

# Elusive accretion discs in low-luminosity AGN



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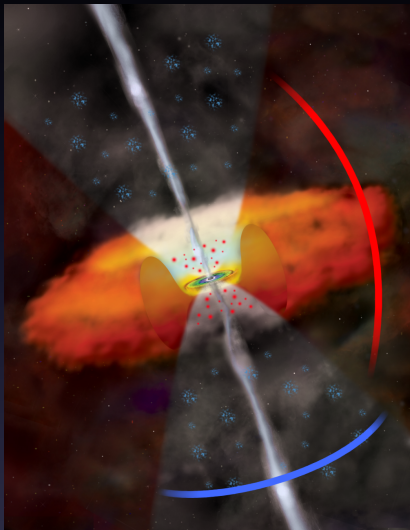
S. Markoff, M.A. Prieto, L. Reb, J.A. Acosta-Pulido

O. González-Martín, D. Espada

# Outline

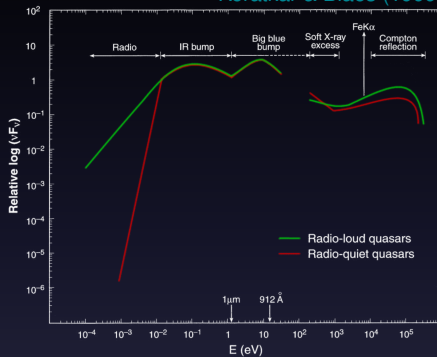
- 1 Introduction
  - The Unified Model
  - LLAGN: Not simply faint AGN
- 2 Observations
  - Method
  - Multiwavelength dataset
  - Sample
- 3 The nature of the IR emission
  - LLAGN at parsec scales
  - A Compact Jet Model
- 4 Summary

# The Unified Model

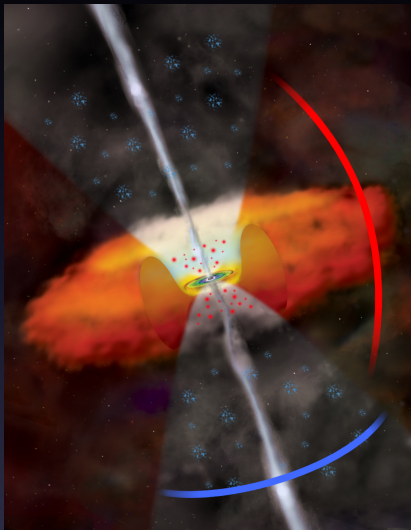


Antonucci (1993), Urry & Padovani (1995)

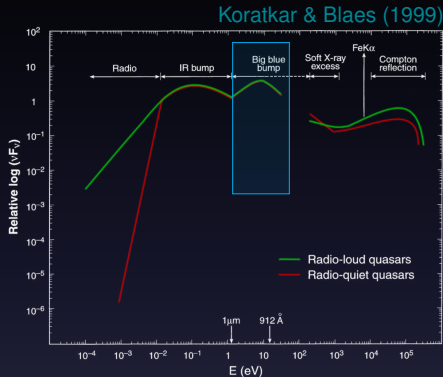
Koratkar & Blaes (1999)



# The Unified Model

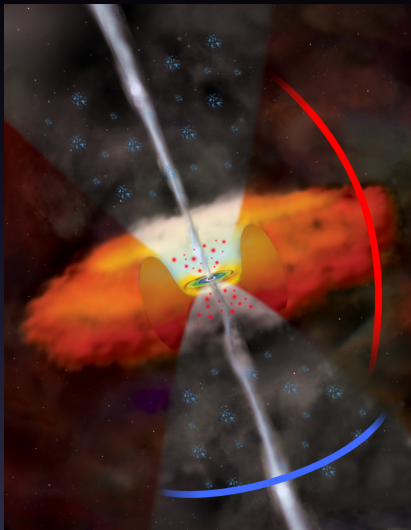


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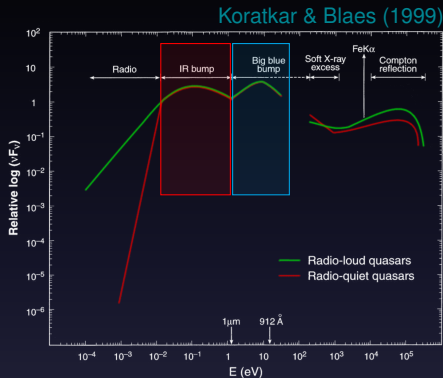


- **Accretion disk** at optical/UV

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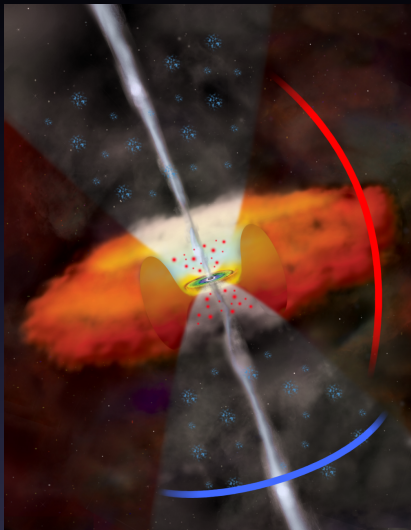


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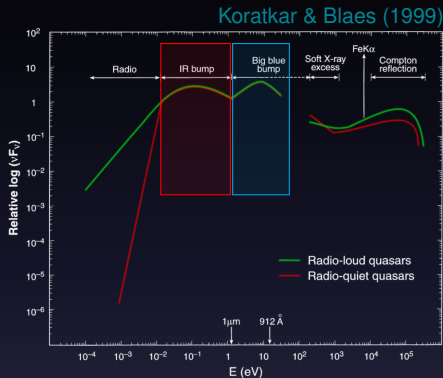


- **Accretion disk** at optical/UV
- **Dust** re-emits in the IR

# The Unified Model



Antonucci (1993), Urry & Padovani (1995)



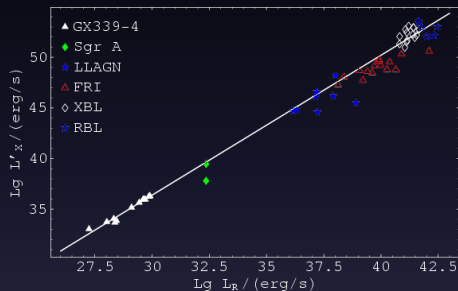
- **Accretion disk** at optical/UV
- **Dust** re-emits in the IR
- $L_{bol} \gtrsim 10^{42}$  erg/s  
(Seyferts, Quasars)

# Not simply faint AGN

- **Majority** of AGN population  
( $\sim 1/3$  of nearby galaxies)
- Low luminosity:  $\lesssim 10^{42}$  erg/s
- **Radiatively inefficient:**  
 $\log(L_{bol}/L_{Edd}) \lesssim -3$

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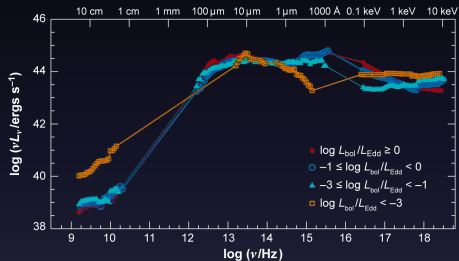
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(Merloni+2003; Falcke+2004)





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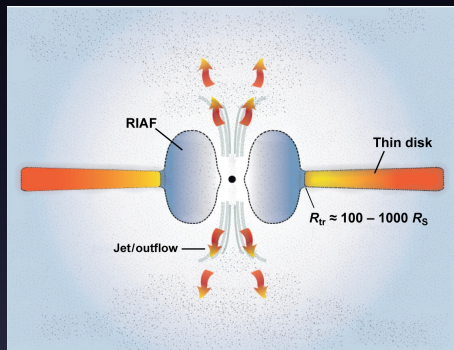
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- Absence of **Big Blue Bump**  
(Ho+1996)



Ho LC. 2008   
Annu. Rev. Astron. Astrophys. 46:475–539

# Not simply faint AGN

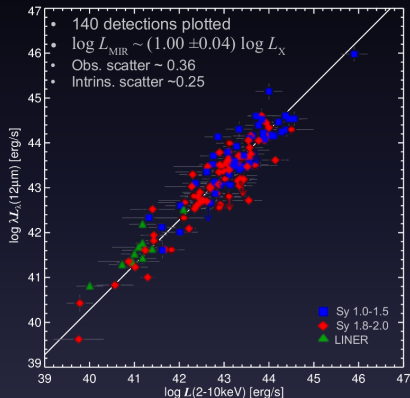
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 $\log(L_{bol}/L_{Edd}) \lesssim -3$
- **Fundamental plane** of BH (Merloni+2003; Falcke+2004)
- Absence of **Big Blue Bump** (Ho+1996)
- Inflow/outflow (ADAF/Jet) explain inefficient accretion



# Standard accretion?

## Similarities with Quasars/Seyferts:

- Optical/X-ray ratio  
 $-1.4 \lesssim \alpha_{ox} \lesssim -0.8$  (Maoz 2007)  
 $\Rightarrow$  **accretion disk?**
- Mid-IR – X-ray correlation  
 $\Rightarrow$  **torus?** (Asmus+2011)



# Not that easy

## Faint nuclei are not easy to study...

- ▶ **Outshined** by galaxy light at arcsec resolution
- ▶ **Sparse data sampling** to constrain models
- ▶ High-angular resolution to avoid bulge, disk, star-formation, etc.
- ▶ **IR range**  $\Rightarrow$  optically faint/obscured nuclei

# Multiwavelength dataset

- Follow-up of high-spatial resolution studies of the brightest and nearest Seyfert galaxies ([Reunanen+2010](#), [Prieto+2010](#))
- Images of the **central region** ( $\sim 30'' \times 30''$ ) for a sample of six nearby **LLAGN** (9-25 Mpc)
- Multiwavelength SEDs at **subarcsec** resolution ( $\lesssim 10$  pc):
  - ▶ VLT/NaCo adaptive optics (NIR)
  - ▶ VLT/VISIR (MIR)
  - ▶ *HST* (optical/UV)
  - ▶ Radio interferometry (VLA, VLBI, VLBA)
  - ▶ ALMA mm/submm interferometry
  - ▶ X-rays (*Chandra*, *XMM-Newton*, *Integral*)

# Multiwavelength dataset

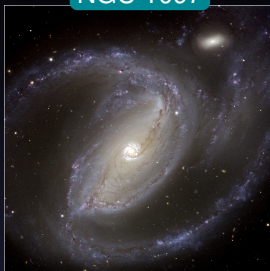
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  - ▶ X-rays (*Chandra*, *XMM-Newton*, *Integral*)
- Characterize the energy output at a **consistent physical scale**

# Sample

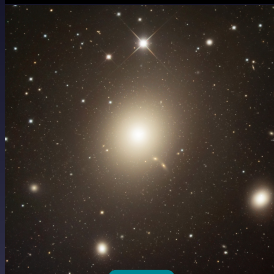
NGC 4594



NGC 1097



NGC 1386



M87



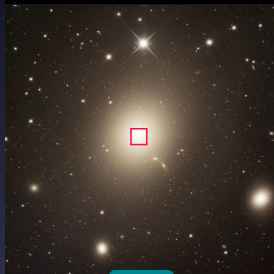
NGC 1052



NGC 3169

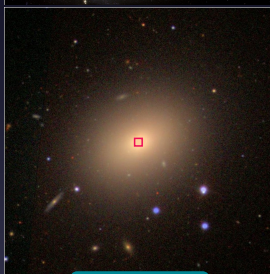
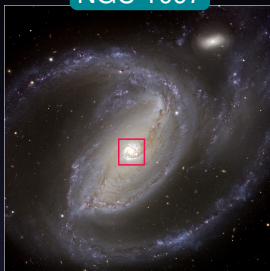
# Sample

NGC 4594



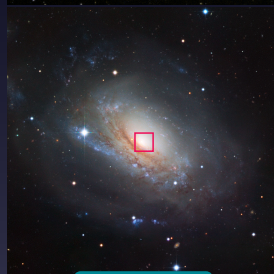
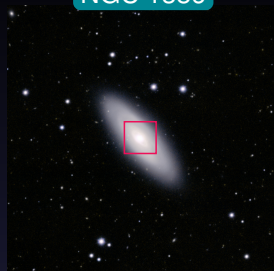
M87

NGC 1097



NGC 1052

NGC 1386



NGC 3169



## Sample

LINER 1

LINER 2

Sy2

NGC 4594

30'' ~ 1.3 kpc



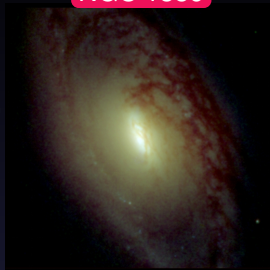
NGC 1097

32'' ~ 2.2 kpc

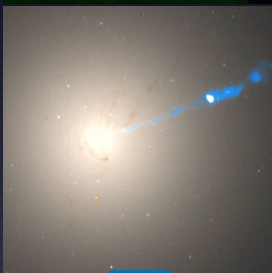


NGC 1386

26'' ~ 1.9 kpc

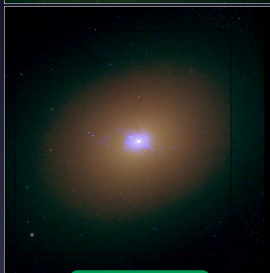


29'' ~ 2.3 kpc



M87

30'' ~ 2.6 kpc



NGC 1052

20'' ~ 2.4 kpc



NGC 3169

## Sample

LINER 1

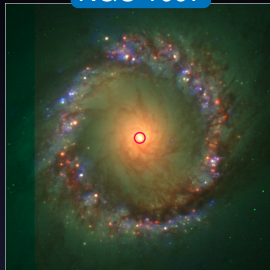
LINER 2

Sy2

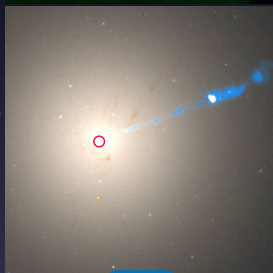
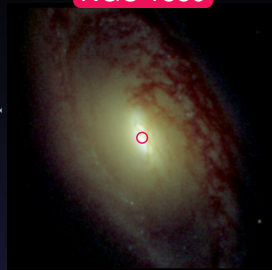
NGC 4594



NGC 1097



NGC 1386



M87

30'' ~ 2.6 kpc



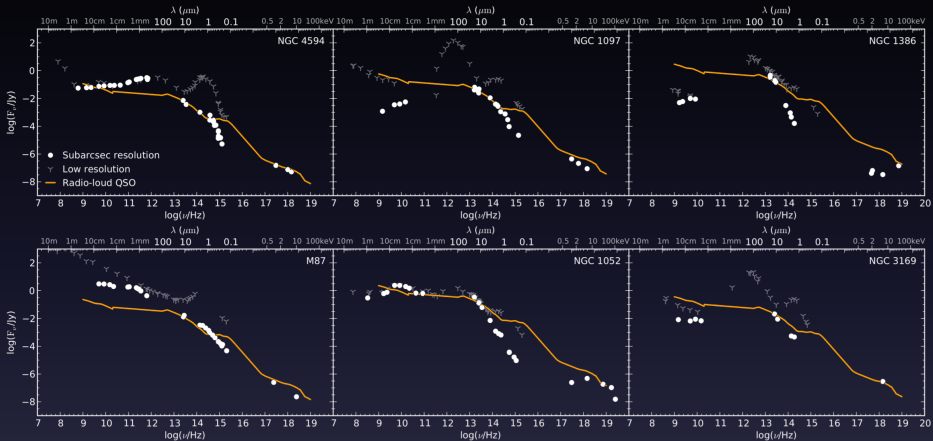
NGC 1052

20'' ~ 2.4 kpc



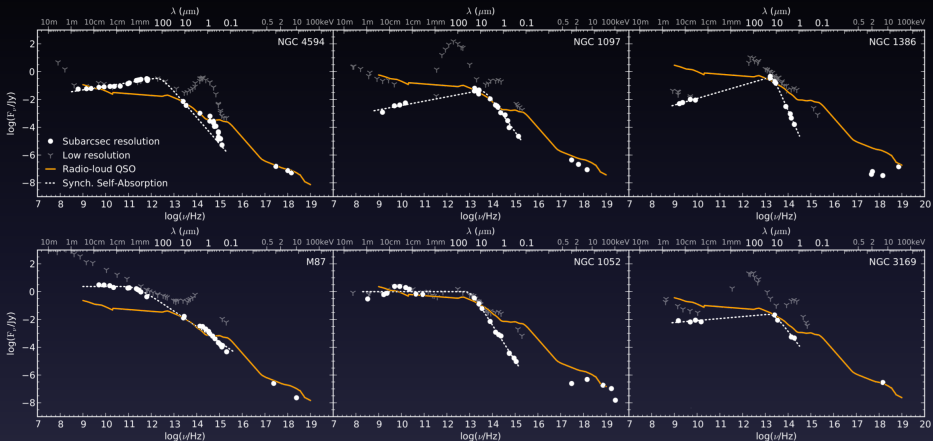
NGC 3169

# LLAGN at parsec scales



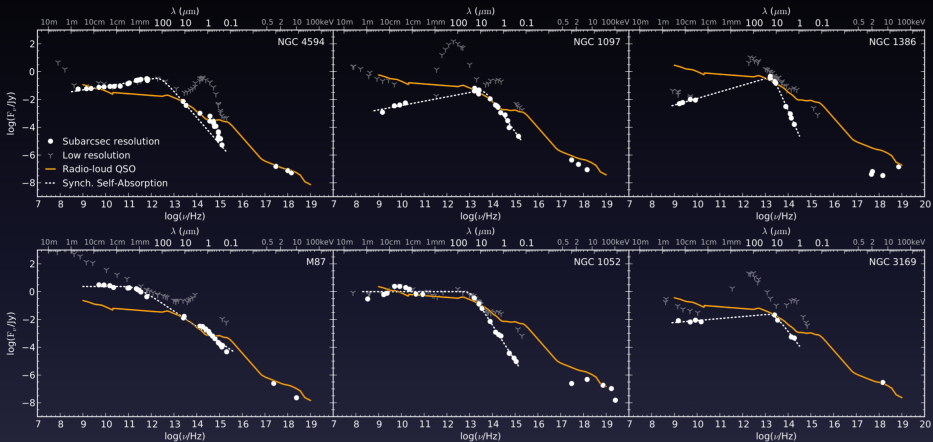
Subarcsec + Low-spatial resolution + Radio-Loud QSO (Elvis+1994)

# LLAGN at parsec scales



Subarcsec + Low-spatial resolution + **Radio-Loud QSO (Elvis+1994)**  
 Self-absorbed synchrotron emission (see also Mason+2012)

# LLAGN at parsec scales



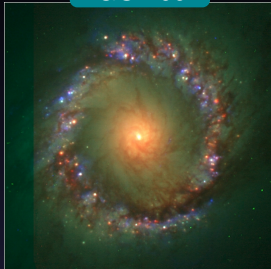
Subarcsec + Low-spatial resolution + **Radio-Loud QSO** (Elvis+1994)  
 Self-absorbed synchrotron emission (see also Mason+2012)  
 Much steeper ( $1 \lesssim \alpha_{thin} \lesssim 3$ ) than typical cooling slope of  $\approx 0.7$

# Compact (radio) Jets?

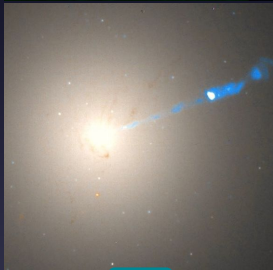
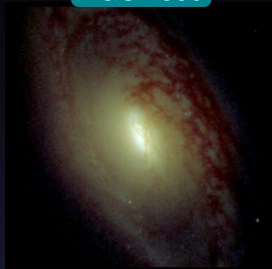
NGC 4594



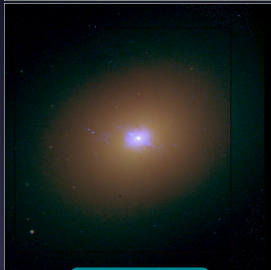
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NGC 3169

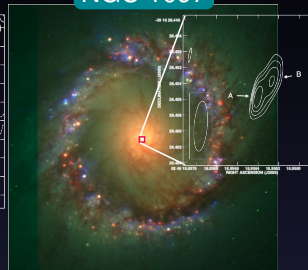
# Compact (radio) Jets?

(Mezcua & Prieto 2014; Hummel+1987; Claussen+1998; Hada+2013)

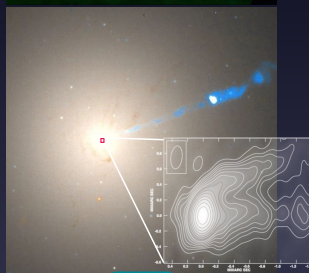
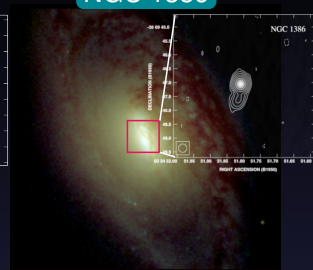
NGC 4594



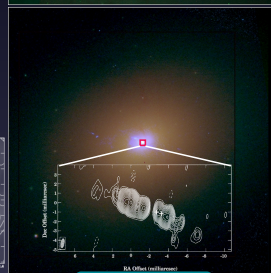
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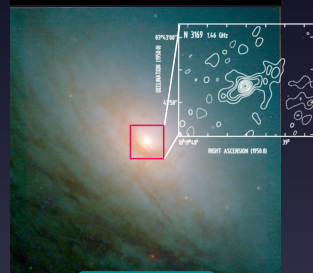
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M87

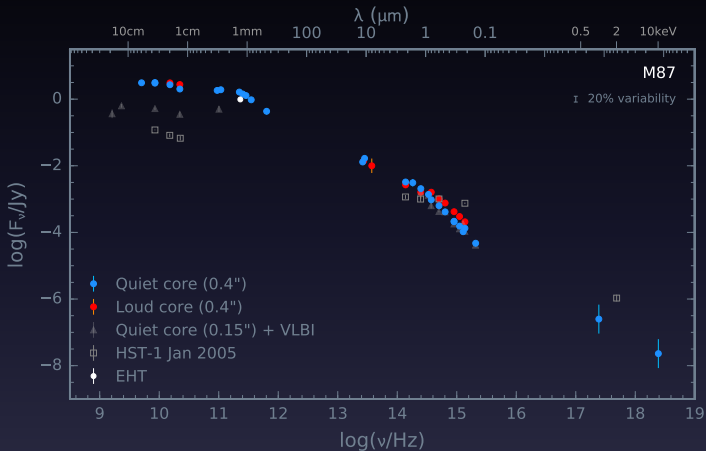


NGC 1052



NGC 3169

## M87

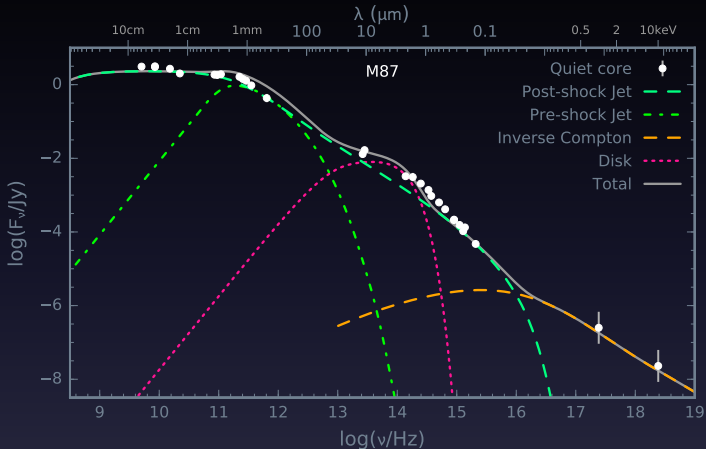


**Quiet** and **Active** periods  
(Prieto, Fernández-Ontiveros, Markoff+2016)





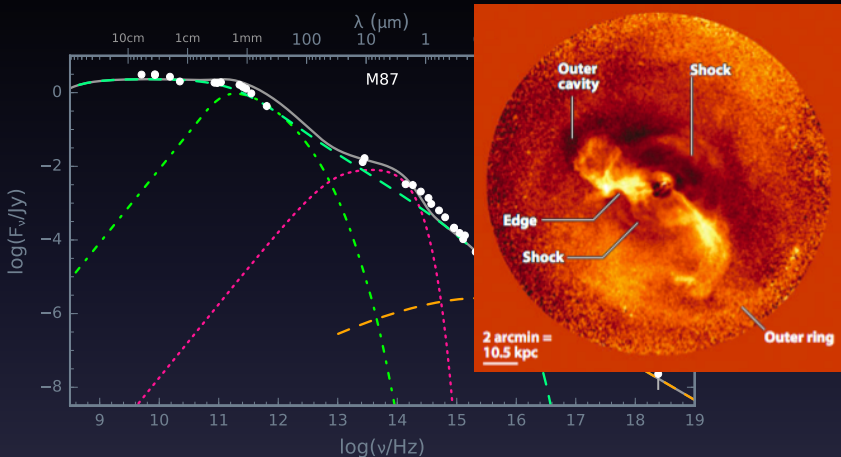
## M87



Jet+disk model,  $P_{jet} \approx 2 \times 10^{42} \text{ erg/s} \approx 2 \times 10^{-6} L_{\text{edd}}$

(Sgr A\*, M81, NGC4051 ; Falcke & Markoff 2000, Markoff+2005,2008, Maitra+2011)

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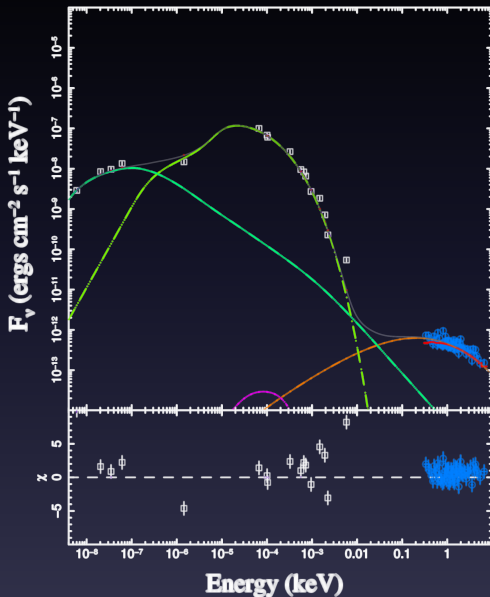


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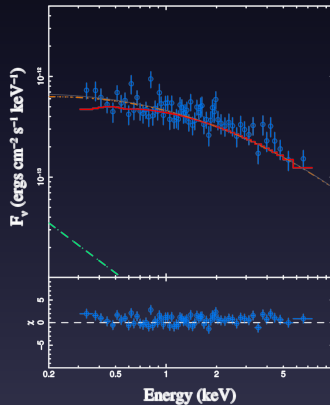
(Sgr A\*, M81, NGC4051 ; Falcke & Markoff 2000, Markoff+2005,2008, Maitra+2011)

Cavities ( $P_{\text{jet}} \sim 10^{44} \text{ erg/s}$ ) but  $\dot{M} \lesssim 6 \times 10^{-5} M_\odot/\text{yr}$  (upper disk limit)  
and  $\dot{M} \lesssim 9 \times 10^{-4} M_\odot/\text{yr}$  from Faraday rotation (Kuo+2014)

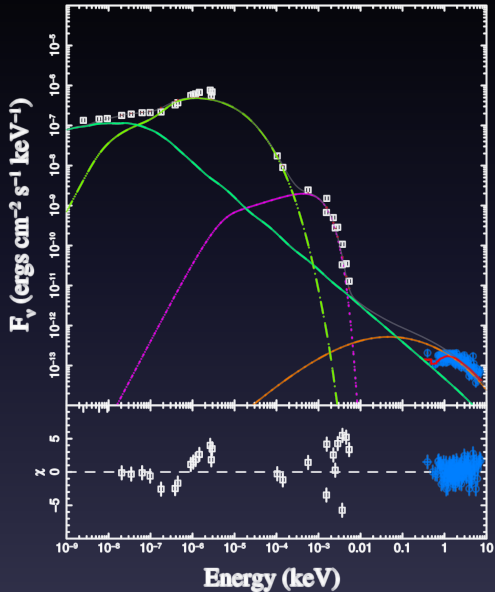
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NGC 1097  
(L. Reb, M.Sc. in prep.)

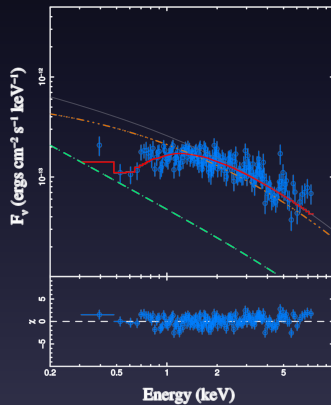


## Sombbrero



NGC 4594

(L. Reb, M.Sc. in prep.)



# Summary

- ▶ High-angular resolution to isolate **faint** nuclei from their host galaxy
- ▶ No features from **accretion disk** or **torus** in the SED
- ▶ **Compact jet**: LLAGN spectra dominated by outflow
- ▶ **Steep power law** ( $1 \lesssim \alpha \lesssim 3$ ) in the mid-IR to optical/UV range
- ▶ Possible **pre-shock** components