Black Holes, Bulges, and the IMF

(or: is the $M_\bullet$-L_{bulge} relation really fundamental ?)

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Laura Ferrarese, Glenn van de Ven & Francesco Shankar
Francesco La Barbera, Ignacio Ferreras, Alexandre Vazdekis, Jesus Falcon-Barroso

Overview

I. The $M_\bullet$ - L_{bul} relation revisited

- Introduction: BH scaling relations
- Importance of imaging quality
- Decomposition method
- Scaling relation results and Discussion

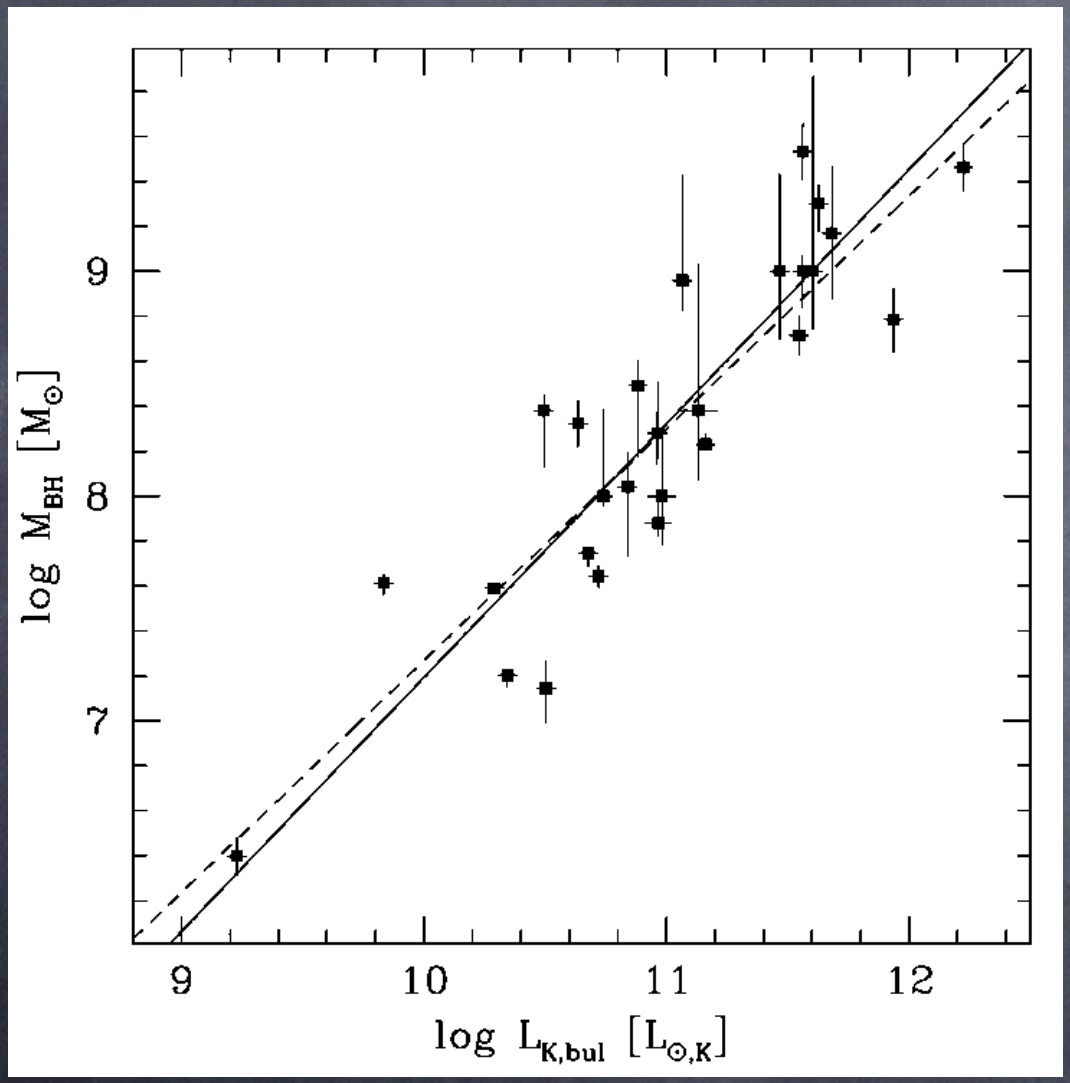
II. $M_\bullet$ and IMF from dynamics and population fitting

III. Future work

IV. Summary

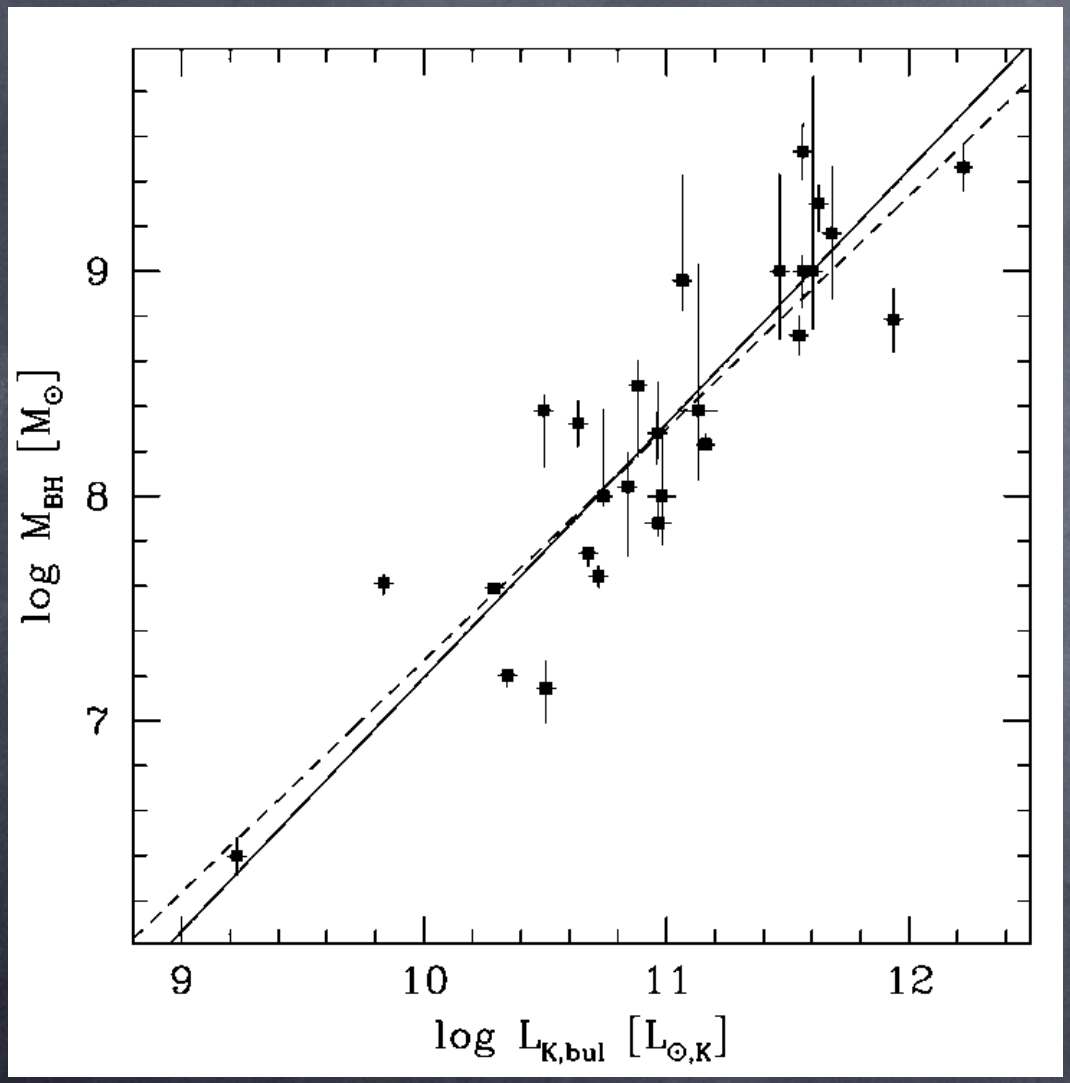
Introduction:
BH scaling relations

Local M• - host galaxy relations



Marconi & Hunt 2003

Local M• - host galaxy relations



Marconi & Hunt 2003

- understand BH-galaxy connection

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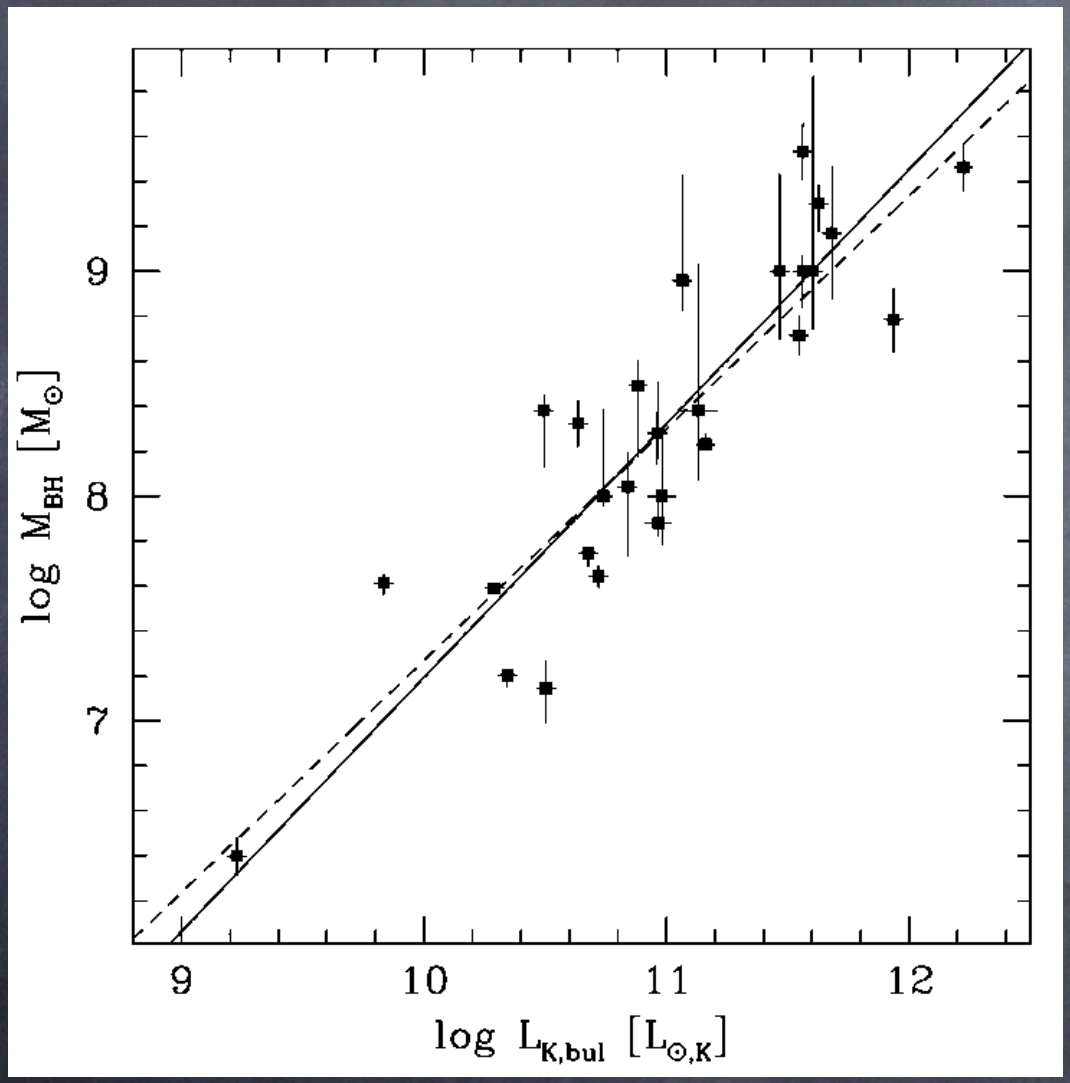

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- understand BH-galaxy connection
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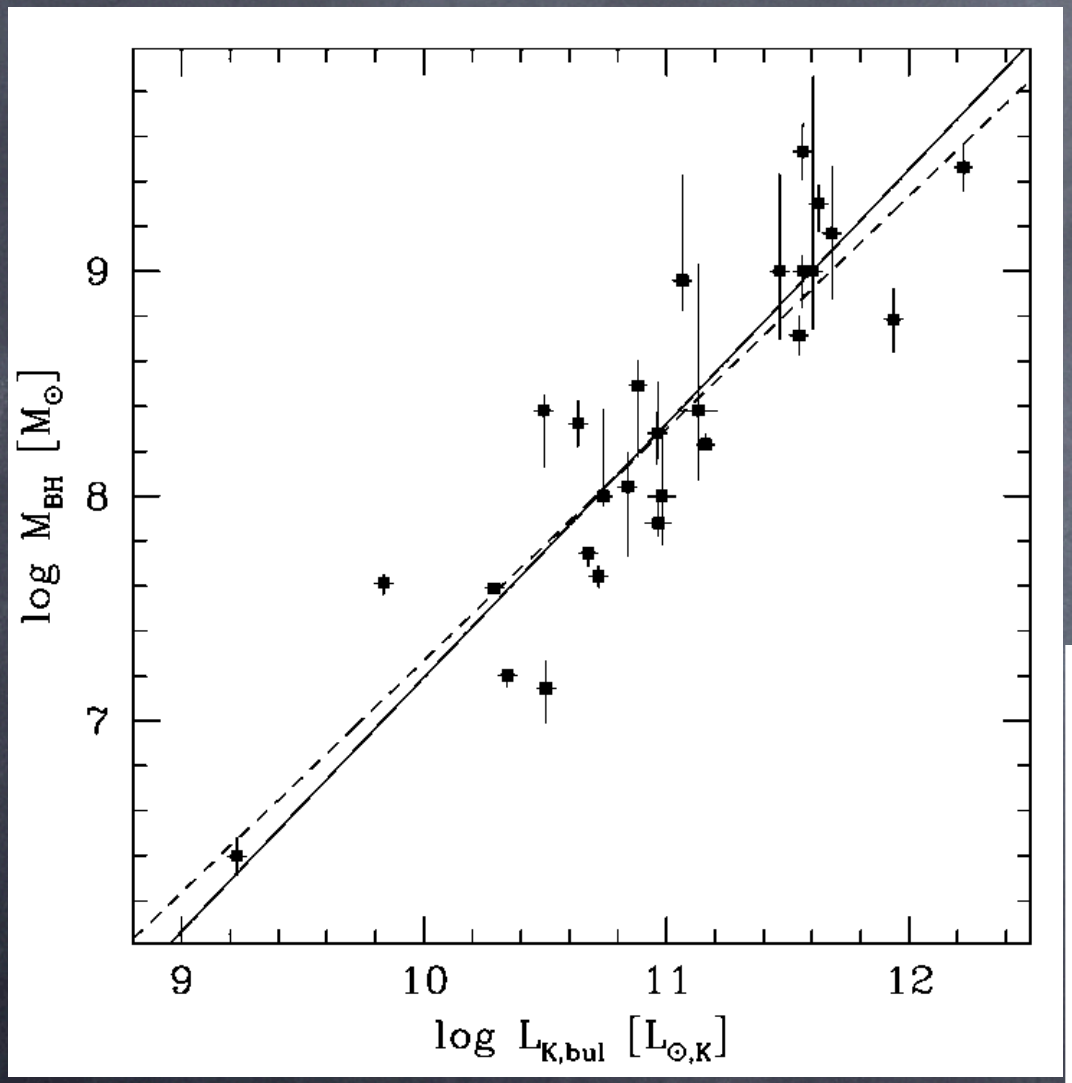

Marconi & Hunt 2003

- understand BH-galaxy connection
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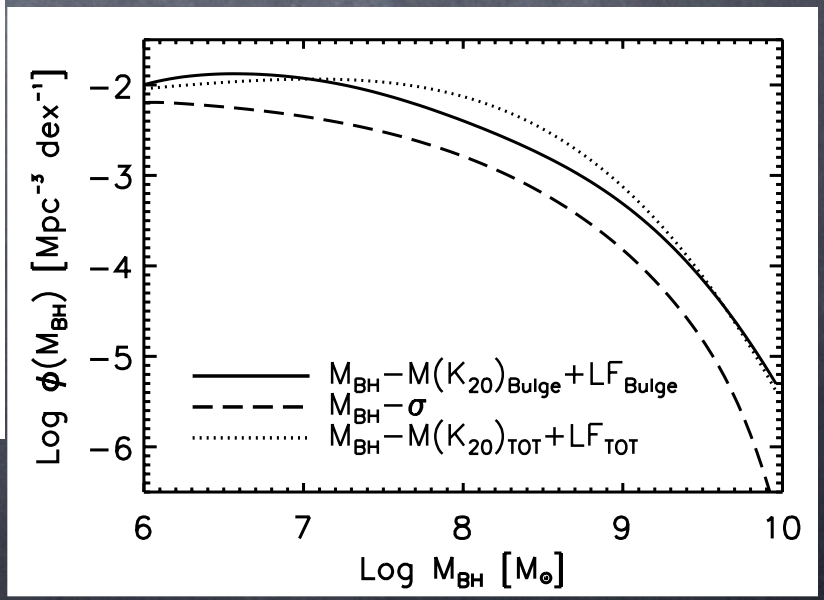
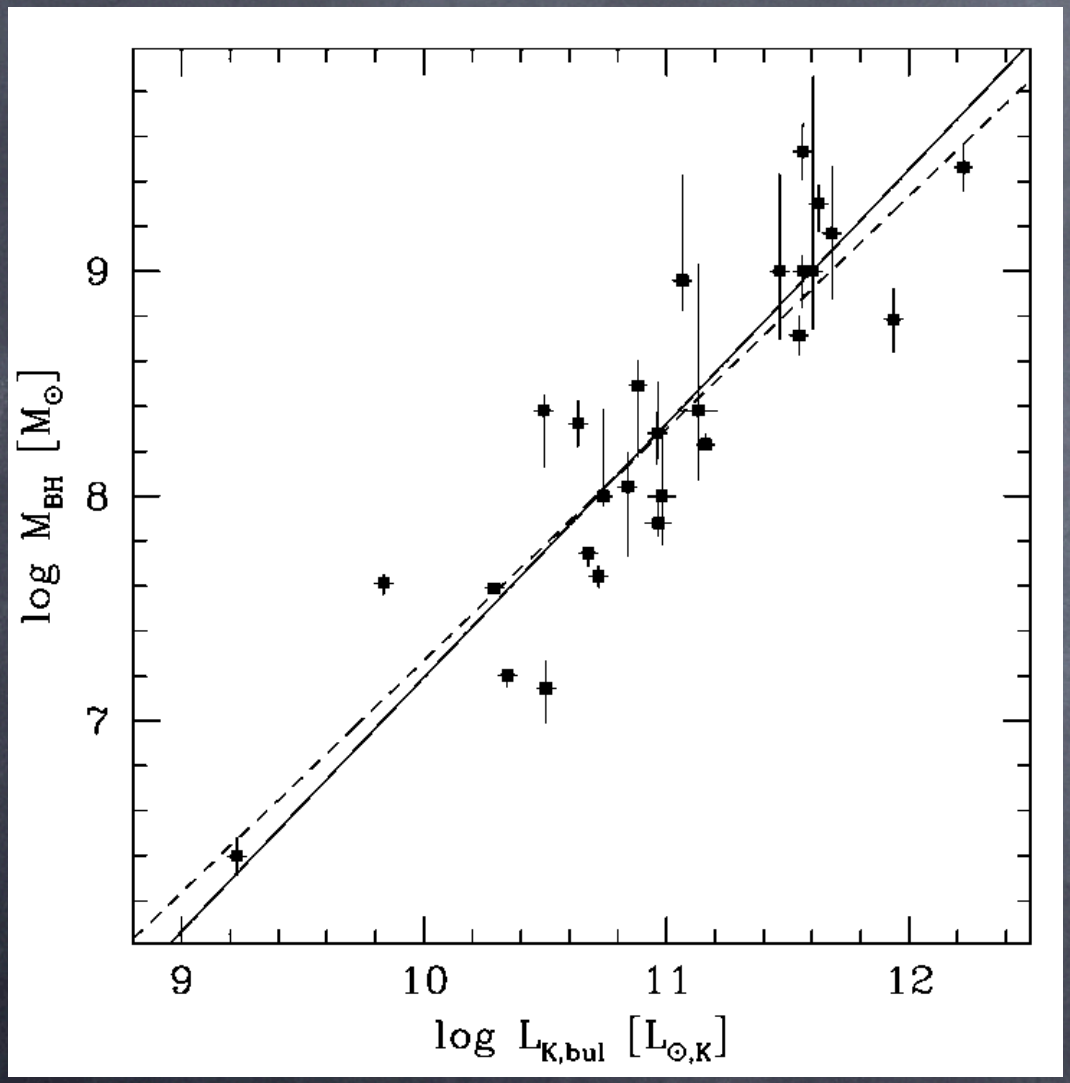
- BHMF



Shankar et al., in prep.

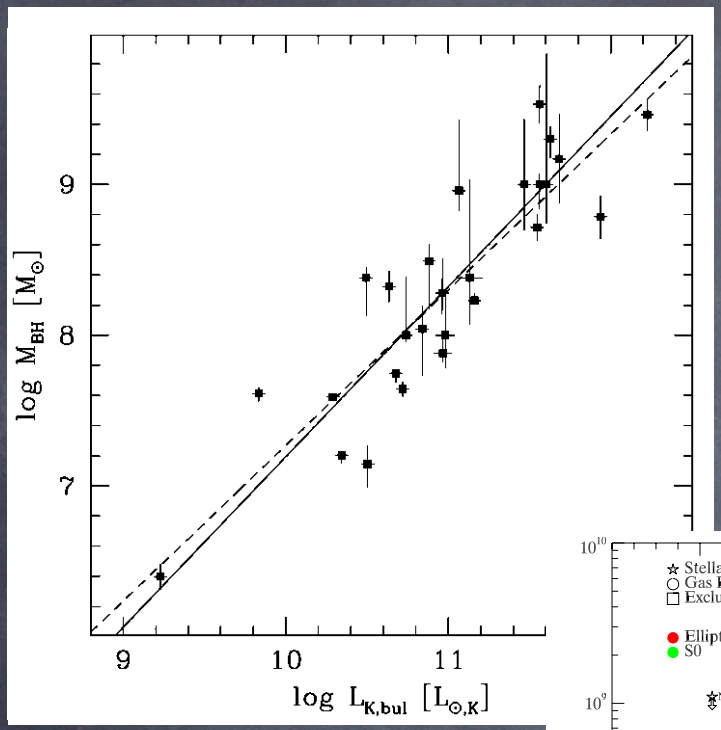
Local M• - host galaxy relations



Marconi & Hunt 2003

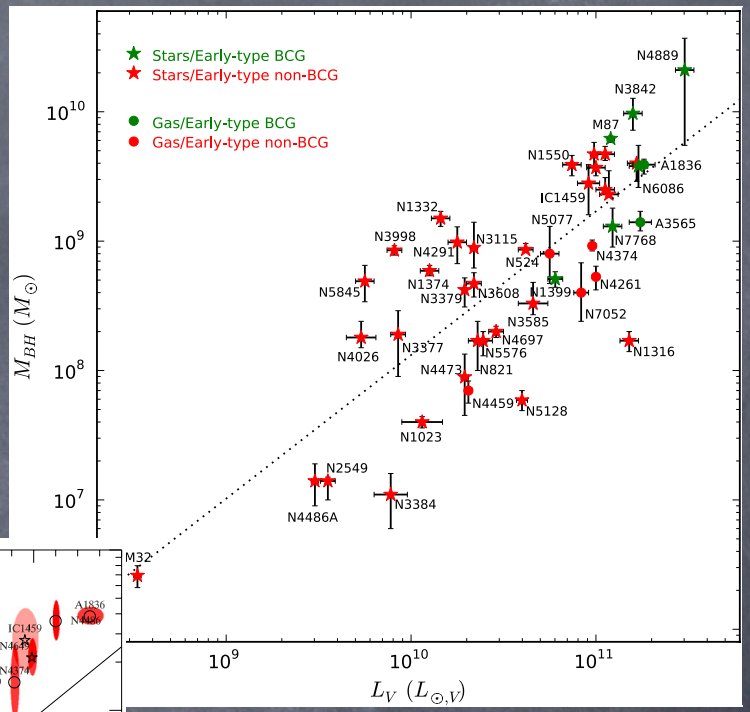
- understand BH-galaxy connection
- e.g. AGN feedback, accretion ↔ merging
- BHMF
- calibrate secondary / indirect M• measurement methods

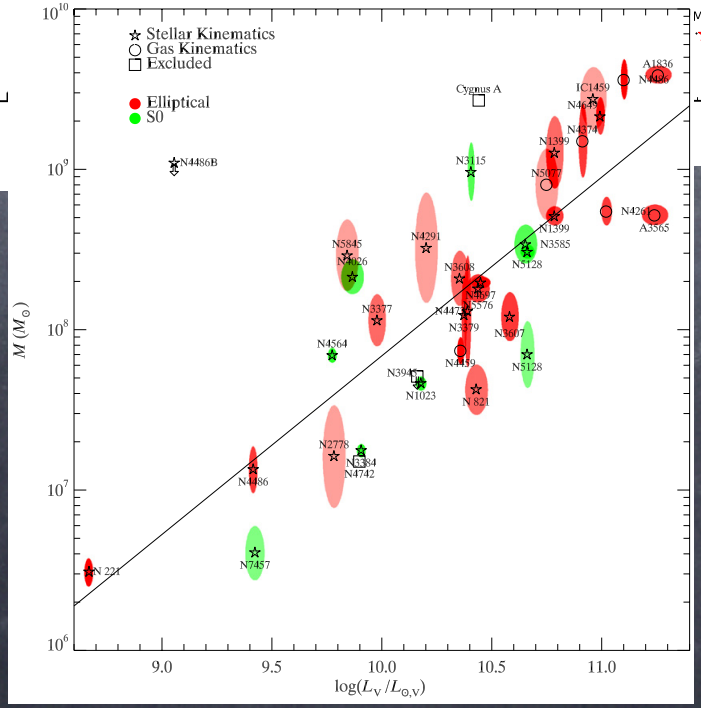
Why another $M_\bullet$ - L_{bul} calibration?



Marconi & Hunt 2003
K-band

Gültekin+09
V-band





McConnell & Ma 2013
V-band

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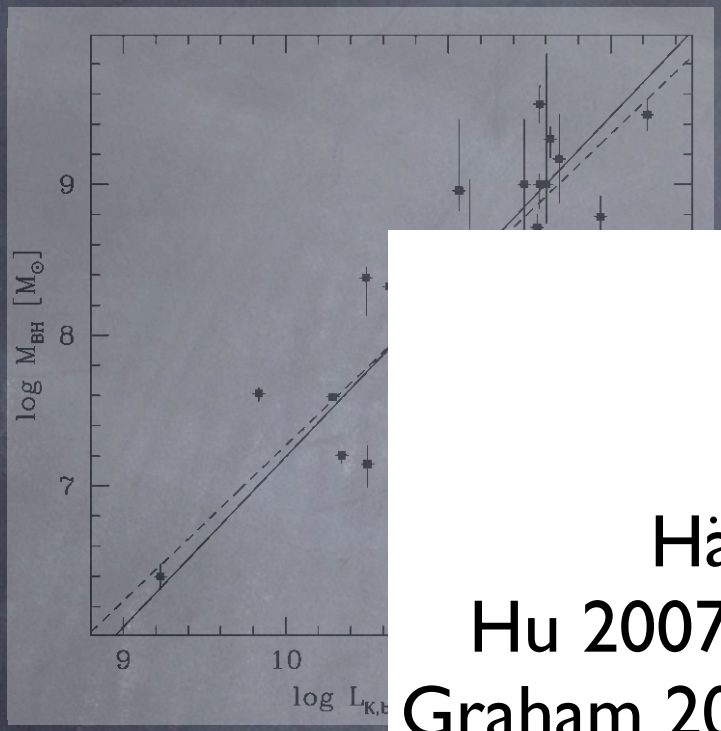
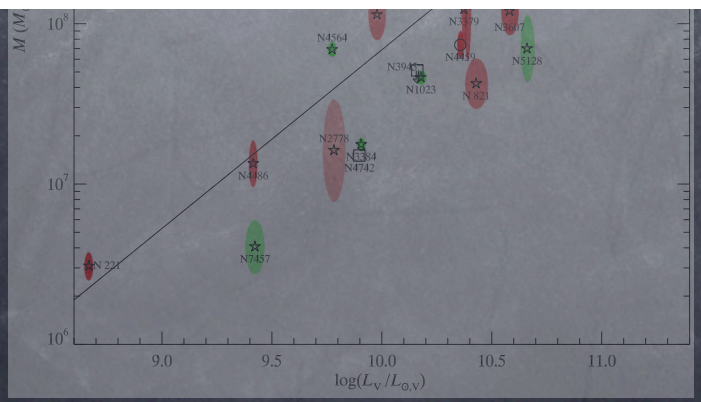
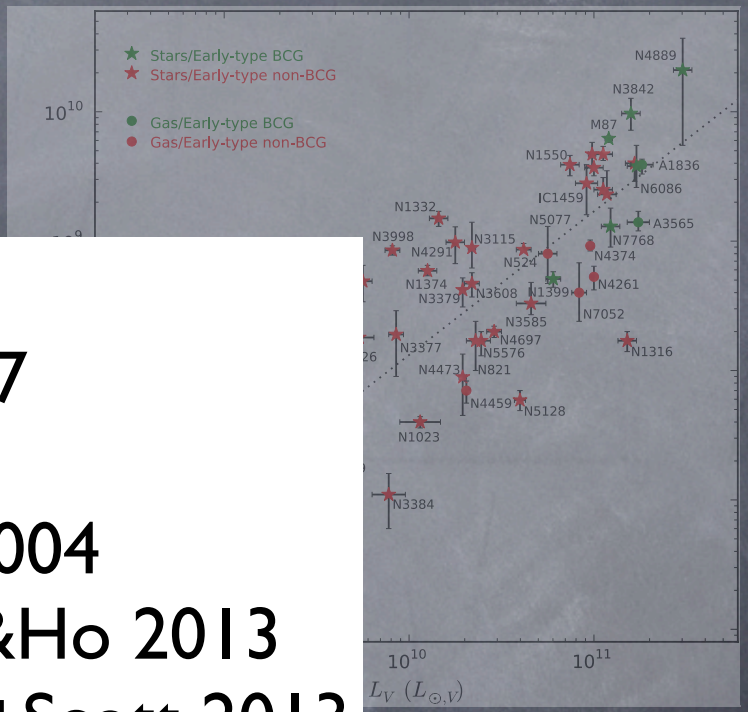


Marconi & Hunt 20
K-band

... +
Graham 2007
Vika+2012
Häring & Rix 2004
Hu 2007, Kormendy&Ho 2013
Graham 2012, Graham+Scott 2013
+ ...





Connell & Ma 2013
V-band

The importance of image quality when deriving L_{bul}

Why NIR (K-band) ?

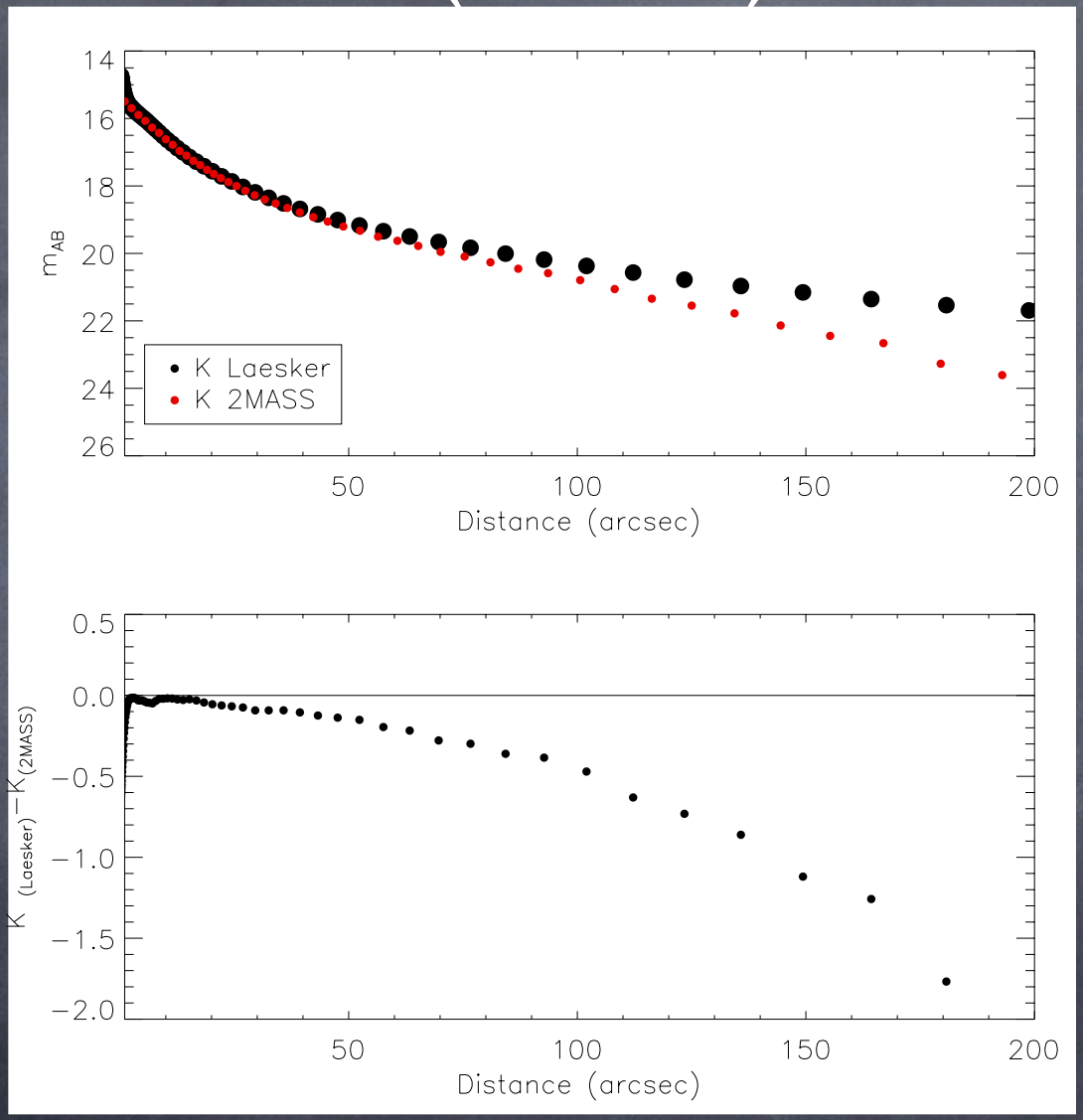
- better tracer of stellar Mass ($M_\star/L$) than visual λ
- little dust extinction

NIR (K-band) !

Pending issues:

huge + variable background → subtraction?

NIR (K-band) !



example: background oversubtraction in 2MASS

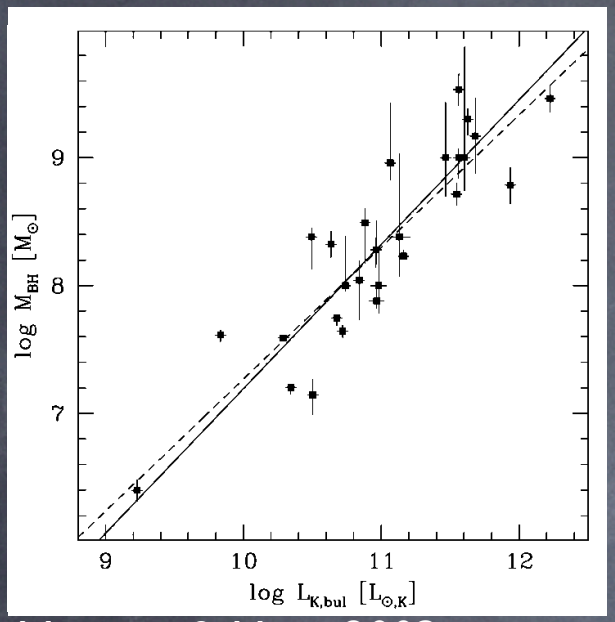
NIR (K-band) !

Pending issues:

huge + variable background → subtraction?

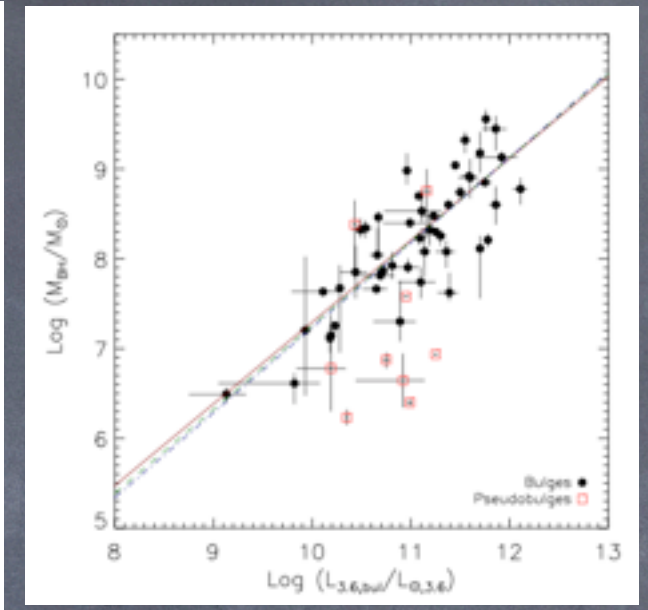
depth
resolution
decomposition

Disparate Results



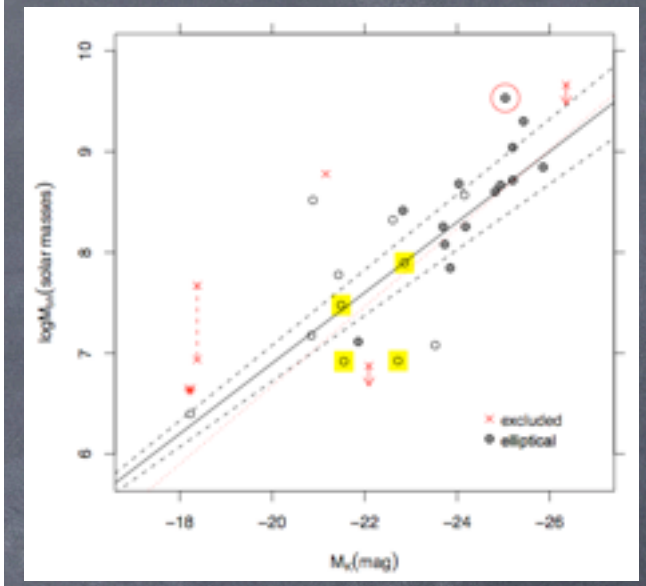
Marconi & Hunt 2003
37 (28) galaxies

b = 1.21±0.13
ε = 0.3



Sani+11
48 galaxies

b = 0.93±0.10
ε = 0.38±0.05



Vika+12
25 (19) galaxies

b = 0.88±0.06
$\varepsilon = 0.52^{+0.10}_{-0.06}$

Solution:
CFHT WIRCam (and some careful reduction)

- seeing FWHM 0.8” (cf. 2MASS: 2” - 3”)
  → nuclei, inner disks

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  $\leftrightarrow \mu_{V,AB} \approx 28$ mag/arcsec^2

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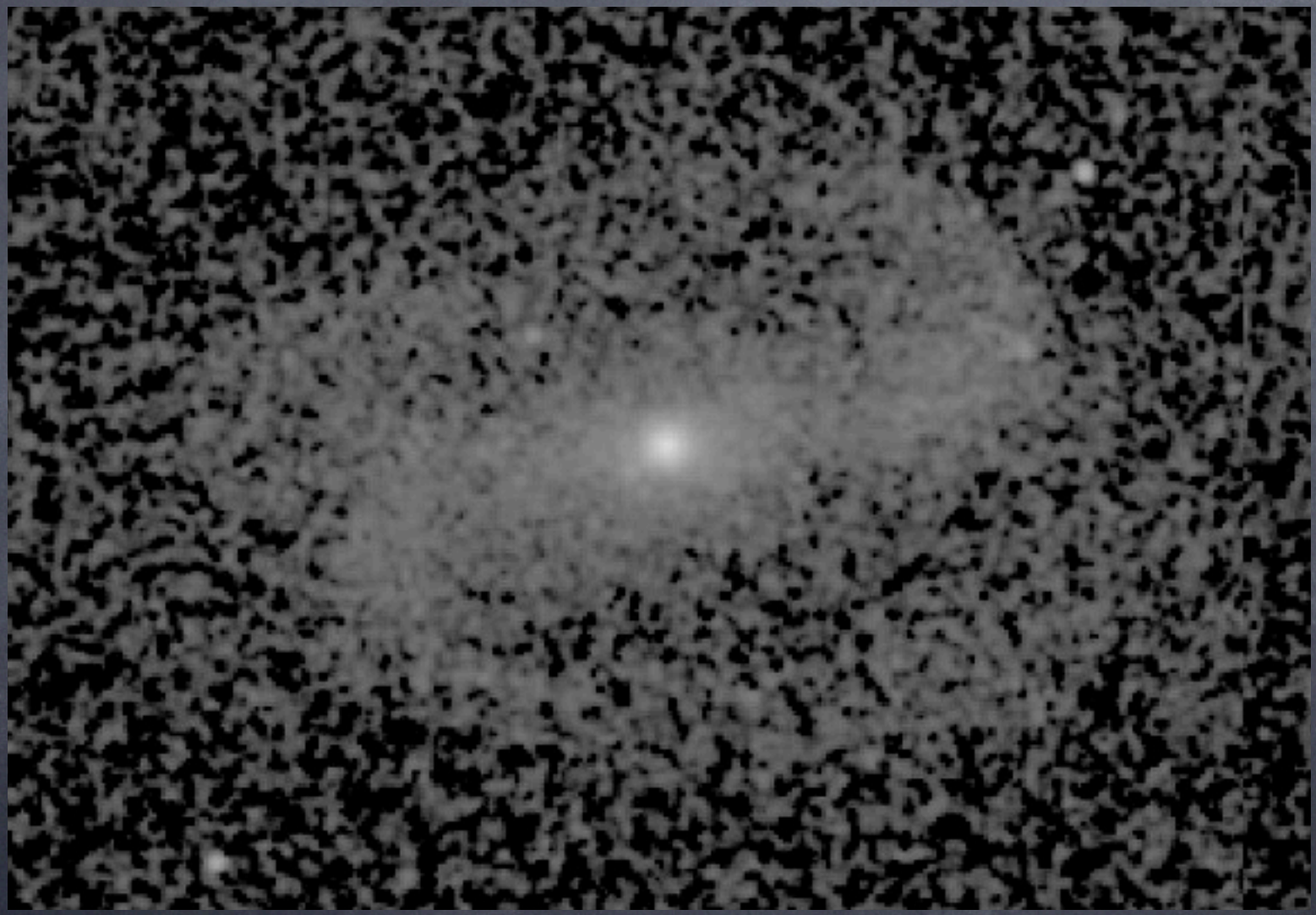
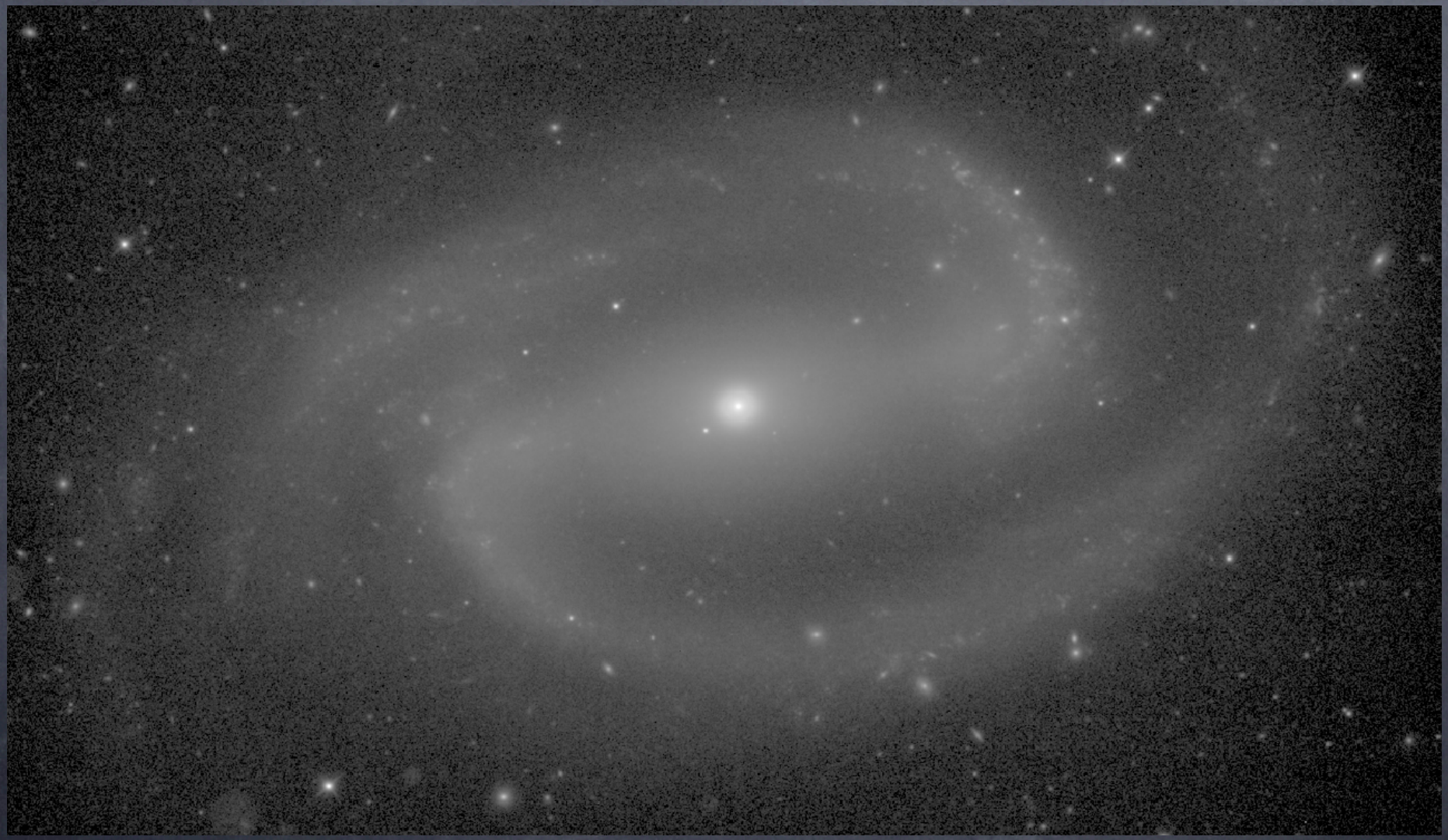
- Wide Field (20' x 20')

- Improved Dithering & Sky Modeling !!

Efforts pay off: 2MASS versus ...



... didicated WIRCam data and reduction.



(note: outer disk extends much farther than shown area)

Deriving L_{bul} : Decomposition with GALFIT3

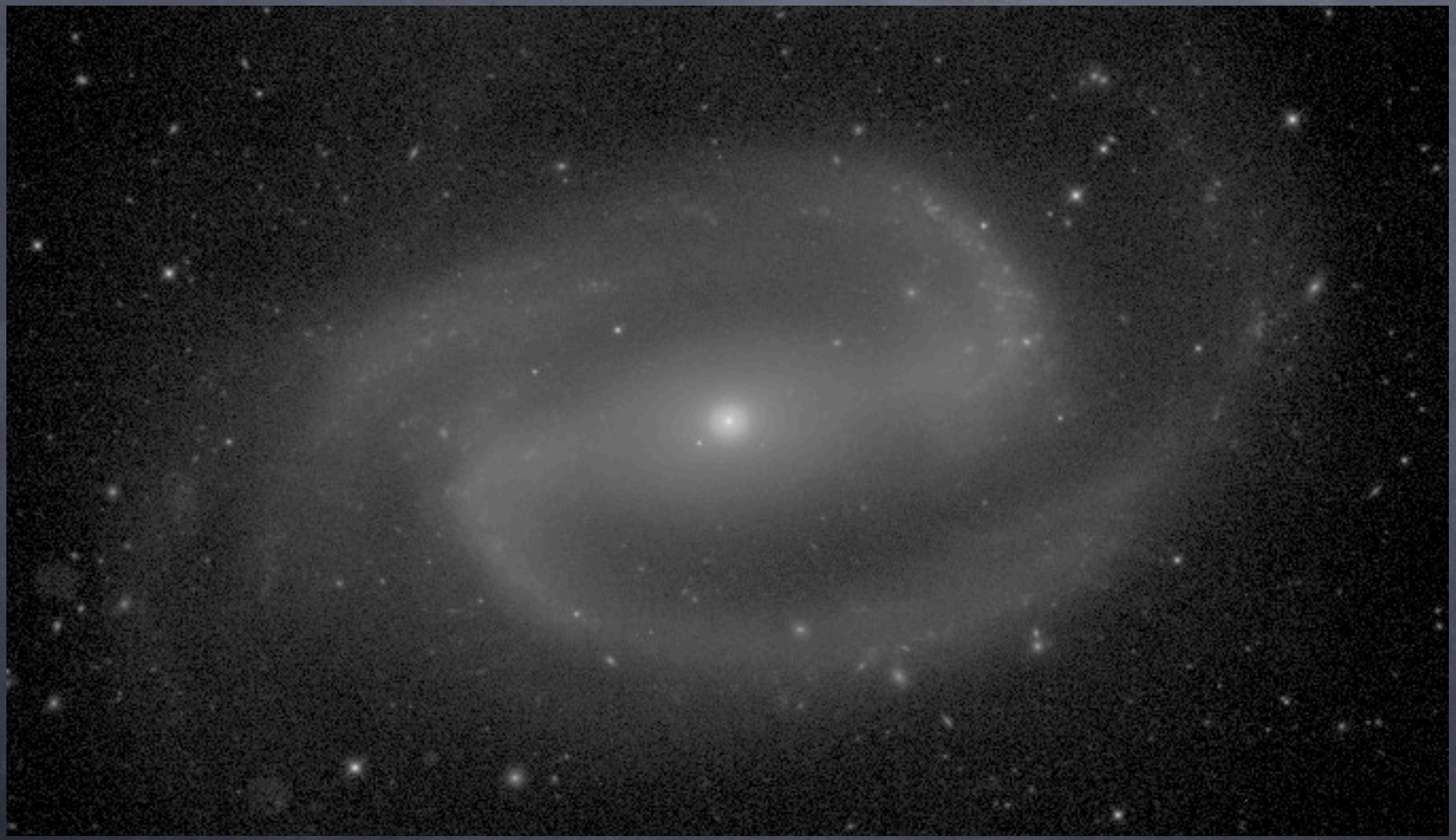
Decompositions: GALFIT

- first "standard model":
  Sérsic Bulge (+ exponential Disk)

  → $L_{b,std}$ & $L_{t,std}$

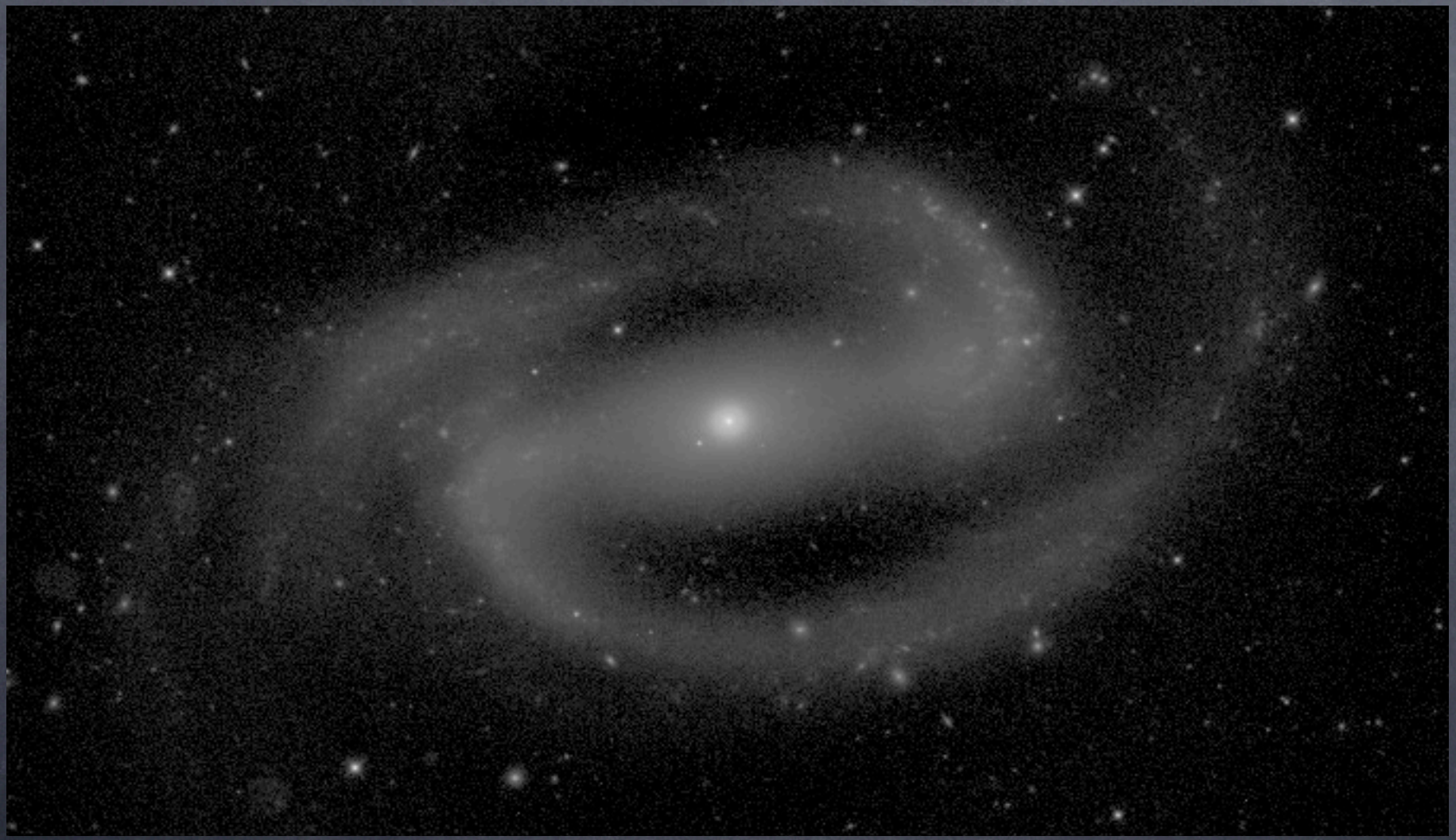
- then "improved model":
  - Ellipticals: mask core
  - other: Nucleus, Bar, Inner Disk, Spiral Arms, Envelope

example: NGC1300



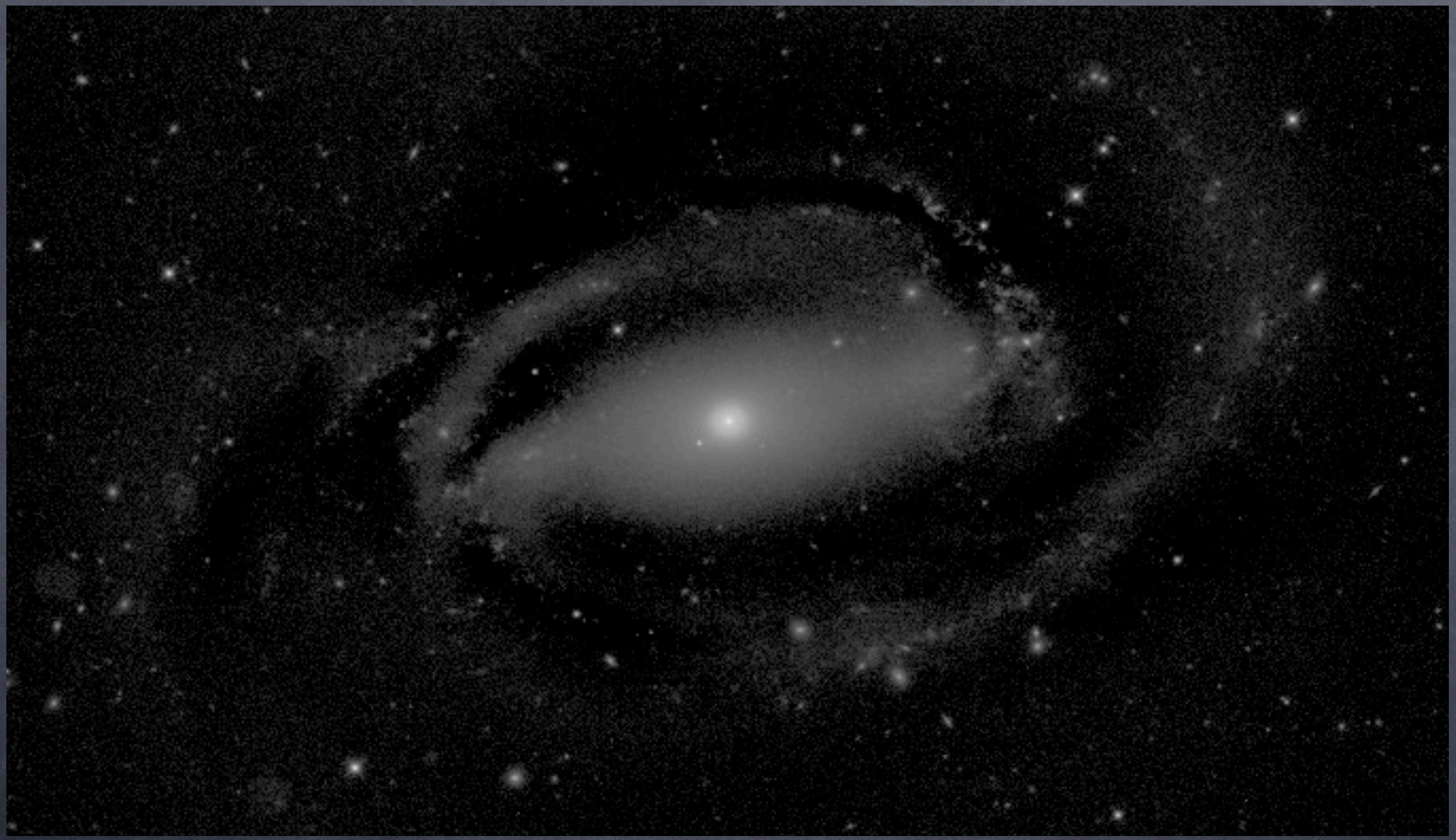
displayed area: approx. 7’ x 4’ (39 x 22 kpc)

subtracted: disk



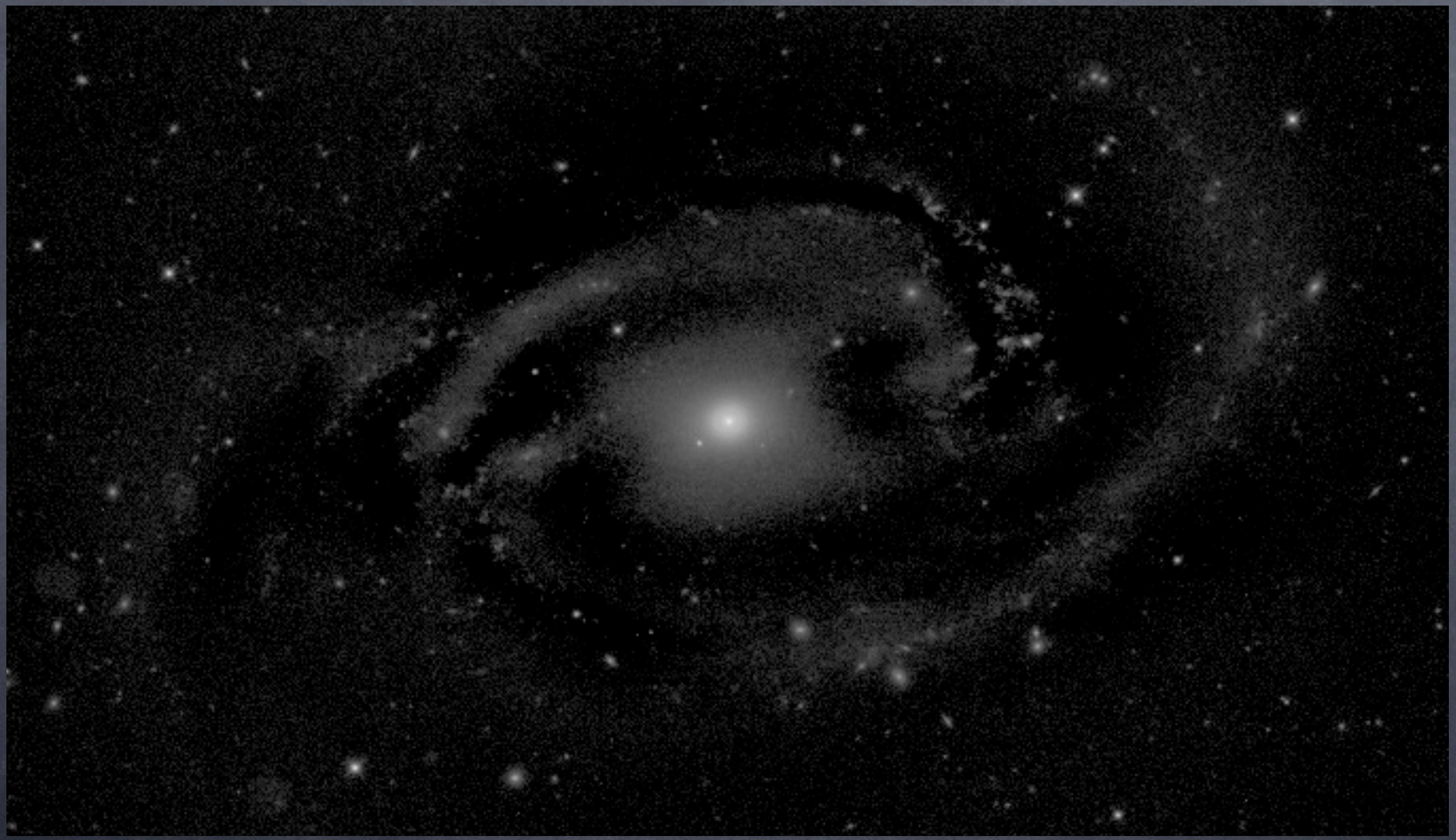
remaining: spiral, bar, bulge, inner disk and nucleus

subtracted: disk and spiral



remaining: bar, bulge, inner disk and nucleus

subtracted: disk, spiral and bar



remaining: bulge, inner disk and nucleus

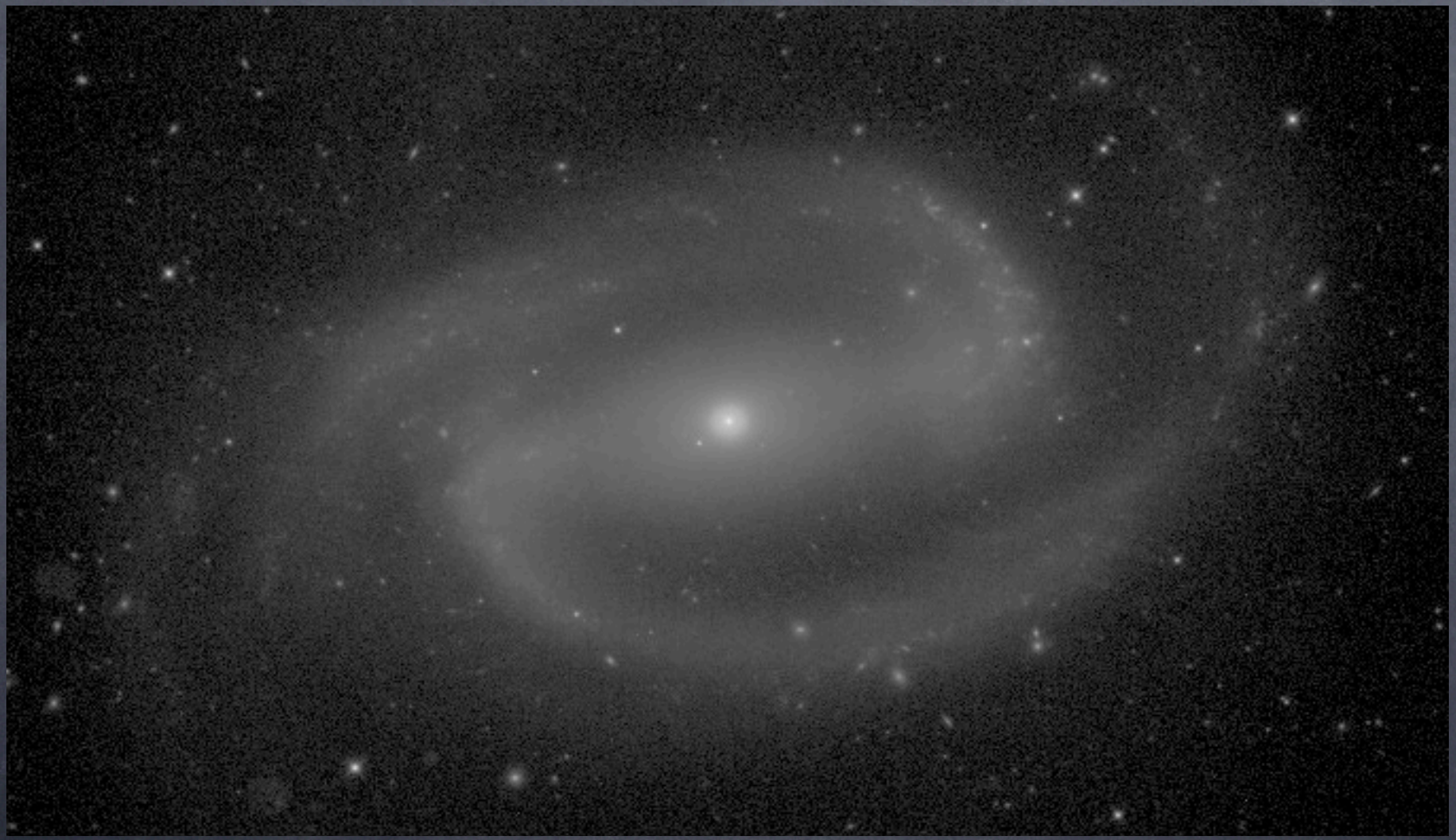
subtracted: disk, spiral, bar and bulge

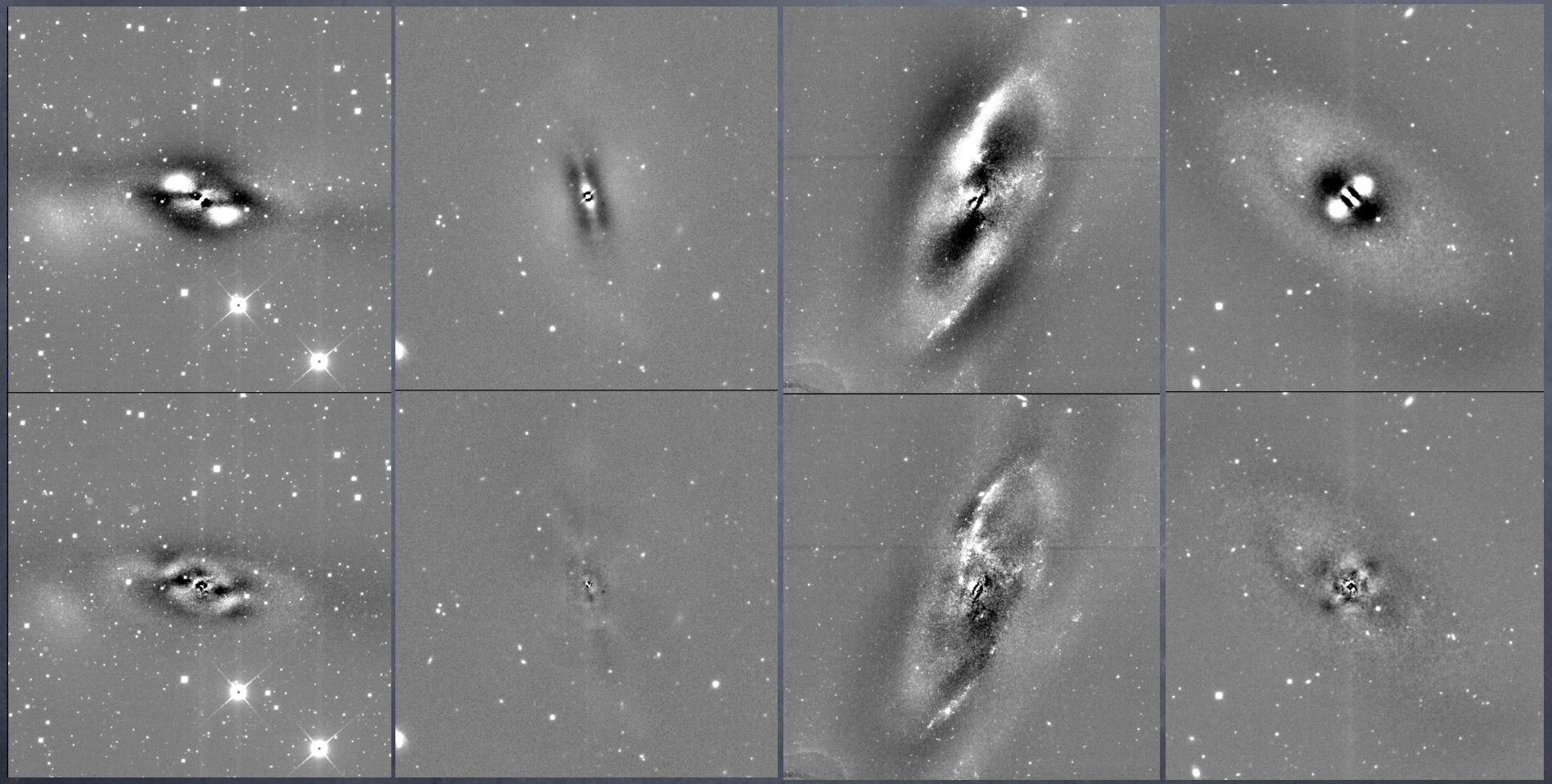
remaining: inner disk and nucleus

subtracted: disk, spiral, bar, bulge and inner disk

remaining: nucleus

... and all components added back in.





"Standard" (Bulge + Disk)

vs

extra component(s) included

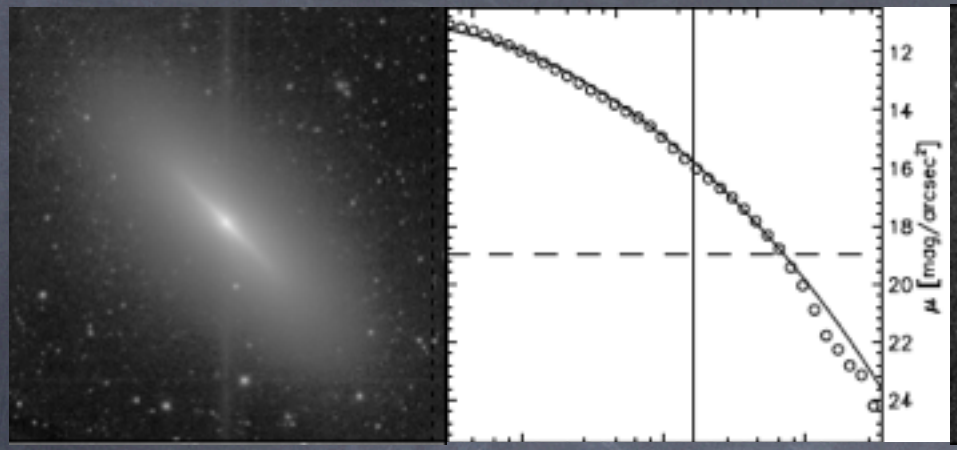
“Envelopes”: necessary but ambiguous

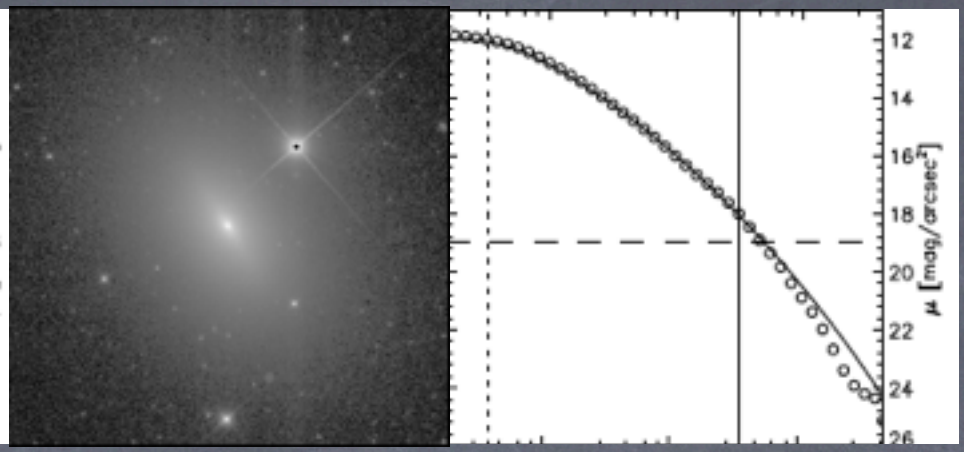
Data

– single Sersic

– (Bulge + Disk)

– (B+D + Envelope)


12
14
16
18
20
22
24
μ [mag/arcsec²]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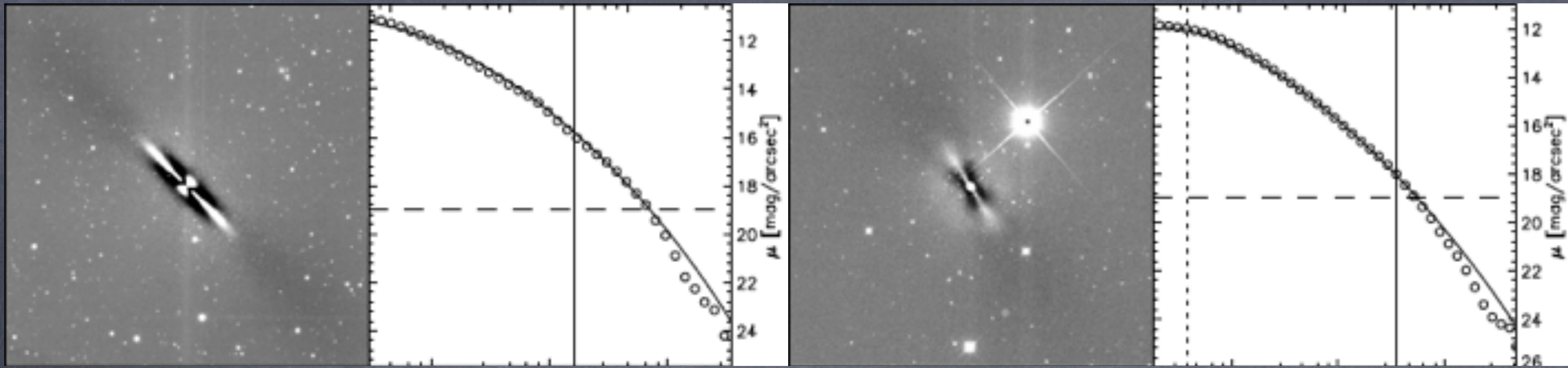
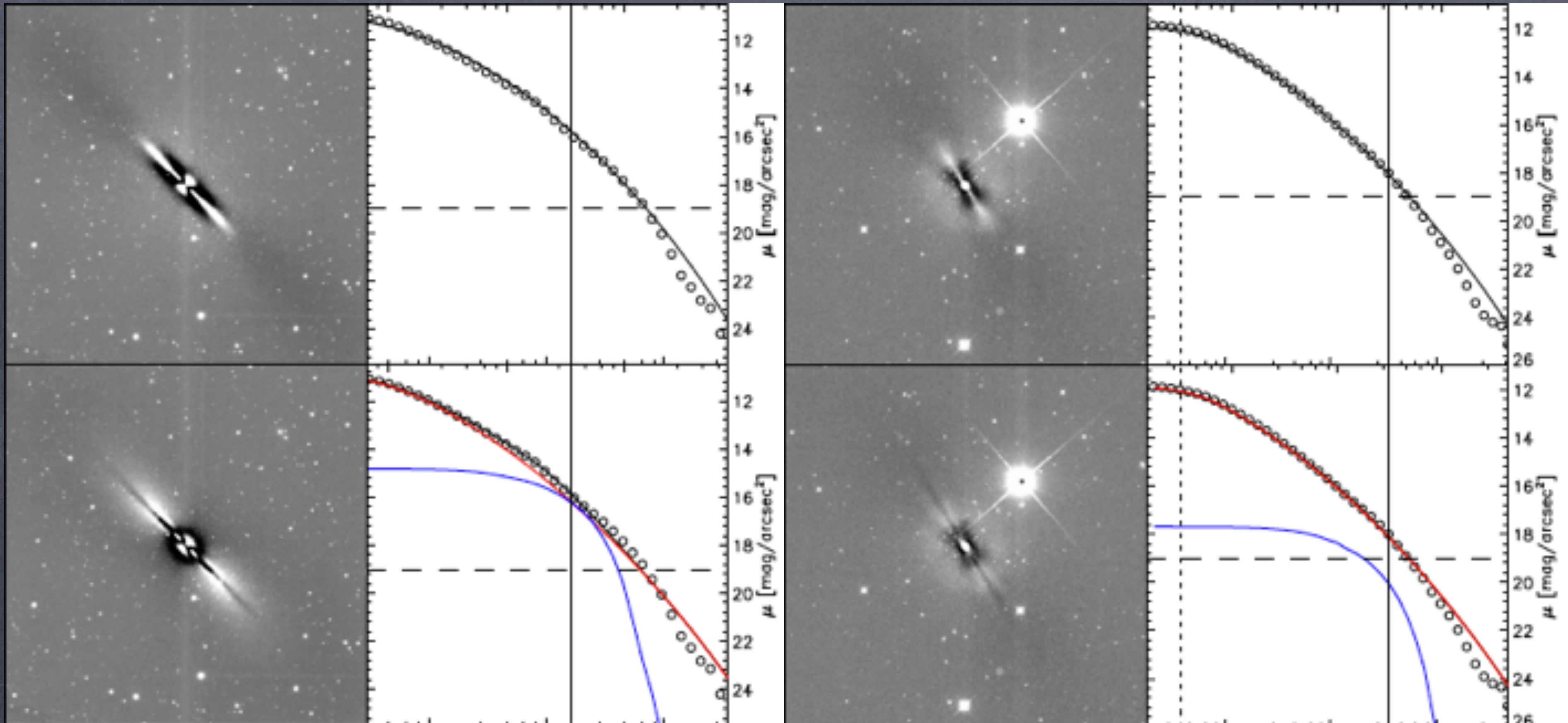

12
14
16
18
20
22
24
μ [mag/arcsec²]
12
14
16
18
20
22
24
26
μ [mag/arcsec²]


μ [mag/arcsec²]
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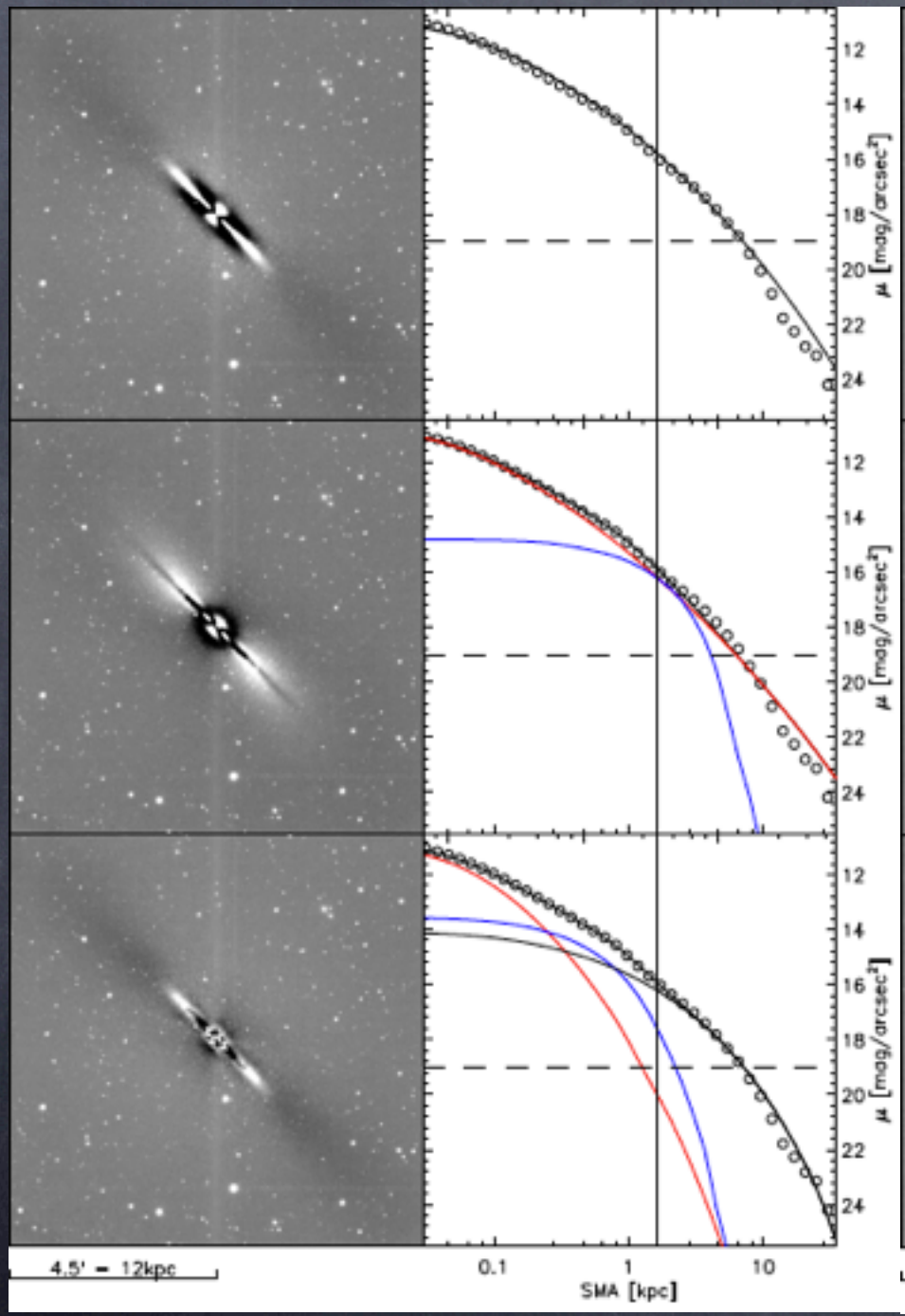
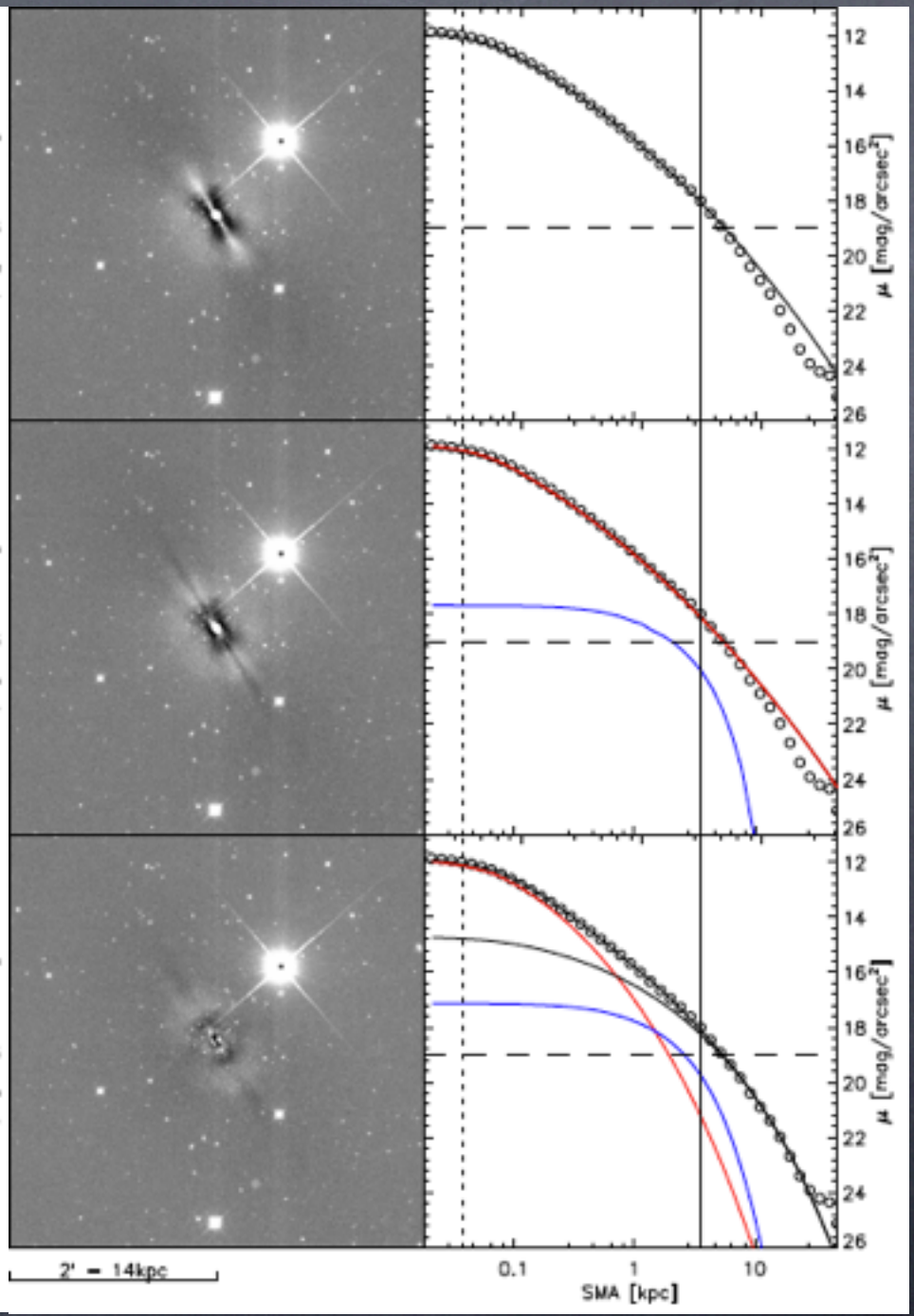
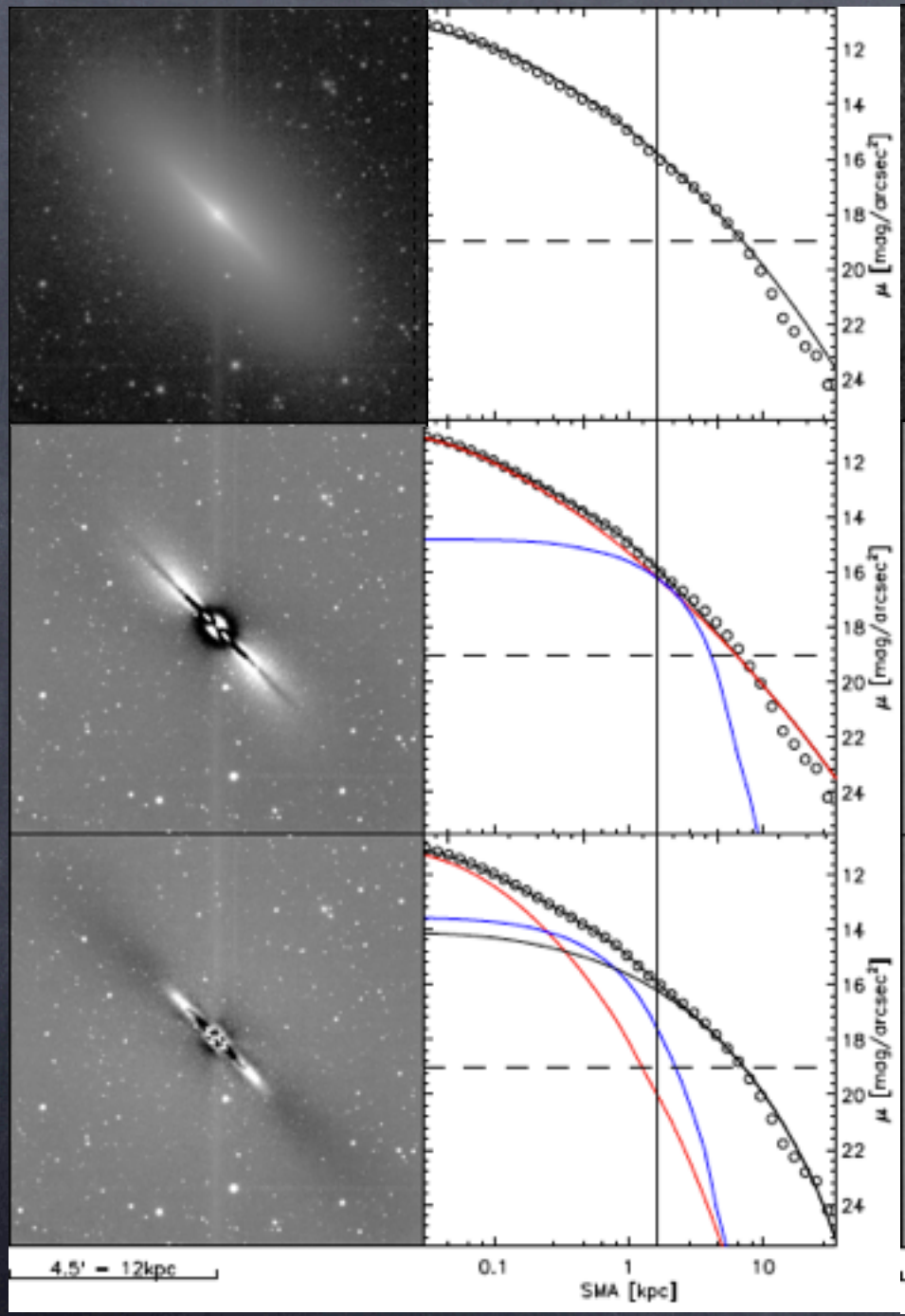

4.5' = 12kpc
0.1
1
10
SMA [kpc]
μ [mag/arcsec²]
12
14
16
18
20
22
24


2' = 14kpc
0.1
1
10
SMA [kpc]
μ [mag/arcsec²]
12
14
16
18
20
22
24
26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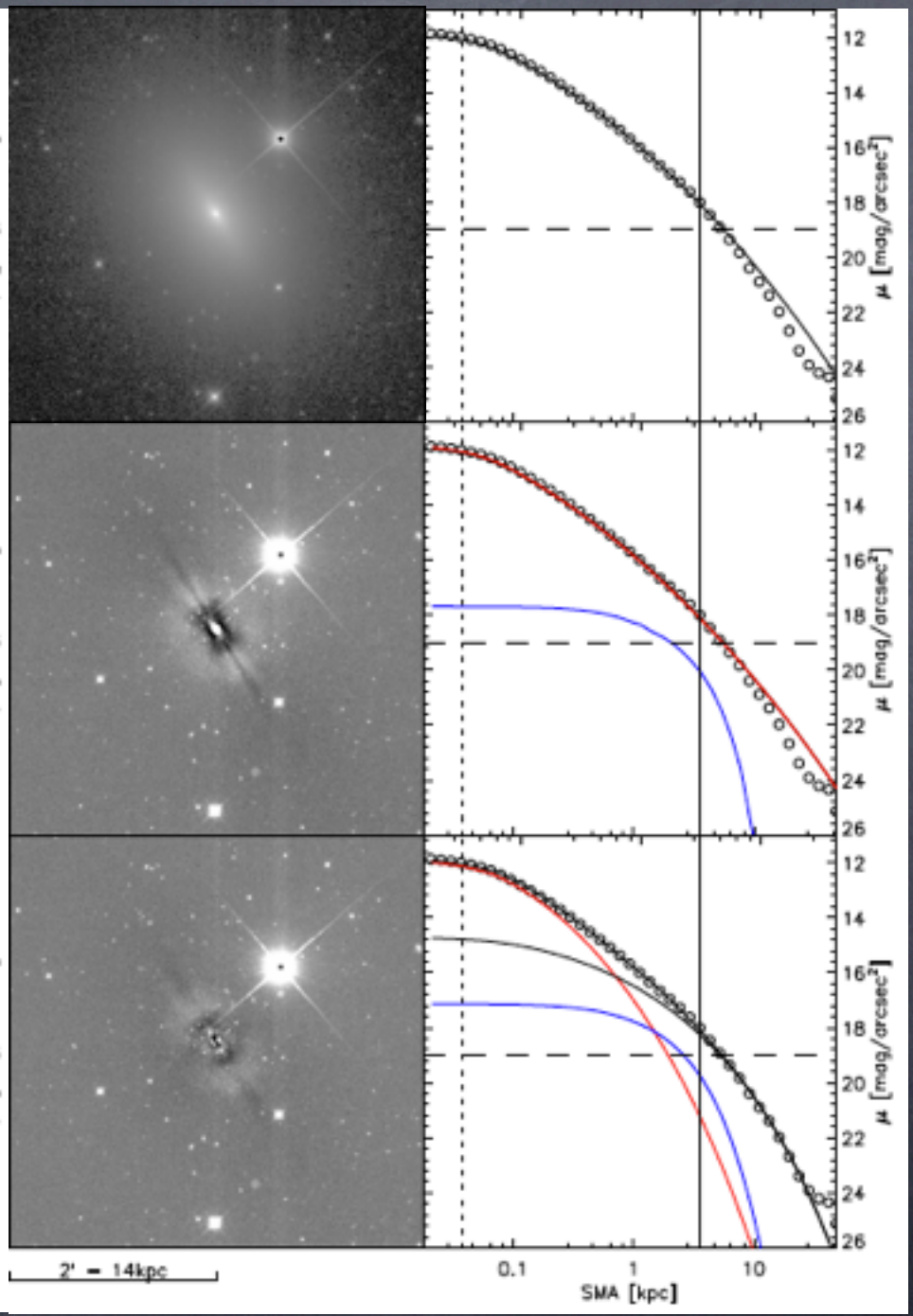
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Decompositions: GALFIT

- first "standard model":
  Sérsic Bulge (+ exponential Disk)

  → $L_{b,std}$ & $L_{t,std}$

- then "improved model":
  - Ellipticals: mask core
  - other: Nucleus, Bar, Inner Disk, Spiral Arms, Envelope

  → $L_{b,min}$, $L_{b,max}$, L_{sph} & $L_{t,imp}$

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  total - disk (- spiral)

  → $L_{b,min}$, $L_{b,max}$, L_{sph} & $L_{t,imp}$ ← total : sum of all components

  only bulge

  "spheroid" : bulge (+ envelope)

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+ nonparametric L_{24}

total - disk (- spiral)

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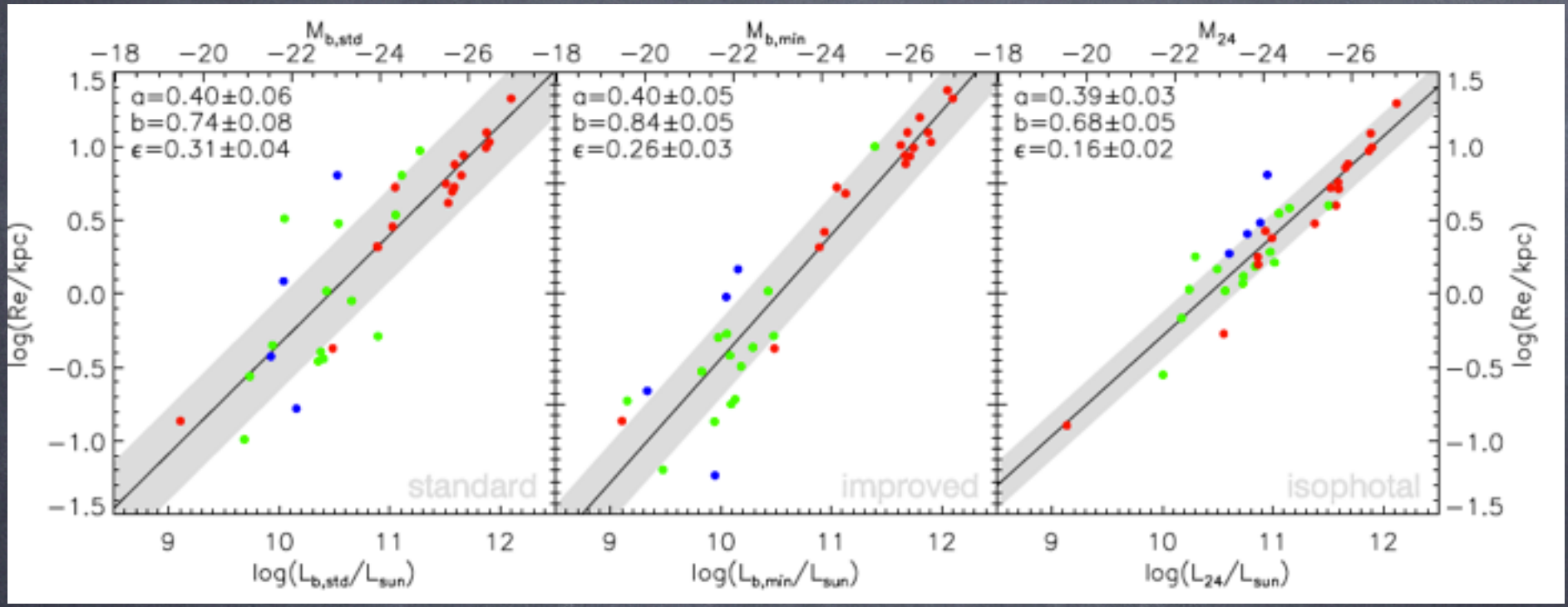
only bulge

"spheroid" : bulge (+ envelope)

Results: improved bulge parameters



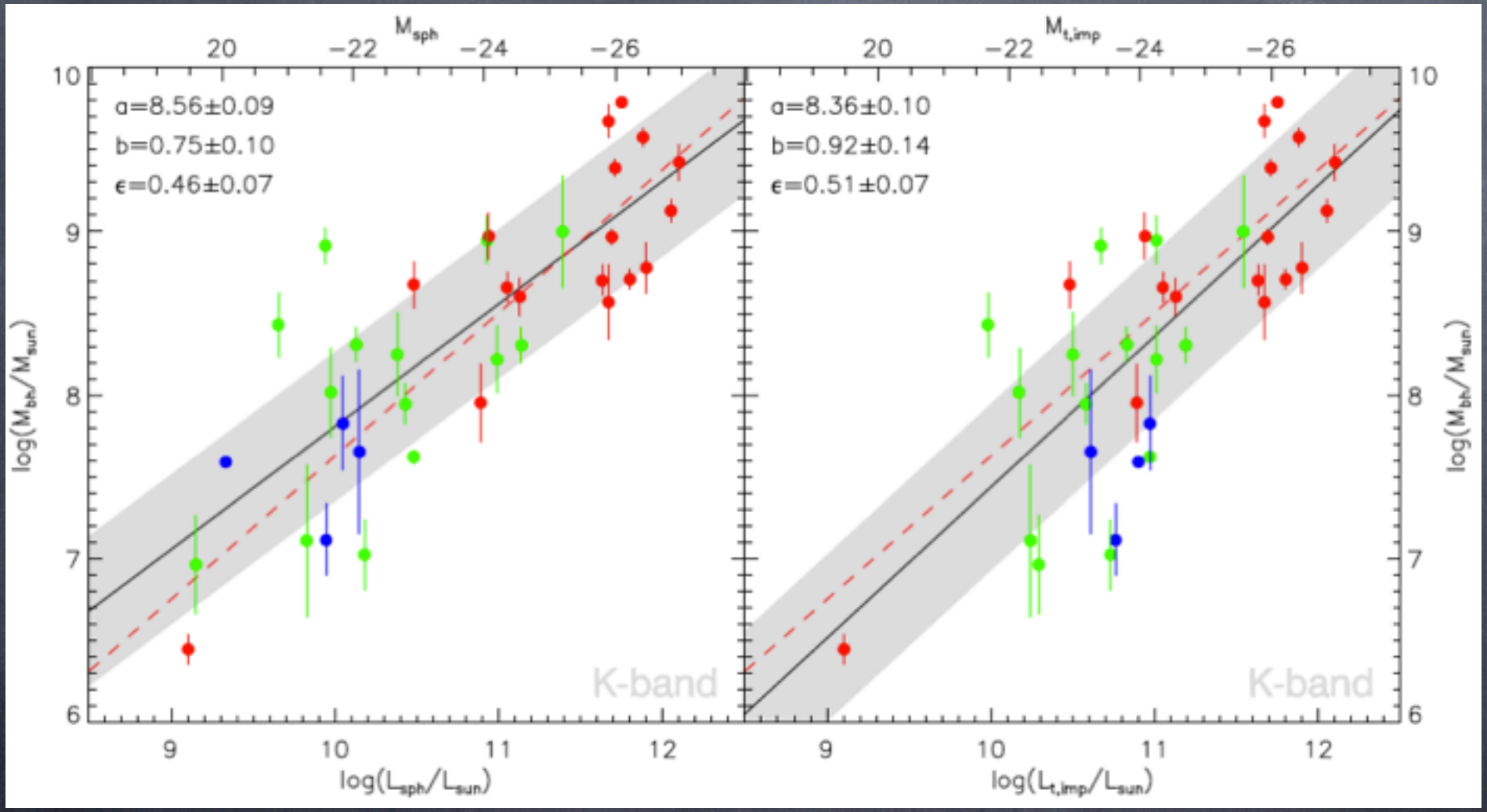
Bulge Size - Lum relation using simple bulge(+disk) model

... and using improved models (detailed decomp.).

However, Size - Lum of the total light distribution is even tighter.

Resulting Scaling Relations

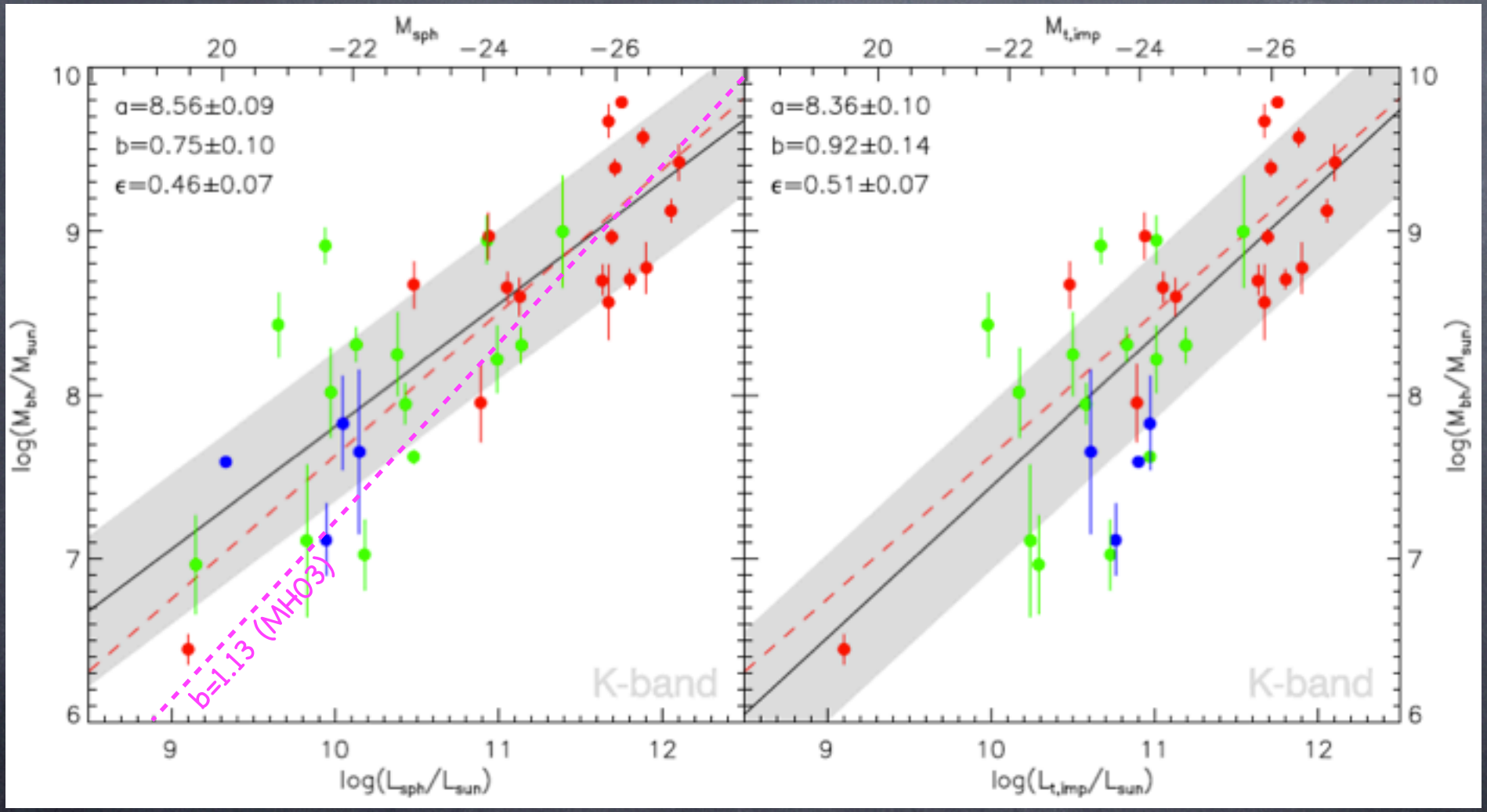
Results: BH Scaling Relations



x-axis: spheroid Luminosity

x-axis: total Luminosity

Results: BH Scaling Relations



x-axis: spheroid Luminosity

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Results

1. The log-slope of the $M_\bullet$-$M_{bul}(L_{bul})$ relation is significantly smaller than unity (0.7±0.1)
2. and it depends on modeling detail.

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2. and it depends on modeling detail.

3. The $M_\bullet$-L_{tot} relation is robustly characterized
4. and its intrinsic scatter is consistent with $M_\bullet$-L_{bul} .

Discussion

1. Correlation does NOT improve when bulge parameters are more reliably determined !
   → $M_\bullet$ - L_{bul} not "fundamental"

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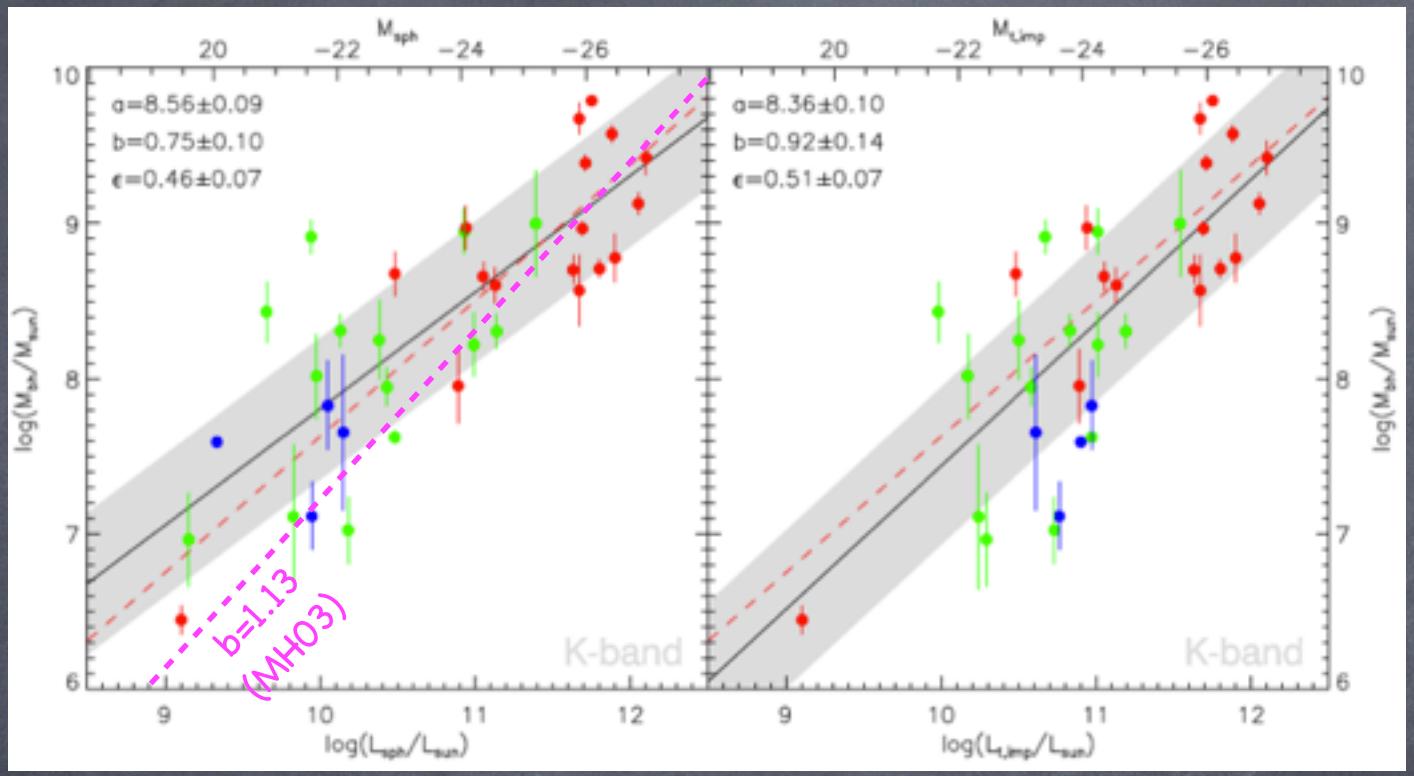
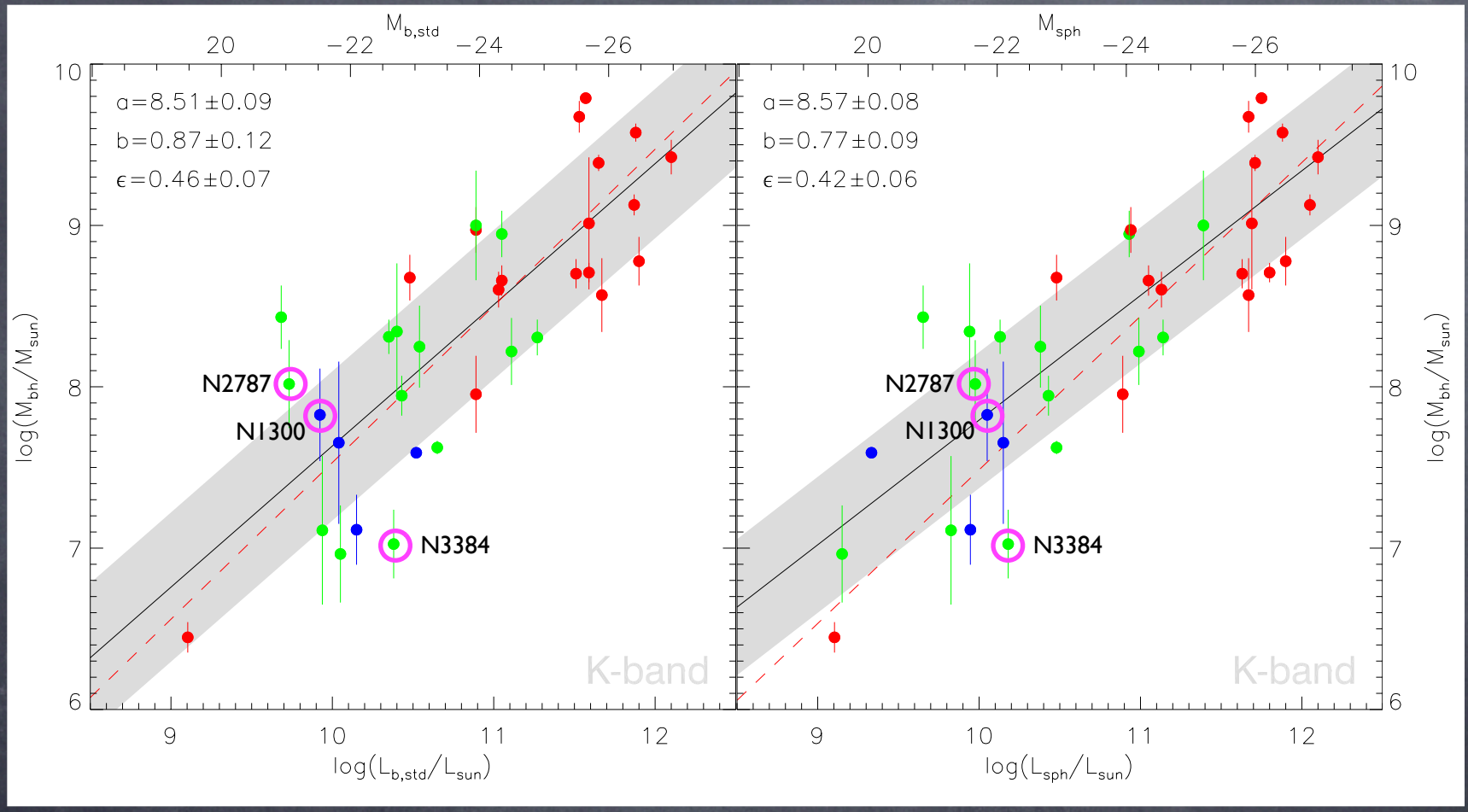
   → $M_\bullet$ - L_{bul} not "fundamental"
2. $M_\bullet$ - L_{tot} ought to be considered, theoretically and as $M_\bullet$ indicator
3. Log-slope << 1 for $M_\bullet$ - M_{bul}
   → consequences for models (AGN feedback, gas accretion mode, mergers)

Discussion



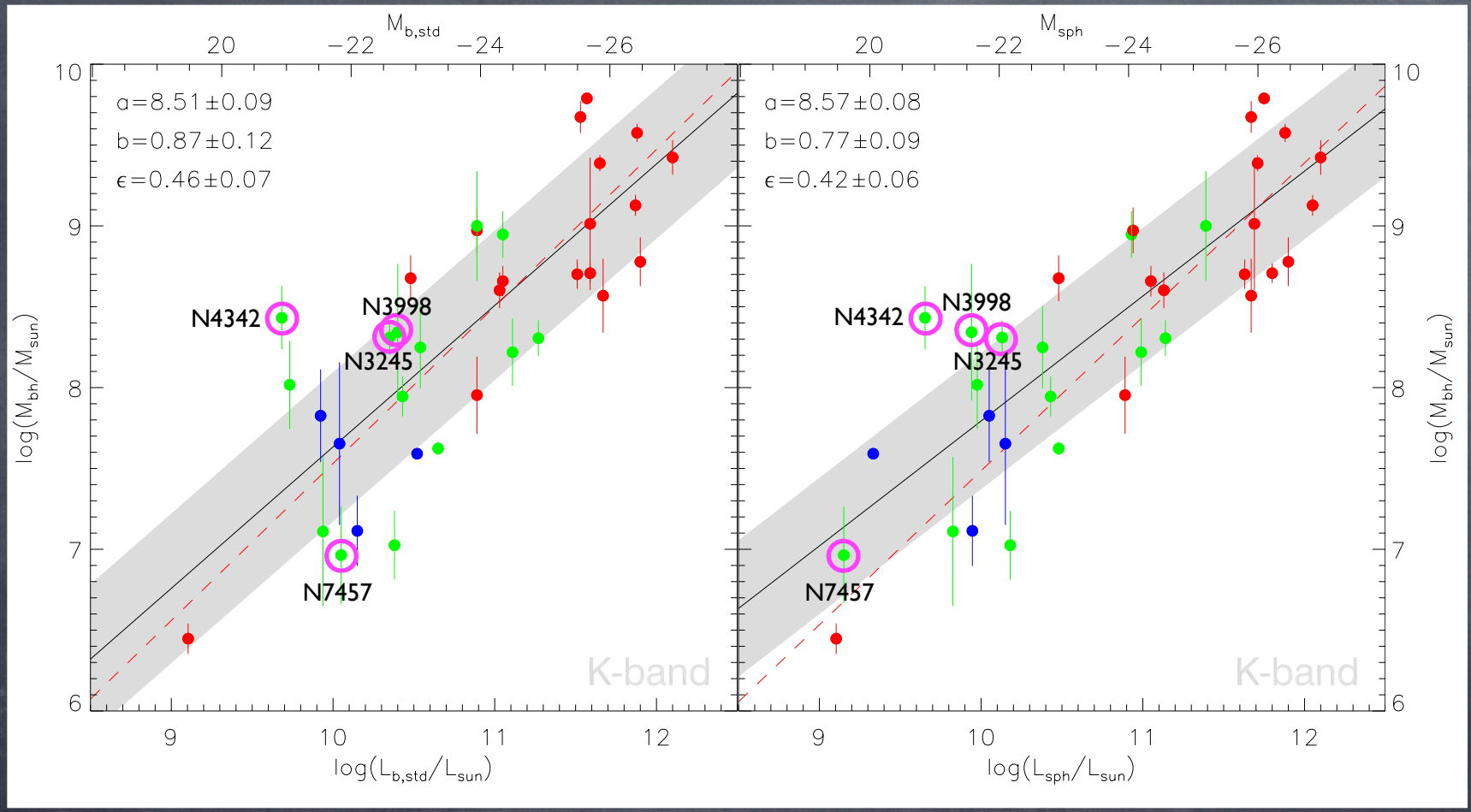
3. Log-slope << 1 for M• - M_{bul}
   → consequences for models (AGN feedback, gas accretion mode, mergers)

Pseudobulges ?



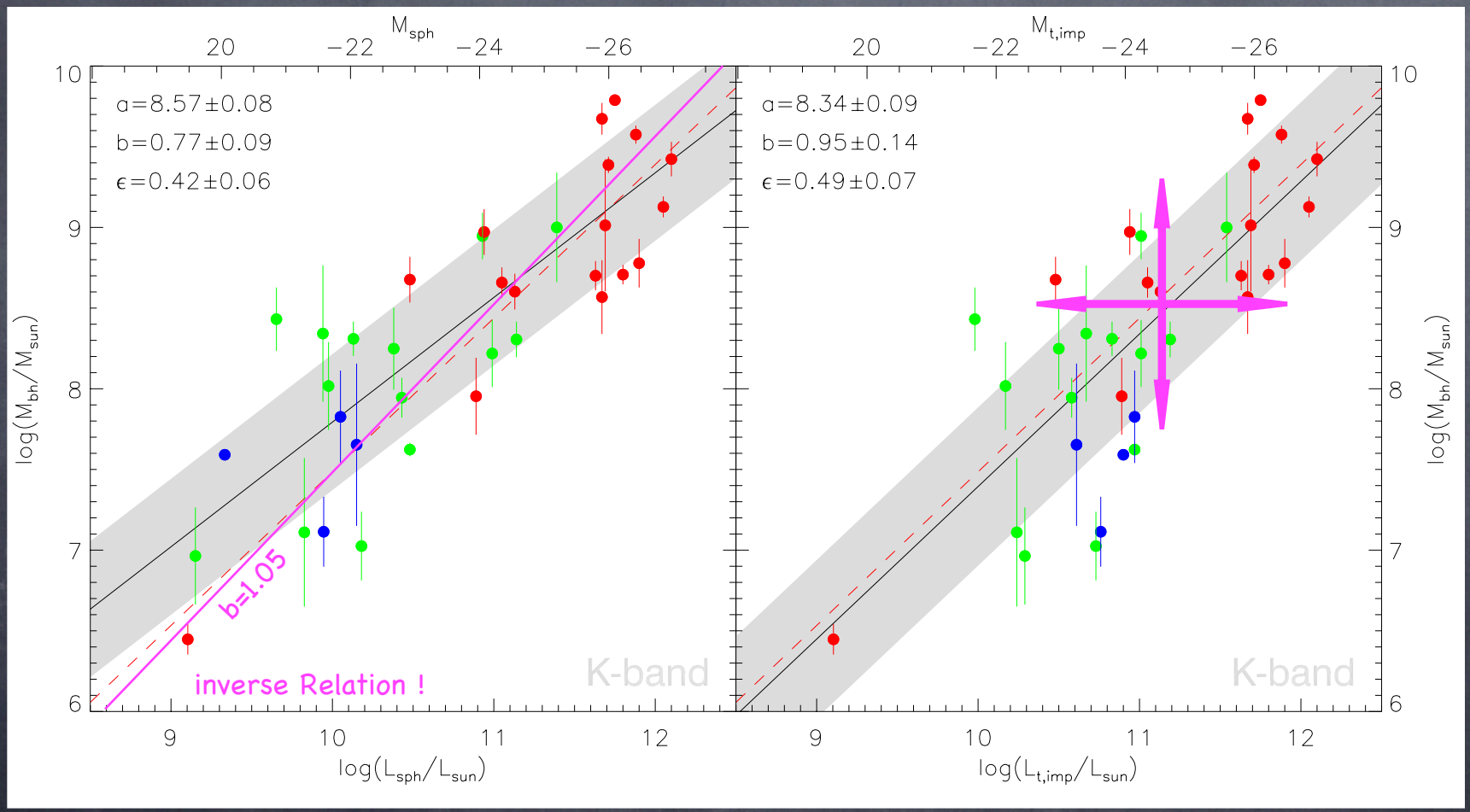
NGC 1300: n = 1.3 → 4.3
NGC 2787: n = 1.5 → 2.8
NGC 3384: n = 2.0 → 2.5

Pseudobulges ?



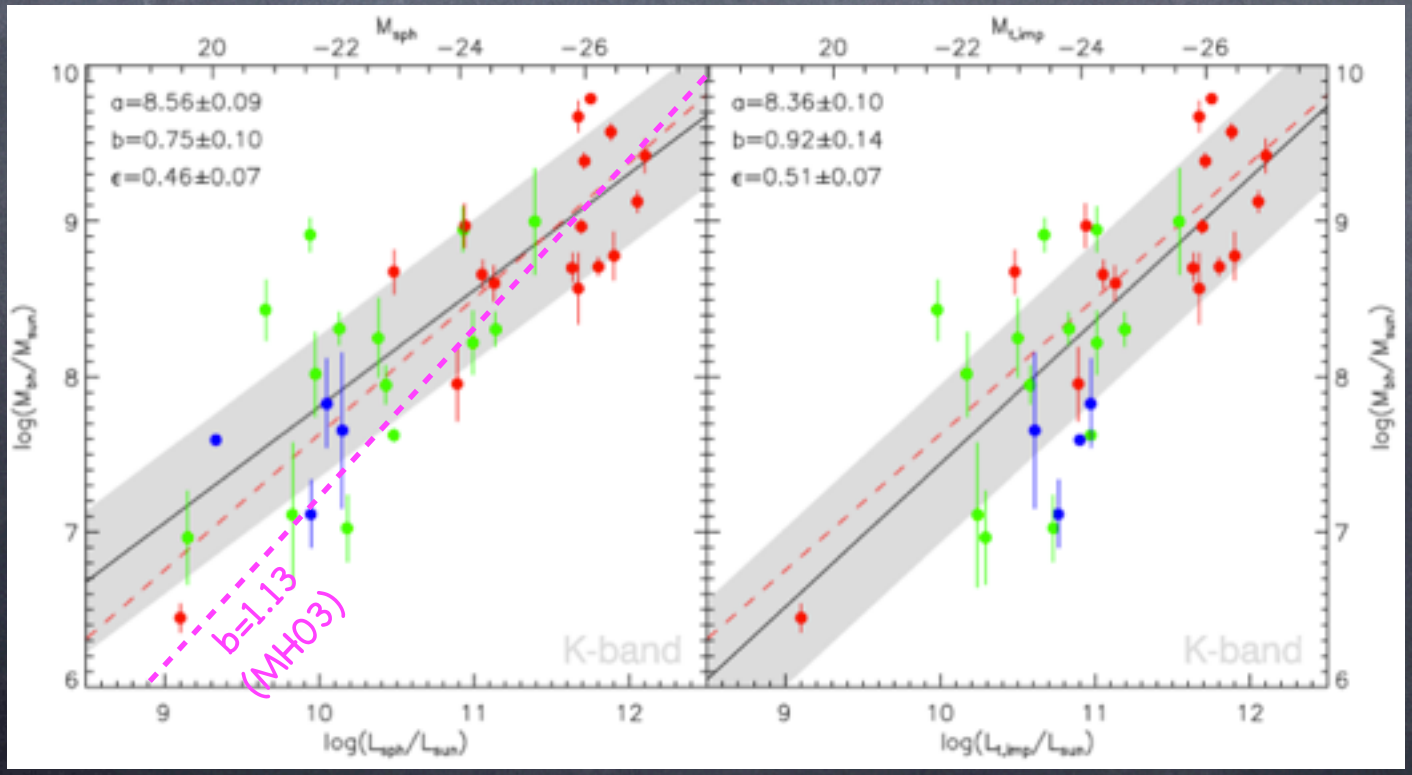
NGC 3245: n = 2.3 → 1.6
NGC 3998: n = 2.6 → 1.4
NGC 4342: n = 5.3 → 1.9
NGC 7457: n = 7.7 → 1.6

Fitting and Scatter Treatment



Summary M• - Mbul

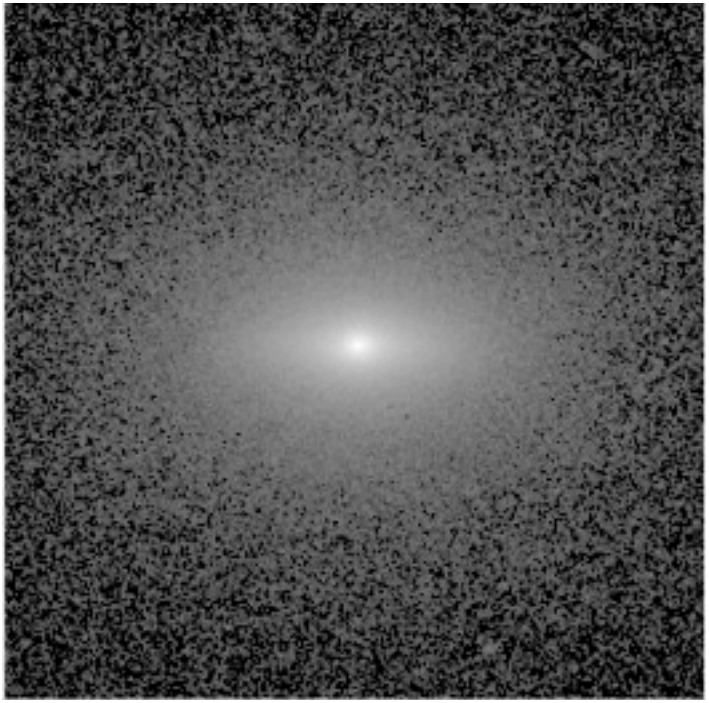
1. shallow M• - M_{bul} (log-slope << 1)
2. bulge properties difficult to determine
3. use NIR M• - L_{tot} instead of M• - L_{bul}



II.
$M_\bullet$ and the IMF
from dynamics and population fitting

A nearby compact L*-galaxy: "b19" (Bernardi+08, Hyde+08)

b19



15 kpc

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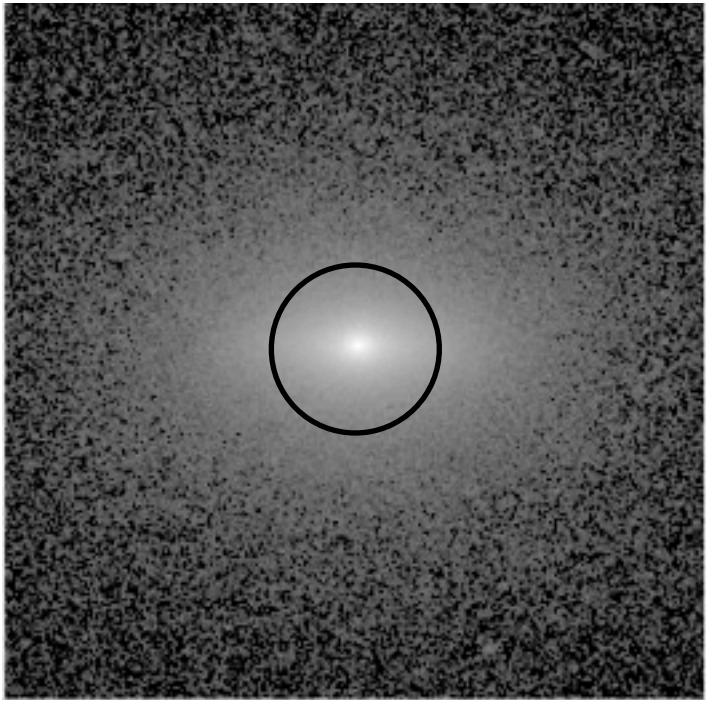

15 kpc

R_e=1.9kpc

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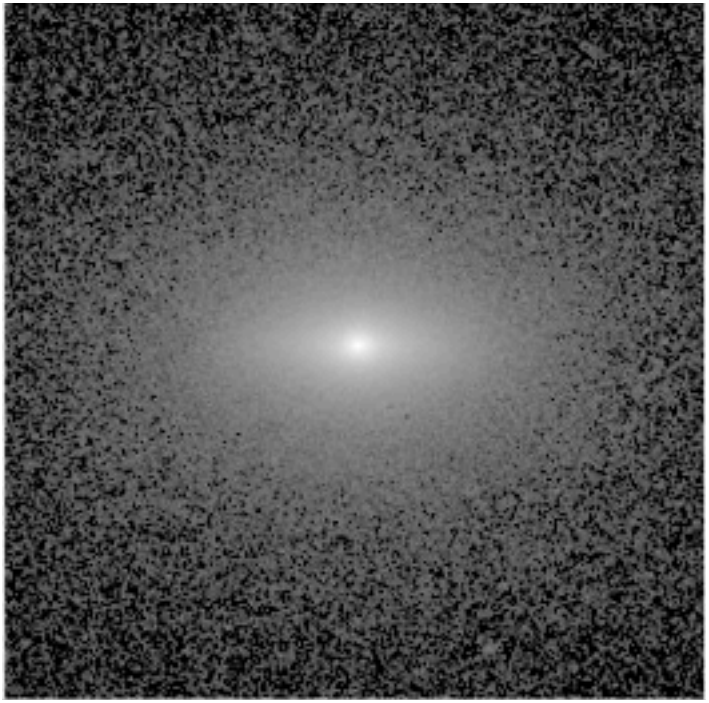
b19



15 kpc

M60

40 kpc

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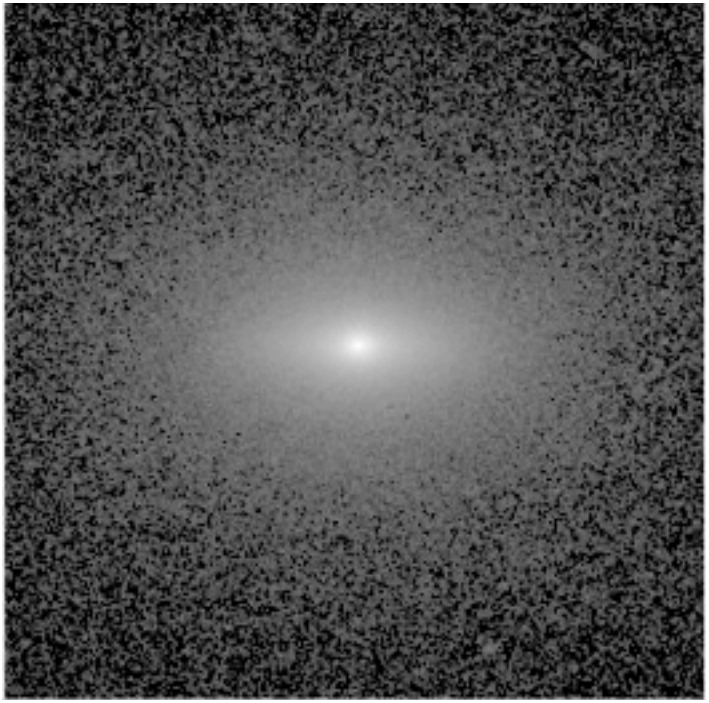
b19



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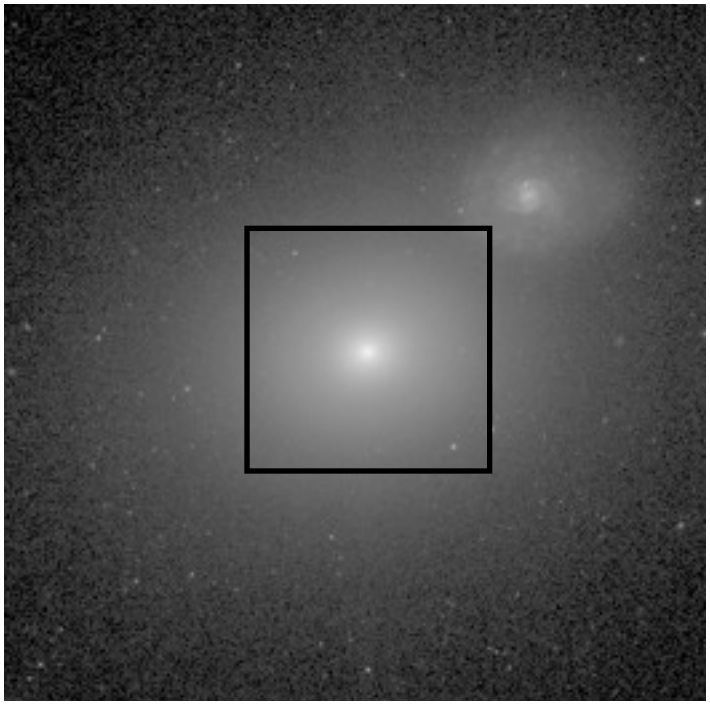

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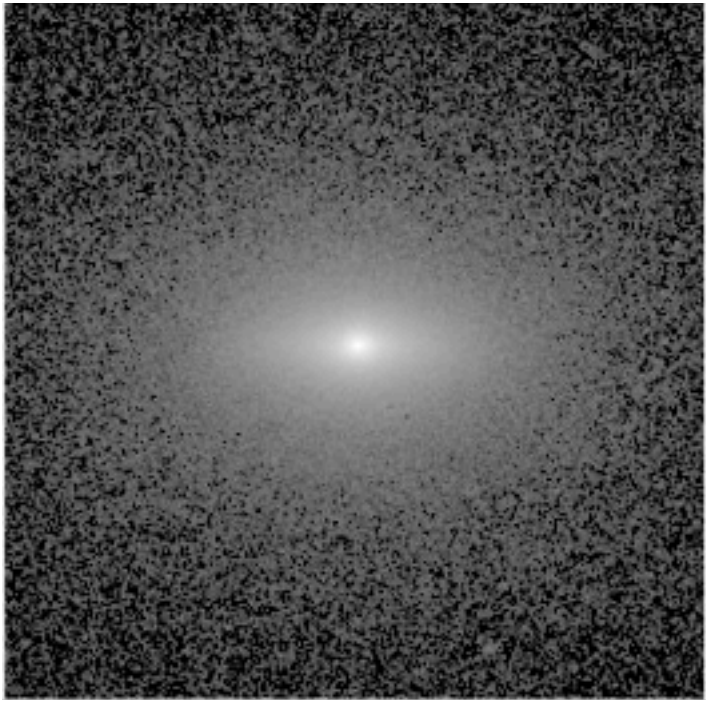

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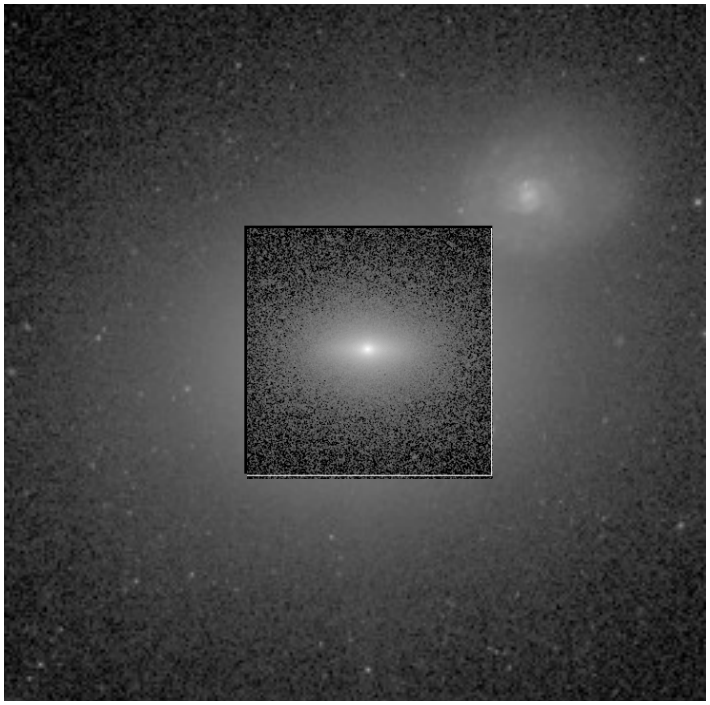

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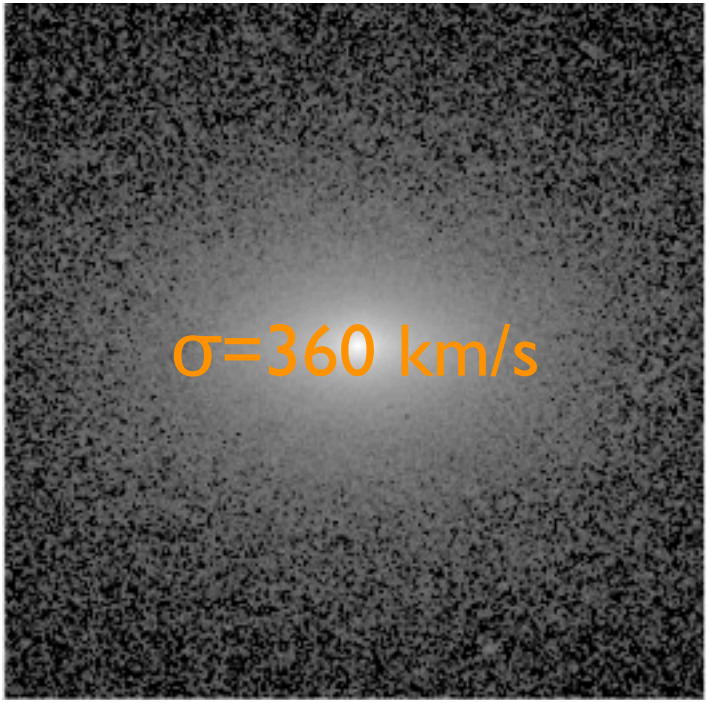

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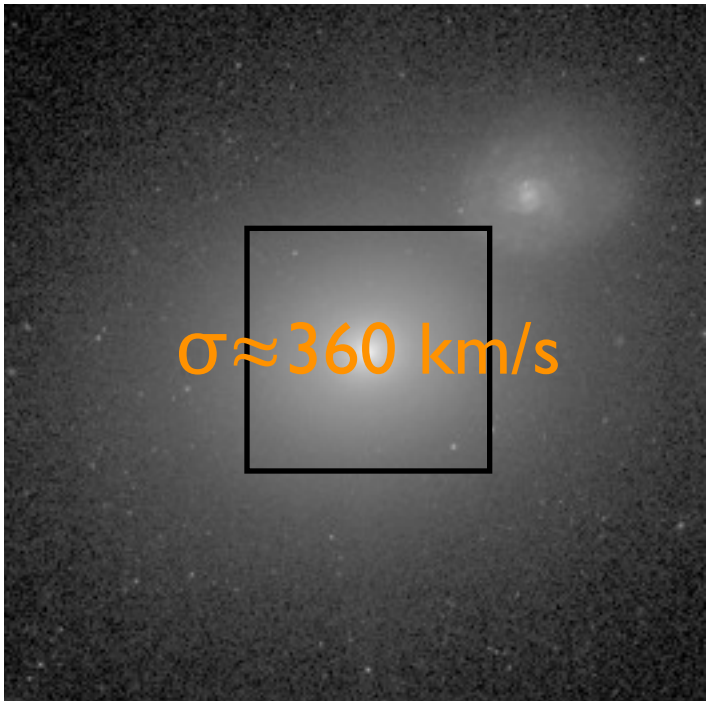

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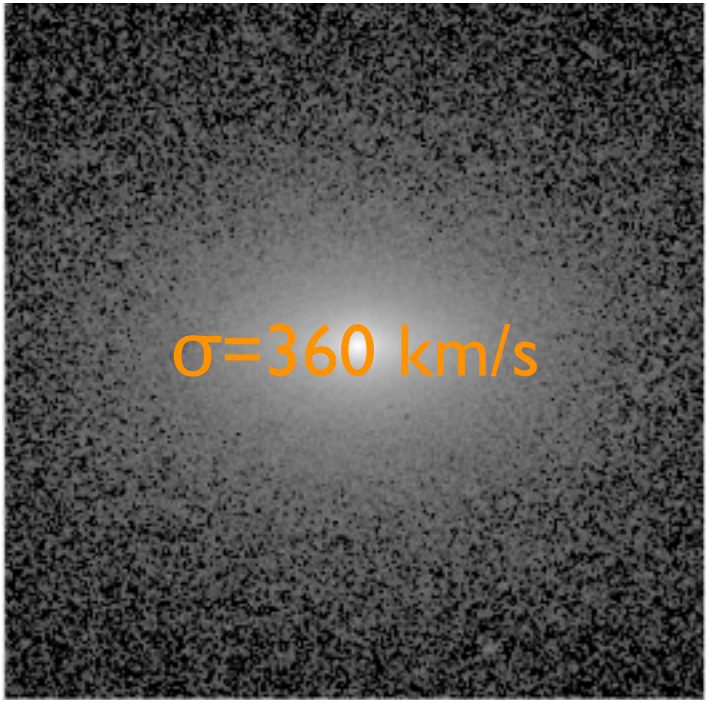

- flattened (q=0.6)
- embedded disk
- R_e = 1.9 kpc
- $L_i = 4.7 \times 10^{10}\ L_\odot$

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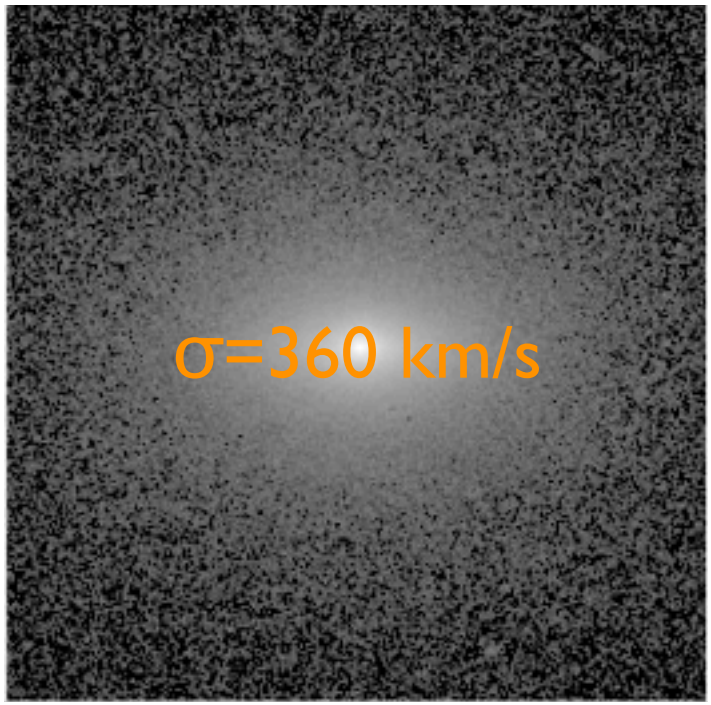
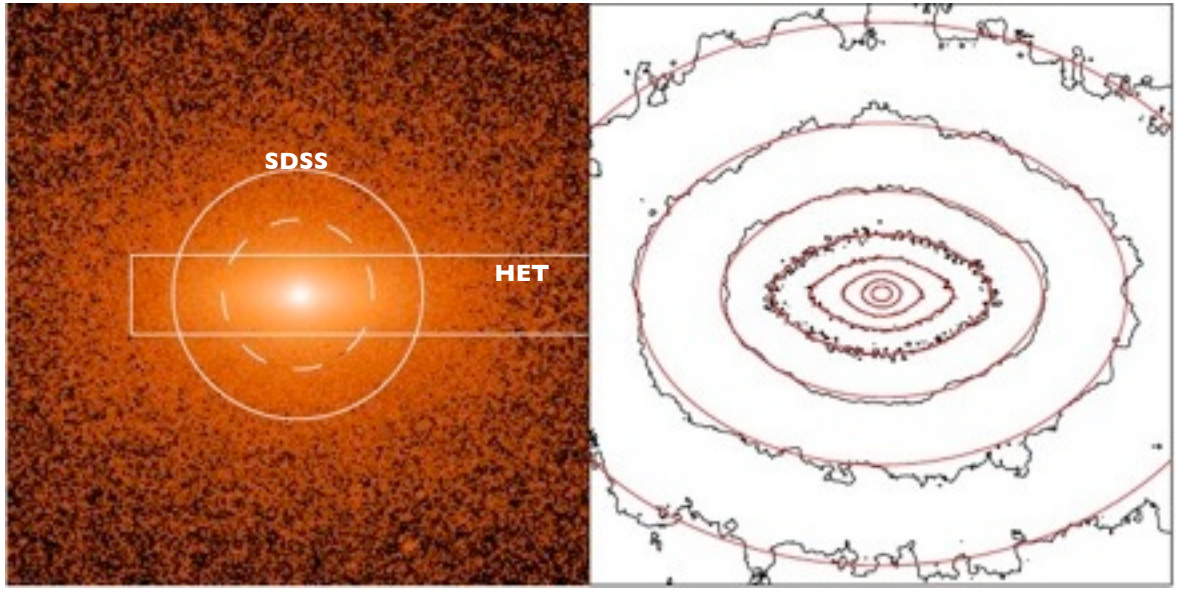


- flattened (q=0.6)
- embedded disk
- R_e = 1.9 kpc
- $L_i = 4.7 \times 10^{10}\ L_\odot$

- steep profile?
- stellar M/L ?
- Übermassive Black Hole? (cf. NGC1277, vdBosch+12)
- Dark Matter?

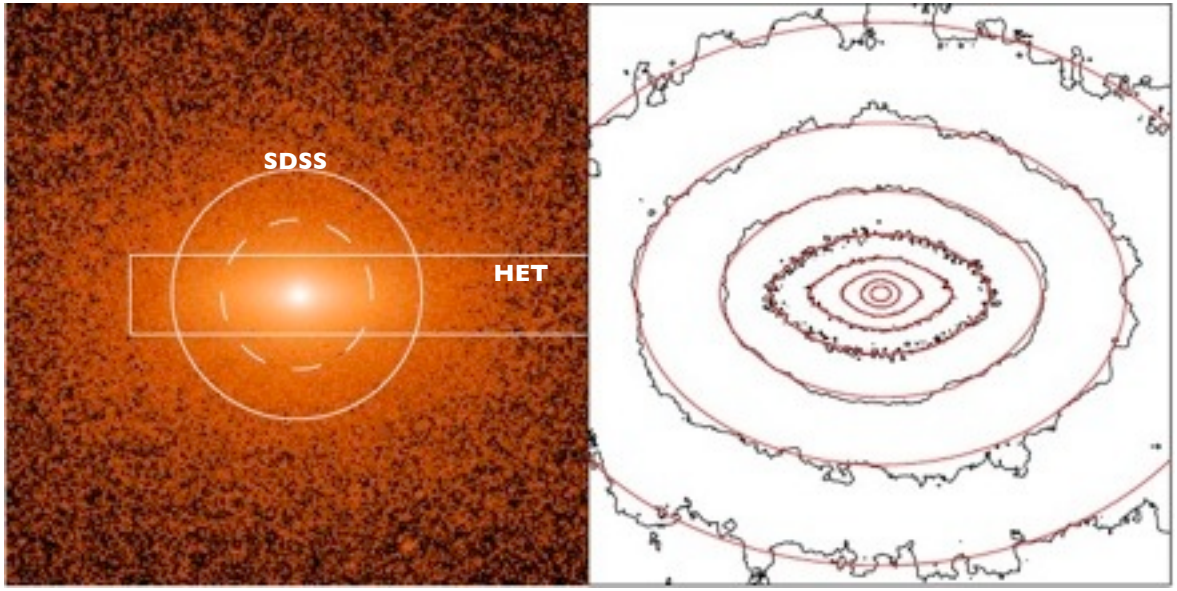
Dynamical Models: Schwarzschild Method



15 kpc MGE

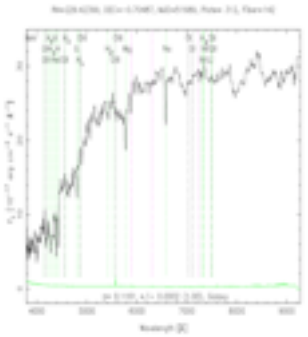
- high-res imaging: HST/ACS

Dynamical Models: Schwarzschild Method



15 kpc MGE

- high-res imaging: HST/ACS
- spectrum: SDSS + HET/LRS



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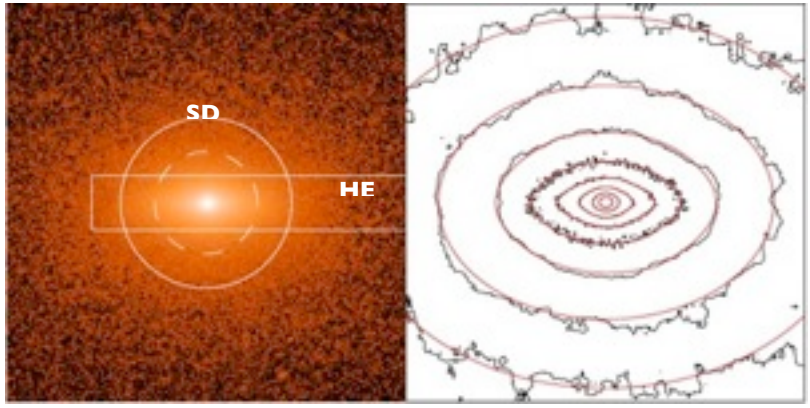

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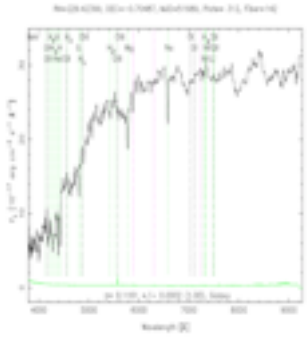

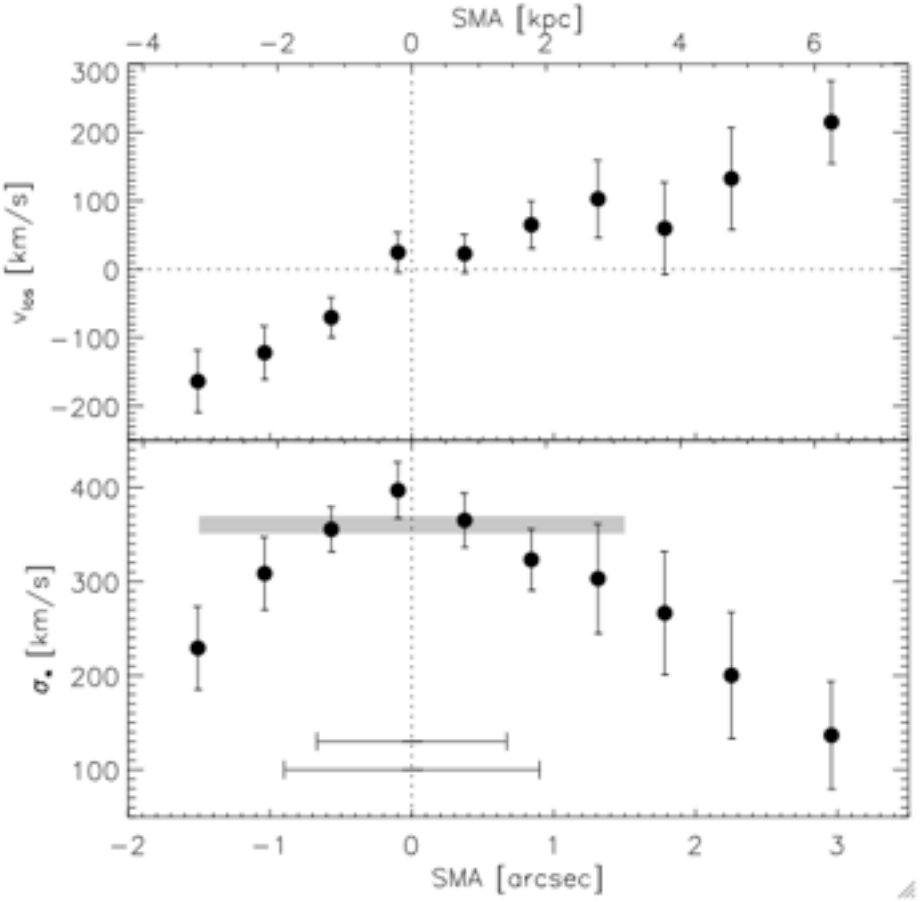

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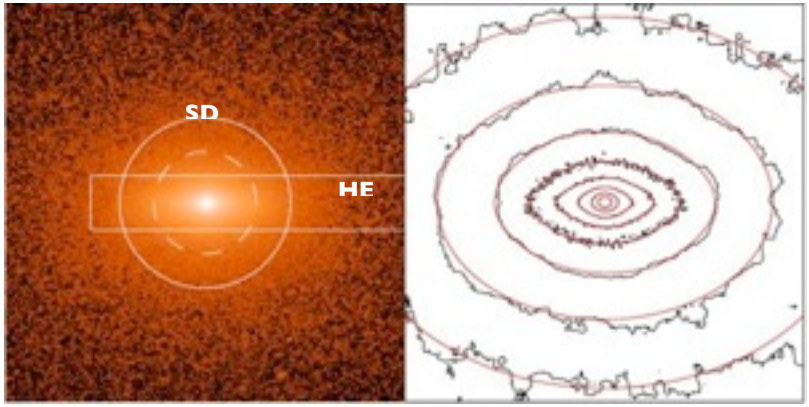

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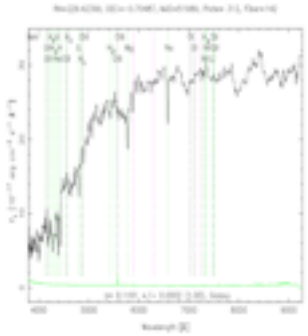

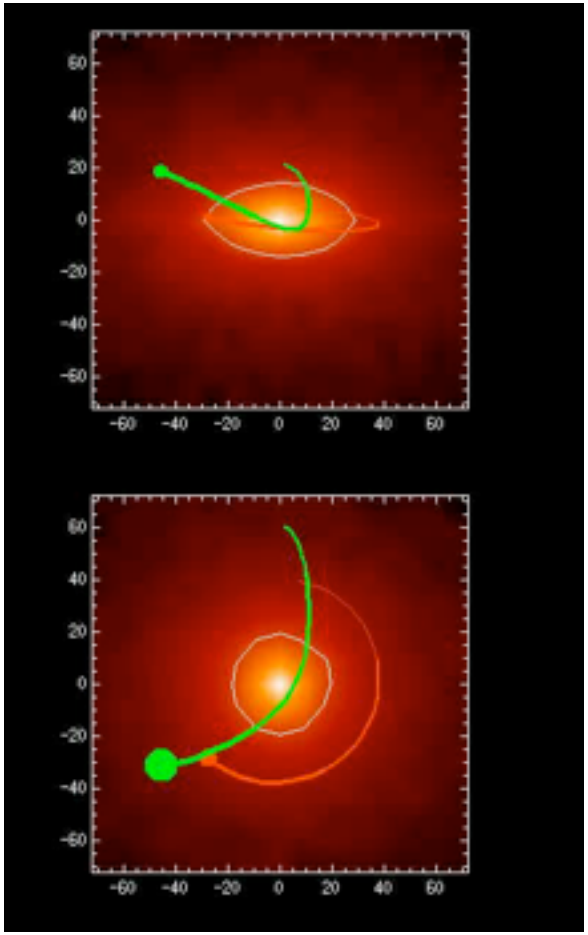

orbit superposition

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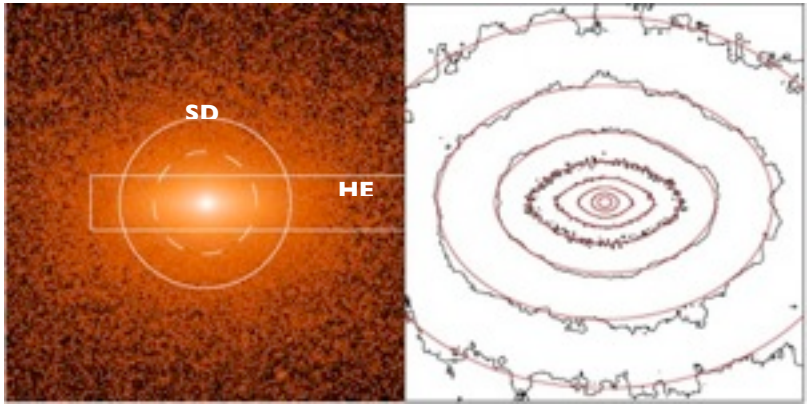

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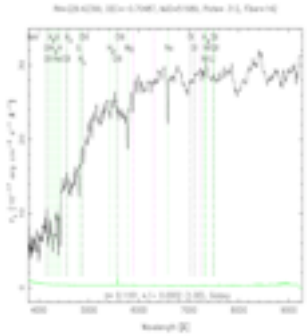
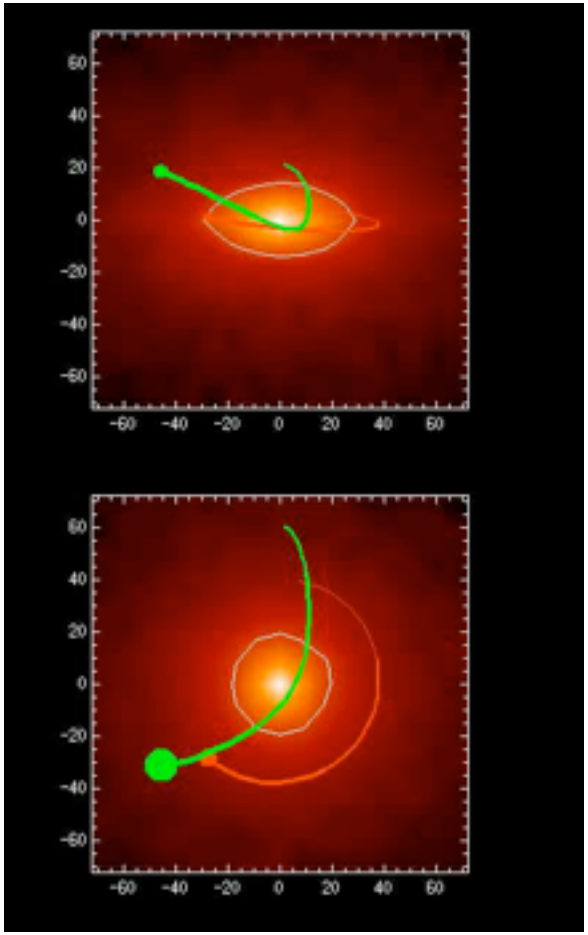


- components:
  Stars (Υ=M/L) + BH(M●) + DM (NFW)



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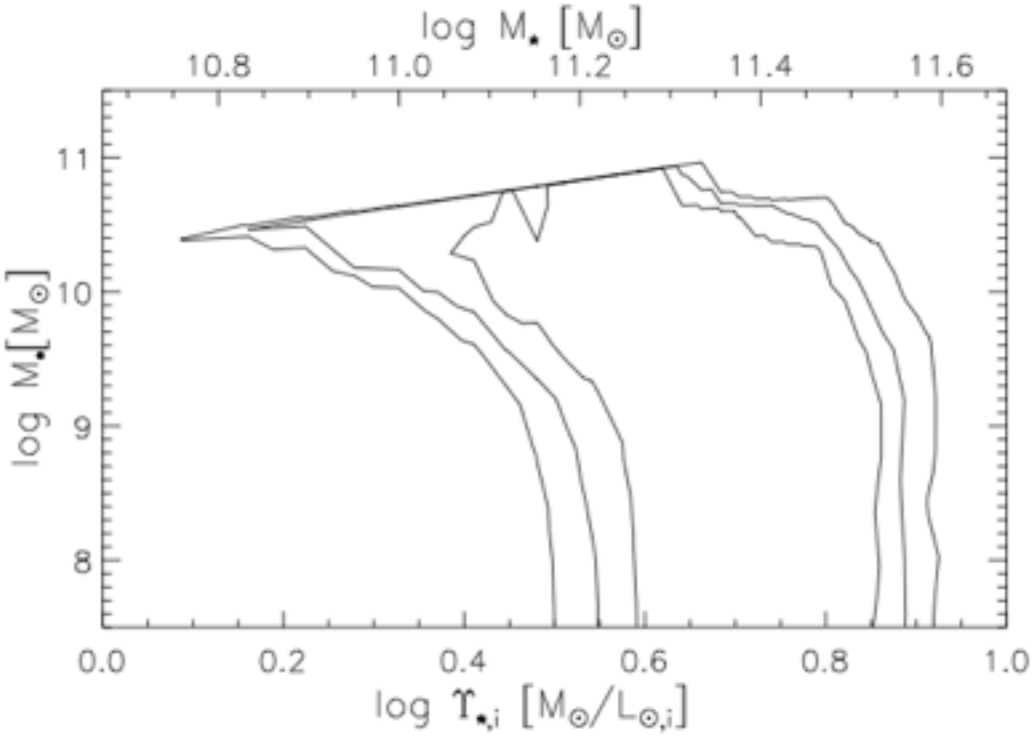

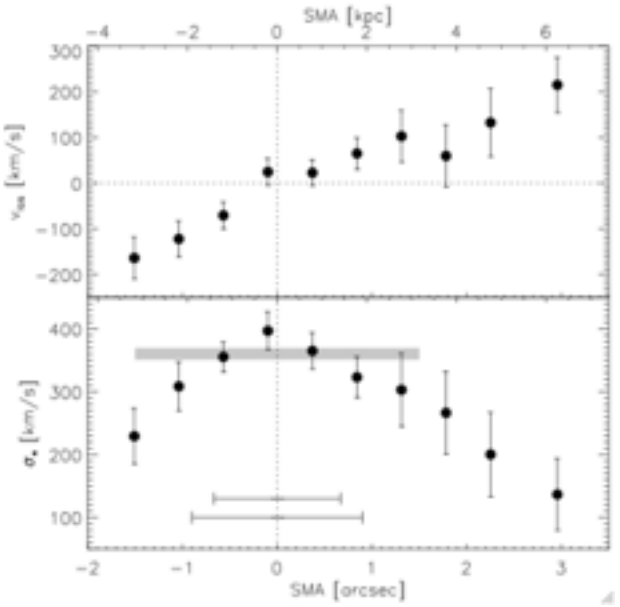

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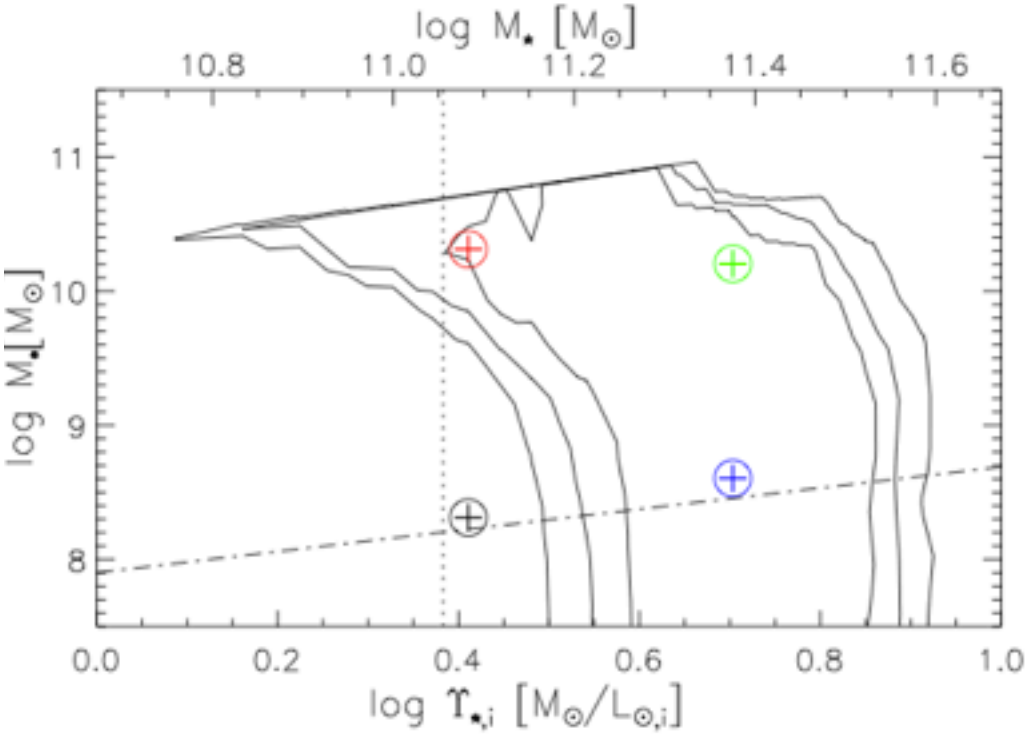
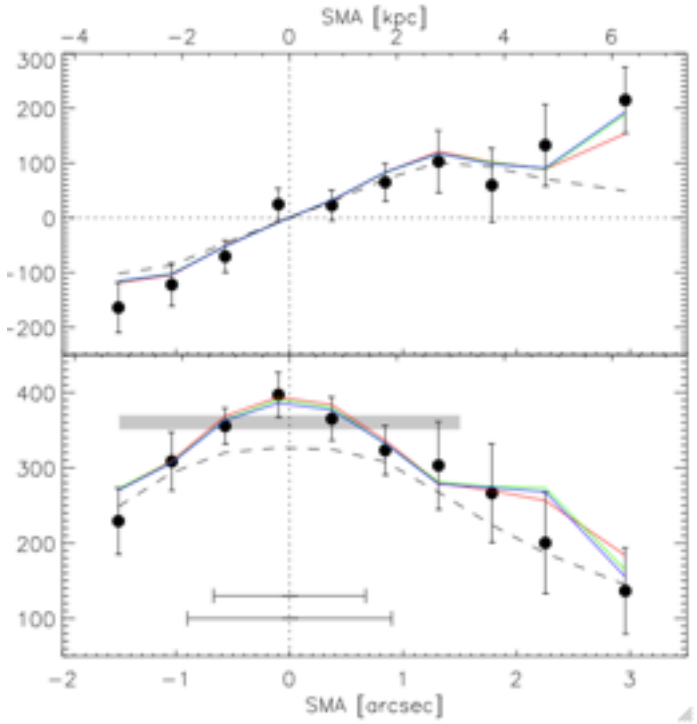
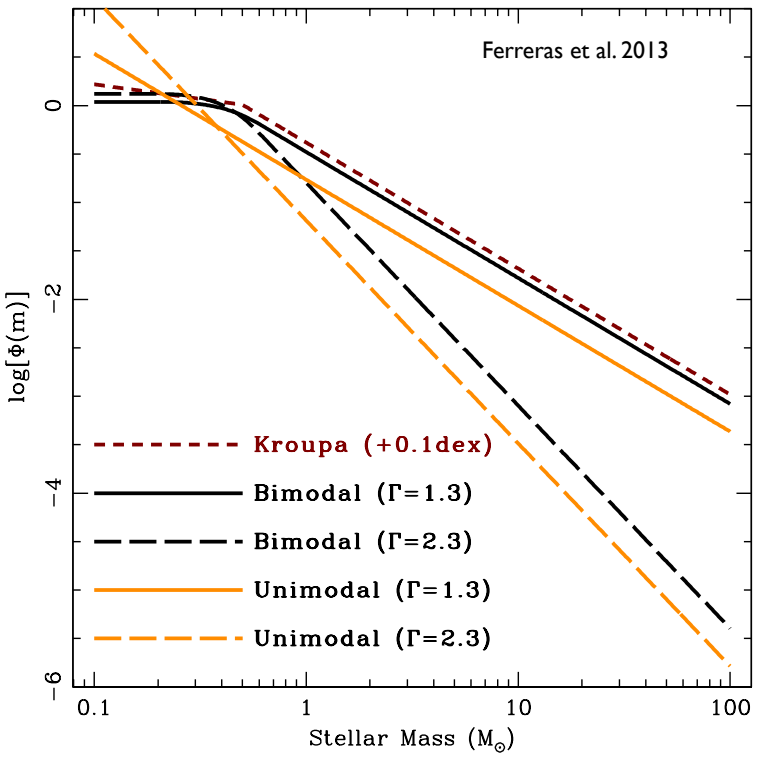




Stelar Population Analysis: Hybrid method



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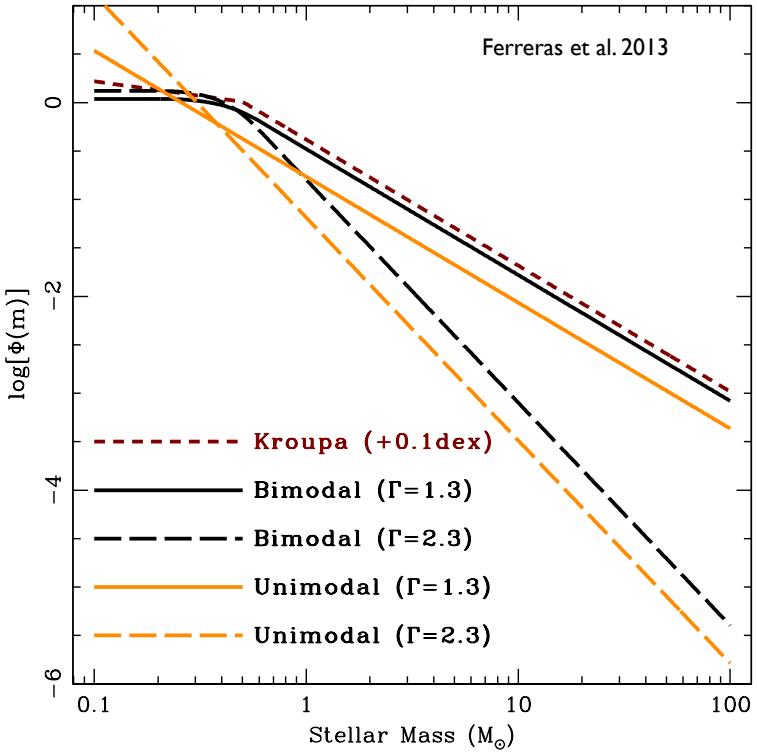

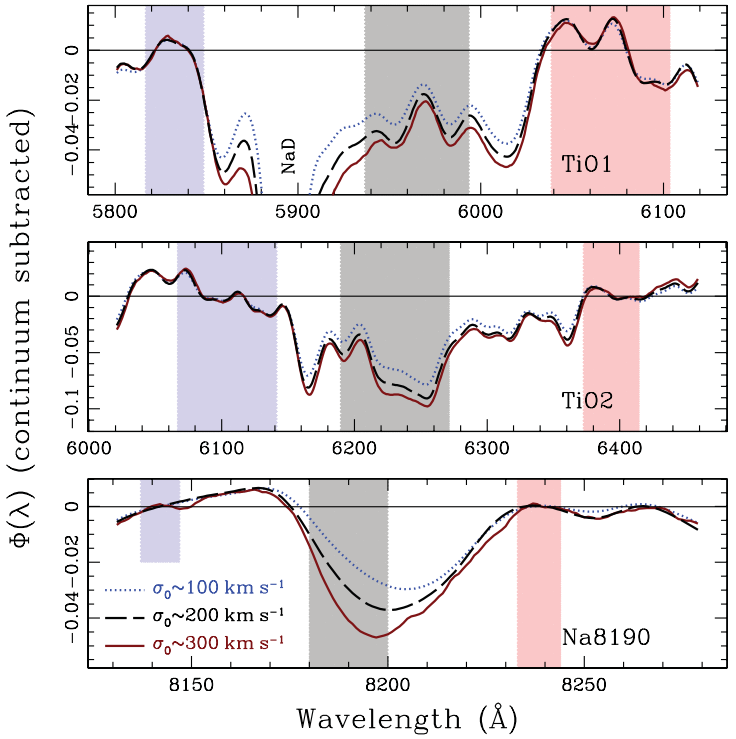

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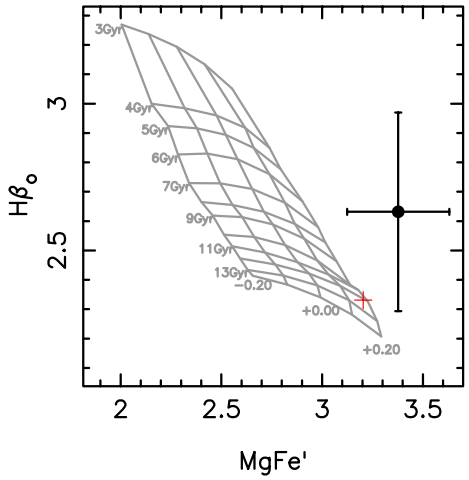

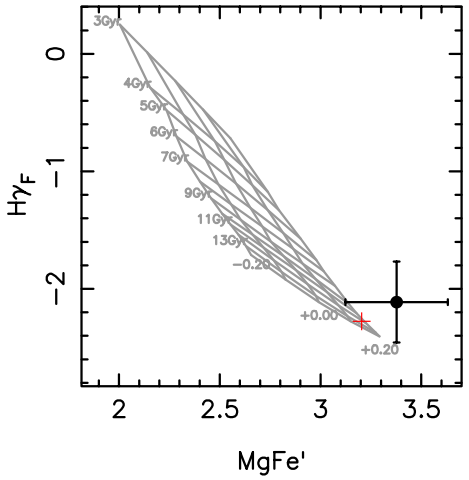

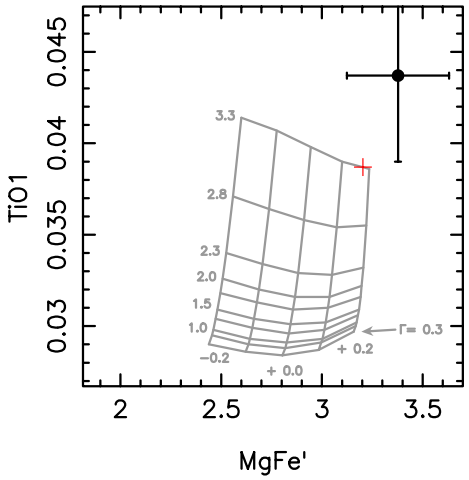

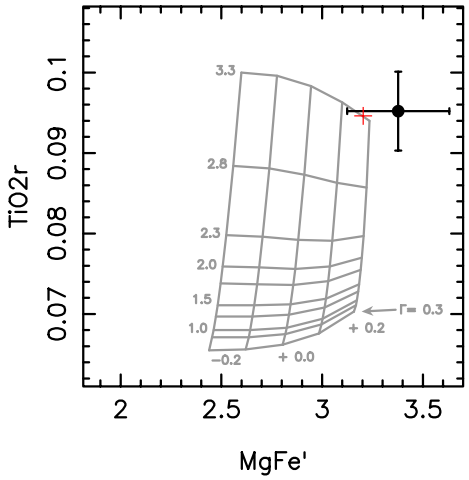

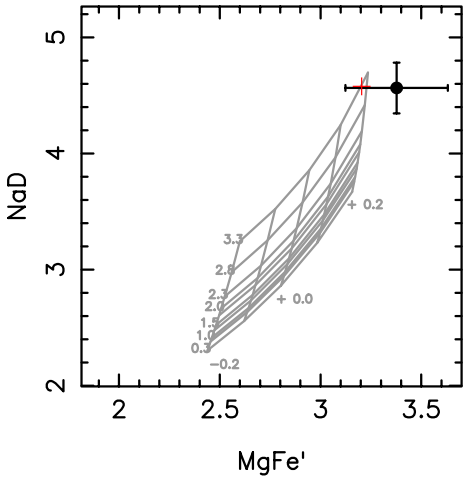

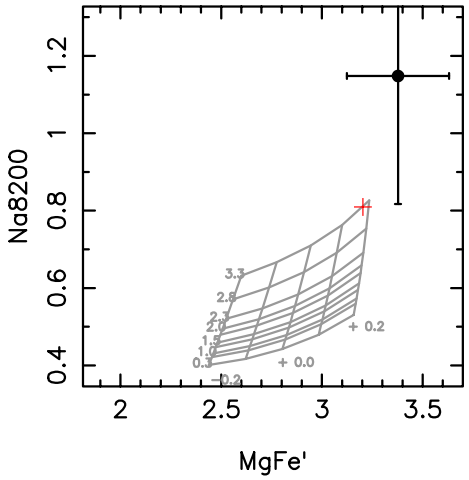

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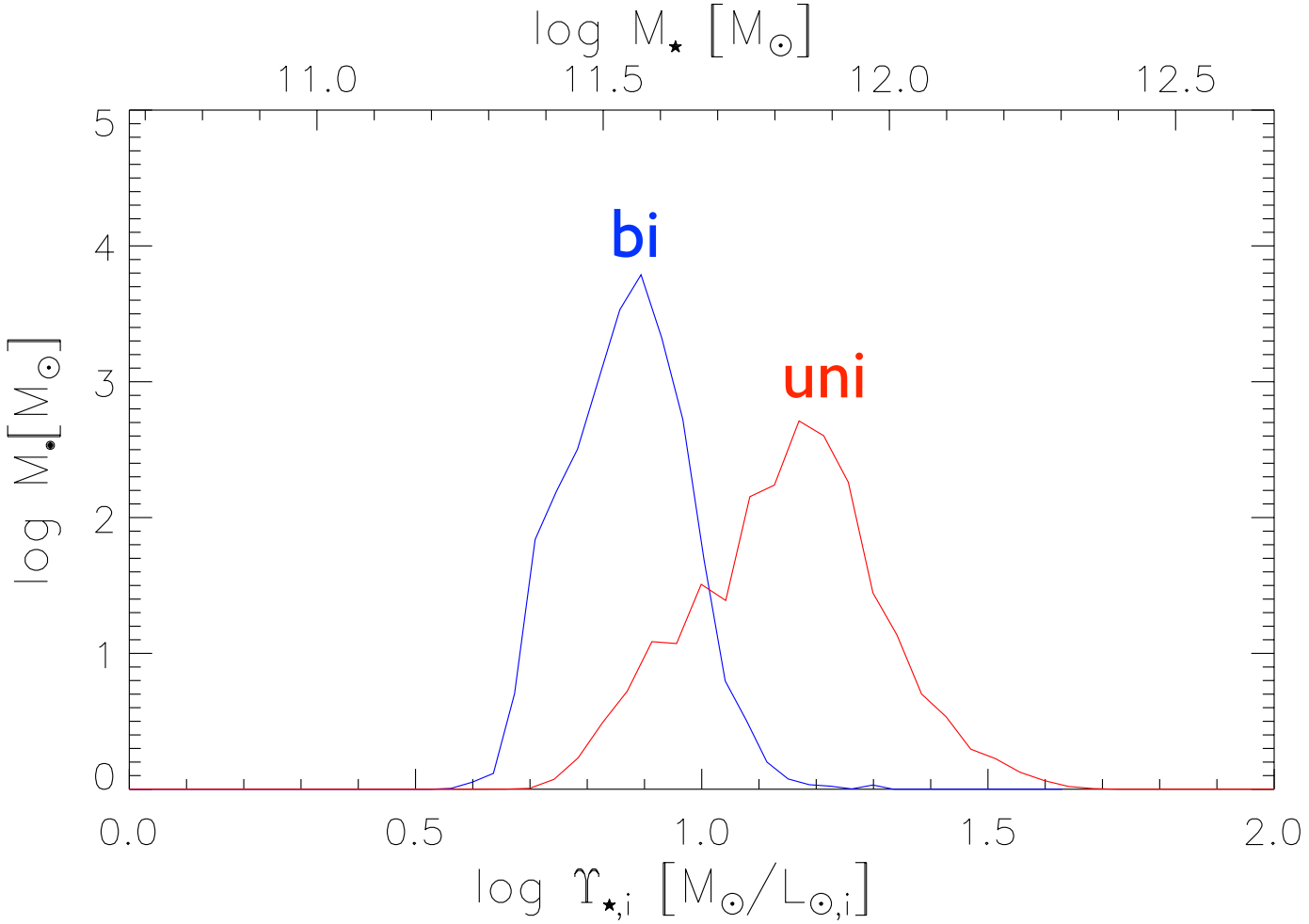

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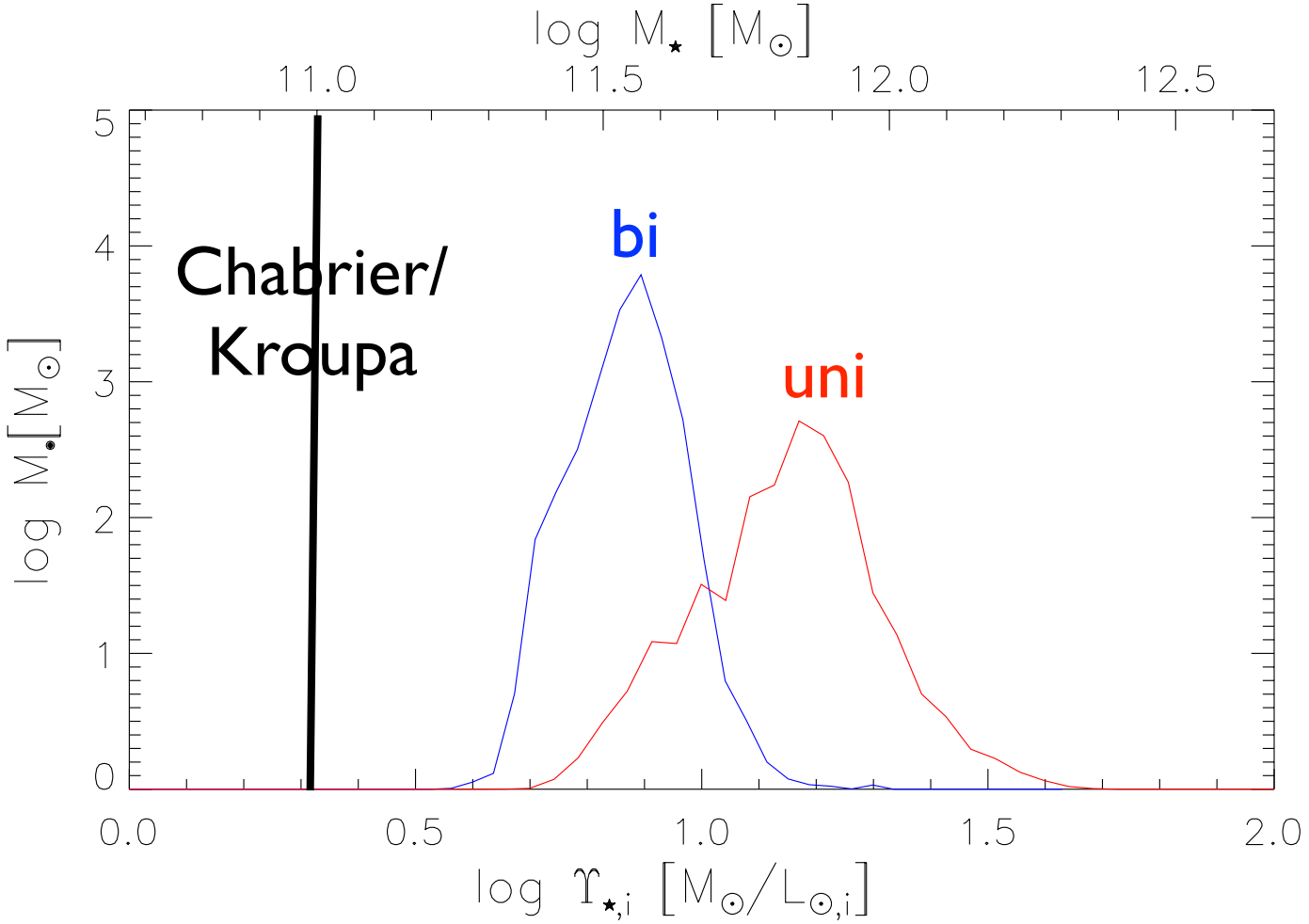

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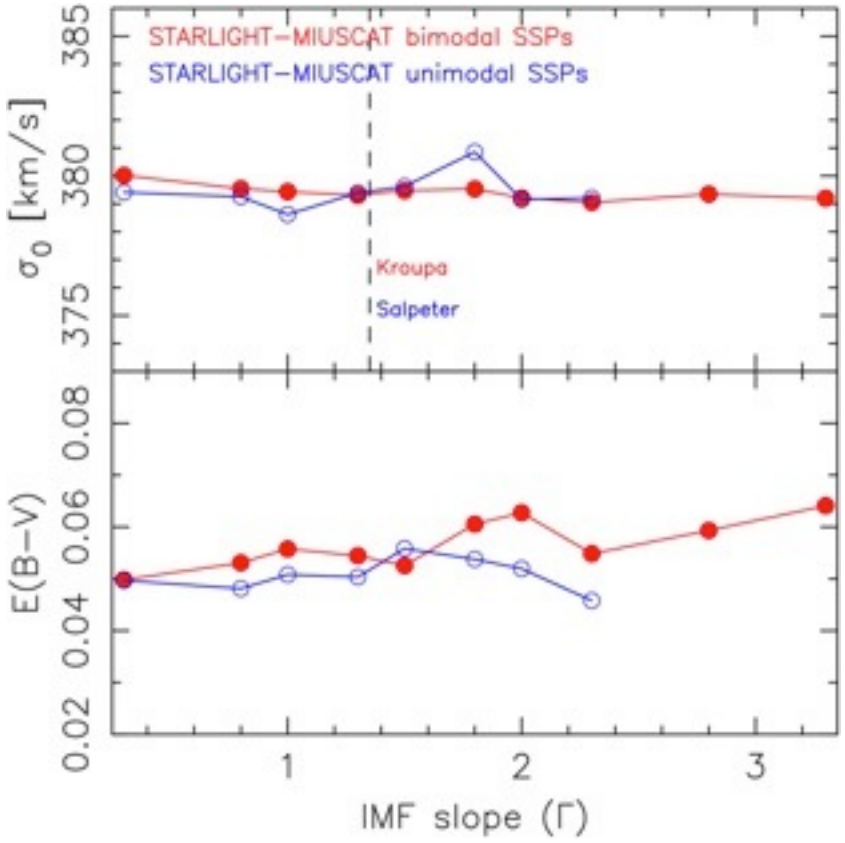
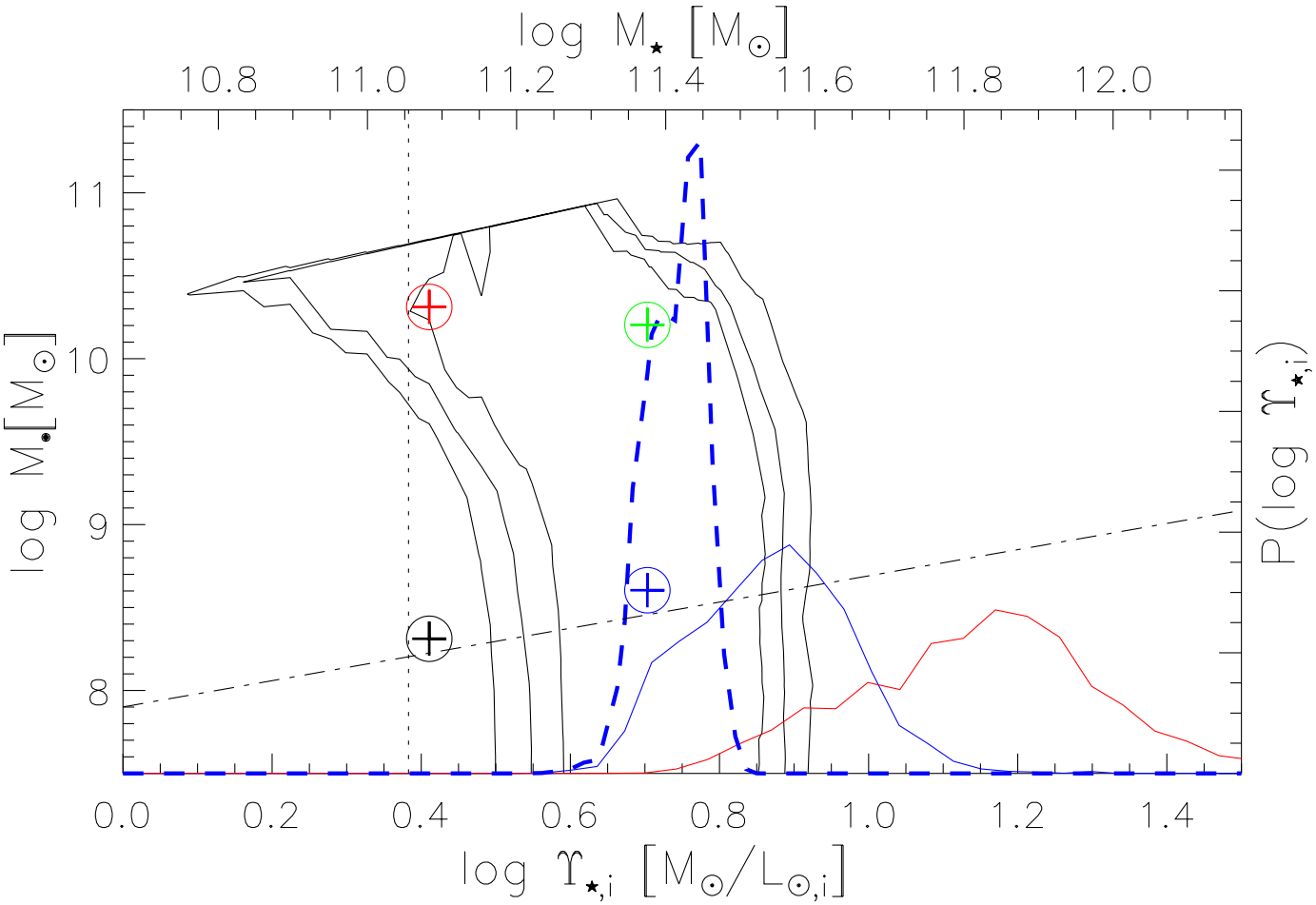


Combined Results



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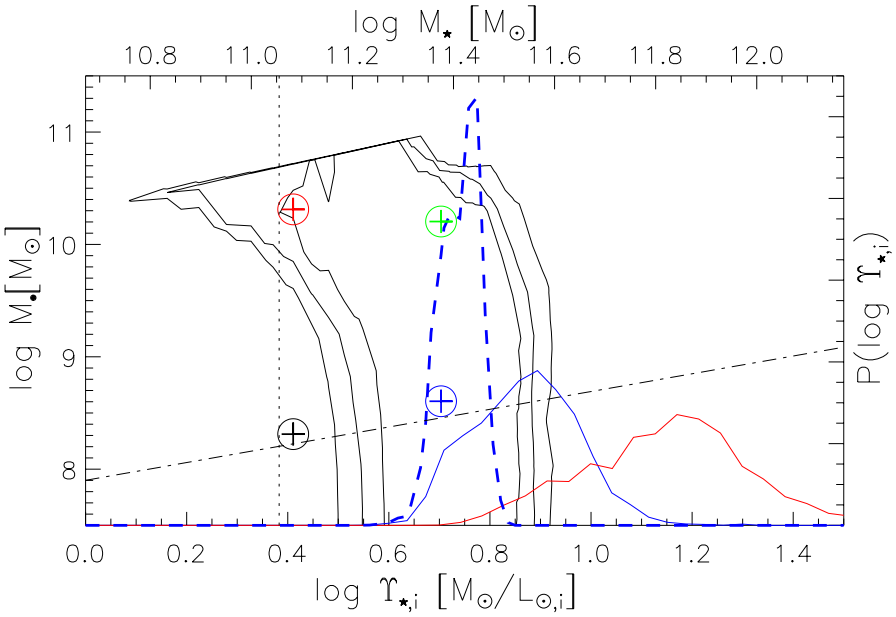
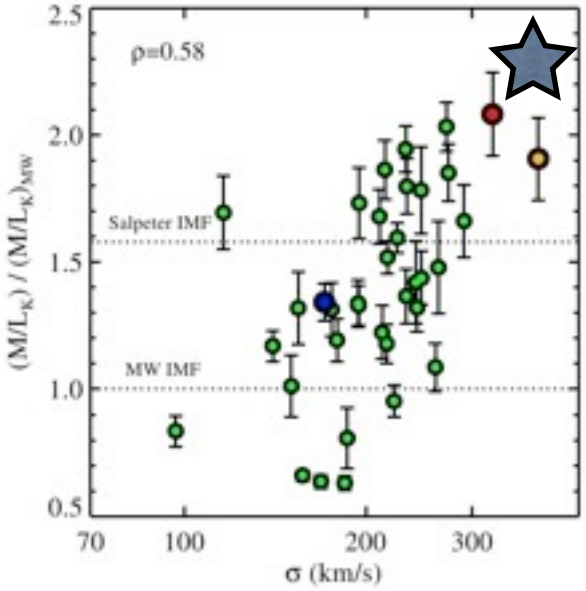




Discussion & Outlook

- connection to z ~ 1...3 galaxies
  (e.g. vDokkum+08, vdWel+08,11) ?
- size growth (e.g. Trujillo+11) inside-out by dry minor merging (e.g. Hilz, Naab, Ostriker 2013)

- IMF reflects ISM conditions (high α/Fe and Z → fast formation ?)
- HETMGS, NGC1277 et al.,
- Letter accepted, FORS2 data arrived

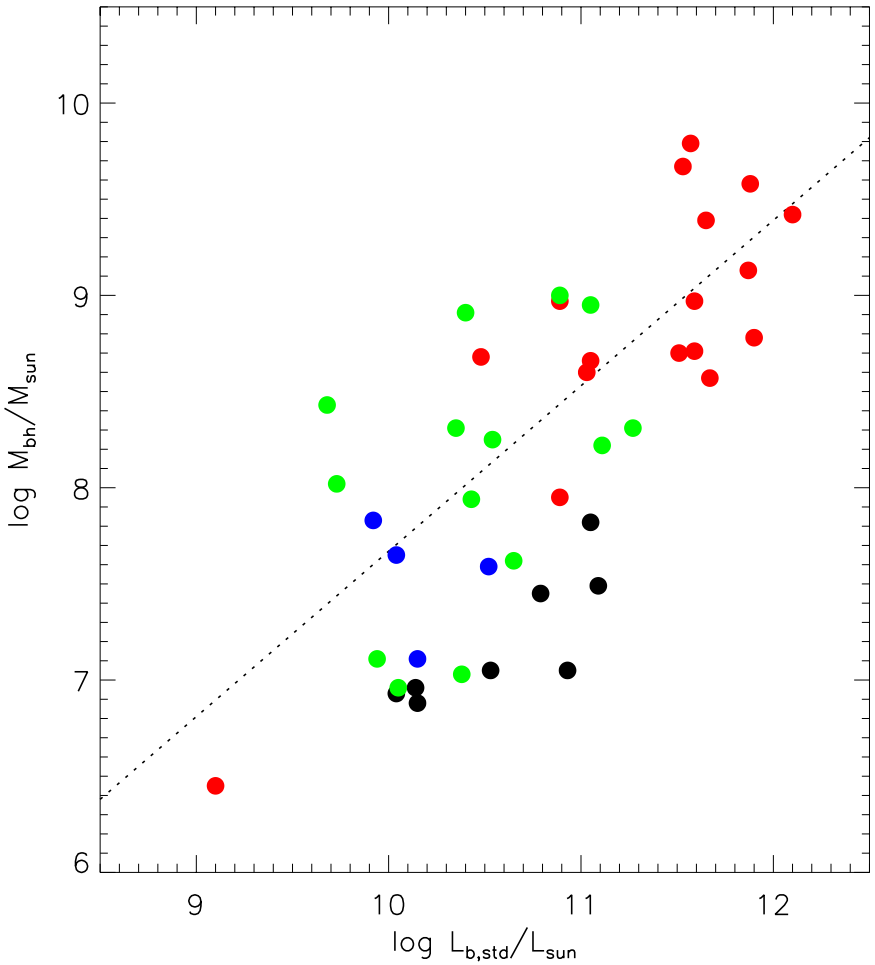
III. Ongoing & future work

Adding low-mass galaxies: Megamasers!

with:

Jenny Greene, Anil Seth, Glenn van de Ven et al.

Adding low-mass galaxies: Megamasers!



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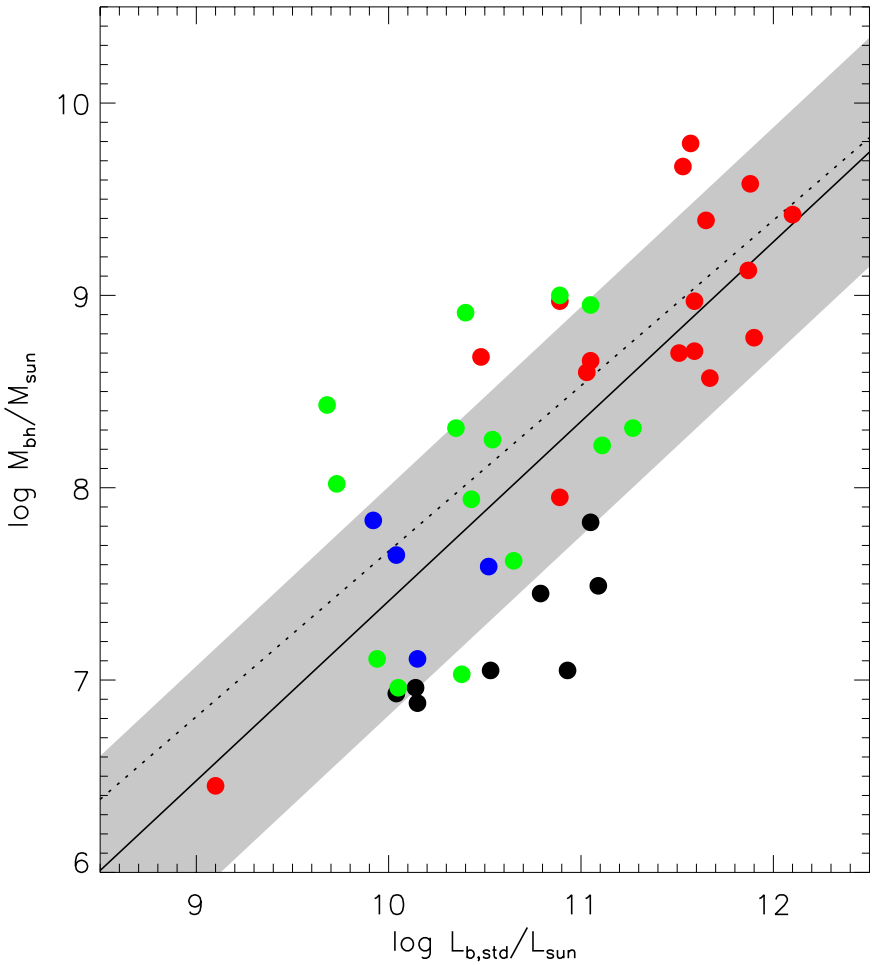

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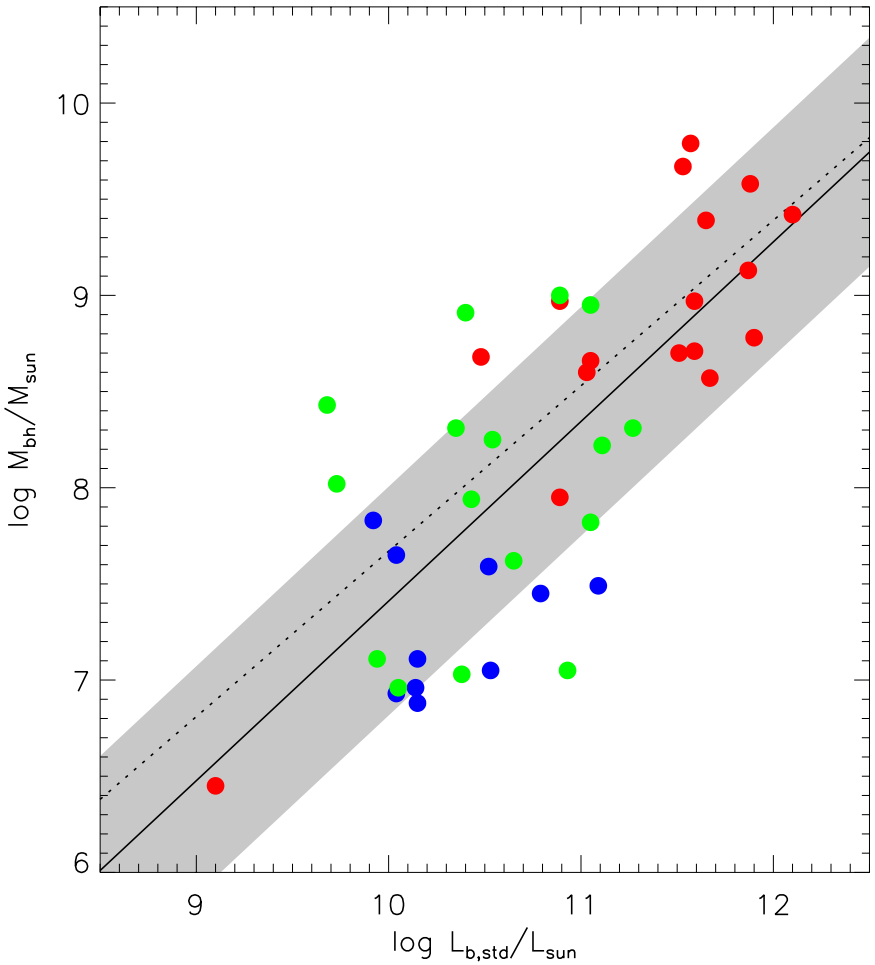
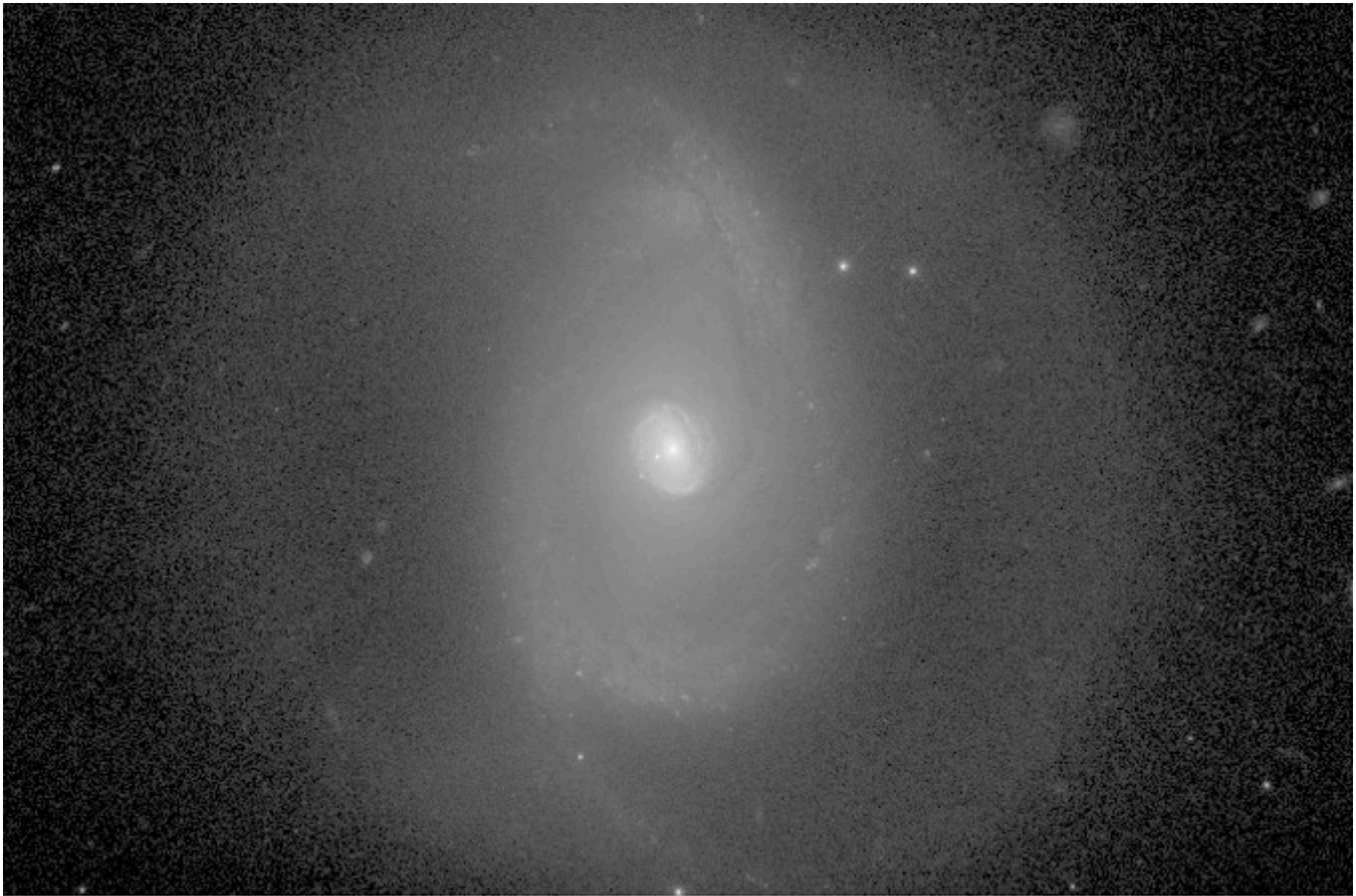


Improving the Decomposition
- Bulge parameters



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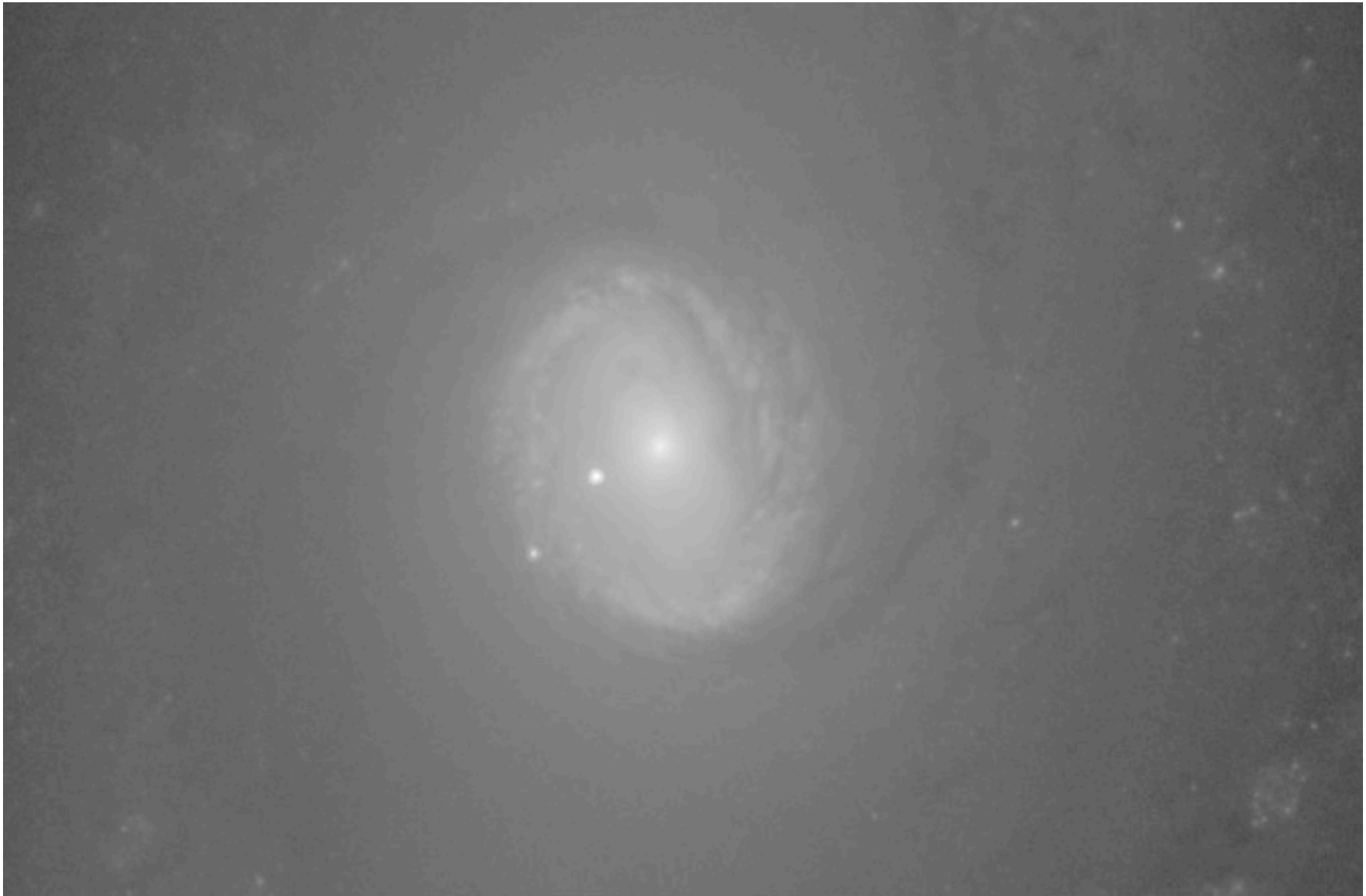

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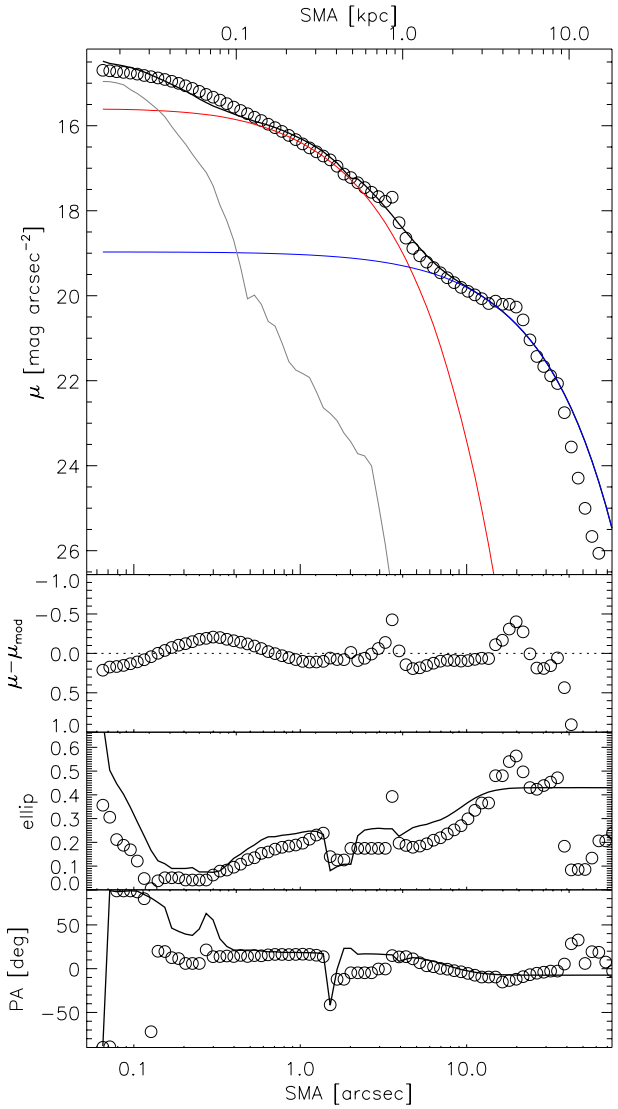

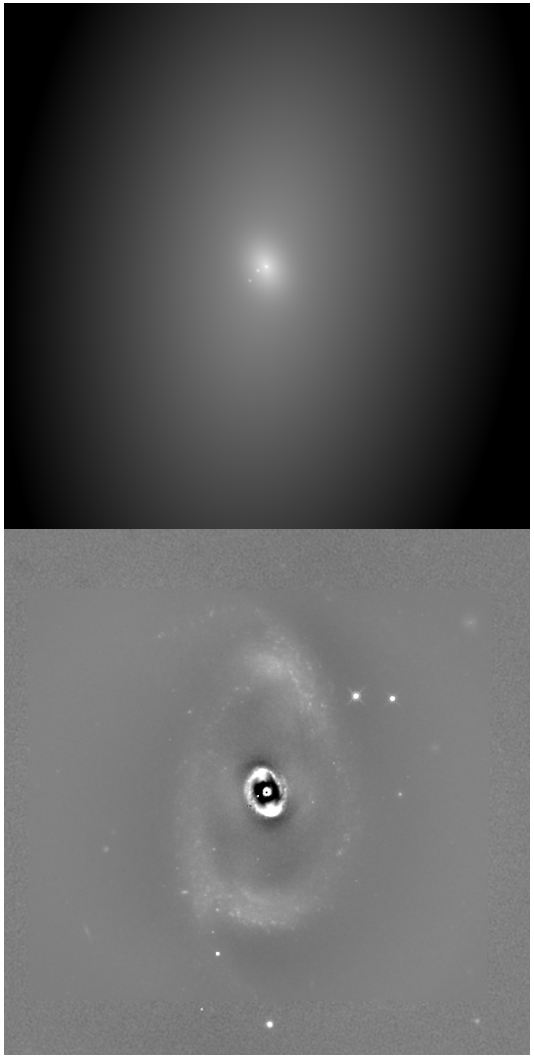

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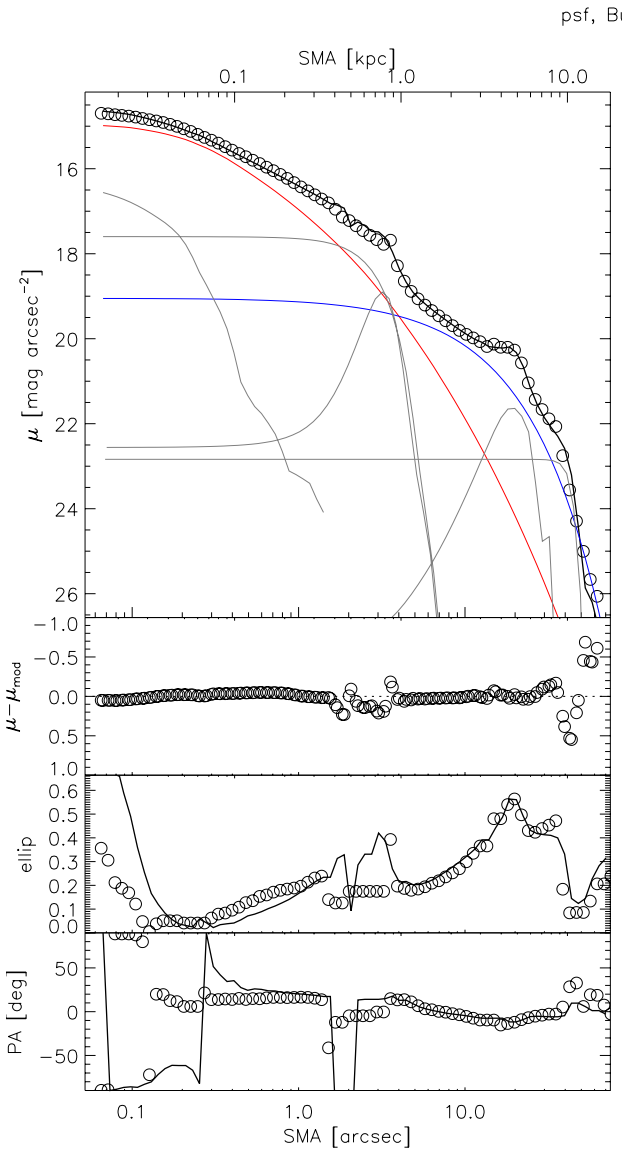

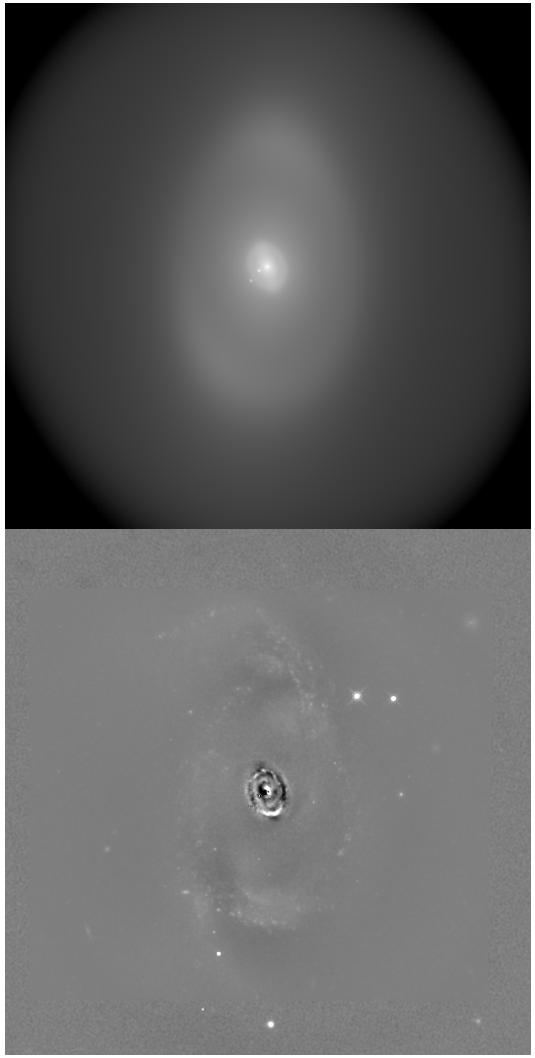

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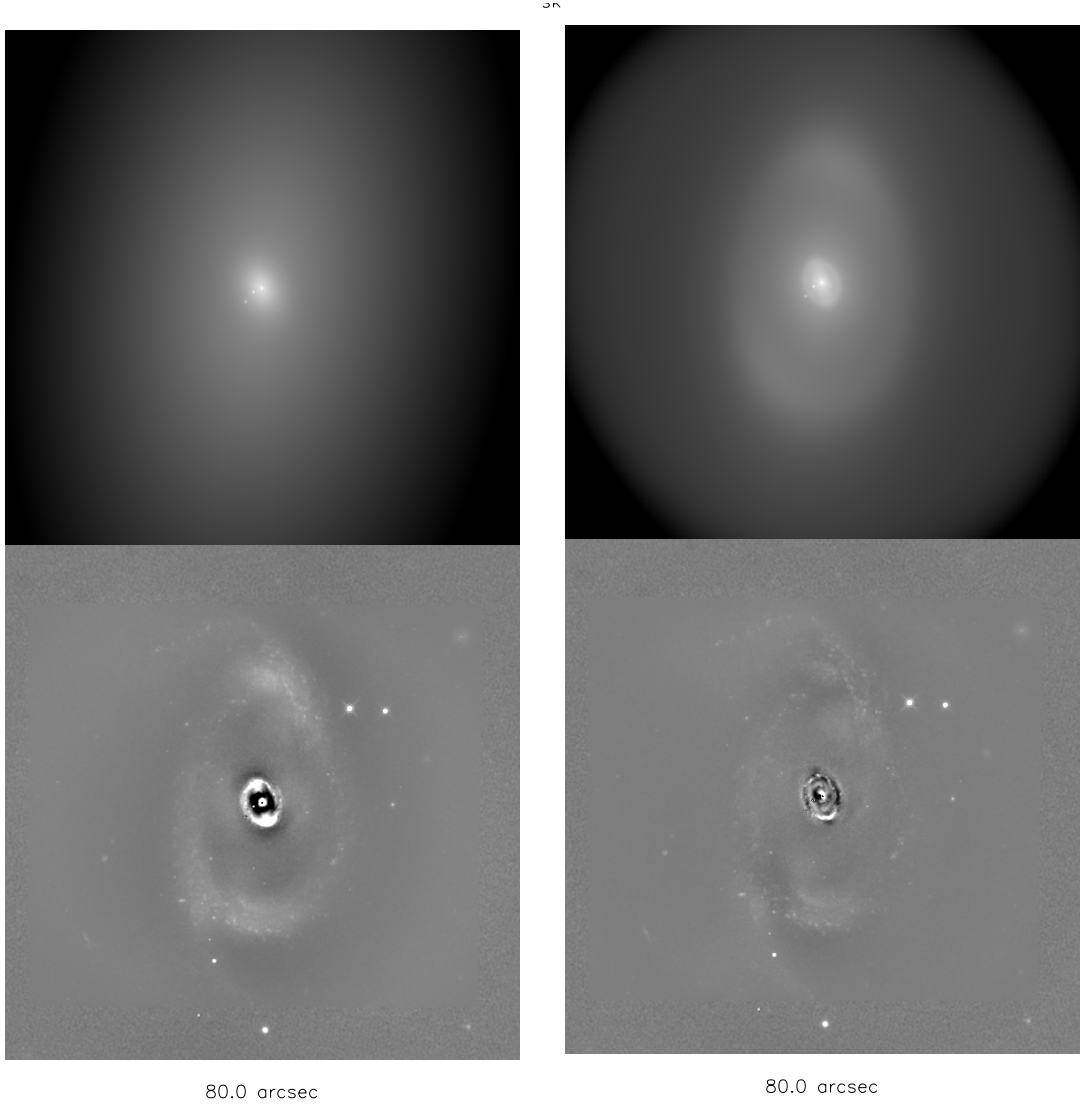

... & more:

hi-res data for “b19”
resolved M_{star} maps for BH hosts
Bayesian and extended correlation fits
....

Take-home:

I. $M_\bullet$ - L_{bul} may not be "fundamental"

II. still a lot t.b.d. on $M_\bullet$ & BH scaling relations

III. IMF is likely variable & important

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Thanks for Watching !