Discovery of massive galaxies at high redshifts

A link with black hole growth?
A puzzling question for numerical simulations?

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Warm Dark matter
Colloque Chalonge 2013

Outline

I. The cosmological frame

Galaxy formation models

II. Principles of galaxy evolution models

Modeling High-z galaxies with the code PEGASE.3

Galaxy counts and individual types

III. The Hubble diagram K-z

IV. Old galaxies and merging in two examples of extreme (z=4) radio galaxies

4C41.17 + TN J2007-1316, Rocca-Volmerange et al. 2013, MNRAS

V Implications on th … **ns**

Recent striking observational discoveries

Models are required to fit all data and to disentangle cosmology and evolution

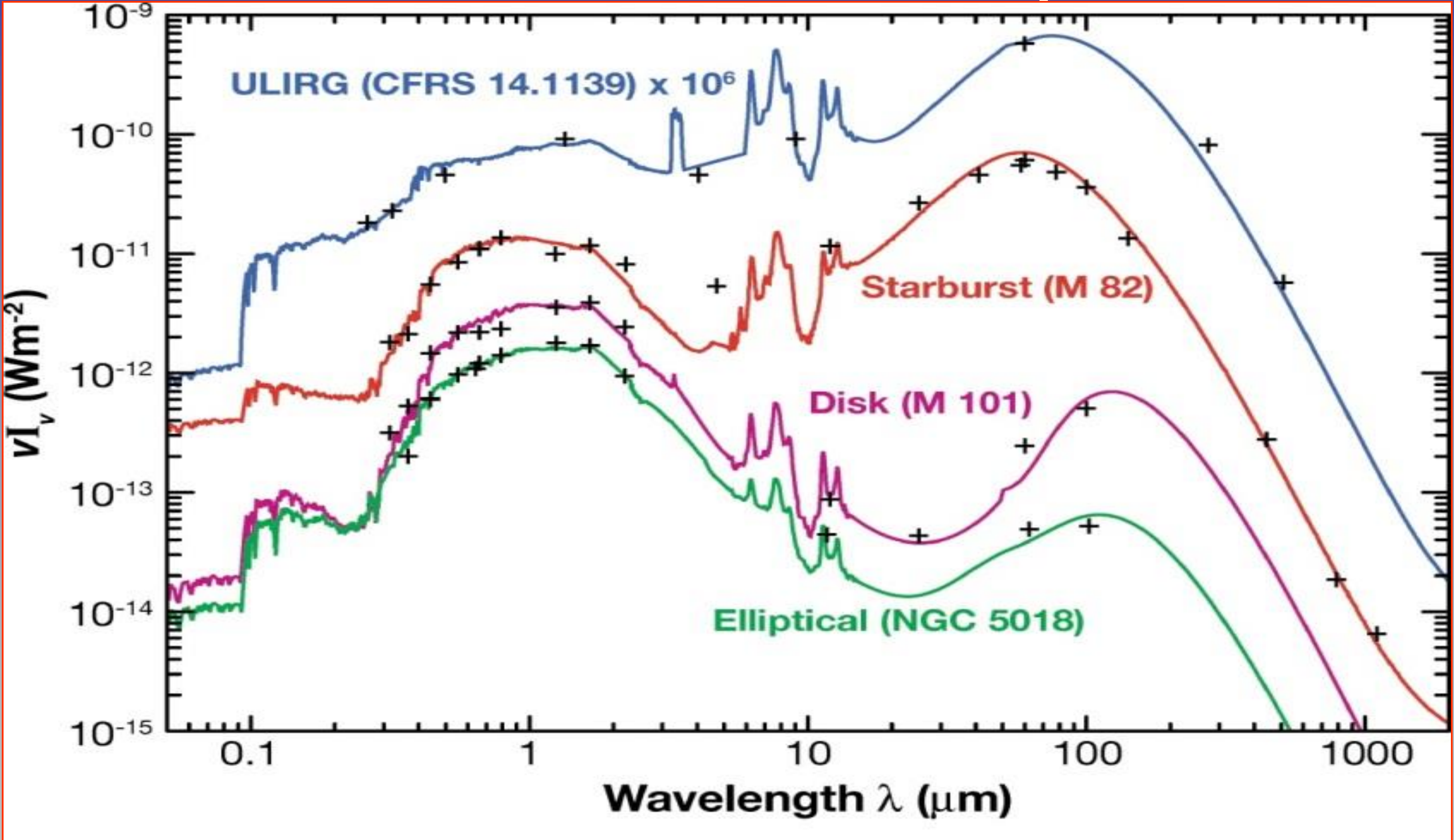
New concept: The template starburst M82

But the prototype of starburst

Embedded in an elliptical galaxy

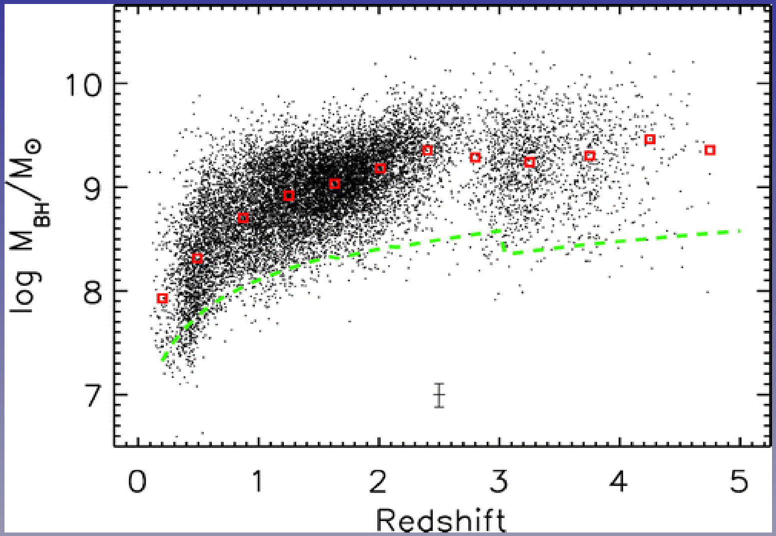
Revealed
by the IR
Satellite IRAS
As ULIRG (Ultra
Luminous Infra red
Galaxies) from dust
emission
Winds are supposed
from exploding
Supernovae

Main Observations : ULIRGs : Starburst and AGN seem not evolved galaxies



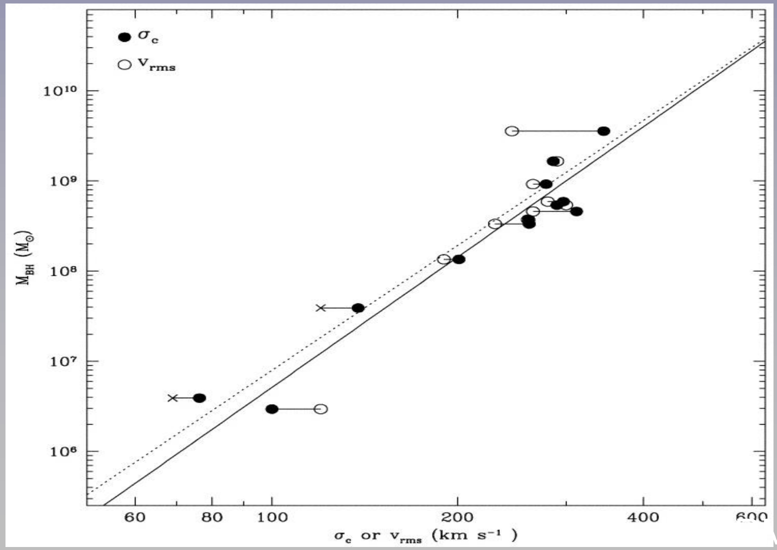
Lagache, G et al. 2005
Annu. Rev. Astron. Astrophys. 43: 727–68

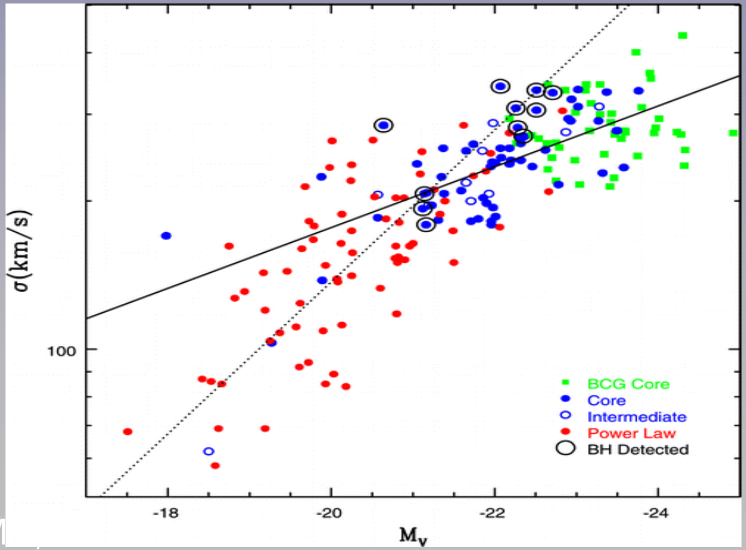
Discovery of massive(10**9MΘ) black holes at z>4



Redshift distribution of the black hole masses
Of the QSOs sample from SDSS DR3
Vestergaard etal. 2008, ApJ, 674, L1

Relation with the Galaxy properties
Merritt et al, 2006, Margorrian et al, 2004



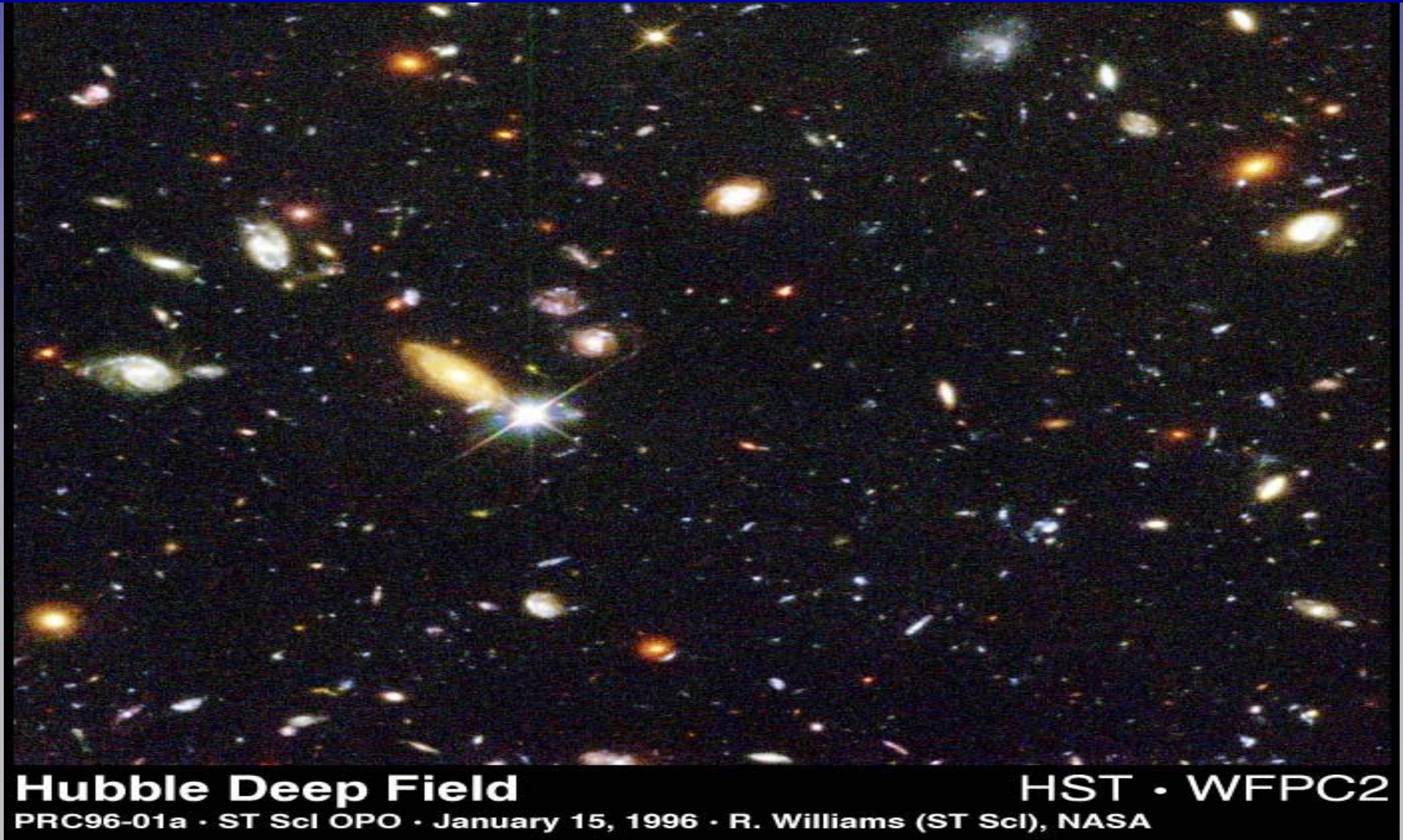


Deeper and deeper multi–λ surveys

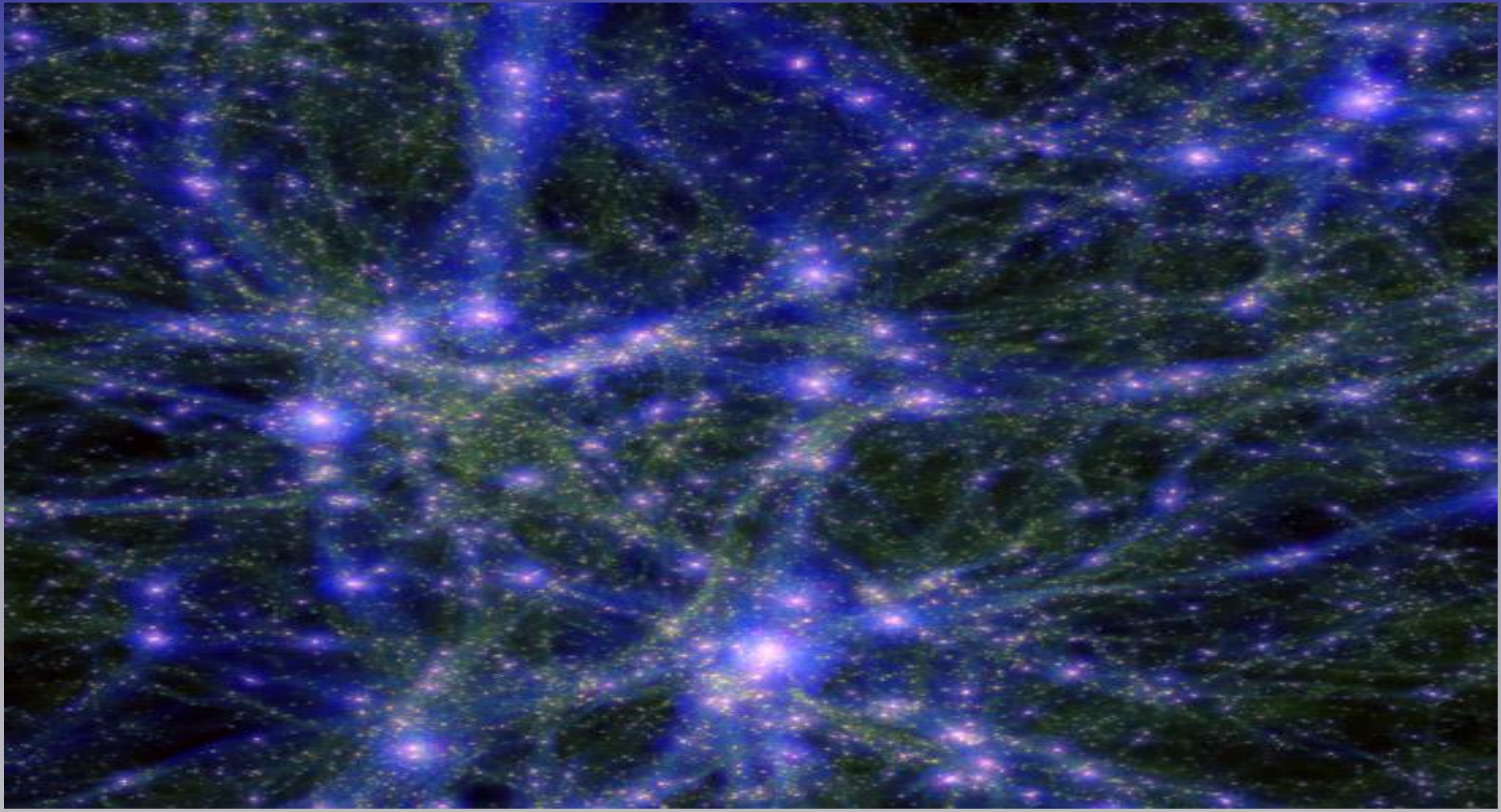
(X, UV, optical,NIR, FIR, radio)

An example In the optical: Hubble Deep Field-N

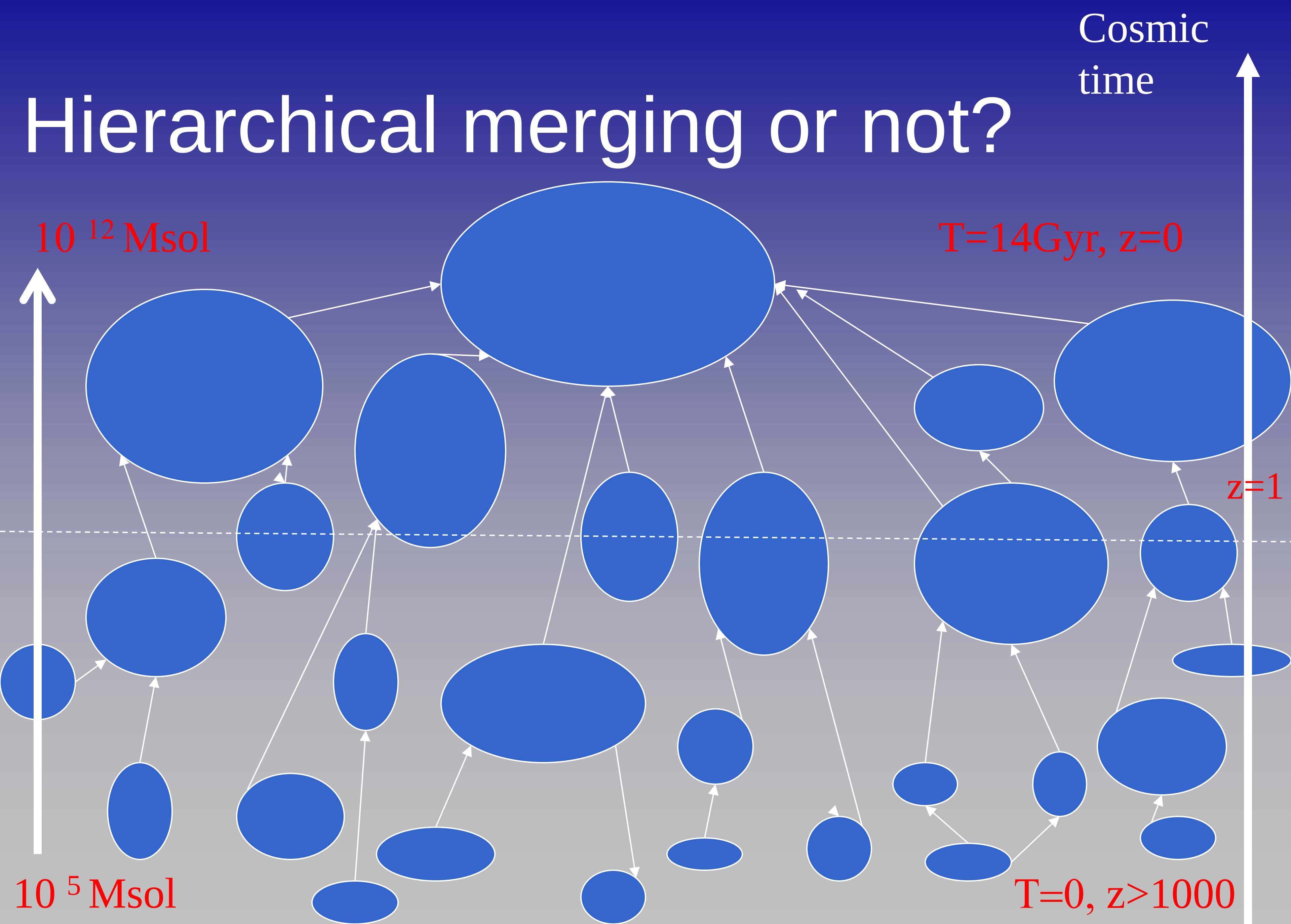
Counts N(m), N(z), N(color) by bin of z



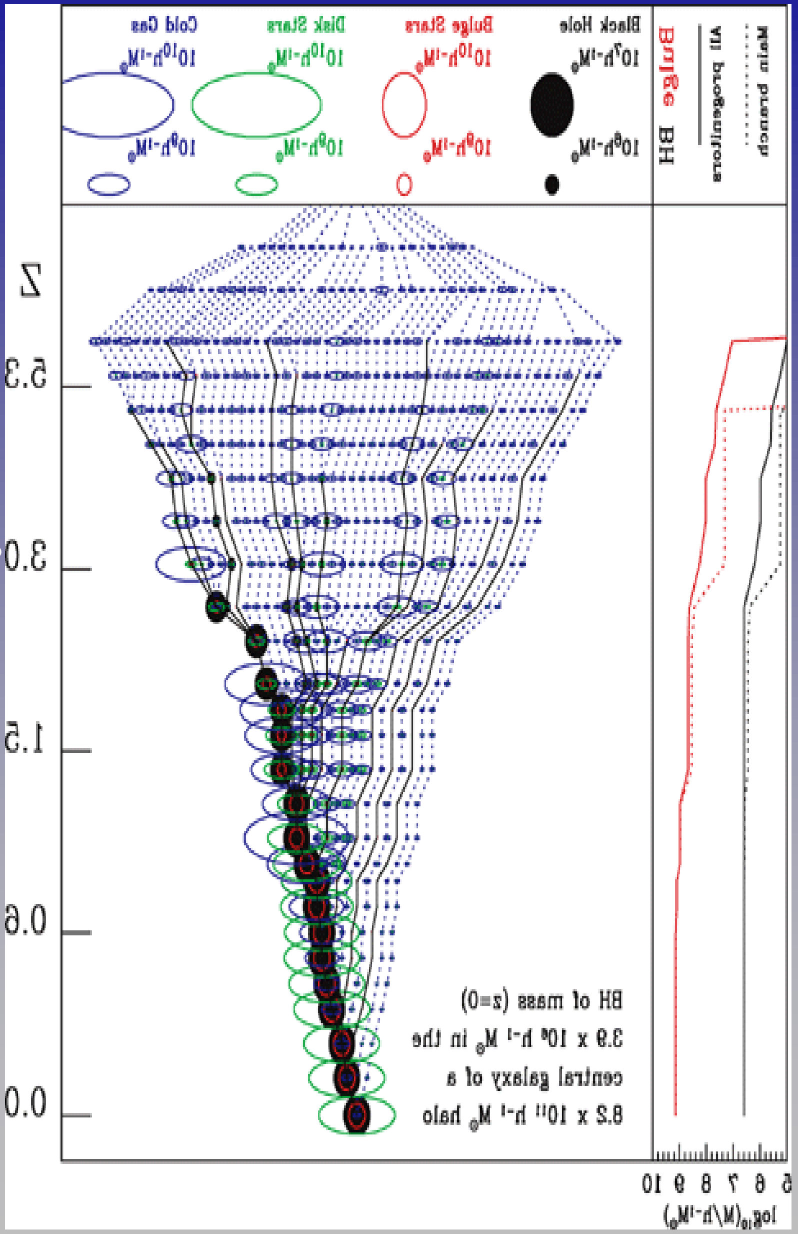
And the convergence to splendid numerical simulations



Hierarchical merging or not?



Among the most recent simulations:
The incorporation of the black hole growth
During galaxy mergers into the semi-analytic model
Based on ΛCDM by Baugh et al.



An example of Hierarchical merging with black hole growth
(Durham group, Malbon et al, 2007, MNRAS)

Or based on the Jeans mass in an expanding universe

The Jeans mass is the stability limit: when a density perturbation will grow once it becomes instable. The relativistic effects can be important.

The expansion is considered as adiabatic, as long as no energy sources is present

$$M_J = \frac{4}{3}\pi\, m_H\, n\left(\frac{2\pi}{K_J}\right)^3 = \frac{4}{3}\pi m_H n \left(\left(\frac{\pi \mathbf{v_s}}{G(\rho + \frac{P}{c^2})} \right)^2 \right)^{\frac{3}{2}}$$

n: total baryon number densi

ρ: mass density

v_s: adiabatic sound speed

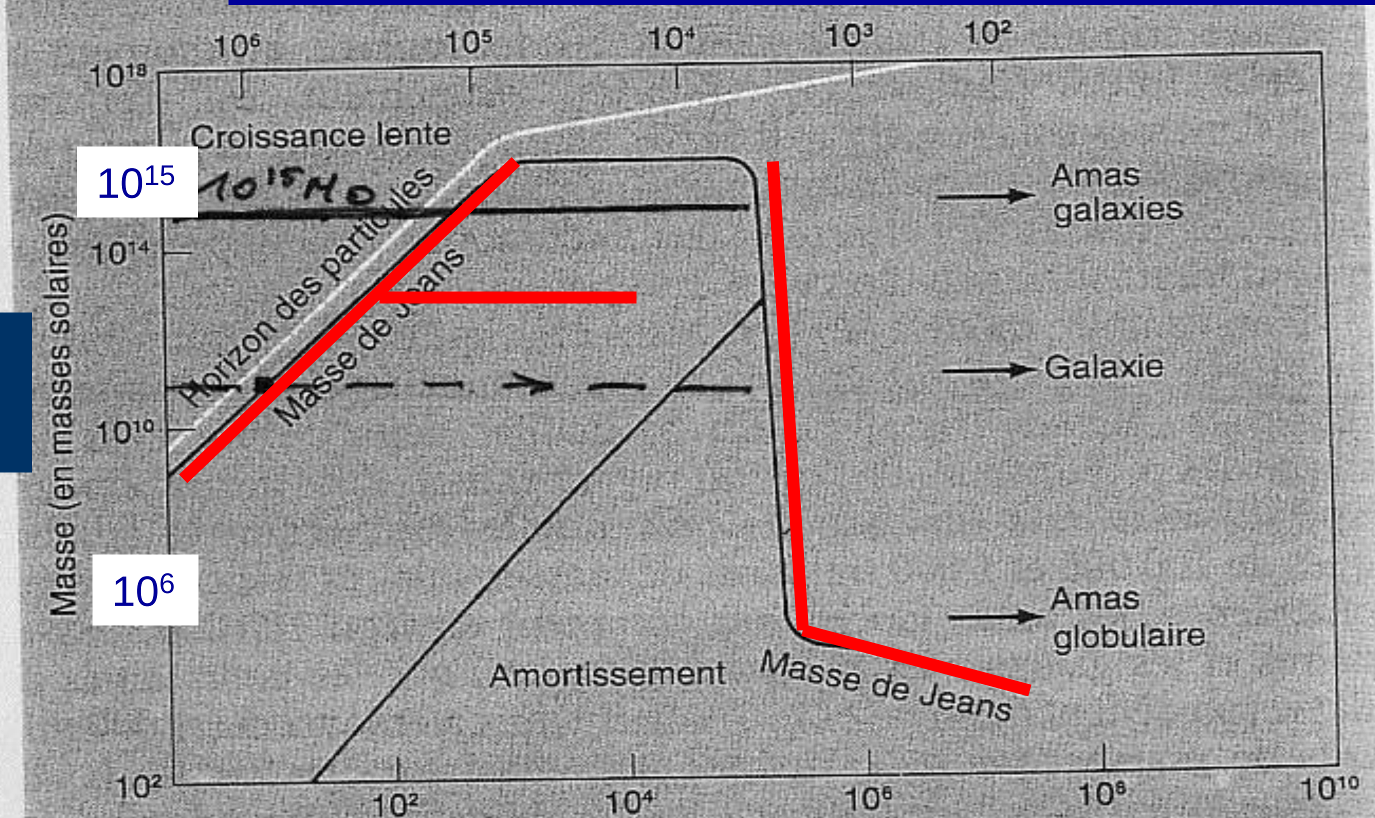
G: gravitation constant

P/c^2 = radiation pressure (relativistic)

UT THE JEANS MASS EVOLVES WITH COSMIC TIME

Versus Temperature °K

M_J



Versus Cosmic time t_{cosmic}

Before recombination M_J 9.10^{**15} Ms

After the recombination M_J $3.2\ 10^{**6}$ Ms

And Evolution of self-gravitating gas cloud with dissipation
Rees & Ostriker, 1977

2 time-scales are in competition

- the free_fall time scale (dynamics)

$$t_{ff} = \frac{1}{\sqrt{G\rho}}$$

- the cooling time scale (radiation)

$$t_{cooling} = \frac{1}{\rho\Lambda(T_G)}$$

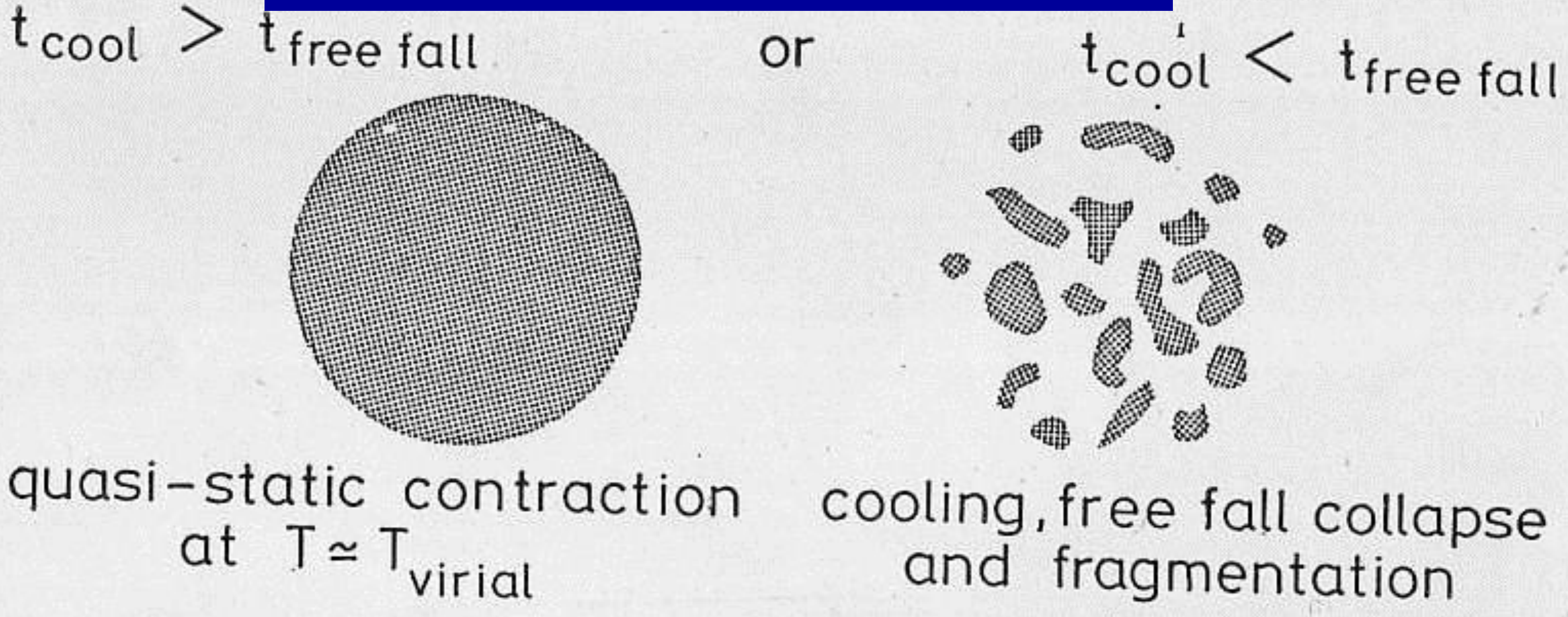
fonction $\Lambda(T_G)$ is the cooling function
depending on atomic properties

2 régimes are possible. They depend on the cooling function

$t_{ff} > t_{cooling}$ cloud fragmentation

$t_{ff} < t_{cooling}$ quasi-static evolution of the cloud

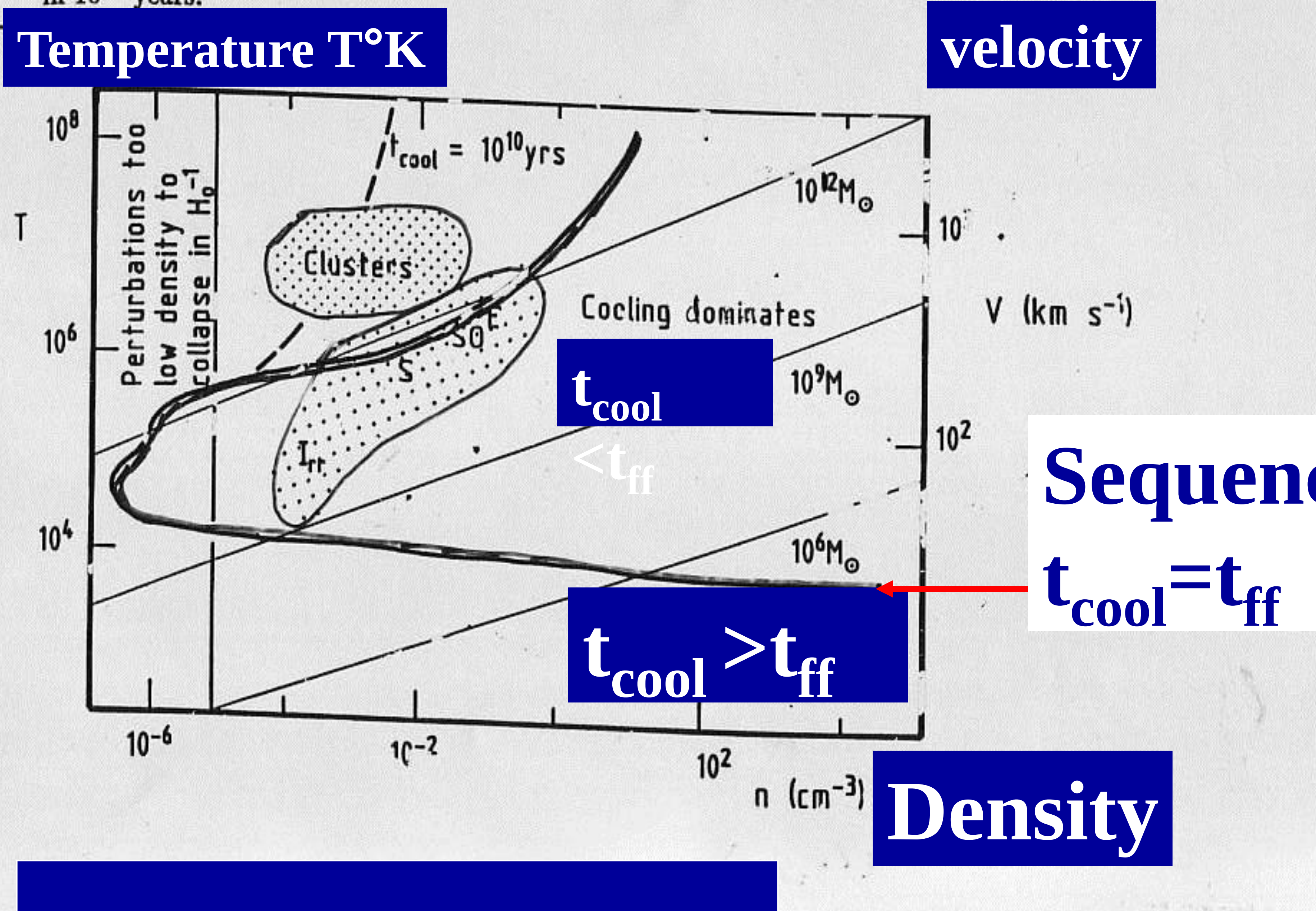
FRAGMENTATION



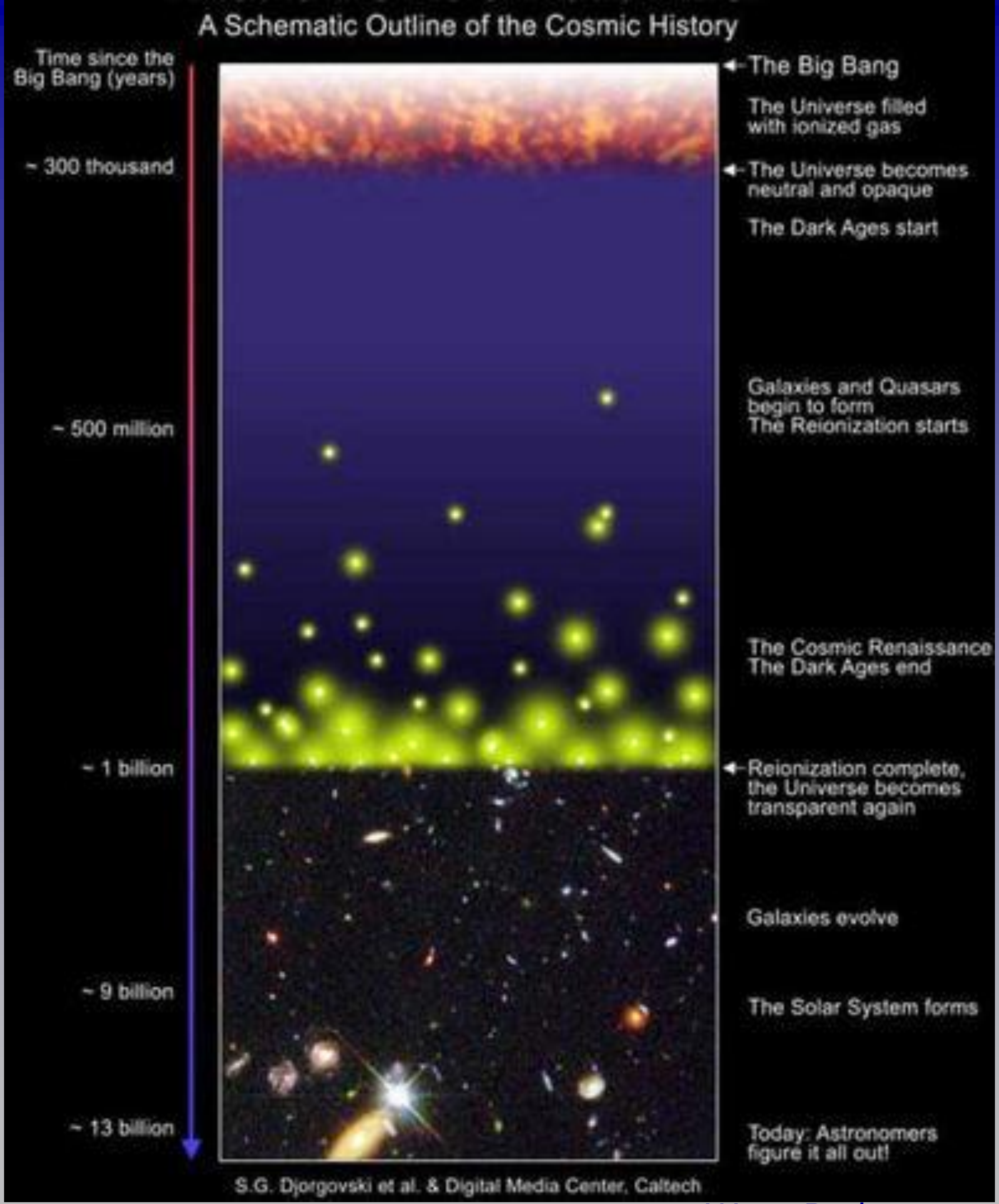
igure 1. *Cooling and contraction of self–gravitating gas clouds.*

VHAT IS SPECIAL ABOUT GALACTIC DIMENSIONS?

there any physics that singles out clouds of galactic dimensions, just as, si ddington and Chandrasekhar, we have known the natural scale of stars? All ave for galaxies is a simple but suggestive physical argument. Two timescales nportant in determining how a self–gravitating gas cloud evolves. The first [illegible] spectrum but by more astrophysical processes as well. The other lines show the loci corresponding to the radiation loss times being equal to the age of the Universe and to perturbations having such low density that they do not collapse gravitationally in 10^{10} years.

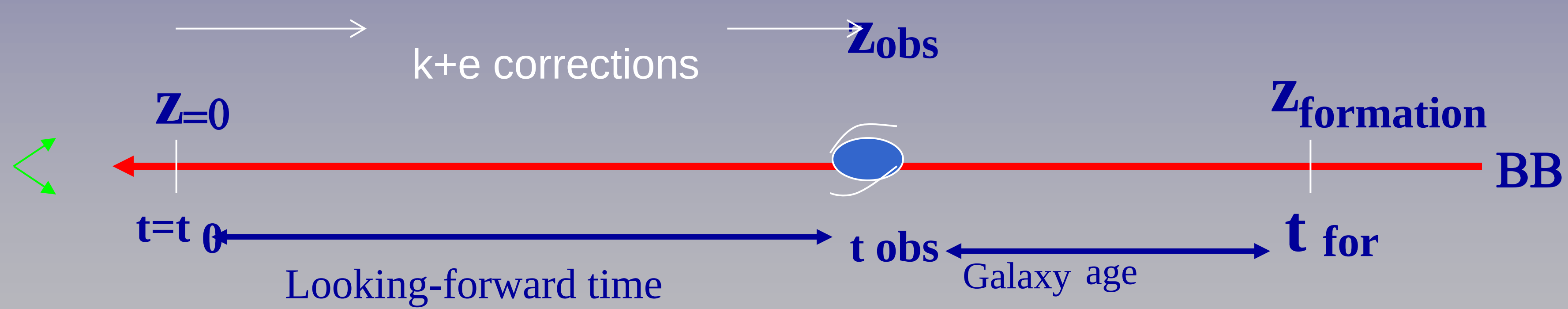


Cosmology pattern



z	Cosmic time
5	**1.2 Gyr**
2	**3.5 Gyr**
1	**6.1 Gyr**
0	**14.5 Gyr**

Redshift z	CosmicTime	Redshift z	CosmicTime	Redshift z	CosmicTim
30	0. 11	2.5	2.7	0.5	9.1
20	0.19	2.	3.5	0.4	10.1
10	0.45	1.5	4.6	0.3	11.0
5	1.20	1.	6.1	0.2	11.9
4	1.6	0.8	7.1	0.1	13.1
3	2.3	0.6	8.1	0	14.5



Relation Redshift
z- temps cosmique t(z) in Gyr
Ho=72km.s-1Mpc-1, $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$

$$H_0 t(z) = \int_0^{1+z} (1 - 2q_0 + 2\frac{q_0}{x})dx$$

Models of evolutionary SEDs

11. **Instantaneous starburst: SSP**
Single Stellar Population (with the adopted IMF)

Sum of SSPs =→ Galaxy types (E, Sp, Im)

Chemical evolution → Z (Graphite, silicates) → Dust
Evolution of Stellar populations, stellar mass
Galaxy spectrum = SUM of stellar spectra
Gas content, ionized gas, etc

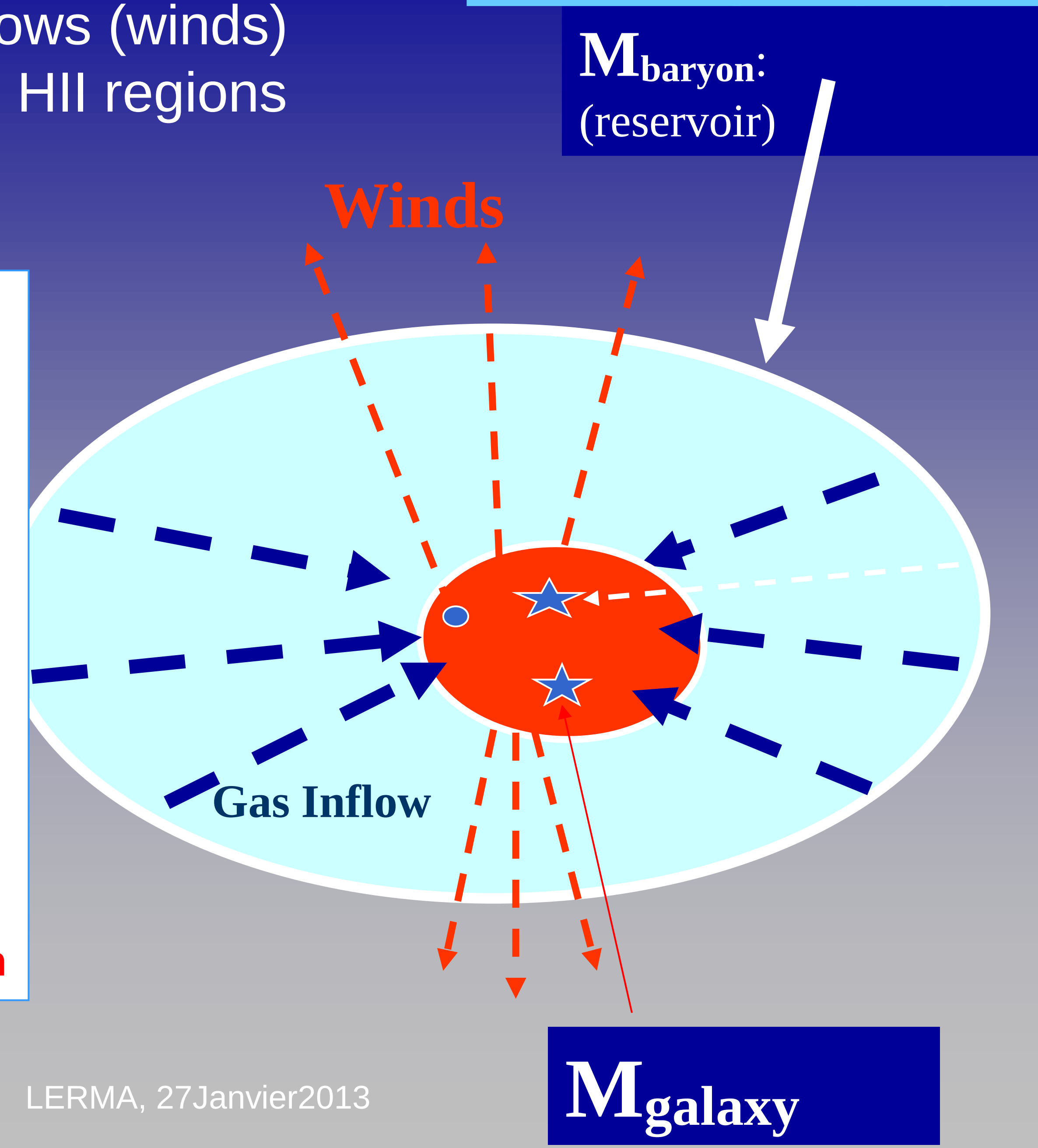
PEGASE.3 model of Galaxy evolution
Accretion + outflows (winds)
Galaxy including HII regions

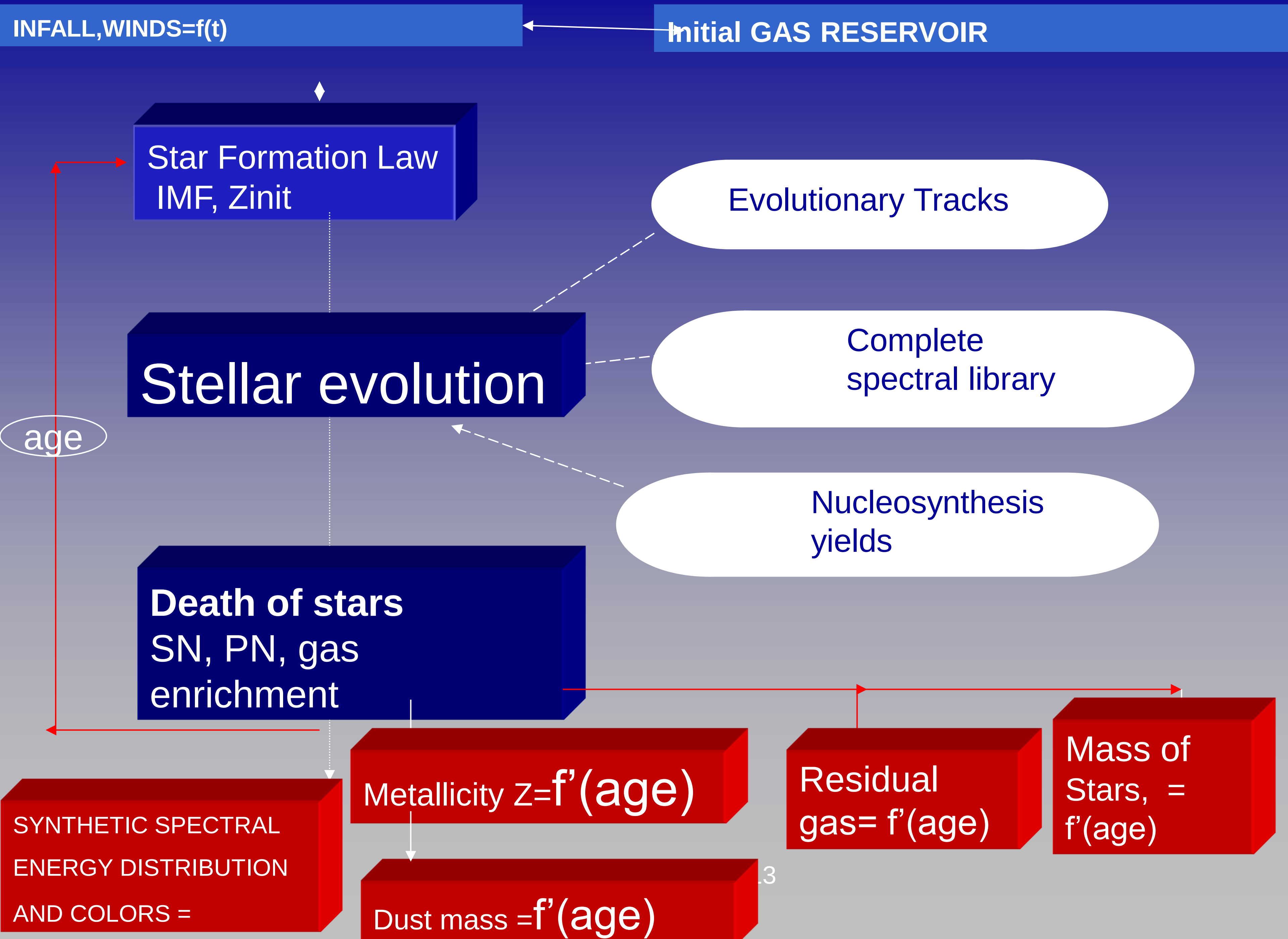
www2.iap.fr/pegas

Scenarios by type:
Four Parameters

- **Star Formation law SFR(t)**
- **Inflow time-scale**
- **Extragalactic winds**
- **IMF**
- **+ RADIATIVE TRANSFER**

Dust absorption and emission




INFALL,WINDS=f(t)
Initial GAS RESERVOIR
Star Formation Law
IMF, Zinit
Evolutionary Tracks
Stellar evolution
Complete
spectral library
age
Nucleosynthesis
yields
Death of stars
SN, PN, gas
enrichment
Metallicity Z=f'(age)
Residual
gas= f'(age)
Mass of
Stars, =
f'(age)
SYNTHETIC SPECTRAL
ENERGY DISTRIBUTION
AND COLORS =
Dust mass =f'(age)

I. STELLAR EVOLUTIONARY TRACKS:1<M/M☼<25
L= F(Teff, age)

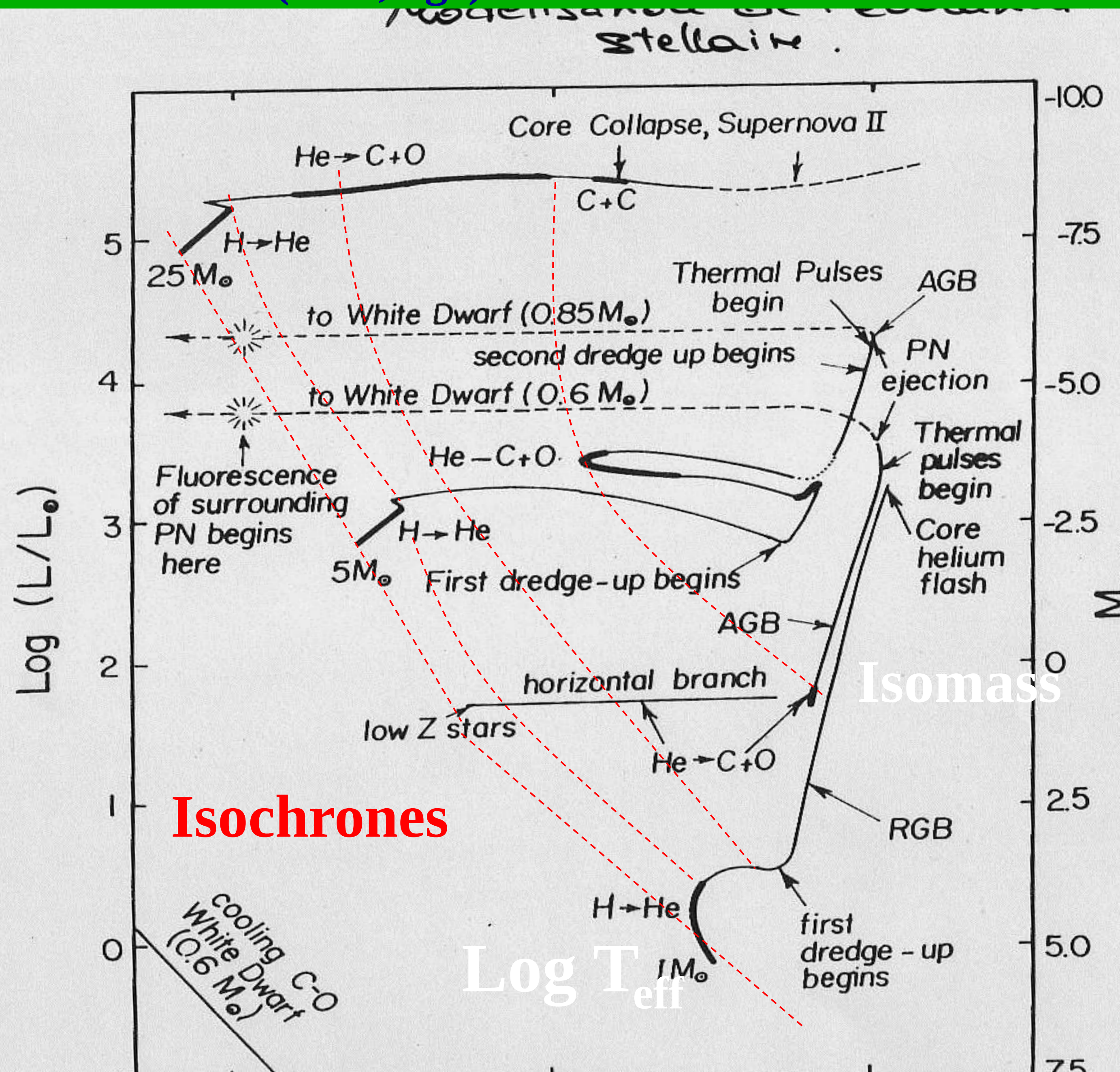
Many Groups from

Padova

Genova

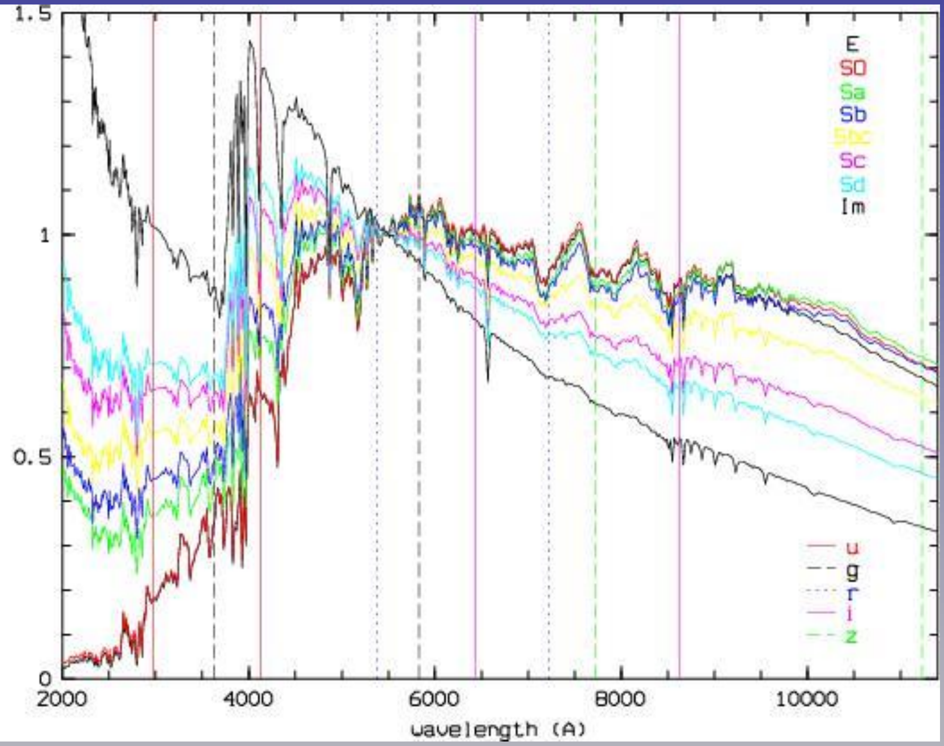
Yales

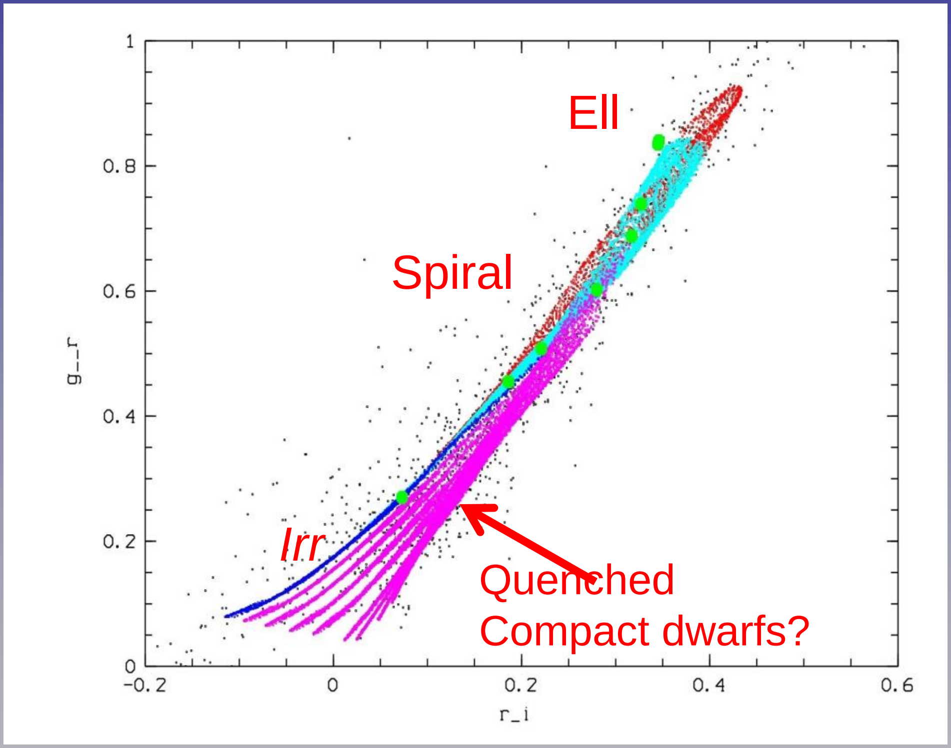
• • •



A variety of scenarios fitting z=0 templates by type in the color-color diagram

Compared to the statistical SDSS survey (SLOAN) Tsalmantsa et al, 2007, 2009 (Consortium GAIA)





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

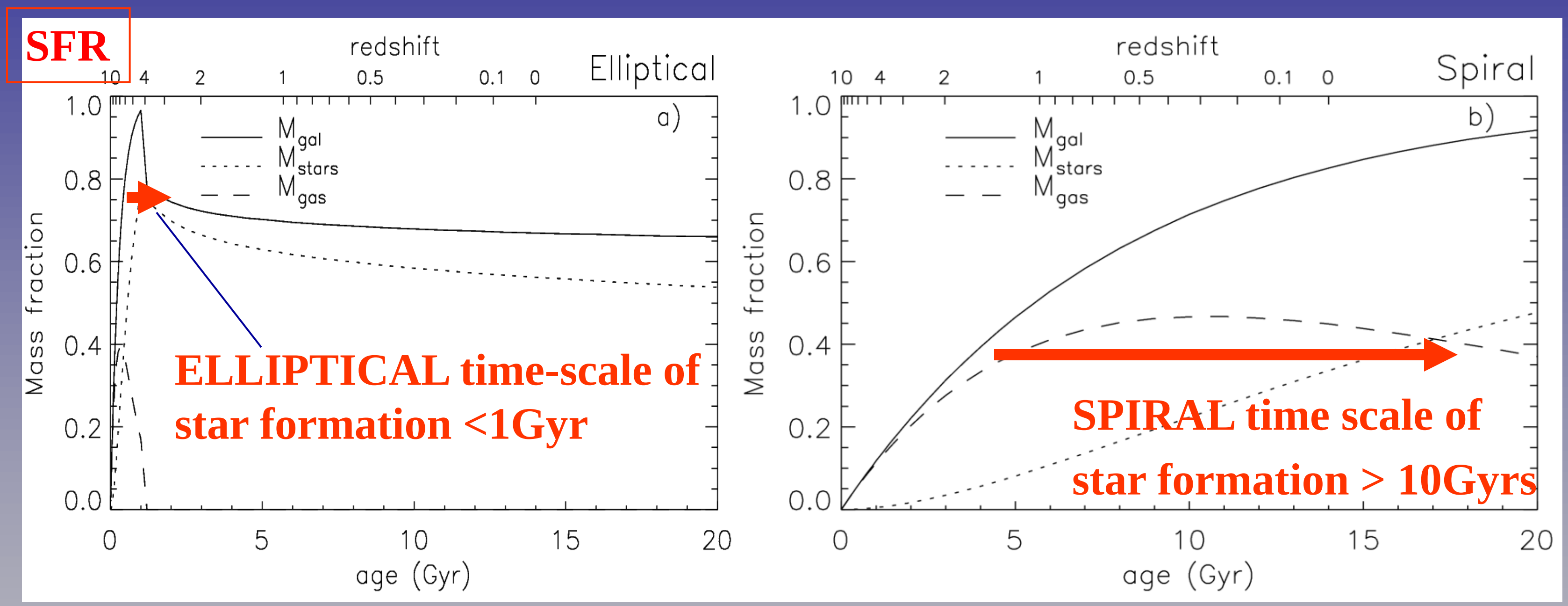
•**1. Phot- z / spectro –z** (Le Borgne, Rocca-Volmerange, Fioc, 2002) (code Z-PEG on http://www2.iap.fr)

2. 0<z<2 Multi-λ faint galaxy counts (Fioc & Rocca-Volmerange, 1999)

A puzzle for Dark Matter models

:

Elliptical galaxy **Spiral Galaxy**



Possible succession of mergers (amplitude, number, etc)
Accretion/infall during a few 100 Myr
Extra galactic winds at 1 to 3 Gyr
Star Formation time scale short ~1Gyr for E and long for Spirals

+ New constraint with Dust (farIR) The new version PEGASE.3

Passive and active stellar emission + nebula emission (HII regions) + chemical enrichment➔ dust emission

- **Dust mass (t, type) fitted on Metallicity enrichment (by types**
- **in particular C and SI, from SN and evolved supergiants/AGB**

- **Grain models (Draine)**
- **scattering/absorbing by Draine's grain population,**

- **Heated from Lyman cont. photons (N_Lyc)⇐➔ Star Formation RATE**

- **Factor for dense media): 2 media: diffuse ISM and HII regions (Zubko et al, 2004)**

- **Radiative transfer (adapted from Varosi &Dwek, 1999)**
- **2 Geometries (disk/slab , spheroid)**

Extinction Modeling

- Extinction A_{λ}(z) (magnitude) depends on time following dust mass, metals and gas content.

- Optical depth

$$\tau_{\lambda} = \frac{\ln 10}{2{,}5} A_{\lambda}(z)$$

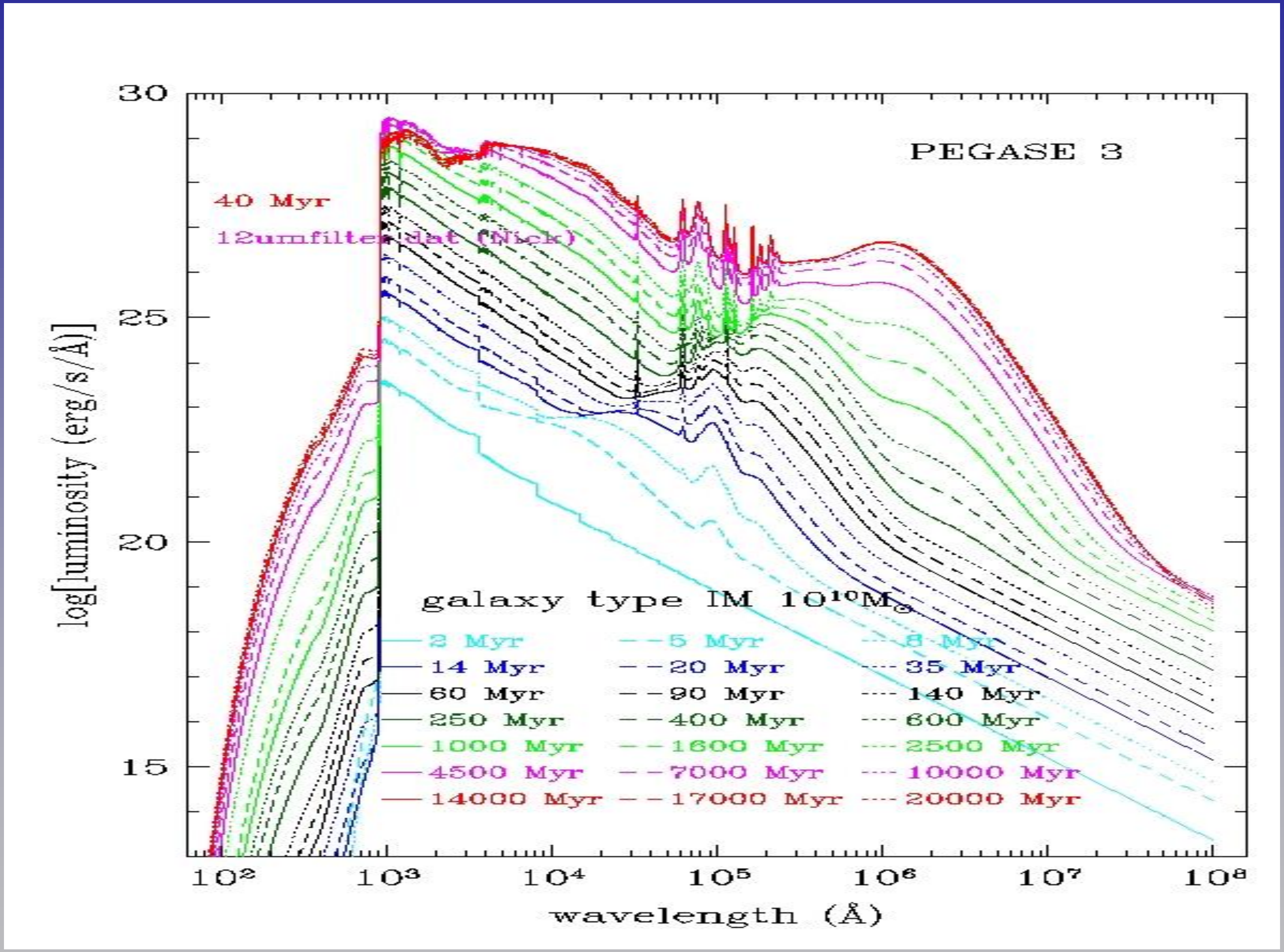
τ_{λ}

$$\tau_{\lambda}(z) = \frac{\ln 10}{2{,}5} \cdot \frac{A_{\lambda}}{A_V}(z) . \frac{A_V}{E_{B-V}}(z) . \frac{E_{B-V}}{N_H}(z) . N_H$$

Possibility to increase the gas density

NHI = K . NHI(ISM) with K=1 to 10

Atlas of synthetic galaxies(optical-FIR)



LERMA, 27Janvier2013

Fioc, Rocca-Volmerange, Dwek , in preparation

To model High-z galaxies in the observer frame

(avoiding analysis in the rest-frame)

1. Building libraries of templates by types

2. defining types as z=0 local templates

3. Predicting templates at z from:
local templates + cosmology+ evolution

Apparent magnitudes at z, t_{obs}

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

Rocca-Volmerange & Guiderdoni, 1988, AA

k- (expansion) corrections

$$k_\lambda^i(z) = M_\lambda^i(z,t_0) - M_\lambda^i(0,t_0)$$

e-(evolution) corrections

$$e_\lambda^i(z) = M_\lambda^i(z,t_z) - M_\lambda^i(z,t_0)$$

Computed with F^i_λ=synthetic flux from library models through the pass-band of the filter λ

k- (expansion) corrections

$$k_\lambda^i = -2.5\log\frac{\int F_\lambda^i(\lambda^{'}/(1+z), t_0 - t_{zfor})R_{\lambda'}d\lambda'}{(1+z)\int F_\lambda^i(\lambda', t_0 - t_{zfor})R_{\lambda'}d\lambda'}$$

e-(evolution) corrections

$$e_\lambda^i(z) = -2.5\log\frac{\int F_\lambda^i(\lambda'/(1+z), t_z - t_{zfor})R_{\lambda'}d\lambda'}{\int F_\lambda^i(\lambda'/(1+z), t_0 - t_{zfor})R_{\lambda'}d\lambda'}$$

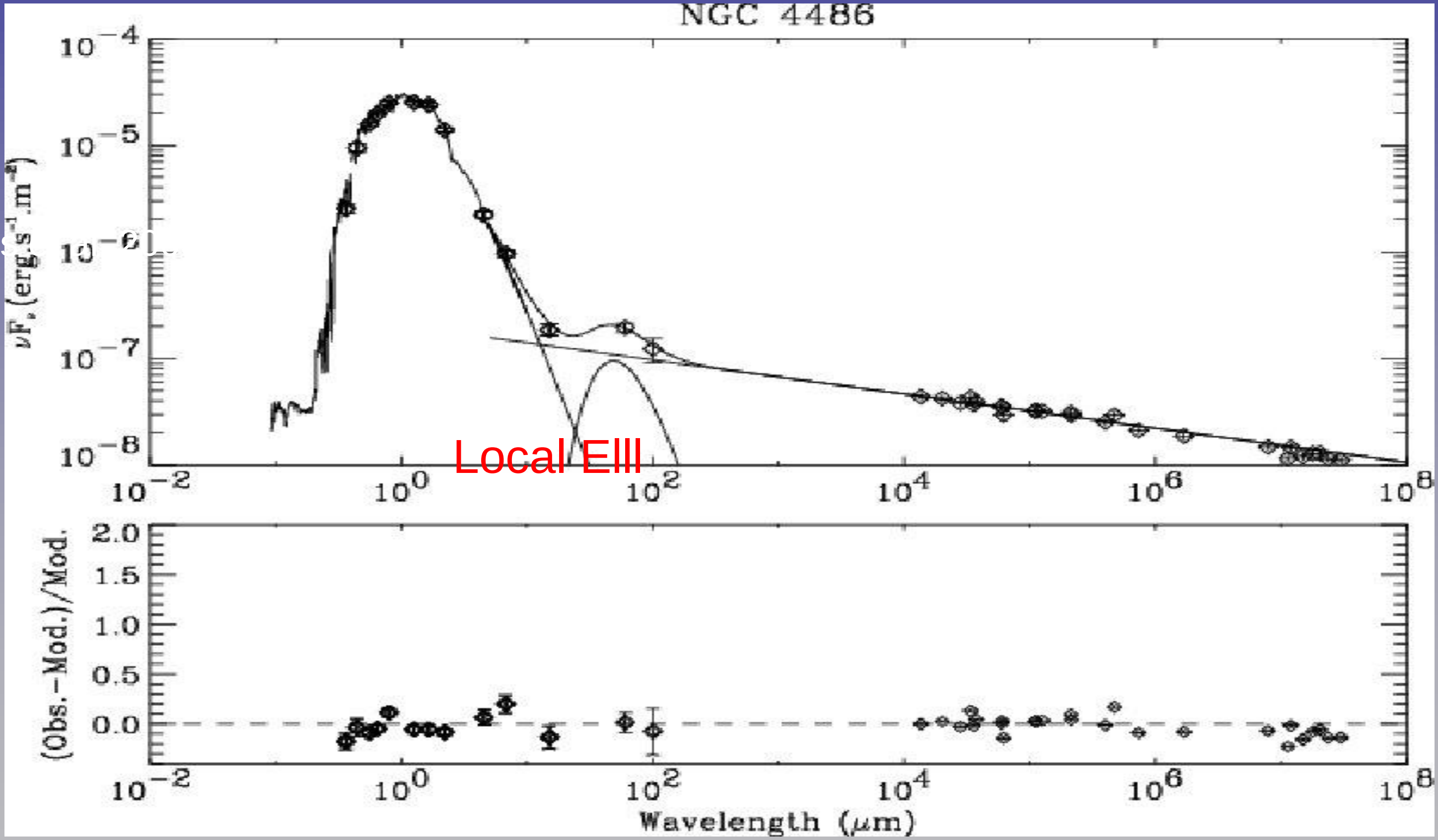
F^i_λ=Apparent flux from synthetic librairies
R_λ=pass-band of the filter λ

Rocca-Volmerange & Guiderdoni, 1988, AA

To model high-z elliptical: the best targets are distant radio galaxies :

Local massive ellipticals are faint in the far Infrared

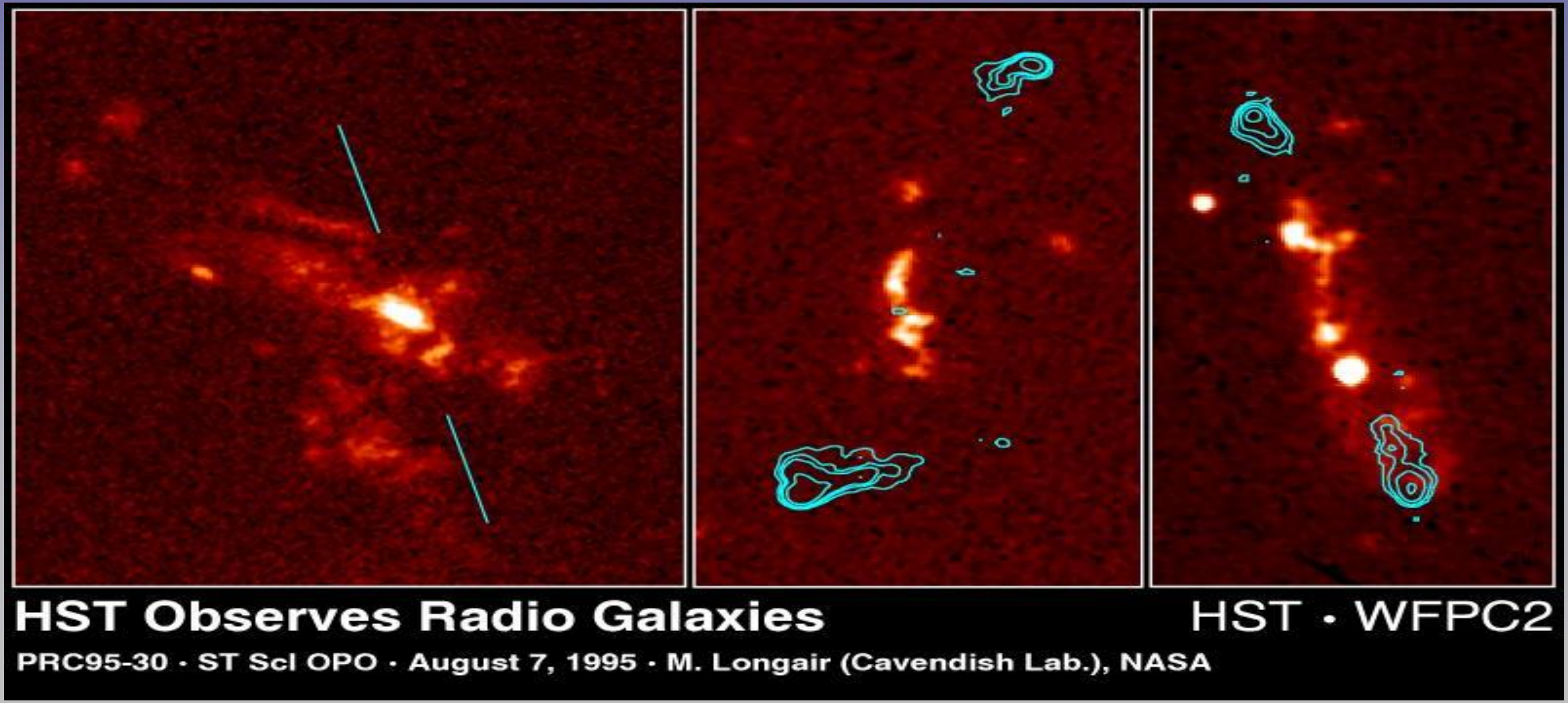
They are dominated by the 1mu peak



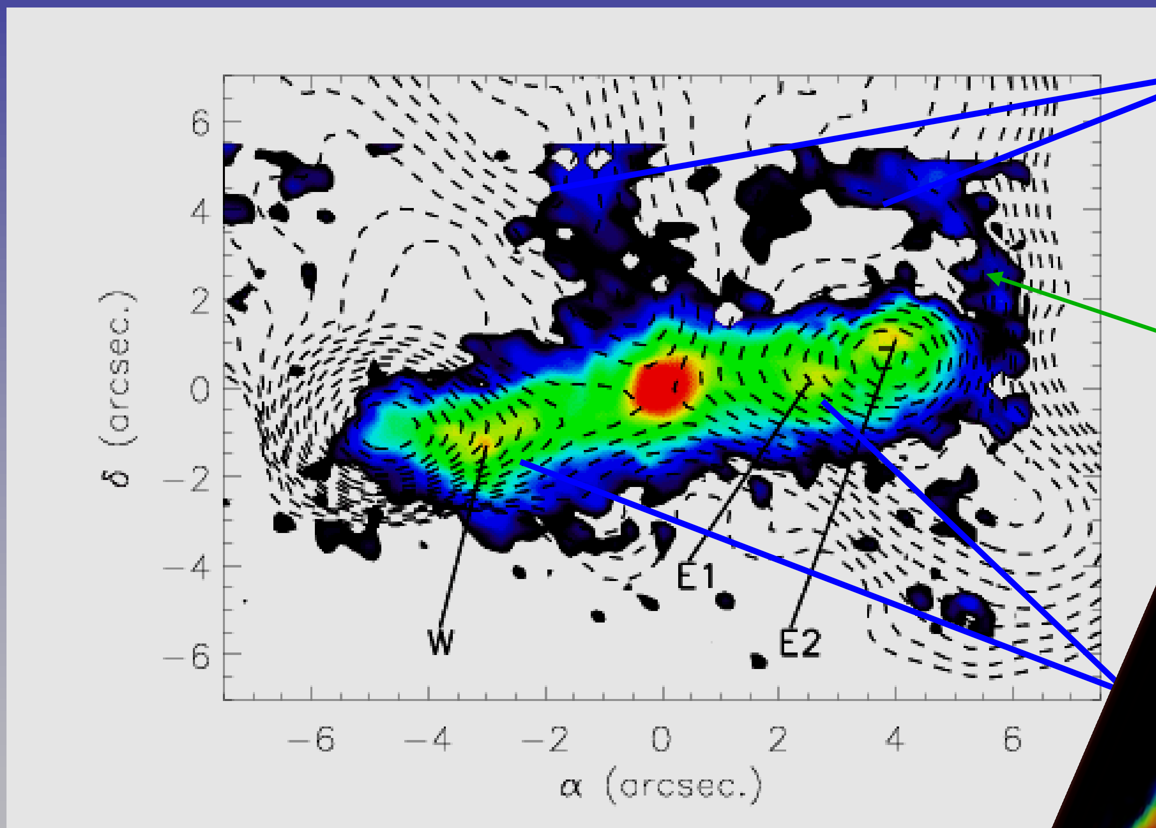
Xilouris et al., 2003,Temi et al, 2004
Not strong sources detected by the IR satellites (IRAS, ISO, Spitzer)
Raleigh-Jeans distribution of the K-M stellar population
Minor peaks @ 50K and 20K

Moreover high-z radio galaxies (hosted by ellipticals) reveal activity of star formation

- Powerful , ultra distant 1<z<7,
- STELLAR, nebular and AGN emissions



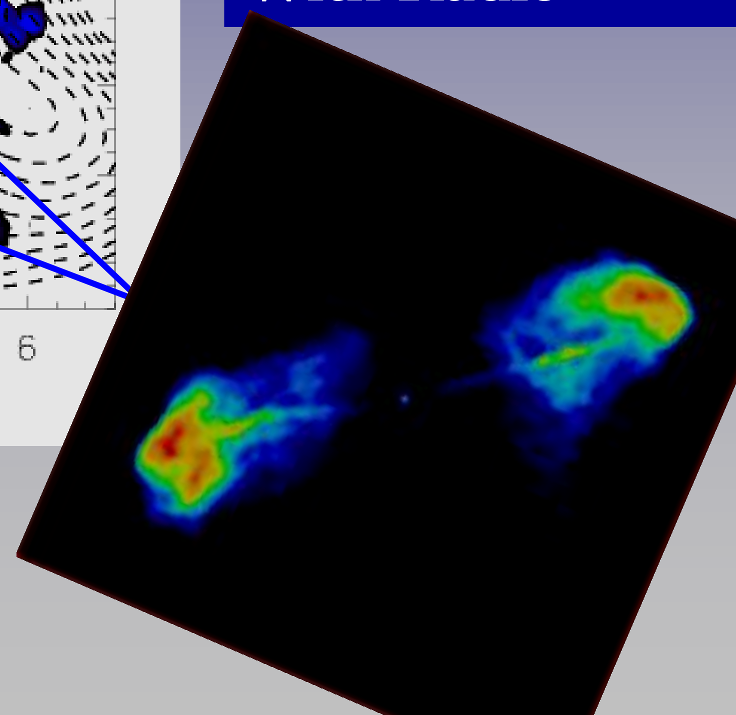
Extension of the Hα cocoon
Of the FR-II radio galaxy 3C171 (z=0.286)



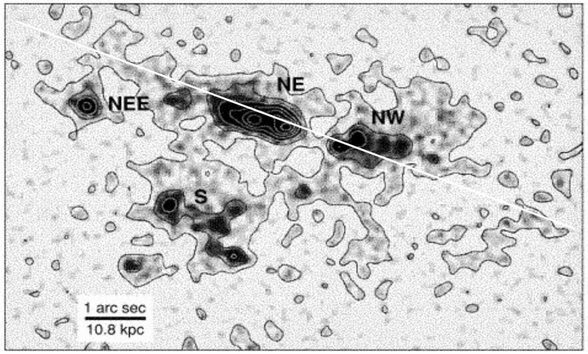
Sharp Emission a
cocoon boundarie

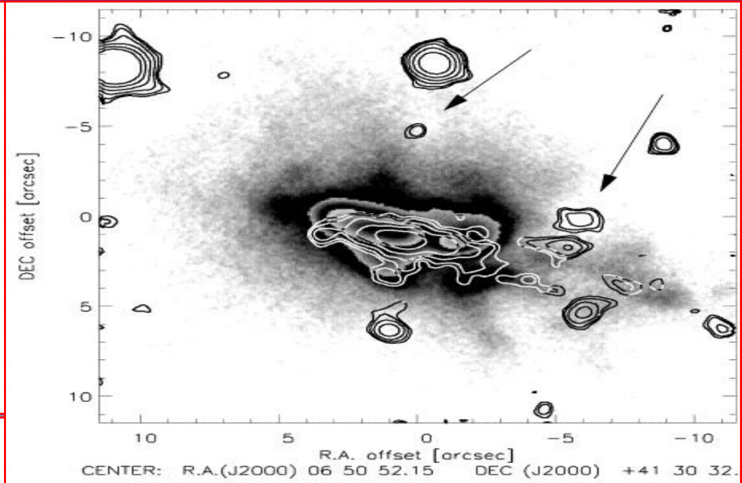
Narrow coupling

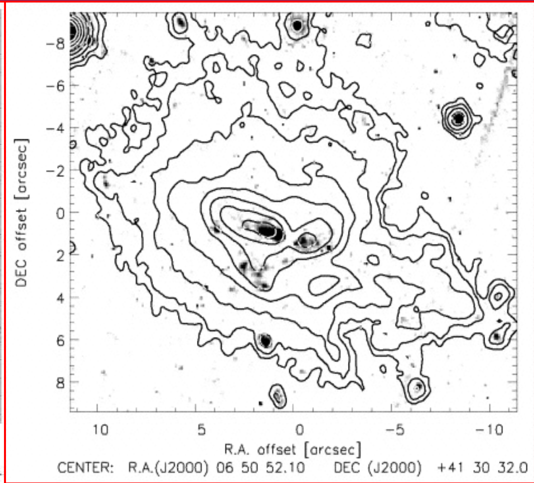
With Radio

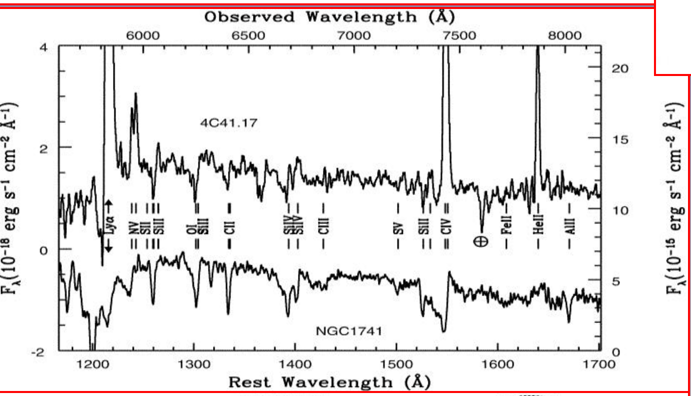


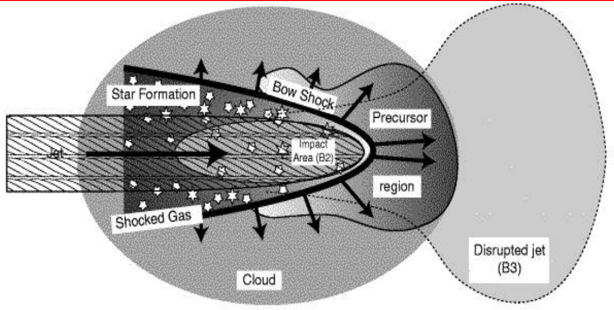
The template distant radio galaxy 4C41.17 (z=3.8)











▪Huge Lyα Clouds of 100-200 kpc of ionized gas (cocoon) (Dey et al, 1997, Van Breugel et al, 1999, Reuland et al, 2003).

▪HIGH-z RADIO GALAXIES are hosted by **MASSIVE ELLIPTICALS** (van Breugel et al, 1998, Penterricci et al, 2001)

Stellar lines are detected along the radio axis (Dey et al, 1997), as WR starbursts

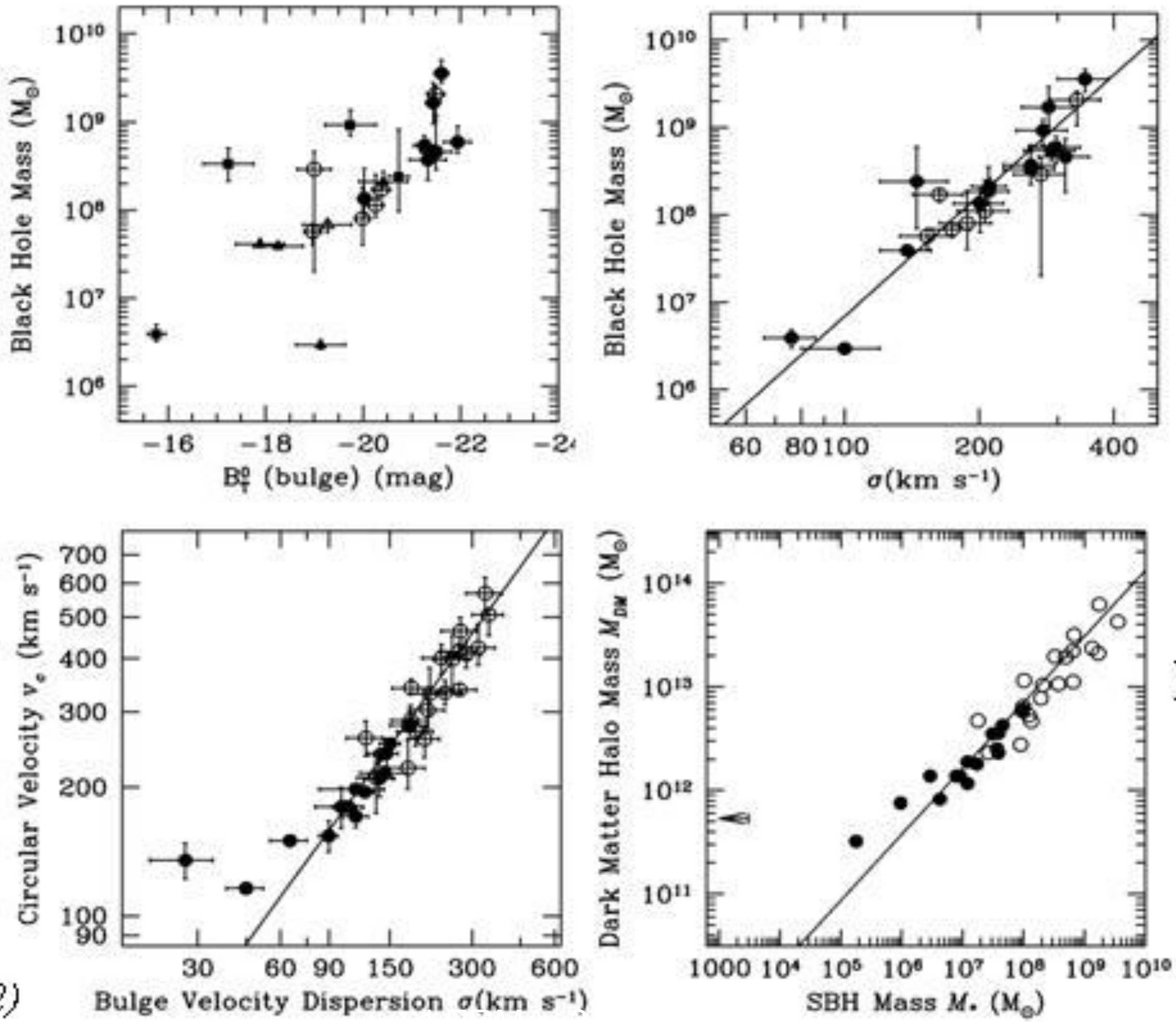
▪**Star formation along the radio jet** and south-East component, Bicknell et al, 2000

Fundamental Correlations Between MBHs and Their Host Galaxies

$M_\bullet$

$\sim L_{b}^{0.9}$

$\sim M_{b}$



$M_\bullet \sim \sigma^{4.5}$

$M_\bullet \sim M_H^{1.6}$

(Ferrarese 2002)

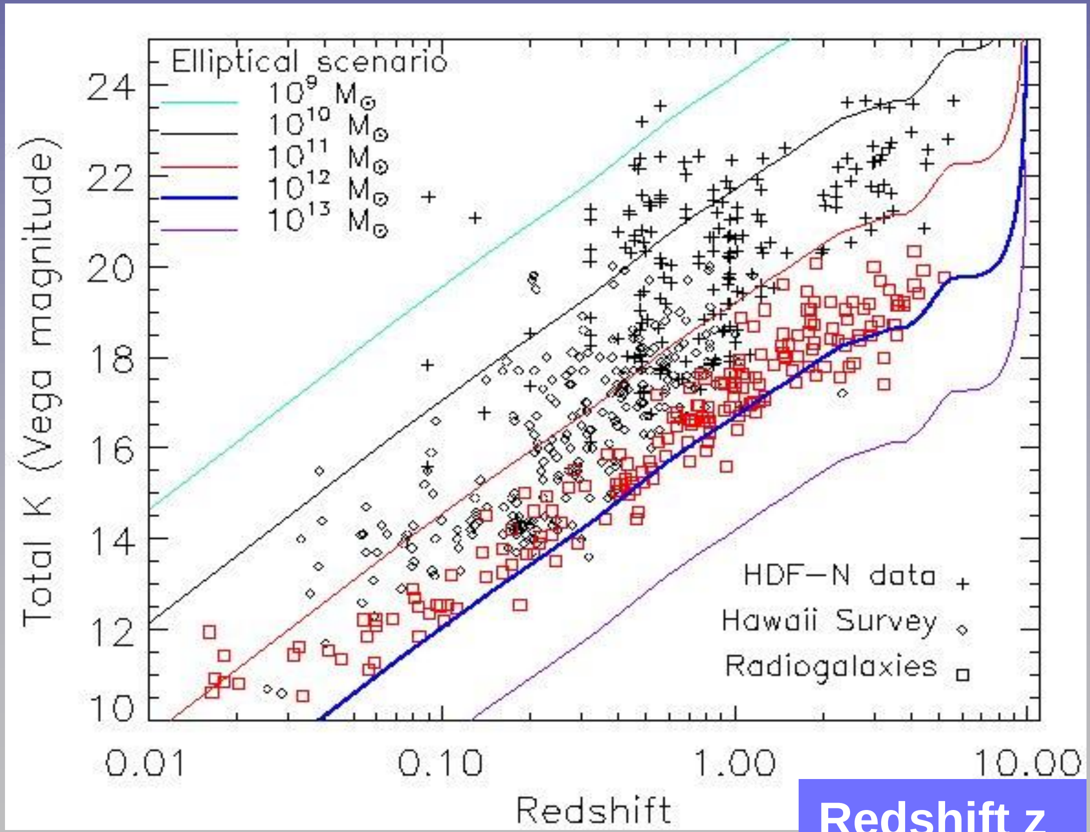
The striking result of the interpretation of the Hubble K-z Diagram with the code PEGASE : ellipticals are old, massive and red from z=4 and more

- powerful radio galaxies are the most massive galaxies
- the sharp limit are Ellipticals of Baryonic Mass 10^{**12} MΘ
- M_{lim} = 10**12 $M_{\odot}$ from
-

Mlim = $M_{crit}$of fragmentation derived from Jeans mass and Cooling Function Rees & Ostriker, 1977 ,

(Rocca-Volmerange, Le Borgne, De Breuck, Fioc, Moy, 2004, AA, 415, 931)

K mag



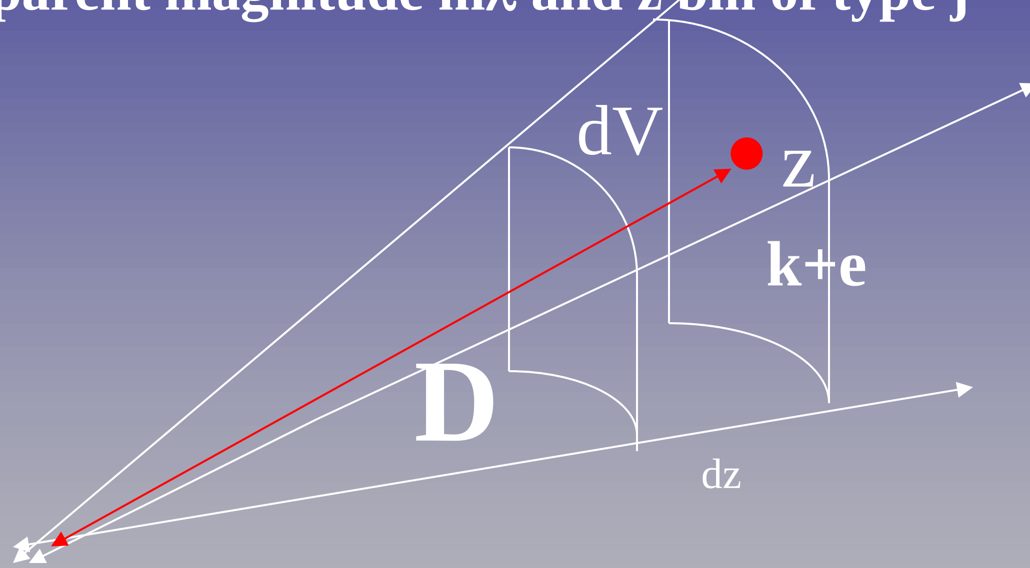
Redshift z

HUBBLE K-z diagram fitted by PEGASE

Modélisation des comptages

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

Galaxy Number density by apparent magnitude mλ and z bin of type j



$$\Phi_j(M^j{}_\lambda(z))$$

z=0 luminosity function by type j for filter λ

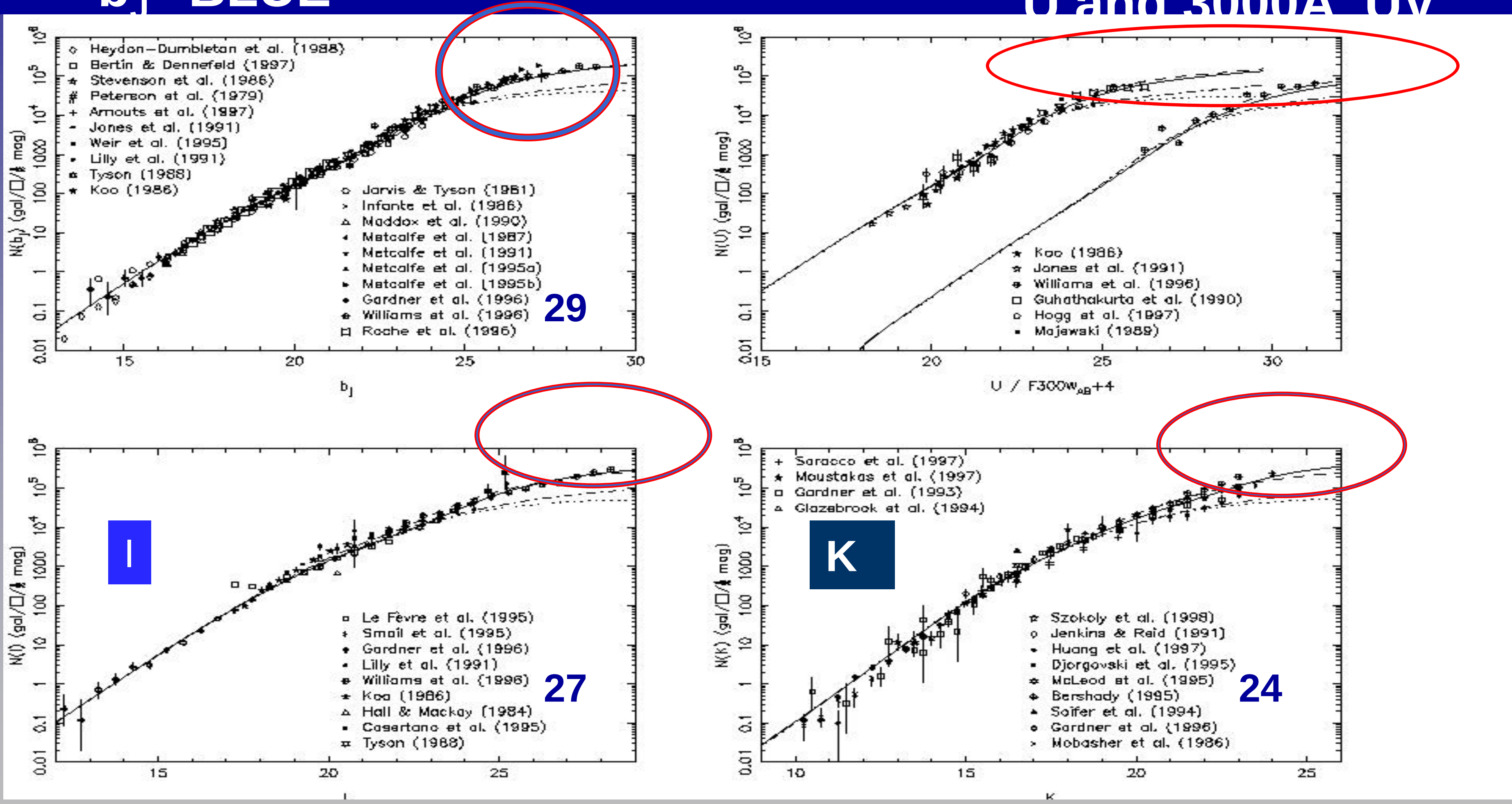
$$m^j{}_\lambda(z) = M^j{}_\lambda(z=0,t_0) + k^j{}_\lambda(z) + e^j{}_\lambda(z) + (m-M)$$

k- and e- corrections are computed from synthetic spectra for all scenarii and all z

Multi-lambda modeling faint galaxy counts: UV—OPTICAL--NIR with evolution scenarios by types

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

b_J BLUE **U and 3000A UV**

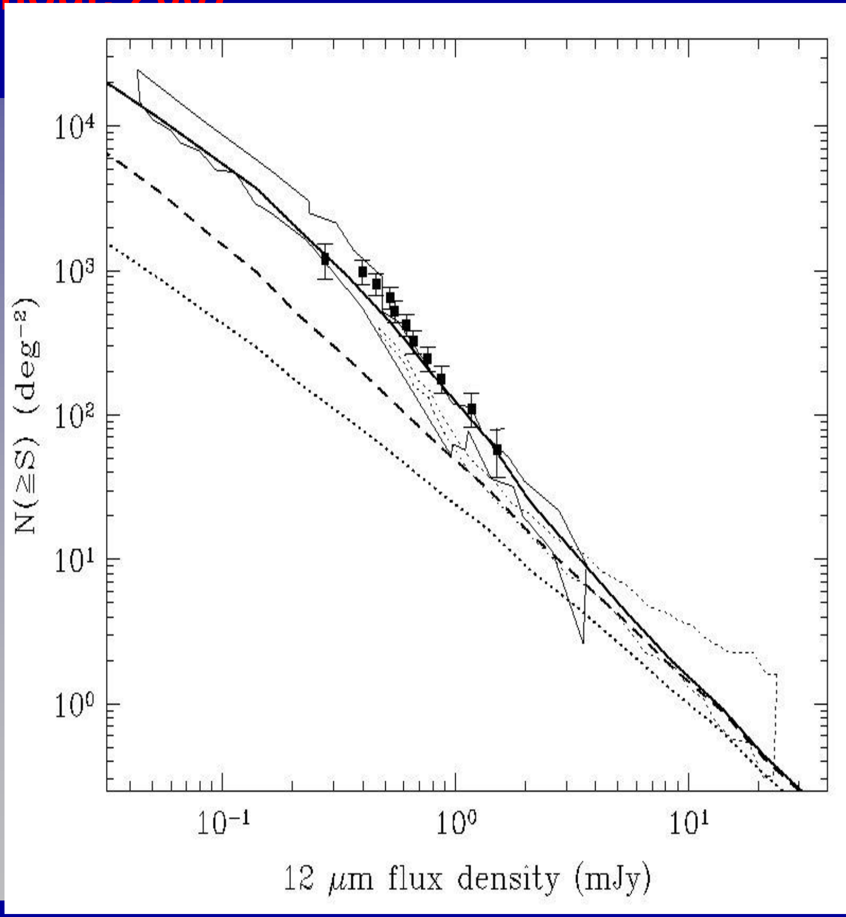


Galaxy population fractions : ELLIPTICAL (26%) :Sa+Sb+Sbc (24%) Sc+Sd+Im (50%)

Confirmed by 9% of IR Ultraluminous Ellipticals (RG and/or AGNs?) to explain the typical IR bump ,all other galaxies are normal Hubble Sequence galaxies

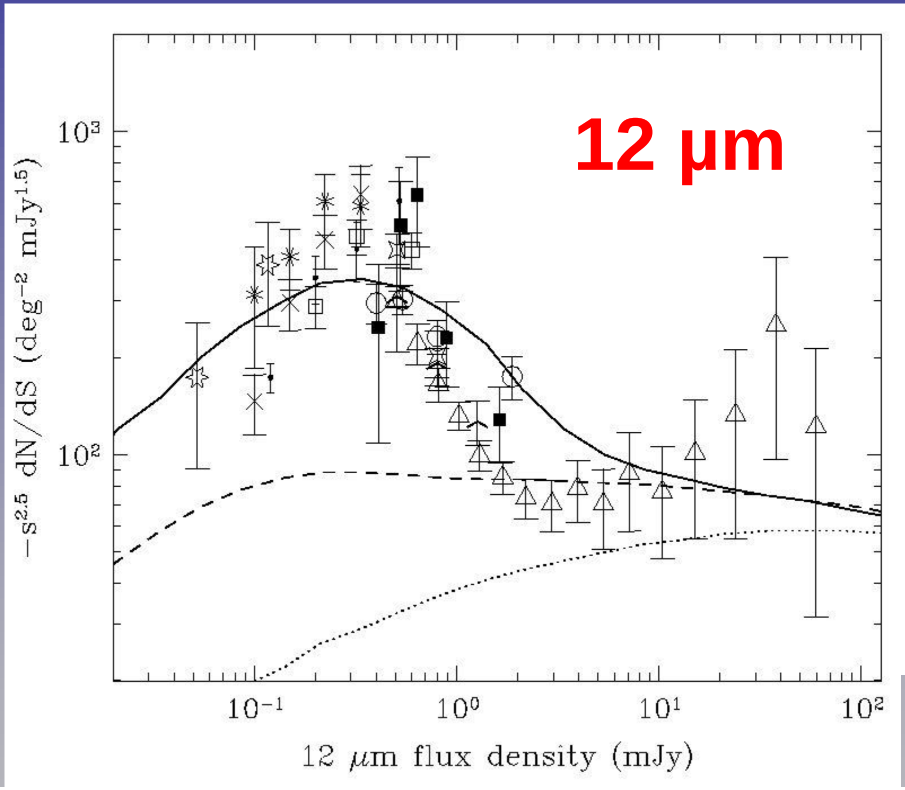
Model: Rocca-Volmerange, de Lapparent, Seymour, 2007

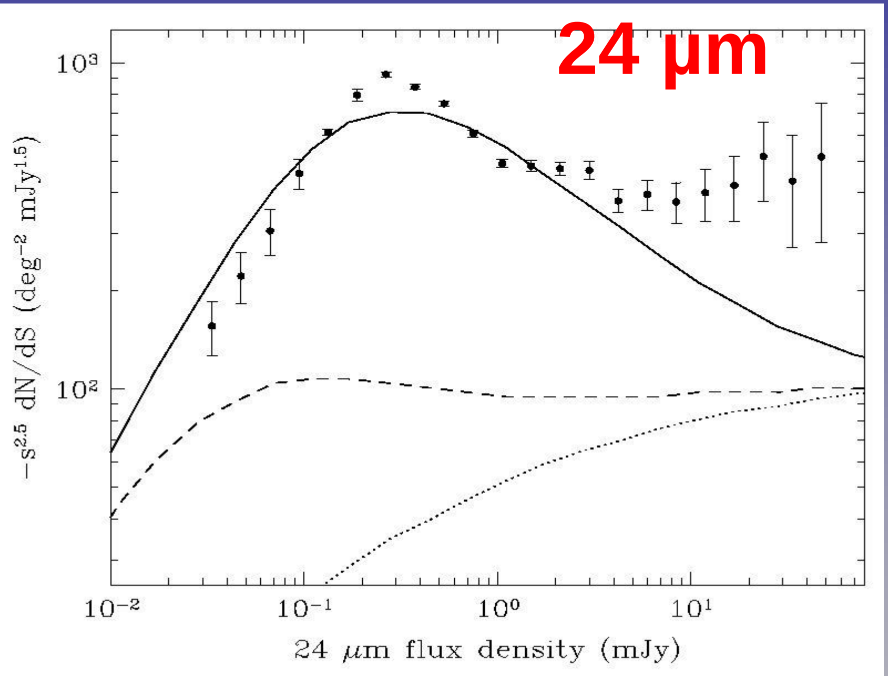
Number Fraction	Type	Magnitude M*
9%	**ultra-bright ellipticals**	**Normal -2.5**
15%	normal ellipticals	model color IRAS LF
24%	Early Spirals	//
50%	Late Spirals	// IRAS LF



Full line: k+e corrections, dashed line: k- corrections, dot line: comoving v

The galaxy population IR excess 12-15 and 24 um discovered in the ISO and Spitzer faint counts is due to 9% of IR Ultra-Luminous massive





(Rocca-Volmerange, Seymour, de Lapparent , 2007, AA)

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

Projet HeRGE

N. Seymour, C. De Breuck, D. Stern,… B. Rocca-Volmerange.
+ 33 co-authors, 2010, 2012)

- **He**rschel **R**adio **G**alaxy **E**volution Project
- 71 powerful (L_3GHz>10^26WHz) radio galaxies at 1<z<5.2
- From Ultra Steep Spectrum radio sample (alpha < -1.3, De Breuck et al., 2000)
- ***Spitzer***, ***Herschel***, SCUBA(JCMT) and LABOCA(APEX)
- *HST*, VLT, Keck, Palomar, VLA, **ALMA**

Articles: Drouart et al., in prep

Wylezalek et al., 2013; Seymour et al., 2012; Ivison et al., 2012; De Breuck et al., 2010; Seymour et al., 2007 …

and team members: M. Lehnert, N. Nesvadba, D. Stern, M. Haas, J. Vernet…

Two selected Radiogalaxies 4C41.17 and TN J2007-1316 (z=3.8)

- Faint AGN contribution
- Evidences of stellar populations
- Continuous flux-calibrated SEDs from
  - ❖ Optical (UV rest-frame)
  - ❖ Spitzer (K-band rest-frame)
  - ❖ Herschel and submm (cold grain peak rest-frame)
  - ❖ negligeable synchrotron emission

Synthetic synthesis method

-LIBRARIES OF STARBURSTS at all ages, various IMF,

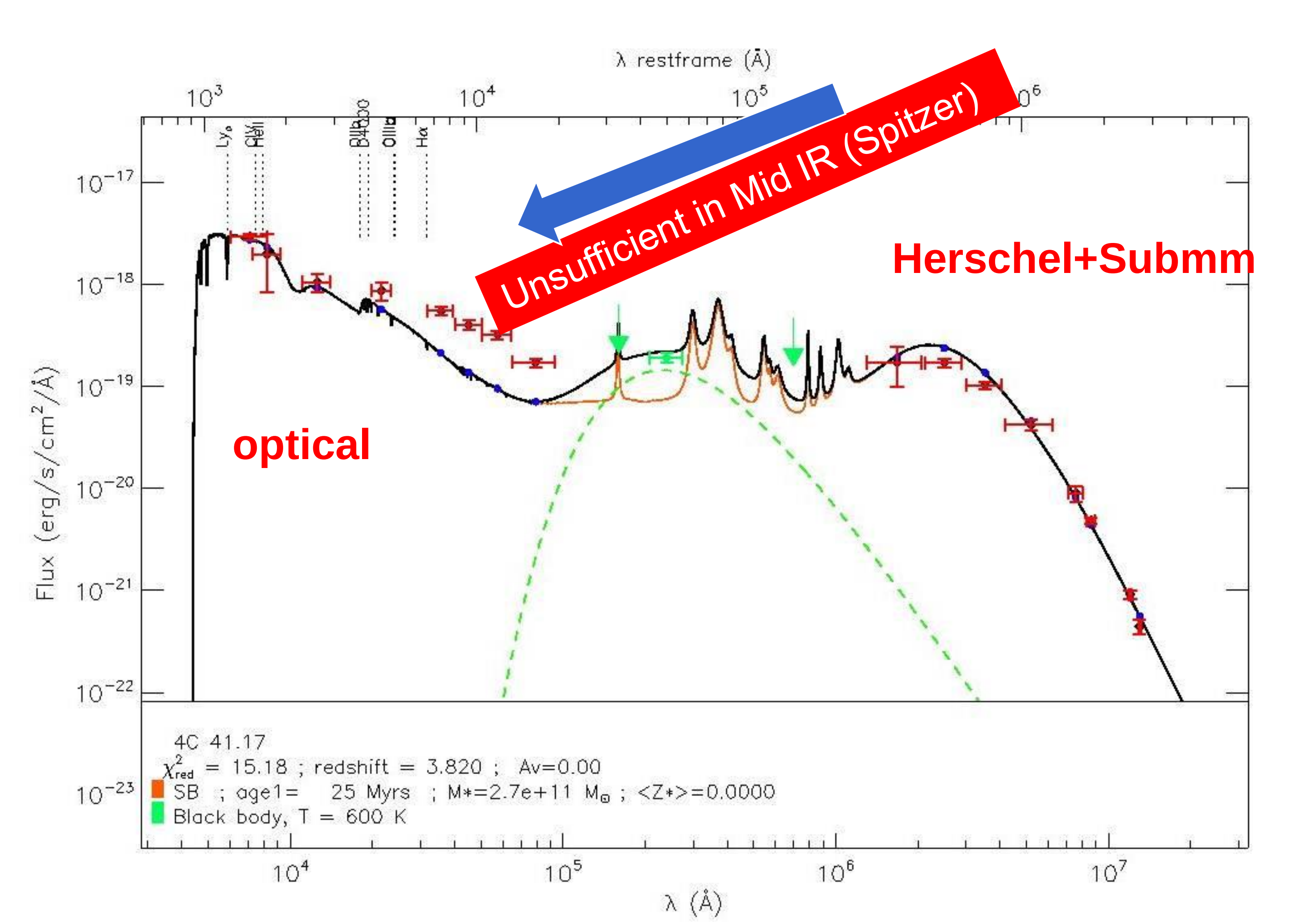
-LIBRARIES OF ELLIPTICALS, SPIRALS and IRREGULARS

- **A $\chi 2$ minimization method on the global coverage of the SEDs**

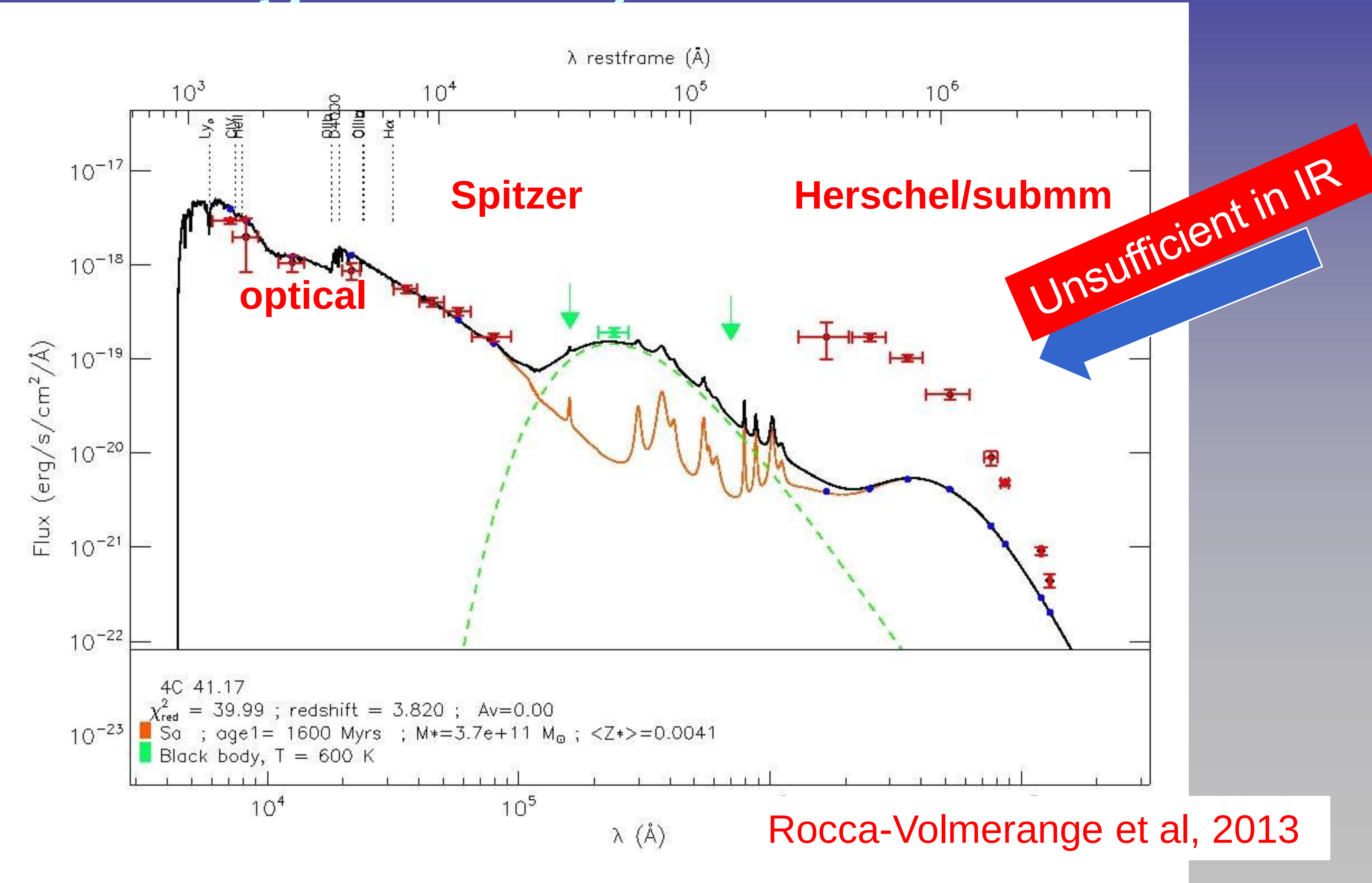
- **A selection of 2 radio galaxies at the same z=3.8**
- **Faint radio power**
- **Evidence of star formation**
- **Observations Herschel + Spitzer + K and optical**
- **Calibration and aperture checked**

OUTPUTs: $\chi 2$ minimum, types, ages and masses of the 2 components

4C41.17 @ z=3.8
One starburst component
25Myr + AGN



4C41.17 : One early type component Sa age 1.6Gyr + AGN



Rocca-Volmerange et al, 2013

1st conclusion

ONE COMPONENT is not sufficient to fit z=4 SEDs

Any early –type population <u>does not fit the far-IR/submm</u>

Any starburst, even evolved, <u>does not fit the mid-IR</u>

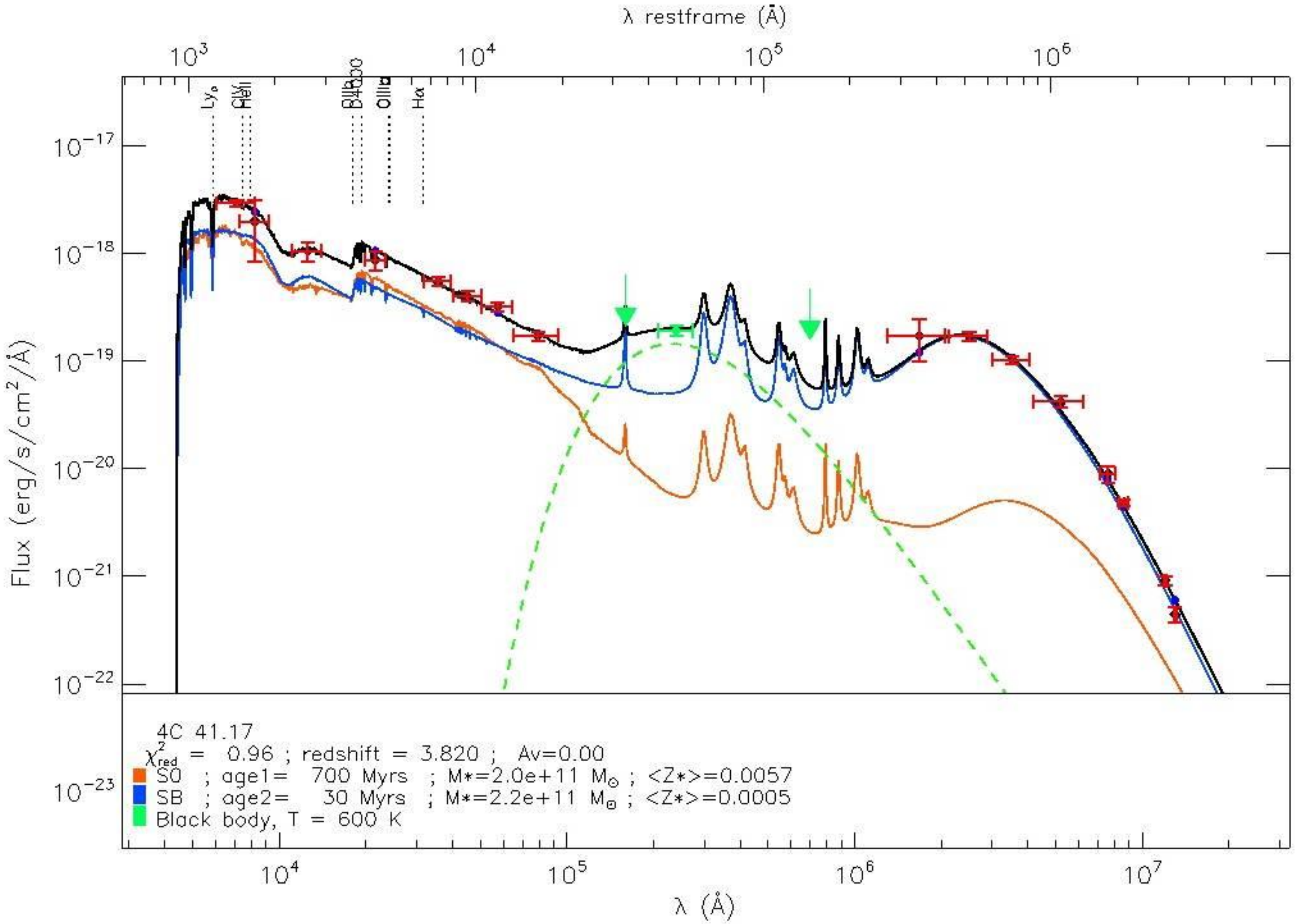
4C41.17: A sum of Two Stellar Population components Starburst at age 30Myrs + Elliptical at age 700Myrs +AGN (600K)

Excellent $\chi2=0.96$, huge masses 10 ^11 M_0, low Z

Observations
Are red points
With error bars

AGN model :
(dashed green)
Pier& Krolik model

One old 0.7 Gyrs
One young stellar
component
of 30Myrs



Rocca-Volmerange et al, 2013, MNRAS

TN J2007-1316 (z=3.8) Two stellar components: + SO/Elliptical at age 1200Myrs Starburst at age 35Myrs

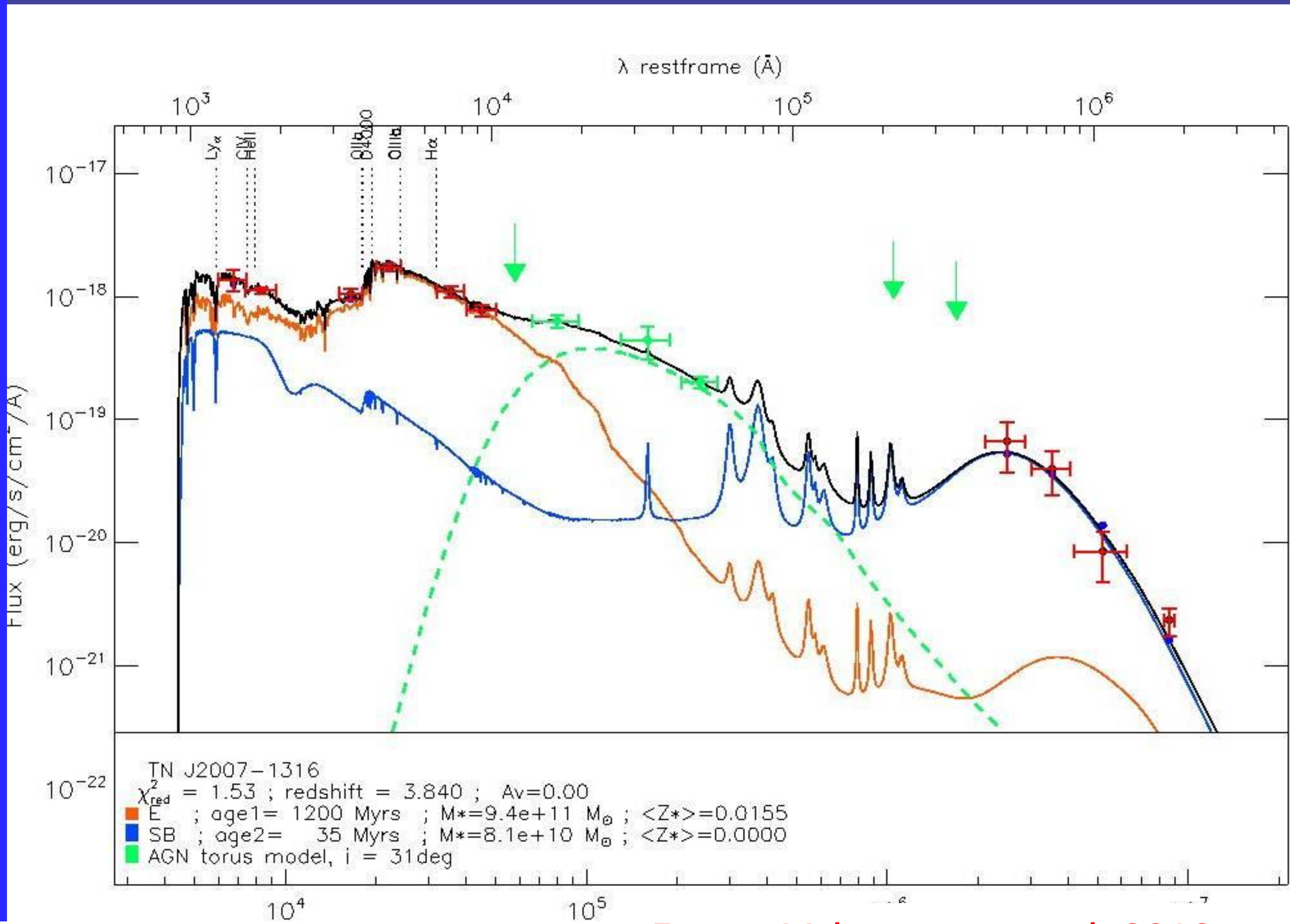
AGN model
Pier & Krolik
(dashed green)

Old Elliptical
At 1.2 Gyr
(red line)

Plus

A starburst
At 35 Myrs
(dark blue)

Green arrows :
Superior limits



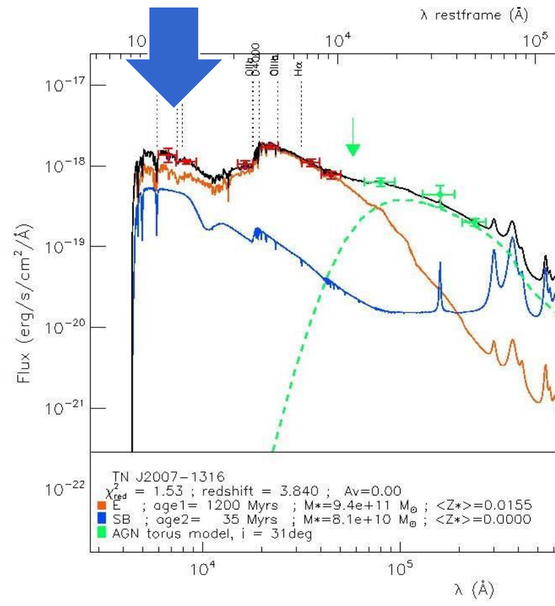
Rocca-Volmerange et al, 2013

2d conclusion

A young population, evolved (age 30Myr)
issued from the evolution of a very short (1Myr) Starburst

•In a dense medium 10^22-23 part/cm2 (x10 NHI ISM)

• fitting simultaneoulsy the 2 peaks :
• the optical (UV rest-frame) from the stellar photospheric (no absorbed) emission
the far-IR/submm emission derived from absorption



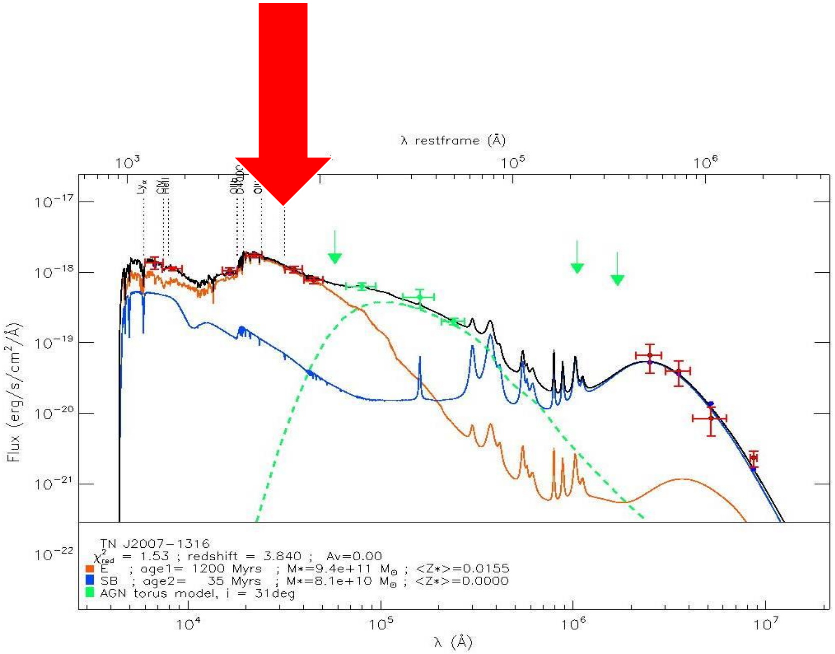
The starburst is from a nearly primitive (or low Z) metallicity

The global initial mass is roughly a few 10^11 M0,
Better spatial resolution is needed.

But this result is robust:
To increase absorption (or optical depth) will increase the farIR by decreasing UV e
To decrease absorption has the opposite effect

3rd conclusion

An REVEALED early-type population
Formed at redshift z=10 is discovered
in Spitzer data



The SED is quite compatible
with the typical 1mum peak
(rest-frame) of early type galaxies.

A striking confirmation of the
K-z old population (RV et al, 2004)
10^12 M0 stellar masses

the red passive sequence of
giant stars
Metallicity Z is O.OO5, compatible with early-type scenarios.

Masses are derived from fitting the sum to the flux calibrated SED
~ 10 ^11-12 M0
This is a strong constraint for Galaxy Evolution models

4th conclusion

Because The 2 radio galaxies are selected for their low AGN activity, AGN model is not constraining.

The AGN peak domain is not well covered by observations

For these two targets:
AGN models are thermal (BB 600K),
Or model c of Pier & Krolic, 1992)

.

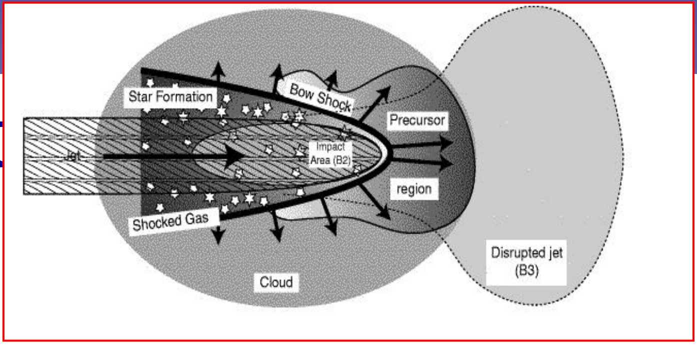
AN old populatio n at z=3.8

+ a merging episode
undergoing an episode of vigorous star formation

These powerful radio-load galaxies are likely a sub population of radio-quiet galaxies (Kriek et al, 2006, Stockton et al, 2008)

Star formation by Merging or jet_cloud interaction

- Issued from jet-cloud int



(Bicknell et al, 2000)

The formed stellar mass Is too huge to form in a so narrow zone

- The most likely process is a gas-rich merging of mass ratio ~1 to 1/10, triggering an extremely short starburst in a dense medium

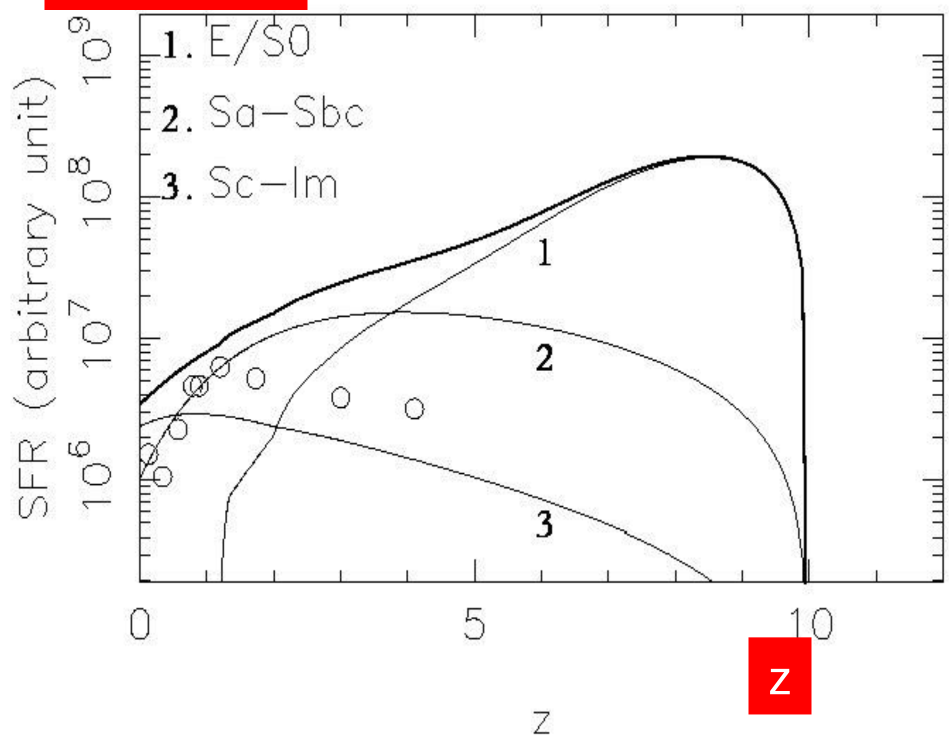
The intense star formation rate is >10^4 M0/yr during 1 Myr

So short time scale would correspond to the short time

Consequences on cosmic SF history

(1) The star formation history is dominated by ellipticals at early epochs (z=10 or more).

SF History



z

Empty circles are data from CFRS,
Deep survey selected on Spiral Sa galaxies

(2) **Rapid increase of SF for spirals 0<z<1** , comparable To CFRS results (Le Fevre et al, 1998): CFRS is selected on Sa spirals

(3) Dwarfs contribute to SFH at low z

These sources are not ULIRGs induced by galaxies in interaction. All are compatble with deep UV-optical-NIR counts

Conclusions

Evolutionary synthesis: in the observer's frame:

- (cosmology + active and passive evolution)
- Local templates + distance + k+ e corrections

Hubble Sequence types + Starburst Evolutions

Radio galaxies are the most distant and massive galaxies

Confirmation of massive early type galaxy hosts

In the K-z diagram (Rocca-Volmerange et al, 2004)

And the fragmentation limit 10^12 M0

Conclusions (following)

Two star formation time-scales:

- Instantaneous ~1-Myr ➔ merging revealed by dust from SN and AGB stars

- Cumulative ~1 Gyr ➔ possible sum of hierarchical merging, the envelop is a τ model.

- Star formation initiates at z_{for}> 4-10 or more,
- z_{for} < 4 is unlikely for the most massive RG

- Evidences of star formation stellar masses with black hole growth is confirmed

Near Future

Evolutionary synthesis with the HERGE sample

G. Drouart’s thesis

Relation AGN-Starburst (localisation, intensity, respective time-scales)

Pegase. 3 available to the community (README on www2.iap.fr)

Article (Fioc, RV, Dwek, in preparation)