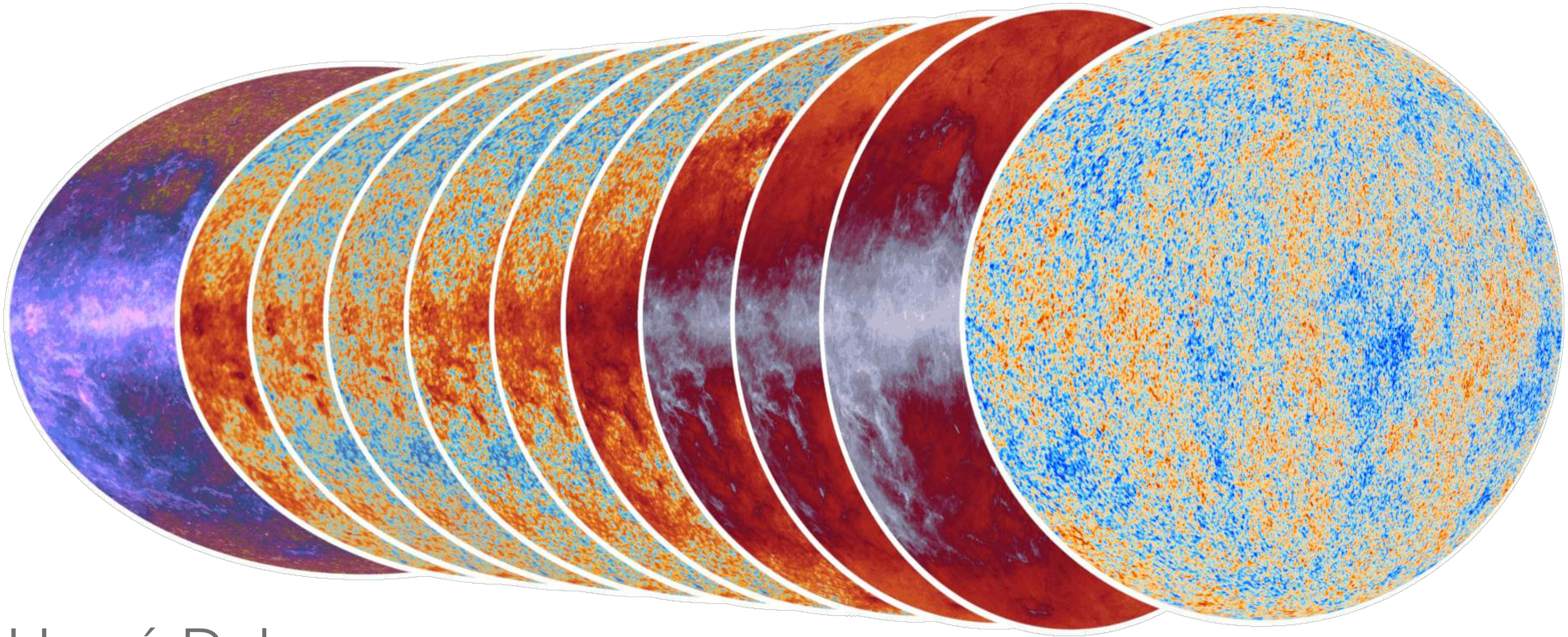
Les fonds cosmiques et les (proto-)amas de galaxies

mieux comprendre la formation des grandes structures



Hervé Dole

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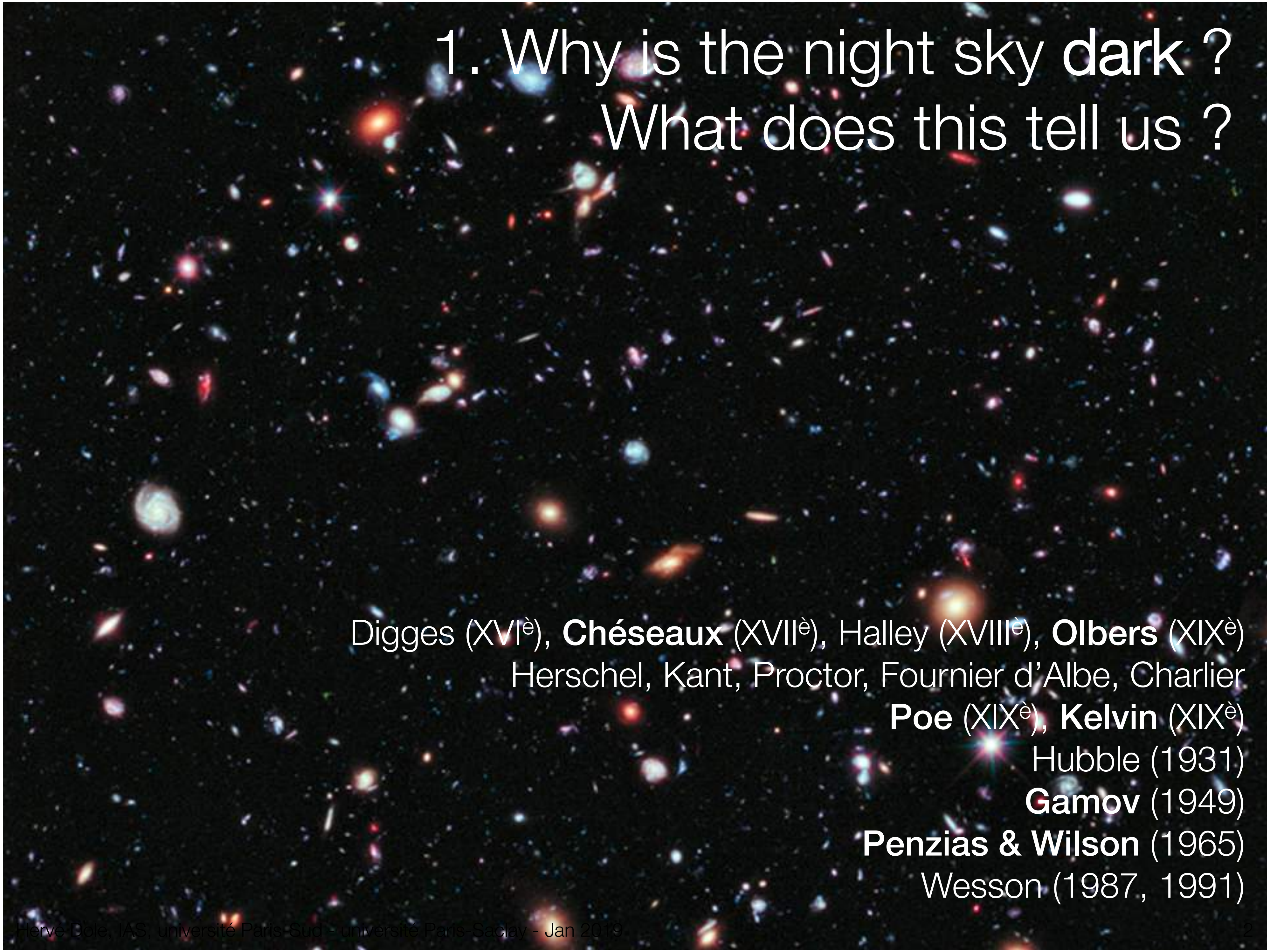
http://www.ias.u-psud.fr/dole/



1. Why is the night sky **dark** ?
What does this tell us ?

Digges (XVIè), **Chéseaux** (XVIIè), Halley (XVIIIè), **Olbers** (XIXè)
Herschel, Kant, Proctor, Fournier d'Albe, Charlier
Poe (XIXè), **Kelvin** (XIXè)
Hubble (1931)
Gamov (1949)
Penzias & Wilson (1965)
Wesson (1987, 1991)

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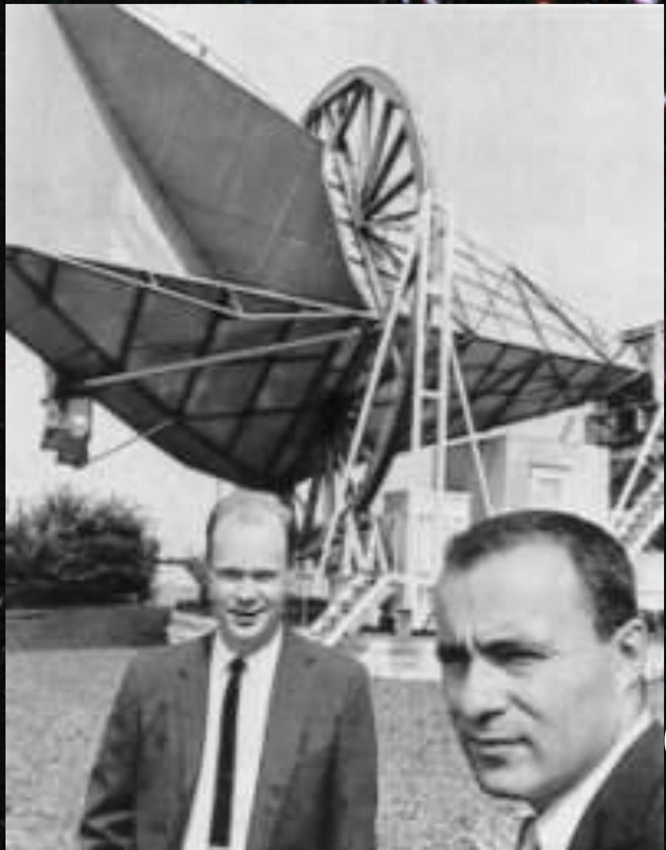

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CMB: Cosmic Microwave Background
(fond cosmologique)

1. Why is the night sky **dark** ?
What does this tell us ?

- finitude vitesse lumière c
- âge fini des objets
- expansion Univers
- faible densité d'étoiles

→ **horizon cosmologique** → oui, ciel noir

- existence d'**émissions reliques**
    - recombinaison: fond cosmologique
    - formation et évolution des galaxies: fond extragalactique
- expansion, et prise en compte de tout le spectre e. m.

→ non, ciel « clair »

Digges (XVIè), **Chéseaux** (XVIIè), Halley (XVIIIè), **Olbers** (XIXè)
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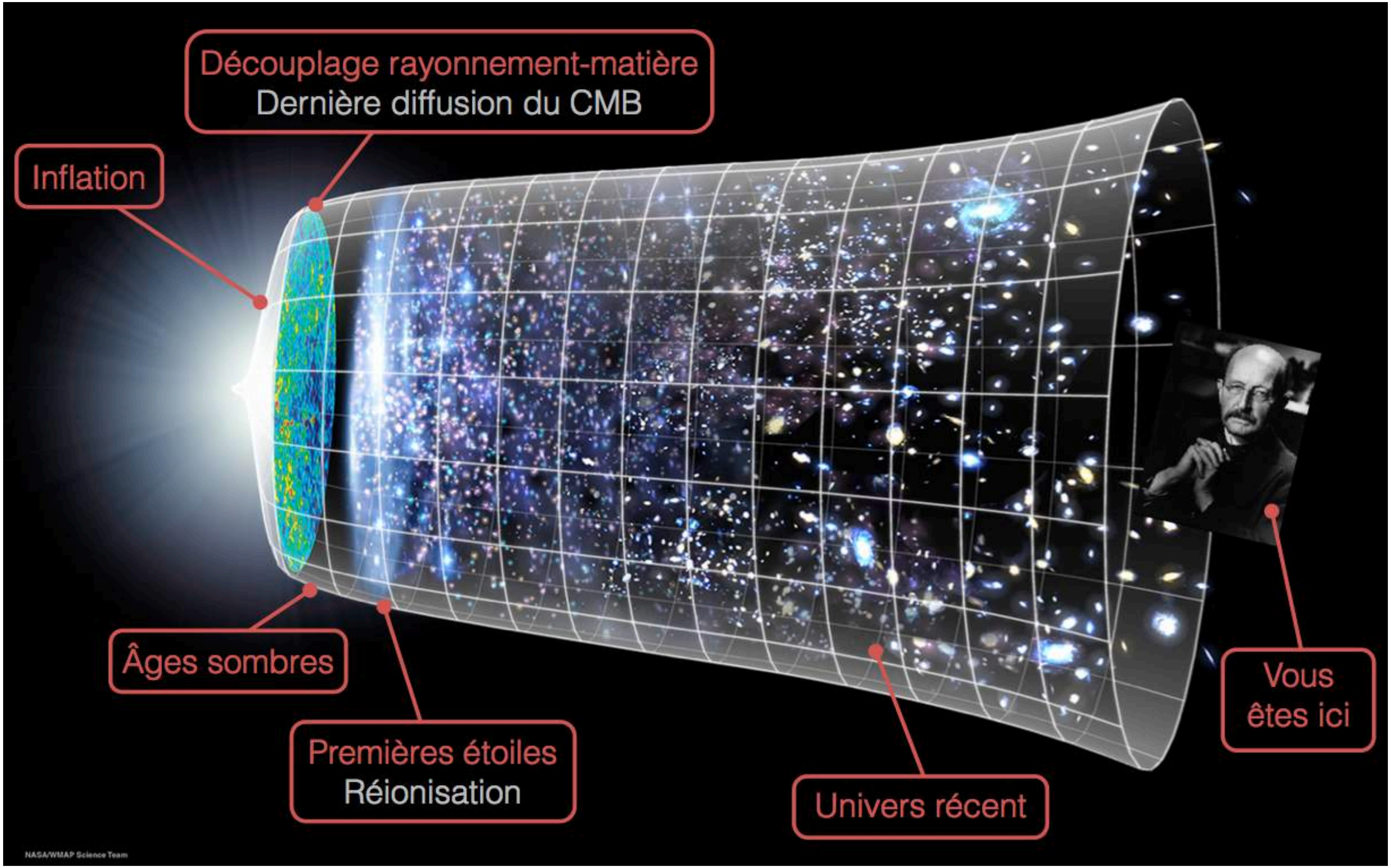
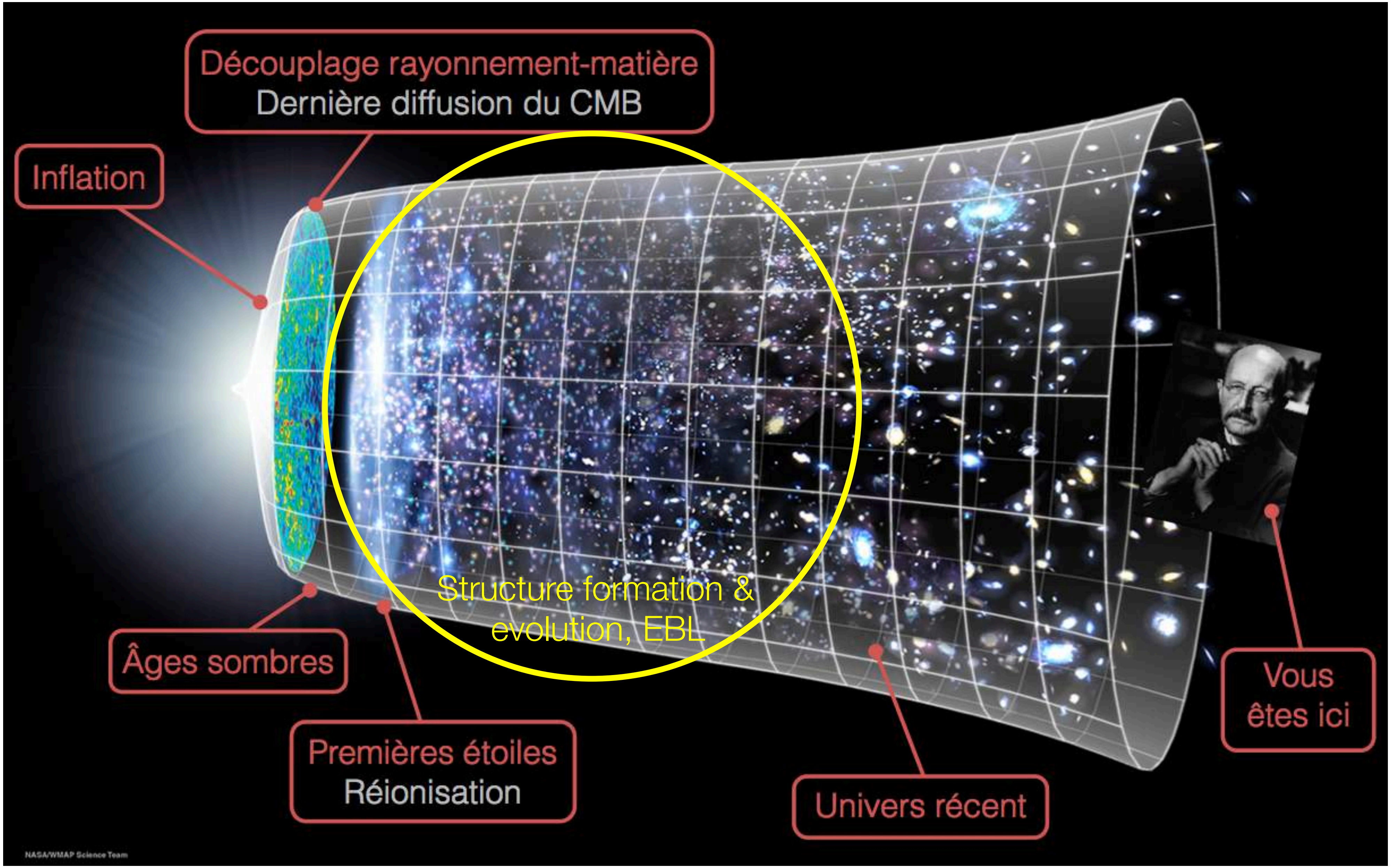
1. a short history of the 13.8b yr old universe



courtesy WMAP, Planck, J. Aumont

1. a short history of the 13.8b yr old universe



courtesy WMAP, Planck, J. Aumont

2. extragalactic background light

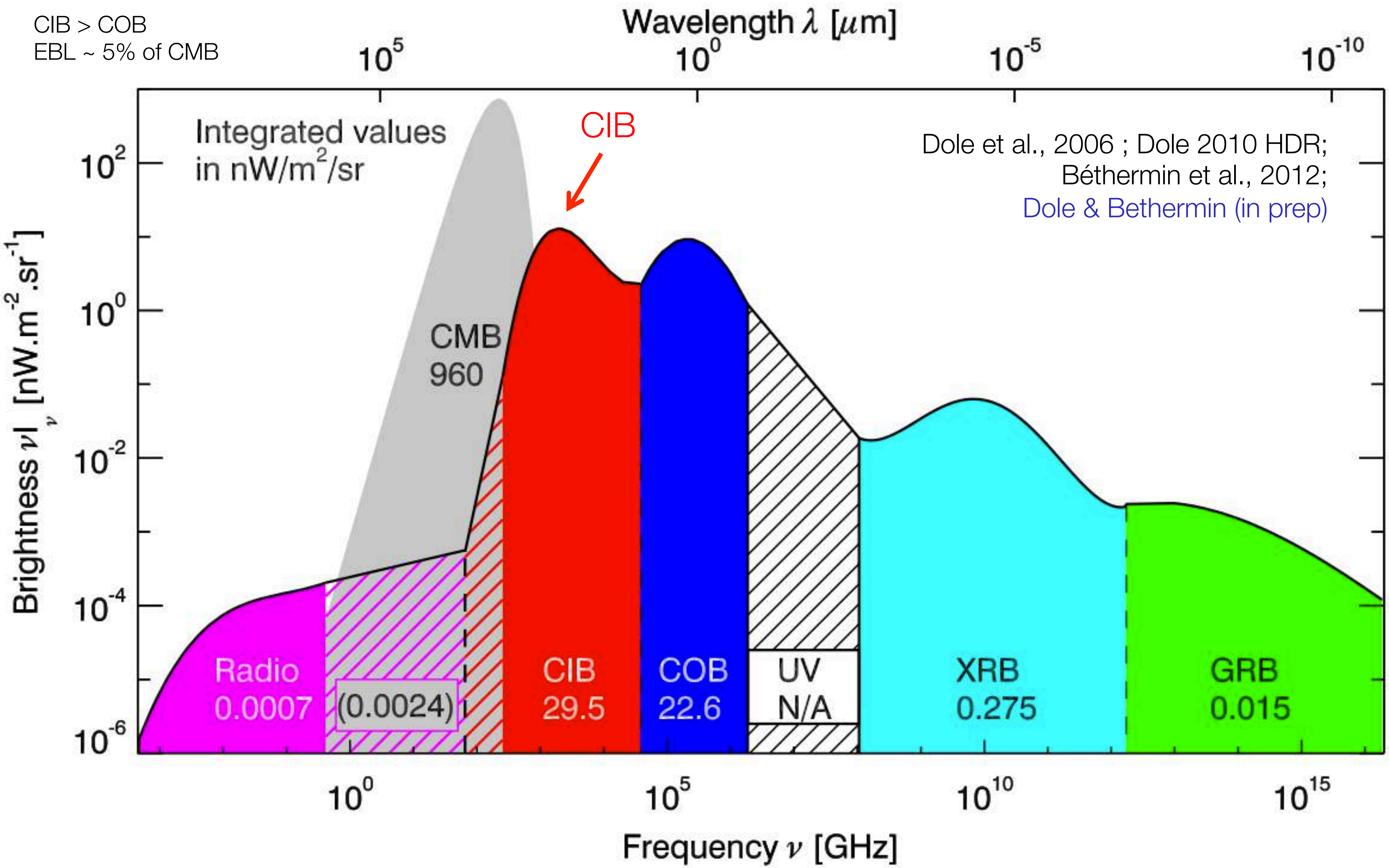
EBL (Extragalactic Background Light) tells us about the processes involved in galaxy formation & evolution (budget for radiation emission by nucleosynthesis & gravitation, presence of dust, …)

CIB (Cosmic Infrared Background) level and structure depend on history of energy production in the post-recombination Universe [Kashlinsky, 2005]

Measuring it has been motivated by better understanding the structure formation & evolution

2. a contemporary view of Universe's SED

CIB > COB
EBL ~ 5% of CMB



2. a contemporary view of Universe's SED

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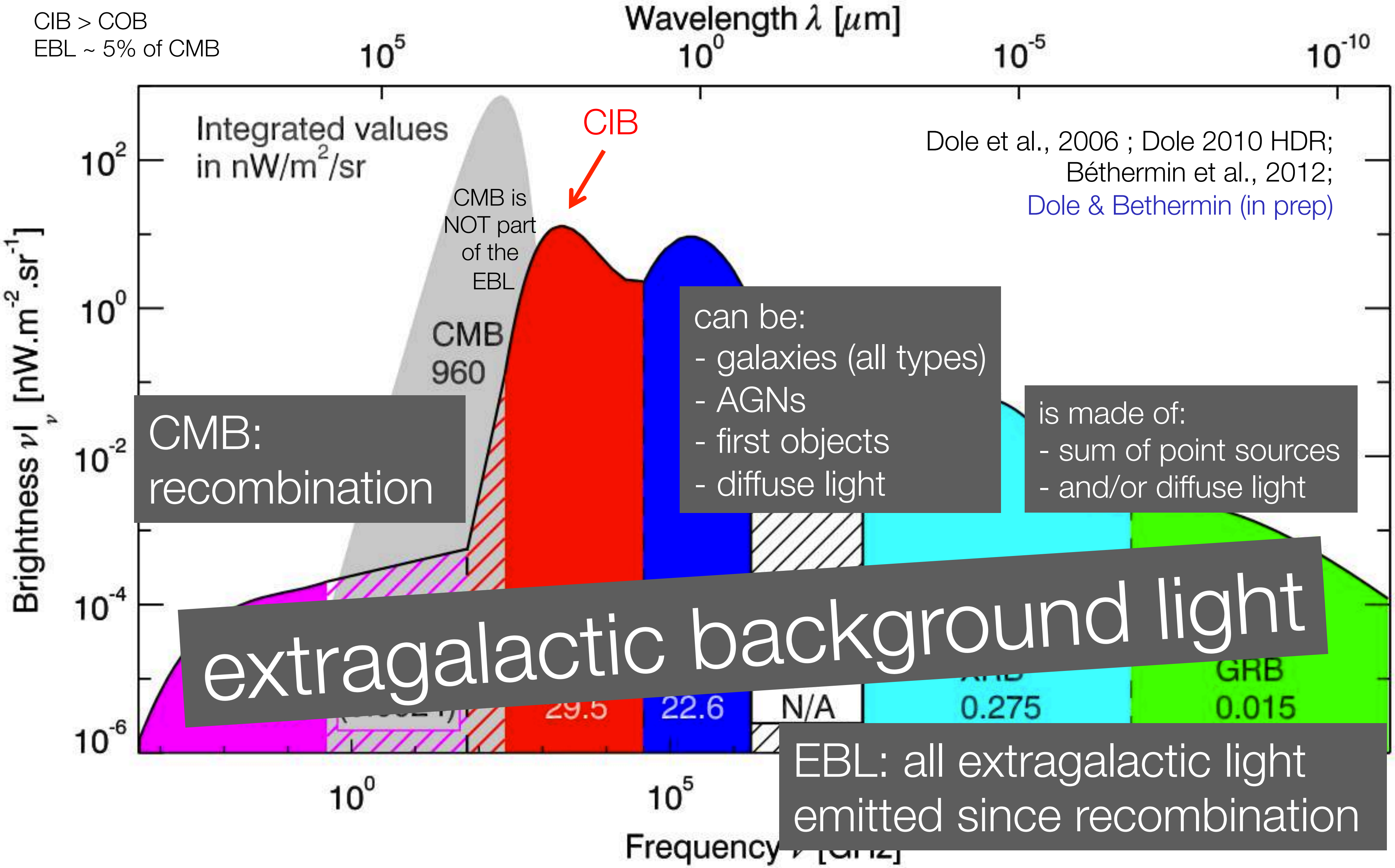


outline

Part I. Cosmic Backgrounds

1. Why is the night sky dark ?
2. Extragalactic Background Light (EBL) introduction
3. EBL / CIB measurement history and interpretation

Part II. Galaxy (proto-)clusters at high redhsift

4. Introduction, review & questions: galaxy clusters
5. How Planck selected high-z high-SFR cluster candidates
   - From Planck to Herschel to Spitzer
   - What do we learn from imaging ?
   - What do we learn from spectroscopy ?
6. What Euclid and JWST will bring us ?
7. Conclusion, perspectives

3. EBL status in 1967 – about 50 years ago

636 NOVIKOV & ZELDOVIČ 1967, ARAA

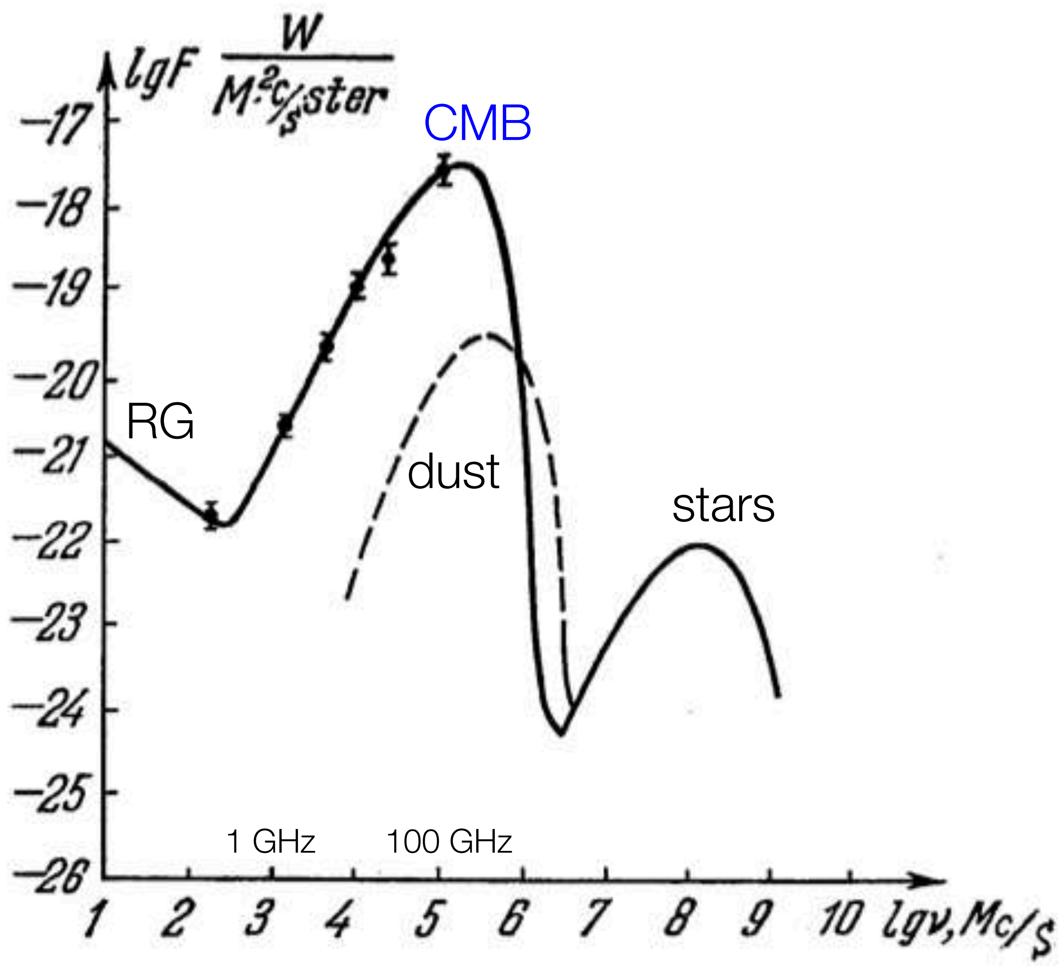


FIG. 1. Averaged spectrum of electromagnetic radiation in the universe. The maximum at lg $\nu \approx 8$ is the radiation of stars; the straight line at lg $\nu < 2.5$ is due to radio galaxies. The dotted line is the radiation of dust with $\bar{\rho} \approx 5 \cdot 10^{-34}$ g/cm³ and $T = 10°$K. The full line with maximum at lg $\nu \approx 5.5$ is the black-body equilibrium radiation at 3°K—the relict radiation. The points give experimental results with their errors.

first predictions in 1967

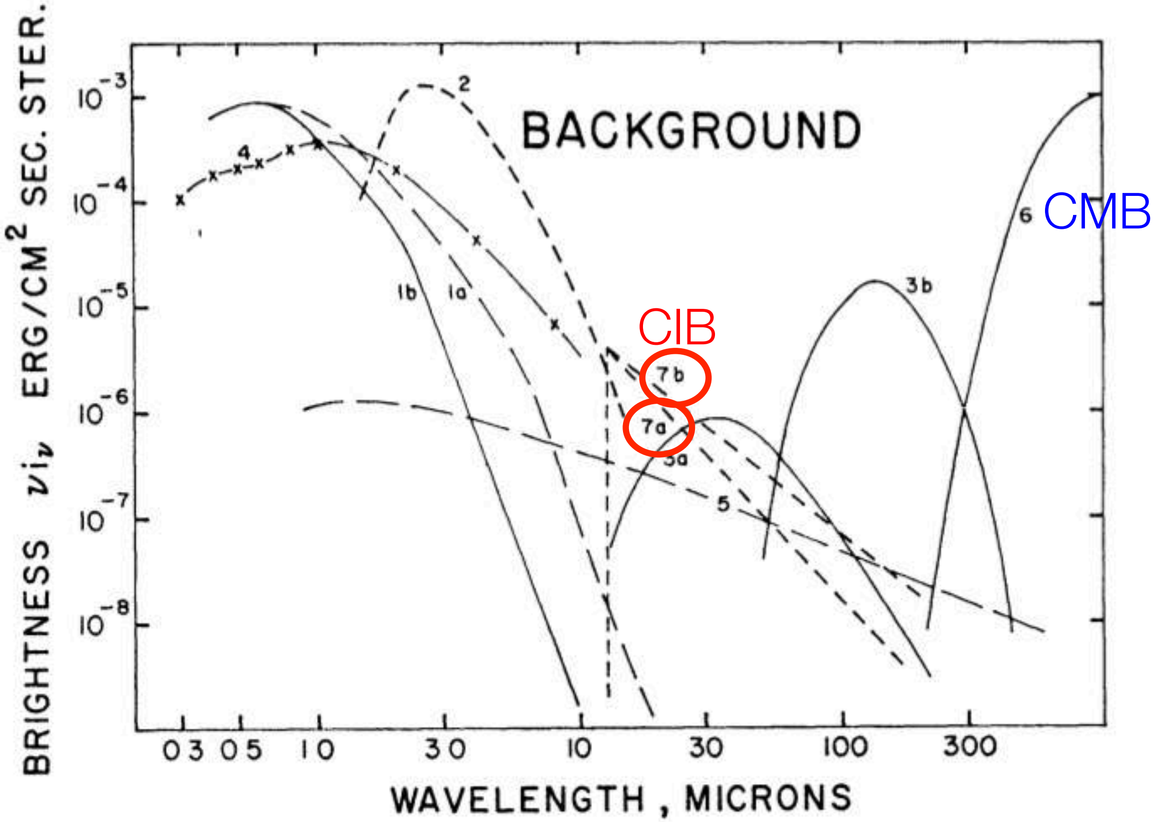
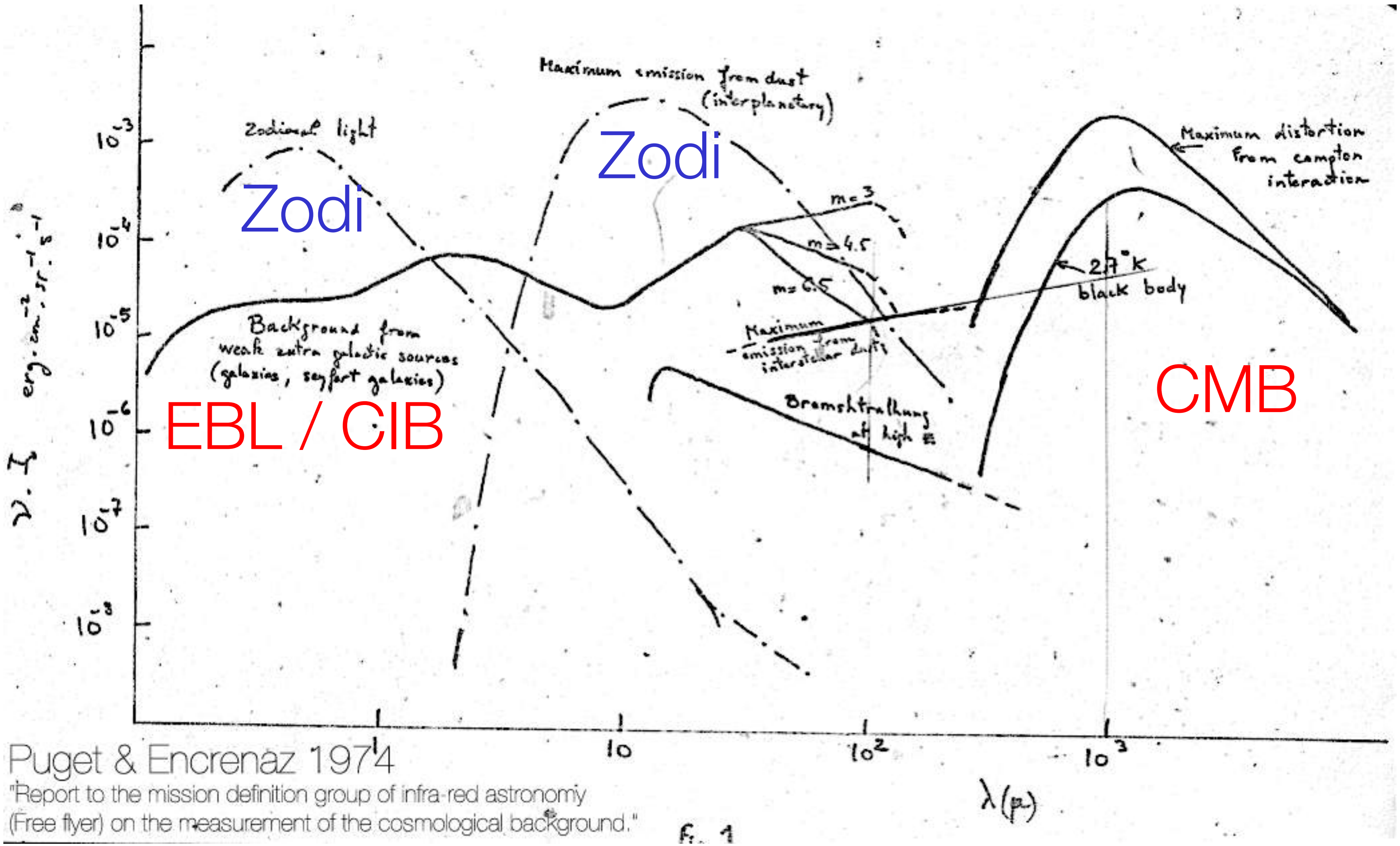


FIG. 8.—Other sources of background radiation. The contribution of local, galactic, and extragalactic sources is plotted as a function of wavelength. The various curves are defined as follows: *1a*, zodiacal light perpendicular to the ecliptic with characteristic particle radius 1.8 μ; *1b*, zodiacal light perpendicular to the ecliptic with characteristic particle radius 0.7 μ; *2*, interplanetary dust (small particles); *3a*, interstellar grains (metallic); *3b*, interstellar grains (dielectric, or "dirty-ice"); *4*, integrated starlight from the Galaxy, perpendicular to the galactic plane; *5*, galactic free-free emission, perpendicular to the plane; *6*, 3° K cosmic background radiation; *7a*, 12.8 μ Ne^+ emission from all galaxies (closed model); *7b*, 12.8 μ Ne^+ emission from all galaxies (open model).

Partridge & Peebles, 1967

a long way … here in 1974



Puget & Encrenaz, 1974

CIB discovery in 1996

Astron. Astrophys. 308, L5–L8 (1996)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

Tentative detection of a cosmic far-infrared background with COBE

J.-L. Puget[1], A. Abergel[1], J.-P. Bernard[1], F. Boulanger[1], W.B. Burton[2], F.-X. Désert[1], and D. Hartmann[2,3]

[1] Institut d'Astrophysique Spatiale, Bât. 121, Université Paris XI, F-91405 Or
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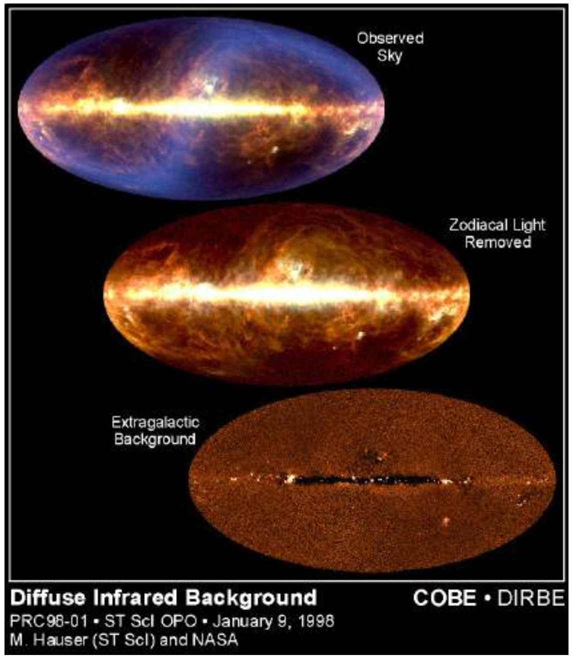
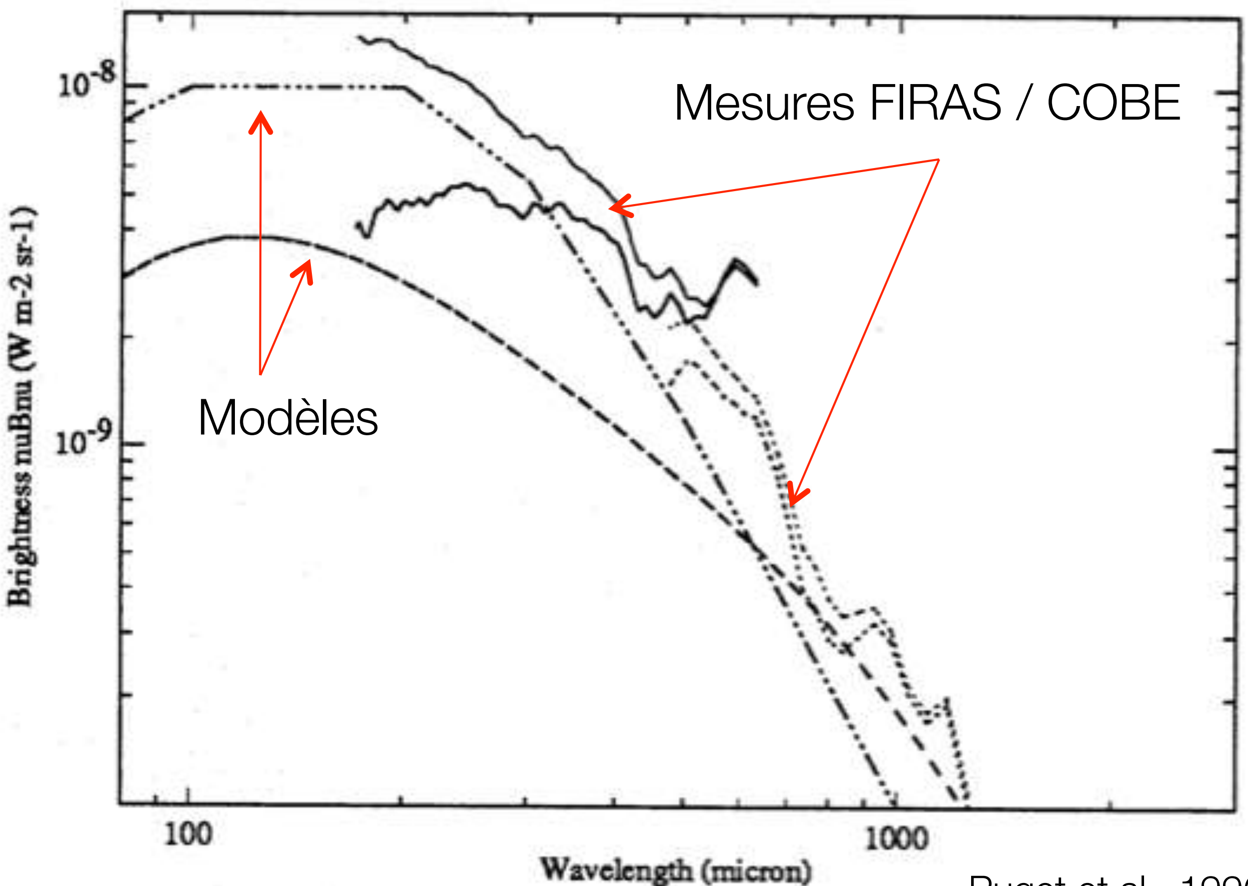
Received 4 August 1995 / Accepted 12 December 1995





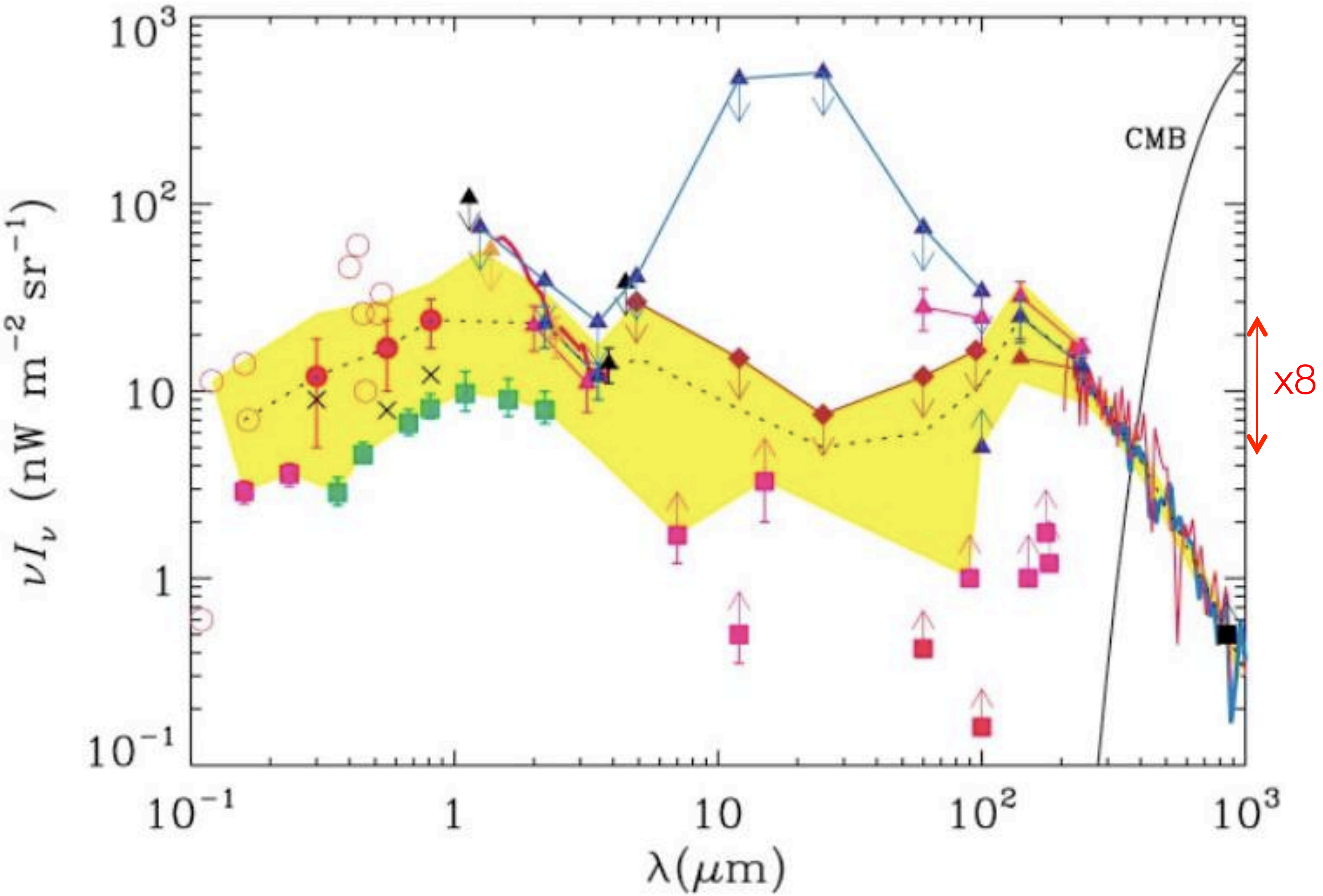
Puget et al., 1996

measurements in the early 2000's...

la lumière zodiacale est le principal contaminant.

a 60um, zodi ~50*CIB

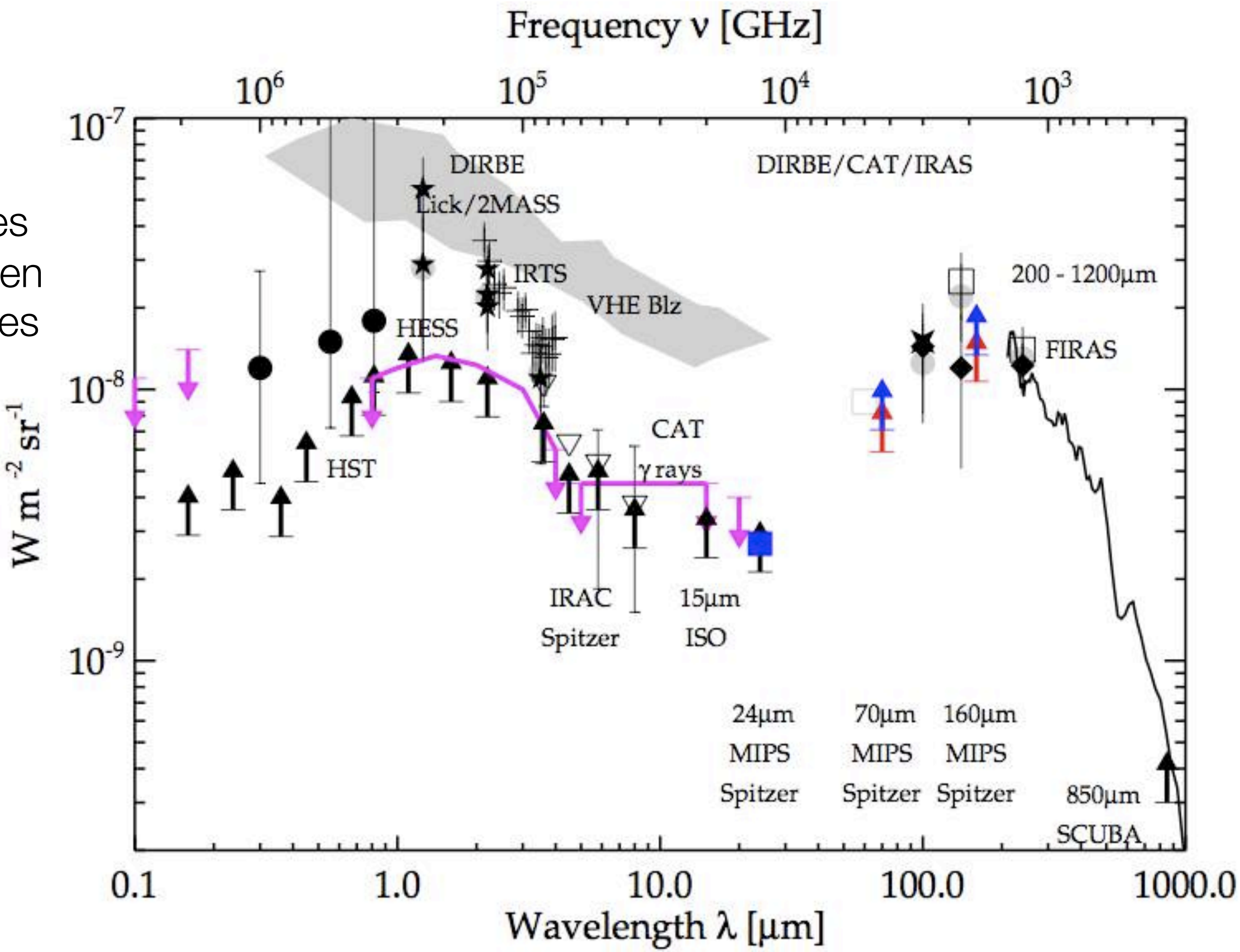
une erreur de 1% sur la soustraction du zodi peut faire changer de moitié la valeur du CIB



Hauser & Dwek, 2001, ARAA

... in the mid 2000's …

apparition de limites inférieures et supérieures, en plus des mesures absolues



Dole et al., 2006; Béthermin, Dole et al., 2010

... in the mid 2000's ...

The Cosmic Infrared Background resolved by Spitzer

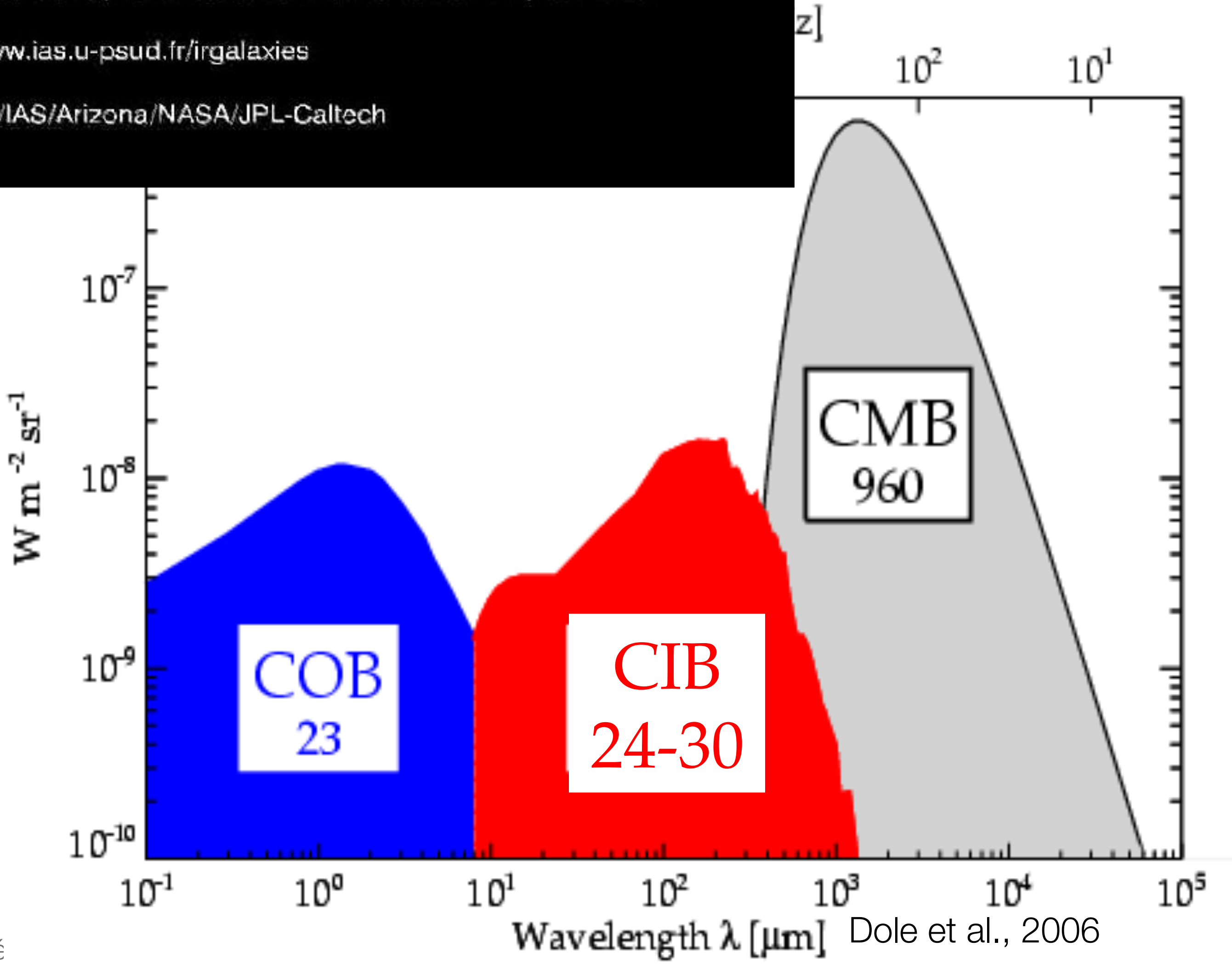
H. Dole et al. (2006)

Institut d'Astrophysique Spatiale, Universite Paris-Sud 11, CNRS

http://www.ias.u-psud.fr/irgalaxies

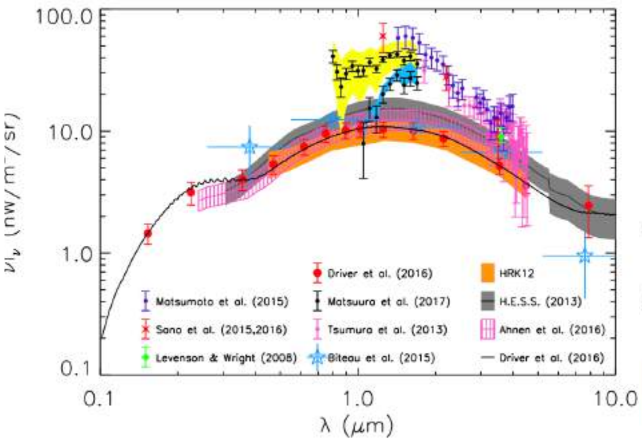
Credit: H. Dole/IAS/Arizona/NASA/JPL-Caltech

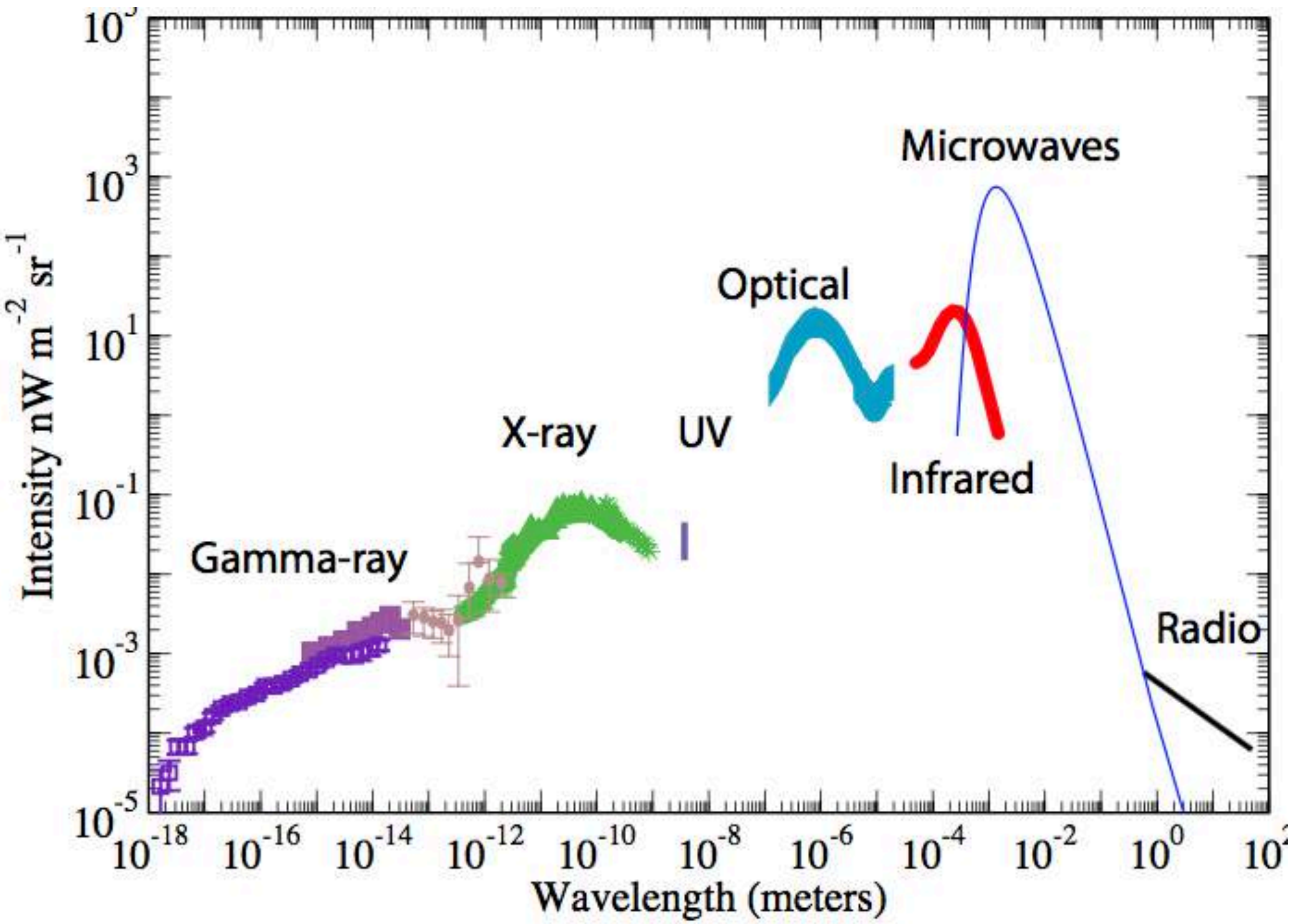
EBL gives the total budget for LSS & galaxy formation & evolution



Dole et al., 2006

... and more recently in the late 2010's

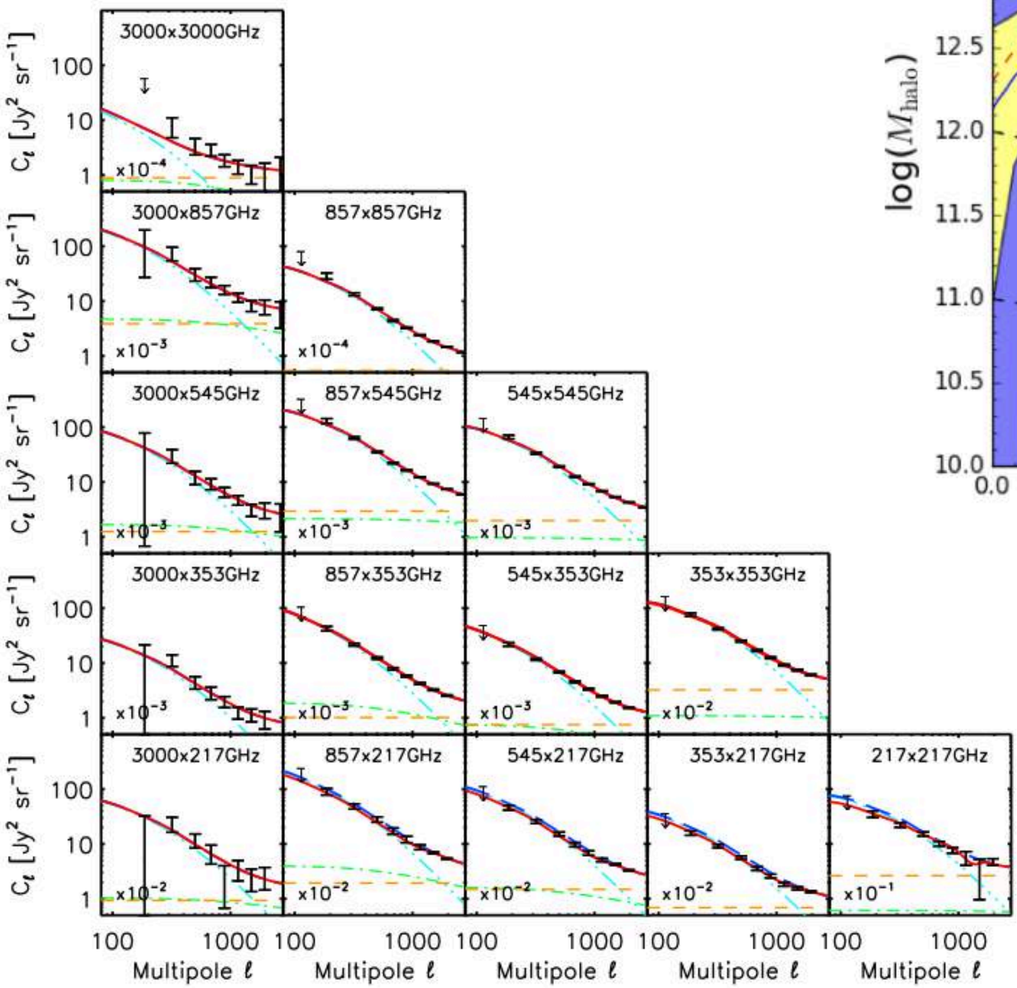


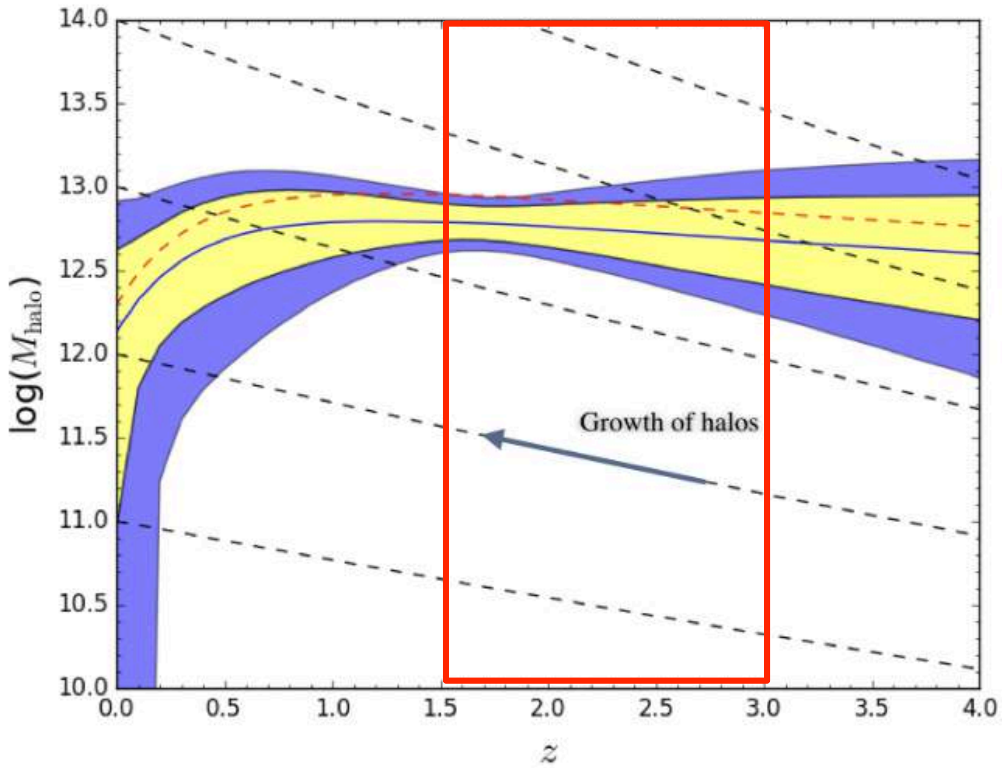


Béthermin et al., 2012, A&A
Cooray et al., 2016
Kashlinsky et al., 2018
Hill et al., 2017
Pilipenko et al., 2017
Andrews et al., 2017

among the results on CIB / EBL fluctuations

Planck Collab., 2013, XXX, A&A

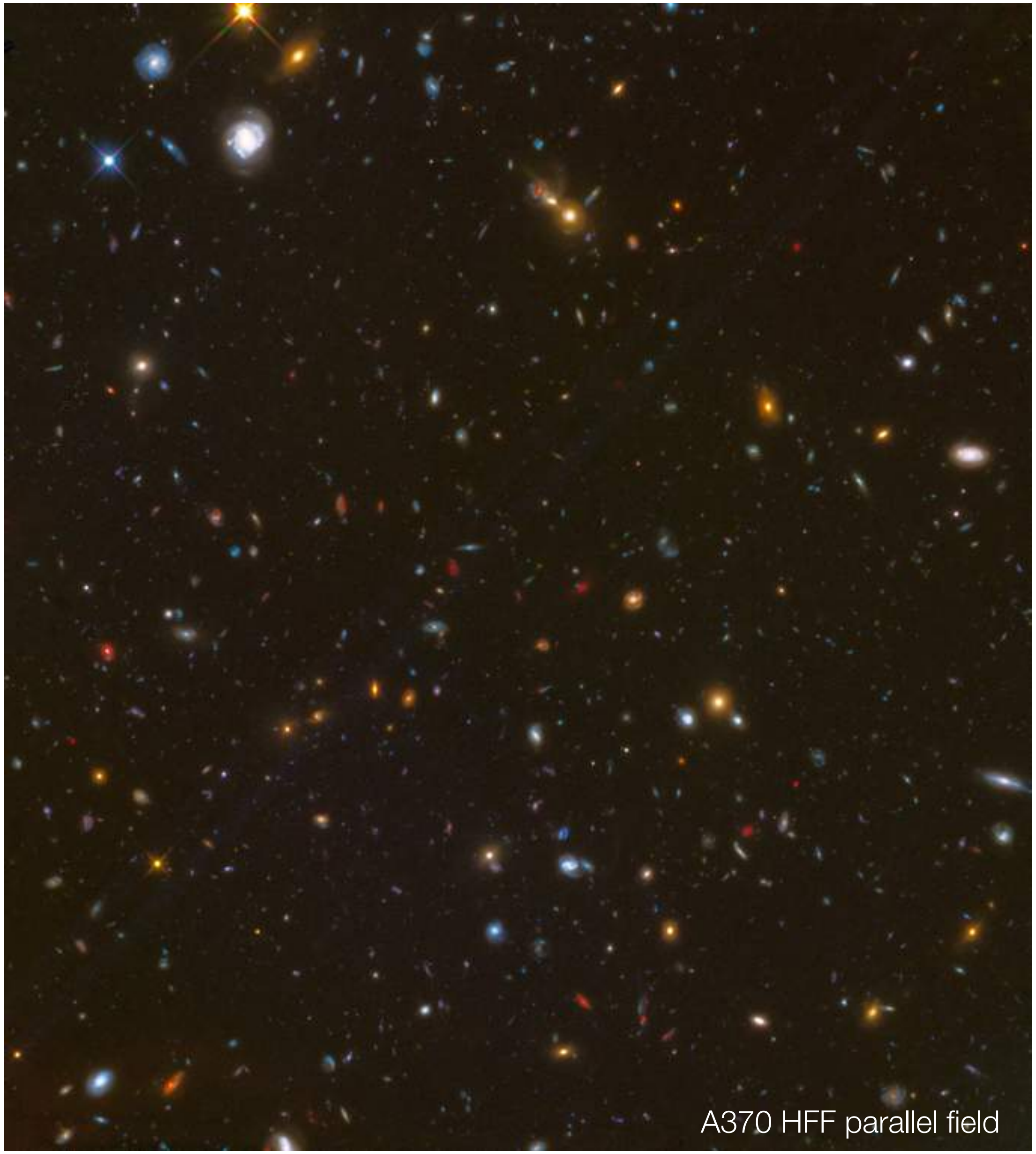




Maniyar, Béthermin, Lagache, 2018

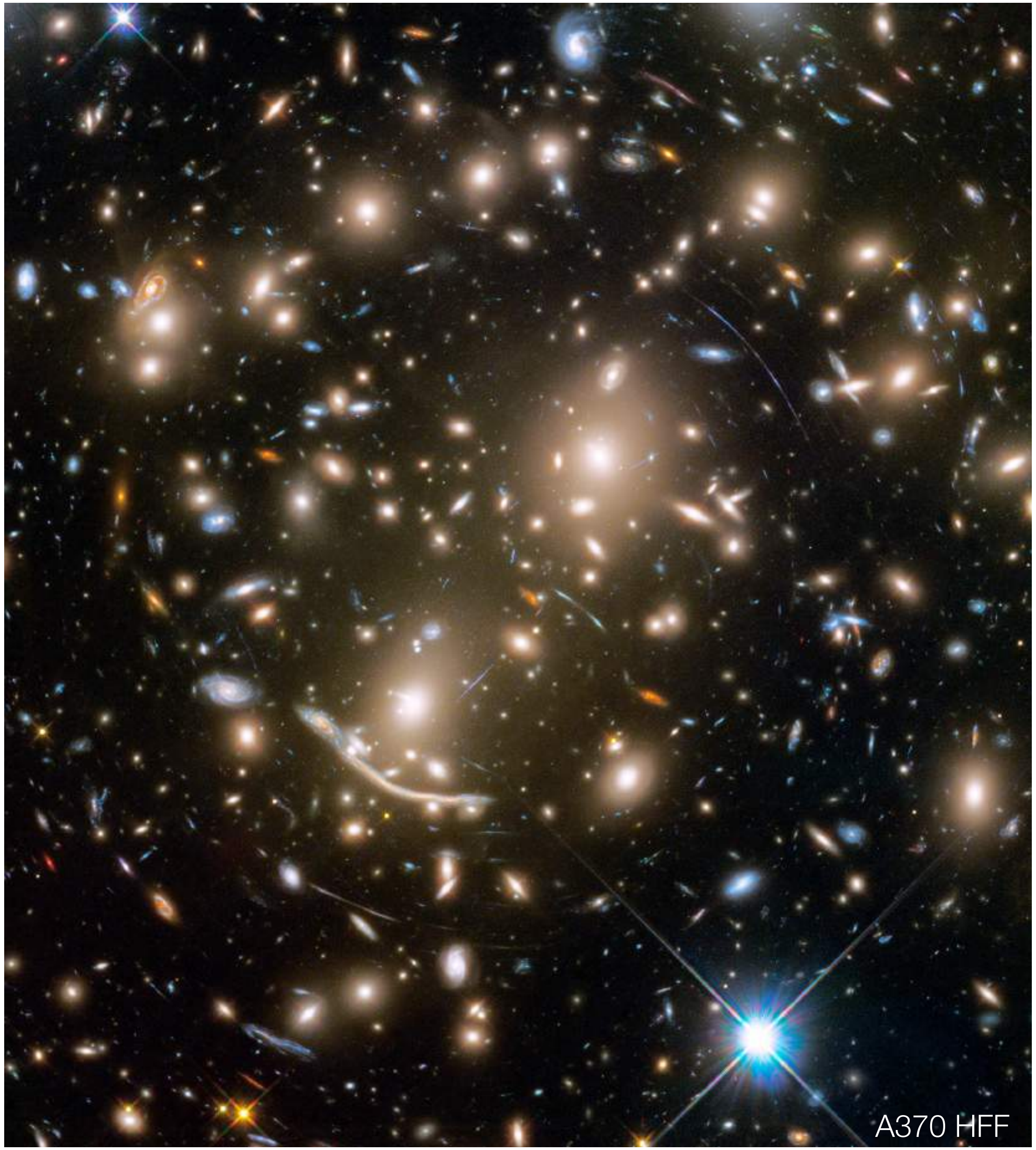
red: sum
blue: 2-halo term
green: 1-halo term
orange: shot noise

+ many other exciting results at other wavelengths



Part II.

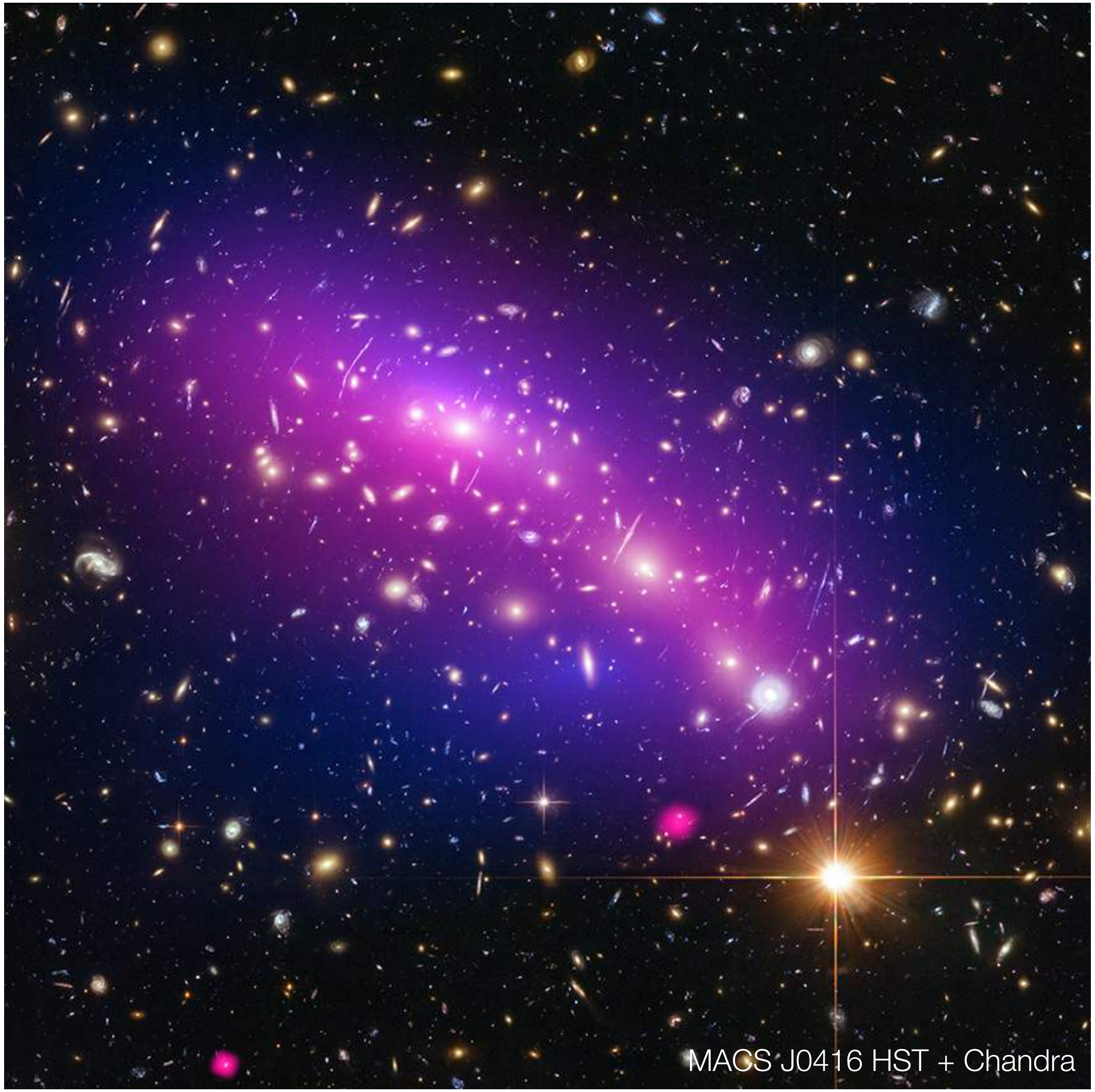
4. galaxy clusters

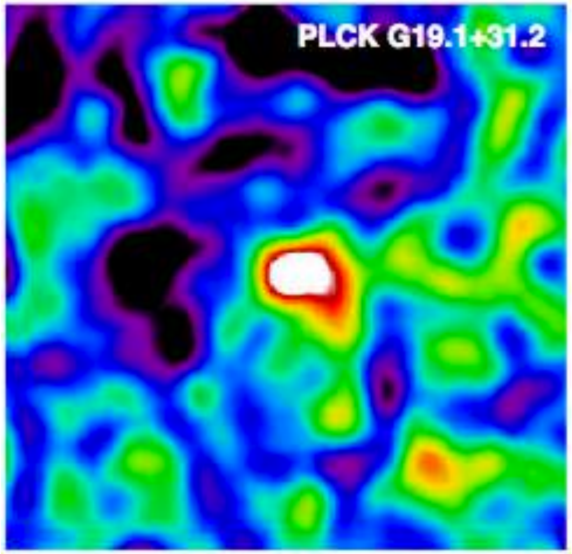


galaxy clusters

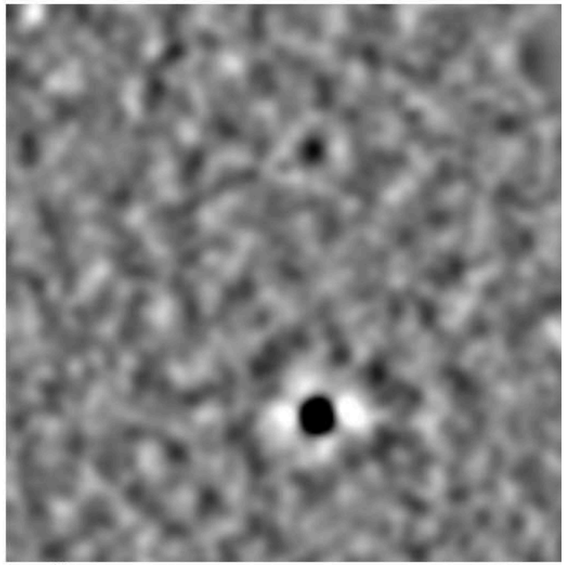
- ~85% dark matter
- ~12-15% hot gas
- ~2-5% stars, galaxies

galaxy clusters in multi-color





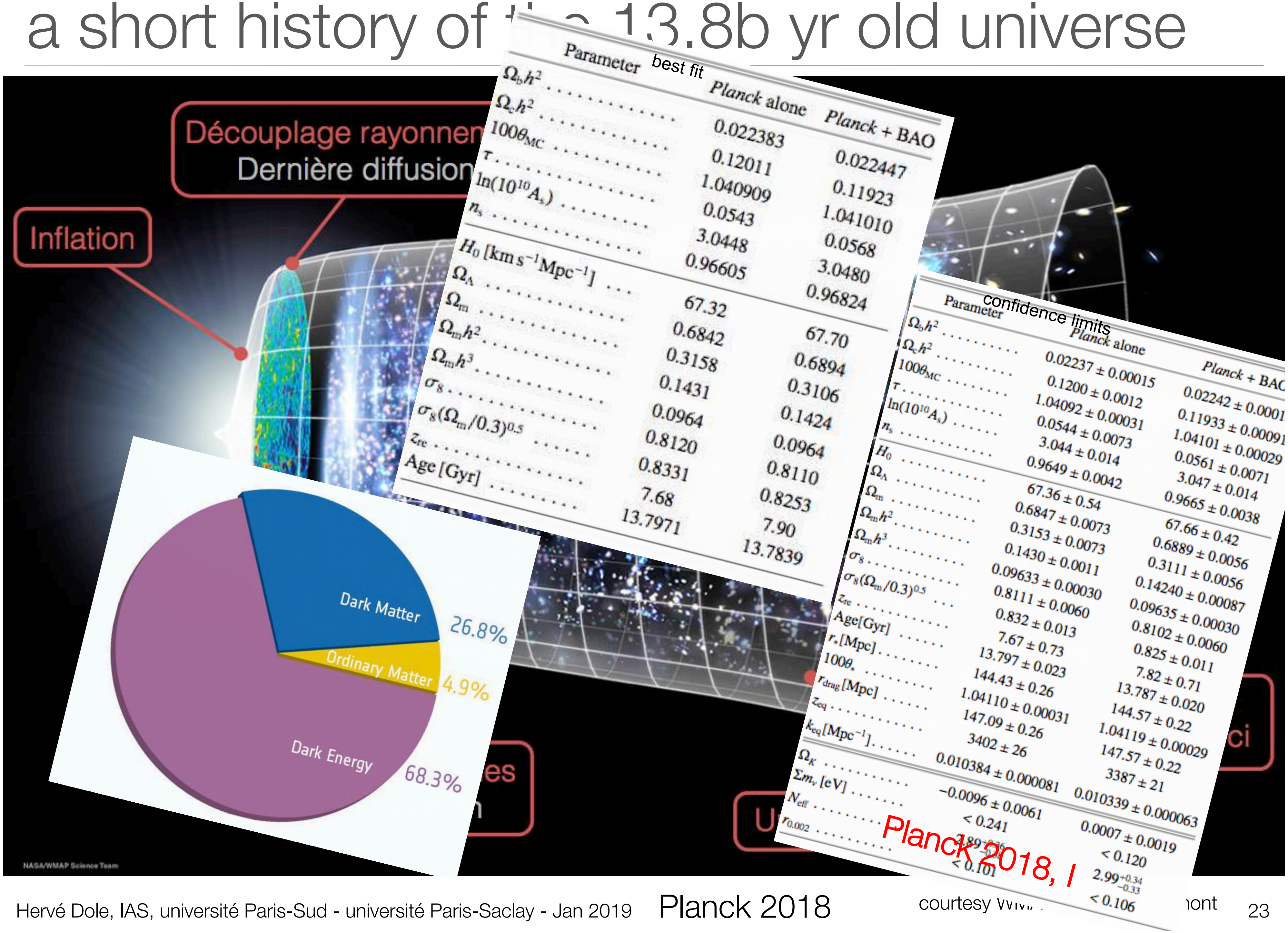
Planck 2011



(d) Cluster-filtered map, zoomed in to 1°-by-1°

Bleem et al., 2015

a short history of the 13.8b yr old universe



best fit

Parameter	Planck alone	Planck + BAO
$\Omega_b h^2$	0.022383	0.022447
$\Omega_c h^2$	0.12011	0.11923
$100\theta_{MC}$	1.040909	1.041010
τ	0.0543	0.0568
$\ln(10^{10} A_s)$	3.0448	3.0480
n_s	0.96605	0.96824
H_0 [km s^{-1}Mpc^{-1}]	67.32	67.70
Ω_Λ	0.6842	0.6894
Ω_m	0.3158	0.3106
$\Omega_m h^2$	0.1431	0.1424
$\Omega_m h^3$	0.0964	0.0964
σ_8	0.8120	0.8110
$\sigma_8(\Omega_m/0.3)^{0.5}$	0.8331	0.8253
z_{re}	7.68	7.90
Age [Gyr]	13.7971	13.7839

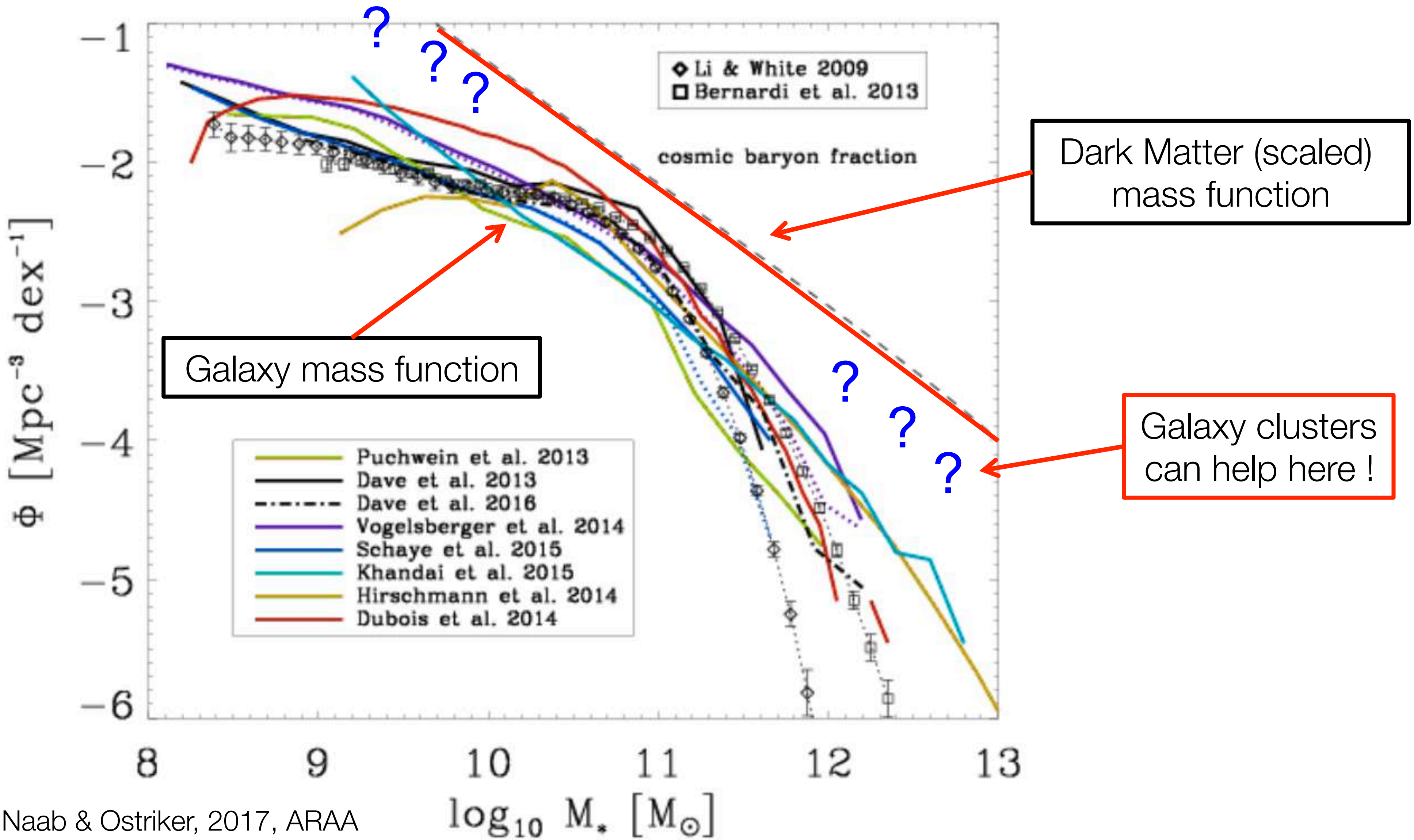
confidence limits

Parameter	Planck alone	Planck + BAO
$\Omega_b h^2$	0.02237 ± 0.00015	0.02242 ± 0.0001
$\Omega_c h^2$	0.1200 ± 0.0012	0.11933 ± 0.00091
$100\theta_{MC}$	1.04092 ± 0.00031	1.04101 ± 0.00029
τ	0.0544 ± 0.0073	0.0561 ± 0.0071
$\ln(10^{10} A_s)$	3.044 ± 0.014	3.047 ± 0.014
n_s	0.9649 ± 0.0042	0.9665 ± 0.0038
H_0	67.36 ± 0.54	67.66 ± 0.42
Ω_Λ	0.6847 ± 0.0073	0.6889 ± 0.0056
Ω_m	0.3153 ± 0.0073	0.3111 ± 0.0056
$\Omega_m h^2$	0.1430 ± 0.0011	0.14240 ± 0.00087
$\Omega_m h^3$	0.09633 ± 0.00030	0.09635 ± 0.00030
σ_8	0.8111 ± 0.0060	0.8102 ± 0.0060
$\sigma_8(\Omega_m/0.3)^{0.5}$	0.832 ± 0.013	0.825 ± 0.011
z_{re}	7.67 ± 0.73	7.82 ± 0.71
Age[Gyr]	13.797 ± 0.023	13.787 ± 0.020
r_*[Mpc]	144.43 ± 0.26	144.57 ± 0.22
$100\theta_*$	1.04110 ± 0.00031	1.04119 ± 0.00029
r_{drag}[Mpc]	147.09 ± 0.26	147.57 ± 0.22
z_{eq}	3402 ± 26	3387 ± 21
k_{eq}[Mpc^{-1}]	0.010384 ± 0.000081	0.010339 ± 0.000063
Ω_K	-0.0096 ± 0.0061	0.0007 ± 0.0019
Σm_ν [eV]	< 0.241	< 0.120
N_{eff}	$2.89^{+0.36}$ [illegible]	$2.99^{+0.34}_{-0.33}$
$r_{0.002}$	< 0.101	< 0.106

Planck 2018

courtesy WM... ...mont

halo mass function: DM, baryons, processes



Naab & Ostriker, 2017, ARAA
See also Moster et al., 2010

galaxy clusters ? protoclusters ?

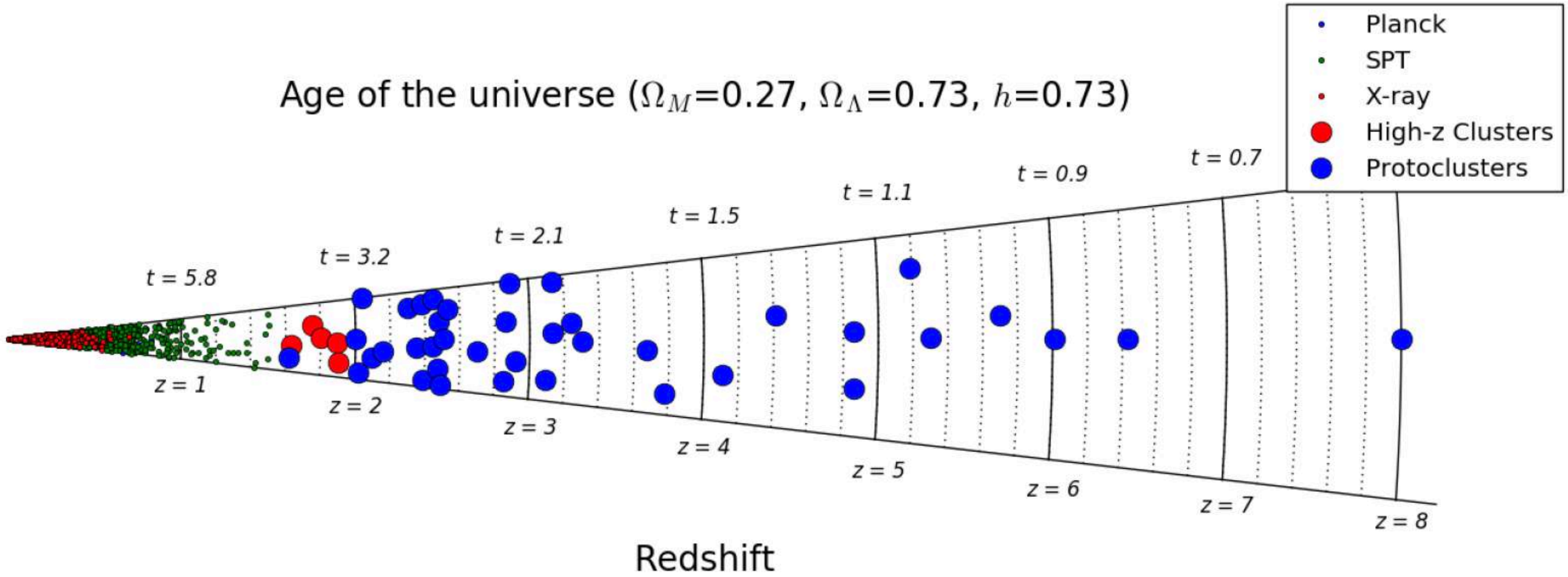
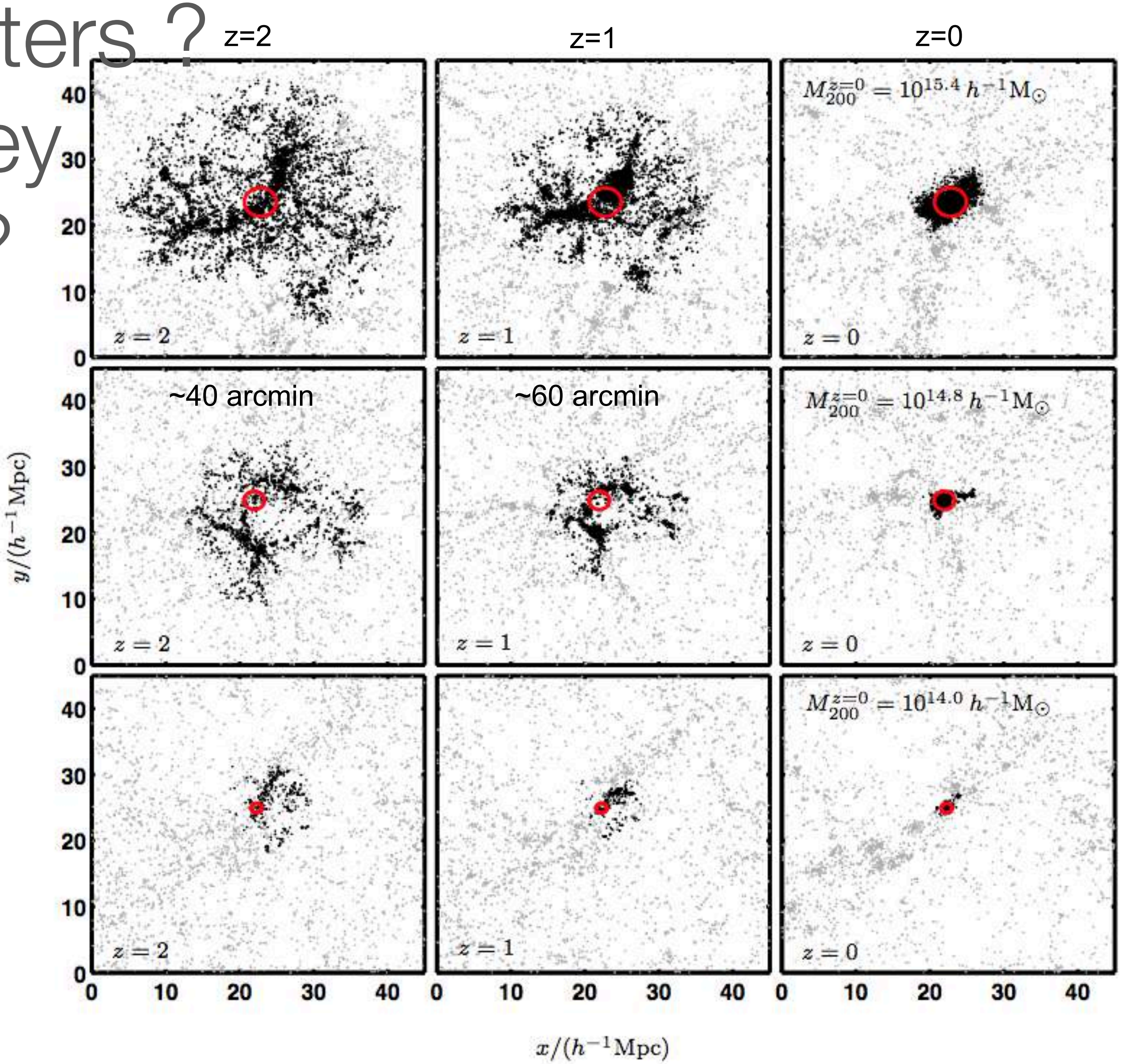


Fig. 5 The distribution of redshifts of protoclusters selected from the literature (large blue symbols). The data for clusters below $z = 1.5$ was taken from the compilation of clusters detected in X-ray and SZ surveys of Bleem et al. (2015). Large red symbols are high redshift clusters at $z > 1.6$. The position of objects along the polar axis holds no information and is used for visibility purposes only. Redshifts and ages (in Gyr) are indicated along the radial axes.

Overzier, 2016

galaxy clusters ? why are they important ?

galaxies

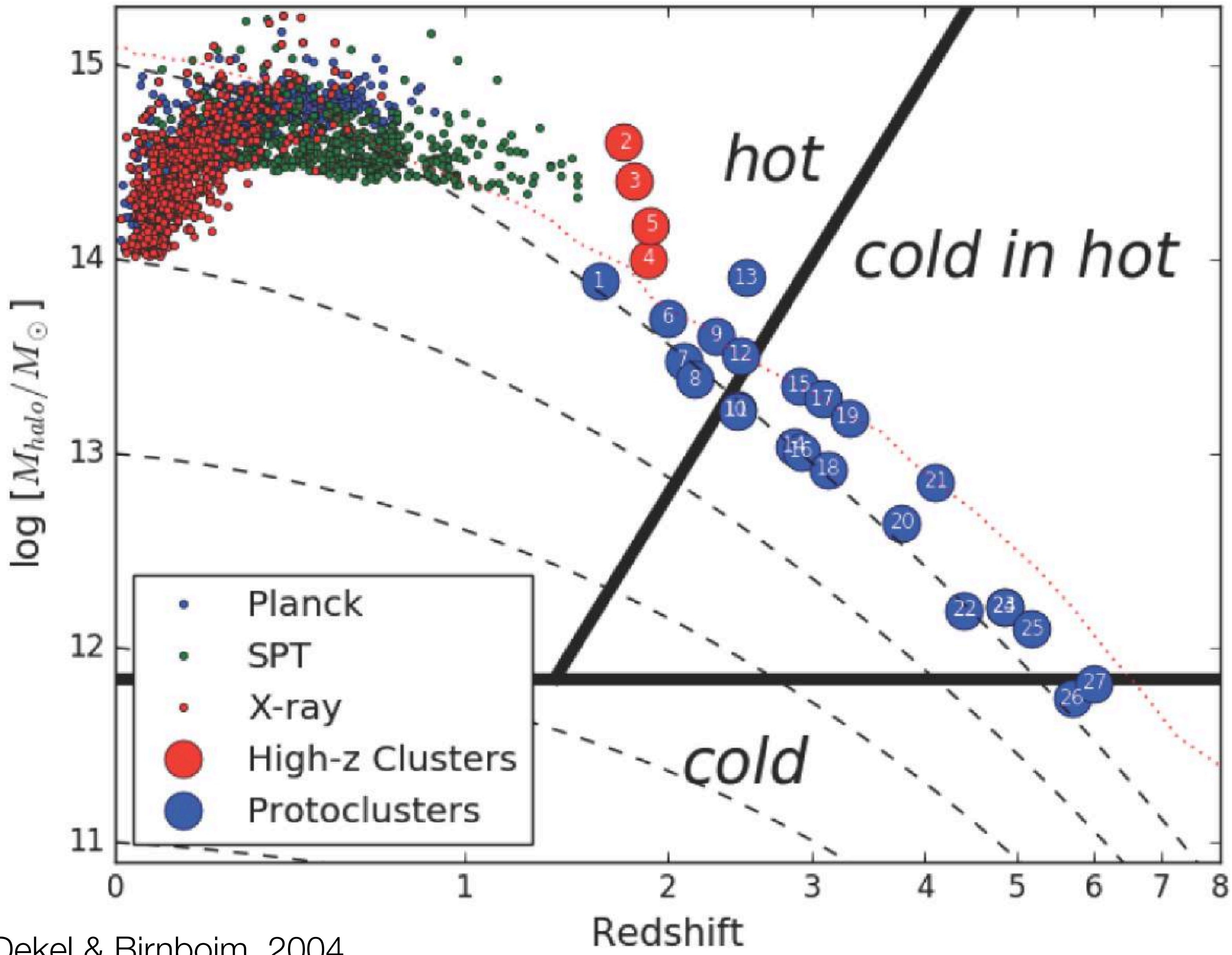


Muldrew et al., 2015

Figure 1. The spatial extent of protoclusters at $z = 2$ (left panel), 1 (centre panel) and 0 (right panel), with final cluster masses of $M_{200}^{z=0} = 10^{15.4}\,h^{-1}\mathrm{M}_\odot$ (top row), $10^{14.8}\,h^{-1}\mathrm{M}_\odot$ (middle row) and $10^{14.0}\,h^{-1}\mathrm{M}_\odot$ (bottom row). Each window is $45 \times 45\,h^{-1}$Mpc comoving, which corresponds to 41 arcmin and 65 arcmin at $z = 2$ and $z = 1$ respectively (Wright 2006). Black points represent a galaxy of stellar mass greater than $10^8\,h^{-1}\mathrm{M}_\odot$ that will end up in the cluster while grey points represent those that will not. (Only 25 per cent of the background galaxies, grey points, are plotted to reduce image size.) The red circle corresponds to the $z = 0$ centre and comoving viral radius of the cluster.

low-z, high-z clusters ? Protoclusters ?

Halo mass



Overzier, 2016
adapted from Dekel & Birnboim, 2004

low-z, high-z clusters ? Protoclusters ?

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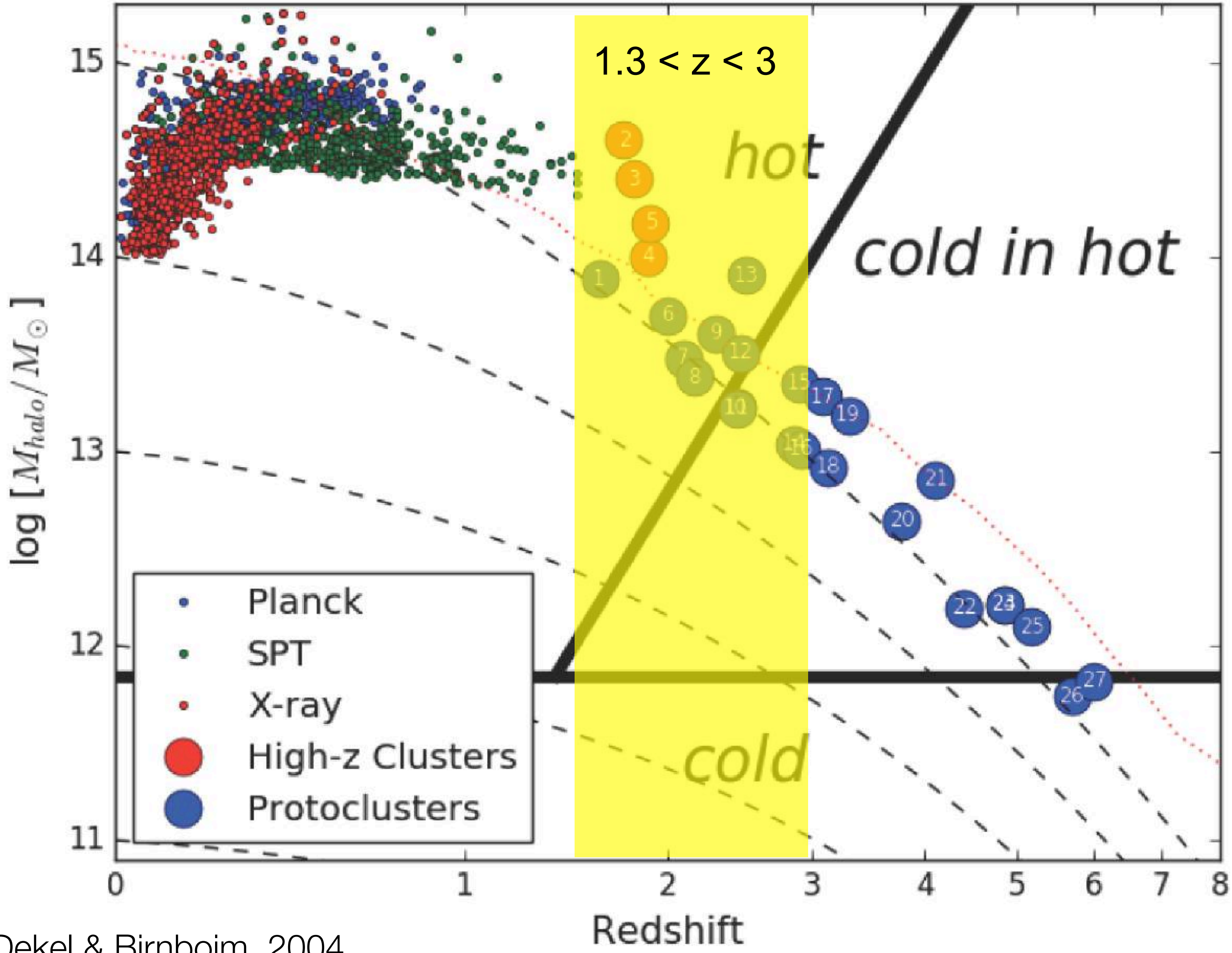
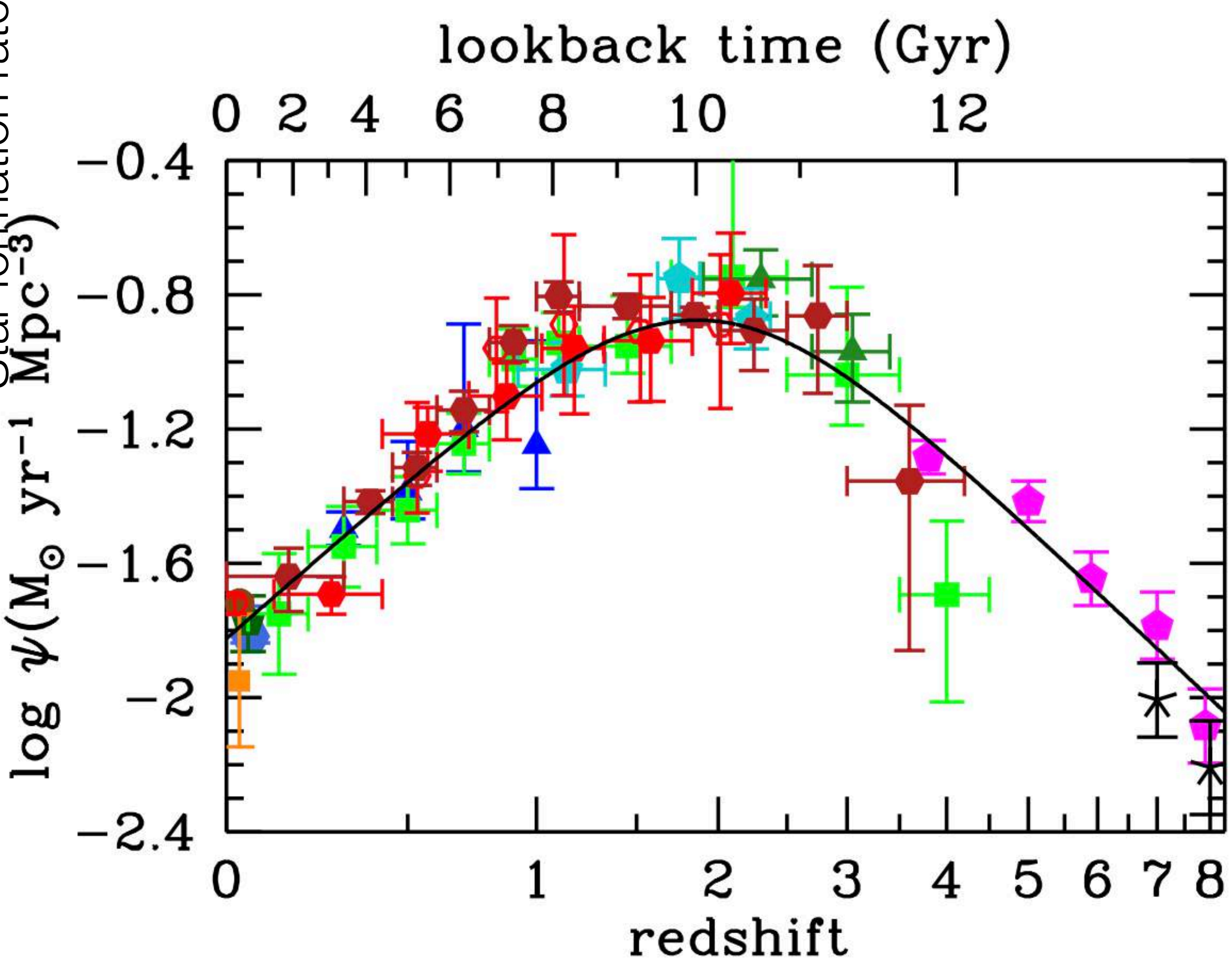


Overzier, 2016
adapted from Dekel & Birnboim, 2004

star formation and stars in the universe

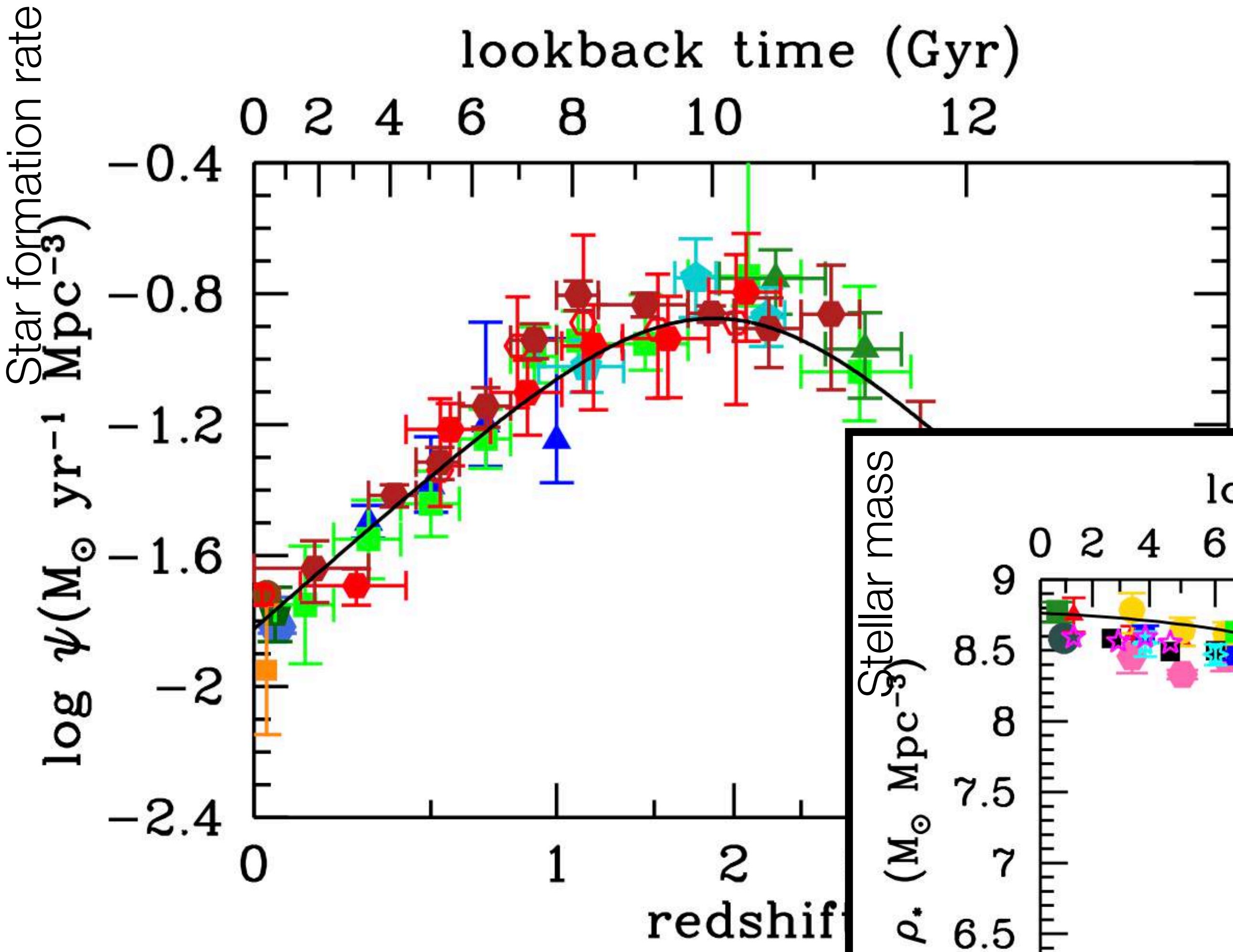
Star formation rate

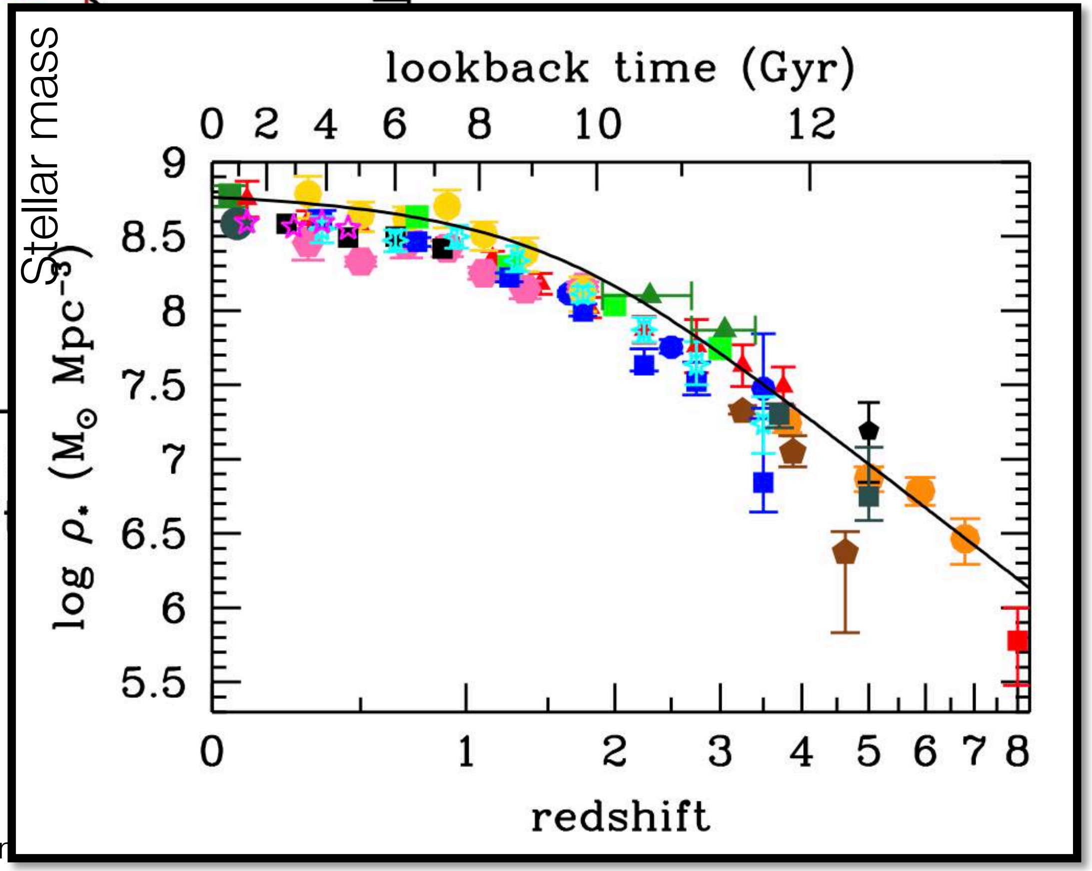


« cosmic noon » at z~2

Madau & Dickinson, 2014, ARAA

star formation and stars in the universe





« cosmic noon » at z~2

Madau & Dickinson, 2014, ARAA

protoclusters are actively star-forming

Star formation rate density

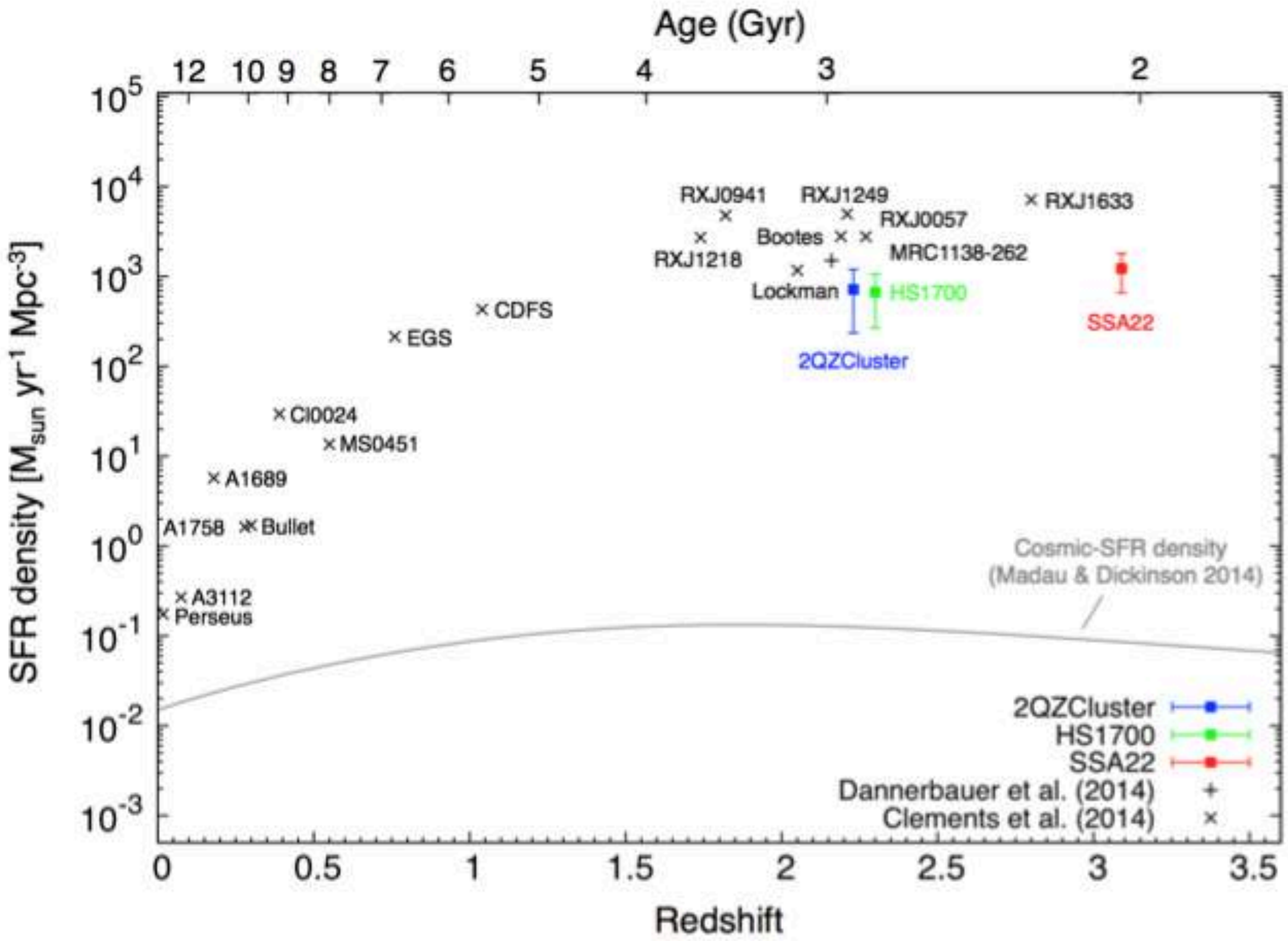
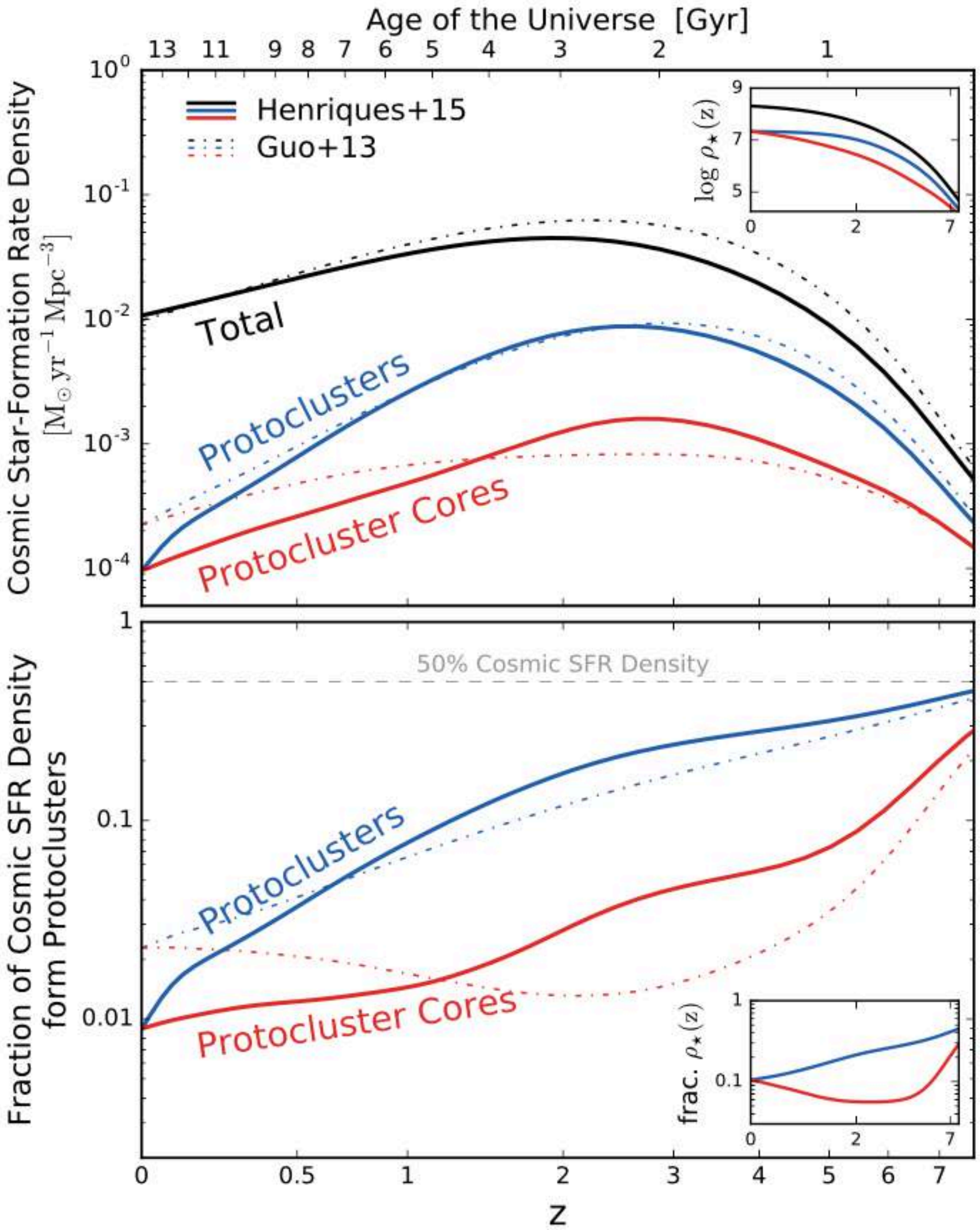


Figure 5. SFR density of clusters, protoclusters and global cosmic SFR densities. The SFR densities of our protoclusters are 10^3–10^4 times higher than the global SFR density (Madau & Dickinson 2014). We show the compilation from Dannerbauer et al. (2014) and data from Clements et al. (2014), which original literature are following; *IRAS* measurements of Perseus from Meusinger, Brunzendorf, & Krieg (2000), BLAST measurements of A3112 from Braglia et al. (2011), *ISO* measurements of A1689 from Fadda et al. (2000), and *Spitzer* measurements of A1758 from Haines et al. (2009), Bullet cluster from Chung et al. (2010), Cl0024+16 and MS0451-03 from Geach et al. (2006). RXJ0057, RXJ0941, RXJ1218, RXJ1249 and RXJ1633 are based on JCMT/SCUBA from Stevens et al. (2010).

Kato+2016

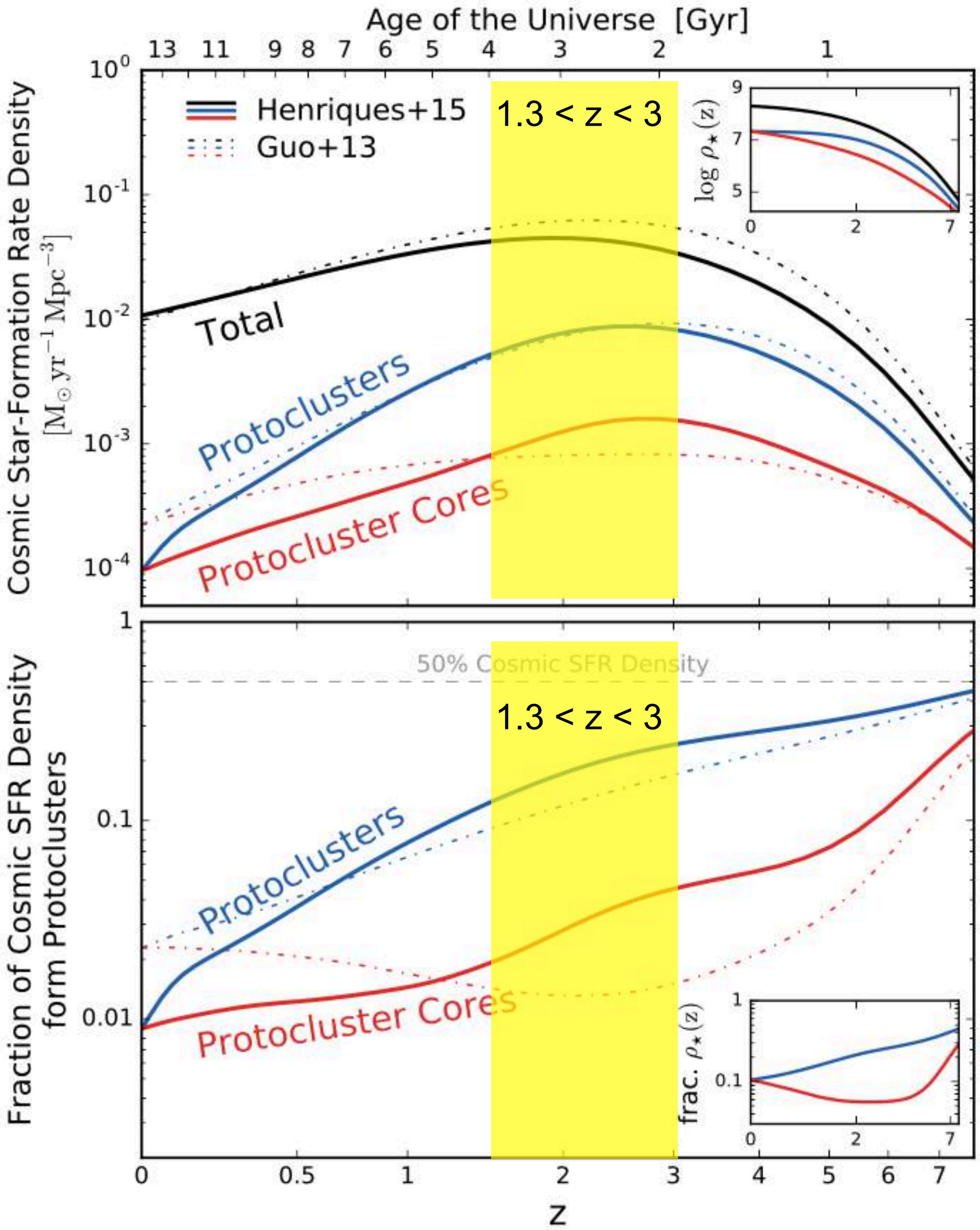
star formation in high-z clusters



Chiang et al., 2017

FIG. 4.— **Upper panel:** SFR density for all galaxies (black), protoclusters (blue), and cores (red). The associated stellar mass densities are shown in the inset. **Lower panel:** Fractional contributions to the total cosmic SFR density of protoclusters (blue) and protocluster cores (red). The associated stellar mass density fractions are shown in the inset.

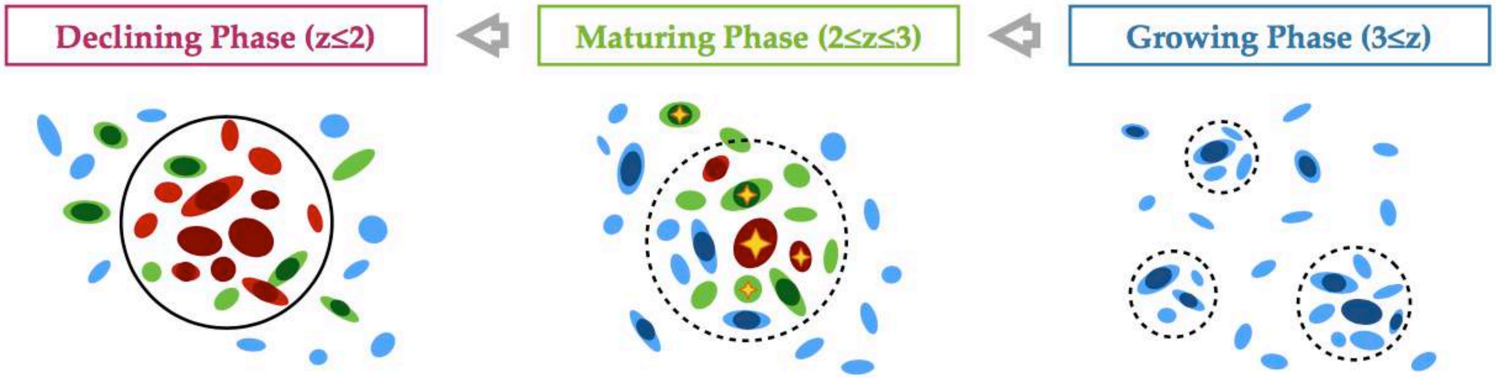
star formation in high-z clusters



Chiang et al., 2017

FIG. 4.— **Upper panel:** SFR density for all galaxies (black), protoclusters (blue), and cores (red). The associated stellar mass densities are shown in the inset. **Lower panel:** Fractional contributions to the total cosmic SFR density of protoclusters (blue) and protocluster cores (red). The associated stellar mass density fractions are shown in the inset.

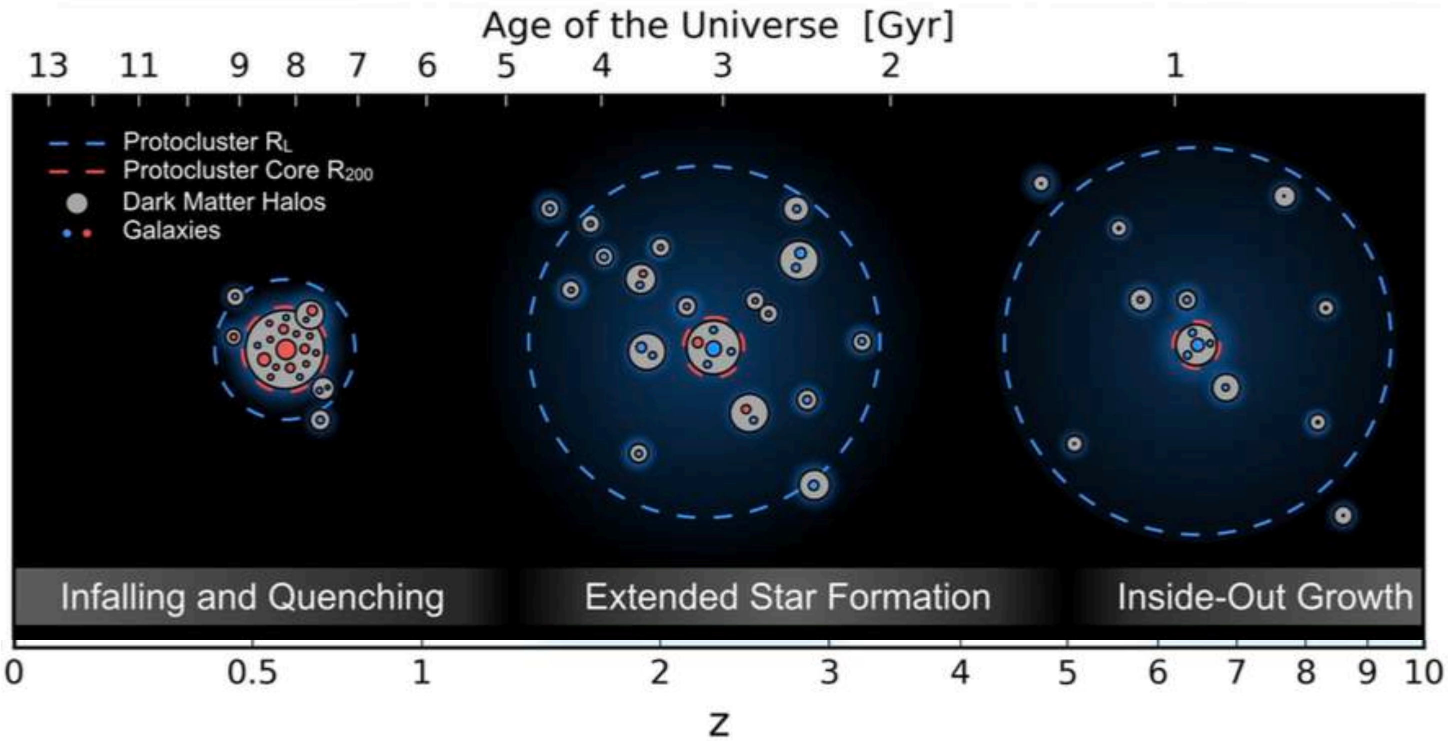
protoclusters, clusters: formation



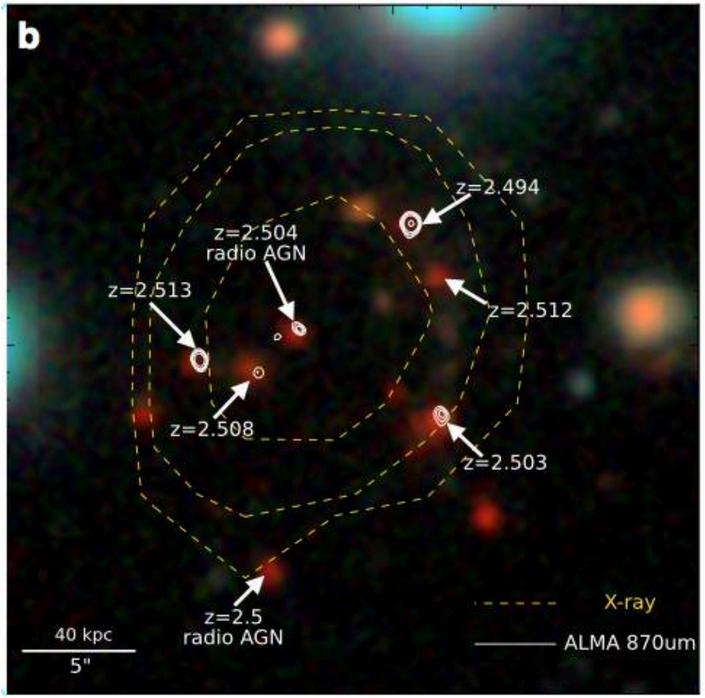
	Declining Phase	Maturing Phase	Growing Phase
Galaxies	Starvation / Environmental quenching	Energetic AGN feedback	Massive galaxy formation
Halo Gas	Cold gas depletion / Superheated plasma	Pre-heating / Core collapse	Cold gas stream in hot gas

Schimakawa et al., 2018
arXiv:1809.08755

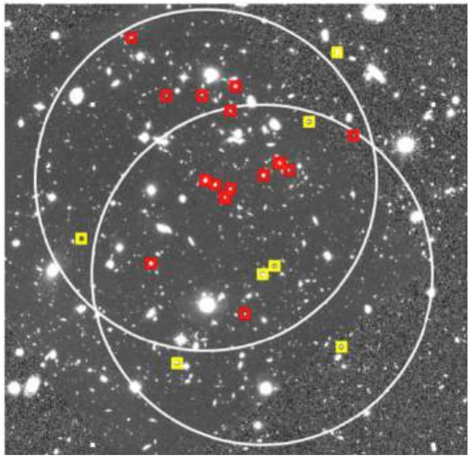
Chiang et al., 2017
arXiv:1705.01634



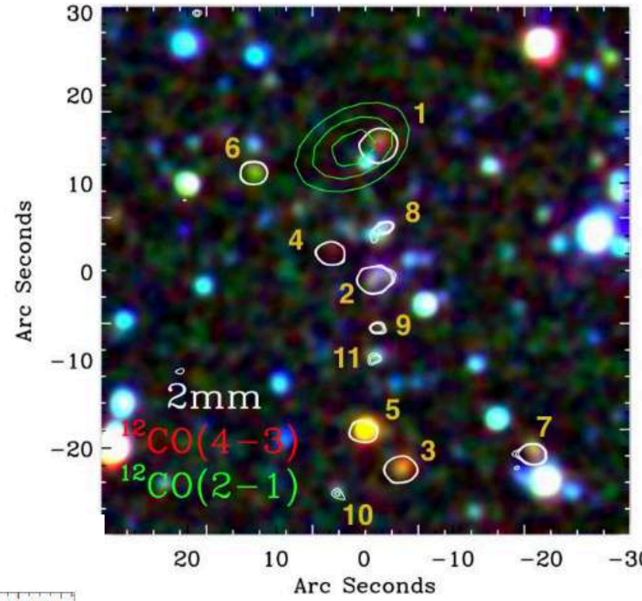
few examples of famous (proto)clusters



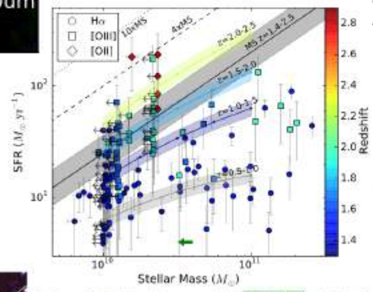
Wang et al., 2016 z=2.5



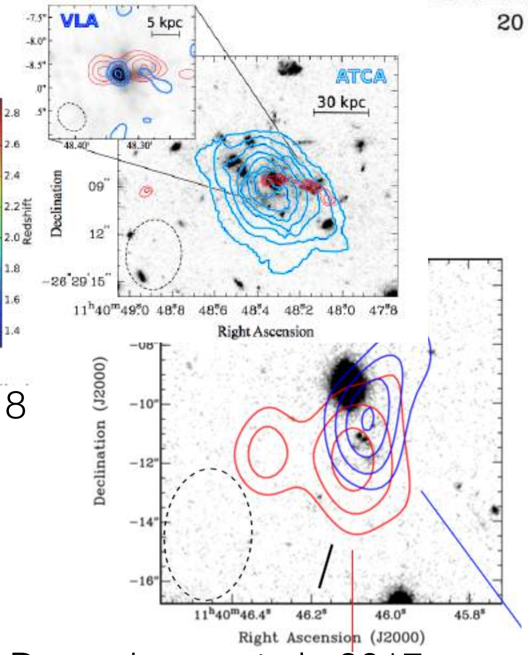
Mei et al., 2015 z=1.9



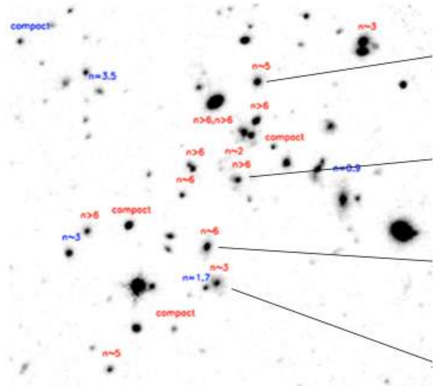
Oteo et al., 2018 z=4.0



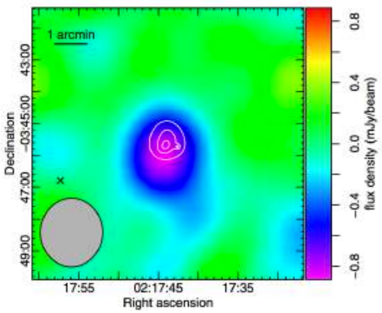
Noirot et al., 2018
z<2.8

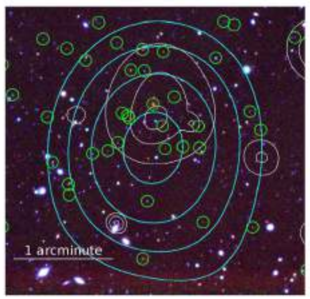


Dannerbauer et al., 2017
Emonts et al., 2018 z=2.16

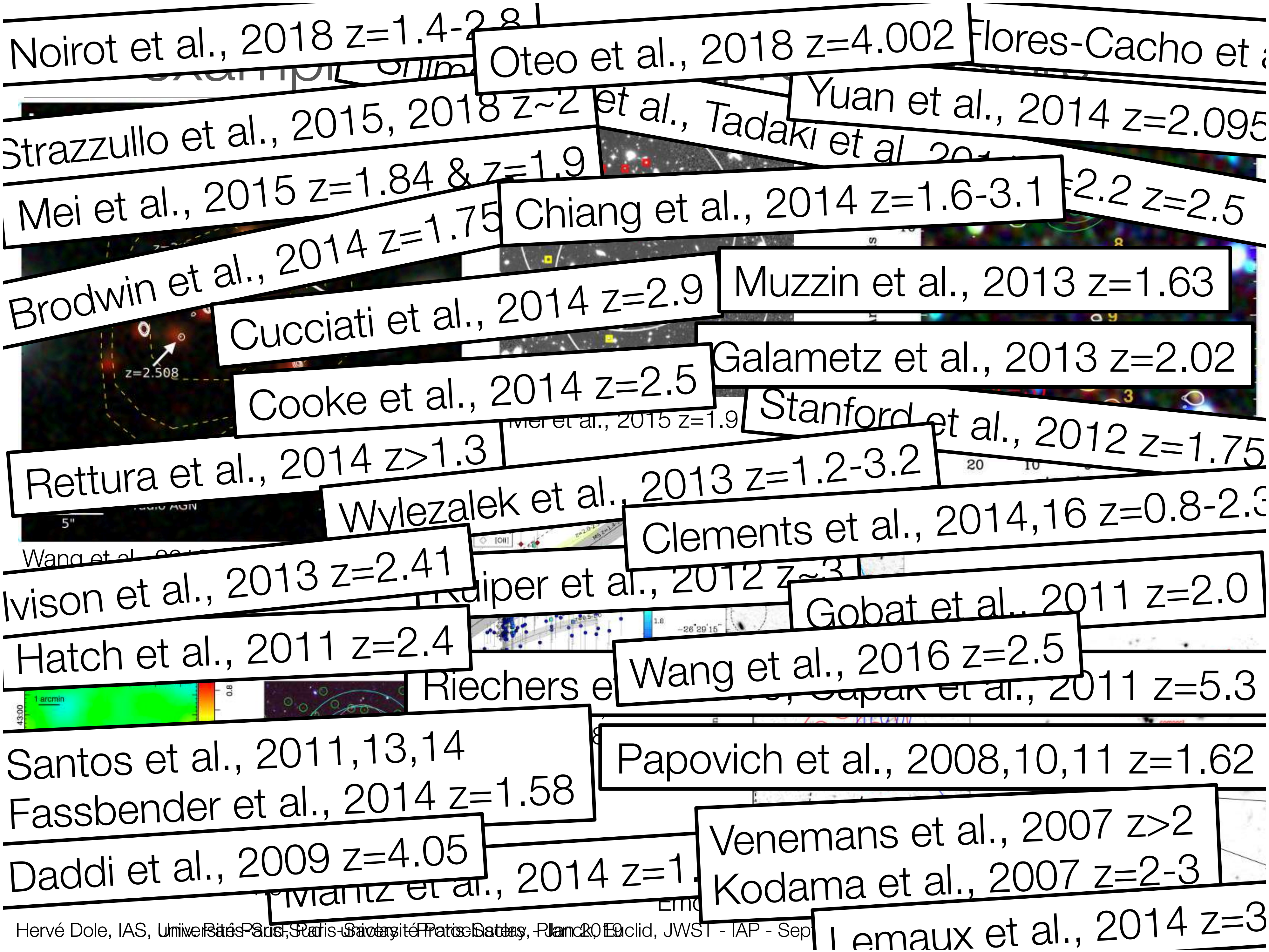


Gobat et al., 2011 z=2.07





Mantz et al., 2014 z=1.9



Noirot et al., 2018 z=1.4-2.8
Oteo et al., 2018 z=4.002
Flores-Cacho et a
Yuan et al., 2014 z=2.095
Strazzullo et al., 2015, 2018 z~2
et al., Tadaki et al
z=2.2 z=2.5
Mei et al., 2015 z=1.84 & z=1.9
Chiang et al., 2014 z=1.6-3.1
Brodwin et al., 2014 z=1.75
Muzzin et al., 2013 z=1.63
Cucciati et al., 2014 z=2.9
Galametz et al., 2013 z=2.02
Cooke et al., 2014 z=2.5
z=2.508
Mei et al., 2015 z=1.9
Stanford et al., 2012 z=1.75
Rettura et al., 2014 z>1.3
Wylezalek et al., 2013 z=1.2-3.2
Clements et al., 2014,16 z=0.8-2.3
5"
Ivison et al., 2013 z=2.41
Kuiper et al., 2012 z~3
Gobat et al., 2011 z=2.0
Hatch et al., 2011 z=2.4
Wang et al., 2016 z=2.5
Riechers et
Capak et al., 2011 z=5.3
1 arcmin
Santos et al., 2011,13,14
Fassbender et al., 2014 z=1.58
Papovich et al., 2008,10,11 z=1.62
Venemans et al., 2007 z>2
Daddi et al., 2009 z=4.05
Mantz et al., 2014 z=1.
Kodama et al., 2007 z=2-3
Lemaux et al., 2014 z=3

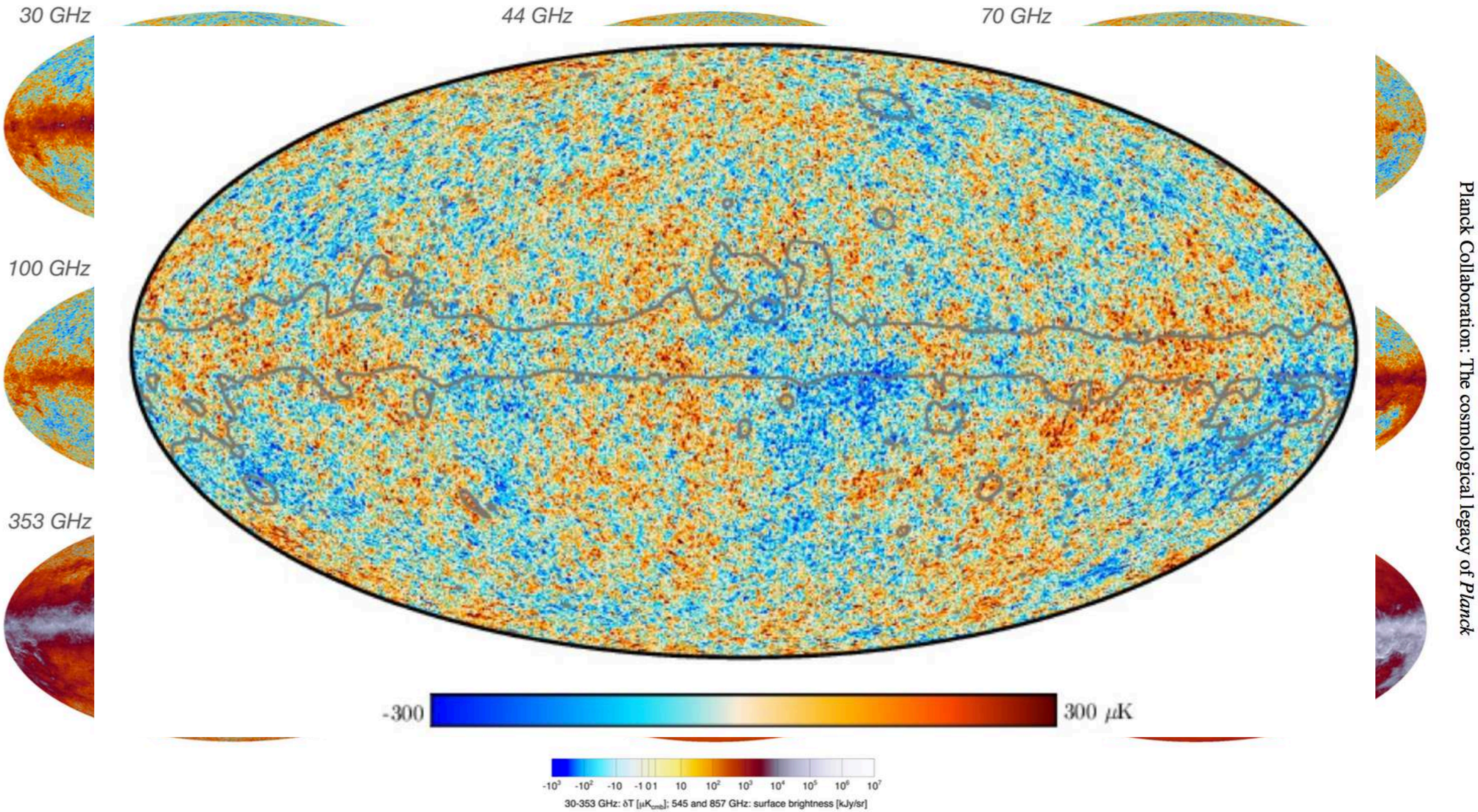
Clusters selected by **stellar mass** and/or **overdensities**
Fairly mature ?
Vis, NIR

Clusters selected by **hot gas**
Relaxed haloes
X-rays, SZ

Clusters selected by **Star formation rate**
Young ?
Submm, radio
NIR, MIR, FIR?

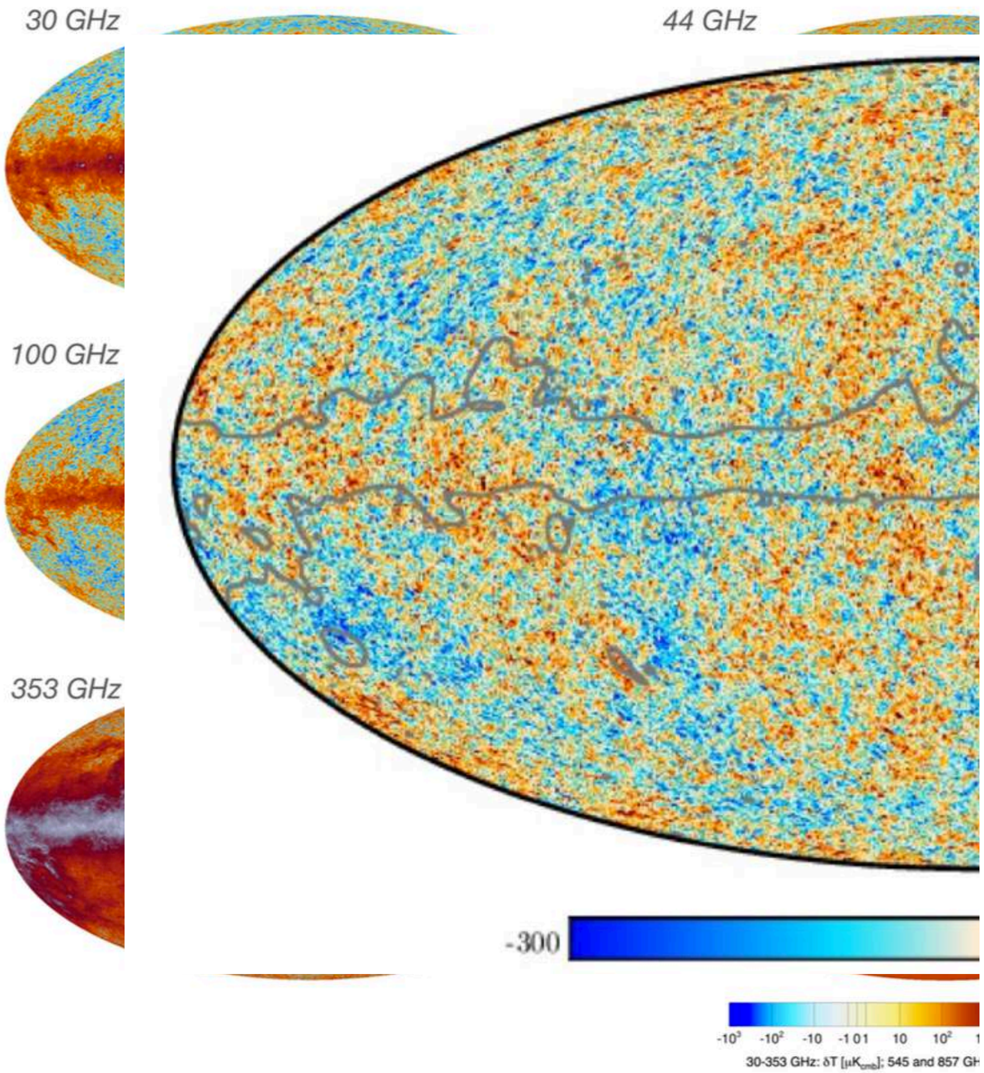
Noirot et al., 2018 z=1.4-2.8
Oteo et al., 2018 z=4.002
Flores-Cacho et al.
Yuan et al., 2014 z=2.095
Strazzullo et al., 2015, 2018 z~2
Tadaki et al.
Brodwin et al.
Muzzin et al., 2013 z=1.63
Cucciati et al., 2014
Cooke et al., 2014 z=2.5
Rettura et al., 2014 z>1.3
Wylezalek et al., 2013
Clements et al., 2014,16 z=0.8-2.3
Ivison et al., 2013 z=2
Kuiper et al., 2012
Gobat et al., 2011 z=2.0
Hatch et al., 2011 z=2.4
Wang et al., 2016 z=2.5
Riechers et al.
Capak et al., 2011 z=5.3
Santos et al., 2011,13,14
Papovich et al., 2008,10,11 z=1.62
Fassbender et al., 2014 z=1.58
Venemans et al., 2007 z>2
Daddi et al., 2009 z=4.05
Mantz et al., 2014 z=1.
Kodama et al., 2007 z=2-3
Lemaux et al., 2014 z=3

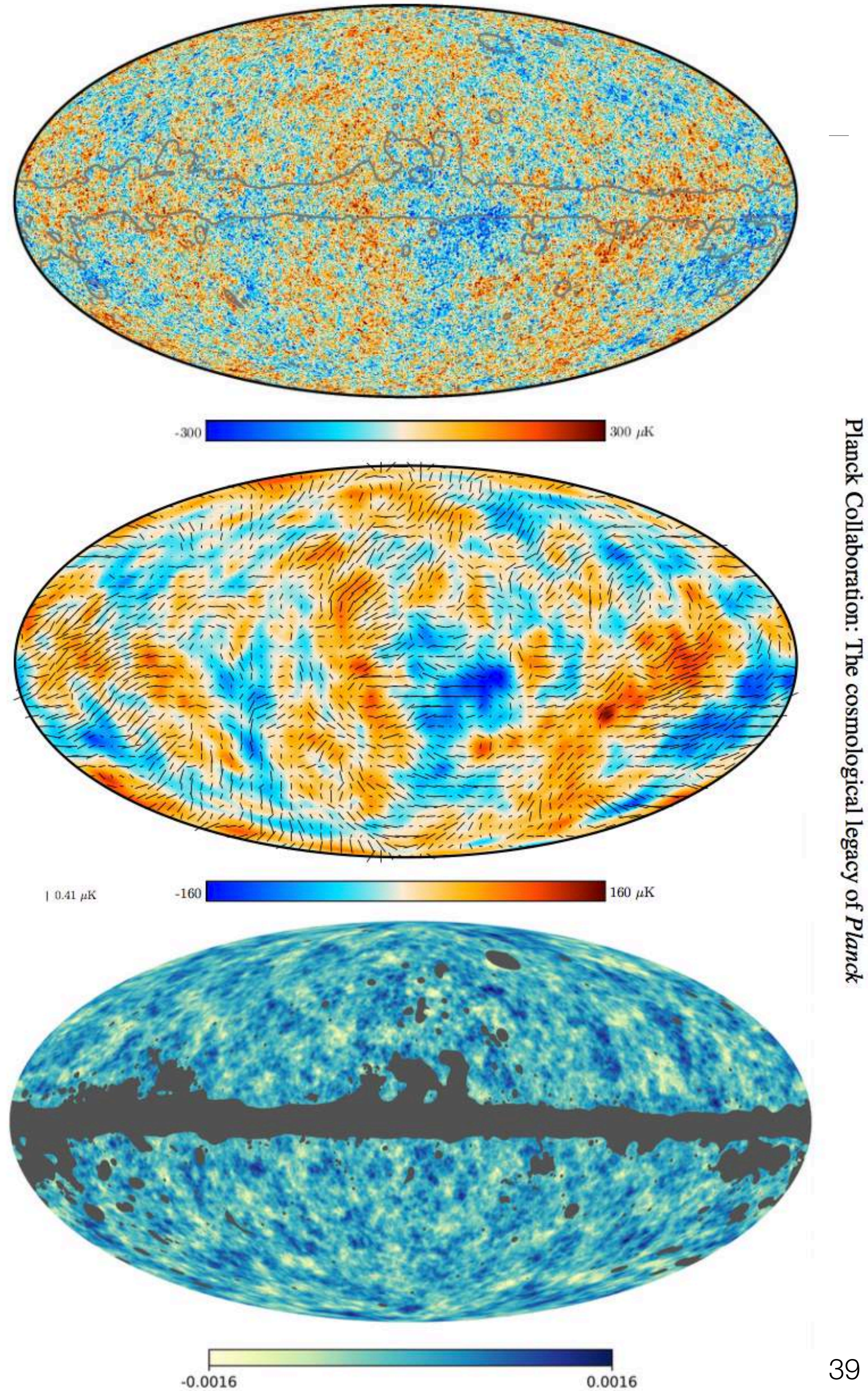
5. How Planck selected high-z high-SFR Cl?



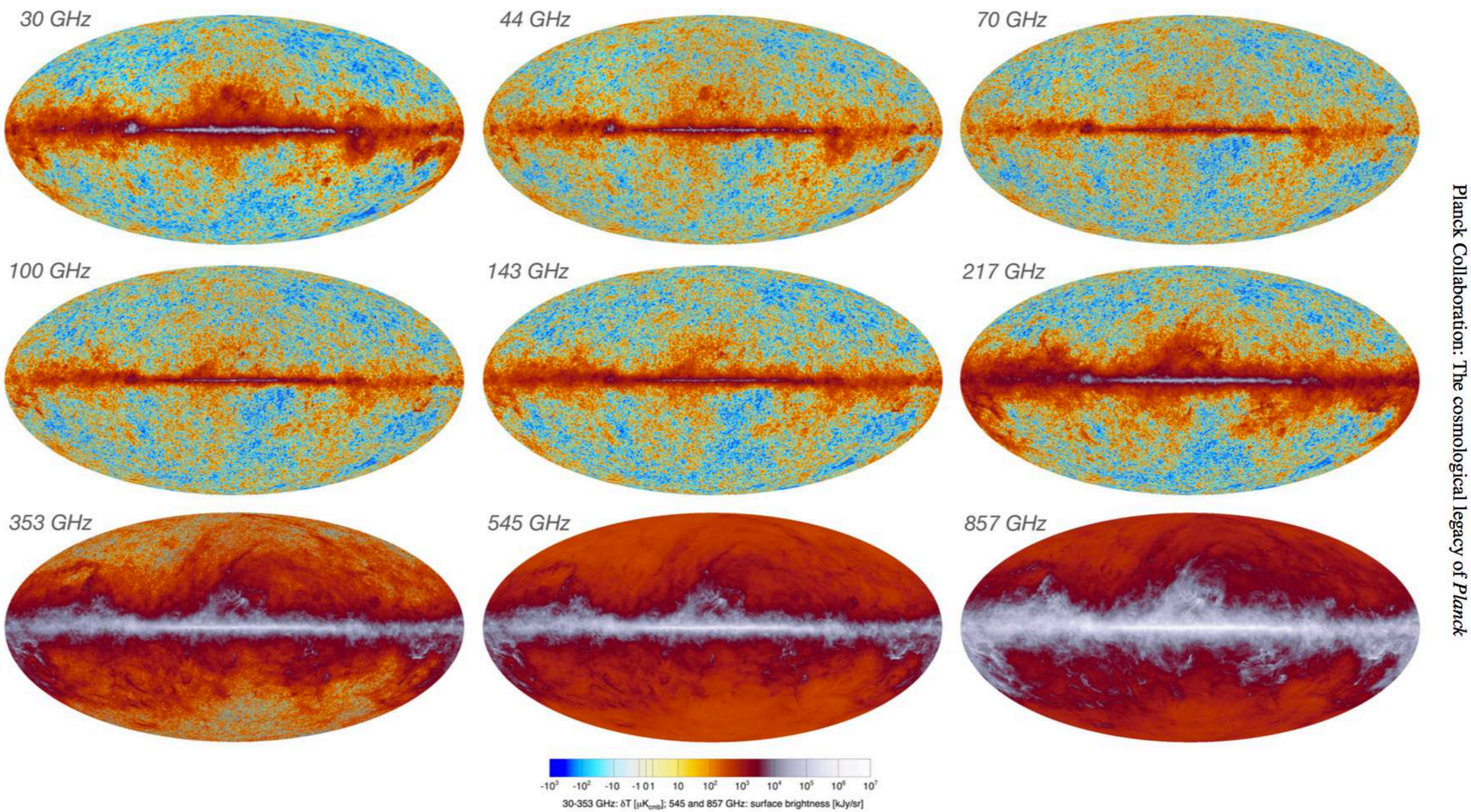
Planck 2018, I

5. How Planck selecte





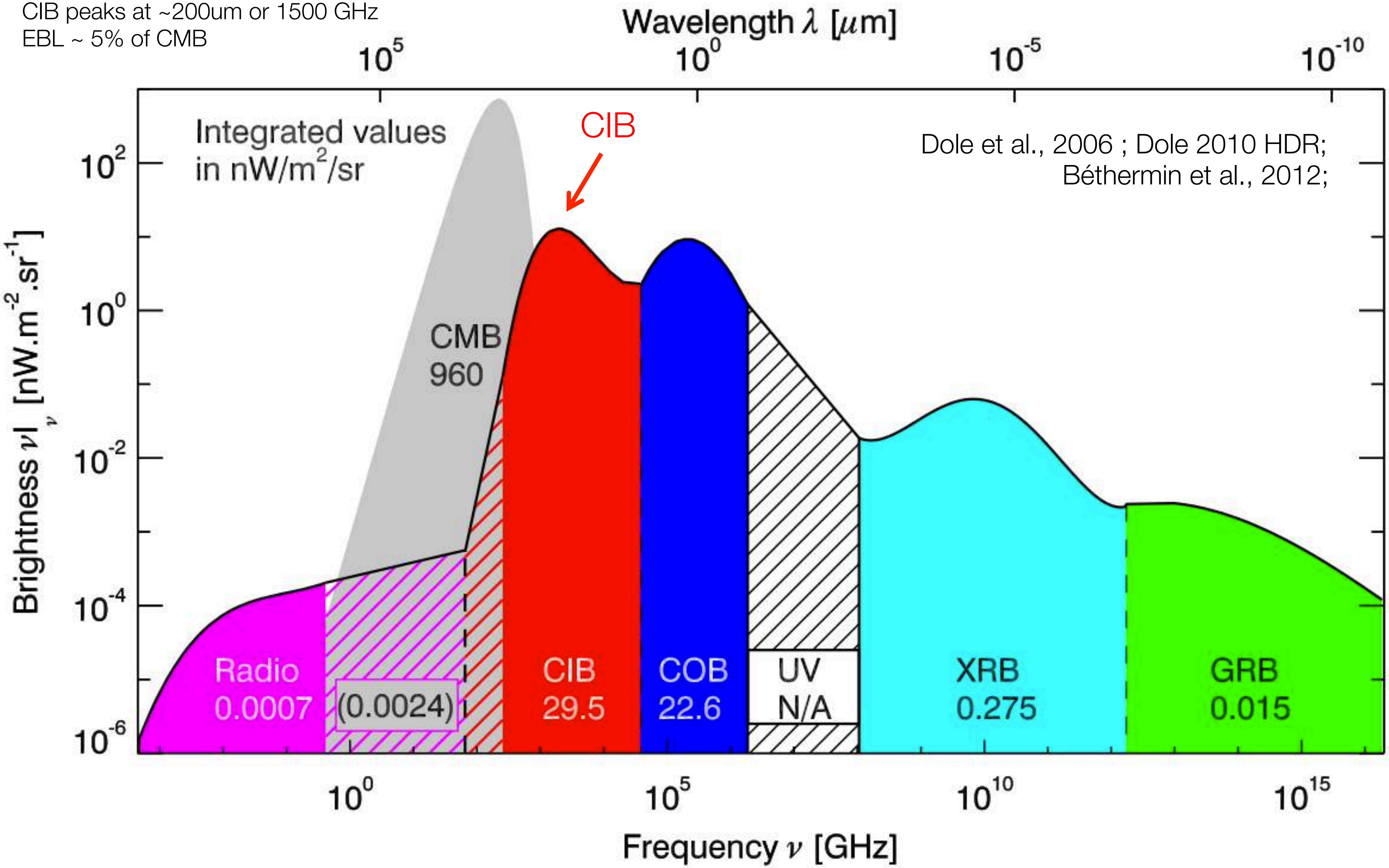
5. How Planck selected high-z high-SFR Cl?



Planck 2018, I

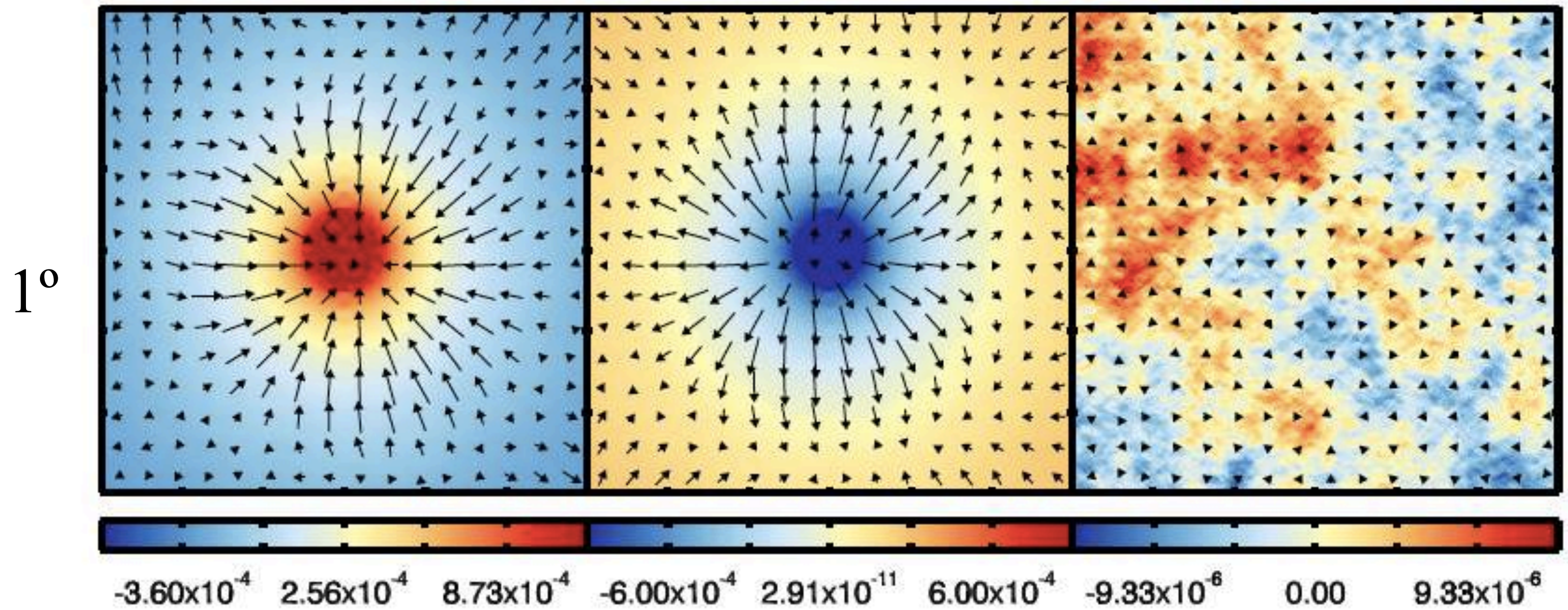
Extragalactic Background Light SED

CIB > COB
CIB peaks at ~200um or 1500 GHz
EBL ~ 5% of CMB



CIB peaks correspond to mass peaks…

545 GHz



... and the CIB probes also high-z SFR

-> a novel method to search for high-z clusters in formation
(CIB > high SFR > massive high-z clusters)

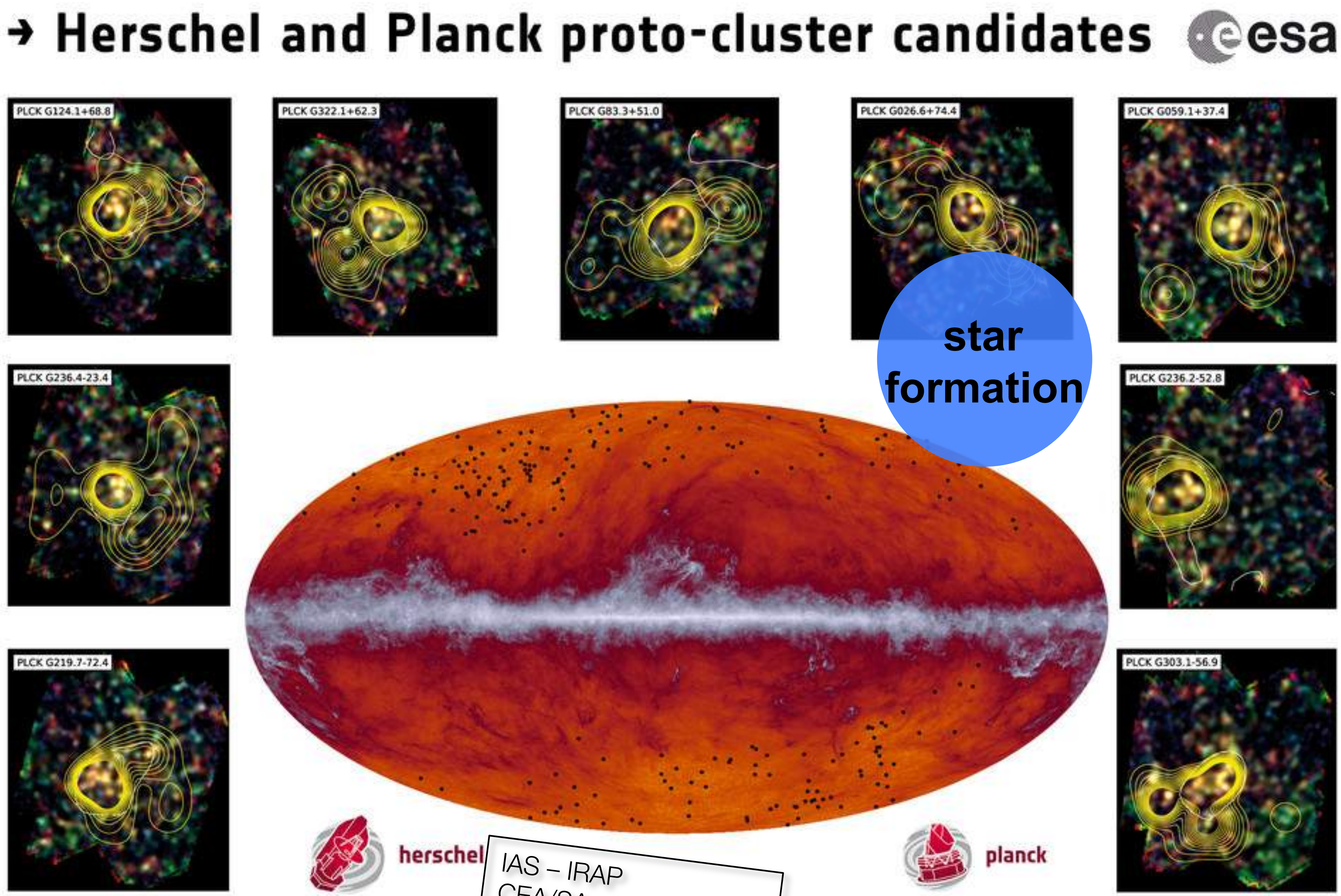
Planck 15 months
Planck Collaboration, 2013, 18

high-SFR high-z clusters

Planck selection:

Cold spots of the CIB

Color selection



star formation

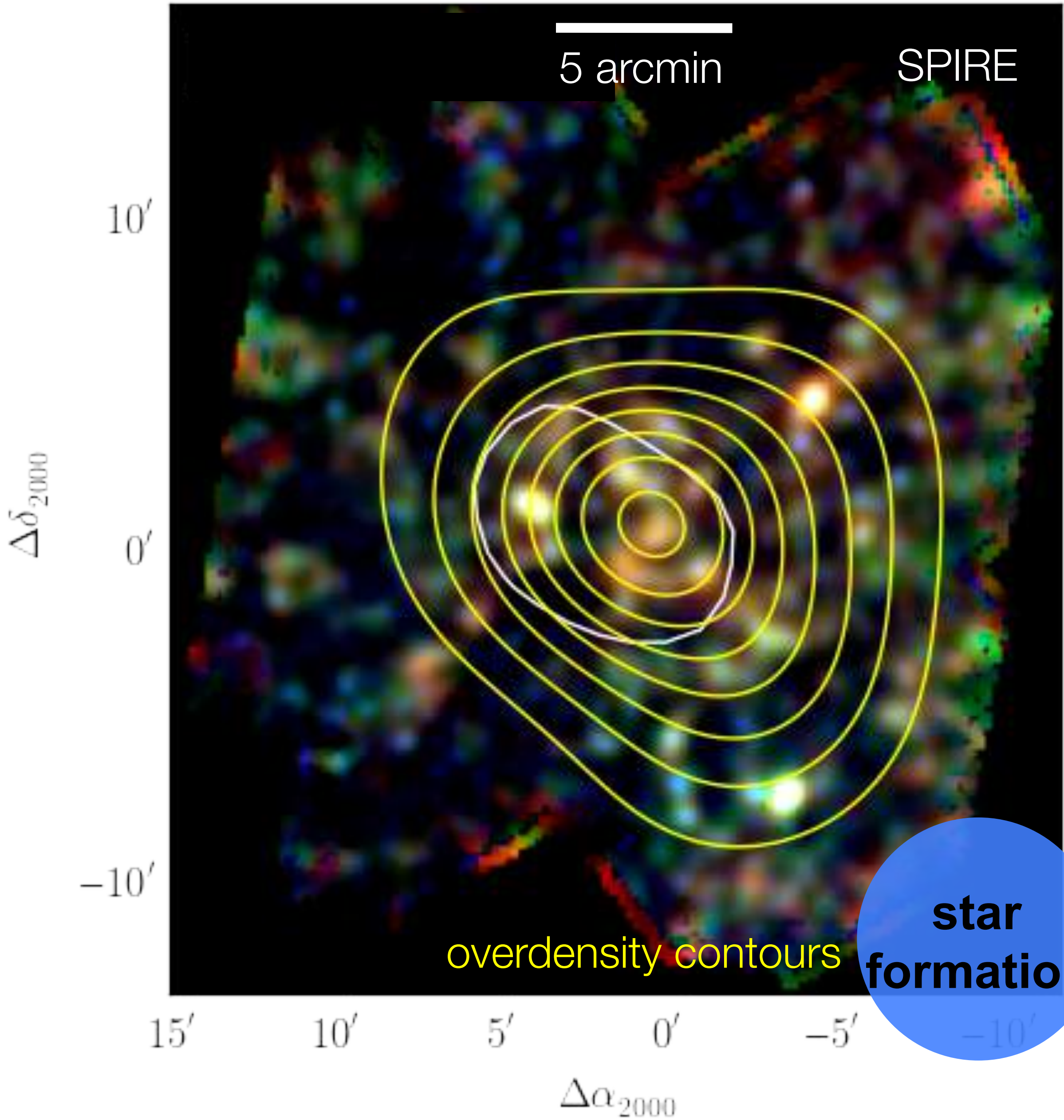
Thèse: David Guéry

IAS – IRAP
CEA/SAp/AIM – LUTh
LAM – IPAG – LPSC
Caltech – UofA – ESAC

Planck Collab., 2015, Int XXVII, arXiv:1506.01962
Planck Collab., 2016, Int XXXIX, arXiv:1508.04171
Press Releases: ESA, NASA, INSU, A&A

the case of one field: Herschel & Spitzer

Herschel-SPIRE
3-color image:
blue = 250um
green = 350um
red = 500um



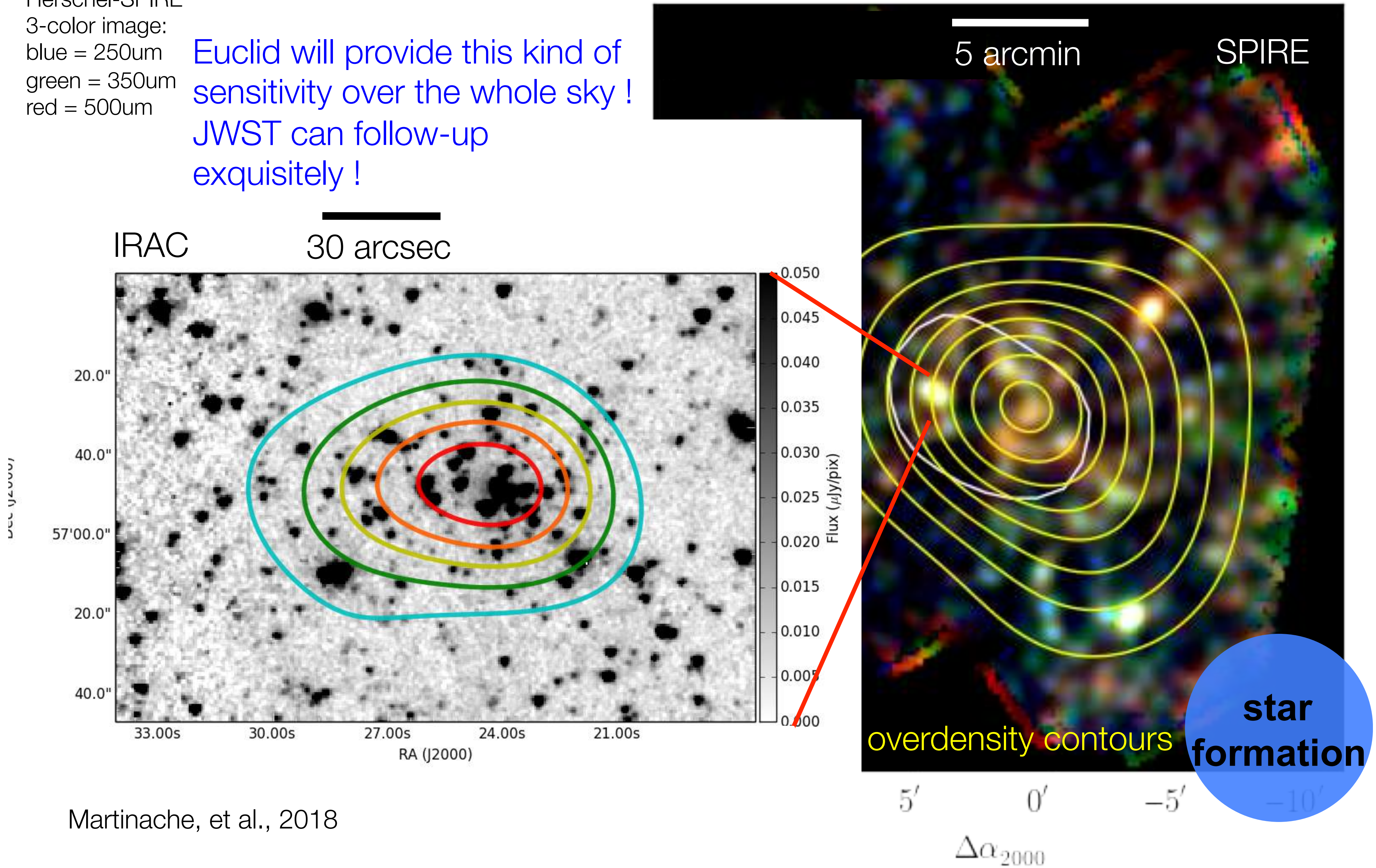
star formation

Thèse: Clément Martinache

the case of one field: Herschel & Spitzer

Herschel-SPIRE
3-color image:
blue = 250um
green = 350um
red = 500um

Euclid will provide this kind of sensitivity over the whole sky ! JWST can follow-up exquisitely !

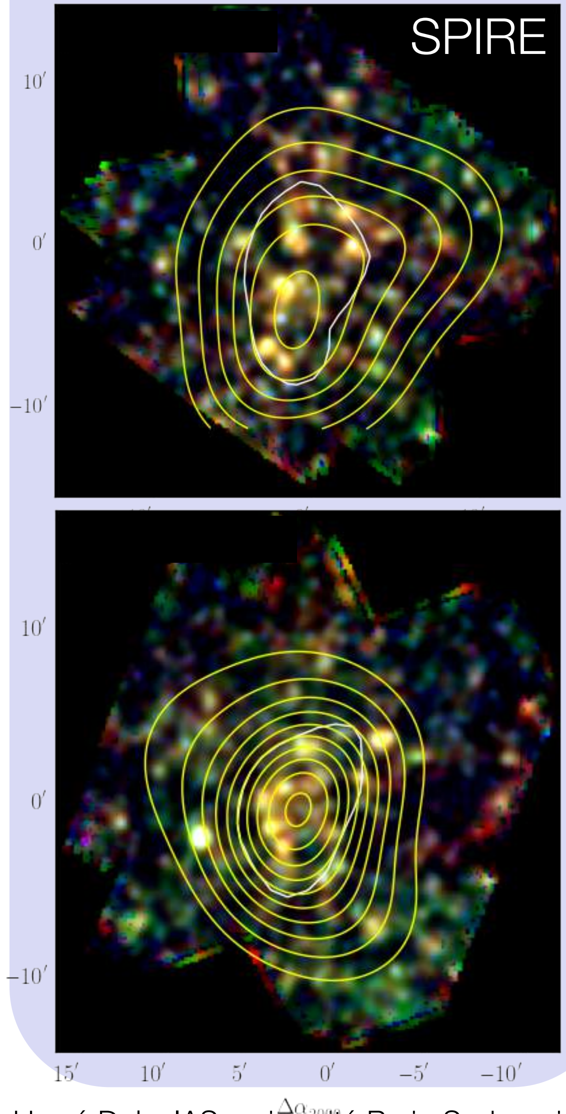


Martinache, et al., 2018

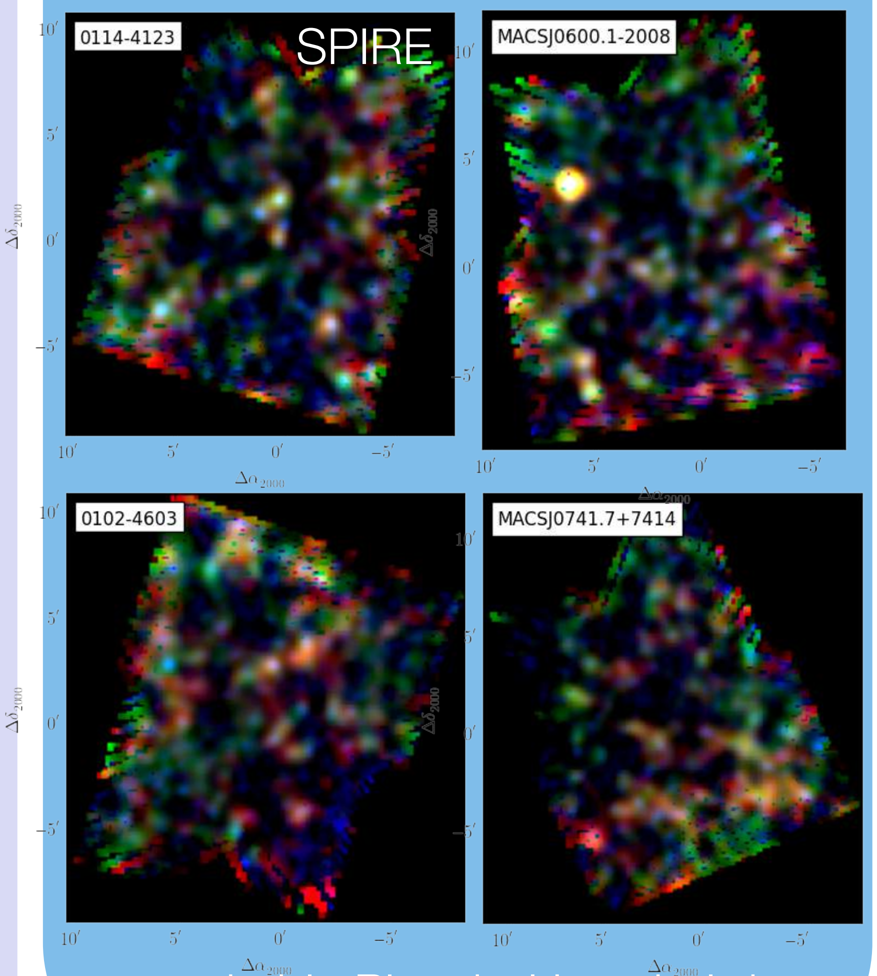
Thèse: Clément Martinache

5.2 what do we learn from imaging ? Overdensities

Planck/Herschel HPASSS
30’ x 30’ (Planck subm)

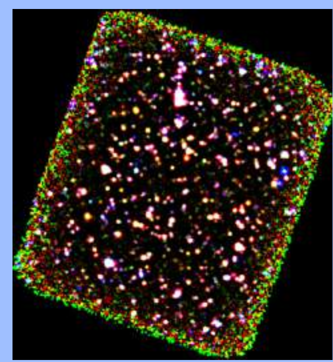


HLS 20’ x 20’
(Egami+2010)



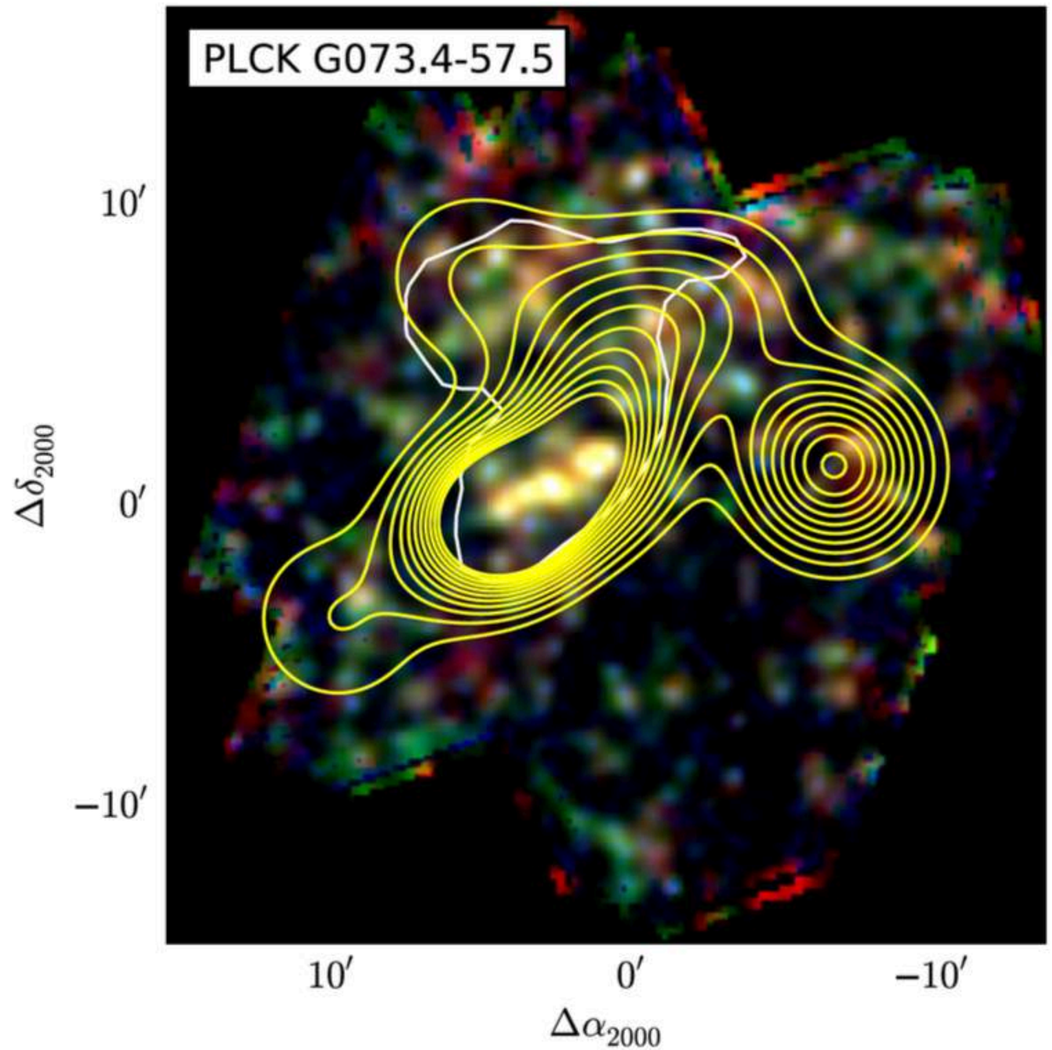
a remarkable Planck+Herschel datase
among others

GOODS 16’ x 10’
(Elbaz+2011)



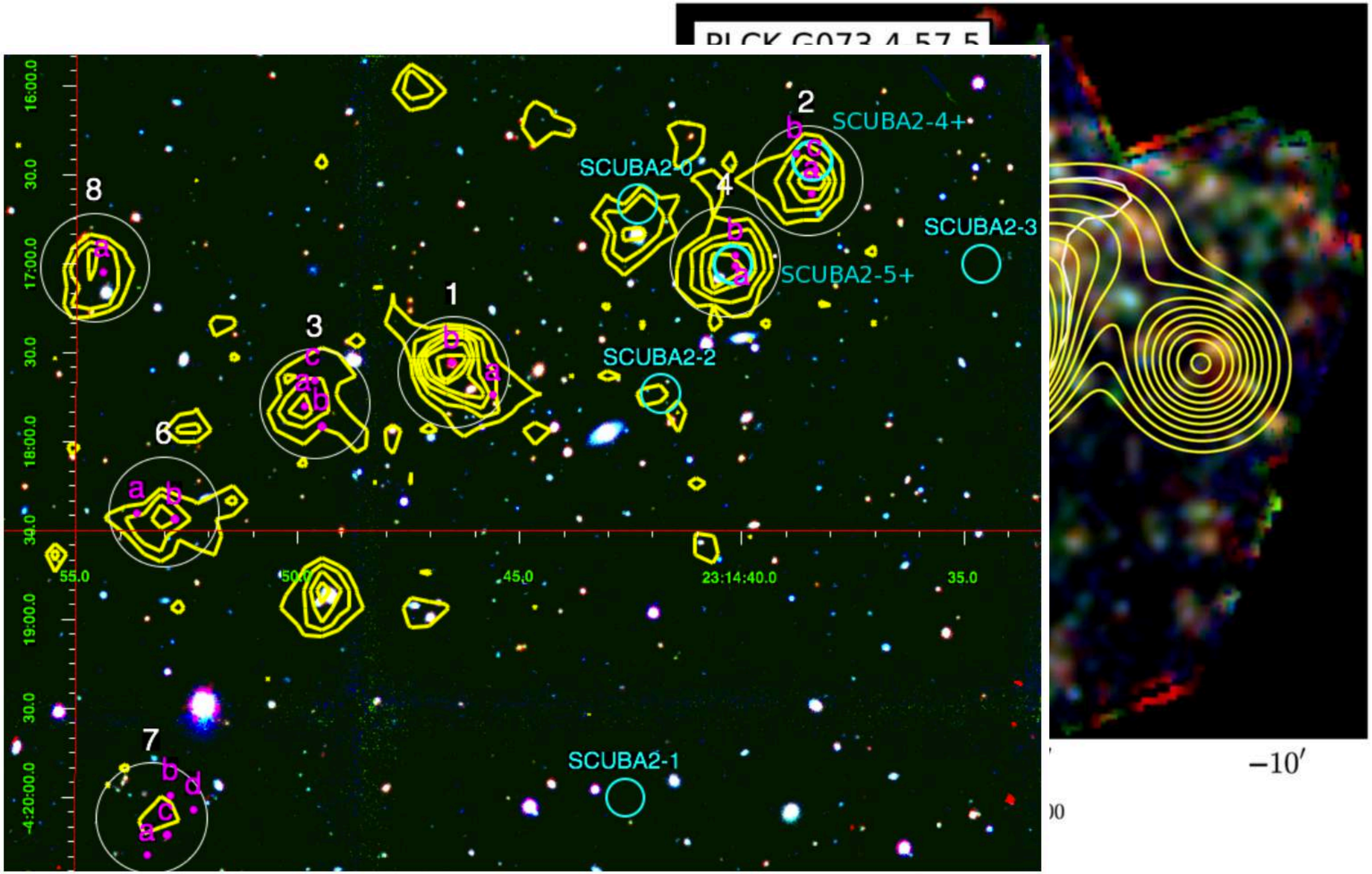
H. Dole & Planck collab

ALMA view of one field



Kneissl et al., 2018, arXiv:1804.06581

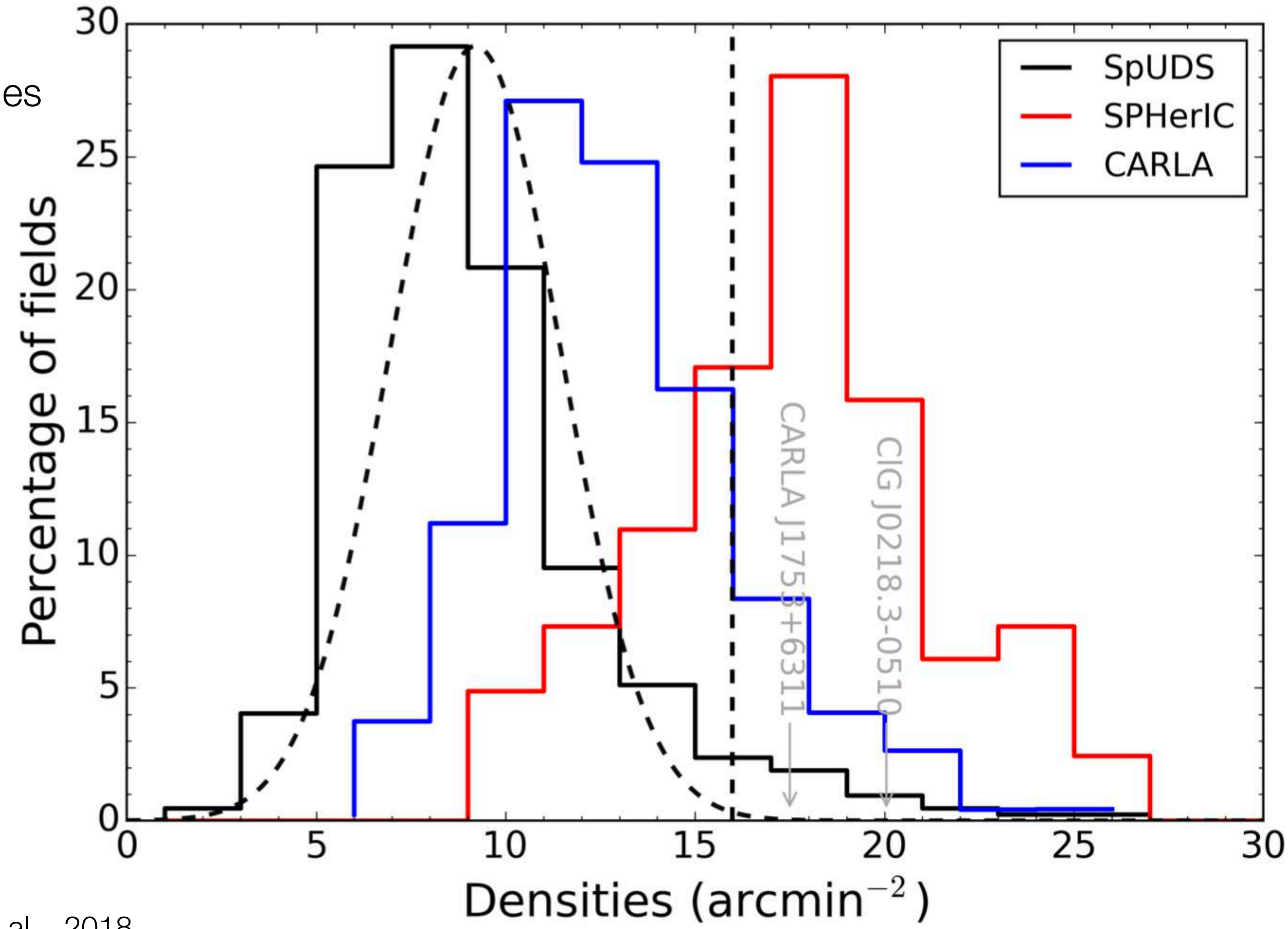
ALMA view of one field



Kneissl et al., 2018, arXiv:1804.06581

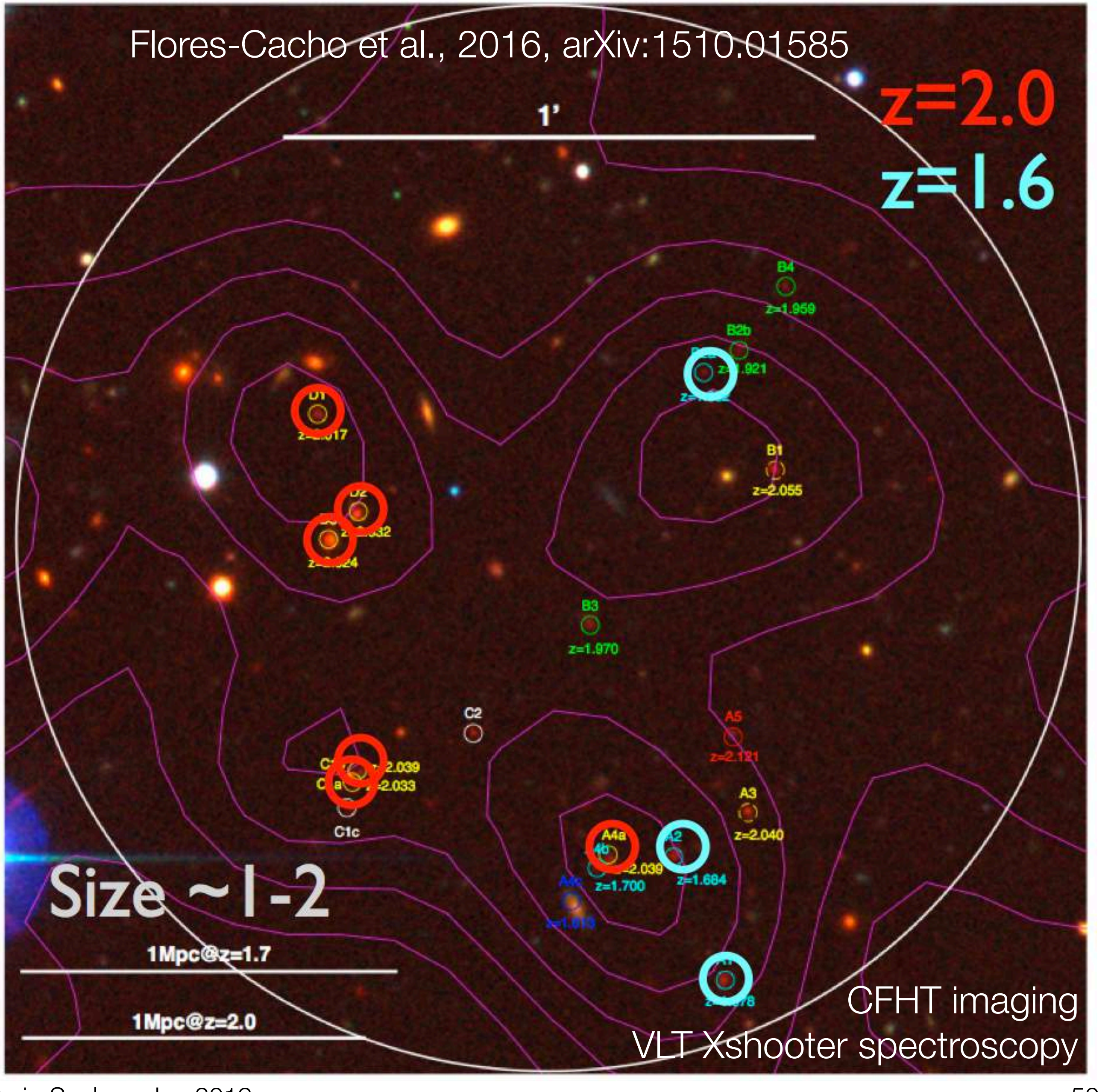
5.2 what do we learn from imaging ? Overdensities

Spitzer overdensities



Martinache et al., 2018

5.3 what do we learn from spectroscopy ?

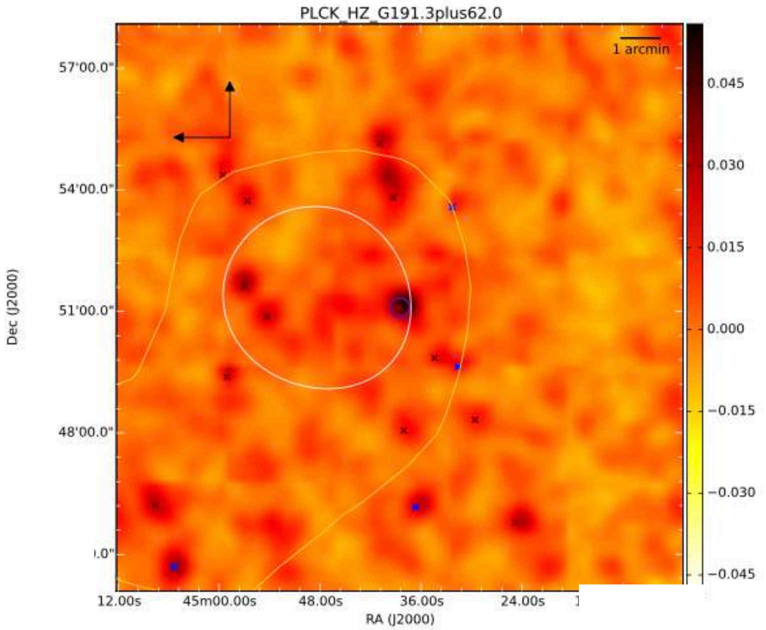


Flores-Cacho et al., 2016

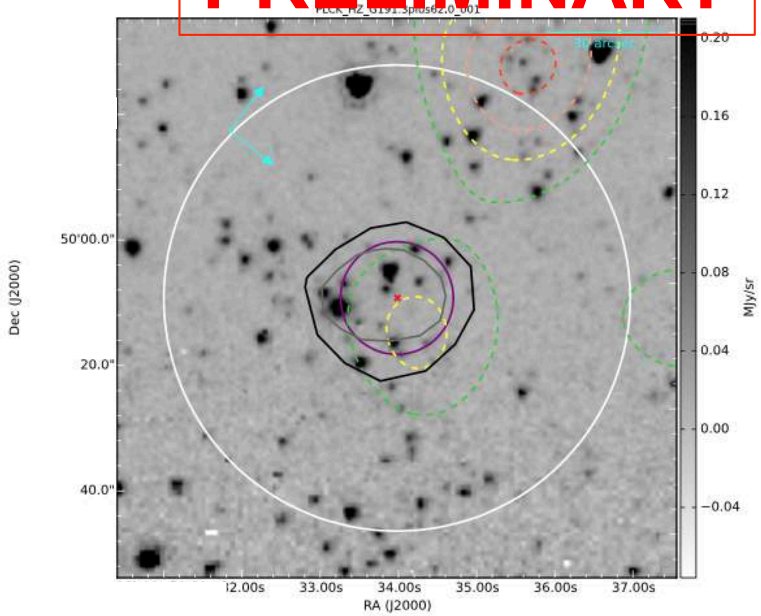
IRAM 30m CO redshift confirmation: 2.55

PLCK_HZ_G191.

PRELIMINARY

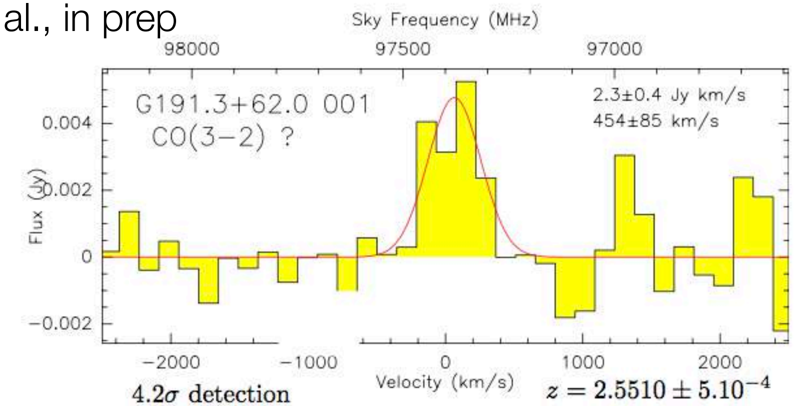


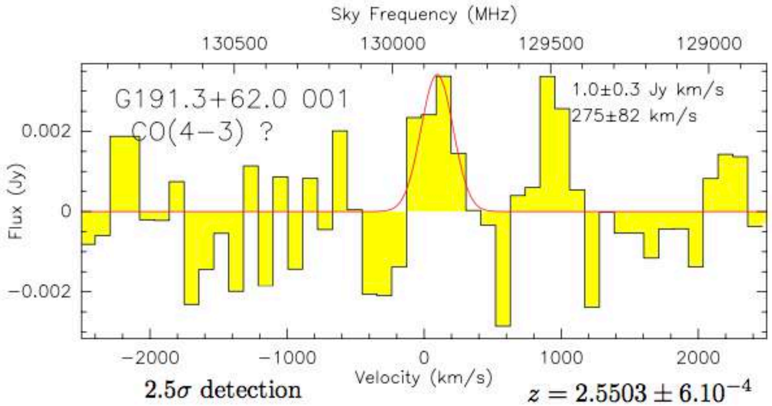
SPIRE 350μm map (about $14' \times 14'$, units of Jy/beam). Purple circles indicate EMIR pointings with CO detections. White lines are overdensity contours of SPIRE red sources ($\frac{S_{350}}{S_{250}} > 0.7$; $\frac{S_{500}}{S_{350}} > 0.7$), starting at 3σ by step of 1σ. The yellow line indicate the isocontour corresponding to 50% of the peak Planck flux (at 545GHz). Blue/red crosses indicate detected blue/red SPIRE sources.



IRAC 4.5μm map (about $1.2' \times 1.2'$, units of MJy.sr).Purple circles indicate EMIR pointings with CO detections. Green-yellow-salmon-orange-red lines are density contours of IRAC red sources ($[3.6] - [4.5] > -0.1$), at mean+2.5-3-3.5-4-4.5σ. The white circle has a radius of $1'$. Black/grey lines indicate SPIRE 350/250μm emission contours at 3σ. Blue/red crosses indicate detected blue/red SPIRE sources.

Martinache et al., in prep



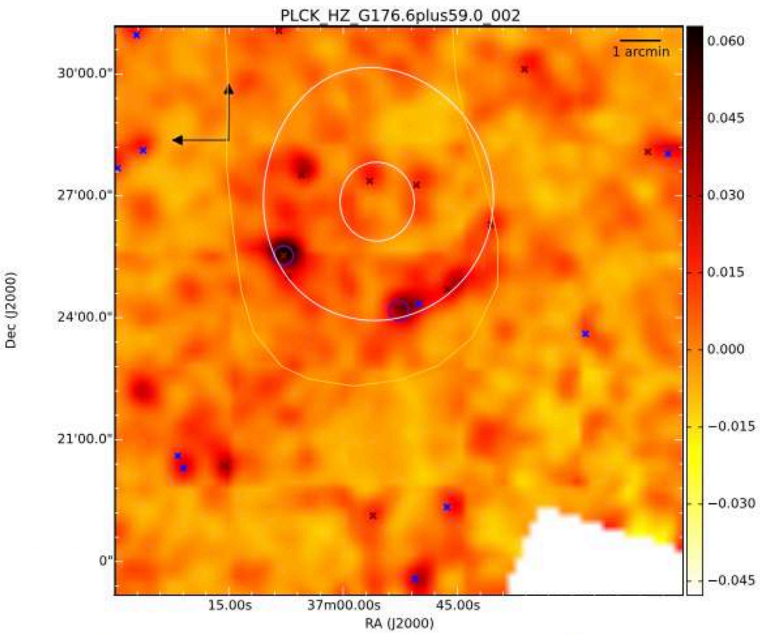


Courtesy Clément Martinache et al.c

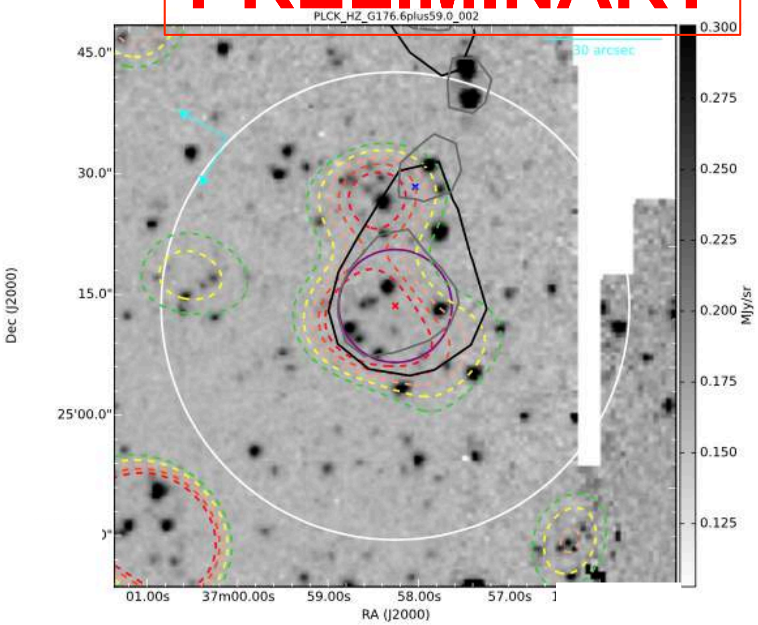
IRAM 30m CO redshift confirmation: >2.6

PRELIMINARY

PLCK_HZ_G176

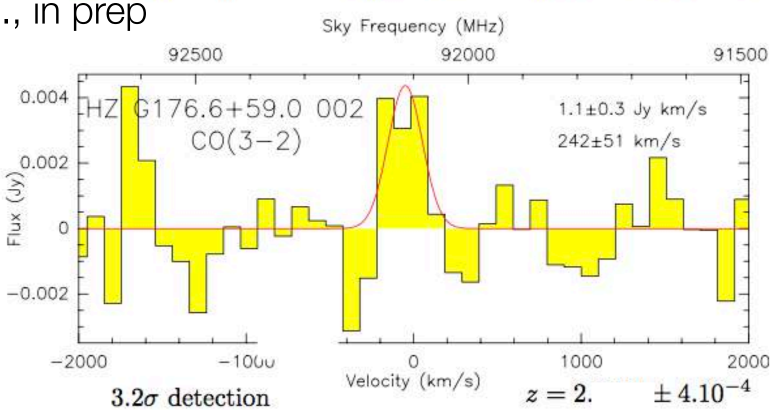


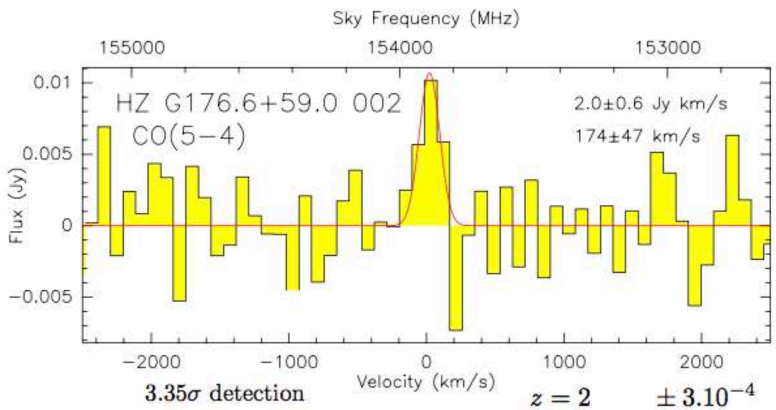
SPIRE 350μm map (about $14' \times 14'$, units of Jy/beam). Purple circles indicate EMIR pointings with CO detections. White lines are overdensity contours of SPIRE red sources ($\frac{S_{350}}{S_{250}} > 0.7$; $\frac{S_{500}}{S_{350}} > 0.7$), starting at 3σ by step of 1σ. The yellow line indicate the isocontour corresponding to 50% of the peak Planck flux (at 545GHz). Blue/red crosses indicate detected blue/red SPIRE sources.



IRAC 4.5μm map (about $1.2' \times 1.2'$, units of MJy.sr).Purple circles indicate EMIR pointings with CO detections. Green-yellow-salmon-orange-red lines are density contours of IRAC red sources ($[3.6]-[4.5] > -0.1$), at mean+2.5-3-3.5-4-4.5σ. The white circle has a radius of $1'$. Black/grey lines indicate SPIRE 350/250μm emission contours at 3σ. Blue/red crosses indicate detected blue/red SPIRE sources.

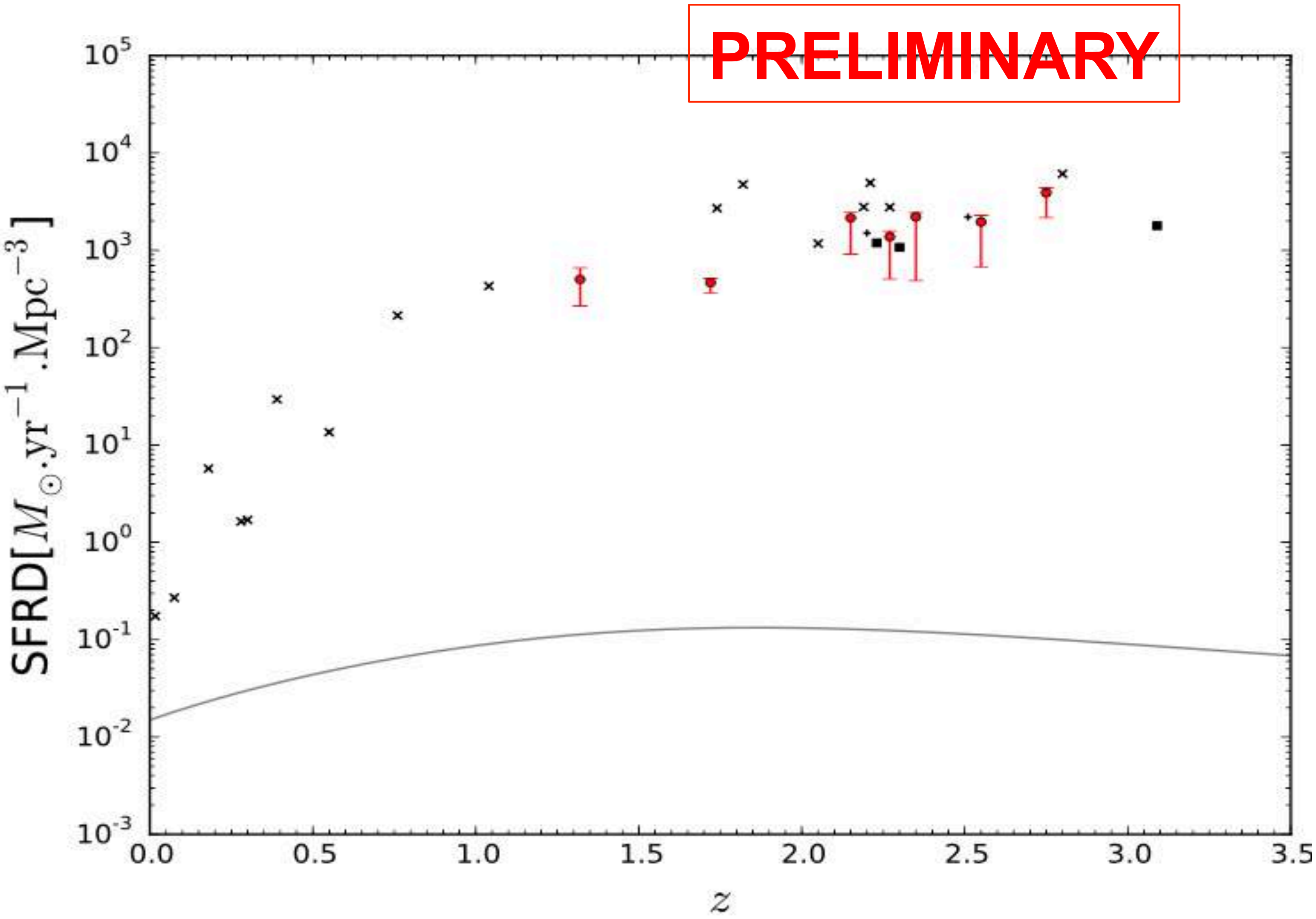
Martinache et al., in prep





Courtesy Clément Martinache et al.c

Star Formation Rate Density



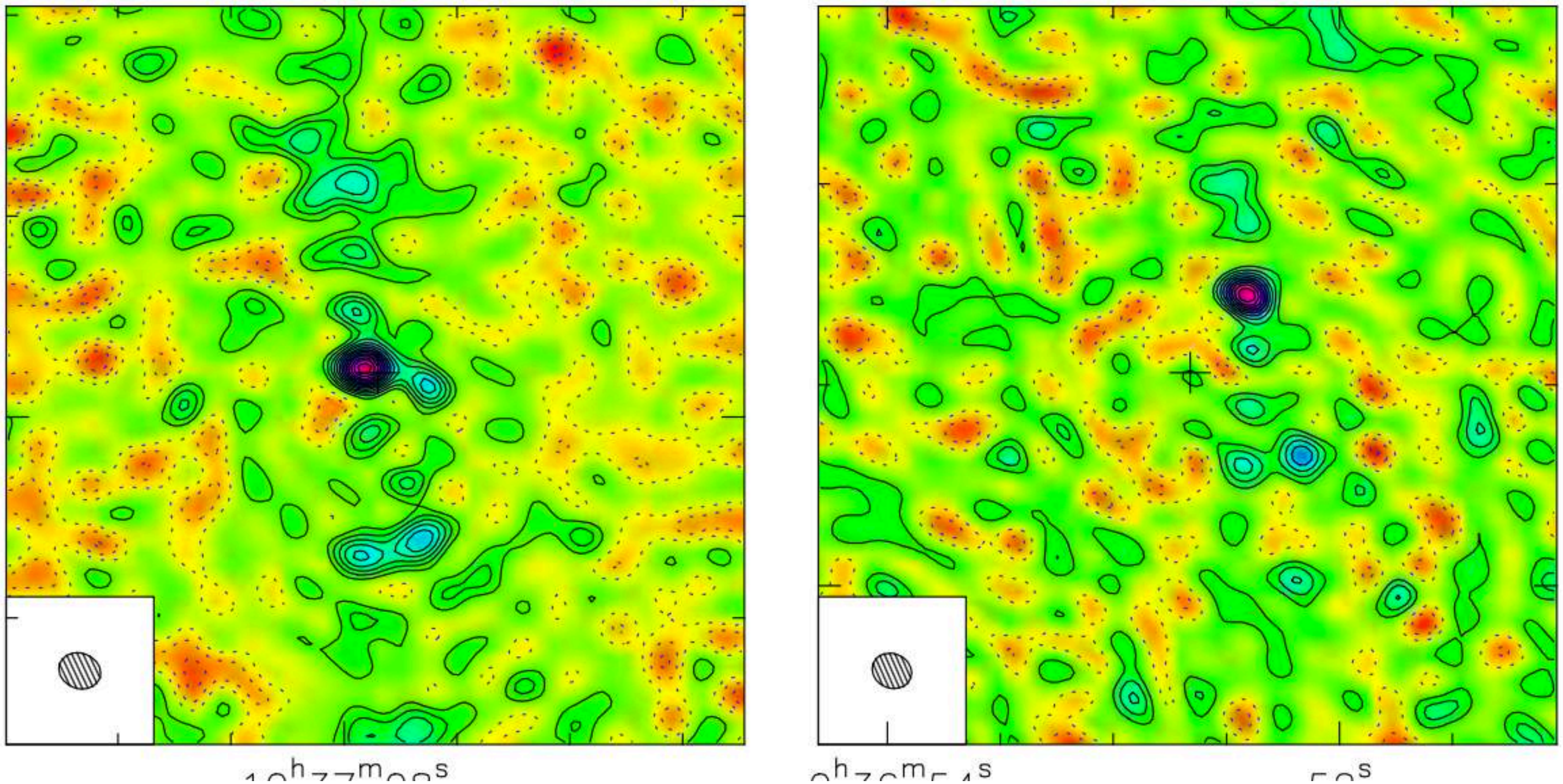
Martinache et al., in prep

Adapted from Kato+2016
Courtesy Clément Martinache et al.

IRAM NOEMA CO at z>2

PRELIMINARY

G1761 G1762

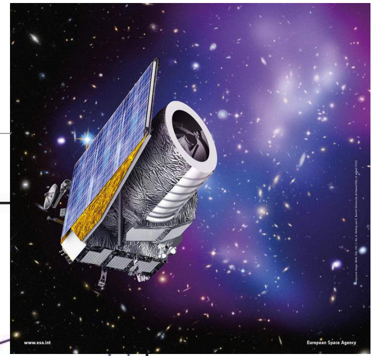


size ~50 arcsec

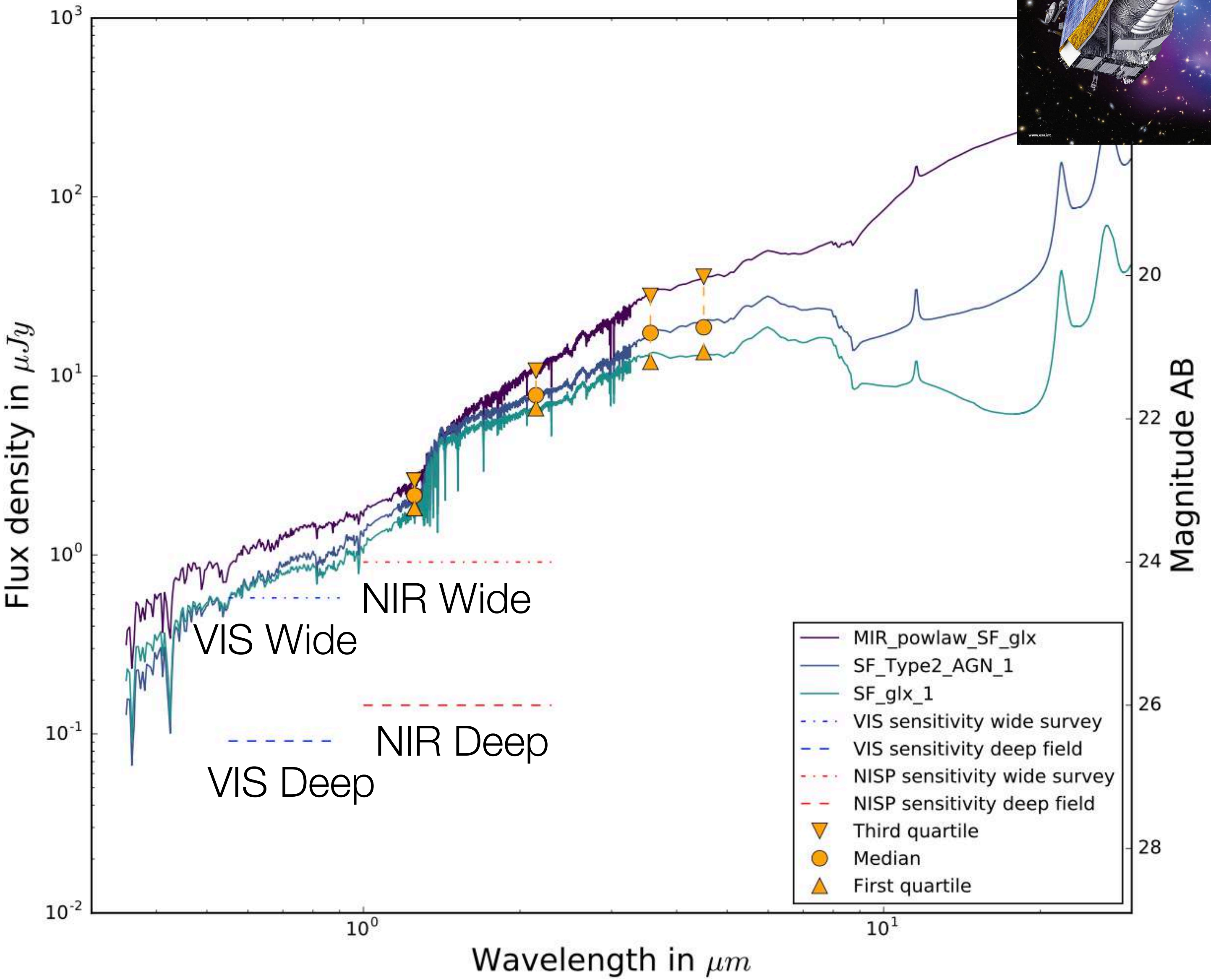
Martinache et al., in prep

Courtesy Clément Martinache et al.

6.1 Euclid great potential



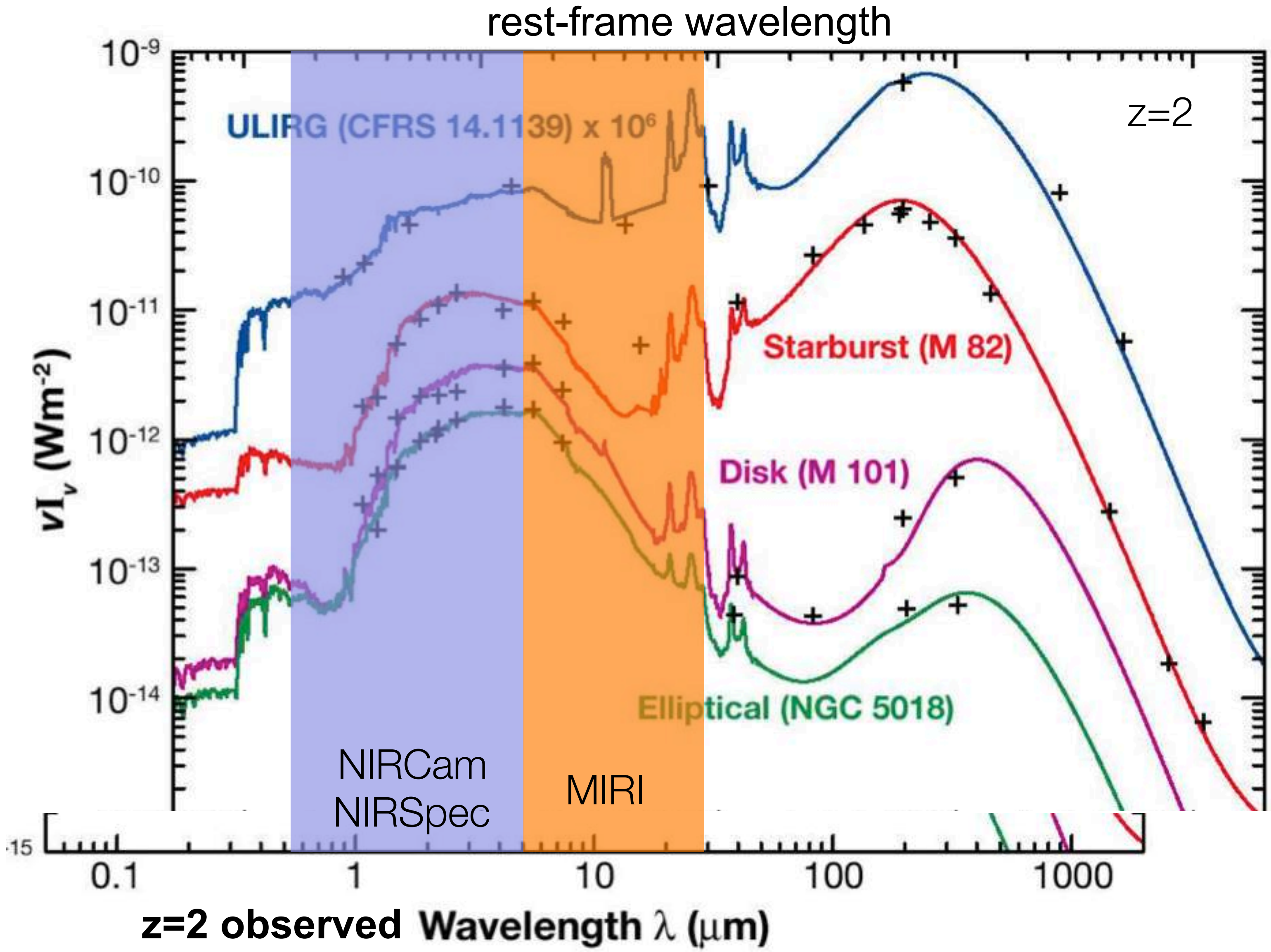
Wang+16
z=2.5 cluster



=> Euclid data will be full of those clusters !

Louis Legrand, Clément Martinache, Benjamin Clarenc, T. Etourneau, H. Dole

6.2 NIR+MIR: a key range for z>1 structures



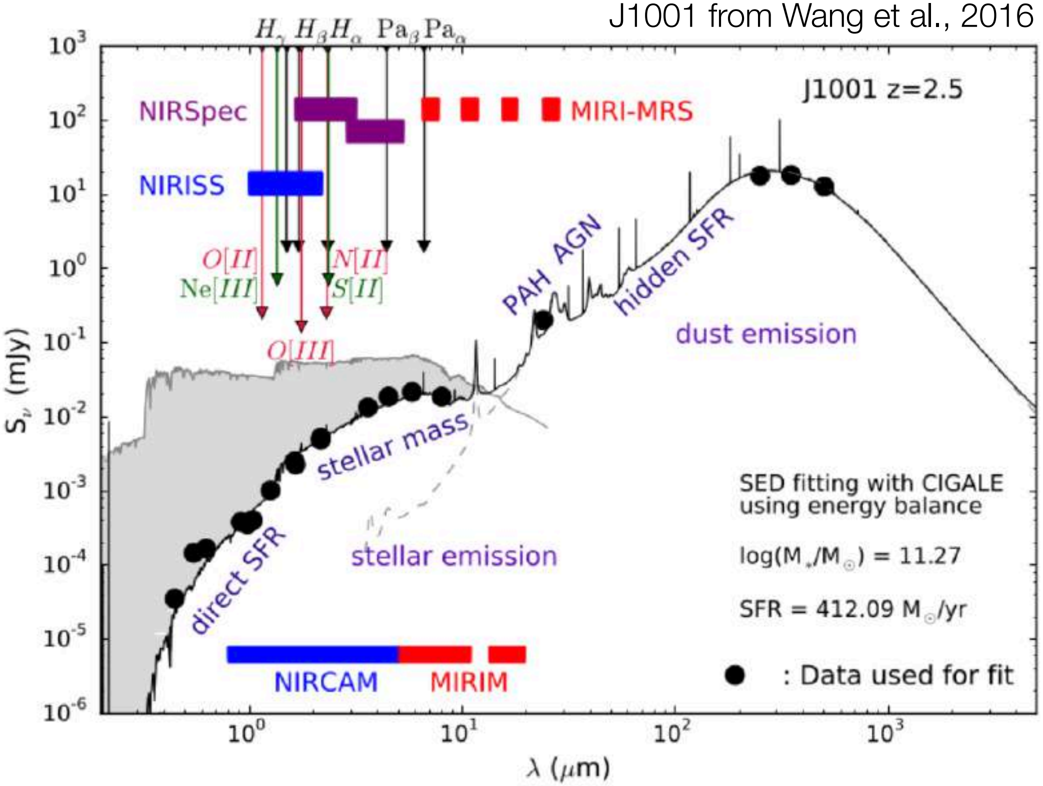
In the redshift range
~1 < z < ~4
MIRI probes
unique spectral
features,
even at low spectral
Resolution

AGN vs SF
H2

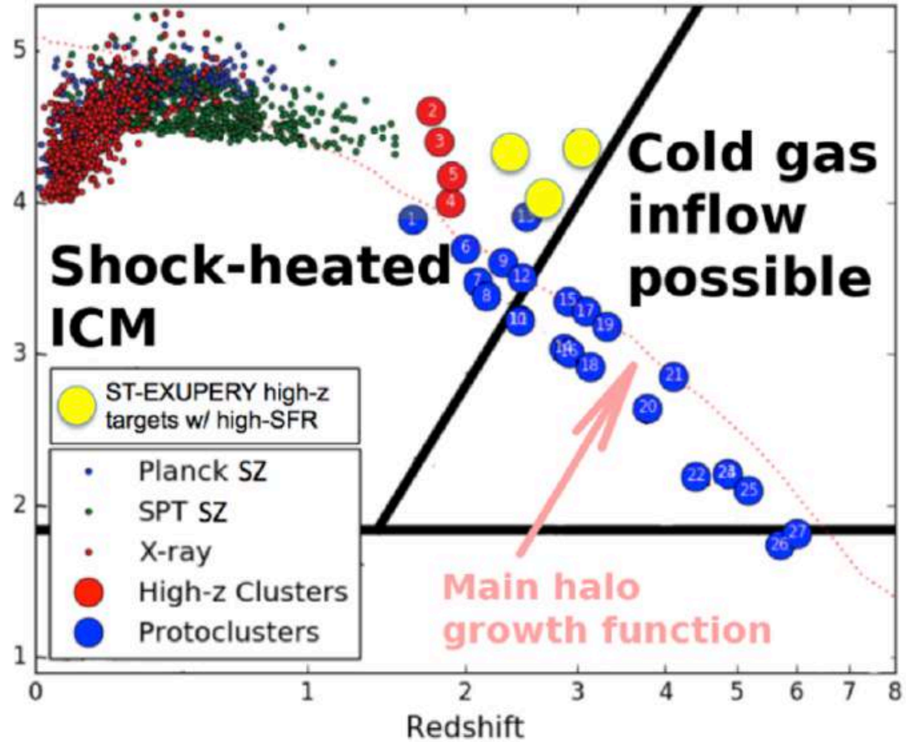
Lagache, Dole, Puget, 2005, ARAA
from Galliano 2004

6.2 great prospects w/ JWST

J1001 from Wang et al., 2016



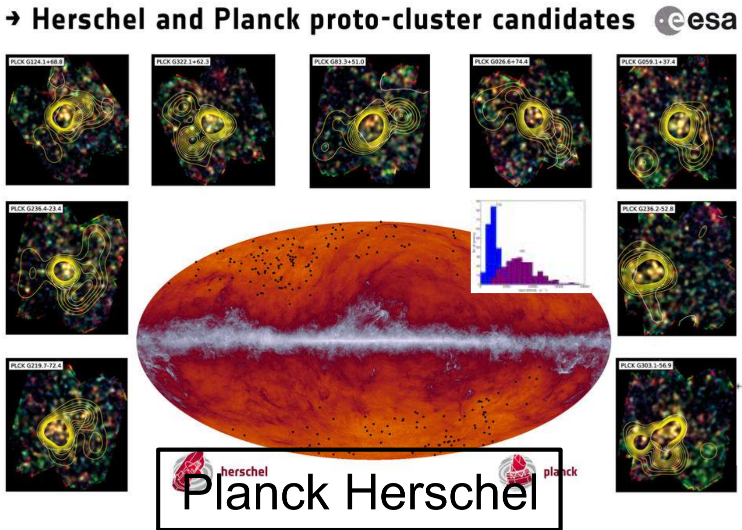
Adapted from Overzier 2016



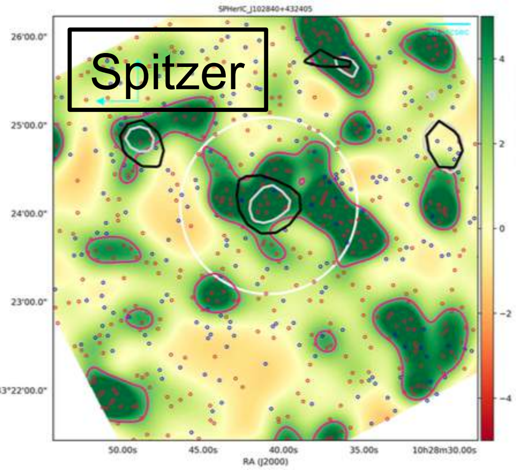
JWST ERS proposal « ST-EXUPERY »

B. Frye, H. Dole, M. Lehnert, C. Martinache, et al.

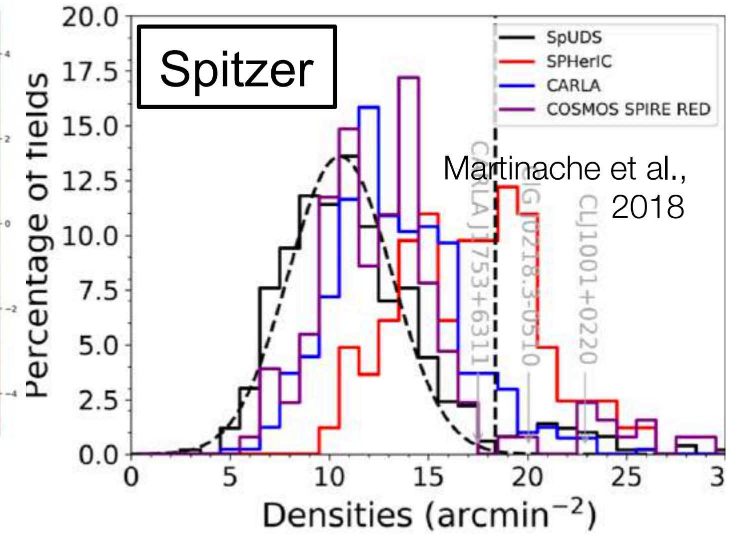
7. conclusions, perspectives

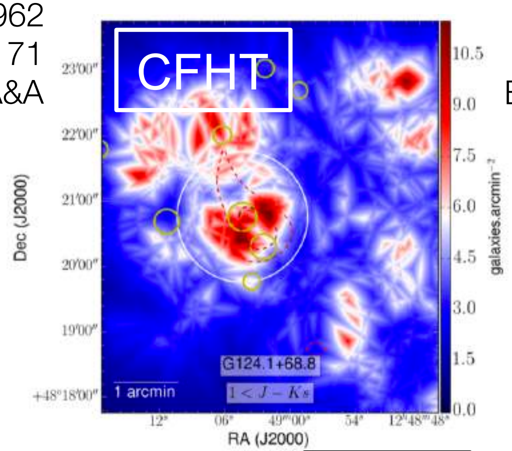


Planck Collab., 2015, Int XXVII, arXiv:1506.01962
Planck Collab., 2015, Int XXXIX, arXiv:1508.04171
Press Releases: ESA, NASA, INSU, A&A

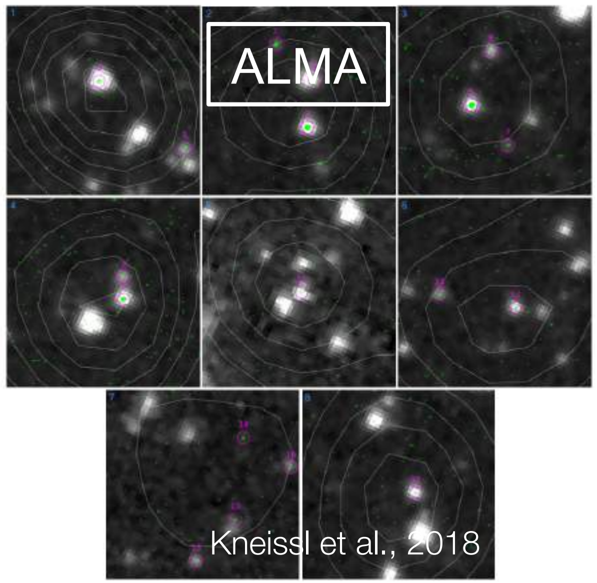


Martinache et al., 2018

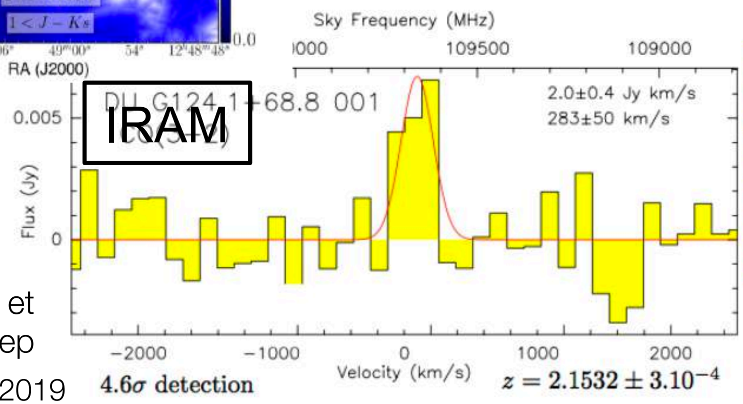


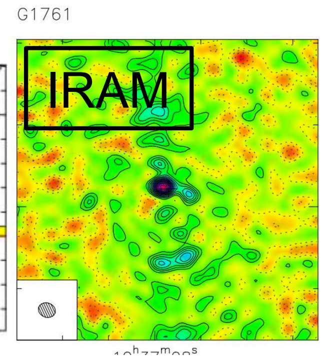


B. Clarenc PhD thesis, 2018

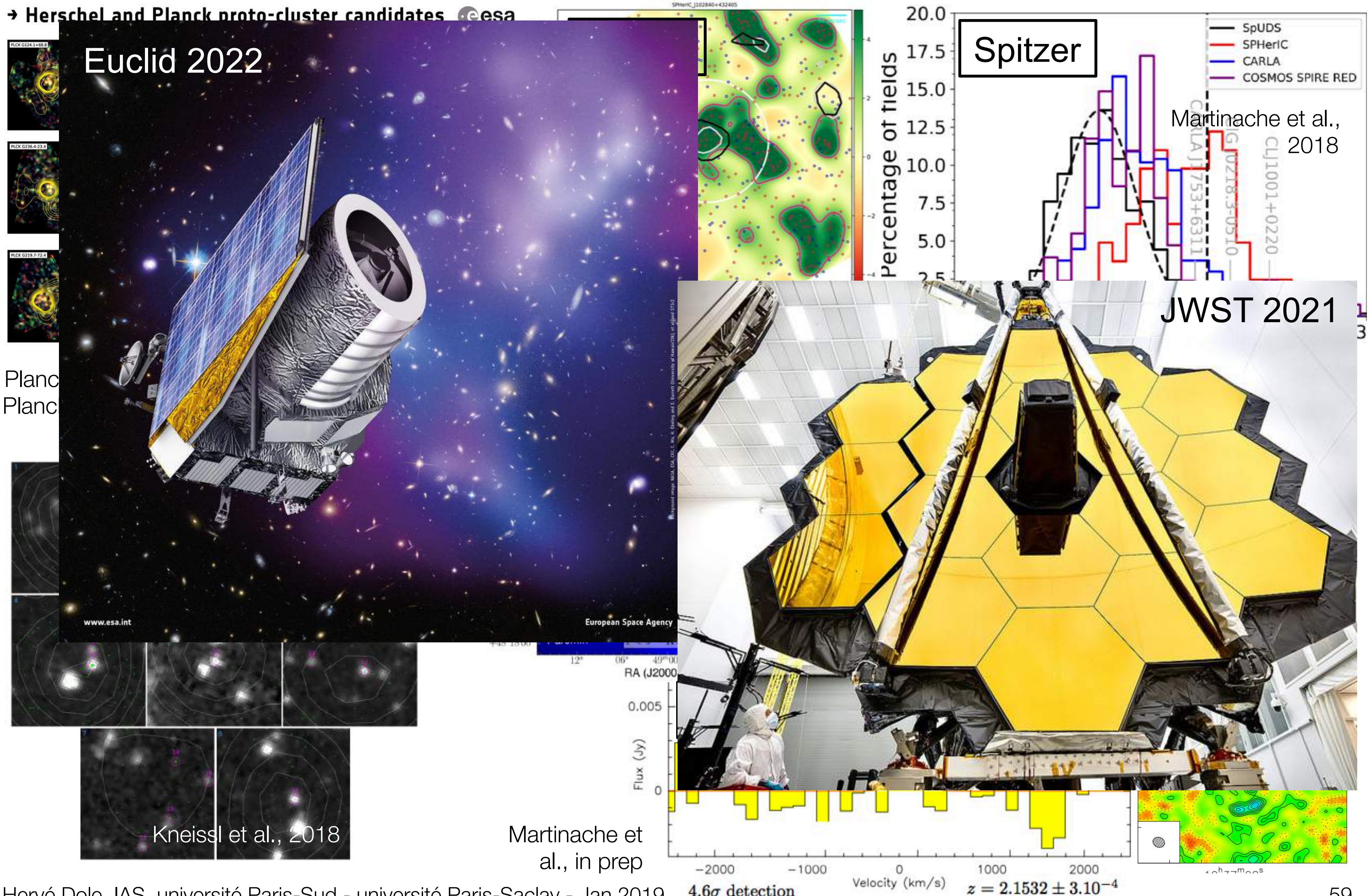


Martinache et al., in prep





7. conclusions, perspectives



some more personal conclusions

(refugees hosted at Université Paris-Sud last september: star party, jazz session)

Thanks: Univ. Paris-Sud, ALCOR, AAV, CRD Paris-Saclay

Science is a collective game also.

Impact of science and culture in our societies.

Curiosity has no color, gender, social or cultural origin: major leverage effect for an inclusive society.

Let's increase our implication as scientists in the society !