



Morphologie des galaxies



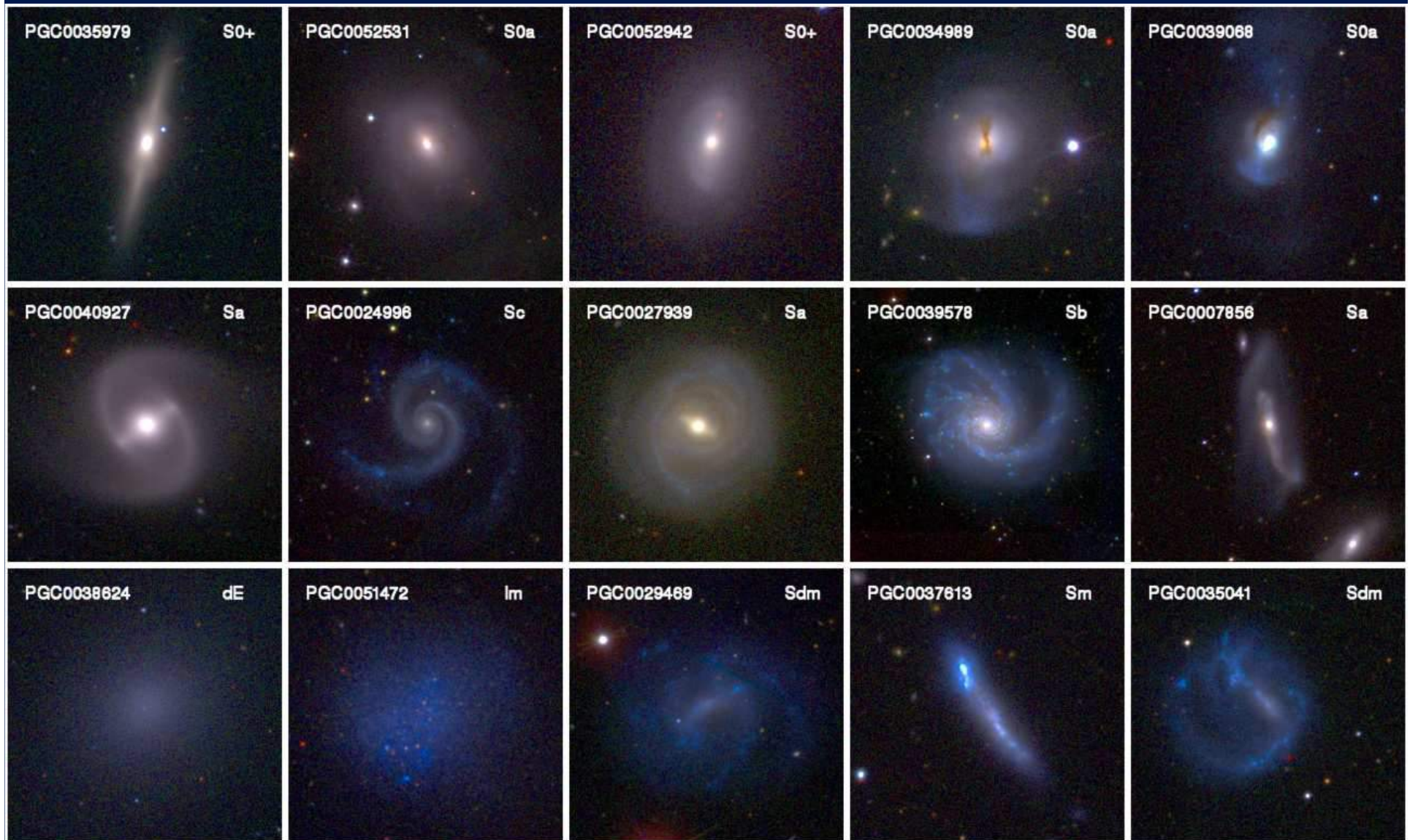
Valérie de Lapparent

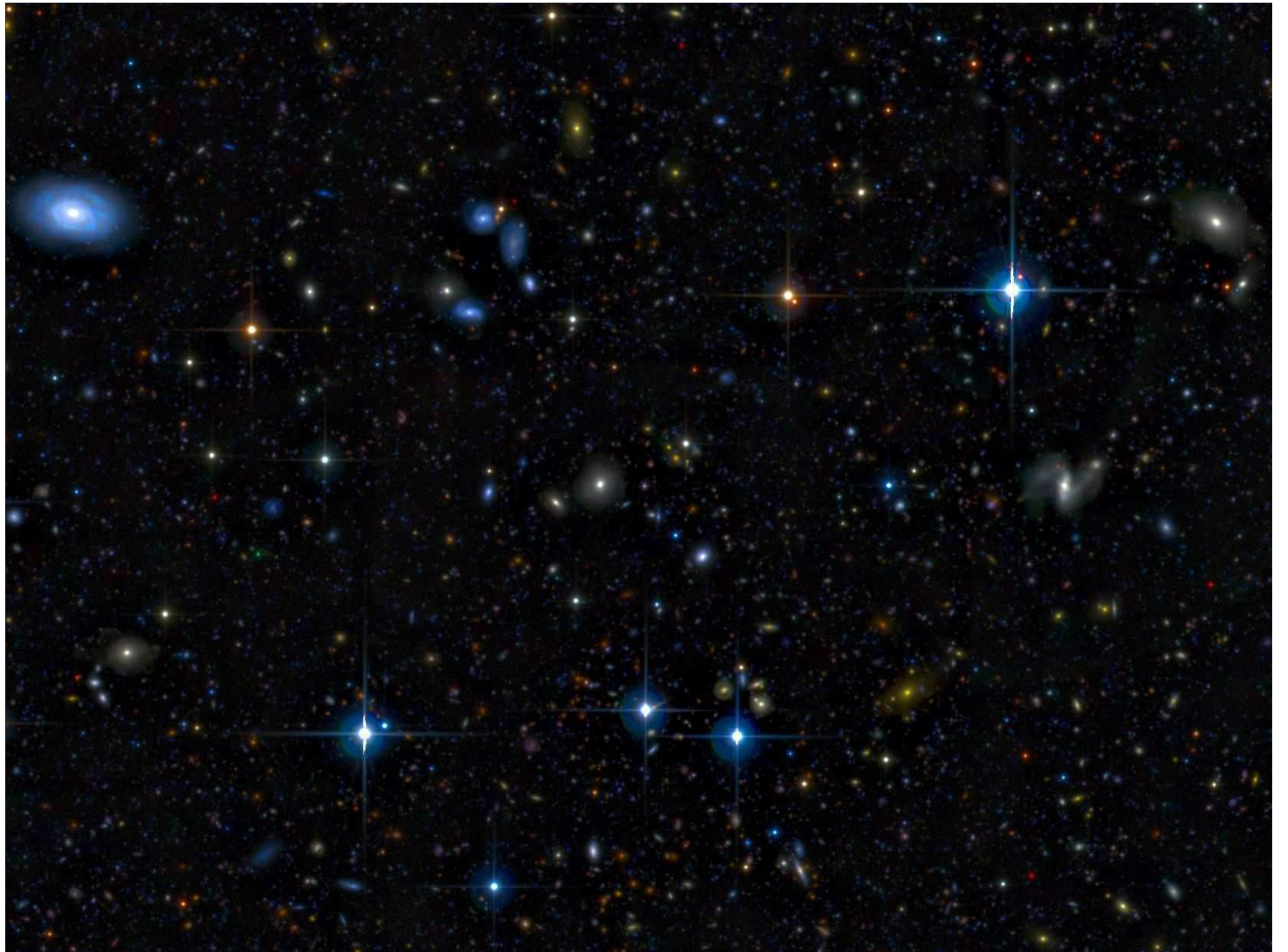
Institut d'Astrophysique de Paris CNRS / UPMC



- La diversité des galaxies
- Le lien avec la toile cosmique
- Catalogue morphologique EFIGI
- La morphologie des galaxies à grande distance
- Le défi technique de la morpho-photo-métrie des galaxies
- L'évolution des galaxies par inférence bayésienne
- Objectifs et perspectives

La diversité des galaxies

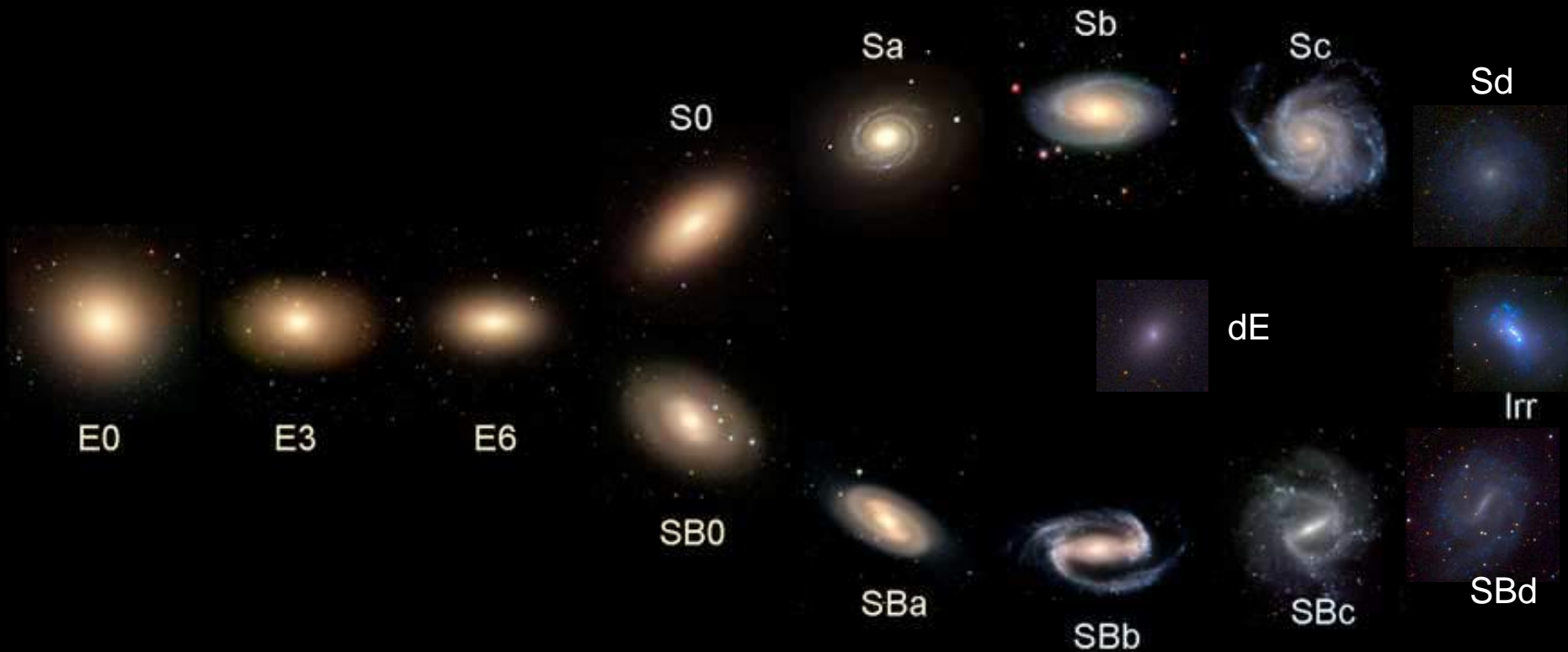






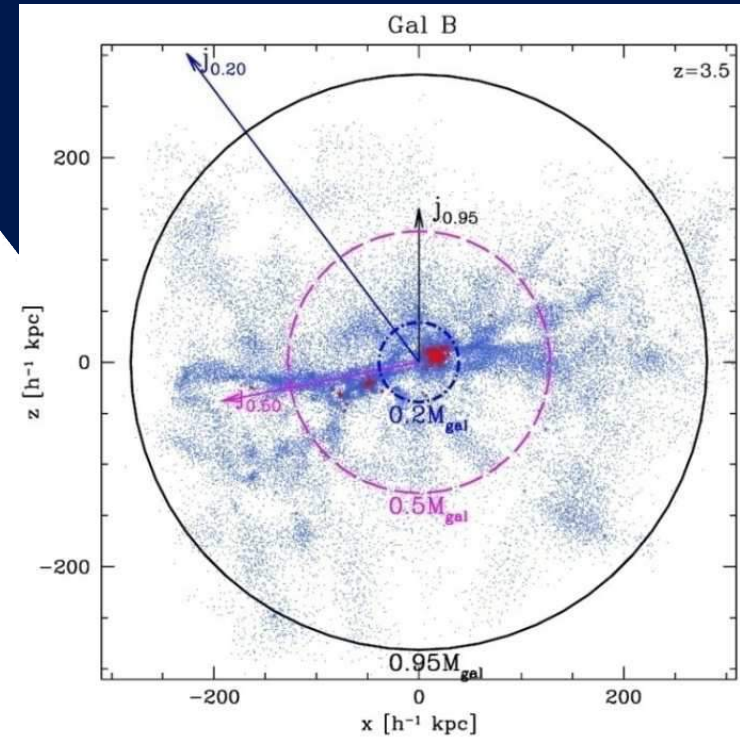
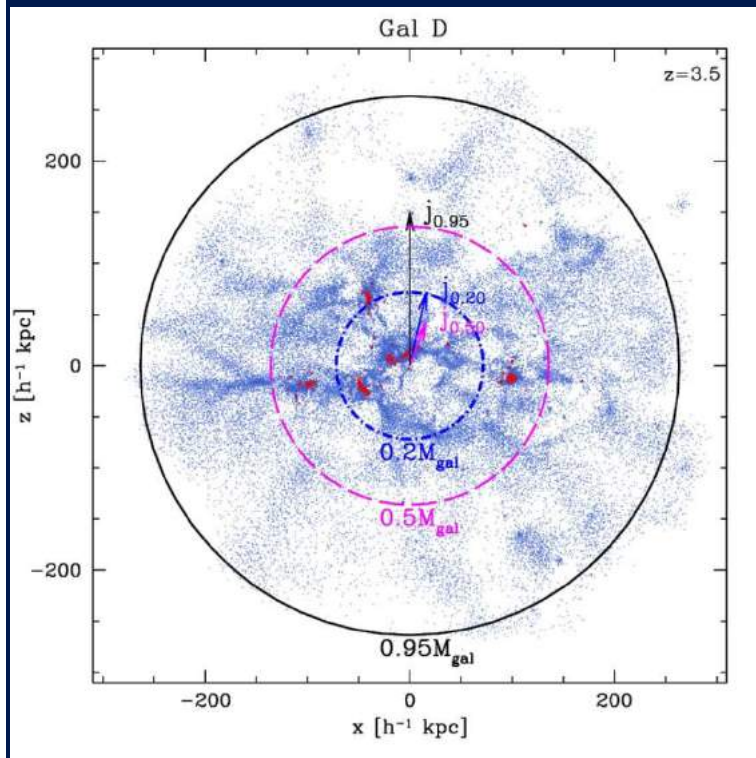
La séquence de Hubble (1926)

Hubble's Galaxy Classification Scheme



Simulations à N-corps + hydrodynamique matière noire + gaz

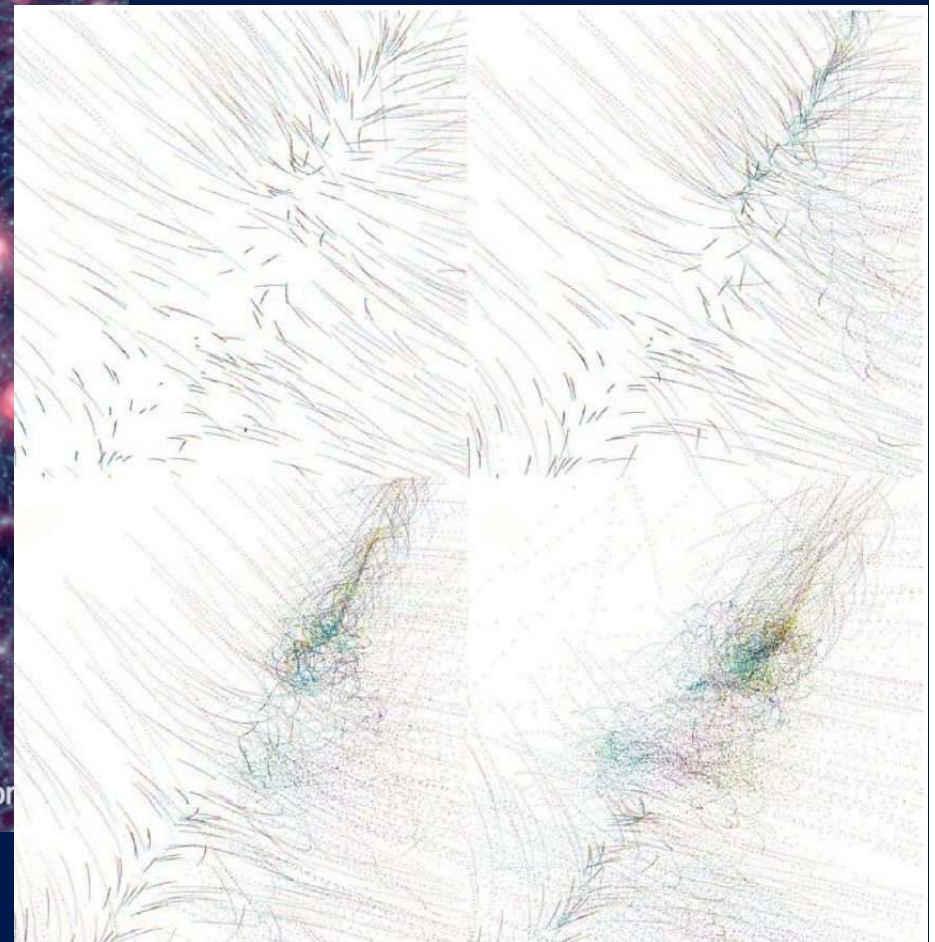
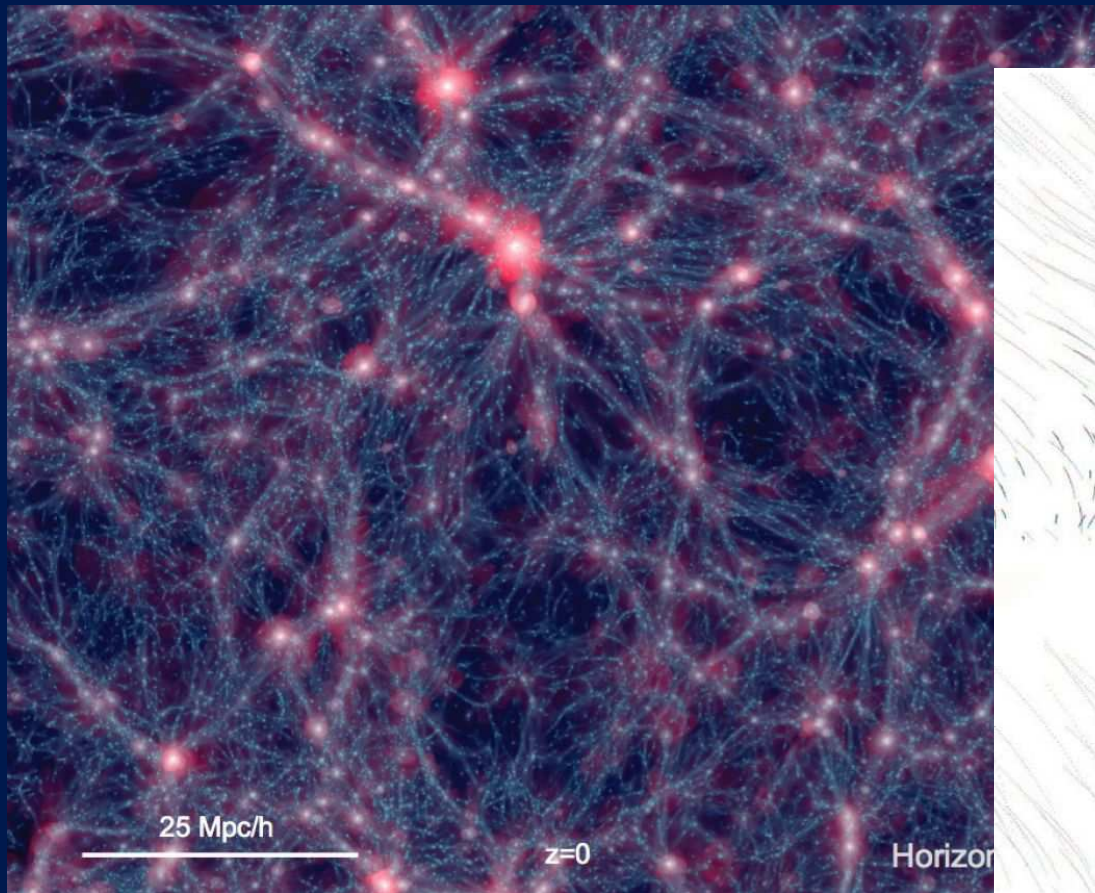
- Morphologie déterminée par la cohérence du moment angulaire du gaz accrété avec le gaz déjà présent



Sales et al. 2012 "GIMIC"

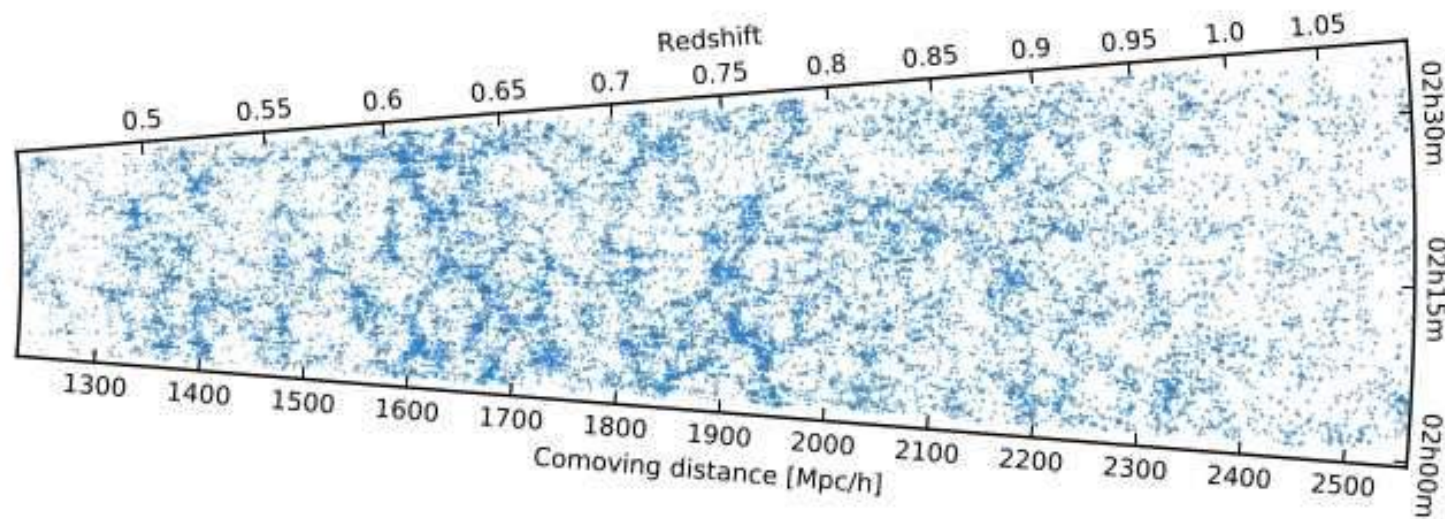
Simulations à N-corps + hydrodynamique matière noire + gaz

→ Accrétion matière par enroulement le long des murs vers les filaments

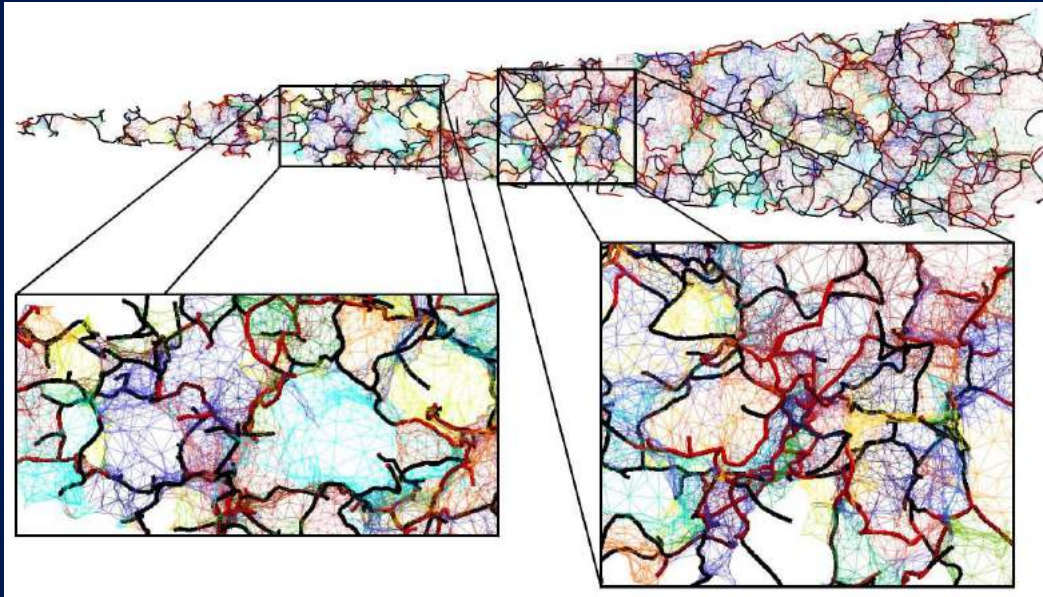


Dubois et al. 2016 Codis et al. 2012

La toile cosmique dans le relevé VIPERS



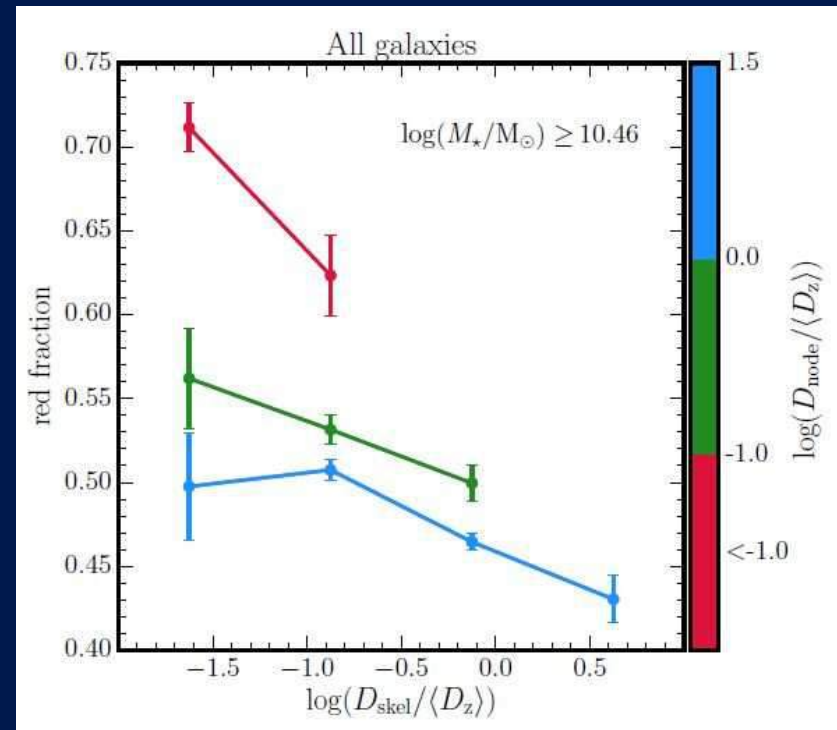
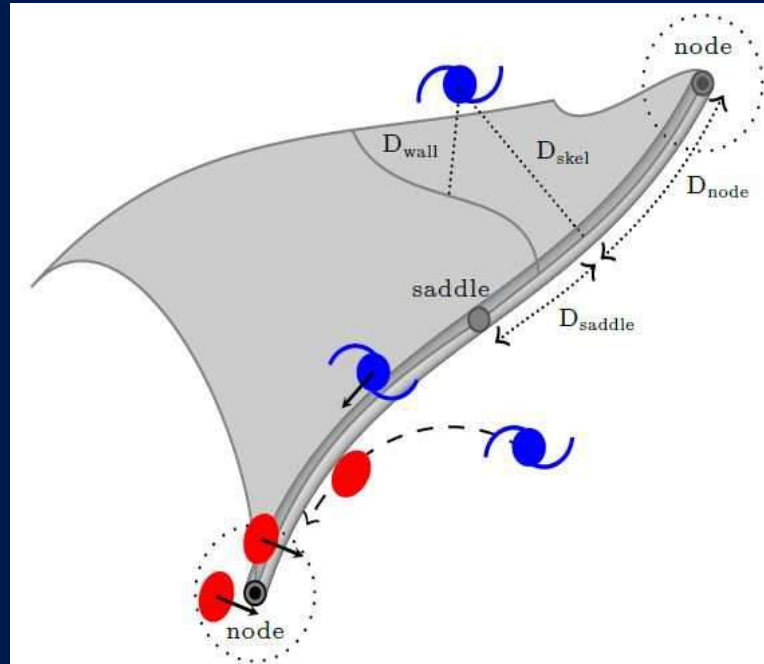
Guzzo et al. 2016



VIPERS

Toile cosmique versus couleur

Kraljic et al. 2018
ANR SPINe (PI : Pichon)



Catalogue morphologique EFIGI

« Extraction de Formes Idealisées de Galaxies en Imagerie »

- 4458 galaxies PGC proches: *ugriz* SDSS ($z < 0.05$)
 - catalogues et images on-line <http://www.efigi.org>
 - 16 attributs de forme (5 niveaux + intervalle de confiance) :
 - proéminence du bulbe / bras spiraux / barres / anneaux
 - courbure bras spiraux
 - texture (floculence, poussière, régions HII),
 - perturbation, contamination, environnement

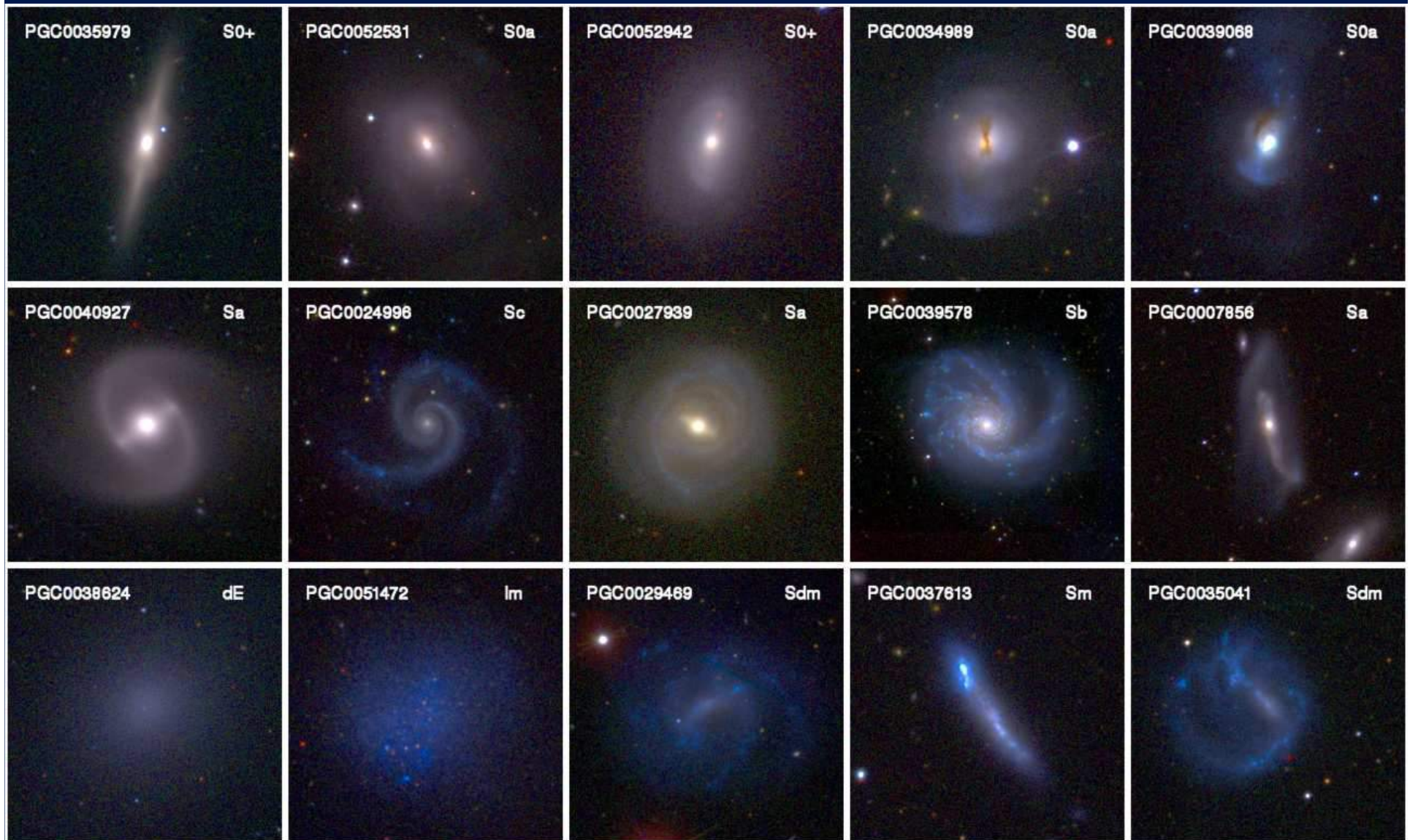


Baillard 2008, Bertin et al. 2011, de Lapparent et al. 2011

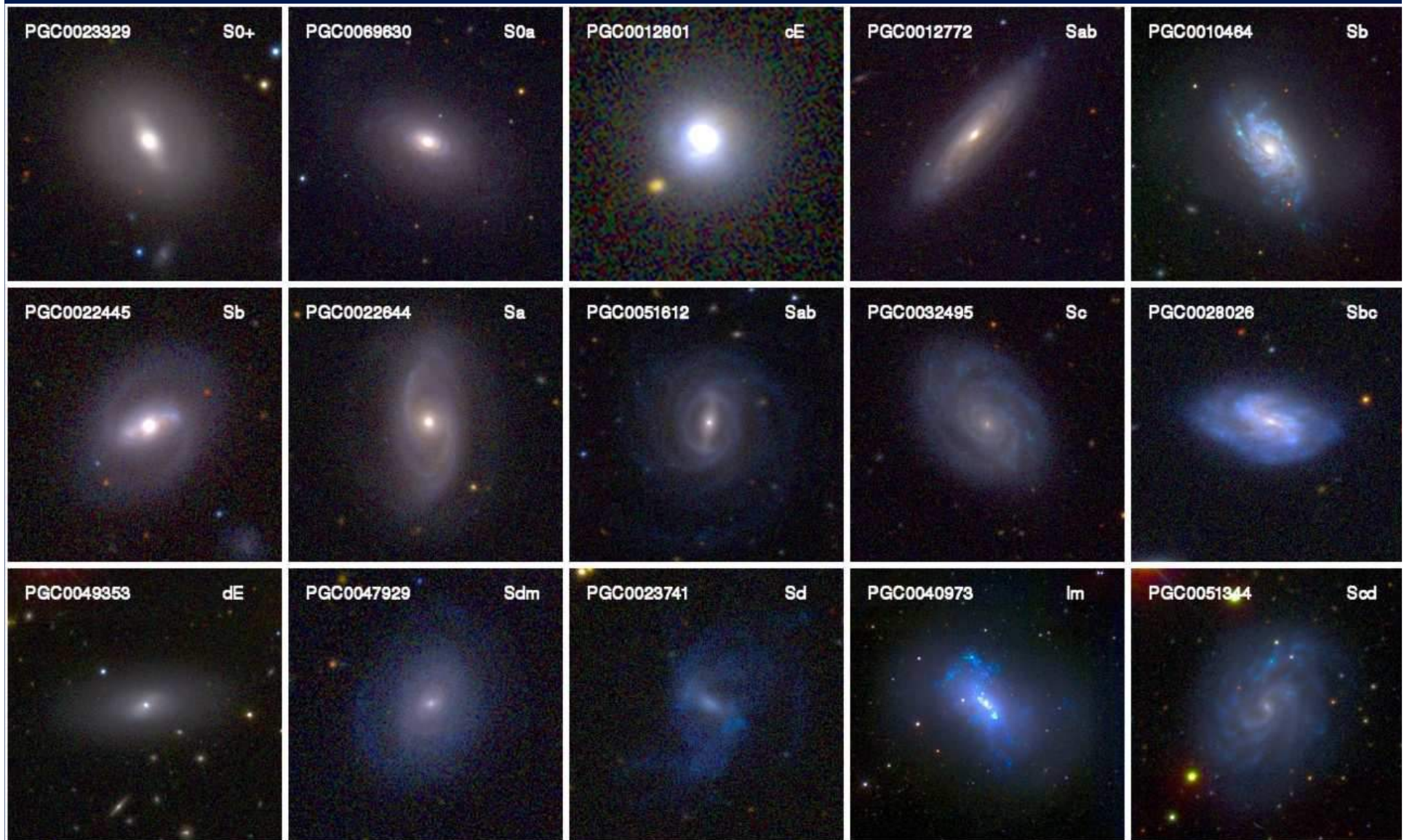
3 ans de classification visuelle (13 astronomes) et homogénéisation (2 astronomes EB + VdL)

The screenshot displays a galaxy classification software interface. On the left, a large image of a galaxy is labeled "PGC0030829" with a red checkmark. Below it is a search box with fields for "PGC number" and "Internal ID", and a "Search" button. The central panel shows "Hubble type" with a red checkmark and "Examples Sb" with three small galaxy images. Below this is a grid of galaxy icons categorized by "Elliptical", "Lent.", "Spiral", and "Irregular". The "Spiral" category is highlighted with a green bar. Below the grid are labels for "E", "S0⁻", "S0⁺", "Sa", "Sb", "Sc", "Sd", "Sm", and "dE". The right side of the interface features a series of sliders and checkboxes for various morphological parameters, each accompanied by a small galaxy image. The parameters include: Multiplicity, Contamination, Perturbation, Inclination, B/TRatio, BulgeEllipticity, BulgeBoxiness, Shell, HotSpots, VisibleDust, DustDispersion, Bar, InternalRing, ExternalRing, ArmThickness, ArmCurvature, CurveIrregularity, Flocculence, ArmContinuity (highlighted in red), ArmStrength, EightShape, and Rotation.

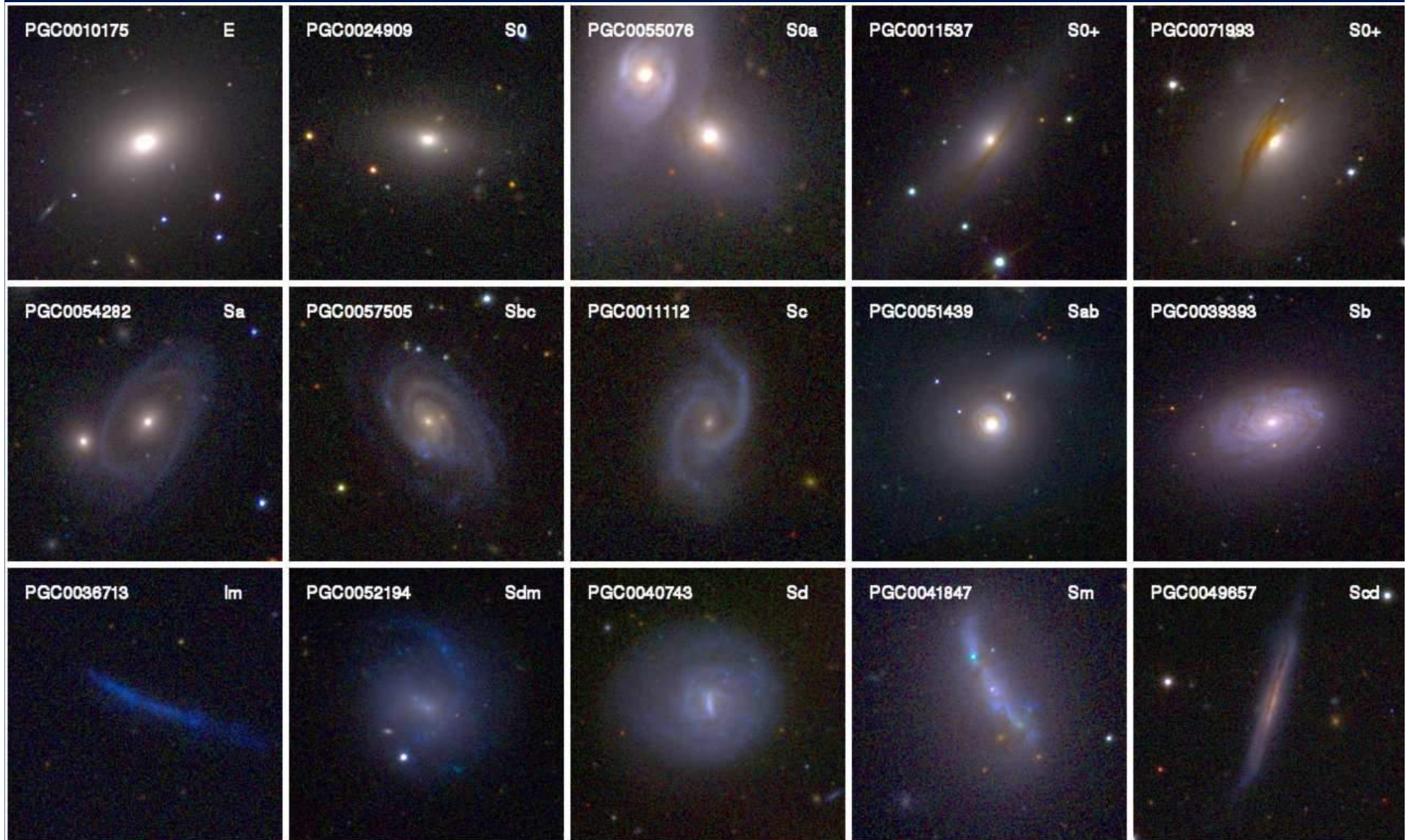
Attribut : Perturbation



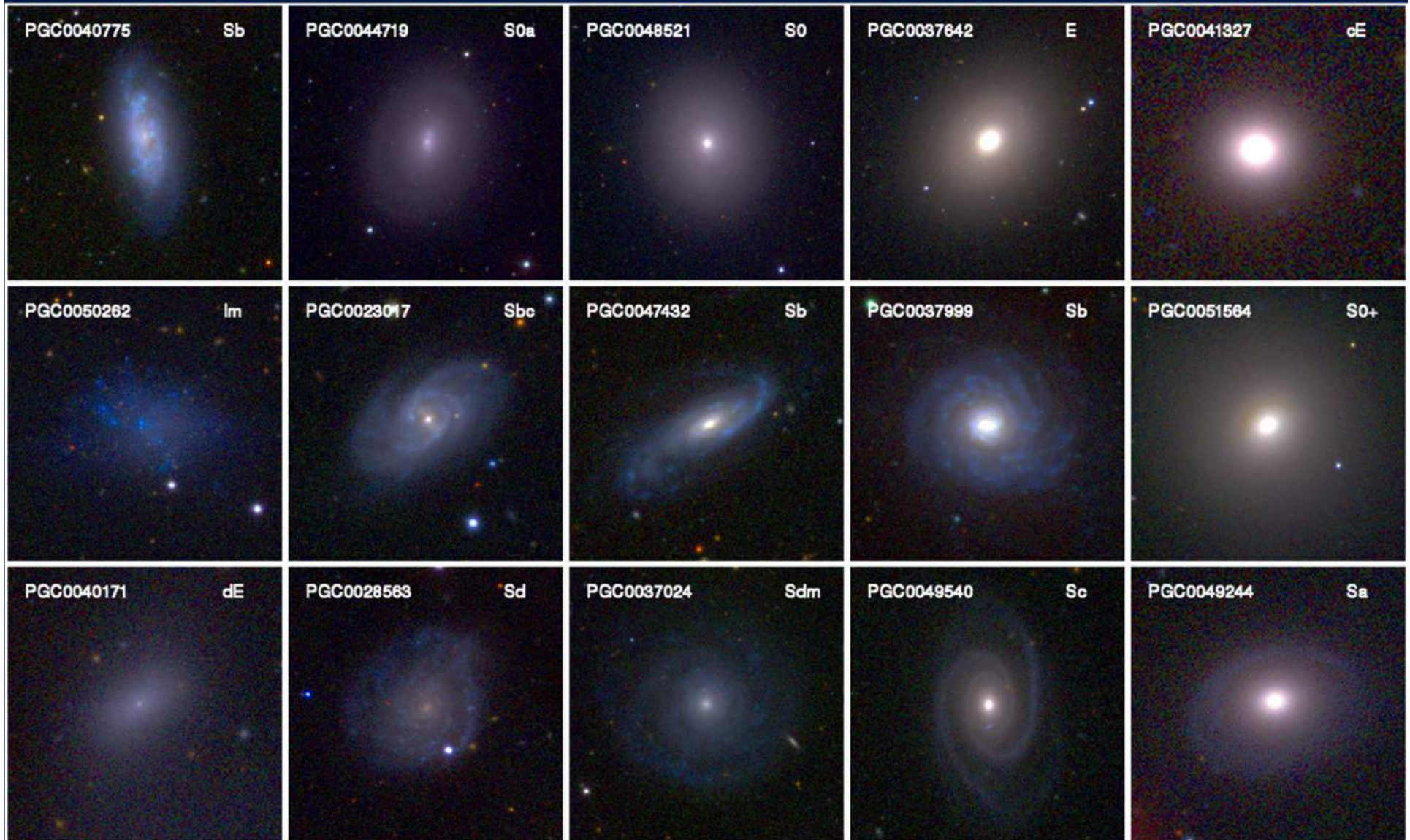
Attribut : Flocculence



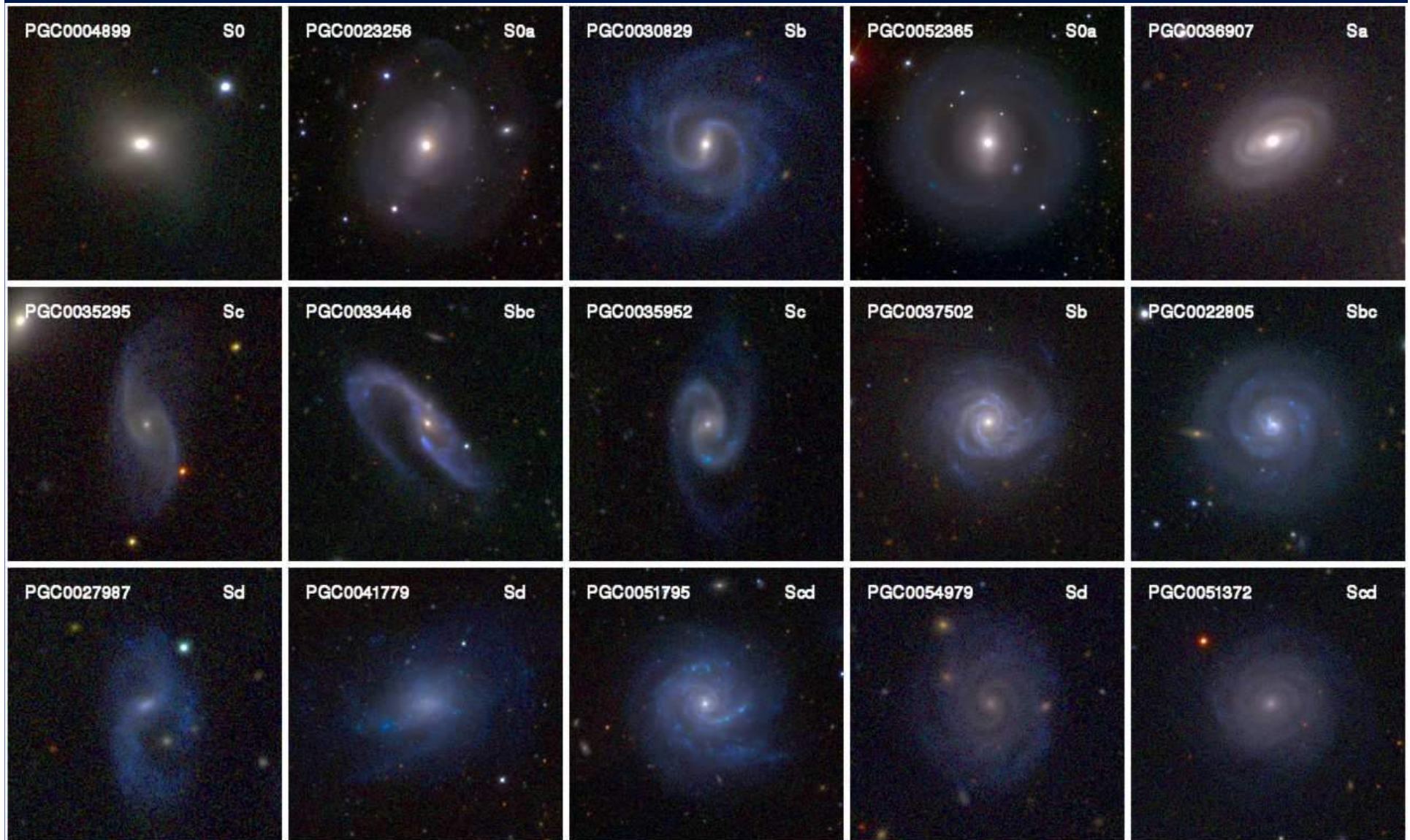
Attribut : Poussière visible



Attribut : Rapport flux Bulbe/Total



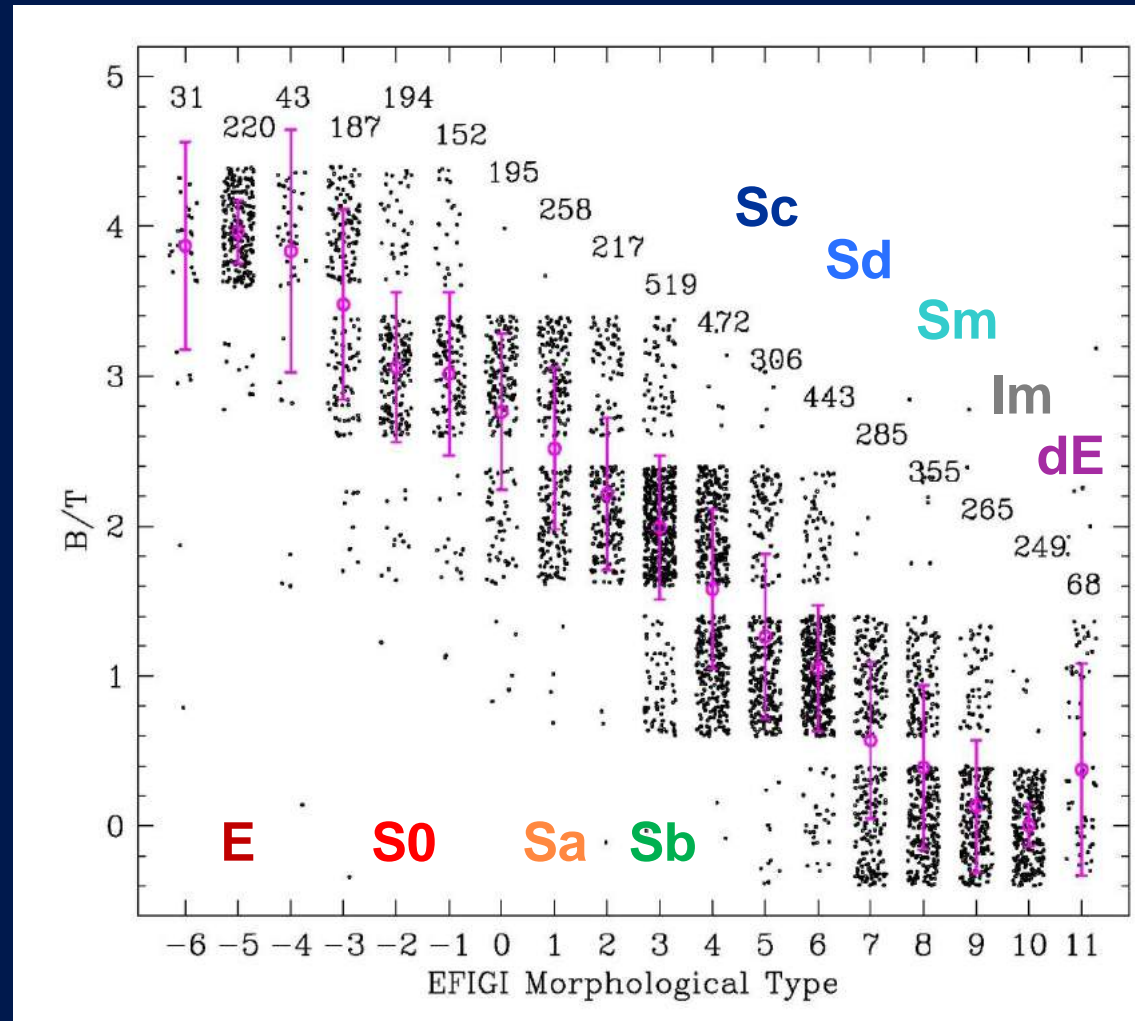
Attribut : Courbure des bras spiraux

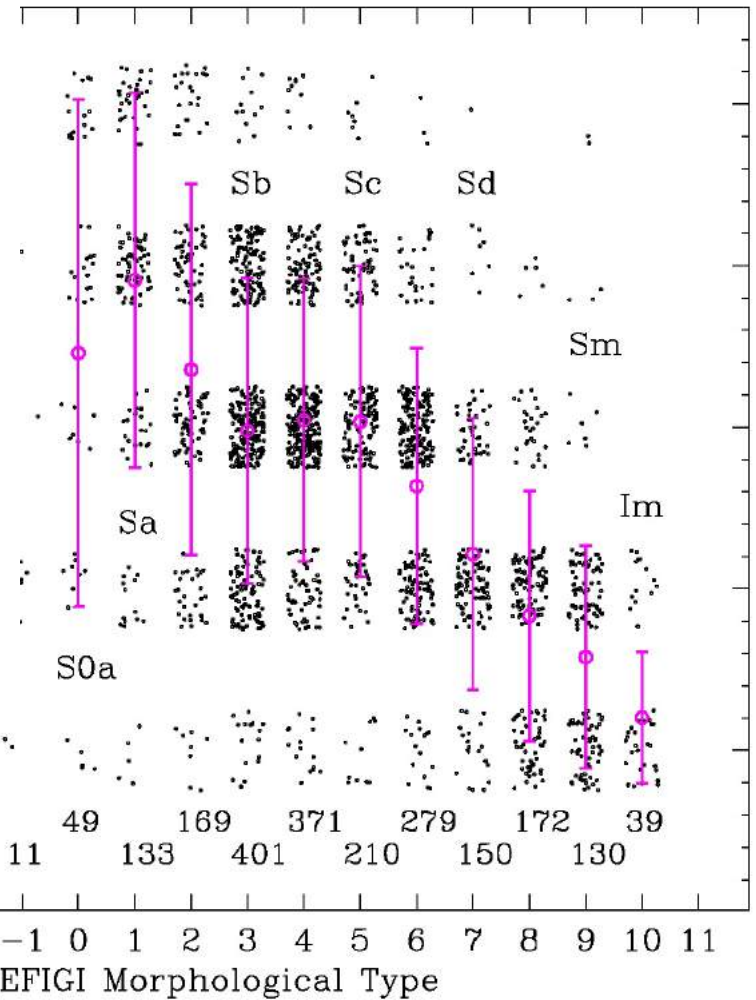
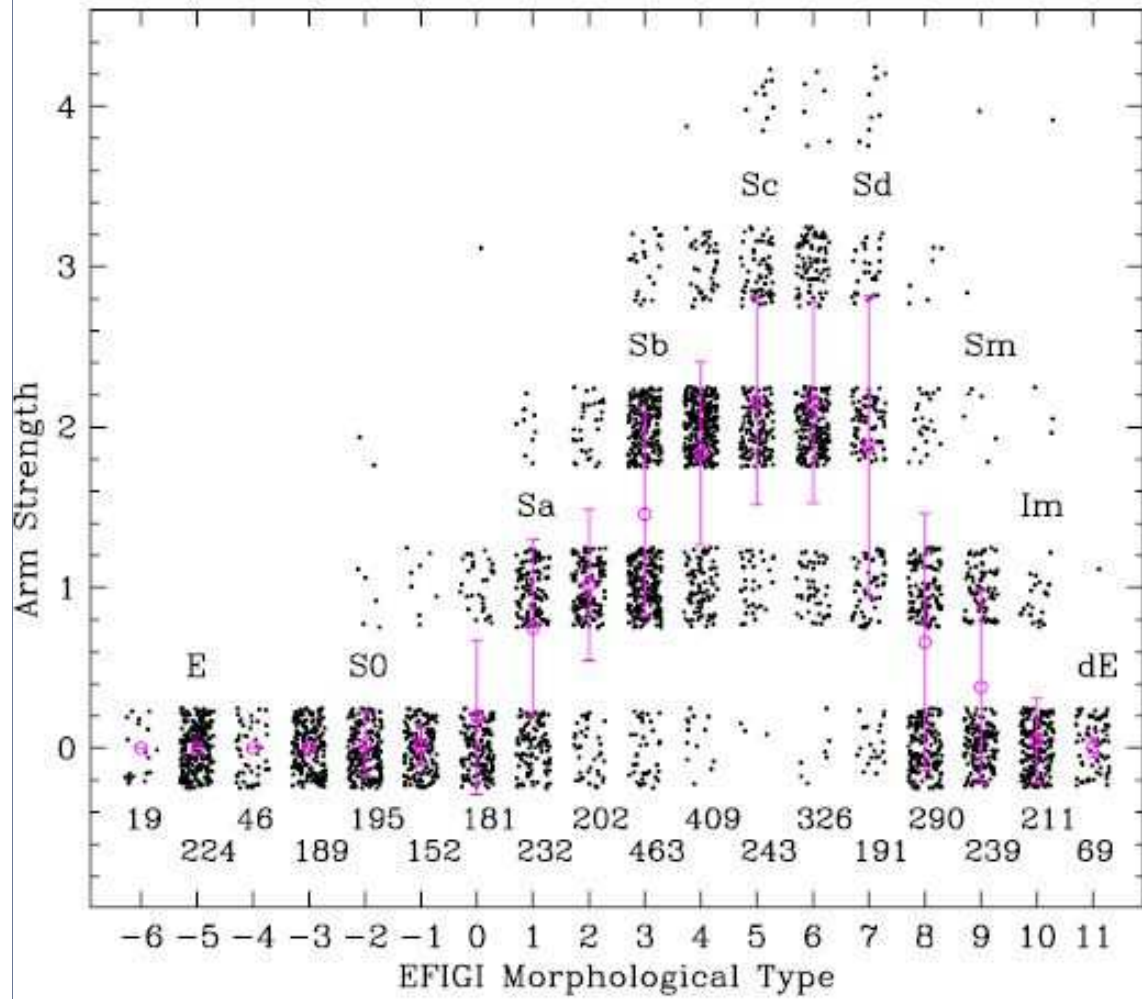


Reconstruction of EFIGI Hubble sequence

Supervised learning tasks using Support Vector Machines :

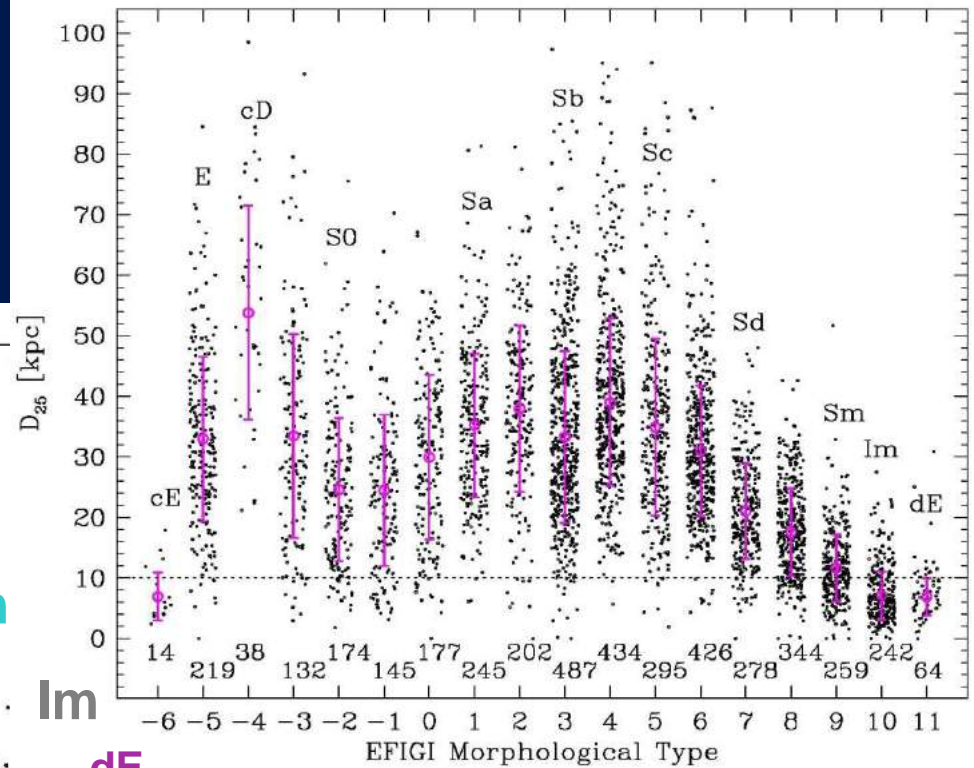
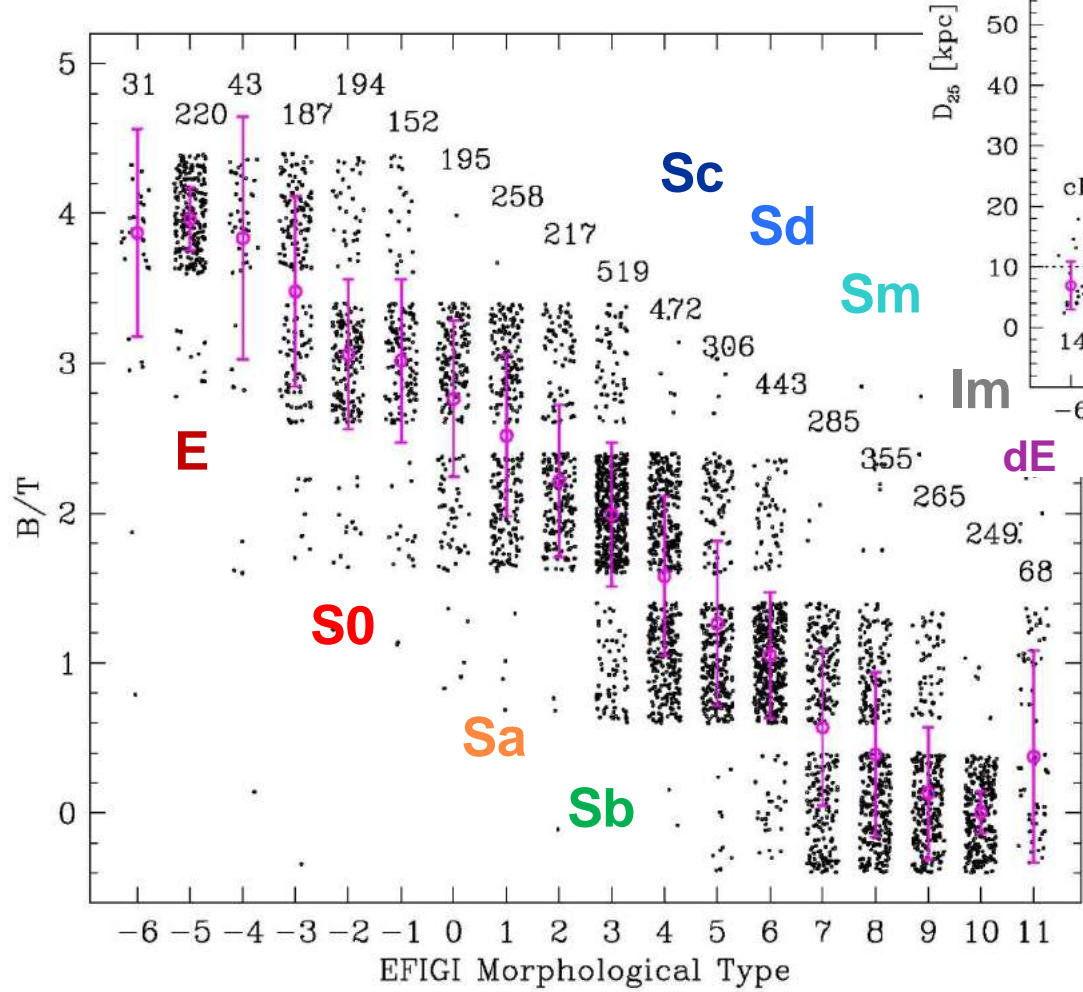
- Bulge/Total flux + Strength spiral arms + Curvature spiral arms



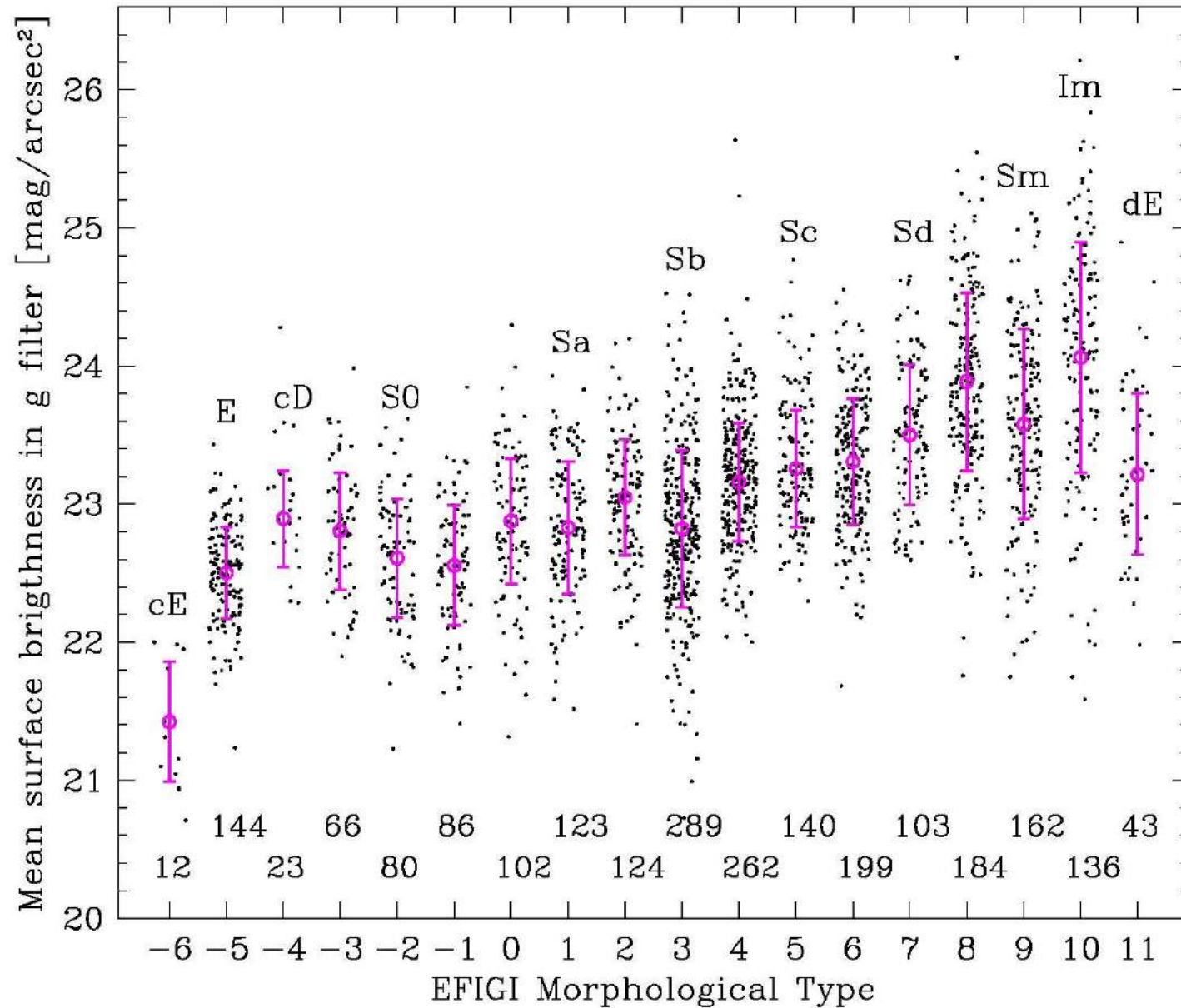


EFIGI Hubble sequence

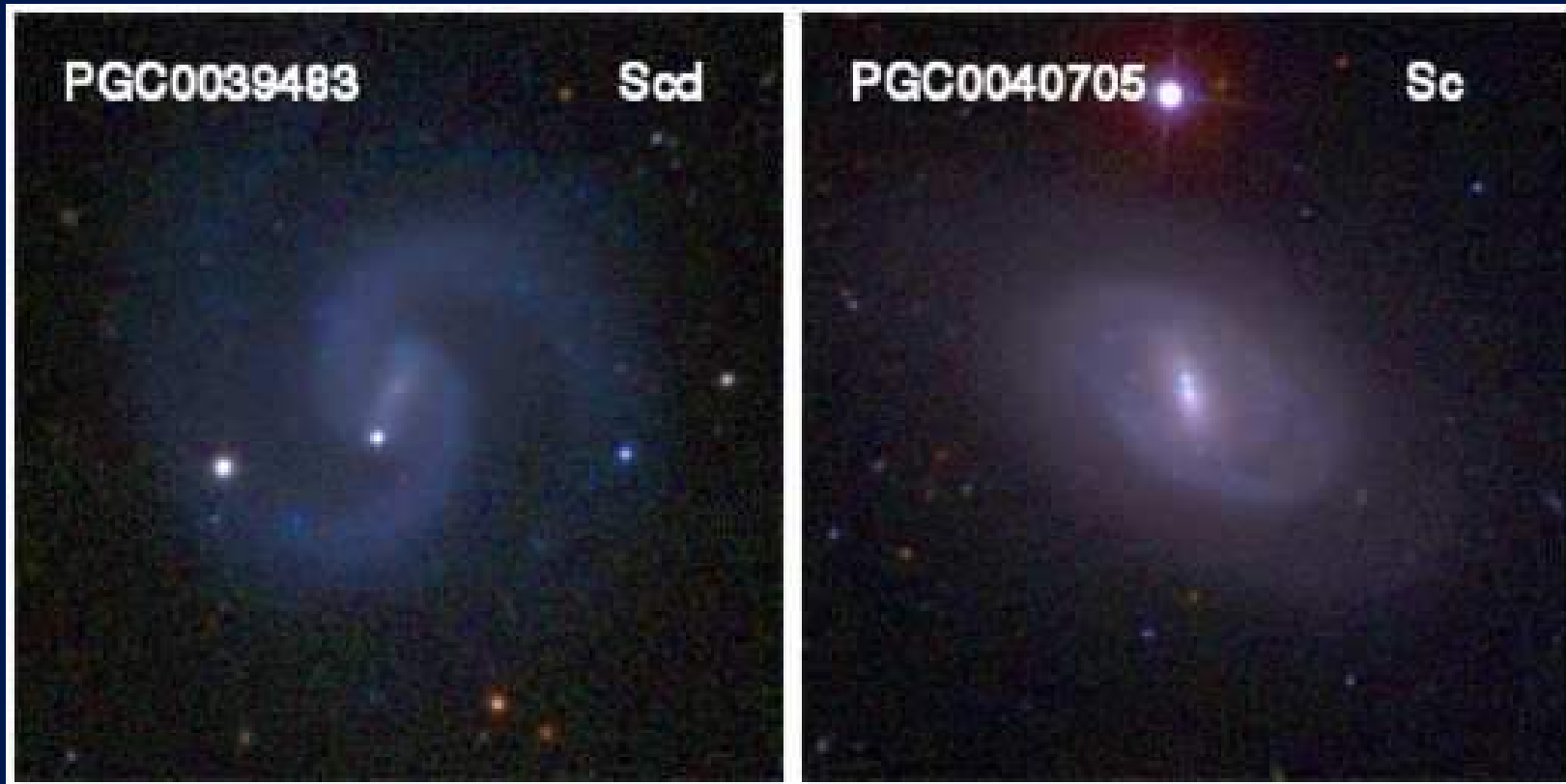
Large size dispersion and variation



EFIGI : variations en brillance de surface



2 galaxies naines spirales



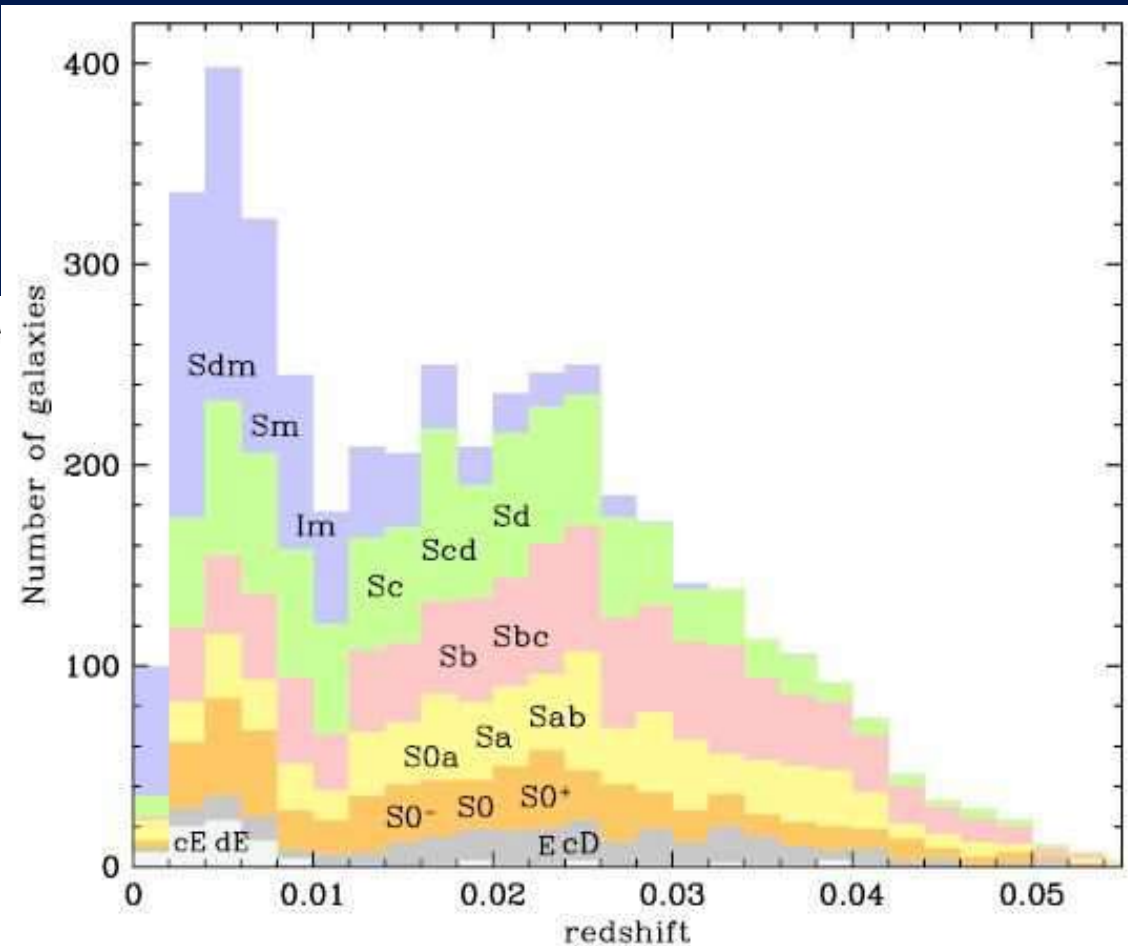
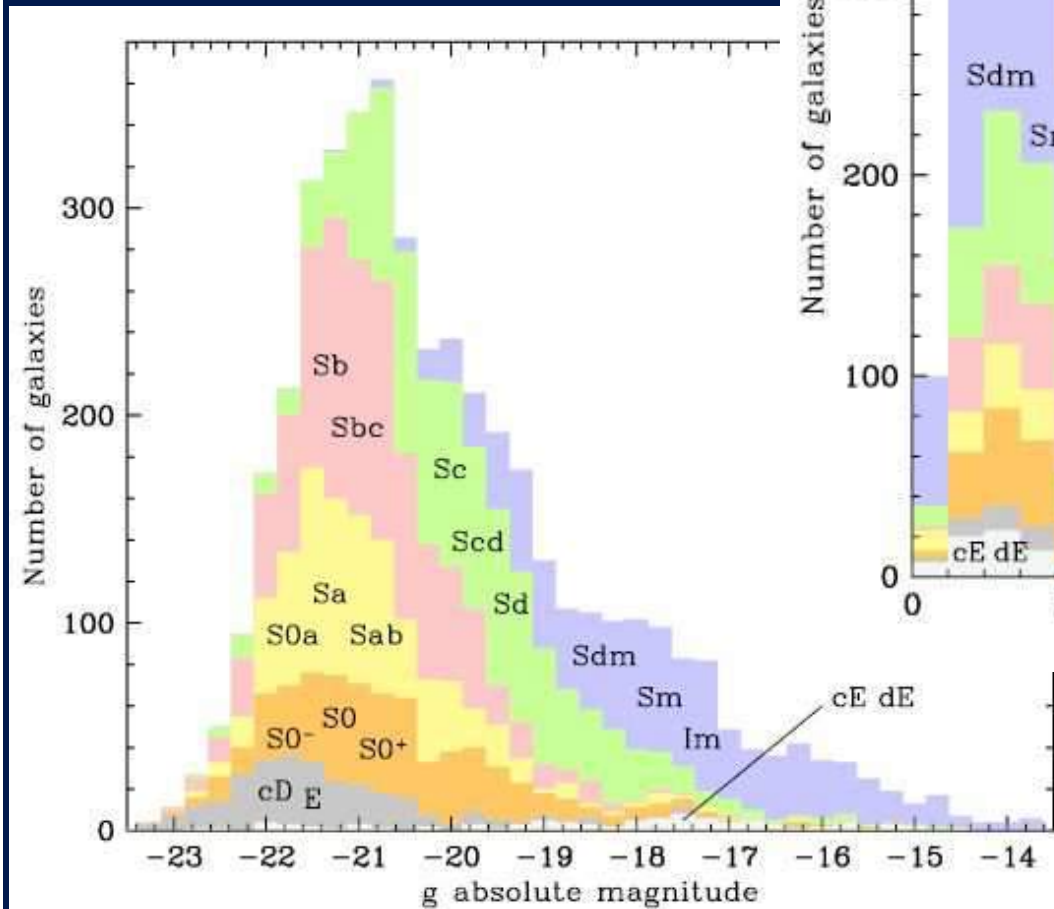
5.7 kpc $M(g) = -16.9$

$z = 0.002638$

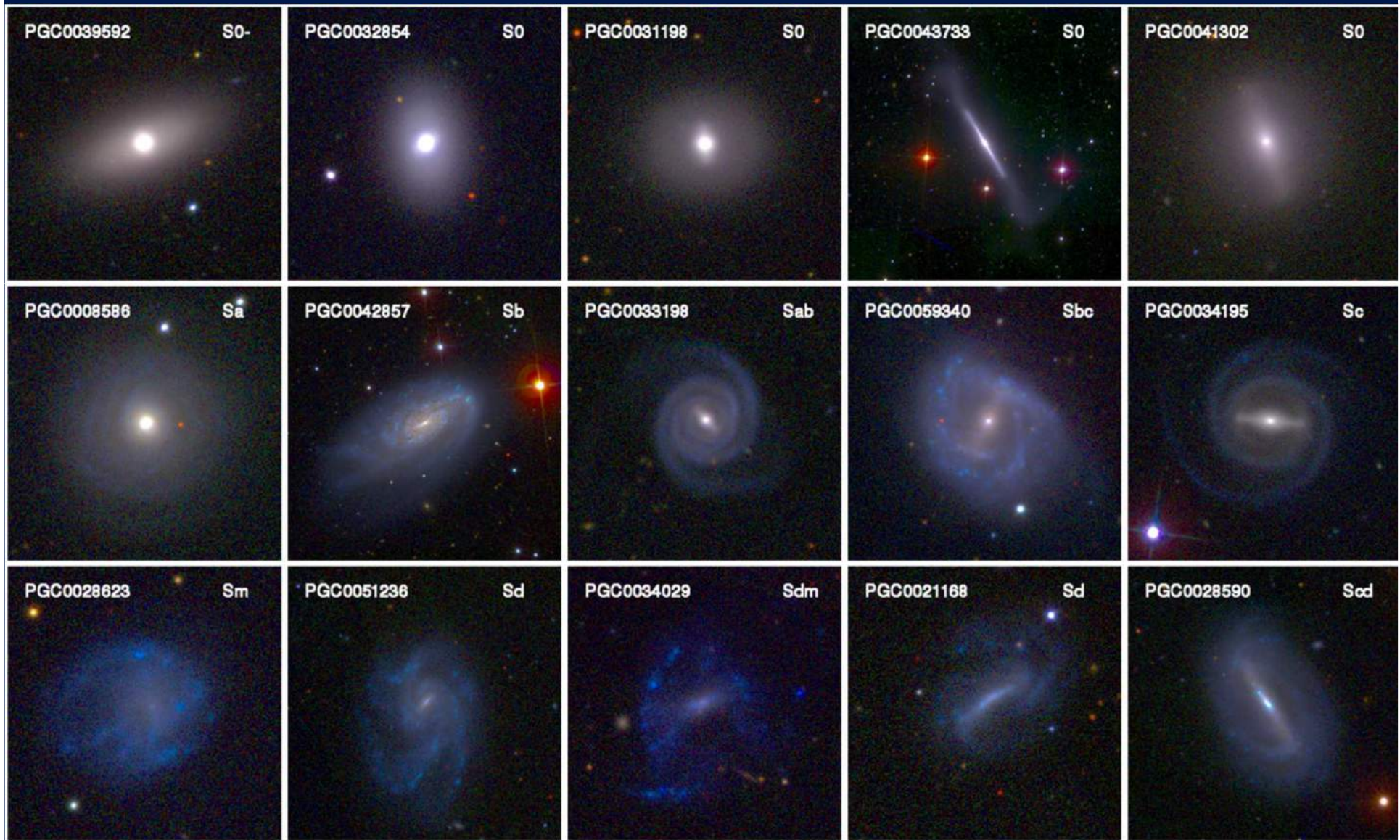
1.9 kpc $M(g) = -14.8$

$z = 0.0006414$

Distribution en magnitude et distance



Attribut : Longueur de barre

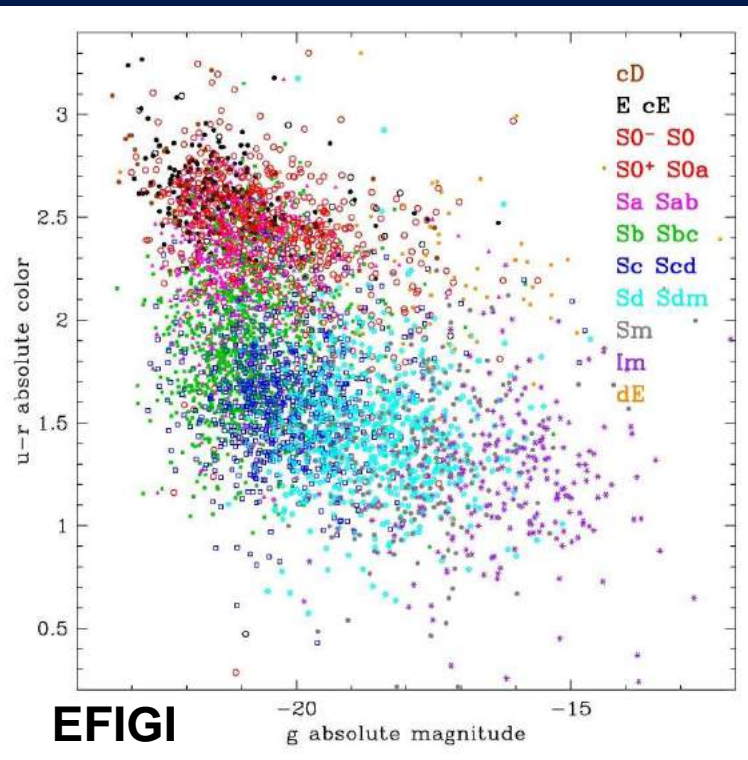


Fractions de galaxies avec barres

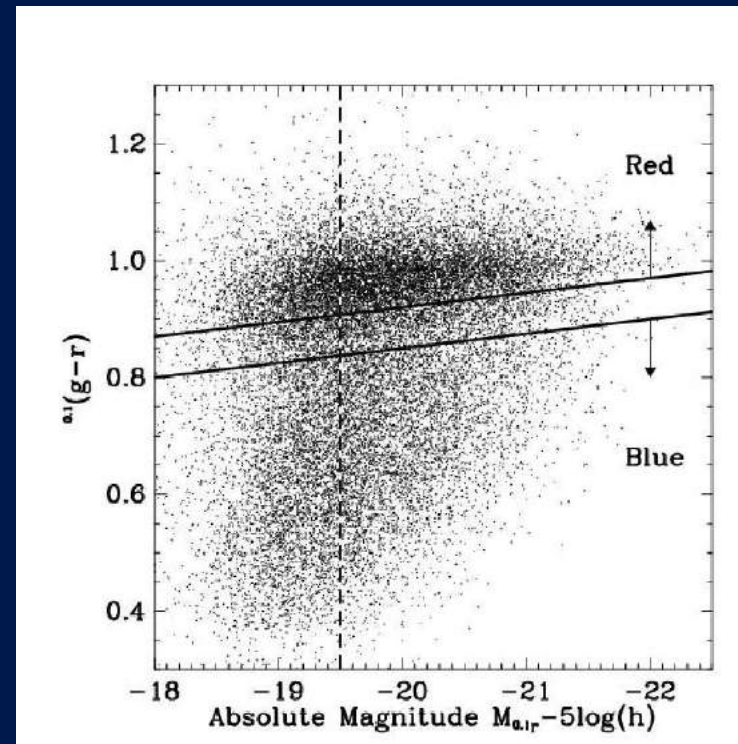
| | |
|------------------------------------|--------|
| S0 ⁻ S0 S0 ⁺ | 23 ± 3 |
| Sa Sab | 61 ± 5 |
| Sb Sbc | 49 ± 3 |
| Sc Scd | 37 ± 3 |
| Sdm Sm | 29 ± 3 |
| Im | 7 ± 2 |
| dE | 9 ± 4 |

de Lapparent, Baillard, Bertin 2011

Bimodality in color-magnitude sequence ?

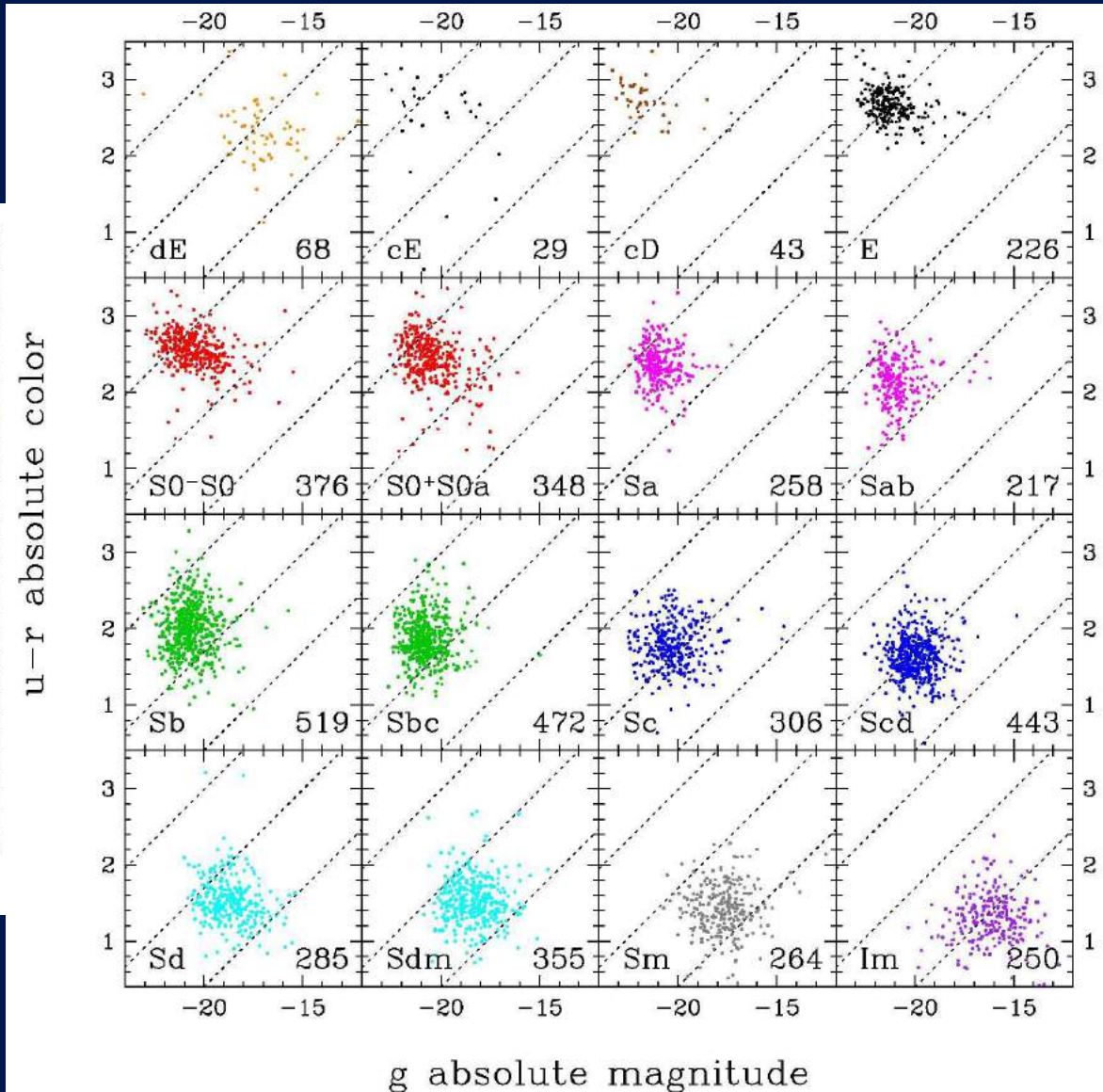
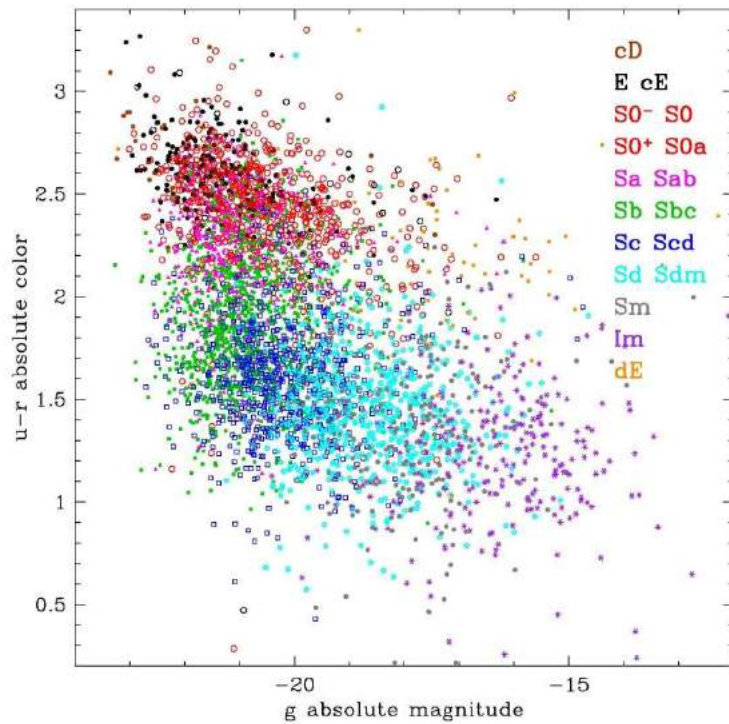


de Lapparent 2011

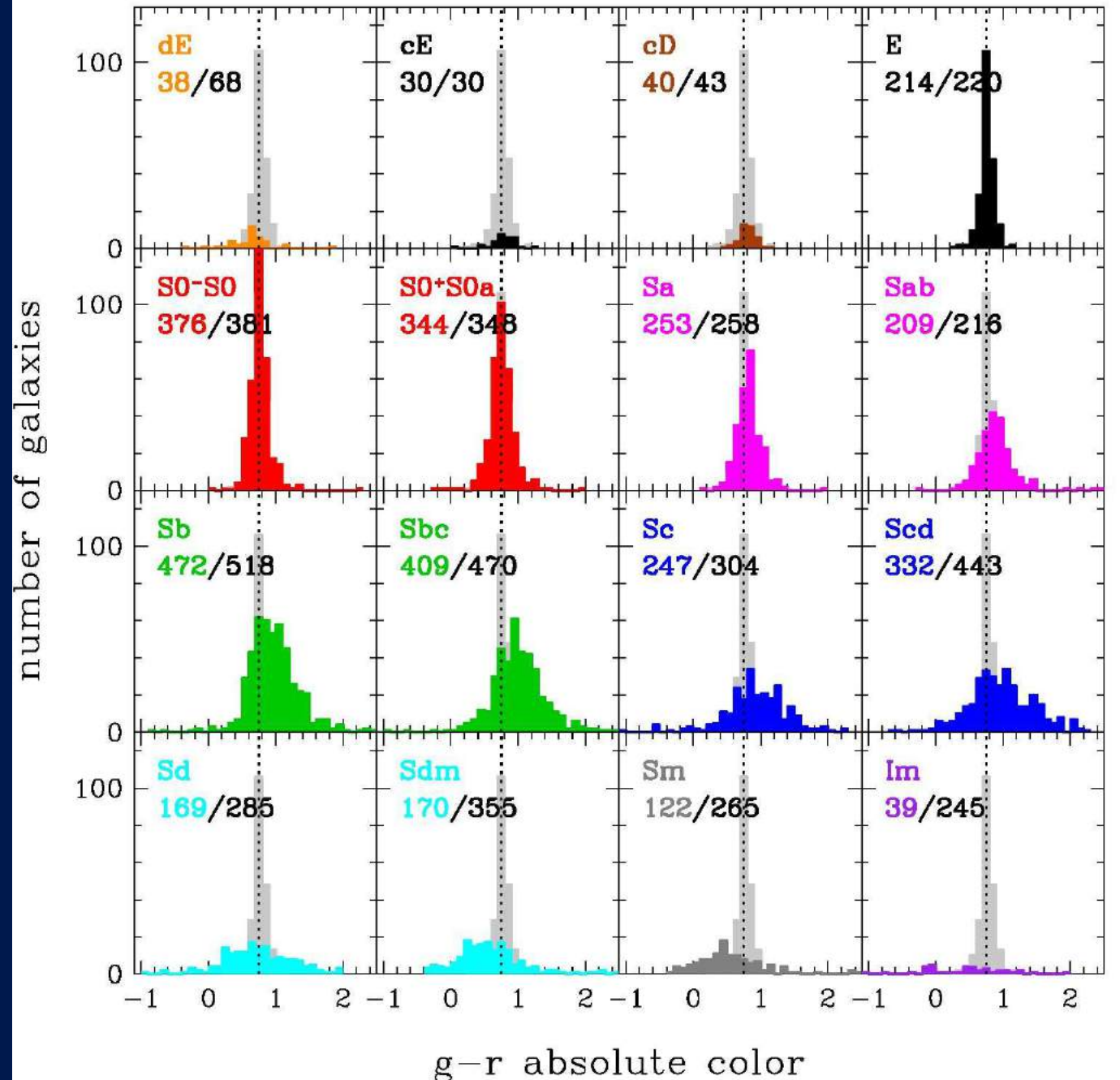


Yan et al. 2006
400 000 galaxies SDSS - DR4

Continuous color-magnitude sequence

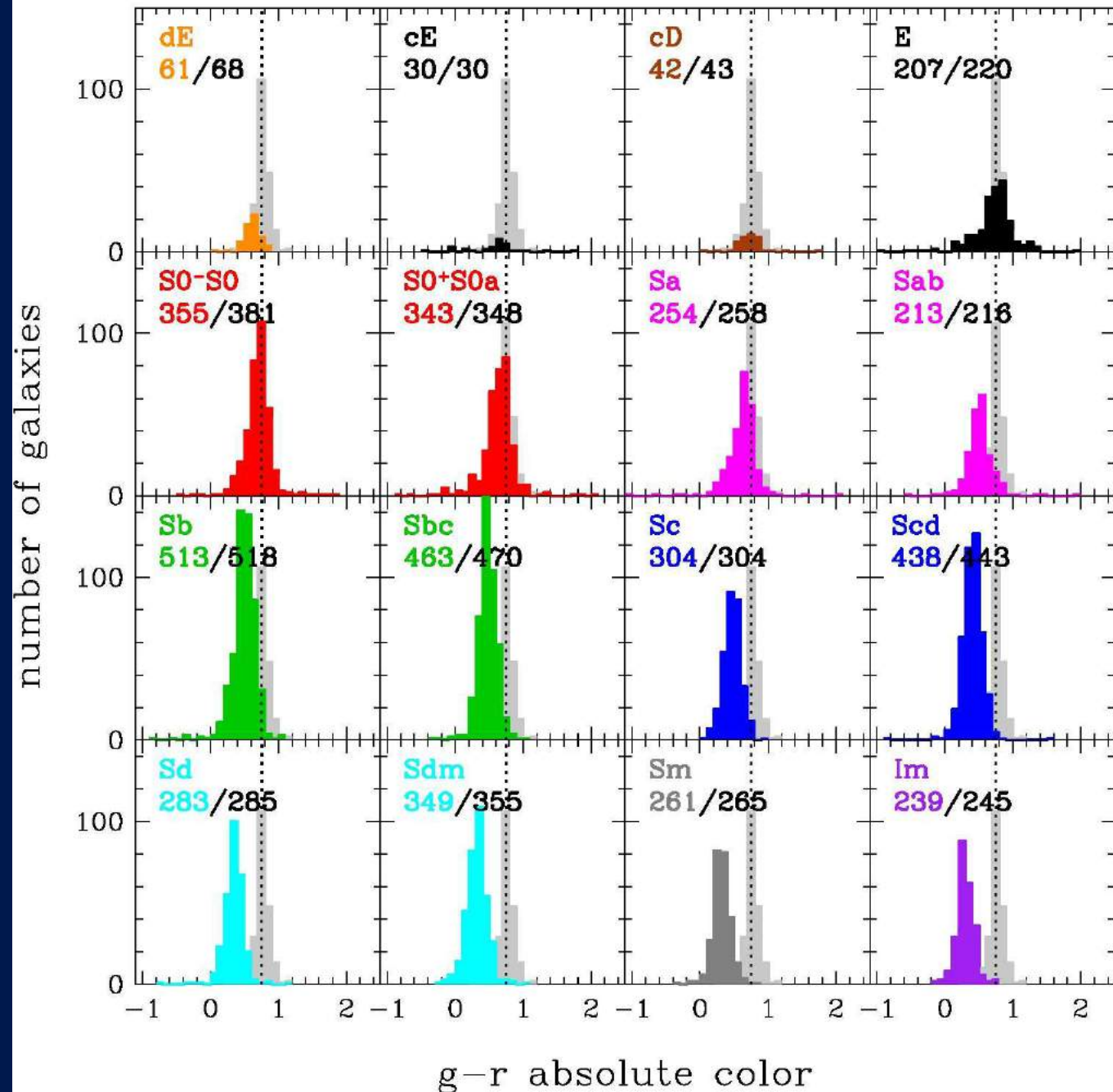


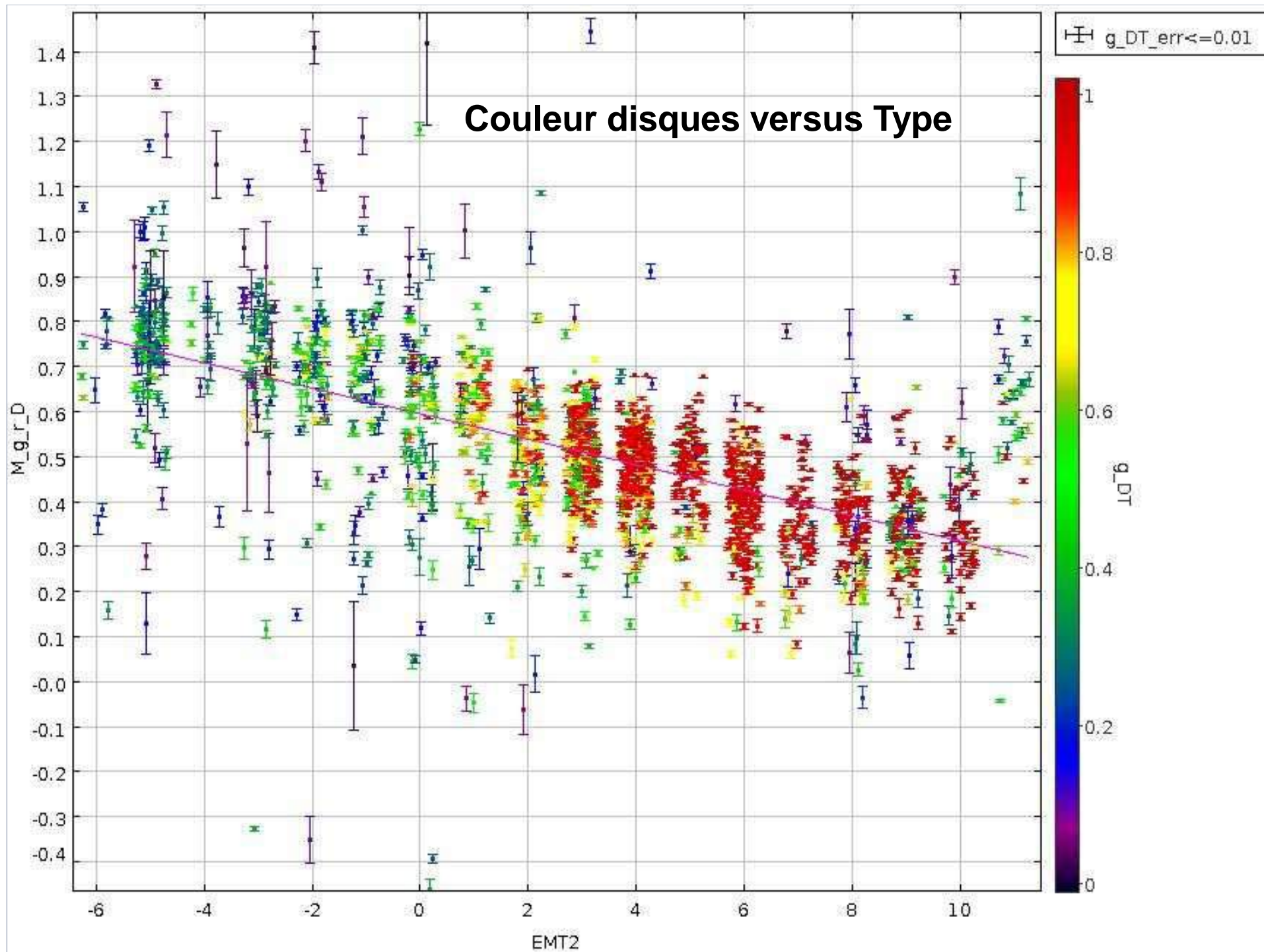
Bulbes



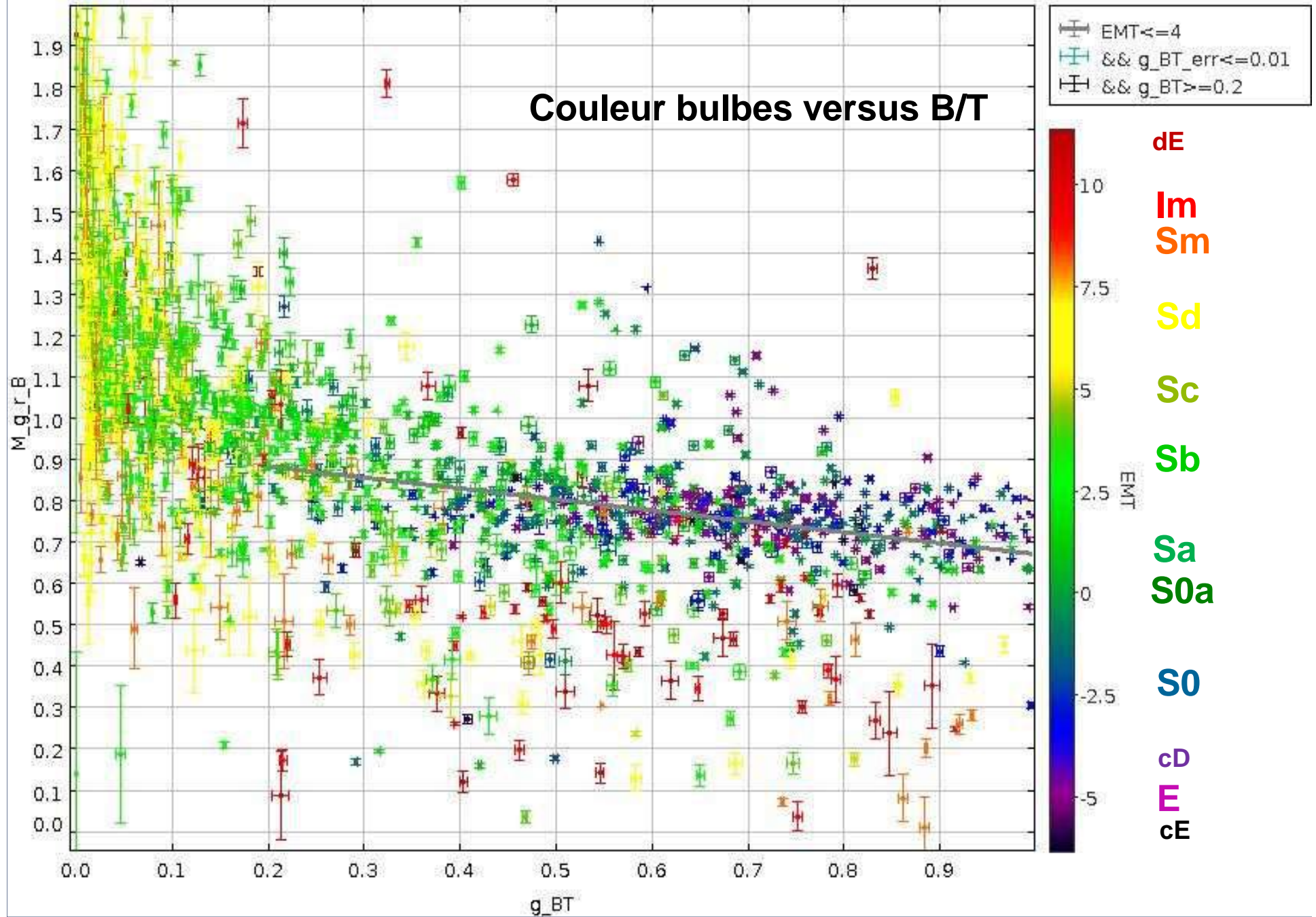
de Lapparent 2011

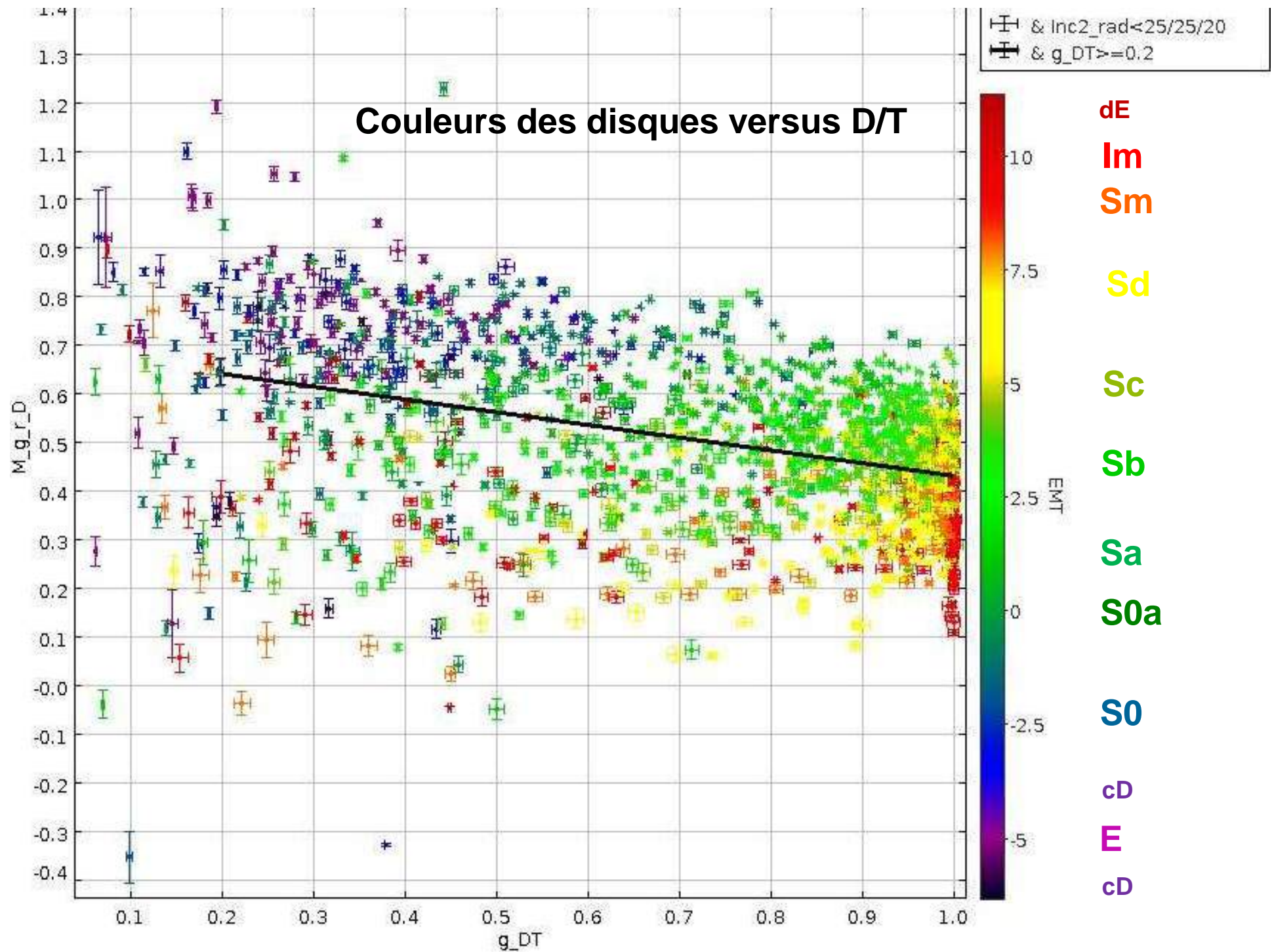
Disques



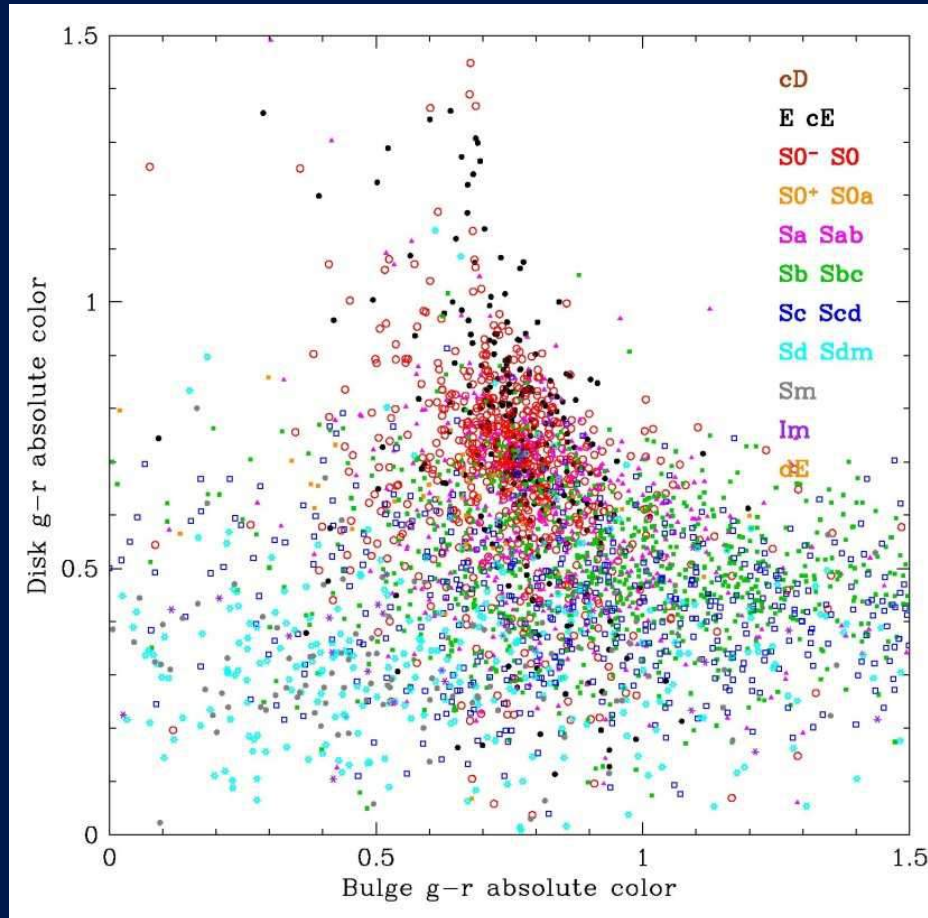


Couleur bulbes versus B/T

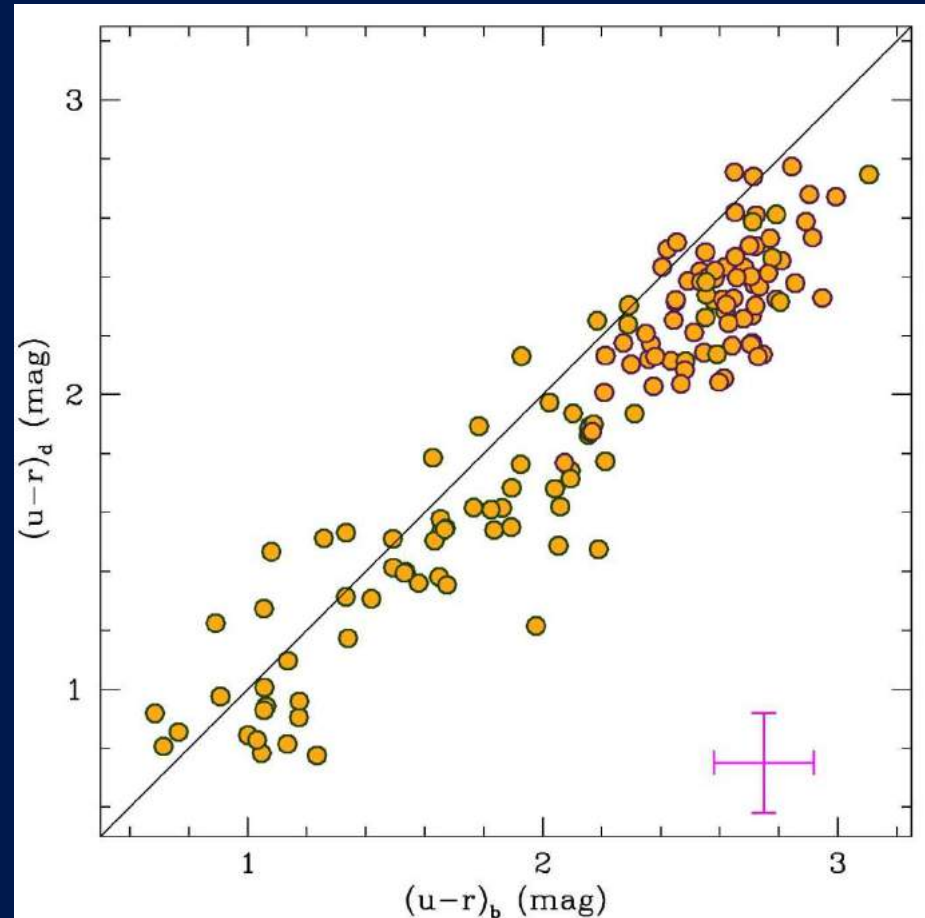




Couleur bulbe versus disque



de Lapparent 2011
4 000 galaxies $g < 16$ (EFIGI/SDSS)



Cameron et al. 2009
10 000 galaxies $B < 20$ (SDSS/2dF)

Bulge + disk modeling

- PSF-convolved profile modeling by *SExtractor* Bertin & Arnouts 1996
 $r^{1/4}$ or Sersic bulges + exponential disk Bertin 2010



de Lapparent & Bertin in prep.

PGC0039859



PGC0039859



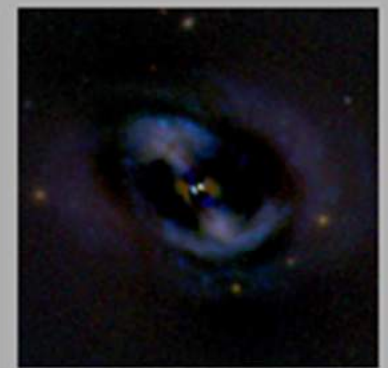
sersic



disk_sersic



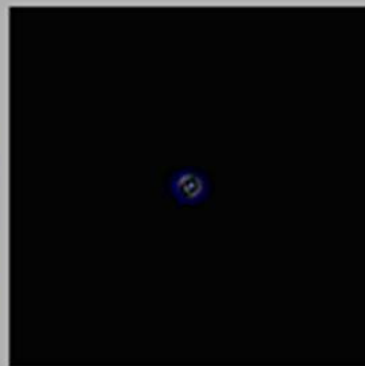
sersic+disk



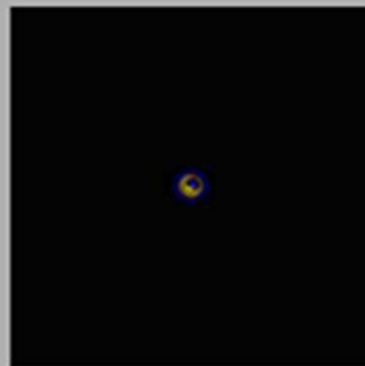
sersic+disk_resid



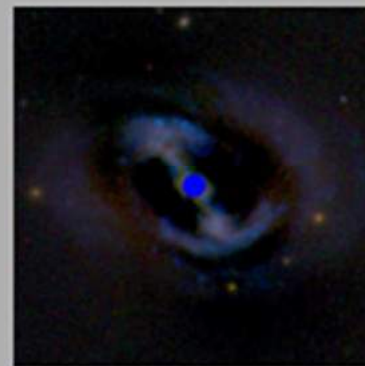
PGC0039859



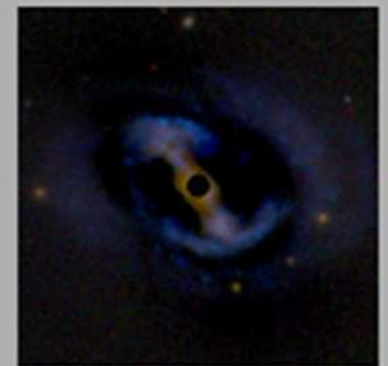
bulge_resid



bulge_detmodel_resid



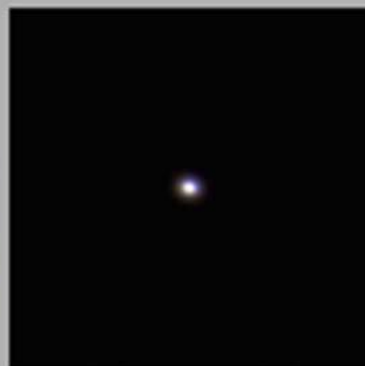
disk_resid



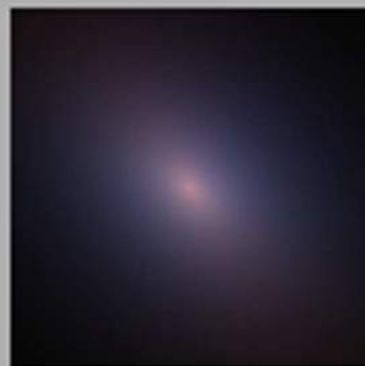
disk_detmodel_resid



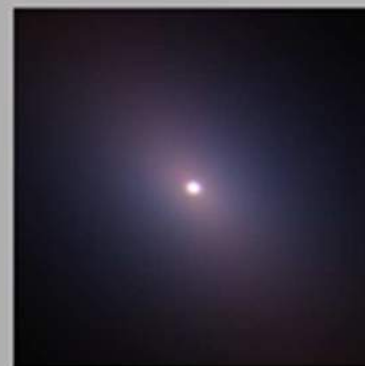
PGC0039859



bulge_model



disk_model



bulge+disk



bulge+disk_resid

PGC0009256



PGC0009256



sersic



disk_sersic



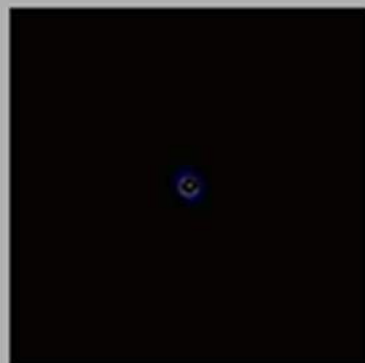
sersic+disk



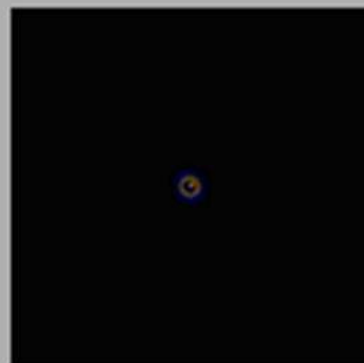
sersic+disk_resid



PGC0009256



bulge_resid



bulge_detmodel_resid



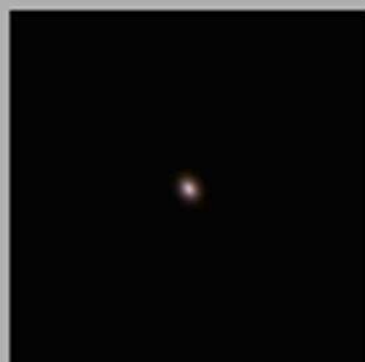
disk_resid



disk_detmodel_resid



PGC0009256



bulge_model



disk_model



bulge+disk



bulge+disk_resid

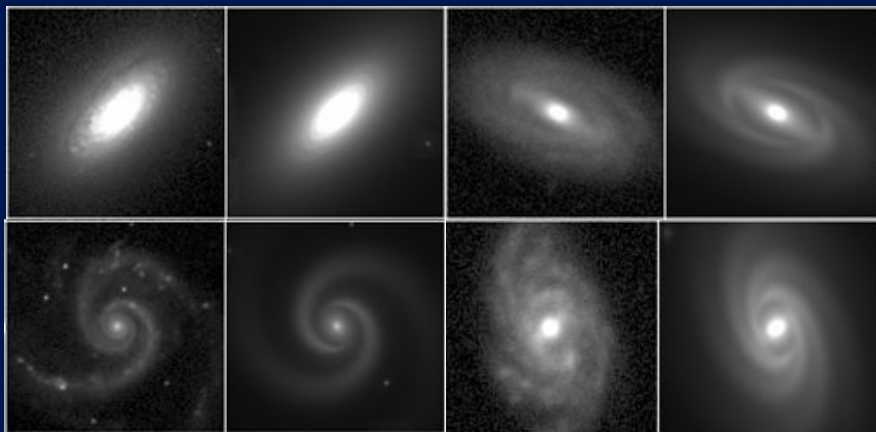
Bulge + disk modeling

- PSF-convolved profile modeling by *SExtractor* Bertin & Arnouts 1996
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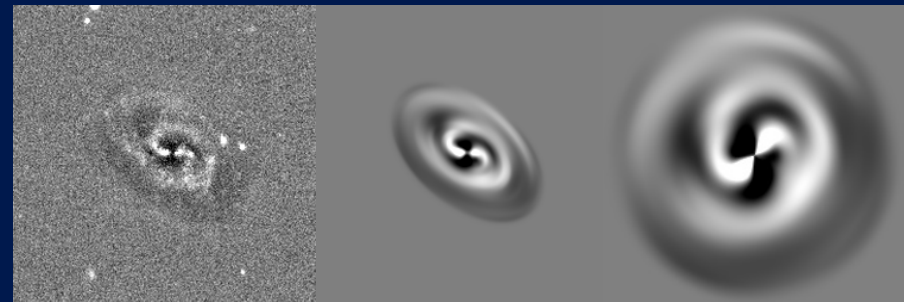


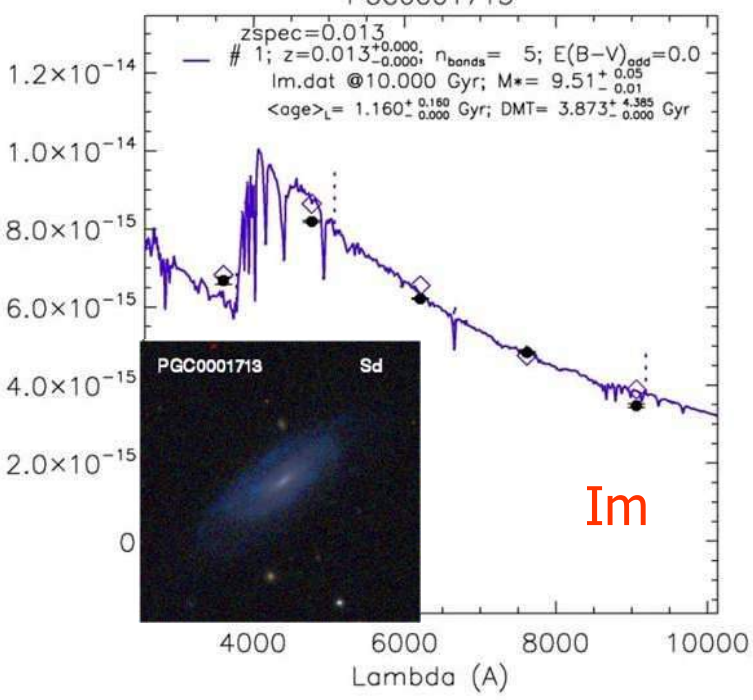
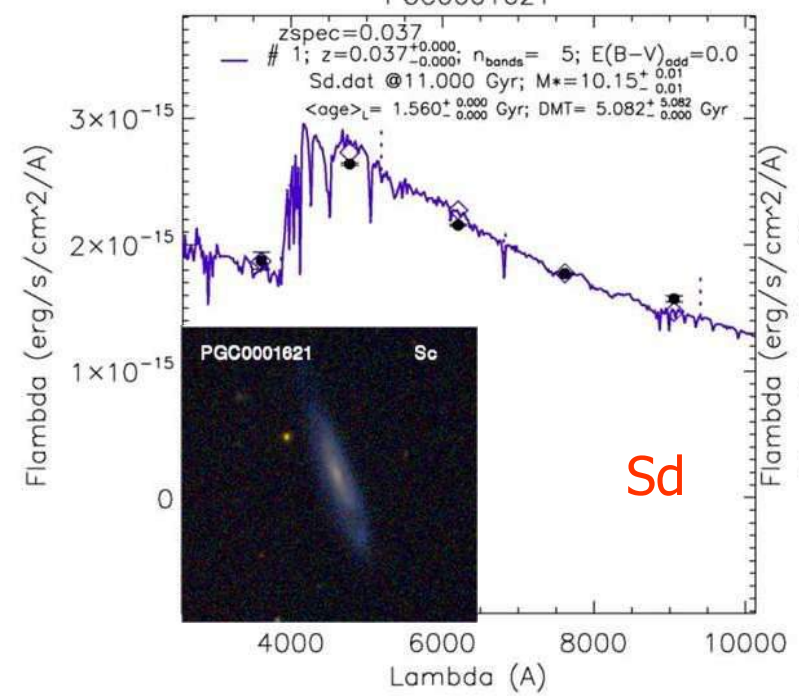
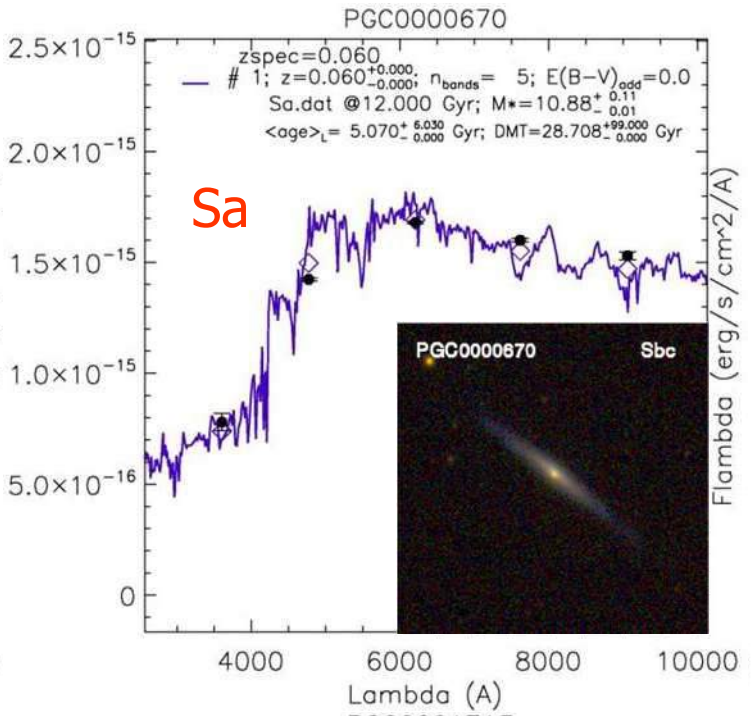
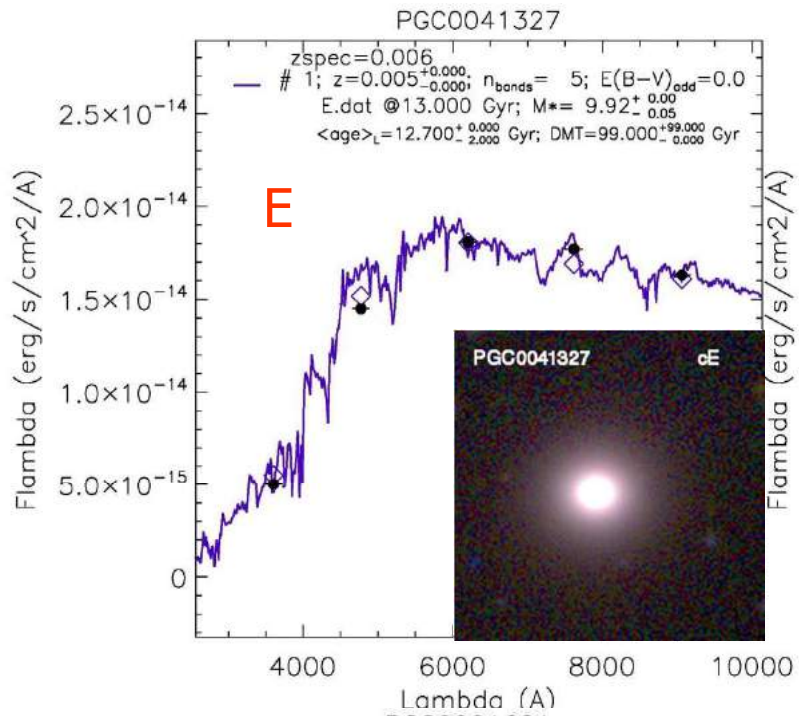
de Lapparent & Bertin in prep.

+ Spiral arms & bars Bertin



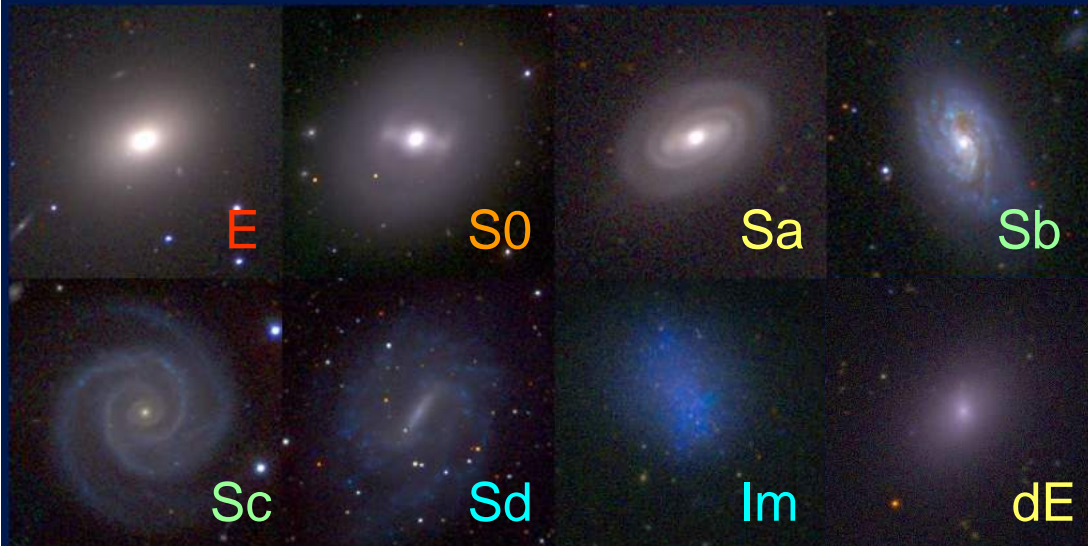
+ Decomposition of residuals
on a ring basis Baillard 2008



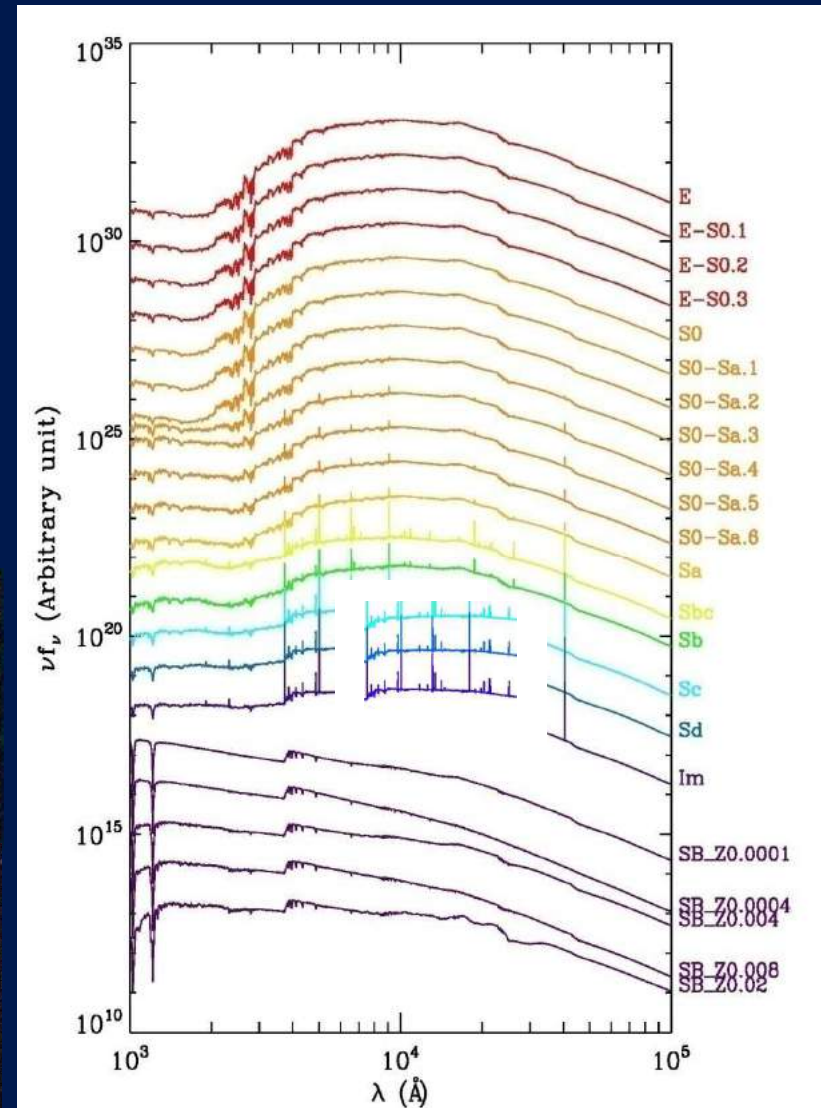


Distinguer les types de galaxies

- Morphologie
- Distribution spectral d'énergie

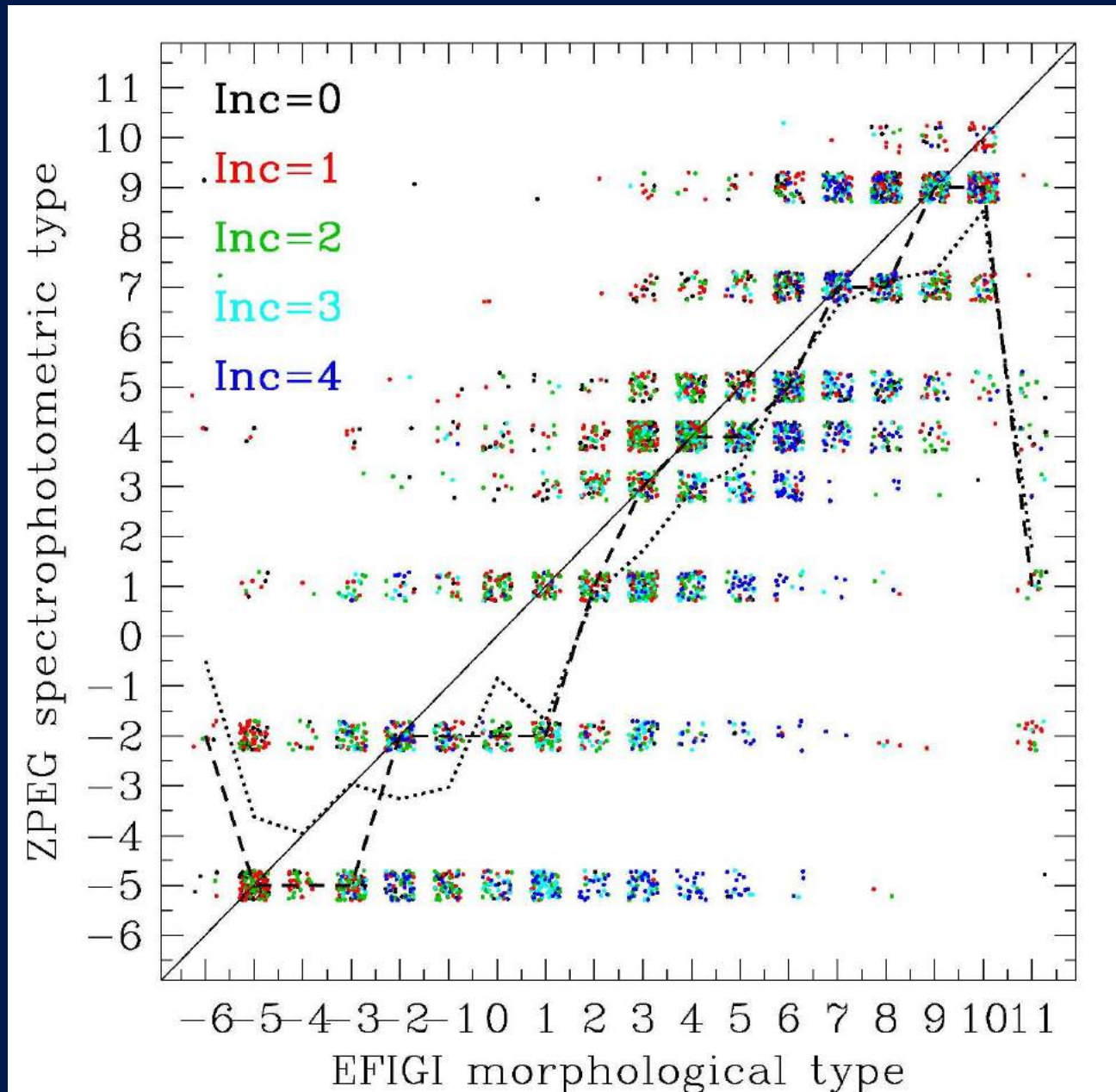


EFIGI (Baillard, Bertin, de Lapparent et al. 2011)

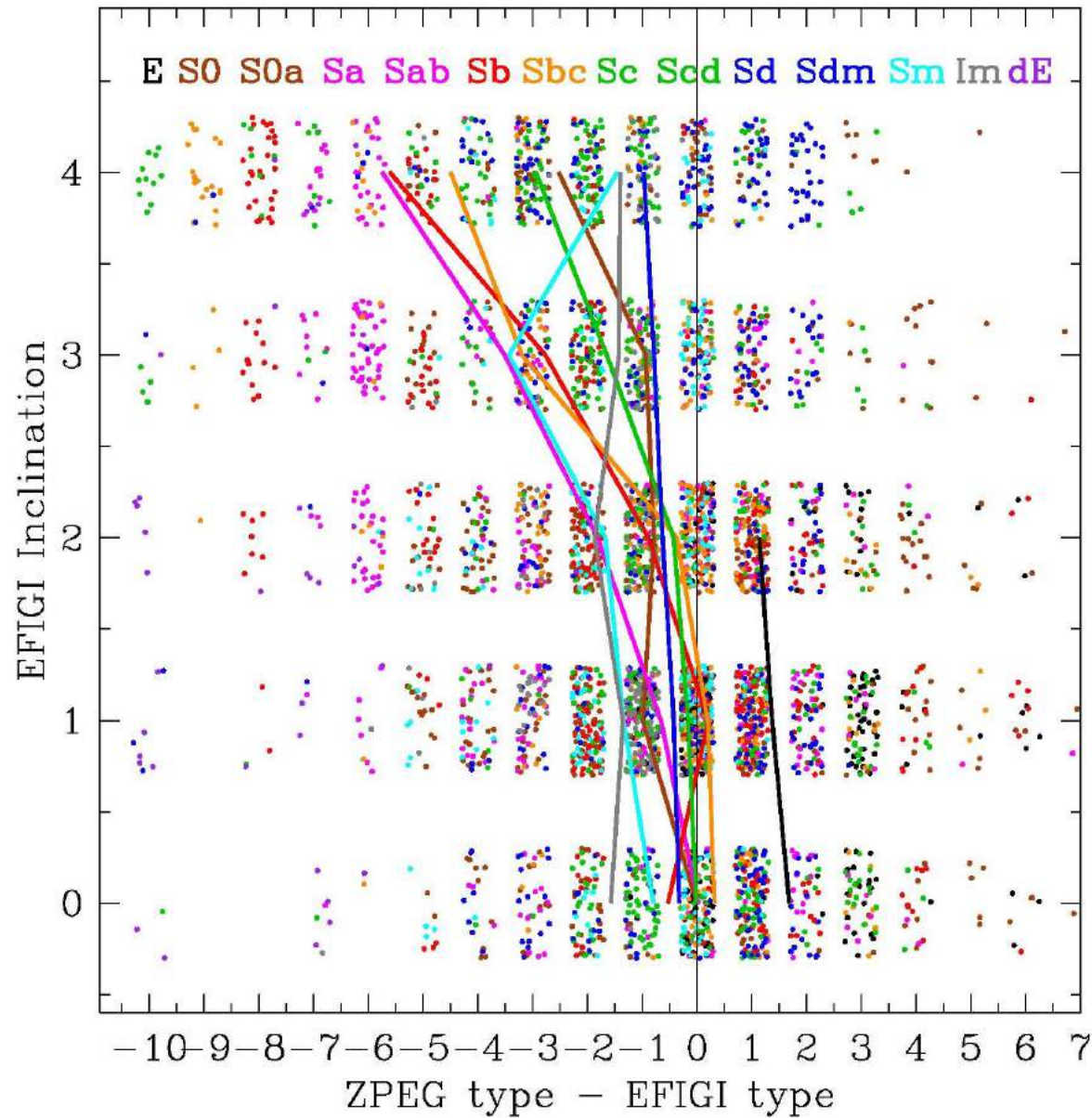


PÉGASE.2 (Fioc et Rocca 1997)

Type morphologique / spectrophotométrique



Différence de type versus inclinaison



de Lapparent 2011

Biais ouverture

- Effets de couleur

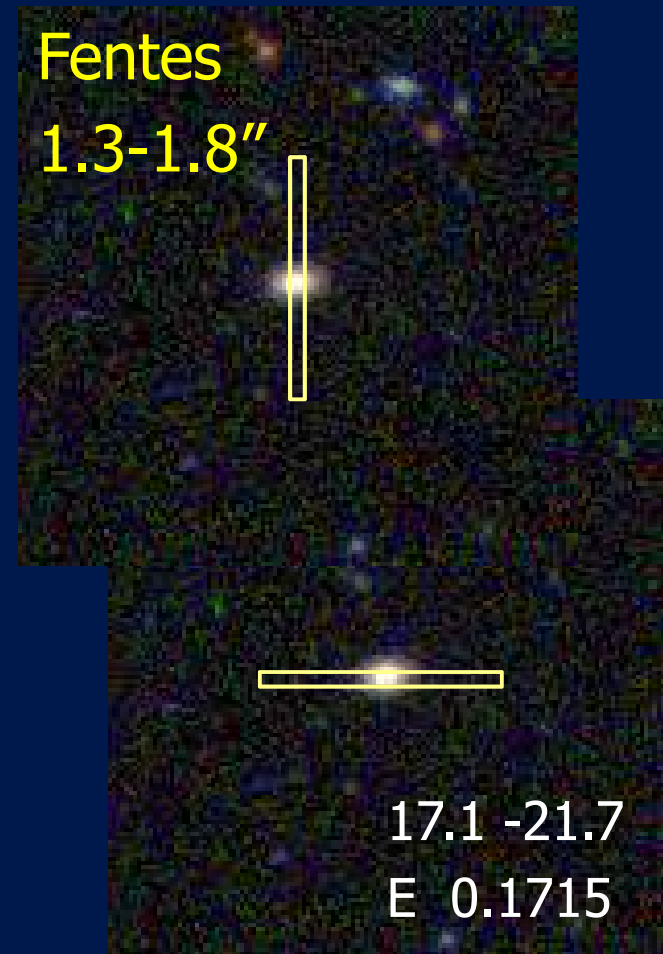
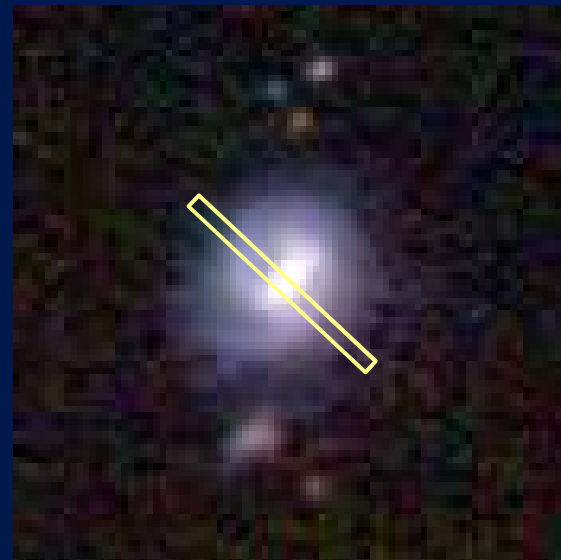
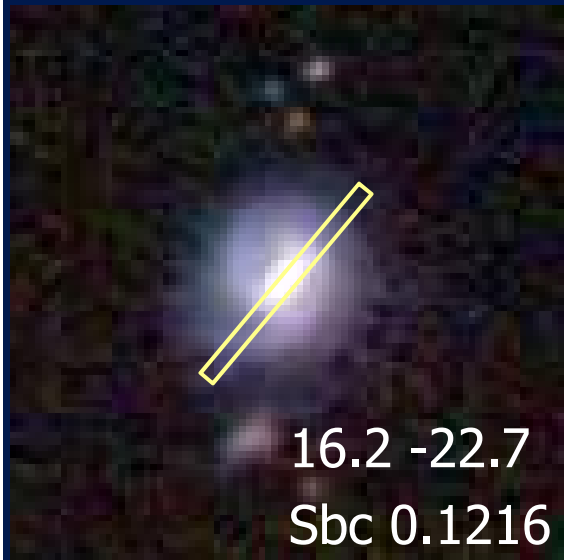
Segalovitz 1975 Vader et al. 1988 Balcells et al. 1994

- Elliptiques : gradients
- Spirales : bulbe-disque

- Effets de distance

Kewley et al. 2004

fibres 3" SDSS >20% à $z > 0.05$

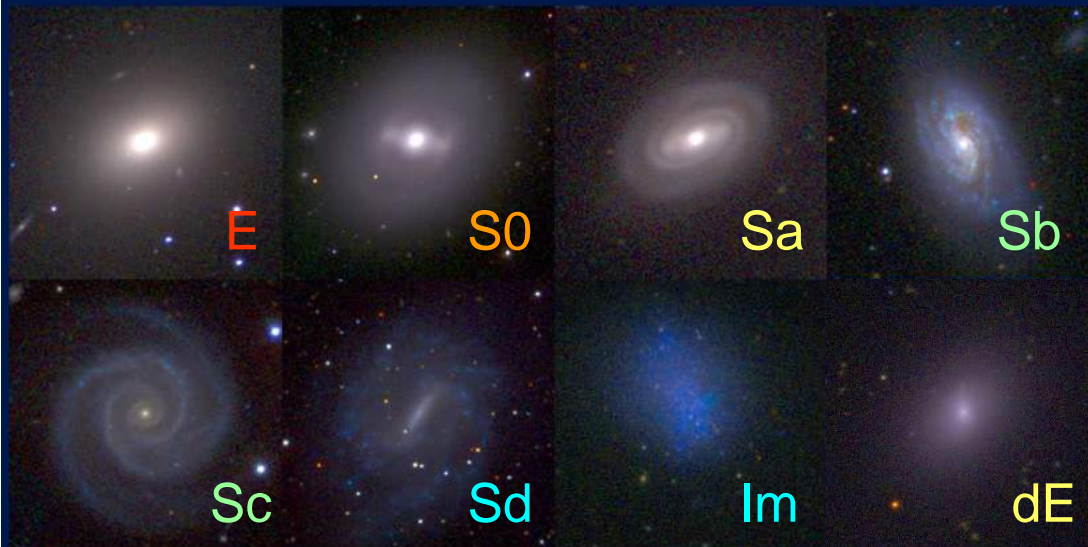


Distinguer les types de galaxies

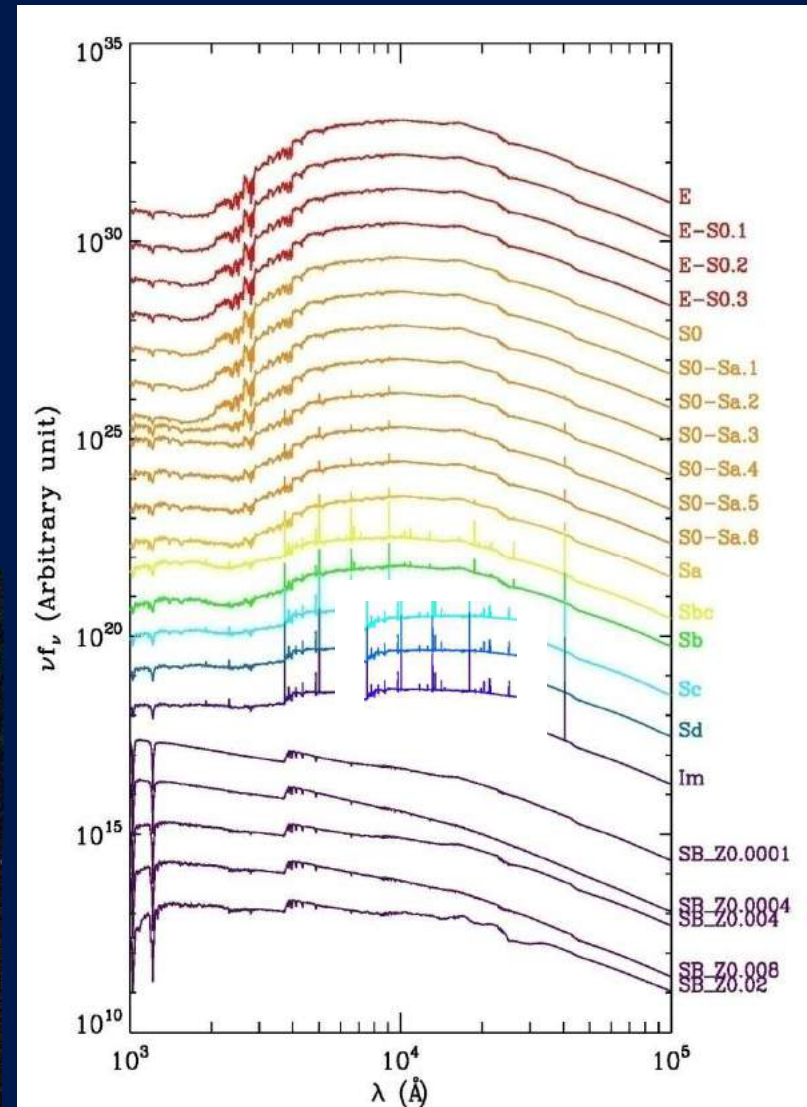
- Morphologie
- Distribution spectral d'énergie

Remplacés par

- Couleurs

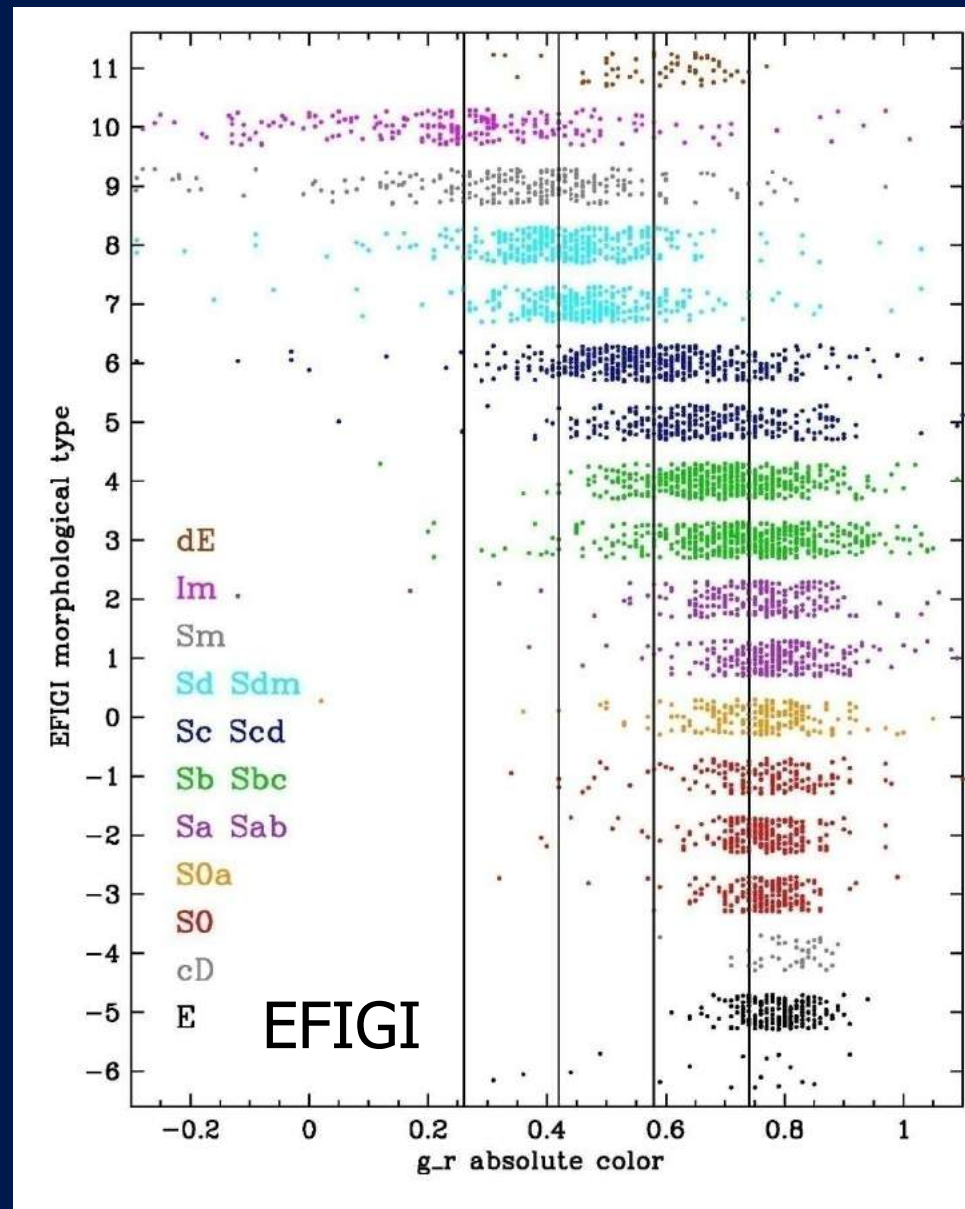


FIGI (Baillard, Bertin, de Lapparent et al. 2011)



PÉGASE.2 (Fioc et Rocca 1997)

Couleur versus type morphologique EFIGI

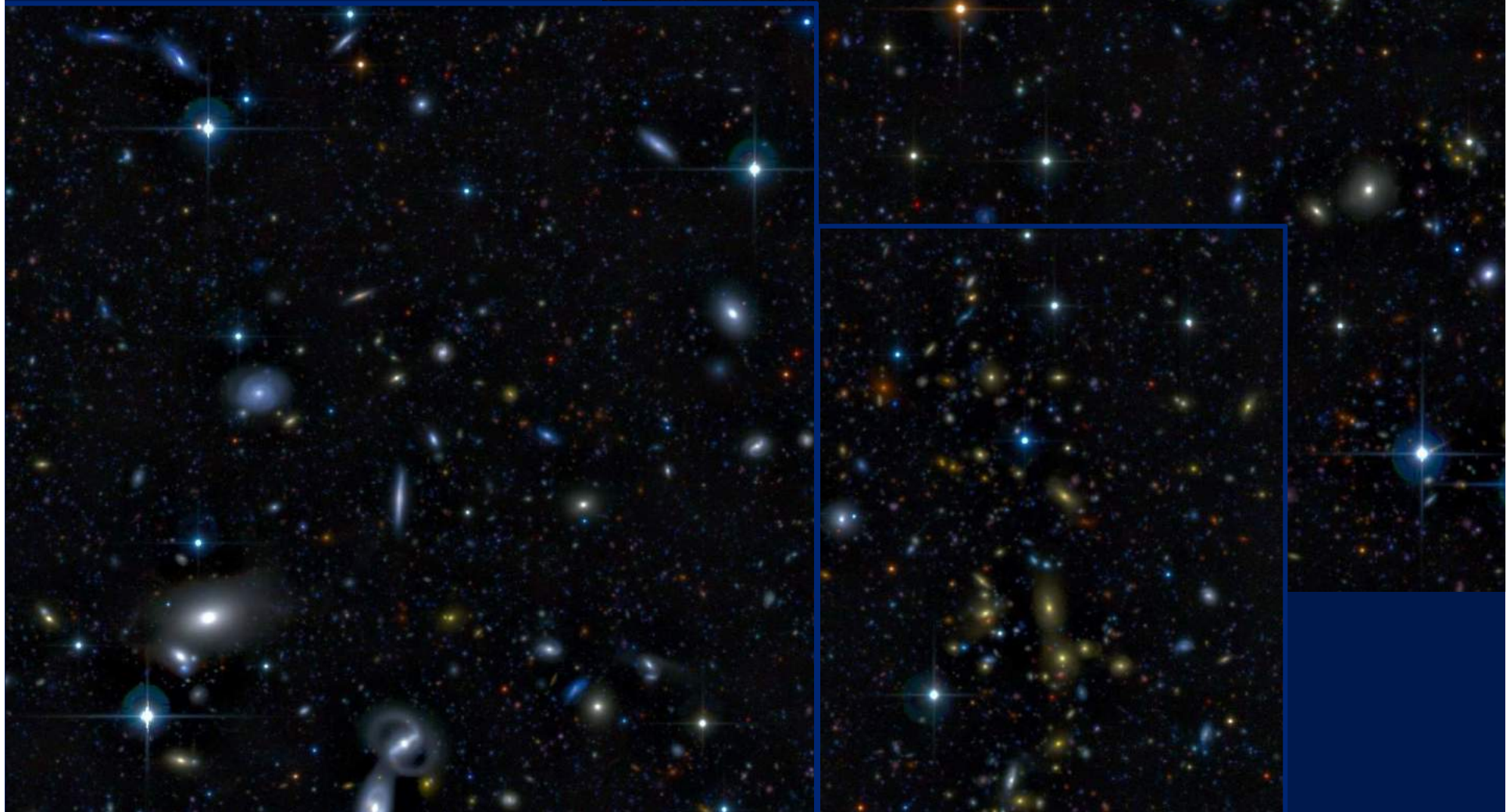


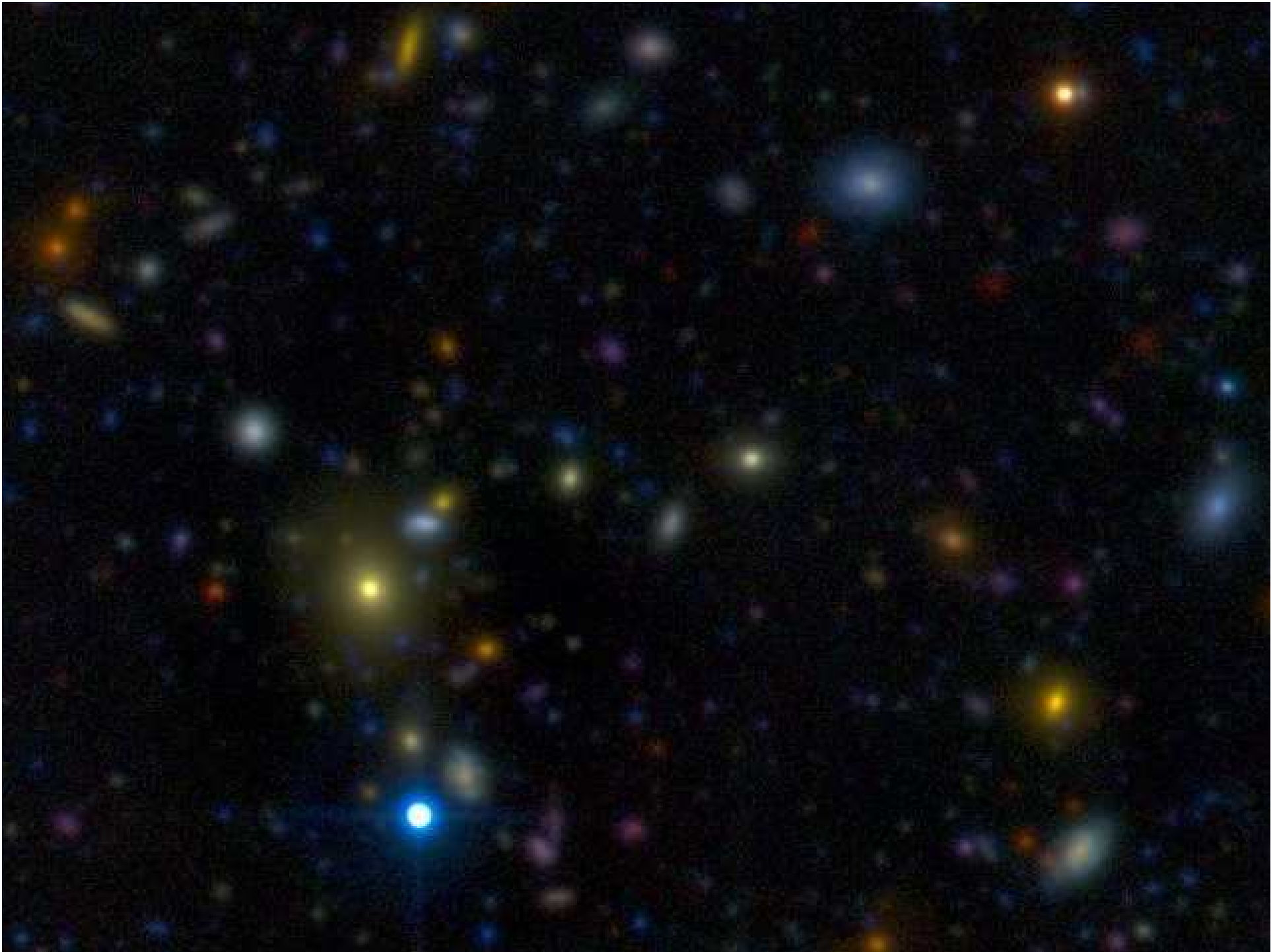
CFHT Legacy Survey

Deep : 4 fields 1 deg²

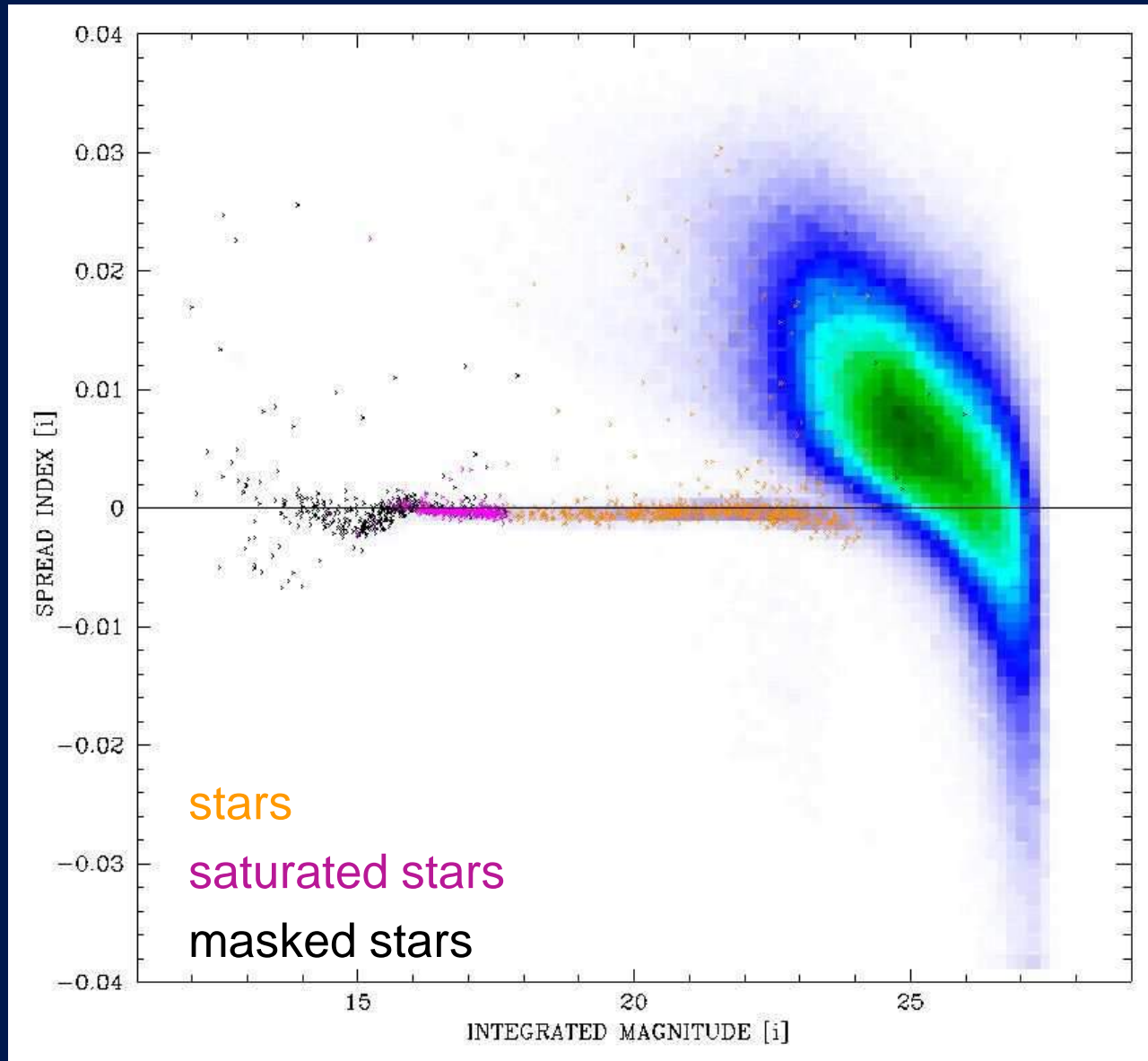
10⁵ galaxies $i < 24$

www.astromatic.net/gallery





Star-galaxy separation by deviations from PSF



de Lapparent & Bertin 2013

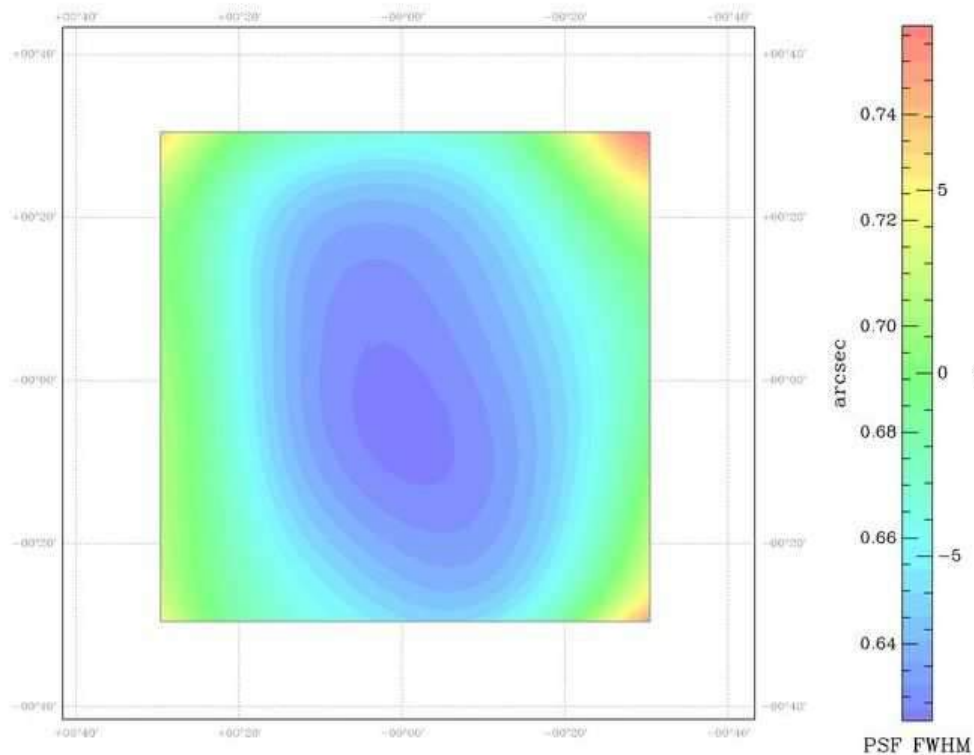
Point-spread function CFHTLS D1-i : PSFEx

➤ seeing 0.6" (pixels 0.186")

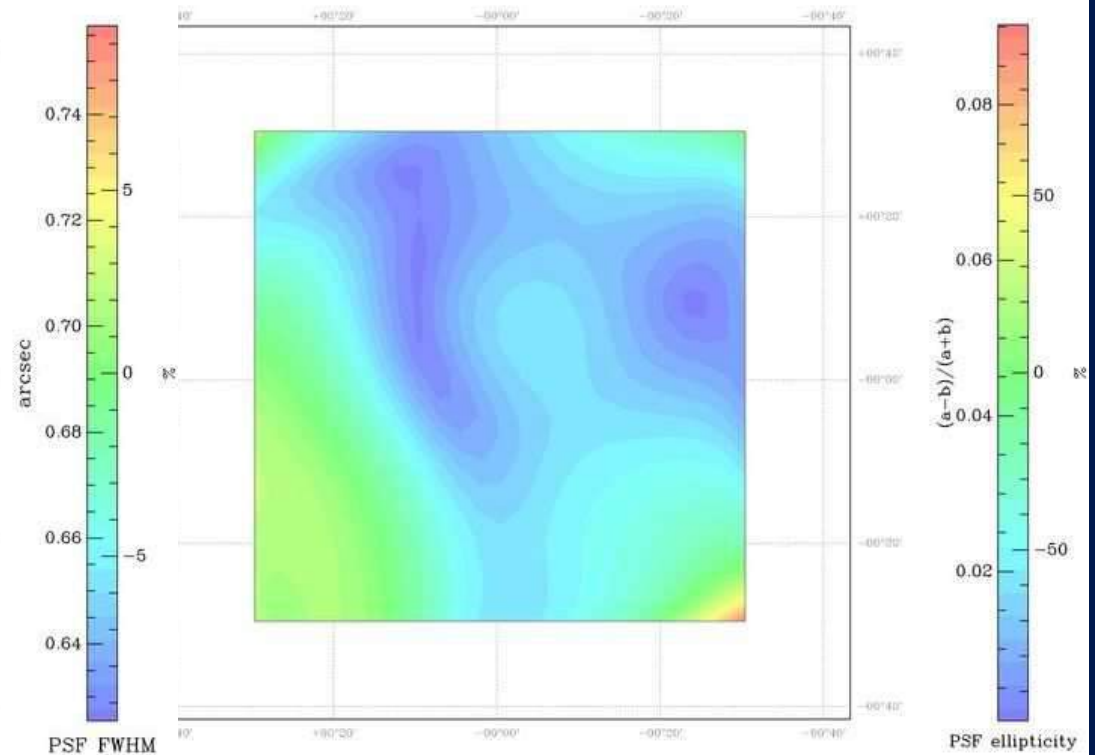
spatial variations of FWHM
(degree 6 polynomial)

Ellipticity 2-5%

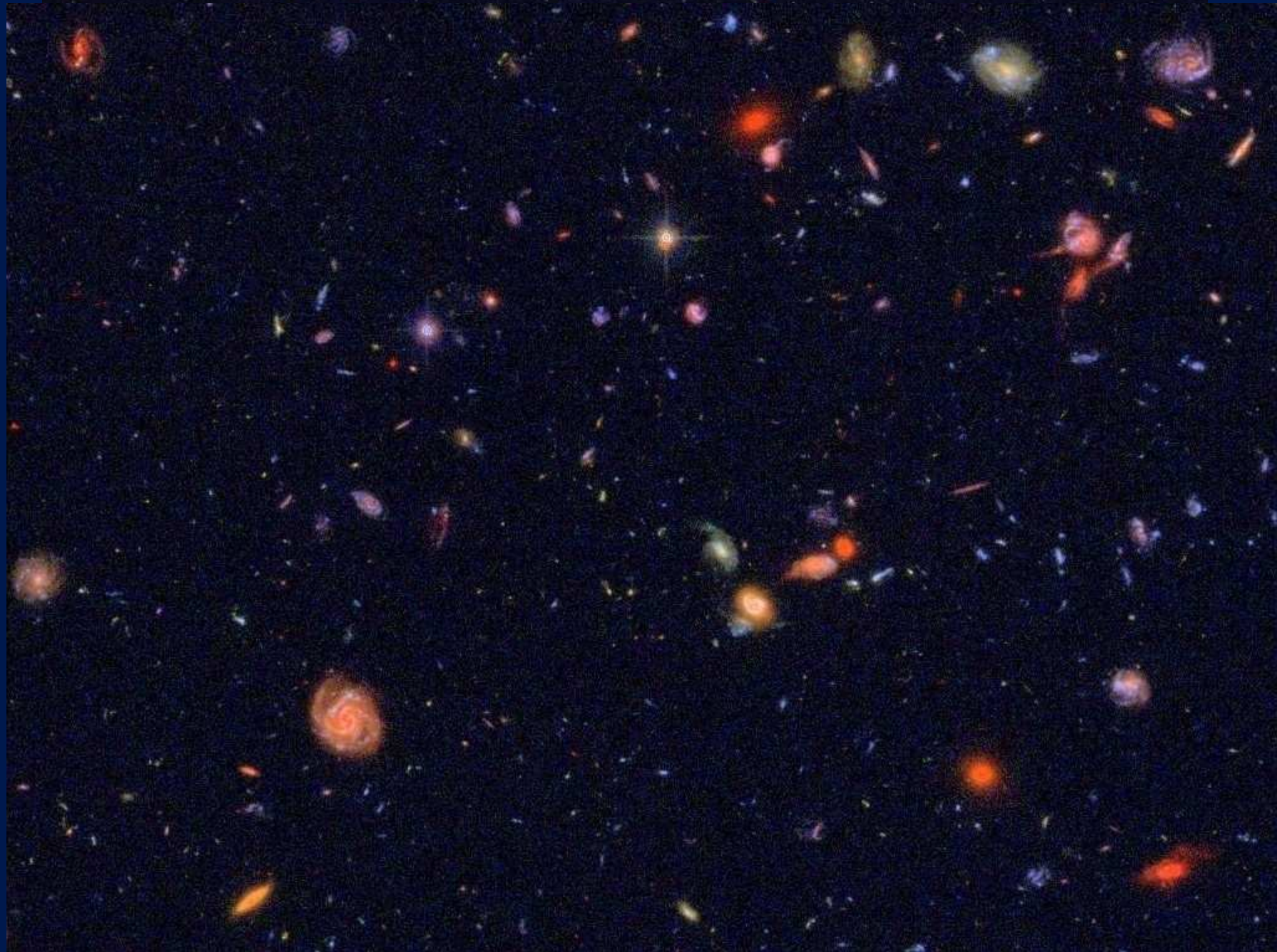
Field CFHTLS-D-85-i-022559-042940-T0006: FWHM map



CFHTLS-D-85-i-022559-042940-T0006: ellipticity map



Télescope Spatial Hubble : L'image la plus profonde de l'Univers

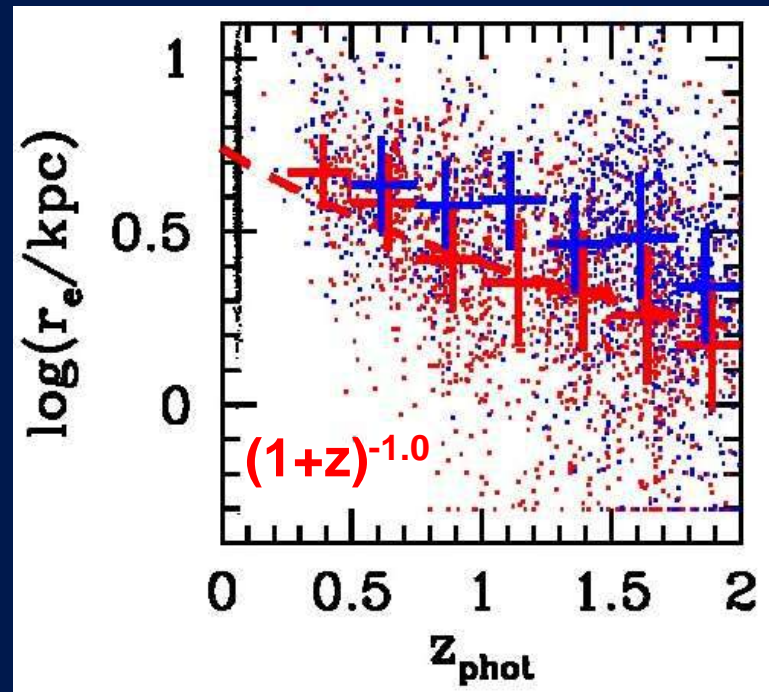


Evolution of galaxy size

- Observed strong evolution since $z \sim 2$

Data in optical + near-IR + mid-IR :

Subaru XMM Deep + UKIDSS Ultra-Deep + Spitzer SWIRE



Star-forming
Passive

Williams et al. 2010

- Red nuggets HST $z \sim 1-2$: compact quiescent galaxies

$$R_e = (1+z)^{-1.6}$$

Damjanov et al. 2010, 2013

Caractériser l'évolution des galaxies

- Morphométrie :

 - mesures précises multi-bande pour chaque galaxie de :

 - forme / profil 2D + flux total

 - taille / rayons d'échelle

 - type morphologique

 - distributions spectrales d'énergies 2D

 - + fréquence et flux des barres, anneaux

 - fréquence des asymétries

 - extinction par les poussières

 - Comptages des galaxies (par type) + fonctions sélection

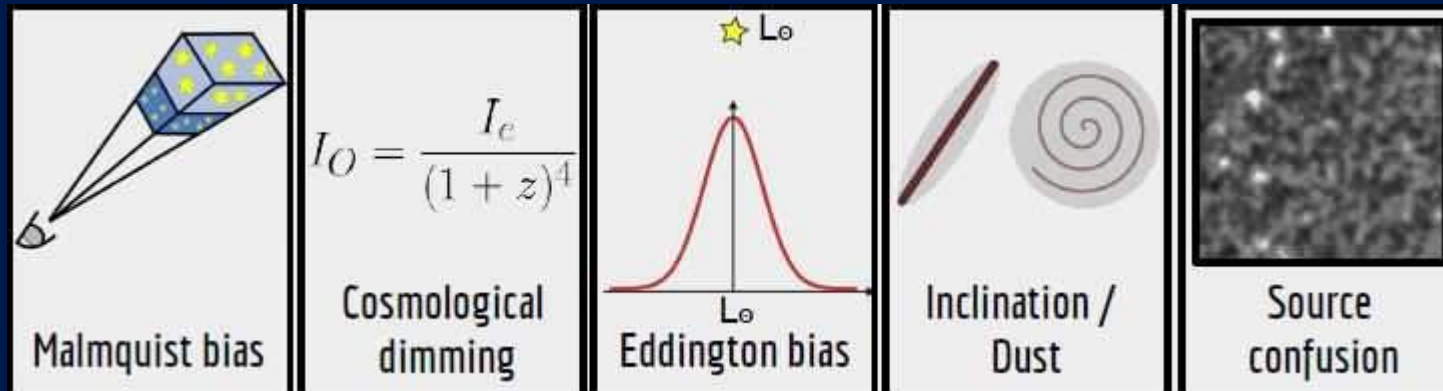
 - fonctions de luminosité / masse / taille

 - ...Identifier les ancêtres des galaxies actuelles + arbres fusions

 - Principal obstacle/défi : photométrie

Biais dans la photométrie des galaxies

- Biais de Malmquist
- Affaiblissement cosmologique
- Biais d'Eddington
- Poussière/extinction et inclinaison
- Confusion des sources



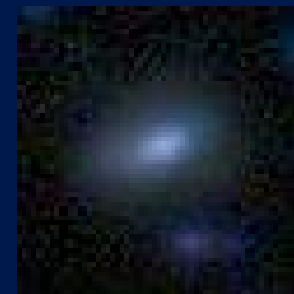
d'après S. Carassou (doctorat 2017)

Photometry of galaxies: surface brightness

- Limiting sky surface brightness (22 mag/arcsec² in B)
- $(1+z)^4$ surface brightness dimming



→ missing higher fraction
of wings in faint galaxies



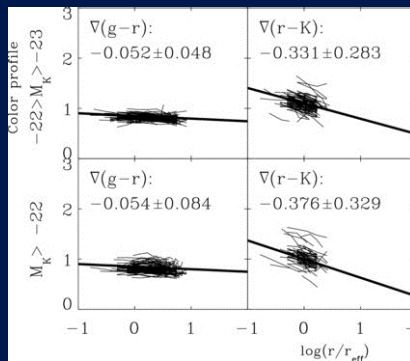
Colors biases in photometry

- Atmospheric differential refraction in wide band photometry



- Color gradients

Segalovitz 1975, Vader et al. 1988



Duho & Myungshin 2013

- Inclination and extinction

Driver et al. 2007

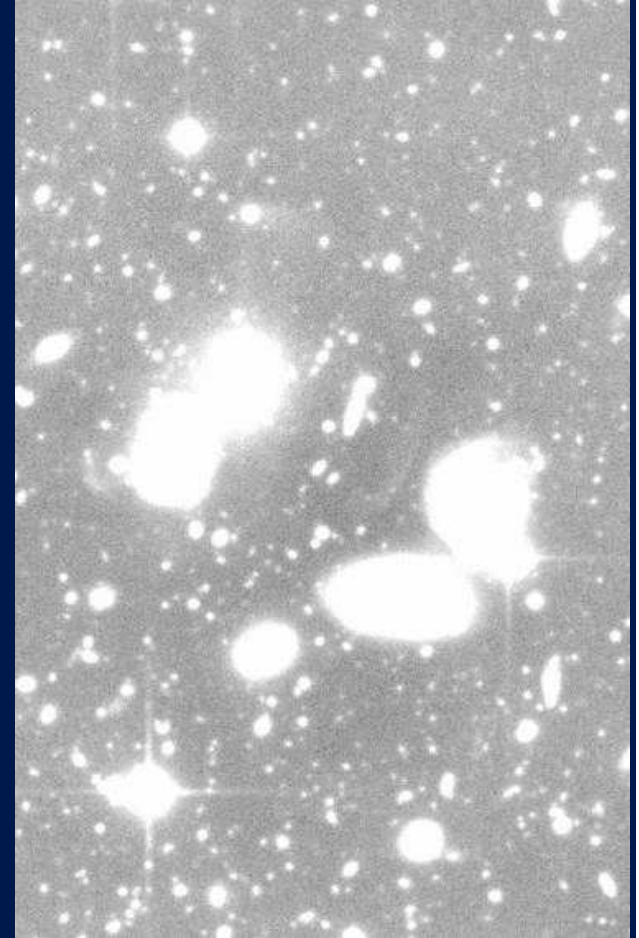


- Differential k-corrections : visibility of disk/bulges versus filter

→ Biases in type/flux as a function of filter/inclination/redshift
Biases in photometric redshifts

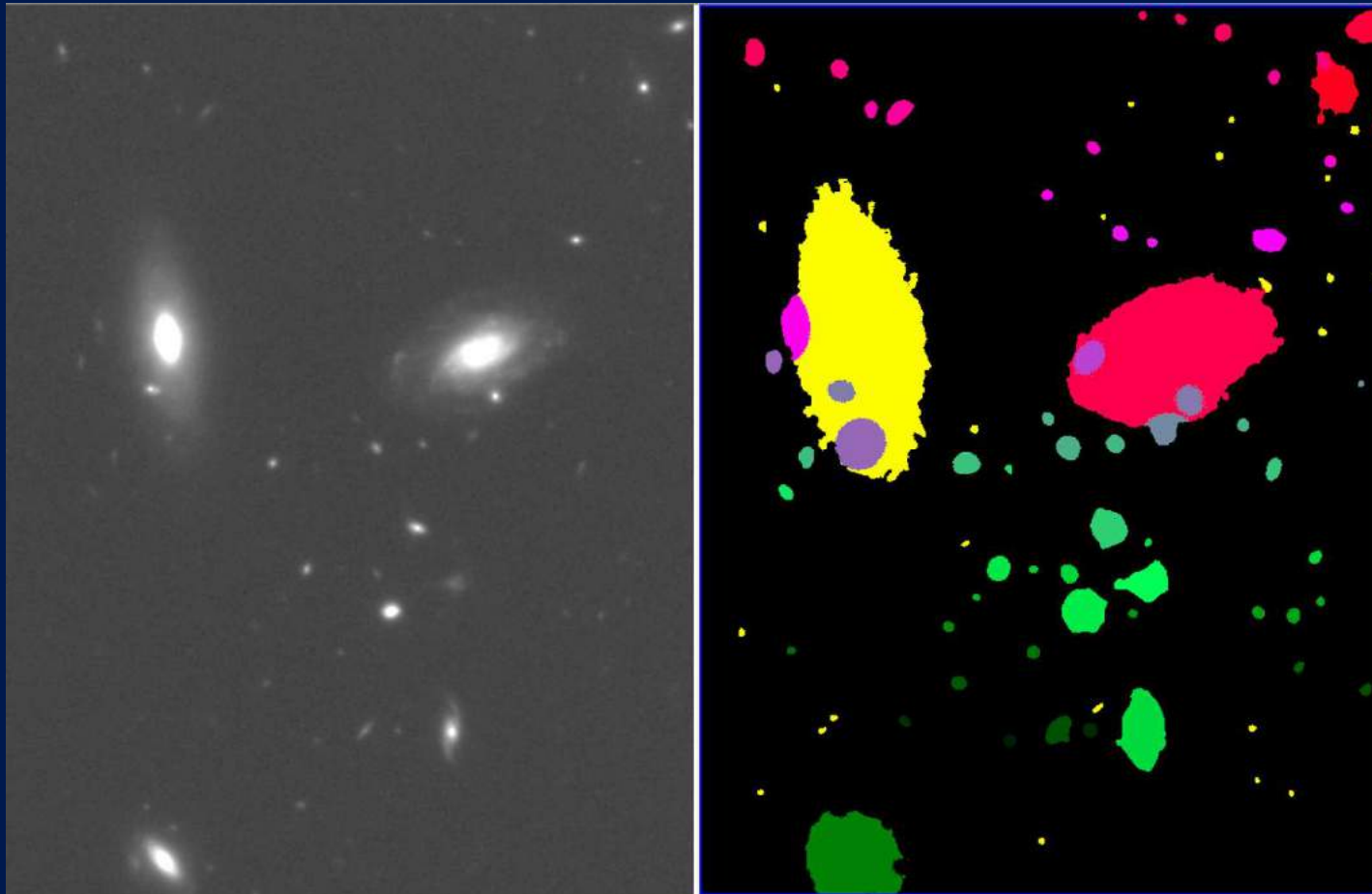
Confusion noise

- Contamination of sky background
 - faint unresolved sources
 - faint extension of bright sources
 - background variations (telescope optics and artefacts: saturated stars, reflections)
- Boosting of fluxes near limit
 - from faint sources
- Spurious detections
 - merging of faint sources below/above limit
- Bias positional accuracy of sources



Photometry of galaxies

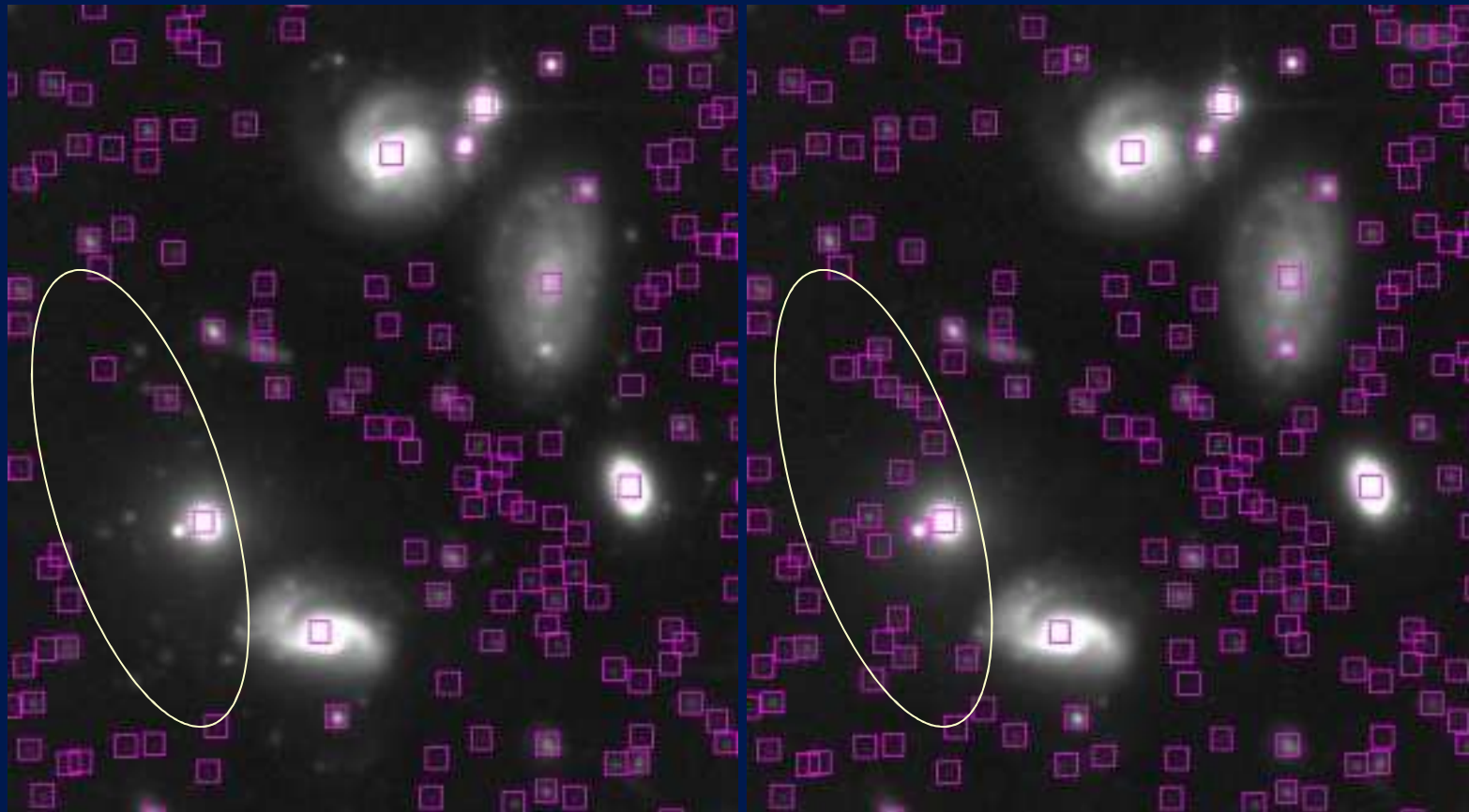
- Deblending : based on minimum threshold for contrast



Bertin & Arnouts 1996 (SExtractor)

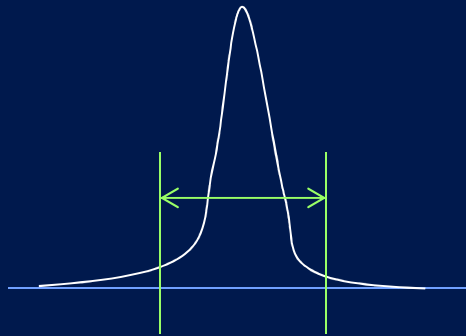
Photometry of galaxies

- Deblending efficiency
separation of faint objects → split of large flocculent objects



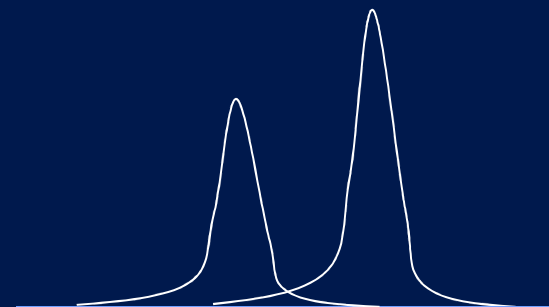
Photometry of galaxies

- Adaptive aperture
2.5 isophotal radius : 6% loss
→ missing flux function of external profile



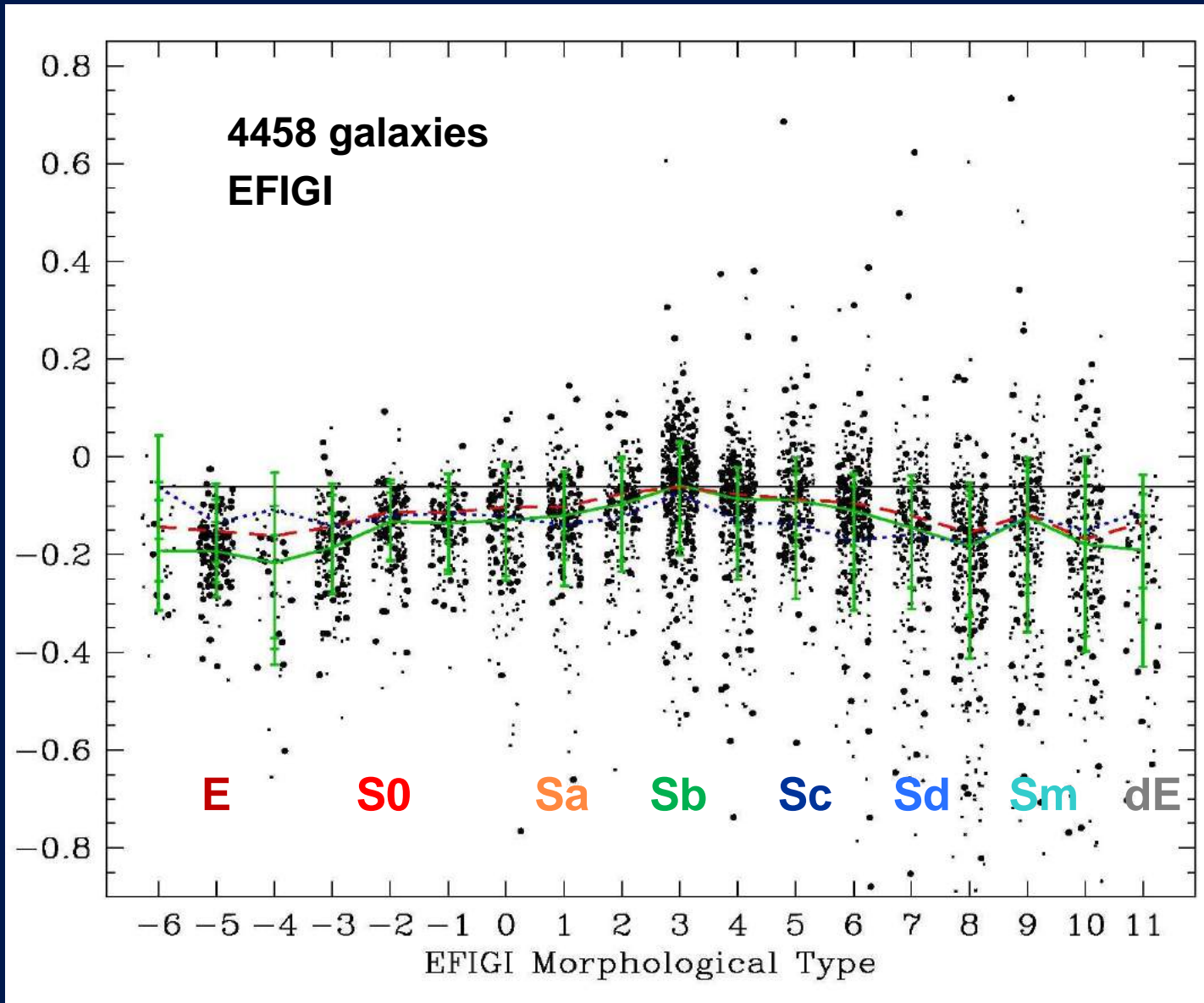
→ Profile fitting recovers wings

- Crowding : flux contamination by neighboring galaxies



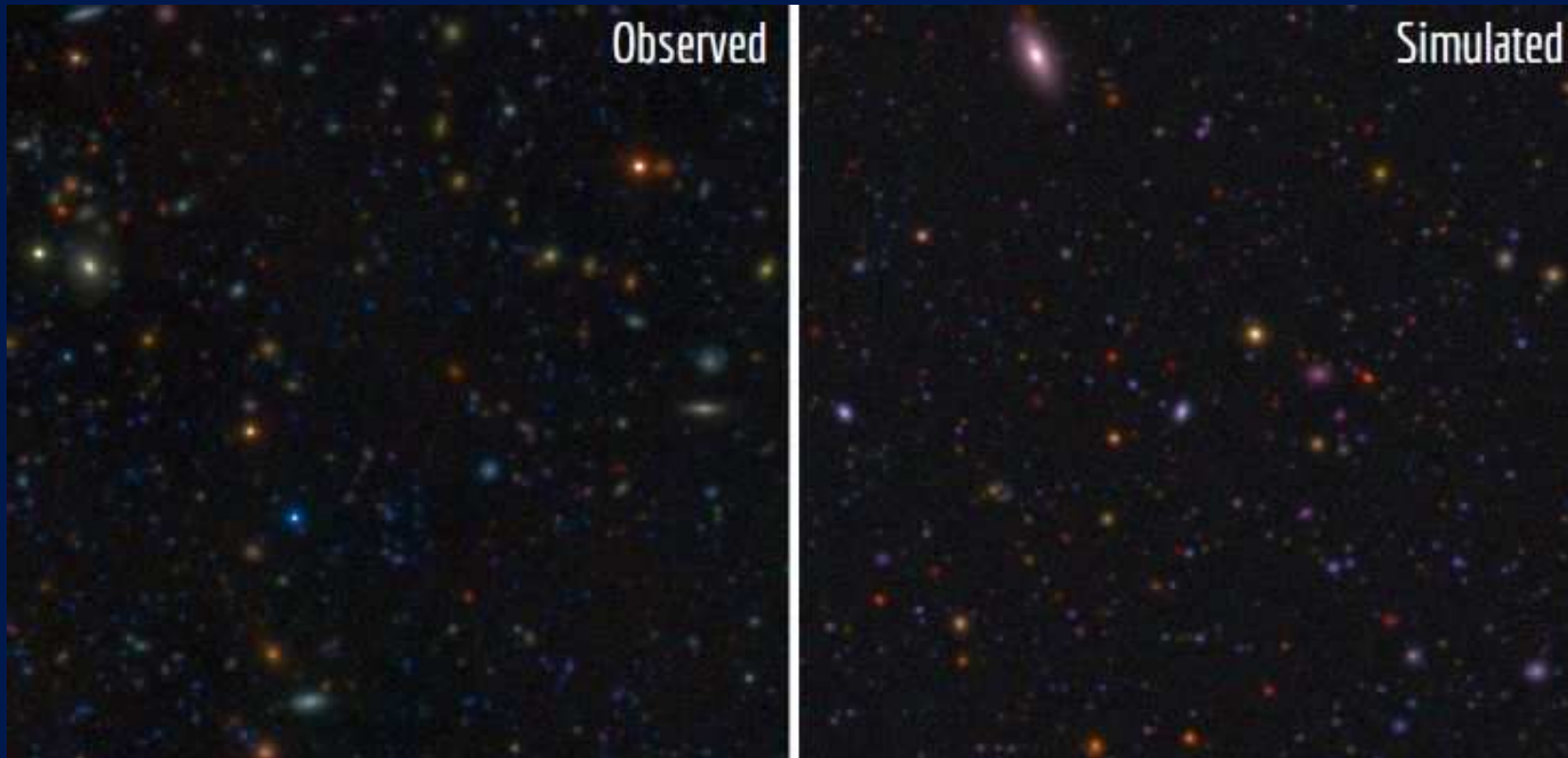
Aperture bias in magnitudes

Integrated mag. – adapt. aperture mag.



Simulation d'images (CFHTLS Deep)

- Modèle de bruit et réponse impulsionnelle réalistes
 - Transmission télescope/instrument/filtre + temps de pose
 - Distances et effets de décalage vers le rouge (corrections-k)
- Tous les biais observationnels sont pris en compte



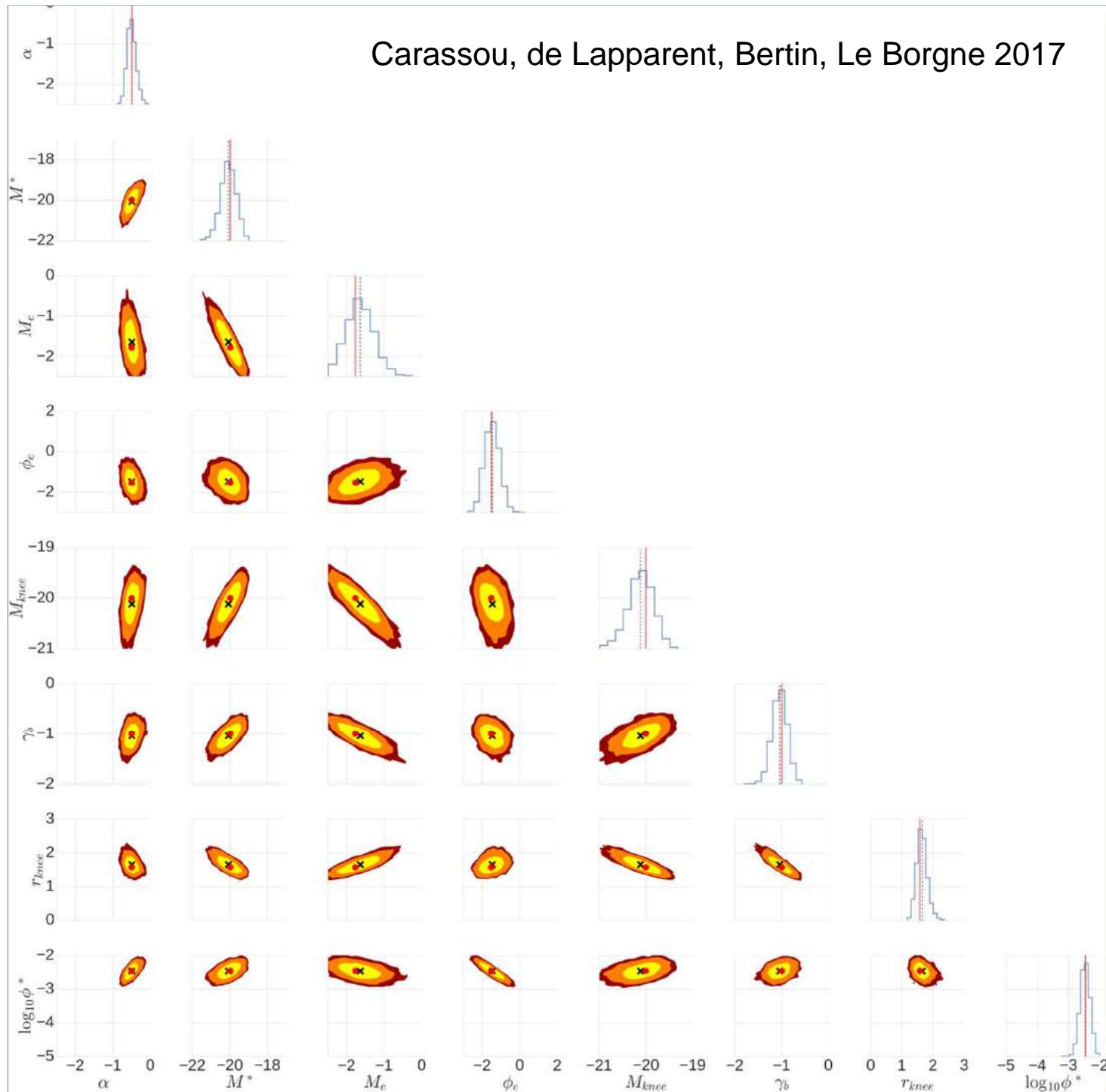
Stuff + SkyMaker ("AstrOmatic.net", Bertin)

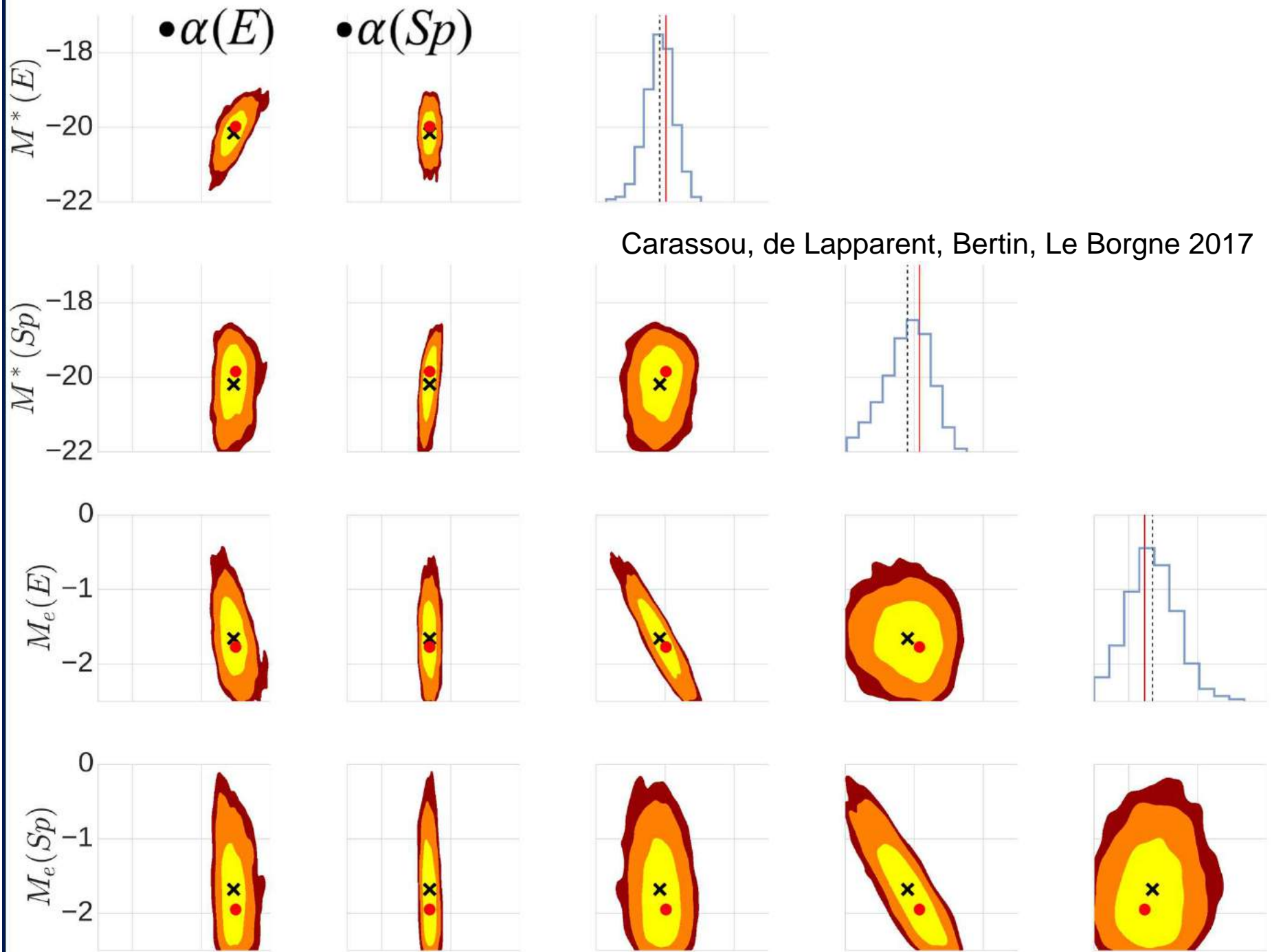
Chaînes de Markov et inférence bayésienne

- Comparaison observations/simulations :
 - observables: flux et taille
 - Exploration itérative de l'espace des paramètres
 - 2/3 populations E, Sp, Irr
 - fonctions de luminosité et évolution
 - fonctions de taille et évolution
- valeurs les plus vraisemblables des paramètres des populations de galaxies

Carassou, de Lapparent, Bertin, Le Borgne 2017
Carassou 2017 (Doctorat)

Carassou, de Lapparent, Bertin, Le Borgne 2017





Chaînes de Markov et inférence bayésienne

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 - fonctions de taille et évolution
- valeurs les plus vraisemblables des paramètres des populations de galaxies
- ... Défis à relever :
- optimisation du temps de calcul (actuellement plusieurs semaines sur grappe de calcul IAP : 50 000h CPU)
 - modélisation plus réaliste des galaxies et populations

Objectifs et perspectives

- Etablir des liens entre :
 - propriétés internes : morphométrie bulbes/disques
 - propriétés collectives : fonctions de corrélation, luminosité/masse
- Contrainte des modèles de formation des galaxies au sein de la toile cosmique
- Lien entre les transformations spectrales et morphologiques
 - + Influence de l'environnement
 - formation d'étoiles continue versus sursauts de formation d'étoiles
 - formation des bulbes et disques (masses et âges)
 - fusions et interactions ← peuplement des halos de matière noire
- Transformations majeures à $z < 1$ (2/3 âge Univers)
- Calibration de l'évolution grand z / grande longueurs d'onde (ALMA, JWST, Euclid)