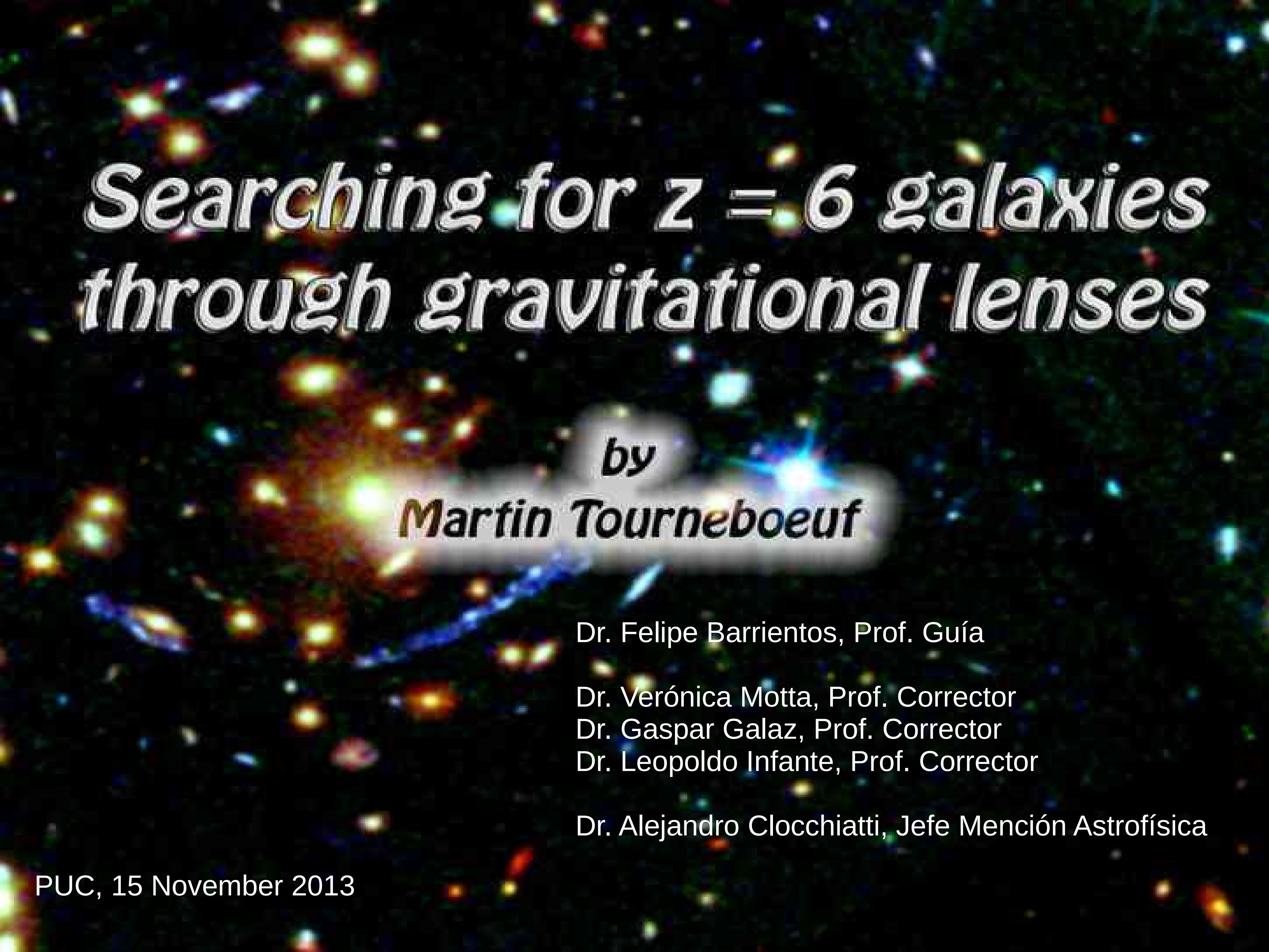


Searching for z = 6 galaxies through gravitational lenses

by

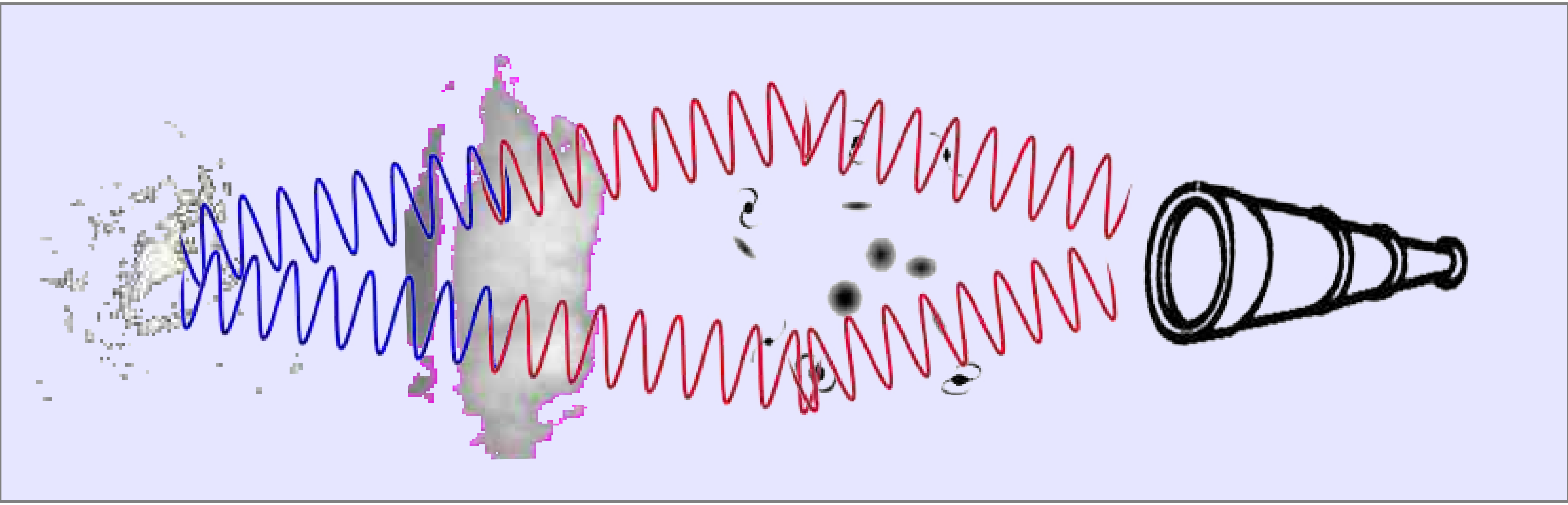
Martin Tourneboeuf

Dr. Felipe Barrientos, Prof. Guía

Dr. Verónica Motta, Prof. Corrector
Dr. Gaspar Galaz, Prof. Corrector
Dr. Leopoldo Infante, Prof. Corrector

Dr. Alejandro Clocchiatti, Jefe Mención Astrofísica

PUC, 15 November 2013



Galaxy
z=6

Cloud
z=5.9

Galaxy cluster
z=1

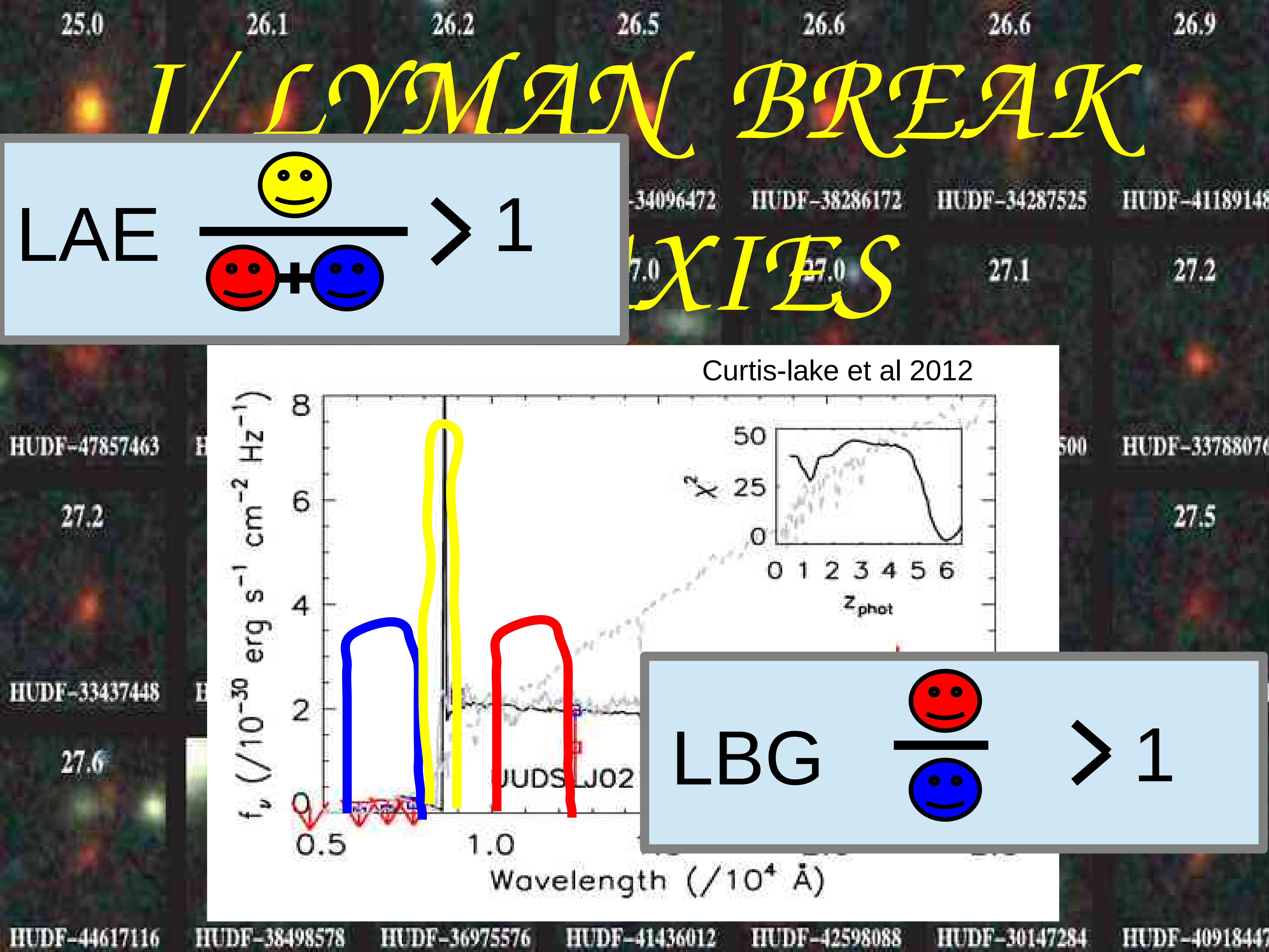
Telescope
z=0

Searching for z=6 galaxies through gravitational lenses

I/ Lyman Break Galaxies
II/ Models
III/ Infra-red reduction

$$\begin{aligned} \lambda_\alpha &\equiv 1215\ \text{Å} \\ R &= 650\ \text{nm} \\ I &= 800\ \text{nm} \\ H &= 1.6\ \mu m \end{aligned}$$

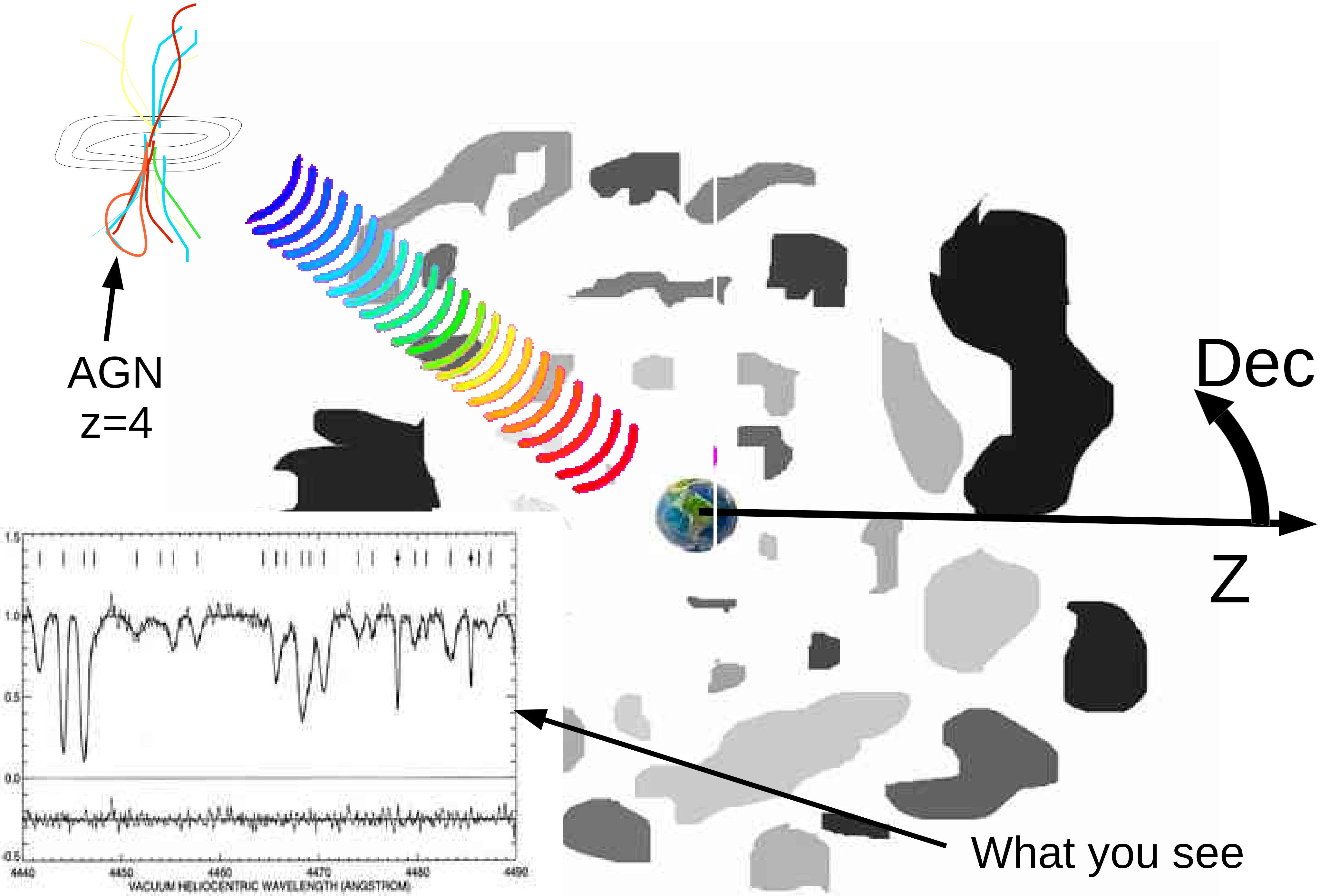
I/ LYMAN BREAK
XIES

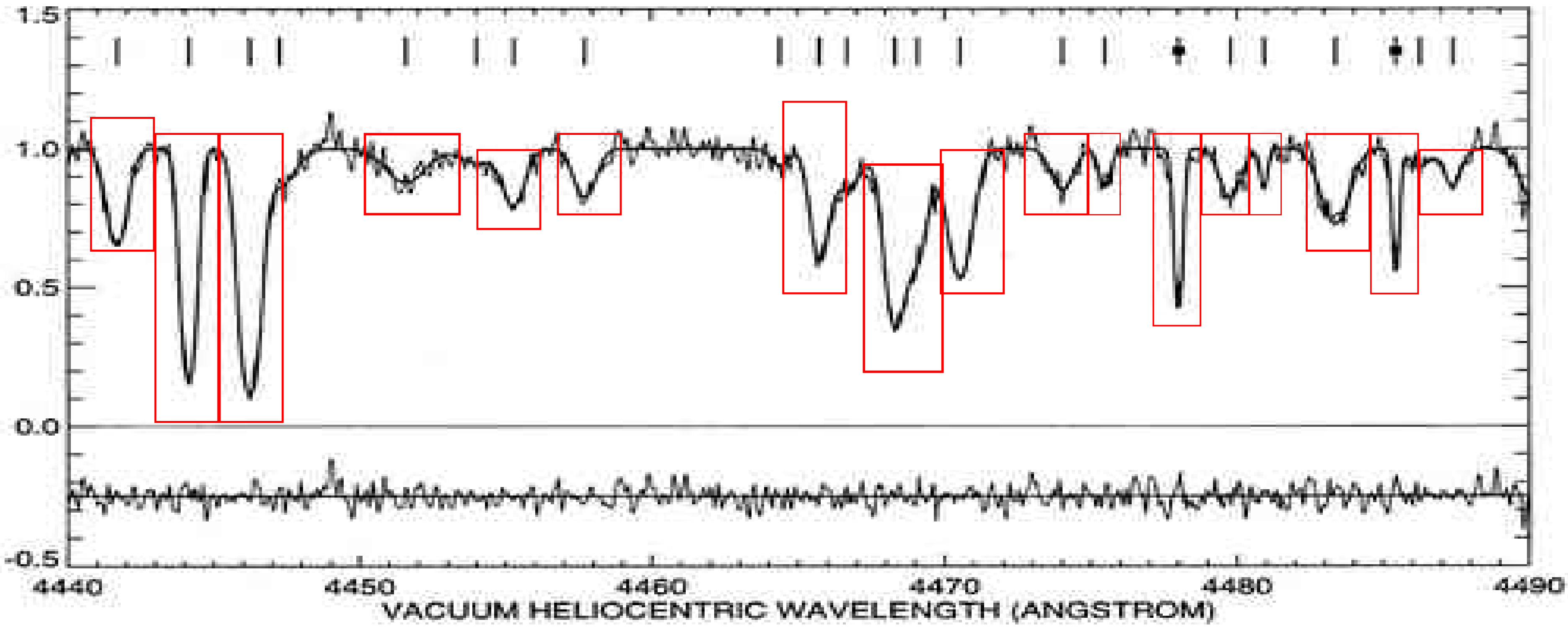


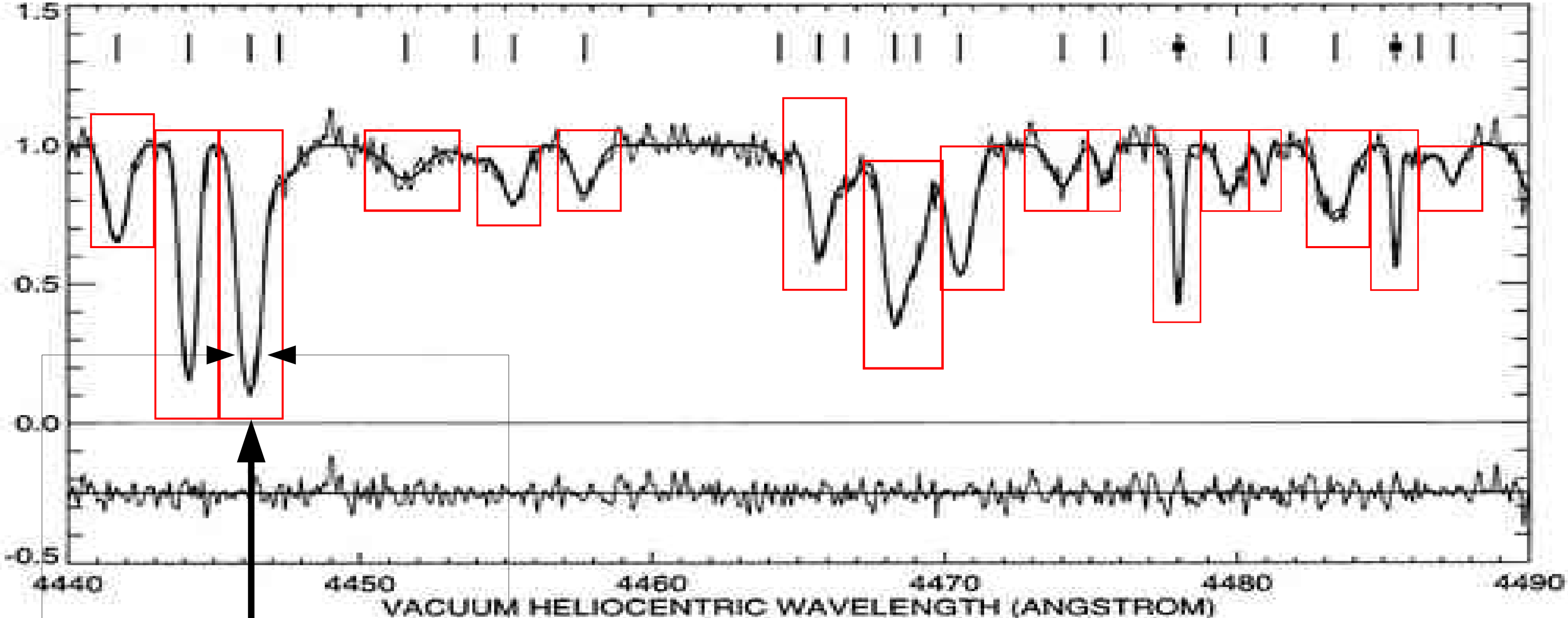
LAE $\frac{☺}{☺ + ☺} > 1$

LBG $\frac{☺}{☺} > 1$

Cloud of H
Dec
Z


AGN
z=4
Dec
Z
What you see
1.5
1.0
0.5
0.0
-0.5
4440
4450
4460
4470
4480
4490
VACUUM HELIOCENTRIC WAVELENGTH (ANGSTROM)


1.5
1.0
0.5
0.0
-0.5
4440
4450
4460
4470
4480
4490
VACUUM HELIOCENTRIC WAVELENGTH (ANGSTROM)

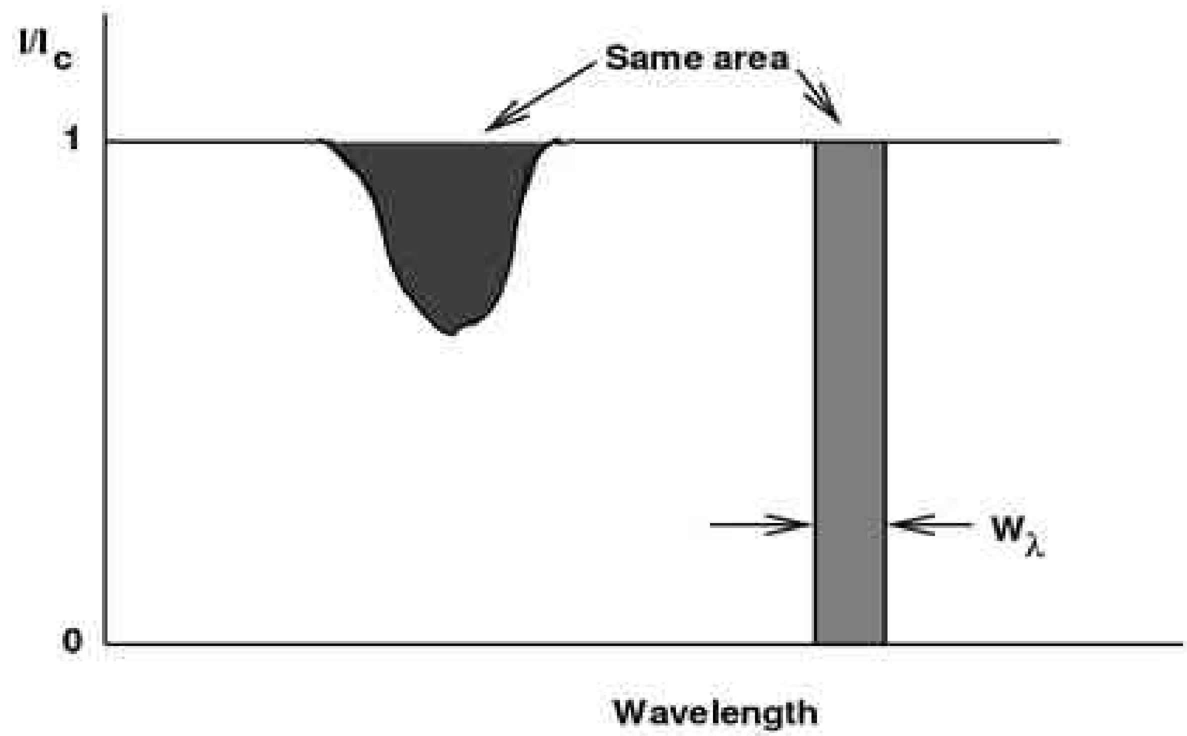


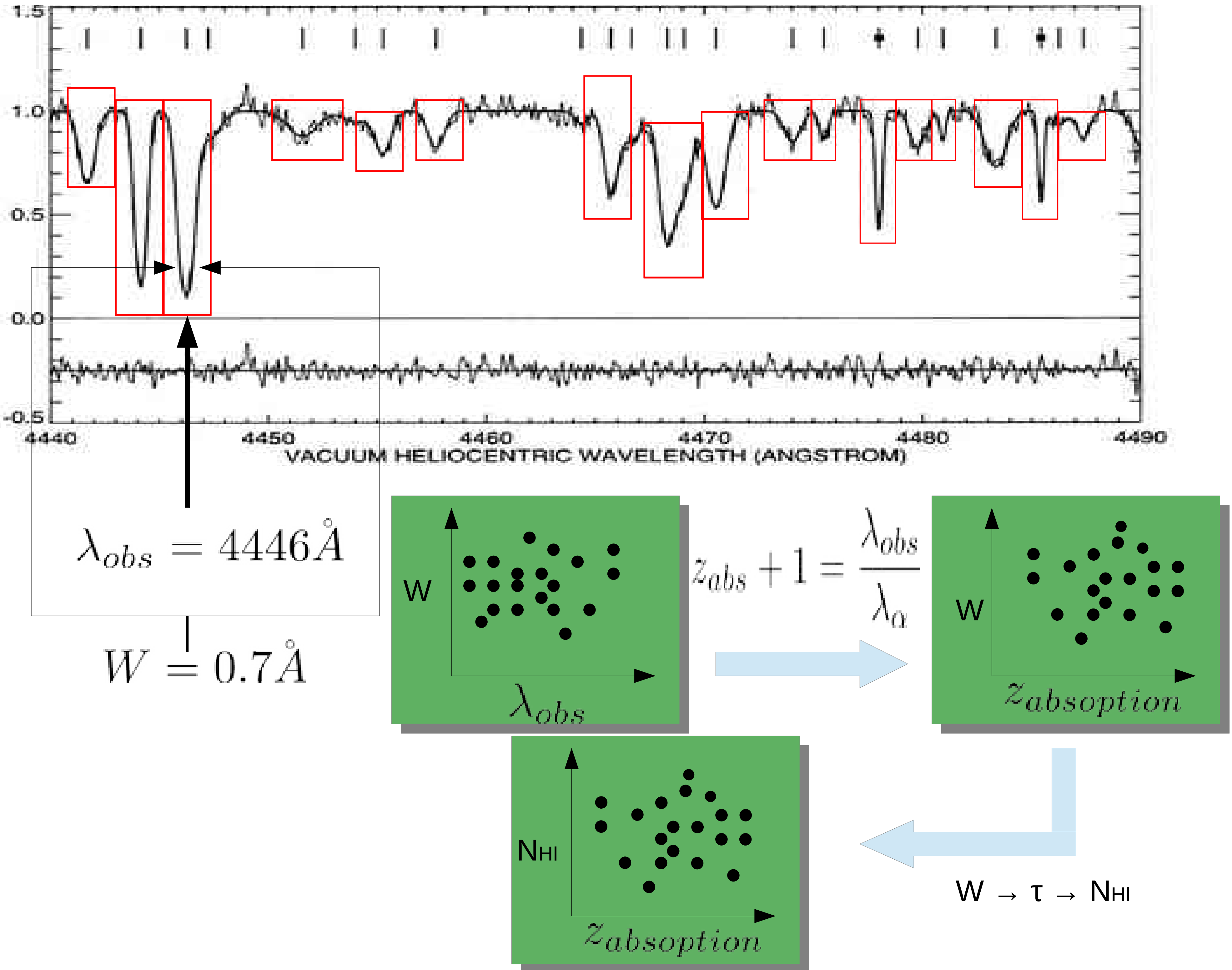
$$\lambda_{obs} = 4446\mathring{A}$$

$$W = 0.7\mathring{A}$$

$$W = \frac{\int F_\lambda(\lambda) d\lambda}{\int d\lambda} \neq FWHM$$

Column density (N_{HI})   Velocity disperssion (b)





1.5
1.0
0.5
0.0
-0.5
4440
4450
4460
4470
4480
4490
VACUUM HELIOCENTRIC WAVELENGTH (ANGSTROM)
$\lambda_{obs} = 4446\mathring{A}$
$W = 0.7\mathring{A}$
W
λ_{obs}
$z_{abs} + 1 = \frac{\lambda_{obs}}{\lambda_\alpha}$
W
$z_{absoption}$
N_{HI}
$z_{absoption}$
W → τ → N_{HI}

$$\begin{cases} LAF(32\%): & (10^{11} < N_{HI} < \times 10^{17.5} cm^{-2}); \\ LLS(20\%): & (10^{17.5} < N_{HI} < 10^{19} cm^{-2}); \\ SLLS(28\%): & (10^{19} < N_{HI} < 10^{20.3} cm^{-2}); \\ DLA(8\%): & (10^{20.3} < N_{HI} < 10^{21.55} cm^{-2}); \end{cases}$$

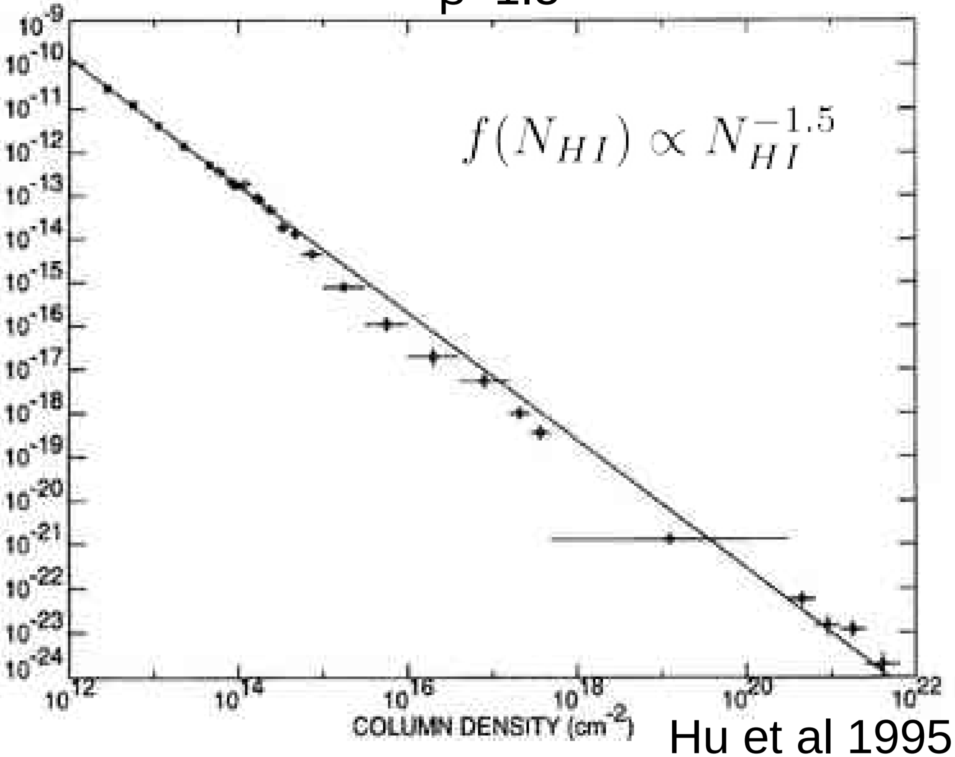
Number of Clouds

$$\boxed{f(N_{HI}, z) = A N_{HI}^{-\beta} (1+z)^{\gamma}}$$

Size of the cloud

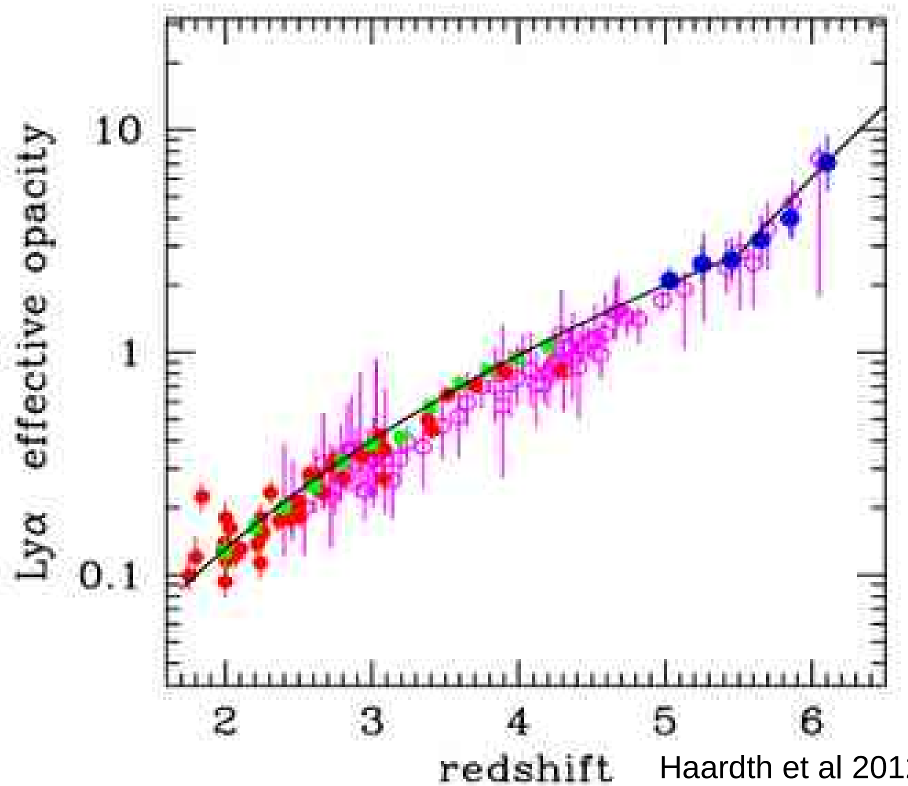
Column density histogram of HI regions

β=1.5

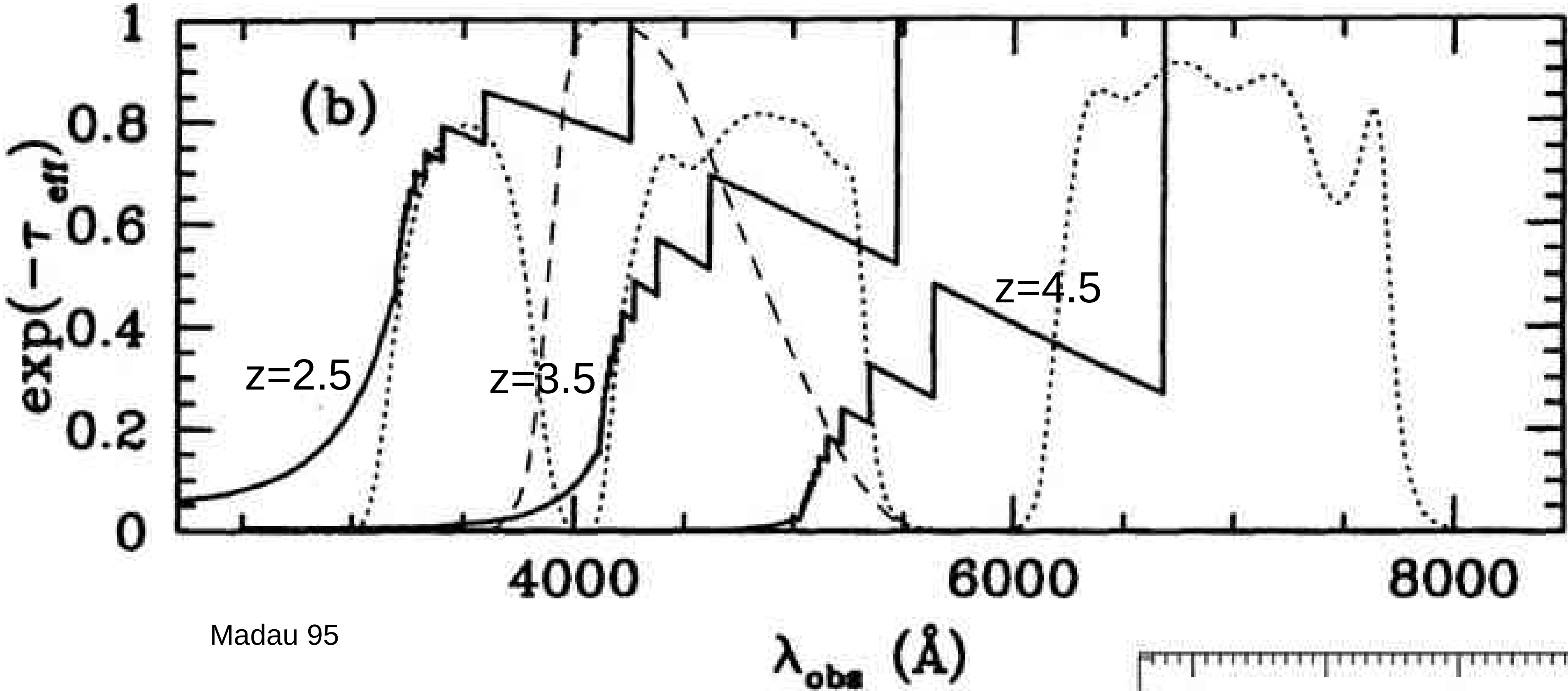


Hu et al 1995

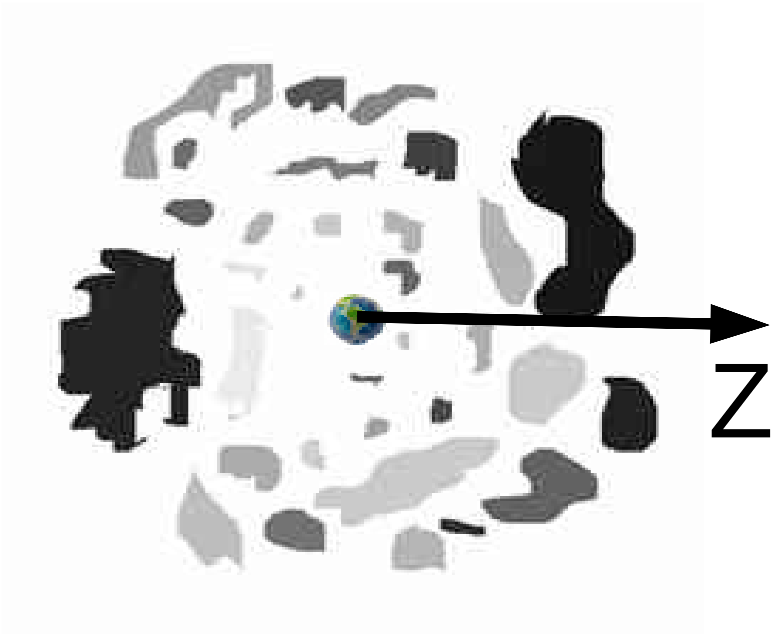
γ=3

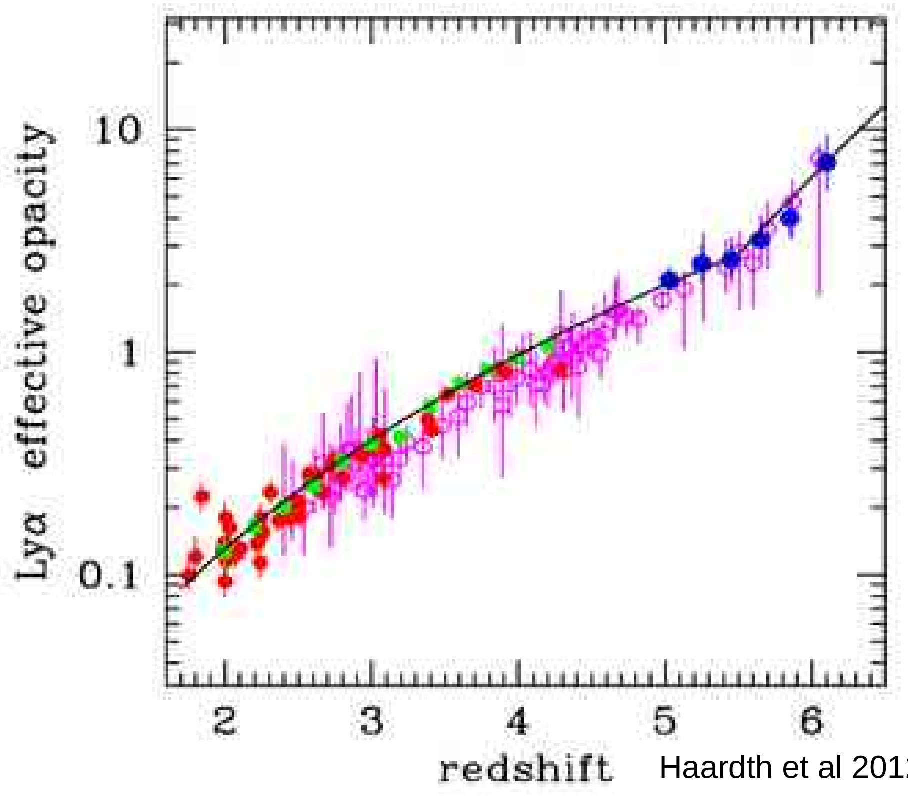


Haardth et al 2012



Madau 95

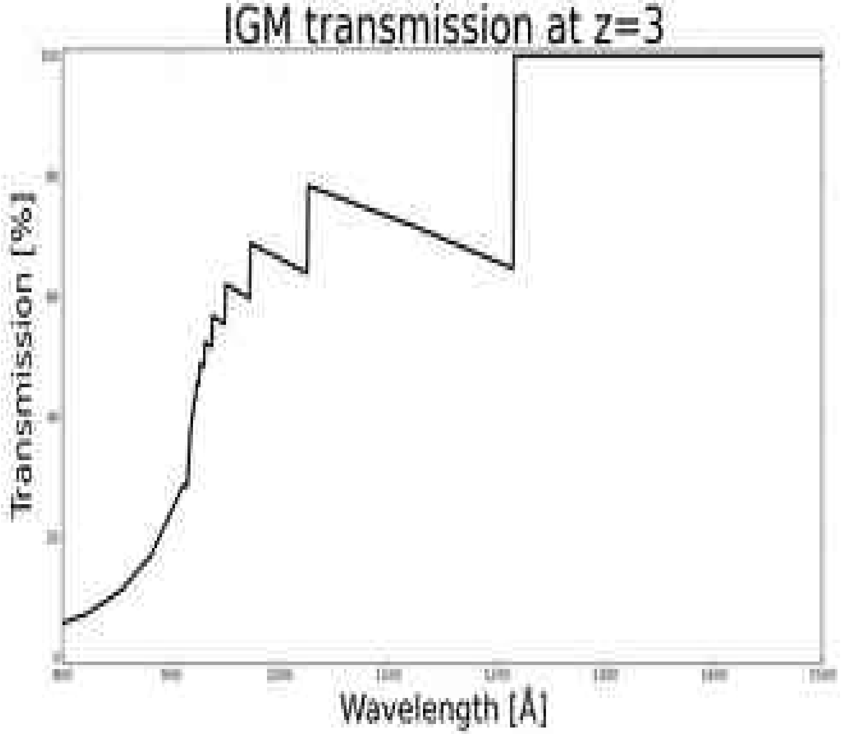


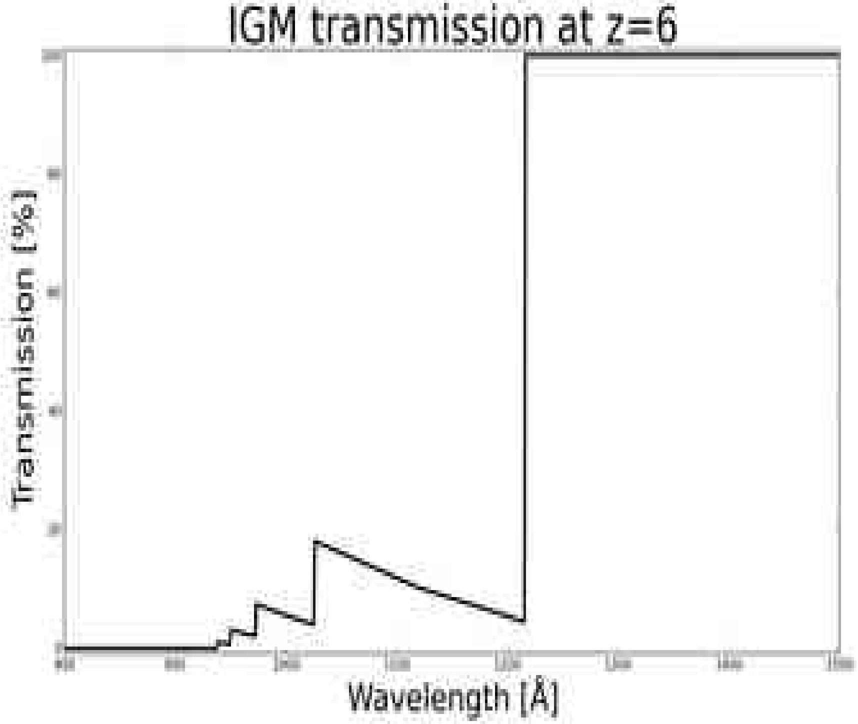


Haardth et al 2012

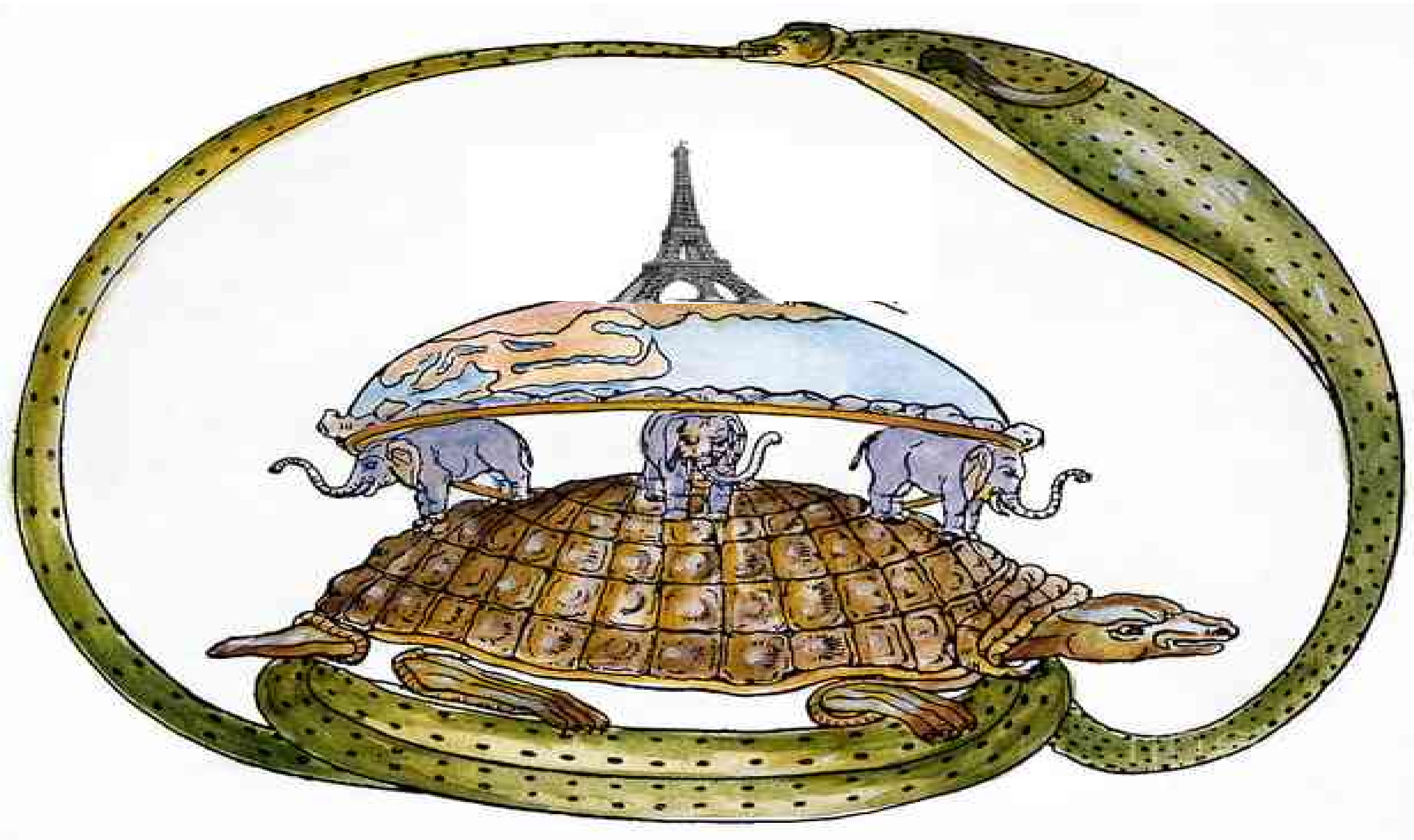
Chapter I (LBG) Conclusion

- The inter-galactic medium proceeds as an optical filter for source-frame wavelength < 1215 Å.
- Larger z = larger absorption

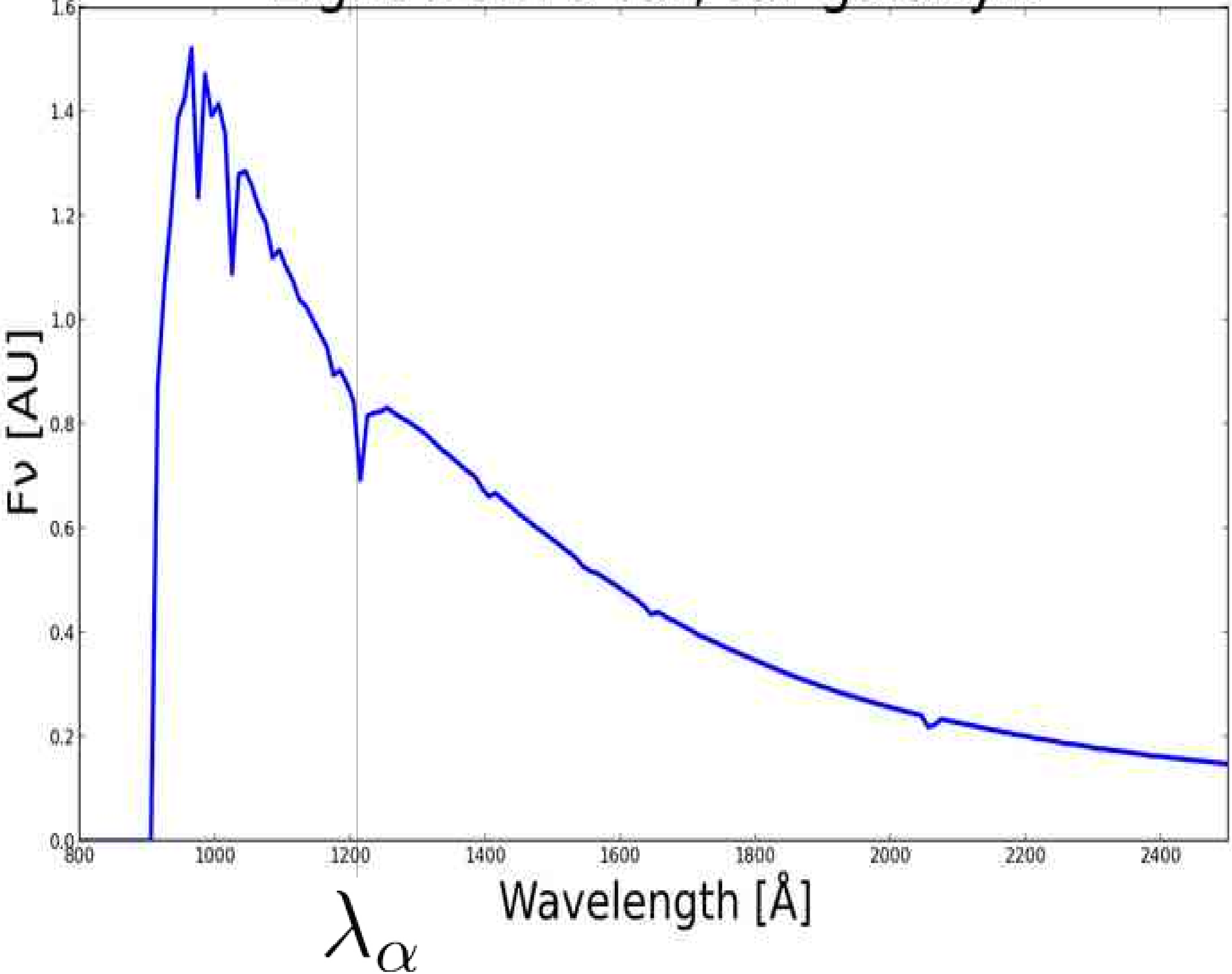




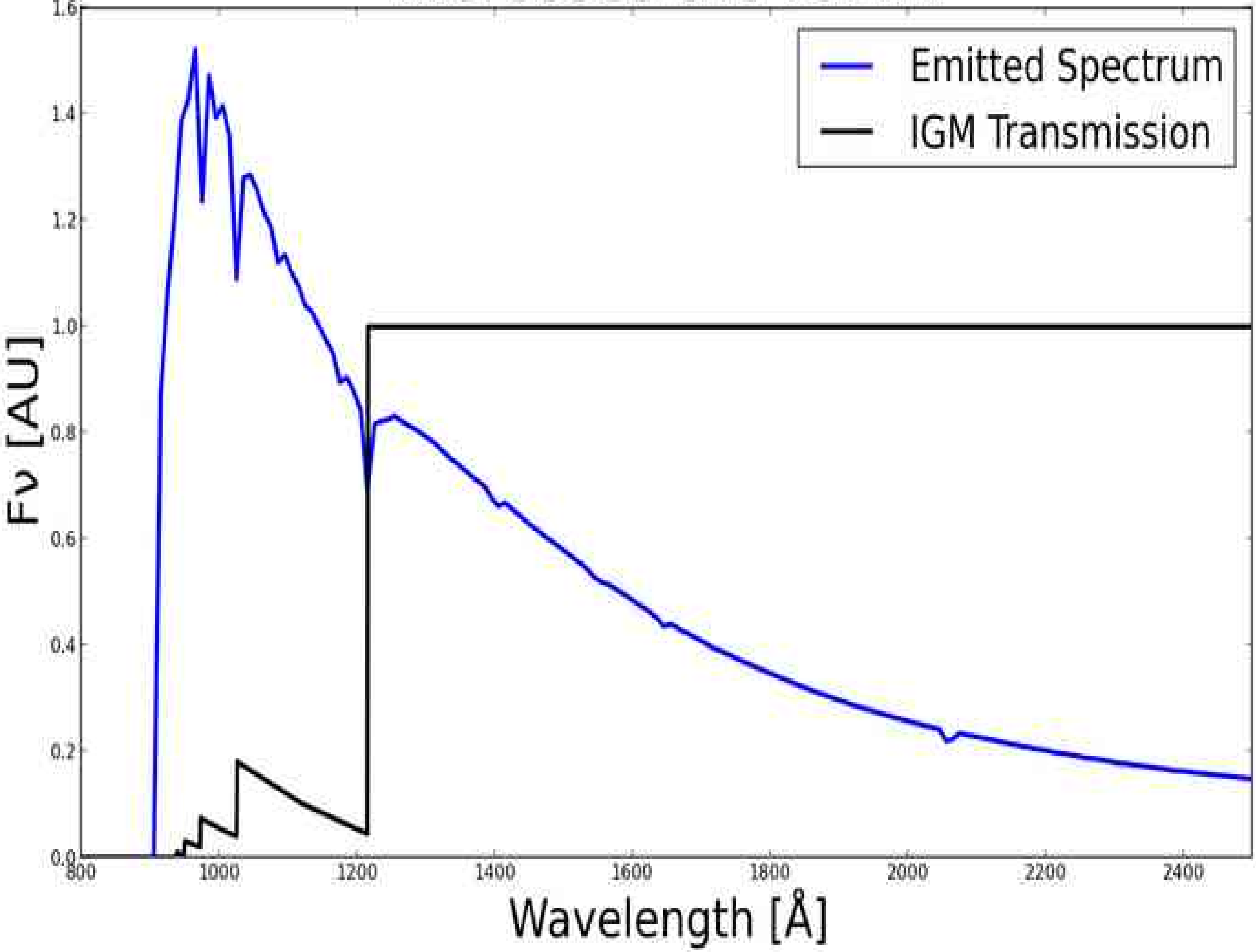
II/ Models



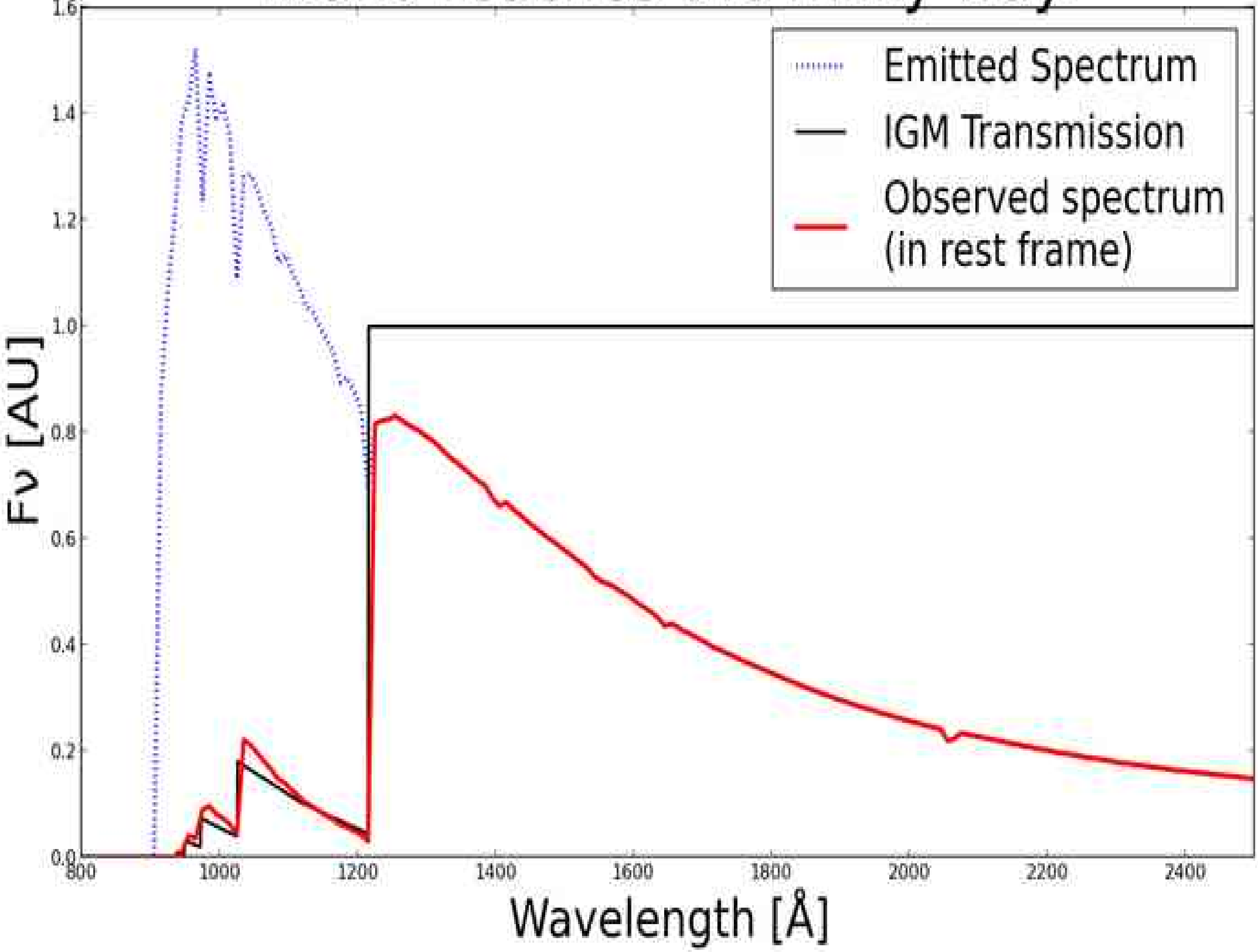
Light from a far, far galaxy...



...crosses the IGM...

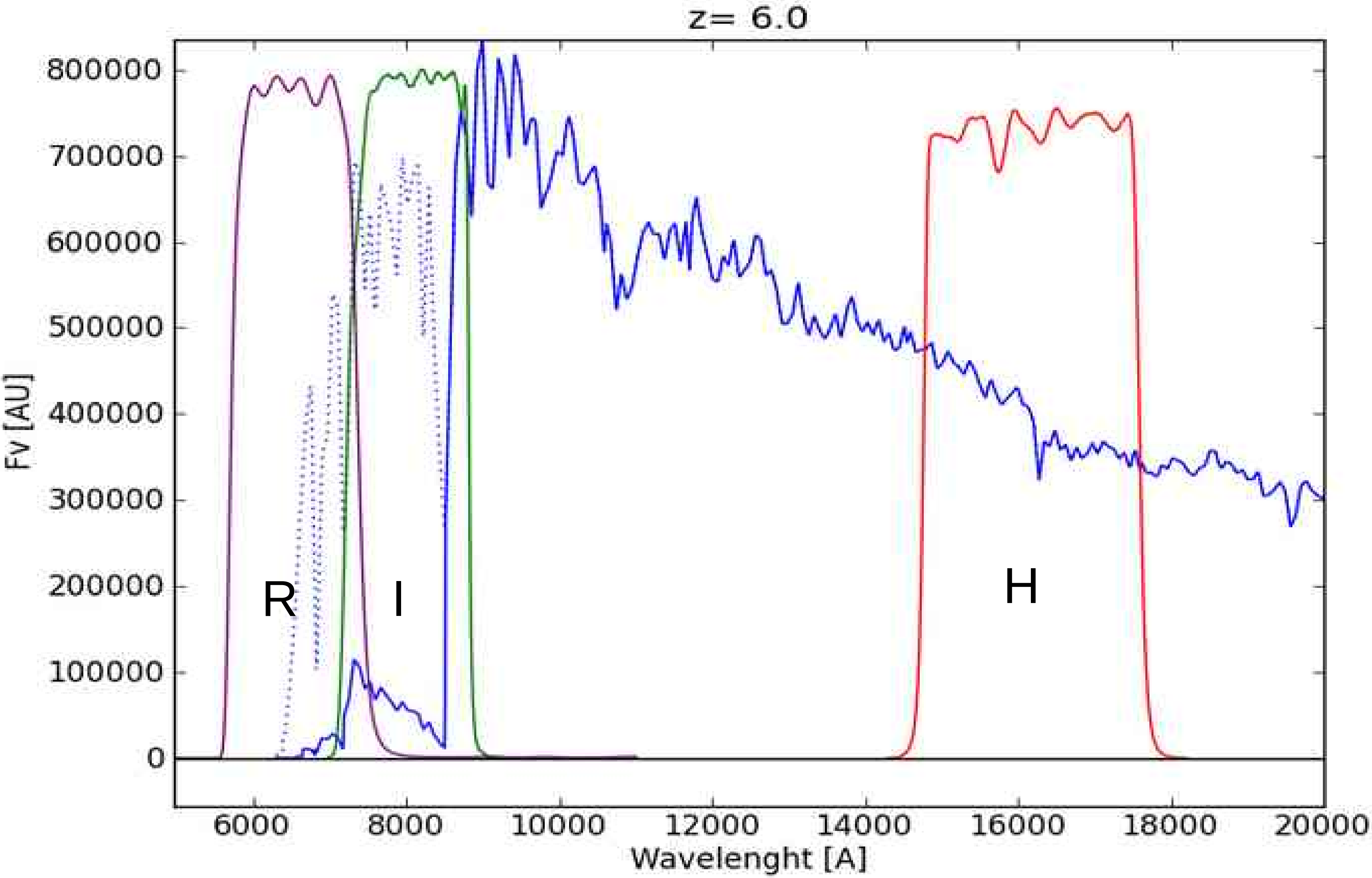


...and reaches the milky way.

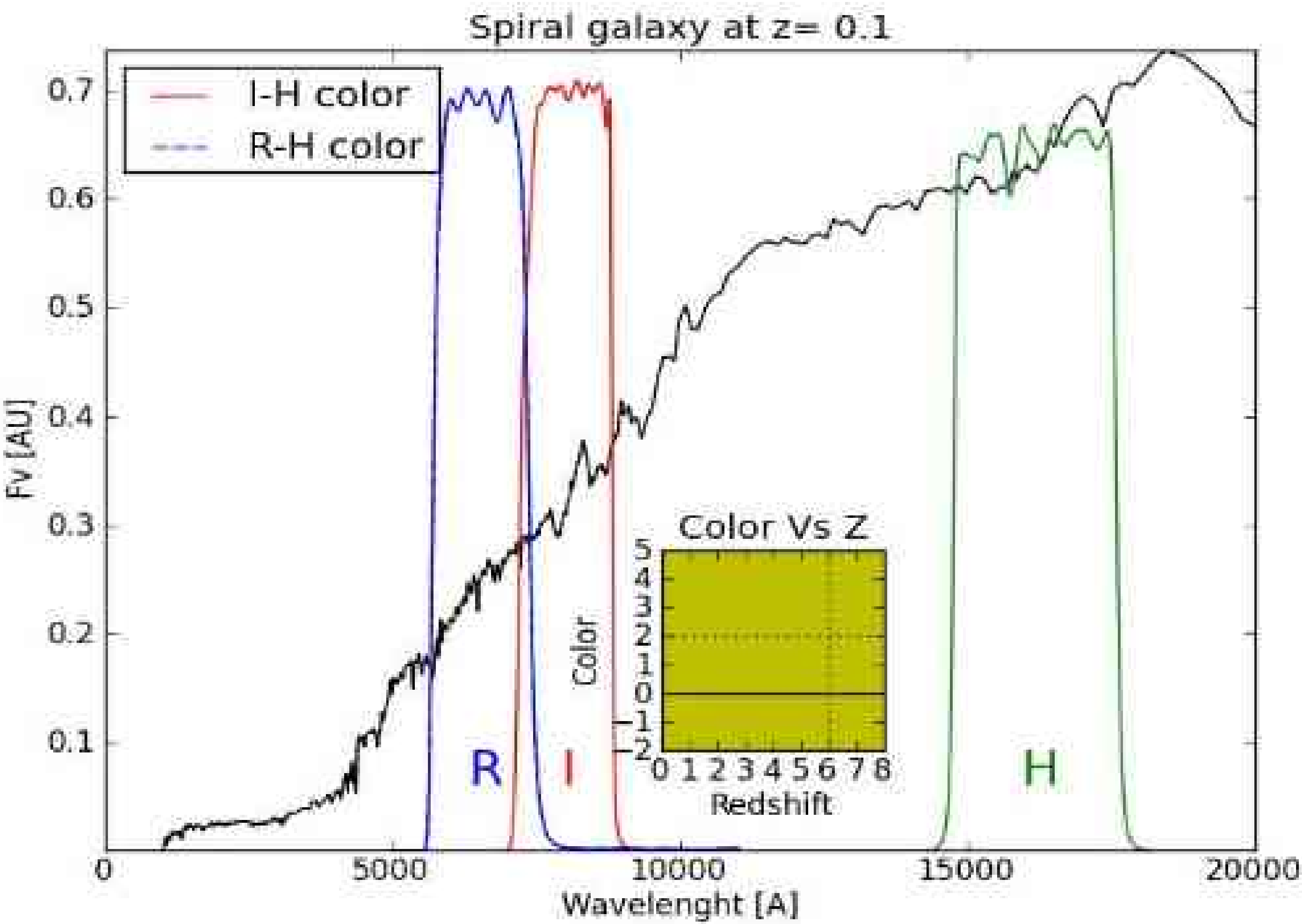


In the observer frame, the situation looks like that:

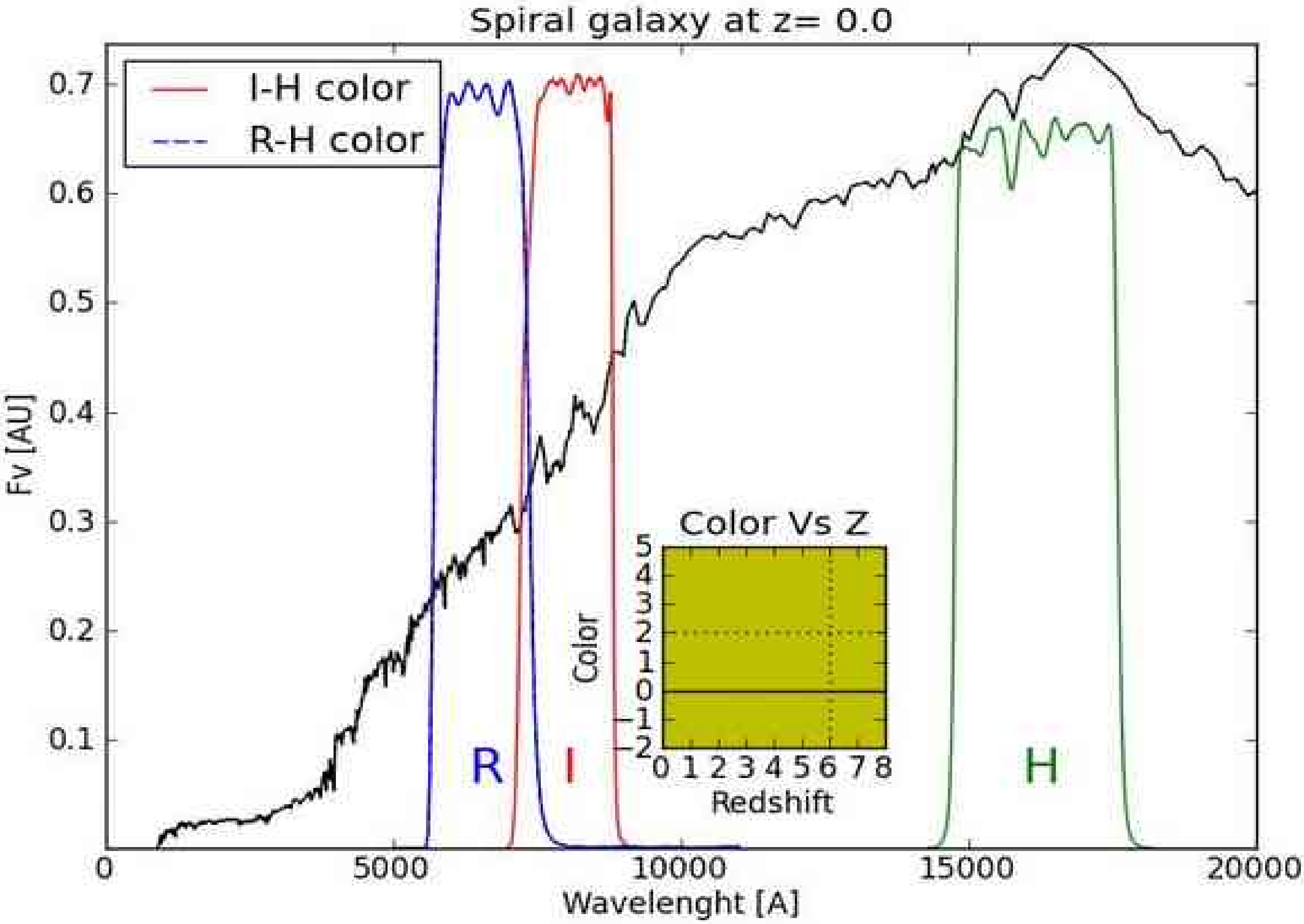
FROM UV TO IR



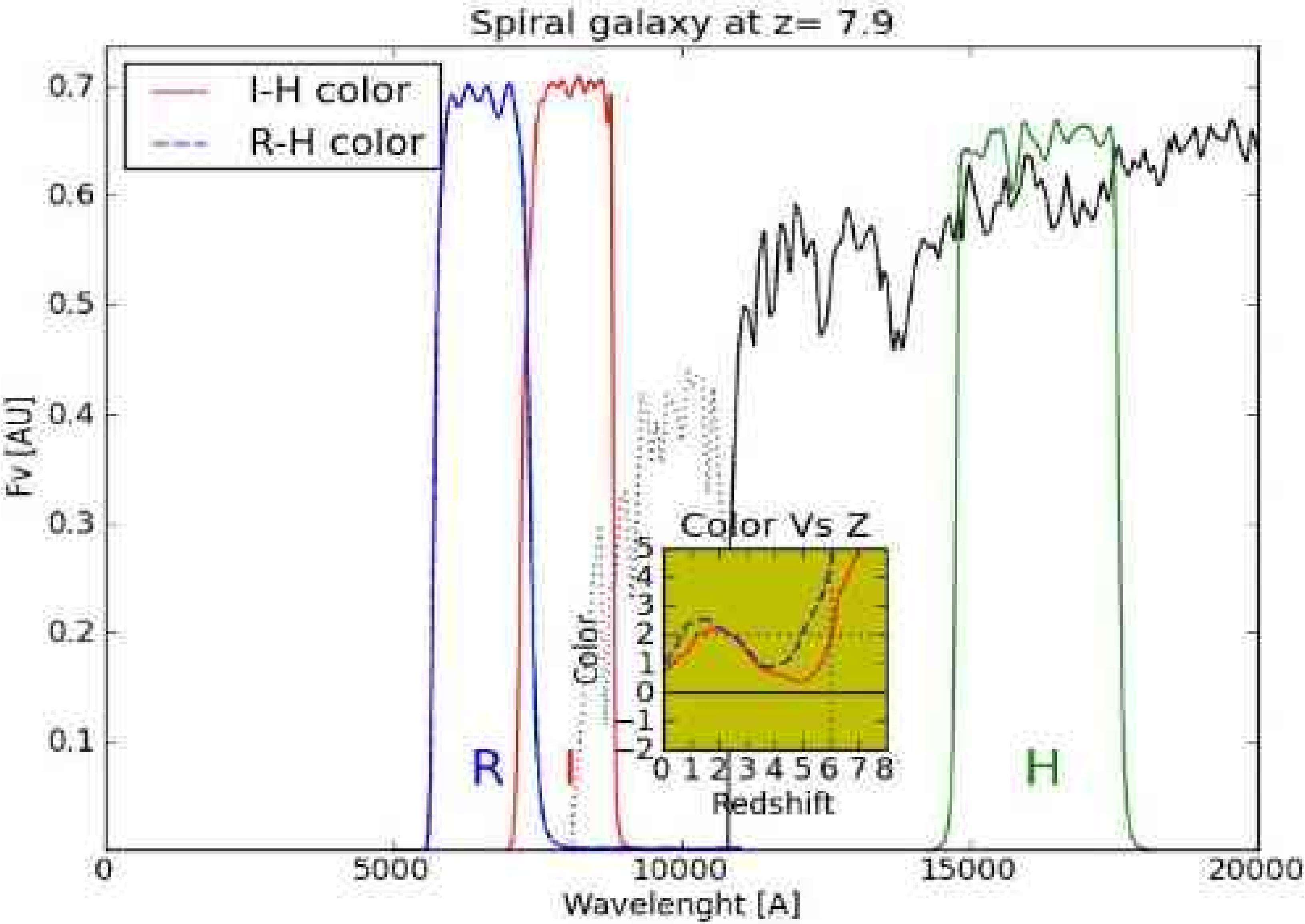
SED translated WITHOUT evolution

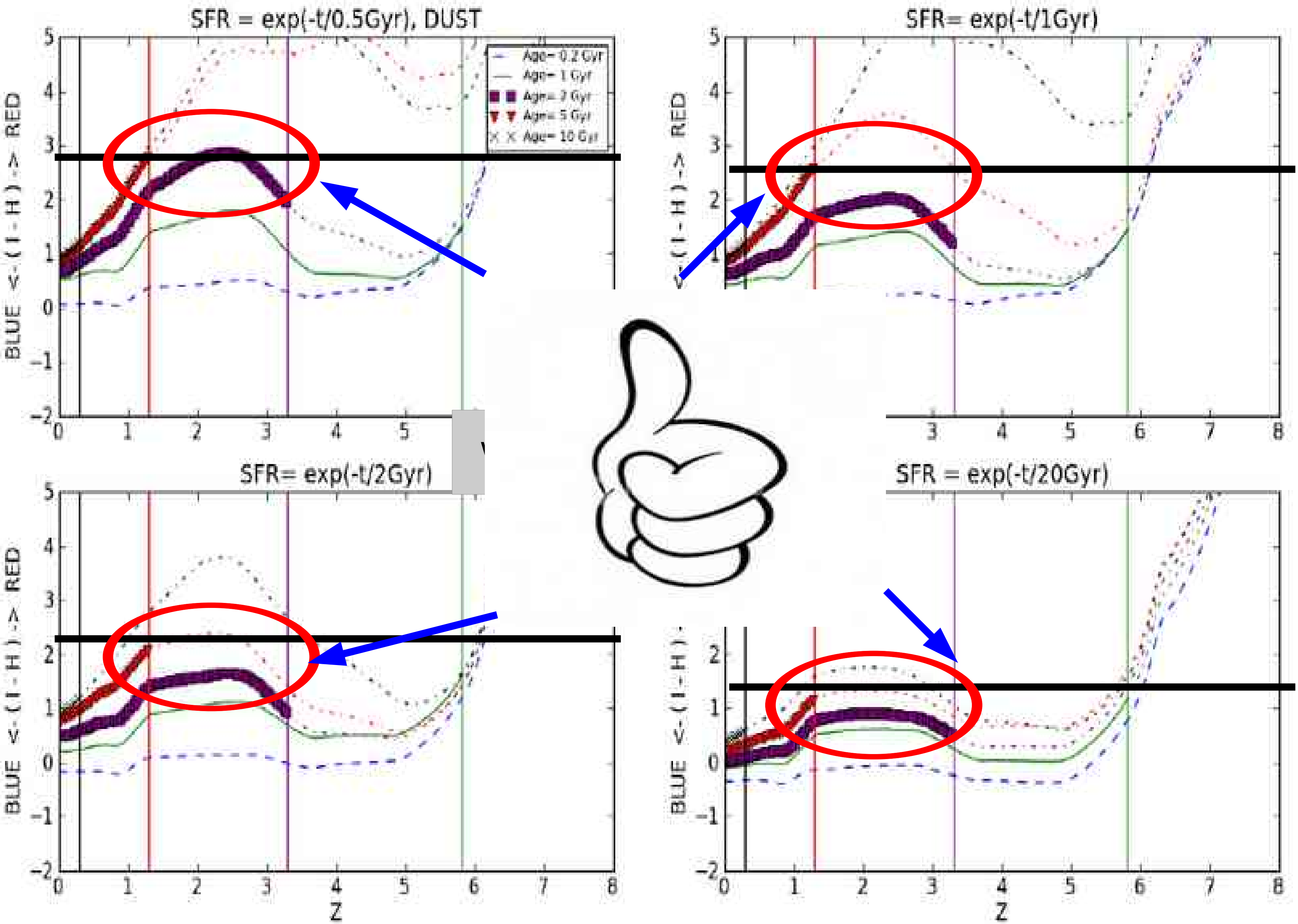


SED translated WITHOUT evolution



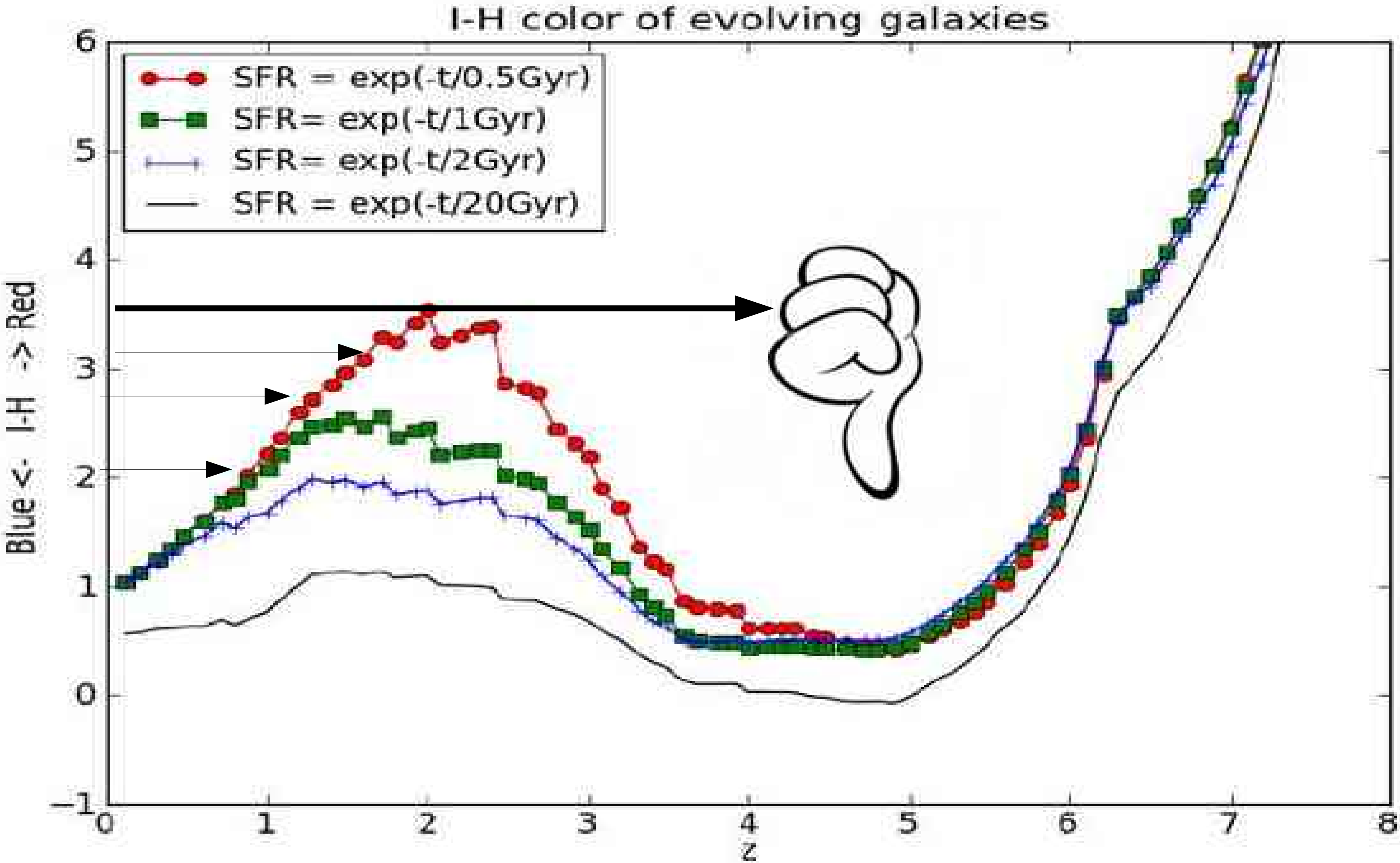
SED translated WITHOUT evolution





SFR = exp(-t/0.5Gyr), DUST
SFR= exp(-t/1Gyr)
SFR= exp(-t/2Gyr)
SFR = exp(-t/20Gyr)
Age= 0.2 Gyr
Age= 1 Gyr
Age= 2 Gyr
Age= 5 Gyr
Age= 10 Gyr
BLUE <- (I - H) -> RED
Z

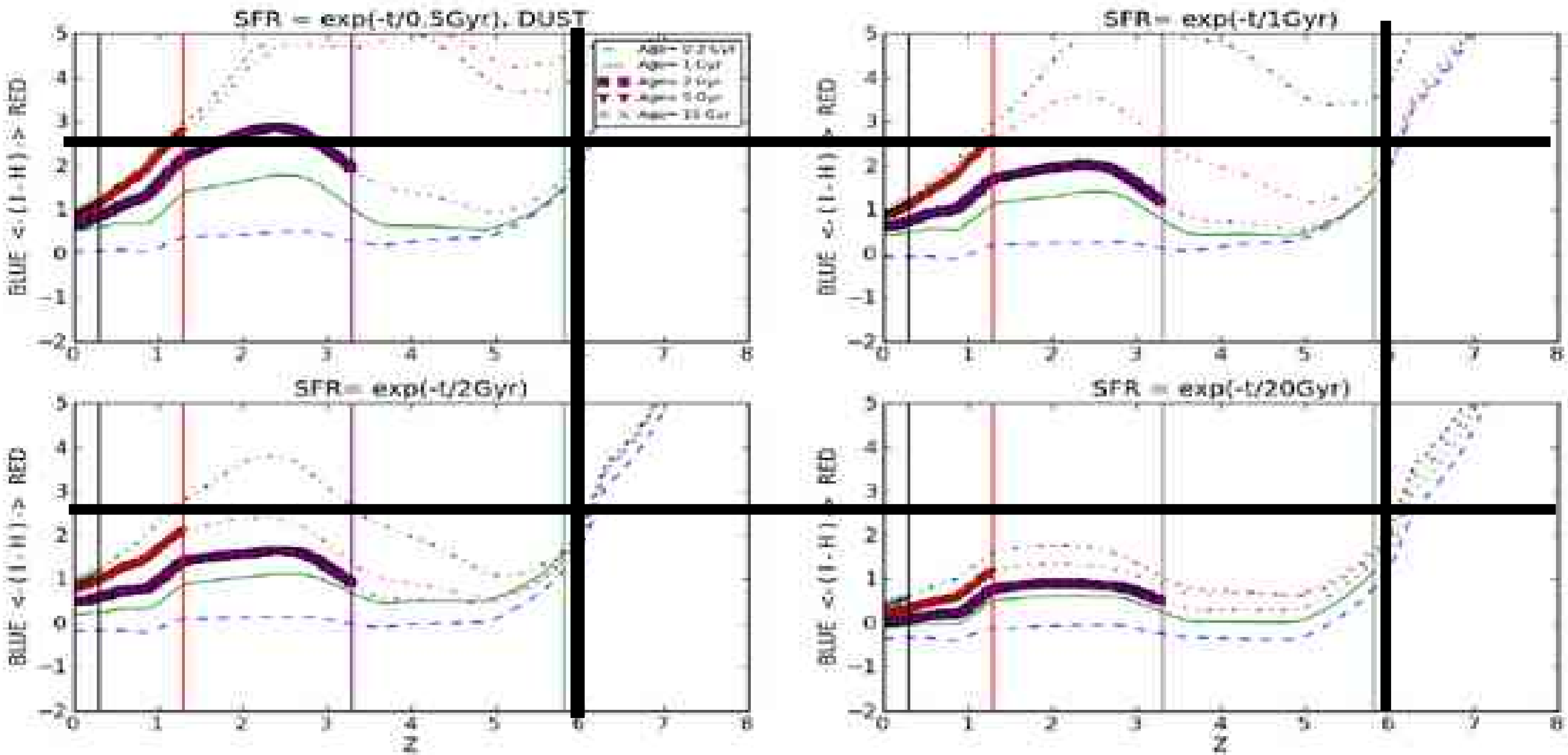
SED translated WITH evolution



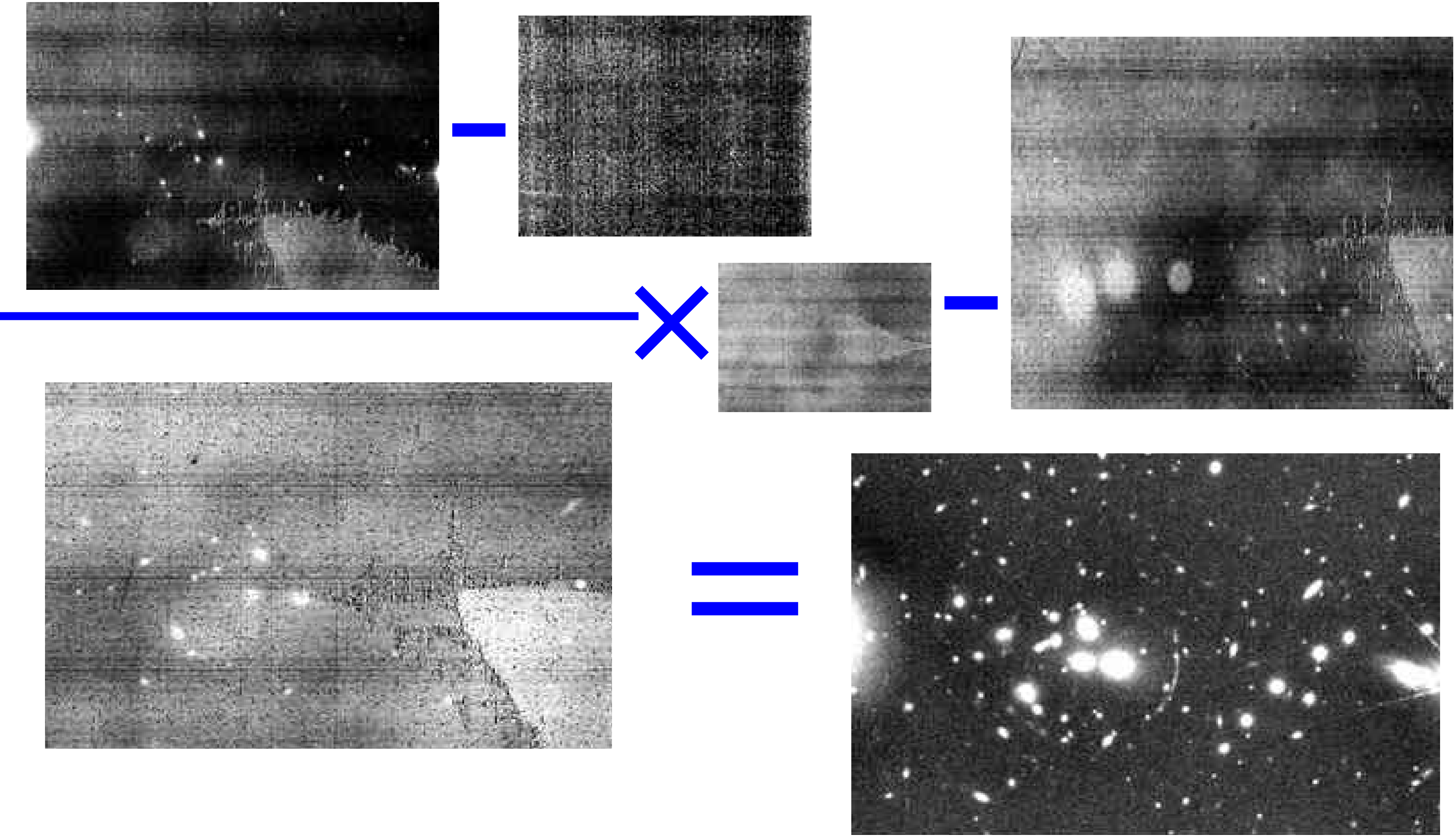
Chapter II (Models) Conclusion

$$I_{800} \quad - \quad H_{1600} \quad > \quad 2.5$$

$$R_{650} \quad - \quad I_{800} \quad > \quad 2$$



Chapter III: Infra-red data reduction



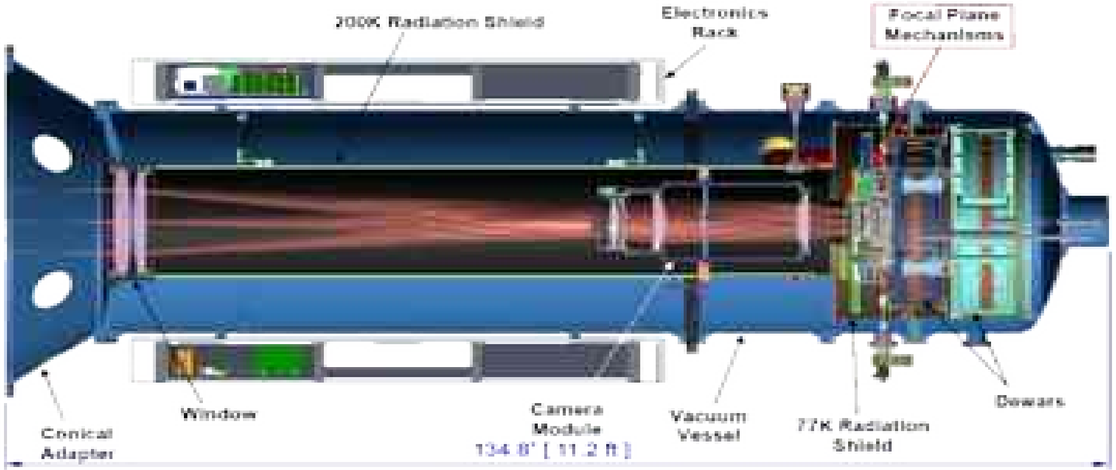
Chapter III: Infra-red data reduction

High sky background (thermal)

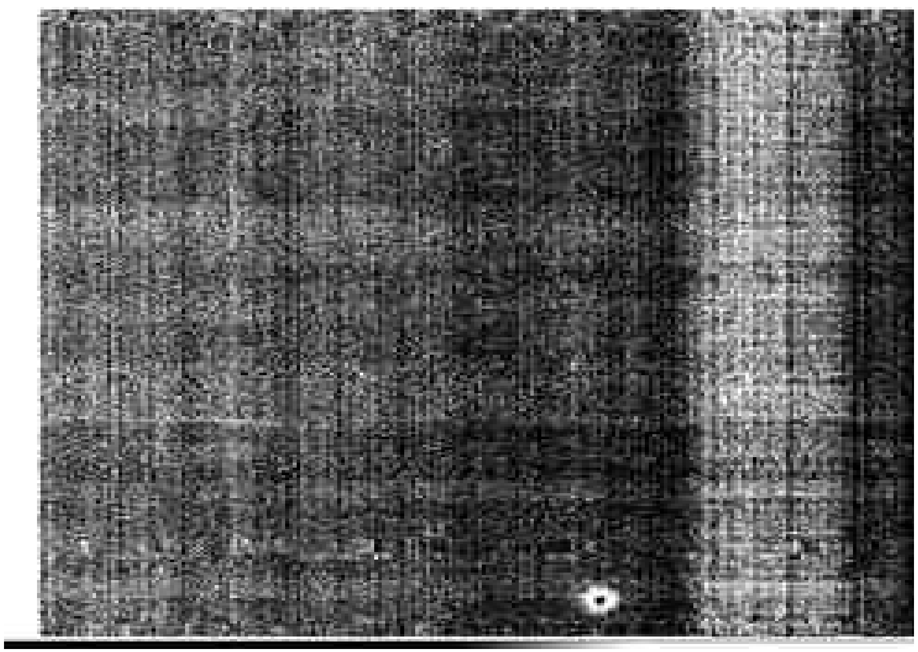
No Bias

Non-linearity correction

$$Reduced = \sum \left[LinearCor \left(\frac{RAW - dark}{flat} \right) - sky \right]$$

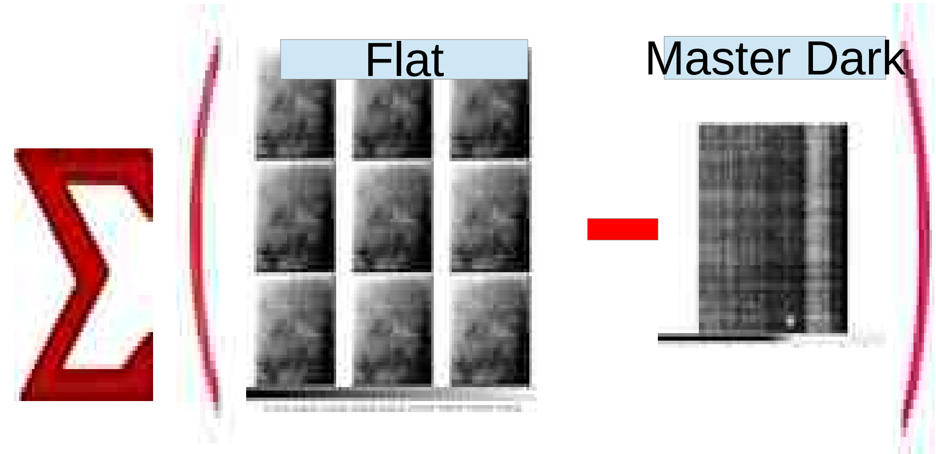


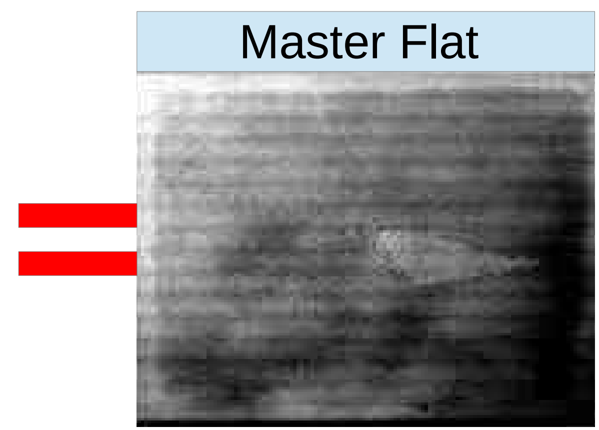
-DARK



$$Reduced = \sum \left[LinearCor\left(\frac{RAW - dark}{flat}\right) - sky \right]$$

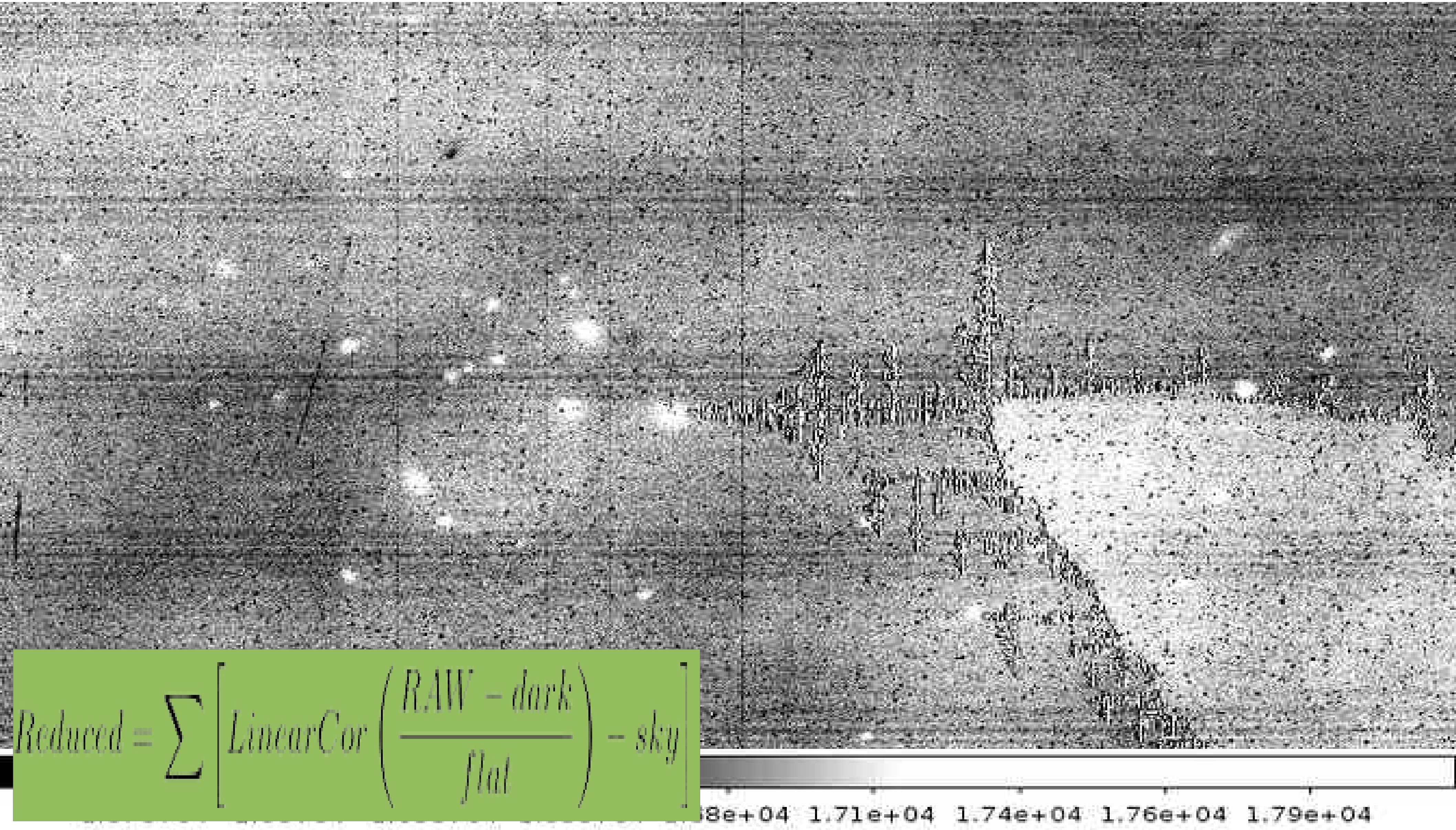
/FLAT





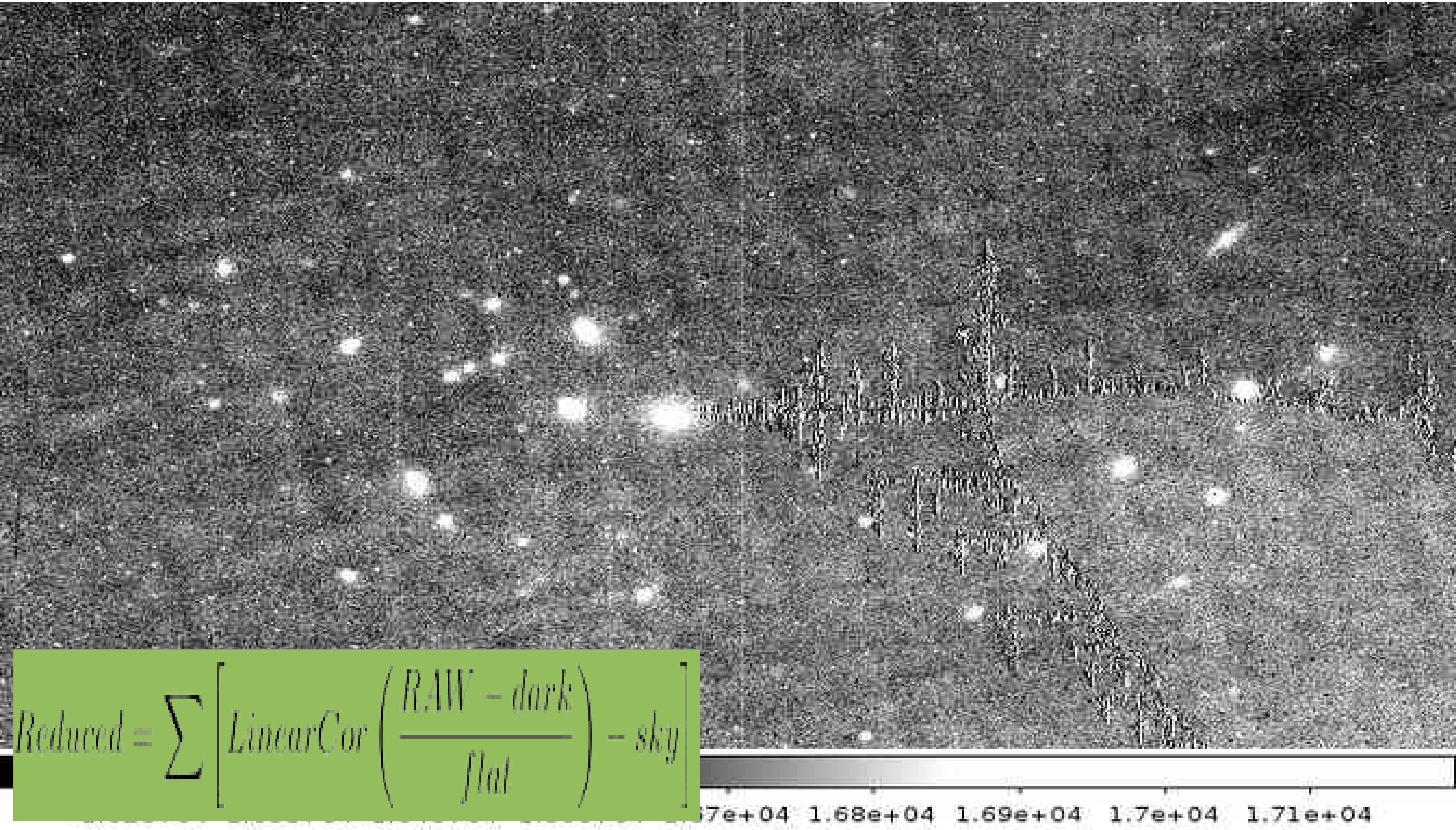
Then, normalize flat :
Flat = Flat / Mean(Flat)

Raw (zoom)



$$Reduced = \sum\left[LinearCor\left(\frac{RAW - dark}{flat}\right) - sky\right]$$

Flat subtraction



$$Reduced = \sum \left[LinearCor\left(\frac{RAW - dark}{flat} \right) - sky \right]$$

Non linearity correction

$$Truecount = Im + Im^{2.5} \times LinCor$$

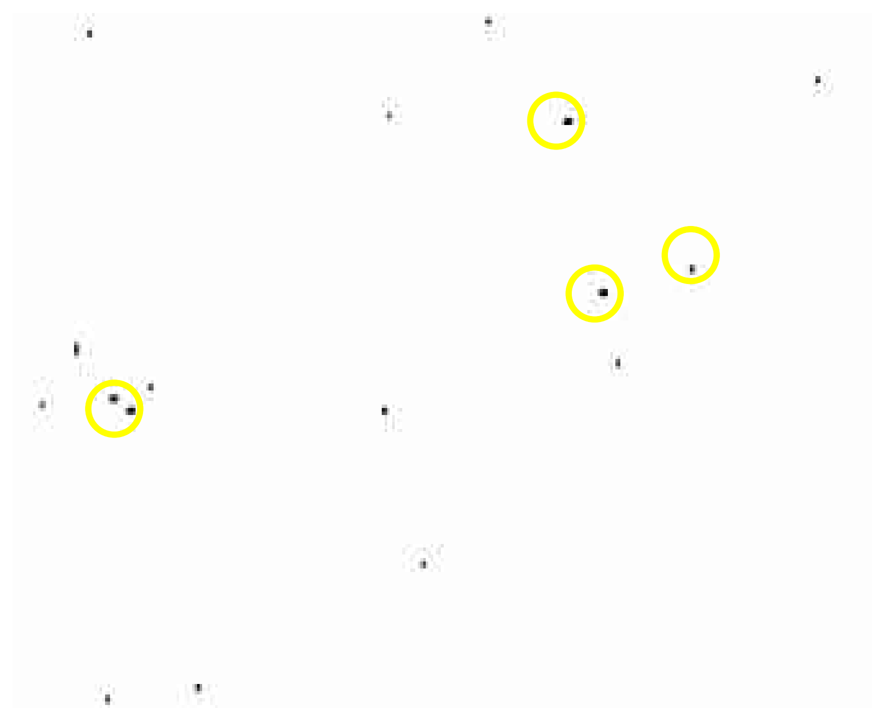
Change result of a factor 5% and 10% for bright stars

$$Reduced = \sum \left[LinearCor\left(\frac{RAW - dark}{flat} \right) - sky \right]$$

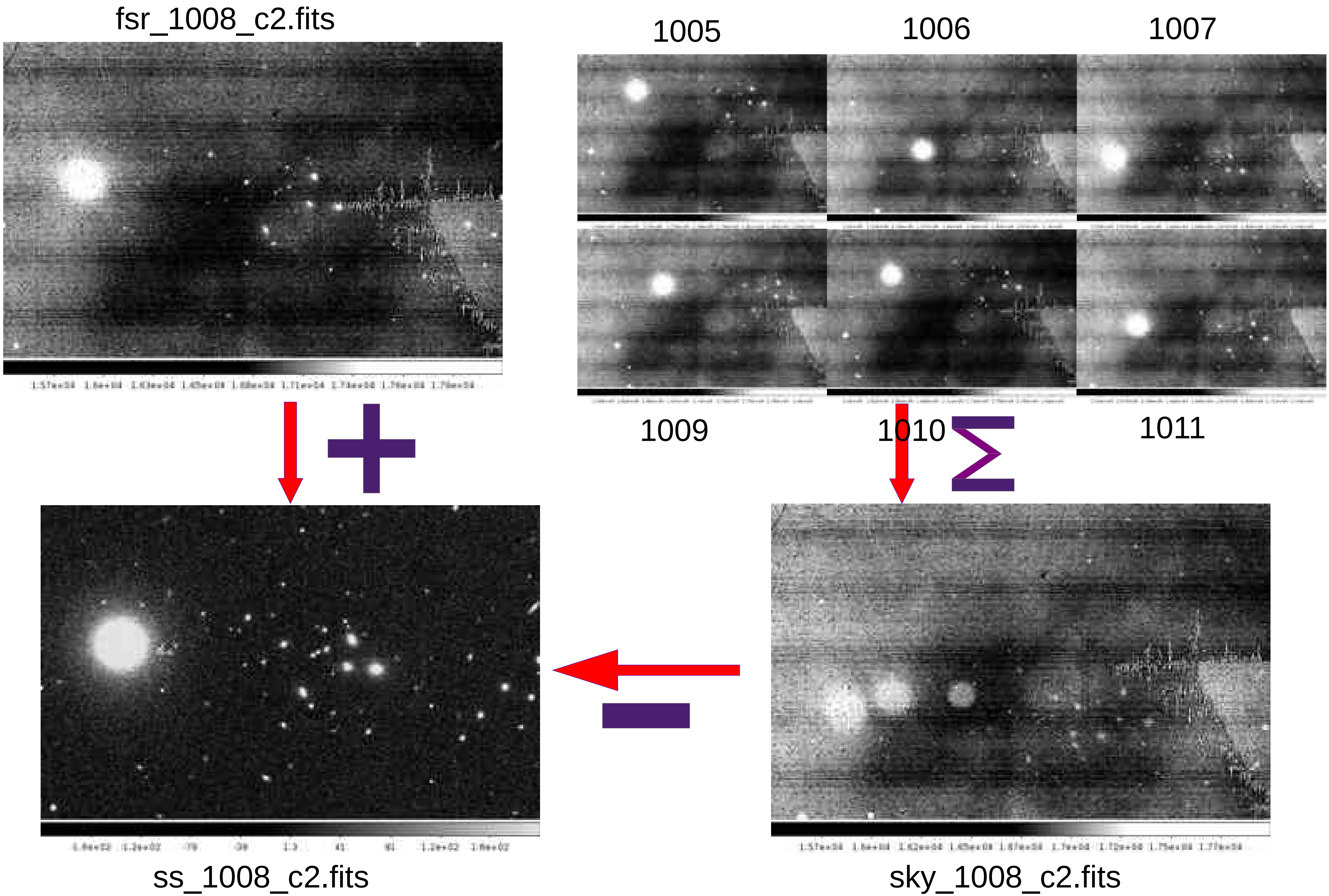
Bad pixel mask

Mask high and low response pixels :

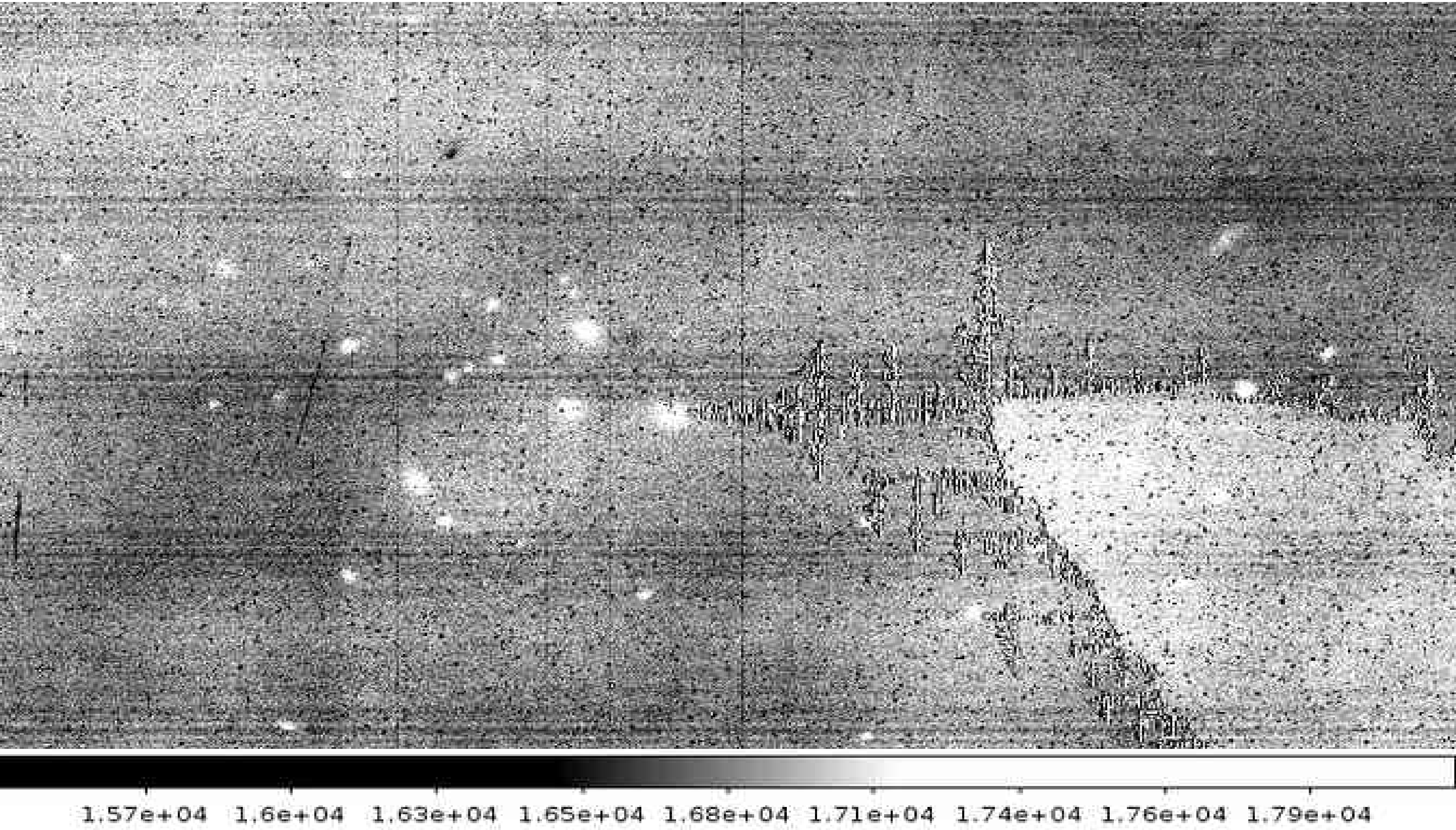
$$BPM = \begin{vmatrix} 0 & if|1 - flat| > 0.2 \\ 1 & else \end{vmatrix}$$



IR Sky Subtraction

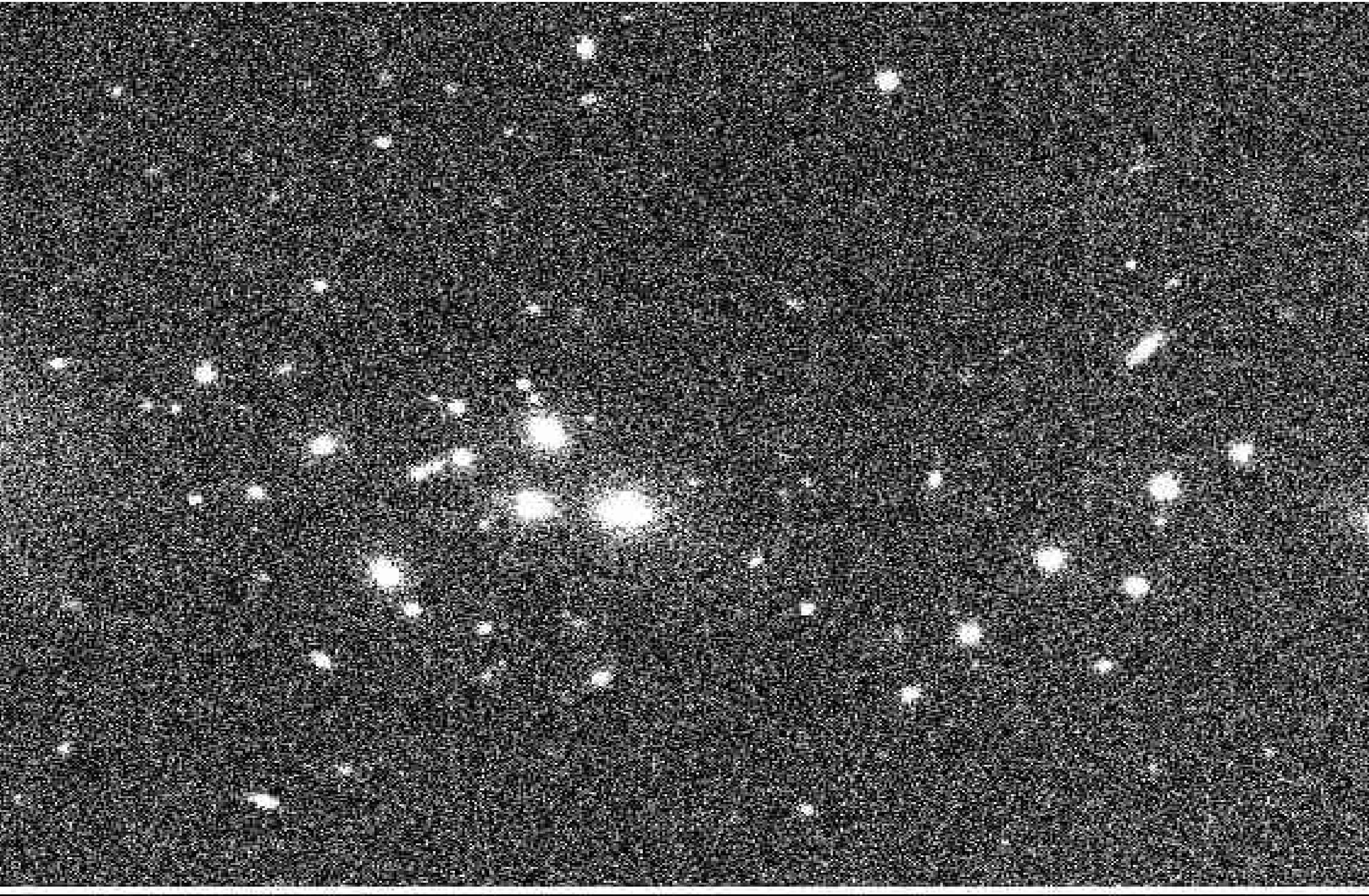


Raw (zoom)

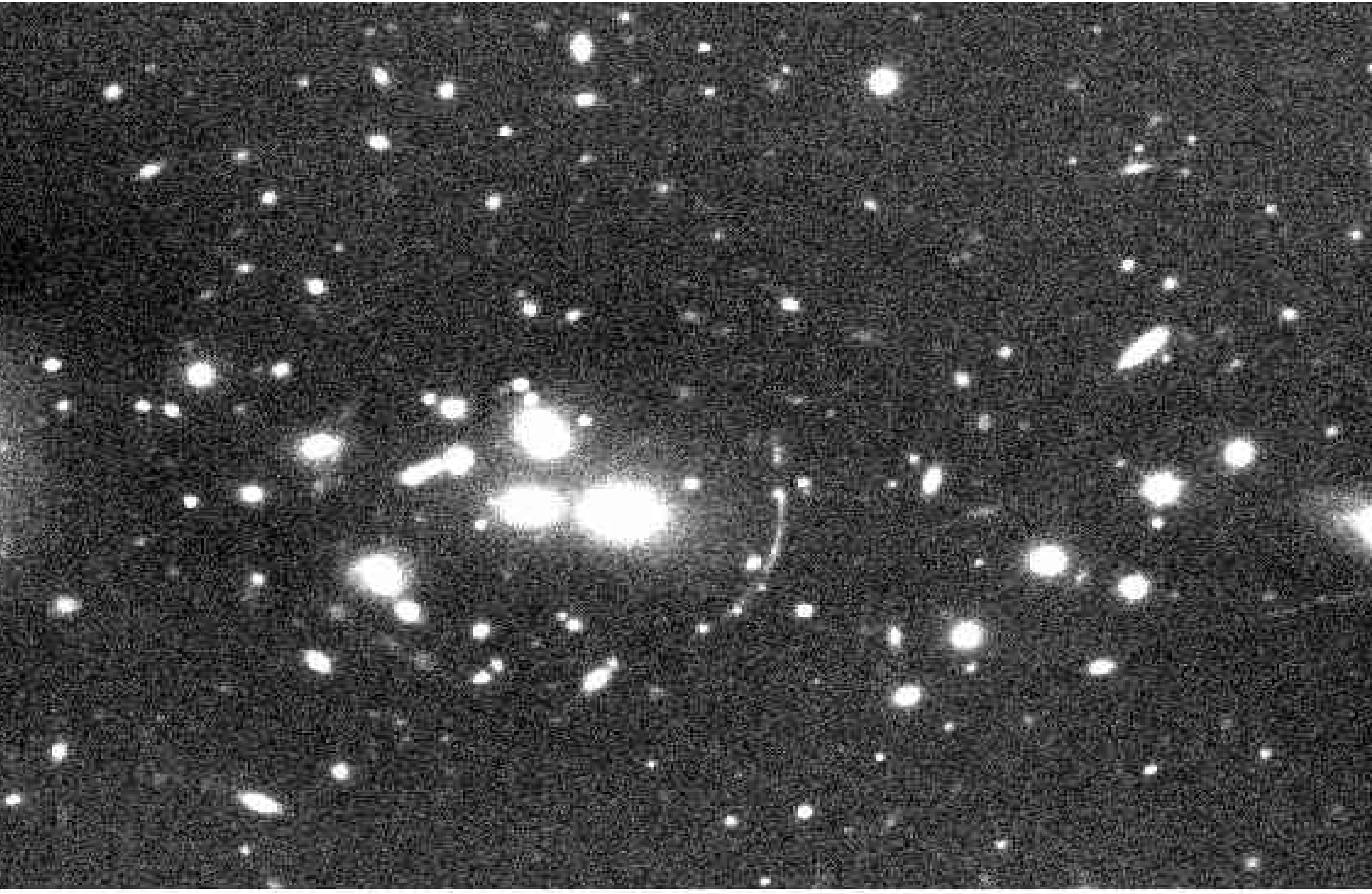


1.57e+04 1.6e+04 1.63e+04 1.65e+04 1.68e+04 1.71e+04 1.74e+04 1.76e+04 1.79e+04

Sky subtraction

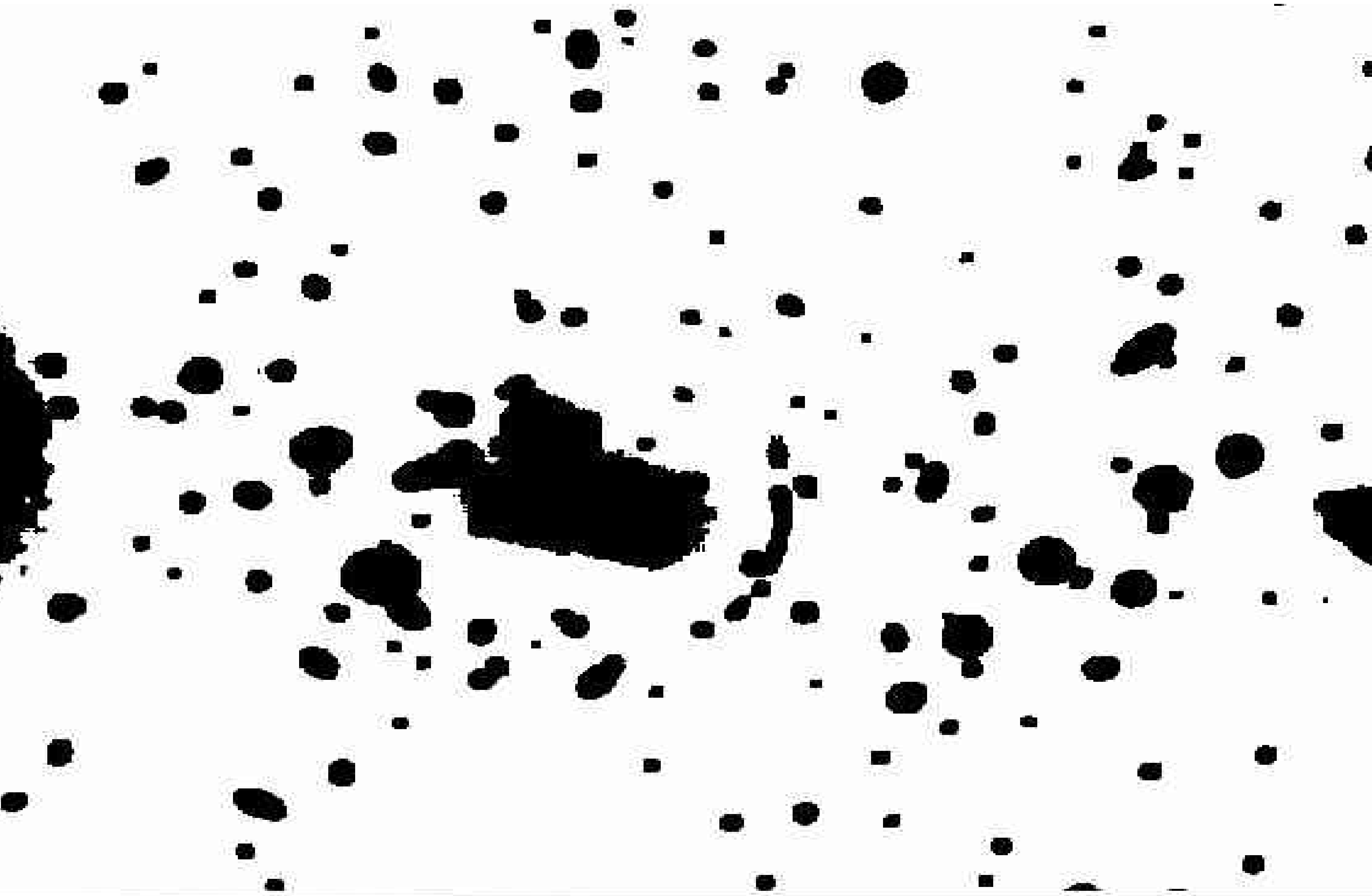


Combination (1st)

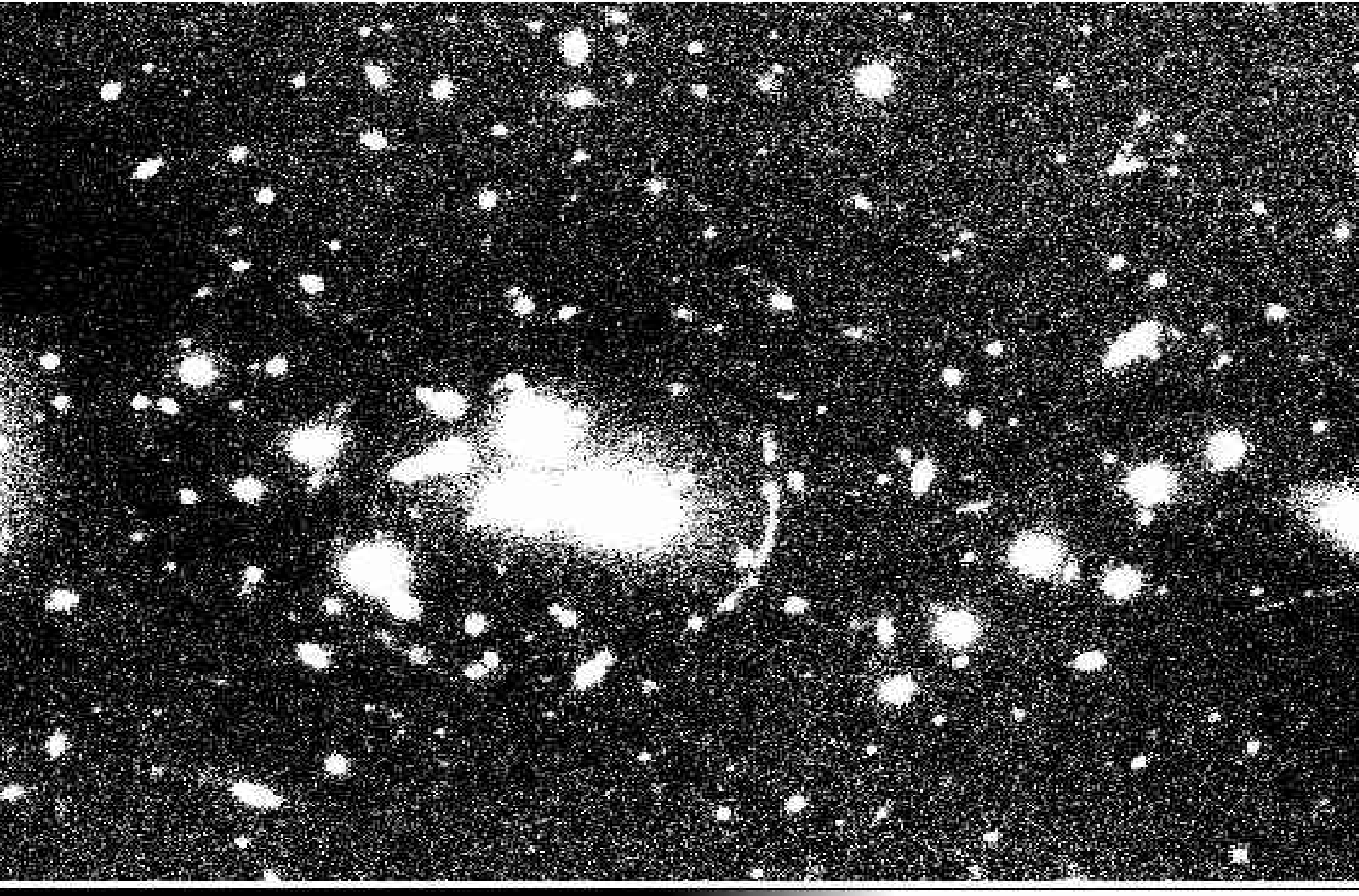


Combination (1st)

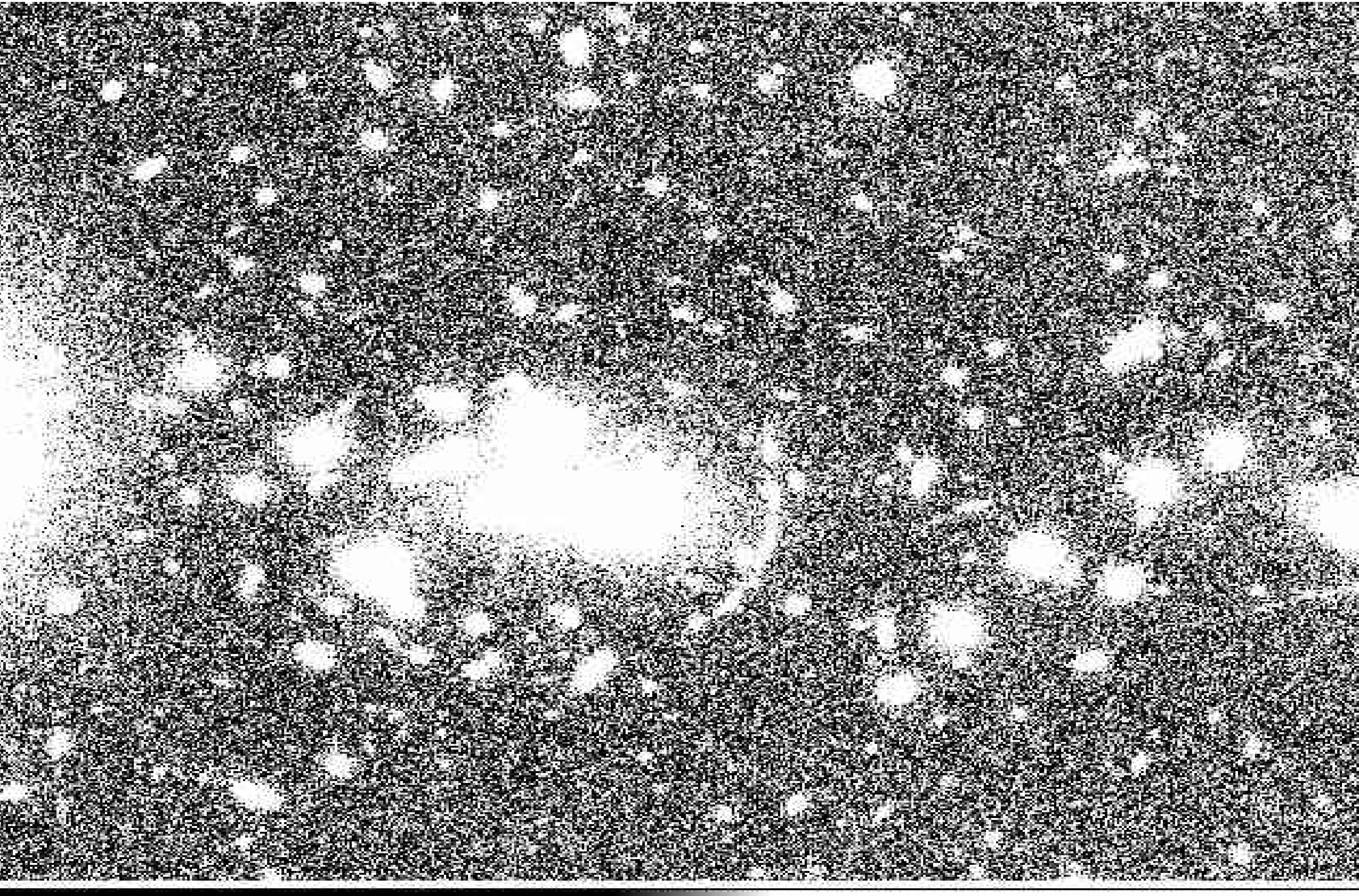
Masks



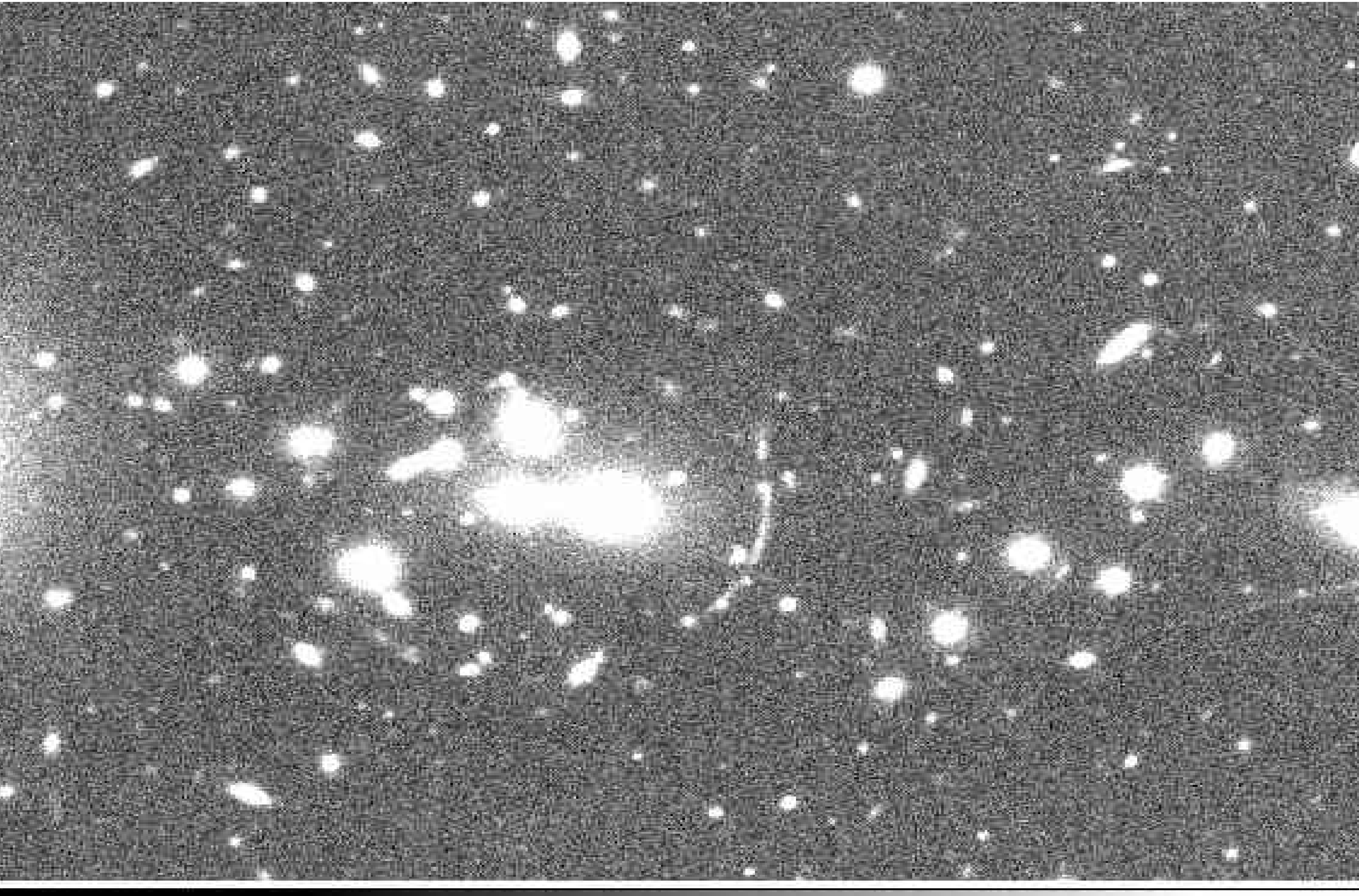
Combination (1st)

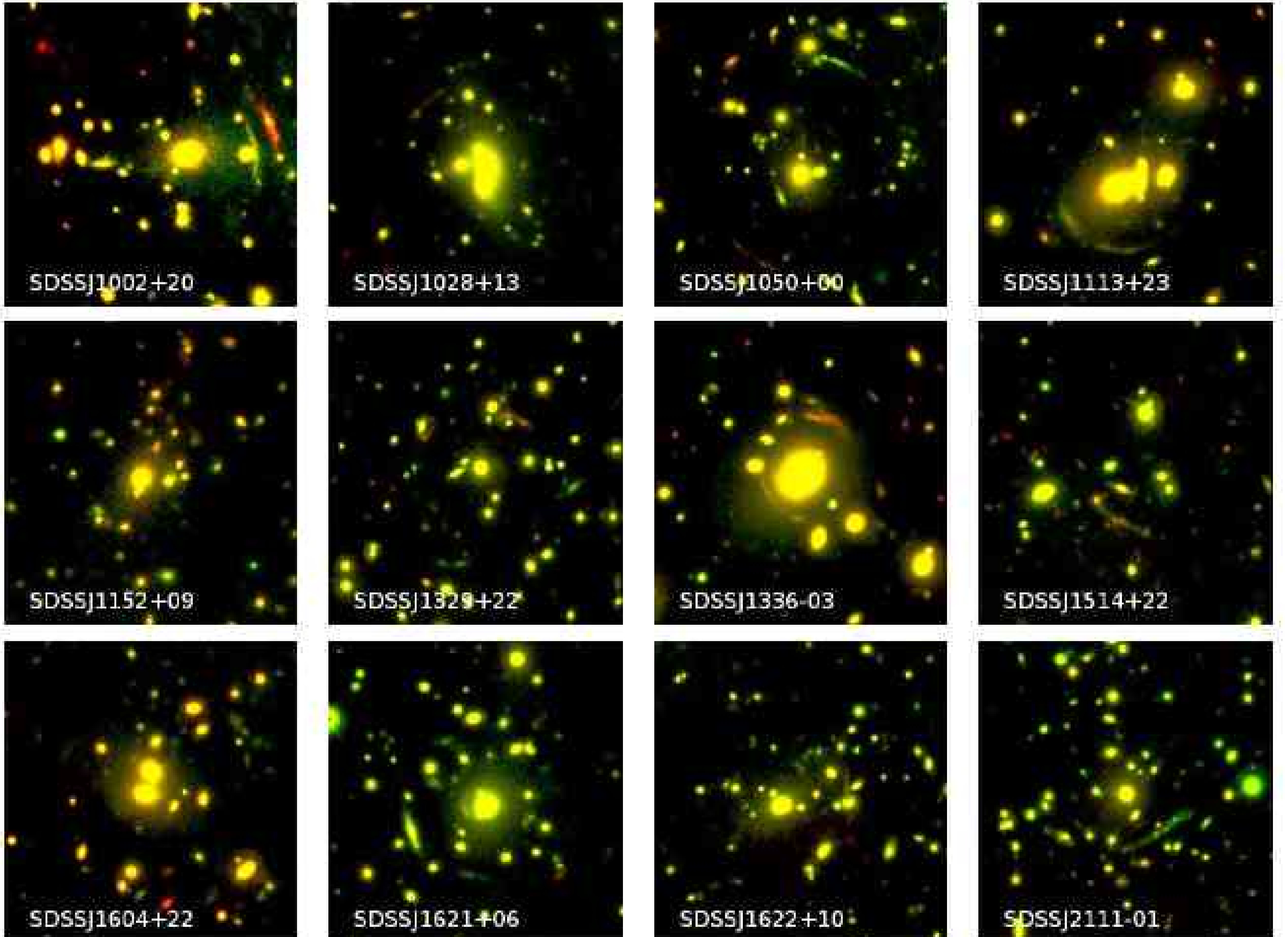


Combination (2nd)



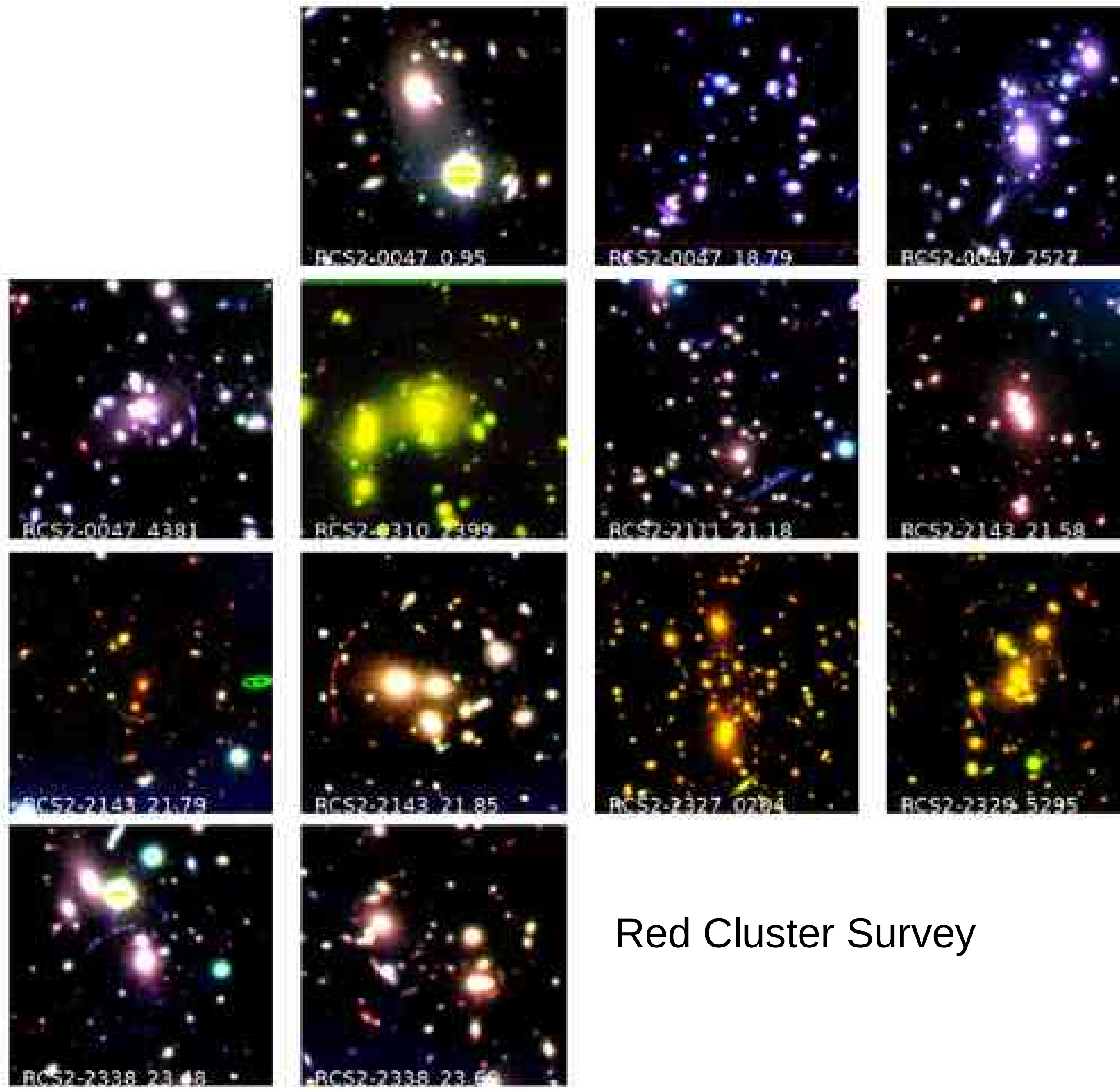
Combination (2nd) =Reduced



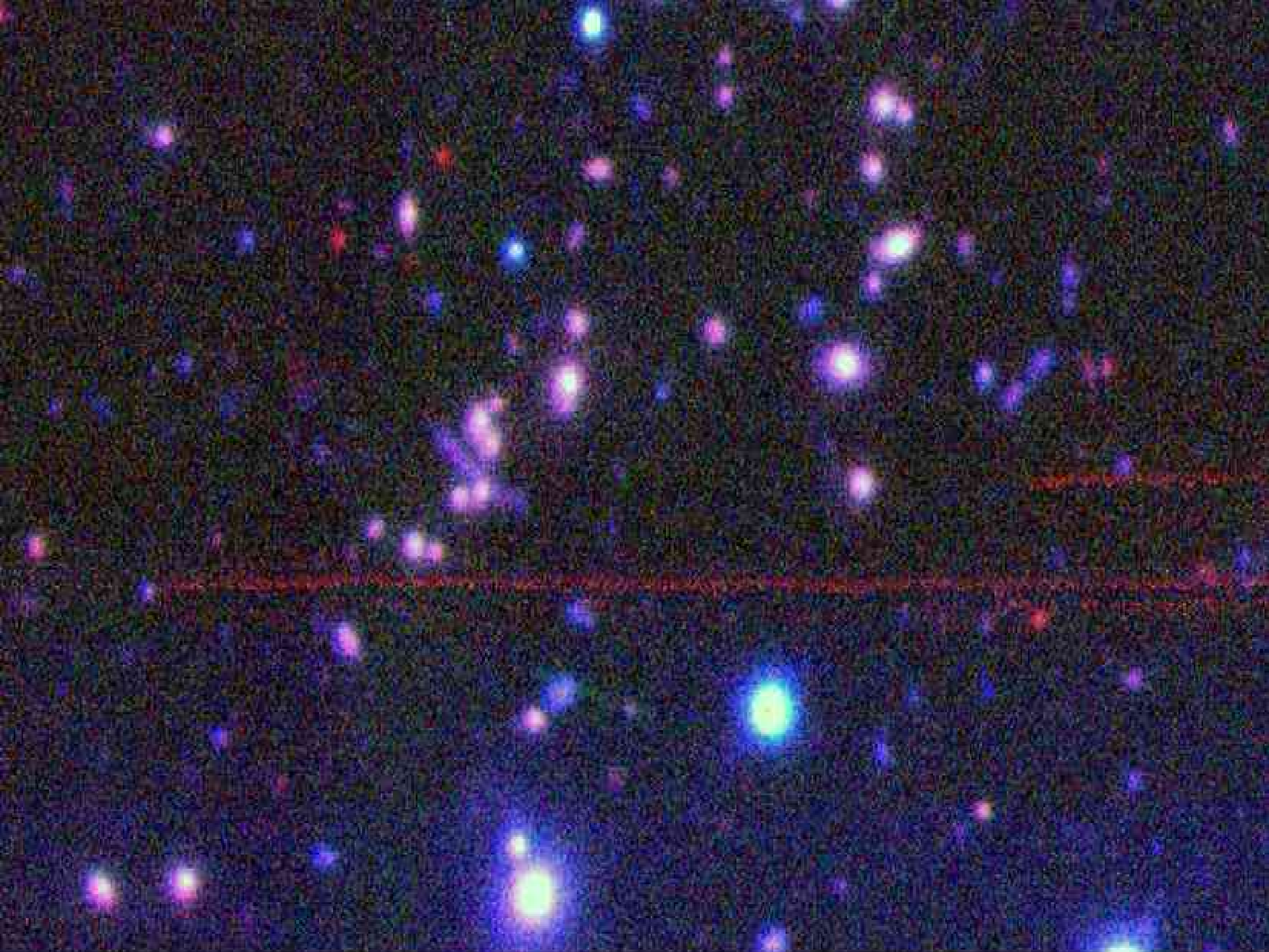

SDSSJ1002+20
SDSSJ1028+13
SDSSJ1050+00
SDSSJ1113+23
SDSSJ1152+09
SDSSJ1329+22
SDSSJ1336-03
SDSSJ1514+22
SDSSJ1604+22
SDSSJ1621+06
SDSSJ1622+10
SDSSJ2111-01

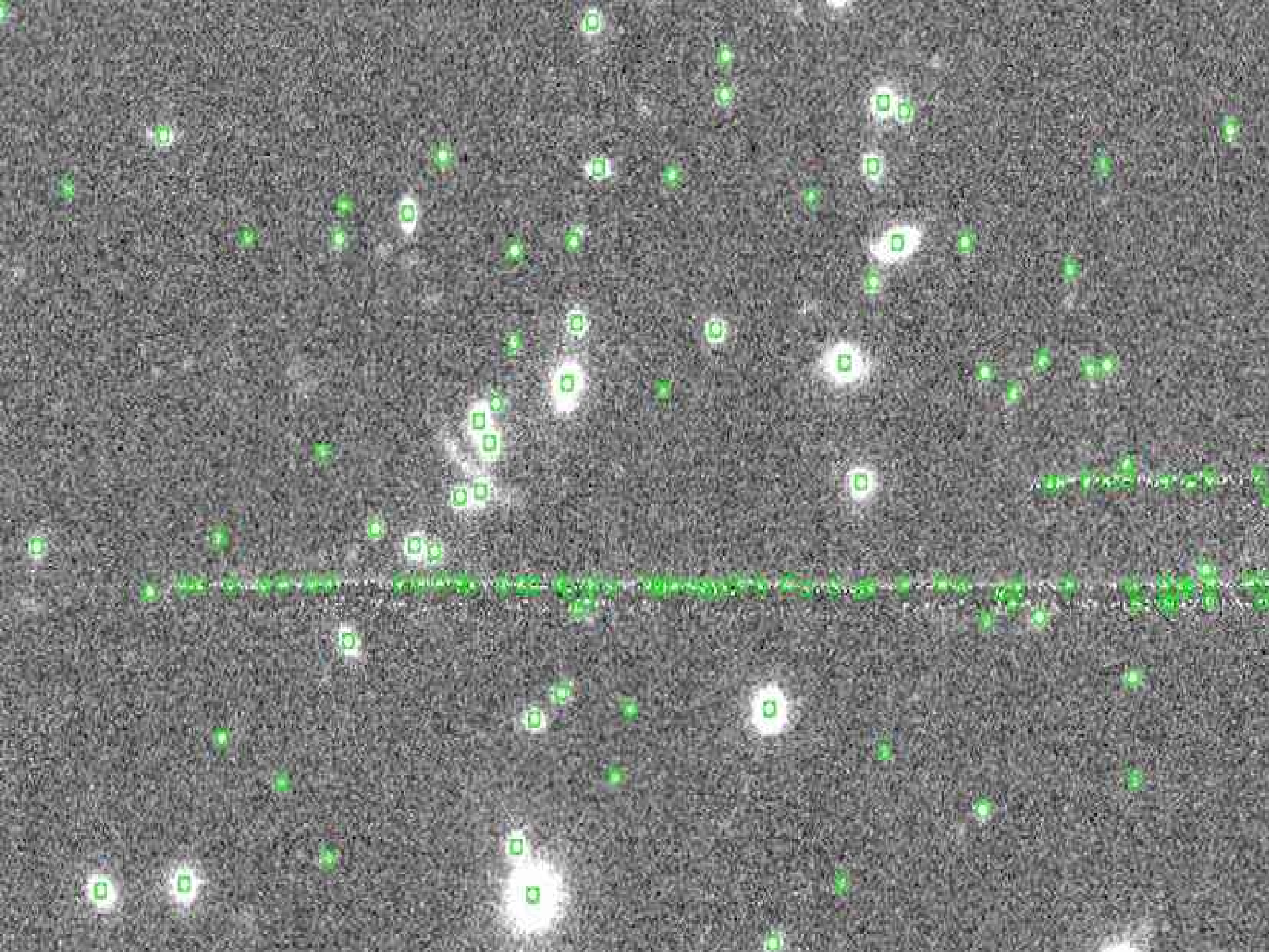
Steps

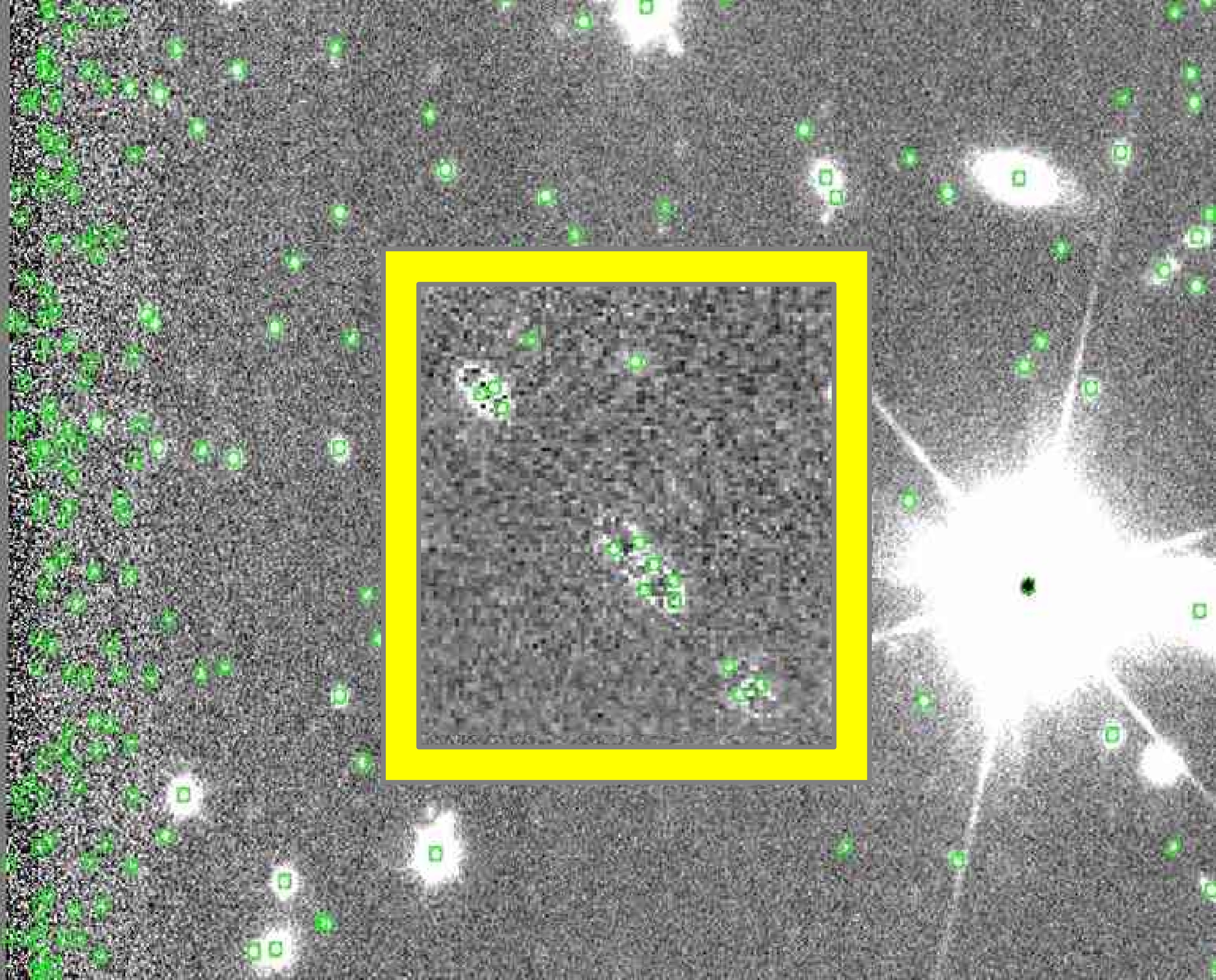
- 1/ Reduce
- 2/ Align (WCS)
- 3/ Calibrate (ZPT)
- 4/ Extract flux
- 5/ Color Selection
- 6/ Reject fake detections

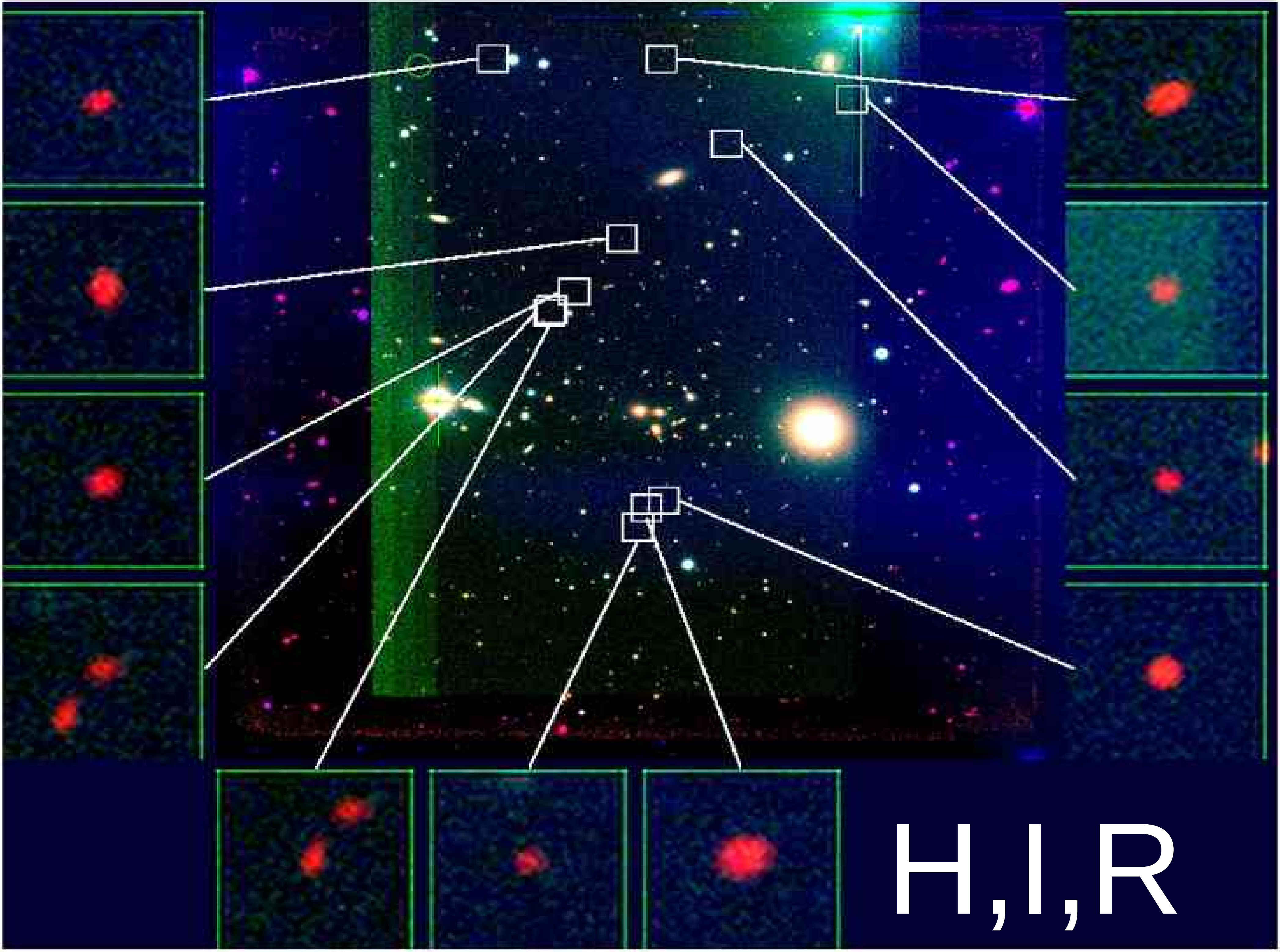


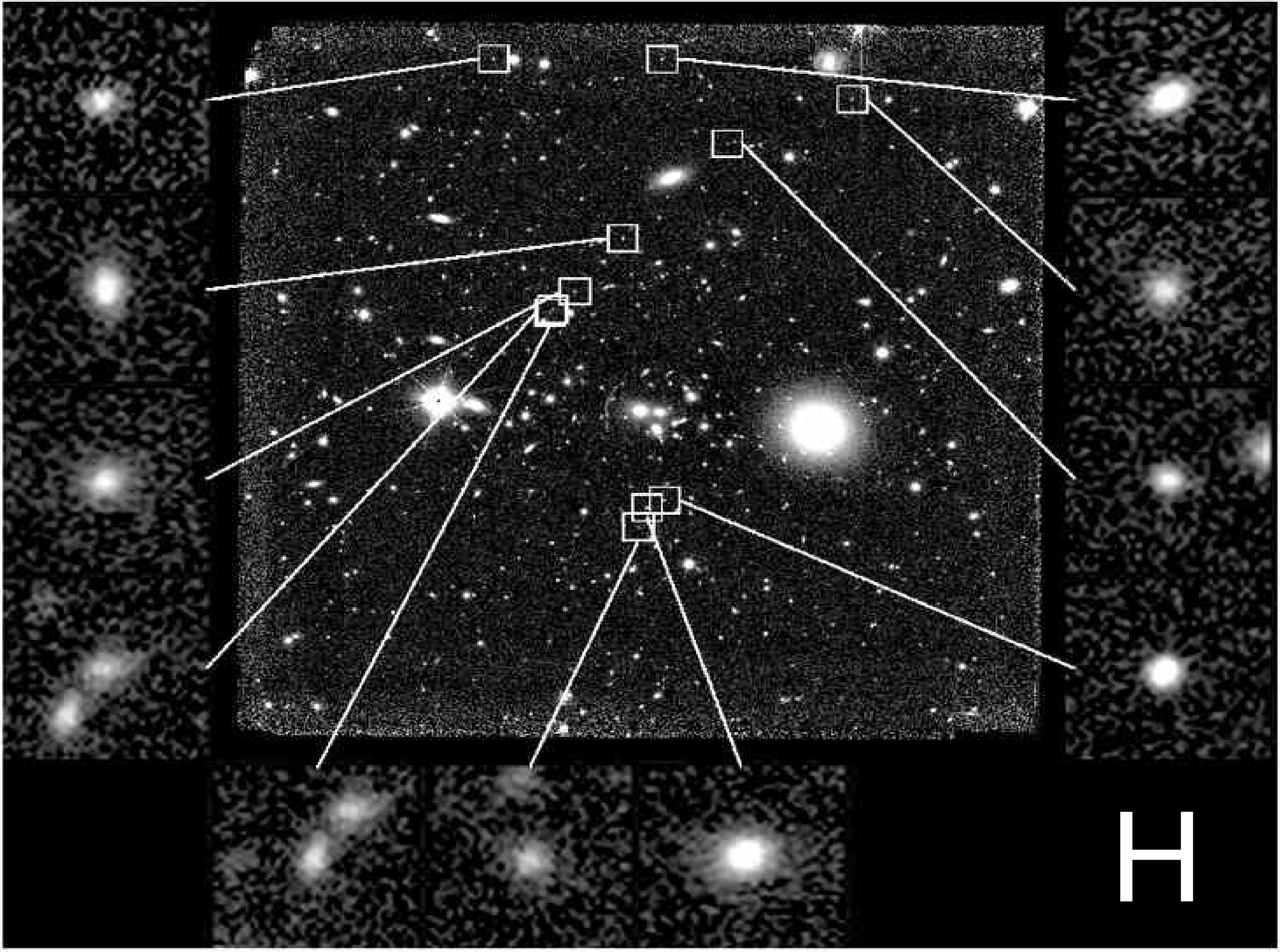
Red Cluster Survey

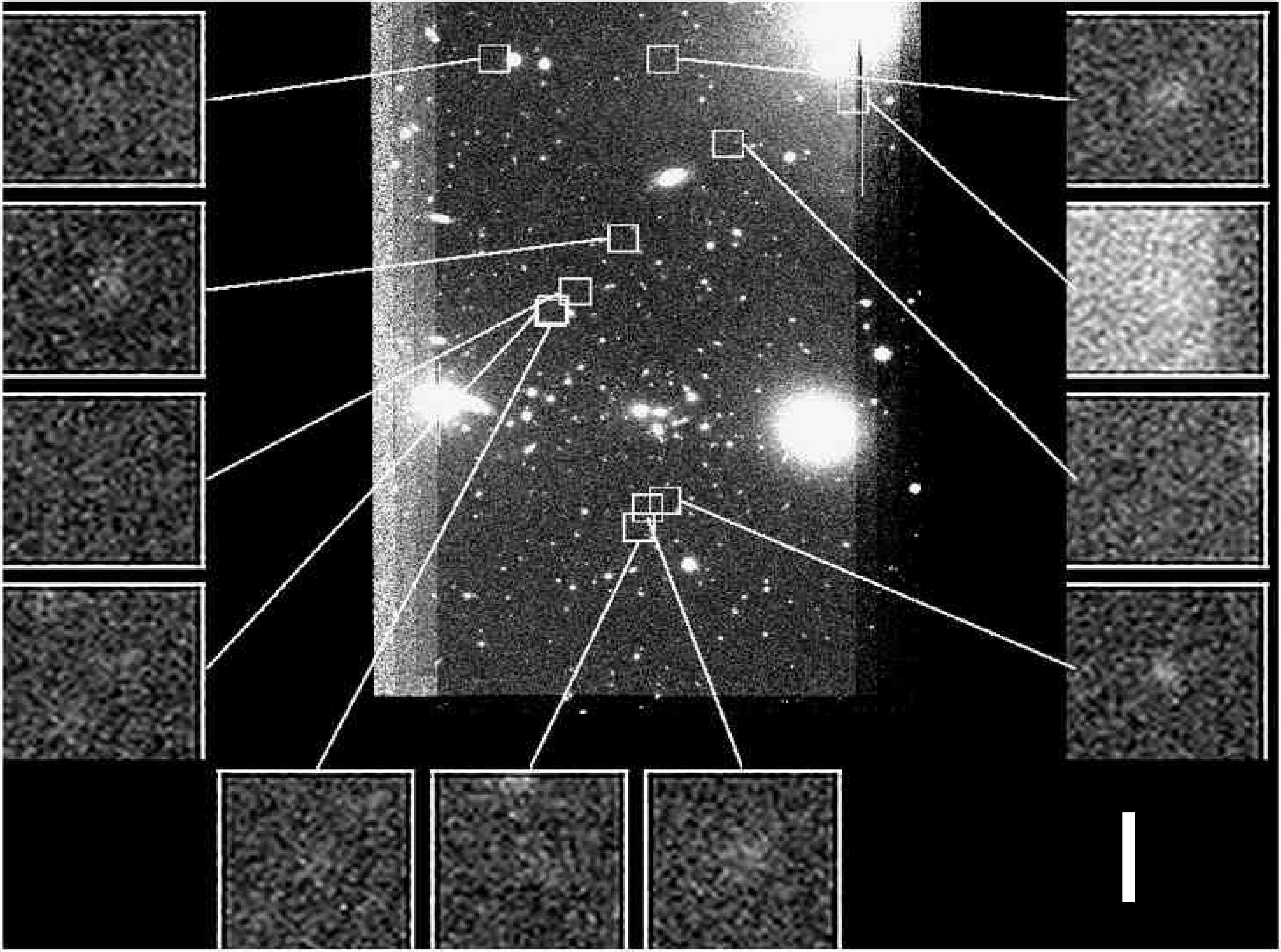


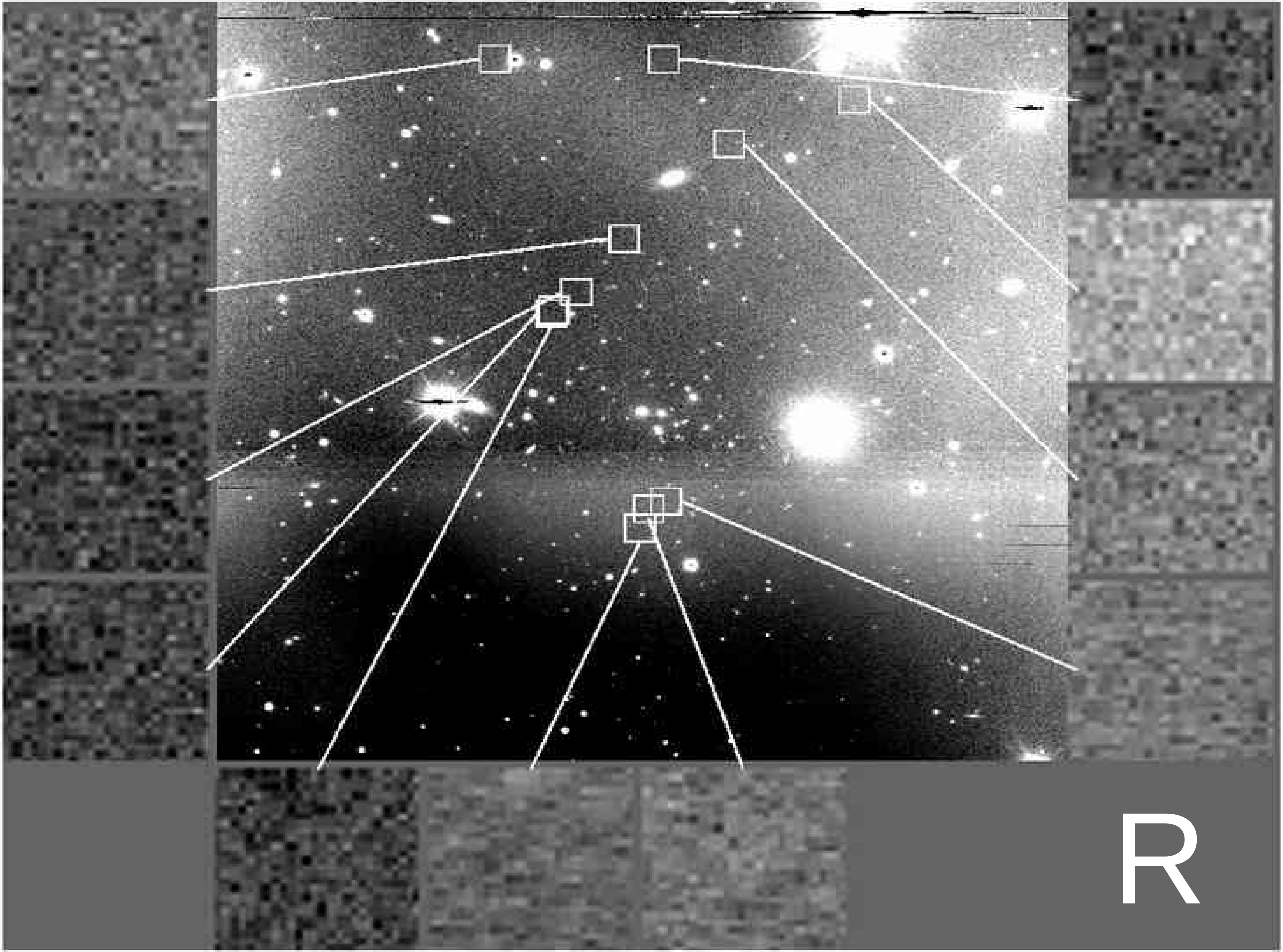


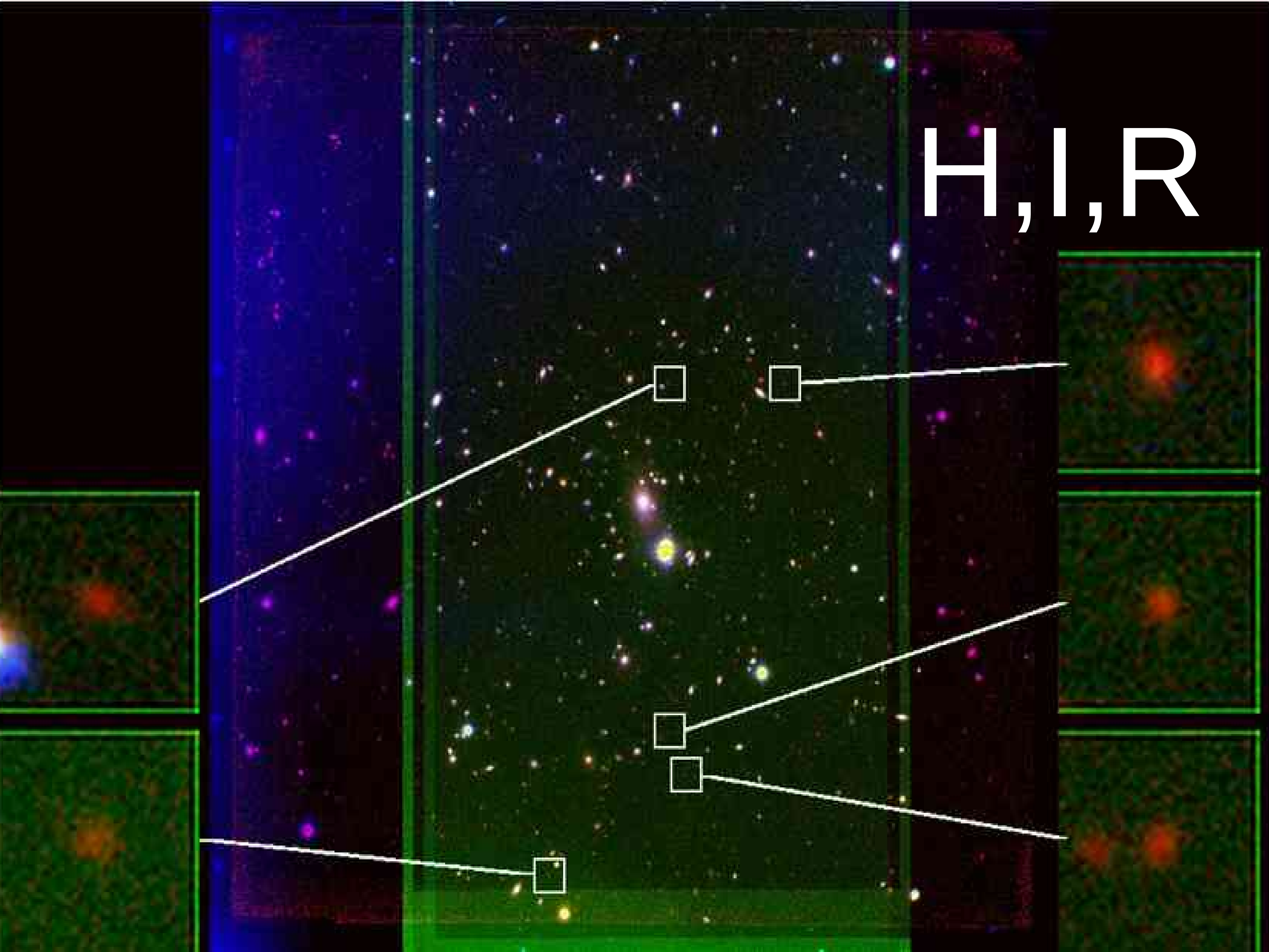


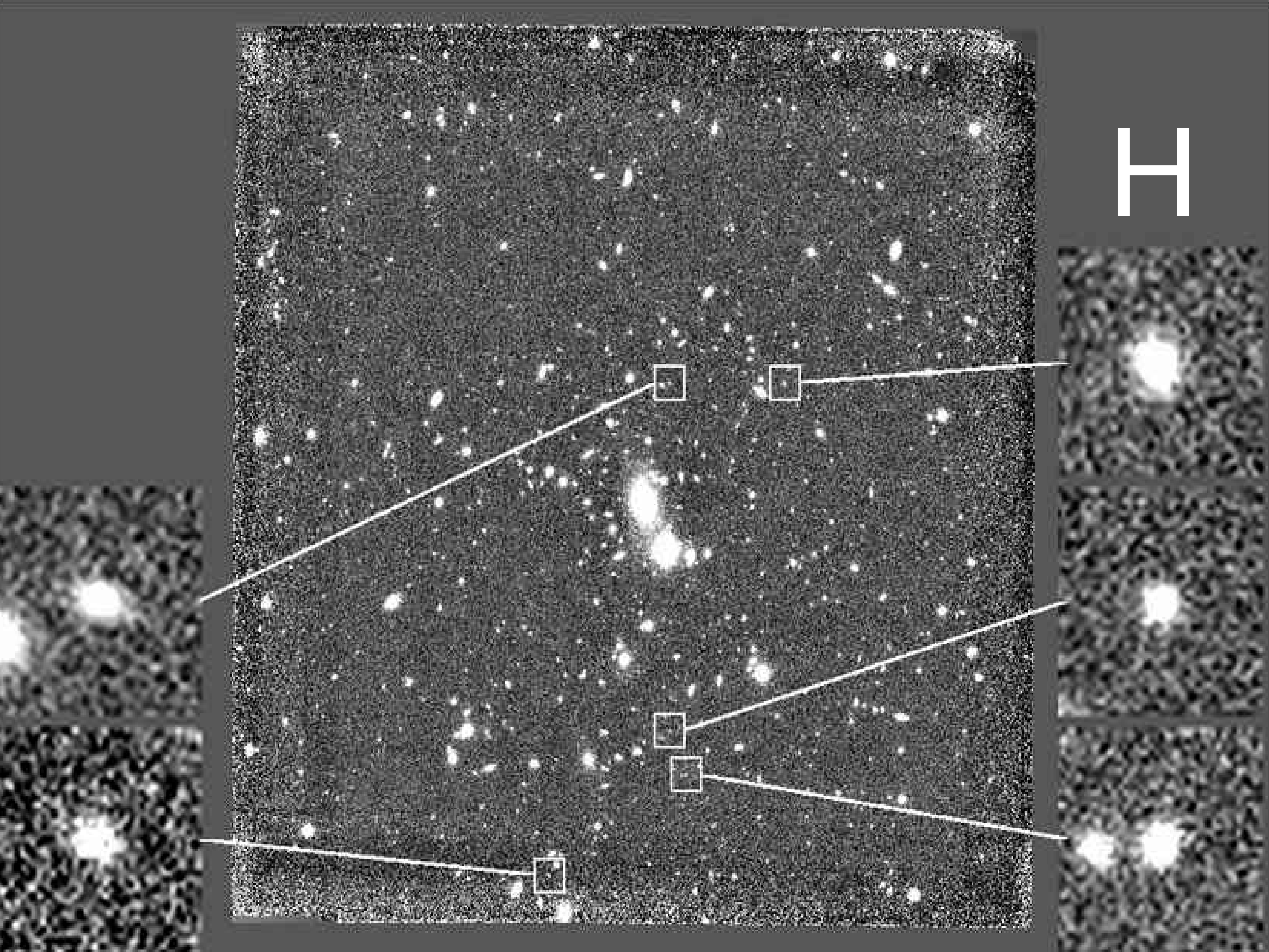

H,I,R

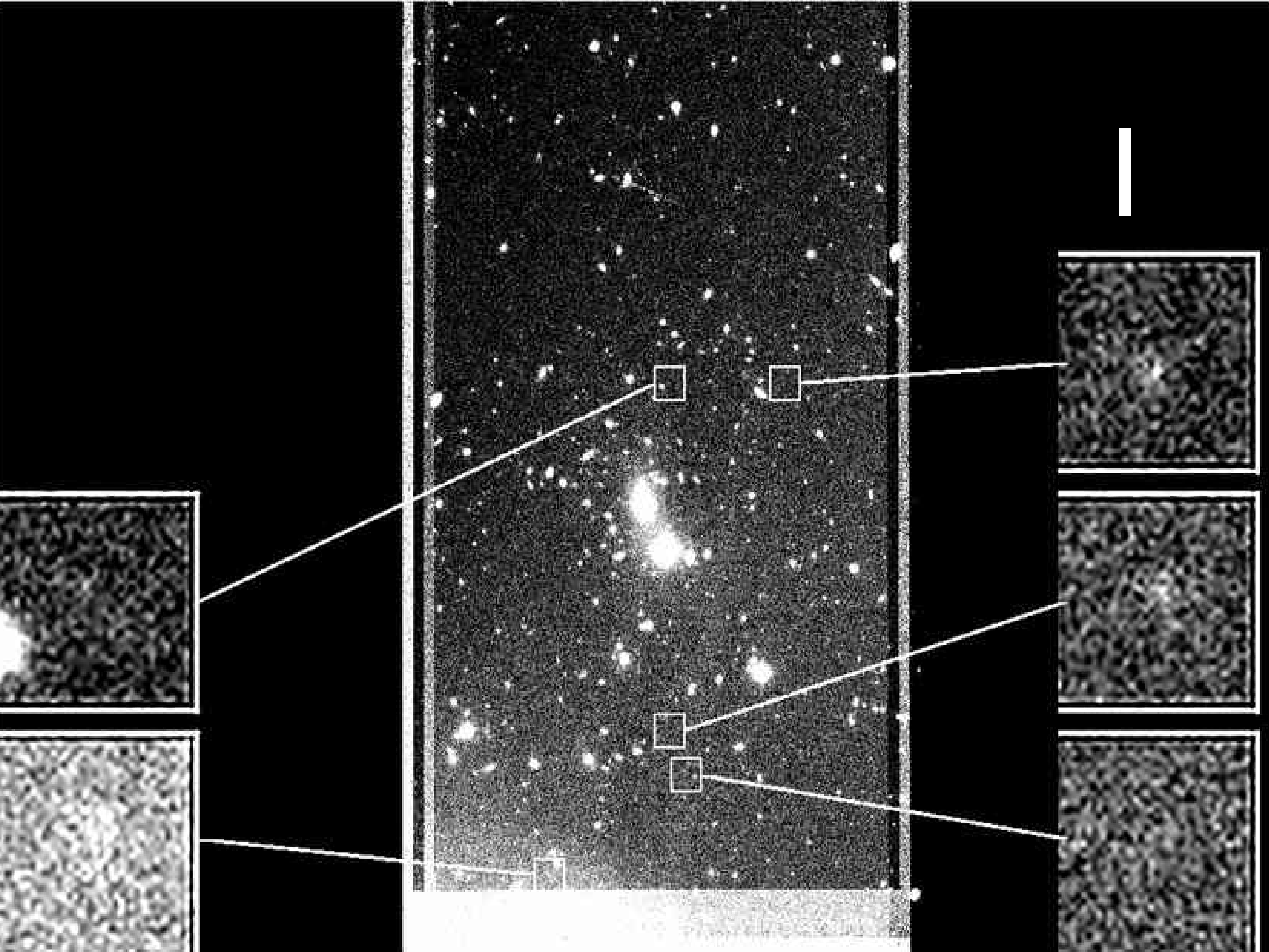

H

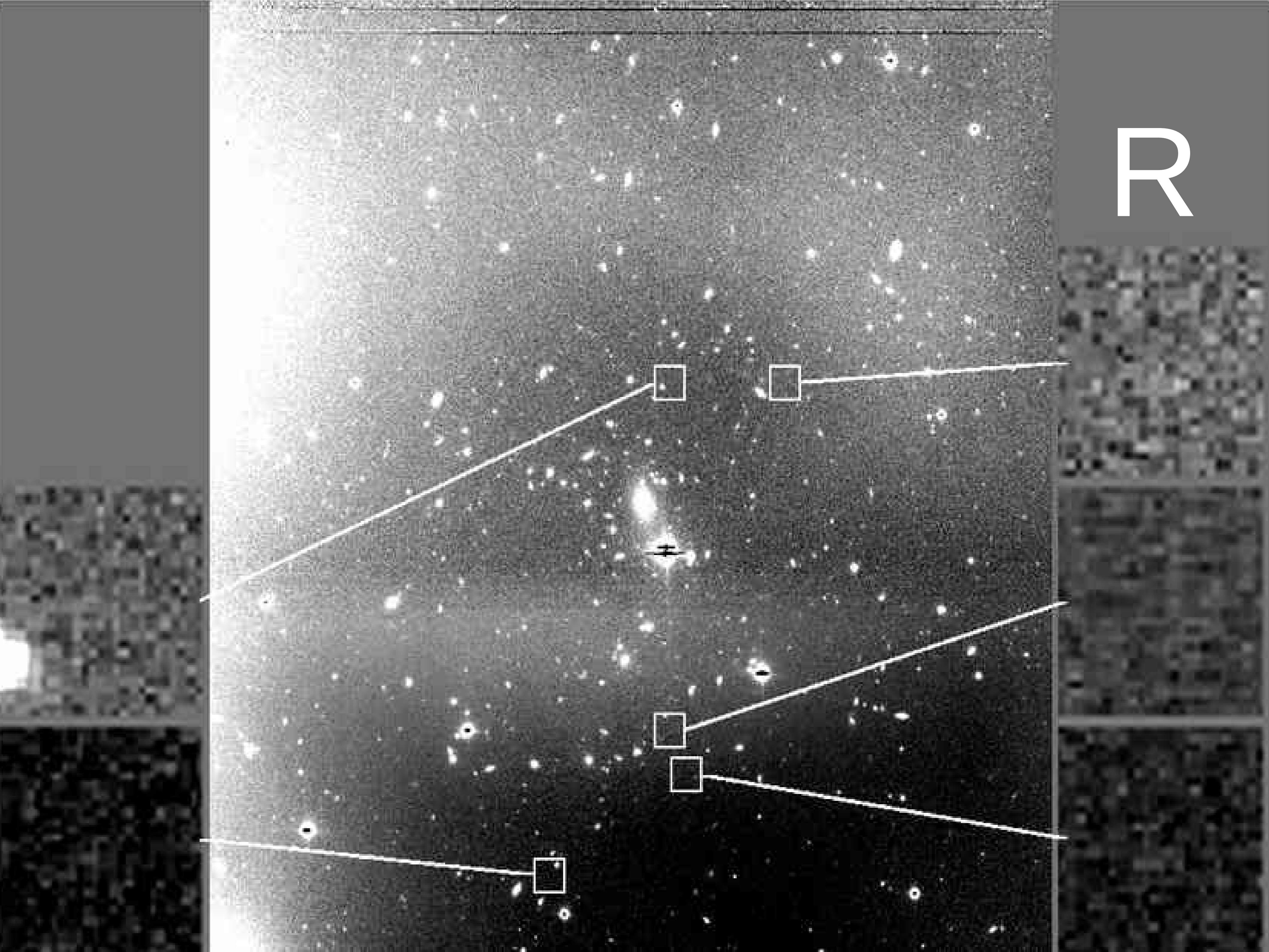


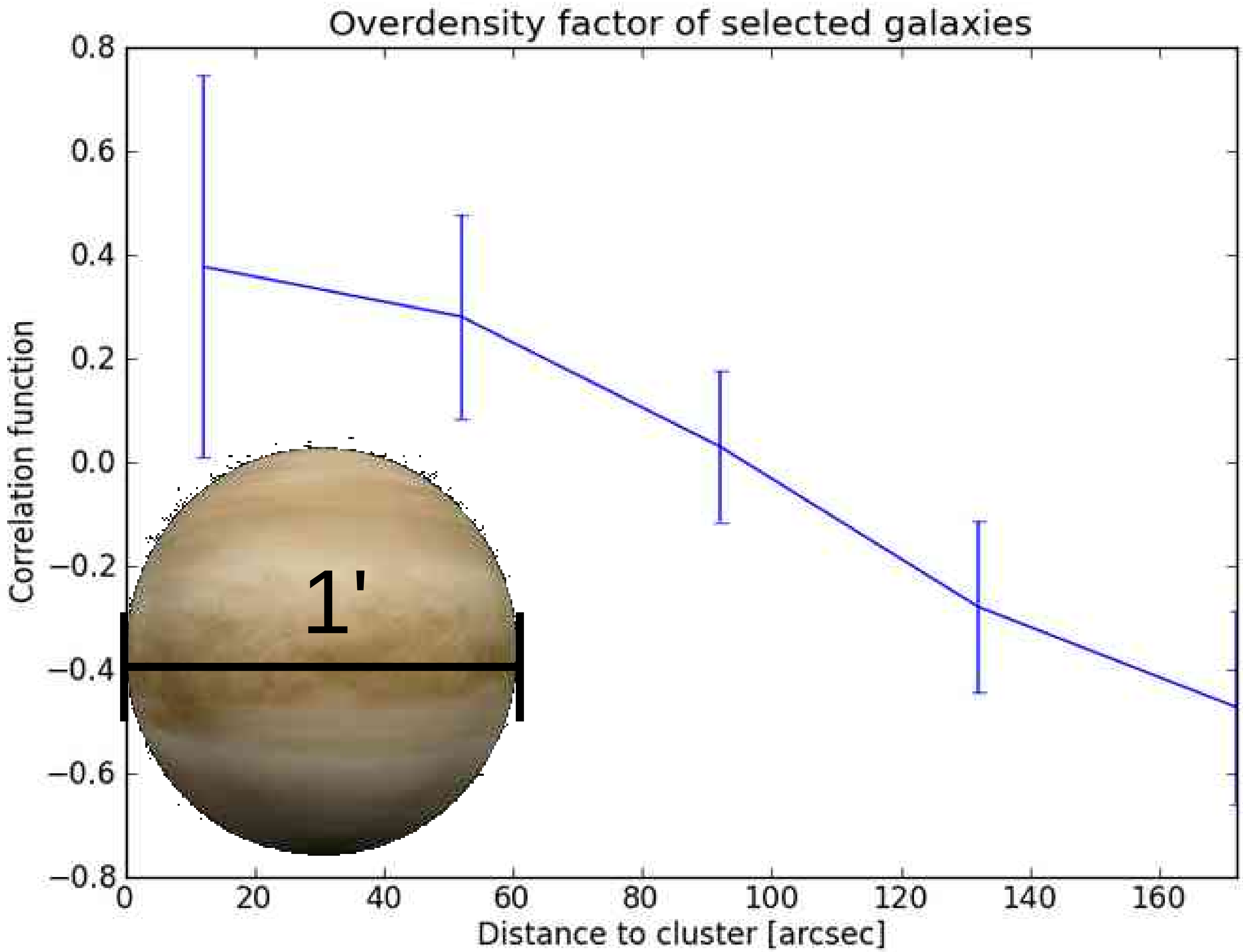

R


H,I,R


H



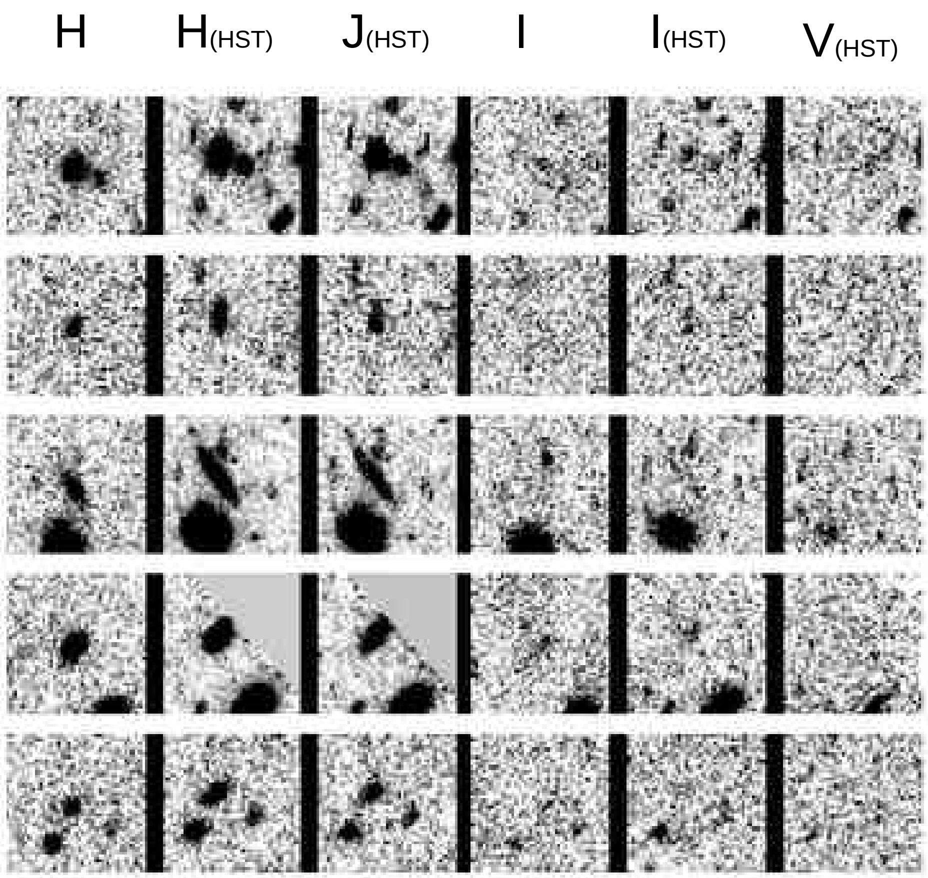

R

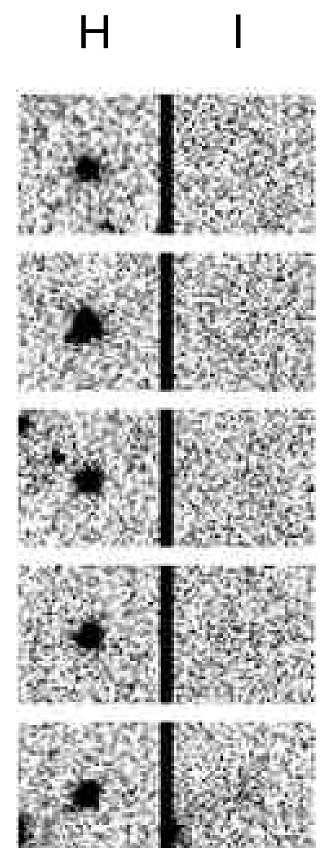


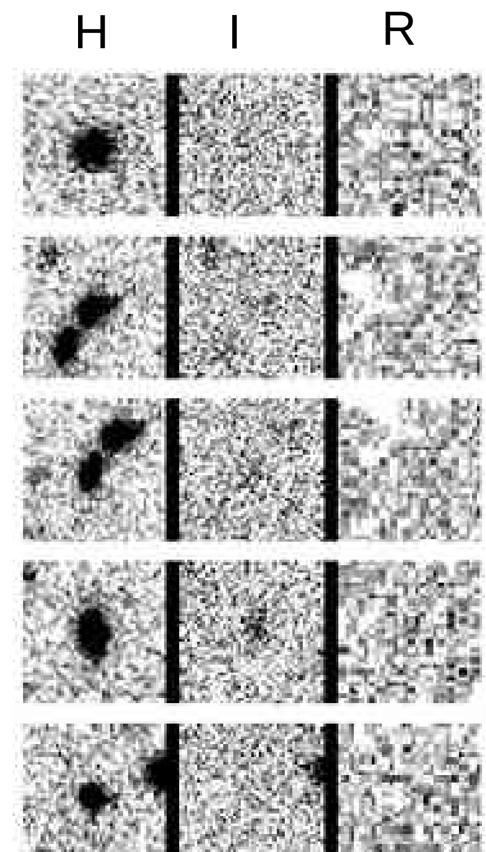
Overdensity factor of selected galaxies
Correlation function
Distance to cluster [arcsec]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
20
40
60
80
100
120
140
160
1'

Chapter III (IR reduction) Conclusion

- Sky subtraction + non-linear correction.
- I Selected 140 red galaxies likely to be i-dropouts with 2 or 3 filters (or 6).







The last slide.

WE SAW

- → The IGM works like a filter, clusters like a lens.
  This permits high redshift studies
- → The color selection to make is I-H >2.5 to get z=6 galaxies
  (i-band dropouts)
- → IR reduction includes non-linear correction
  and careful sky subtraction

WE CONCLUDE

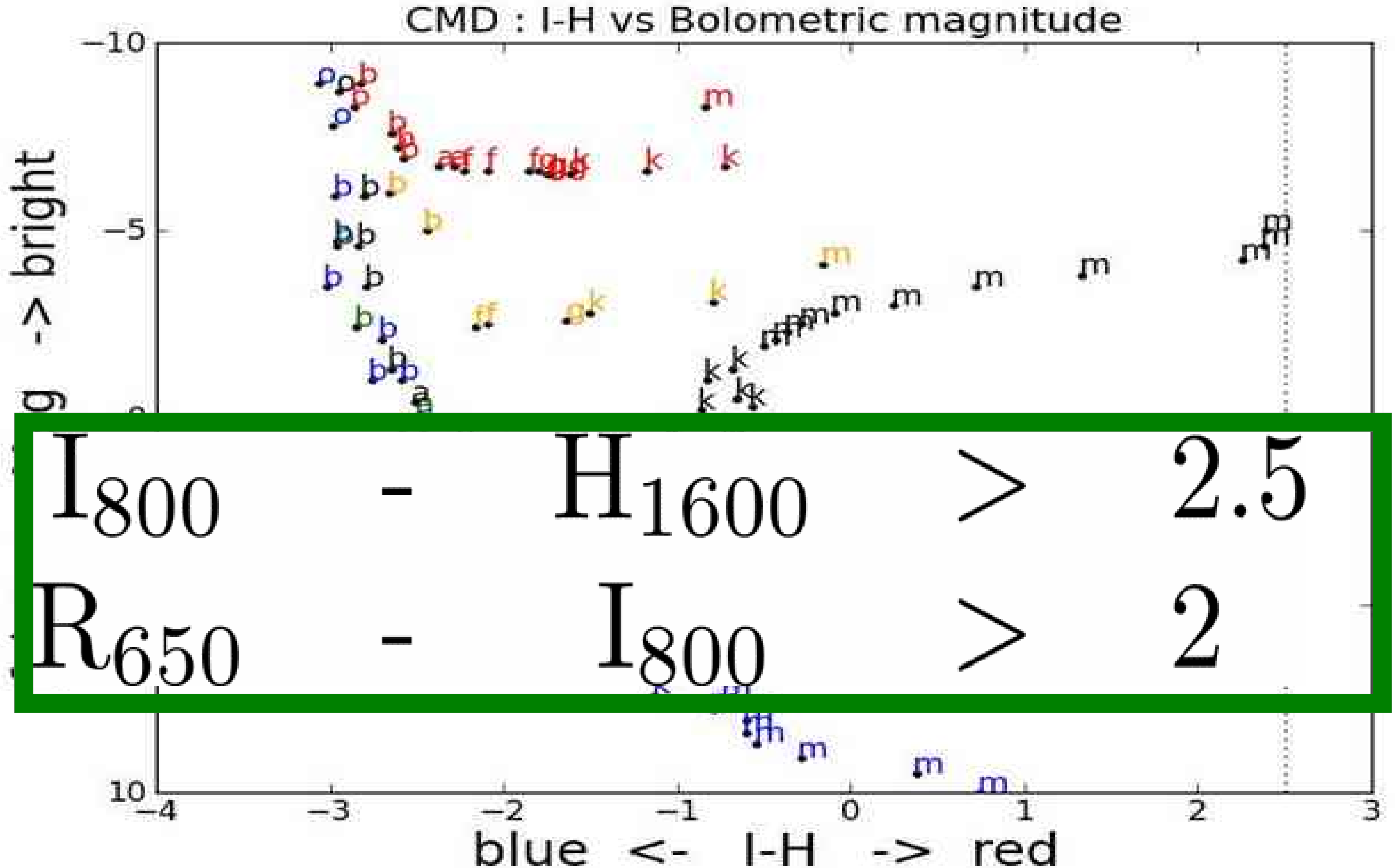
- → Contaminants may be modeled.
- → 140 candidates selected
  Supposed to be at z>6
- → i-dropouts: are correlated with foreground
  galaxy clusters

FUTURE WORK

- → Spectroscopy: analyze the candidates,
  Photo-z and high resolution
- → Test fields, study the density of i-dropouts
  without gravitational magnification
- → More accurate estimation
  of source luminosity

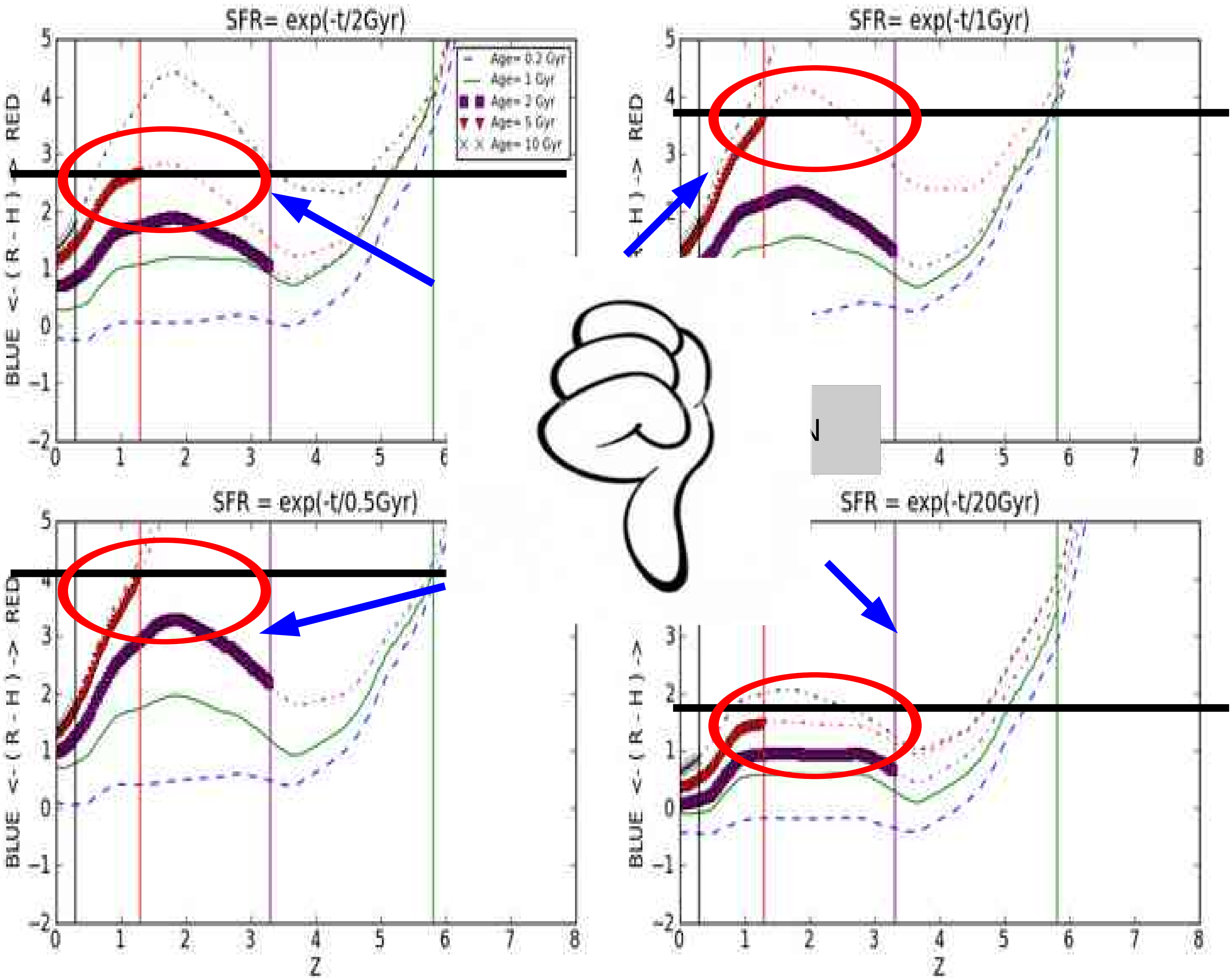
QUESTIONS ?

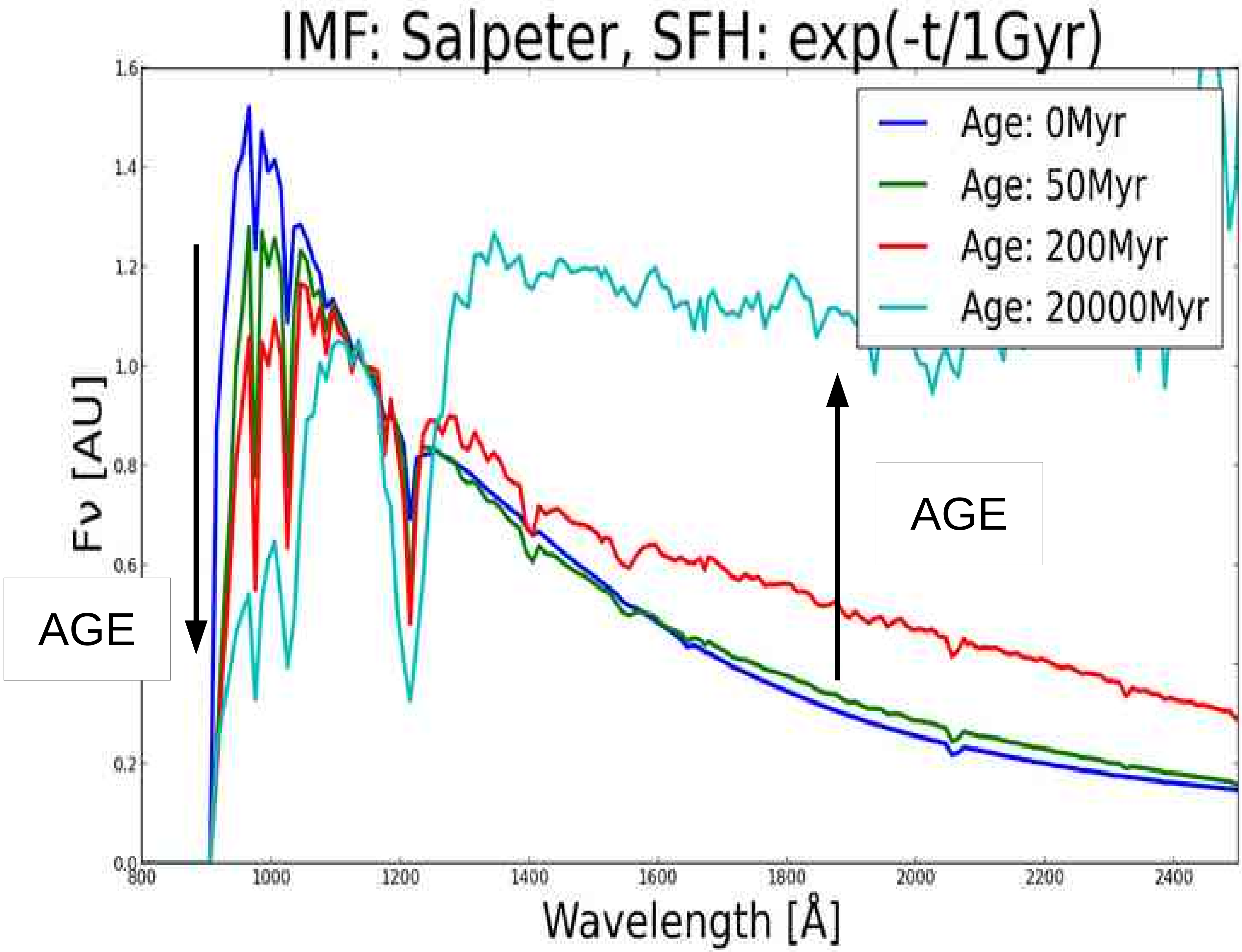
STARS



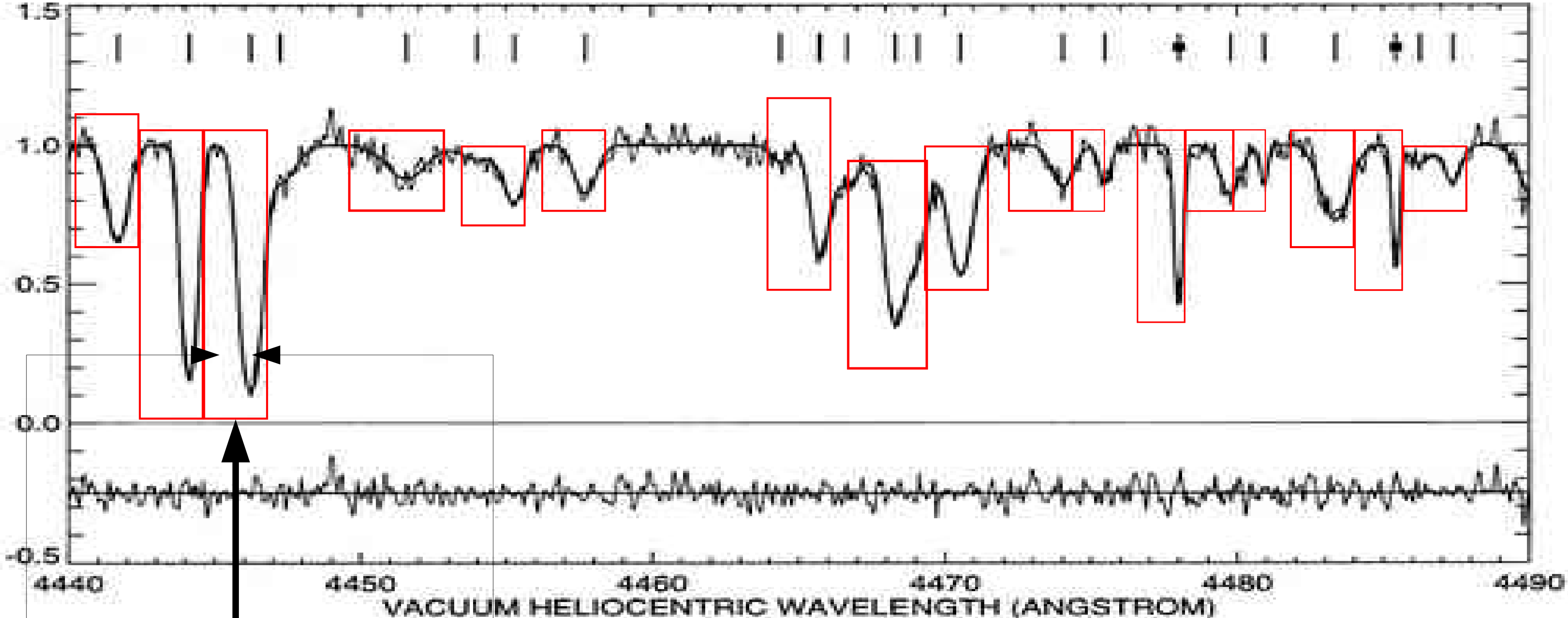
$$I_{800} - H_{1600} > 2.5$$

$$R_{650} - I_{800} > 2$$


SFR= exp(-t/2Gyr)
SFR= exp(-t/1Gyr)
SFR = exp(-t/0.5Gyr)
SFR = exp(-t/20Gyr)
Age= 0.2 Gyr
Age= 1 Gyr
Age= 2 Gyr
Age= 5 Gyr
Age= 10 Gyr
BLUE <- (R - H) -> RED
Z

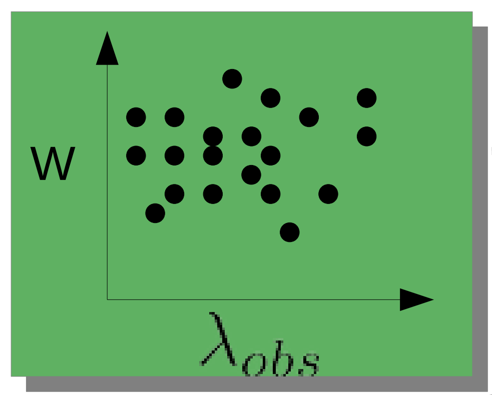


IMF: Salpeter, SFH: exp(-t/1Gyr)
Age: 0Myr
Age: 50Myr
Age: 200Myr
Age: 20000Myr
AGE
AGE
Fν [AU]
Wavelength [Å]
0.0
0.2
0.6
0.8
1.0
1.2
1.4
1.6
800
1000
1200
1400
1600
1800
2000
2200
2400

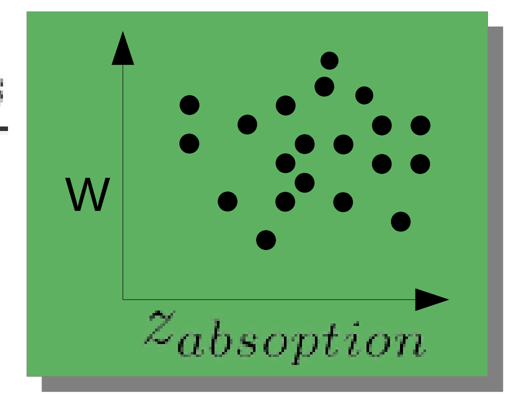


$$\lambda_{obs} = 4446\mathring{A}$$

$$W = 0.7\mathring{A}$$



$$z_{abs} + 1 = \frac{\lambda_{obs}}{\lambda_\alpha}$$



Number of clouds

Normalization

Size of the cloud

$$\tau_{\lambda_\alpha} = \boxed{\frac{\lambda_{obs}}{\lambda_\alpha^2}} \int \boxed{\frac{\partial^2 N}{\partial W \partial z}} \boxed{W} dW$$

$$W_\lambda = \frac{\lambda_\alpha^2}{c}\int_0^\infty \left(1 - e^{-\sigma N_{HI}}\right)$$