The Formation of Galaxy Nuclei

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Hubble Space Telescope image of NGC 3621

Galaxy Anatomy

Elliptical

Spiral

Nucleus

disk

bulge

Black Hole

Nuclear Star Cluster

5 pc
15 ly
10^7 M_{sun}

10 kpc
30 kly
10^{10} M_{sun}

10 kpc
30 kly
10^{10} M_{sun}

Anil Seth, Missouri, Mar. 2011

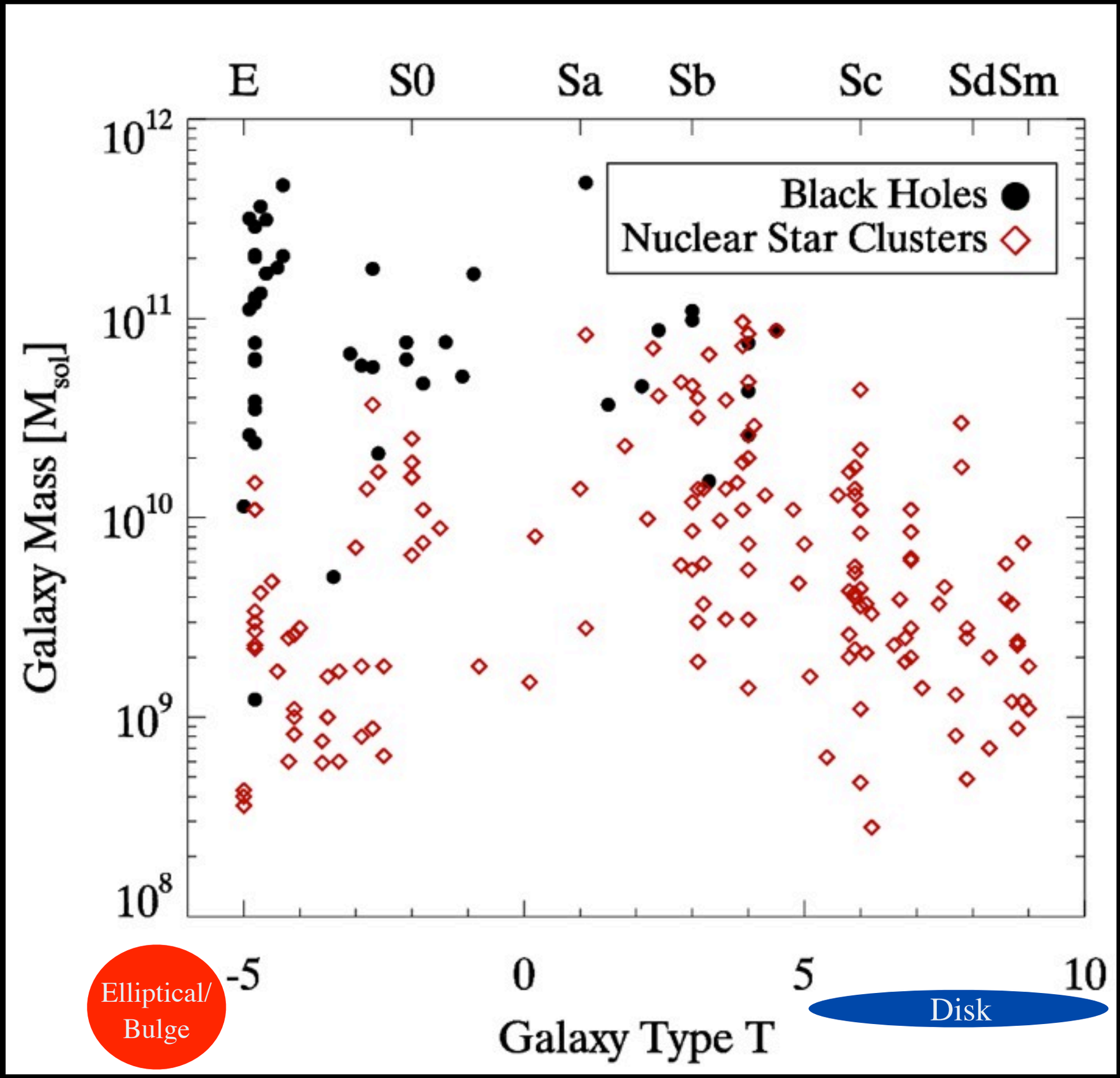
SDSS Image

NGC 4244

All galaxies have black holes!

75% of galaxies have nuclear star clusters.

Black holes are hard to find!



Data from: Böker+ 2002, Côté+ 2006, Carollo+ 1998-2002 Seth+ 2006, 2008a, Gültekin 2009

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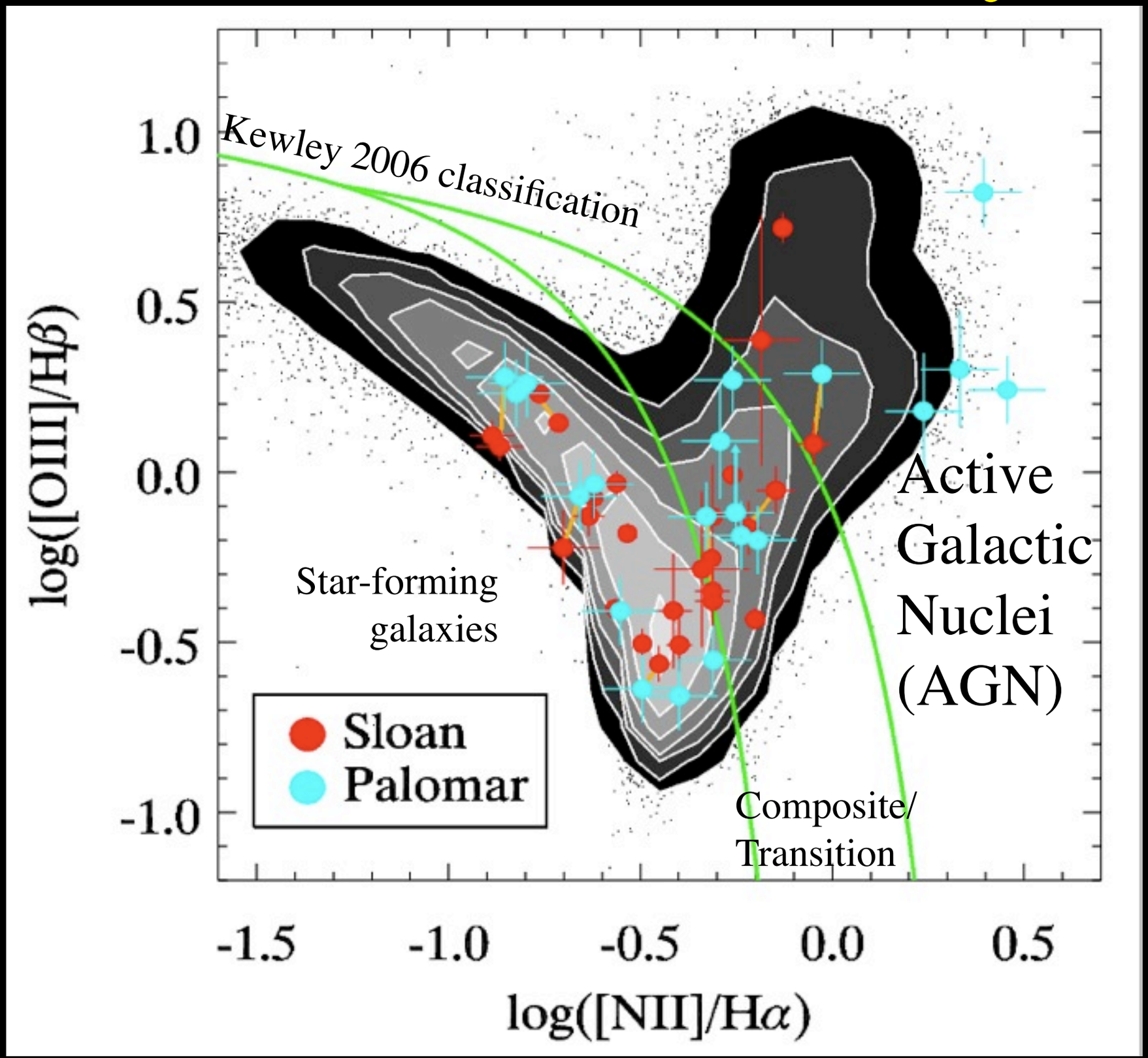
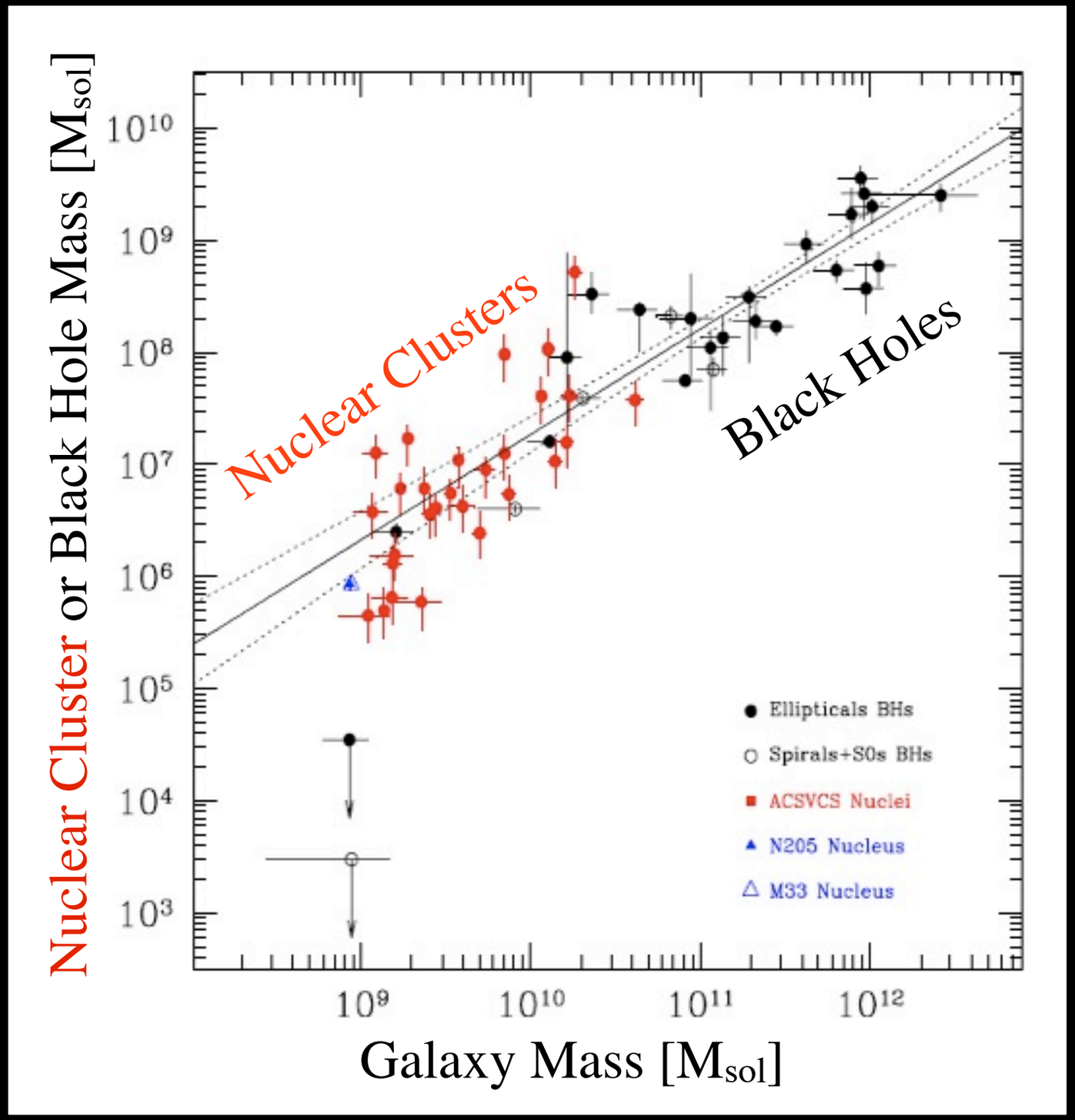
NSCs & BHs commonly coexist



Seth+ 2008a

>10% of NSCs have AGN-type spectra suggesting black hole accretion

A surprisingly simple relationship

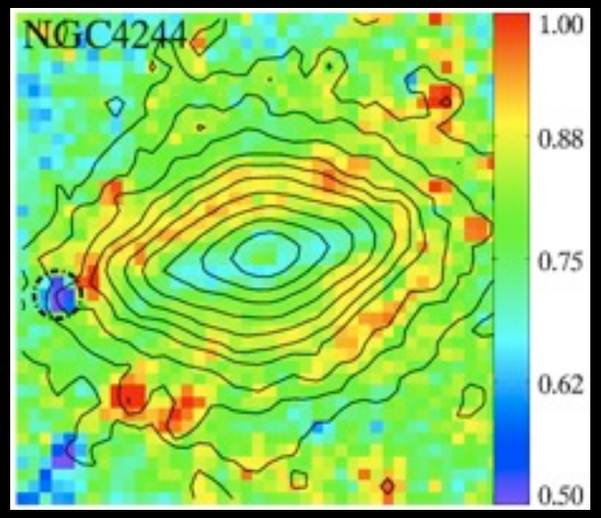


Ferrarese + 2006 (for Elliptical Galaxies)

- NSC and black hole masses correlated with galaxy masses and bulge velocity dispersions. (Wehner & Harris 2006, Rossa+ 2006, Ferrarese+ 2006, Graham & Driver, 2007 Erwin & Gadotti 2010)
- Suggests links between galaxies, nuclear star clusters and black holes

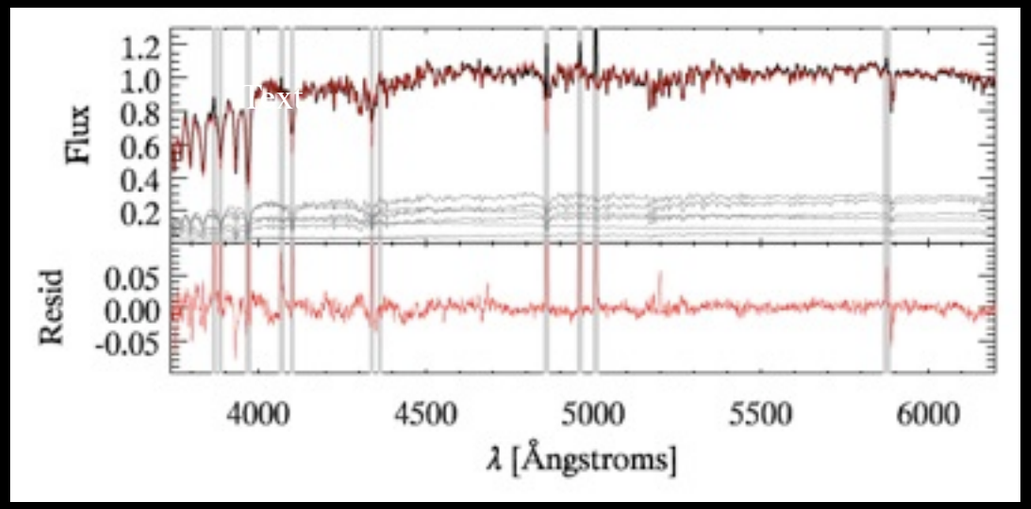
Resolving Nearby Nuclear Star Clusters

1) Morphology



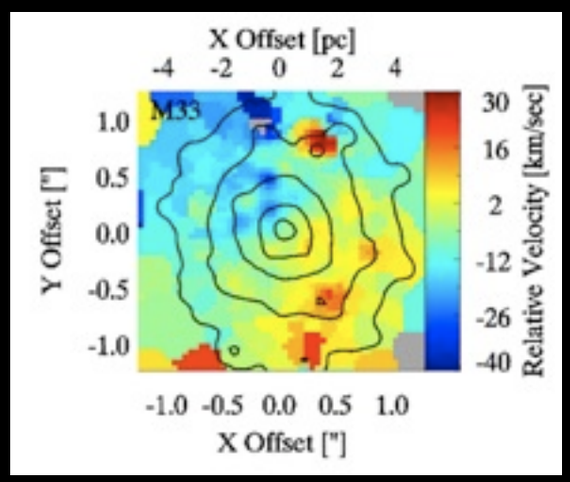
Hubble Space Telescope Imaging

2) Stellar Ages



Optical Spectra (Magellan, MMT, VLT)

3) Kinematics



Adaptive optics infrared spectra (Gemini, VLT)

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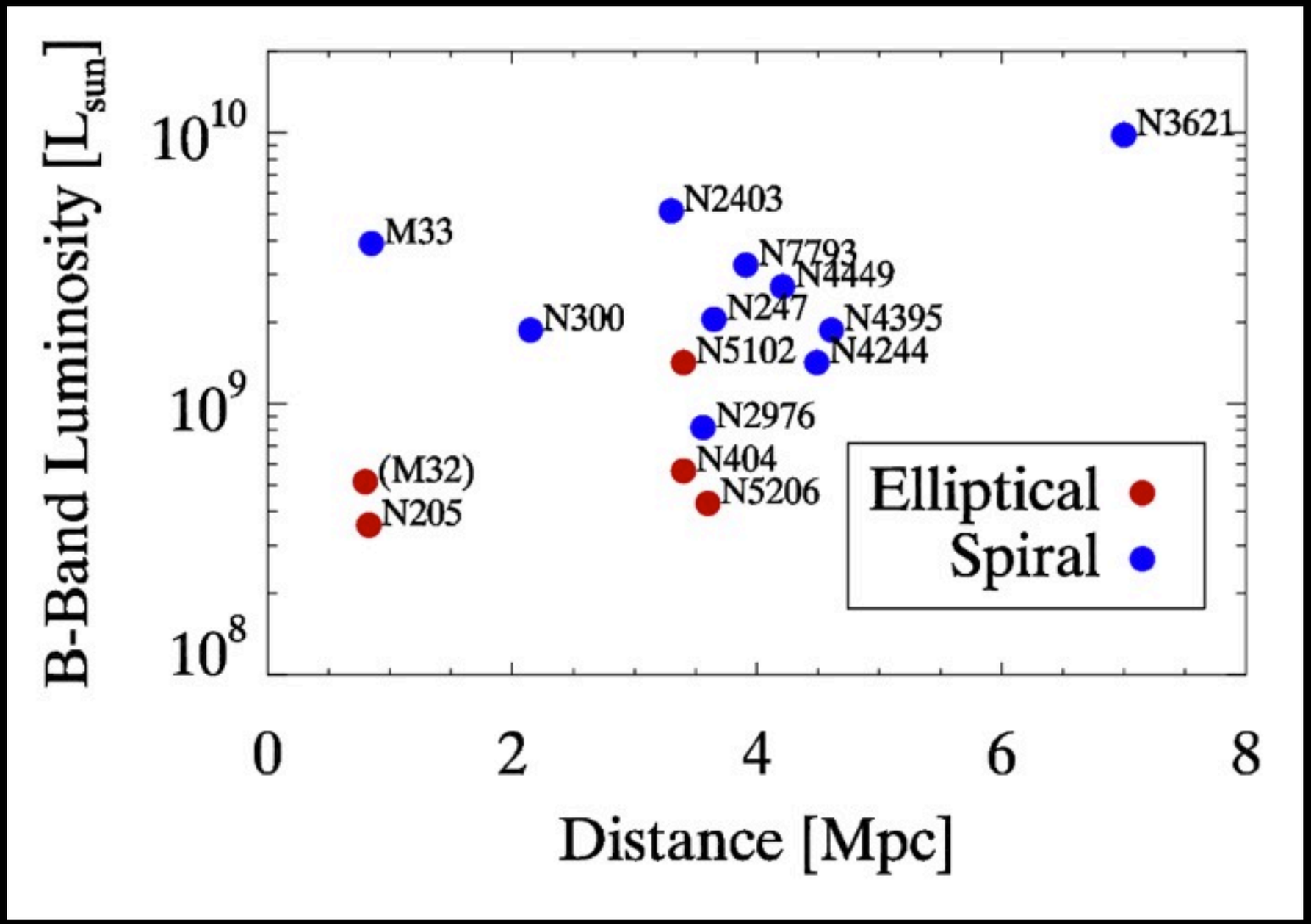
Nearby Nuclear Star Cluster Survey



Seth+ 2008b, Seth+ 2010, Seth 2010, Neumayer+ *in prep*

Primary Collaborators:

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(ESO)

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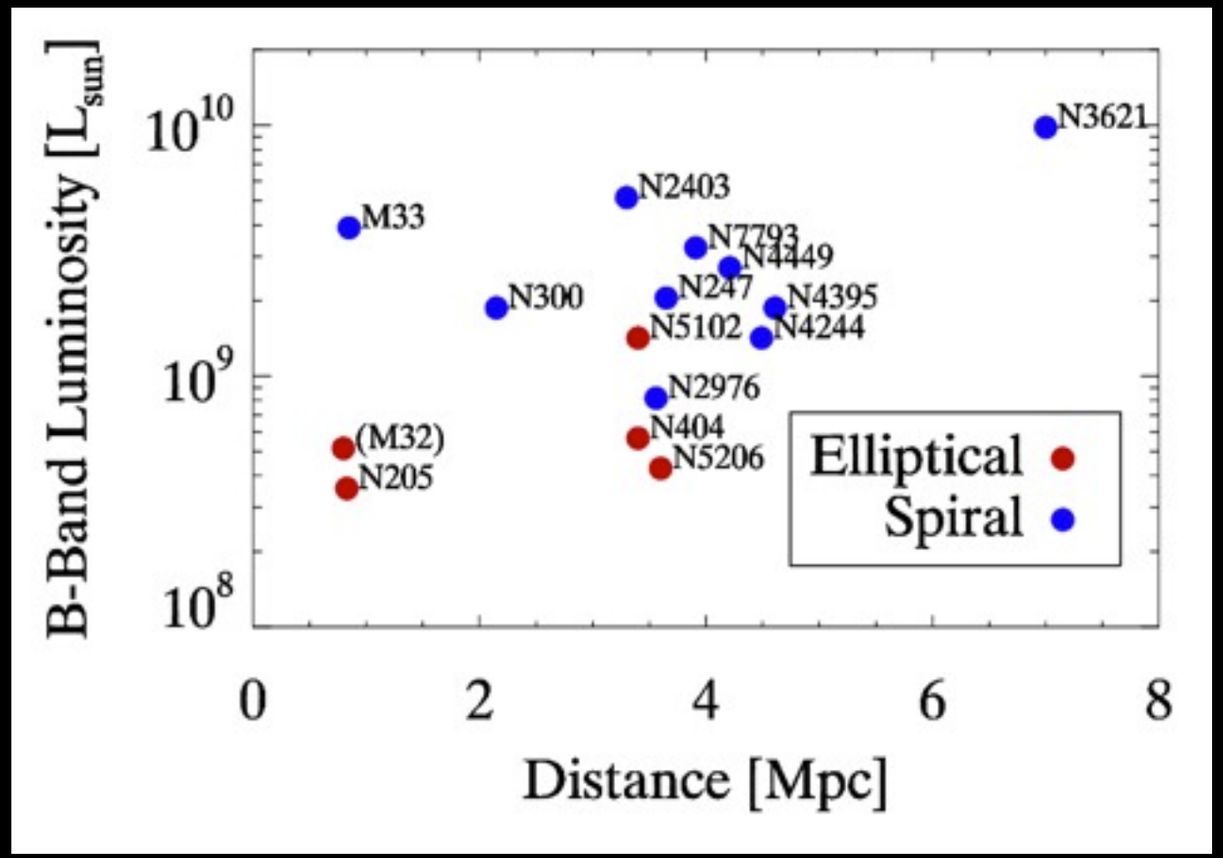
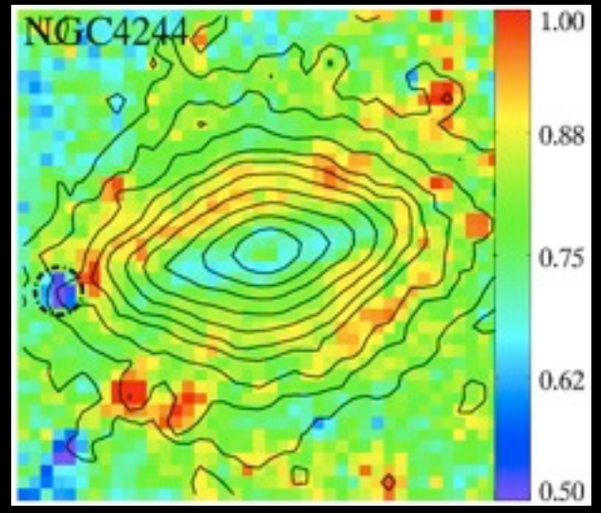
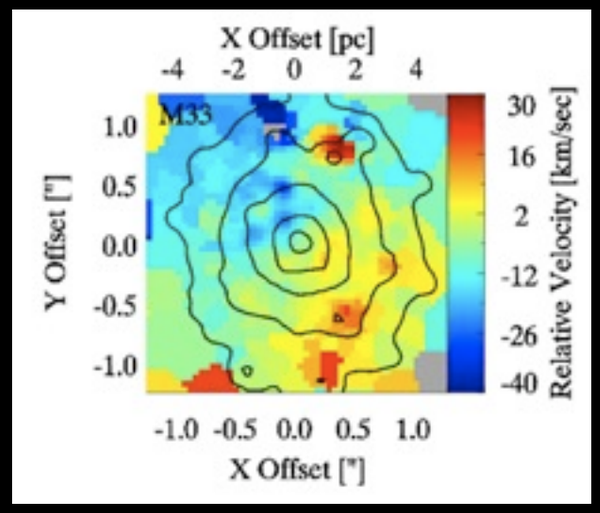
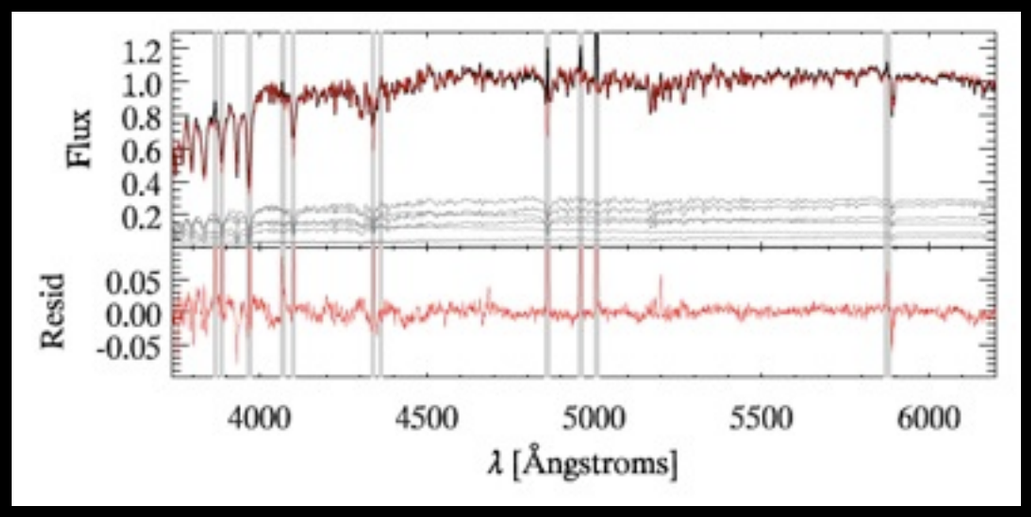


Survey Goals

- Study the formation of nuclear star clusters







- **Find and measure the mass of the smallest central black holes**

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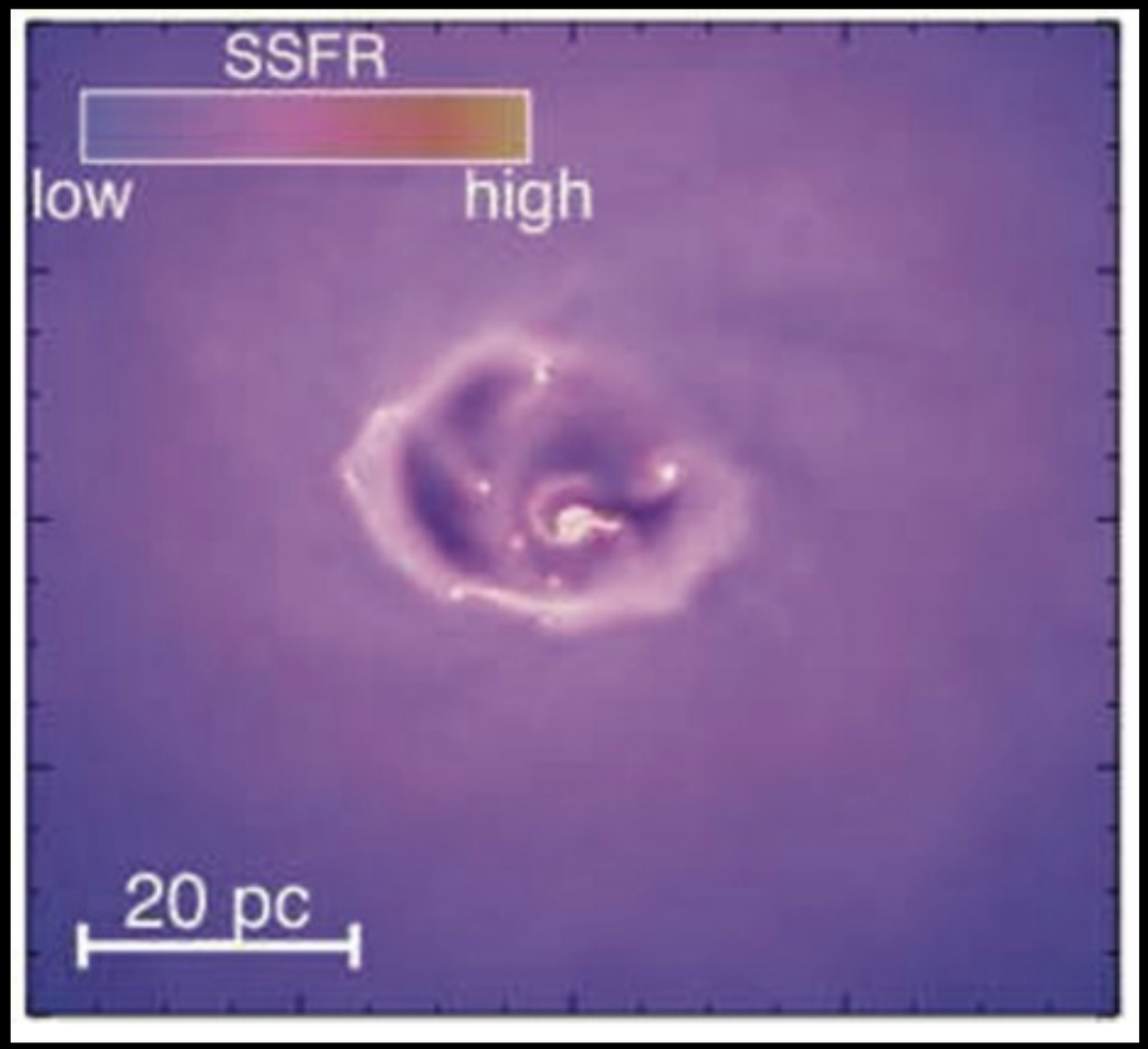
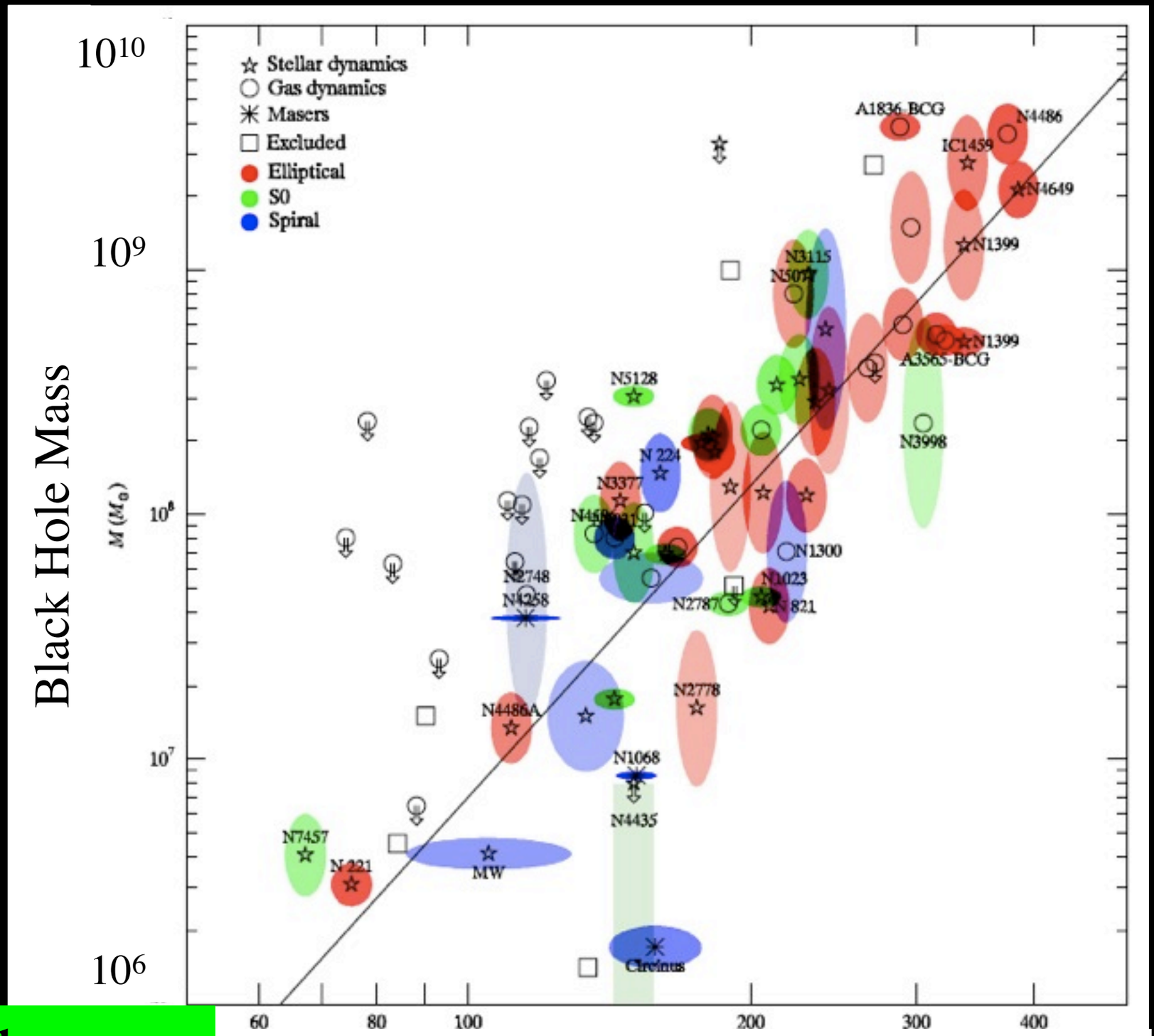
The BH - NSC connection



- Both are fed from the same events?
  (e.g. Hopkins & Quataert 2010a,b)
- NSC formation results in BH formation?
  (e.g. Portegies Zwart 2004, Vespirini 2010, Davies+ 2011)

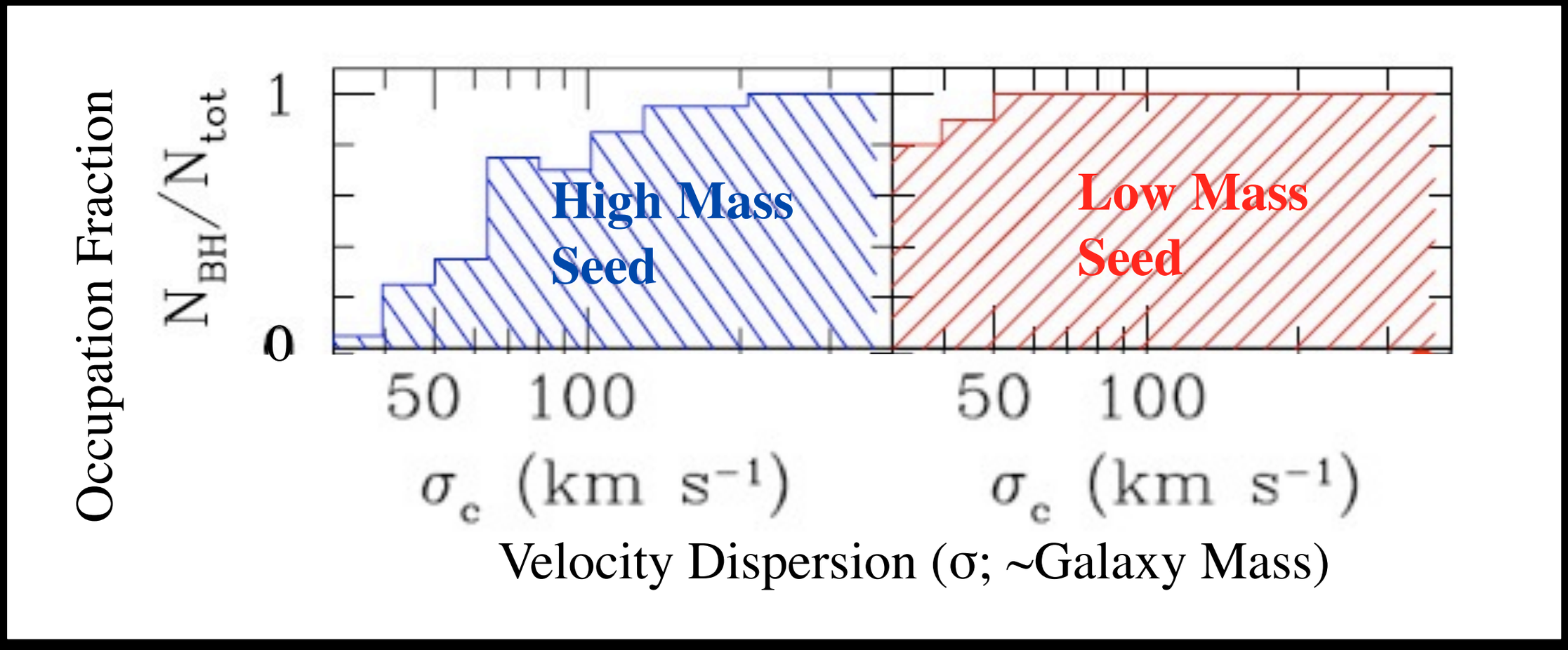
Need to study systems with nuclear star clusters and black holes



Nearby Nuclear Star Cluster Sample

Gultekin+ 2009

The number of low mass galaxies with black holes is sensitive to how black holes formed in the early universe



Volonteri+ 2008

NGC404:

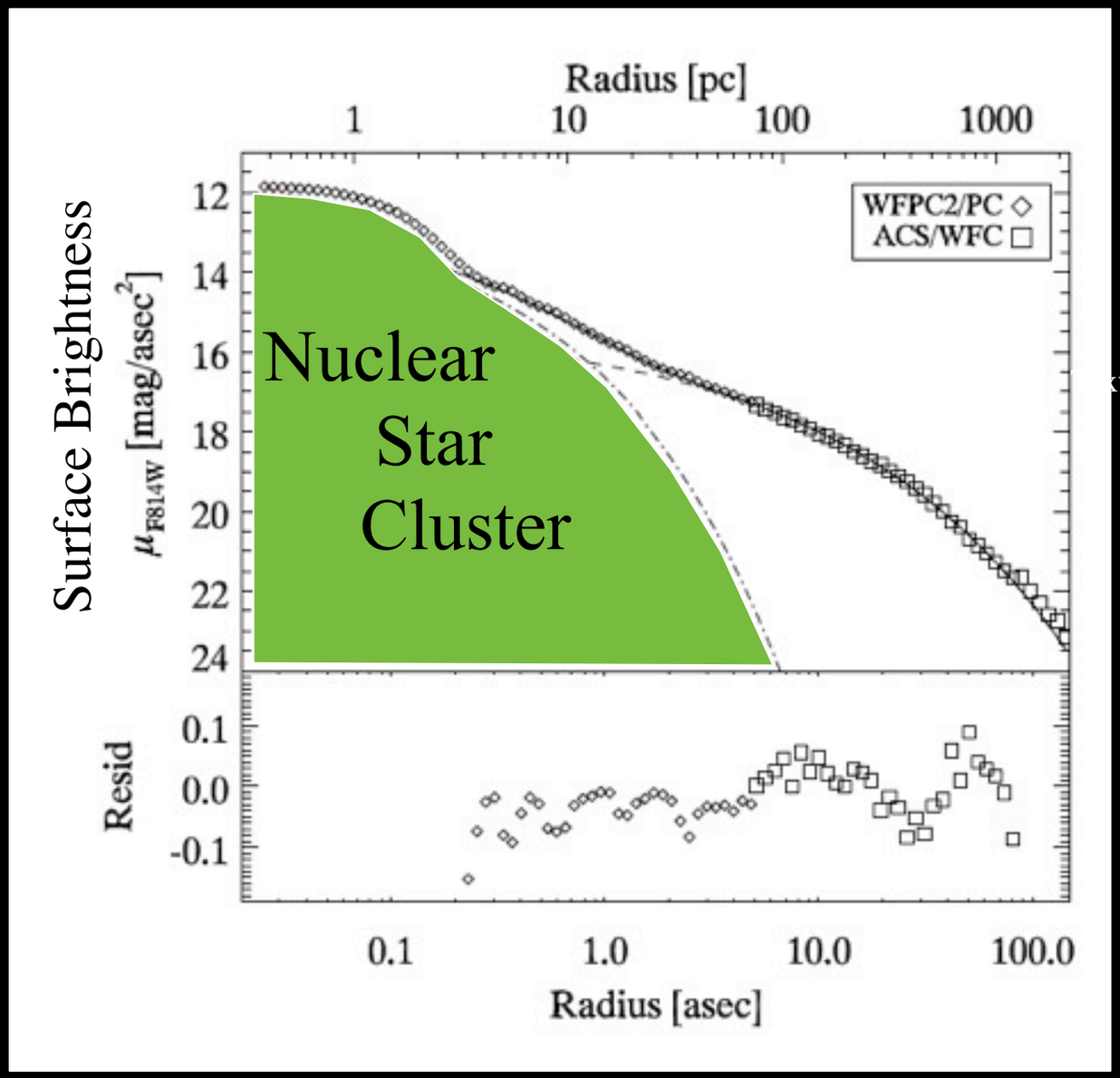
(D~3 Mpc, σ=35 km/s)

- Nearest S0-type galaxy
- $M_{stellar} \sim 10^9 M_\odot$

- Strong evidence for black hole accretion: variable UV emission, compact dust & hard X-ray emission (Maoz+ 2005, Seth+ 2010, Binder+ 2011)

GALEX UV Image of NGC 404

Dynamical detection of black holes (NGC404)



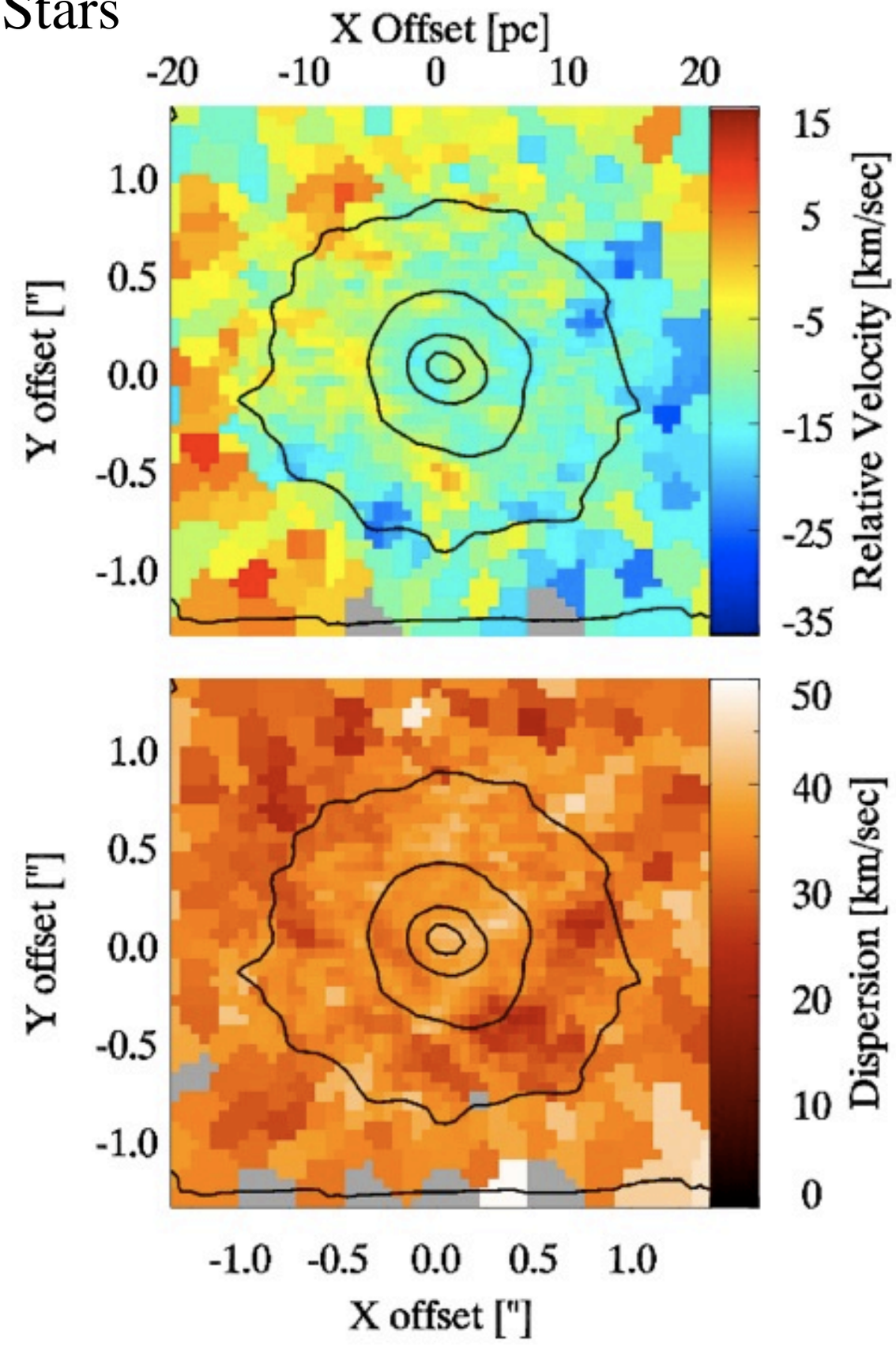
Seth+ 2010

Ingredients:

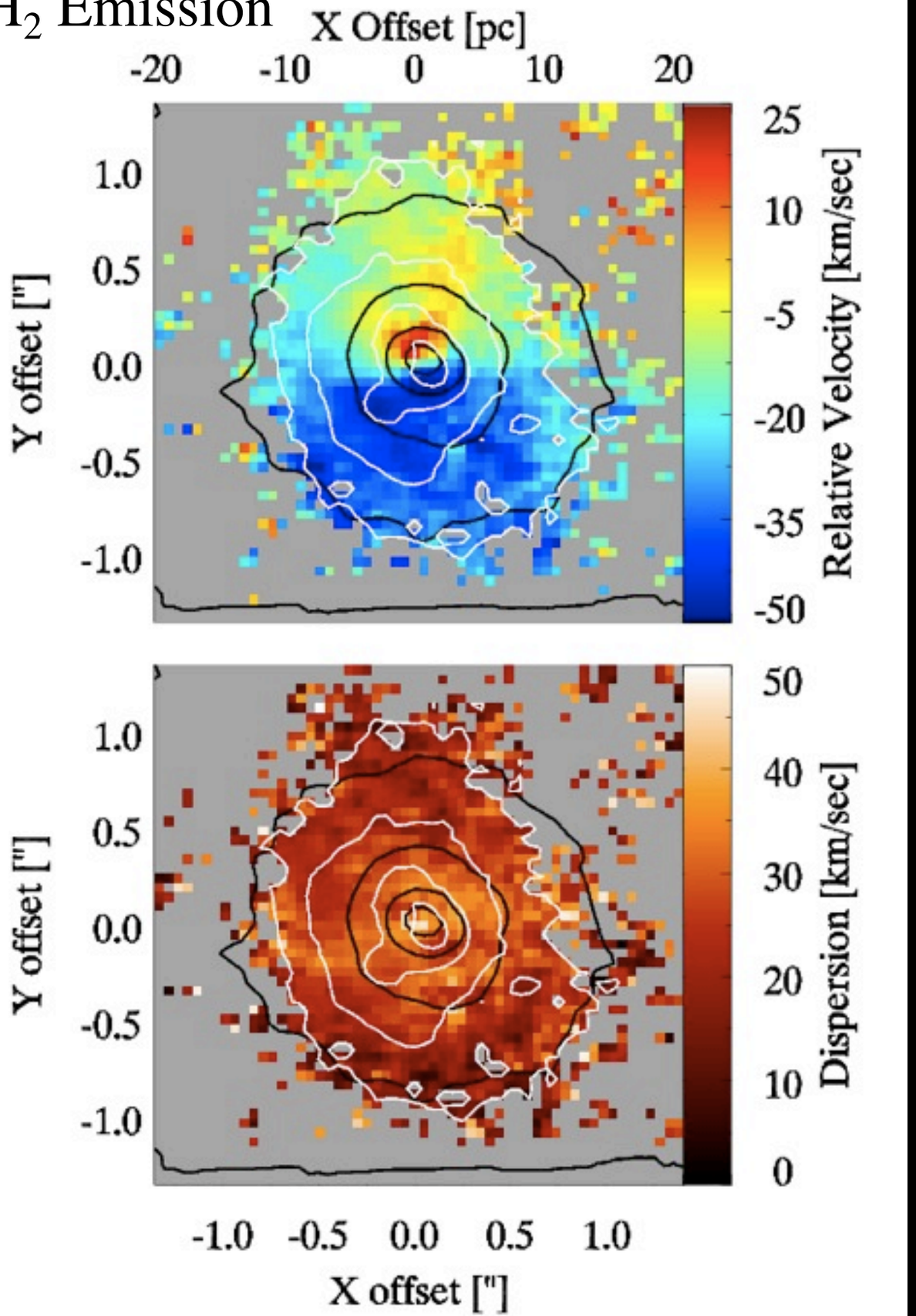
1) Stellar Mass Profile
   - Luminosity Profile
   - fit a Mass-to-Light ratio for stellar light

2) Dynamical Tracer

Stars



H_2 Emission



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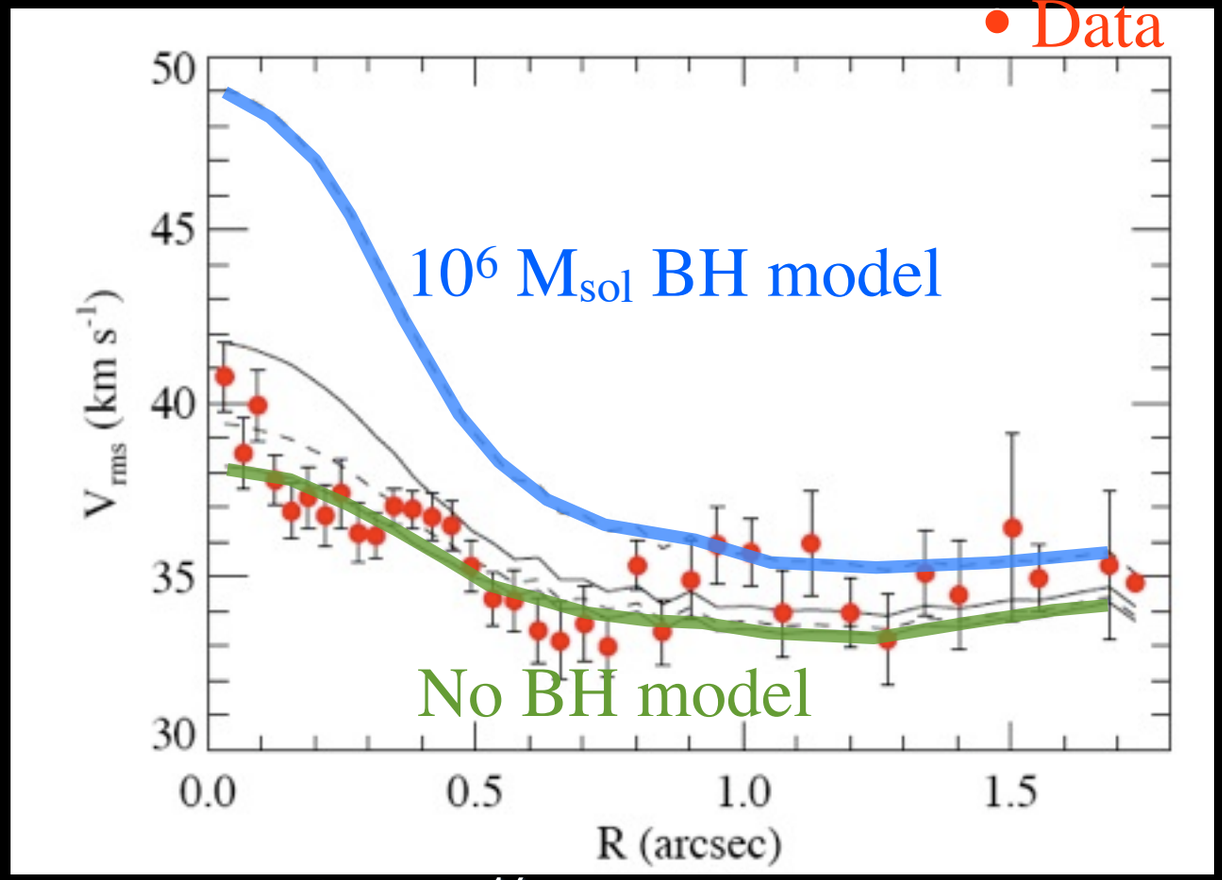
Limits on the BH mass: Stars

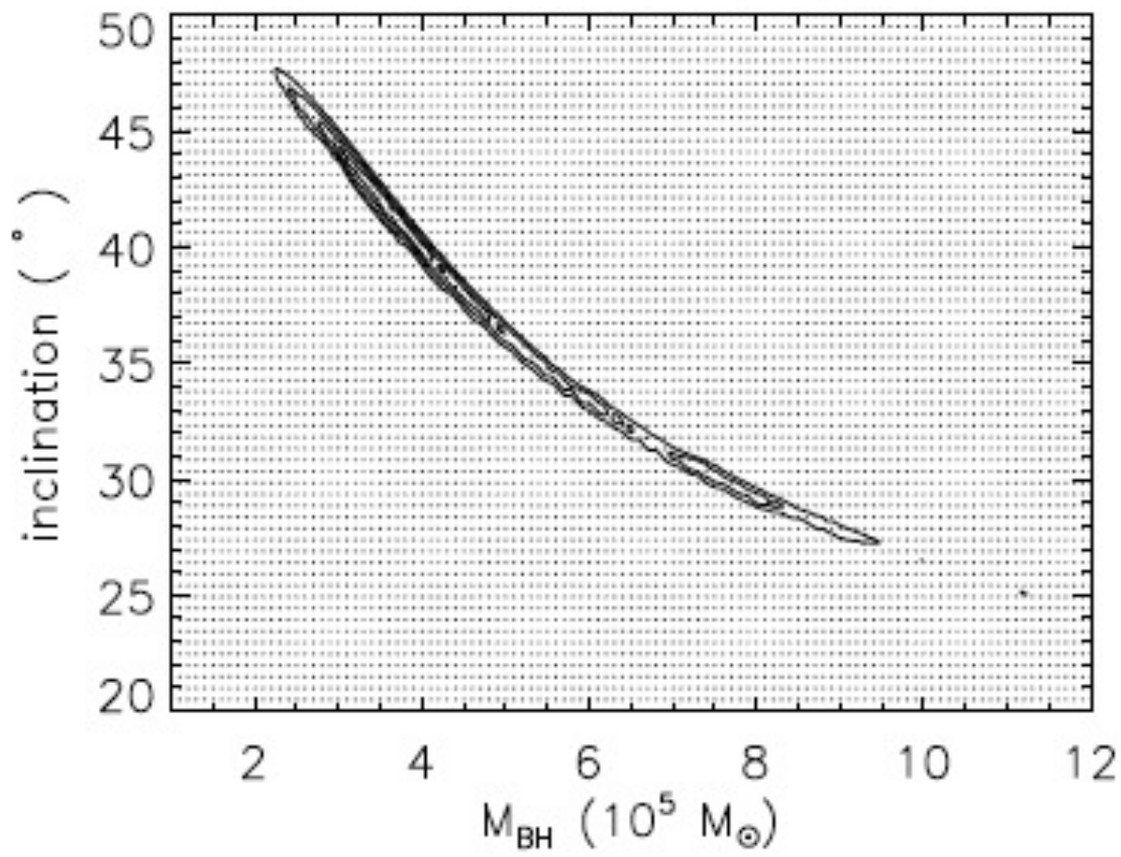
- Model using Jeans Eq. (Cappellari 2008)
- Fit M_{BH}, anistropy & mass-to-light ratio
- $M_{BH} < 1x10^5\ M_\odot$ at 3σ (~$0.5x10^5\ M_\odot$)

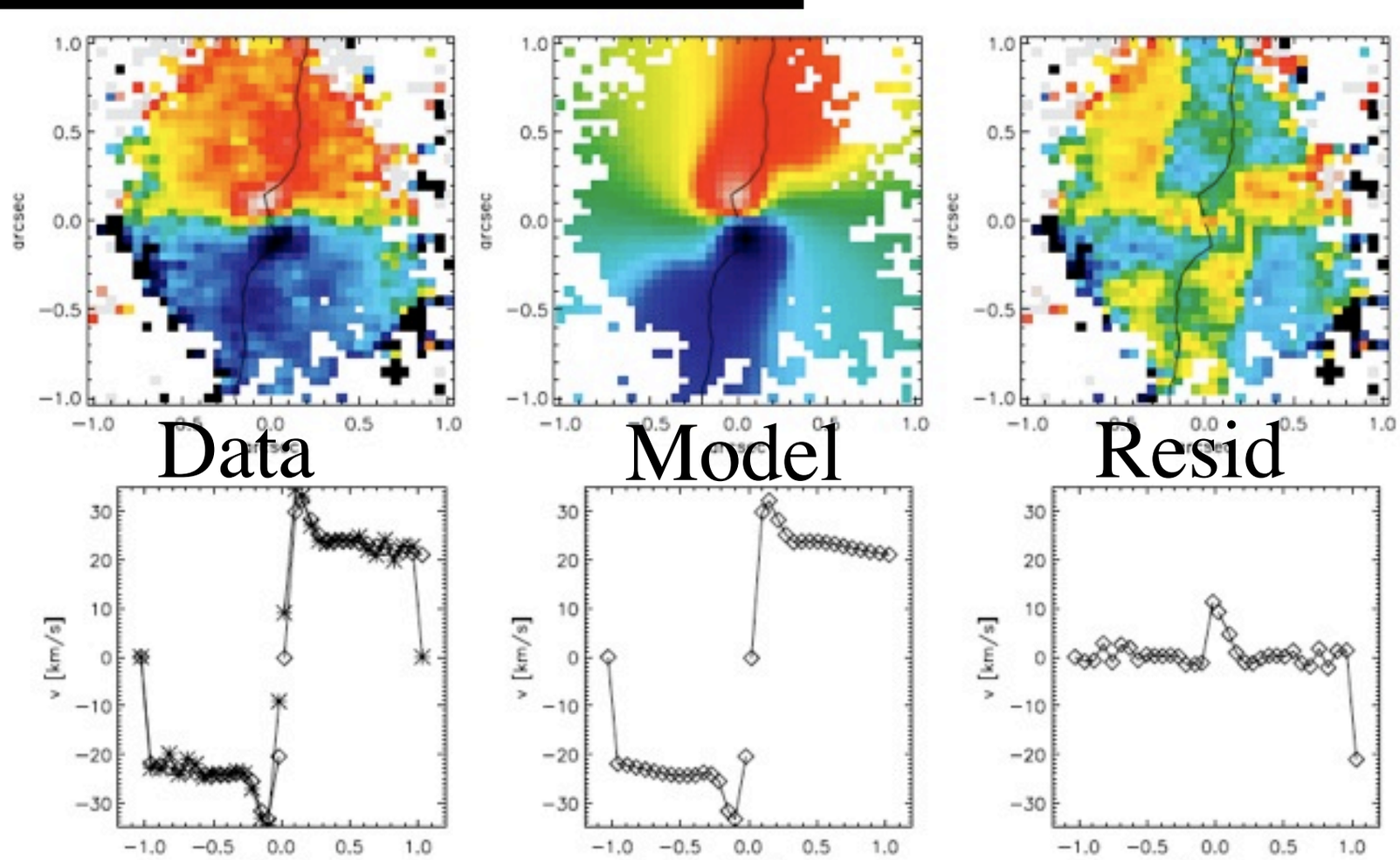


$V_{rms}=(V^2+\sigma^2)^{½}$

Limits on the BH mass: H_2 Gas

- Data require two thin disks
- Fit inner inclination, and M_{BH}
- Best fit $4.5 \pm 3 \times 10^5\ M_\odot$ (3σ)





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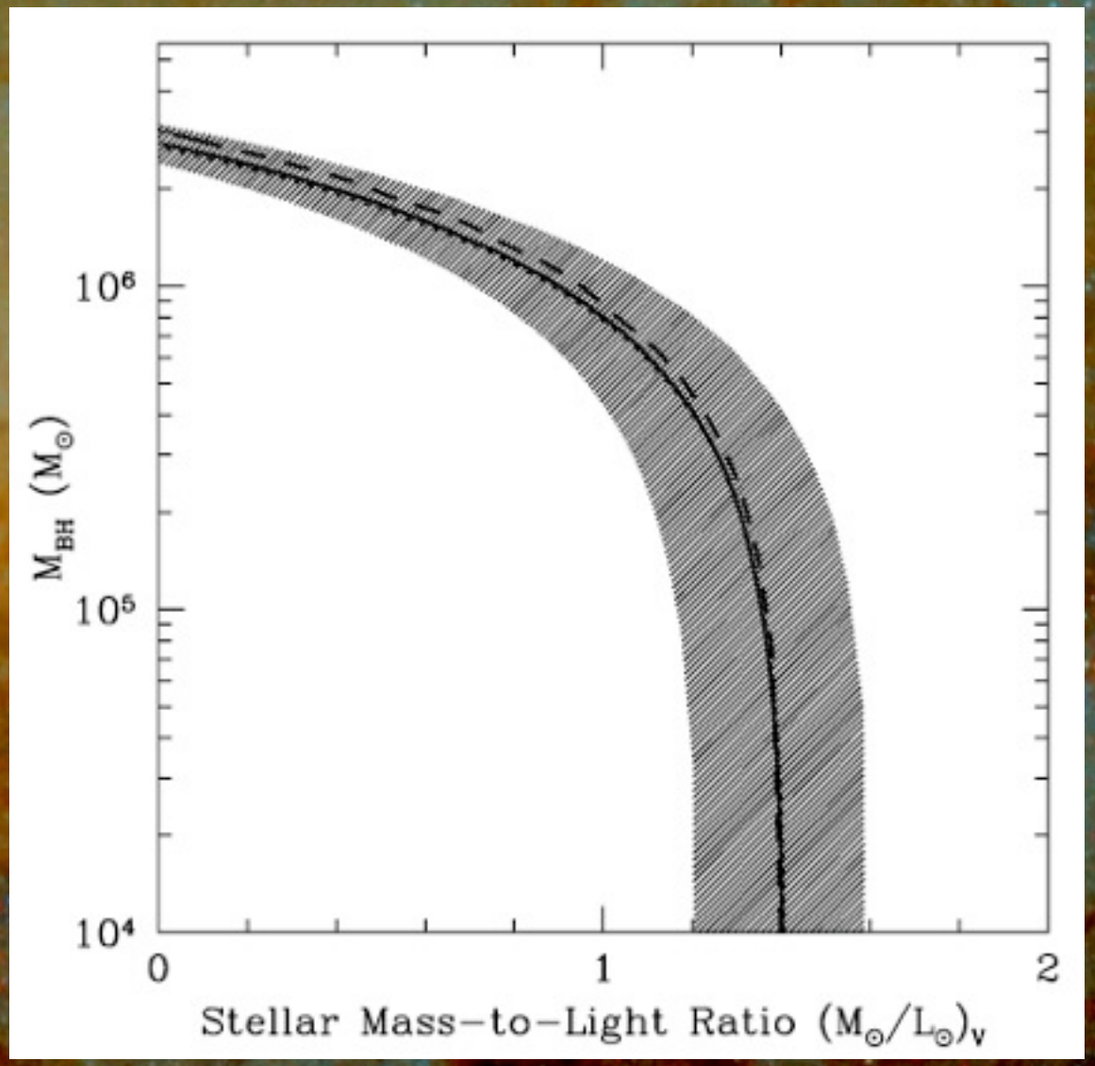
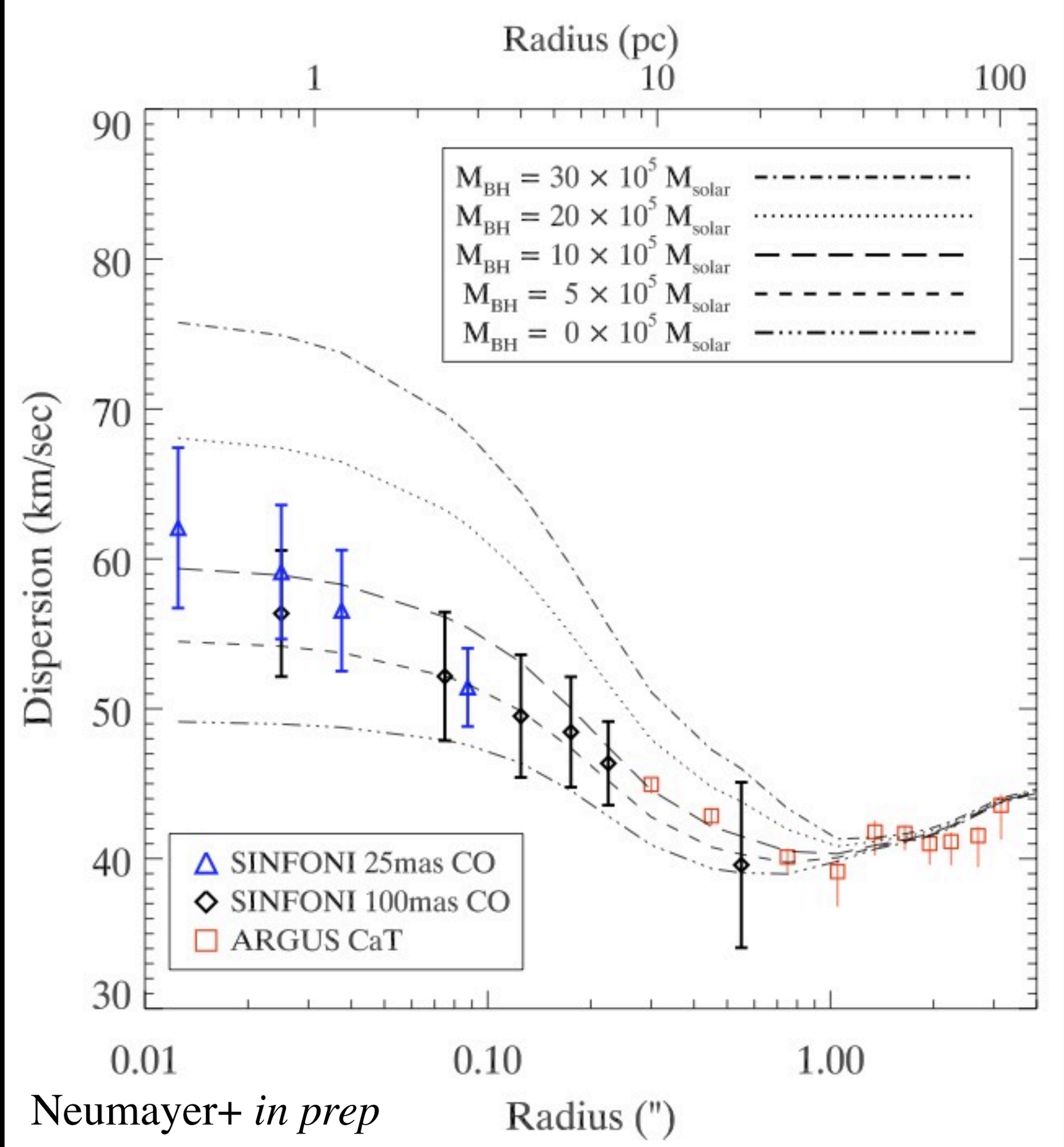
NGC 3621, Sd galaxy



- [NeV] lines detected (Satyapal+ 2007)
- Integrated dispersion of 43 km/sec, $M_{BH} < 3x10^6\ M_\odot$ (Barth+ 2009)
- X-ray source suggests $M_{BH} > 10^3\ M_\odot$ (Gliozzi+ 2009)



Neumayer+ *in prep*

NGC 3621

best fit BH mass is $6.5 \times 10^5 M_\odot$

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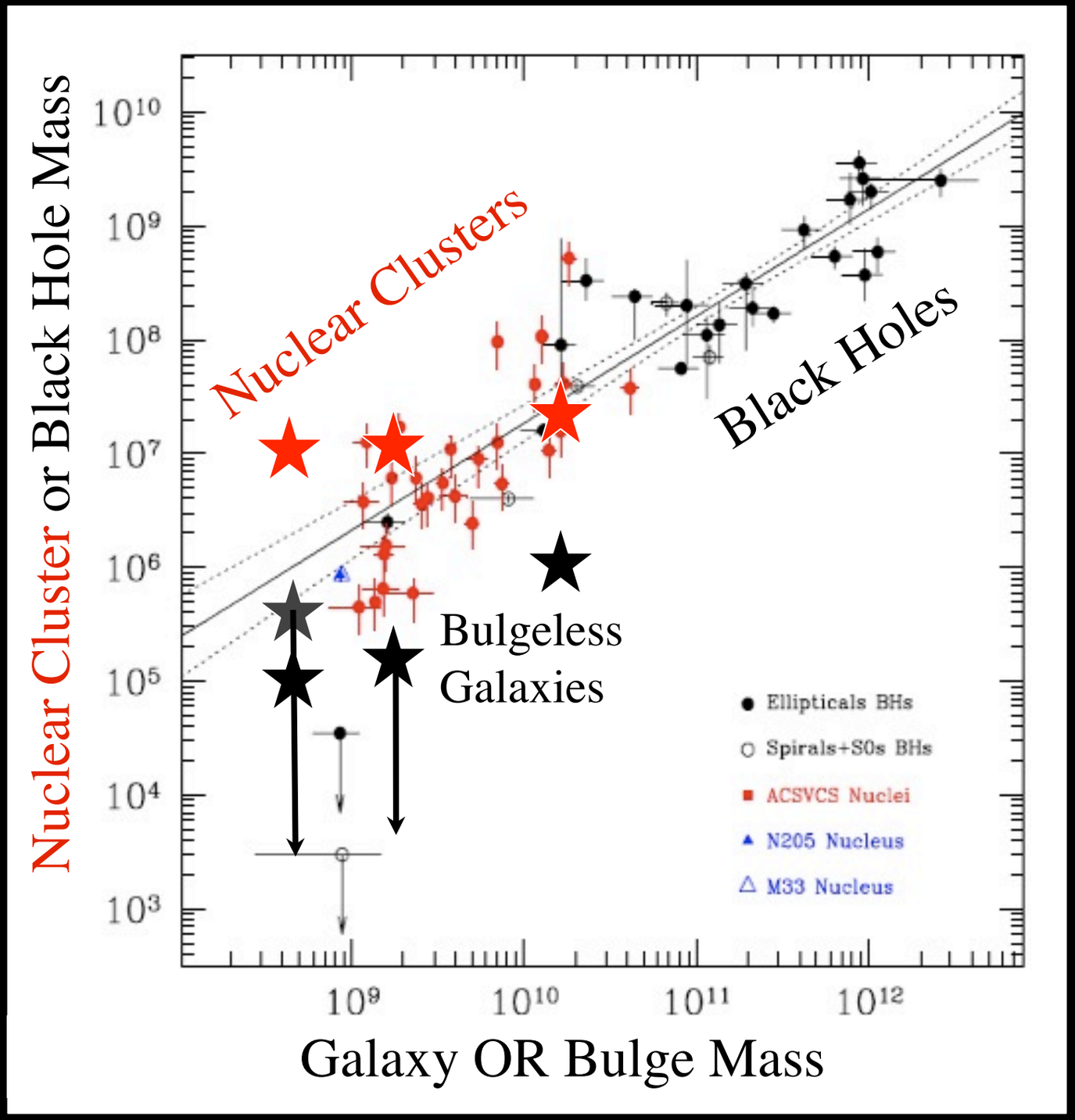
Scaling Relations



Ferrarese+ 2006

- Probing below the mass of previously detected black holes.
- Dynamical NSC masses
- What galaxy components are correlated?
- More to come!

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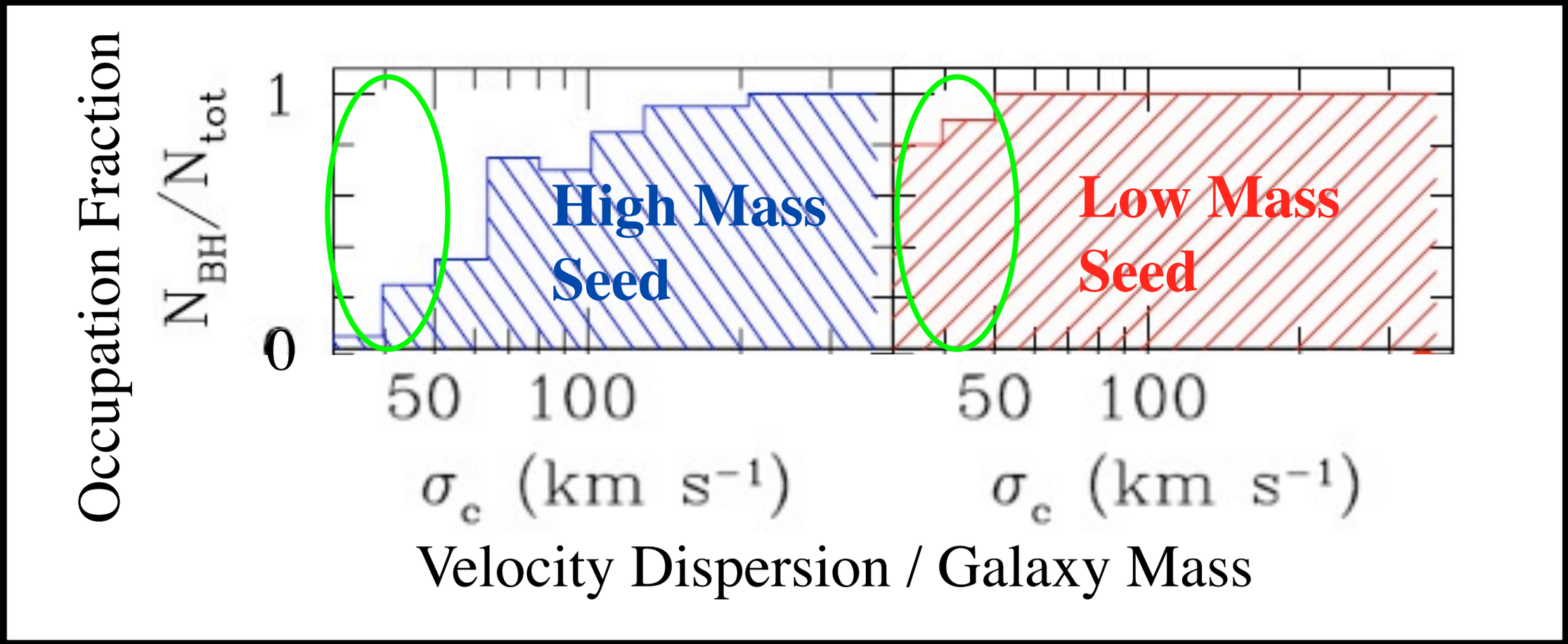

Volonteri+ 2008

The Future is Bright

Low mass galaxies with nuclear star clusters are abundant in the nearby universe!

Future adaptive optics technology will enable resolution of nuclear star clusters and low mass black holes in ~150 lower mass systems

Large Synoptic Survey Telescope will enable detection of low-mass black holes via tidal disruption of stars and variability

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