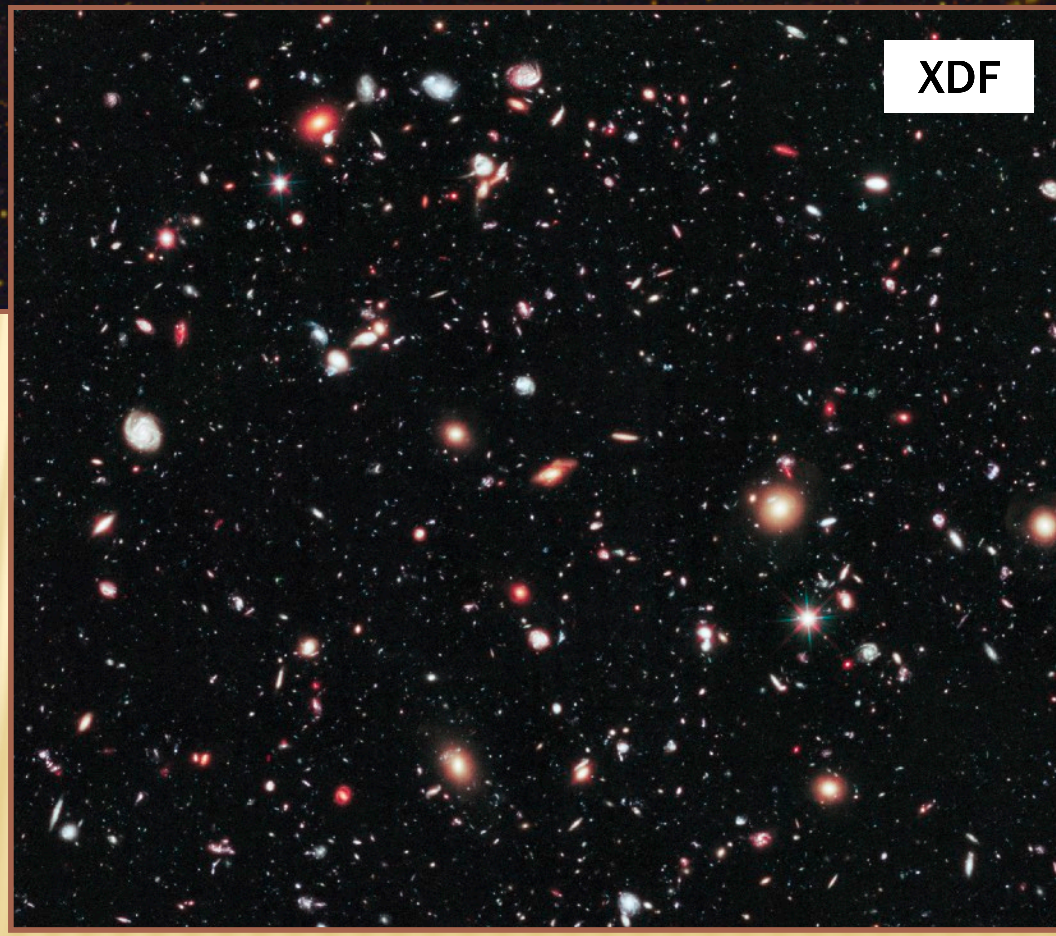
CHEF bases for astronomical data analysis

Yolanda Jiménez Teja
Observatório Nacional, Rio de Janeiro
Coordenação de Astronomia e Astrofisica
E-mail: yojite@iaa.es, yolanda@on.br

The era of big data

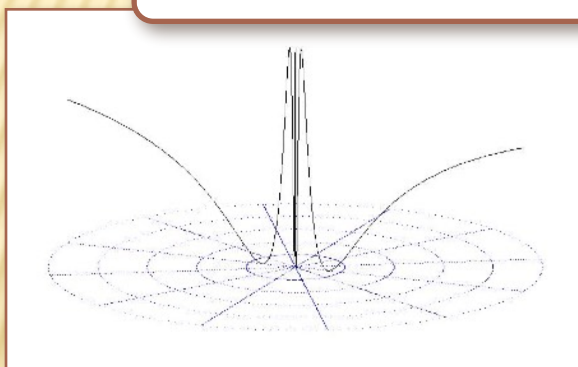


- J-PAS expectations: measuring 100M galaxies and a few million quasars with dz/(1+z) ~ 0.003 and 300M galaxies with dz/(1+z) ~ 0.01

The CHEF polar basis is **separable** in *r* and *θ*
(Jiménez-Teja & Benítez, 2012)

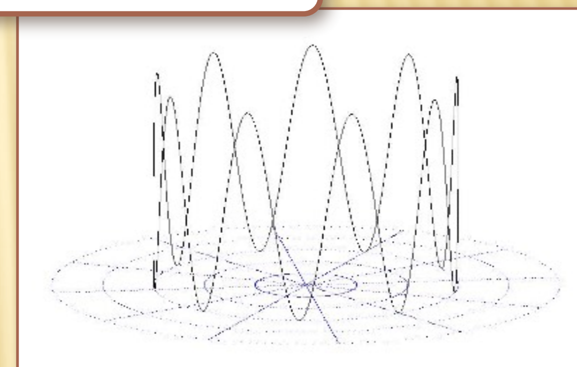
Chebyshev rational functions in *r*

$$TL_n(r;L) = T_n\left(\frac{r-L}{r+L}\right)$$



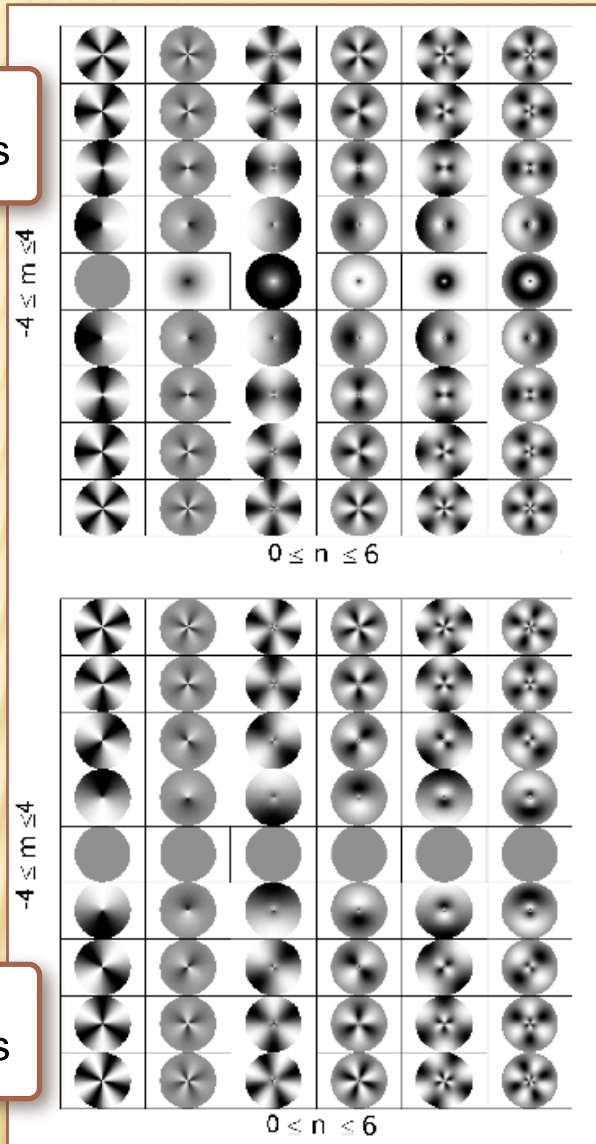
Fourier series in *θ*

$$e^{im\theta}$$

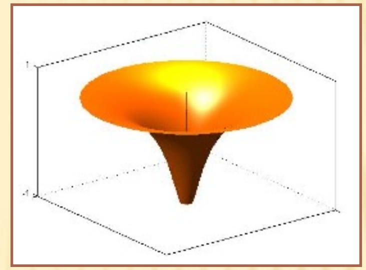


$$\left\{\phi_{nm}(r,\theta;L)\right\}_{nm} = \left\{\frac{1}{C\pi} TL_n(r;L)\, e^{im\theta}\right\}_{nm},$$ with $$C = \begin{cases} \sqrt{2}, & \text{if } n = 0 \\ 1, & \text{cc.} \end{cases}$$

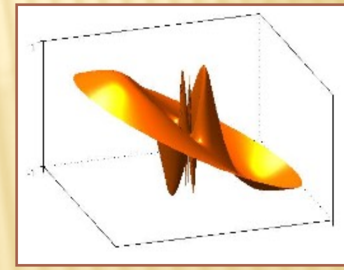
Real components



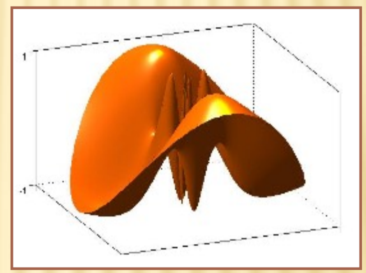
Imaginary components



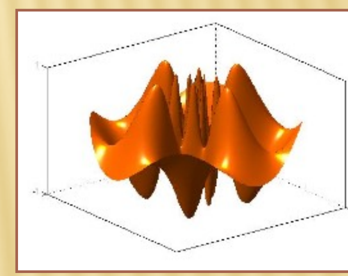
$n = 2, \; m = 0$



$n = 6, \; m = 1$

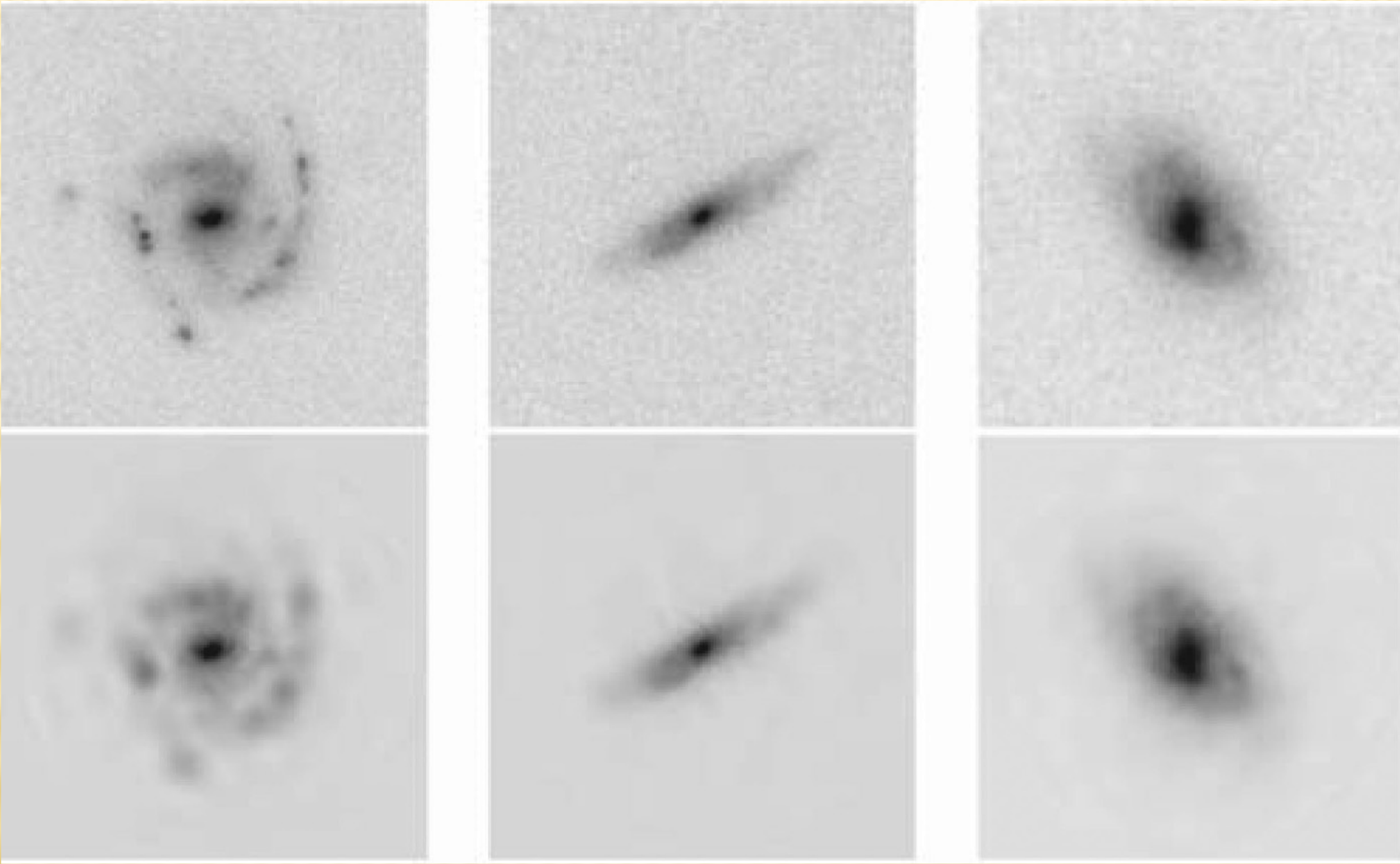


$n = 6, \; m = 2$



$n = 10, \; m = 4$

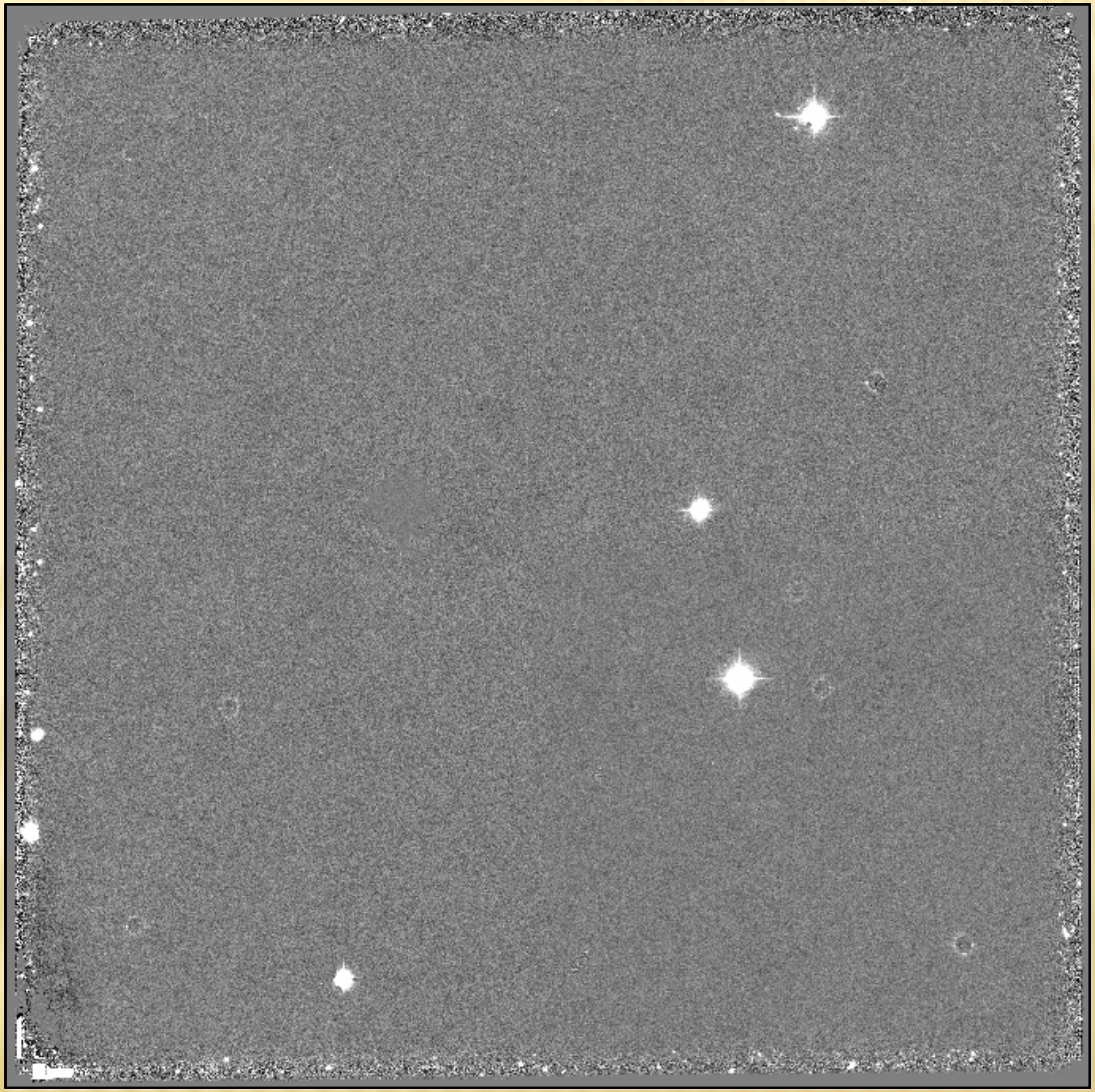
Jiménez-Teja & Benítez, 2012

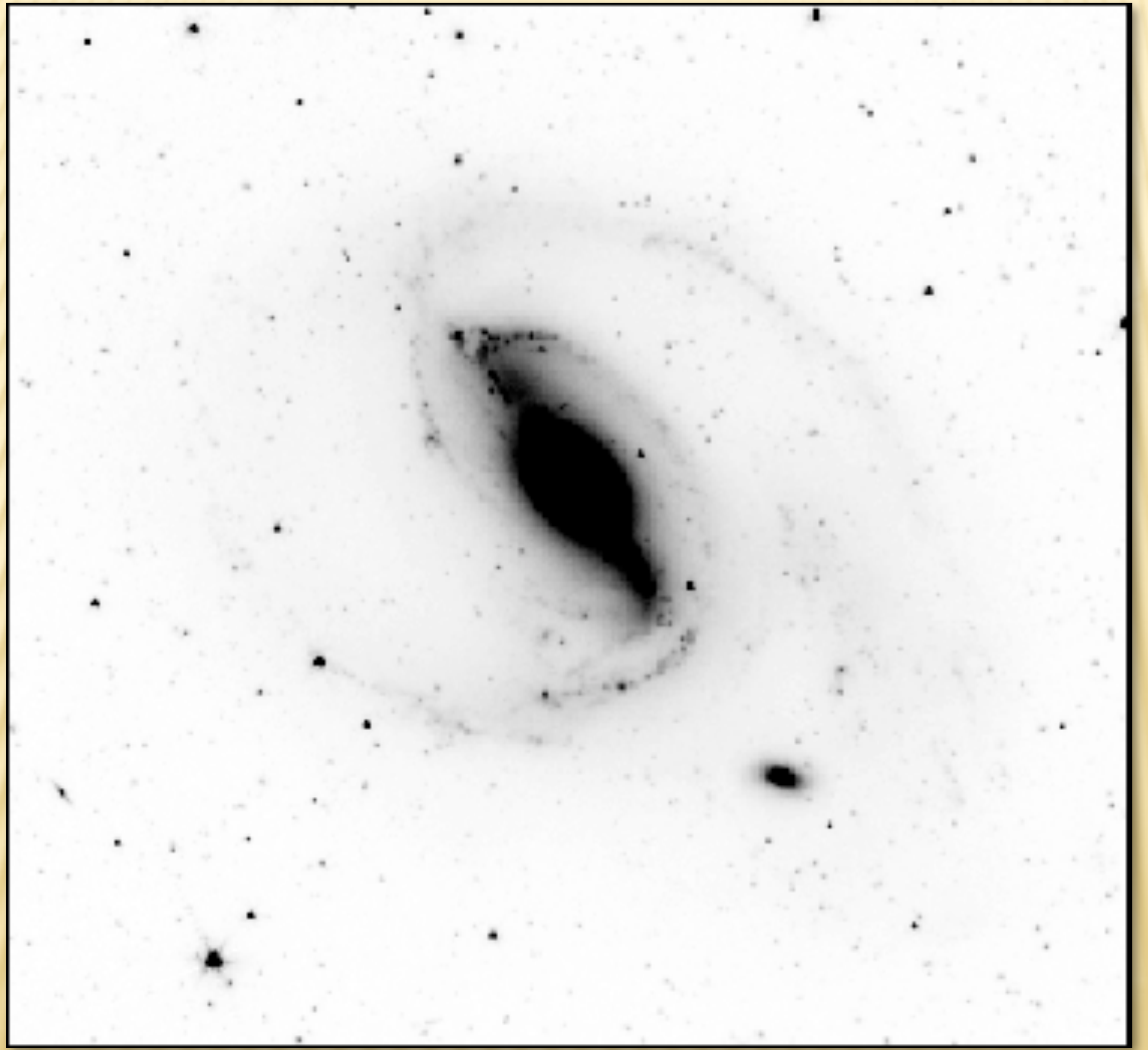


ALHAMBRA field #5: Original F814W

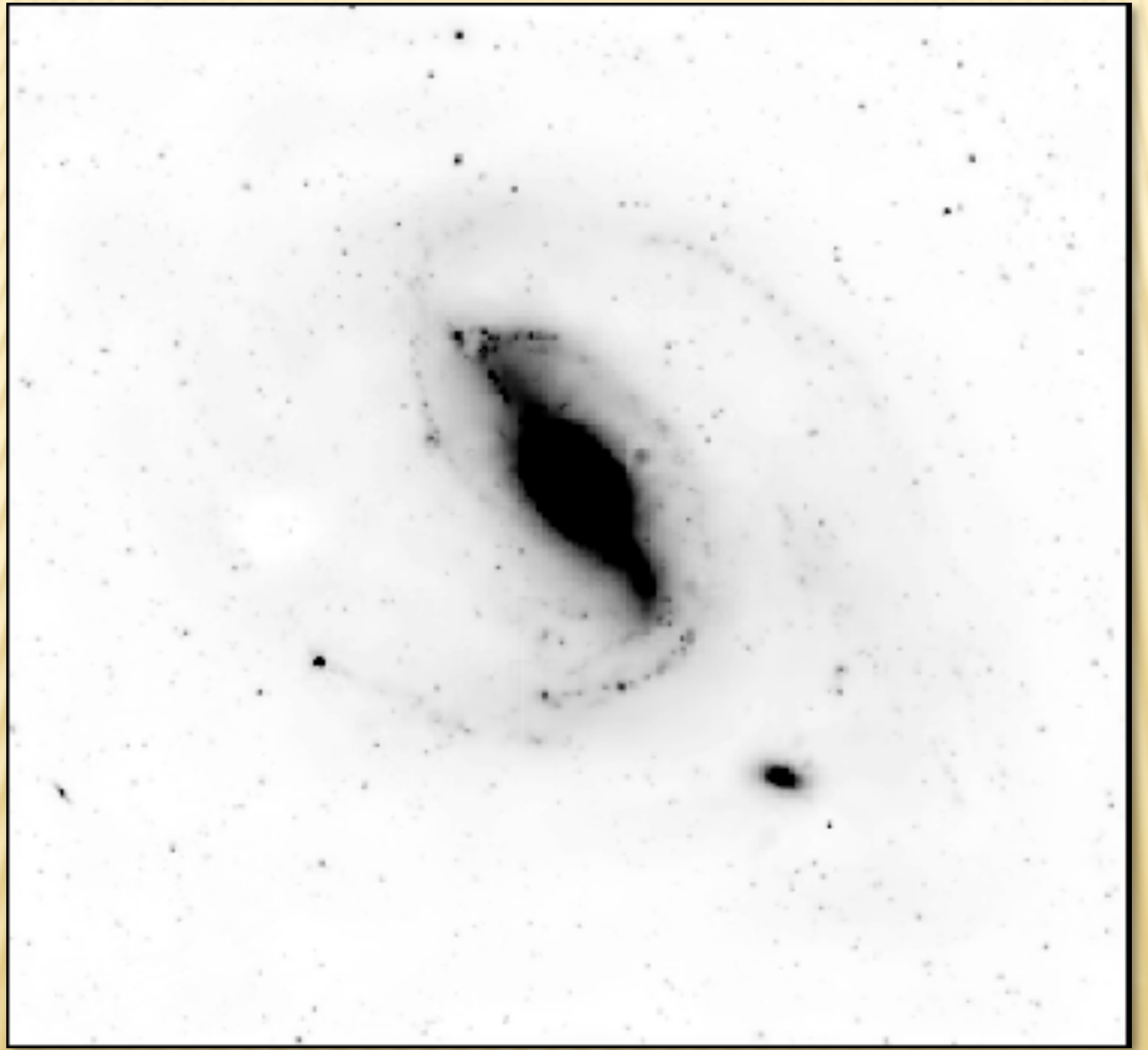
ALHAMBRA field #5: CHEF model

ALHAMBRA field #5: Residual

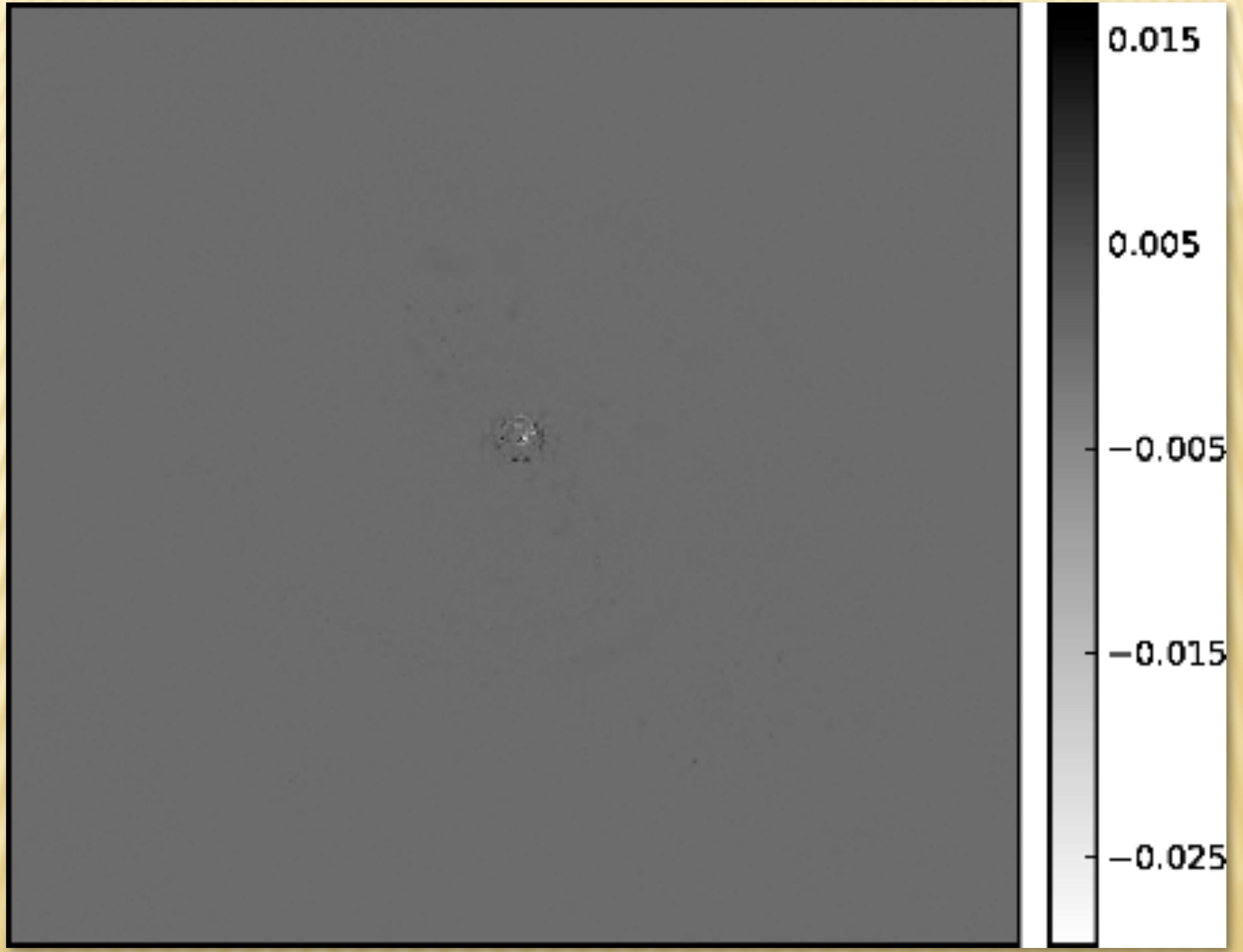




NGC 1097



CHEF model


0.015
0.005
−0.005
−0.015
−0.025

Measuring photometry and morphology using the CHEF coefficients
(Jiménez Teja & Benítez, 2012)

$$I_p^n = \begin{cases} 2\sum_{j=0}^{n}\binom{n}{j}(-1)^j L^{-j/2}\dfrac{R^{p+j/2+1}}{2p+j+2}\mathrm{Re}\left[e^{in\pi/2} i^{n+j}\,{}_2F_1\left(n, 2p+j+2, 2p+j+3; \dfrac{-i\sqrt{R}}{\sqrt{L}}\right)\right], & \text{if } n>0 \\ \dfrac{R^{p+1}}{p+1}, & \text{if } n=0 \end{cases}$$

Flux: $F = 2\pi \sum_{n=0}^{+\infty} f_{n,0} I_1^n$

Rms radius: $R^2 = \dfrac{2\pi}{F}\sum_{n=0}^{+\infty} f_{n,0} I_3^n$

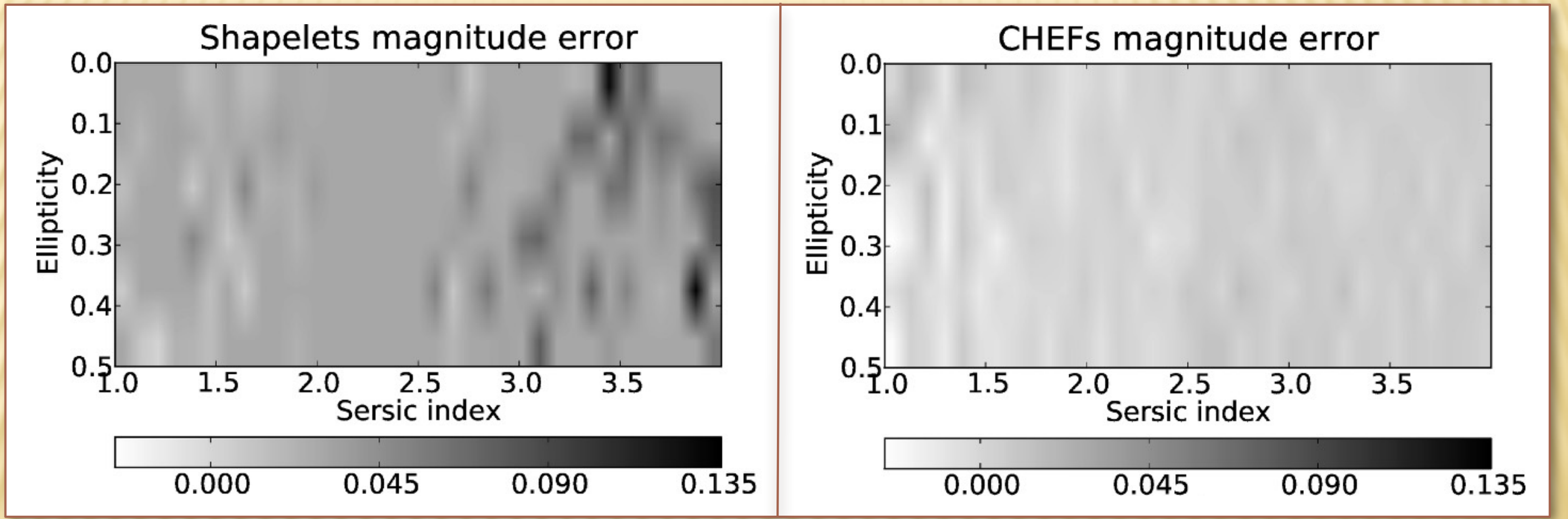
Centroid: $x_c + i\,y_c = \dfrac{2\pi}{F}\sum_{n=0}^{+\infty} f_{n,1} I_2^n$

Ellipticity: $e = \dfrac{\sum_{n=0}^{+\infty} f_{n,-2} I_3^n}{\sum_{n=0}^{+\infty} f_{n,0} I_3^n}$

Shear estimator:

$$\varepsilon = \frac{\sum_{n=0}^{+\infty} f_{n,-2} I_n^3}{\sum_{n=0}^{+\infty} f_{n,0} I_n^3 + \dfrac{\sqrt{2}}{2}\left[\sum_{i,j=0}^{+\infty}\left(-f_{i,-2}f_{i,2} - f_{i,2}f_{j,-2} + \left(f_{i,-2}+f_{i,2}+f_{i,0}\right)f_{j,0} + \left(f_{j,-2}+f_{j,2}+f_{j,0}\right)f_{i,0}\right)I_3^i I_3^j\right]^{1/2}}$$

Sample of 350 mock galaxy images of 100x100 pixels, with Sérsic profiles whose index ranges from 0.5 to 4 and sheared with different levels of ellipticity. Gaussian noise added.

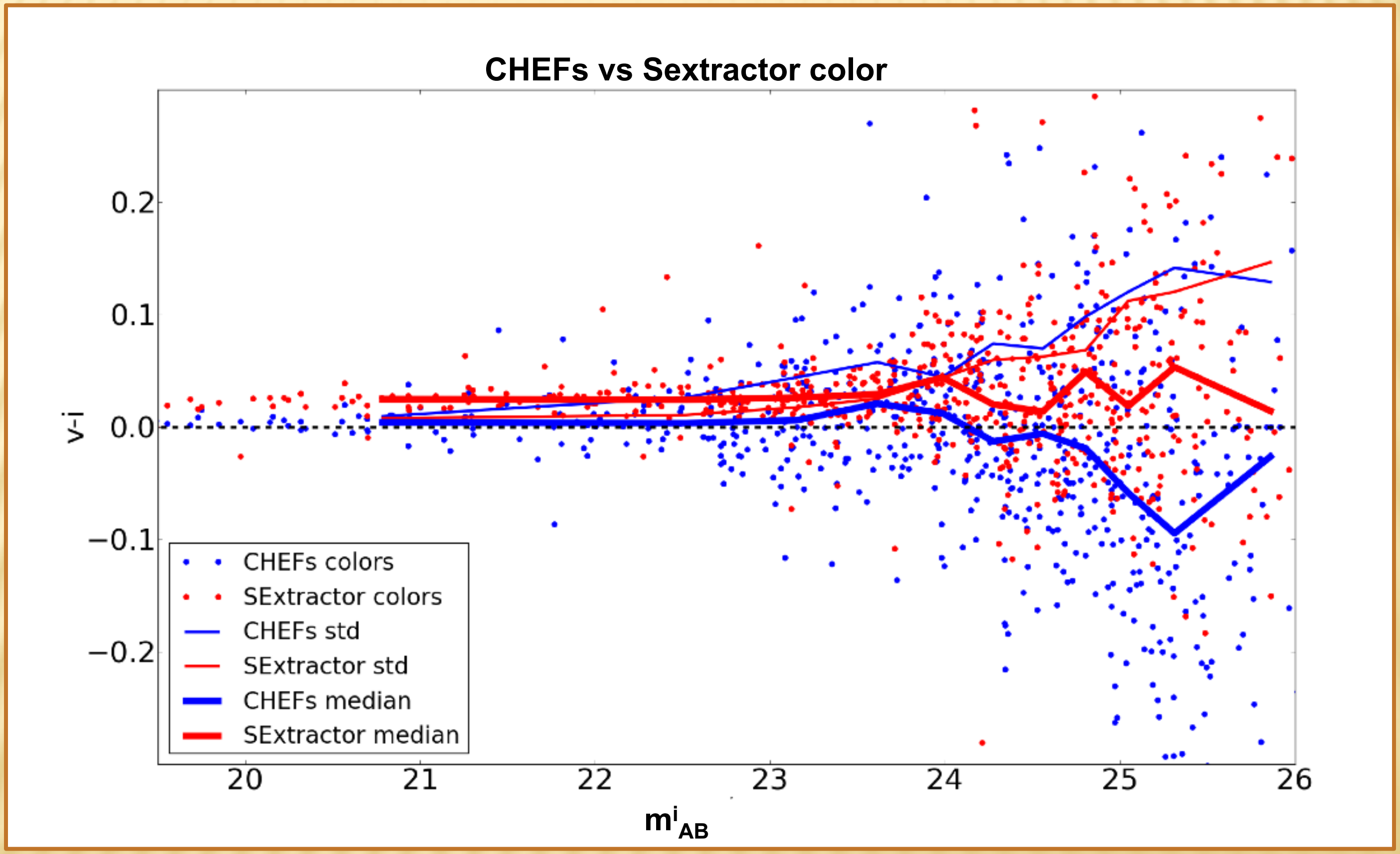


Maximum error of ≈ 13.5%

Maximum error of ≈ 1.6%

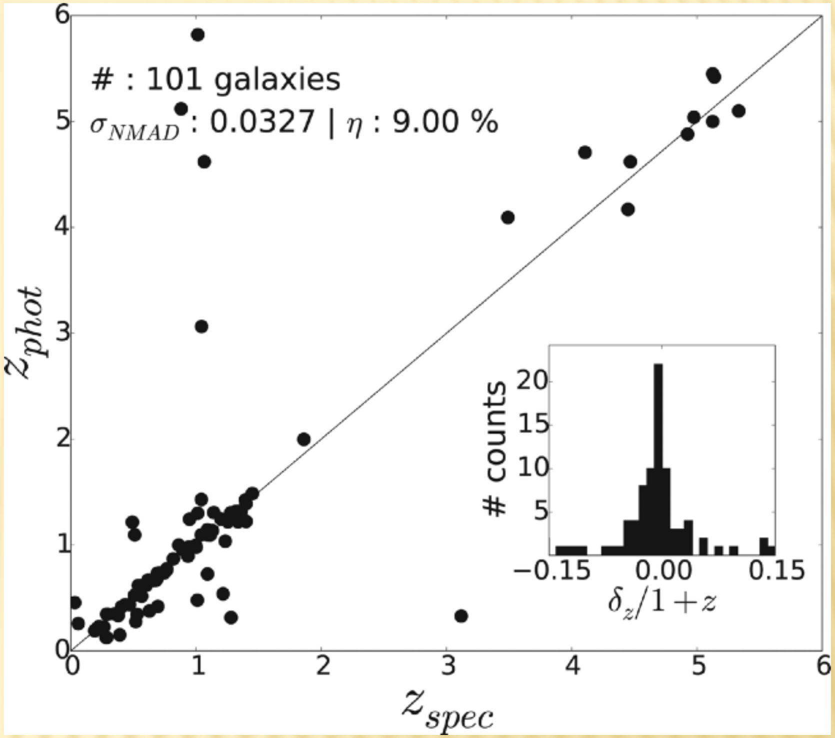
Jiménez-Teja & Benítez, 2012

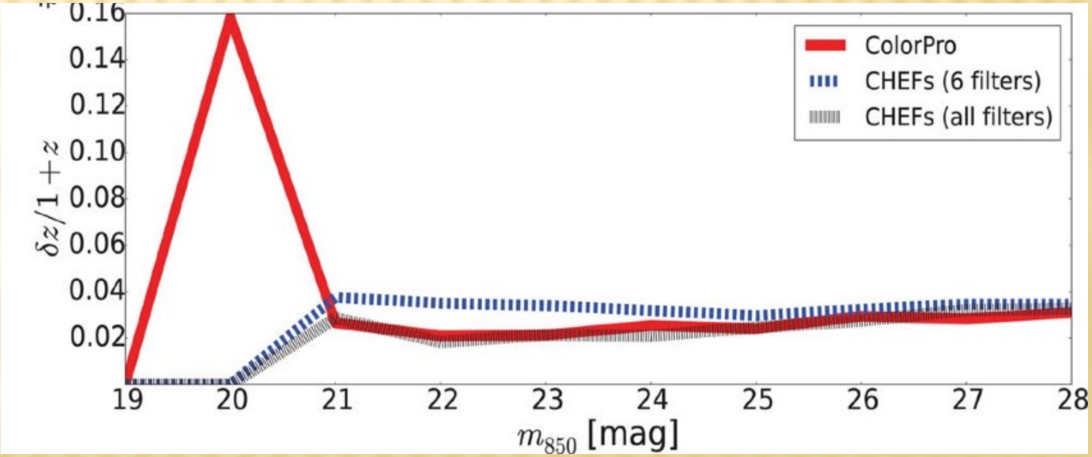
As the CHEFs provide us with total magnitudes, we could measure the colors in these images (which should be zero) **WITHOUT NEEDING THE PSF**. We compared the CHEF colors with the SExtractor ones, calculated by the usual method of degrading the images to the worst PSF and measuring in 3 arcsec apertures (Jiménez-Teja et al. 2015).



XDF catalogue
(Jiménez-Teja et al. 2015)

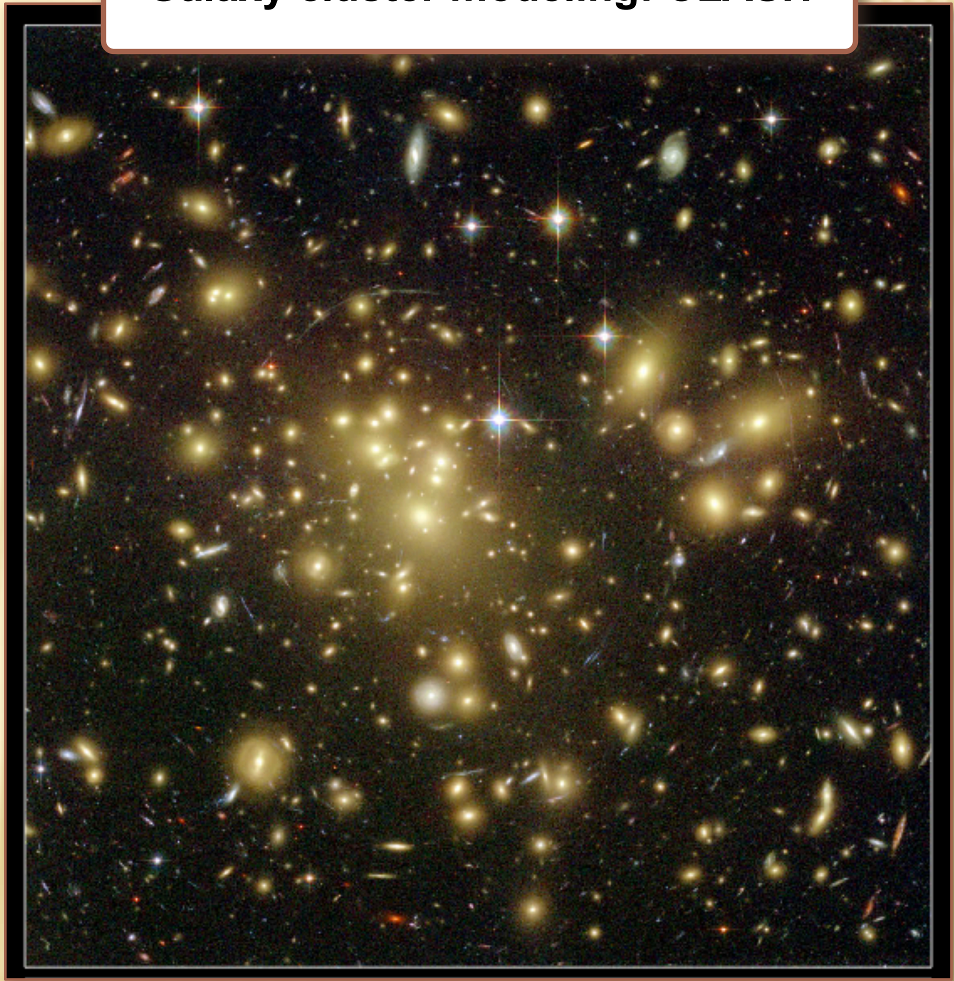
- 35732 sources (10823 with S/N>=5)
- Area: 10.8 arcmin2
- 4 near infrared and 5 optimal bands, observed with WFC3 and ACS cameras in HST, respectively.
- Exposure time: 27 days.
- Typical depth: 30 AB mag in most filters.
- Photometric redshift average error: 2%
- No need for **PSF homogenisation** or **degradation of the images.**





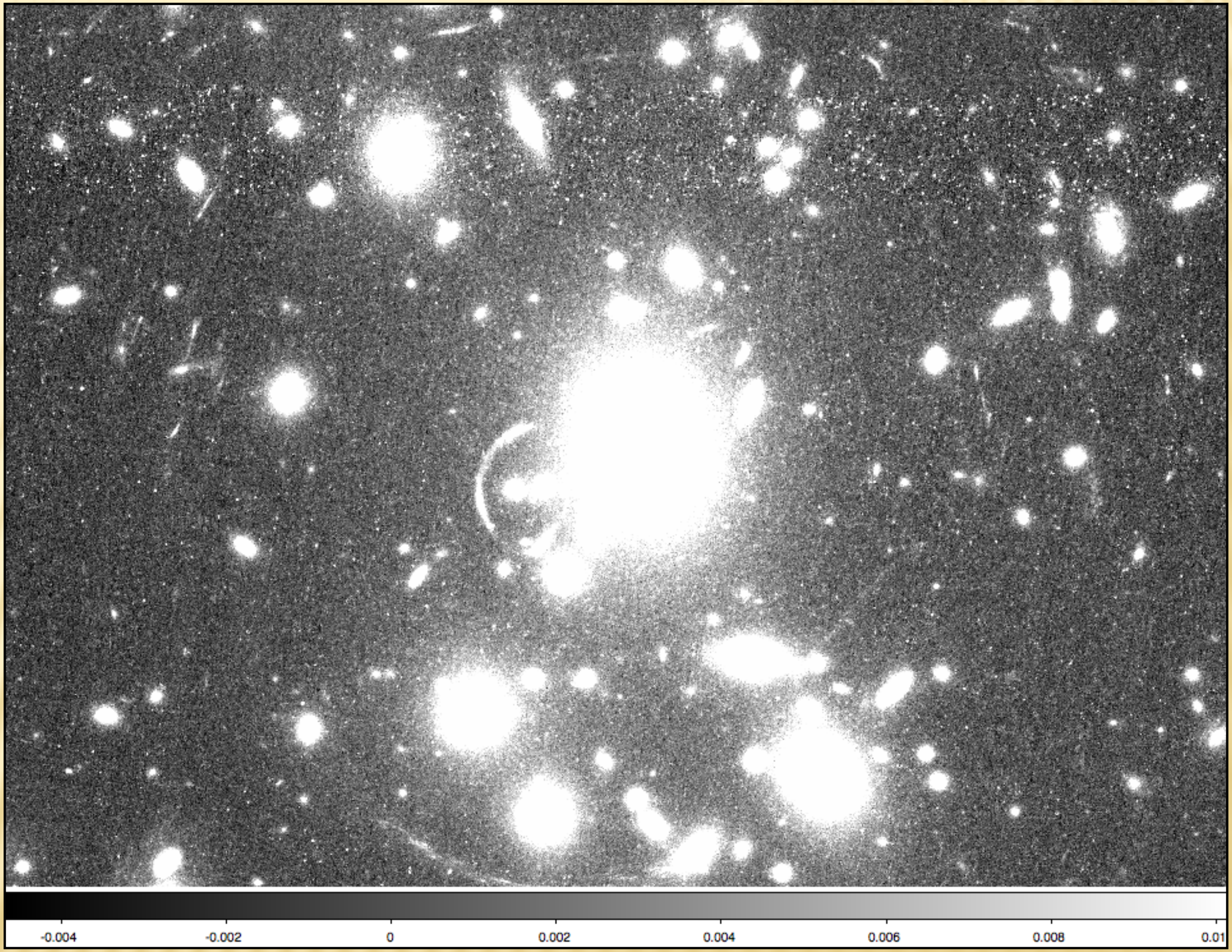
Galaxy cluster modeling: CLASH

• CLASH (Cluster Lensing And Supernova Survey with Hubble) was one of the 3 multicycle treasury projects in 2010 (just two in Extragalactic Astronomy). It was devoted to dark matter studies and it had 550 Hubble orbits to observe 23 different galaxy clusters.



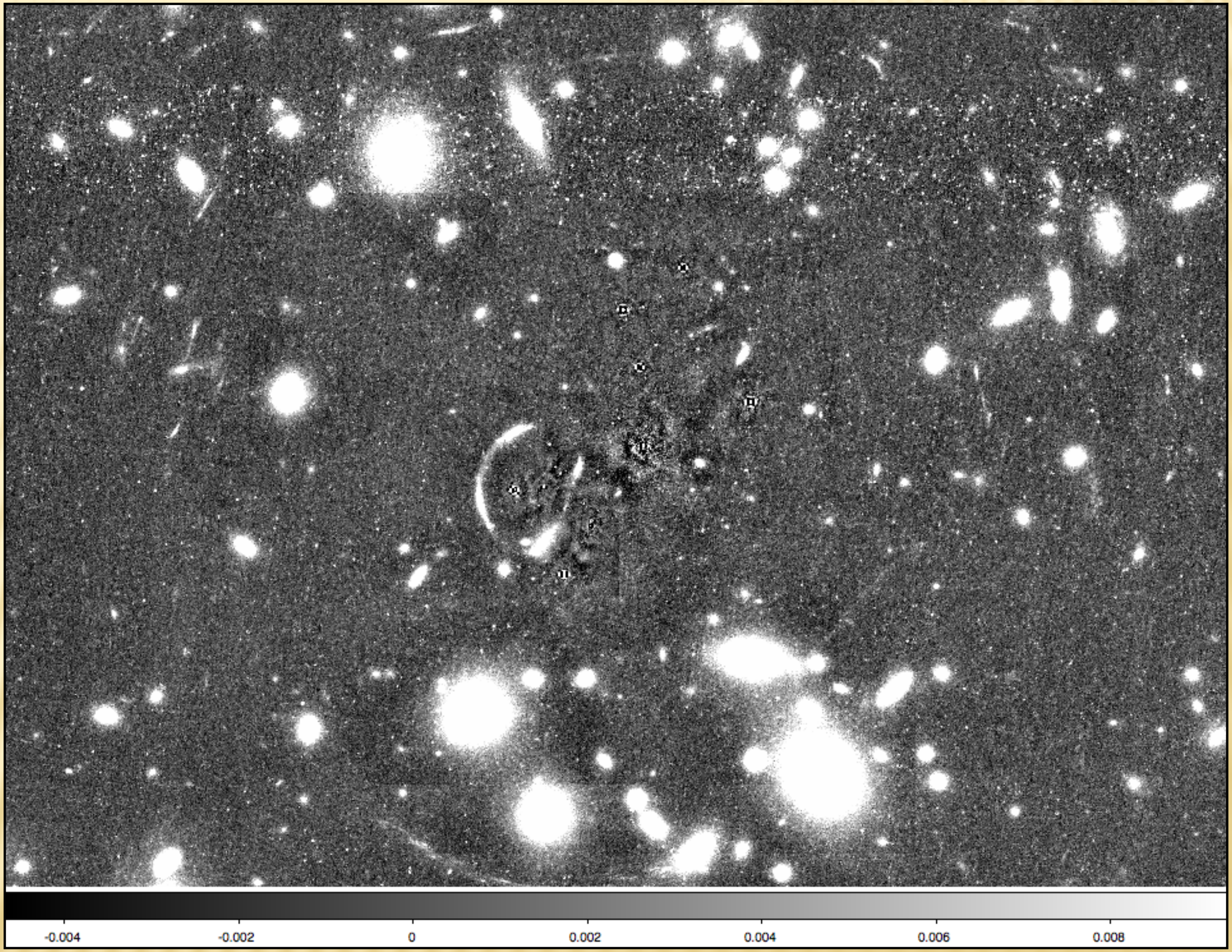
ABELL1703
(F850)

(Zitrin et al, 2010)



ABELL1703 (F850)

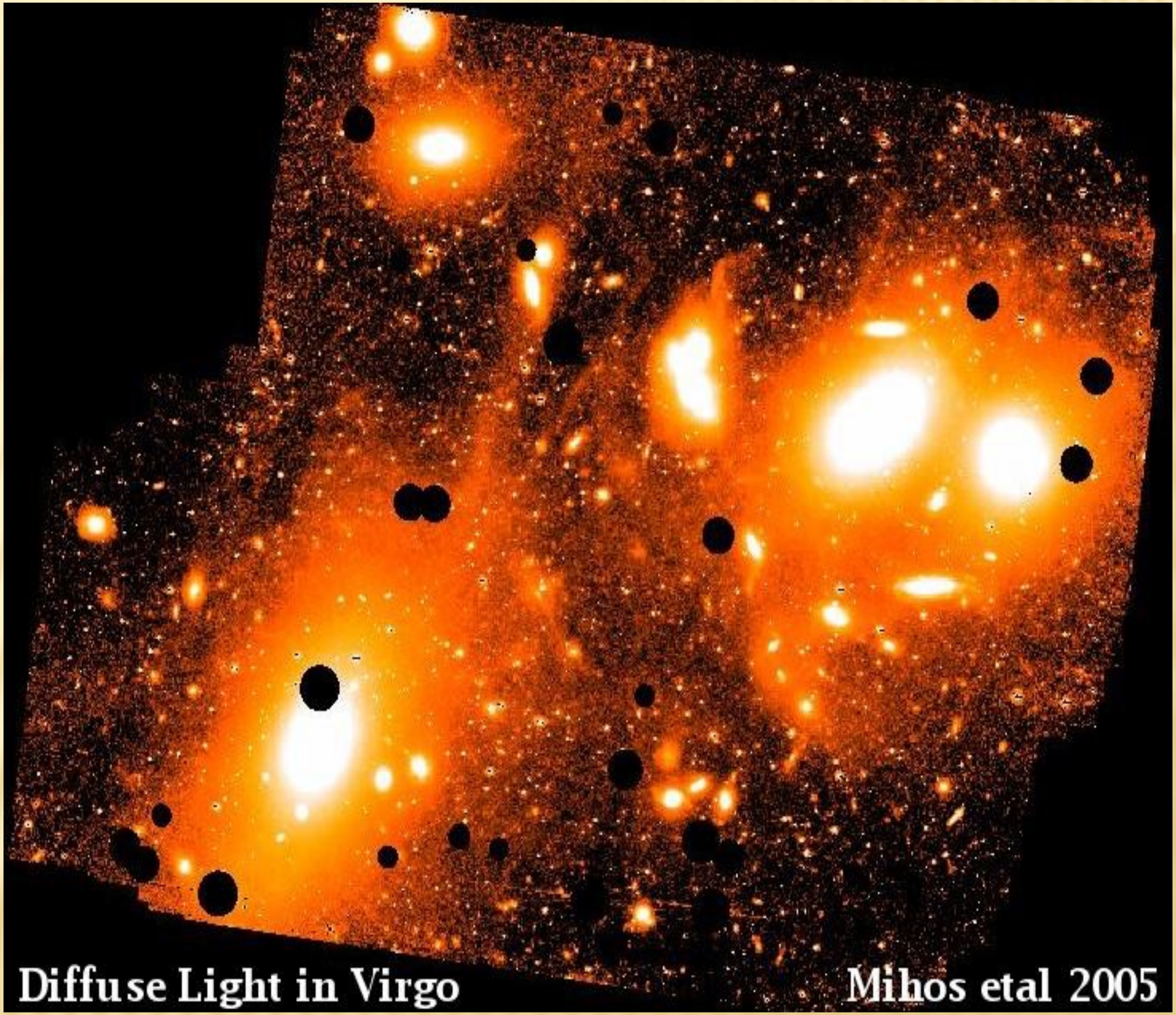
(Zitrin et al, 2010)



ICL

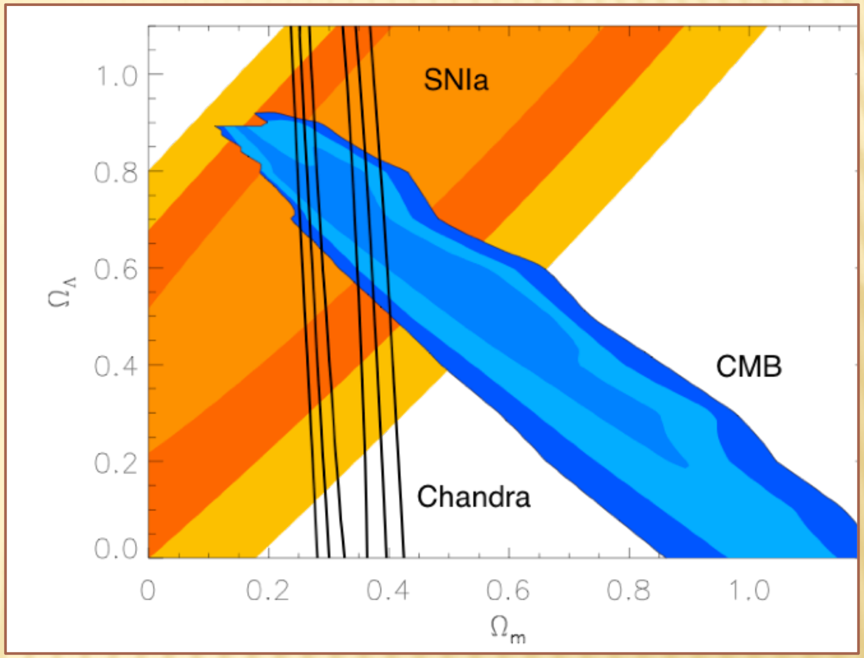
The **intracluster light (ICL)** is defined as a luminous component consisting of stars that are gravitationally bound to the cluster potential but do not belong to any galaxy in the cluster.

ICL fraction = 10-50% of the optical light of the cluster (Zibetti et al. 2005, Rudnick et al. 2011, Contini et al. 2014).



Why is ICL interesting?

- To understand the **hierarchical process of accretion of the clusters**.
- To understand the **metal enrichment** of the intracluster gas, still an open problem.
- To **constrain cosmological parameters** independently of the other methods, by measuring the baryon fraction in clusters (e.g. Allen et al. 2002, 2004; Lima et al. 2003; Lin & Mohr 2004).



(Allen et al. 2002)

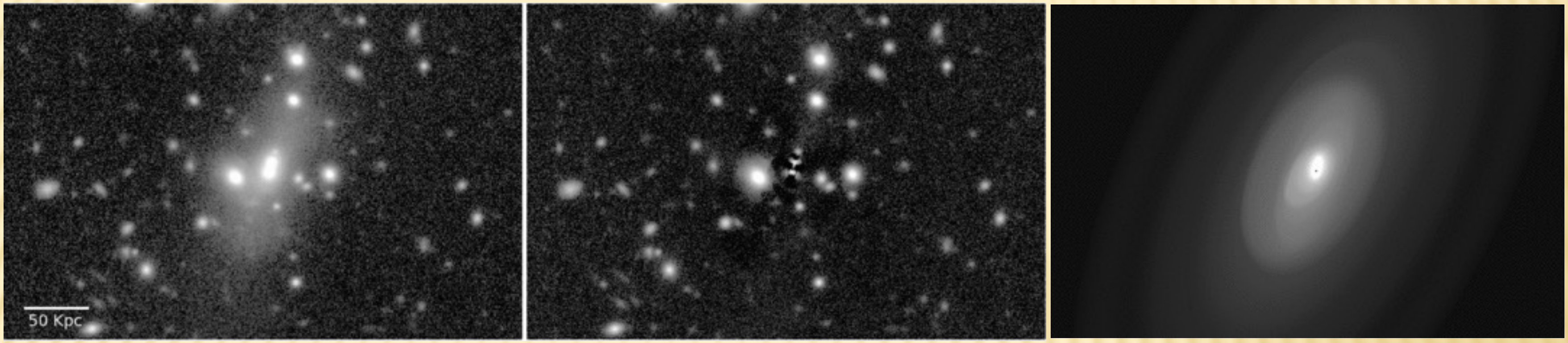
What do we know about the ICL fraction?

- **Real measurements:** existing techniques in the literature yield different results in the ICL fraction, up to a factor of 4, using the same data (Rudick et al. 2011; Cui et al. 2014).
- **Cluster mass:** correlated (Zibetti et al. 2005; Lin & Mohr 2004) vs constant or very weak dependence (Krick & Bernstein 2007; Murante et al. 2007; Contini et al. 2014)
- **Age:** non-linearly correlated (Krick et al. 2006; Rudick et al. 2011; Krick & Bernstein 2007; Contini et al. 2014).
- **Dynamical state:** correlated (Pierini et al. 2008; Adami et al. 2013).

Usual techniques (I)

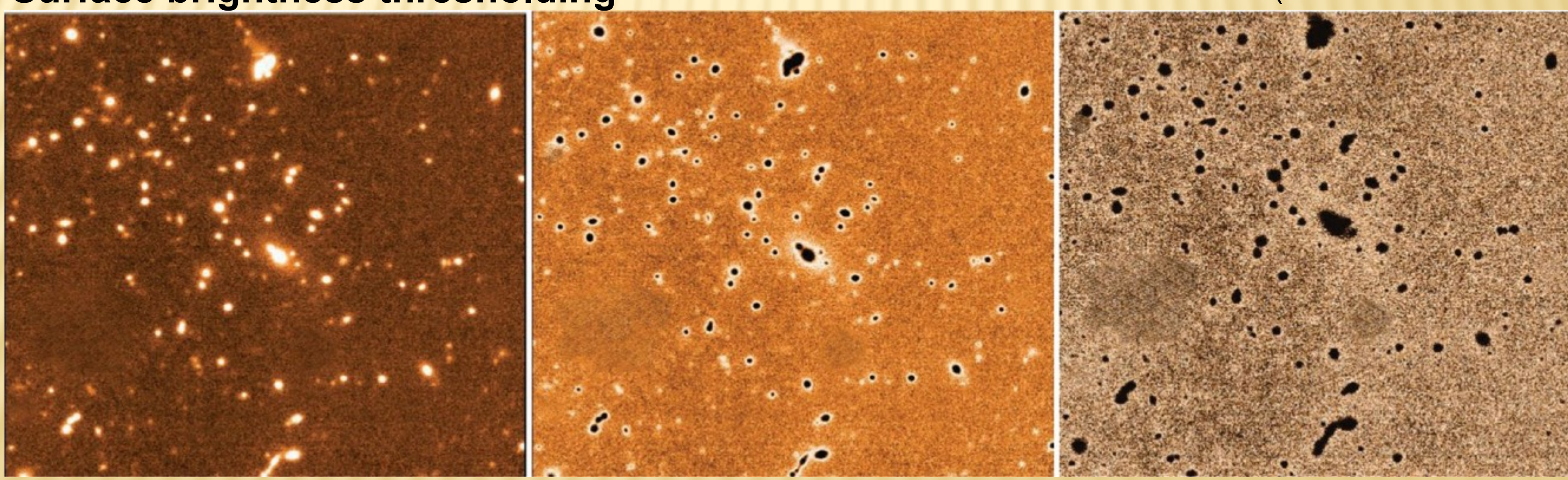
BCG+ICL modelling

(Gonzalez et al. 2005)



Surface brightness thresholding

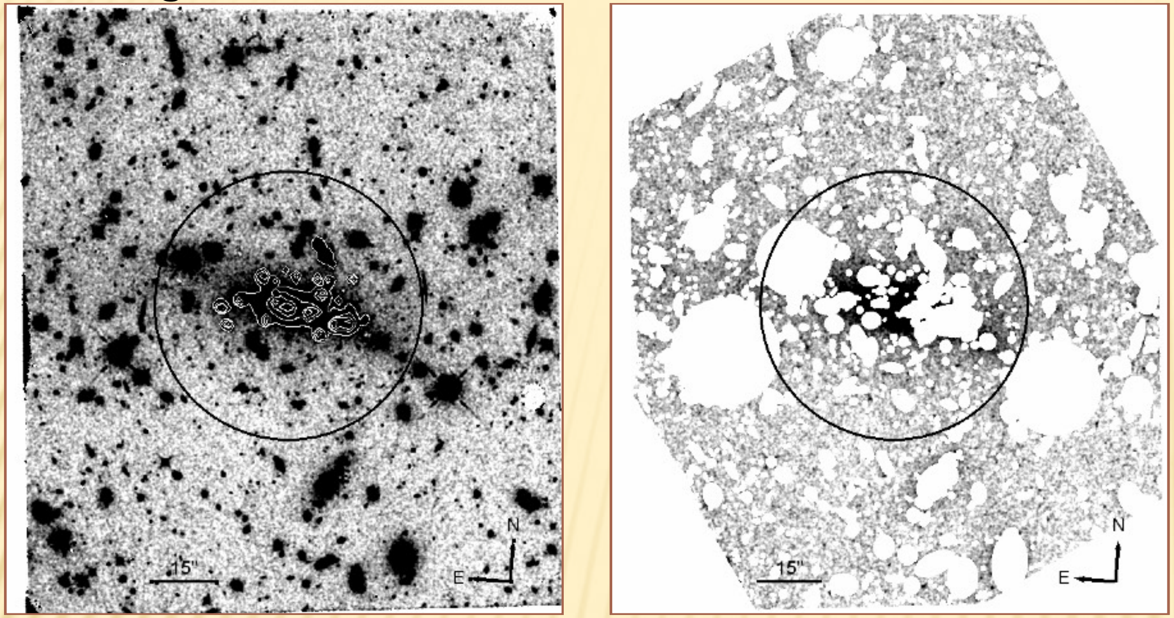
(Burke et al. 2012)



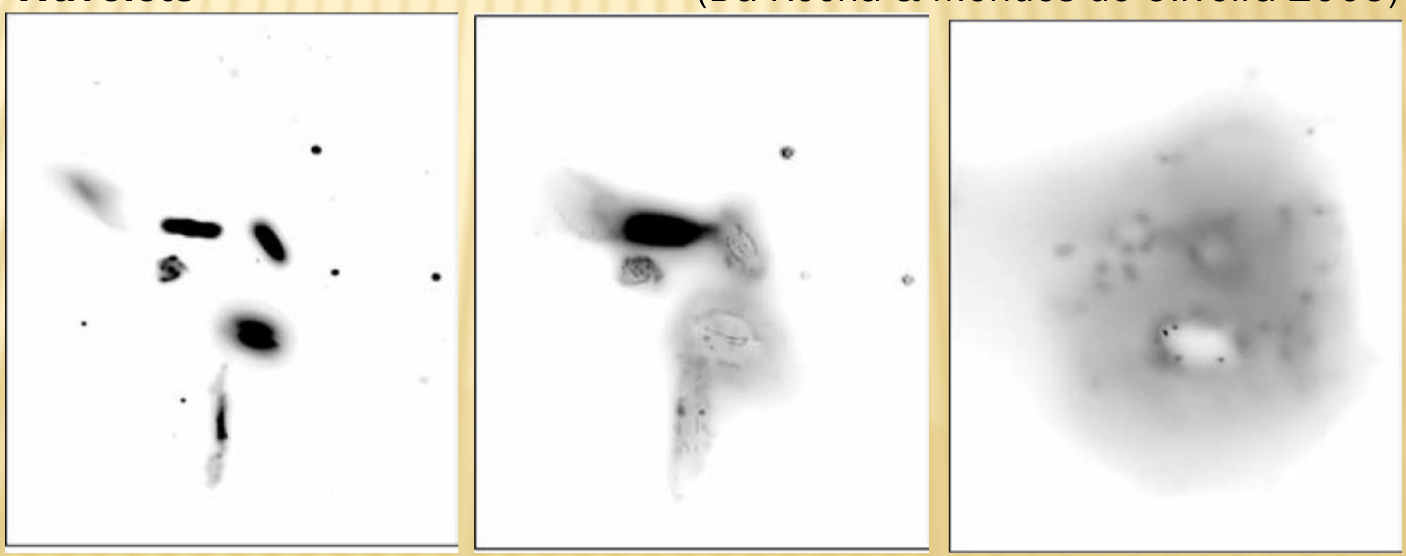
$\mu_J = 19$ mag arcsec^{-2} $\mu_J = 21$ mag arcsec^{-2}

Usual techniques (II)

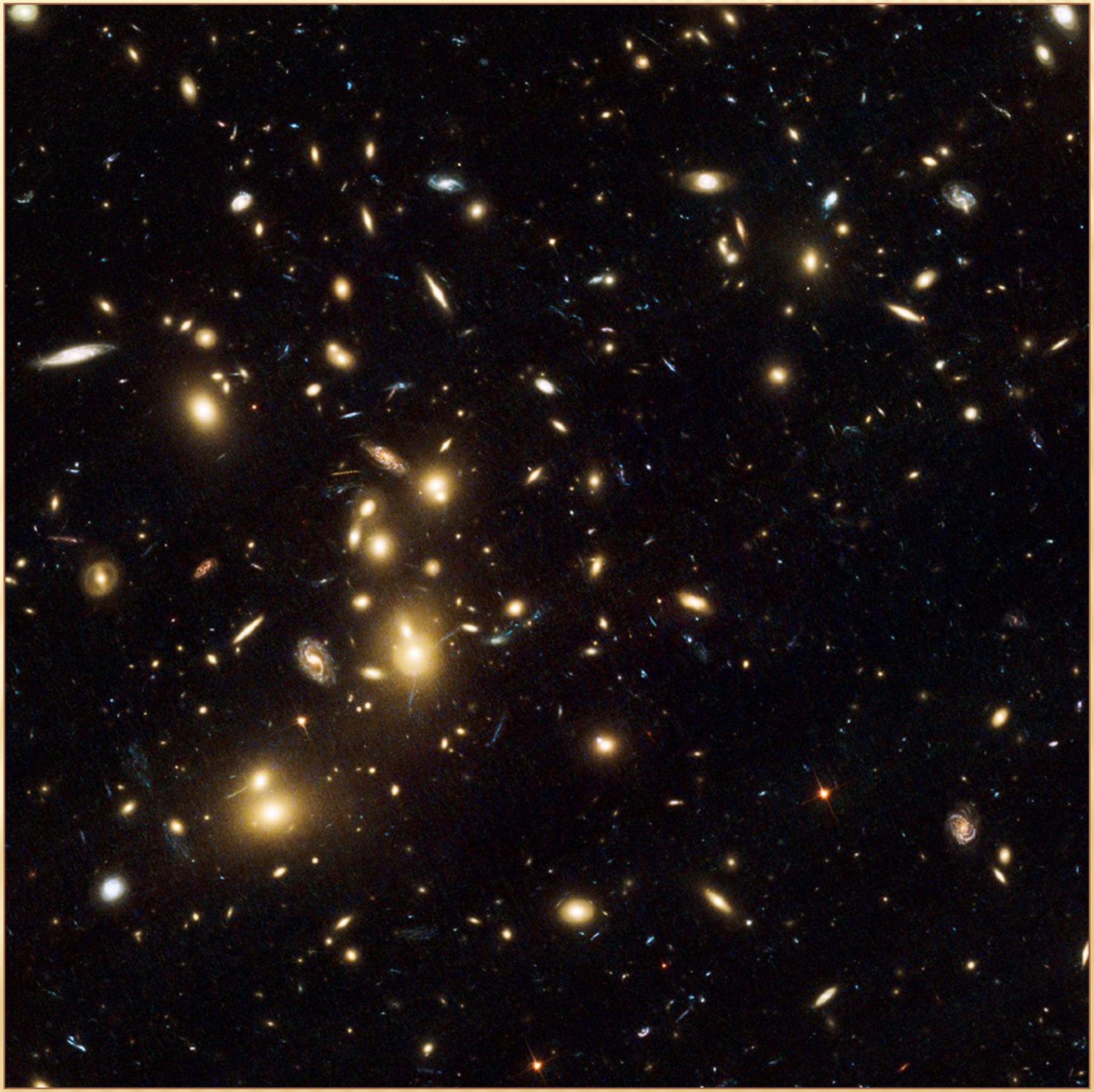
Masking (DeMaio et al. 2015)



Wavelets (Da Rocha & Mendes de Oliveira 2005)

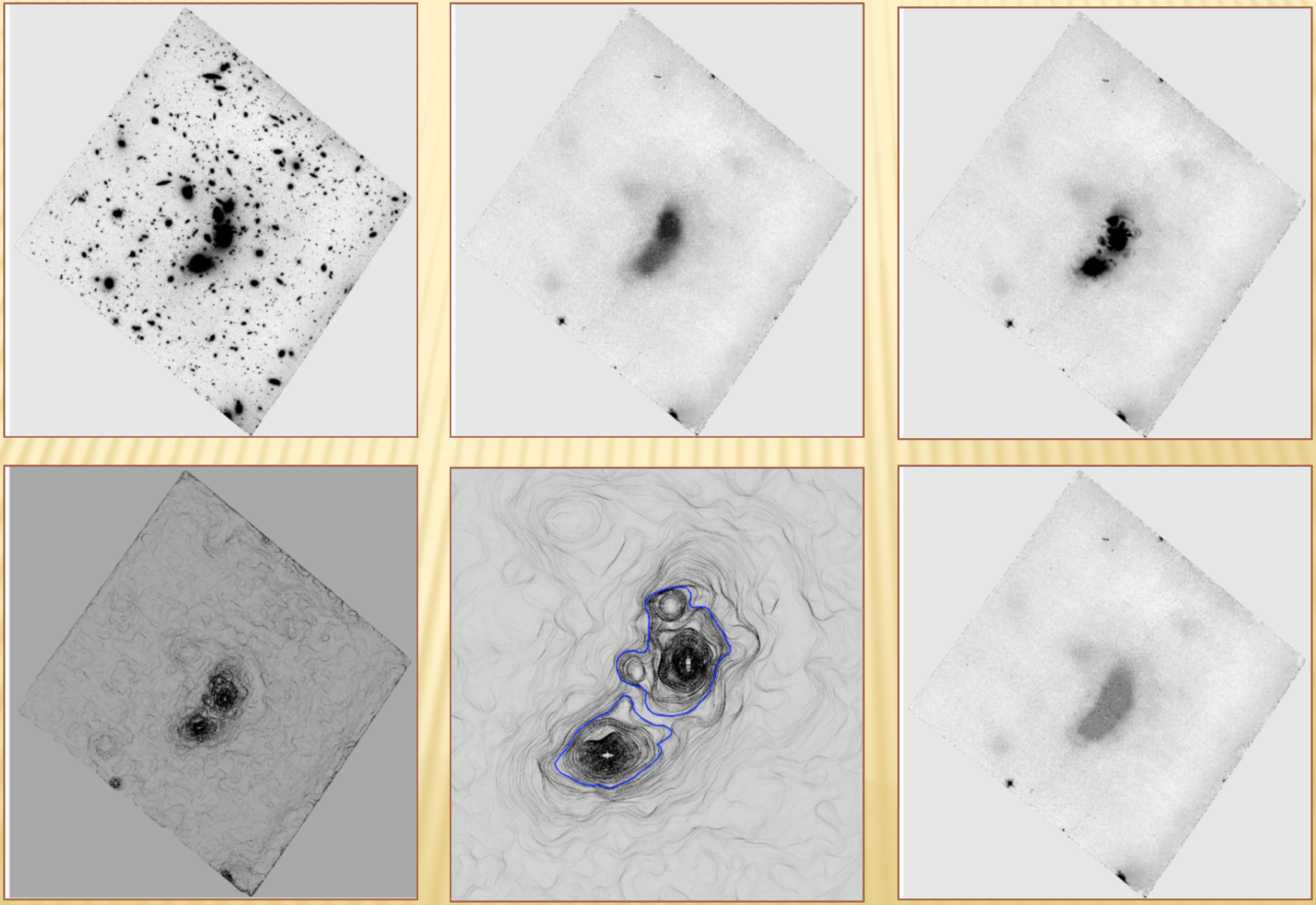


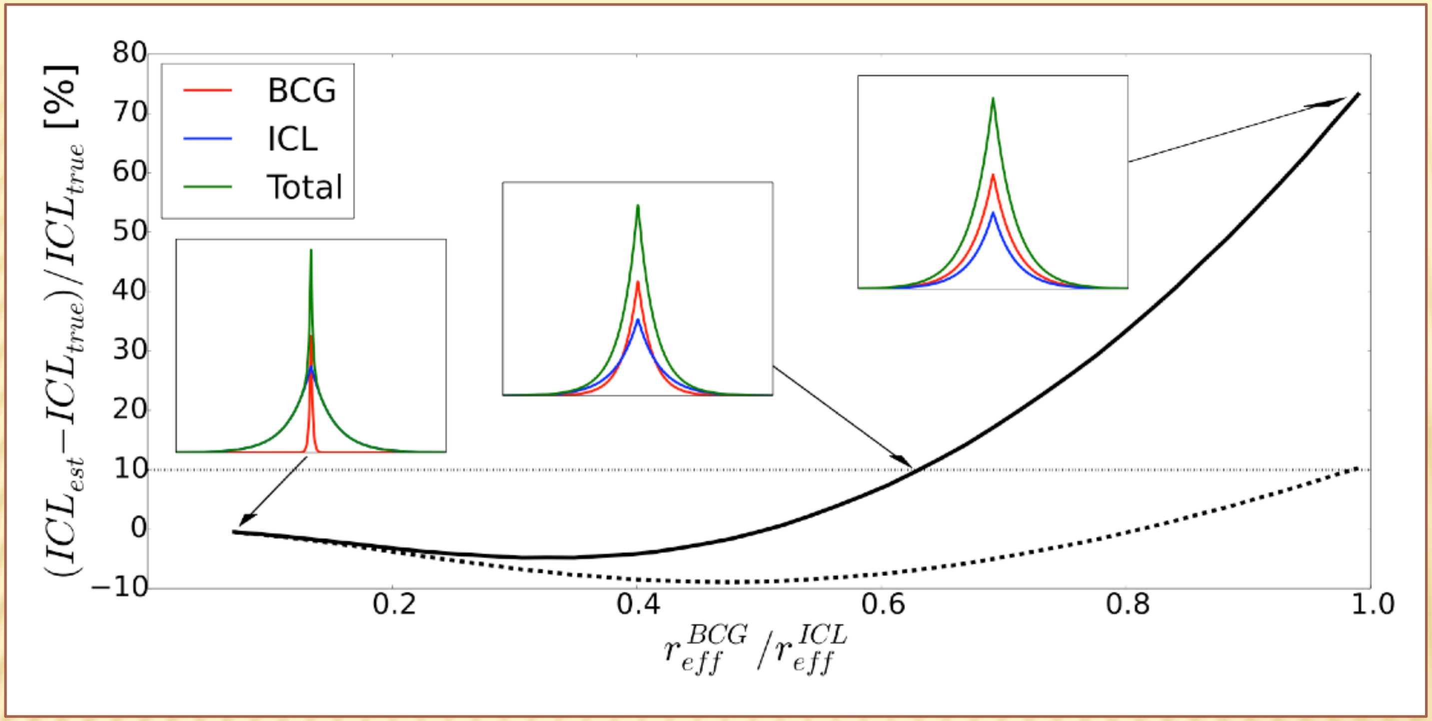
Abell 2744
(Pandora system)



Measurement of the ICL: CHEFs + Differential Geometry + Multiscale analysis

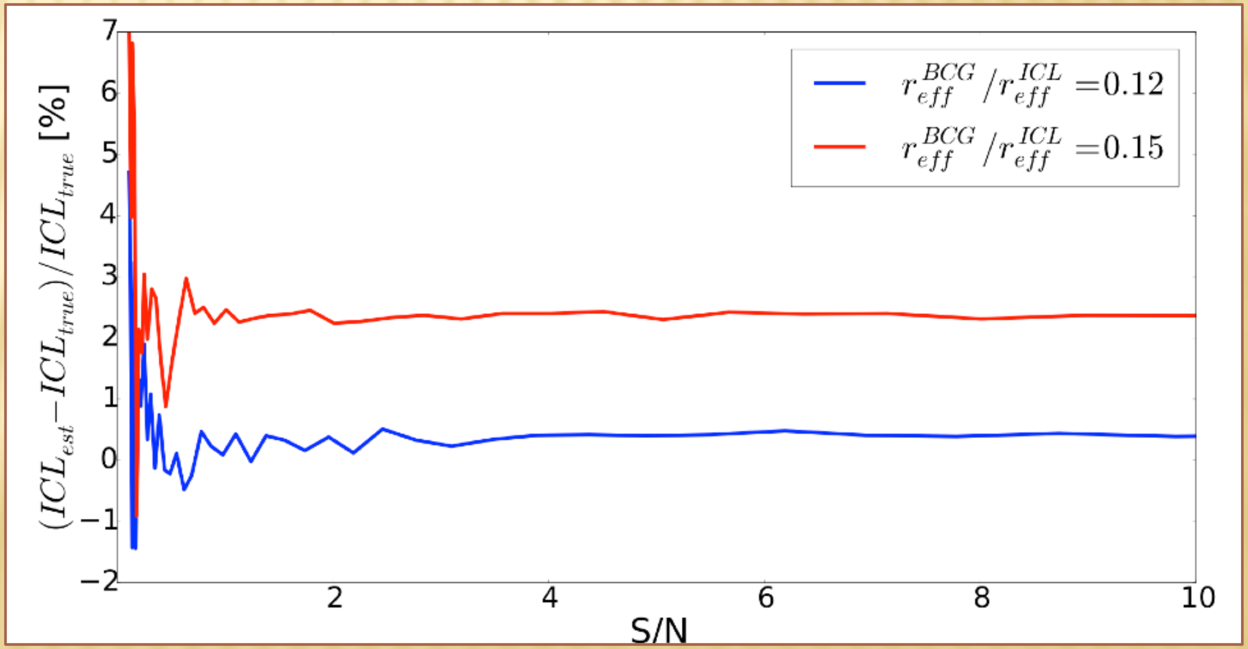
(Jiménez-Teja & Dupke, 2016)





(Jiménez-Teja & Dupke, 2016)

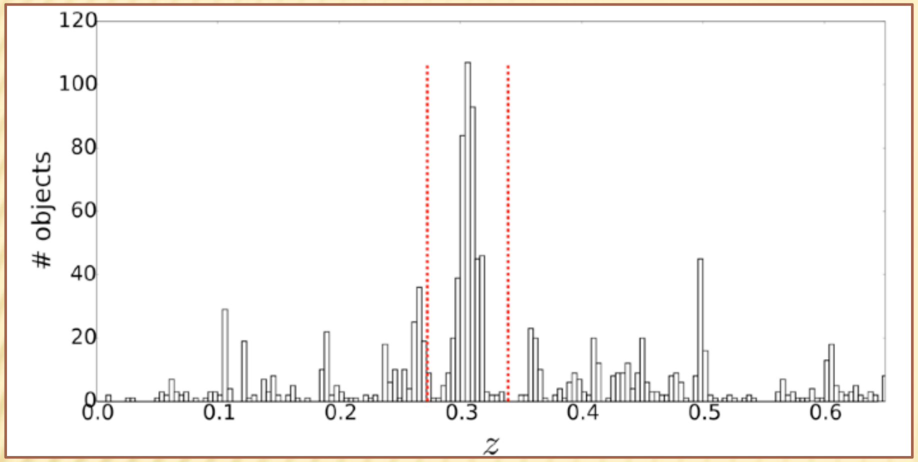
"Average cluster" in range z~0.2-0.3 (Zibetti et al. 2005)

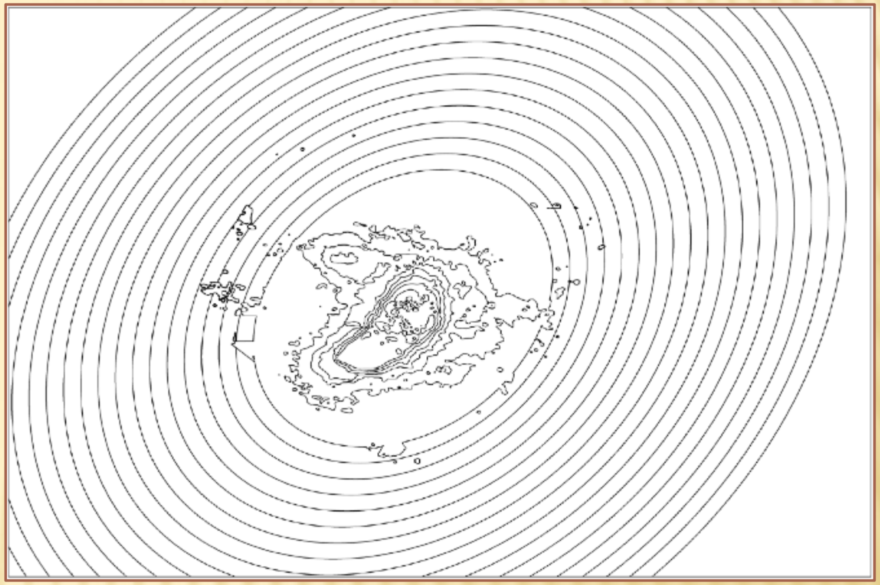


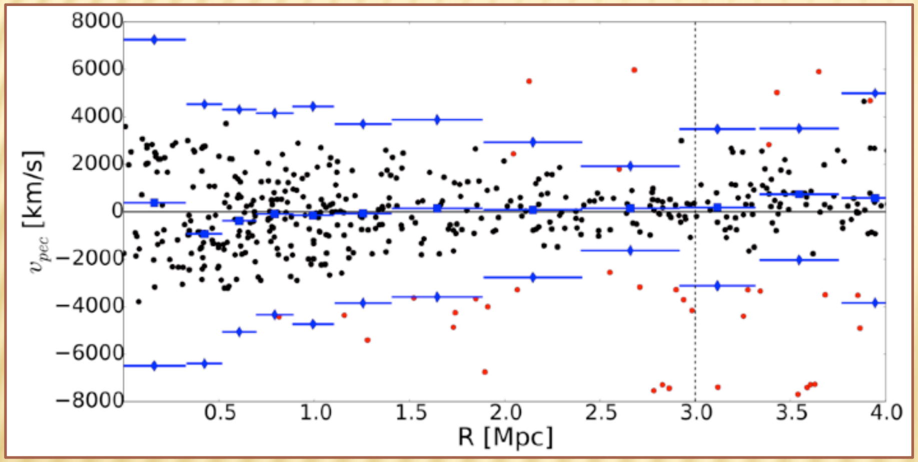
ICL surface brightness in [24.5,37] mag/arcsec^2

Measurement of the ICL

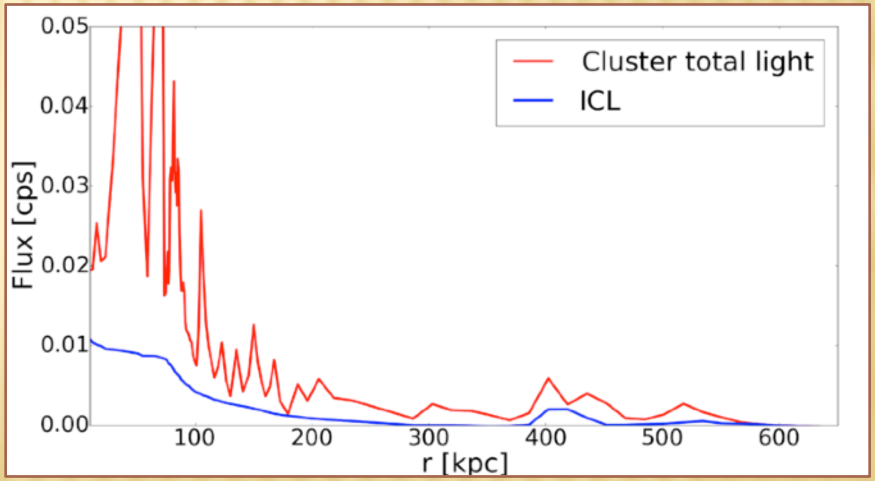
(Jiménez-Teja & Dupke, 2016)







Cluster membership: PEAK+shifting gapper methods (Fadda et al. 1996, Owers et al. 2011)



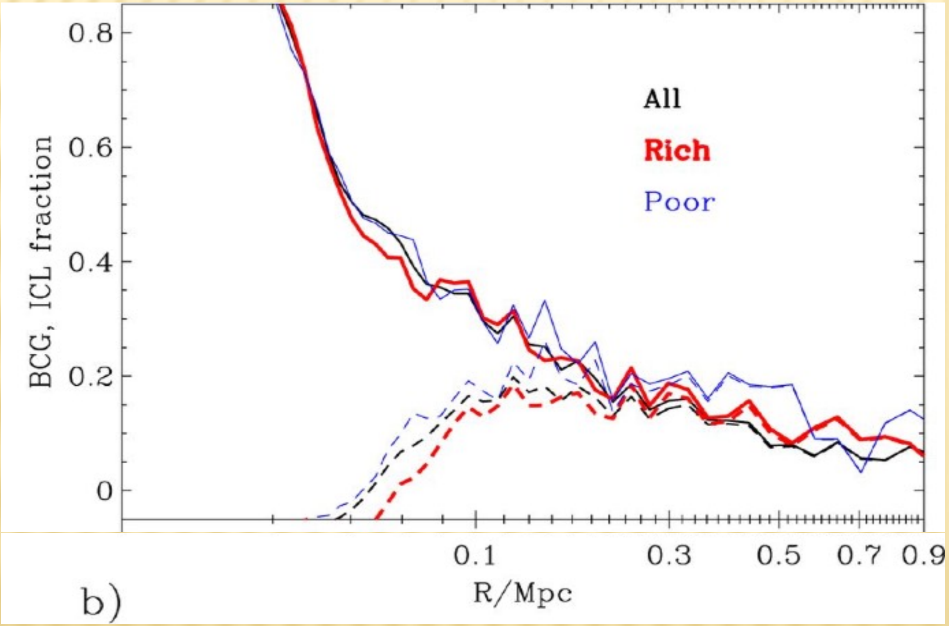
ICL fraction = 19.17±2.87%

Results in the literature

- Numerical simulations predict an ICL fraction between 6%-24%for a cluster at redshift z~0.3 (Contini et al. 2014).

- Zibetti et al. (2005): analysis of 683 clusters from SDSS between z=0.2-0.3.

- Krick & Bernstein (2007): 14±5% (r band), 11±5% (B band), measured with ground-based images.

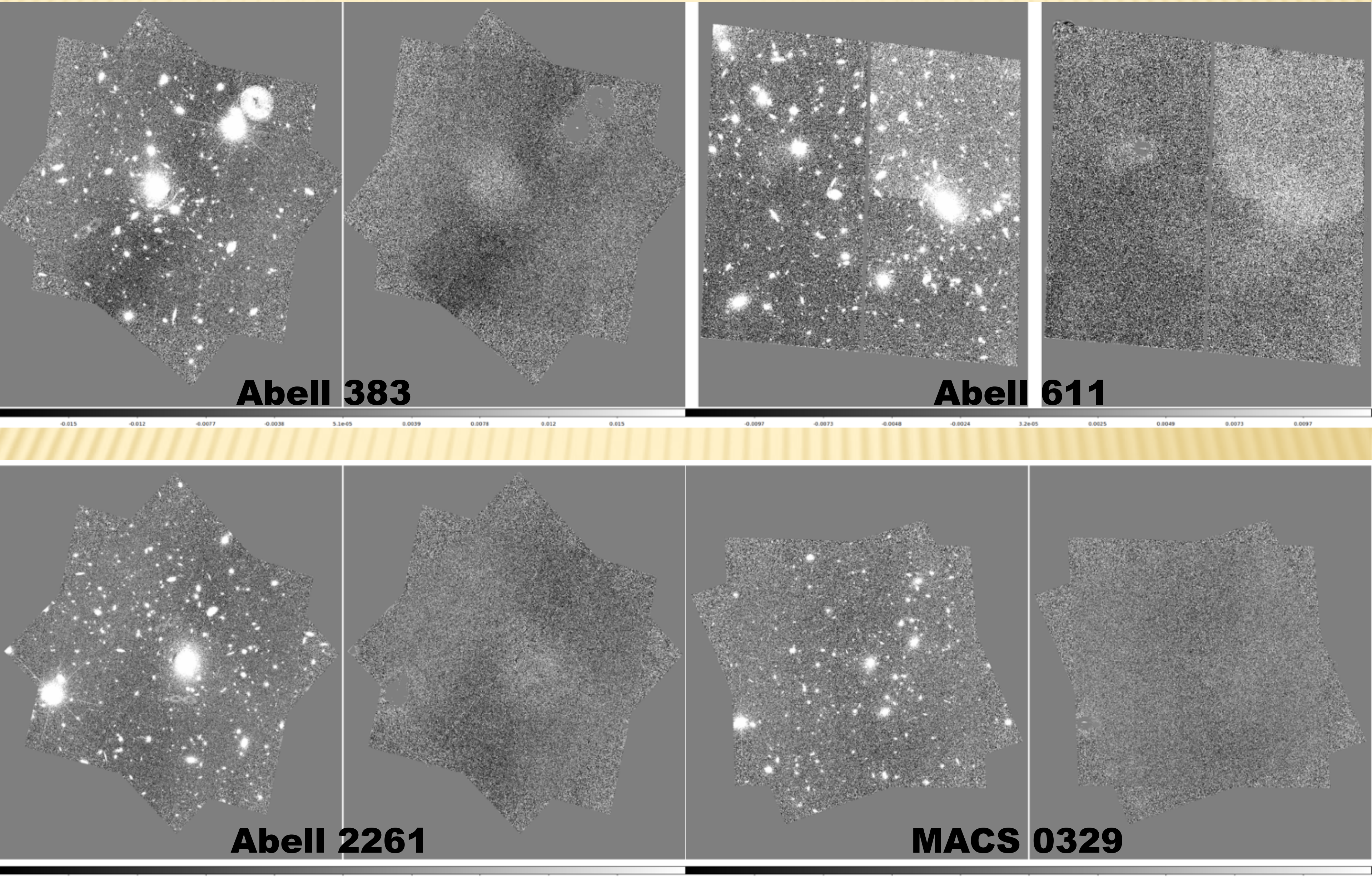


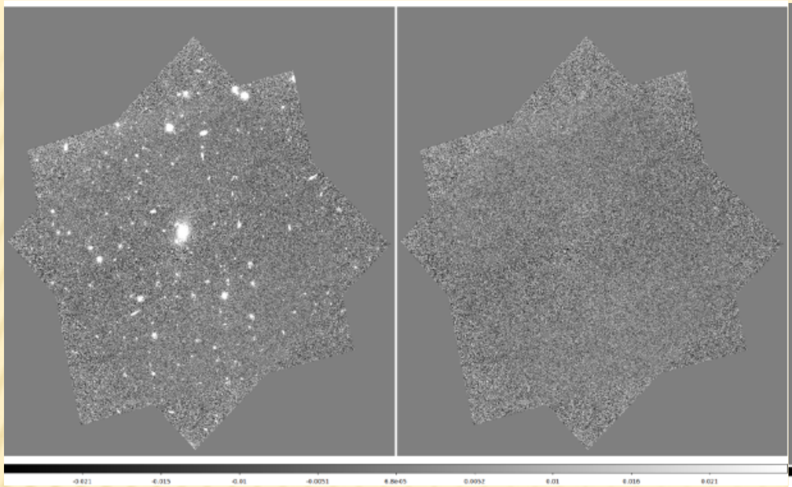
Zibetti et al. (2005)

Montes & Trujillo (2014):
- 4% (stellar mass density)
- 5.1% (surface brightness)
- 10.5% (radial distance)

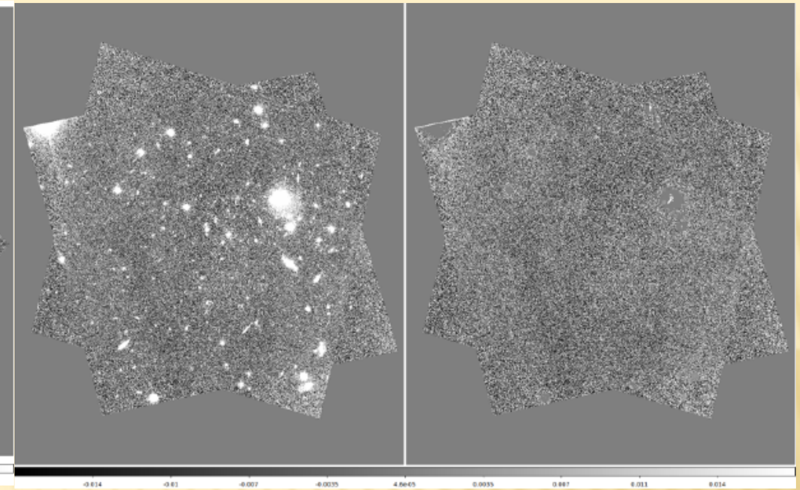
Using the same HST data of Abell 2744.

Work in progress: CLASH & FF clusters (Jiménez-Teja & Dupke, in prep)

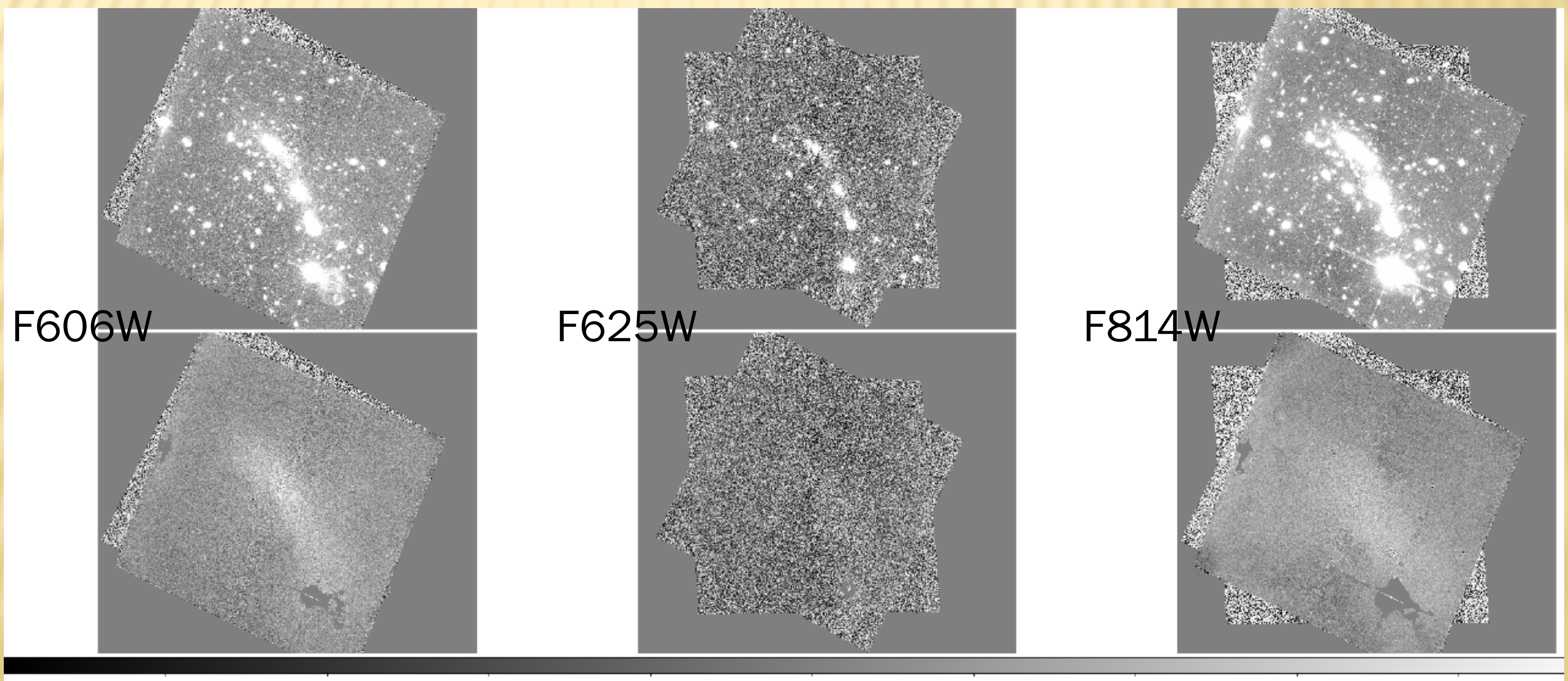




MACS 0429



MACS 0744

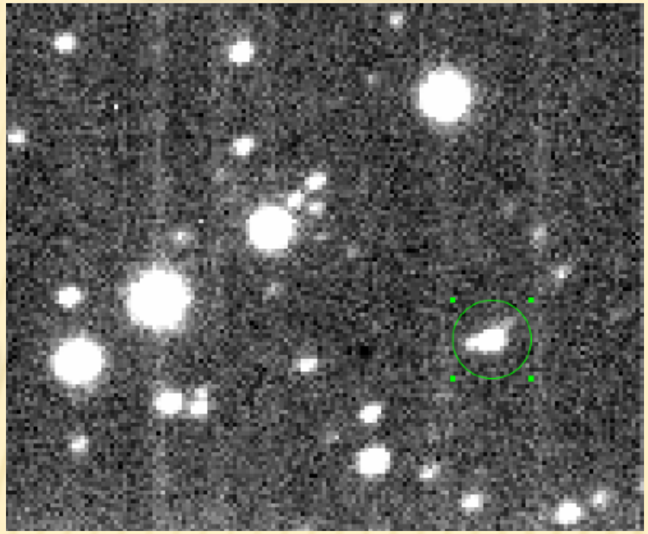


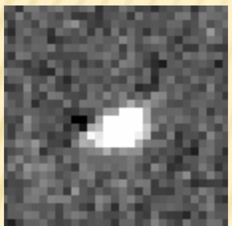
MACS 0416

(Jiménez-Teja & Dupke, in prep)

Not only useful for extragalactic people!!!

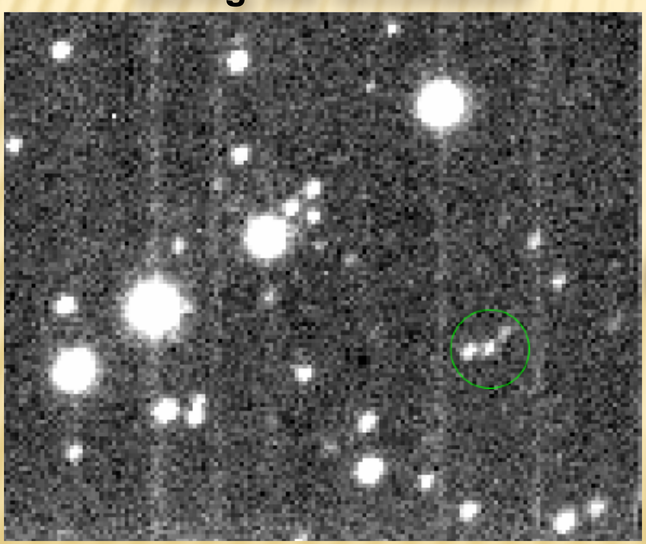
Before the occultation

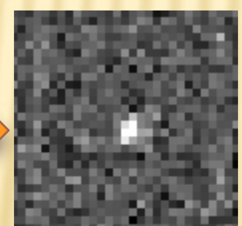




Occulted star

During the occultation





TNO

(Alvarez-Candal et al., 2014)

To accurately determine the photo centers of the occulted star and the TNO (2002 KX_{14}), we need to remove the light contamination of nearby stars and the TNO before the occultation.

The strategy consisted on modeling the three objects **during the occultation** and removing them from the stacked image obtained **before the event**, previously shifting the CHEF models because of the alignment of the images and the TNO non-sideral motion.

THANK YOU!