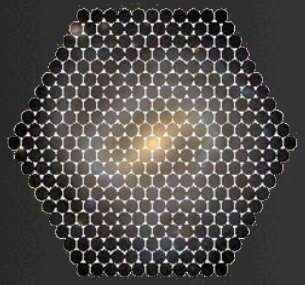
SEAGal

Galaxy evolution
(from spectral synthesis)
in 1 & 2 D



CALIFA

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William Schoenell
Jean M. Gomes
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Laerte Sodré

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Rosa González Delgado
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Sebastian Sánchez
Bernd Husemann
Clara Cortijo
Rafael L. Fernández
+ …

UFSC @ Florianópolis

IAA @ Granada

Outline

0 – Fossil methods & spectral synthesis: an intro

1 – A tour through the STARLIGHT-SDSS project

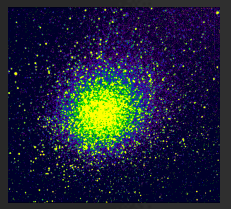
- 100's of different ways of looking at SFHs

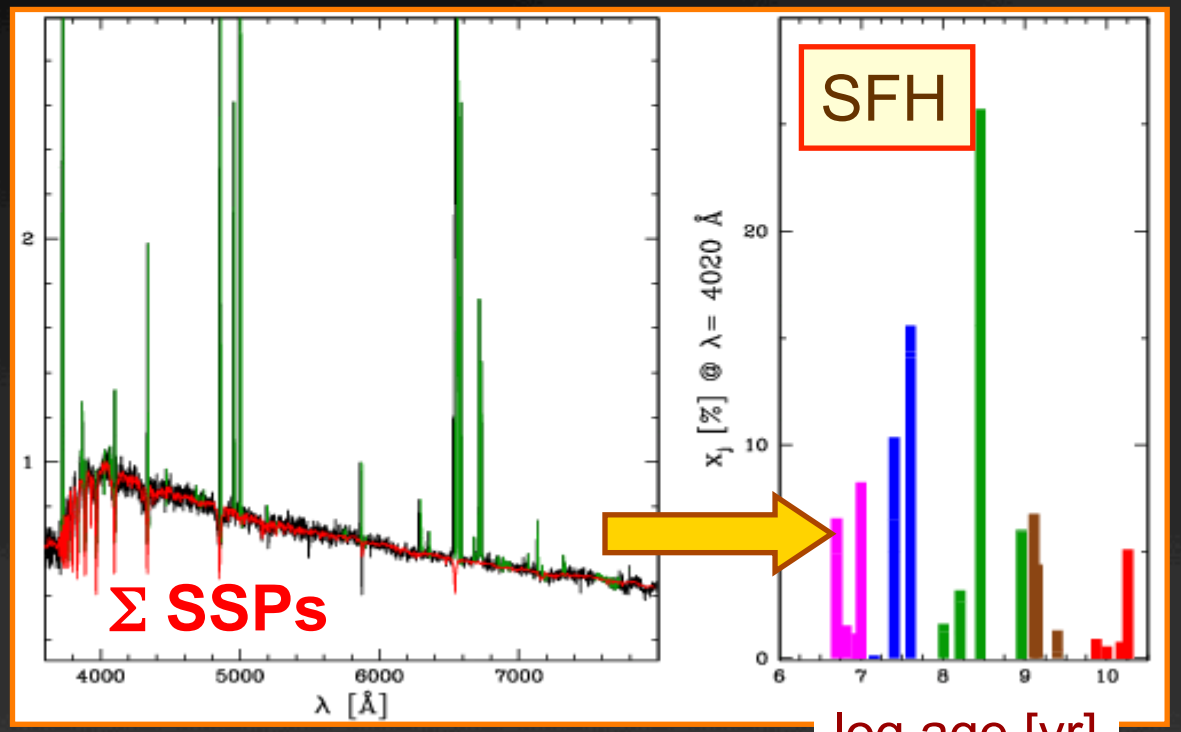
...a preamble to the main feature:

➔ **2** – Galaxy evolution in 2D: CALIFA

- Spatially resolved mass and metallicity growth

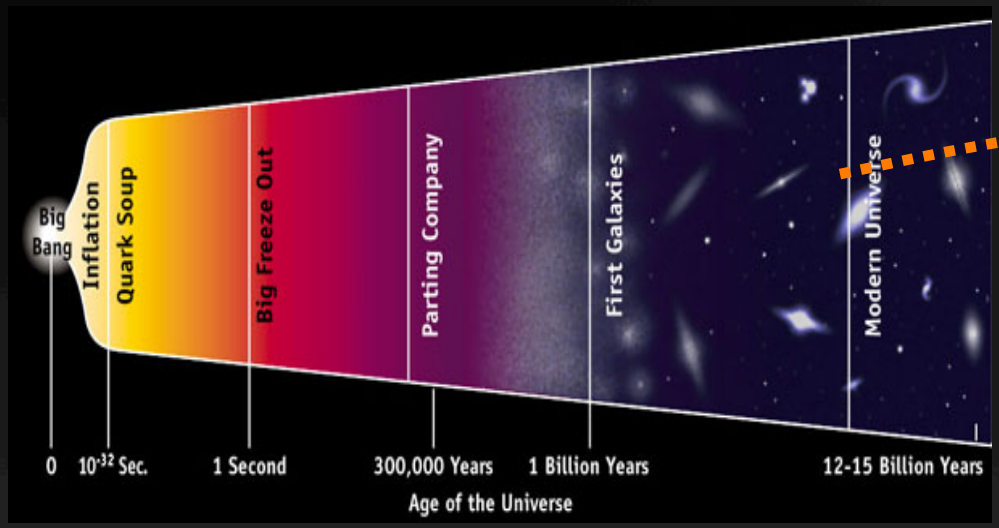
0 – Fossil Methods: A quick tour

$= M_1$  $+ M_2$  $+ M_3$  $+ \ldots$



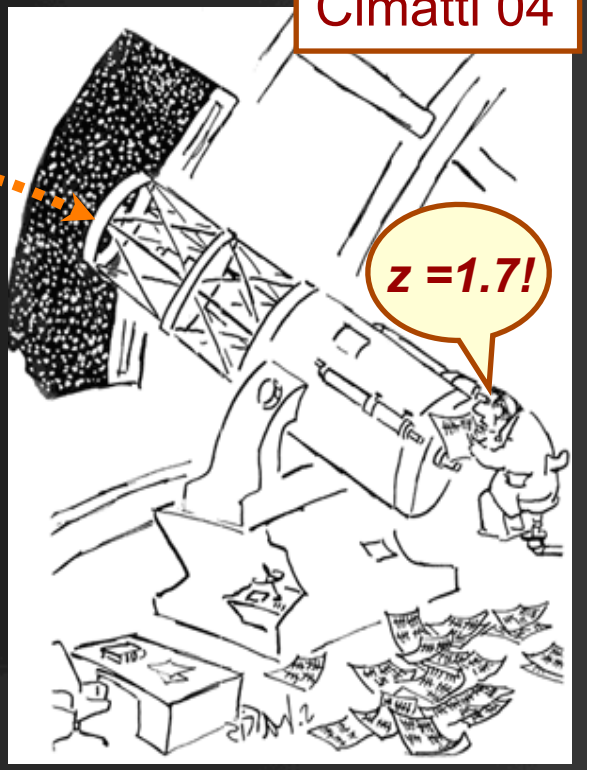
#1: The time-machine method

redshift ⇔ time



t ----------→

Cimatti 04



➔ Get information directly from the past!

Compare properties of galaxies at ≠ z's

(CAVEAT: Not the same galaxy at ≠ z's, of course!!)

Rodrigues 2008
Mannucci 2009

➔ $Z_{gas}(z)$…

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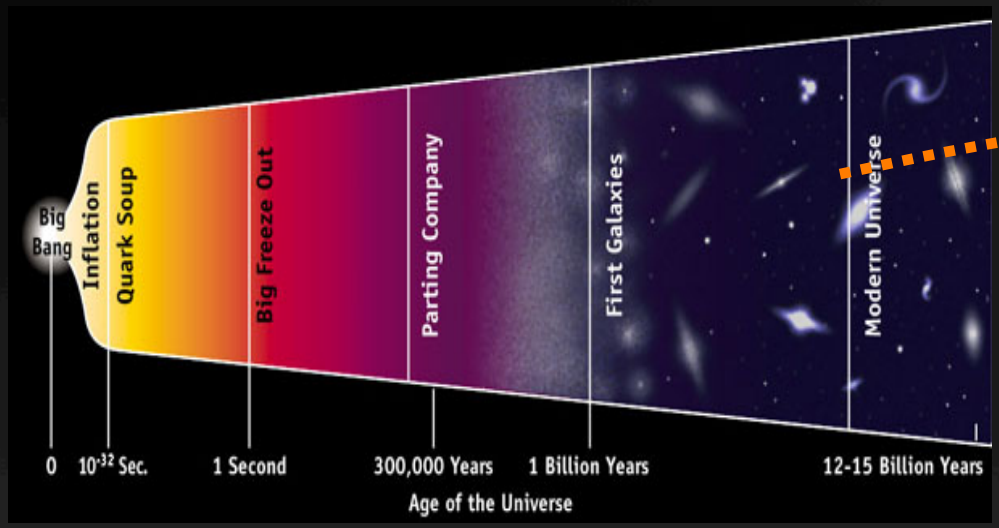
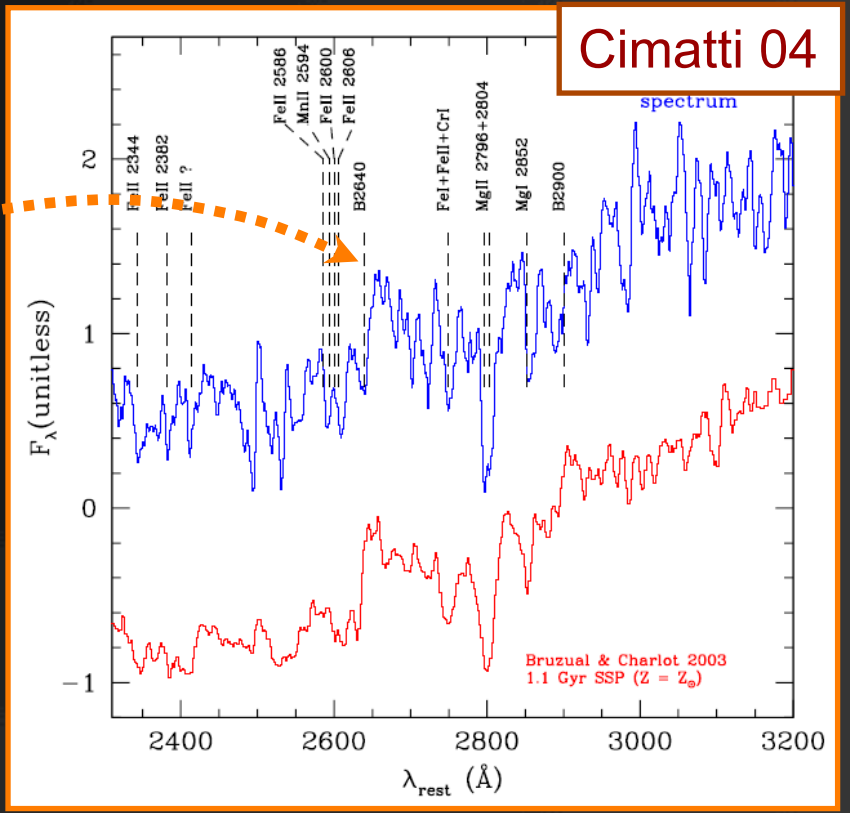


t ----------→

Cimatti 04



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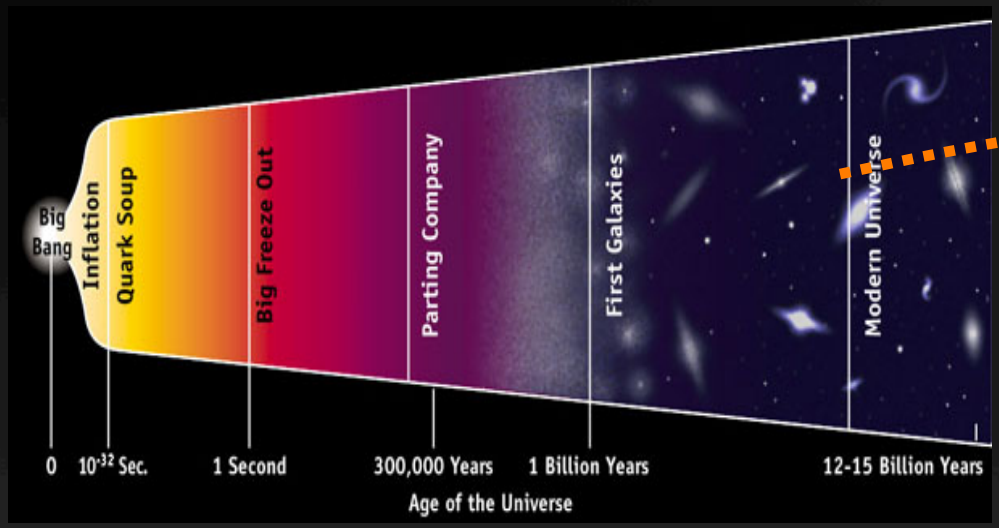
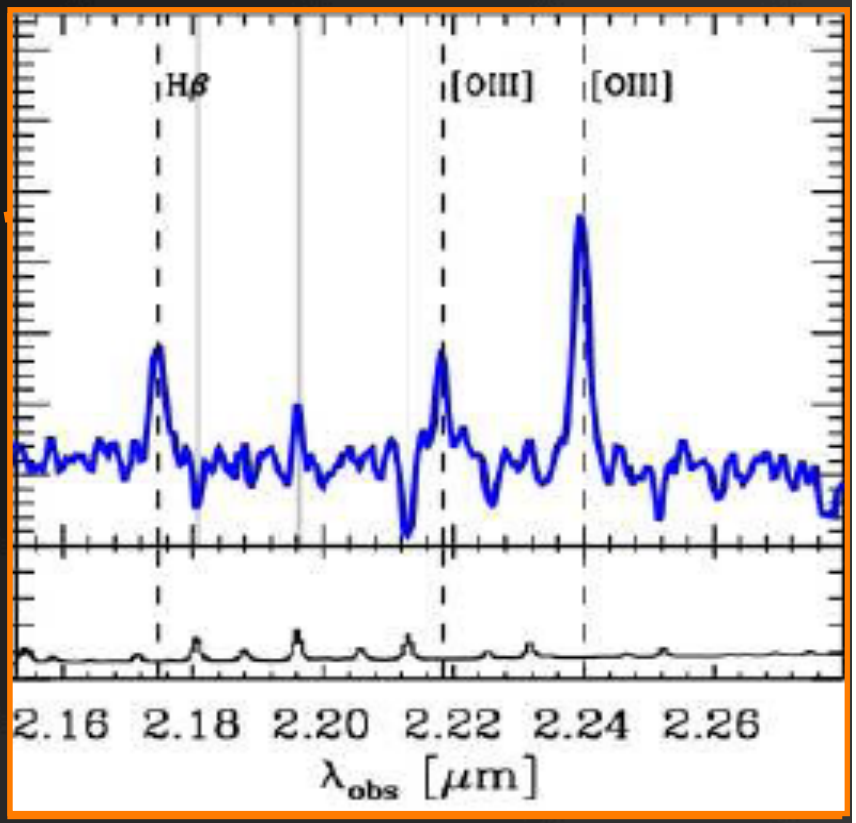


t ----------→



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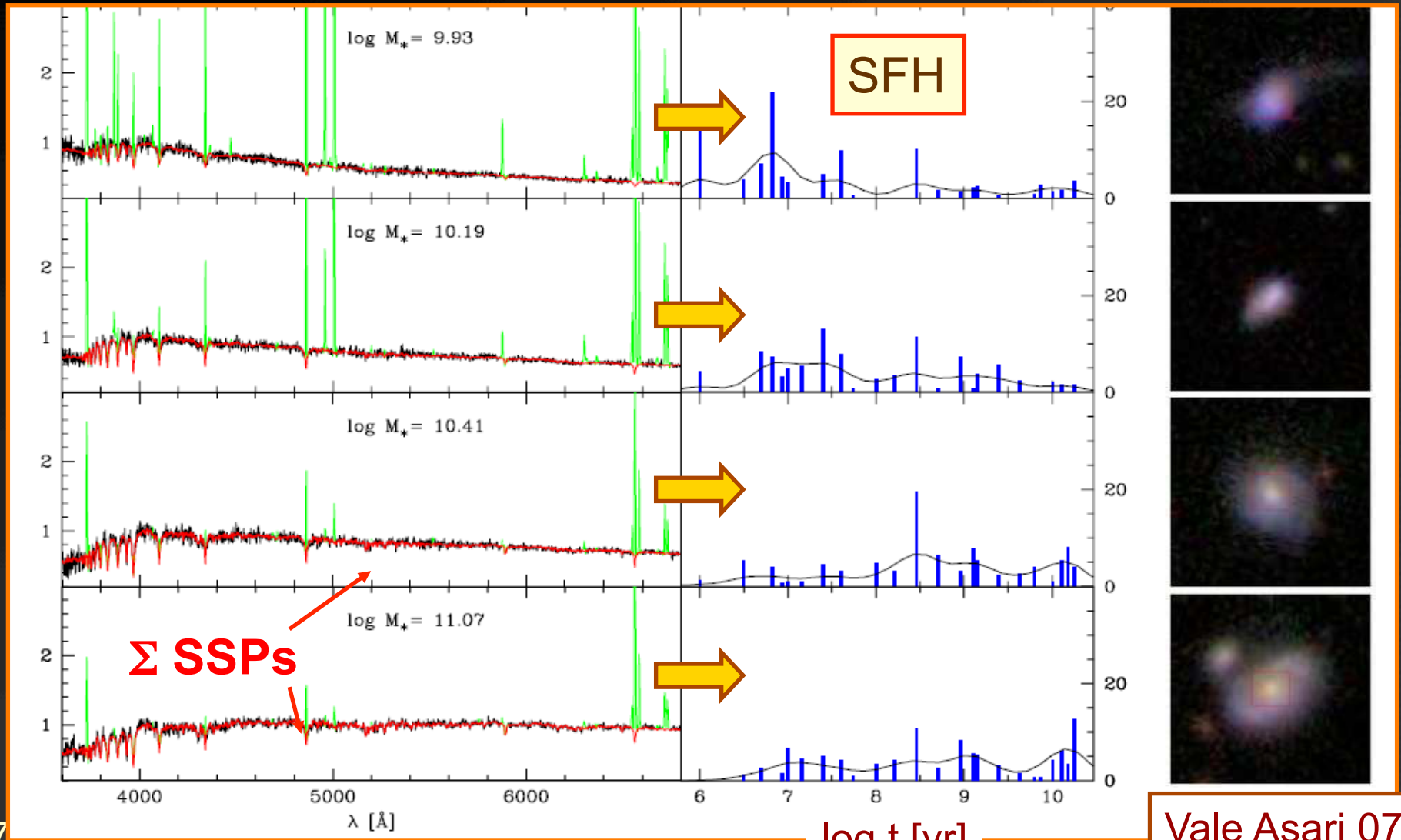
➔ $Z_{gas}(z)$…

#2: The fossil method

Retrace history of each galaxy from its stellar populations



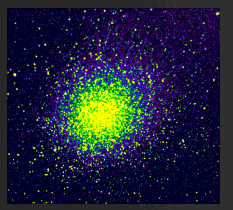
Vale Asari 07

#2: Decomposing galaxy spectra: The basics...

$= M_1$

$+ M_2$

$+ M_3$



$+ \ldots$

$$L_{gal}(\lambda) = \sum_{t,Z} M_{SSP}(t,Z) \times SSP(\lambda;t,Z) \times e^{-\tau(\lambda)}$$

Observables Full spectrum: F_λ	***SFH: mass or light fractions*** → ***Pop vector***	***Spectral Base*** SSPs from BC03, Granada, Pegase, "CB07", Vazdekis, …	***Dust:*** ***1 τ_V?*** ***2τ_V?*** ***$\tau_V(t,Z)$?*** ***…***

Inverse Population Synthesis: How?

Hypothesis space ("priors")

Only 1 Z? Z = Z(t)?
A_λ = ? Dust geometry? $A_\lambda(t,Z)$?
Kinematics?
Which base? (clusters, models,...)
Which SFH parameters?

Observables space → Parameter space

Method

Brute force discrete grid search?
Convex-algebra?
Markov-Chains?
PCA? AI-techniques?
Comparisons to library of models?
Compression on input or output?
How to deal with degeneracies?

Inverse Population Synthesis: How?

Maaaannnyyy methods!

- STEllar Content via Maximum A Posteriori – Ocvirk 05, Koleva 08
- Active Instance-Based Machine Learning – Solorio 05
- Bayesian Latent Variable modelling – Nolan 06
- Principal Component Analysis – Li 05, Wild 07, Yan-Mei 12
- Direct fitting – Tadhunter 05, Moustakas 06, Chilingarian 07
- Markov Chains + tricks – CF 04, 05, ... STARLIGHT
- Data compression + tricks – Panter 03, 06, 07, 08... MOPED
- Convex Algebra – Pelat 97, Moultaka 00
- (Bayesian) Comparison to library of models – Gallazzi 05, 06, 08...

- ...

Inverse Population Synthesis: How?

Maaaannnyyy methods!

Huge diversity in:

- Math / elegance / speed
- **1000** "Technicalities" (masks, kinematics, extinction, ...)
- Physical ingredients
- Input & Output
- Public availability
- ...

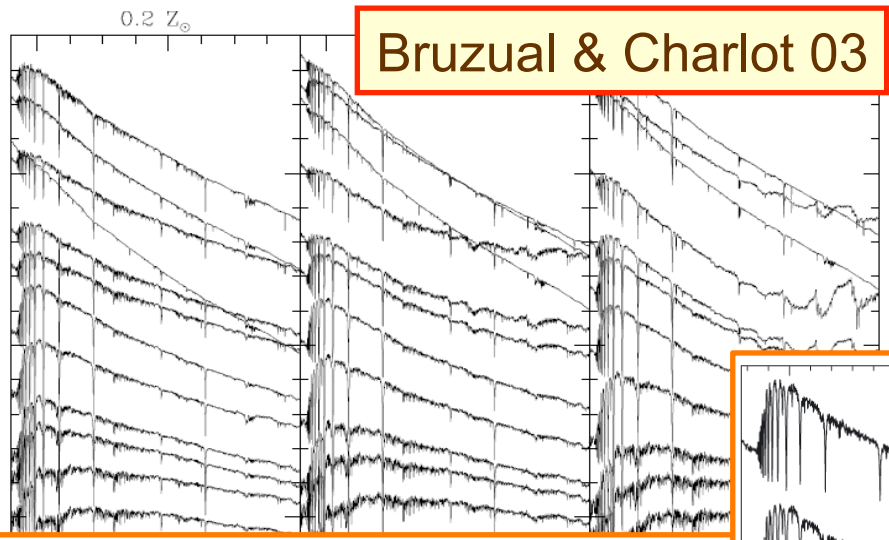
But ~ convergence on results!

The main source of discrepancies is **ingredients**, **not** inversion method. (…Chen et al 2010)

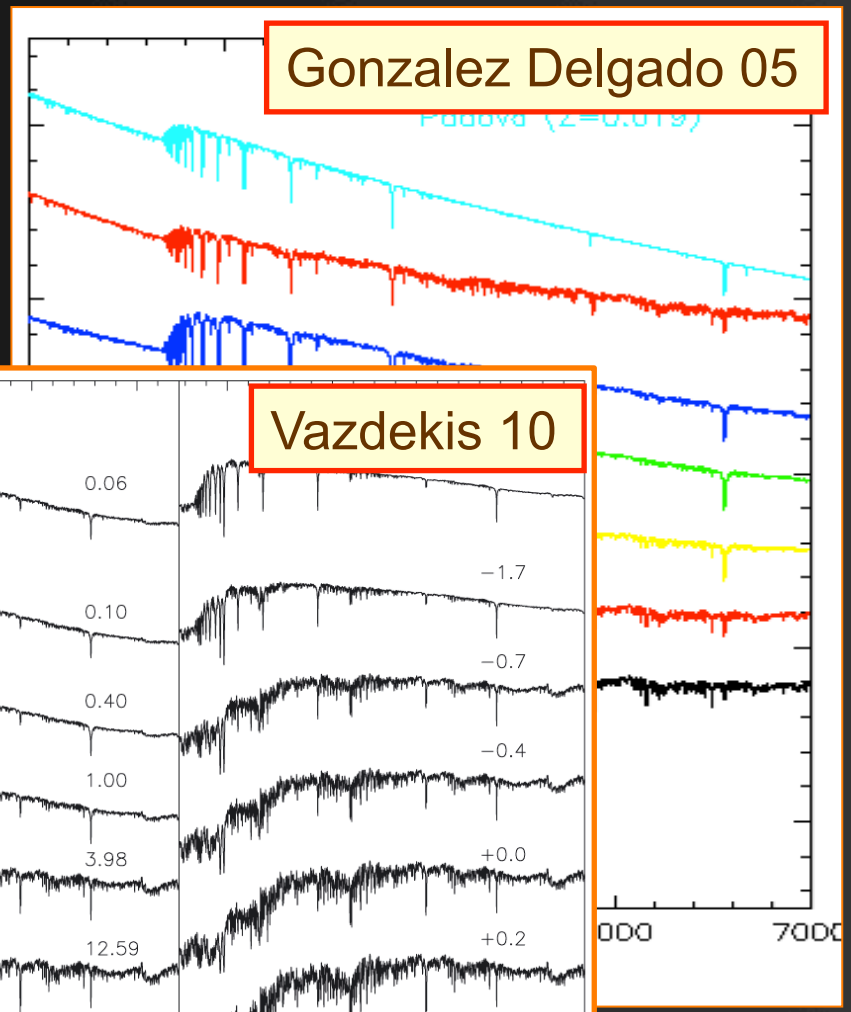
The main ingredient: SSP(λ;t,Z) ← evolutionary synthesis

Improvements in spectral libraries → Predictions on ~ Å scales!

Bruzual & Charlot 03

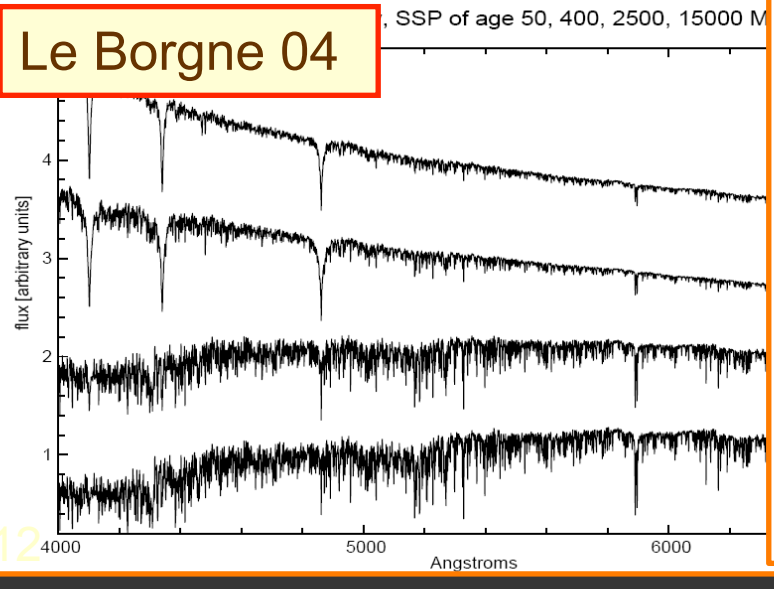


Gonzalez Delgado 05



Vazdekis 10

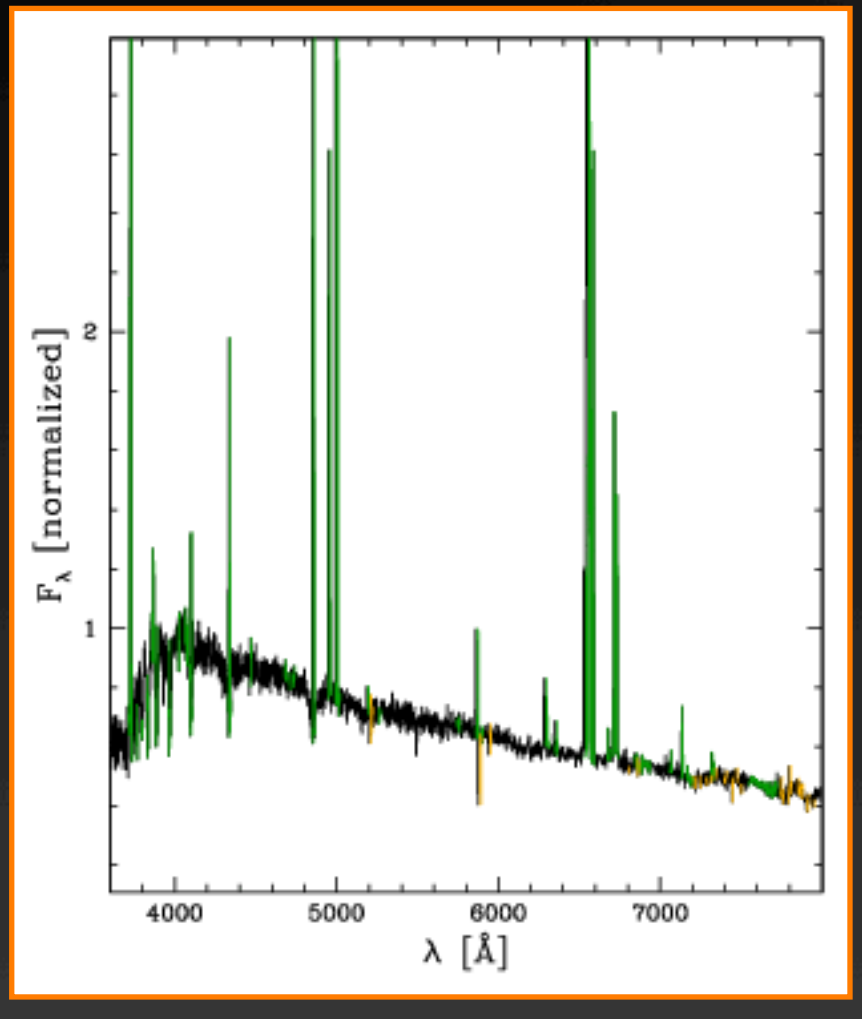
Le Borgne 04



STARLIGHT: ➔ Input

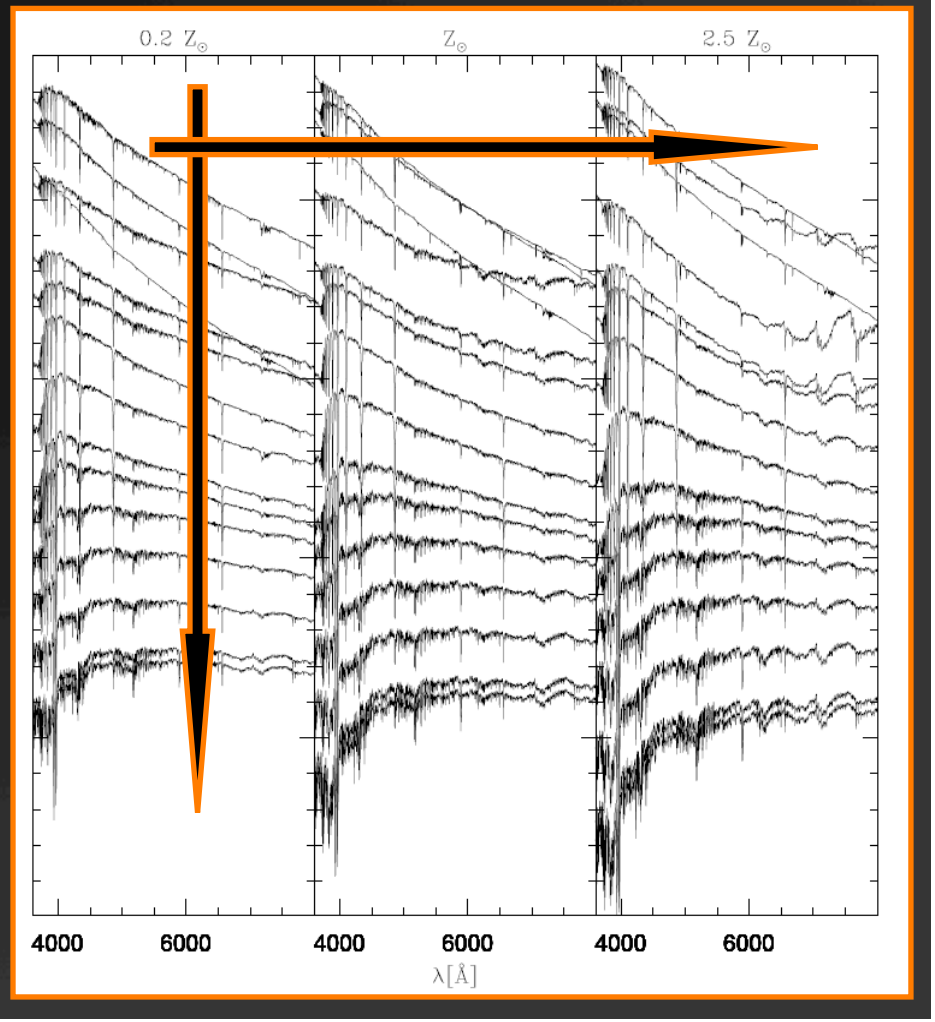
(A) Observed spectrum

eg, a SF galaxy from the SDSS



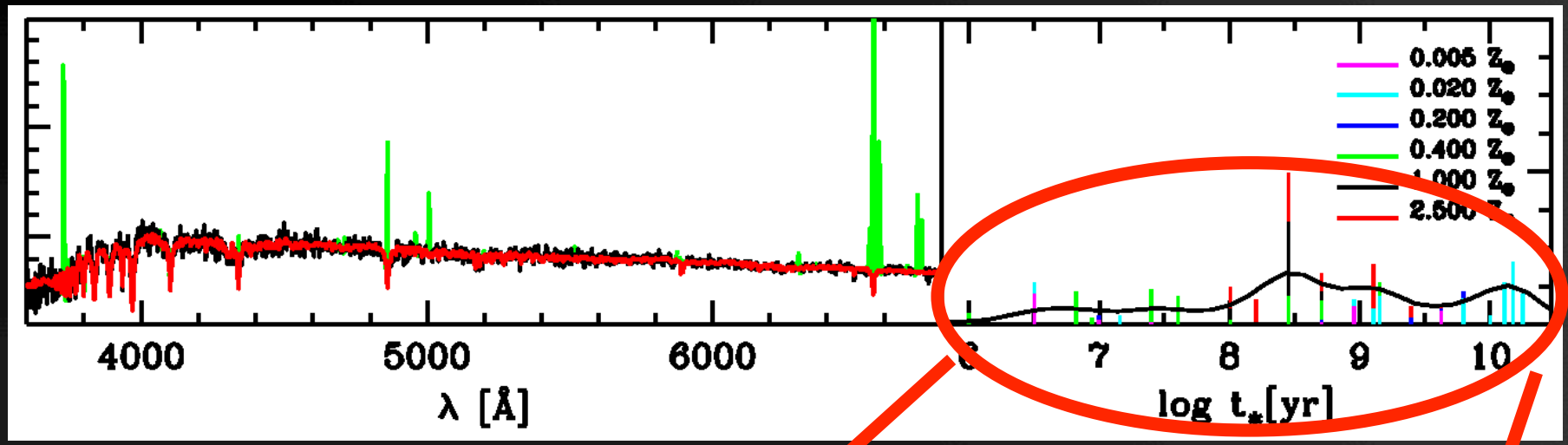
(B) Spectral Base: SSP(λ;t,Z)

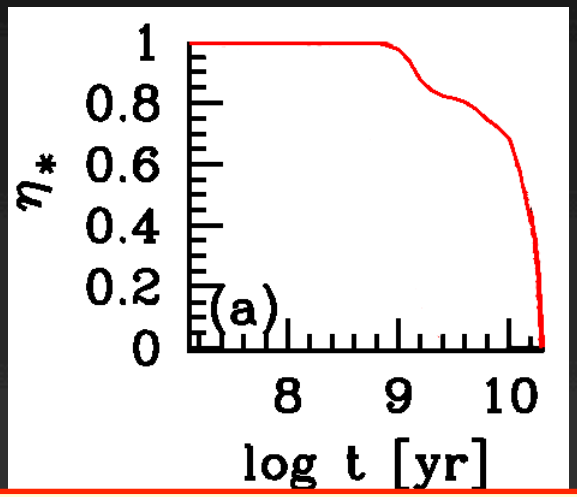
eg, N >> 1 SSPs from BC03

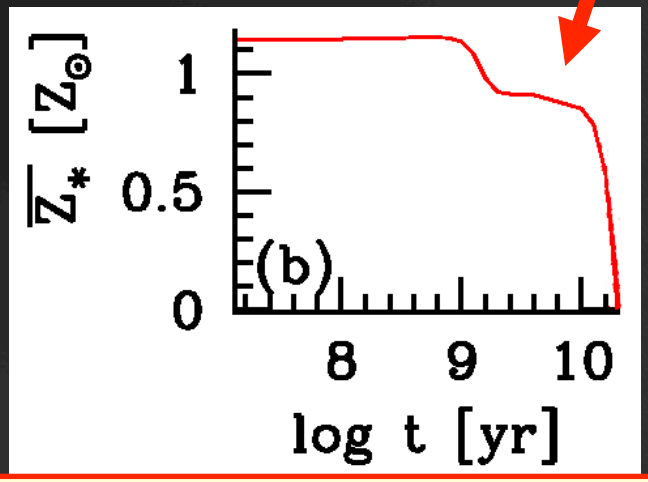


STARLIGHT: Output ➔

➔ Galaxy properties: Stellar mass, σ_*, A_V, <age>, <Z_*>, SFH, …





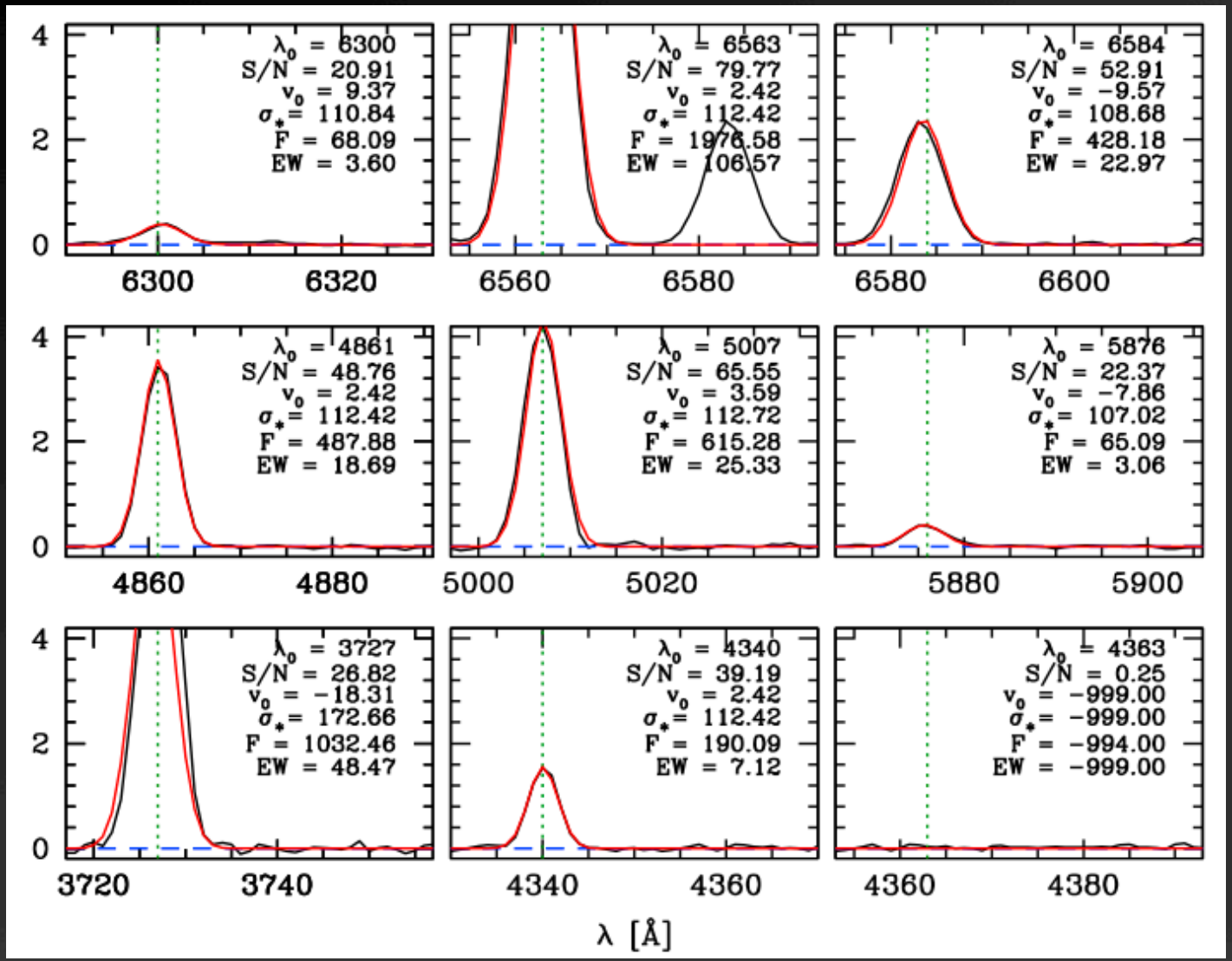


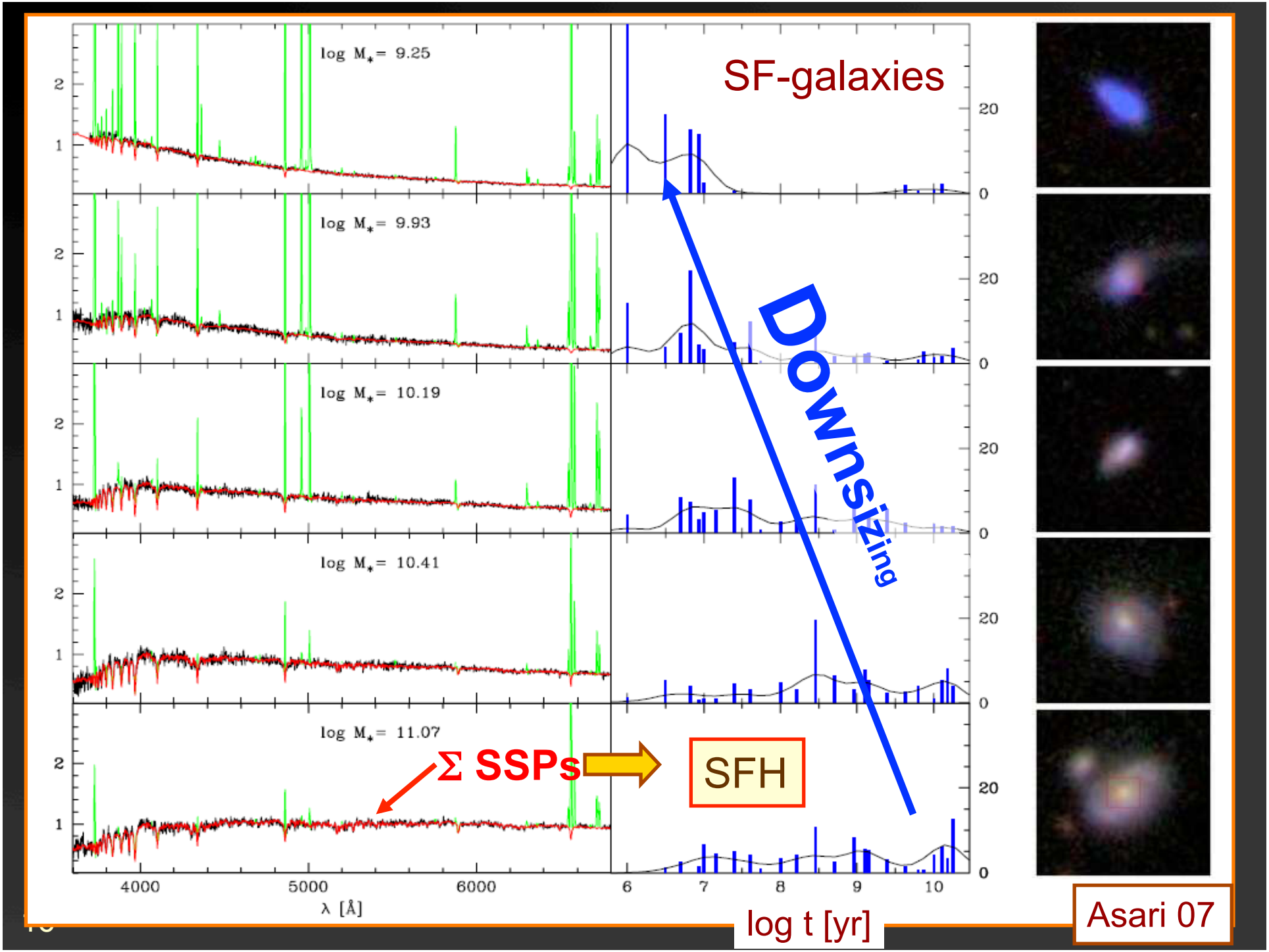
➔ **$M_*(t)$: mass assembly history**

➔ **$Z_*(t)$: chemical evolution**

STARLIGHT: Bonus product ☺

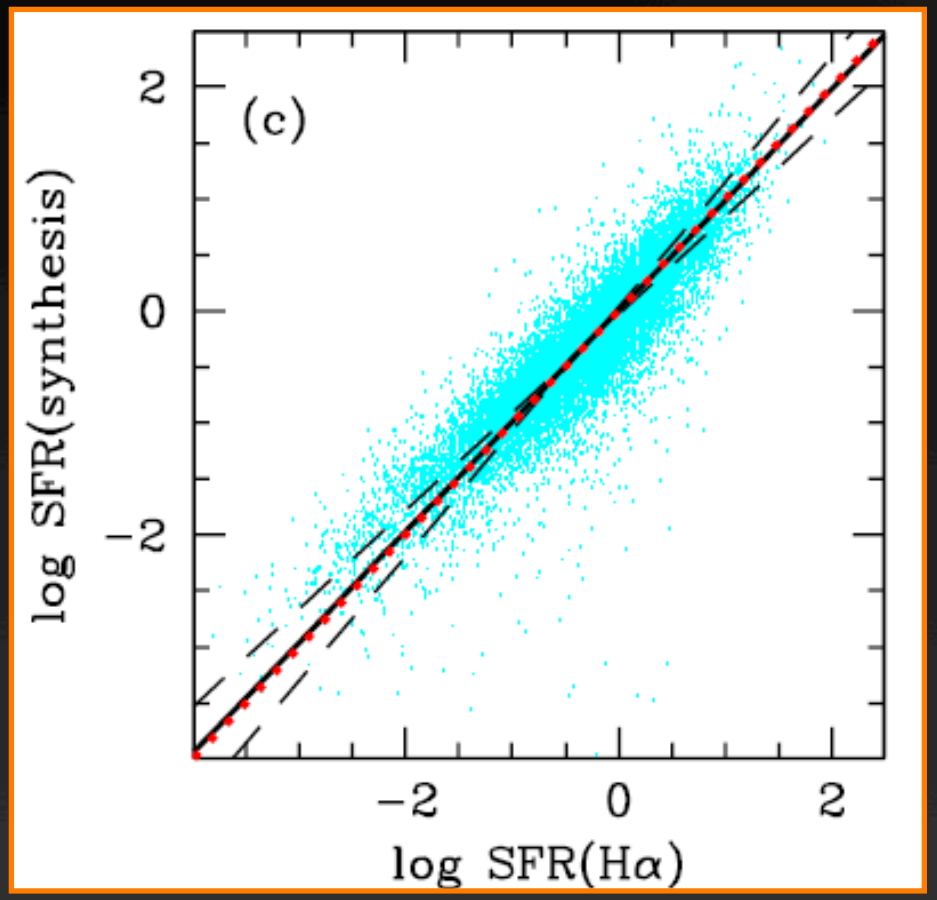
➔ Emission lines from residual spectrum



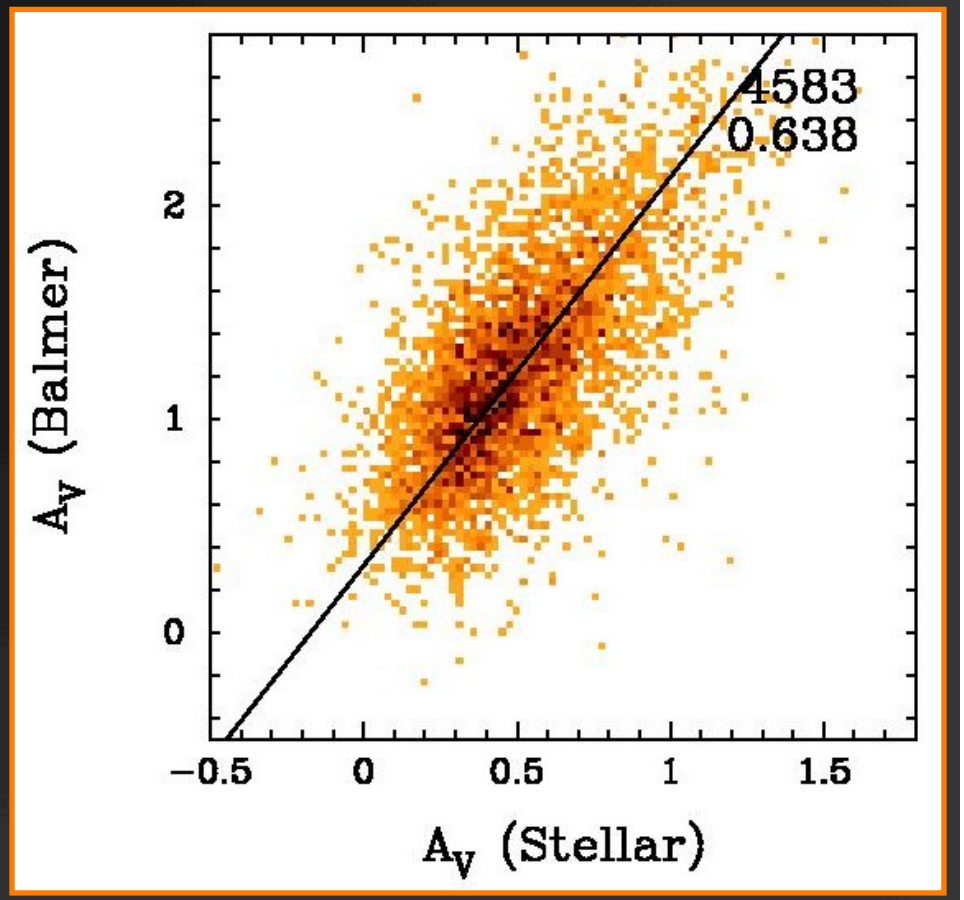

log M*= 9.25
log M*= 9.93
log M*= 10.19
log M*= 10.41
log M*= 11.07
SF-galaxies
Downsizing
Σ SSPs
SFH
λ [Å]
log t [yr]
Asari 07

Sanity checks: Good news ☺☺☺

SFR(Synt) ~ SFR(Hα) !!!



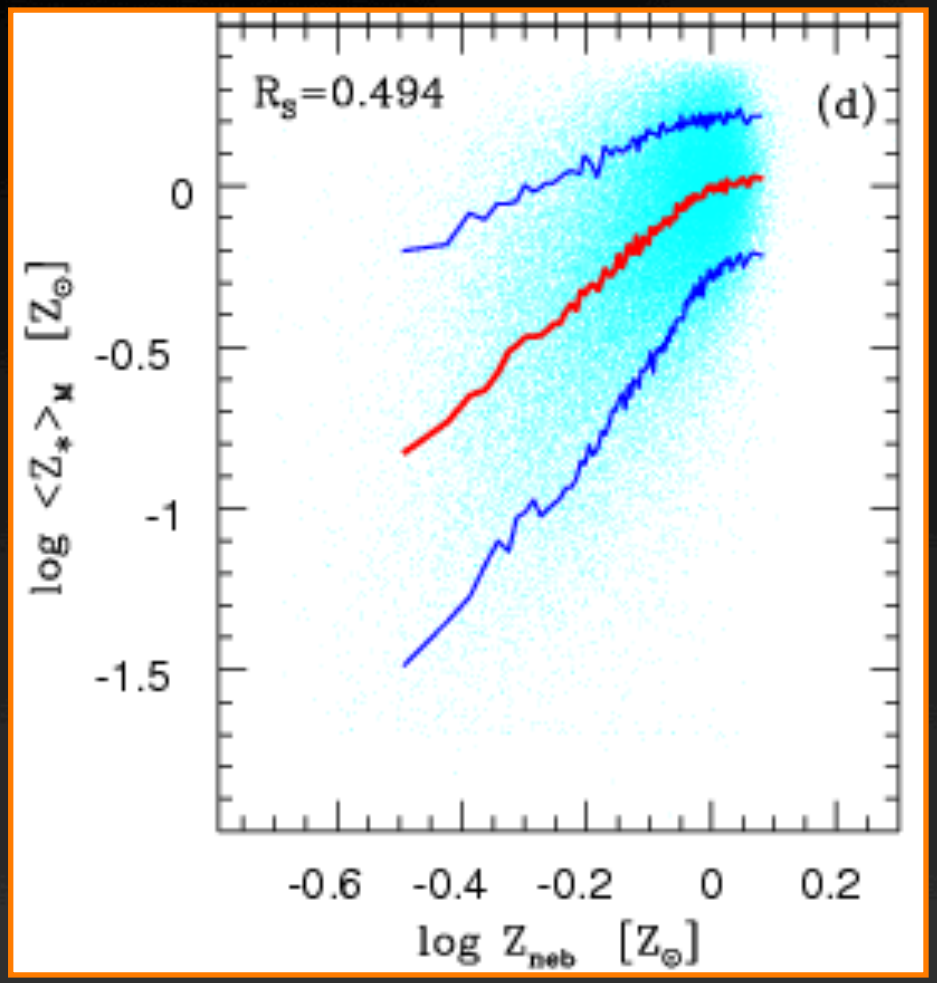
A_V(Hα/Hβ) ~ 2 A_V(stars)

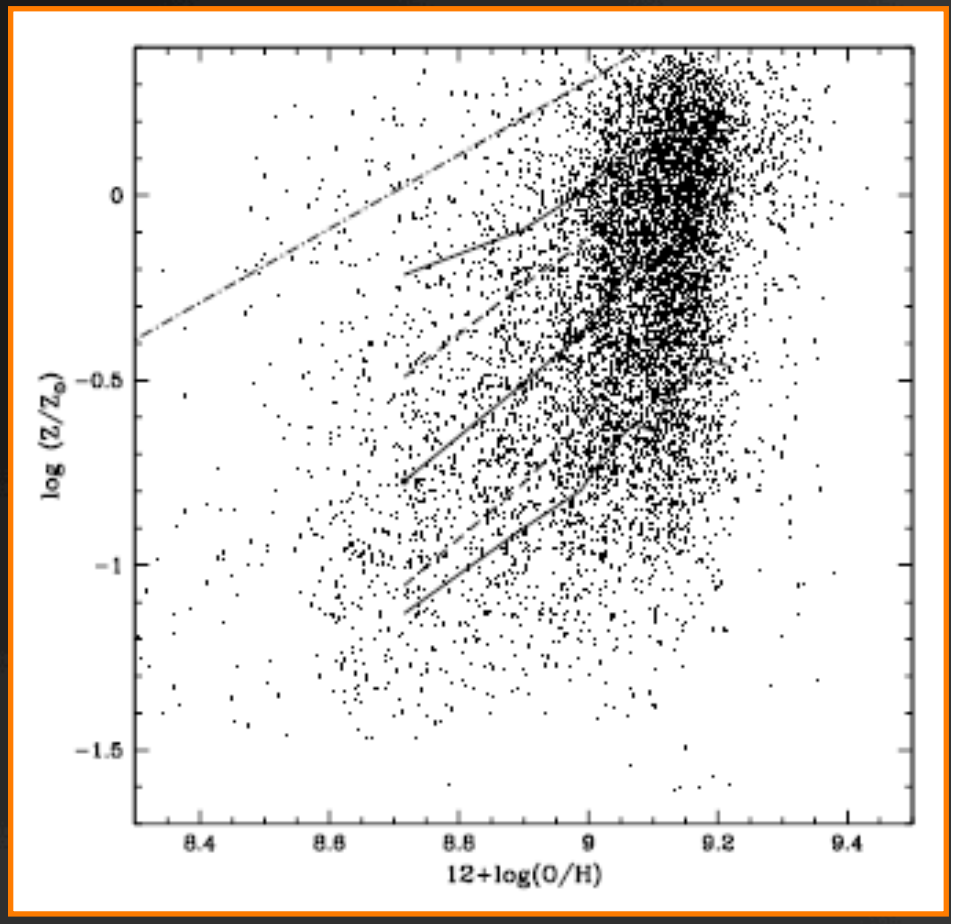


Asari 07, CF 05, Gomes 09

Sanity checks: Good news ☺☺☺

Z(stars) α Z(gas)



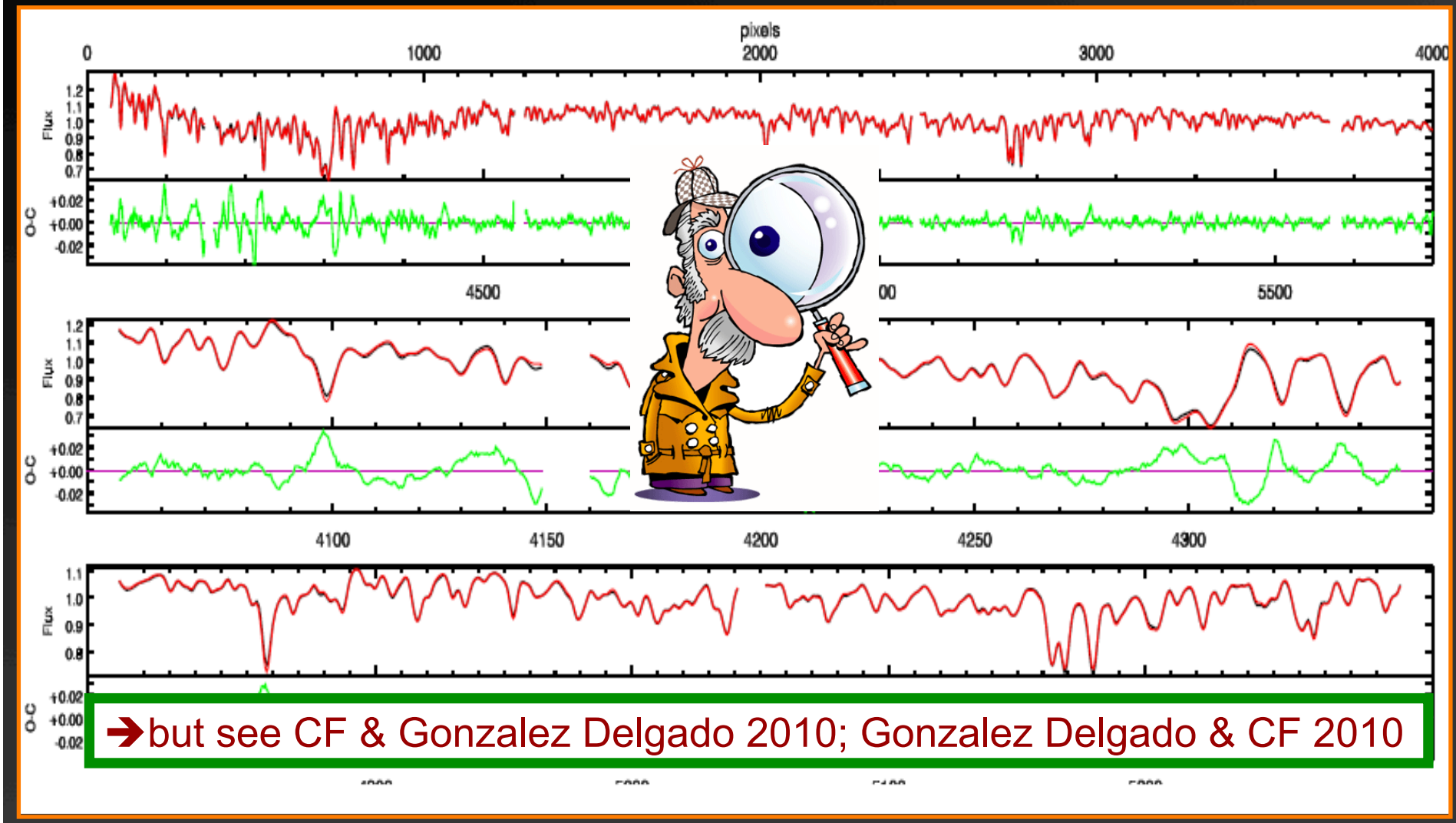


CF 05, 07, Asari 07, Panter 08

Gallazzi 05, 06, 08

Sanity checks: Good news ☺☺☺

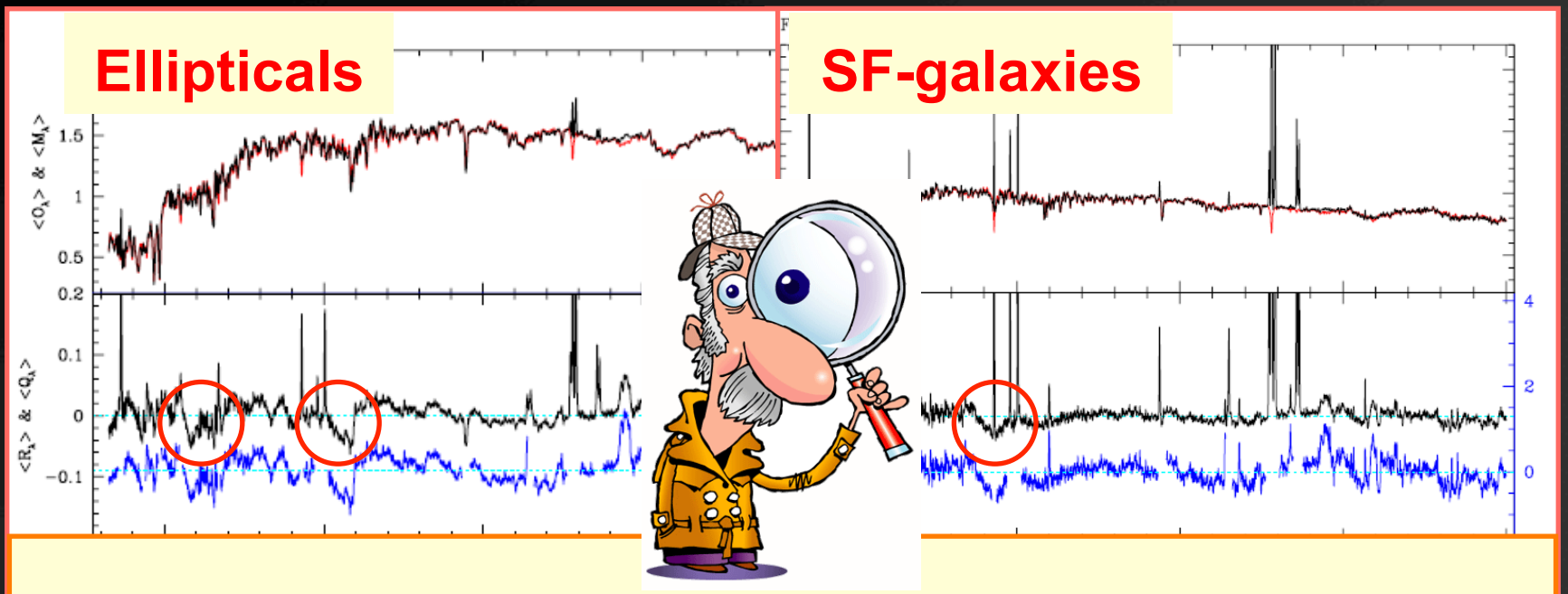
★ Koleva 08: Fit globular clusters & find same t & Z as from CMD



➔ but see CF & Gonzalez Delgado 2010; Gonzalez Delgado & CF 2010

Sanity checks: Problems … ☹😐☺

Residuals: ~ within errors, but systematic!



- α-bands not fitted in massive ellipticals ...

  P. Coelho's + J. Walcher models fix this!

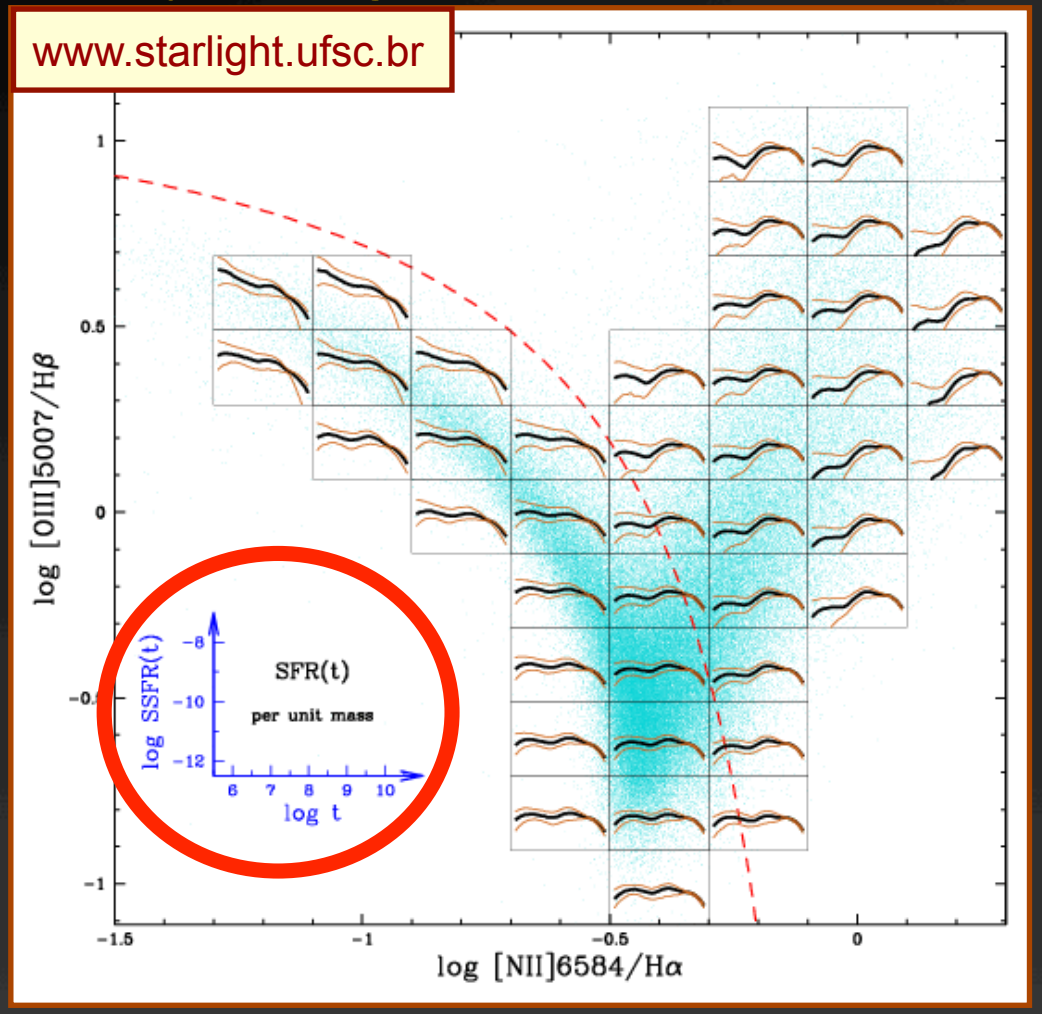
- Hβ–missfit (& etc) with STELIB ...

  MILES+Granada fixes this!

1 – Amazing things you can do with this stuff

A ~ random journey through the SDSS + STARLIGHT database

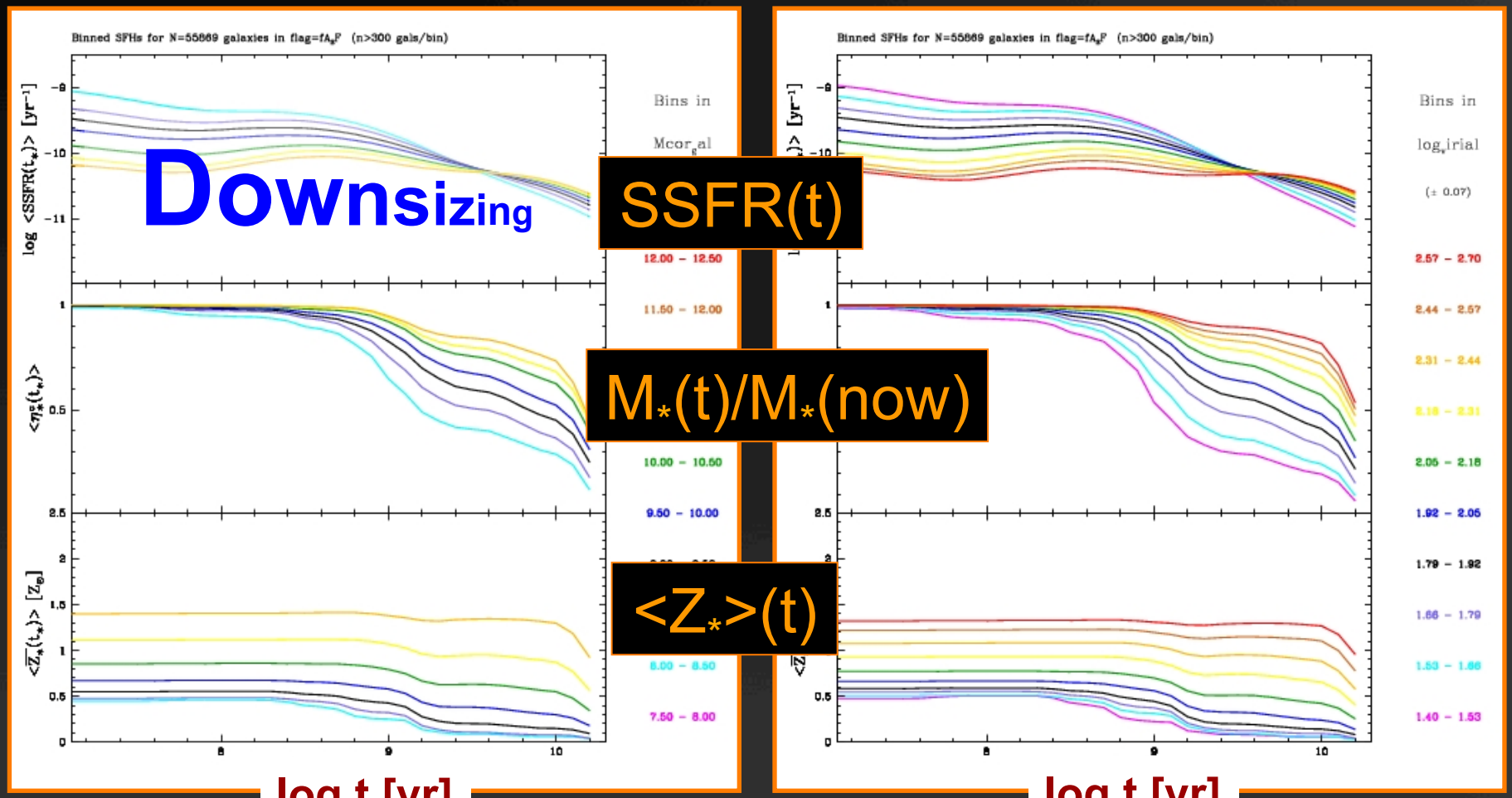
www.starlight.ufsc.br



SFHs & $Z_*(t)$ – Star Forming Galaxies

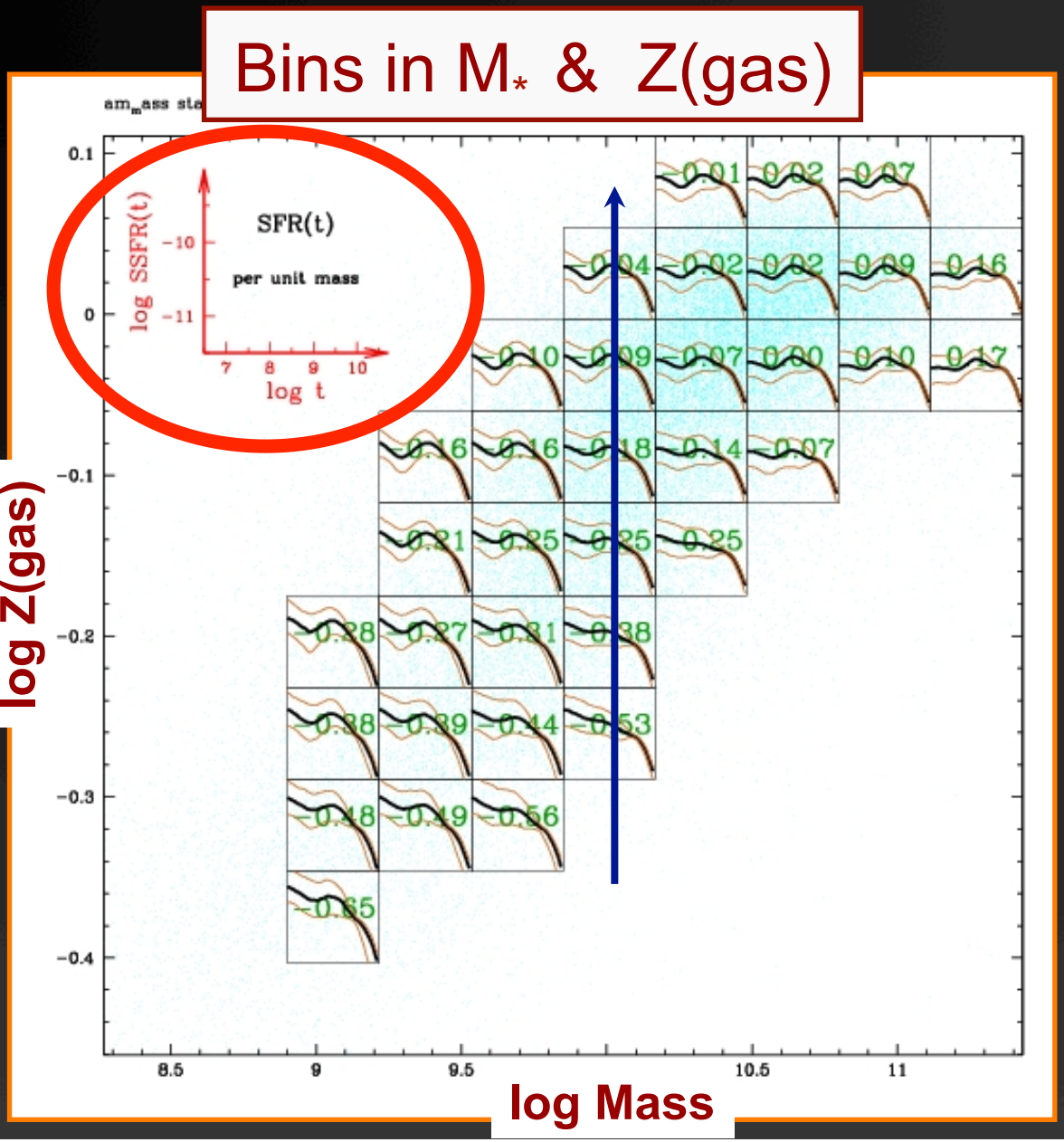
Bins in stellar mass

Bins in $v_{esc} \sim (GM/R)^{1/2}$



CF 07, Asari 07, Panter 08

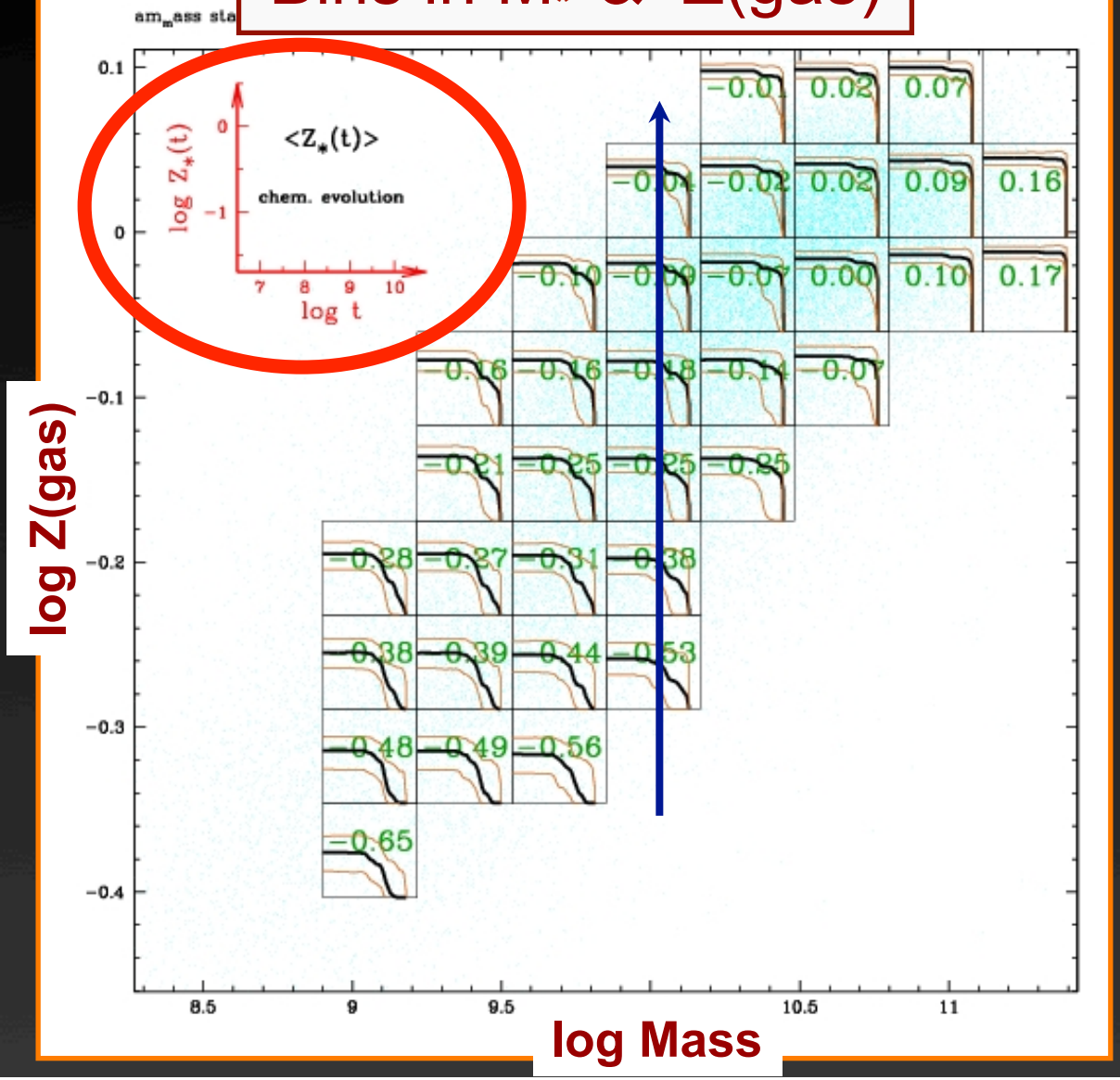
SFHs & $Z_*(t)$ – The M_*-Z_{gas} relation SSFR(t)



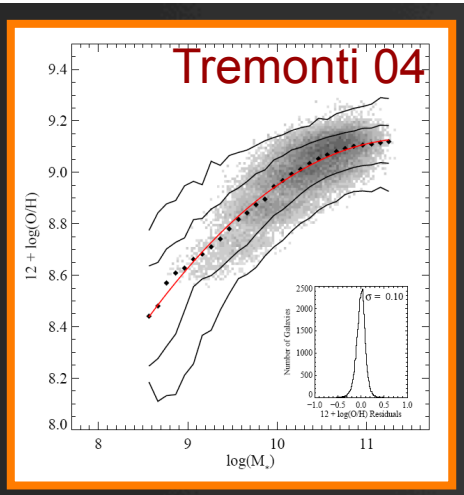
SFHs & $Z_*(t)$ – The M_*-Z_{gas} relation

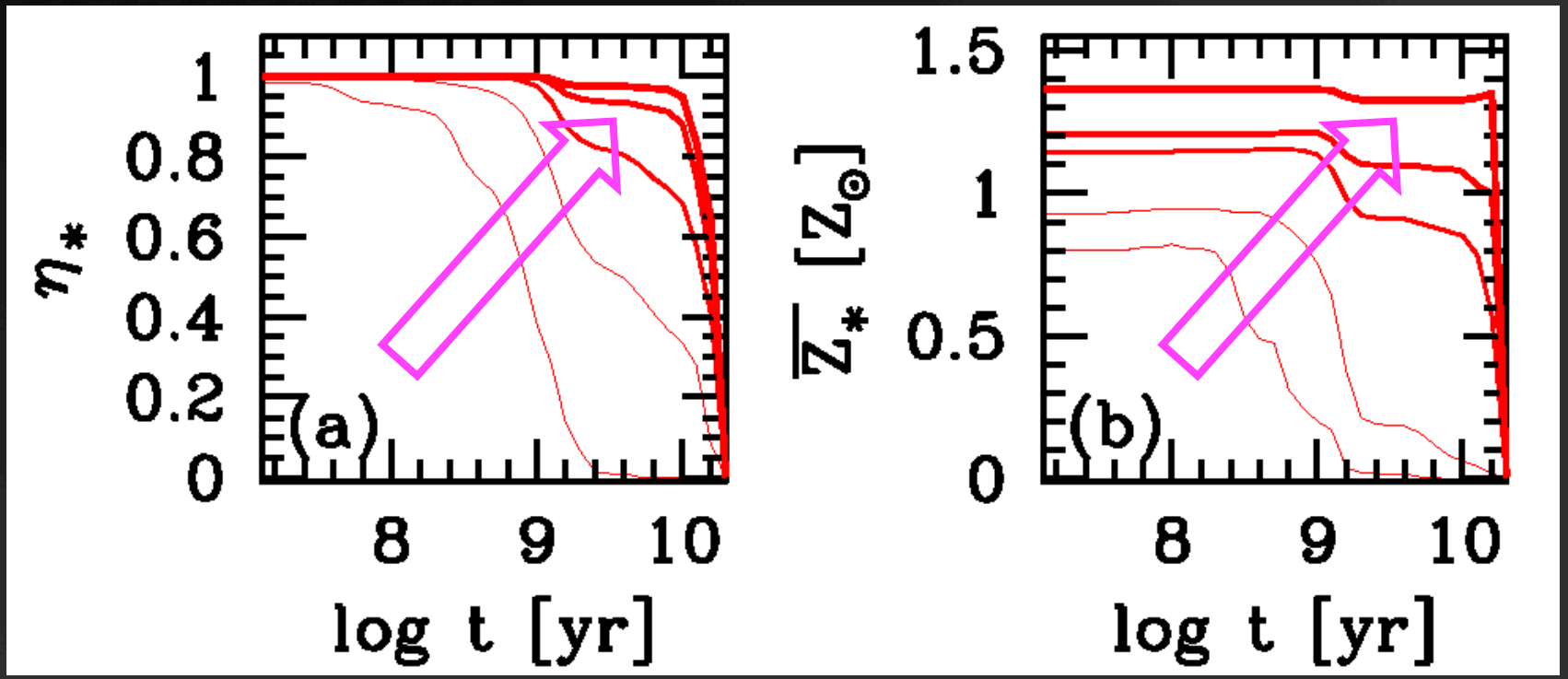
$Z_*(t)$

Bins in M_* & Z(gas)



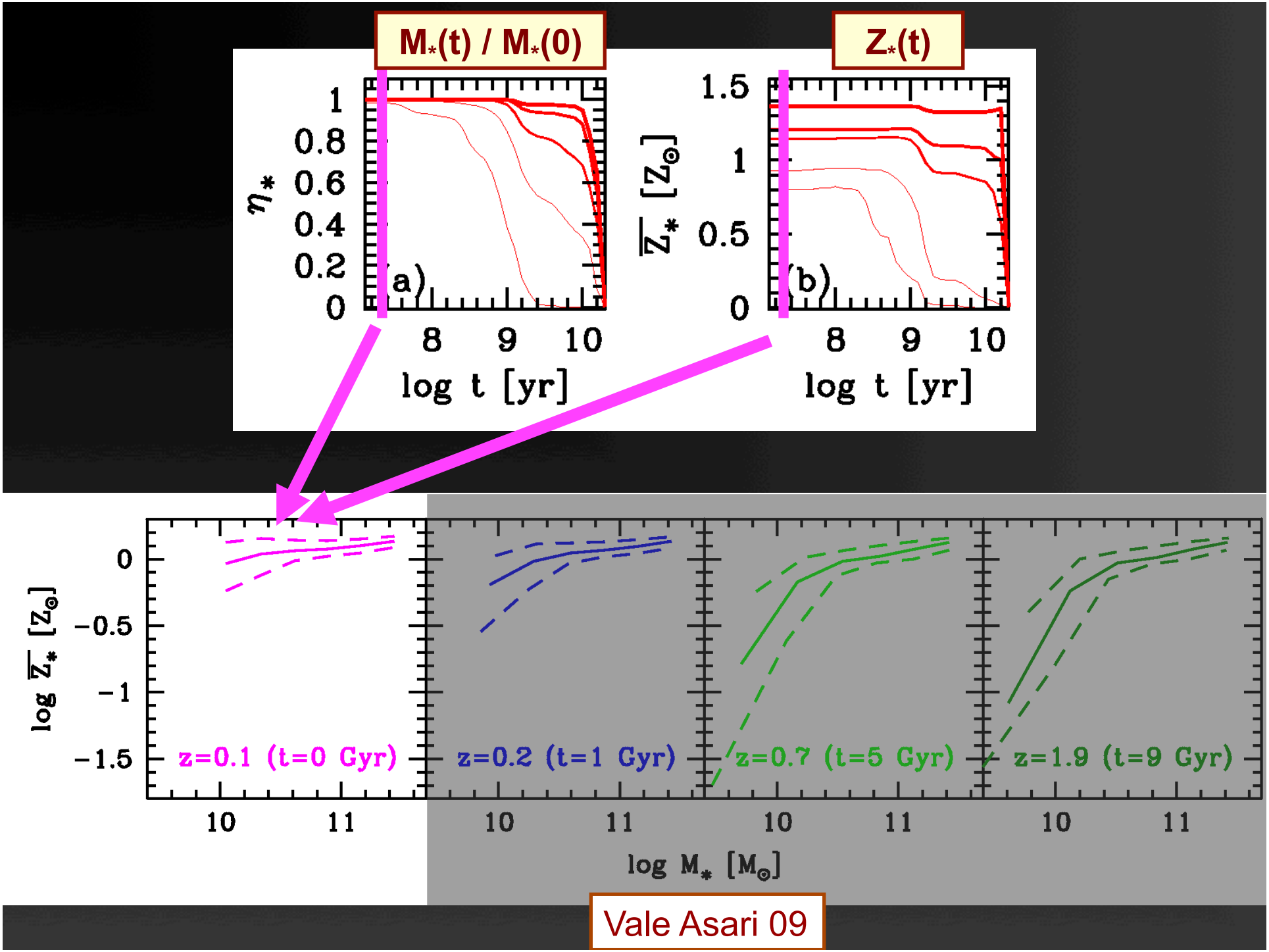
The cosmic evolution of the M-Z relation

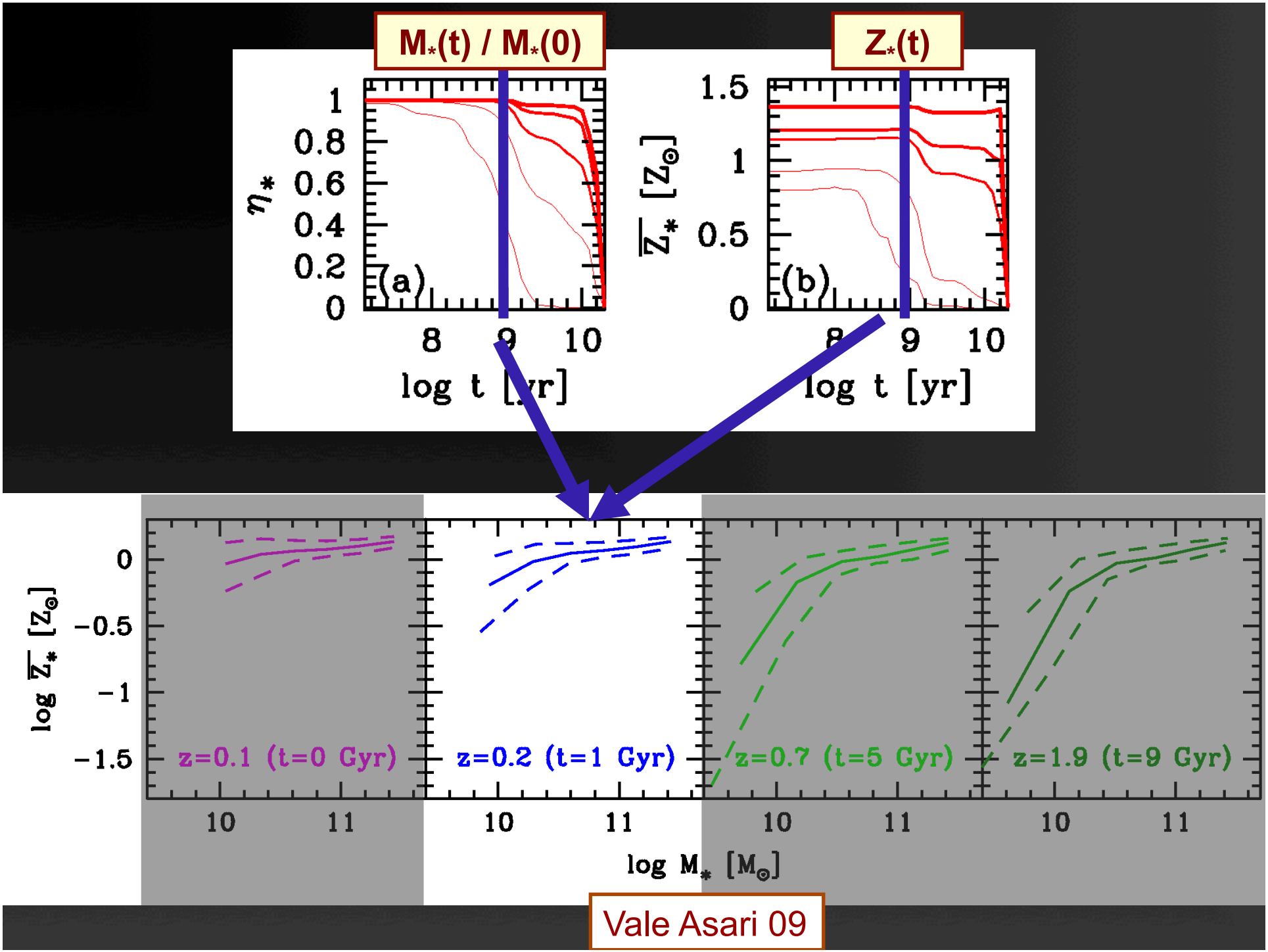


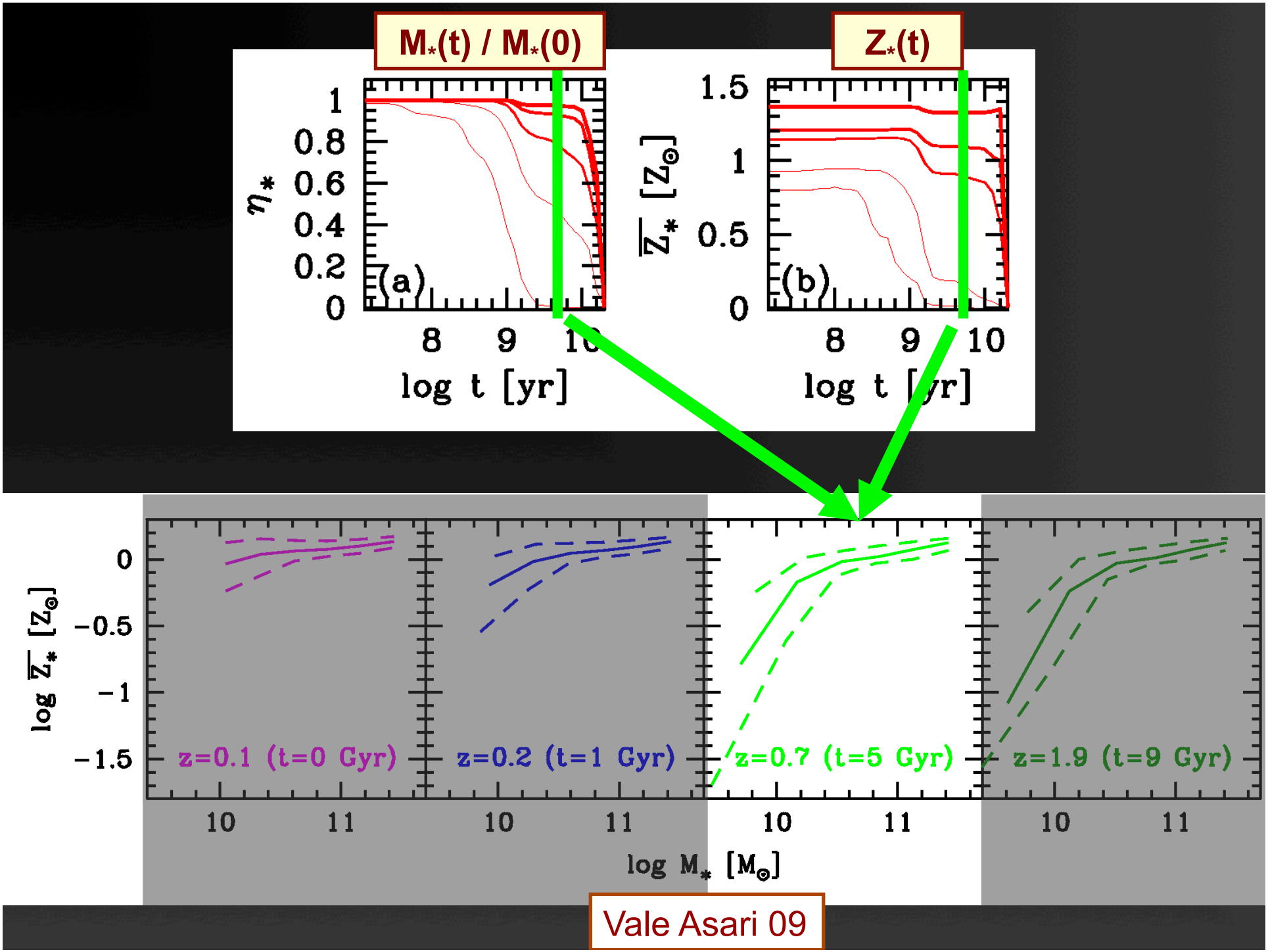


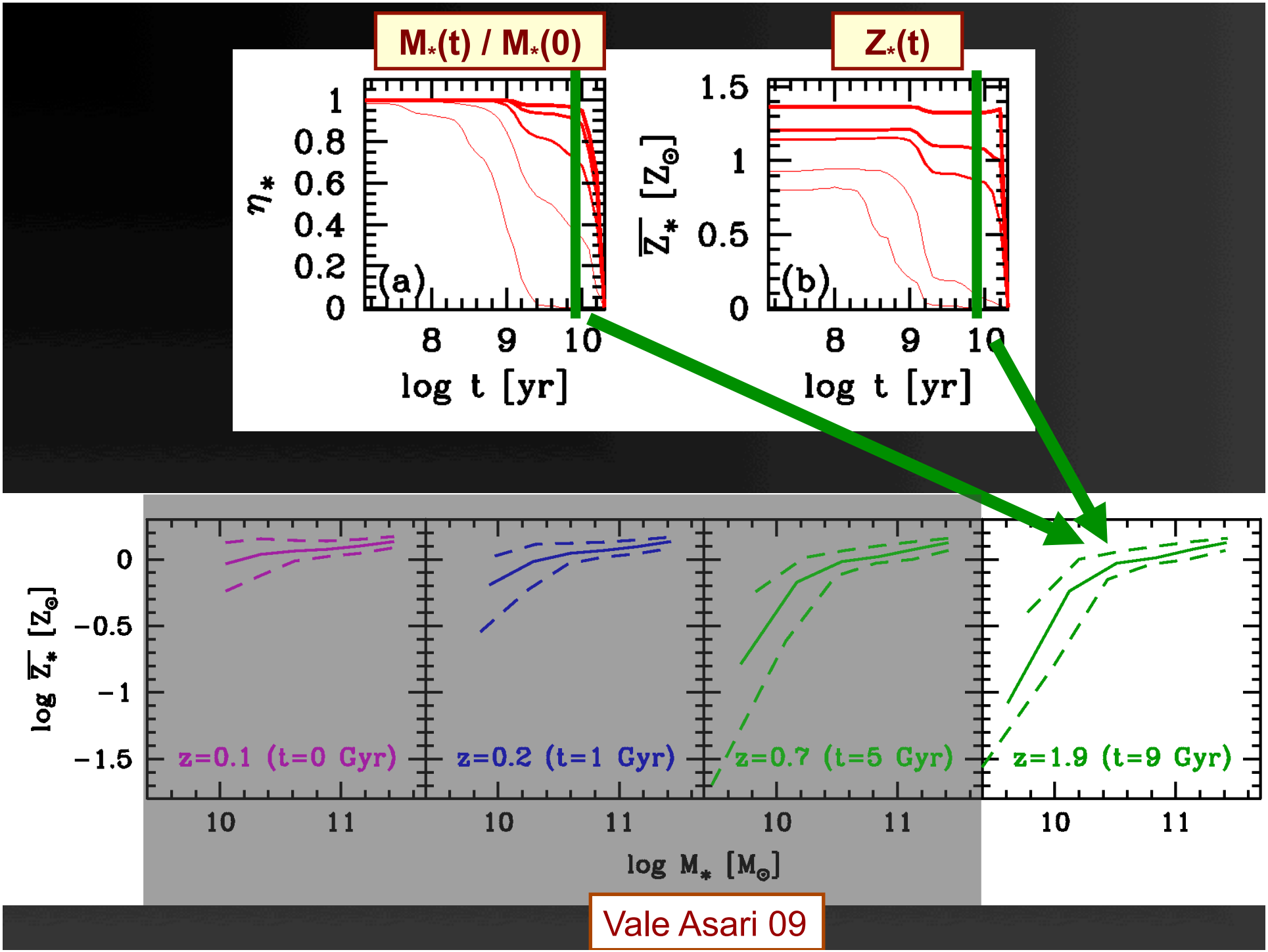
➔ $M_*(t)$: build up of stellar mass

➔ $Z_*(t)$: build up of metals


M*(t) / M*(0)
Z*(t)
η*
1
0.8
0.6
0.4
0.2
0
(a)
8
9
10
log t [yr]
Z* [Z⊙]
1.5
1
0.5
0
(b)
8
9
10
log t [yr]
log Z* [Z⊙]
0
−0.5
−1
−1.5
z=0.1 (t=0 Gyr)
z=0.2 (t=1 Gyr)
z=0.7 (t=5 Gyr)
z=1.9 (t=9 Gyr)
10
11
log M* [M⊙]
Vale Asari 09


M*(t) / M*(0)
Z*(t)
η*
(a)
(b)
log t [yr]
log t [yr]
log Z* [Z⊙]
z=0.1 (t=0 Gyr)
z=0.2 (t=1 Gyr)
z=0.7 (t=5 Gyr)
z=1.9 (t=9 Gyr)
log M* [M⊙]
Vale Asari 09


M*(t) / M*(0)
Z*(t)
η*
(a)
(b)
log t [yr]
log t [yr]
log Z* [Z⊙]
z=0.1 (t=0 Gyr)
z=0.2 (t=1 Gyr)
z=0.7 (t=5 Gyr)
z=1.9 (t=9 Gyr)
log M* [M⊙]
Vale Asari 09

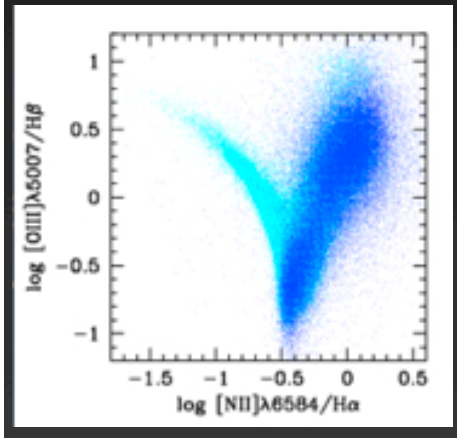

M*(t) / M*(0)
Z*(t)
η*
(a)
(b)
log t [yr]
log t [yr]
log Z* [Z⊙]
z=0.1 (t=0 Gyr)
z=0.2 (t=1 Gyr)
z=0.7 (t=5 Gyr)
z=1.9 (t=9 Gyr)
log M* [M⊙]
Vale Asari 09

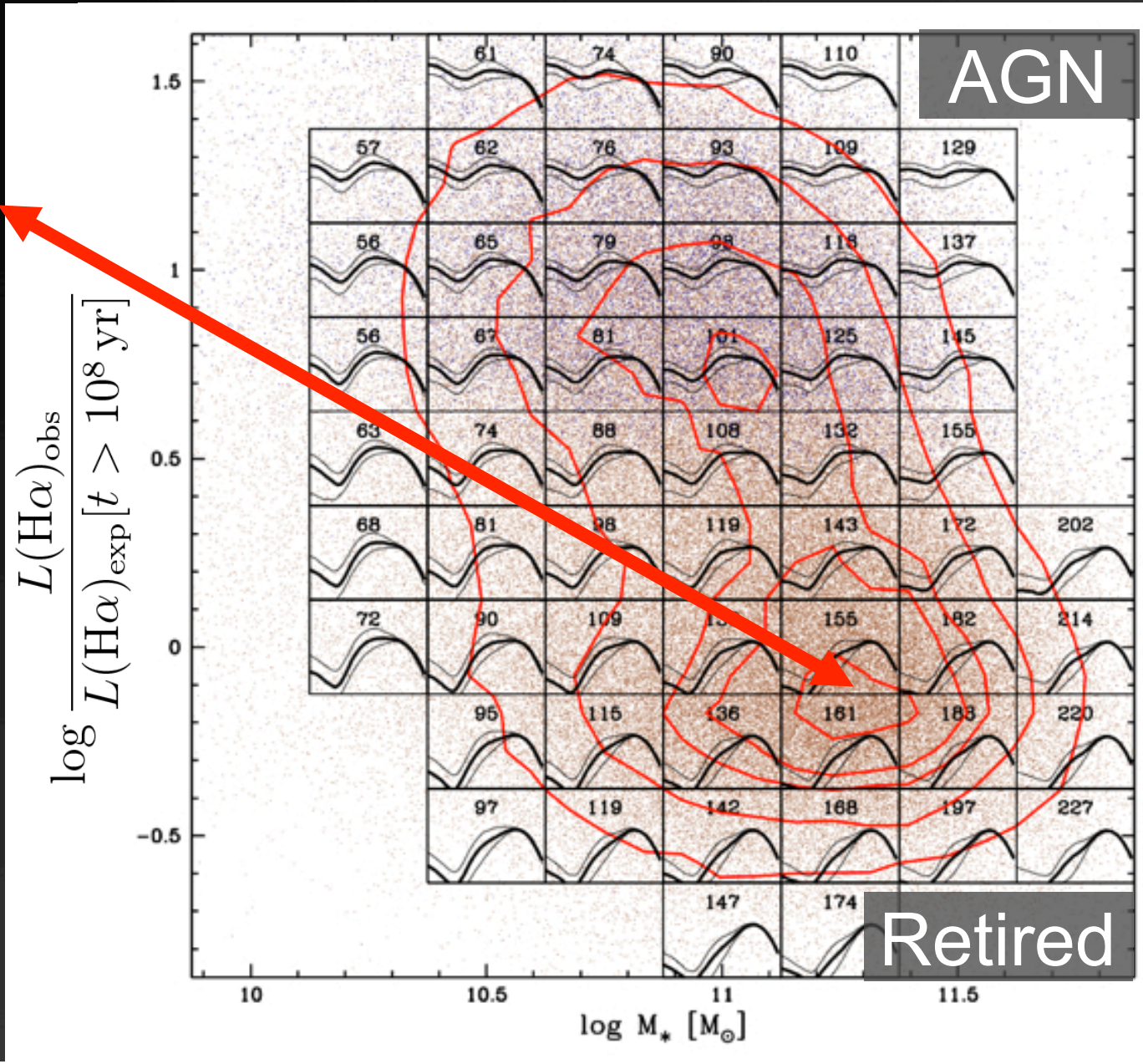
Retired galaxies disguised as AGN!

Ionization by old & hot stars produce LINER-like emission lines

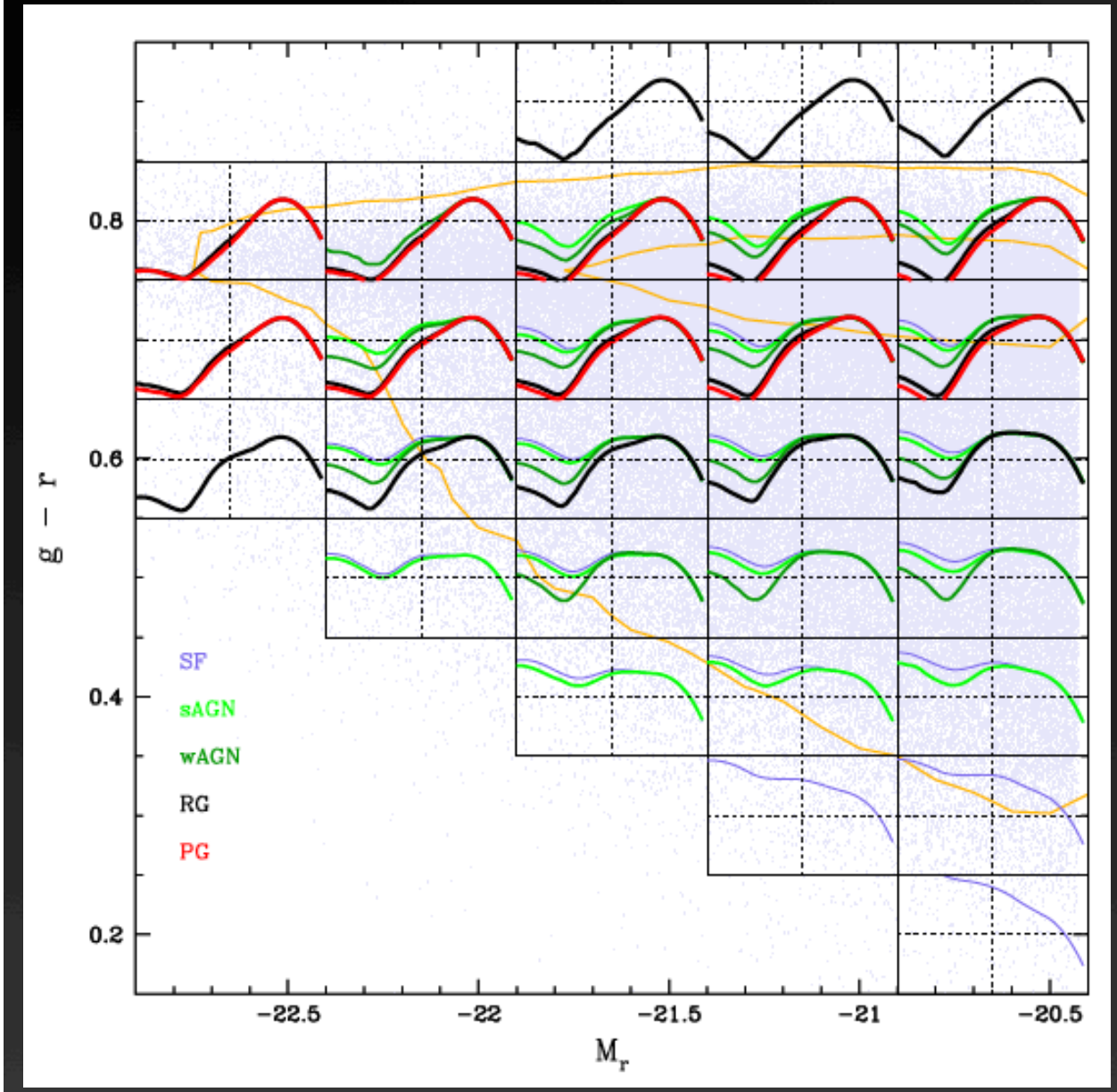
➔ **fake AGN!!**

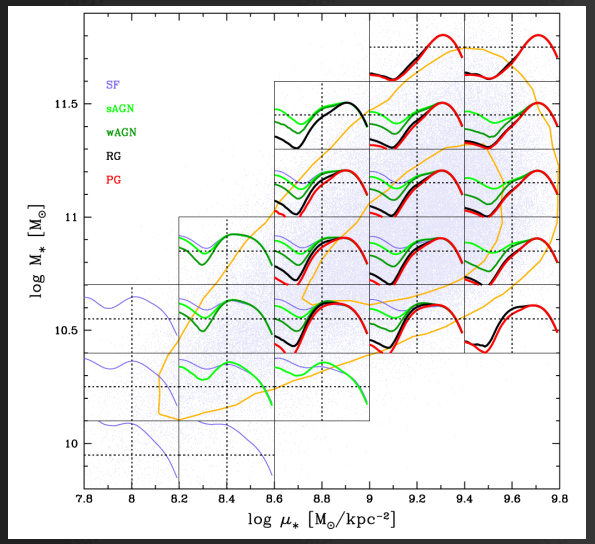
Binette 94, Stasinska 08, CF 10, 11

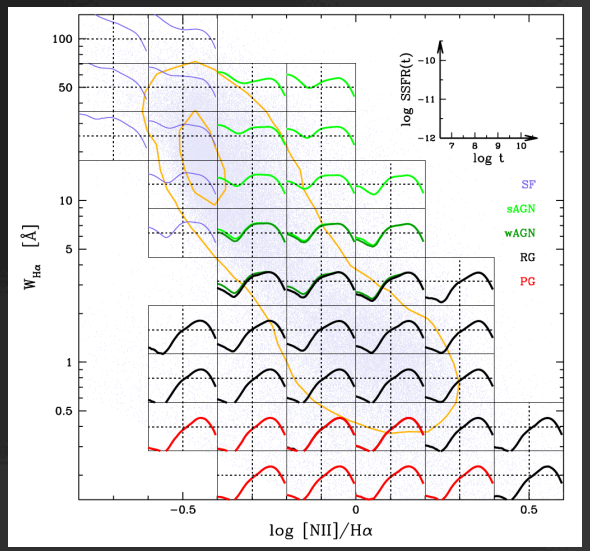




SFHs in the CMD, and etc





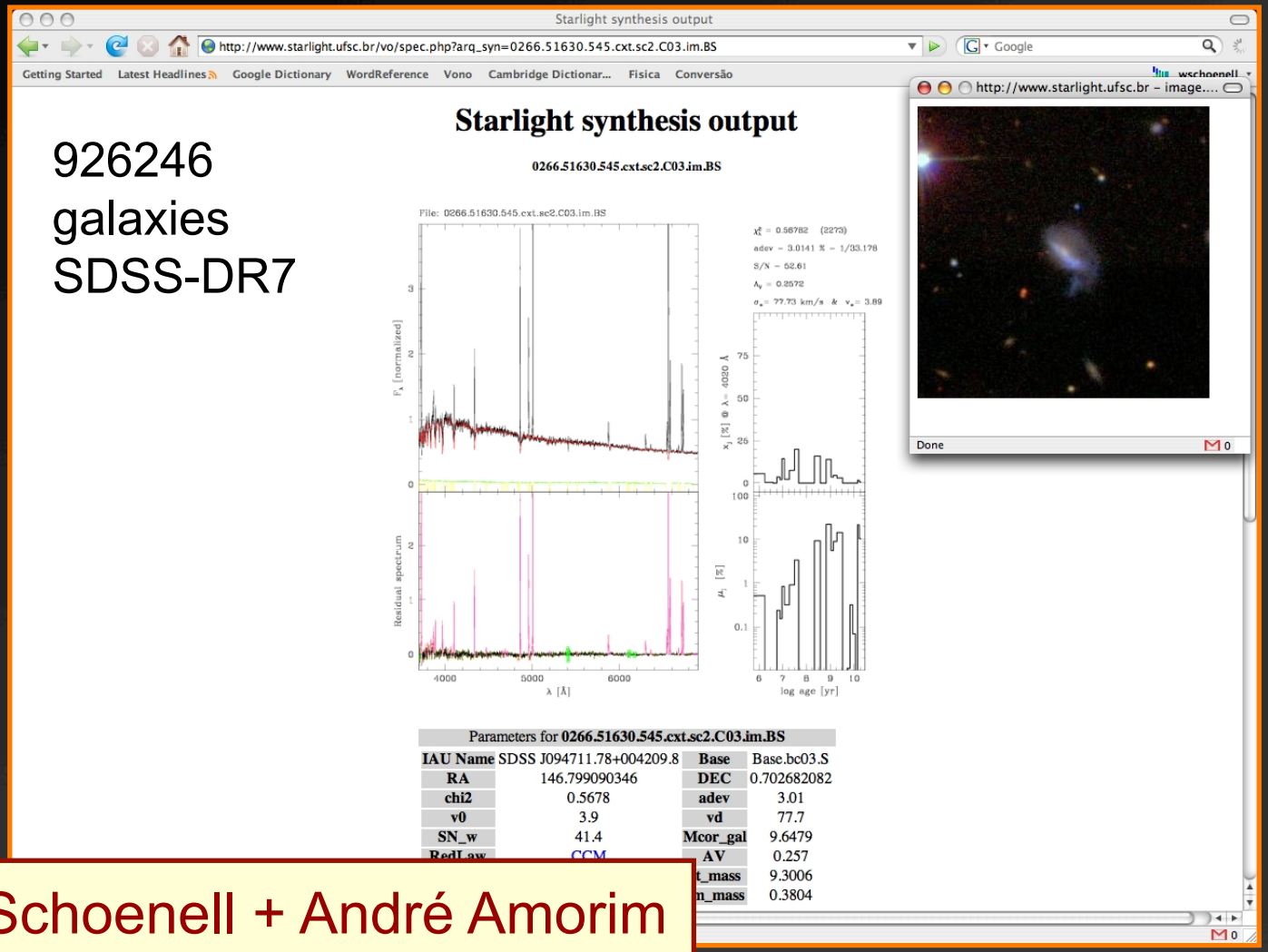


CF et al 11

Starlight

www.starlight.ufsc.br

926246
galaxies
SDSS-DR7



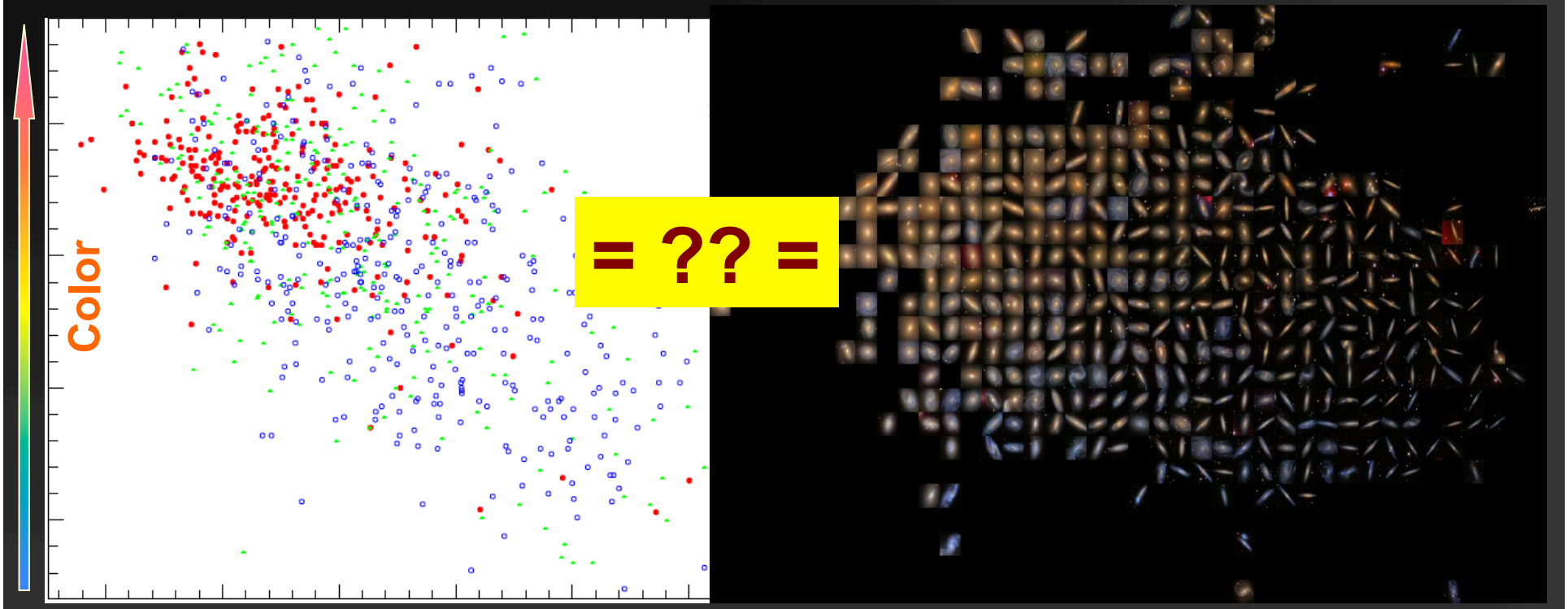
William Schoenell + André Amorim

Great, but this is all **1D**! (integrated spectra)

Do size / shape / looks matter?

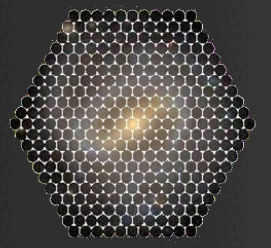
Can galaxies be treated as point sources?

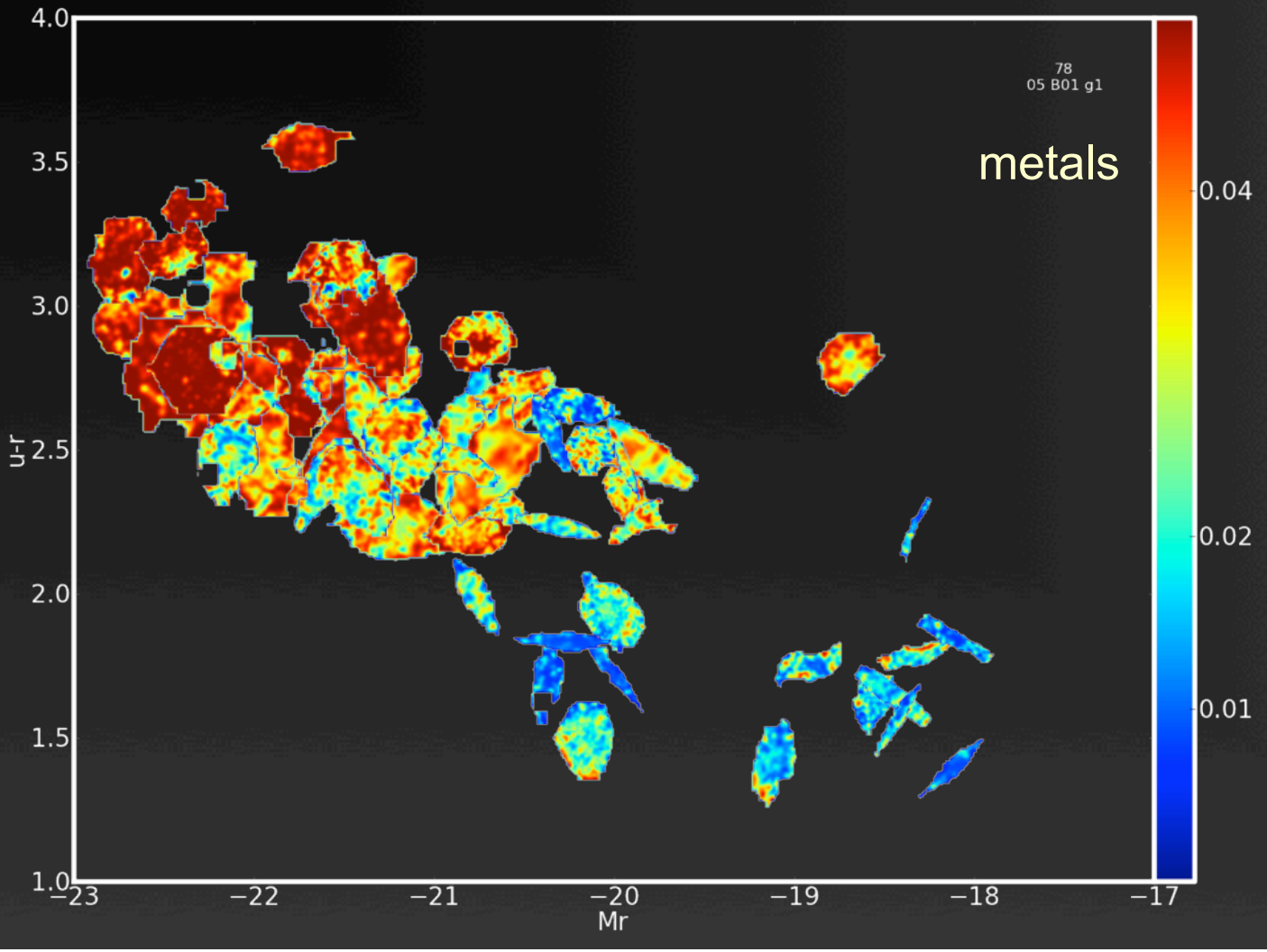
What can we learn from F(λ,x,y)?



2 – Galaxy evolution in 2D

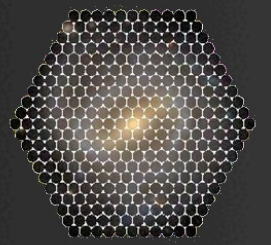
Spatially resolved mass and metallicity growth





2 – Galaxy evolution in 2D

Spatially resolved mass and metallicity growth



Calar Alto Legacy Integral Field Area survey

~ 80 members / 13 countries

- PI: S. F. Sánchez
- PS: C. J. Walcher
- Board chair: R. Kennicutt

210 dark nights in 3 years:

- PPAK@3.5m CAHA
- Full optical wavelength range
- ~2000 spectra per galaxy

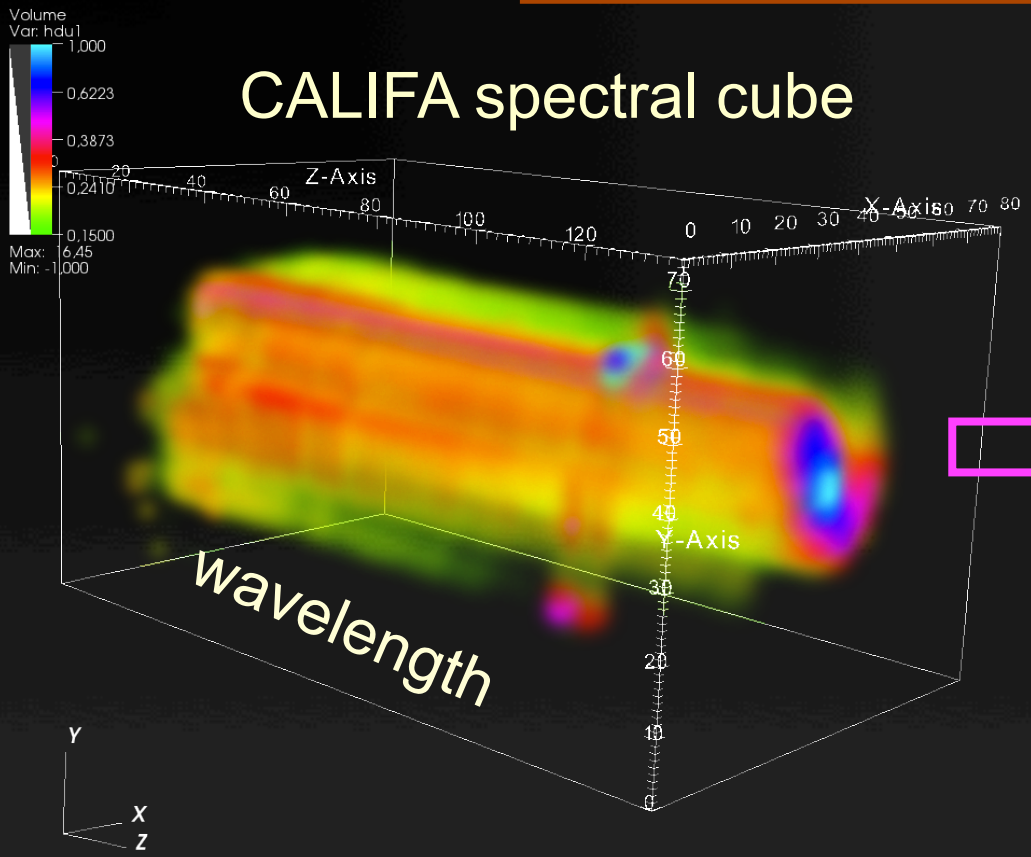
Sample:

- ~20 galaxies per 1x1 mag bin in the CMD
- + diameter selection …

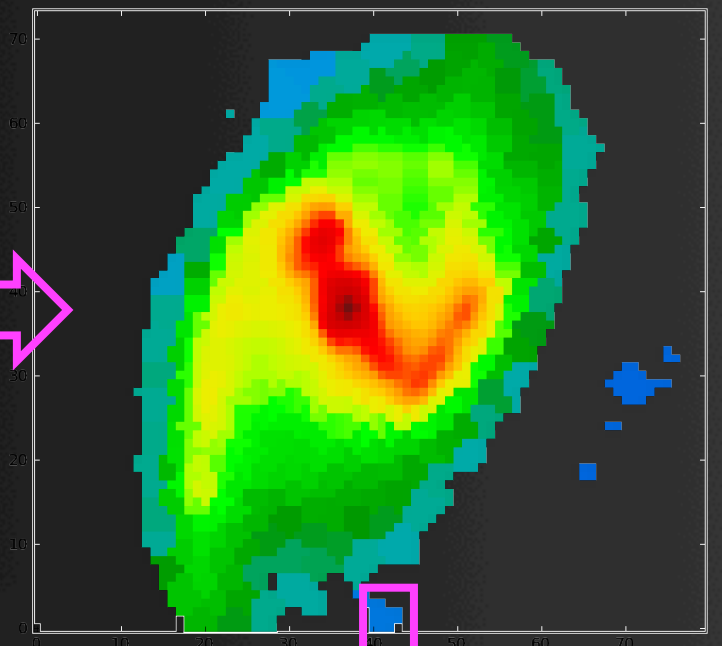
Preliminary results!

The PIPELINE

CALIFA spectral cube



spatial binning



Output spectra corrected for:

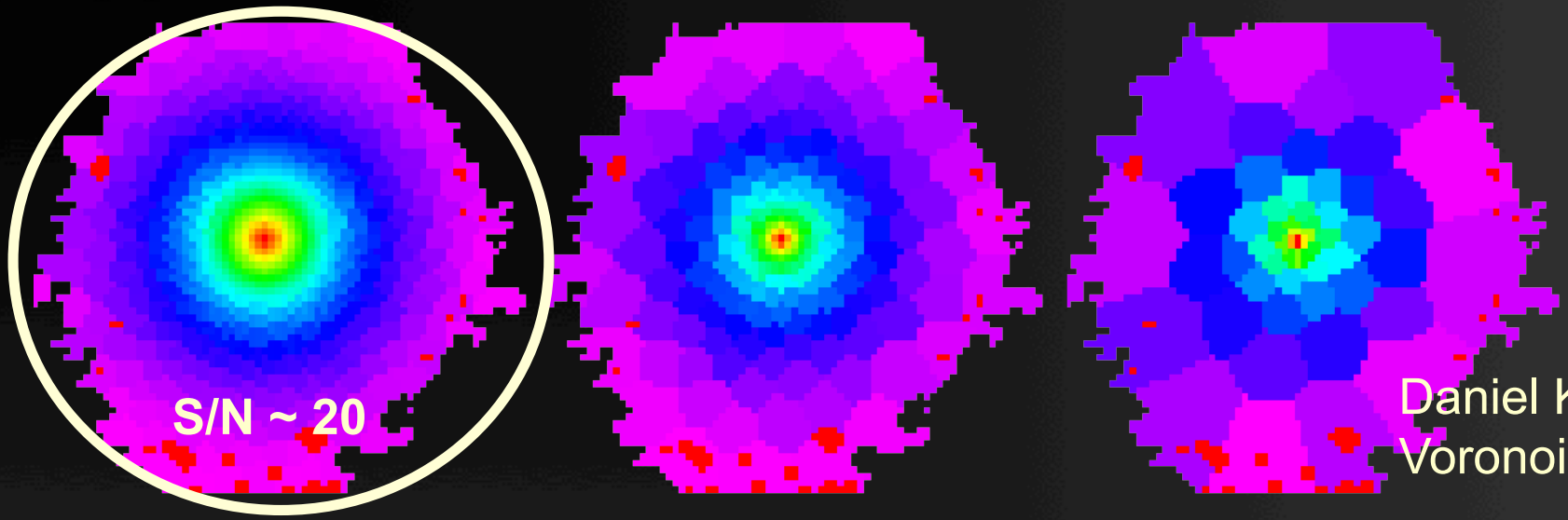
- redshift
- Galactic extinction
- uniform λ scale

STARLIGHT

M_* , v_* , σ_*, A_V, <age>, $<Z_*>$, SFH

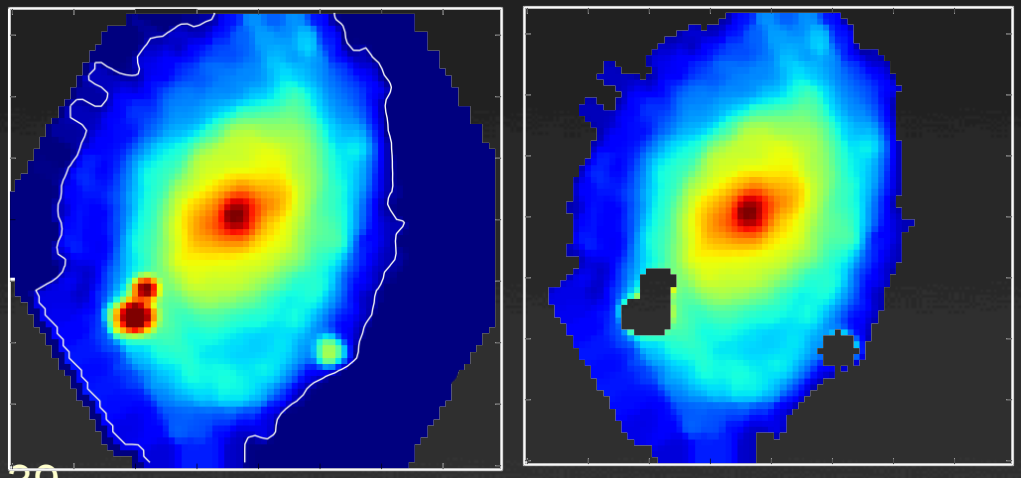
as a function of x & y!!

The PIPELINE (some "details")



Daniel Kupko's Voronoi code

Spatial masks – Nadine Backsmann



+

Spectral masks
Bad pixel flags
Correlated errors
Calibration issues

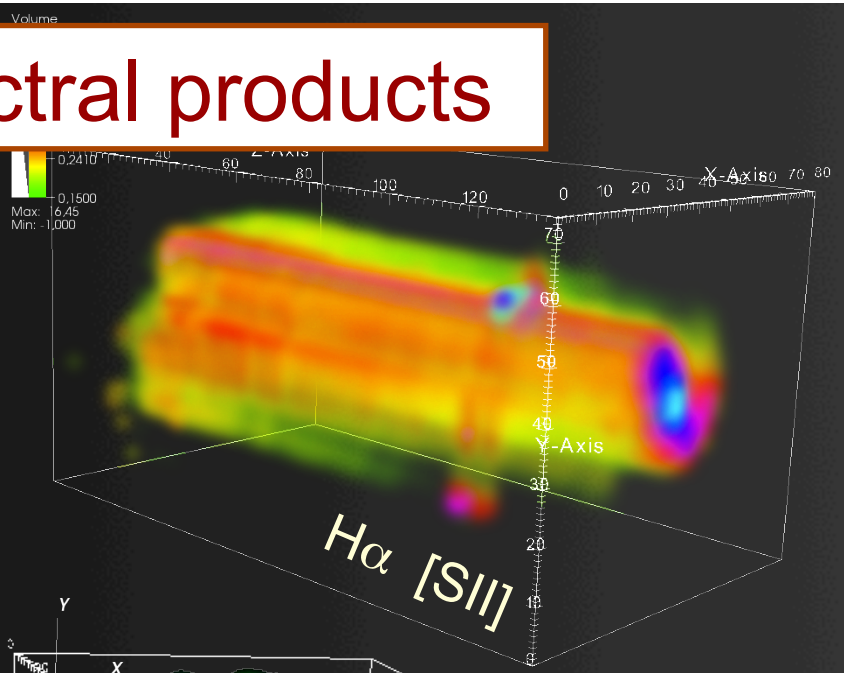
...

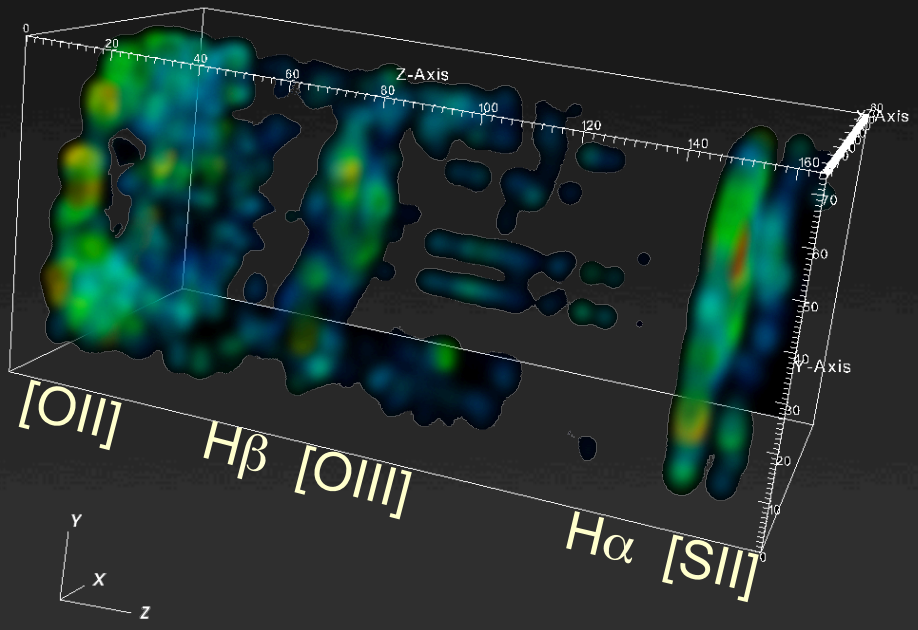
PIPELINE spectral products

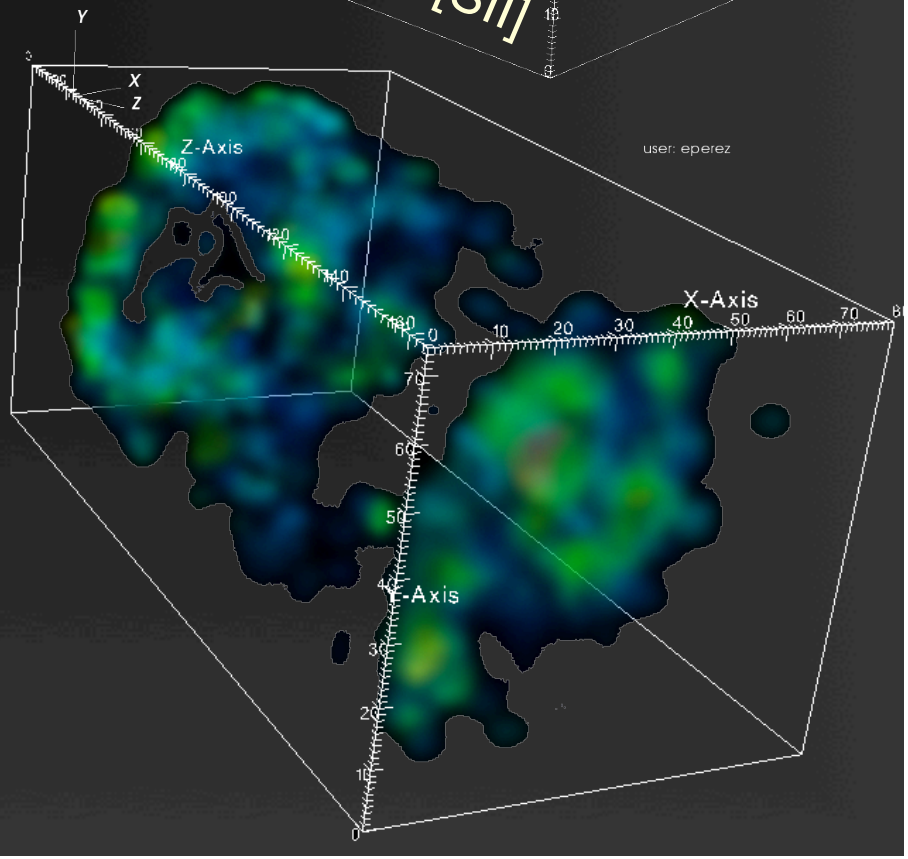
Spectral cubes:

- Data
- Fit: stars
- Residual: gas

➔ Useful for emission line work…







STARLIGHT

SFH products

READ Starlight output

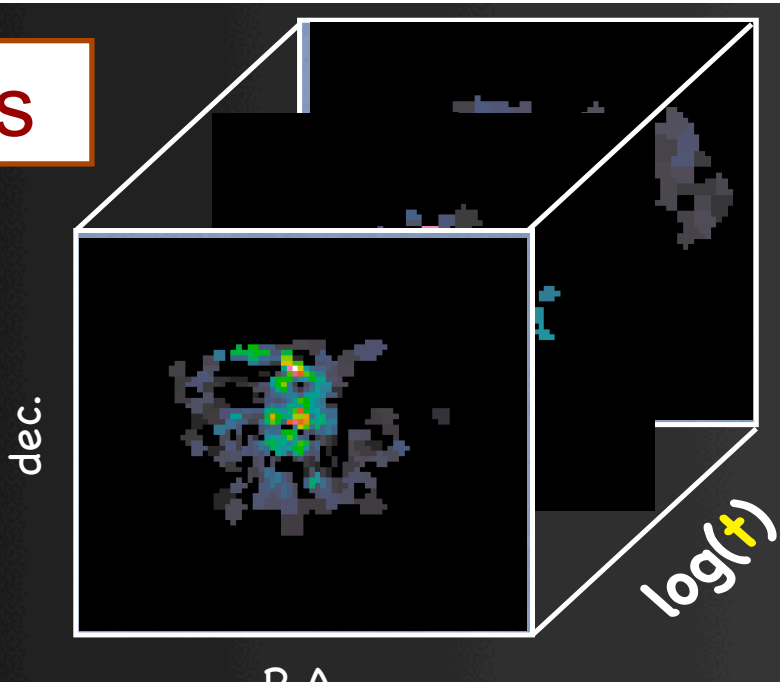
Mages Dict[z, t]

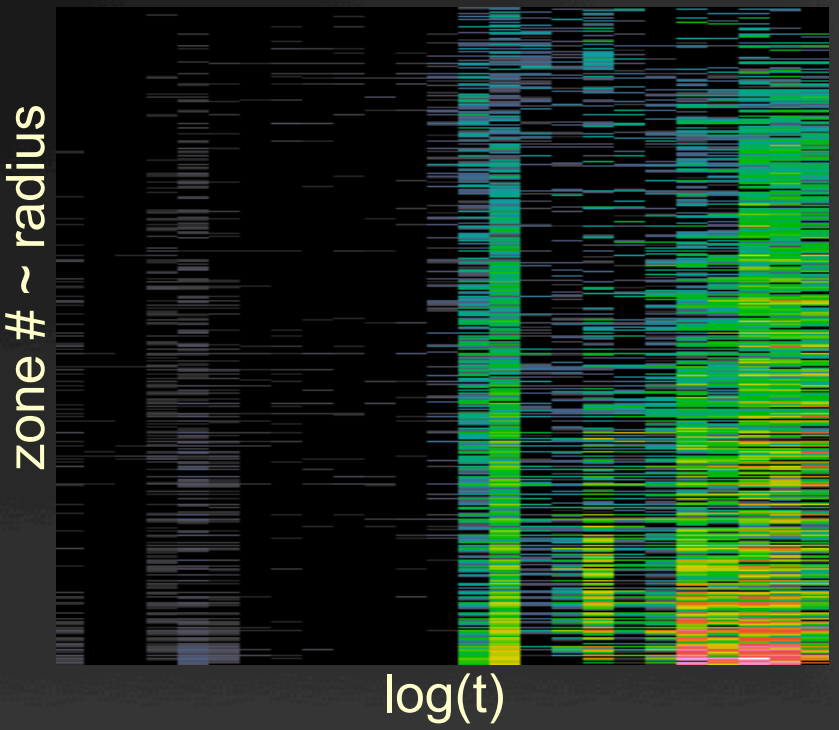
Σ_z

Mage bins[t]

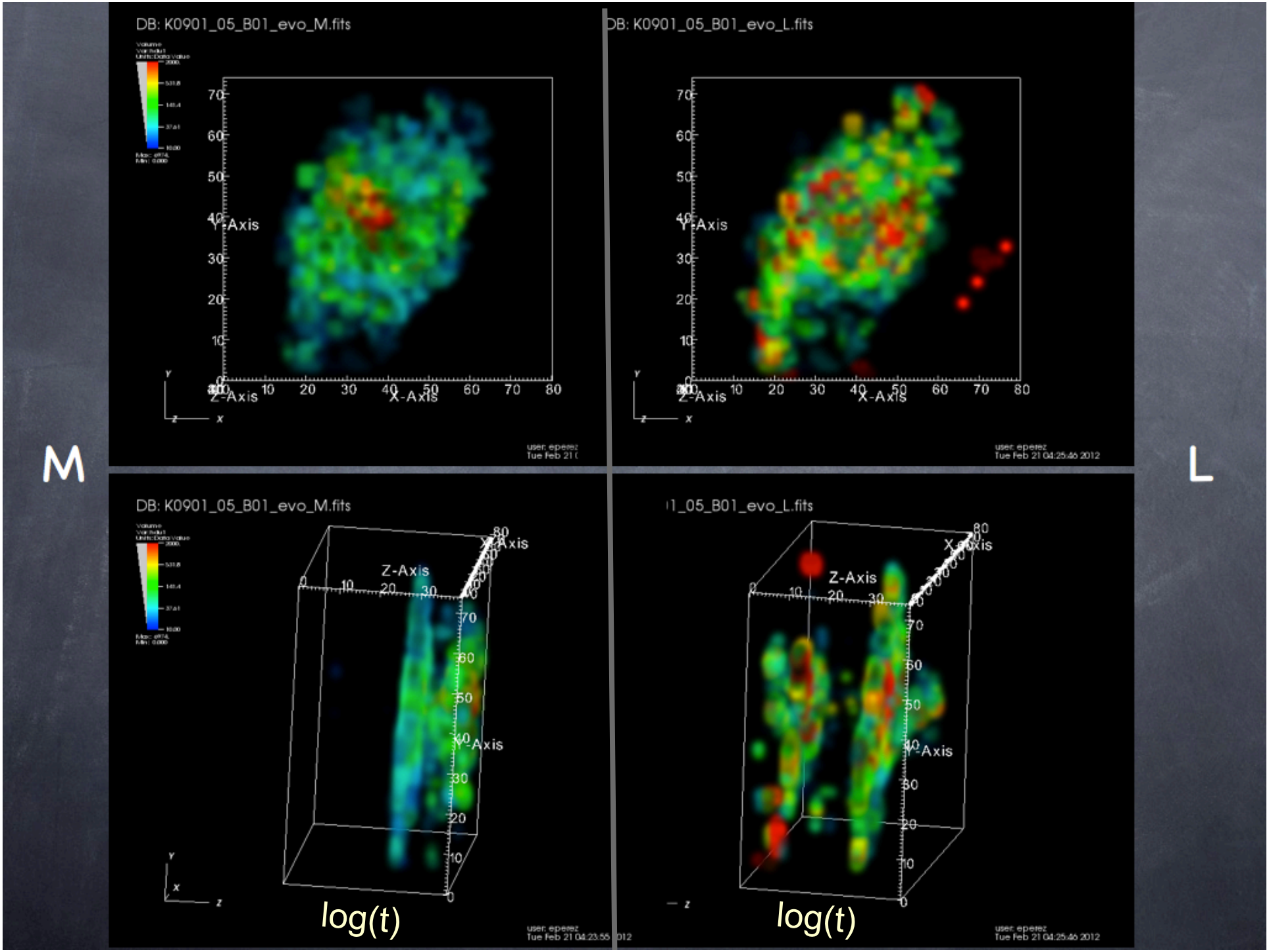
Mages_cube[t,y,x] = zone(y,x) x Magebins[t] / area(zone)

Mcen[zone,t] = zone(y,x) x Magebins[t] / area(zone)

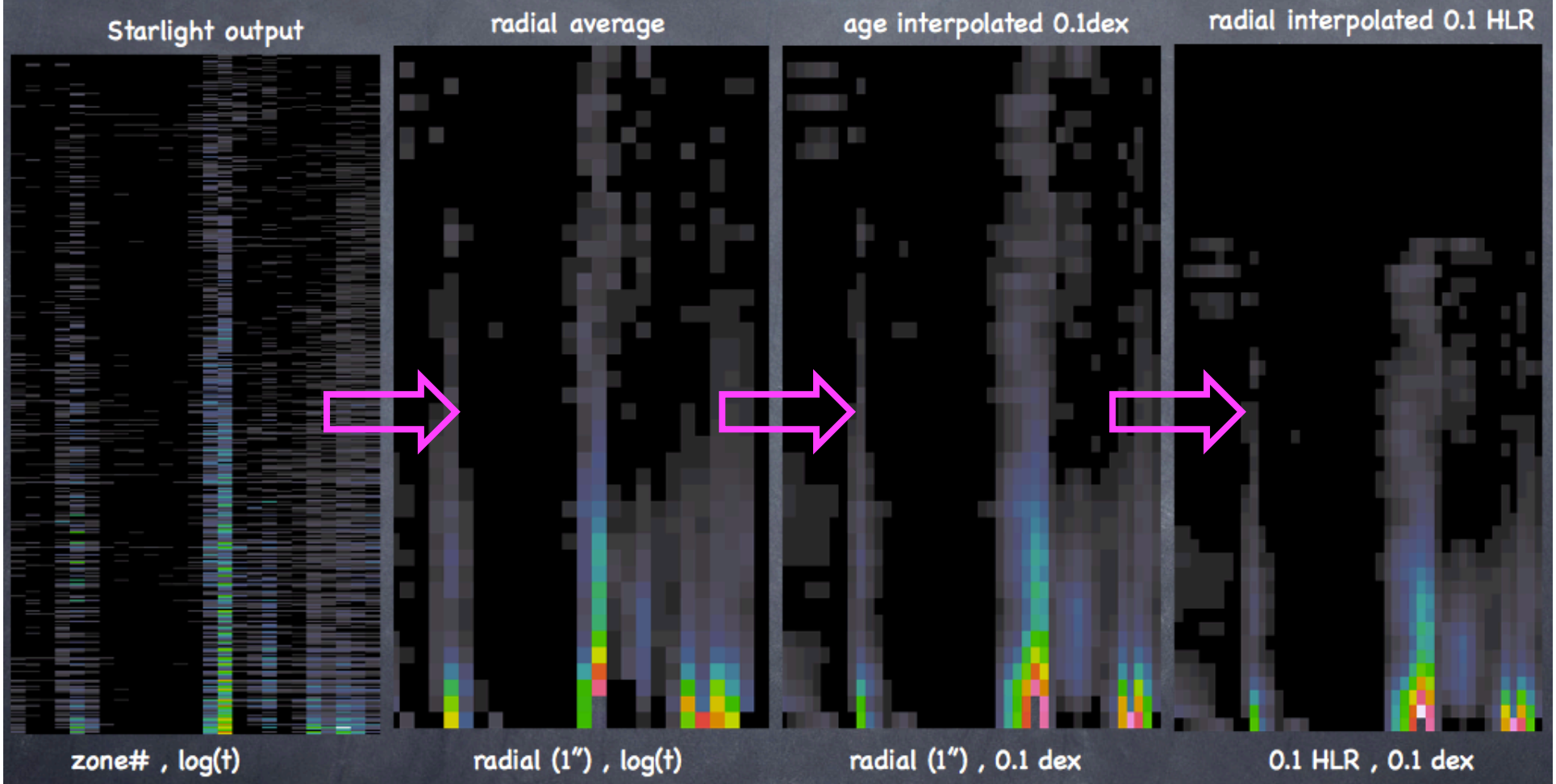


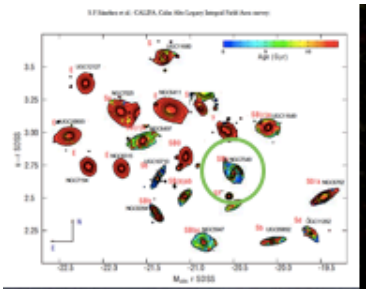


L(t) M(t) Z(t)

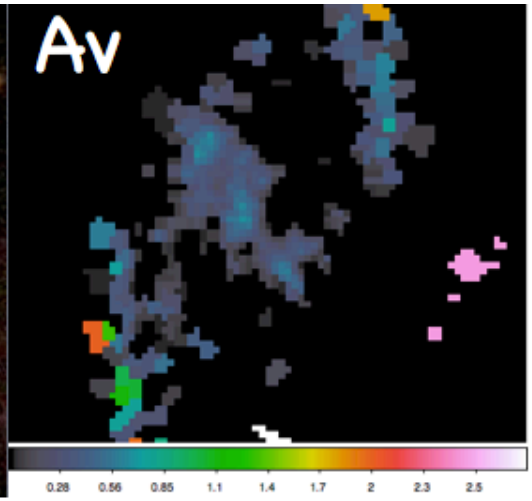

DB: K0901_05_B01_evo_M.fits
DB: K0901_05_B01_evo_L.fits
Y-Axis
Z-Axis
X-Axis
M
L
log(t)
log(t)

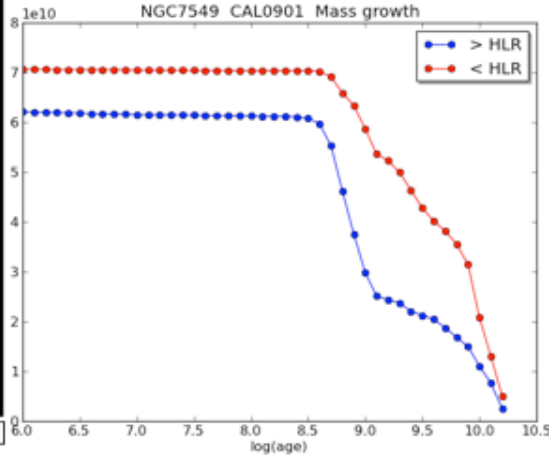
SFHs: spatial & temporal resampling…

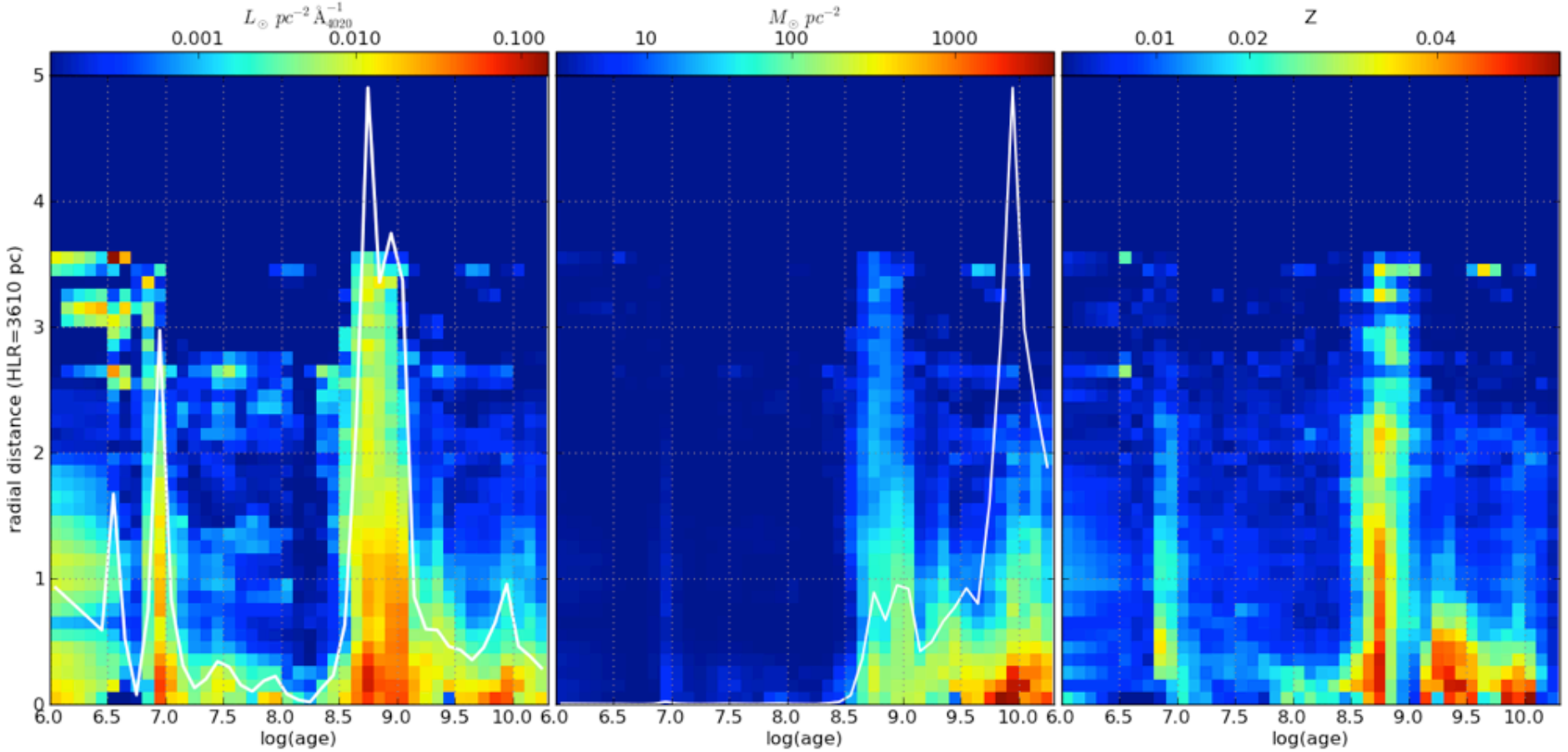


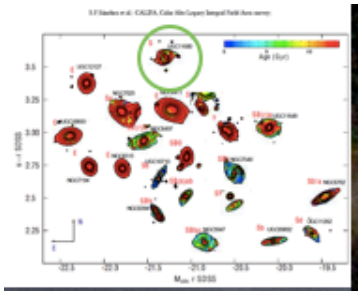


NGC7549
K0901

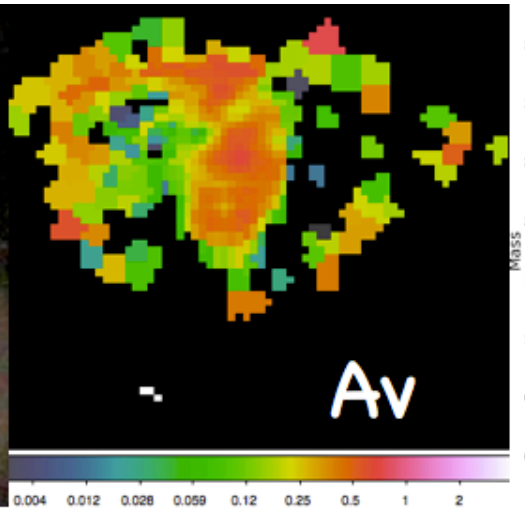


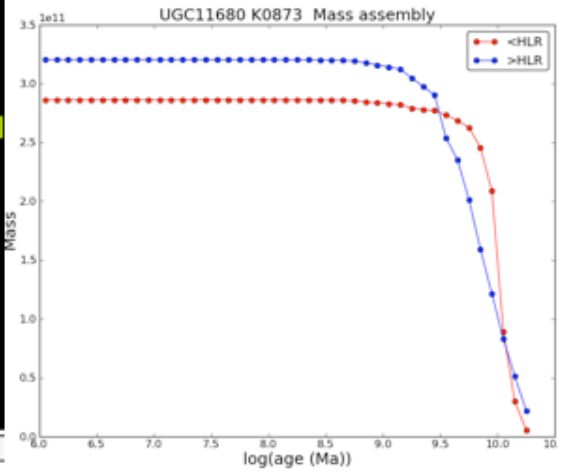


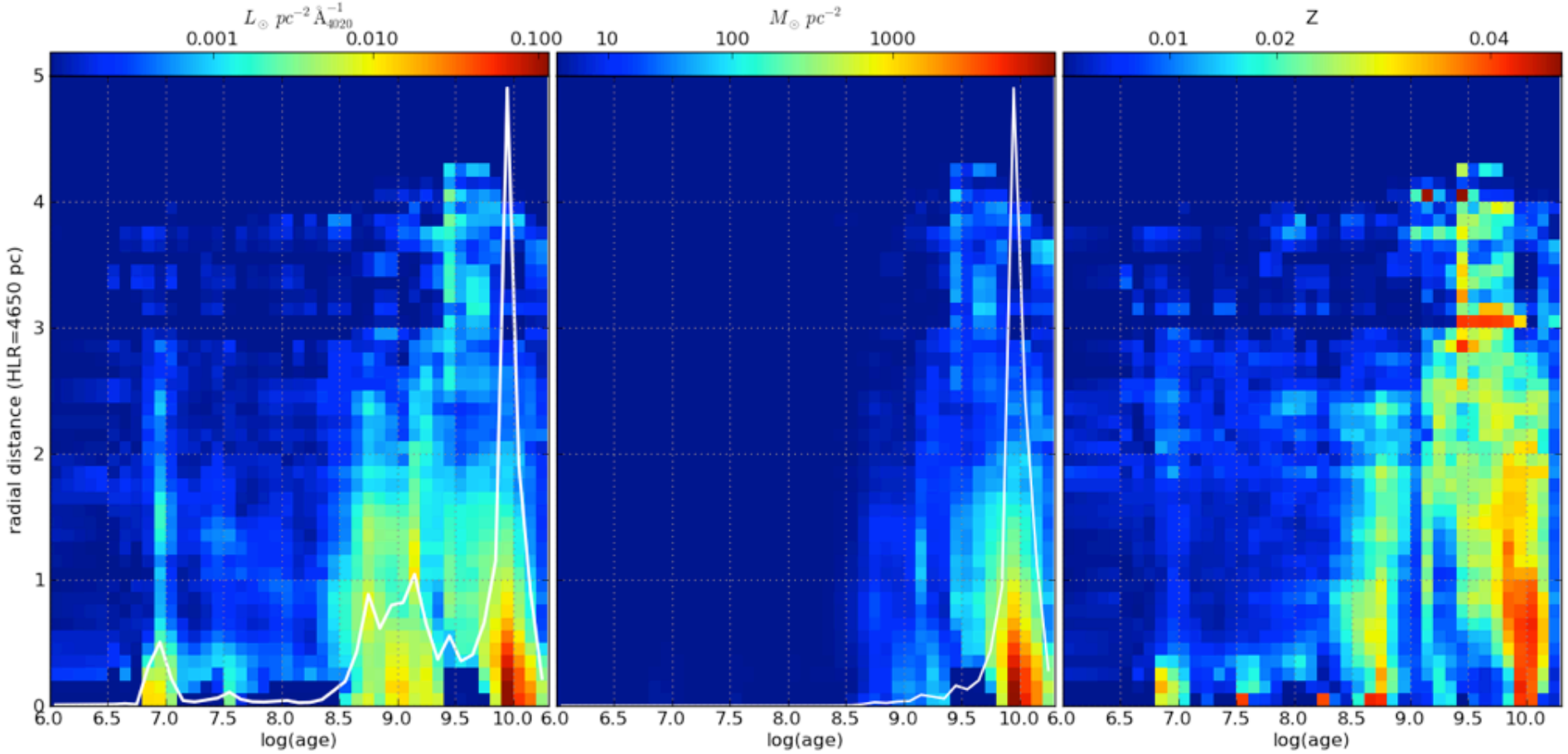


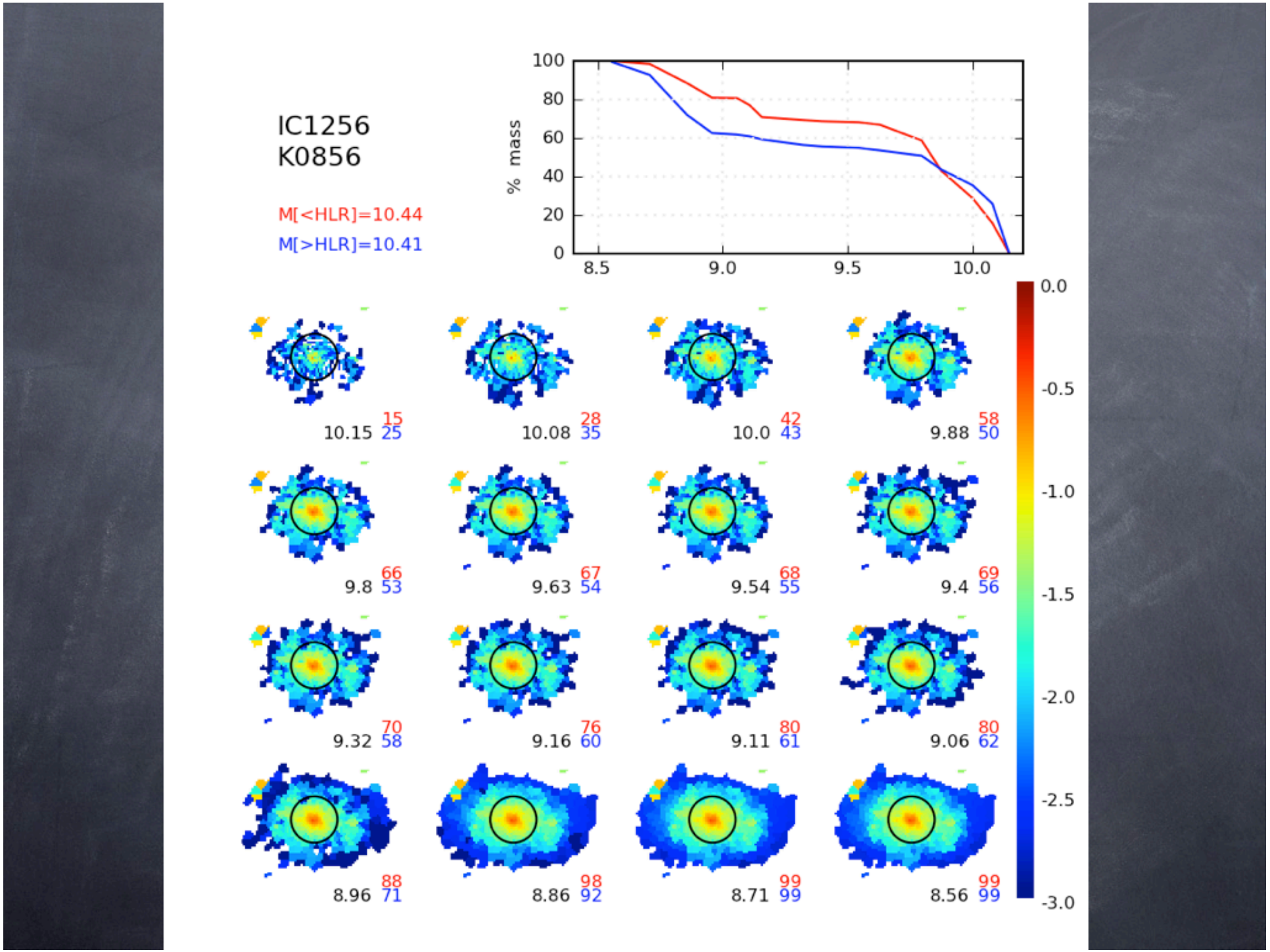


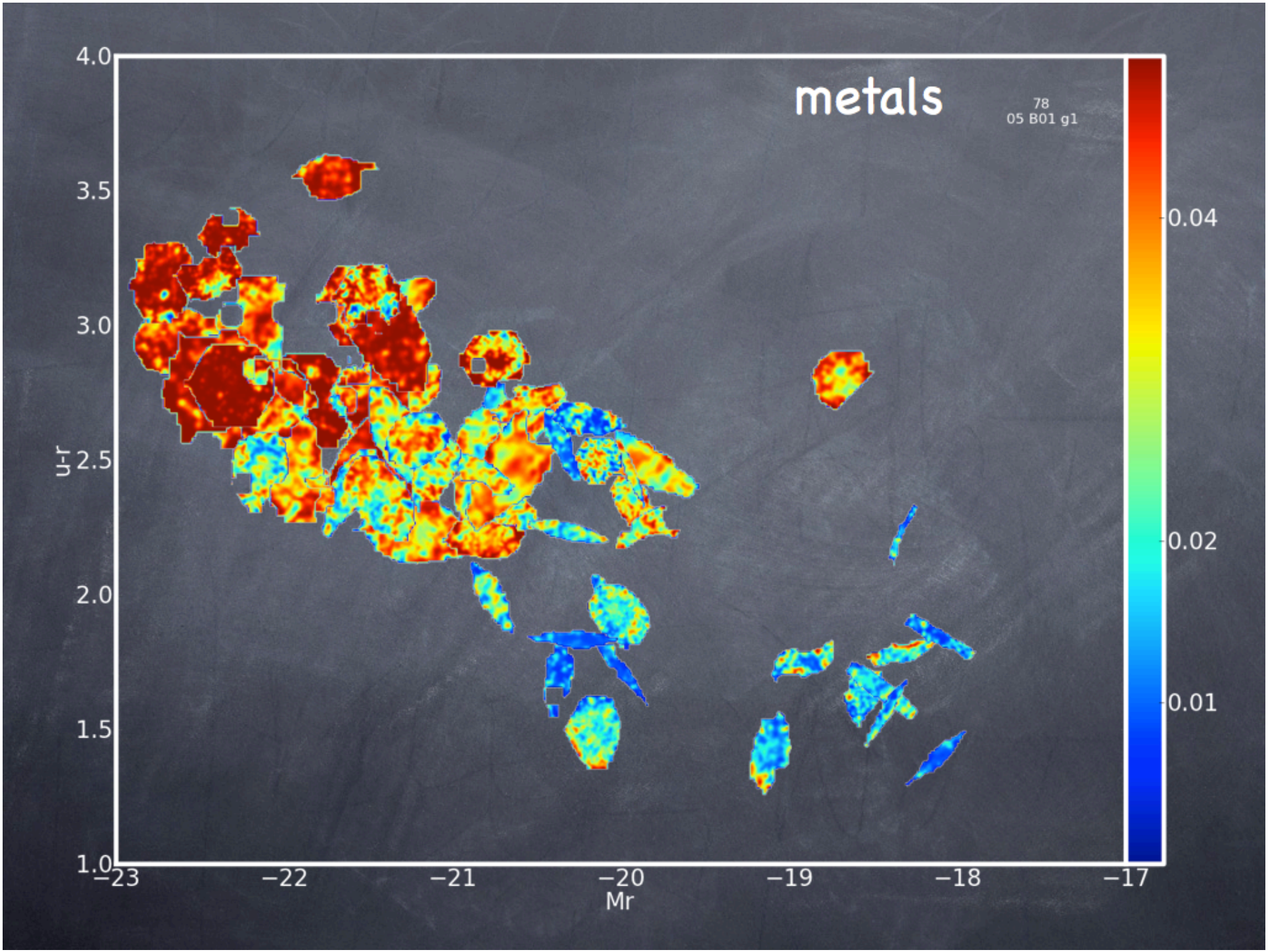
UGC11680
K0873

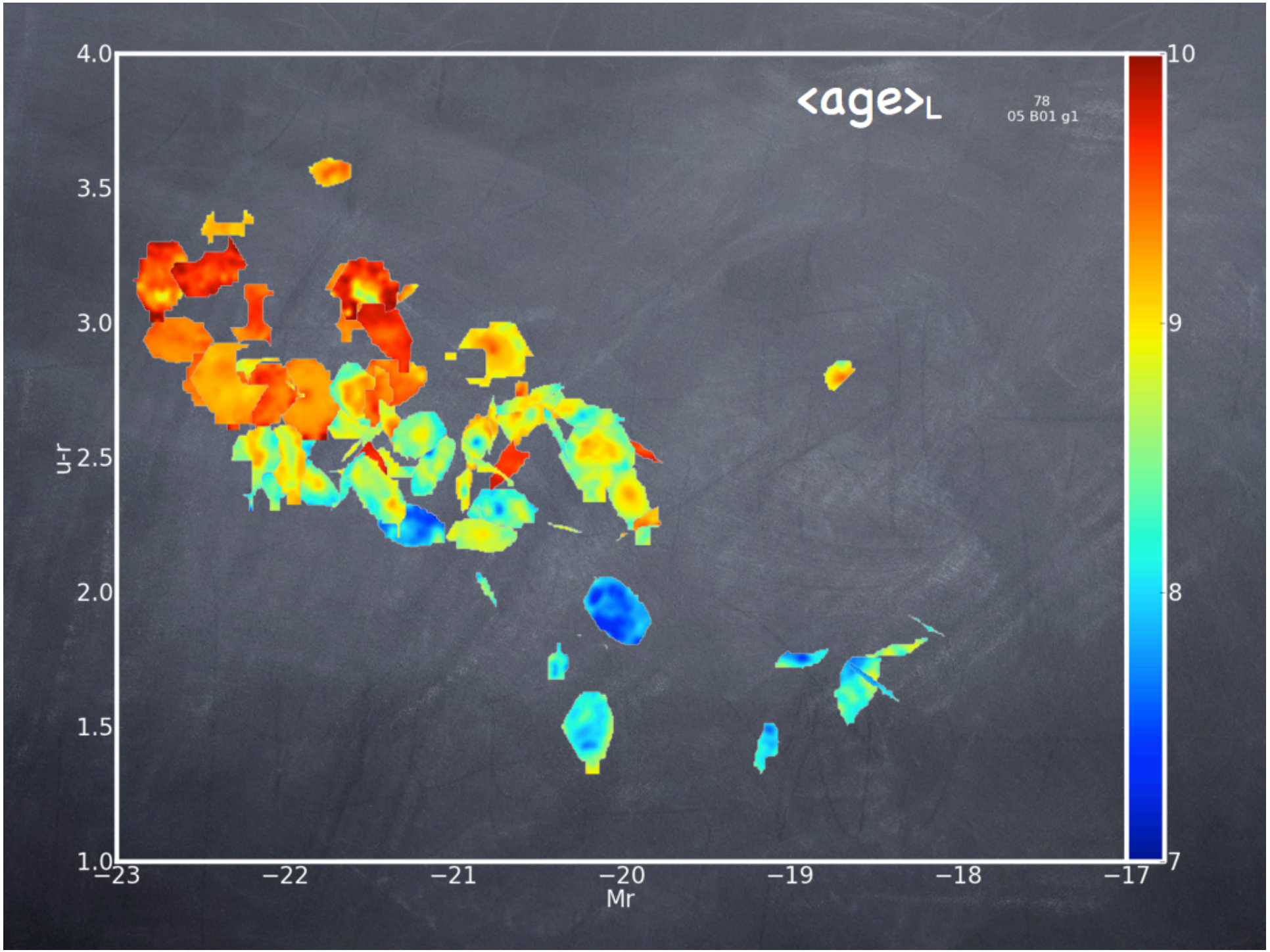


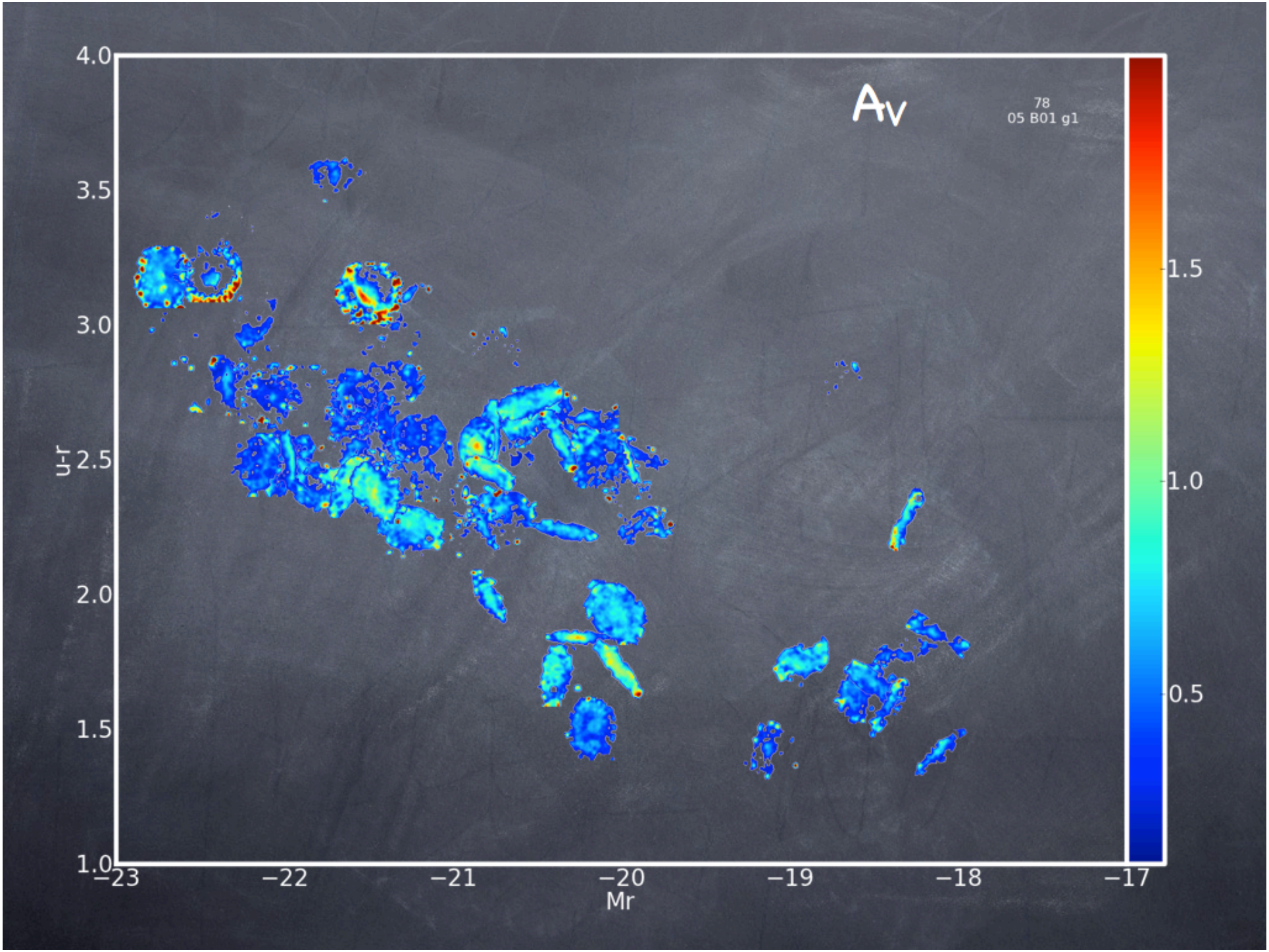




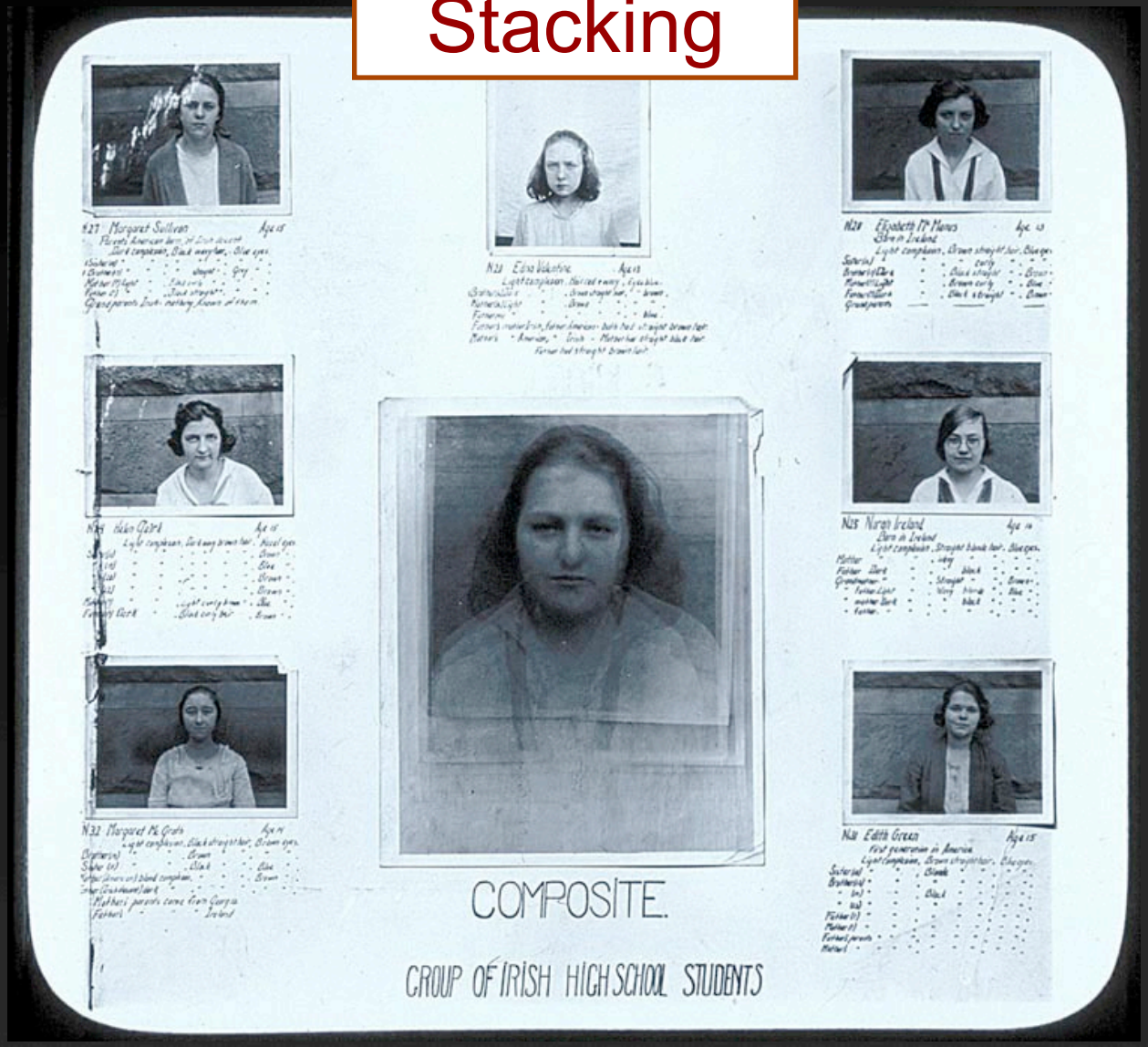

IC1256
K0856
M[<HLR]=10.44
M[>HLR]=10.41
% mass
100
80
60
40
20
0
8.5
9.0
9.5
10.0
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
10.15 15 25
10.08 28 35
10.0 42 43
9.88 58 50
9.8 66 53
9.63 67 54
9.54 68 55
9.4 69 56
9.32 70 58
9.16 76 60
9.11 80 61
9.06 80 62
8.96 88 71
8.86 98 92
8.71 99 99
8.56 99 99


metals
78
05 B01 g1
4.0
3.5
3.0
2.5
2.0
1.5
1.0
u-r
−23
−22
−21
−20
−19
−18
−17
Mr
0.04
0.02
0.01


<age>L
78
05 B01 g1
4.0
3.5
3.0
2.5
2.0
1.5
1.0
u-r
−23
−22
−21
−20
−19
−18
−17
Mr
10
9
8
7

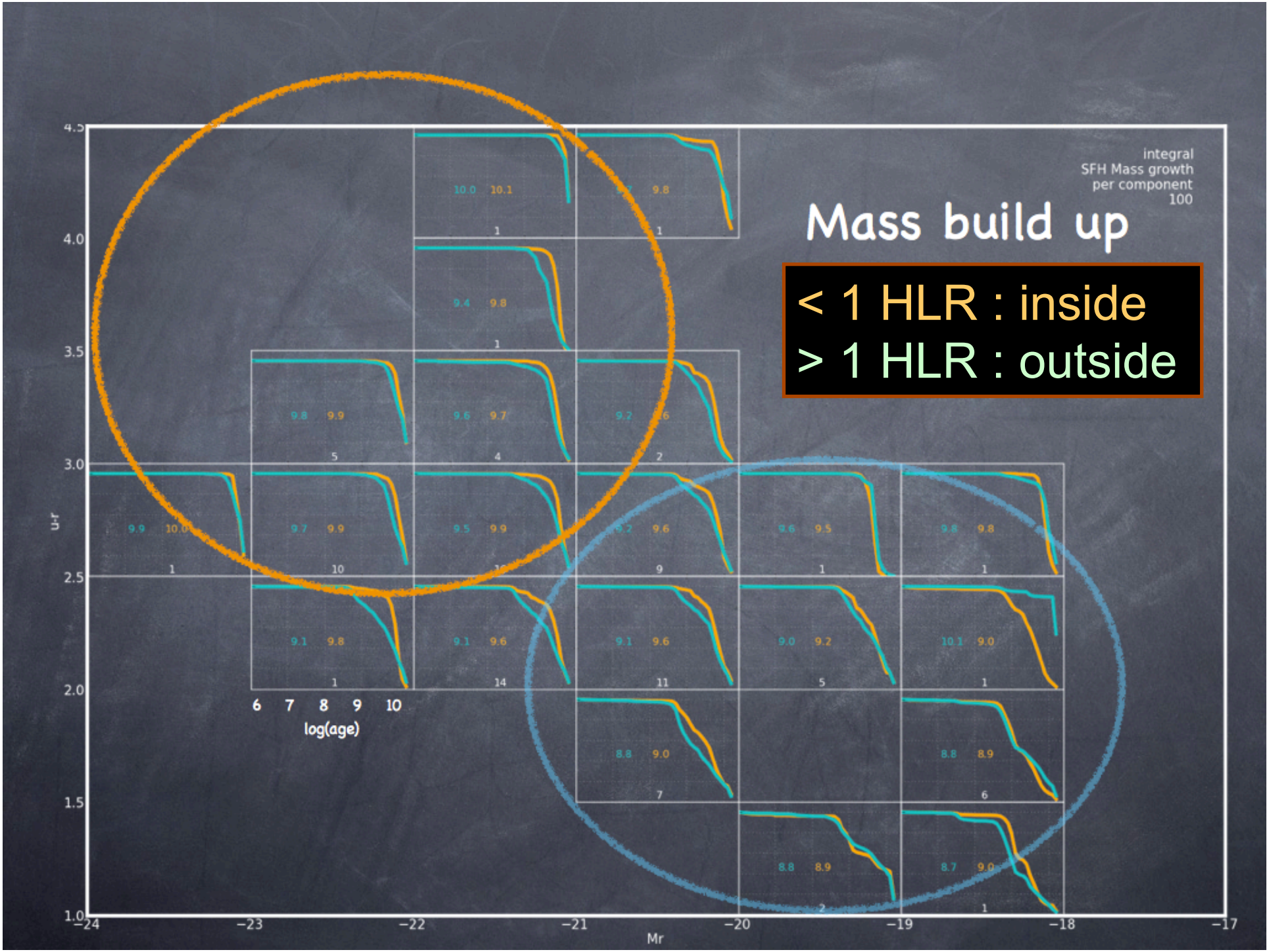

A_V
78
05 B01 g1
4.0
3.5
3.0
2.5
2.0
1.5
1.0
u-r
−23
−22
−21
−20
−19
−18
−17
Mr
1.5
1.0
0.5

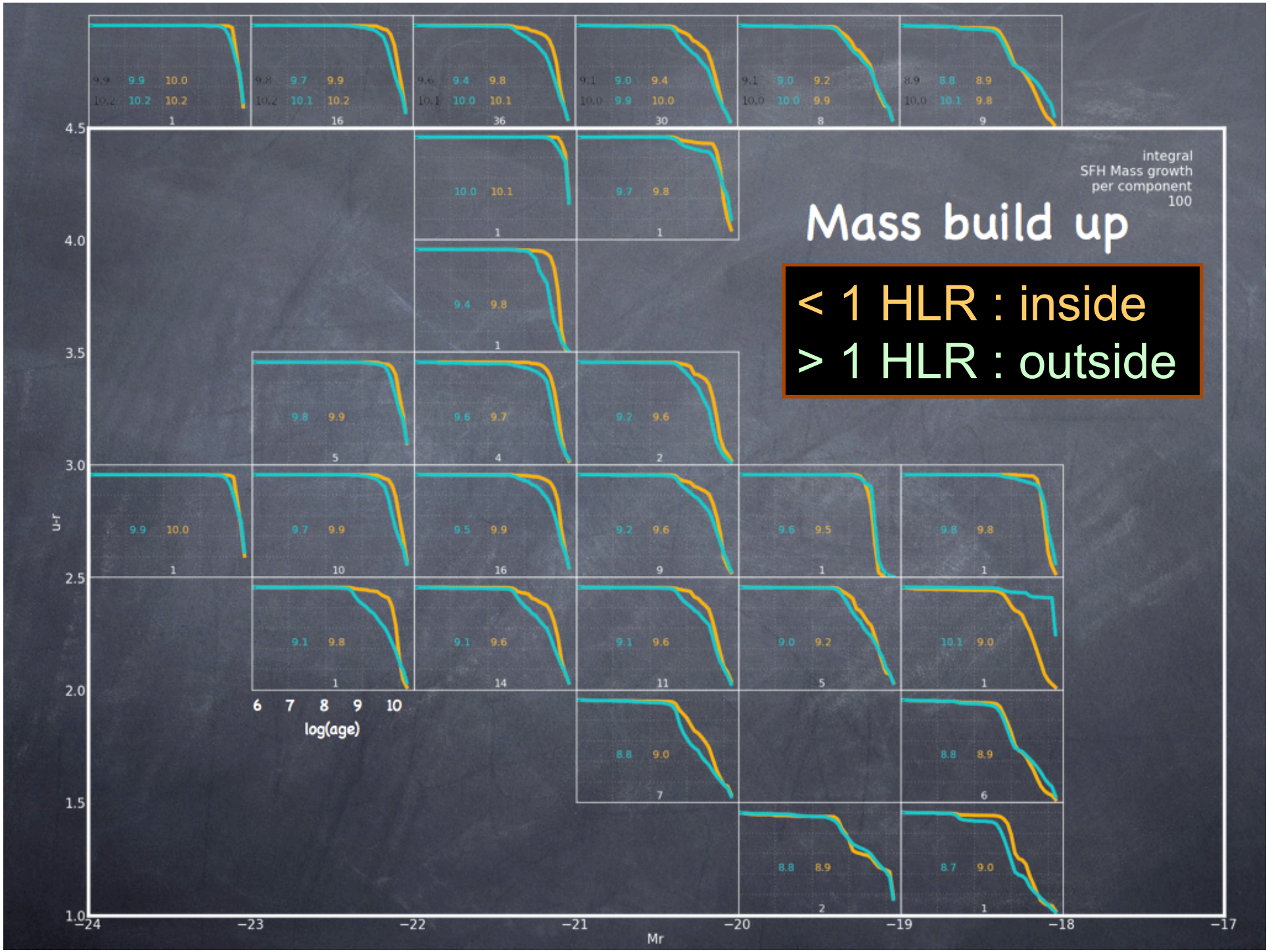
Stacking

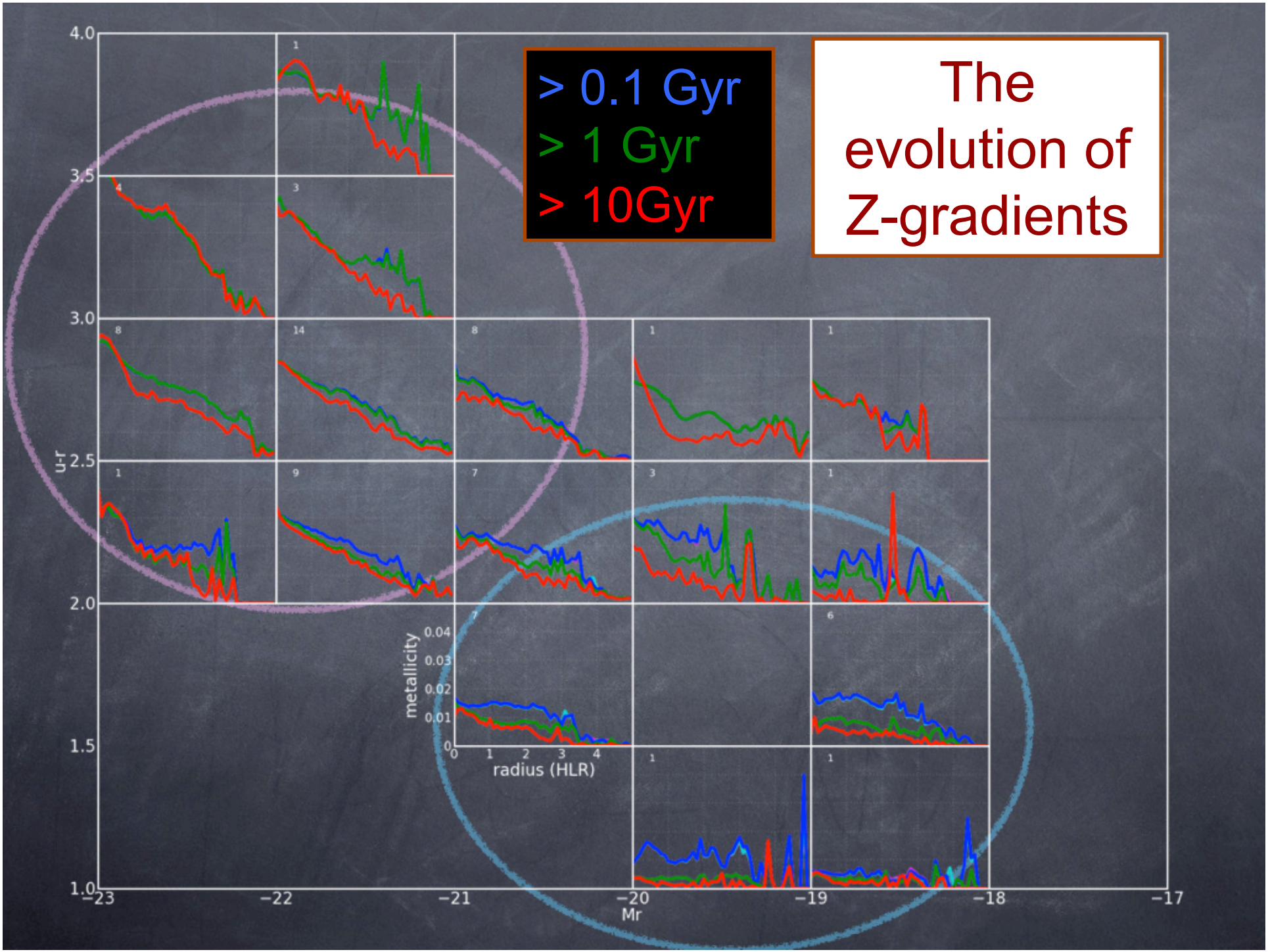


Francis Galton, 1878

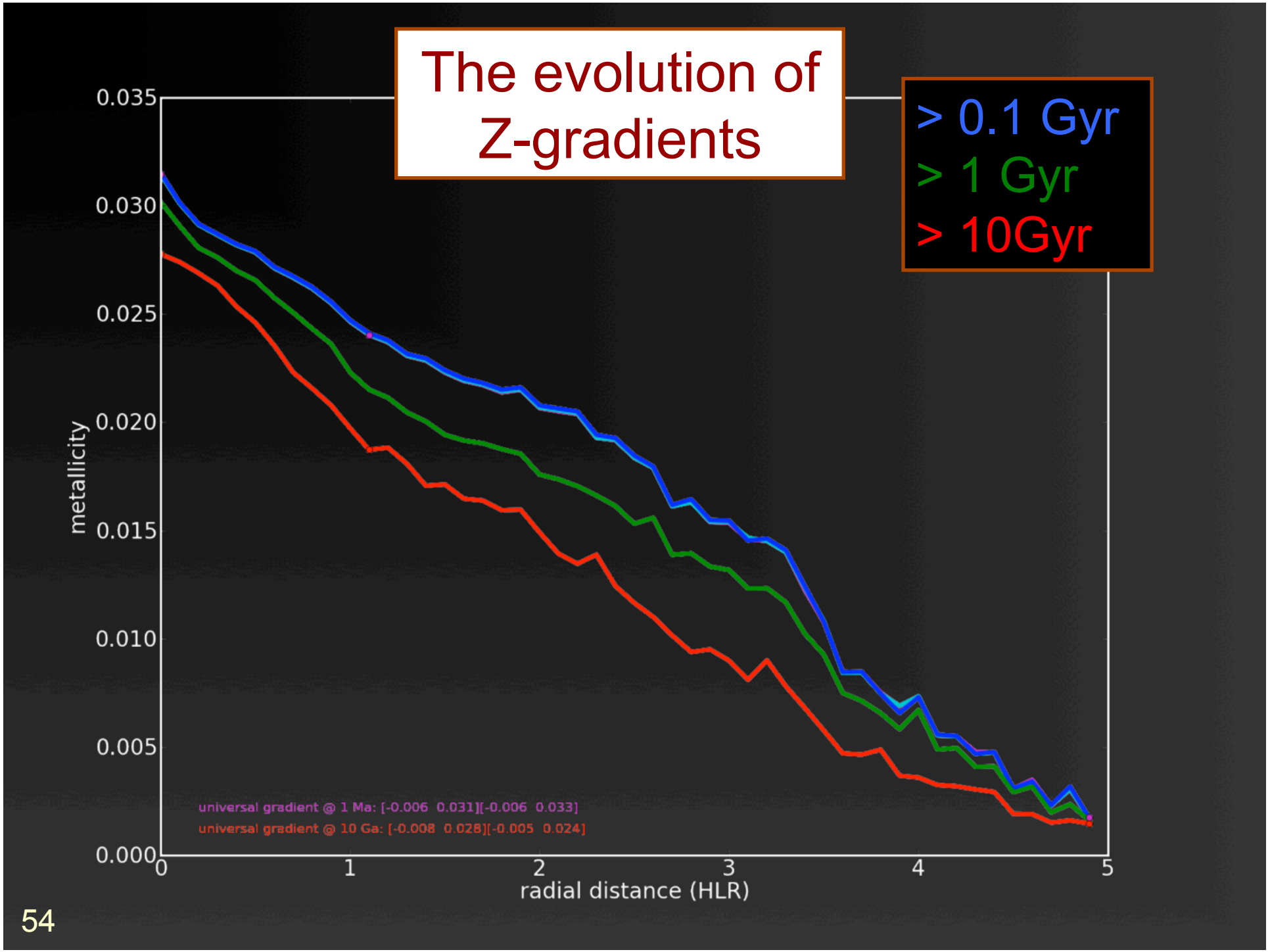
"Composite portraits made by combining those of many different persons into a single figure." *Nature* 18 : 97-100

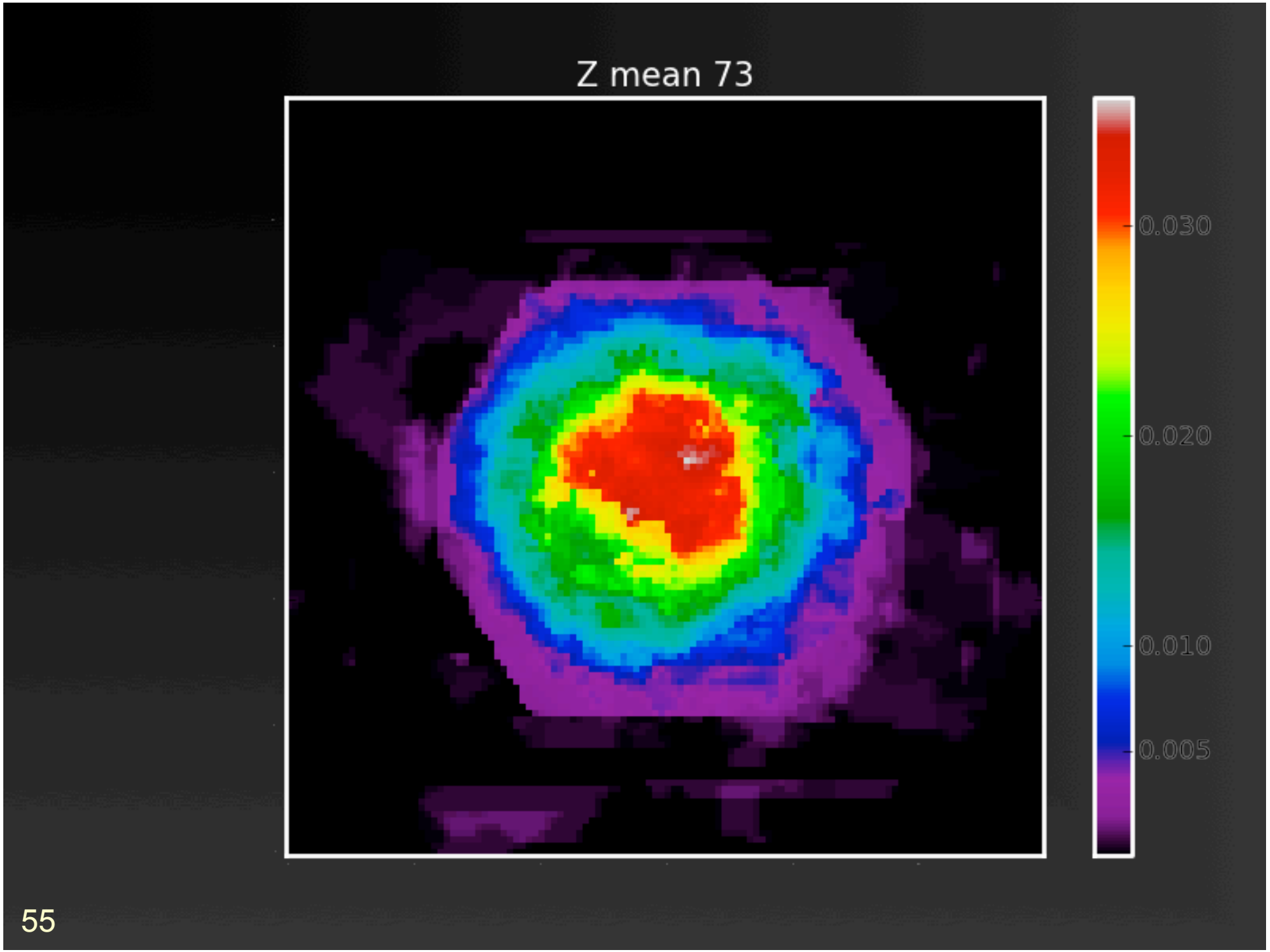

integral
SFH Mass growth
per component
100
Mass build up
< 1 HLR : inside
> 1 HLR : outside
u-r
Mr
log(age)


integral
SFH Mass growth
per component
100
Mass build up
< 1 HLR : inside
> 1 HLR : outside
u-r
Mr
log(age)

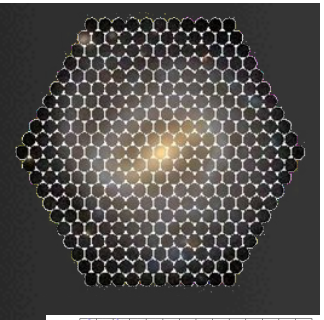

> 0.1 Gyr
> 1 Gyr
> 10Gyr
The evolution of Z-gradients
u-r
Mr
metallicity
radius (HLR)

The evolution of Z-gradients

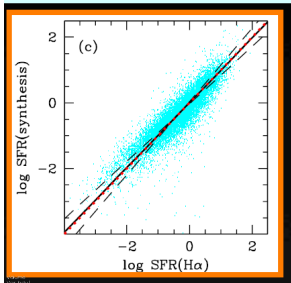


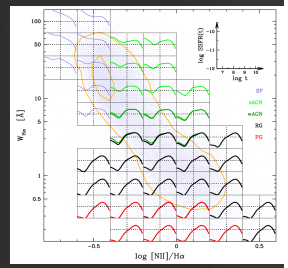

Z mean 73
0.030
0.020
0.010
0.005

Summary



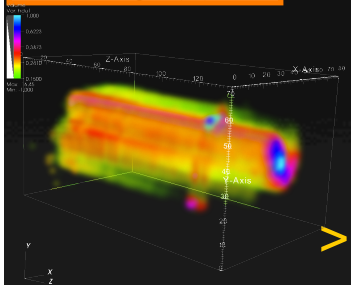
> Fossil methods / full spectral fitting have matured ***a lot*** in the past 10 years

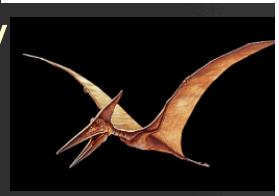




> 1D spectral synthesis – STARLIGHT+SDSS

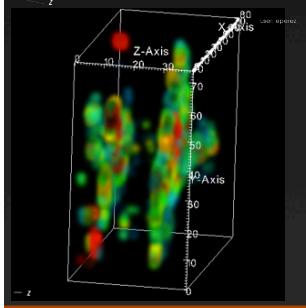
- Gives you *what* happened *when*
- SFHs as a function of whatever you want to study
- A gold mine for theorists & observers

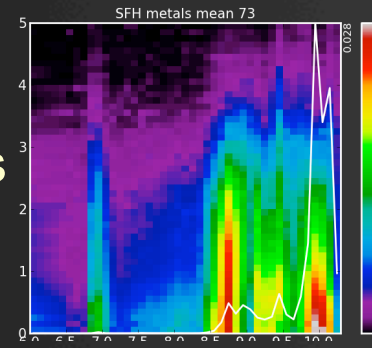




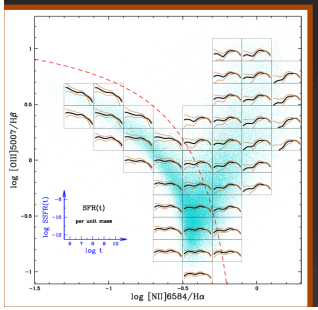
> 2D spectral synthesis: STARLIGHT+CALIFA

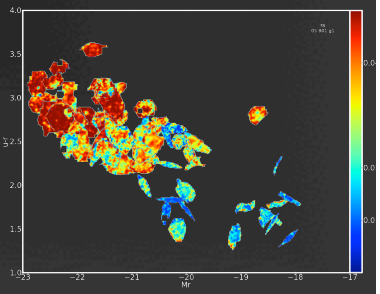
- Gives you *what* happened *when* & *where*
- The build up mass & metals in bulges & discs





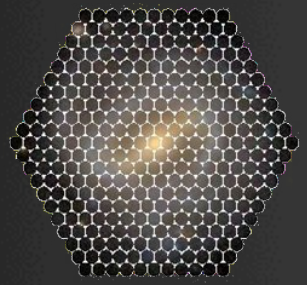
> + couple w/emission line info
+ UV, IR, …
+ kinematics
+ templates for aperture corrections
+ etc…





SEAGal

Galaxy evolution
(from spectral synthesis)
in 1 & 2 D



CALIFA

Natalia Vale Asari
Grazyna Stasinska
Abílio Mateus
William Schoenell
Jean M. Gomes
Marielli Schlickmann
Laerte Sodré

Roberto Cid Fernandes
&
Enrique Pérez

Rosa González Delgado
Rubén García Benito
Sebastian Sánchez
Bernd Husemann
Clara Cortijo
Rafael L. Fernández
+ …

UFSC @ Florianópolis

IAA @ Granada

Some SEAGal papers @www.starlight.ufsc.br

Can retired galaxies mimic active galaxies? Clues from the Sloan Digital Sky Survey

G. Stasińska,[1⋆] N. Vale Asari,[1,2] R. Cid Fernandes,[1,2] J. M. Gomes,[1,2] M. Schlickmann,[2] A. Mateus,[3] W. Schoenell,[2] L. Sodré Jr[4] (the SEAGal collaboration)†

2008

The evolution of the mass–metallicity relation in SDSS galaxies uncovered by astropaleontology

N. Vale Asari,[1,2⋆] G. Stasińska,[2] R. Cid Fernandes,[1] J. M. Gomes[1,3] M. Schlickmann,[1] A. Mateus[4] and W. Schoenell[1] (the SEAGal collaboration)†

2009

Alternative diagnostic diagrams and the 'forgotten' population of weak line galaxies in the SDSS

R. Cid Fernandes,[1⋆] G. Stasińska,[2] M. S. Schlickmann,[1] A. Mateus,[1] N. Vale Asari,[1,2] W. Schoenell[1] and L. Sodré Jr[3] (the SEAGal collaboration)†

2010

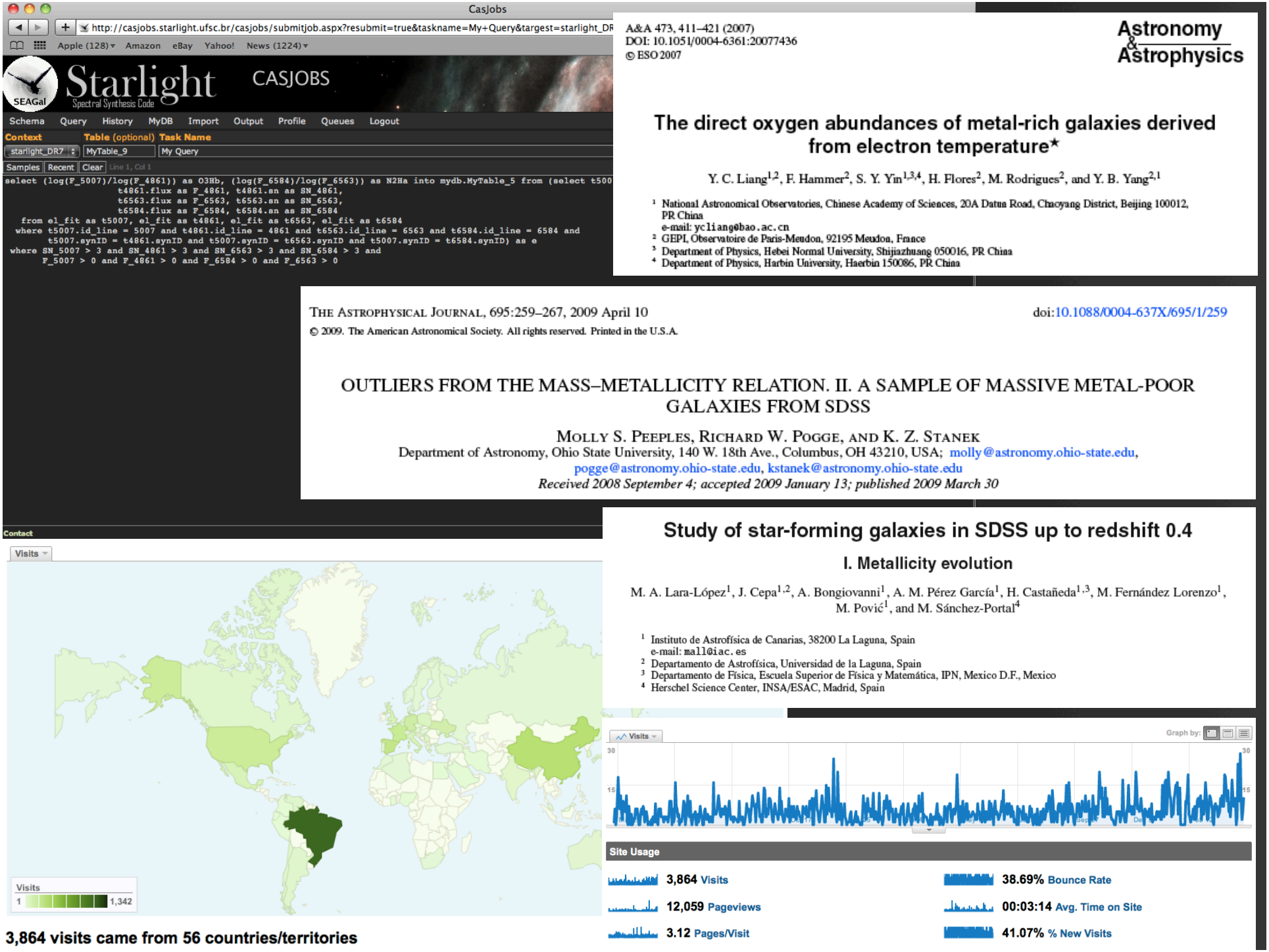
A comprehensive classification of galaxies in the SDSS: How to tell true from fake AGN?

R. Cid Fernandes[1], G. Stasińska [2], A. Mateus[1], N. Vale Asari[1]

2011

Virtual Observatory: 926246 galaxies
www.starlight.ufsc.br

William Schoenell + André Amorim


CasJobs
http://casjobs.starlight.ufsc.br/casjobs/submitjob.aspx?resubmit=true&taskname=My+Query&targest=starlight_DR
Apple (128) Amazon eBay Yahoo! News (1224)
Starlight
Spectral Synthesis Code
SEAGal
CASJOBS
Schema Query History MyDB Import Output Profile Queues Logout
Context Table (optional) Task Name
starlight_DR7 MyTable_9 My Query
Samples Recent Clear
select (log(F_5007)/log(F_4861)) as O3Hb, (log(F_6584)/log(F_6563)) as N2Ha into mydb.MyTable_5 from (select t500
t4861.flux as F_4861, t4861.sn as SN_4861,
t6563.flux as F_6563, t6563.sn as SN_6563,
t6584.flux as F_6584, t6584.sn as SN_6584
from el_fit as t5007, el_fit as t4861, el_fit as t6563, el_fit as t6584
where t5007.id_line = 5007 and t4861.id_line = 4861 and t6563.id_line = 6563 and t6584.id_line = 6584 and
t5007.synID = t4861.synID and t5007.synID = t6563.synID and t5007.synID = t6584.synID) as e
where SN_5007 > 3 and SN_4861 > 3 and SN_6563 > 3 and SN_6584 > 3 and
F_5007 > 0 and F_4861 > 0 and F_6584 > 0 and F_6563 > 0
Contact
Visits
Visits
1 1,342
3,864 visits came from 56 countries/territories
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DOI: 10.1051/0004-6361:20077436
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Astronomy & Astrophysics
The direct oxygen abundances of metal-rich galaxies derived from electron temperature*
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OUTLIERS FROM THE MASS–METALLICITY RELATION. II. A SAMPLE OF MASSIVE METAL-POOR GALAXIES FROM SDSS
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Study of star-forming galaxies in SDSS up to redshift 0.4
I. Metallicity evolution
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Visits
Graph by:
30
15
Site Usage
3,864 Visits
12,059 Pageviews
3.12 Pages/Visit
38.69% Bounce Rate
00:03:14 Avg. Time on Site
41.07% % New Visits