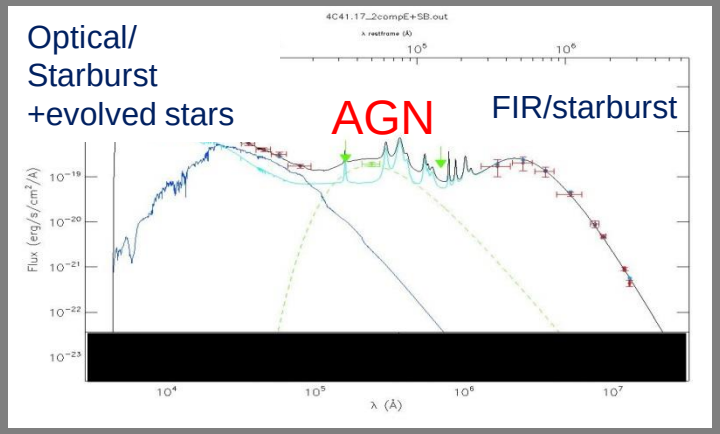
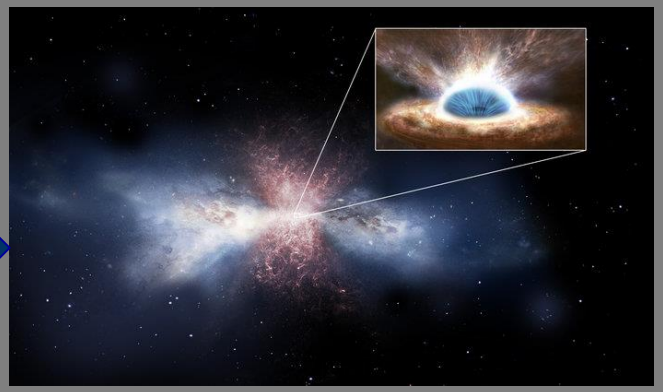
STAR FORMATION and Black HOLE MASSES with Gaia





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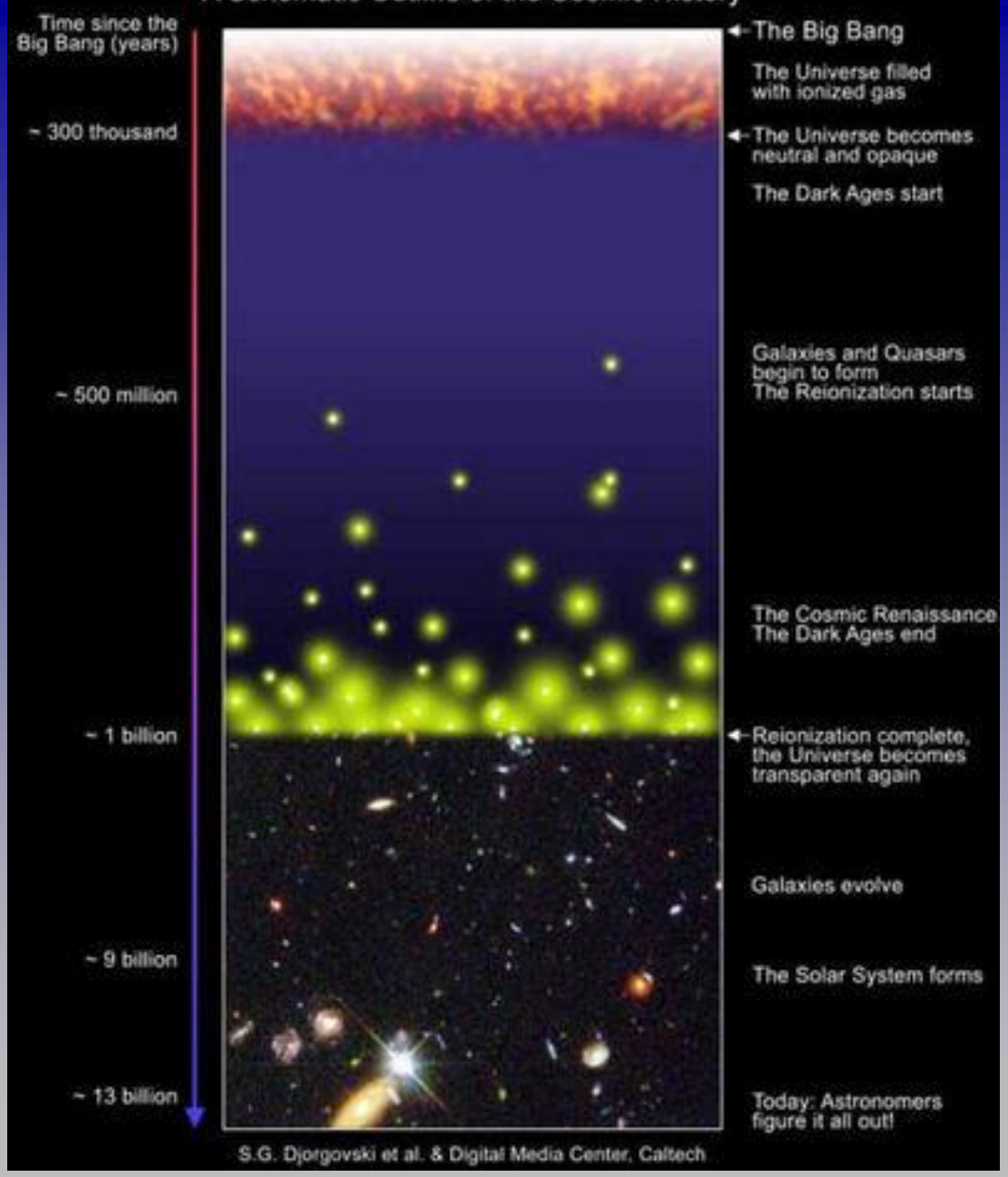
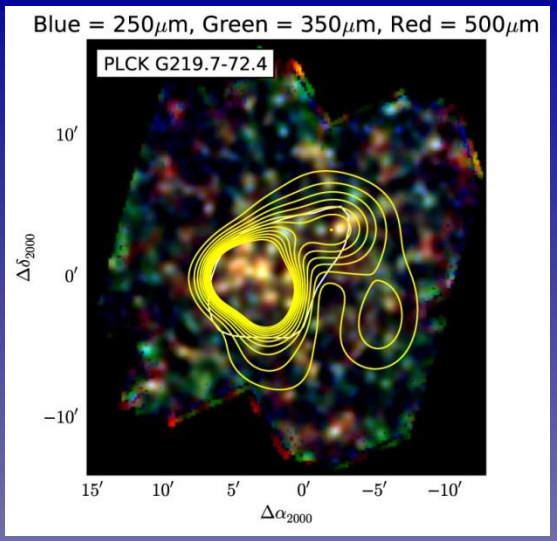
Collaborations Michel Fioc(IAP), Guillaume Drouart (Chalmers), Carlos De Breuck(ESO) and others



Cosmology pattern + scenario of Star Formation history

Distance, Universe expansion, age (lookback time with evolution) + extinction (Z)

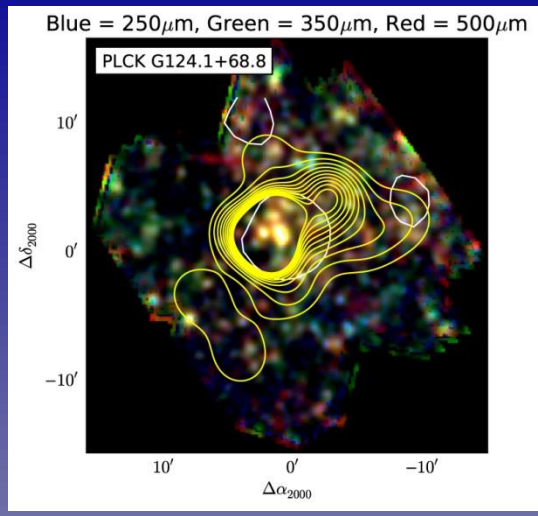
z	Cosmic time
5	1.2 Gyr
2	3.5 Gyr
1	6.1 Gyr
0	14.5 Gyr



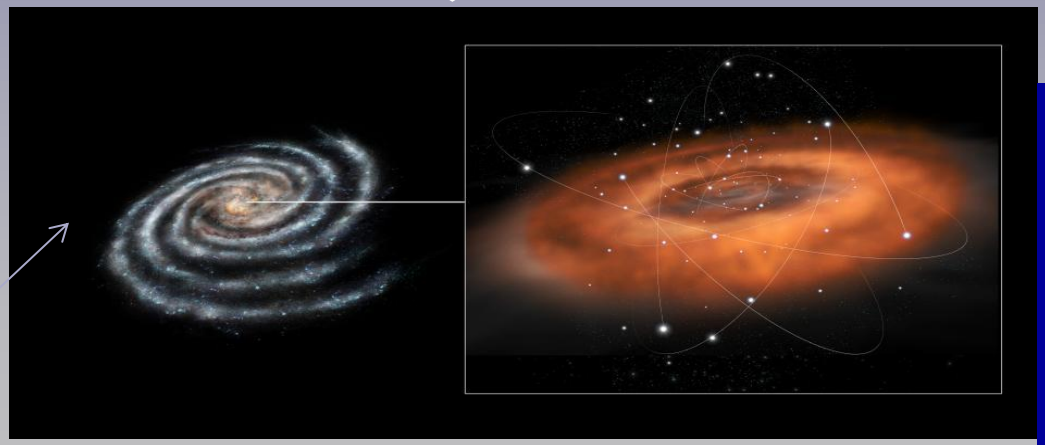
From Planck and Herschel
At high z (> 4)
Intense multiλ fluxes of galaxies: starburst?

Angular concentration of galaxies: clusters and protoclusters ?

To the Galactic Center

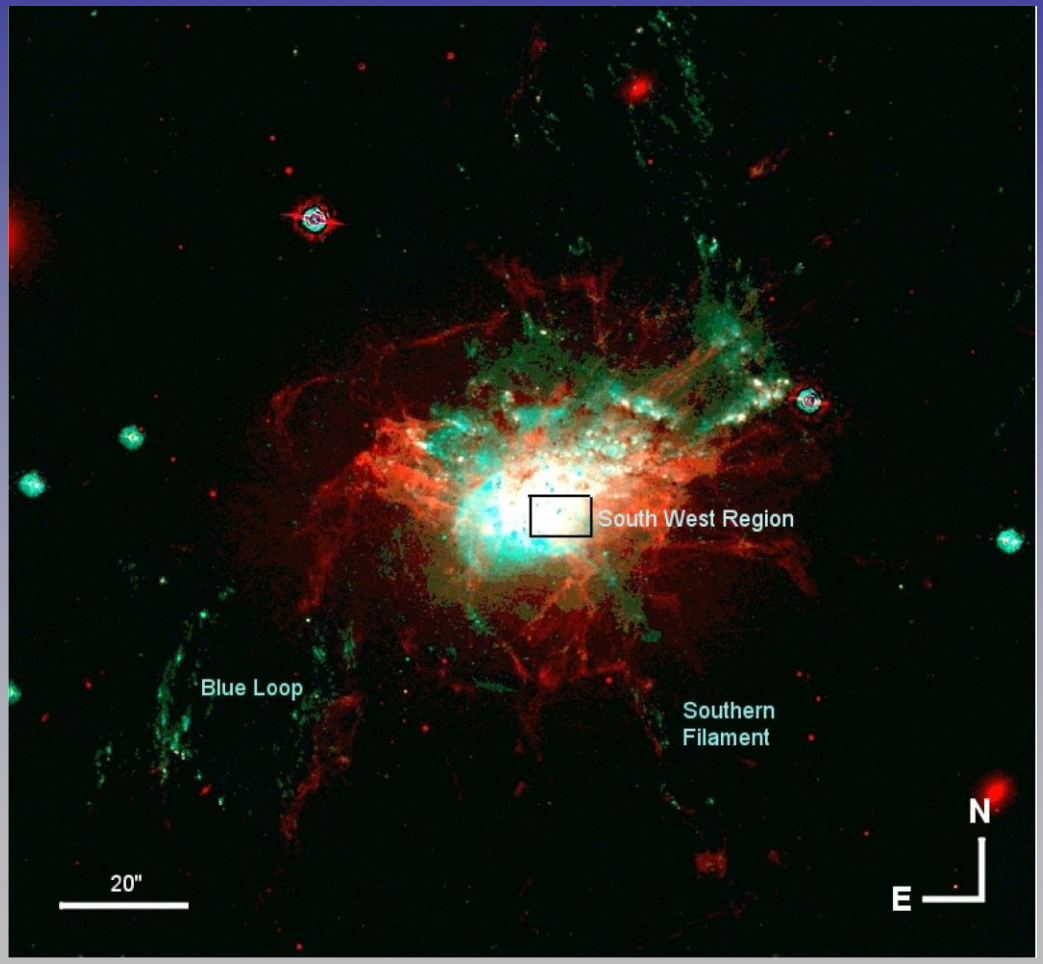


z=0



To Our Galaxy Center

Star formation process by filaments in the radio galaxy NGC1275 Canning et al, 2010



Context

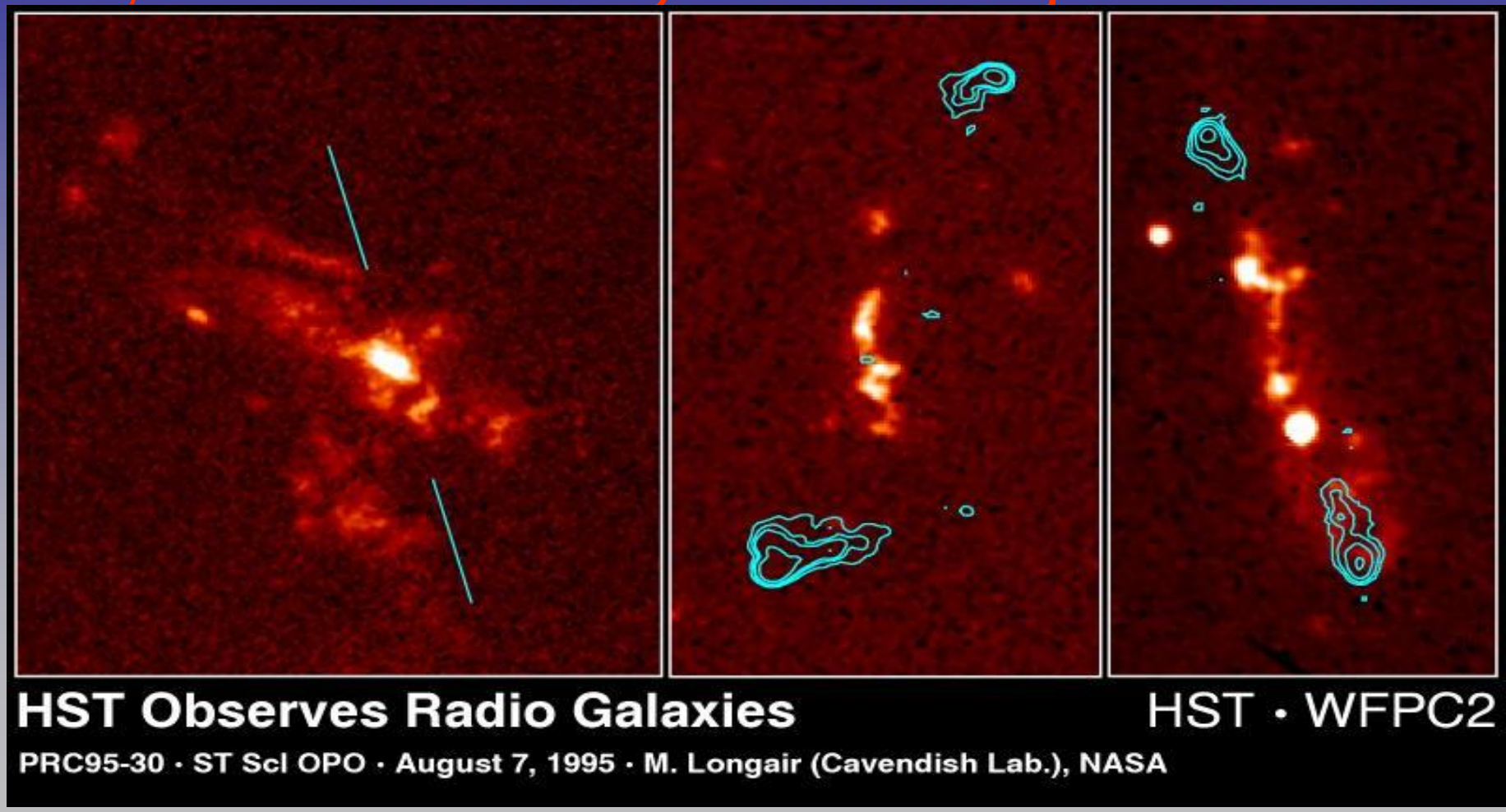
- The Star formation laws by types (4 main parameters)

- Galaxy Black holes / Stars with Gaia :

- Galactic Center (see Gillessen's, Paumard's talks)
- Possible Dwarf Galaxies (see Livanou's talk)
- Distant Radio galaxies/AGNs , this talk

The link AGN-Star formation
🡐🡒 Supermassive -stellar Black Holes
from supernovae remnant s SNRs)

POSSIBLE EVIDENCES OF THE ALIGNMENT OF Radio Galaxies and , star formation by interaction jet-cloud



Projet HeRGE

N. Seymour, C. De Breuck, D. Stern,
… G. Drouart, 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., 2014

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

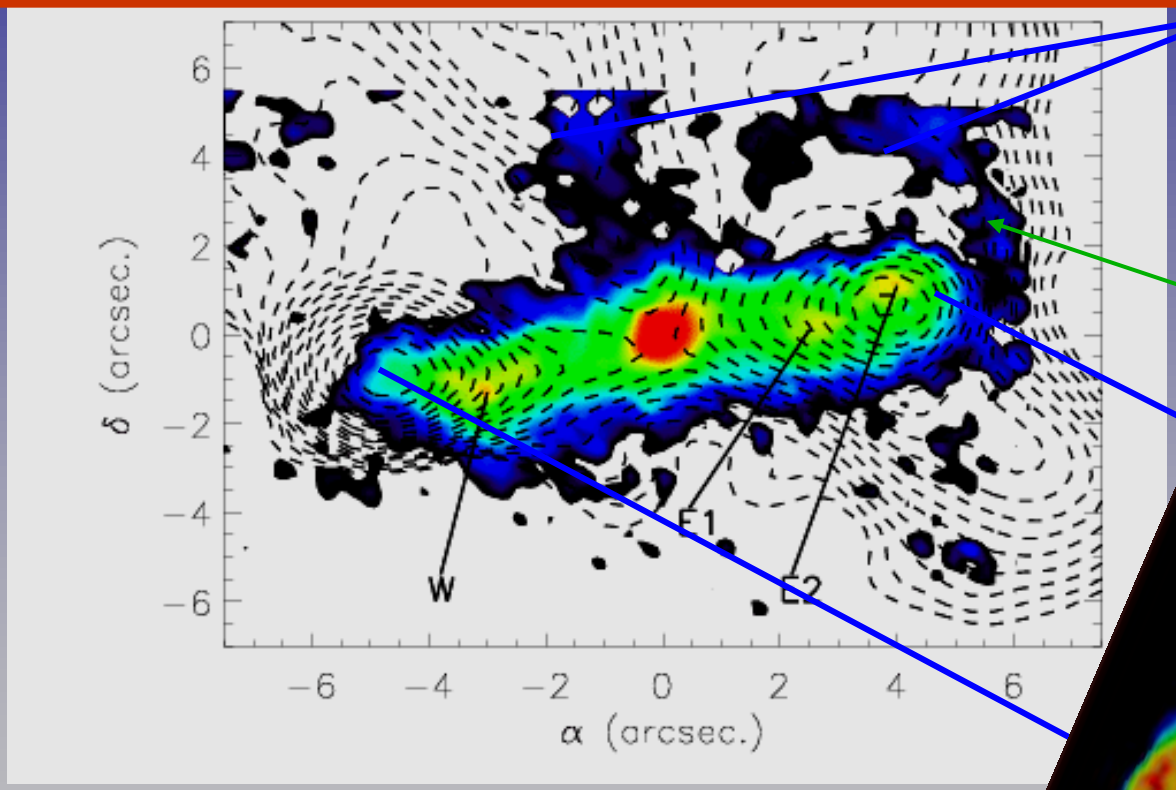
and team members: M. Lehnert, N. Nesvadba, D. Stern, M. Haas, J. Vernet…

Large scale ionized gas envelop but requires disentangling QSOs/SFRs

THE HUGE IONIZED COCOON, coherence with radio emission

Exemple Hα from 3C171 (z=0.286)

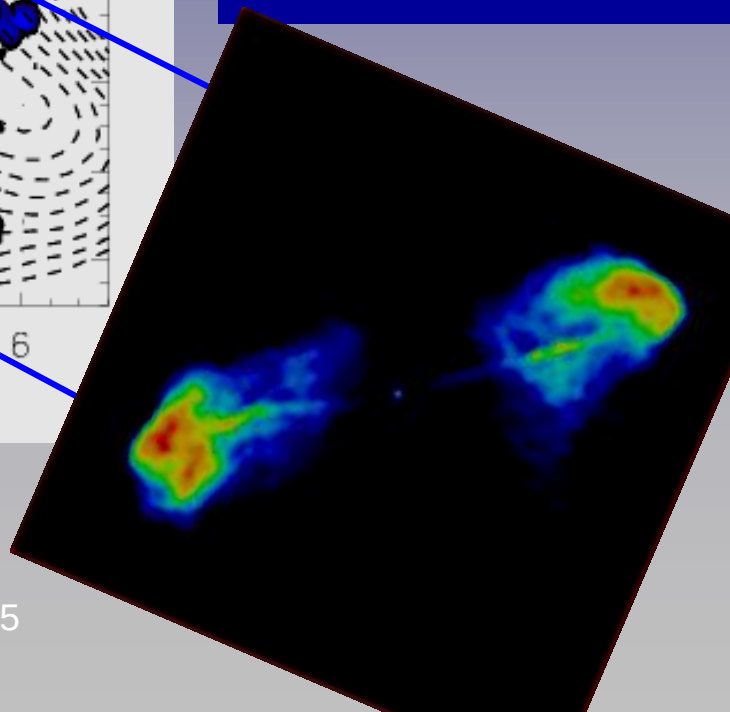
Rocca-V & Moy 2003NewAR..47..267R



Sharp Emission at cocoon boundaries

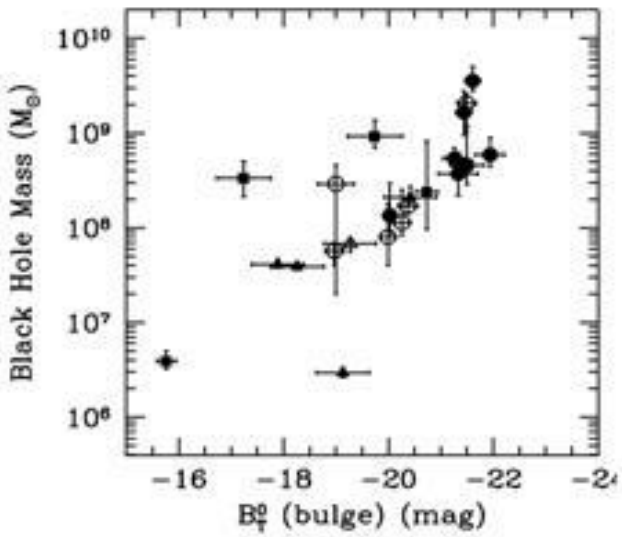
Narrow coupling

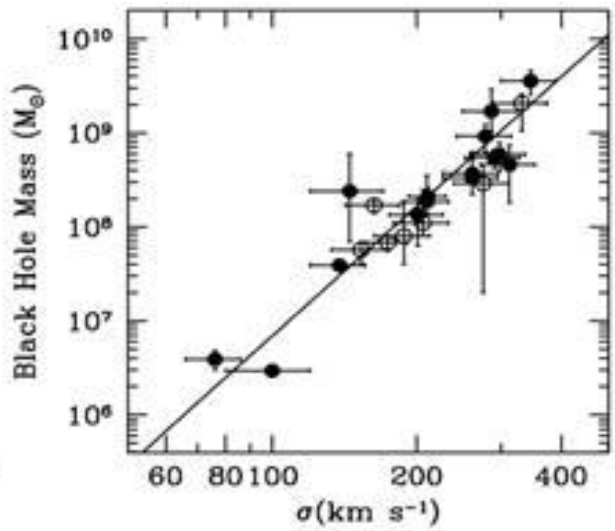
With Radio



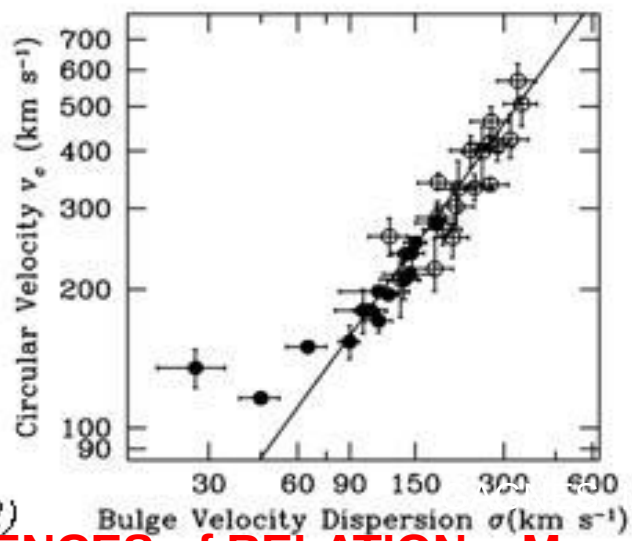
Fundamental Correlations Between MBHs and Their Host Galaxies

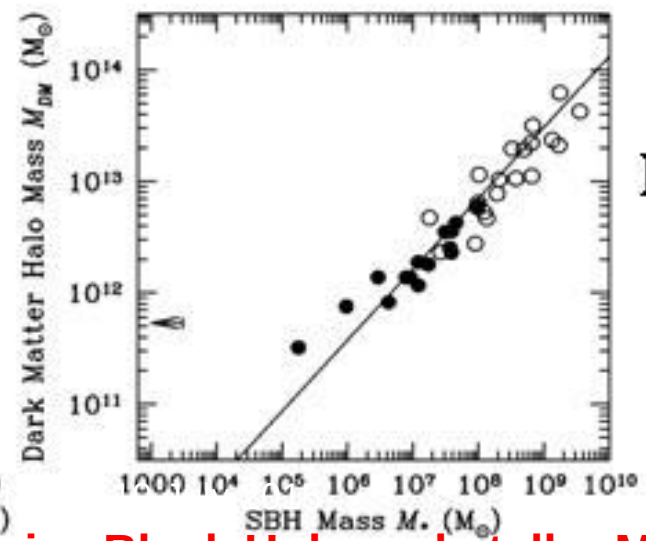
$M_\bullet \sim L_{\rho}^{0.9} \sim M_{\rho}$





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





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

(Ferrarese 2002)

EVIDENCES of RELATIONs Massive Black Hole and stellar Masses

- ***Radio Galaxies the best targets SED (Optical-Spitzer+ Herschel + submm)***

- ***Stellar black holes + neutron stars = Supernova Remnant***

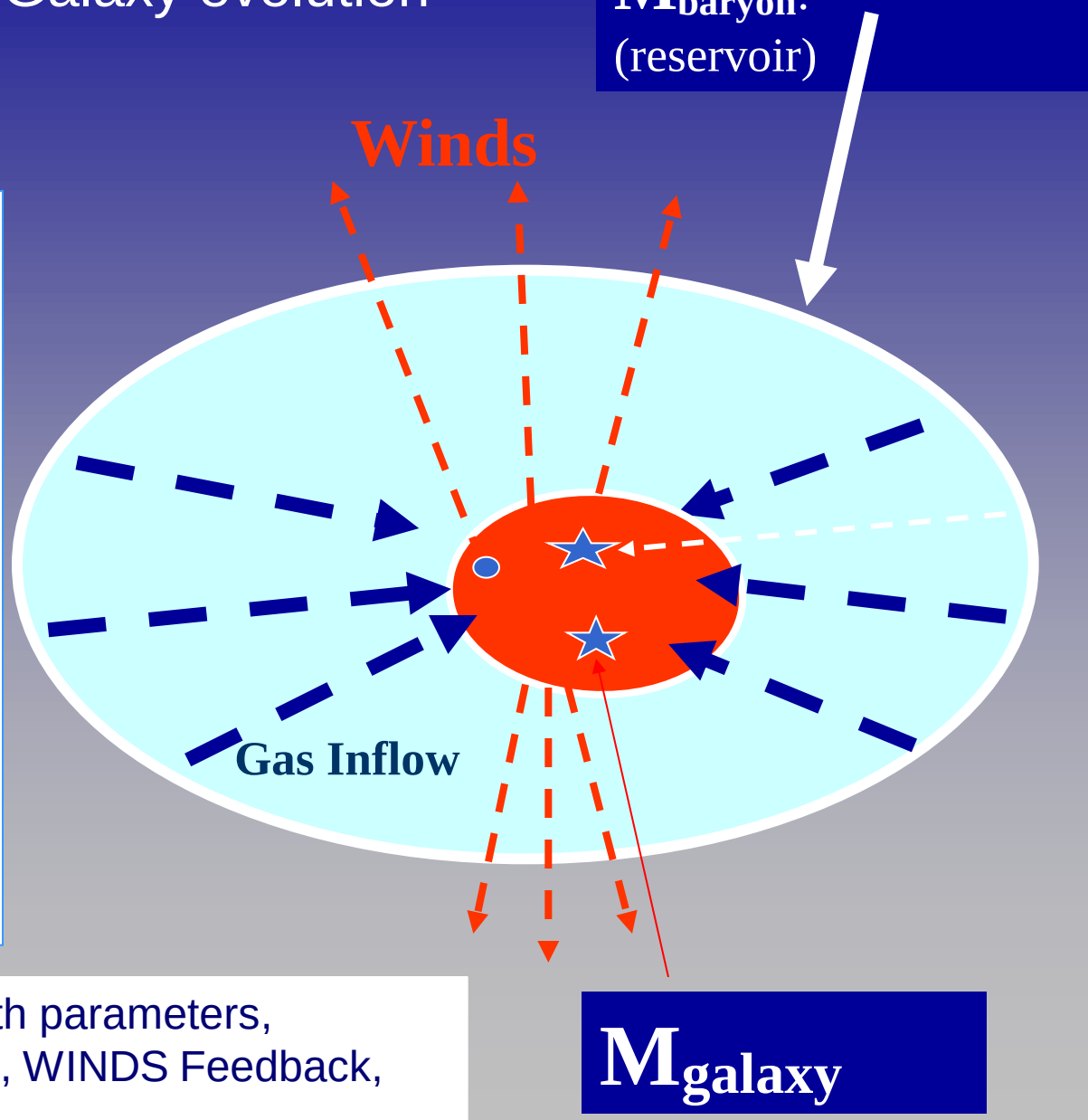
- ***Accumulated number of remnants = f(Star formation history)***
- ***Modeling of Star formation history and evolution with Pegase3 ➔ SNR masses***
- ***Comparison to supermassive black hole masses***
- ***Considerations on migration of SNRs by dynamical friction***

www2.iap.fr/pegase

PEGASE model of Galaxy evolution

Scenarios by type:
Four Parameters

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



MAIN QUESTIONS:: mass growth parameters,
Star formation laws , Quenching, WINDS Feedback,
Metal-enrichment,

MODELLING with the code Pegase

stellar, dust and nebular emissions (z=0—10…)

Fioc, Rocca-Volmerange et al, 1997, and near submission of Pegase.3 (Fioc, Rocca-Volmerange, Dwek)

- **Star formation laws by types and stellar evolution principles (Fioc & Rocca-Volmerange, 1999) ➔ Pegase2**
- **Coherent with the chemical evolution (O, C, Si, Fe) by types +**
- **Grain models (Draine, 1993) (C, Si, PAHs)**

Attenuation + Radiative Transfer (monte-Carlo)

For Two Spatial distribution (disk, spheroïd)

- **Dust Emission from N_Lyc🡐🡒 Star Formation RATE**
- **2 media: diffuse ISM and HII regions (Zubko et al, 2004)**

Extinction Modeling

Extinction $A_\lambda(z)$ (magnitude) depends on metallicity evolution and dust mass

Optical depth

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

PEGASE.2

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

PEGASE.3

$$\tau_\lambda(Z) = \kappa_\lambda \frac{M_{dust}}{2\pi R^2}$$

Monte Carlo simulations of radiative transfer

κ_λ= opacity per surface unit depend on bulge / disk

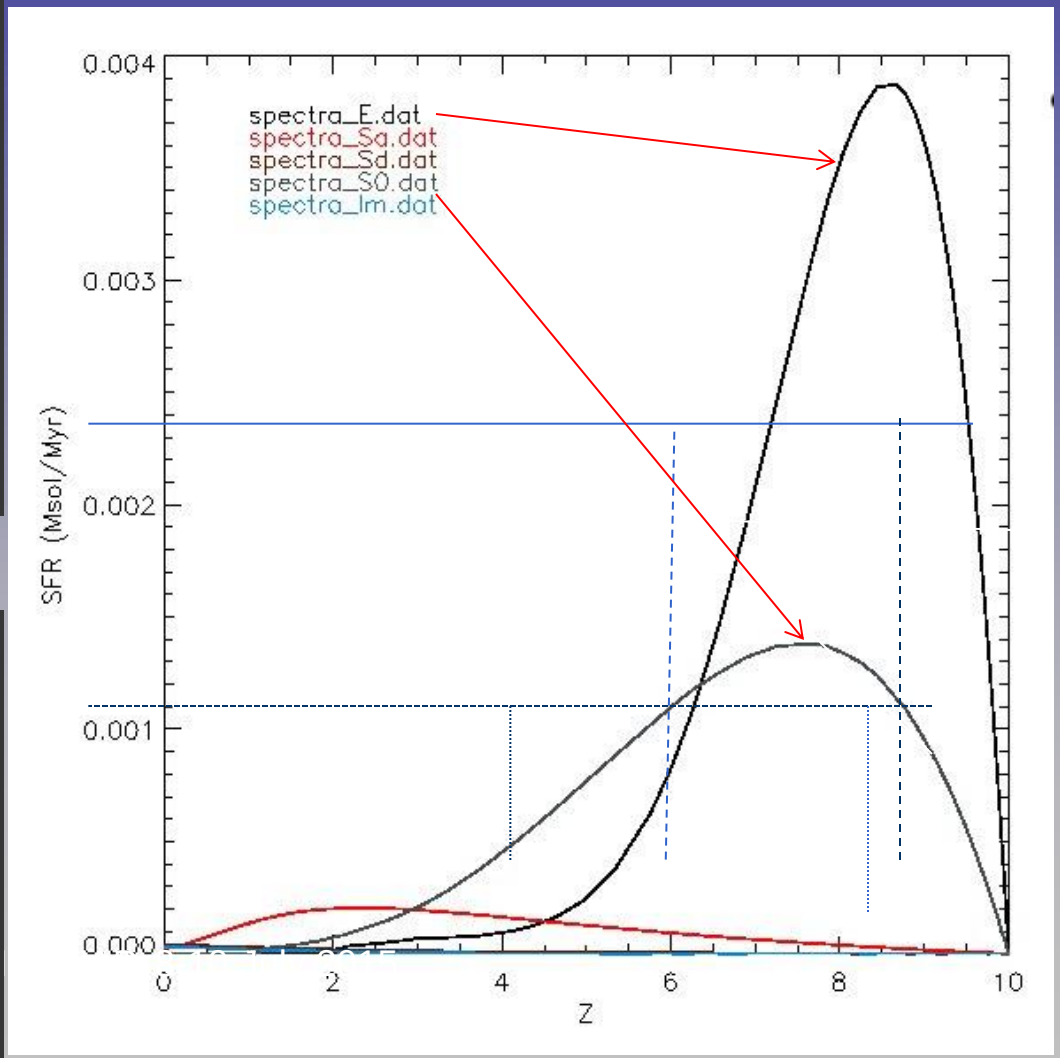
Possibility to increase the gas density

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

Star formation laws fitted on SEDs of the local Hubble SEQUENCE

SFR(z) by types

zfor =10 adopted
Equivalent to z>5



Rocca-Volmerange et al, 2015 (ApJL, 803, L8) + Rocca-Volmerange & Guiderdoni, 1988, Fioc's thesis, 1998
Le Borgne & RV, 2002, RV et al, 2004,

Star formation laws by types

$$SFR = \frac{p_2}{p_1}.\exp(-\frac{t}{p_1})$$

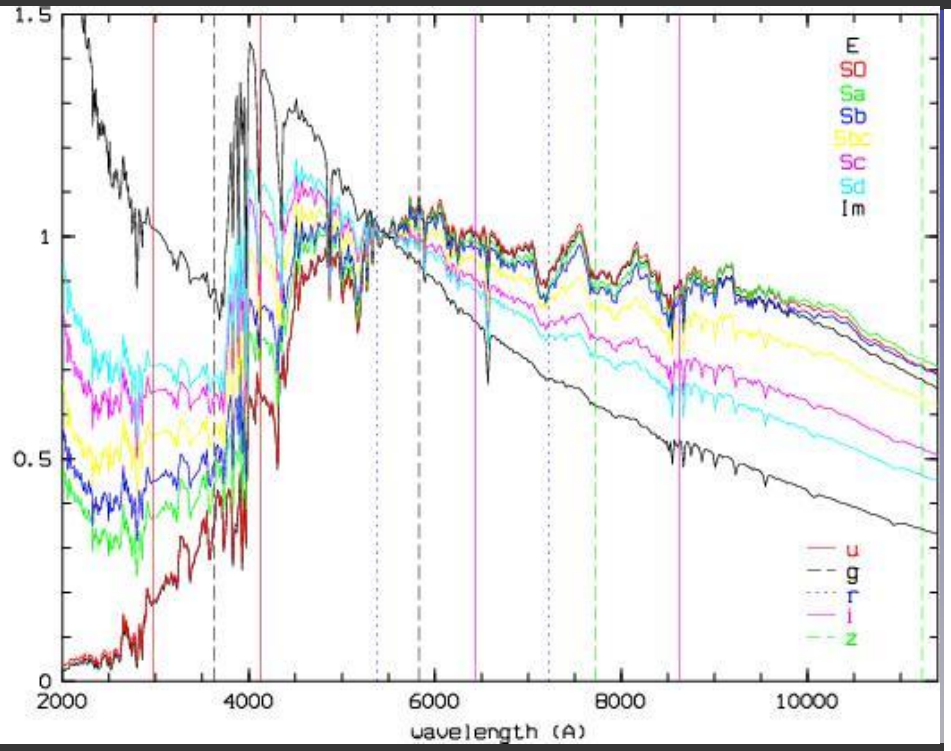
$$SFR = \frac{M_{gas}^{p1}}{p_2}$$

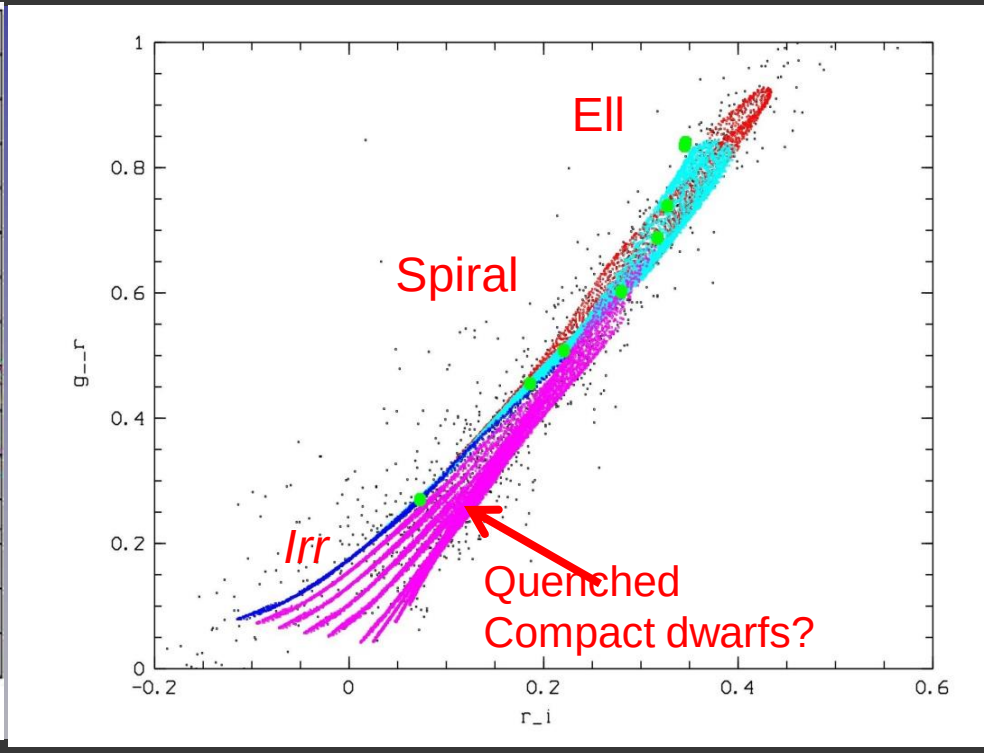
type	P1	p2 Myr/Msun	infall	winds
Elliptical Elliptical	0.6-1.5	100-1500	Y	Y
spiral	0.8-1.5	2000-10000		N
Irr-IM	1.0-2.0	14000-20000		N

+ Starbursts (delta functions, Instantaneous SFR)

The Pegase templates (Ell, Spiral,Irr) fit the local z=0 SDSS.3 data (black points)

Tsalmantsa et al, 2007, 2009 (Consortium GAIA)



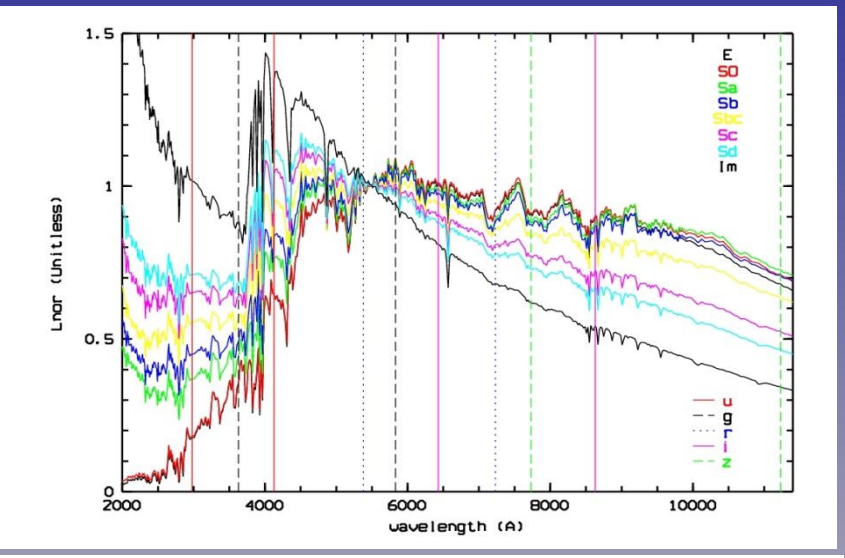


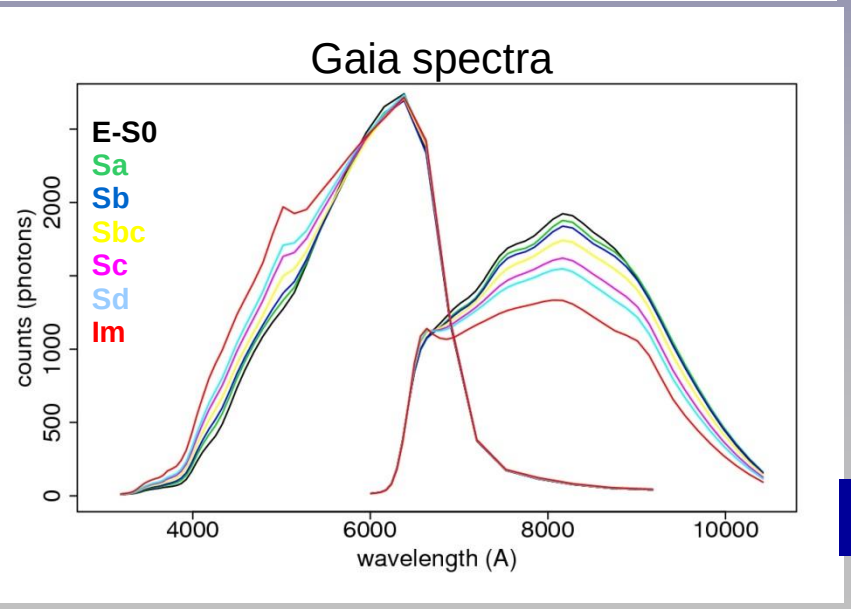
PEGASE.2 SCENARIOS ARE ALSO ROBUST :

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

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

WITH the Gaia BP/RP instruments : Classification and parametrization of the simulated Gaia spectra Tsalmantza, Kontizas, Rocca-Volmerange, Bayler-Jones et al, 2007, 2009





Gaia BP/RP spectra

↓ Discrete source classifier

Galaxy spectra

↓ Av

Galaxy spectra with known Av

↓ z

Galaxy spectra with known Av, z

↓ Galaxy type & Astrophysical Parameters

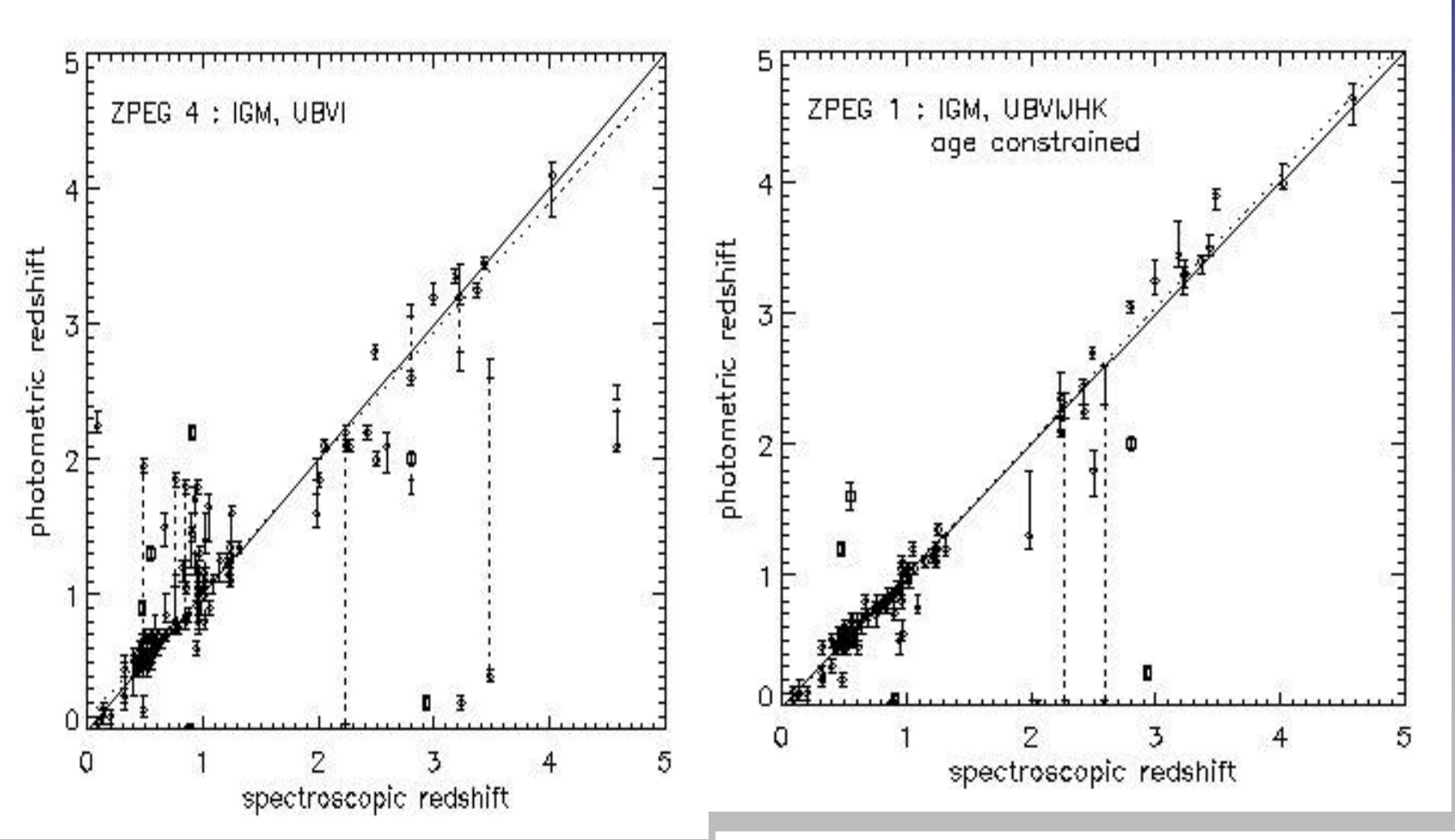
Galaxy spectra with known Av, z, type, APs

The results presented here are produced using Support Vector Machines for galaxy spectra with noise and **G=18.5**

OTHER CALCULATIONS FOR G=15 and 20

Validation of the Pegase templates

PHOTO-z / SPECTRO-z



Le Borgne & Rocca-Volmerange, 2002: The code Z-PEG

From the Hubble K-z Diagram

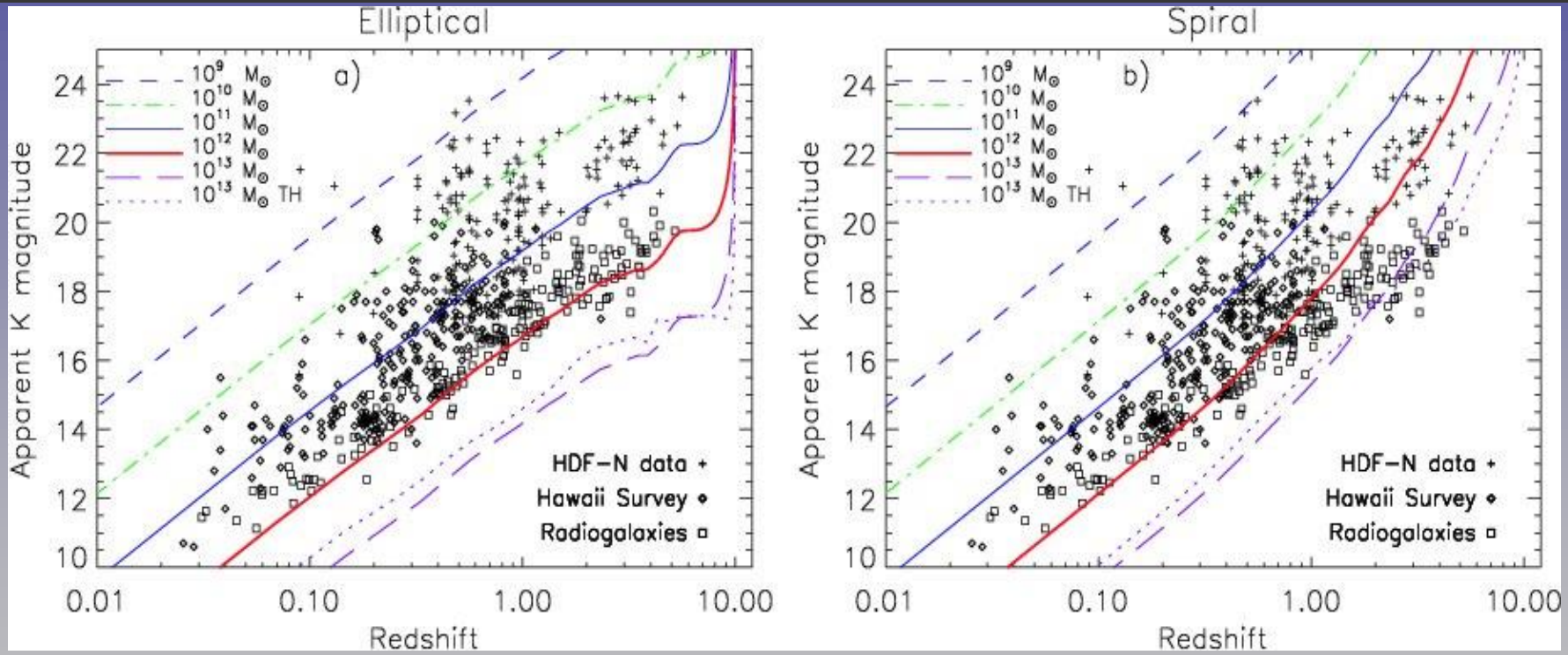
The most massive galaxies at z>4 are elliptical (and not spiral)

They are radio, hosting a supermassive black hole

Their Baryonic Mass is 10^{12} MΘ (red line)**

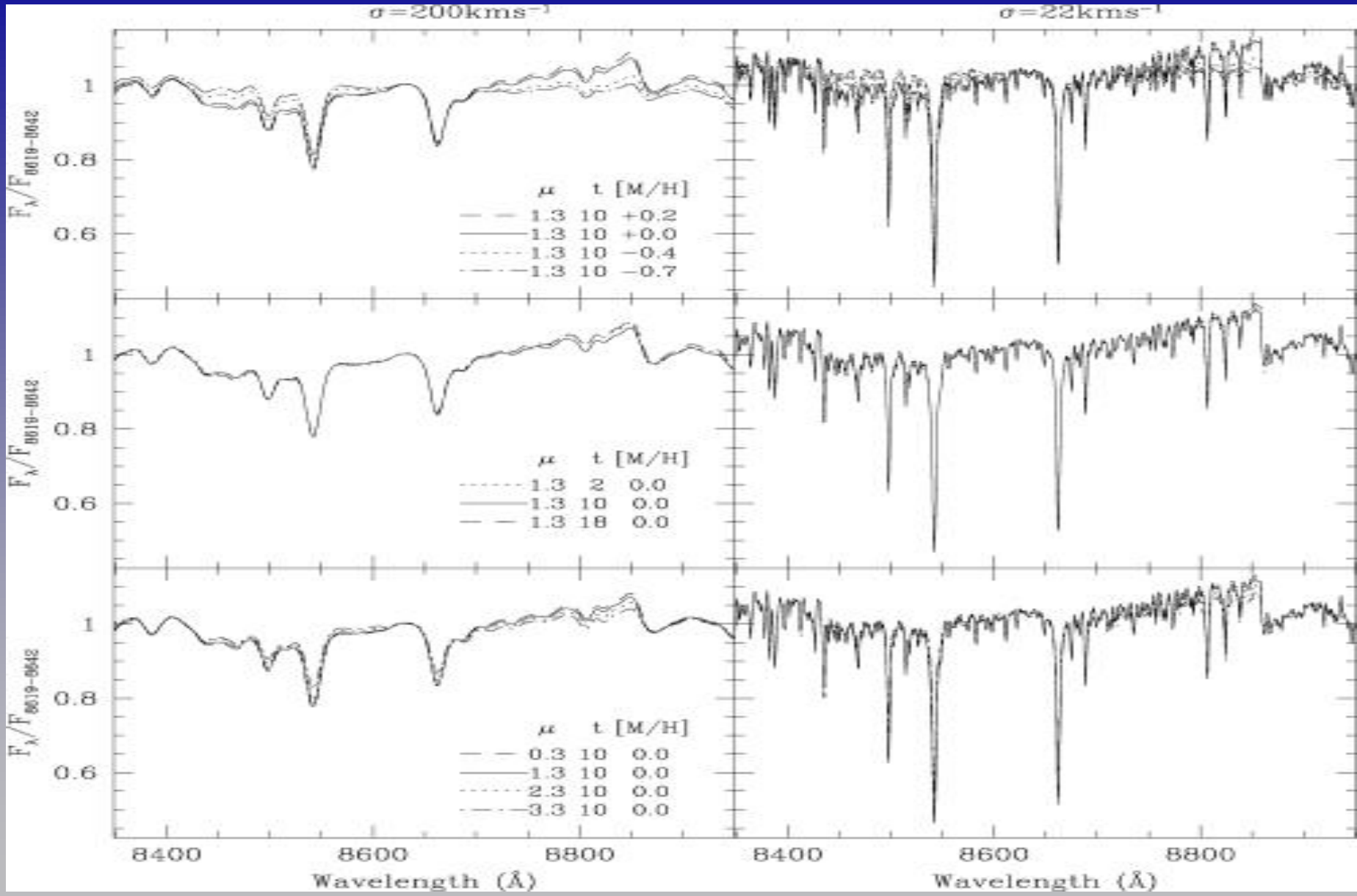
Hubble K diagrams

•



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

Redshift z



Gaia/RVS Spectral Energy Distributions with PEGASE at Low (left) and high (right) spectral resolution

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

- Faint AGN contribution
- Evidences of young and old stellar populations
- Continuous flux-calibrated SEDs from

❖ Optical (UV rest-frame)

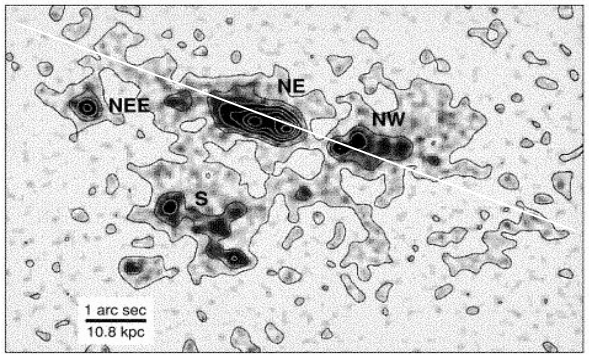
❖ Spitzer (K-band rest-frame)

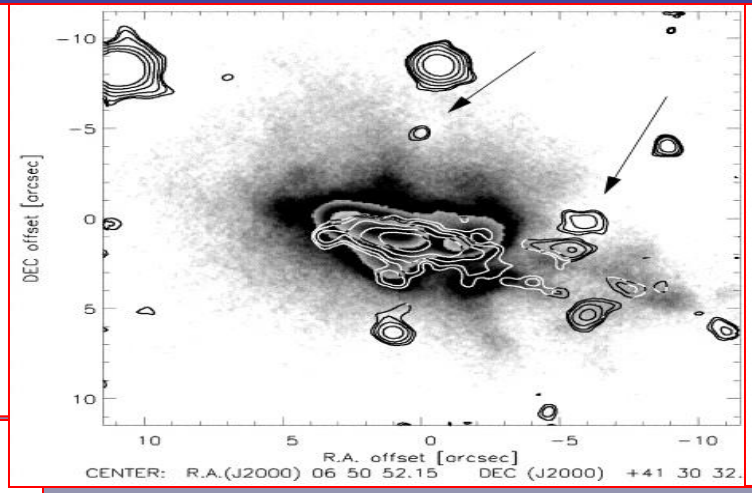
❖ Herschel and submm (cold grain peak rest-frame)

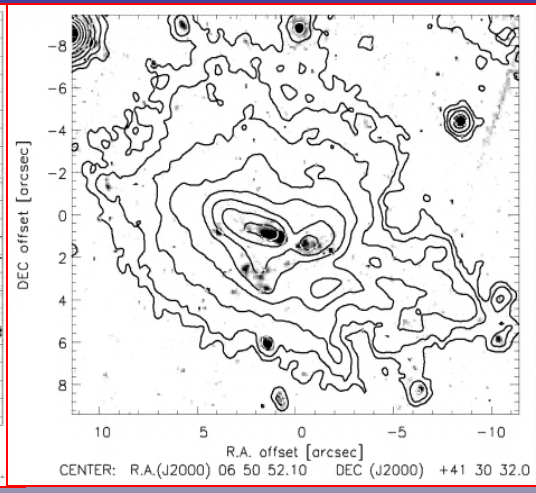
- Negligeable synchrotron emission

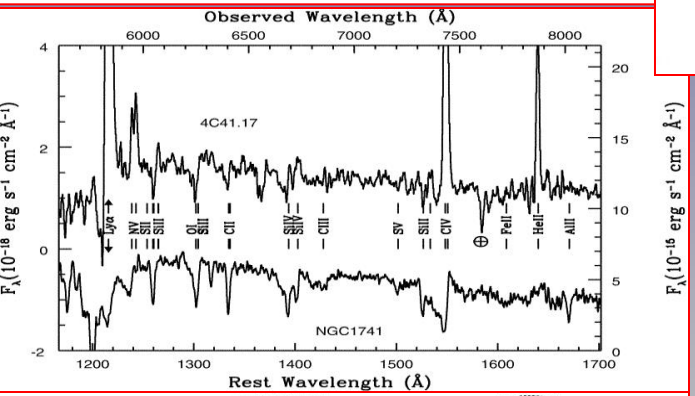
High-z radio galaxies and Giant Lyα Clouds

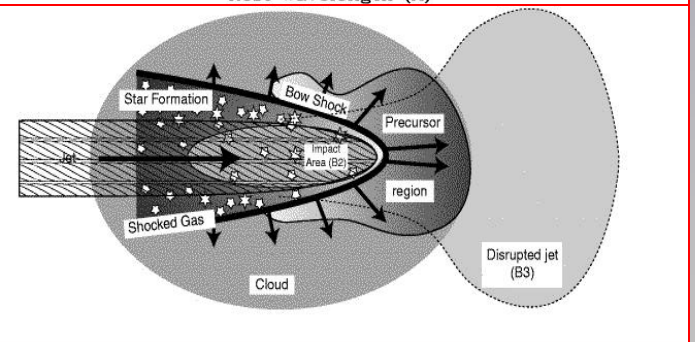
The template distant radio galaxy 4C41.17 (z=3.8)



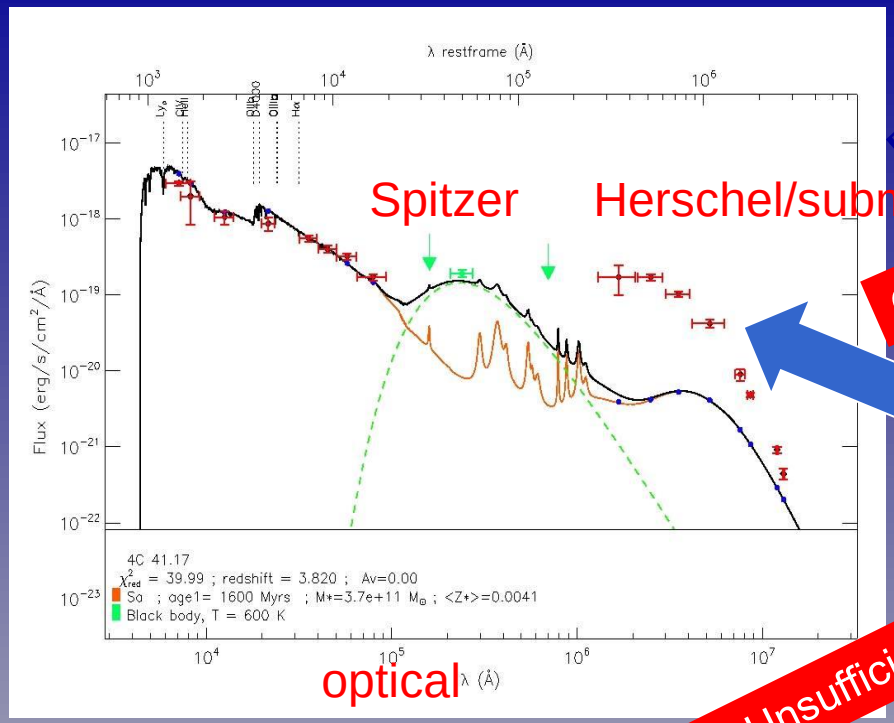


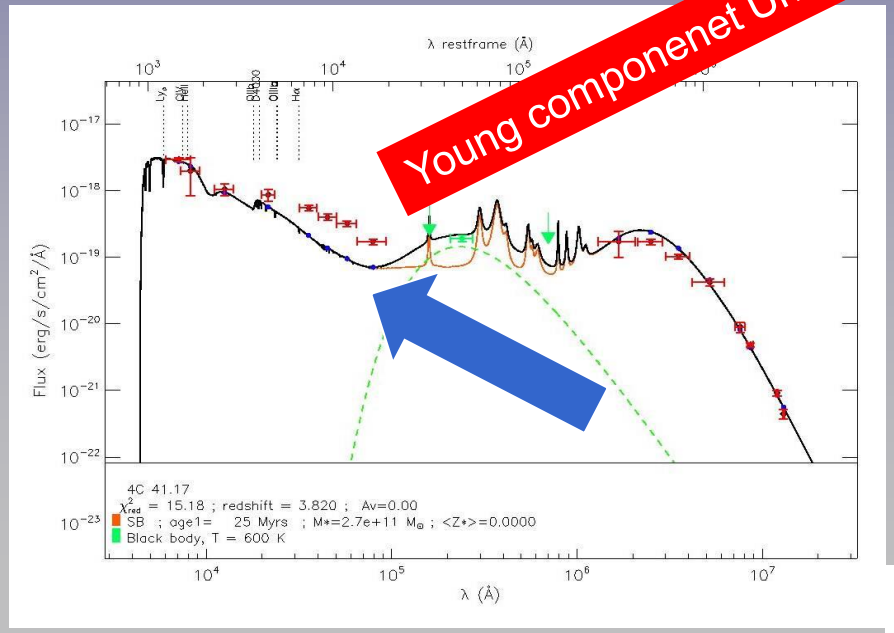






- **Huge Lyα Clouds of 100-200 kpc of ionized gas (cocoon)** (Dey et al, 1997, Van Breugel et al, 1999, Reuland et al, 2003).
- **HIGH-z RADIO GALAXIES are hosted by MASSIVE ELLIPTICALS**
- **Stellar lines are detected along the radio axis** (Dey et al, 1997), as WR starbursts
- **Star formation along the radio jet and south-East component, Bicknell et al, 2000**



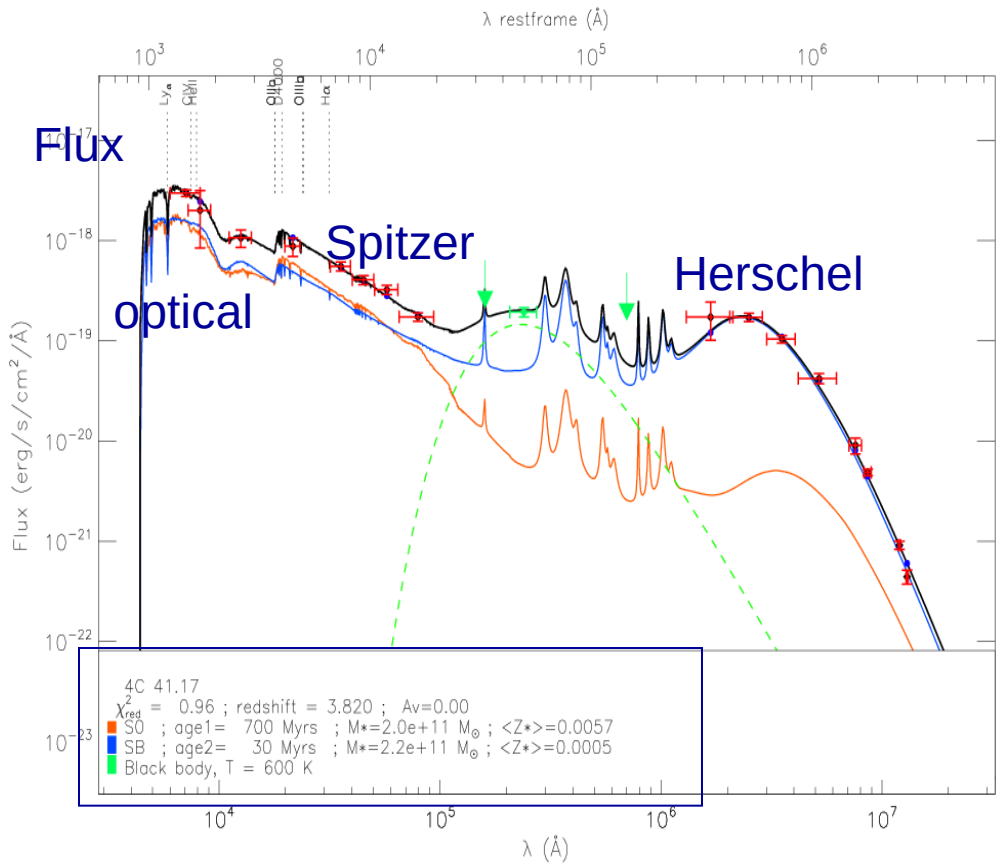


Old component Unsufficient in the FIR

Young componenet Unsufficient in Mid IR (Spitzer)

Rocca-Volmerange et al, 2013

The z=3.8 radio galaxy 4C41.17 with HERSCHEL, SPITZER and optical SED: Sum of a massive starburst and an evolved (~1Gyr) galaxy by spectral evolutive synthesis with the code Pegase.3



Rocca-Volmerange, Drouart, Fioc And the HeRGé group., MNRAS, 2013

Observations (red crosses)

Best-fits are the SUM (Black line) of

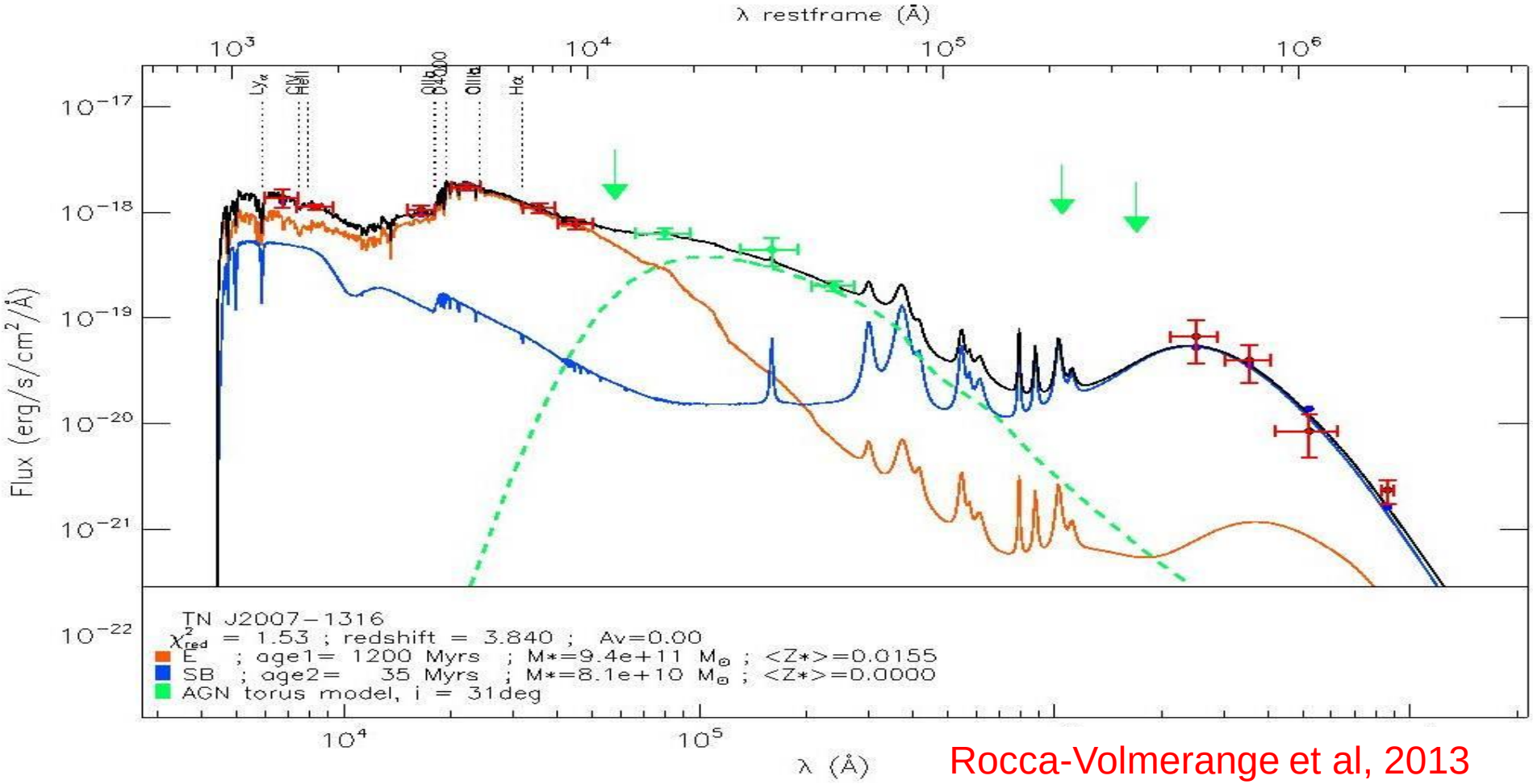
Massive starburst at 30Myrs (blue)

Evolved early type at 700Myrs (orange)

AGN model (dashed green)

Procedure :Khi2 min. in the observer frame, multiple template libraries by types,

TN J2007-1316 (z=3.8) : data red crosses total:black line + AGN (dashed green Elliptical at age 1.2 Gyrs (orange line) Starburst at age 35 Myrs (blue line)



Rocca-Volmerange et al, 2013

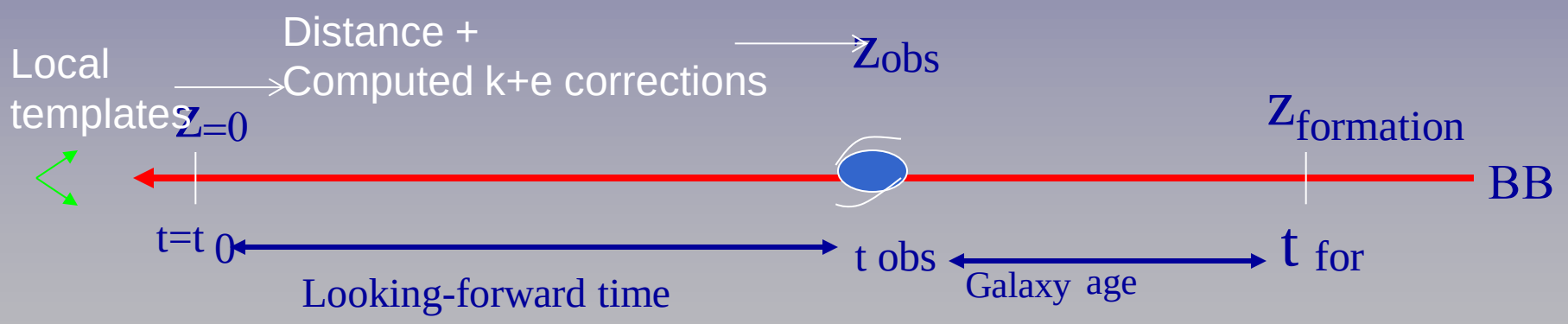
Ages, Stellar mass and SNR mass after best-fits calibrated on observed data for 4C41.17 and TN J2007-1316

Rocca-Volmerange et al., 2015, ApjL, 803, L8

Galaxy component	Age Myr	Star mass (10+11 Msun)	SNR Mass (10+9 Msun)	SNR/ Star mass ratio	Z
4C41.17/Burst	**30**	2.2	**8.5**	0.04	0.005
4C41.17 SO	700	2.0	**4.3**	0.02	0.0057
TN**J2007-1316/Burst**	**35**	0.8	**3.4**	0.04	0.0001
TNJ2007/Ell	1200	9.4	**19.0**	0.02	0.0155

Stellar masses (~$10^{12}M_0$) and SNR masses (10^9M_0)
SNR/star mass ratio (~10^{-2}) , similar to local galaxies

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- cosmic time t(z) in Gyr

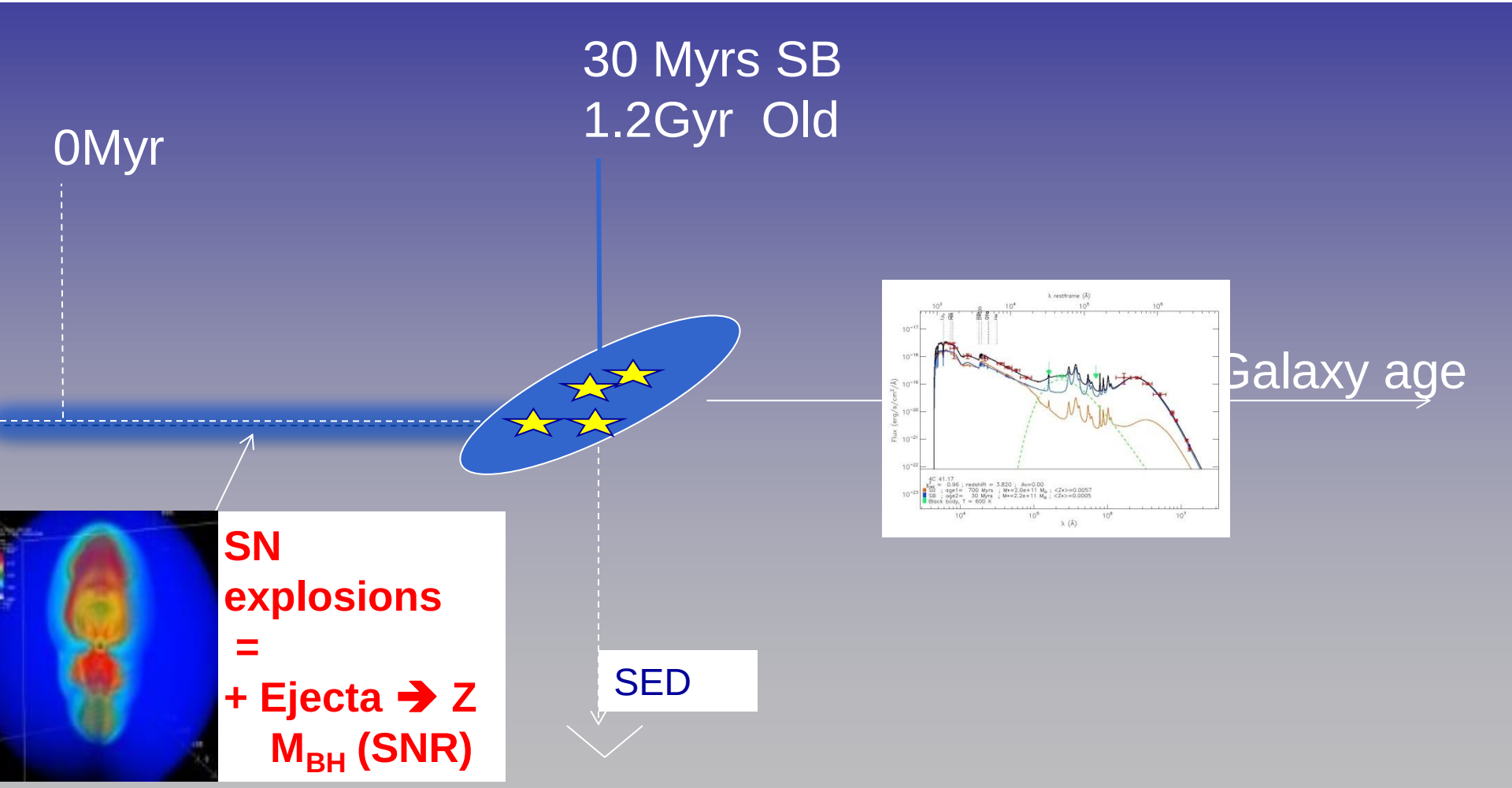
Ho=72km.s-1Mpc-1, $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$

Rocca-Volmerange et al. 1988

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

CORRECTIONS FOR COSMOLOGY AND EVOLUTION

The observed SED ←→ Current Galaxy age
Supernovae already exploded

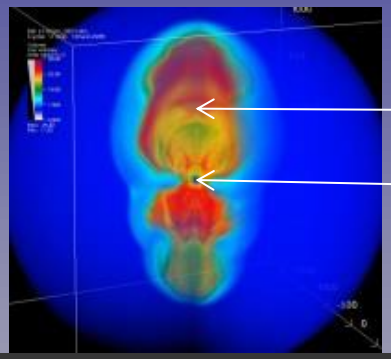


Pegase coherently follows :

i) Z metallicity to dust grain evolution

ii) N number and mass of SNRs

iii) SED from still alived stars



Metal ejecta (from yields)
Stellar black hole
(or neutron star) =SNR

Stellar BH mass $m_{BH/N} = m_{SN} - m_{ejecta}$ (including winds)

Number stellar BH formed at the starburst/galaxy age t_B

$\Phi\ (m_{supernova}) \times m\ (t_B)$ **from IMF and SN evolution**

$M^{Starburst}_{SNR}$ **for SSP**

M^{Gal}_{SNR} **for Σ SSPs**

ACCUMULATED number of SUPERNOVAE explosions

➔

Gas Ejecta and metals ➔ Interstellar enrichment

+

Supernovae Remnants (SNR):

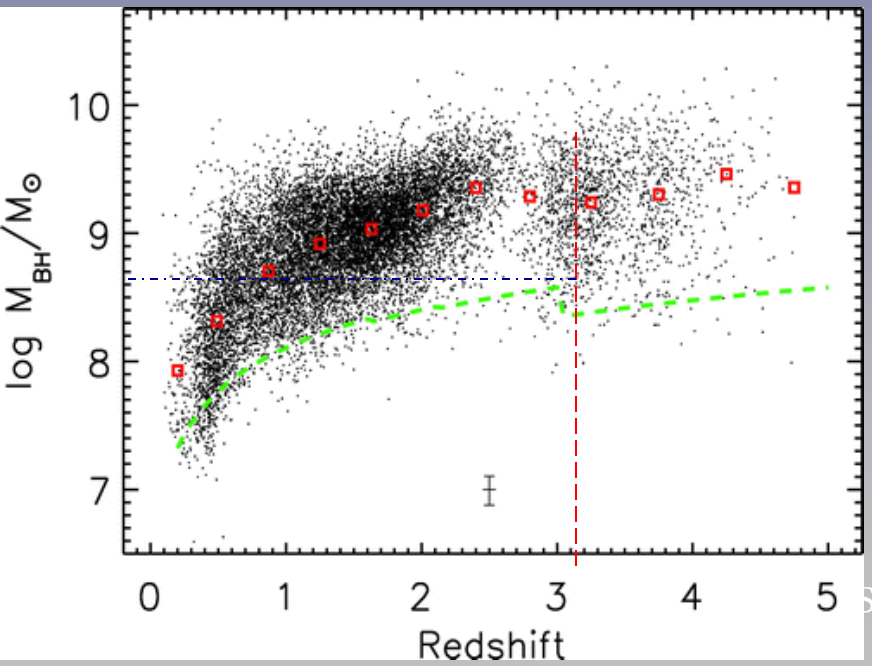
neutron stars and stellar black holes

Star mass of SSP and old population @ z=3.8
several 10 (+11) Msun

And SNR mass of SSP and old population @ z=3.8
= several 10 (+9) Msun

Rocca-Volmerange et al, 2015, ApJ, 803, L8

COMPARABLE with



M_{SMBH} = 10 (+9.3) Msun at z=3.8 from SDSS3, et al, 1998

M_{SMBH} ~ 10 (+9) Msun à z~ 2.5 from Ha / VLT
Nesvadba et al, 2011

How stellar black hole mass

resulting from past SN explosions

might explain the growth of

supermassive black hole mass

Possible transfer of SNRs from explosion site to the central supermassive black hole by dynamical friction

= loosing angular momentum

= migration inwards to the core

The dynamical friction respects the galaxy age

$$t_{fric} = \frac{19}{lnL} Gyr\left(\frac{ri}{5kpc}\right)2 \frac{\sigma}{200km\ s-1} 10^8 Mo/M(SNR)$$

$$= 0.095\ Gyr << 1Gyr\ Hubble\ time$$

For ri=0.25kpc, MSNR=2 10^7, σ=400km s-1

Binney & Tremaine, 2008

The migration process from dense star clusters

The excellence of the Gaia photometry be able:
To relate the Surrounding stellar population and the black hole accretion flow

Galactic center
Dense star clusters

And more depending on sensitivity

Black hole formation in primitive galaxies

« Stellar black hole seeds accrete quasi-spherically and grow supra-exponentially in the early universe In stellar clusters fed by dense cold-flows and reach masses)of > 10^4 Msun by z~15 (Alexander & Natarajan, 2014, Science)

The accretor as a stochastic dynamical objets

Other factors accelerating star formation, etc

- Low signatures of stellar black holes
  The catalogue of SNR in the Milky WAY= ~300 SNRs…

- Stellar BH mass is in agreement with
- Still luminous star populations (SEDs)
- Metallicity (SN ejecta) From Ha / VLT
- Dust emission (Herschel emission)

- All issued from the same star formation history

- No direct relation of starburst with the variability of AGN

- Possible numerical simulations to form elliptical and dense bulges (van Dokkum et al, 2013, 2014)

THE TOOL BOX **PEGASE**

PEGASE.2 (www2.iap.fr/pegase) 8 spectral types (Ell→Irr) for evolutionary SED synthesis with Metals, Dust and Geometrical Effects (Fioc & Rocca-Volmerange, 1997, 1999)

free access

free access

CODE Z-PEG

Photometric redshifts (Le Borgne & Rocca-Volmerange, 2002)

NEB-PEG

Nebular emission PEGASE+CLOUDY +MAPPINGSIII (Moy & Rocca-V, 2001, 2002)

PEGASE-HR (R= 10000),

High spectral resolution with ELODIE library

Le Borgne, Rocca-Volmerange B., Lançon A. , Prugniel P. , Soubiran C. , 2004,

PEGASE.3 from UV to Far-IR (evolution + grains) Fioc, Rocca-Volmerange,Dwek, README ready

X-Rays-Optical-IR

D. Le Borgne, PhD thesis , 2003,

Atlas of synthetic galaxies(optical-FIR)