SBH masses in galaxies and properties of galactic nuclei

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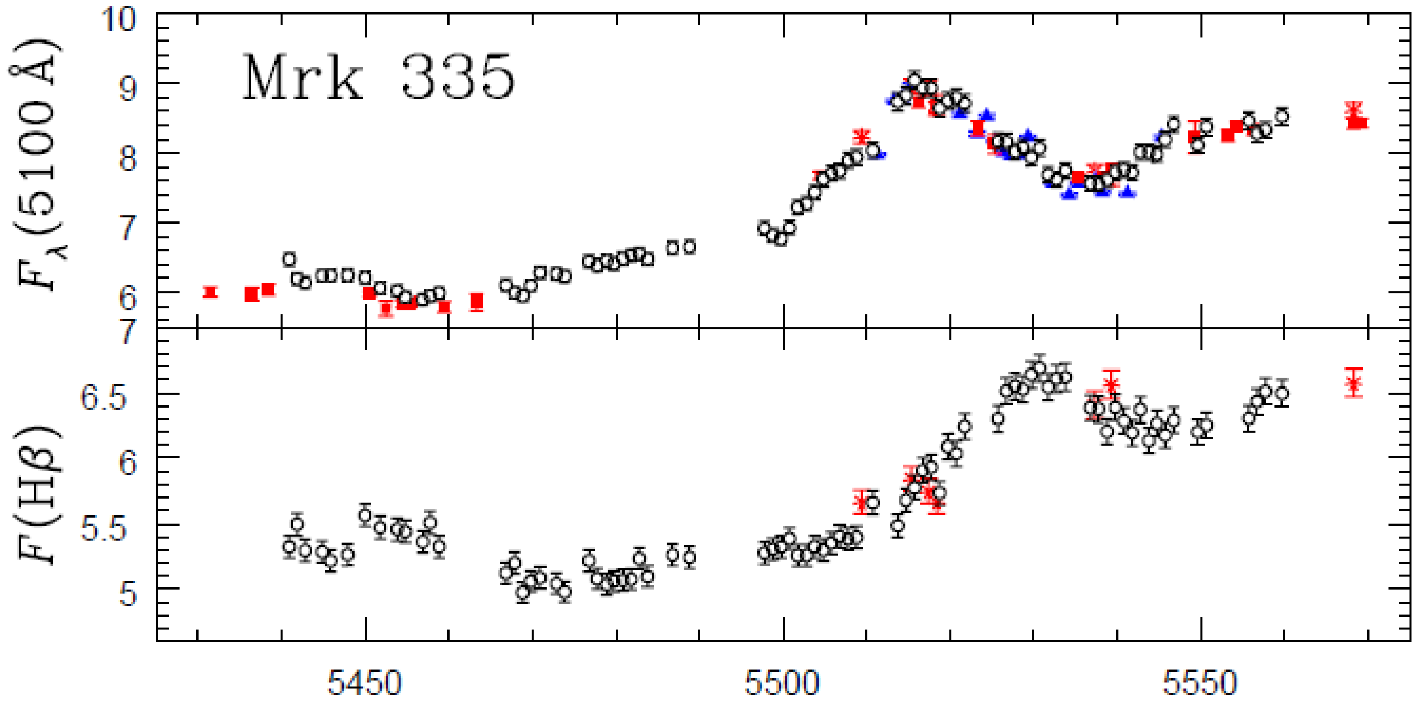
Measuring black hole masses in distant quasars

- AGNs are used as tracers of the black hole population up to high redshift
- Their masses can be inferred from their luminosity and emission-line widths using scaling relationships based on reverberation mapping of relatively local (hence bright) AGNs.
- These scaling relationships are often used incorrectly, thus biasing the black hole mass scale.

Reverberation Mapping



Grier + 2012

Emission-line variations follow those in continuum with a small time delay (14 days here) due to light-travel time across the line emitting region.

SHARP

Reverberation-Based Masses

"Virial Product" (units of mass)

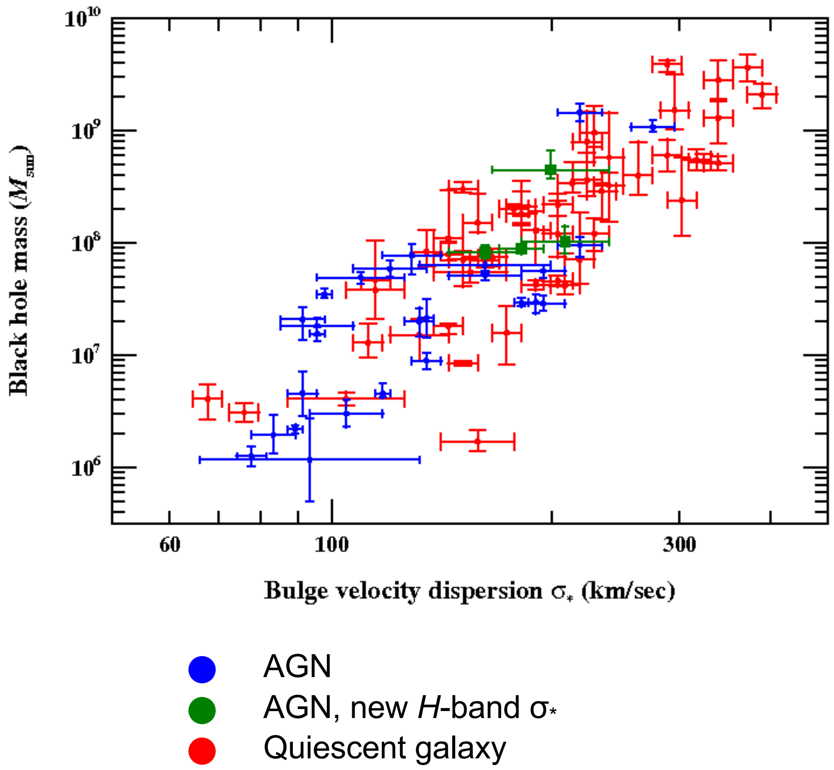
$$M_{\mathrm{BH}} = f\left(R\Delta V^{2} / G\right)$$

Observables:
R = BLR radius (reverberation)
ΔV = Emission-line width

Set by geometry and inclination
(subsumes everything we don't know)

If we have independent measures of M_{BH}, we can compute an ensemble average <*f* >

The AGN M_{BH}– σ_* Relationship

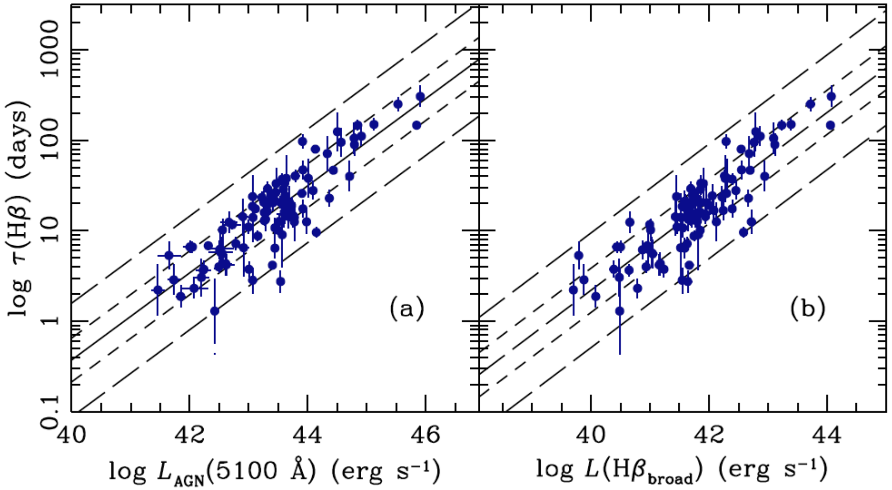


Grier+ 2013, ApJ, 773:90

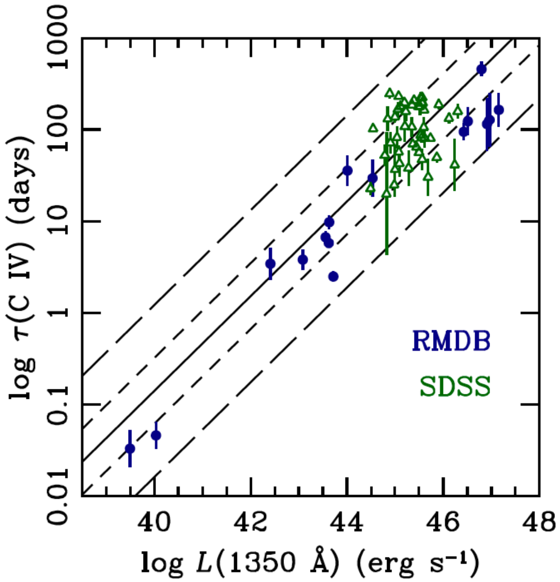
- Assume zero point of most recent quiescent galaxy calibration.
- Maximum likelihood places an upper limit on intrinsic scatter $\Delta \log M_{BH} \sim 0.40$ dex.
    - Consistent with quiescent galaxies.

The $R-L$ Relation

Hβ

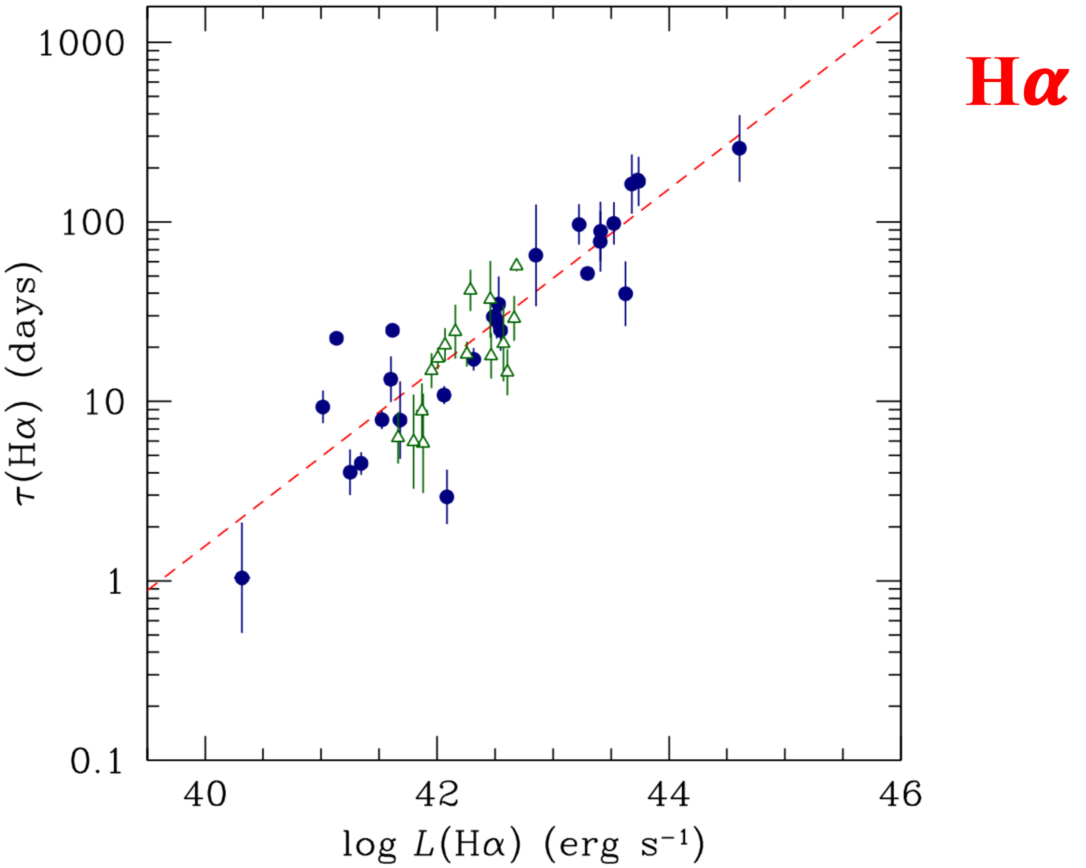


CIV



Dalla Bonta` + 2020

The *R–L* Relation



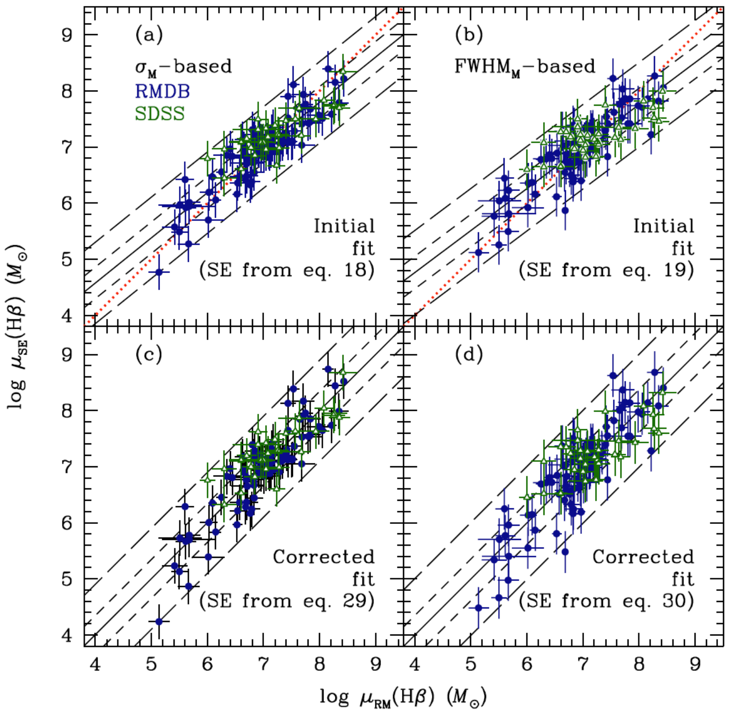
Dalla Bonta` et al., to be submitted

Estimating masses of black holes in quasars with single-epoch spectroscopy

Hβ

$$\log M_{\rm SE} = \log f + 7.530 + 0.703\,[\log L({\rm H}\beta) - 42] + 2.183\,[\log \sigma_{\rm M}({\rm H}\beta) - 3.5]$$

$$\log M_{\rm SE} = \log f + 7.015 + 0.784\,[\log L({\rm H}\beta) - 42] + 1.387\,[\log {\rm FWHM_M}({\rm H}\beta) - 3.5]$$



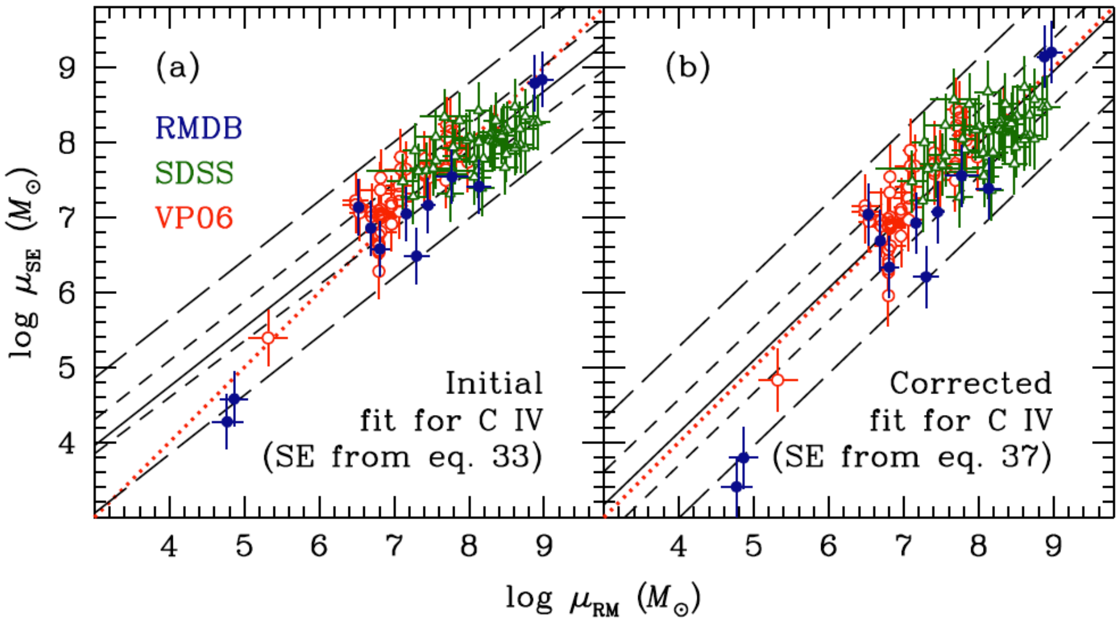
Third parameter: Eddington ratio
(Du + 2016, 2018; Grier + 2017, Du & Wang 2019, Fonseca Alvarez et al. 2020, Martínez-Aldma + 2019)

Dalla Bonta` et al. 2020

Estimating masses of black holes in quasars with single-epoch spectroscopy

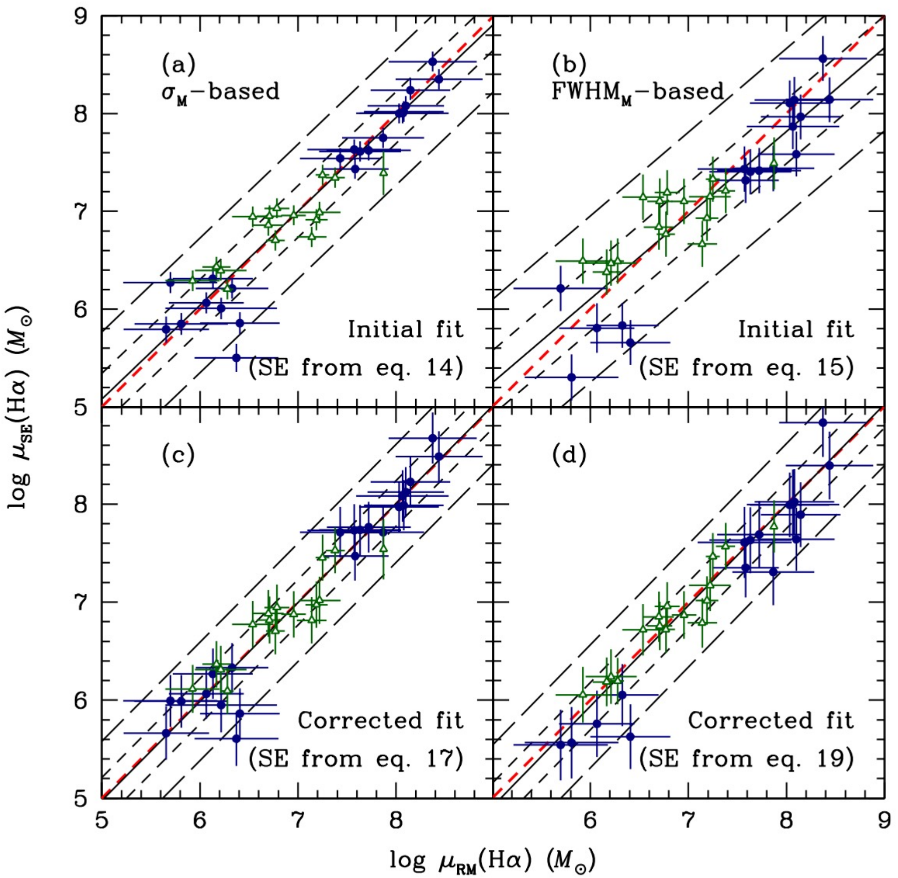
CIV

$$\log M_{\rm SE} = \log f + 7.934 + 0.761\,[\log L(1350\,\text{Å}) - 45] + 1.289\,[\log \sigma_{\rm M}({\rm C\,IV}) - 3.5]$$



Dalla Bonta` et al. 2020, Dalla Bonta` & Peterson 2022

Single Epoch Masses with Hα

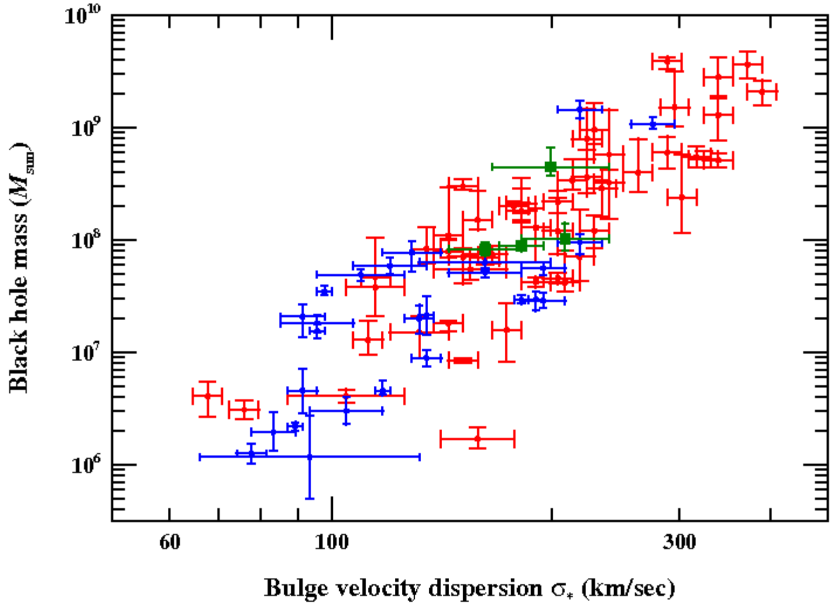


including all RM database from Dalla Bonta`+ 2020 and SDSS–RM database (Shen+ 2015, Shen+ 2024)

We remeasured the emission-line lags detrending the light curves

Dalla Bonta` et al. to be submitted

The AGN M_{BH}– σ_* Relationship



- AGN
- AGN, new *H*-band σ_*
- Quiescent galaxy

Grier+ 2013, ApJ, 773:90

- Assume zero point of most recent quiescent galaxy calibration.
- Maximum likelihood places an upper limit on intrinsic scatter $\Delta \log M_{BH} \sim 0.40$ dex.
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SBH masses with VESPER@SHARP

Dynamical measurements: gas vs star

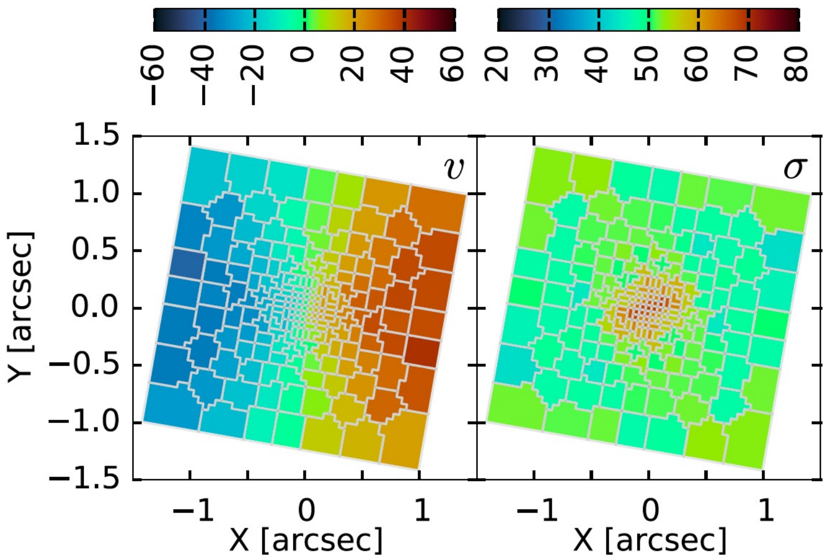
The sphere of influence must be resolved

Sphere of influence: region of space within which the gravitational potential of the SBH dominates over that of the surrounding stars.

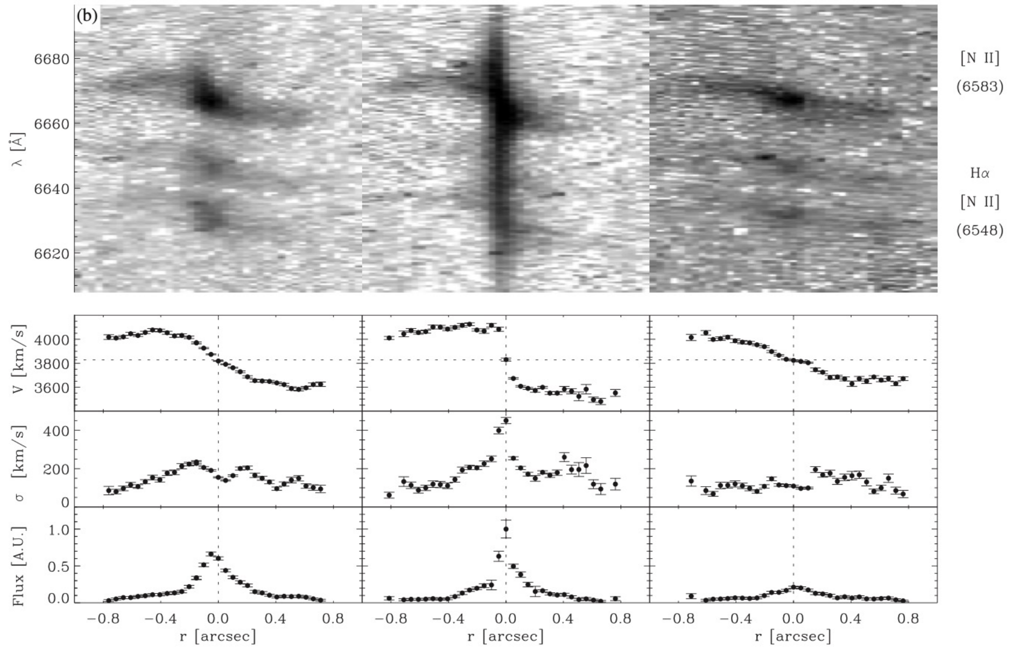
$$r_{\rm BH} \sim 0.4 \left(\frac{M_{\rm BH}}{10^6 M_\odot} \right) \left(\frac{100\,{\rm km/s}}{\sigma} \right)^2 {\rm pc}.$$

$$\theta_{\rm BH} \sim 0\farcs1 \left(\frac{M_{\rm BH}}{10^6 M_\odot} \right) \left(\frac{100\,{\rm km/s}}{\sigma} \right)^2 \left(\frac{1\,{\rm Mpc}}{D} \right).$$

Dynamical measurements



Merrell +2023



Dalla Bontà +2009

Kormendy & Ho 2013, for a review

Evolution of galaxies closely entwined with nuclear properties

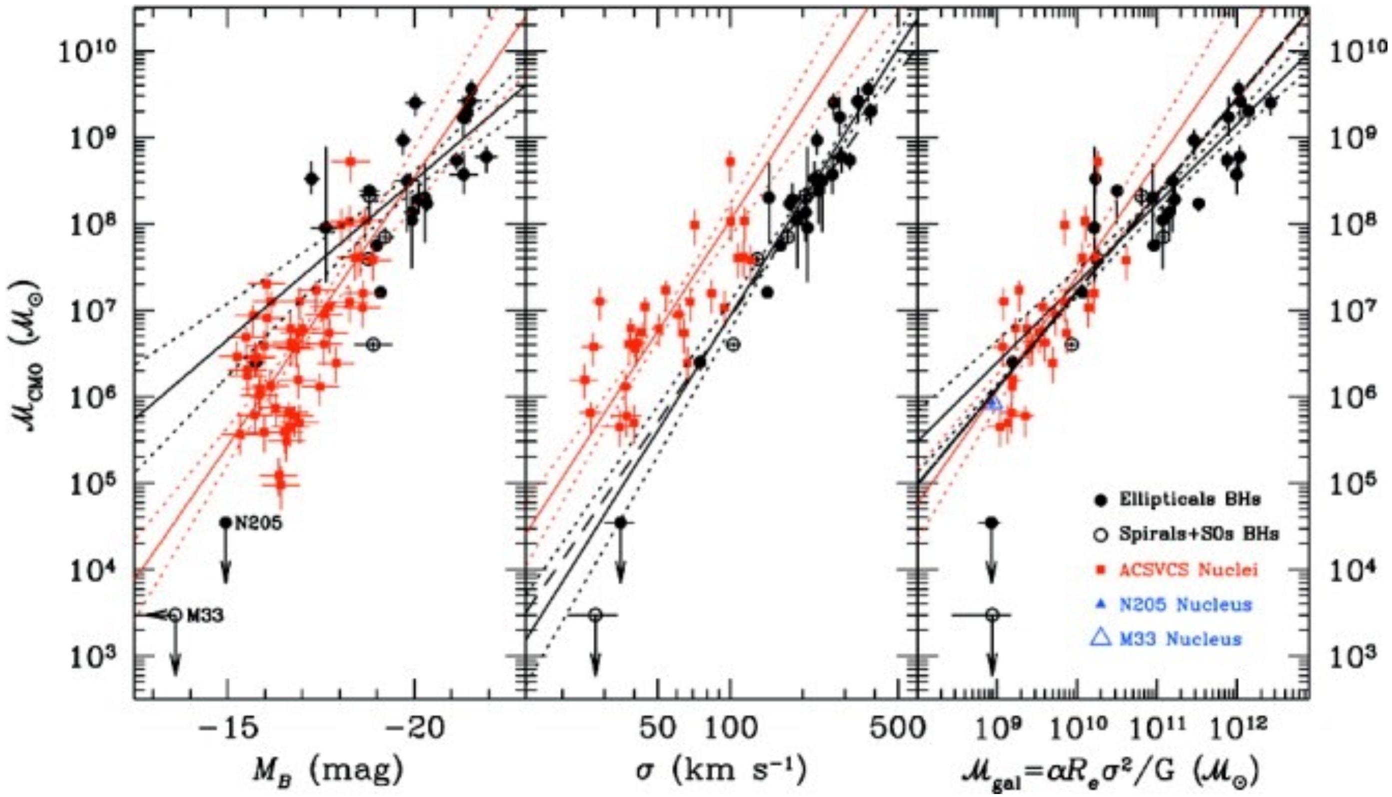
Central Massive Objects:

Nuclear Clusters (**NCs**, see Neumayer, Seth, and Böker 2020 for a review)

and

Supermassive Black Holes (**SBHs**)

Scaling relations

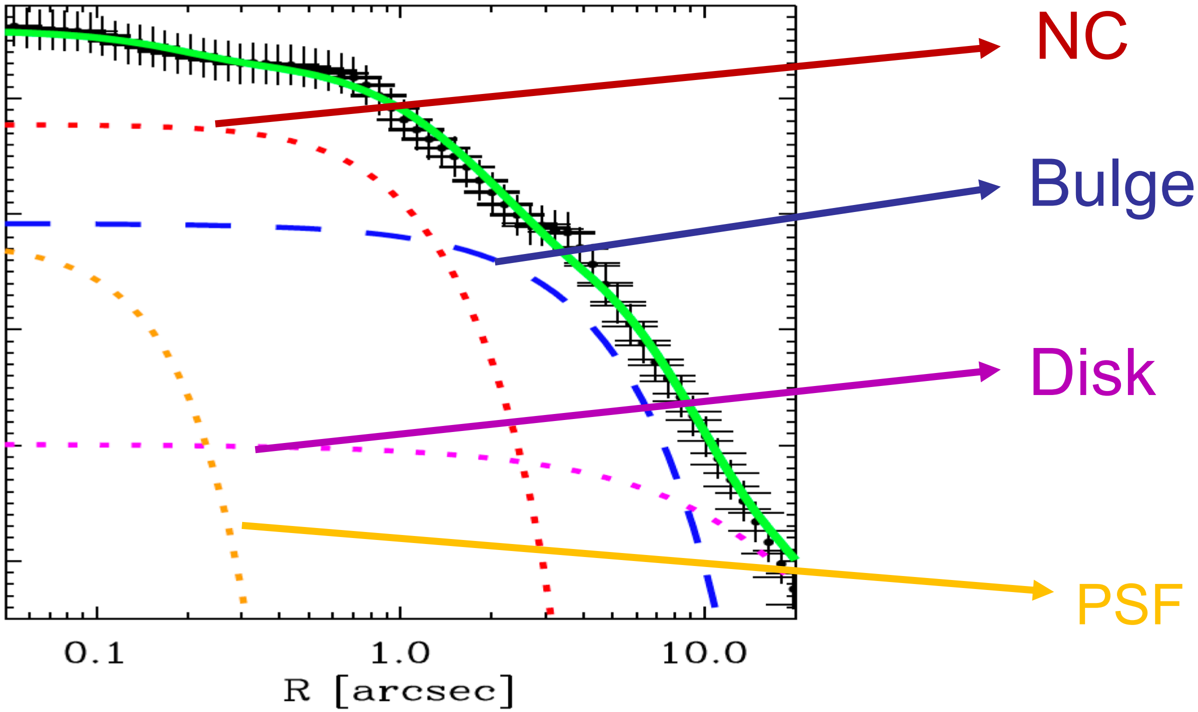


Ferrarese, Coté, Dalla Bontà et al. 2006, ApJ, 644, L21

see also Wehner & Harris 2006, ApJ, 644, L17

MICADO high resolution imaging

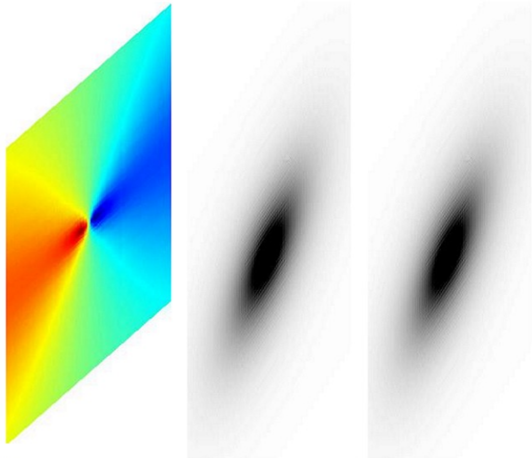
NGC 383



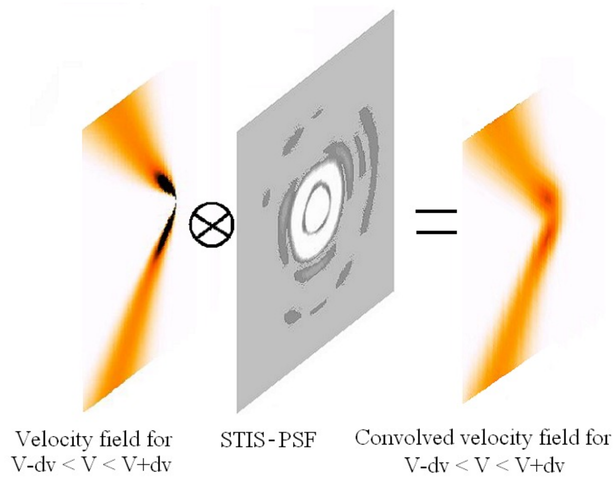
Adapted from Portaluri 2014

see also Dalla Bontà et al. 2018 for 2D-photometric decomposition

VESPER@SHARP high resolution IFU



$V = \sqrt{\frac{M}{L} V_*^2 + \frac{GM_\bullet}{R}}$ $\sigma = \sigma_0 + \sigma_1 \exp[-(R^2/2\sigma_h^2)]$ $I = I_0 \exp[-(R/h)]$



$$v_c(r) = \left[\frac{GM(r)}{r}\right]^{1/2} = \qquad (1)$$

$$= \left[\frac{GM_\bullet}{r} + \left(\frac{M}{L}\right)_{\rm NC} v_{\rm NC}^2(r) + \left(\frac{M}{L}\right)_\star v_\star^2(r)\right]^{1/2}$$

SHARP unique capabilities

Within a distance of 100 Mpc it will be possible to detect an NC with Re= 10pc

It will be possible to:

- ❖ determine the low mass end of the SBH mass function
- ❖ discover the formation/evolution scenarios of NCs and SBHs

SHARP unique capabilities

Both NEXUS and VESPER will play a fundamental role in understanding the structure and evolution of galactic nuclei, guiding us toward a comprehension of the high-redshift universe