GHOSTS

Probing the Outskirts of Disk Galaxies

Roelof de Jong (AIP)

GHOSTS Survey team:

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Benne Holwerda (Leiden)
Antonela Monachesi (MPA)
Chris Purcell (WVU)
Anil Seth (Utah)
Jonathan Sick (Queens)
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Marija Vlajic (AIP)
Dan Zucker (Macquarie/AAO)

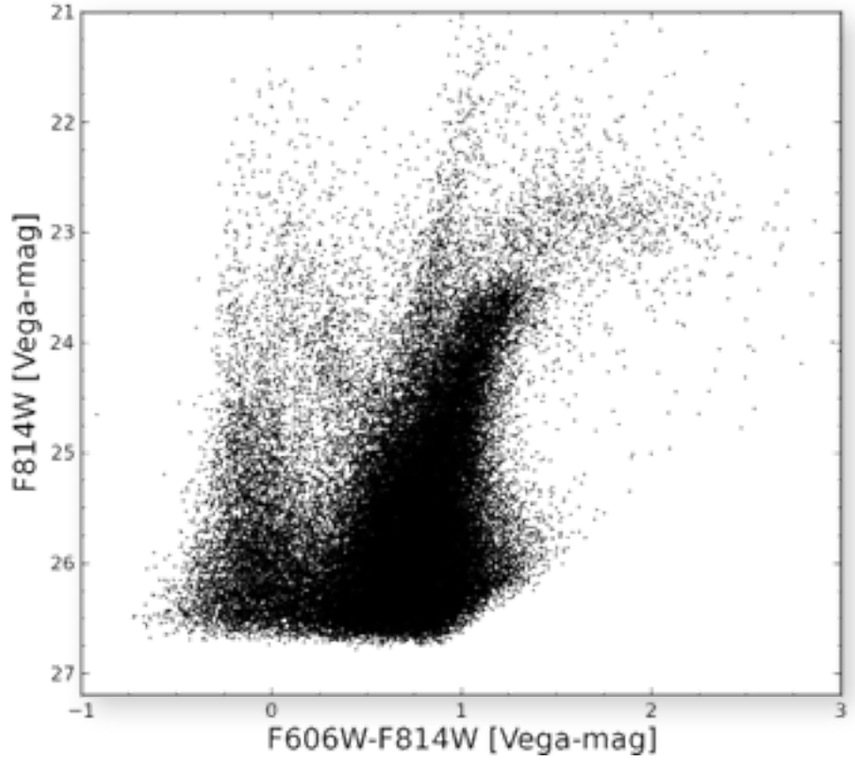
Galaxy
Halos
Outer Disks
Substructure
Thick Disks
Star Clusters

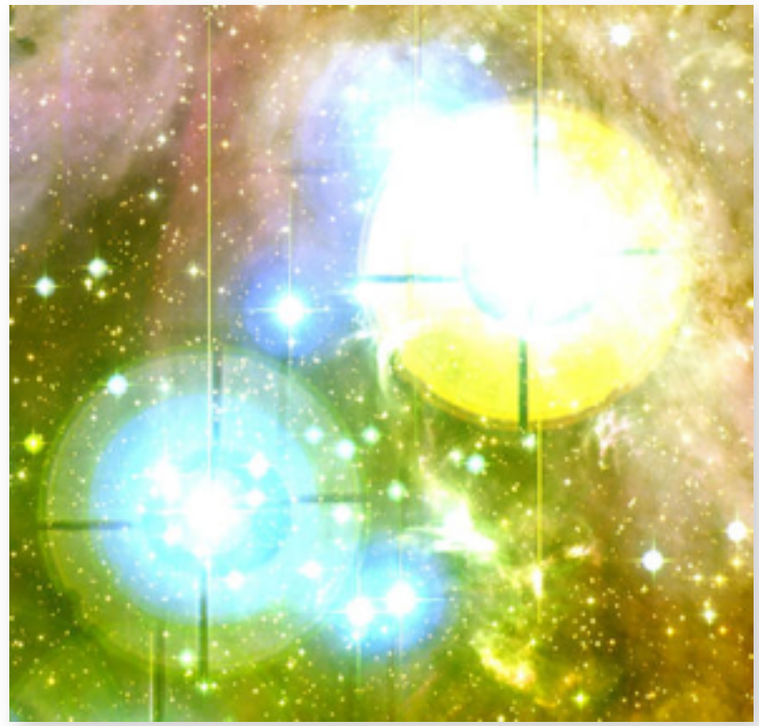
GHOSTS The Survey

- GHOSTS samples the *resolved stellar populations* in the outskirts of 18+ nearby disk galaxies with a large HST ACS/ WFPC2/WFC3 survey
- HST allows us to go to larger distances (more galaxies), denser regions (disk outskirts) and larger radii (less contamination)
- Science goals of GHOSTS:
  - Structure, substructure and metallicities of stellar halos
  - Stellar age/metallicity distributions in disk outskirts (scaleheigth/length, disk heating, truncations, warps)
  - Globular cluster systems

GHOSTS Why resolved populations?

- **Populations provide better resolved information on ages & metallicities than possible from integrated light**
- **Fainter surface brightness areas can be studies as star counts are not flat-field limited, but Poisson noise and contamination limited**
- **Scattered light (PSF halos) are of no concern**





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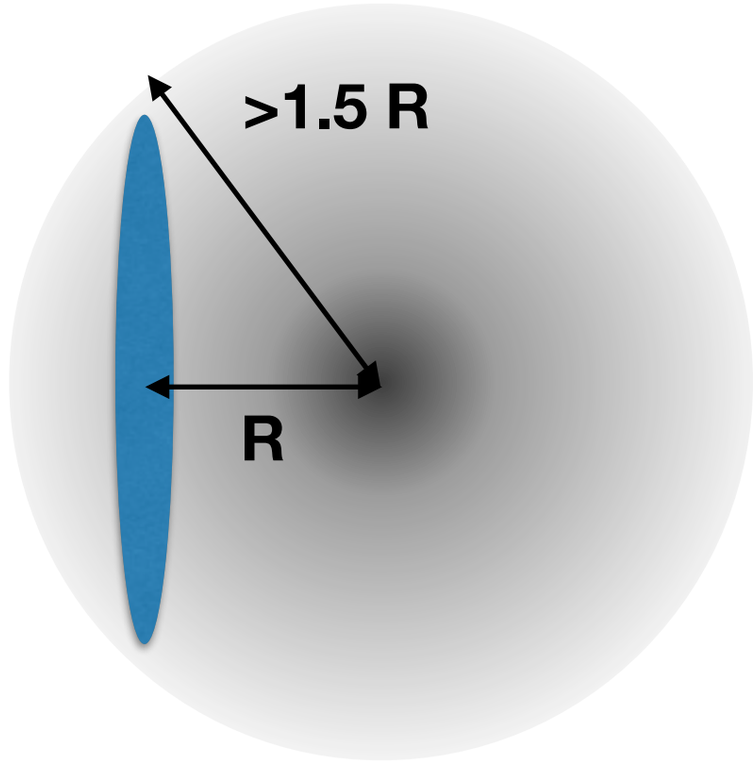
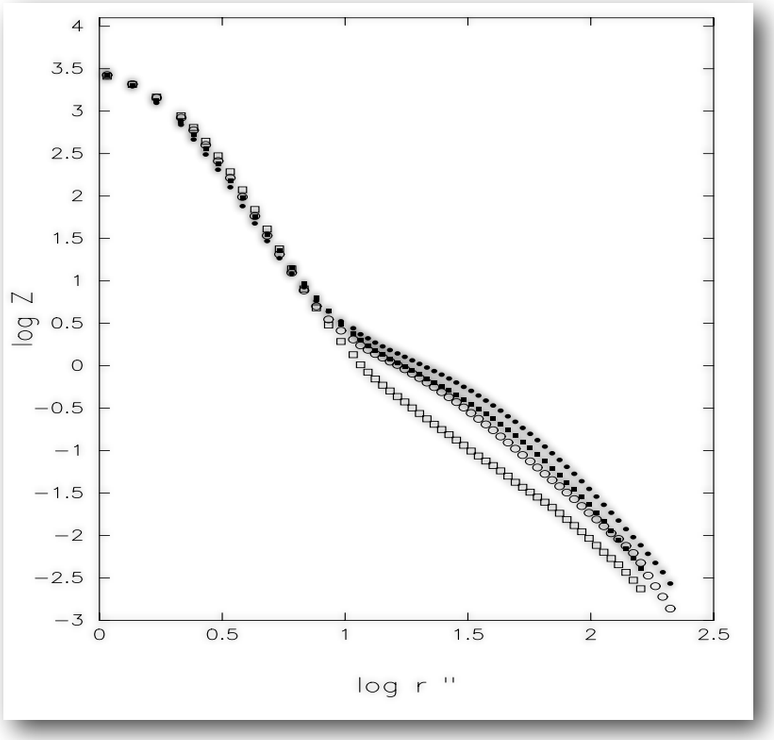
GHOSTS Scattered light: be cautious!

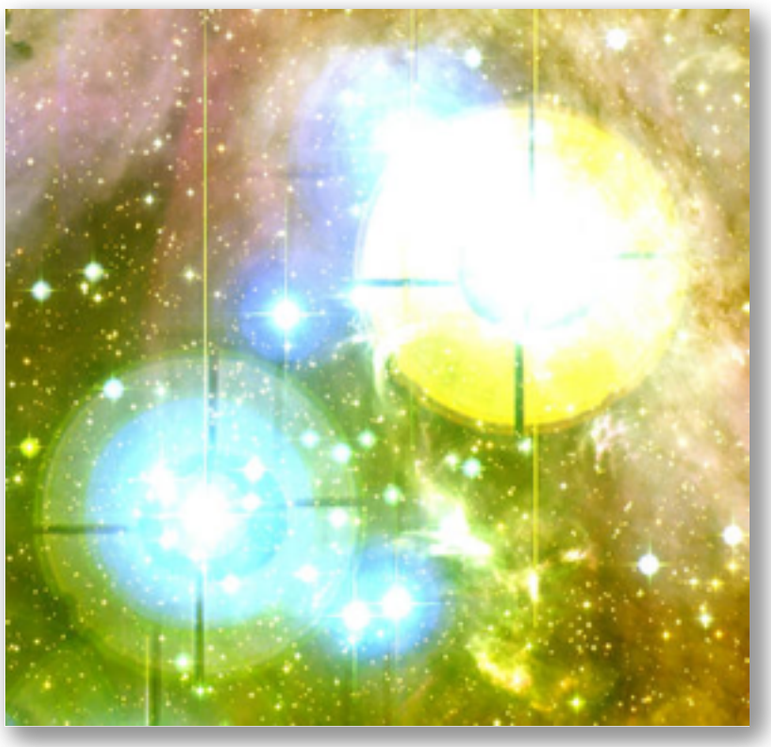
- Scattered light (PSF halos) can easily mimic thick disks or halos if not properly accounted for in integrated light measurements (de Jong 2008; Sandin 2014, 2015)
- The effect is the full 2D convolution of the PSF with the galaxy, checking a 1D cross-cut is *insufficient*
- You need a PSF profile that extends *at least 1.5x* further than the radius you are trying to measure the galaxy surface brightness



GHOSTS PSF: other problems

- Seeing variations (for r<10 arcsec)
- Filter dependence (especially i-band)
- Variations over longer time scales (dusty mirror, sky conditions?)
- Image ghosts, non-symmetric structures
- Detector diffusion and bias variations (HST, Spitzer!)
- Field location





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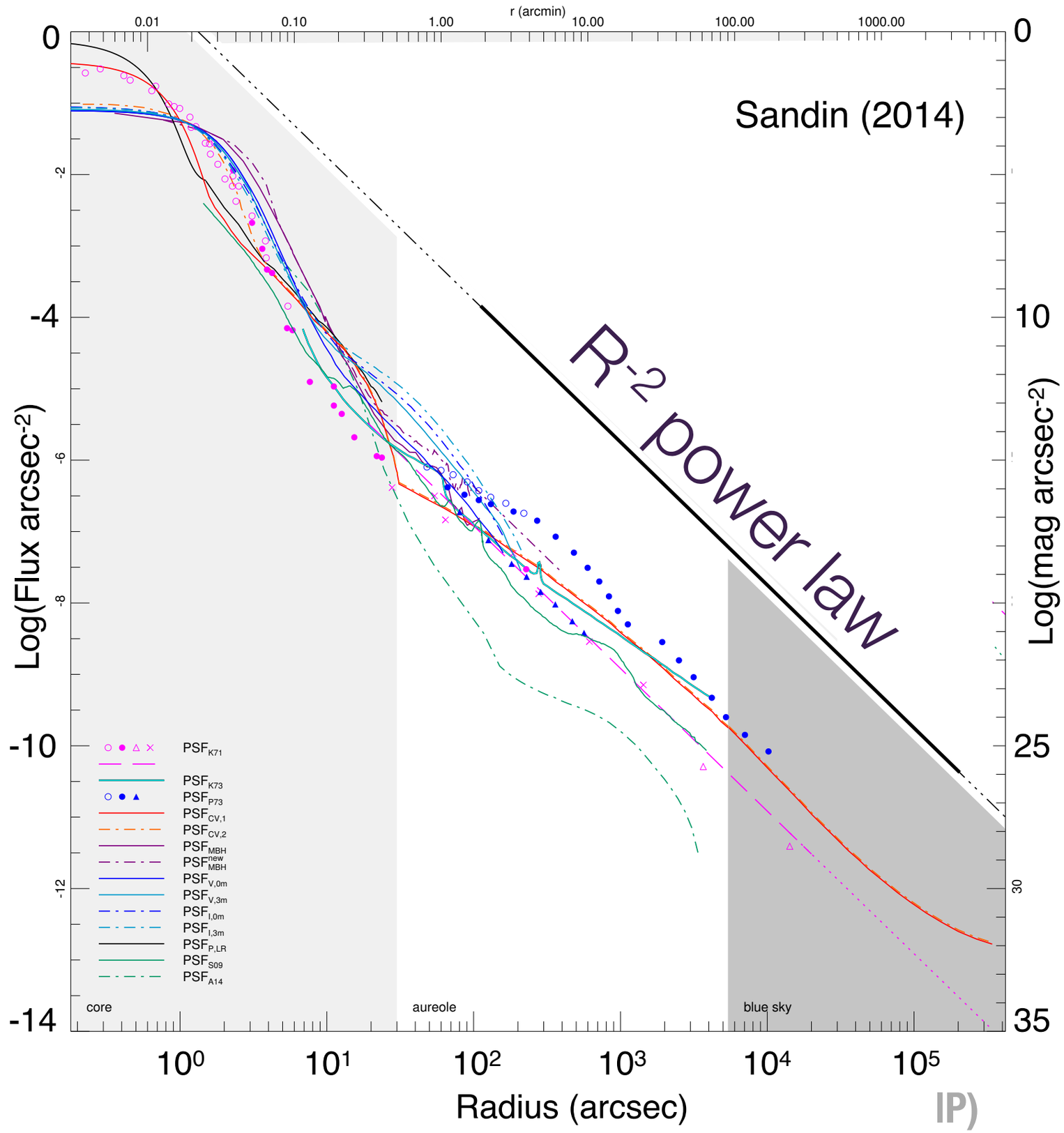
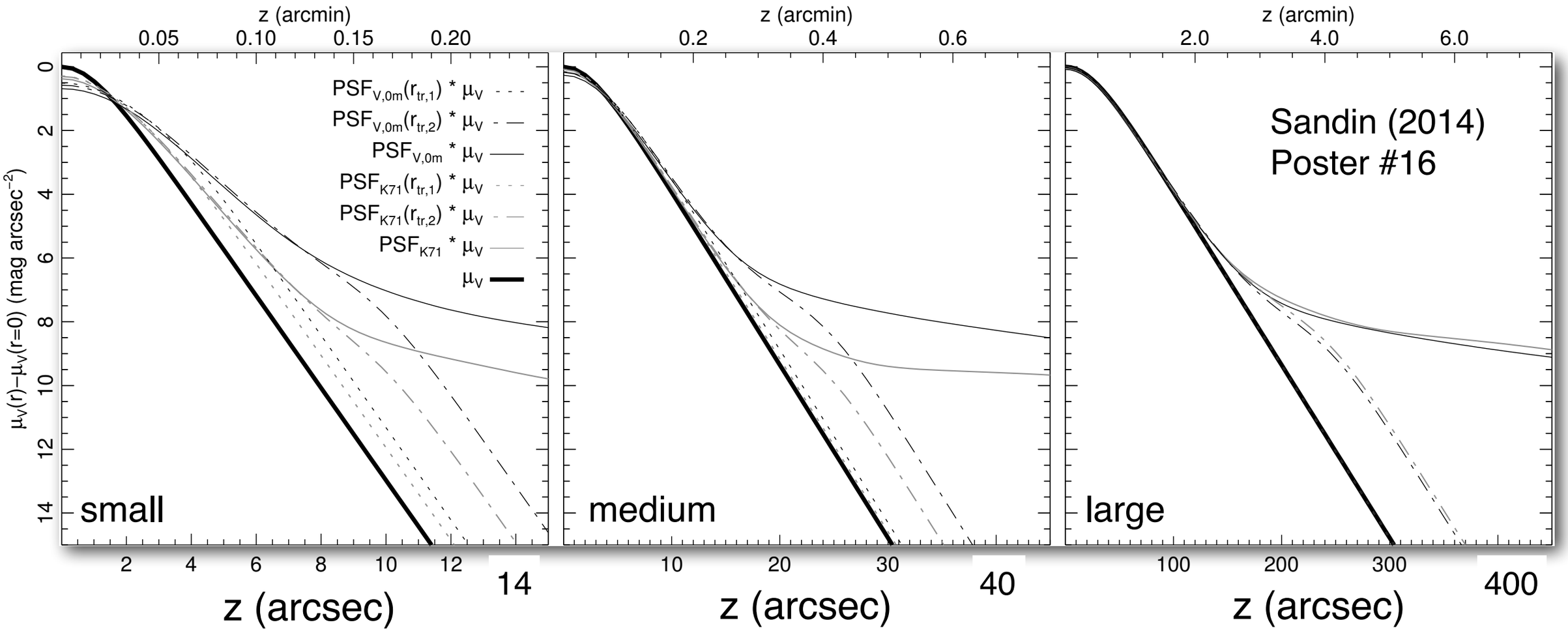
GHOSTS PSF: R^{-2} power law profiles

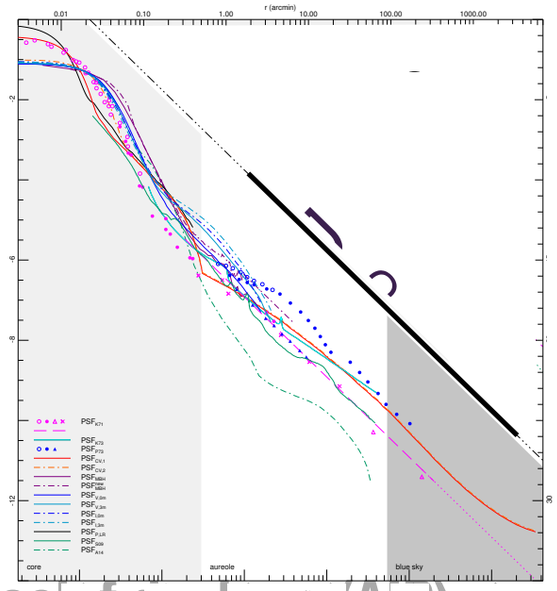
- **Outside the inner ~Gaussian core (<10”) PSFs behave like ~ R^{-2} power laws**



GHOSTS PSF: R^{-2} power law profiles



- **This means that the effect is essentially independent of galaxy size and that you are better off measuring intermediate size galaxies**



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GHOSTS ACS Observations

NGC 0247
NGC 0253
NGC 0891
NGC 2403
NGC 3031
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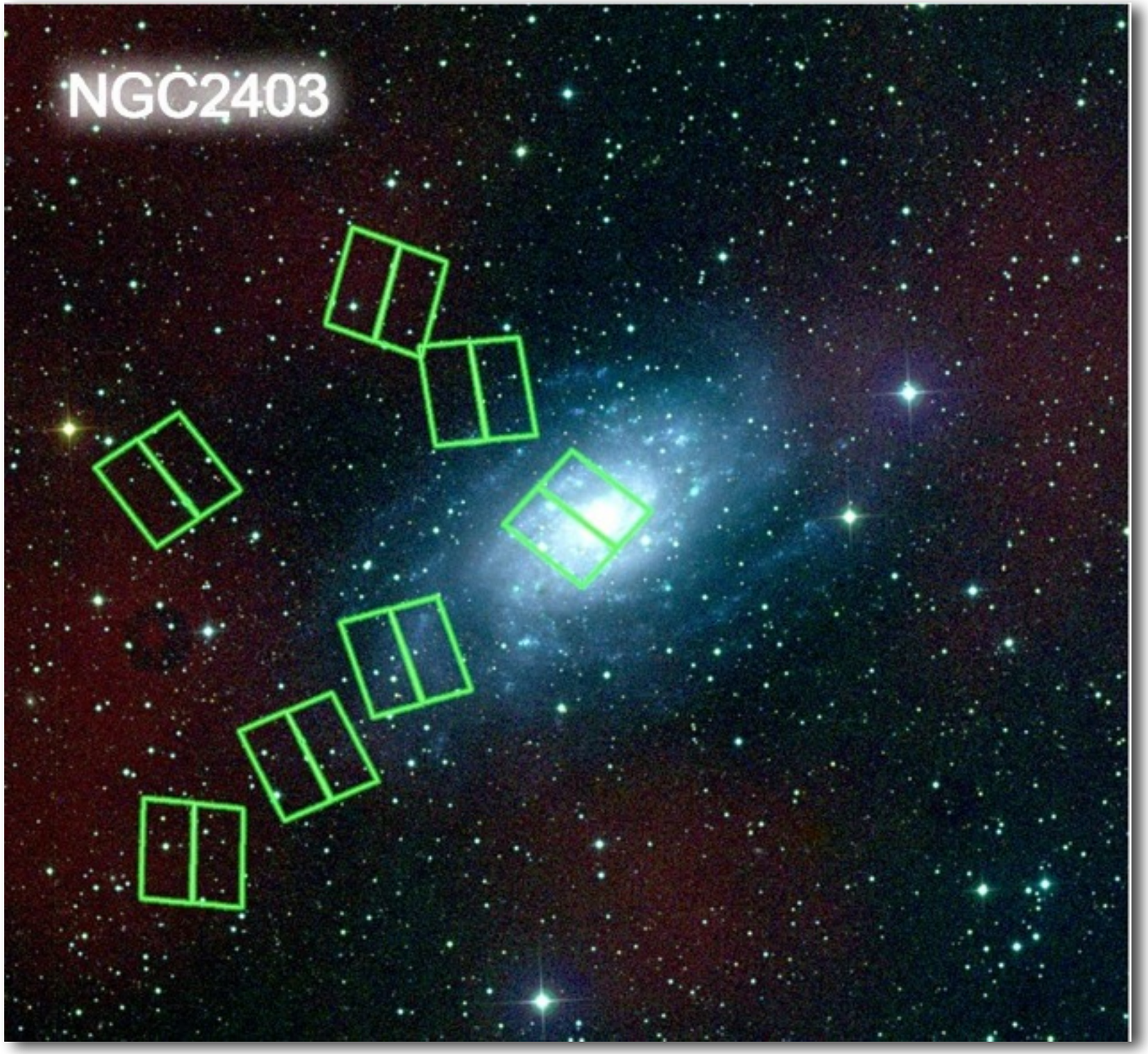

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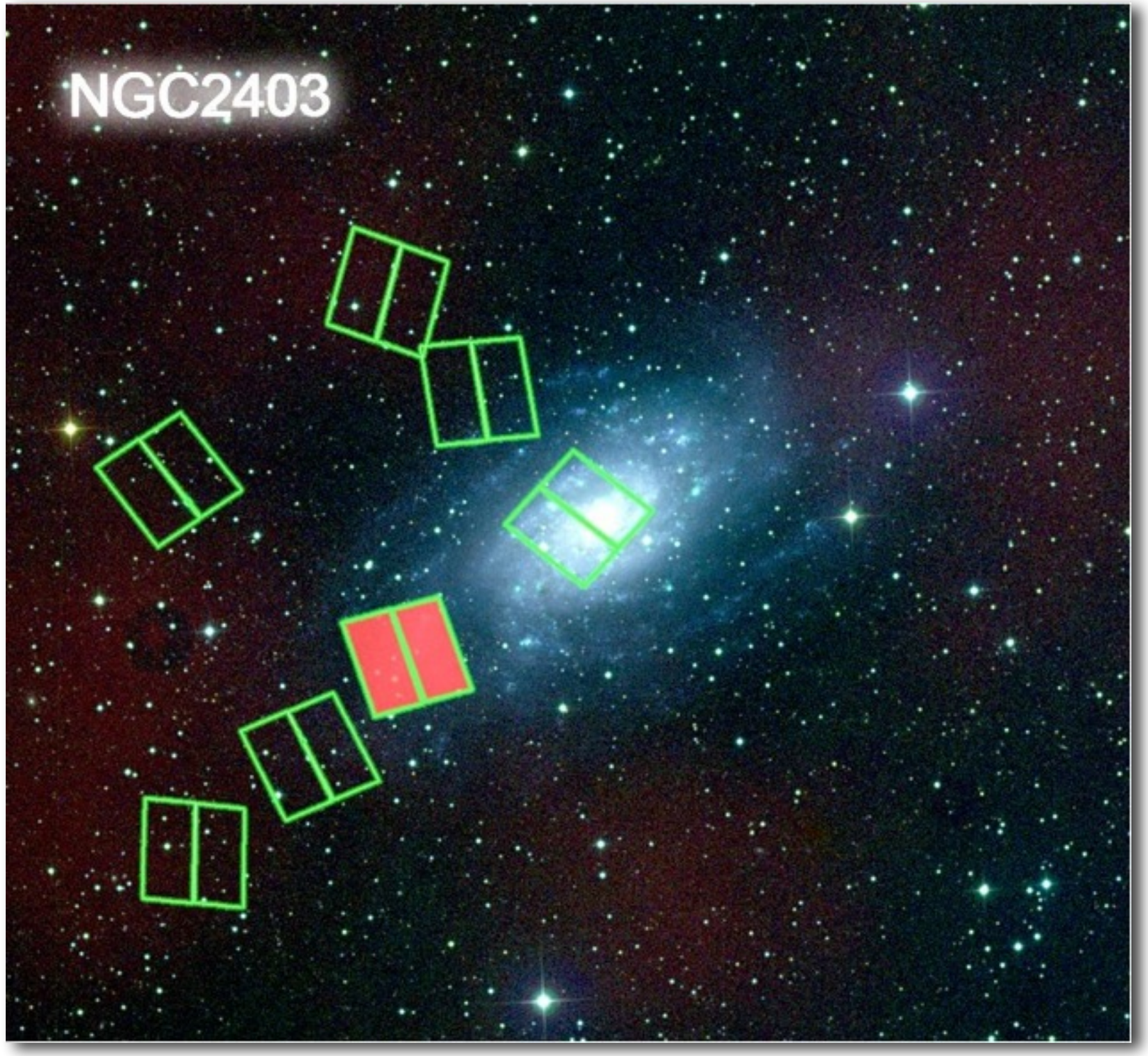

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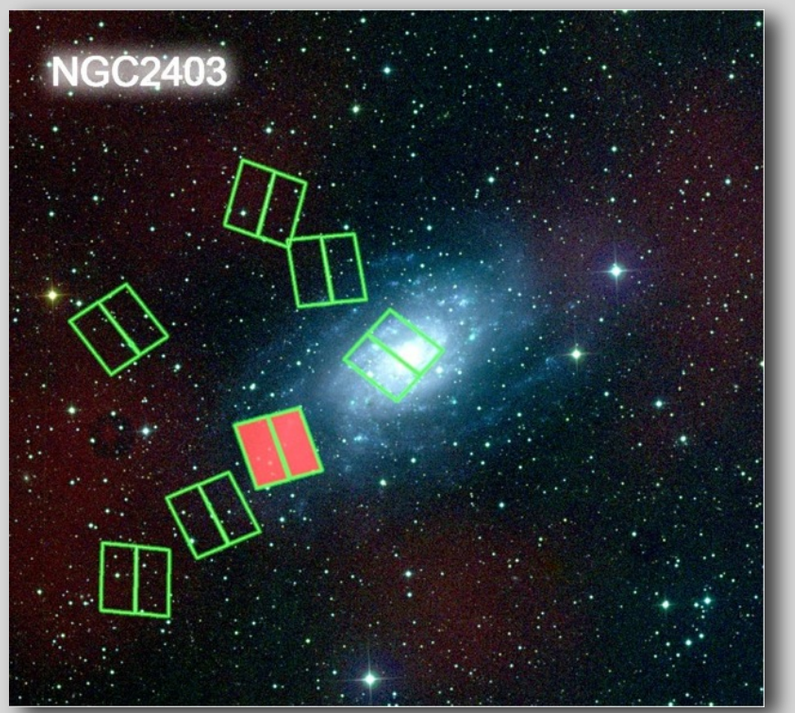

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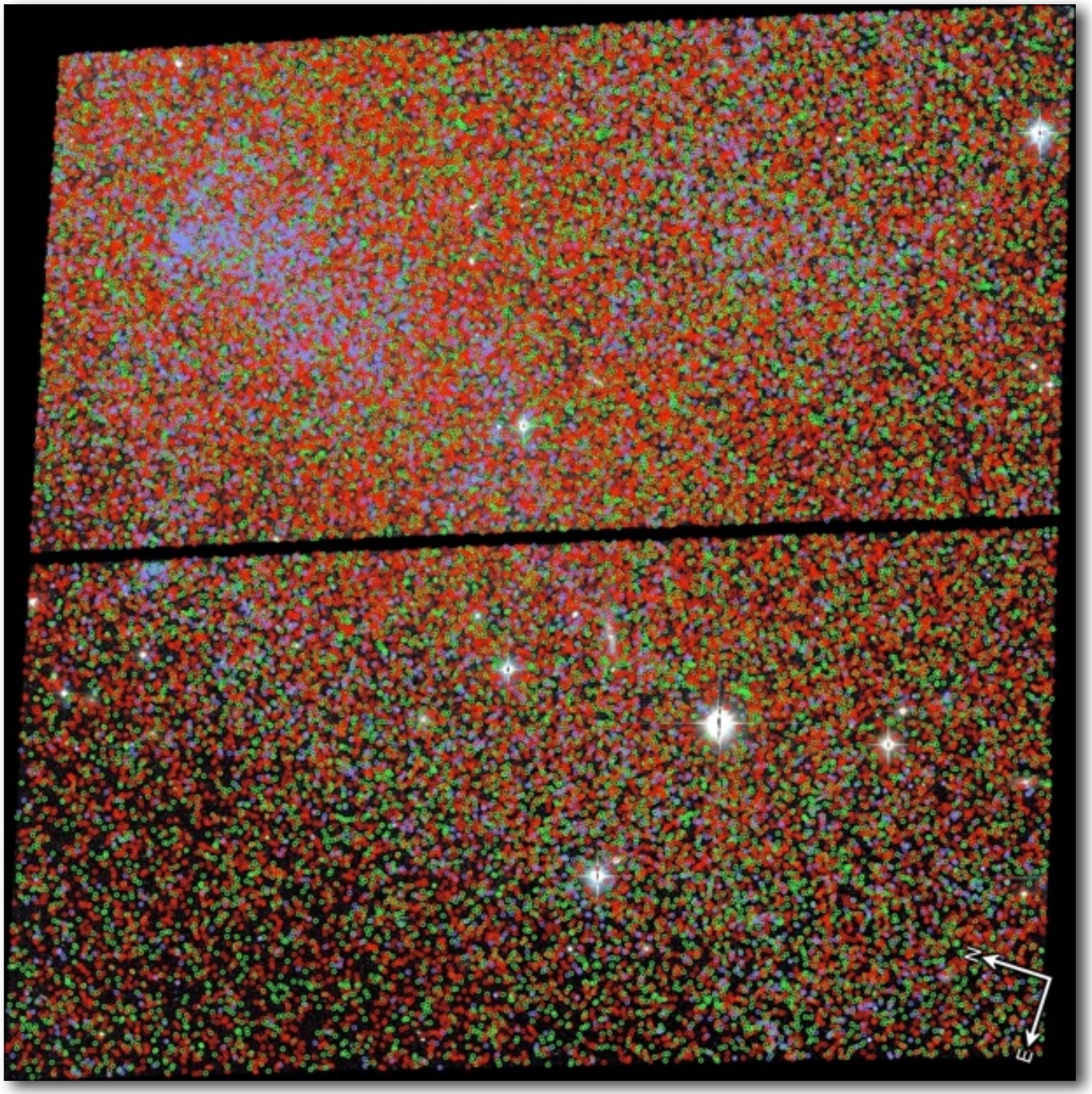

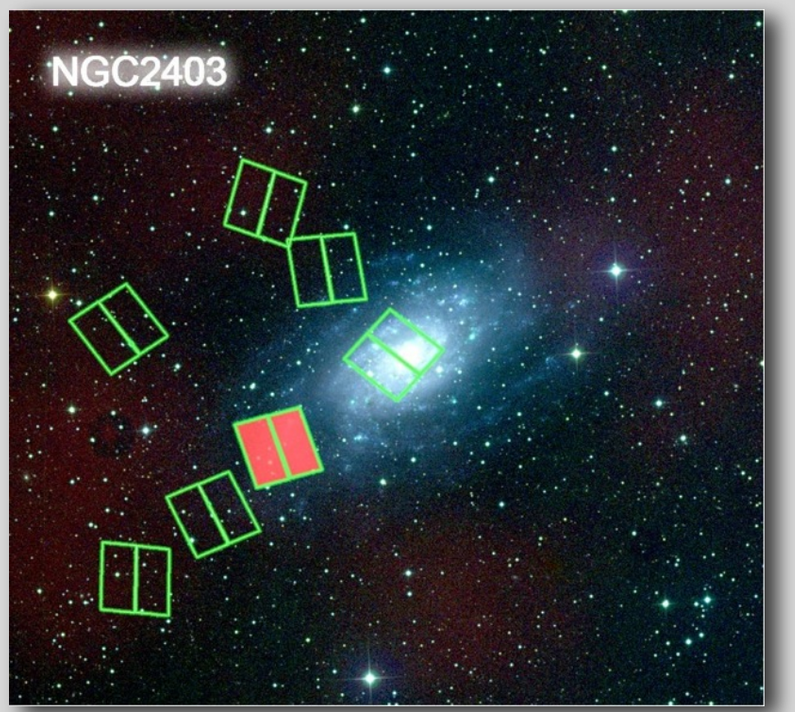

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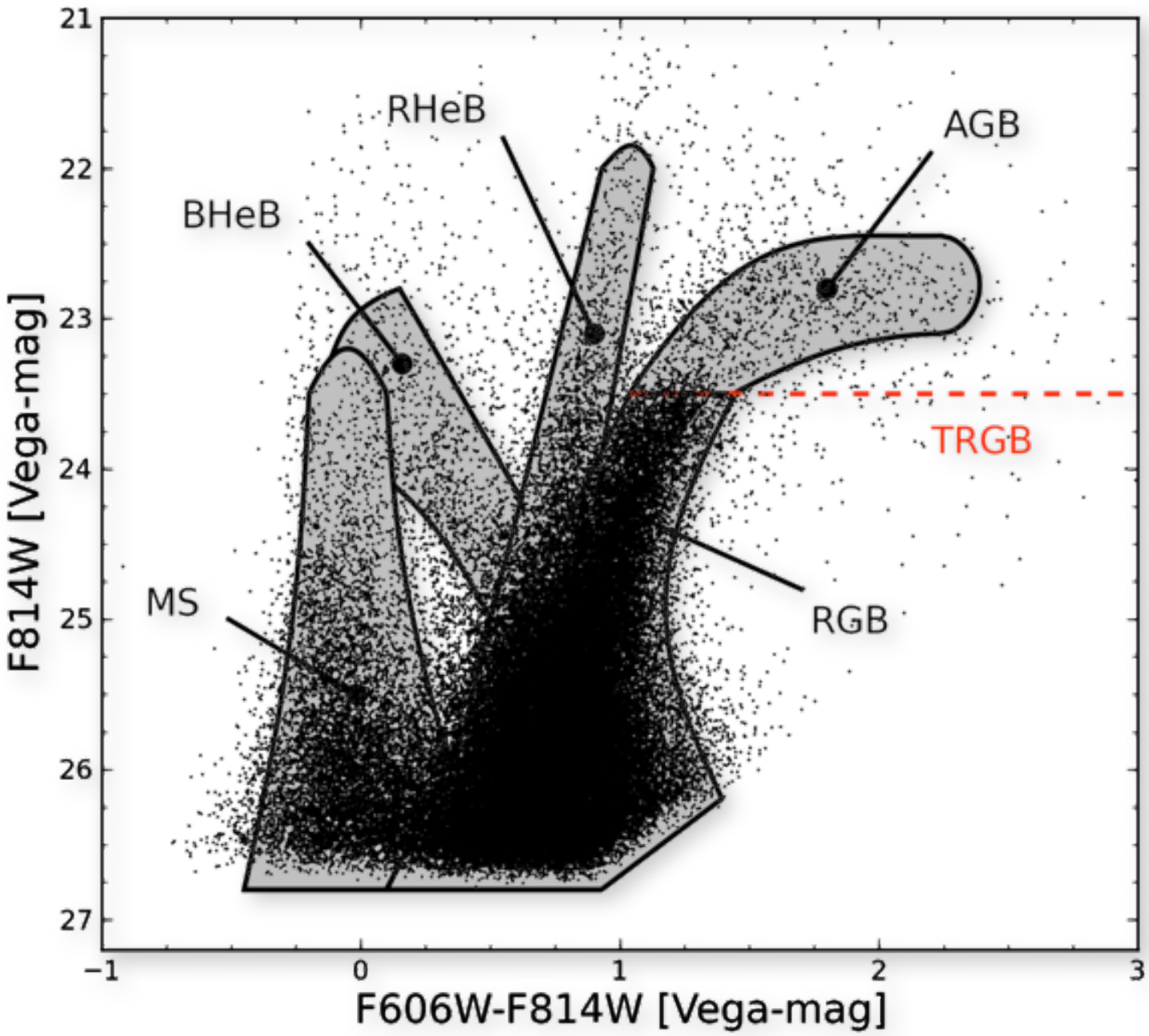

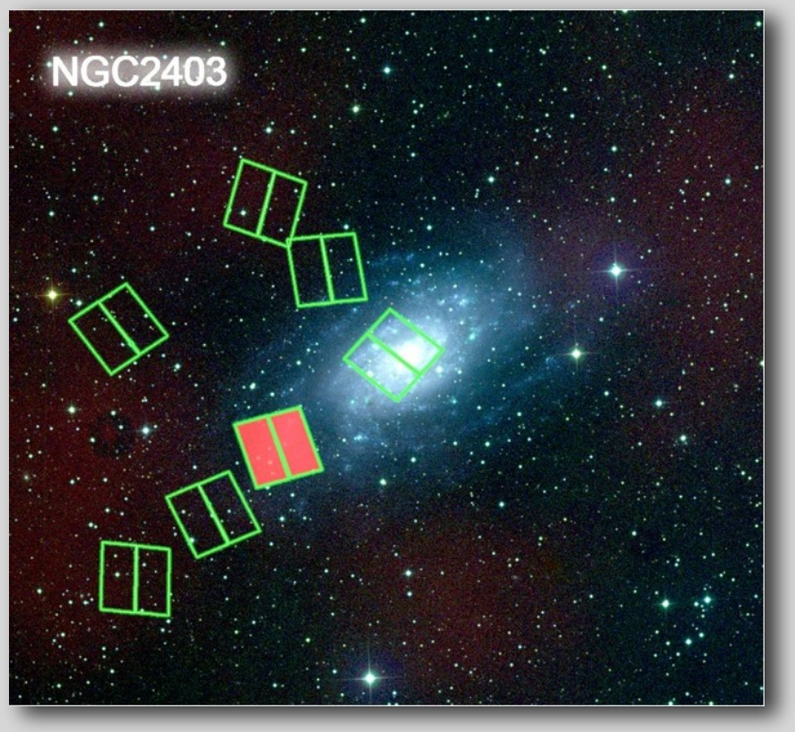

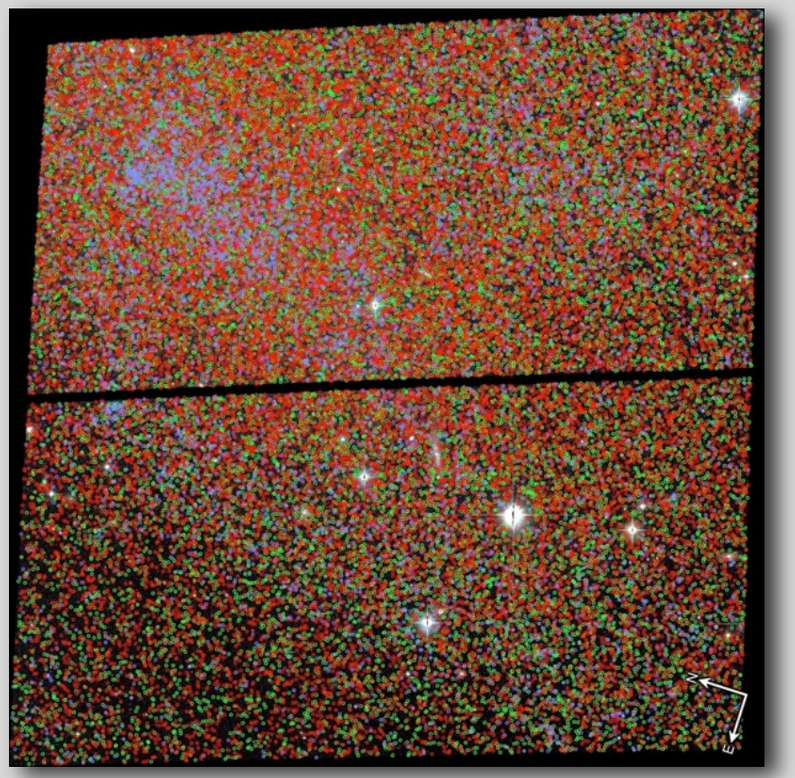

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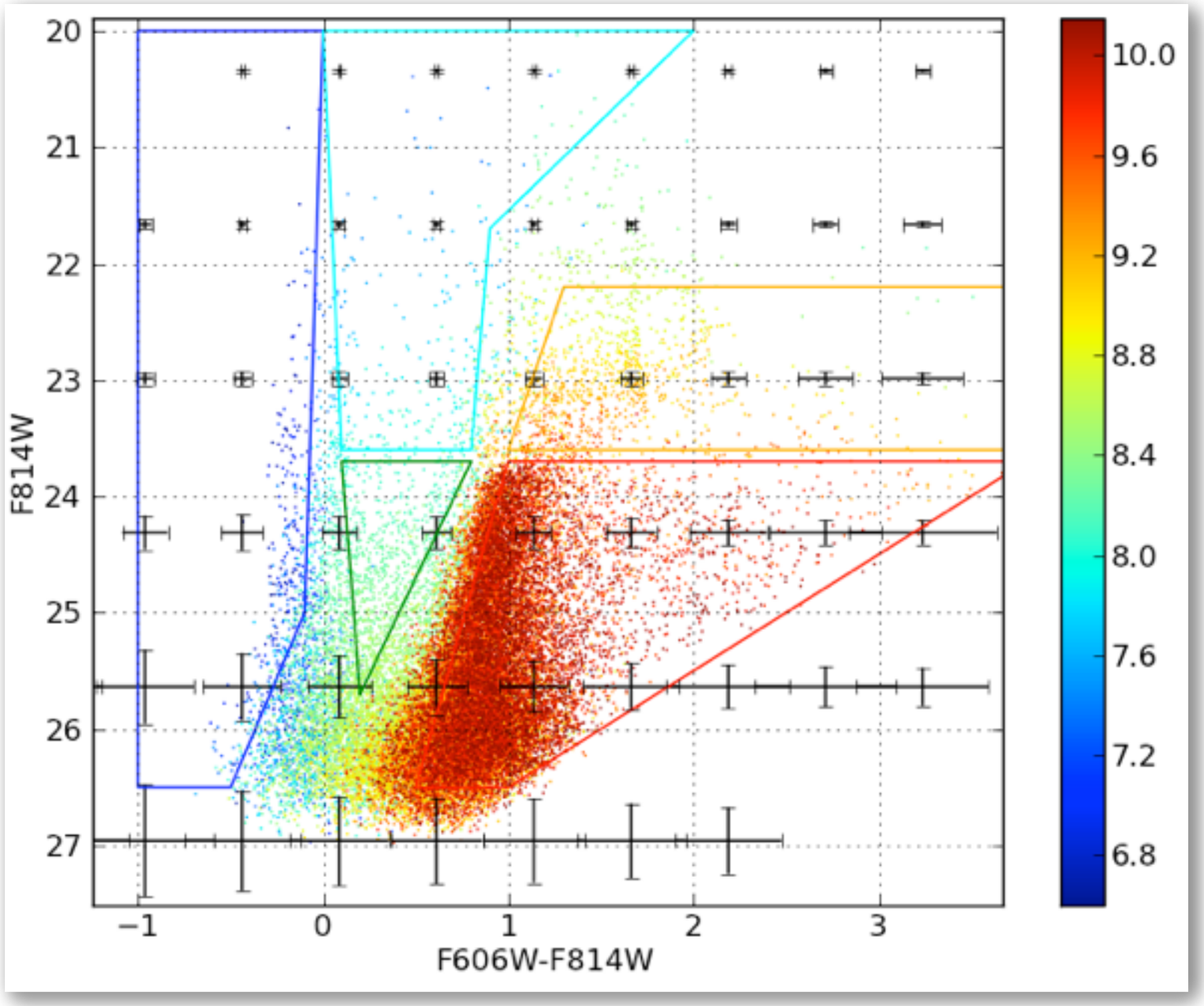

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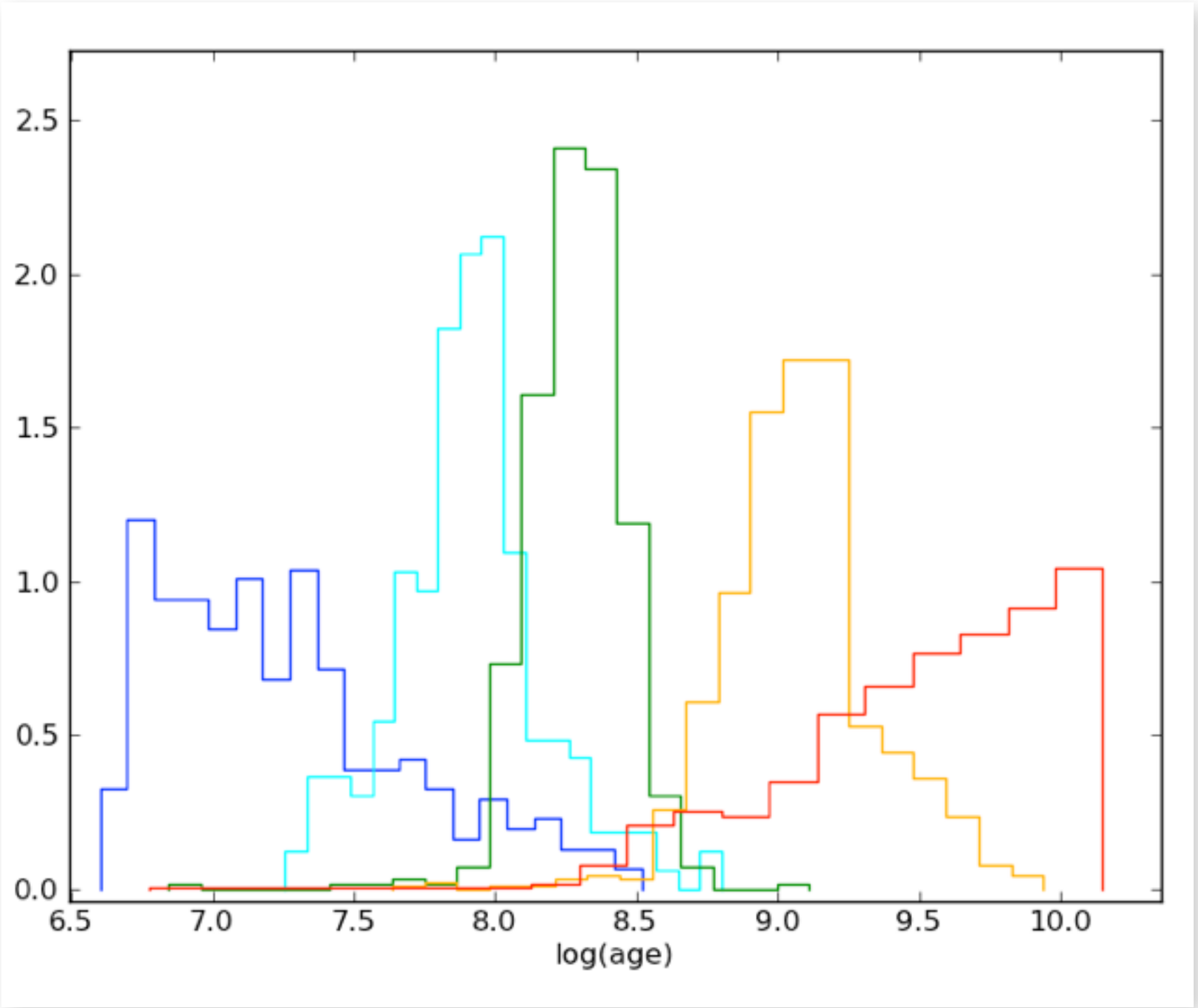

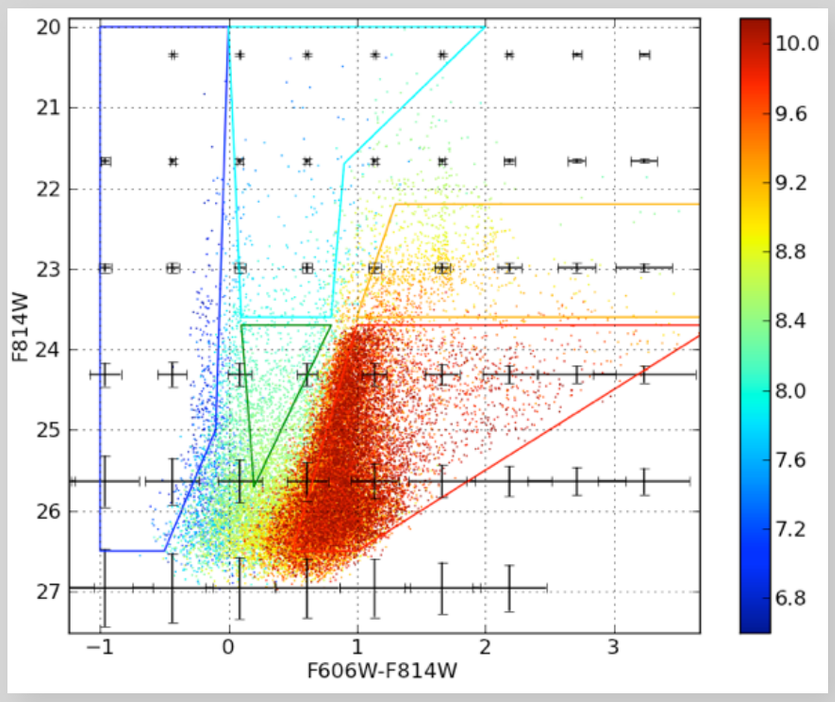

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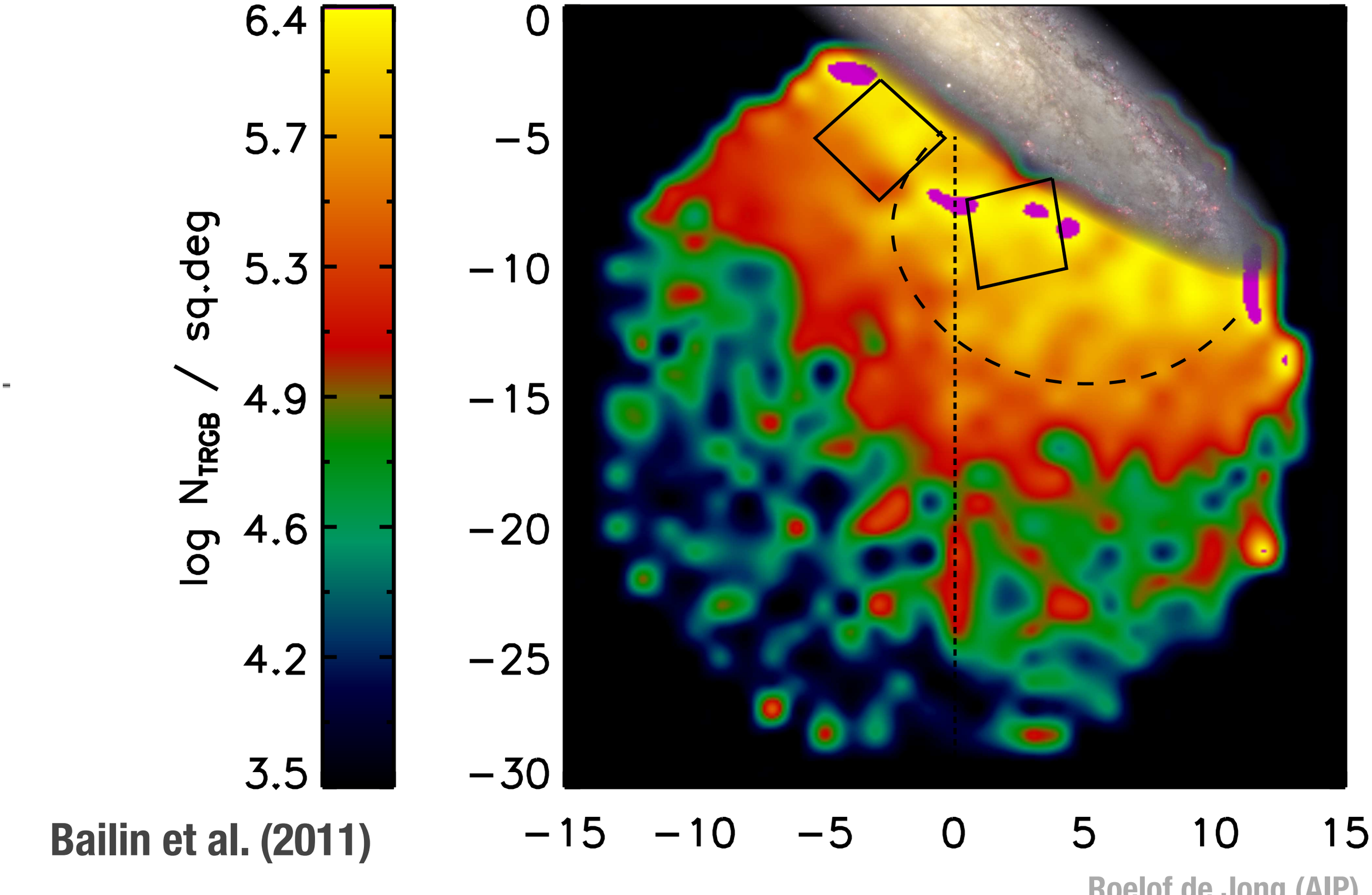
GHOSTS Why HST? - NGC 253



Bailin et al. (2011)

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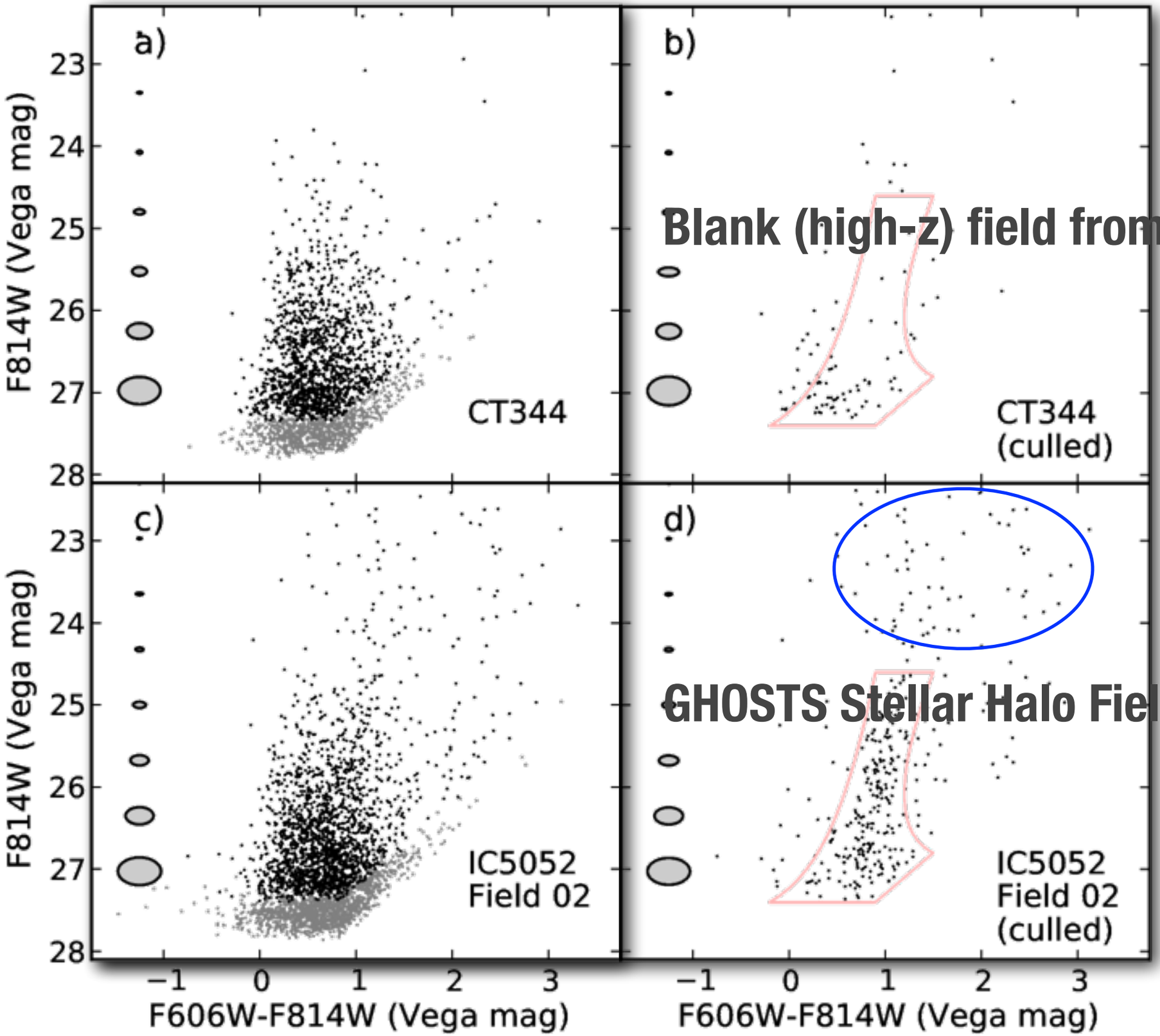
GHOSTS Why HST?



Blank (high-z) field from archive

MW halo foreground
Radburn-Smith in prep.

GHOSTS Stellar Halo Field

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GHOSTS Sample Overview

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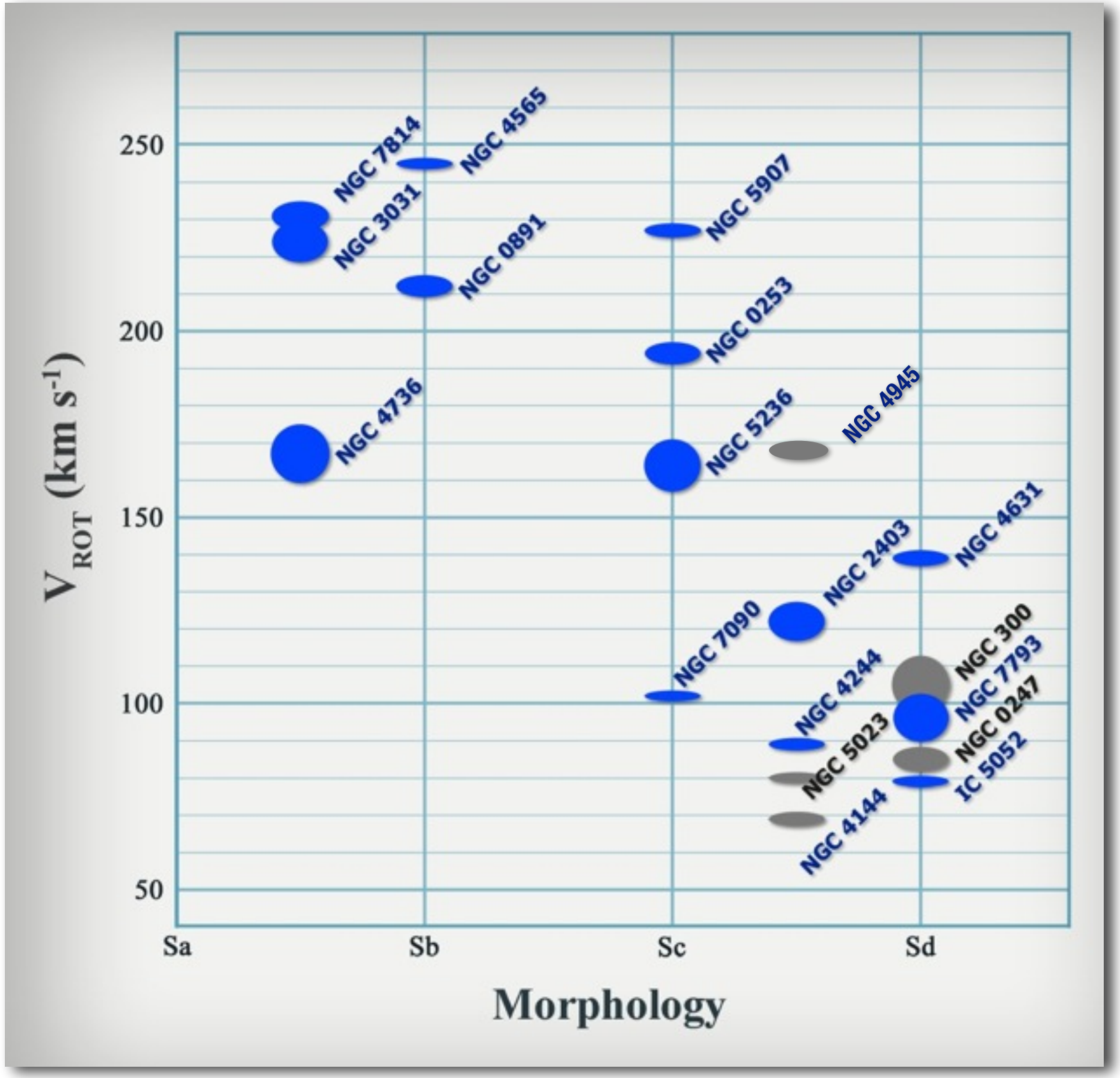

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GHOSTS Stellar Halo Profiles

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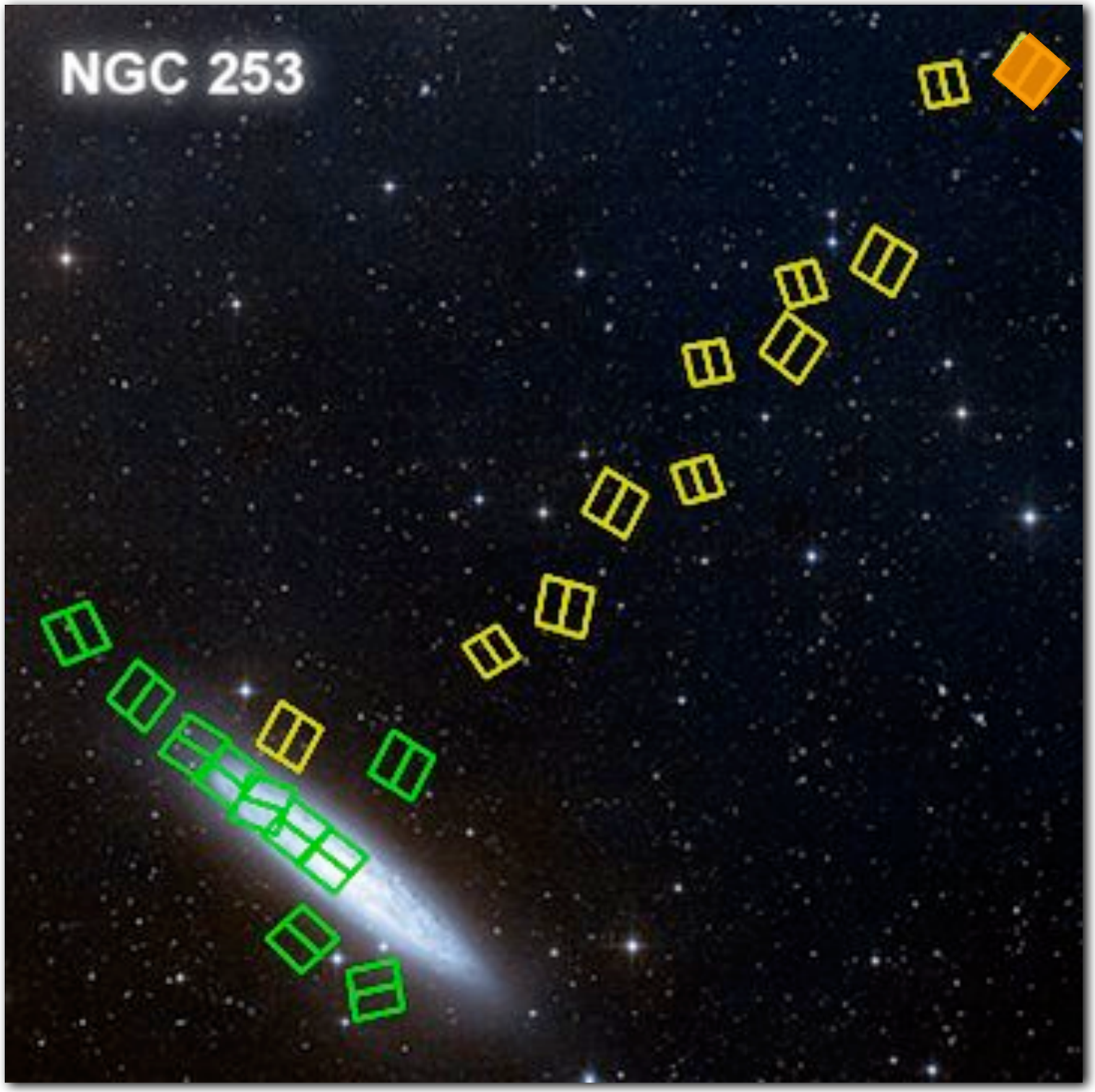

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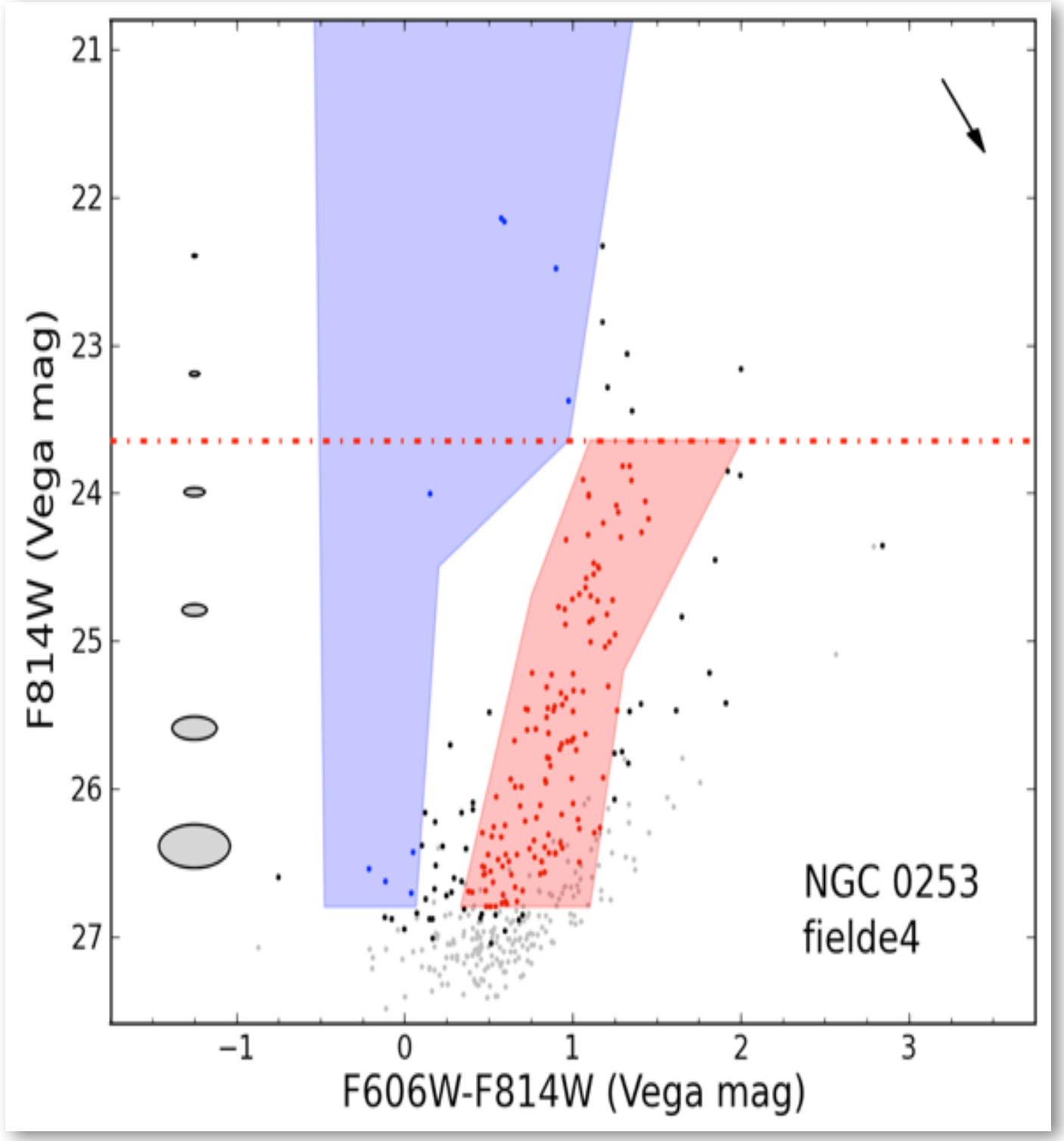

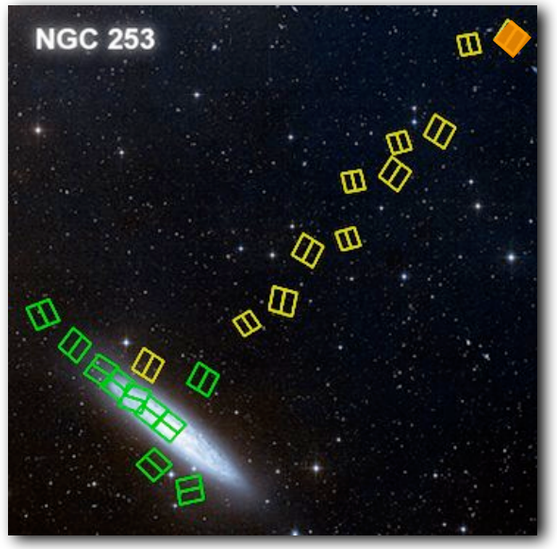

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GHOSTS Stellar Halo Profiles

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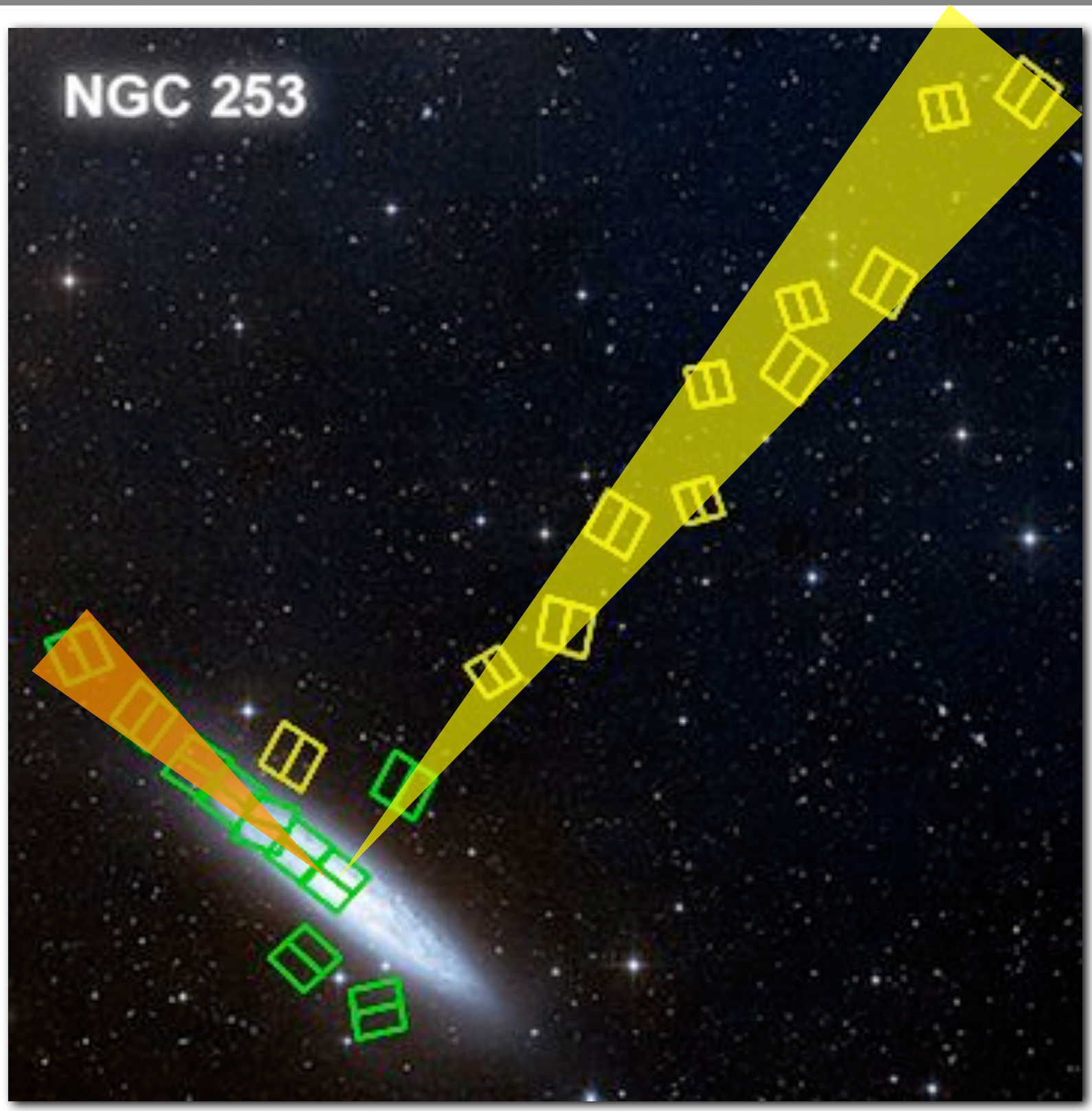

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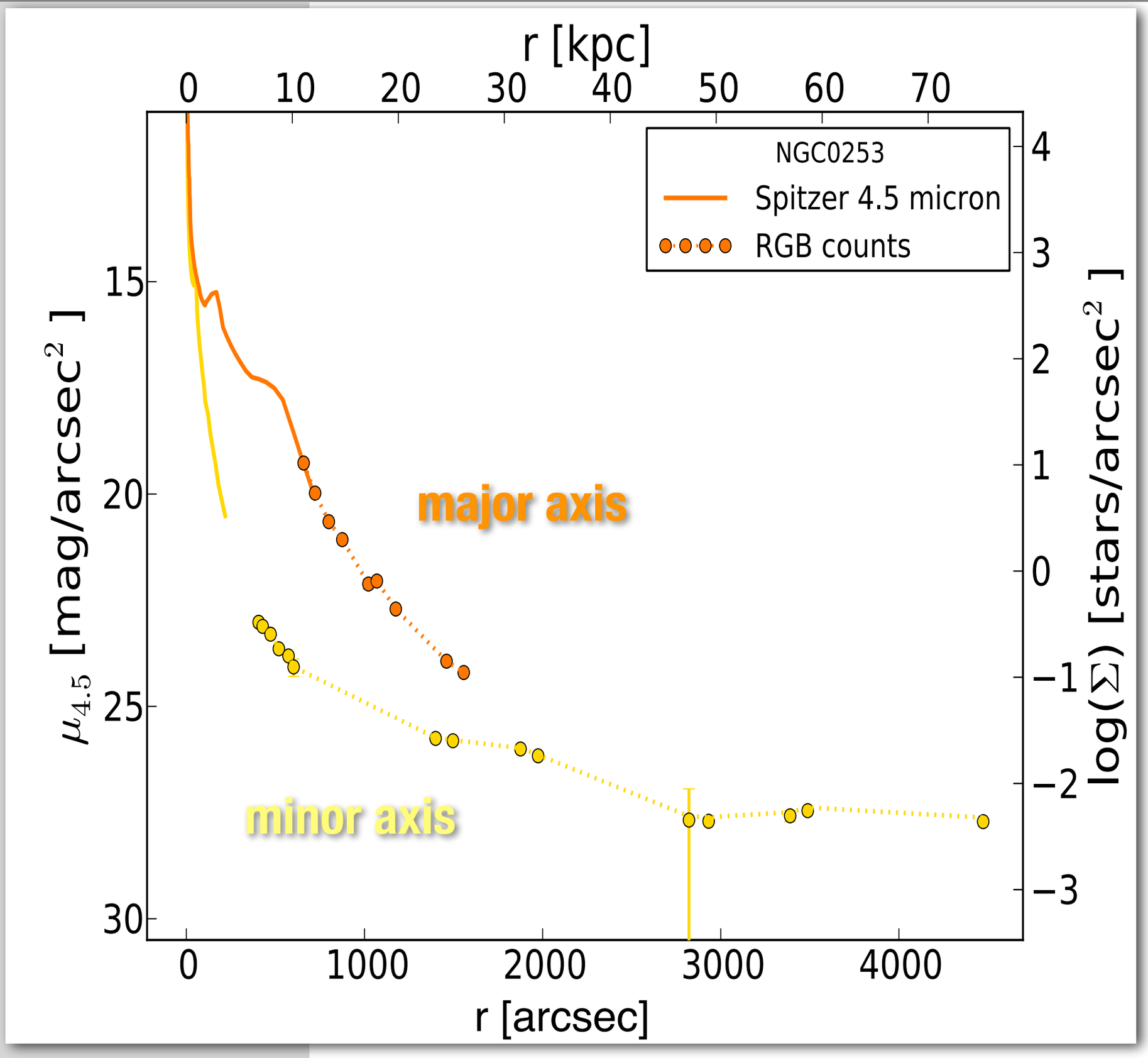
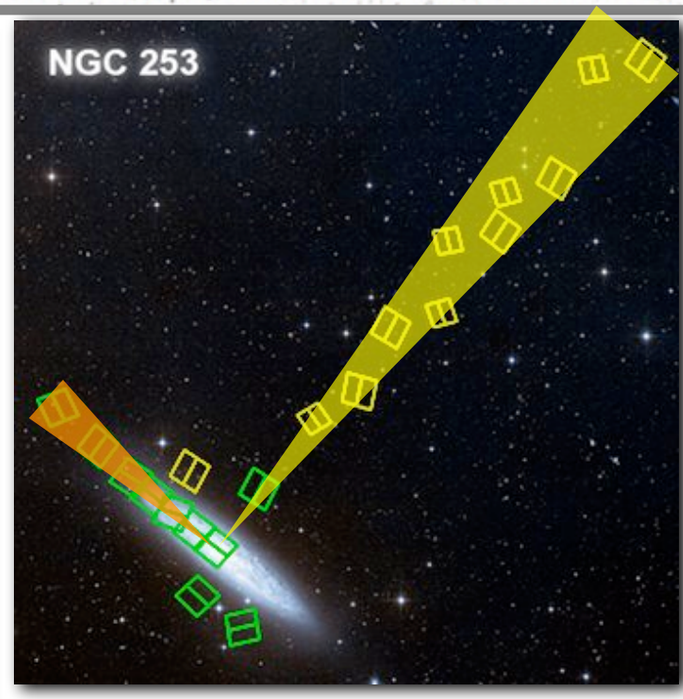
GHOSTS Stellar Halo Profiles





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GHOSTS Stellar Halo Profiles

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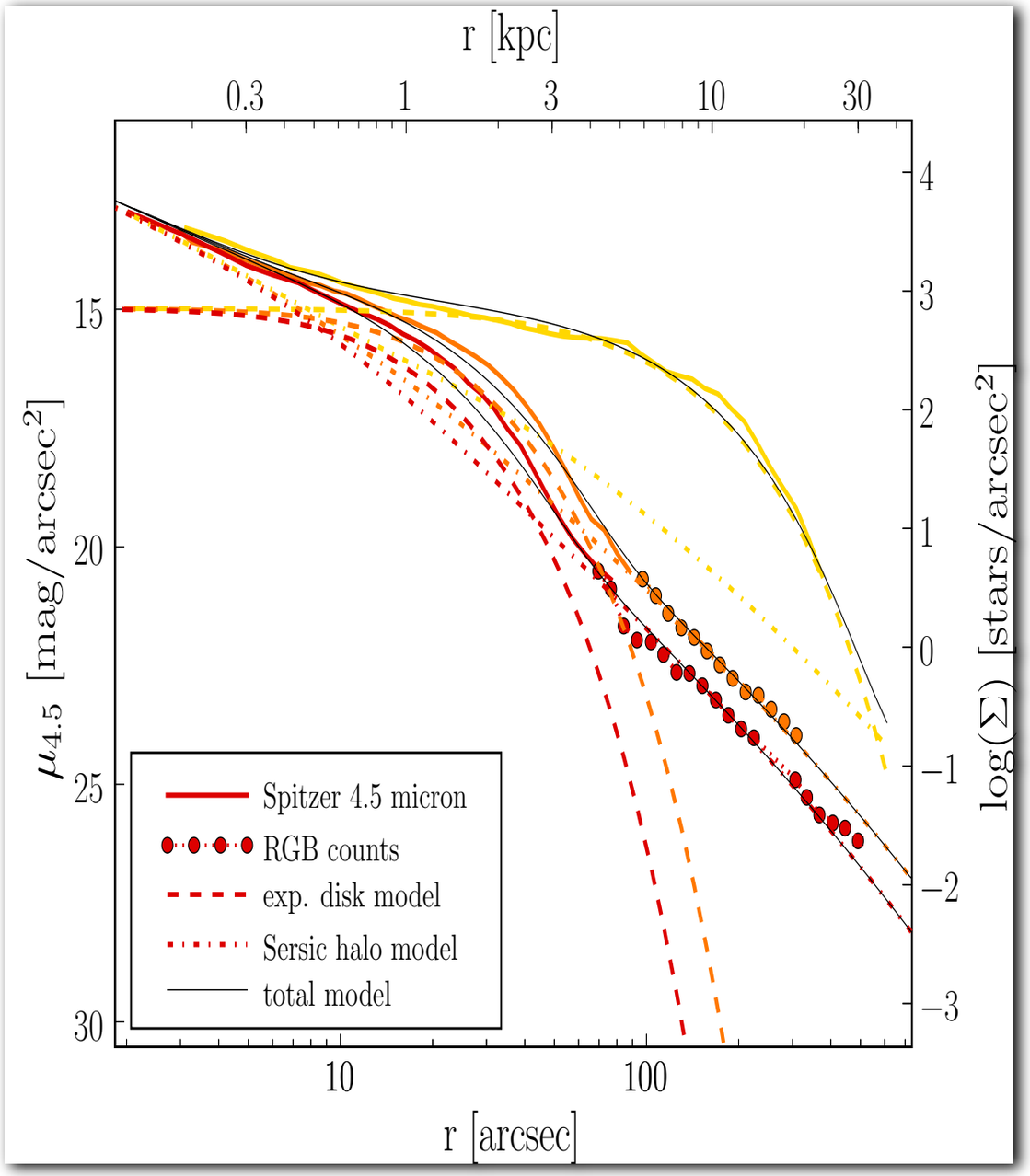

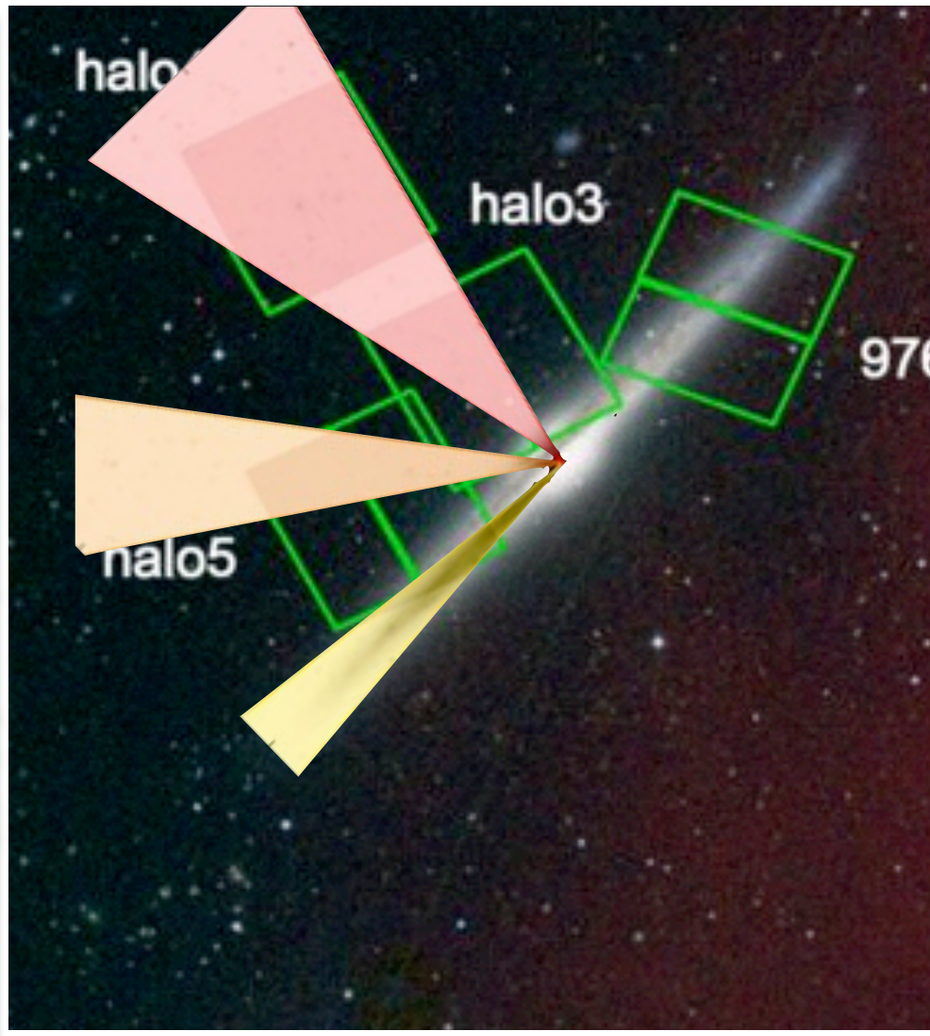

- **Most galaxies fitted with single strongly flattened Sersic spheroid and exponential disk**

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GHOSTS Stellar populations distribution

NGC 0247
NGC 0253
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NGC 2403
NGC 3031
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NGC 5236
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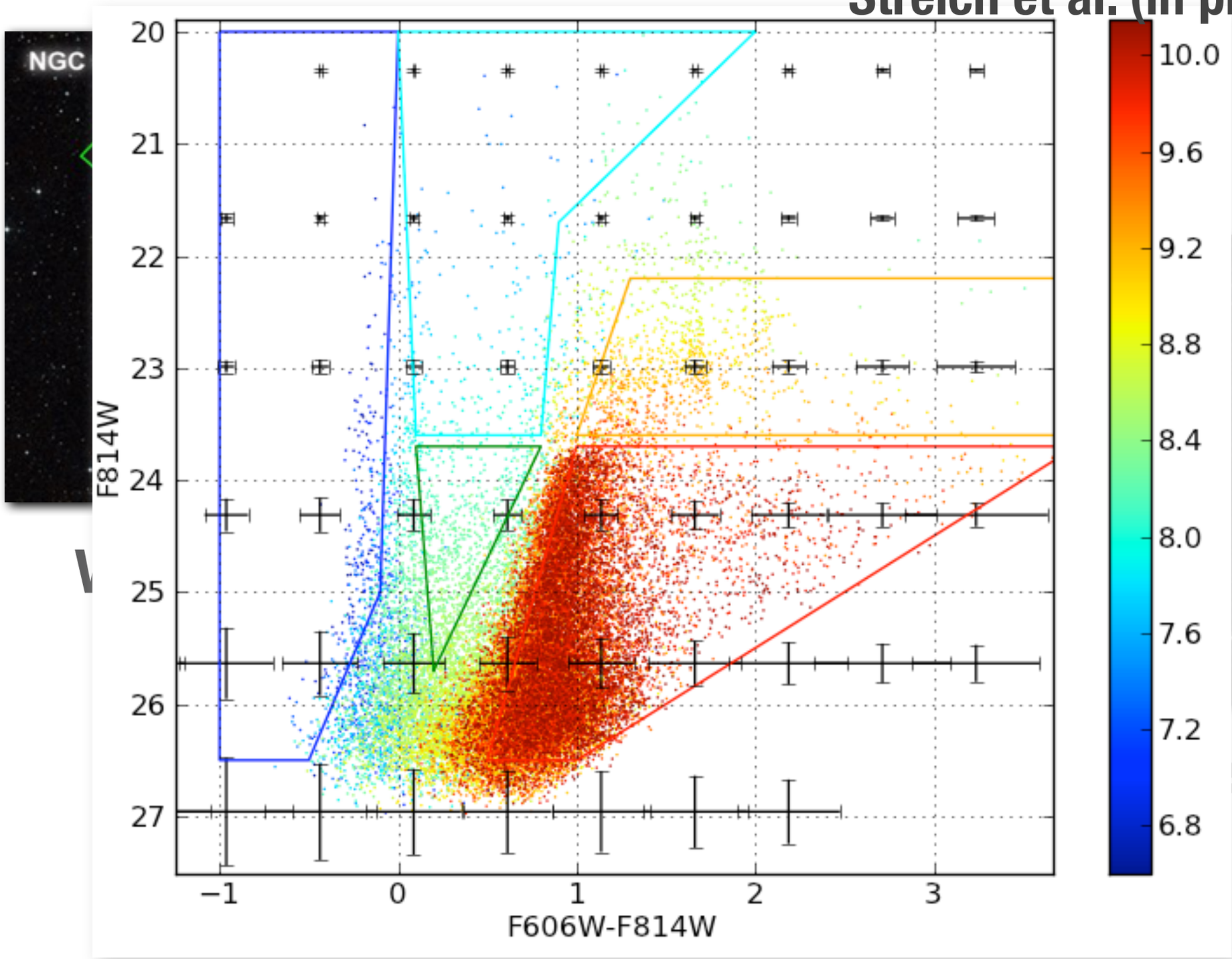
Streich et al. (in prep)



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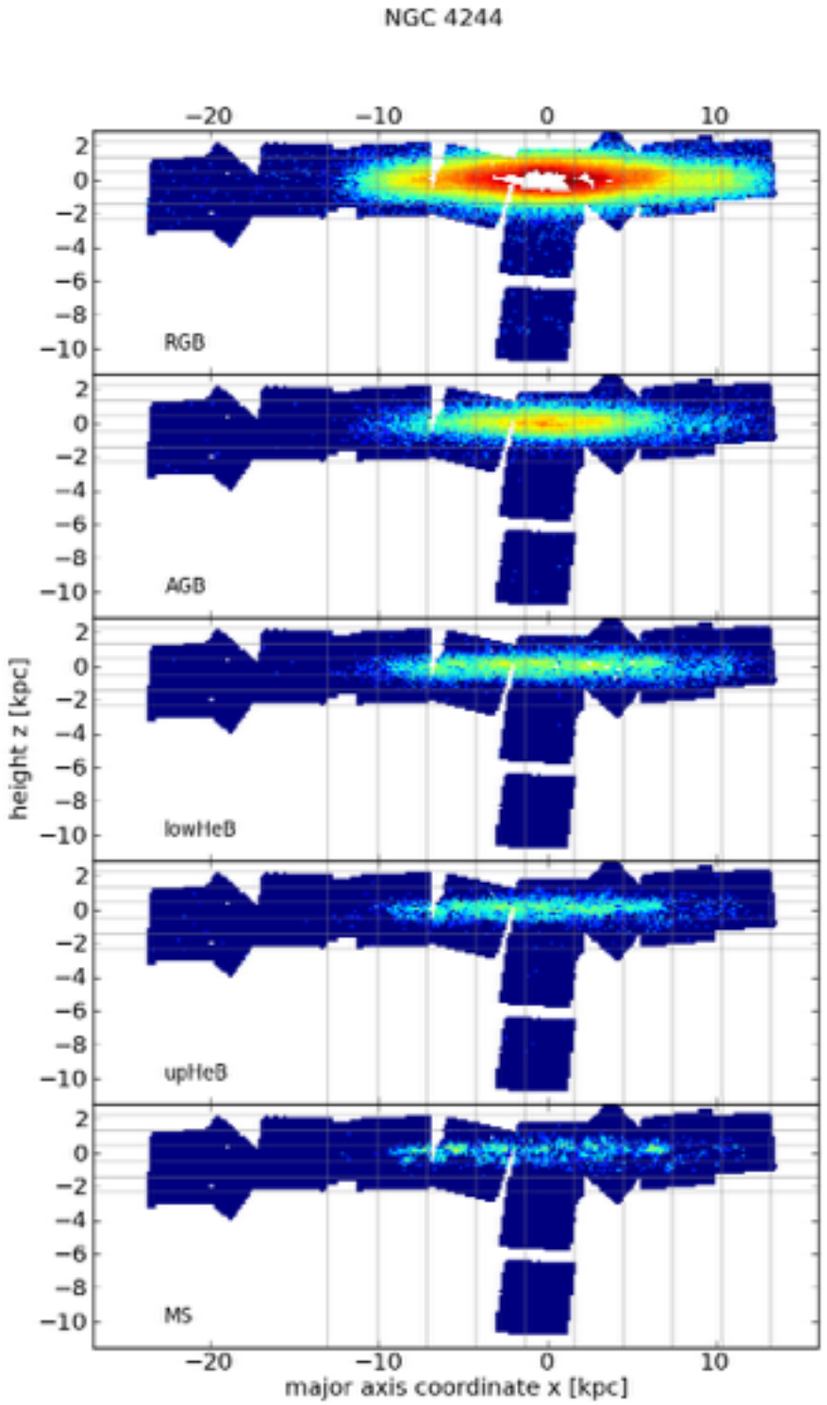
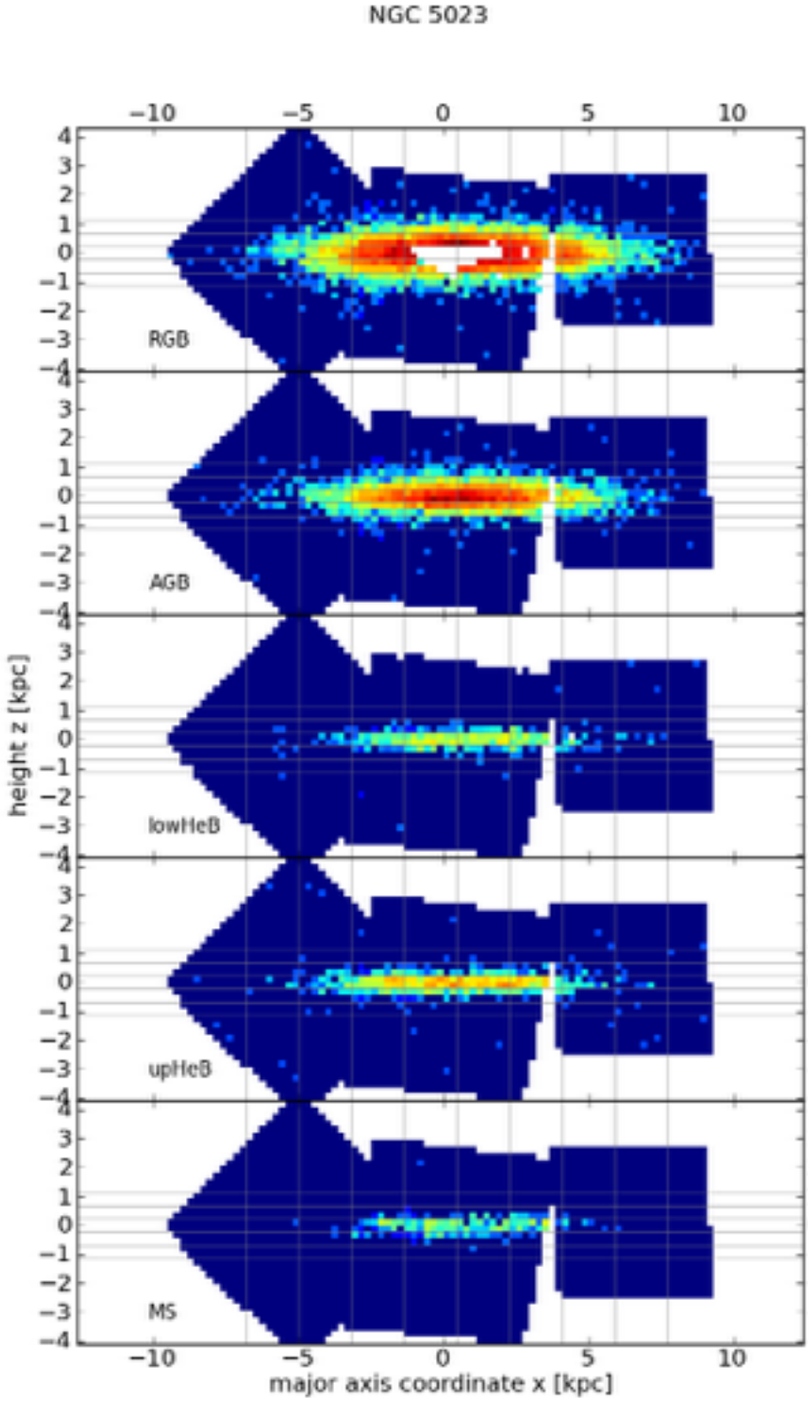
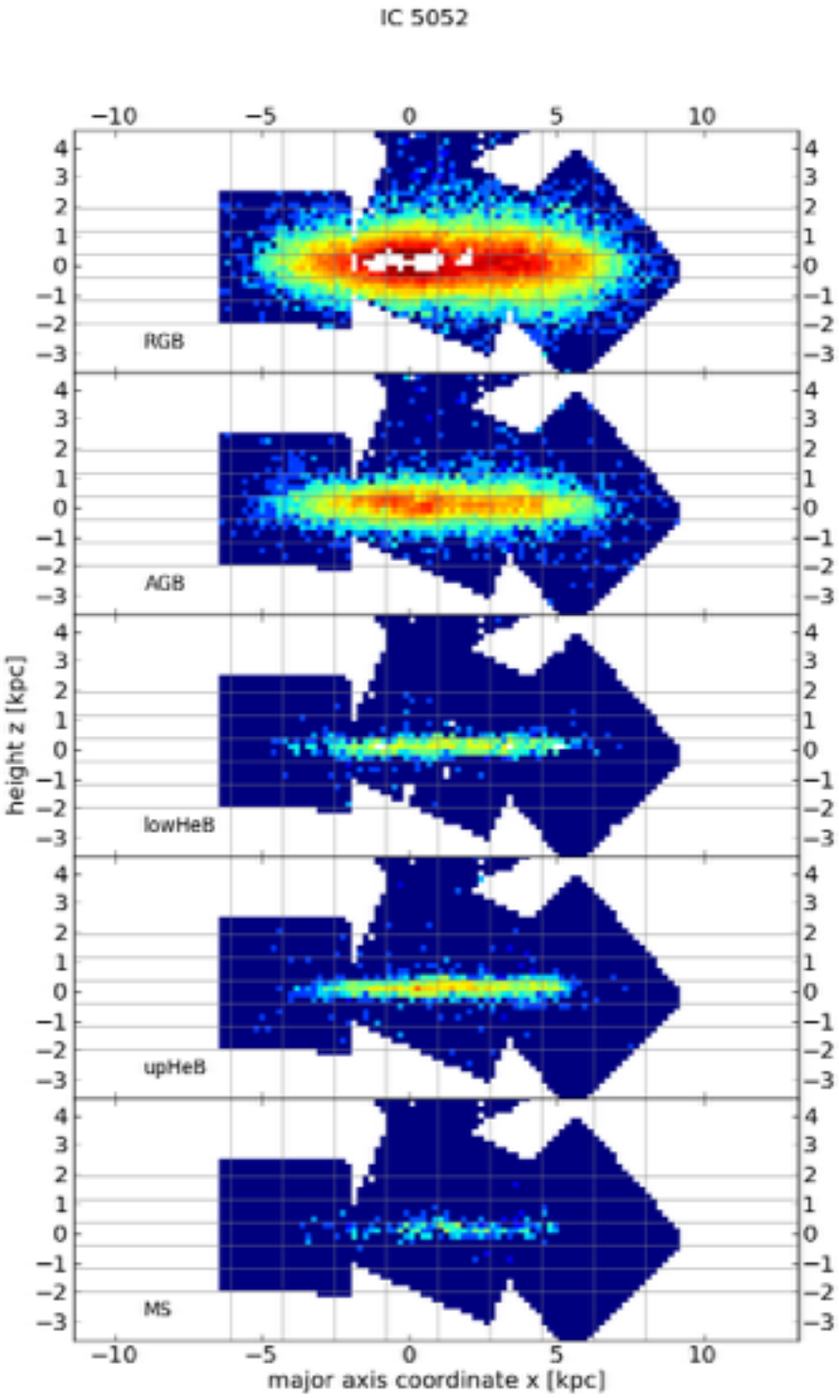


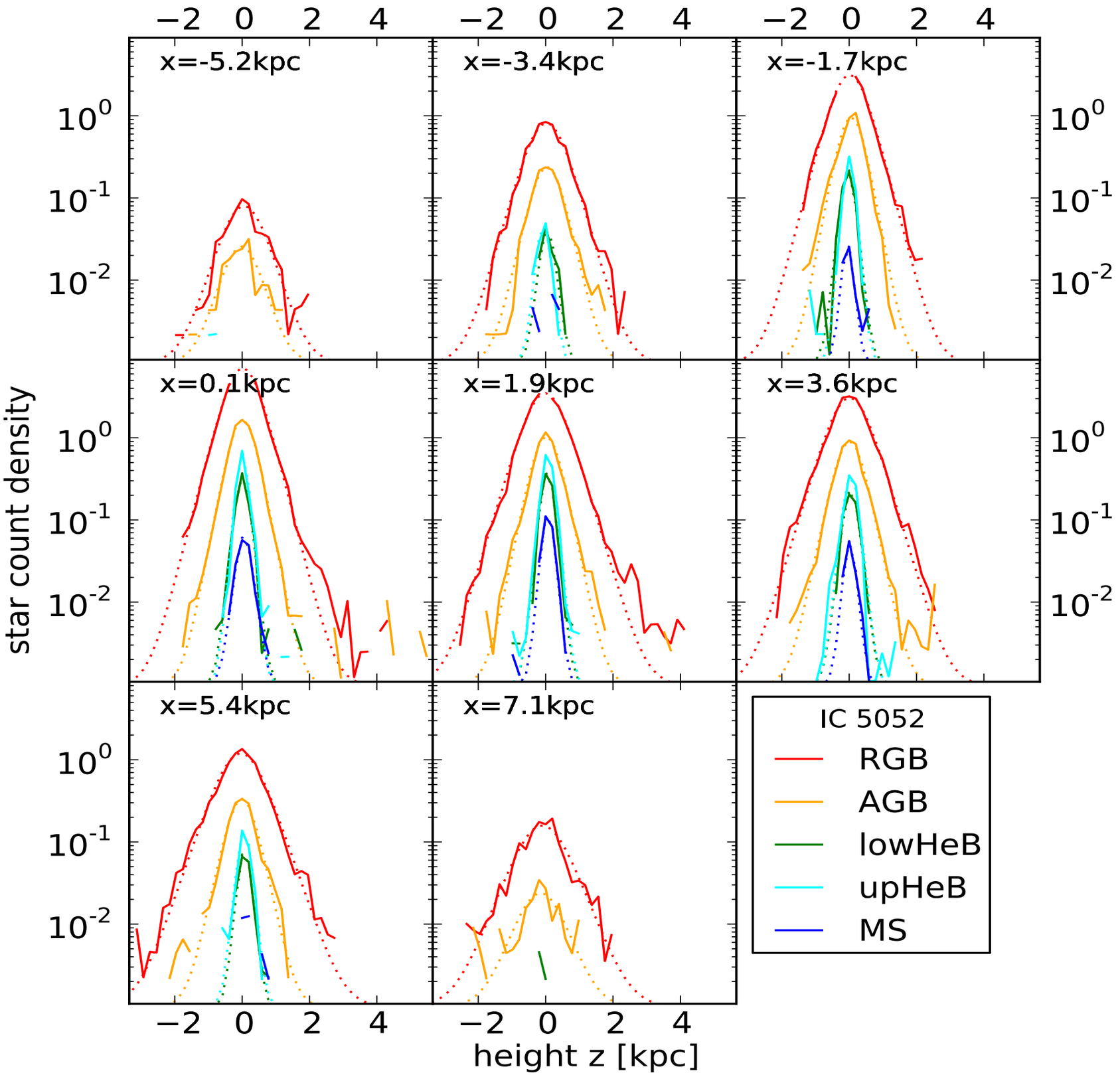


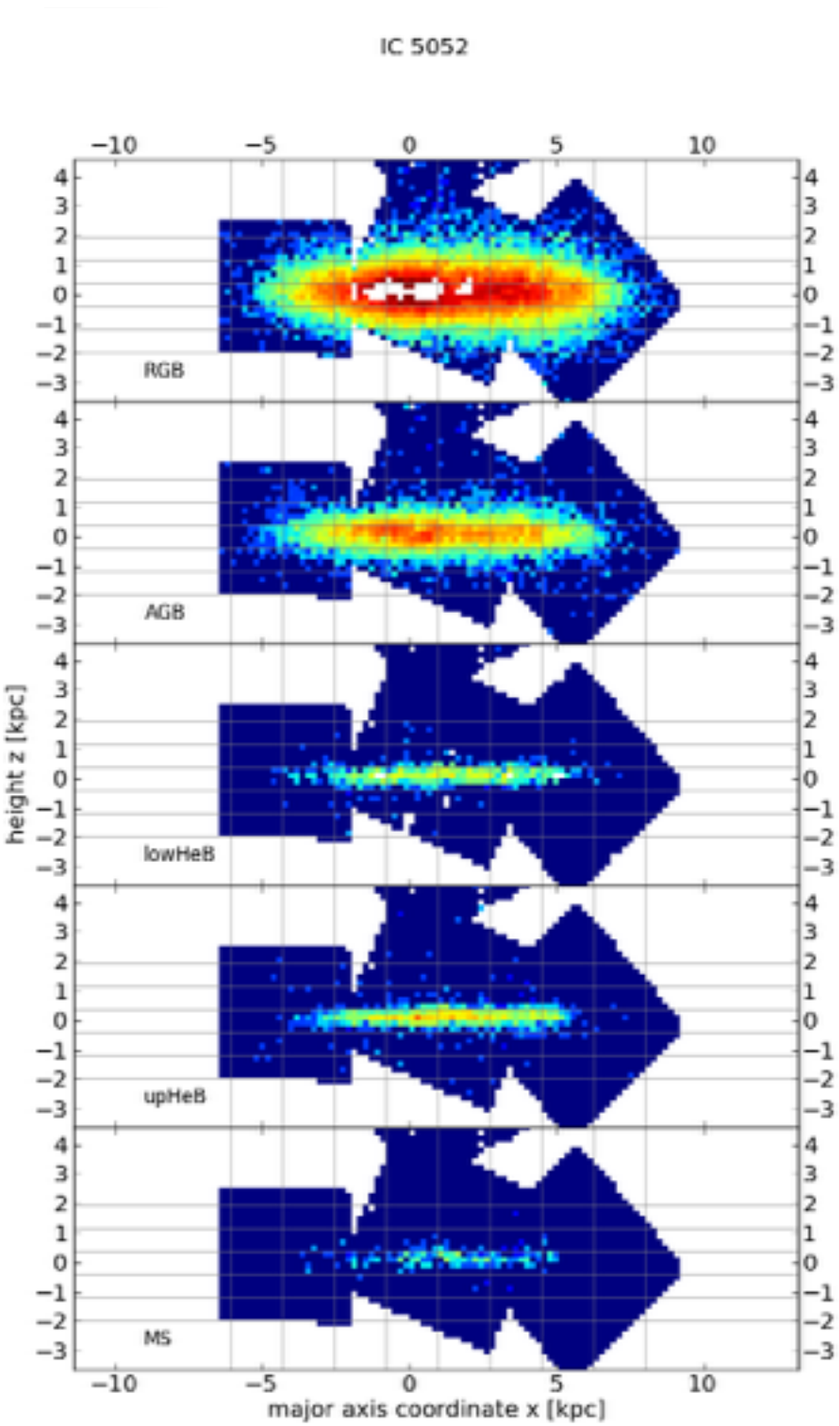


NGC 7793
NGC 7814

GHOSTS Stellar populations distribution

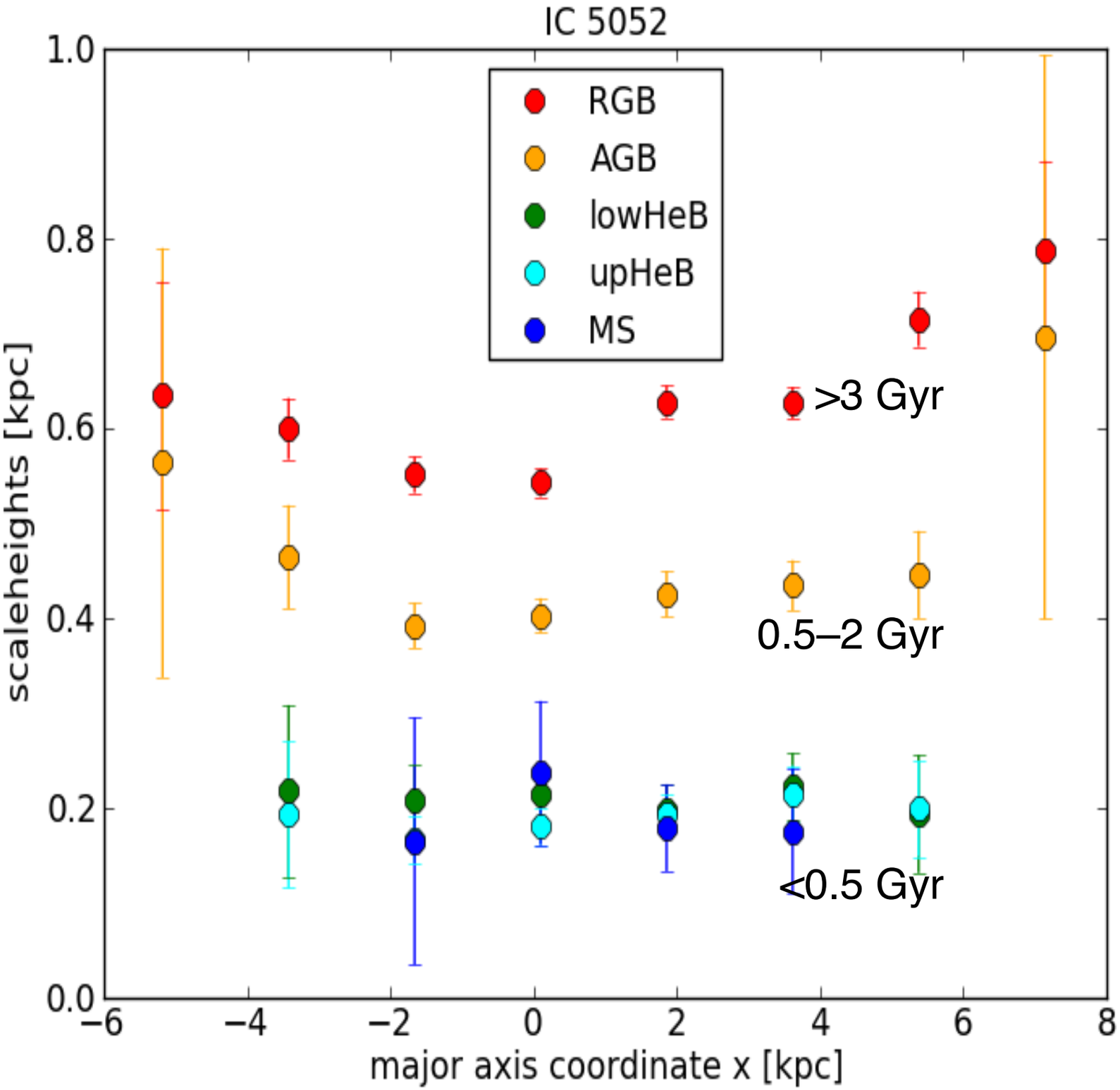
Streich et al. (in prep)

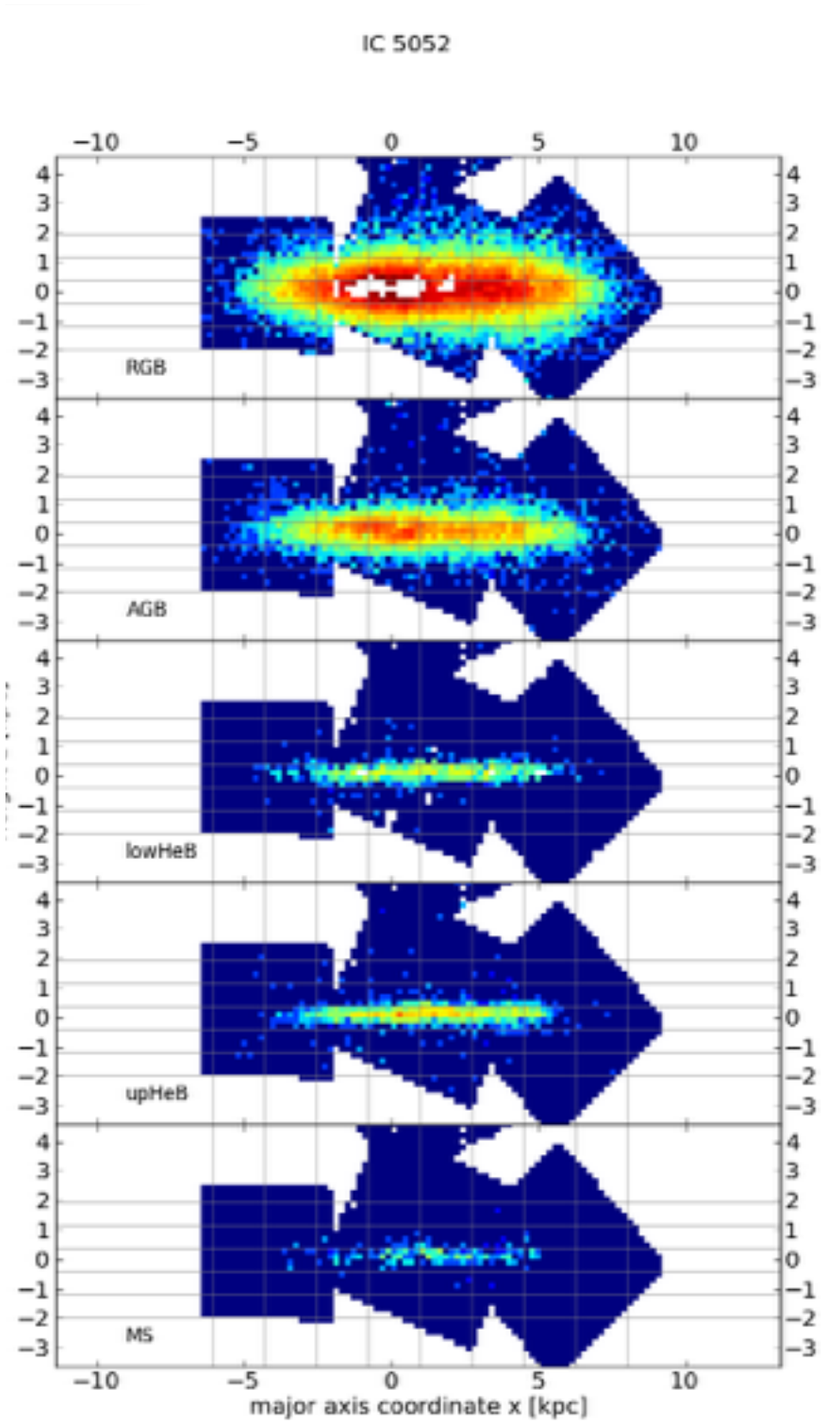




GHOSTS Stellar populations distribution

Streich et al. (in prep)





GHOSTS Disk heating at low rate

NGC 0247
NGC 0253
NGC 0891
NGC 2403
NGC 3031
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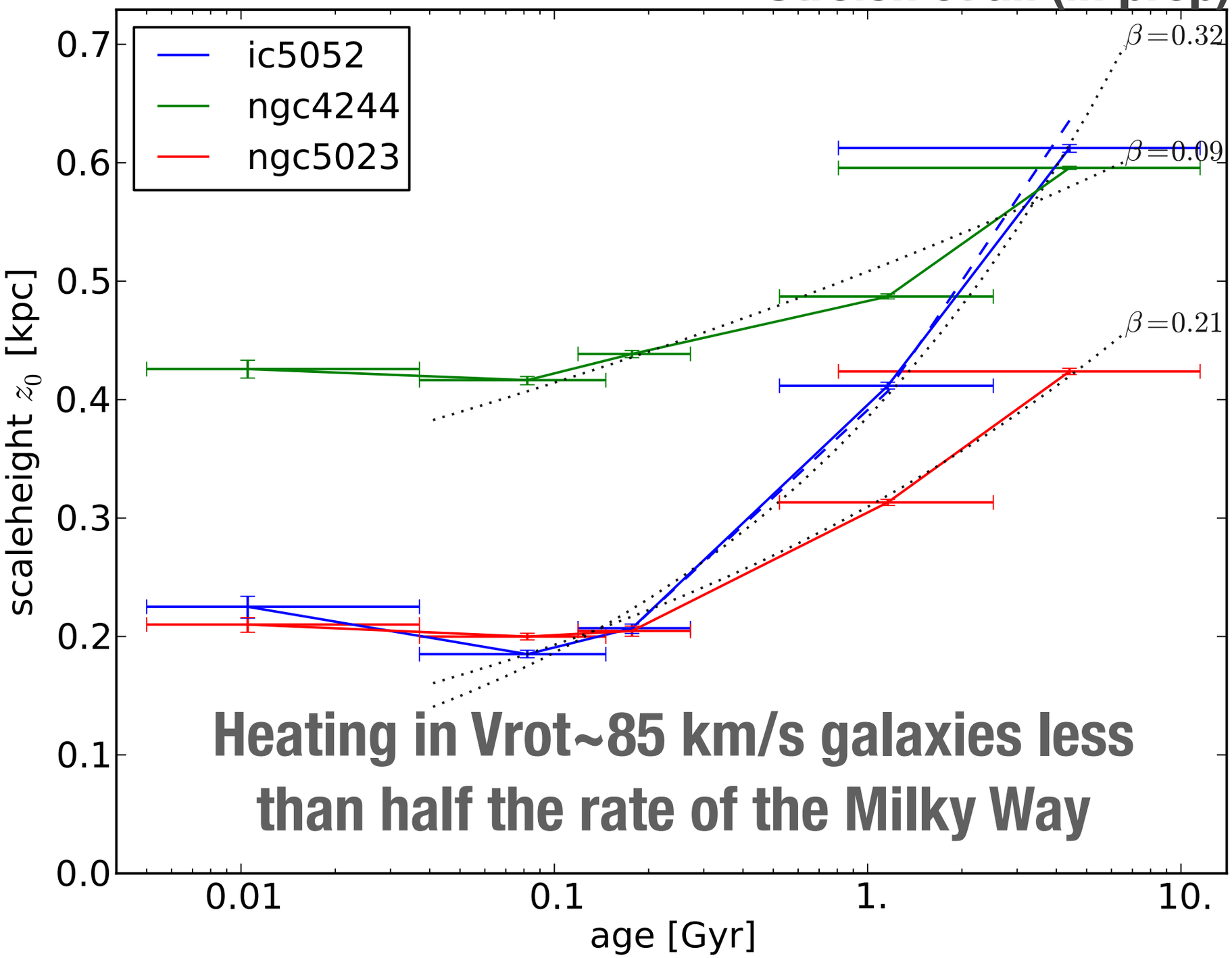

Heating in Vrot~85 km/s galaxies less than half the rate of the Milky Way

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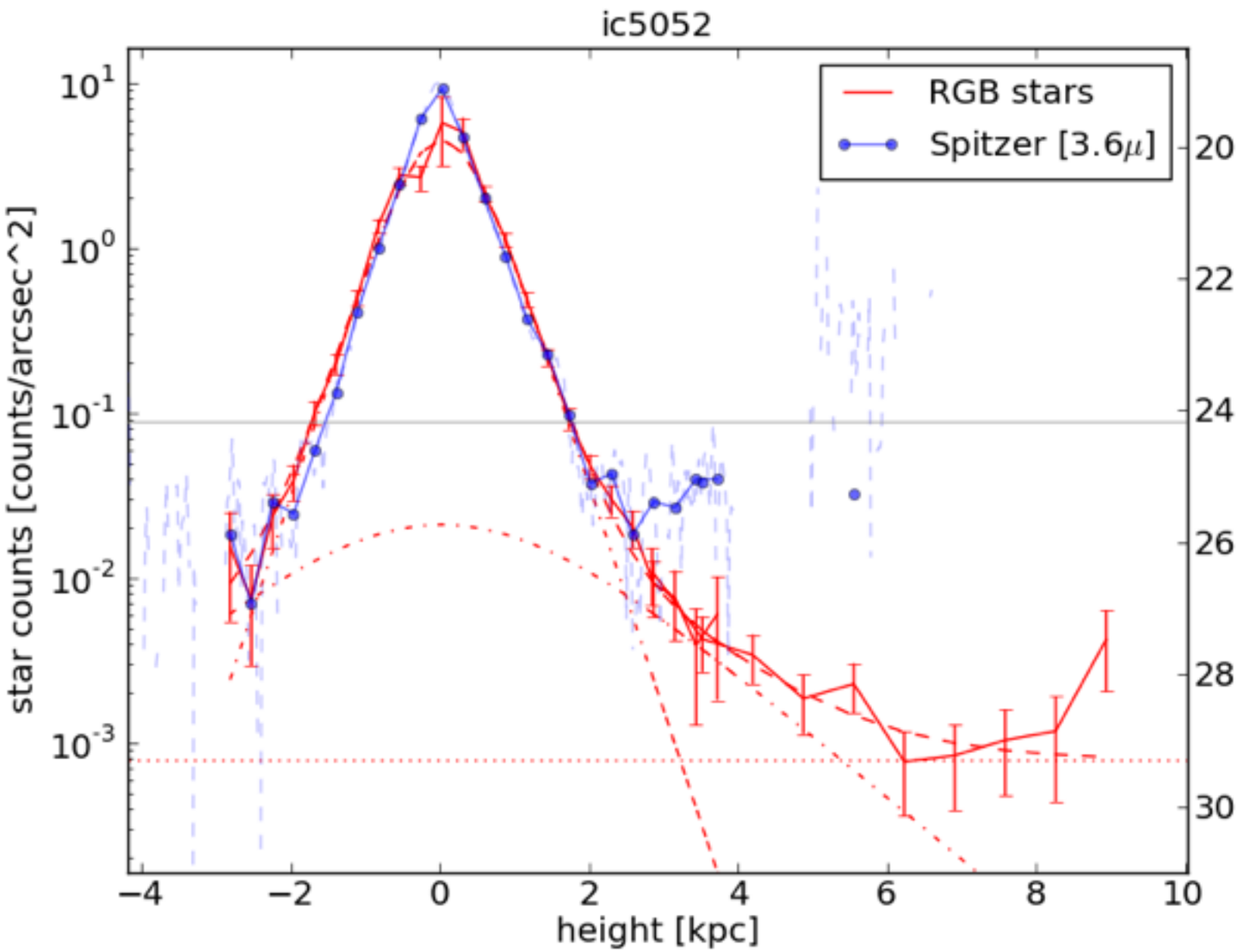
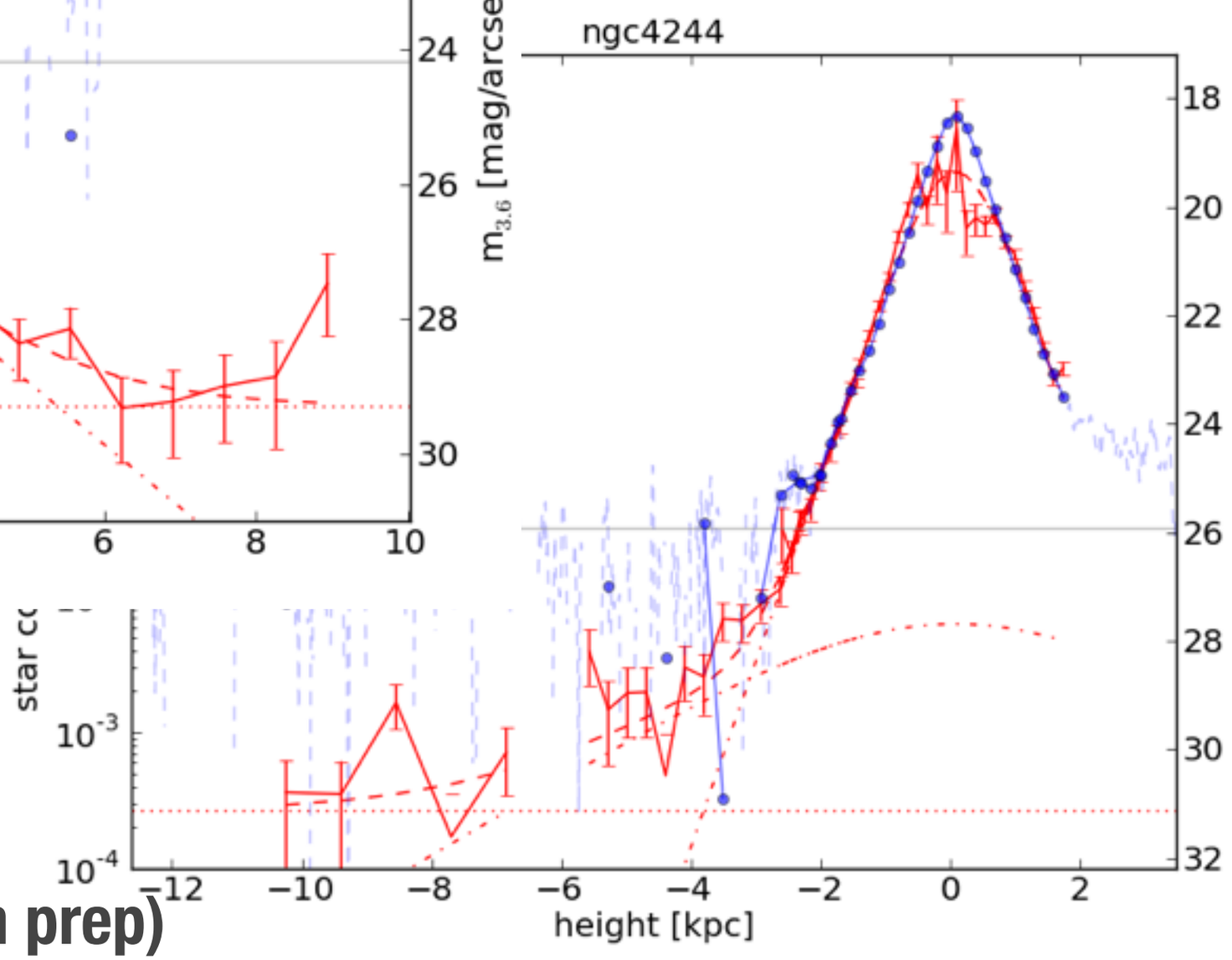
GHOSTS Thick disks or stellar halos?





- Scaleheight 4x RGB thin disk
- Luminosity <1% RGB thin disk

NGC 5236
NGC 5907
NGC 7793
NGC 7814

Streich et al. (in prep)

GHOSTS Disk heating in massive galaxies

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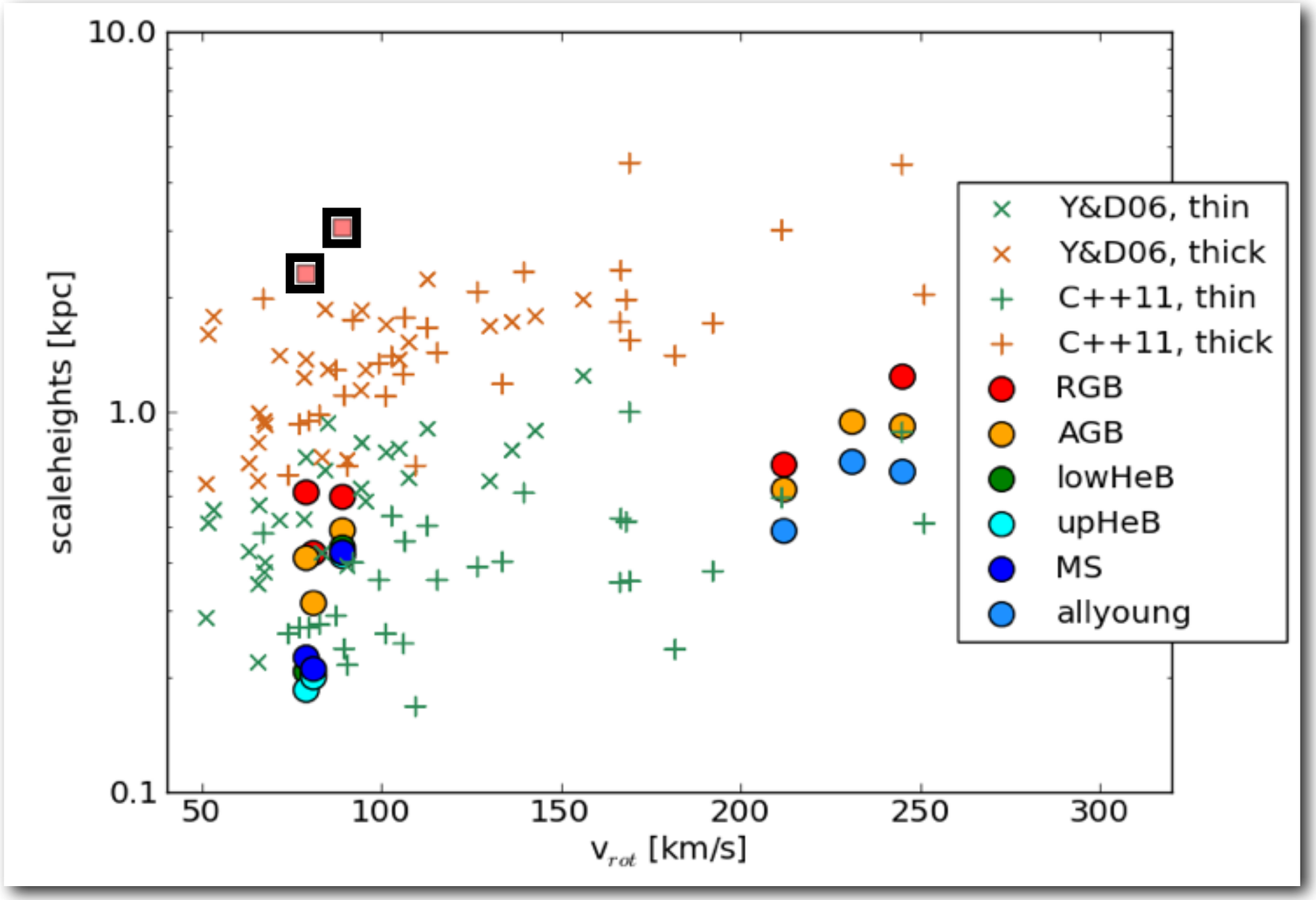

- **No sign of ubiquitous thick disks with ~50% mass fractions of thin disk**

Streich et al. (in prep)

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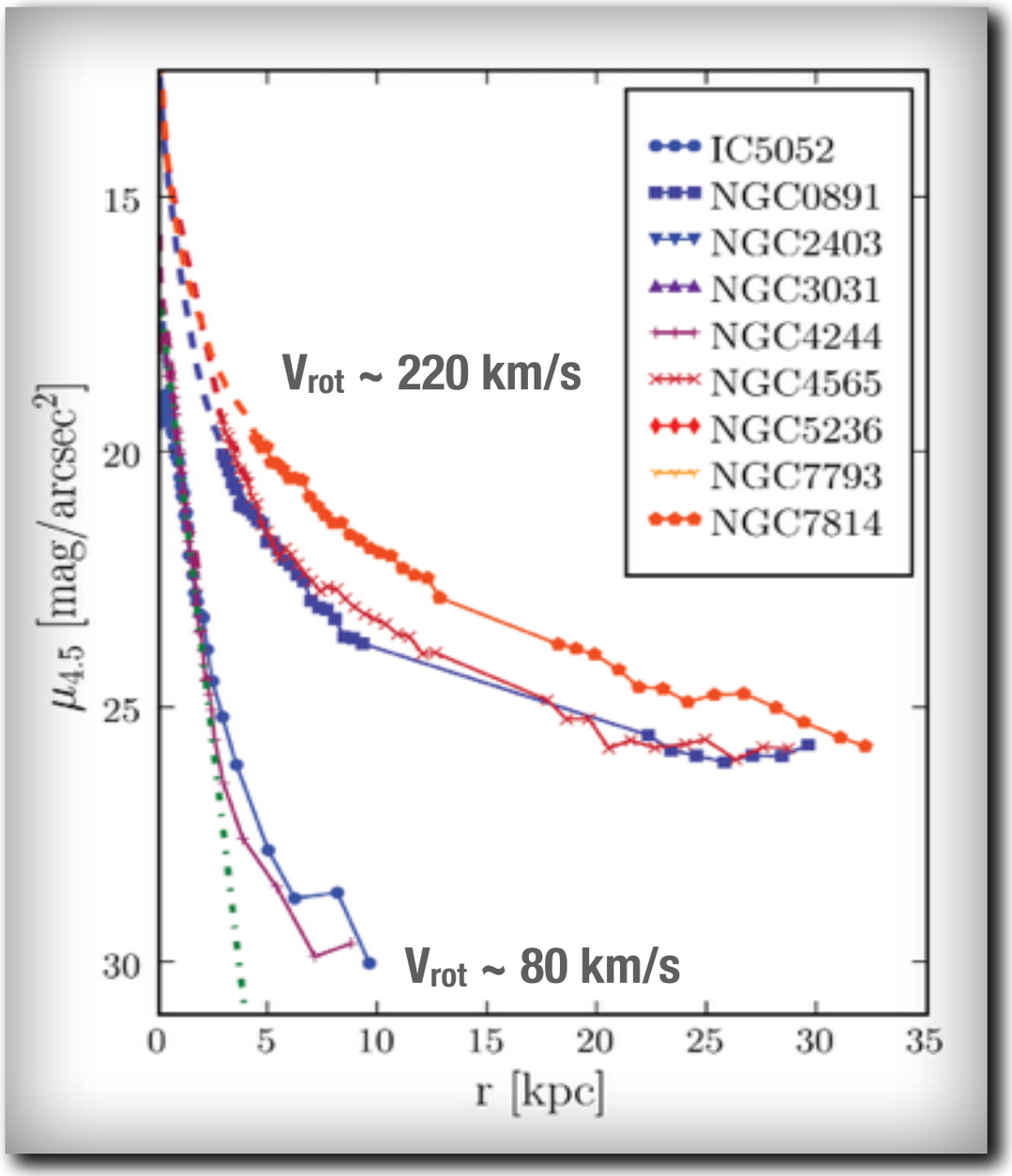
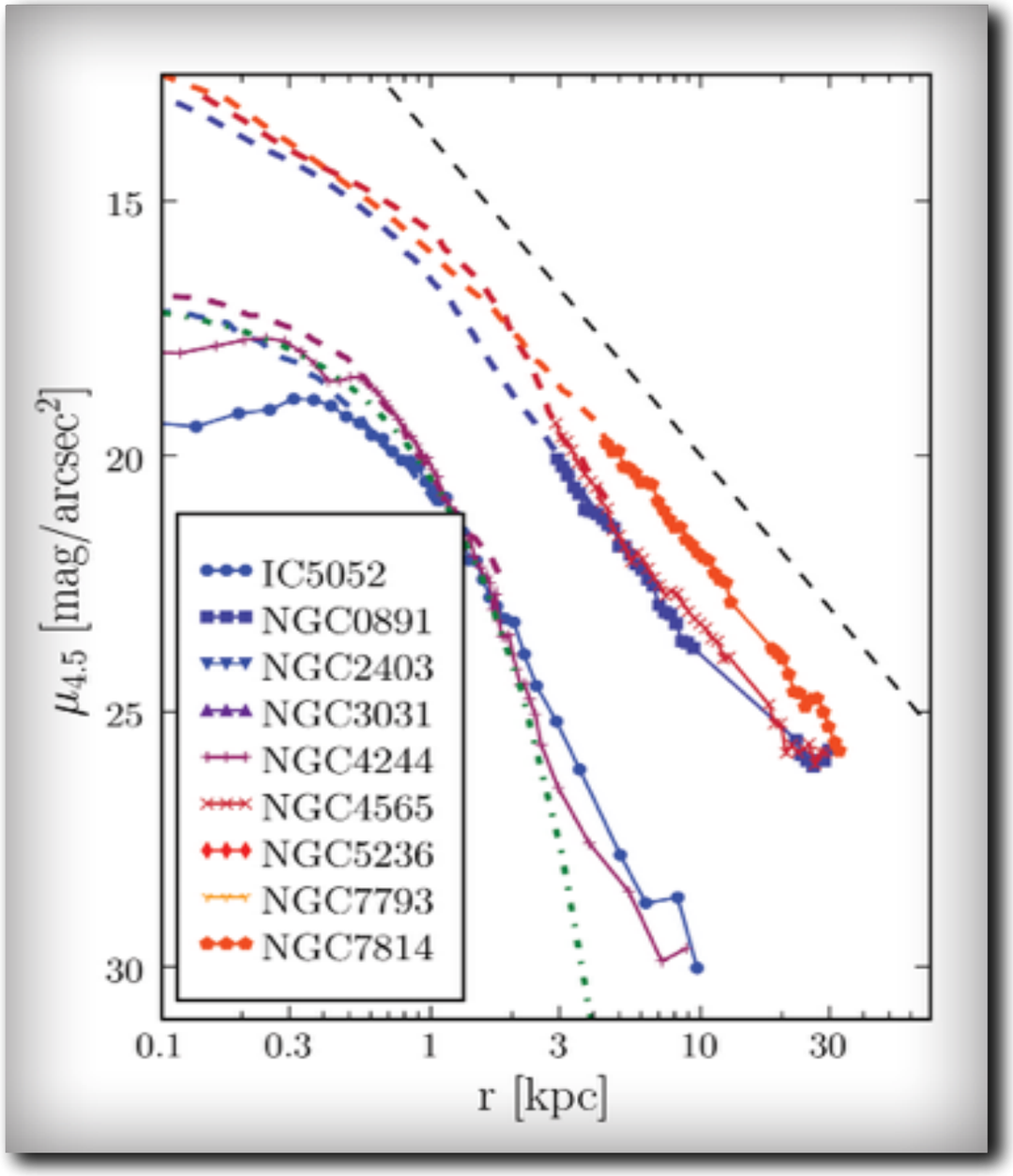
GHOSTS Stellar Minor Axis Profiles





- Larger galaxies have fractionally larger envelopes
- Profiles correlate more with bulge-to-disk ratio than V_{rot}
- Inner halos are compact (Sersic n~5) and flat (c/a~0.3)

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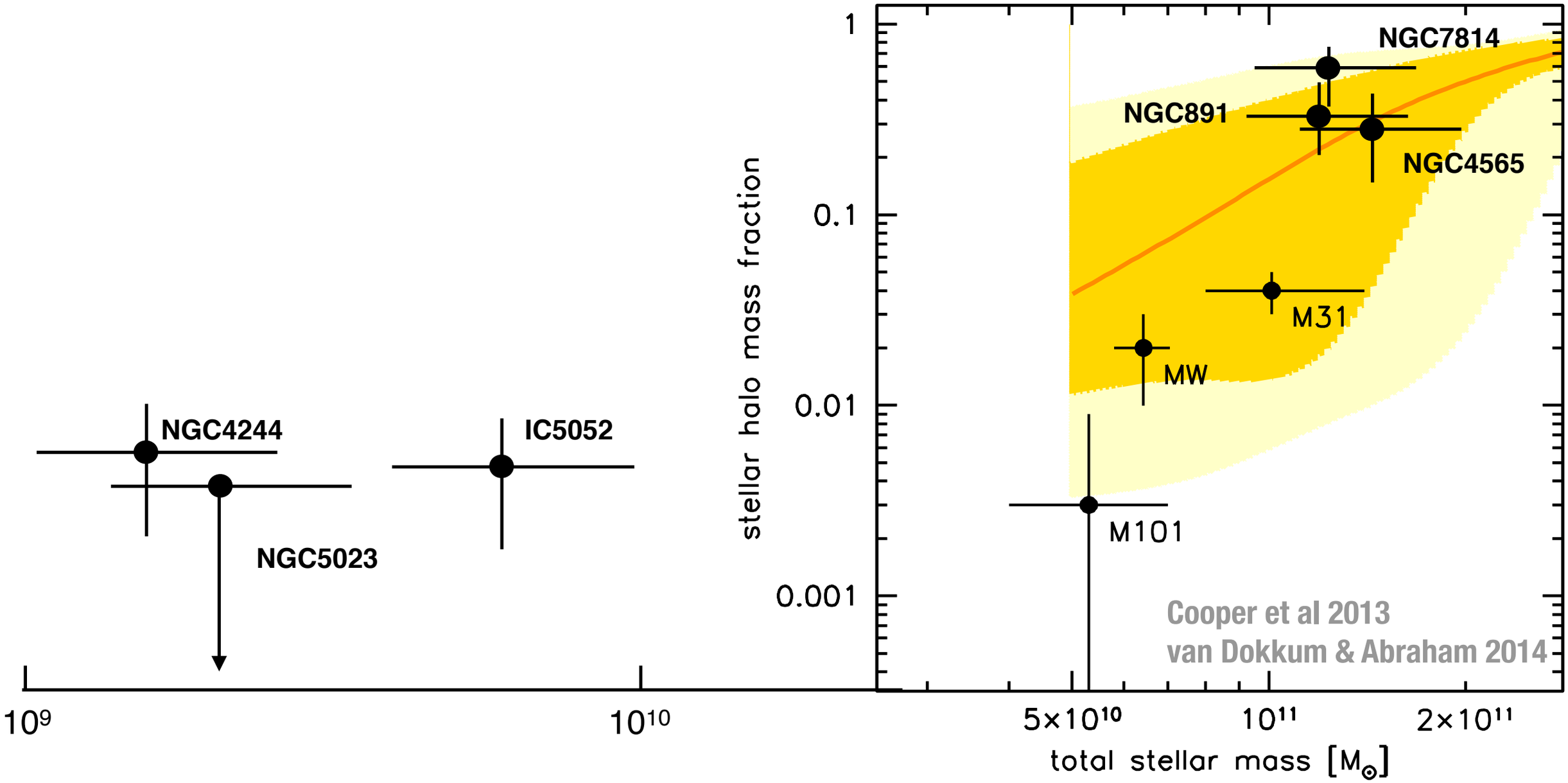
GHOSTS Mass fraction of stellar halos



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Roelof de Jong (AIP)

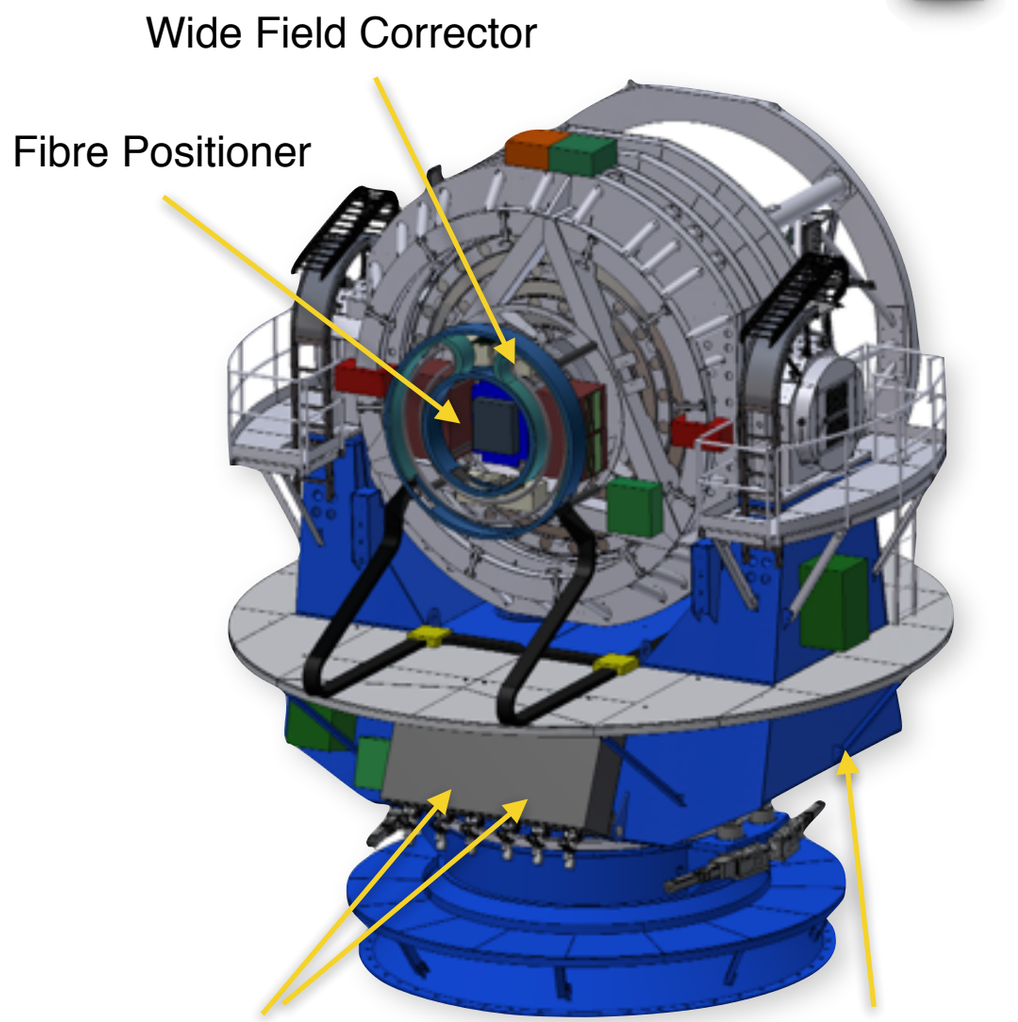
4MOST – 4m Multi-Object Spectroscopic Telescope

- Next generation spectroscopic survey facility selected for the VISTA telescope of ESO

- Specs:
  - 2.7 degree diameter Field-of-View
  - ~2400 fibres
  - Resolution R~5000 and R~20,000
  - Wavelength 390-930 nm

- Permanent survey mode for 5 years with many surveys in parallel starting in 2021
- Will observe >20 million objects in 5 years

- Ideal for complement Gaia mission for MW halo studies, eROSITA galaxy cluster dark halos and AGN, cosmology surveys, etc.

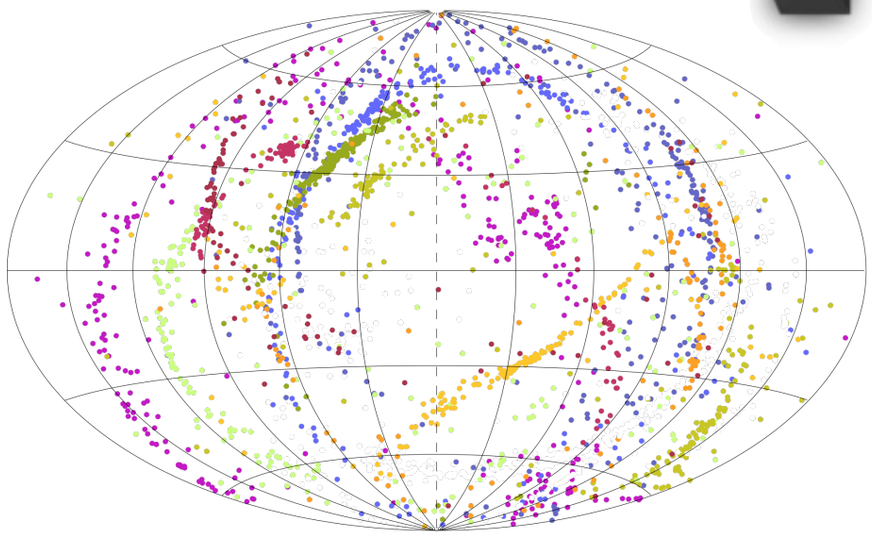


VISTA telescope

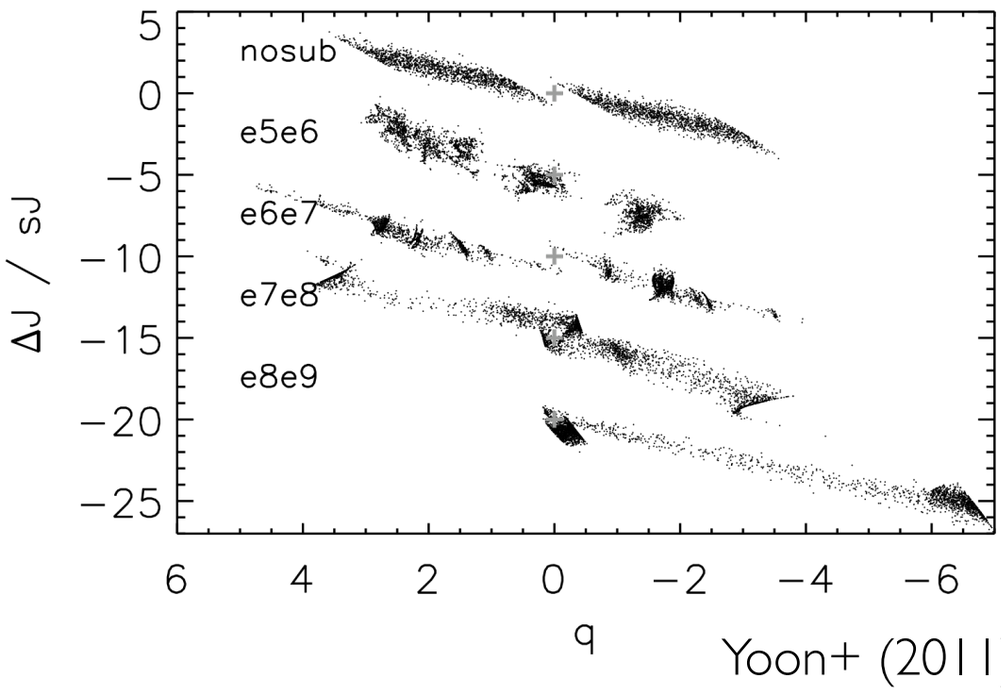
Roelof de Jong (AIP)

4MOST MW halo survey

- Obtaining spectra of >10^6 halo stars allows:
  - Determining the Milky Way 3D potential from streams to ~100 kpc
  - Measuring the effect of baryons:
    - has there been significant adiabatic contraction?
    - is there a disk-like DM component?
    - does the DM respond to the bar?
  - Determine the mass spectrum of Dark Matter halo substructure by the kinematic effects on cold streams of 10^3–10^5 $M_\odot$
  - Extremely metal-poor star abundances constrain the nature of first stars



Cooper+ (2010)



Yoon+ (2011)

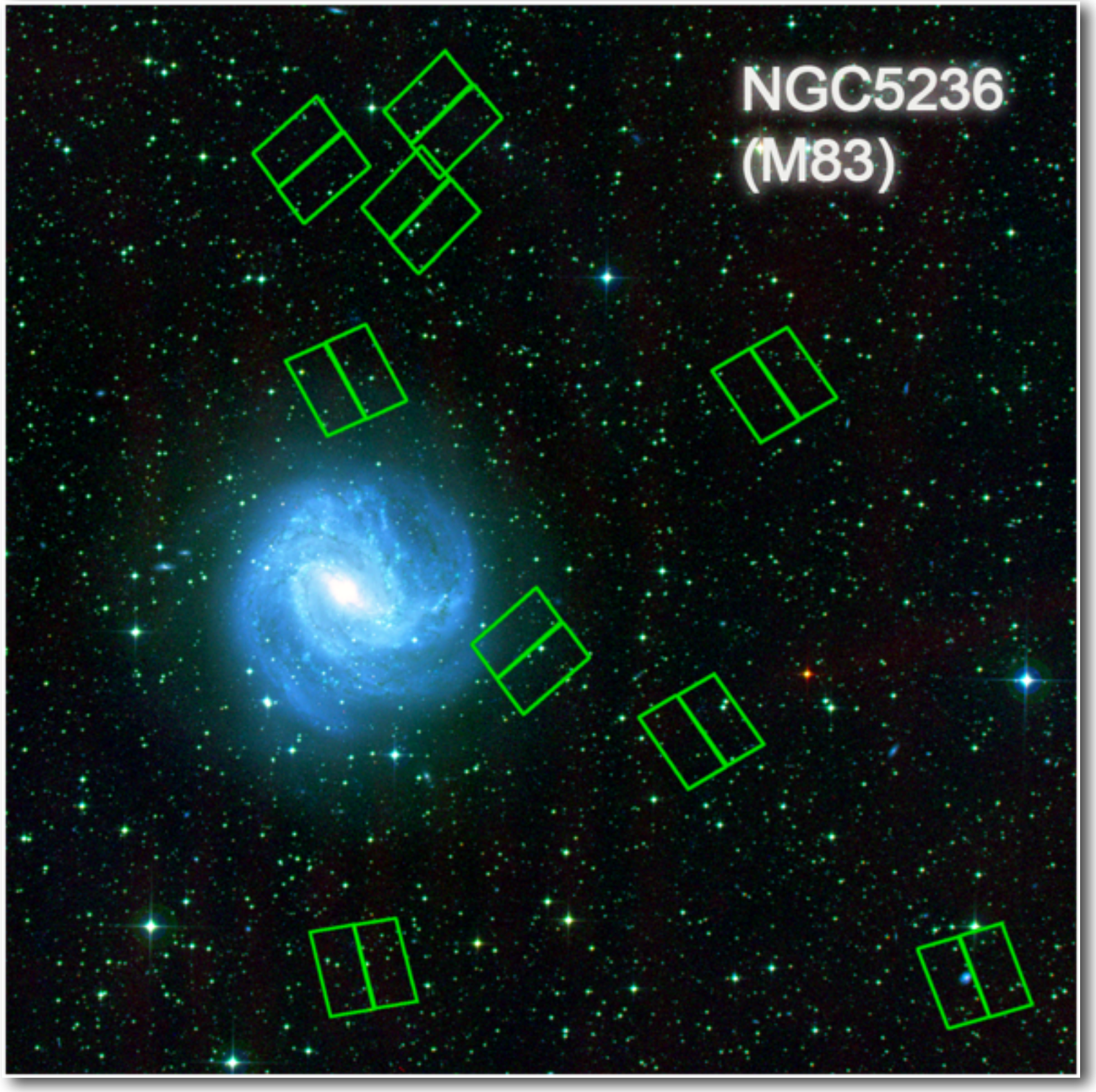
GHOSTS Summary

- Small galaxies of V_{rot} ~ 80–90 km/s have:
  - no thick disks and small, metal-poor halos (<1% of stellar mass)
  - disk heating rate lower than in Milky Way
- Massive disk galaxies of V_{rot} > 220 km/s have:
  - morphologies that can be fitted by just two components: a (broken) exponential disk and a flattened Sersic profile halo
  - halo mass fractions of 20%–70%
  - very flattened (c/a ~ 0.3–0.4) inner halos (<25 kpc)
  - very compact halos with Sersic index 4–6
- Halo parameters, substructure, colours & metallicities covered in the next talk by Antonela Monachesi

http://archive.stsci.edu/prepds/ghosts

GHOSTS Stellar Streams & Substructure

NGC 0247
NGC 0253
NGC 0891
NGC 2403
NGC 3031
NGC 4244
NGC 4565
NGC 4631
NGC 4736
NGC 5023
NGC 4945
IC 5052
NGC 5236
NGC 5907
NGC 7793
NGC 7814



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GHOSTS Stellar Streams

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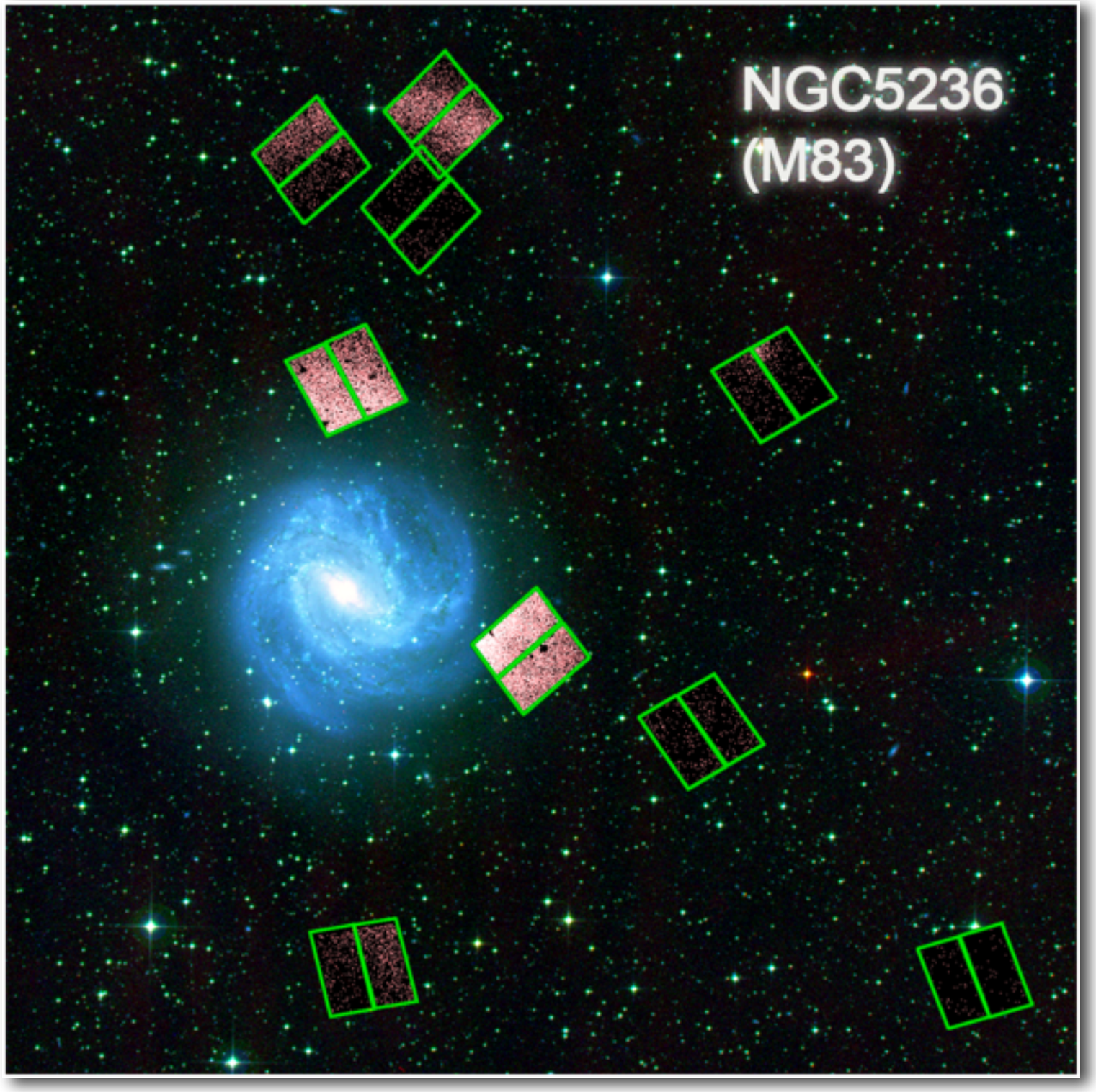

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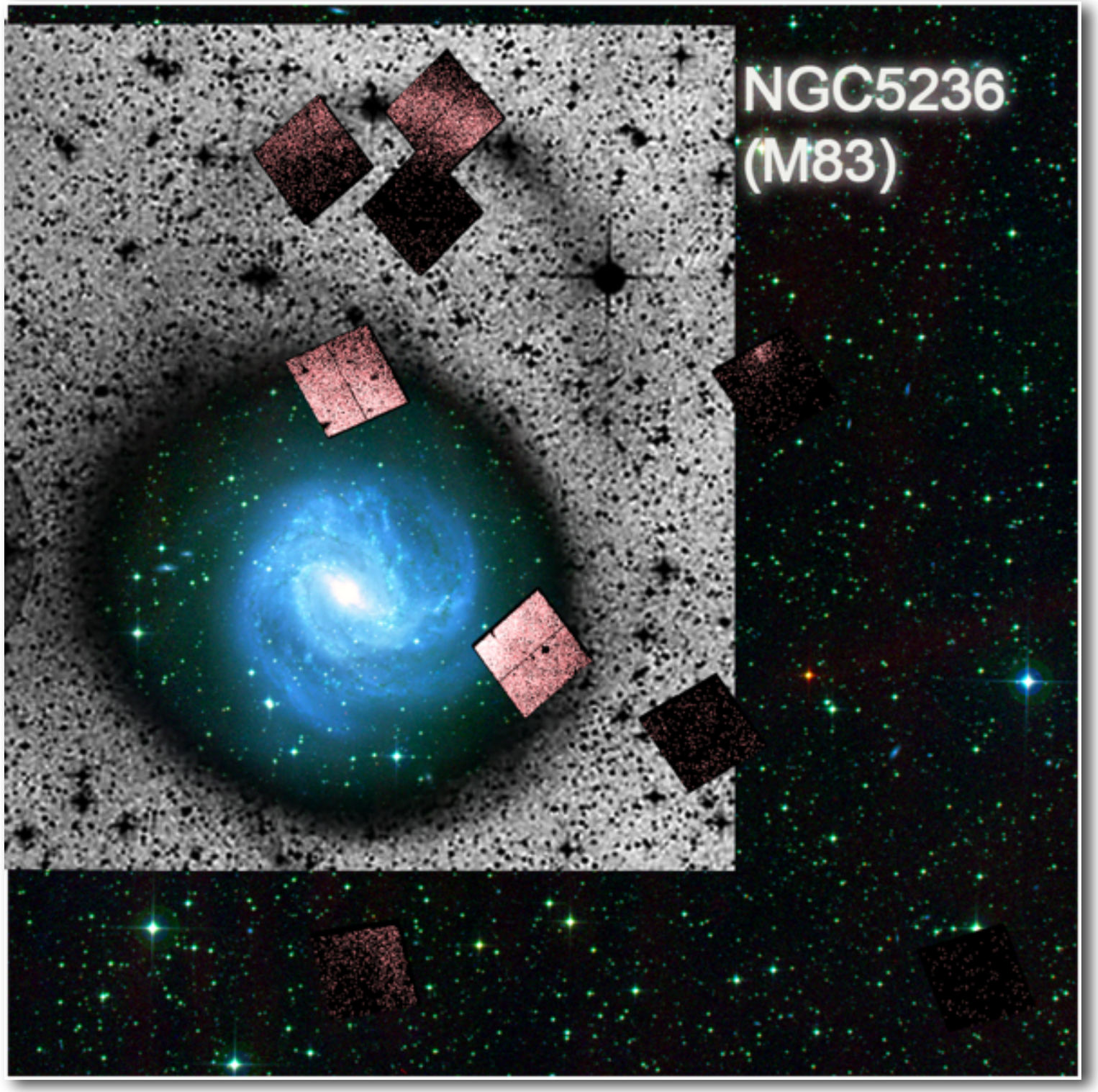

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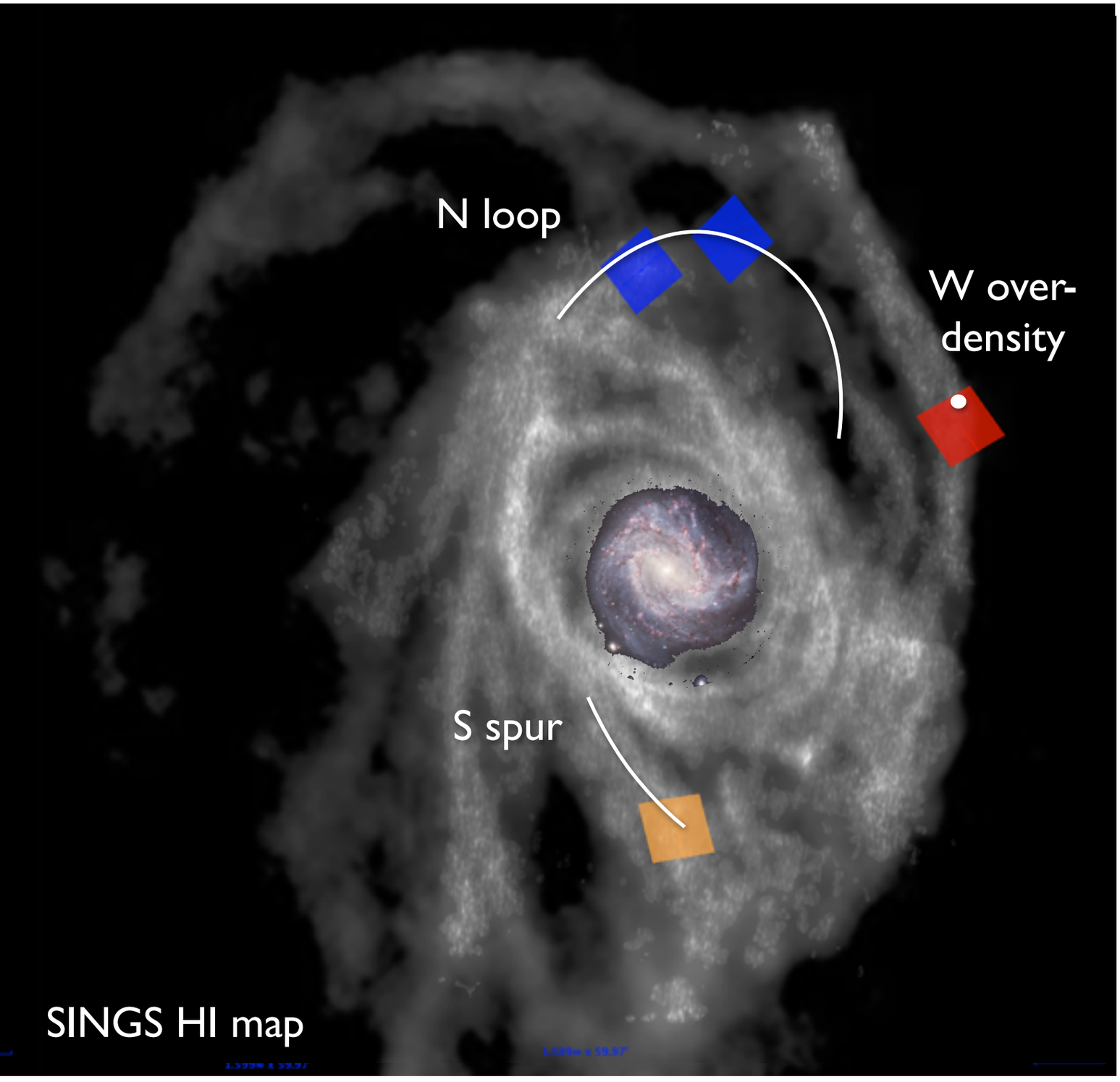
GHOSTS M83: A new dwarf companion?



- M83 surrounded by large HI streams

- Possible origin:
  - primordial accretion
  - gas rich satellite
  - tidal stripping

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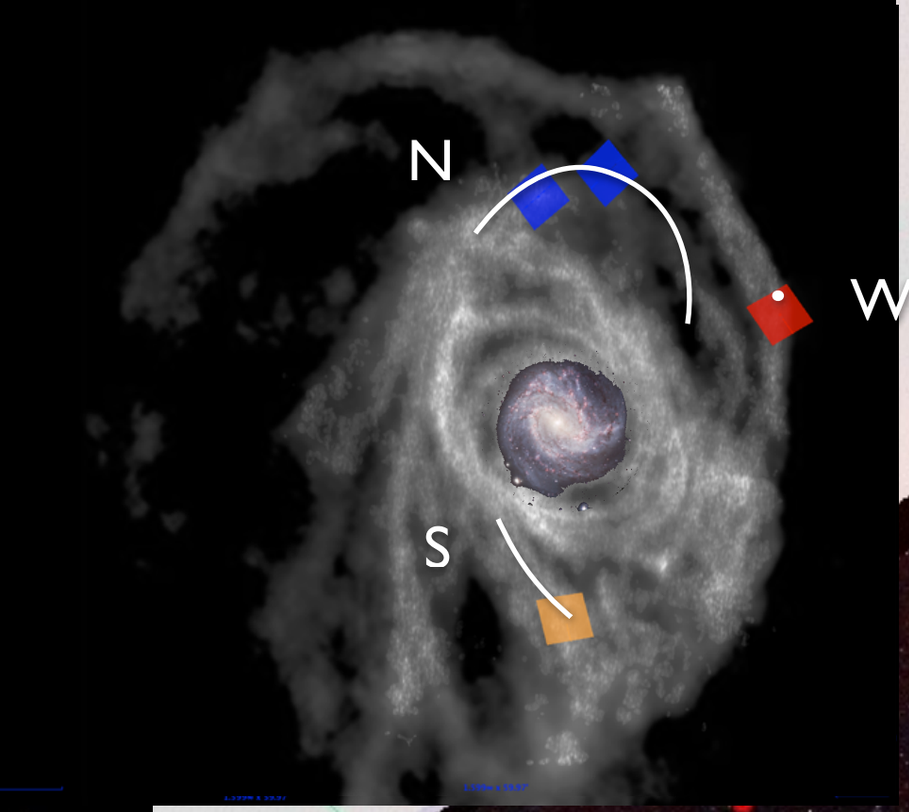
N
W
S

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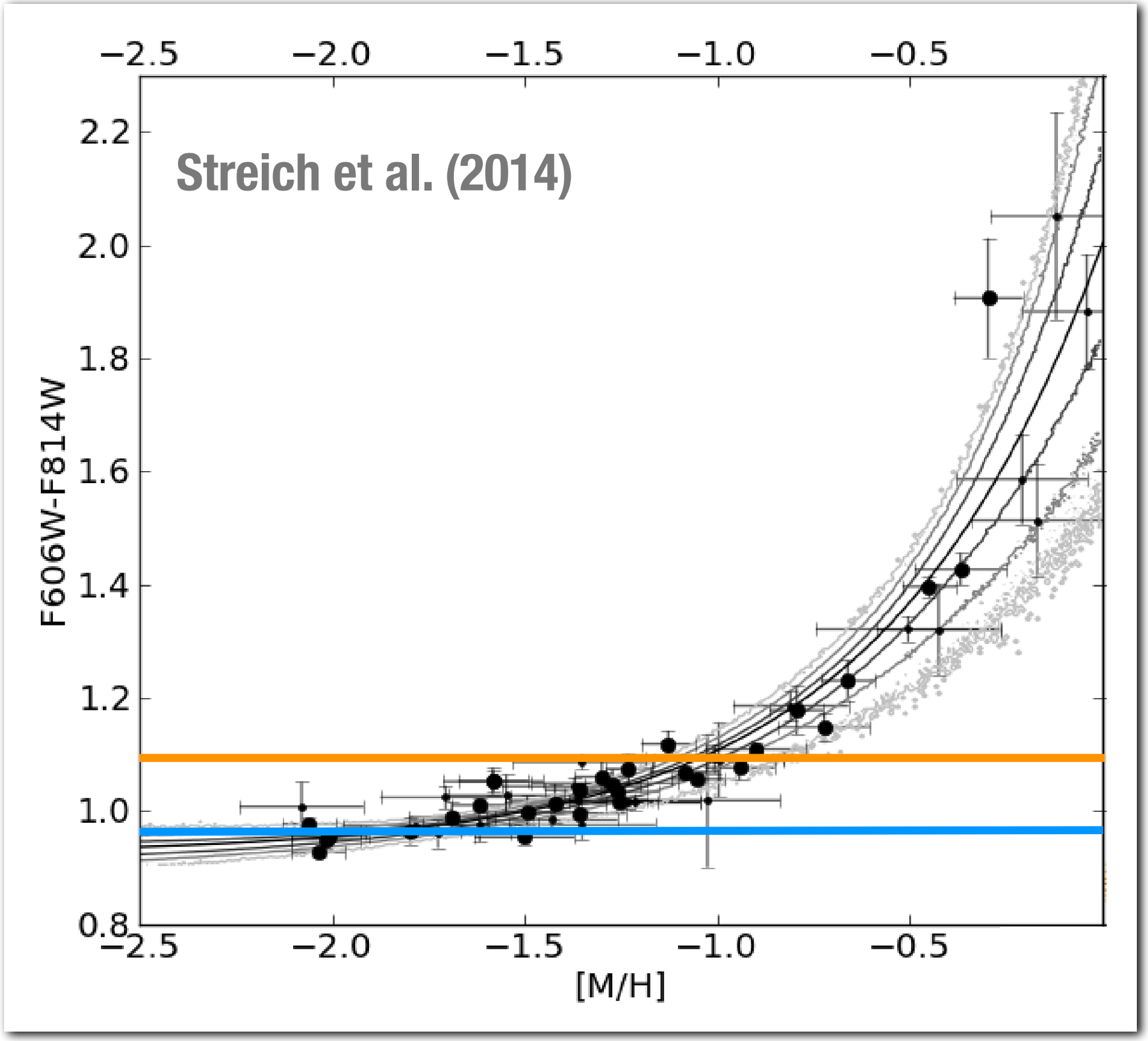
GHOSTS MW Globular Clusters



[Fe/H] ~ -1.0

[Fe/H] ~ -1.5–-4.0

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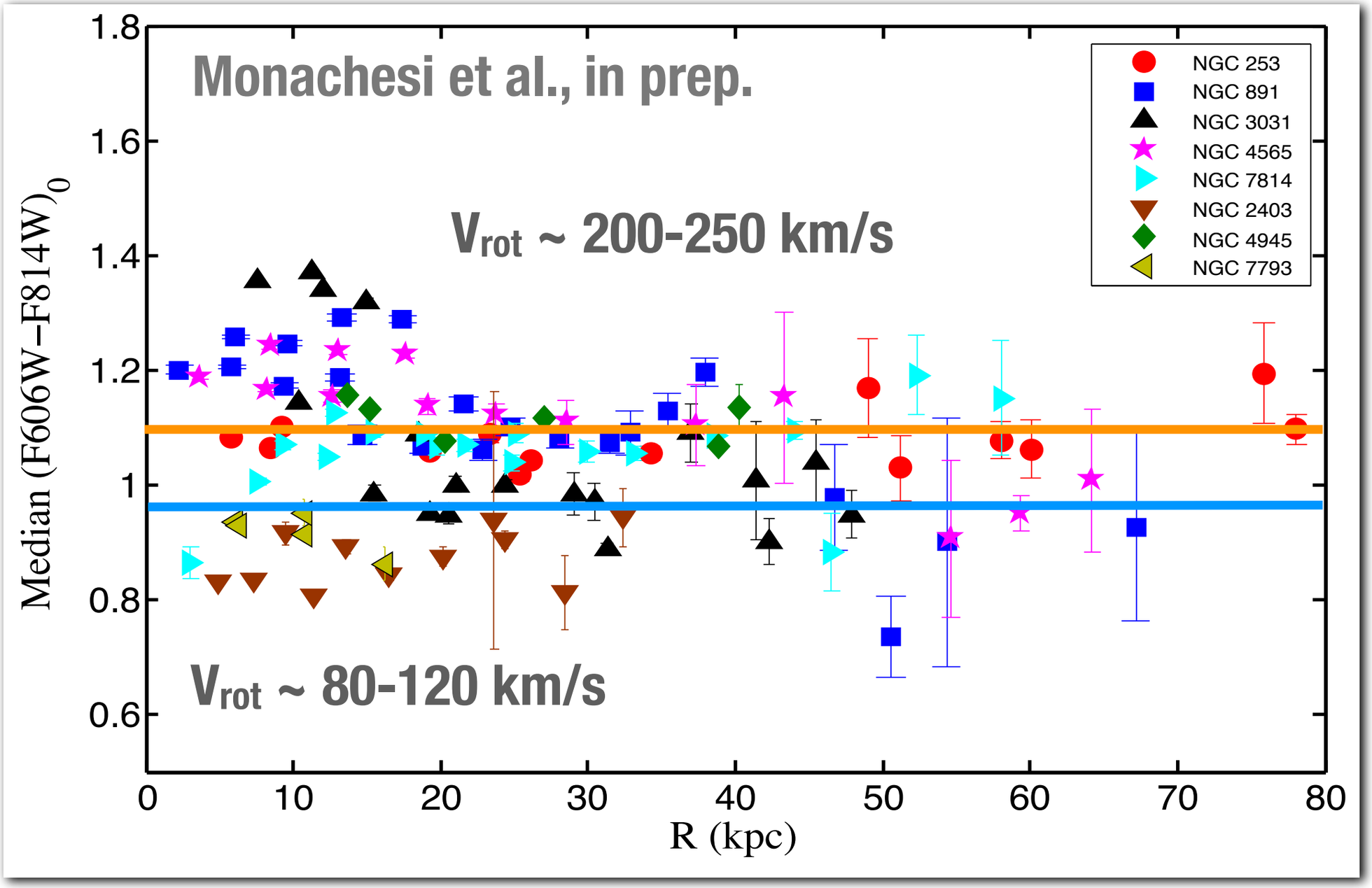
GHOSTS Stellar Halo Color Profiles



[Fe/H] ~ -1.0

[Fe/H] ~ -1.5-4.0

- Most galaxies no significant color gradients between 20-80 kpc
- RGB halos of small galaxies bluer than most metal-poor MW globulars, probably younger population

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