Present and past of black hole-galaxy scaling relations

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A low-z, observational take on black-hole-galaxy coëvolution

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Black hole "demographics"

- What black holes live in what galaxies.
- Black hole: mass, activity, occupation, multiplicity, location, spin.
- Galaxy: bulge mass, luminosity, size, velocity dispersion, globular cluster system, spiral arm pitch

Why care about demographics?

- An answer in the back of the books for theorists.
- Learn about initial conditions, seed mass distribution from smallest black holes.
- Seeing how demographics evolve may tell us how black holes grow and/or how galaxies evolve.

We can measure SMBH masses

- Sgr A*
- Stellar dynamical
- Megamasers
- Gas dynamical [ALMA!]

Primary

- Reverberation mapping

Secondary*

- Single epoch

Tertiary

We can measure SMBH masses

See Poster by Anna Pancoast

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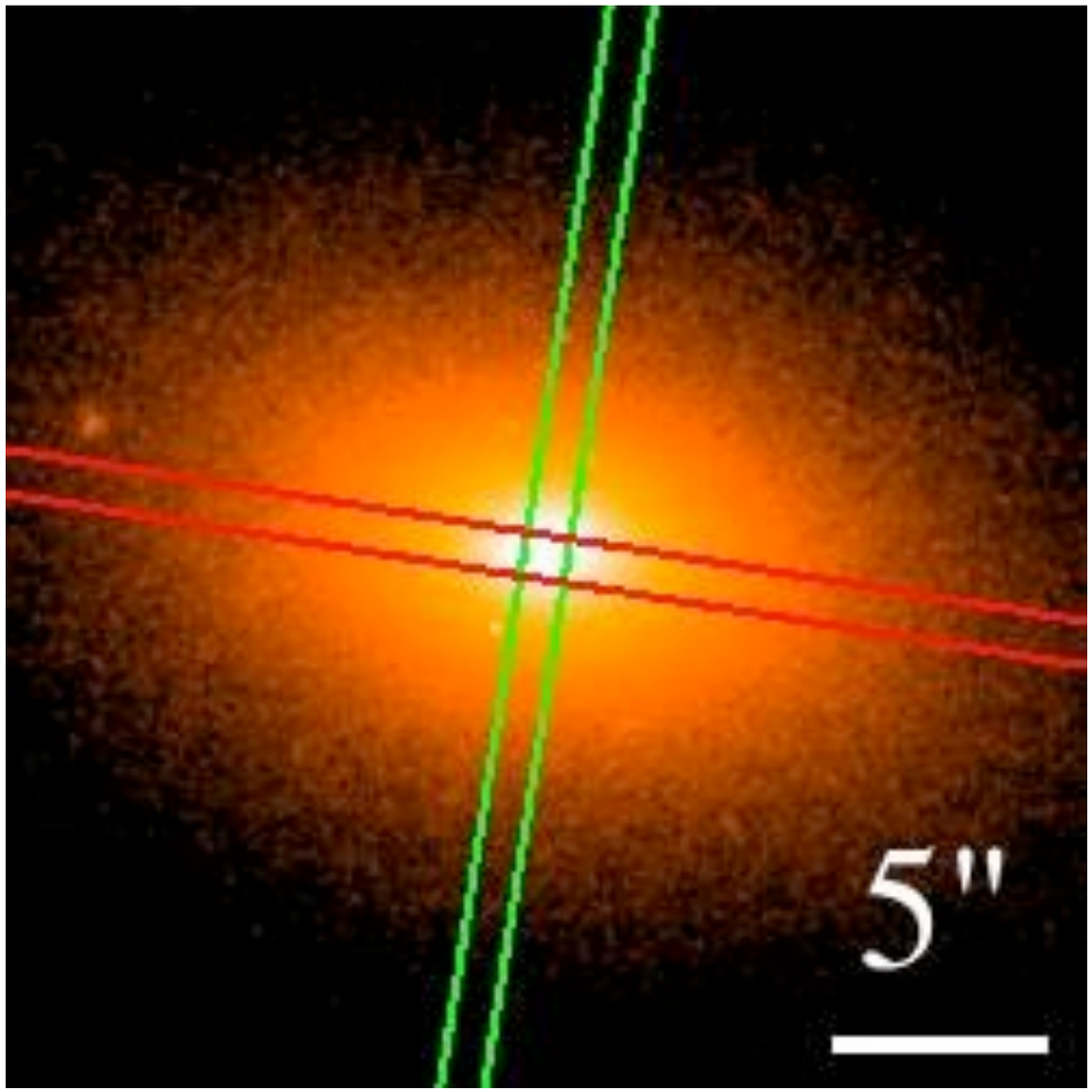
- Reverberation mapping
- Single epoch

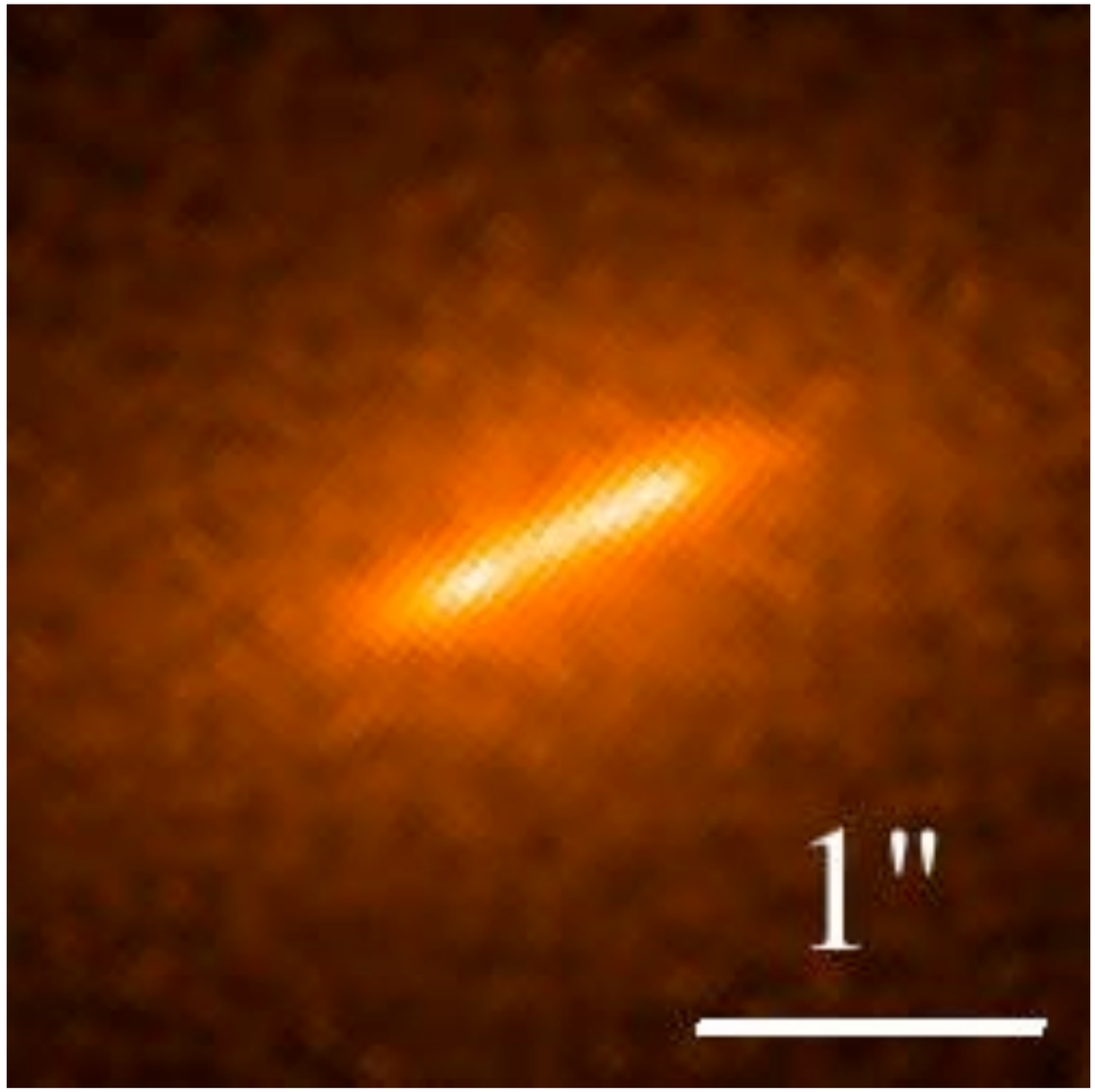
Primary

Secondary*

Tertiary

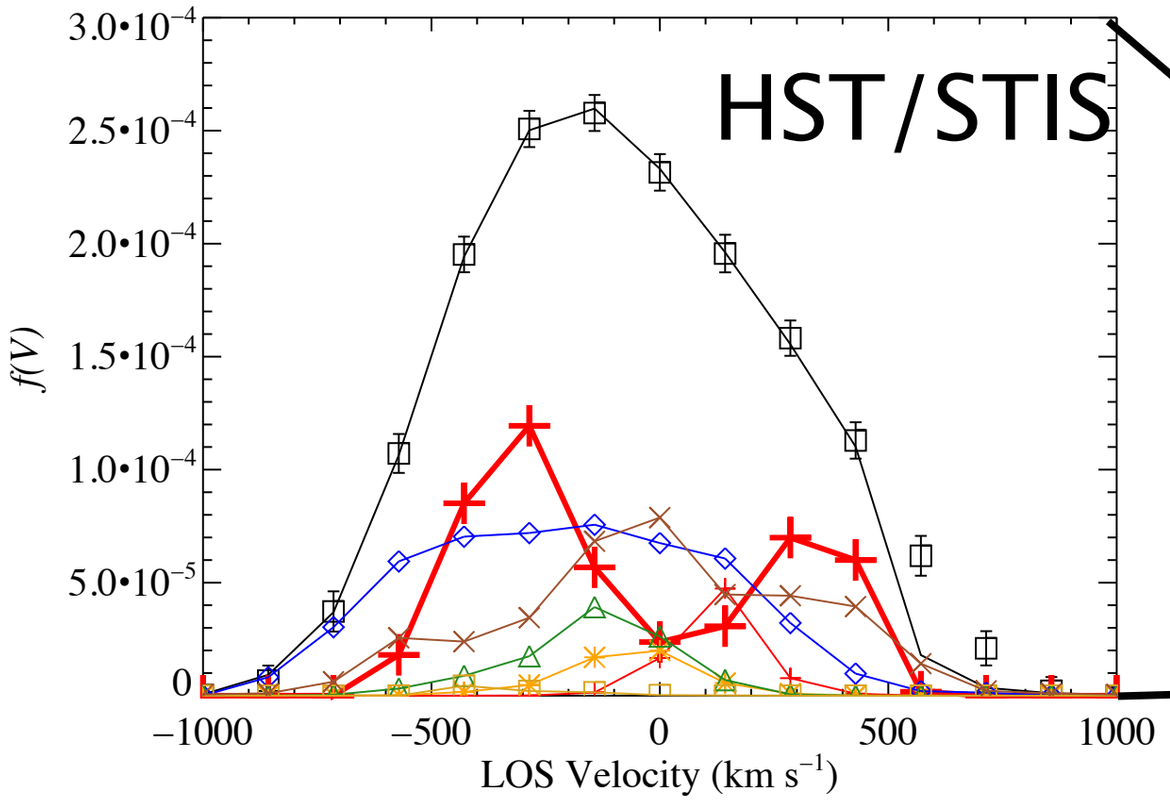
BH mass of NGC 3706

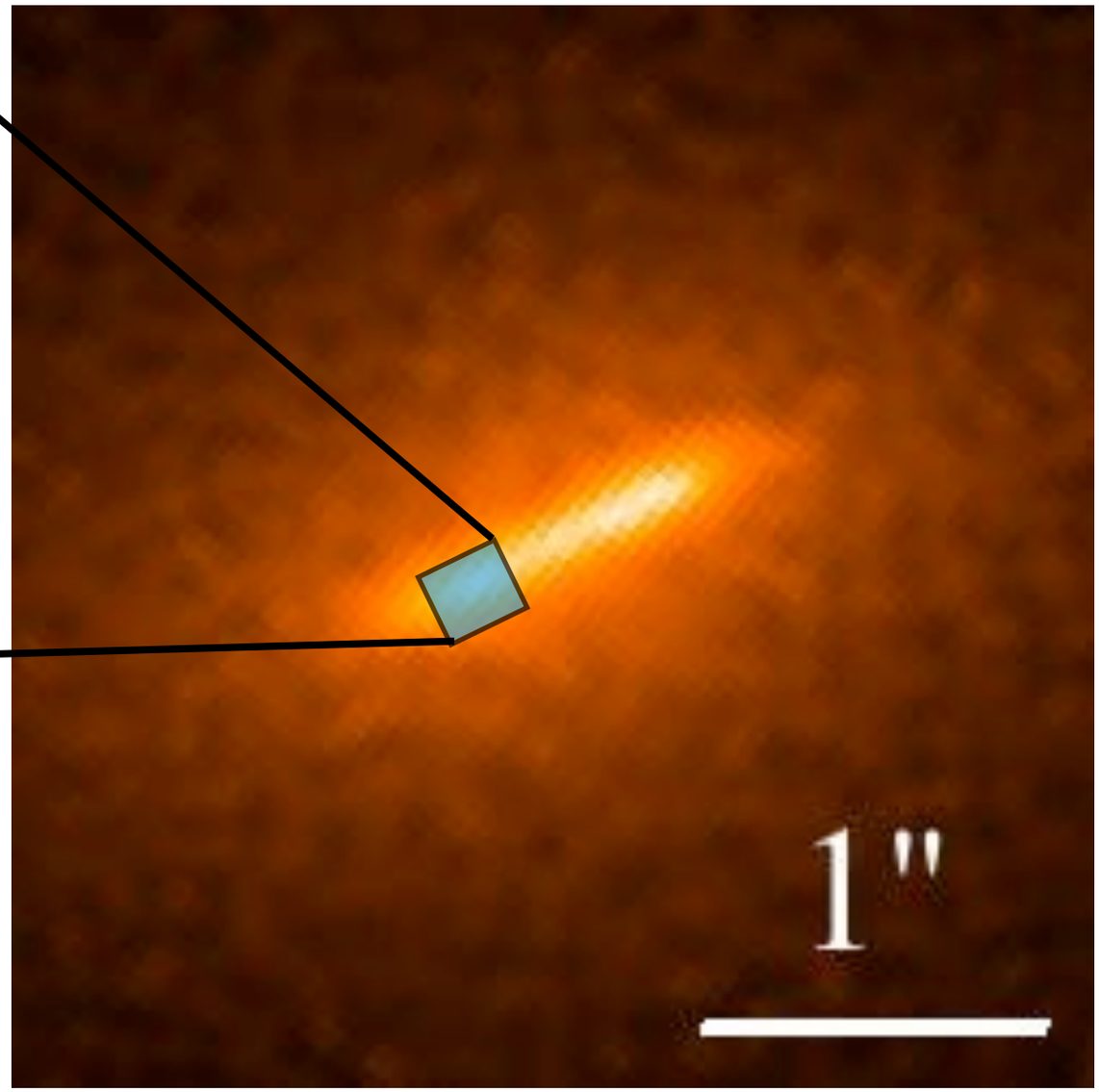




KG+, submitted

N3706 has a stellar ring that rotates in both directions



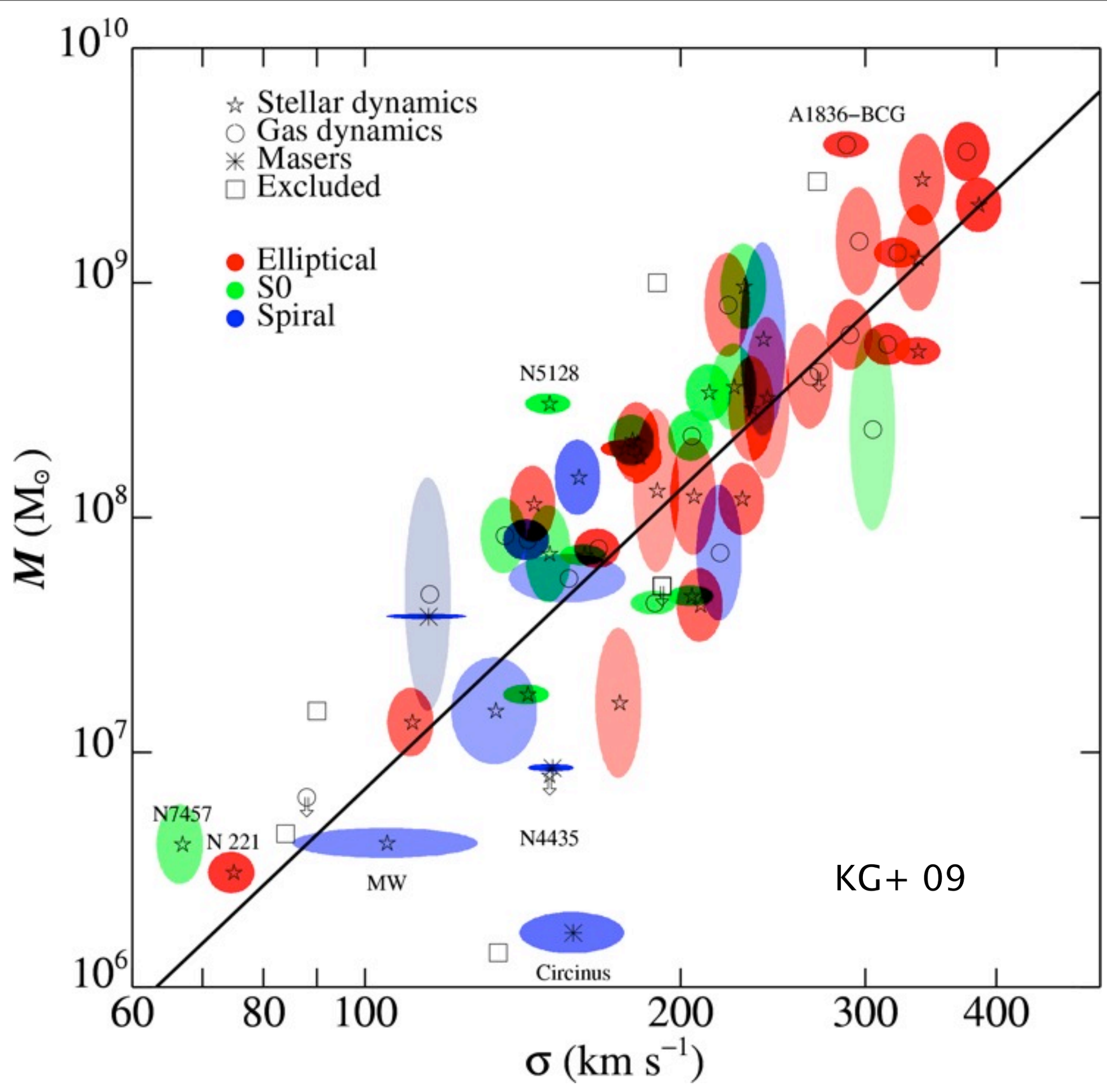


Velocity

KG+, submitted

SMBH Masses correlate with host galaxy properties.

- Galaxy bulge luminosity (M–L)
  - Kormendy 93; Kormendy & Richstone 95
- Galaxy bulge mass ($M–M_{bulge}$)
  - Dressler 89; Magorrian+ 98
- Stellar velocity dispersion (M–σ)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N4435
Circinus
KG+ 09
M (M⊙)
σ (km s−1)
10^10
10^9
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Quasar feedback predictions

$$M_{\rm crit} < \frac{1}{2\pi}\frac{\sigma_T}{G^2 m_p c}\frac{f_{\rm gas}}{f_w}\sigma^5$$

Energy-conserving

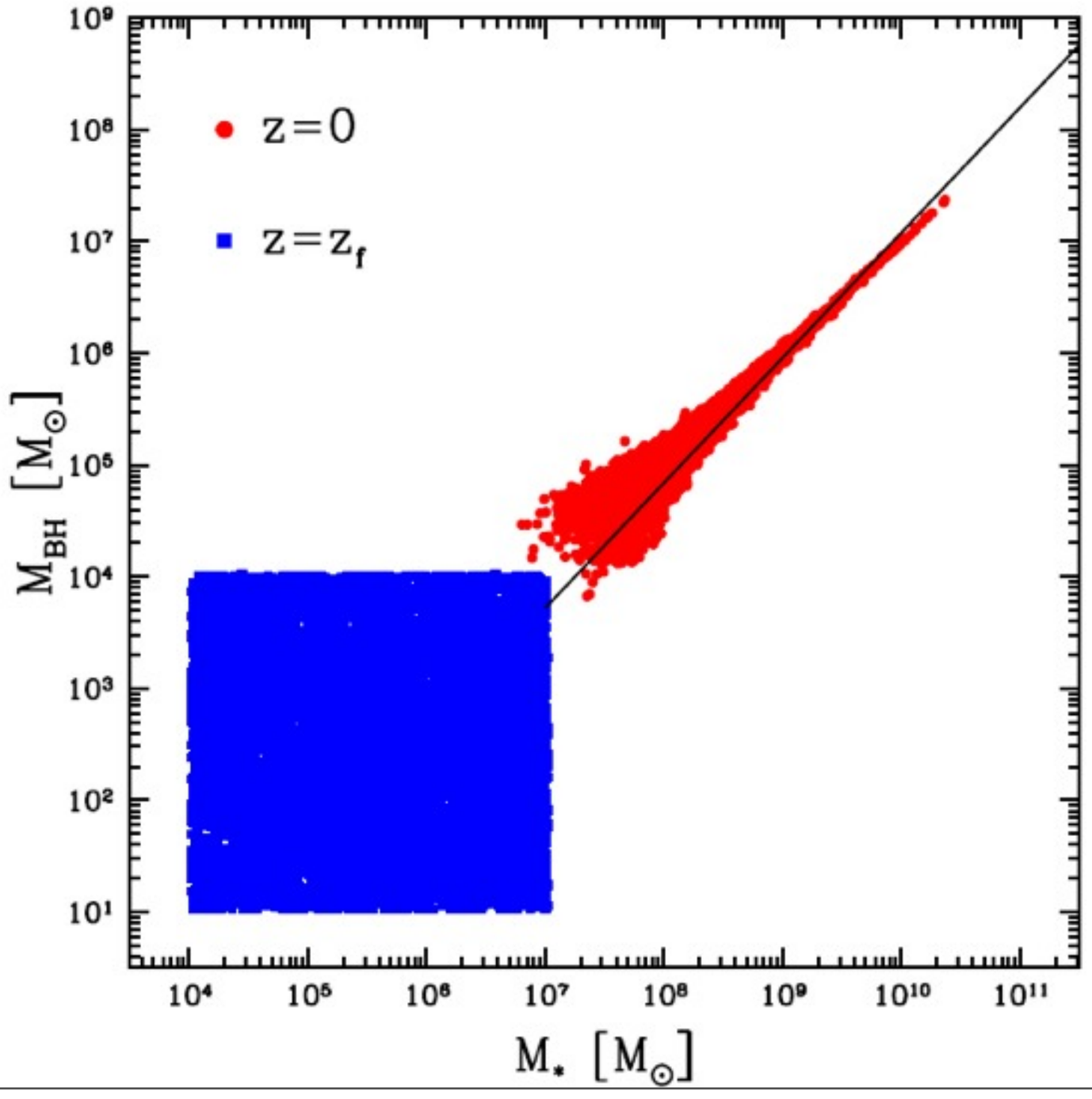
Silk & Rees 98

$$M_{\rm crit} < \frac{1}{2\pi}\frac{\sigma_T}{G^2 m_p}\frac{v_w}{c}\frac{f_{\rm gas}}{f_w}\sigma^4$$

Momentum-conserving

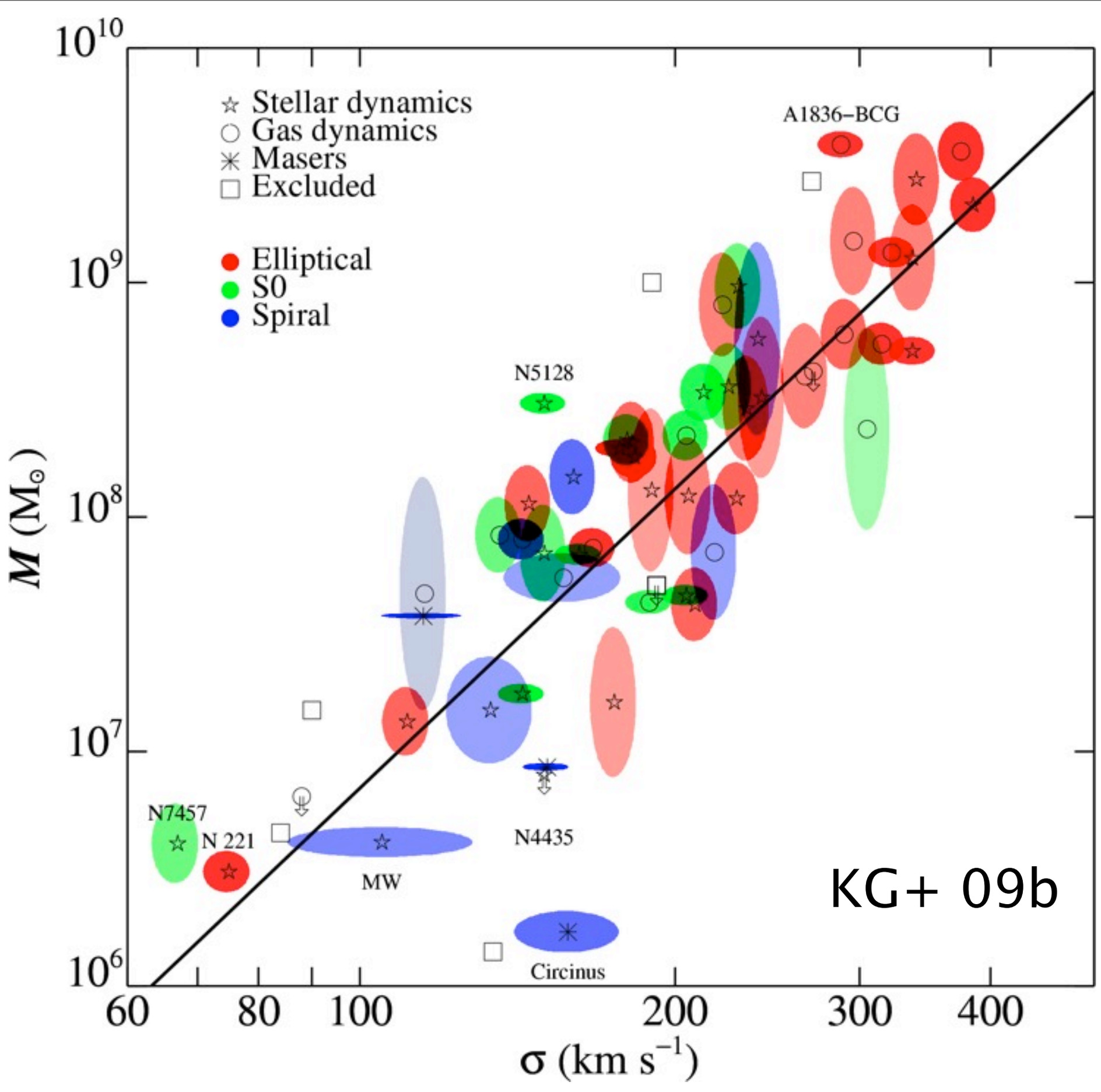
Fabian 99

Or just BH/galaxies merging?



Mergers

Peng 07
Jahnke & Maccio
10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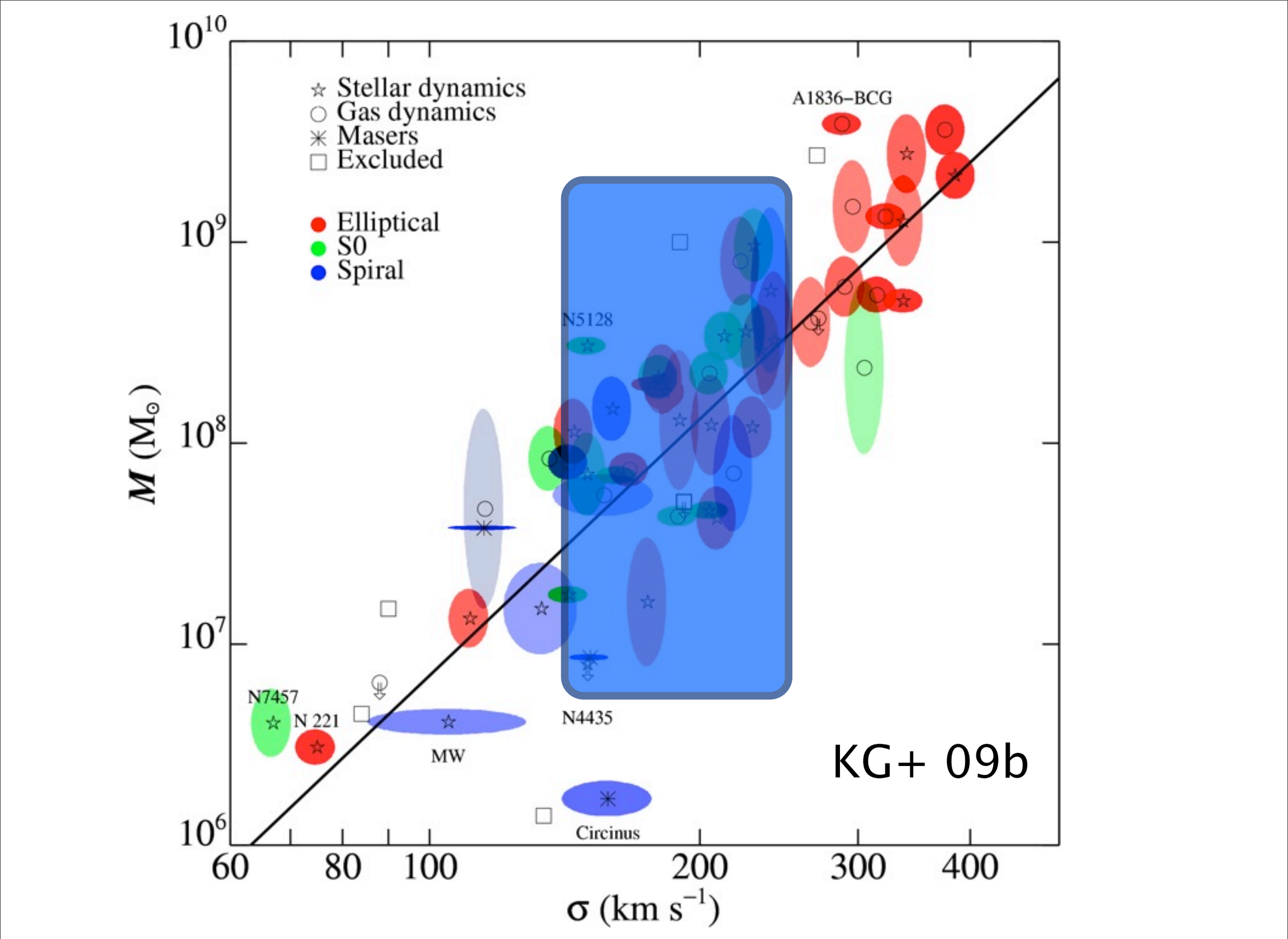
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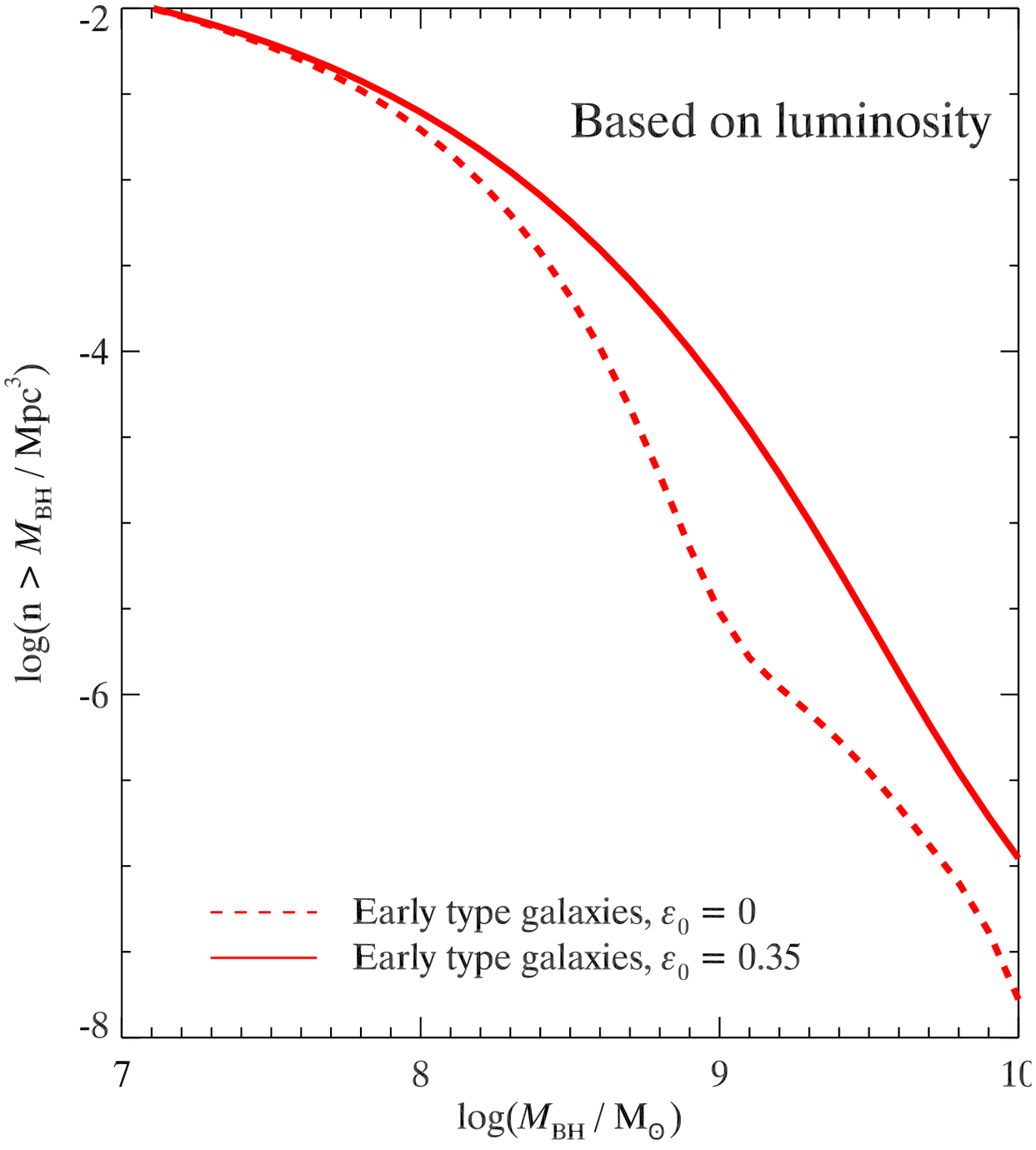
KG+09b measured the intrinsic or cosmic scatter

- The scatter is 0.44 ± 0.06 dex, log-normal in the mass direction.
- The scatter is smaller, 0.31 ± 0.06, for just the ellipticals, but it is only a 2 sigma result. We need to be cautious about slicing and dicing the sample and claiming a low-significance deviation.

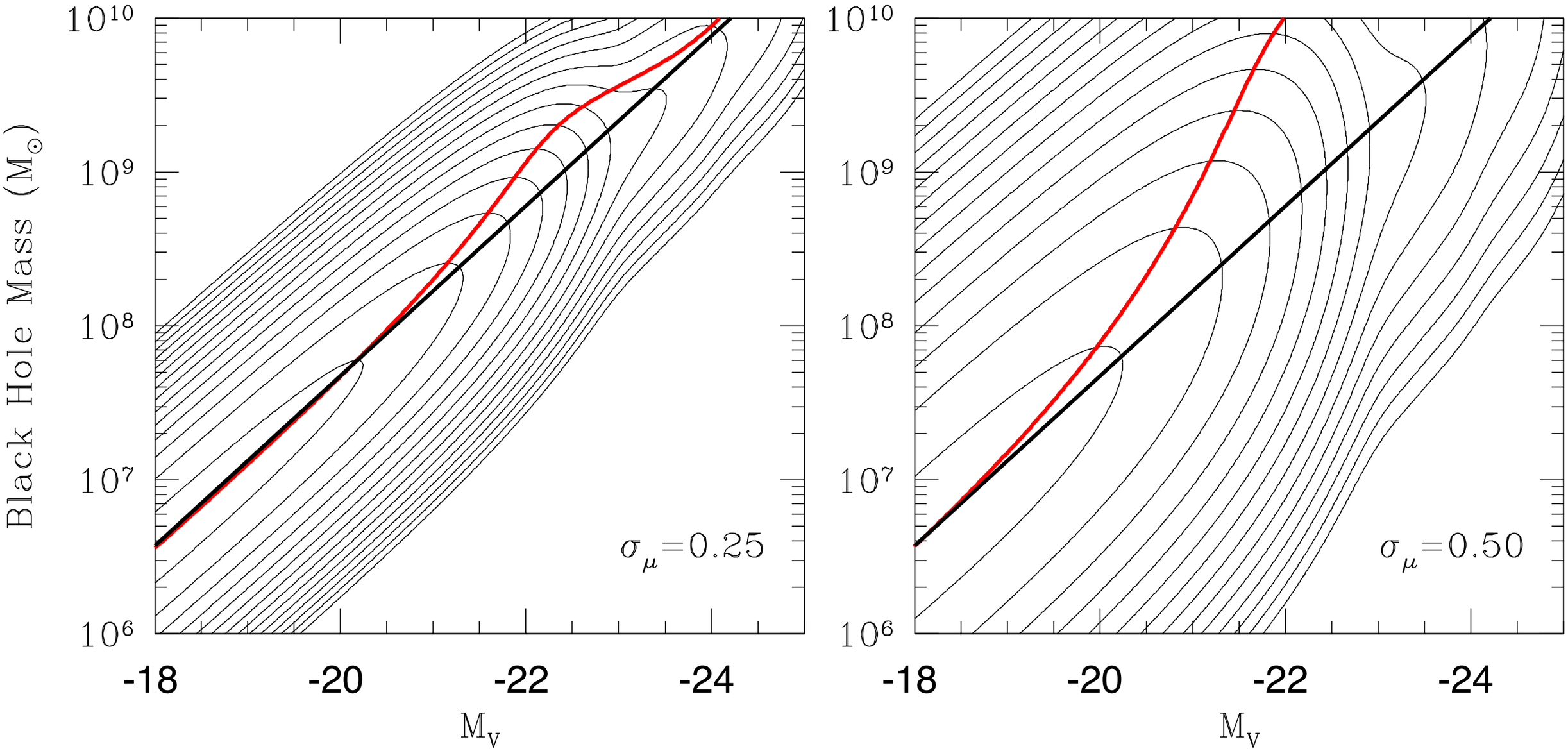
Scatter matters



Cumulative number density of BHs

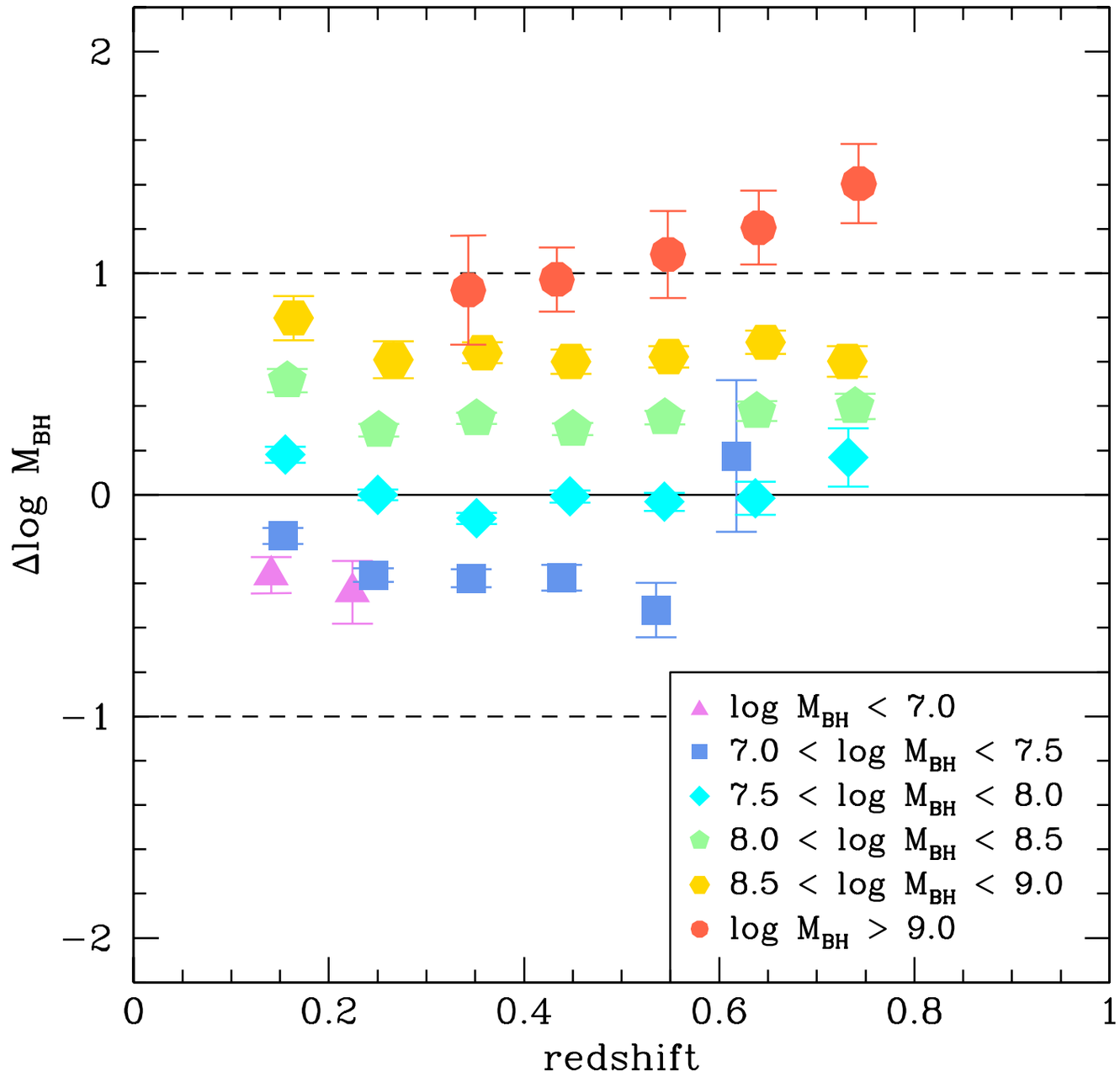
KG+09

Redshift evolution bias



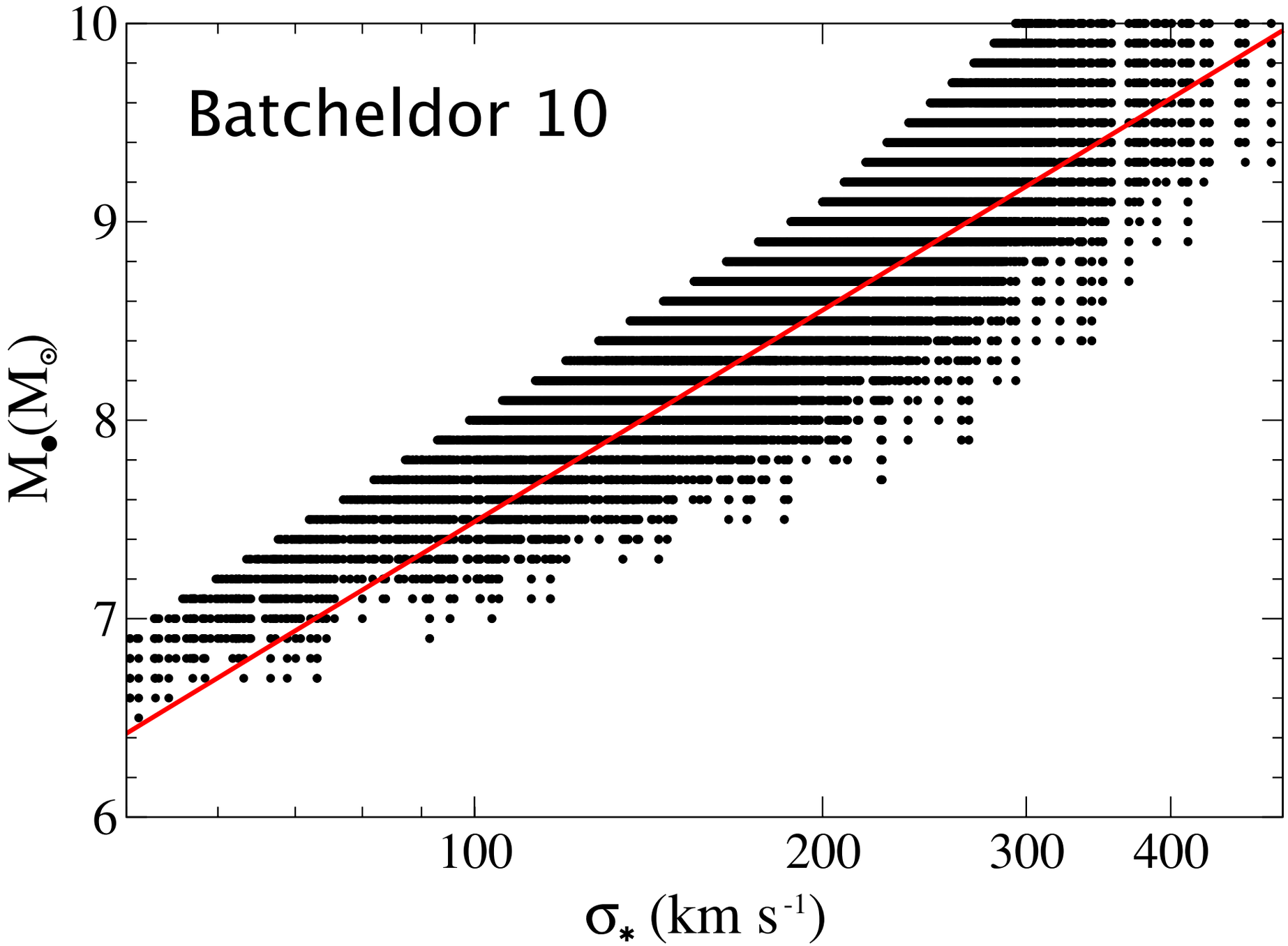
Lauer+ 07

Redshift evolution bias

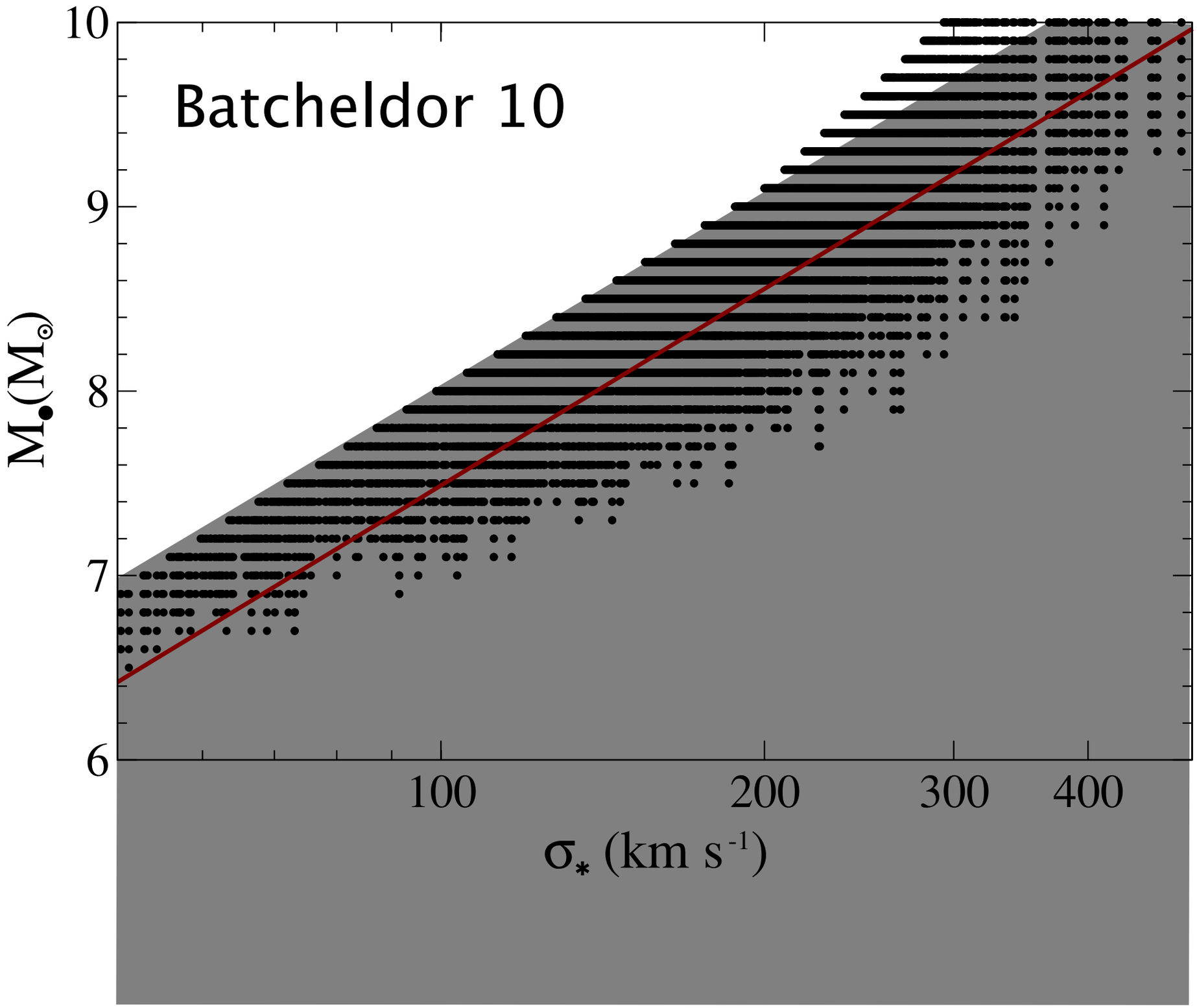


Salviander & Shields (2013)
See also:
Woo+08, Merloni+10

Scatter Matters

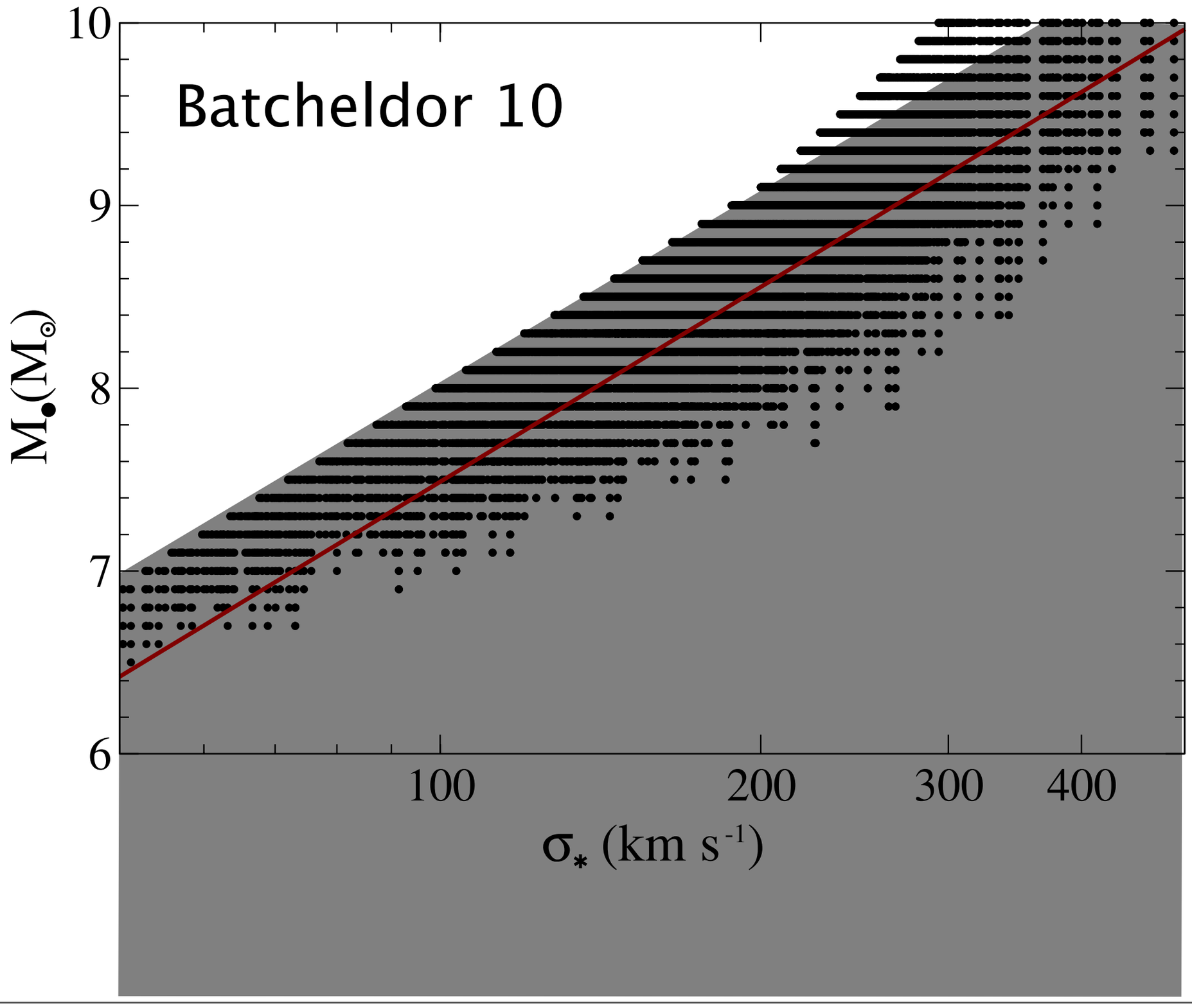


Scatter Matters



What if we only saw the tip of the iceberg?

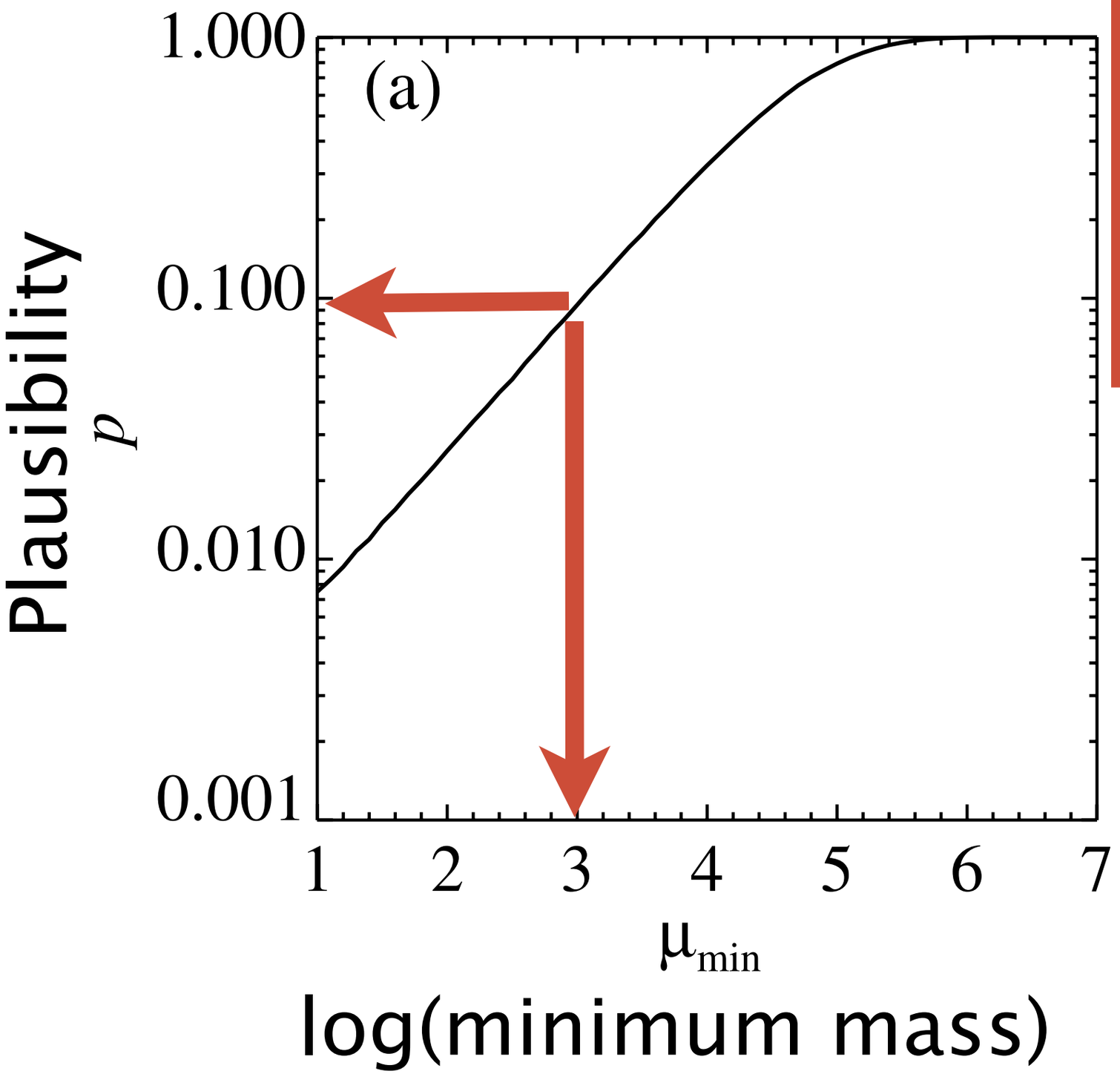
Scatter Matters



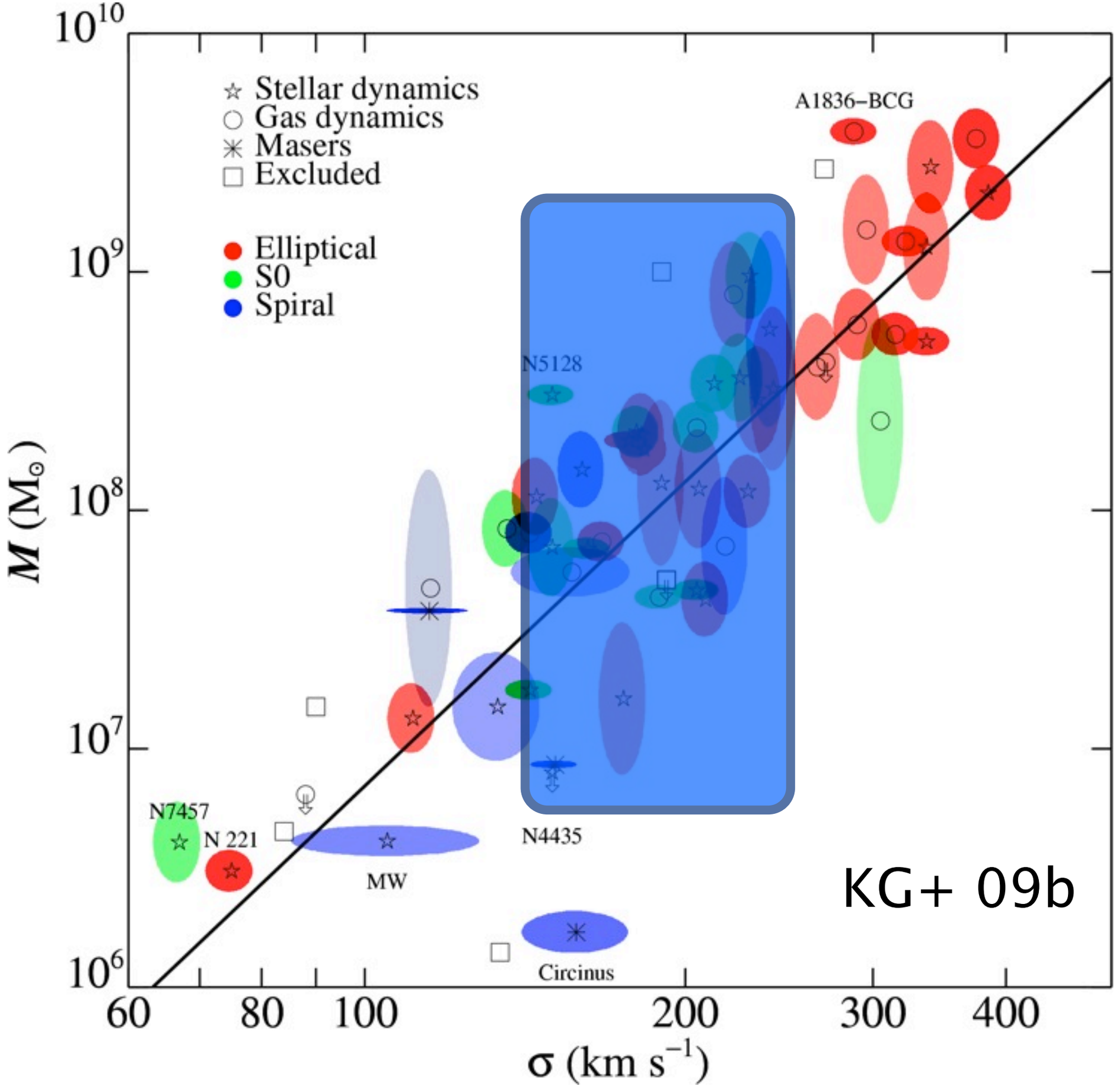
What if we only saw the tip of the iceberg?

Then why are there so few non-detections?

KG+12 quantified the "why so few nondetections" argument.



Bottom line:
It's a ridgeline relation, not an envelope relation.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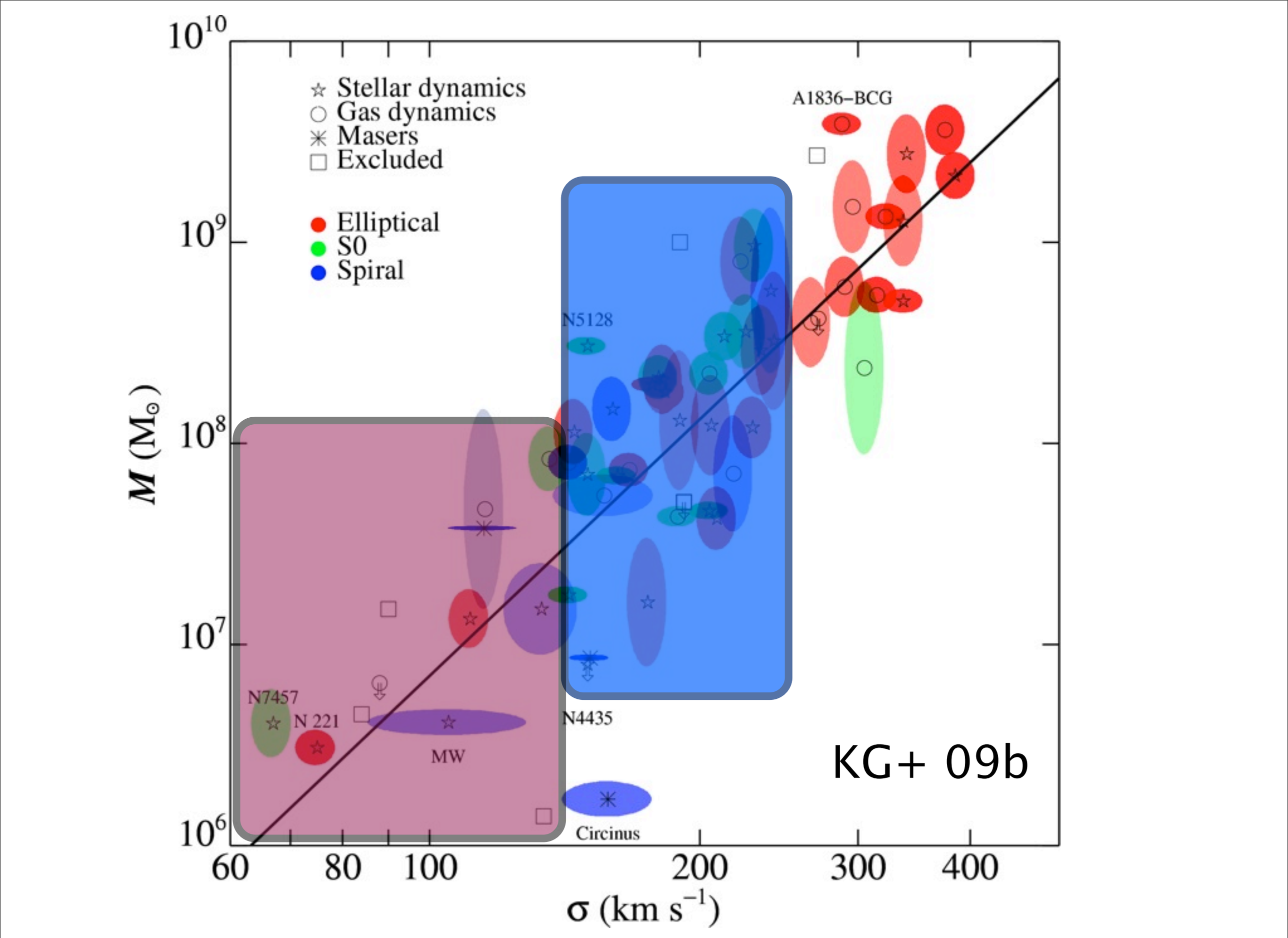
M ($M_\odot$)
σ (km s^{-1})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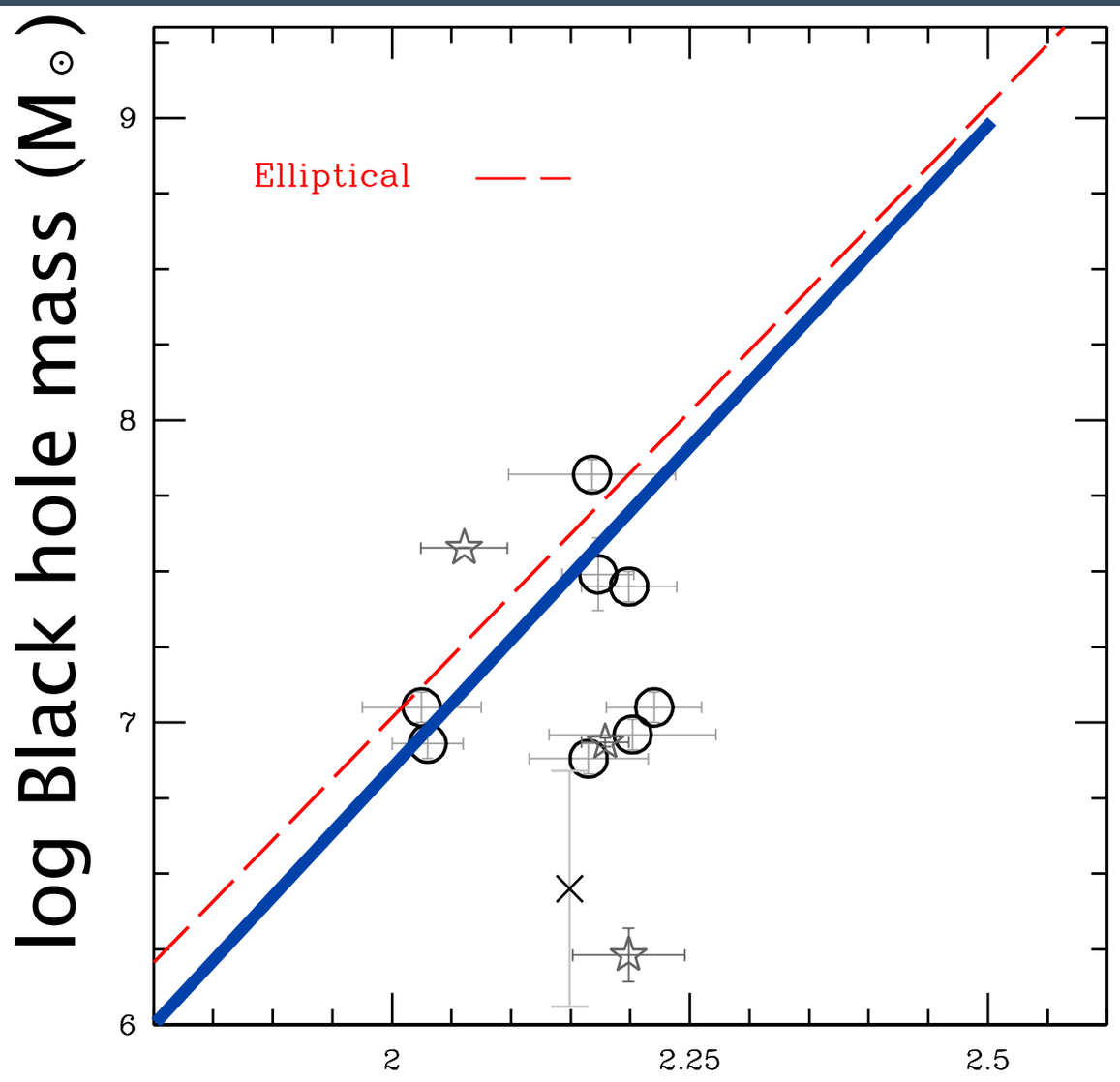
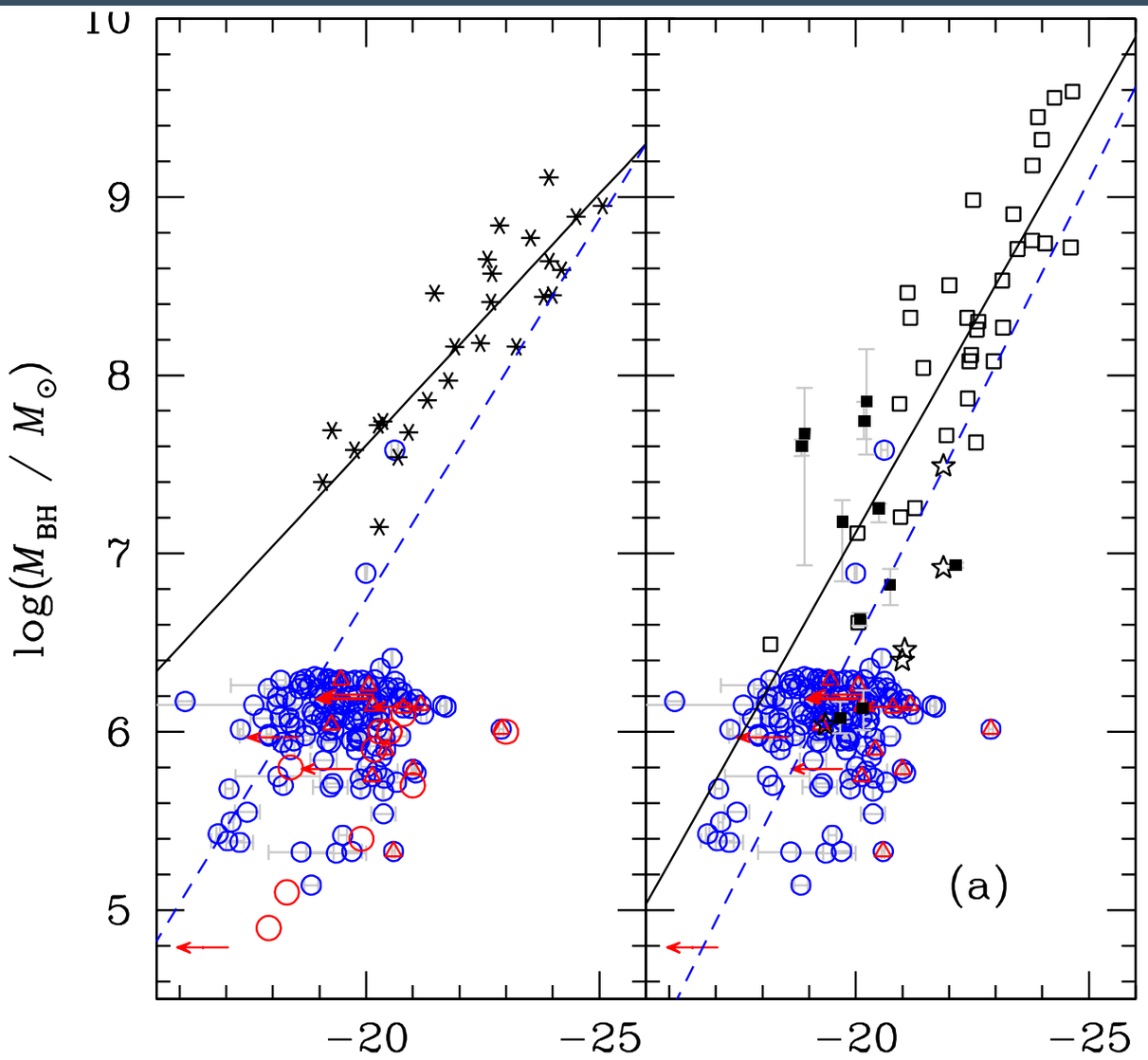
The low end is important.

- Closer to initial conditions.
- BH seed mass distribution.
- Spirals dominate distribution.
- Evolution not finished?
- Other physics in competition?

Black holes in small galaxies are **undermassive.**

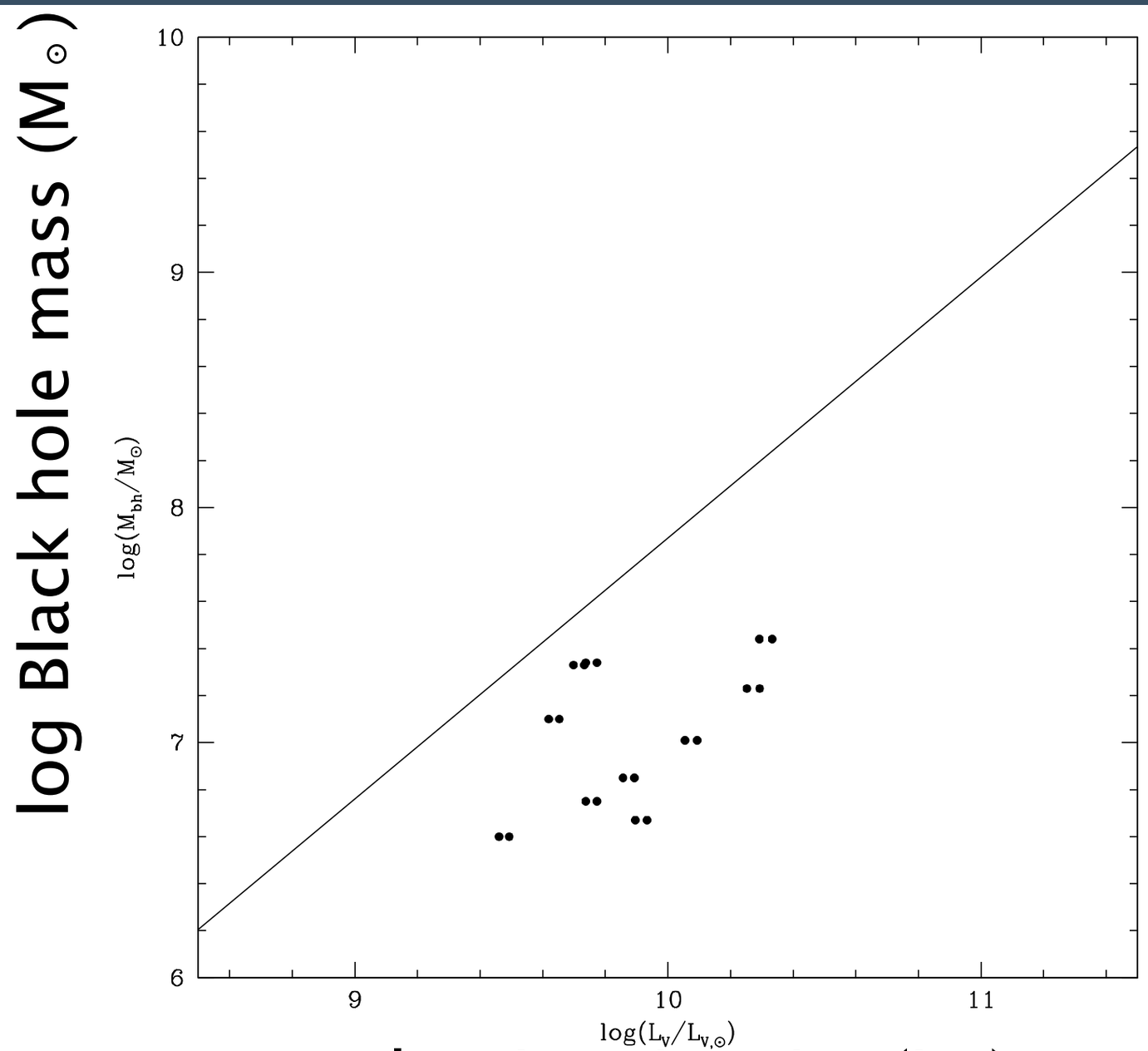


Greene+10

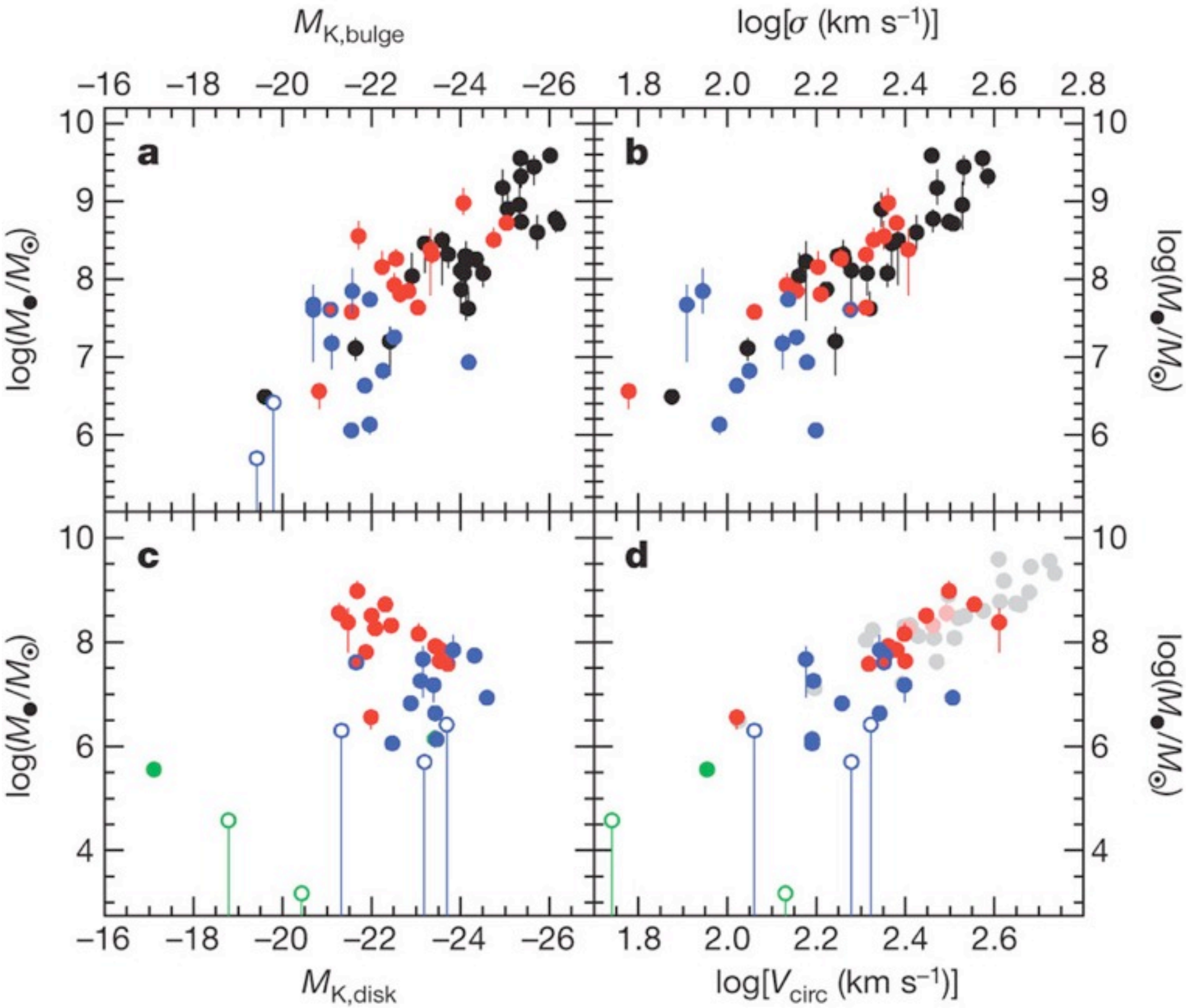


Jiang+11

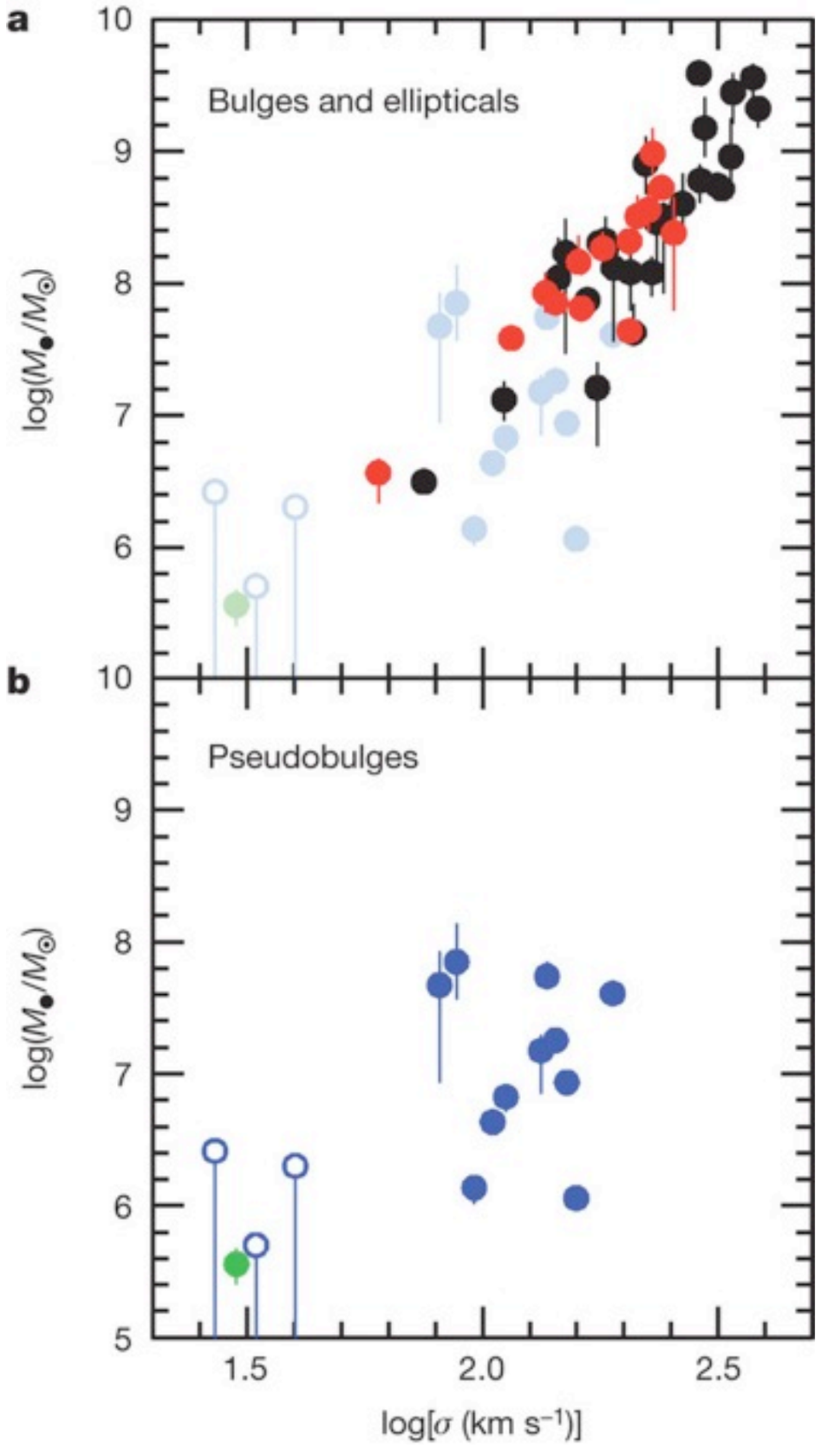
Feedback may not work in small BHs, but that is a prediction of QSO feedback, not evidence against it.



Mathur+ 2012

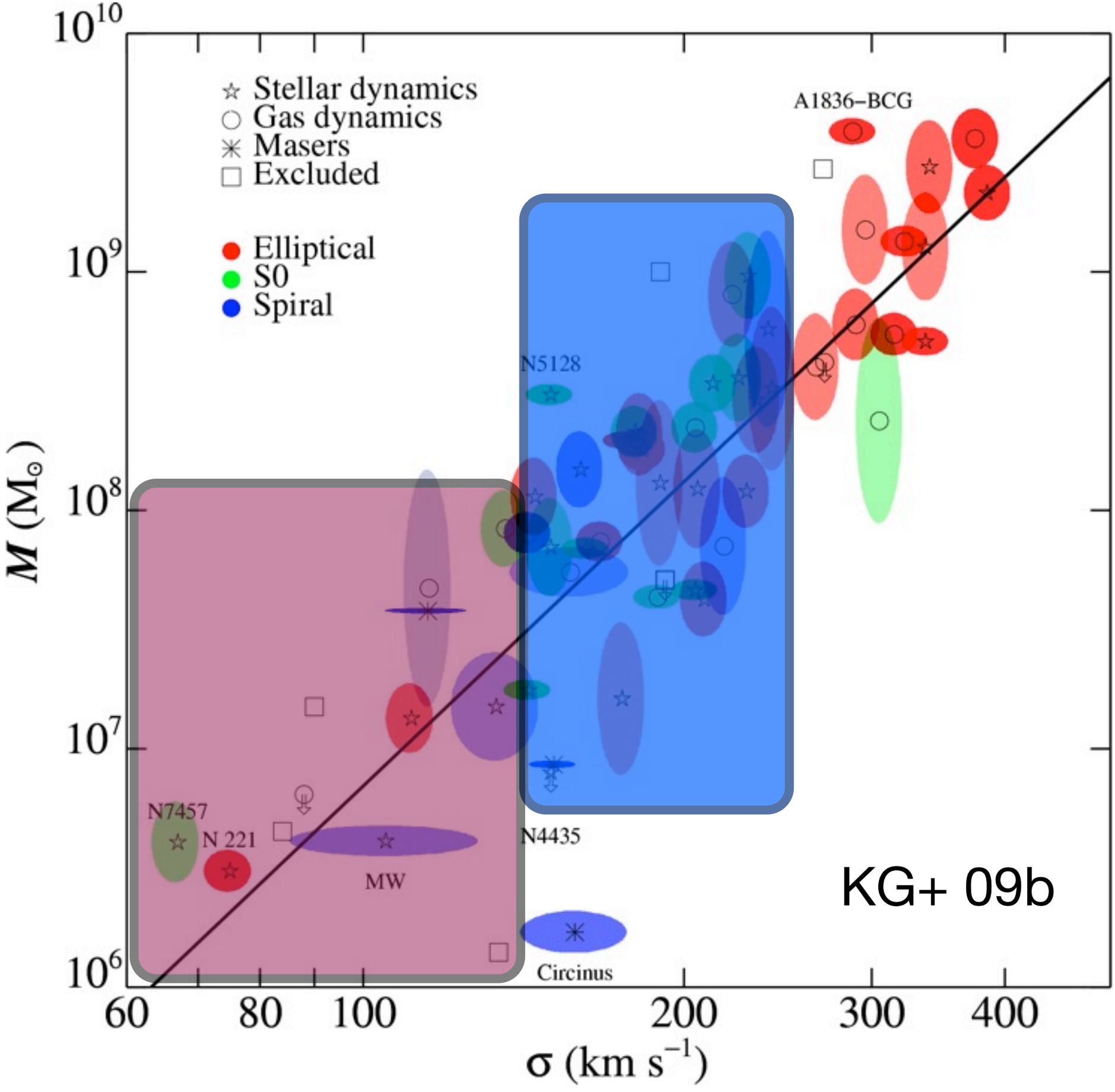


Kormendy & Bender (2012)



See also poster by Vardha Bennert

Kormendy+ (2012)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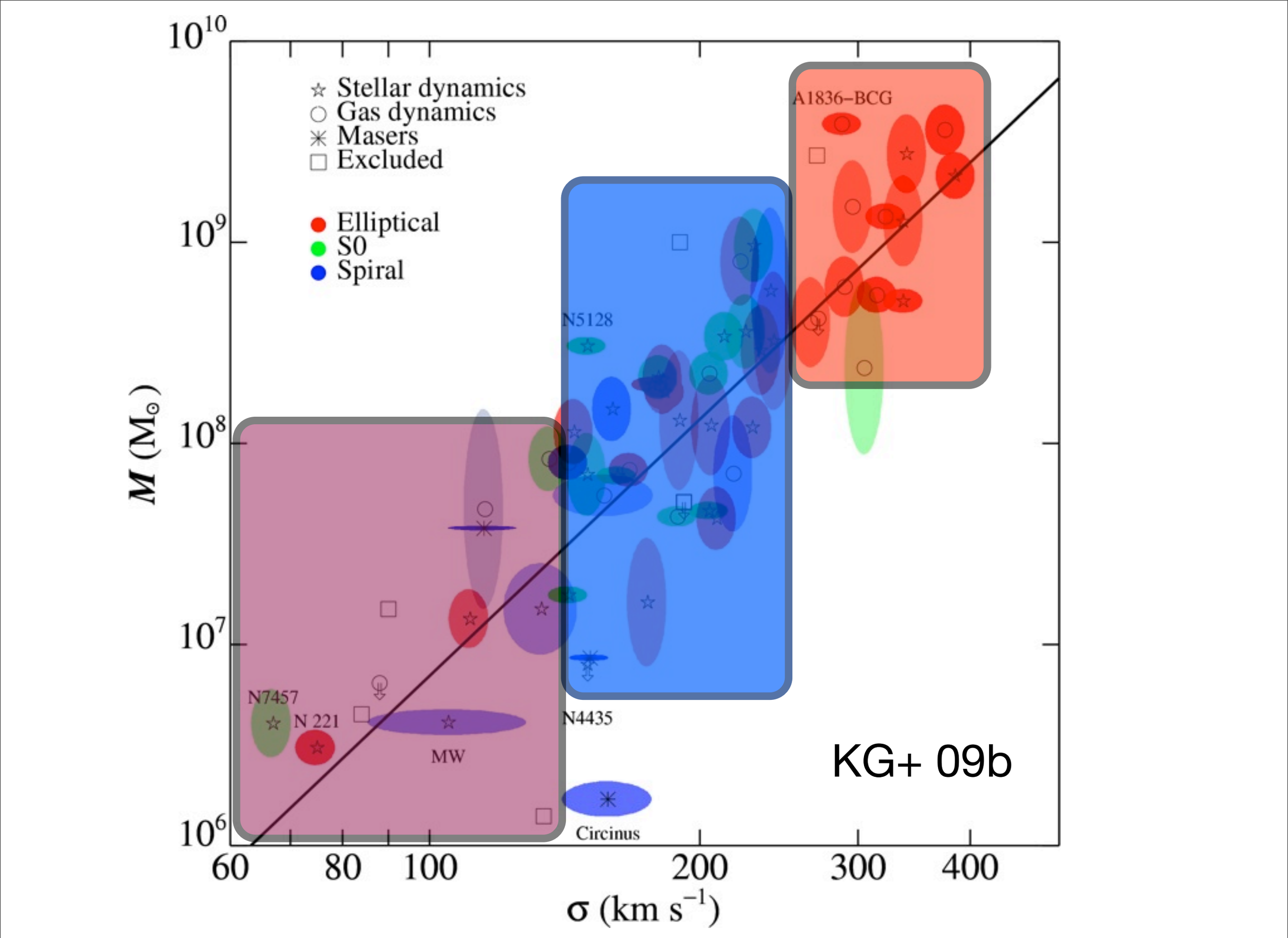
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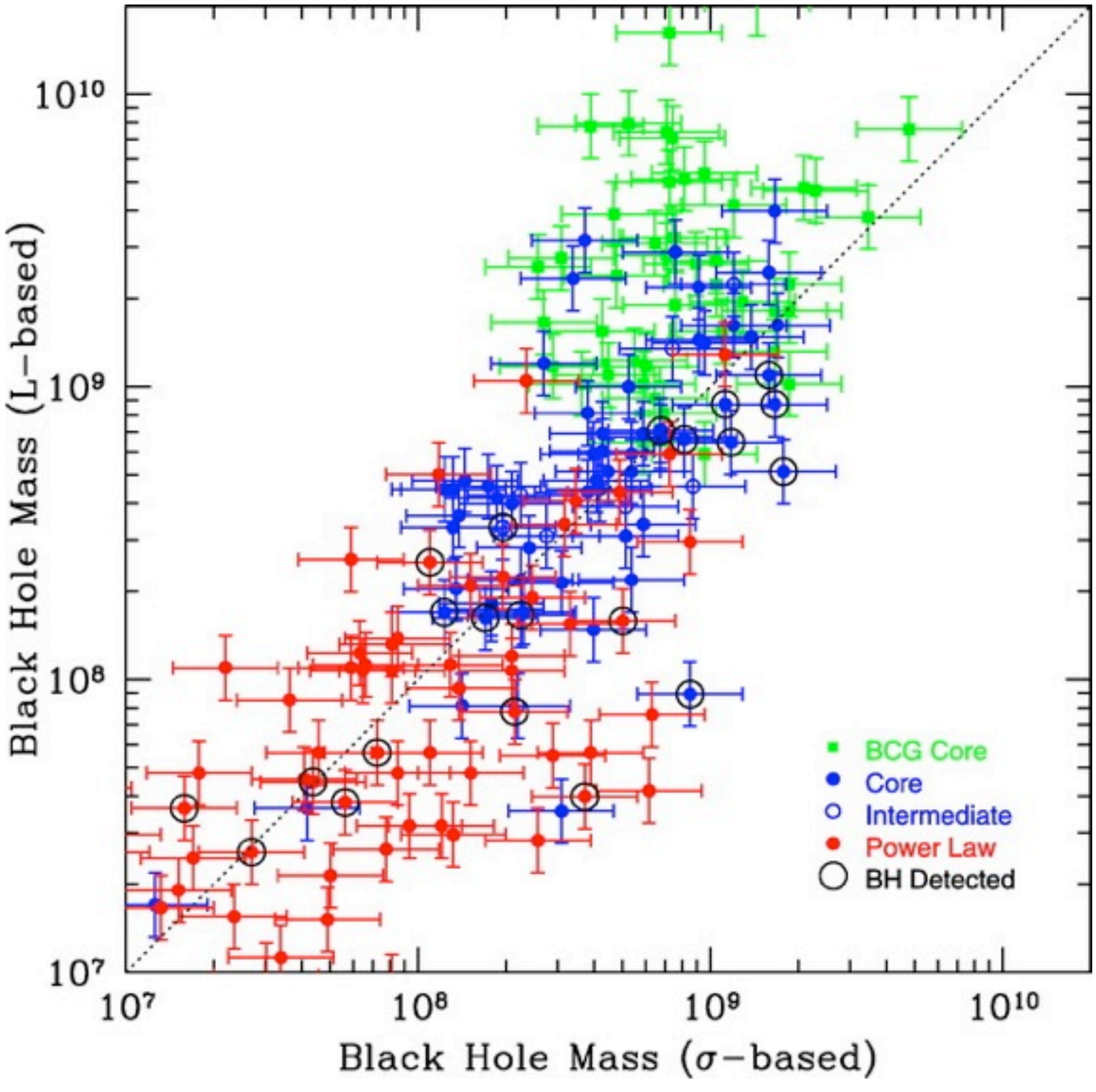
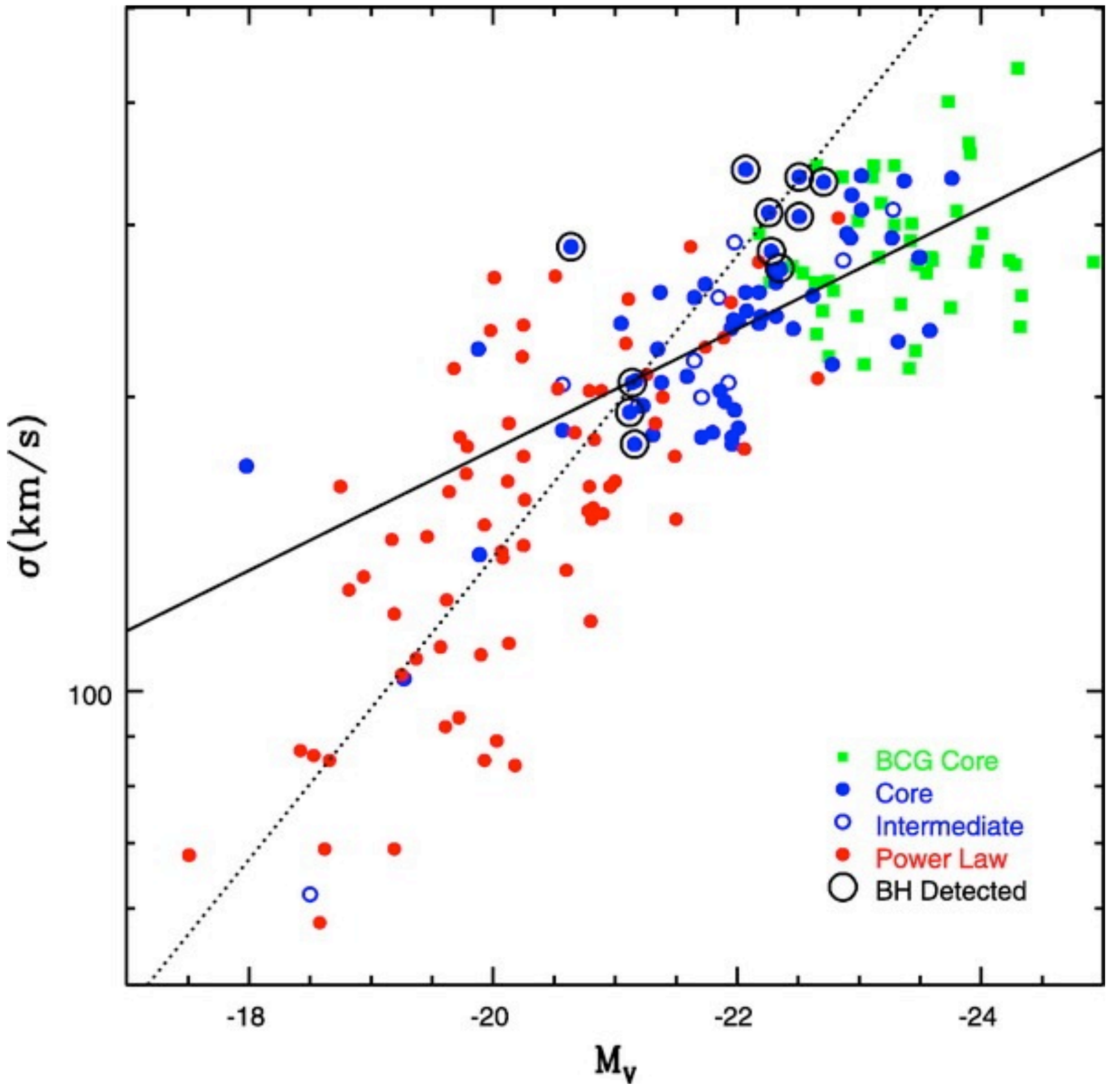
The high-end is important.

- Implied quasar masses ~10^{10}
- “Extremes of the universe”
- X-ray background implies an upper limit.
- Cooling flows in clusters seem to require big BHs.

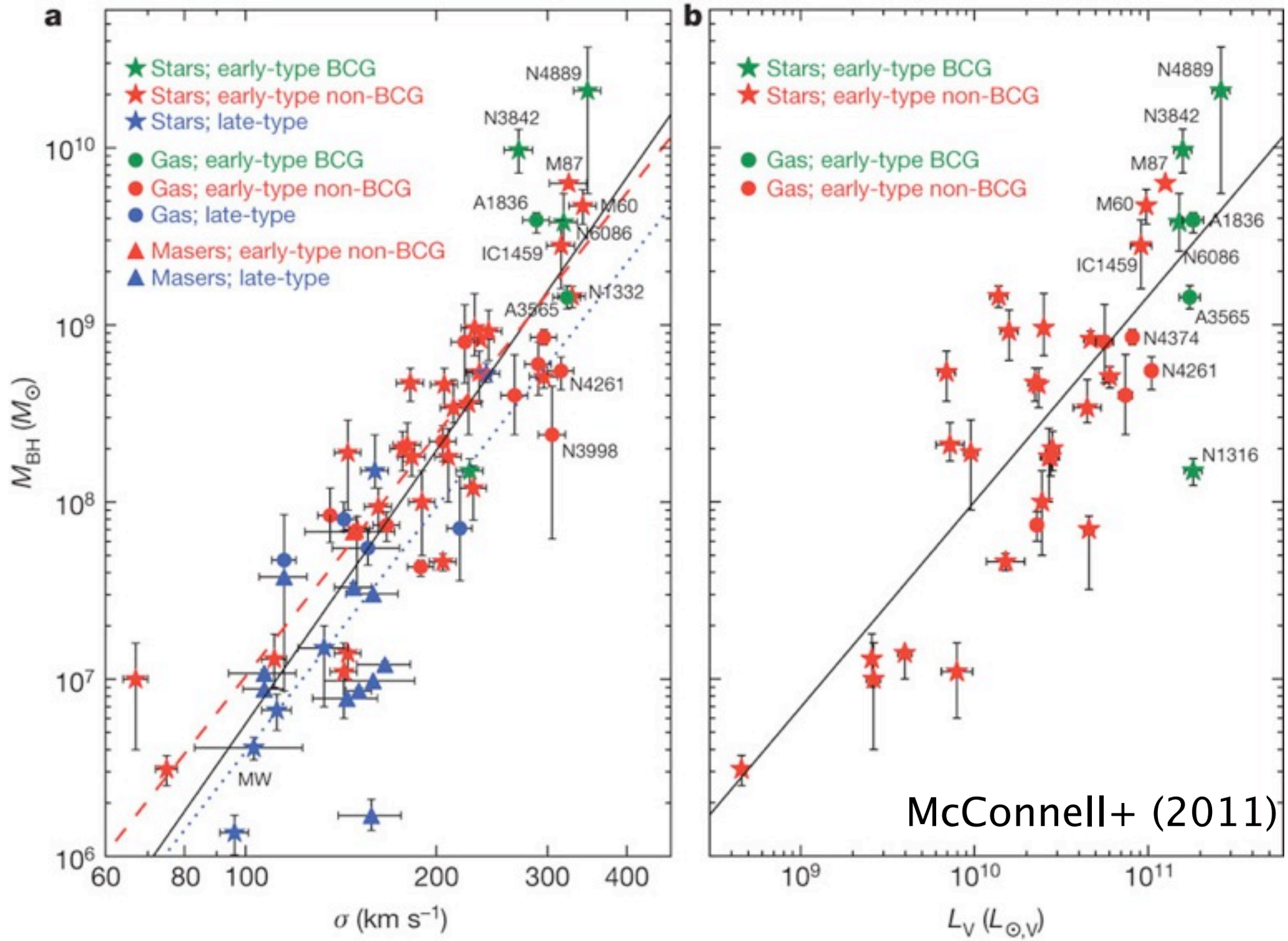
Which is right, M–σ or M–L?



Lauer +07


σ(km/s)
100
-18
-20
-22
-24
M_V
BCG Core
Core
Intermediate
Power Law
BH Detected

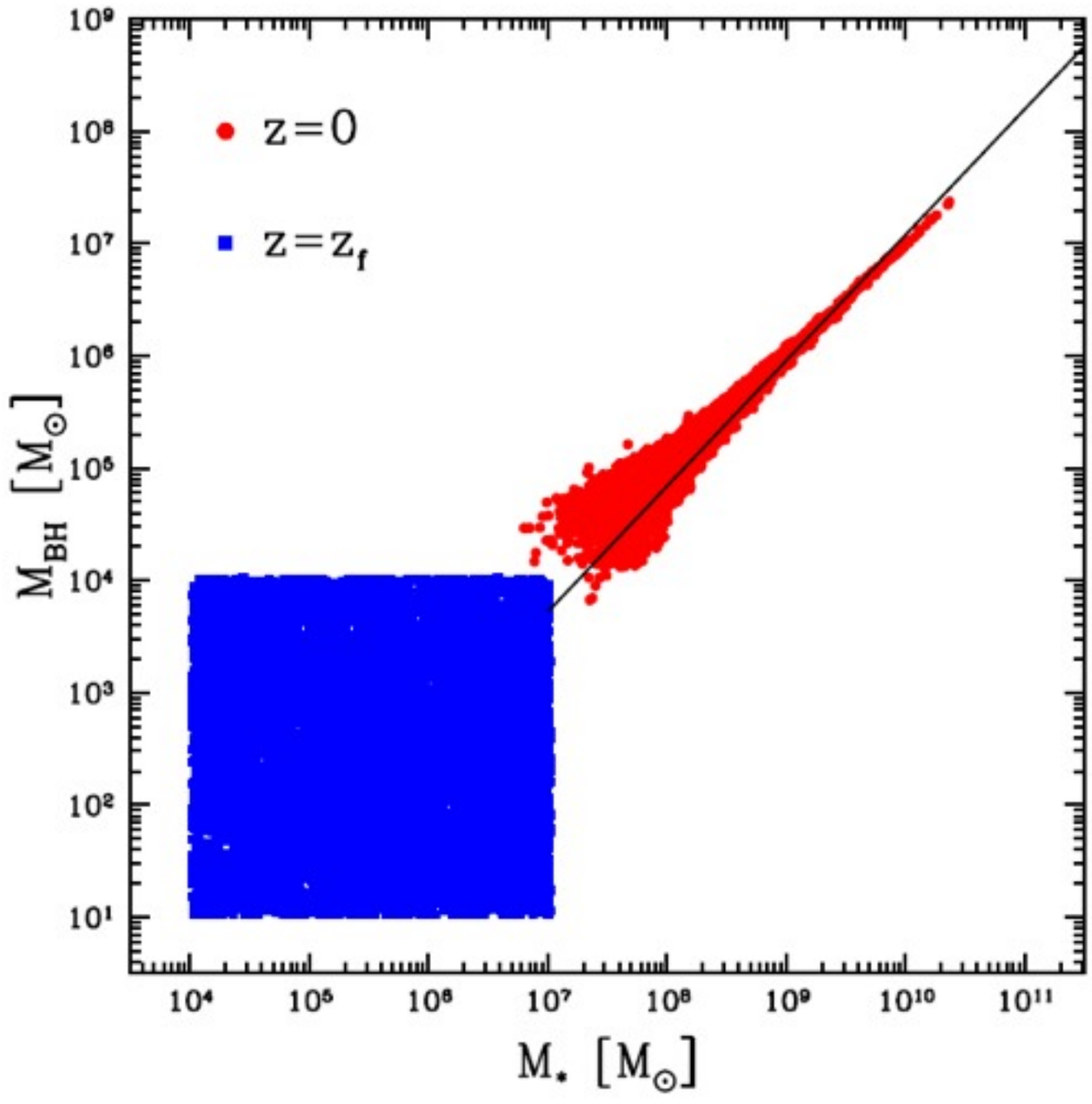
BCGs have big black holes.



McConnell+ (2011)

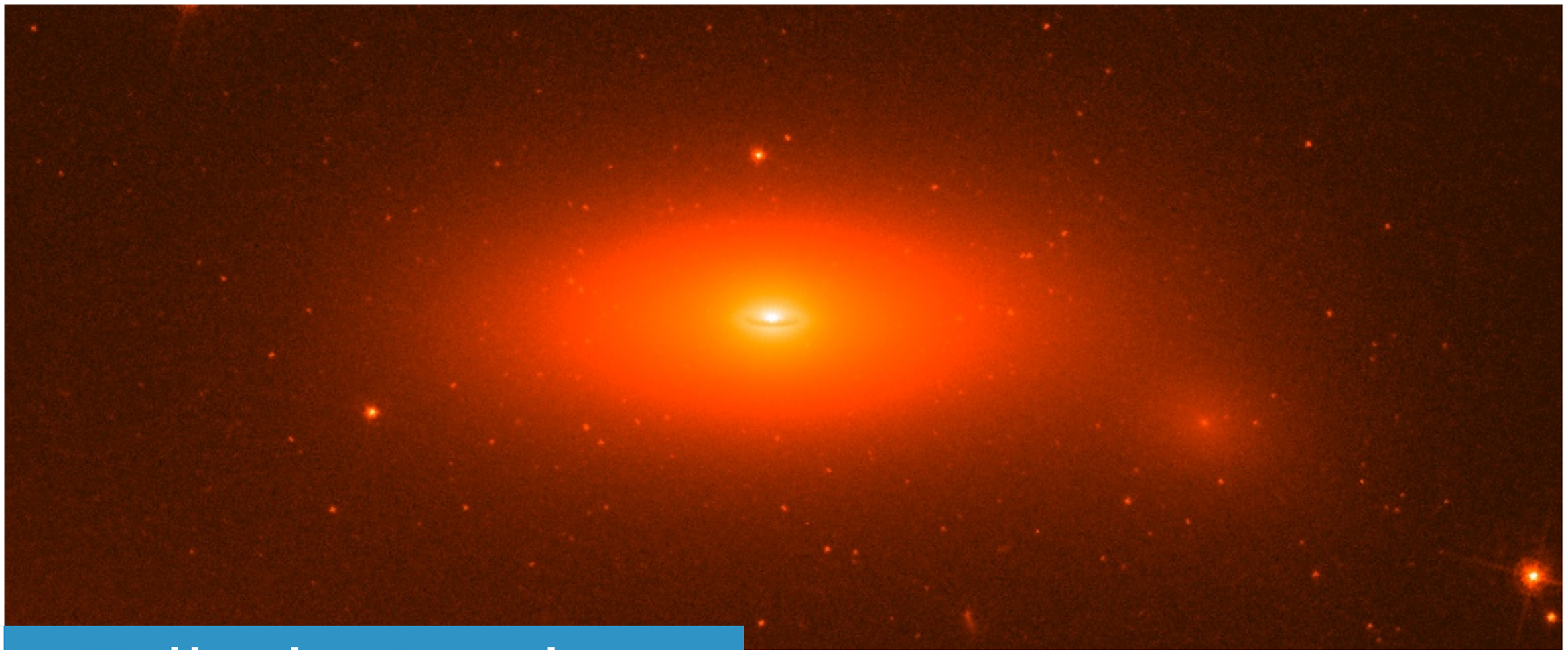
Is the scatter smaller?

Prediction:



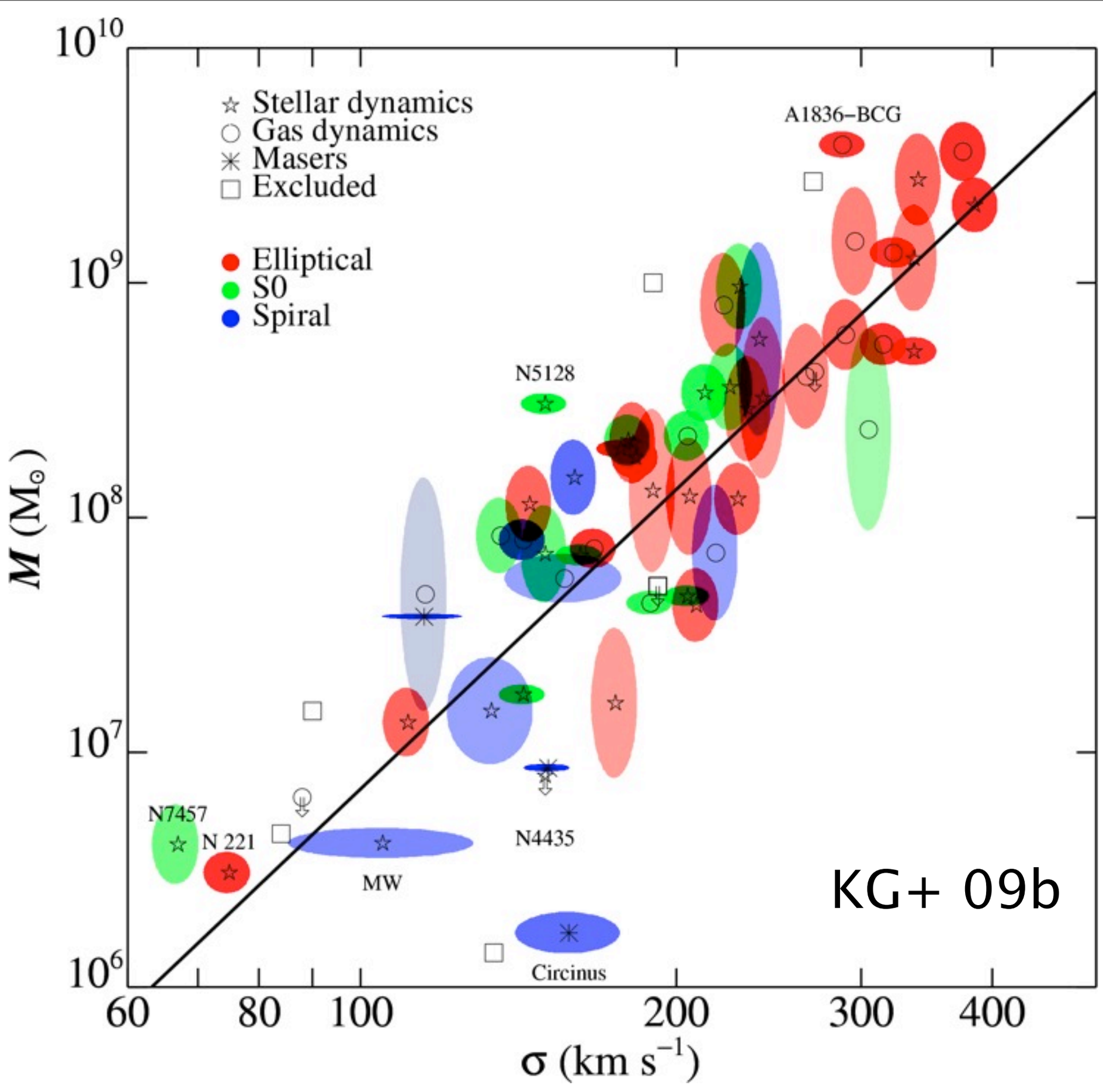
Jahnke
+10

NGC 1277 and other extreme outliers



Talks by Bogdan, van den Bosch, and Shields

van den Bosch+ 2012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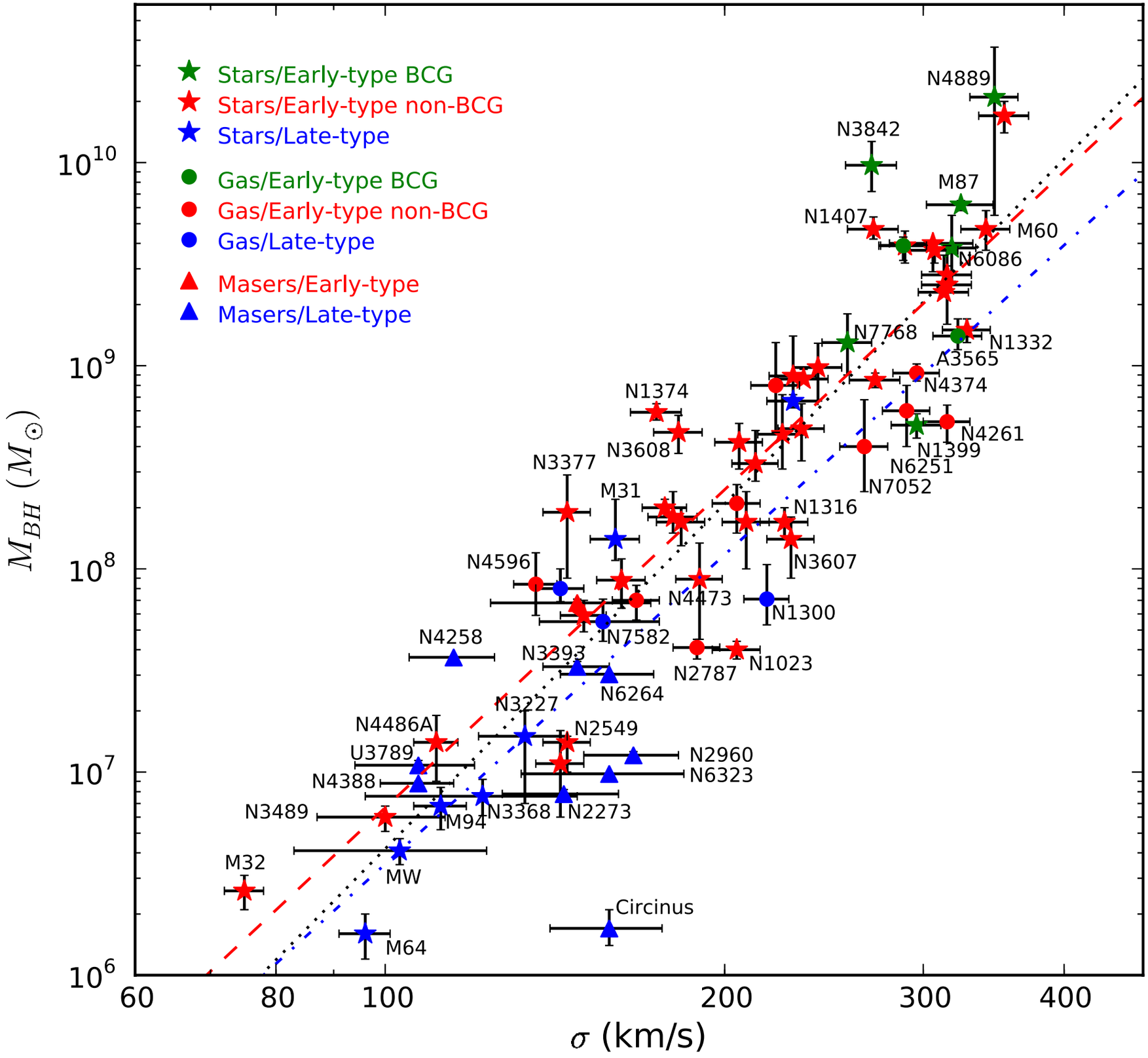

McConnell & Ma (2013)

The more BH mass measurements we have, the more we can do.

- Look at differences in physically motivated subsamples
  - Central surface brightness profile: power-law vs. core (McConnell & Ma 2013 vs. Graham & Scott 2013)
  - Morphology: ellipticals vs. non-ellipticals, etc.
  - Barred vs. unbarred (Graham & Li 2009 vs. Graham & Scott 2013)

The more BH mass measurements we have, the more we can do.

- Look for trends across galaxy size.
  - Is scatter constant across galaxy size? Do we really know what's going on in the tails of the distributions? (i.e., NGC 1277)
  - Does the black hole occupation fraction decrease in small galaxies?

The more BH mass measurements we have, the more we can do.

- Look for deviations from log-linear relation.
- Which (if any) scaling relationship is correct at the high end?
- Where/how do the deviations at the low end start?

Status of the BH scaling relationships: It's complicated

- We have known that BH mass scales with host galaxy properties for a long time.
- The smallest galaxies don't play by the same rules. [Caveats: maser selection effects? systematics in Hα masses?]
- Largest galaxies may not play by the same rules. [Caveats: small numbers, early going in the big BH game.]
- Extreme outliers. [Caveats: selection effects]
- Increasing numbers of BH mass measurements should advance our understanding of the underlying physics.