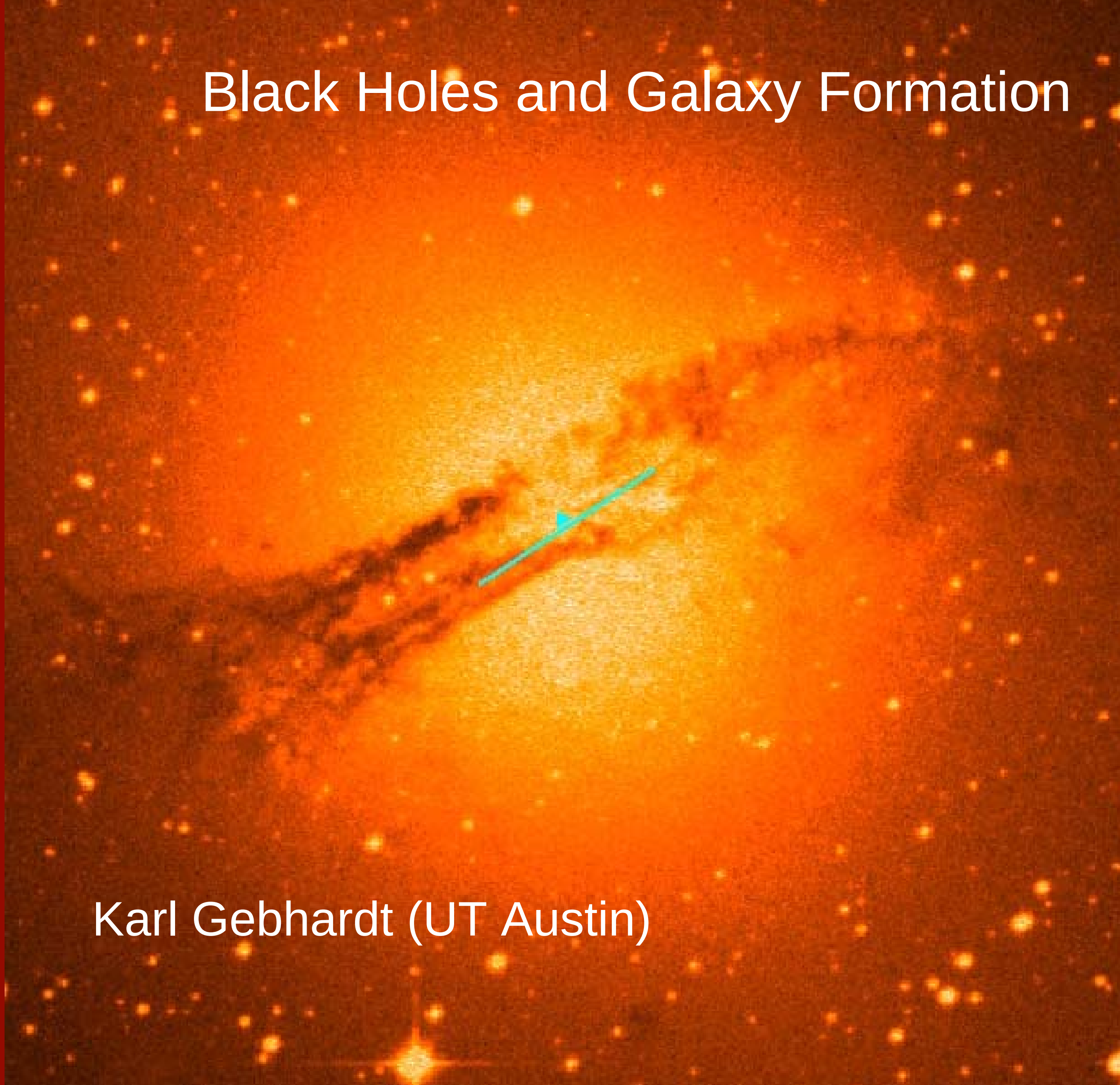
Black Holes and Galaxy Formation



Karl Gebhardt (UT Austin)

If you want to understand how galaxies evolve (and possibly form), you need to understand growth of black holes:

- Tight correlations (sigma, mass, light, dark halo, n, etc.)
- BH growth tracks galaxy growth (compare integrated star formation history to that of AGN activity)
- First stars are likely very massive and may have produced massive BHs of over 50 Msun; these may be seeds for galaxies
- AGN jets clearly have global impact on host

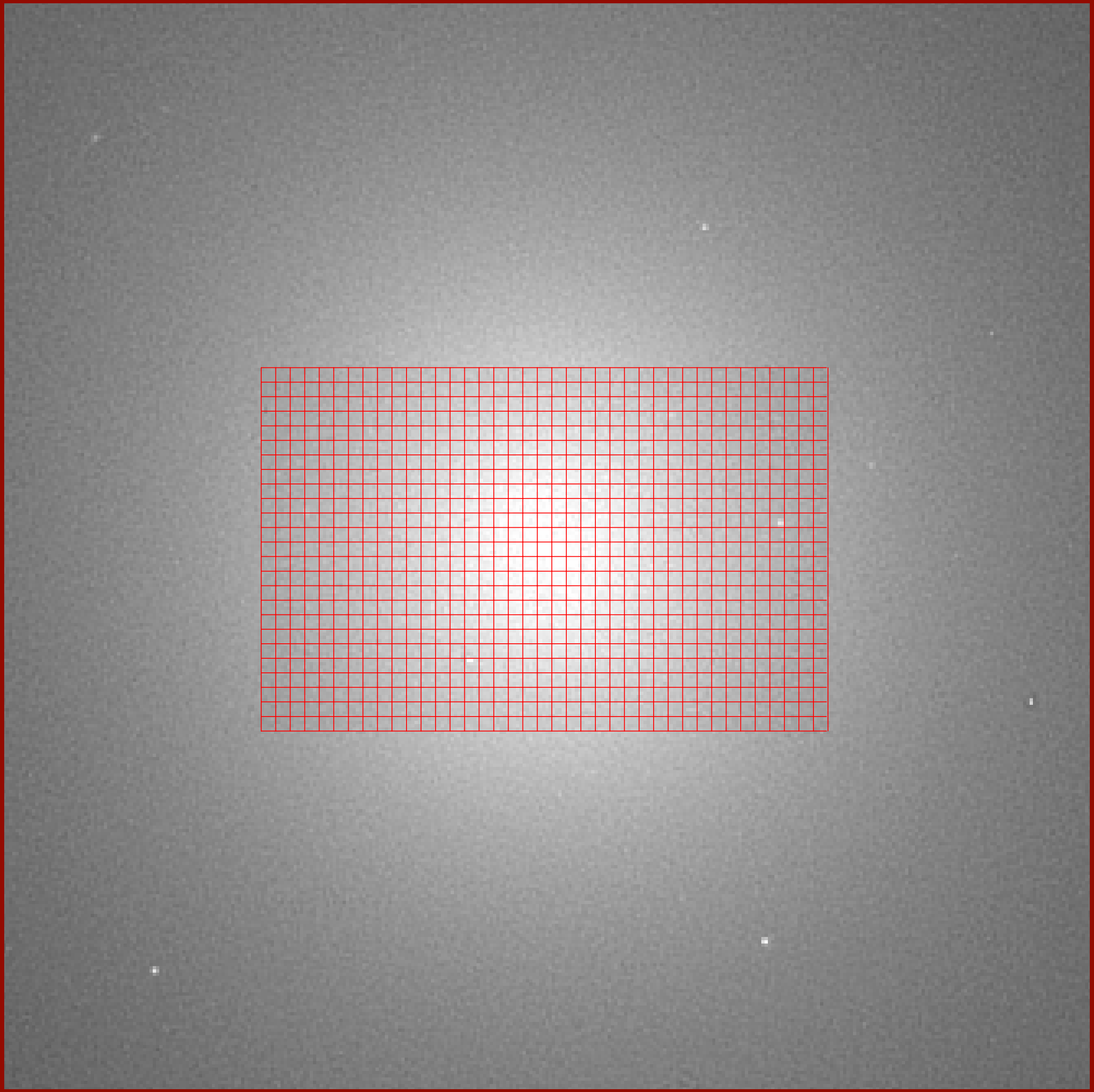
How BHs grow is very important for gravitational wave studies.

GOALS:

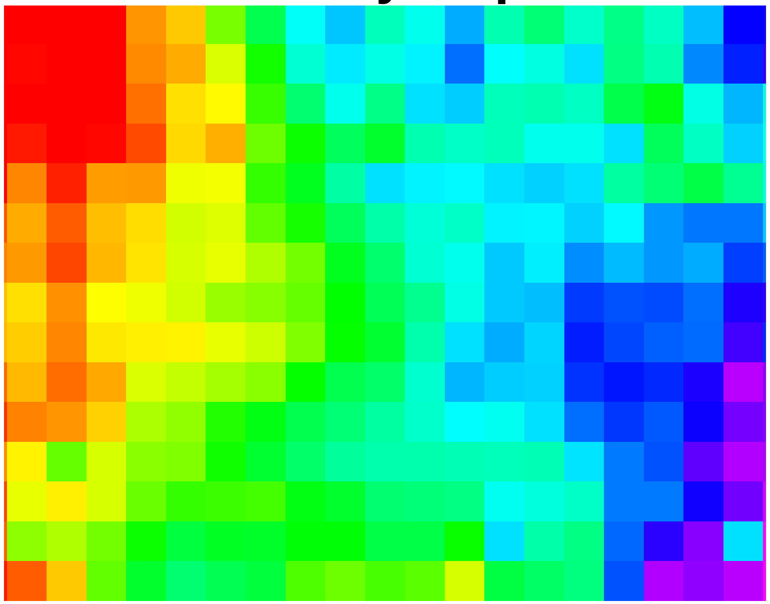
- establish observational correlations (and scatter)
- find most massive BHs; connected to mergers
- find seeds (globular clusters?)
- watch BH and bulge grow (AGN)
- evolutionary observations (hardest, but doable with quasars)

Gemini GMOS/IFU observations has opened up a new avenue to study the most massive black holes.

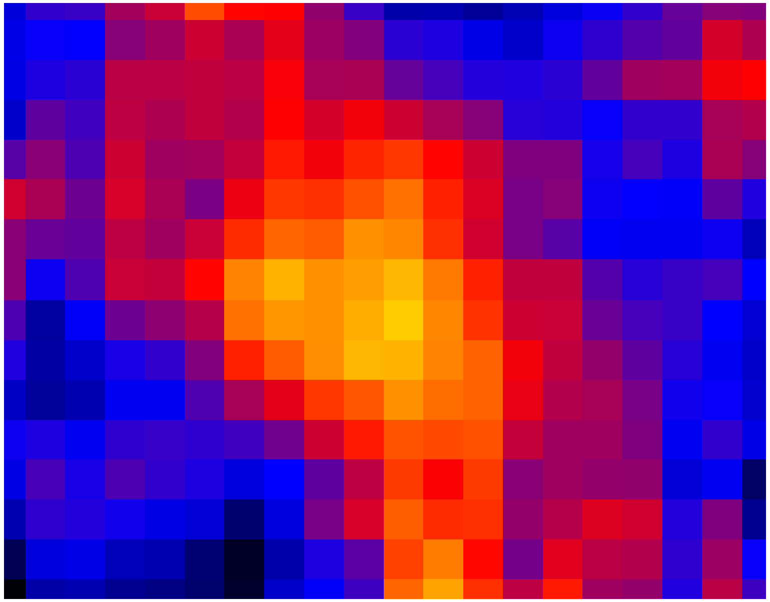
Here is the IFU overlay on N4472 from Gebhardt & Busch (04):



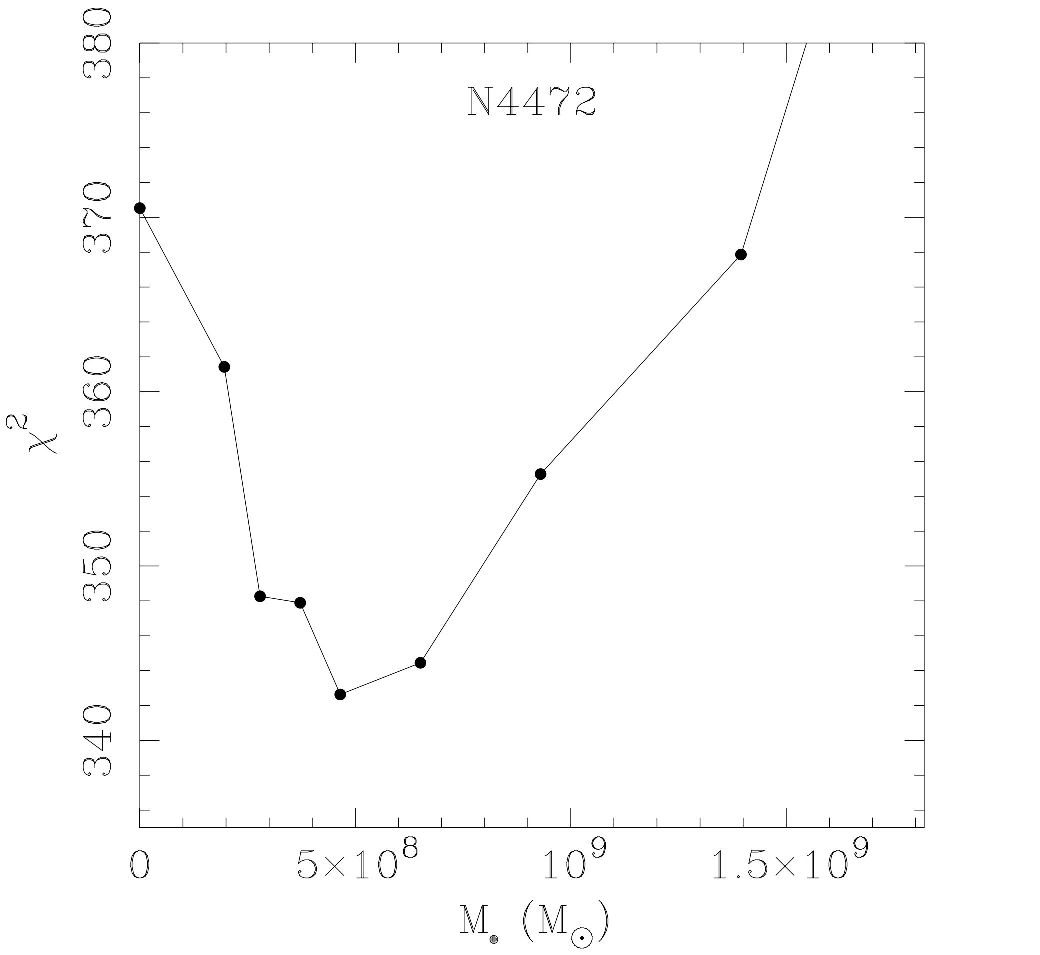
Velocity Map



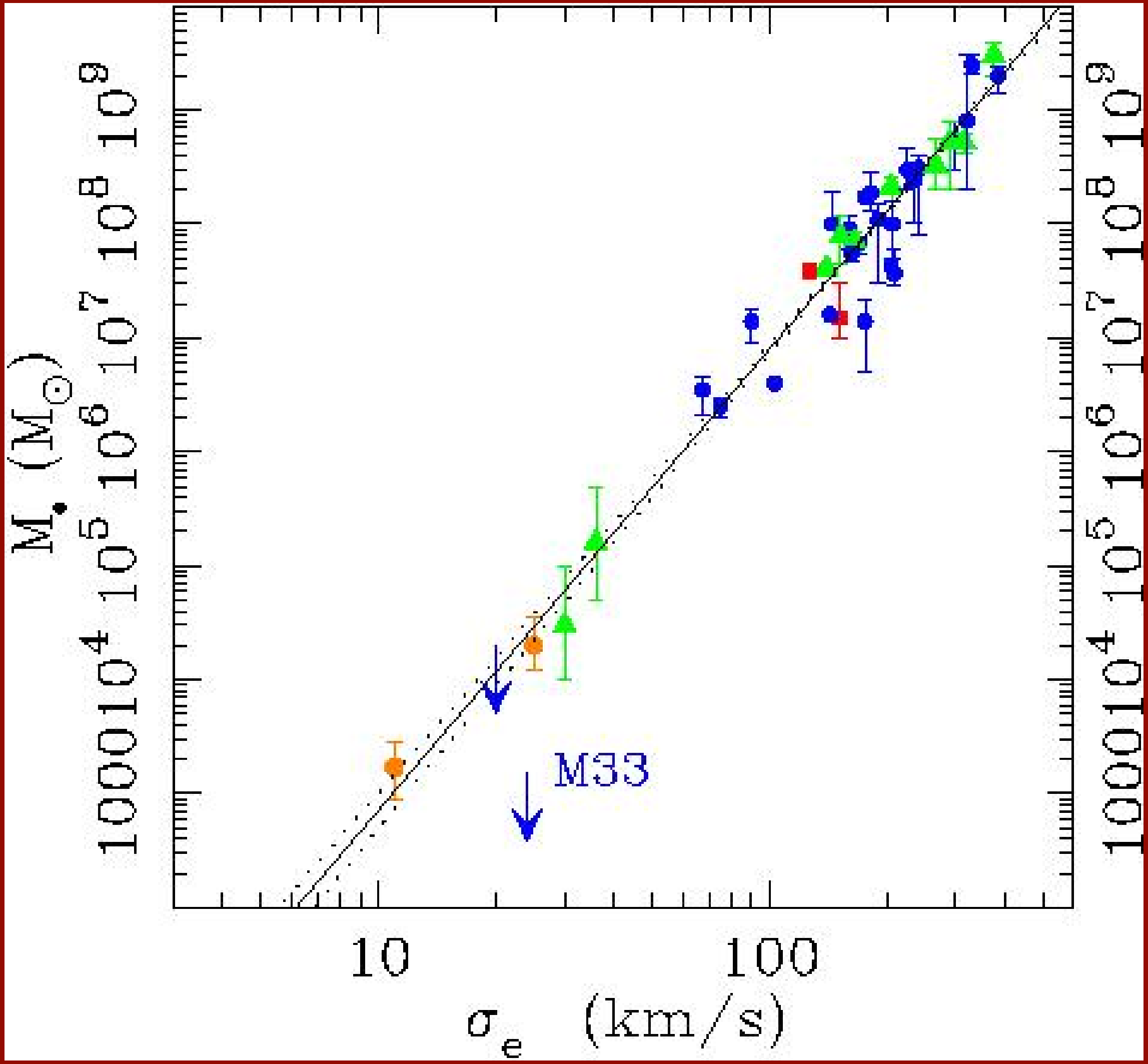
Dispersion Map



Orbit models for the 2D kinematic data for N4472 provide a well measured BH:



Current BH/sigma correlation using published results



Theoretical Models for BH correlations

Silk & Rees 98

Ostriker 00

Haehnelt & Kauffman 00

Nulsen & Fabian 00

Blandford 99

Adams et al 01, 03

Burkert & Silk 01

Balberg & Shapiro 02

Sellwood 02

MacMillian & Henrickson 02

Ciotti & van Albada 01

Colgate et al 03

King 03

Mathur & Grupe 04

Sirota et al 04

Granato et al 03

Tyler et al 03

Haehnelt 03

Ilvin et al 03

Merritt & Poon 03

Murray et al 04

Bromley et al 04

Springel et al 04

Sommerville et al 05

These differ by slope, normalization, and scatter

Theoretical Models fall into a few general camps:

• BH feedback (winds, jets): e.g., Silk & Rees, Murray etal

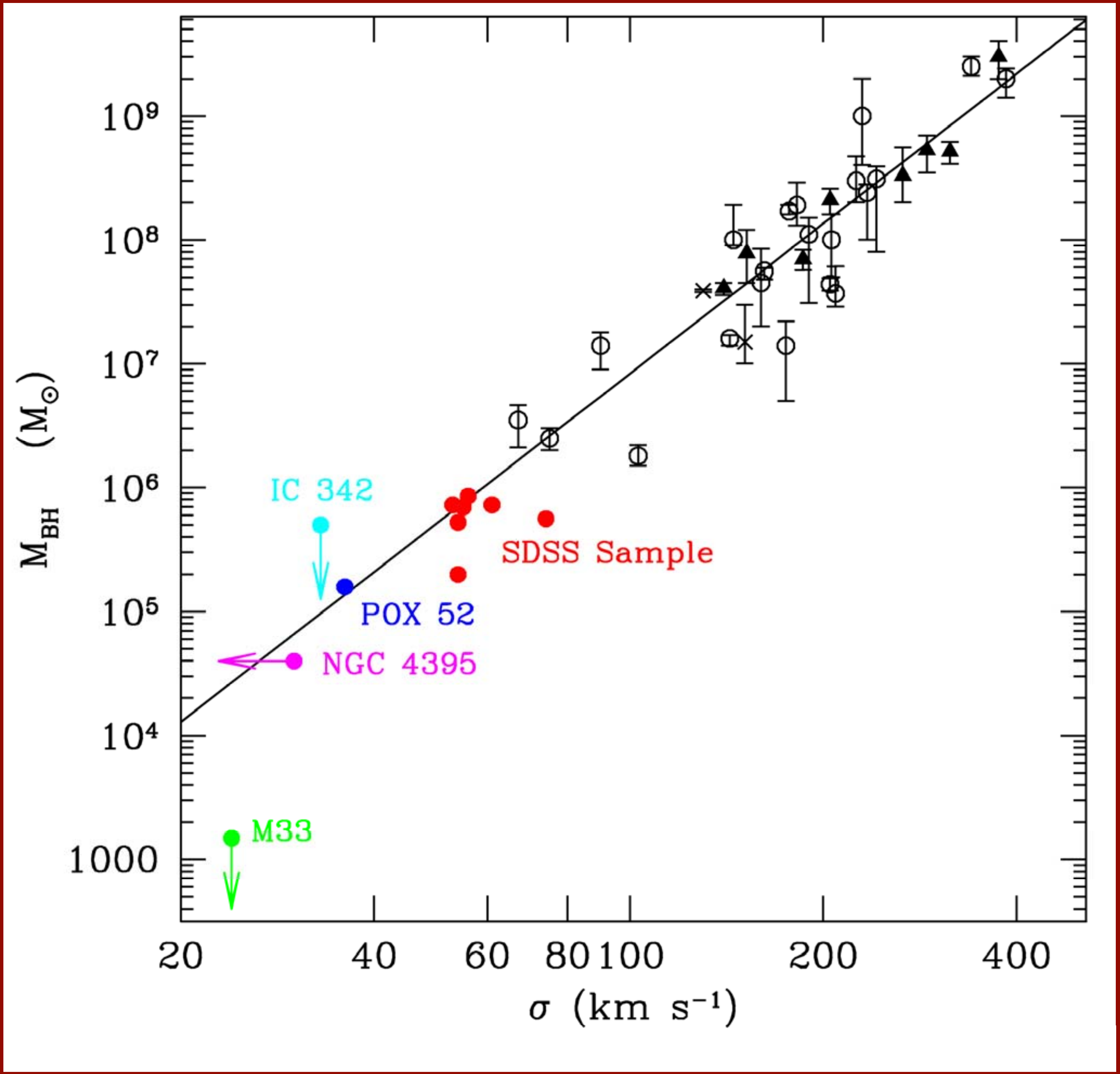
• Direct infall: e.g., Adams etal.

• Galaxy instabilities: e.g., Sellwood

Feedback models also explain galaxy color bi-modality! Large BHs tend to halt star formation (Springel, DiMatteo, Hernquist 04; Sommerville et al. 05)

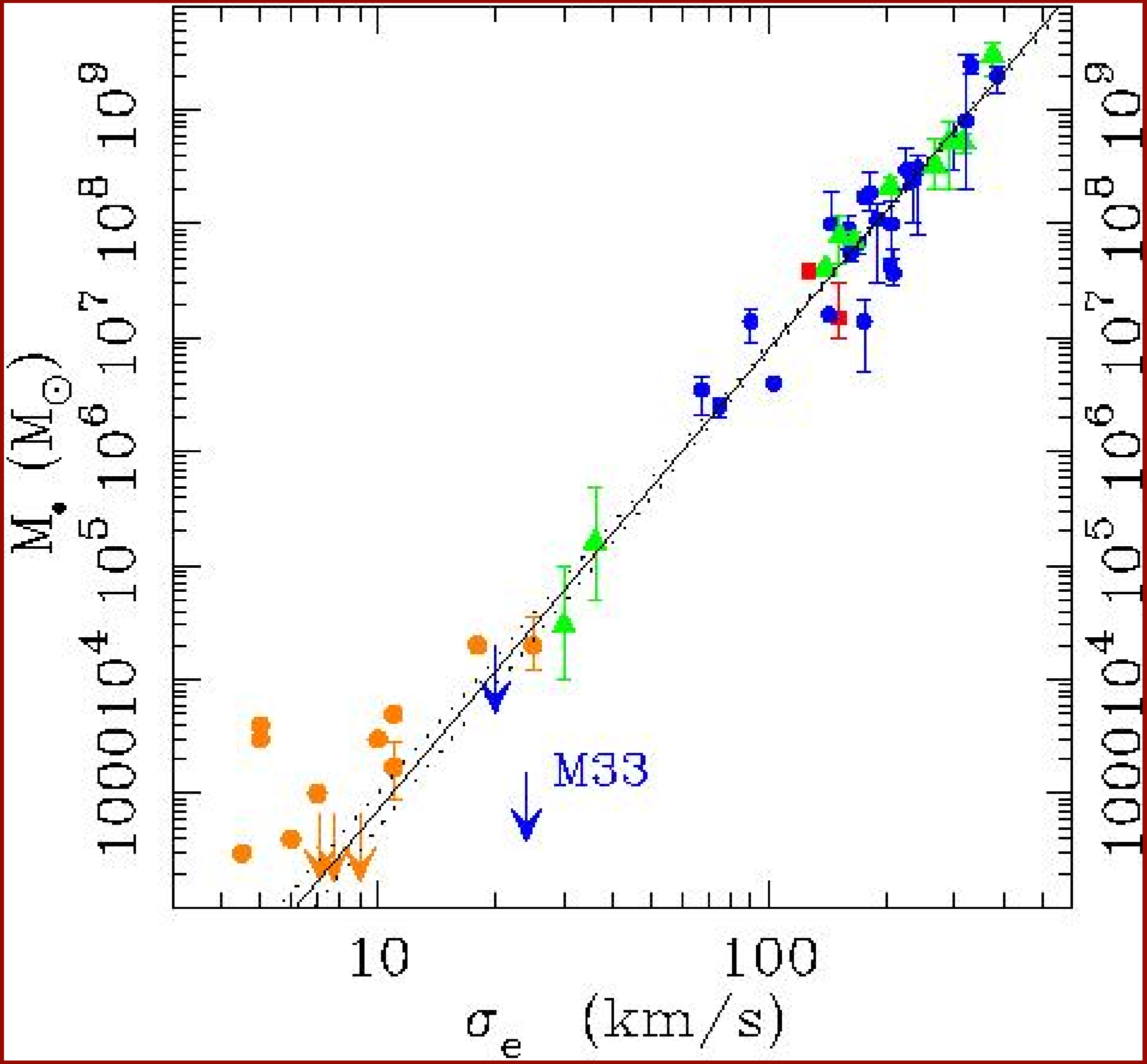
How to improve observational constraints:

• slope: probably not that important (easy to adjust in models)
• scatter: complicated by messy galaxy process
• extent: very important for most theoretical models
• evolution: probably the most important (but the hardest);
  look as a function of redshift (time) or,
  look as a function of type (young vs. old)



Barth, Greene, and Ho have measured low-luminosity AGNs in SDSS.

BH/sigma correlation with both galaxies and globular clusters (using isotropic models)

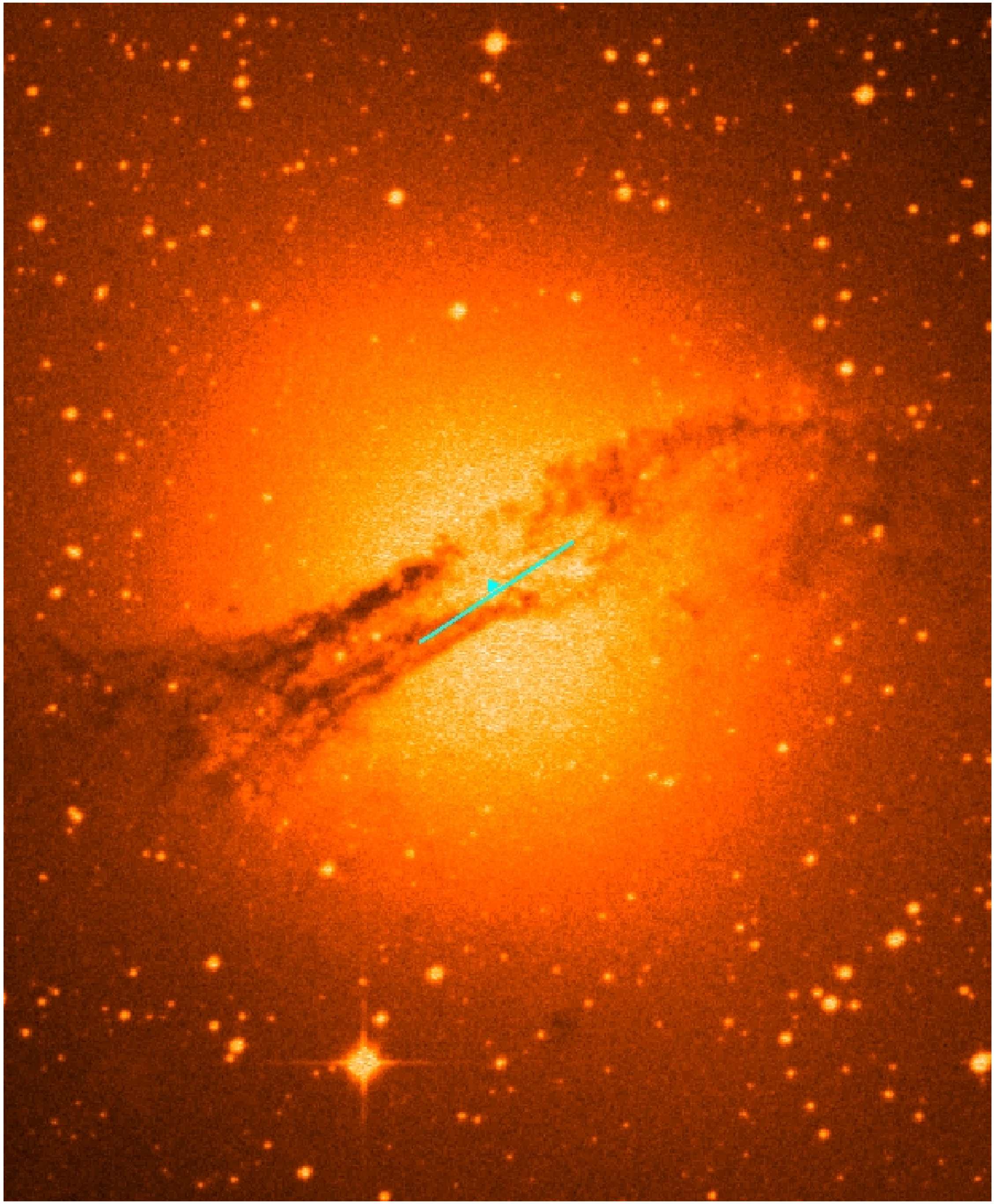


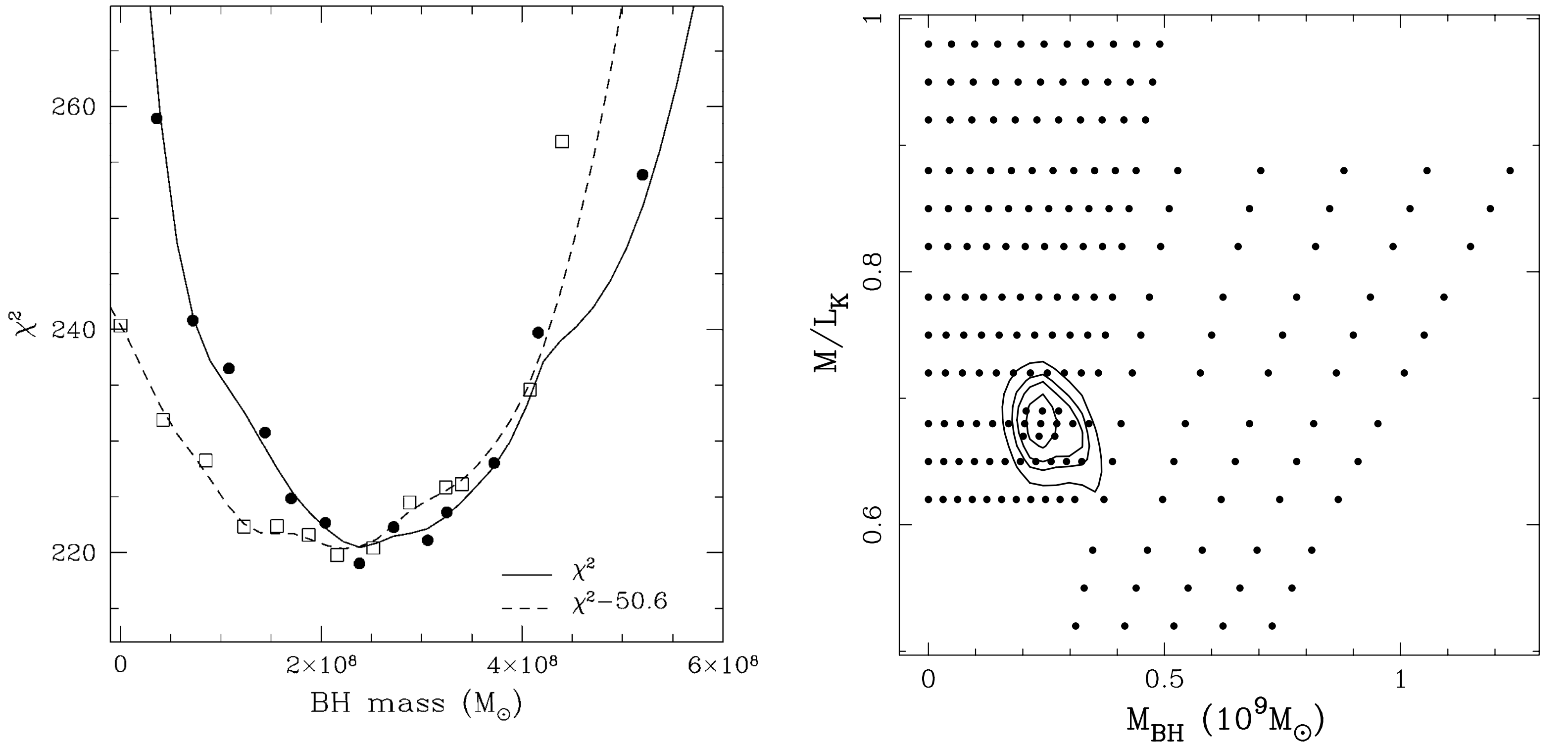
The advent of NIR spectrographs with good spatial resolution opens up a new regime for BH studies.

Data for CenA was taken with Gemini GNIRS.

NIR IFU behind AO will revolutionize this field.

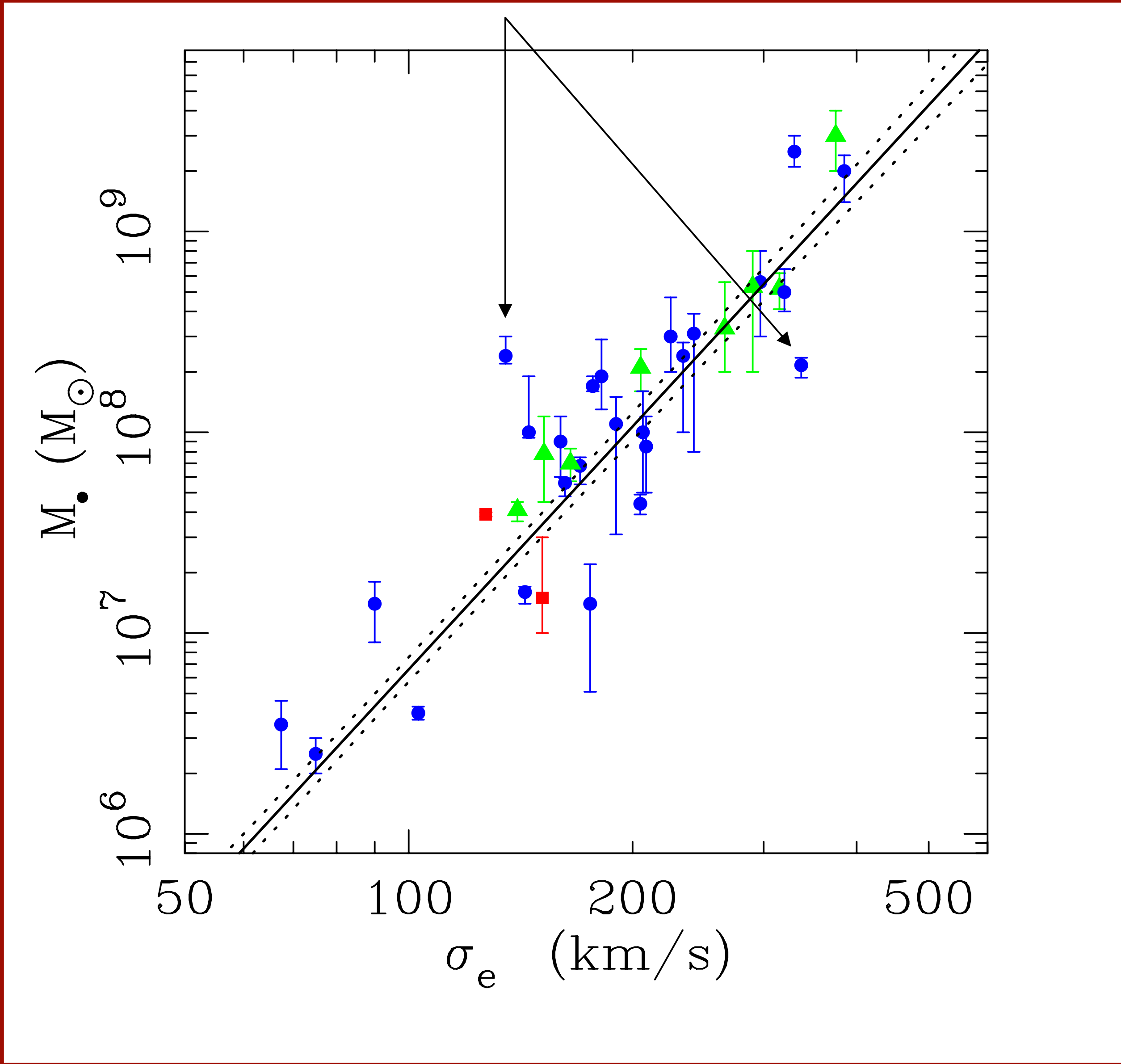
First must calibrate the CO bandhead (Silge and KG 03).



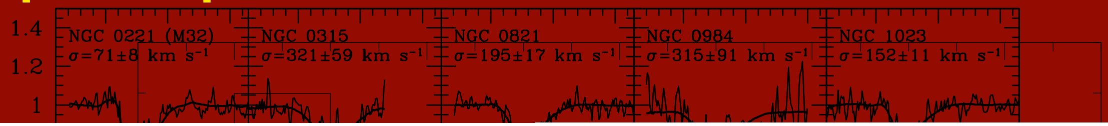


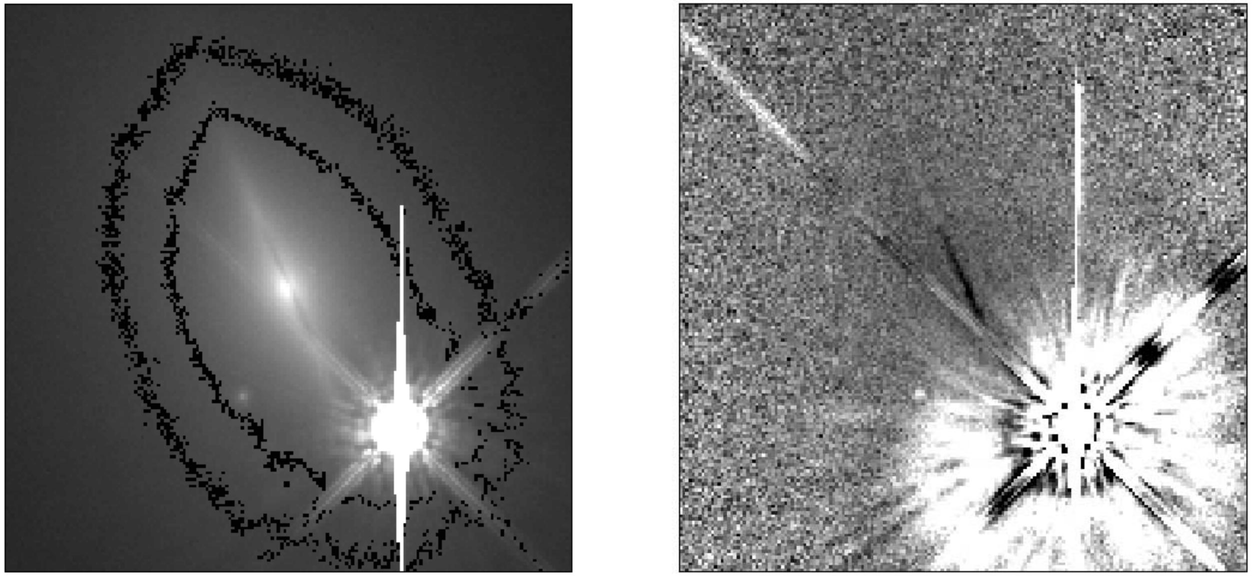
1D and 2D χ^2 distribution for Gemini GNIRS data on CenA (Silge et al 05), based on orbit-based models.

The newest additions to the BH family



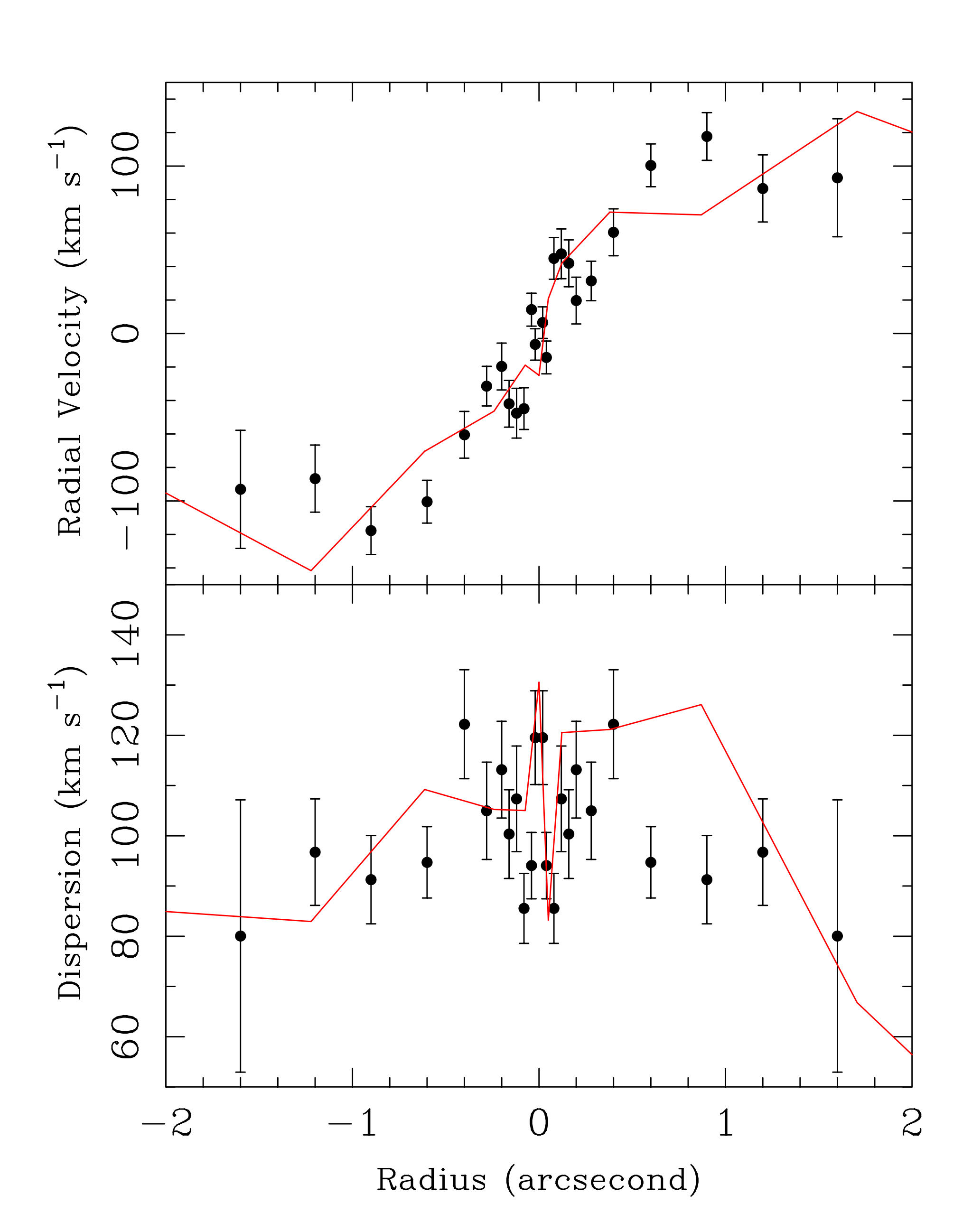
Adaptive Optics will take over from HST BH studies





N4486A has a 9th mag star 2.5” from nucleus. Keck AO NIR spectroscopy worked extremely well.

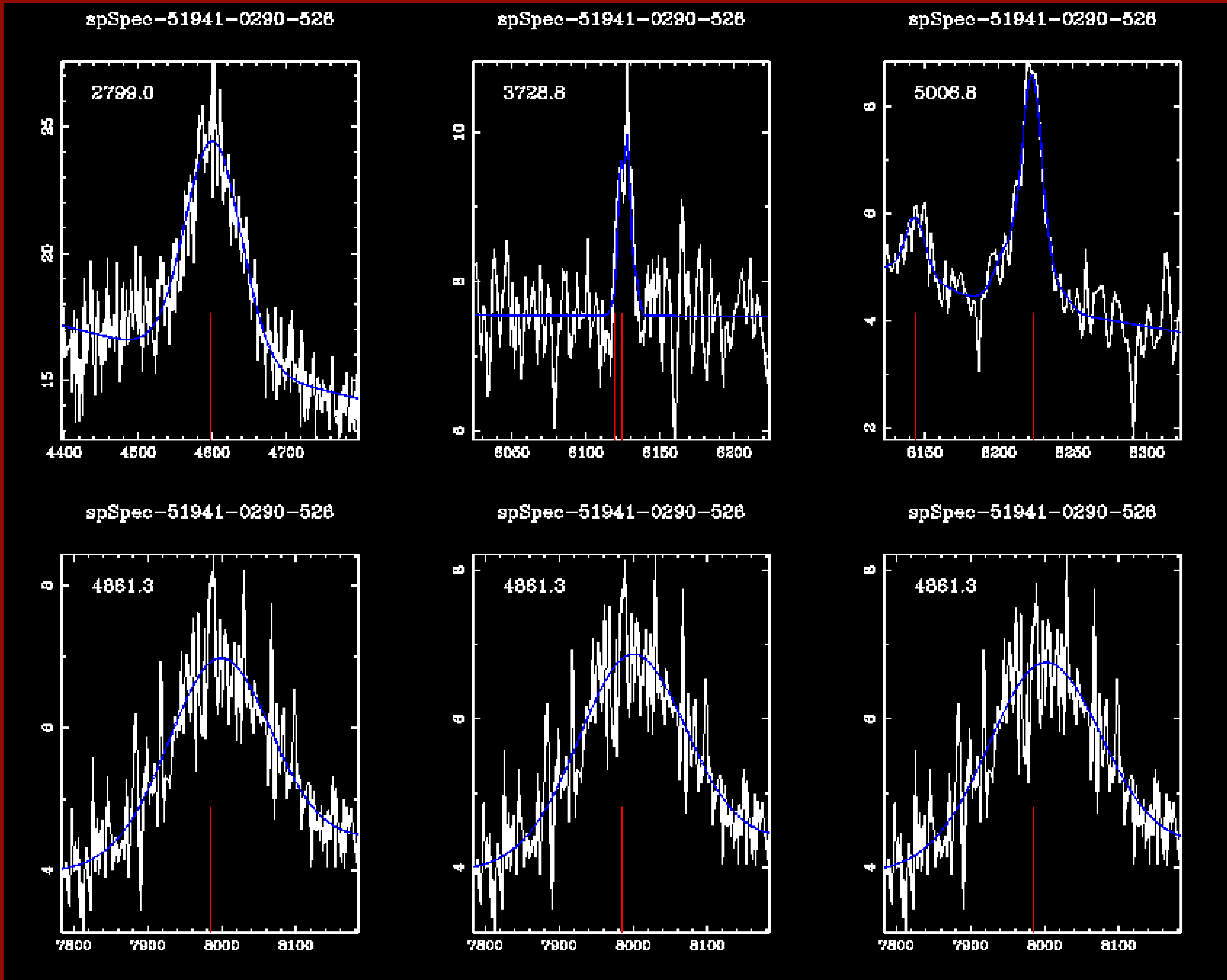
SB slope



Head to head comparison of Keck/AO kinematics against data from HST/STIS. The Keck data is better both in S/N and spatial resolution.

Evolution of Black Hole Correlations

- Spatially-resolved kinematics have limited applications.
- Must use integrated light for both BH and host galaxy.
- BH mass from Hbeta or MgII, sigma from narrow lines. Calibration is key.
- Potentially apply to all QSOs, and get redshift evolution.
- SDSS is an excellent database for this study.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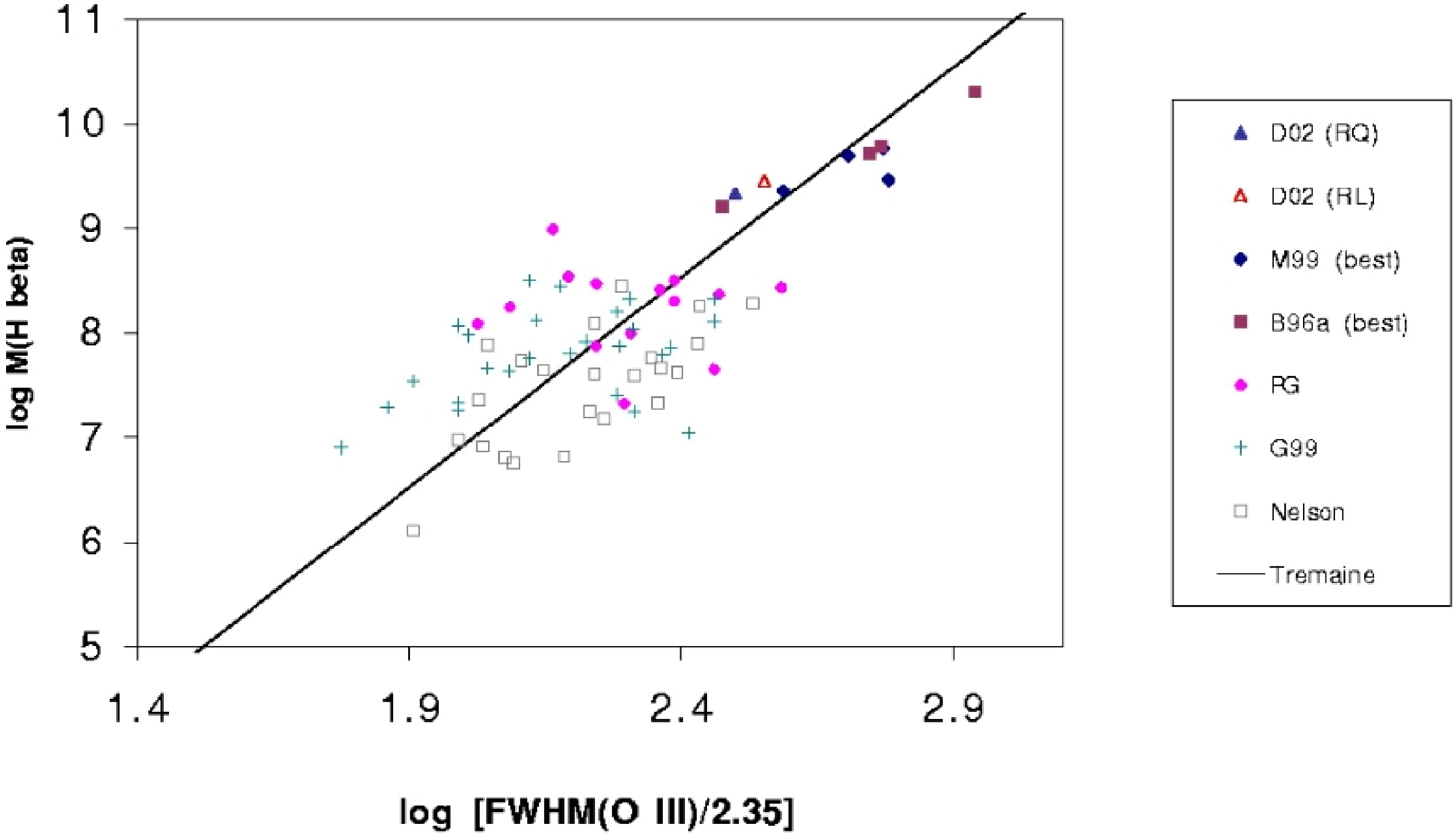
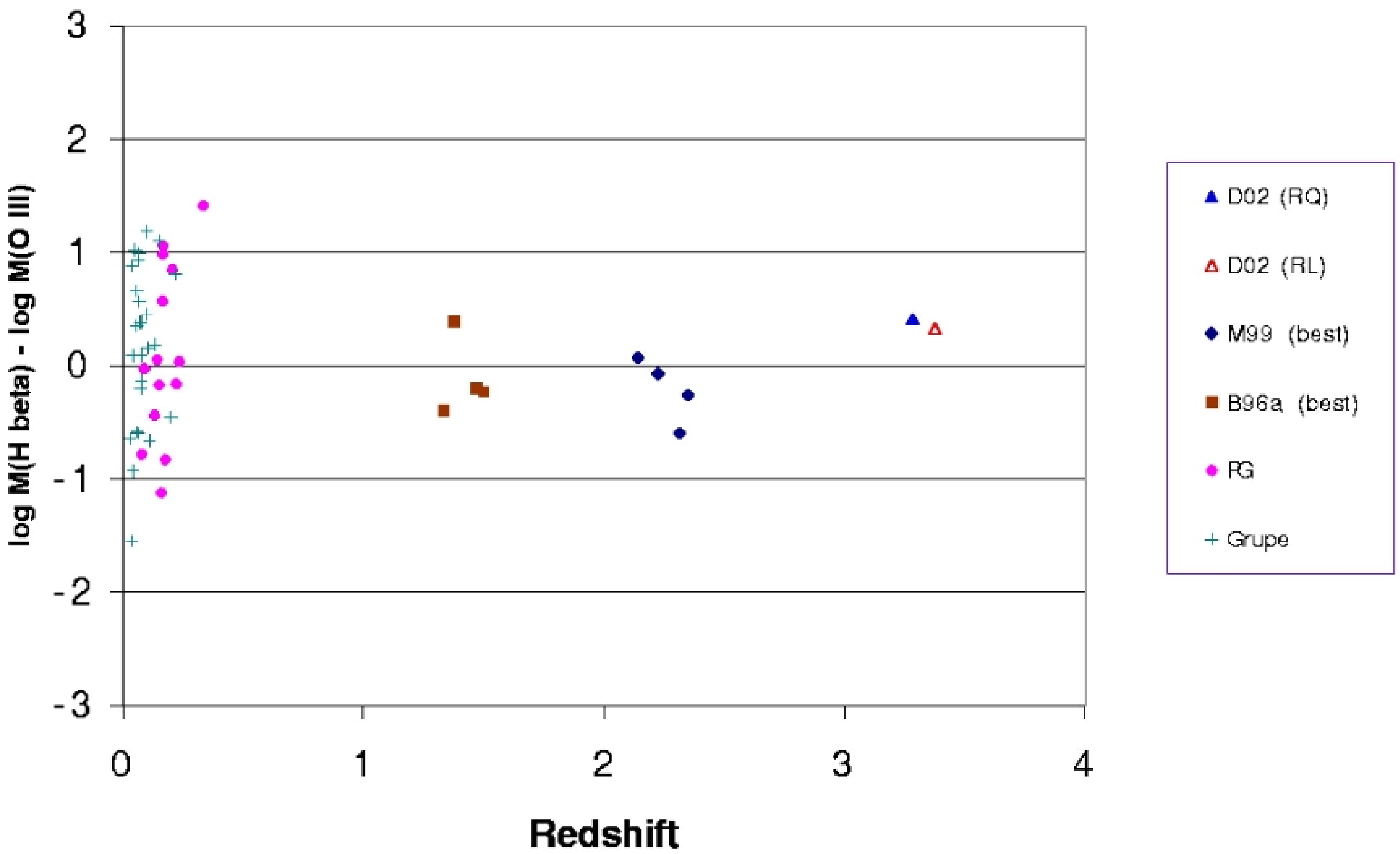
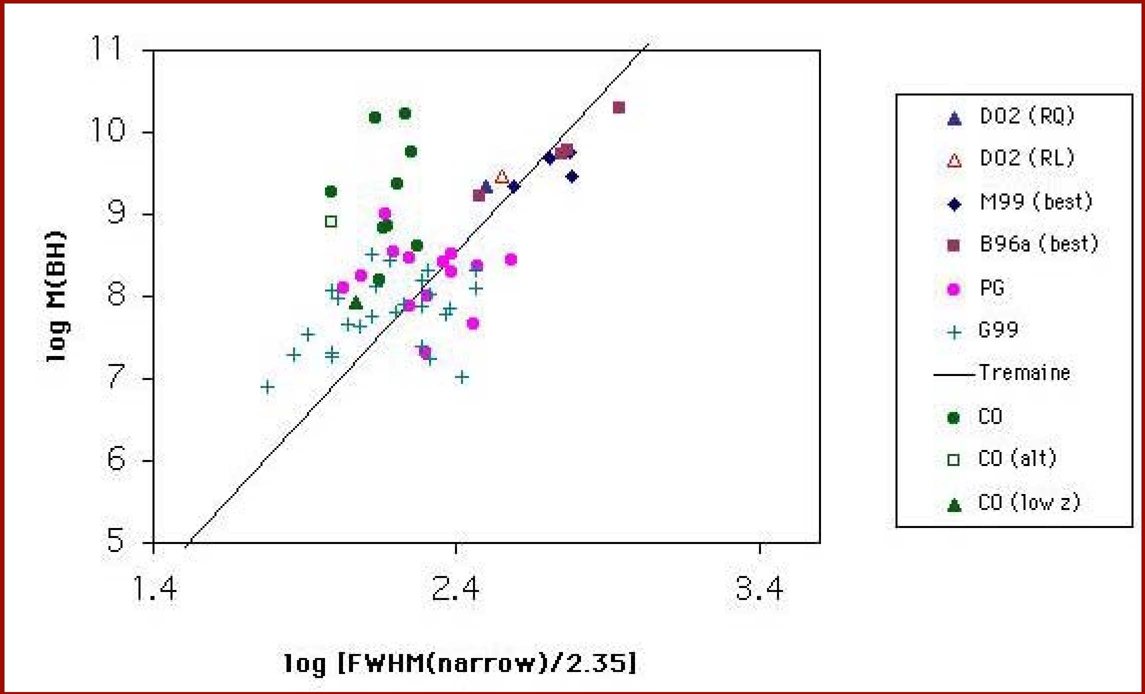
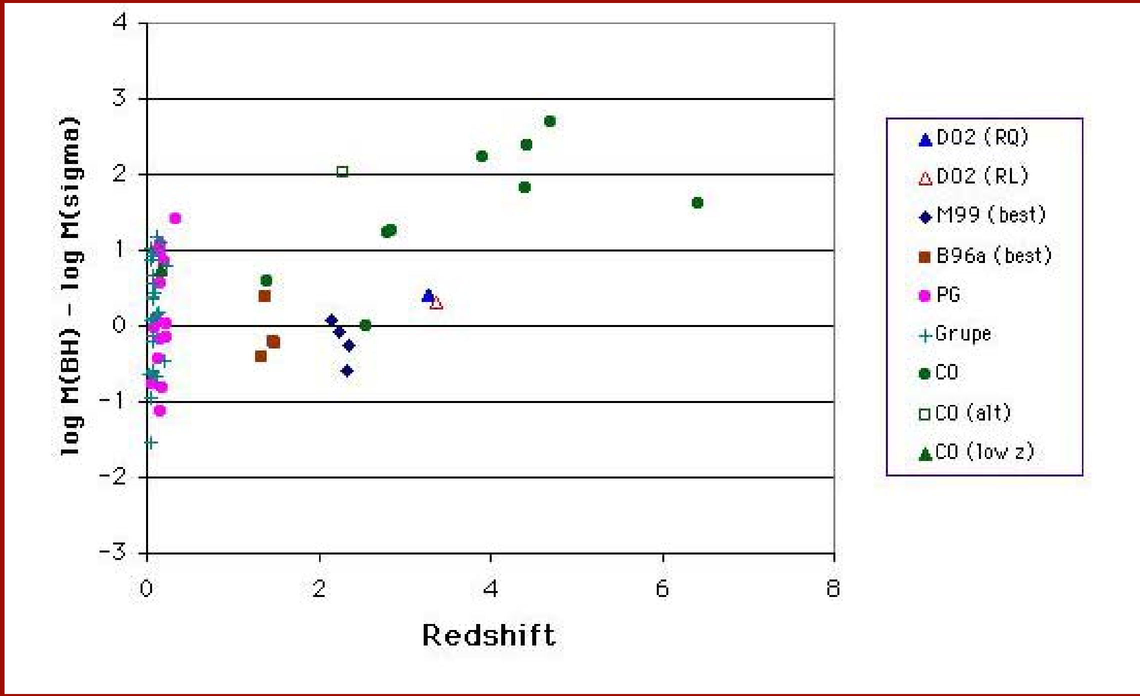
Shields, KG, Salviander et al. 03



Offset of BH mass from sigma correlations vs redshift







Compilation from Shields and Salviander using CO linewidth. Walter et al is z=6.4 point.

Conclusions

- About 40 nearby black holes with well measured masses; this will grow to about 100 soon.

- We are starting to measure BH evolution. From the most recent studies, it appears that BHs grew first. Evidence is:
    - massive BHs exist at early times
    - deviation from BH/sigma at early times
    - Cen A has 8 times larger BH
    - theoretical models work well

- Future for black studies is very promising. IFU in optical regions will open up studies in largest galaxies and in globular clusters.

- IR IFUs behind AO will offer new regime in BH studies. We will be able to measure those galaxies that have significant dust and are actively accreting.