Looking for
Intermediate Mass Black Holes
in the center
Low Luminosity AGN

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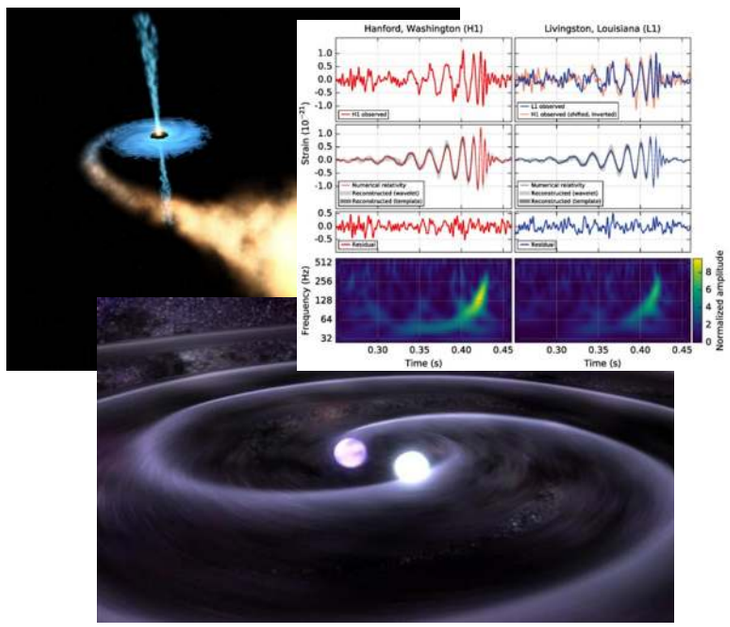
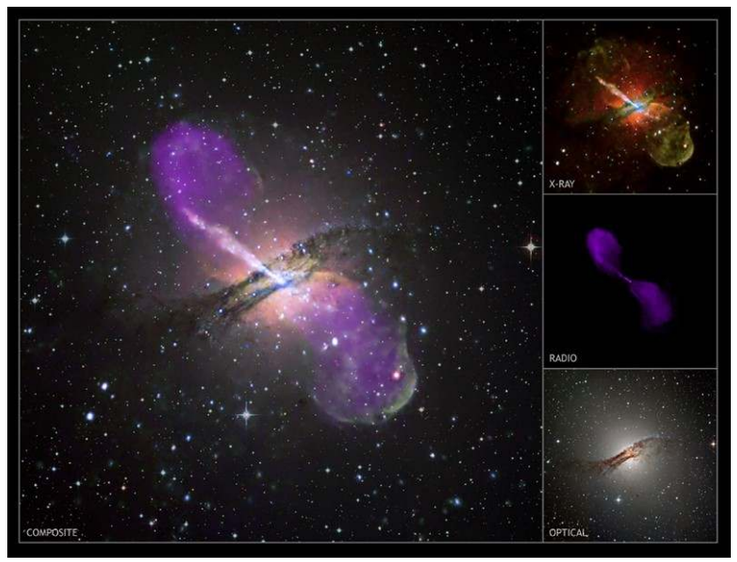
Breaking the limits 2016

Intermediate Mass Black Holes

- Existence of **galactic BHs** (<$10^2 M_{sol}$) and **supermassive BHs** (>$10^5 M_{sol}$) is firmly established.
  - Notable scarcity in the **intermediate** range.
    - Do **IMBHs** exist?



NASA, Ligo



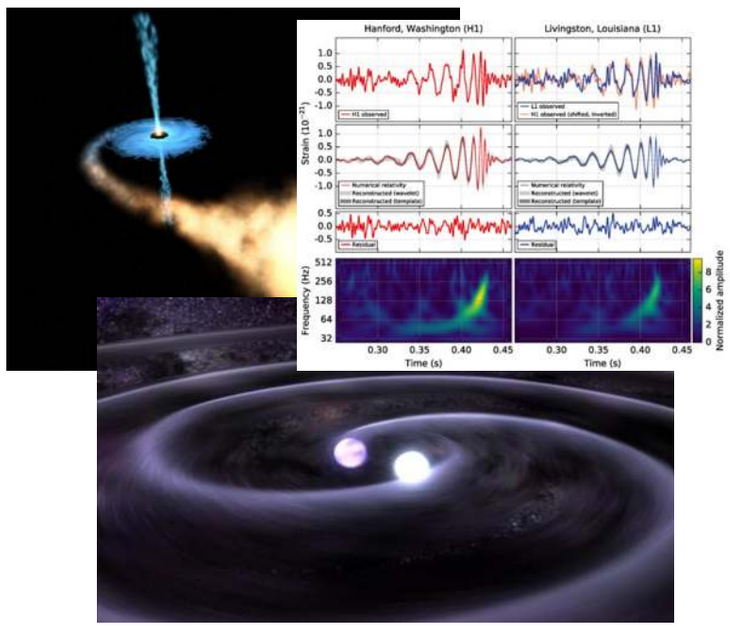
X-ray - NASA, CXC, R.Kraft (CfA), et al.;
Radio - NSF, VLA, M.Hardcastle (U Hertfordshire) et al.;
Optical - ESO, M.Rejkuba (ESO-Garching) et al.

Why do we care?

- Predicted by plausible scenarios
  - *Evolution of Pop III stars*
  - *BH mergers in clusters*

- They are the likely **Seeds** of SMBHs (?)

- Probe galaxy **formation** in different mass regimes



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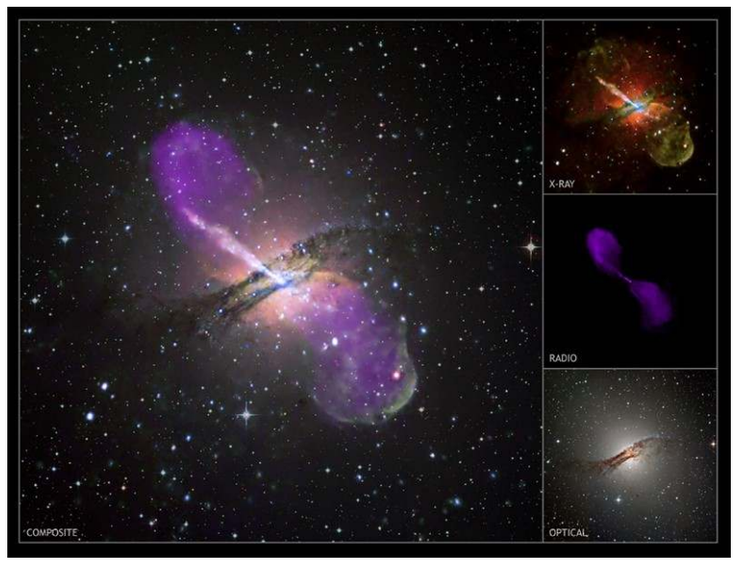
?



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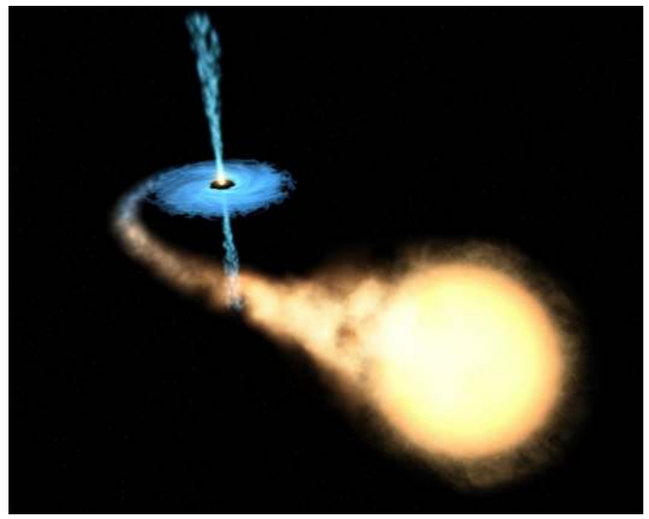
Measuring the Black Hole Mass

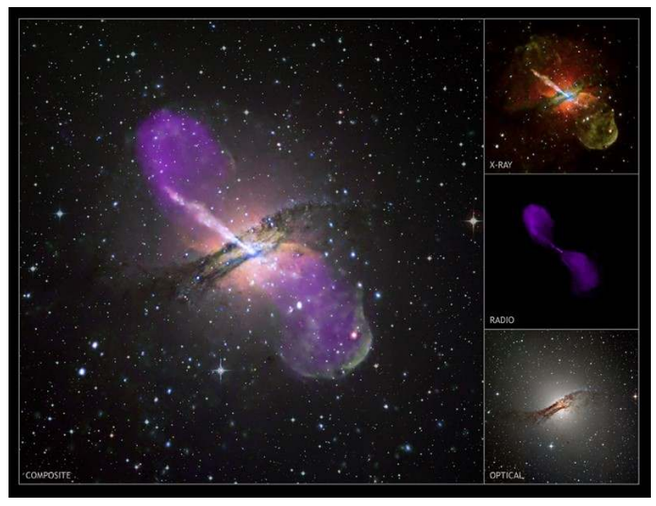
X-ray and Radio:



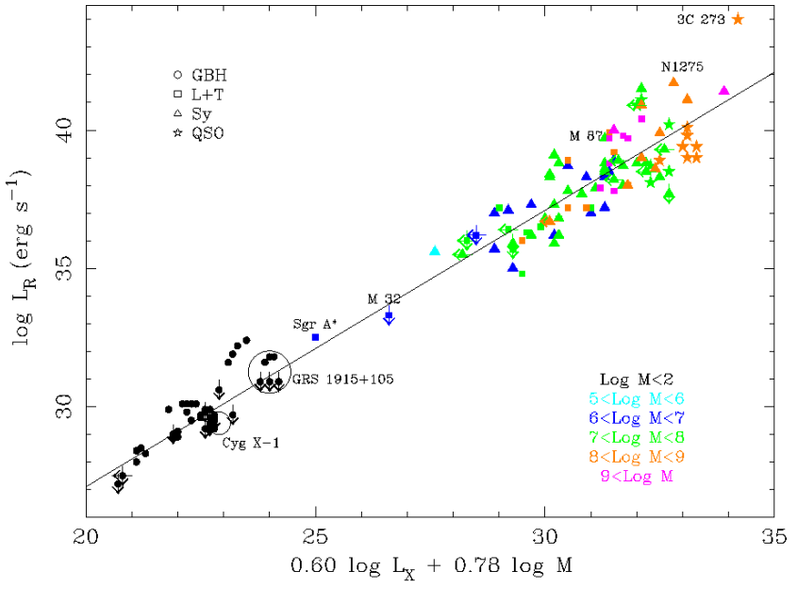
➢ Are they **accreting** mass ?

- **Eddington** Luminosity (L~1.3 10^{38}M/Msol)

*- Can be exploited to uncover **IMBHs**:*
HOWEVER:
Super Eddington Accretion. M82 X-2
But, ESO 243-49 HLX-1 and M82 X-1(?).



- **Fundamental Plane** of BH activity



Heinz & Sunyaev 2003;
Merloni et al. 2003;
Falcke et al. 2004

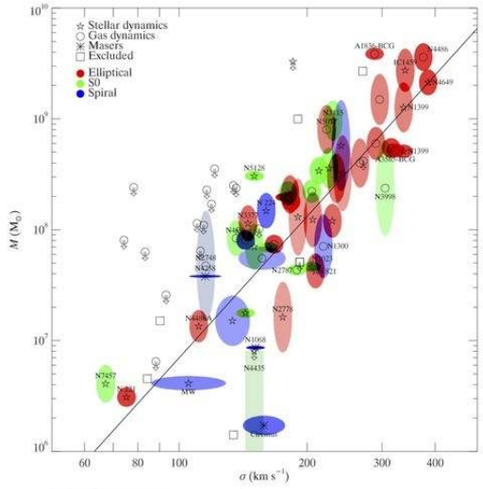
- Scale-invariance of disk-jet mechanism.
- Estimate masses from GBHs to AGN.
- Large inherent scatter.

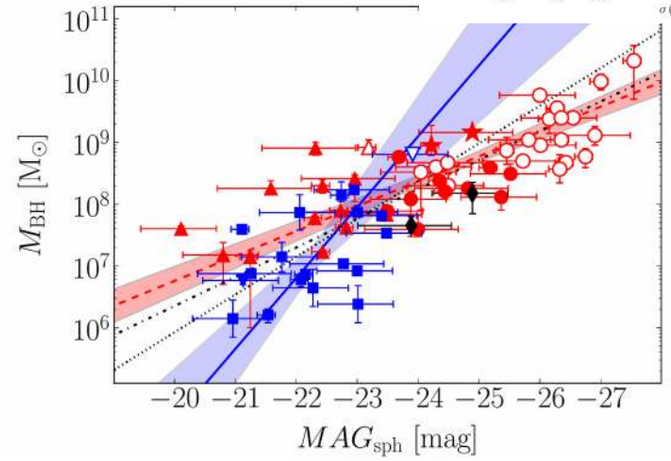
Measuring the Black Hole Mass

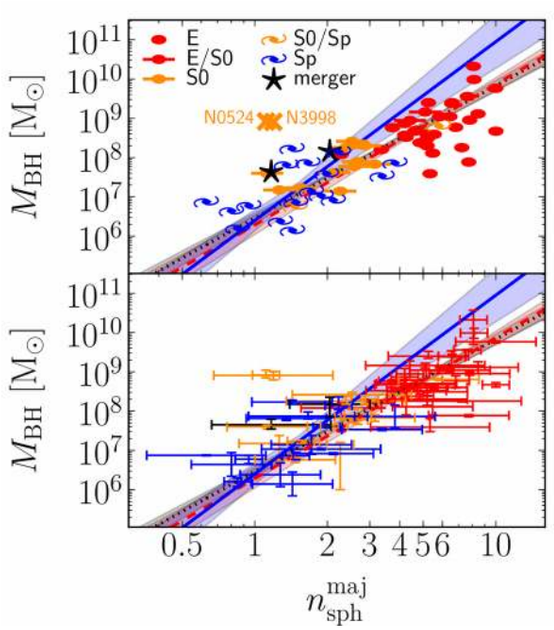
BH mass and Galactic properties

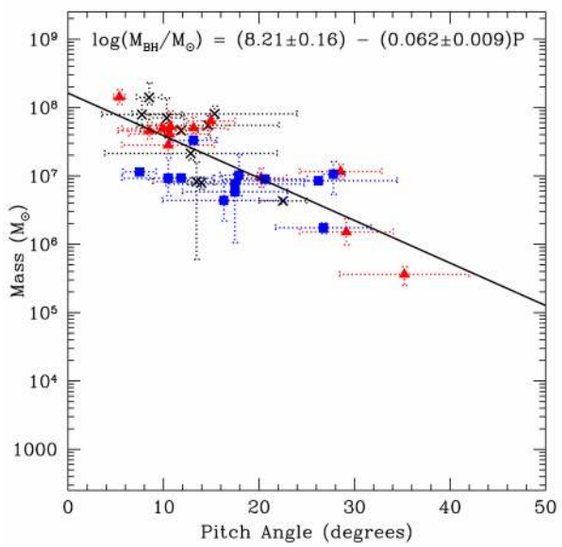
- The M_{BH}-σ relation
  - *Direct mass measurement*
    HOWEVER:
  - *Low mass –> Small sphere of influence.*
  - *Luminosity bias.*

- The M_{BH}-L relation
  - *Can be applied on more distant sources*
  - *No spectroscopy required*
  - *Depends on distance estimation*







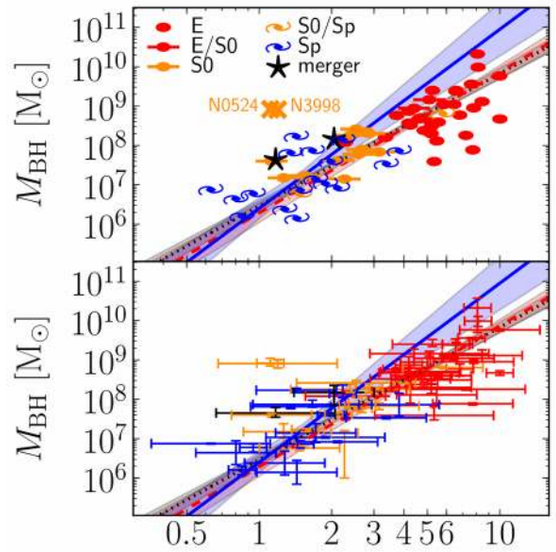


- The M_{BH}-n_{sph} and M_{BH}-*PA* relation
  - Independent of distance and of other relation
  - Empirical relations. Underlying physics not yet fully established
  - Limited to low z.

Looking for IMBHs in LLAGN

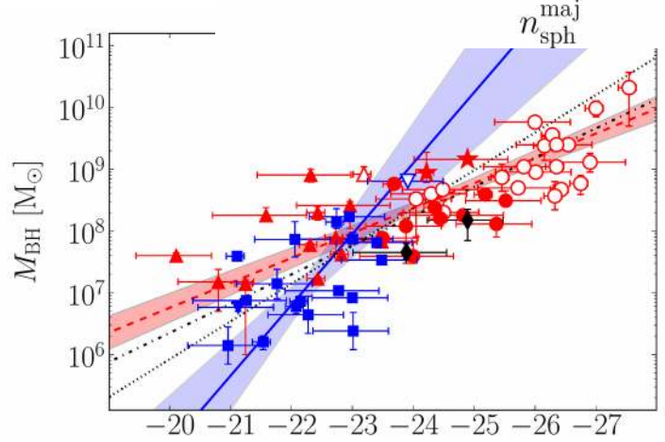
- **Motivation**: **M_{BH}-L** relation by Graham & Scott (2013), reveals **40 IMBHs** in **LLAGN.**

  - ***M_{BH}-L*** *revised by Savorgnan et al. (2016)*
  - ***LLAGN*** *most likely have* ***low mass*** *central* ***BH***
  - *We aim to confirm* ***IMBH*** *candidates and inspect the validity of* ***M_{BH}-Galactic properties relations*** *in the* ***low mass regime.***



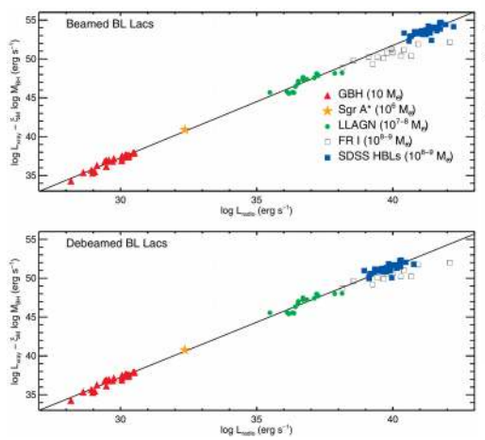
- **Our sample: 7 LLAGN** from the GS13 list.

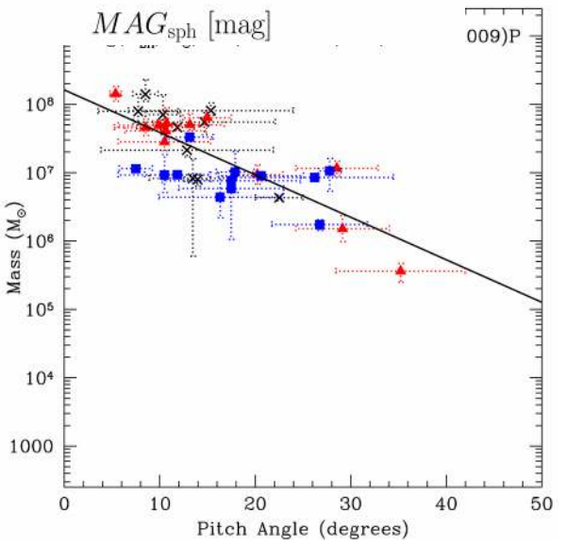
  - *Multiple high res, X-ray obs. (Chandra, XMM-Newton)*
  - *Proprietary VLA, radio observations*
  - ***IR****, high res, Spitzer, HST observations*
  - *Optical obs. from: Vatt, Palomar 48-inch Schmidt, SDSS, KPNO, Bok Telescope, JKT.*



- **Our approach:** Multiple **methods** – state of the art **tools**.

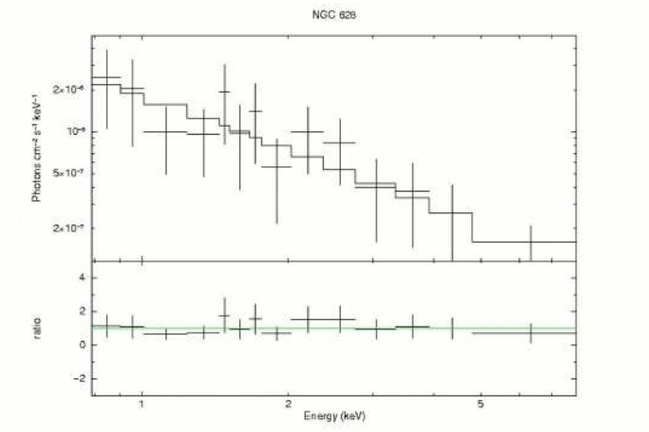
  - ***M_{BH}-L*** *relation (Savorgnan et al. 2016)*
  - ***M_{BH}-n_{sph}*** *relation (Savorgnan 2016)*
  - ***M_{BH}-PA*** *relation (Berrier 2013)*
  - ***Fundamental plane*** *of BH activity (Plotkin et al. 2012)*



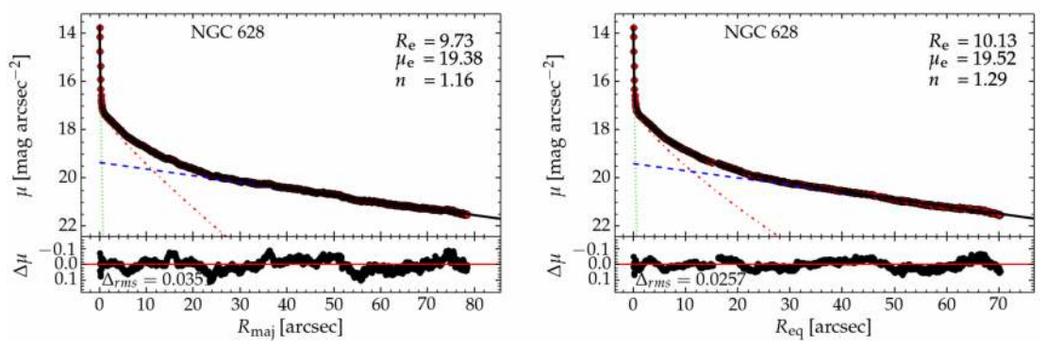


Data analysis

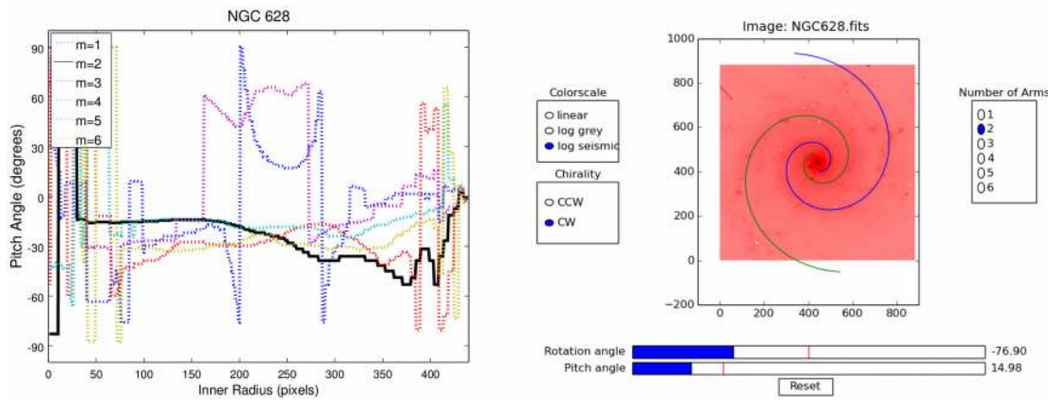
- **Multiple X-ray** observations
  - *All sources fitted with absorbed power-law consistent with GBH "hard state".*
  - *No significant flux variability*



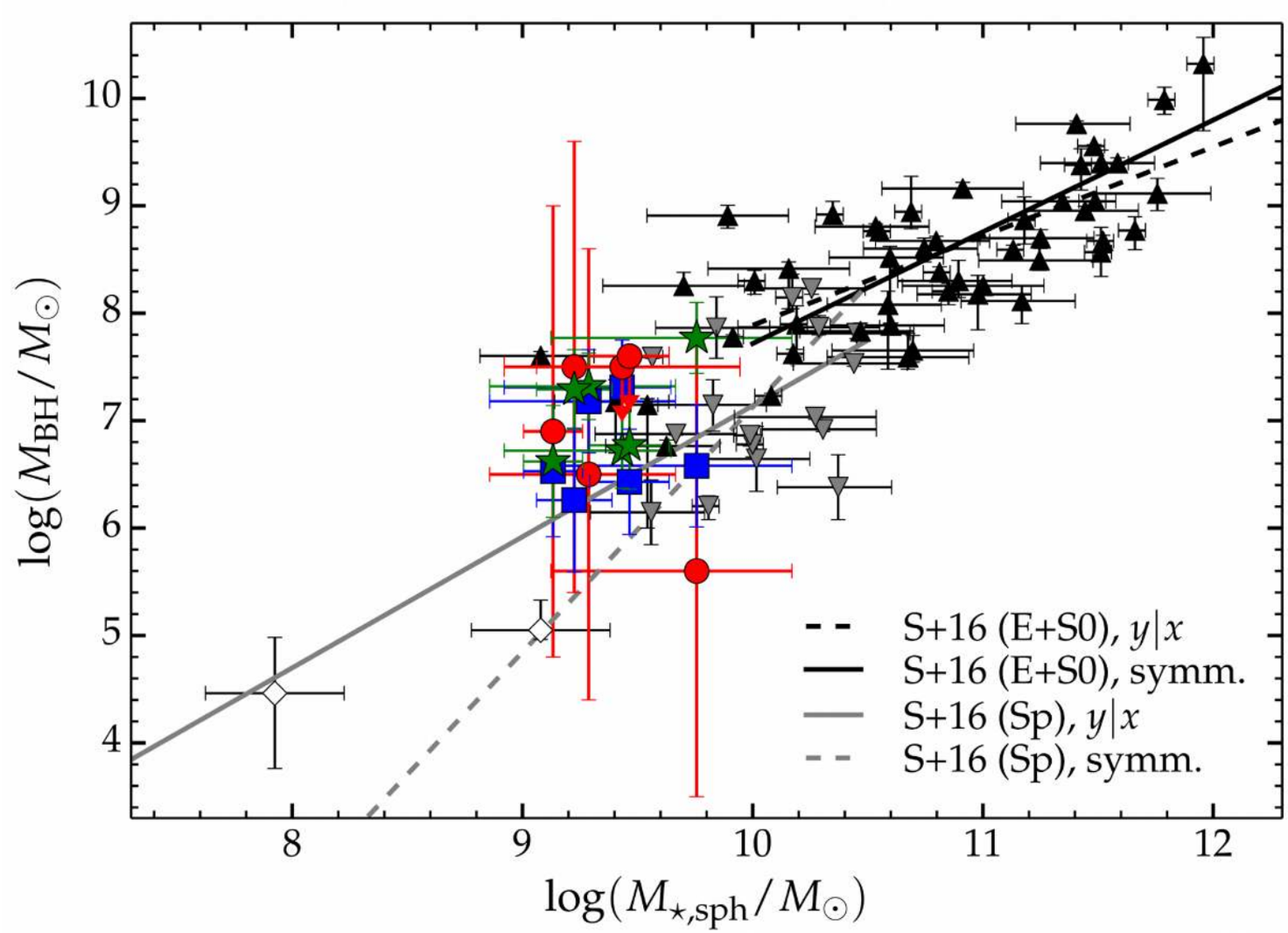
- **IR** analysis - **Morphological** decomposition
  - *Masking contaminating sources*
  - *Decompose photometric components disc, bulge, bar, point-source, etc*
  - *State of the art tools:* **`profiler`**, **`isophote`** *(Ciambur 2015, 2016)*



- **Spiral arms** analysis
  - *Images* ***deprojected*** *to face-on*
  - *2-D Fast Fourier Transform*
  - ***Harmonic*** *mode corresponding to* ***constant PA*** *over largest range of* R_{in}



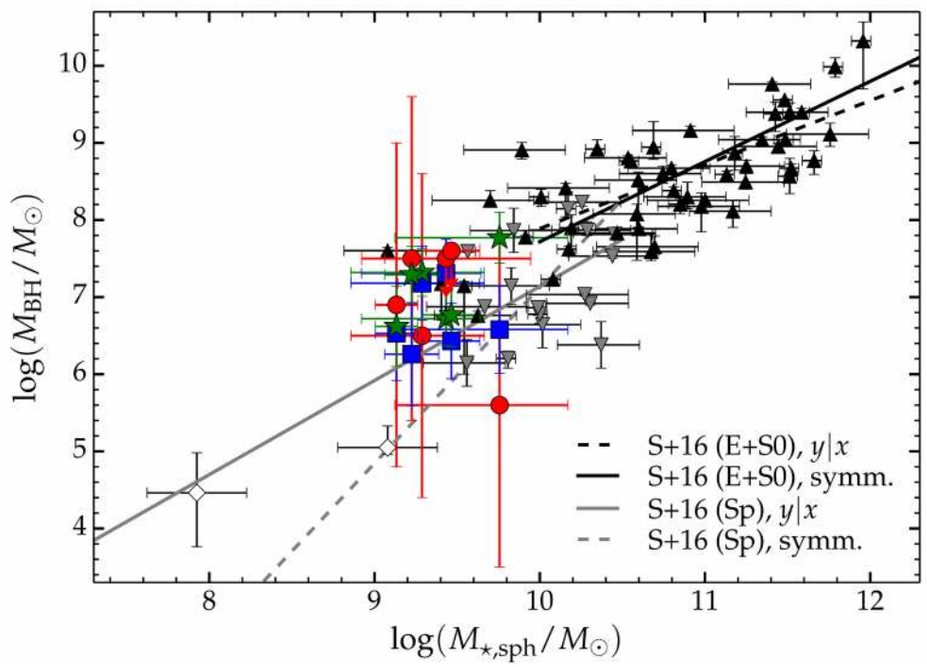
Results



Source	$\log(M_{BH})^c$	$\log(M_{BH})^d$	$\log(M_{BH})^e$	$\log(M_{BH})^f$	$\log(M_{BH})^g$
	[FP-BH]	[GS13]	$[M_{BH} - n_{sph}]$	$[M_{BH} - M_{sph}]$	$[M_{BH} - PA]$
NGC 628	< 7.5	4.9±1.0	6.7±0.4	6.3±0.7	7.3 ± 0.5
NGC 3185	6.5±2.1	5.3±0.9	7.3±0.3	6.1±0.8	7.2 ± 0.5
NGC 3198	6.9±2.1	4.4±1.0	6.6±0.5	6.0±0.8	6.5 ± 0.6
NGC 3486	5.6±2.1	4.3±1.0	7.7±0.3	6.7±0.7	6.4 ± 0.6
NGC 3507	7.5±2.1	5.4±0.9	7.3±0.3	6.1±0.8	6.1 ± 0.6
NGC 4314	< 7.6	5.5±0.9	6.8±0.5	6.4±0.7	6.4 ± 0.6
NGC 4470	< 7.9	4.9±1.0	–	–	7.5 ± 0.5

Conclusions

- **None** of the sources in our sample are **IMBHs**
- The **GS13** “broken” **M_{BH}-L_{sph}** relation **underestimates** the **Black hole mass**.
- The **revised M_{BH}-Lsph** relation, **correctly** estimates **BH** masses



- We demonstrate – for the first time – that the different **scaling** relations are **consistent** in the **low mass** regime.
- Our multiple-method approach **CAN** be used to discover **IMBHs**, in **LLAGN** and **dwarf** galaxies with **low luminosity** bulges.
- We expect **~8 sources** in the **GS13** list to lie in the **IMBH** range. Their analysis will be the next step in this **ongoing** project