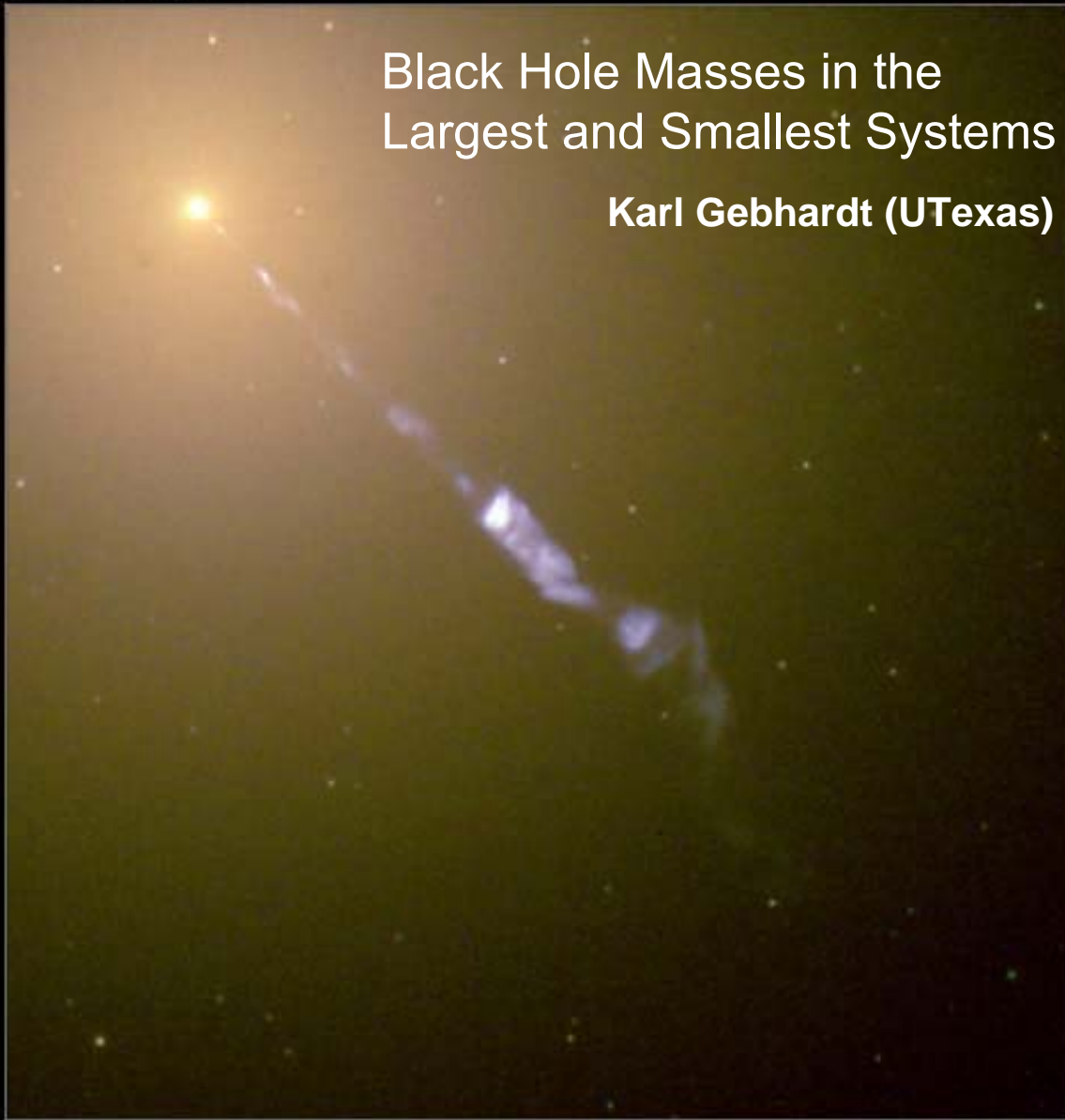


The M87 Jet

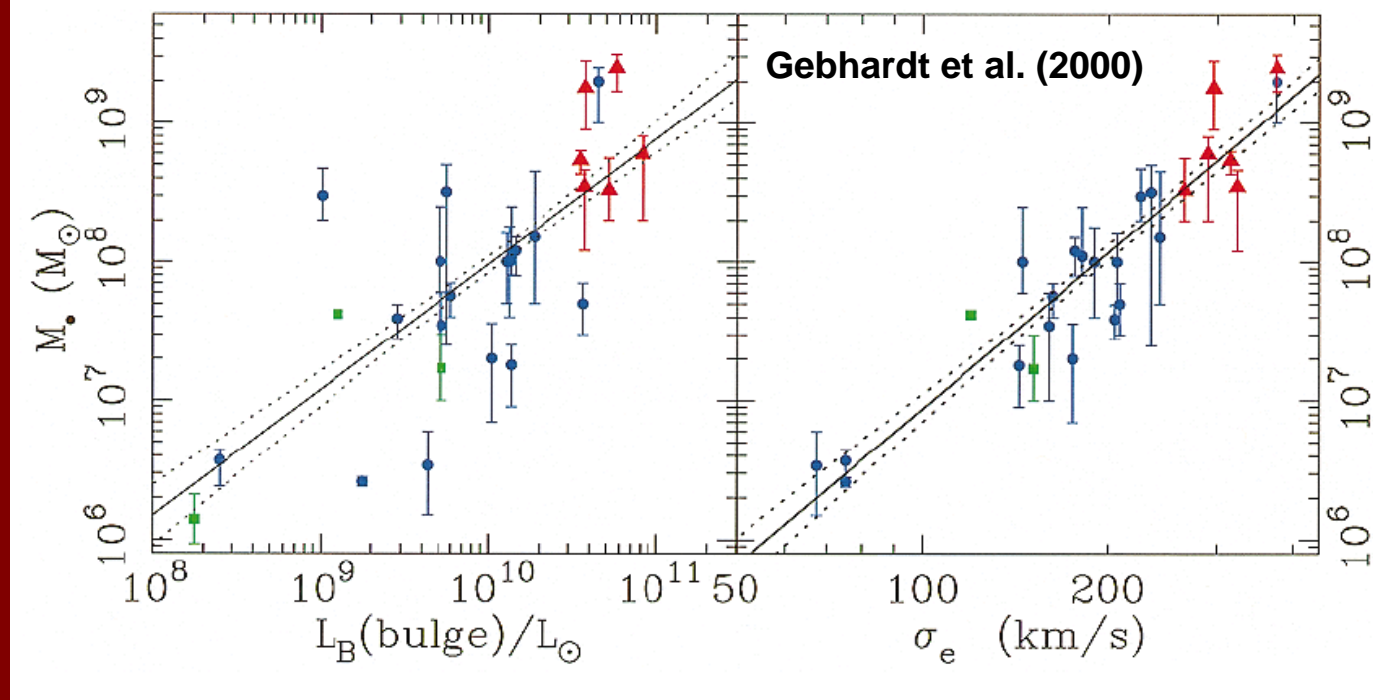
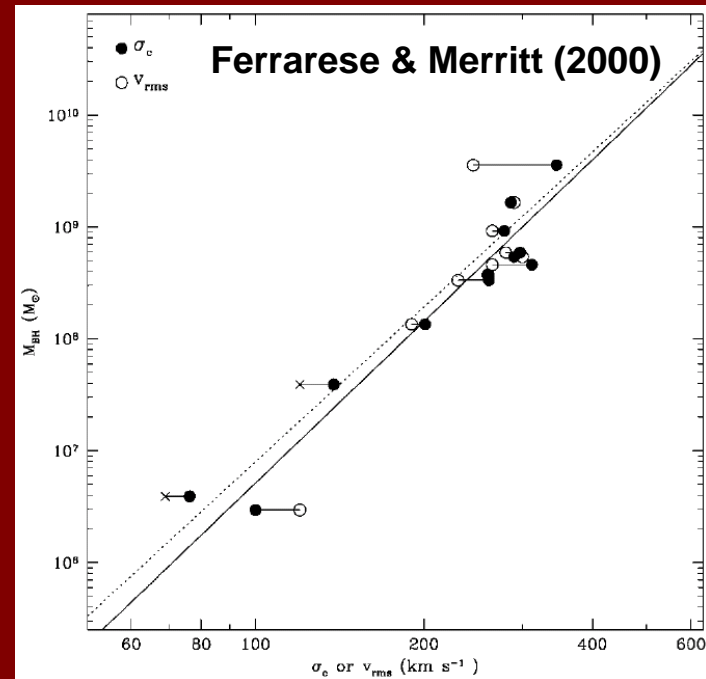
Black Hole Masses in the Largest and Smallest Systems

Karl Gebhardt (UTexas)



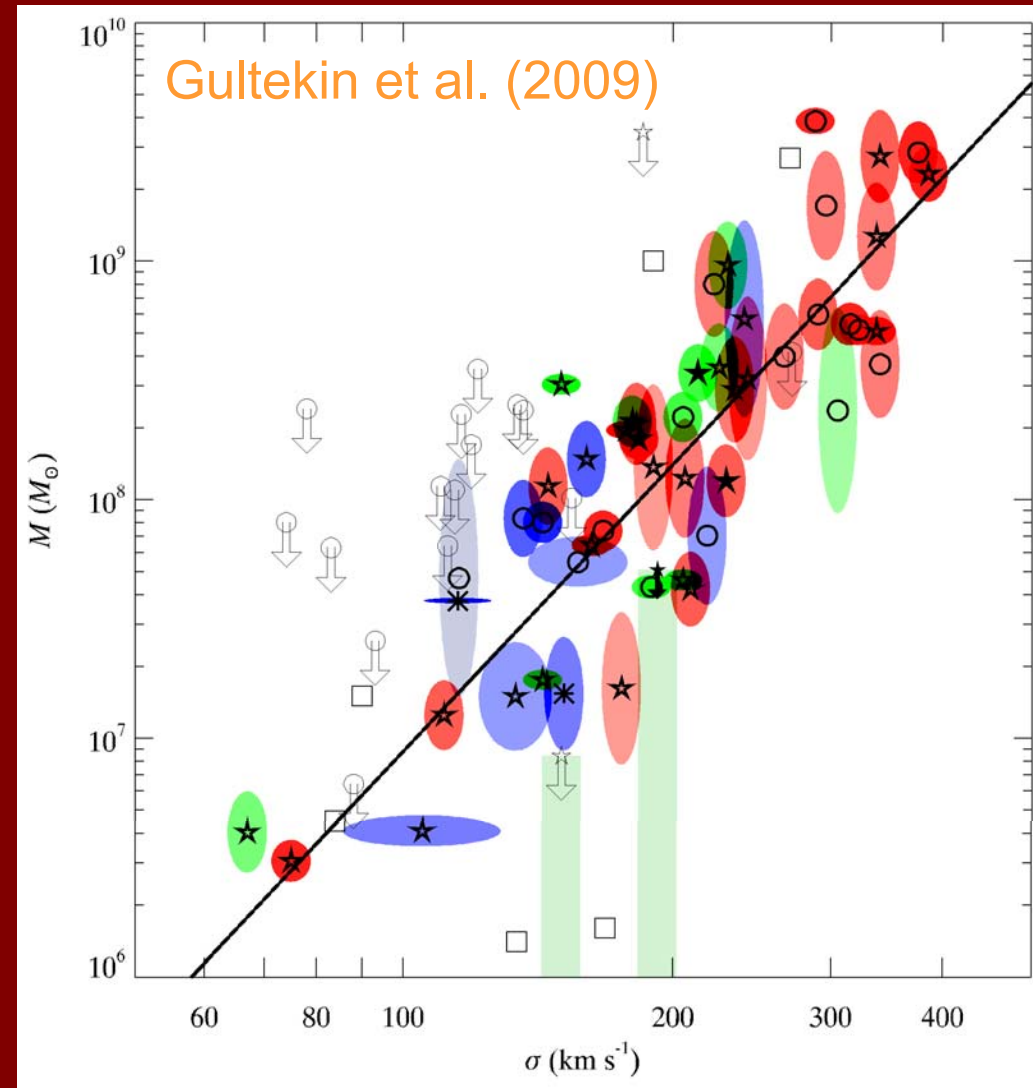
The original papers on the BH correlations suggest that the intrinsic scatter is consistent with zero.

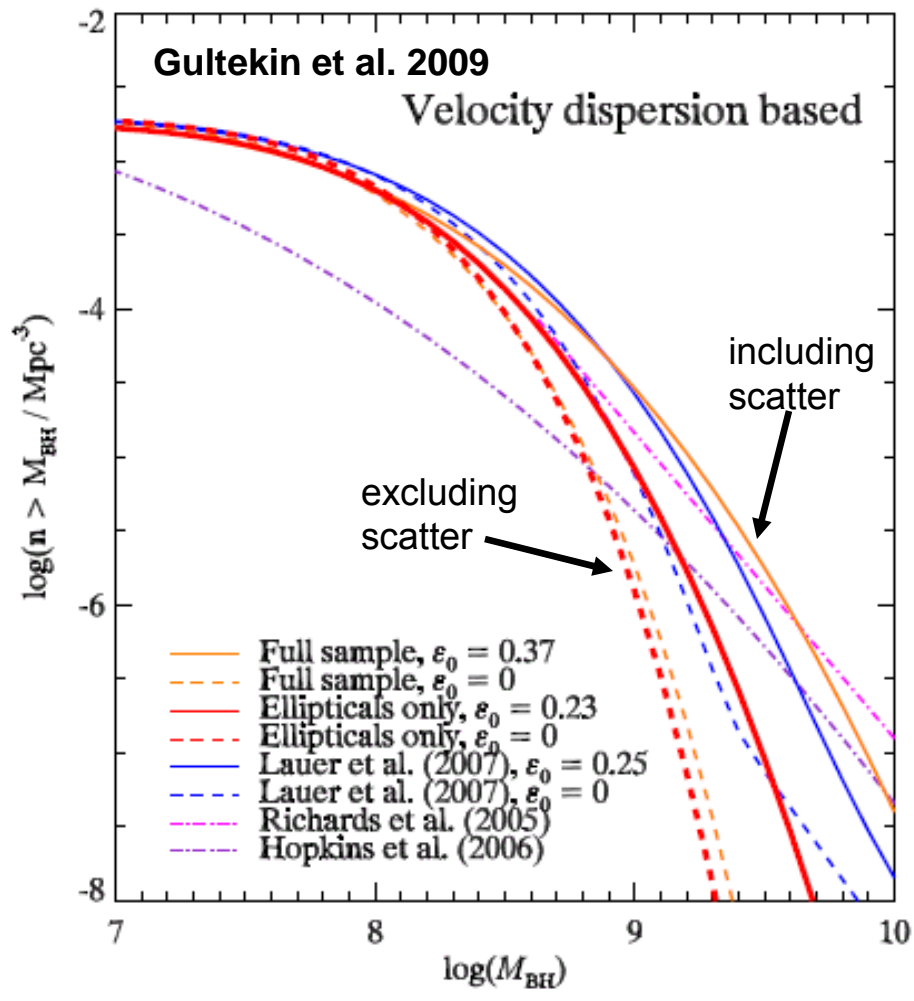
- There are many reported BH correlations
- Suffer from inhomogeneous measures
- Concern at the upper end
- How low do the correlations extend



Current Results:

- Power law slope of 4 (+-0.3)
- Intrinsic scatter of 0.39 dex
- Scatter for ellipticals is 0.25
- Distribution is Gaussian in $\log M$
- Evolution of BH correlations are biased by the scatter
- Biggest black holes are determined by scatter
- Not clear what determines the scatter

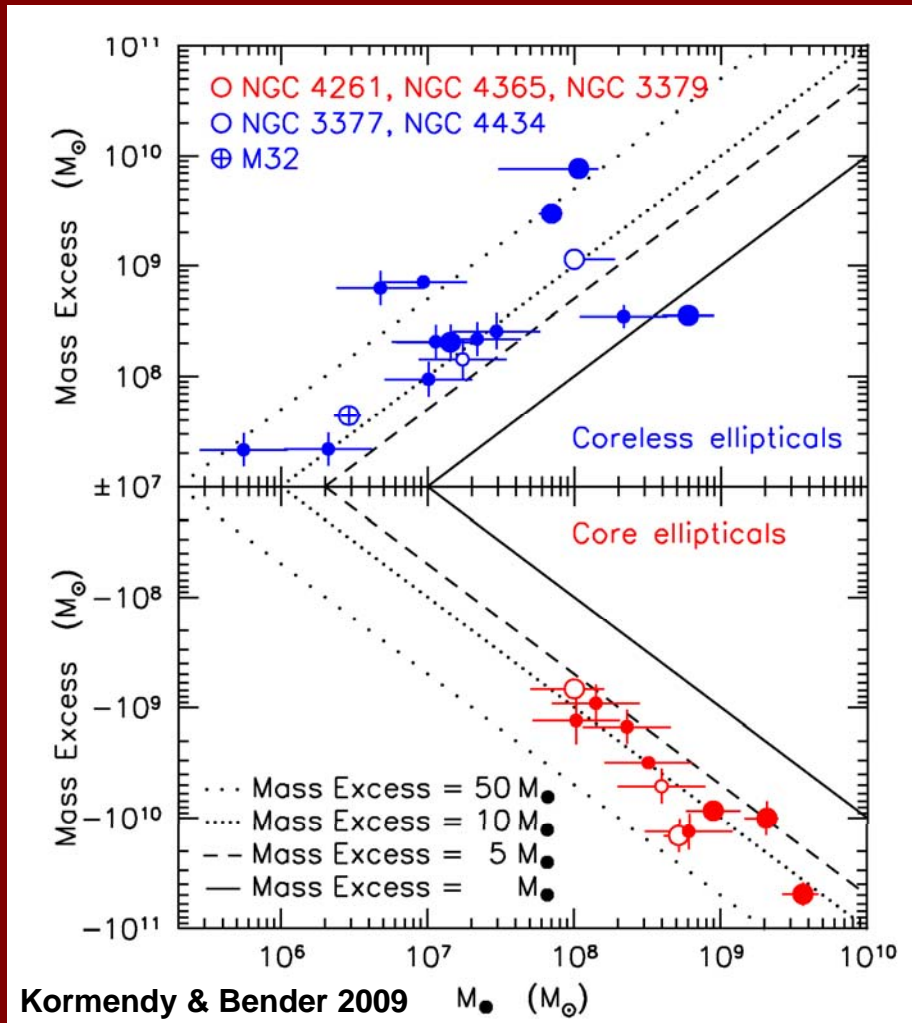




Number density of black holes depends critically on understanding the intrinsic scatter.

Lauer et al. 2007, Faber et al. 1997, Ebizusaki et al. 1991 suggest the galaxy core is due to BH merging.

Evidence for BH scouring is also seen in kinematics, with tangential orbits.



But, we have a problem. For galaxies with recently measured masses:

Galaxy	BH mass	Increase	Reason
M87	6.4e9	2-3x	Dark halo included in models (kg & Thomas 09)
N4649	4.5e9	2x	Better phase space? (Shen & kg 09)
N3379	3e8	2x	Triaxial models (van den Bosch et al 09)
N4697	2.5e8	1.5x	Dark halo inc. (Forestell et al. 09)

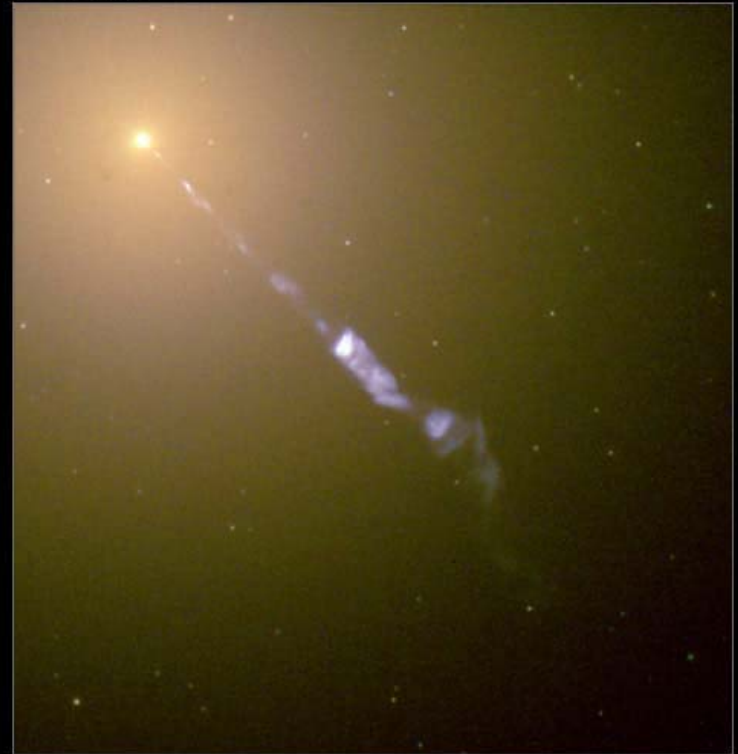
In order to understand what is going on, we need:

- Adaptive optics on large telescope: after some initial growing pains, AO systems are delivering
- Dynamical models: the models are now nearly as general as possible, with triaxial models and made-to-measure techniques (N-body+Schwarzschild)
- Multiple technique: galaxies studied with multiple observing techniques is growing, by combining stellar and gaseous data (including X-rays).

M87 re-analysis, with dark matter

- Kinematics from Sauron and long-slit in the central regions (van der Marel 94)
- Globular cluster velocities to $8 R_e$
- X-ray data out to similar radii
- Need to include both BH and DM, especially due to M87's large core
- Requires a new mode to run the library of orbits
- Want 10 BHs, 10 M/Ls, 10 DM scale radii, 10 DM circ velocity, and each model takes a few hours
- This would not be possible without the TACC (Texas Advanced Computing Center) and the 5800 and 60,000 node systems

The M87 Jet

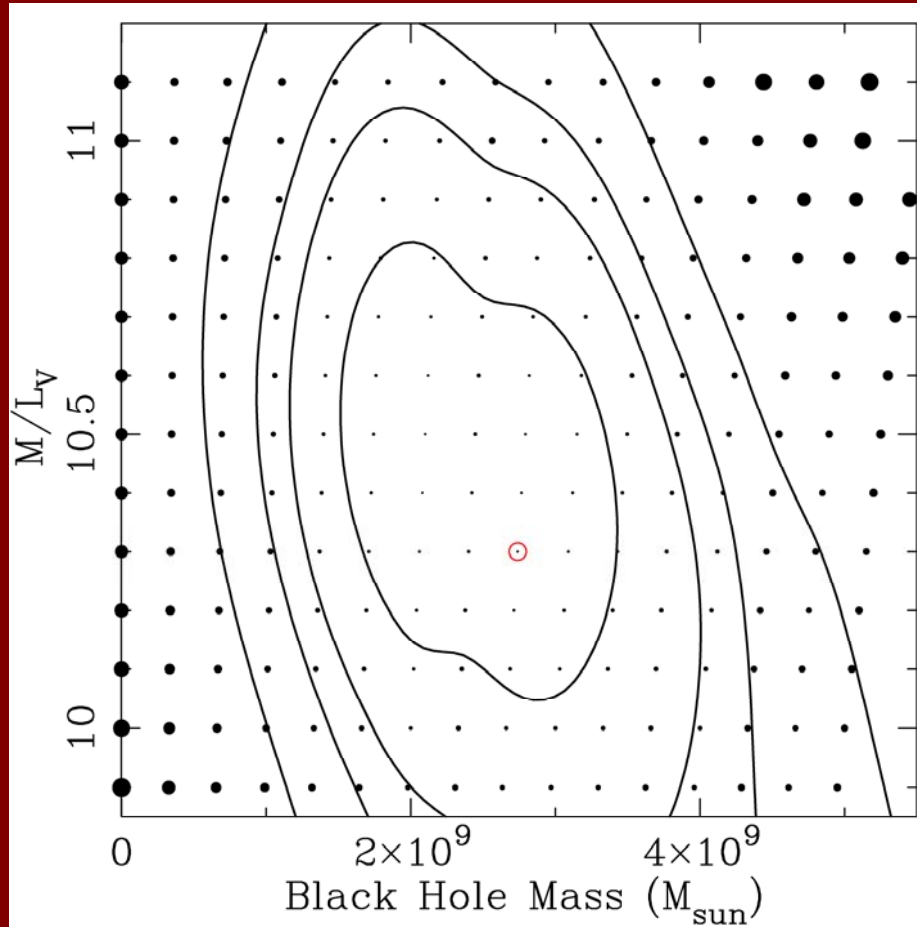


Hubble
Heritage



Lonestar at the Texas
Advanced Computing Center

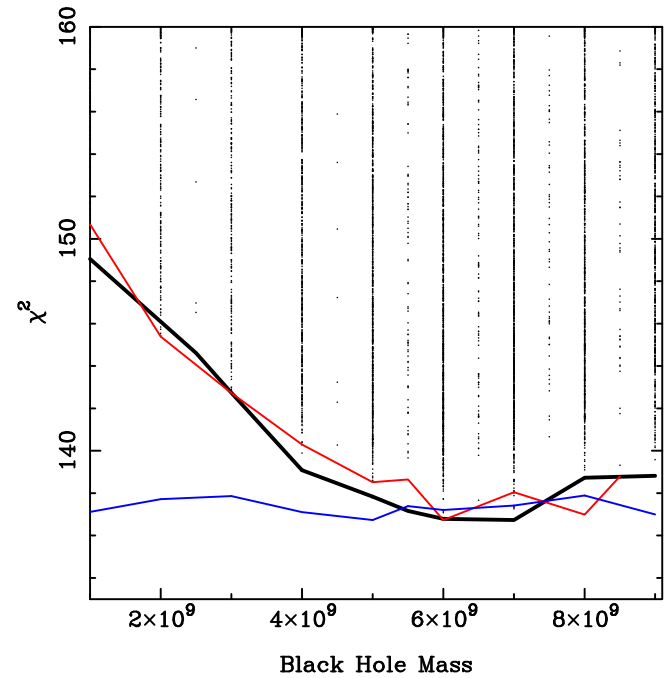
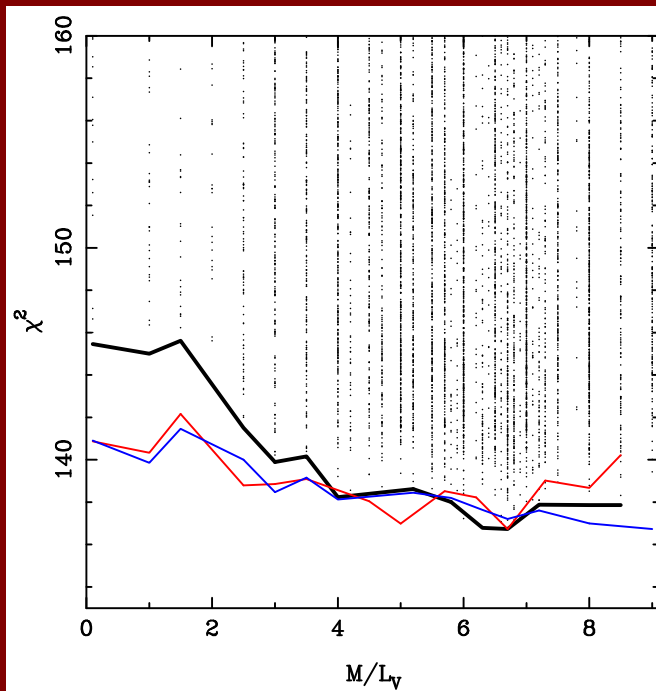
M87 results without a dark halo



- Best-fitted BH mass is $2.5 \text{ e}9$ using stellar data only
- HST gas mass is $3.5(+/-1)\text{e}9$
- Previous stellar dynamical masses are around $1\text{-}3\text{e}9$
- Everything is consistent

But.....

M87 BH models with a dark halo (kg and Thomas 09)



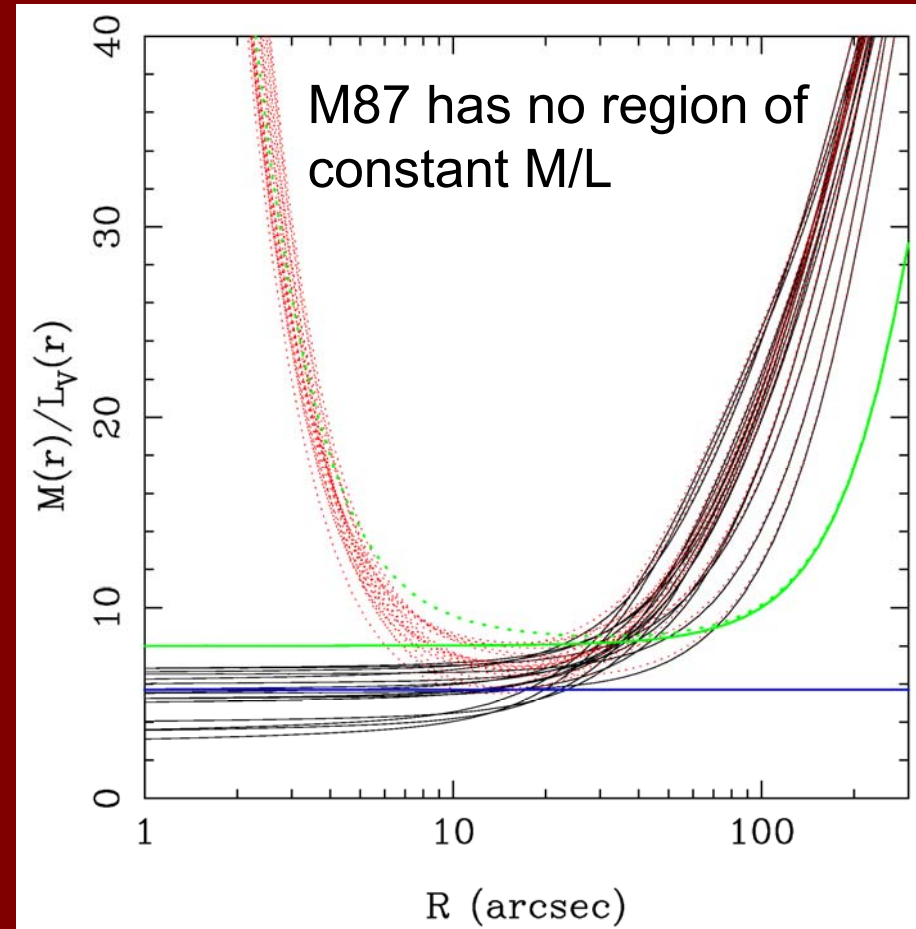
After 70,000 hours on the TACC computers:

1. Best-fitted BH mass is $6.4(+0.5)e9$
2. M/L went from 10.5 (no DM) to 6 (with DM); the M/L derived from stellar population work is 6
3. DM profile close to X-ray profile (a bit more massive)

BH changed since:

1. M/L decreased
2. Significant contribution to central kinematics from large radii in projection
3. Orbit structure changed due to DM inclusion

- BH masses at the upper end need to be re-evaluated
- Larger BH masses have a significant consequence on understanding space density of BHs
- For example, if M87 has a $6.4e9$ BH, it will help problem of the large inferred BH mass from QSO
- Could have a significant effect on the measured BH correlations, which feed back into galaxy evolution models
- Next logical extension is to include triaxial models (R. van den Bosch)



All of the work with understanding the BH correlations need to include systematic effects

Gemini/NIFS laser AO data for M87

Josh Adams, kg, Richstone, Lauer, Tremaine

- 24 10-minute exposures
- laser AO using AGN as TT

Outer Radii data from SAURON
(to 30") and VIRUS-P (to 250")

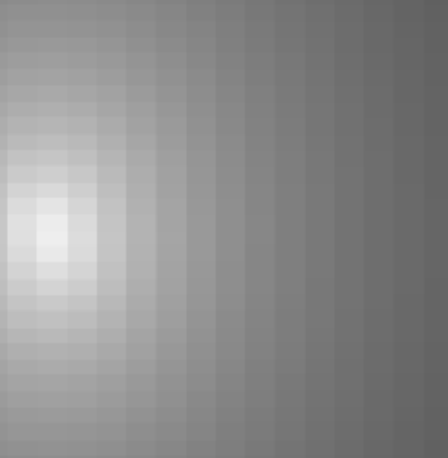


VIRUS-P on the McDonald 2.7m provides largest field IFU; Jeremy Murphy's kinematic analysis for M87 extends to 3.5 Re.

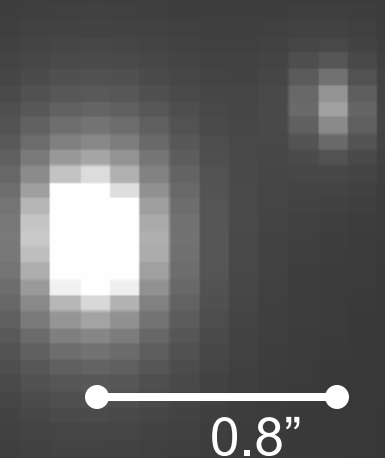


M87 central region reconstructed from NIFS AO data

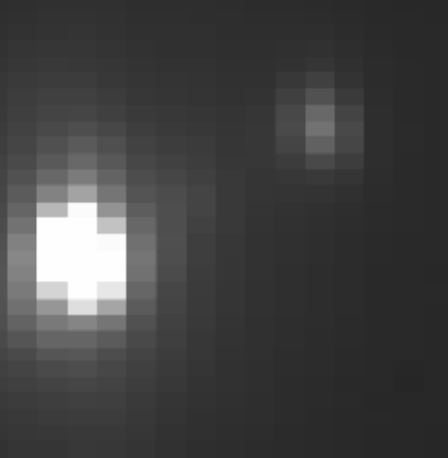
Stellar continuum model



AGN components model



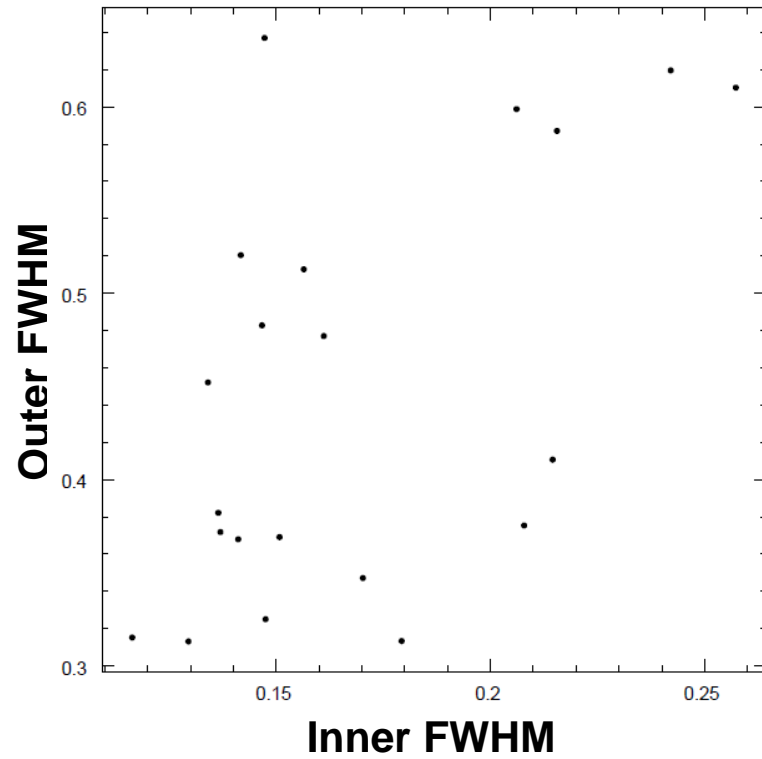
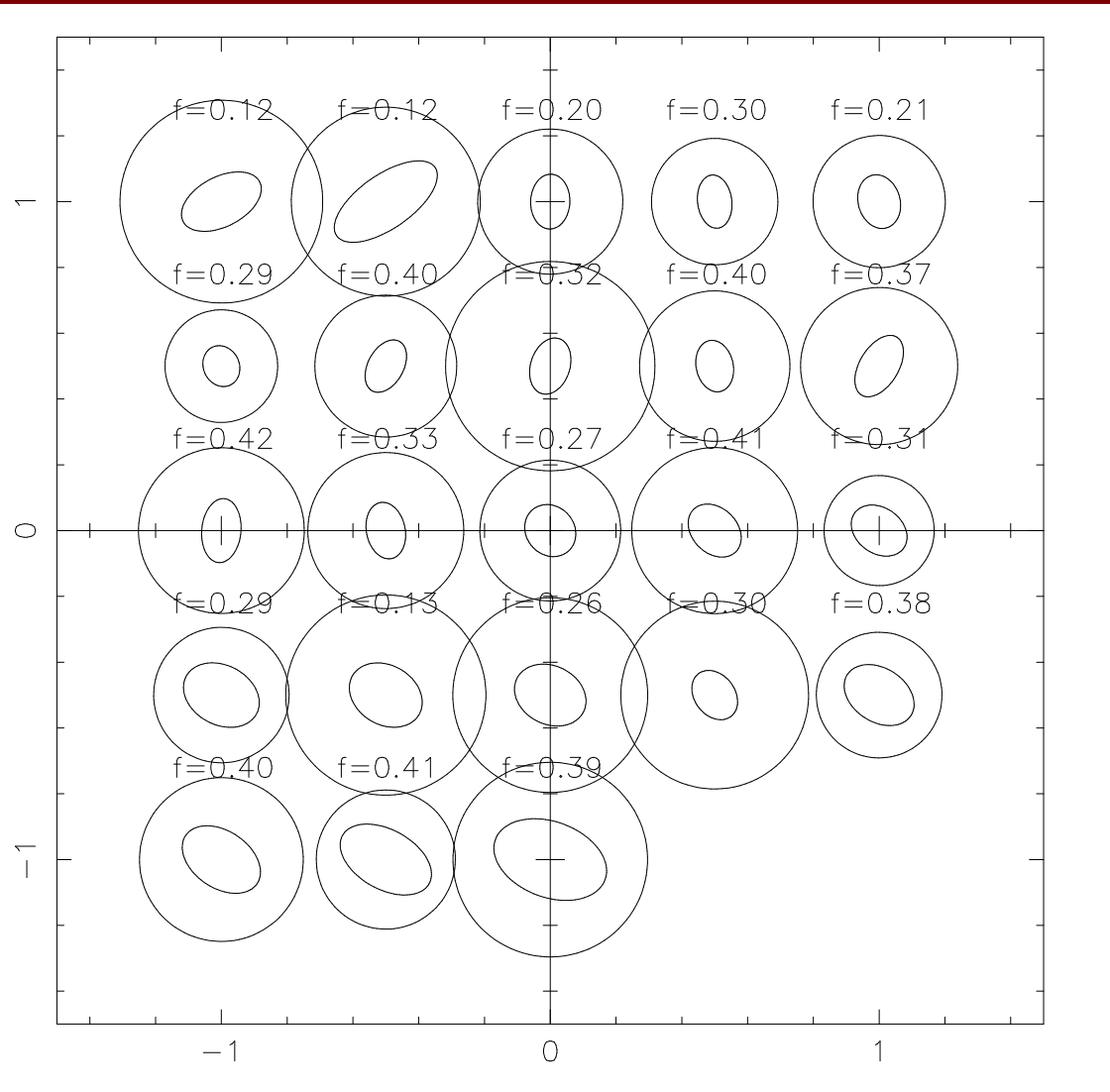
Raw data



Residuals

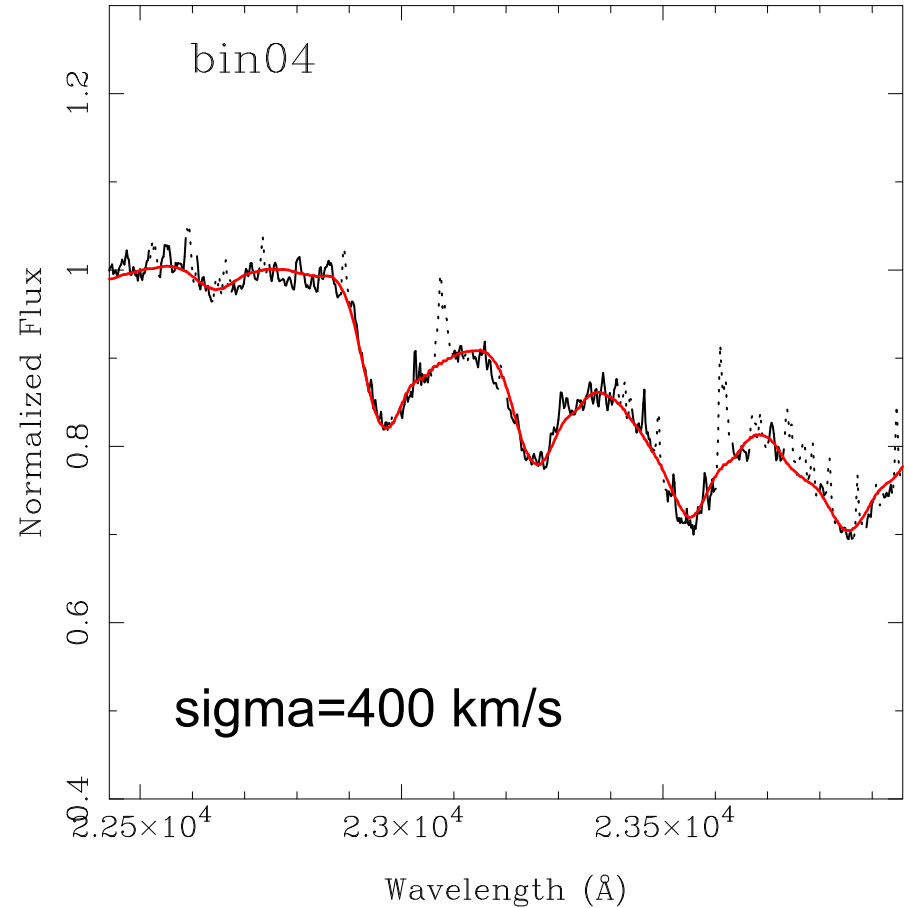
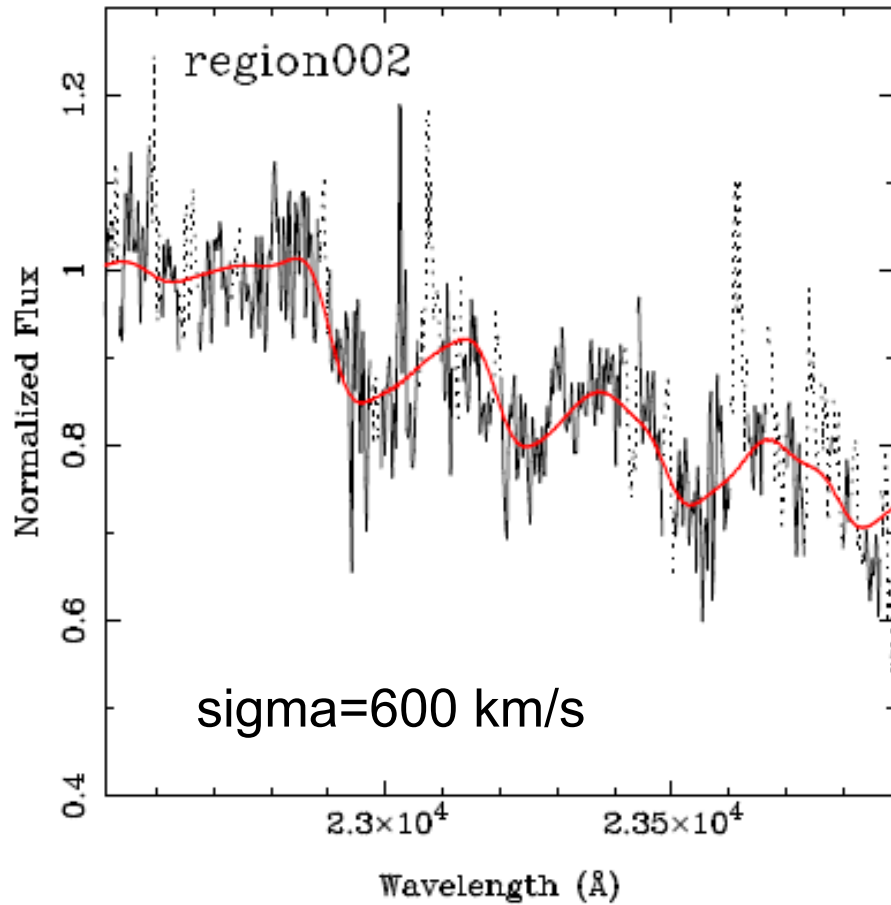


Understanding PSF is very important for M87 analysis



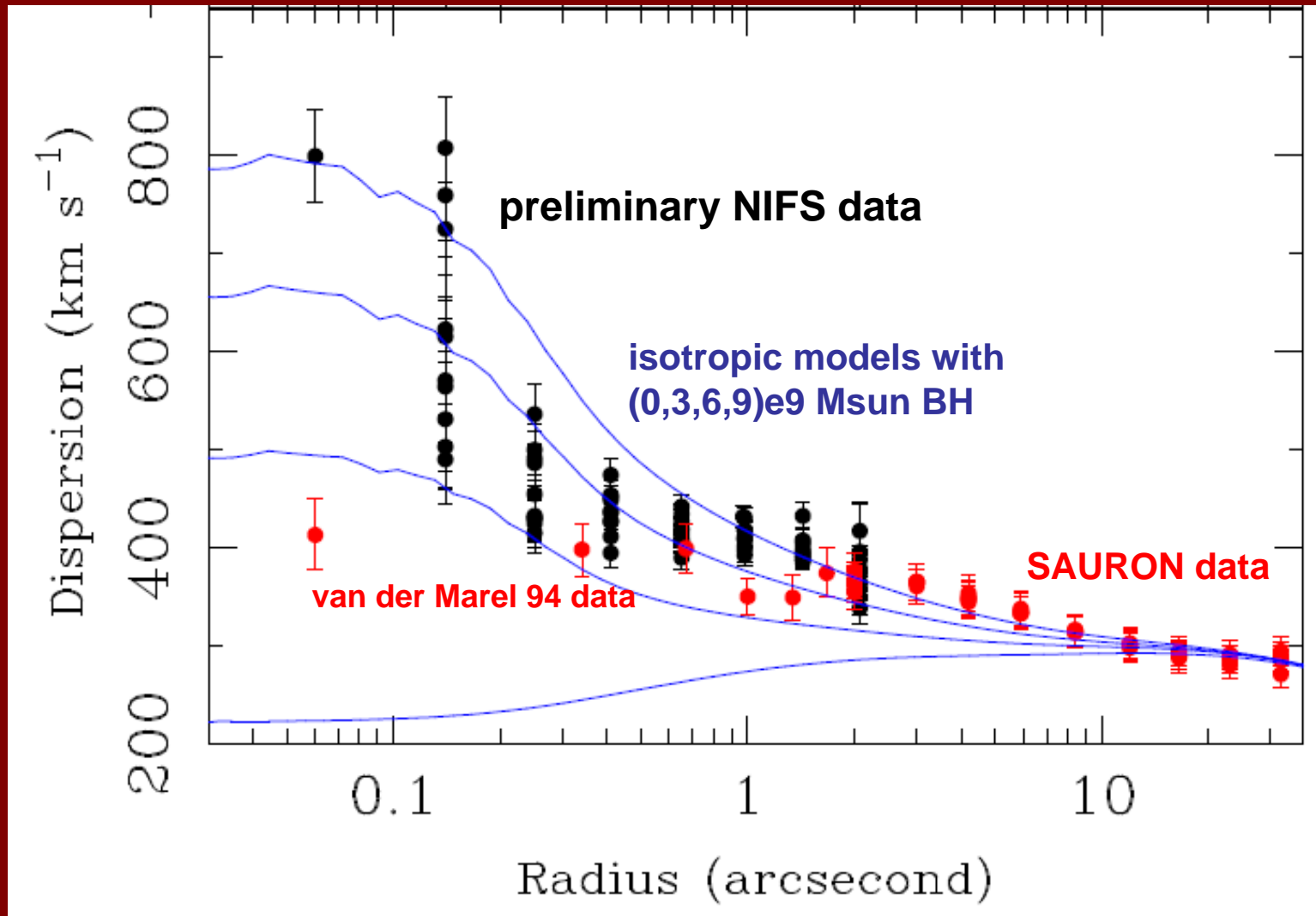
from Josh Adams et al. 2009

Gemini/NIFS Spectra in Center and Outer Regions



Once dispersions get this fat, it is hard to measure them robustly.

Dispersion profile, with isotropic models overlaid



Furthermore, the LOSVDs are very non-Gaussian (double-humped)

- AO will be the key for understanding systematics
- Large AO programs are producing now (Nowak and Bender et al. have 6 galaxies with VLT; Seth has a similar number with Gemini; McConnell on Keck; Lu on Keck with M31)
- In some cases, the large radii kinematics are required
- Pushing to lower masses....

