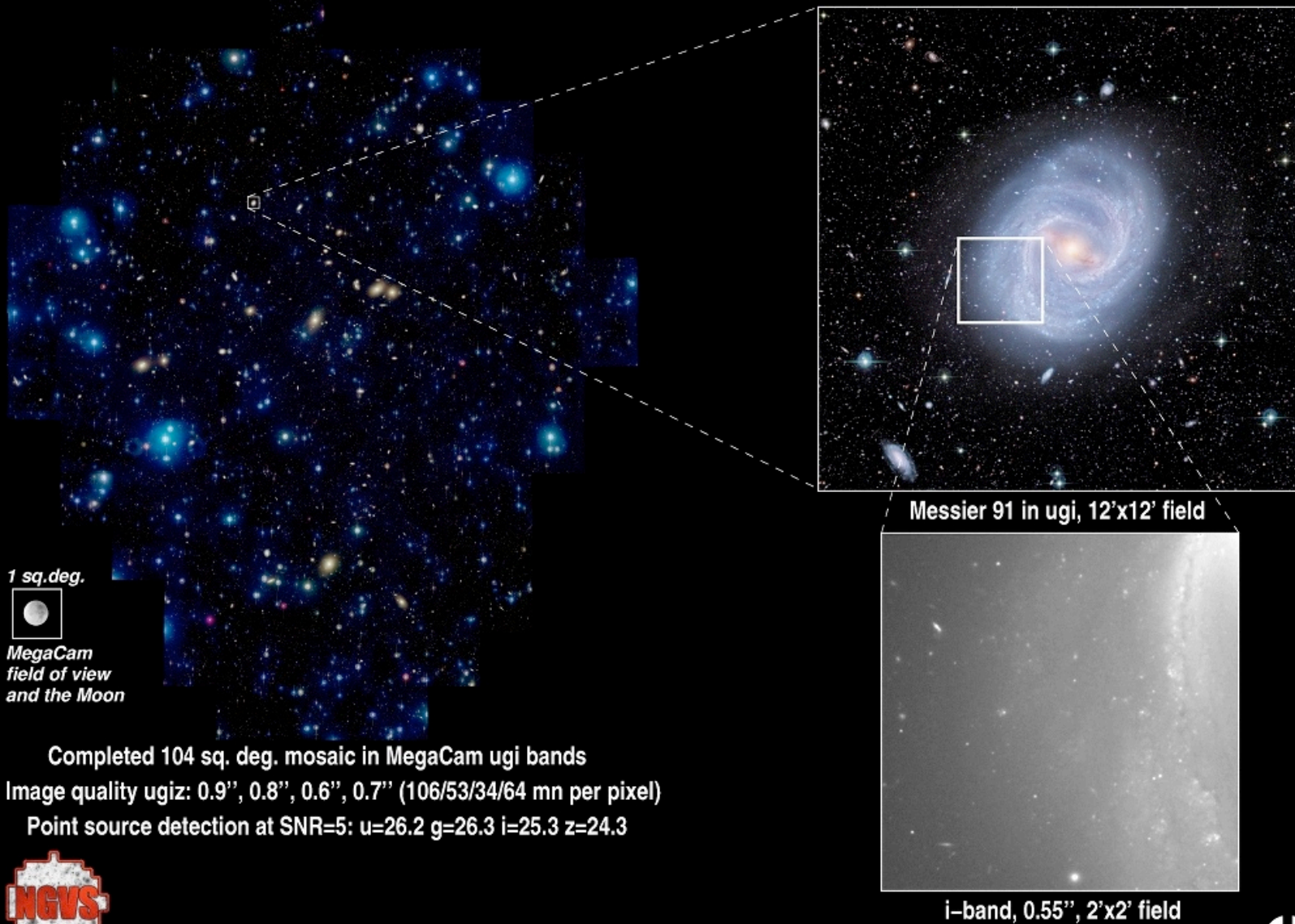


Galaxies in the Core of the Virgo Cluster: Results from the Next Generation Virgo Cluster Survey



The Next Generation Virgo Cluster Survey

The NGVS is a sub-arcsecond survey captured on Mauna Kea, Hawaii



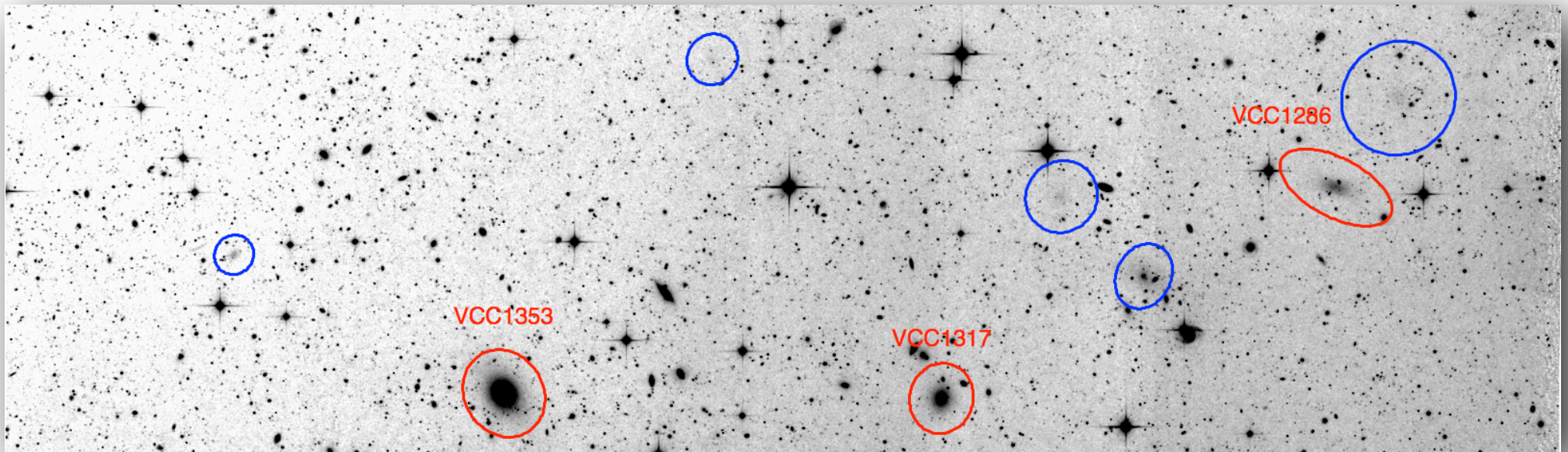
Talk Outline

I. The Next Generation Virgo Cluster Survey (NGVS)

II. Results from the Central Four Square Degrees

- Galaxy Identification and Analysis
- Spatial Distribution
- Scaling Relations
- Colour-Magnitude Relations
- Nucleation
- *Observed and Intrinsic Shapes* (RSJ - Tuesday afternoon)

III. Summary



The Next Generation
Virgo Cluster Survey
(NGVS)

The NGVS Team

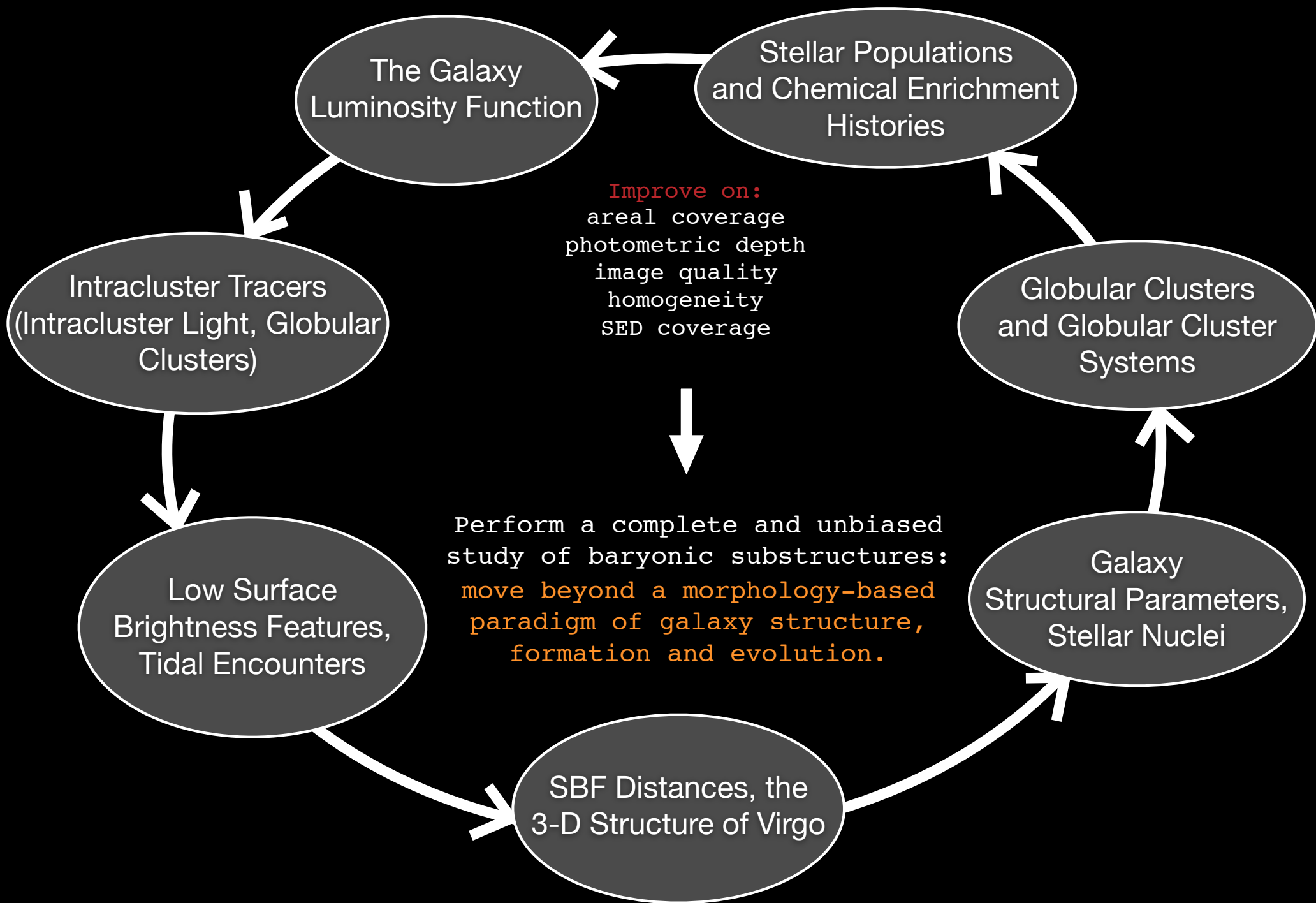


Chantal Balkowski
Michael Balogh
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Raphael Gavazzi
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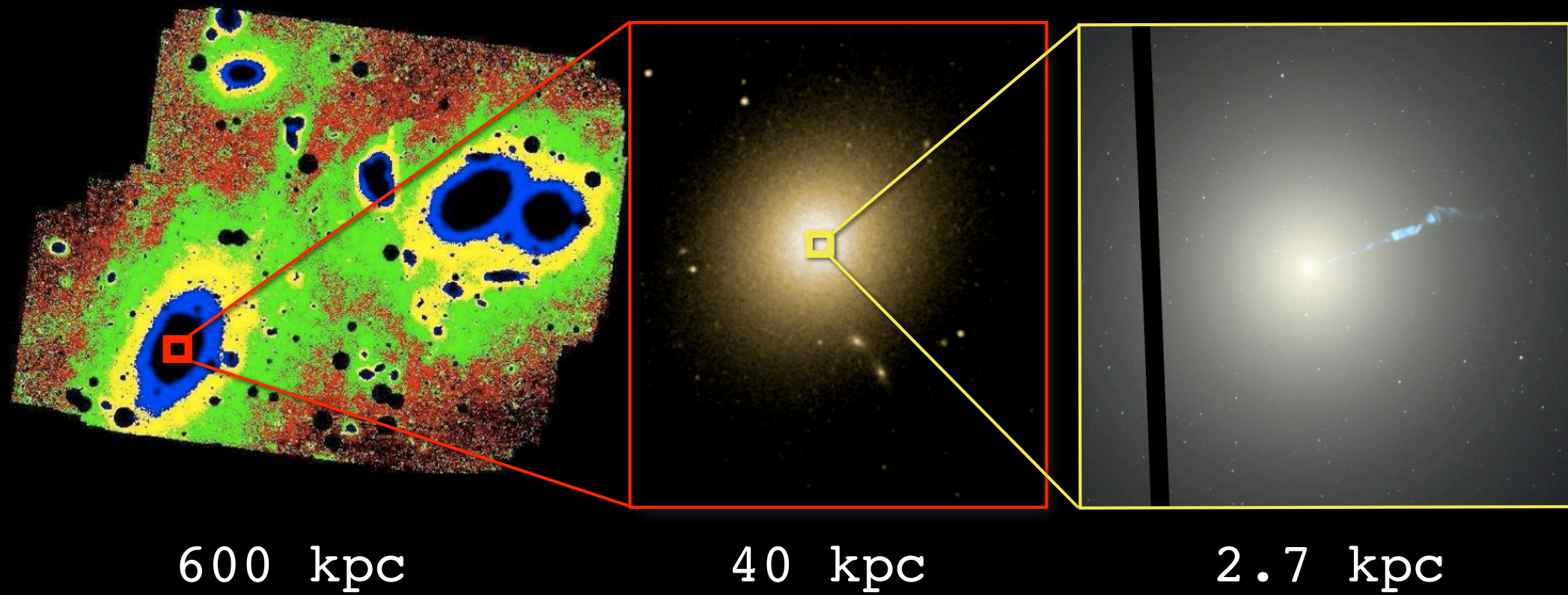
Patrick Hudelot
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Simona Mei
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*With Special Thanks to the CFHT Team, in particular:
Todd Burdullis, Glenn Morrison, Stephane Arnouts, MaryBeth Laychak,
Billy Mahoney, Adam Draginga, Nadine Manset & Daniel Devost*

NGVS: Virgo Science



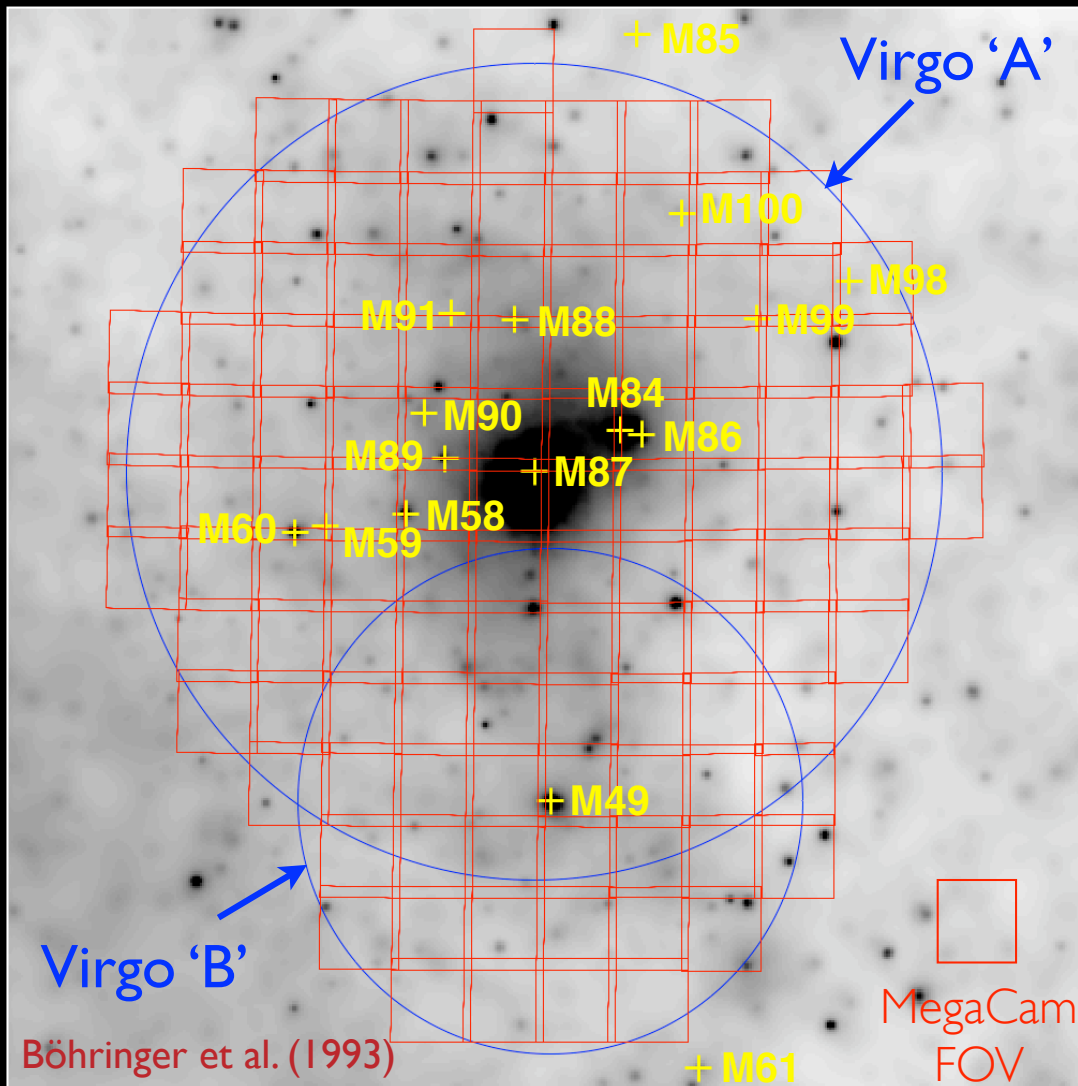
NGVS: Virgo Science



The CFHT Next Generation Virgo Cluster Survey

- CFHT MegaCam programme to fully image Virgo within R_{200} for its two main sub-clusters.

Virgo in X-rays



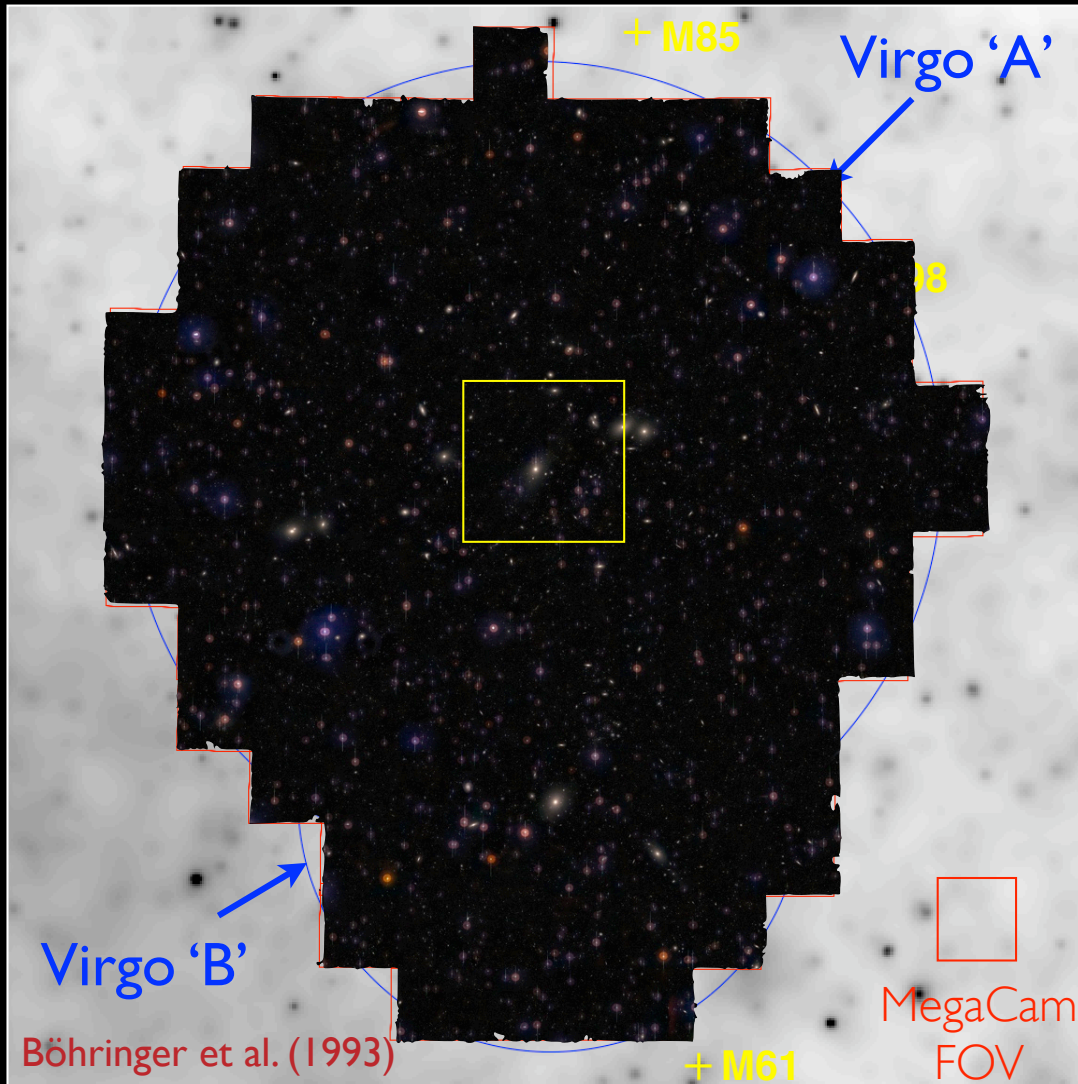
- $\Omega = 104 \text{ deg}^2$
- Five filters (u*g'r'i'z')
- $g \approx 25.7 \text{ mag}$ ($10\text{-}\sigma$ depth) \rightarrow corresponding to a mass of $M \sim 4 \times 10^4 M_{\odot}$ for old stellar populations.
- $\mu_g \approx 29 \text{ mag arcsec}^{-2}$ ($2\text{-}\sigma$ depth)
- sub-arcsec resolution in all filters ($0.55''$ in i-band).
- 15TB of raw data, 40TB of data products; advanced data analysis has taken 84 years of CPU time to date and is carried out on a 500-node cloud computing infrastructure (CANFAR).

For details see Ferrarese et al. (2012)

The CFHT Next Generation Virgo Cluster Survey

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Virgo in NGVS



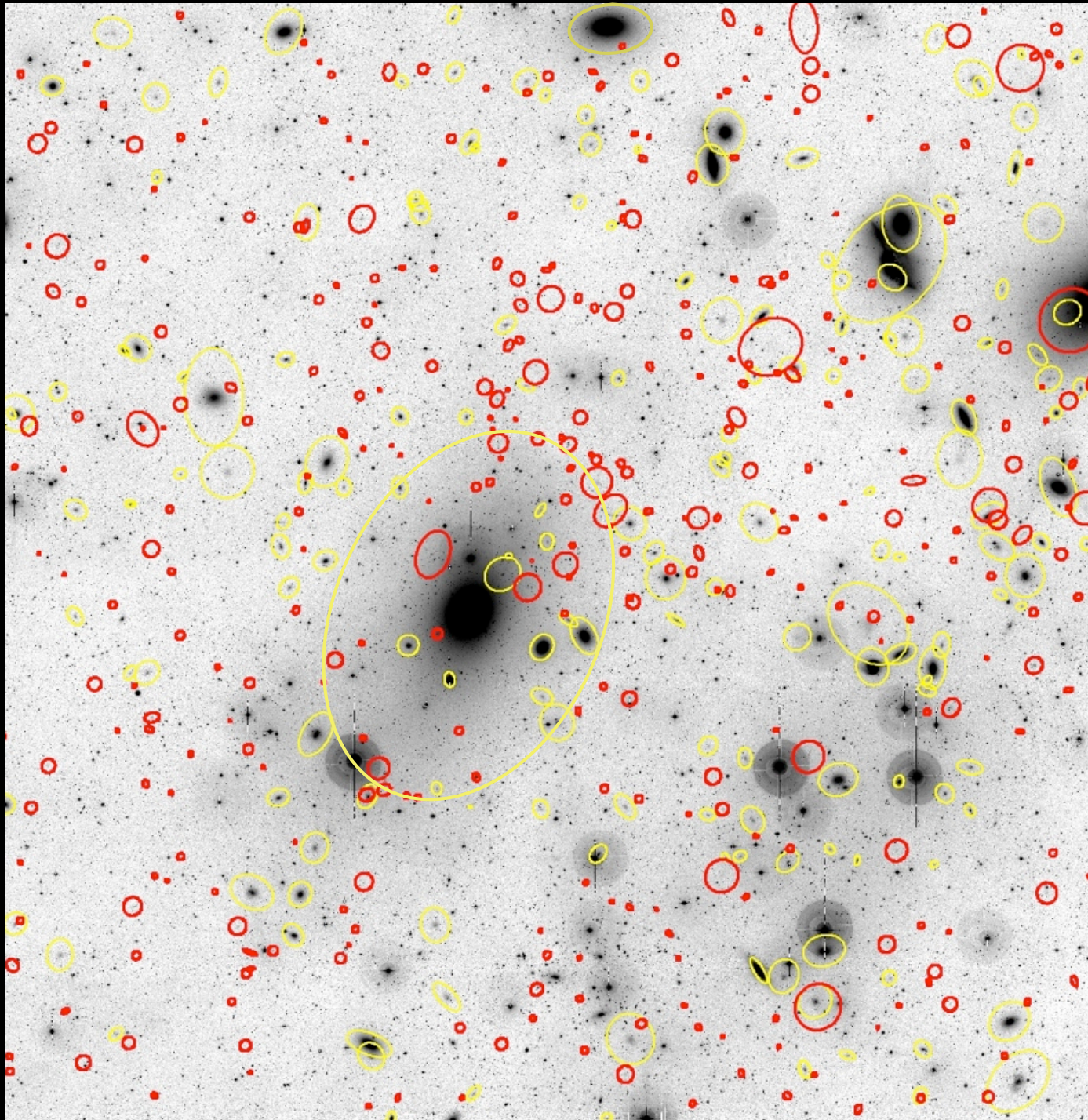
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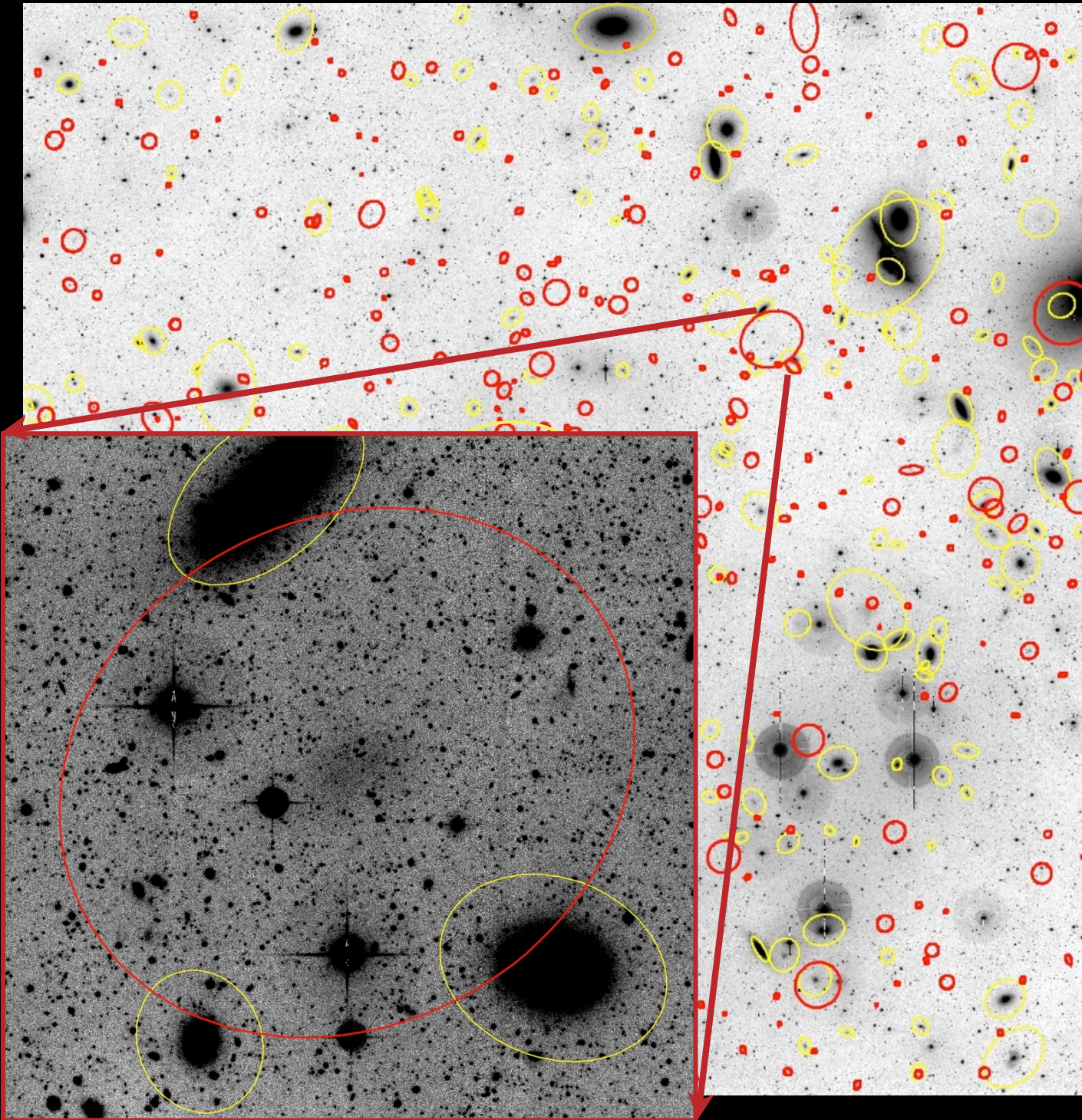
For details see Ferrarese et al. (2012)

Results from the Central Four Square Degrees:

I. Galaxy Identification and Analysis



- Identification of Virgo members in the core region
 - $2^\circ \times 2^\circ = 580 \times 580$ kpc
- 179 VCC galaxies:
 - $-23 < M_g < -11.5$
 - $4 \times 10^{11} < M_*/M_\odot < 1 \times 10^7$
- 317 previously undetected galaxies:
 - $-13.5 < M_g < -6.5$
 - $7 \times 10^7 < M_*/M_\odot < 10^5$
 - a lower limit!
- Two (independent) pipelines developed for the measurement of photometric and structural parameters:
 1. ELLIPSE-based pipeline
 2. GALFIT-based pipeline



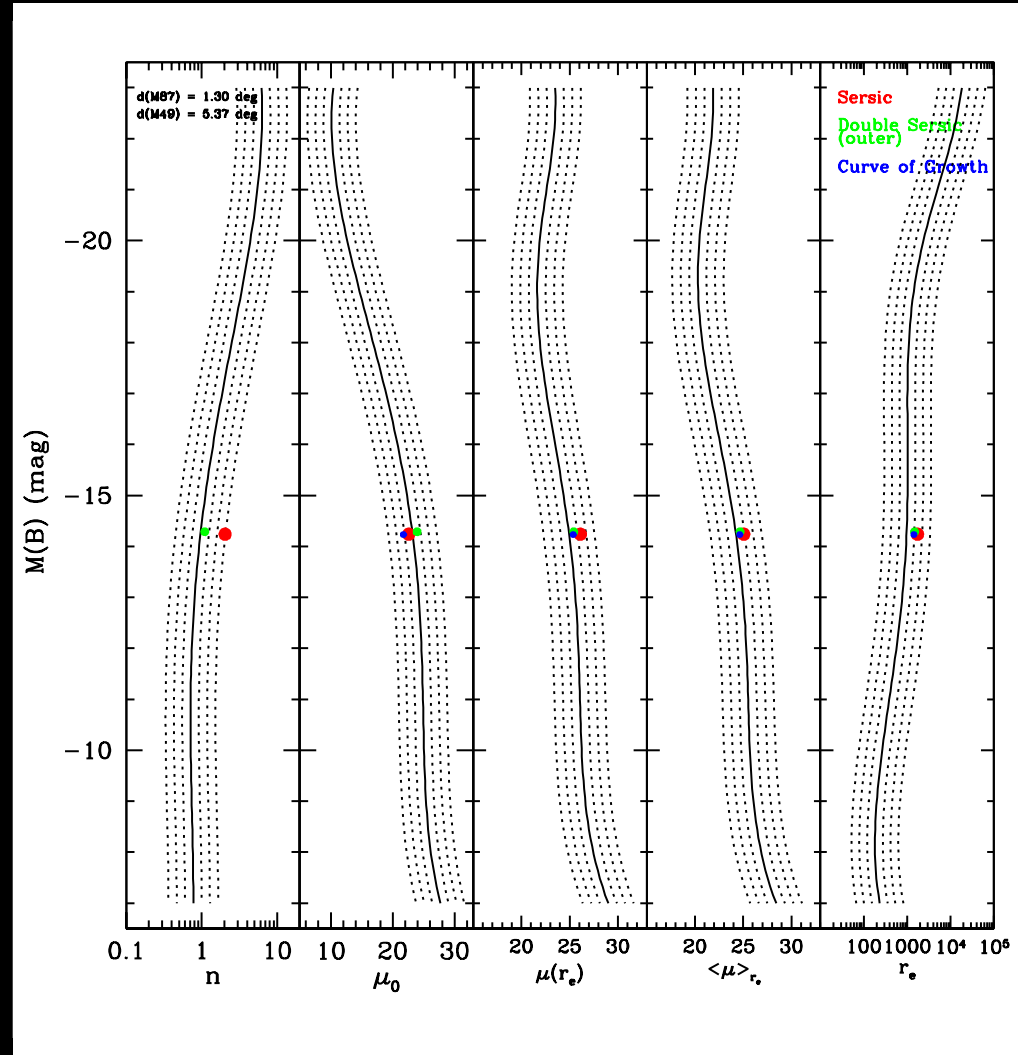
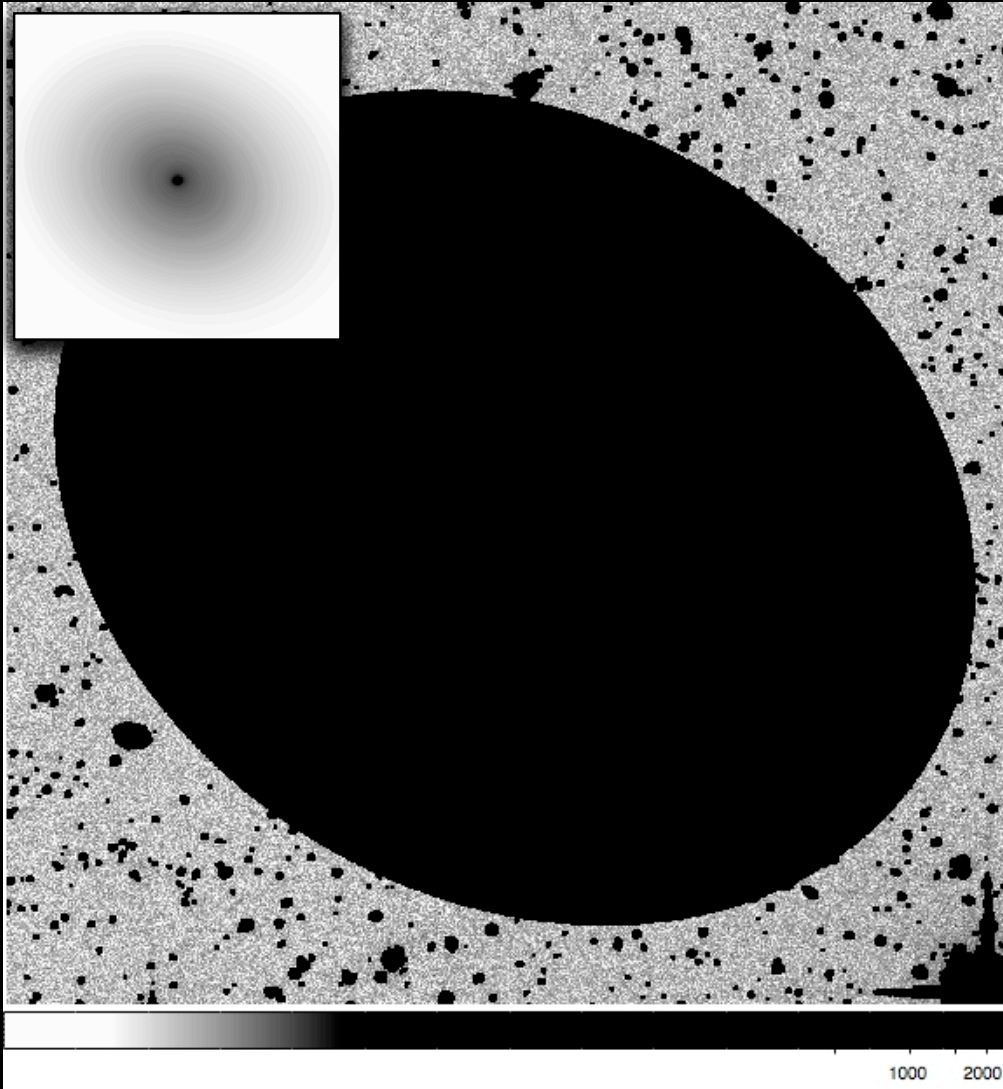
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ELLIPSE-Based Measurement of Galaxy Photometric and Structural Parameters

NGVS12:27:08.417+13:20:08.64

VCC972

$M(g) = -14.69$ mag



*Sky Estimate (first iteration)
(including additional sky estimate)*

Results from the
Central Four Square
Degrees:

III. Scaling Relations

A Seemingly Mature Field...

Barazza et al. (2003), Binggeli et al. (1984), Binggeli et al. (1985), Binggeli et al. (1987), Binggeli et al. (1988), Binggeli & Cameron (1991), Binggeli & Cameron (1993), Bower et al. (1992), Burstein et al. (1987), Busarello et al. (1997), Caldwell (1983), Caon et al. (1990), Caon et al. (1994), Capaccioli (1987), Capaccioli (1989), Capaccioli et al. (1992), Cote et al. (2006), Cote et al. (2007), de Vaucouleurs (1977), de Vaucouleurs & Olson (1982), Ferrarese et al. (1994), Ferrarese et al. (2006a), Ferrarese et al. (2006b), Gavazzi et al. (2002), Gavazzi et al. (2005), Graham & Colless (1997), Graham (2002), Grant et al. (2005), Janz & Lisker (2008), Janz & Lisker (2009), Jerjen & Binggeli (1997), Jerjen et al. (2000), Kormendy (1985), Kormendy et al. (2009), Longo et al. (1983), Lisker et al. (2006), Lisker et al. (2007), Lisker et al. (2009), Lotz et al. (2004), McDonald et al. (2009), Michard (1985), Michard (1994), Prugniel et al. (1992), Prugniel et al. (1993), Prugniel & Simien (1997), Reaves (1983), Rines & Geller (2008), Ryden & Terndrup (1994), Sandage & Binggeli (1984), Sandage et al. (1985), Young & Currie (1998), ...

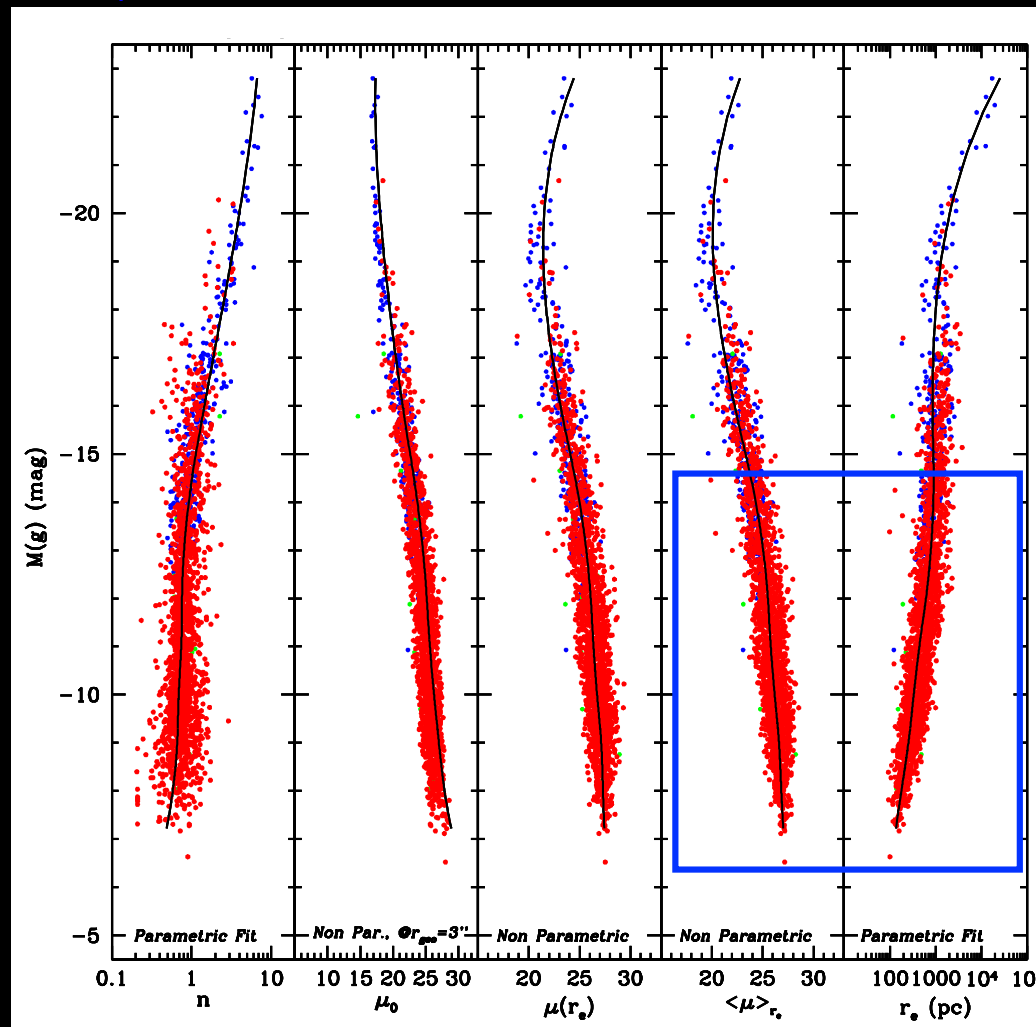
- areal coverage
- photometric depth
- image quality
- homogeneity
- SED coverage



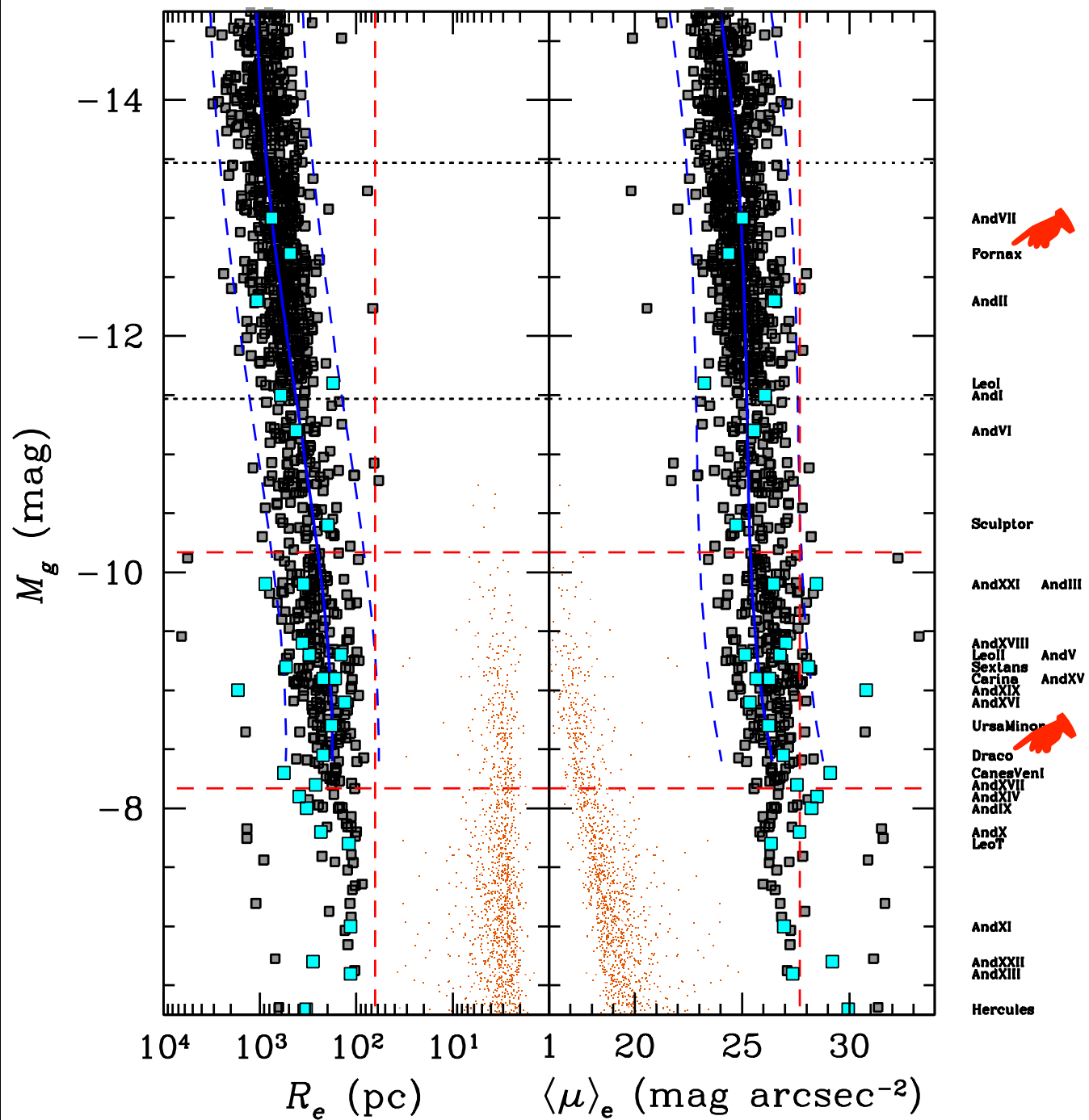
- complete and unbiased sample
- uniform analysis

Scaling Relations in the Cluster Core

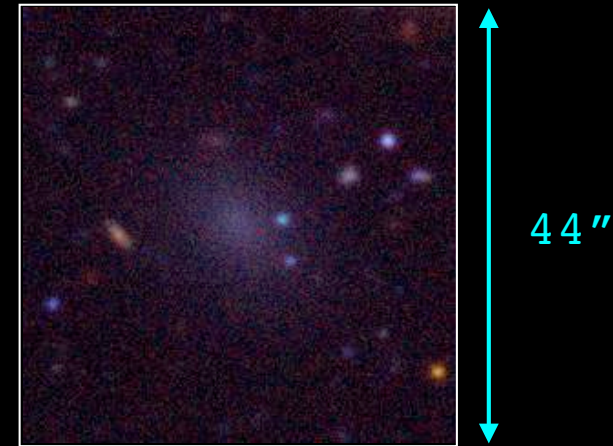
- Galaxies spanning *a factor of ~2 million in luminosity* define non-homologous, but continuous scaling relations.
- Such continuity suggests that the various processes involved in the assembly of progressively more massive systems (mergers, harassment, accretion, ram pressure stripping, etc) act **continuously**, albeit with different weights, across the entire luminosity range.



Scaling Relations in the Cluster Core



Fornax @ Virgo



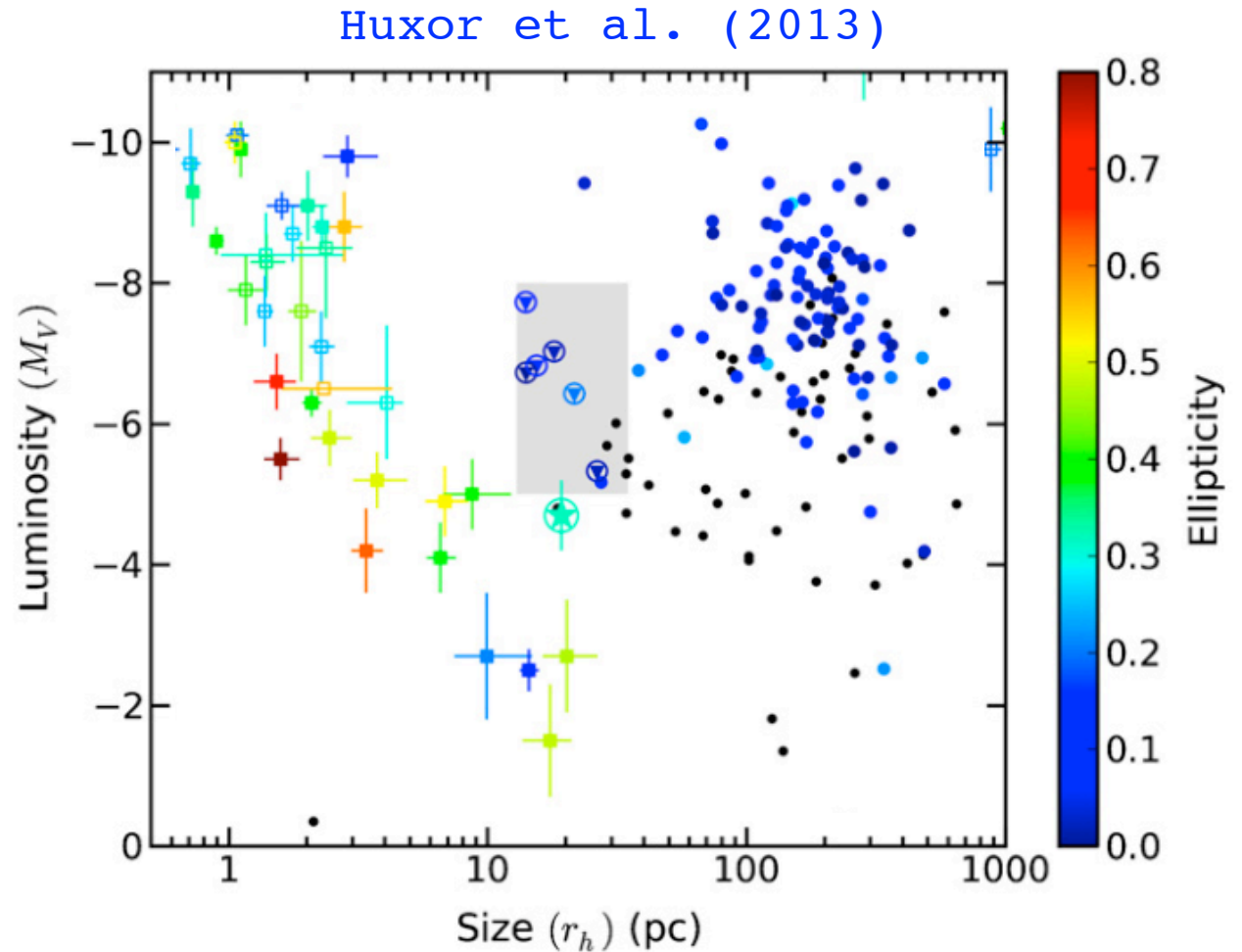
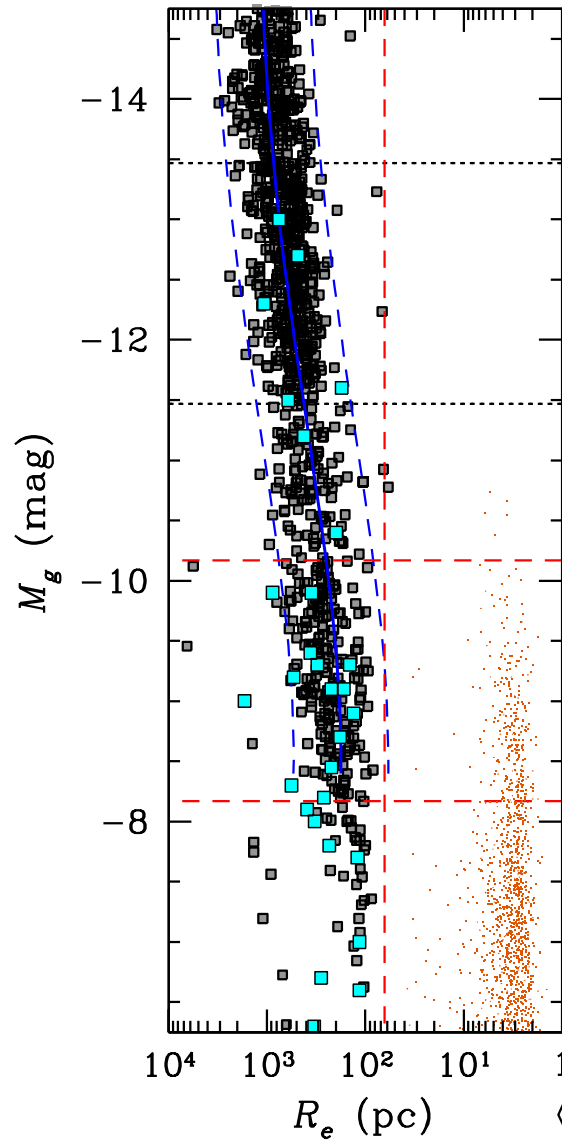
Draco @ Virgo



	Fornax measured (model)	Draco measured (model)
mag	19.37 (19.42)	22.19 (22.18)
R_e	9.05" (8.81")	2.24" (2.21")
n	1.08 (1.0)	1.19 (1.10)
q	0.78 (0.74)	0.69 (0.69)

Scaling Relations in the Cluster Core

- Virgo a new (and richer) alternative to the Local Group for the study of low-mass stellar systems.



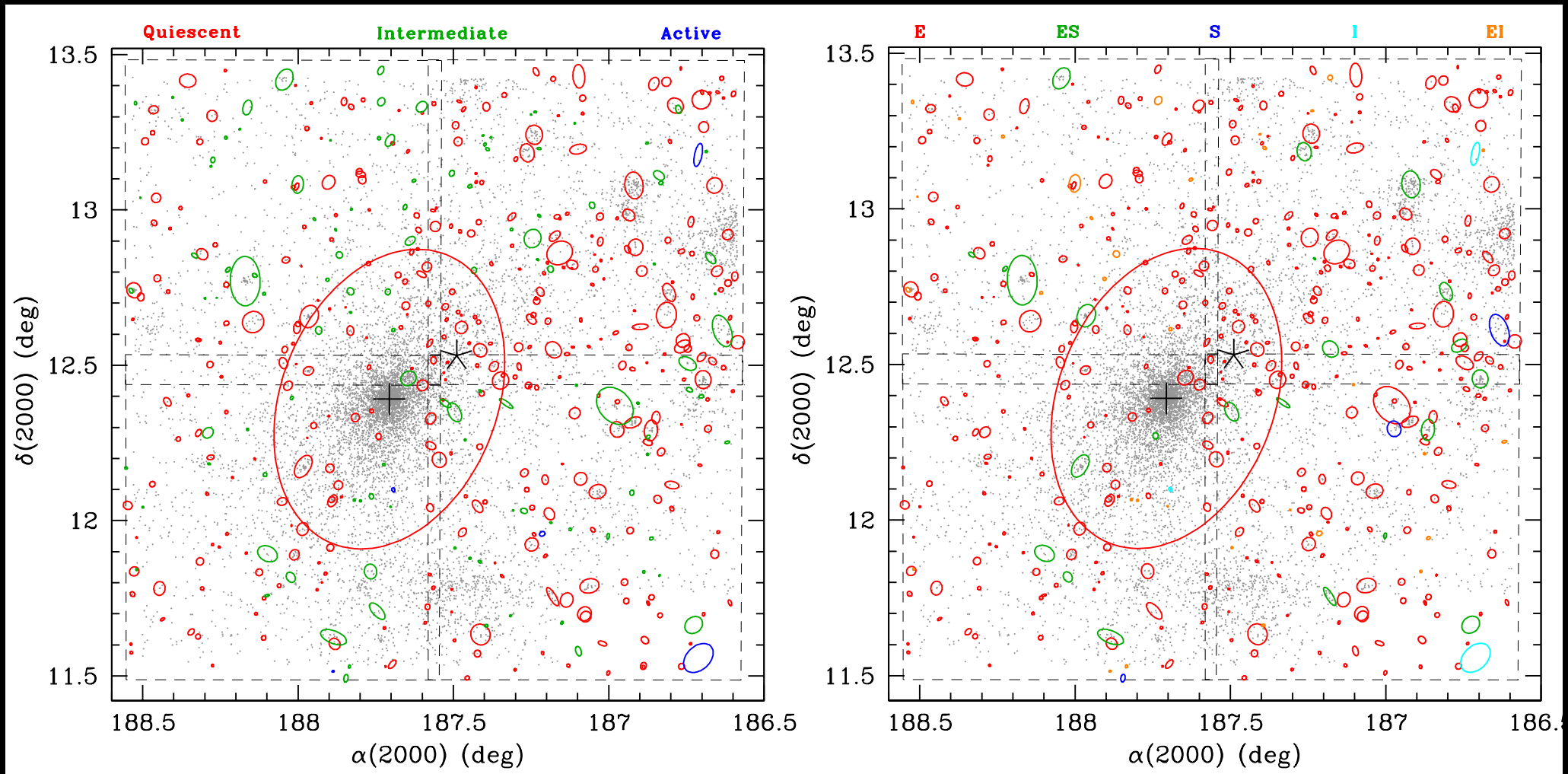
Results from the
Central Four Square
Degrees:

III. Spatial Distribution

Spatial Distribution #2

+ centre of M87

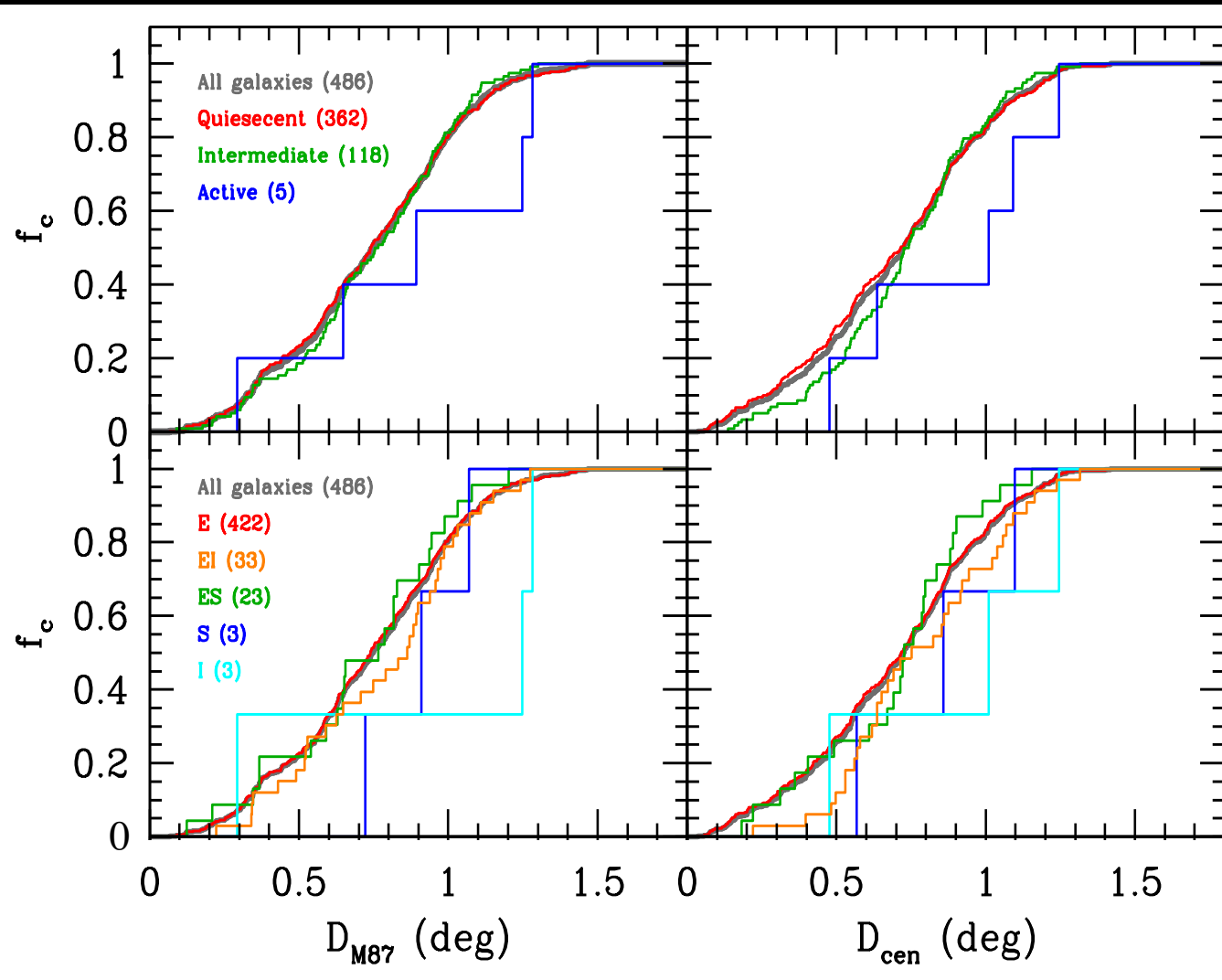
* centroid of galaxy distribution



Star Formation Code

Structure/Morphology Code

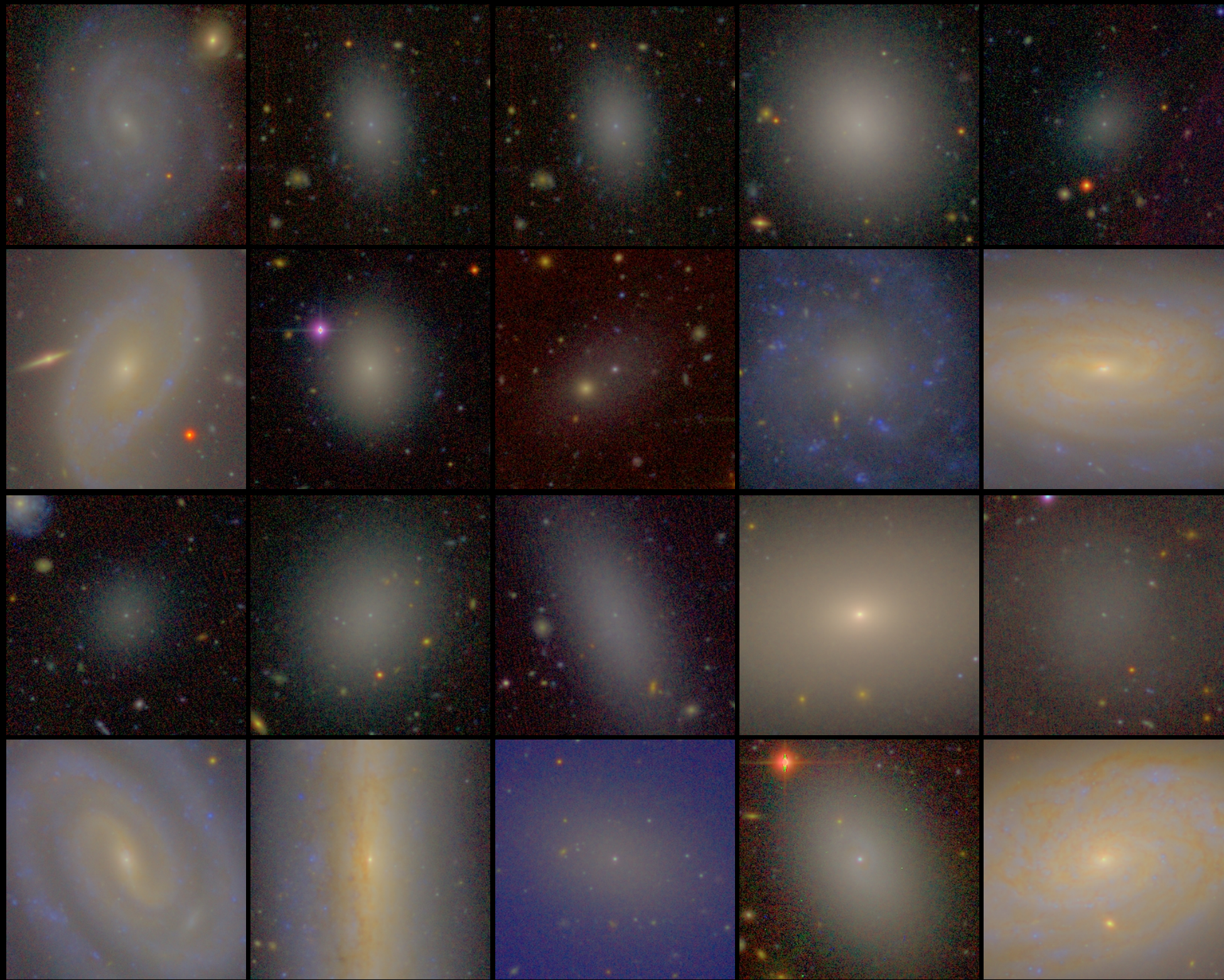
Central Concentration



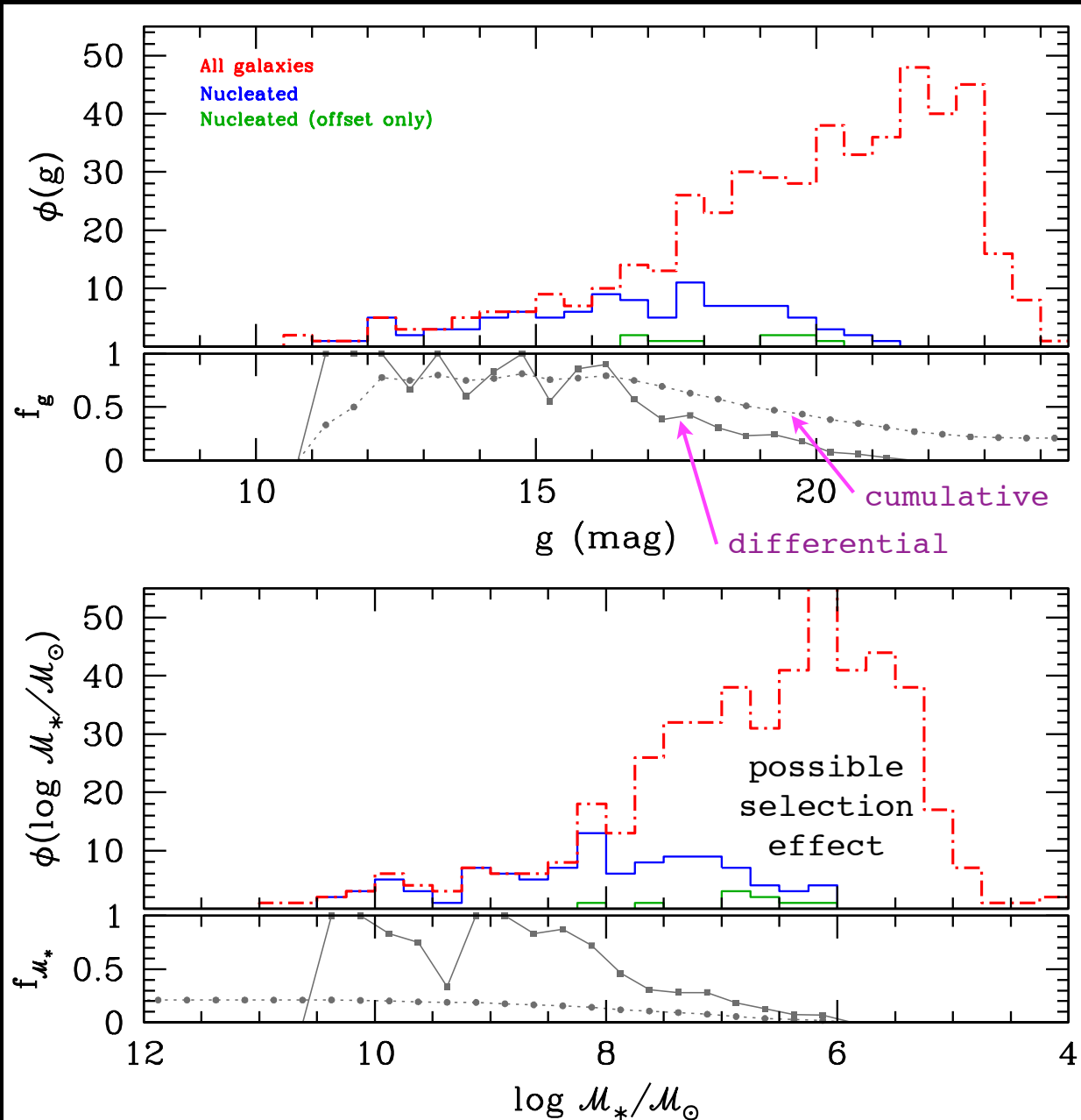
- Virgo's core is highly deficient in star-forming galaxies.
- The small number of galaxies that are actively forming stars are far more spatially extended than the dominant population of quiescent galaxies
 - ➔ Consistent with interloping galaxies on the near/far side of the cluster ($\pm 2\sigma$ back-to-front depth = 2.4 Mpc; Mei et al. 2007).
- Galaxies with a even modest level of star formation avoid the cluster centre.

Results from the
Central Four Square
Degrees:

IV. Nucleation



Nucleation Frequency as a Function of Magnitude and Mass



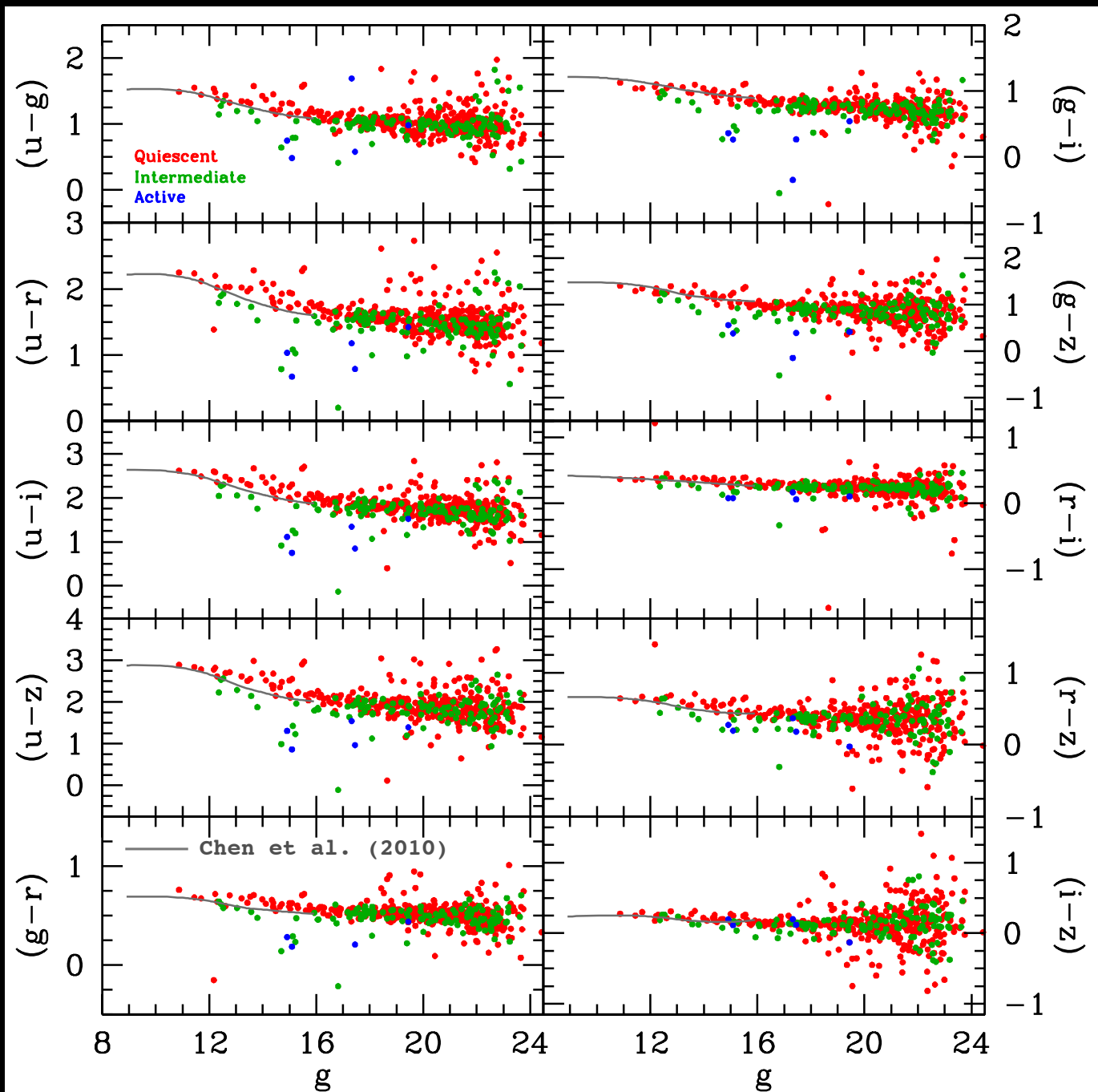
- Presence of a central nucleus established from:
 1. Model residuals in ELLIPSE and GALFIT analyses (1D + 2D).
 2. Inspection of stacked ugriz images (median i-band FWHM = 0.55").
 3. Inspection of colour images.
 4. χ^2 test for fits of Sersic vs. Sersic plus nucleus vs. higher order models for surface brightness profiles.
- Overall frequency:

$$f_n = (102/488) \approx 21\%$$
- But frequency among galaxies with $M_* \geq 10^8 M_\odot$ consistent with previous studies (e.g., [Seth et al. 2008](#)).

Results from the
Central Four Square
Degrees:

V. Colour-Magnitude Relations

ugriz Colour-Magnitude Relations



- Cluster core is almost totally deficient in Blue Cloud galaxies.
 - Red sequence is continuous over a range of \sim a million in luminosity.
 - S-shaped CMR in some bandpasses (Janz & Lisker 2009; Chen et al. 2010).
 - Small but systematic red offset relative to ACSVCS: a sample of 100 ETGs scattered over the cluster
- ➔ qualitatively expected on the basis of extreme environment (e.g., quenching/strangulation during infall).

Summary

Summary

- NGVS is the widest contiguous field surveyed to this depth in the optical.
 - ugriz imaging to $g \sim 25.7$ and $\mu_g \sim 29$ mag arcsec⁻² covering ~ 100 deg².
- In the core region, a nearly three-fold increase in census of galaxies down to $M_* \sim 10^5 M_\odot$.
 - A strong deficiency in star-forming galaxies.
 - Red sequence population is continuous to limit of the survey.
 - Global scaling relations spanning a factor of ~ 2 million in stellar mass are also continuous.
 - Nuclei are common $M_* \sim 10^8 M_\odot$, becoming much less common below this point.
 - Virgo is a special environment for studying the relationship between various types of stellar systems.
- Upcoming NGVS papers focusing on the Virgo core region:
 - Globular clusters (Durrell et al. 2014, Puzia et al. 2014).
 - Globular cluster dynamics (Peng et al. 2014, Zhu et al. 2014).
 - NGVS-IR and source classification in the uIK diagram (Muñoz et al. 2014).
 - UCDs (Zhang et al. 2014, Liu et al. 2014).
 - Low-mass galaxies (Ferrarese et al. 2014, Côté et al. 2014, Sanchez-Janssen et al. 2014).



The Next Generation Virgo Cluster Survey

Photo by J.-C. Cuillandre