Virgo Redux:

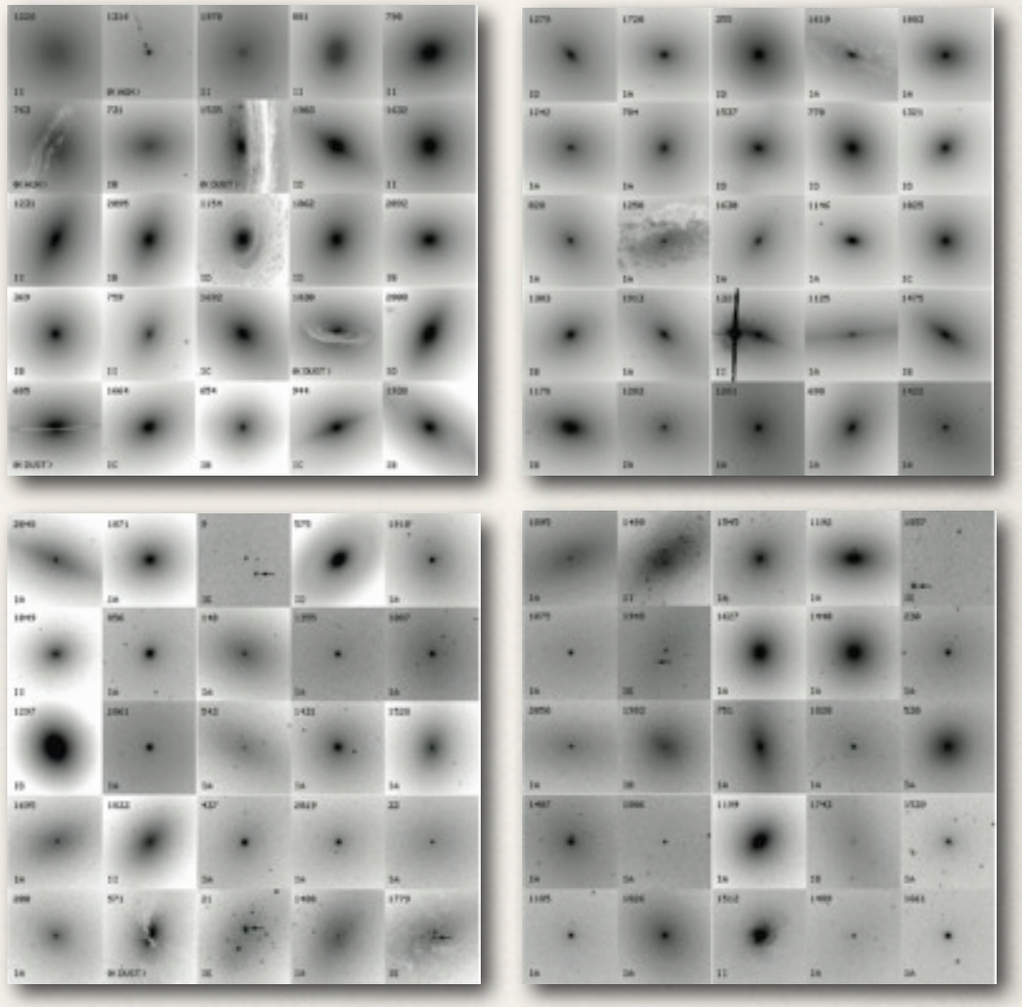
The Structure and Stellar Populations of the Central Regions of Early-Type Galaxies

Lisa Glass, Laura Ferrarese, Patrick Côté, Andrew Zirm, John Blakeslee, Andrés Jordán, Simona Mei, Eric Peng, Michael J. West

June 30, 2011

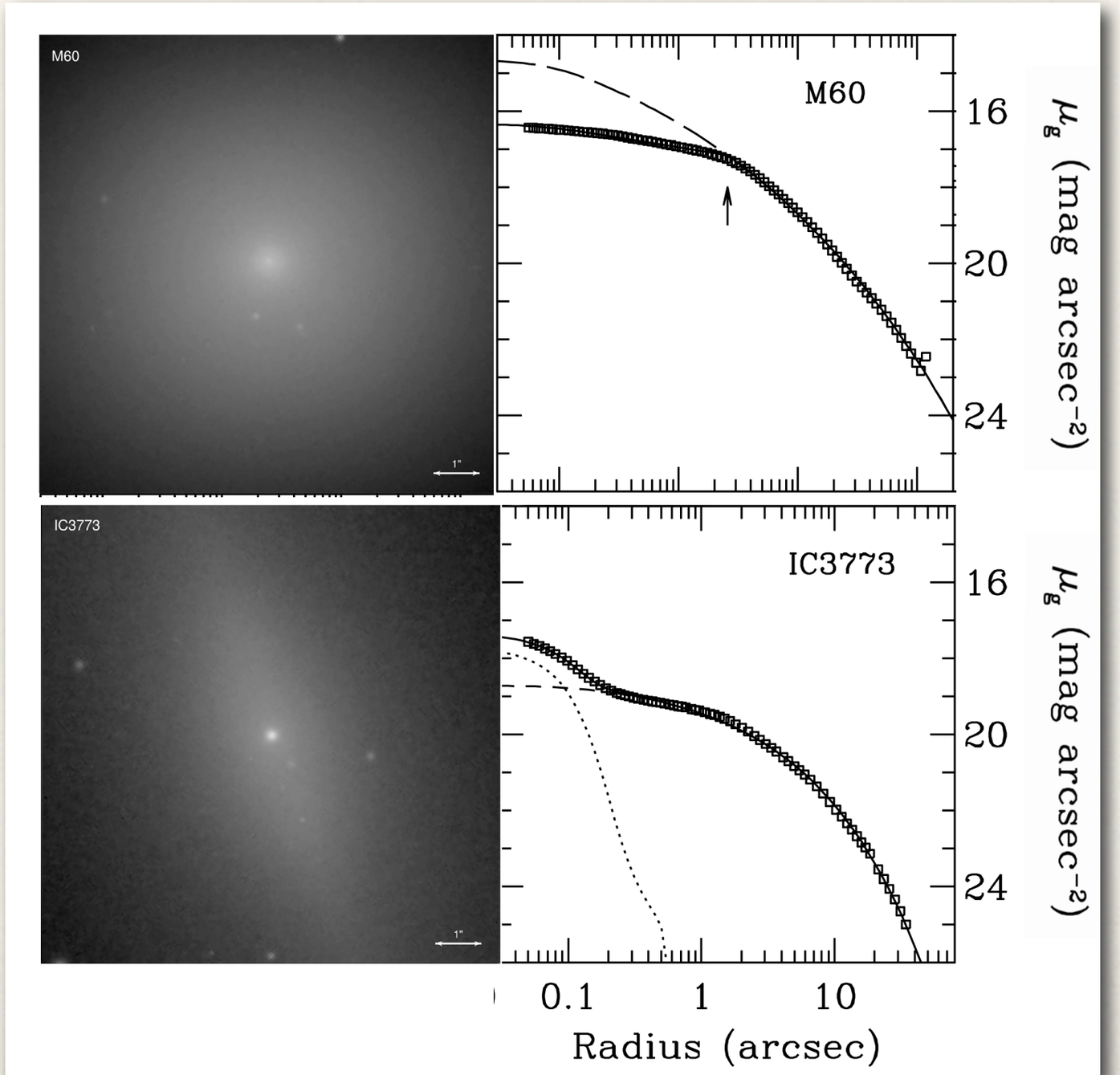
ACS Virgo Cluster Survey (ACSVCS; see Côté et al. 2004)

- HST/ACS F475W (~g) and F850LP (~z) imaging survey
- 100 early-type galaxies (E, S0, dE, dE,N, or dS0) in the Virgo cluster.
- 0.1 arcsec resolution = 8.0 pc
- Spans factor of over 500 in B-band luminosity.
- Complete down to M_B~-19.2 mag, 44% complete down to its limiting magnitude of M_B~-15.2 mag



Central Light Deficit to Excess

(Ferrarese et al. 2006; Côté et al. 2006,2007; Glass et al. 2011)



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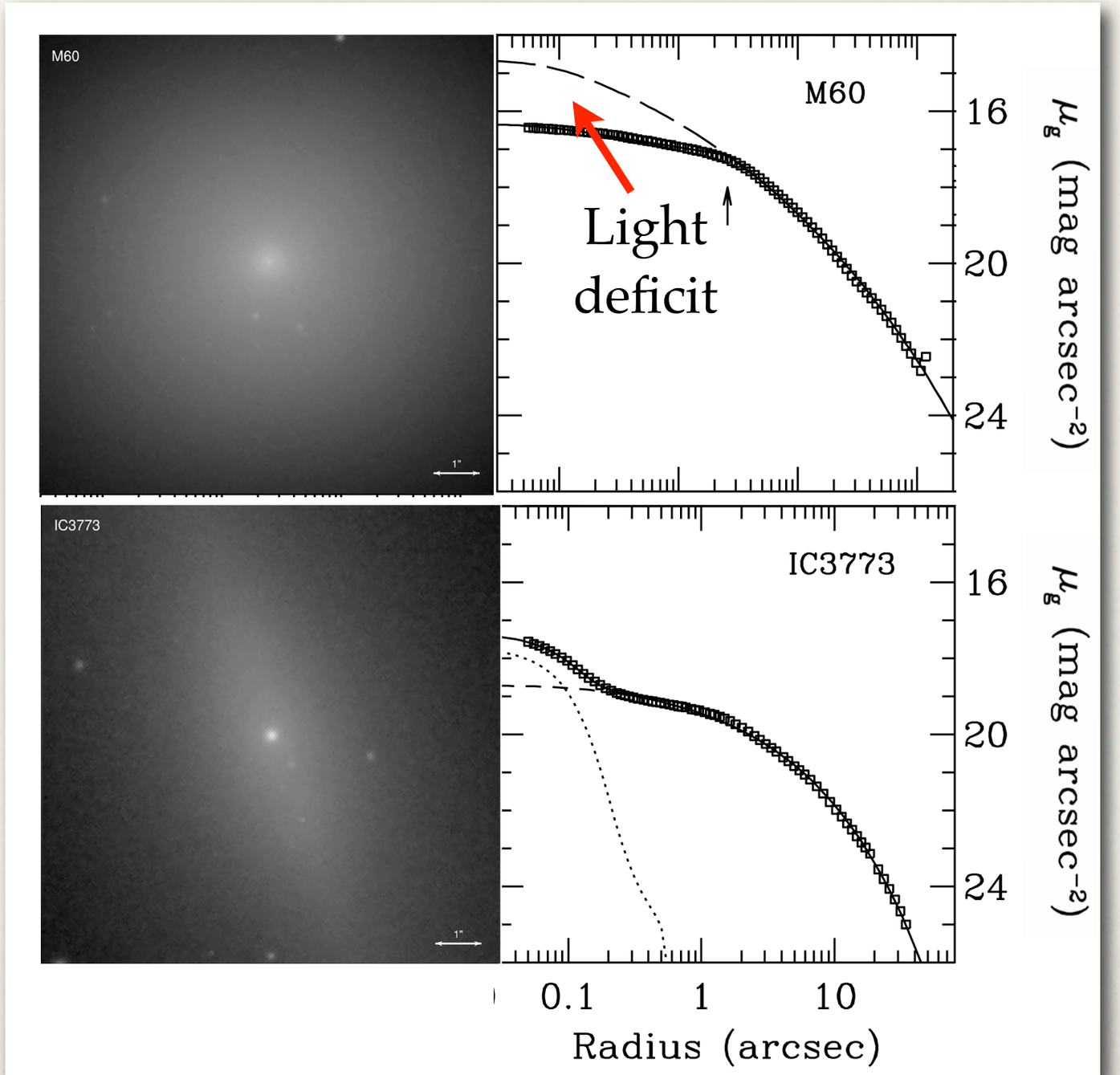

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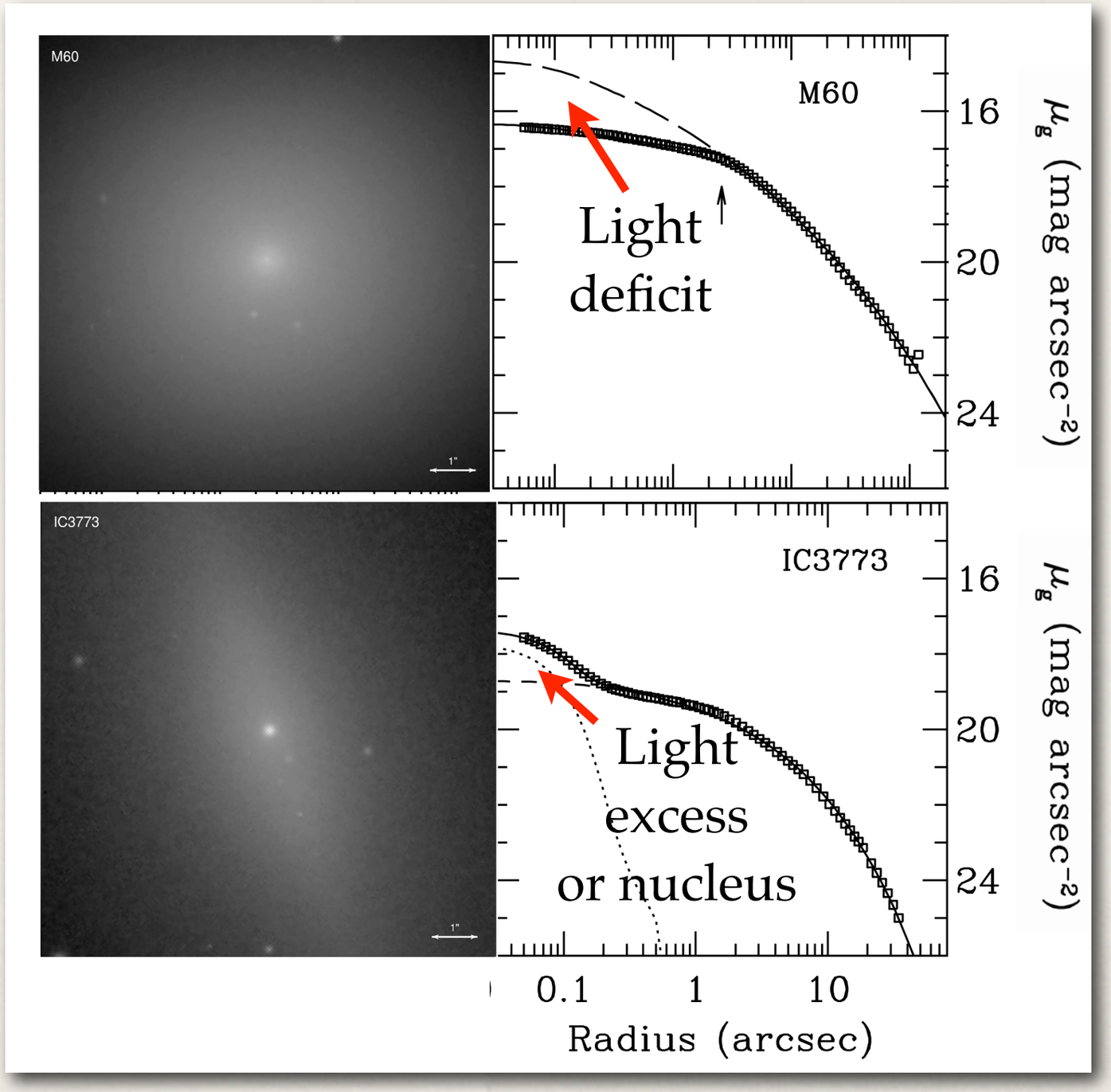

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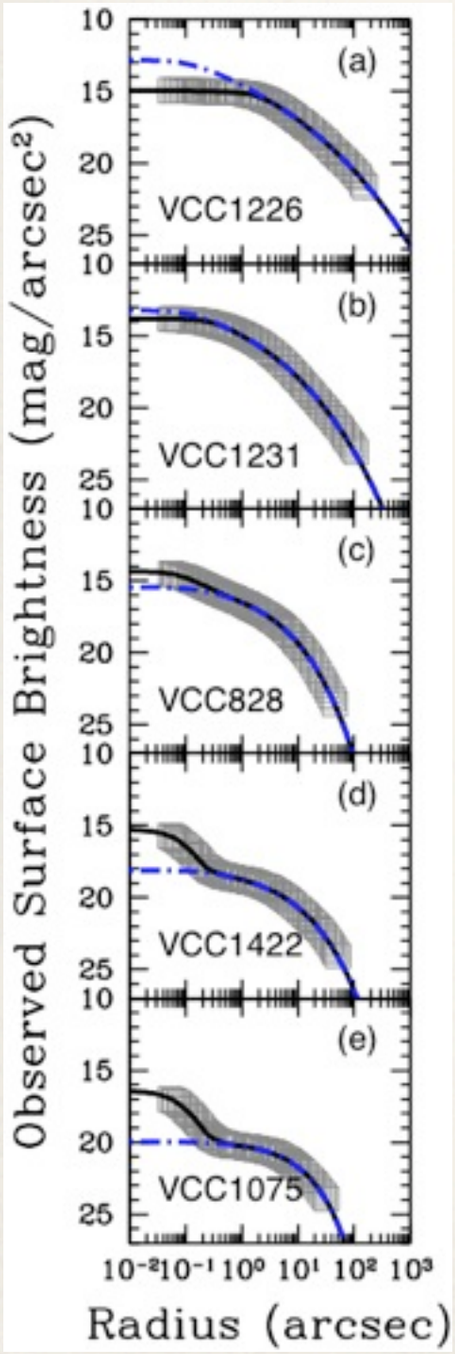

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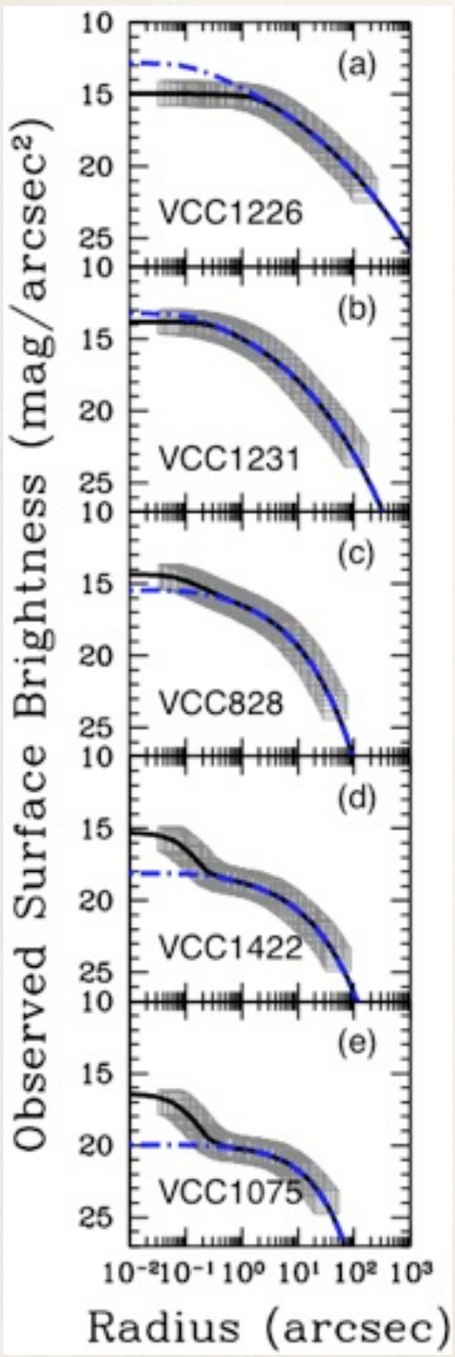

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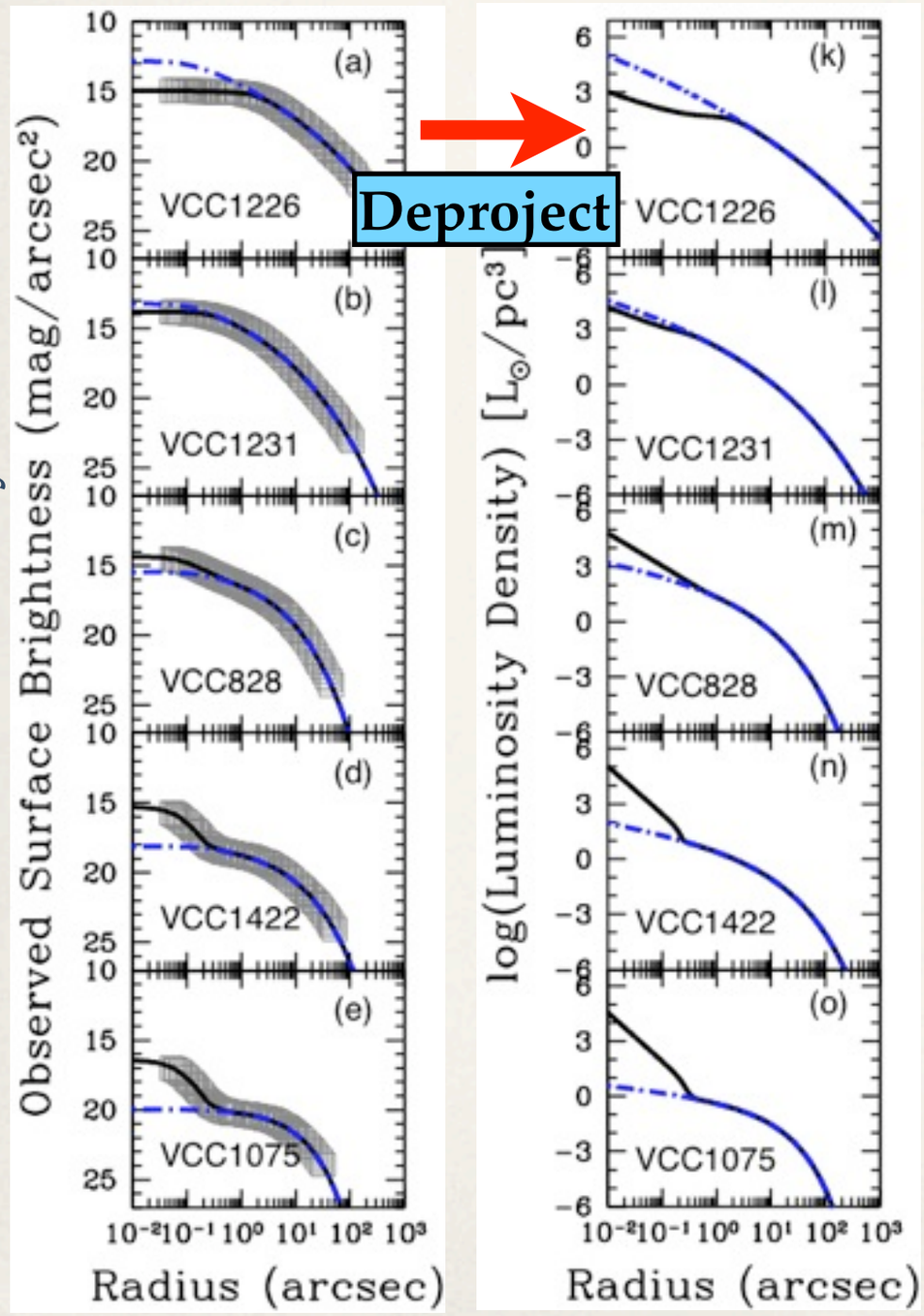

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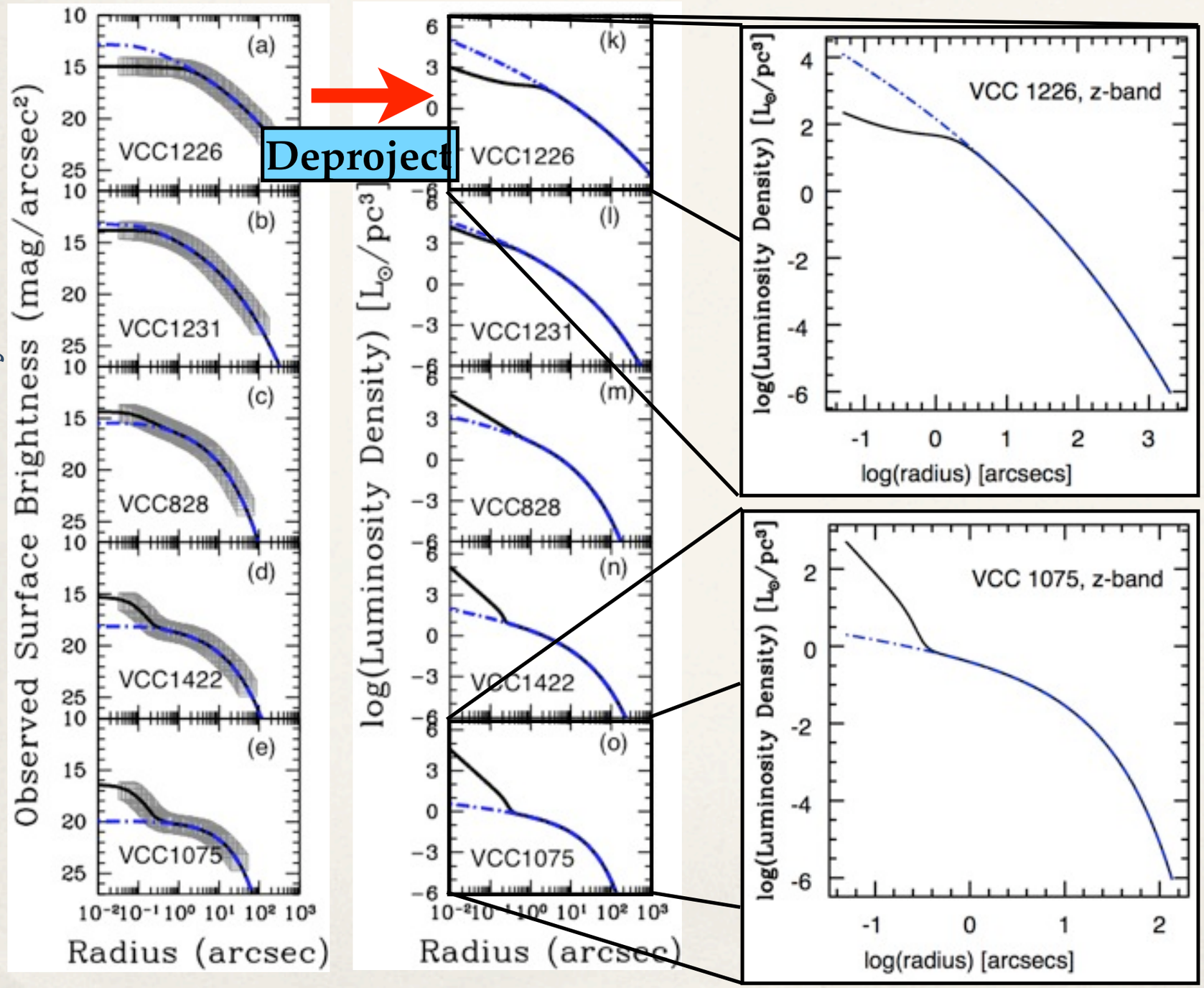

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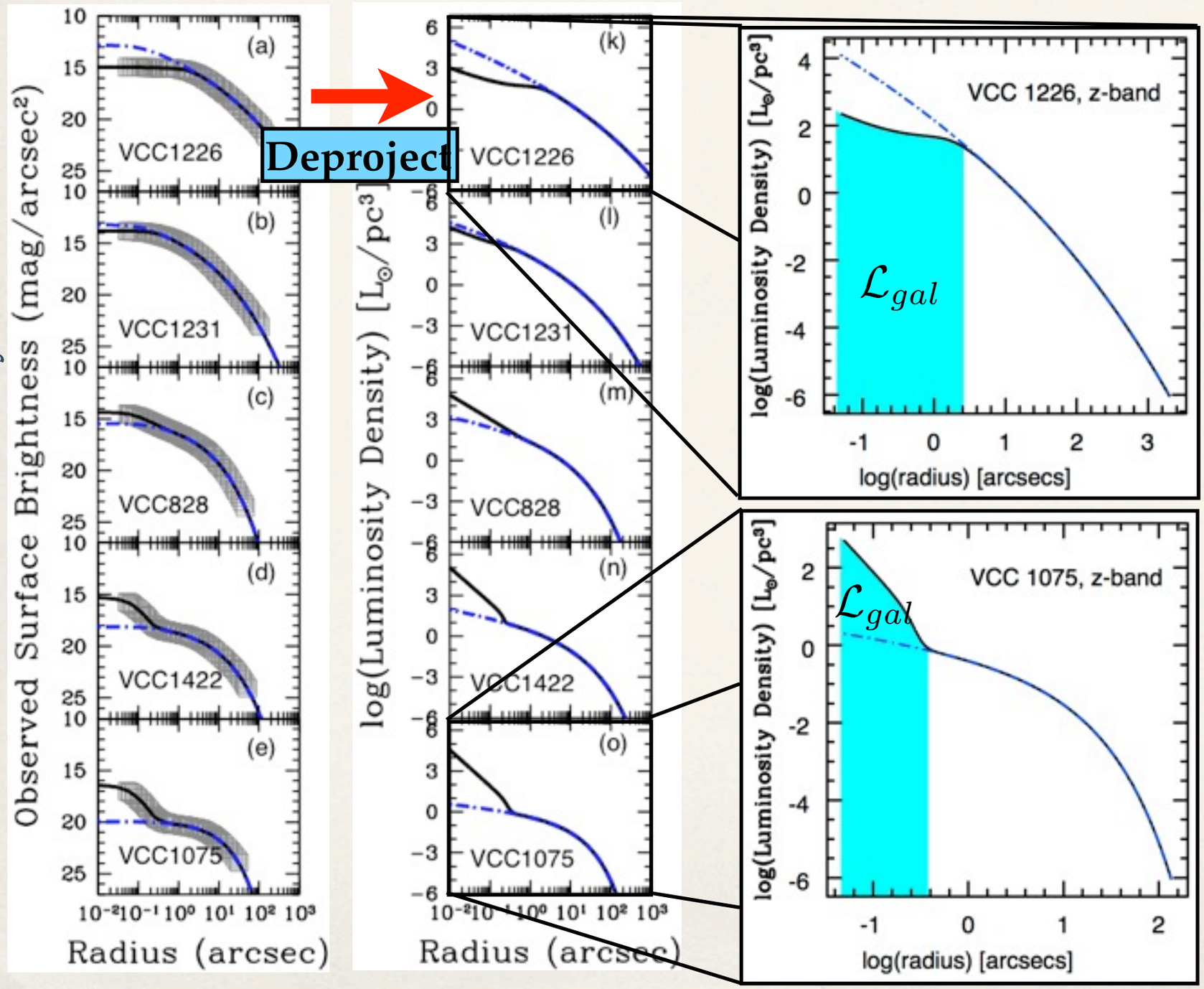

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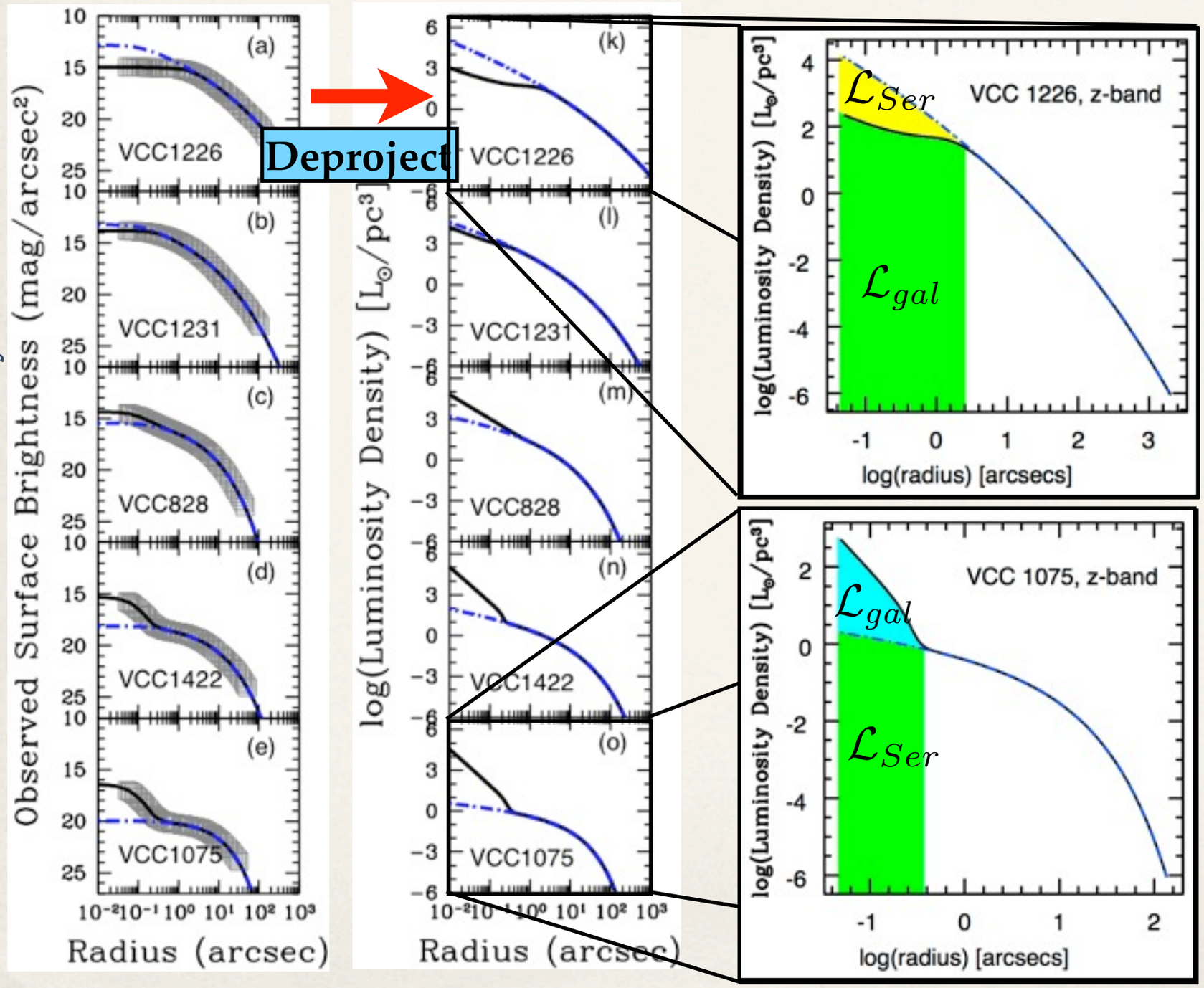

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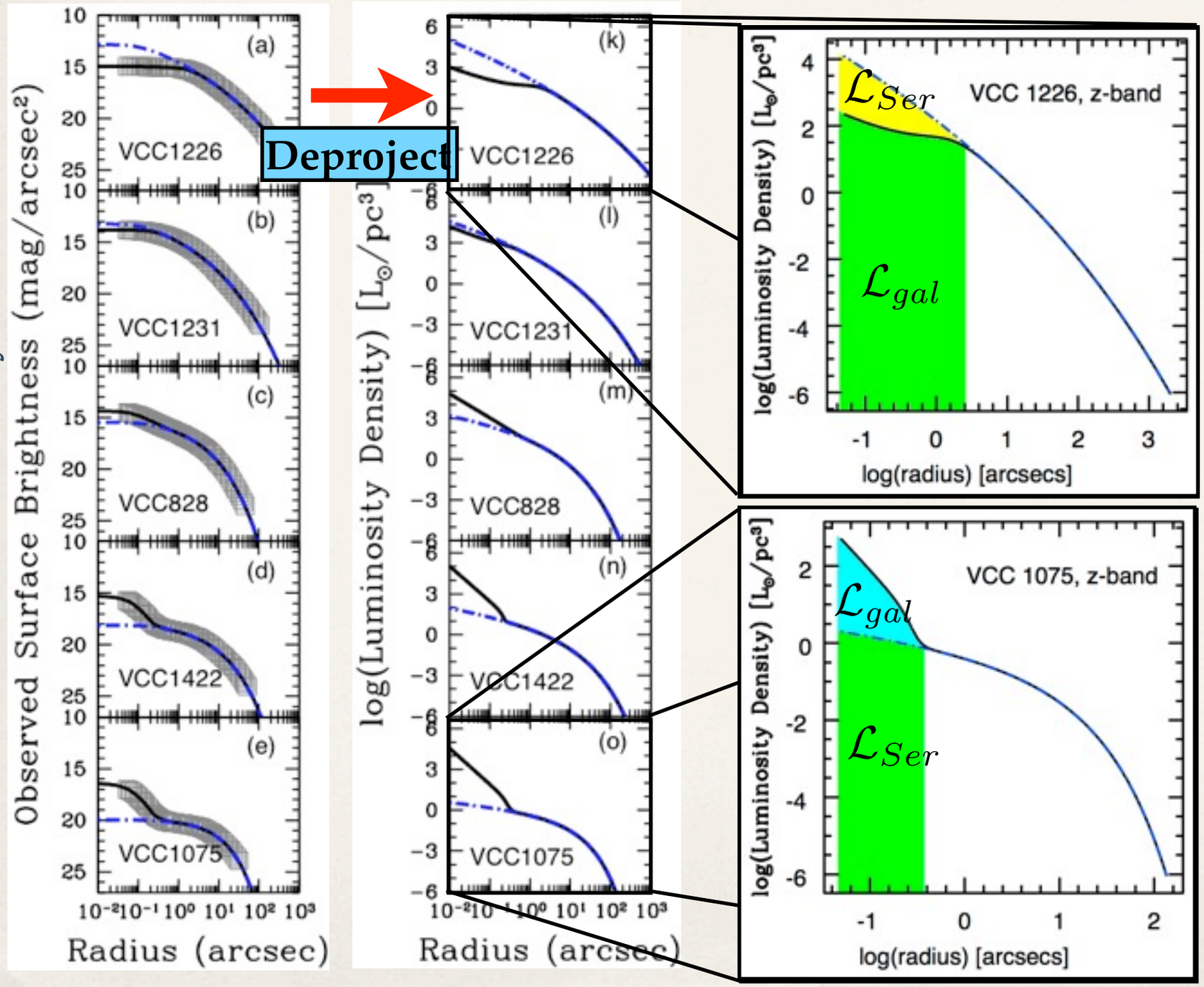

Define:

$$\Delta_{3D} \equiv log\left(\frac{\mathcal{L}_{gal}}{\mathcal{L}_{Ser}}\right)$$

$\Delta_{3D} < 0 \Rightarrow$ Light Deficit

$\Delta_{3D} > 0 \Rightarrow$ Light Excess

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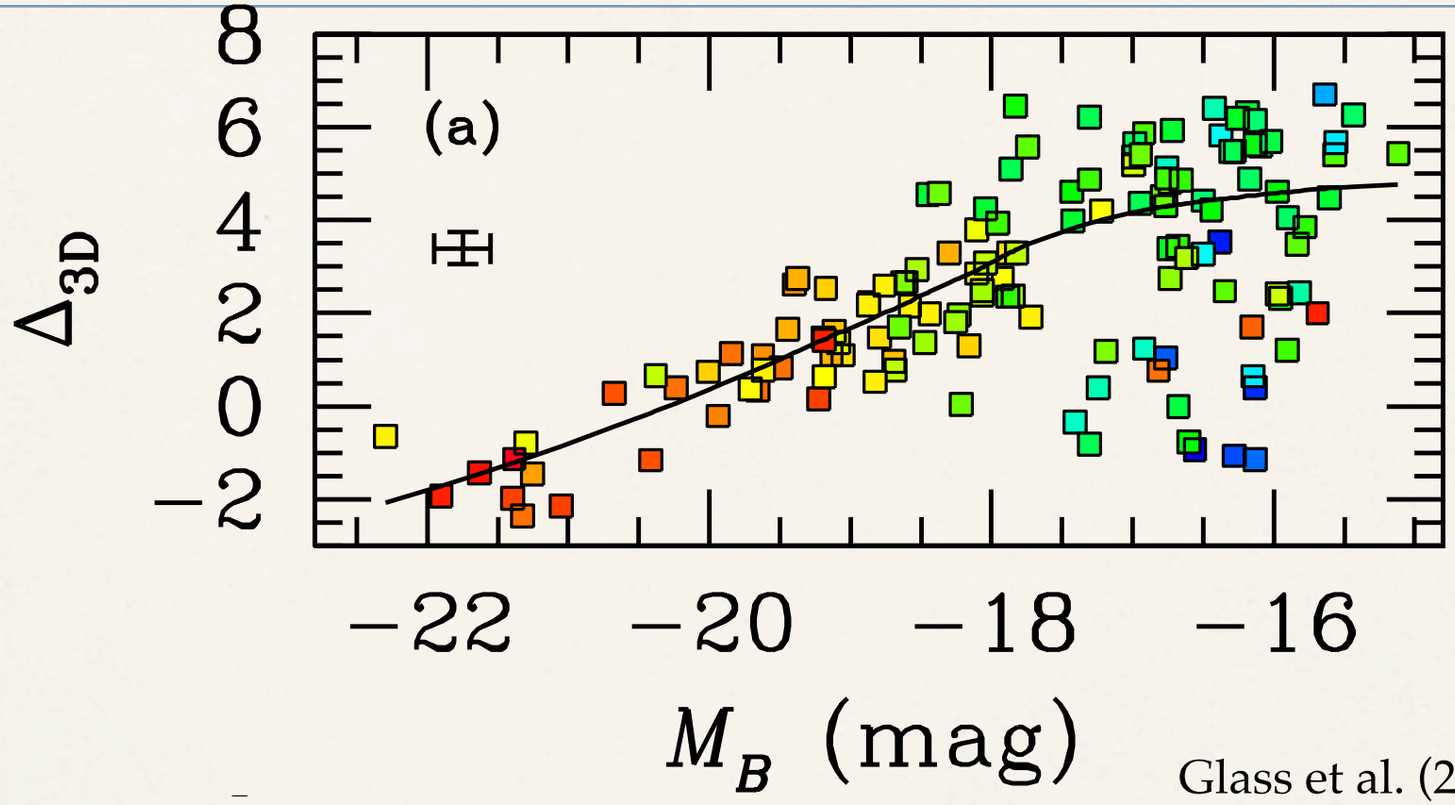

Glass et al. (2011)

- Early-type galaxies transition from central light deficits to central light excesses (or nuclei) along the luminosity function.
  - Should replace “core/power-law dichotomy” paradigm
- Approximately 3/4 of early-type galaxies are nucleated, three times more than previously thought.

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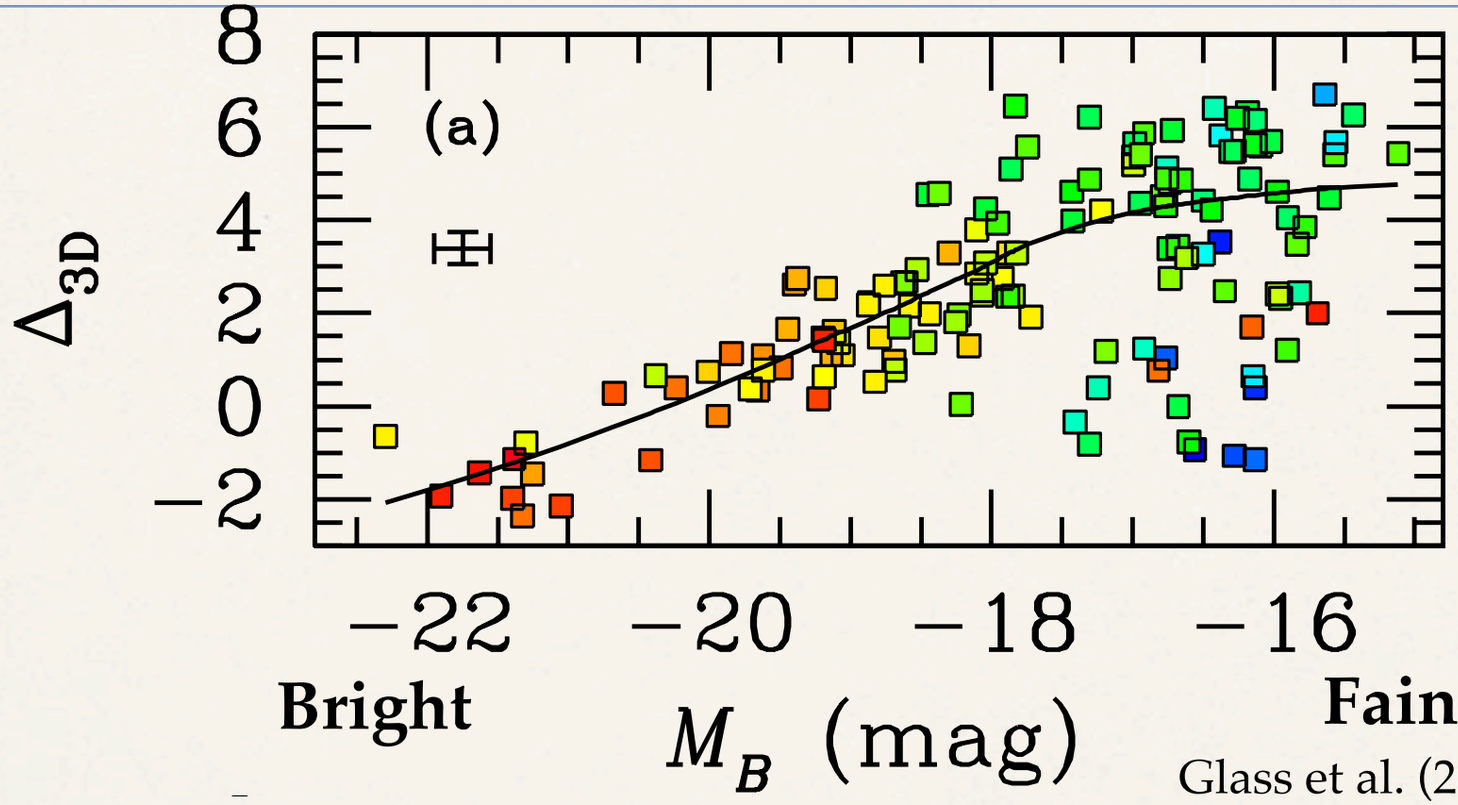

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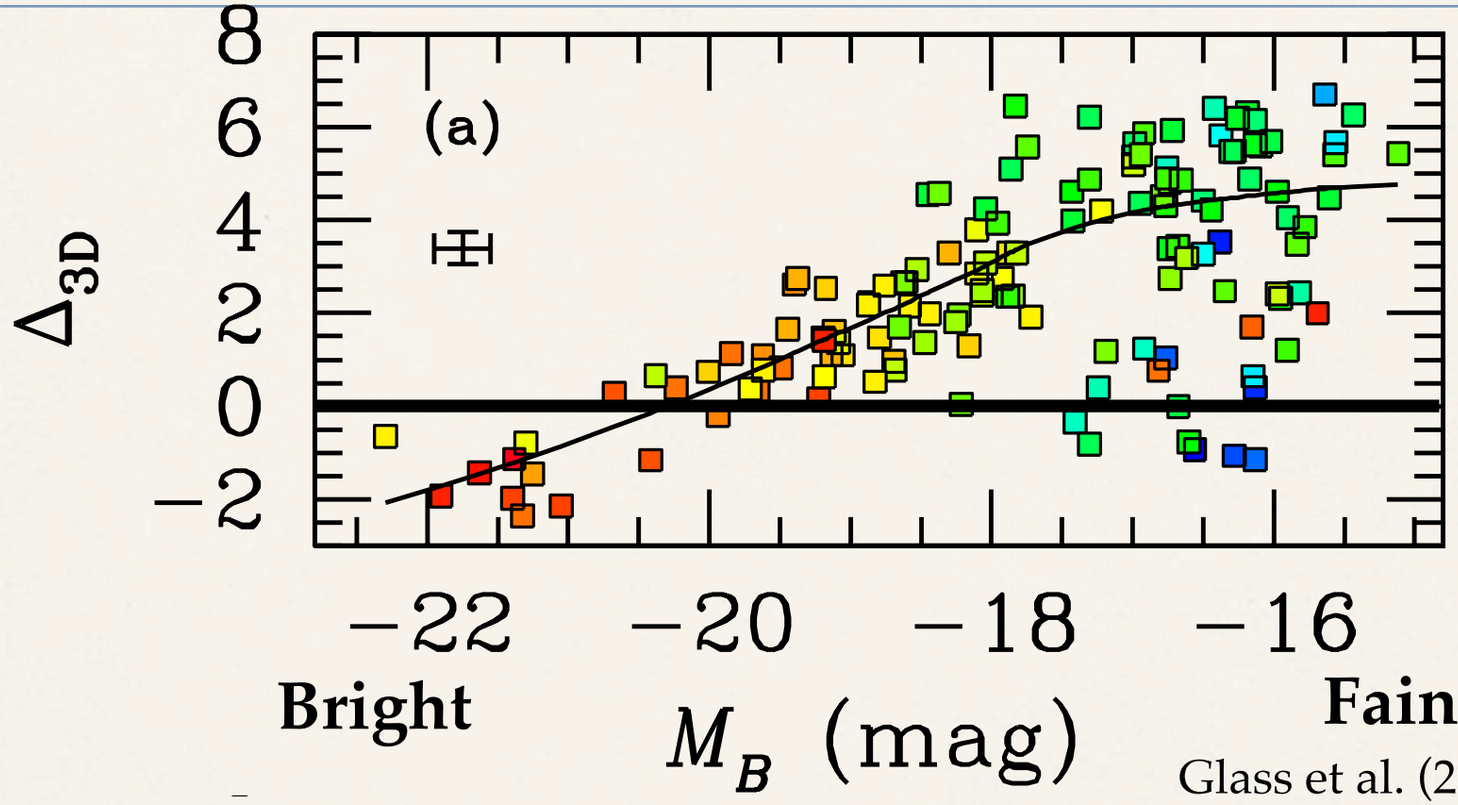

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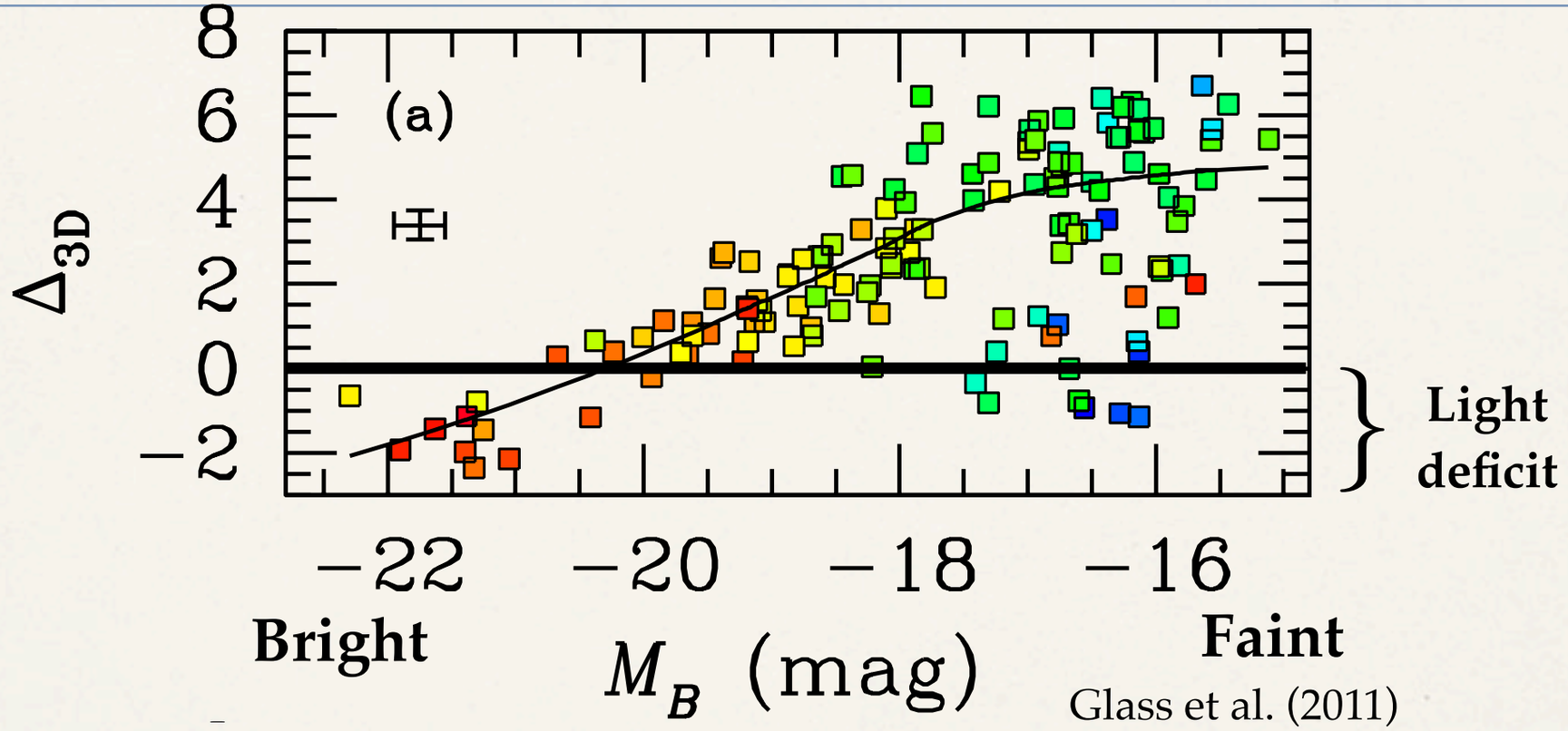

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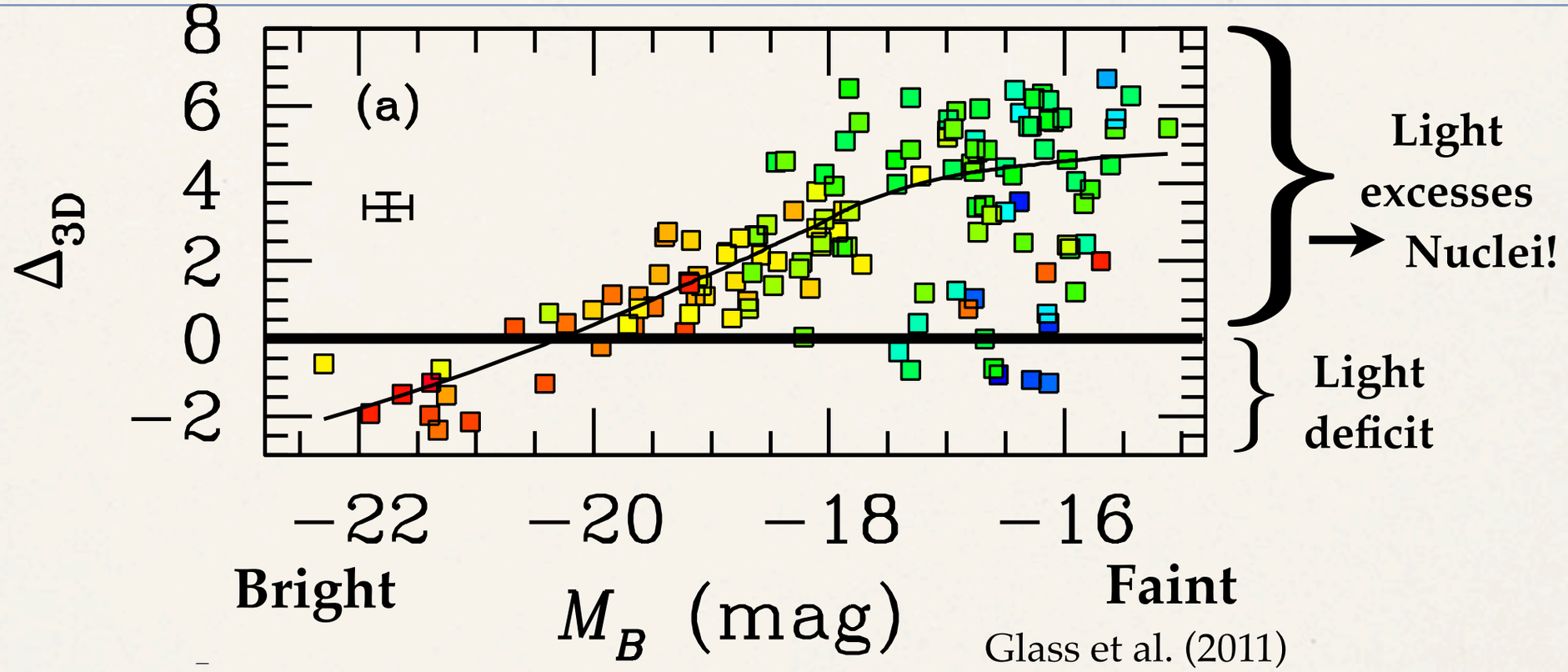

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Models

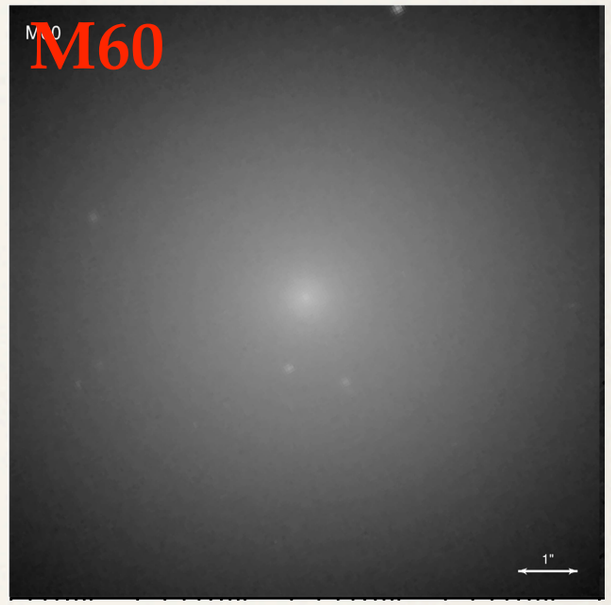
- **Light Deficits**
  - Core scouring from supermassive black hole (SBH) binaries (e.g., Faber et al. 1997)

- **Light Excesses/Nuclei**

1. Gas infall (e.g., Mihos & Hernquist 1994; Emsellem & van de Ven 2008; Hopkins et al. 2009)

2. Globular cluster mergers through dynamical friction (e.g., Tremaine et al. 1975; Bekki et al. 2004; Hartmann et al. 2011)

3. $r^{-7/4}$ density cusps from two-body relaxation around a central SBH (e.g., Bahcall & Wolf 1976)



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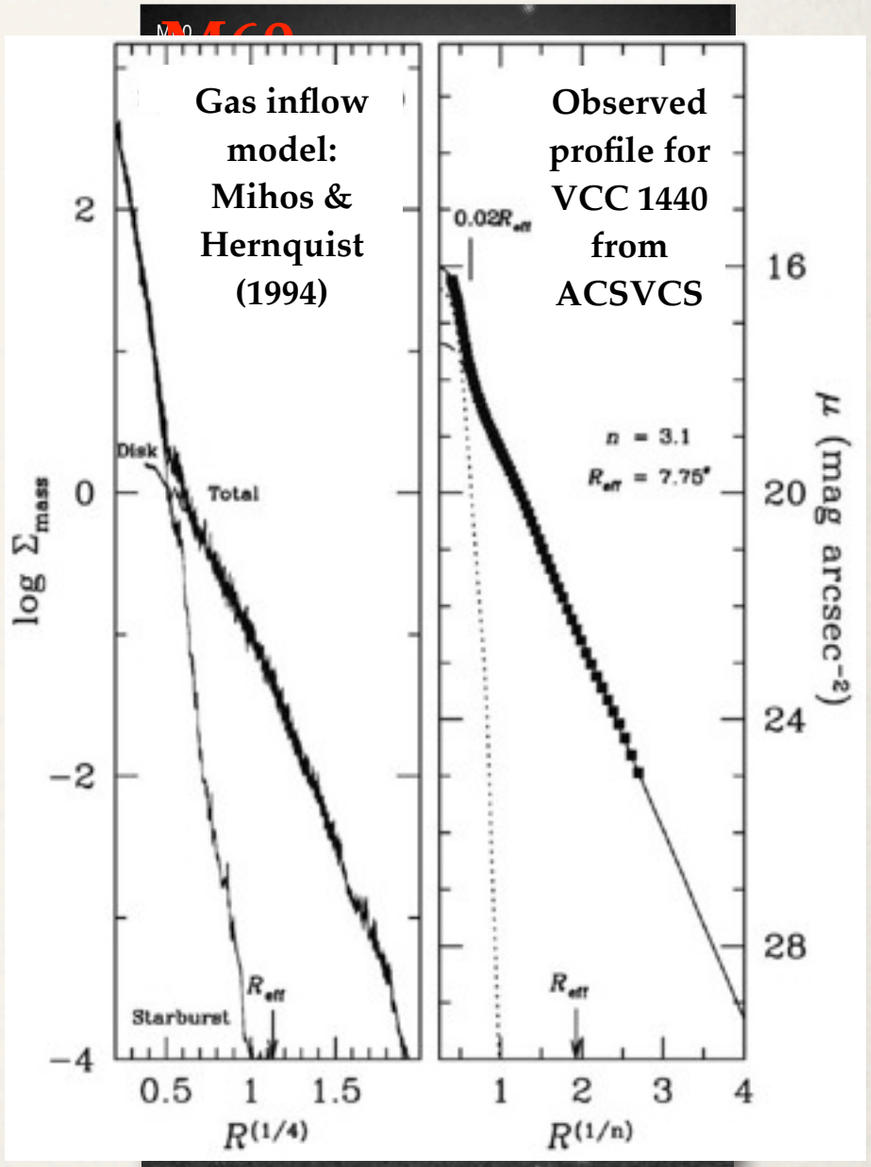

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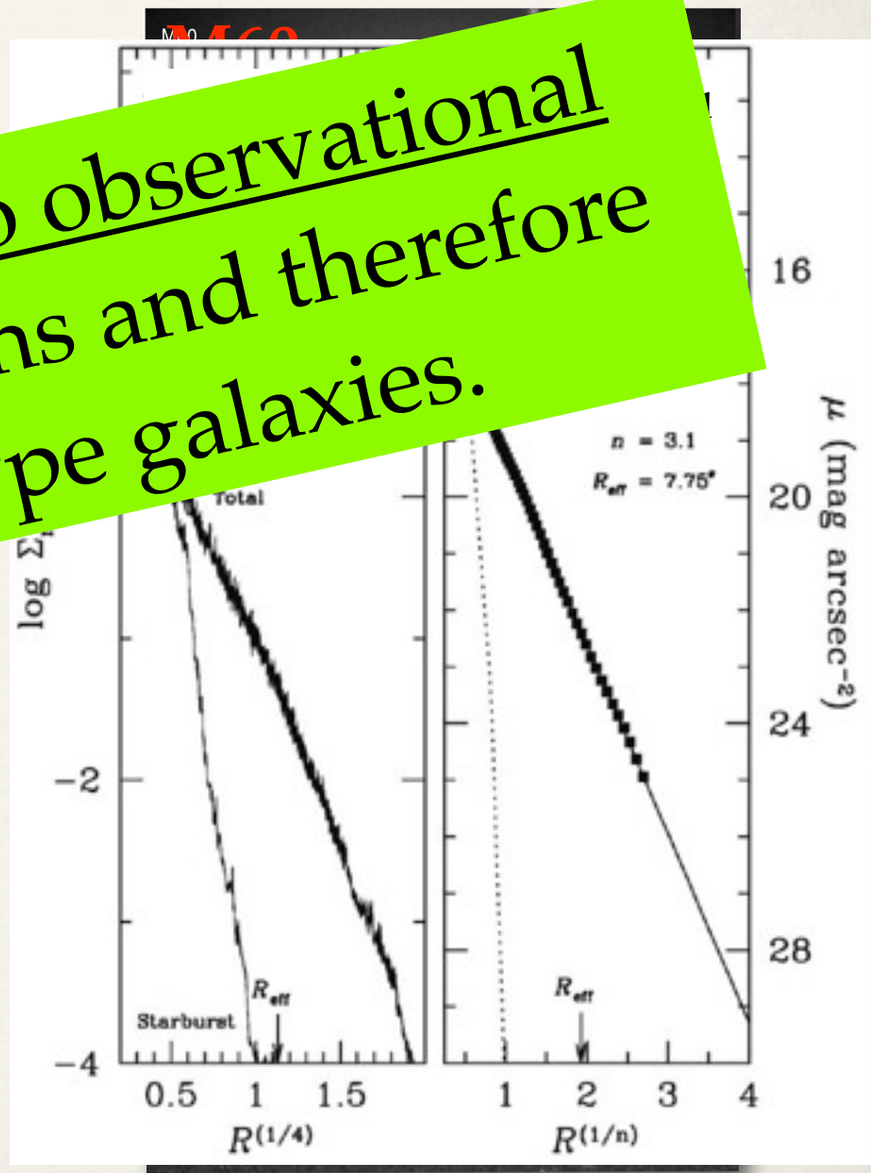
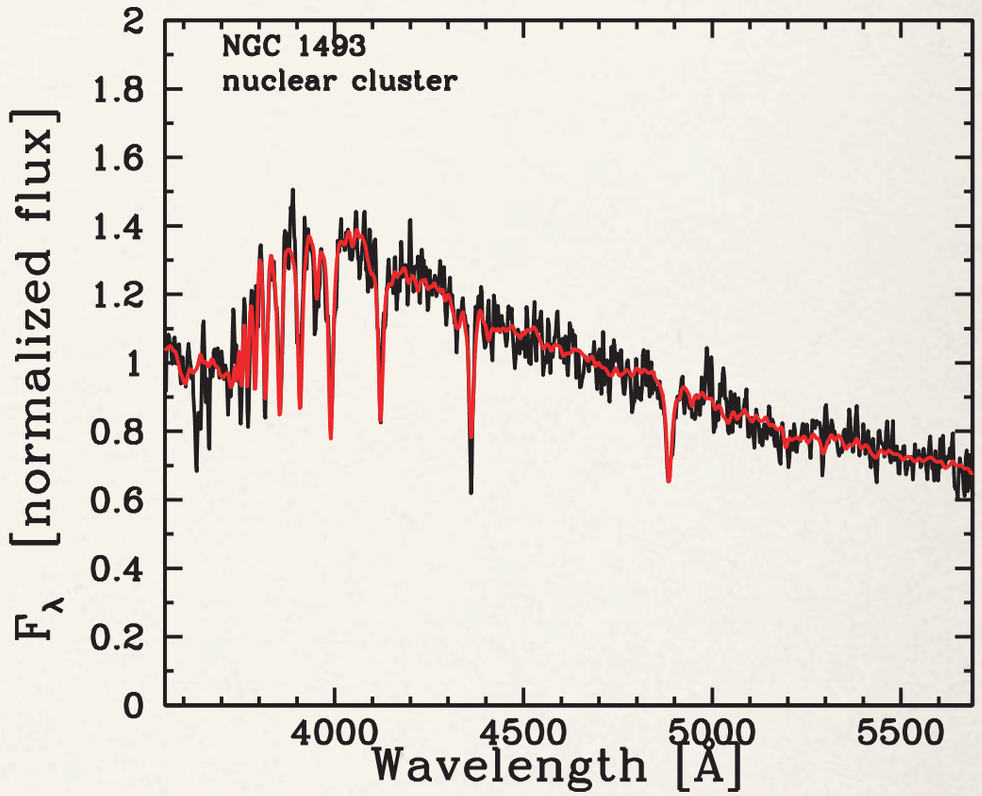
Until now, there has been almost no observational constraints on the stellar populations and therefore formation of nuclei in early-type galaxies.



Côté et al. (2007)

Observational Constraints: Spectroscopy

- High spatial resolution spectroscopy of nuclei to obtain detailed analysis of stellar populations, star formation history, and chemical enrichment of nuclei.
- Impossible from the ground
- Awarded 33 orbits in Cycle 18 to obtain STIS/G430L spectroscopy of 11 nuclei in Virgo (Co-Is: Côté, Ferrarese, Jordán, Maraston, McDermid, McLaughlin, Sarzi)
- Sample includes 2 compact elliptical (cE) galaxies
- Currently being executed



Rossa et al. (2006)

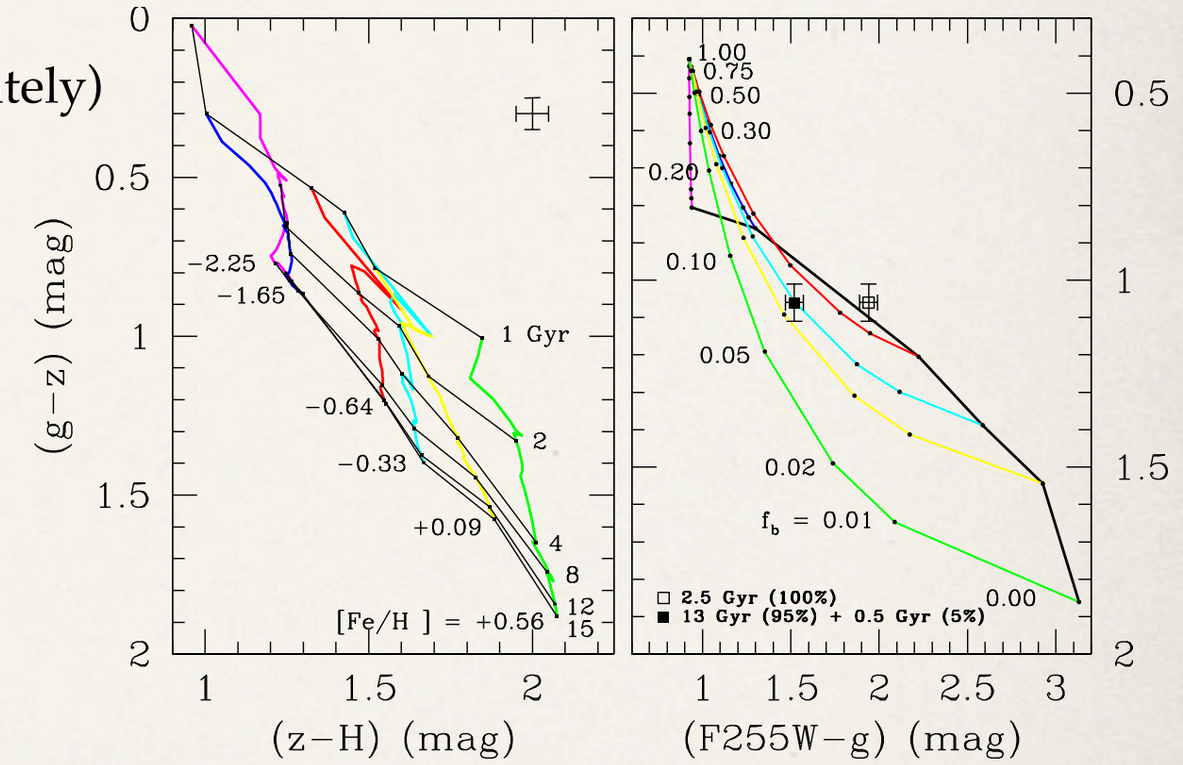
Hubble Space Telescope Cycle 18 GO Proposal <ID>

The Nuclear to Global Connection: a Detailed View of Compact Stellar Nuclei in a Complete Sample of Virgo Ellipticals

Principal Investigator: Ms. Lisa Glass

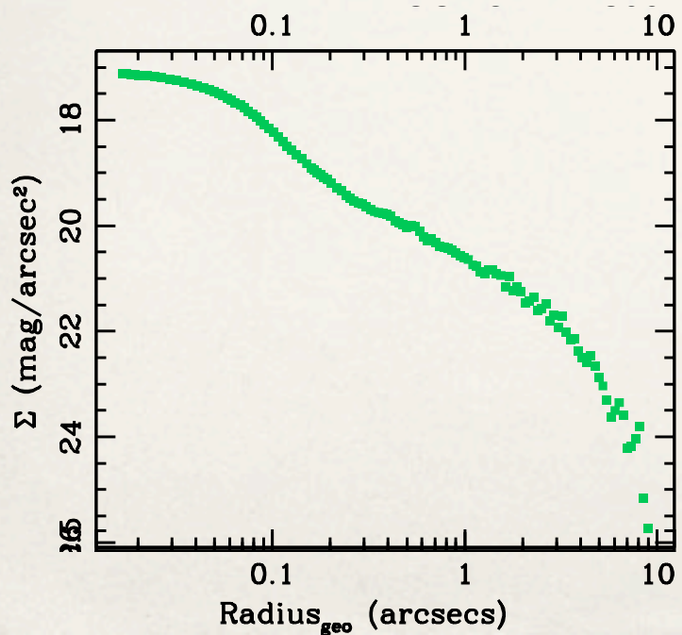
Observational Constraints: SEDs with Virgo Redux

- "Virgo Redux" proposal submitted to STScI in 2006 after call for backup proposals in case of ACS failure.
  - Requested 200 orbits to image all ACSVCS galaxies in the IR with NICMOS and the UV with WFPC2.
- ACS did (unfortunately) fail, but it meant that we (fortunately) got the data.
- We therefore have imaging of ~100 early-type galaxies in Virgo:
  1. WFPC2/F300W
  2. ACS/F475W (~g-band)
  3. ACS/F850LP (~z-band)
  4. NICMOS/F160W (~H-band) + CFHT/H-band + 2MASS/H-band
- Goal: Leverage expanded filter baseline to break age-metallicity degeneracy and learn about the stellar populations of the nuclei.

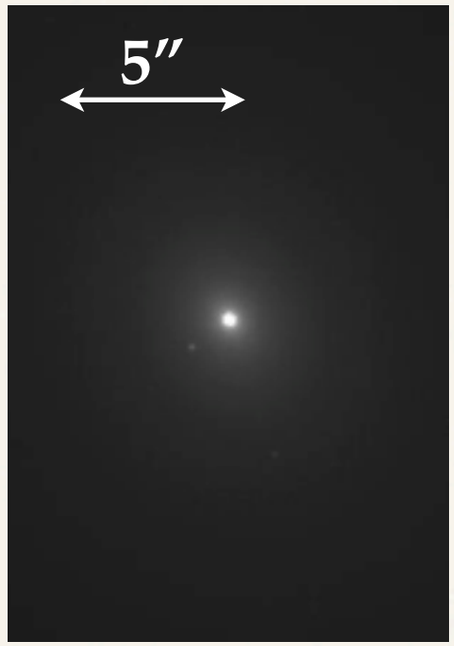


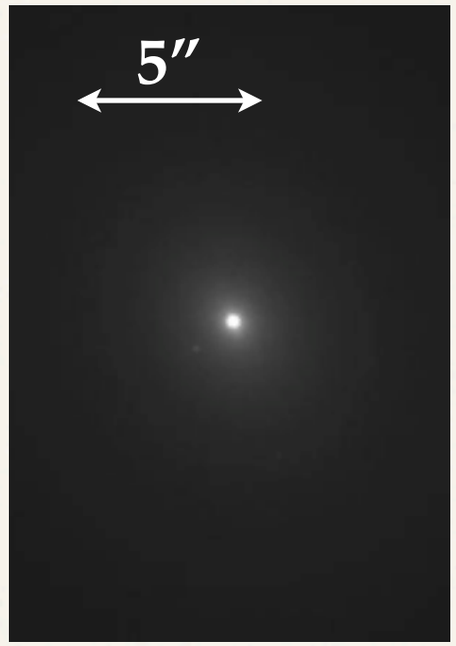
Surface Brightness Profiles e.g., VCC 1871

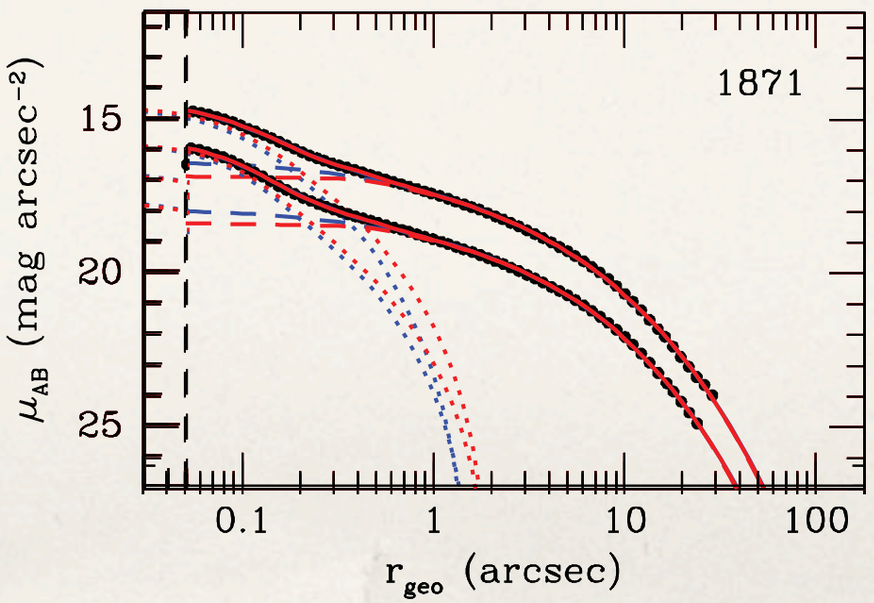
WFPC2/F300W



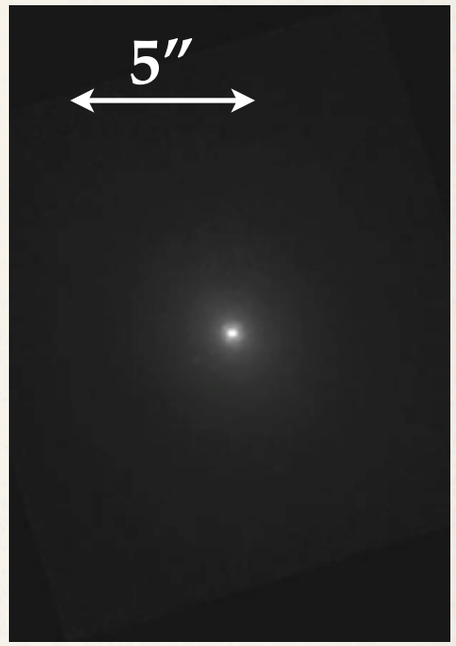
ACS/F475W & F850LP

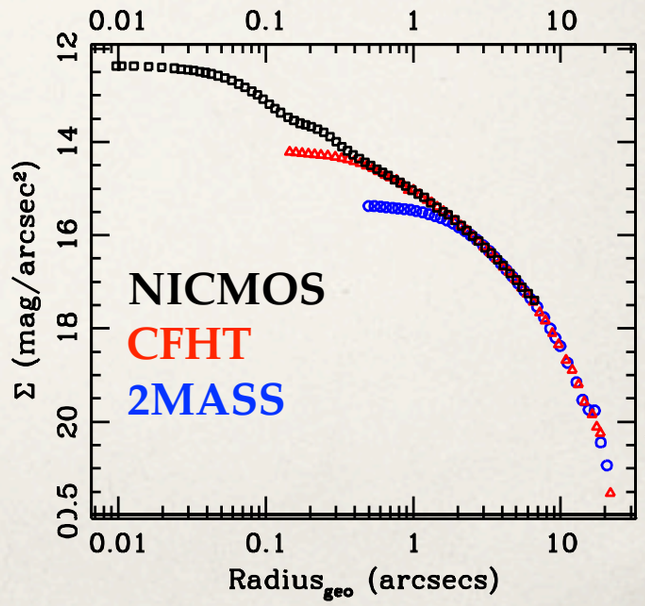






NICMOS/F160W





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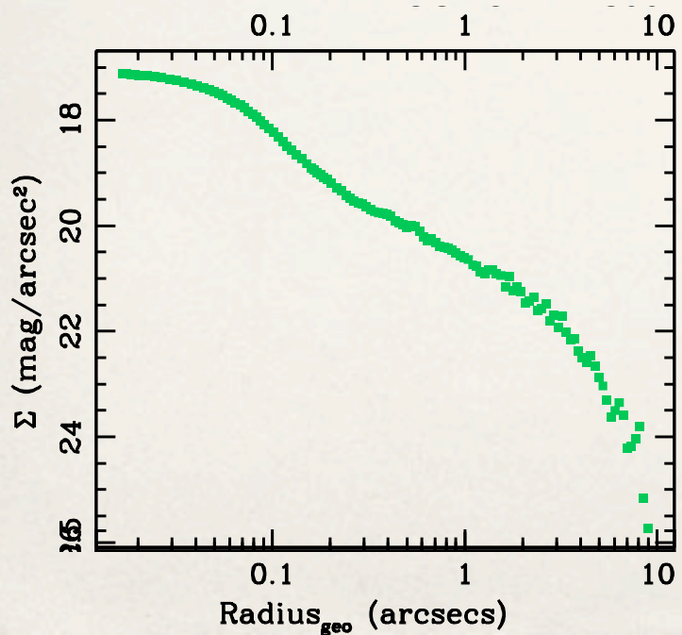
e.g., VCC 1871

Next step: fit modified Sérsic models

WFPC2/F300W



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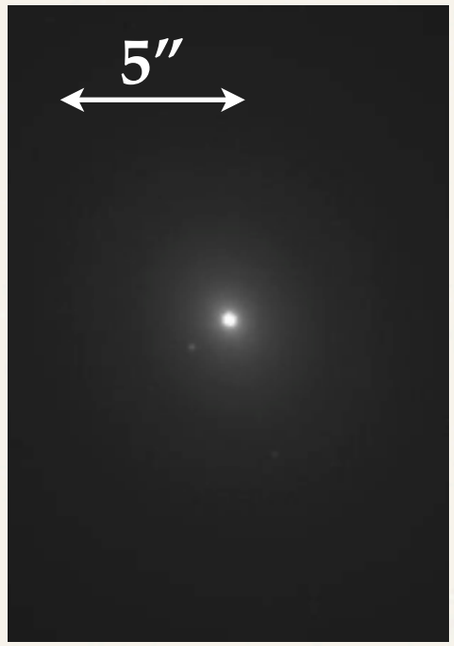

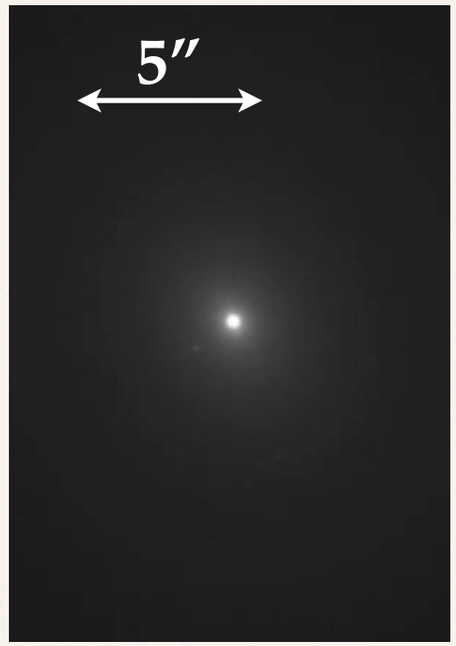

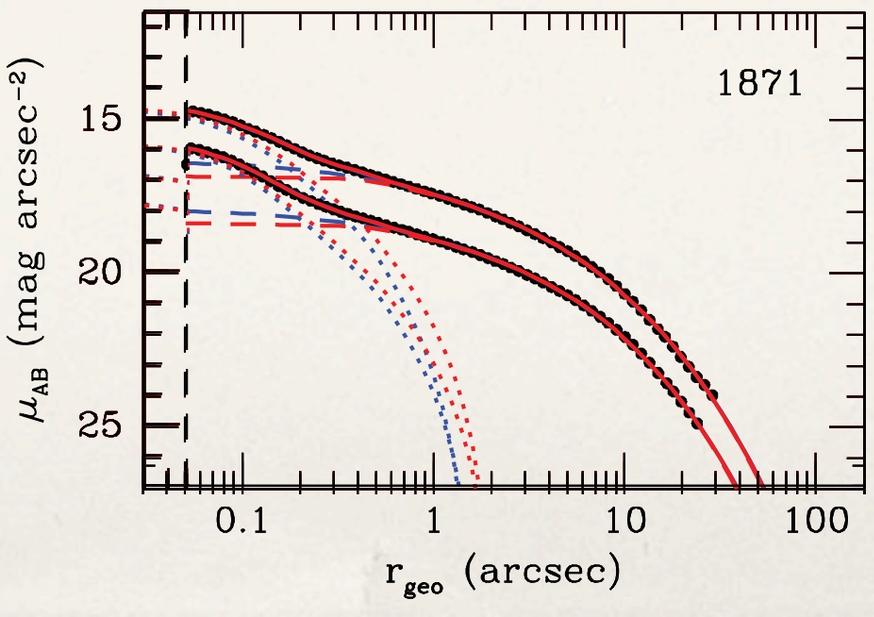

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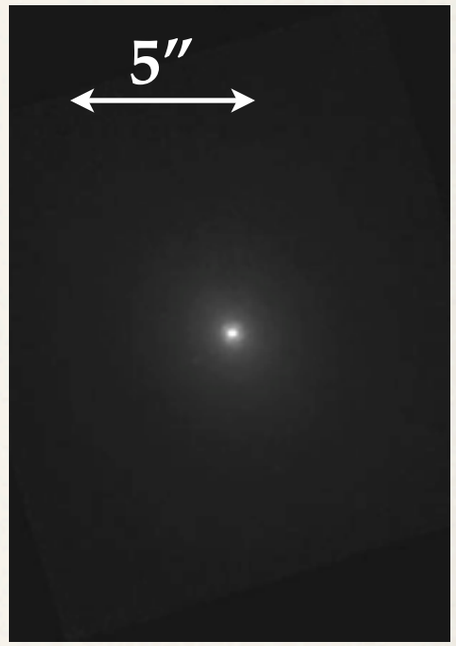

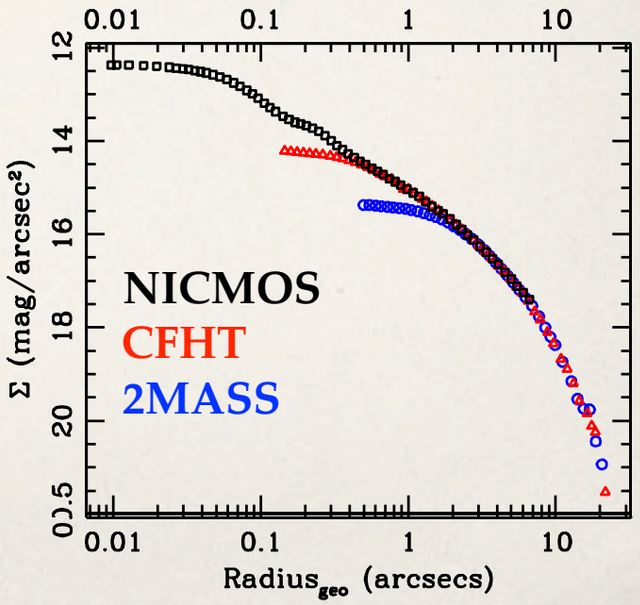

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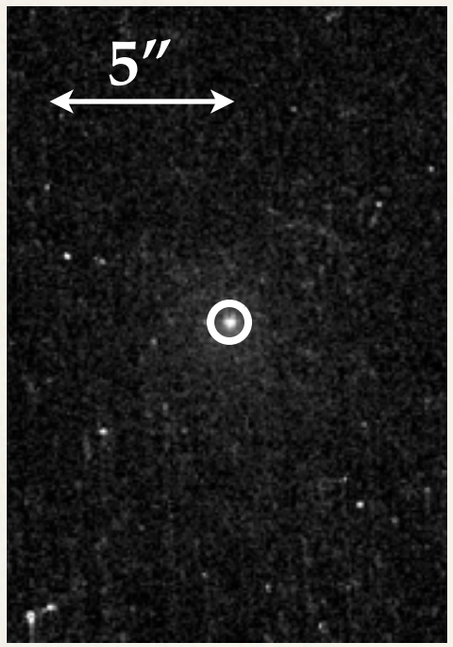

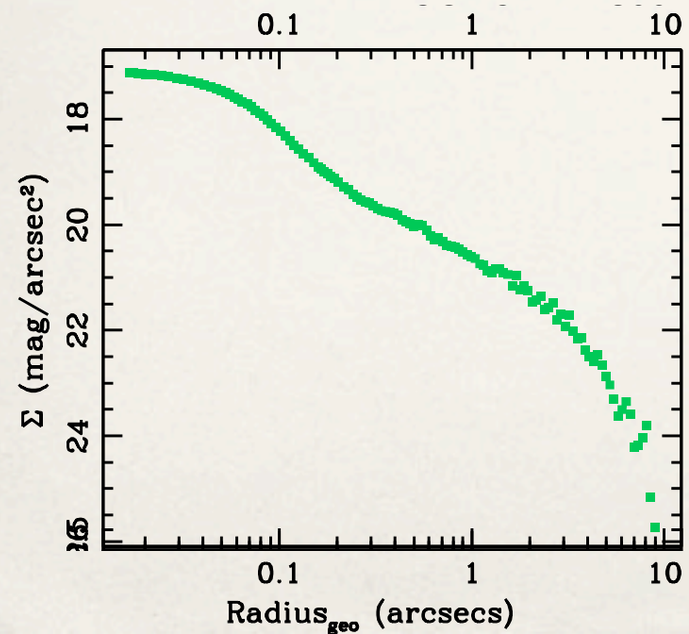

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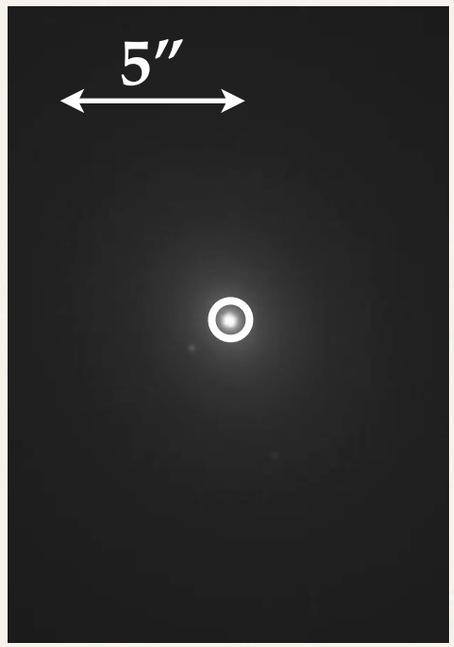

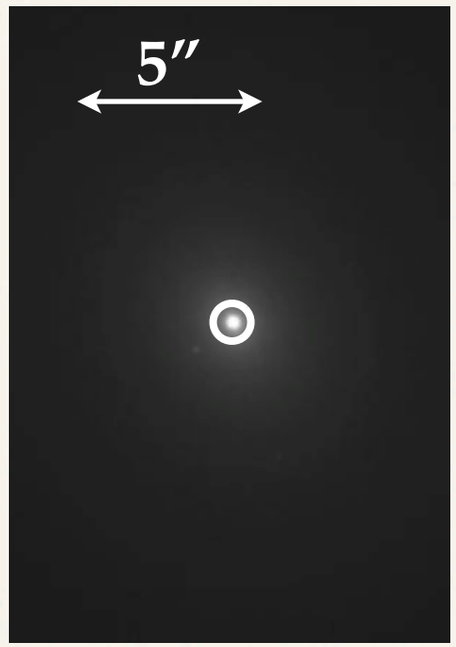

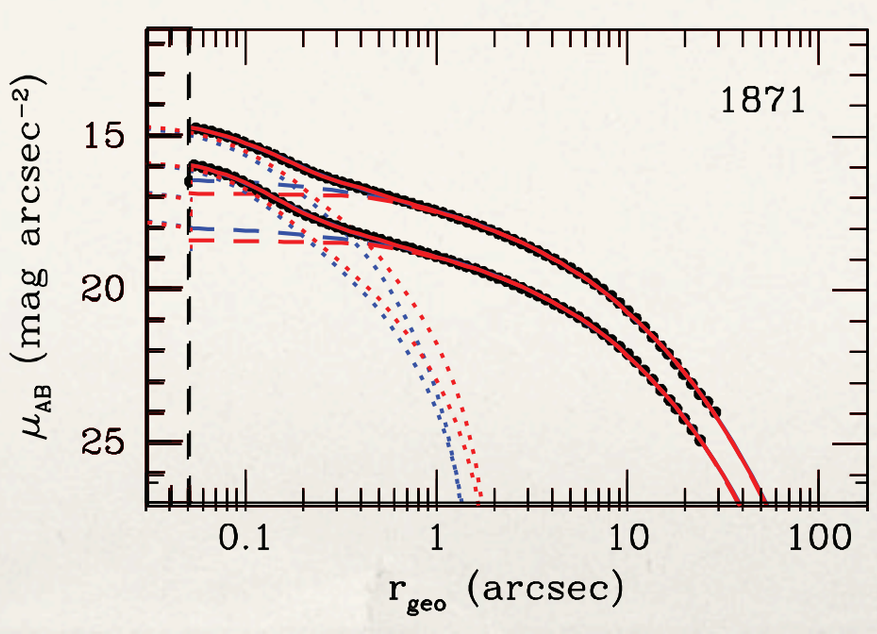

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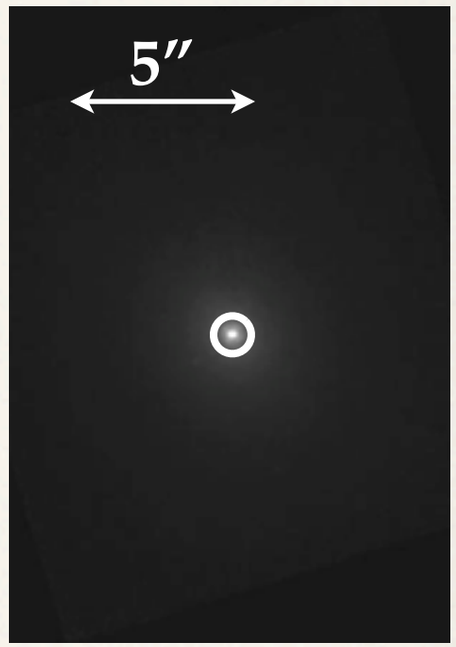
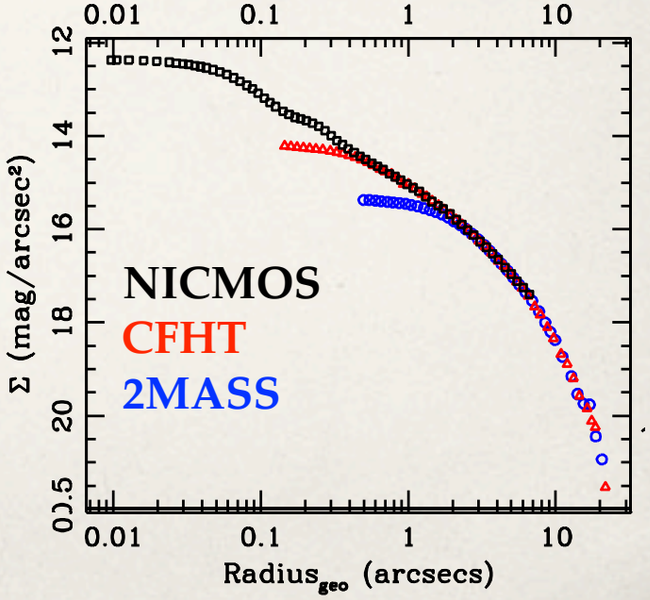
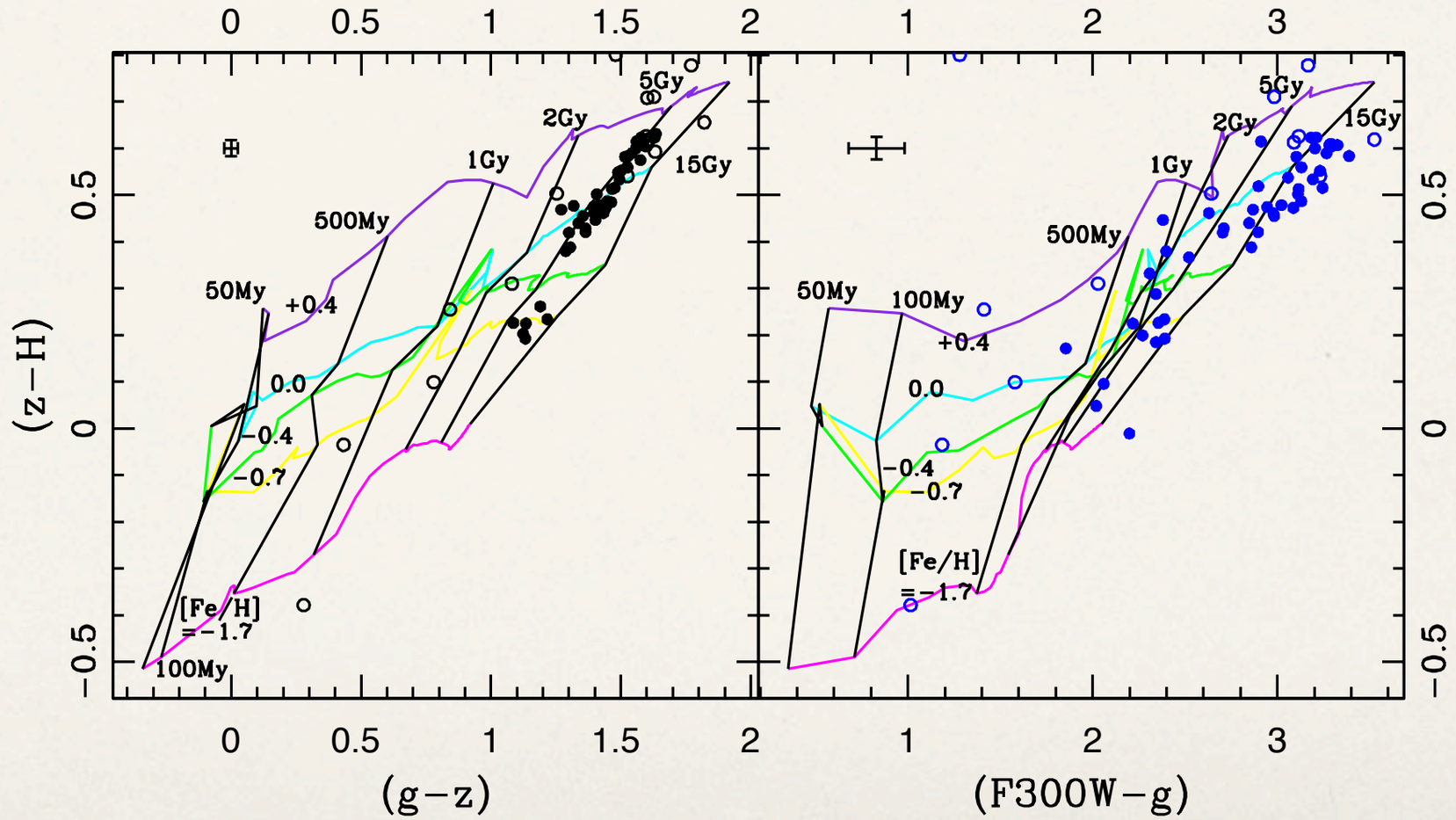




Central Aperture Photometry

- Some preliminary results from Virgo Redux
- Central aperture photometry (1” aperture) + Bruzual and Charlot (2003) stellar synthesis tracks



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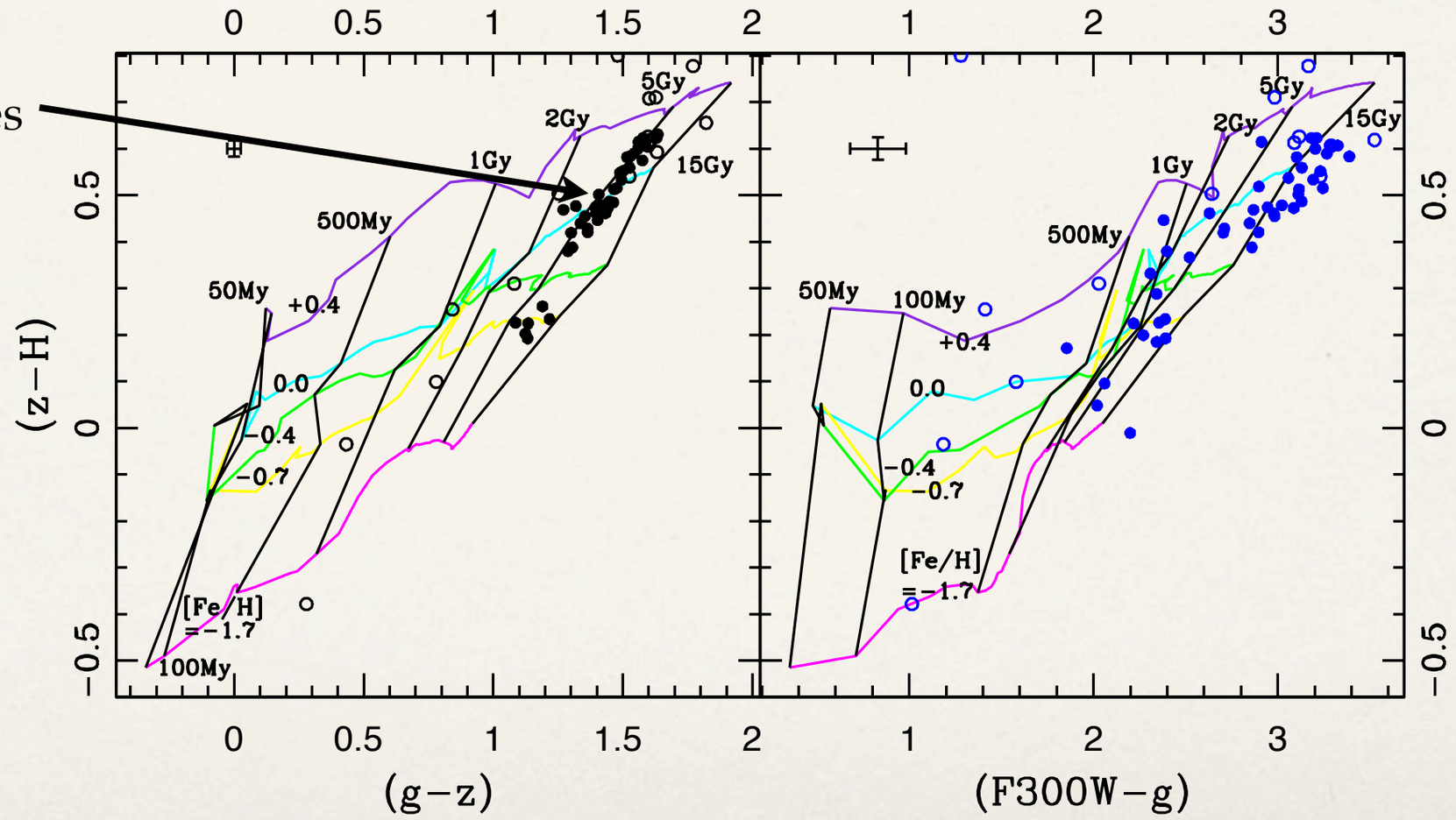
Tight correlation along intermediate ages with metallicity gradient



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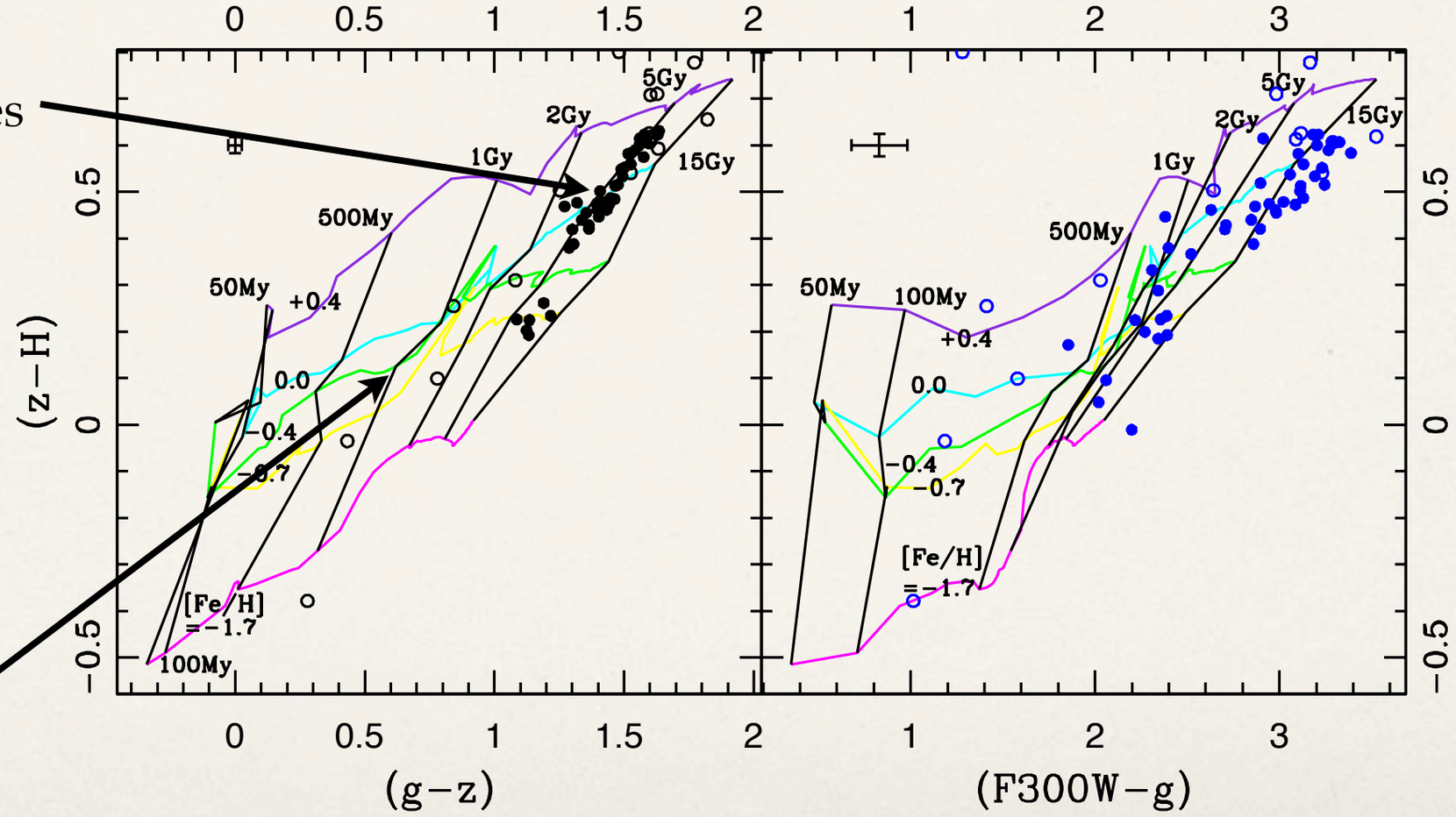

Non-nucleated dwarfs bluer, younger, and metal poor. Possible dIrr transition objects?

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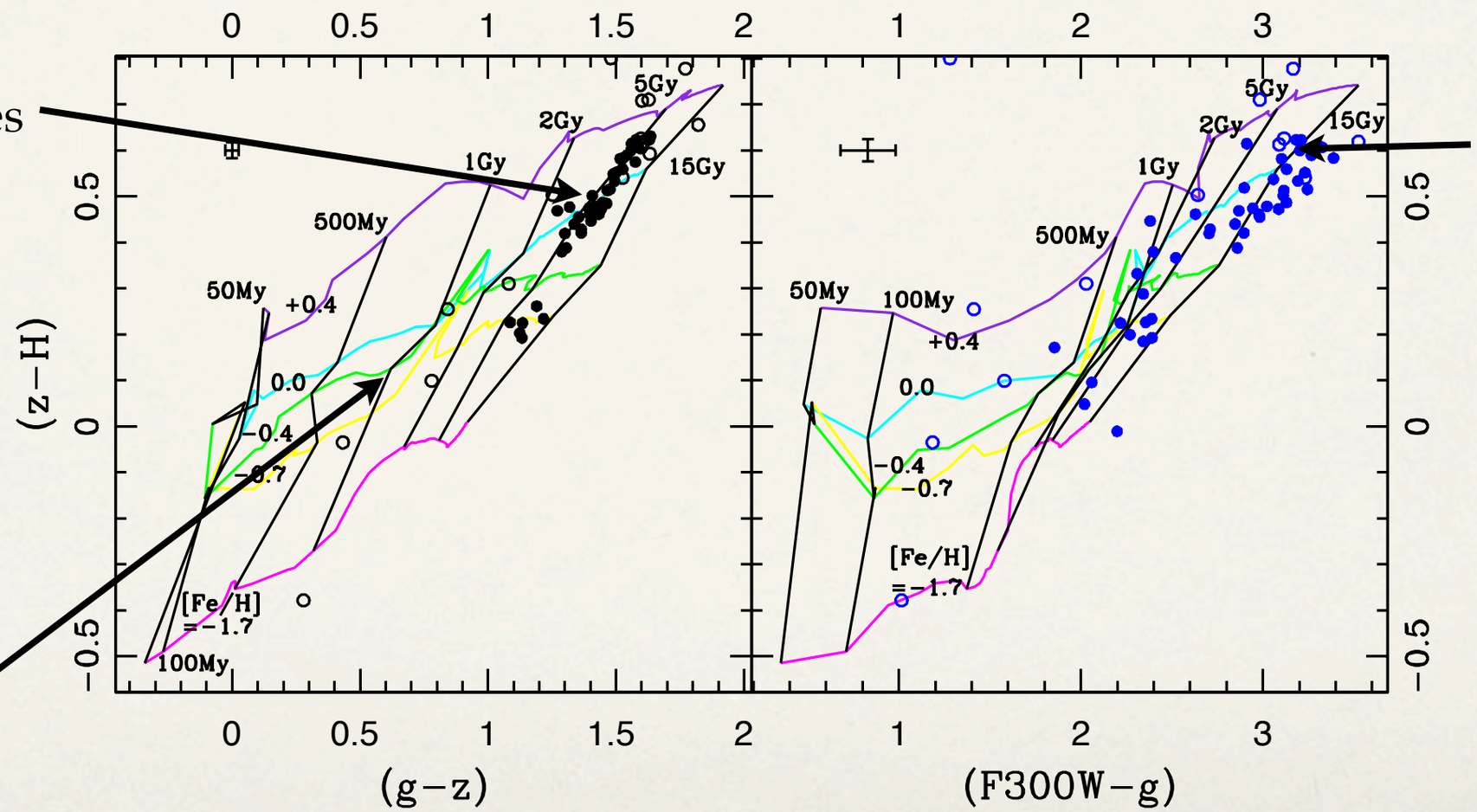
Tight correlation along intermediate ages with metallicity gradient



Wider spread in (F300W-F475W). Still investigating instrumental effects (e.g. CTE); may also represent physical processes (e.g., internal dust, “frosting” from young stars)

Non-nucleated dwarfs bluer, younger, and metal poor. Possible dIrr transition objects?

Central Aperture Photometry

- Some preliminary results from Virgo Redux
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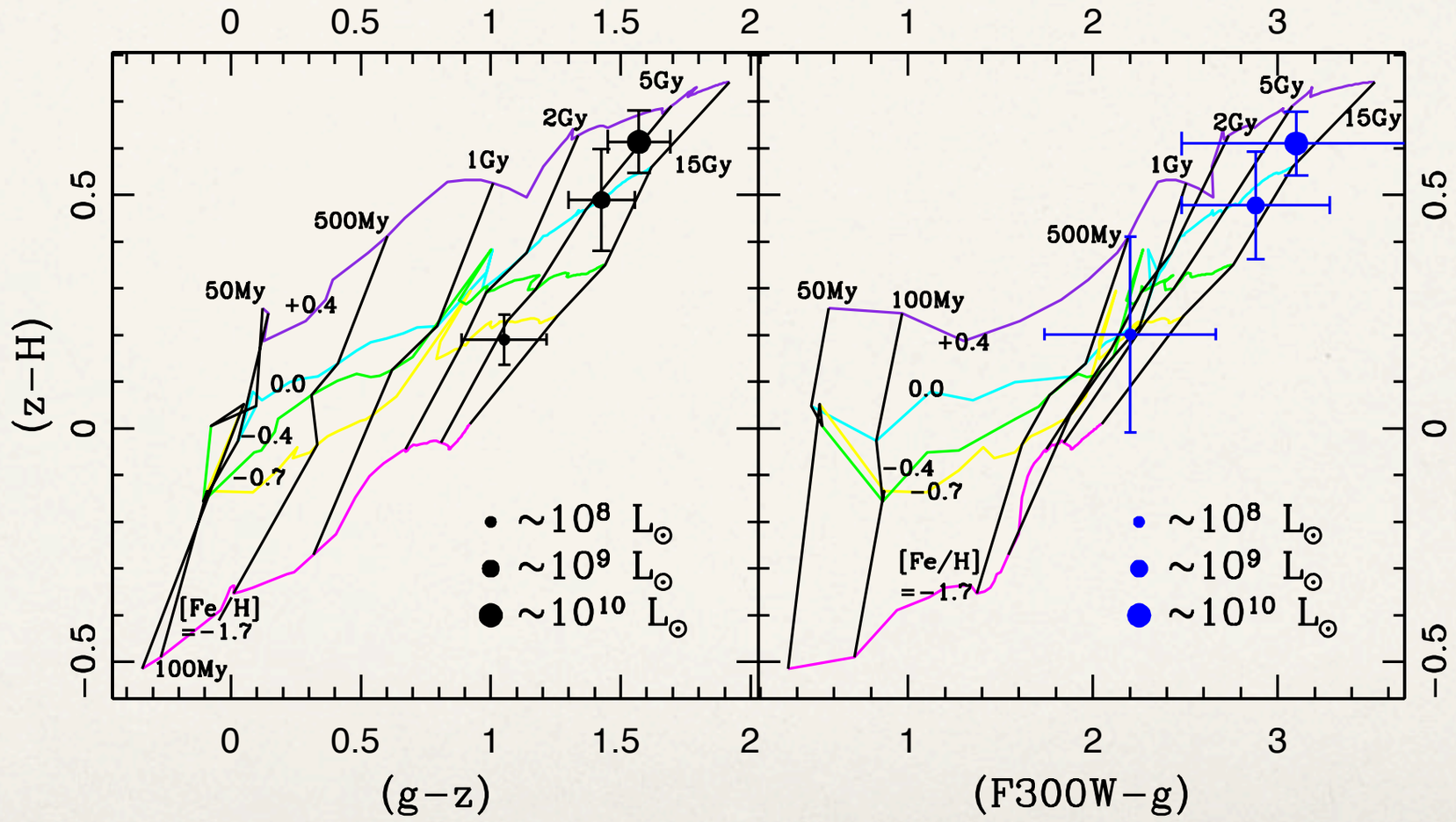

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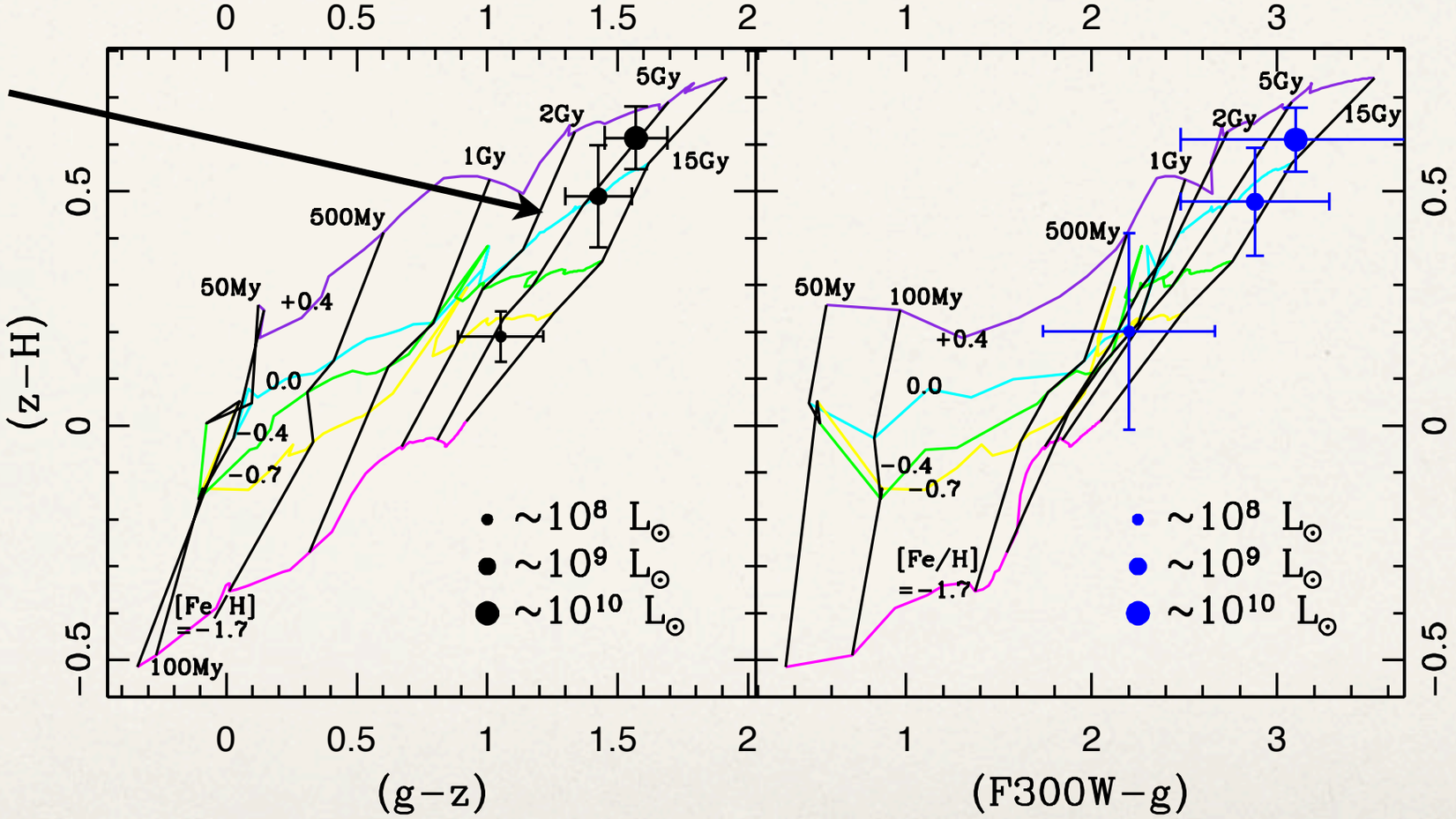
Nuclear ages similar across luminosity function



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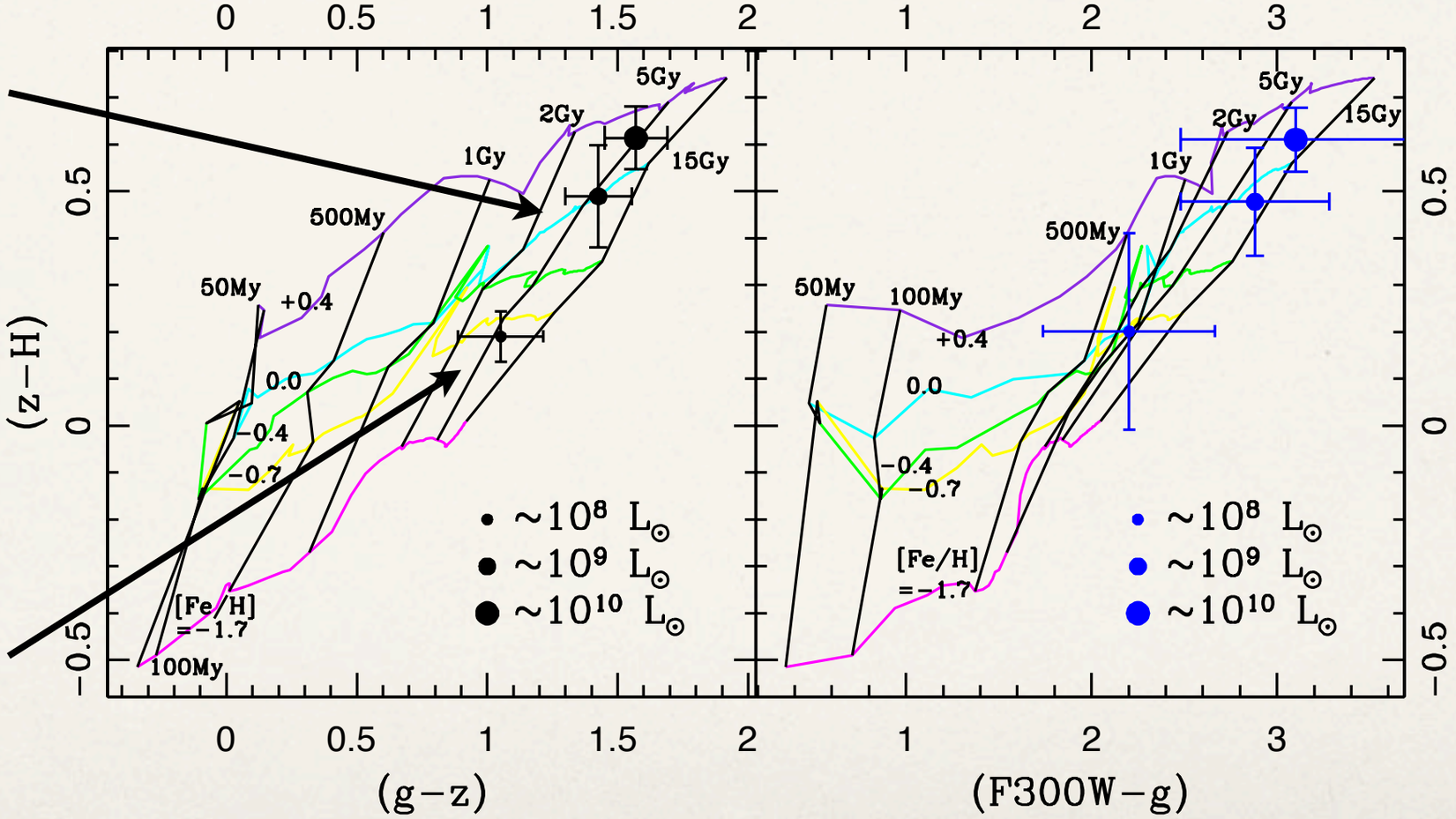
Nuclear metallicity increases with luminosity



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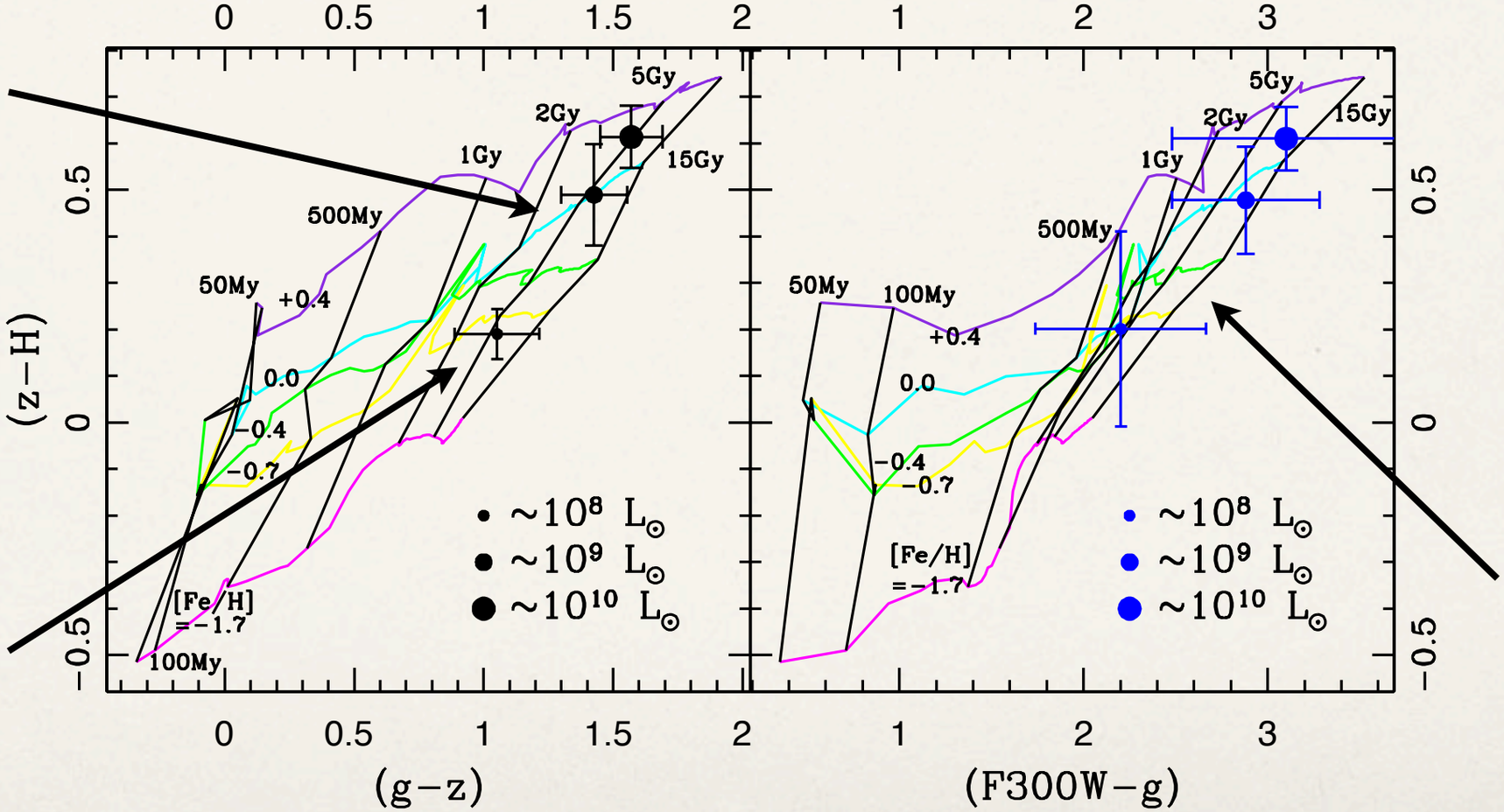

Nuclear metallicity increases with luminosity

Consistent within uncertainties although there is an indication that nuclei in fainter galaxies are younger.

Summary

- Nuclei are ubiquitous in early-type galaxies fainter than $M_B \sim -20$ mag.
- They form part of a larger sequence of central light deficit to excess along the luminosity function.
- There are two new programs underway to investigate the formation mechanism and stellar populations of nuclei:

1. An HST/STIS program to obtain spectra of a subsample of nuclei in Virgo for detailed stellar population study.
2. Virgo Redux, comprising HST imaging from the IR to the UV of the ACS Virgo Cluster Survey galaxies.
    - SEDs to break age-metallicity degeneracy.
    - Promising preliminary results.