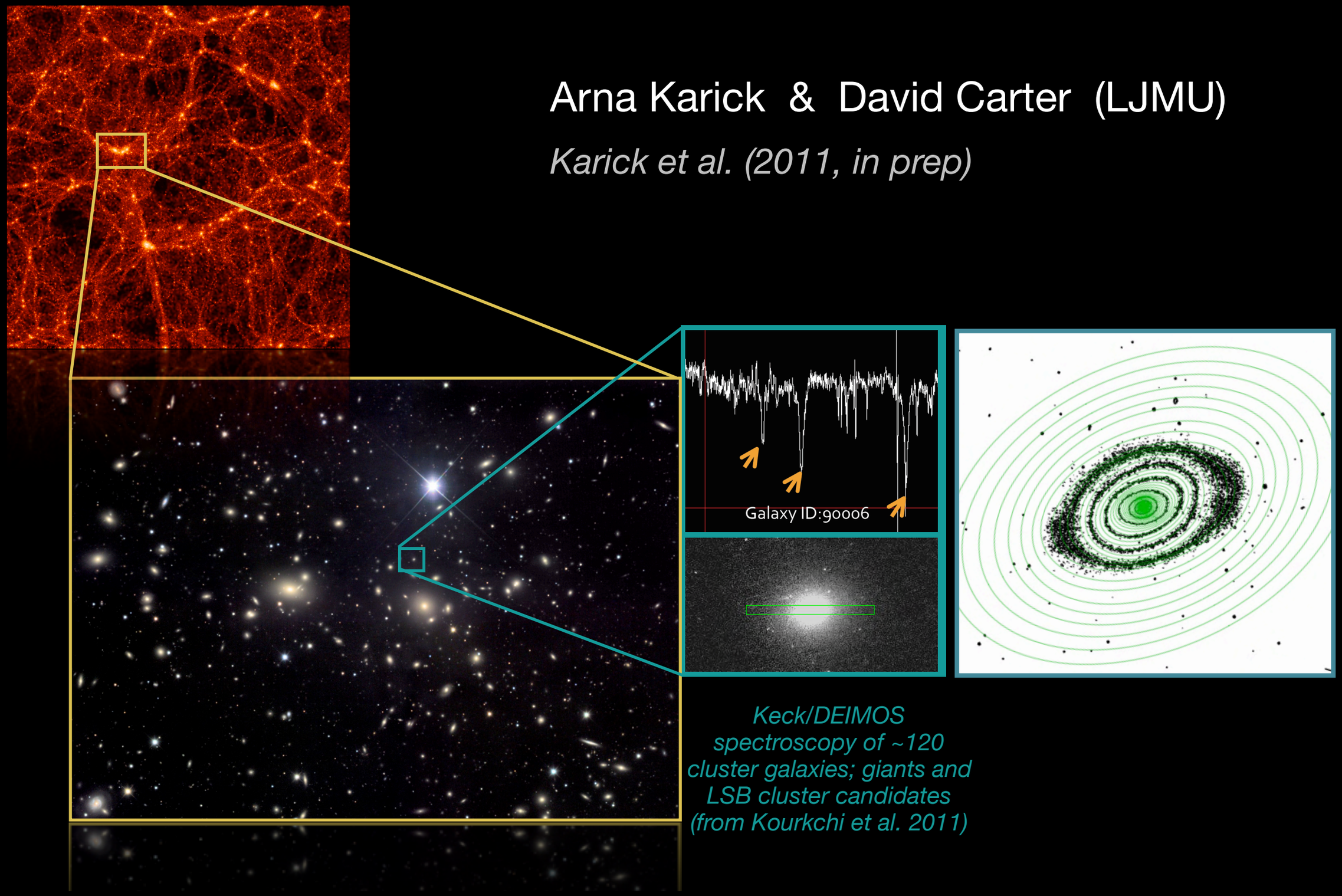
The HST/ACS Coma Cluster Treasury Survey:

Isophote Parameters and Structural Analysis of Galaxies

Arna Karick & David Carter (LJMU)

Karick et al. (2011, in prep)



Keck/DEIMOS spectroscopy of ~120 cluster galaxies; giants and LSB cluster candidates (from Kourkchi et al. 2011)

Scientific Motivation:

Understanding the internal structure of galaxies has been critical to our current theories of galaxy formation...

Elliptical, dE (and UCD) galaxies:

FITTING FUNCTIONS: scale sizes, “core” and “power law” galaxies?

nuclear star clusters, bulges, scouring from BHs.

➙ do these galaxies follow distinct evolutionary routes?

Bulges and bars in spiral and S0 (+E) galaxies:

ISOPHOTES: twists, bulges, embedded disks, strong and weak bars – gas inflows, bulge-bar-disk composition.

HST/ACS results in a factor of ~3 improvement in resolution (~50 pc) compared to previous Coma studies using WFC2... (eg E–dE connection: Graham et al. 2003, 2004)

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Scientific Motivation:

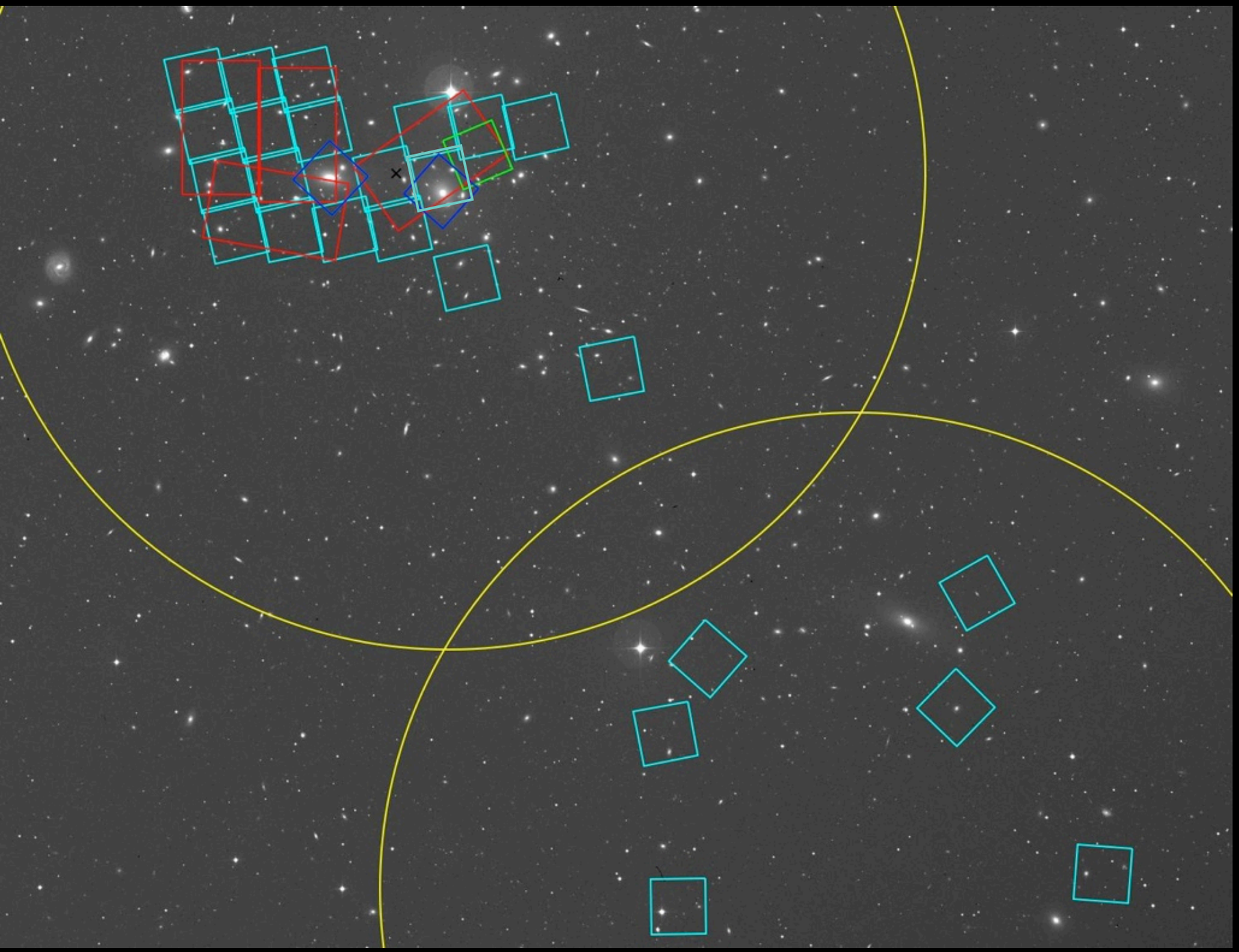
How are these galaxy properties - and by inference their formation histories - affected by the dense cluster environment?...

- ☑ evidence for morphological transformations of cluster dwarfs by “harassment”, interactions – embedded disks?
- ☑ evidence for warps and twists in galaxies? dust? shells? tidal distortion of galaxies?
- ☑ variation in bar fraction within the cluster environment. Most studies are based on field samples. Is there evidence for *induced bars* in the core?
- ☑ Homogeneous analysis of the structure and isophote parameters of ALL galaxies in the dense cluster environment.

Bar+disk fractions for 35 cluster S0 galaxies:

Marinova et al. (2011, in prep)

Observations and Sample Selection:



- covers ~270 arcmin^2 of the cluster core and infall region
- F814W (I) & F475W (g)
- FOV: 202″ x 202″
- resolution ~ 0.05″/pix
  ACS PSF ~ 0.1”
  spatial resolution ~ 50 pc

- GO-11711 Cycle-17 (SBF)
  PI: Blakeslee
  F814W & F475W

- GO-10397 Cycle-13 (debris)
  PI: West & Gregg
  F814W

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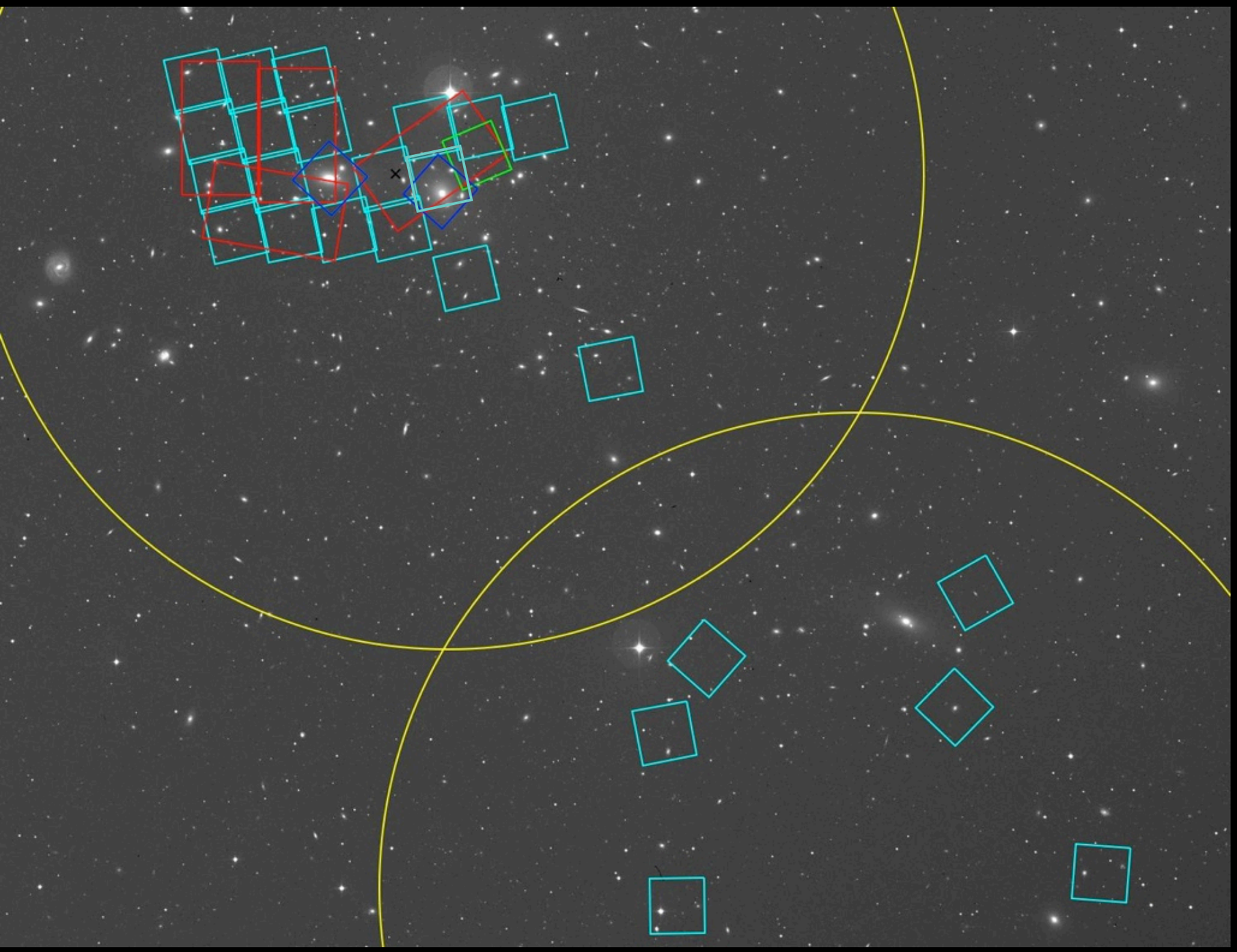


SPECTROSCOPY

MMT/Hectospec
(Marzke et al. *in prep*
Smith et al. 2009)

Keck/LRIS
(Chiboucas et al. 2010)

GALAXY SAMPLE

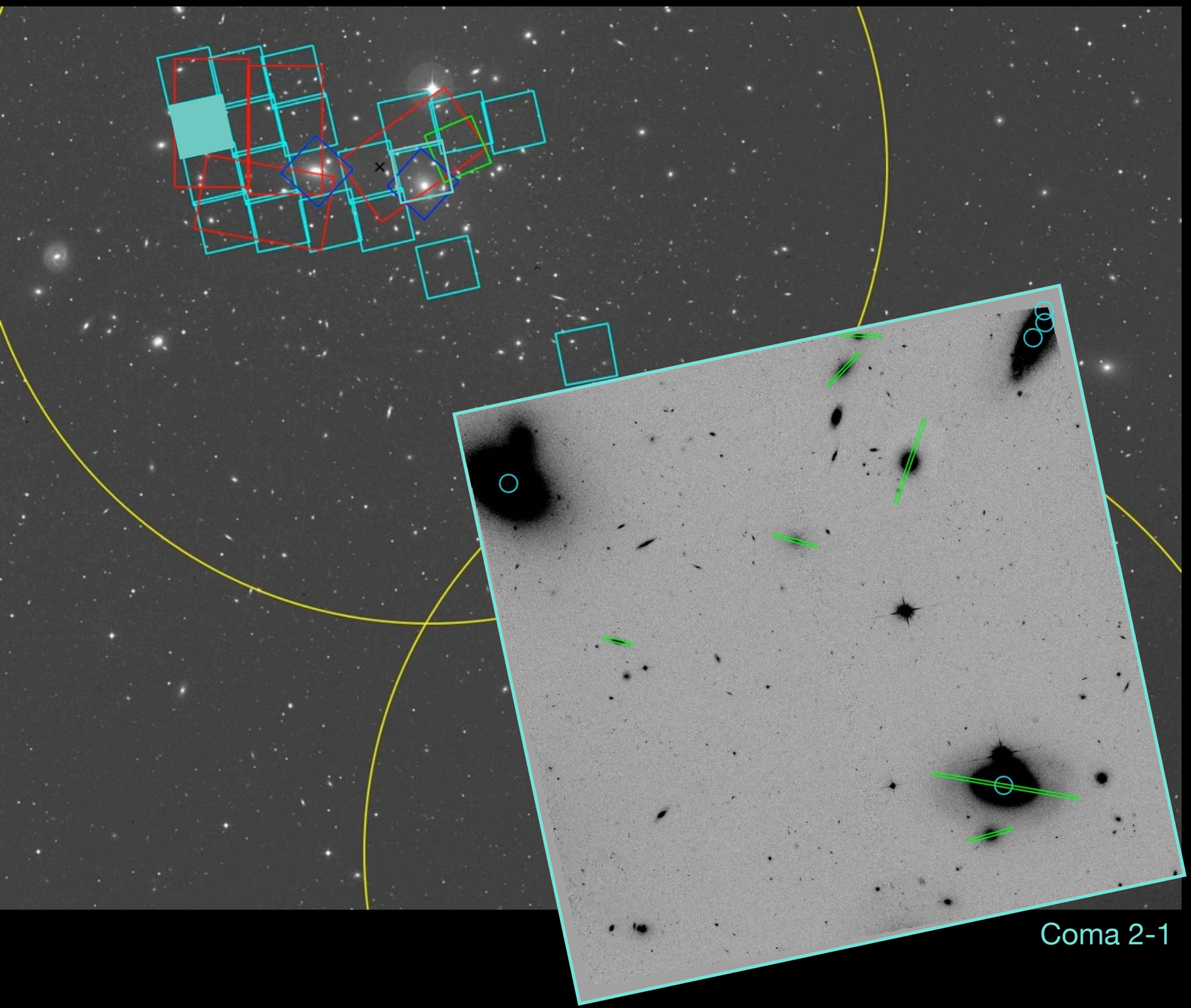
N = 225 confirmed
cluster galaxies

Luminosity: $13.2 < I < 22.5$

SB: $\sim 18.5 < \mu_I < \sim 27.0$

All morphological types

Observations and Sample Selection:



Coma 2-1

SPECTROSCOPY

MMT/Hectospec
(Marzke et al. *in prep*
Smith et al. 2009)

Keck/LRIS
(Chiboucas et al. 2010)

GALAXY SAMPLE

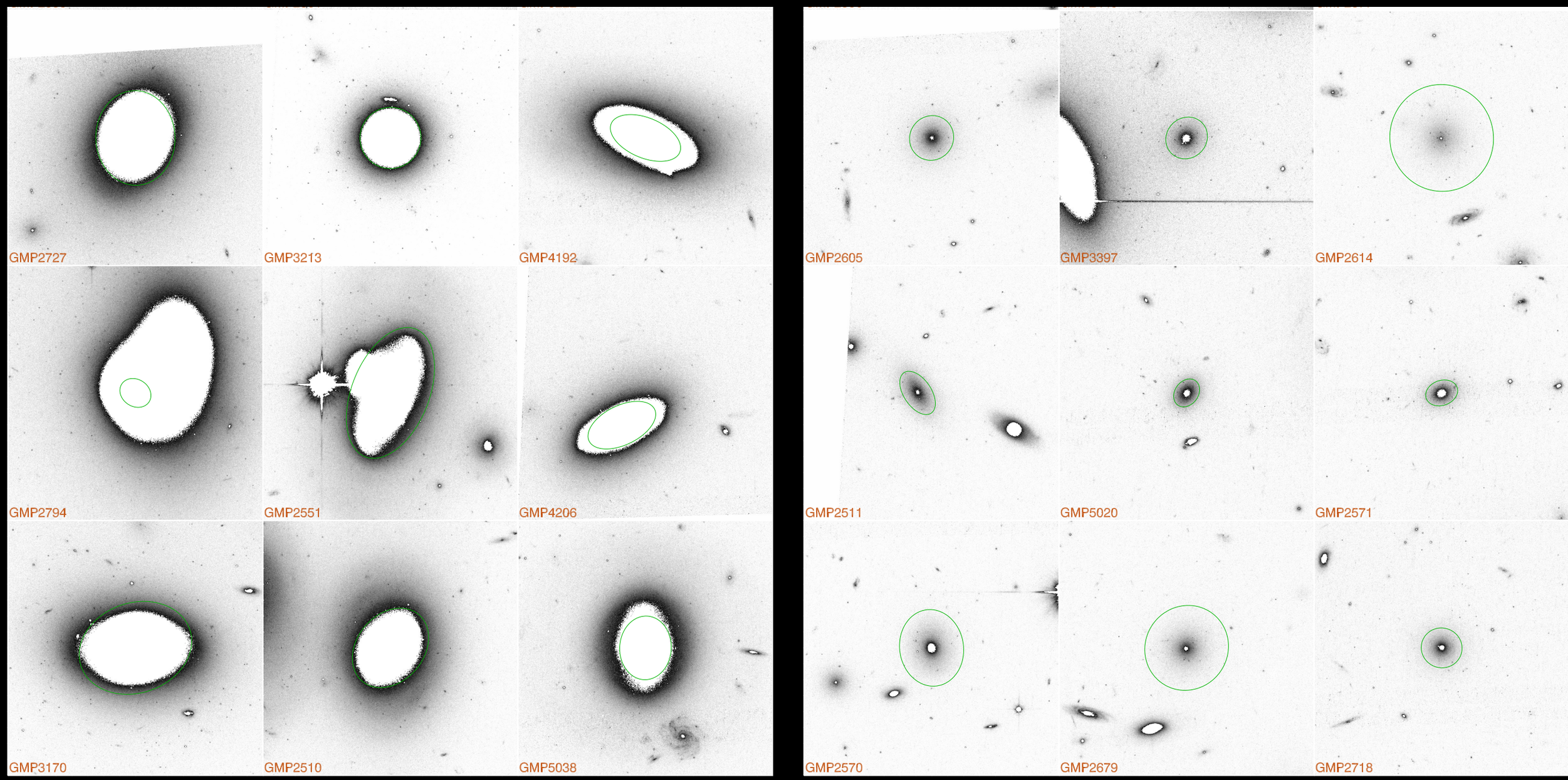
Overlap with the *Structural Parameters Catalogue*:
(Hoyos et al. 2011)

Includes ‘failed’ galaxies from automated 2-D GALFIT fitting

Observations and Sample Selection:

bright cluster galaxies....

faint cluster galaxies



Green ellipses represent the effective radius of each galaxy as measured by GALFIT

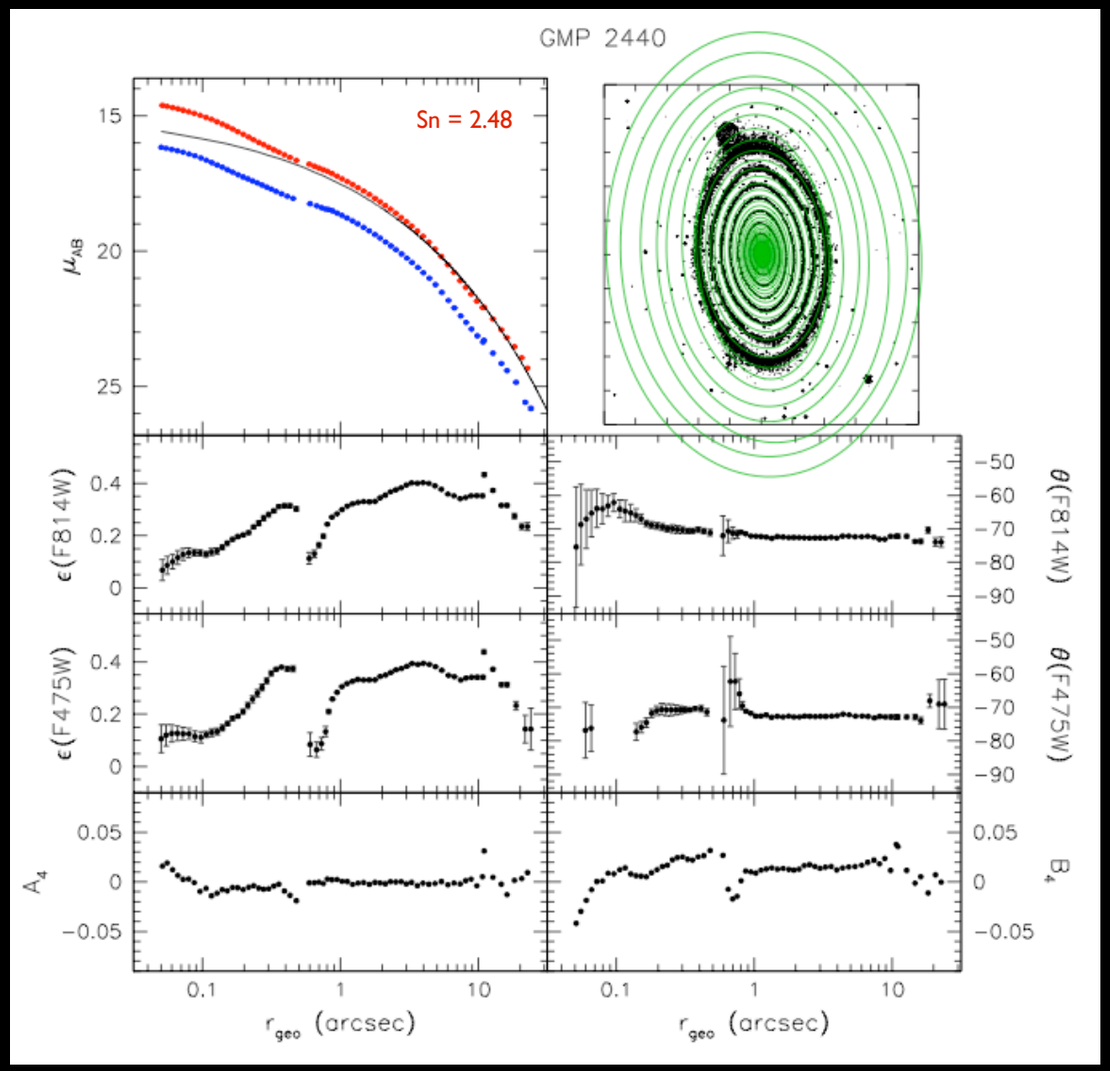
Analysis:

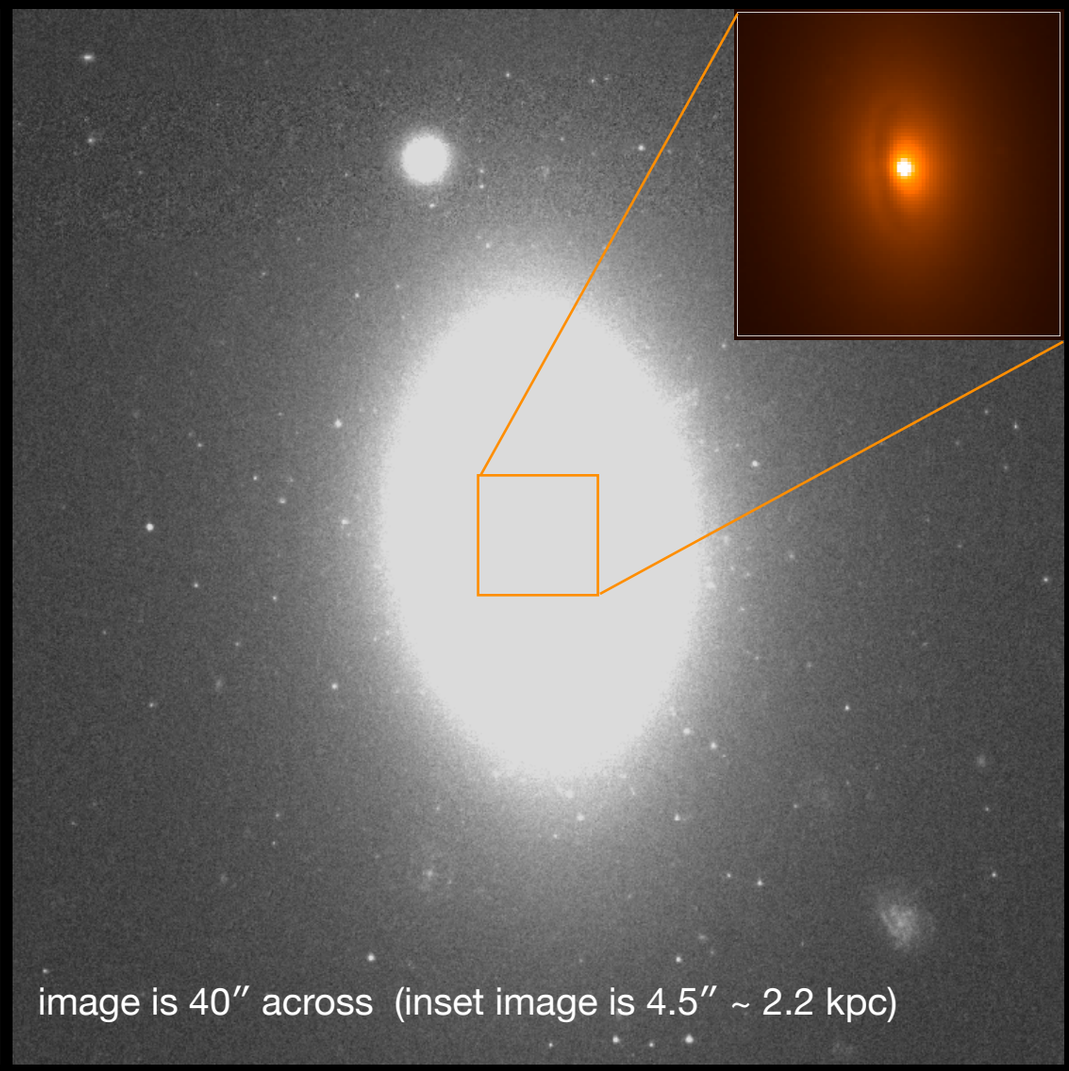
IRAF task ELLIPSE to extract isophotal intensities and produce 1D - surface brightness profiles
Method is similar to the analysis of HST/ACS Virgo cluster galaxies (Ferrarese et al. 2006)

- ☑ ellipticity (ϵ) and position angle (Θ) are allowed to vary
- ☑ Es and dEs: compare to the 2D - GALFIT surface brightness profiles
- ☑ F475W, F814W ratio images are used to identify the presence of dust
- ☑ identify bars, twists in position angle Θ in early-types (triaxial galaxies)
- ☑ determine galaxy inclinations
- ☑ fit 1D - Sersic profiles: IDL script based on *mpfitfun.pro* - X^2 minimization + equal weights
  eg. Stott et al. (2011) for BCGs: $0.7 < z < 1.3$
- ☑ identify galaxies requiring multi-component fits
- ☑ FUTURE: 'core-sersic', 'sersic-sersic'? profiles when necessary (Graham et al. 2003)
  ACS-PSF varies across the FOV - Thomas Puzia (Ferrarese et al. 2006)

Example 1:

GMP 2440: Bright early-type galaxy (E4/S0) with embedded disk.
(Godwin, Metcalfe & Peach 1983)





Top left: black line - GALFIT result

Not in Marinova et al. (2011, in prep)

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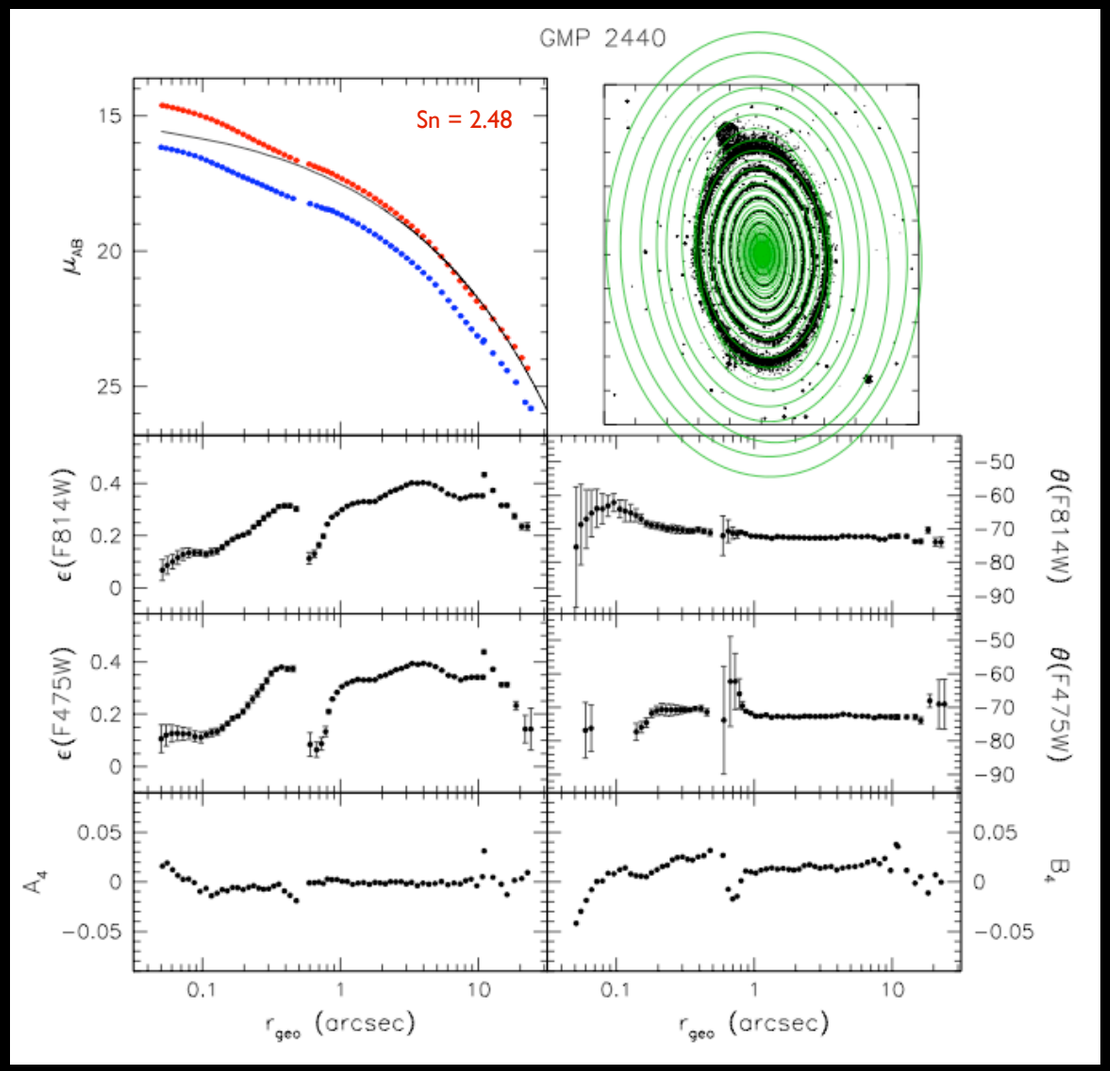

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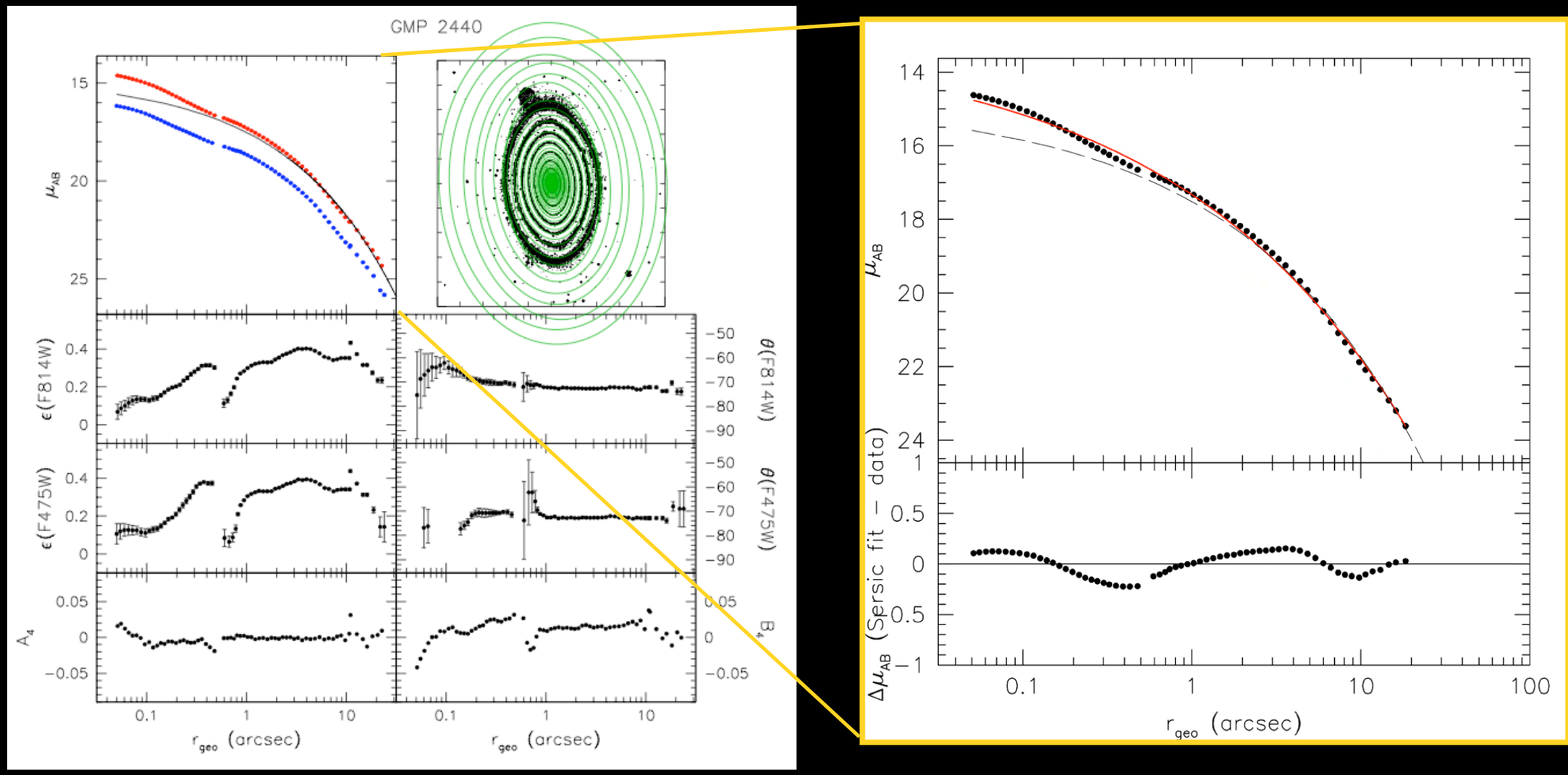
Example 1:

GMP 2440: Bright early-type galaxy (E4/S0) with embedded disk.

- GALFIT:
  fixed ellipticity and position angle — μ (re) = 19.78 re = 4.44″ Sn = 2.48
- IRAF. ELLIPSE + IDL:
  X^2 (~1.0) minimization with equal weighting — μ (re) = 19.63 re = 4.03″ Sn = 3.20



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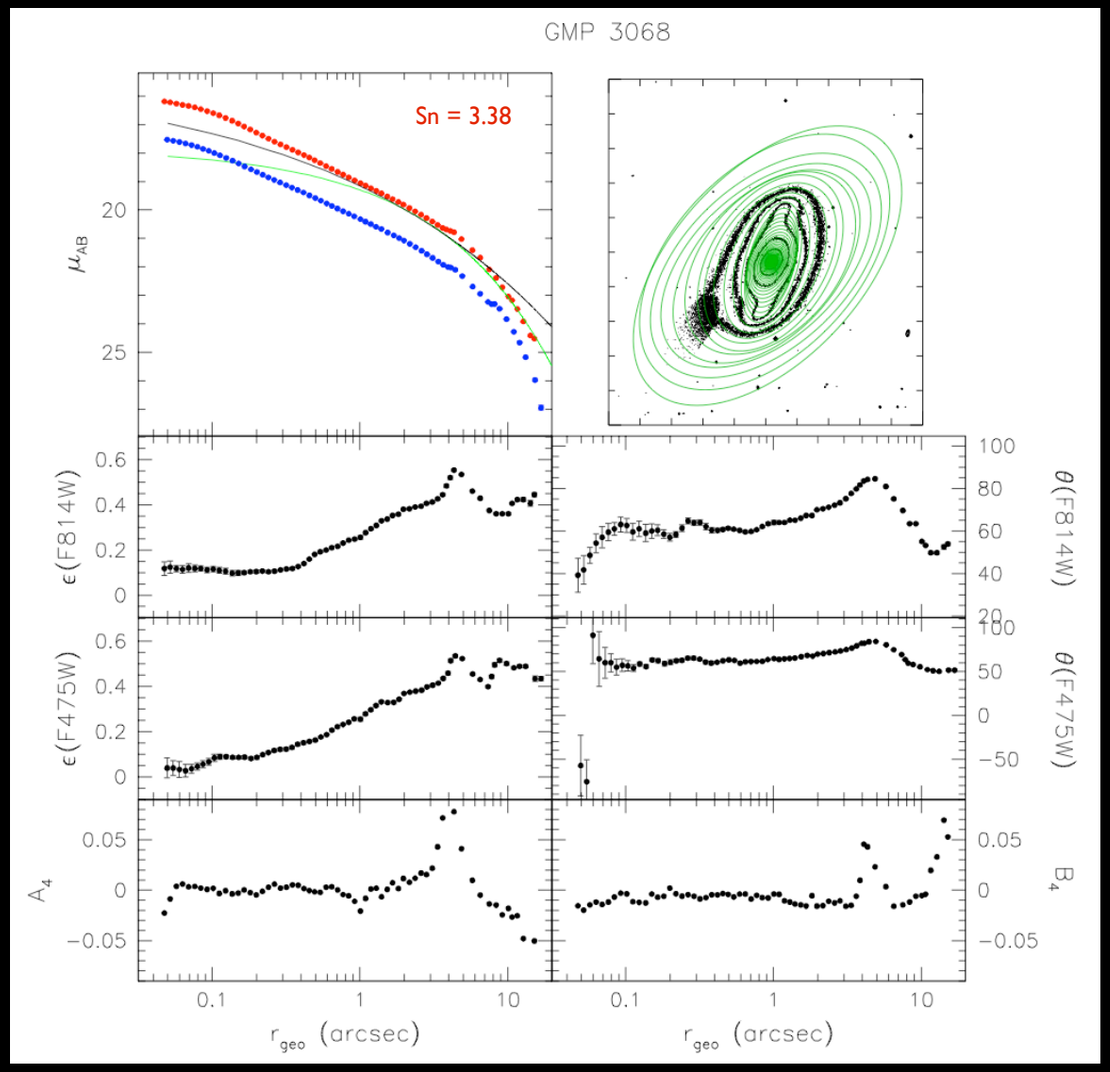
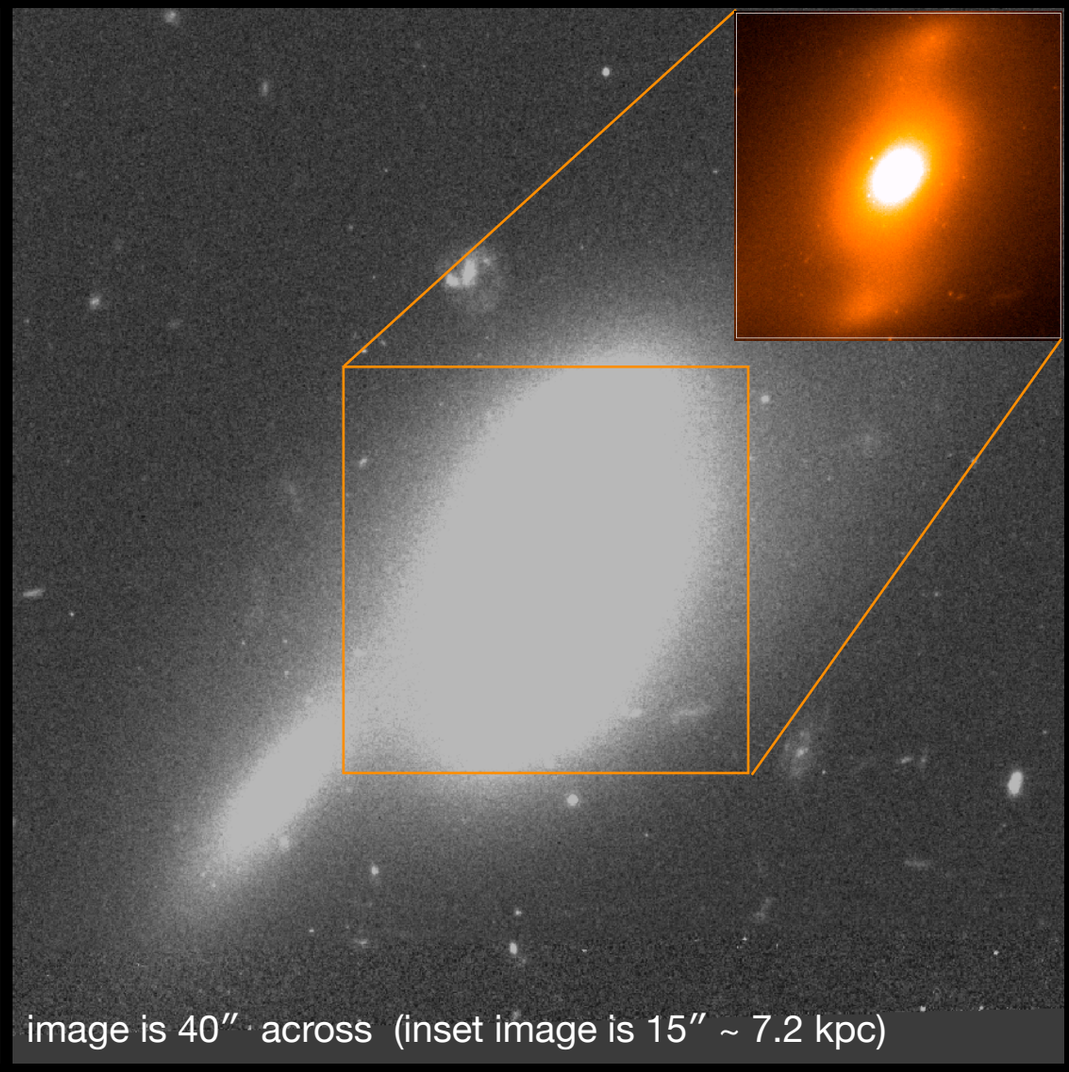
Example 2:

GMP 3068: Barred S0 galaxy

- careful masking + modelling of neighboring galaxies
- intracluster light and galaxy halo light is problematic
- Taster : ϵ = 0.55, sma $_{(obs)}$ = 3.42 kpc, sma $_{(depr)}$ = 4.00 kpc



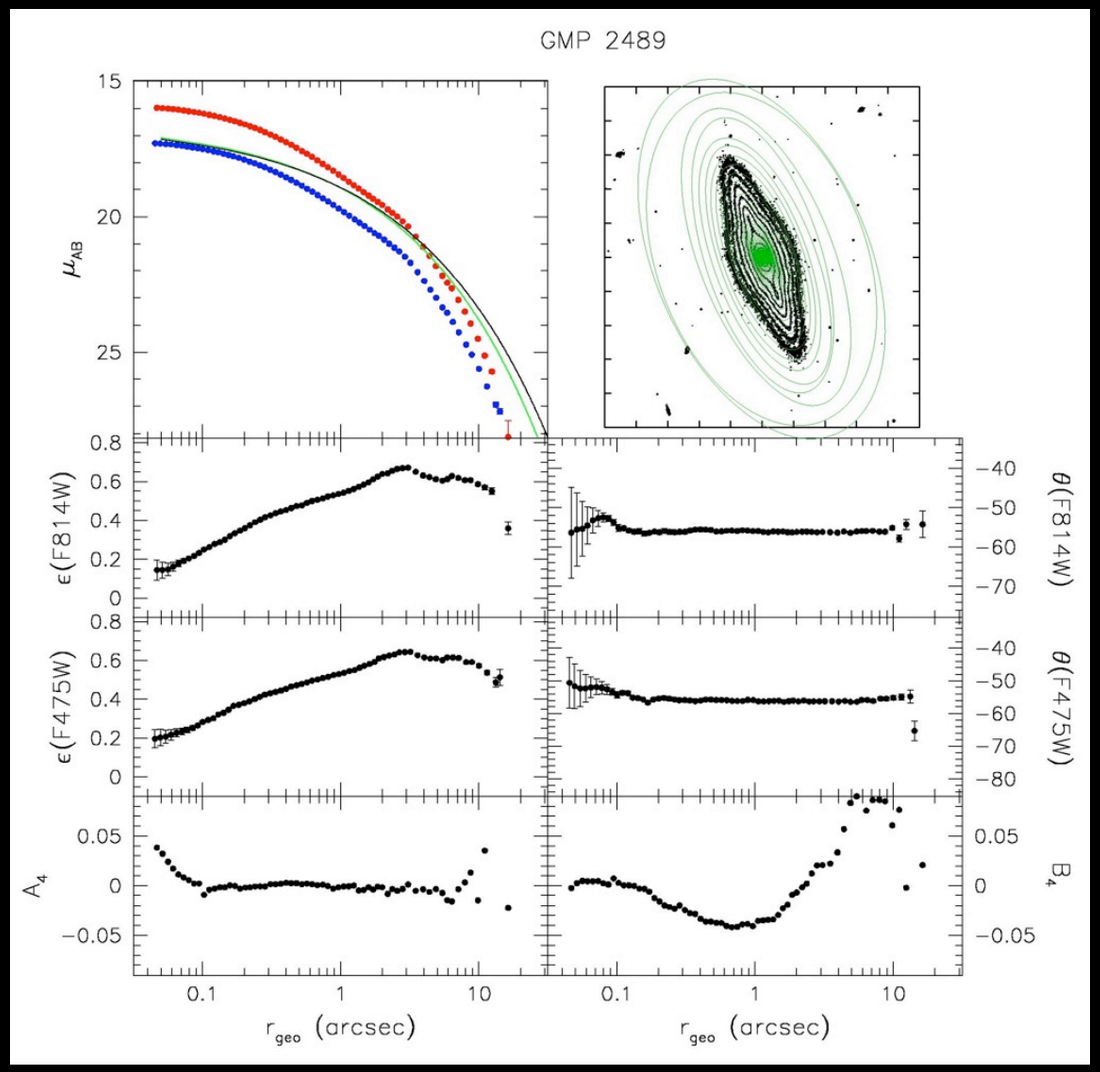


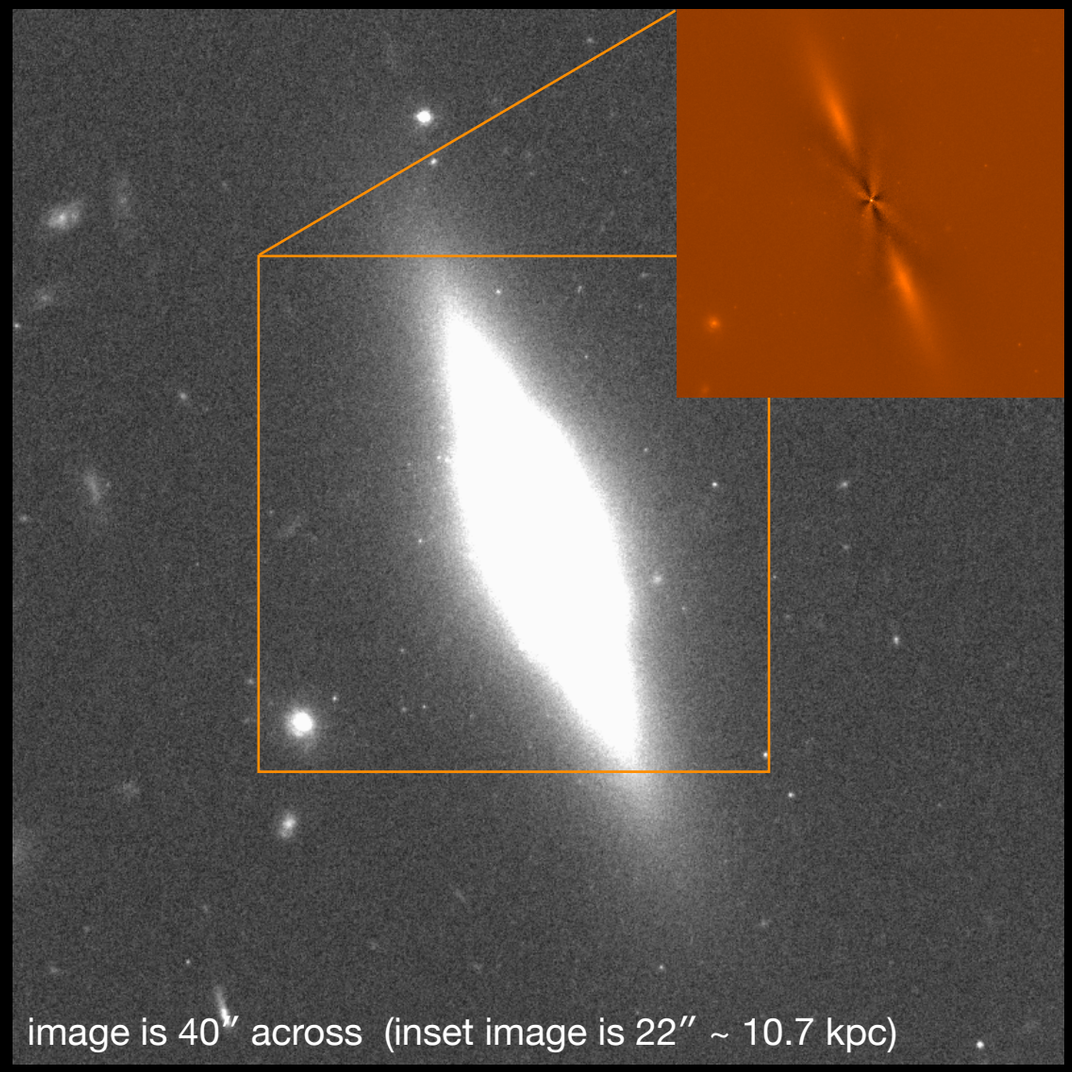
Top left: black line - GALFIT result, green line - (Kourckchi et al. 2011)

Rigorous analysis in Marinova et al. (2011, in prep)

Example 3:

GMP 2489: Bright early-type galaxy (S0- NED)





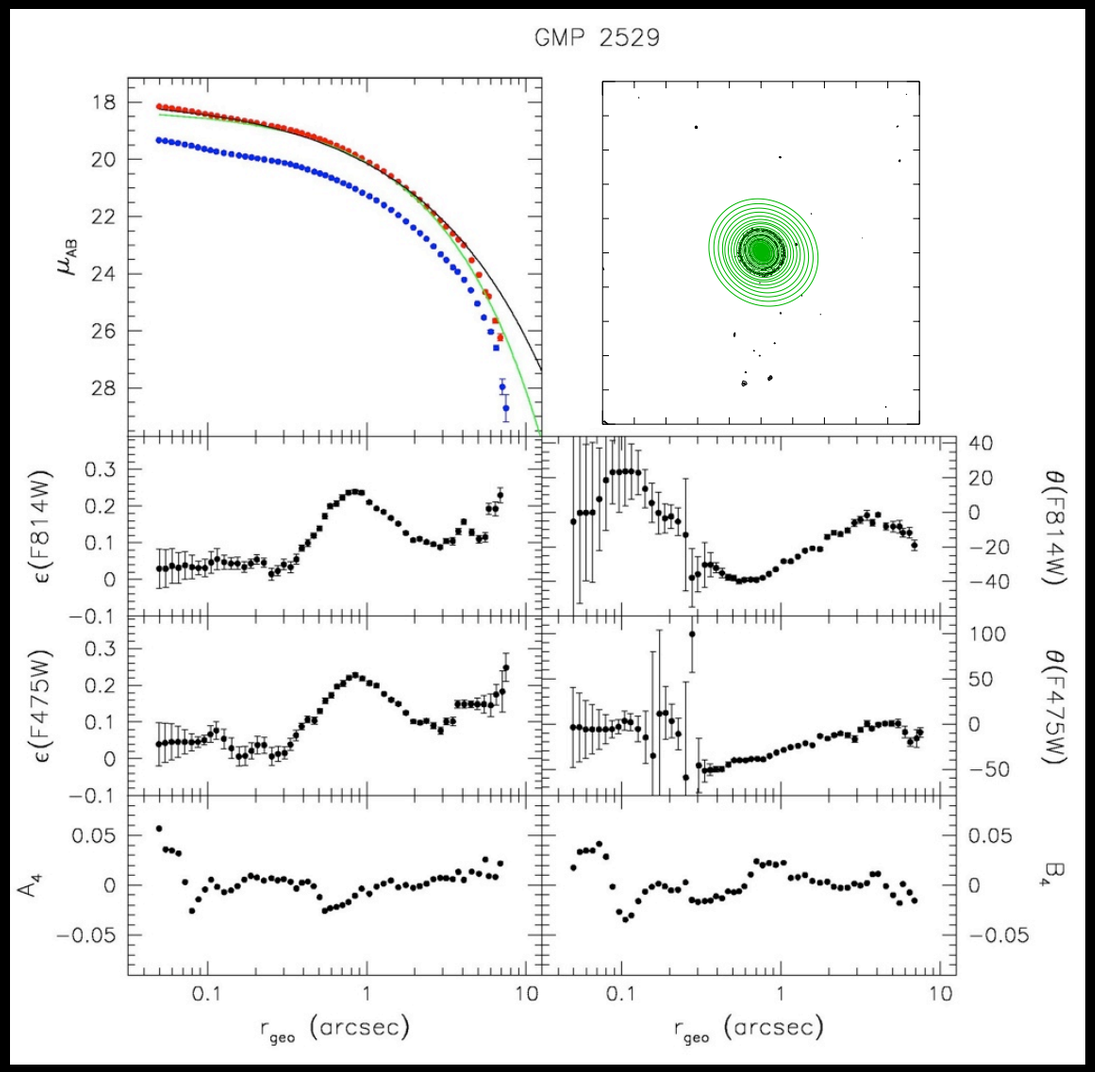
Top left: black line - GALFIT result, green line - (Kourckchi et al. 2011)

Not in Marinova et al. (2011, in prep)

Example 4:

GMP 2529: Bright early-type galaxy (E3 - NED)

- Luminosity: I_{gal} = 16.7 mag (M_I = –18.7)
- classified as having weak spiral structure in Marinova et al. (2011)
  = upper limit prediction for Virgo dEs ~20% (de Rijke et al. 2003)



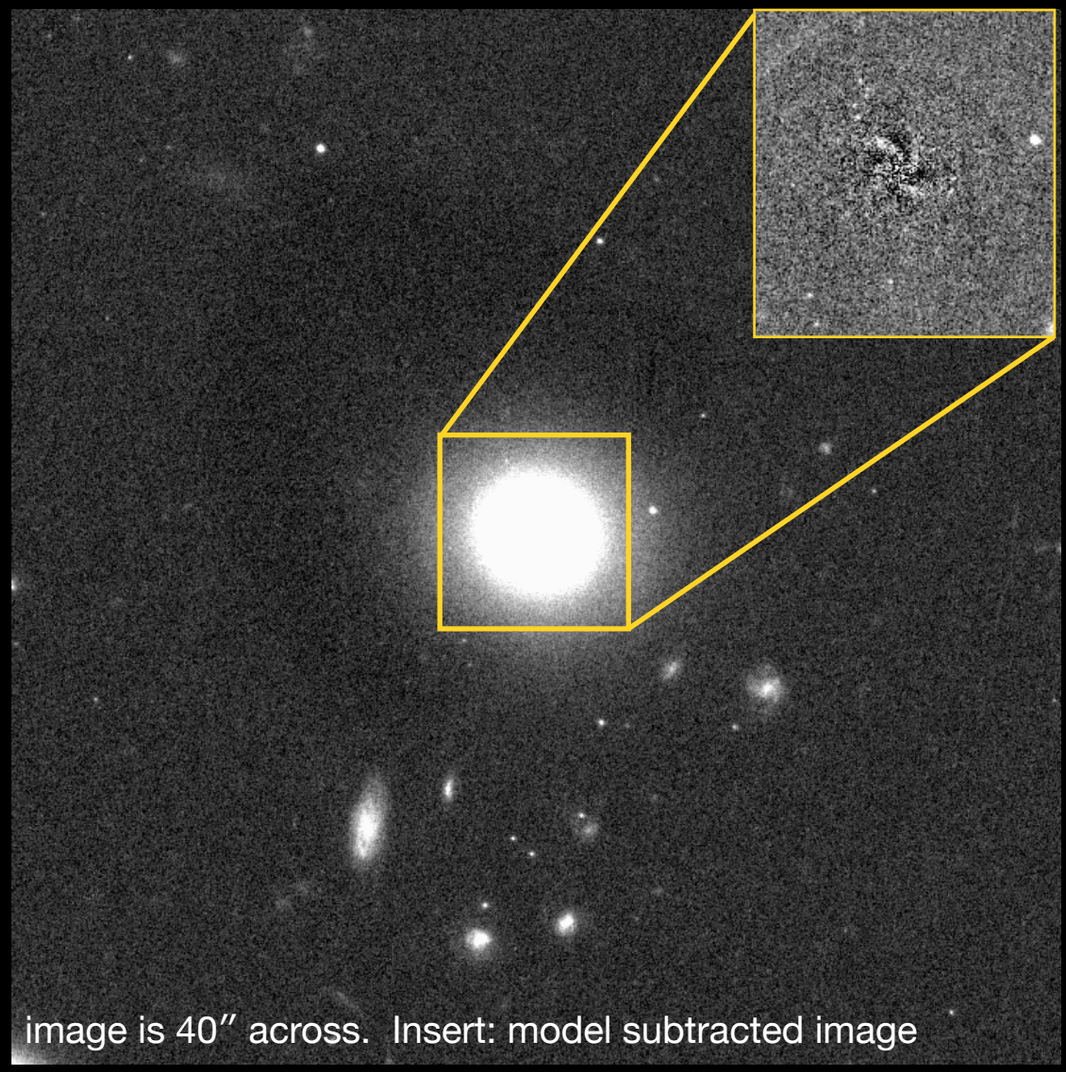
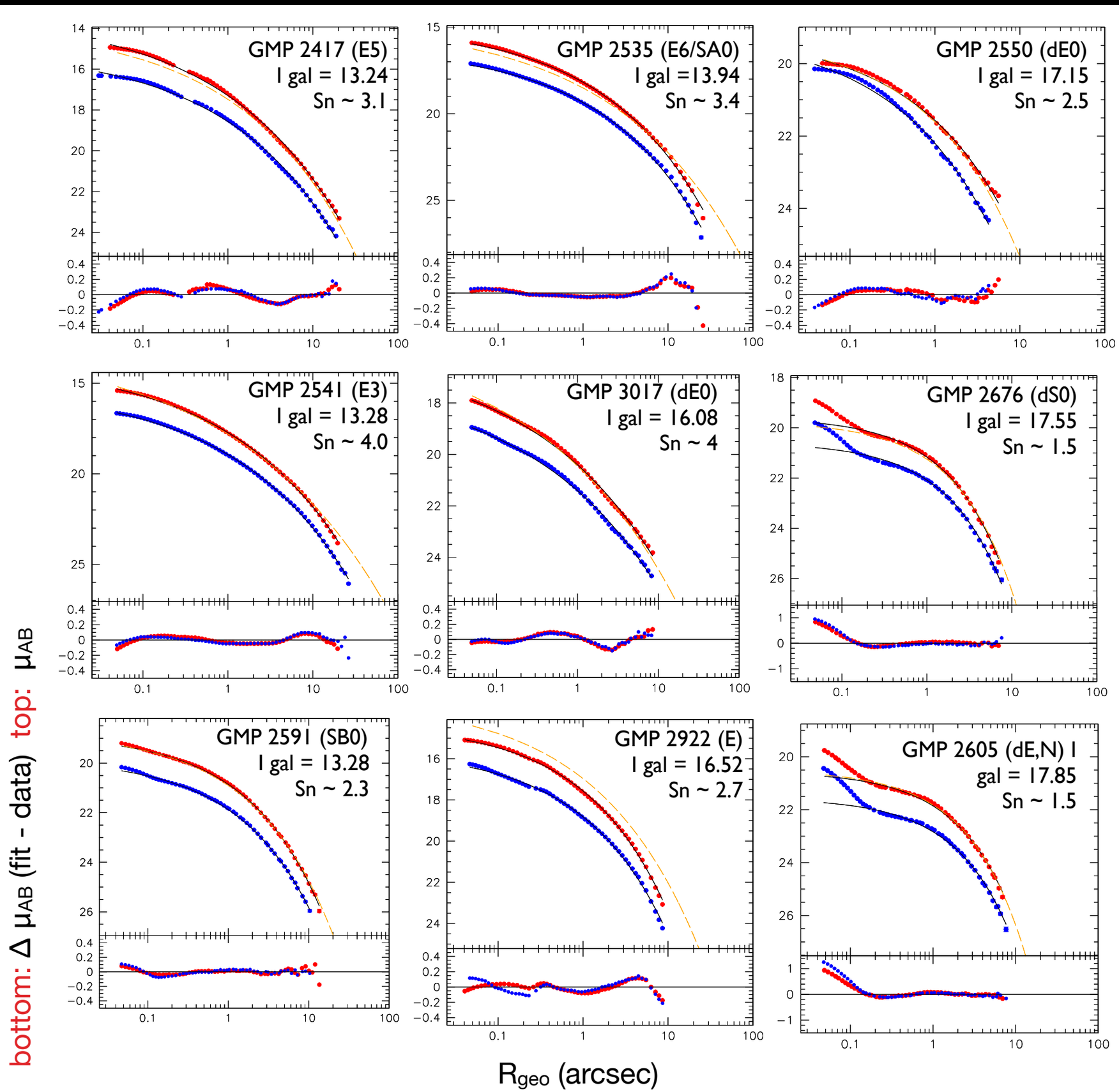


image is 40″ across. Insert: model subtracted image

Many more fits like this:
faint but otherwise normal Es + non-core dEs + dwarfs with disks & bars

... more details in Marinova et al. (2011, in prep)

Evaluation of the Structural Parameters Catalogue:



N=202 galaxies

Roughly 36%
'best-fit' by a

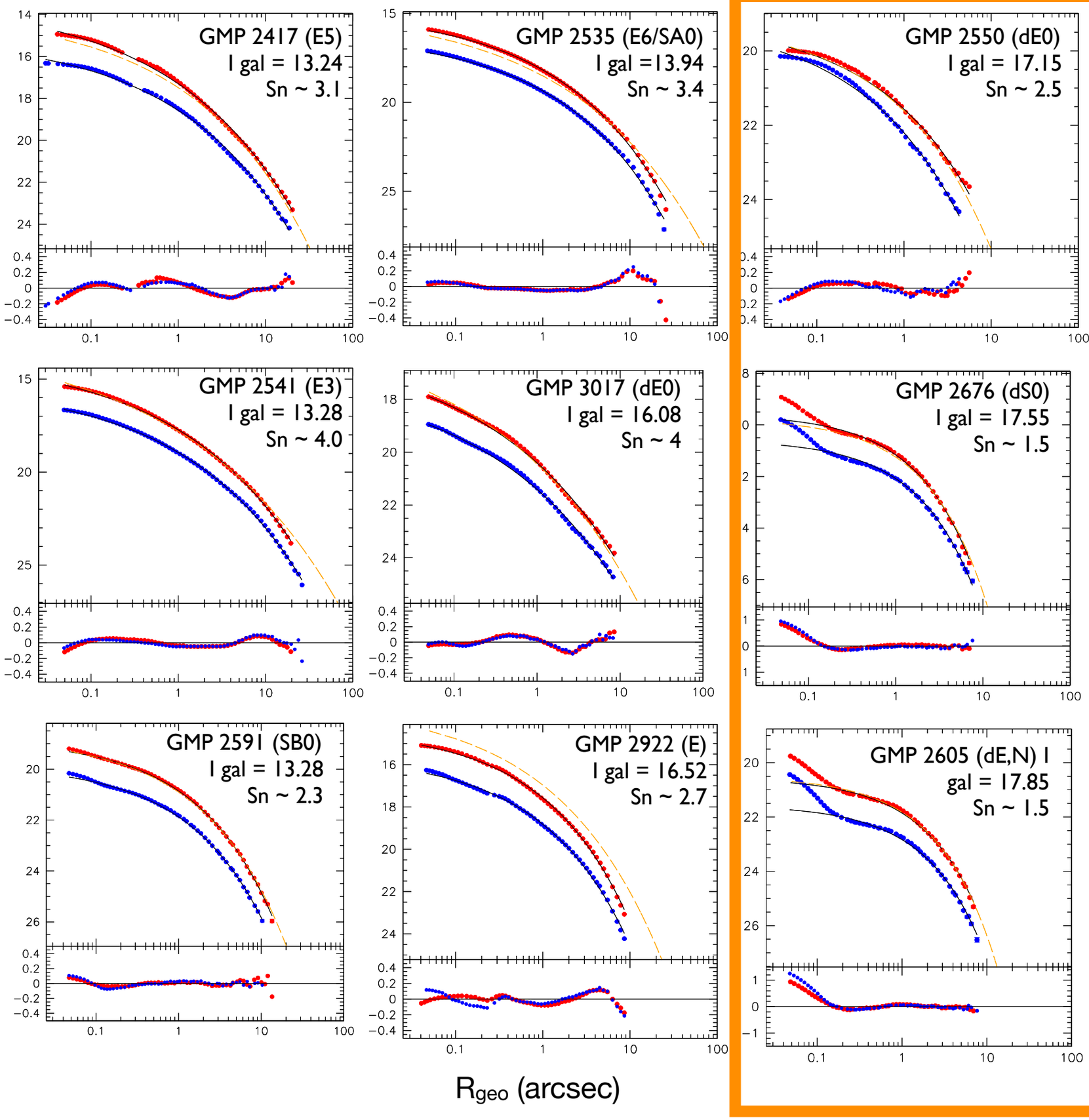
single-Sersic
OR
single-Sersic + *core*
+ *sersic*

Es + S0s + dEs
some with weak bars or disks

remainder require
2-component fits
(or more..)

nuclear star cluster
core
halo

Evaluation of the Structural Parameters Catalogue:



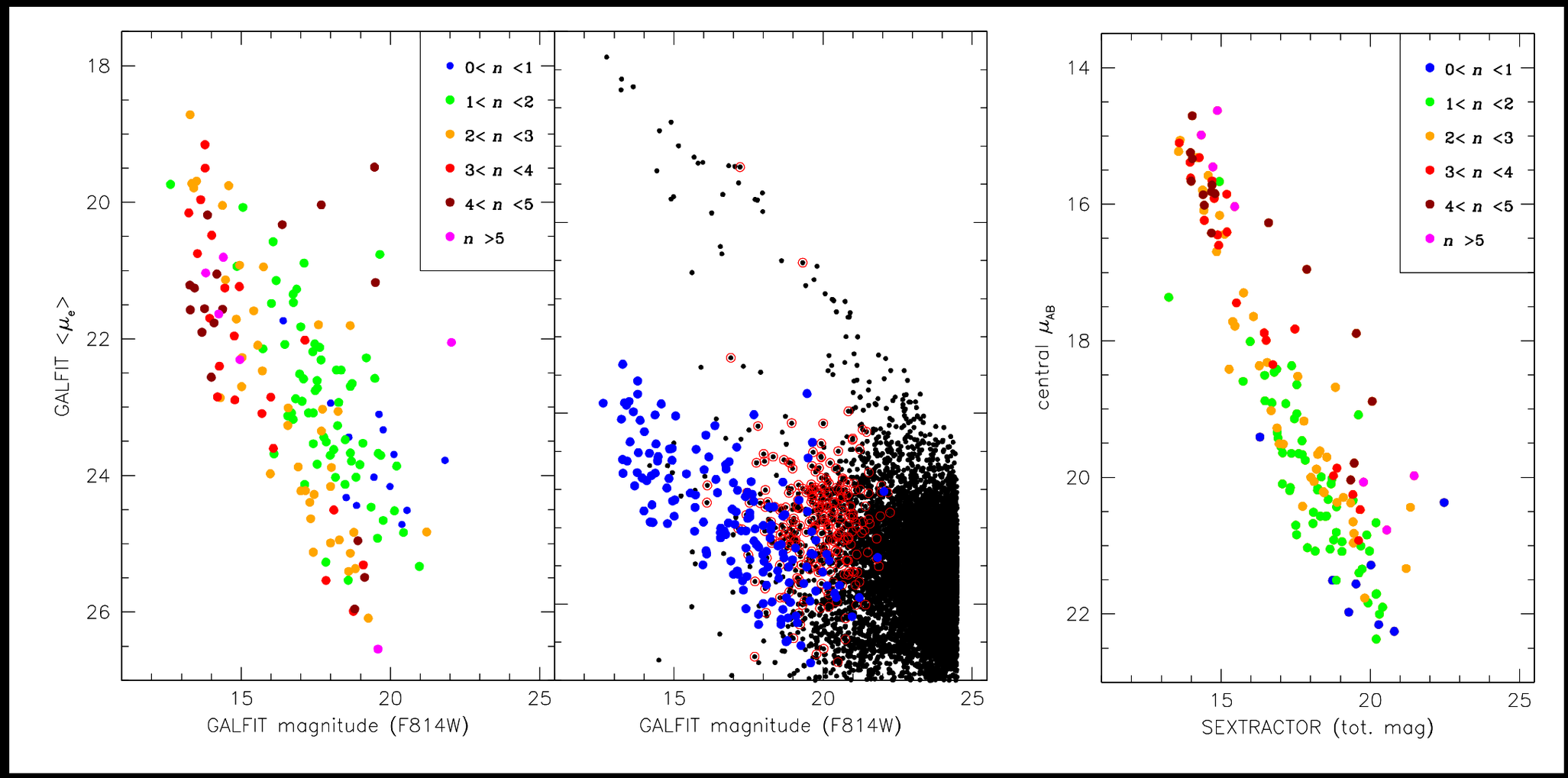
See Mark den Brok's talk on

THURSDAY

Colour gradients -- comments on structure -- of giant and dwarf early type galaxies in the Coma cluster

Evaluation of the Structural Parameters Catalogue:

The HST/ACS Coma Cluster Treasury Survey III: Catalogue of Structural Parameters from Single-Sersic fits (Hoyos et al. 2011)

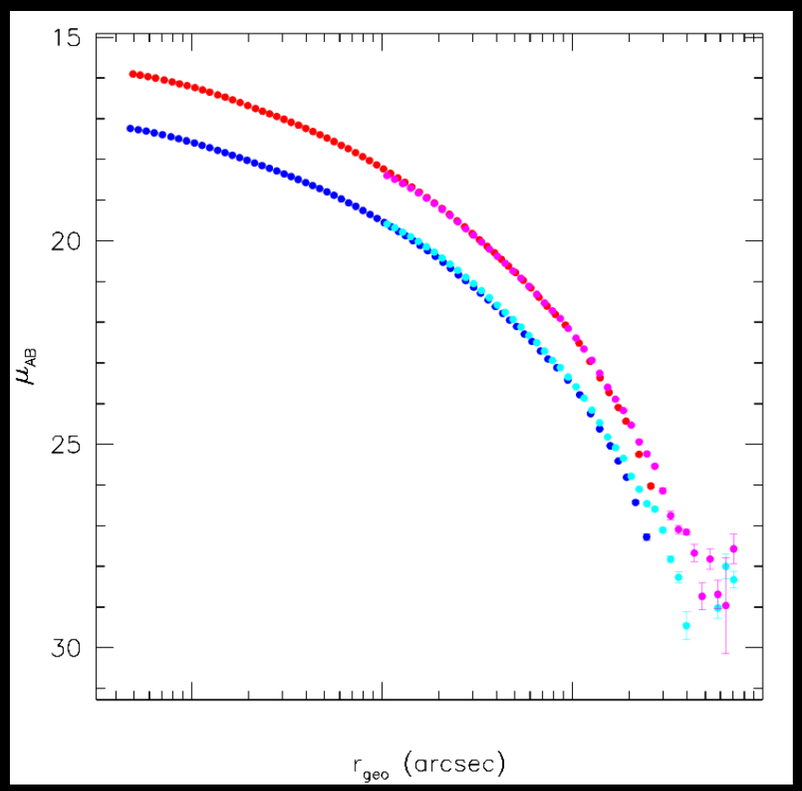


Caveat & Further work:

Dealing with the 'sky' is not trivial!

Intracluster light and galaxy halos are problematic...

SDSS - DR8
Improved sky subtraction
Model Intracluster light



Match SDSS g & i band fits to ACS data (John Lucey)

The Structure of Coma cluster galaxies:

Although we still have a lot of details to sort out... *plenty of good science to follow*

- ☑ Core of the cluster contains a wide variety of Hubble types

- ☑ Of the thirty-five S0s: ~60 % have bars - similar results to Virgo.
  Of the hundred dwarf galaxies: 9% have weak spiral structure and/or weak bars
  == upper limit prediction for Virgo dEs ~20% (de Rijcke et al. 2003)

- ☑ Evaluation of the semi-automatic GALFIT analysis:
  Single-Sersic profiles fit well for many bright early-type galaxies and are consistent with the 1-D surface brightness profiles (despite fixed PA and ellipticity).
  Many more galaxies are well fit: ~36% galaxy sample

- ☑ NEXT: Focus on the bright-early type galaxies: *improved fitting* + *sky estimates (ICL)*
  == dE-E-S0 relations, formation of Es and S0s in dense environments...

- ☑ BUT!.... (there is always a but...)
  Galaxies are more complex than they first appear.
  We must take care when fitting profiles == not to over interpret the fits

- ☑ Implications for high redshift studies...
  Caution: correlations of Sersic Index with galaxy morphology and effective radius at high-z

THANKS...

“There is a theory which states that if ever for any reason anyone discovers what exactly the Universe is for and why it is here it will instantly disappear and be replaced by something even more bizarre and inexplicable.”

Douglas Adams (1952 - 2001)

The internal structure of galaxies plays a pivotal role in guiding our understanding of how galaxies form and evolve...

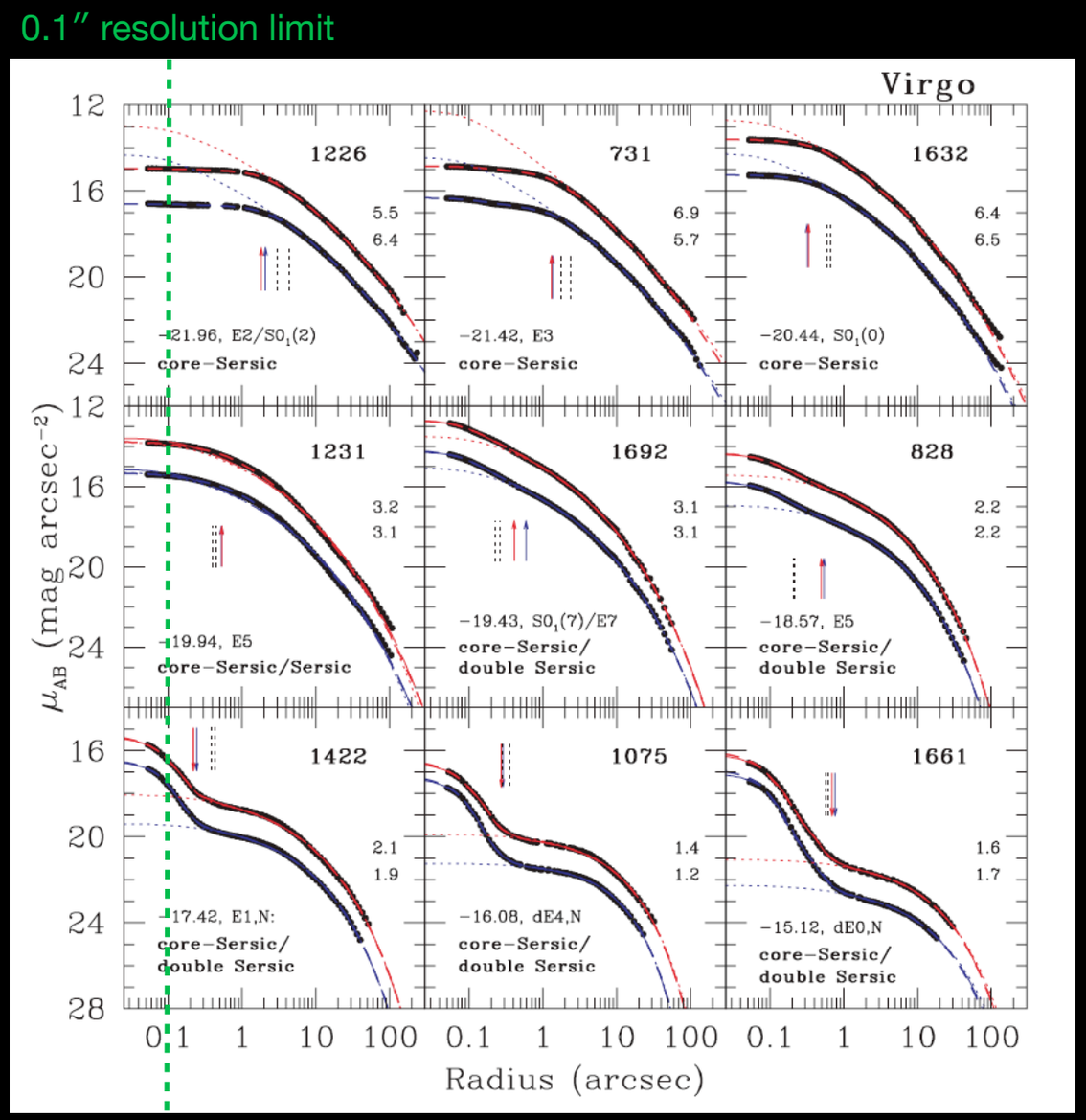


Fig 1: from Cote et al. (2007)

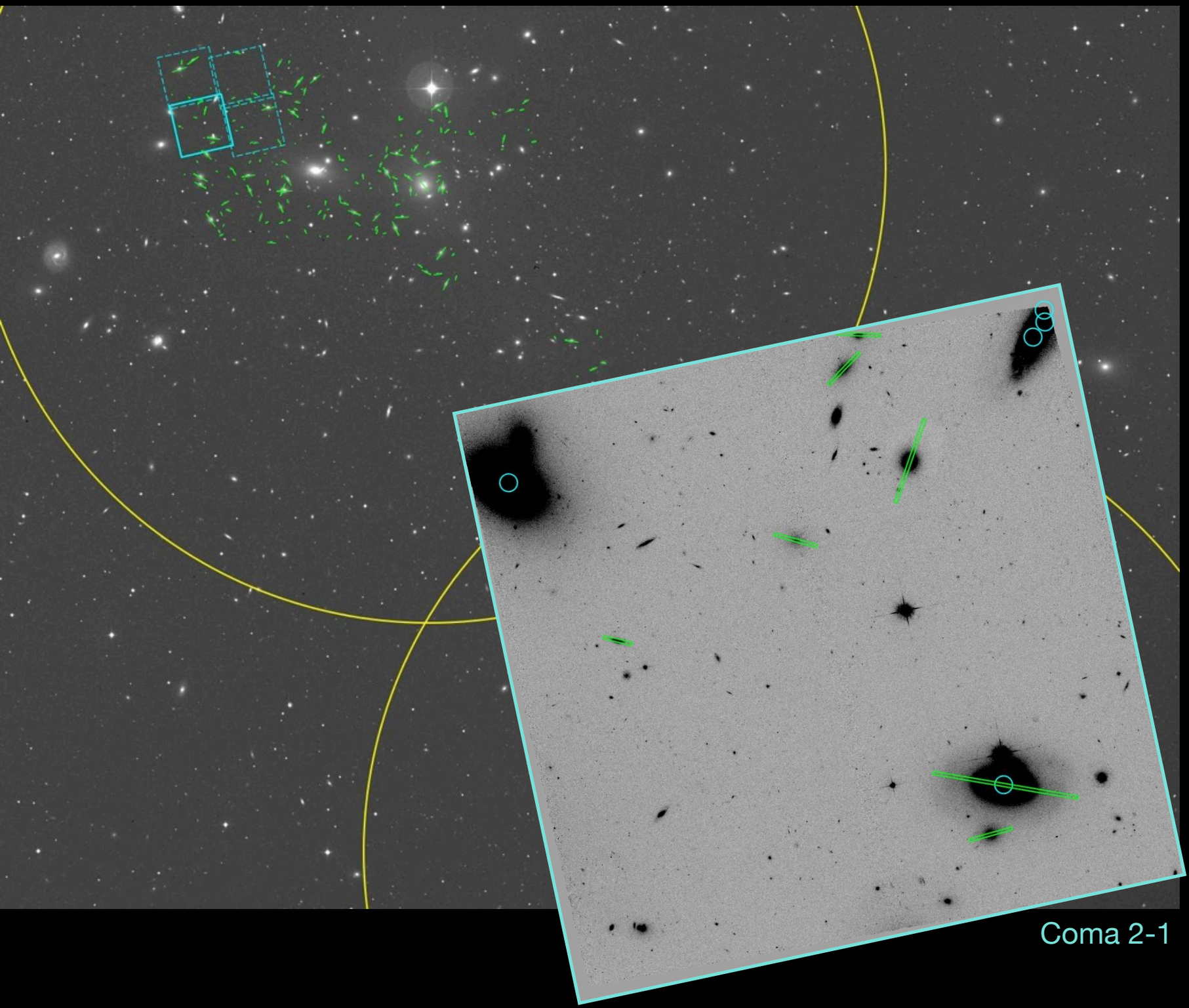
HST/ACS Virgo & Fornax Surveys: Central brightness profiles of early-type galaxies.

"Pioneering HST studies of the centers of early type galaxies suggested and apparently abrupt transition in central stellar density – the so called "core/power law dichotomy" (Ferrarese et al. 1994, Lauer et al. 1995)...

...these findings prompted the widely held view that the bright (core) and faint (power law) galaxies follow distinct evolutionary routes (Faber et al. 1997)"

NOTE: For HST/ACS Virgo observations, the images are a factor 6 higher resolution than in Coma. The survey is better matched to the CFHT Next Generation Virgo Cluster Survey (NGVS) - Ferrarese PI

Observations and Sample Selection:



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GALAXY SAMPLE

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Includes ‘failed’ galaxies from automated 2-D GALFIT fitting

The superior resolution of HST allows us to see things in Coma that we have never seen before...

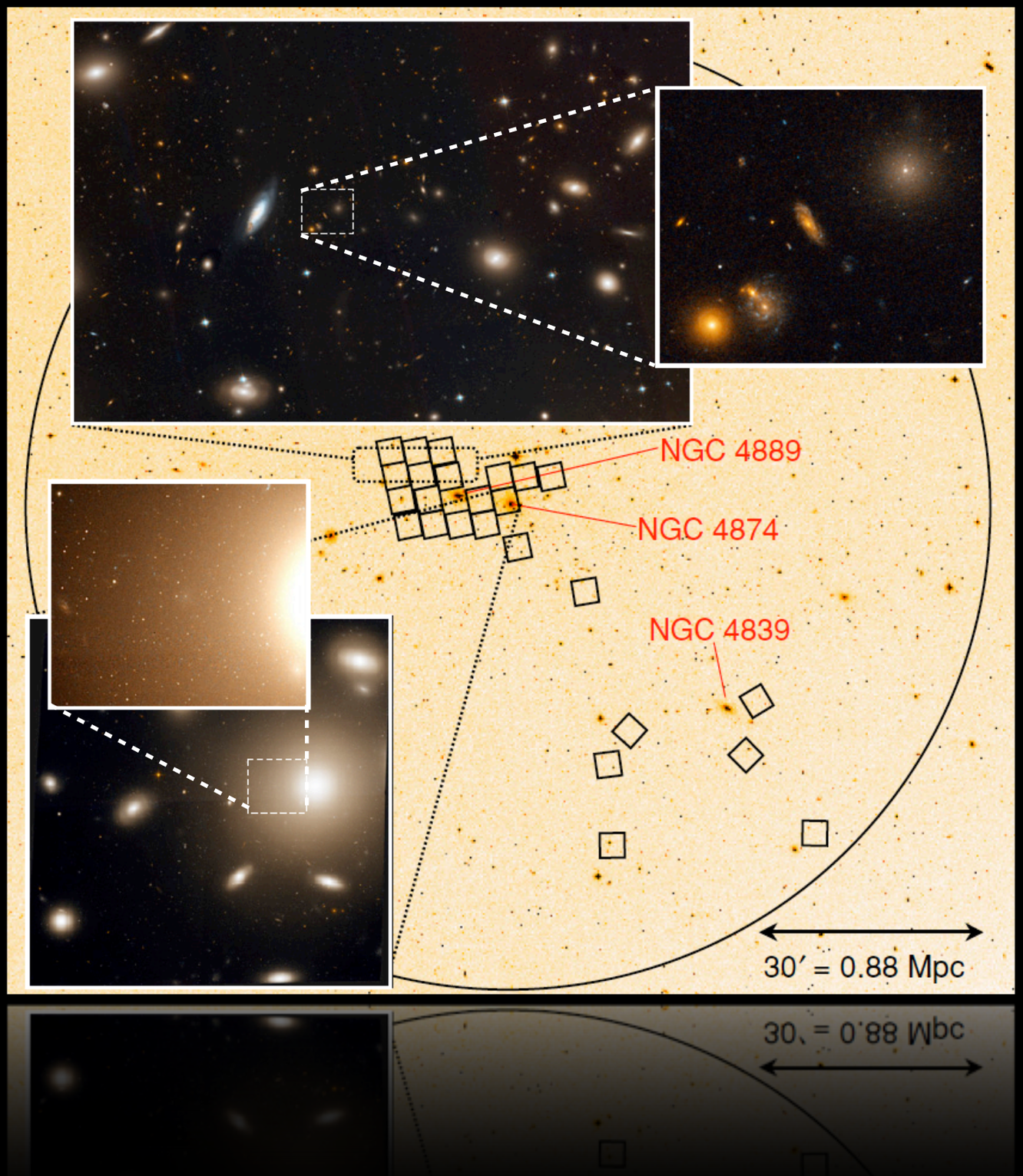


Fig. 1 from Hammer et al. (2009):
Data Description and Source Catalogs

DSS wide-field image of the Coma cluster showing the location of 25 fields observed as part of the HST-ACS Coma Cluster Treasury survey

The large circle extends 1.9 Mpc from the center of the Coma cluster, or two-thirds the cluster virial radius.

Motivation - 1

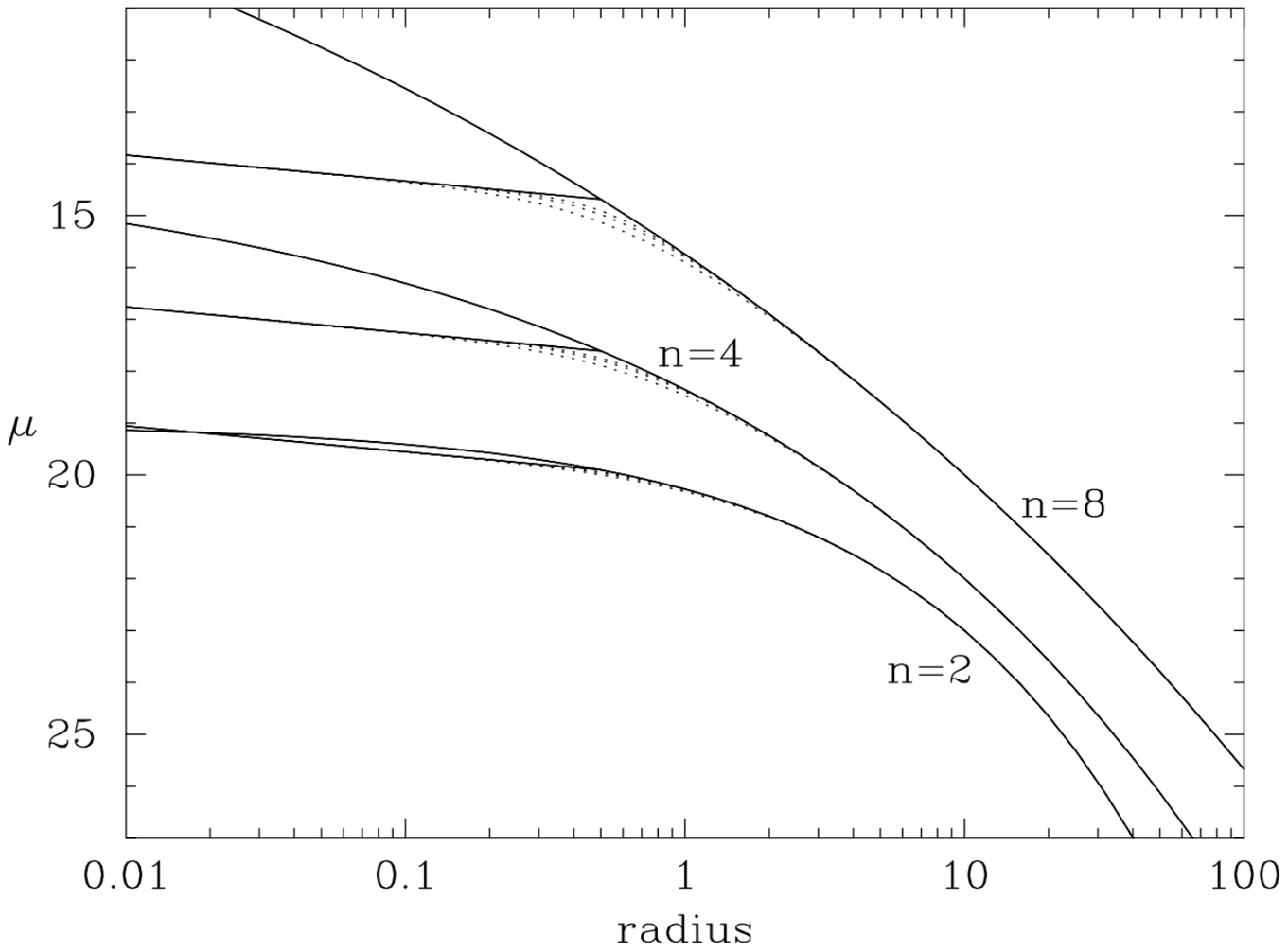
A subregion of this image is shown in the small inset, which includes a nucleated dwarf early-type galaxy that is a member of the Coma cluster (upper-right corner).

0.05″/pixel = 24 pc /pixel

Motivation - 2

The large inset at bottom left shows the entire visit-19 field at the center of the Coma cluster, including the central cD galaxy NGC 4874; a subregion of this image shows the large number of unresolved GCs observed in the galaxy halo.

The internal structure of galaxies plays a pivotal role in guiding our understanding of how galaxies form and evolve...



$$I(r) = I_b 2^{(\beta-\gamma)/\alpha} \left(\frac{r}{r_b}\right)^{-\gamma} \left[1 + \left(\frac{r}{r_b}\right)^{\alpha}\right]^{(\gamma-\beta)/\alpha}$$

$$I_{\rm S}(R) = I_e \exp\left\{-b_n\left[\left(\frac{R}{R_e}\right)^{1/n} - 1\right]\right\}$$

$$I_{\rm cS}(R) = I'\left[1 + \left(\frac{R_b}{R}\right)^{\alpha}\right]^{\gamma/\alpha} \exp\left[-b_n\left(\frac{R^{\alpha} + R_b^{\alpha}}{R_e^{\alpha}}\right)^{1/(\alpha n)}\right]$$

Nuker, Sersic (1969), Graham et al. (2003+)

Also King models for purely stellar systems.