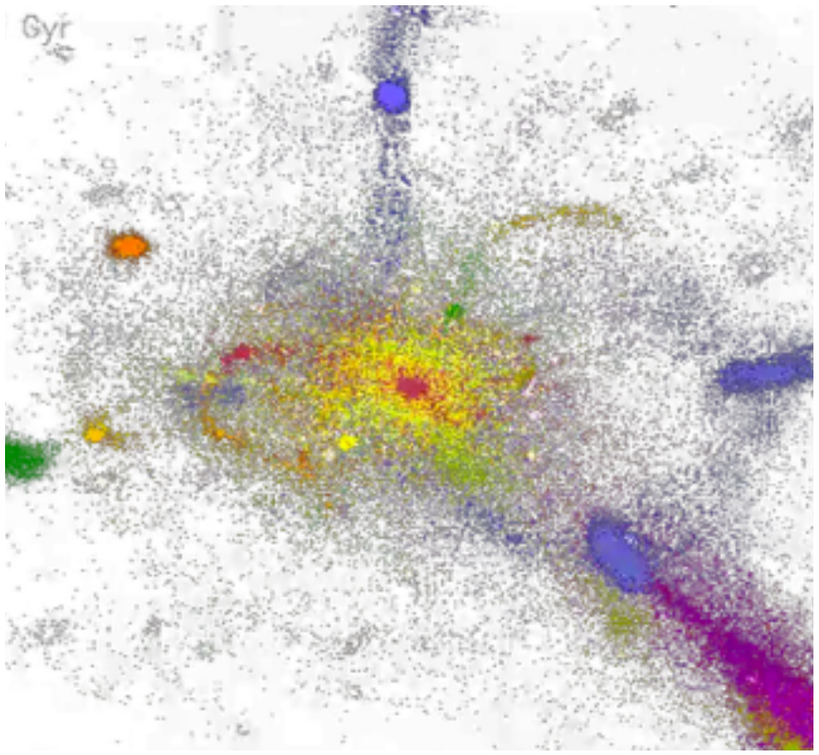
Galaxy archeology using the diffuse light traced by deep imaging

Pierre-Alain Duc

Tenerife, EWASS 2015

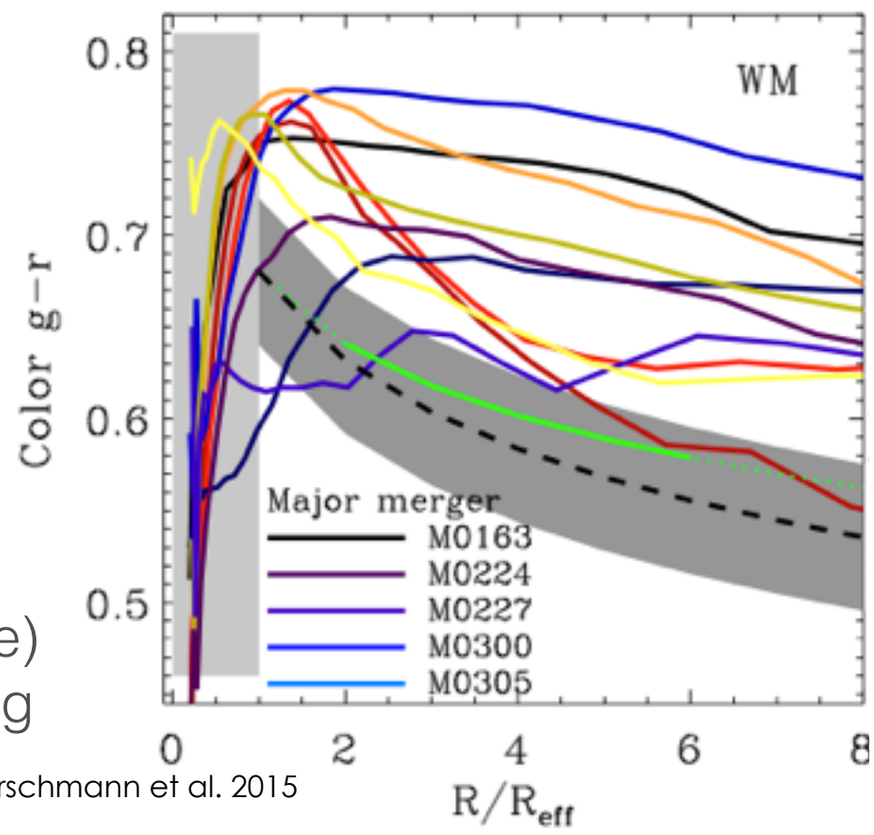
Motivations: probing the mass assembly of galaxies with galactic archeology

Predictions from numerical simulations



© Aquarius, A. Helmi et al.

- ✓ Galaxies surrounded by relics of past mergers: streams evolving into diffuse halos



Hirschmann et al. 2015

- ✓ Color profiles (Z,age) depends on merging history

Constrains from observations

McConnarchie et al. 2011,

- ✓ Stream forest disclosed around LG galaxies with resolved stellar populations

Martonez-Delgado et al., 2010

- ✓ Prospects with diffuse light at larger distances

Deep imaging of massive nearby galaxies with MegaCam on the CFHT

- Volume-limited sample of 260 massive ETGs with D < 42 Mpc (Altas^{3D})

- Comparison sample of 120 massive LTGs from Altas^{3D} parent sample

Cappellari et al, 2011

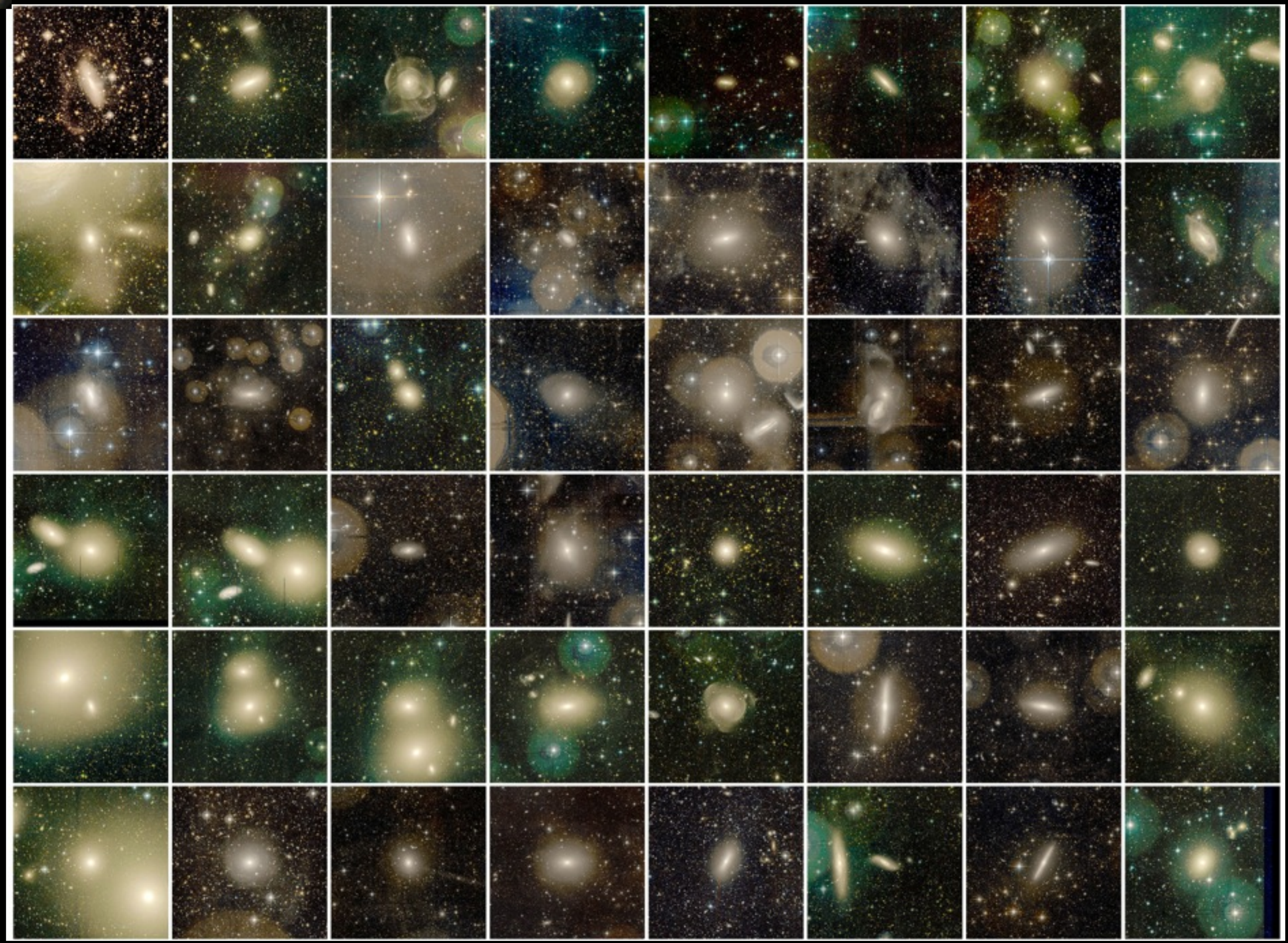
- Observed with the large field of view camera MegaCam (multiband:u,g,r,i) on the CFHT, as initially Atlas3D regular programs, followed by a Large CFHT Program (MATLAS, ->2015), and complemented for Virgo galaxies with the NGVS

Duc et al, 2015

Ferrarese et al, 2011

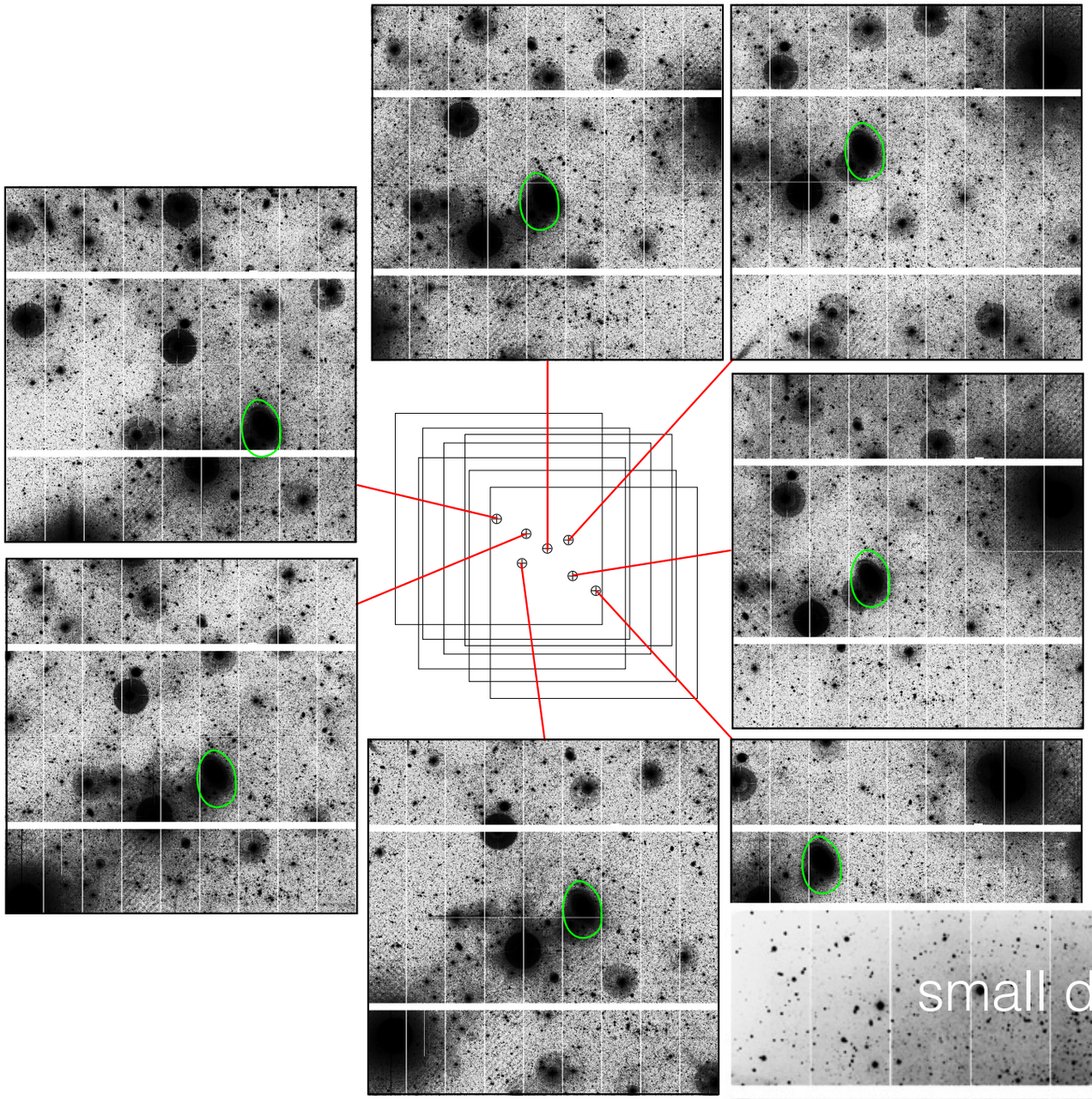
SDSS images of the Atlas^{3D} ETGs

MegaCam images of the Atlas^{3D} ETGs



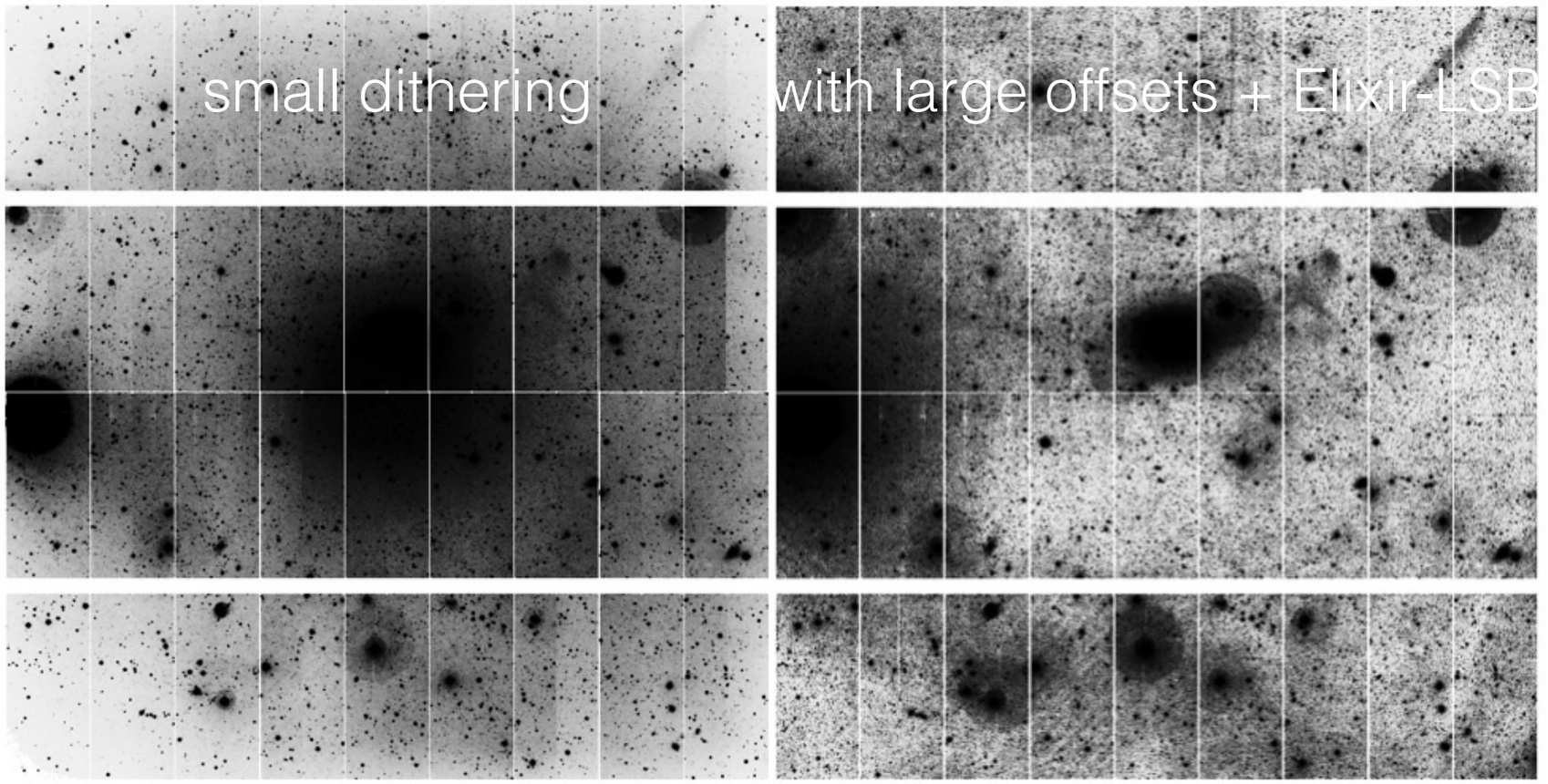
A dedicated imaging strategy and data-reduction technique

- ✓ optimized for the detection of extended low surface brightness features
- ✓ resulting in a gain of several mag with respect to regular techniques

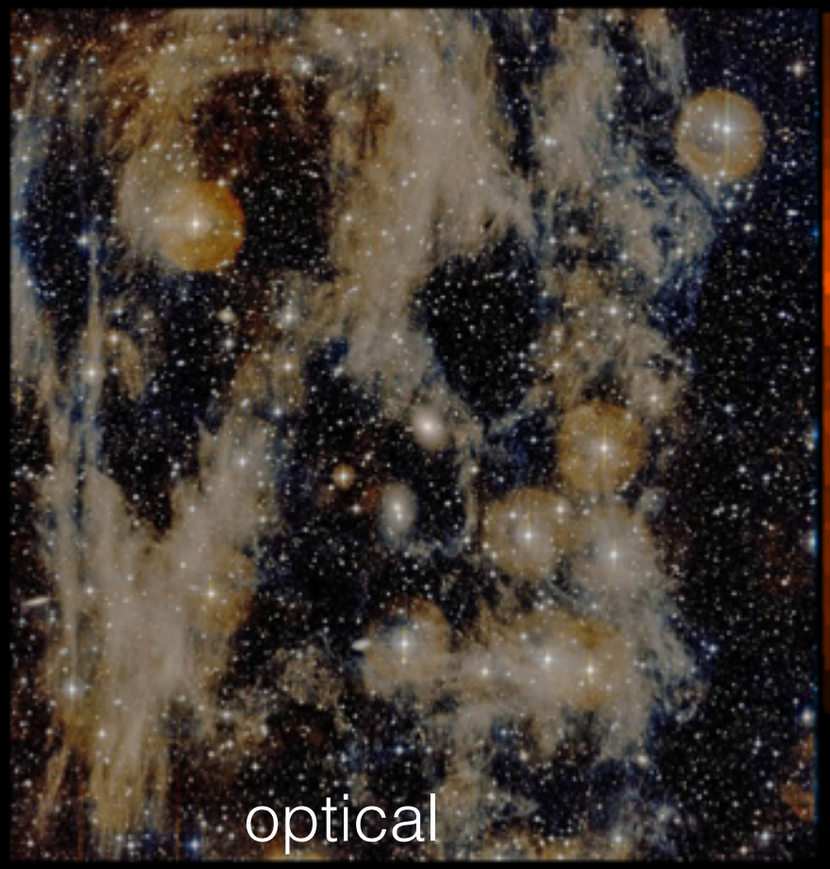


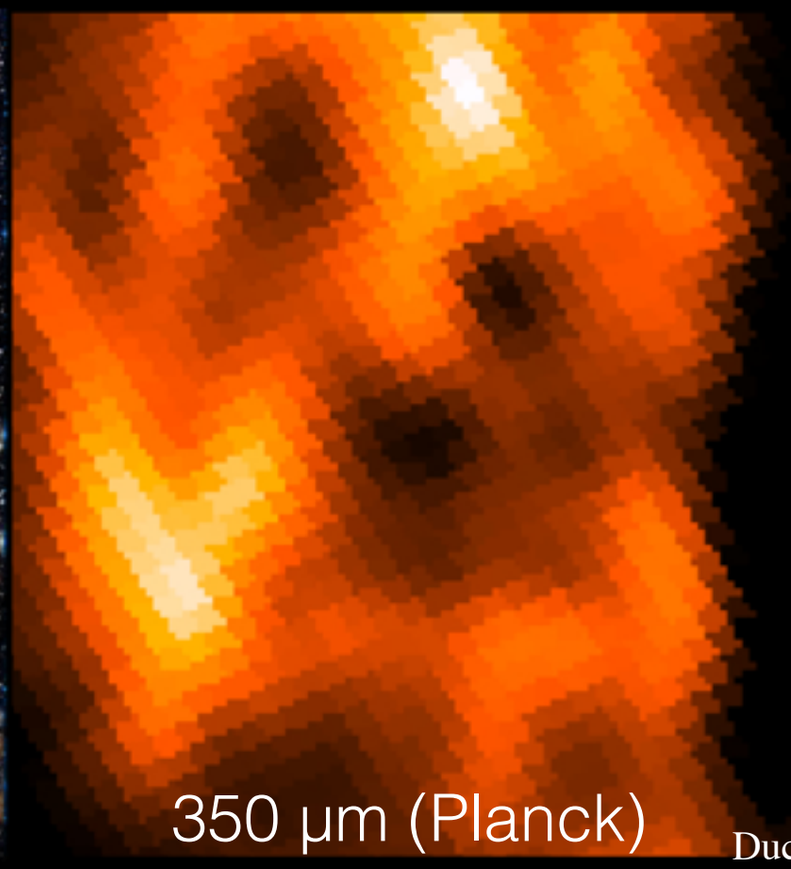
Duc et al., 2015

- ✓ limiting magnitude of about 28.5-29 mag.arcsec^{-2} (g) over **scales of 10”**



Issues with deep imaging: Galactic cirrus



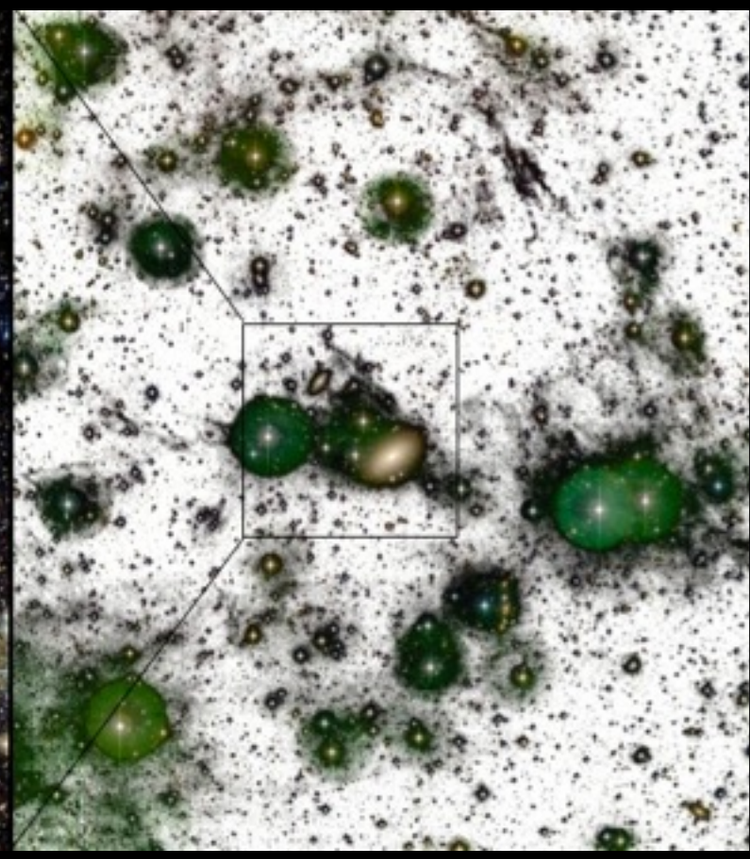


Duc et al., 2015

- ✓ Extended, with a filamentary structure and colors resembling stellar streams

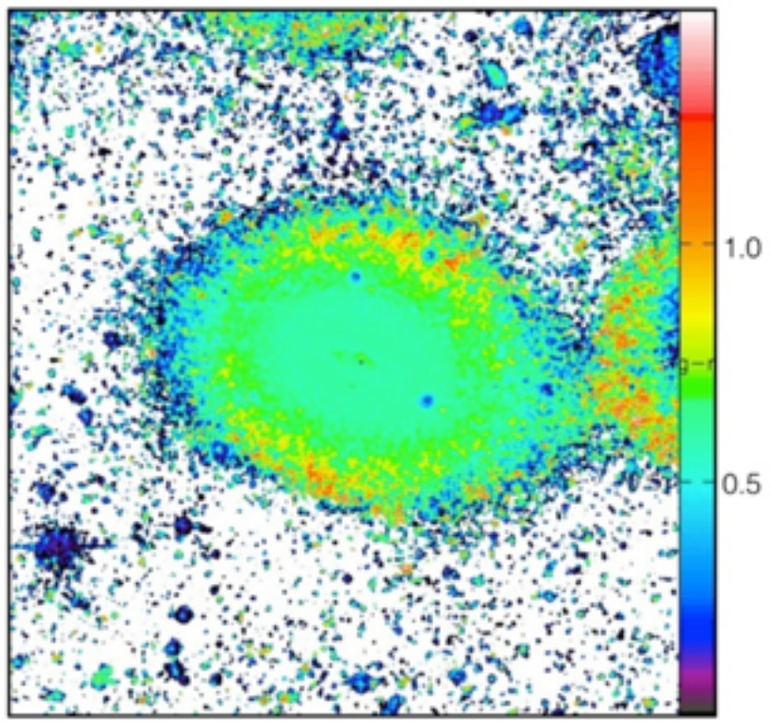
- ✓ Can be identified at other wavelength (far UV, far IR), masked, but not subtracted…

- ✓ Allows us to study the distribution of dust clouds at unprecedented spatial resolution



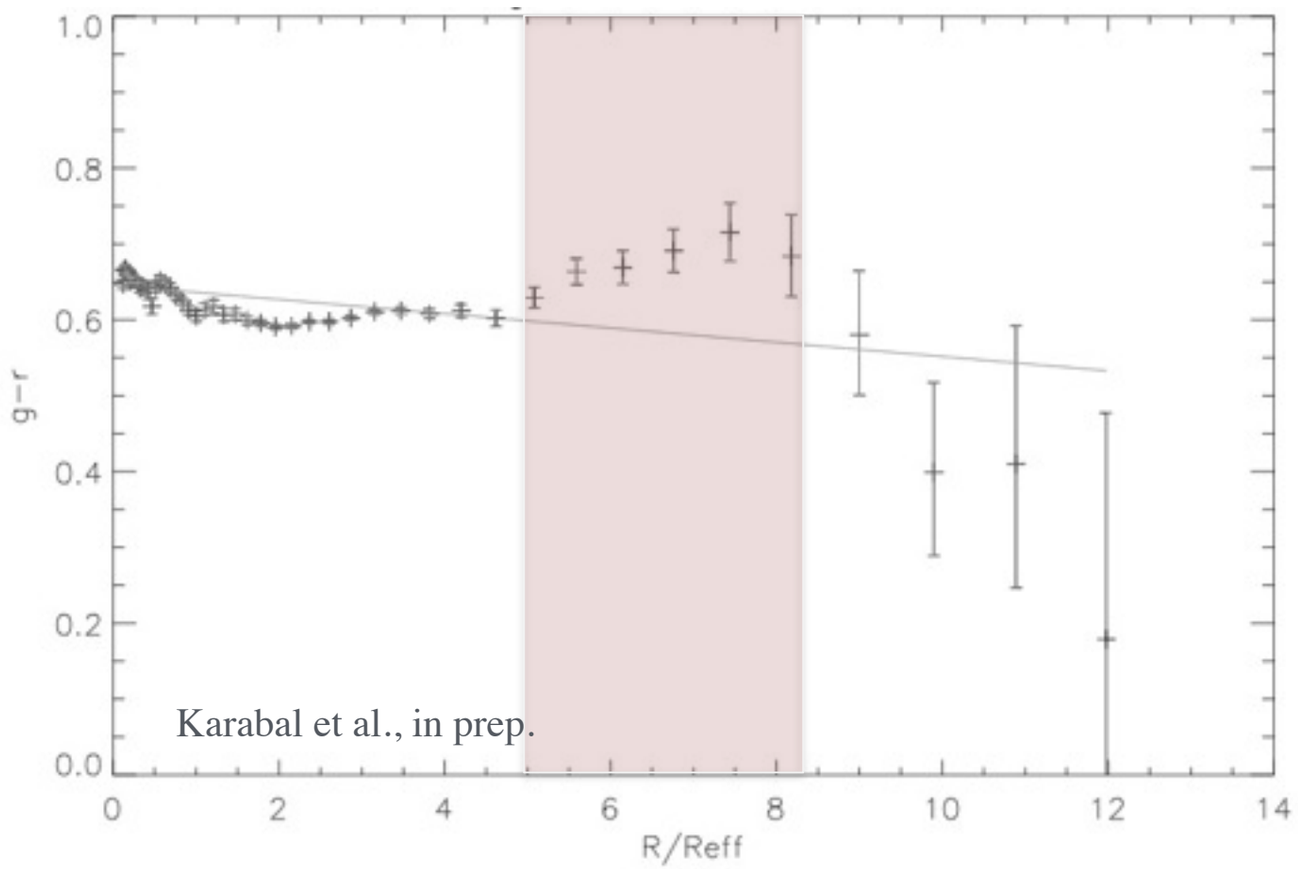
Issues with deep imaging: scattered light from galaxies

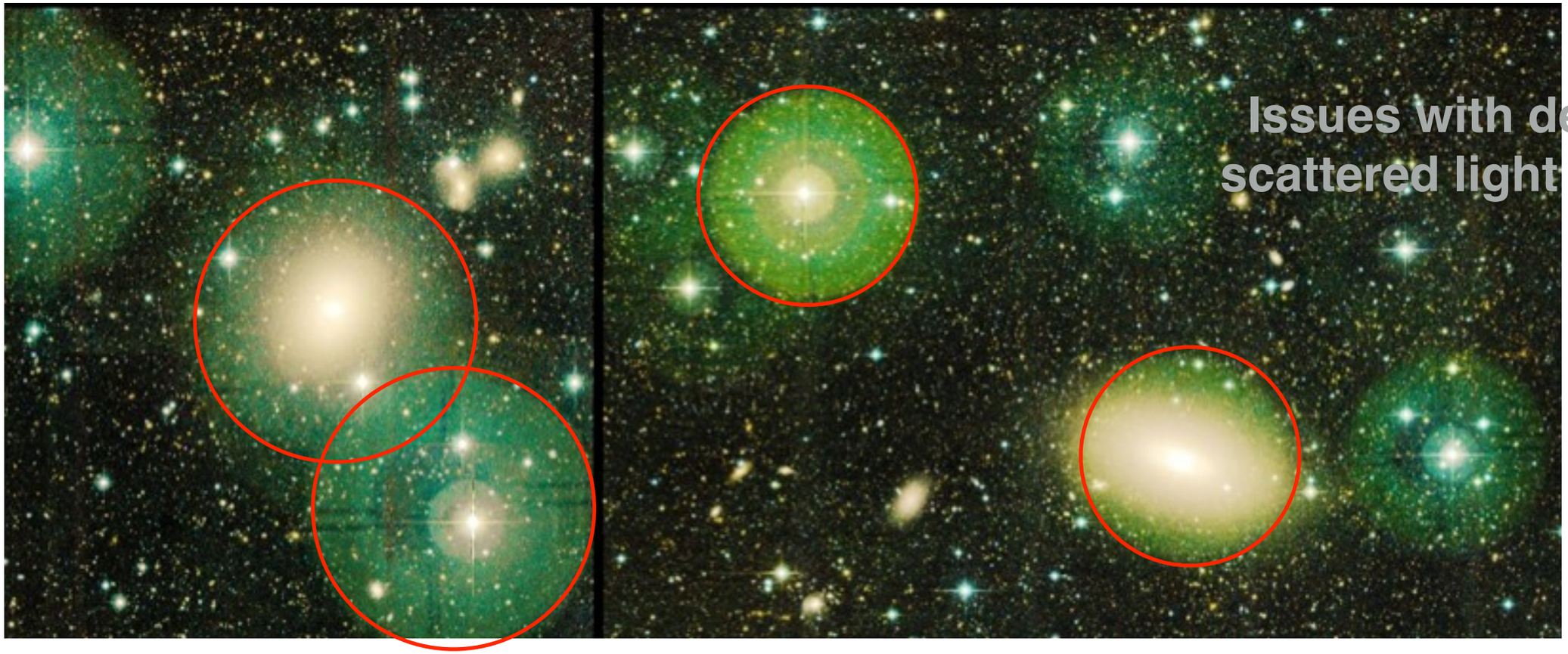
- ✓ similar shapes but more diffuse: mimic galaxy halos



- ✓ shows us as a red ring on color maps, and reddening on color profiles

- ✓ directly visible in the r band around small or edge-on galaxies with bright compact nucleus





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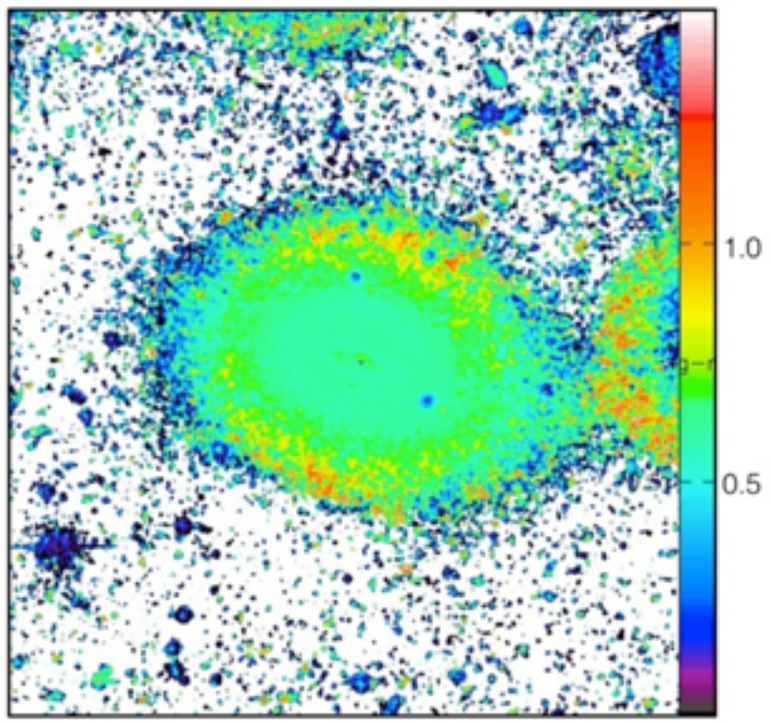

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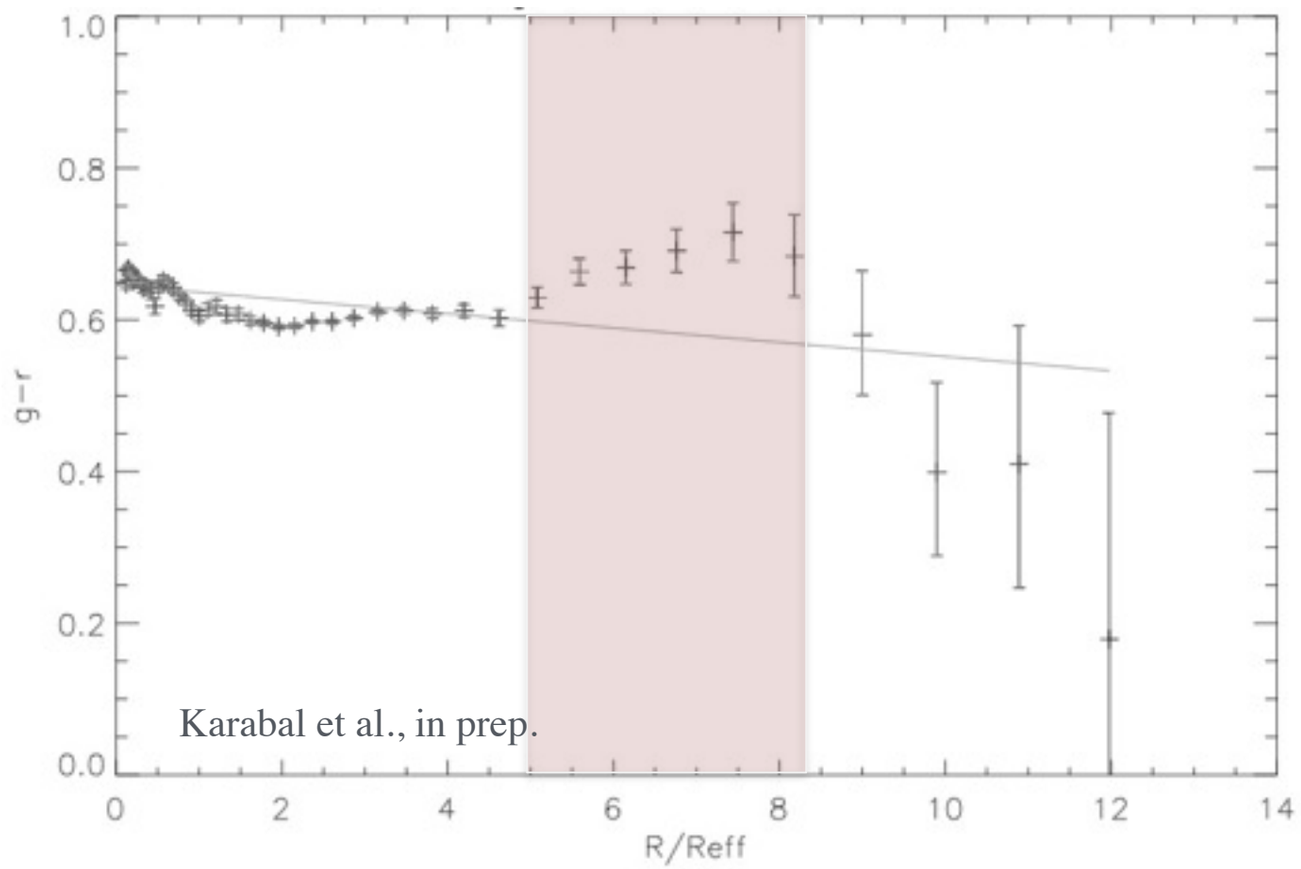
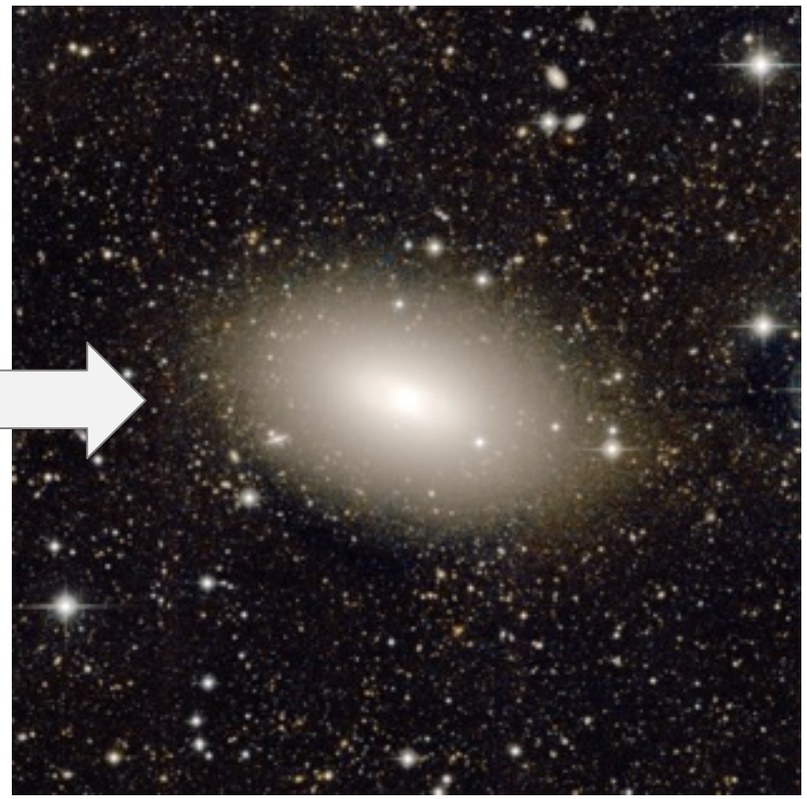
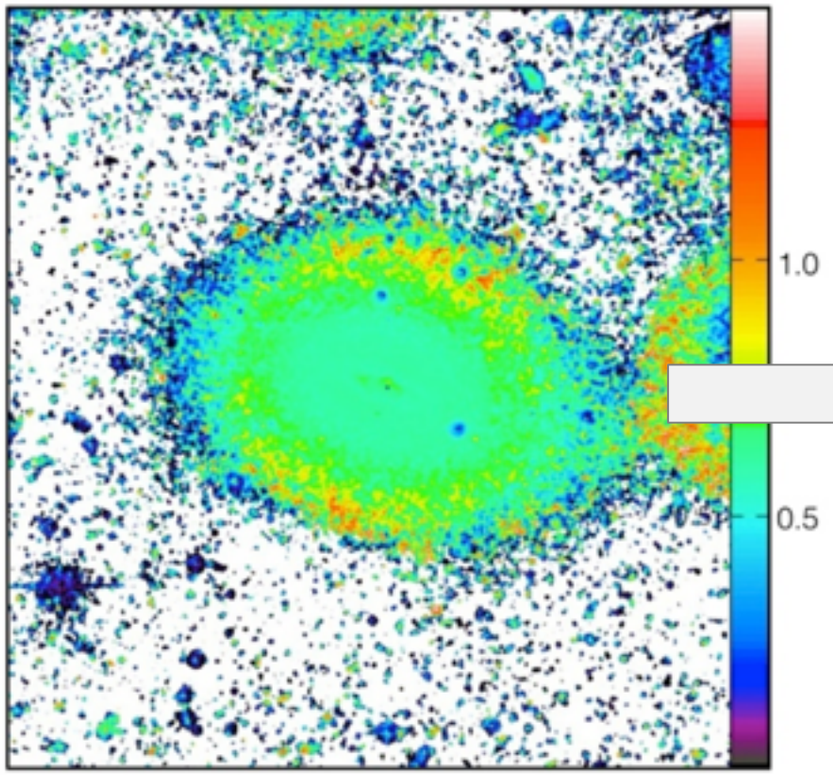
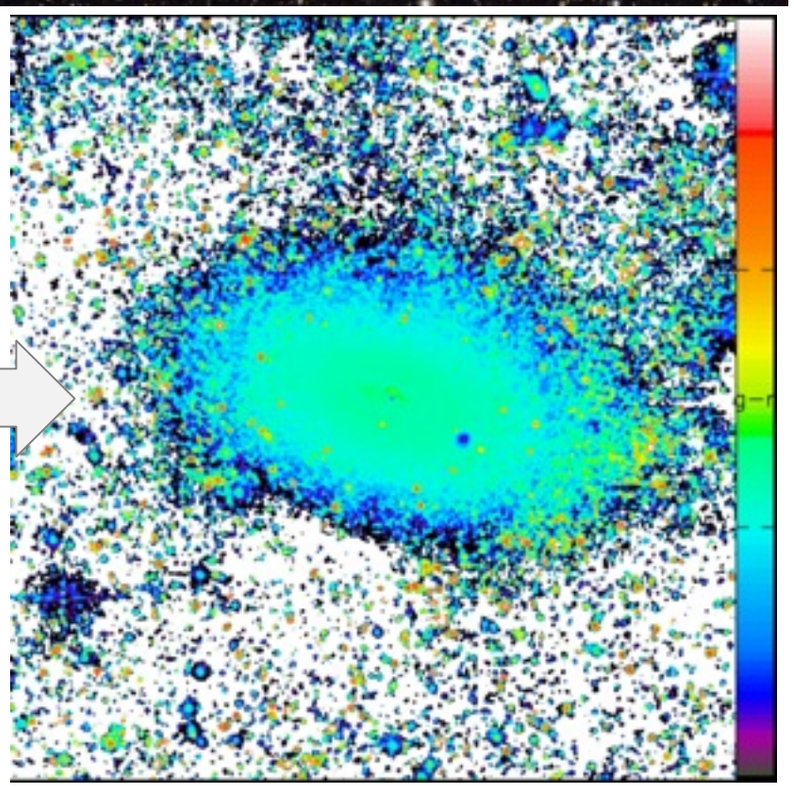


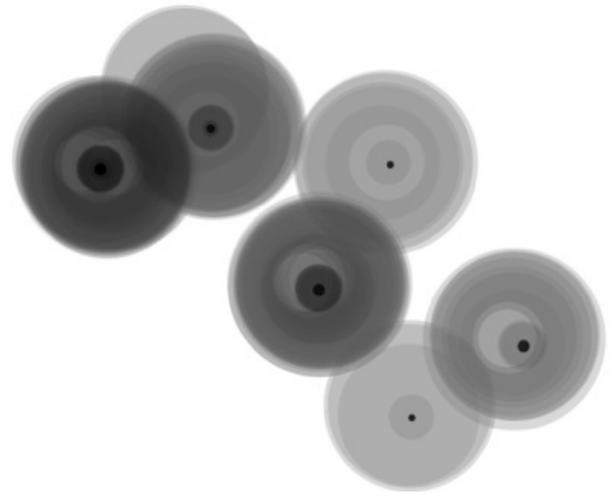
Issues with deep imaging: scattered light from galaxies corrected







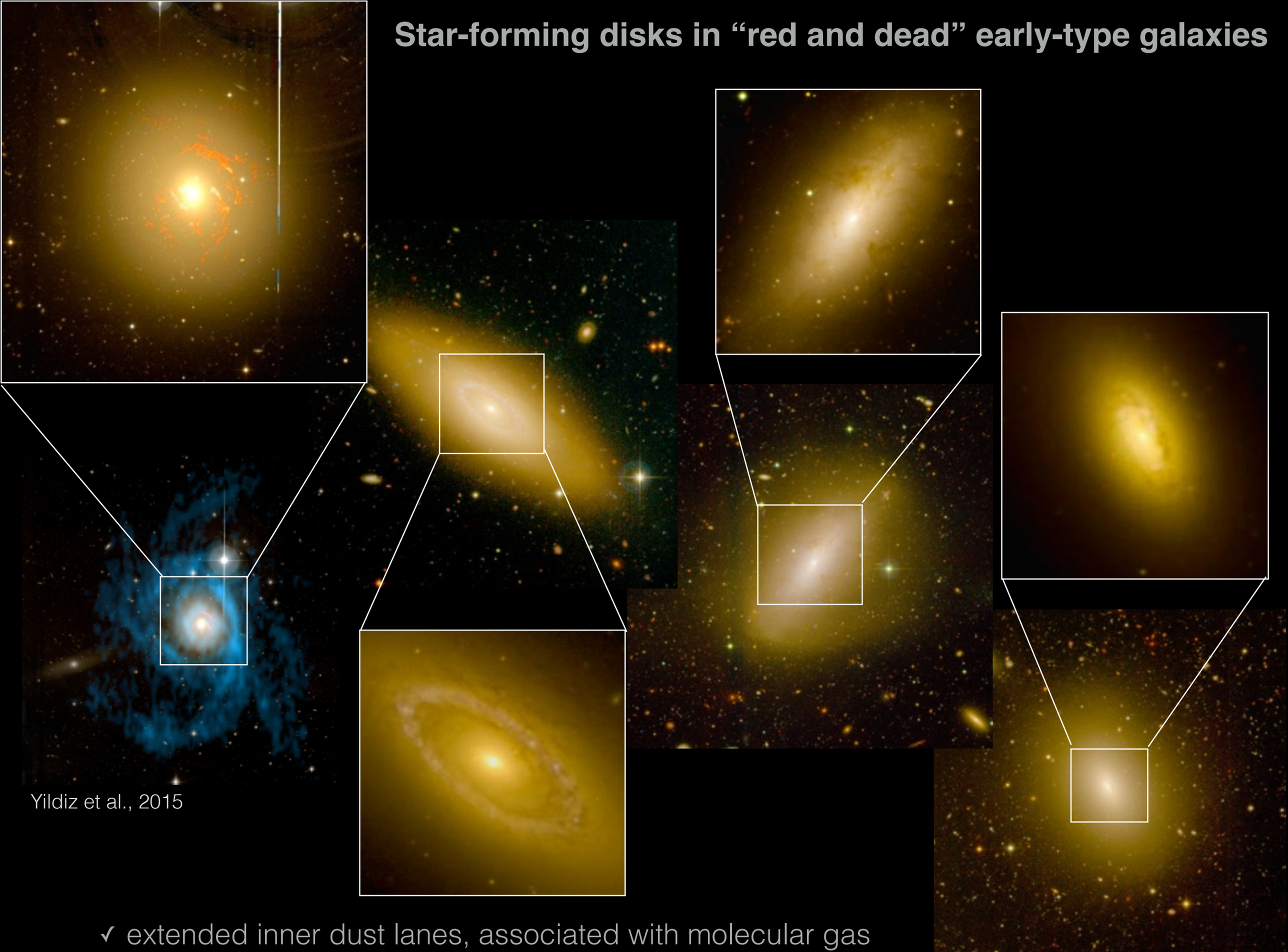
- ✓ Contamination level varying as a function of galaxy size, inclination, compactness, seeing color
- ✓ A proper measurement of the PSF,including outer wings, should be made: critical for decontamination
- ✓ Deconvolution techniques developed
- ✓ On-going efforts to make a physical model of the internal reflections with ray tracing experiments, allowing for a direct correction.



Star-forming disks in “red and dead” early-type galaxies

✓ outer star-forming disks, associated with HI gas

Star-forming disks in “red and dead” early-type galaxies



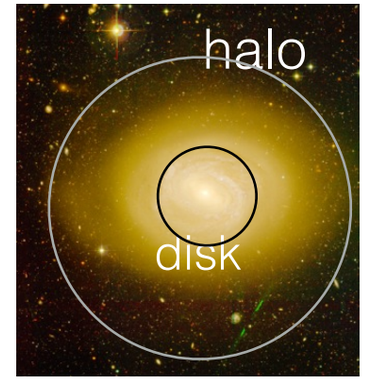
Yildiz et al., 2015

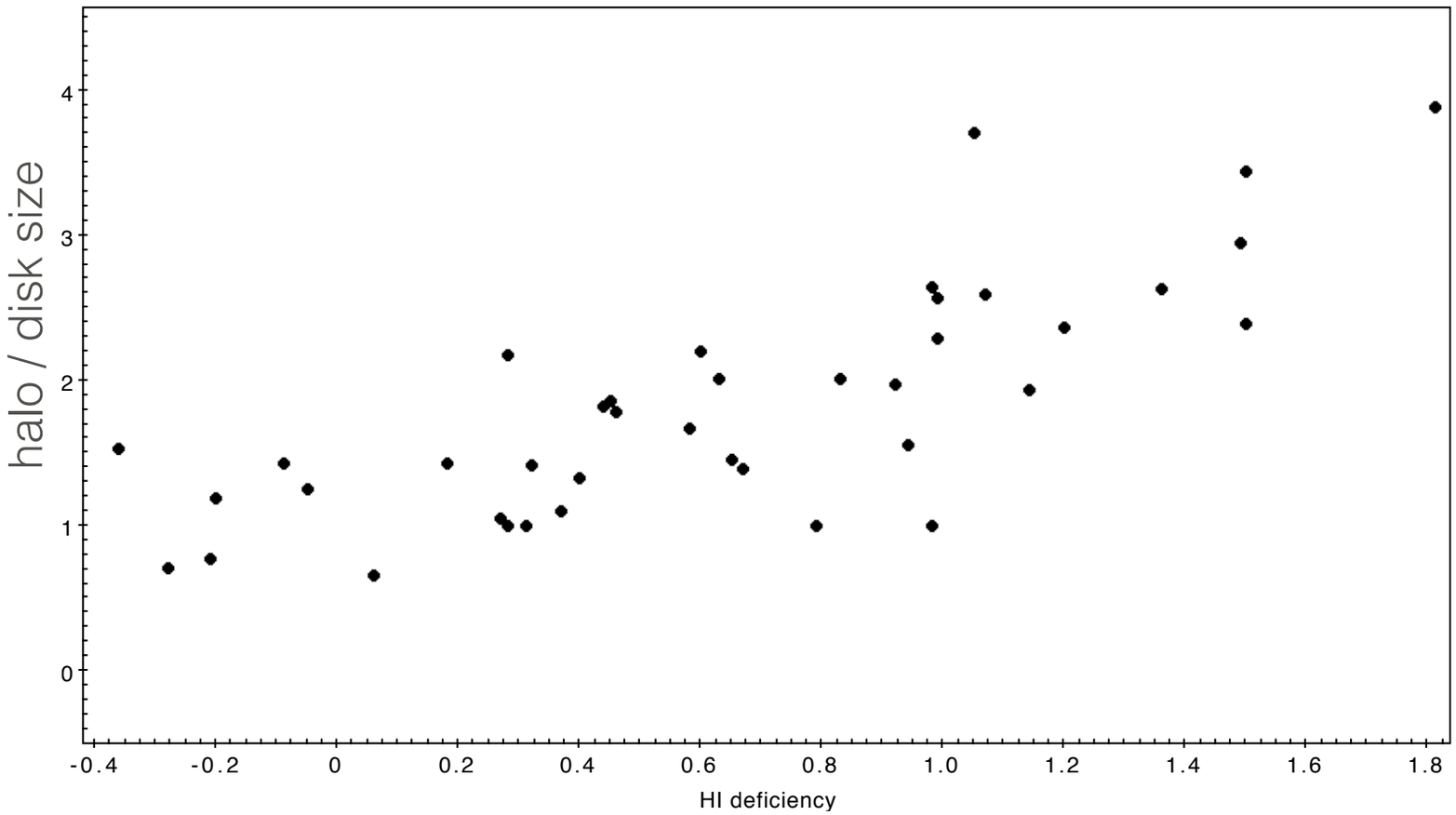
✓ extended inner dust lanes, associated with molecular gas

Dead disks/halos in star-forming late-type galaxies

- ✓ Virgo Cluster: sequence of LTGs with increasing halo size … or decreasing star-forming disk

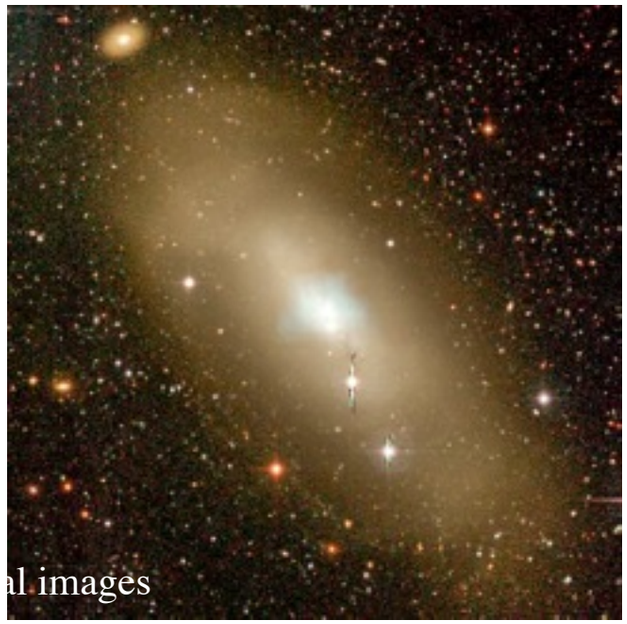
Generating the old stellar « halo »





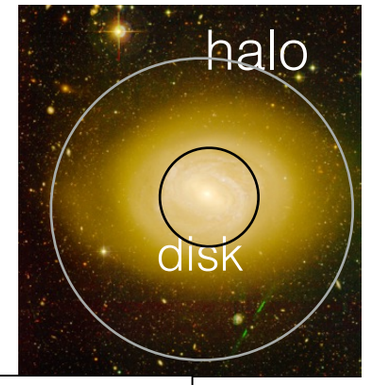
- ✓ Star formation truncation linked with the HI deficiency

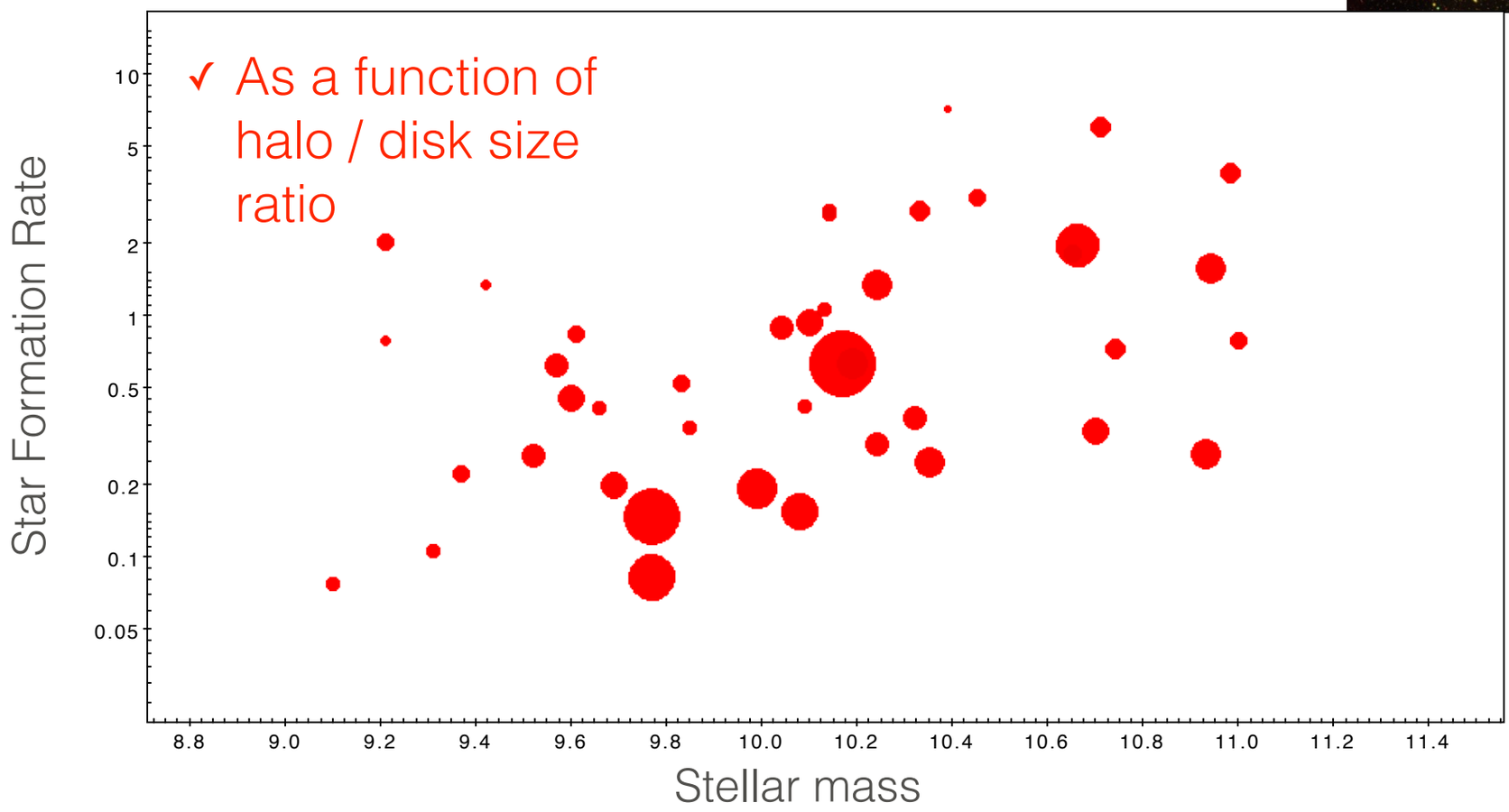
HI (VIVA: Chung et al) on deep optical images



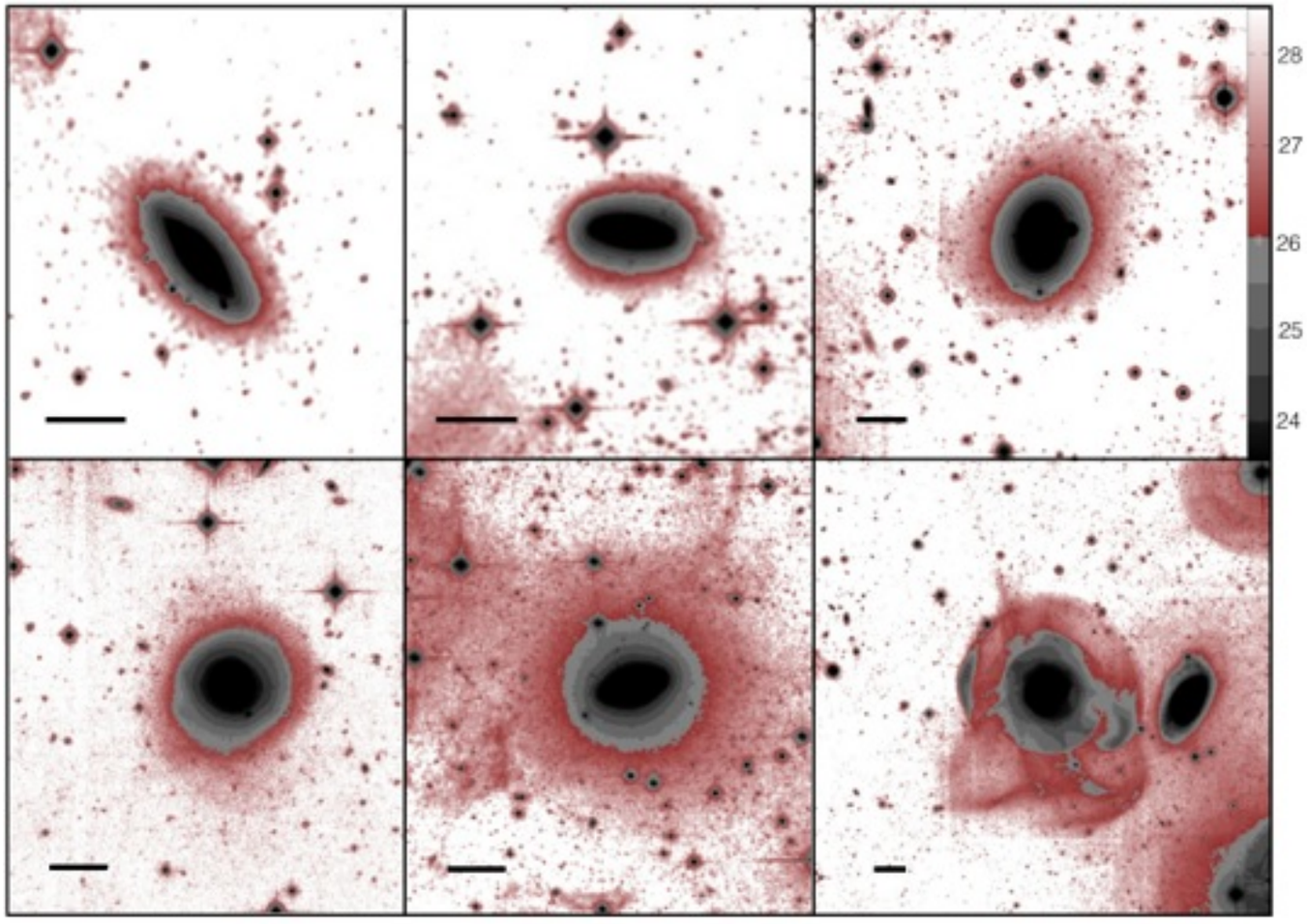
Star formation quenching

- ✓ Outside in quenching of star formation consistent with ram pressure as the major actor

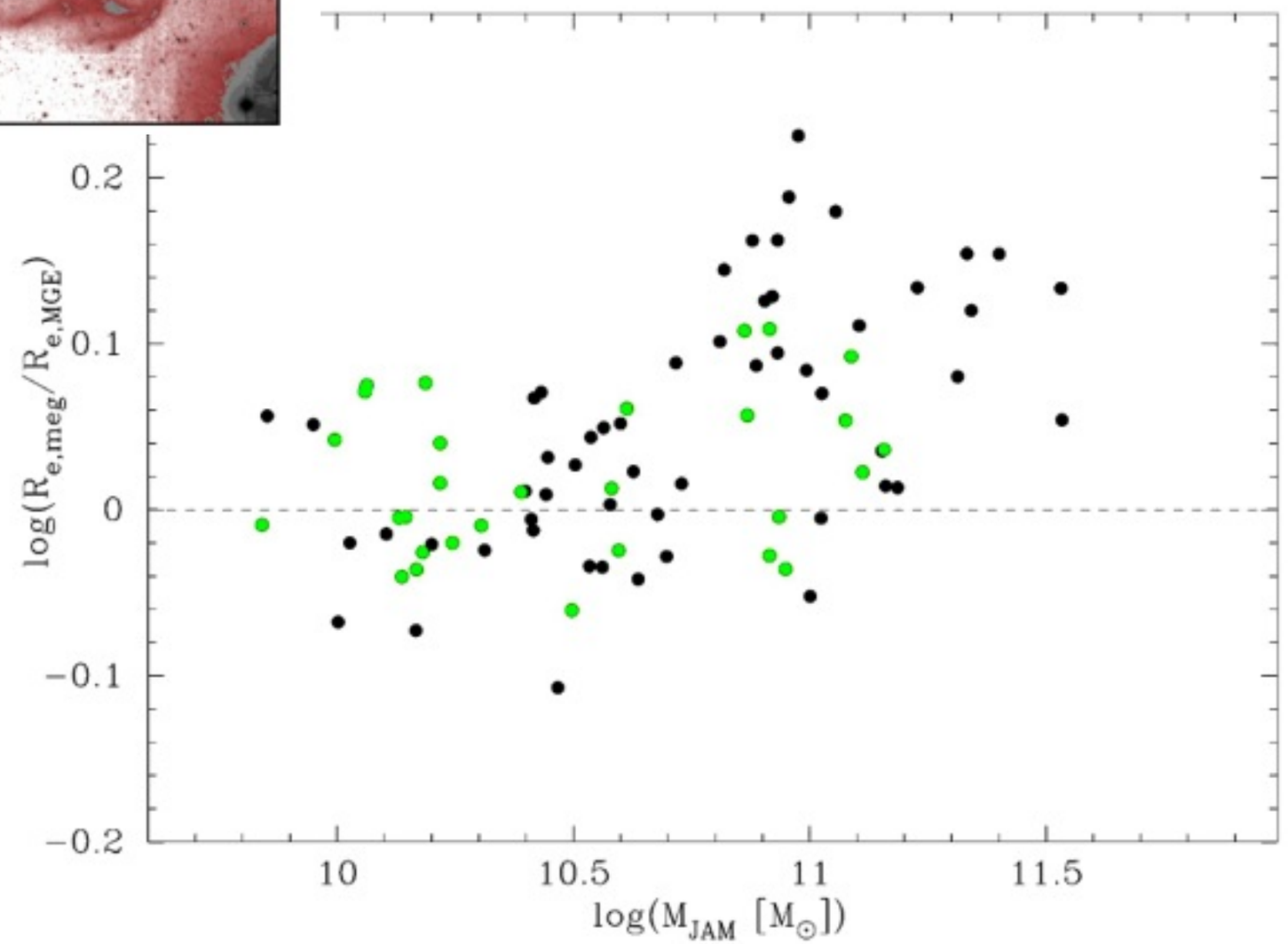




Deep imaging and the fundamental scaling relations of ETGs



- ✓ The stellar mass in the galaxies « halo » (beyond isophote of 26 mag arcsec^{-2}) is small: 6 percent on average
- ✓ However systematic changes with mass, galaxy type

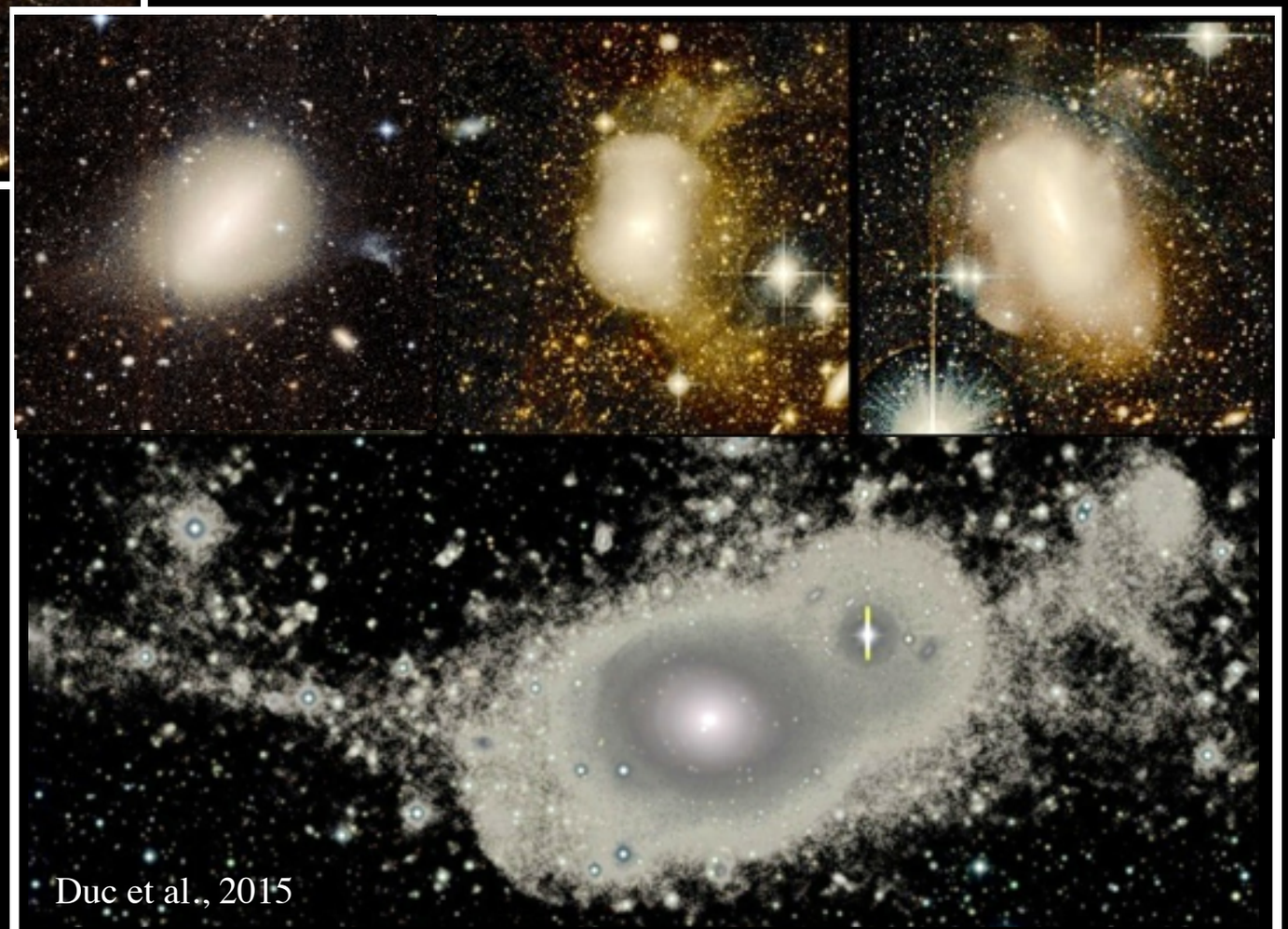


- ✓ Effective radius changed by a factor of up to 1.6 for galaxies more massive than 10^{11} Mo
- ✓ uncertainties in Re, total stellar mass contribute to the scatter of the size-mass relation, and SFR-mass main sequence

Deep imaging and the detection of fine structures

- ✓ Diffuse tidal plumes … … revealing on going tidal interactions

- ✓ Typical life time of tails of 1-2 Gyr



- ✓ Perturbed isolated central body and gas rich tidal tails … revealing past wet major mergers

Duc et al., 2015

Deep imaging and the detection of fine structures

- ✓ Narrow stellar streams … … revealing on going / past gas-poor minor mergers

- ✓ Typical survival time of >4 Gyr

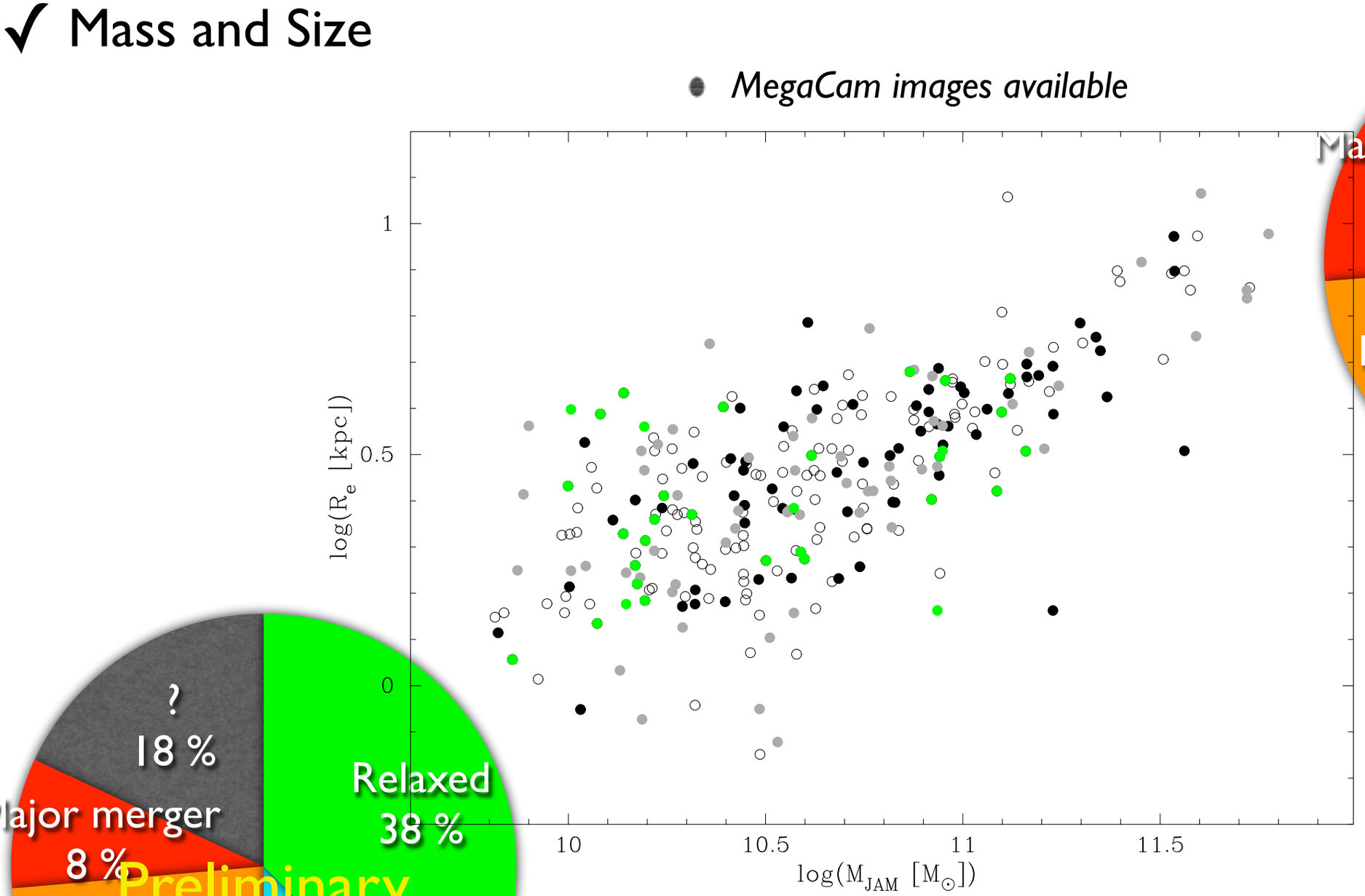
- ✓ Sharp-edge shells…… revealing past intermediate mass mergers

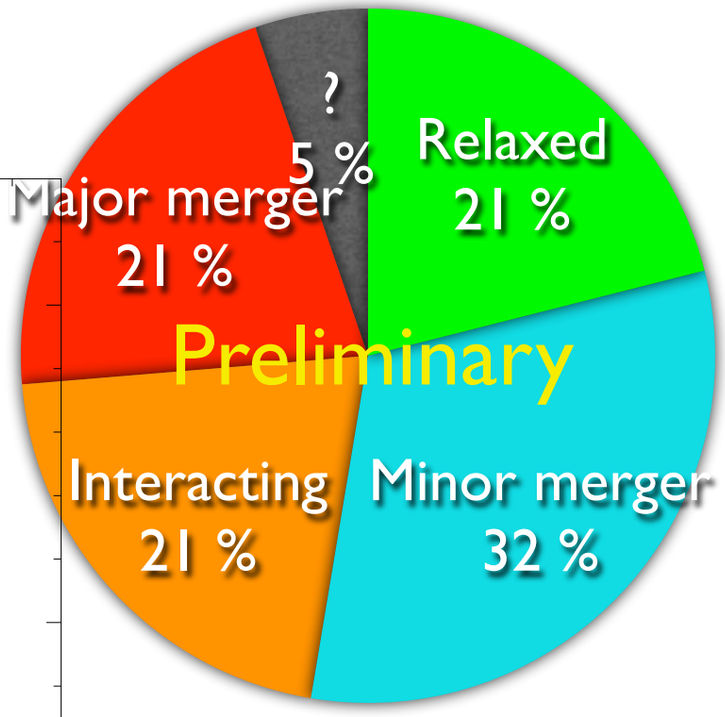
MATLAS

NGVS

Correlating fine structure index with:

✓ Mass and Size





log(M)>11*

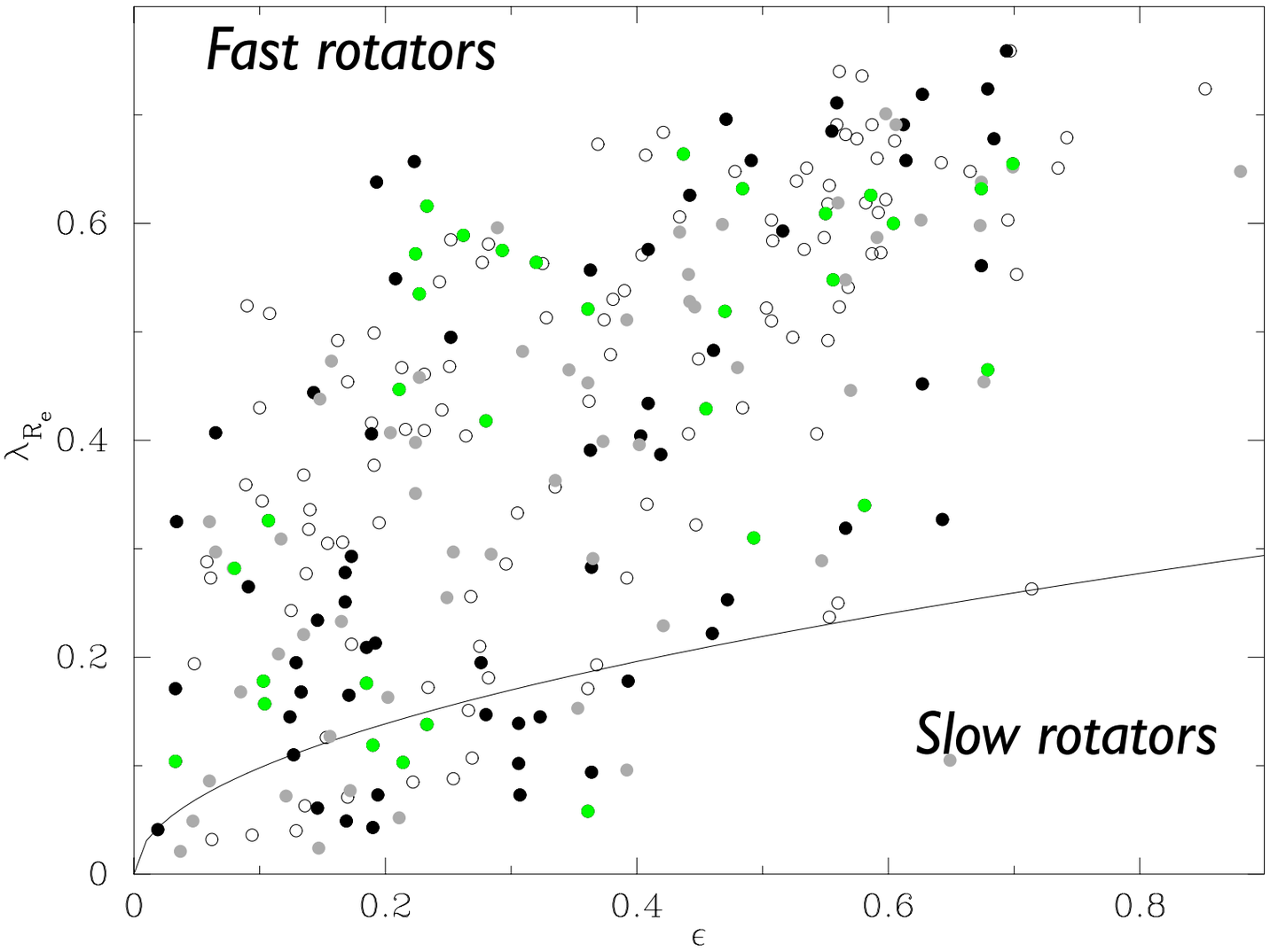
Outside Virgo!

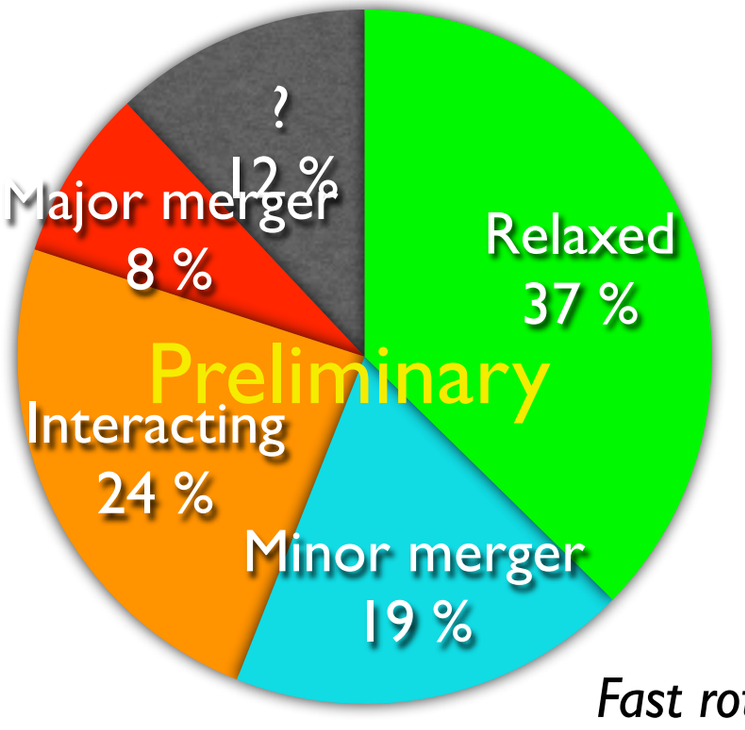
log(M)<11*

- Low mass galaxies more relaxed

Correlating fine structure index with:

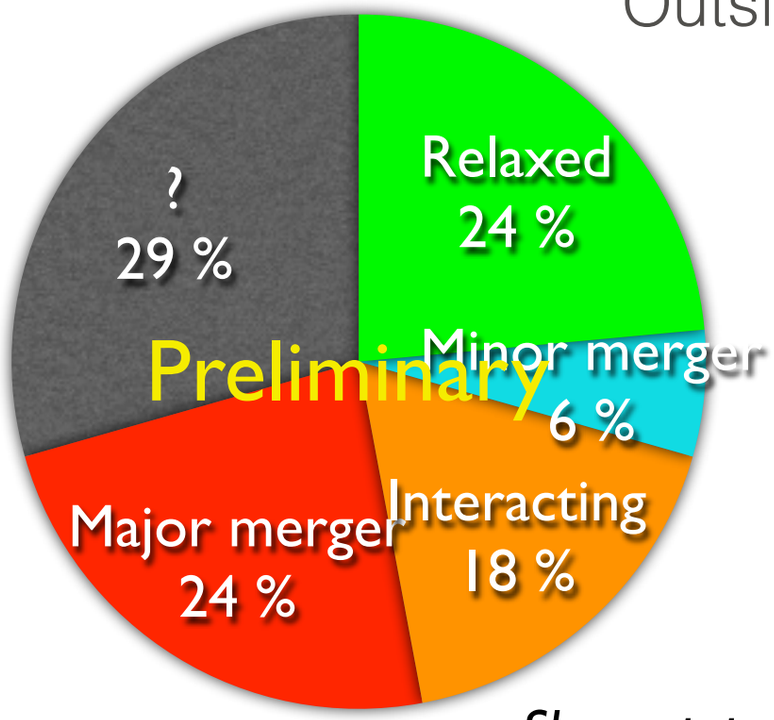
✓ Stellar kinematics





Fast rotators

Outside Virgo!



Slow rotators

- Fast rotating ETGs more relaxed than slow rotating ones

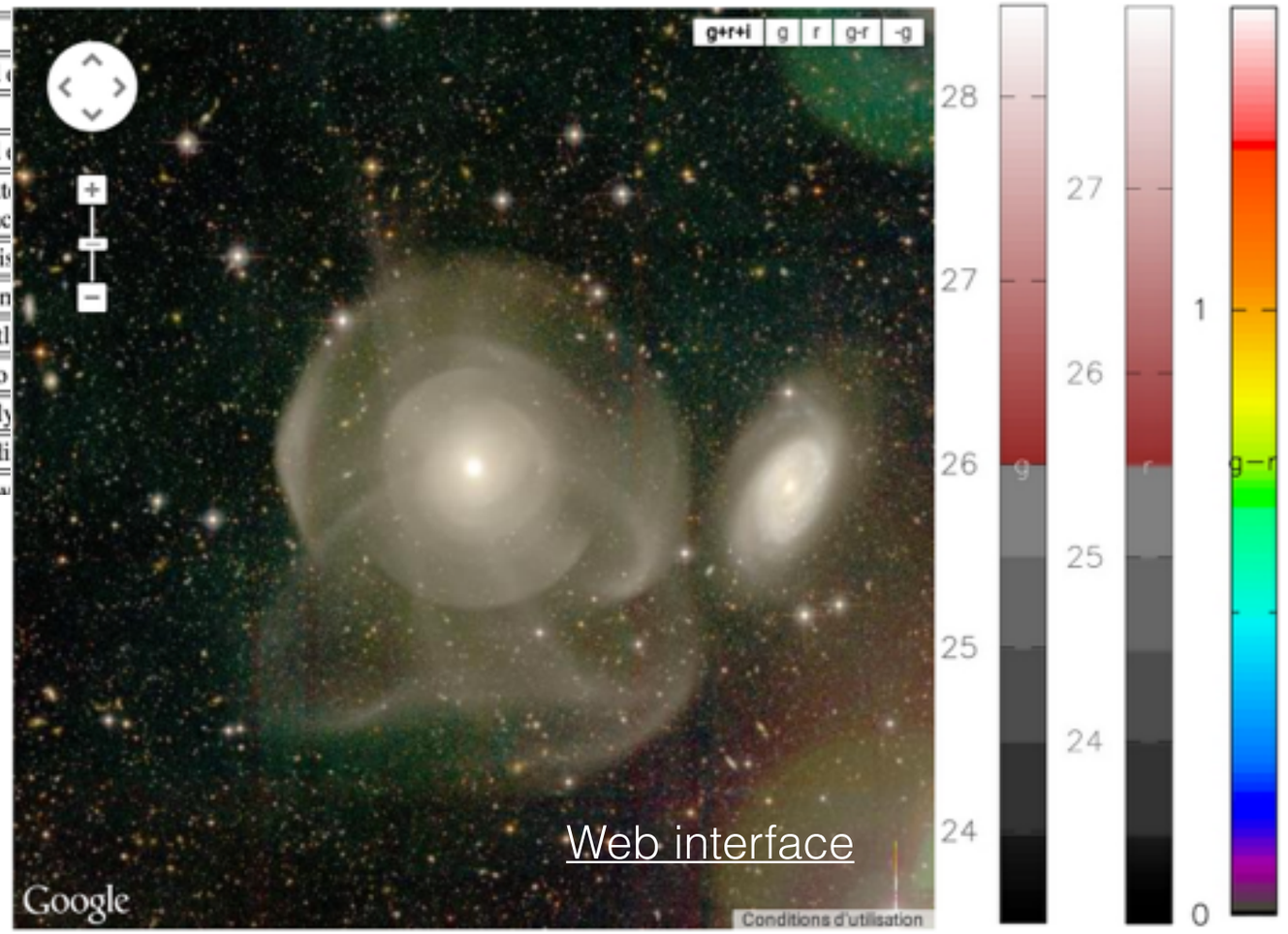
http://matlas.in2p3.fr/

Early-type galaxies as seen with deep optical images

The 92 ETGs galaxies in this list are presented in Atlas3D Paper XXIX, Duc et al., 2014, MNRAS in press. See tables 2 and 3 for explanations on the morphological class adopted here. Clicking on the galaxy name gives access to the jpeg true color images, surface brightness and color maps, residual images after galaxy model subtraction. Images may be explored with a navigation tool. A pdf version of the image catalog is available here.

Galaxy	Class	Comments
NGC0448	I+s	The ETG is in a tidal interaction with a disturbed companion.
NGC0474	M+s+r+ph	The ETG is surrounded by multiple concentric shells and hosts several radial streams. Its outer halo reaches the disk of the unperturbed companion spiral galaxy, NGC 0470.
NGC0502	M+t?+r?+ah-wc-h	The stellar halo of the ETG is asymmetric, possibly due to the presence of a diffuse tidal tail and/or a shell.
NGC0509	R-pc	
NGC0516	R-pc	
NGC0524	U-pc-h	The ETG is surrounded by galactic cirrus and
NGC0525	R-pc-h	
NGC0661	U+ah-pc	The ETG is surrounded by galactic cirrus and
NGC0680	I+t+s+r+ph+wl-wc	The ETG is tidally disturbed, showing two ext going interaction or a past major merger is unc
NGC0770	I+t-pc	The ETG lies within a prominent tidal tail. It is
NGC0936	C+s+wl	A stellar stream hosting a tidally disrupted con
NGC1023	U+ah-h	The stellar halo of the ETG seems to be slightl
NGC1121	U-h	The ETG totally lies within the reflection halo
NGC1222	M+t+r?+ph+pl	The ETG exhibits multiple signs of a relatively
NGC1248	R-pc-h	The ETG does not show any evident sign of di
NGC1266	C+s?+wl-pc	The ETG has several low mass companions, w

om this on-



Web interface

- ✓ Data (jpg maps) publicly available online for 92 galaxies

NGC0474

Map size: 142.89 kpc
Map center: (0.76 kpc, -18.04 kpc)

Recenter map
Combined maps
SDSS comparison

Conclusions

- ✓ Tremendous progress in deep imaging techniques (despite cirrus and scattered light problem)
- ✓ Evidence for outside in star formation quenching due to ram pressure
- ✓ Large number of massive galaxies (400) observed, giving unbiased constrains for numerical simulations
- ✓ Frontiers between early and late type galaxies blurred
- ✓ Presence of collisional debris, strong function of galaxy mass, internal dynamics, etc….