Cosmic Star Formation history by galaxy types from optical to mid-IR surveys

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IAP, July 2008

Cosmic Star Formation History by types requires:

- Star formation law by galaxy types
  - Evolution of stellar mass, gas content and metals
  - Types: Ellipticals, spirals and irregulars, and others as Starbursts (mass fraction, age, initial metallicity)?

  Observations: multi spectral SEDs, colors, EW of lines

- Galaxy number densities by types by redshift bin
  - Volume element evolution with z
  - Luminosity functions observed at z=0
  - Evolution, k- corrections, distance modulus, IGM extinction

  Observations: multi spectral faint galaxy counts (cumulative, differential)

Crucial times of galaxy formation/evolution

- Z=0 (calibration, galaxy age <13Gyr)
- Statistical tracers of evolution at z=0:

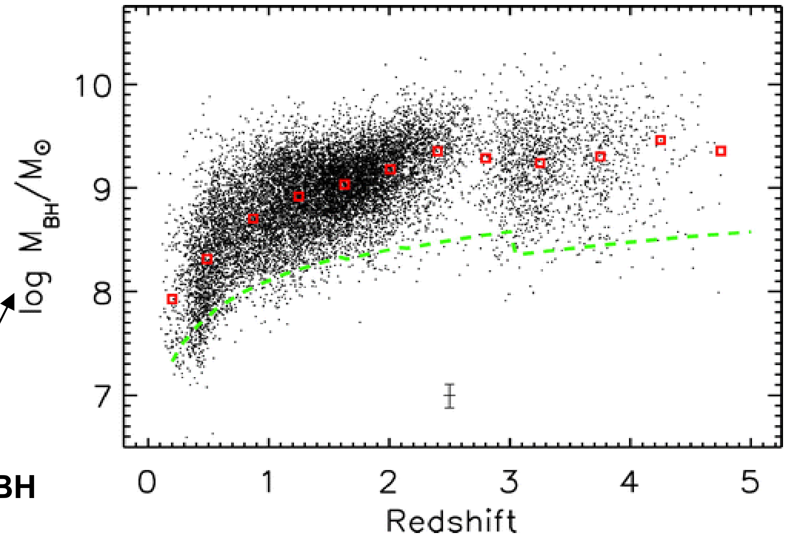
  red sequence, z=0 color-color diagrams by types of the Hubble sequence

- 0< z < zfor

  By types: star formation laws, M/L, time-scales of mass accumulation (hierarchical merging,gravitational collapse), dissipation efficiency (emission lines, dust emission, stars)

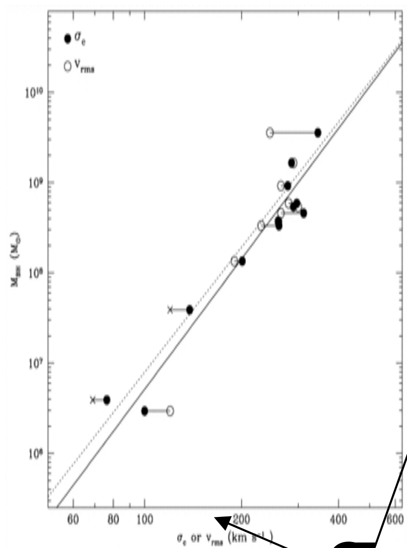
Moreover models need to be consistent with:

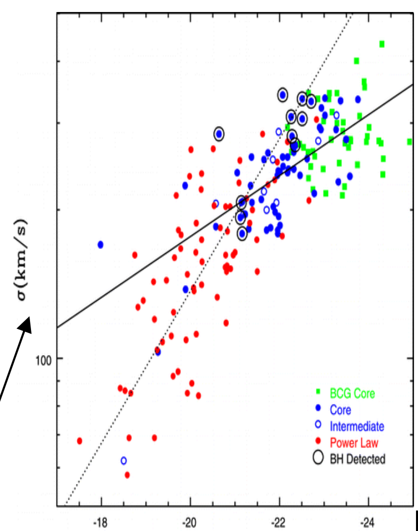
i) the relation σ/ Mass of black holes (10**9M⊙ at z>4)



- •Redshift distribution of the black hole masses of the SDSS/DR3 QSOs sample Vestergaard et al. 2008, ApJ, 674, L1
- •Relation with galaxy properties (σ, Mv) Merritt et al, 2006, Margorrian et al, 2004

M_{BH}





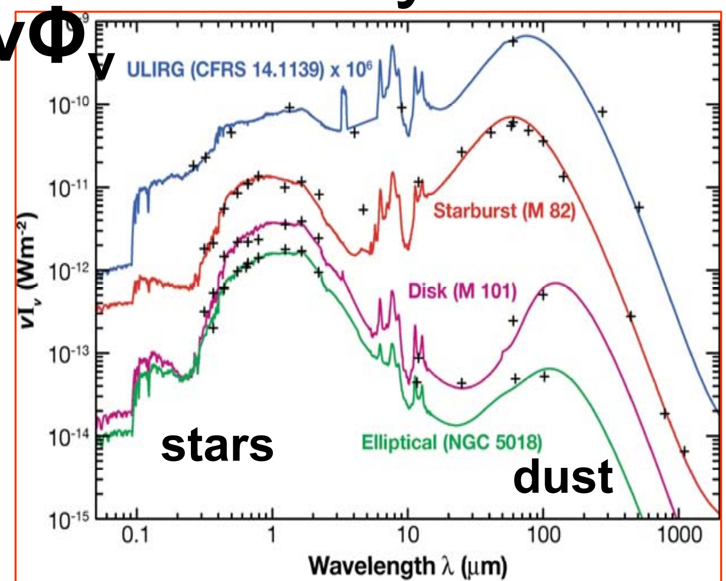
σ km/s

M_V

ly 200

ii) the discovery of ULIRGS

$\nu\Phi_\nu$

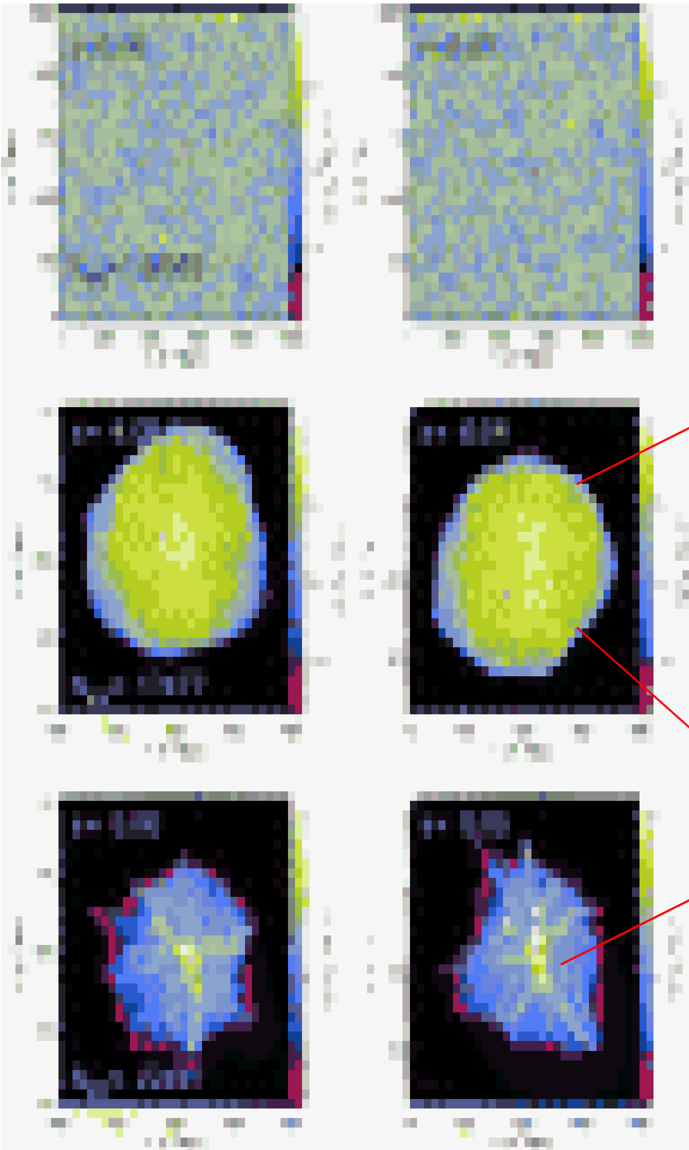


Galliano's thesis, 2004

λ

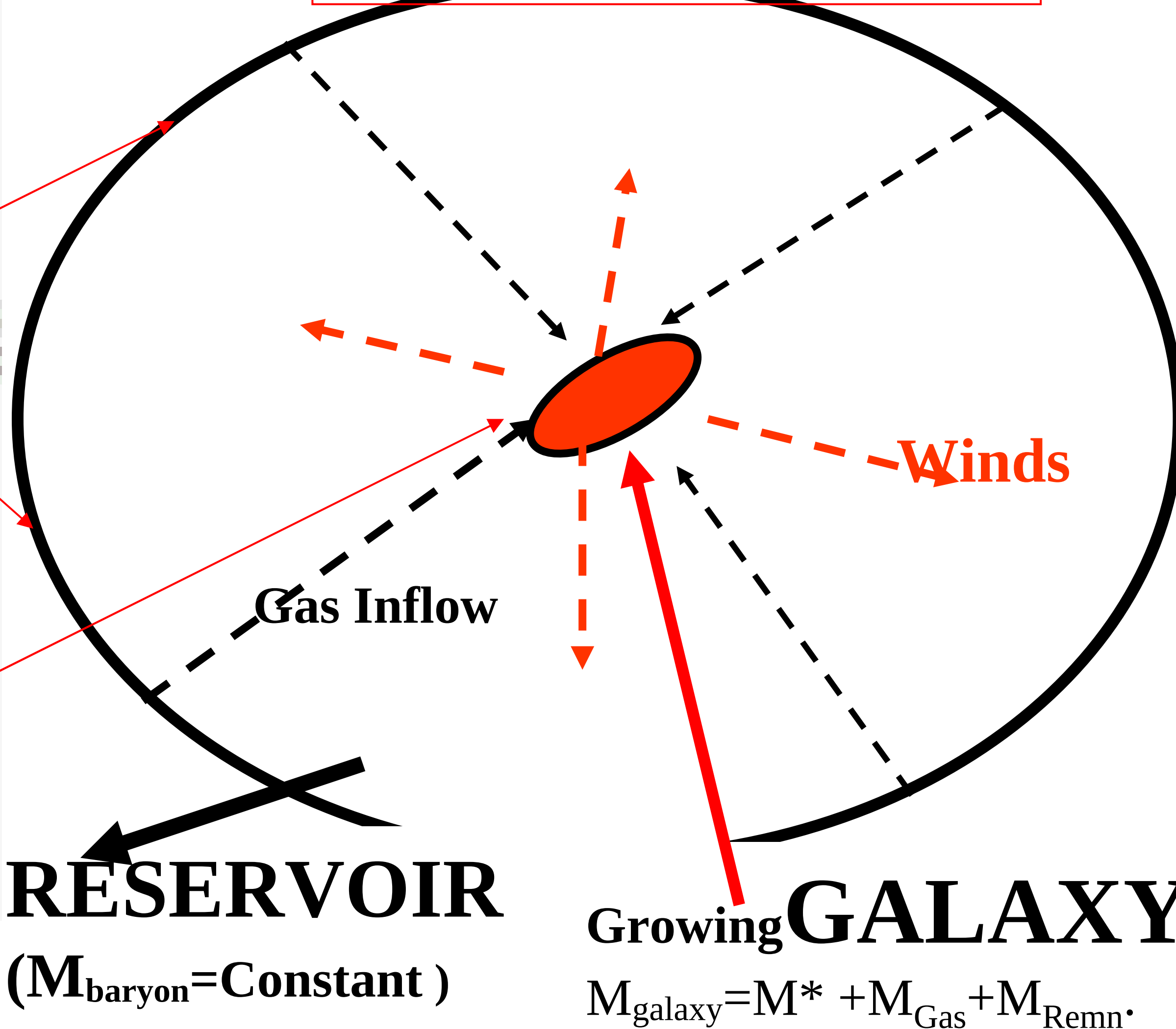
Scheme of SFR scenarios for the Hubble sequence:

SFR α Mgas of the galaxy embedded within the reservoir + exchanges as infall and galacticwinds



Recent Model by Yi et al, 2006

PEGASE scenarios, 1997, 2002



PEGASE site: http://www2.iap.fr/pegase

Star formation parameters by types

$$SFR = \frac{M_{gas}^{p1}}{p_2}$$

+ possibility of Starbursts (delta functions at various ages and initial metallicity)

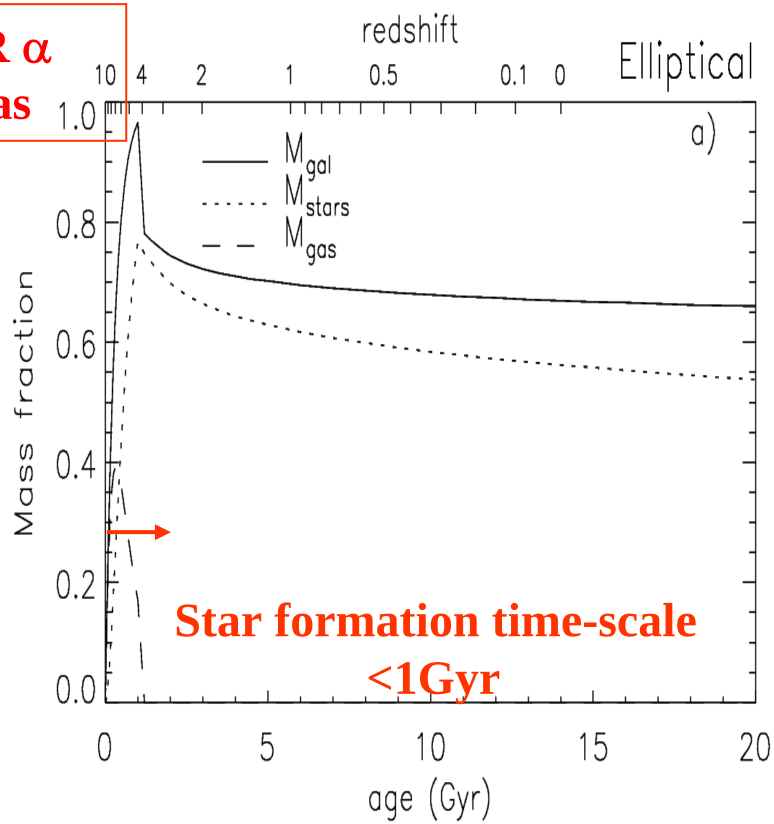
For all types: IMF
Transfer with 2 geometries
Gas, metals, dust, extinction
Are consistently predicted with

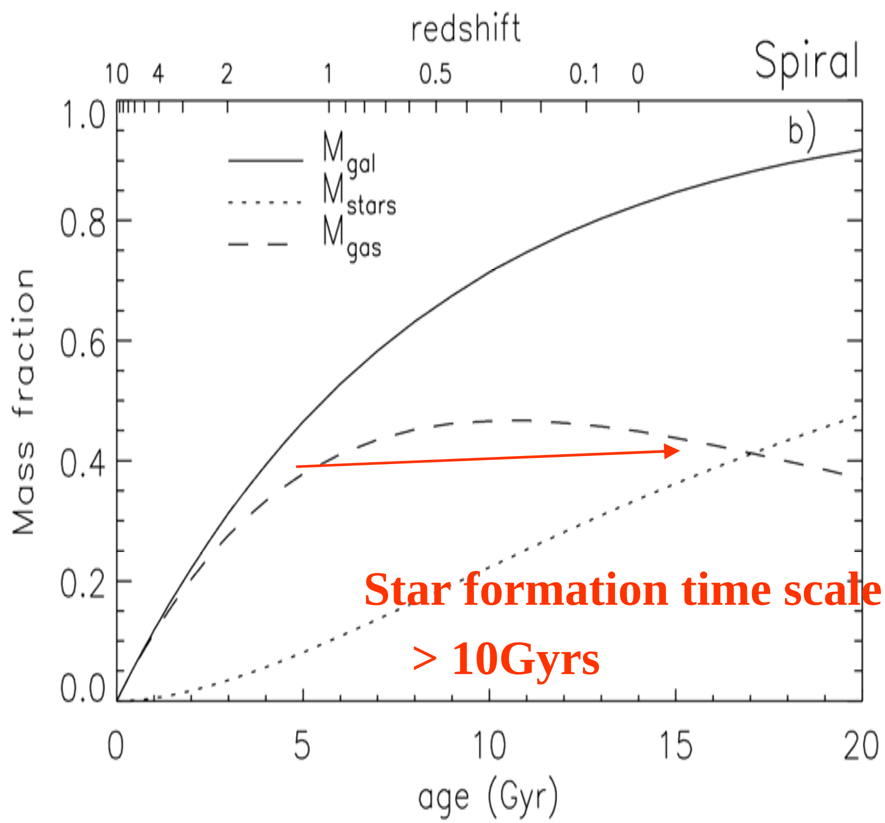
type	p1	p2 Myr/MΘ	zfor	winds
Ell	0.6-1.5	100-1500	10-30	Y
Spiral	0.8-1.5	2000-18000	10-30	N
Irr-IM	1.0-2.0	14000-20000	<5	N
Yields grains,				

Main SFR time scales by galaxy types (RV et al, 2004)

Elliptical (winds) Spiral

SFR α Mgas

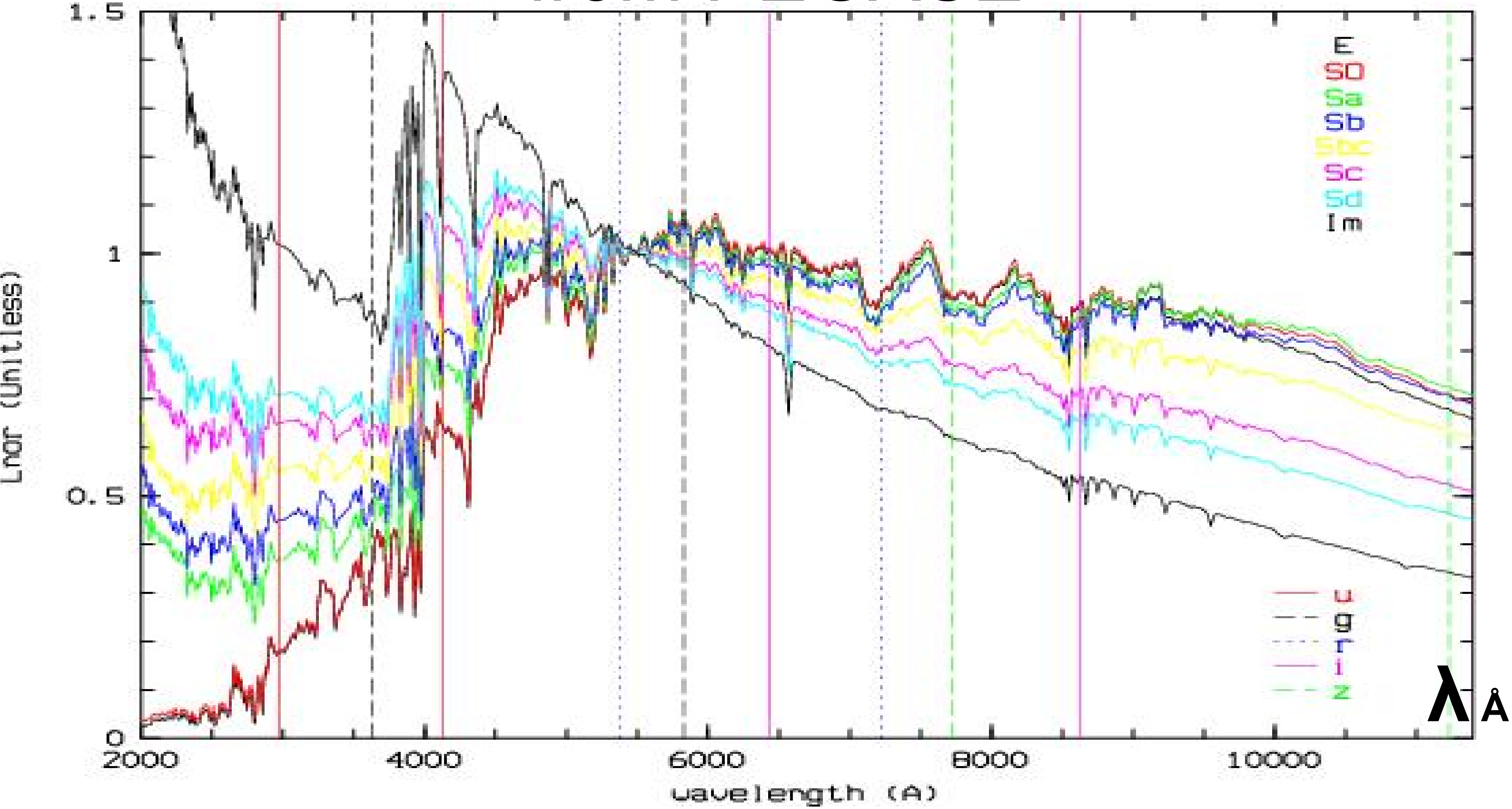




Mgalaxy (full line), Mstar (t) (dot line), Mgas(dashed line)

Note: ULIRGs are modelled as ultra massive ellipticals (see below)
Rocca-Volmerange, de Lapparent, Seymour, Fioc, 2007, AA, 475, 801

Stellar emission from Z=0 Templates from PEGASE



PEGASE.2 SCENARIOS by types ARE ROBUST IN THE UV/OPTICAL/NIR

(Fioc & Rocca-Volmerange, 1997, Fioc's PhD thesis 1997, Le Borgne & Rocca-Volmerange, 2002)

I. Z=0 tests of evolution templates

1. SEDs of ellipticals In the UV-optical domain

- The case of M87,
  The majority of local ellipticals are old
  13 Gyrs or more,
  gas-poor (after suffering galacticwinds),
  so dust-poor
  and of low star formation activity.

Rocca-Volmerange, MNRAS,236,47)

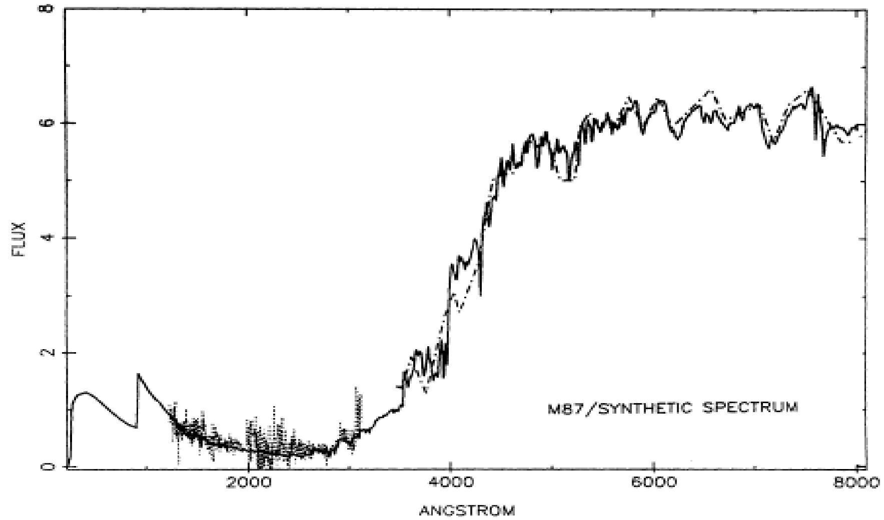


Figure 2. A comparison of the *IUE* and visible observed spectra of M87 (Bertola *et al.* 1980) with our UV-hot model at age 13 Gyr. Flux units for observational data are 10^{-14} erg s^{-1} Å^{-1} cm^{-2}.

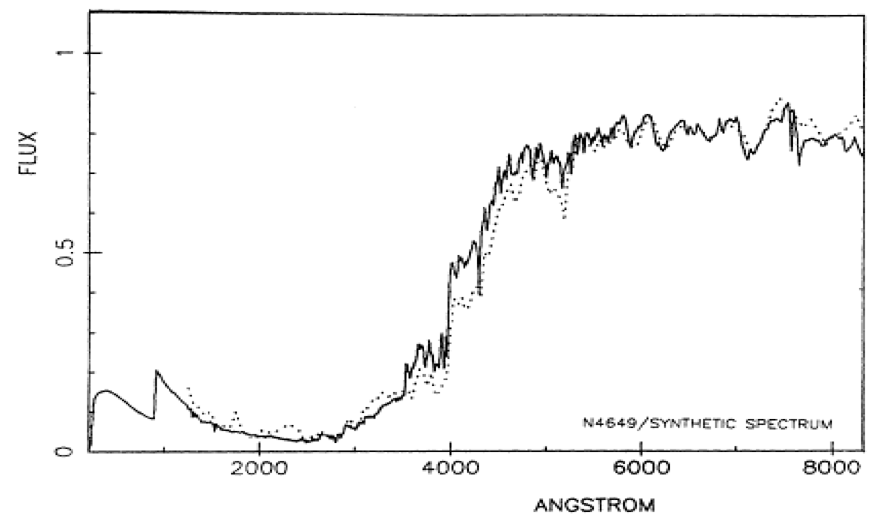
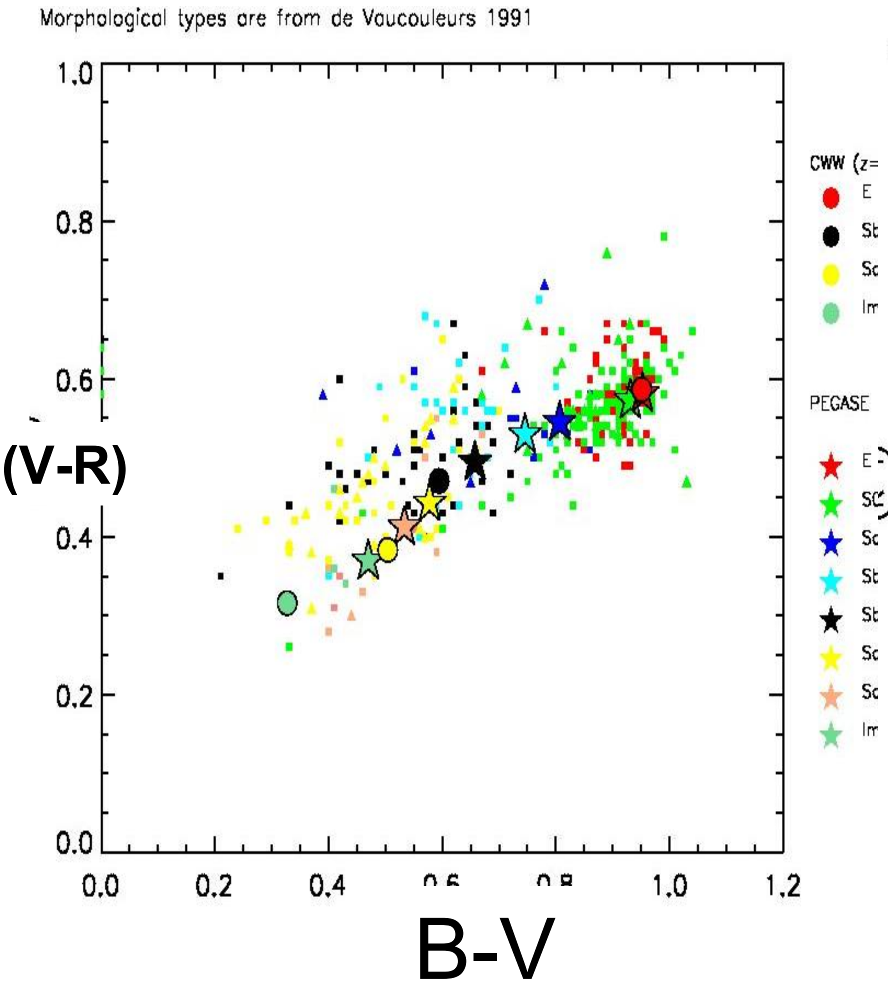


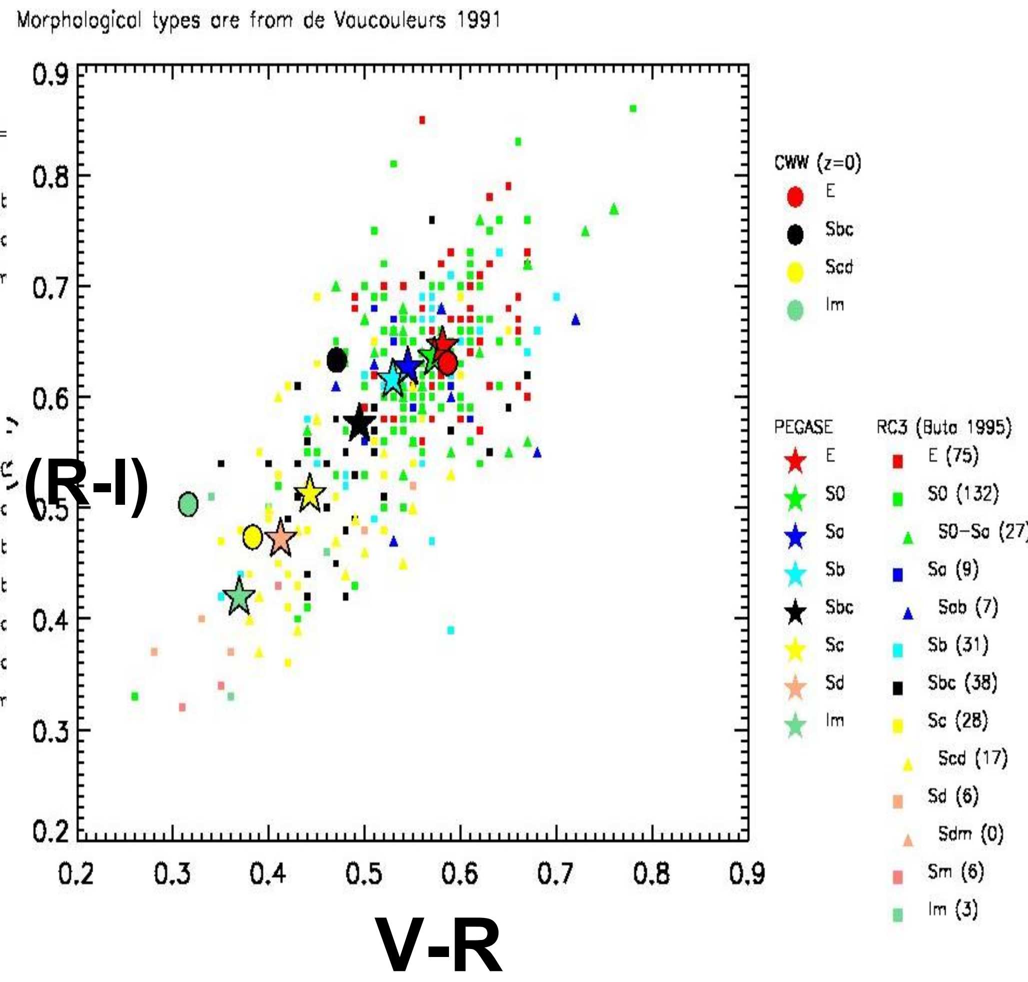
Figure 3. A comparison of the *IUE* and visible observed spectra of NGC4649 (Bertola *et al.* 1982) with our UV-hot model at age 13 Gyr. Flux units for observational data are 10^{-14} erg s^{-1} Å^{-1} cm^{-2}.

Results at z=0 (following)
2. color-color diagrams

Fits of the RC3 catalogue with PEGASE.2 And Coleman&Wu,

From Yuko Kakazu, 2008





The well-known problem of δ(U-B) excess [0, 0.30] appears in the U band

II. Intermediate redshifts z=0➔ 4

Apparent magnitudes:

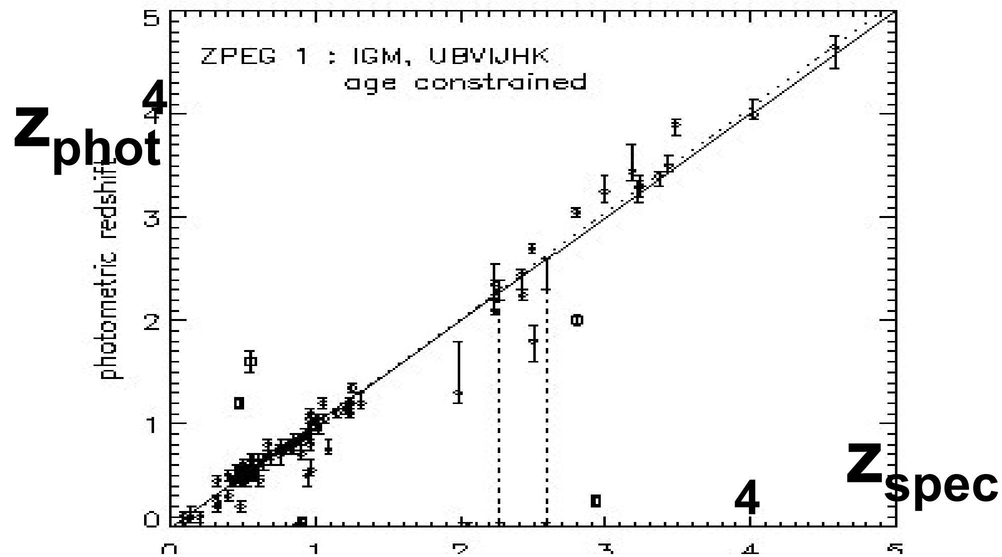
$$m_\lambda = M_\lambda(z=0, t_0) + k_\lambda(z) + e_\lambda(z) + (m-M)_{bol} + A_\lambda$$

TESTS of validity on:

- Photometric redshifts
- Color-color diagrams
- Faint galaxy counts in the optical

Based on SEDs and EVOLUTION scenarios

PHOTOMETRIC with PEGASE (Z-PEG , Le Borgne et al, 2002) versus SPECTROSCOPIC z=0 to 4 (HDF-N, William et al, 1996)



Various constraints , the best accuracy σ=0.07

D. Le Borgne, B. Rocca-Volmerange: Photometric Redshifts with PÉGASE

Z-PEG Model	IGM ext.	UBVI	JHK	age constraint	$z < 1.5$	all z	Figure
1	x	x	x	x	Δz=−0.0214 σ_z=**0.0980**	−0.0844 **0.4055**	2
2	x	x	x		Δz=0.0251 σ_z=**0.1156**	−0.0621 **0.4441**	5
3		x	x		Δz=0.0252 σ_z=0.1156	−0.0589 0.5738	5
4	x	x			Δz=0.1273 σ_z=0.3179	−0.0040 0.5840	7
FSLY[a]	x	x	x		Δz=−0.0037 σ_z=0.1125	−0.0579 0.2476	
MIBV[b]	x	x	x		Δz=0.026 σ_z=0.074		

3. The evolution of stellar mass by types

• **The best tracer Is the Hubble K band diagram**

Data from De Breuck et al, 2002:

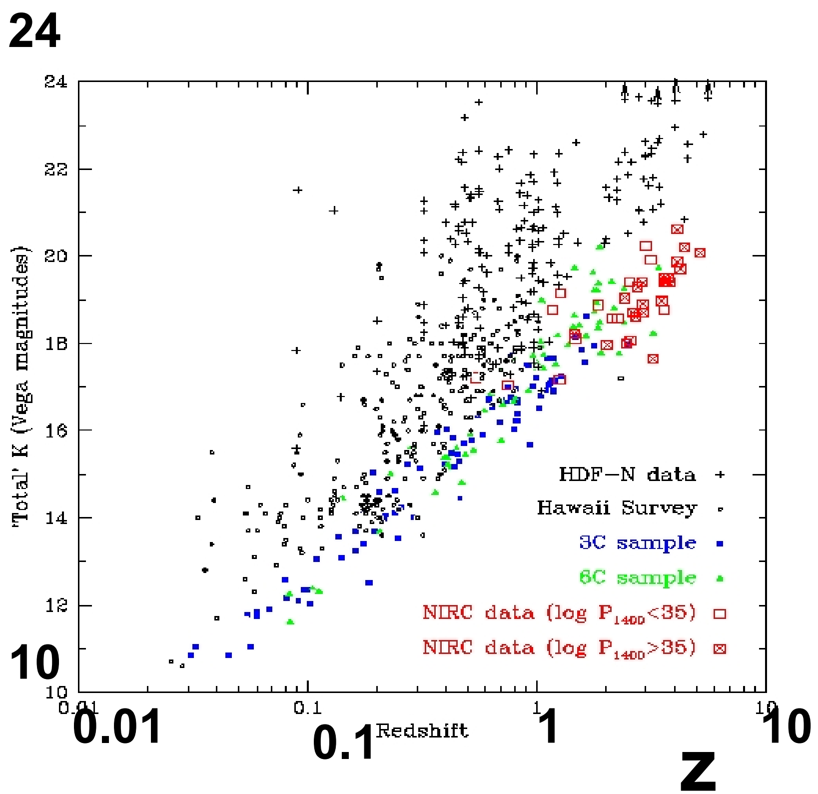
Normal galaxies (+)

And radio galaxy hosts up to z=4

Sharp cut traced by high-z radiogalaxy hosts

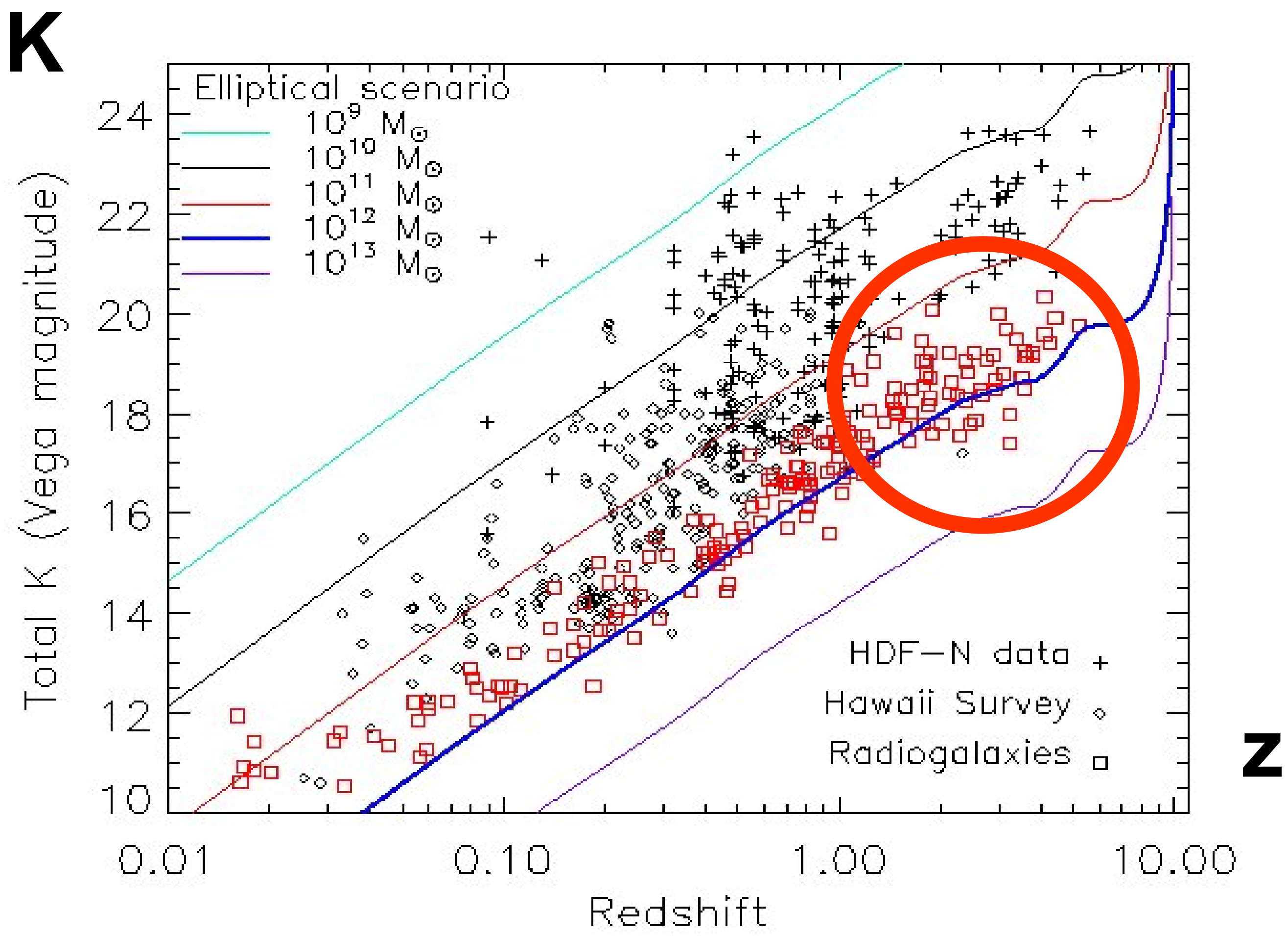
Unsuccessfully explained for years by Cosmology, radiotypes

K band



Models of Ellipticals, baryonic mass 10**9 to 10** 12 MΘ

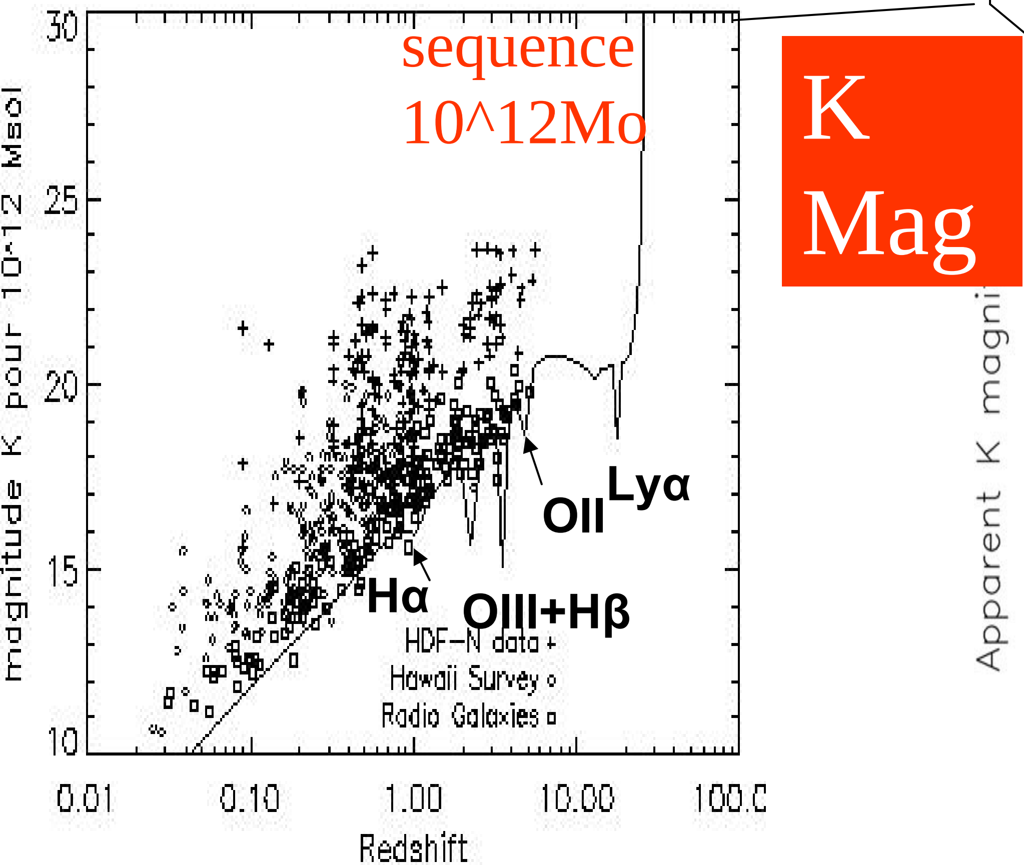
10**12 Msol is the superior limit, even at z=4

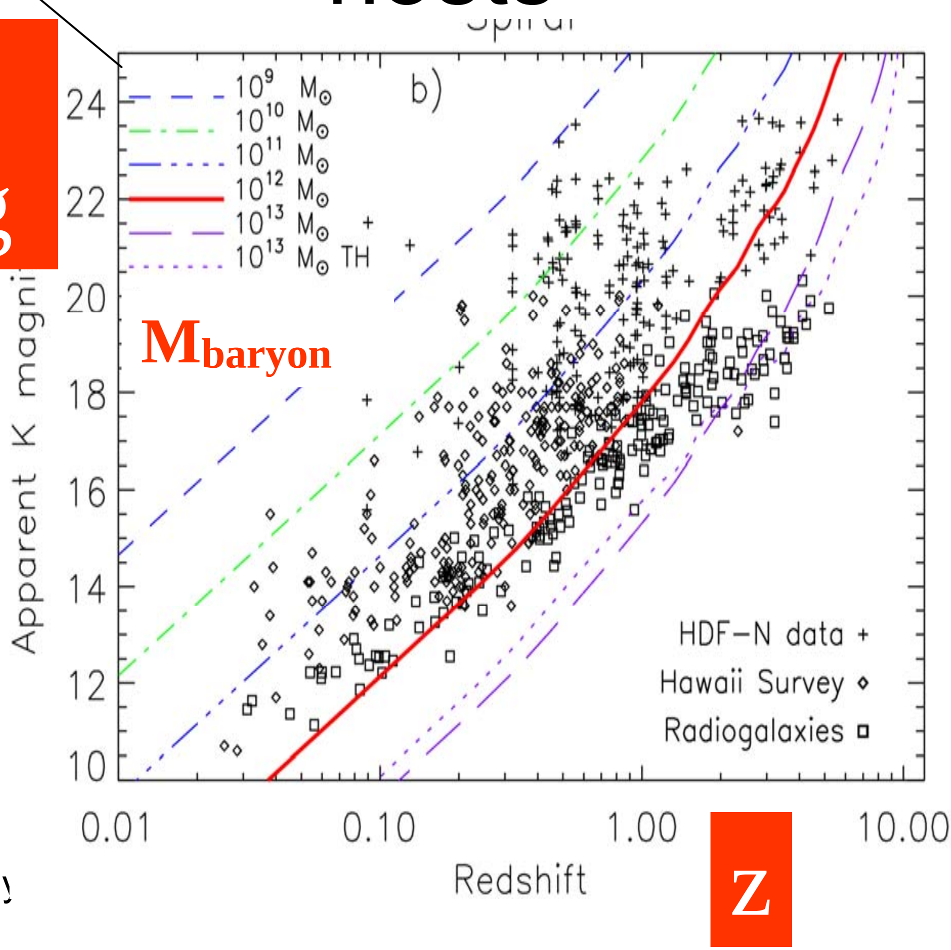


Rocca-Volmerange, Le Borgne, De Breuck, Fioc, Moy, 2004, A & A, 415, 931

Similar superior limit $10^{12}M_\odot$ when computed @ z_{for}=30 + AGN emission lines

The high-z spiral models do not fit high-z radio galaxy hosts





The superior Mass is compatible with the fragmentation limit predicted by models

The gravitational collapse driven by the balance of cooling and free-fall time scales (Rees & Ostriker, 1977, Silk 1977) gives the critical parameters between the two regimes :

Mcrit = ~ 1012 Mo**

Rcrit = ~75 kpc

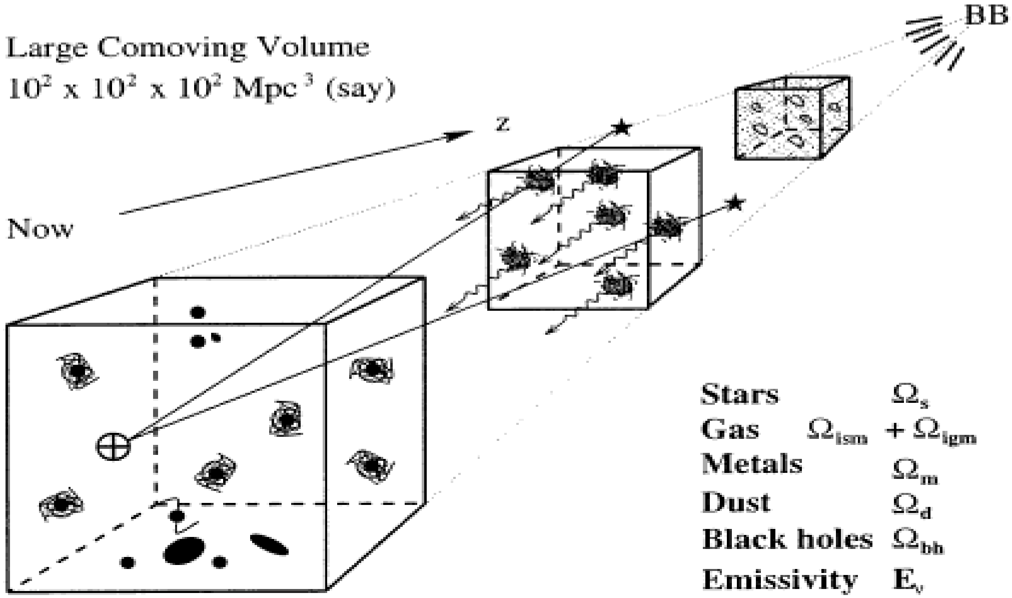
M > Mcrit, Quasi-static regime

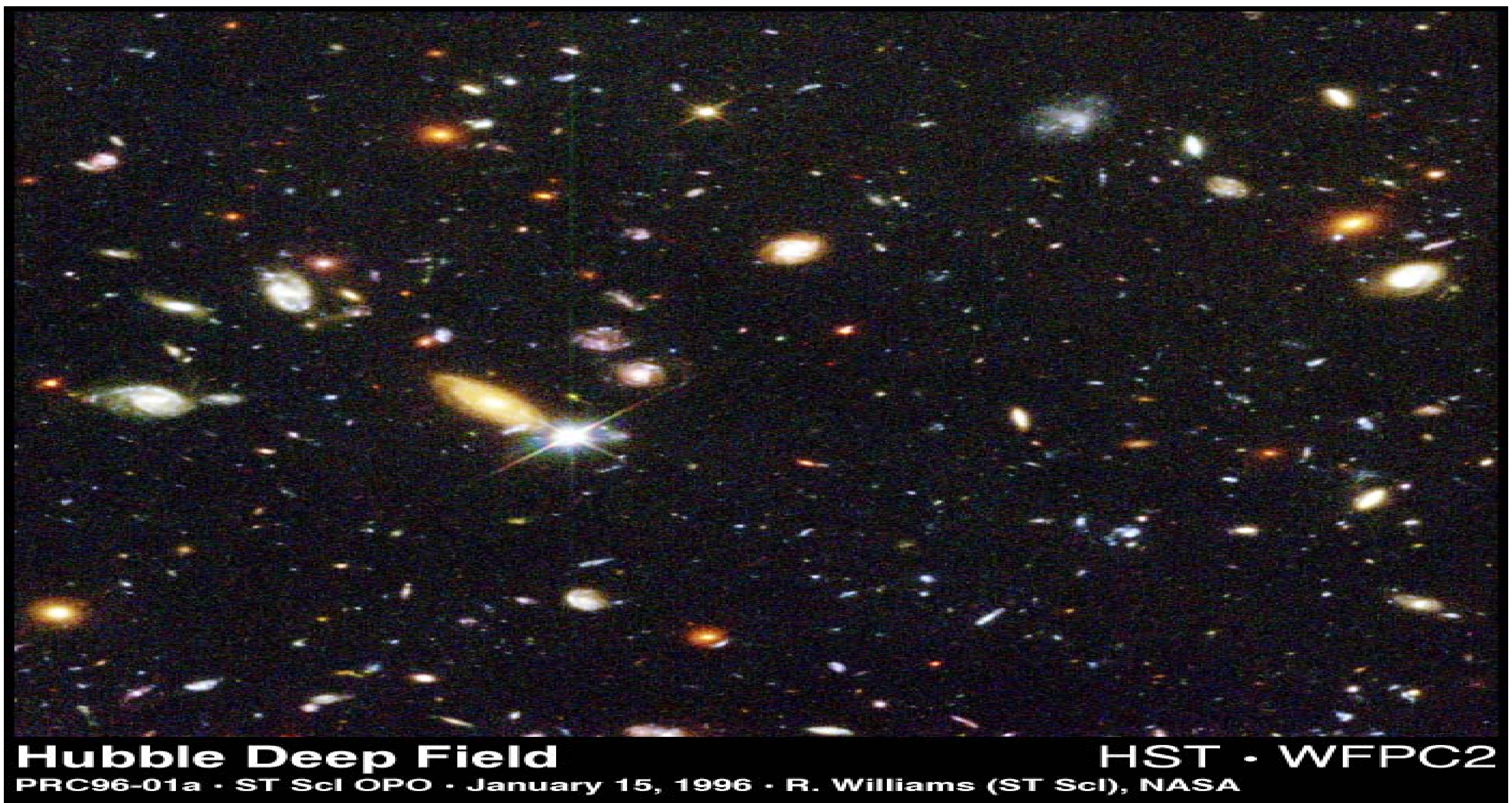
M < Mcrit, collapse, fragmentation, star formation

Consequences from the optical-NIR

1. **10**12 Msol is a superior limit of baryonic galaxy mass (including stellar halo but excluding dark mass,baryonic or not)**
2. **The most massive galaxies form at early epochs**
3. **They are ellipticals.**
4. **From the 4000A break, they may be LBG and/or EROS**
5. **The most massive galaxies are powerful radio emitters with massive AGNs (compatible with massive BHs)**
6. **Cooling time scale < Gravitational time scale**

4. Faint Galaxy counts





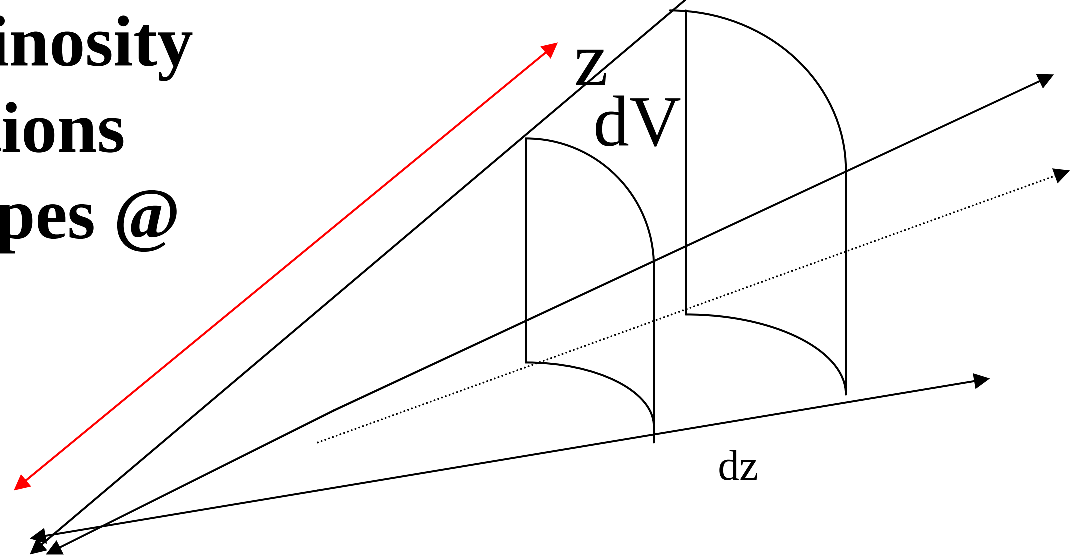
Models of faint counts

Comoving volume element ↗ with z

$$d^2A_j(m_\lambda, z) = \Phi_j(M^j{}_\lambda)(1+z)^3 \frac{dV}{dz} dm_\lambda dz$$

Number of galaxies of magnitudes mλ and at redshift z

Luminosity functions by types @ z=0

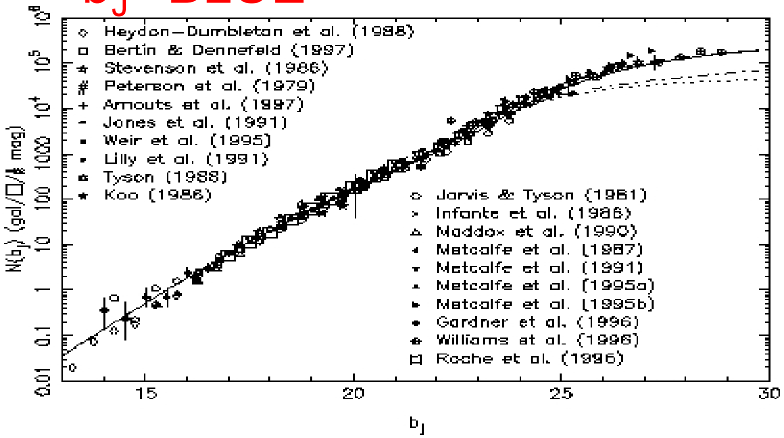


$$m^j{}_\lambda = M^j{}_\lambda(z=0, t_0) + k^j{}_\lambda(z) + e^j{}_\lambda(z) + (m-M)_{bol} + A$$

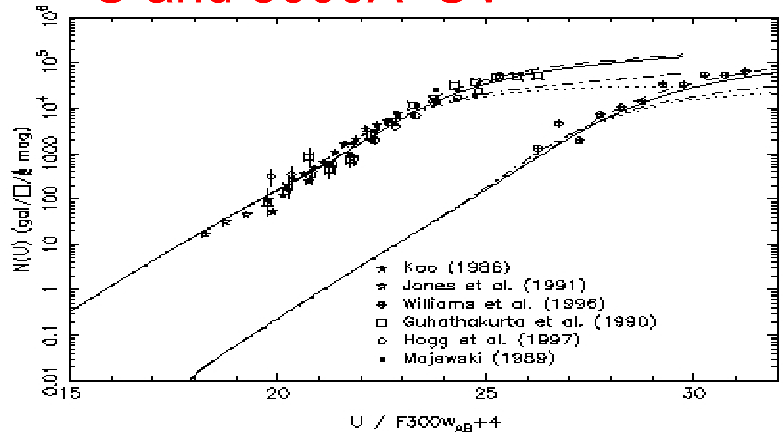
k- et e- corrections for all types from PEGASE

GALAXY POPULATIONS
FROM the deepest UV—OPTICAL--NIR (UBVIRJHK) COUNTS

b_J BLUE

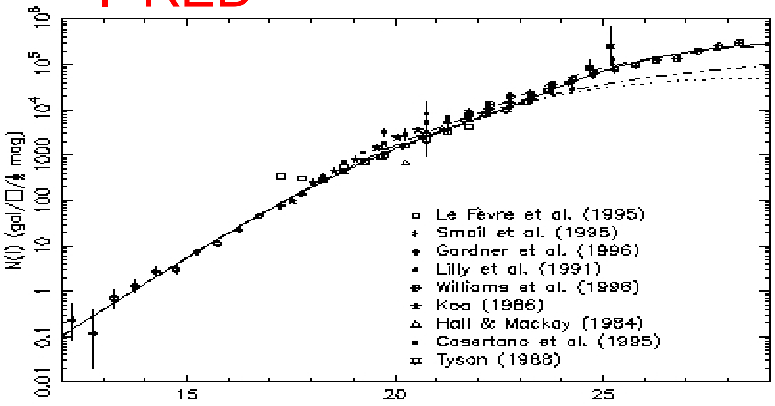


U and 3000A UV

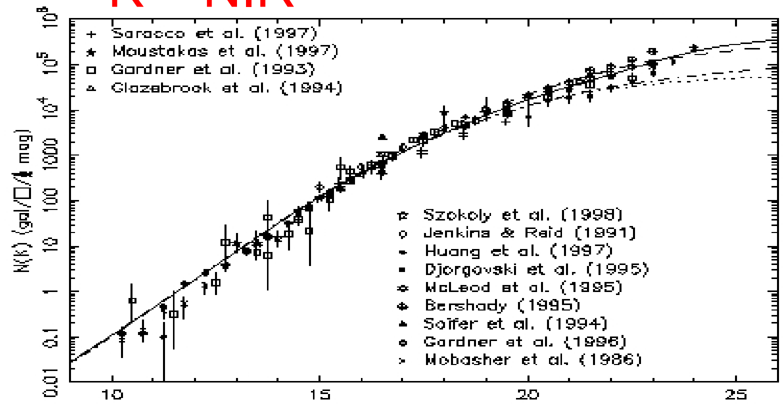


Early massive ellipticals models are needed to

I RED



K NIR



constrain the Hawaiian and +HDF-N Surveys In B, I and K bands

One distribution fits galaxy counts with evolution scenarios by type

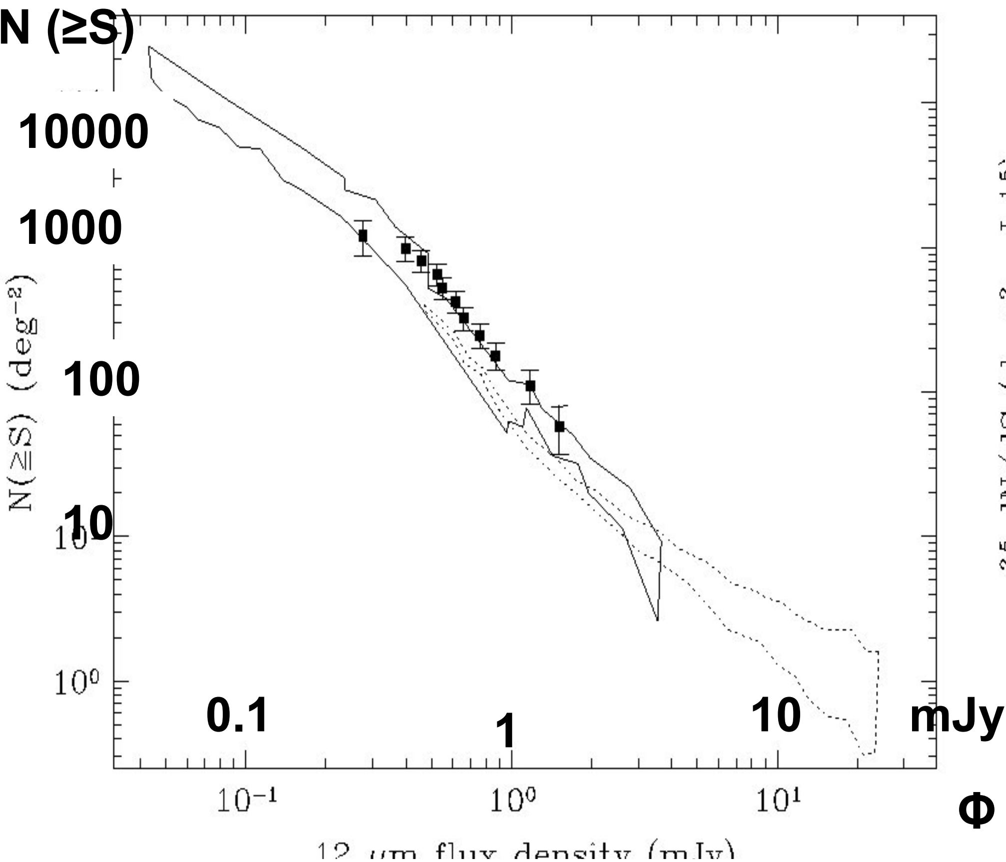
ELLIPTICAL (26%) Sa+Sb+Sbc (24%) Sc+Sd+Im (50%)

(Fioc and Rocca-Volmerange, 1999, AA,344,393)

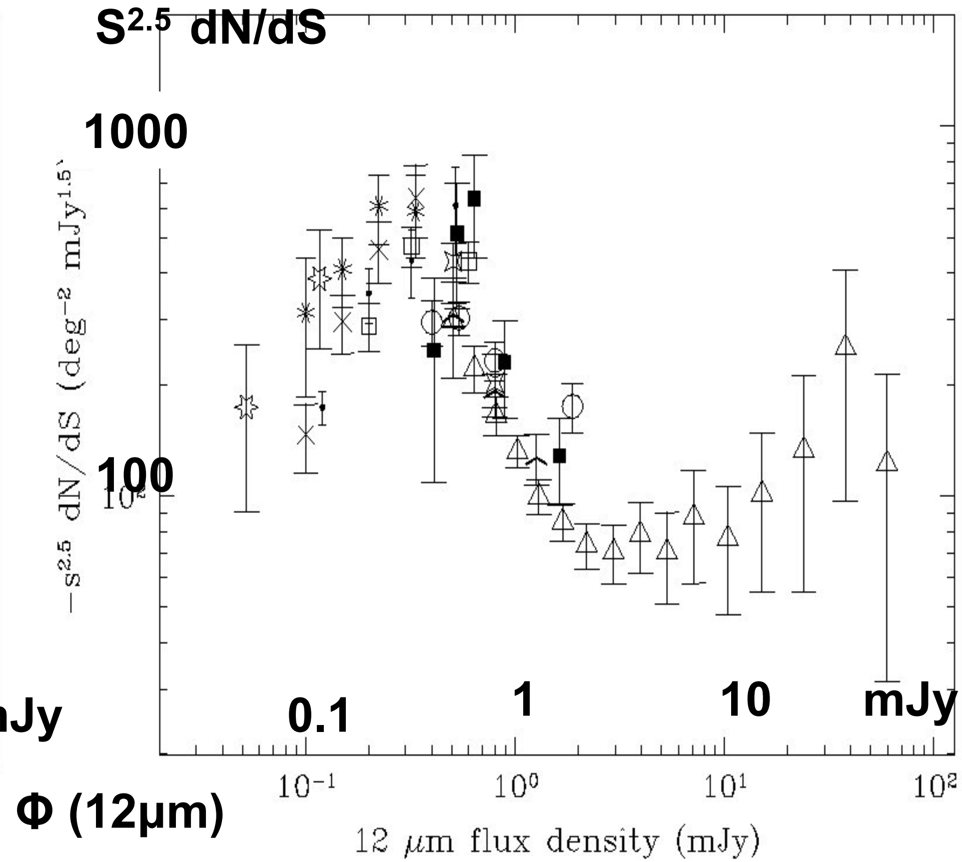
Are similar galaxy populations identified from the mid-IR?

The new ISO-ESS survey : faint galaxy counts at 12um (■), Seymour, Rocca-Volmerange and de Lapparent, 2007, A&A, 475, 791

compared to the 15um(Δ, □, ○) surveys, Altieri et al, 1999, Aussel et al, 1999, Elbaz et al, 1999



Cumulative N (≥S)



Differential S$^{2.5}$ dN/dS, normalized to Euclidia

A typical Excess of faint galaxies is observed at 0.3mJy from 12um,15um counts also observed from Spitzer galaxy counts @24um (Papovich et al, 2004)

Extension of PEGASE to Dust emission, consistent with metal evolution by types

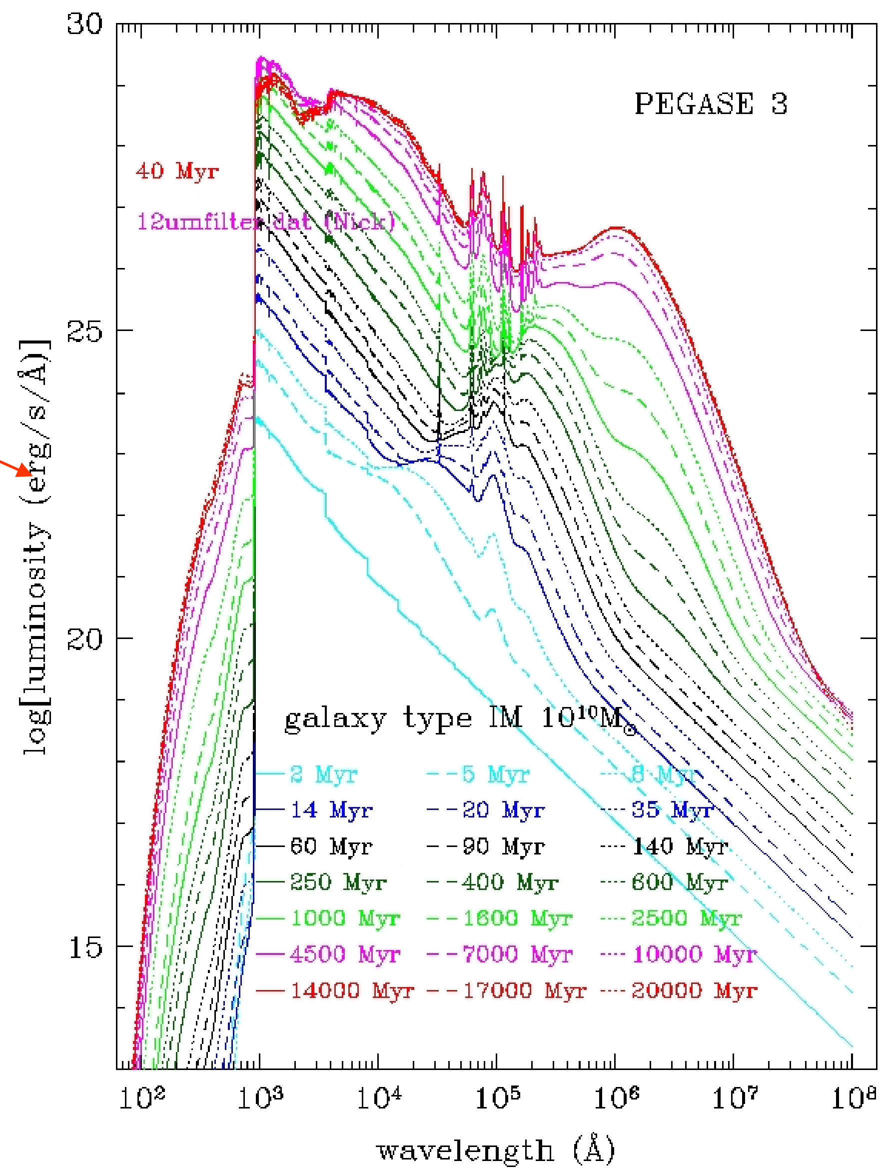
Characteristics of PEGASE.3

(Fioc, Dwek, Rocca-V., to be submitted.)

- •8 types of SFR: Elliptical→Irr
- •2 media: HII regions + ISM
- •Models of grains (Draine) silicates, graphite PAH
- •Transfer models
- •2 geometries (slab, spheroid)

Outputs for all galaxy types:

- •masses (dust, metals, gas, stars)
- •templates SEDs at all z (100-10^8A)
- • by types

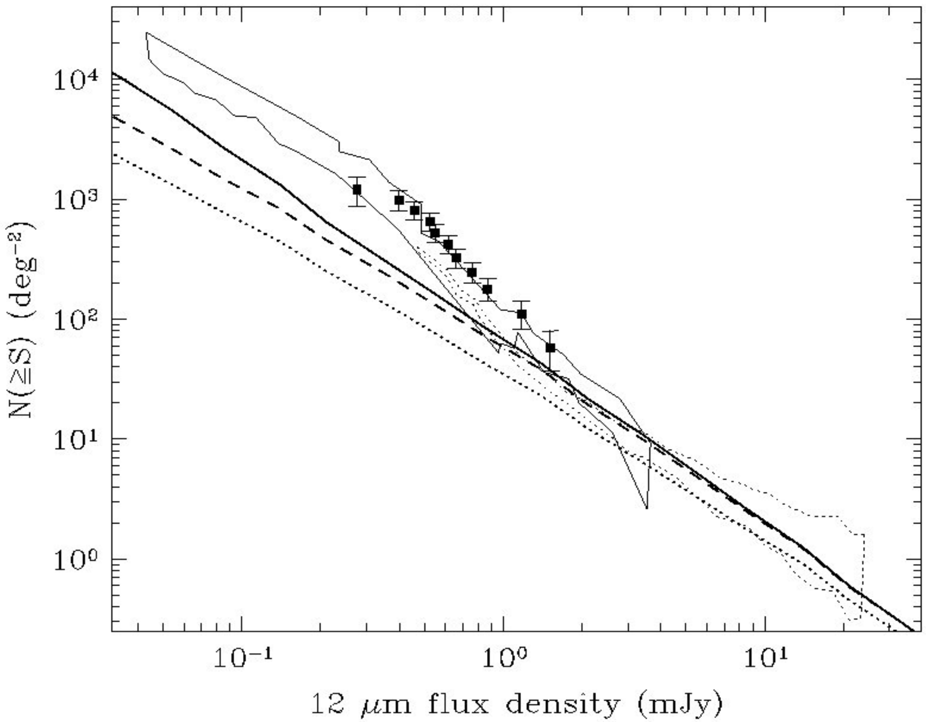


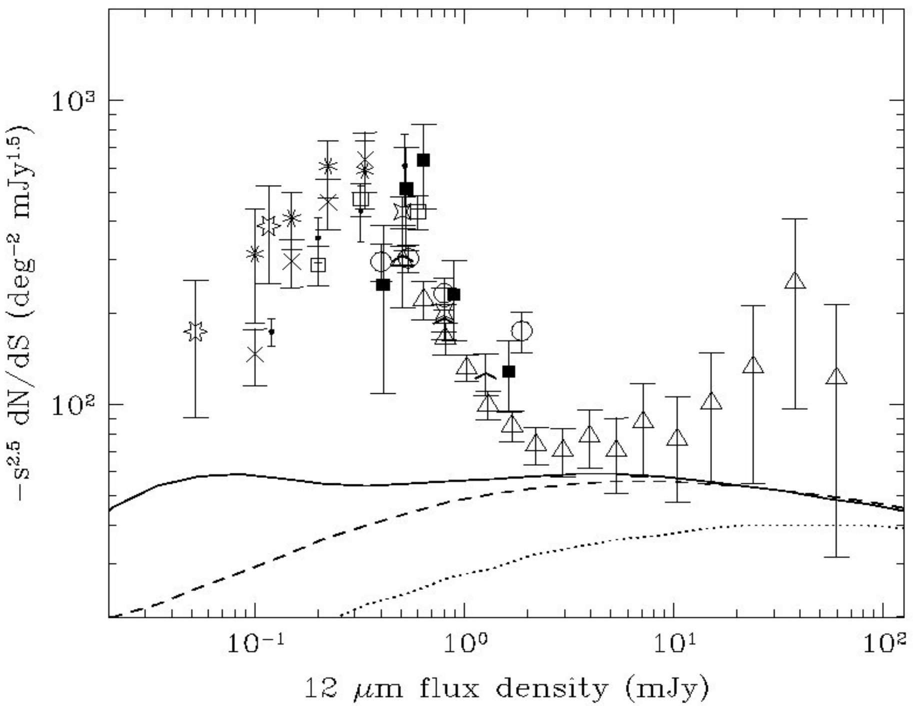
•The galaxy number fractions by types fitting optical counts (ELLIPTICAL:26%, Sa+Sb+Sbc: 24%, Sc+Sd+Im : 50%)

›are modeled at 12um with similar scenarios including stellar + dust emission using the code PEGASE.3

›using observed Luminosity function (Rush etal, 1993, Fang et al, 1998) and M*(12um) calibrated on optical-12um colors by types

are unable to reproduce the typical excess





Expansion + Evolution + k-corrections (full line), only k-corrections (dashed), only volume expansion (dotted)

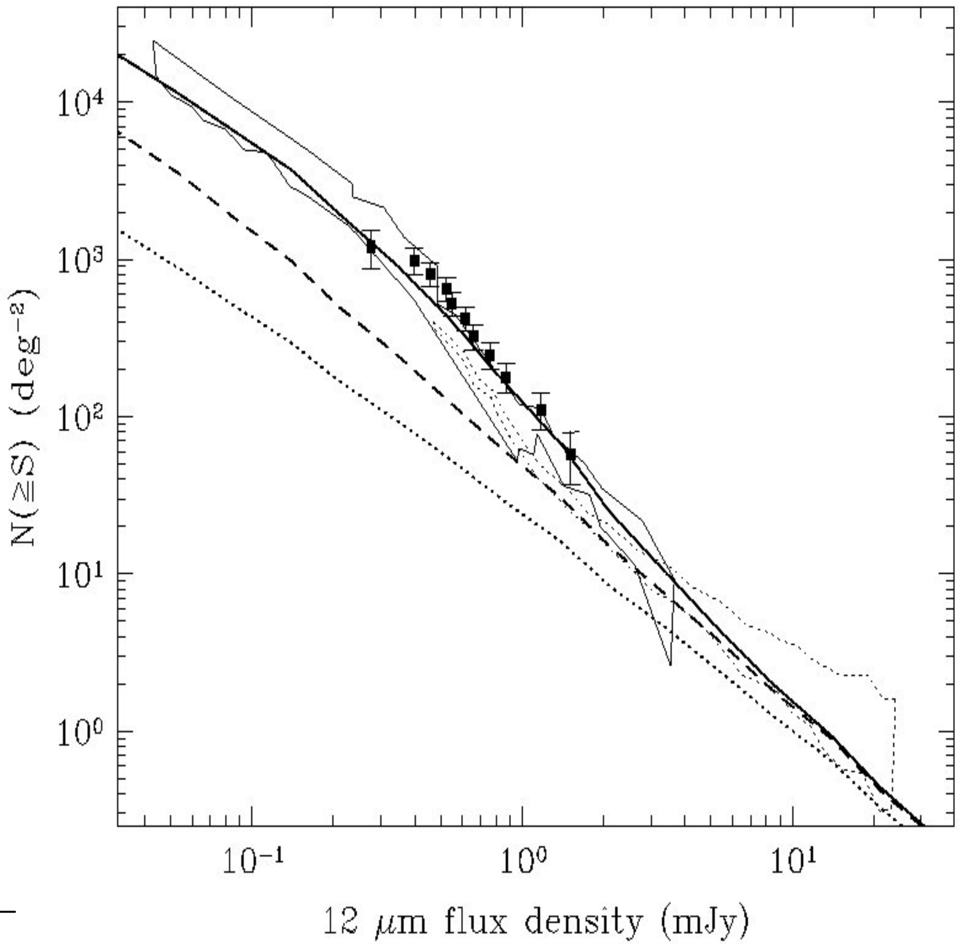
TO FIT the galaxy excess @ 12um

9% of Ultraluminous Ellipticals ($\Delta m(12)= -2.5$)

Dusty and partly extincted in the optical

See previously line identificatio

Number	Type	Magnitude M* at 12um(IR)
Fraction **9%**	**ultra-bright ellipticals**	**Normal -2.5**
15%	normal ellipticals	model color IRAS LF
24%	Early Spirals	//
50%	Late Spirals	// IRAS LF



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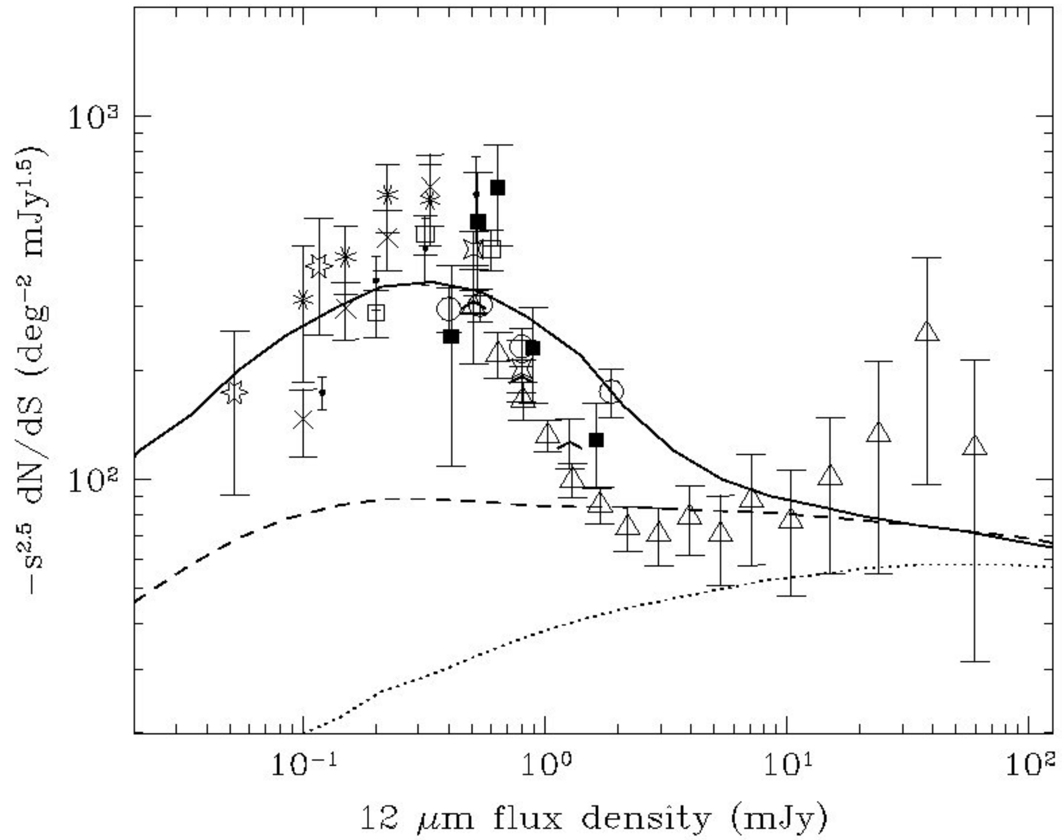
Rocca-Volmerange, de Lapparent, Seymour, Fioc, 2007, AA, 475, 801

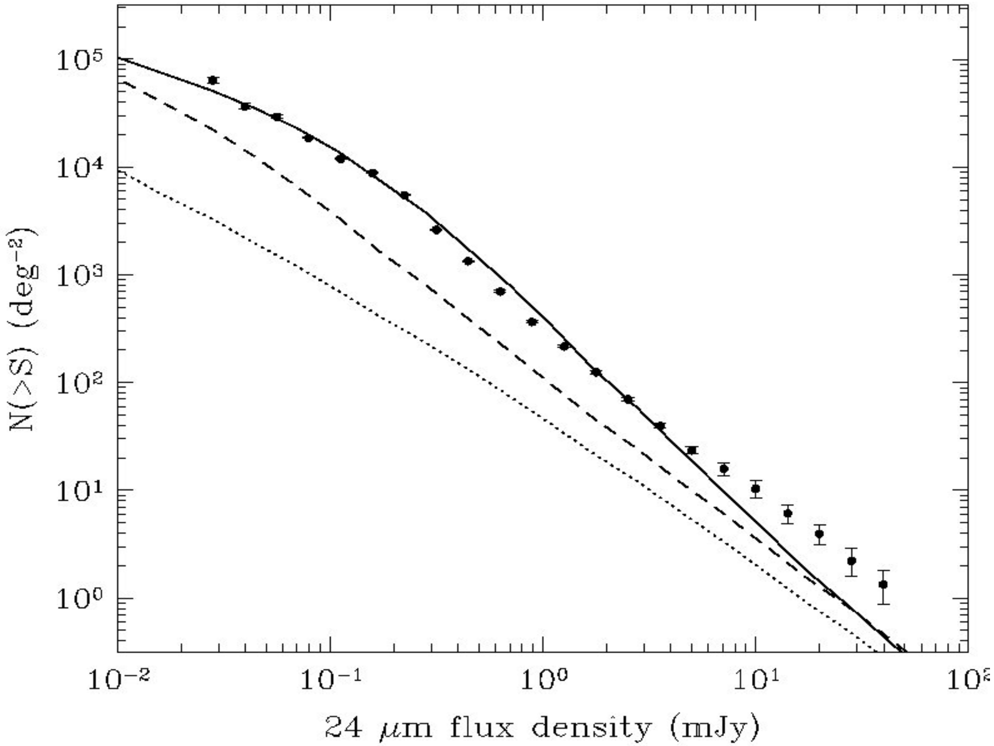
The ultra bright elliptical fraction (9%) fits the 0.3mJy excess observed in differential faint counts at 12um

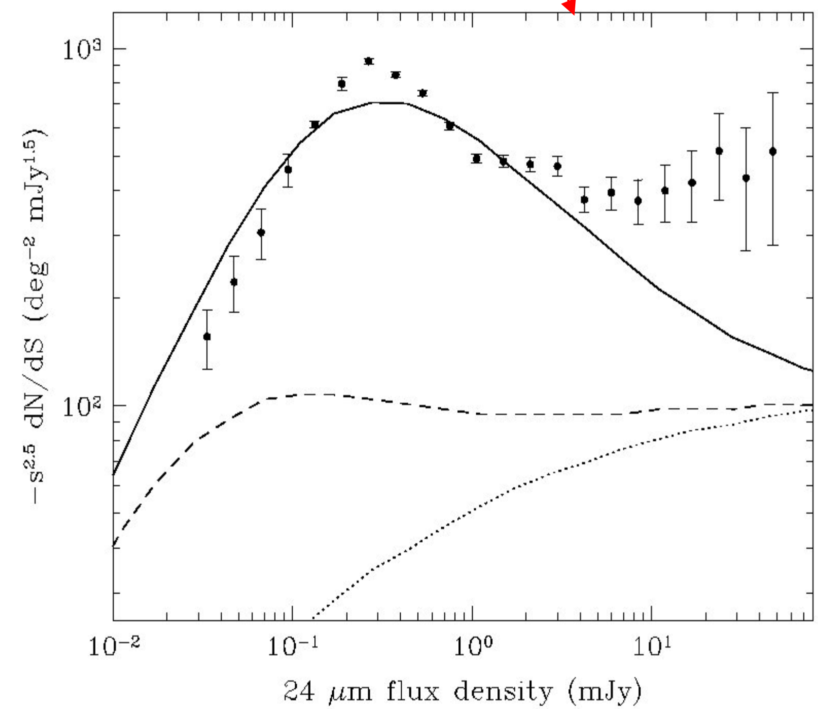


Full line: expansion + k + e corrections, dashed line: expansion + k- corrections,
Dotted line: expansion Standard Cosmology (Ω_M=0.3, Ω_Δ=0.7)

The same model (RV et al, 2007) also fits cumulative and differential 24um/MIPS counts

(Papovich et al 2004)





THE EXCESS POPULATION ARE DUSTY, EVOLVED, ELLIPTICAL GALAXIE
BRIGHTER BY 5 MAGNITUDES THAN NORMAL ELLIPTICALS @ 24 mu

The origin of the excess is due to the k-correction

The nature of mid-IR galaxy excess at 12 um

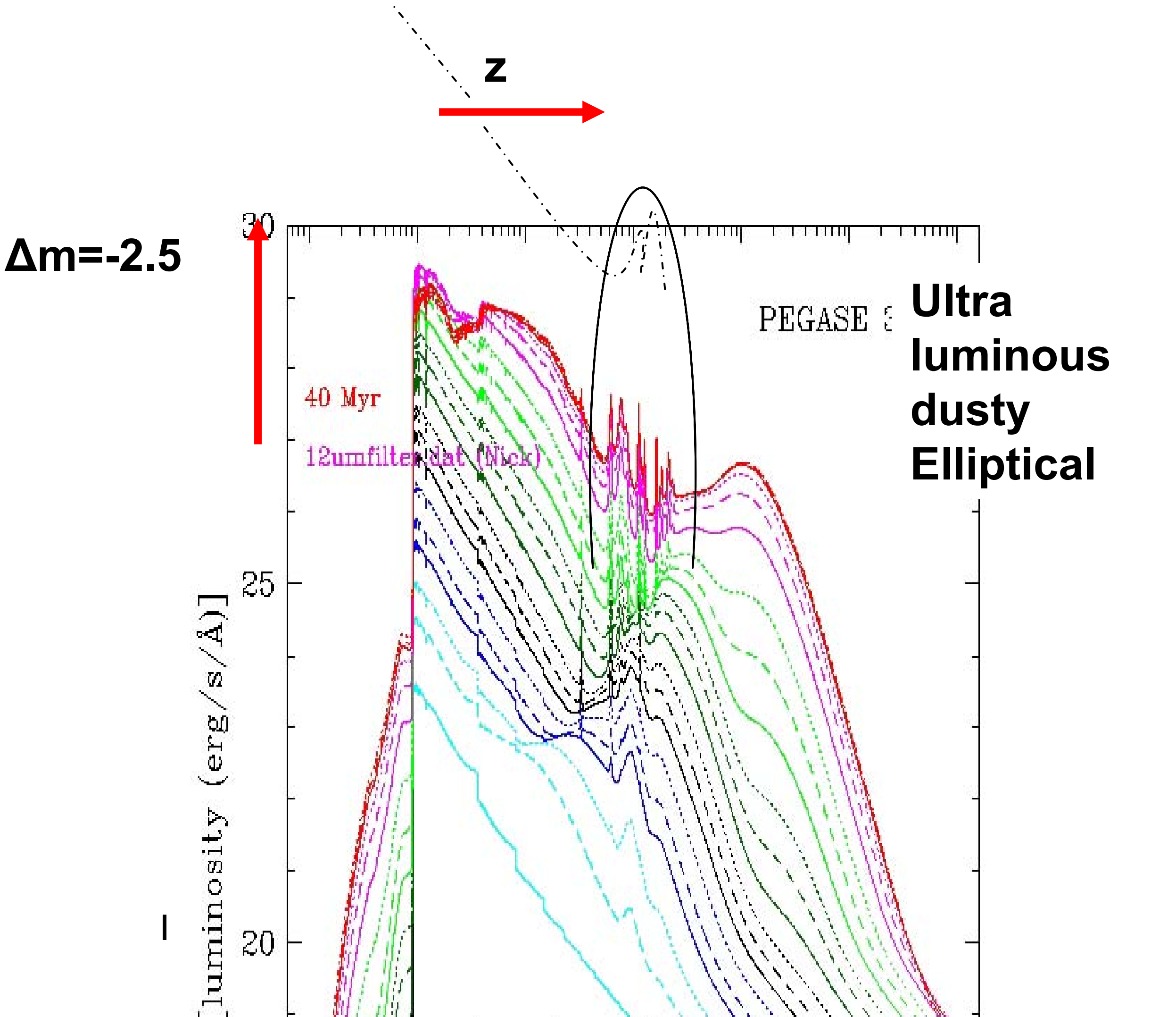
Is due to the stellar Rayleigh-Jeans slope of an ultra massive stellar population Of ellipticals

redshifted at 12um
➔ z > 1-2 from 12mu

➔ z > 2 from 24mu

The Rayleigh -Jeans of spirals is not hard enough
No need of adding starbursts

Redshifted OLD STELLAR POPULATION



Results

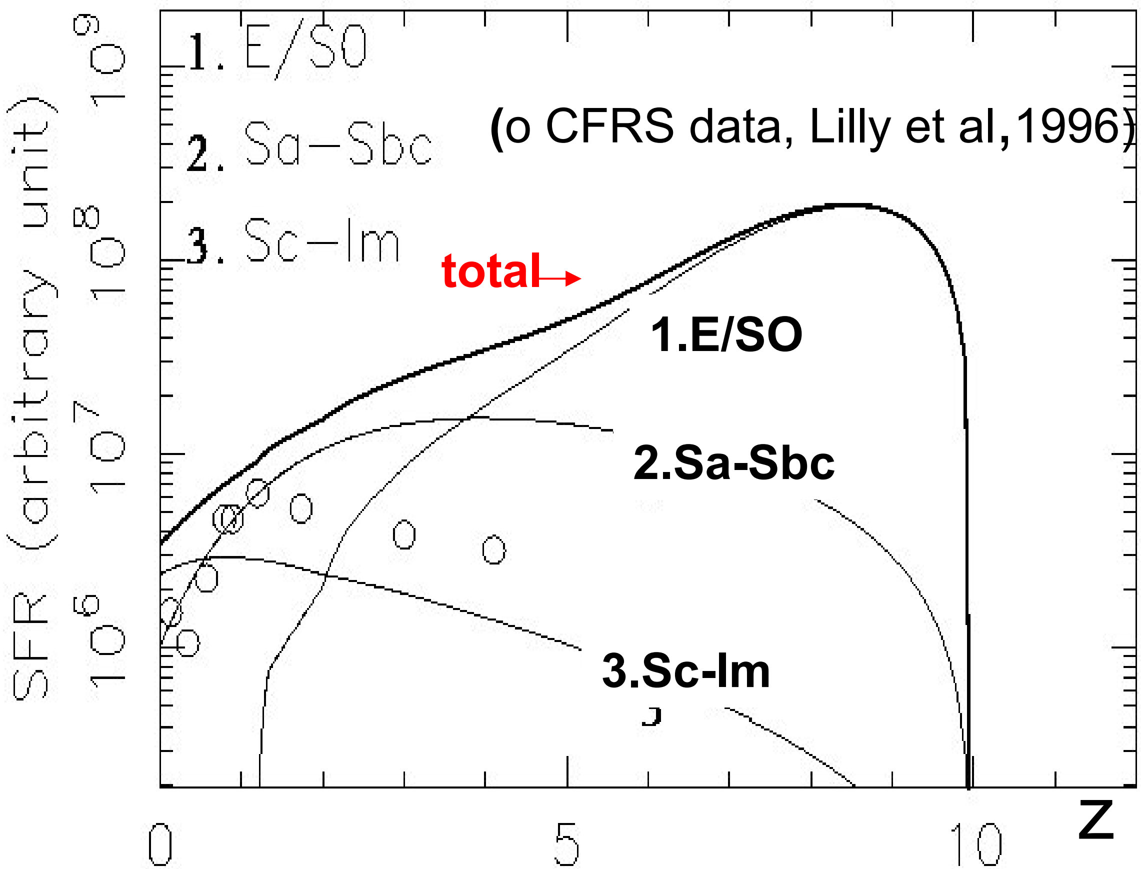
- Model including 9% of ellipticals, ultra-bright in IR (dusty and massive) matches the number density excess observed in MID-IR surveys at 12um and 24um
- This population of ellipticals, ultra-luminous in IR is partly absorbed in the UV-optical; it seems normal in optical surveys
- The rest of populations are of standard types with similar number fractions in the optical and IR, so they remain compatible with the results from UV/optical/NIR faint counts

Cosmic SF history from fits of faint counts

•1. At high z, the star formati
history is dominated by the
strong evolution of ellipticals
 the only scenario able to fit
the K-band deepest counts

2. The empty circles trace
the SFH from the CFRS,
selected from I band and
biased towards massive
 spirals Sa. It is compatible
with the SFH of massive
spiral models

•3. The late types are most
missing in CFRS



Zfor=10 is a lower limit, z=30 is also valid
ref: Rocca-Volmerange, 2000, Millenium meeting, SA
Rocca-Volmerange et al, 2007, AA, 475, 801

The Cosmic peak of SFR between z= 10 to 4

explained by

- The intense phase of star formation of elliptical scenarios
- Multi-spectral faint galaxy counts are excellent tracers of SFH
  - all star masses (0.9—120Mo) are taken into account.
  - Completness to B=29
  - Templates are reddened
  - Selection biases reduced: all types are counted (irregulars in the UV, ellipticals in the red)
  - Infrared excess in faint counts also favors old red populations

With our templates, the determination of luminosity functions by inversion would have to converge to similar results

(see poster Damien Le Borgne)

Constraints on evolution scenarios: they are robust up to z=4 high z of formation >5

Hierarchical merging from z=10 to 4 (example: Li et al, 2007)

OR

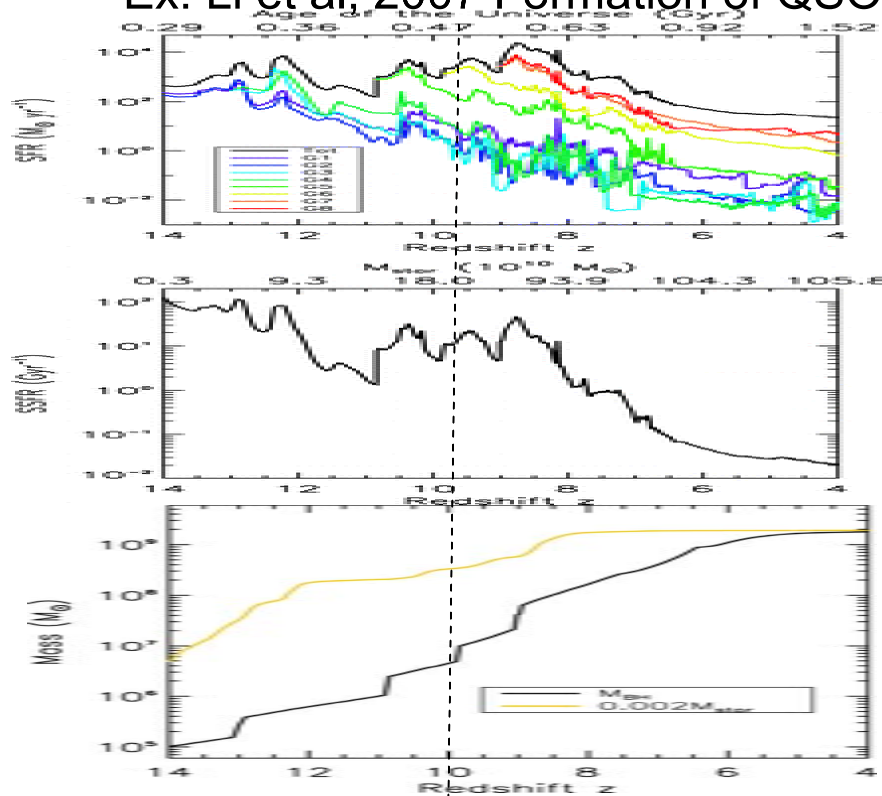
Dissipative gravitational collapse from z=10 a few massive halos with

a deep potential well (AGN?)

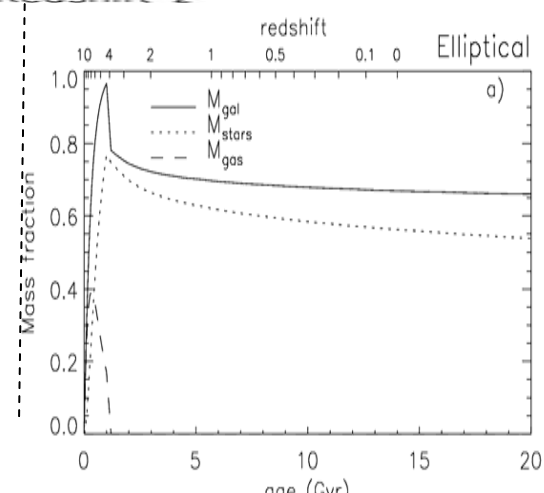
The 2 previous scenarios have different time-scales

Deeper surveys IR-Submm
Connexion with γ-rays (GRB)

Ex: Li et al, 2007 Formation of QSOs



PEGASE model



Conclusion

- **Scenarios by types are required to define the various time scales of SFH**
- **From z=0 to 4, the most massive galaxies are ellipticals, up to $10^{12}M_\odot$ for RG hosts.**
- **The connexion AGN-starburst is still debated**
- **Mid-infrared excess is due to k-corrections of the stellar emission of ultra-luminous elliptical galaxies**
- **Far-IR and submm with Herschel are keys for cold dust**
- **The physical process of mass accumulation for 5<z<10 or more is not yet solved**

A new ISOCAM/LW10 deep galaxy survey *ISO*-ESS @ 12um on the ESO-Sculptor area (optical data)

Seymour, Rocca-Volmerange, de Lapparent, 2007, AA, 475, 791

•~ 800 arcmin2, large enough for statistics
• **covering 80% of the ESO SCULPTOR Field**
(z-survey and deep optical photometry BVR, de Lapparent et al, 2003)

• **ISO filter LW10 (λ_{eff} ~12um) similar to 12um IRAS filter**
➔ solid flux calibration
•**Survey is complete down to 0.24mJy (after completeness corrections)**

•As deep as the GT deep surveys at 15um (Aussel et al, 1999, Elbaz et al, 1999, Flores et al, 1999, Altieri et al, 1999)
•DATA Processing, thanks to the CEA software PRETI (Stark et al, 1999), transient correction (Abergel et al, 1996)

=> Catalogue of 120 galaxies (77 have z, all have BVR colours).