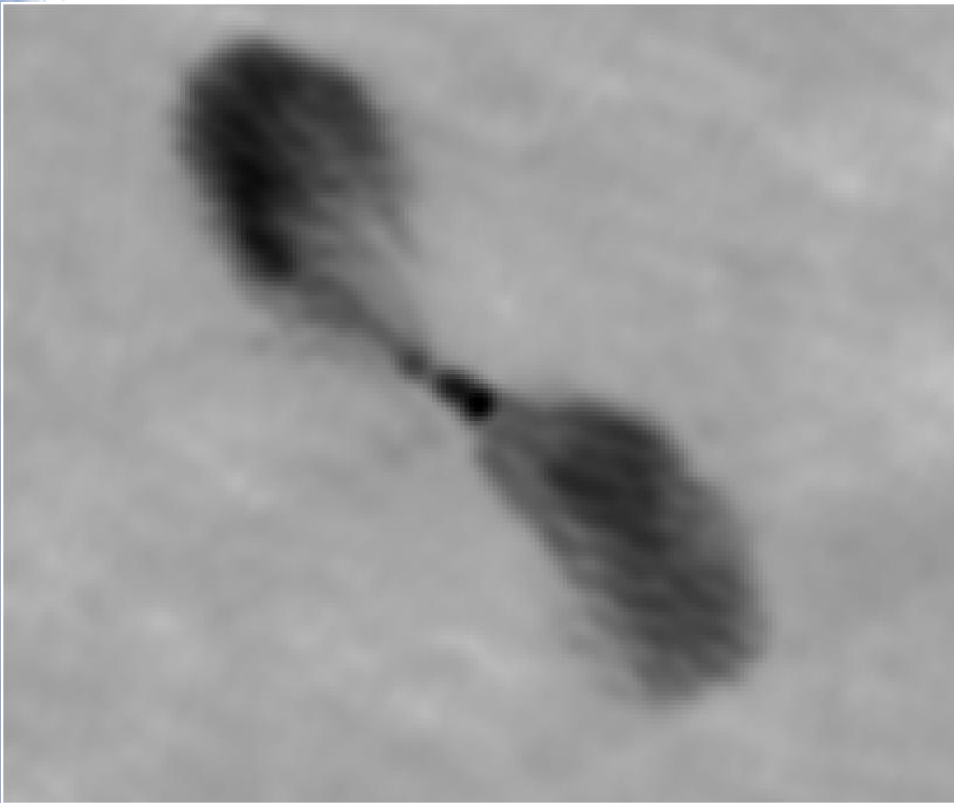
Bright (at low  $\nu$ ) and large (tens to hundreds of kpc) extragalactic radio sources essentially come in only two morphological types:

## Cyg A – FR-II

- most (radio) luminous
- edge brightened
- hot spots + collimated jets
- Quasars, BLRGs, HIGs, LIGs

## Cen A – FR-I

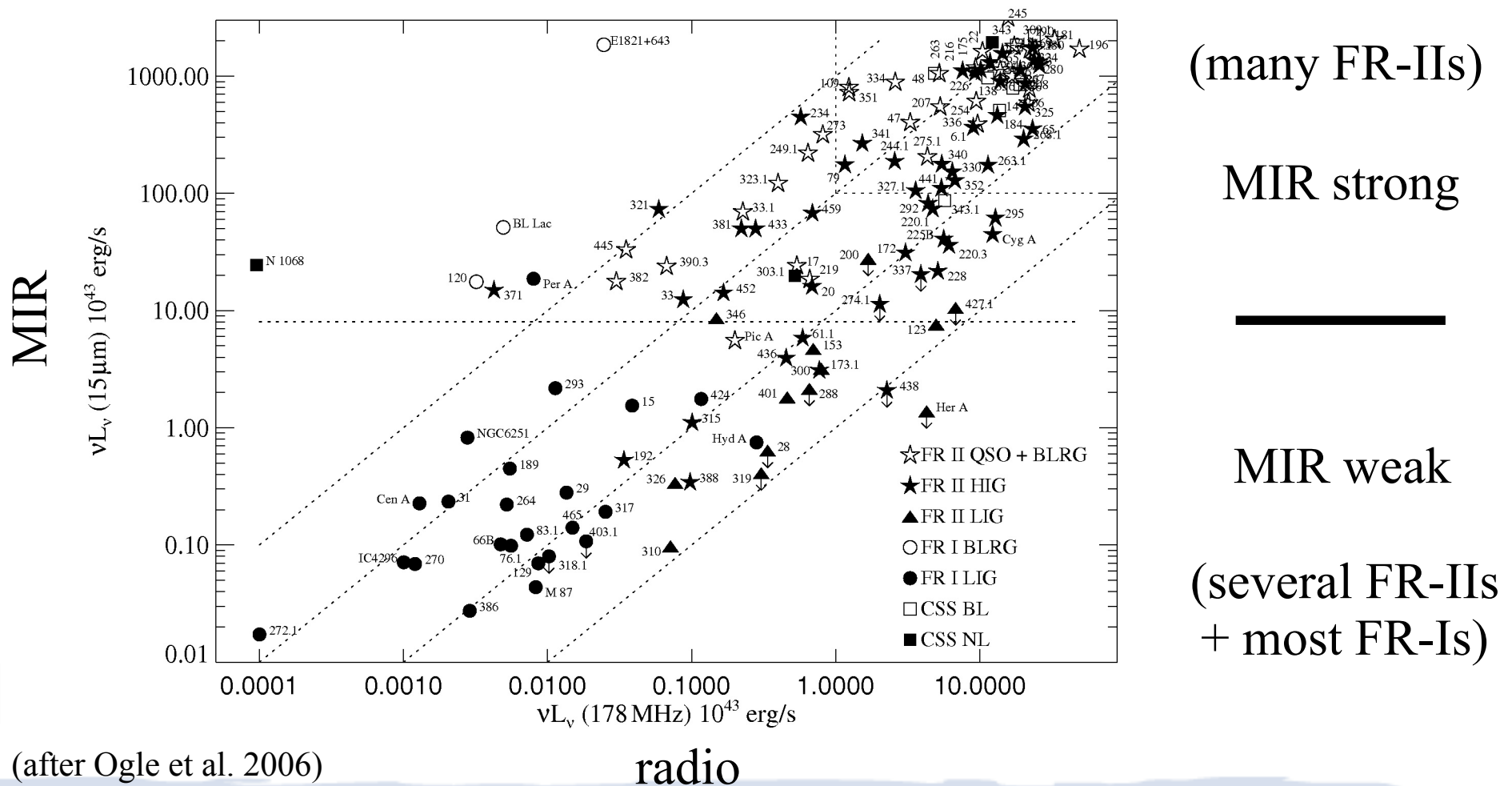
- less (radio) luminous
- edge darkened
- disrupted jet
- LIGs, WLRGs



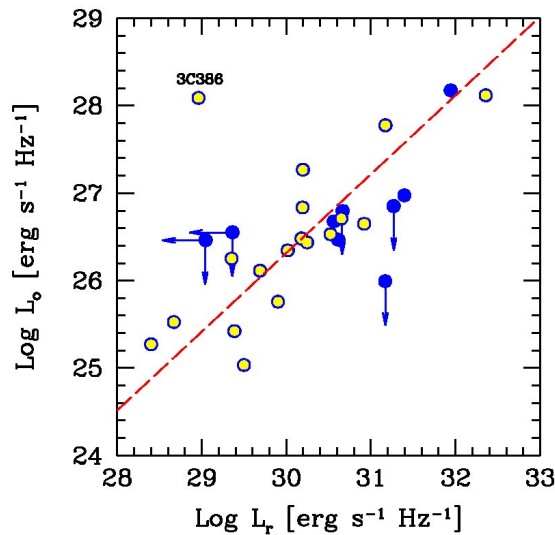
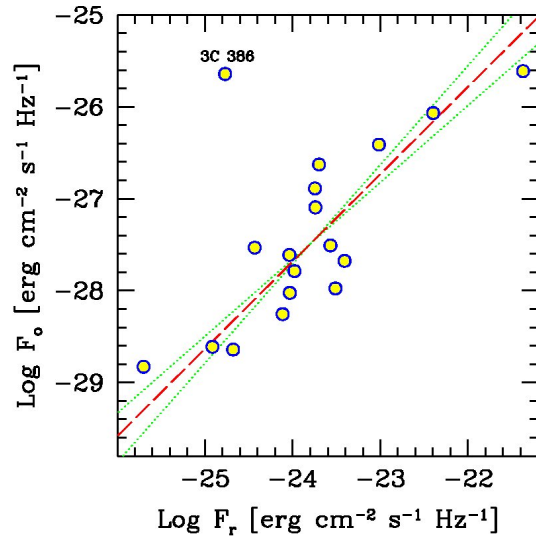
# The MIR perspective

- ISO: FR-Is and some FR-IIIs have little warm dust  
(e.g. Meisenheimer et al. 2001, Müller et al. 2004)

<=> many FR-IIIs and almost all FR-Is are LIGs with weak optical line emission



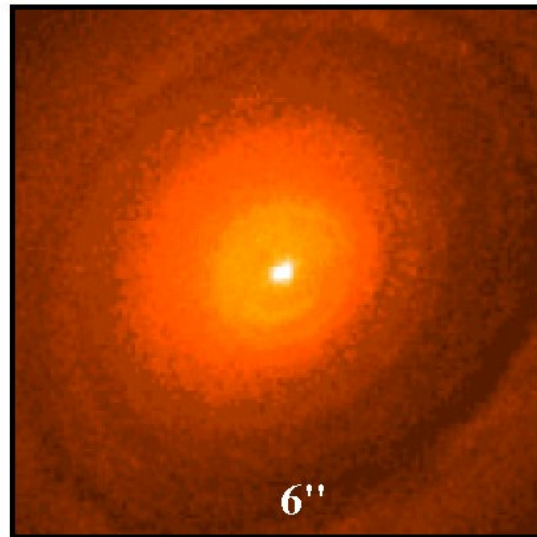
# The central engine in FR-Is



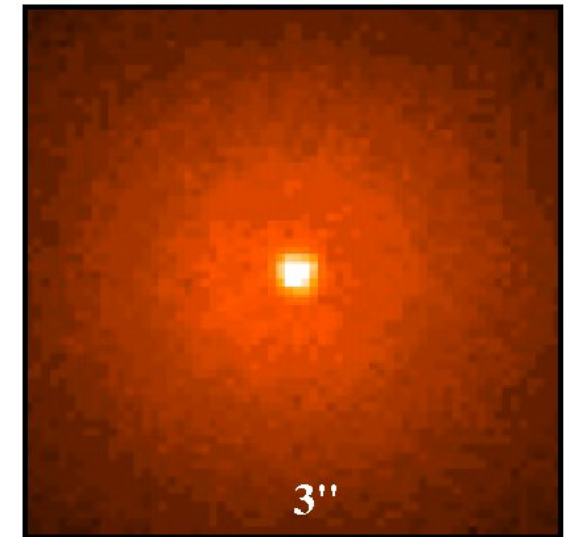
(e.g. Chiaberge et al. 1999,  
Balmaverde et al. 2006,  
Evans et al. 2006)

- Optical point sources in centers of FR-Is
- Correlation of radio/optical/X-ray cores  
=> synchrotron from base of a jet
- High detection rate ( $\sim 85\%$ )  
=> nucleus unobscured
- No broad emission lines and little MIR  
=> no “torus” and no radiatively efficient accretion

**3C 31**



**3C 66B**



# Observations

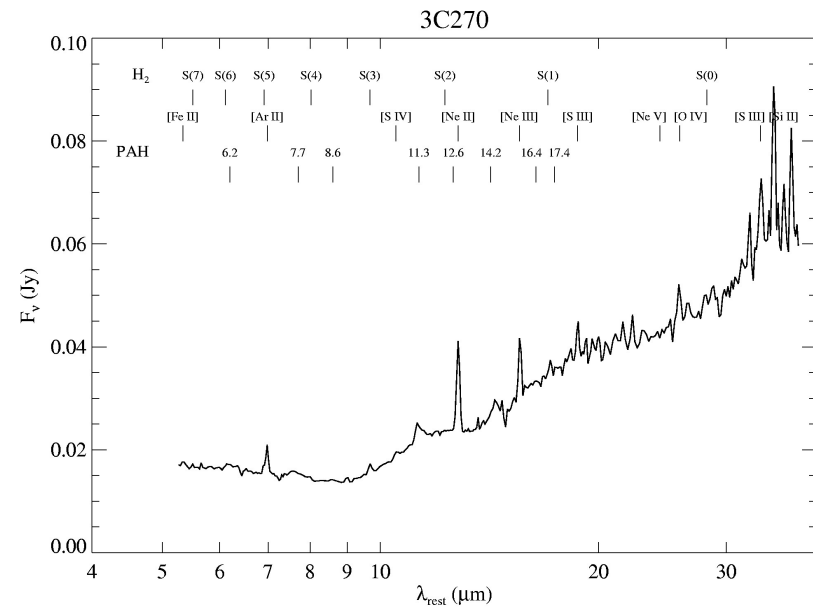
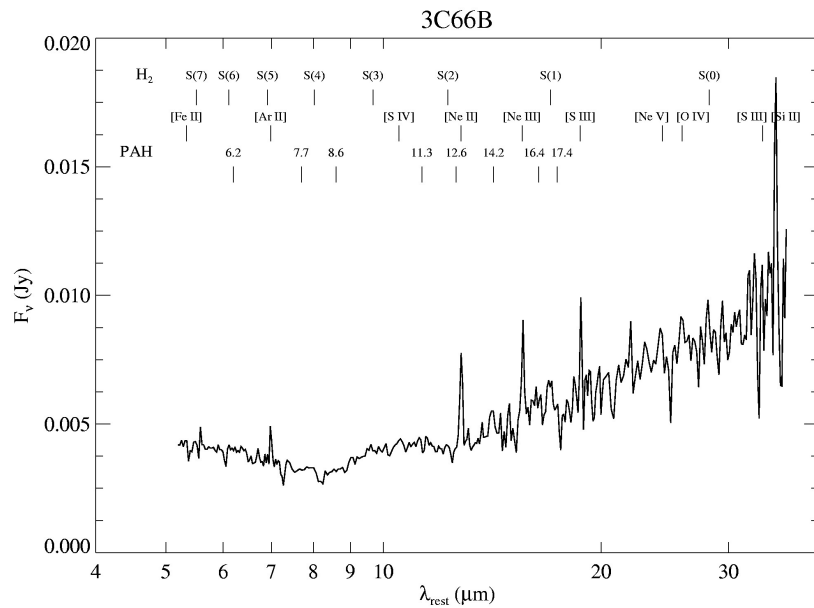
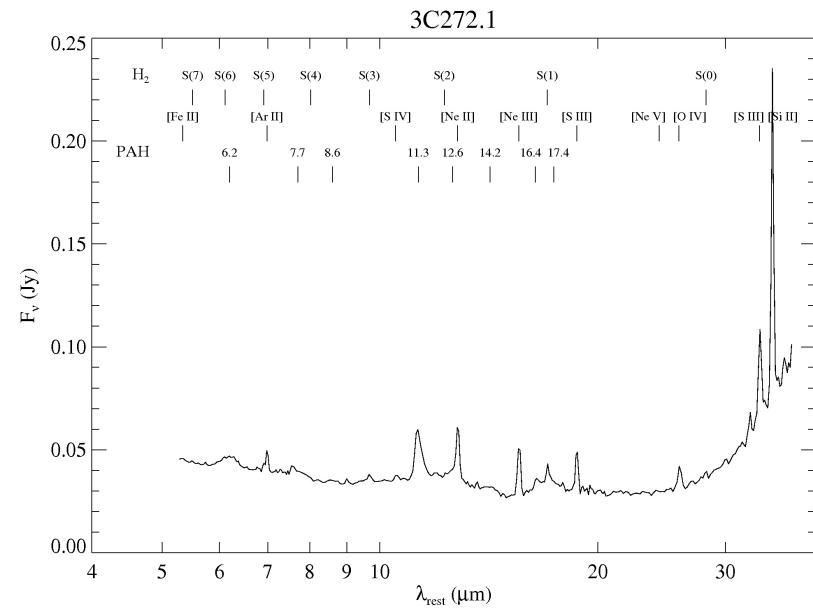
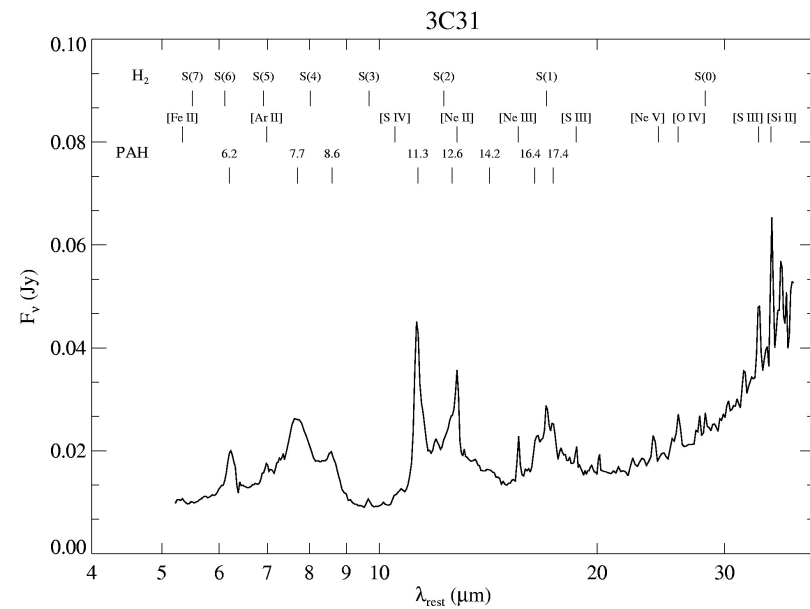
MIR spectra of 25 FR-Is with Spitzer/IRS 5-36.5  $\mu\text{m}$   
(15 with optical CCCs)

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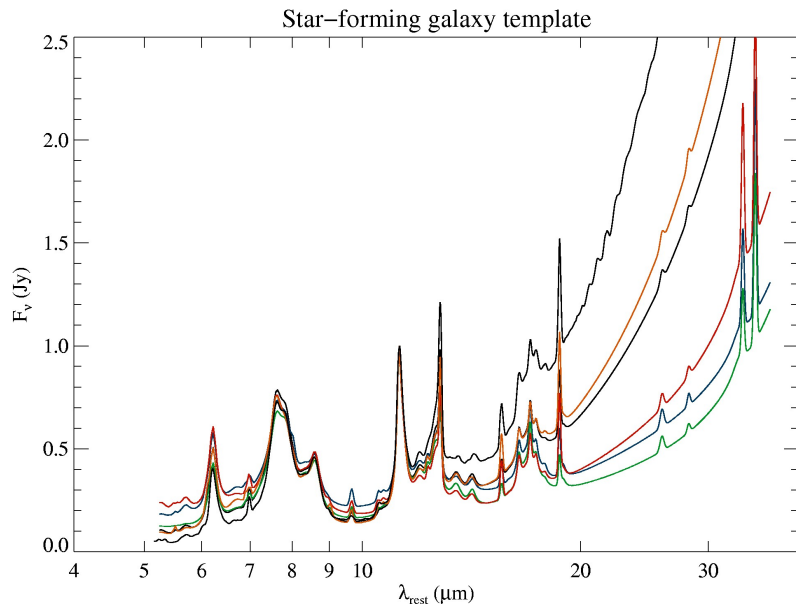
- possibly detect warm nuclear dust by reprocessed thermal emission
- if MIR in fact non-thermal: observations should be consistent with other core measurements and synchrotron prediction
- because of IRS aperture (3.6'' - 10.7'') and faintness of AGN host contributions possible
  - Stellar emission
  - Star formation

# MIR spectra of FR-I radio galaxies



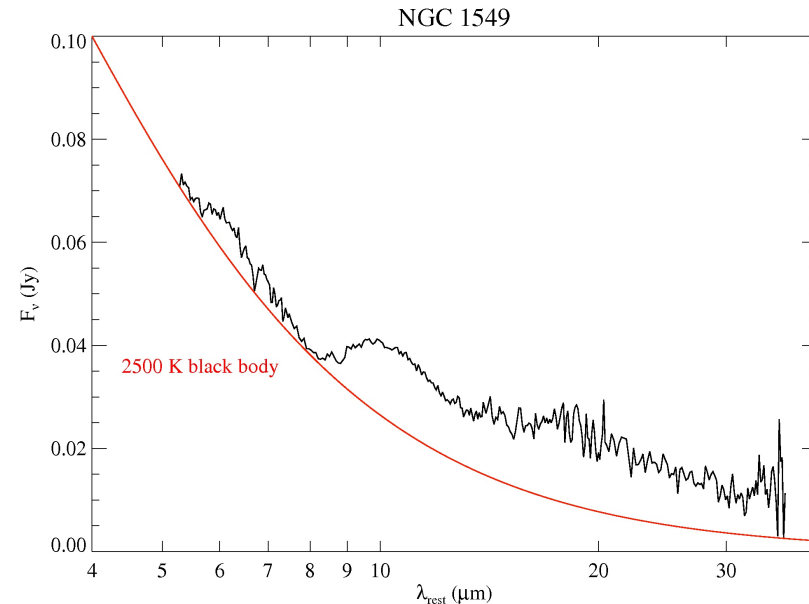
# Host galaxy contributions

## Star formation



- red spectral slope  
=> possible contaminant
- subtract star forming template  
(Smith et al. 2007)
- scale to 11.3  $\mu\text{m}$  PAH

## Stellar emission



- Stellar photospheres +  
dust from AGB stars
- blue spectral slope over IRS range
- compare FR-I with spectrum of  
early-type galaxy (Bressan et al. 2006,  
Kaneda et al. 2008)

MIR continuum not from stars or SF: thermal or non-thermal?

# “Nuclear” SEDs

(Landau et al. 1986)

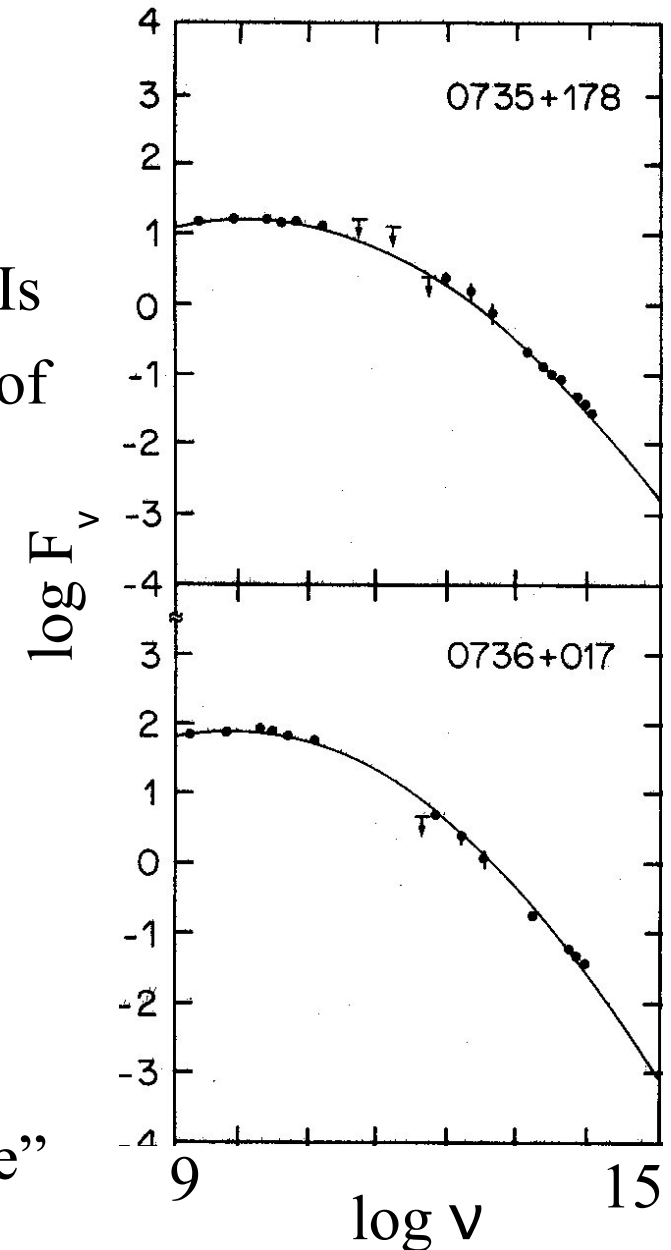
- use radio core (VLA, VLBA/I) + optical CCCs (HST) data to estimate non-thermal core contribution
- many BL Lacs aligned counterparts of FR-Is
- parabola well suited to approximate SEDs of BL Lac cores in  $\log \nu$  vs.  $\log F_\nu$

=> fit nuclear FR-I data with parabola

$$\log F_\nu = C + (\log \nu - B)^2 / A$$

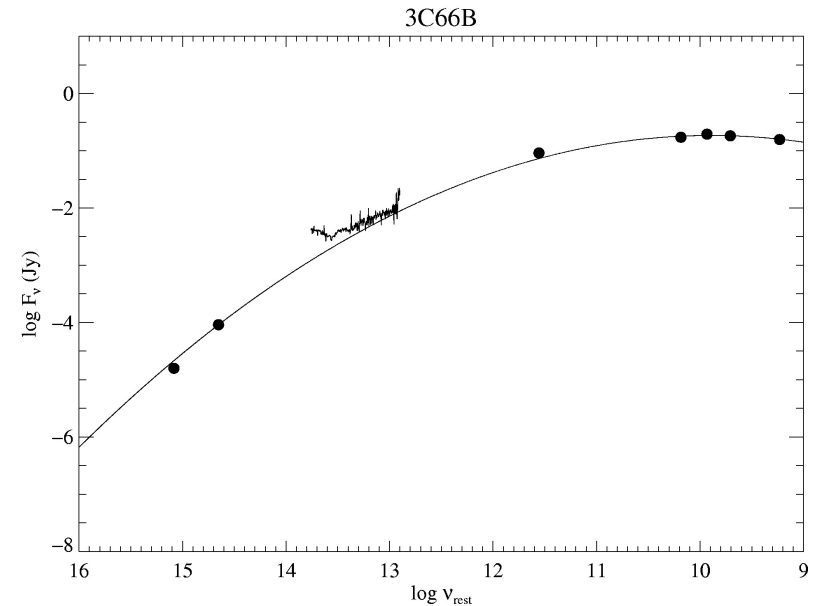
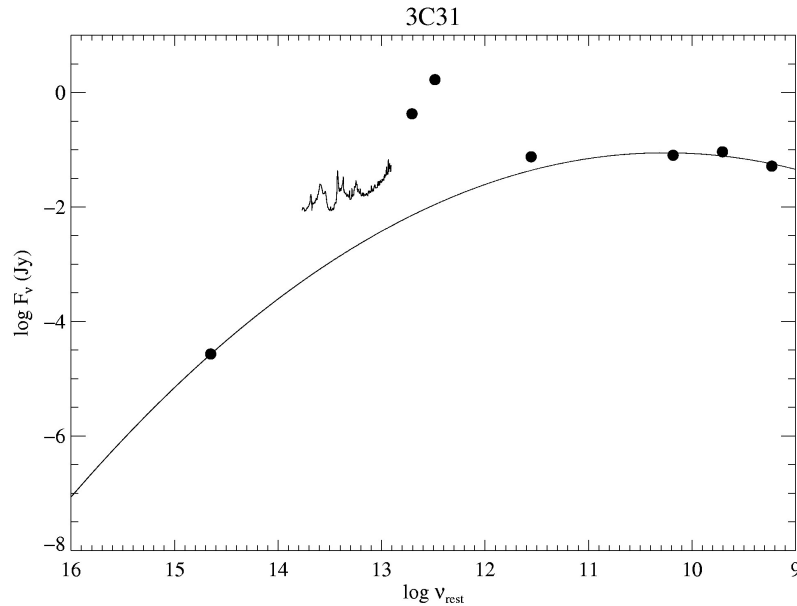
log of peak frequency

“curvature”



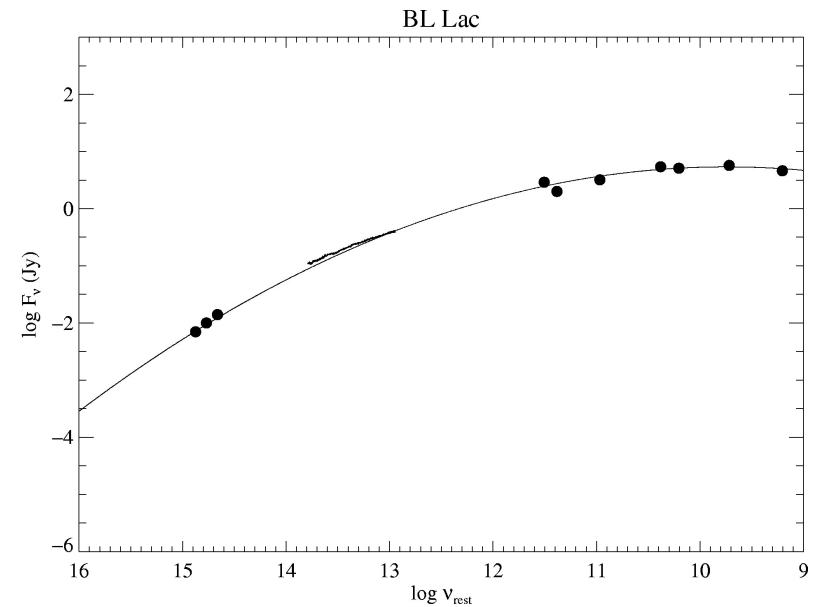


# “Nuclear” SEDs

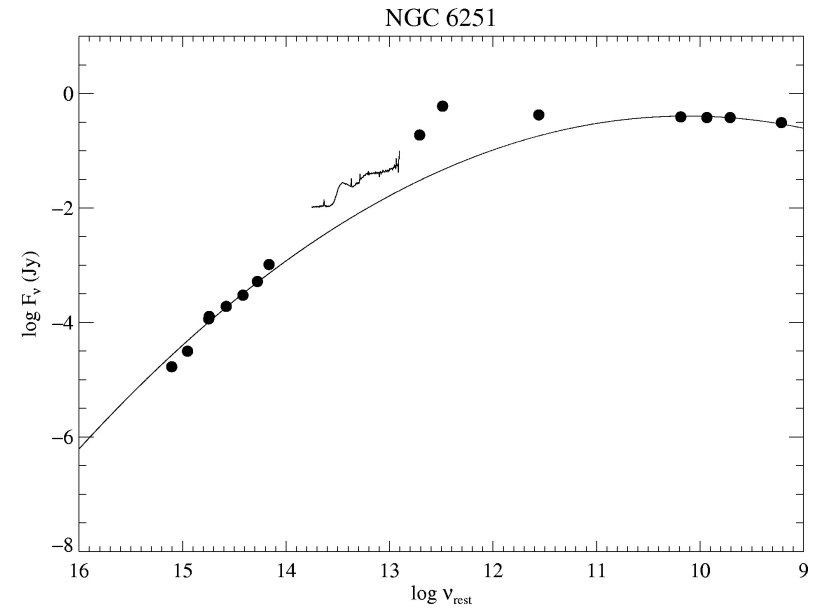
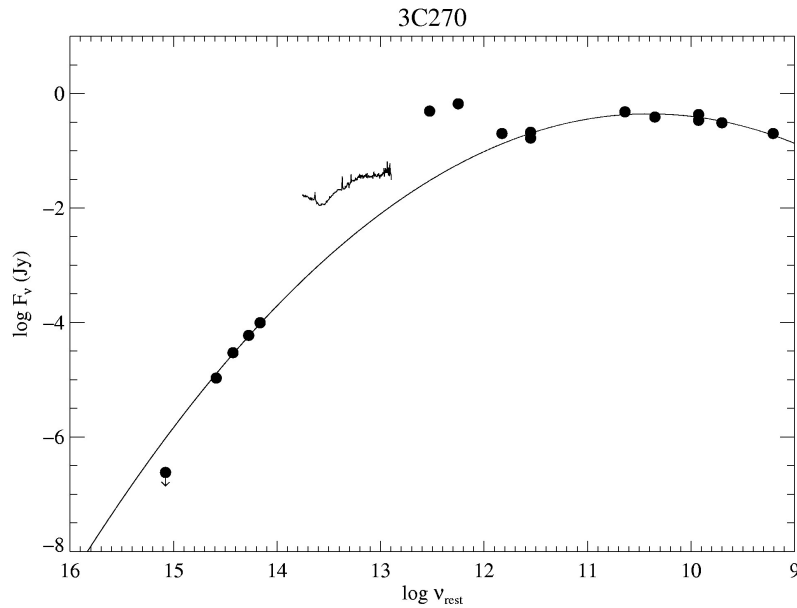


Excess over core SED  
due to host galaxy:  
5 / 15 objects

Spectra synchrotron dominated:  
MIR emission non-thermal  
6 / 15 objects



# “Nuclear” SEDs

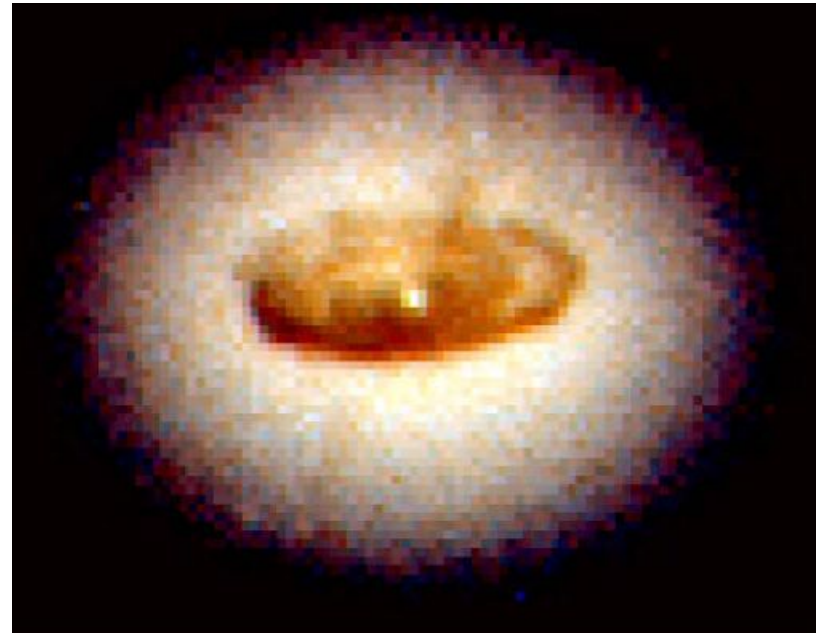
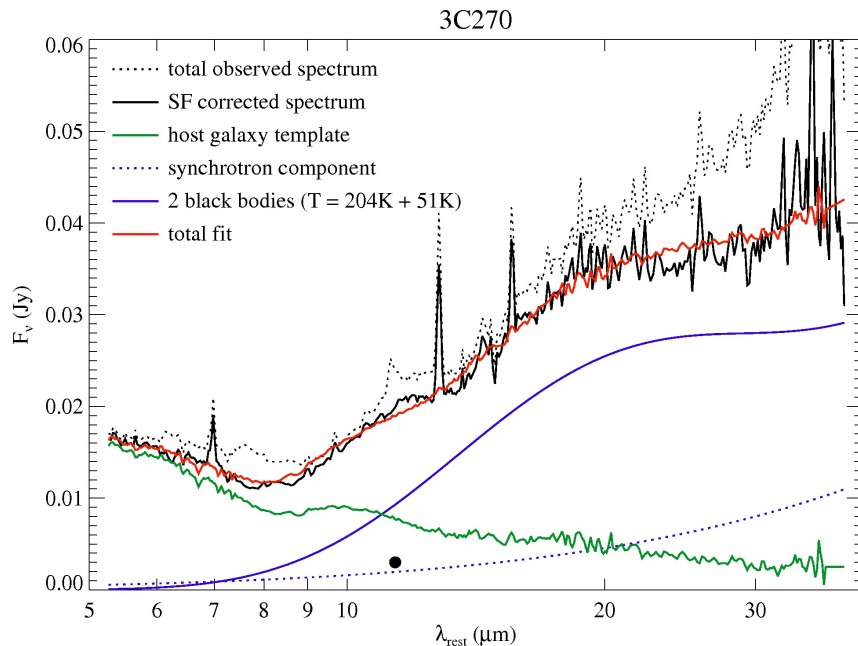


MIR continuum in excess of core emission  
which is not due to stellar processes or SF  
for 4 / 15 objects:

3C15  
3C84  
3C270  
NGC 6251

FR-Is with warm dust!

# 3C270 – NGC 4261

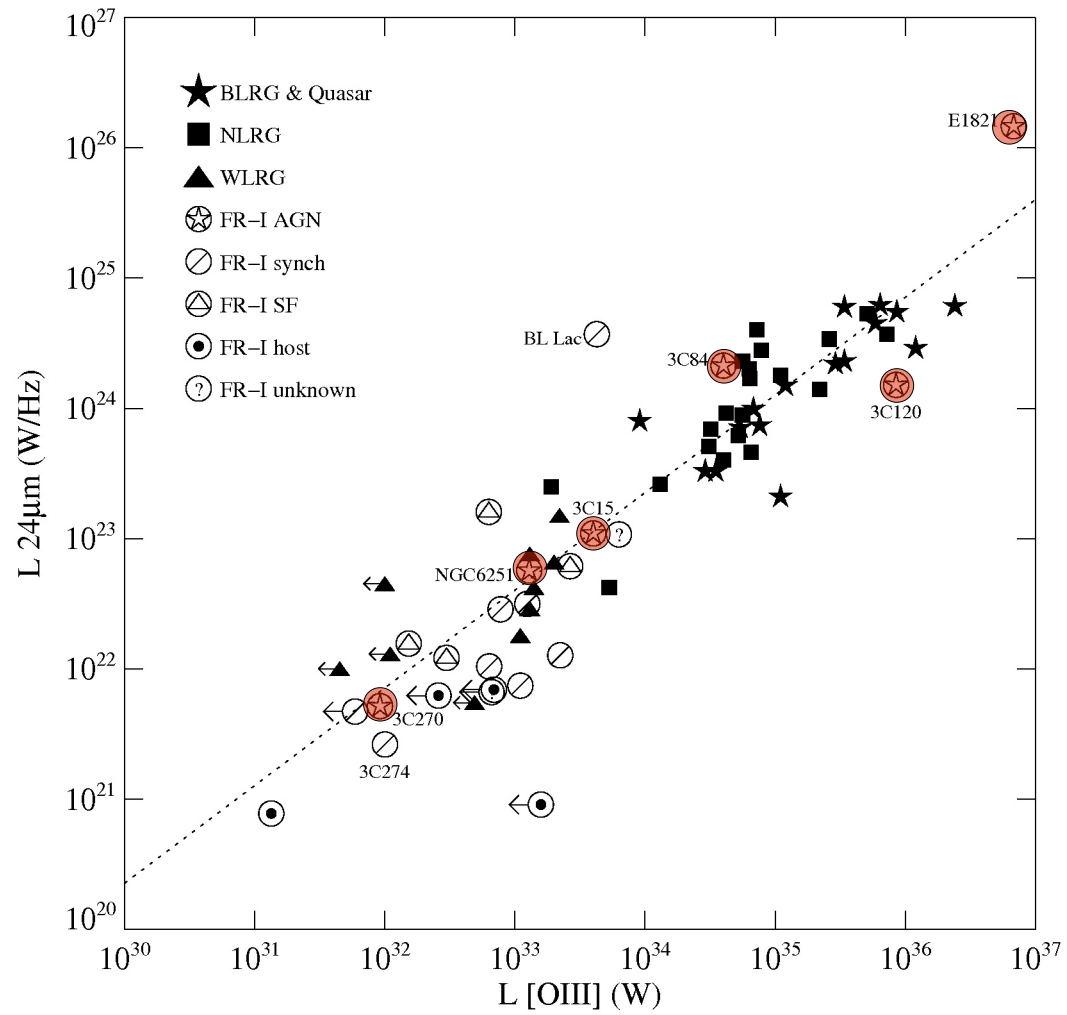


- tentative broad  $H\alpha$  in polarized light (Barth et al. 1999)
- $\sim 300$  pc nuclear dust disc in silhouette (Jaffe et al. 1993)
- moderate X-ray properties ( $L_X \sim 1 \times 10^{41}$  erg/s,  $N_H \sim 5 \times 10^{22}$  cm $^{-2}$ ) + marginal Fe  $K\alpha$  detection (e.g. Sambruna+ 2003, Zezas+ 2005, Rinn+ 2005, ...)
- Seyfert-type nuclear emission-line ratios (Ferrarese et al. 2006)
- $\sim 200$  K warm dust ( $\nu L_\nu \sim 4 \times 10^{41}$  erg/s @  $15 \mu\text{m}$ )

Hidden AGN at low(er) luminosity ??

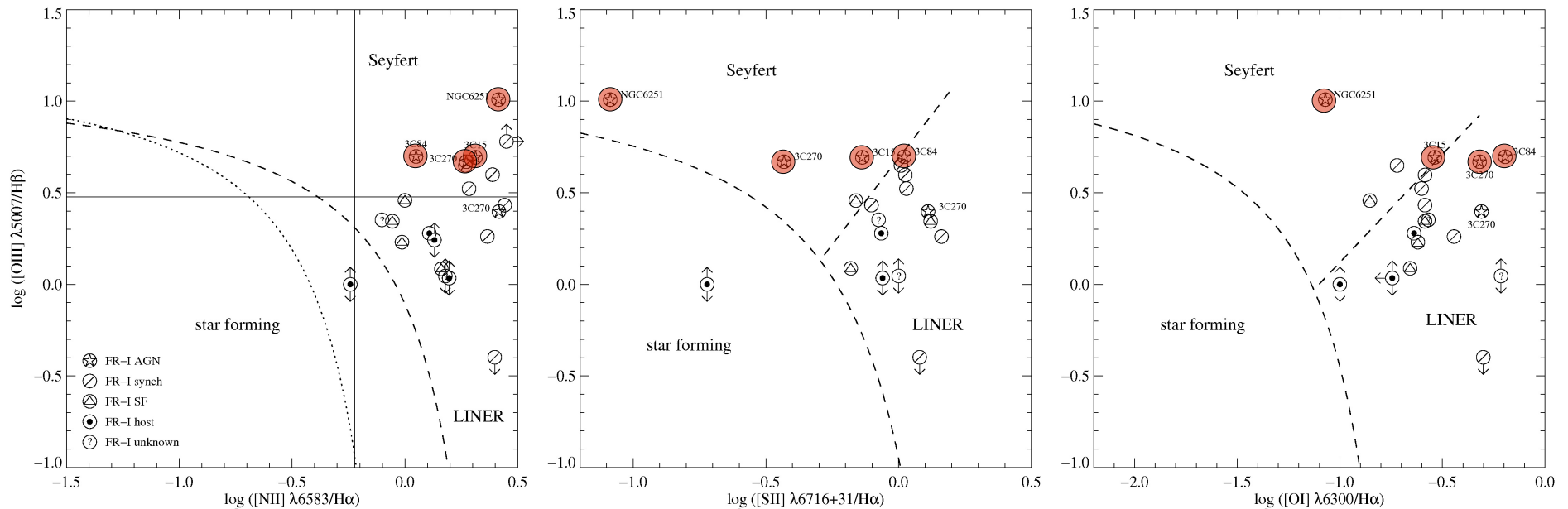


# $L_{24\mu\text{m}}$ vs. $L_{[\text{OIII}]}$



(Tadhunter et al. 2007, Dicken et al. 2009)

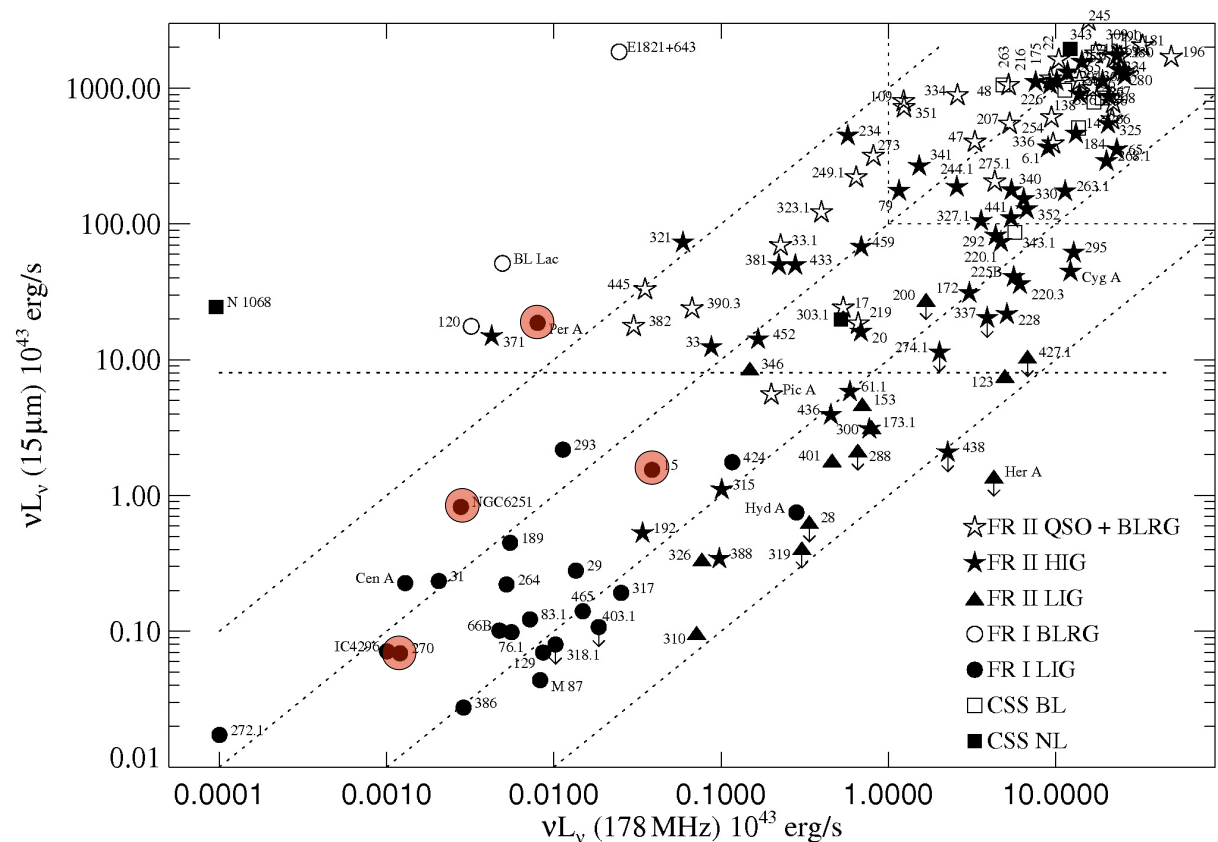
# Optical emission-line diagnostics



- FR-Is show LINER or Seyfert ratios, no HII or transition sources
- Synchrotron-dominated sources close to Seyfert/LINER border
- FR-Is with Seyfert spectra show warm dust
- FR-Is with LINER spectra and warm dust are LINER type-1 (see also Sturm et al. 2006)
- Does warm dust come with the presence of broad emission lines ?

# Summary

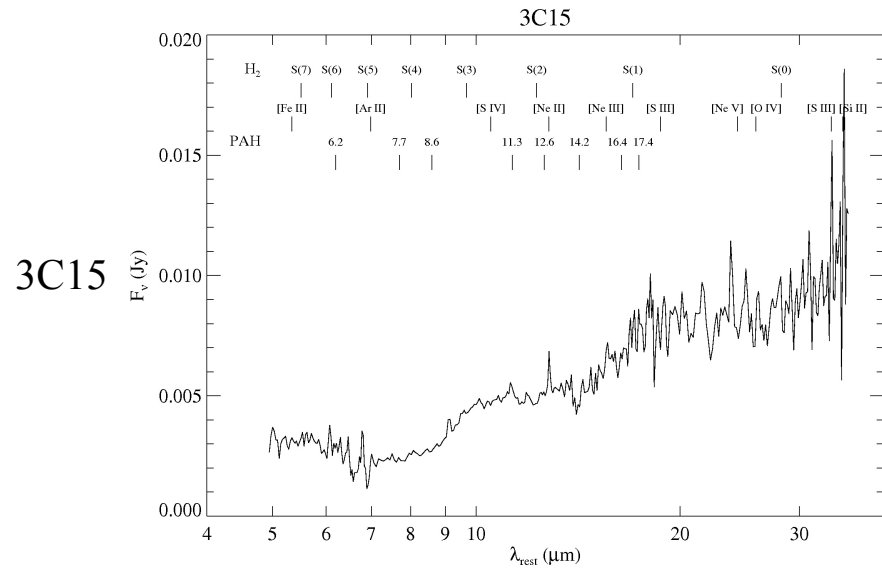
- Most FR-Is lack significant dust emission
- But some FR-Is have warm dust !
- Not adequate to generalize on associations between FR-I galaxies and “non-thermal only” AGN
  - Where is the dust ?
  - What heats it ?



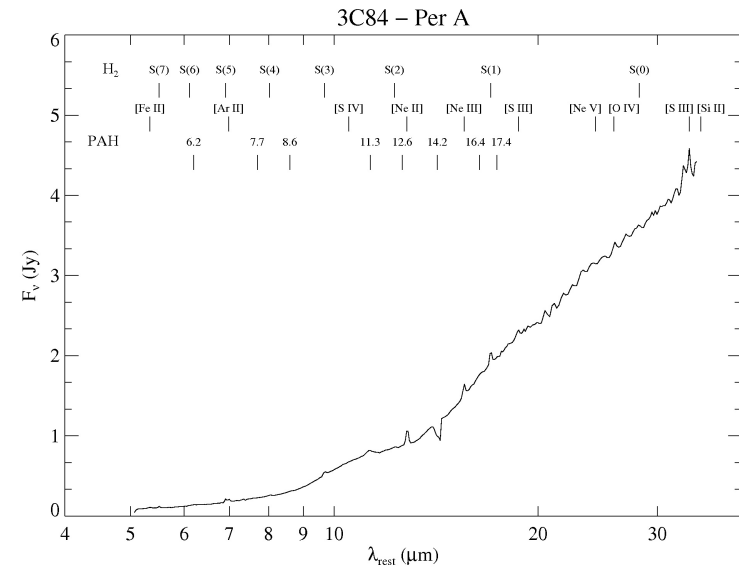
The End....?



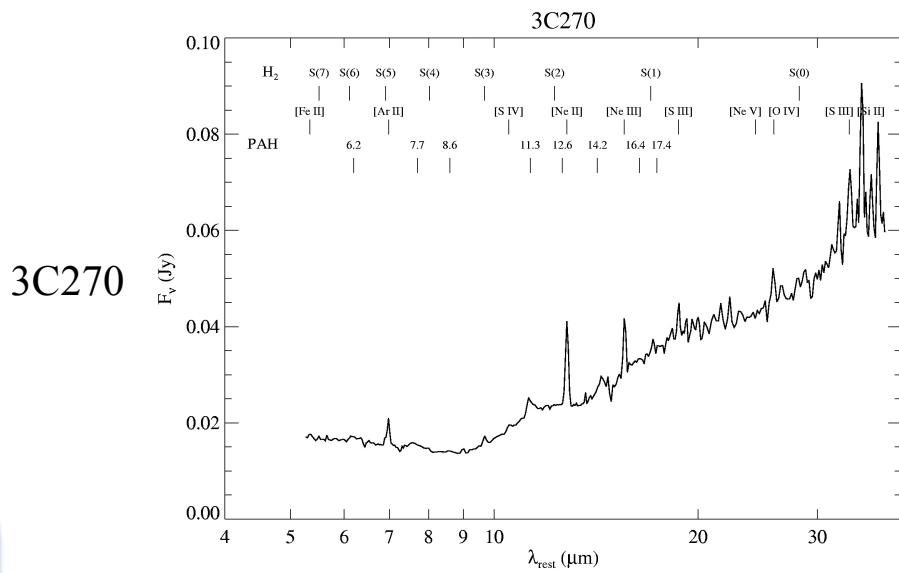
# FR-I spectra



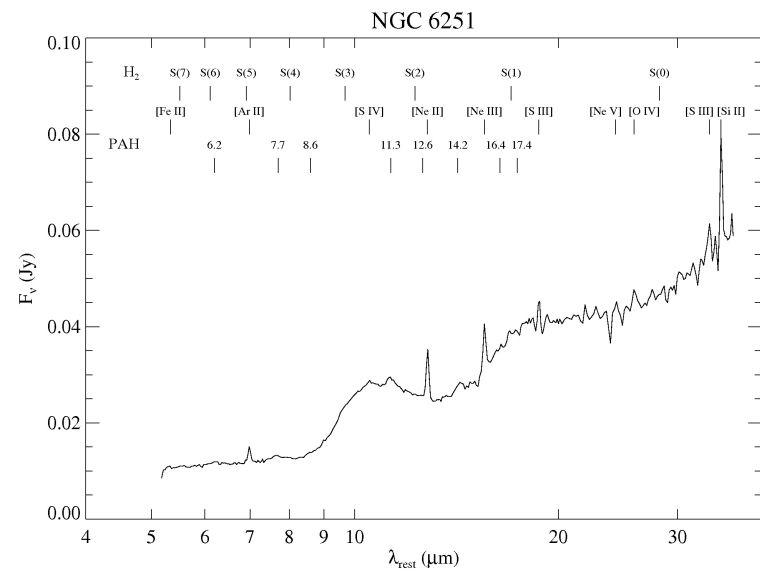
3C15



3C84



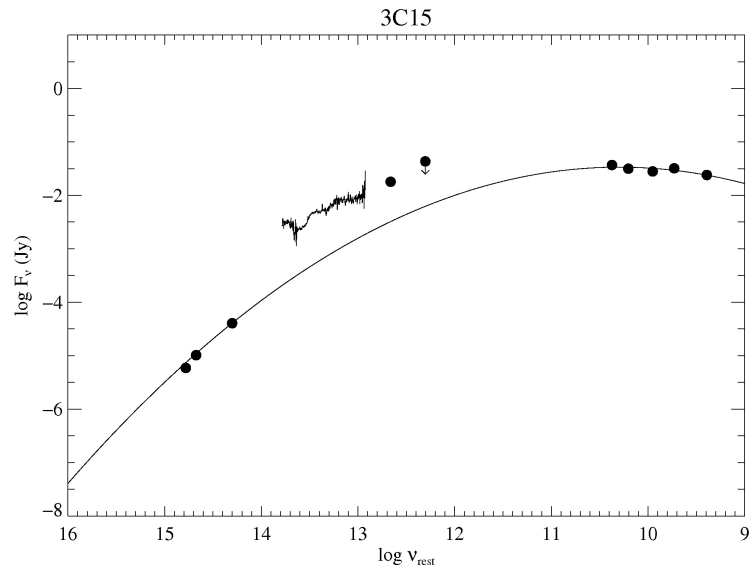
3C270



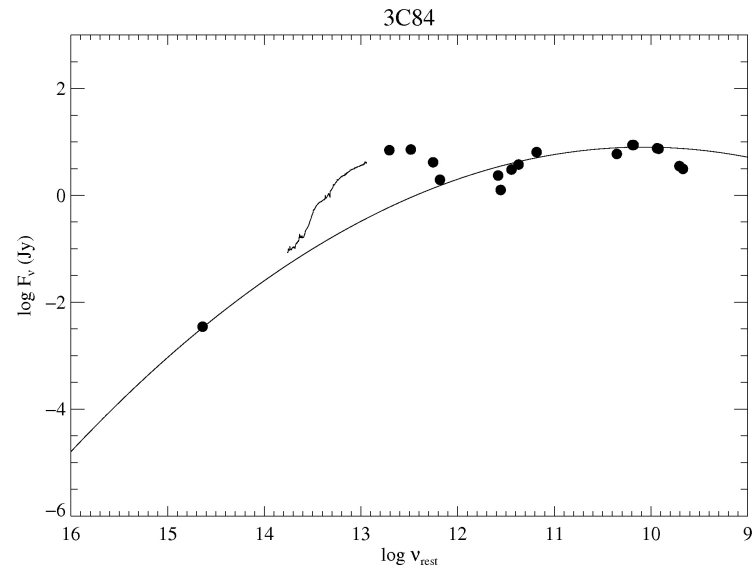
NGC 6251

# FR-I nuclear SEDs

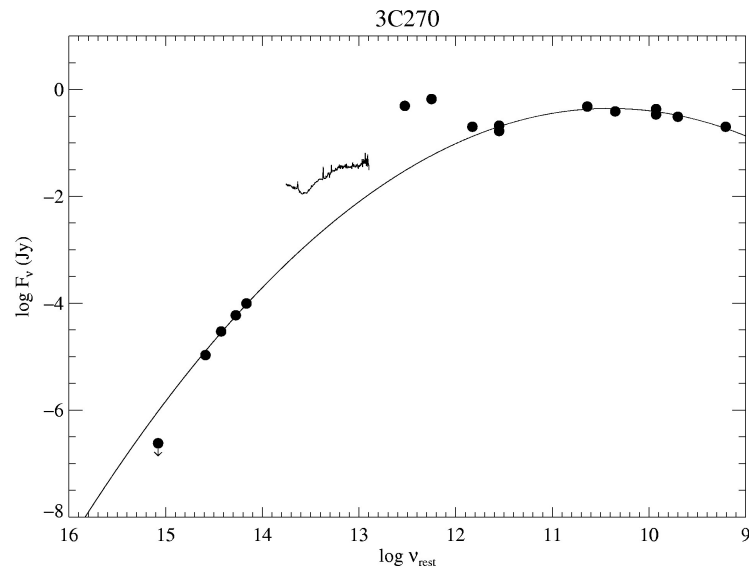
3C15



3C84



3C270



NGC 6251

