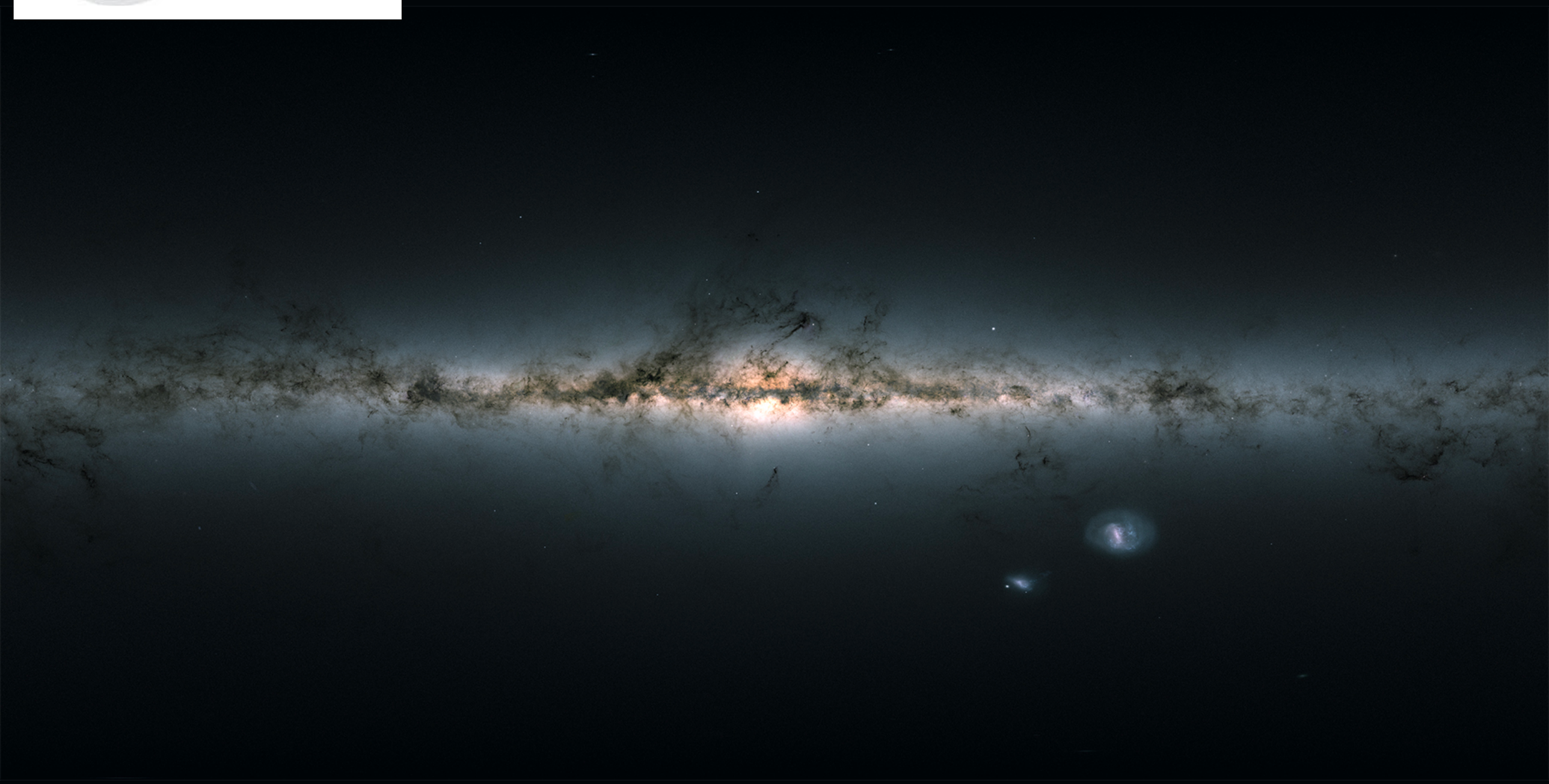
laure.ciesla@lam.fr

Galaxy Evolution

Laure Ciesla

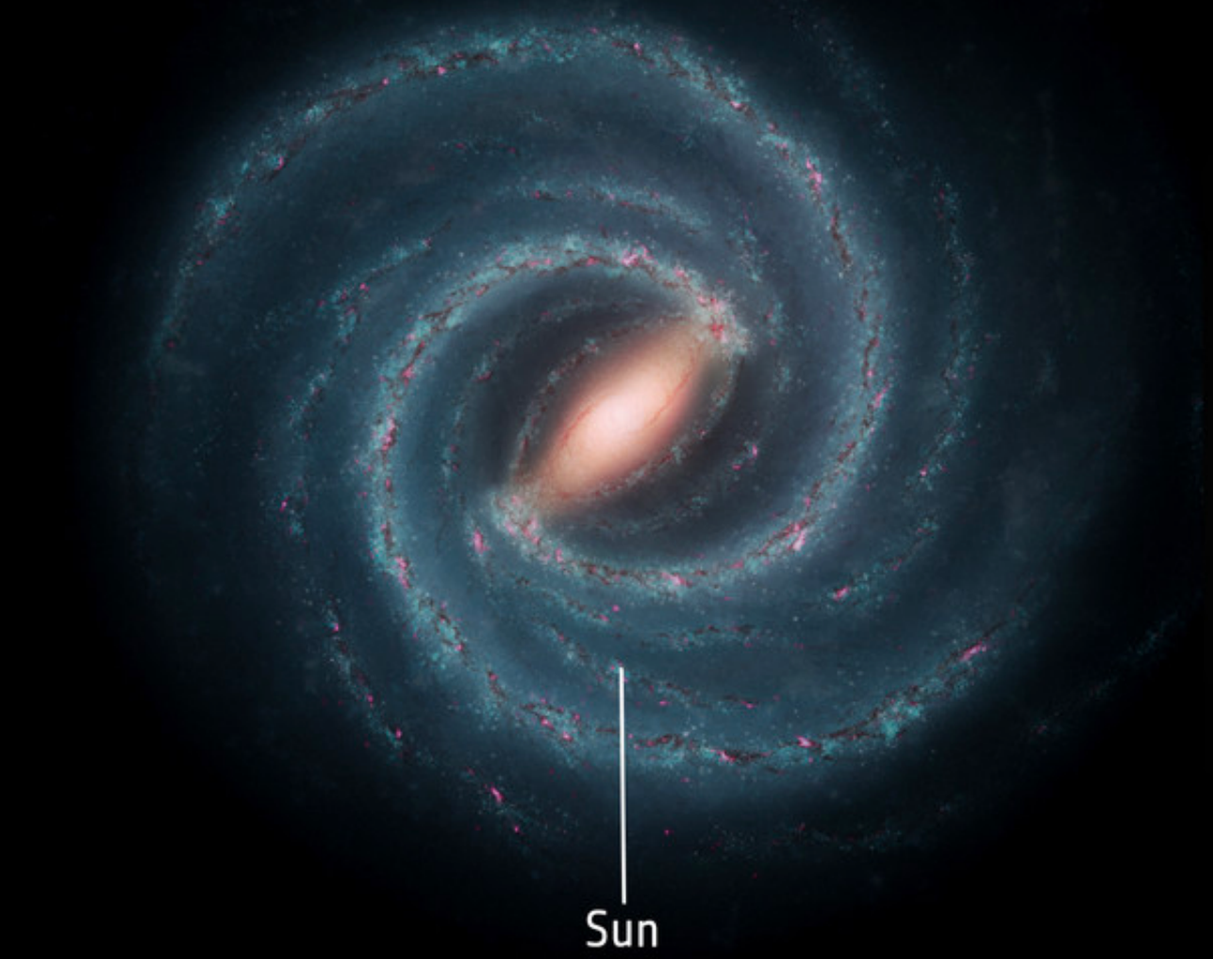
gaia

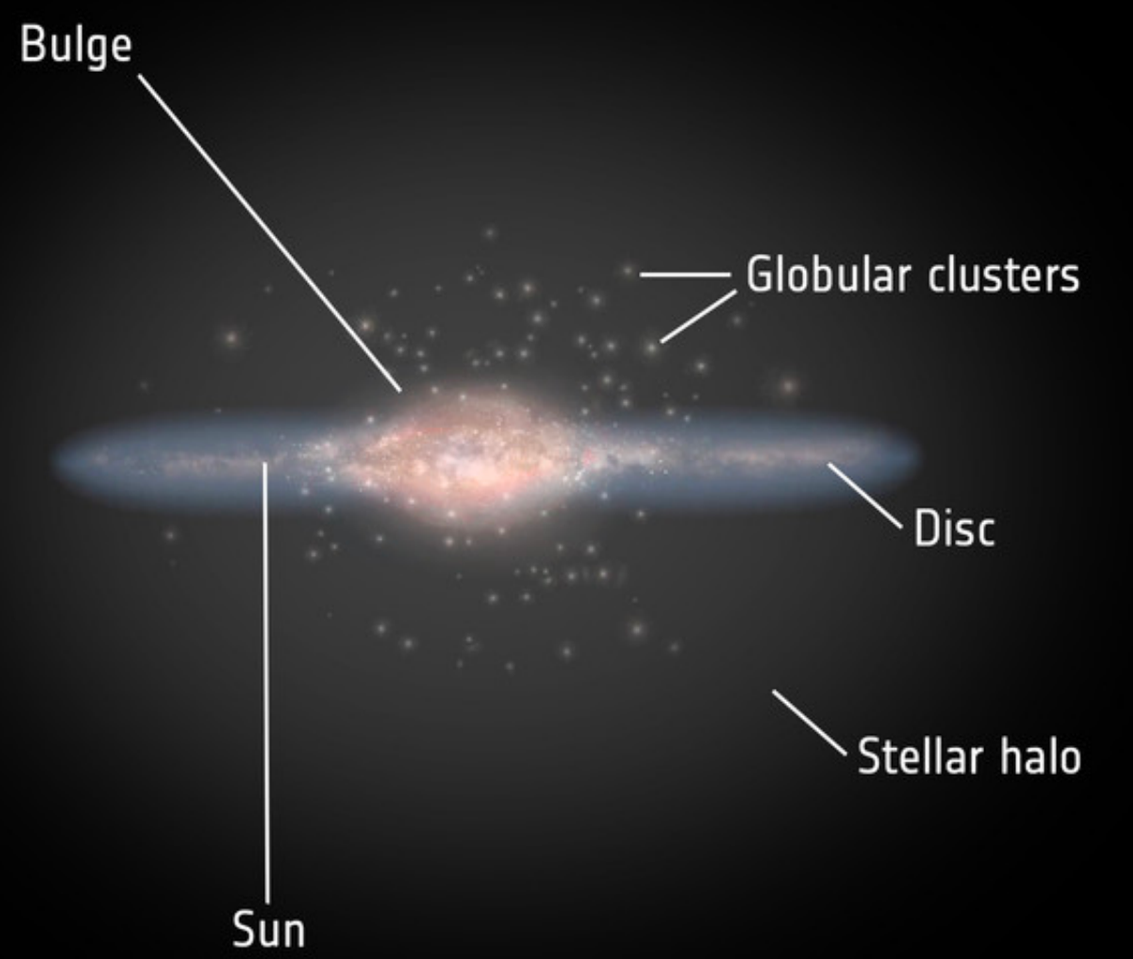


$M_{MW} = 9.6 \times 10^{11} M_{sol}$

1.7 billion stars on this image

→ ANATOMY OF THE MILKY WAY





www.esa.int

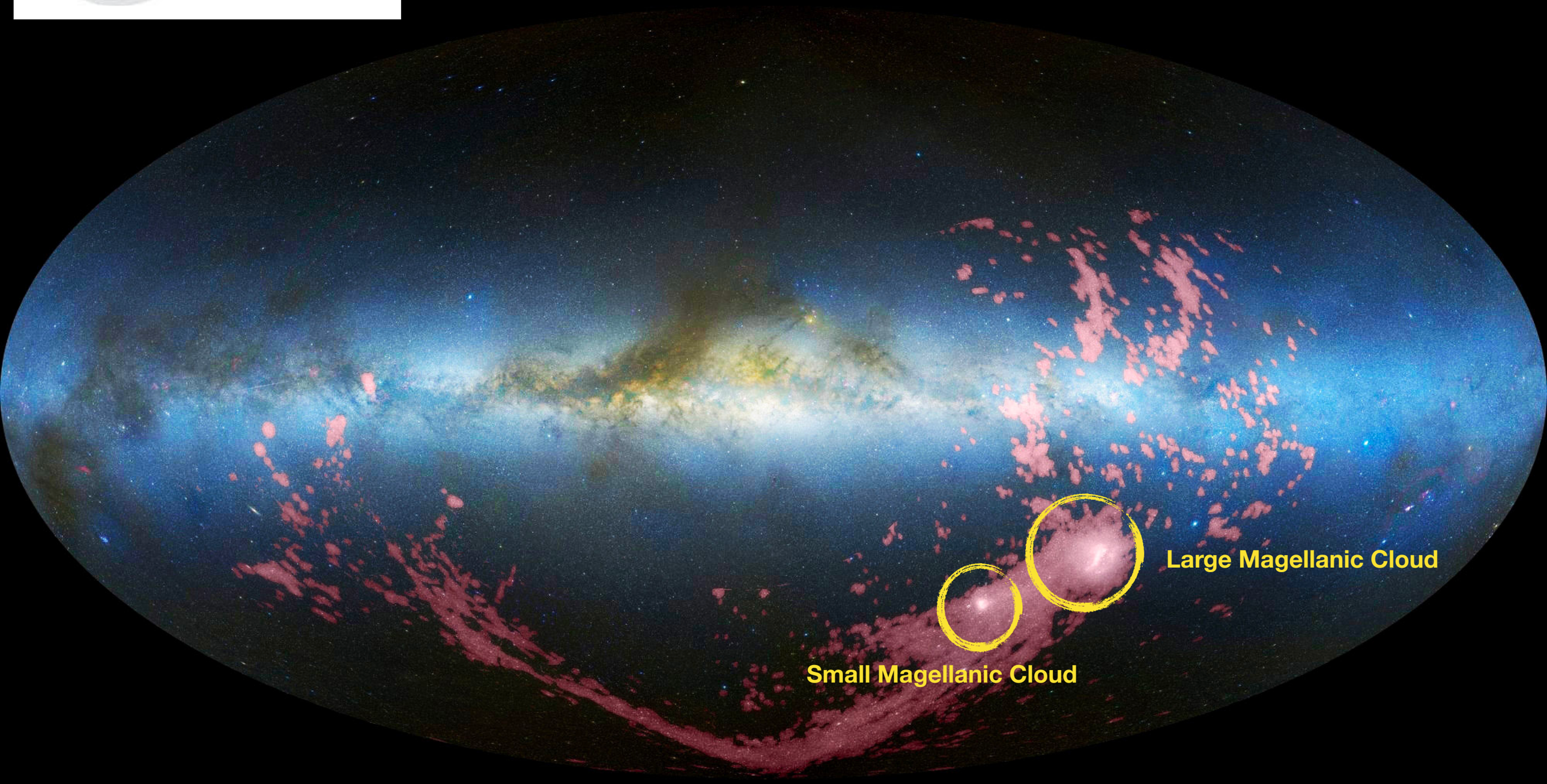
European Space Agency

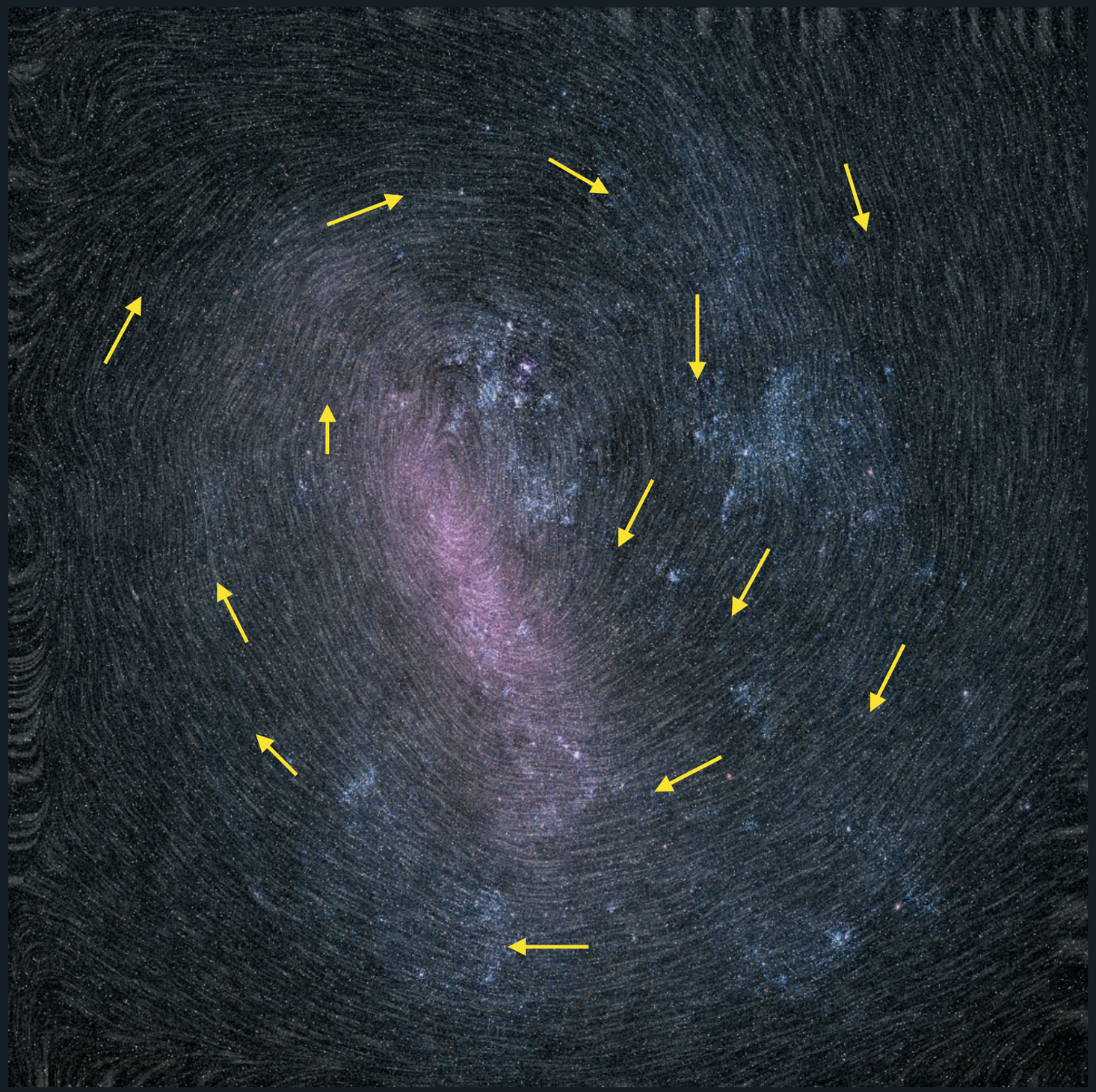
gaia

Large Magellanic Cloud

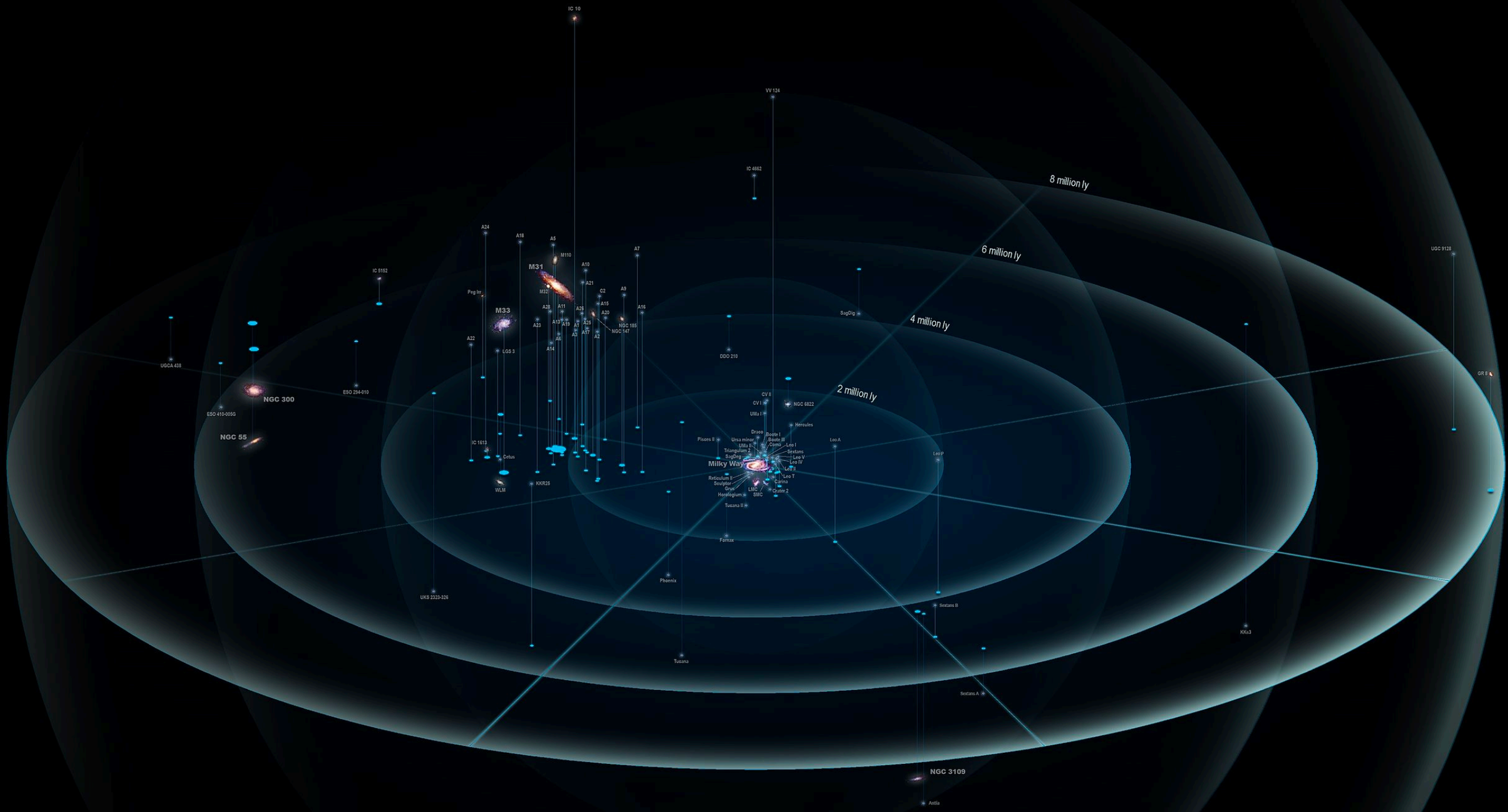
Small Magellanic Cloud

gaia

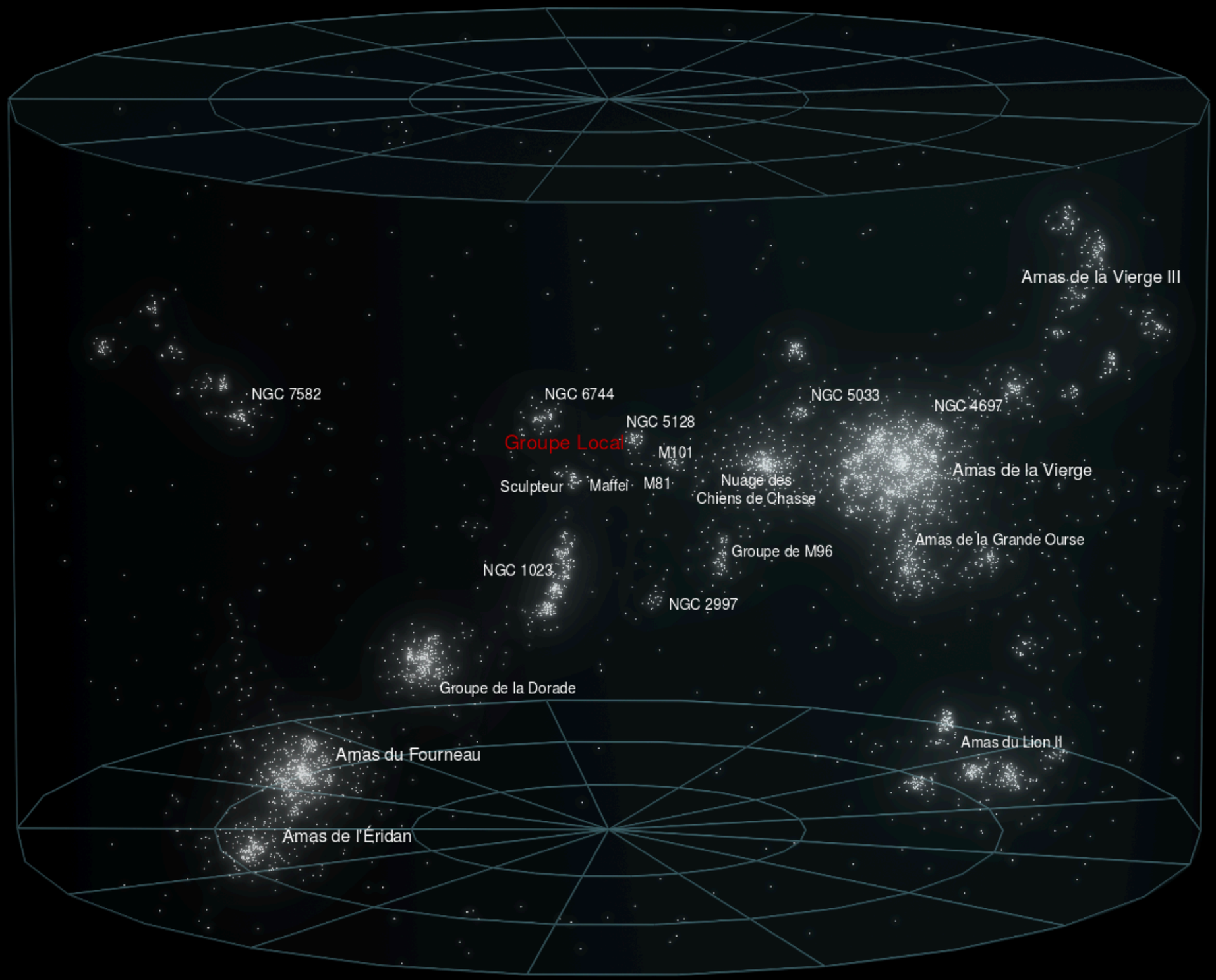


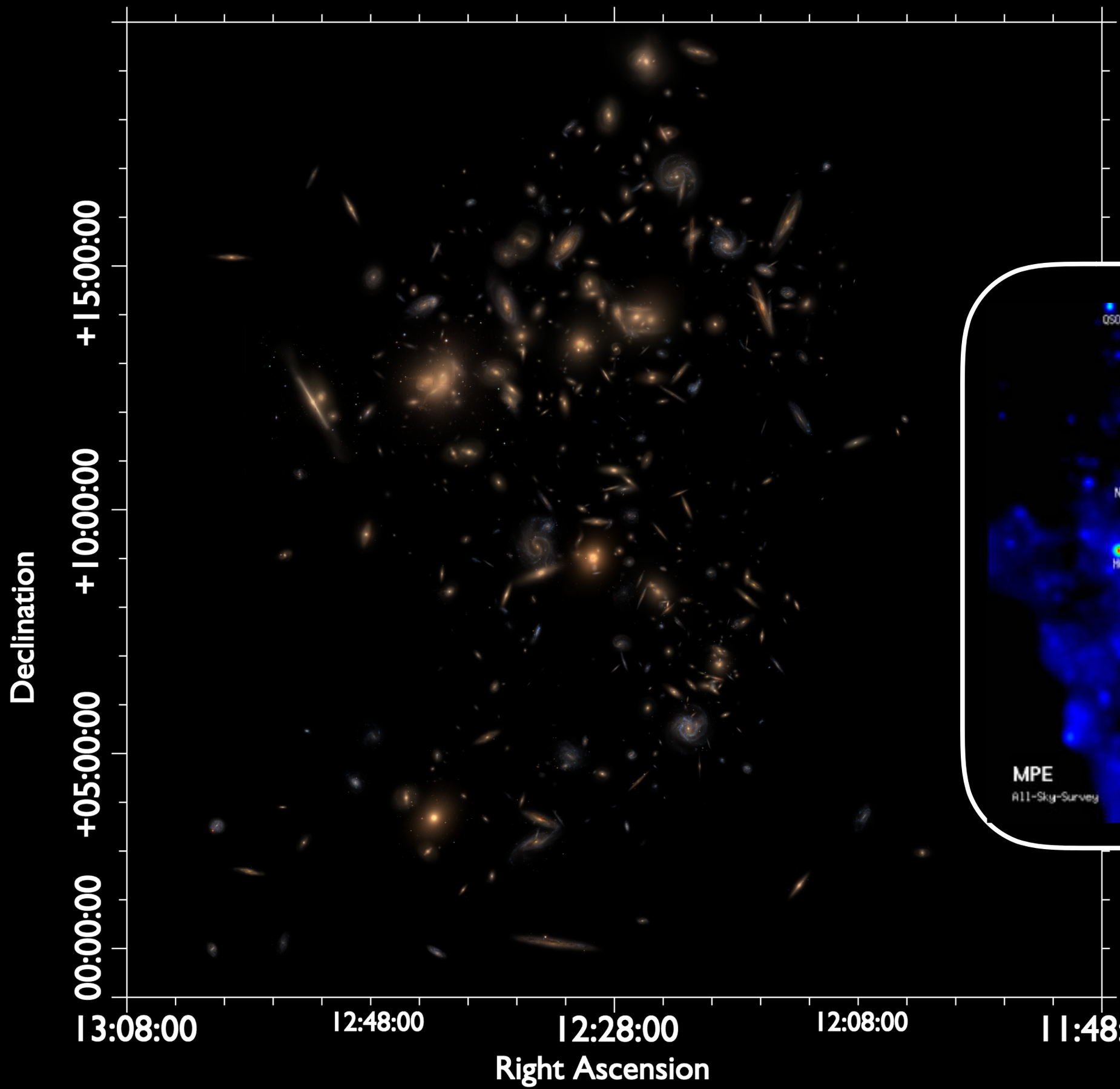


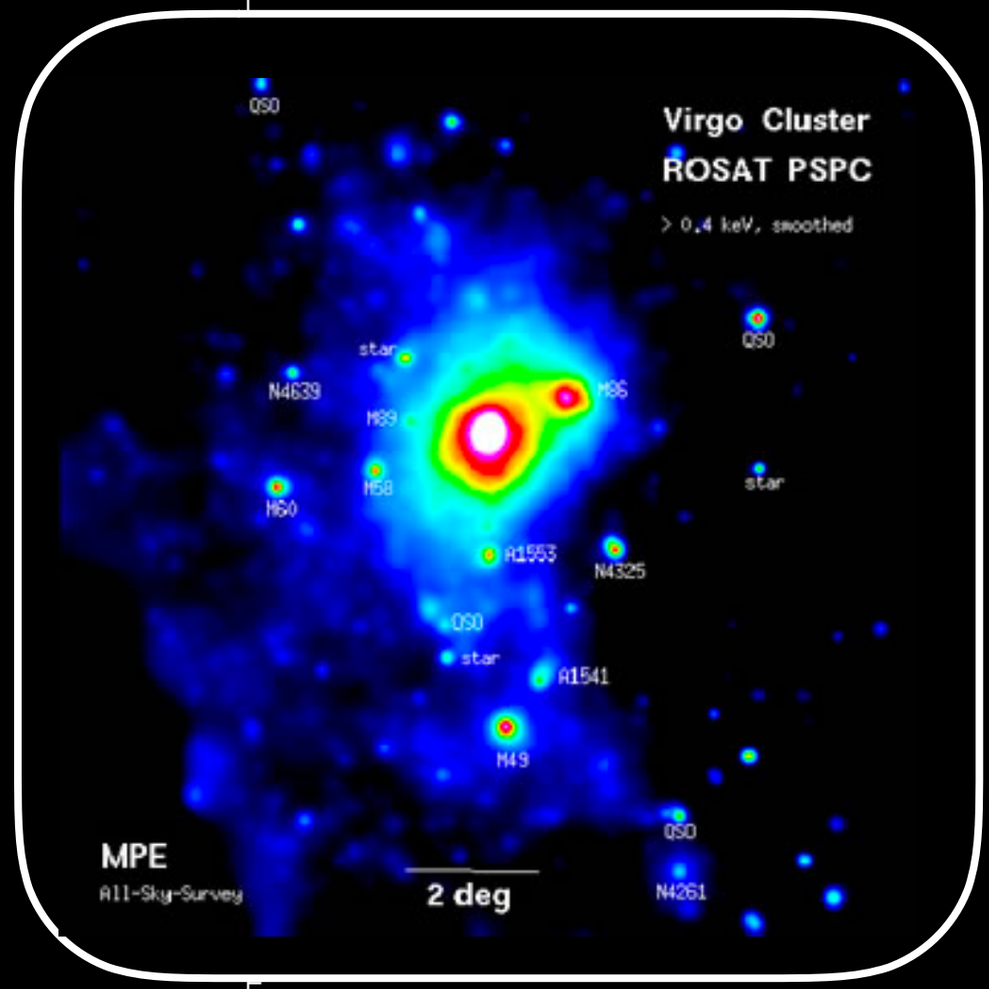
Local Group and nearest galaxies



Superamas de la Vierge

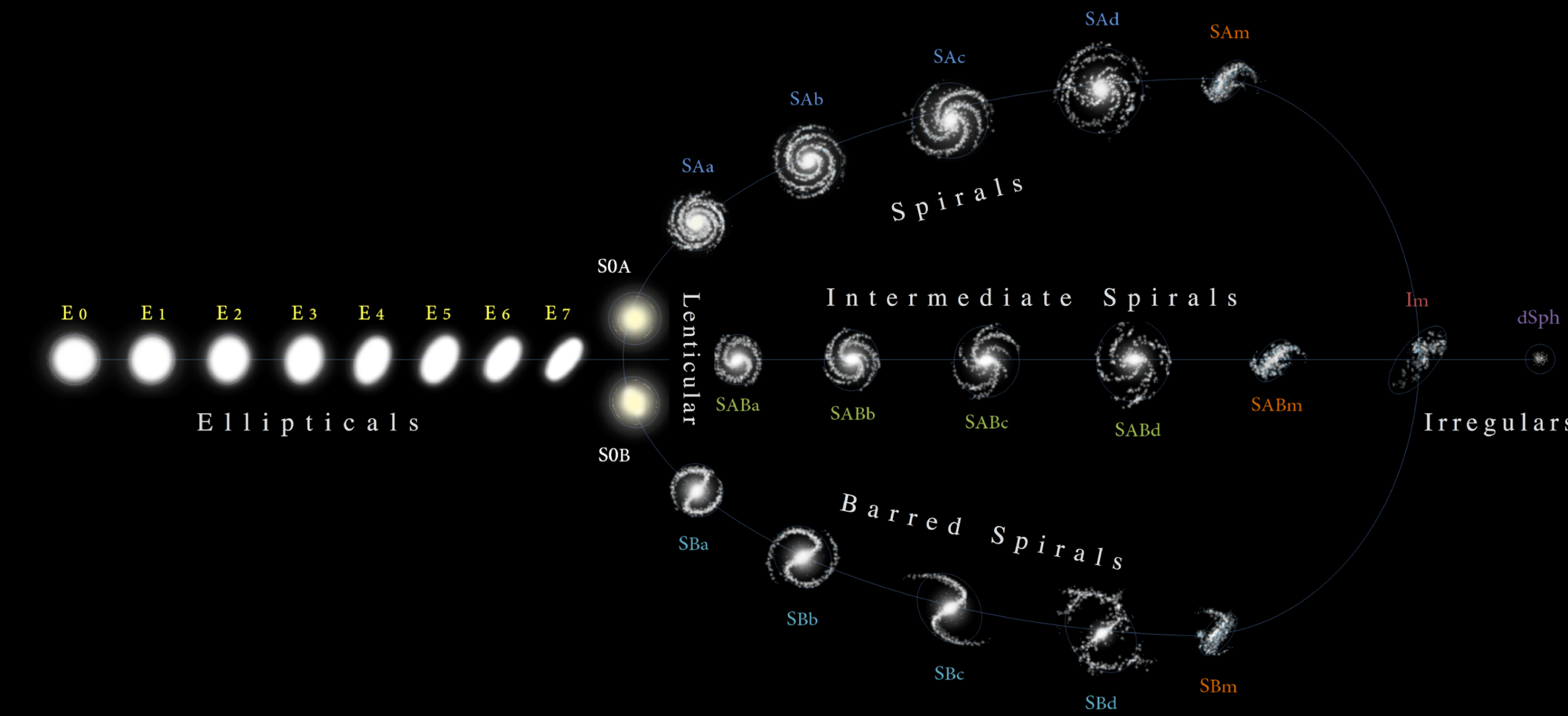



+15:00:00
+10:00:00
+05:00:00
00:00:00
Declination
13:08:00
12:48:00
12:28:00
12:08:00
11:48:00
Right Ascension


Virgo Cluster
ROSAT PSPC
> 0.4 keV, smoothed
QSO
star
N4639
M86
M89
M58
M60
star
A1553
N4325
QSO
star
A1541
M49
QSO
N4261
MPE
All-Sky-Survey
2 deg

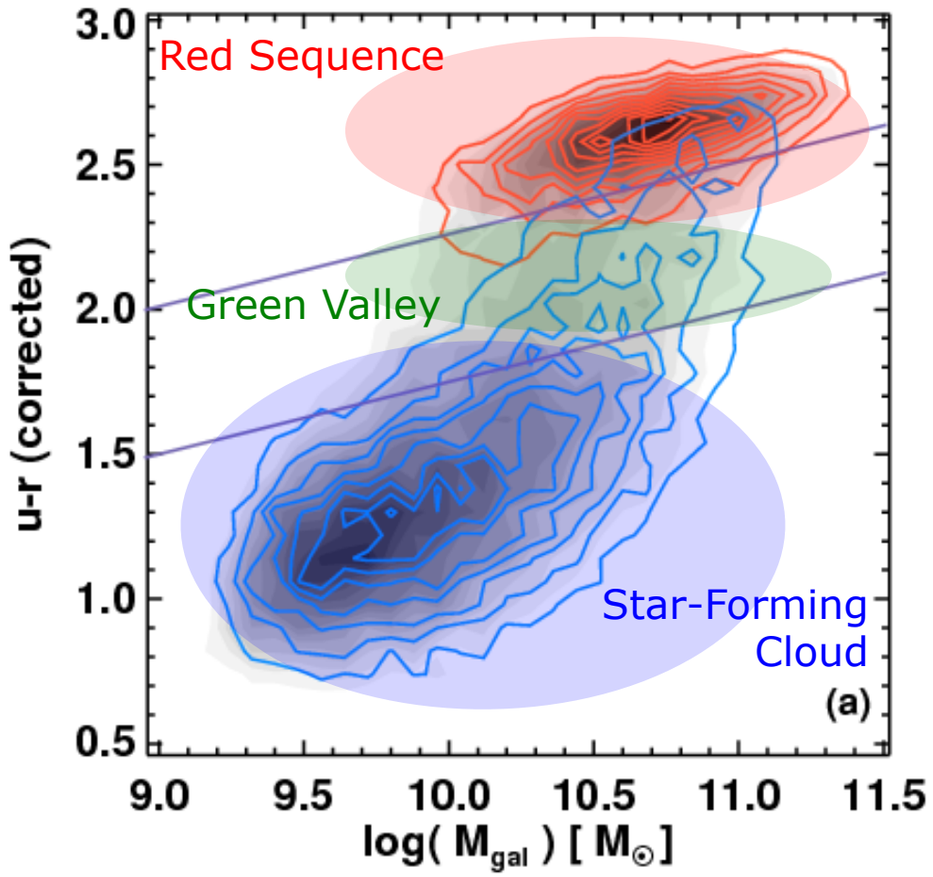
Galaxies have different shapes

HUBBLE-DE VAUCOULEURS DIAGRAM



Optical (Hubble)

Galaxies have different colors


Red Sequence
Green Valley
Star-Forming
Cloud
(a)
u-r (corrected)
log(M_gal) [M_⊙]
3.0
2.5
2.0
1.5
1.0
0.5
9.0
9.5
10.0
10.5
11.0
11.5

Alatalo+14

What are the mechanisms responsible for galaxies' quenching?

Two observational evidences

Silk+77, Kauffmann+06

We find more passive galaxies in dense environment

What are the mechanisms responsible for galaxies' quenching?

Two observational evidences

Silk+77, Kauffmann+06

Massive galaxies become more rapidly passive

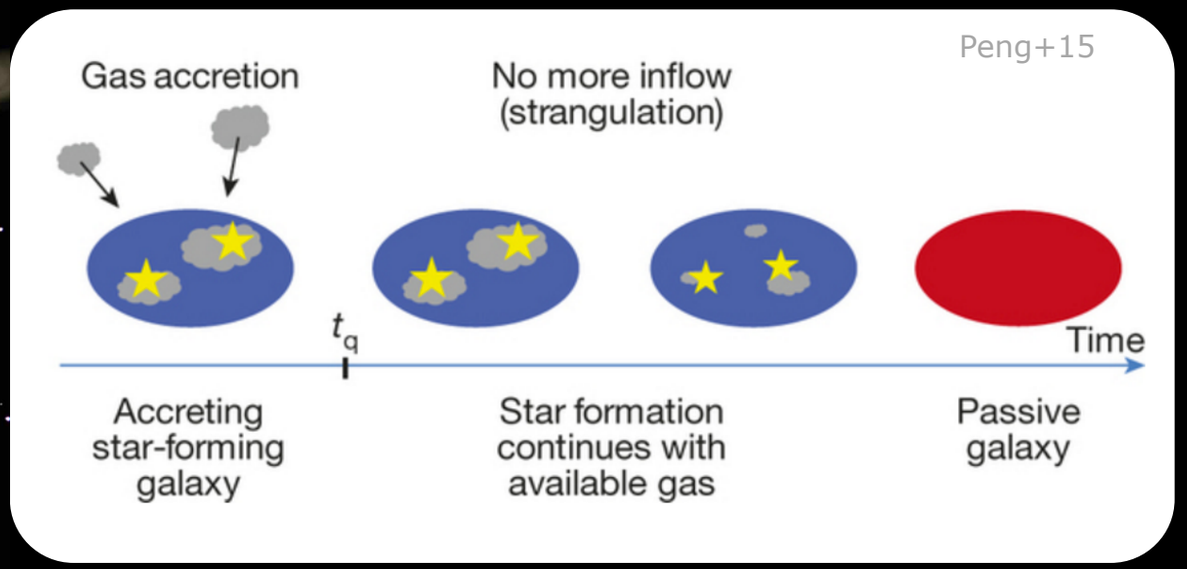
What are the mechanisms responsible for galaxies' quenching?

Several scenarios proposed

Gaz

Slow process: Strangulation

e.g. Peng+15



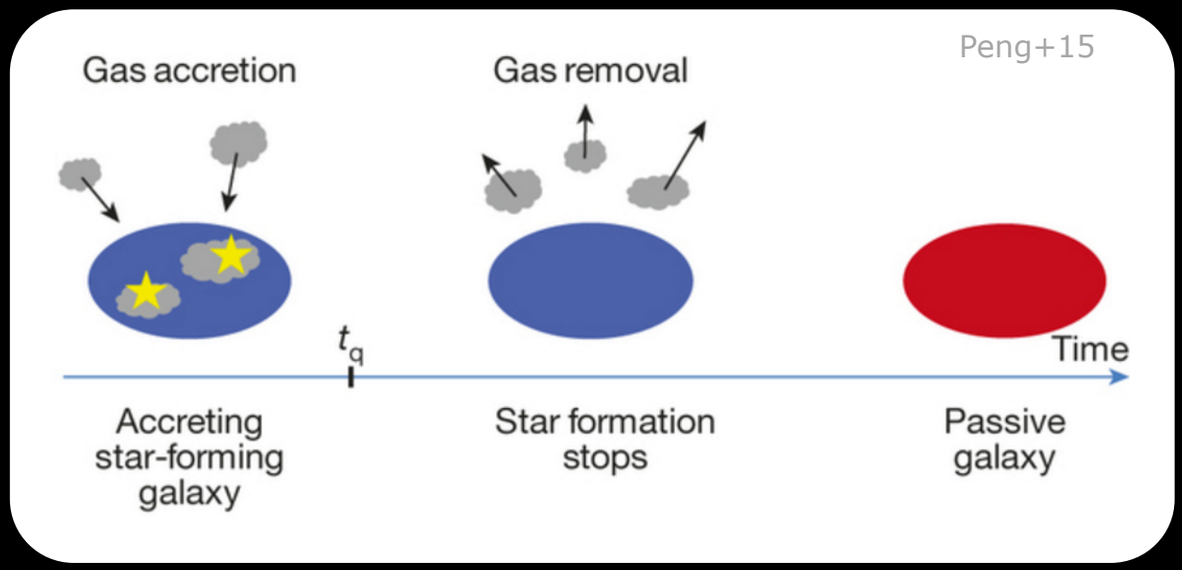
What are the mechanisms responsible for galaxies' quenching?

Several scenarios proposed

Gas

Fast process: Gas stripping

e.g. Gunn&Gott72, Larson+90, Tonnesen&Bryan09

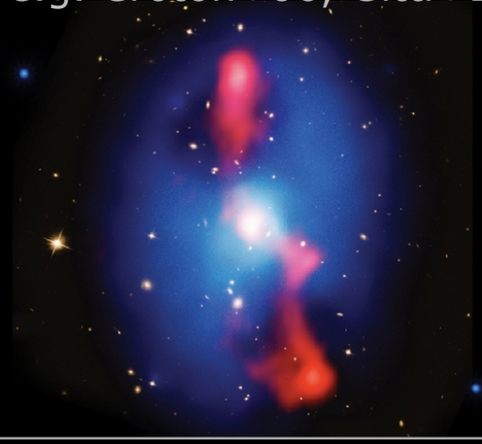


What are the mechanisms responsible for galaxies' quenching?

Several scenarios proposed

Feedback processes

Nuclear
e.g. Croton+06, Gitti+12

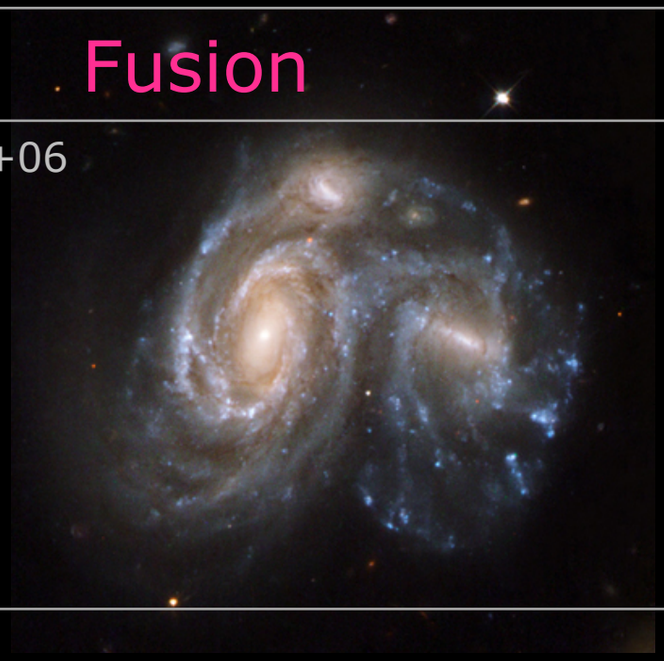


Stellar
e.g. Genzel+14

Morphological
e.g. Martig+09

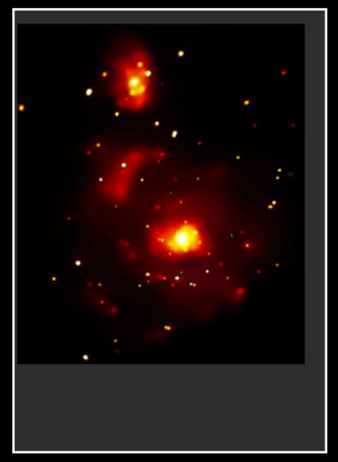
Fusion

e.g. Conselice+06

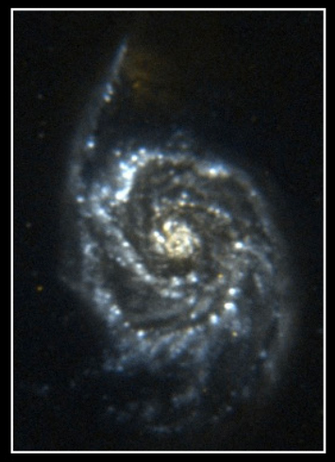


Diminution of Star Formation Efficiency

e.g. Schreiber+15, Ciesla+17



X ray

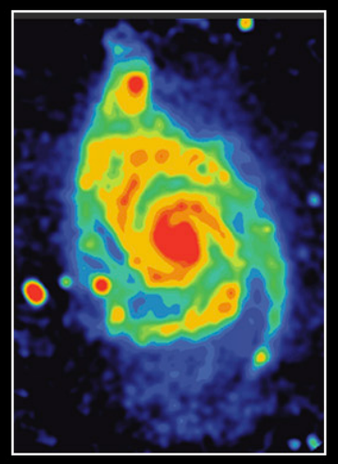


UV

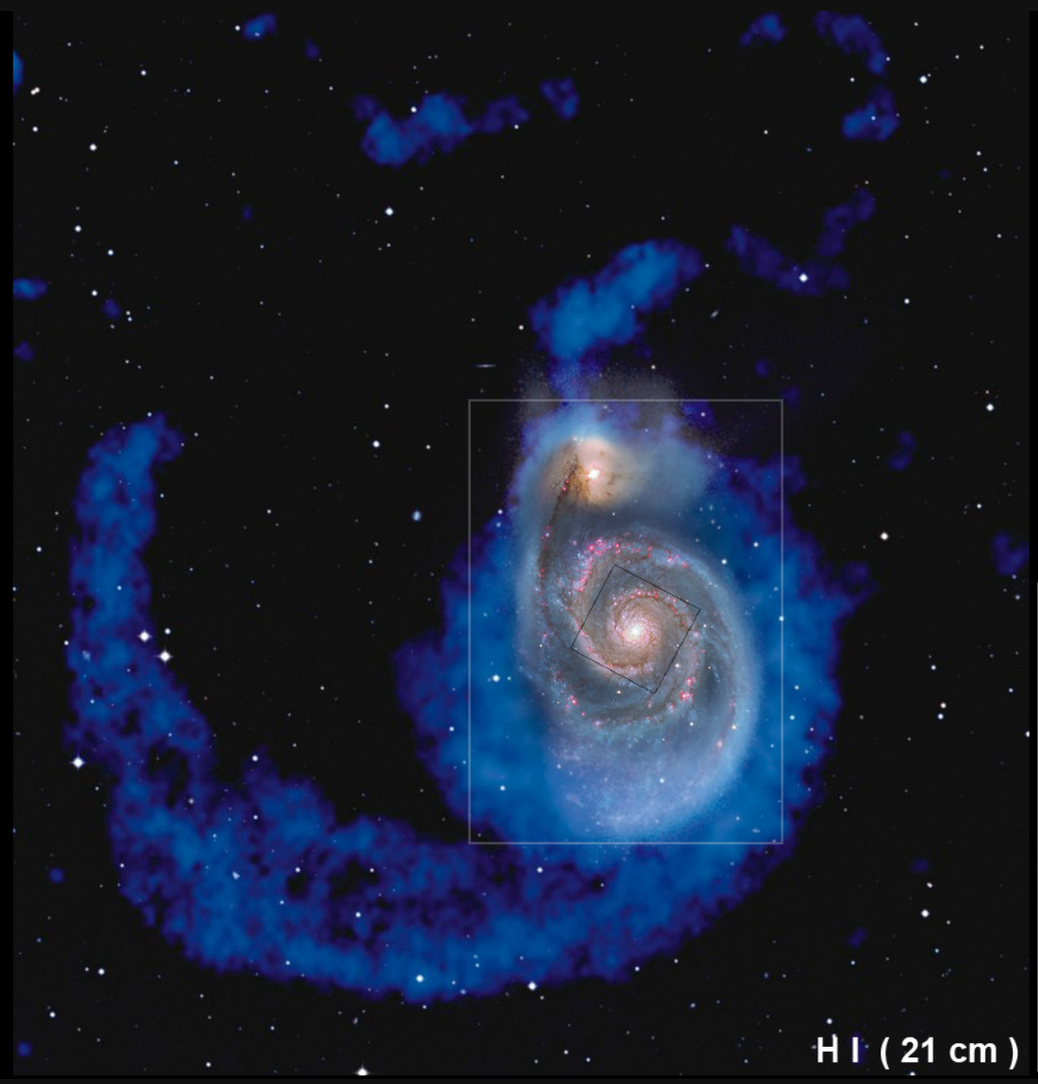
Optical

NIR

MIR



Radiocontinuum



H I (21 cm)

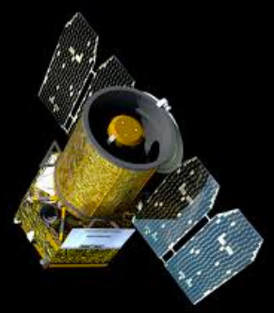
Optical (HST)

CO (2.6 mm)

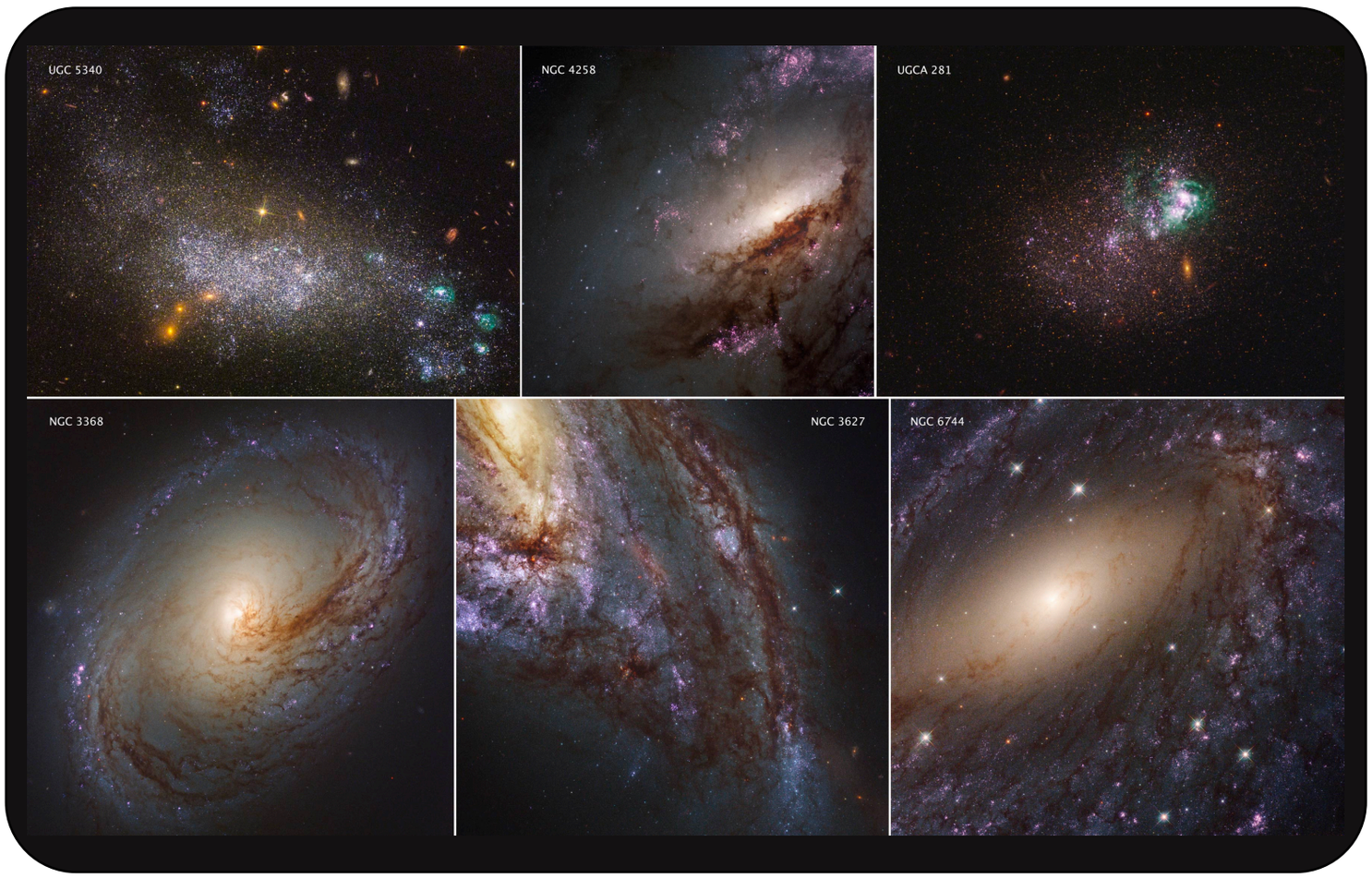

Radio
Infrared
Visible
Ultra-violet
X-ray

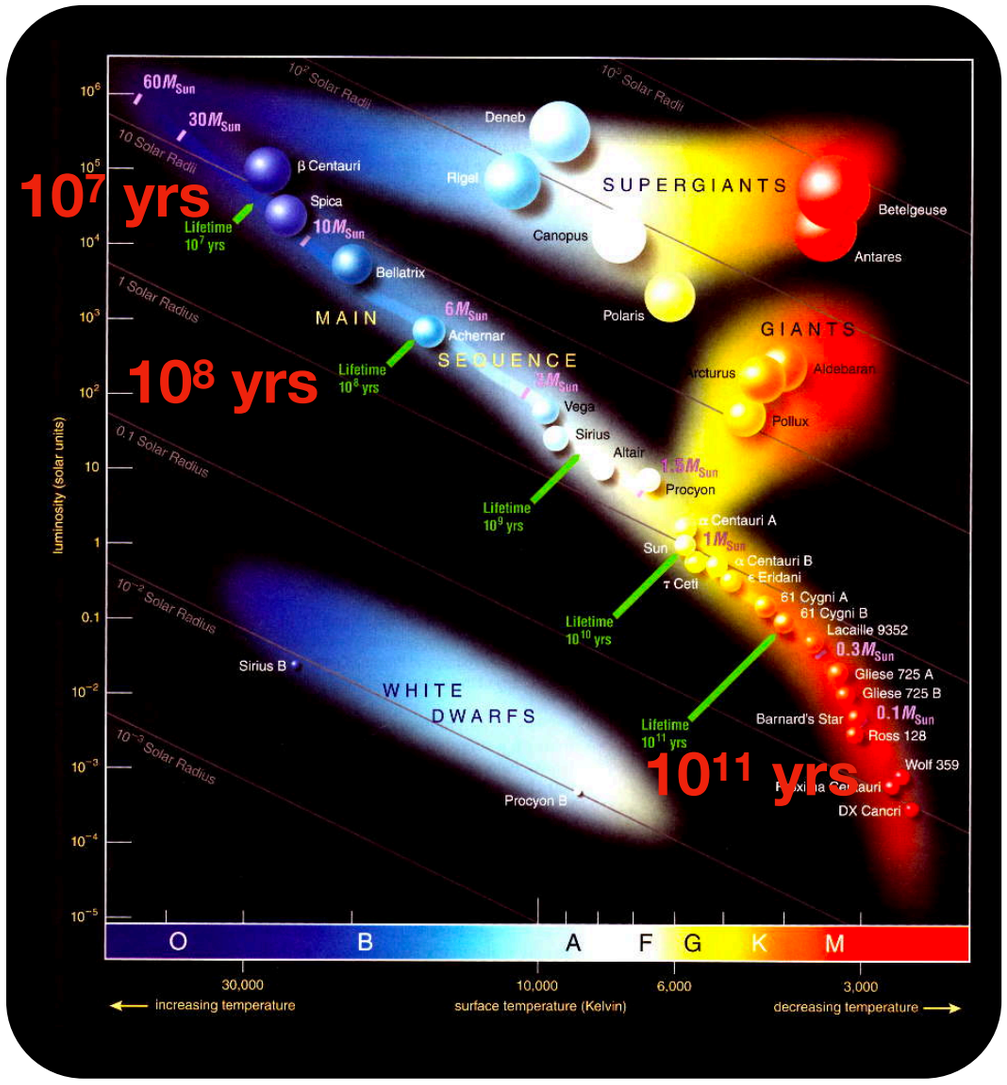
Probing the SFR with Halpha and UV

Hubble Space Telescope

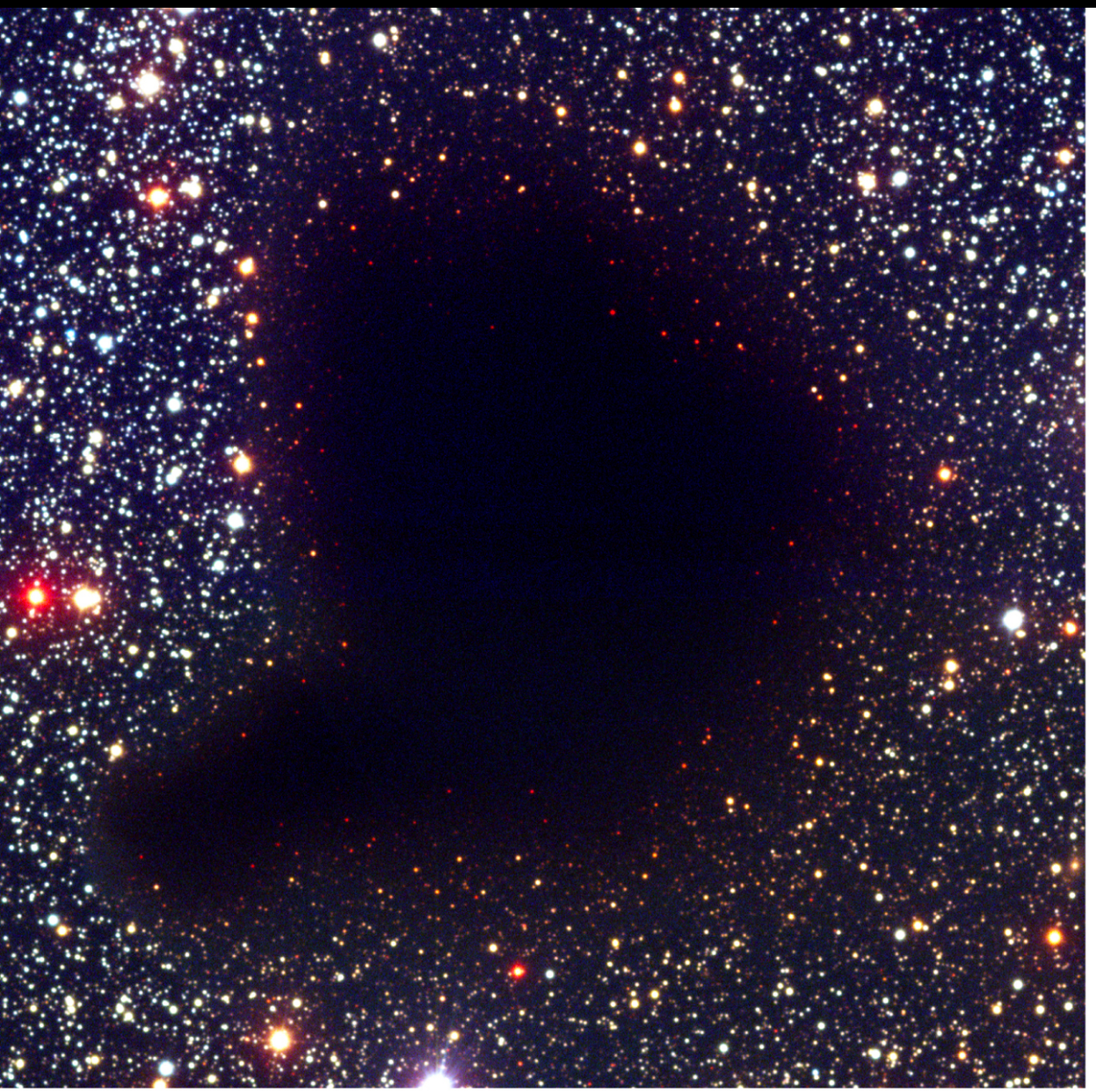


GALEX





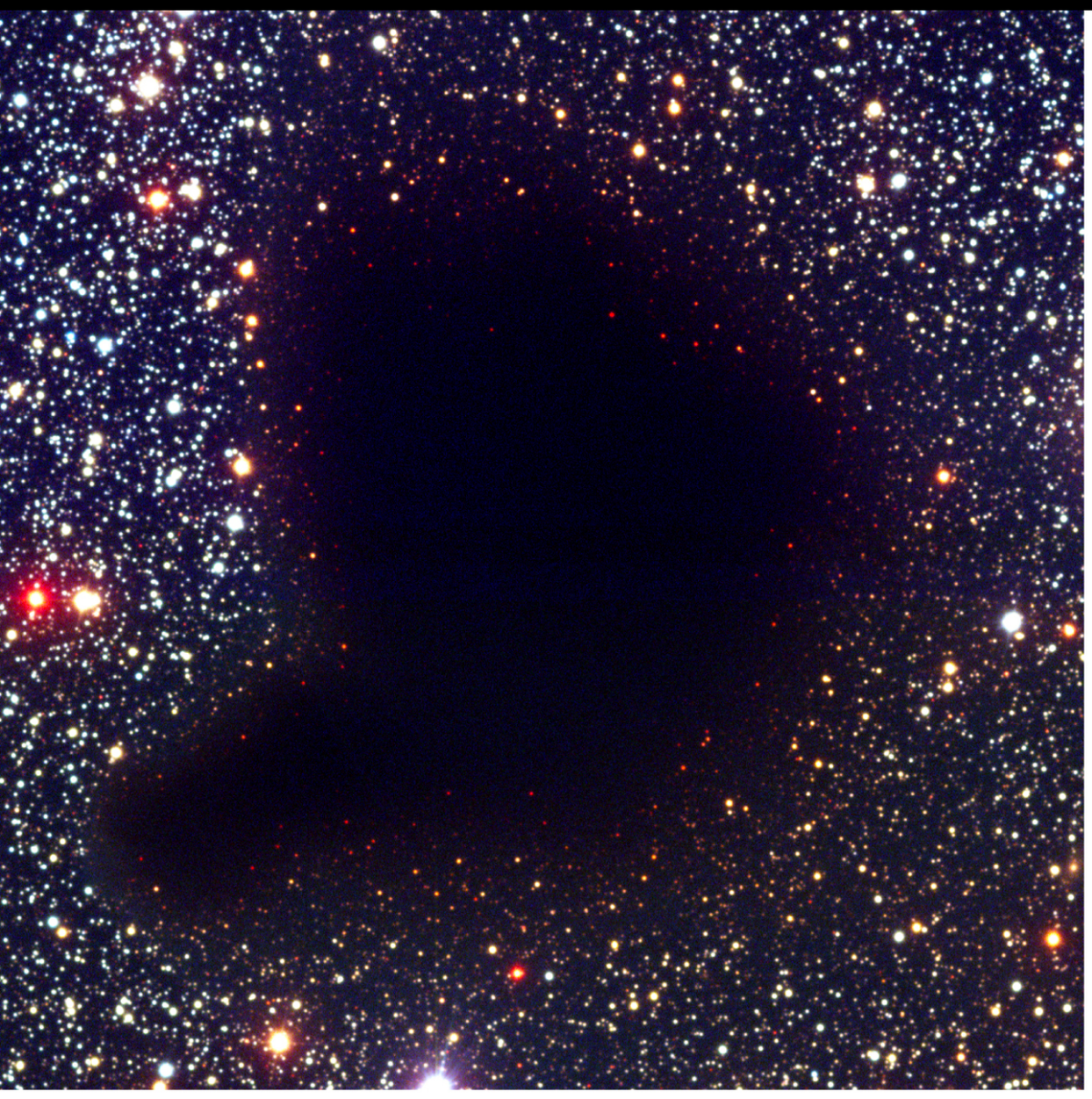
Probing the SFR with infrared



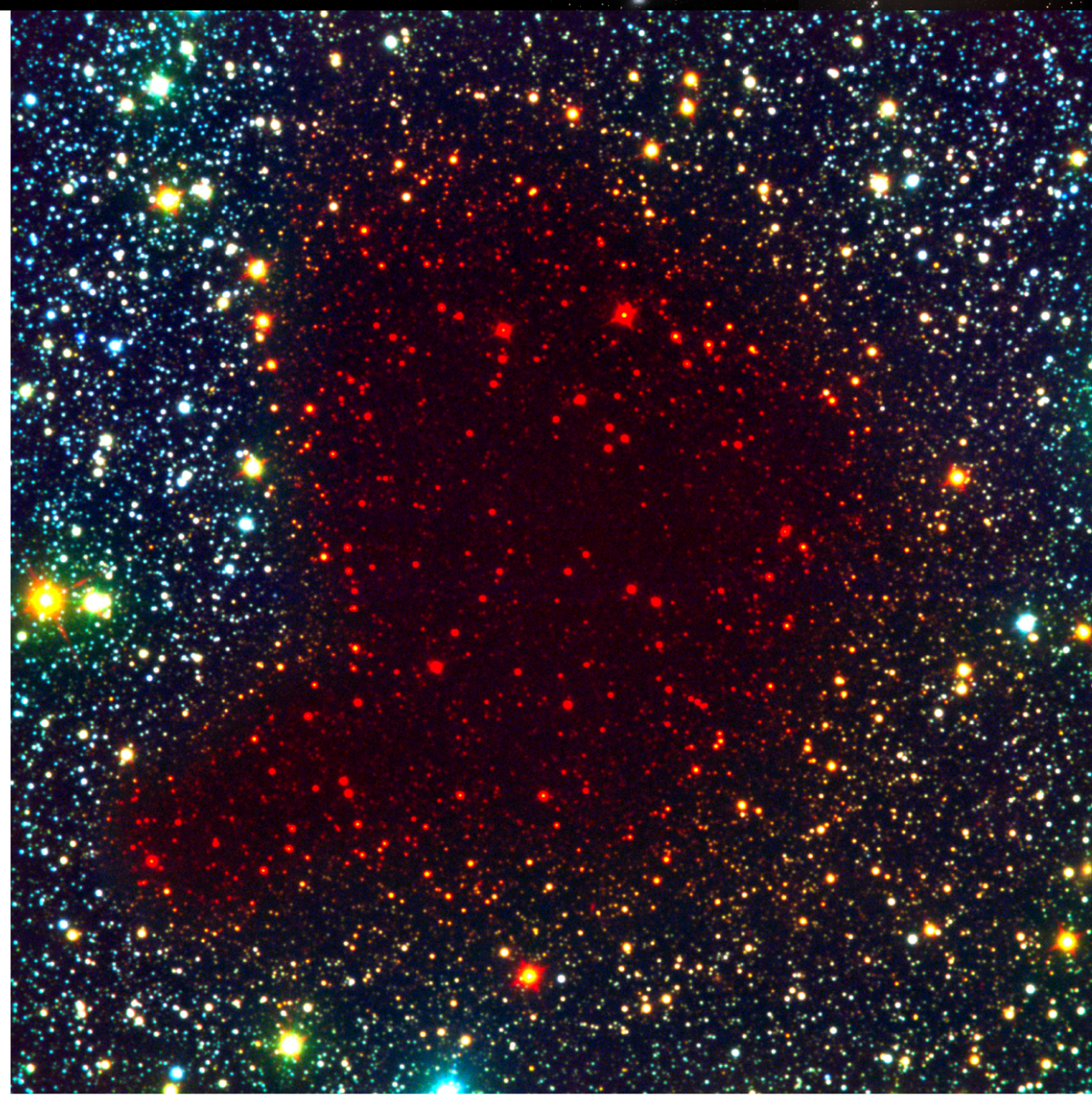
B, V, I

ESO PR Photo 02c/01 (10 January 2001)

Probing the SFR with infrared



B, V, I

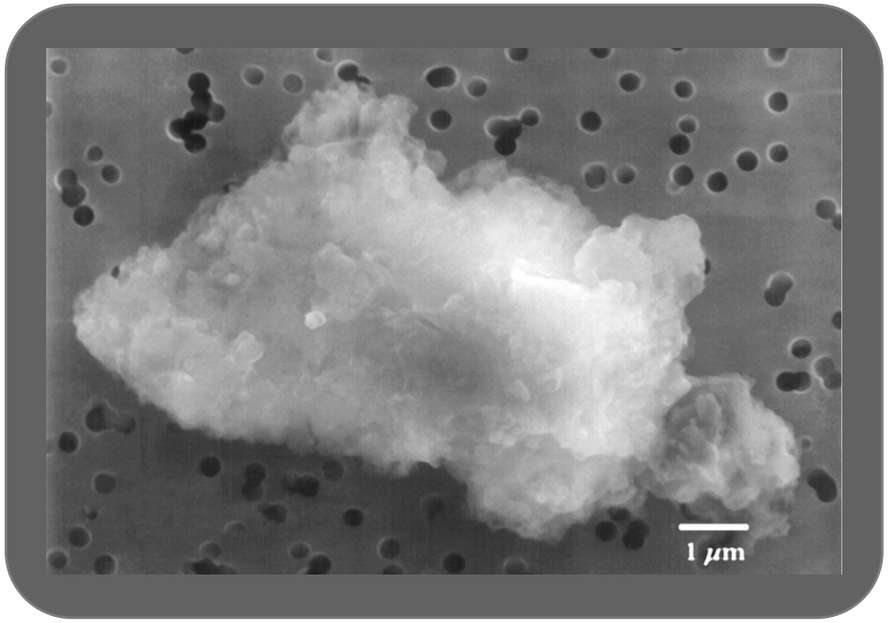


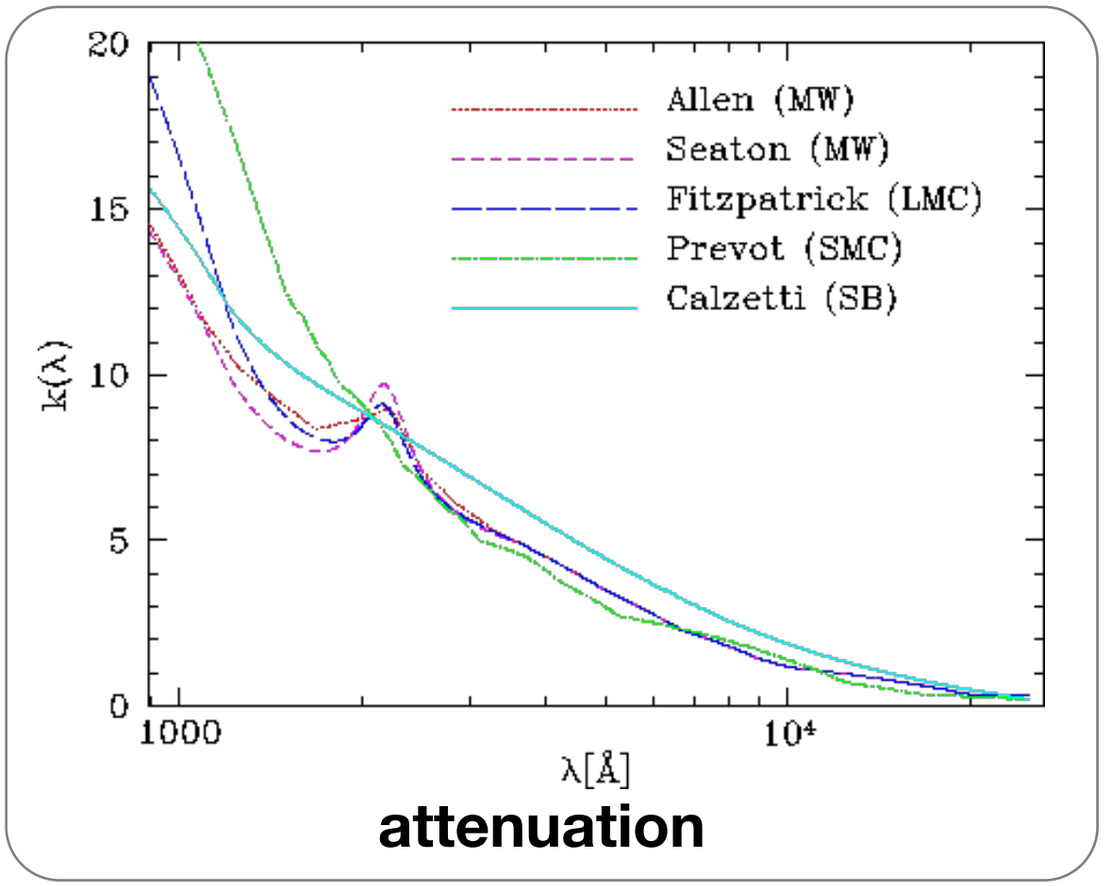
B, I, K

Pre-Collapse Black Cloud B68 (comparison)
(VLT ANTU + FORS 1 - NTT + SOFI)

ESO PR Photo 02c/01 (10 January 2001)

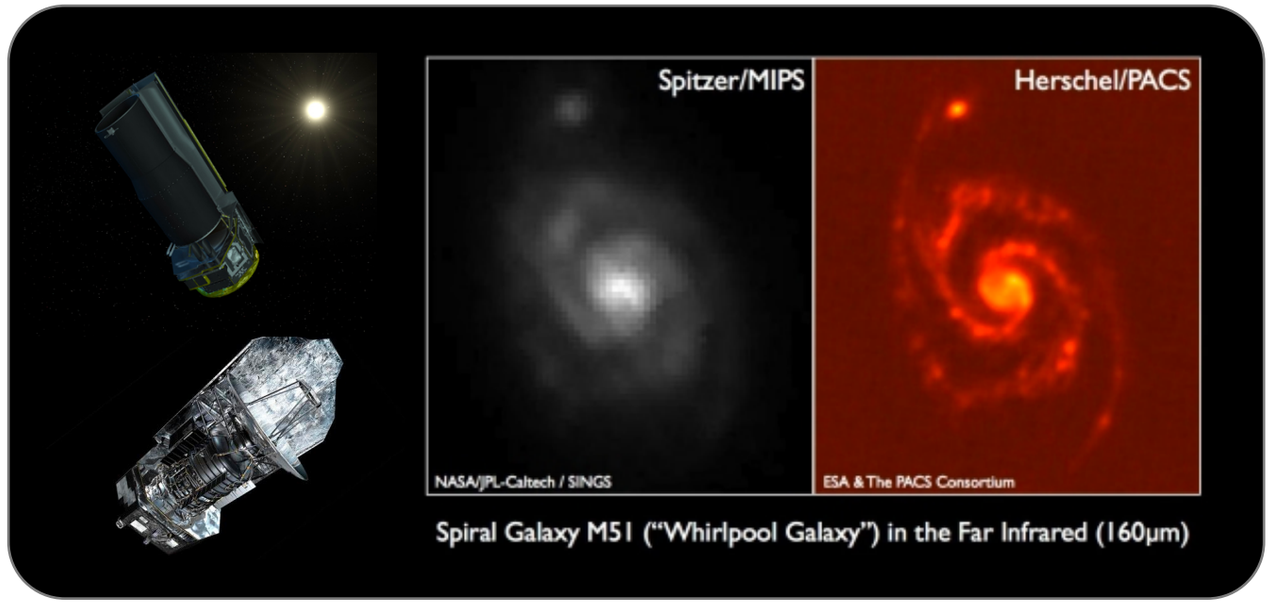
Probing the SFR with infrared



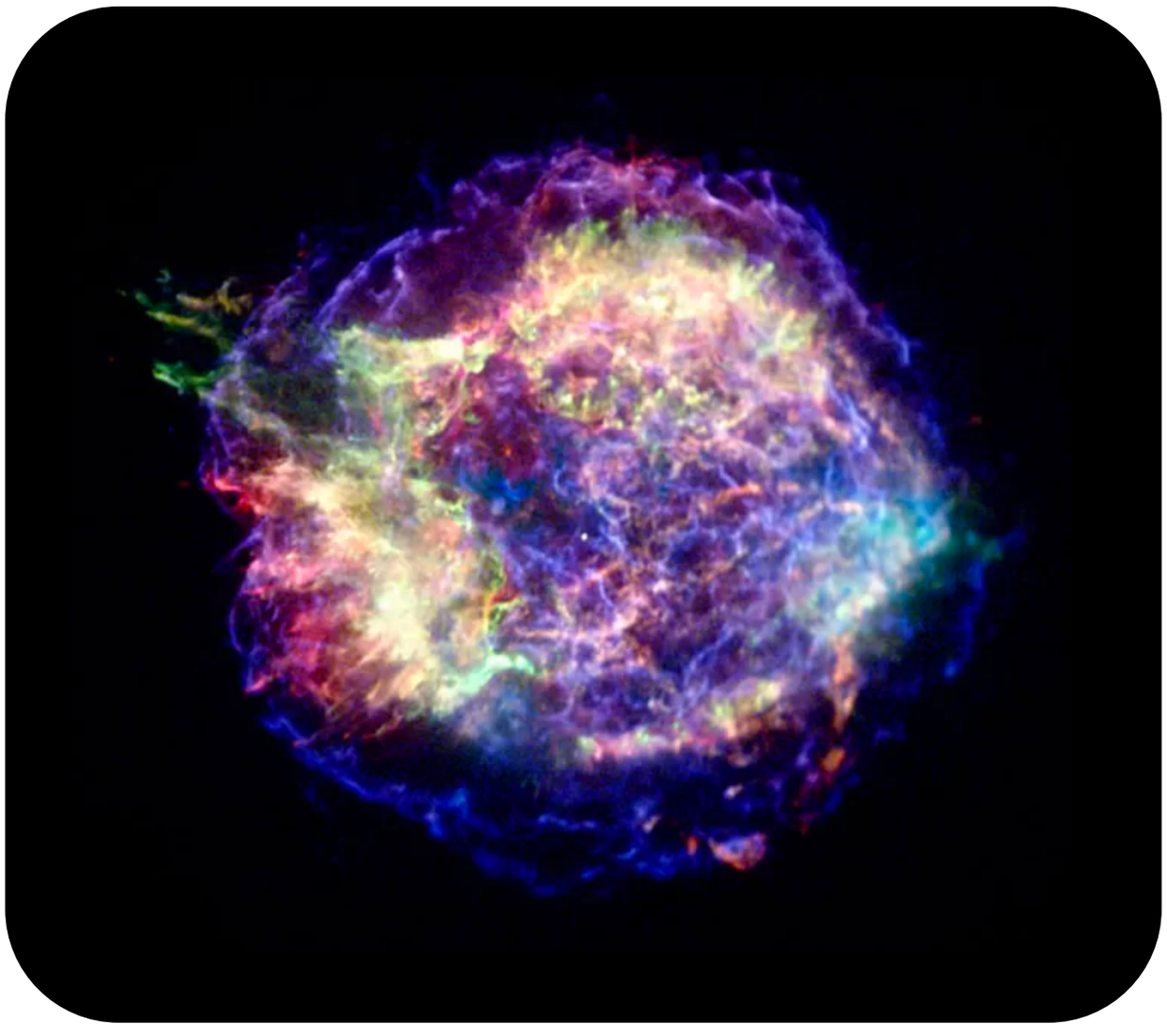


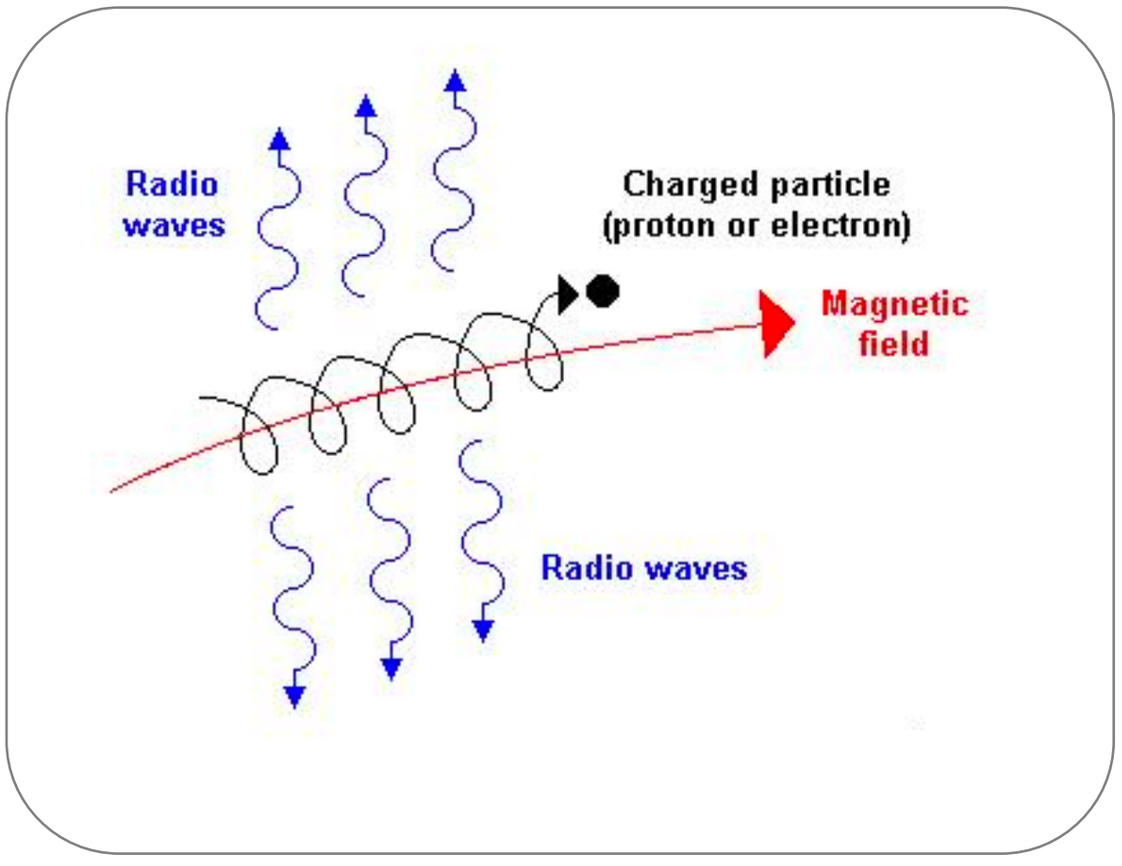
attenuation

Probing the SFR with infrared



Probing the SFR with radio

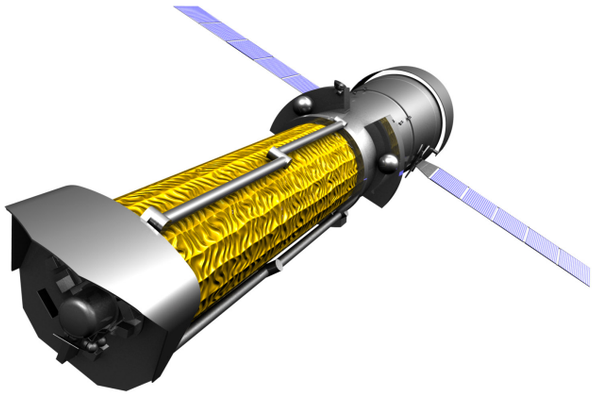


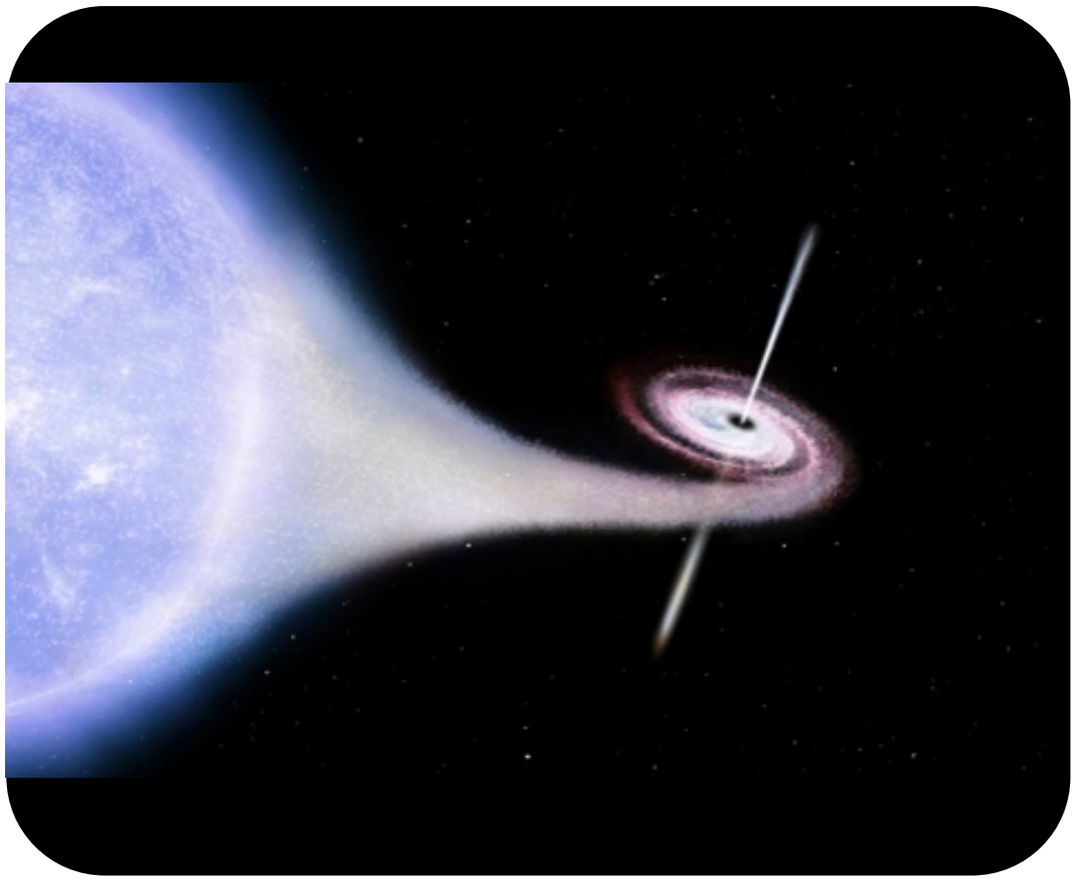


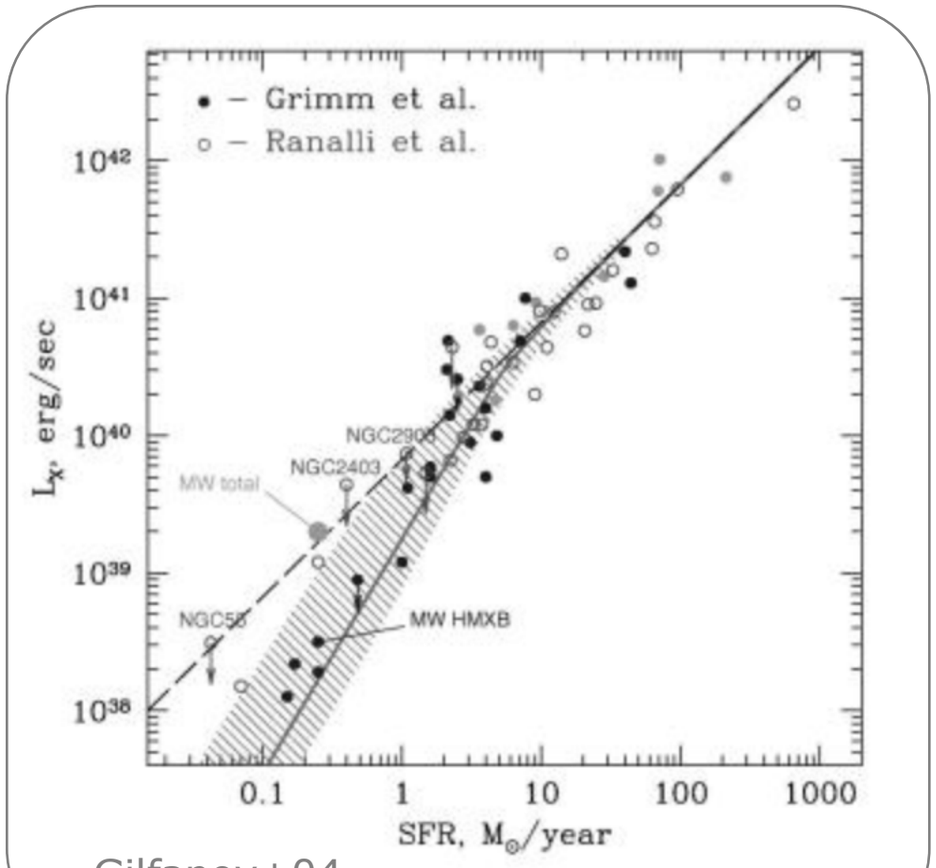
Supernova: death of a massive star

In supernova remnant: synchrotron emission seen in radio

Probing the SFR with X-ray







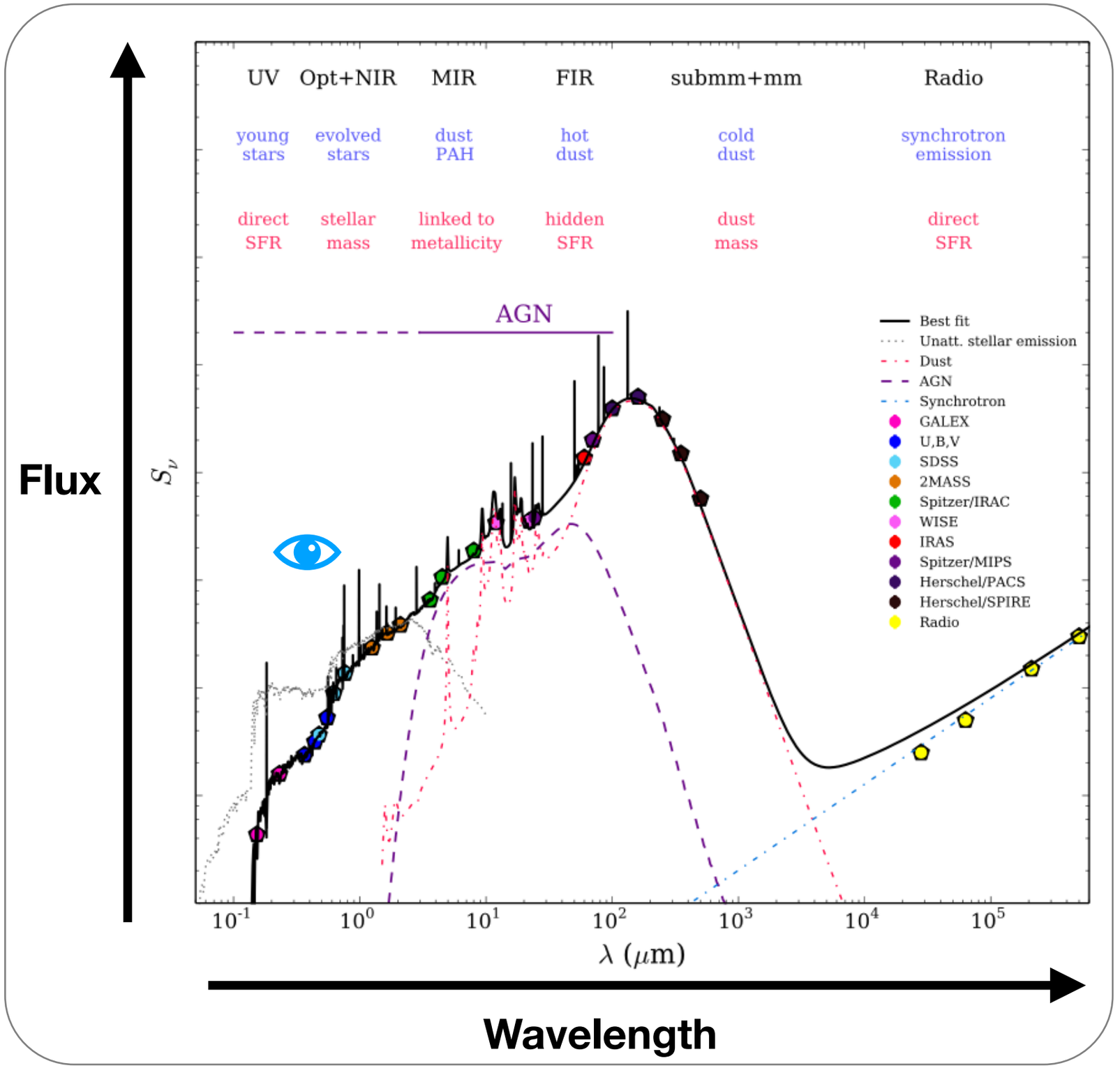
Gilfanov+04

Star Formation Rate Calibrations

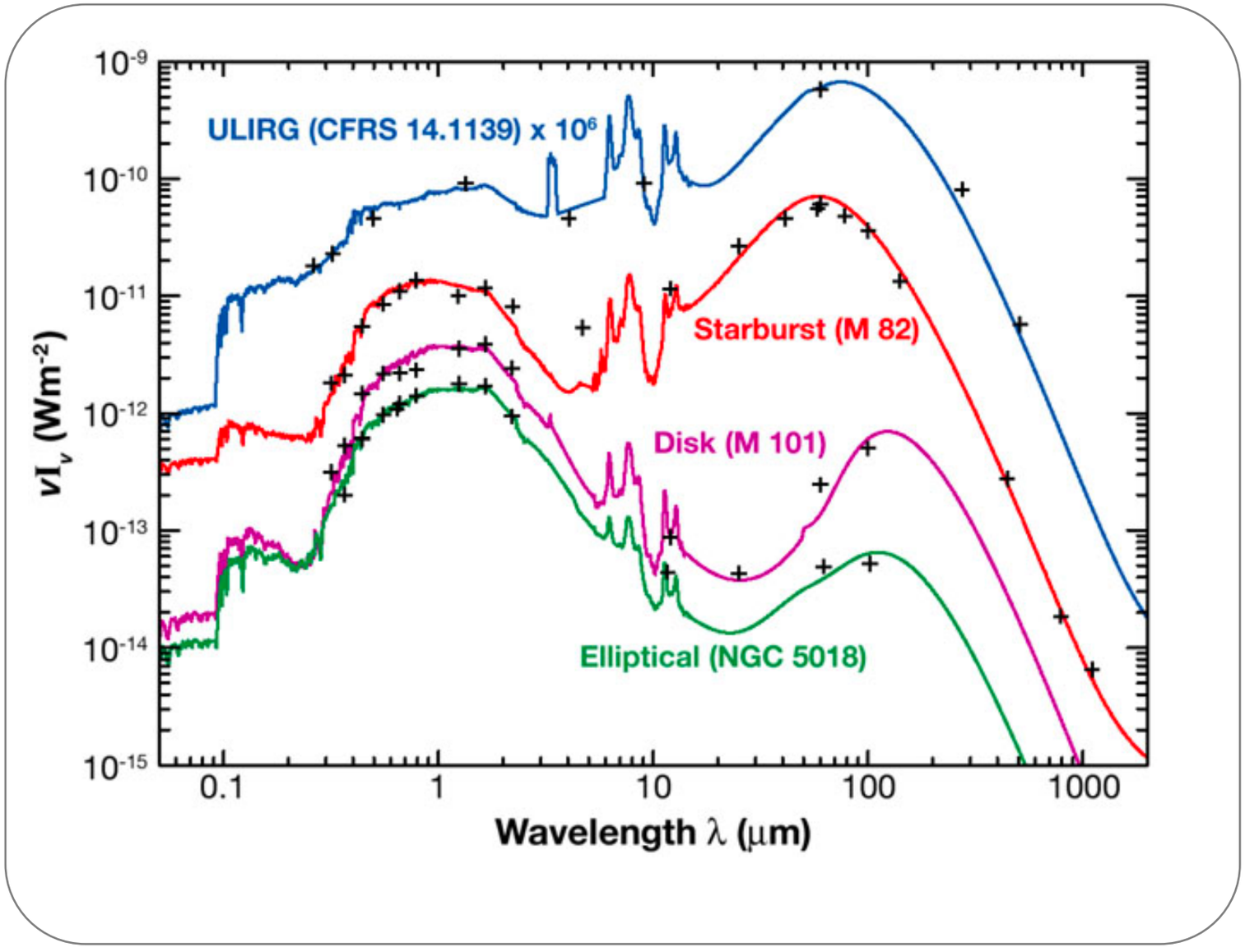
Band	Age Range (Myr)[a]	L_x Units	$\log C_x$
FUV	$0-10-100$	ergs s^{-1} (νL_ν)	43.35
NUV	$0-10-200$	ergs s^{-1} (νL_ν)	43.17
Hα	$0-3-10$	ergs s^{-1}	41.27
TIR	$0-5-100$[b]	ergs s^{-1} (3–1100 μm)	43.41
24 μm	$0-5-100$[b]	ergs s^{-1} (νL_ν)	42.69
70 μm	$0-5-100$[b]	ergs s^{-1} (νL_ν)	43.23
1.4 GHz	$0-100$:	ergs s^{-1} Hz^{-1}	28.20
2–10 keV	$0-100$:	ergs s^{-1}	39.77

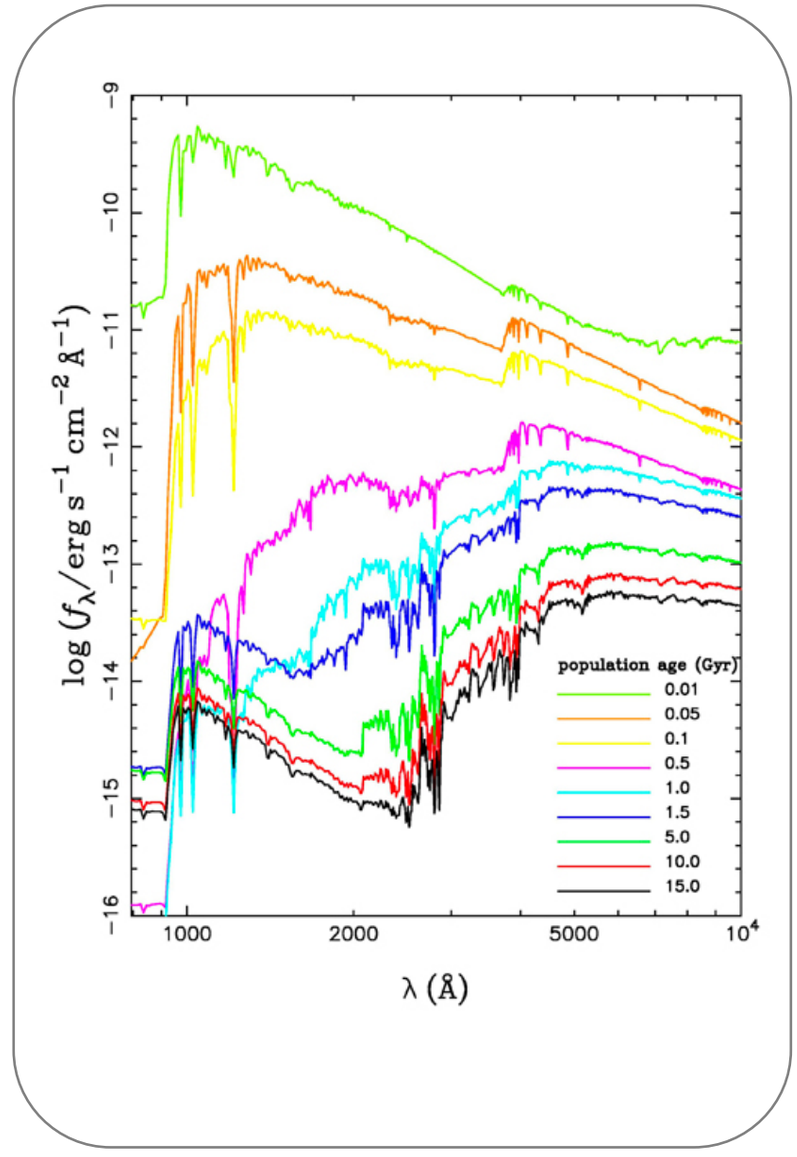
Kennicutt & Evans 2012

Spectral Energy Distribution (SED)

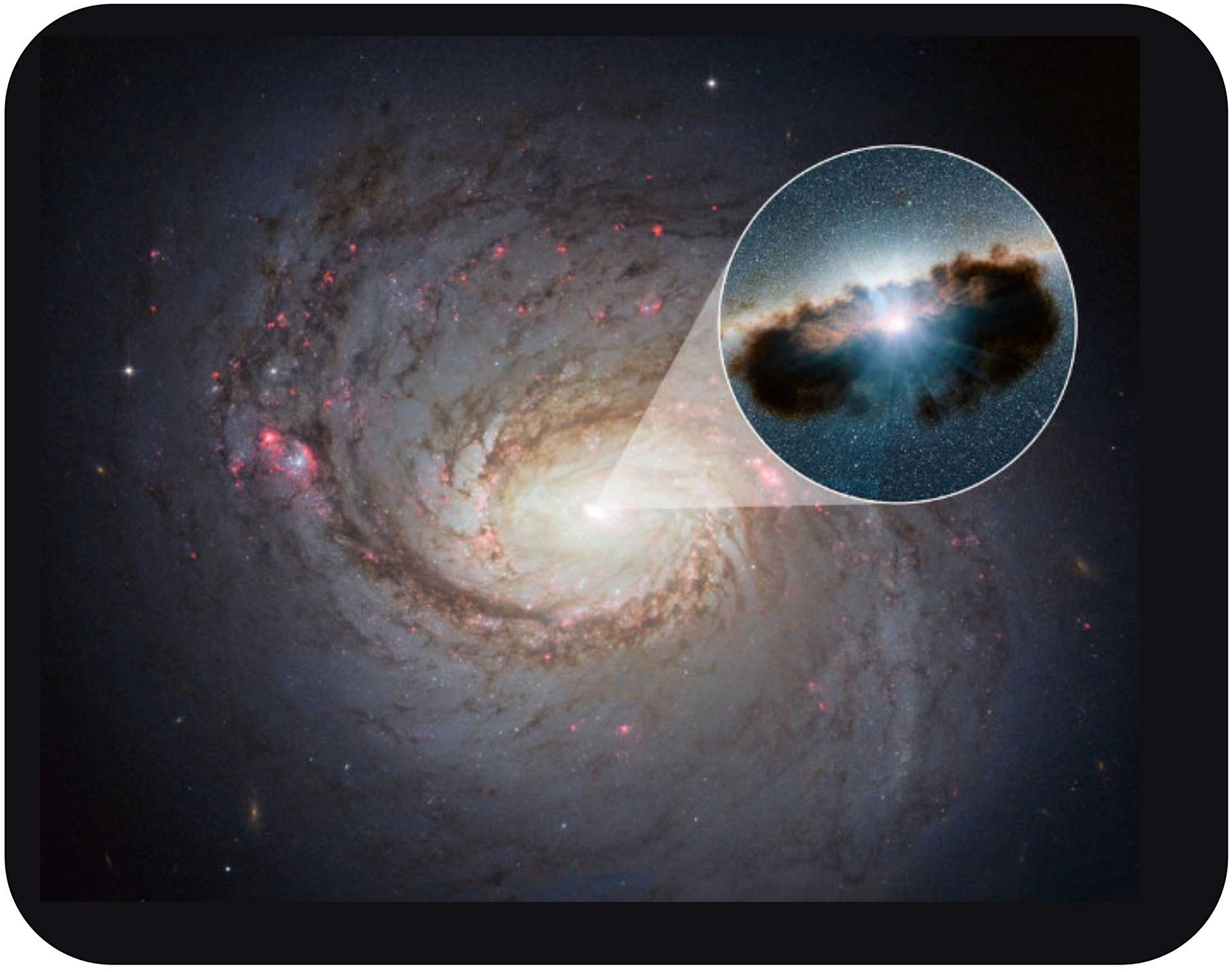


Spectral Energy Distribution (SED)

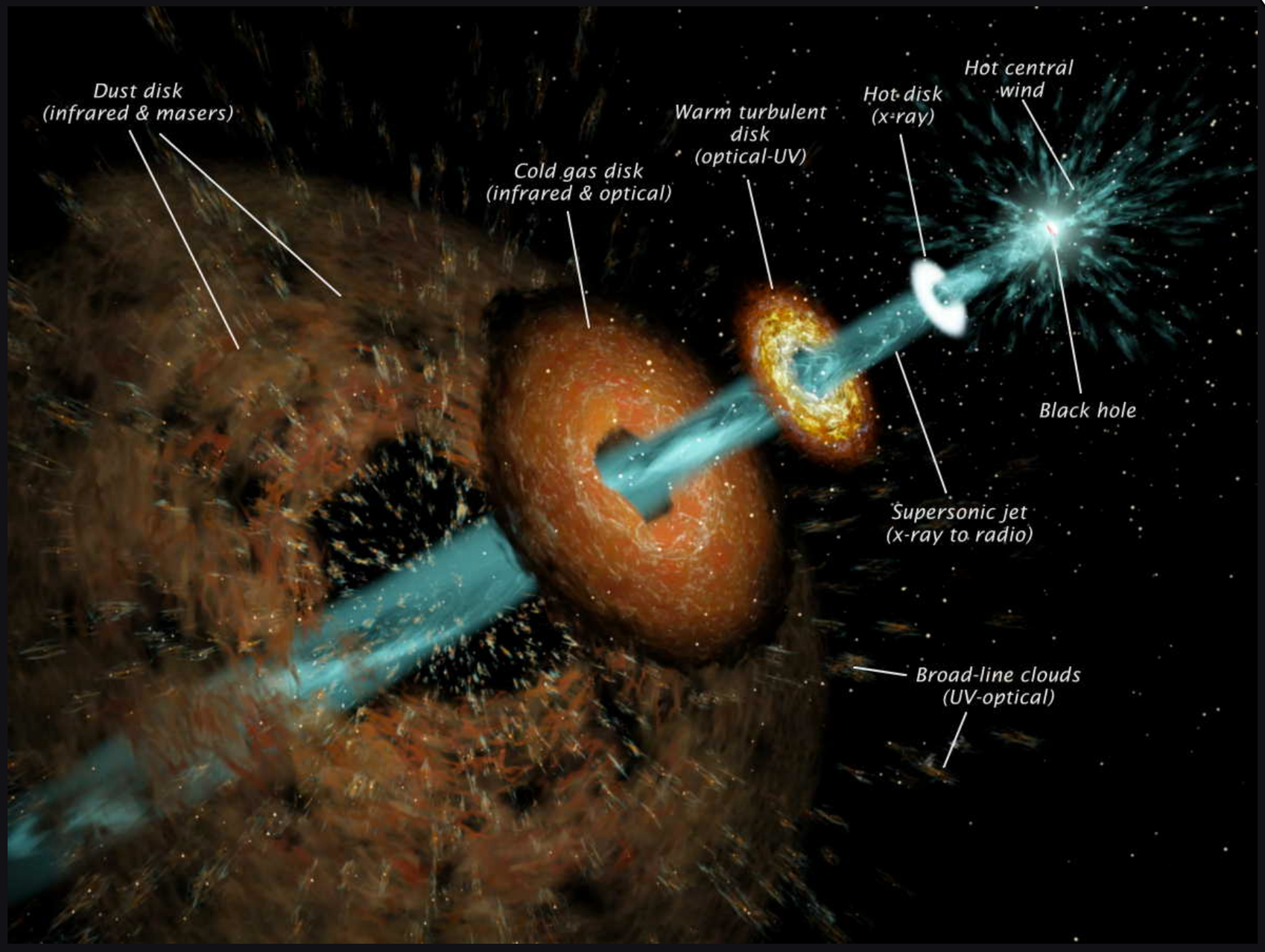




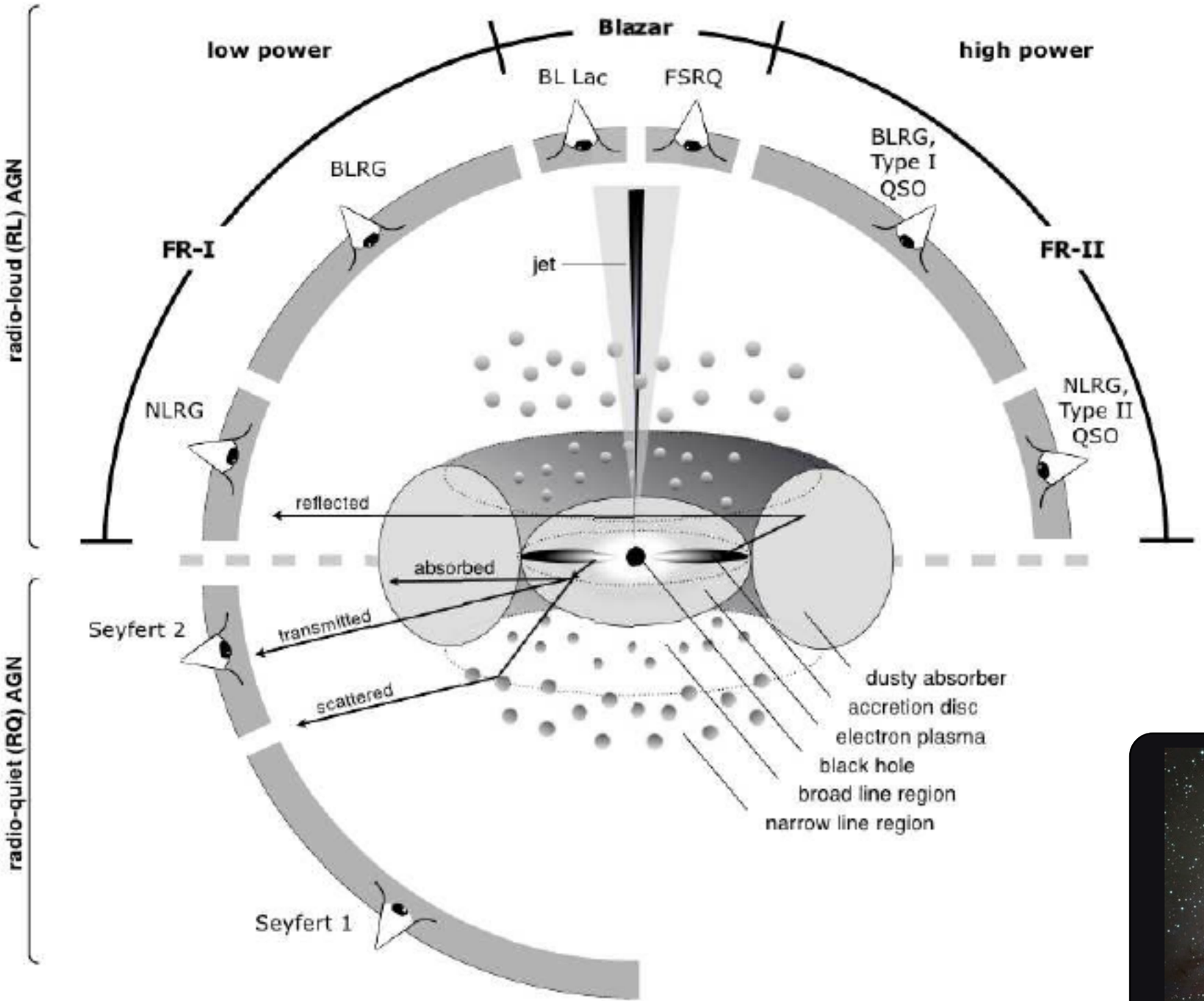
Active Galactic Nuclei

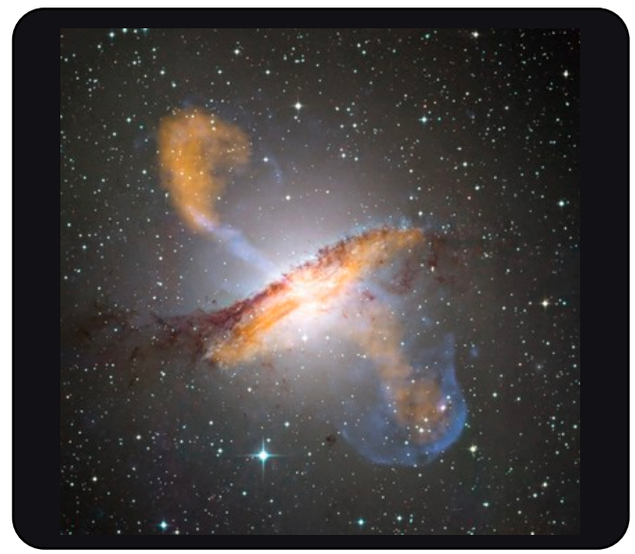


Active Galactic Nuclei

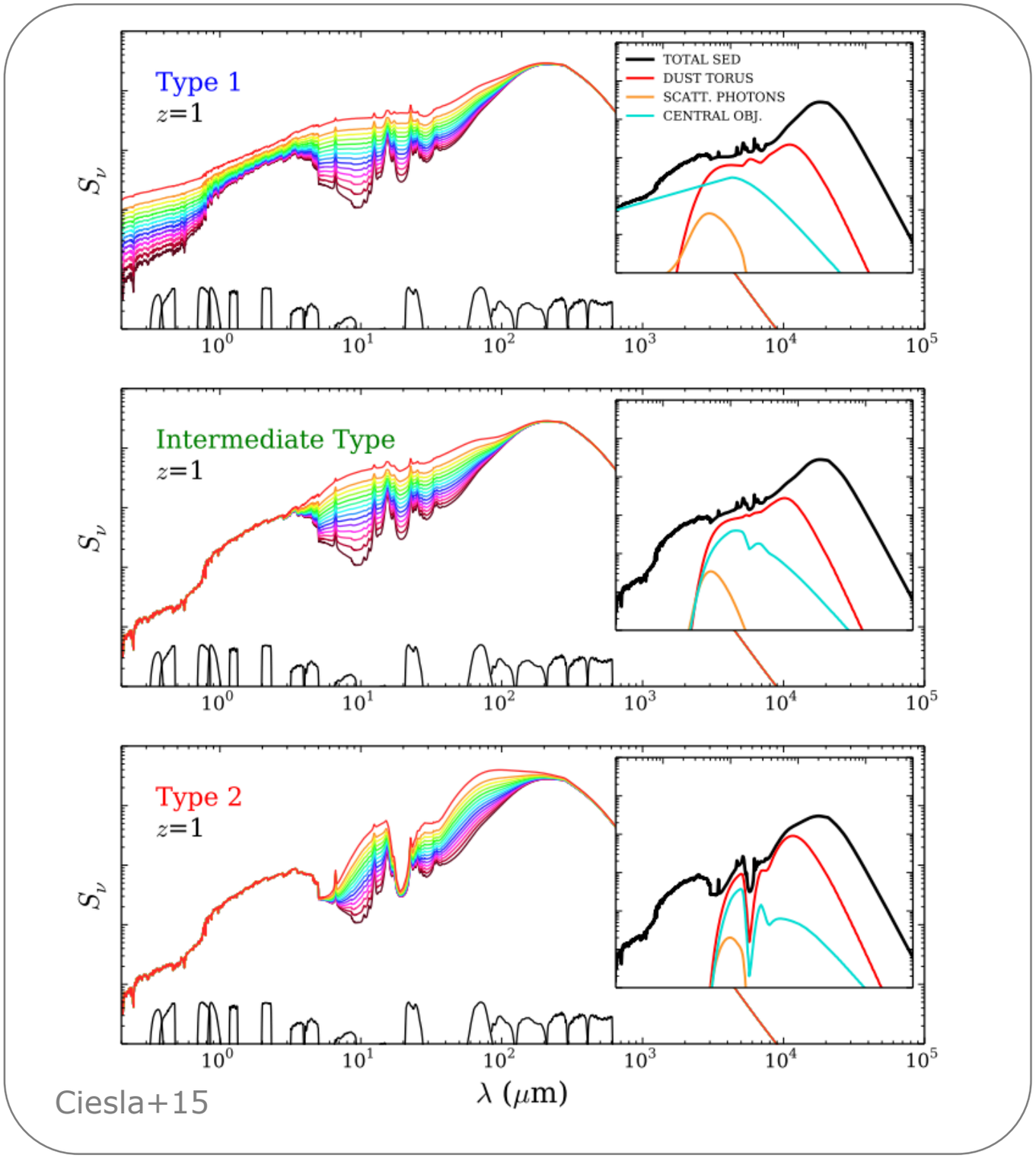


Active Galactic Nuclei





Active Galactic Nuclei



Ciesla+15

Code is public: http://cigale.lam.fr/

Modeling SEDs with CIGALE

SFH:

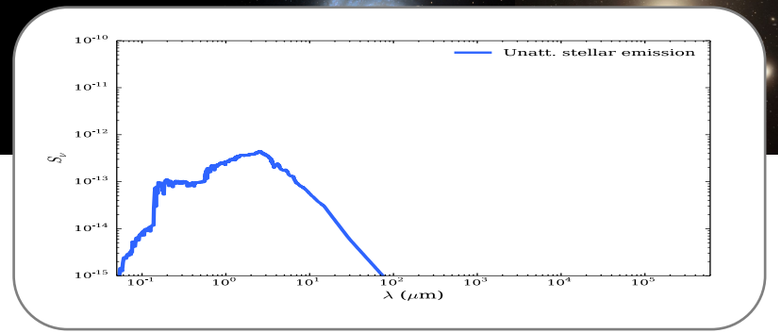
Analytical (exp-dec, delayed, …)

Complex (SAM, etc…)

Stellar Populations:

Bruzual&Charlot 03

Maraston+05



Attenuation:

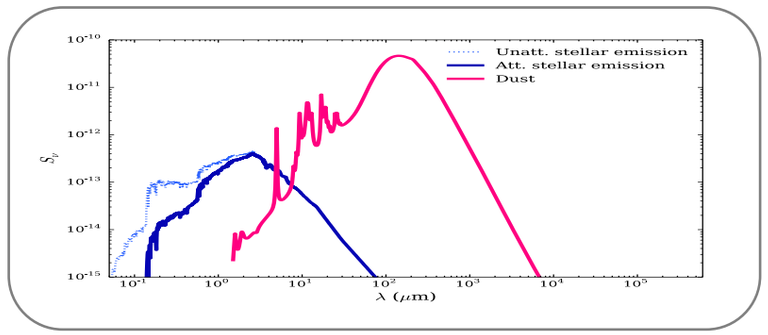
Calzetti law, power law, Charlot&Fall

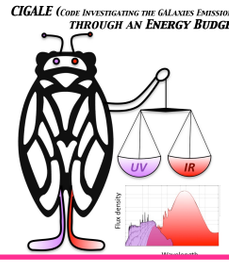
Dust emission:

Dale+14,

Draine&Li 07 + updates

Casey+12



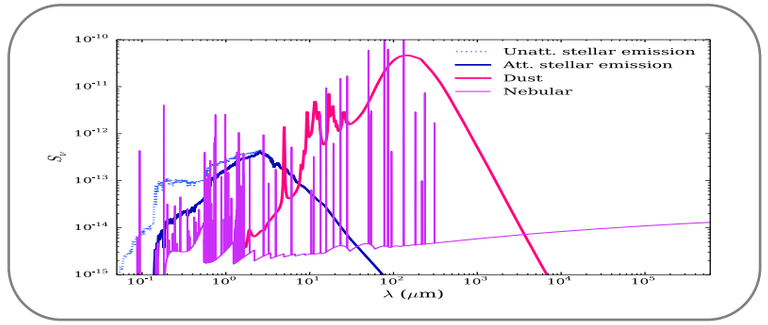


Analysis:

χ^2 computation + probability distribution function analysis

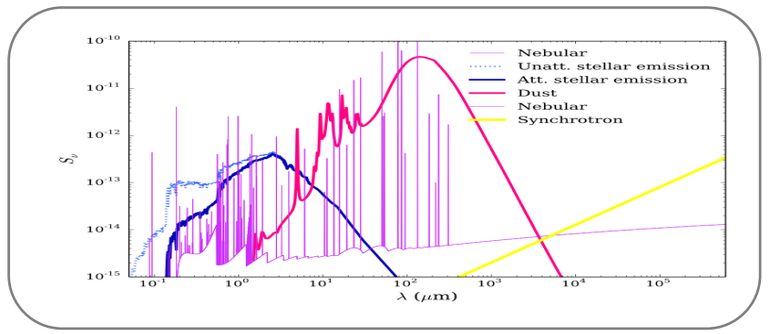
Nebular emission:

Inoué models



Synchrotron from SF:

FIR-radio correlation



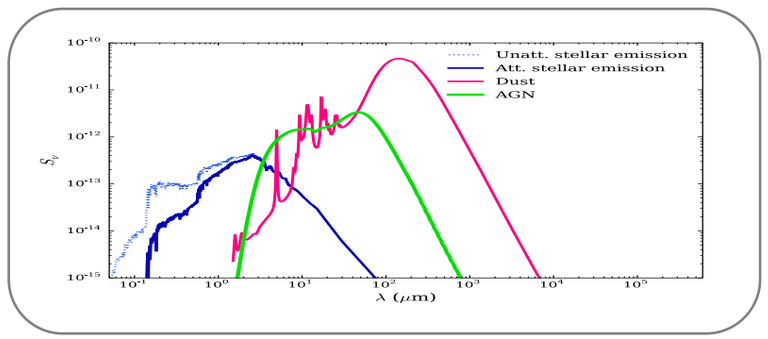
Boquien +, in prep

Ciesla+15 (AGN)

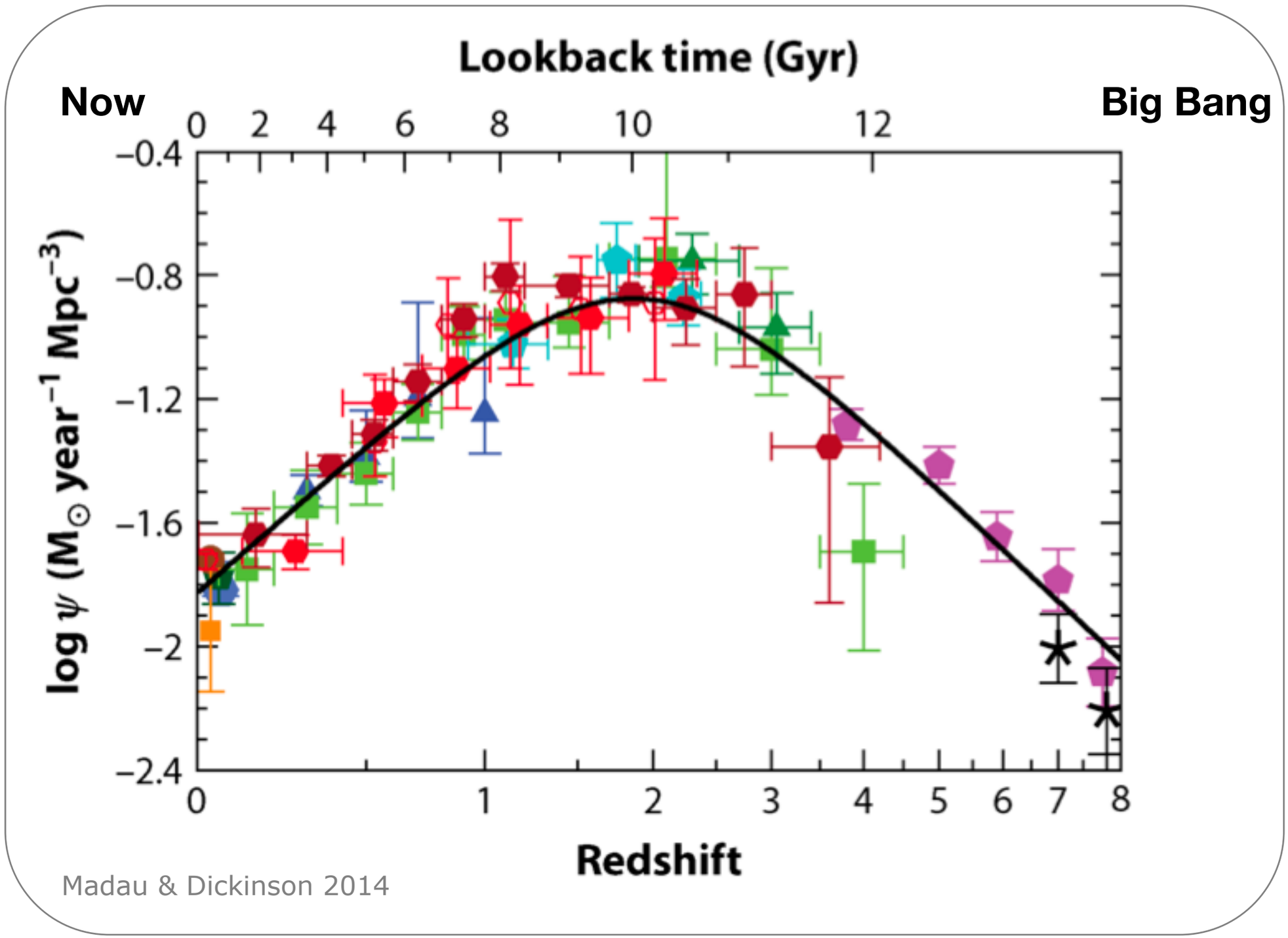
Lo Faro+17 (Attenuation laws)

AGN:

Fritz+06

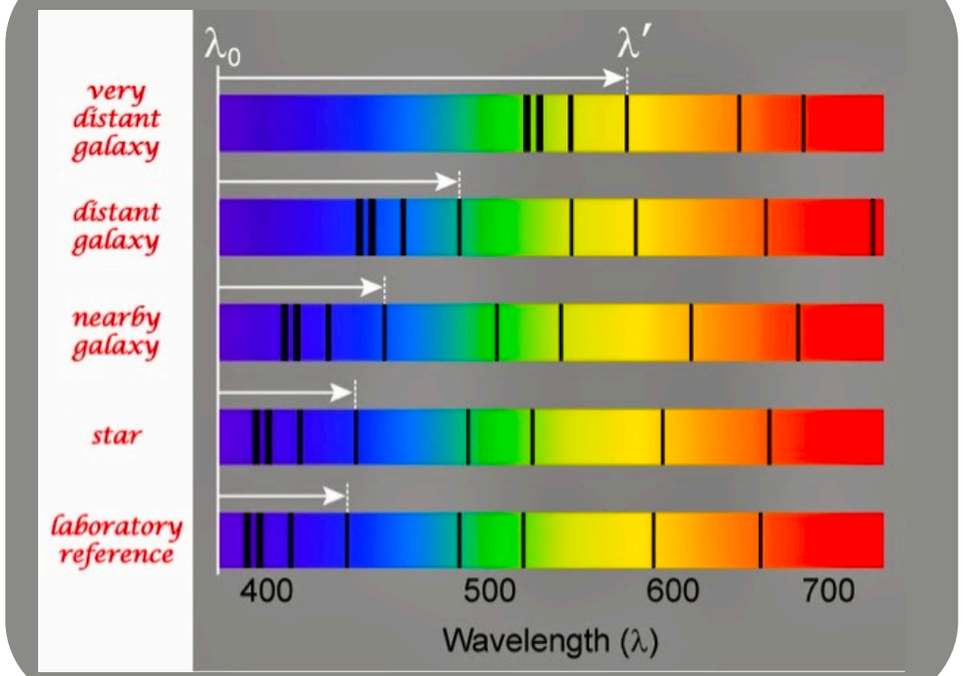


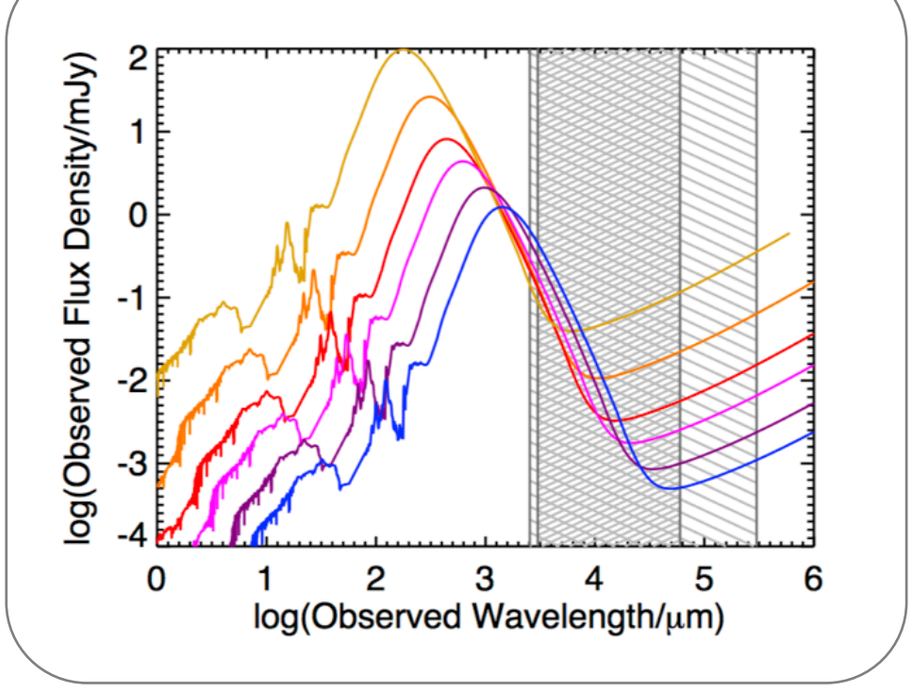
Star Formation Rate Density

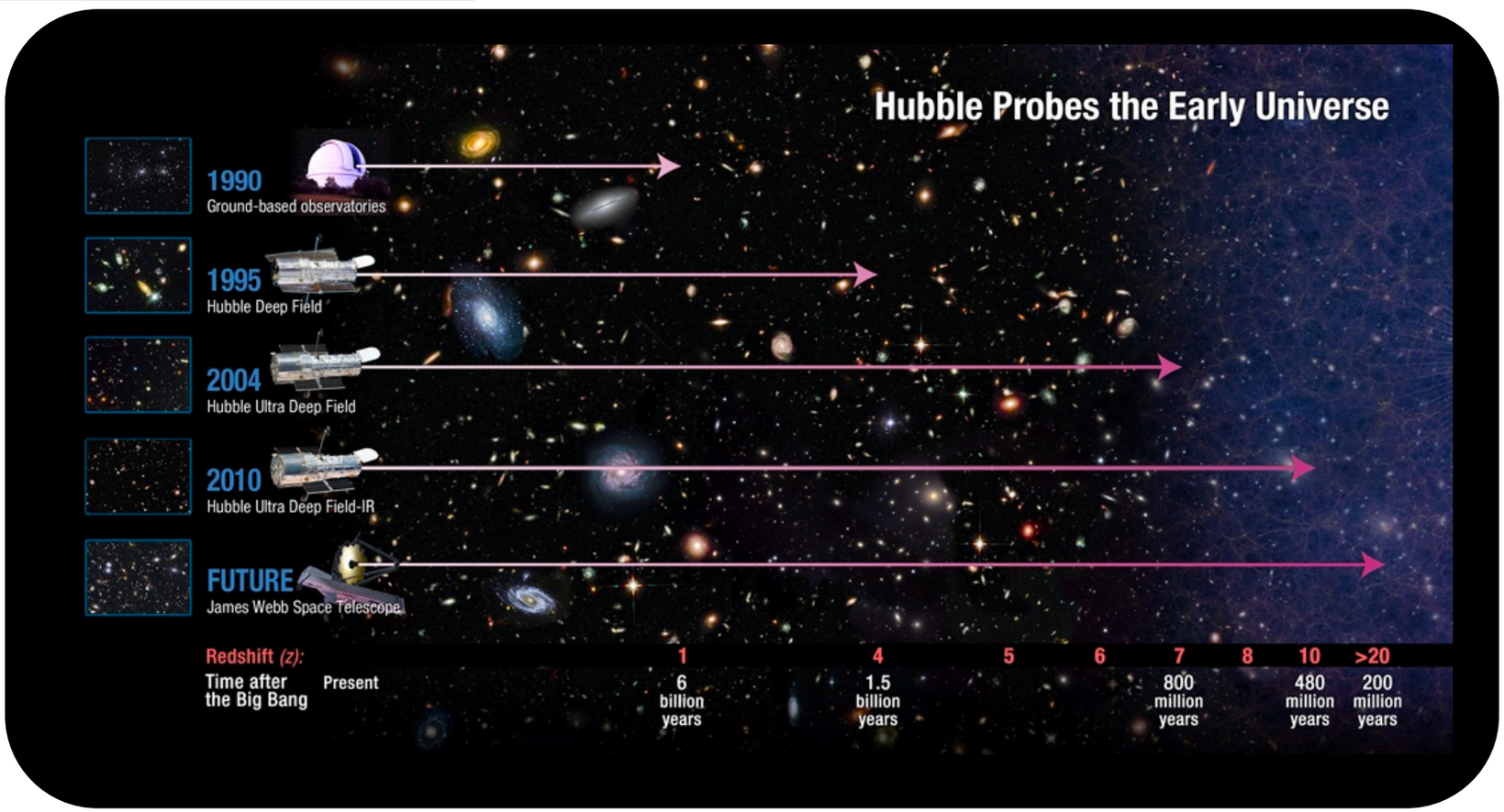


Madau & Dickinson 2014

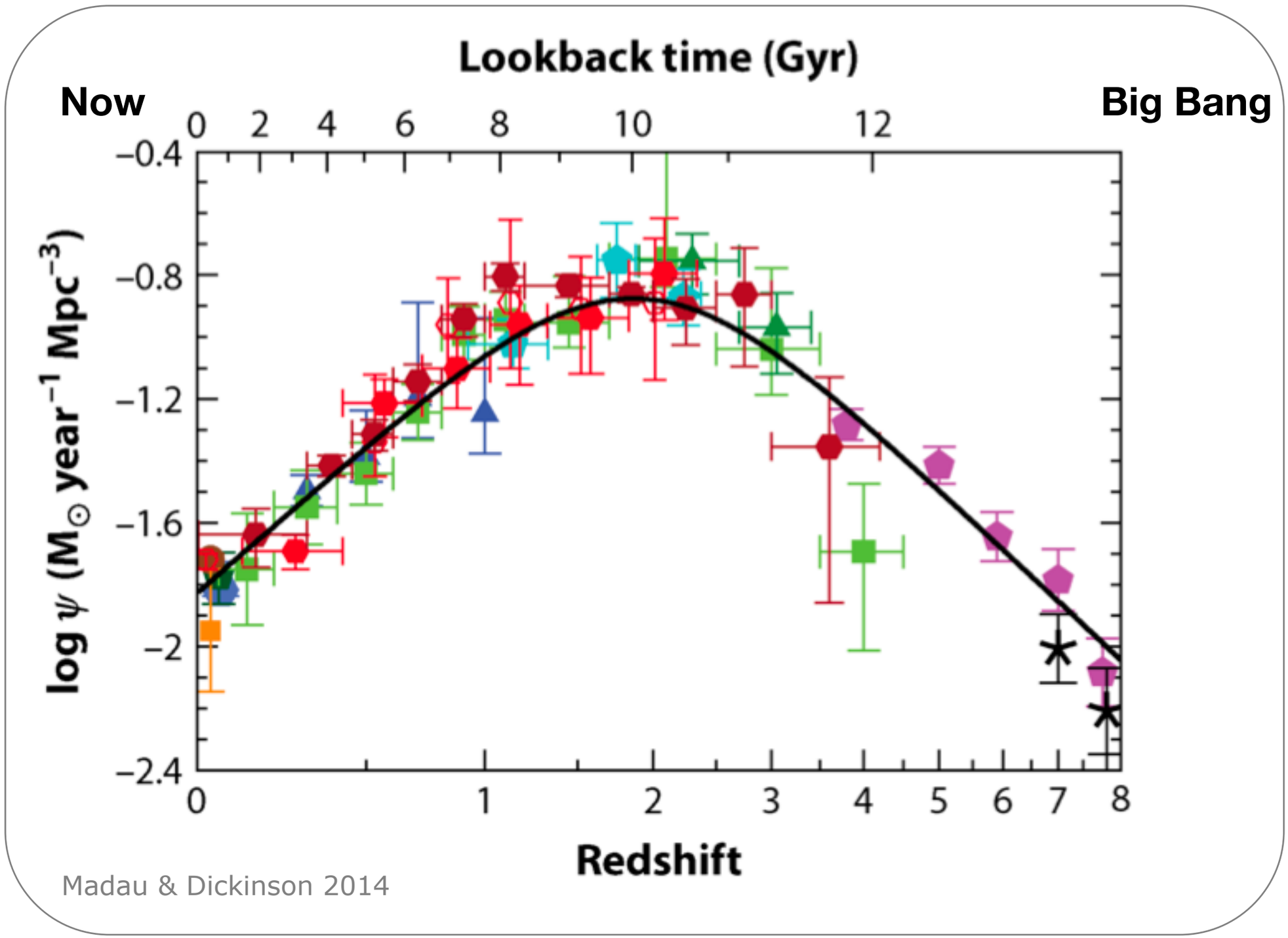
Redshift


λ_0
λ'
very distant galaxy
distant galaxy
nearby galaxy
star
laboratory reference
400
500
600
700
Wavelength (λ)


log(Observed Flux Density/mJy)
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5
6
log(Observed Wavelength/μm)

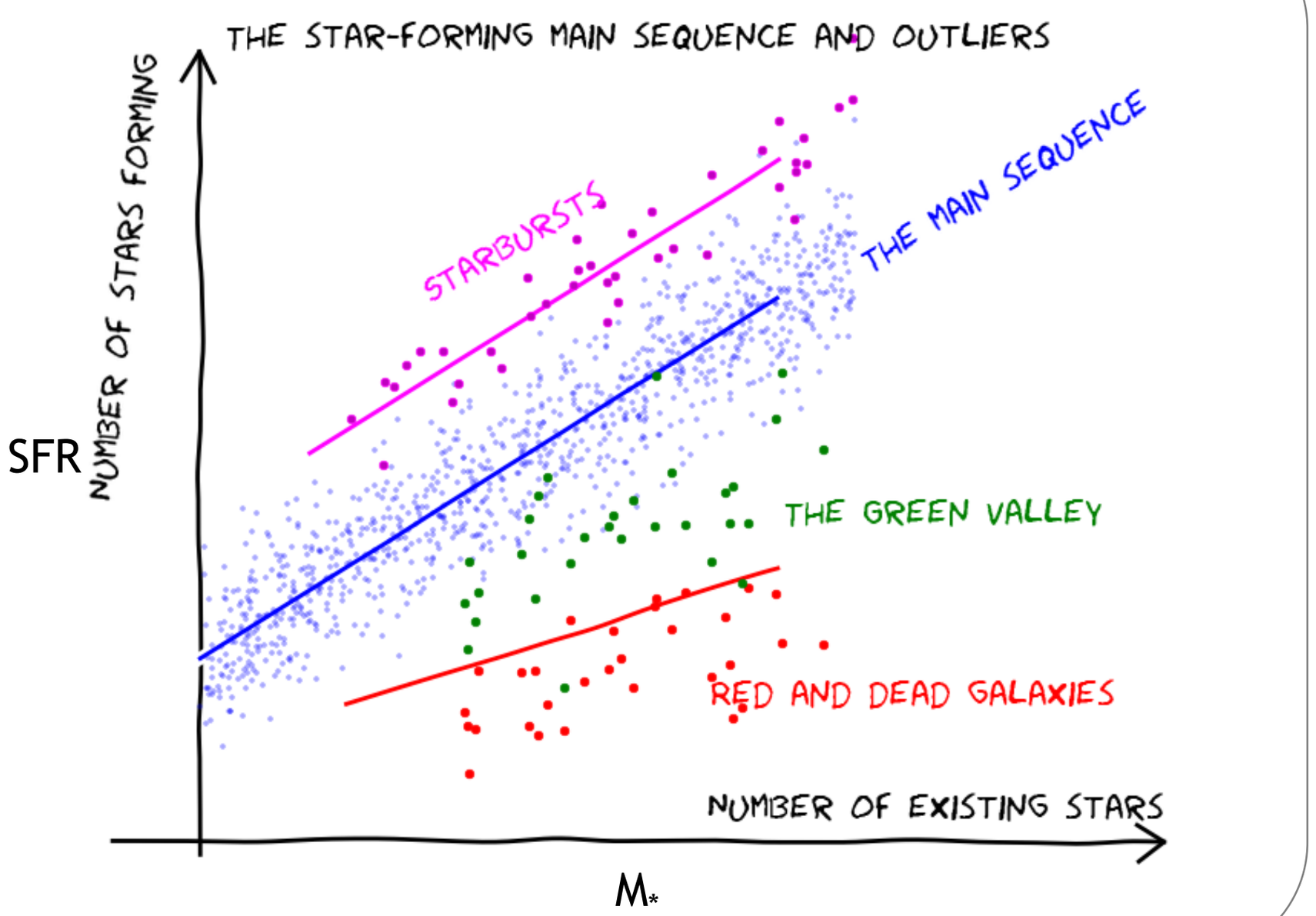

Hubble Probes the Early Universe
1990
Ground-based observatories
1995
Hubble Deep Field
2004
Hubble Ultra Deep Field
2010
Hubble Ultra Deep Field-IR
FUTURE
James Webb Space Telescope
Redshift (z):
Time after the Big Bang
Present
1
6 billion years
4
1.5 billion years
5
6
7
800 million years
8
10
480 million years
>20
200 million years

Star Formation Rate Density



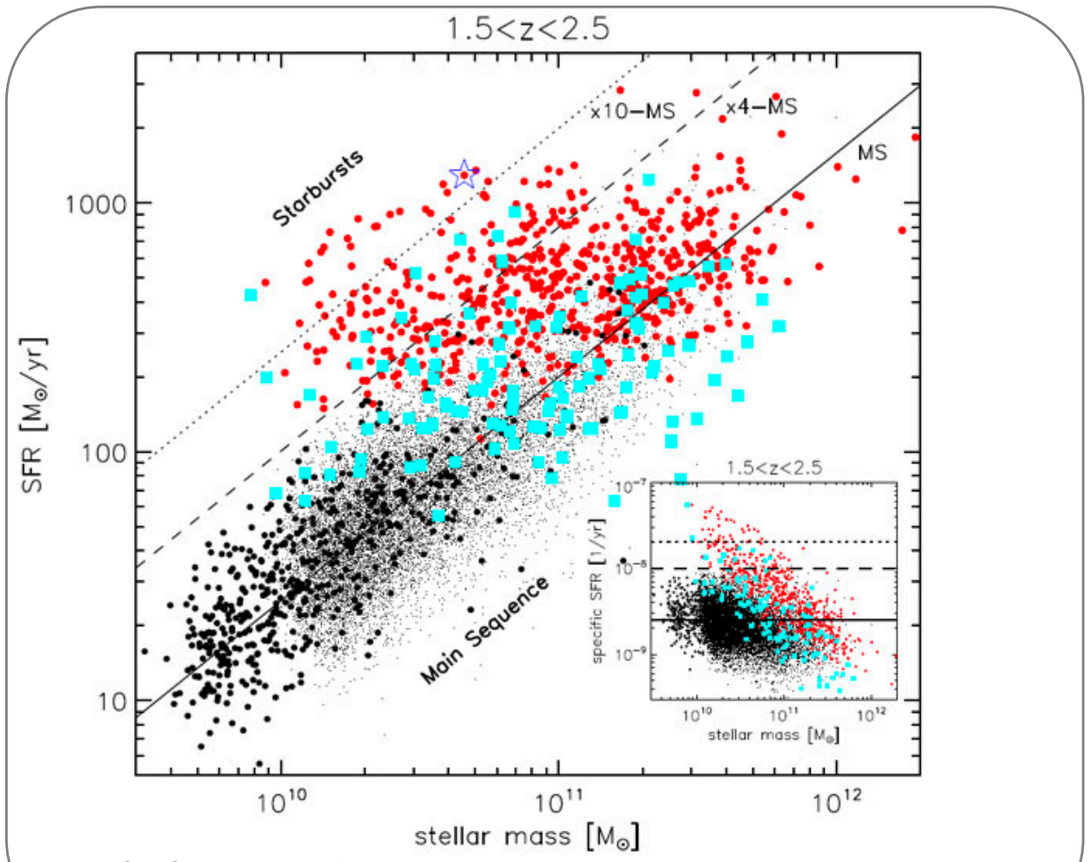
Madau & Dickinson 2014

The galaxy star-forming Main Sequence

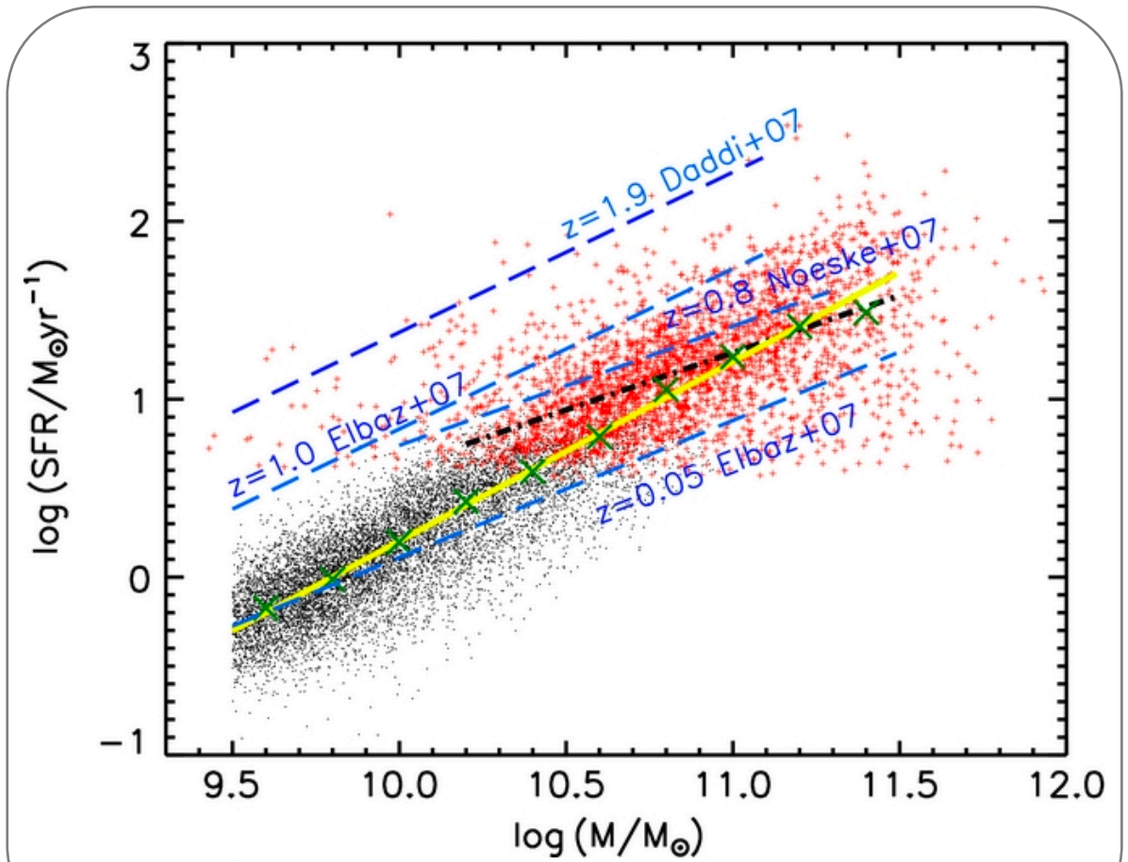


Noeske+07, Elbaz+07, Daddi+10, Rodighiero+11, Elbaz+11, Schreiber+15

The galaxy star-forming Main Sequence

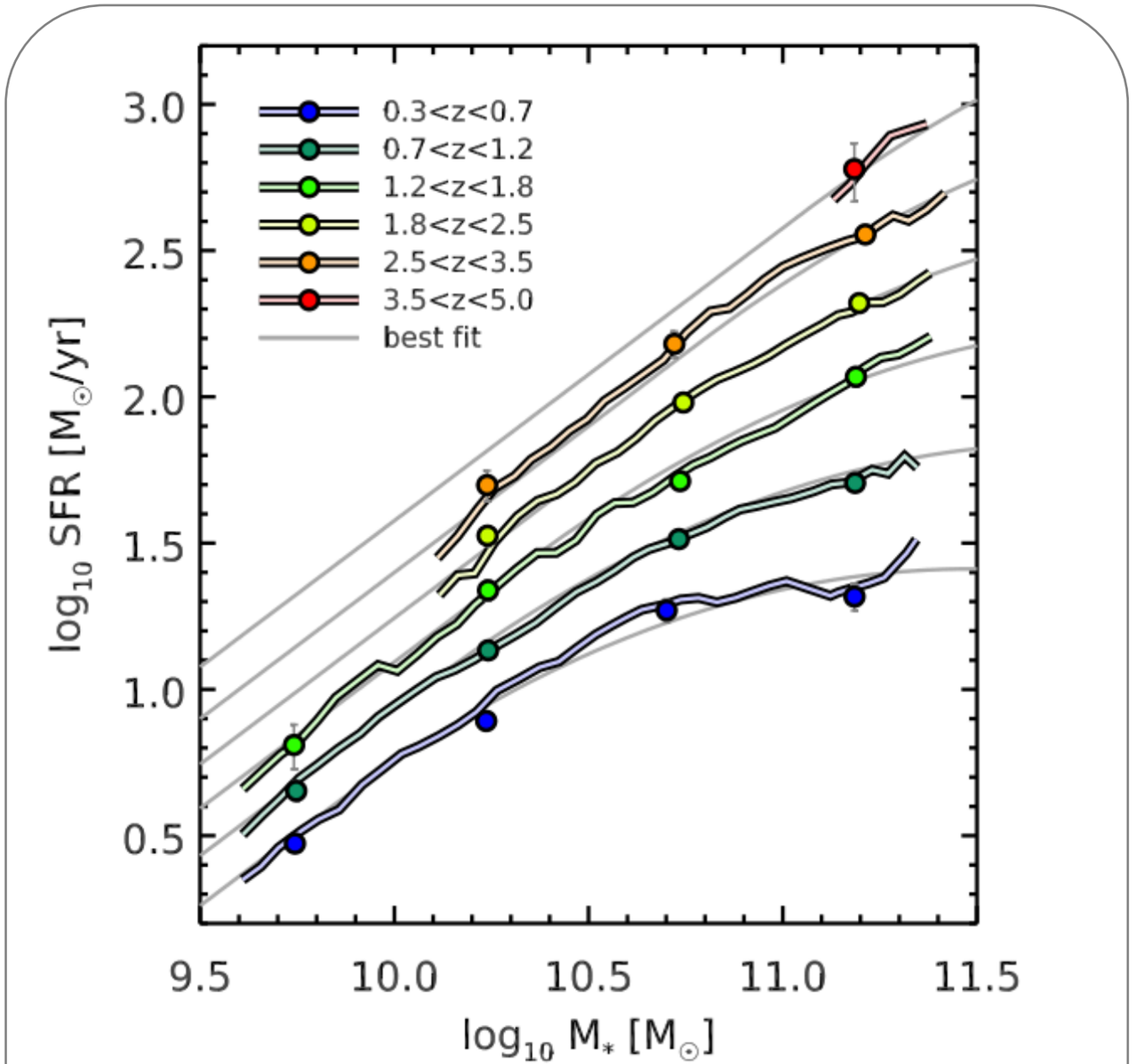


Rodighiero+12



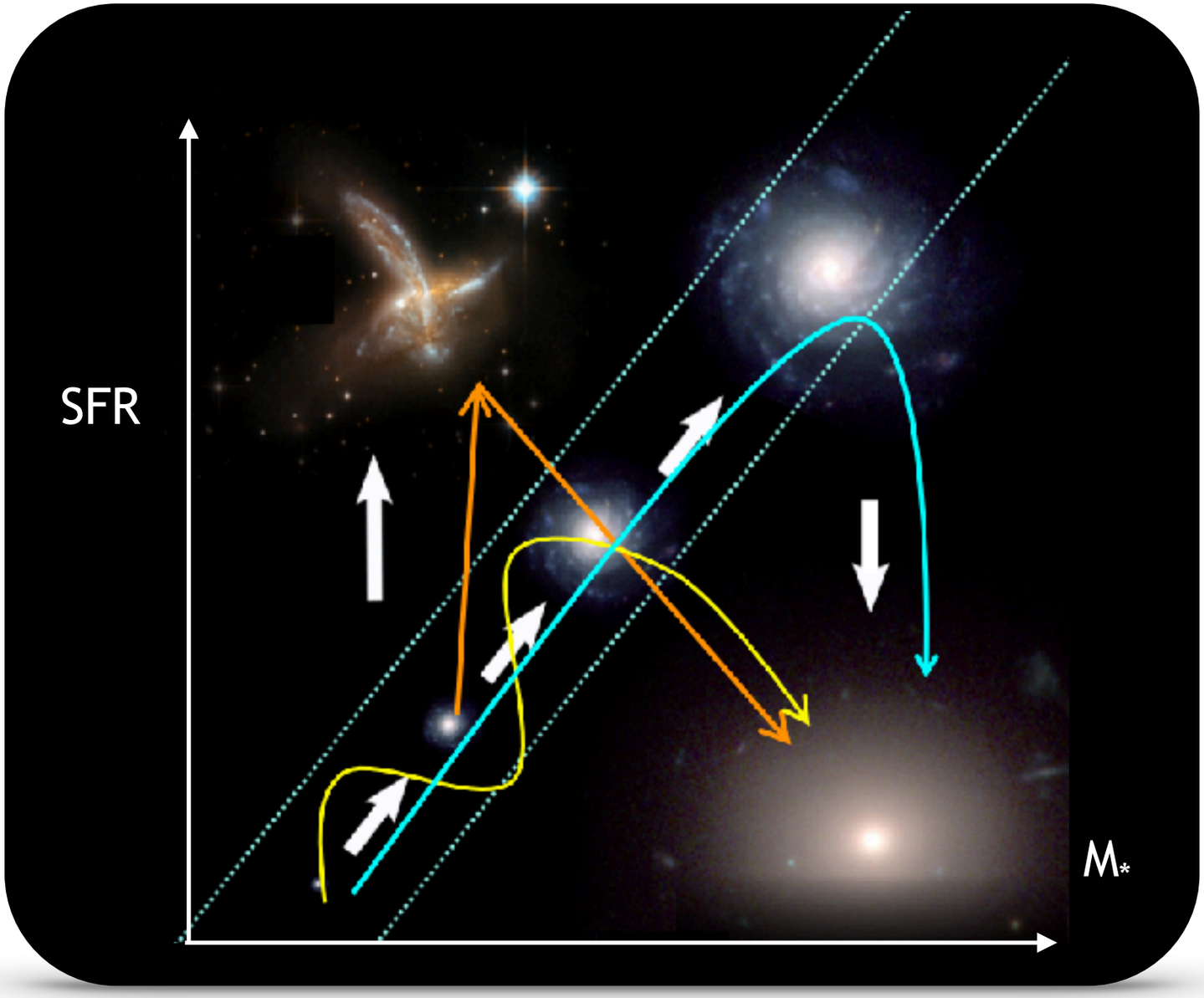
Guo+13

The galaxy star-forming Main Sequence

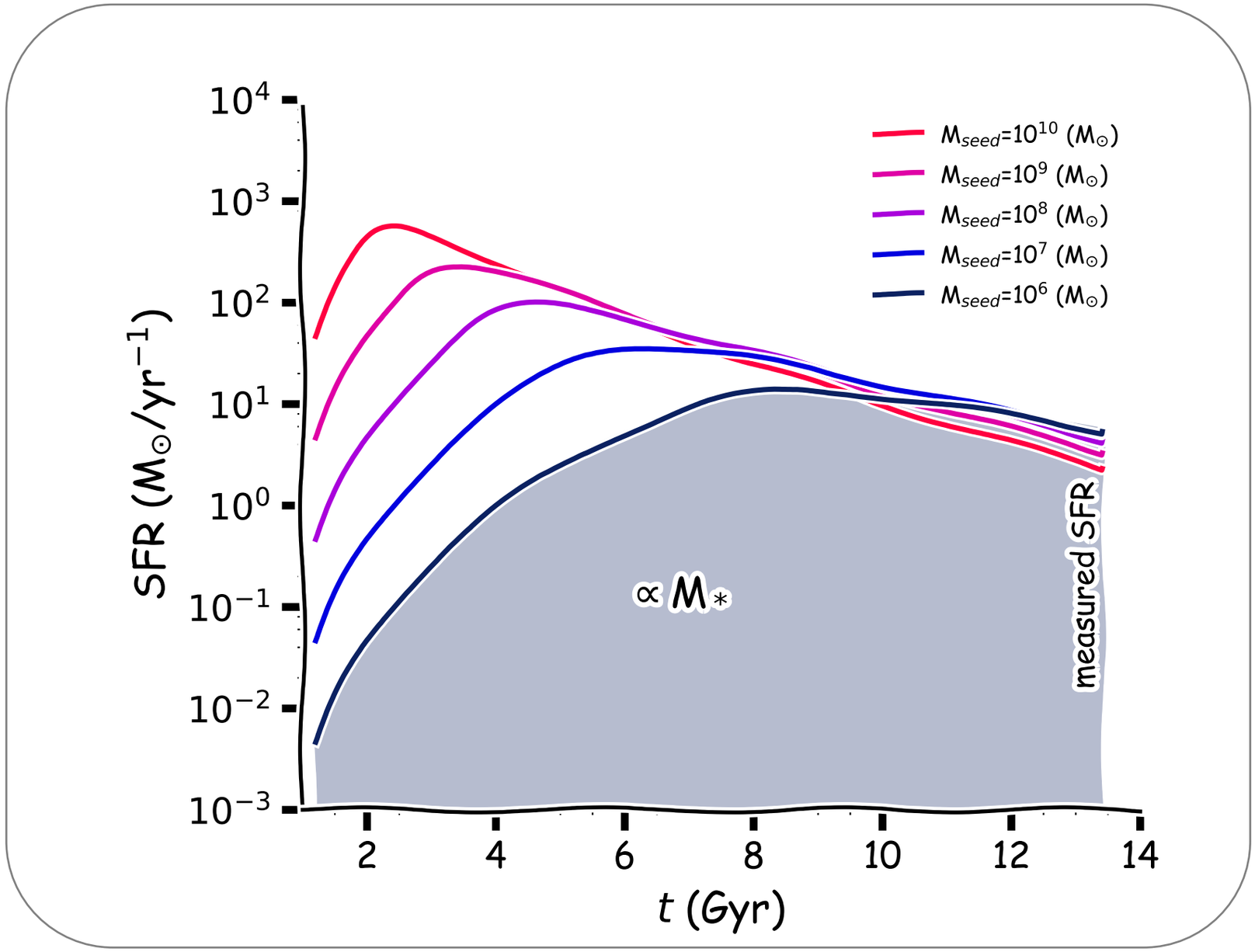


Schreiber+15

The galaxy star-forming Main Sequence



Star Formation History of Galaxies

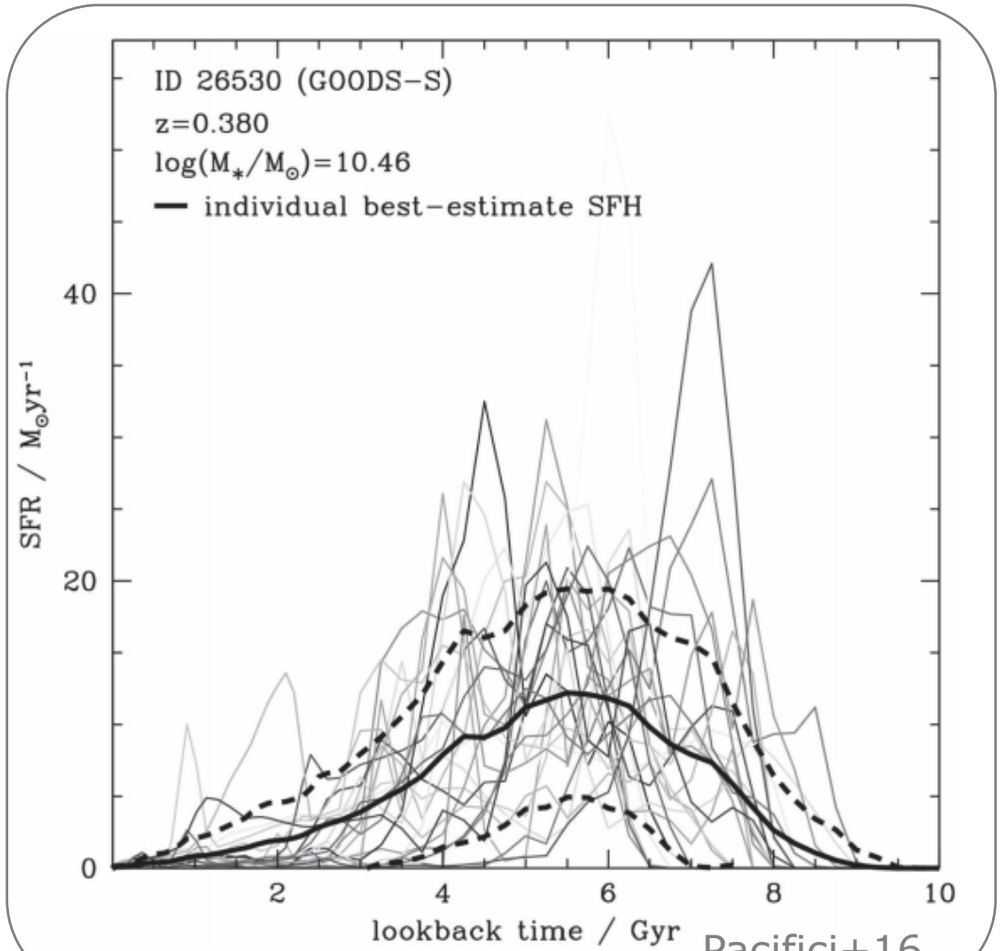


Lee+10, Pacifici+13, Behroozi+13, Pacifici+16Papovich+01, Maraston+10, Pforr+12, Gladders+13, Simha+14, Buat+14, Ciesla+15; Abramson+16, Ciesla+16, Iyer&Gawiser17, Ciesla+17a, Abramson+17

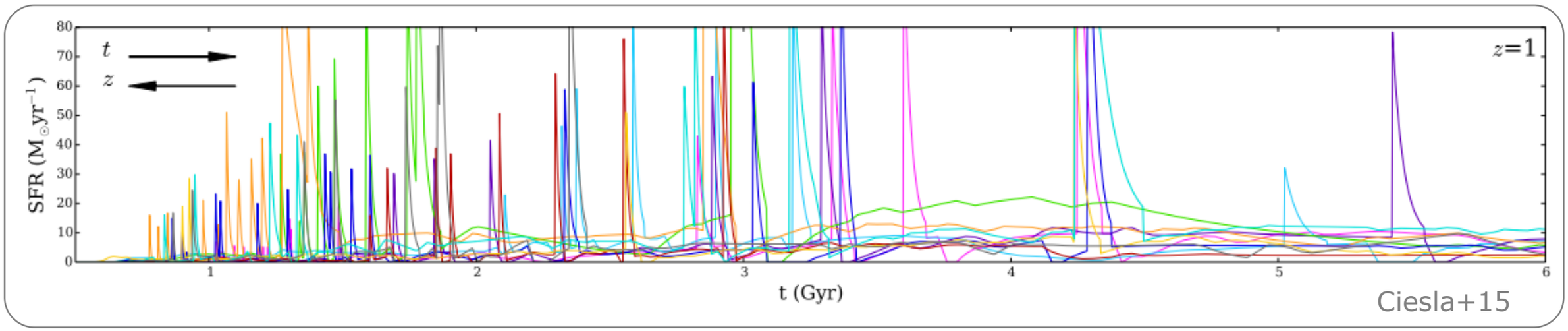
SFH of individual galaxies

Star Formation History

SFH of **individual** galaxies expected to be **more stochastic**

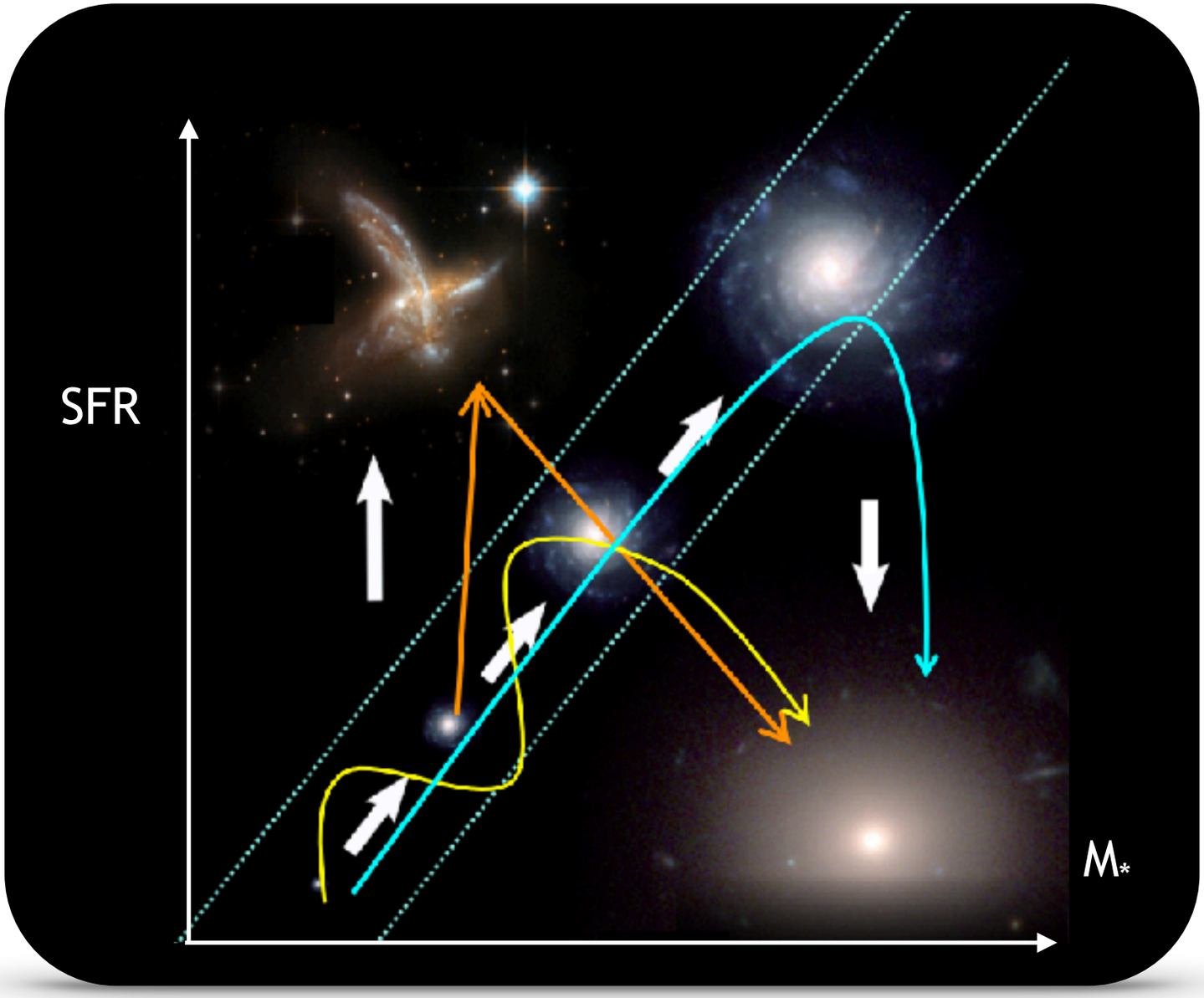


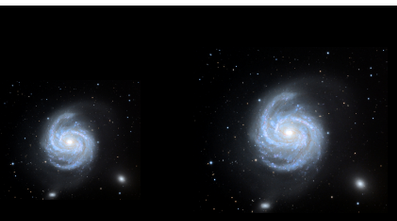
Pacifici+16



Ciesla+15

The galaxy star-forming Main Sequence





Thank you!