



# Morphologie des galaxies

Valérie de Lapparent

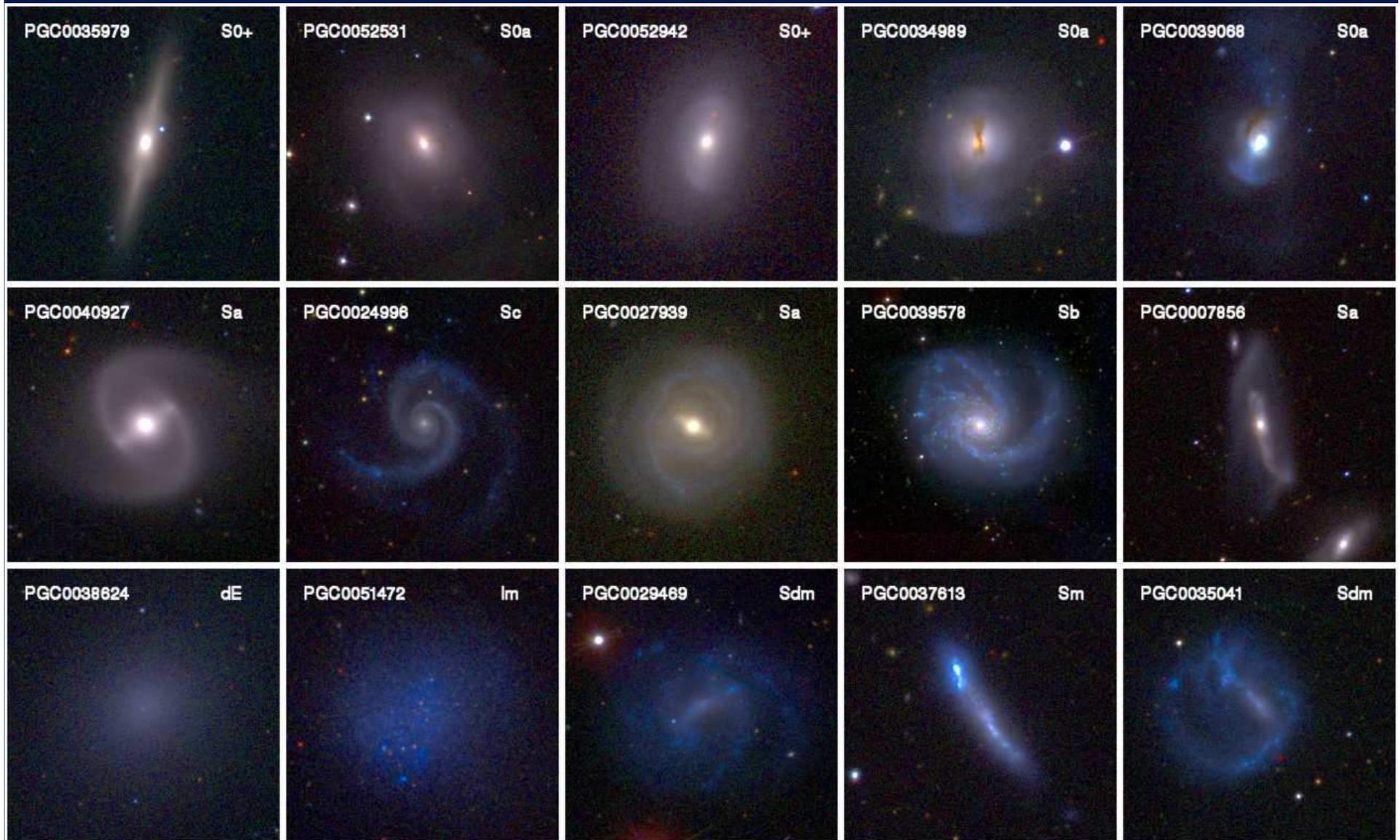


Institut d'Astrophysique de Paris CNRS / UPMC

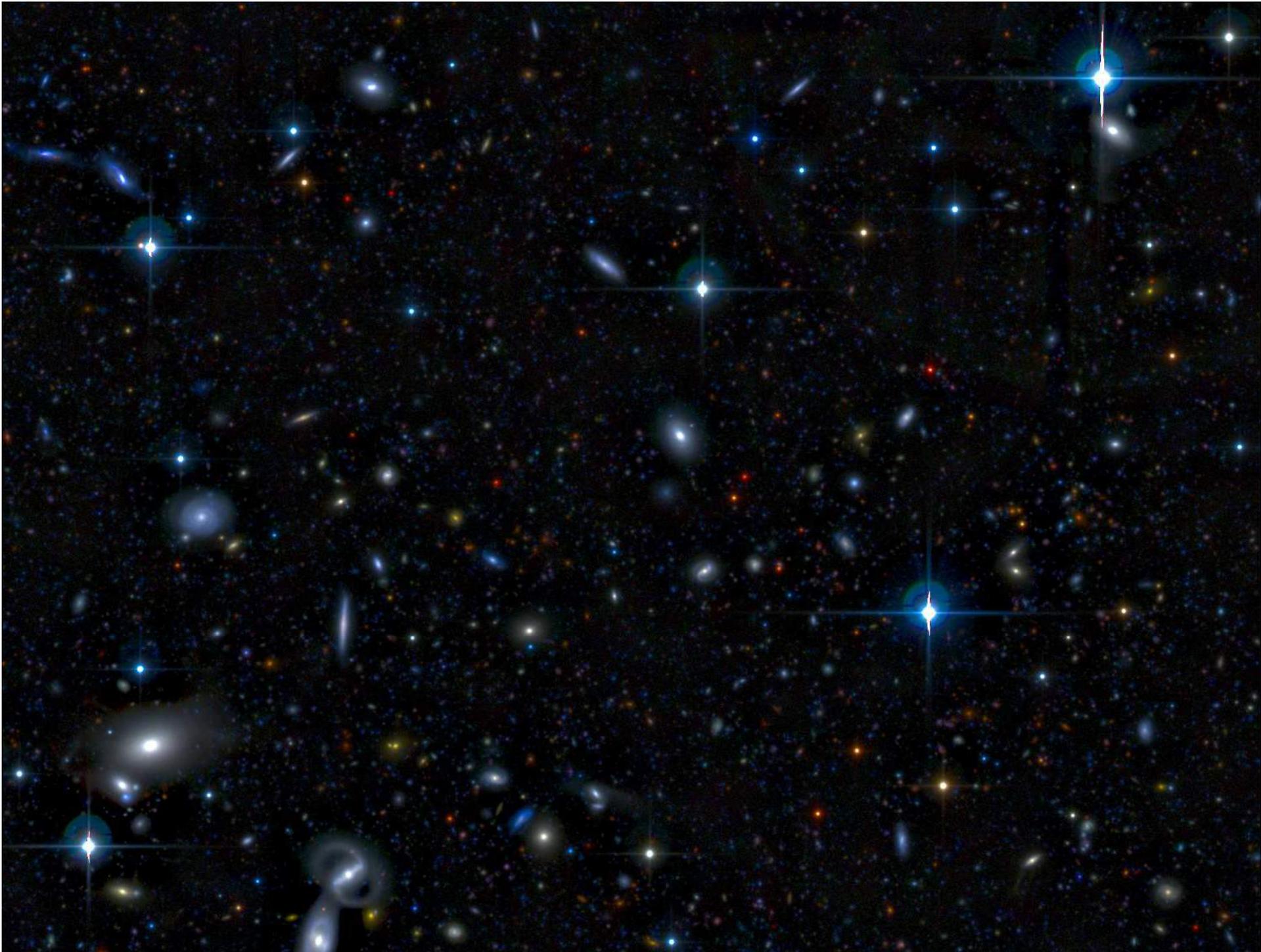


- La diversité des galaxies
- Le lien avec la toile cosmique
- Catalogue morphologique EFIGI
- La morphologie des galaxies à grande distance
- Le défi technique de la morpho-photo-métrie des galaxies
- L'évolution des galaxies par inférence bayésienne
- Objectifs et perspectives

# La diversité des galaxies

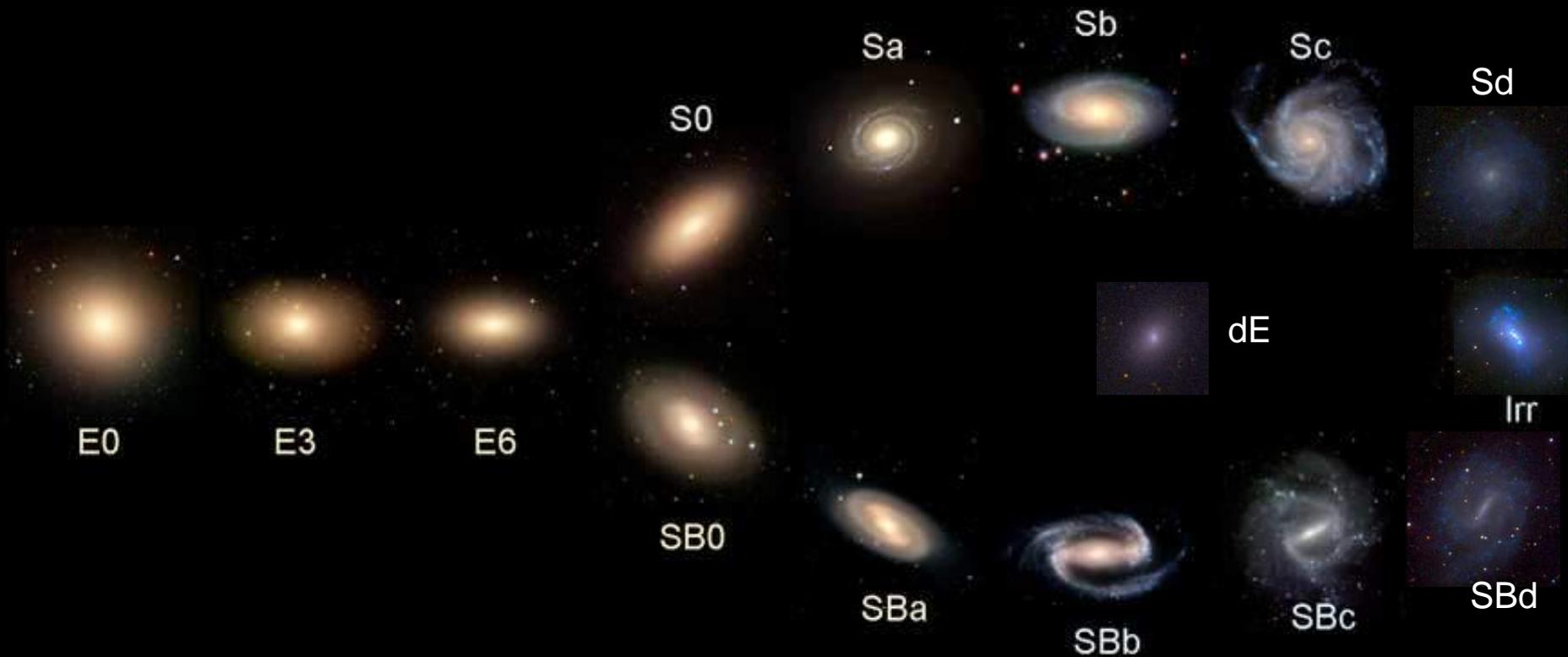






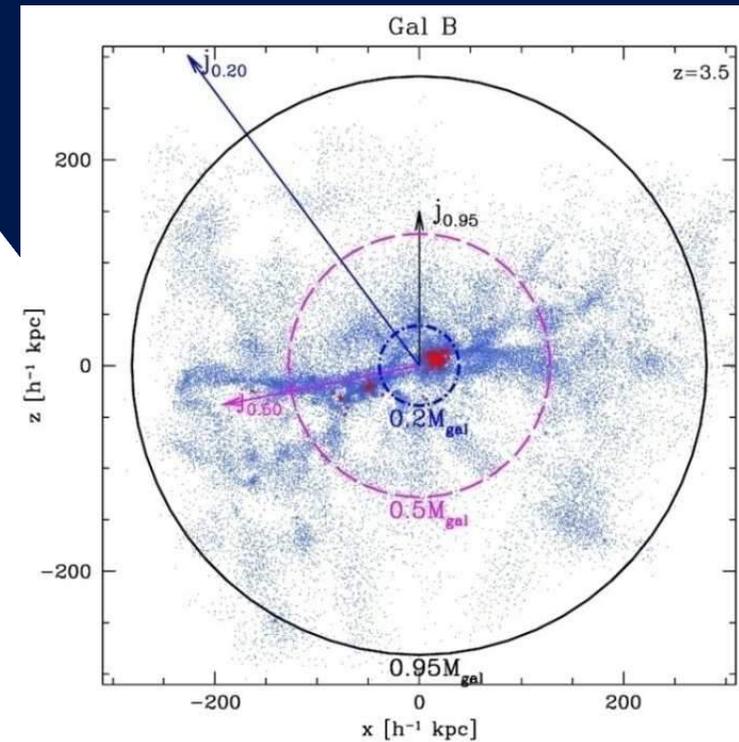
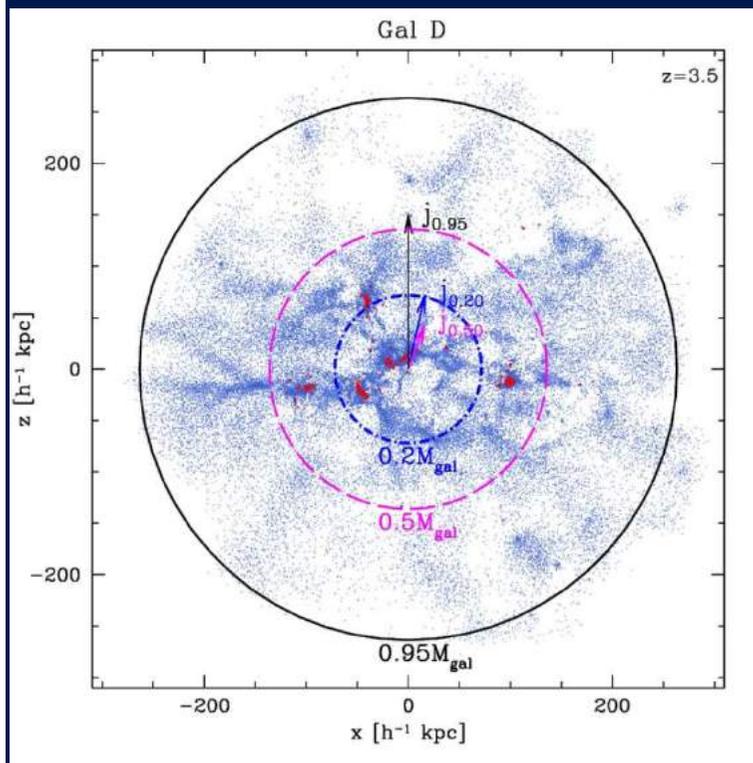
# La séquence de Hubble (1926)

## Hubble's Galaxy Classification Scheme



# Simulations à N-corps + hydrodynamique matière noire + gaz

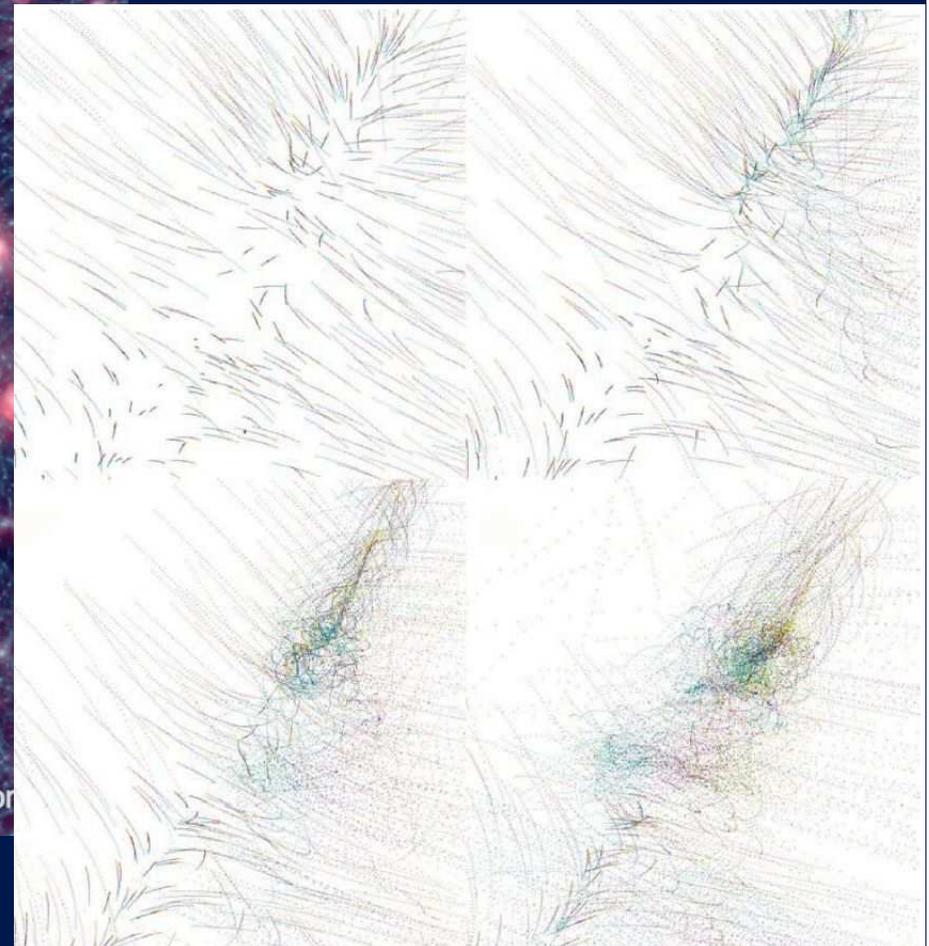
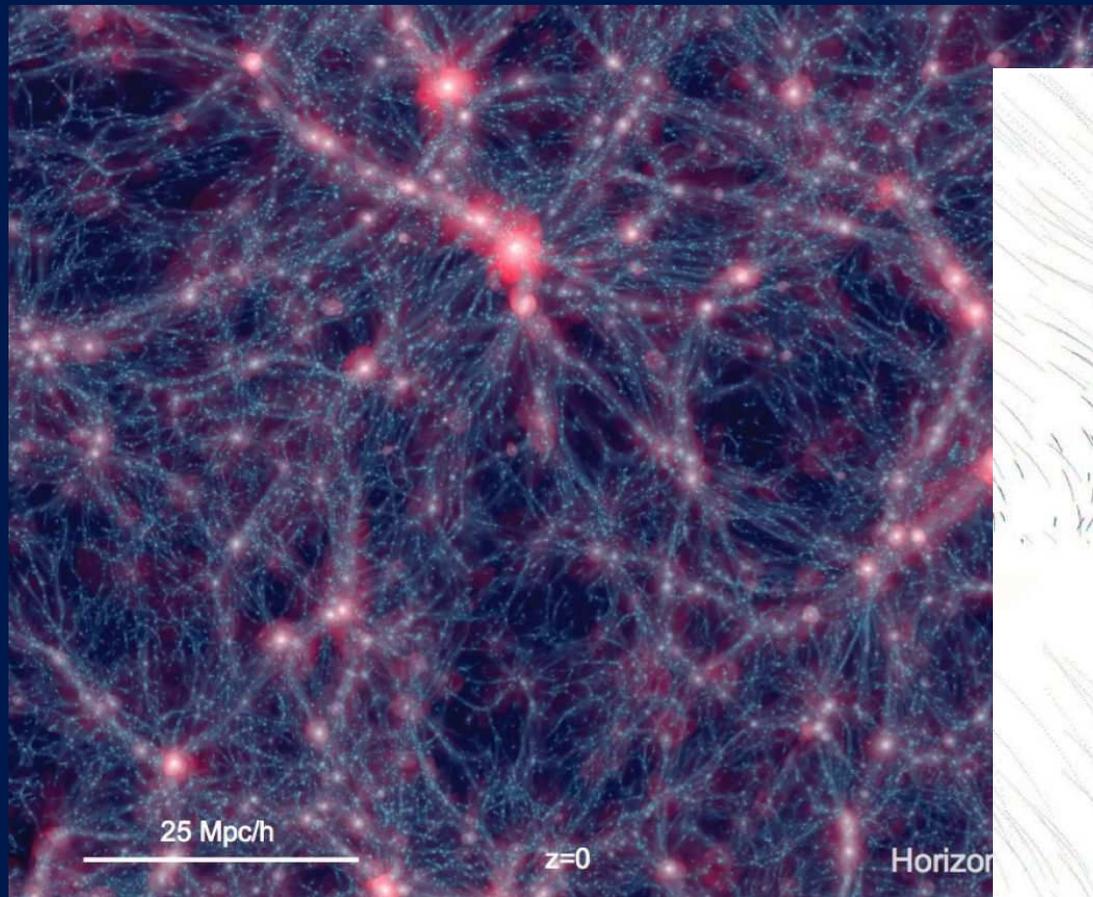
- Morphologie déterminée par la cohérence du moment angulaire du gaz accrété avec le gaz déjà présent



Sales et al. 2012 "GIMIC"

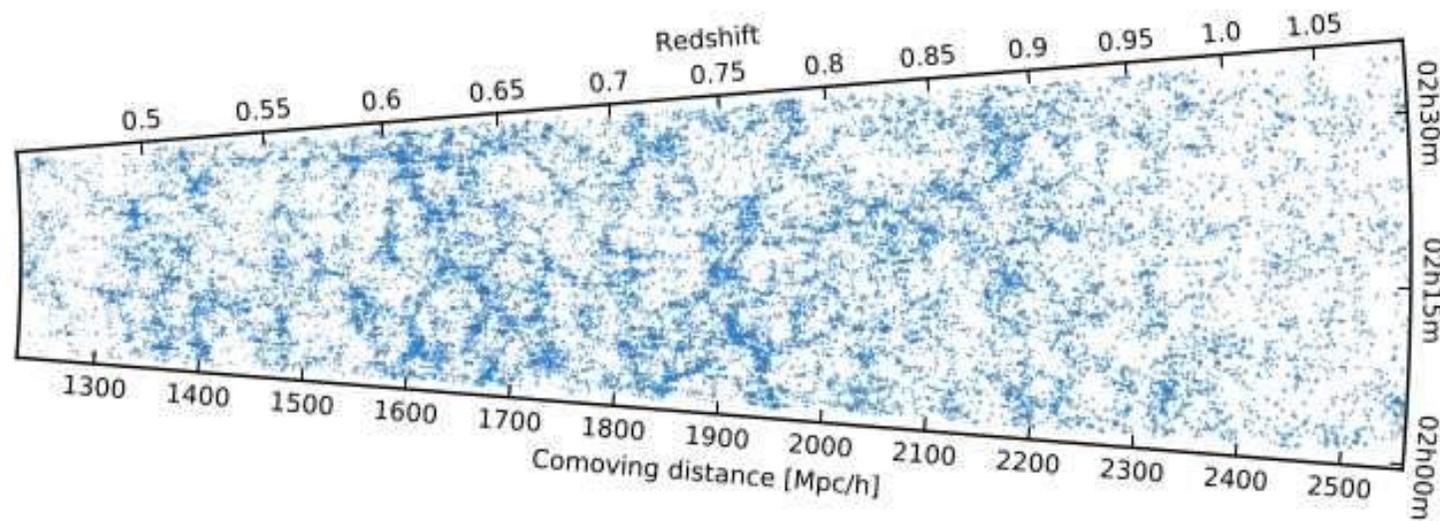
# Simulations à N-corps + hydrodynamique matière noire + gaz

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

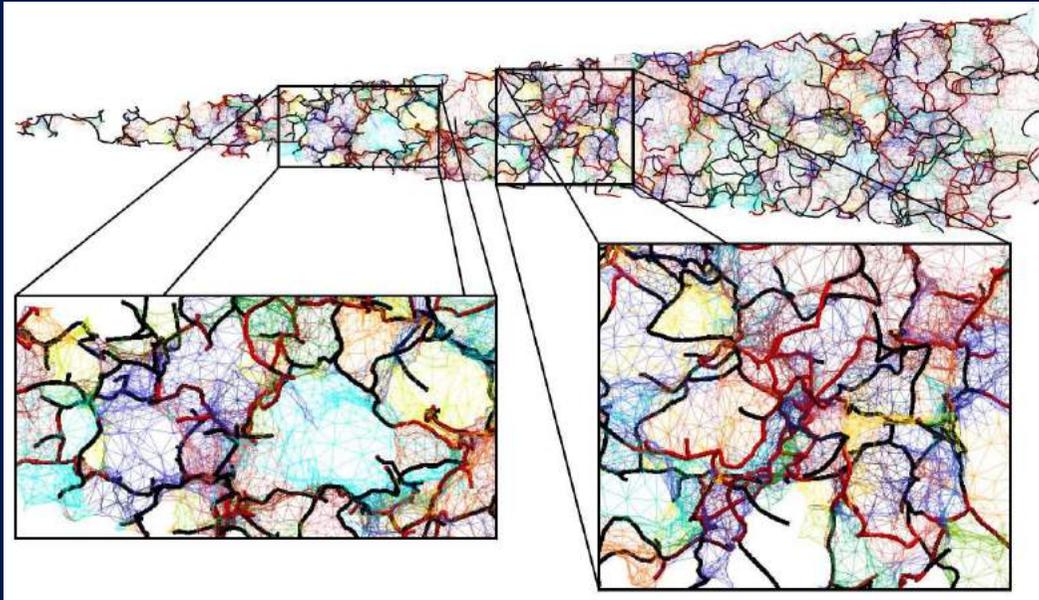


Dubois et al. 2016    Codis et al. 2012

# La toile cosmique dans le relevé VIPERS



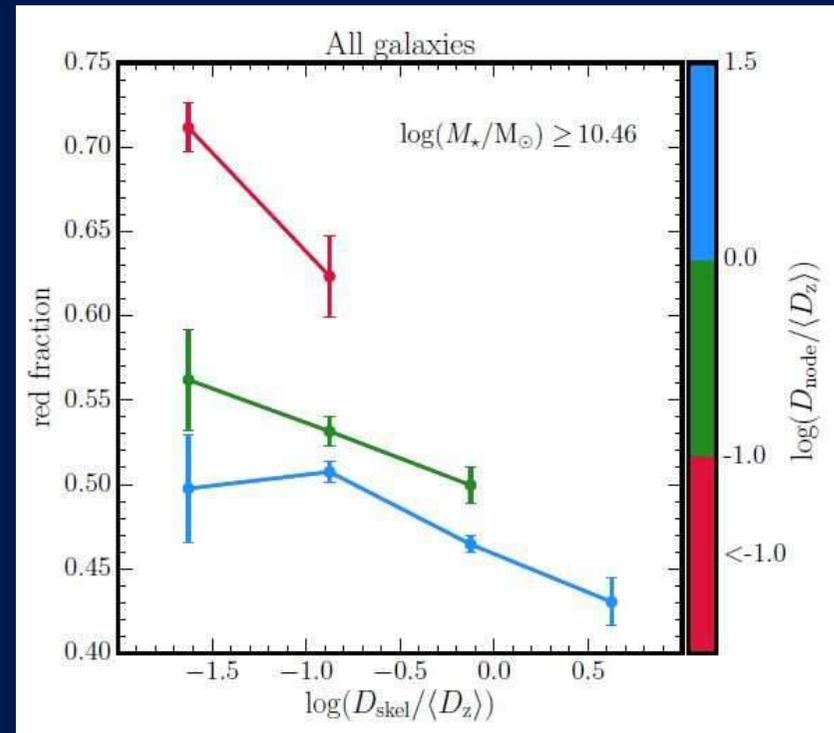
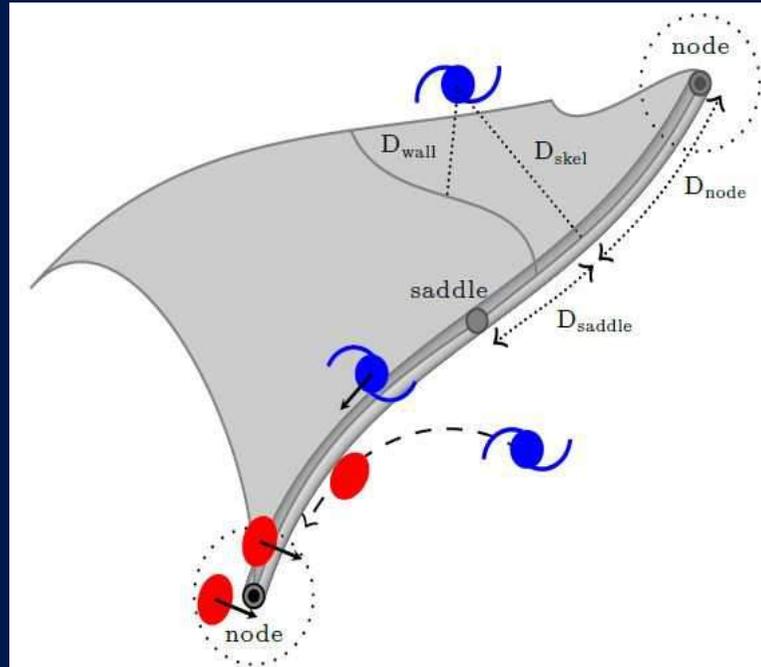
Guzzo et al. 2016



# VIPERS

## Toile cosmique versus couleur

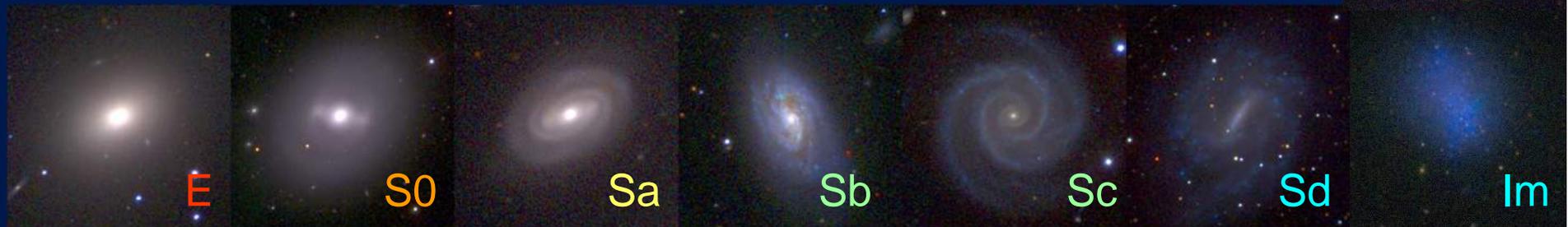
Kraljic et al. 2018  
ANR SPINe (PI : Pichon)



# 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



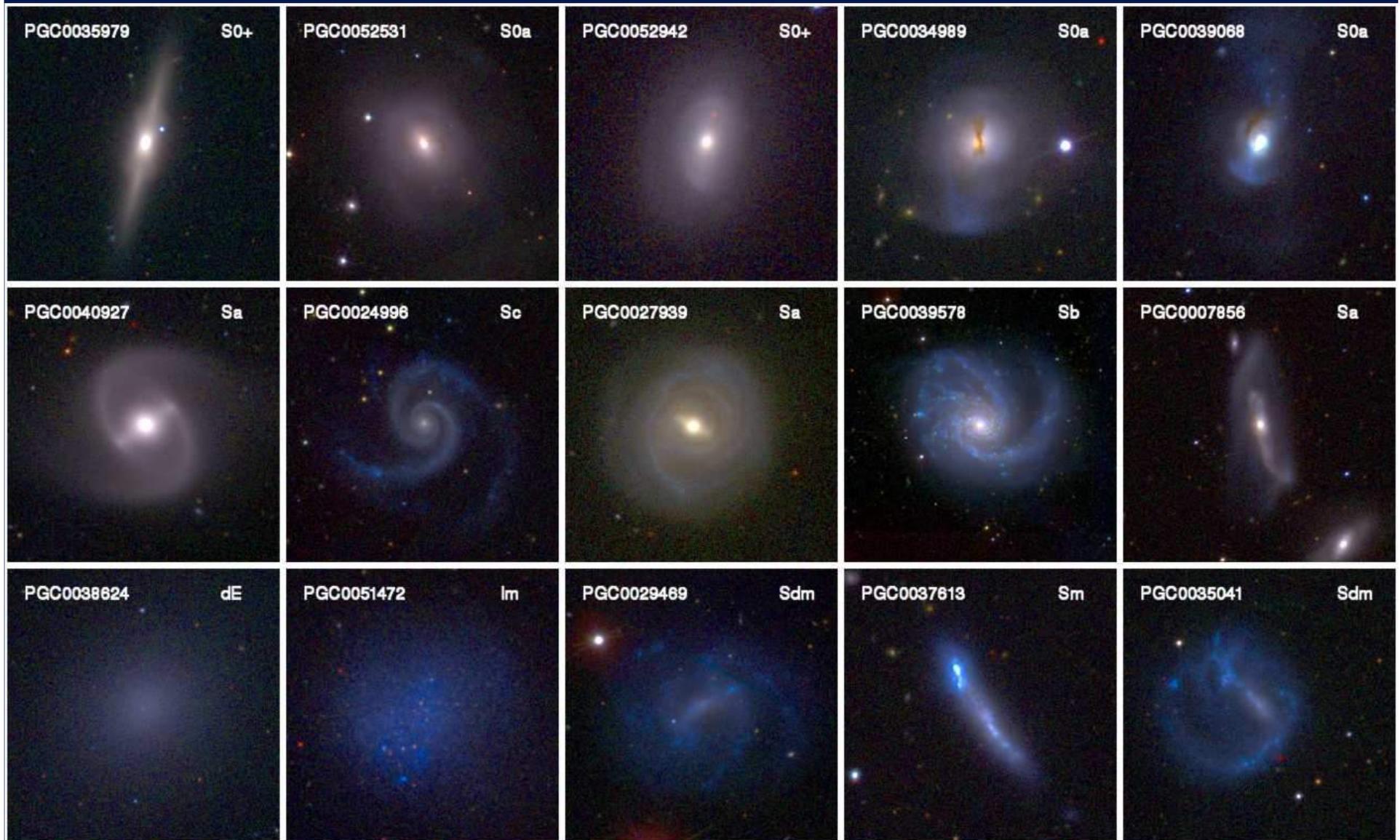
Baillard 2008, Bertin et al. 2011, de Lapparent et al. 2011

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

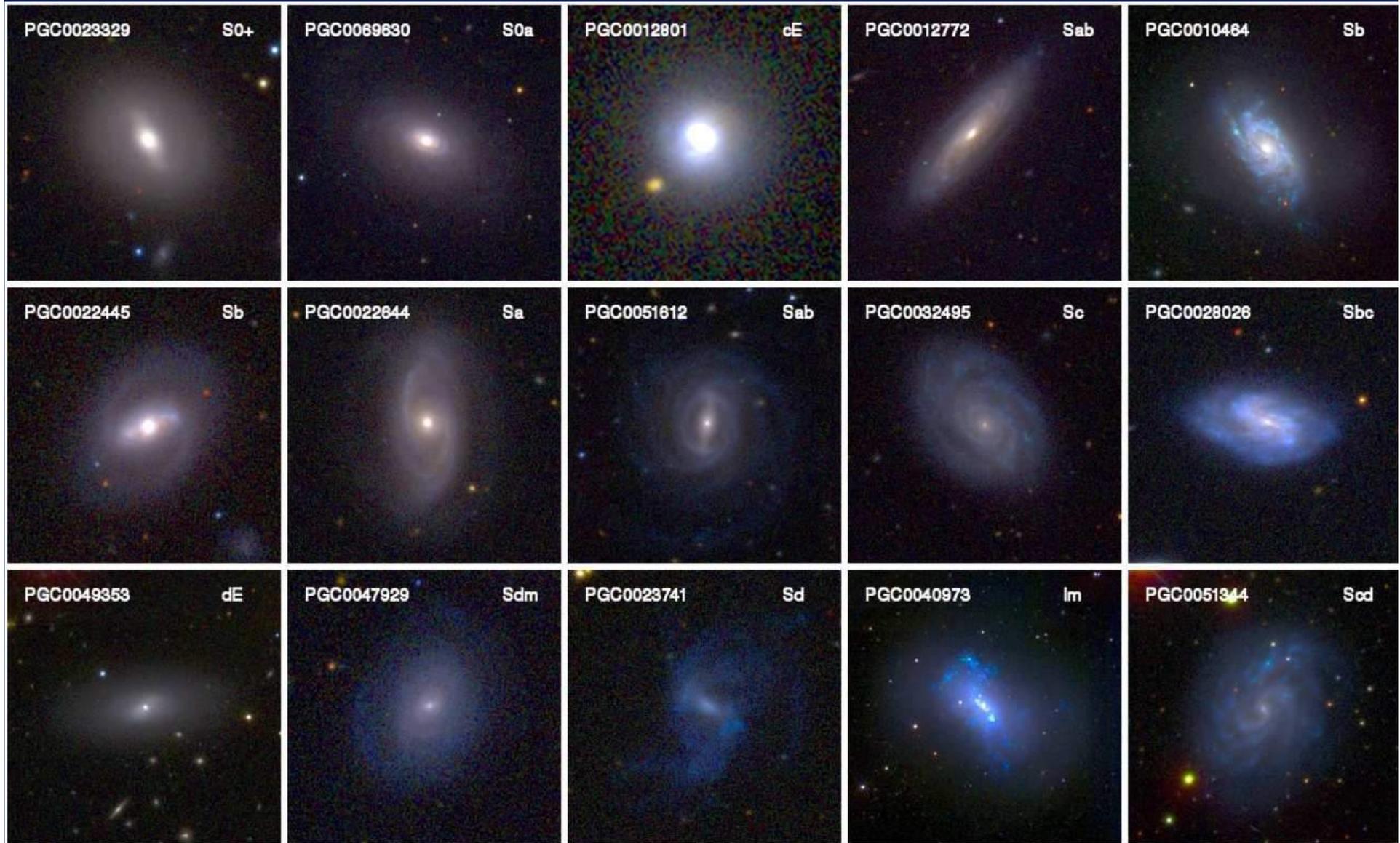
The interface displays the following components:

- Target Galaxy:** PGC0030829 ✓ (Sb)
- Hubble type:** Hubble type ✓ (Sb)
- Examples Sb:** Three representative Sb galaxies.
- Classification Hierarchy:**
  - Elliptical: cE, cD
  - Lent.: S0<sup>0</sup>, S0a, S0<sup>+</sup>
  - Spiral: Sa, Sb, Sc, Sd, Sm
  - Irregular: Im, dE
- Morphological Parameters (all checked):**
  - Multiplicity ✓
  - Contamination ✓
  - Perturbation ✓
  - Inclination ✓
  - B/TRatio ✓
  - BulgeEllipticity ✓
  - BulgeBoxiness ✓
  - Shell ✓
  - HotSpots ✓
  - VisibleDust ✓
  - DustDispersion ✓
  - Bar ✓
  - InternalRing ✓
  - ExternalRing ✓
  - ArmThickness ✓
  - ArmCurvature ✓
  - CurveIrregularity ✓
  - Flocculence ✓
  - ArmContinuity ✓
  - ArmStrength ✓
  - EightShape ✓
  - Rotation ✓
- Search Interface:** PGC number, Internal ID, Search button.

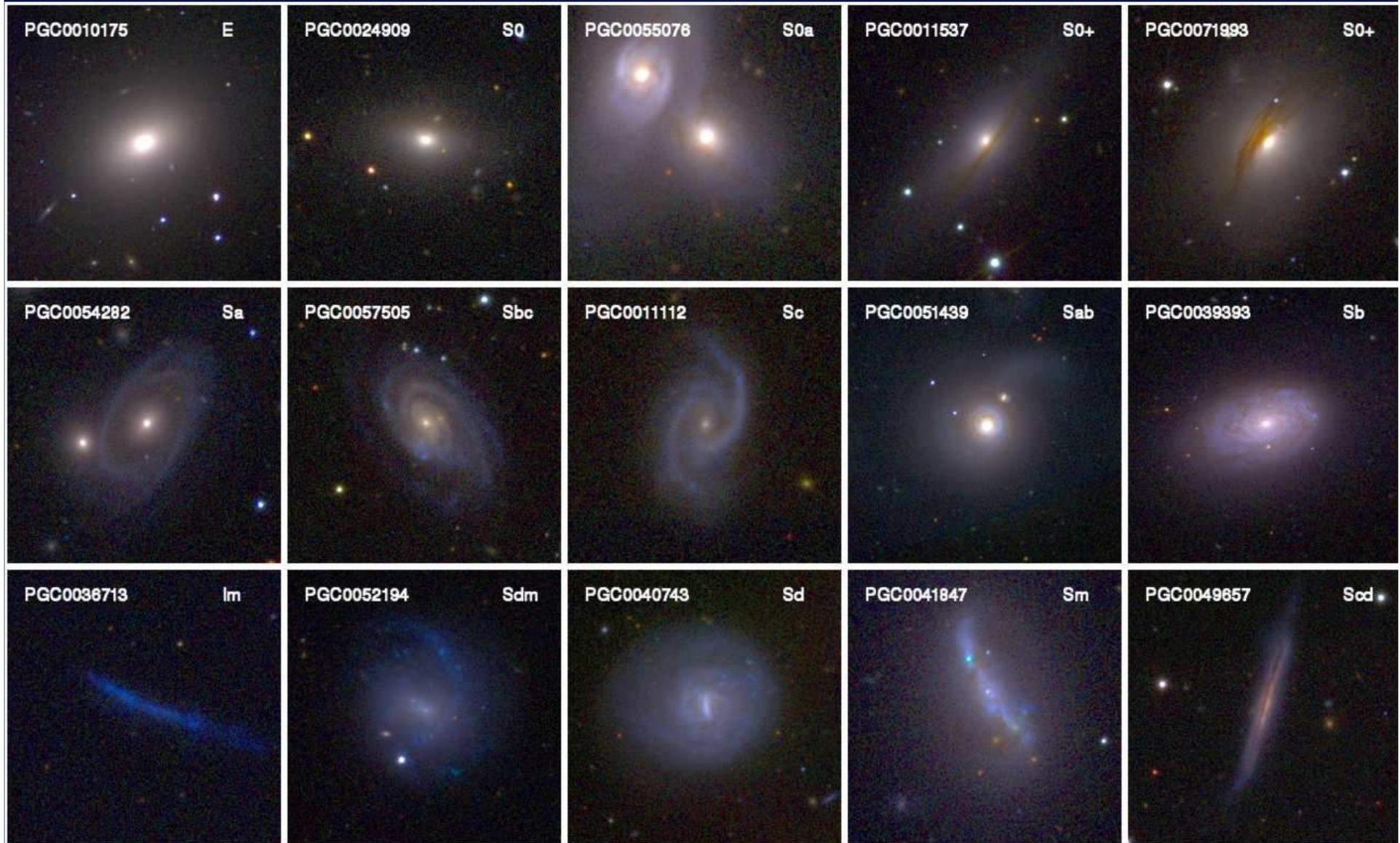
# Attribut : Perturbation



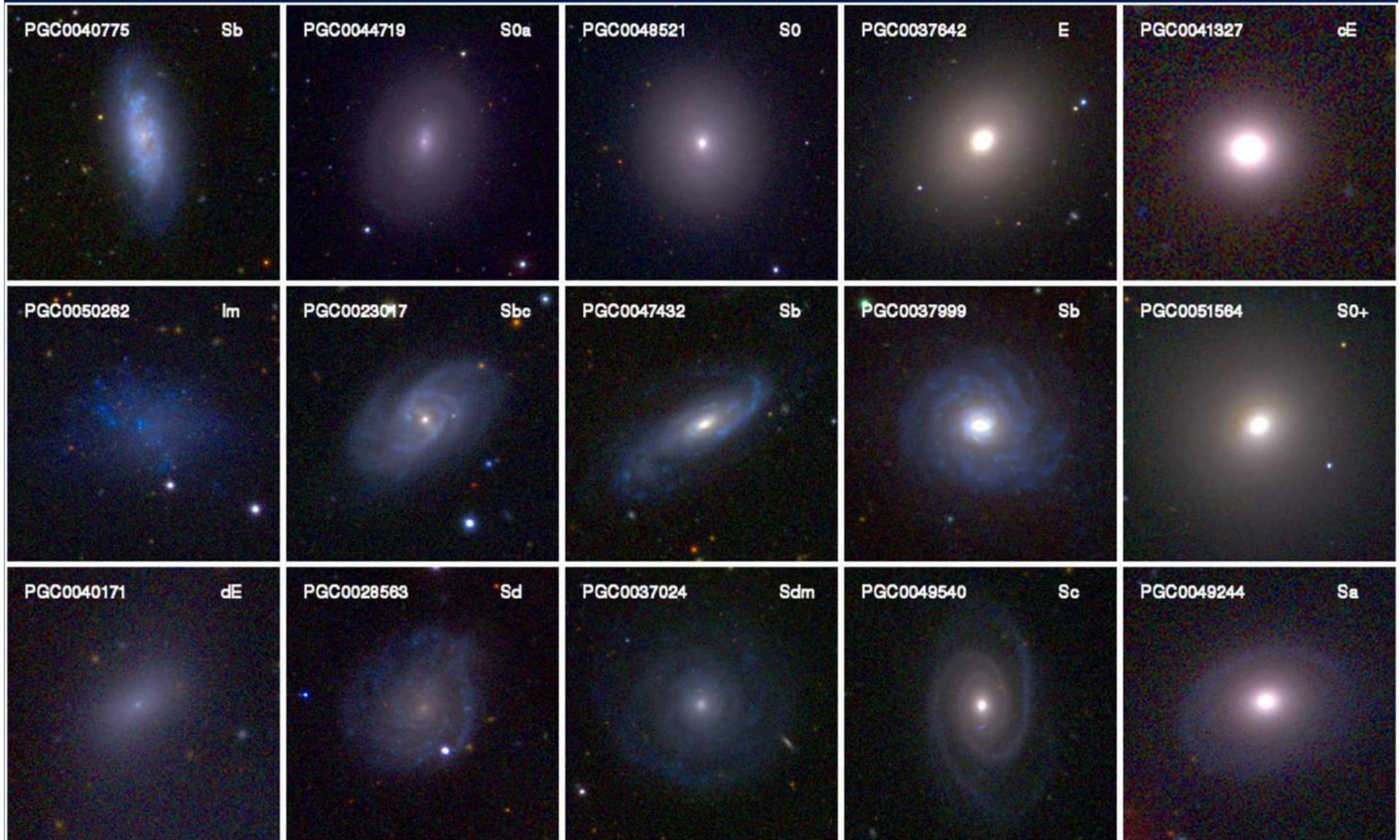
# Attribut : Flocculence



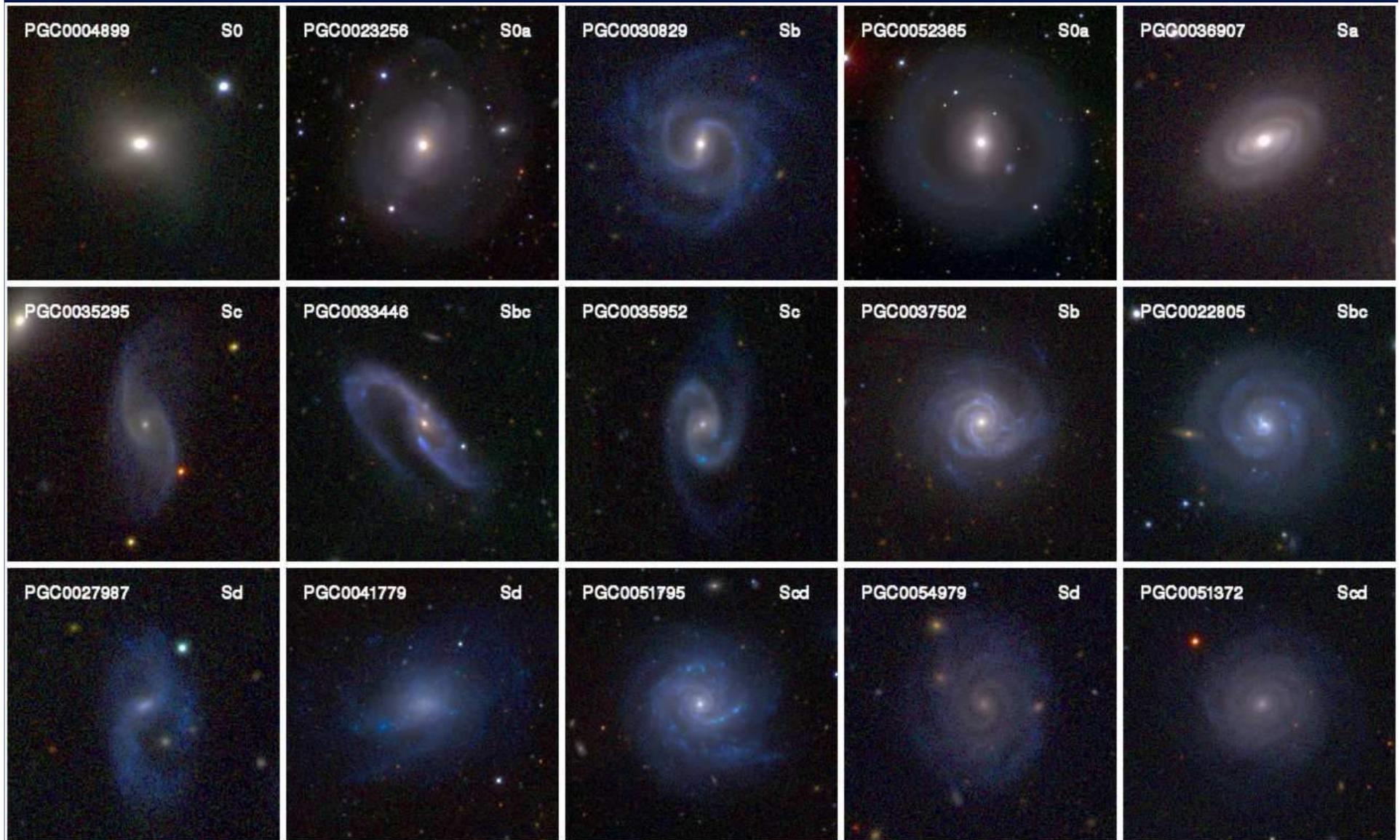
# Attribut : Poussière visible



# Attribut : Rapport flux Bulbe/Total



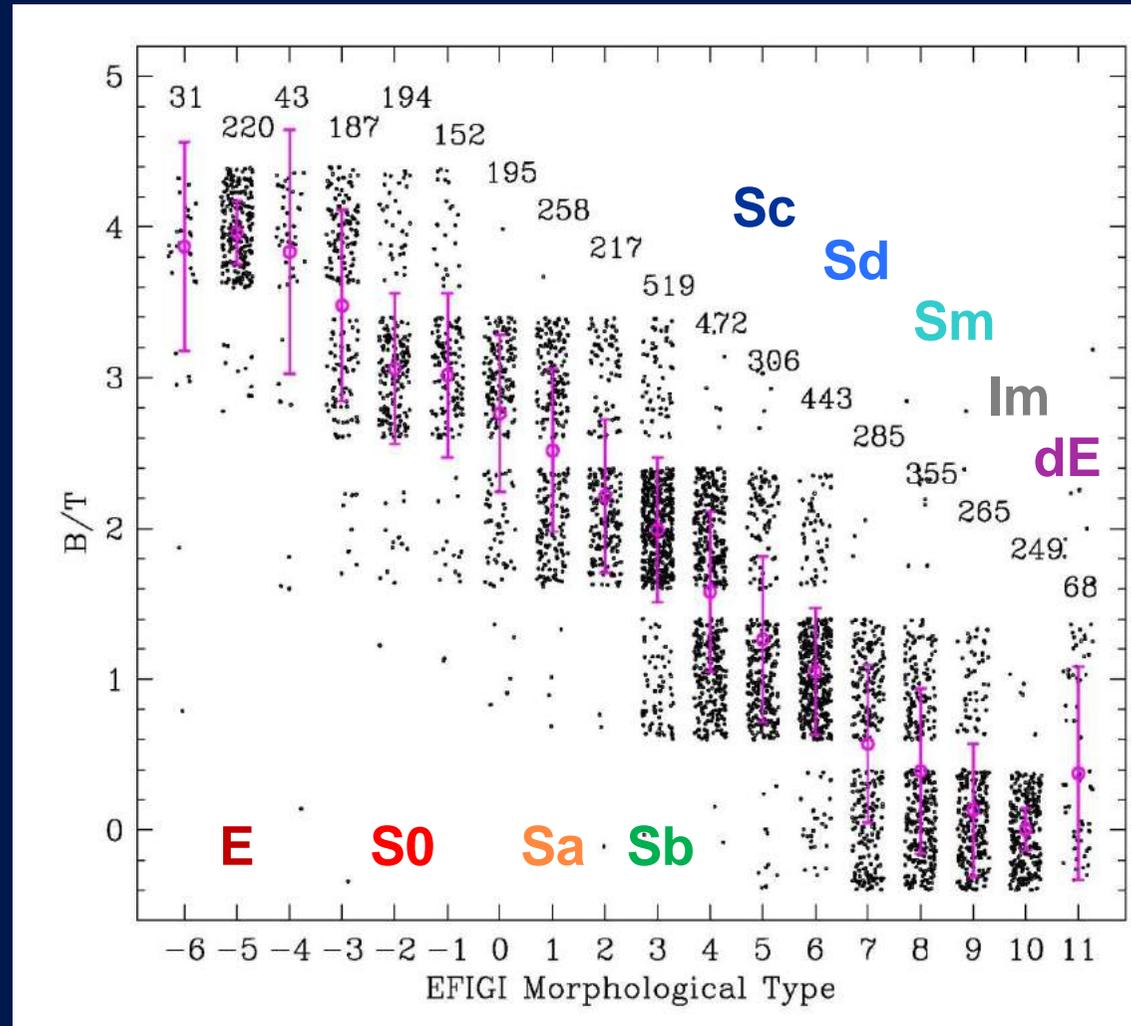
# Attribut : Courbure des bras spiraux

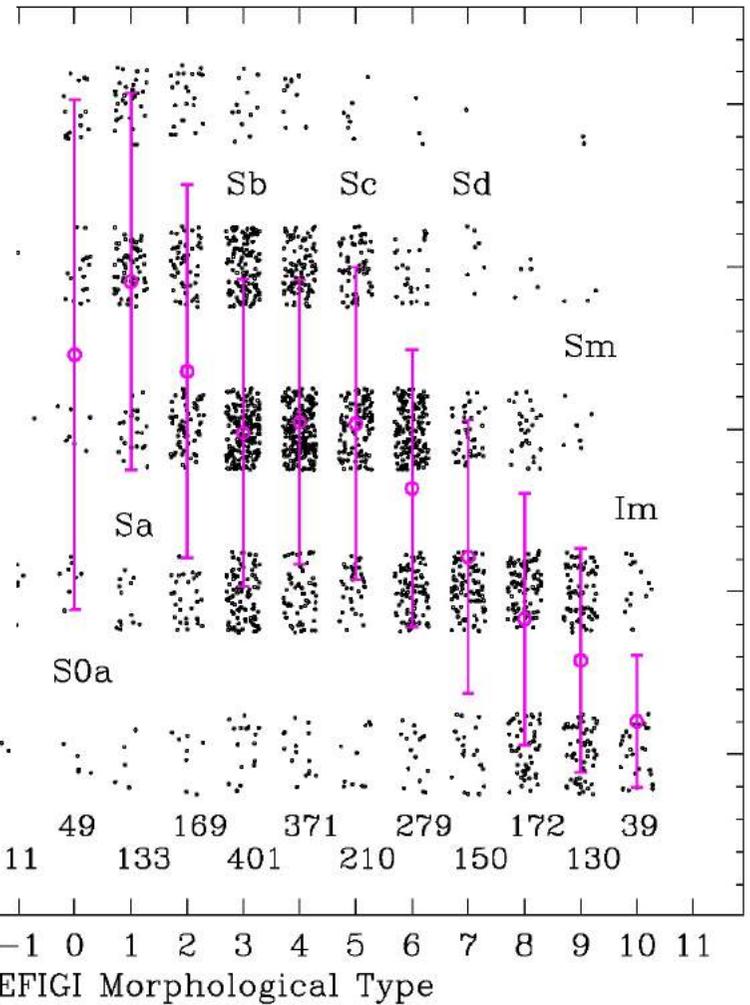
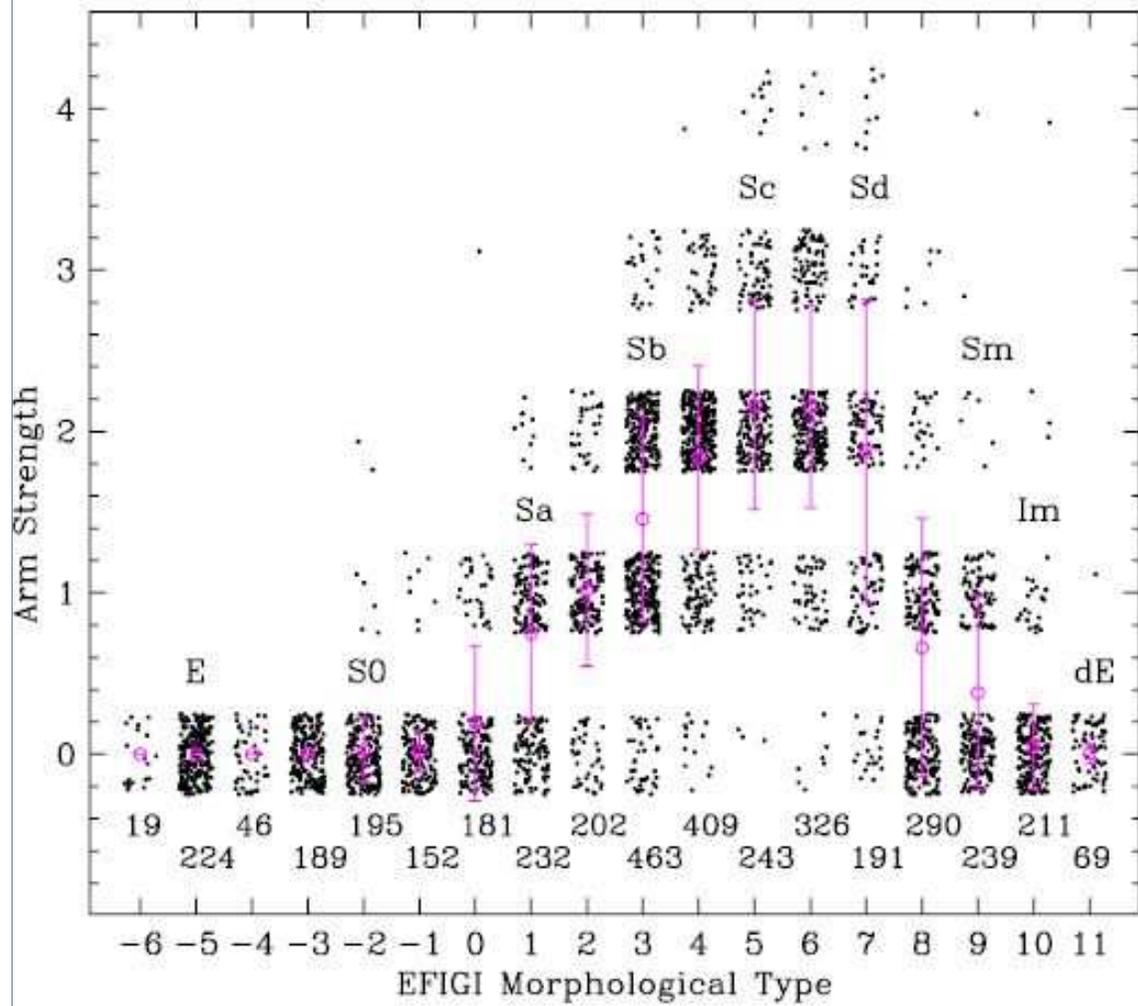


# Reconstruction of EFIGI Hubble sequence

Supervised learning tasks using Support Vector Machines :

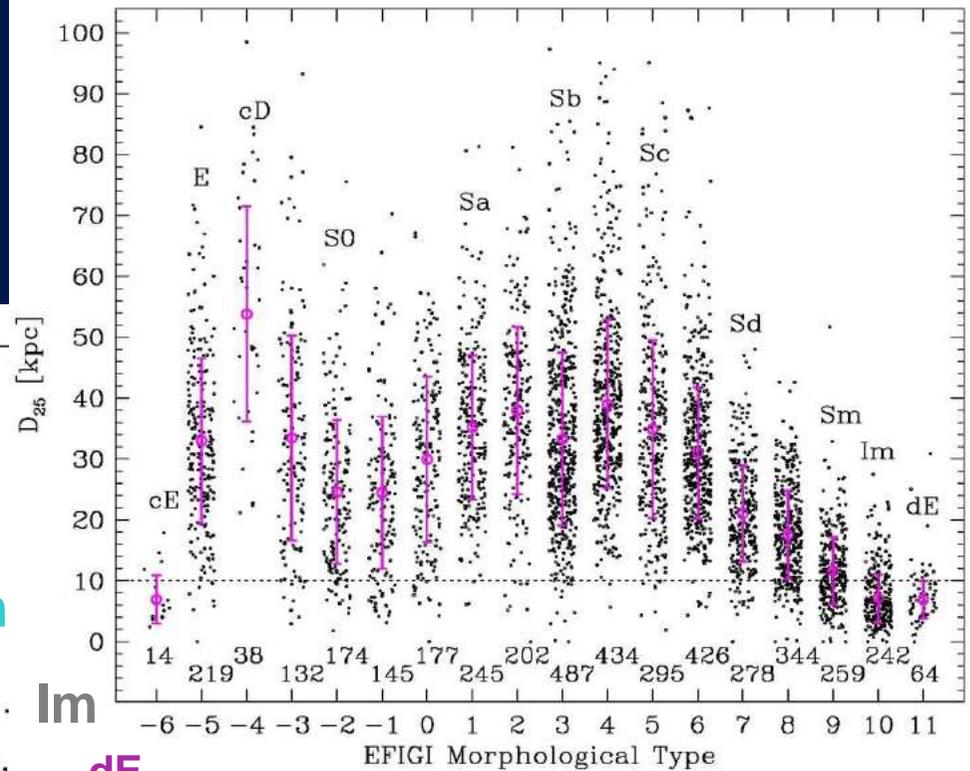
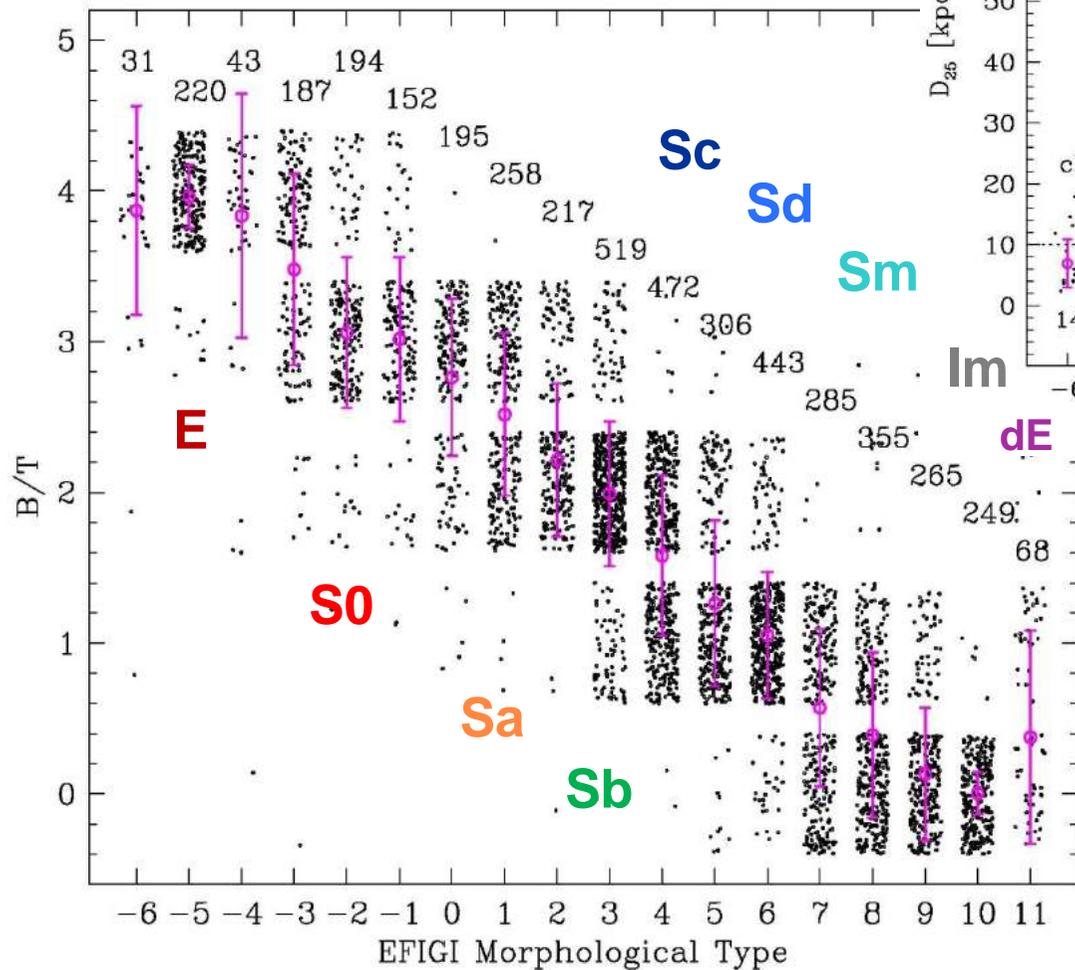
- Bulge/Total flux + Strength spiral arms + Curvature spiral arms



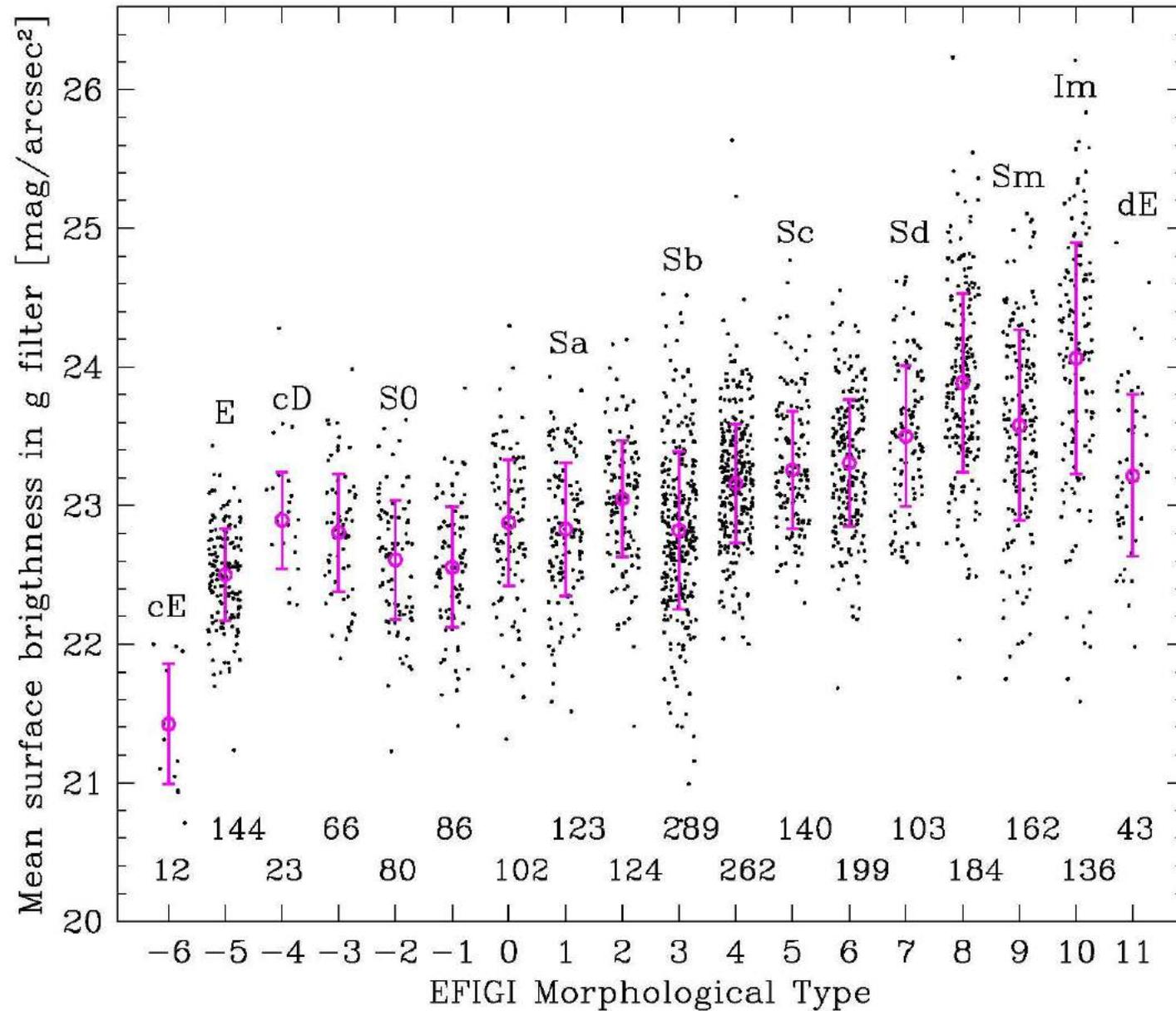


# EFIGI Hubble sequence

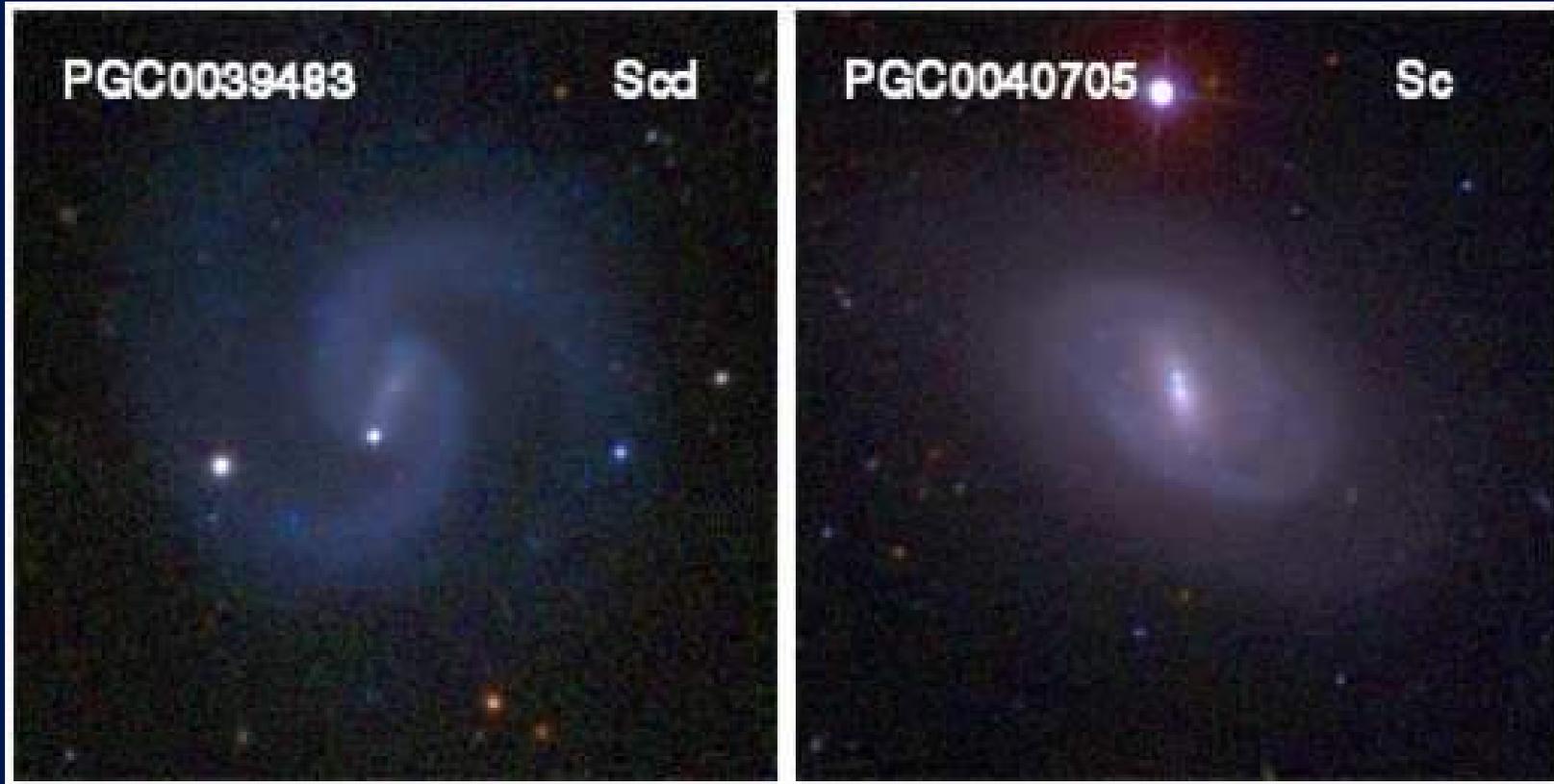
## Large size dispersion and variation



# EFIGI : variations en brillance de surface



# 2 galaxies naines spirales



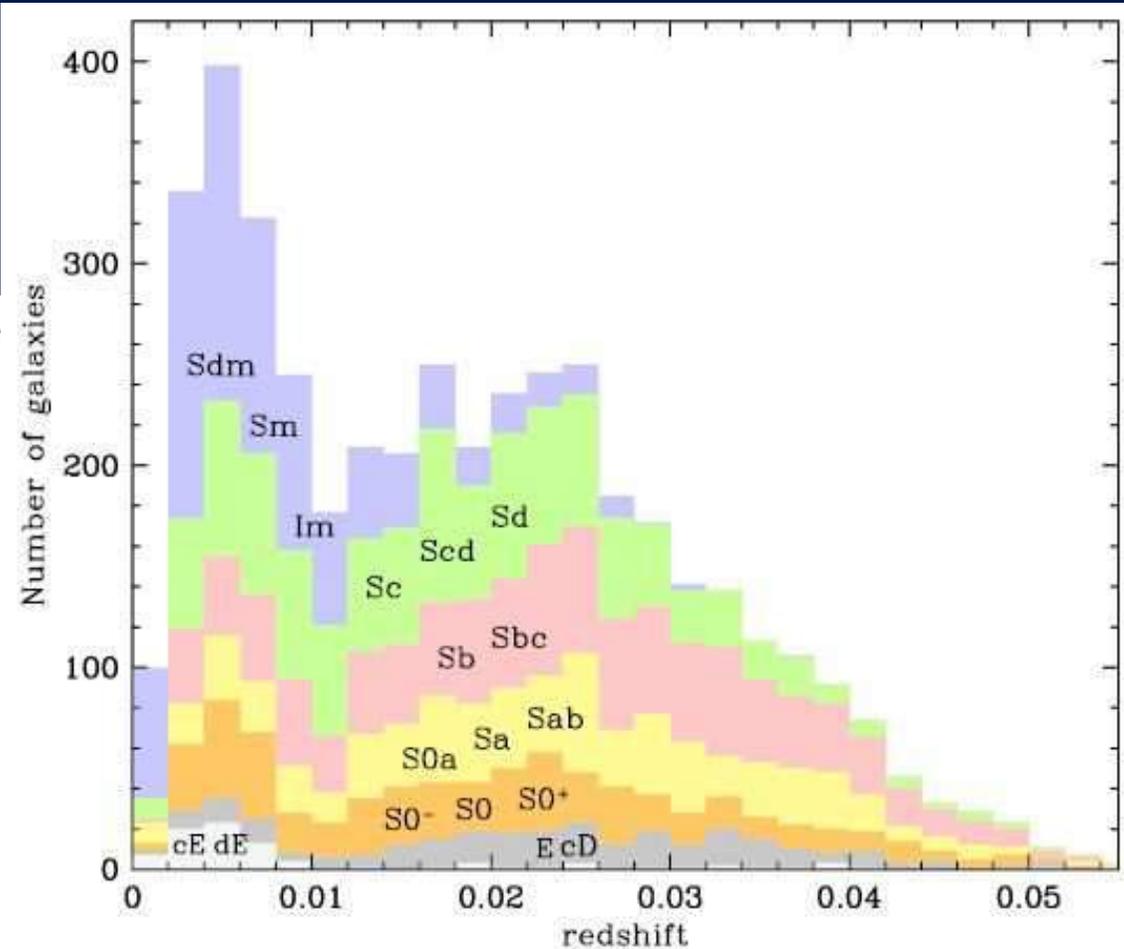
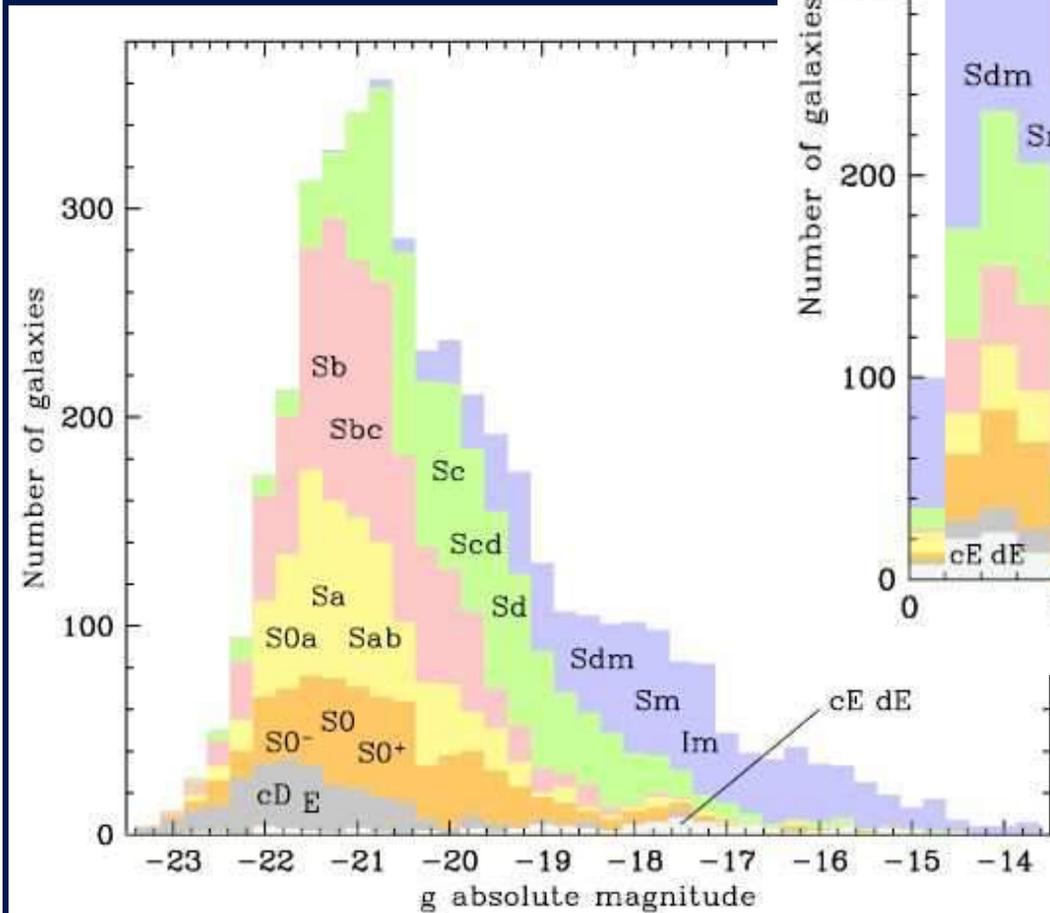
5.7 kpc  $M(g) = -16.9$

$z = 0.002638$

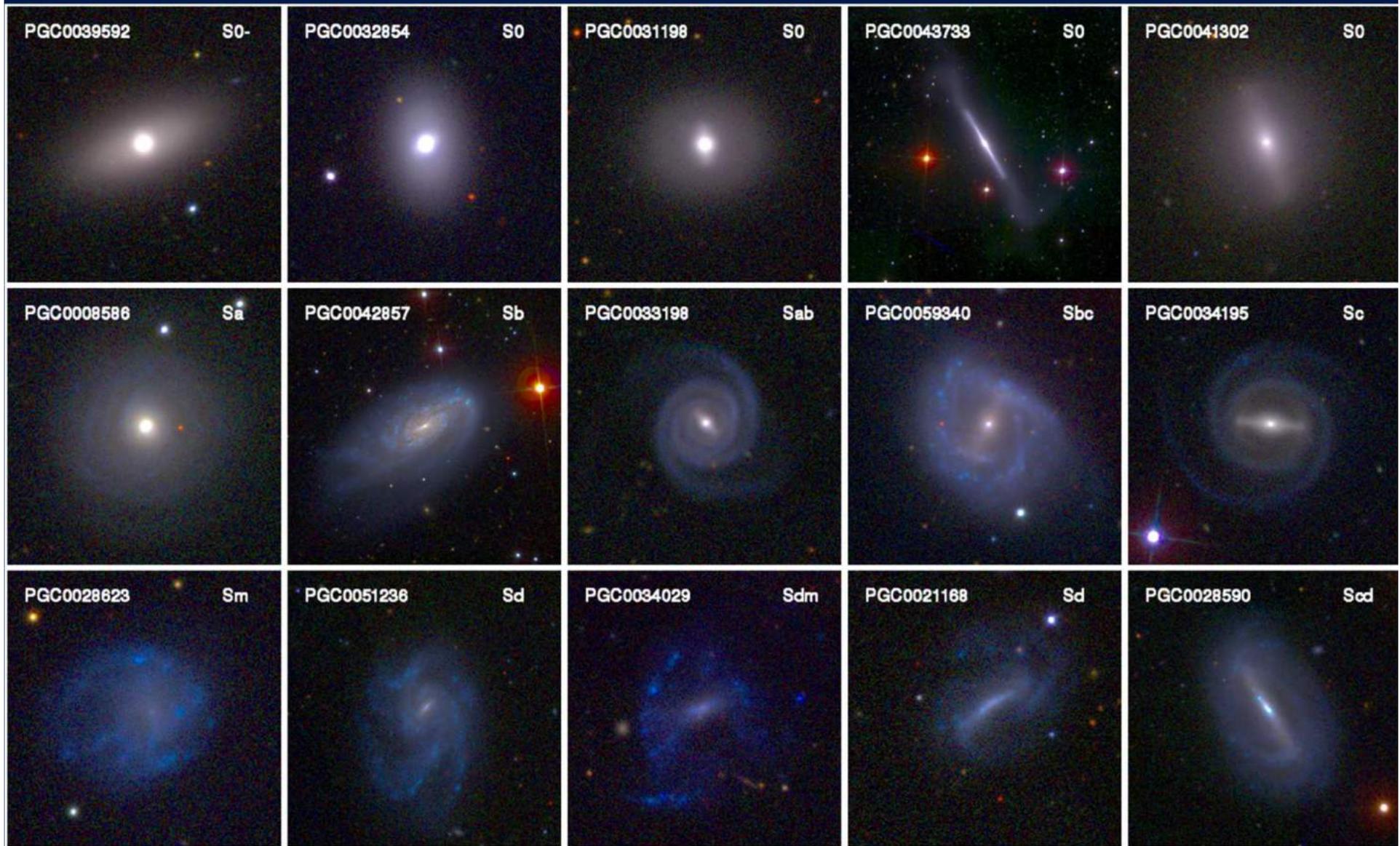
1.9 kpc  $M(g) = -14.8$

$z = 0.0006414$

# Distribution en magnitude et distance



# Attribut : Longueur de barre

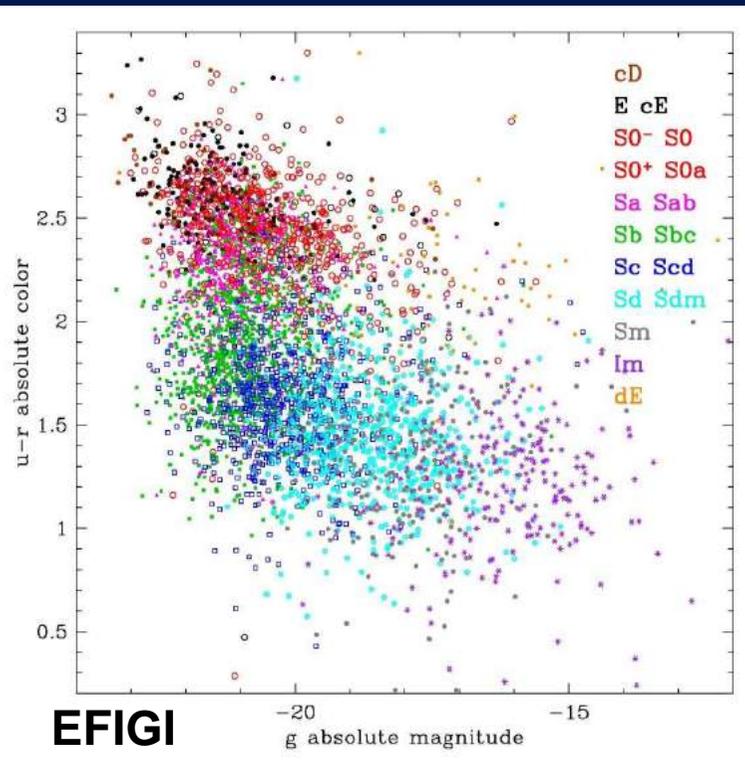


# Fractions de galaxies avec barres

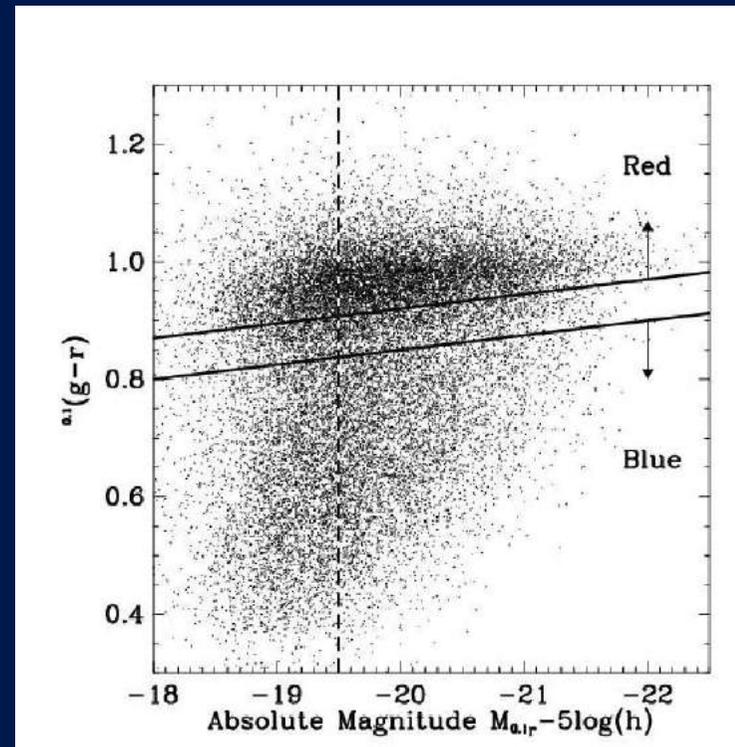
S0 <sup>-</sup> S0 S0 <sup>+</sup>	23 ± 3
Sa Sab	61 ± 5
Sb Sbc	49 ± 3
Sc Scd	37 ± 3
Sdm Sm	29 ± 3
Im	7 ± 2
dE	9 ± 4

de Lapparent, Baillard, Bertin 2011

# Bimodality in color-magnitude sequence ?

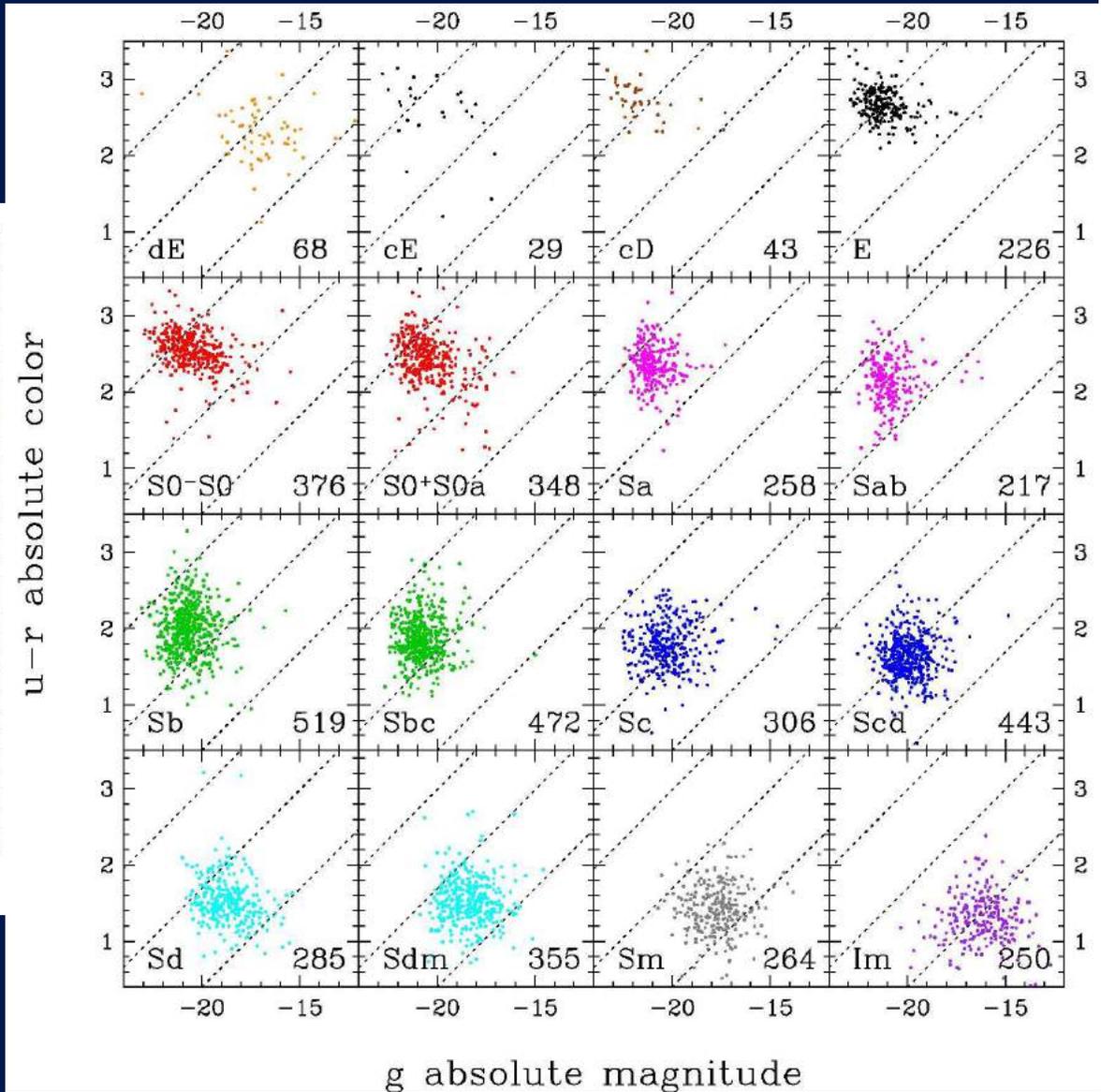
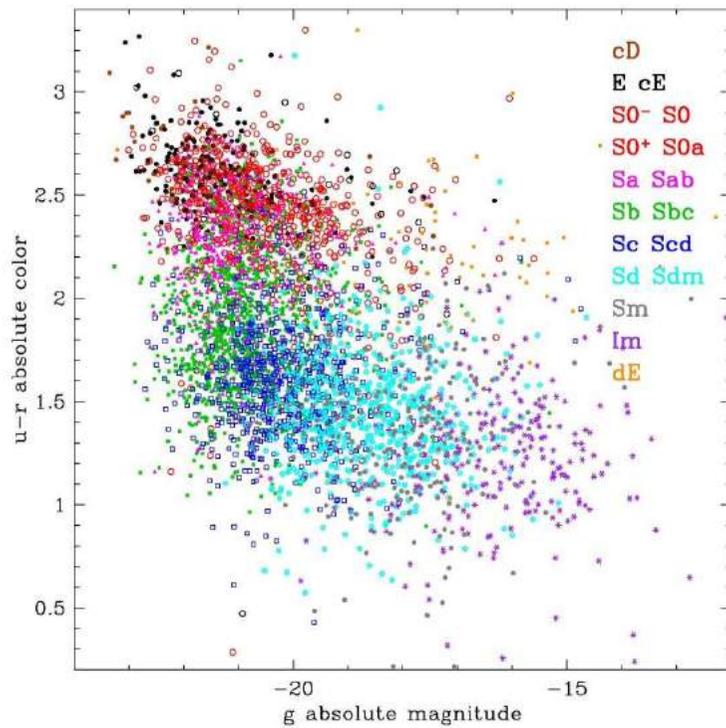


de Lapparent 2011

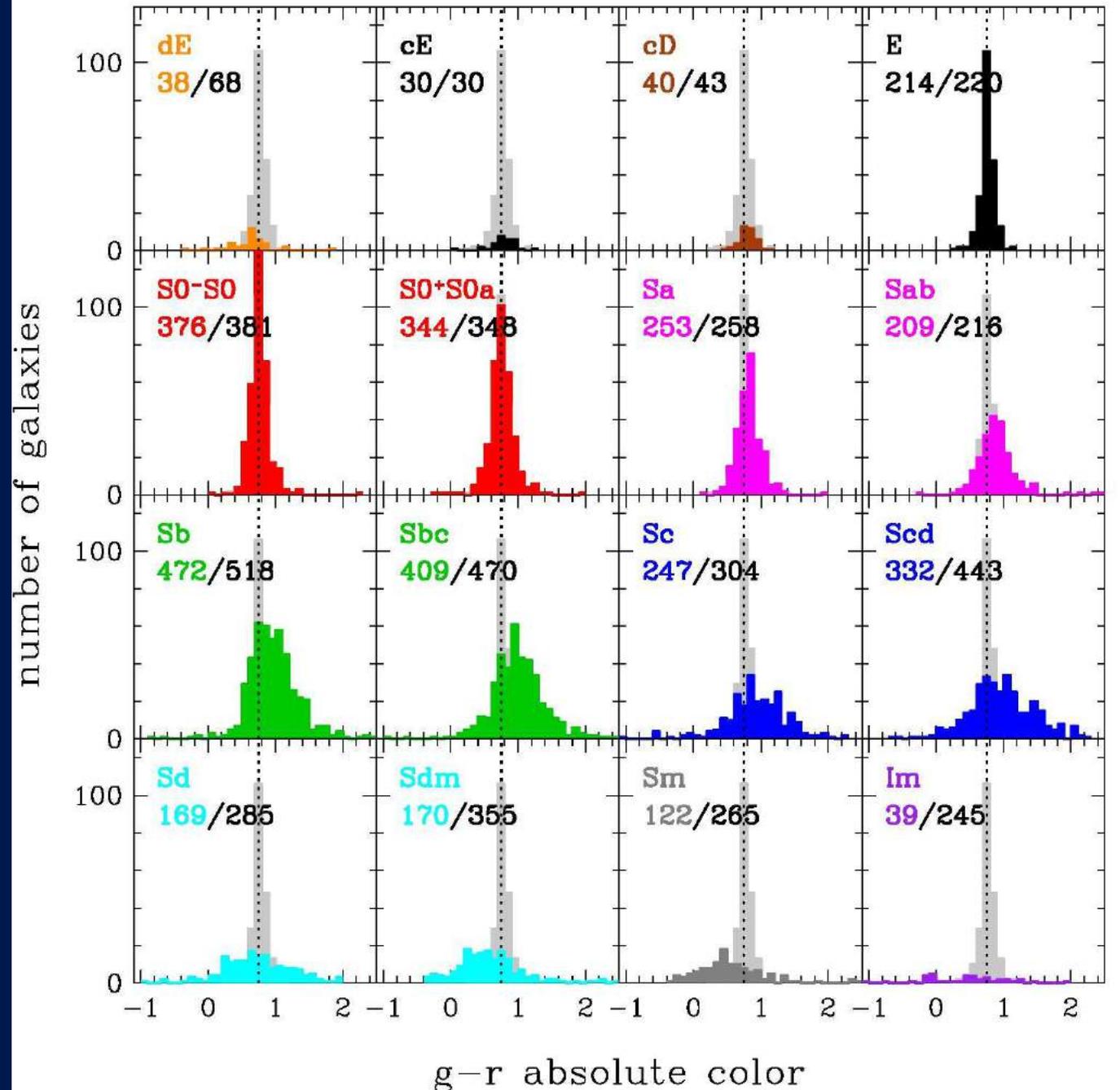


Yan et al. 2006  
400 000 galaxies SDSS - DR4

# Continuous color-magnitude sequence

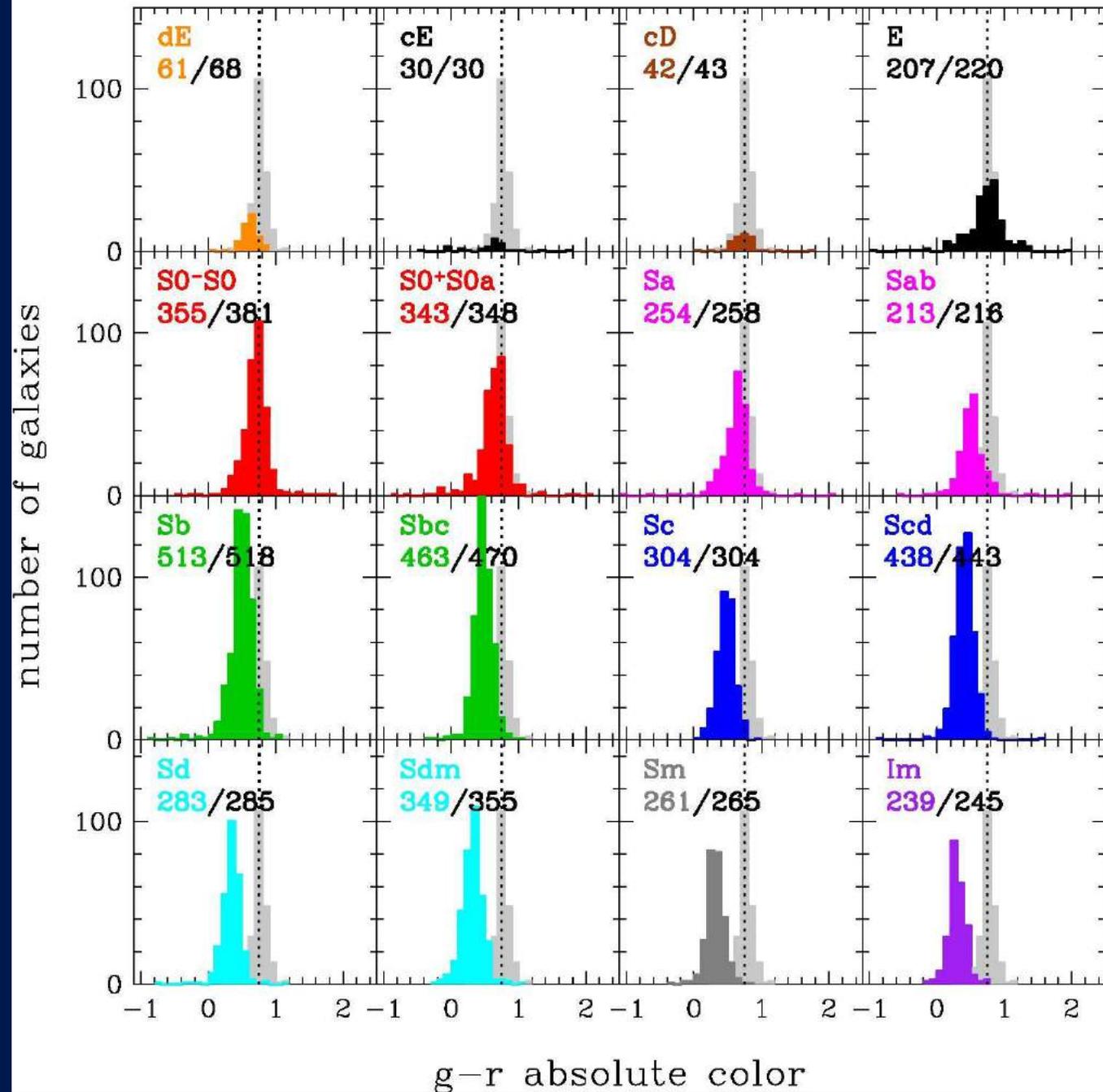


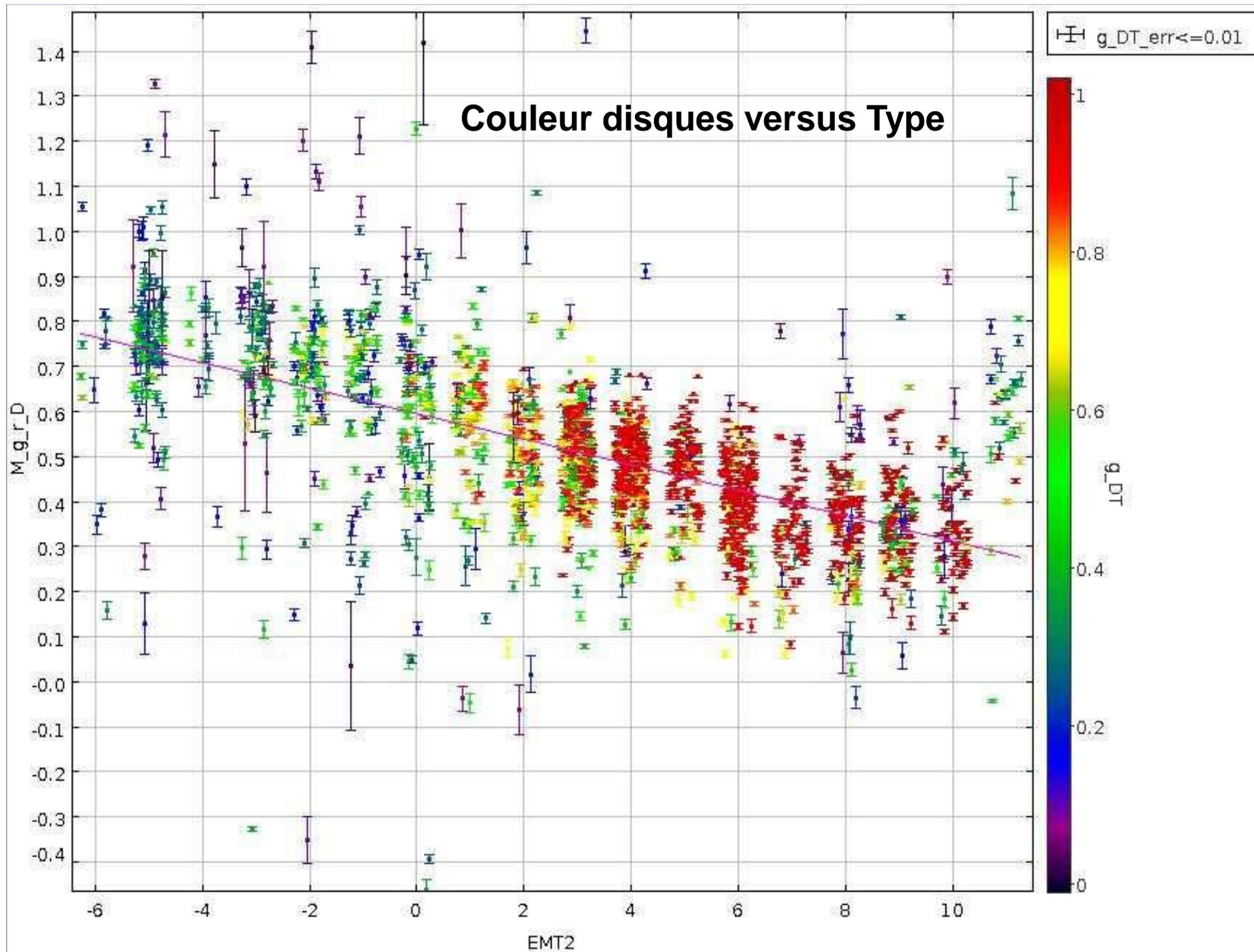
# Bulbes



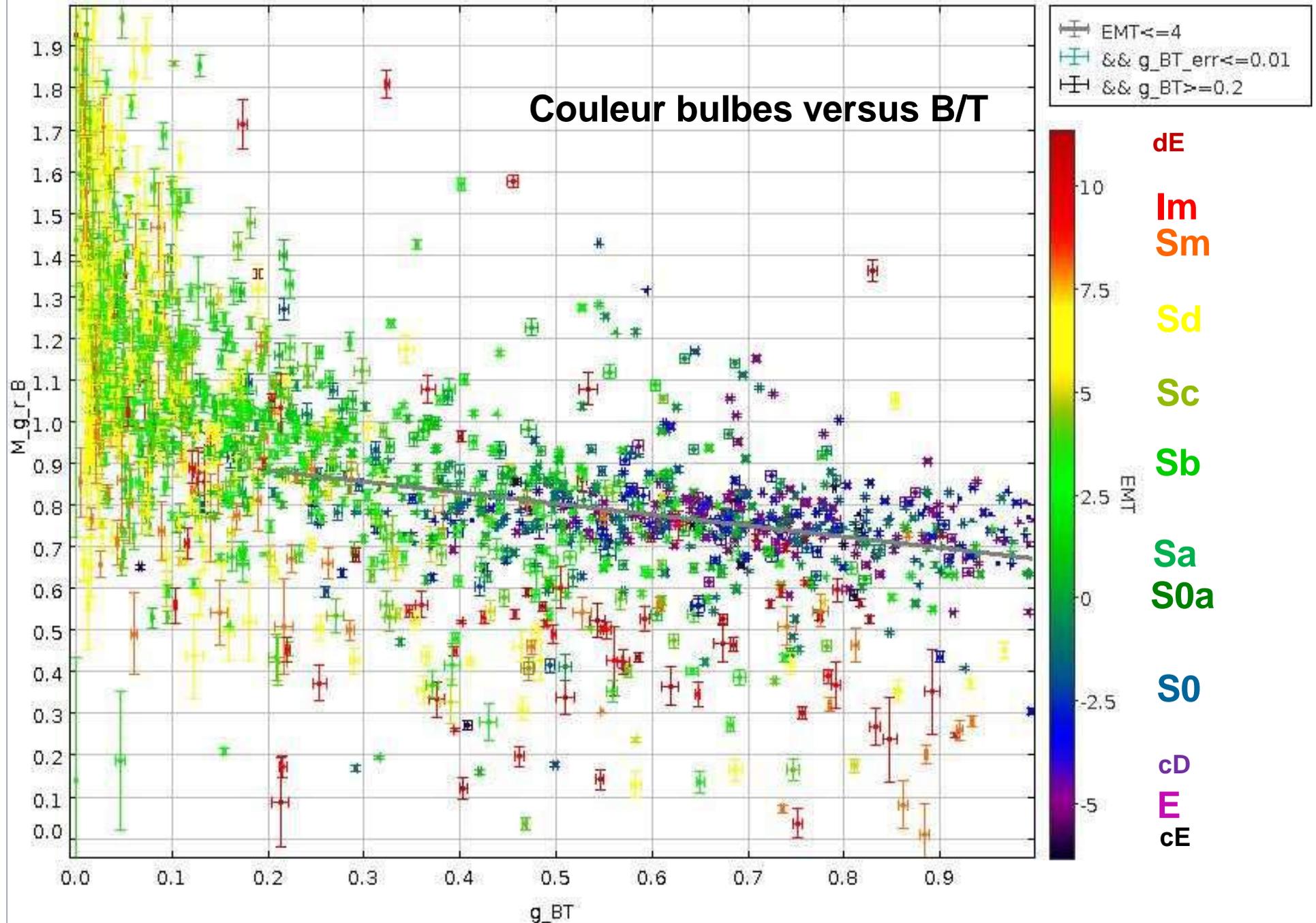
de Lapparent 2011

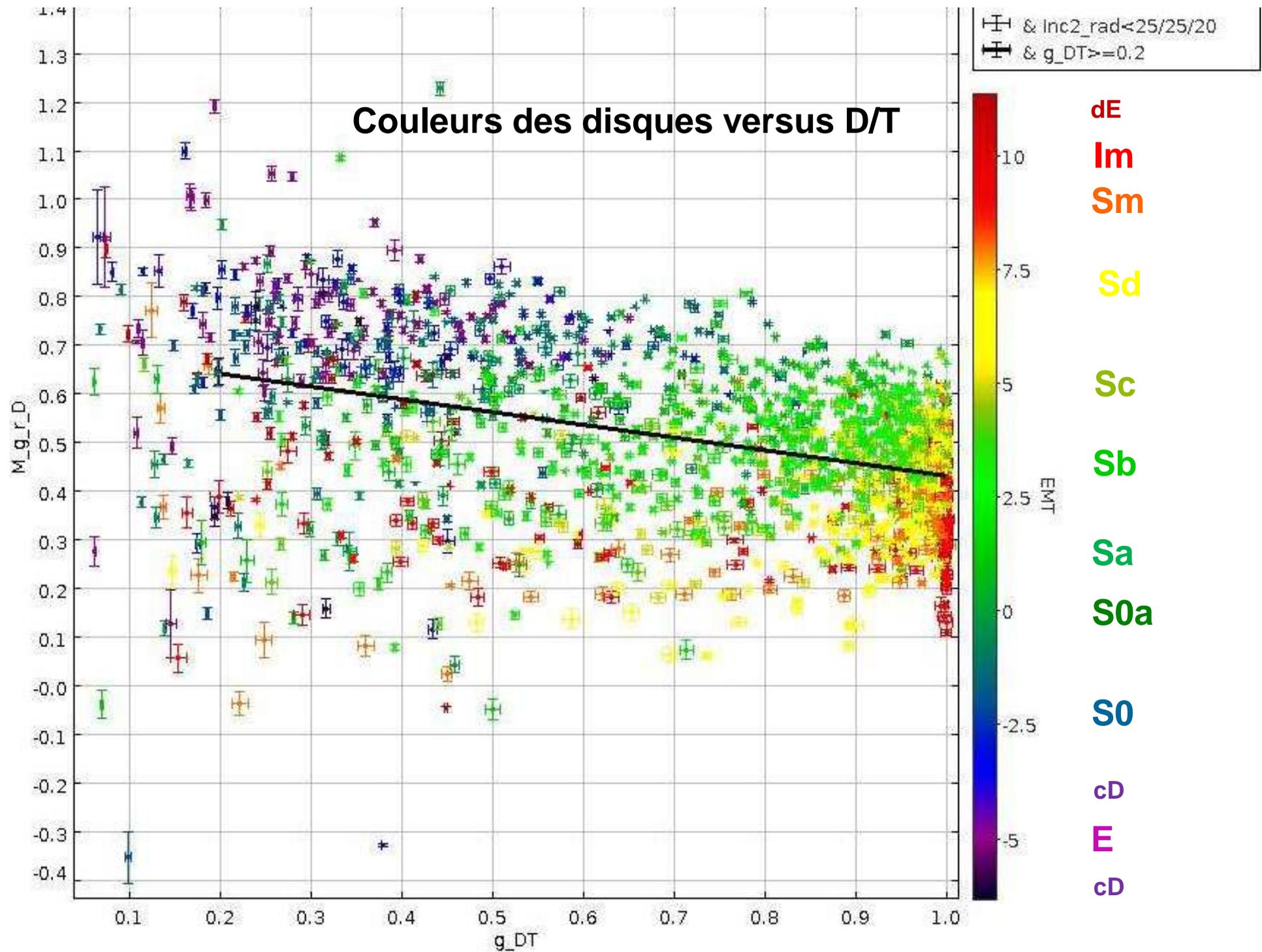
# Disques



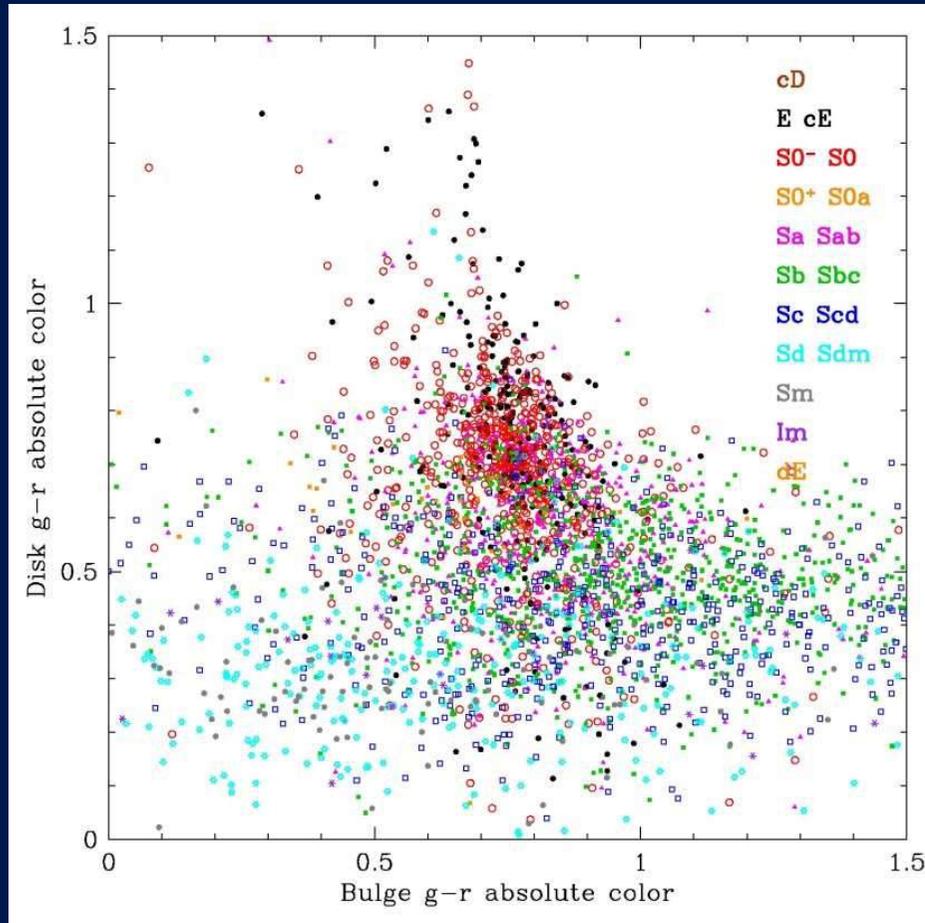


# Couleur bulbes versus B/T

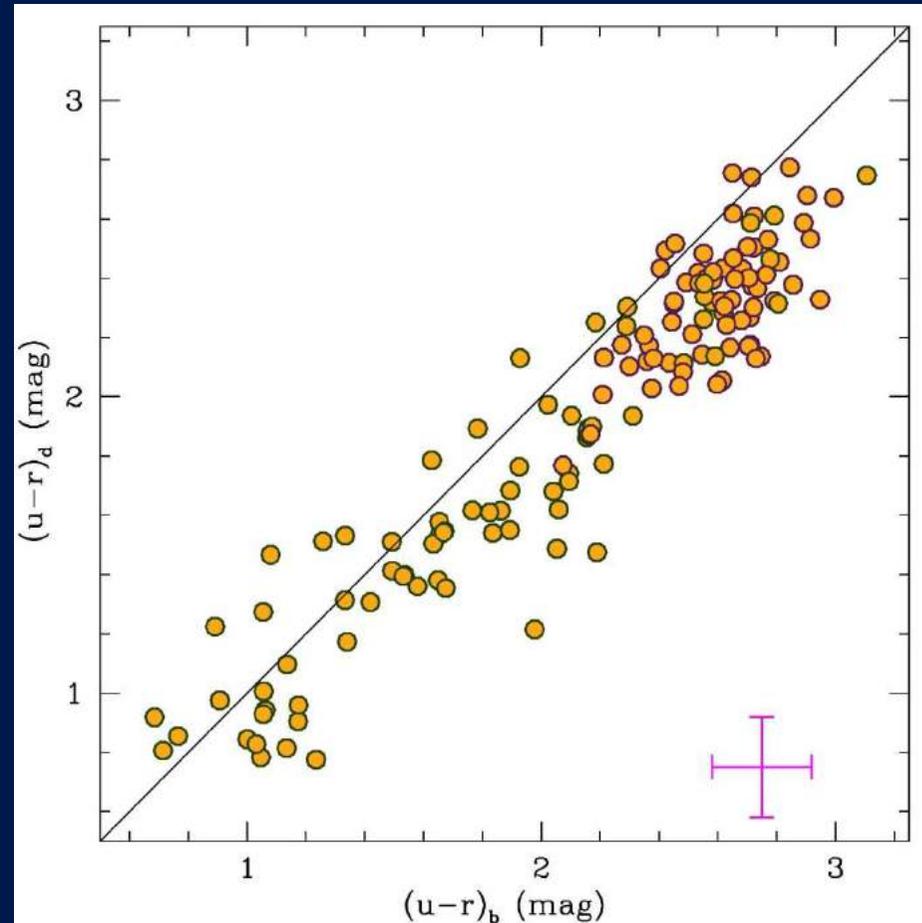




# Couleur bulbe versus disque



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



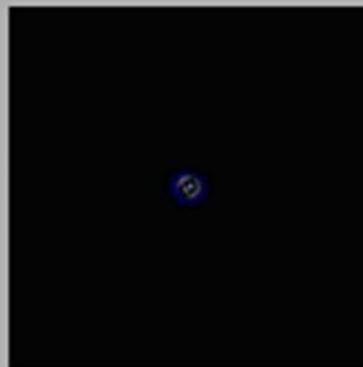
sersic+disk



sersic+disk\_resid



PGC0039859



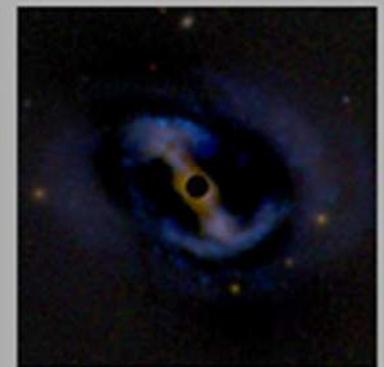
bulge\_resid



bulge\_detmodel\_resid



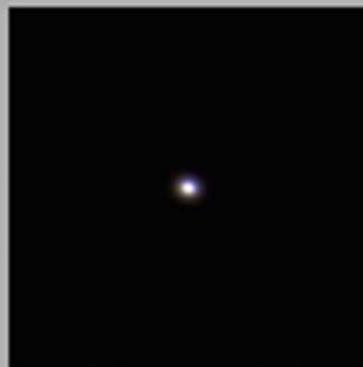
disk\_resid



disk\_detmodel\_resid



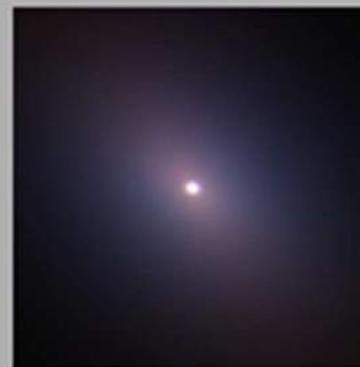
PGC0039859



bulge\_model



disk\_model



bulge+disk



bulge+disk\_resid

# PGC0009256



PGC0009256



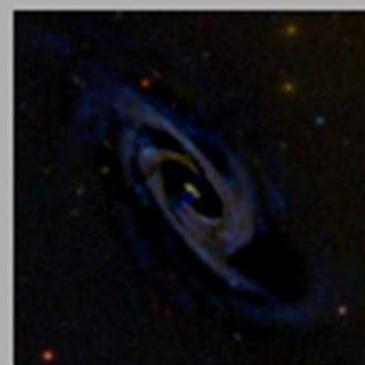
sersic



disk\_sersic



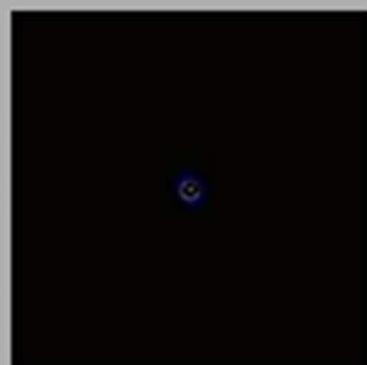
sersic+disk



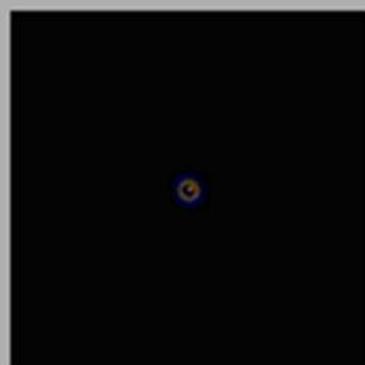
sersic+disk\_resid



PGC0009256



bulge\_resid



bulge\_detmodel\_resid



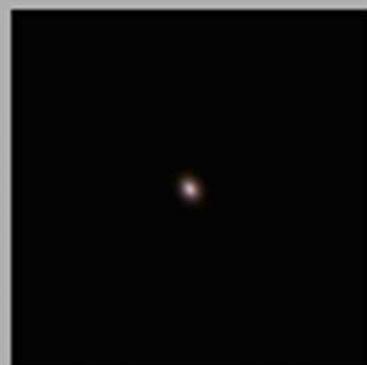
disk\_resid



disk\_detmodel\_resid



PGC0009256



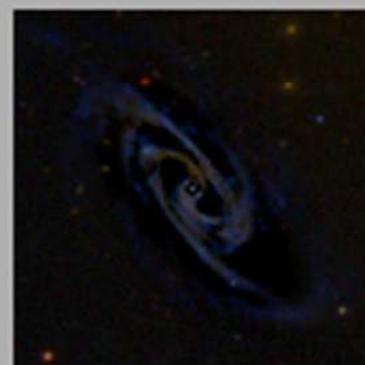
bulge\_model



disk\_model



bulge+disk



bulge+disk\_resid

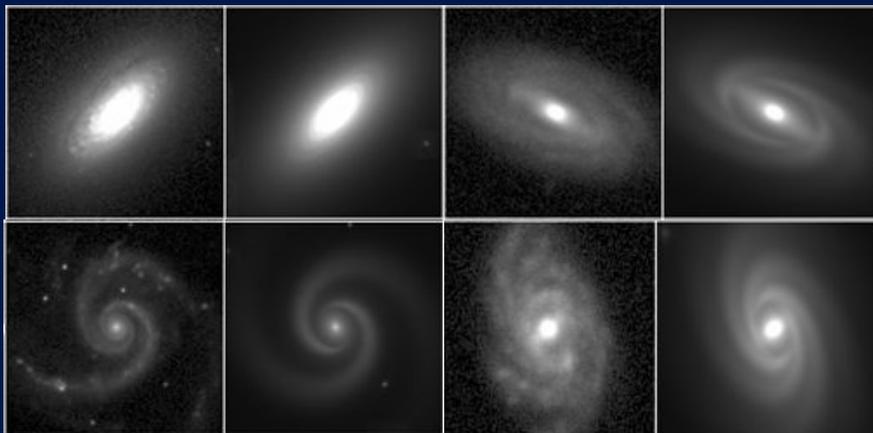
# Bulge + disk modeling

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

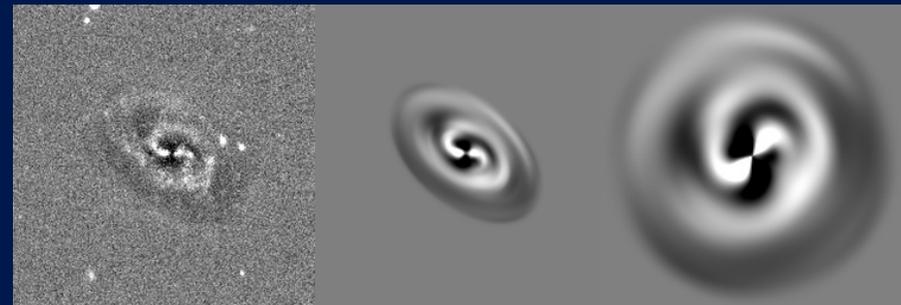


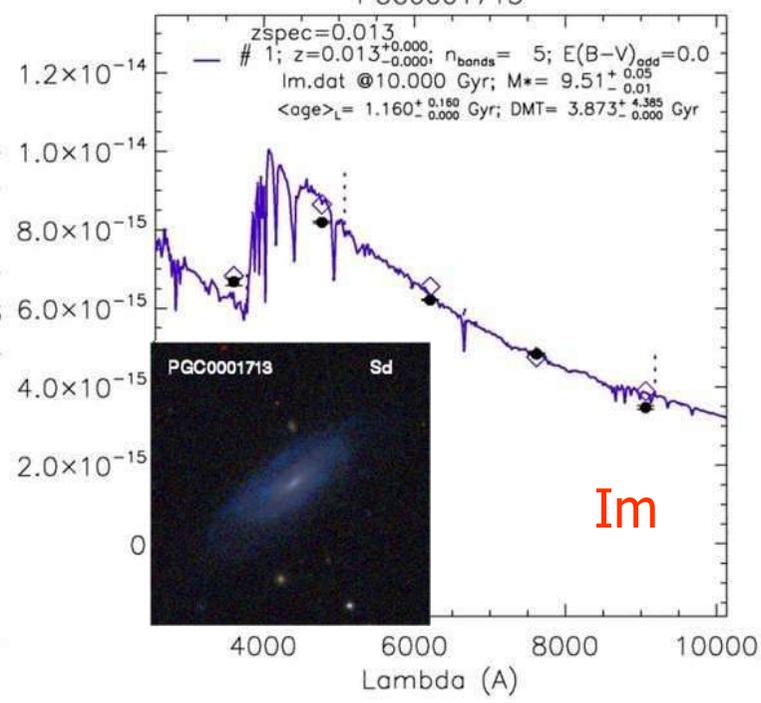
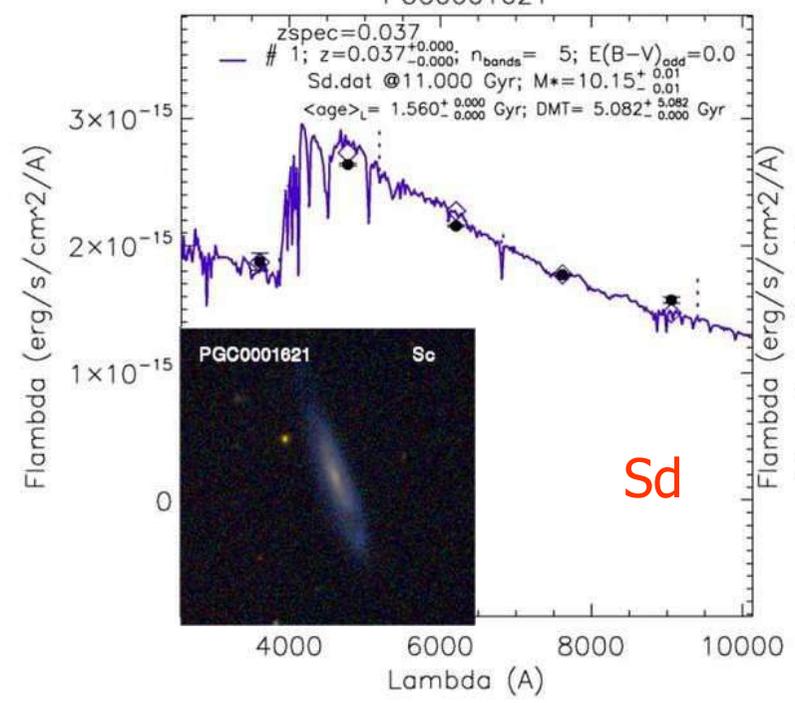
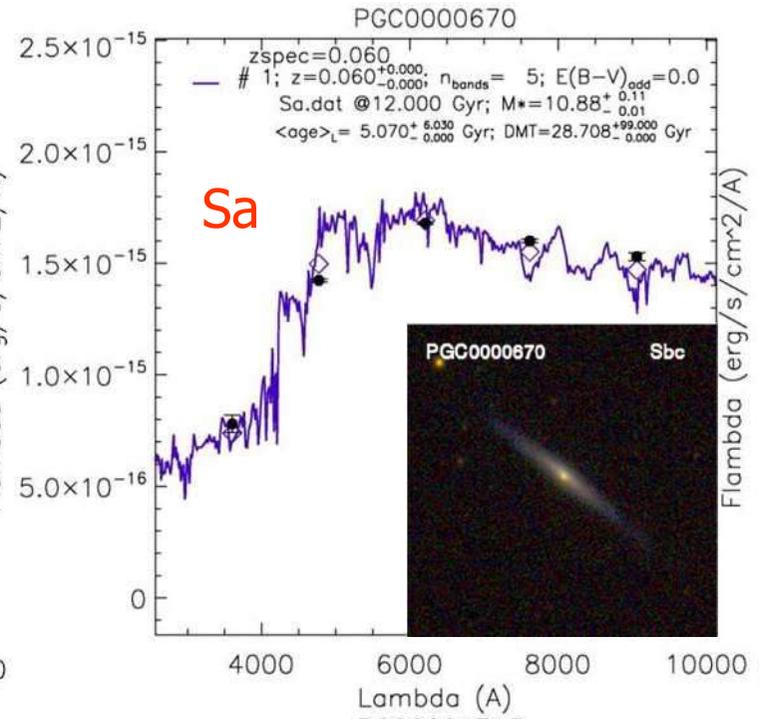
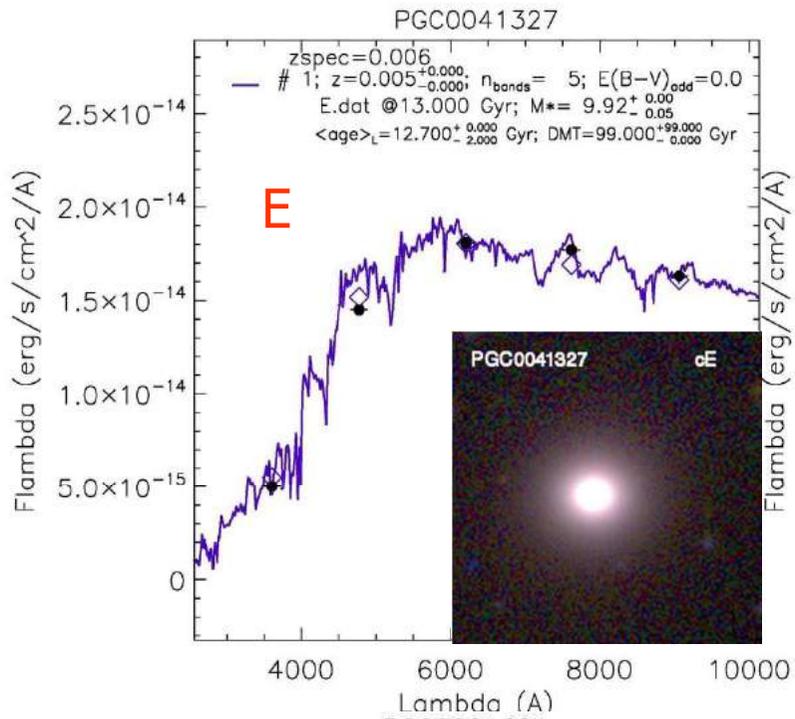
de Lapparent & Bertin in prep.

+ Spiral arms & bars Bertin



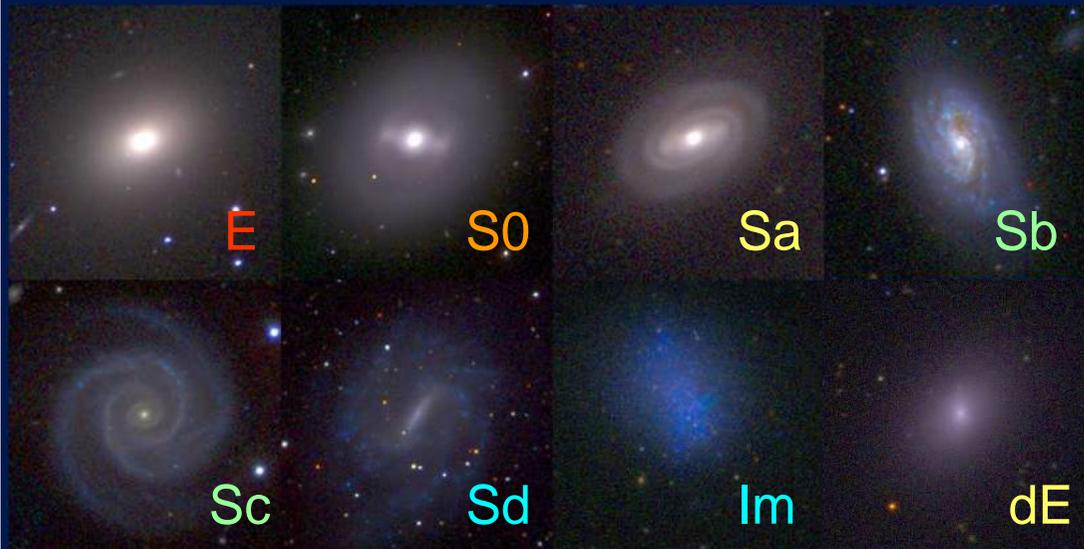
+ Decomposition of residuals  
on a ring basis Baillard 2008



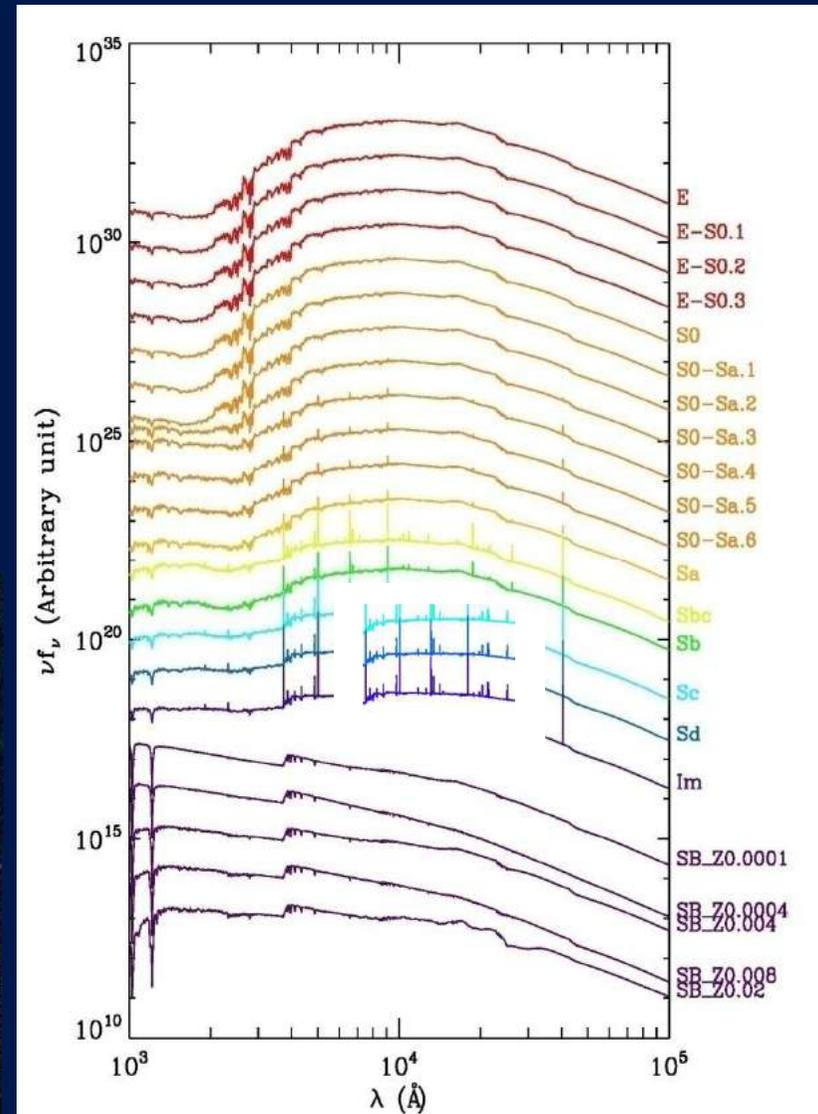


# Distinguer les types de galaxies

- Morphologie
- Distribution spectral d'énergie

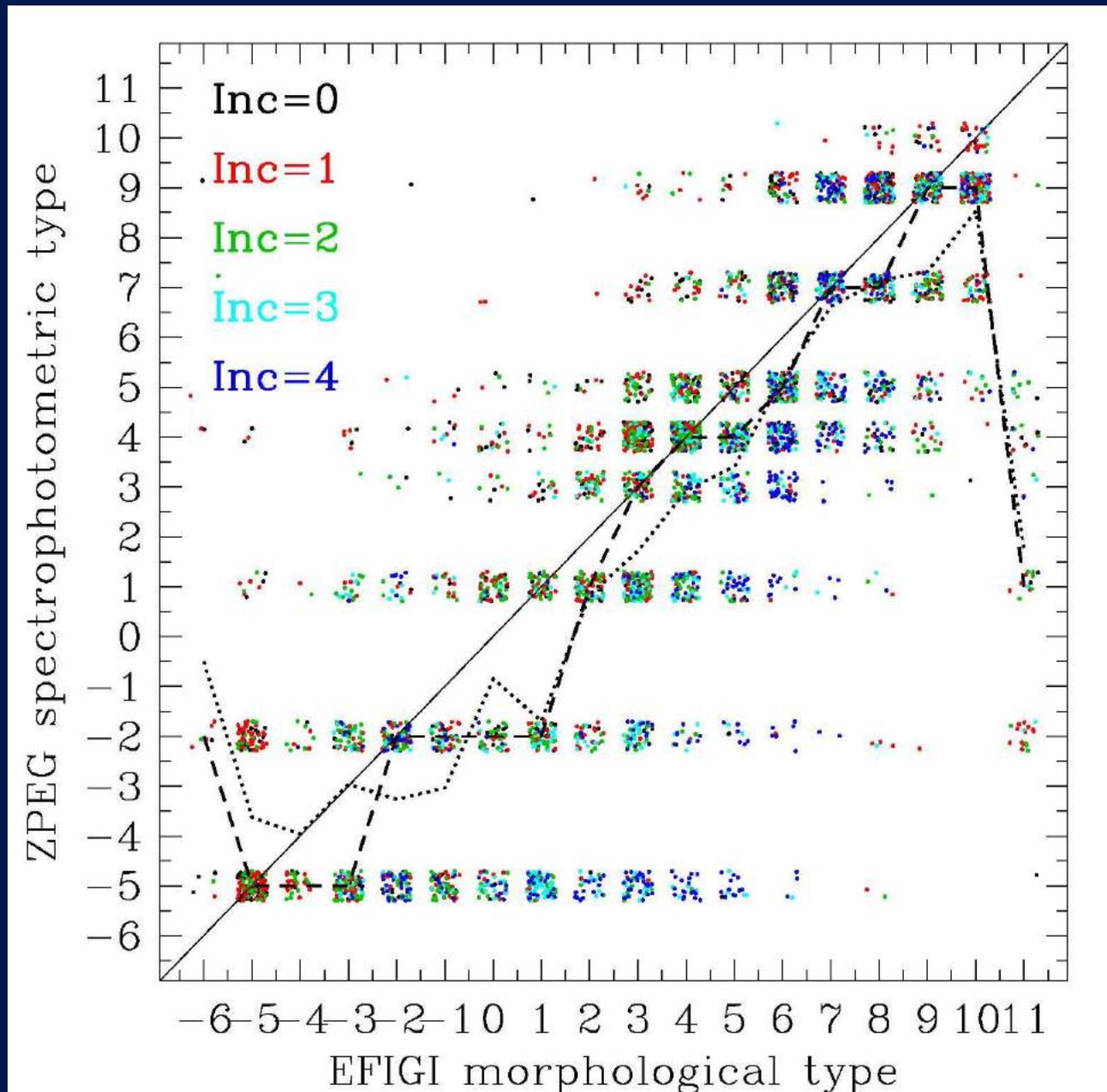


EFIGI (Baillard, Bertin, de Lapparent et al. 2011)

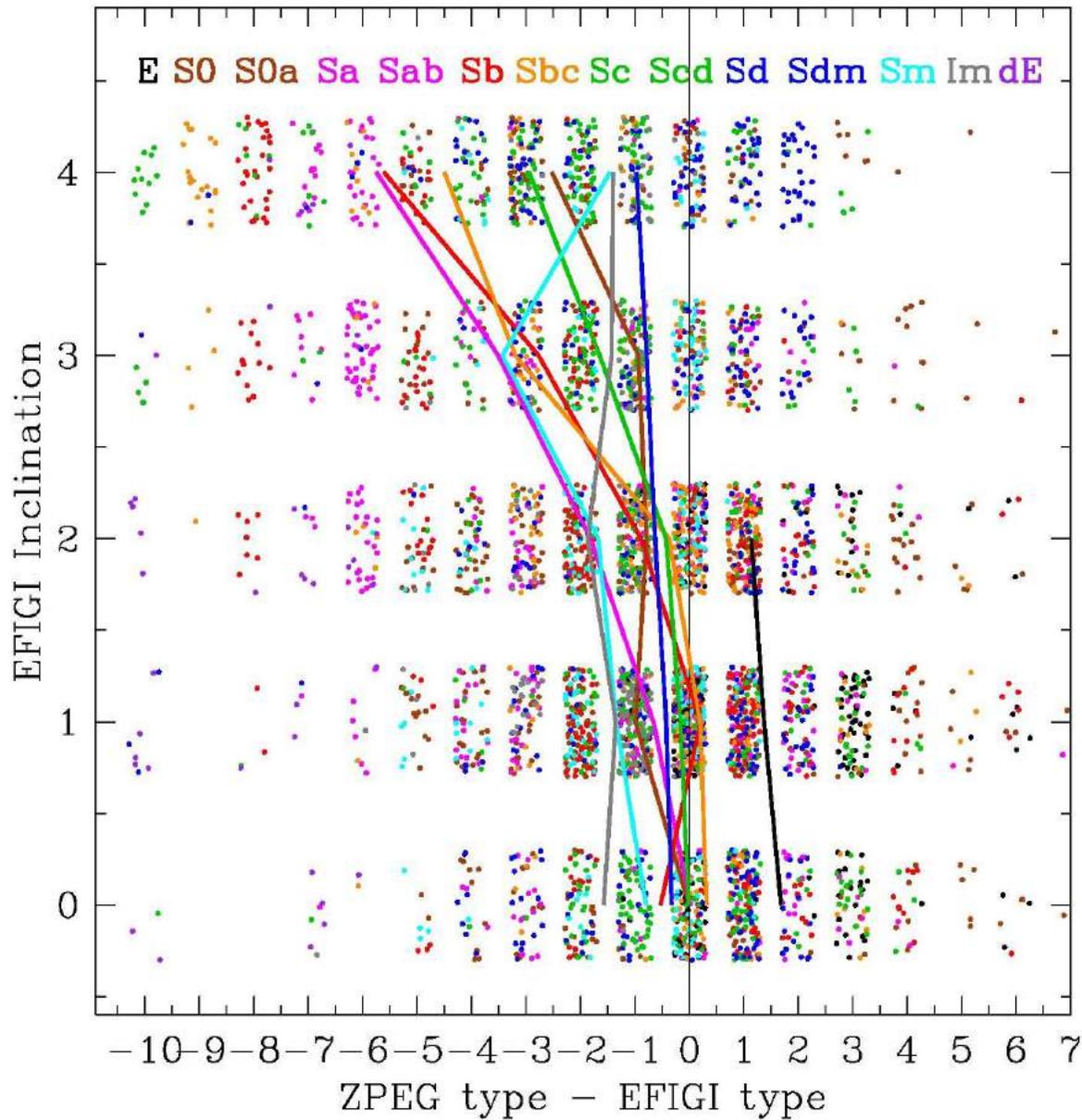


PÉGASE.2 (Fioc et Rocca 1997)

# Type morphologique / spectrophotométrique



# Différence de type versus inclinaison



de Lapparent 2011

# Biais ouverture

- Effets de couleur

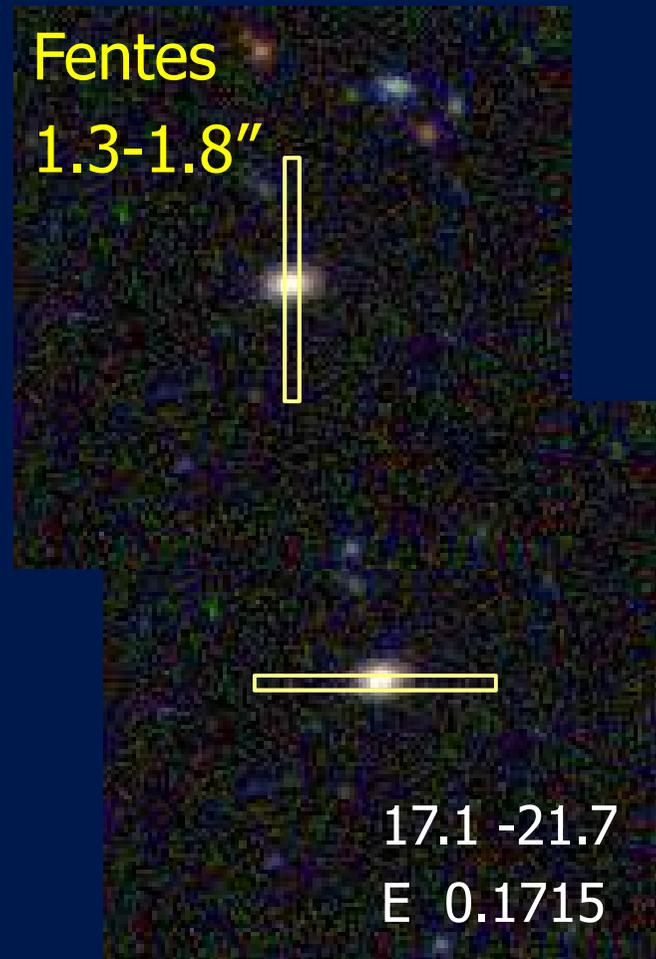
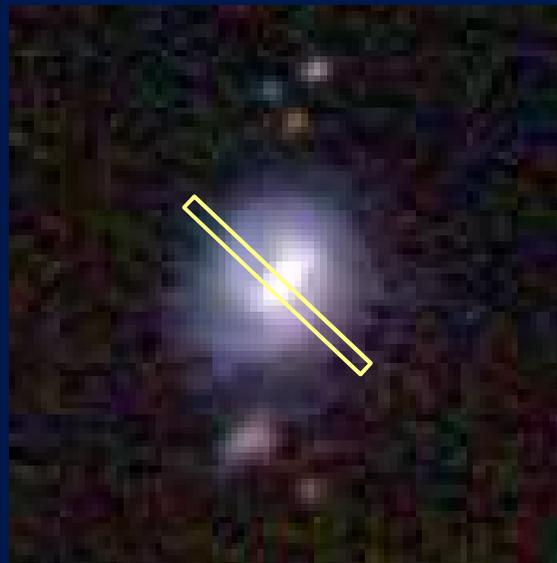
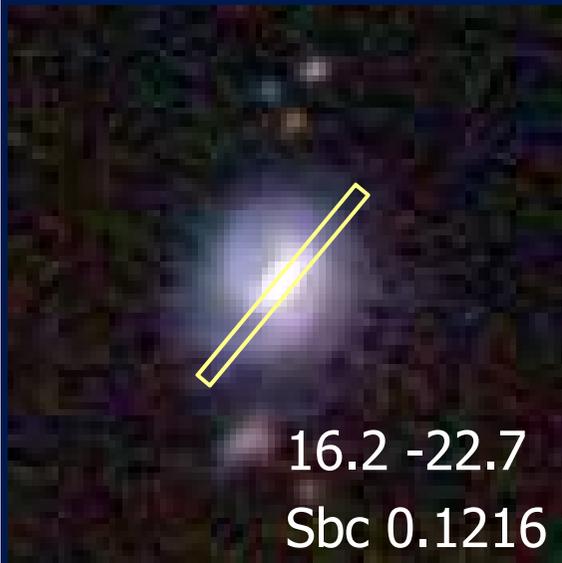
Segalovitz 1975   Vader et al. 1988   Balcells et al. 1994

- Elliptiques : gradients
- Spirales : bulbe-disque

- Effets de distance

Kewley et al. 2004

fibres 3" SDSS >20% à  $z > 0.05$

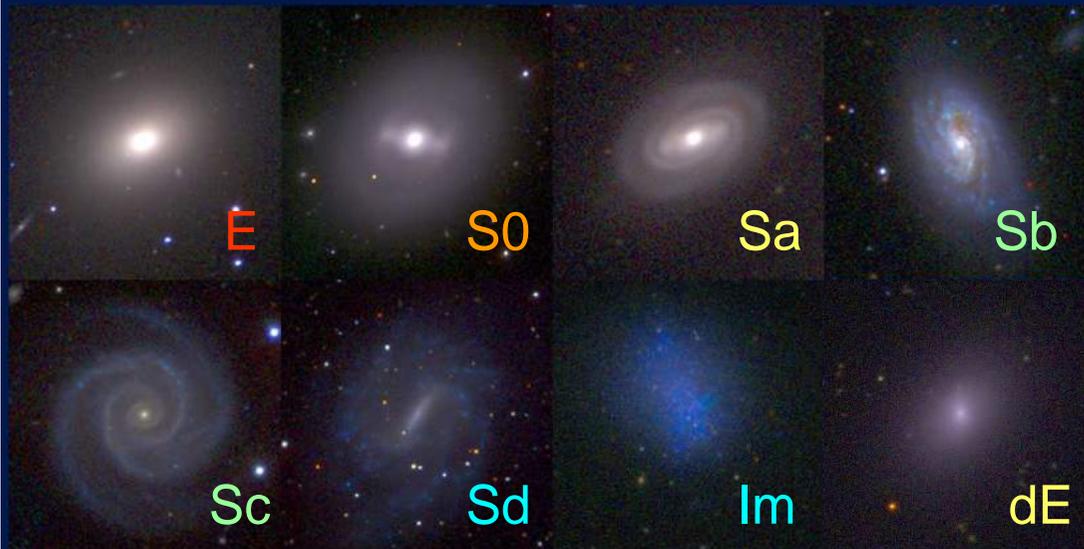


# Distinguer les types de galaxies

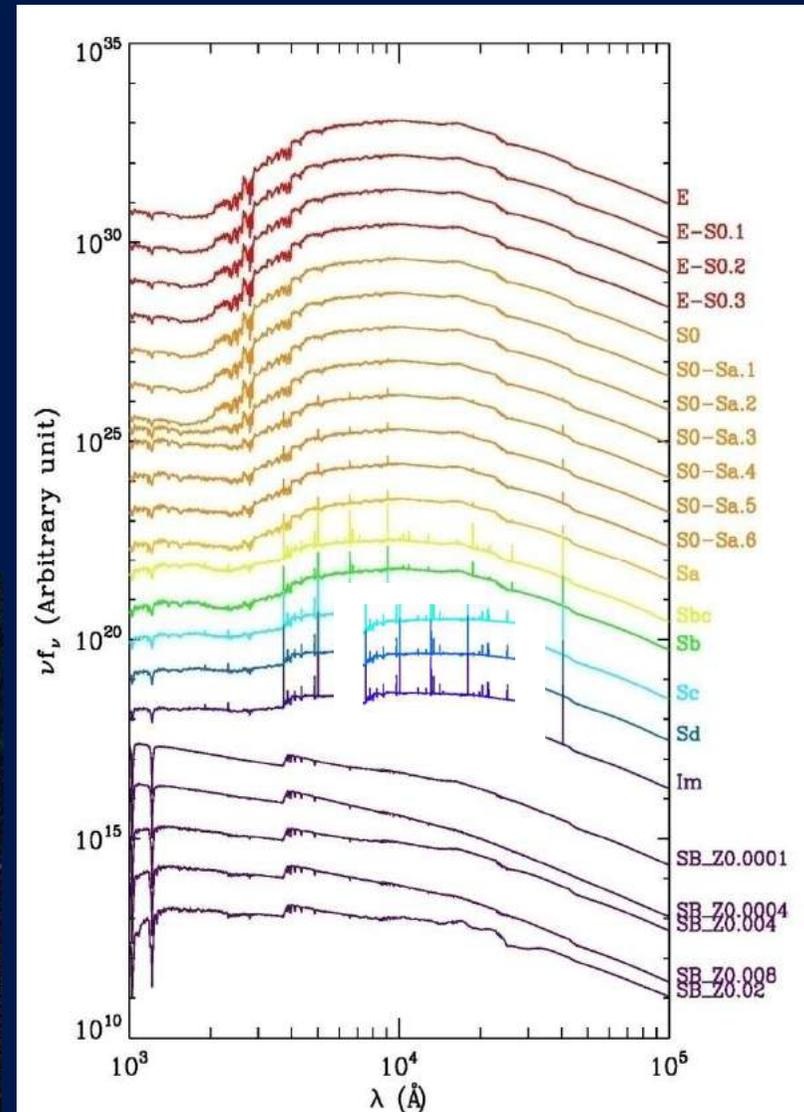
- Morphologie
- Distribution spectral d'énergie

Remplacés par

- Couleurs

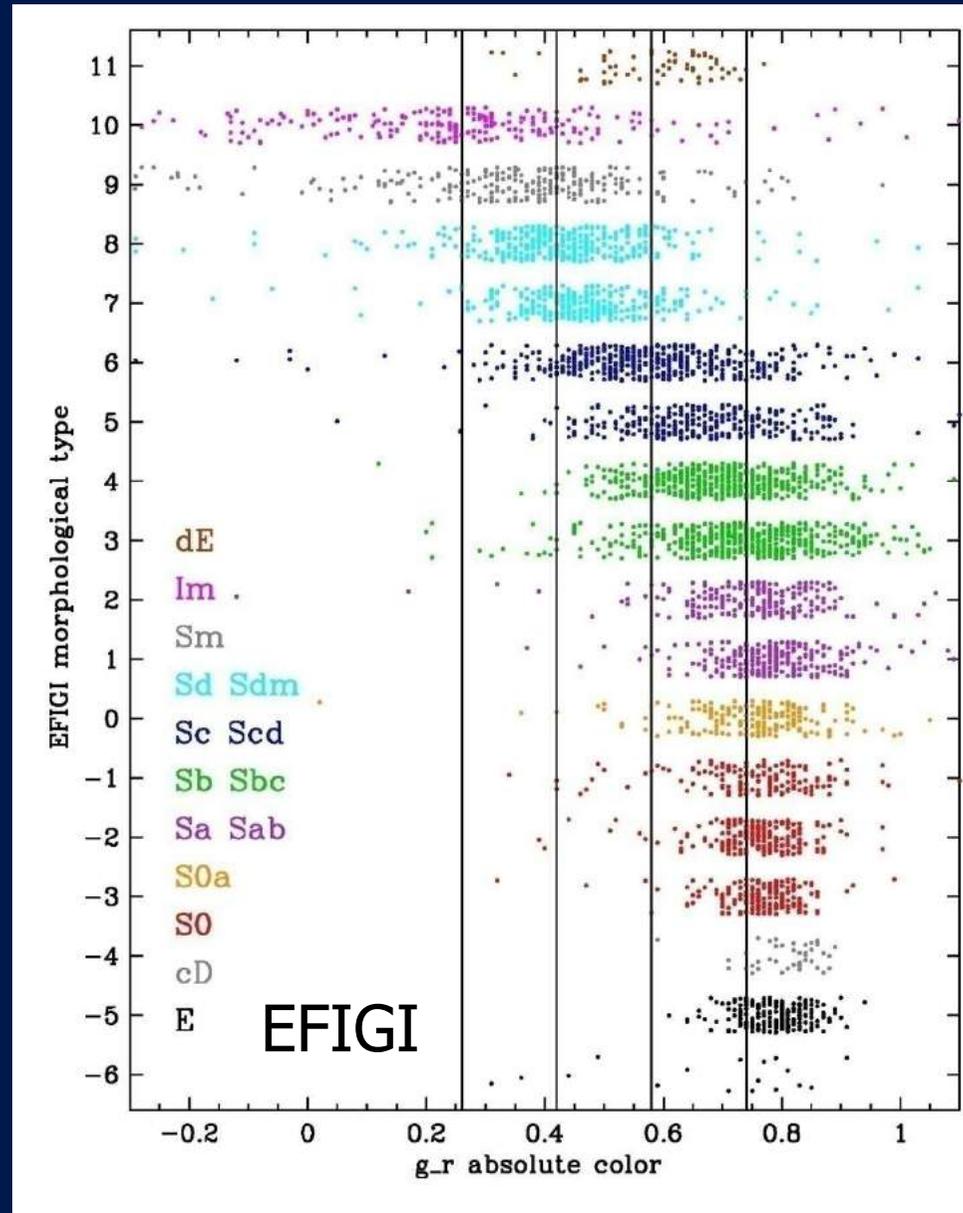


FIGI (Baillard, Bertin, de Lapparent et al. 2011)



PÉGASE.2 (Fioc et Rocca 1997)

# Couleur versus type morphologique EFIGI

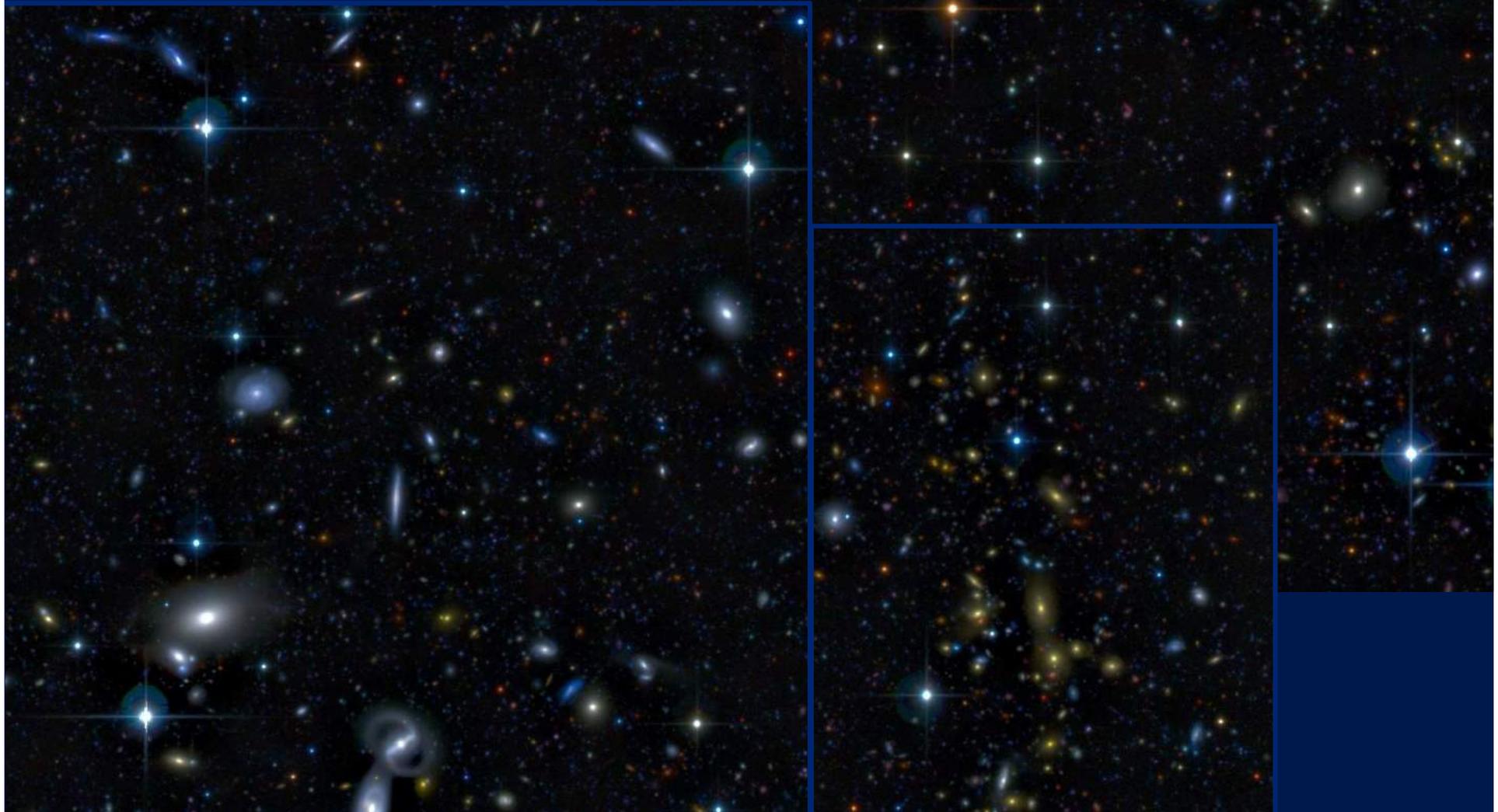


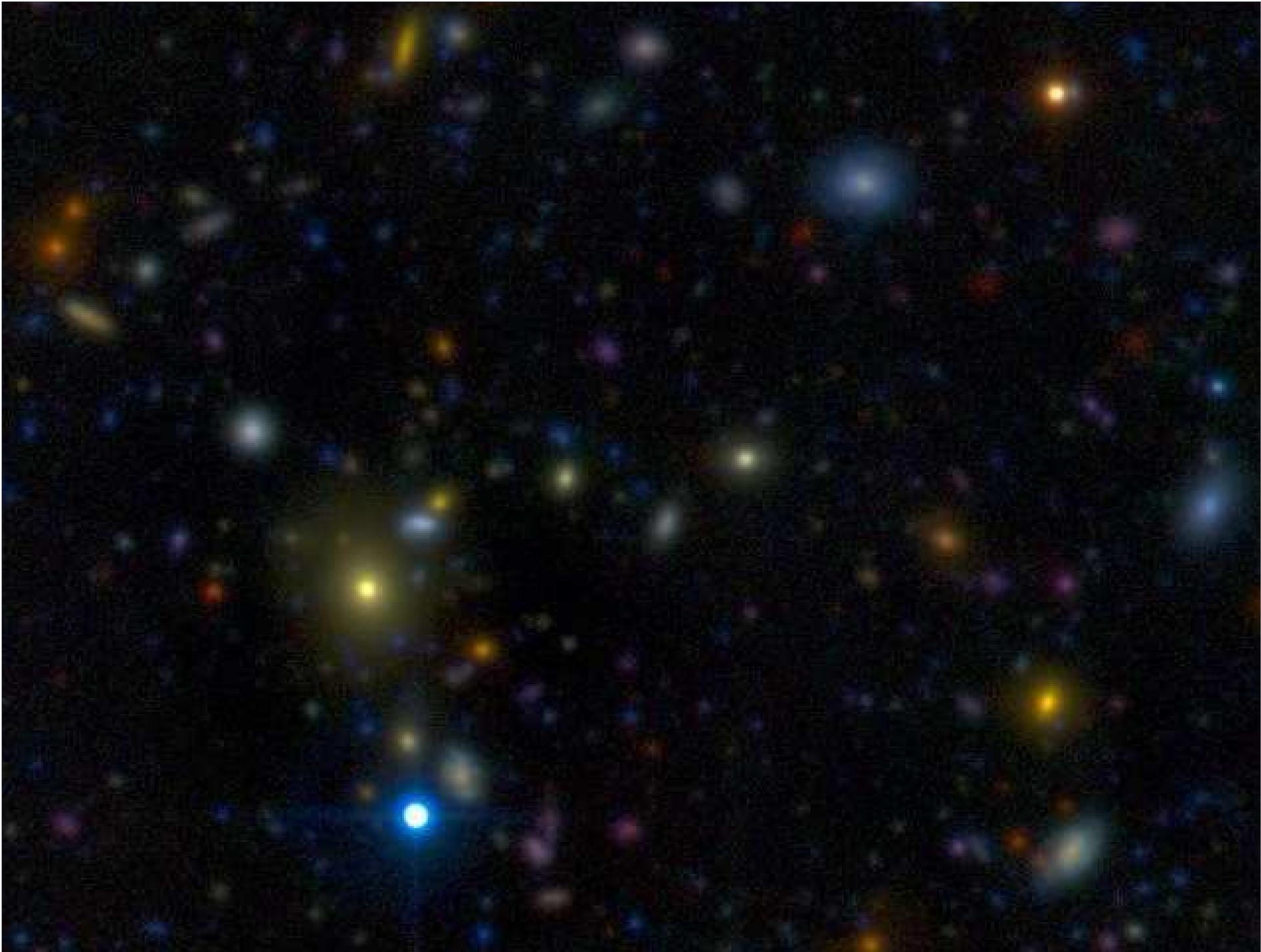
CFHT Legacy Survey

Deep : 4 fields 1 deg<sup>2</sup>

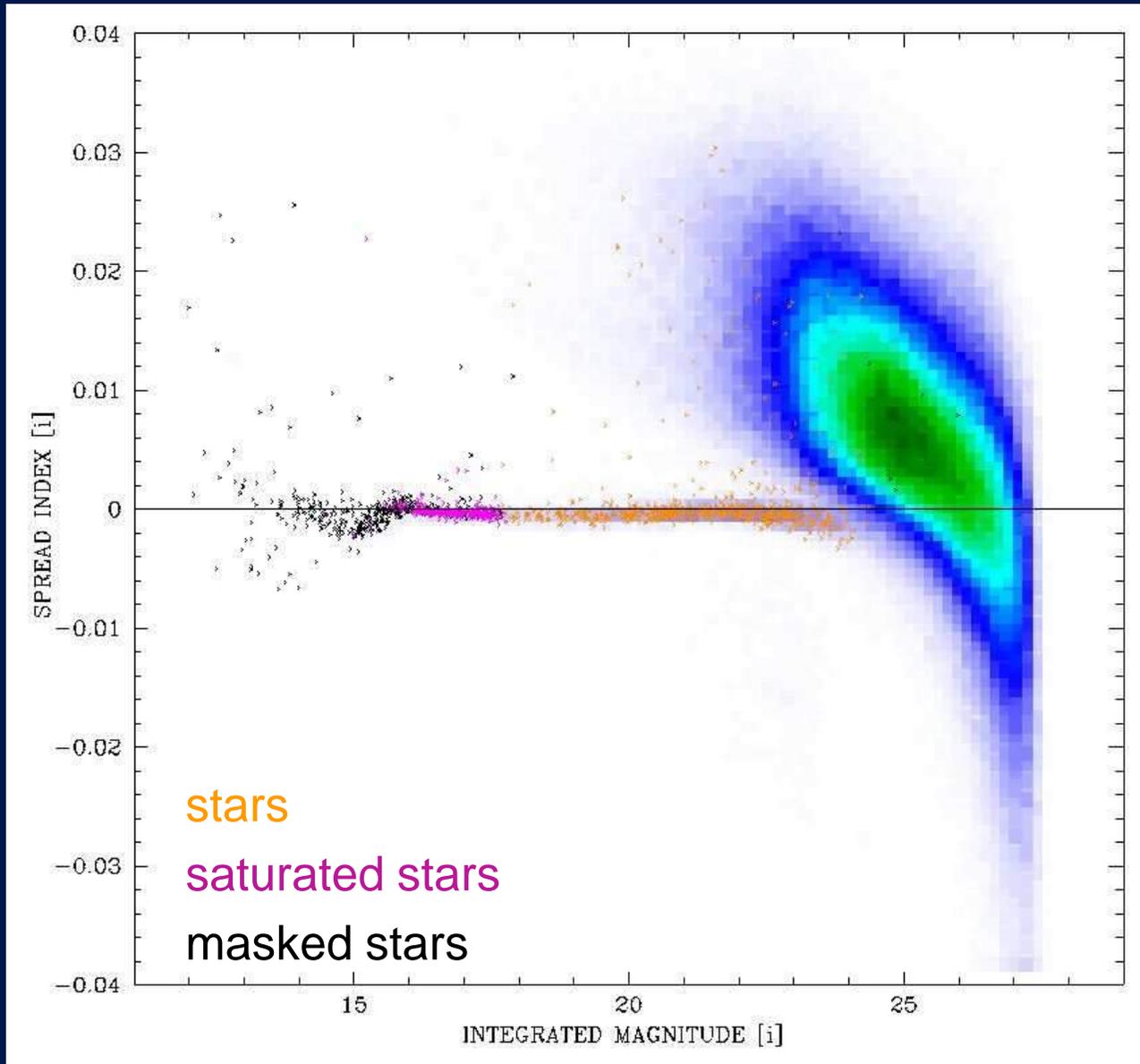
10<sup>5</sup> galaxies  $i < 24$

[www.astromatic.net/gallery](http://www.astromatic.net/gallery)





# Star-galaxy separation by deviations from PSF



de Lapparent & Bertin 2013

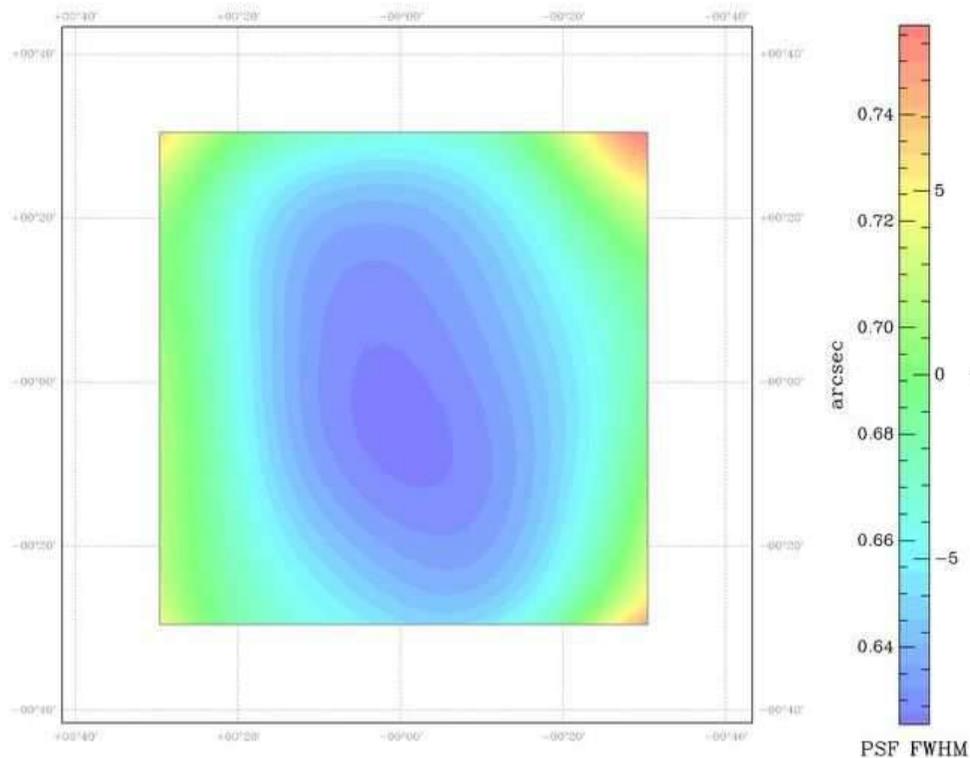
# Point-spread function CFHTLS D1-i : PSFEx

➤ seeing 0.6" (pixels 0.186")

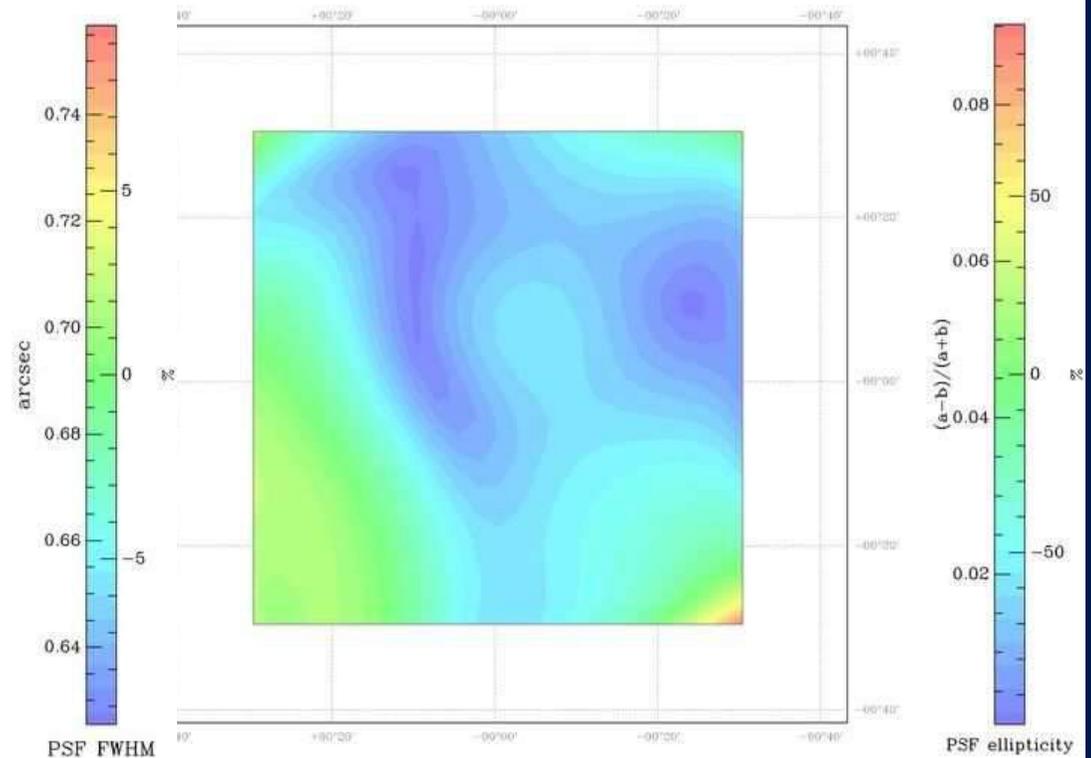
spatial variations of FWHM  
(degree 6 polynomial)

Ellipticity 2-5%

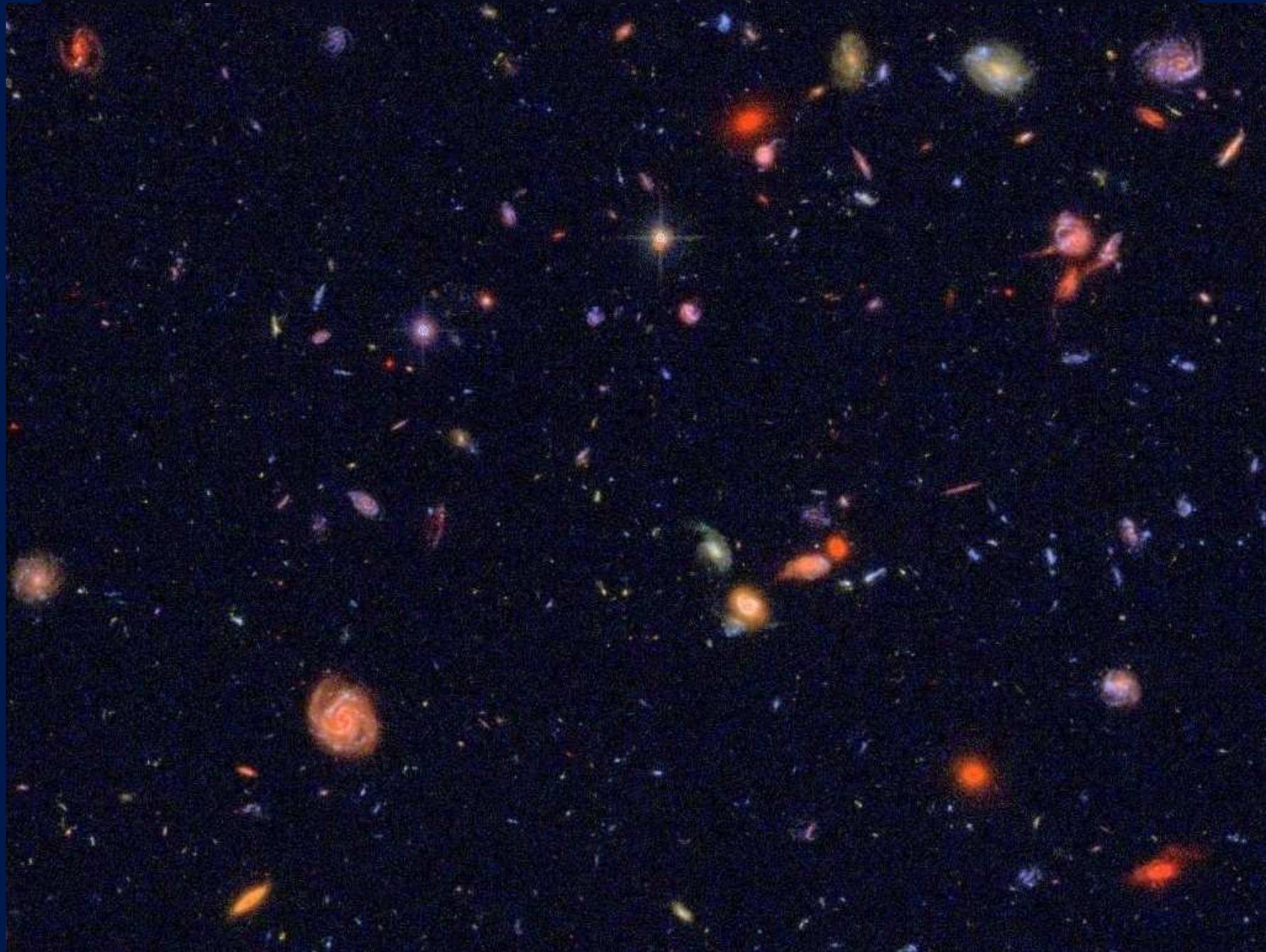
Field CFHTLS-D-85-i-022559-042940-T0006: FWHM map



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



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

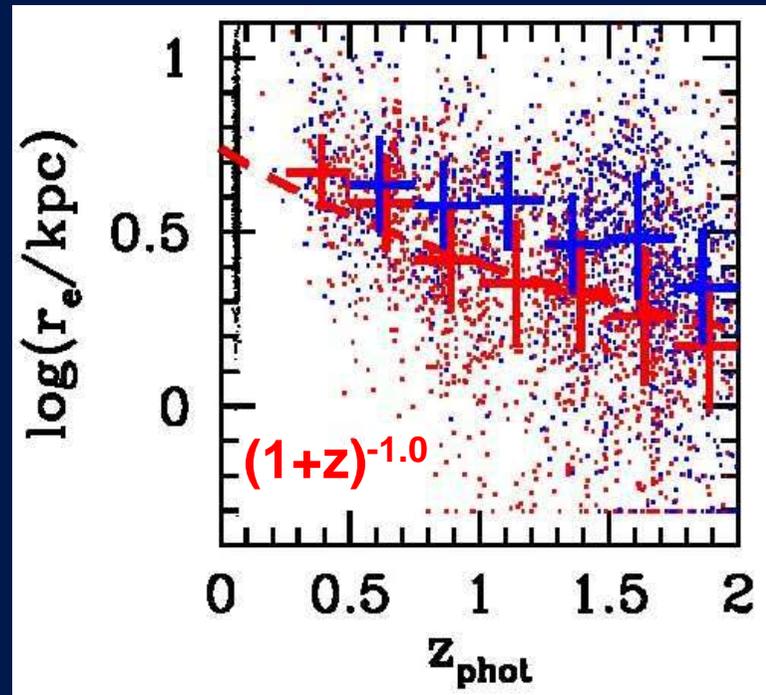


# Evolution of galaxy size

- 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

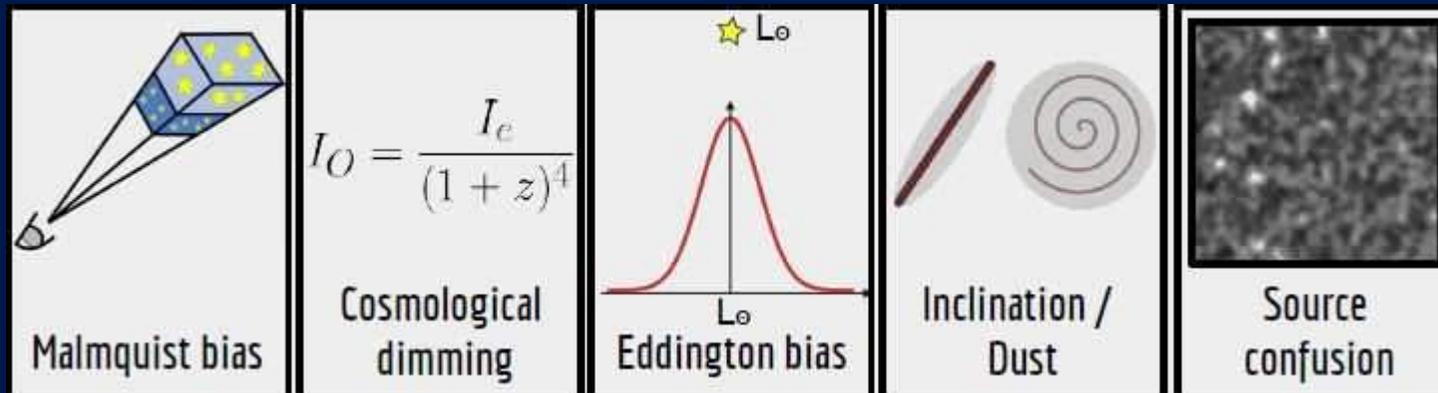
  - fonctions de luminosité / masse / taille

- ...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/arcsec<sup>2</sup> in B)
- $(1+z)^4$  surface brightness dimming

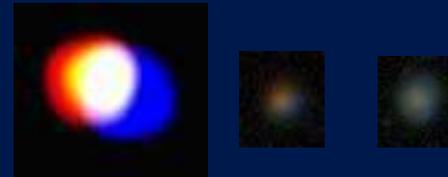


→ missing higher fraction  
of wings in faint galaxies



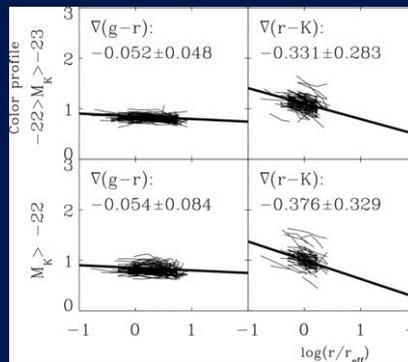
# Colors biases in photometry

- 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

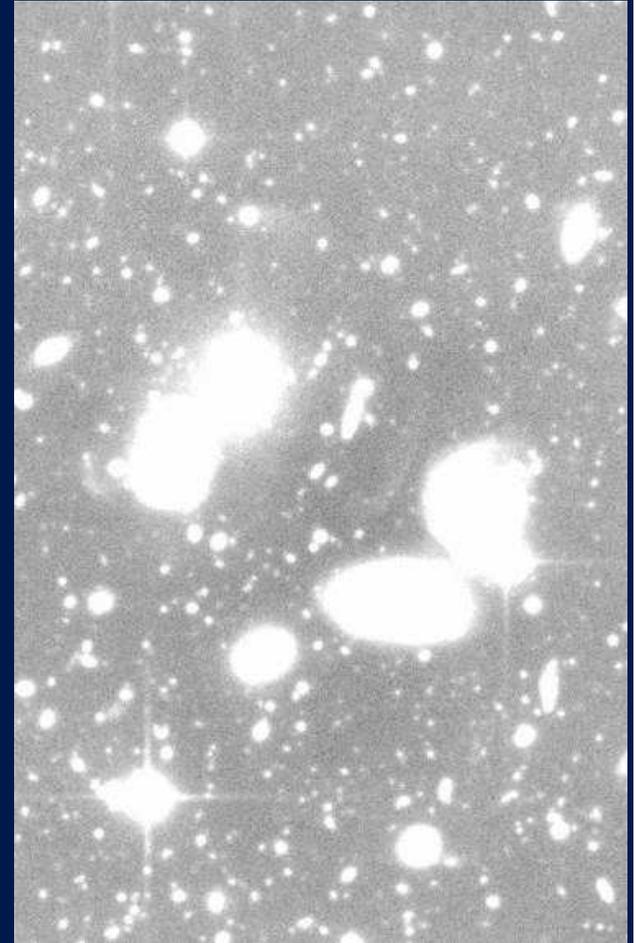


- Differential k-corrections : visibility of disk/bulges versus filter

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

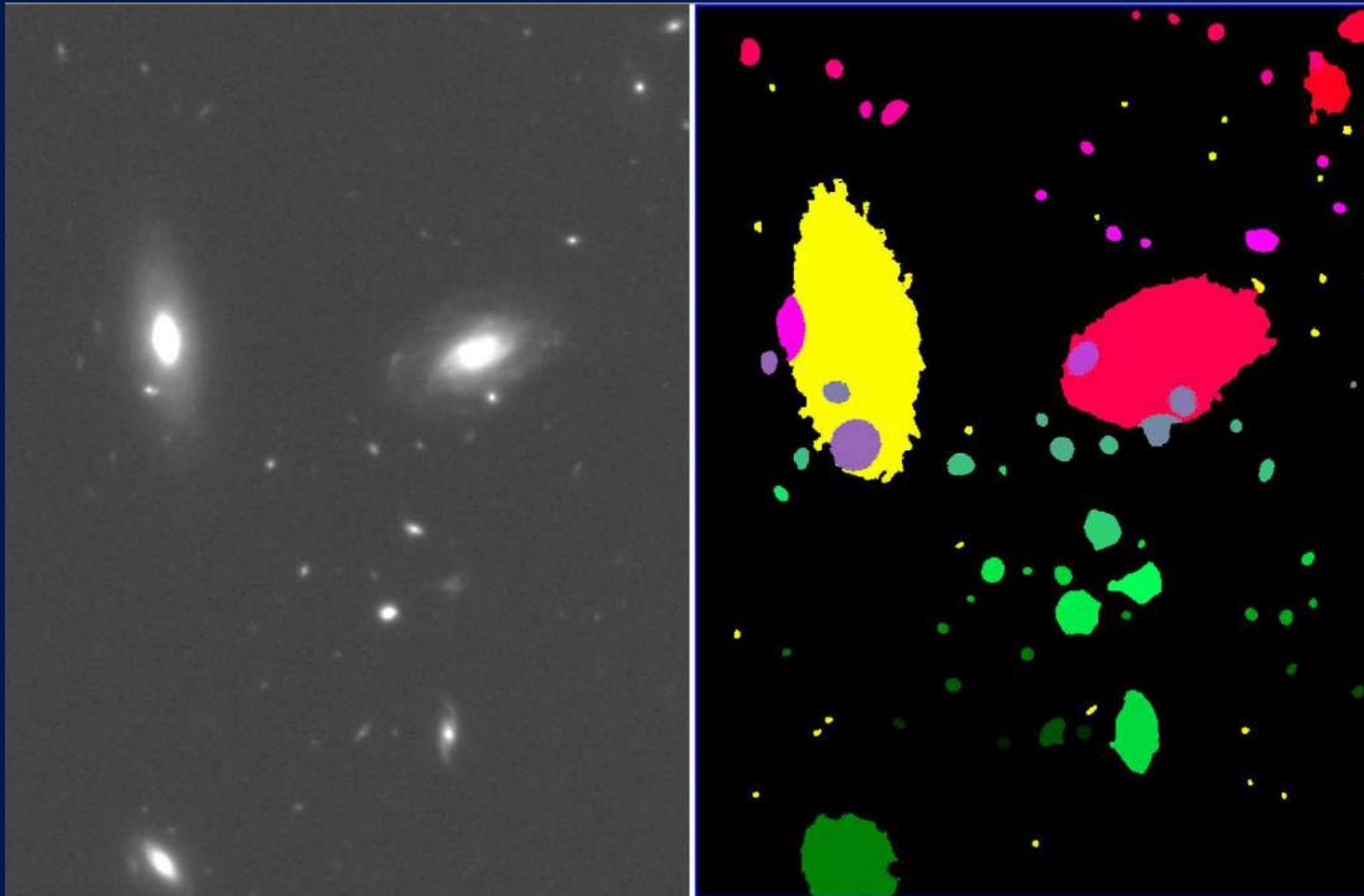
# Confusion noise

- 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

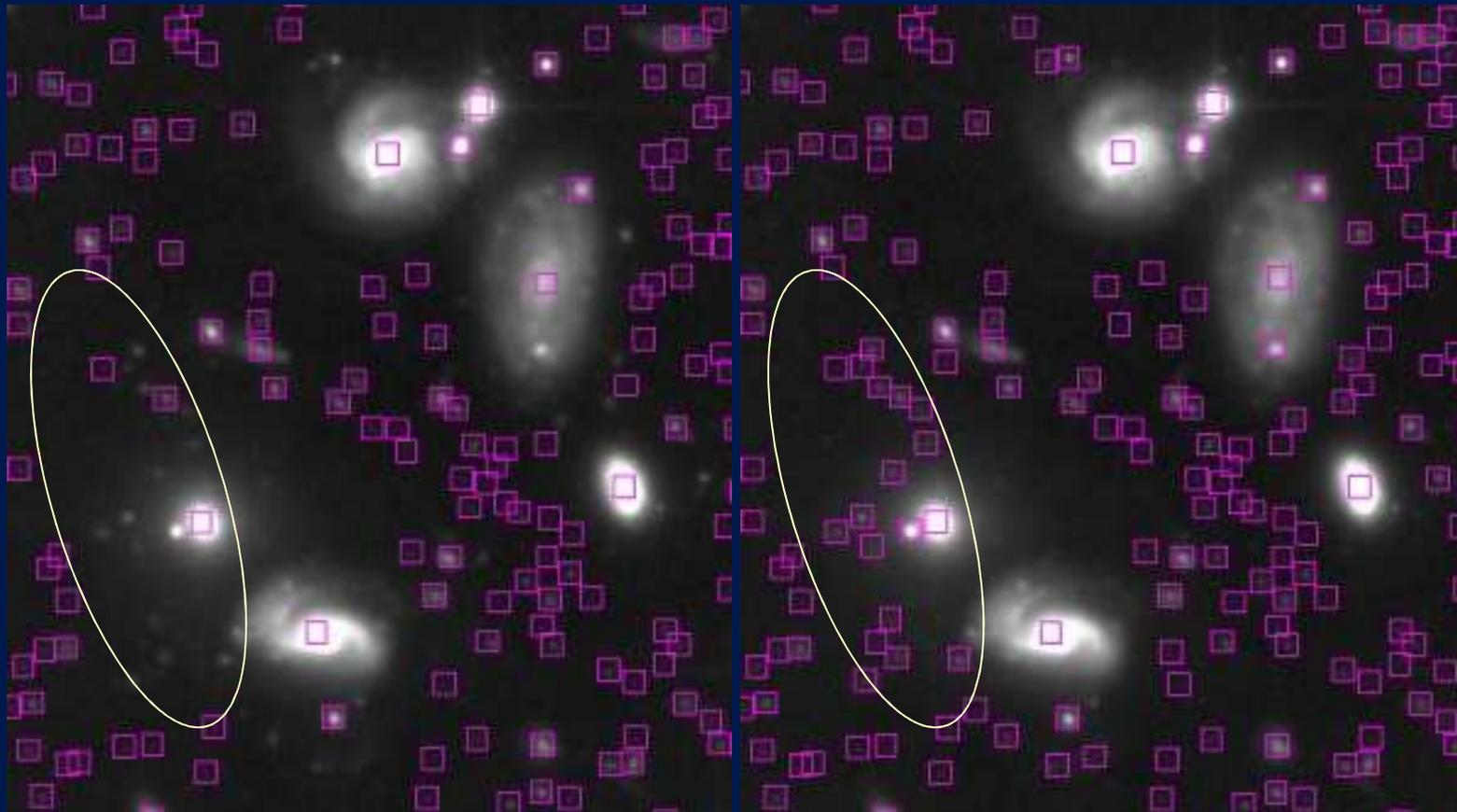
- Deblending : based on minimum threshold for contrast



Bertin & Arnouts 1996 (SExtractor)

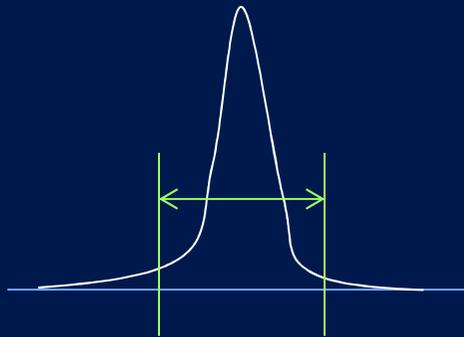
# Photometry of galaxies

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



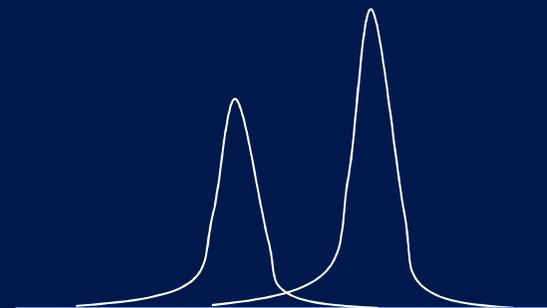
# Photometry of galaxies

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



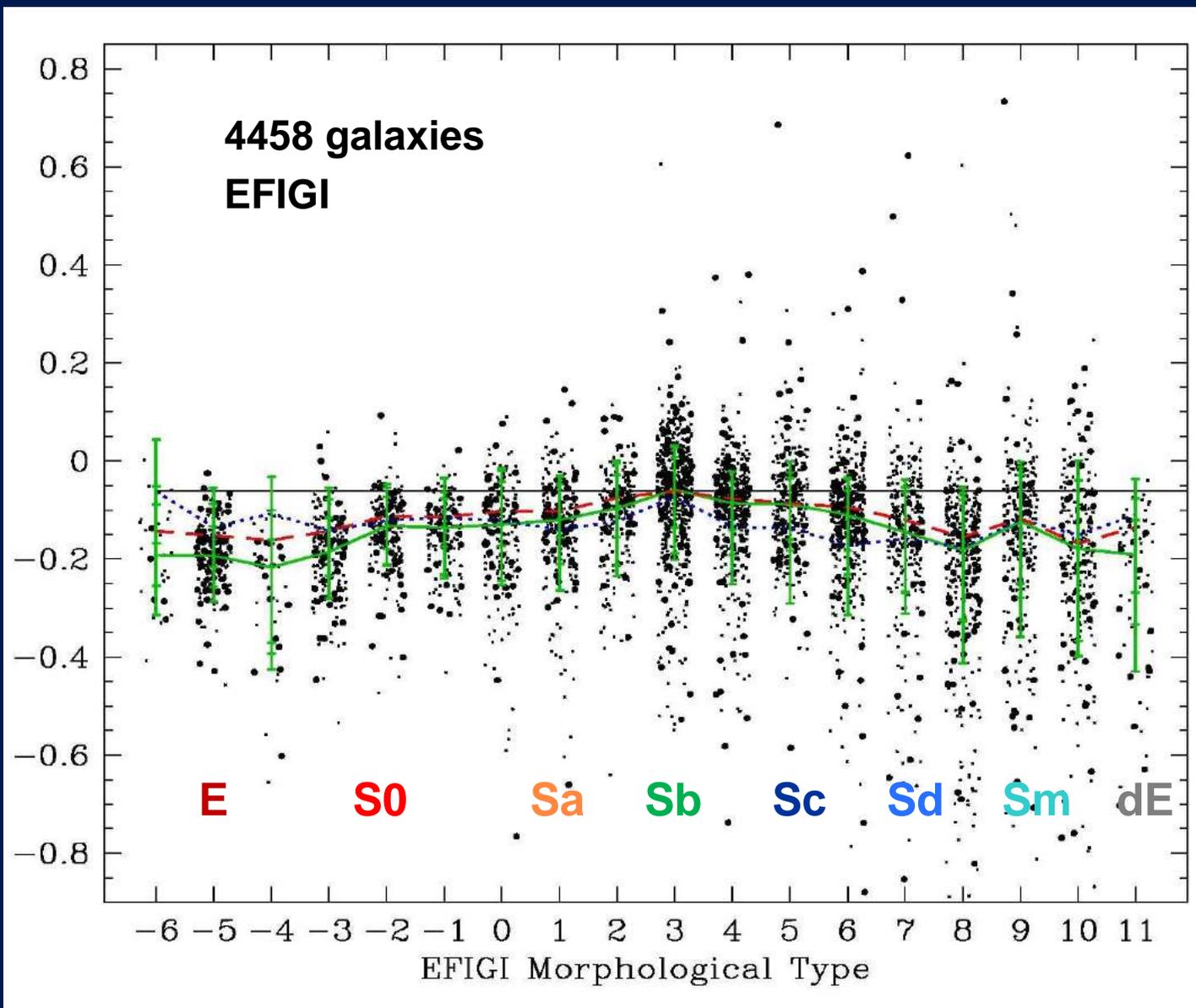
→ Profile fitting recovers wings

- Crowding : flux contamination by neighboring galaxies



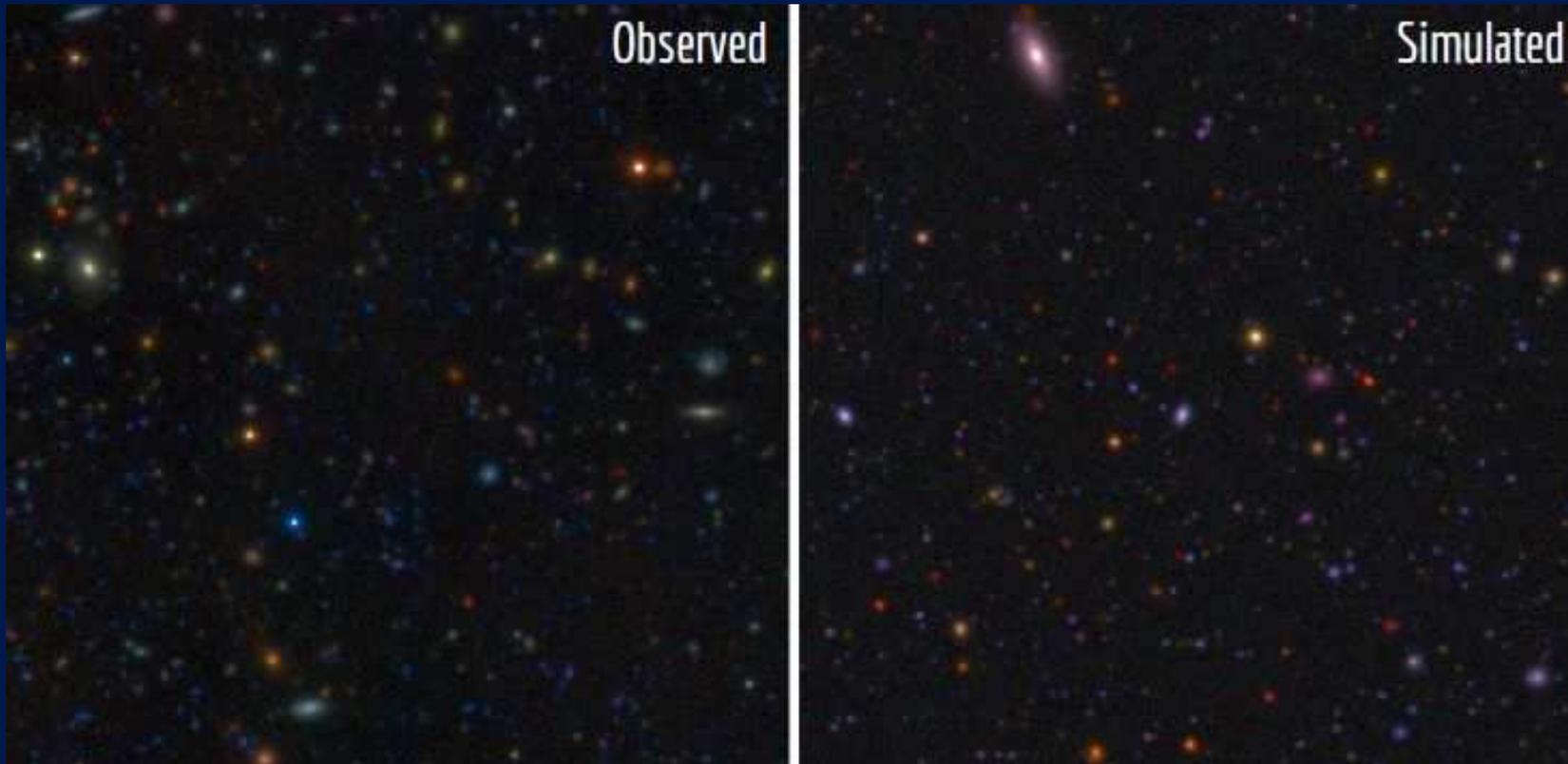
# Aperture bias in magnitudes

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



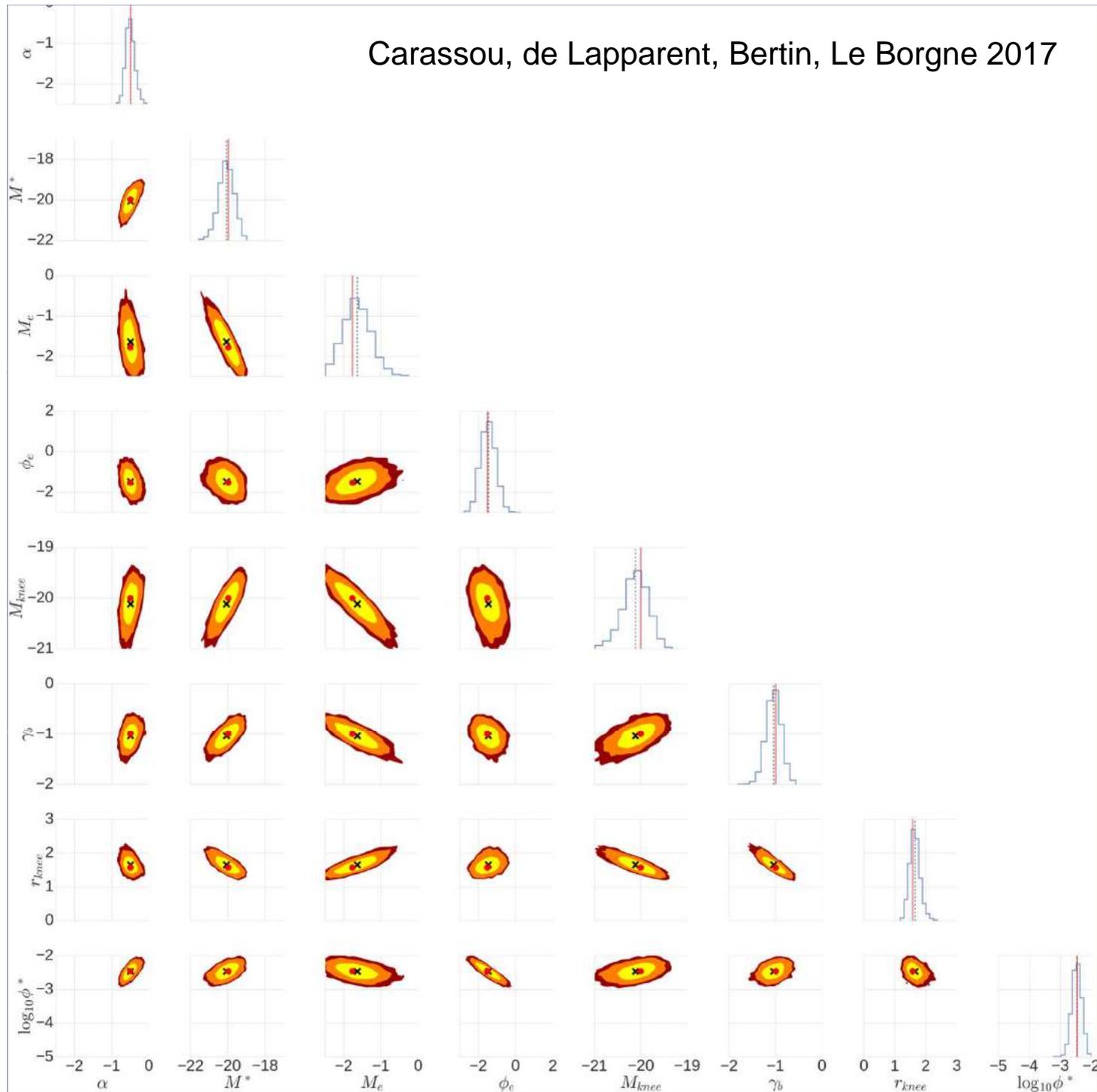
Stuff + SkyMaker ("AstrOmatic.net", Bertin)

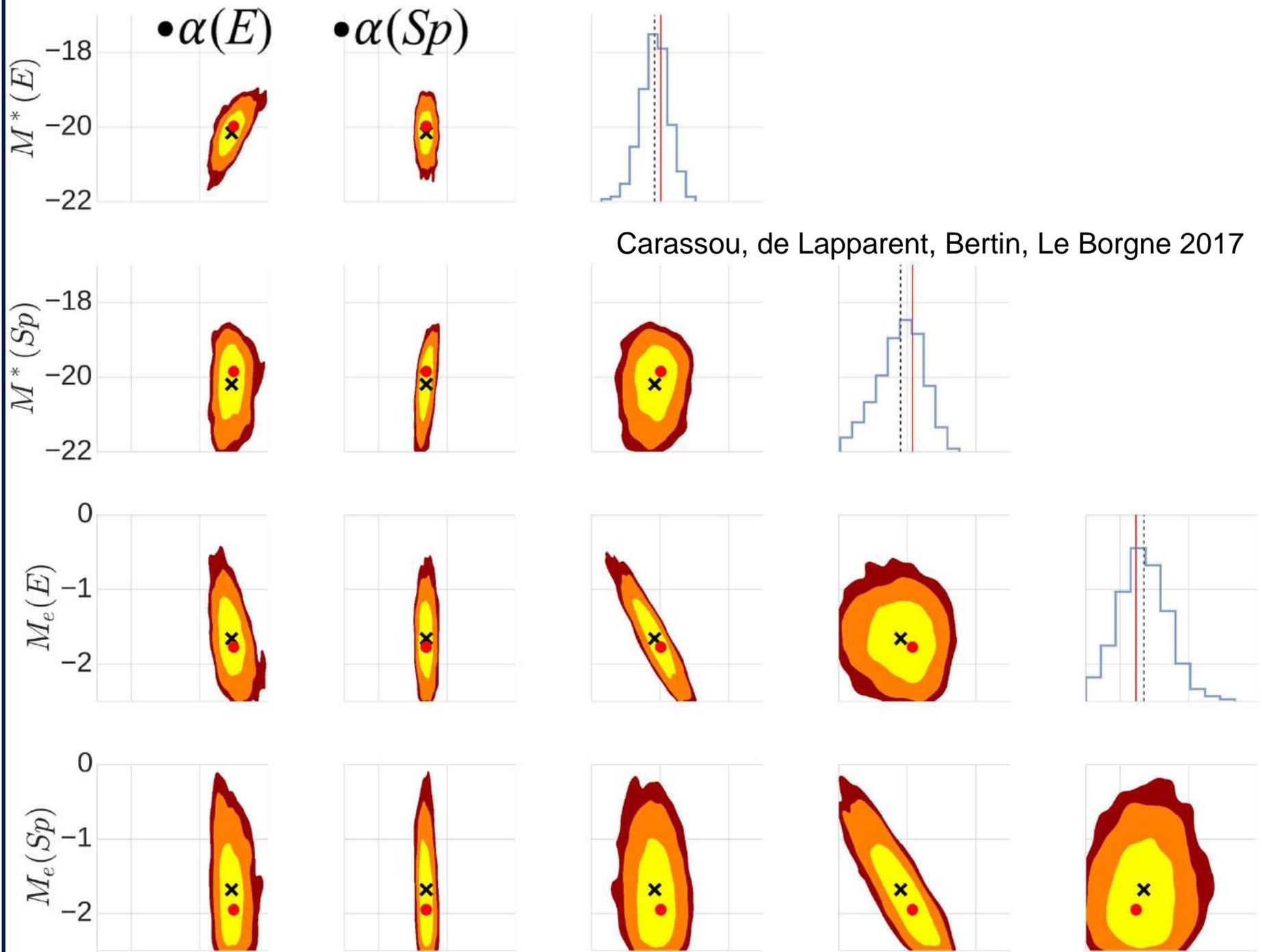
# Chaînes de Markov et inférence bayésienne

- 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

- Comparaison observations/simulations :
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    - 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
- ... 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)