« Propriétés et évolution des galaxies »

David Elbaz (delbaz@cea.fr)

Service d'Astrophysique - CEA Saclay
Tel: 01 69 08 54 39

La bimodalité des galaxies

Master Recherche M2 Astronomie & Astrophysique

Enseignement thématique des parcours M2 - Galaxies

http://david.elbaz3.free.fr/master_m2

The Astrophysical Journal, 600:681–694, 2004 January 10

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

Ivan K. Baldry,[1] Karl Glazebrook,[1] Jon Brinkmann,[2] Željko Ivezić,[3] Robert H. Lupton,[3]
Robert C. Nichol,[4] and Alexander S. Szalay[1]
Received 2003 July 7; accepted 2003 September 25

ABSTRACT

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We trace the bimodality of the distribution from luminous to faint galaxies by fitting double Gaussians to the color functions separated in absolute magnitude bins. Color-magnitude (CM) relations are obtained for red and blue distributions (early- and late-type, predominantly field, galaxies) without using any cut in morphology. Instead, the analysis is based on the assumption of normal Gaussian distributions in color. We find that the CM relations are well fitted by a straight line plus a tanh function. Both relations can be described by a shallow CM trend (slopes of about -0.04, -0.05) plus a steeper transition in the average galaxy properties over about 2 mag. The midpoints of the transitions ($M_r = -19.8$ and -20.8 for the red and blue distributions, respectively) occur around $2 \times 10^{10}\ \mathcal{M}_\odot$ after converting luminosities to stellar mass. Separate luminosity functions are obtained for the two distributions. The red distribution has a more luminous characteristic magnitude and a shallower faint-end slope ($M^* = -21.5$, $\alpha = -0.8$) compared to the blue distribution ($\alpha \approx -1.3$, depending on the parameterization). These are approximately converted to galaxy stellar mass functions. The red distribution galaxies have a higher number density per magnitude for masses greater than about $3 \times 10^{10}\ \mathcal{M}_\odot$. Using a simple merger model, we show that the differences between the two functions are consistent with the red distribution being formed from major galaxy mergers.

Subject headings: galaxies: evolution — galaxies: fundamental parameters — galaxies: luminosity function, mass function — galaxies: photometry

On-line material: color figures

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

Ivan K. Baldry,[1] Karl Glazebrook,[1] Jon Brinkmann,[2] Željko Ivezić,[3] Robert H. Lupton,[3]
Robert C. Nichol,[4] and Alexander S. Szalay[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\rm Petro} < r_{\rm limit}, \tag{1}$$

$$\mu_{r,50} < \mu_{r,50,{\rm limit}}, \tag{2}$$

$$r_{\rm PSF} - r_{\rm model} > s_{\rm limit}. \tag{3}$$

$$0.004 < z < 0.080$$

$$M_r = r - k_r - 5 \log (D_L / 10 \text{ pc}), \tag{4}$$

$$C_{ur} = (u_{\rm model} - k_u) - (r_{\rm model} - k_r). \tag{5}$$

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

IVAN K. BALDRY,[1] KARL GLAZEBROOK,[1] JON BRINKMANN,[2] ŽELJKO IVEZIĆ,[3] ROBERT H. LUPTON,[3]
ROBERT C. NICHOL,[4] AND ALEXANDER S. SZALAY[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\text{Petro}} < r_{\text{limit}} \qquad (1)$$

''Petrosian'' magnitude = flux in an aperture that depends on the surface-brightness profile of the object, a modified version of the flux quantity defined by Petrosian (1976)

For galaxy photometry, measuring flux is more difficult than for stars, because galaxies do not all have the same radial surface brightness profile, and have no sharp edges. In order to avoid biases, it is necessary to measure a constant fraction of the total light, independent of the position and distance of the object. To satisfy these requirements, the SDSS has adopted a modified form of the Petrosian (1976) system, measuring galaxy fluxes within a circular aperture whose radius is defined by the shape of the azimuthally averaged light profile.

The Petrosian radius ***r*****P** is defined as the radius at which $R_P(r_P) = 0.2$ with:

$$\mathscr{R}_{\rm P}(r) \equiv \frac{\int_{0.8r}^{1.25r} dr'\, 2\pi r' I(r') / [\pi(1.25^2 - 0.8^2) r^2]}{\int_0^r dr'\, 2\pi r' I(r') / (\pi r^2)} ,$$

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

Ivan K. Baldry,[1] Karl Glazebrook,[1] Jon Brinkmann,[2] Željko Ivezić,[3] Robert H. Lupton,[3]
Robert C. Nichol,[4] and Alexander S. Szalay[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\mathrm{Petro}} < r_{\mathrm{limit}} = 17.77 \quad (1)$$

$$\mu_{r,50} < \mu_{r,50,\mathrm{limit}} = 24.5 \text{ mag arcsec}^{-2} \quad (2)$$

The second equation sets the surface-brightness limit ($\mu_{r,50}$ is the mean surface brightness within the Petrosian half-light radius). This is necessary to avoid targeting too many objects that are instrumental artifacts.

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

Ivan K. Baldry,[1] Karl Glazebrook,[1] Jon Brinkmann,[2] Željko Ivezić,[3] Robert H. Lupton,[3]
Robert C. Nichol,[4] and Alexander S. Szalay[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\rm Petro} < r_{\rm limit} = 17.77 \quad (1)$$

$$\mu_{r,50} < \mu_{r,50,{\rm limit}} = 24.5 \text{ mag arcsec}^{-2} \quad (2)$$

$$r_{\rm PSF} - r_{\rm model} > s_{\rm limit} = 0.3 \quad (3)$$

La troisième équation vise à séparer les galaxies des étoiles:

r_{PSF}= magnitude de la partie centrale à l'intérieur de la PSF (point spread function)

r_{model}= magnitude obtenue en ajustant le profil de brillance de la galaxie avec un profil de de Vaucouleurs (pour le bulbe) et un profil exponentiel (pour le disque)

On exige que les objets soient au moins 0.3 magnitudes plus brillants que des sources ponctuelles

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

IVAN K. BALDRY,[1] KARL GLAZEBROOK,[1] JON BRINKMANN,[2] ŽELJKO IVEZIĆ,[3] ROBERT H. LUPTON,[3]
ROBERT C. NICHOL,[4] AND ALEXANDER S. SZALAY[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

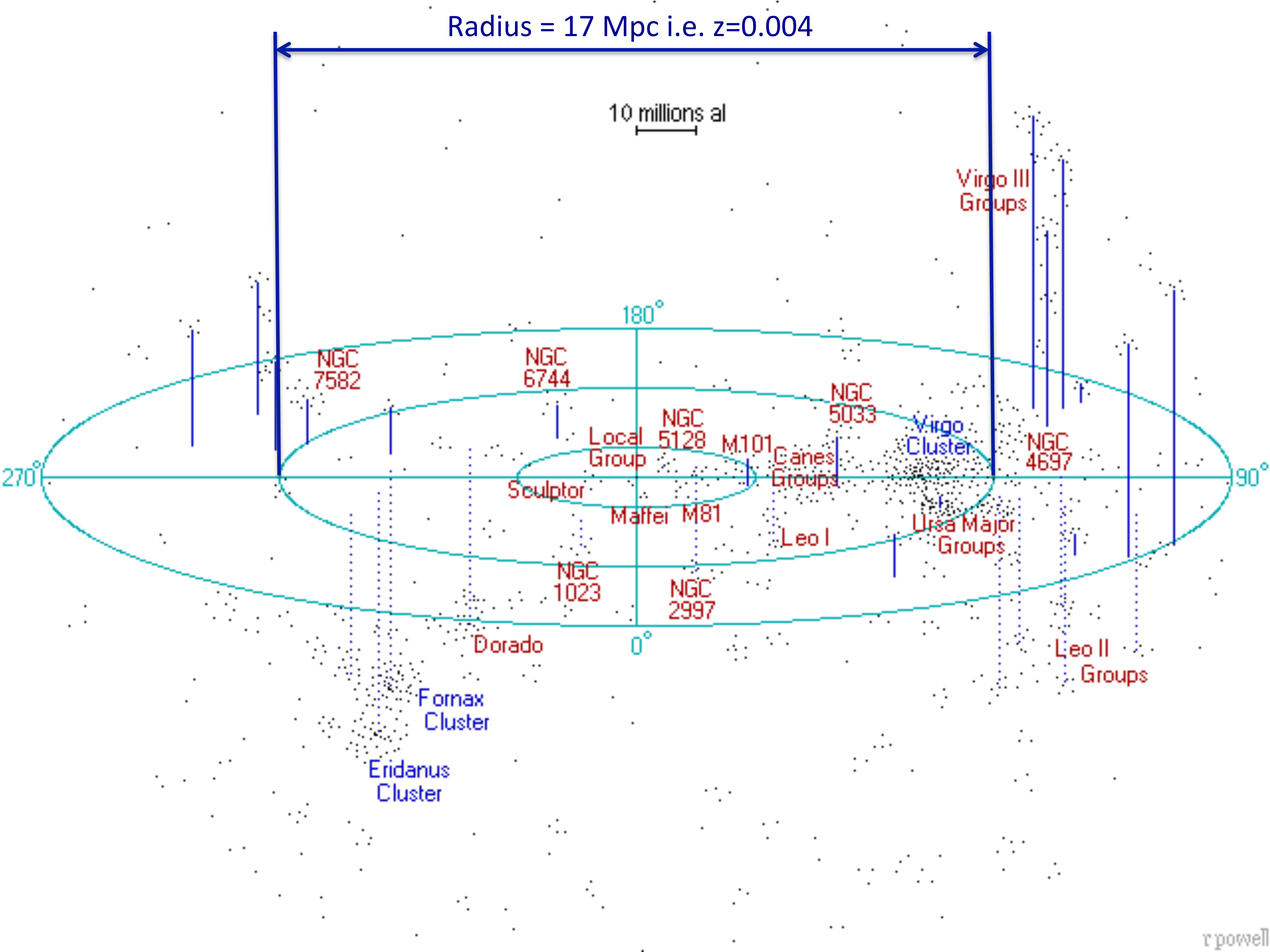
$$r_{\rm Petro} < r_{\rm limit} = 17.77 \quad (1)$$

$$\mu_{r,50} < \mu_{r,50,{\rm limit}} = 24.5 \text{ mag arcsec}^{-2} \quad (2)$$

$$r_{\rm PSF} - r_{\rm model} > s_{\rm limit} = 0.3 \quad (3)$$

$$\boxed{0.004 < z < 0.080}$$

Pourquoi 0.004 < z ?



Radius = 17 Mpc i.e. z=0.004
10 millions al
Virgo III Groups
180°
NGC 7582
NGC 6744
NGC 5033
NGC 5128
Local Group
M101
Canes Groups
Virgo Cluster
NGC 4697
270°
90°
Sculptor
Maffei
M81
Leo I
Ursa Major Groups
NGC 1023
NGC 2997
Dorado
0°
Leo II Groups
Fornax Cluster
Eridanus Cluster
r powell

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

Ivan K. Baldry,[1] Karl Glazebrook,[1] Jon Brinkmann,[2] Željko Ivezić,[3] Robert H. Lupton,[3]
Robert C. Nichol,[4] and Alexander S. Szalay[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

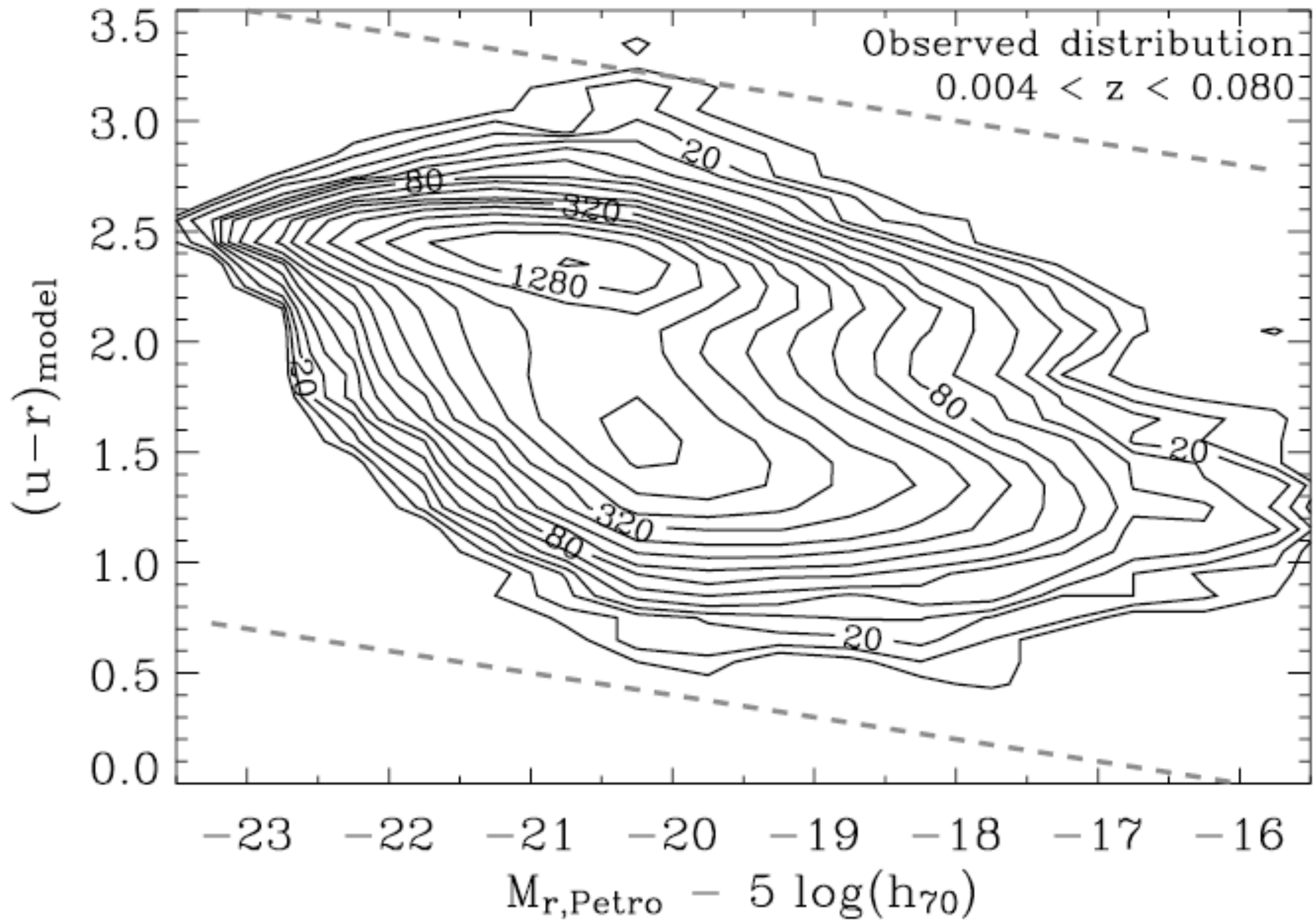
$$r_{\rm Petro} < r_{\rm limit} = 17.77 \quad (1)$$

$$\mu_{r,50} < \mu_{r,50,\rm limit} = 24.5 \text{ mag arcsec}^{-2} \quad (2)$$

$$r_{\rm PSF} - r_{\rm model} > s_{\rm limit} = 0.3 \quad (3)$$

$$\boxed{0.004 < z < 0.080}$$

Pourquoi z < 0.080 ?



Contours= nombre de galaxies par intervalle de magnitude

FIG. 1.—Observed bivariate distribution of the sample in rest-frame color vs. absolute magnitude. The contours are determined for galaxy number counts in 0.1 color × 0.5 mag bins (with a total of 66,846 galaxies). The contour levels are on a logarithmic scale, starting at 10 and doubling every two contours. The dashed lines represent the limits used in the double-Gaussian fitting described in § 4.

3.1. *Correcting for Incompleteness*

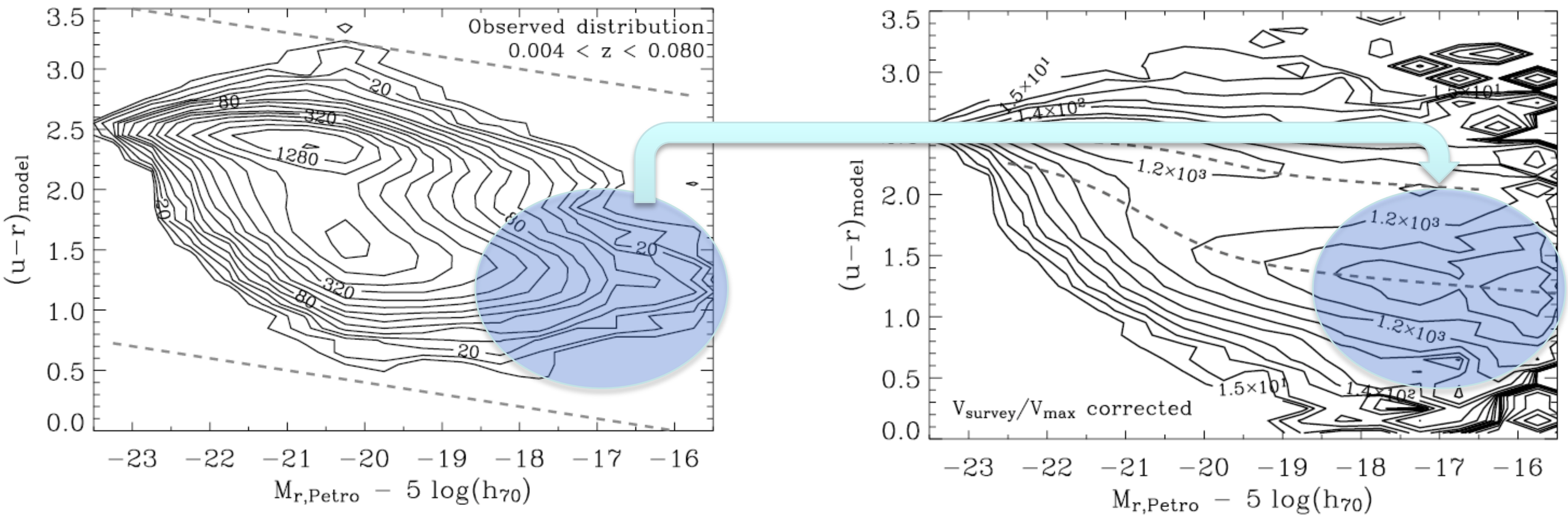
Before the distribution is analyzed, there are two significant incompleteness issues to deal with:[9] (1) galaxies of a given absolute magnitude and spectral type can be observed only within a certain redshift range, which in some cases is much less than the redshift range of the sample, and (2) some galaxies are not observed because of fiber collisions.

To correct for the first issue, we weight each galaxy by a $V_{\rm survey}/V_{\rm max}$ factor before recomputing the bivariate distribution, where $V_{\rm max}$ is the maximum volume over which the galaxy could be observed within the sample redshift range ($0.004 < z < 0.08$, $V_{\rm survey} = 9.3 \times 10^6$ Mpc^3). We calculate $V_{\rm max}$ by iterating to a solution for the k-correction at $z_{\rm min}$ and $z_{\rm max}$. The factor, $V_{\rm survey}/V_{\rm max}$, varies from about 1.4 for the brightest galaxies (set by $r > 13.5$), down to 1.01 at $M_r \approx -21$, up to 450/650 for the faintest galaxies (set by $r < 17.5/17.77$).

($V_{\rm survey}/V_{\rm max} \lesssim 1.2$). Note also that this correction factor is principally a function of M_r, with little dependence on color at these low redshifts (r-selected sample), which means that this correction is important for the determination of the luminosity functions but *not* for the CM relations.

Après correction de complétude

**le nombre des galaxies
les moins brillantes était artificiellement sous-estimé**



Contours= nombre de galaxies par intervalle de magnitude

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

IVAN K. BALDRY,[1] KARL GLAZEBROOK,[1] JON BRINKMANN,[2] ŽELJKO IVEZIĆ,[3] ROBERT H. LUPTON,[3]
ROBERT C. NICHOL,[4] AND ALEXANDER S. SZALAY[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\rm Petro} < r_{\rm limit} = 17.77 \quad (1)$$

$$\mu_{r,50} < \mu_{r,50,\rm limit} = 24.5 \text{ mag arcsec}^{-2} \quad (2)$$

$$r_{\rm PSF} - r_{\rm model} > s_{\rm limit} = 0.3 \quad (3)$$

$$0.004 < z < 0.080$$

$$M_r = r - k_r - 5\log(D_L/\ 10\ \text{pc}), \quad (4)$$

r = magnitude apparente

5 log(D_L/10pc) = module de distance pour passer en magnitude absolue

k_r= correction-k sur la magnitude r pour ramener la magnitude à la longueur d'onde au repos

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

IVAN K. BALDRY,[1] KARL GLAZEBROOK,[1] JON BRINKMANN,[2] ŽELJKO IVEZIĆ,[3] ROBERT H. LUPTON,[3] ROBERT C. NICHOL,[4] AND ALEXANDER S. SZALAY[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\mathrm{Petro}} < r_{\mathrm{limit}} = 17.77 \tag{1}$$

$$\mu_{r,50} < \mu_{r,50,\mathrm{limit}} = 24.5 \text{ mag arcsec}^{-2} \tag{2}$$

$$r_{\mathrm{PSF}} - r_{\mathrm{model}} > s_{\mathrm{limit}} = 0.3 \tag{3}$$

$$0.004 < z < 0.080$$

$$M_r = r - k_r - 5 \log (D_L / 10 \text{ pc}), \tag{4}$$

$$C_{ur} = (u_{\mathrm{model}} - k_u) - (r_{\mathrm{model}} - k_r). \tag{5}$$

Couleur u-r dans le référentiel au repos donc avec les corrections k en bandes u et r

QUANTIFYING THE BIMODAL COLOR-MAGNITUDE DISTRIBUTION OF GALAXIES

Ivan K. Baldry,[1] Karl Glazebrook,[1] Jon Brinkmann,[2] Željko Ivezić,[3] Robert H. Lupton,[3]
Robert C. Nichol,[4] and Alexander S. Szalay[1]

We analyze the bivariate distribution, in color versus absolute magnitude ($u-r$ vs. M_r), of a low-redshift sample of galaxies from the Sloan Digital Sky Survey (2400 deg^2, $0.004 < z < 0.08$, $-23.5 < M_r < -15.5$). We

$$r_{\rm Petro} < r_{\rm limit} = 17.77 \tag{1}$$

$$\mu_{r,50} < \mu_{r,50,\rm limit} = 24.5 \text{ mag arcsec}^{-2} \tag{2}$$

$$r_{\rm PSF} - r_{\rm model} > s_{\rm limit} = 0.3 \tag{3}$$

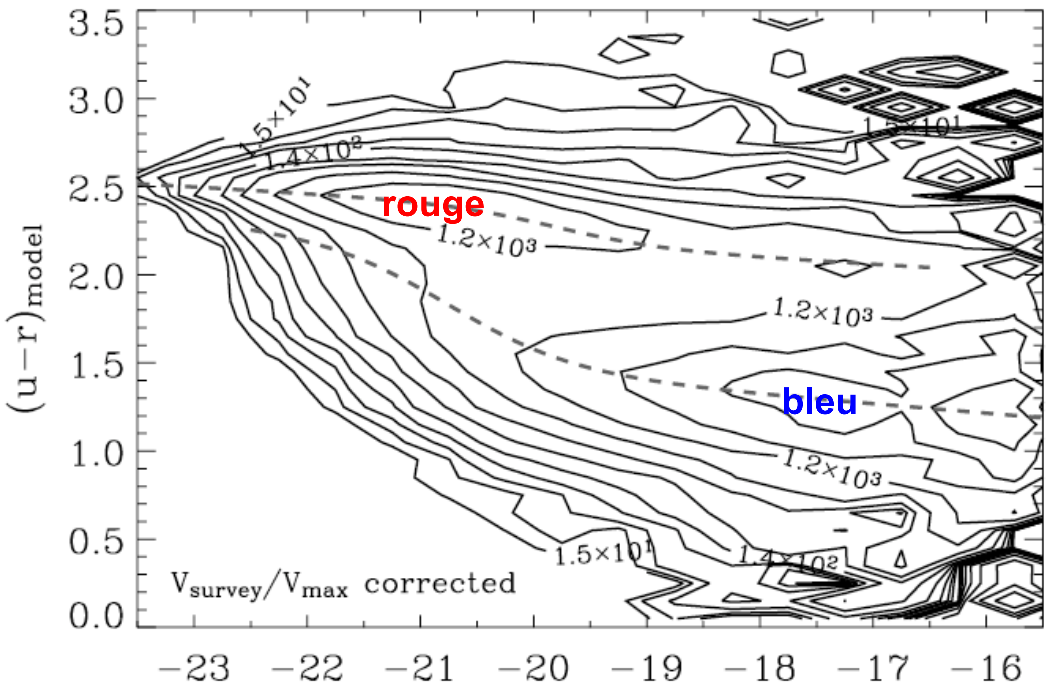
$$0.004 < z < 0.080$$

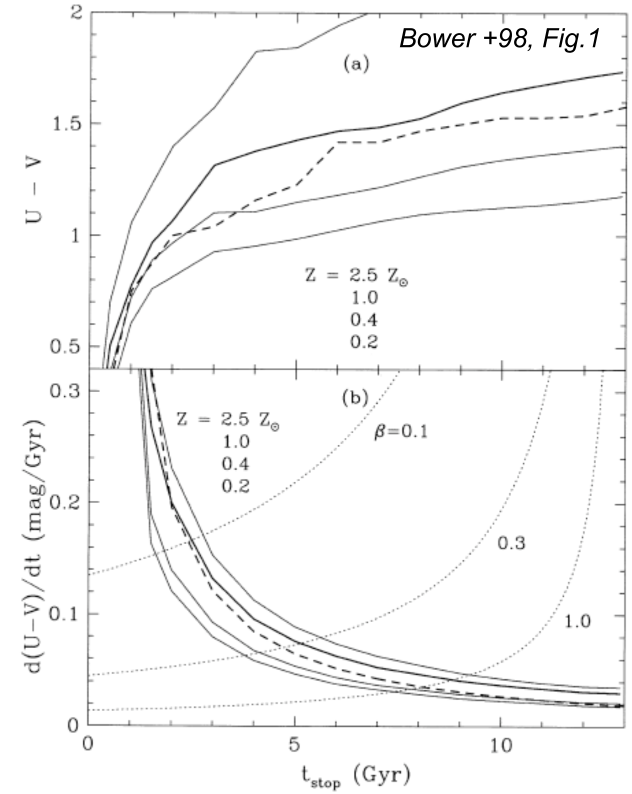
$$M_r = r - k_r - 5\log(D_L/\ 10\ {\rm pc}), \tag{4}$$

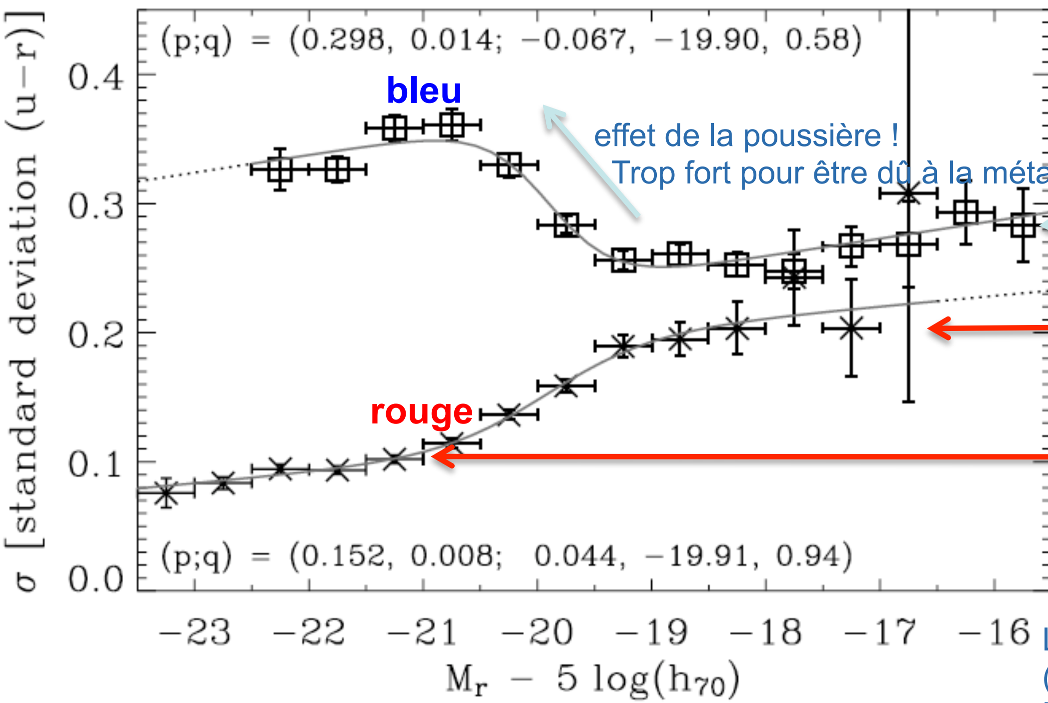
$$C_{ur} = (u_{\rm model} - k_u) - (r_{\rm model} - k_r). \tag{5}$$

$$\log(\mathcal{M}/L_r) = a + bC_{ur}, \tag{12}$$

La conversion de la luminosité en bande r, L_r, en masse d'étoiles dépend du type d'étoiles. La couleur u-r permet d'avoir une idée approximative de la population stellaire dominante et donc du rapport M/L_r à appliquer pour déduire la masse stellaire des galaxies







effet de la poussière !
Trop fort pour être dû à la métallicité.

Plus grande dispersion
car ≠ d'âges des populations stellaires

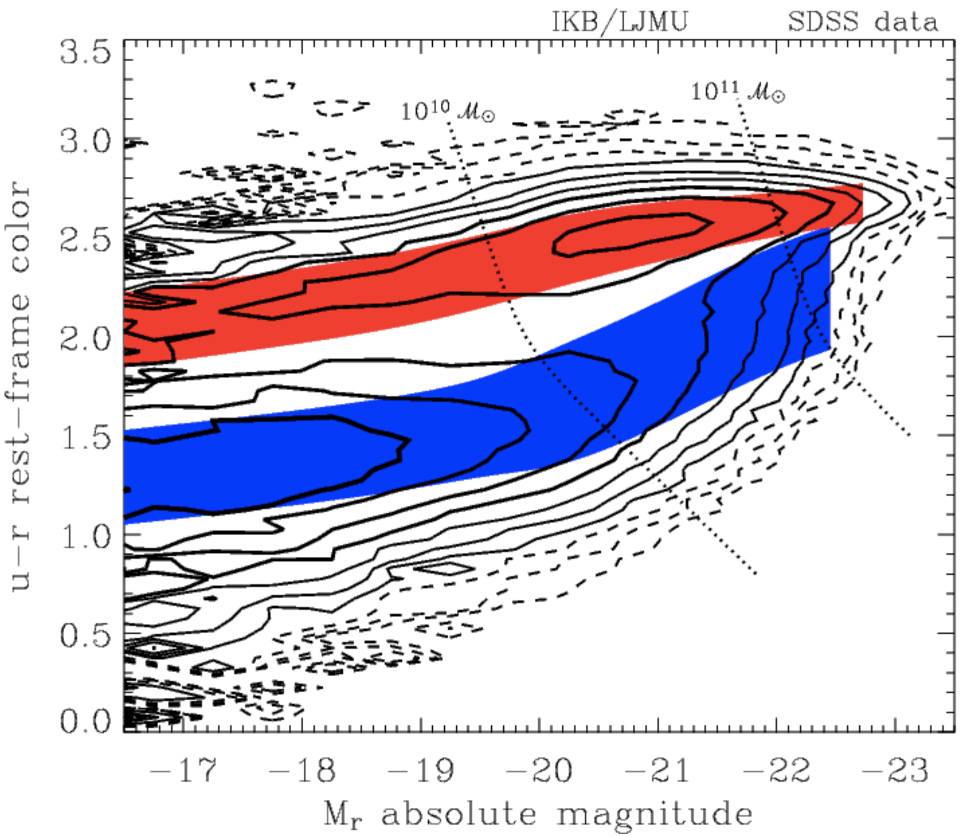
Forte dispersion car pollution par étoiles jeunes, les gals E moins massives ont eu de la formation stellaire récente

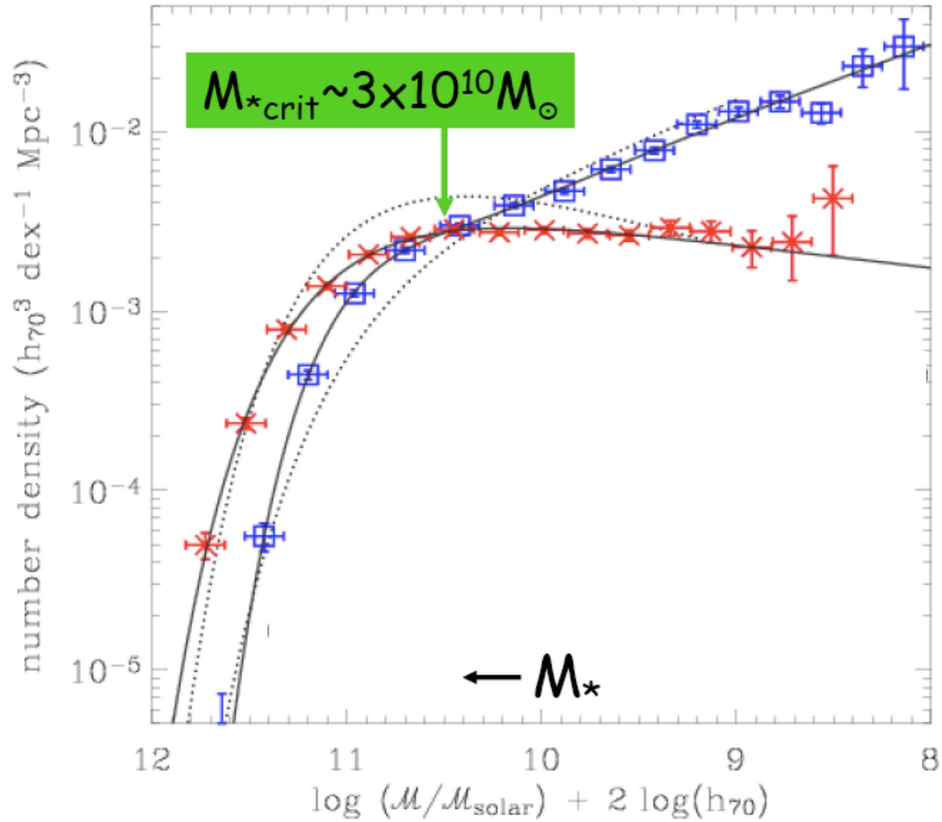
Faible dispersion : pas d'effet d'âges des populations stellaires, mais rougissement dû à plus grande métallicité des galaxies + lumineuses (OK avec faible pente)

Les galaxies B au plus fort taux de formation d'étoiles (les + lumineuses) sont les plus afectées par l'extinction. Normal ? Oui... Car densité plus grande !

La bimodalité des galaxies

The black solid and dashed contours represent the number density of galaxies: logarithmically spaced with four contours per factor of ten. The distribution is called bimodal because if a color histogram is plotted there are two peaks corresponding to a red sequence (generally early types) and a blue sequence (late types). The red and blue shaded regions show the mean and dispersion (plus/minus 1 sigma) of the red and blue sequences based on the fitting described by Baldry et al. (2004).

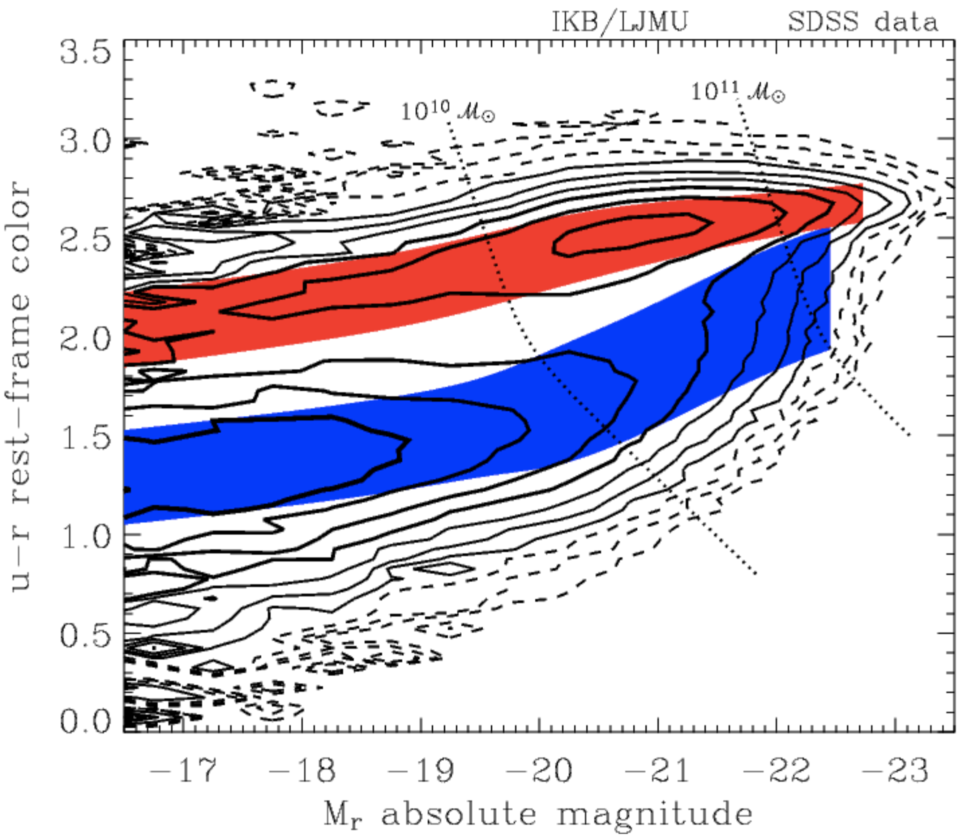


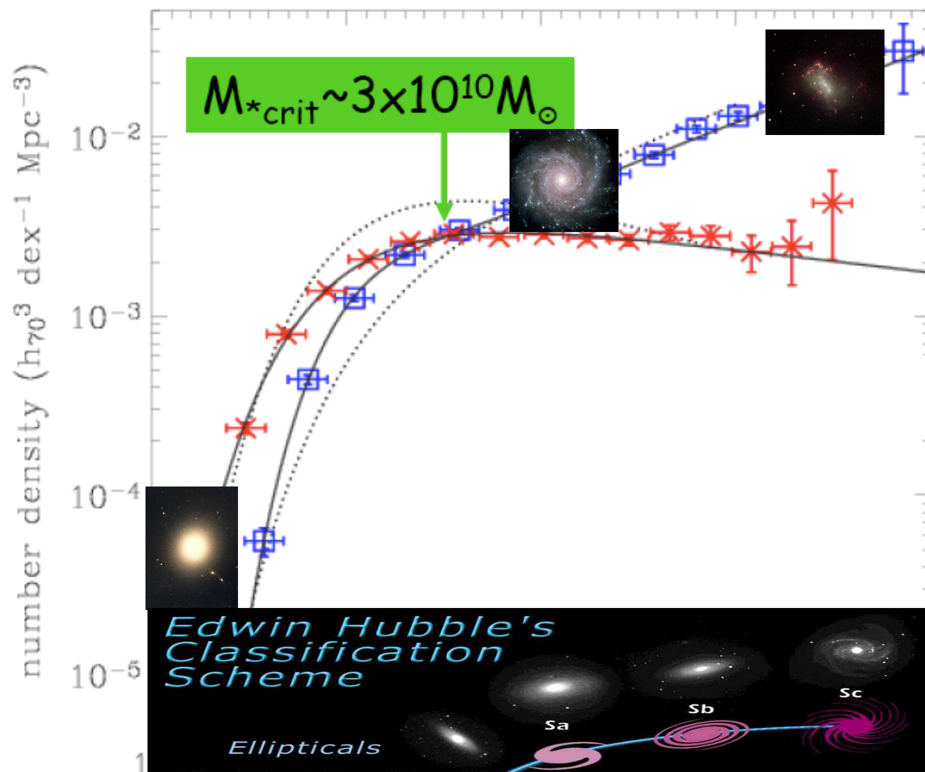


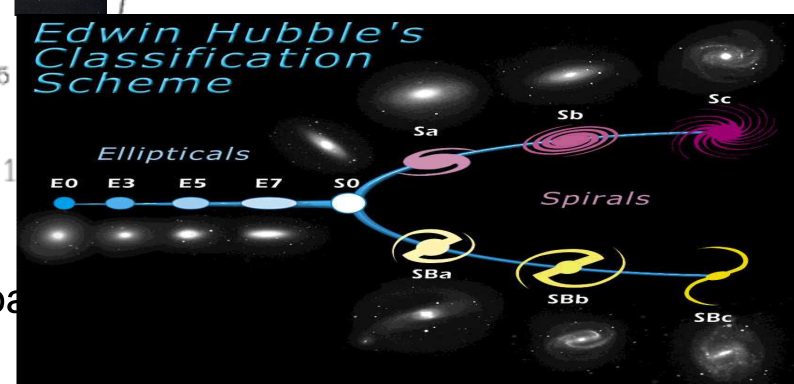
Baldry et al. (2004). Galaxies from the Sloan Digital Sky Survey at z<0.1

La bimodalité des galaxies

The black solid and dashed contours represent the number density of galaxies: logarithmically spaced with four contours per factor of ten. The distribution is called bimodal because if a color histogram is plotted there are two peaks corresponding to a red sequence (generally early types) and a blue sequence (late types). The red and blue shaded regions show the mean and dispersion (plus/minus 1 sigma) of the red and blue sequences based on the fitting described by Baldry et al. (2004).







Baldry et al. (2004). Galaxies from the Sloa

« Quantifying the bimodal color-magnitude distribution of galaxies »

Baldry, Y.K., Glazebrook, K., Brinkmann, J. et al.
2004, Astrophysical Journal 600, 681

les 5 étapes-clés

1. **Contexte & question centrale**

question centrale:
classer les galaxies en catégories et en déduire leur histoire passée

- *contexte:*
• bimodalité dans la relation couleur - magnitude entre spirales et elliptiques connue avant, mais séparation en types morphologiques (ou Hdelta, D4000) et utilisation de magnitudes apparentes.
• les galaxies rouges sont dans les régions les plus denses en galaxies -> suggère un lien avec leur histoire
• la masse des galaxies rouges a augmenté de z=1 à aujourd'hui, donc elles ne résultent pas d'une formation très tôt, mais ont dû fusionner (dry mergers, Bell +03)

2. **Apport de l'étude, nouveauté** *lum intrinsèques pour gd nb de gals*

→ observations
→ modélisation/théorie
→ les deux ?

- Avec les grands relevés spectroscopiques, il est devenu possible d'établir une relation couleur - magnitude absolue.
- SDSS: magnitudes et redshifts à z<0.1 (univers local) pour 66 846 galaxies.

3. **Résultat principal**

– Nette séparation en luminosité absolue des galaxies rouges et bleues
– Coupure à 2-3 x 10^{10} Msol
– Explication proposée : fusions majeures

4. **Limites de l'étude**

- effets d'ouverture, d'extinction
- interprétation fusions majeures suppose que la formation d'étoiles s'arrête ensuite : mergers = killers... Pas démontré.
- comment expliquer l'absence de galaxies « vertes » ? (green valley)
- si les galaxies massives sont rouges aujourd'hui, cela peut être parce qu'elle étaient bleues dans le passé et non pas uniquement par mergers.

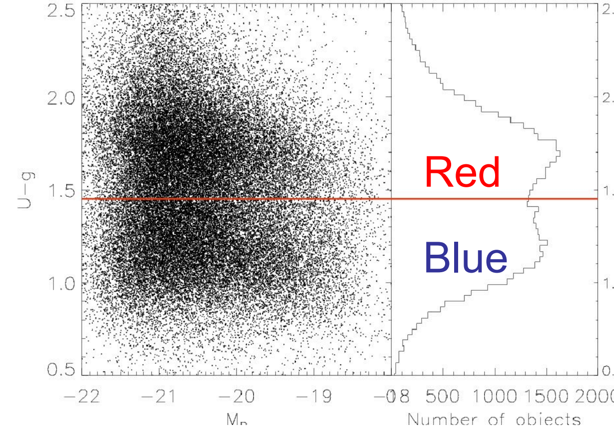
5. **Quelle suite ?**

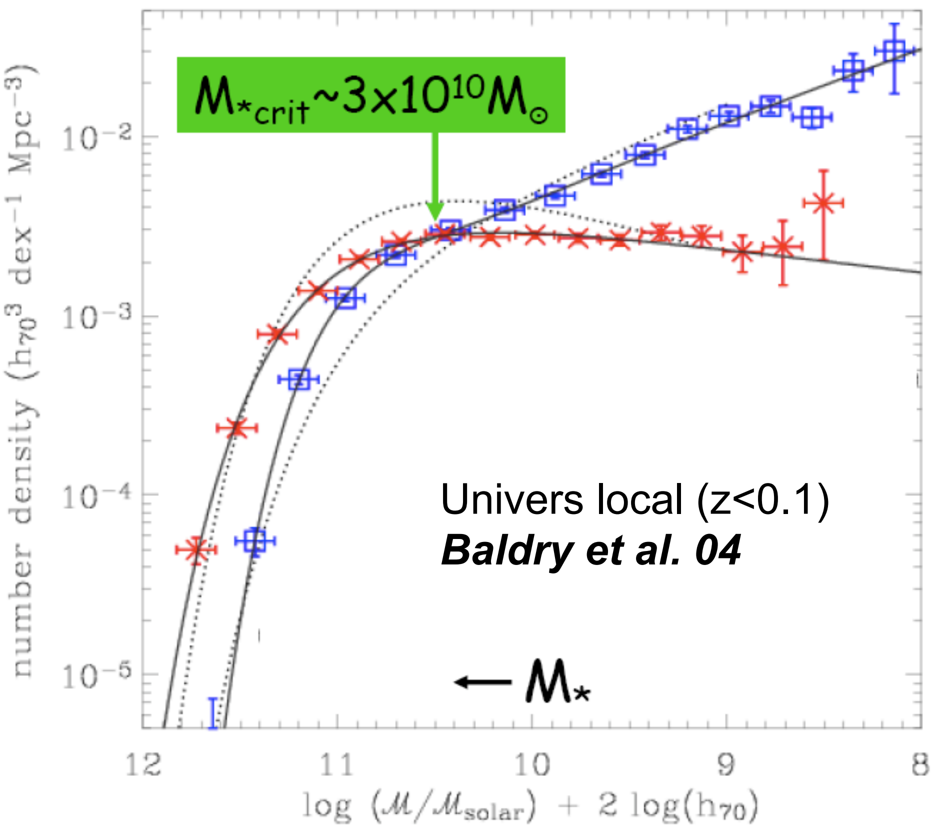
→ nouvelle problématique, nouvelles observations requises, adapter les modèles

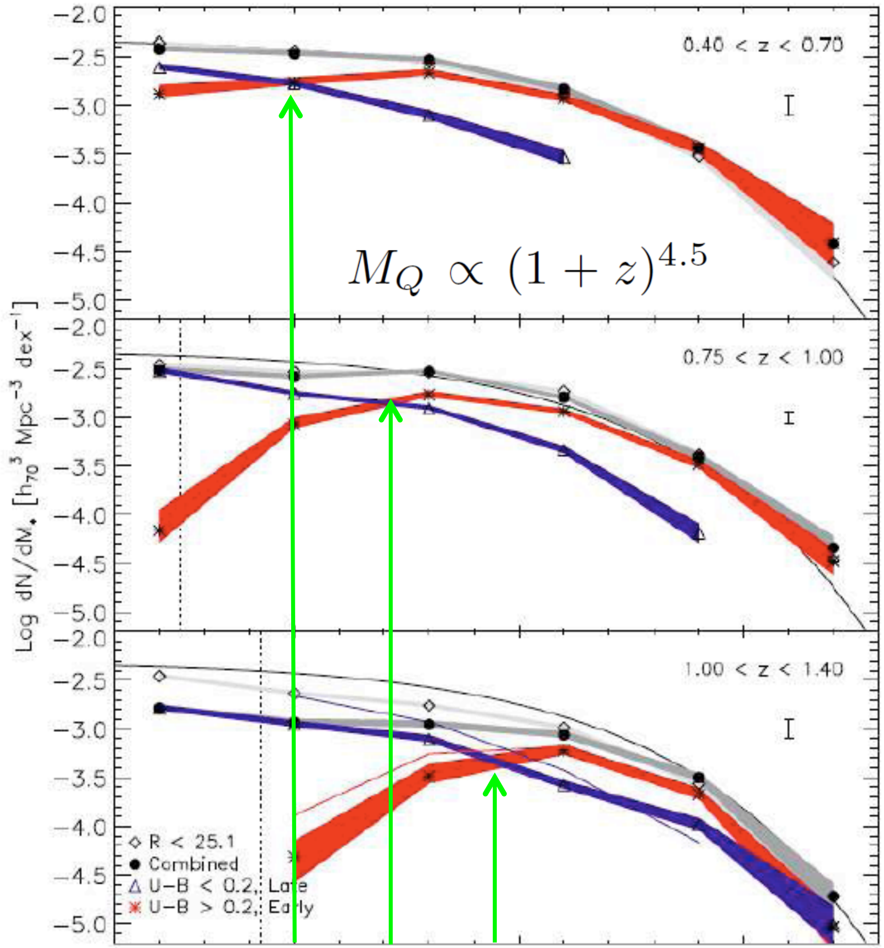
- prendre en compte l'extinction par la poussière et la corriger
- utiliser le taux de formation d'étoiles comme critère de séparation
- évolution de la bimodalité avec le redshift pour remonter à son origine
- effets d'environnement : voir comment ces propriétés varient avec l'environnement.

Galaxy bimodality and downsizing

M_Q= mass above which star formation is quenched

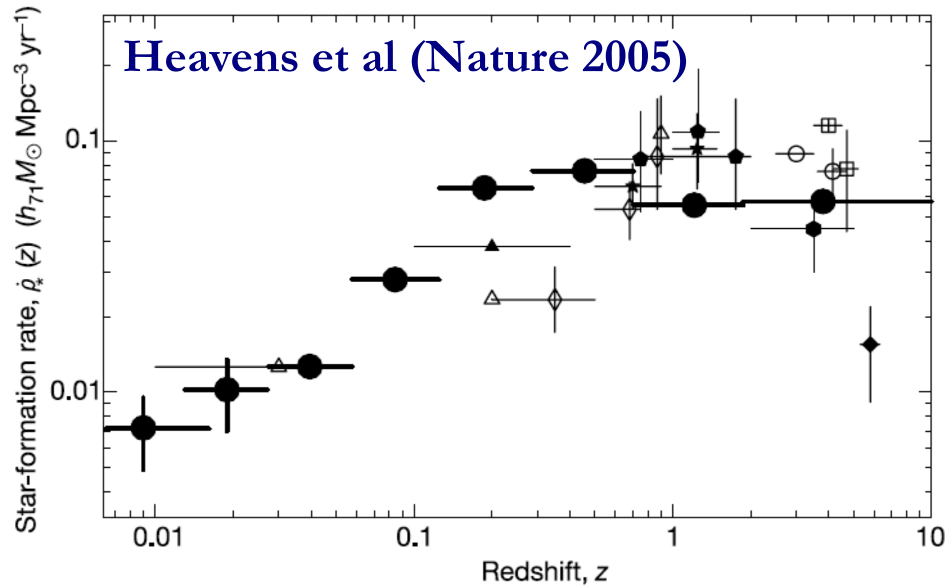


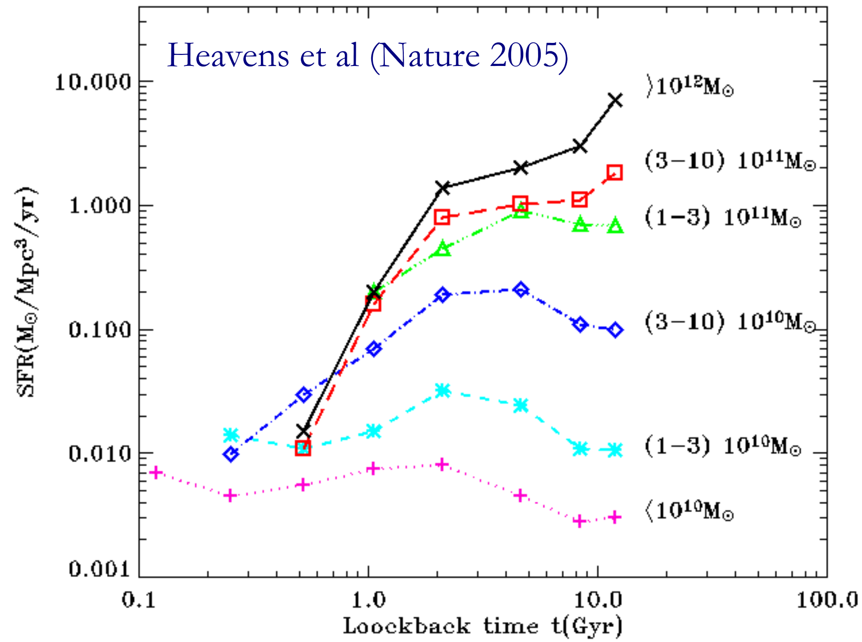


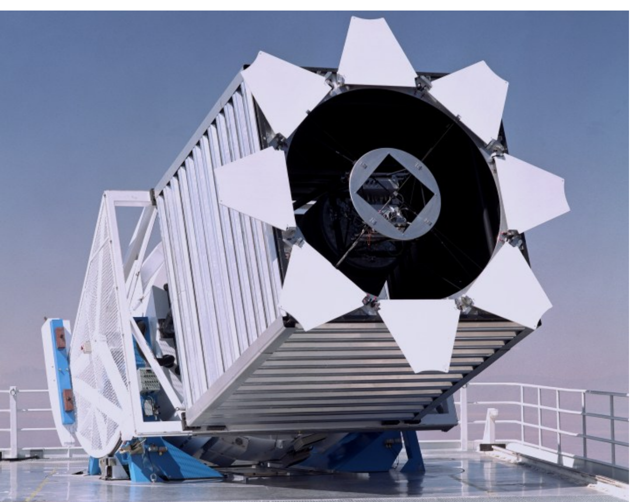


Bundy et al. 06

"Downsizing"







SDSS 2.5 m telescope (New Mexico)

Classification spectro-morphologique des galaxies

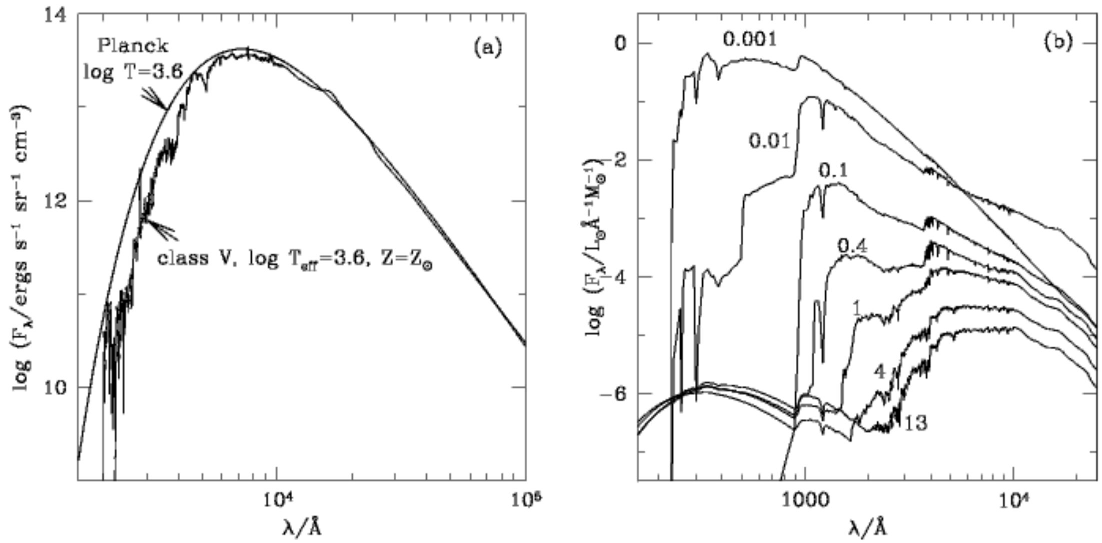
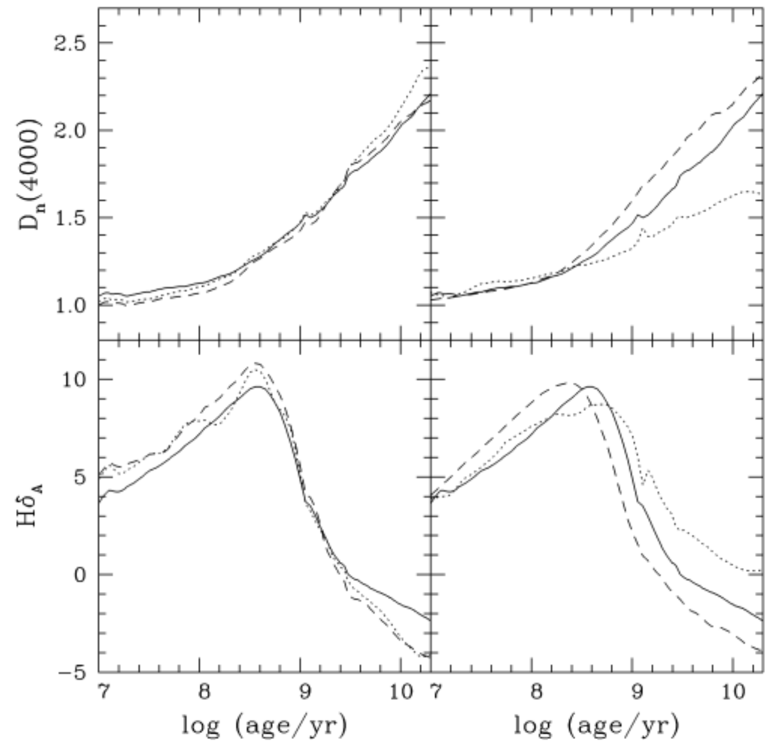
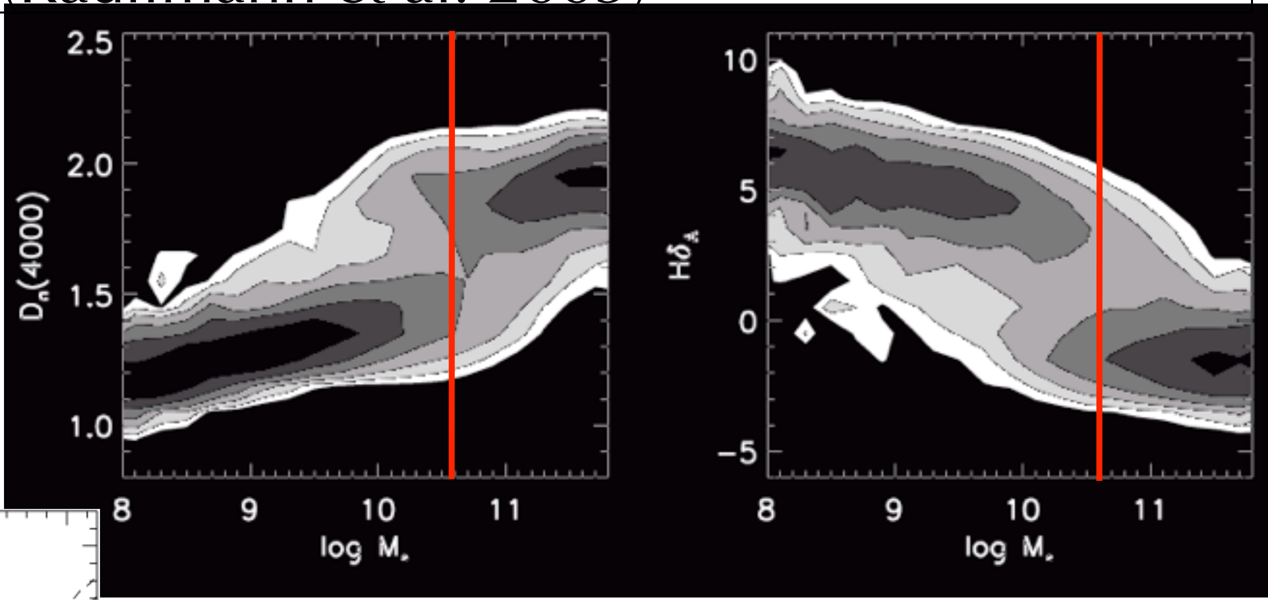


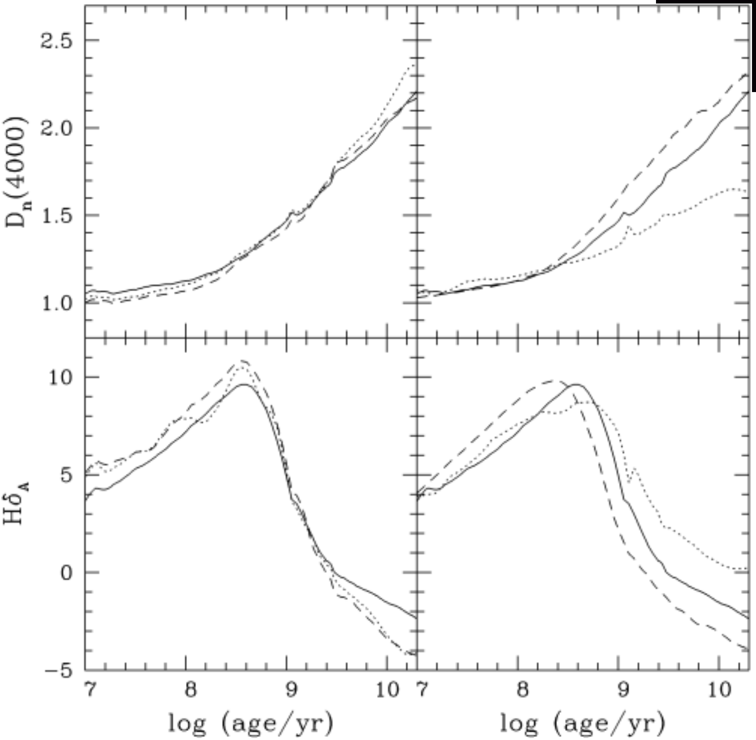
Fig. 2. — (*a*) Spectral energy distribution of a main sequence (luminosity class V) star with $\log T_{\rm eff} = 3.6$ compared to that of an unblanketed blackbody model with the same temperature. (*b*) Spectral evolution of an instantaneous burst stellar population with solar metallicity and a Salpeter IMF. Ages (in Gyr) are indicated next to the spectra.



La bimodalité dans les populations de galaxies (Kauffmann et al. 2003)

SDSS : 10^4 °^{2}, Hém.Nord
$ugriz$, 10^6 spectres
$r < 17.77$
(Sloan Digital Sky Survey)





2 grandes familles de galaxies locales :

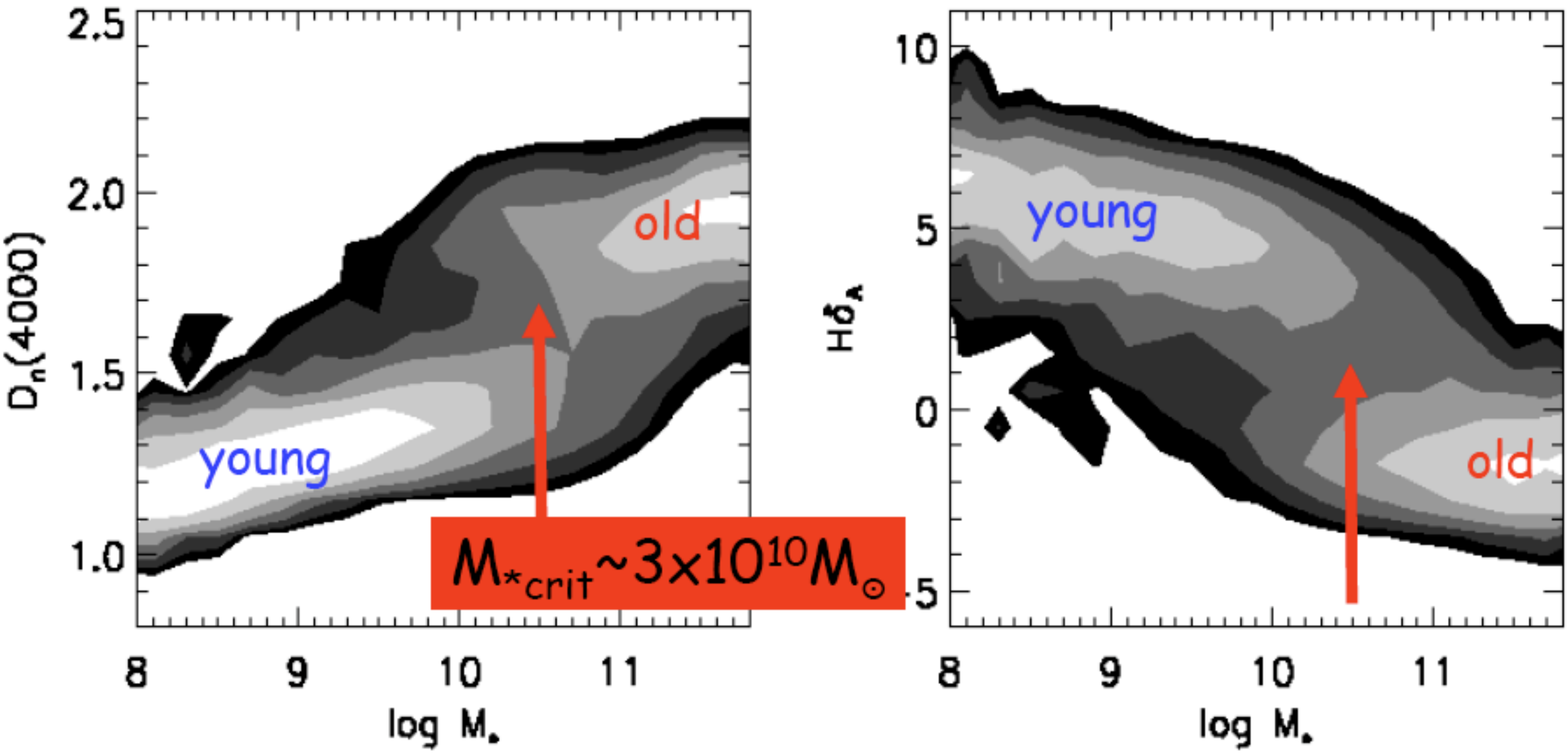
-rouges, de type précoce, peu ou pas de SF
= aussi les plus massives

-bleues, de type tardif, avec formation d'* (SF)
= les moins massives

L'échelle de transition dans la bimodalité
(SDSS, Kauffmann et al. 2003)

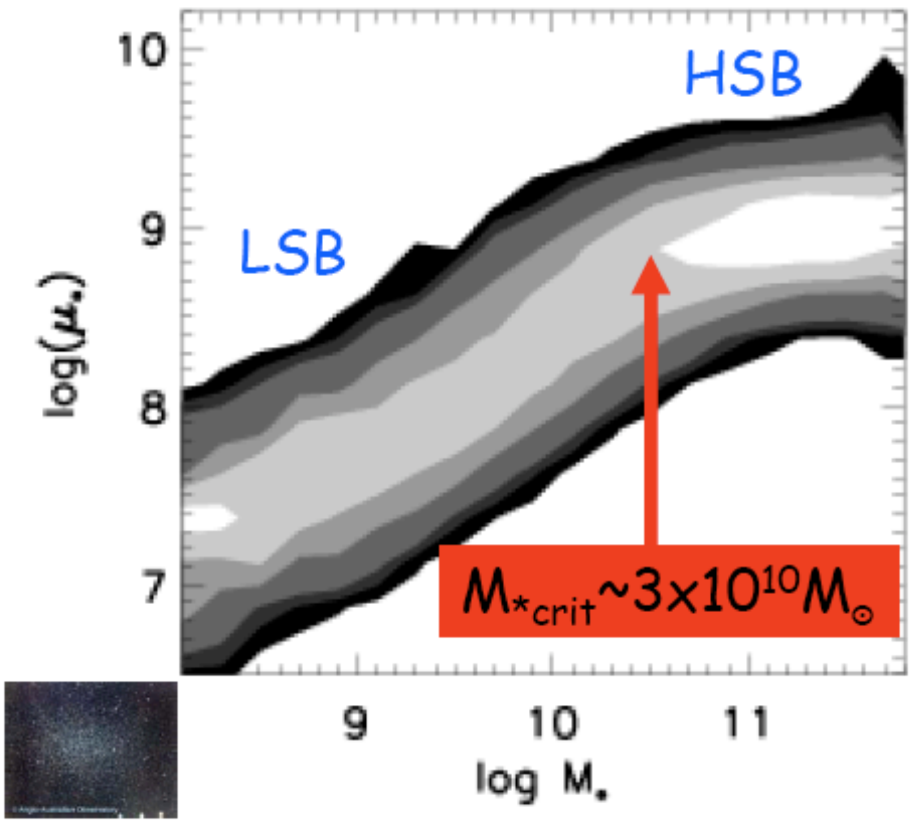
Discontinuité à 4000 Angstroms

Raie nébulaire en absorption, Hδ

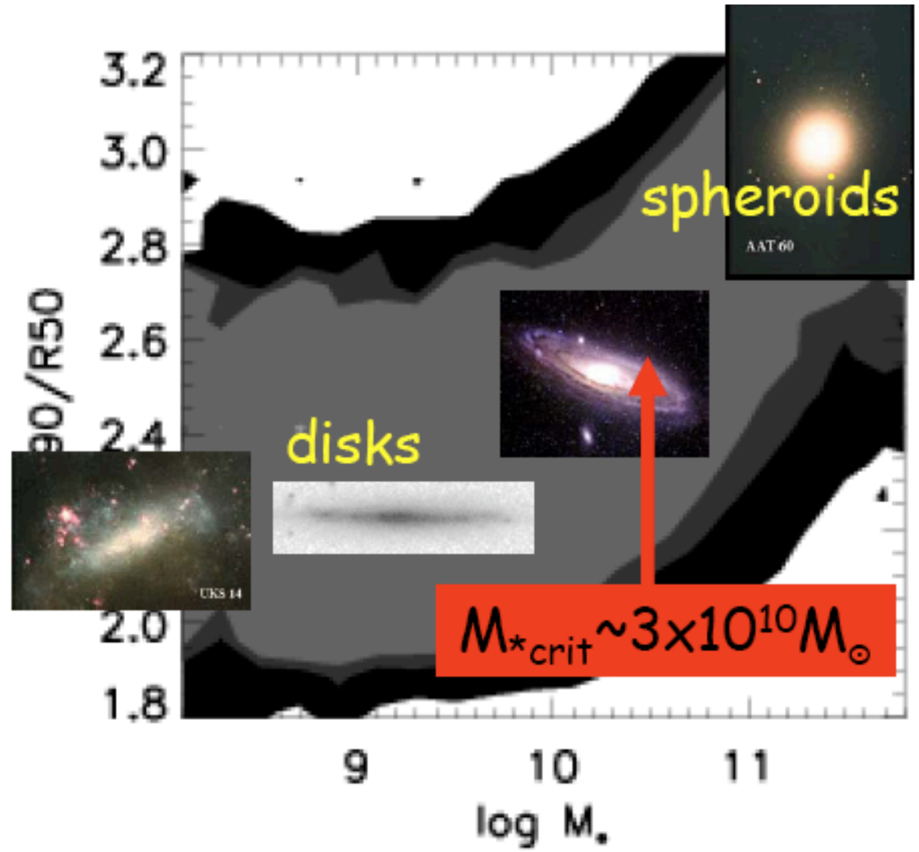


L'échelle de transition dans la bimodalité
(SDSS, Kauffmann et al. 2003)

Brillance de surface



Bulbe/disque



Bimodalité

La morphologie et la couleur sont deux manières d'identifier les galaxies en lien avec leur histoire. Il est apparu que les galaxies étaient divisées en deux grandes familles: les galaxies rouges et les galaxies bleues. Une division qui se rapproche de la division en galaxies de type précoce (rouges) et tardif (bleues), avec une interprétation différente de celle de Hubble: les galaxies précoces (early-type galaxies) sont celles qui ont formé leurs étoiles tôt dans l'histoire de l'univers et qui sont aujourd'hui constituées d'étoiles froides et rouges. Les galaxies de type "tardif" (late-type galaxies) continuent de former des étoiles et leurs étoiles jeunes et massives sont responsables de leur couleur bleue. On parle de *bimodalité* des galaxies et on a constaté que ces deux familles pouvaient être distinguées aussi par leurs caractéristiques spectrales: discontinuité à 4000 Å, raies d'absorption de Balmer (Hδ,…).

Dans les deux cas, ségrégation morphologique & bimodalité, on mesure la signature a posteriori de l'histoire des galaxies.

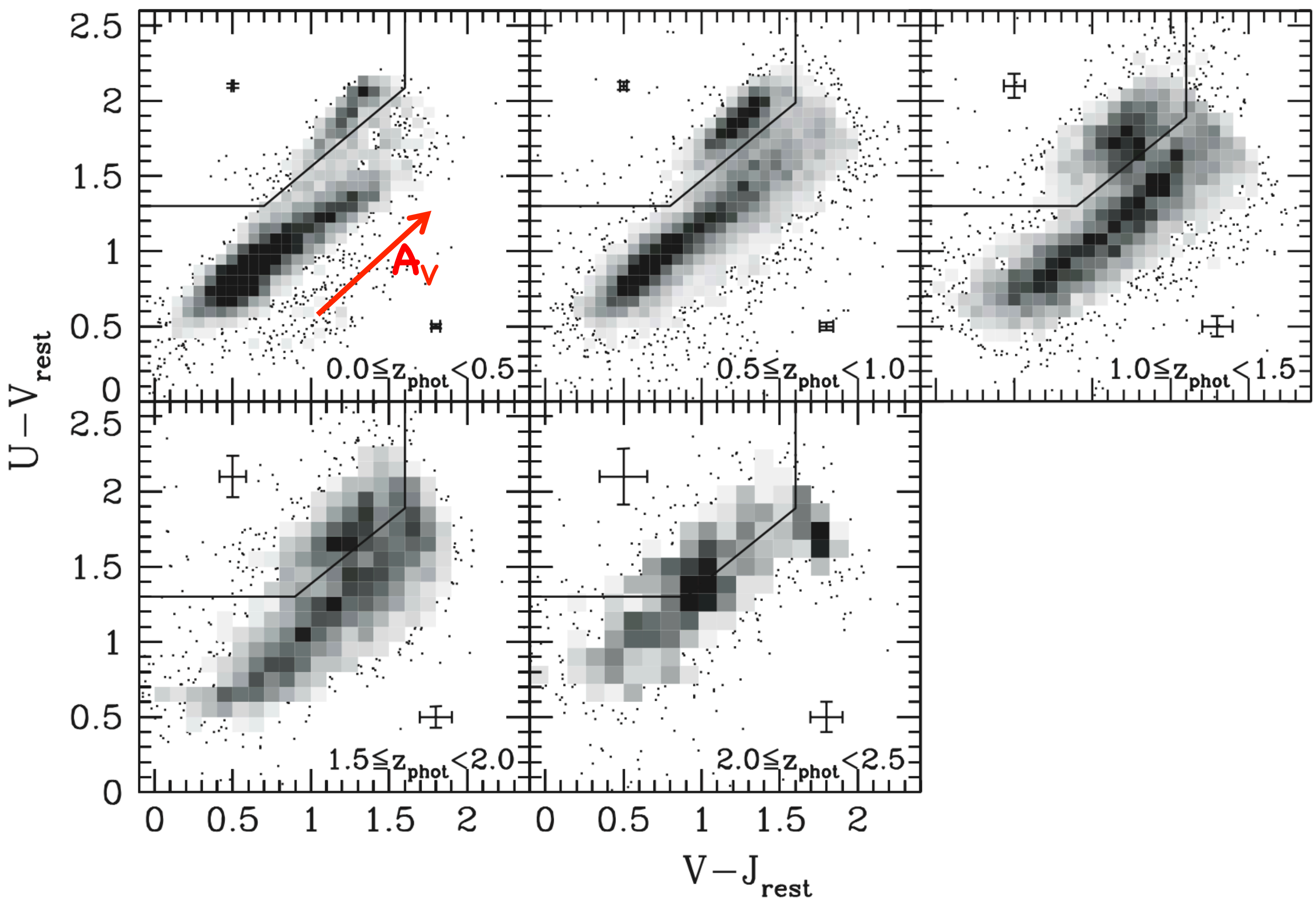
Problème: la séparation discontinue entre galaxies bleues et rouges avec une masse critique... Quelle origine physique ?

Une troisième signature est utilisée: la *relation activité - densité*; la mesure directe du *taux de formation d'étoiles instantané* des galaxies et son lien avec l'environnement.

DETECTION OF QUIESCENT GALAXIES IN A BICOLOR SEQUENCE FROM $Z = 0$–2*

Rik J. Williams[1], Ryan F. Quadri[1], Marijn Franx[1], Pieter van Dokkum[2], and Ivo Labbé[3,4]

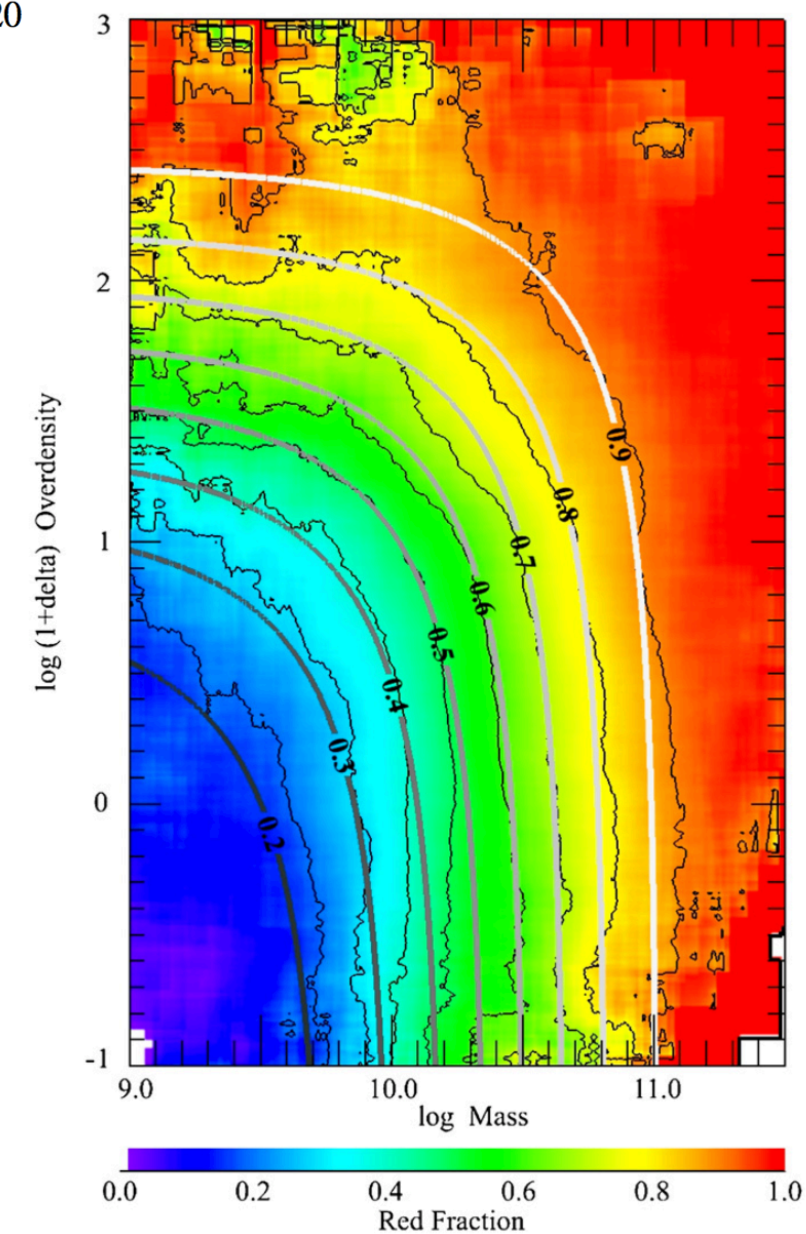
The Astrophysical Journal, 691:1879–1895, 2009 February 1

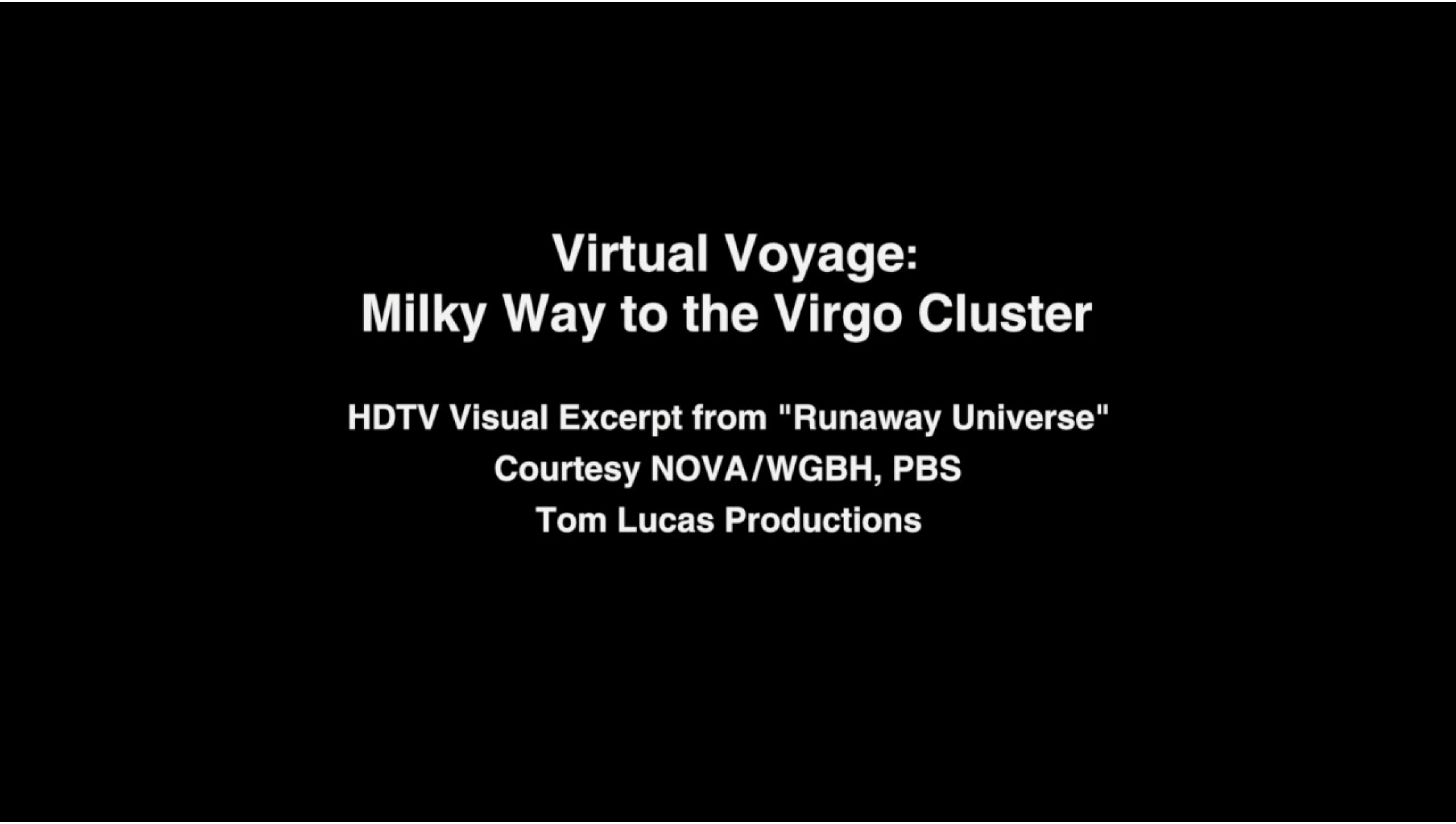


MASS AND ENVIRONMENT AS DRIVERS OF GALAXY EVOLUTION IN SDSS AND zCOSMOS AND THE ORIGIN OF THE SCHECHTER FUNCTION*

YING-JIE PENG[1], SIMON J. LILLY[1], KATARINA KOVAČ[1], MICOL BOLZONELLA[2], LUCIA POZZETTI[2], ALVIO RENZINI[3],

THE ASTROPHYSICAL JOURNAL, 721:193–221, 2010 September 20





positions de 100 000 étoiles Hipparcos + galaxies (Brent Tully, université de Hawaii)