Galaxy Evolution: computational challenges

Unveiling the power of the deepest images of the Universe

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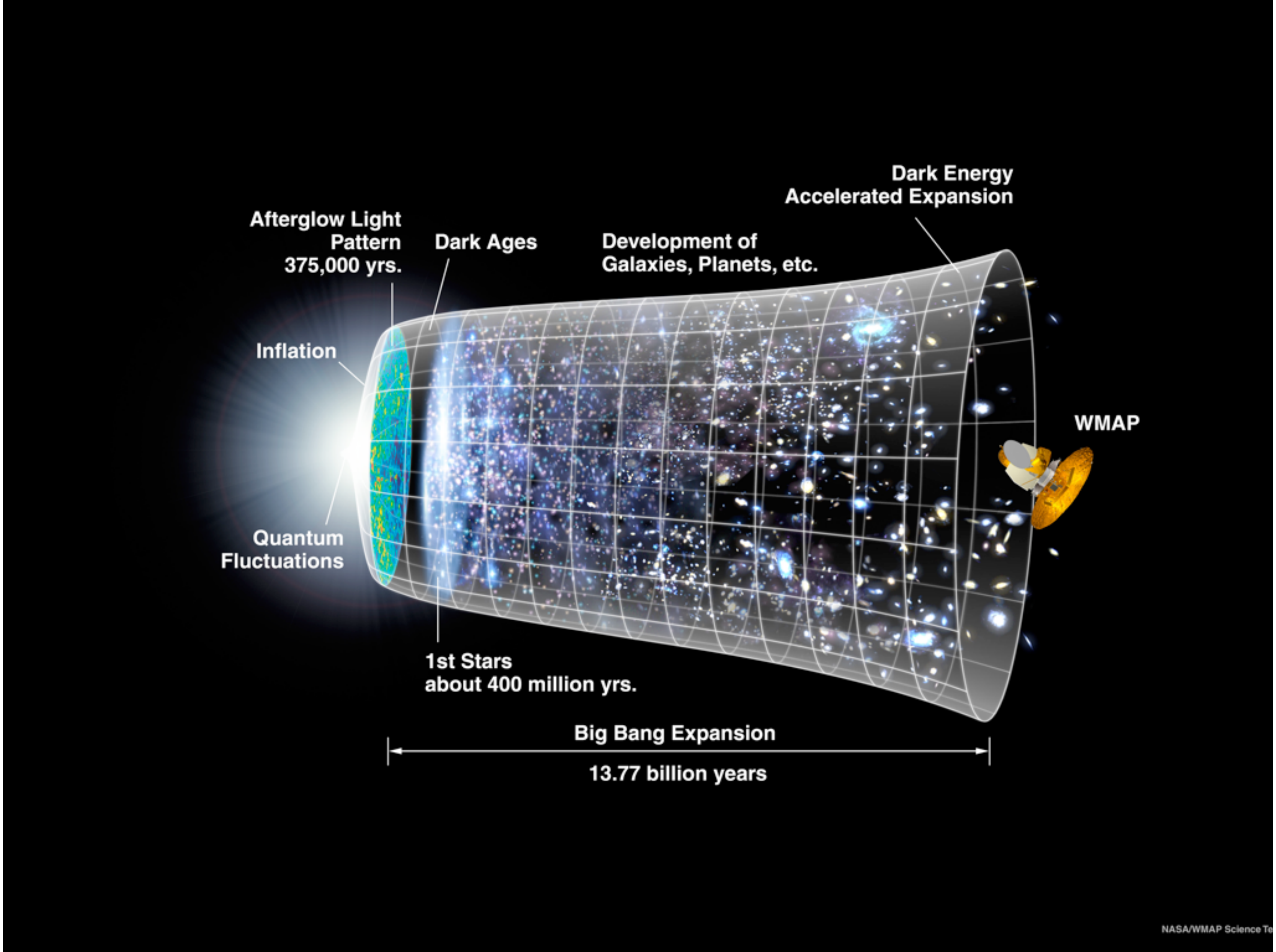

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years
NASA/WMAP Science Te

Scientific aim: to study the birth and early phase of galaxy evolution.

- When did first stars and galaxies appear?
- How did galaxies build up and assembled?
- Which are the main physical processes involved?

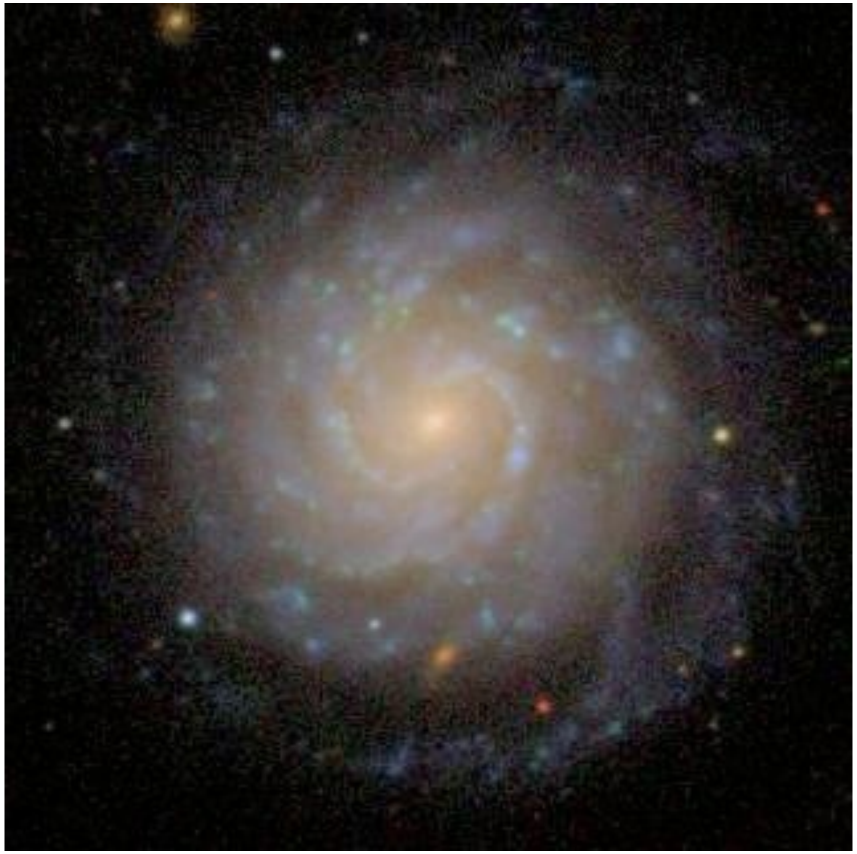
Telescopes are “time machines”

1M.light-year

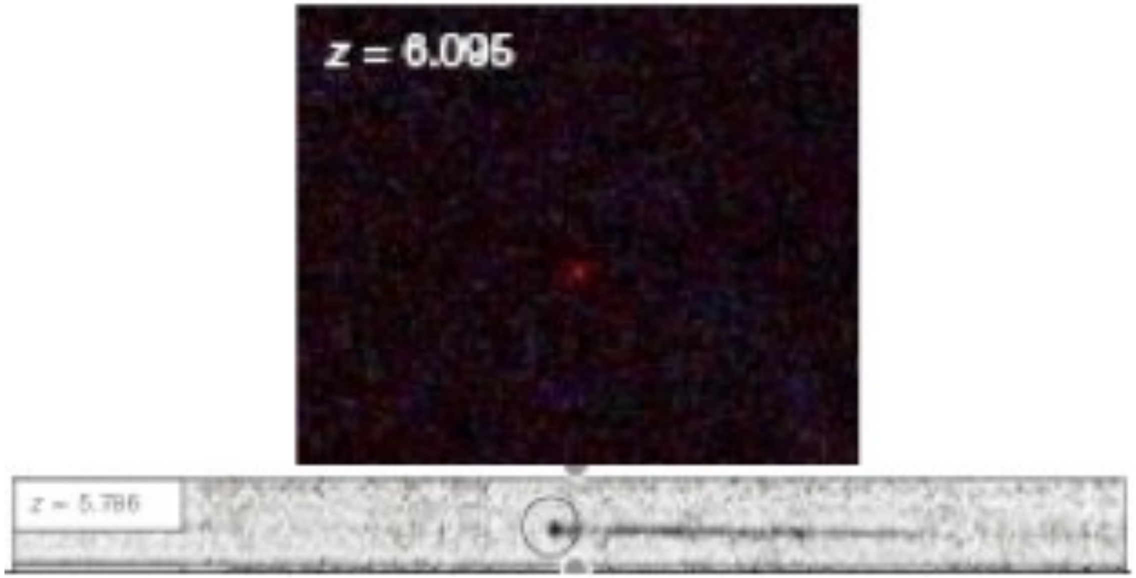
10G light years

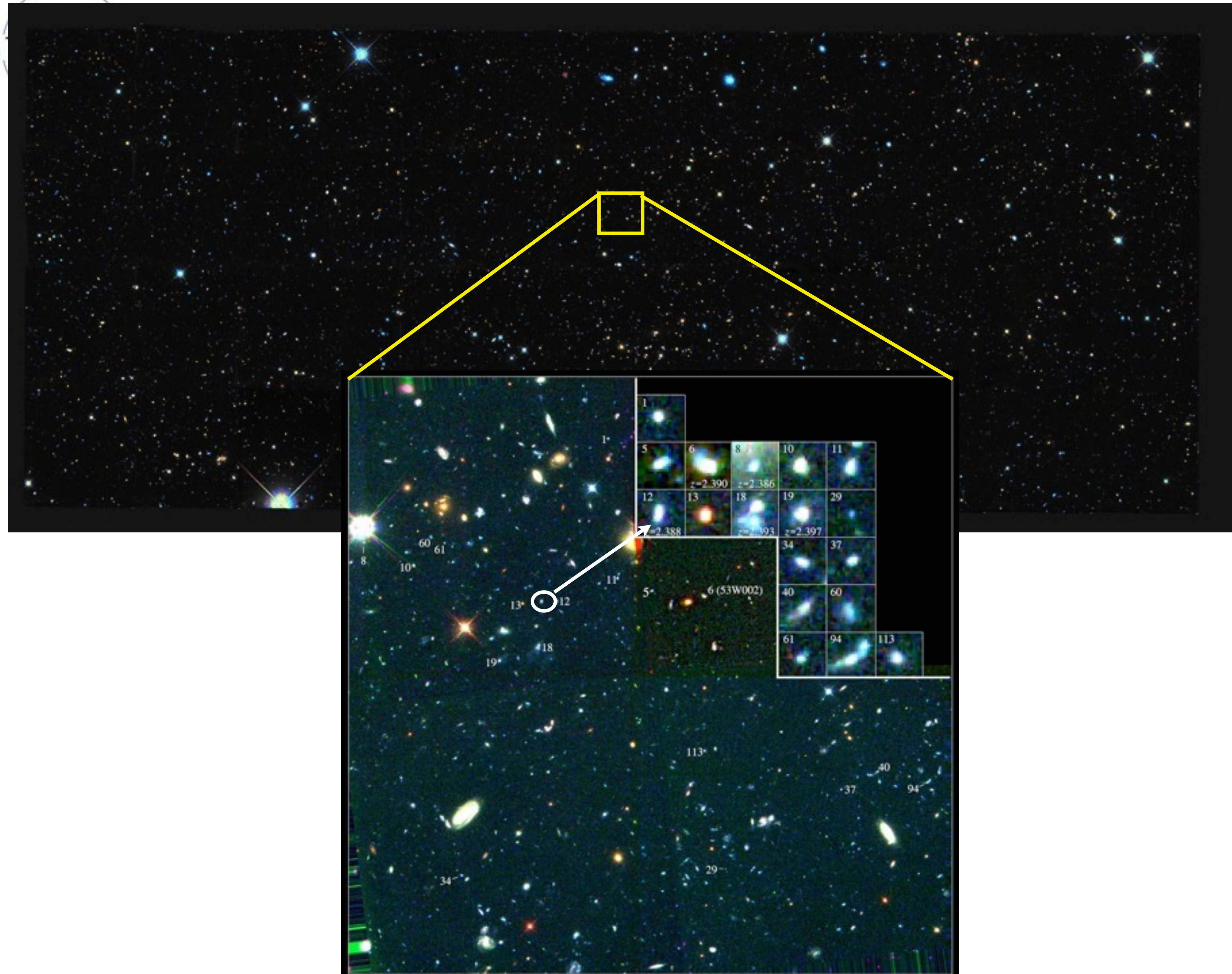
Today we can observe the Universe as it was ~13 Gyrs ago

A galaxy in the local, "old" Universe

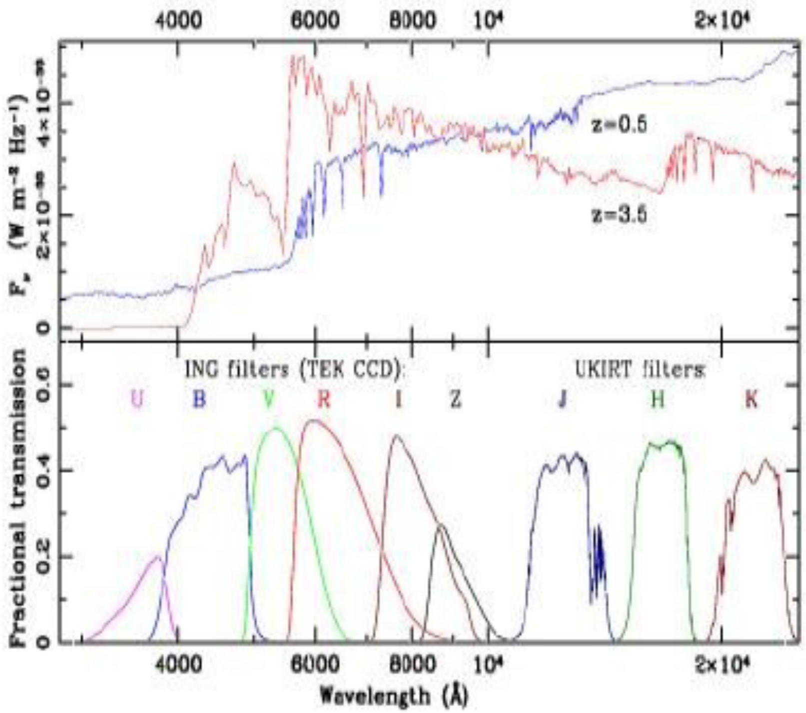


A galaxy in the high redshift, "young" Universe



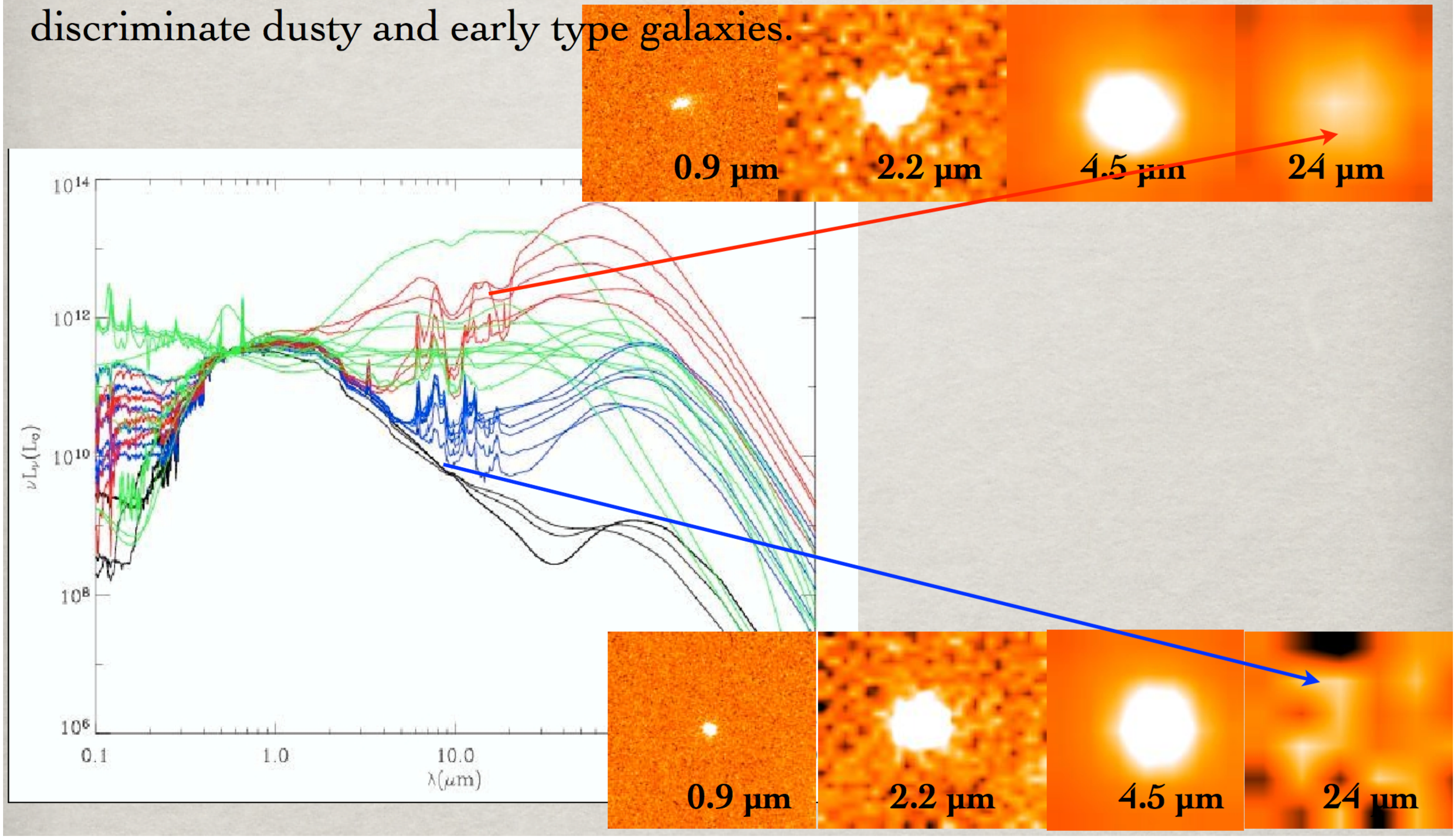


R. Windhorst (Arizona State University) and NASA



4000
6000
8000
10^4
2×10^4
F_ν (W m^{-2} Hz^{-1})
0
2×10^{-33}
4×10^{-33}
z=0.5
z=3.5
ING filters (TEK CCD):
UKIRT filters:
U
B
V
R
I
Z
J
H
K
Fractional transmission
0
0.2
0.4
0.6
Wavelength (Å)

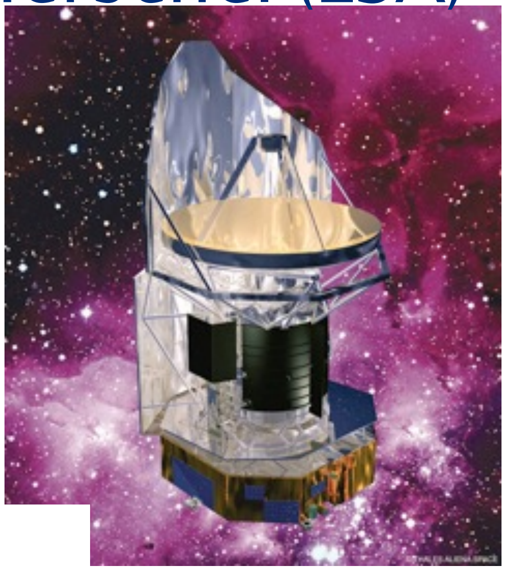
MIPS imaging at 24μm with Spitzer Space Telescope as a tool to discriminate dusty and early type galaxies.



Methodology: concentrate all the major telescope from space and ground on few selected regions of the sky and observe as long (=as far) as possible

Spitzer (NASA)

Herschel (ESA)



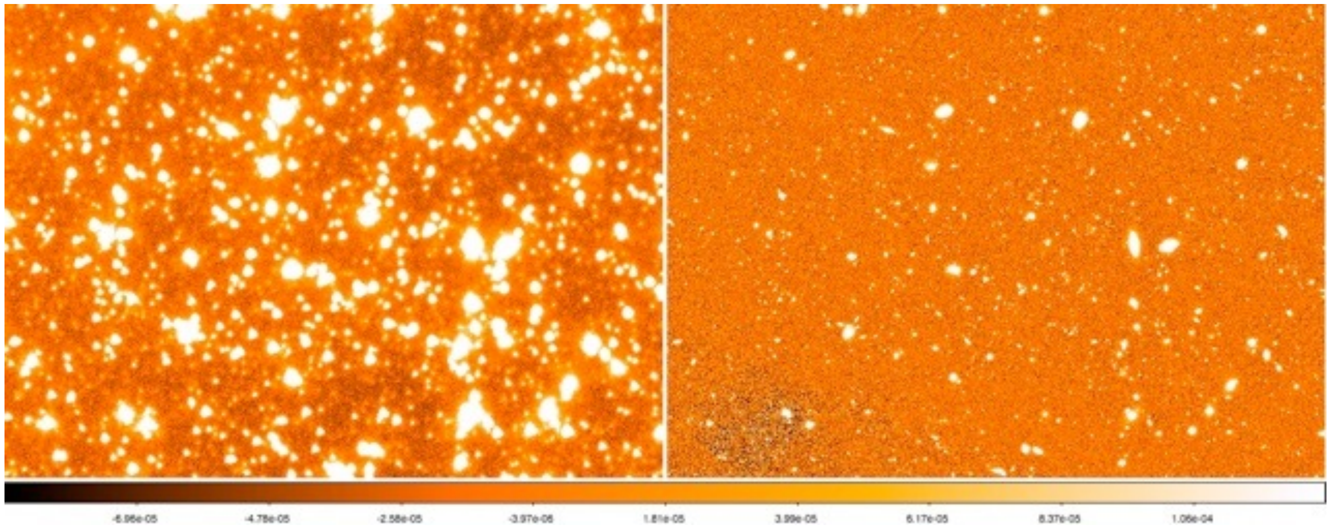
Hubble Space Telescope (NASA+E

XMM (ESA)

VLT (ESO)

The investments in telescope times are huge (each observation 100-1000 hours of telescope time). Equivalent cost of telescope time only: several M€

These efforts are beyond the capacity of any single groups: PUBLIC SURVEYS
-> All data are “immediately” public



Public surveys delivers processed “clean” images that are not yet usable for science.
Need to be translated into catalogs.
This task:

- is time consuming / expensive: a bottleneck that hampers full scientific exploitation of the data;
- is still subject to considerable uncertainties: it presents conceptual challenges that need to be addressed

INAF-OAR is a leader in the exploitation of the deepest multi-frequency data.

1. Develop and fully validate new tools for data analysis of ultradeep surveys;
2. Analyze all the data from public surveys in a coherent and well characterized way;
3. To deliver the final catalogs to the worldwide community;
4. To use these data to address some of the hottest question about early galaxy evolution;
5. To establish the know-how for the future space missions, most notably EUCLID.

ASTRODEEP
Making Europe the world leader in the exploitation of the deepest multi-frequency data.

FP7 SPACE Program
4yr Program
European Coordinator: Adriano Fontana

INAF-OAR
University of Edinburgh
CEA (Paris)
CDS (Strasburg)

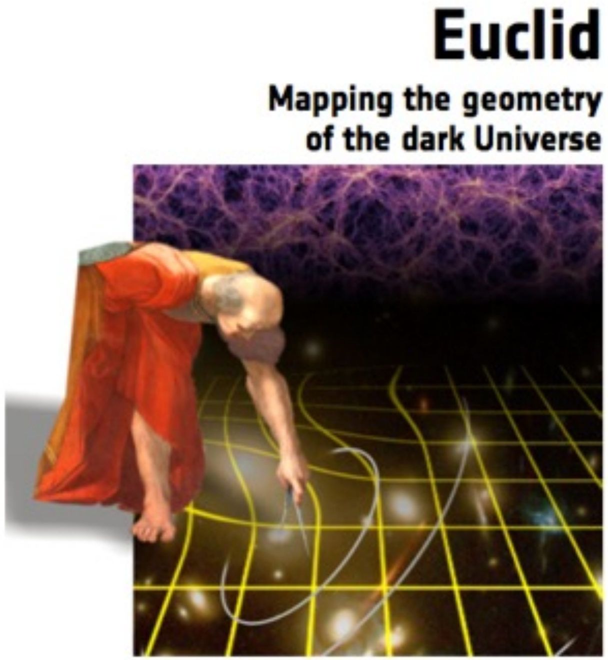
+ Dip. Matematica
Univ. la Sapienza (M. Falcone)

5 To establish the know-how for the future space missions, most notably EUCLID.

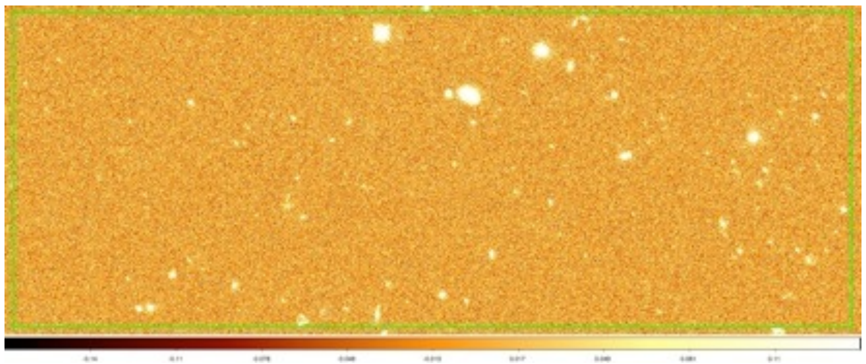
Euclid is the next ESA space mission.
It will survey half of the sky to investigate the nature of dark matter and dark energy.

Its deep observations are a 10000x scaled version of the ASTRODEEP data.

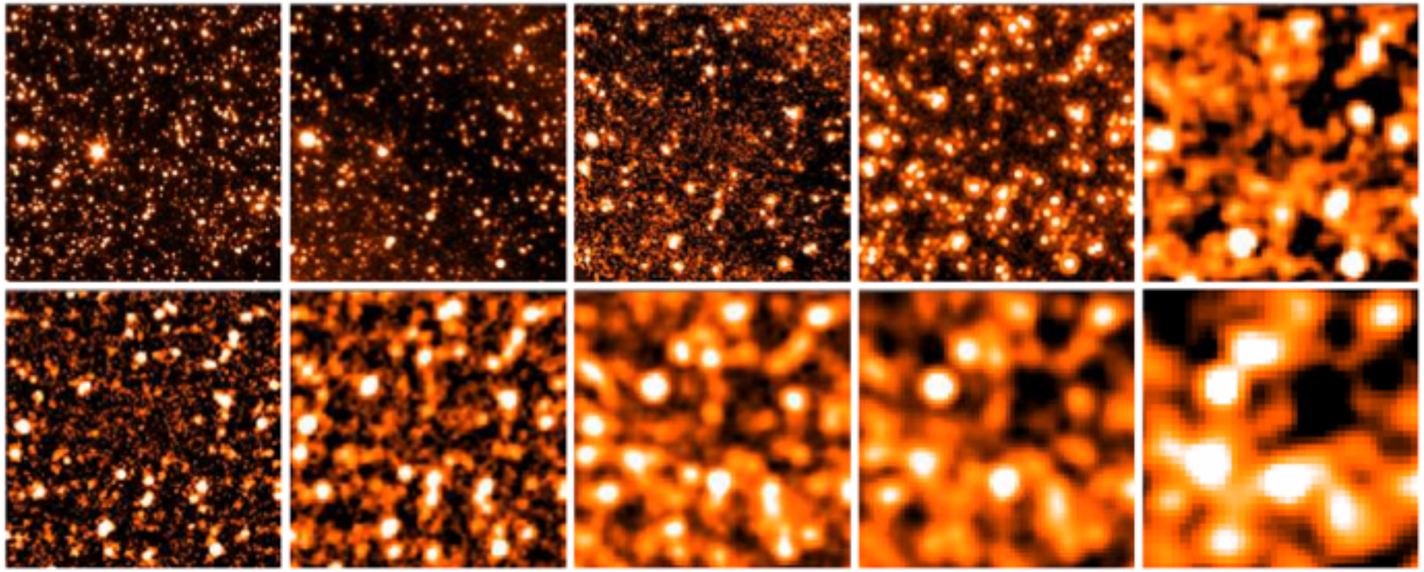
Our goal is to use the ASTRODEEP data to simulate the Euclid deep surveys and to test our analysis software on the huge dataset expected from Euclid



OAR is leader of 2 (out of 9) units for the development of the Euclid Software:
OU-NIR (A. Grazian)
OU-MER (A. Fontana)

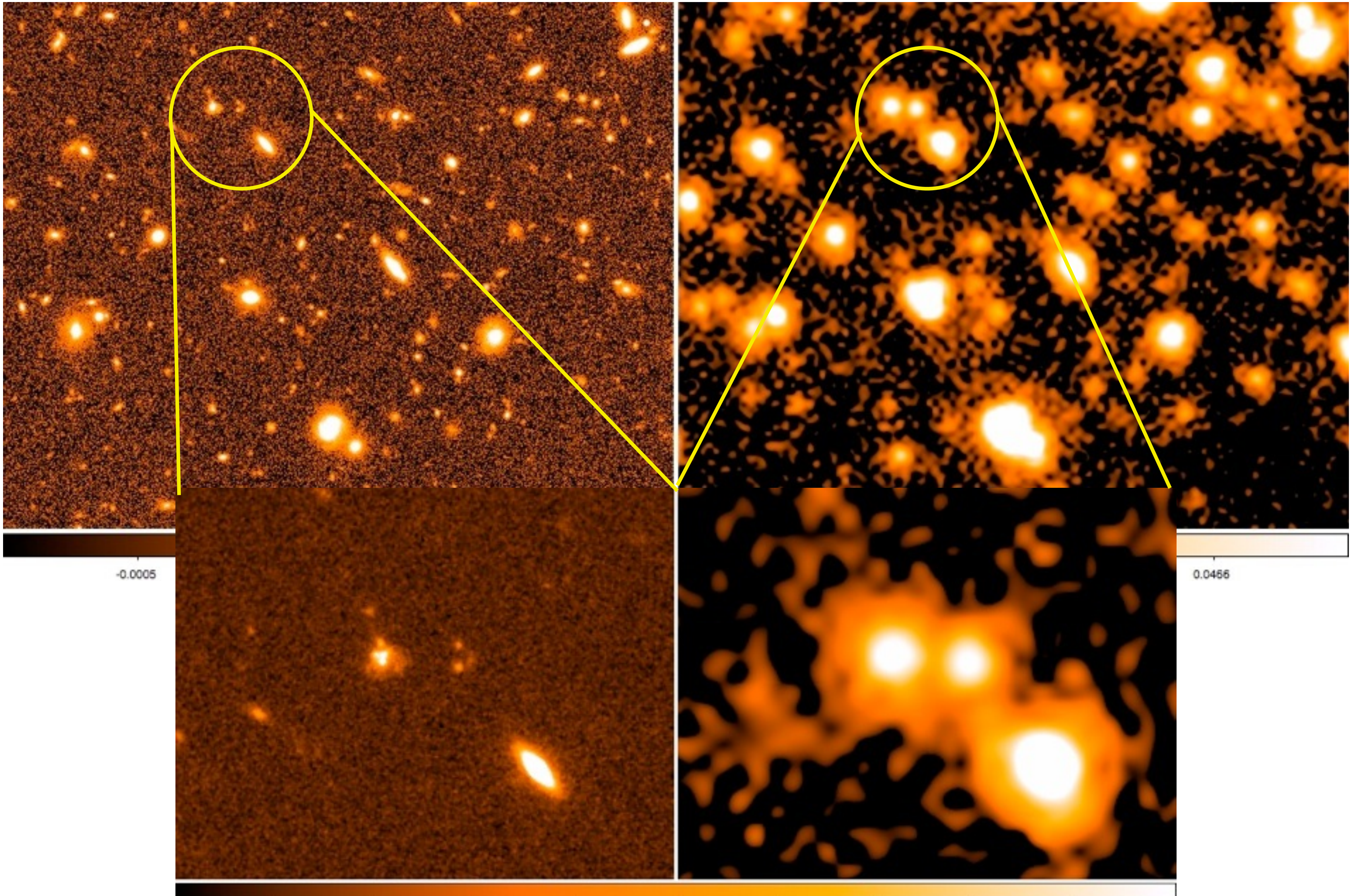


1 Develop and fully validate new tools for data analysis of ultradeep surveys;



The key unresolved problem is how to cope with the different resolution and depth of the various datasets.
Several solutions have been proposed but never fully explored and characterized.

One of the ASTRODEEP goal is to fully characterize the different approaches and to develop state-of-the-art software that implements them.
Deliverables:
- Scientific publications
- Software will be publicly distributed.



-0.0005
0.0466

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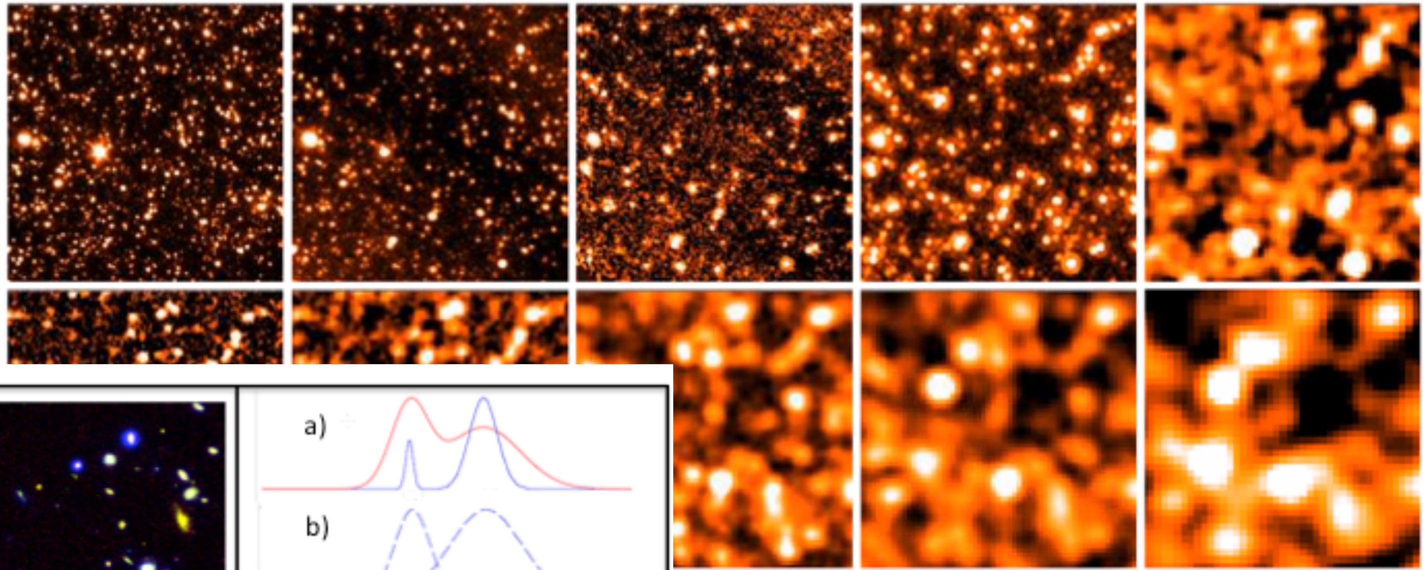

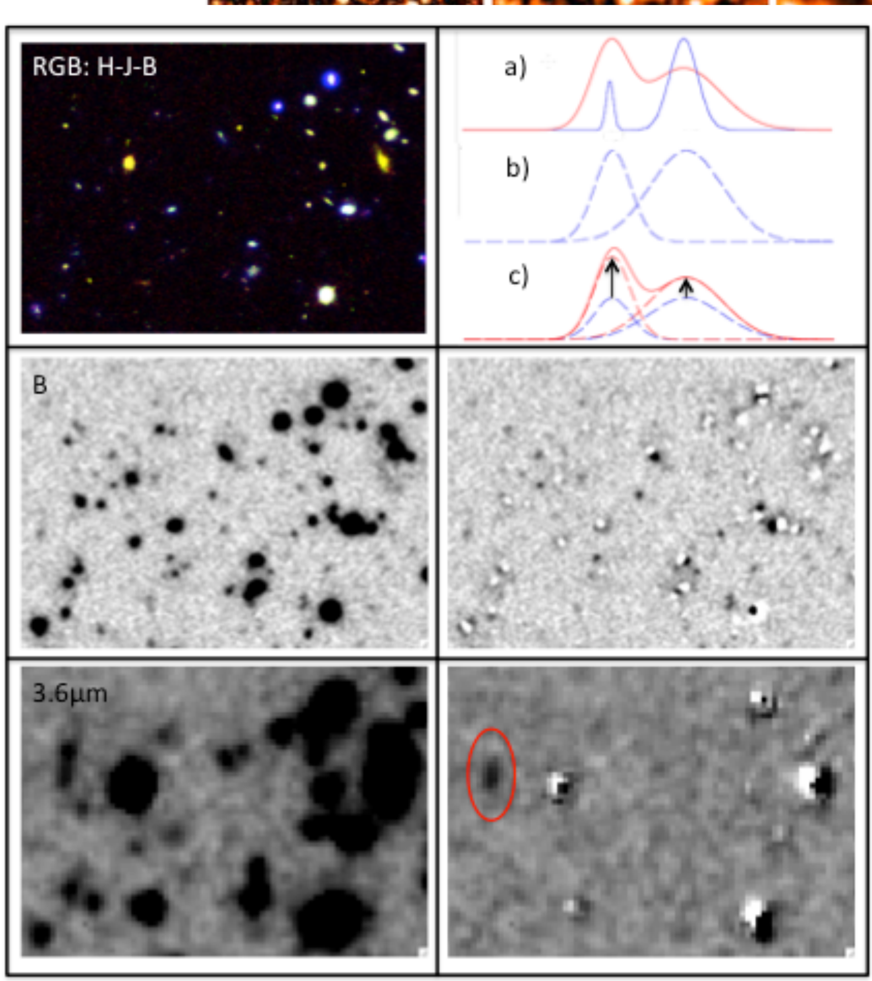

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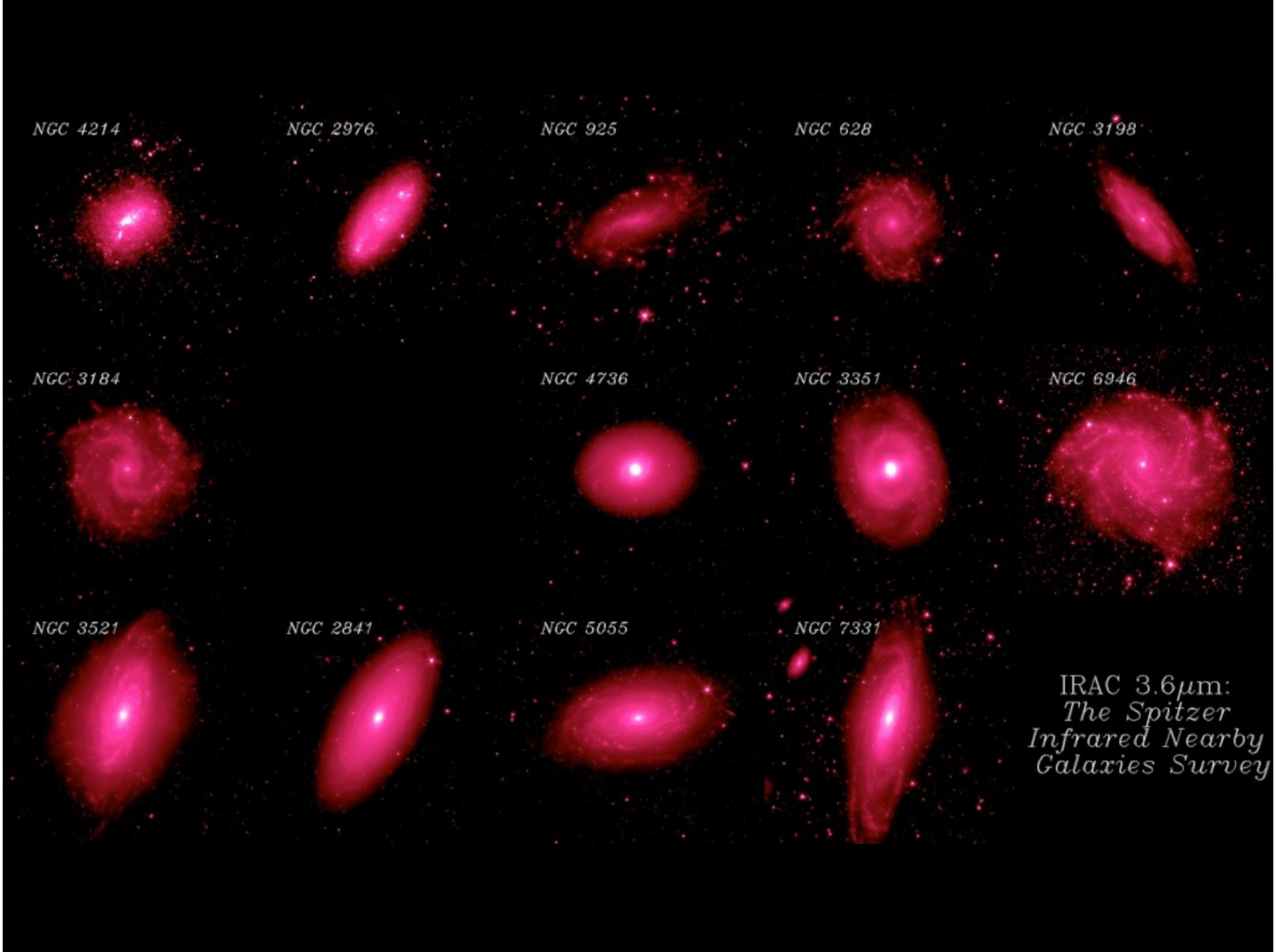
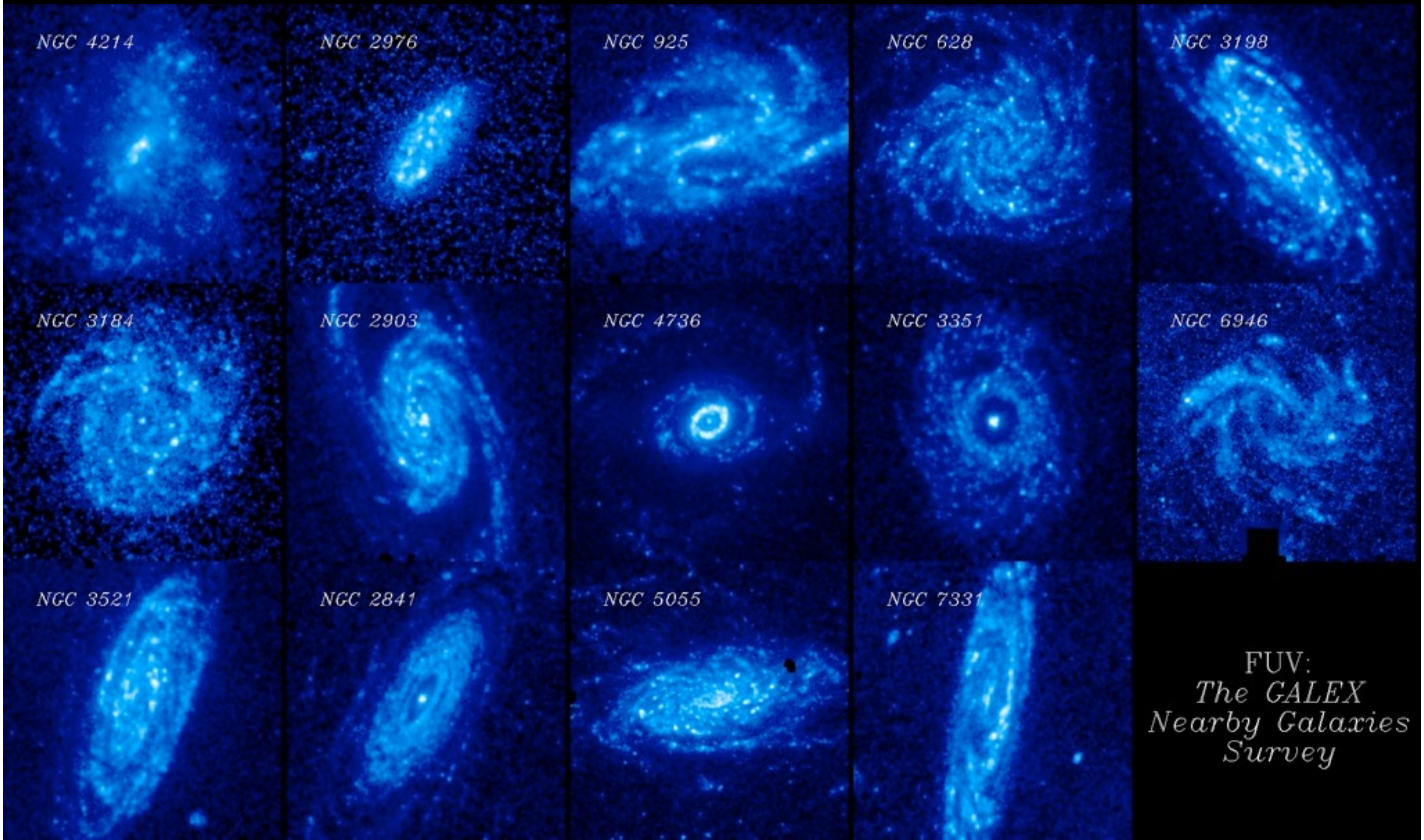

NGC 4214
NGC 2976
NGC 925
NGC 628
NGC 3198
NGC 3184
NGC 4736
NGC 3351
NGC 6946
NGC 3521
NGC 2841
NGC 5055
NGC 7331
IRAC 3.6μm:
The Spitzer
Infrared Nearby
Galaxies Survey


NGC 4214
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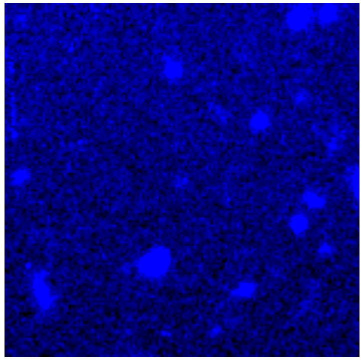
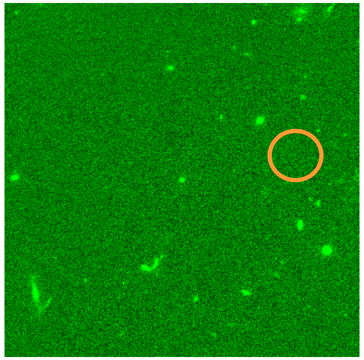
NGC 628
NGC 3198
NGC 3184
NGC 2903
NGC 4736
NGC 3351
NGC 6946
NGC 3521
NGC 2841
NGC 5055
NGC 7331
FUV:
The GALEX
Nearby Galaxies
Survey

The very concept of detection is also poorly defined..

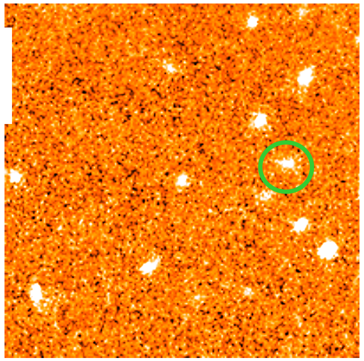
U VIMOS
FWHM 1”

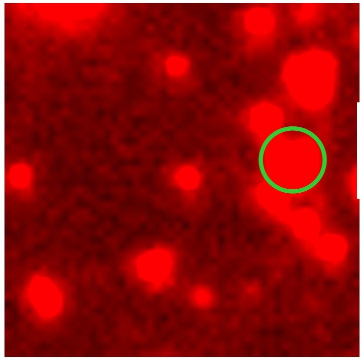




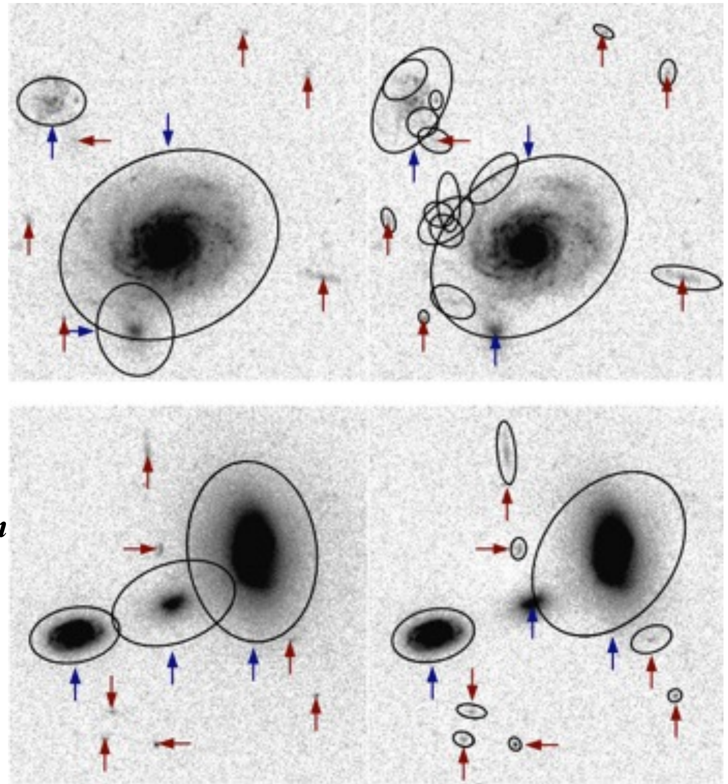
z ACS
FWHM 0.1”

K ISAAC
FWHM 0.5”

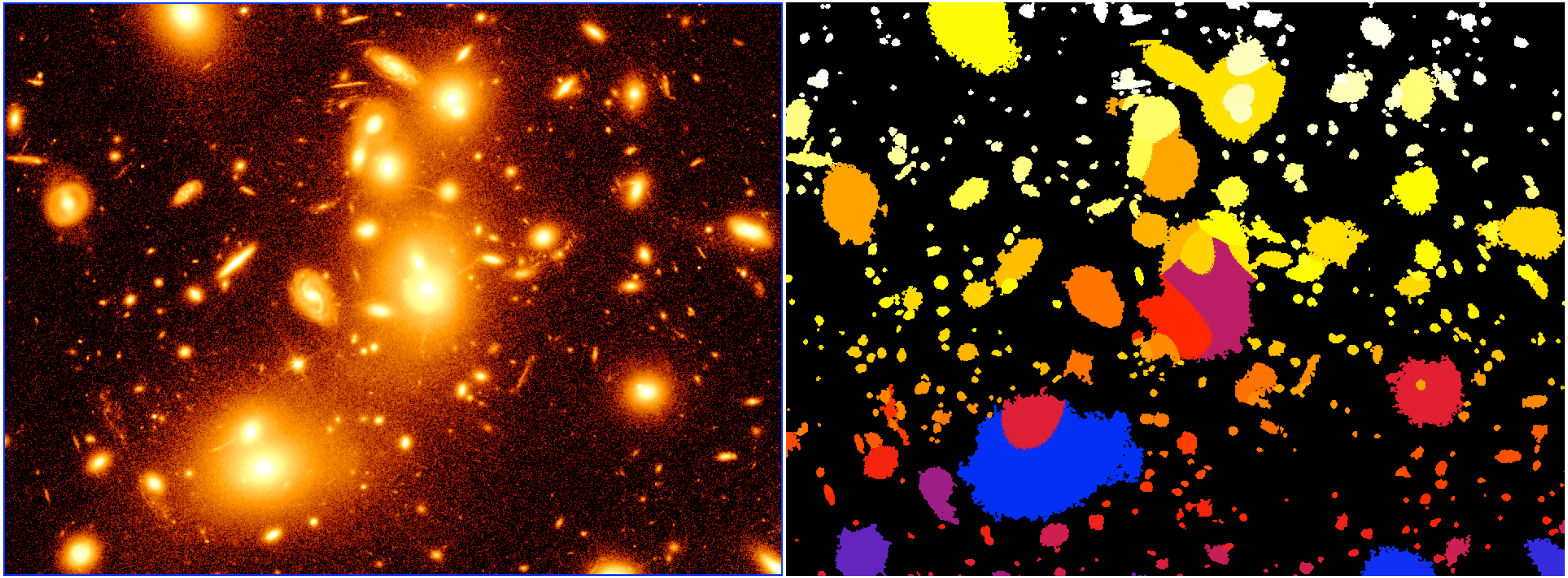




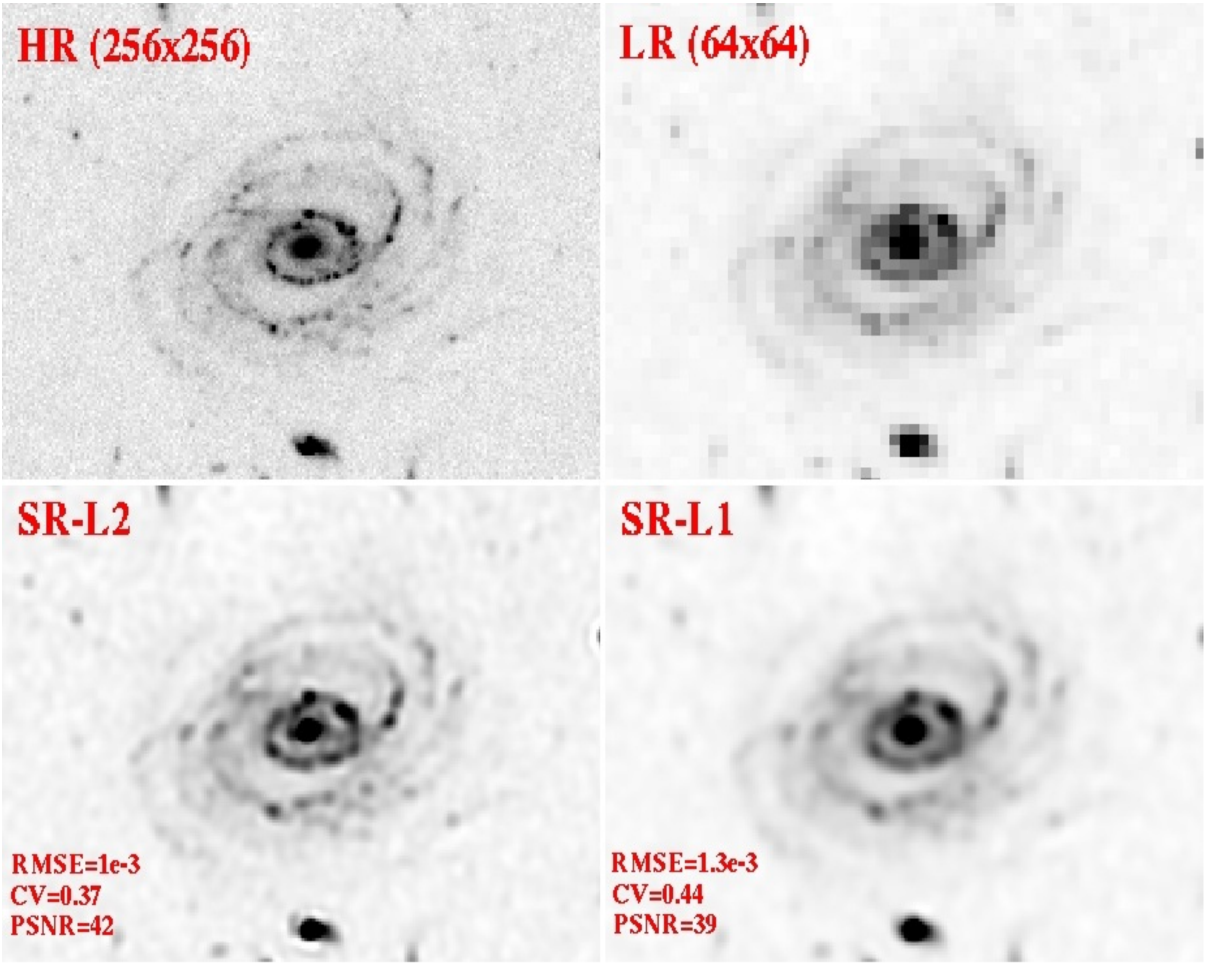
Spitzer – 4.5 μm
FWHM 1.6”



Frontier Fields: Abell 2744



Super-Resolution



Given a set of “LR frames” with sub-pixel shifts between them we can reconstruct an higher resolution image

$$E(\underline{x}_H) = \frac{1}{2}(\|\underline{x}_L - K\underline{x}_H\|_2^2 + \lambda f(\underline{x}_H))$$

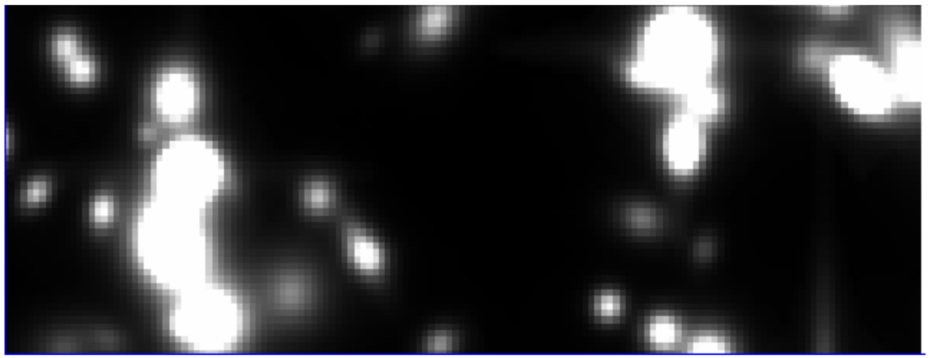
Solution $\boldsymbol{X_H}$ found by minimization of an energy function (requires regularization)

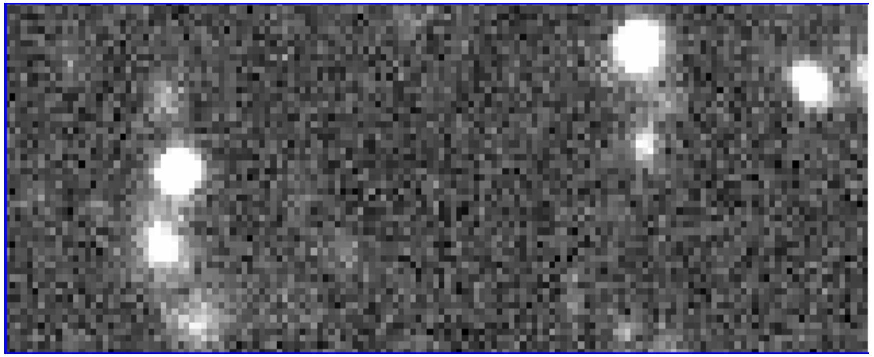
Image Denoising

We can consider an image ***f*** as the sum of a structural part (***u***, with “regular” properties) plus a texture part (***v***, e.g. the “noise”).
It can be shown that the two can be separated by means of “Total Variation” techniques (e.g. Rudin, Osher & Fatemi 1992)

$$\inf_{(u,v)\in BV\times L^2/f=u+v}\left(\int |Du| + \lambda \|v\|_{L^2}^2\right)$$

Reference simulated image w/o noise





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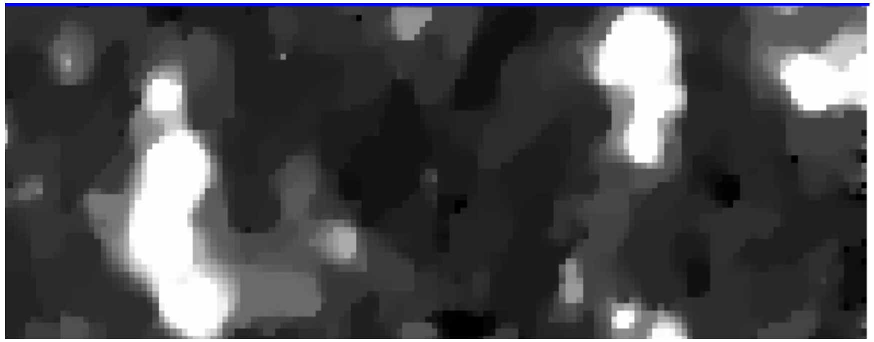

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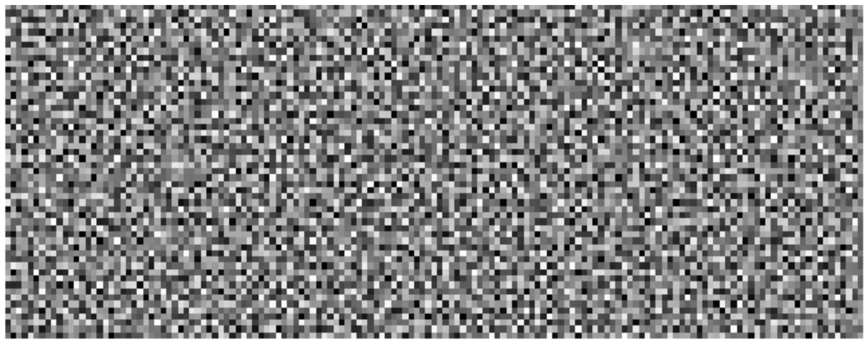
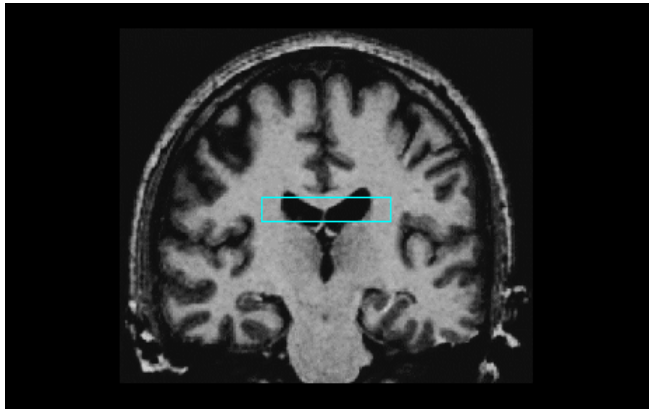
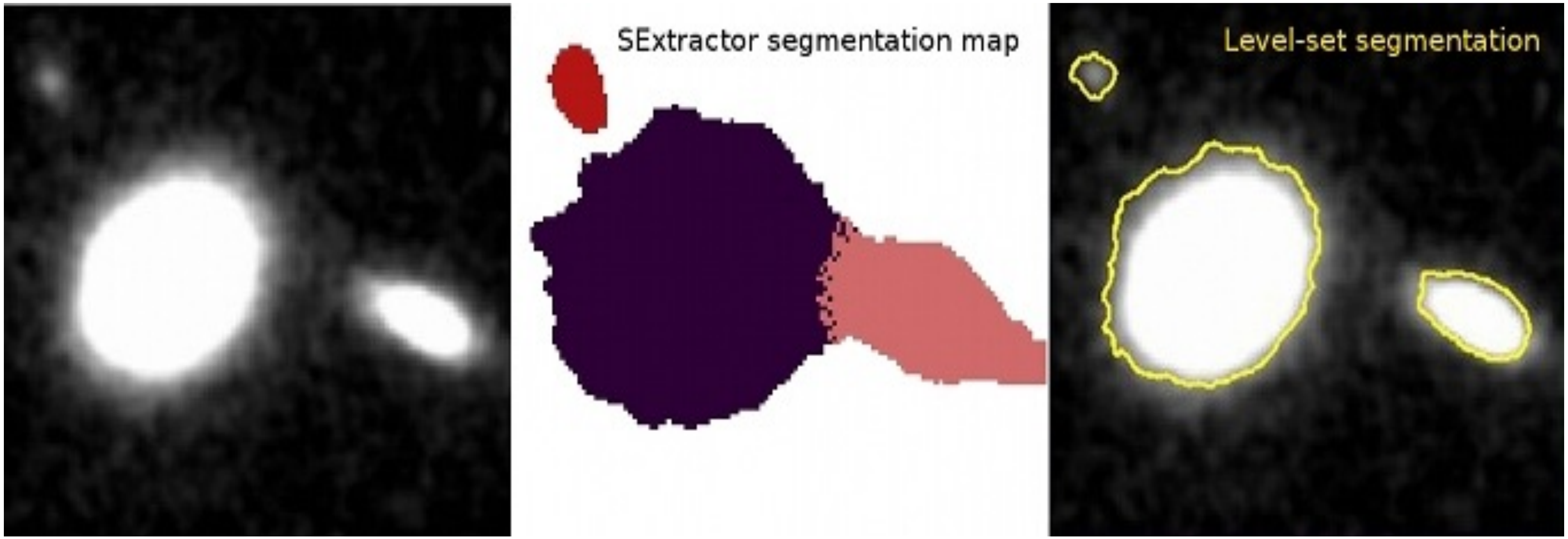


Level-set image segmentation



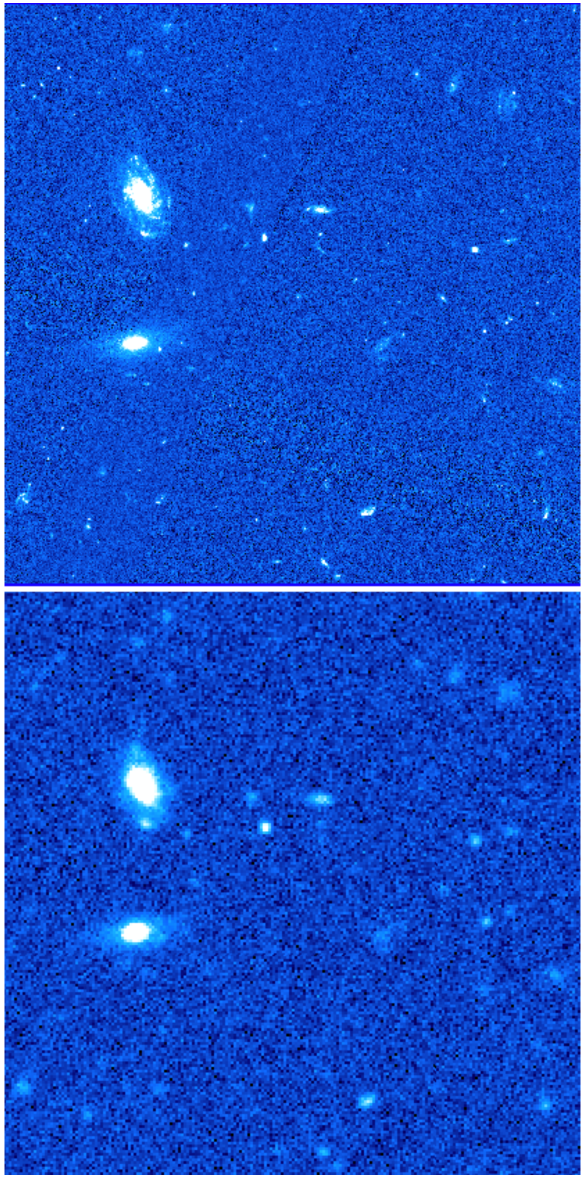
Active contours evolving with velocity proportional to the image gradient in each pixel (e.g. Sethian 1996).

object segmentation through border detection

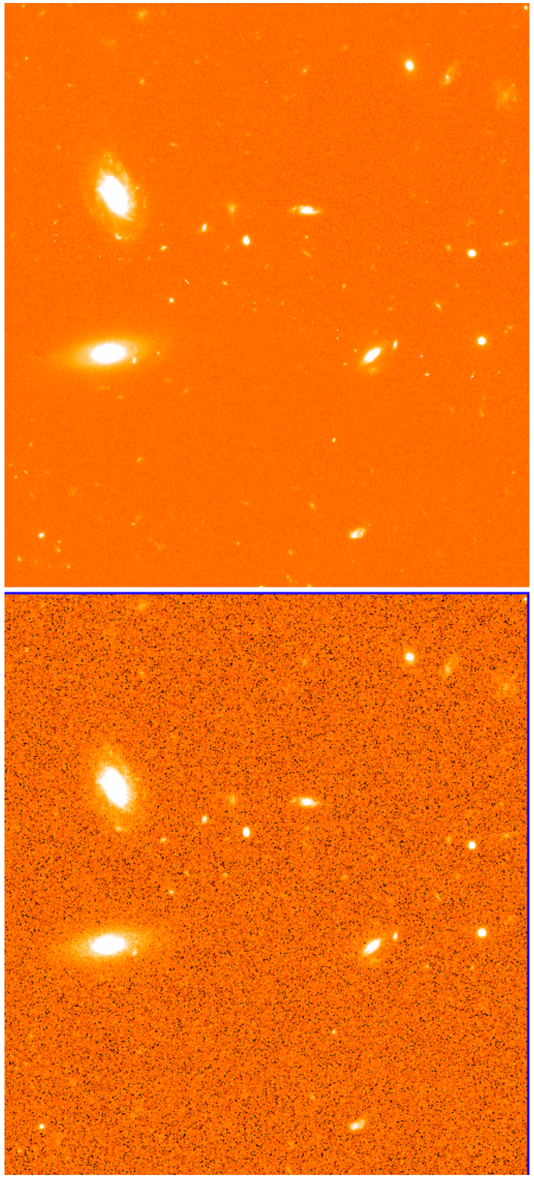


5 To establish the know-how for the future space missions, most notably EUCLID.

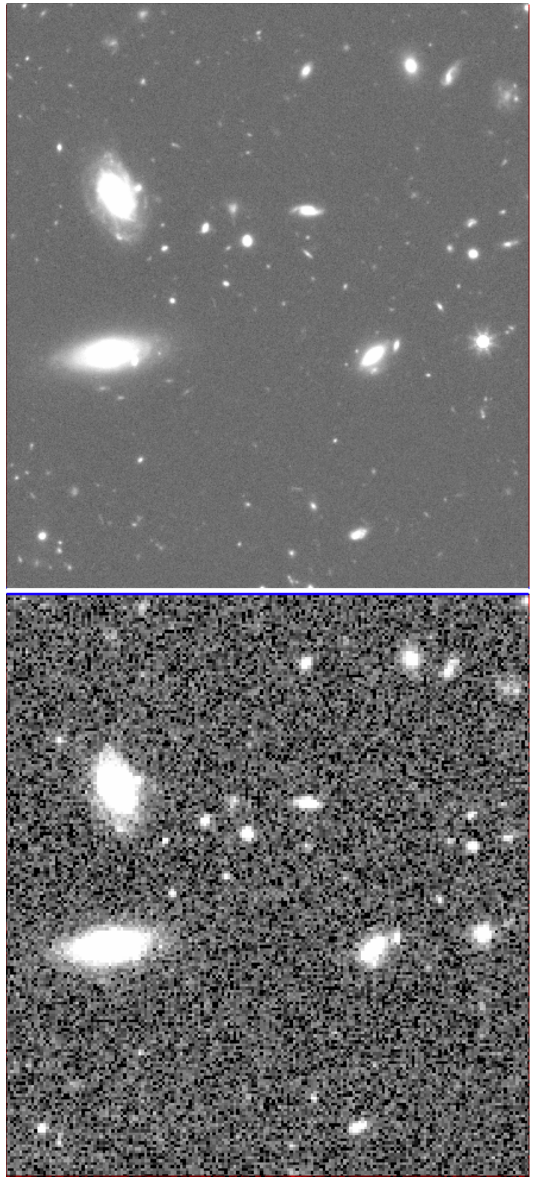
F435W to G band



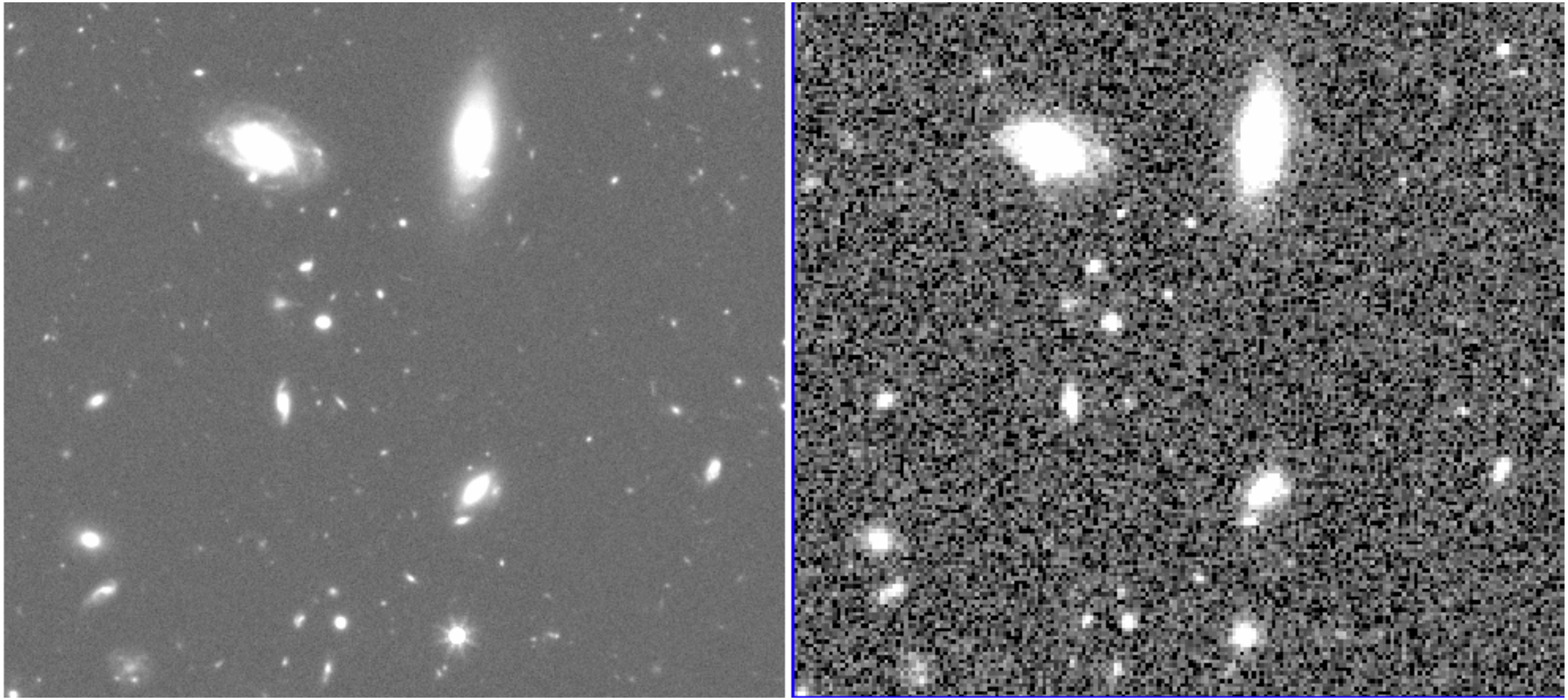
F814W to VIS* band



F125W to J band



F814W VIS*



Internal evaluation of photometric accuracy

For each object, compute the r.m.s. of its 10 realization, and then compute the average trend.