



Nuclear star clusters: observational status

C. Jakob Walcher (ESA/RSSD)

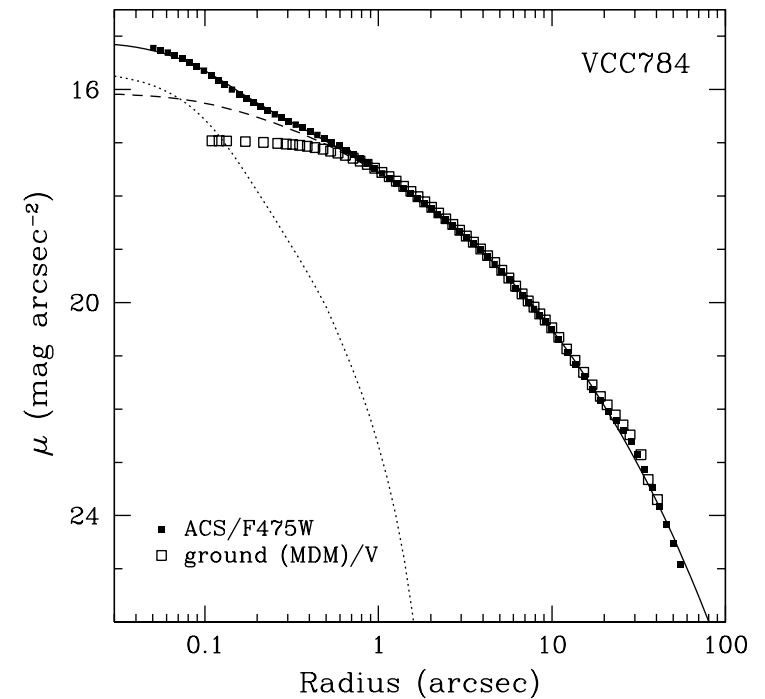
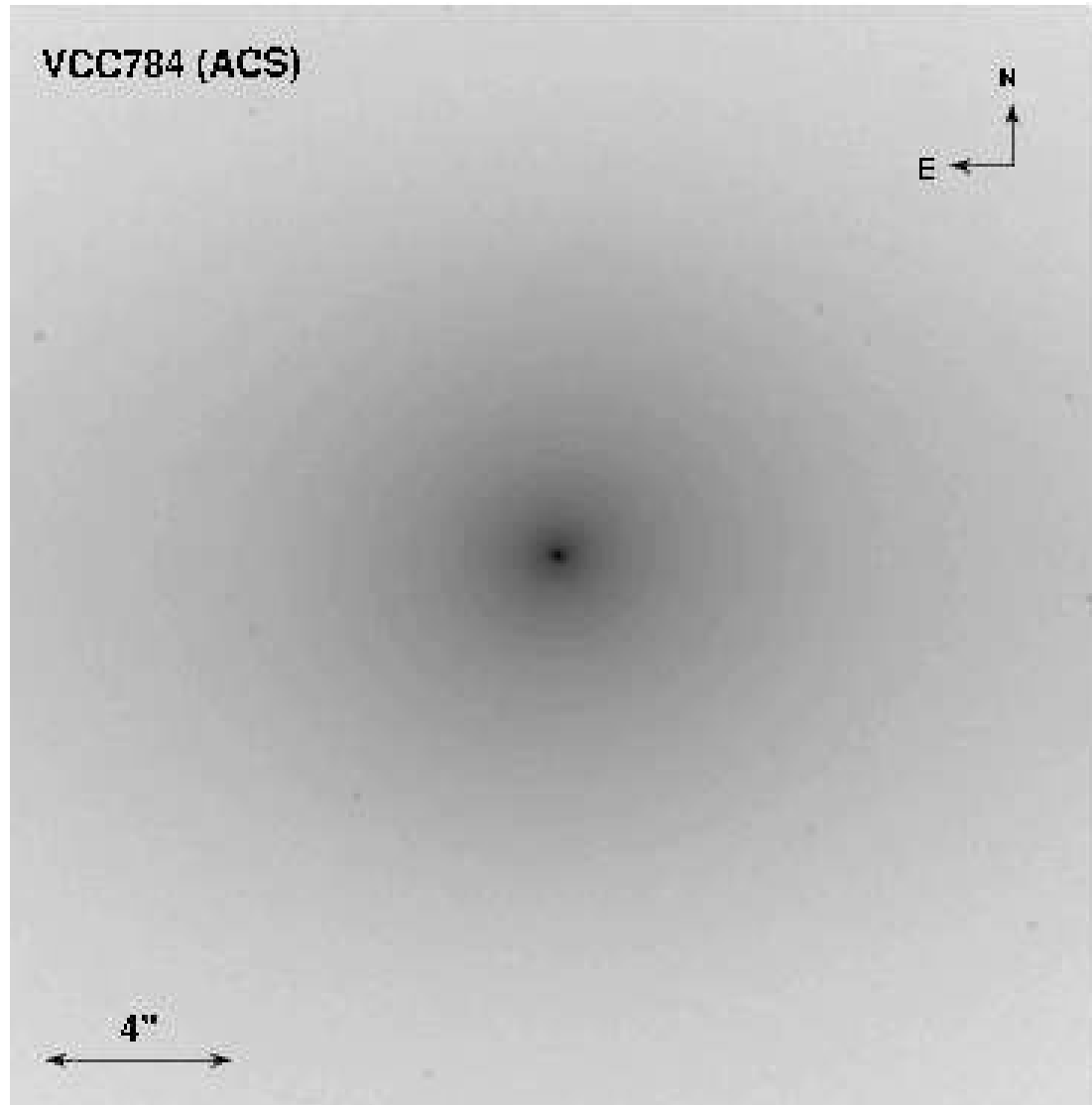


Existence of NCs



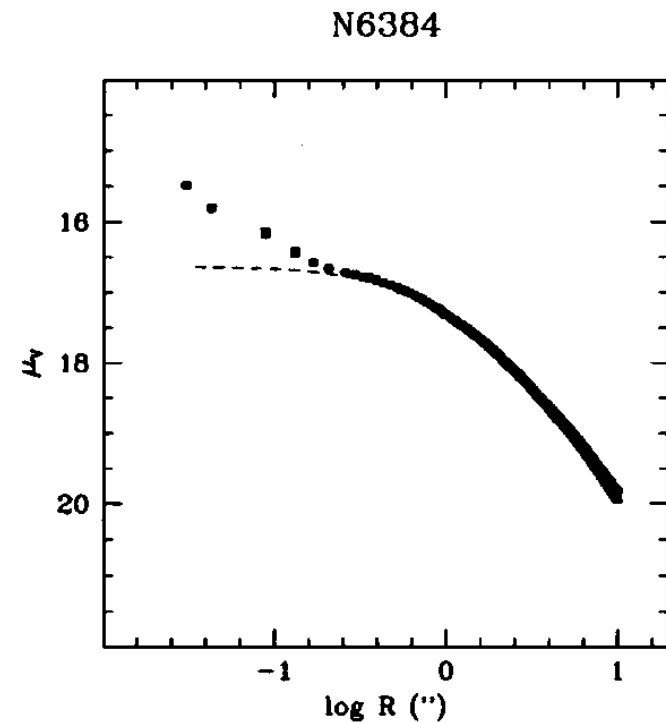
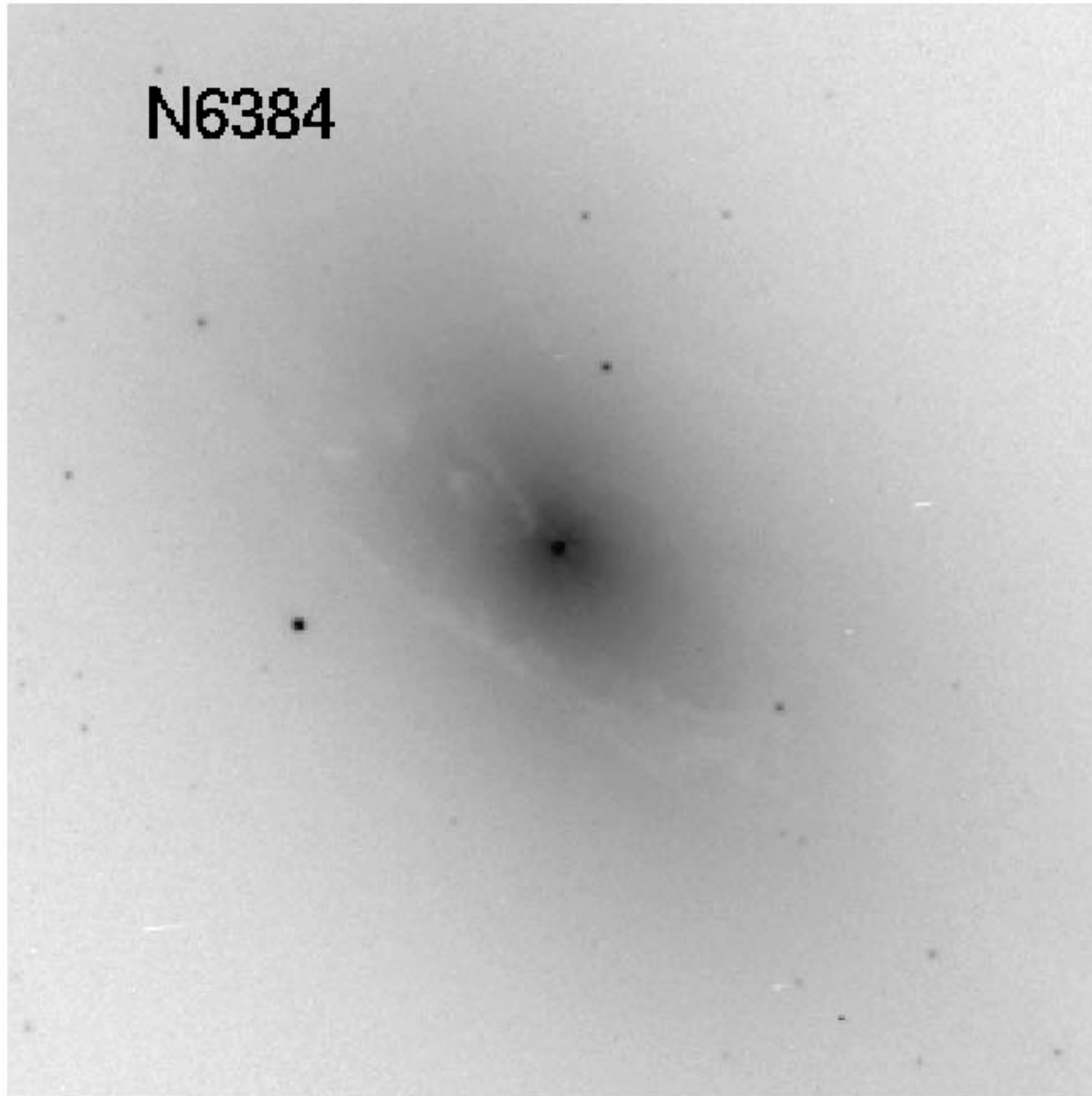
NGC300, Animation Credit: NASA, Z. Levay and G. Bacon

Nucleated Ellipticals



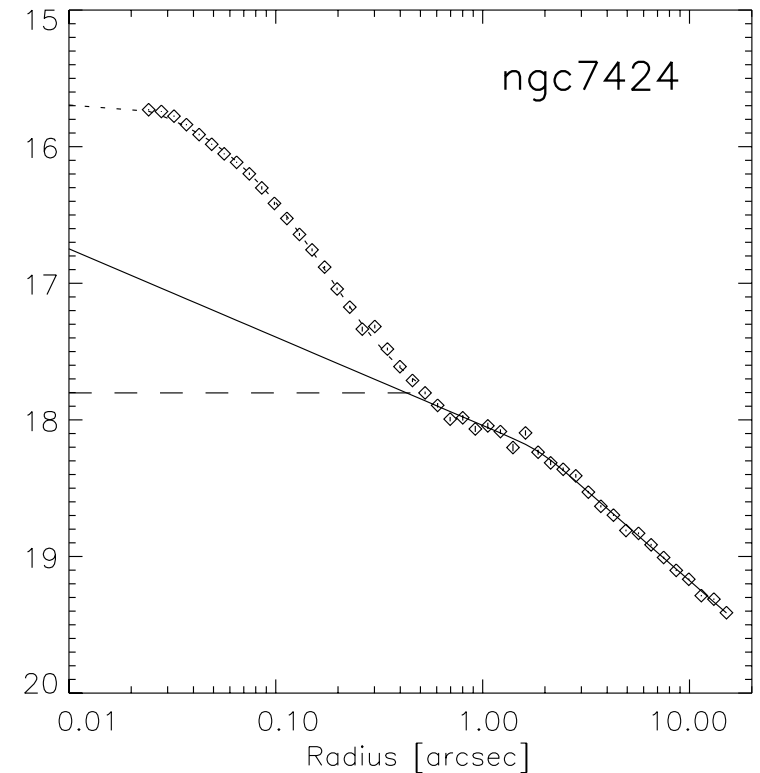
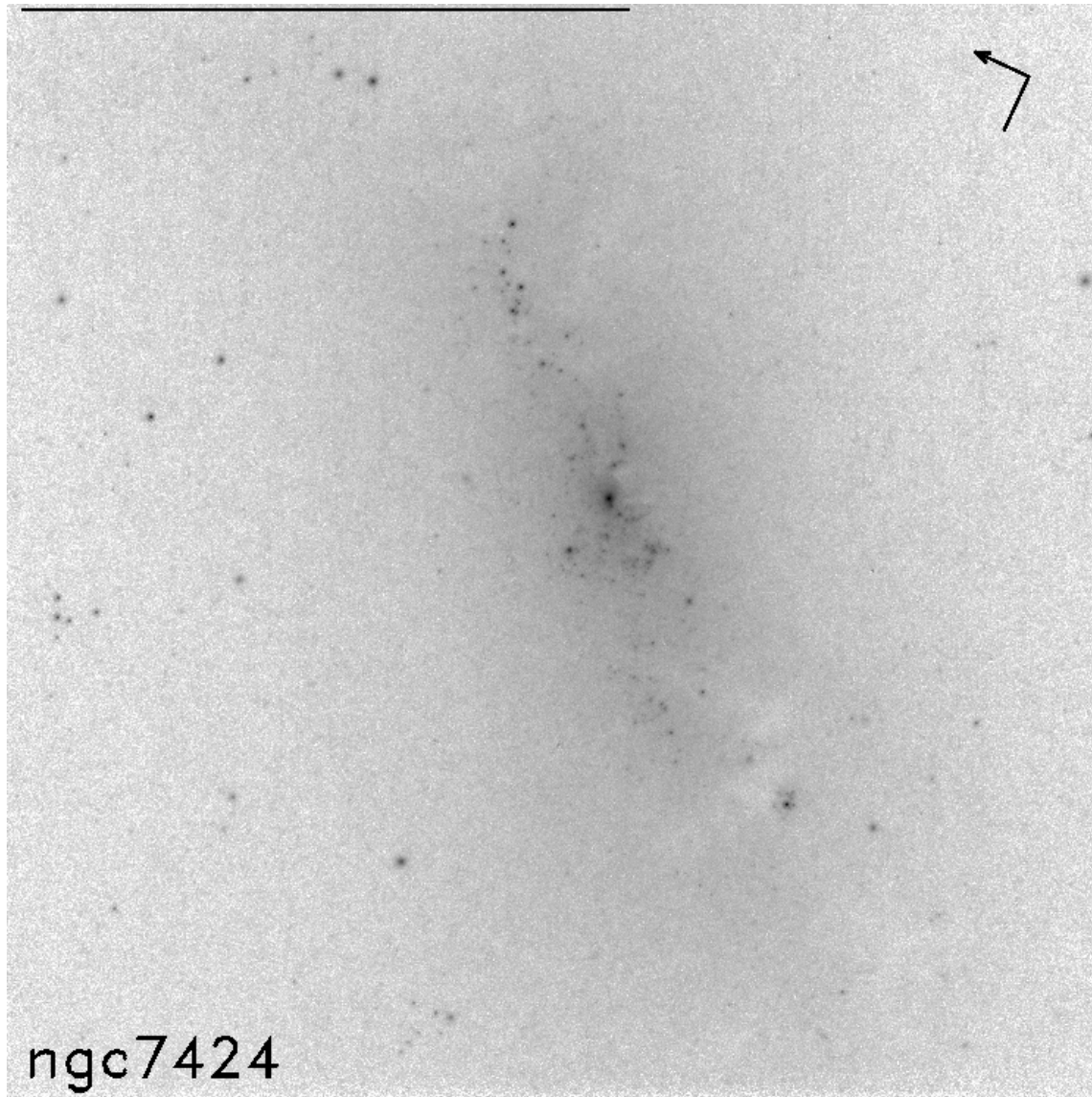
HST/ACS
Coté et al. 2006
(also Lauer et al. 2005)

Nucleated Spiral



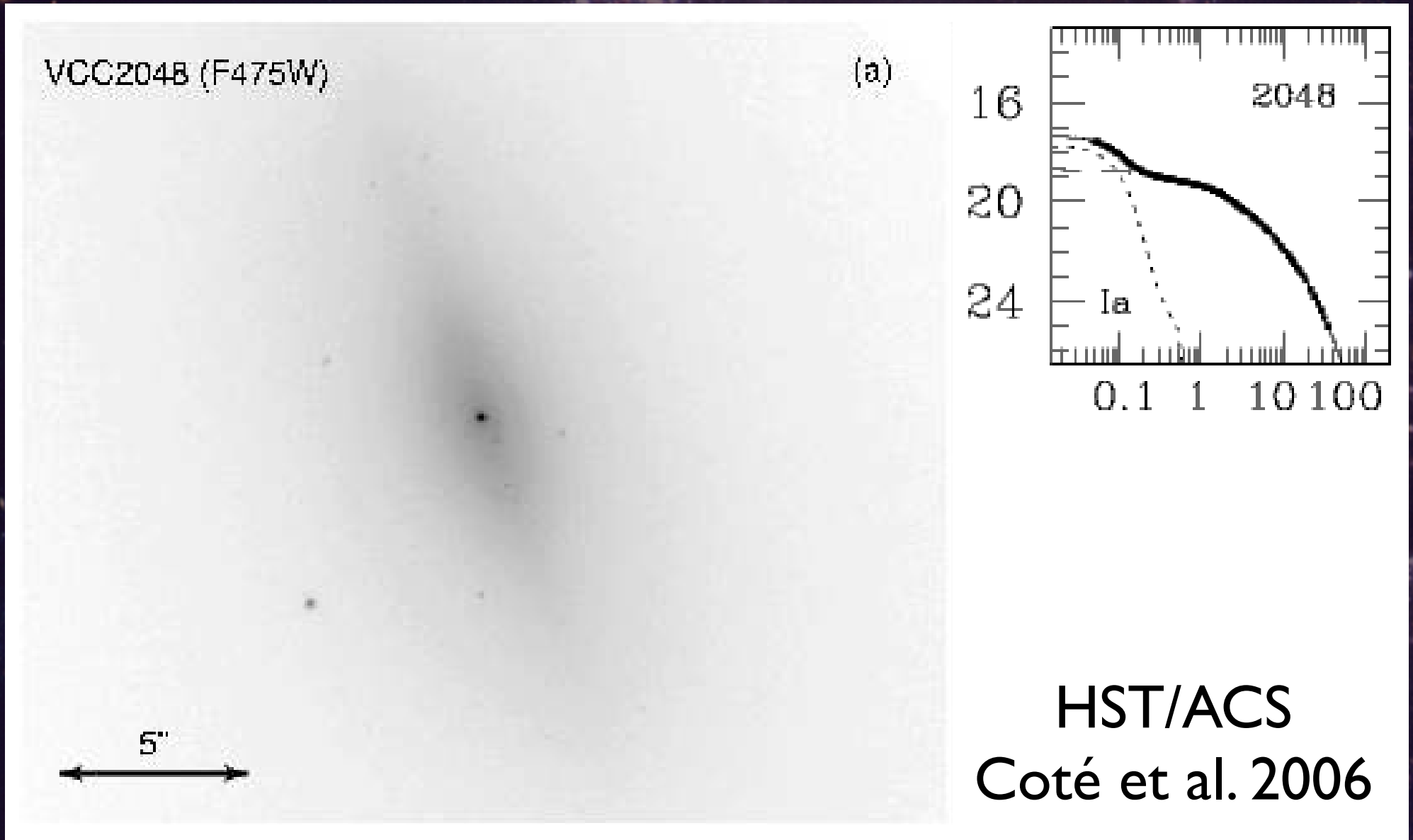
HST/WFPC2
Carollo et al. 1998

Nucleated pure disk



HST/WFPC2
Böker et al. 2002

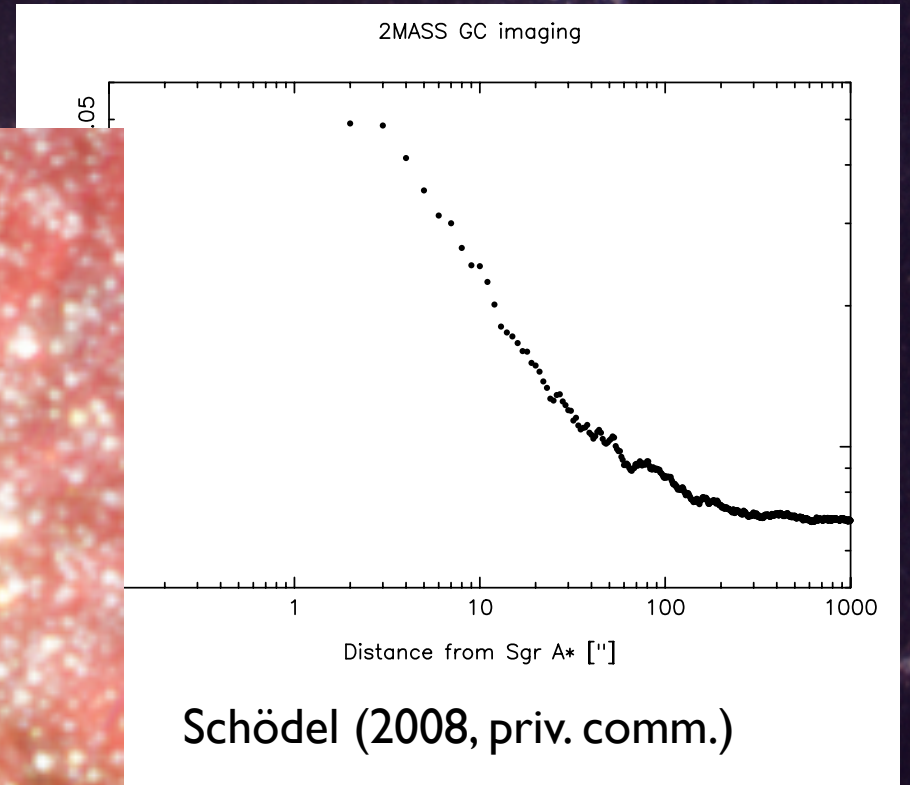
Nucleated dE



Milky Way



MW Spitzer



$r_e \sim 5-8 \text{ pc}$

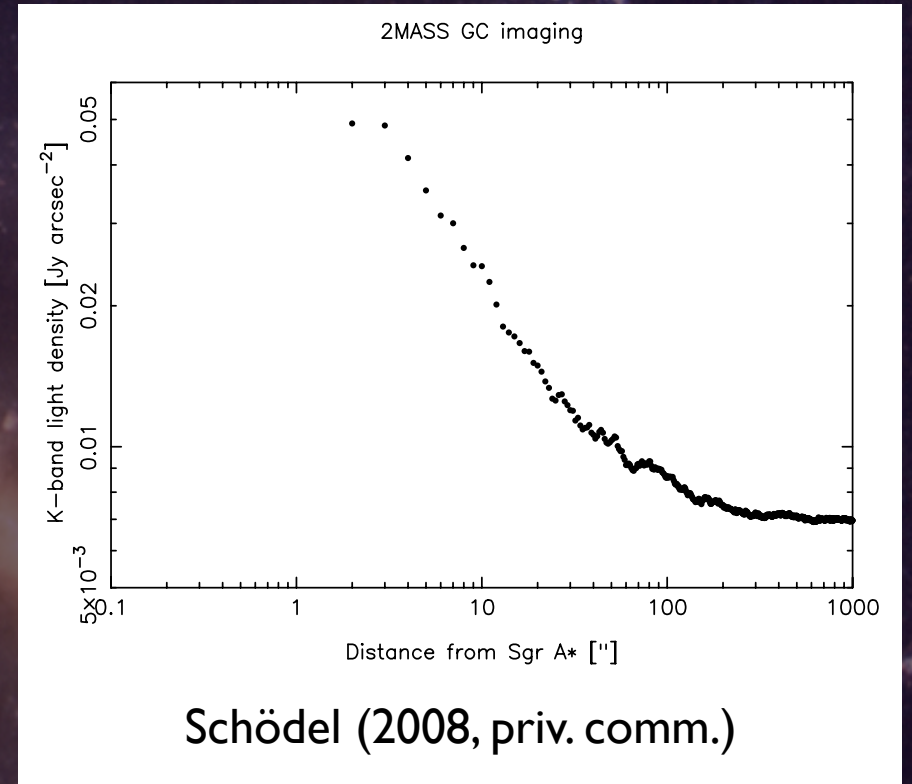
Milky Way



MW Spitzer

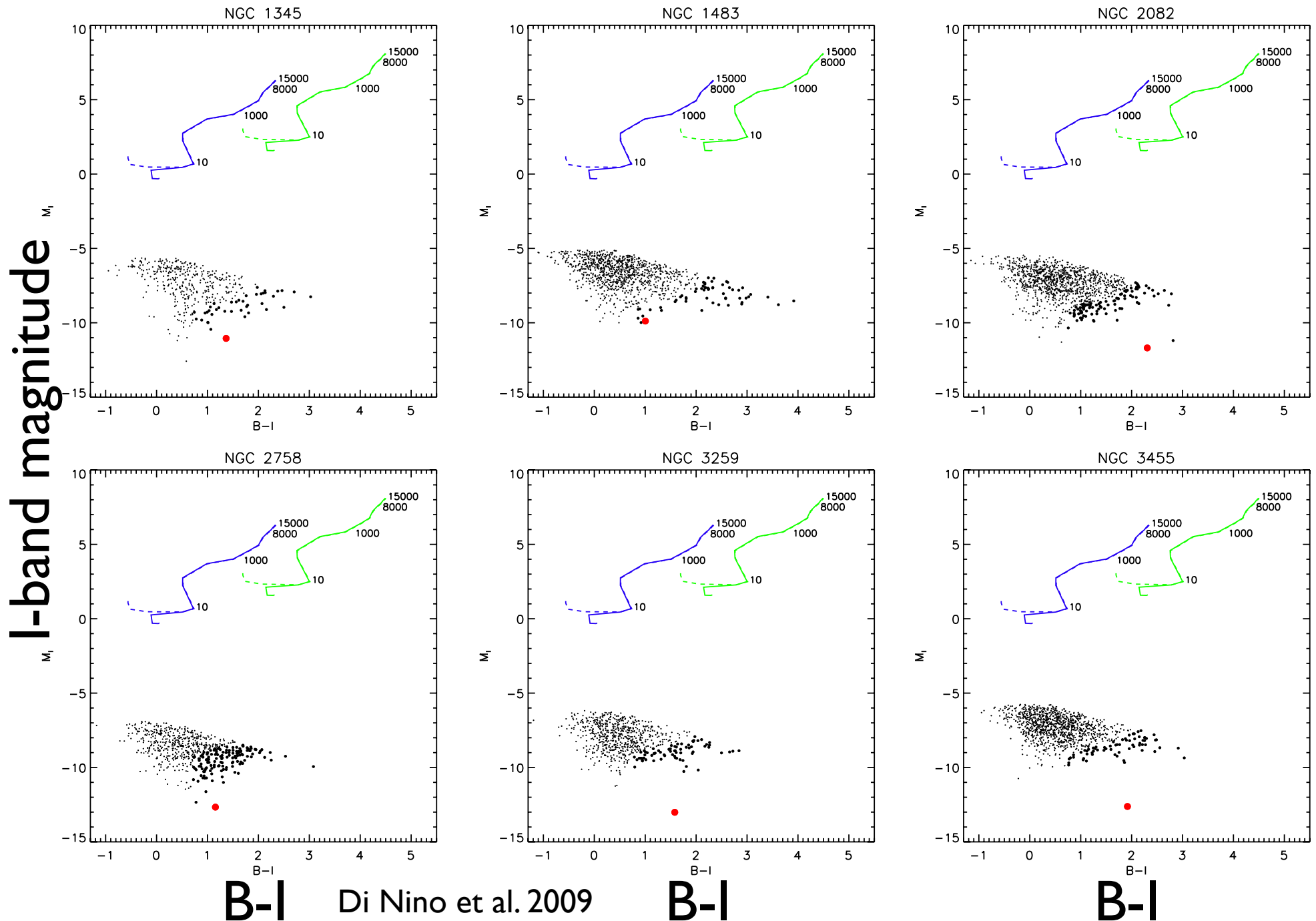


NGC300 HST/ACS

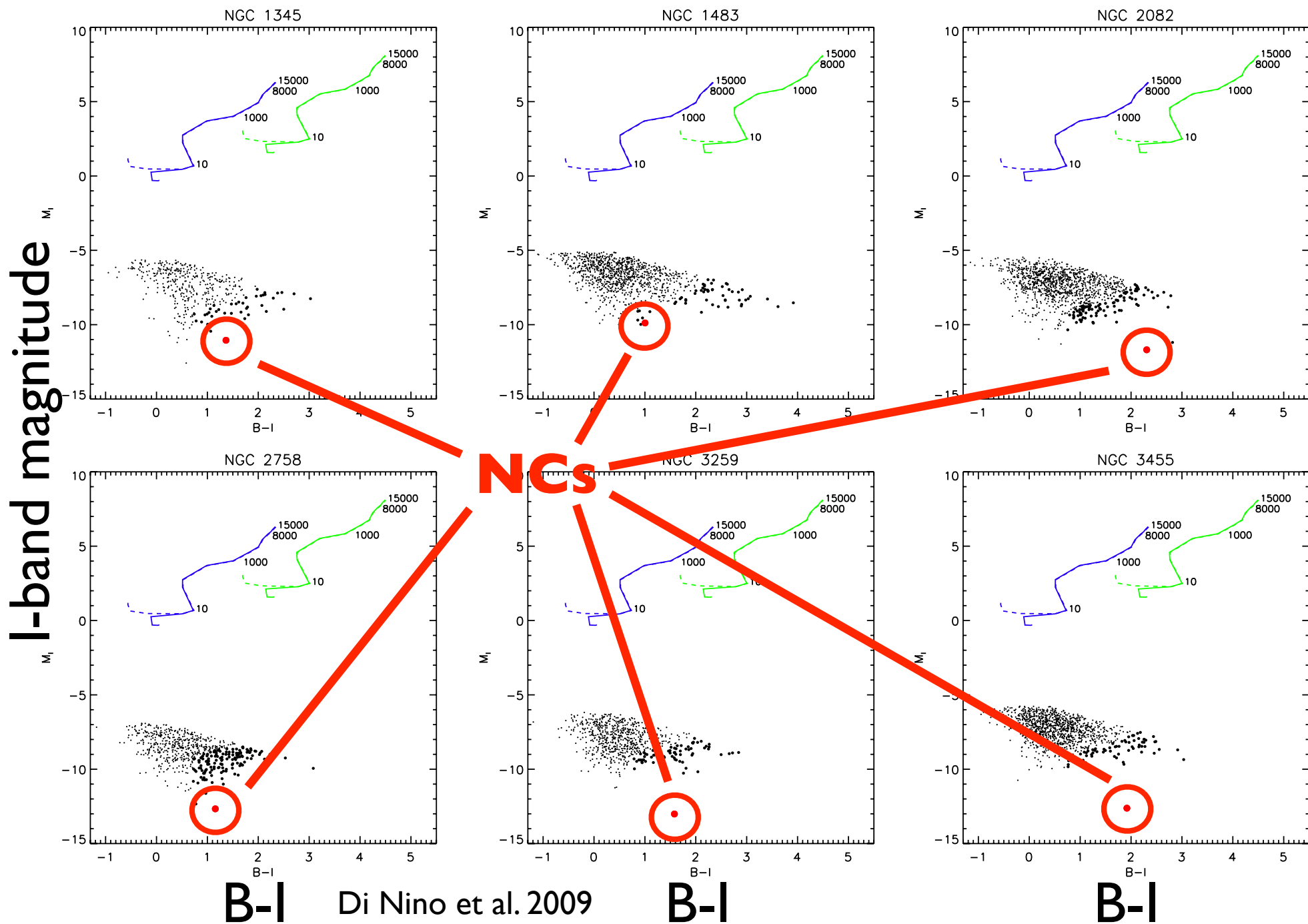


$r_e \sim 5-8 \text{ pc}$

NCs and the other clusters



NCs and the other clusters



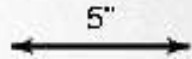
A warning

There is a long history to the subject (e.g. Sandage, Binggeli, Freeman). But really need HST for detection and size measurements.

VCC2048 (F475W)

Original

(a)



FWHM = 0.5''

(b)

FWHM = 0.9''

(c)

FWHM = 1.4''

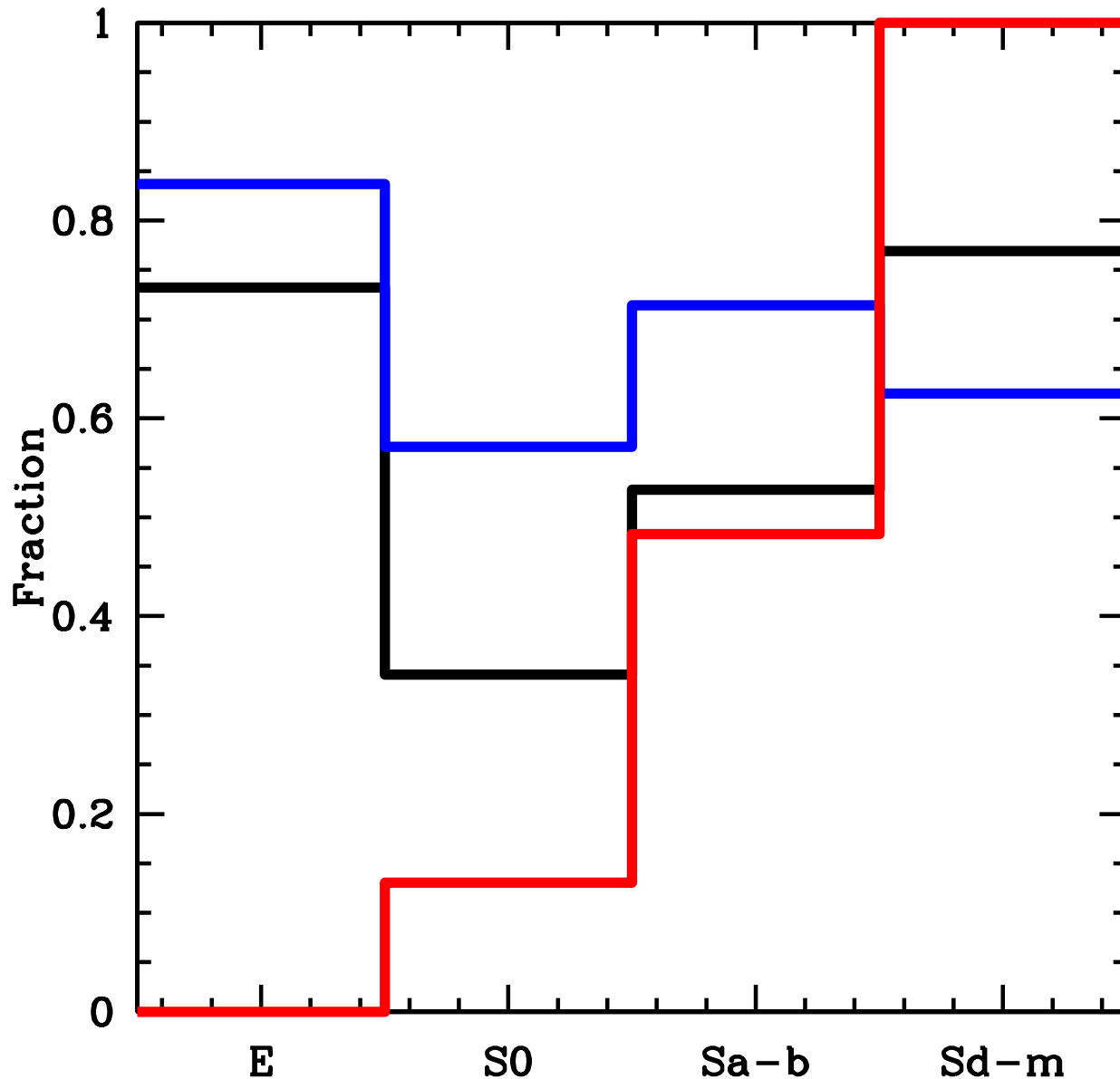
(d)

A warning

There is a long history to the subject (e.g. Sandage, Binggeli, Freeman). But really need HST for detection and size measurements.

Every time you say something about the nucleus of a galaxy you have to make sure you resolve the NC ($\sim 5\text{pc}$). Even with HST ($0.05''$) this is only possible to a distance of 20 Mpc

Nucleation frequency



overall:
63%

black: all

red: $M_I < -18.5$

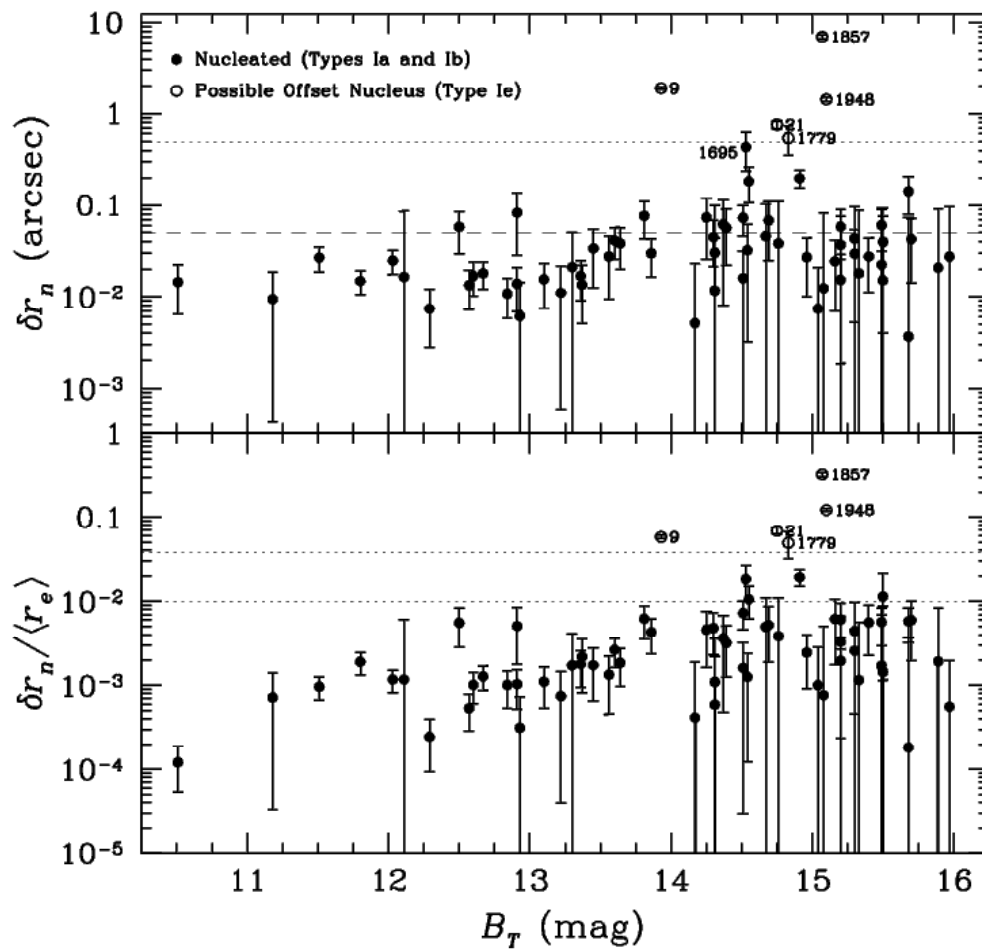
blue: $M_I > -18.5$



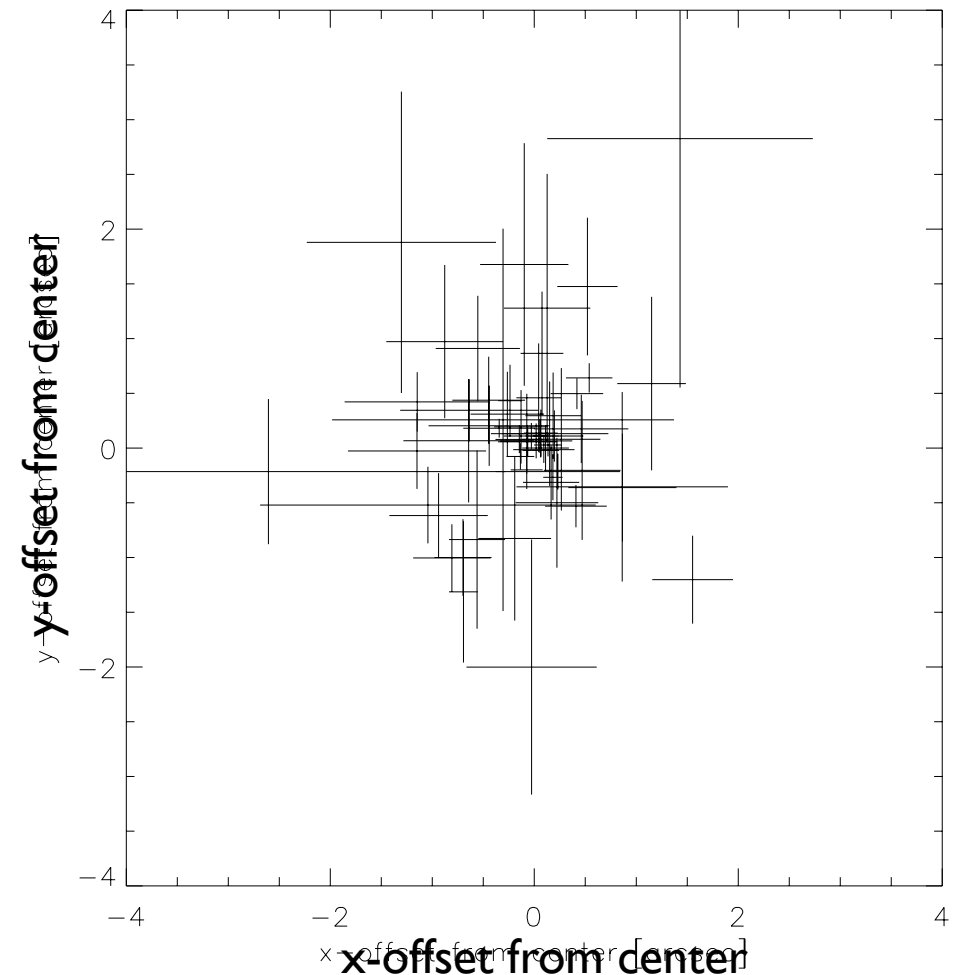
Just how nuclear are
Nuclear Clusters?

Just how nuclear are NCs?

From photometry



Cote et al. 2006

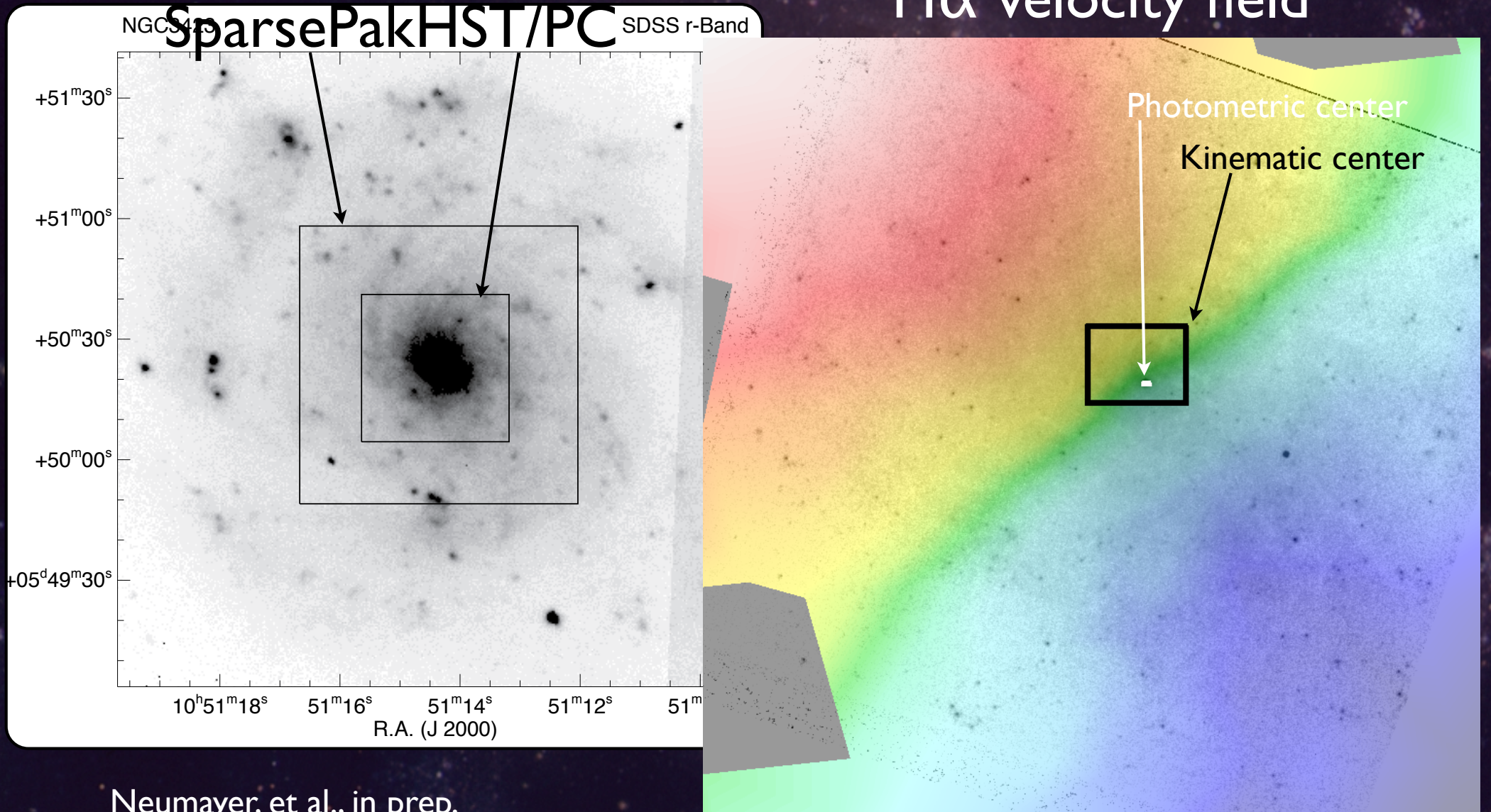


Böker et al. 2002

Just how nuclear are NCs?

From kinematics

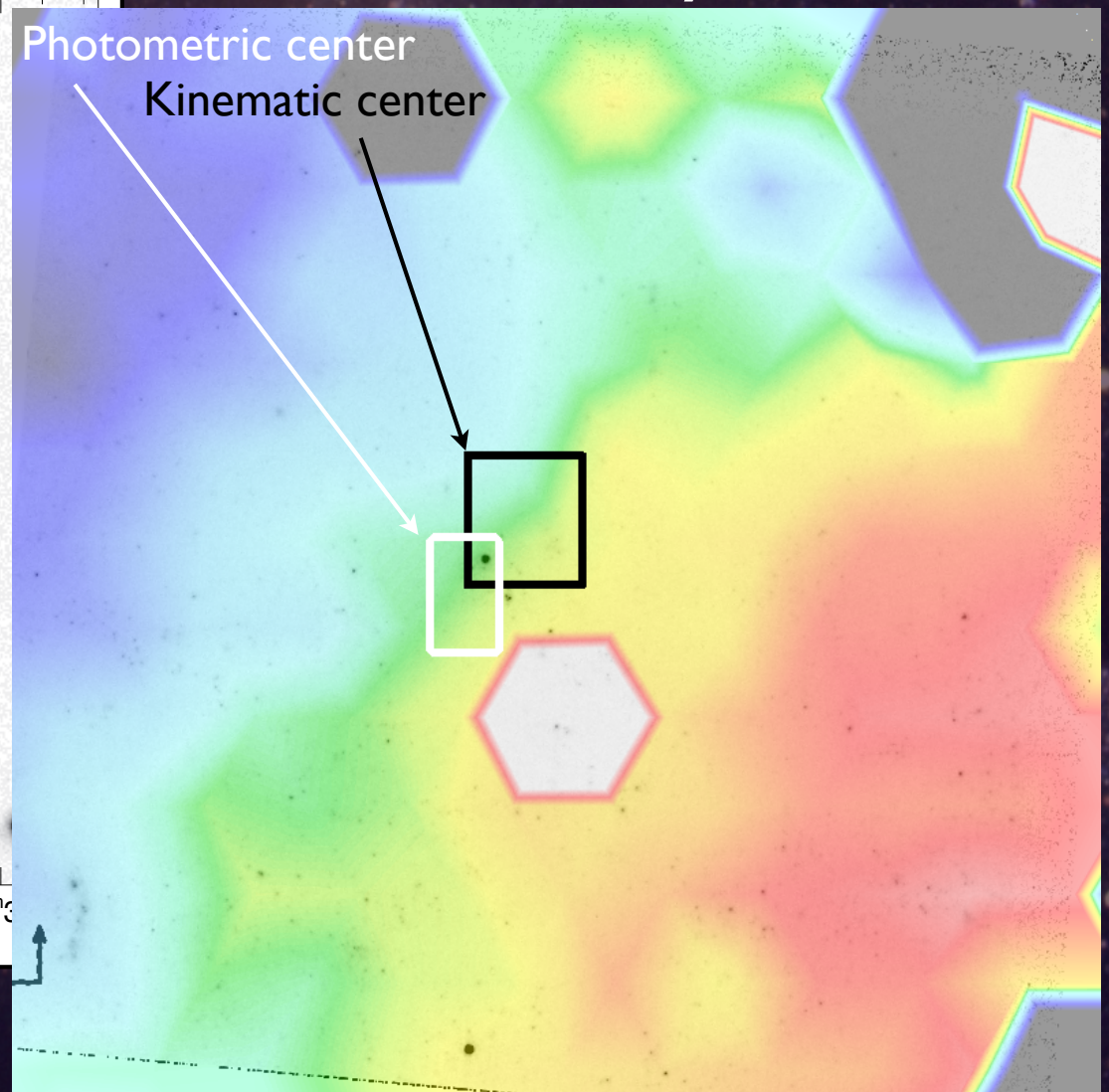
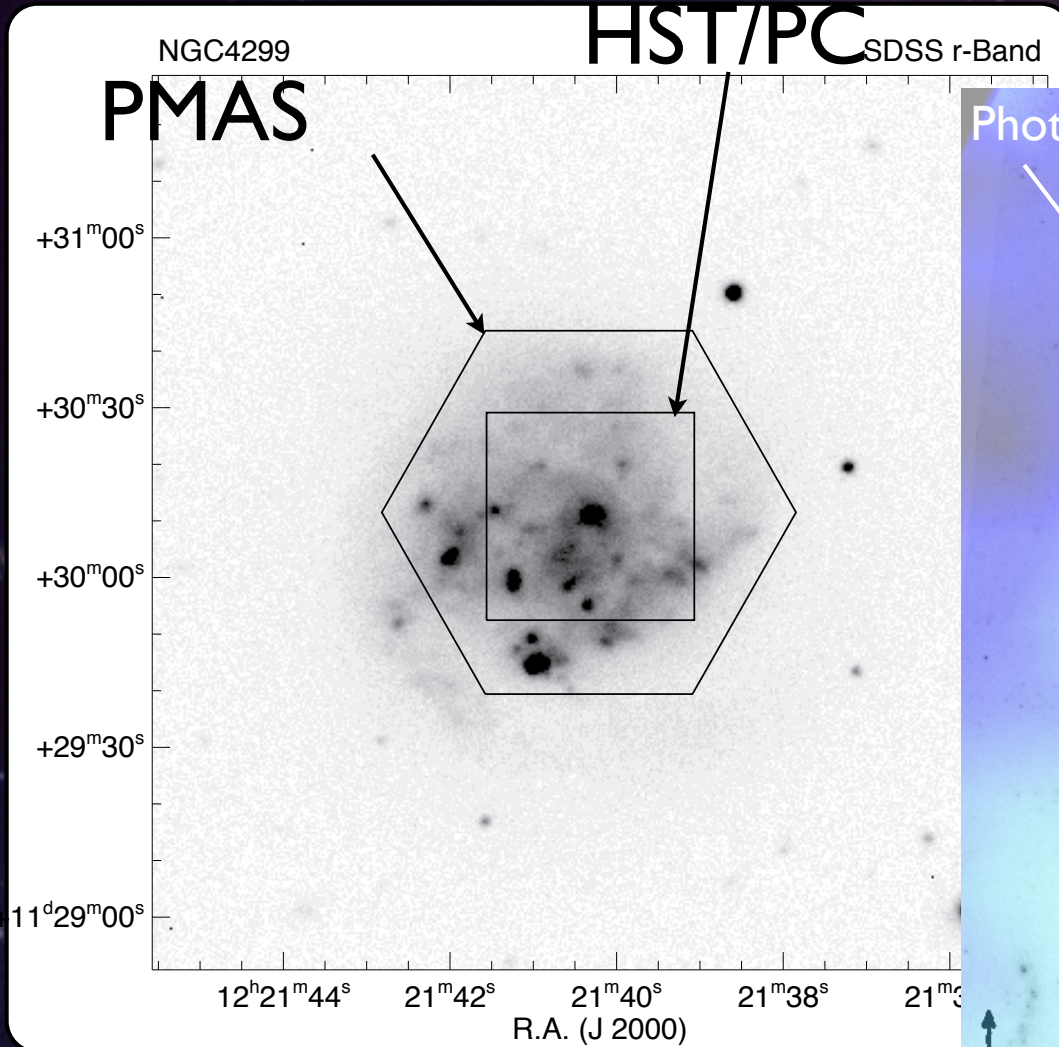
H α velocity field



Just how nuclear are NCs?

From kinematics

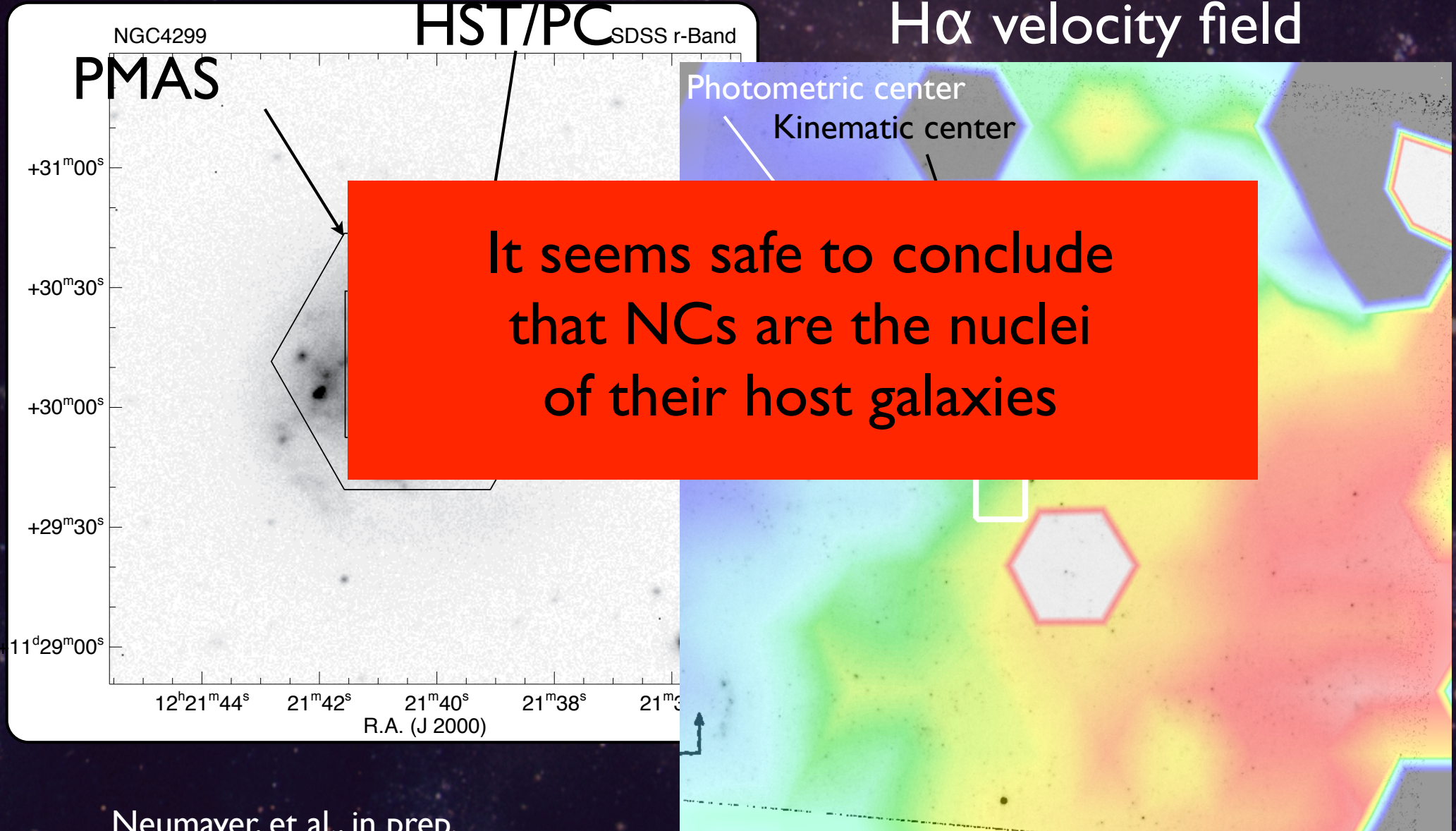
H α velocity field



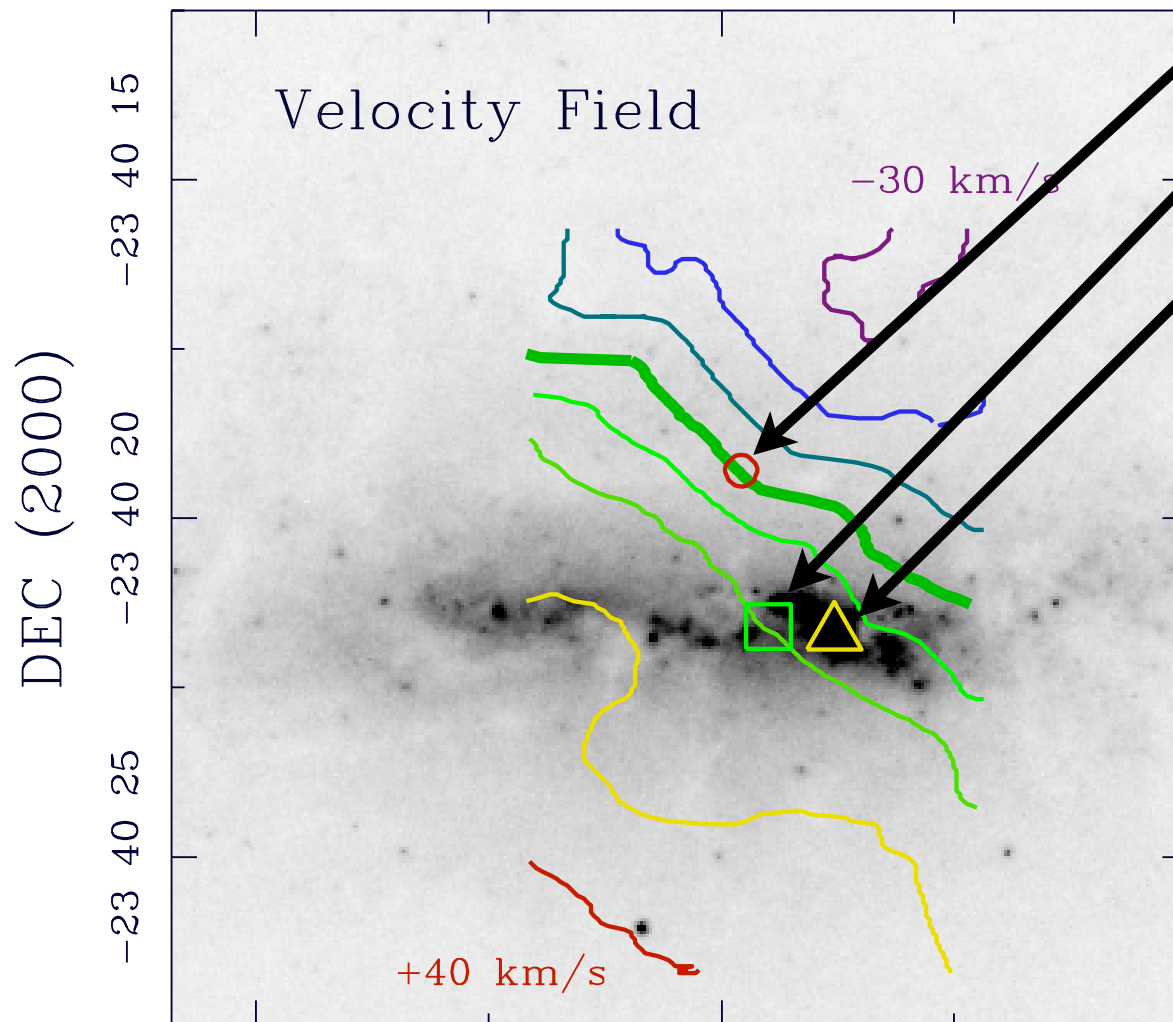
Just how nuclear are NCs?

From kinematics

H α velocity field



Odd case I in pure disk



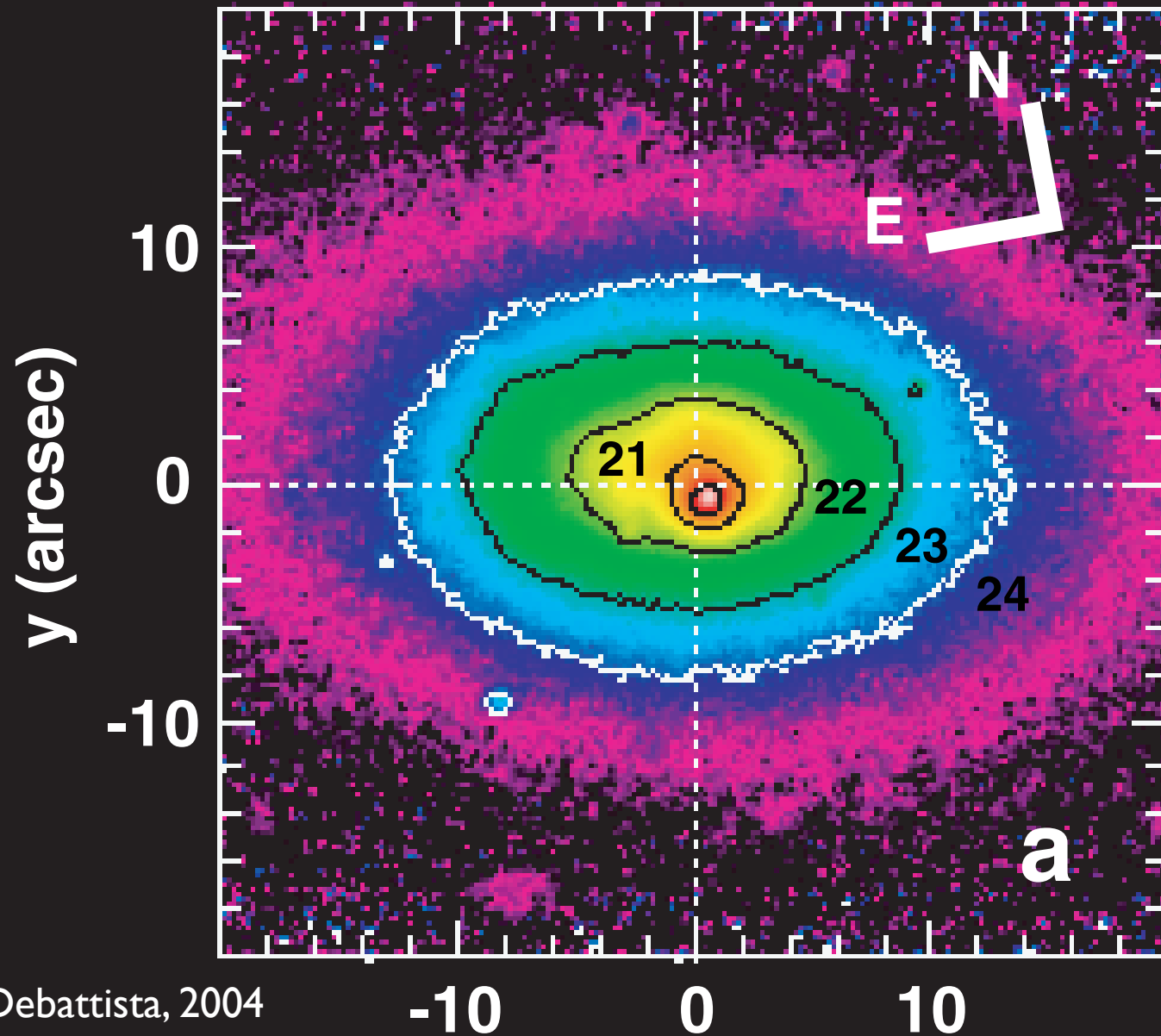
Kinematic Center
Photometric Center
Nuclear Cluster

KC and NC
offset?

Caveats:

- bar influence
- youngest NC

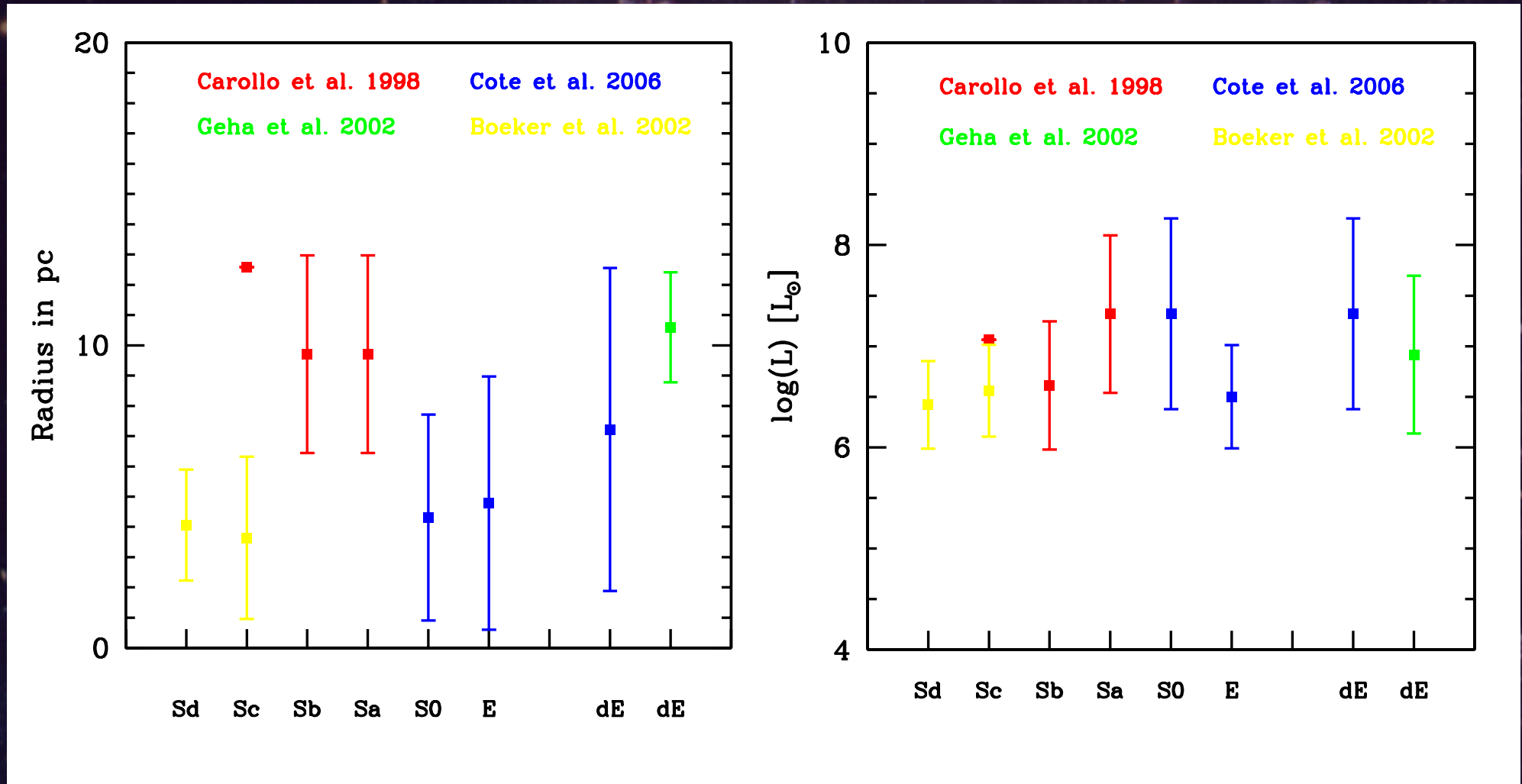
Odd case 2 in dE





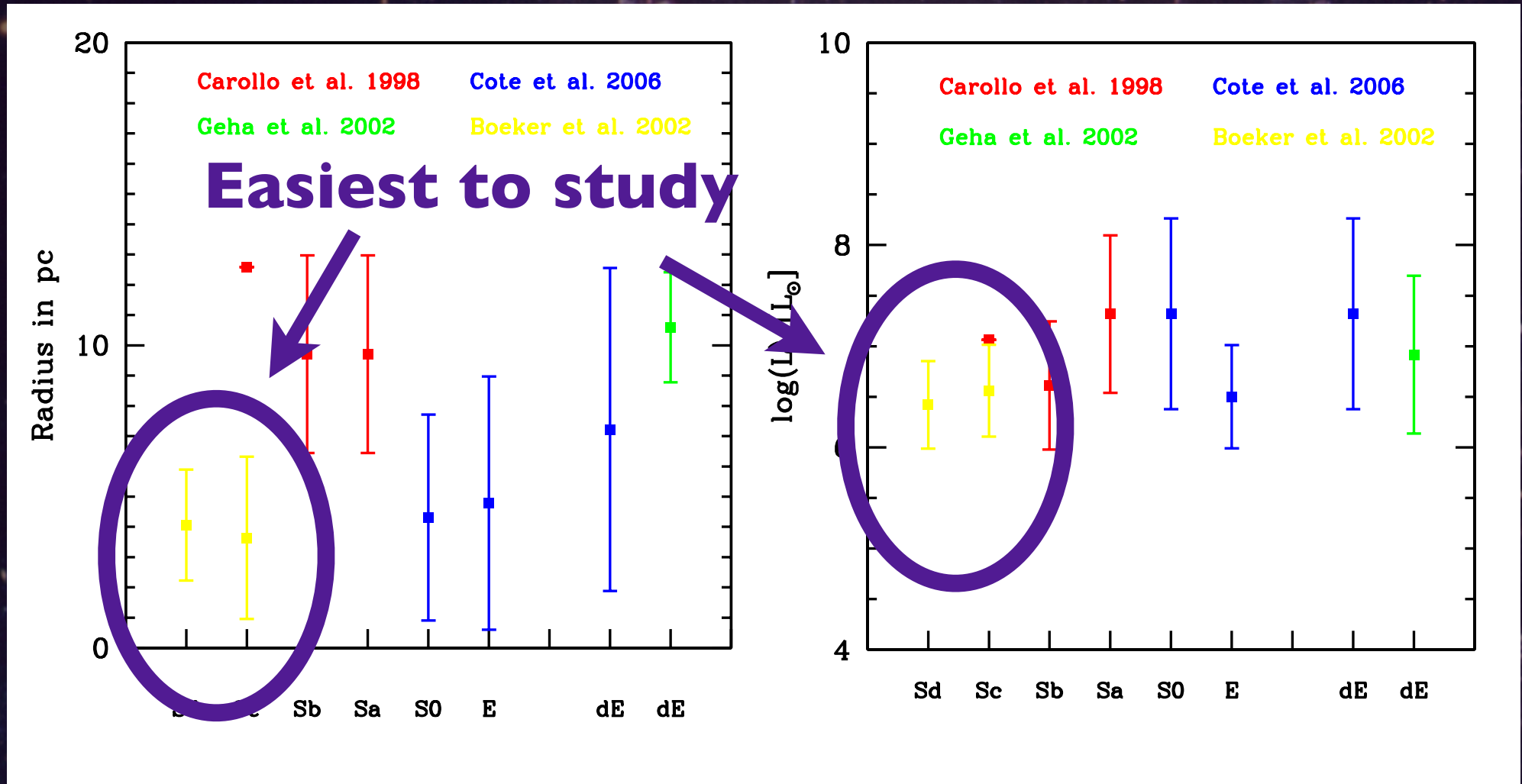
Integrated Properties

Properties over Hubble type



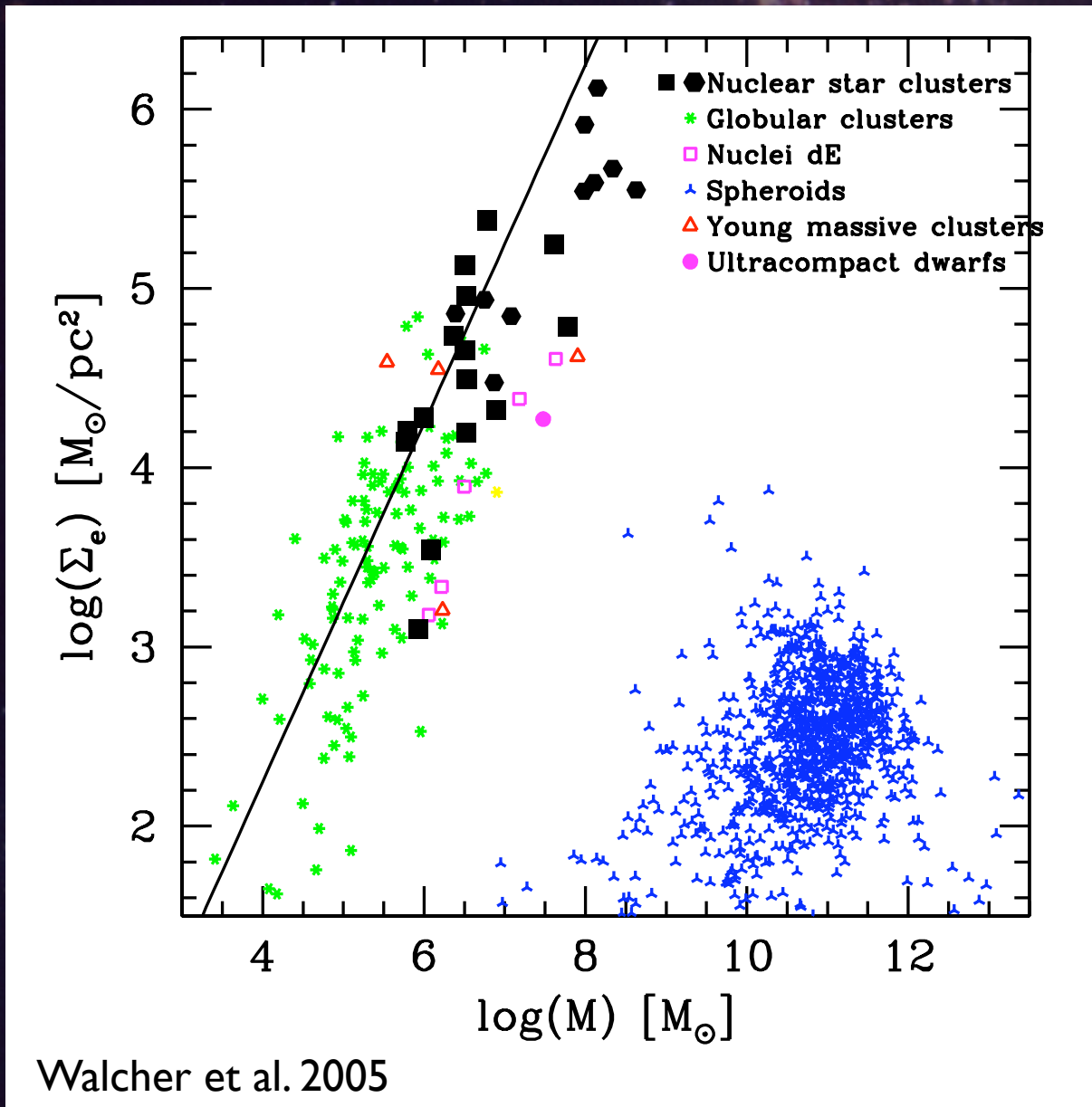
Radius depends most on authorship!
NCs are the same over the full Hubble sequence

Properties over Hubble type



Radius depends most on authorship!
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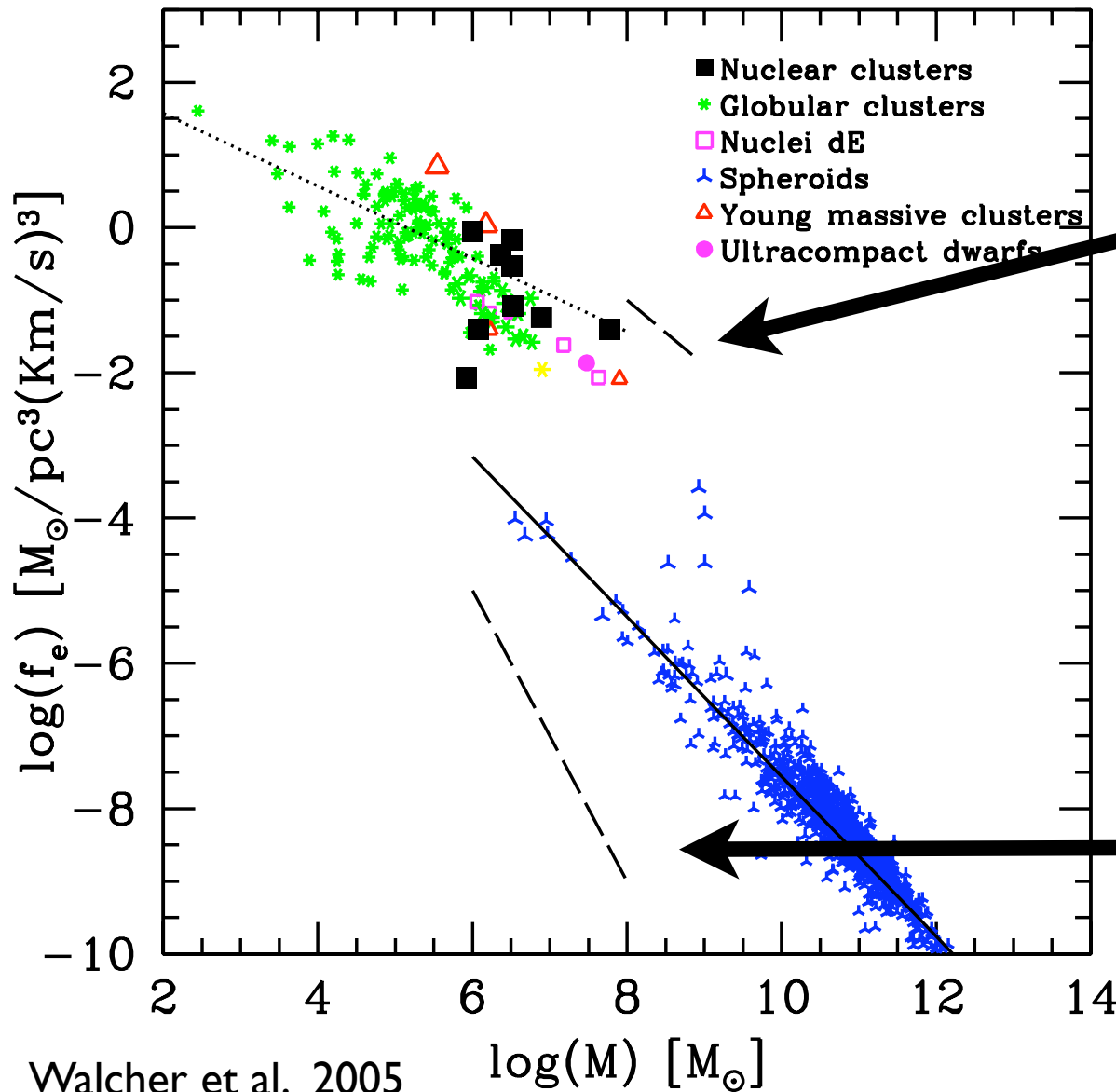
NCs are massive star clusters



Low velocity
dispersions
10-40 km/s

Highest stellar
volume densities
in the universe

Phase space densities



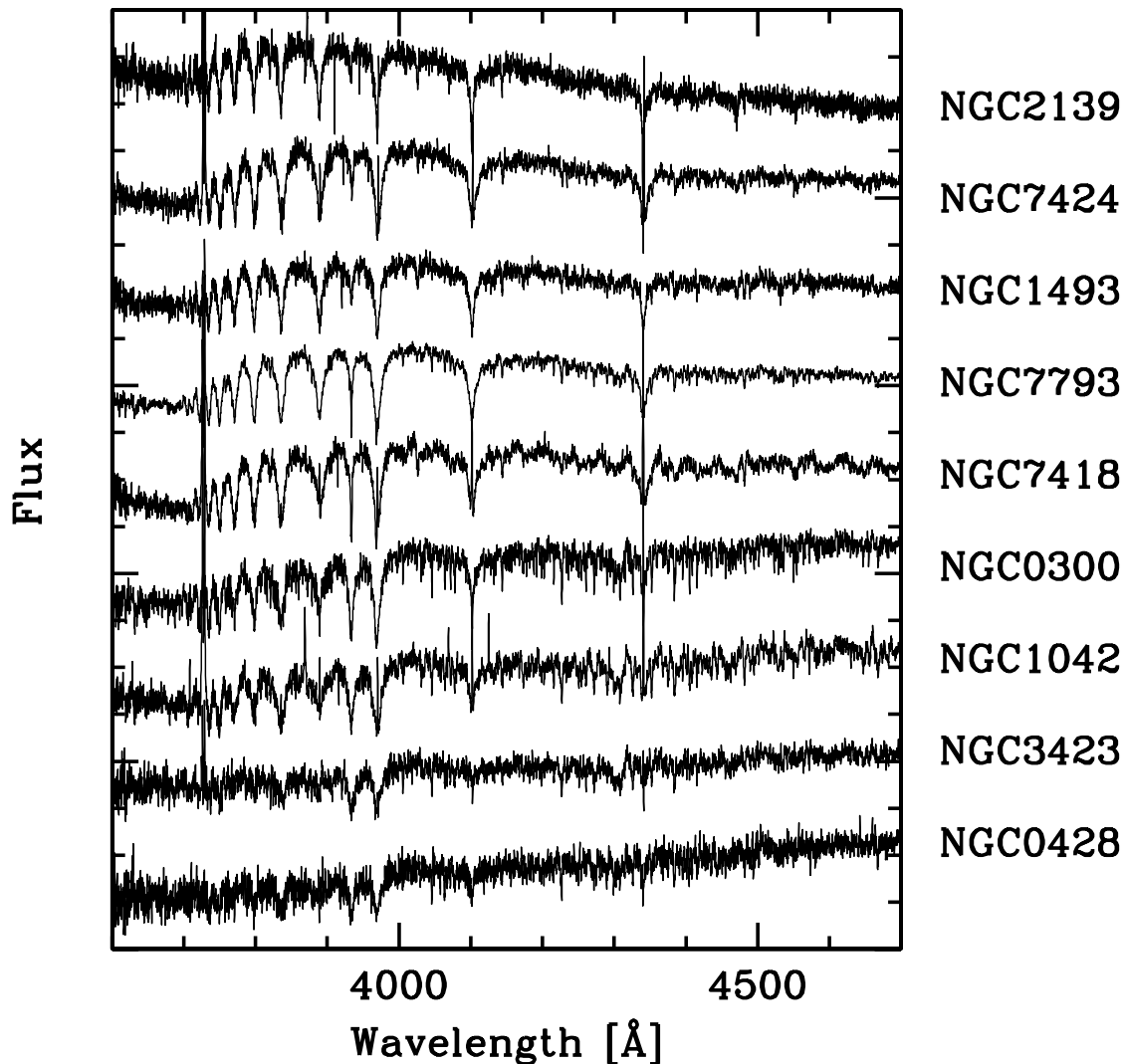
Capuzzo-Dolcetta & Miocchi, 2008

Mergers lower phase space density

Hernquist et al., 1993

Star formation histories

in gas-rich, bulge-less galaxies



UVES/VLT, Walcher et al. 2006

Recurrent star formation, because:

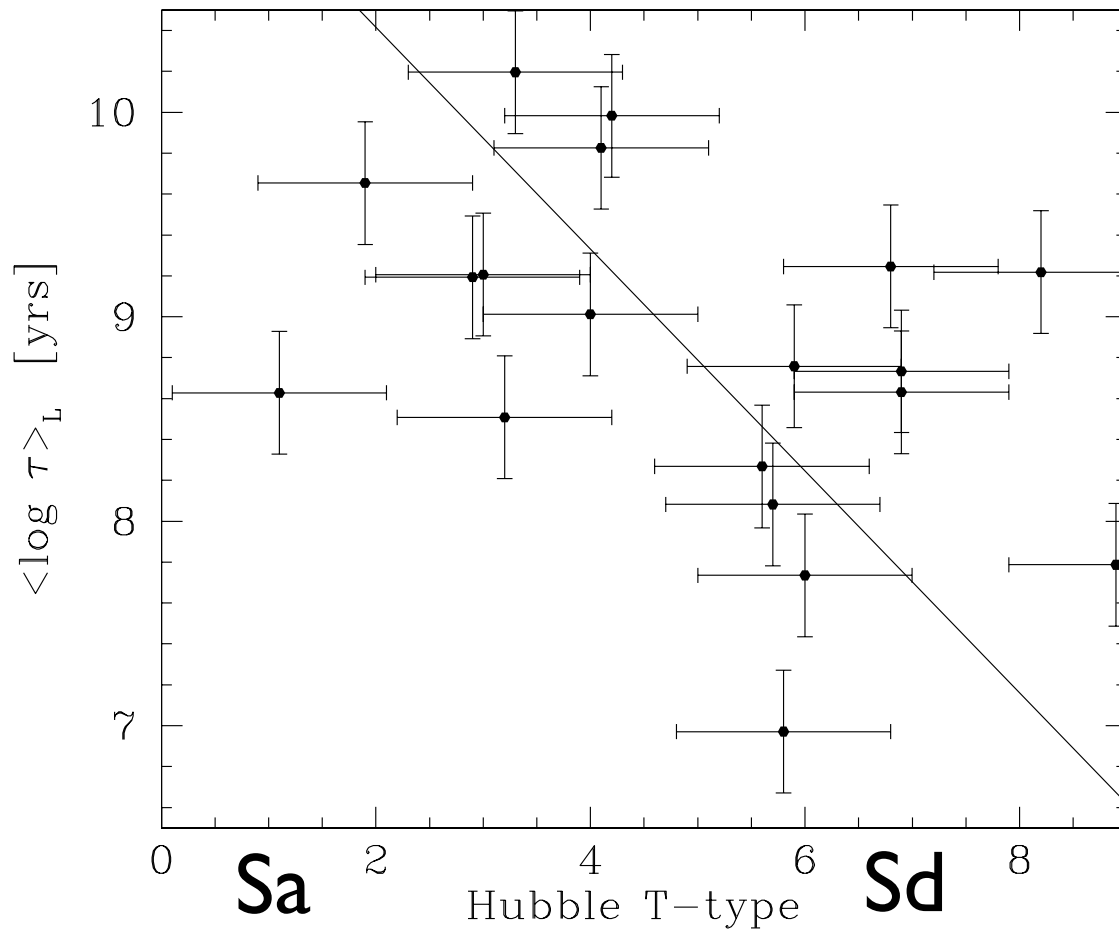
- SSPs do NOT fit
- $T_{\text{lum}} \sim 10^8 \text{ years} \ll T_{\text{Hubble}}$
- 60% have emission lines

$$\Delta T_{\text{burst}} \sim 10^8 \text{ years}$$

$$\Delta M \sim 2.5 \times 10^5 M_{\odot}$$

Star formation histories

in earlier type spirals



Rossa et al. 2006

Either shutoff of
star formation
OR
earlier onset of
effective star
formation

Star formation histories

in early type galaxies



Star formation histories

in early type galaxies

Good question!



Star formation histories

in early type galaxies

Good question!

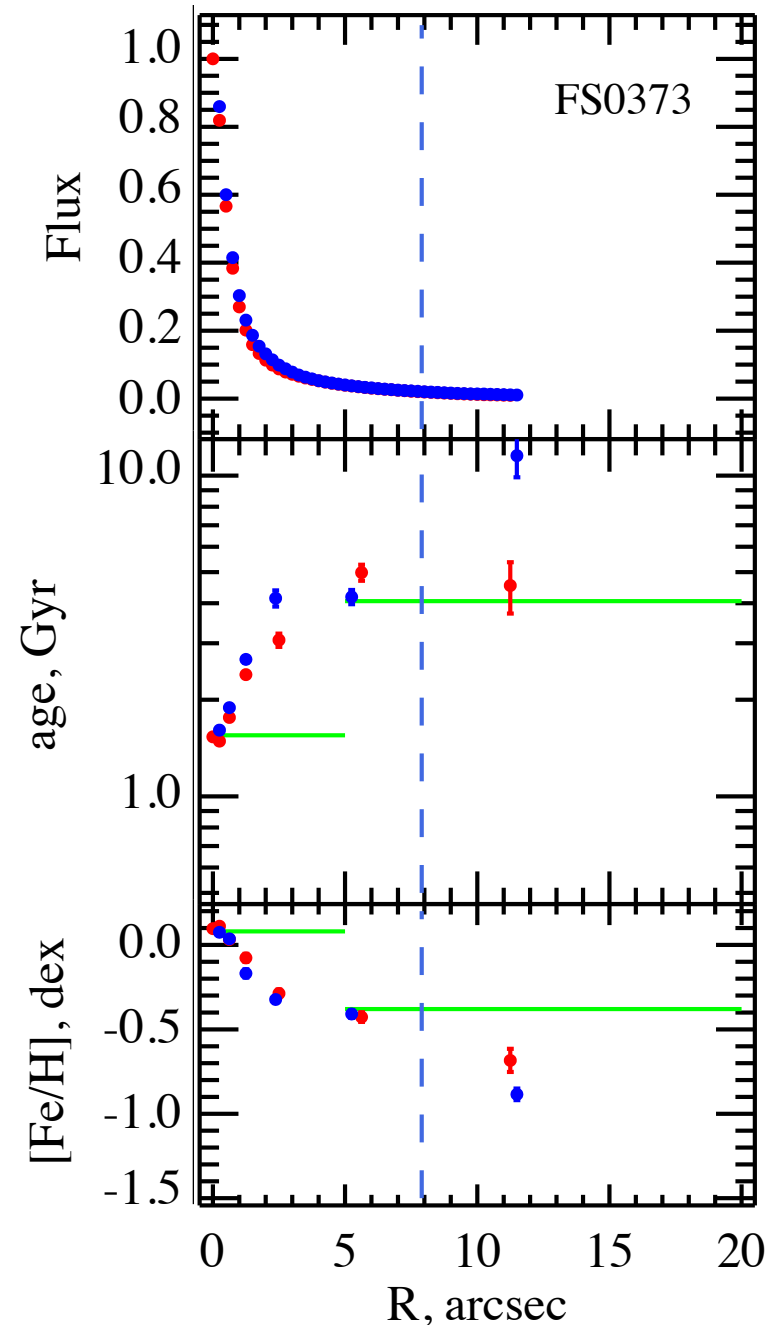
- Imaging from space: nuclei are younger than their hosts but older than 2 Gyr (Lotz et al. 2004, Cote et al. 2006)
- Spectra from ground: In S0's the central regions are younger and α -enhanced (Silchenko et al.). dE nuclei are younger and can form stars later than their hosts (Chilingarian et al. 2007, Koleva et al. 2009)
- We would need a STIS program for resolution, but NCs too faint!

Star formation

in early type galaxies

Good question

- Imaging from space: nuclei are young but hosts but older than 2 Gyr
- Spectra from ground: In S0's younger and α -enhanced (Silberman et al. 2007) younger and can form stars (Chilingarian et al. 2007, Koleva et al. 2009)
- We would need a STIS program to see if NCs too faint!



Koleva et al. 2009

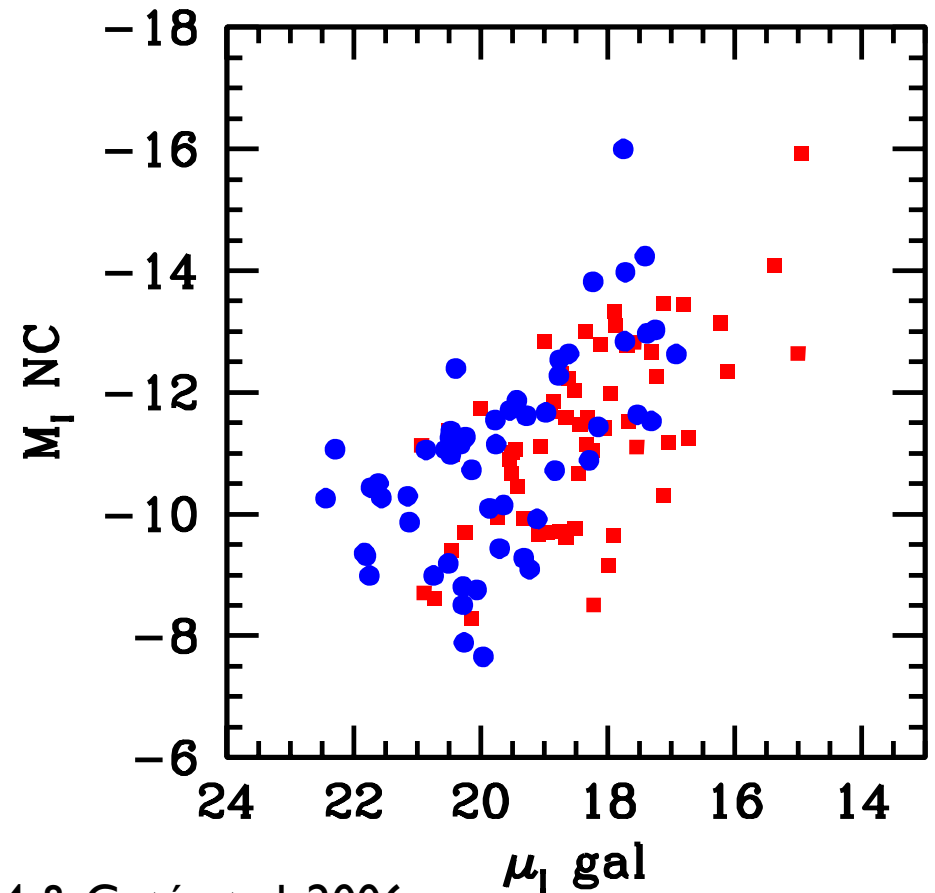
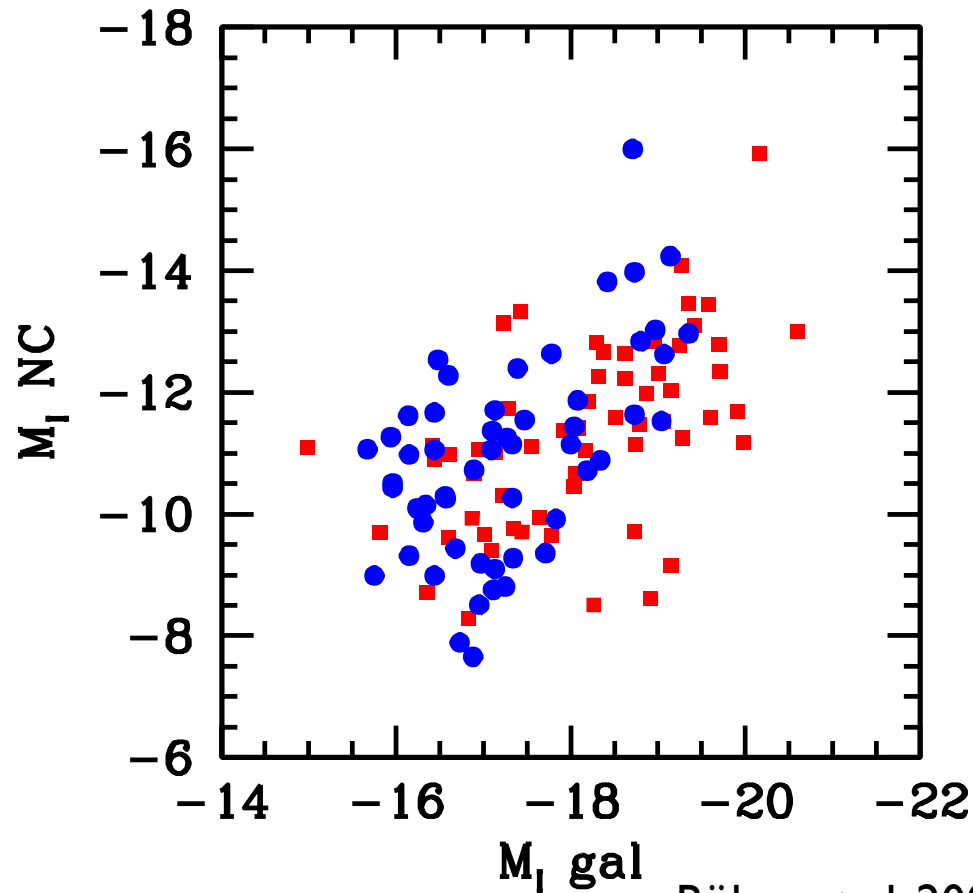
Star formation histories

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He that has plenty of goods shall have more



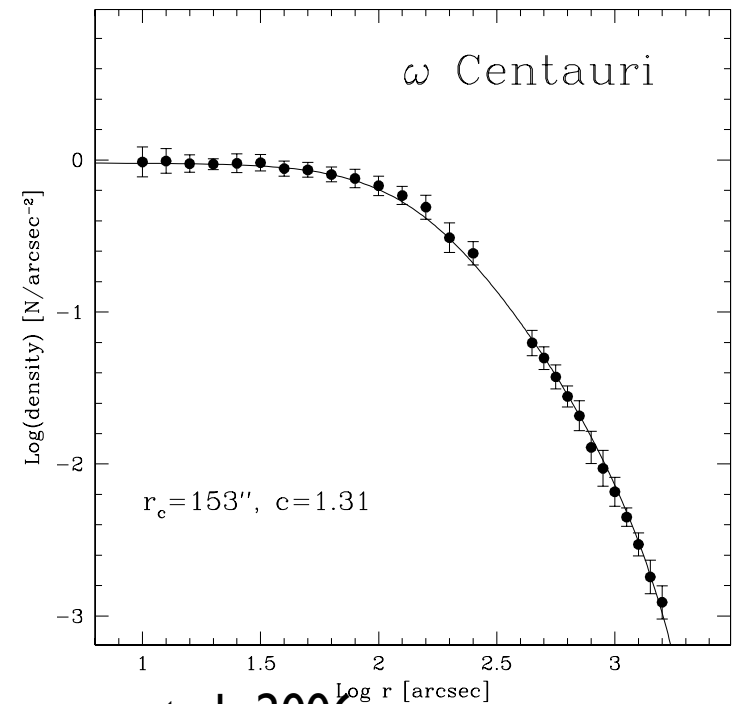
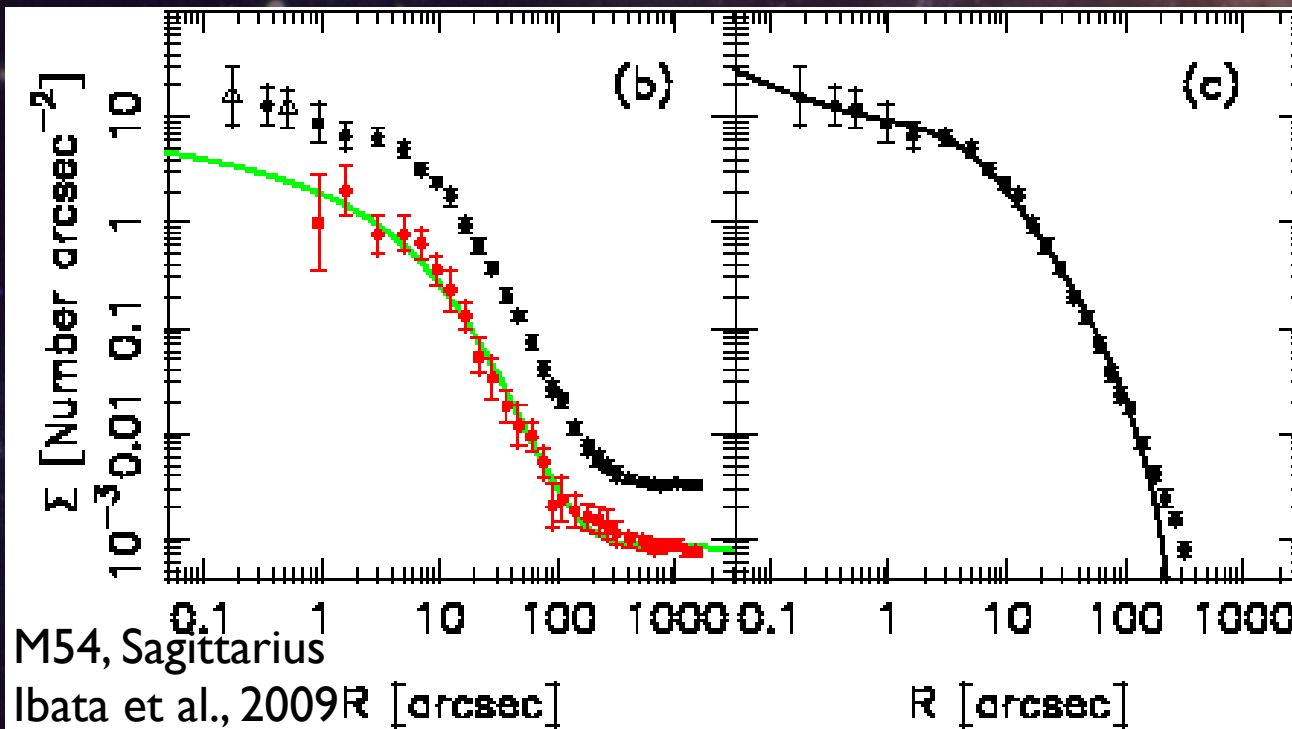
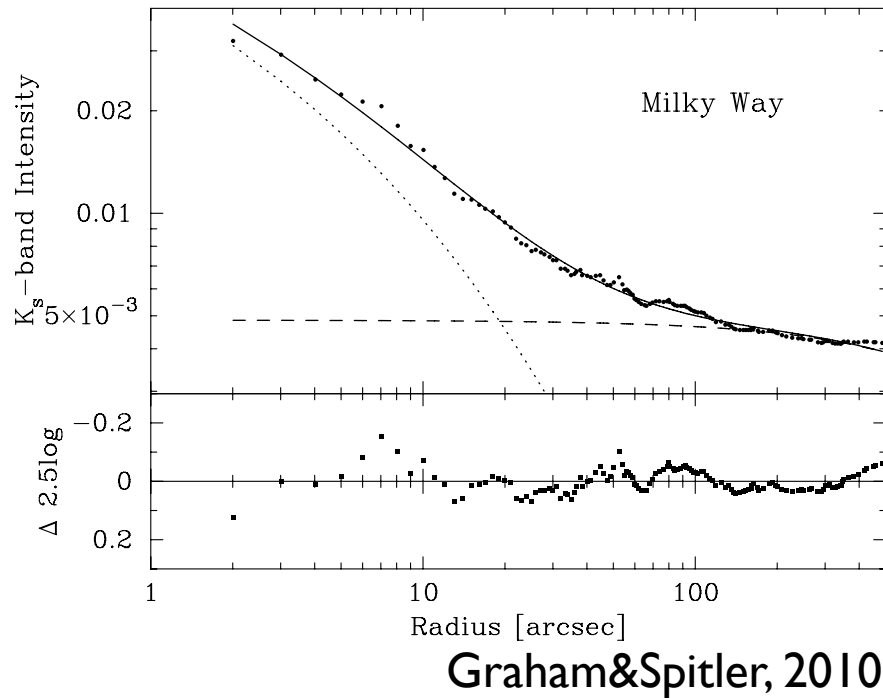
Böker et al. 2004 & Côté et al. 2006



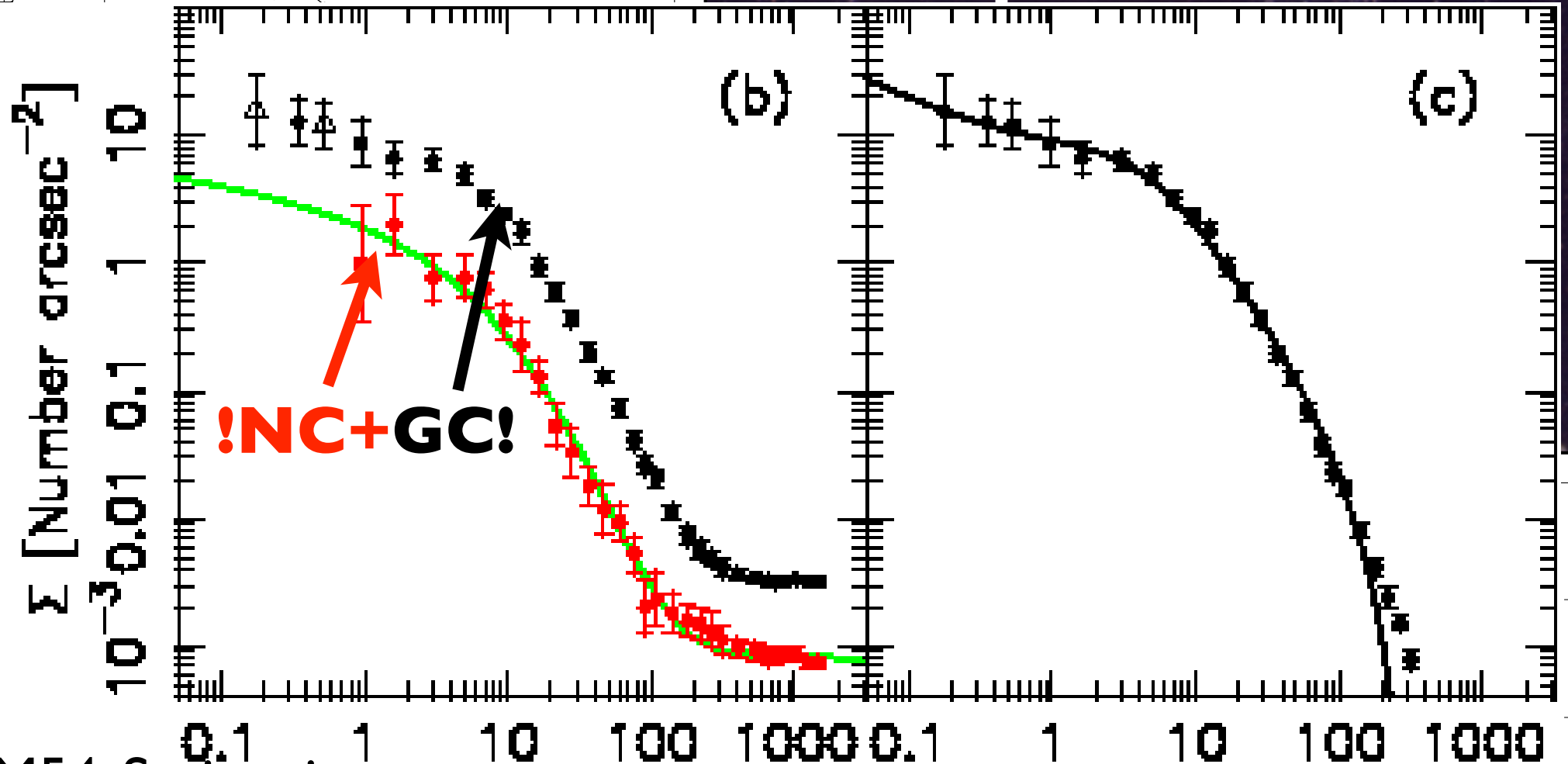
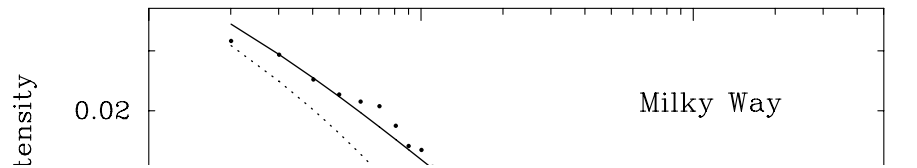
NC internal structure

SB profiles

- In MW and M32 Sersic with $n \sim 2-3$? (Graham&Spitler 2010)
- For GCs people use King (sometimes with cusp)



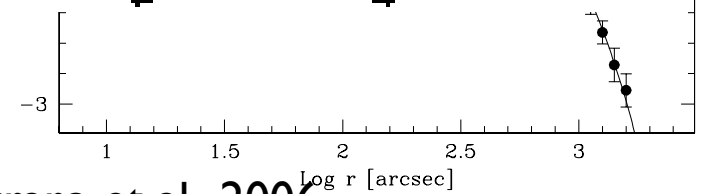
SB profiles



M54, Sagittarius

Ibata et al., 2009

R [arcsec]



Ferraro et al., 2006

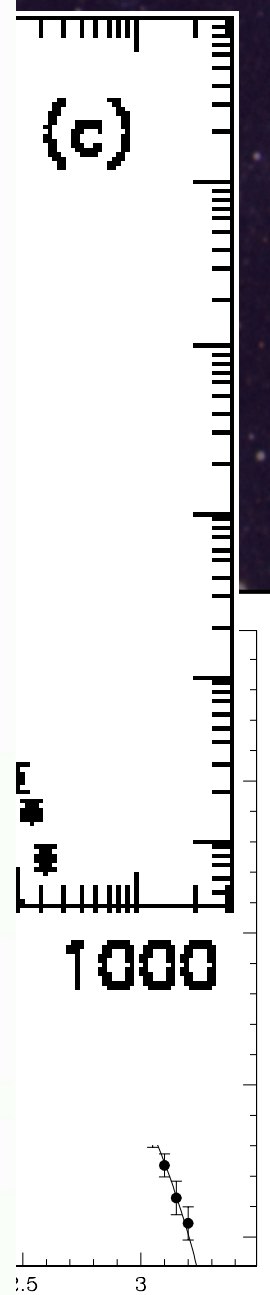
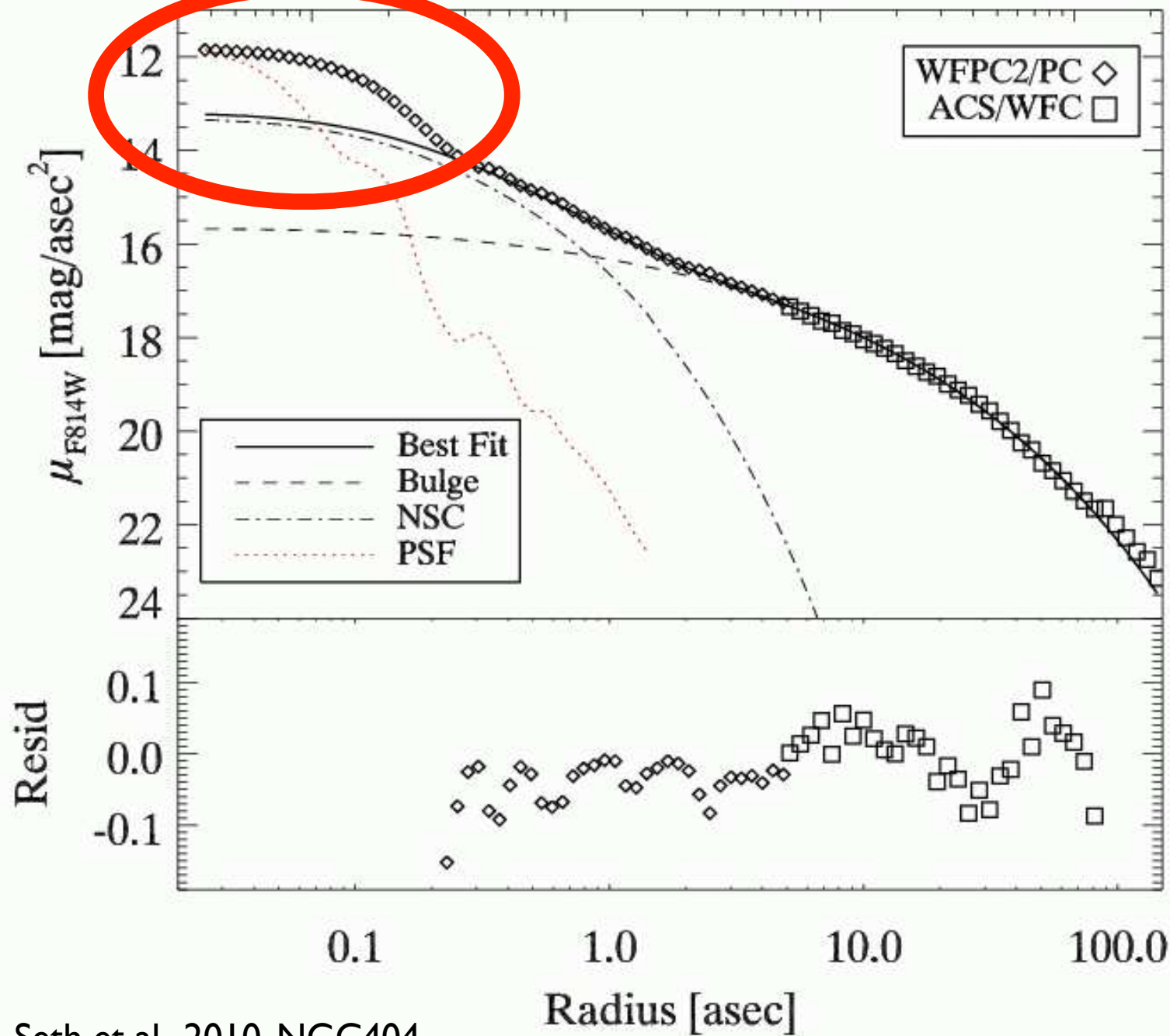
Σ [Number arcsec⁻²]

10⁻³ 0.01 0.1 1 10

M54, Sag
Ibata et al.

density
0.02

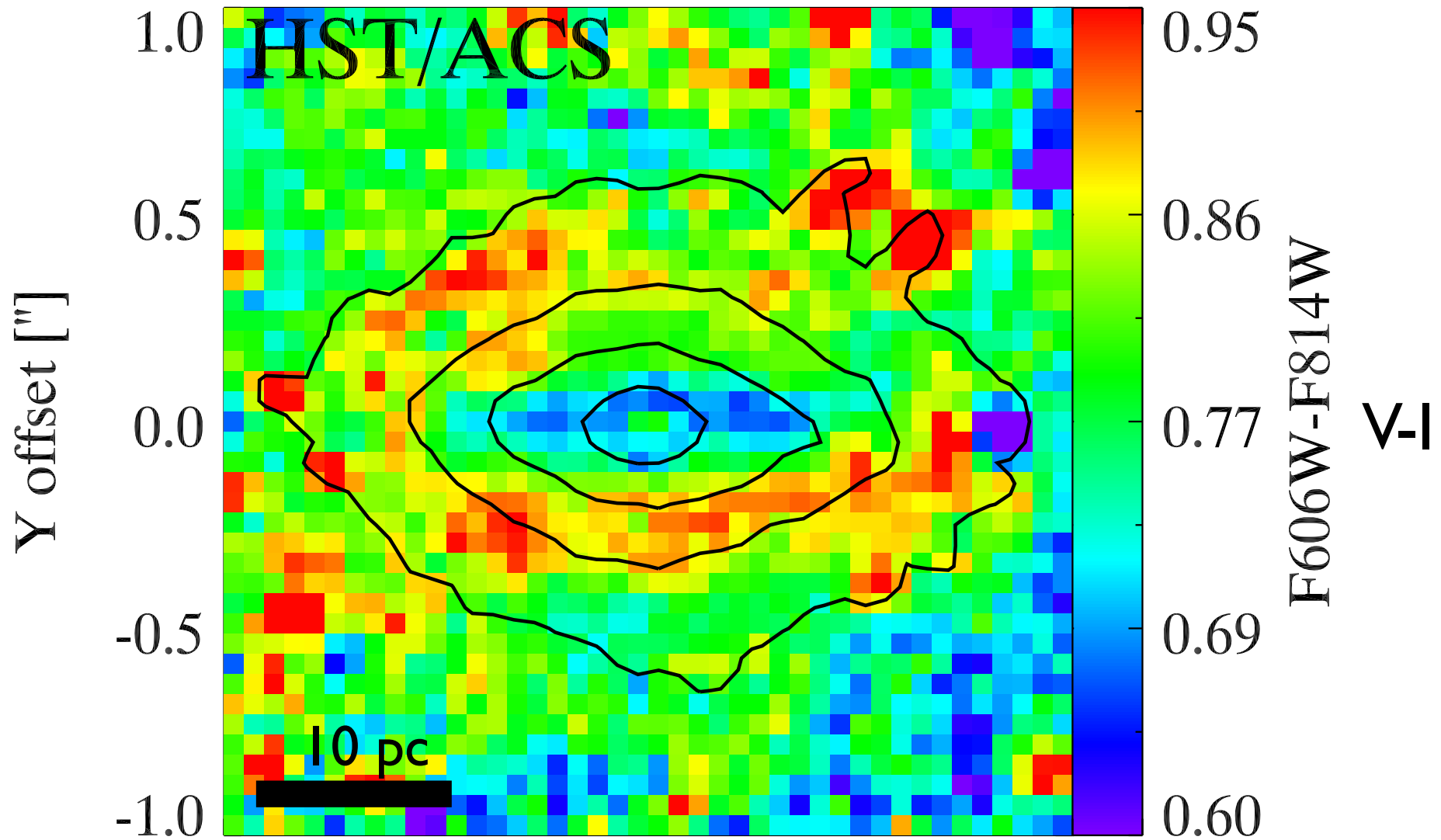
Central cusp



Seth et al., 2010, NGC404

Ferraro et al., 2006

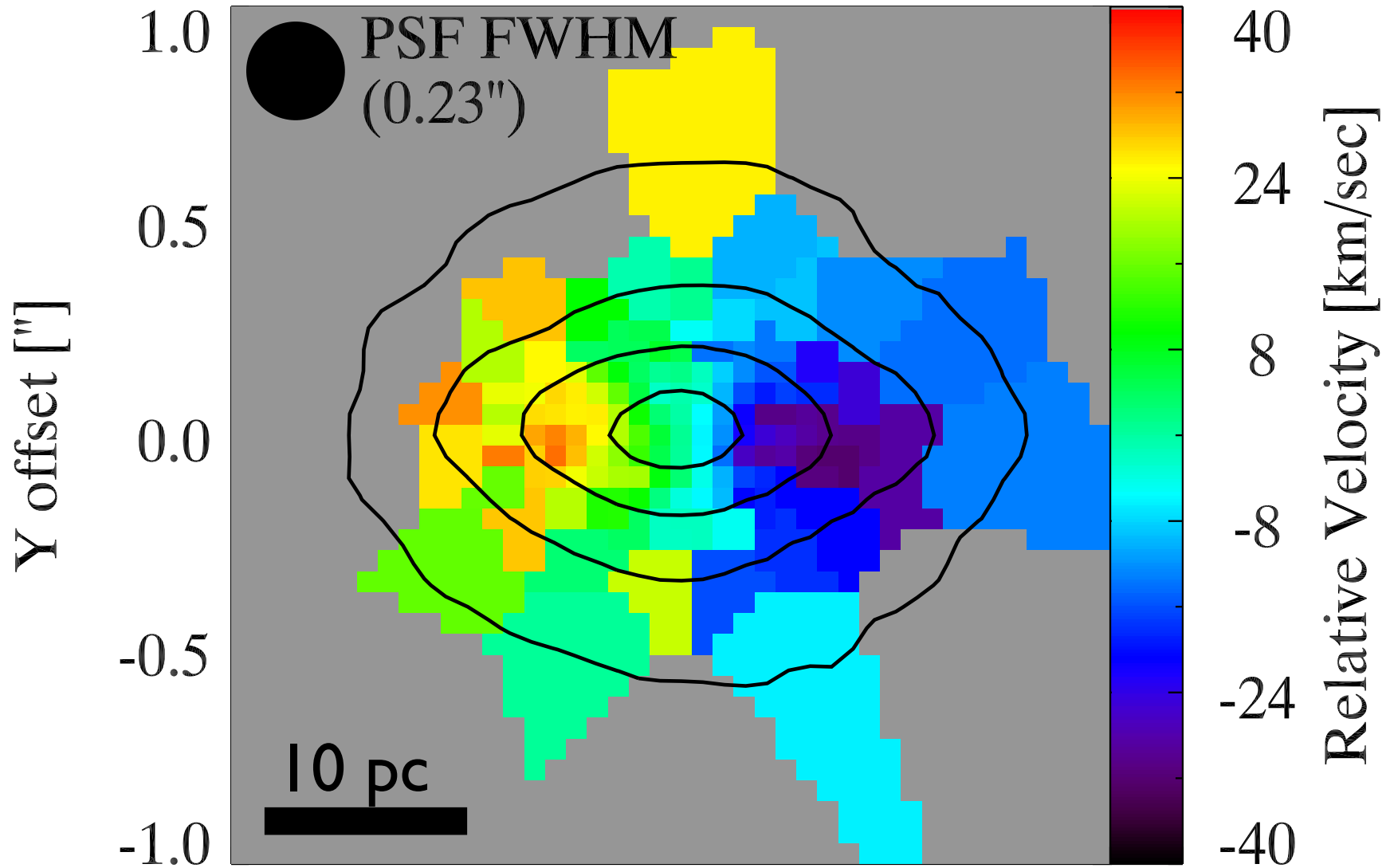
Blue disks around NCs



NGC4244, ACS/HST, Seth et al. (2006)

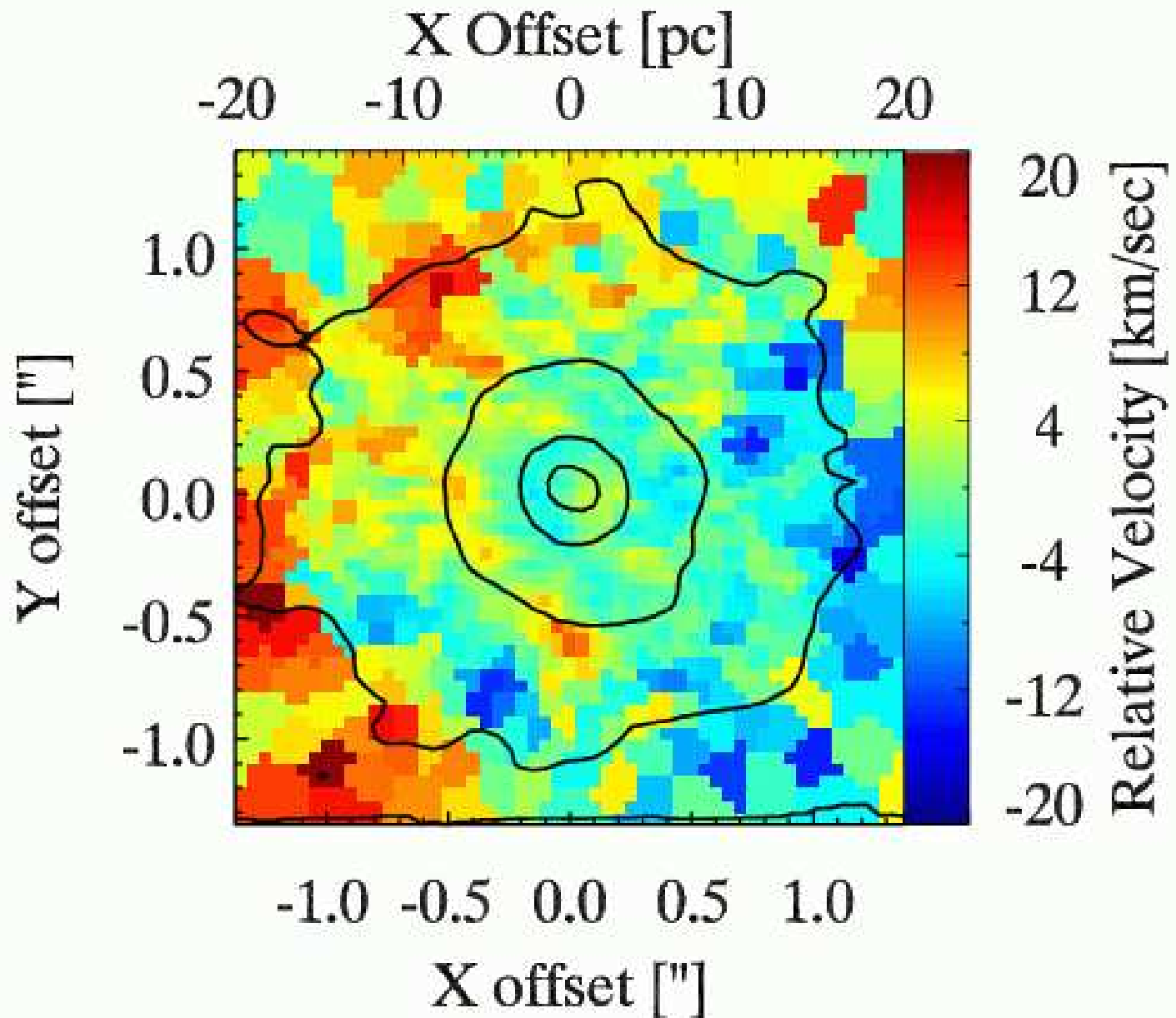
See also e.g. Marconi et al. 2003

NCs rotate ...



Seth et al., 2009, NGC4244

... and counterrotate!



Seth et al. (2010)
NGC404

NCs and BHs

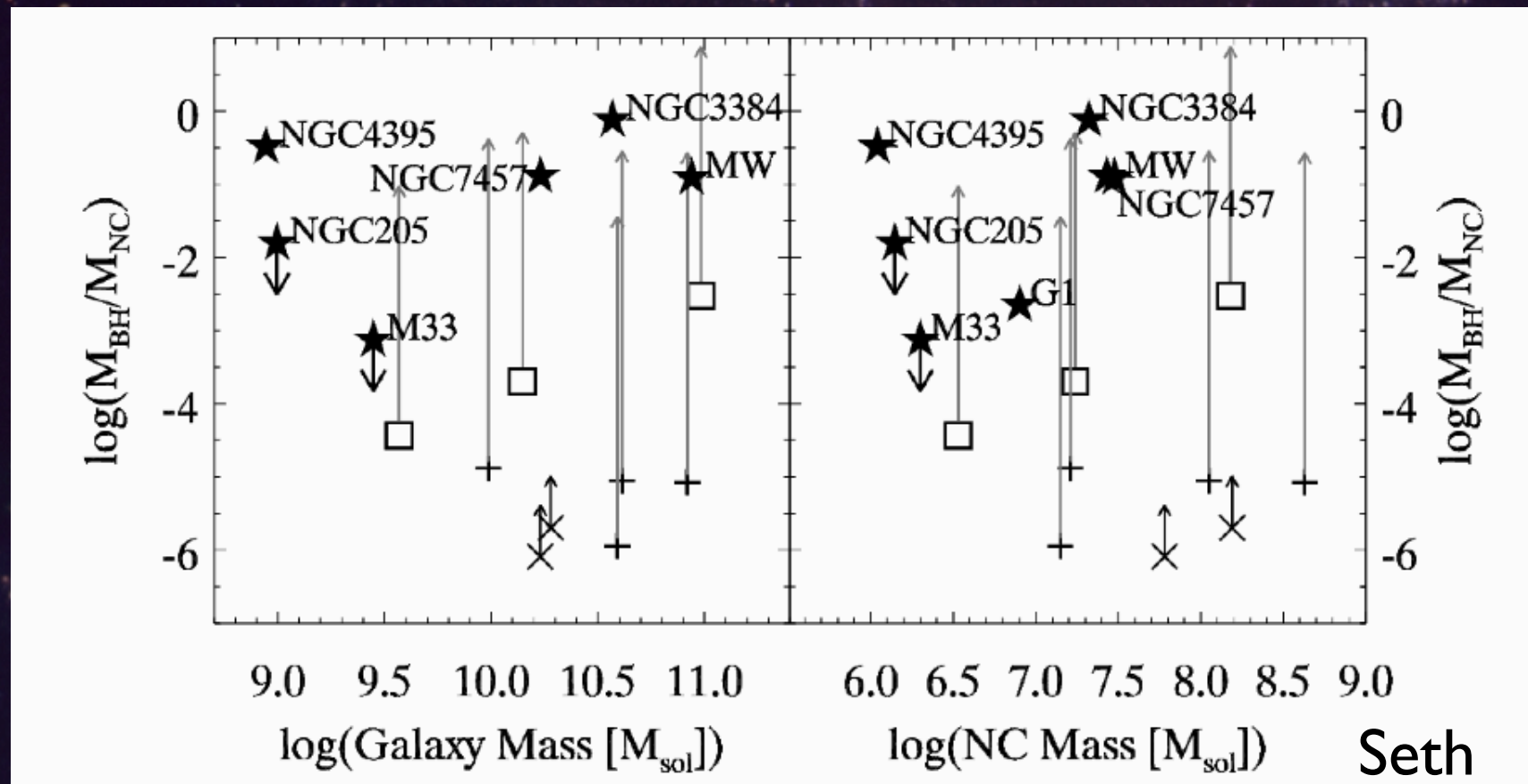
NC coevolution with their host galaxies
can not only be studied in terms of mass,
but also in terms of stellar populations!

NCs and BHs coexist

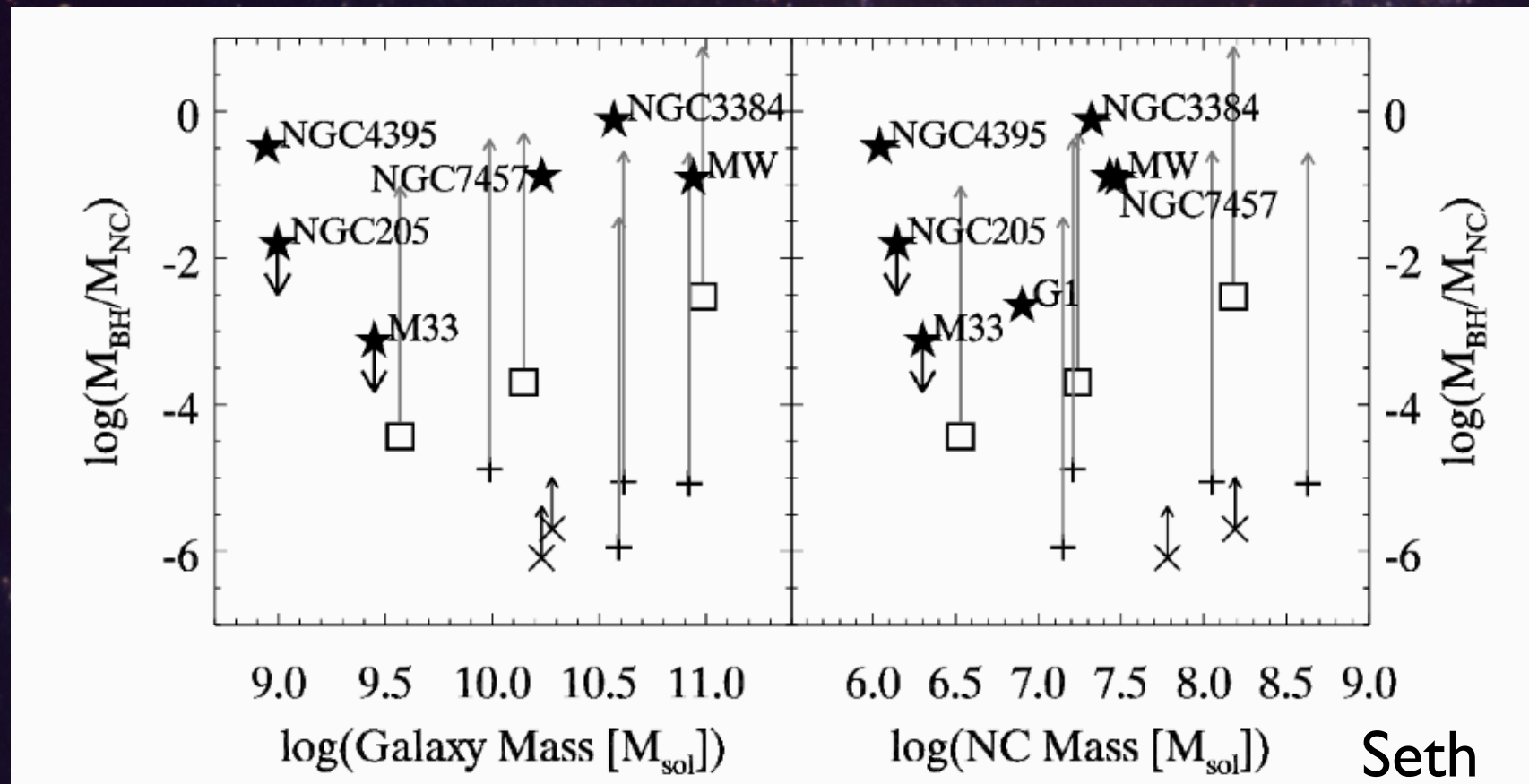
For example in pure disks,
4 cases are known

- NGC4395 Filippenko & Sargent 1989
- NGC 3621 Satyapal et al. 2007, Barth et al. 2008
- NGC1042 Shields et al. 2008
- NGC 4178 Satyapal et al. 2009

NCs and BHs coexist

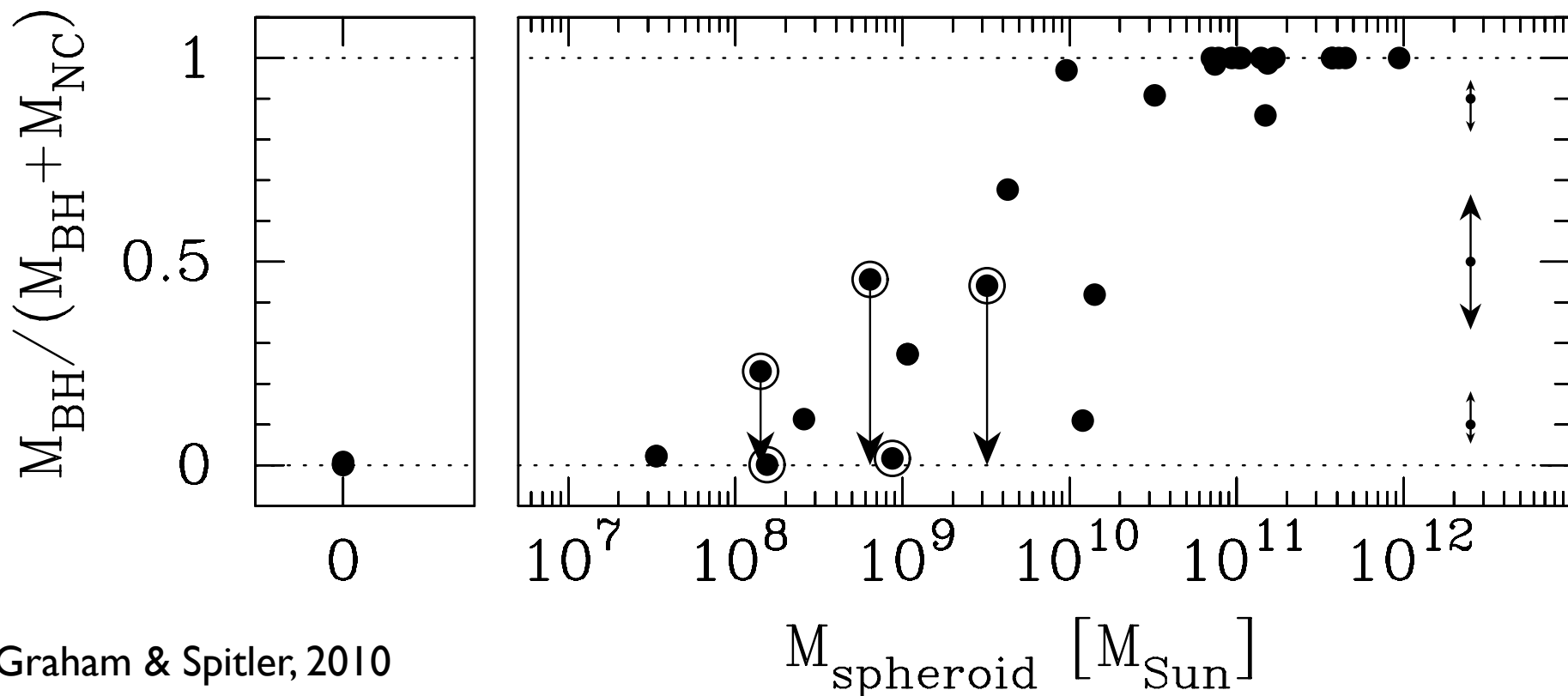
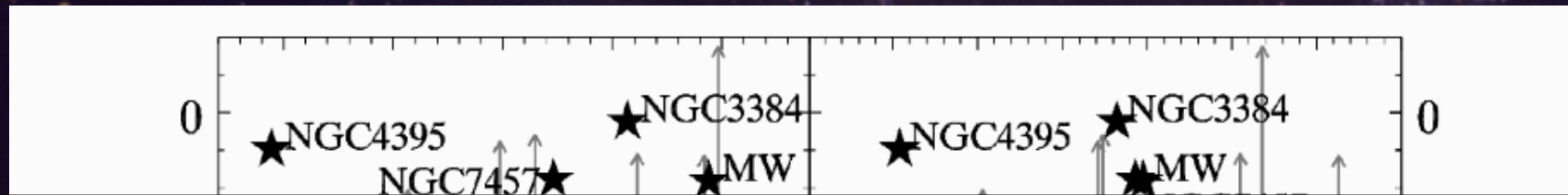


NCs and BHs coexist



Every time you say something about the nucleus of a galaxy you have to make sure you resolve the NC ($\sim 5\text{pc}$). Even with HST ($0.05''$) this is only possible to a distance of 20 Mpc

NCs and BHs coexist



Graham & Spitler, 2010

resolve the NC ($\sim 5 \text{ pc}$). Even with HST ($0.05''$)
 this is only possible to a distance of 20 Mpc

NCs and BHs coexist

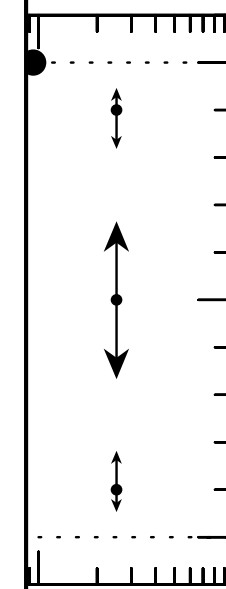
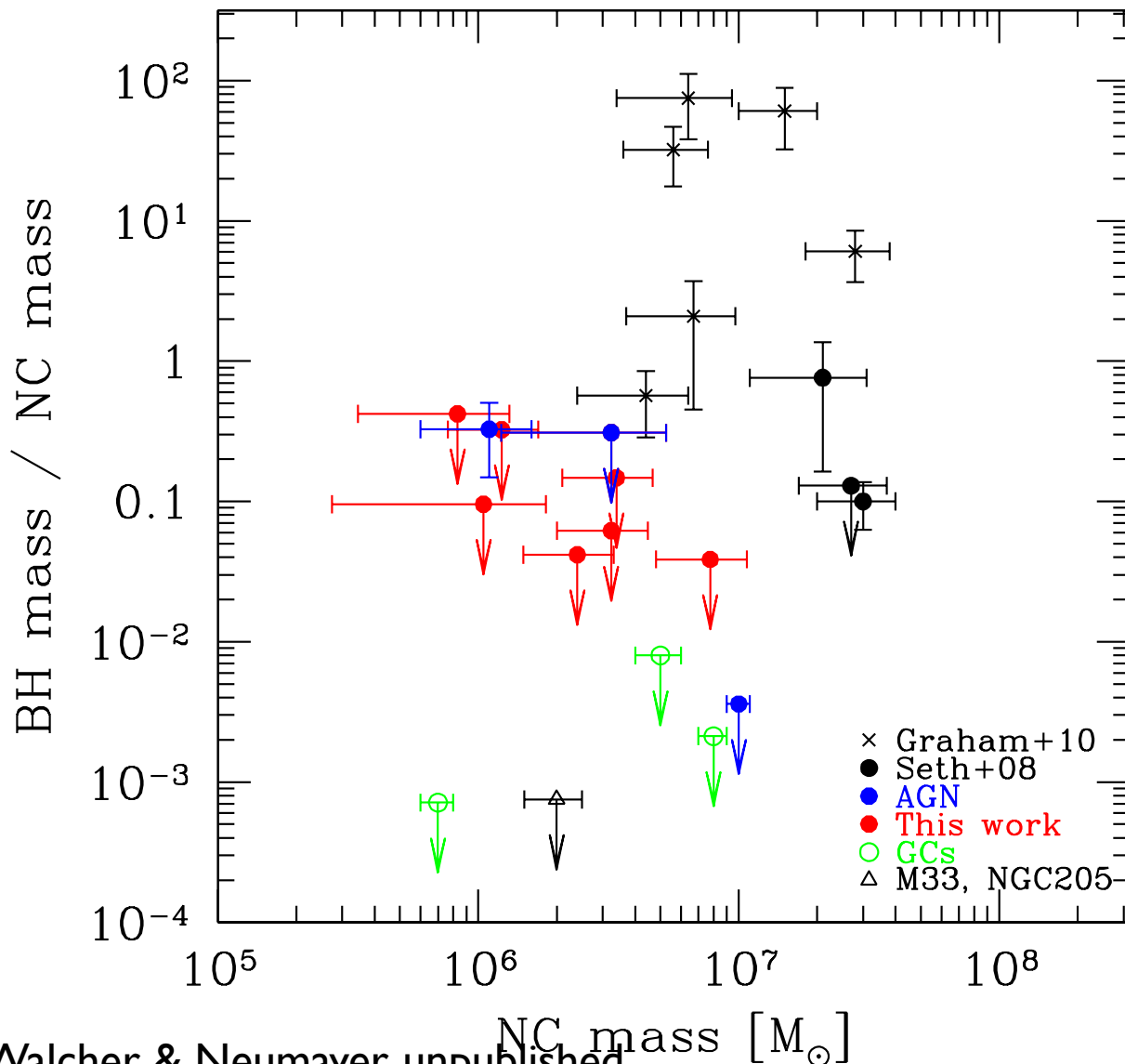
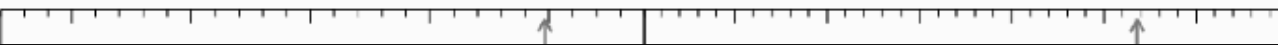
$$M_{\text{BH}} / (M_{\text{BH}} + M_{\text{NC}})$$

0.5

Graham & S

RESOLV

this is

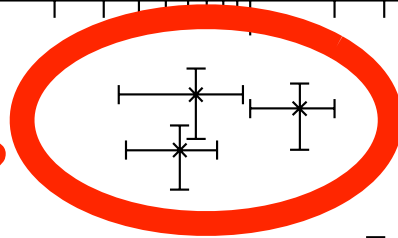


12

0.05)
Mpc

NCs and BHs coexist

Should we believe this?



$$M_{\text{BH}} / (M_{\text{BH}} + M_{\text{NC}})$$

0.5

Graham & S

RESOLV

this is

BH mass / NC mass

10^1
1
0.1
 10^{-2}
 10^{-3}
 10^{-4}

10^5

10^6

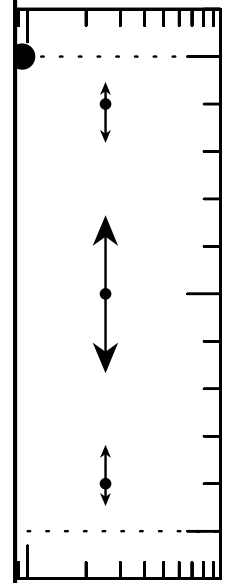
10^7

10^8

NC mass [M_{\odot}]

Walcher & Neumayer, unpublished

- × Graham+10
- Seth+08
- AGN
- This work
- GCs
- △ M33, NGC205



12

0.05

Mpc

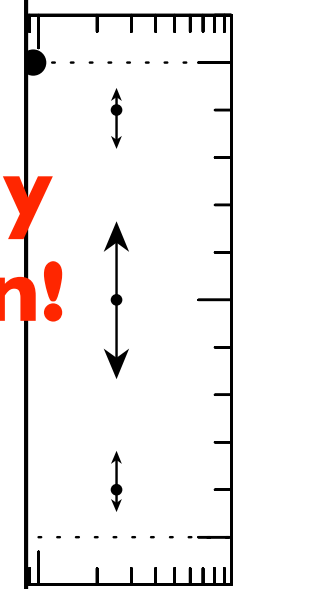
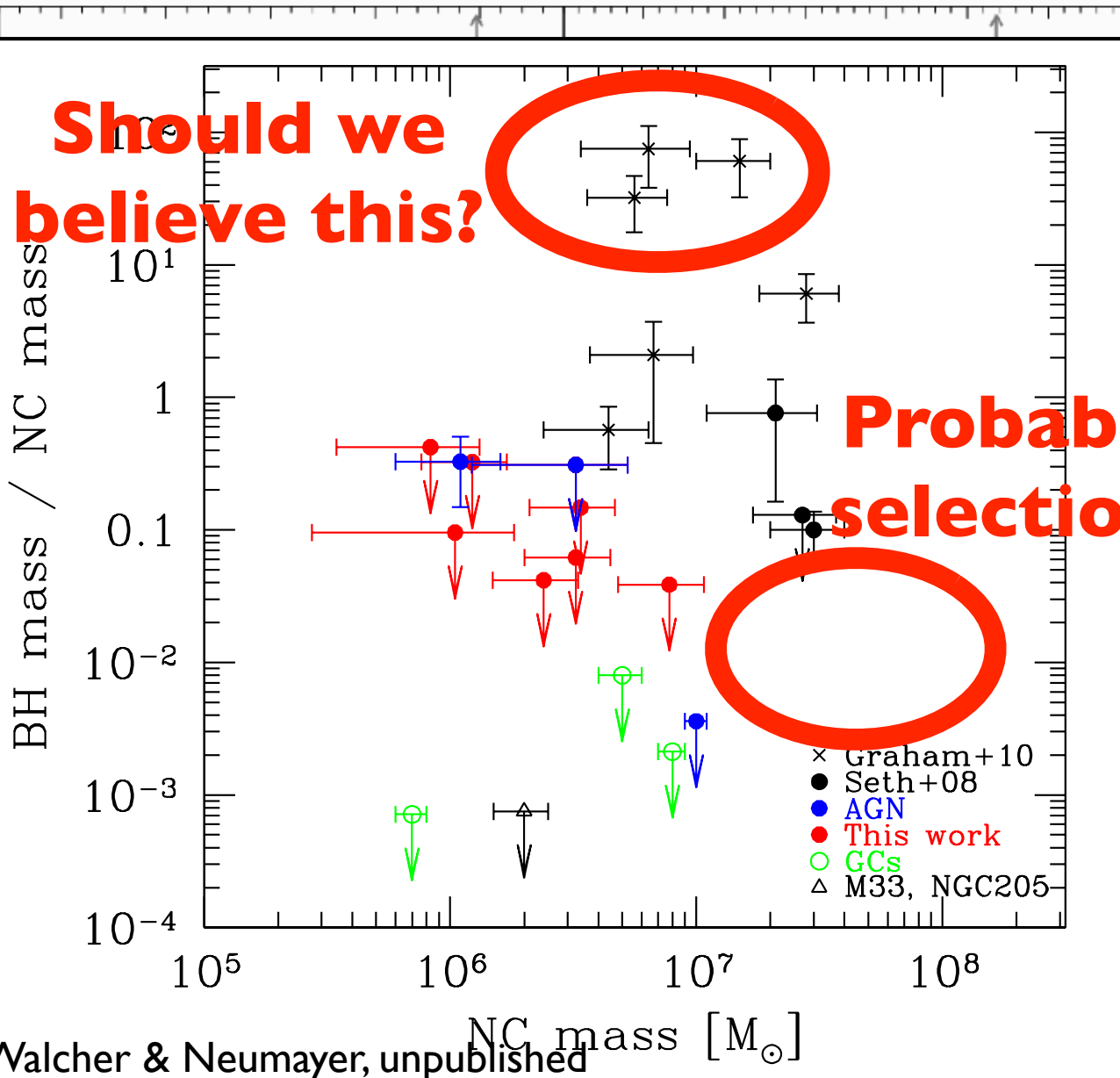
NCs and BHs coexist

$$M_{\text{BH}} / (M_{\text{BH}} + M_{\text{NC}})$$

Graham & S

RESOLV

this is



12

0.05
Mpc

They cannot all lie on the same relation!

- Galaxies and their BHs
- NCs (GCs) and their BHs
- Galaxies and their NCs

Summary

- >75% of all galaxies from E to Sd have Nuclear Star Clusters in their photometric and kinematic centers.
- These NCs are massive, compact star clusters that form stars recurrently as long as there is a gas supply. Some of them contain massive Black Holes.
- NCs probably have complex spatial and kinematic structures. → ongoing work
- I believe that NC structure and BH masses are interdependent and not well enough understood.

A proposed paradigm for NC formation in a pure disk

- 1) Disks form without a nucleus
- 2) Through random sampling of the cluster mass function a massive cluster forms with a likelihood proportional to the total integrated surface SFR (SB)
- 3) Once the cluster is formed it wanders to the kinematic center and keeps growing through accretion of gas and other clusters
- 4) When the NC is massive enough to dominate the local central potential it becomes the true nucleus