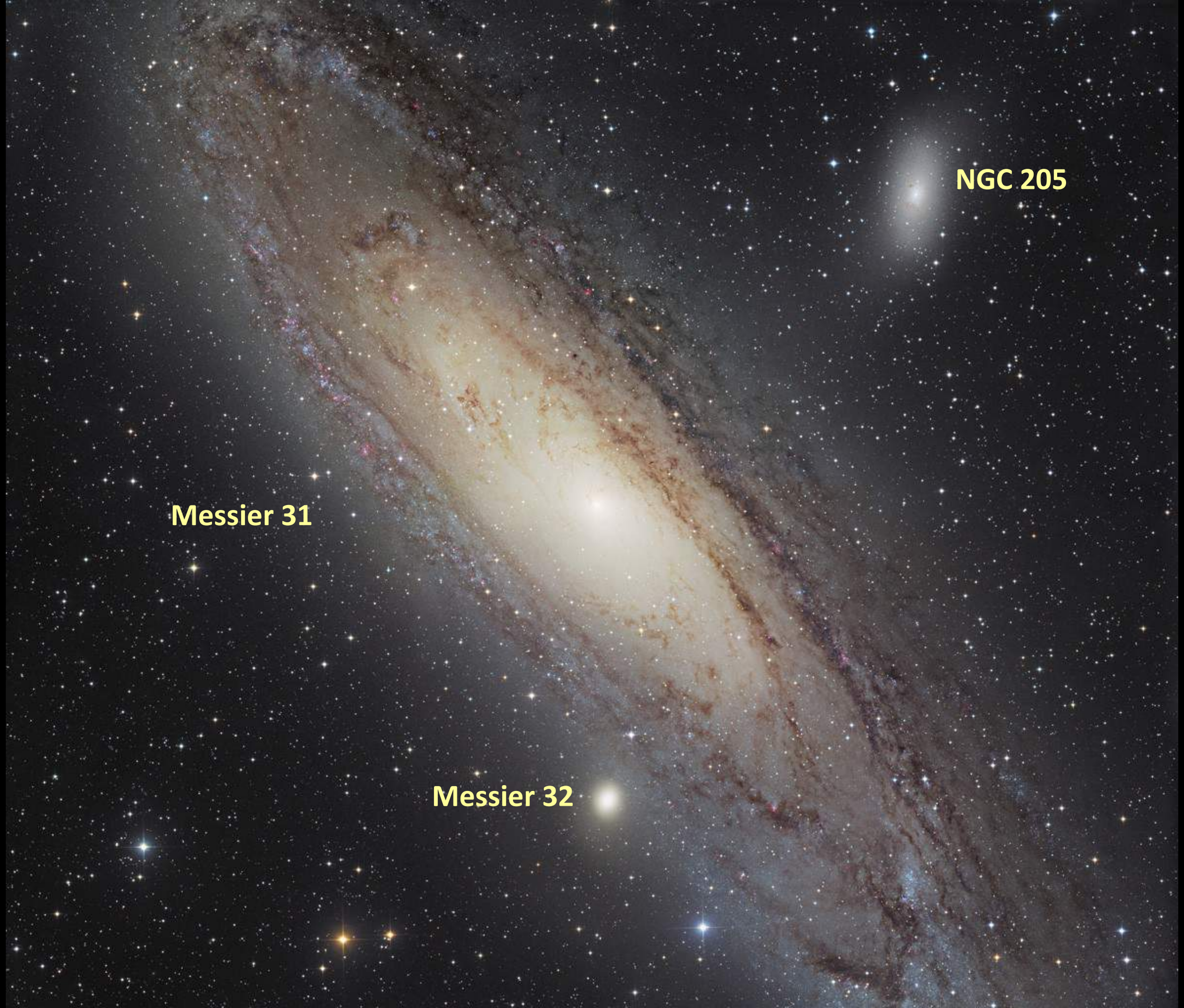
Galaxies de type précoce

Dynamique
& Processus de formation

Eric Emsellem

Types précoce & tardif ?

Messier 33
©Gendler, Subaru


NGC 205
Messier 31
Messier 32

ESO 325- G0004

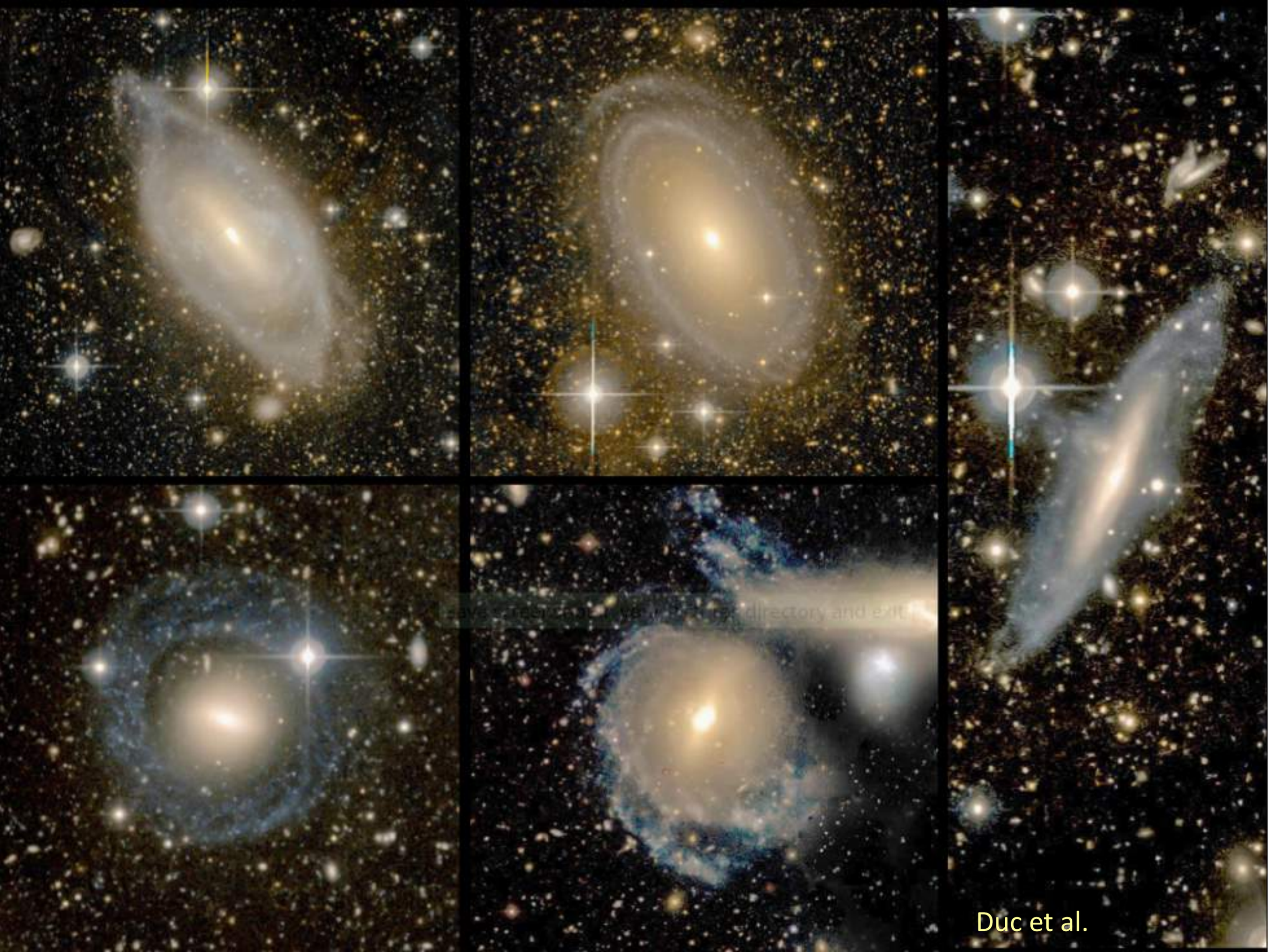
NASA/ESA (HST)

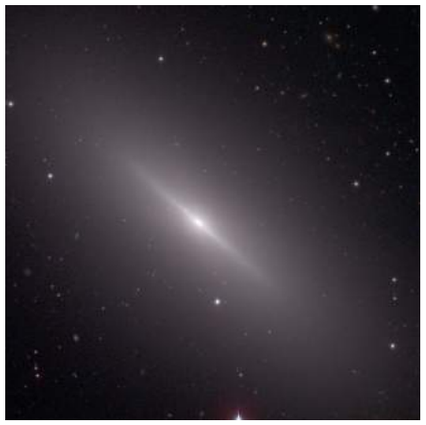
NGC 3115
©CGS

Messier 104

NGC 1277

Duc et al.

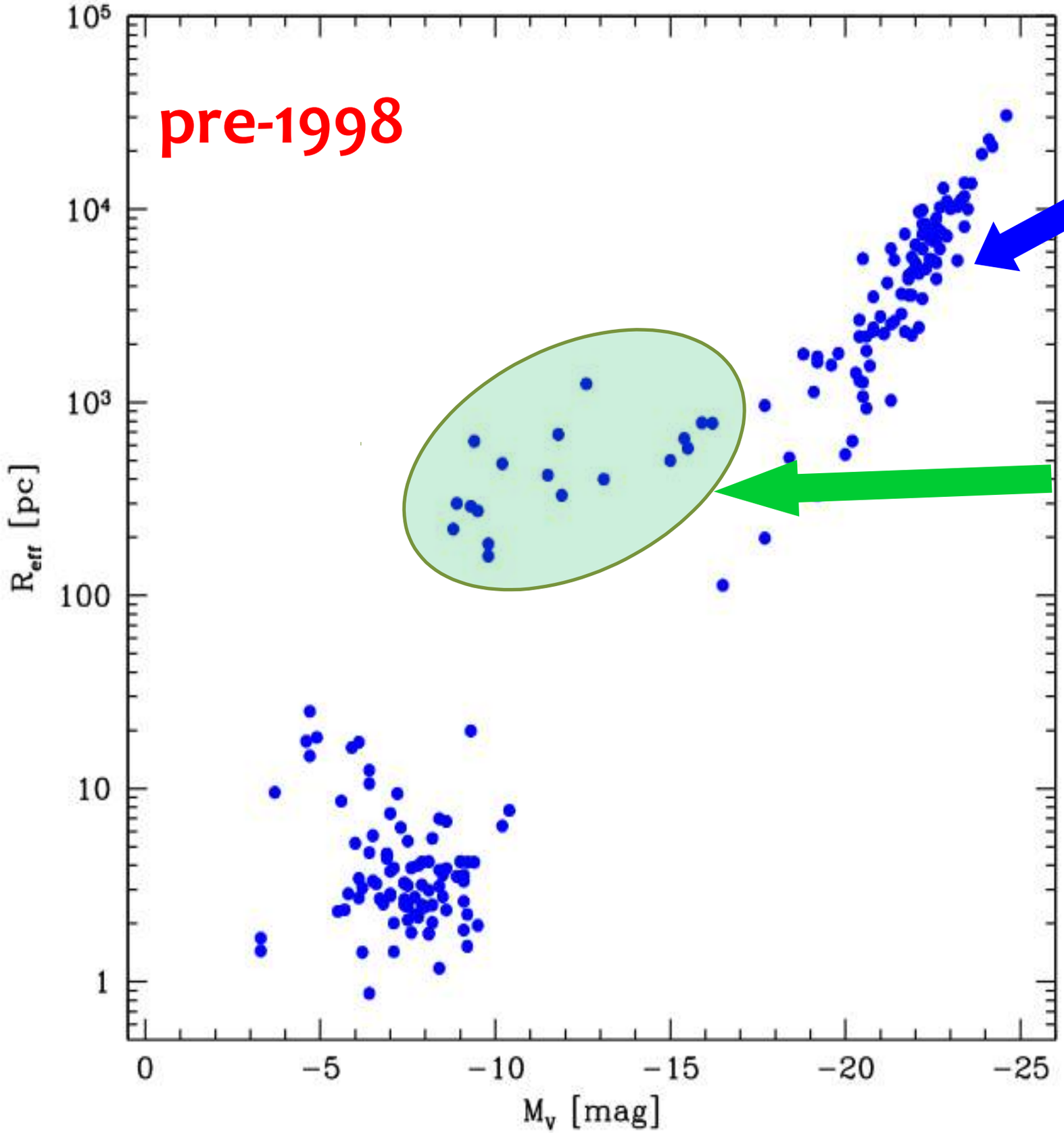

Duc et al.



Sommaire

- ***Propriétés : Taille & Masse des « ETG »***
  - Distribution, évolution
  - Processus de formation : première approche
- **Dynamique**
  - Anisotropie, Moment angulaires
    - Rotateurs lents/rapides versus *E / S0s*
  - In-situ, Ex-situ, Environnement*, Relations d'échelle*
- ***Campagnes d'observations***
  - Califa, SAMI, MaNGA
  - Résultats : plan fondamental, Rotateurs, Environnement
- **Vers les masses extrêmes** *(si le temps le permet)*

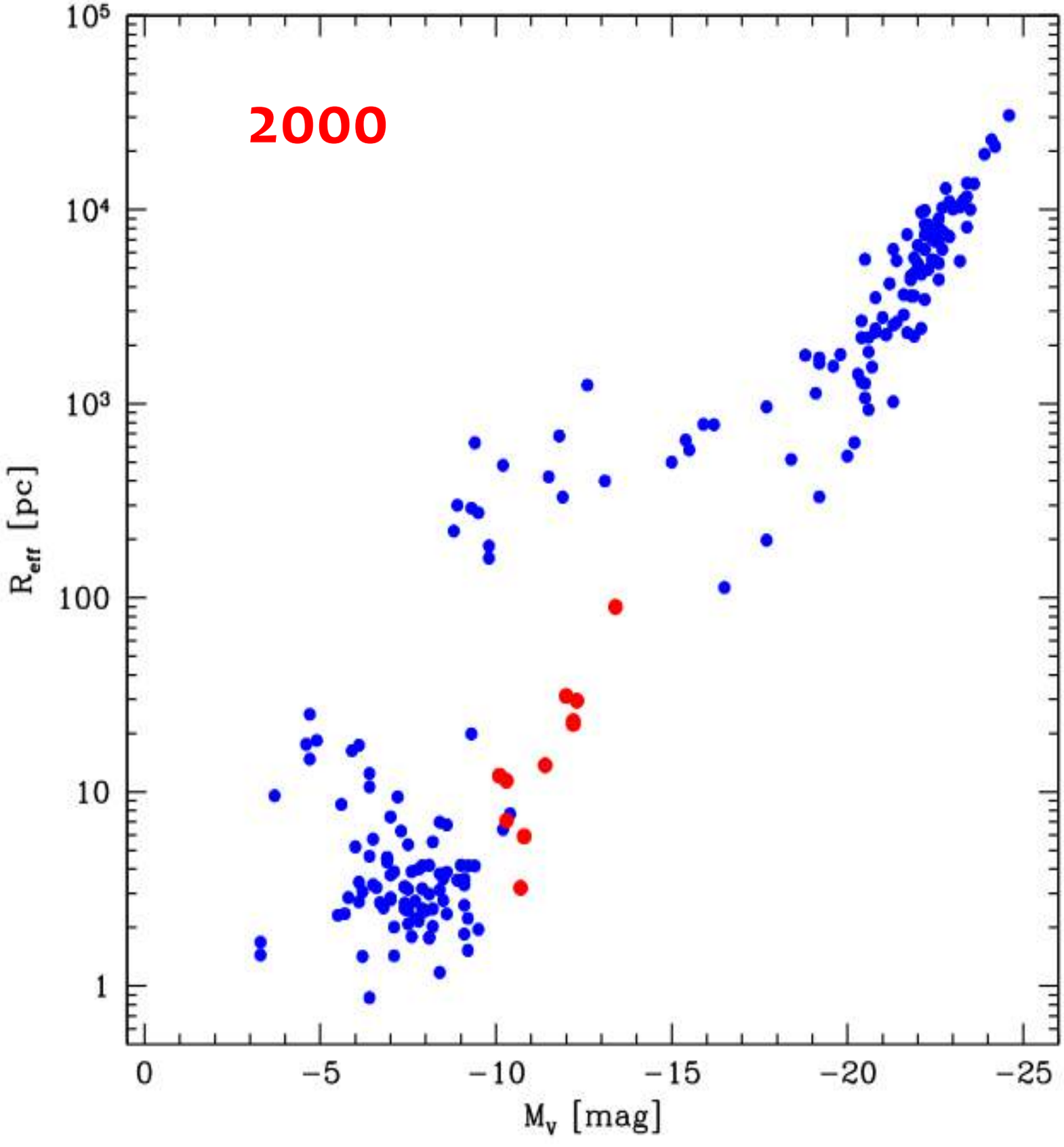
Galaxies ETG : Plan Rayon-Masse



Adapté de
Misgeld & Hilker (2011)

Sources princippales :
Bender et al. (1993)
Mateo (1998)
Harris (1998)

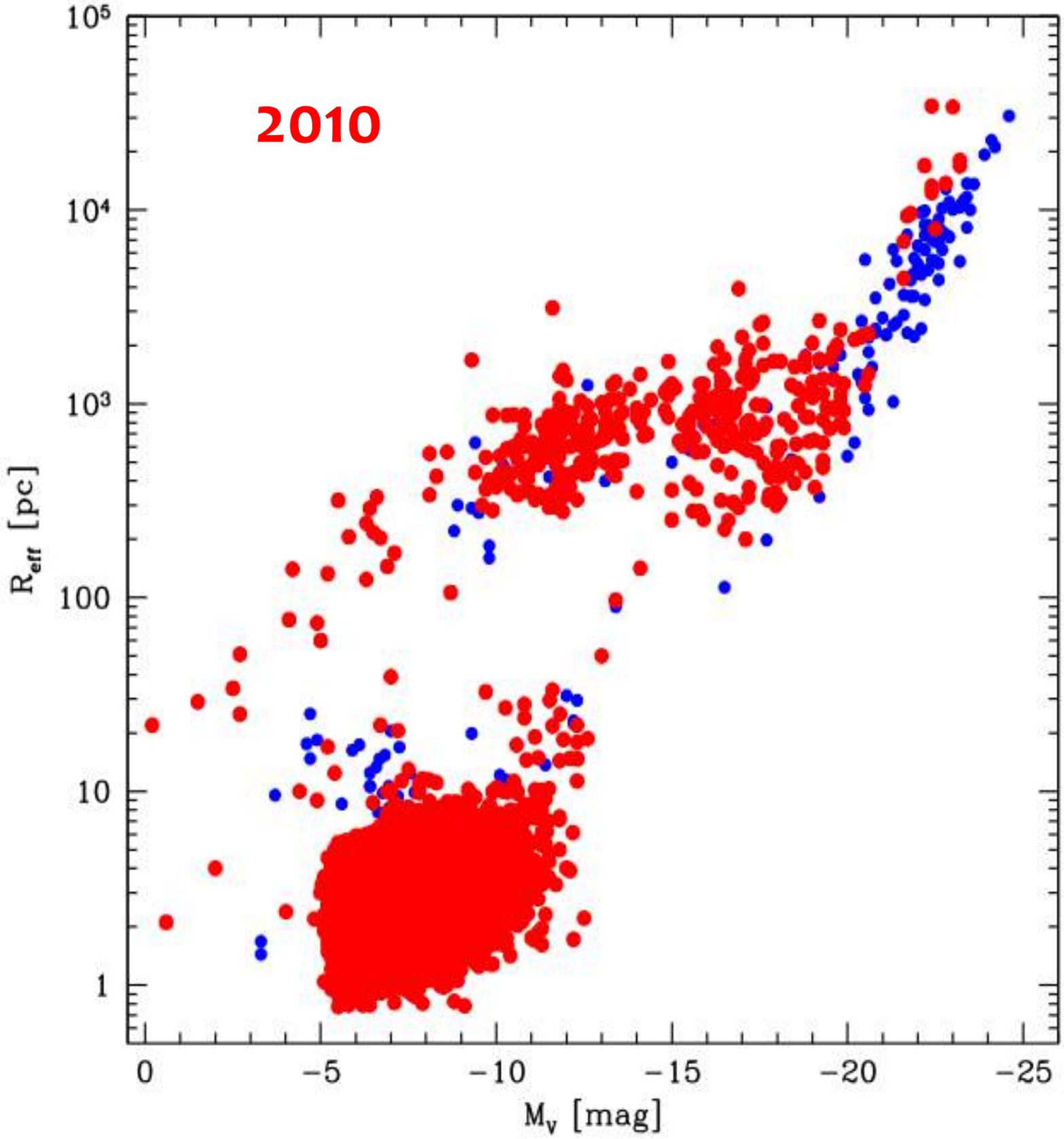
Galaxies ETG : Plan Rayon-Masse



Adapté de
Misgeld & Hilker (2011)

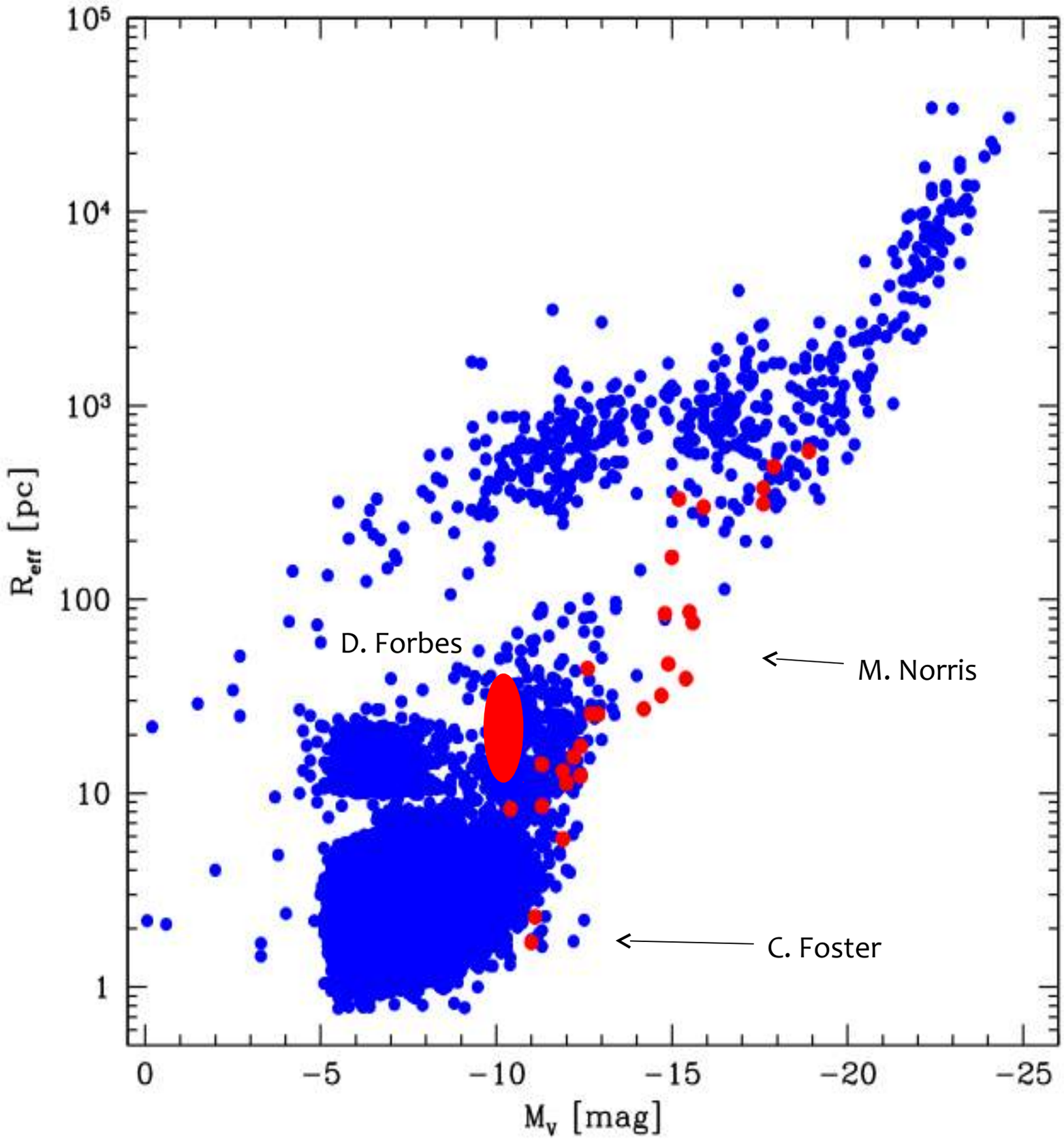
Source principales :
Bender et al. (1993)
Mateo (1998)
Harris (1998)
Holland et al. (1999)
Hilker et al. (1999)
Drinkwater et al. (2000)

Galaxies ETG : Plan Rayon-Masse



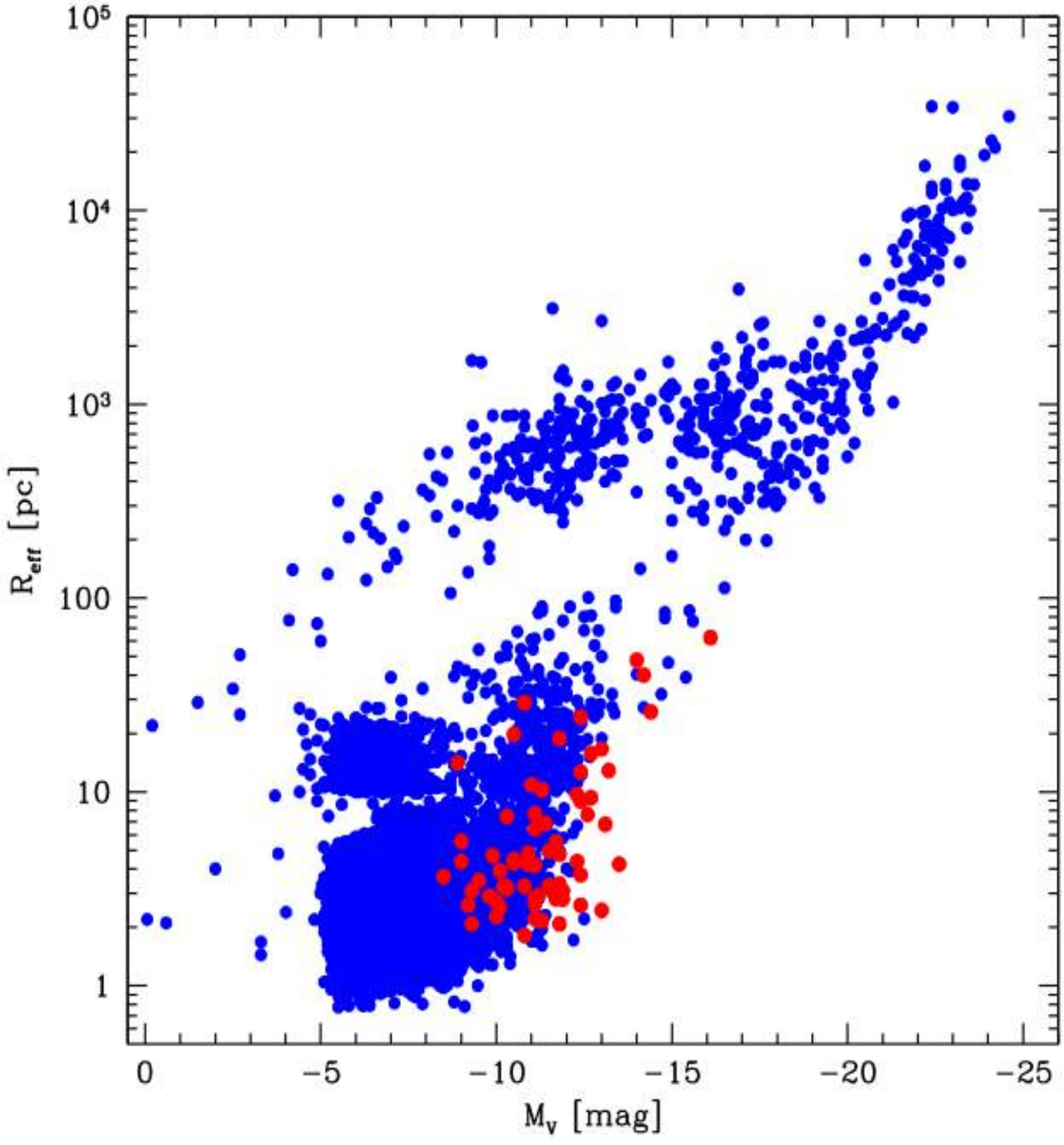
Adapté de
Misgeld & Hilker (2011)
Brodie et al (2011)

Galaxies ETG : Plan Rayon-Masse



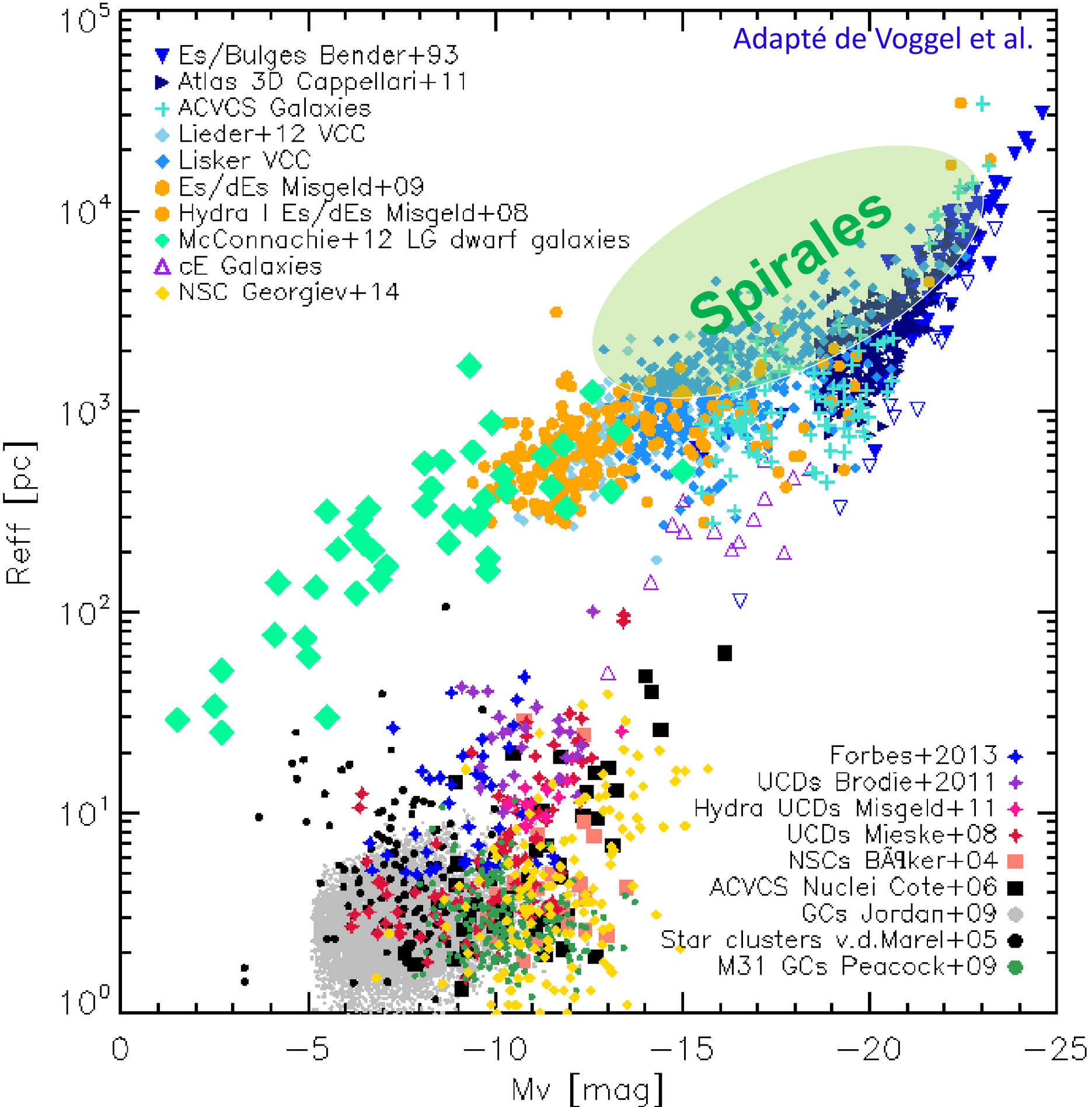
Adapté de
Misgeld & Hilker (2011)
Brodie et al. (2011)
Brüns & Kroupa (2012)

Galaxies ETG + Noyaux : Plan Rayon-Masse

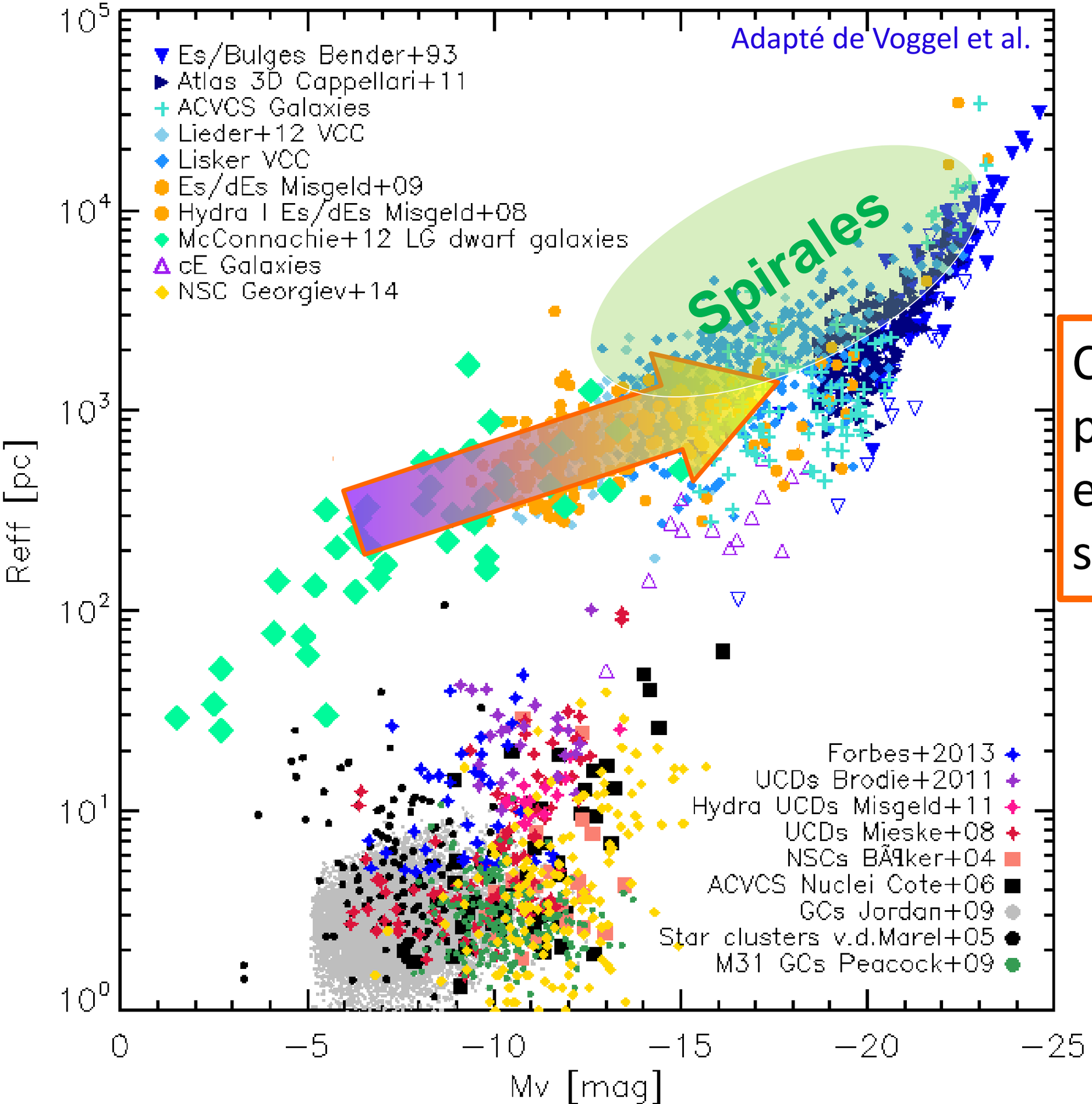


Noyaux :
Böker et al. (2004)
Rossa et al. (2006)
Cote et al. (2006)

Une vue globale du Plan Rayon-Masse

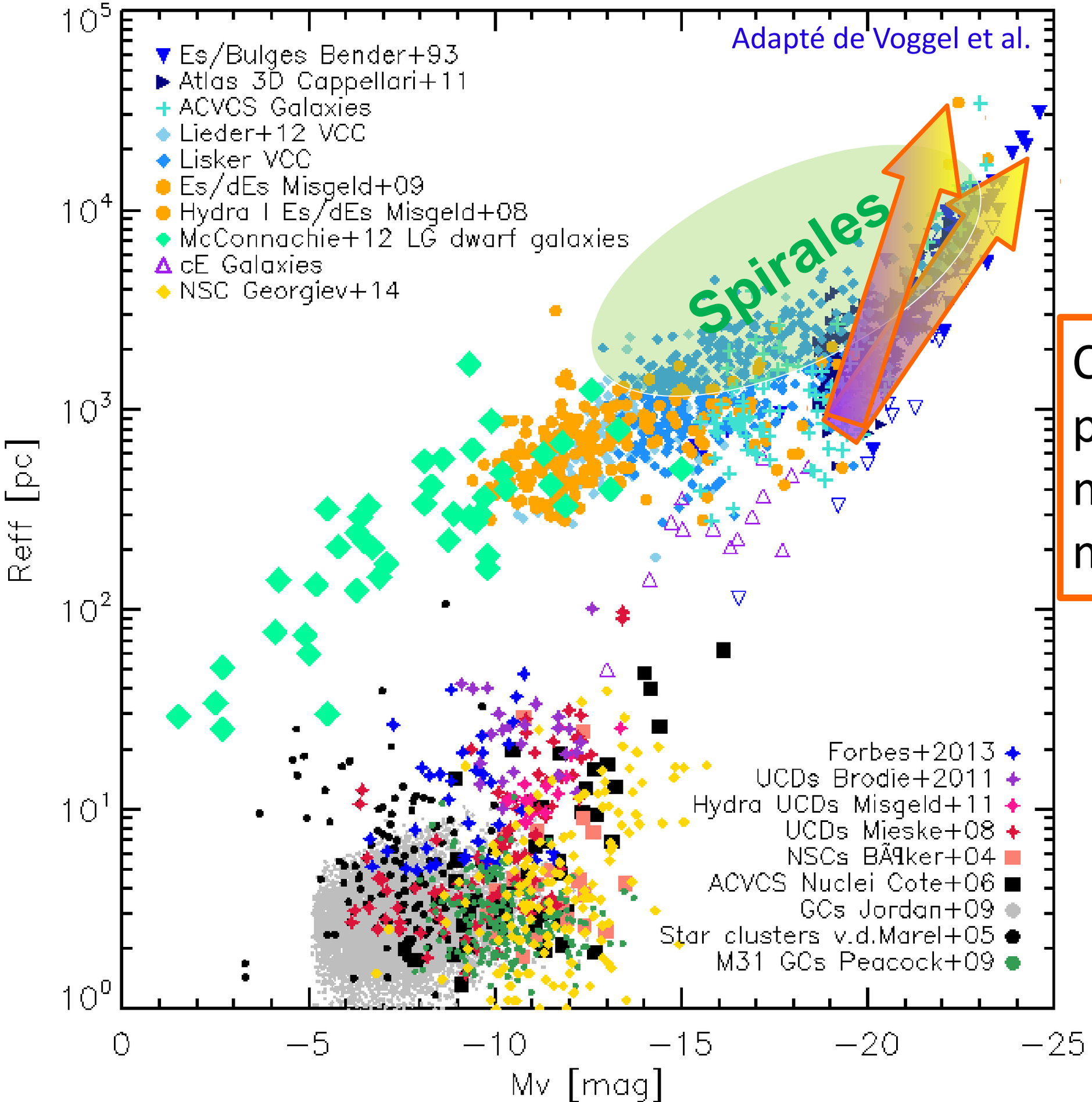


Une vue globale du Plan Rayon-Masse



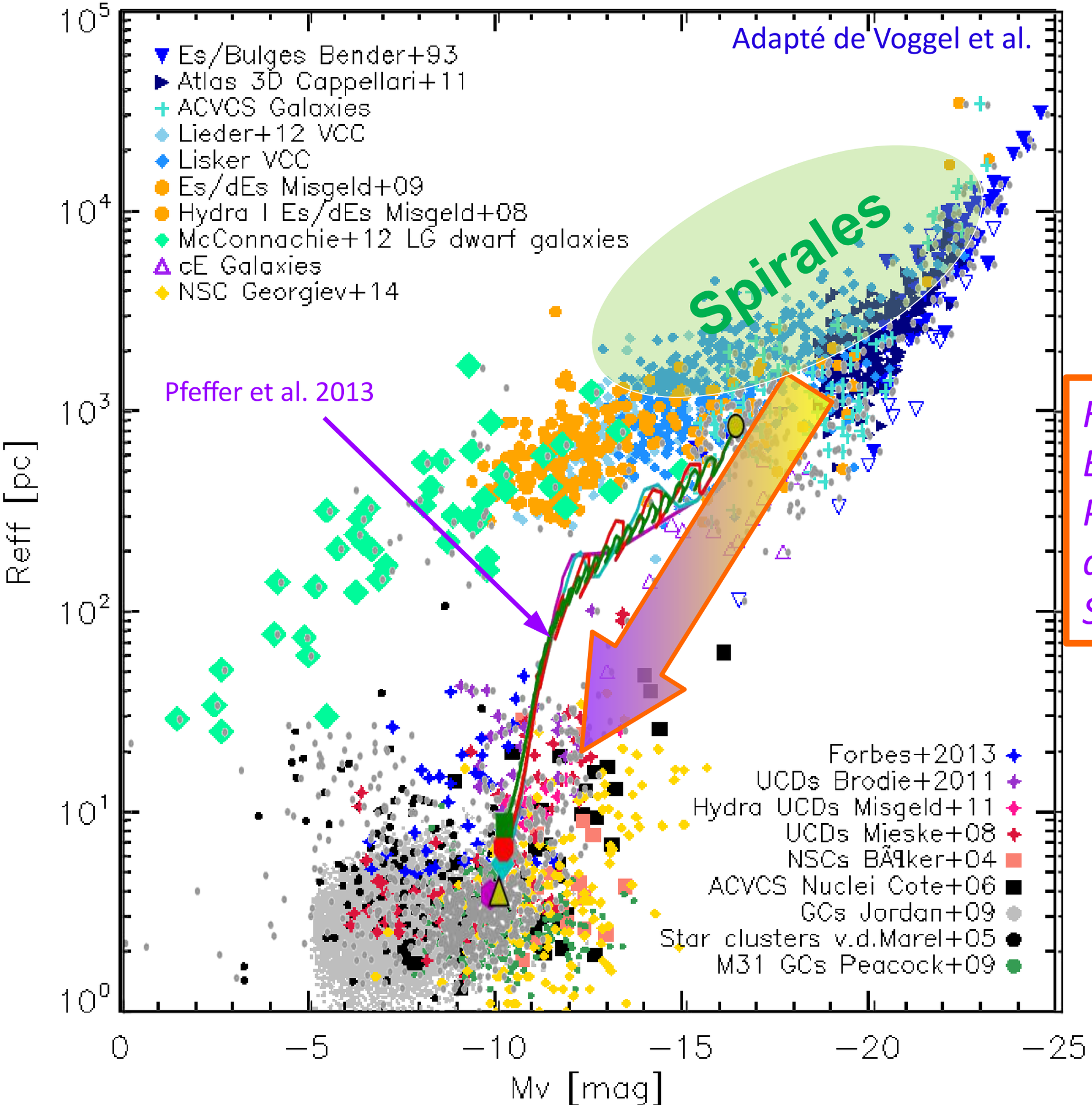
Croissance par accrétion et formation stellaire

Une vue globale du Plan Rayon-Masse



Croissance par fusions mineurs et majeures

Une vue globale du Plan Rayon-Masse



Harassement
Epluchage
Pression dynamique
Strangulation

Taille

Accrétion

Fusions mineures

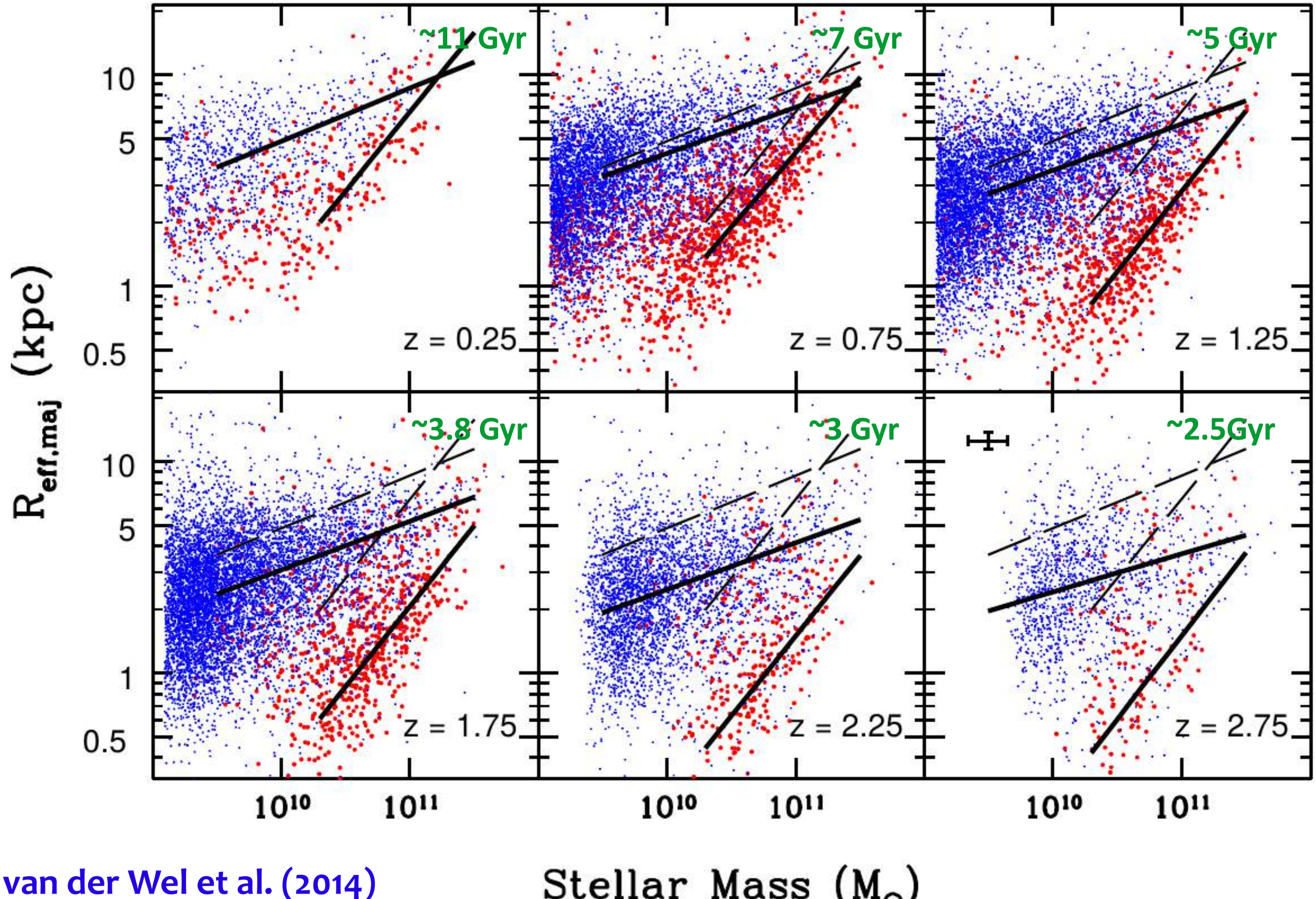
Fusions majeures

Éjection

Épluchage

Masse Stellaire

Evolution en fonction du redshift



van der Wel et al. (2014)

Quid de la Dynamique ?

Le Graal

(la fonction de distribution)

f[x, y, z, Vx, Vy, Vz, [Fe/H], age, …, t]

Le Graal – Dynamique

(la fonction de distribution)

f[x, y, z, Vx, Vy, Vz, ~~[Fe/H], age~~, …, t]

Le Graal – Dynamique (dans le monde réel)

(la fonction de distribution)

f[x’, y’, ~~z,~~ ~~Vx, Vy,~~ Vz’, ~~[Fe/H], age, …, t~~]

Prototype de fusion majeure

NGC 7252
©ESO

Paradigme

2 Spirales ⇒ 1 galaxie elliptique

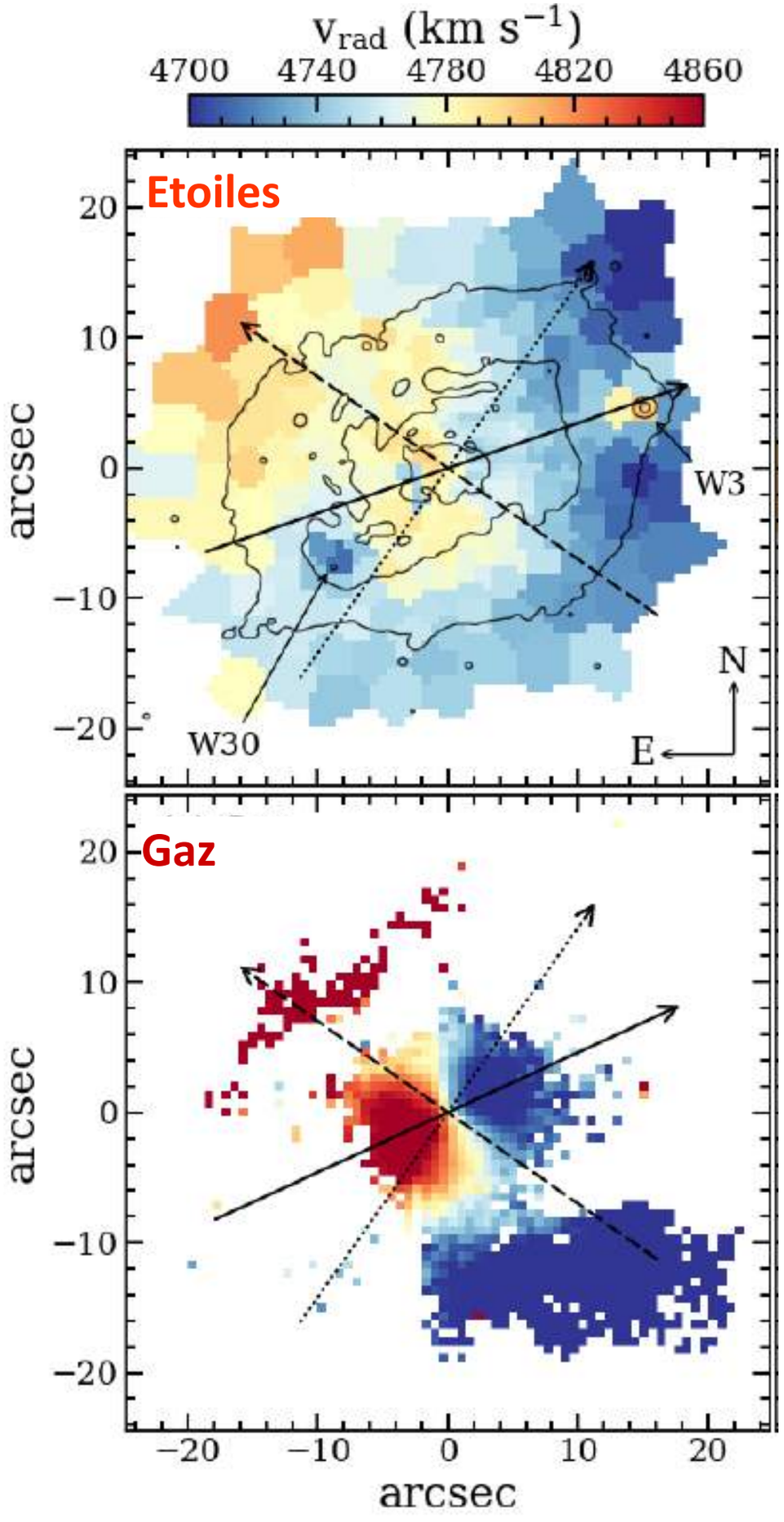
Types tardifs ⇒ type précoce

NGC 7252

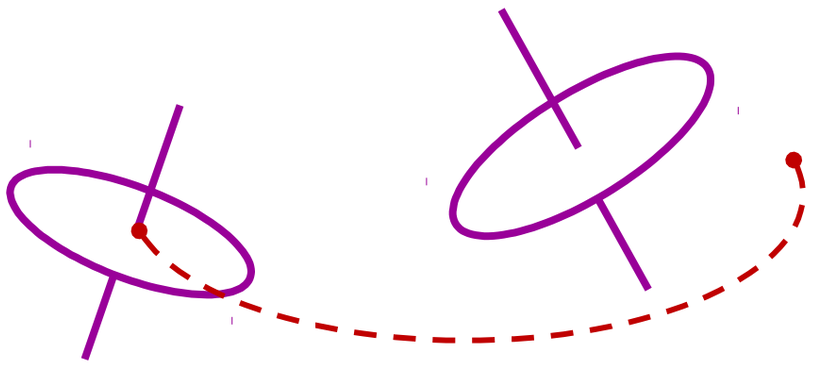
NGC 7252

Dynamique des étoiles / du gaz

- ***Structures complexes***
  - ***Coeur cinématiquement découplé***
  - Disque central de gaz
  - Moment angulaire stellaire non nul



Weaver et al. (2018)

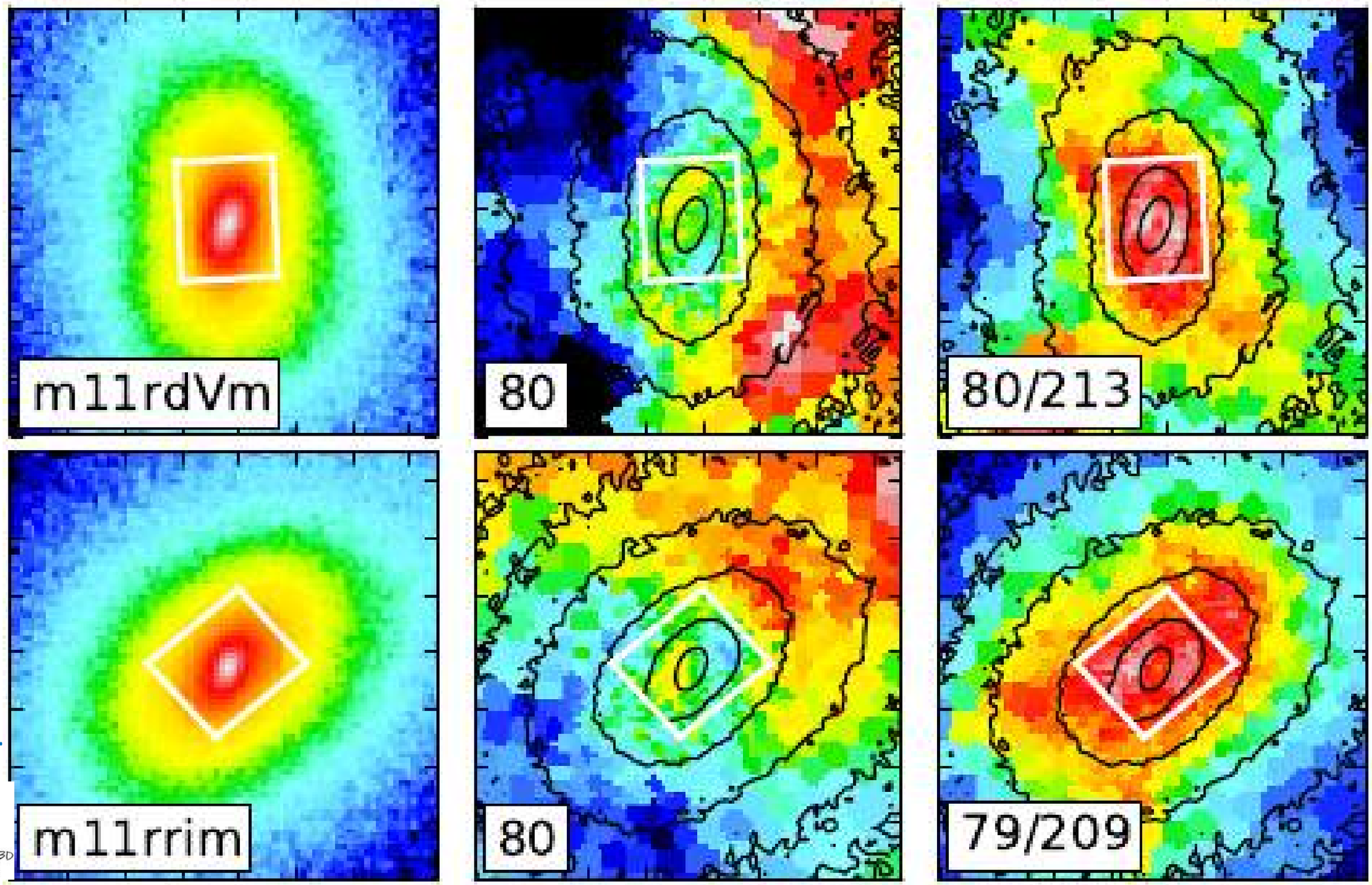


- Fusions de 2 galaxies → il reste du moment angulaire
- **Galaxies à faible moment angulaire**

  ⇒ Structures dynamiques complexes (non régulières)

  & parfois Coeurs Découplés

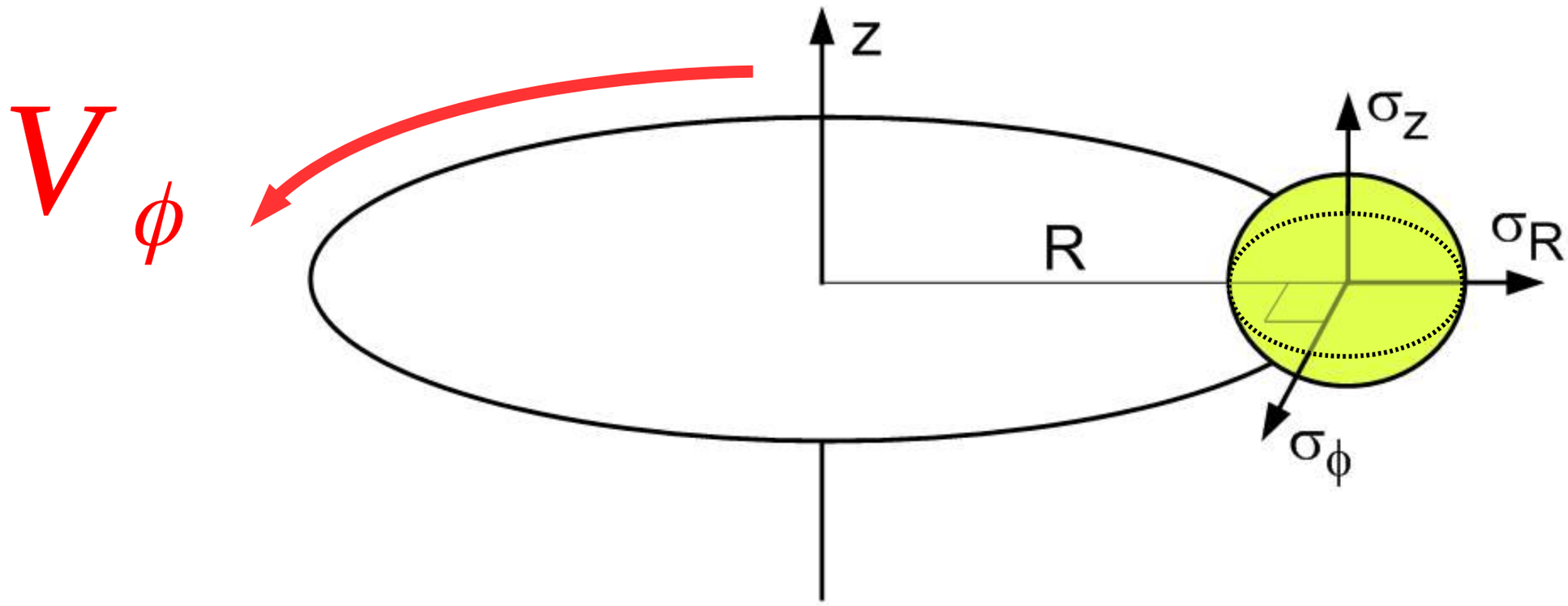
Luminosité | **Vitesse** | **Dispersion**



Bois, EE, FB et al. 2011

Caractérisation dynamique

Rotation ⇒ ***vitesse moyenne***

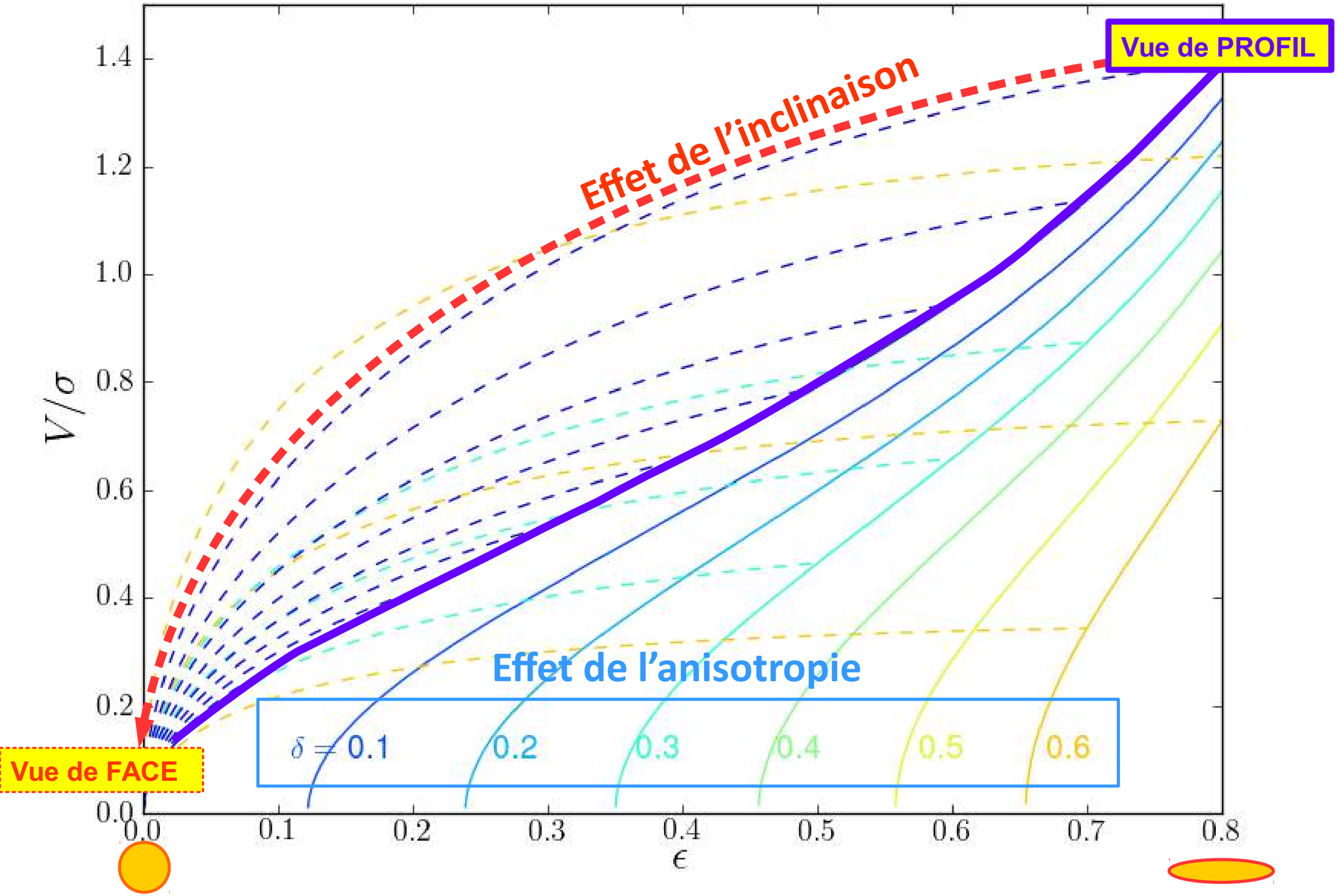


& Anisotropie ⇒ **forme du tenseur de dispersion**

$$\beta_z \Rightarrow 1-\frac{\sigma_z^2}{\sigma_R^2} \qquad \beta_\phi \Rightarrow 1-\frac{\sigma_\phi^2}{\sigma_R^2}$$

Caractérisation dynamique : l'anisotropie

⇒ Prédictions des modèles



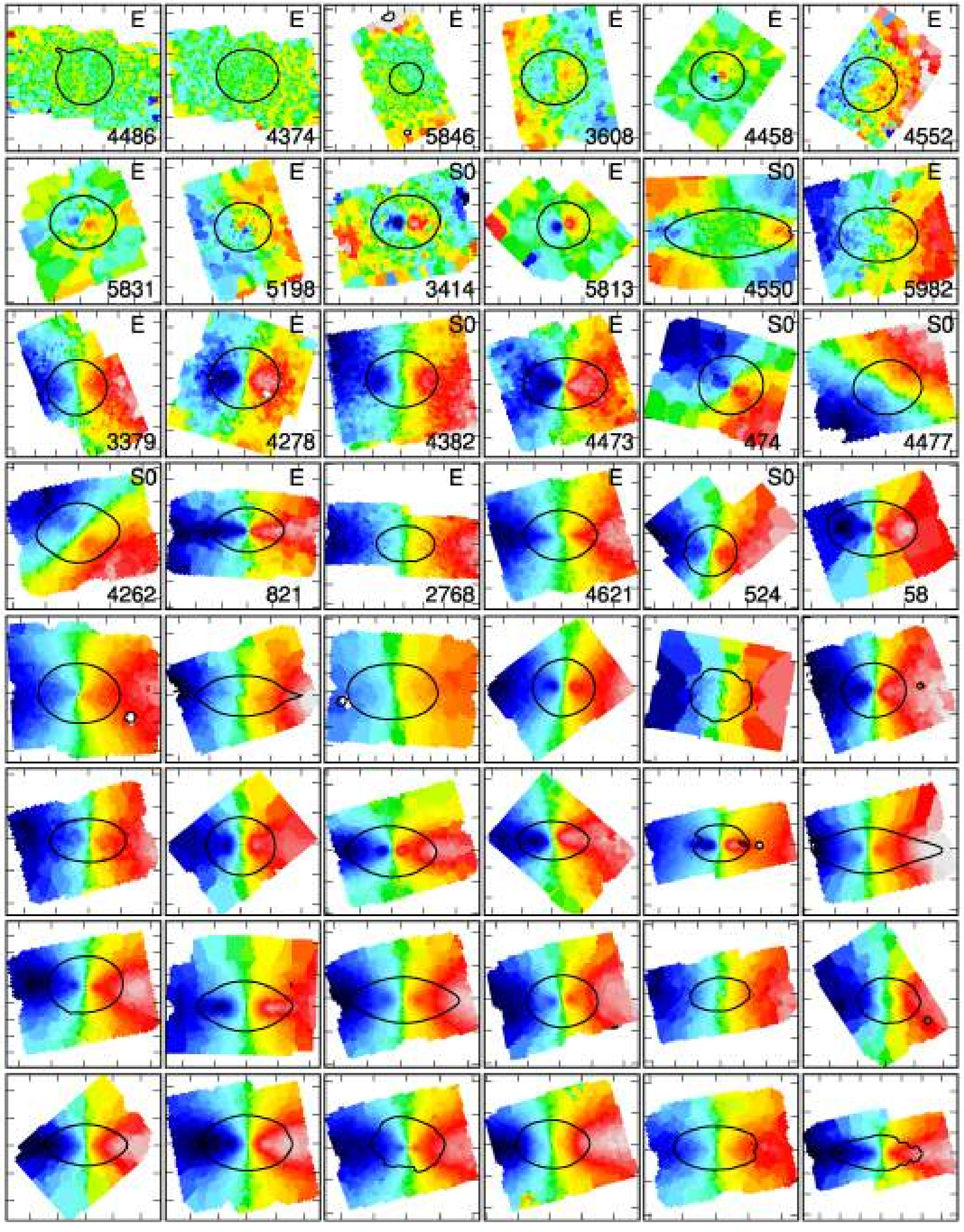
Emsellem et al., 2007

Moment Angulaire

$$\lambda_R \equiv \frac{\langle R \cdot |V| \rangle}{\langle R \sqrt{V^2 + \sigma^2} \rangle}$$

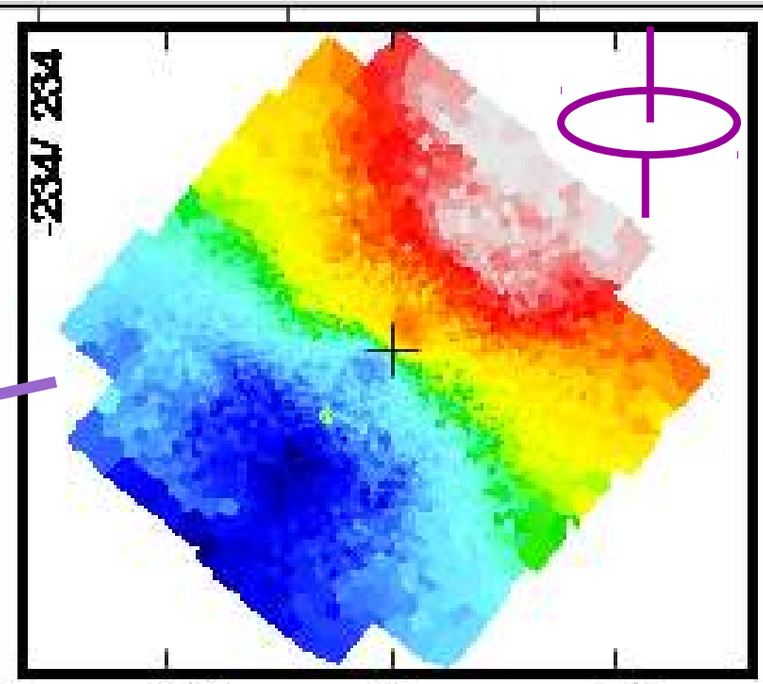
Moyenne spatiale ⇒ Spectrographe intégral de champ

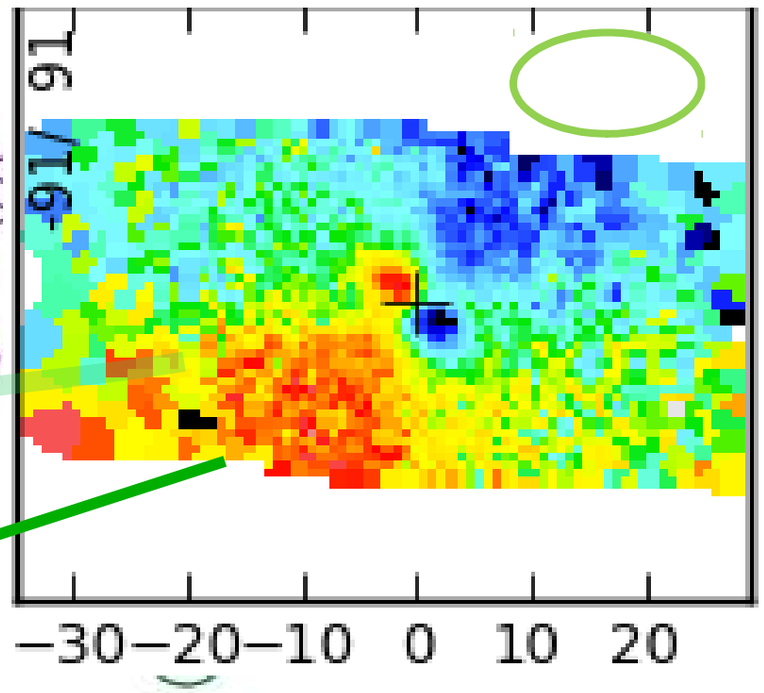
Proportionnel à la Masse



Moment angulaire

Régulier / non Régulier





λ_R (Re)

ϵ_e

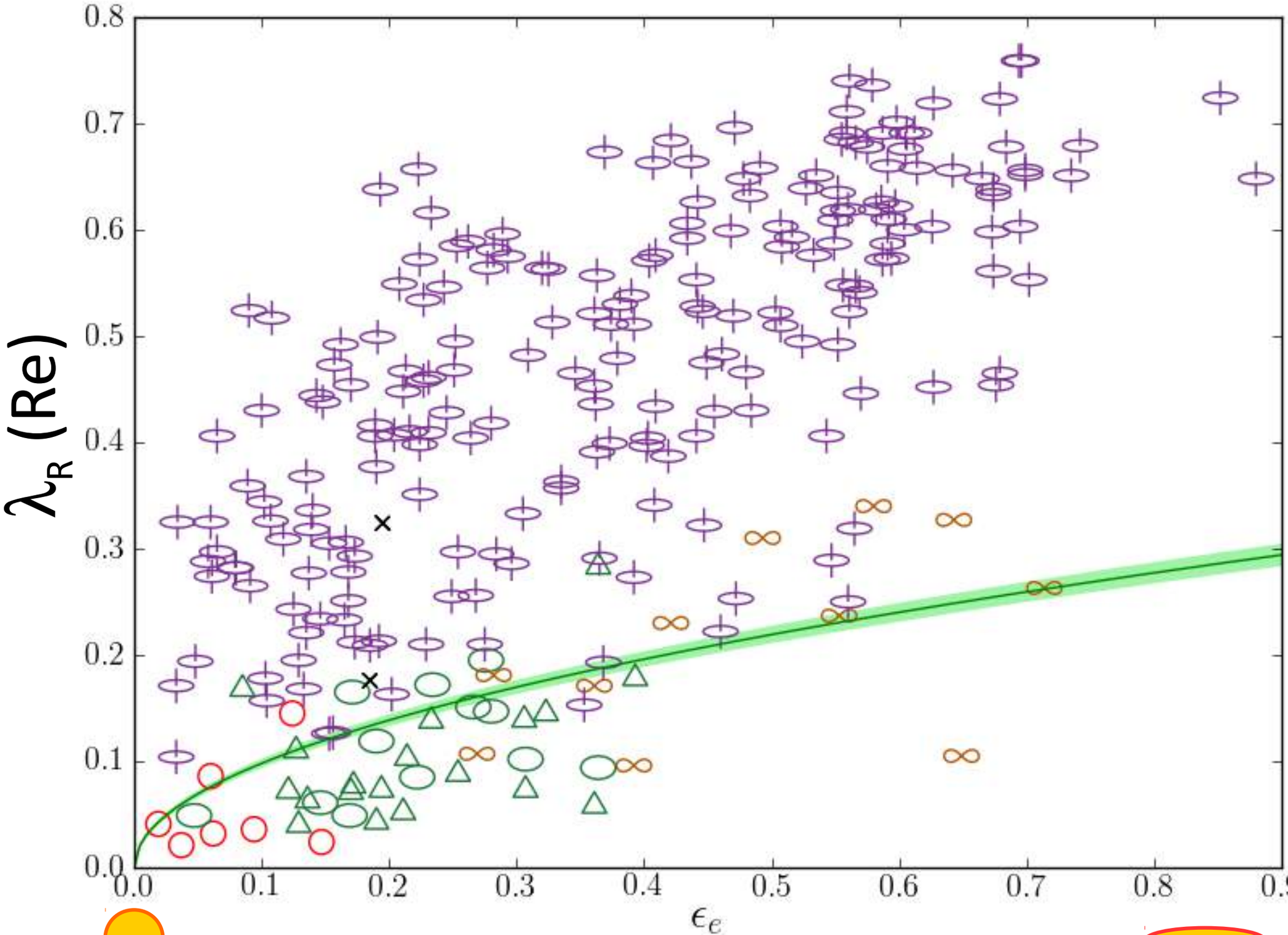
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

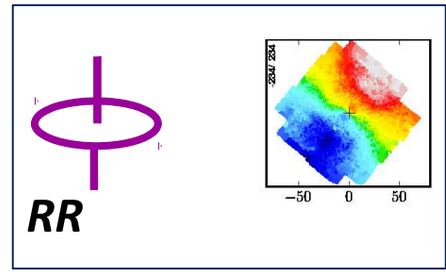
Emsellem, MC, DK et al., 2011 (PIII)

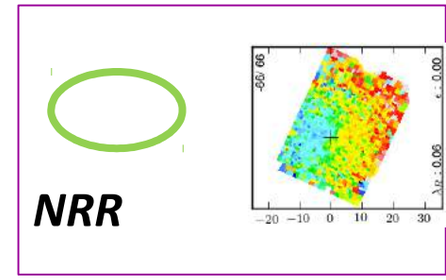
Krajnović, EE, MC et al., 2011 (PII)

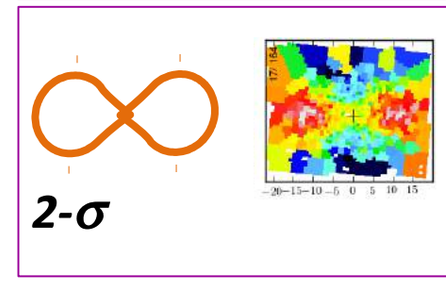
Non-Rotateurs

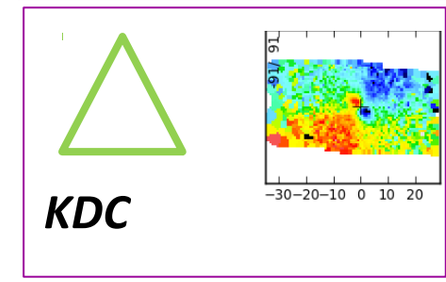
λ_R et Structures Cinématiques

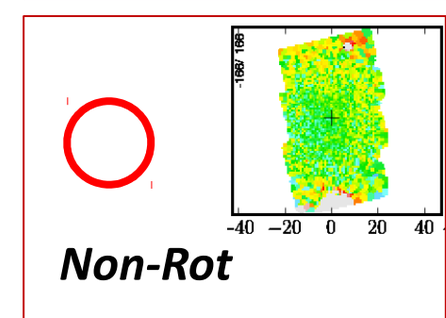








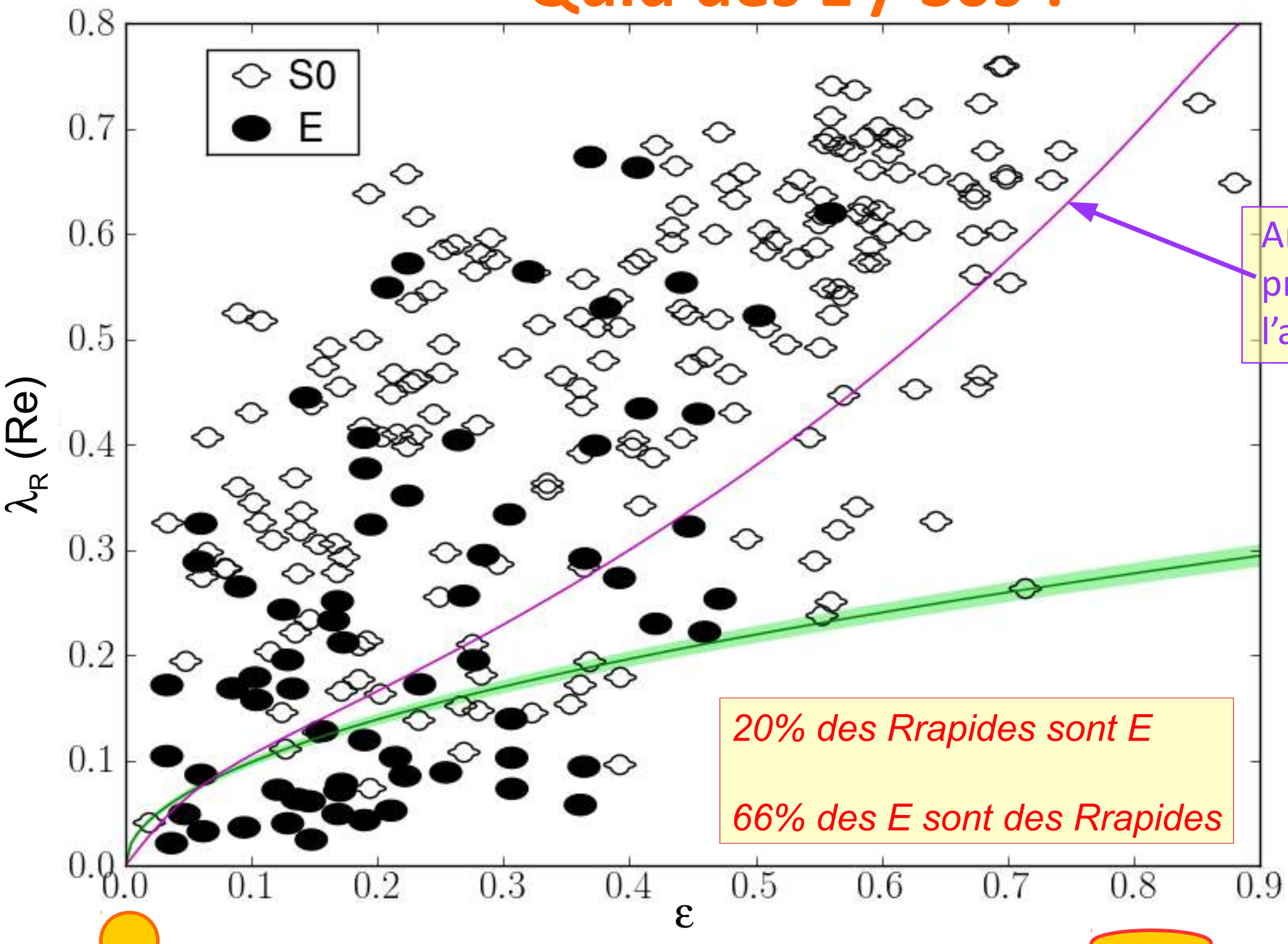




Emsellem, MC, DK et al., 2011 (PIII)

Rotateurs Lents / Rapides

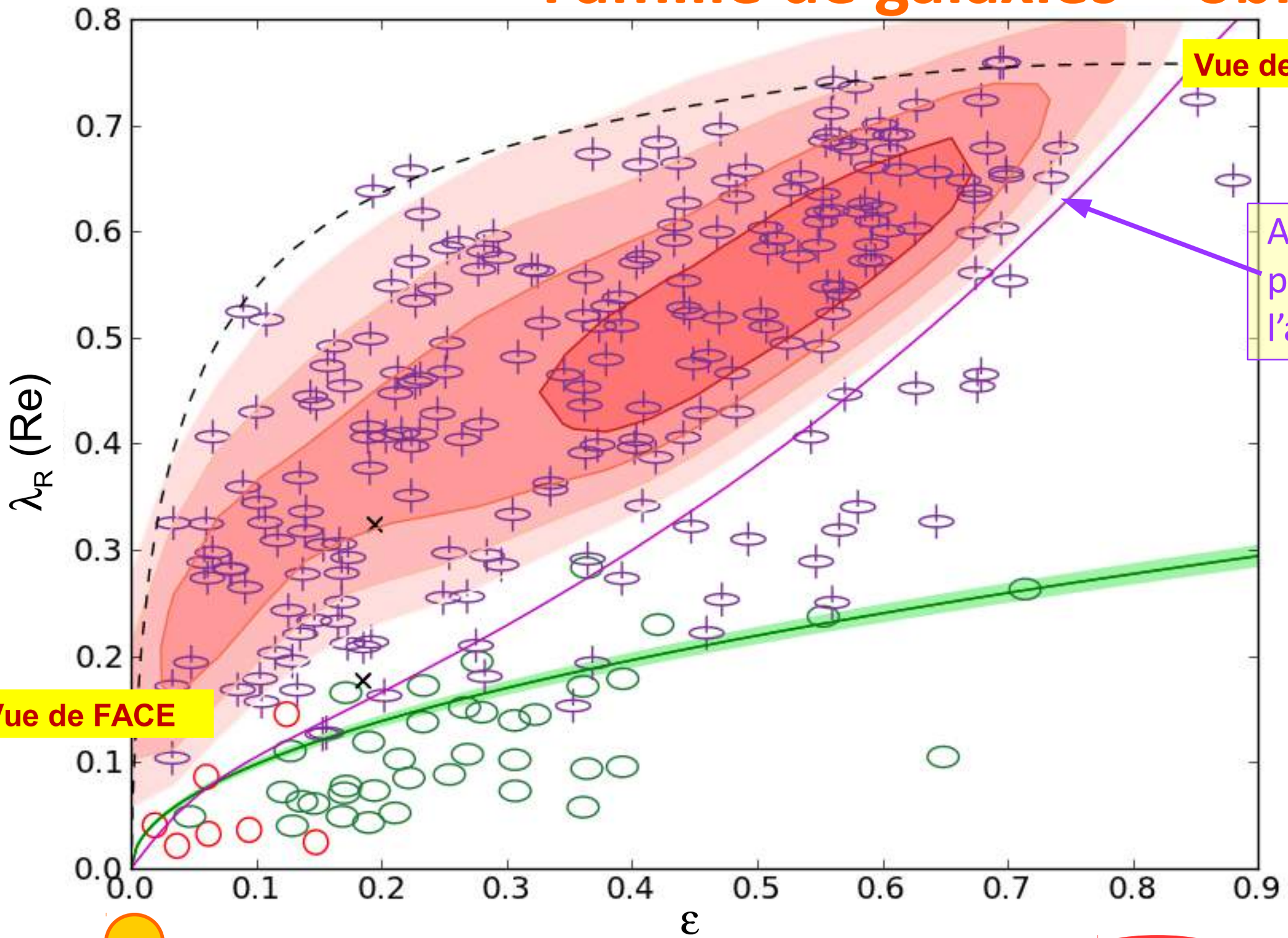
⇒ Quid des E / S0s ?



Emsellem, MC, DK et al., 2011 (PIII)

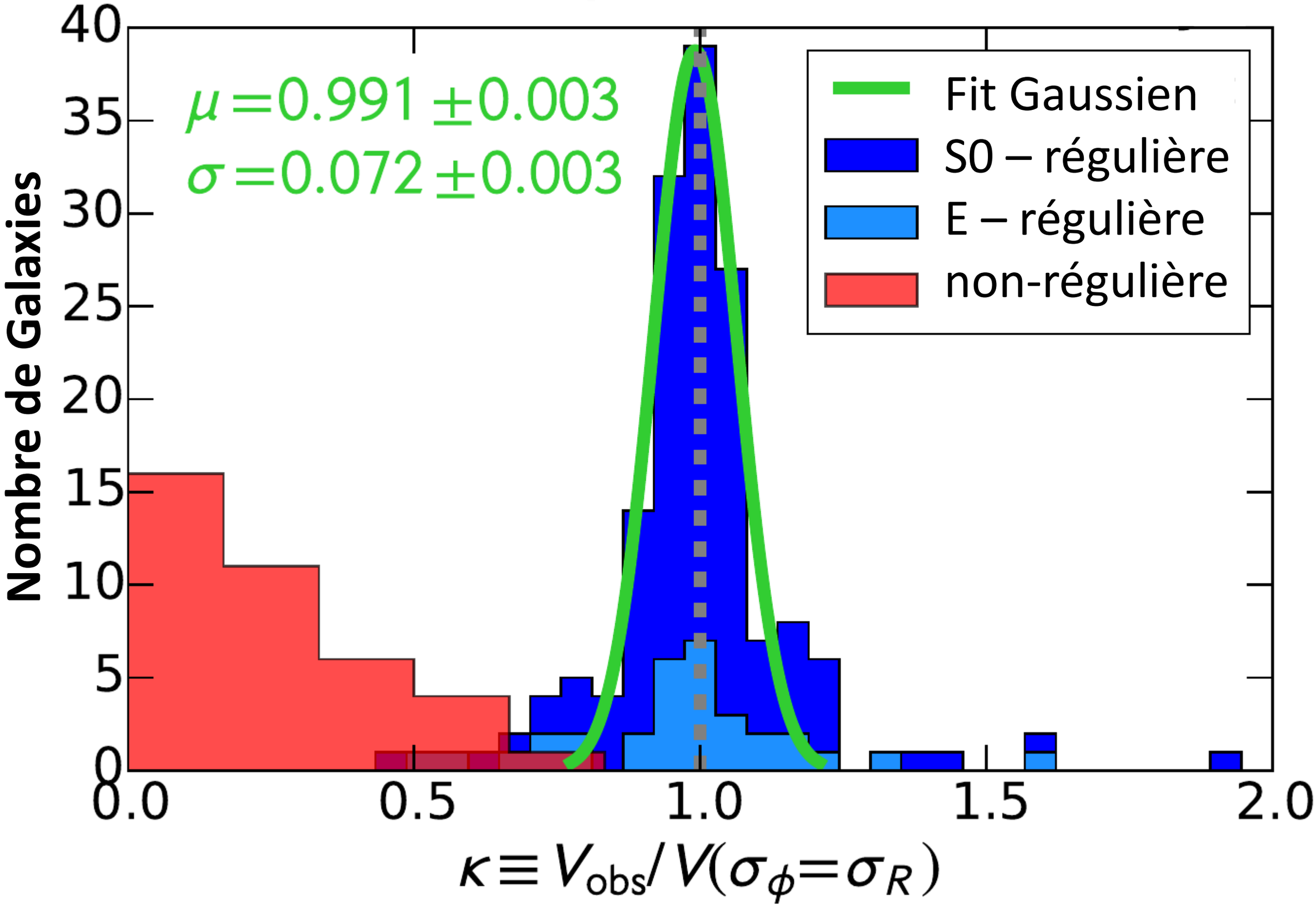
Rotateurs Rapides

⇒ Famille de galaxies « oblates »

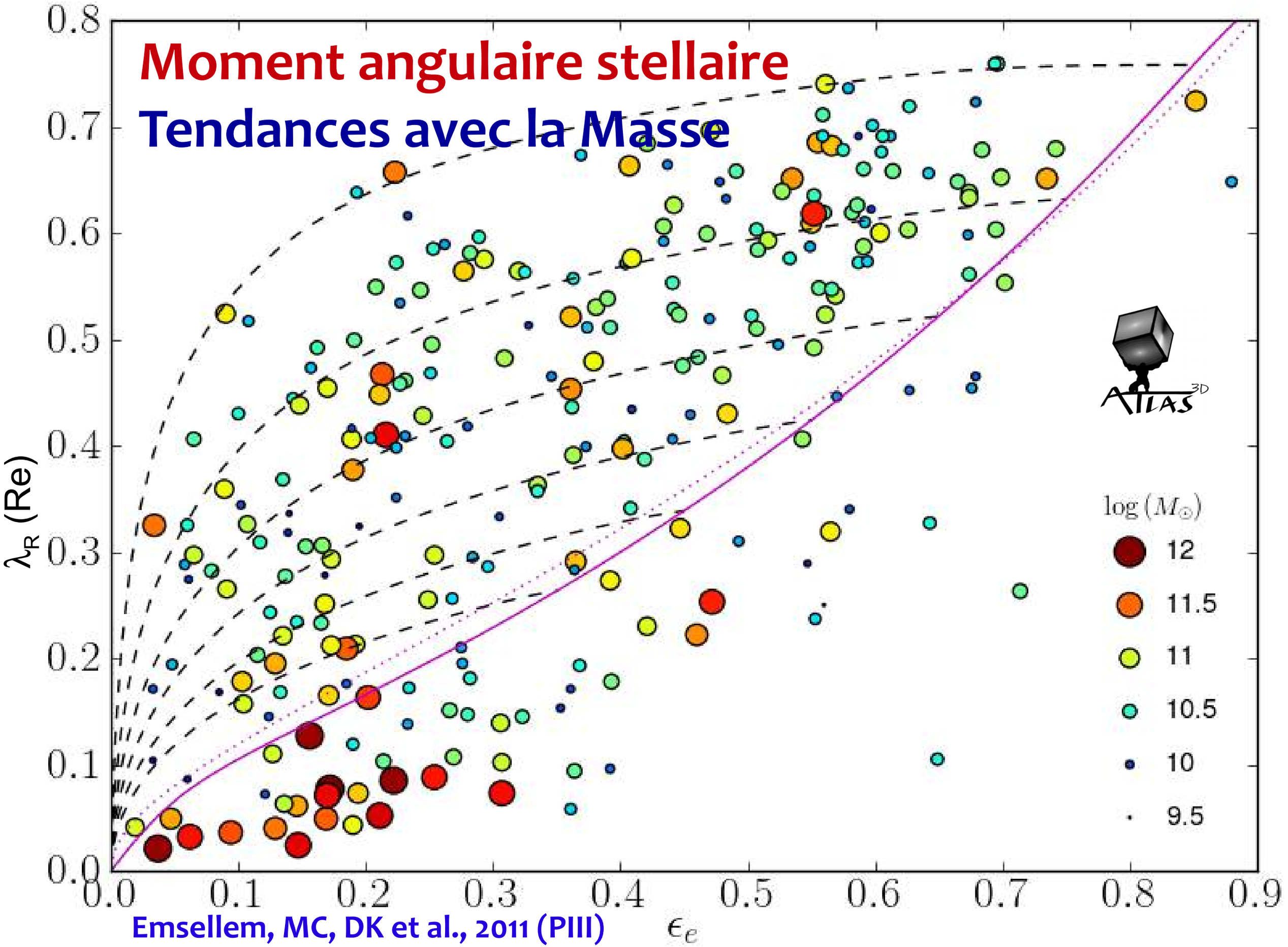


Emsellem, MC, DK et al., 2011 (PIII)

Rotateurs lents / rapides : *Dichotomie ?*



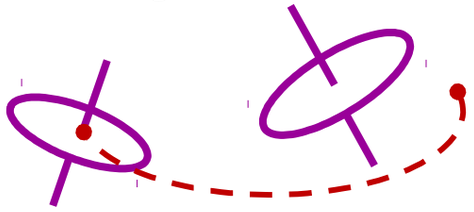
Moment angulaire stellaire
Tendances avec la Masse

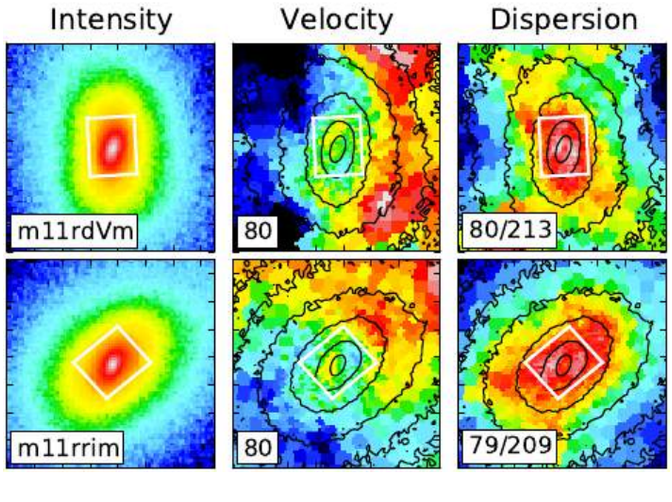


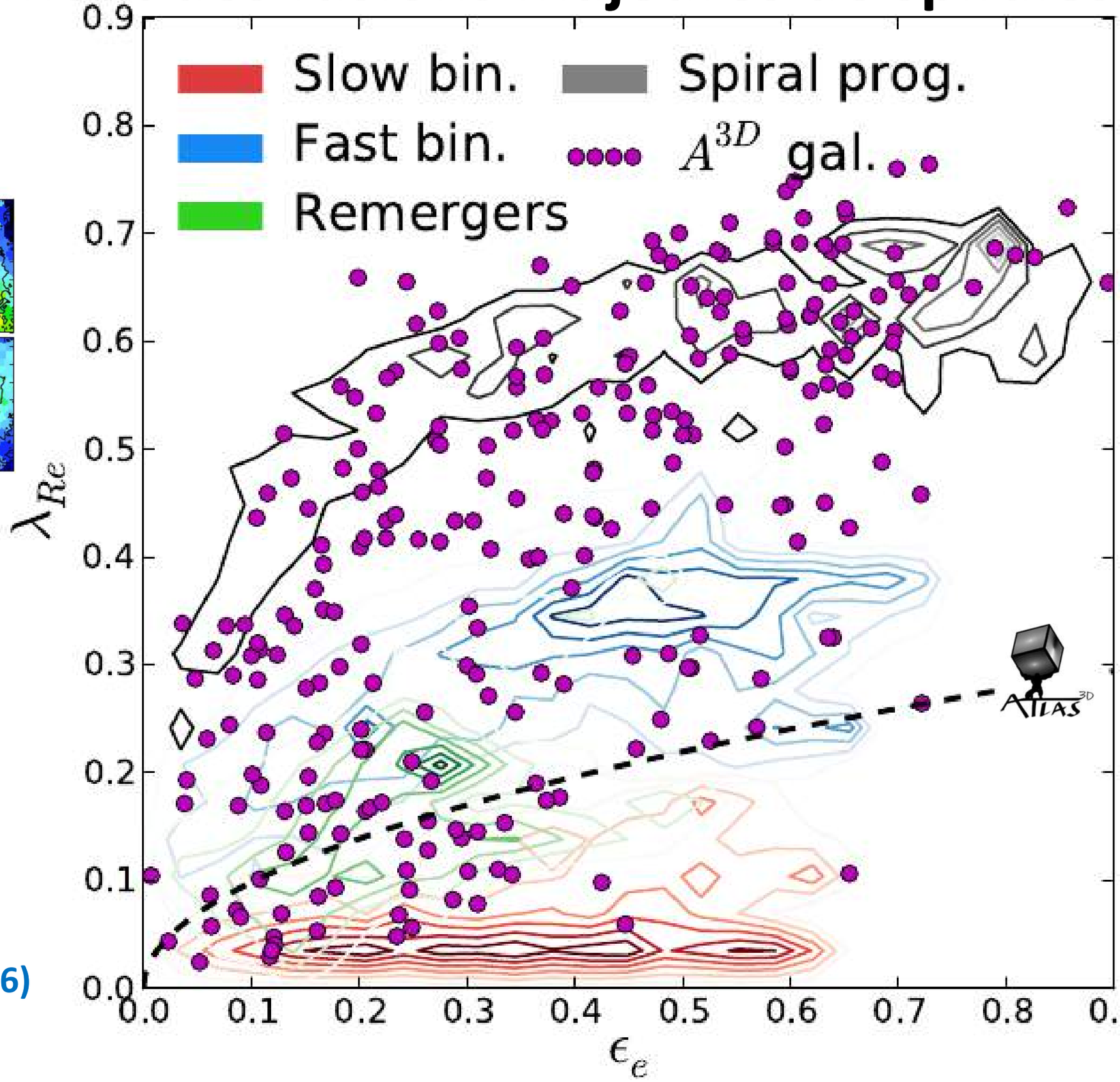
Emsellem, MC, DK et al., 2011 (PIII)

Rotateurs lents

⇒ pas seulement des fusions majeures de spirales

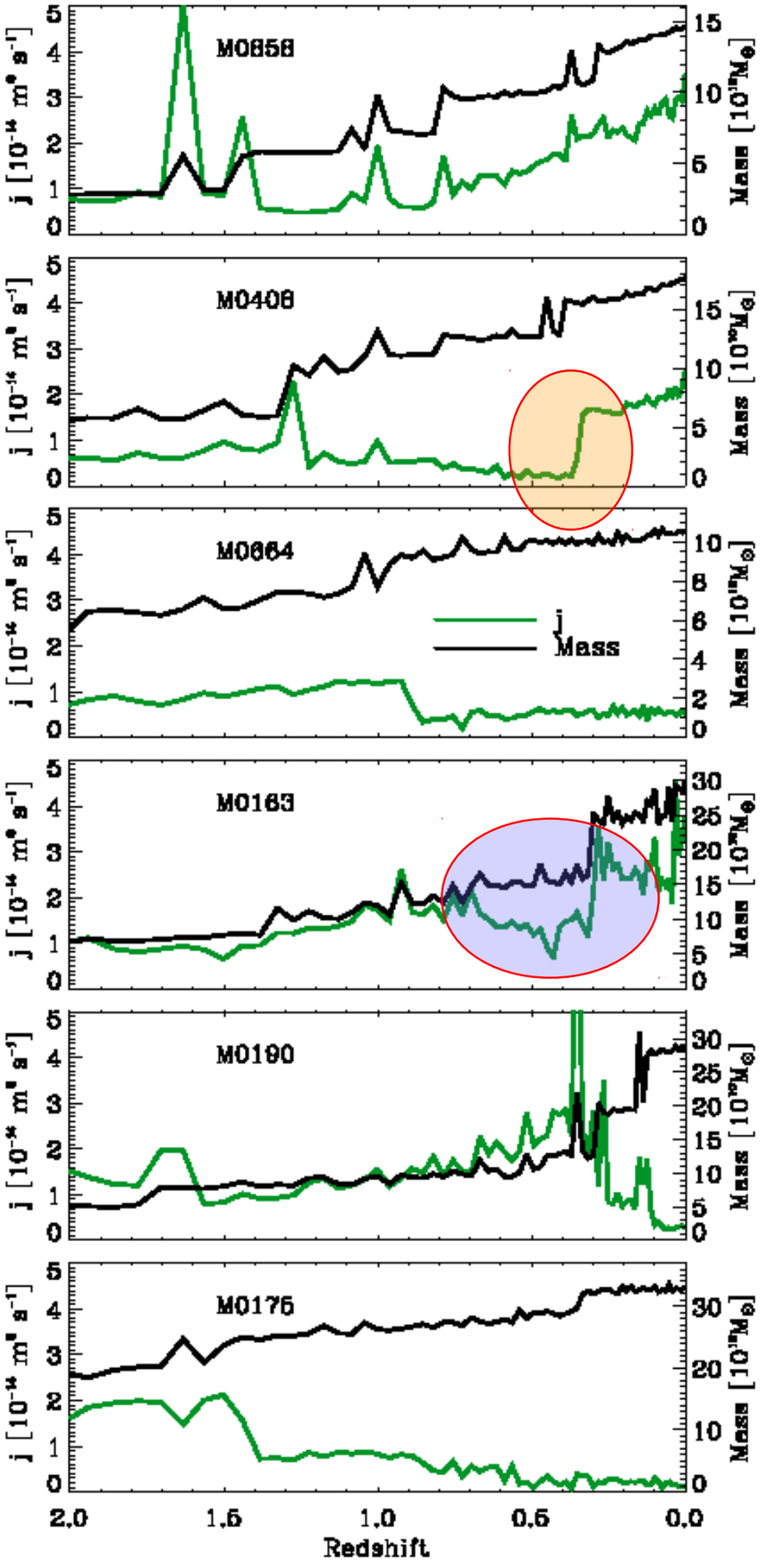


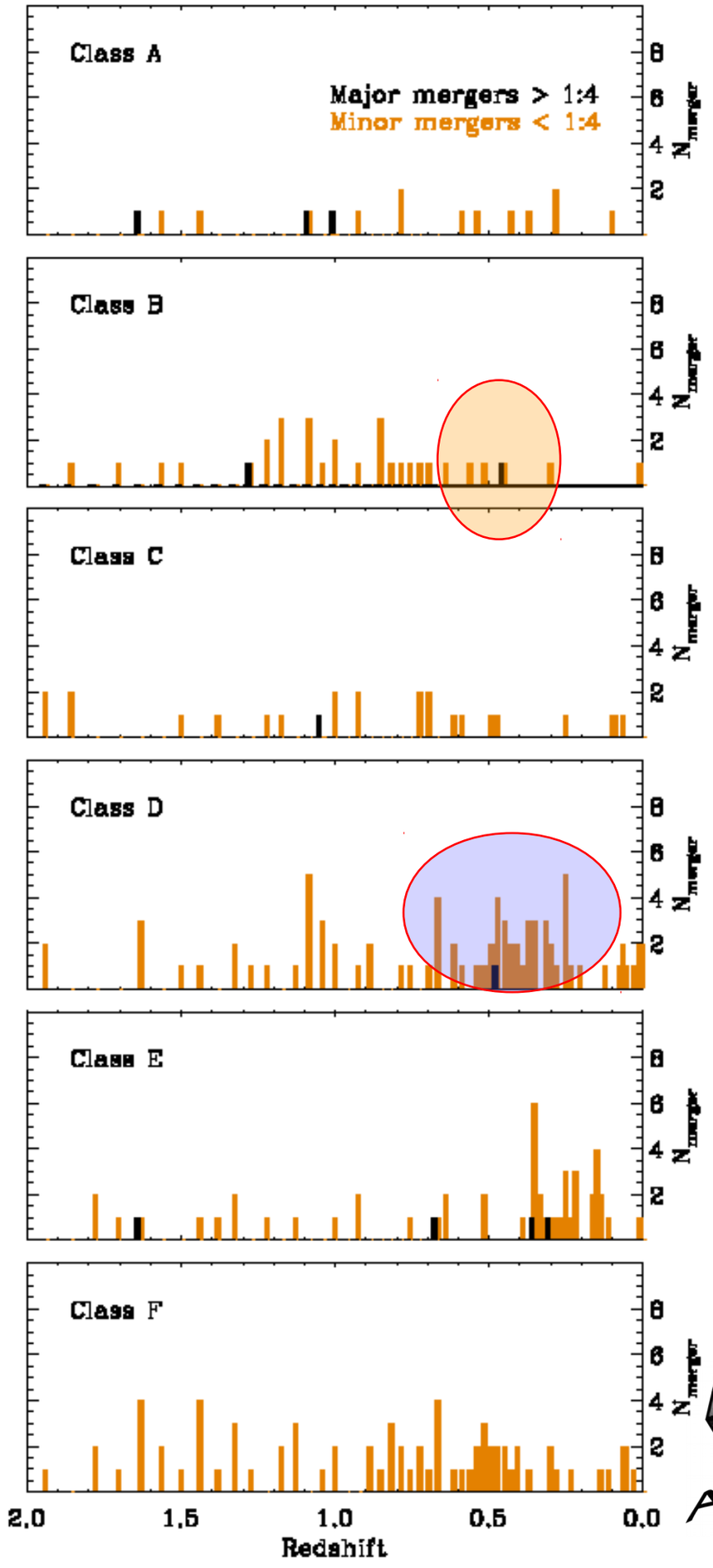




Bois, EE, FB et al. 2011 (P6)

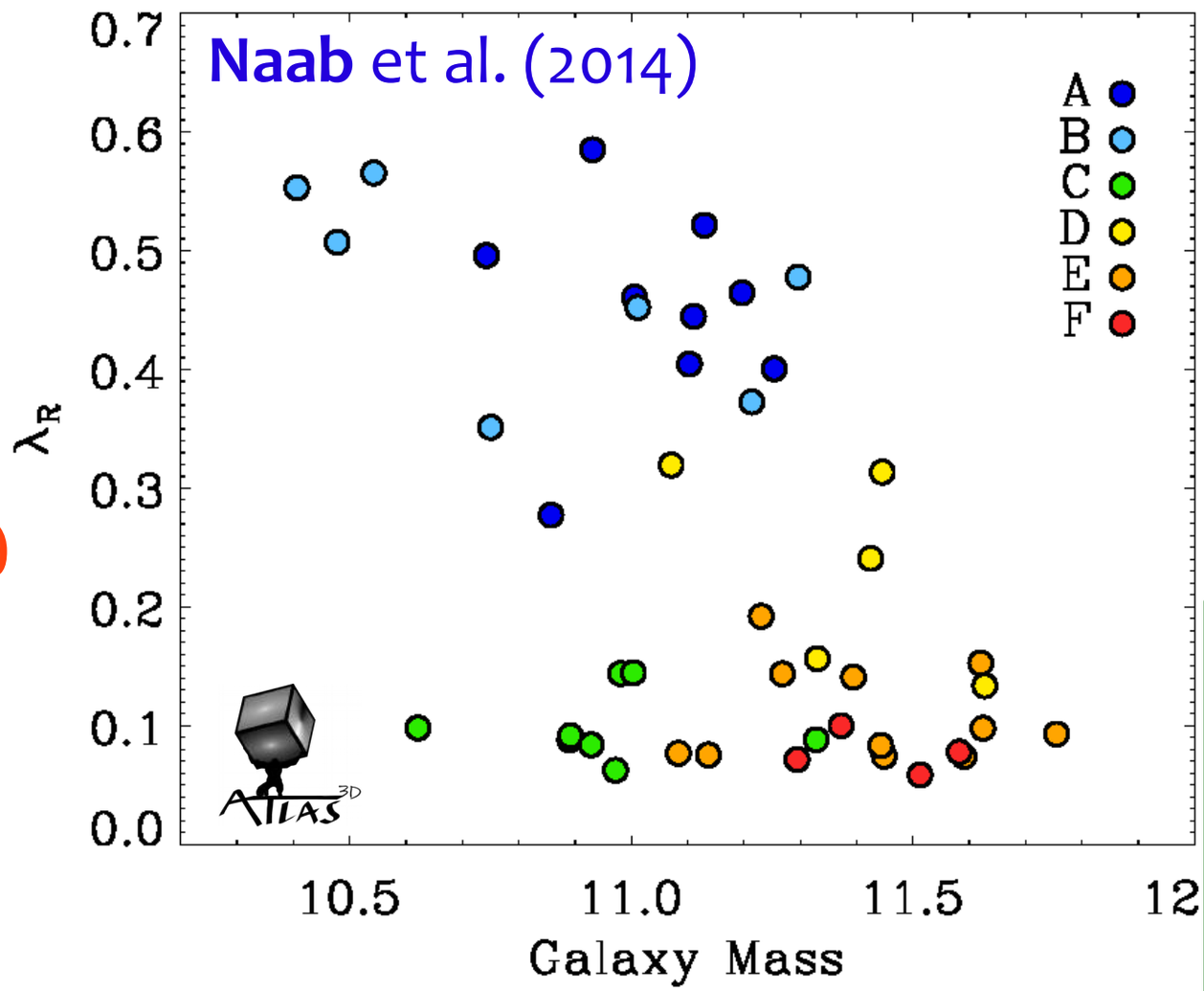
Pas de scénario unique!





Naab, Oser, EE et al. (2014)

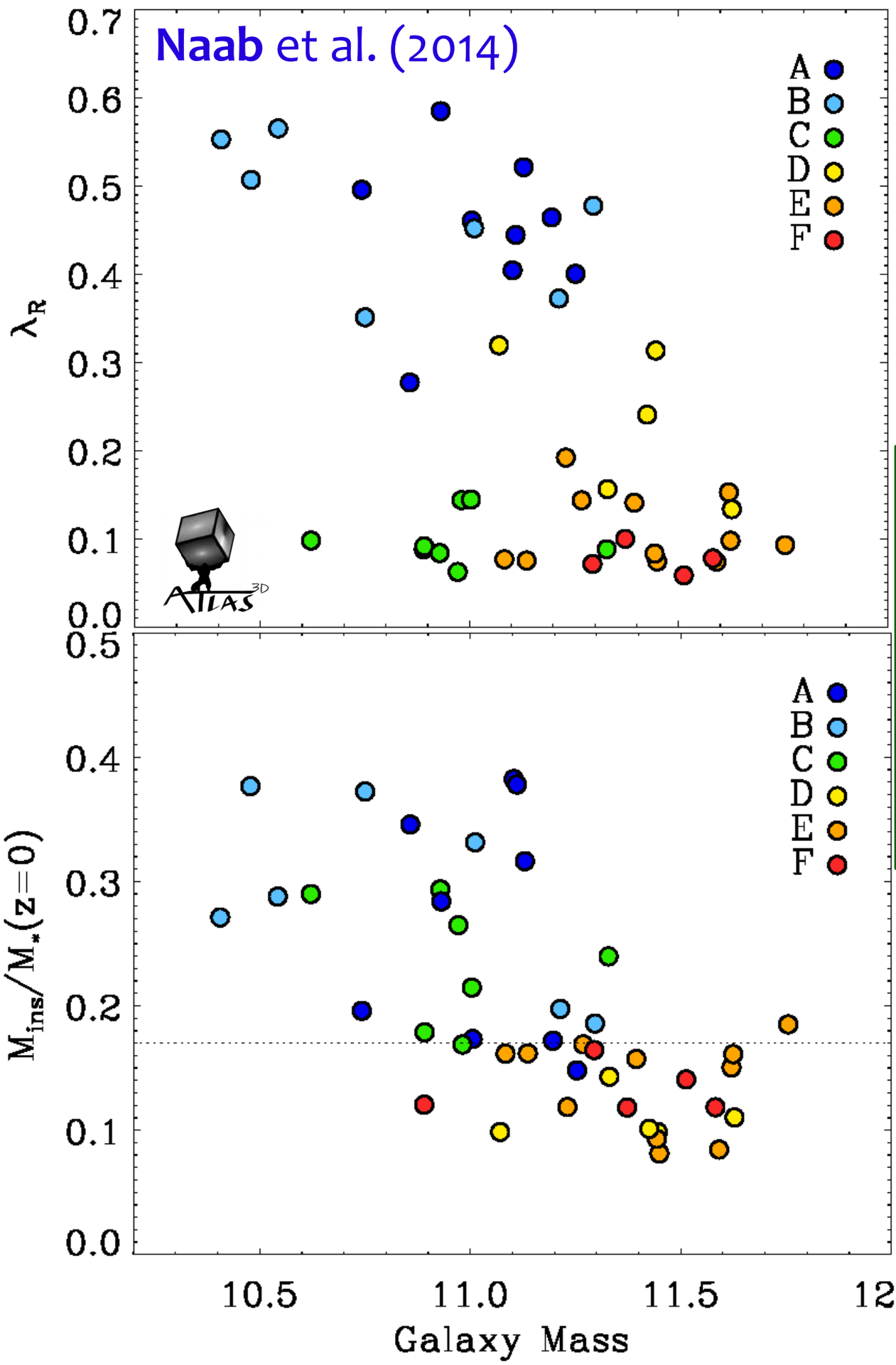
Moment Angulaire



Différents régimes de masse

⇒ Grande dispersion en λ_R

Naab et al. (2014)

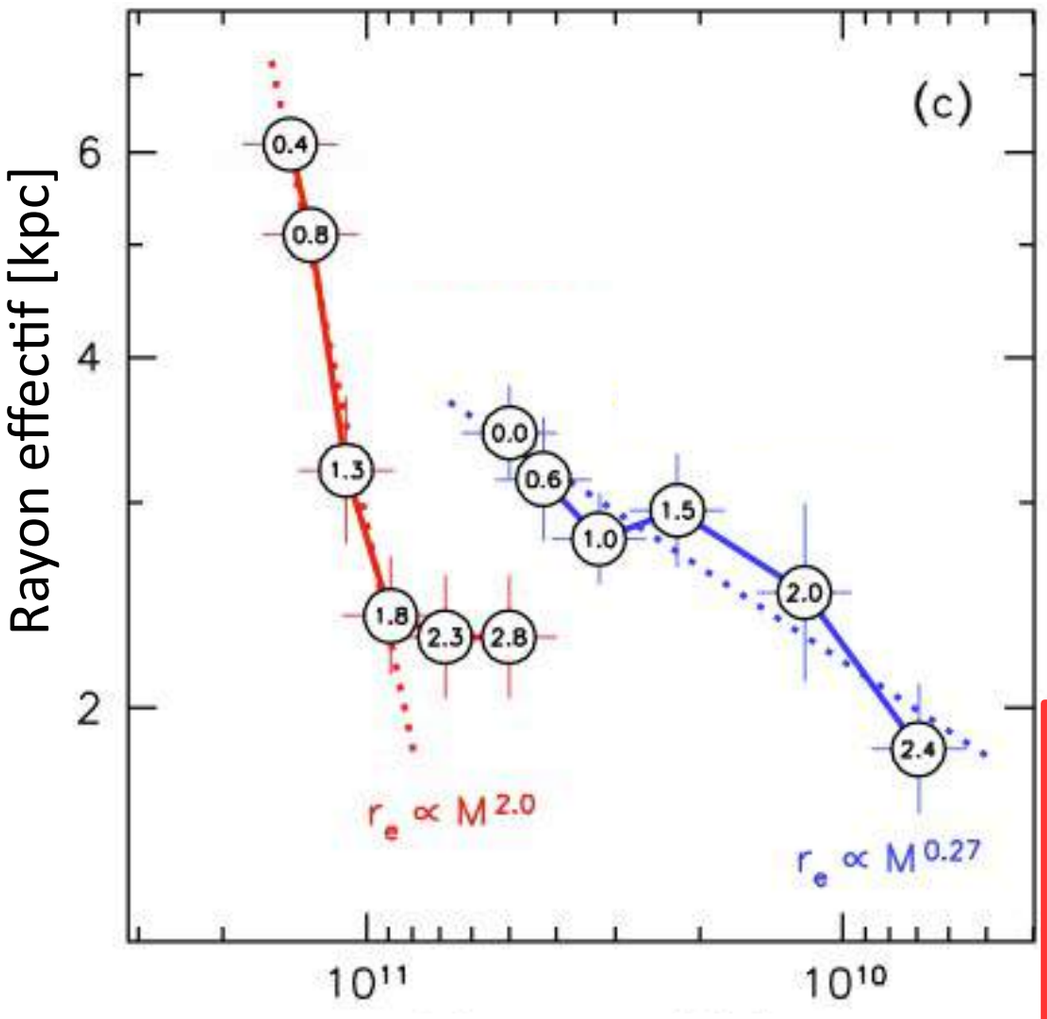


Mass Stellaire In-Situ

Différents régimes de masse

⇒ Grande dispersion en λ_R

van Dokkum et al. (2013)



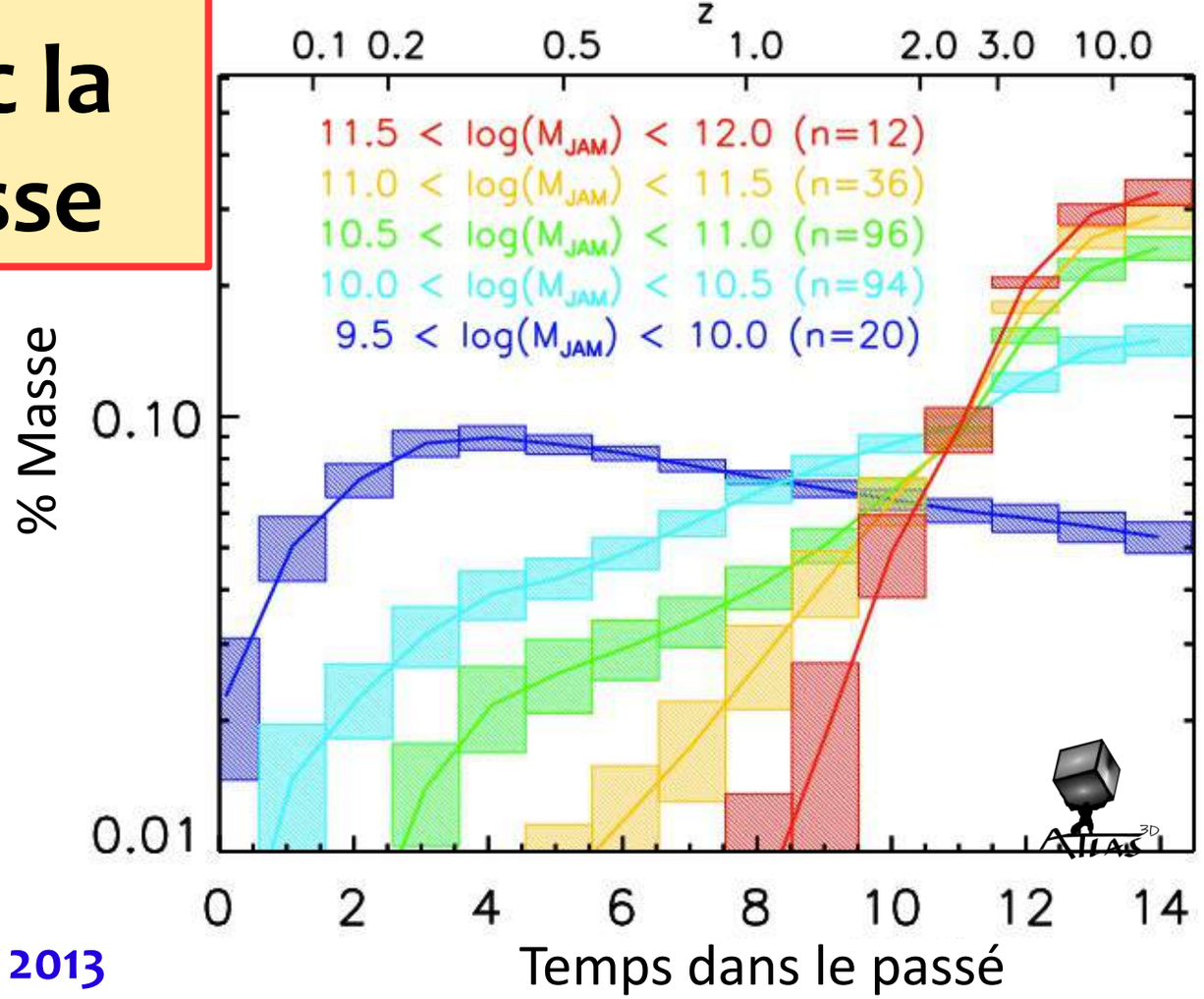
OBSERVATIONS

Galaxies de petites masses

- L'évolution est plus lente
- La croissance se fait à tout rayon
- La croissance se fait sur de longues durées

Tendances avec la Masse

McDermid et al. (2015)



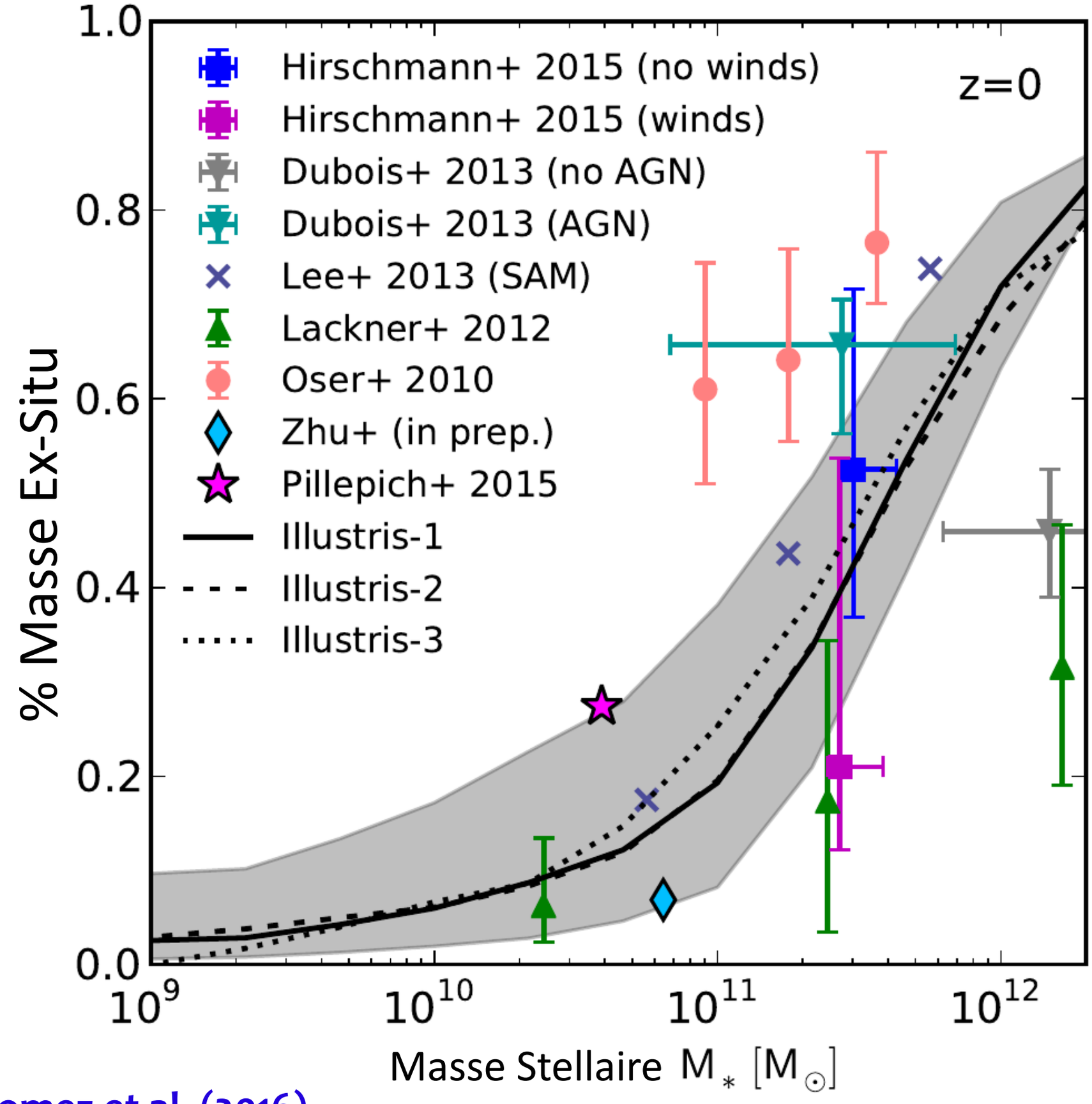
SIMULATIONS

→ **2 phases de formation / assemblage**
(e.g. Oser et al. 2010)

- Phase précoce rapide (z>2) – **In Situ**
- Phase tardive étendue (z<3) – **Ex Situ**

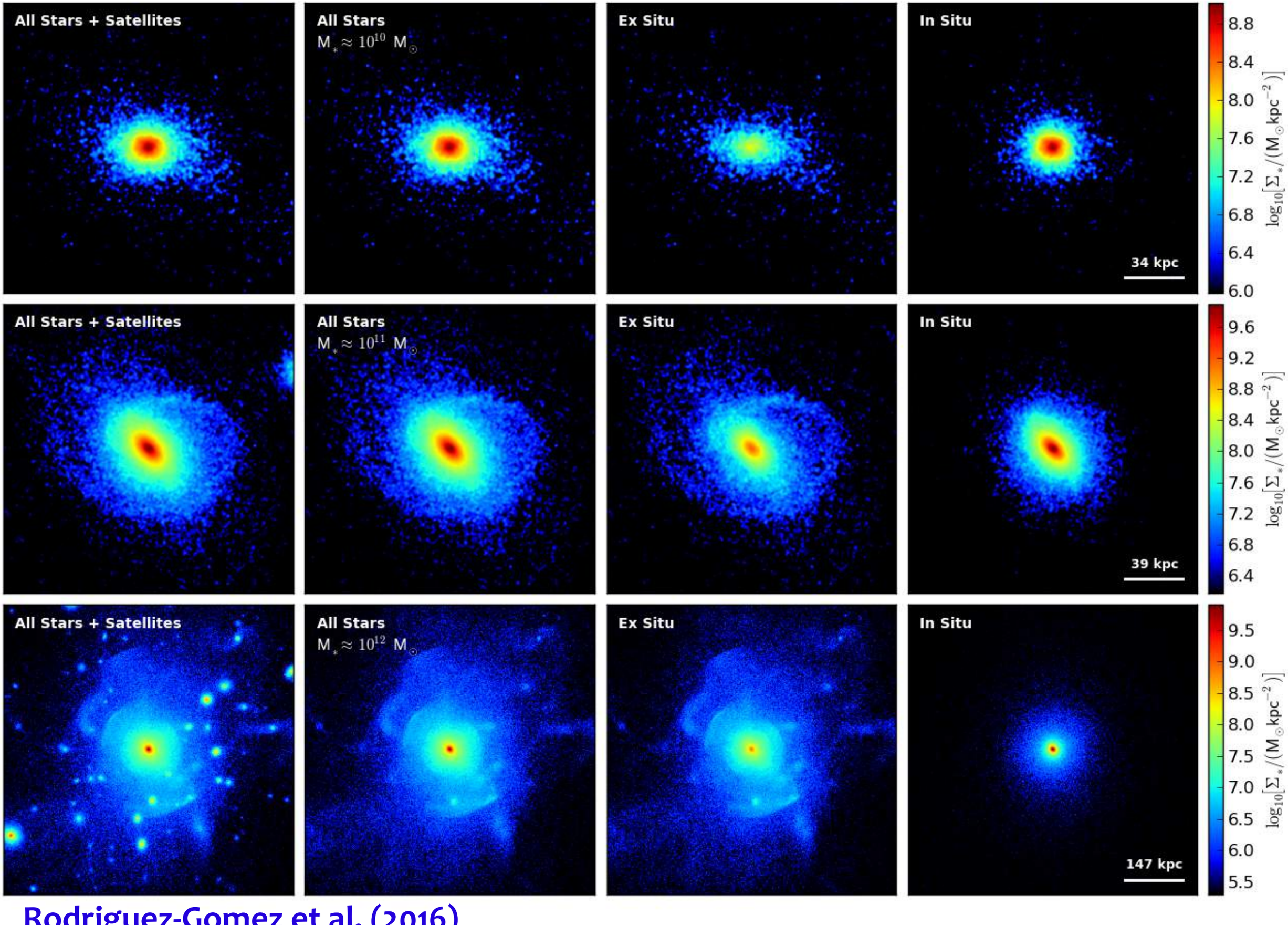
Bezanson et al. 2009 /Patel et al. 2013 /van Dokkum et al. 2013

Formation versus Assemblage: *In-Situ vs Ex-Situ*



Rodriguez-Gomez et al. (2016)

Formation versus Assemblage: *In-Situ vs Ex-Situ*



Rodriguez-Gomez et al. (2016)

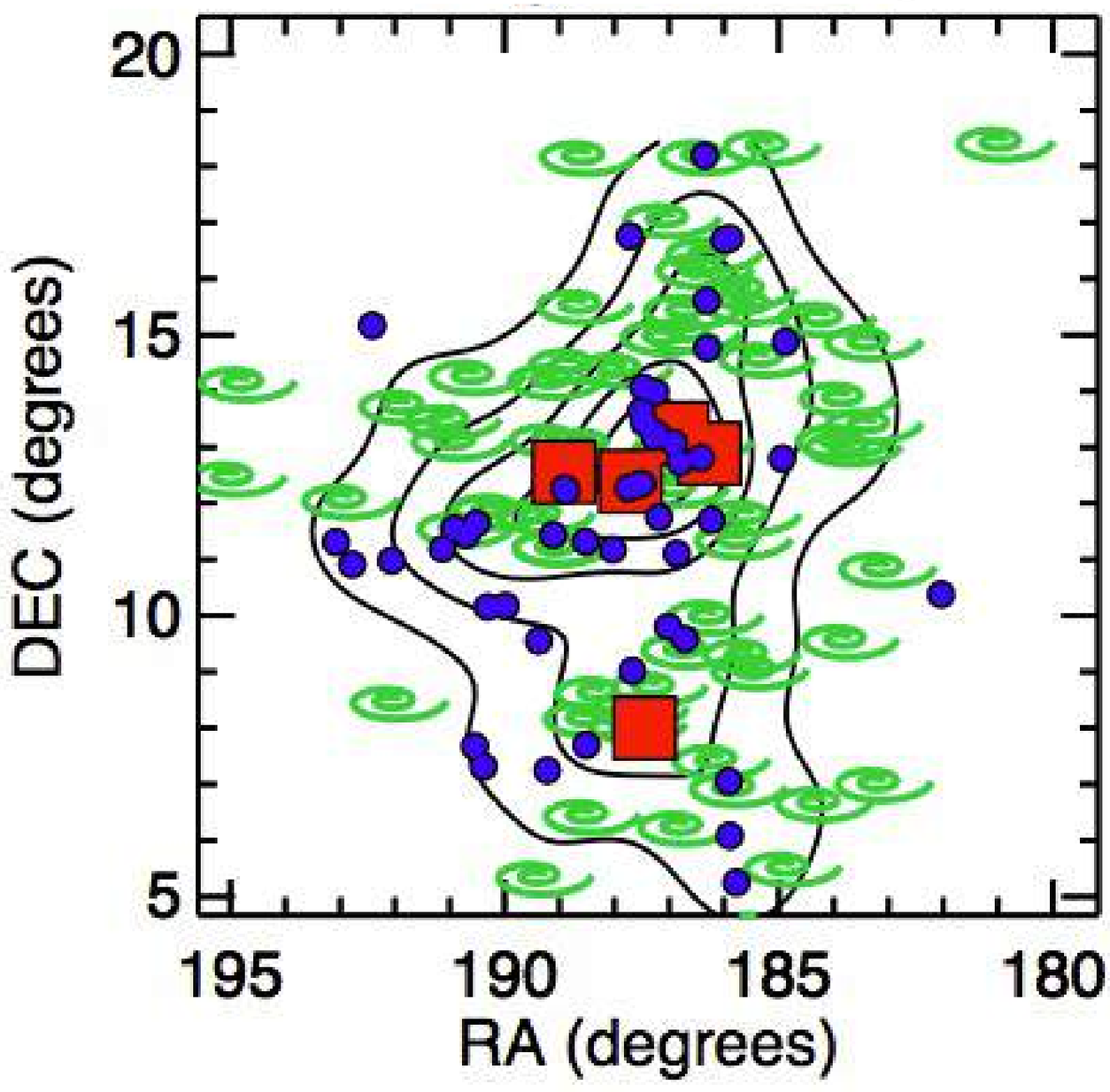
Rotateurs lents

Environnement ?

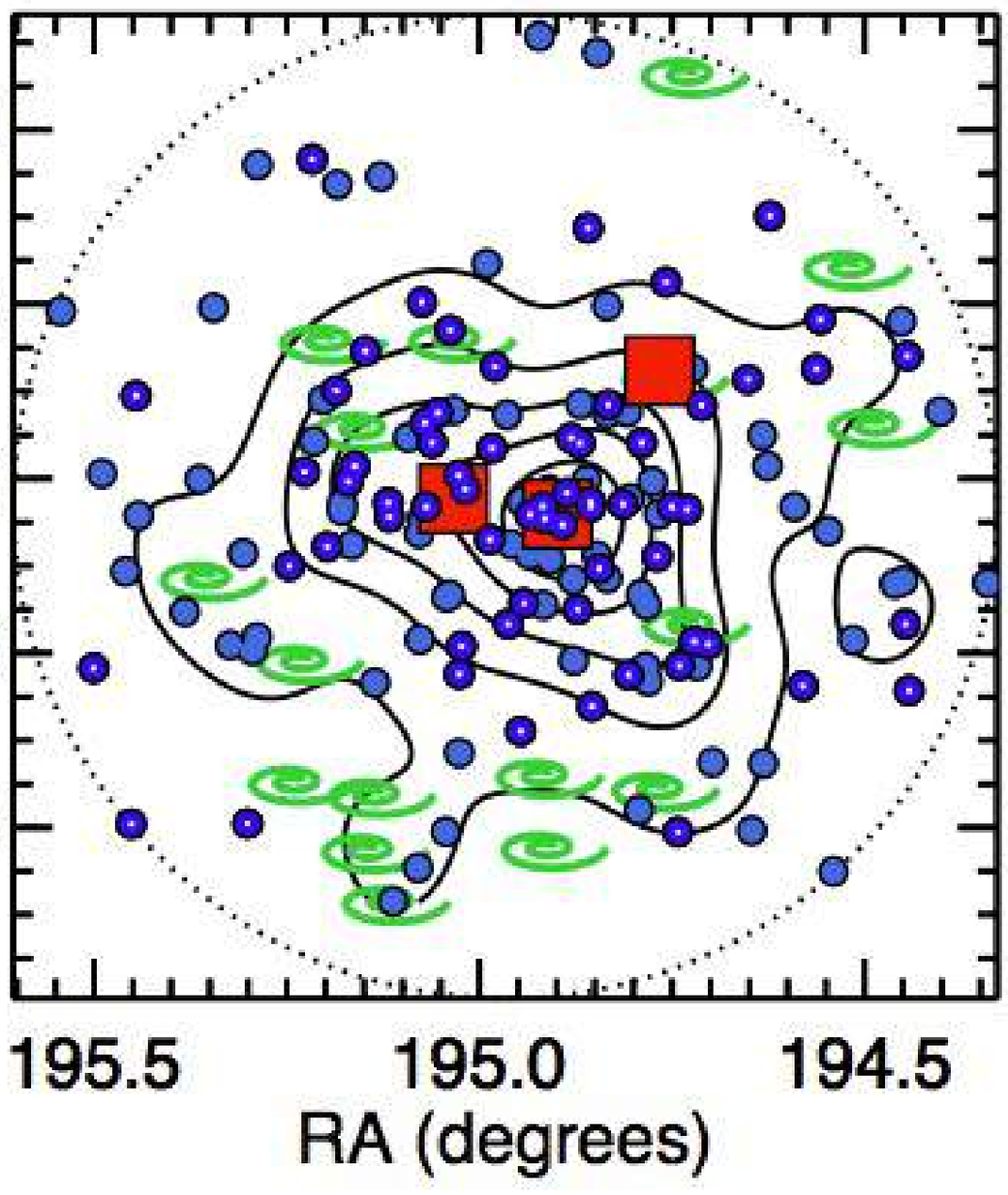
⇒ Formation efficace @ densités fortes de galaxies

Importance de l'échelle des groupes

Amas de la Vierge



Amas de Coma



Cappellari (2013)

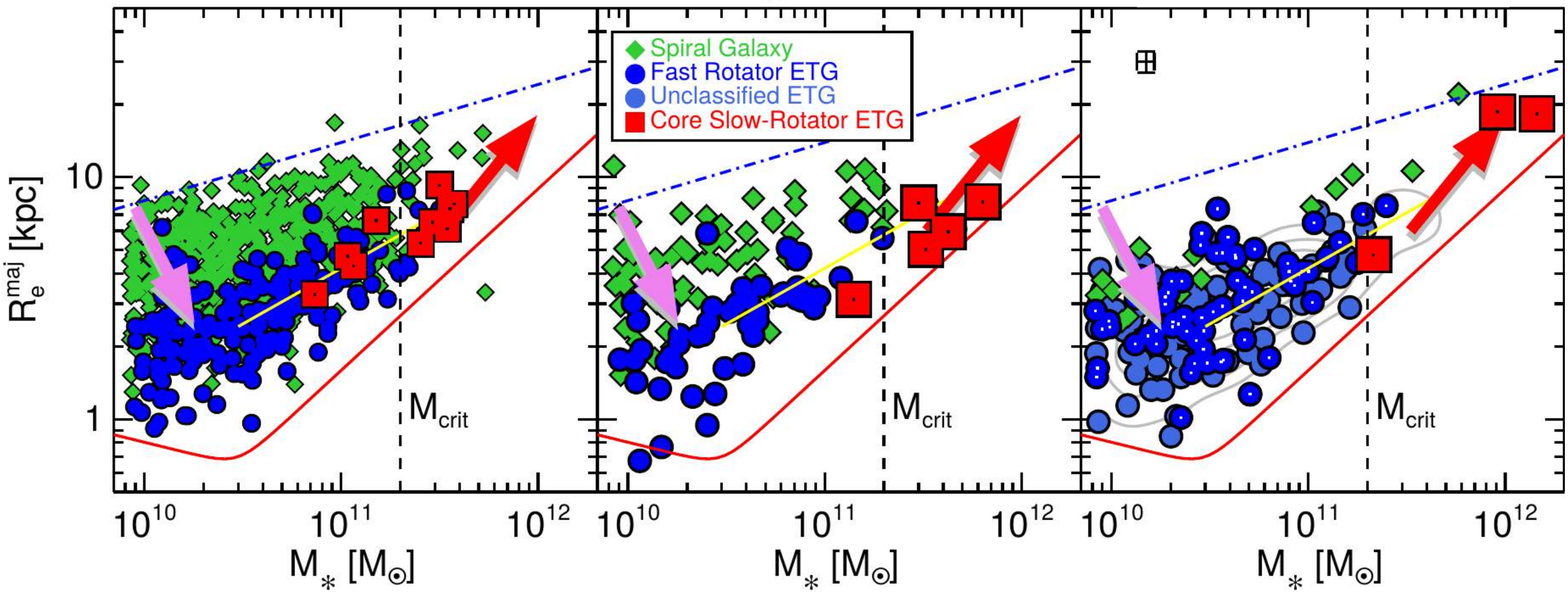
Evolution à grandes densités ?

Densité de Galaxies

Champ ou groupes

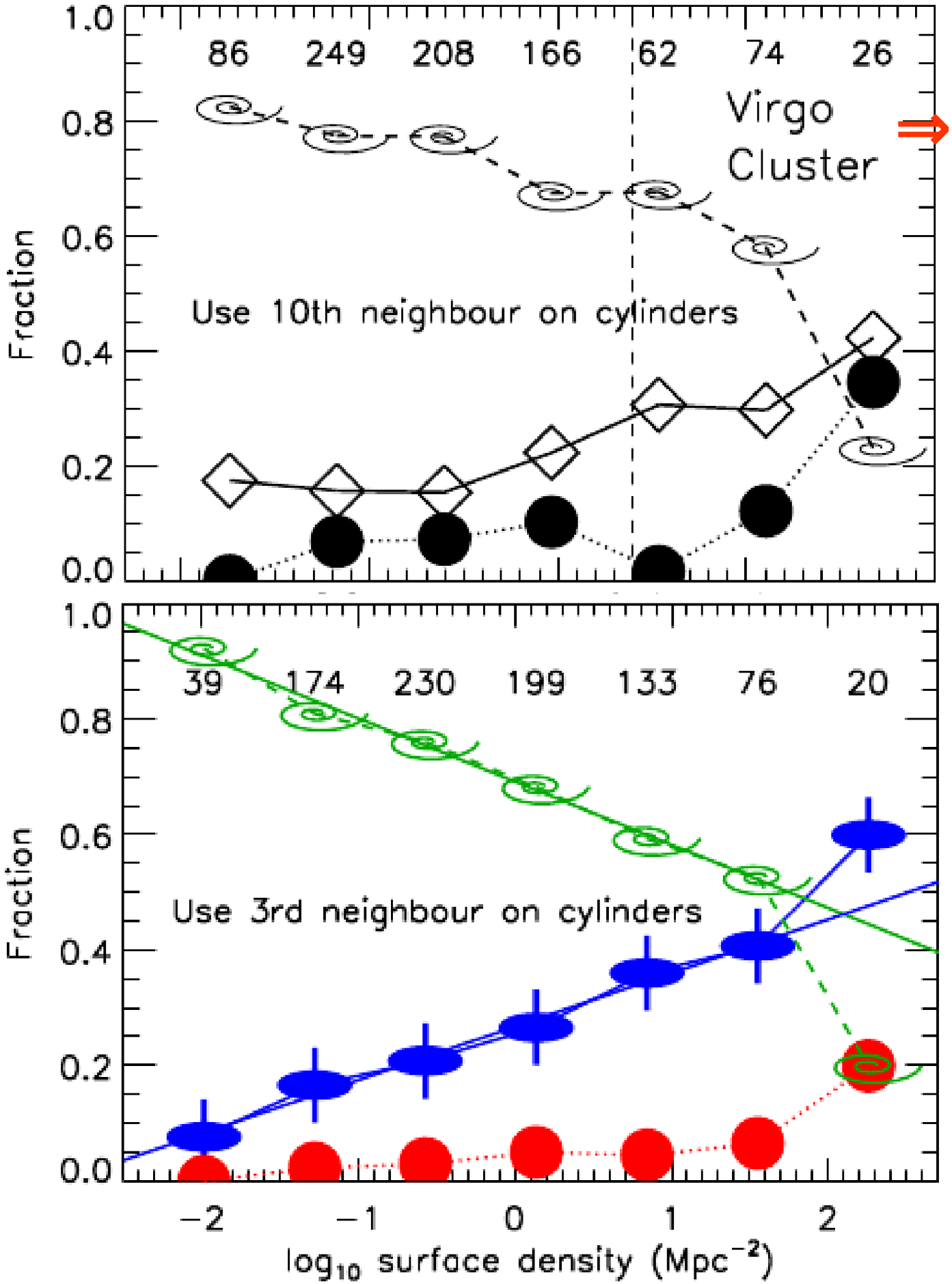
Amas de la Vierge

Amas de Coma



Cappellari (2017)

Relation Morphologie - Densité



⇒ à la Dressler (1980)

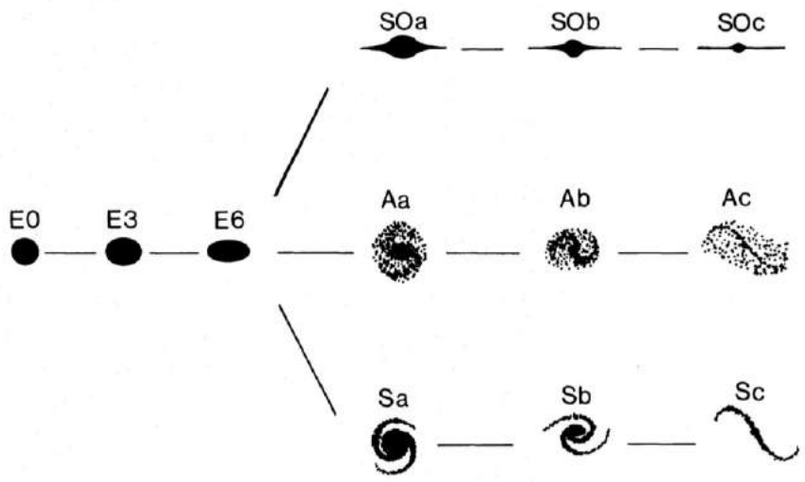
FR

SR

Cappellari, EE, DK et al., 2011 (PVII)

Classification dynamique : le “peigne ATLAS3D”

van den Bergh 1976



Cappellari, Emsellem, Krajnović et al., 2011 (PVII)

Cappellari, Emsellem, Krajnović et al., 2011 (P7)

Galaxies spirales

Galaxies de type précoce

Spiraux

Bras S

Inclinée

De profil

NGC2775

NGC 3351

NGC2776

NGC 7814

NGC 4013

NGC 5907

Sa

Sb

Sc

NGC 4486

NGC 5576

E0

E4

NGC 3379 (E0)

NGC 0524 (S0)

NGC 4477 (SB0)

NGC 0936 (SB0)

NGC 4660

NGC 5866

NGC 5308

NGC 4452

E5

S0a

S0b

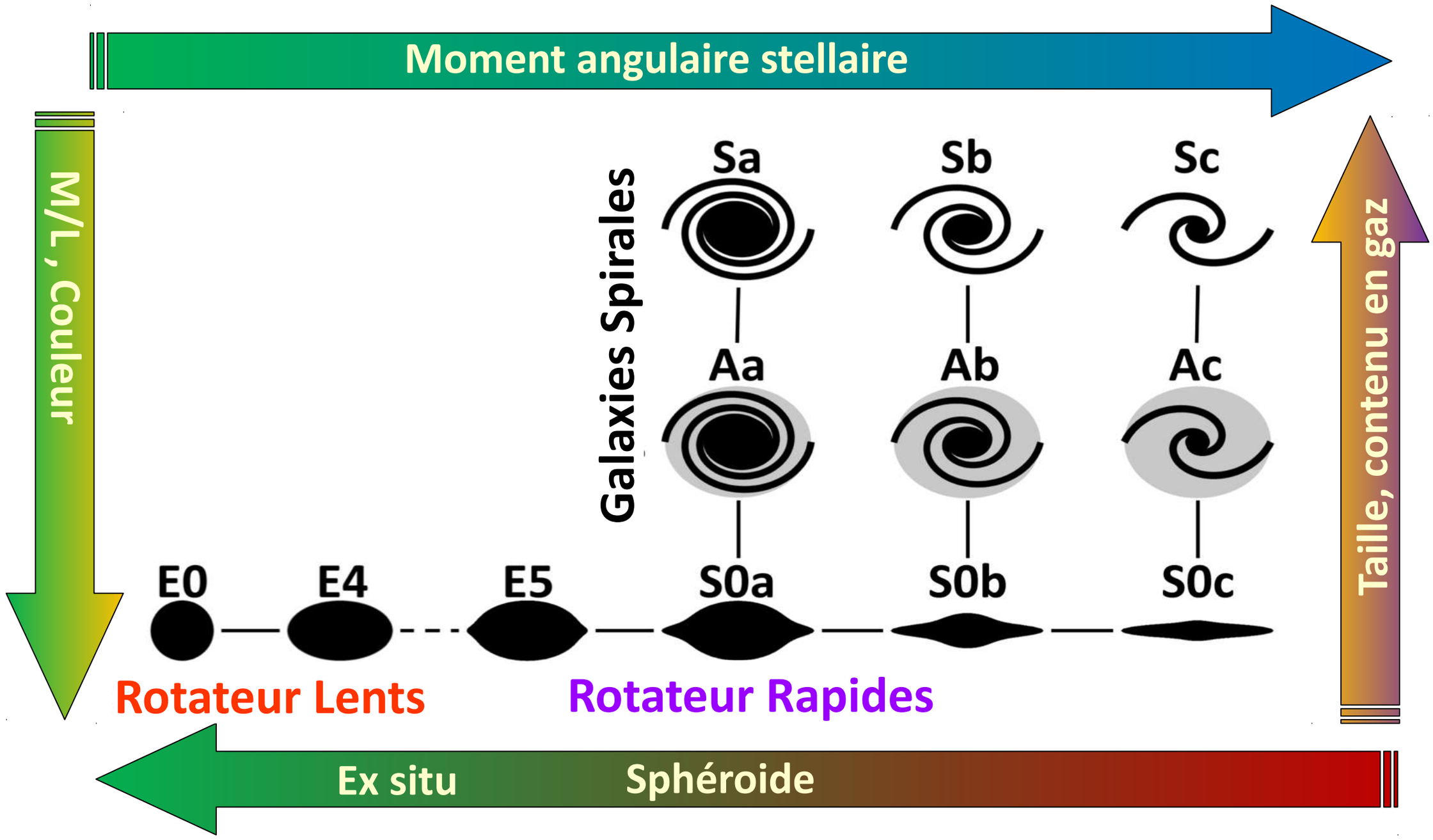
S0c

Lents

Rapides

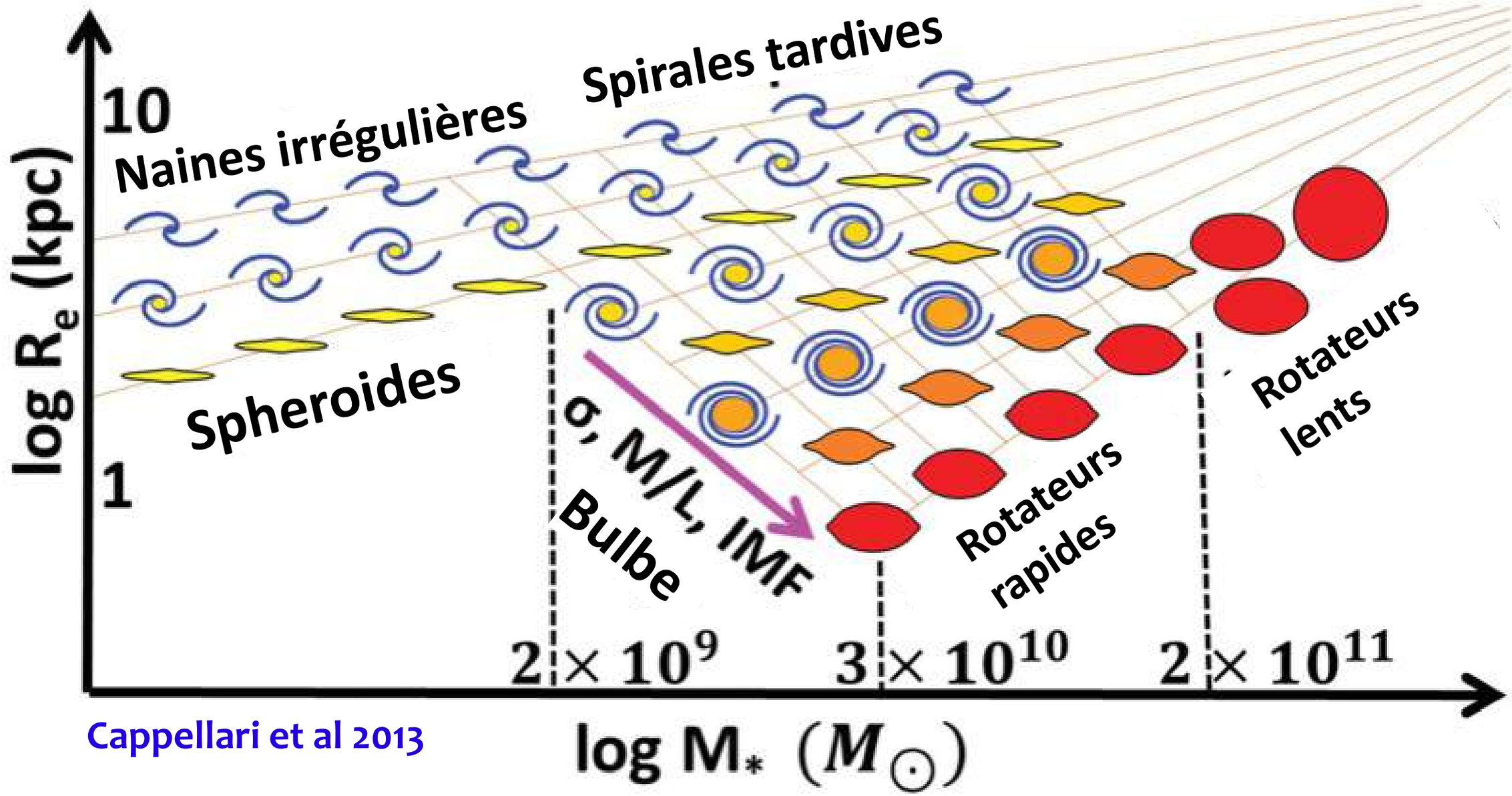
Disque Stellaire

Séquence Dynamique des Galaxies



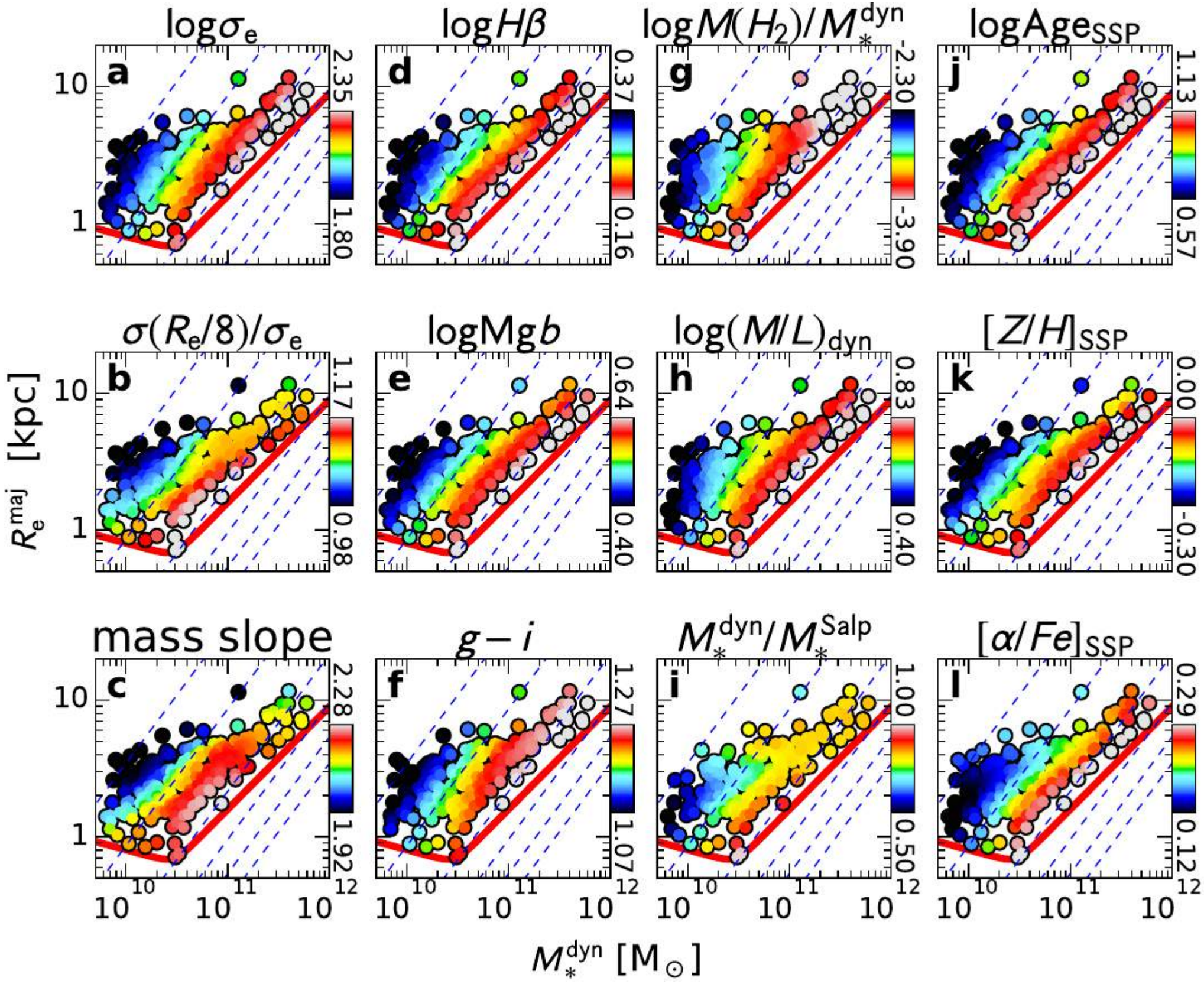
Cappellari, Emsellem, Krajnović et al., 2011

Vue globale du plan Rayon-Masse



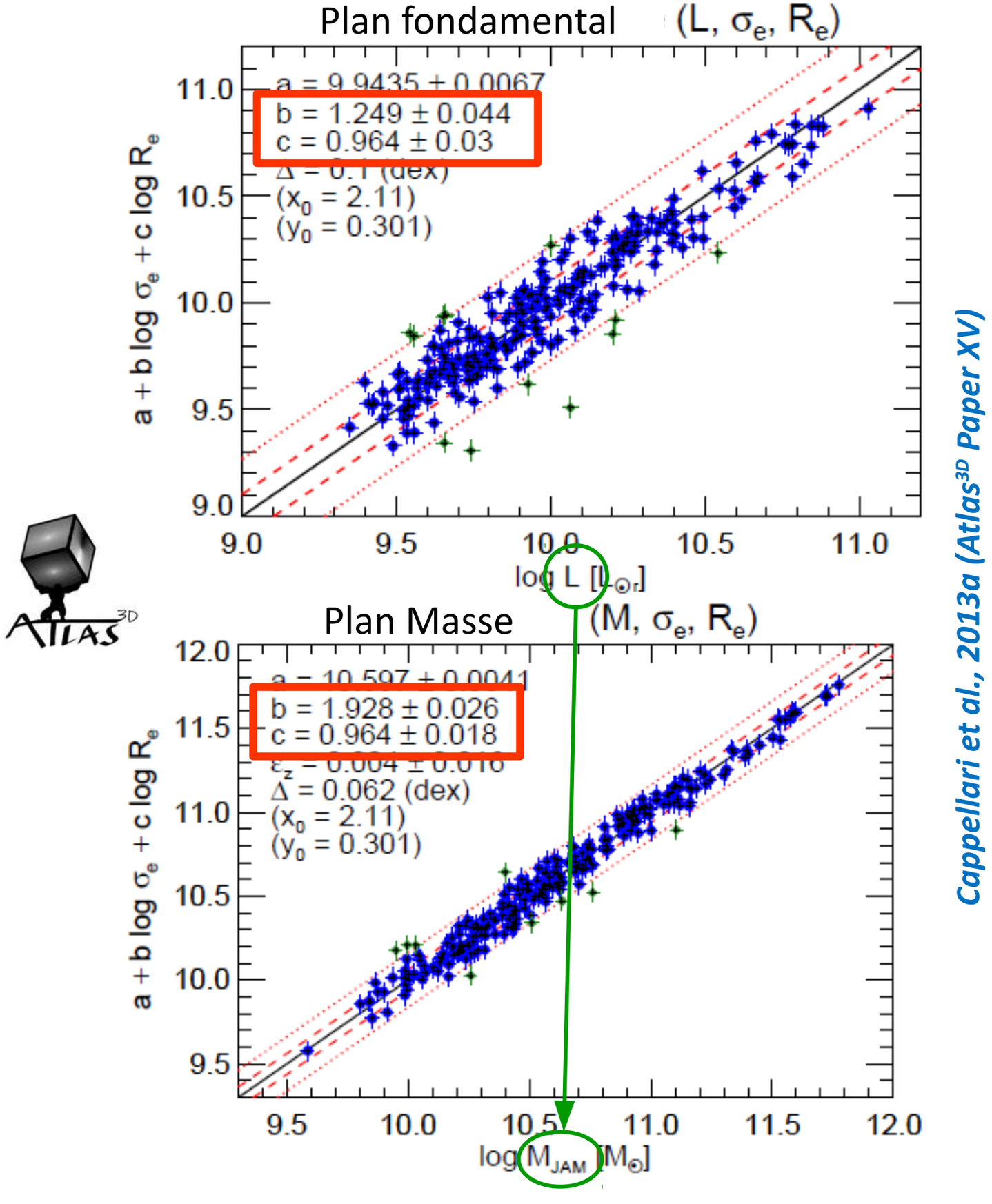
Cappellari et al 2013

Plan Masse-Rayon : σ meilleur “proxy”



Cappellari et al., 2013 – Atlas^{3D} XX, Cappellari 2016

Relation d'echelle: le plan fondamental?



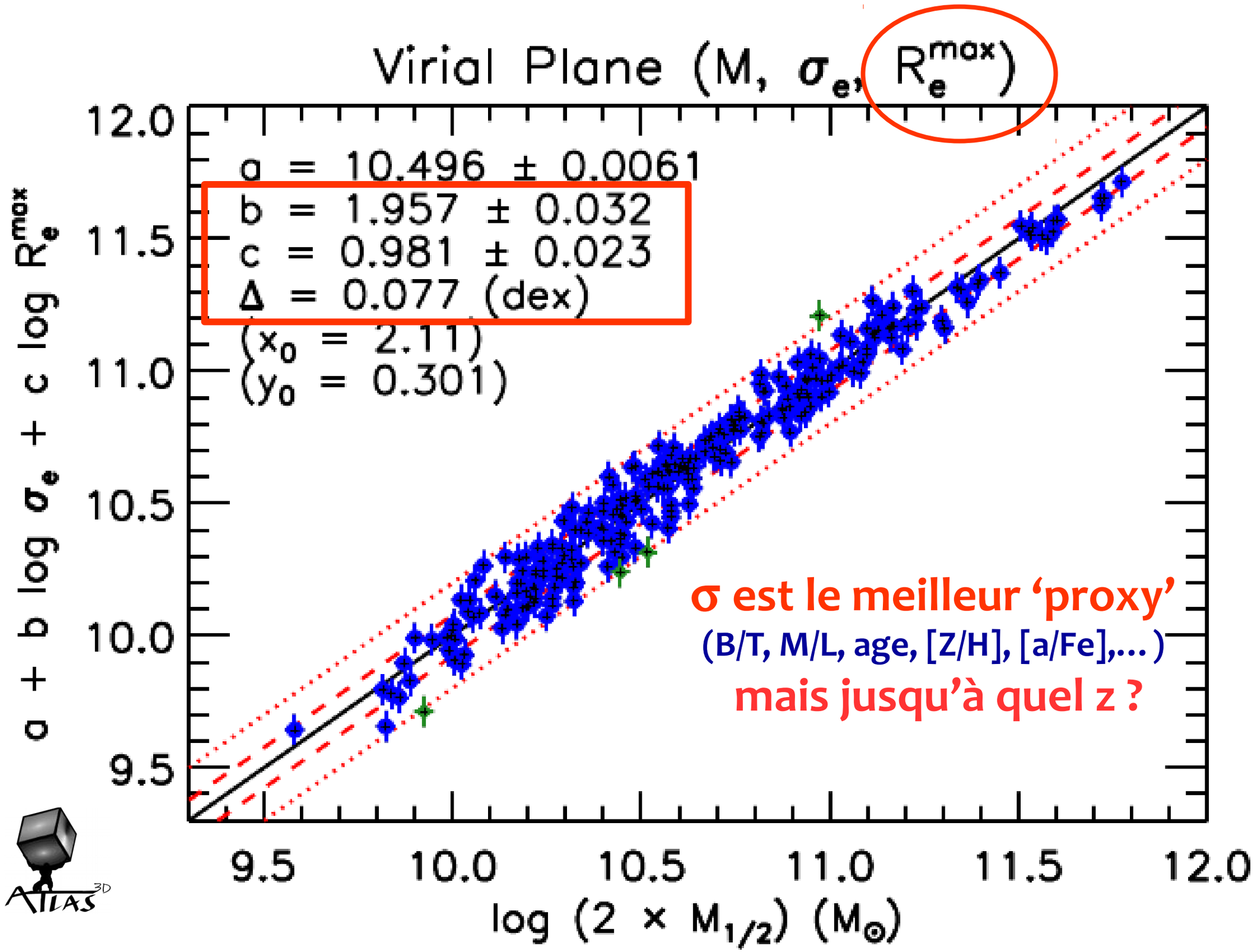
Cappellari et al., 2013a (Atlas^{3D} Paper XV)

VIRIEL

b = 2

c = 1

⇒ Vers un Plan Viriel

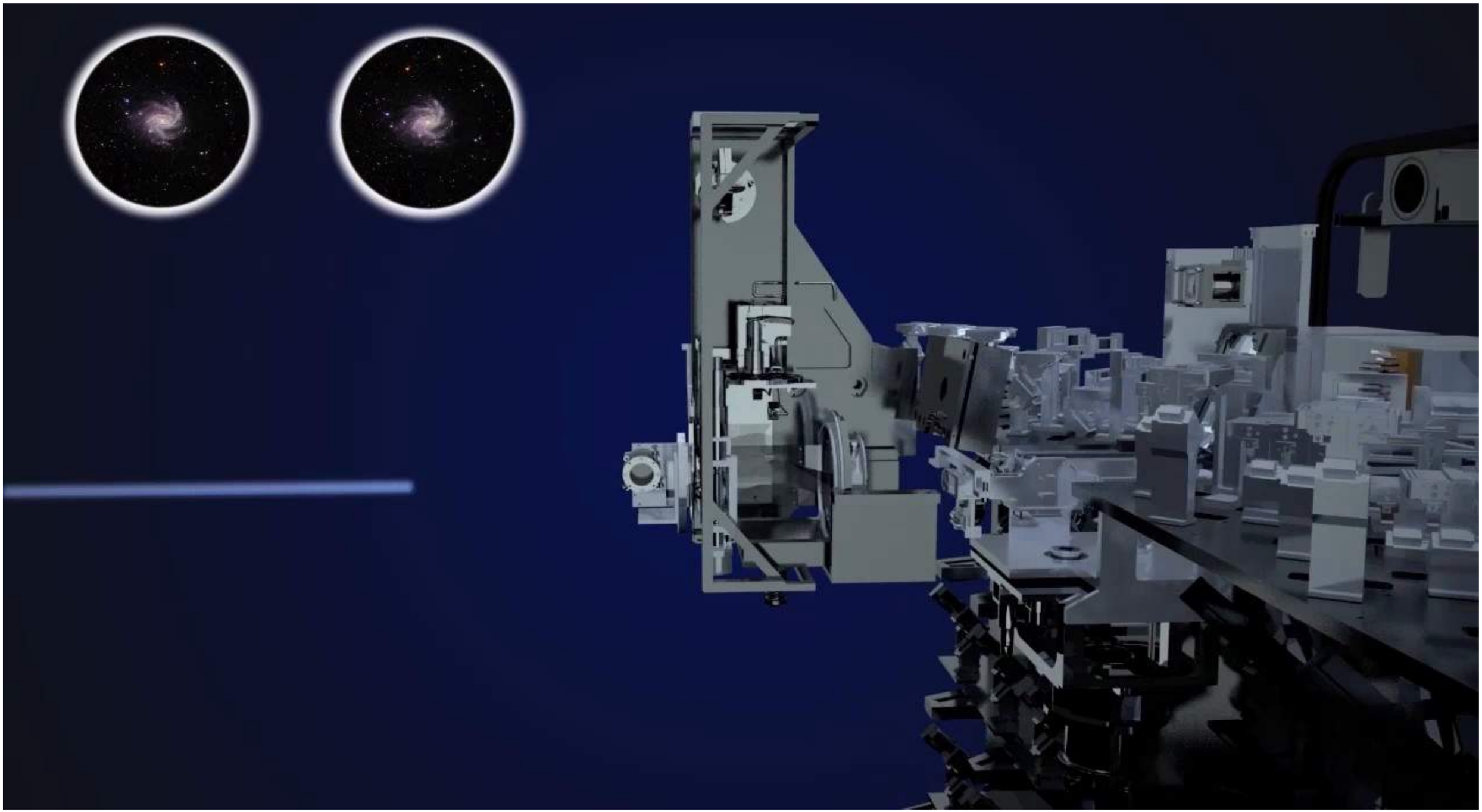


Cappellari et al., 2013 – P15

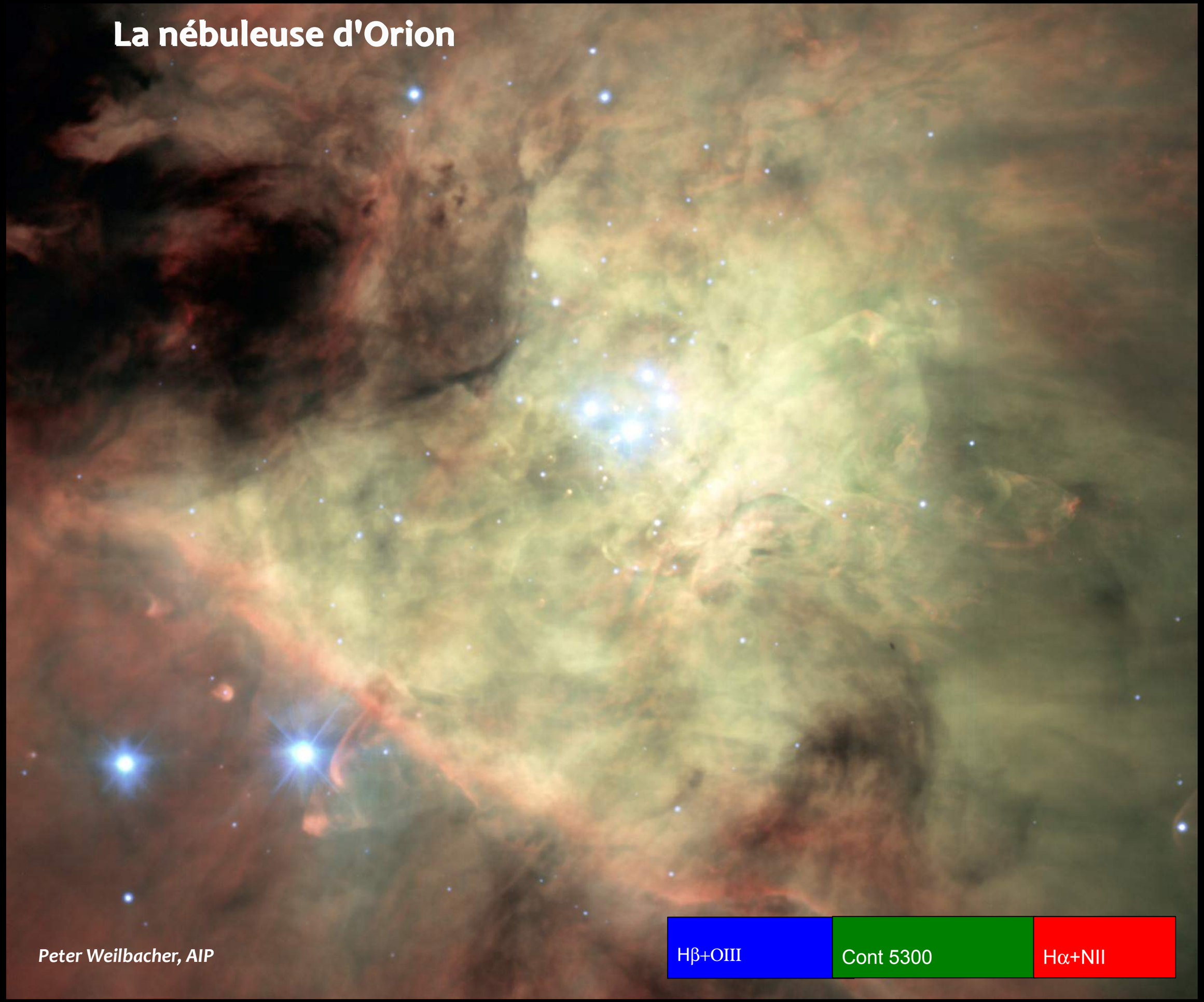
MUSE

- 1x1 arcminute @ 0.2"
- 465-930nm, R~3000
- 90,000 spectres pas pose
- 35 % d’efficacité
- Peut travailler avec l'optique adaptative

PI: Roland Bacon

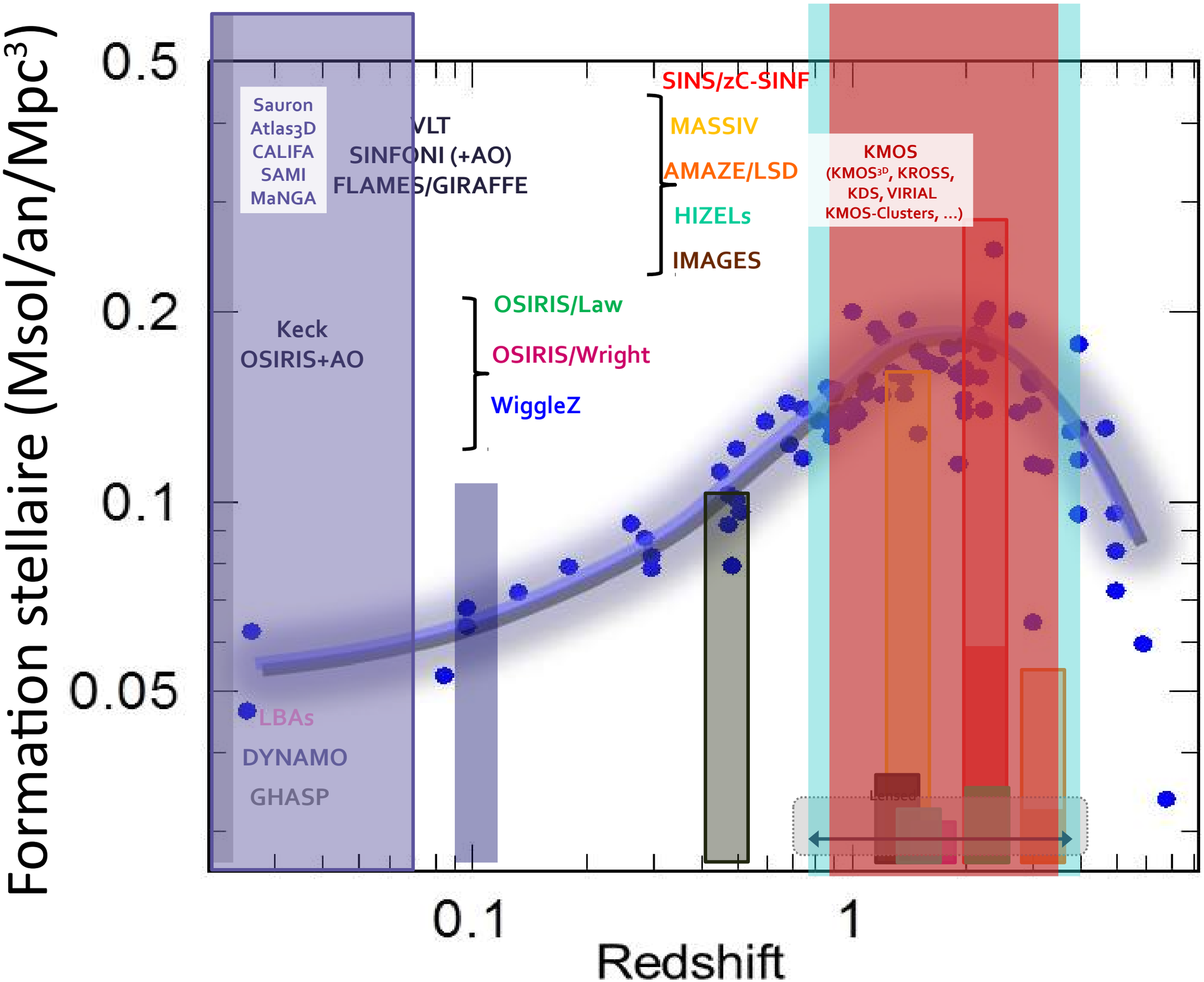


La nébuleuse d'Orion



Peter Weilbacher, AIP

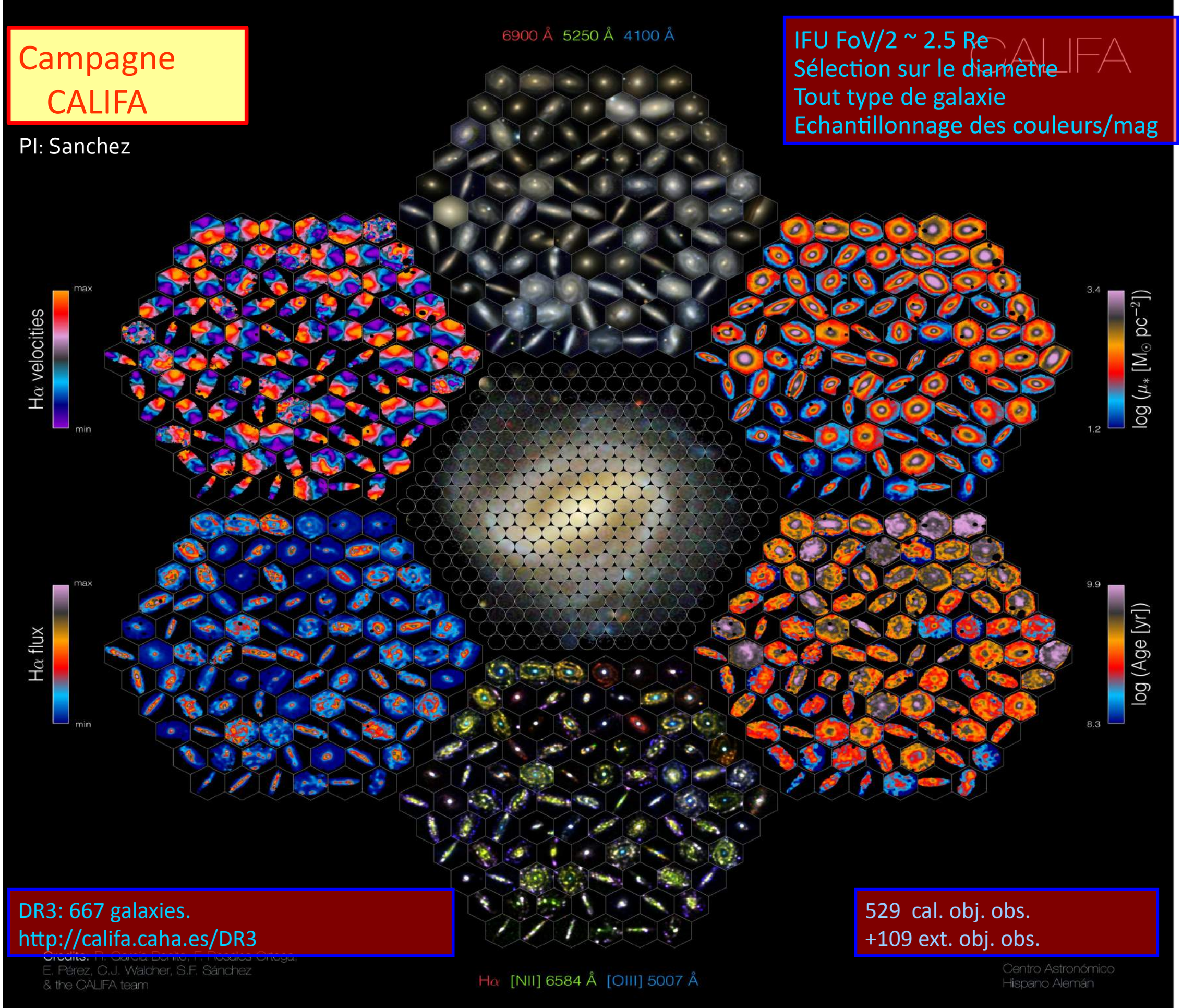
Campagnes avec Spectrographie Intégrale



Campagne CALIFA

PI: Sanchez

IFU FoV/2 ~ 2.5 Re
Sélection sur le diamètre
Tout type de galaxie
Echantillonnage des couleurs/mag



DR3: 667 galaxies.
http://califa.caha.es/DR3

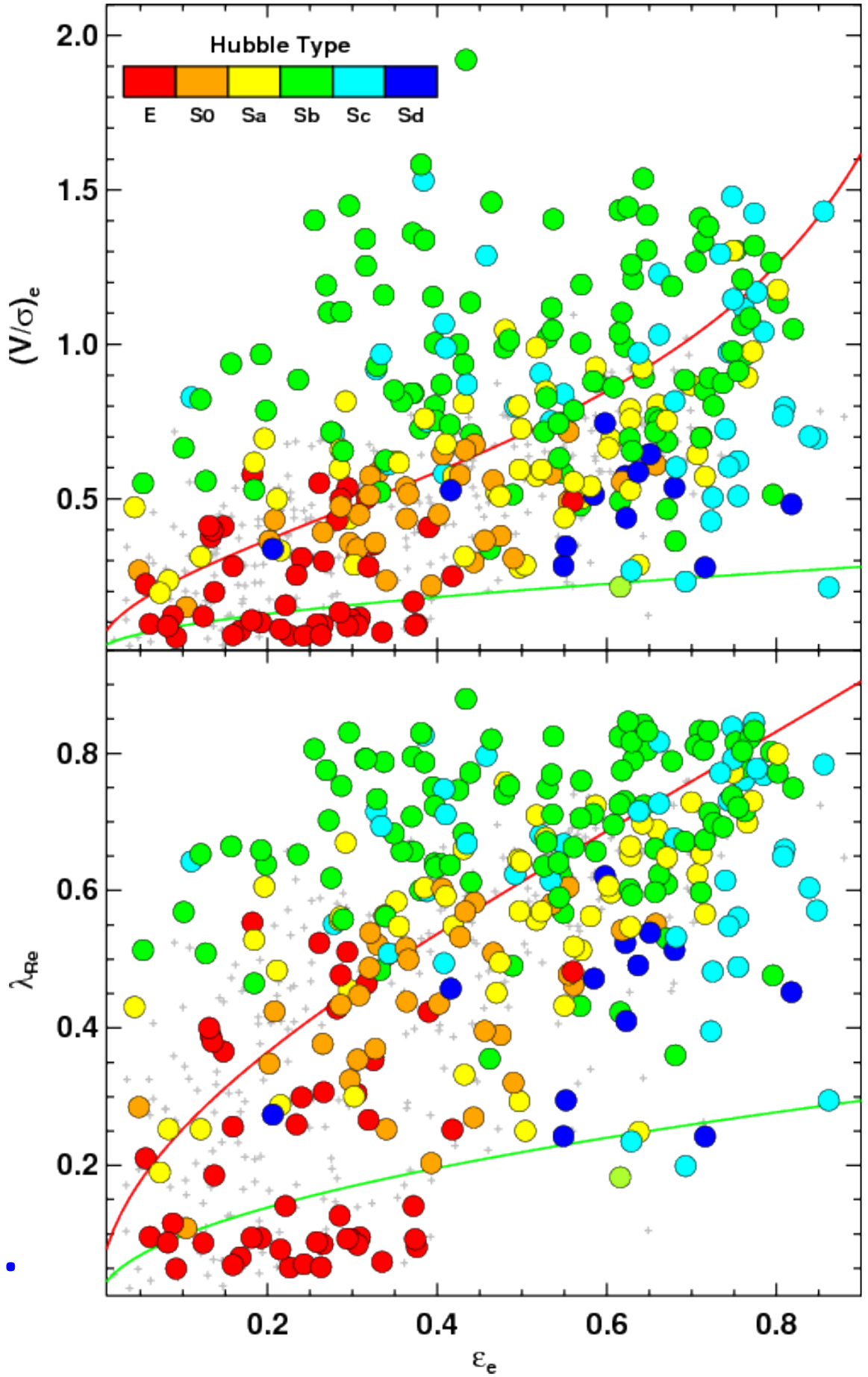
529 cal. obj. obs.
+109 ext. obj. obs.

Credits: R. García-Benito, I. Márquez Ortega, E. Pérez, C.J. Walcher, S.F. Sánchez & the CALIFA team

Centro Astronómico Hispano Alemán

λ_R vs Type de Hubble

(CALIFA)



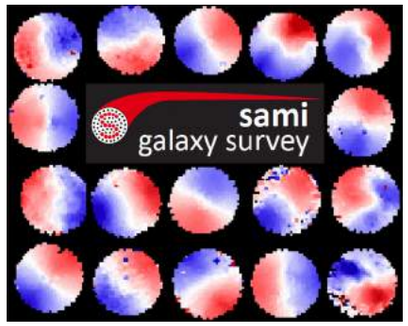
Falcon-Barroso, et al.

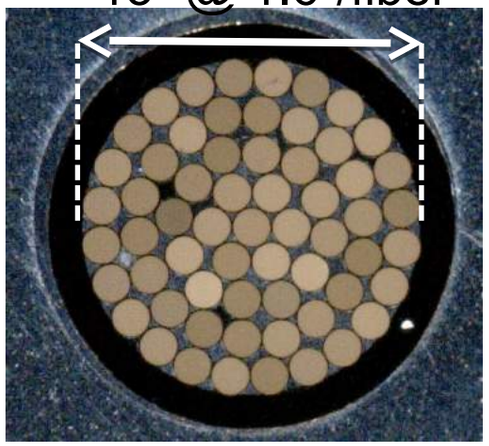
SAMI: Example de données

Spectrographe à 2 bras avec couverture dans le bleu

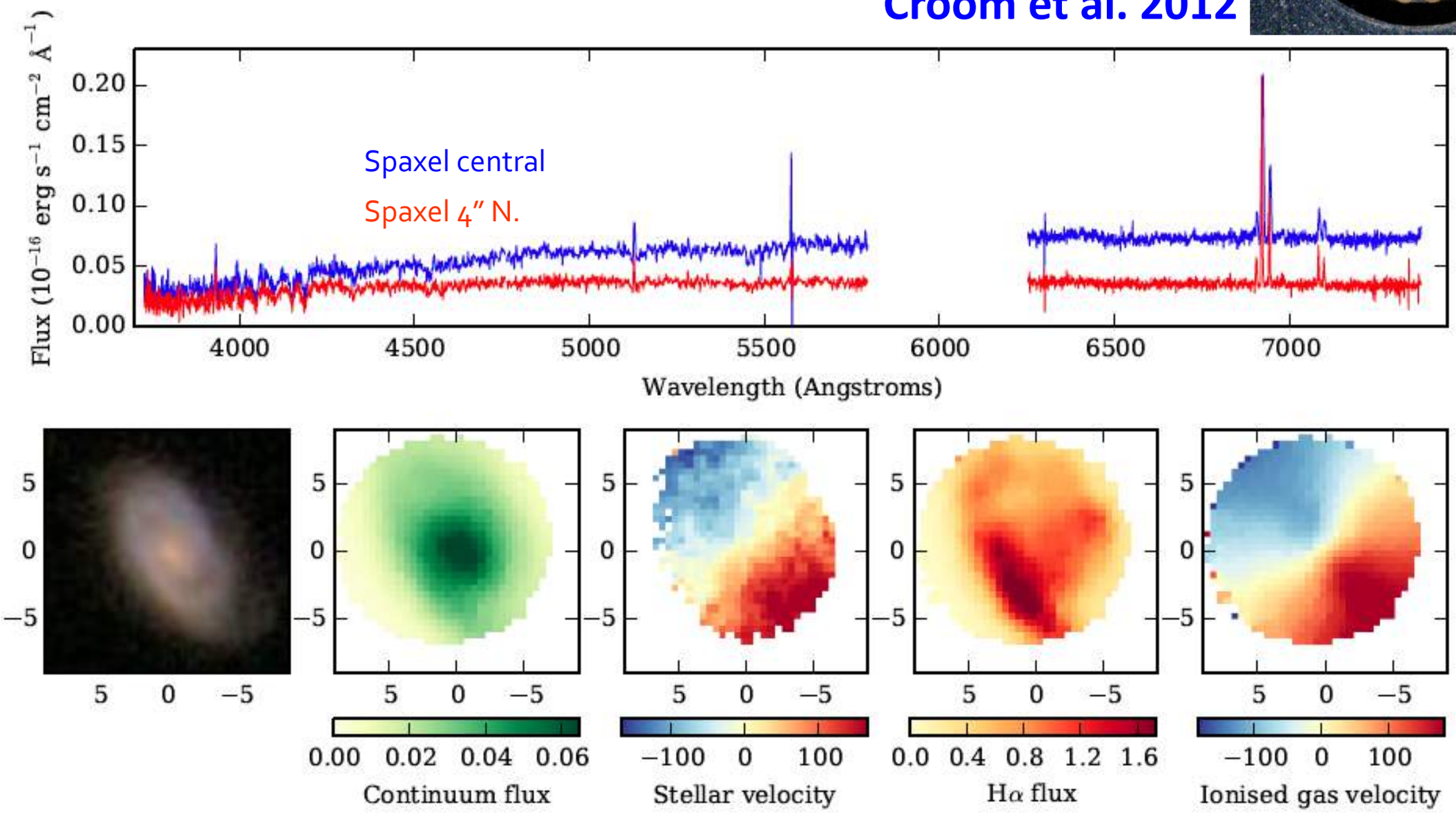
et Hα à haute résolution spectrale

> 1500 galaxies

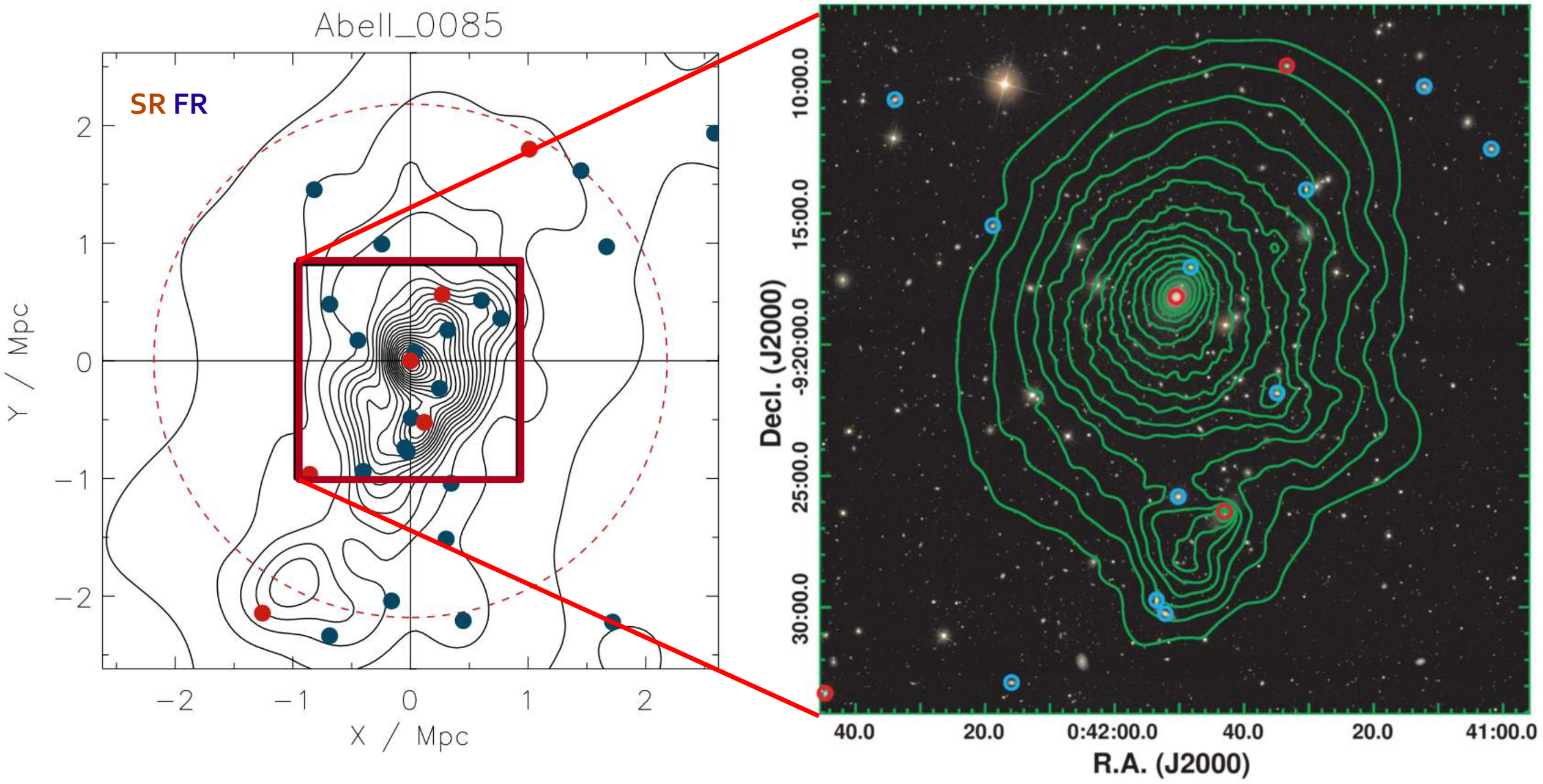




Croom et al. 2012

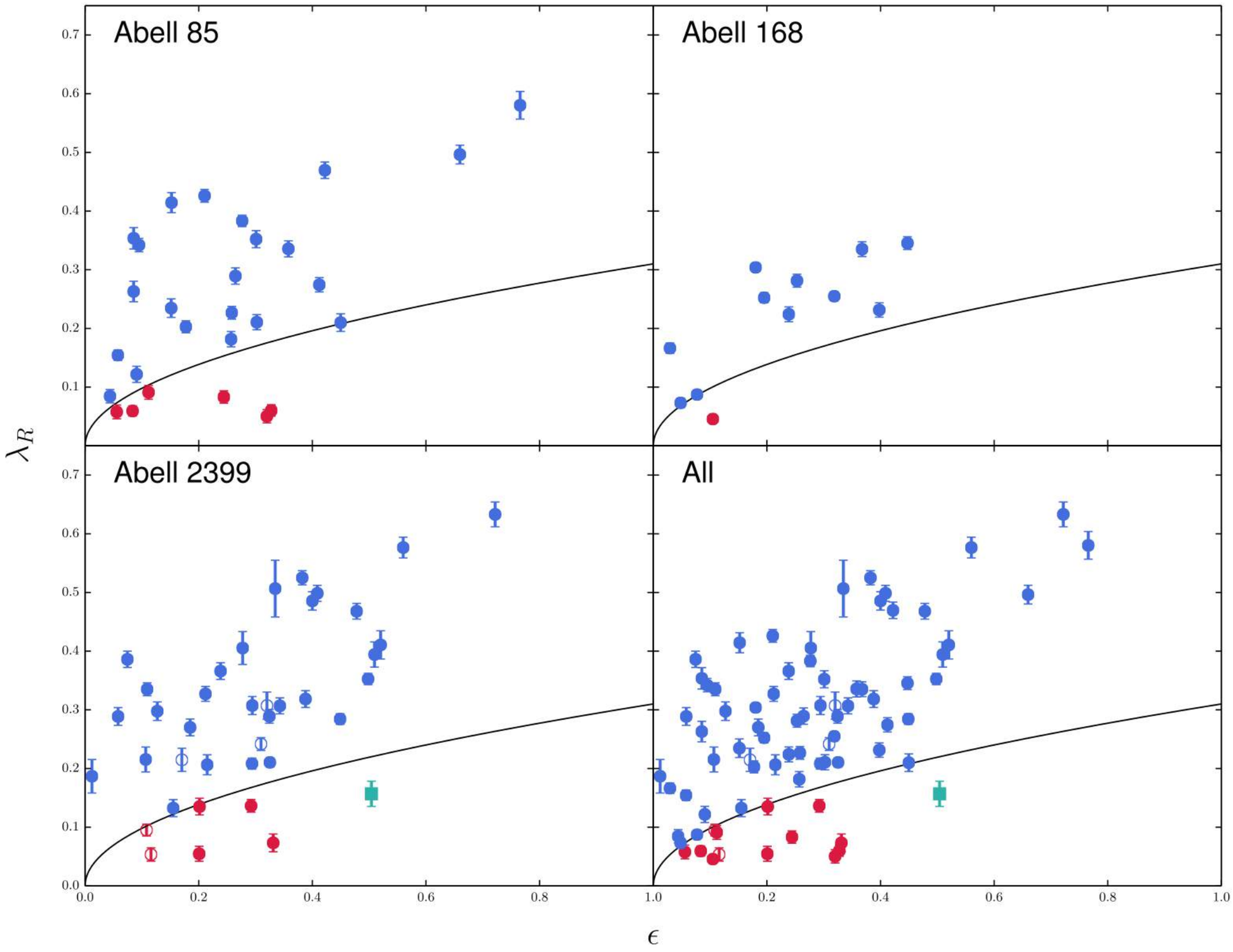


Relation morphologie - densité



Fogarty et al. 2014

Moment angulaire dans les Amas de galaxies



Fogarty et al. 2014

Partie de SDSS-IV

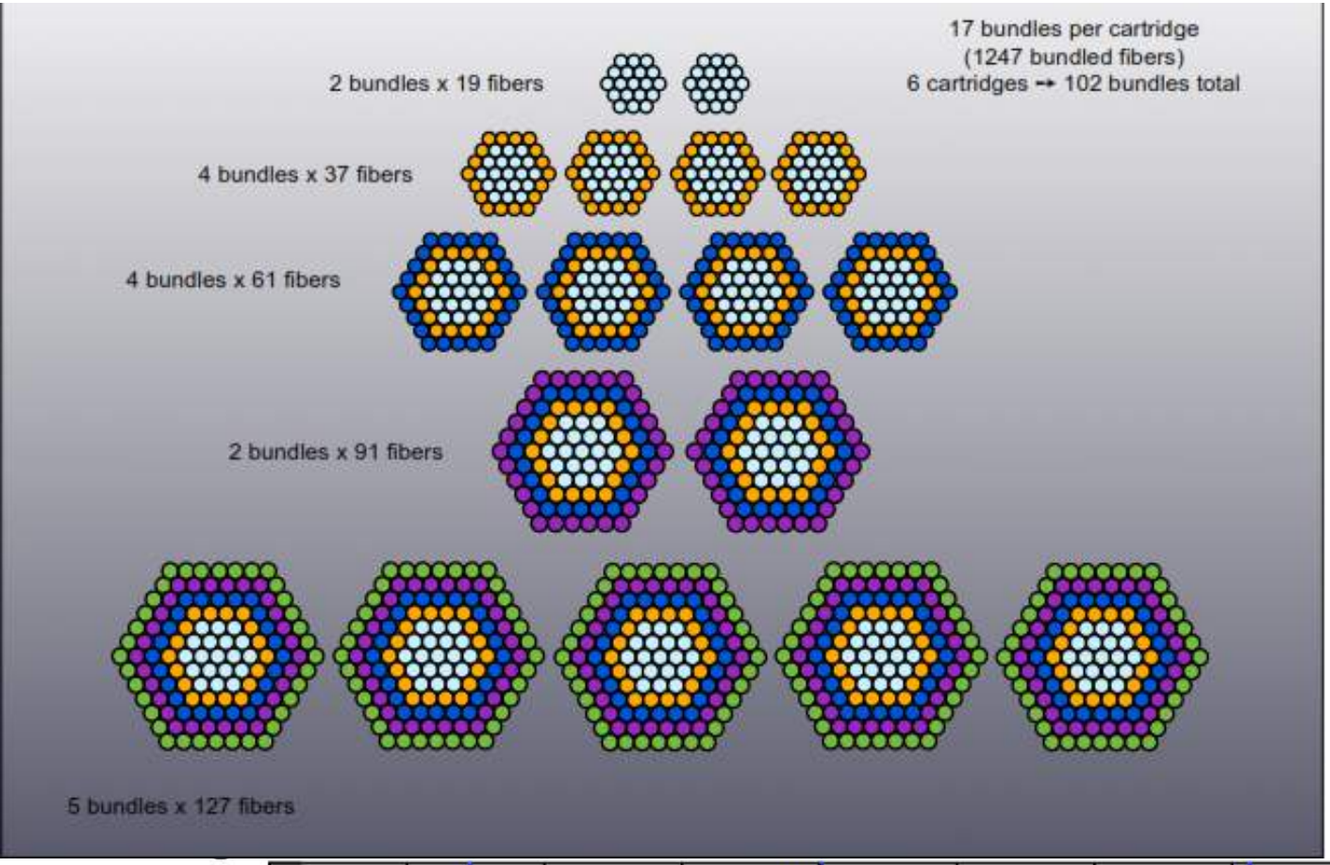
10,000 galaxies entre 2014 et 2020

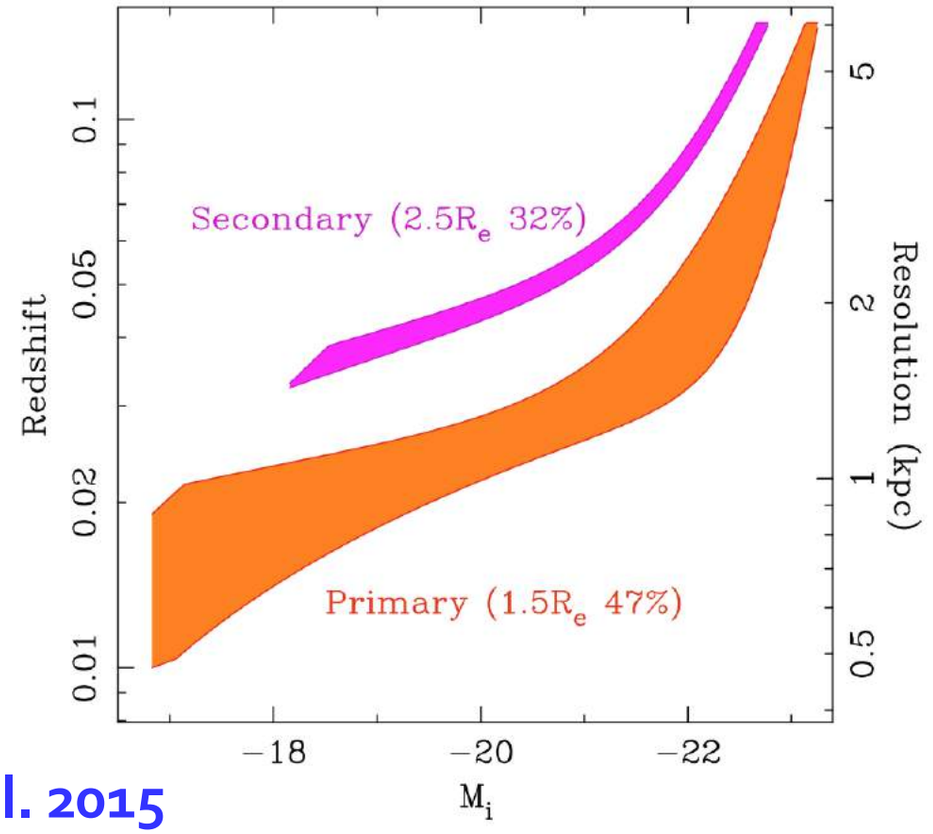
« Multi hexabundle IFU » sur télescope SDSS 2.5m

Utilise le spectrographe BOSS

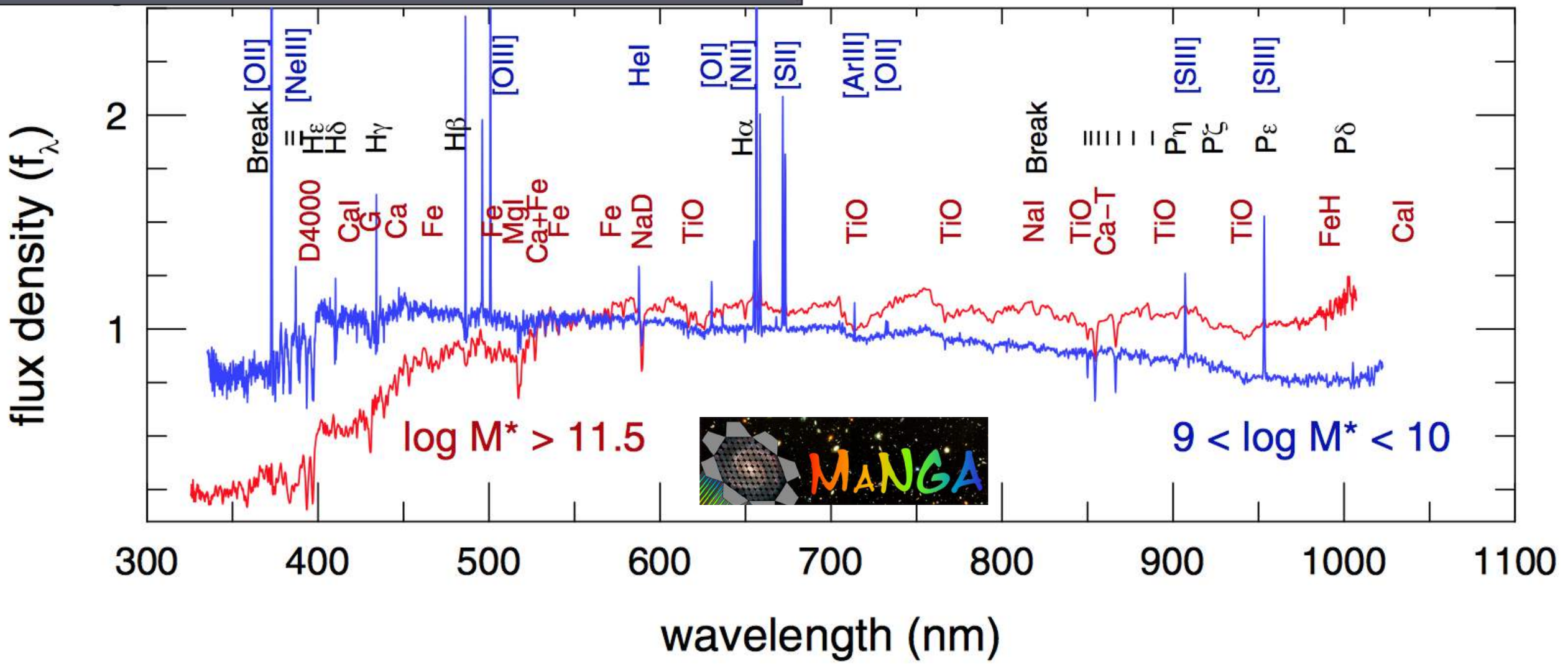
Démarré en Juillet 2014 ⇒ **déjà ~ 5000 galaxies !**

Plus de 100 projets déclarés ...

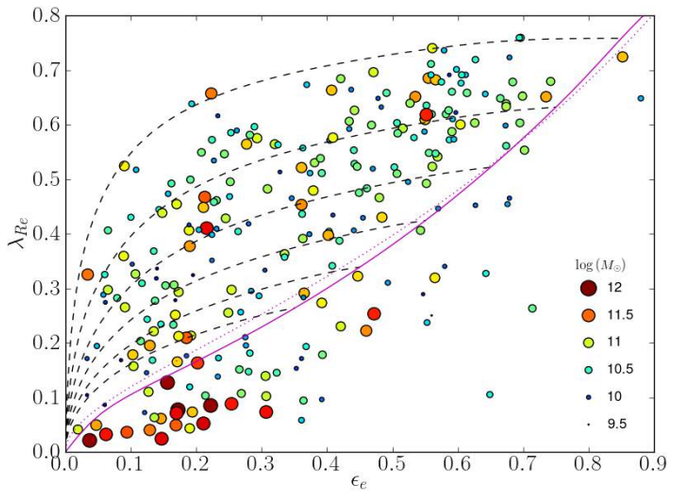




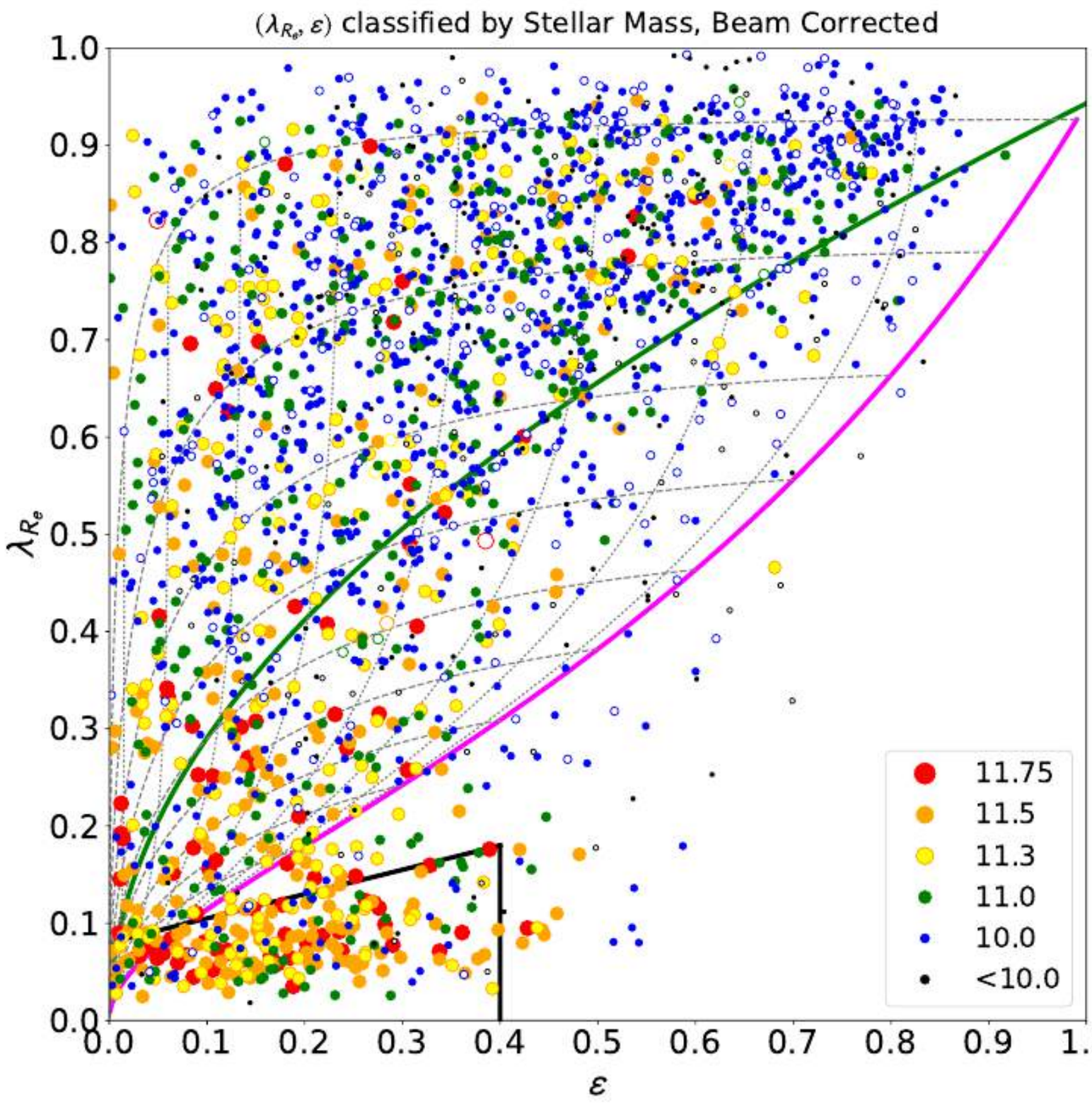
Bundy et al. 2015



Moment angulaire

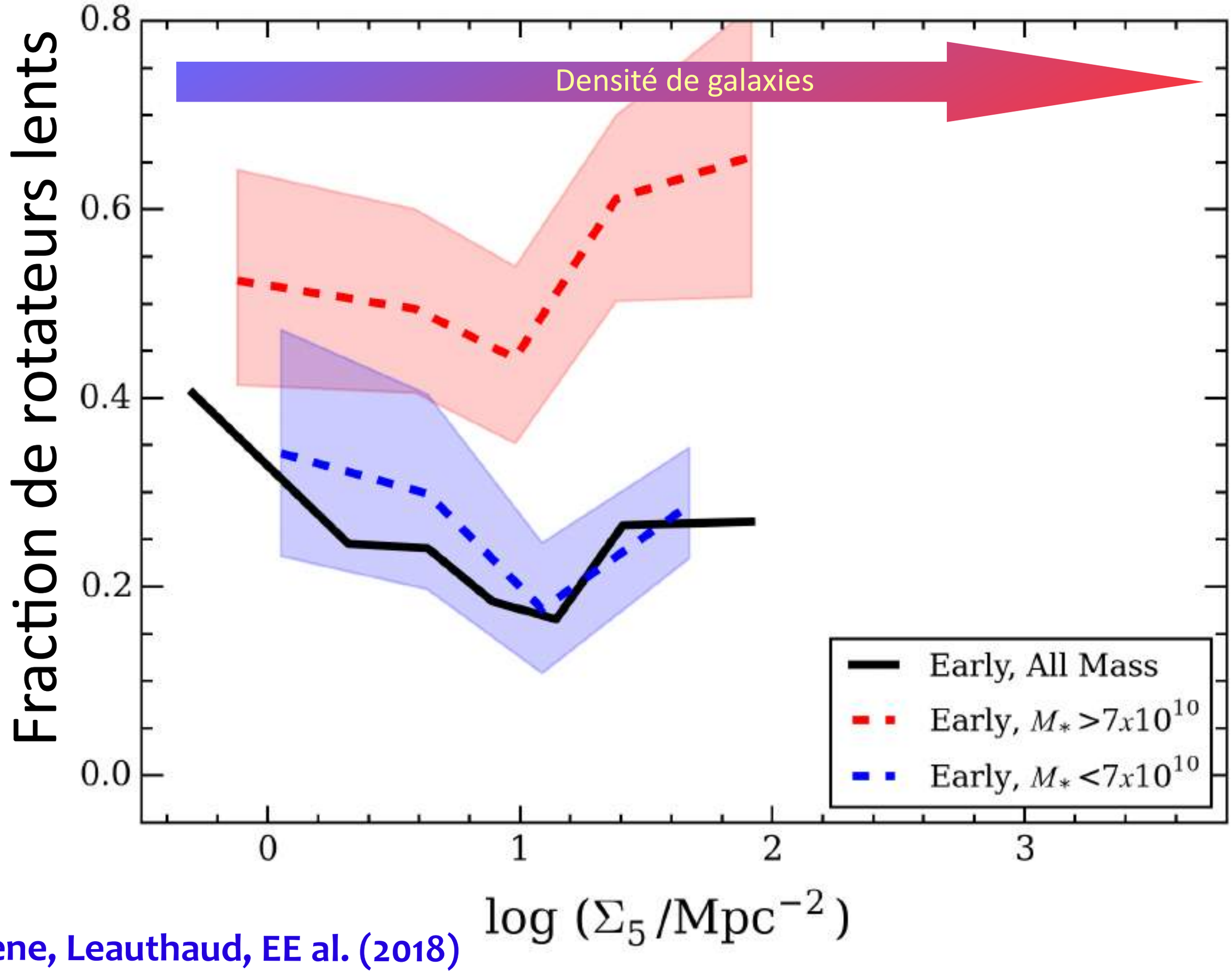


Emsellem et al. (2011)



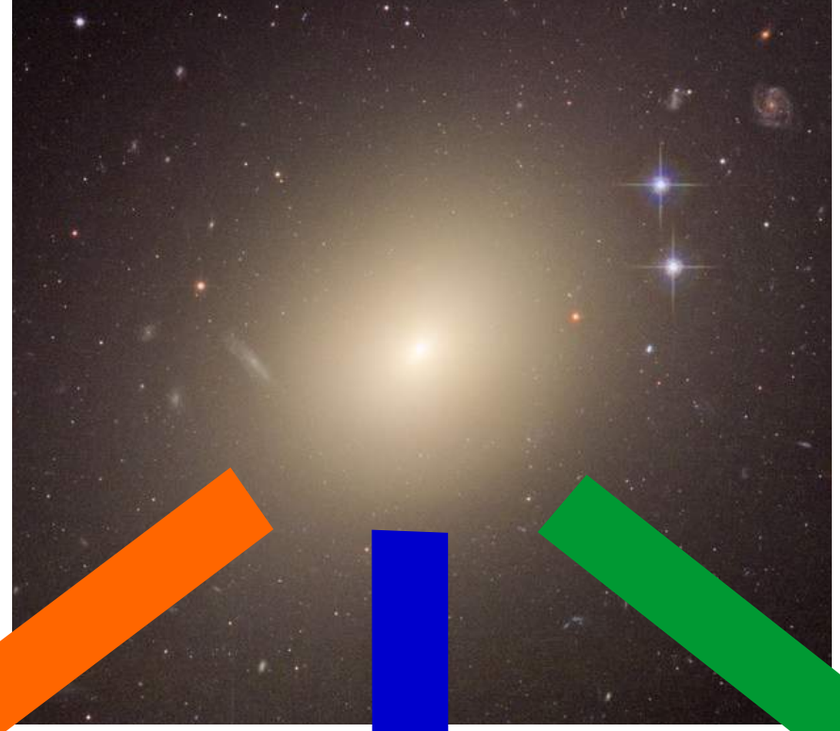
Graham et al. (2018)

Environnement ou Masse ?



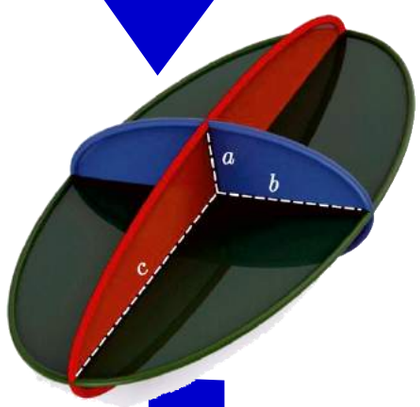
Greene, Leauthaud, EE al. (2018)

Que se passe-t-il au delà de $M > 10^{11.5}\ M_\odot$?



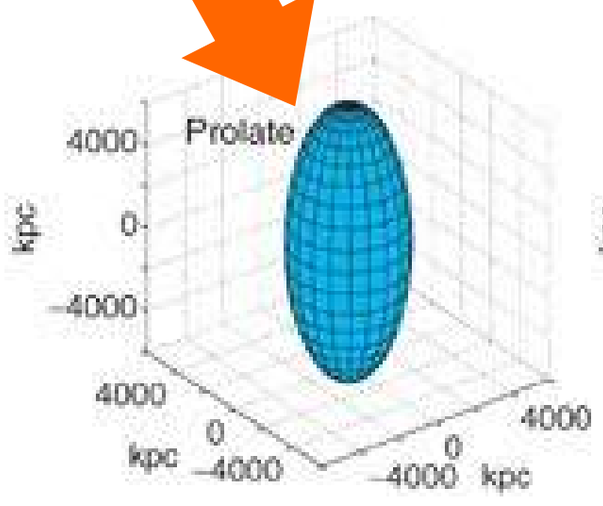

RUGBY
WORLD CUP
2015
GILBERT

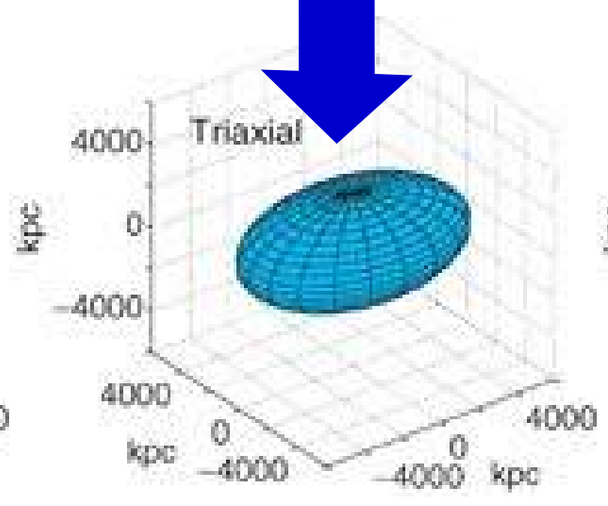
Ou

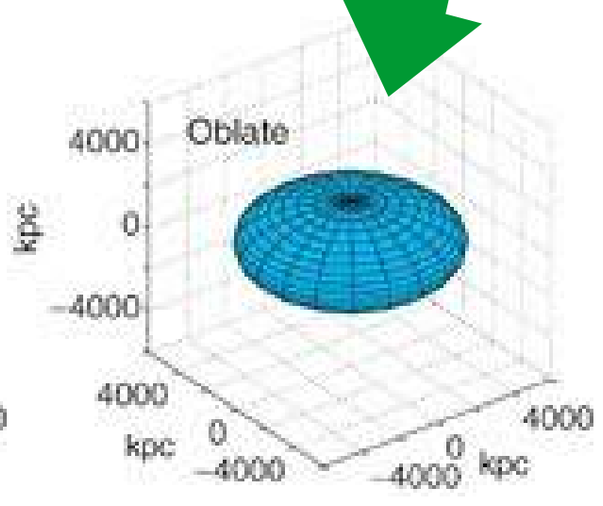

a
b
c

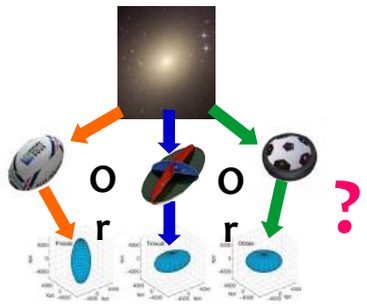
Ou

?


Prolate
4000
0
−4000
kpc
4000
0
−4000
kpc
4000
0
−4000
kpc

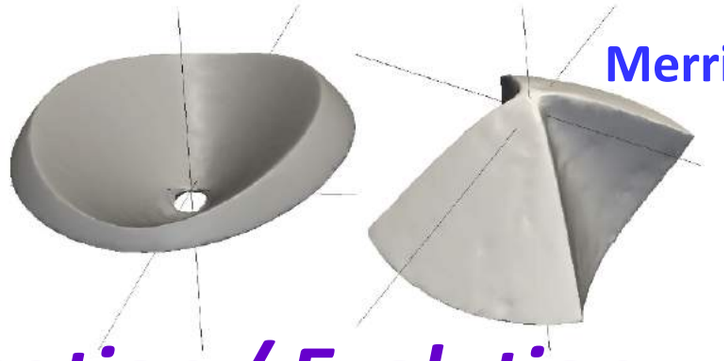

Triaxial
4000
0
−4000
kpc
4000
0
−4000
kpc
4000
0
−4000
kpc


Oblate
4000
0
−4000
kpc
4000
0
−4000
kpc
4000
0
−4000
kpc



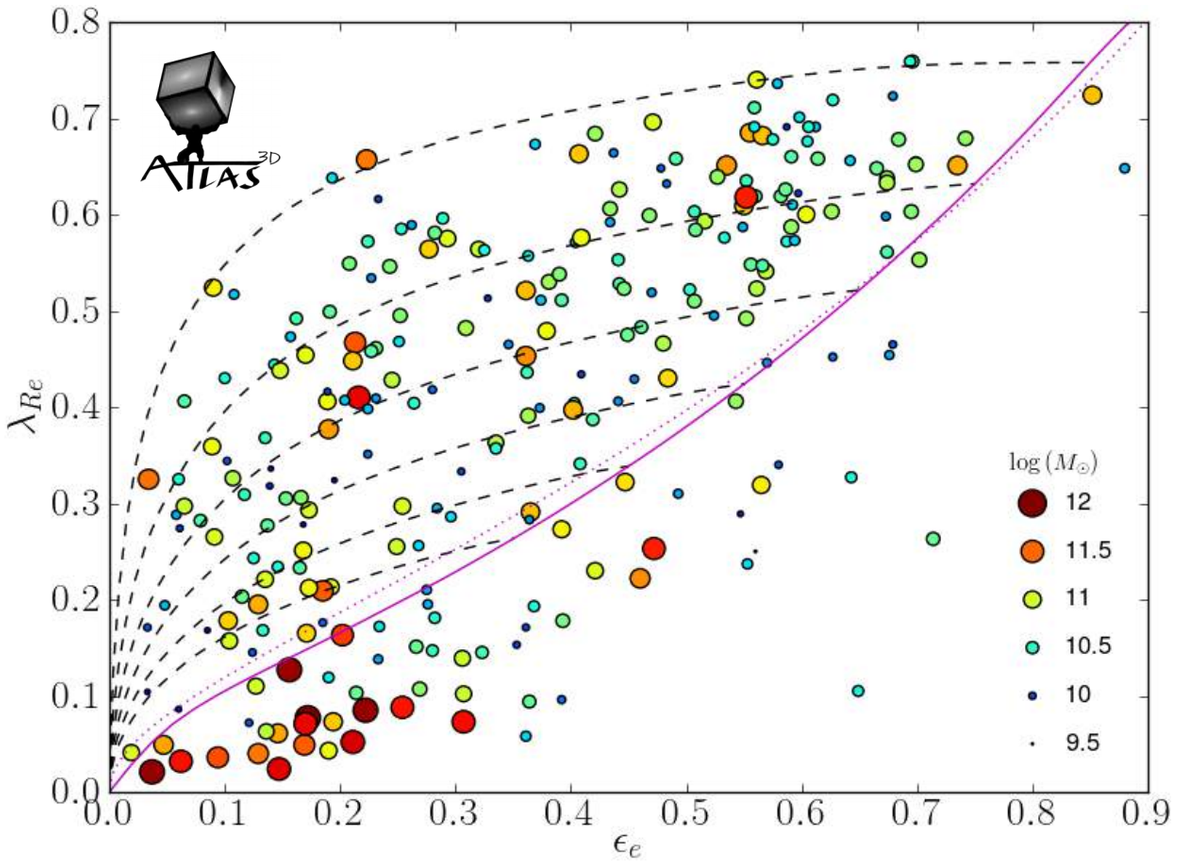
Pourquoi nous en préoccuper ?

- ***Structure Orbitale***
  - Morphologie, Dynamique, Masse



Merritt 2013

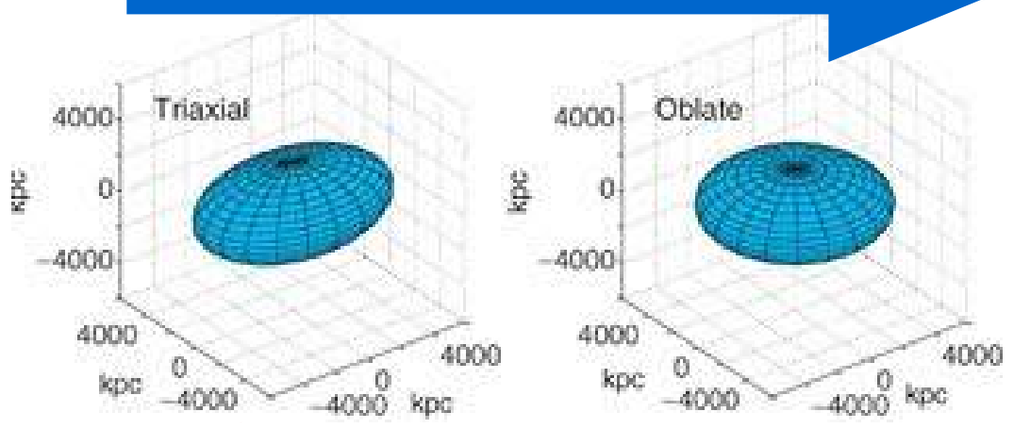
- ***Contraintes sur les processus de Formation / Evolution***



Emsellem, Cappellari, Krajnović et al. 2011

- ***Tendances avec la Masse***
  - Moment Angulaire

Géométrie

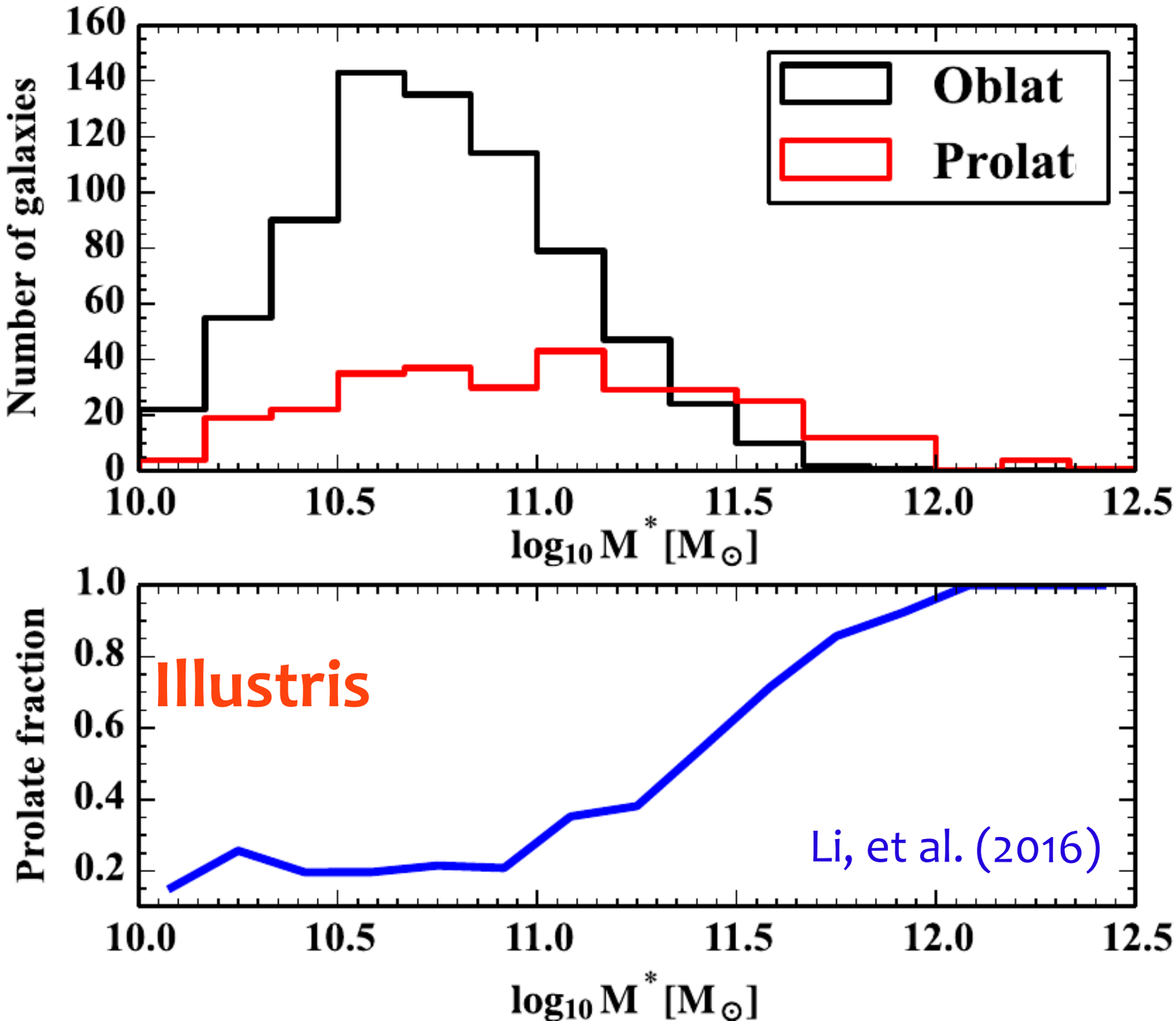


Masse

Predictions des Simulations

- > $10^{11.5}$ $M_{\odot}$: fraction des ***systèmes prolats*** augmente dramatiquement

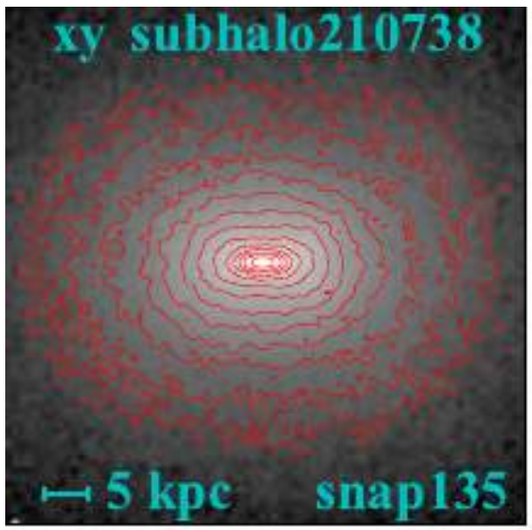
[voir aussi Tsatsi et al. 2017, Weaver et al. 2018]

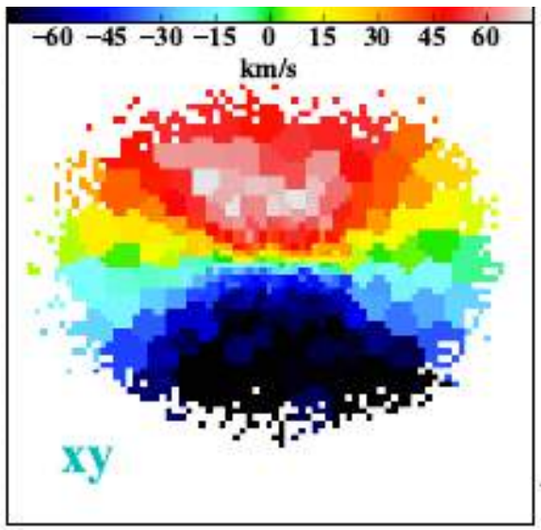


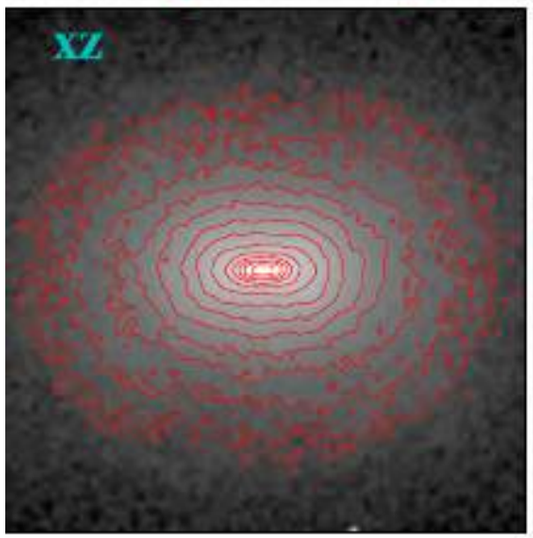
Predictions des Simulations

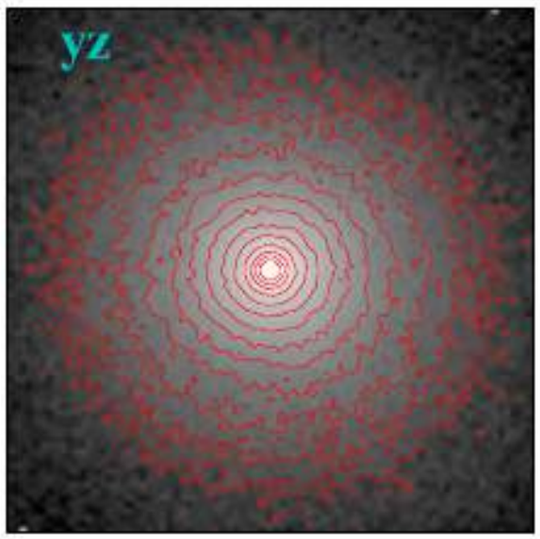
- Fusions majeures « sèches » ($z < 1$)

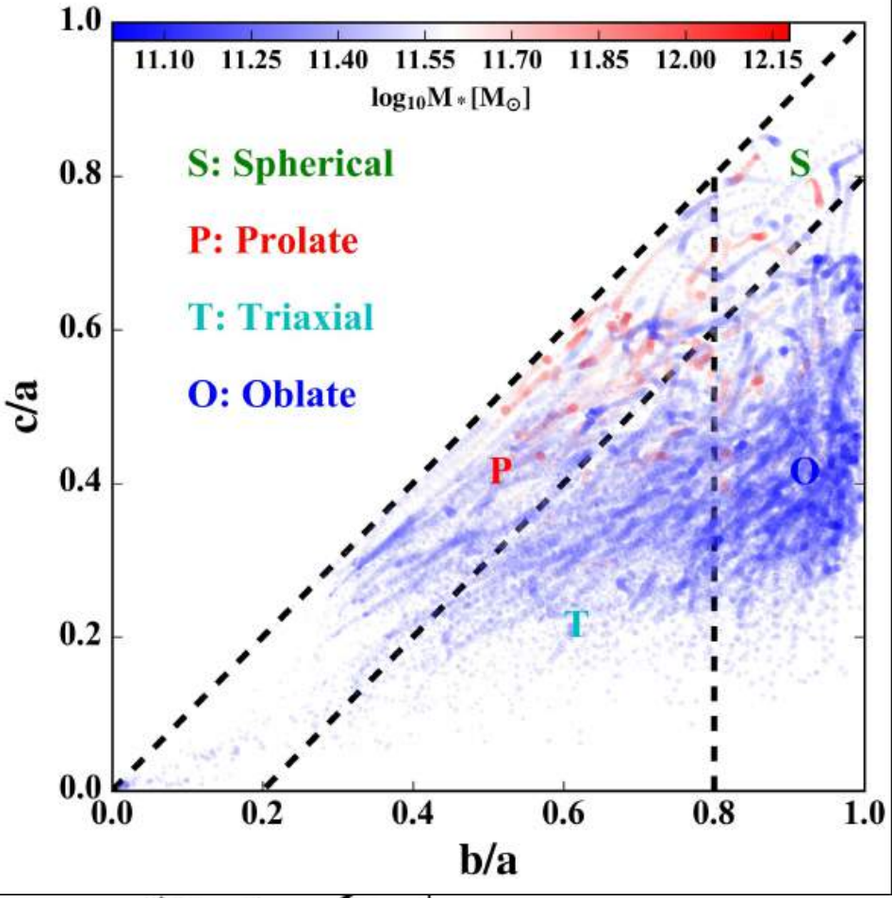
Li, Shude, EE et al. (2018)

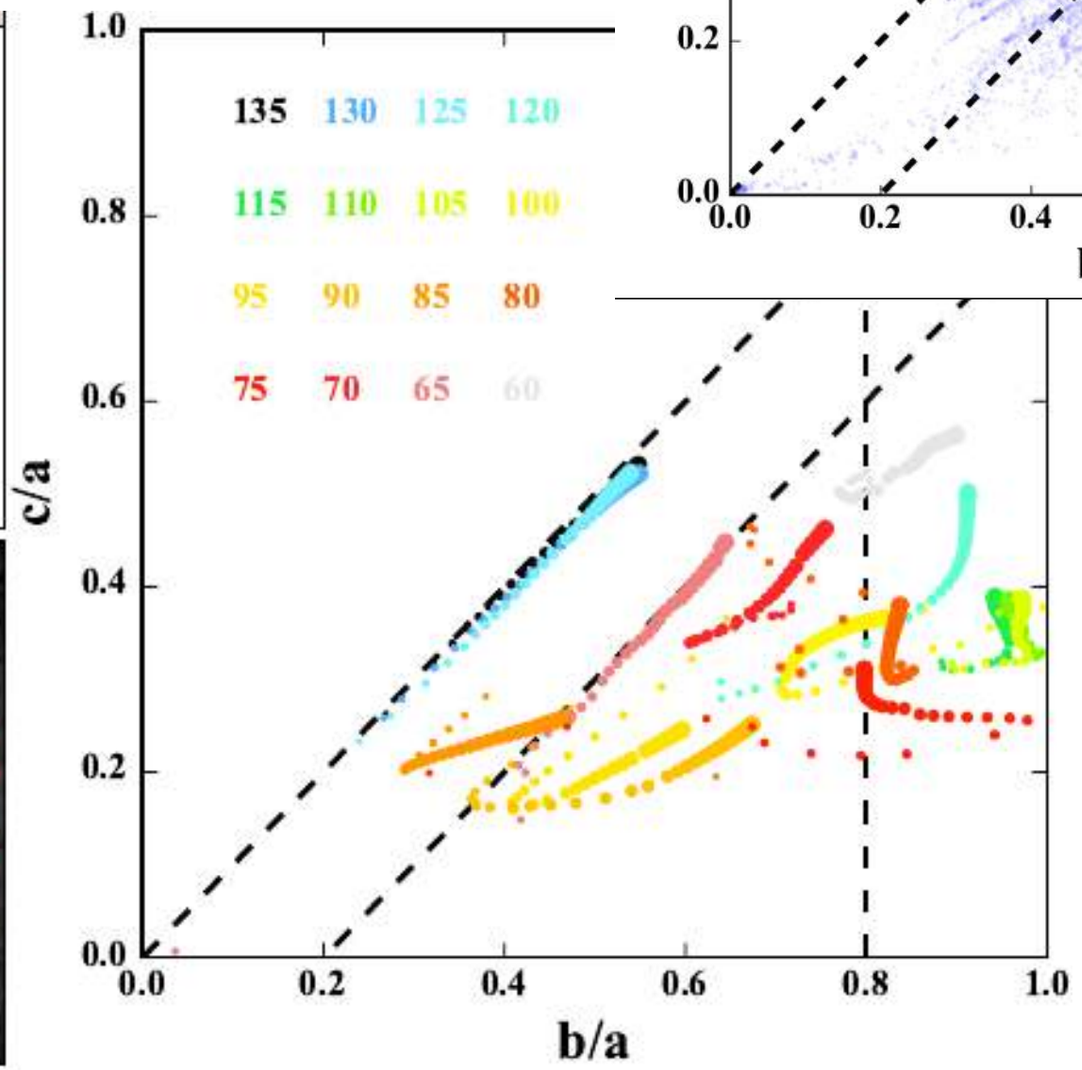


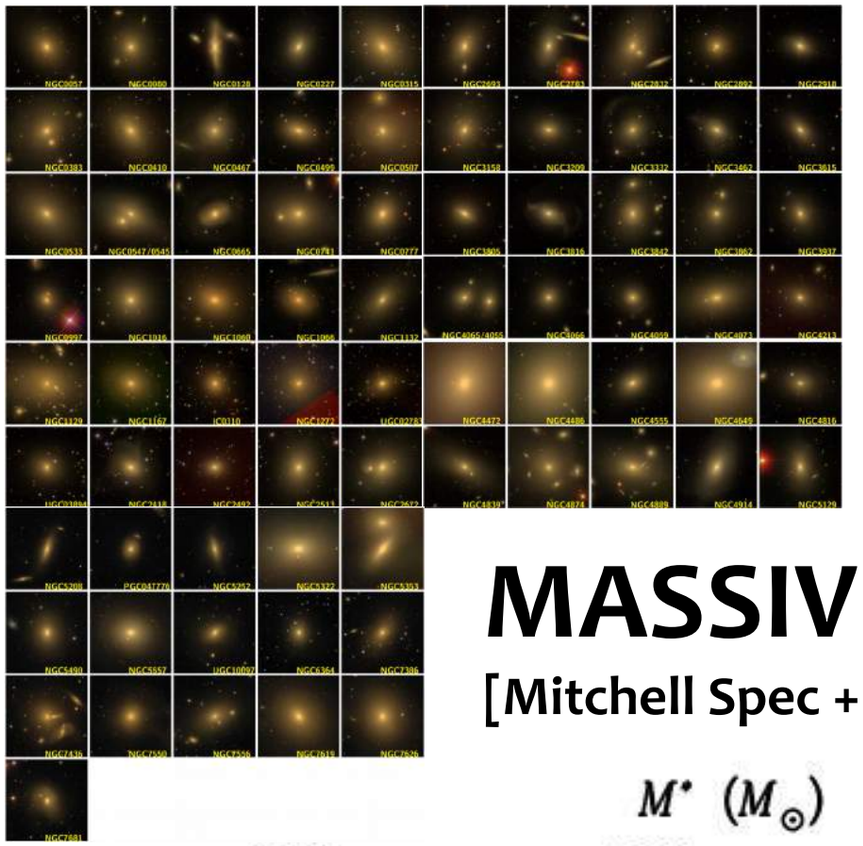






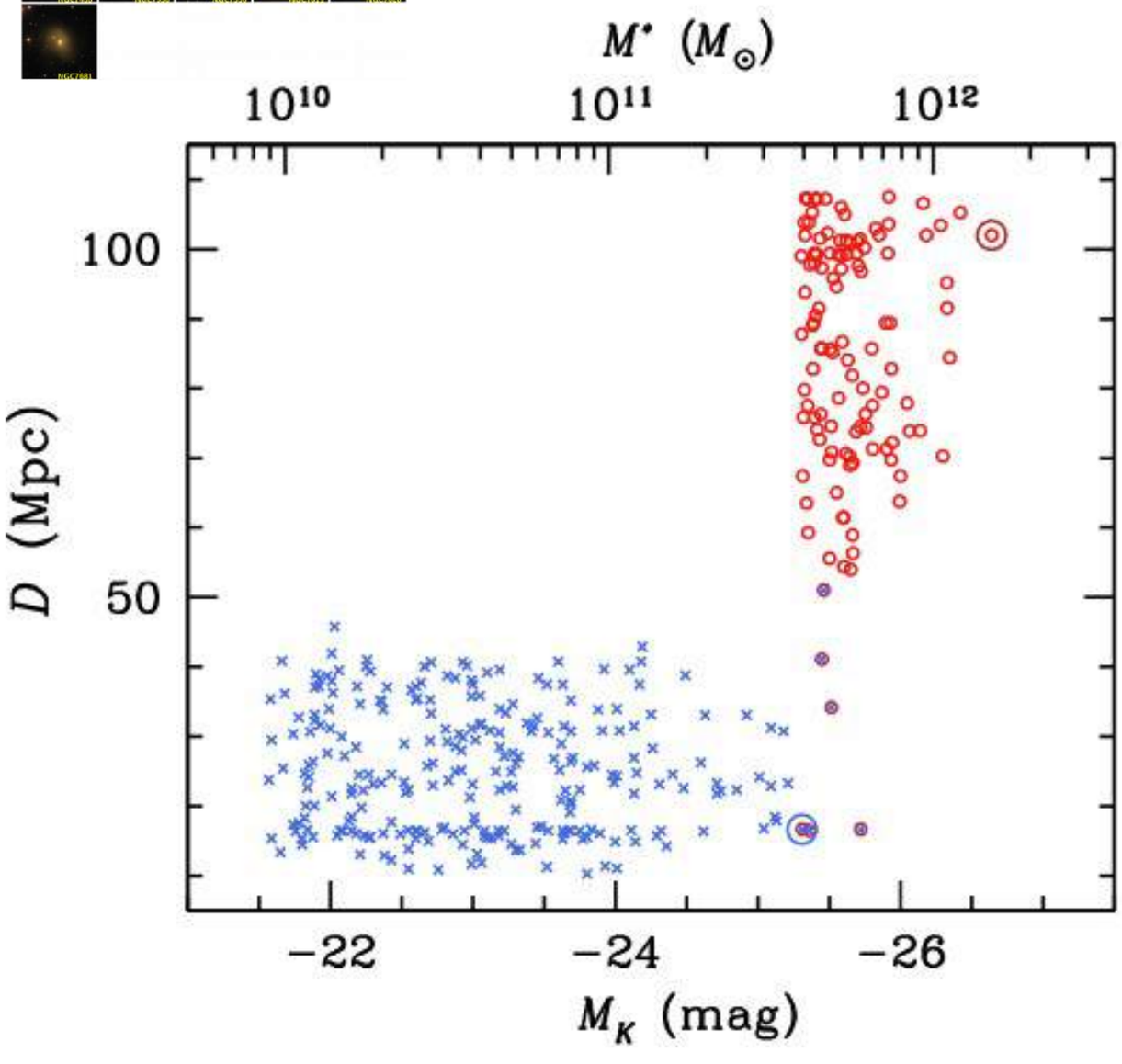




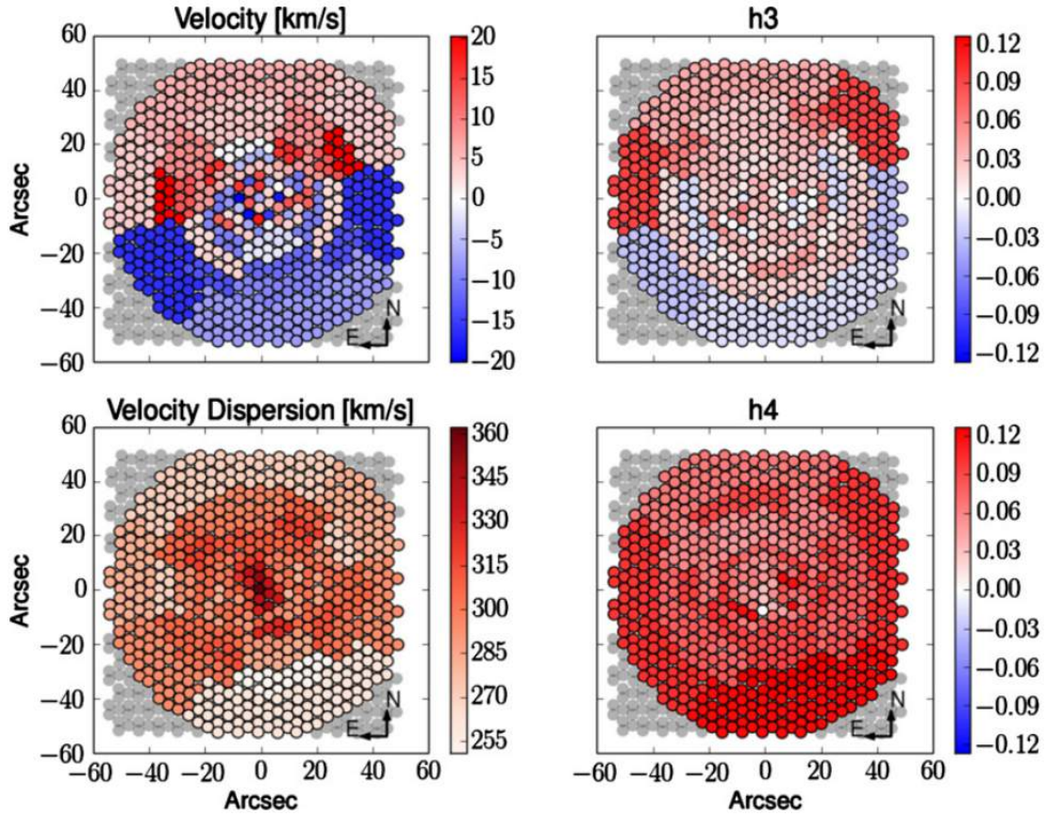


MASSIVE

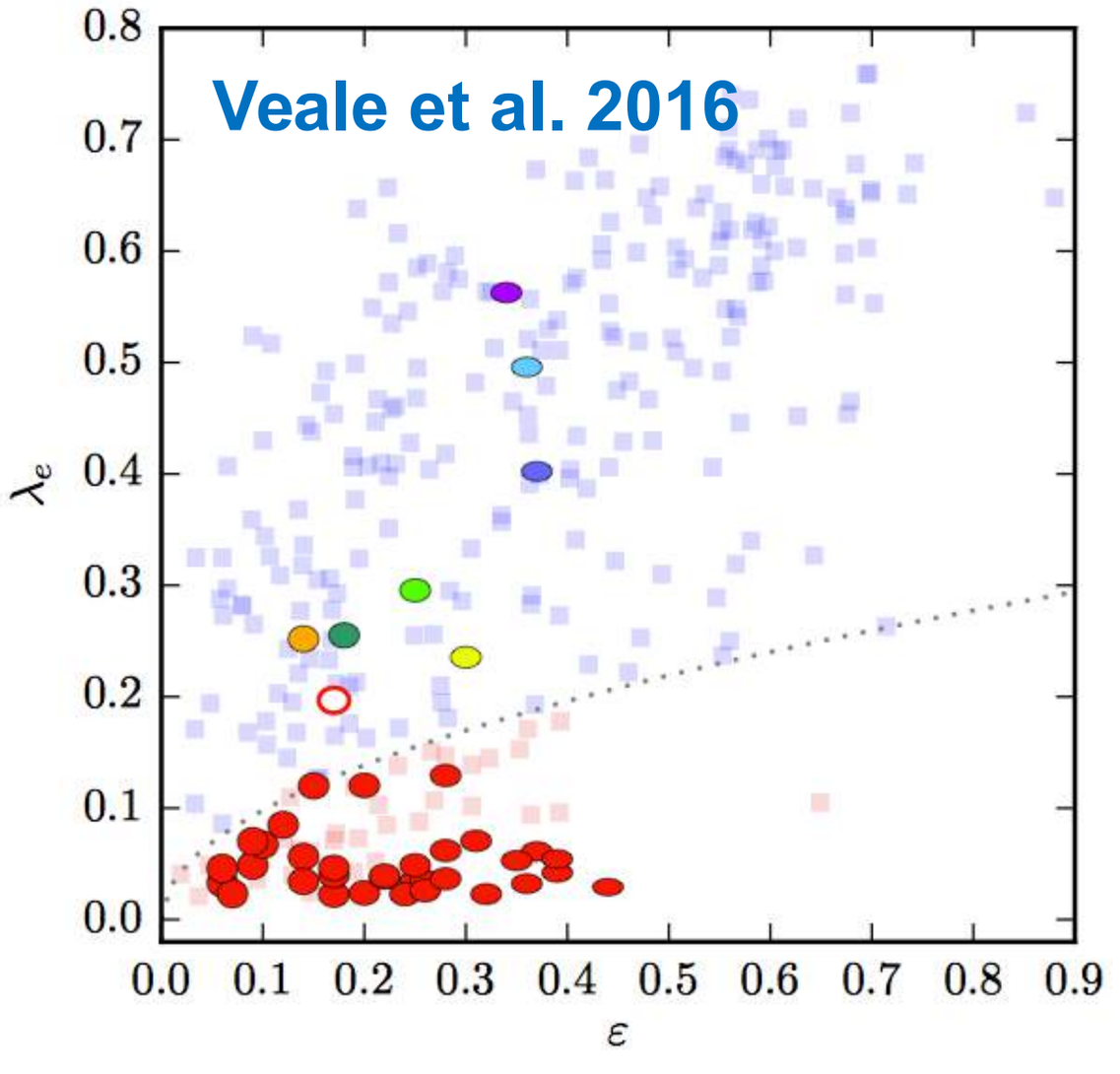
[Mitchell Spec + AO-NIFS]



Ma et al. 2014



Veale et al. 2016



Le Projet

Un programme GTO MUSE

PI Eric Emsellem

Buts:

Etat dynamique, contenu en matière noire,

SFH, IMF + Test des prédictions des simulations

Approche:

Contenu stellaire+dynamique (2 Re)

Des galaxies les plus massives dans les régions les plus denses

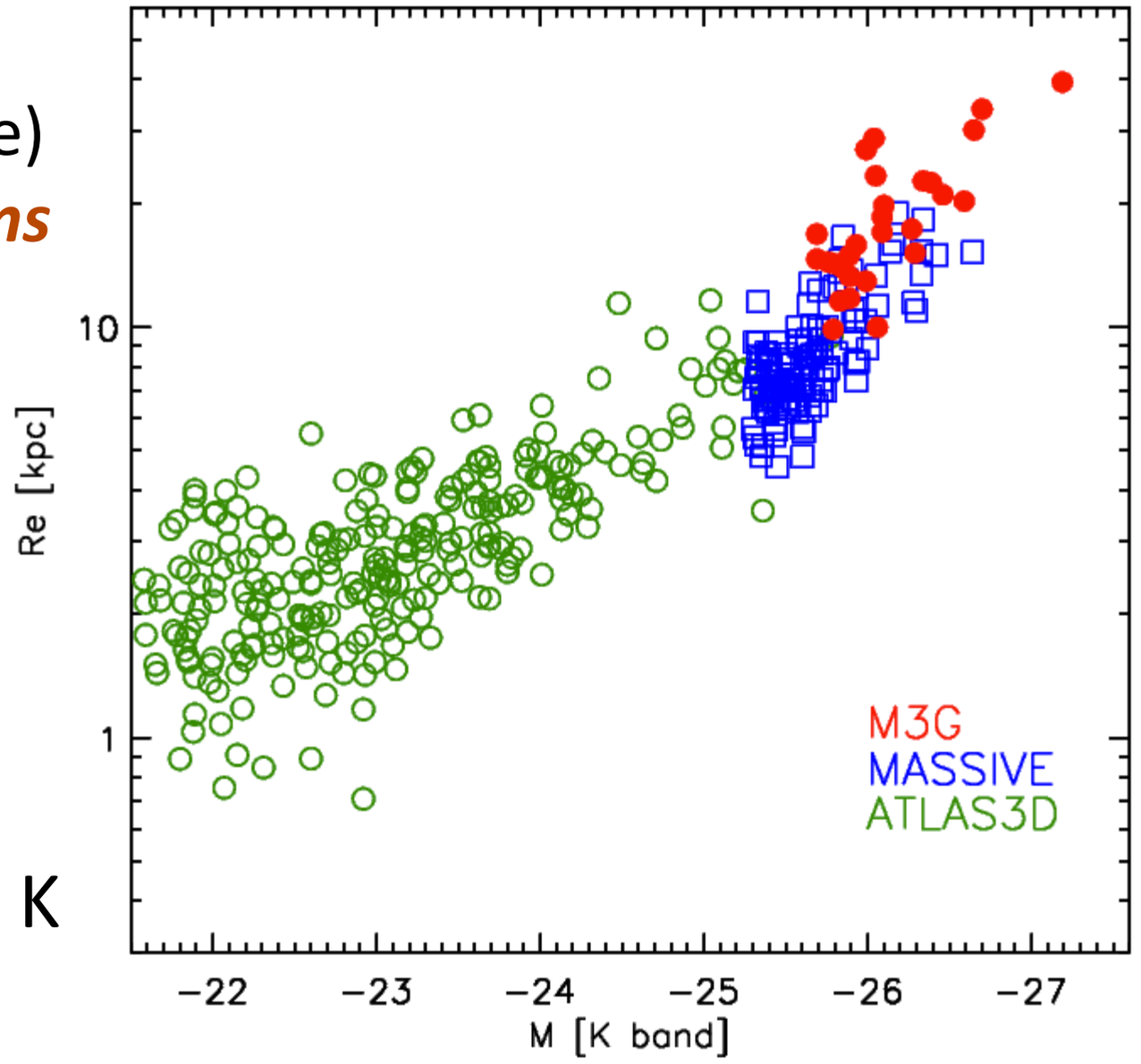
→ **2** sous-échantillons (z~0.04)

I – Super Amas Shapley

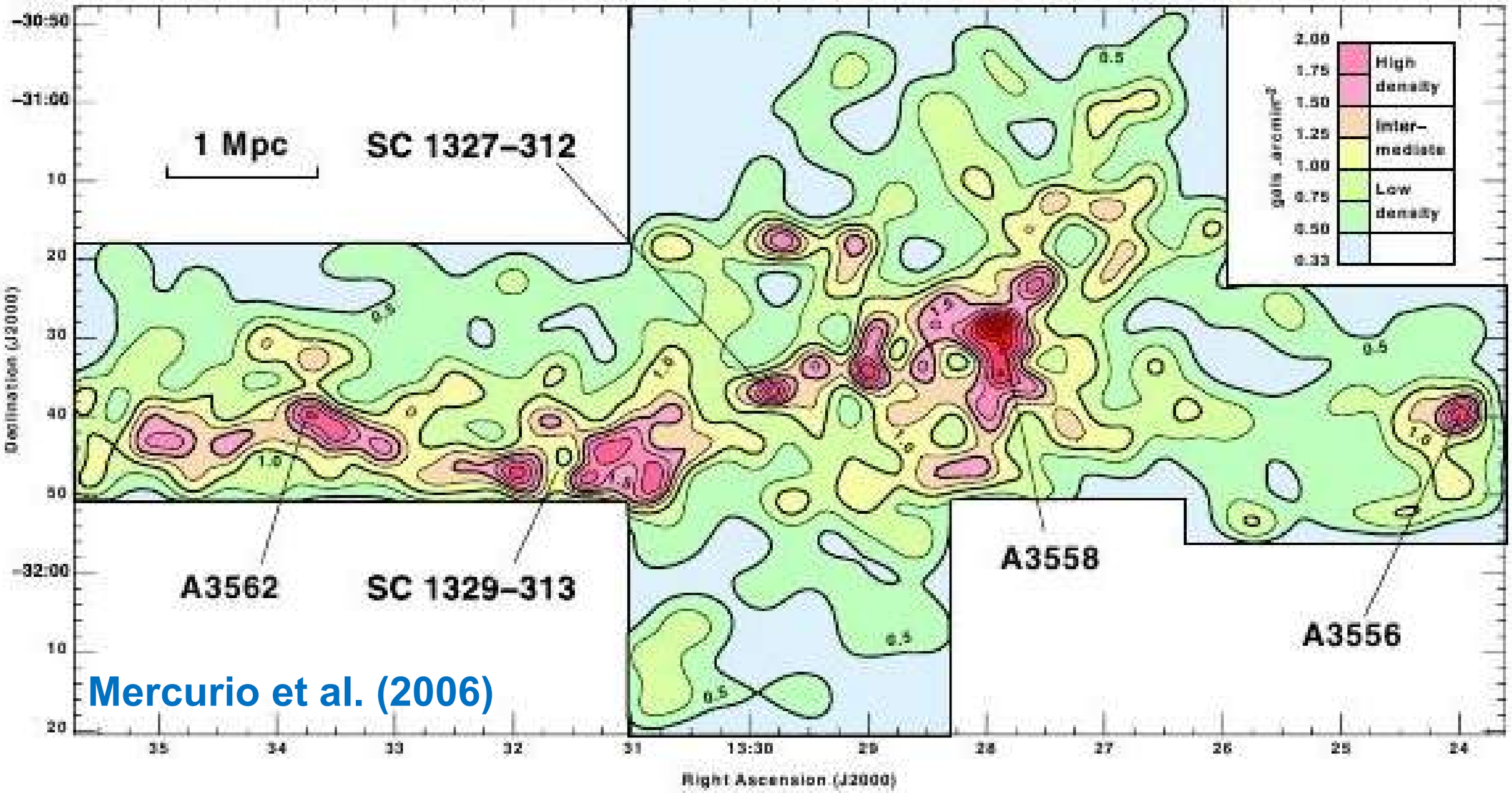
+

II – BCGs amas riches

Plus brillantes que -25.7 mag en K



Super Amas de Shapley



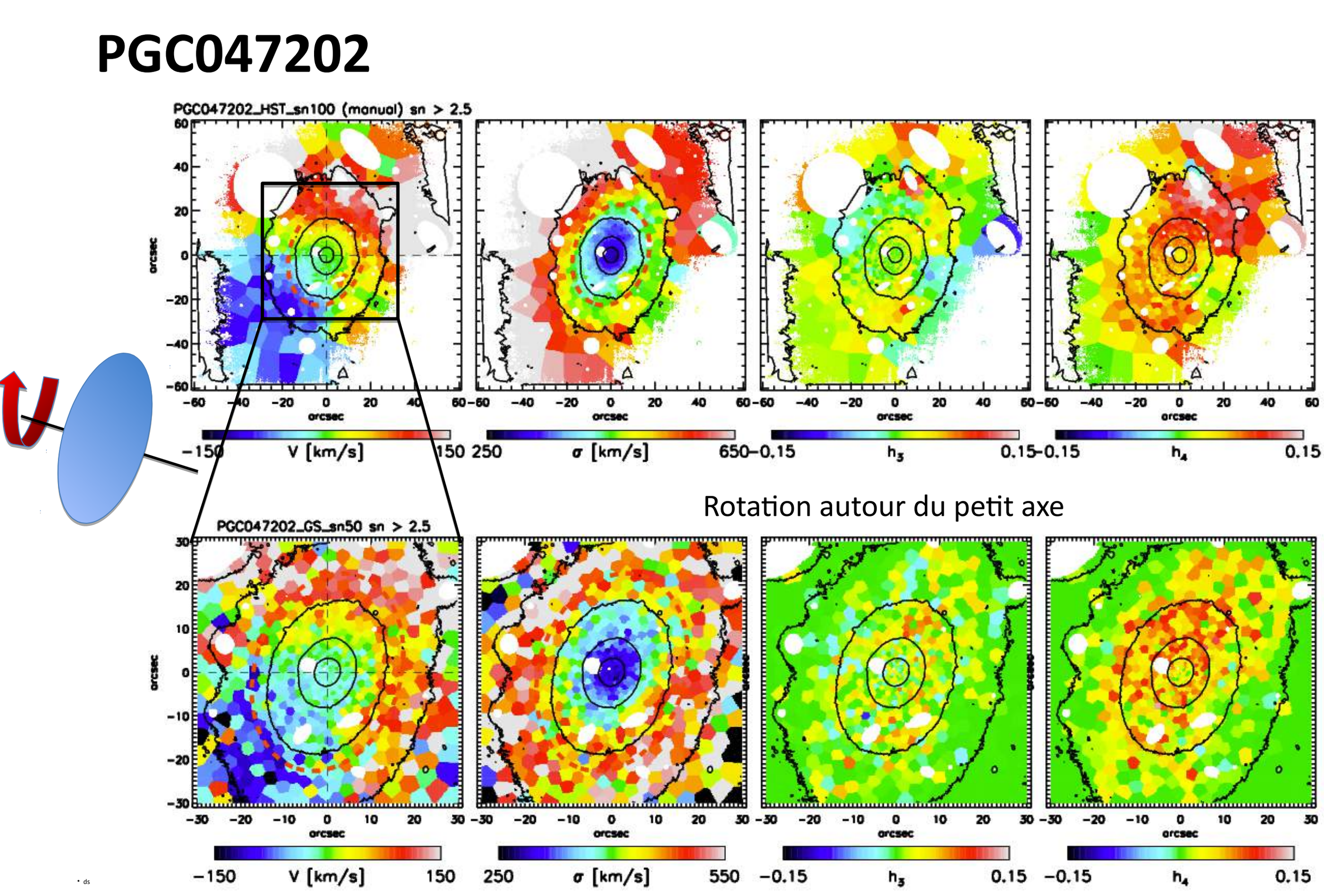
Mercurio et al. (2006)

~200 Mpc [~1kpc / arcsec]

PGC047202

La galaxie la plus massive dans Shapley

PGC047202



Rotation autour du petit axe

ds

PGC007300

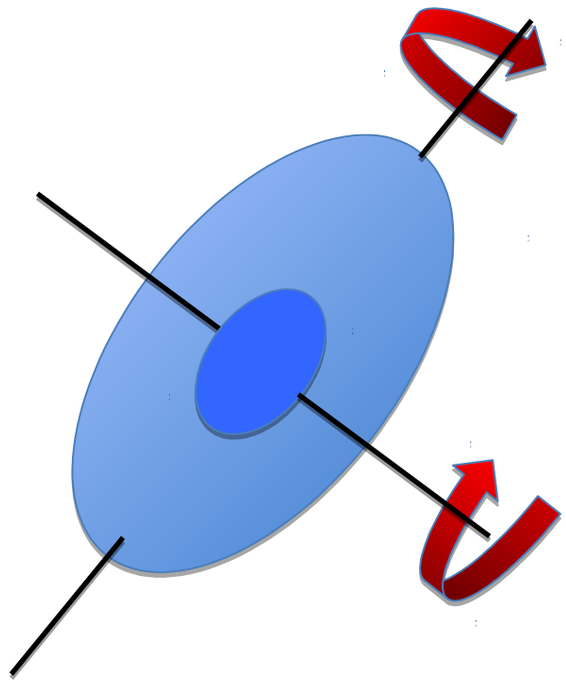
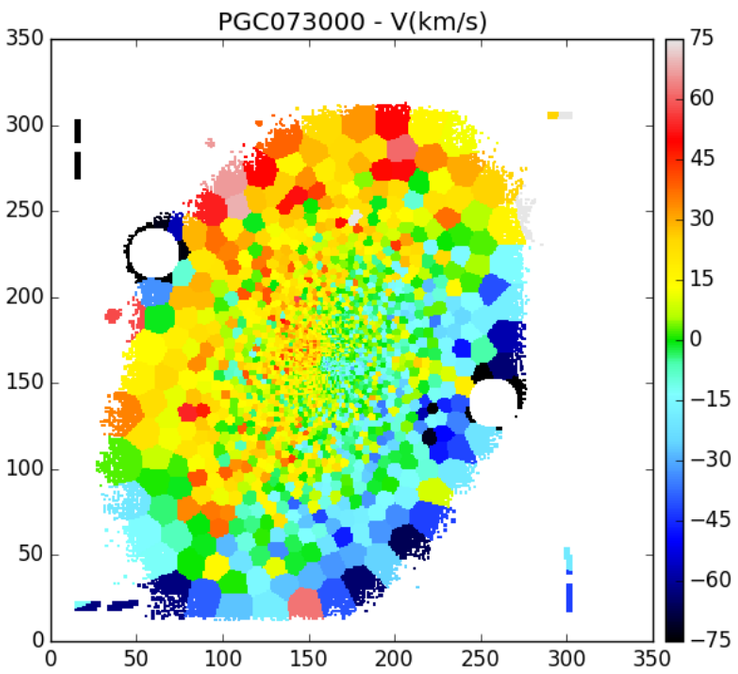
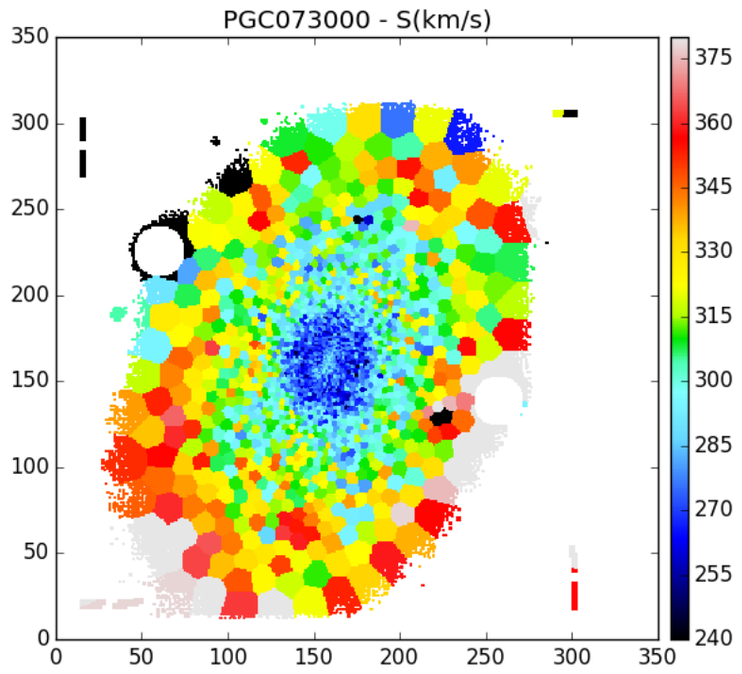


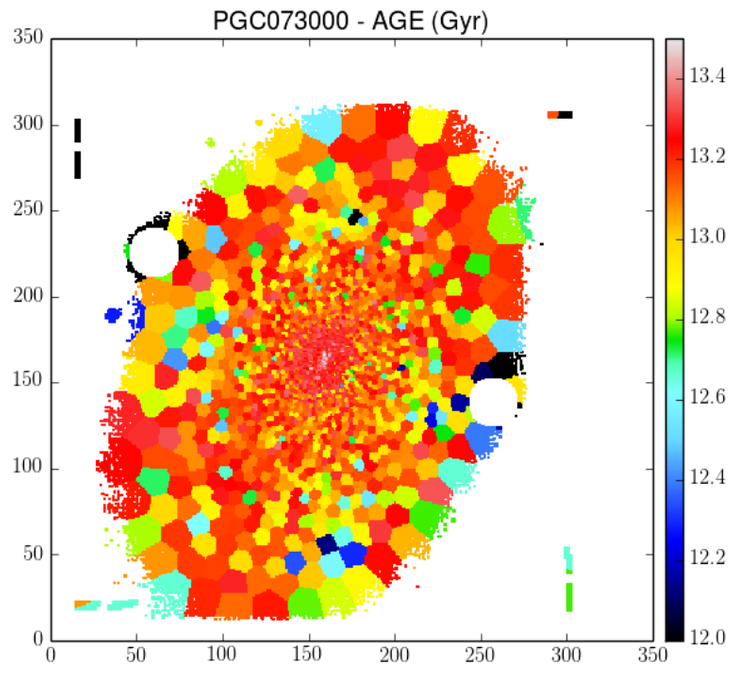
Image couleur MUSE

Vitesse

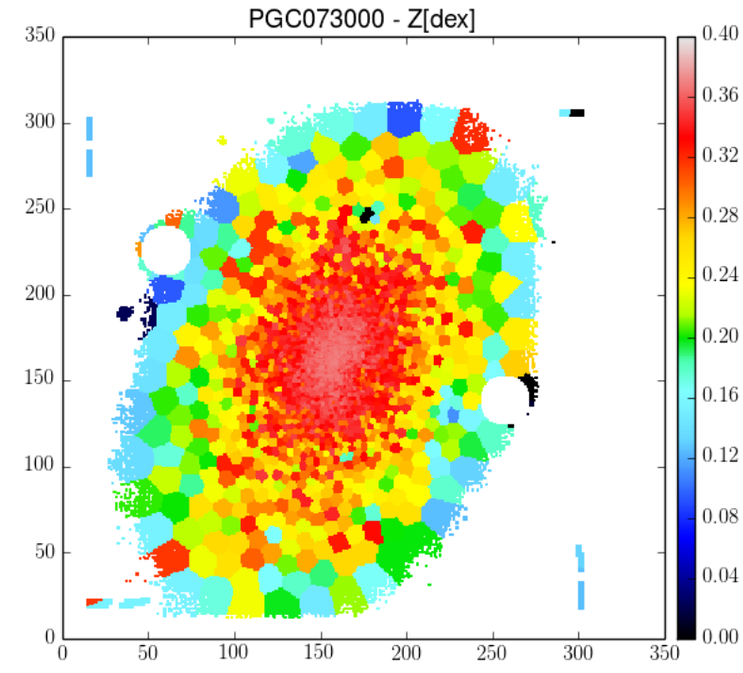


Dispersion





Age

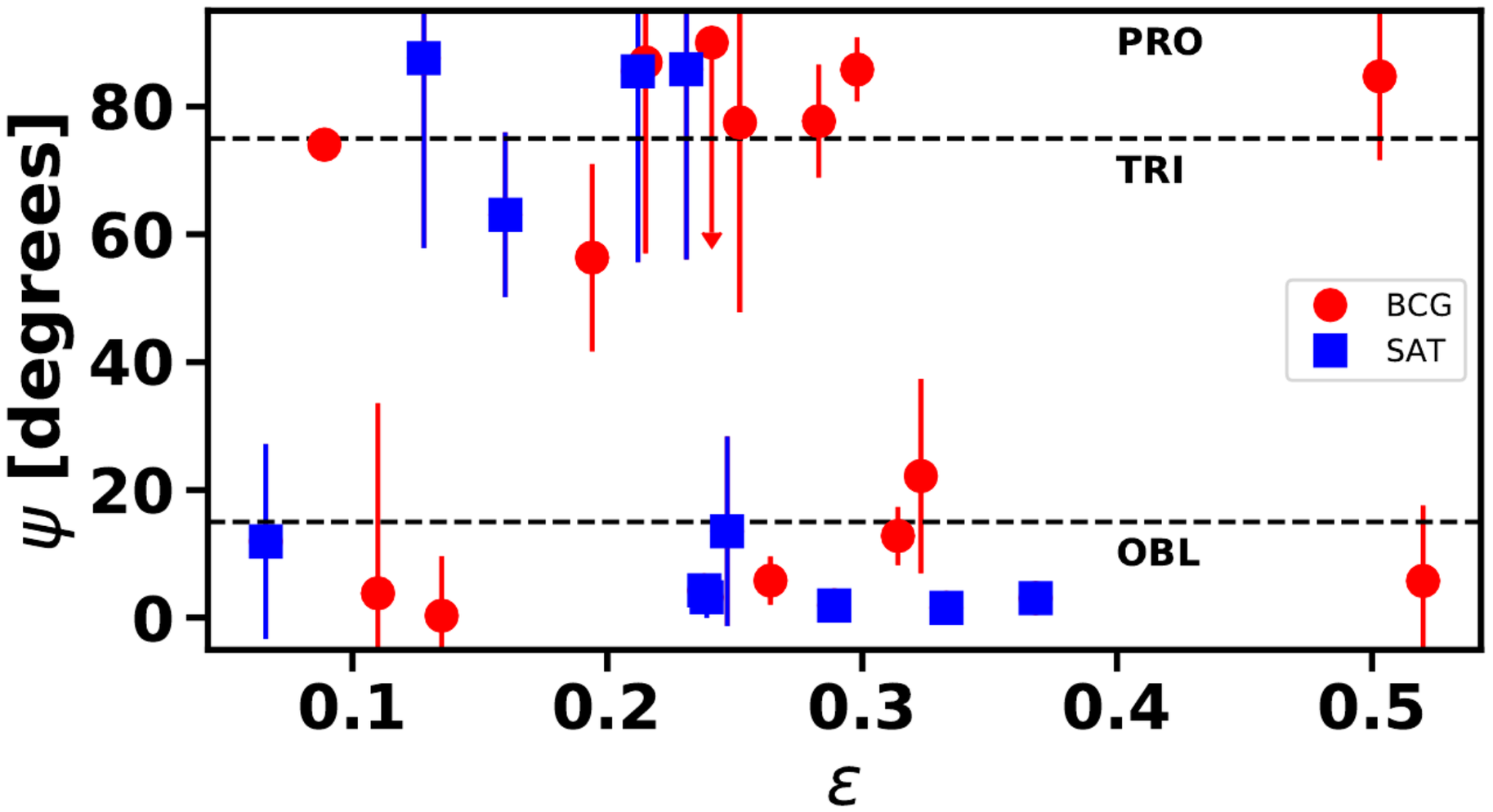


Metallicity

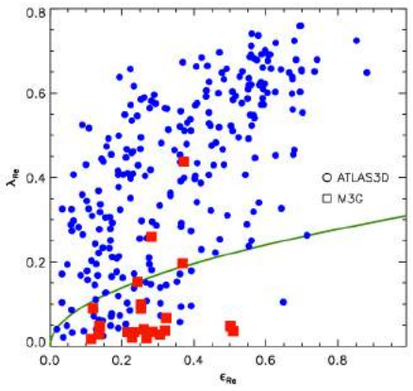
Premiers Résultats

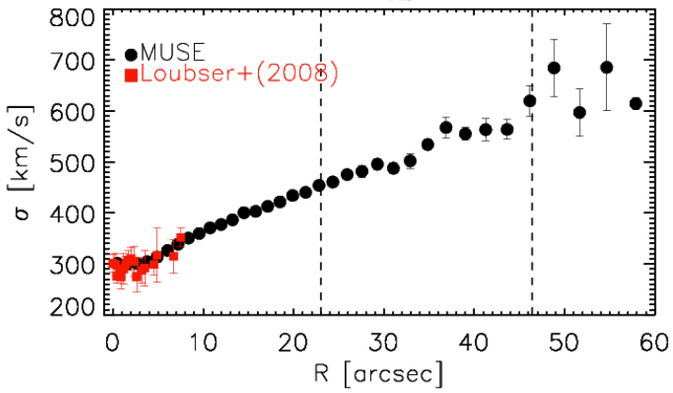
> ½ BCGs montre une rotation « prolate »

(un peu moins de 50 %, pour l'échantillon total)



Krajnović, EE, et al. 2018



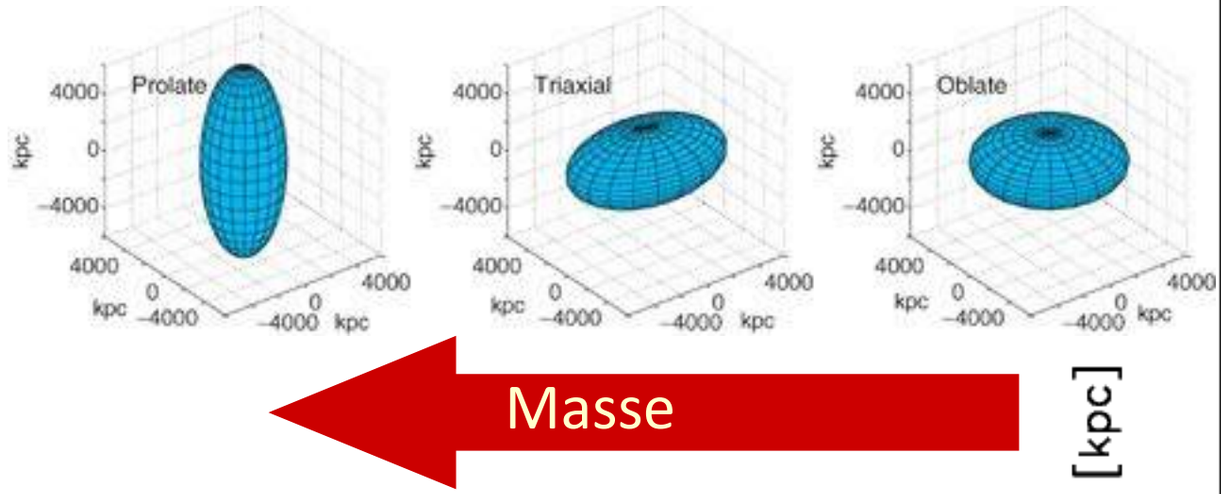


Premiers Résultats

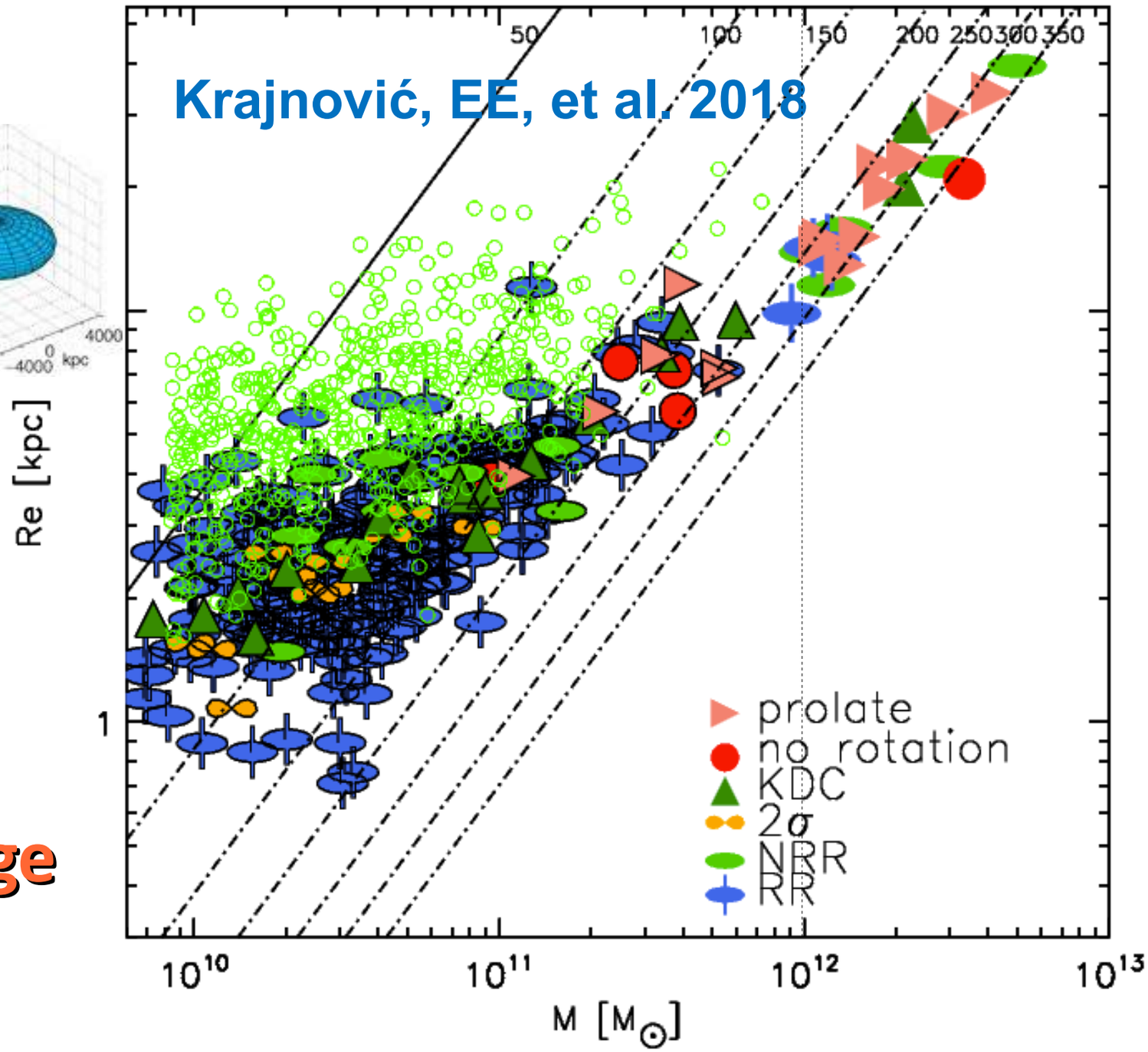
La morphologie des galaxies change avec la Masse

Oblat ⇒ Faiblement Triaxial ⇒ Prolat ?

Géométrie



Masse



La suite

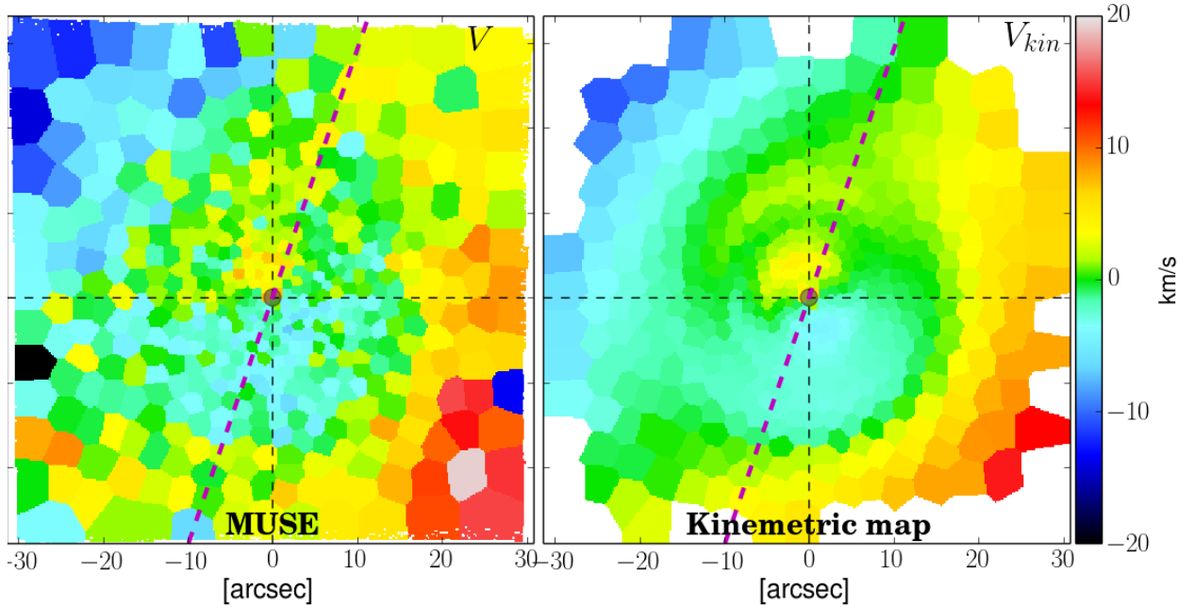
Modèles dynamiques

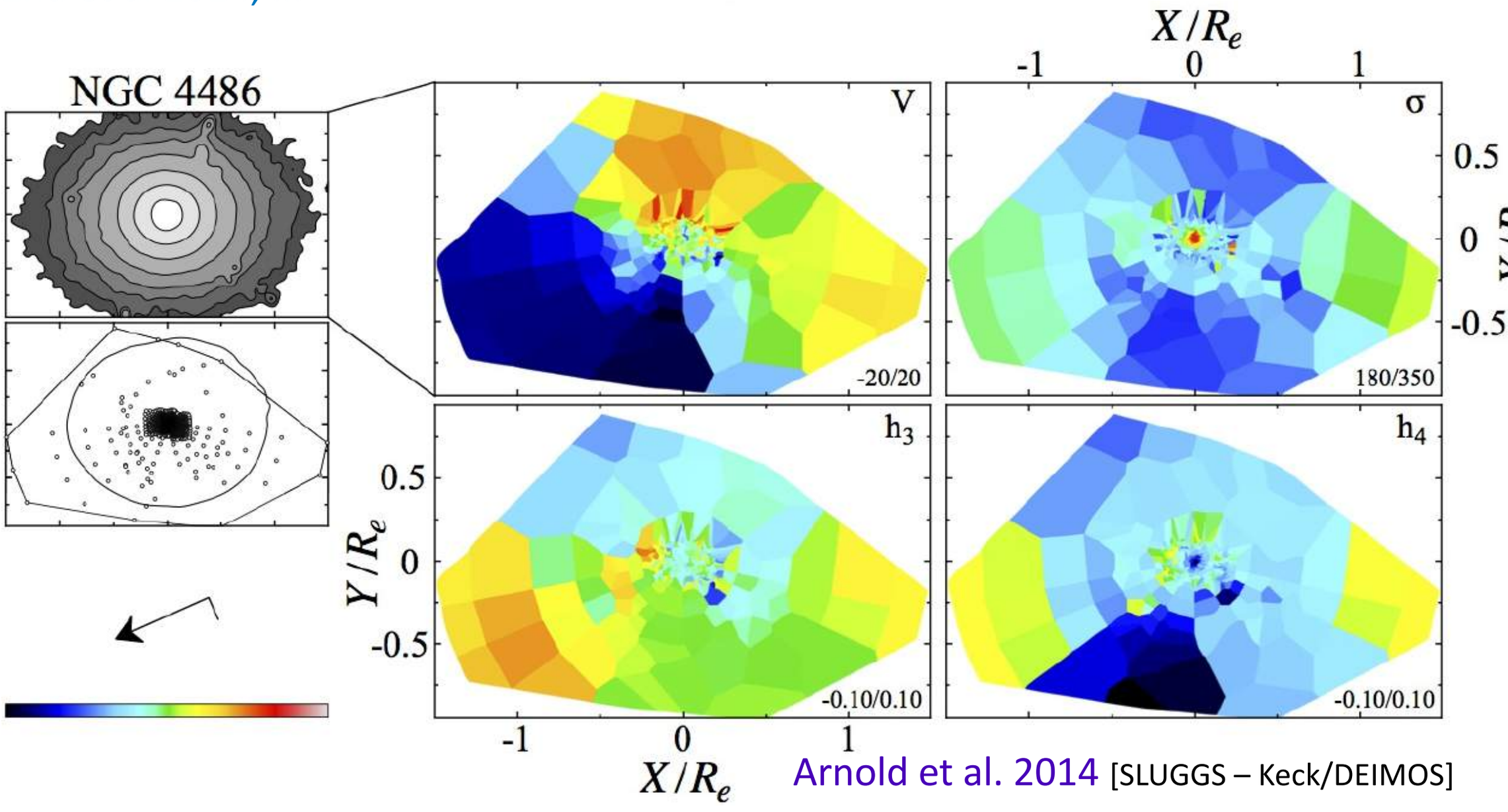
Histoire de l'assemblage

Rappel: M 87

Voir aussi Murphy et al. 2011,
Romanowsky et al. 2012,
Longobardi et al. 2013,
Agnello et al. 2014,
Zhu et al 2014, ...

Emsellem, Krajnović, Sarzi 2014





Arnold et al. 2014 [SLUGGS – Keck/DEIMOS]

Les galaxies de type précoce

Classifications historiques

Grande variété de structures morphologiques et dynamiques

E / S0s ⇒ confusion des types, difficile à séparer

Recommandation ⇒ ne **pas** utiliser, surtout à grand redshift !

Classification dynamique

Avec les instruments modernes (IFU) : efficace et pertinente

Relation morphologie-densité, principalement liée à la masse

Plan du Viriel enfin retrouvé

Processus de formation et d'assemblage

Perspective intéressante via le prisme du plan Masse – Rayon

Ex-situ versus **In-situ**

Complexité des parcours évolutifs

A très grande masse : fusions majeures sèches, forme prolate

Le futur ?

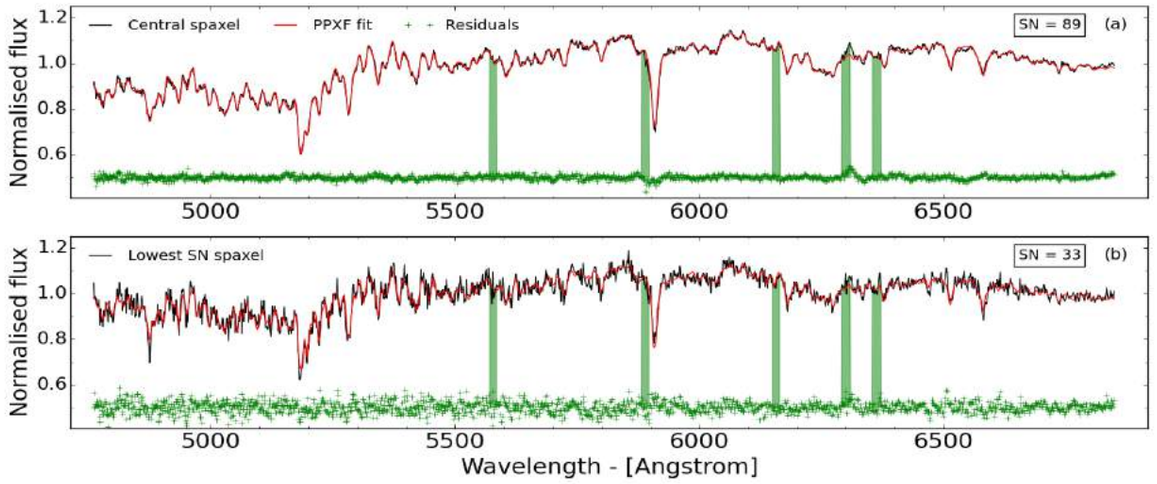
Instruments présents (MUSE, ALMA,…) et futurs (JWST, ELT,…)

Nouvelles campagnes (MaNGA, LSST, Euclid, ...)

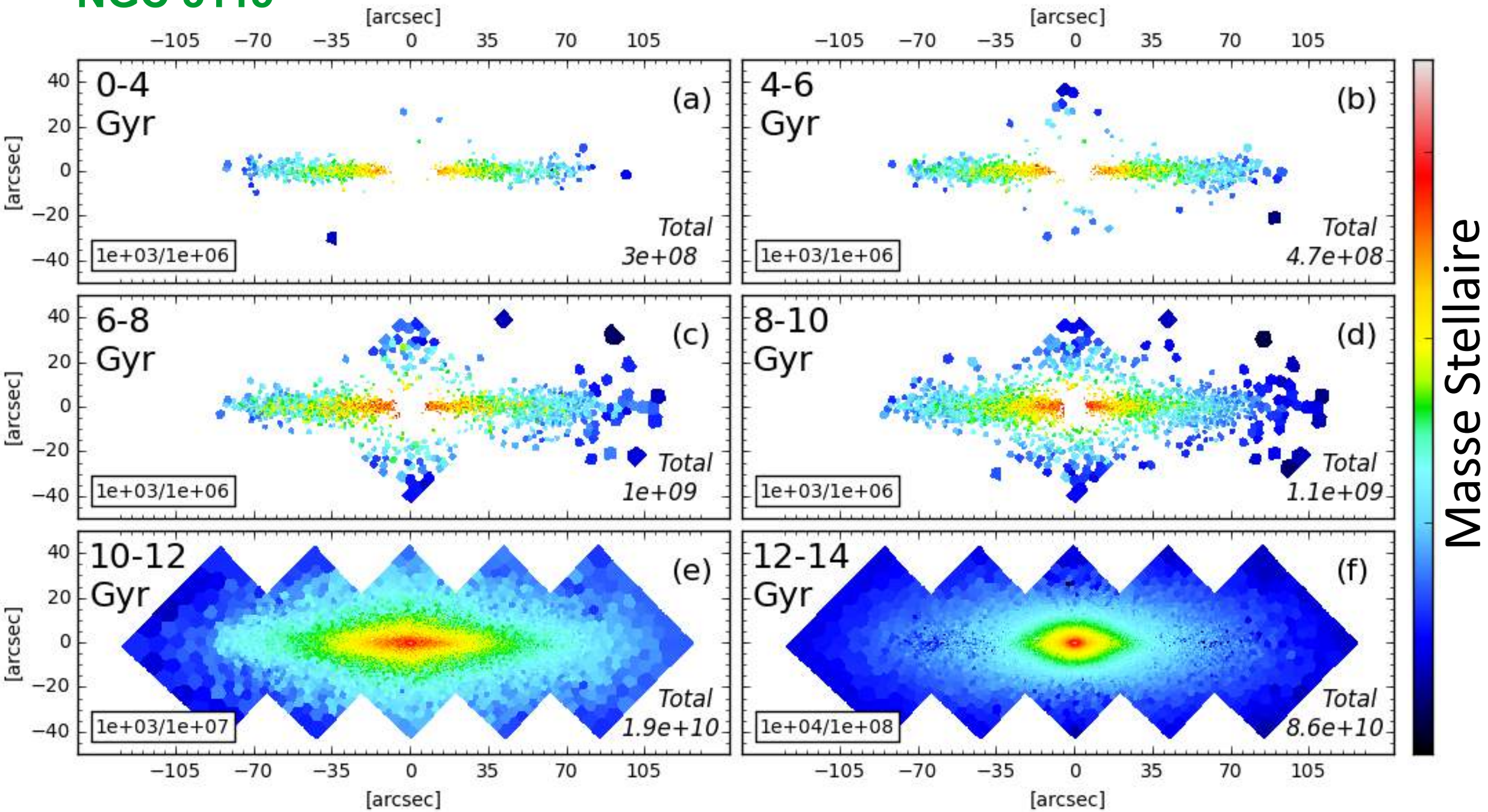
Besoin de simulations numériques (contexte cosmologique)

Décomposition spectrale

⇒ reconstituer l'évolution et l'assemblage



NGC 3115

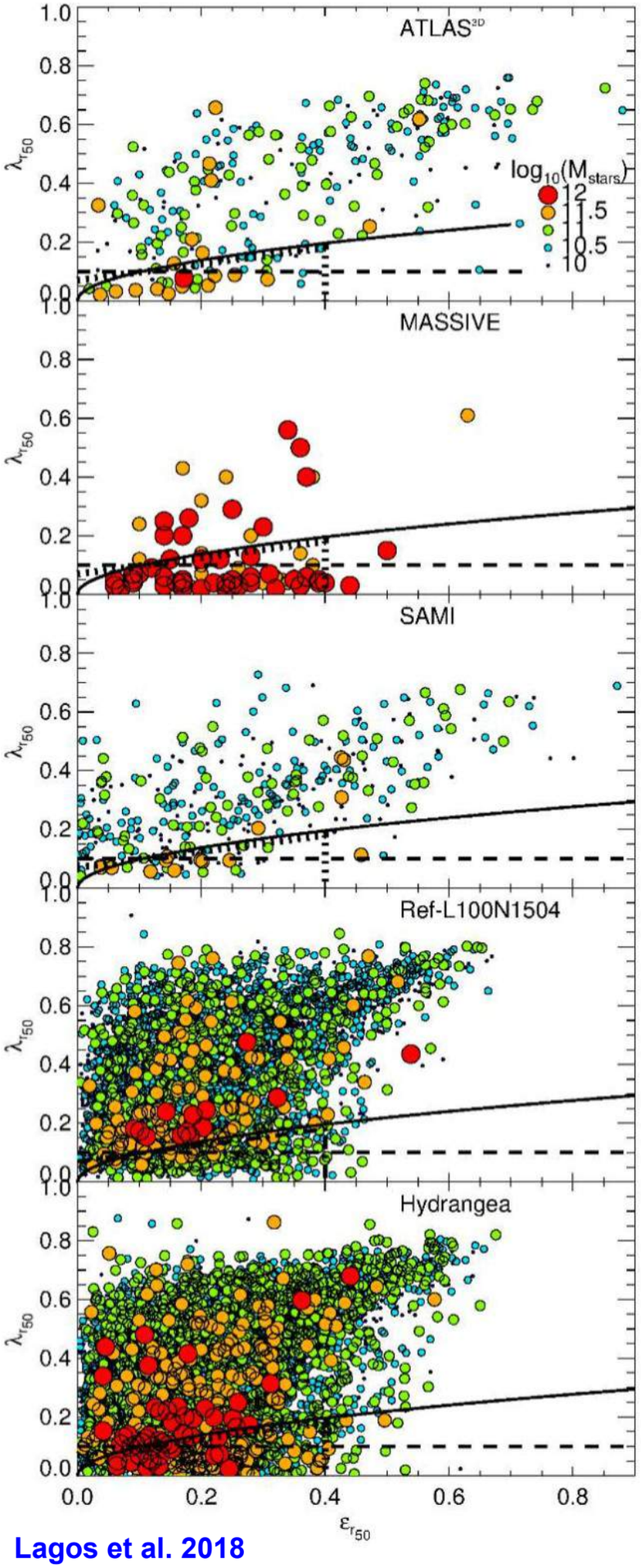


Guérou, EE et al. 2016

Galaxies de type précoce

Dynamique

& Processus de formation



Lagos et al. 2018