Astronomical Data Analysis

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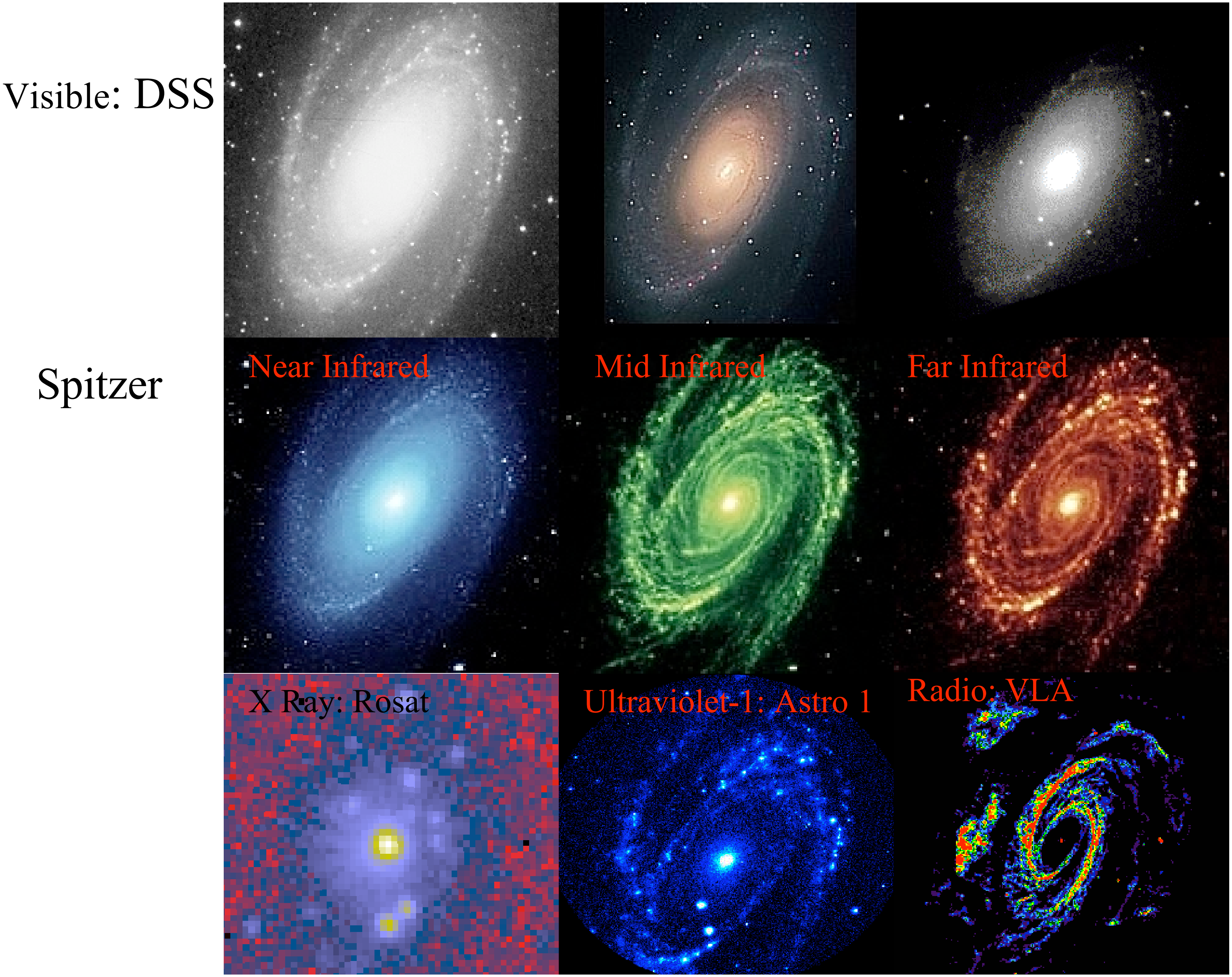
M81 - Spiral Galaxy



-Detection of Galaxies in ISOCAM infrared images

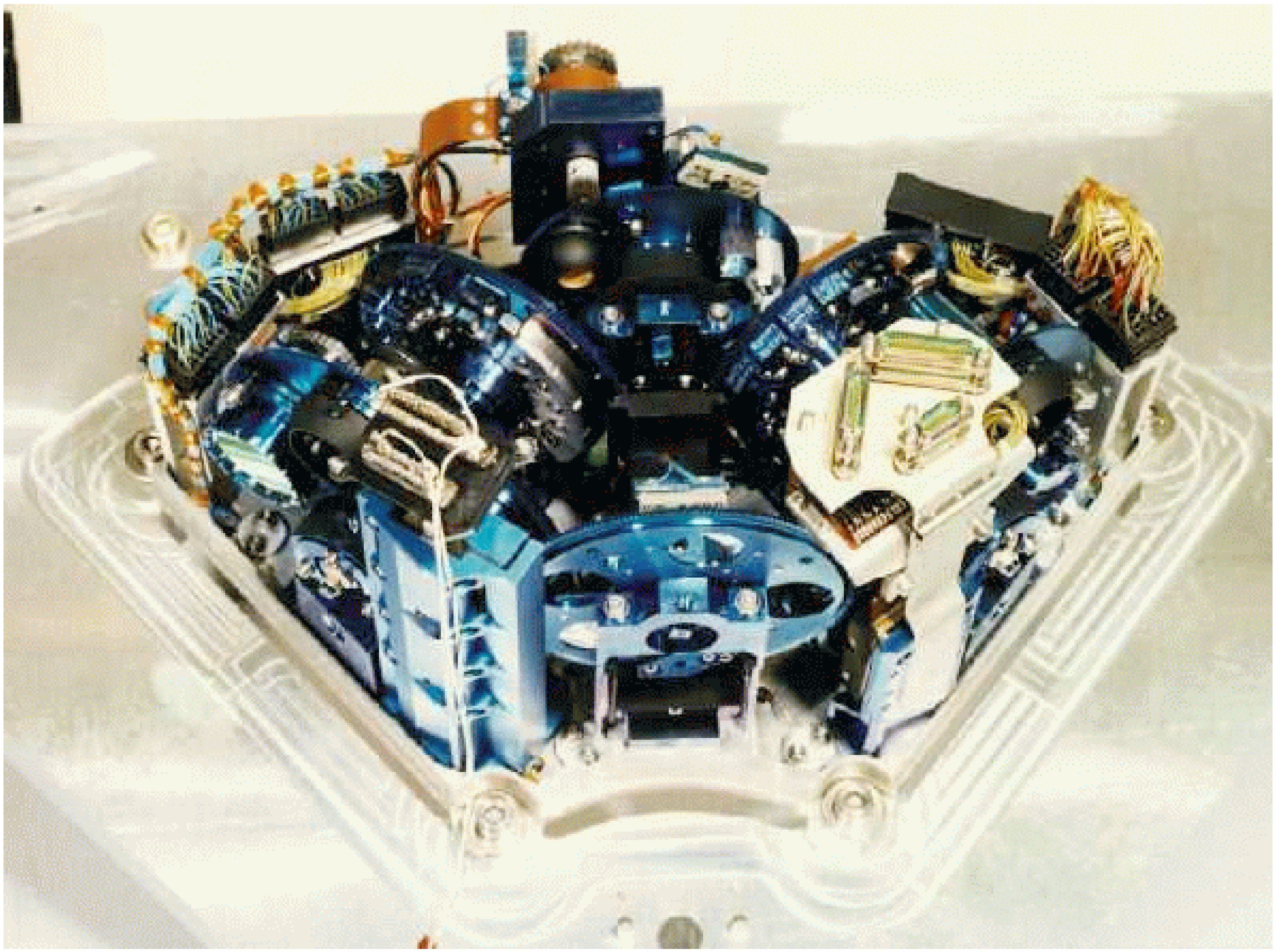
- Search for exo-planet in infrared images: Deconvolution

- Weak lensing observation and mass map reconstruction

- Analysis of catalog of galaxies

- Analysis of the cosmological microwave background

INFRARED SPACE OBSERVATORY (ISO): ISOCAM Camera



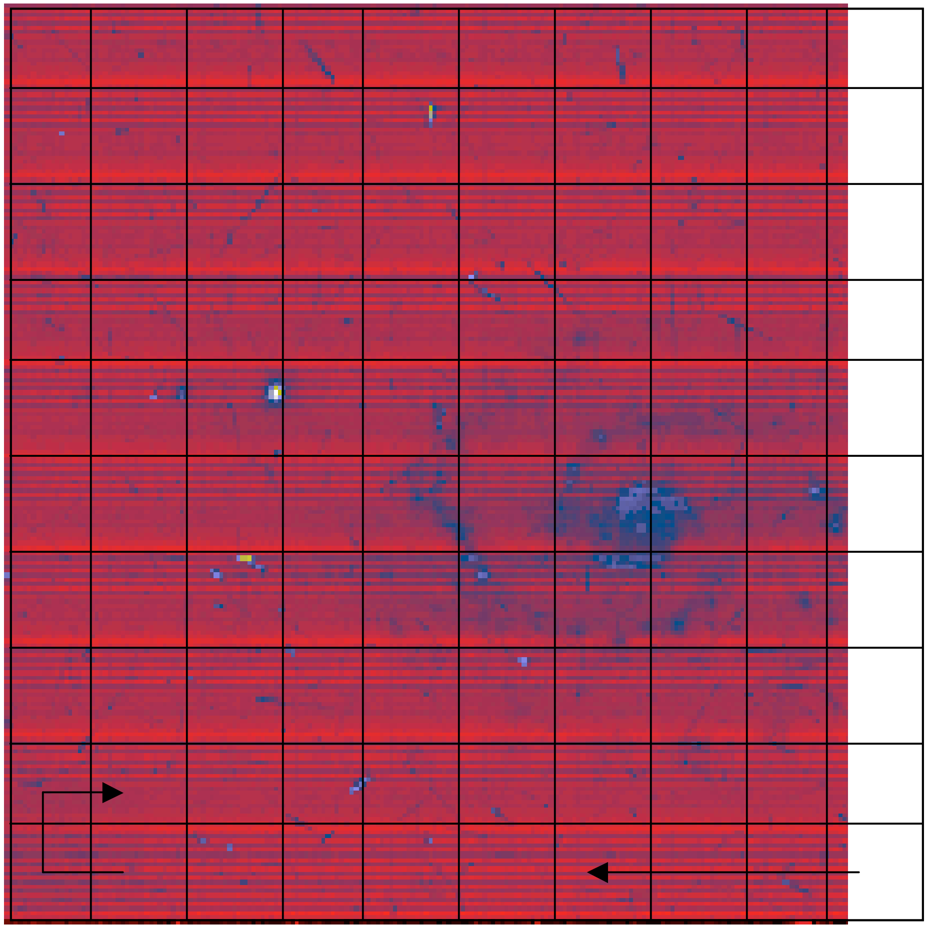
ISOCAM Data Calibration Steps

-Dark correction

-Flat field correction

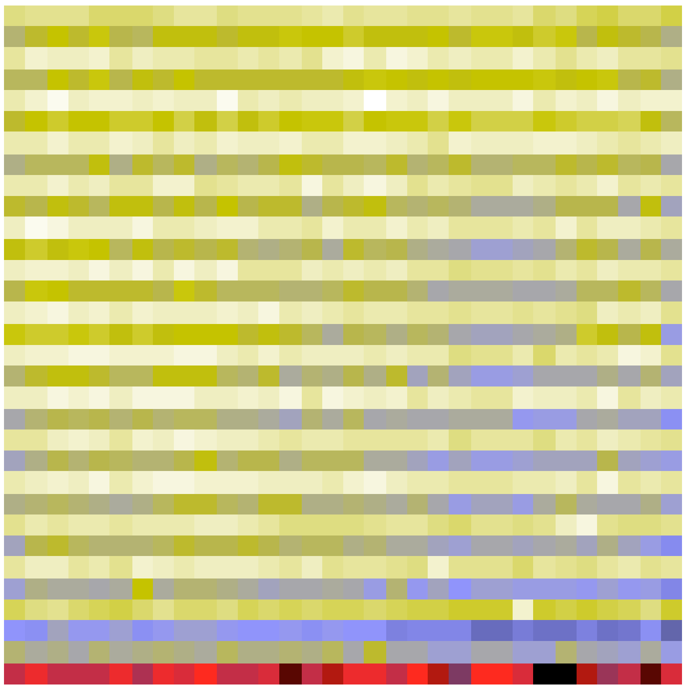
-Transient correction

-Deglitching

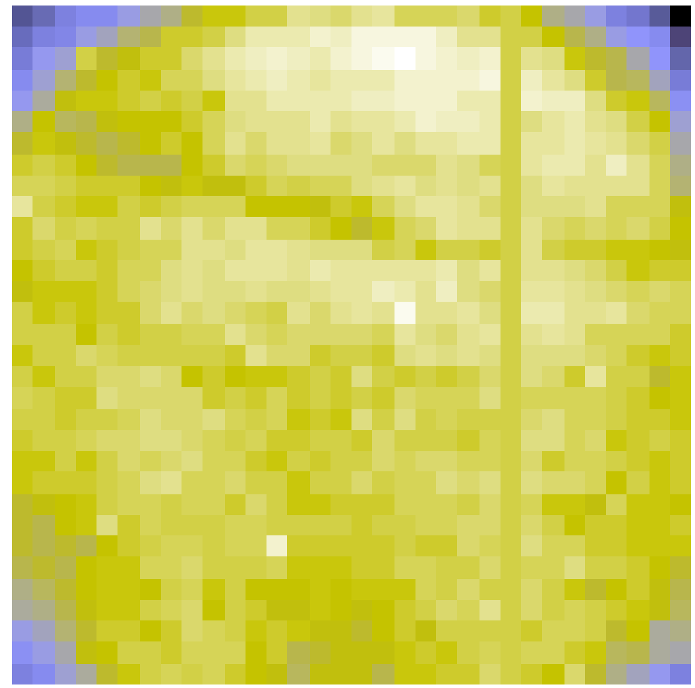


ISOCAM

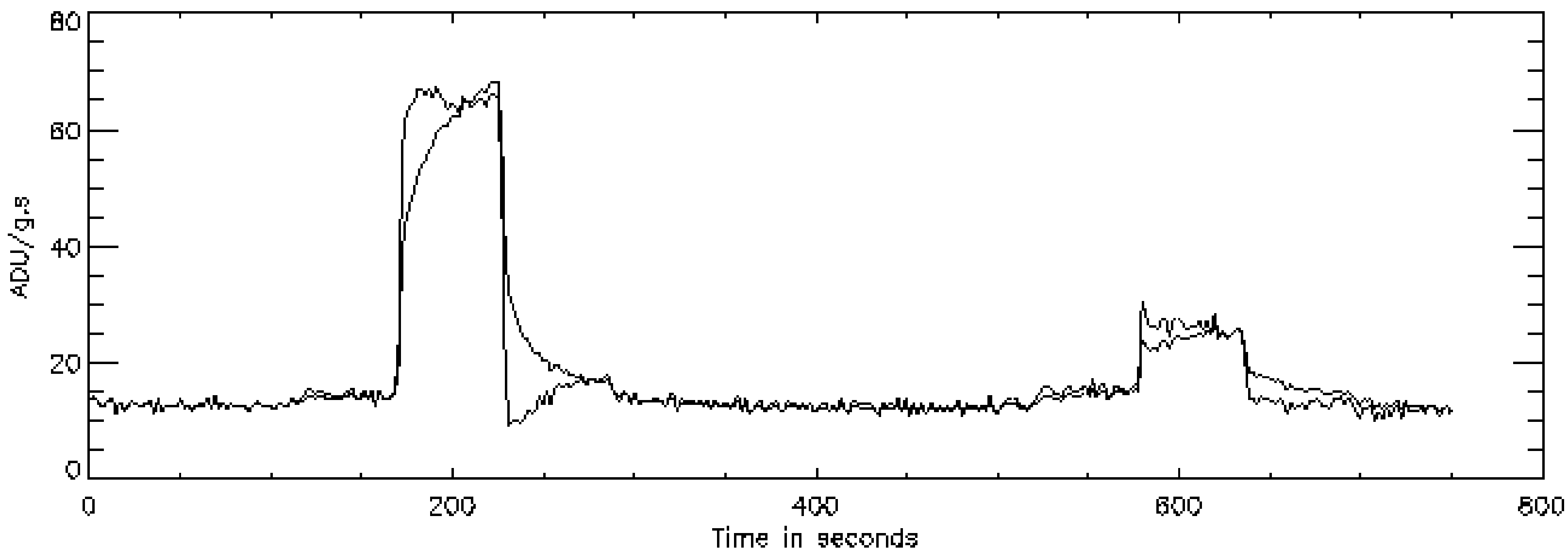
Dark Image



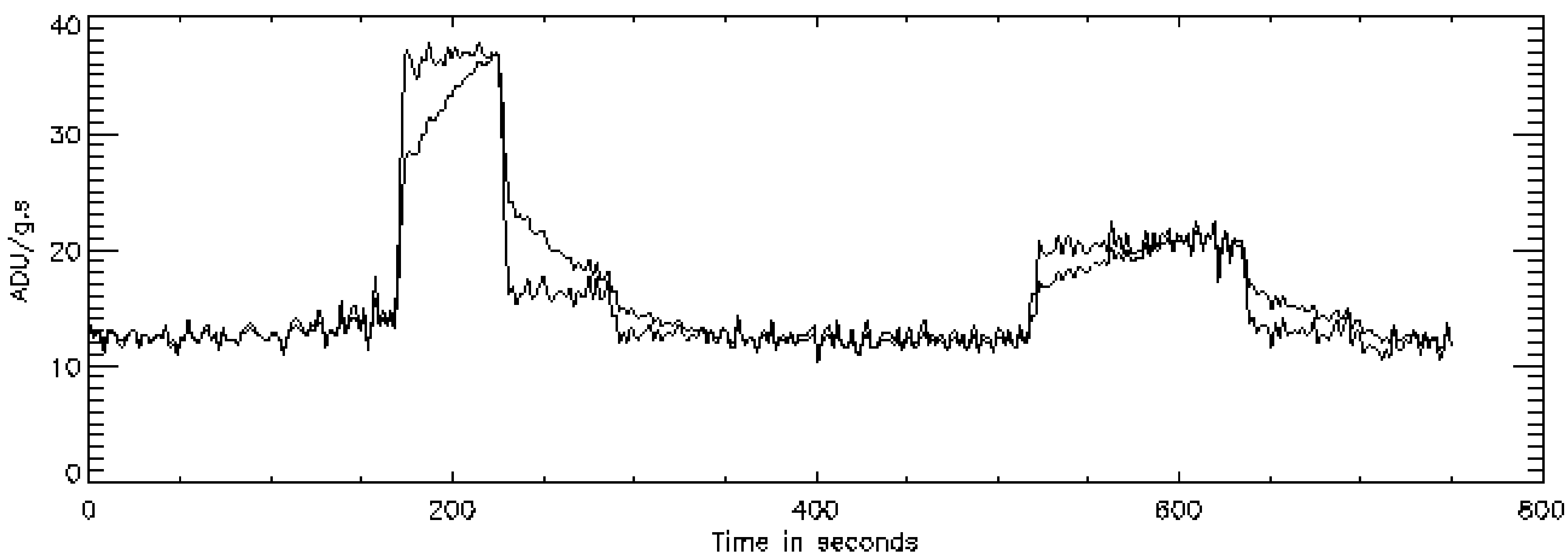
Flat Image



I = (Data - Dark)/Flat

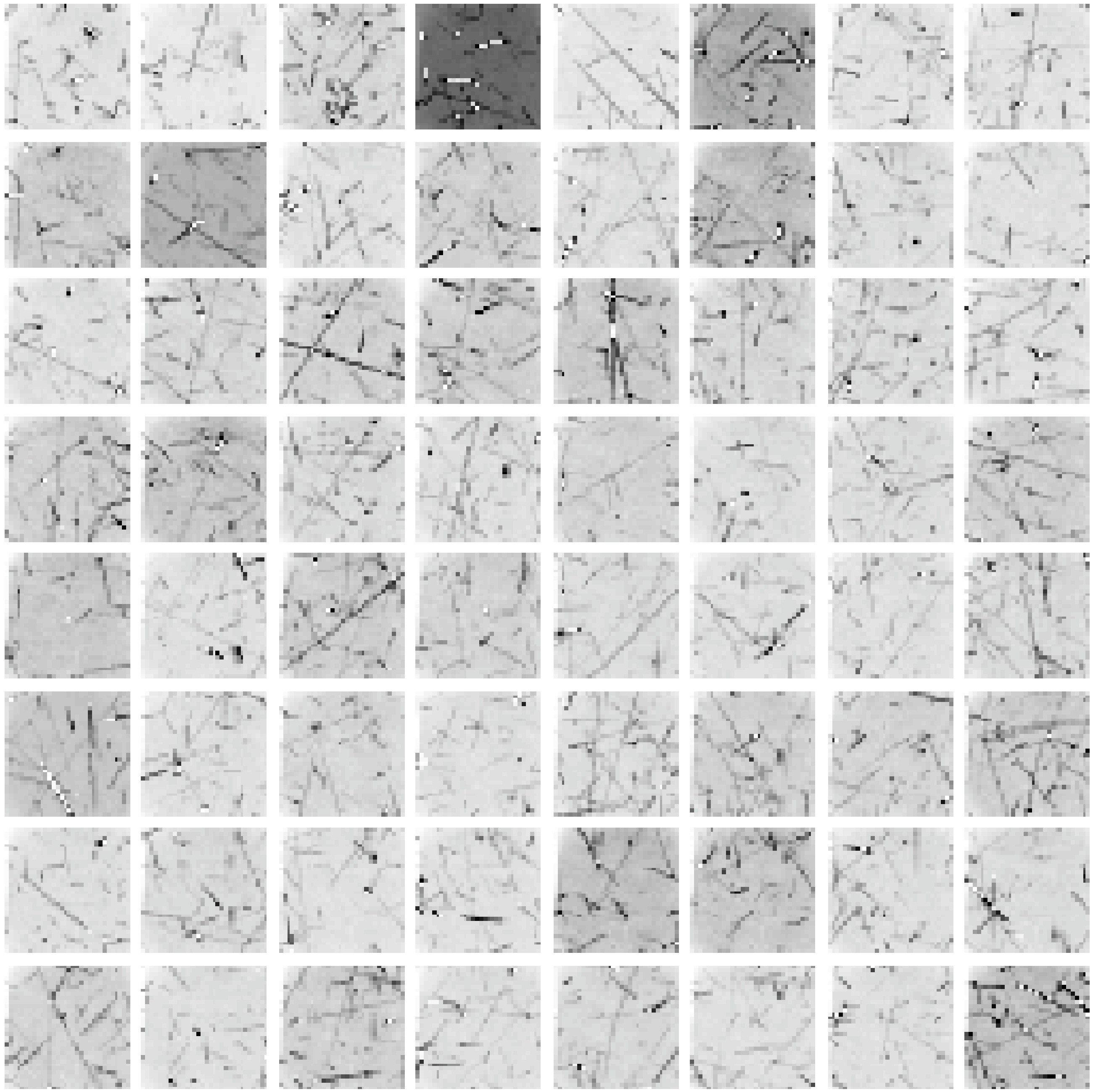


ADU/g.s
0
20
40
60
80
0
200
400
600
800
Time in seconds

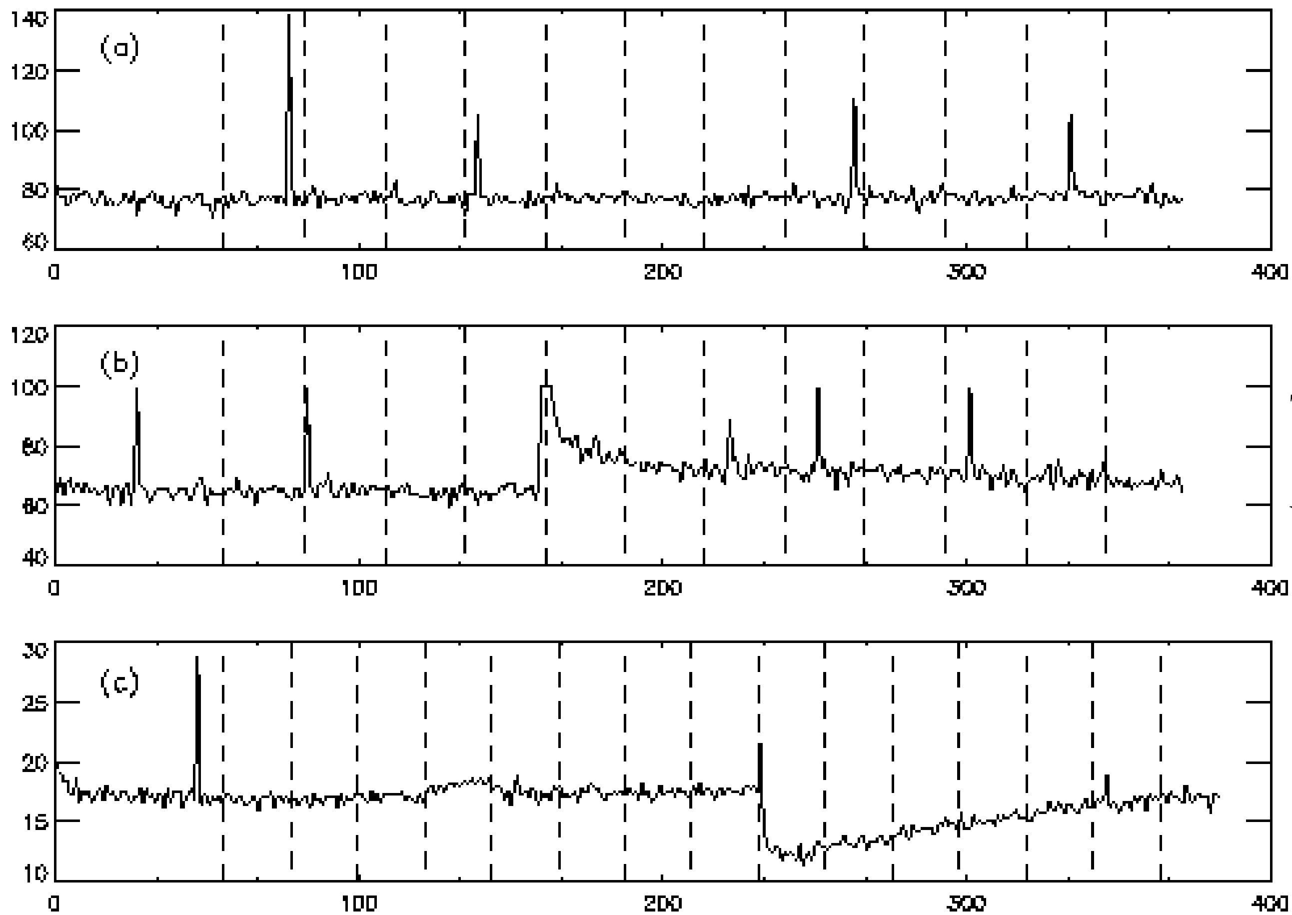


ADU/g.s
0
10
20
30
40
0
200
400
600
800
Time in seconds

Cosmic Rays



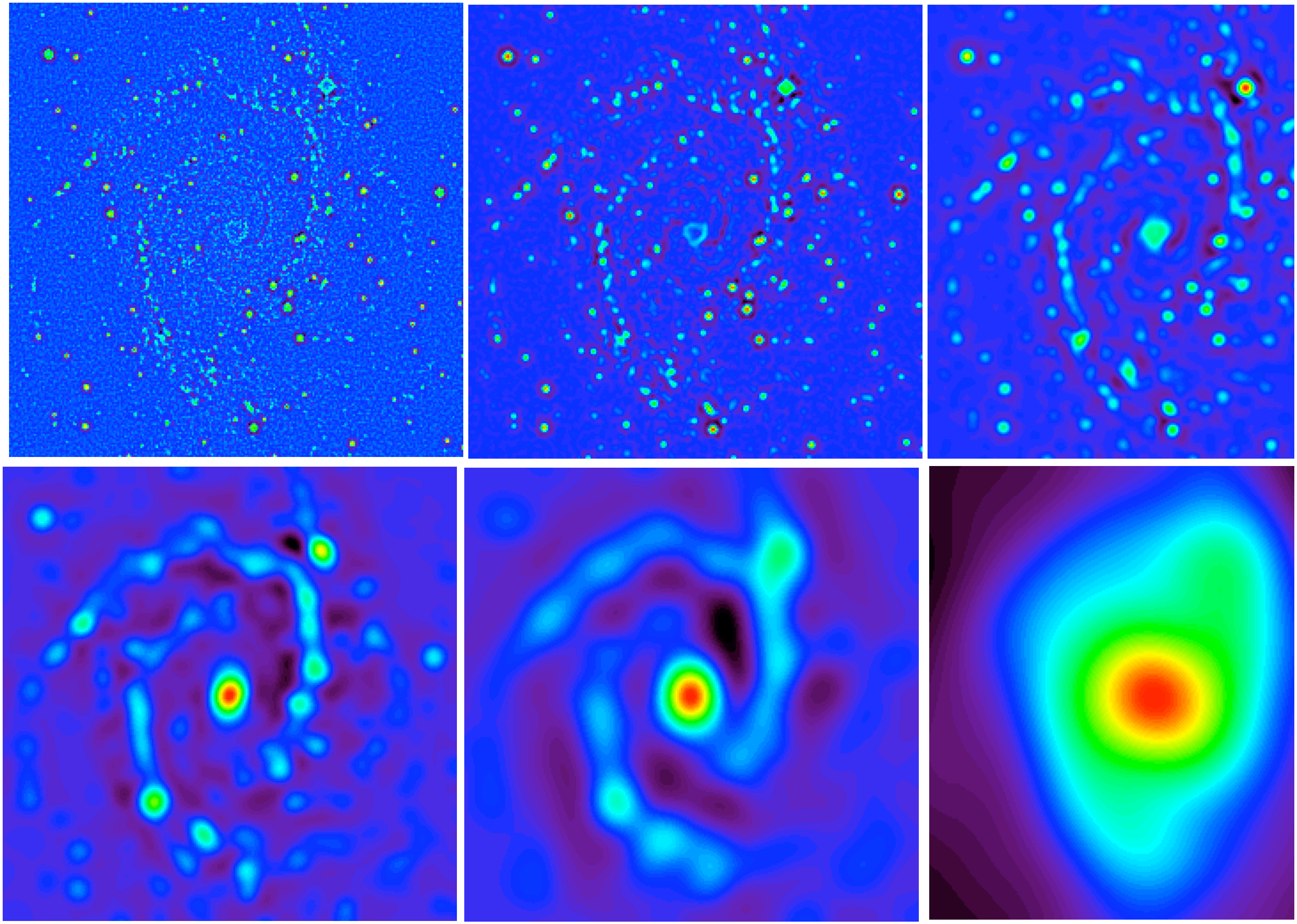
A glitch is the result of an energy deposit from a charged particles in ISOCAM detectors. This energy deposit is spatially localised and it takes a limited period of time to the detector to recover for it.



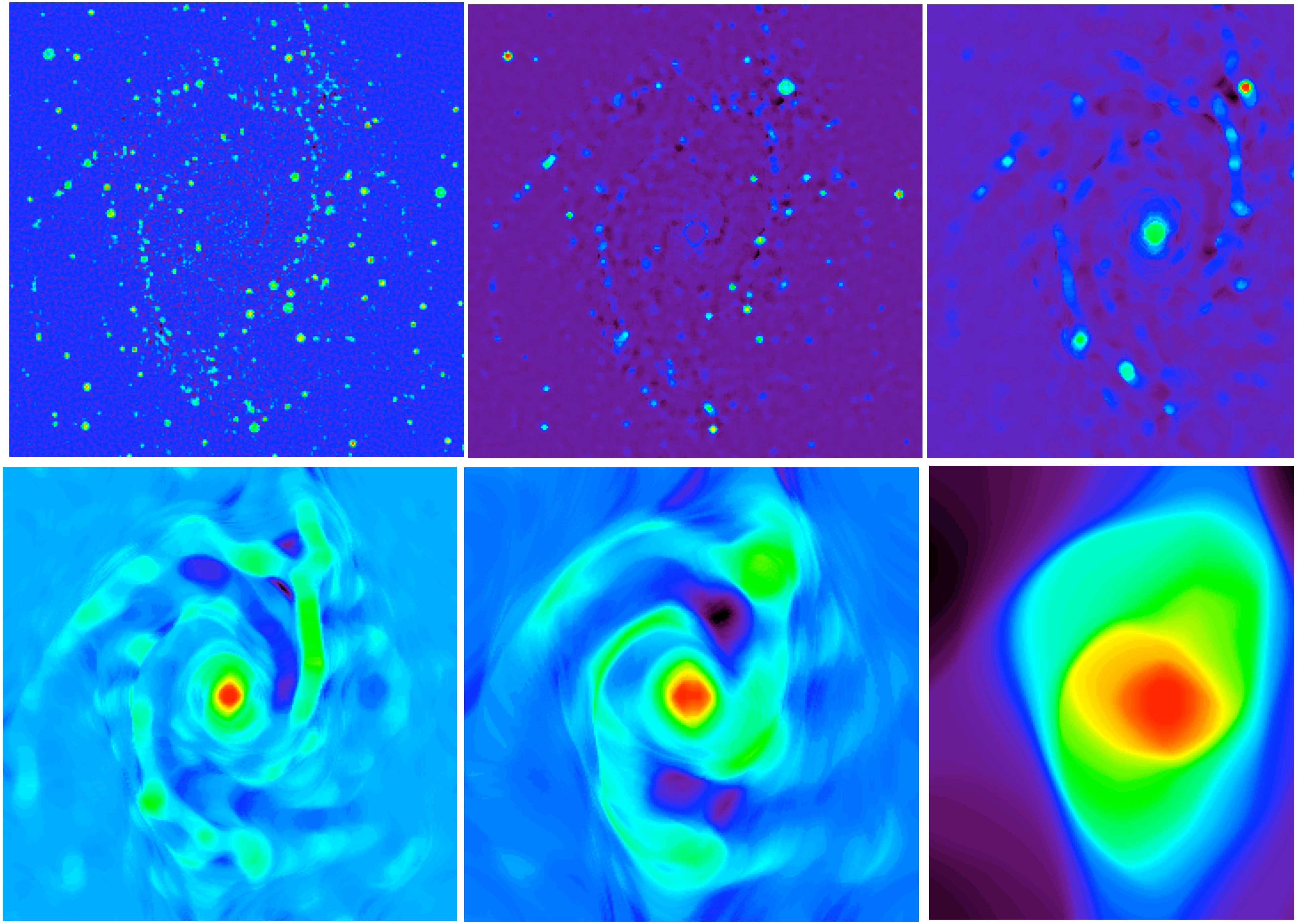
Type-A, common glitches

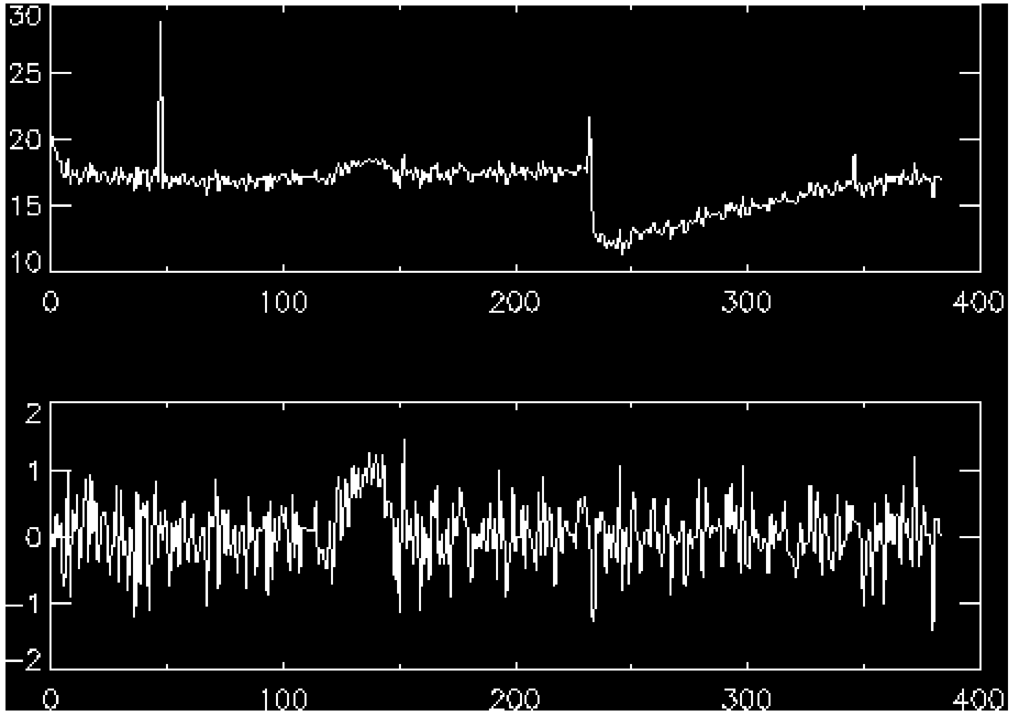
Type-B, faders: the pixel value decreases slowly until a stabilized value is reached.

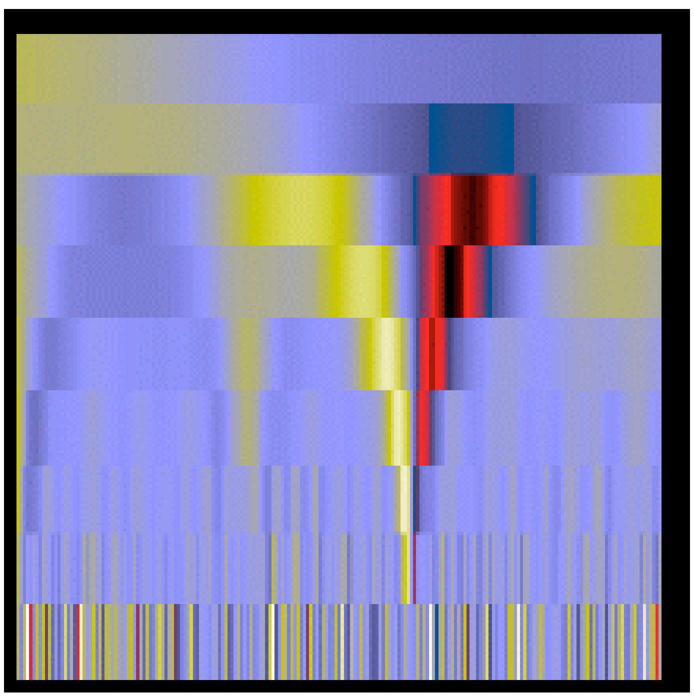
Type-C, dippers: the pixel value decreases first below the stabilized value, and then increase slowly until the stabilized value is reached

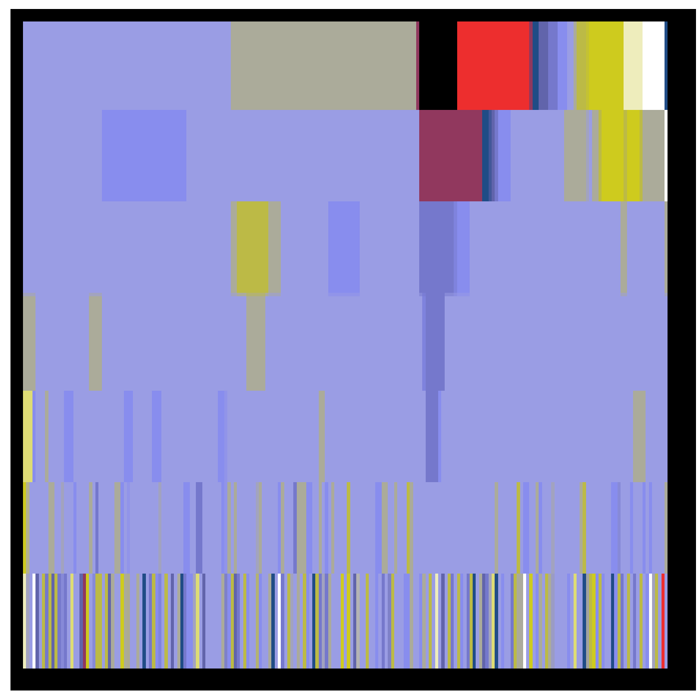


The Multiscale Median Transform

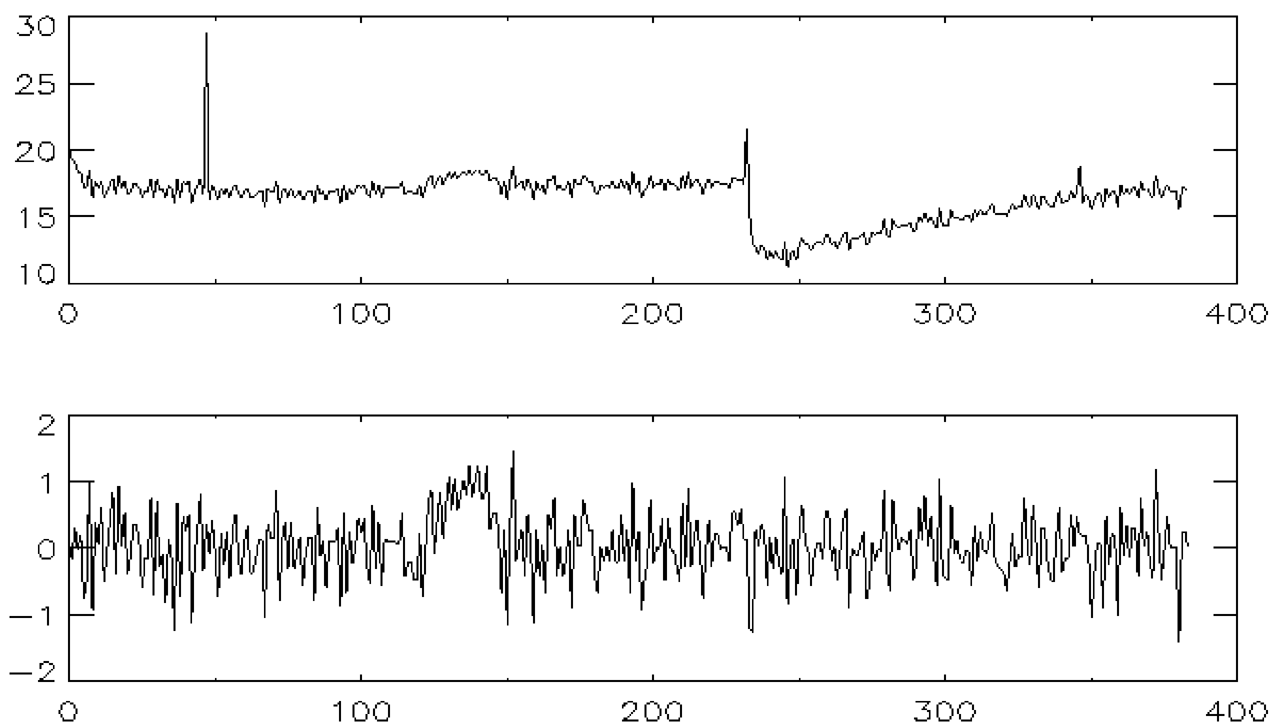


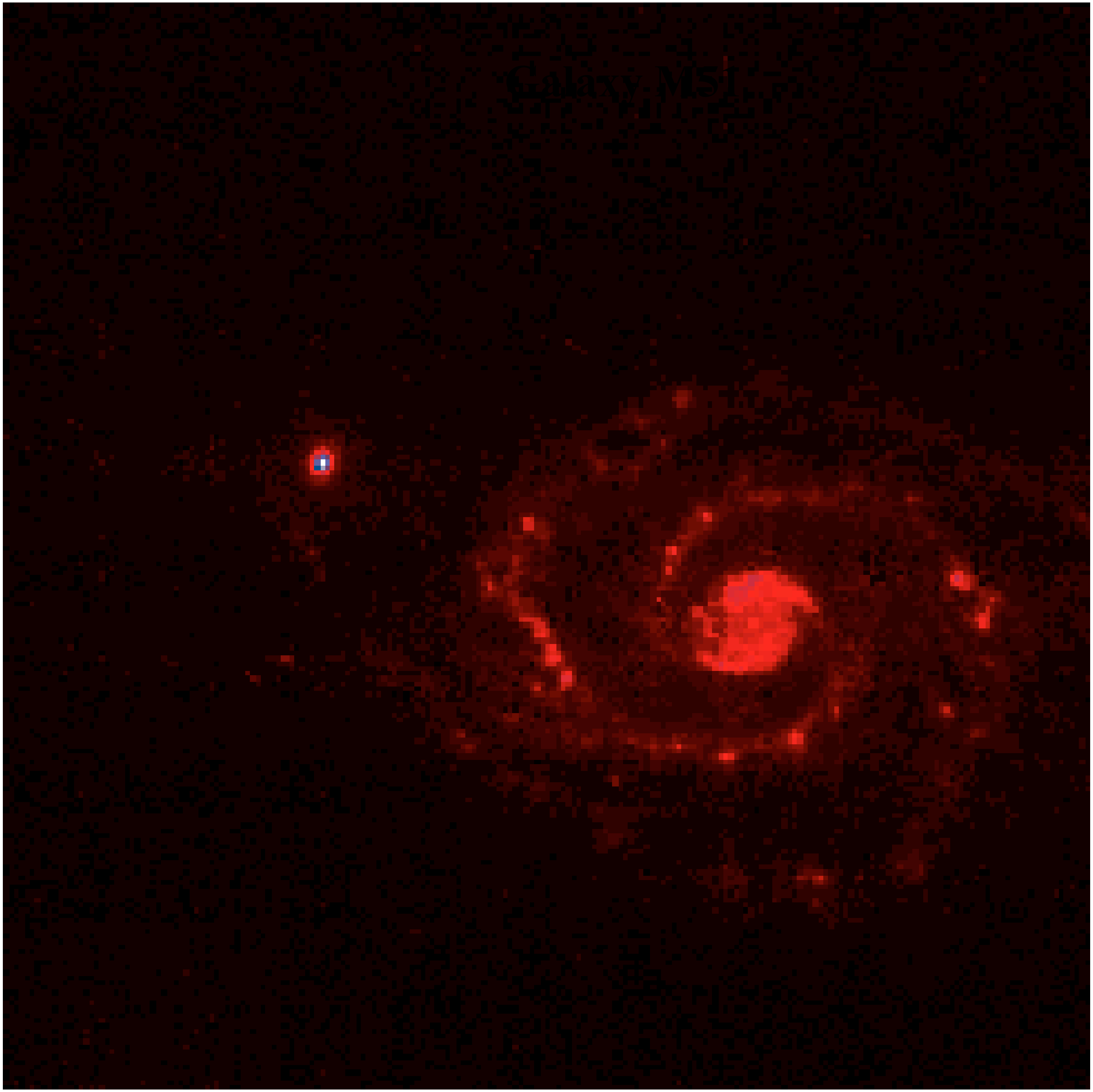

30
25
20
15
10
0
100
200
300
400
2
1
0
−1
−2
0
100
200
300
400



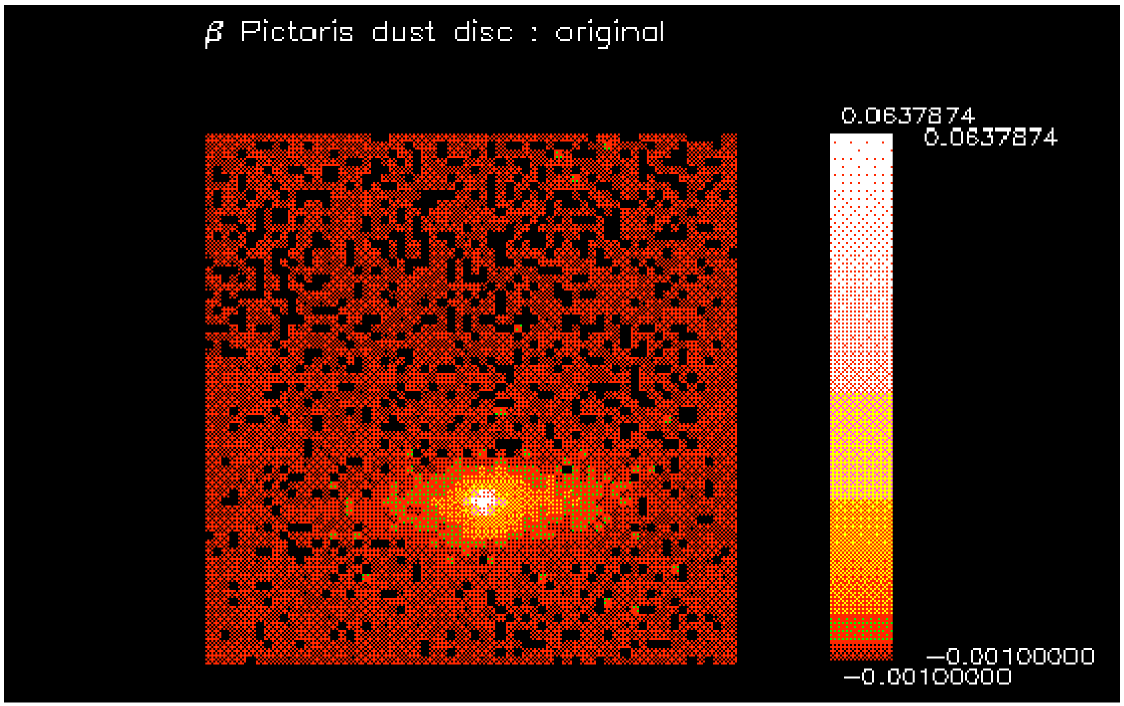


The calibration from pattern recognition consists in searching only for objects which verify given conditions. For example, finding glitches of the first type is equivalent to finding objects which are positive, strong, and with a temporal size lower than that of the sources.

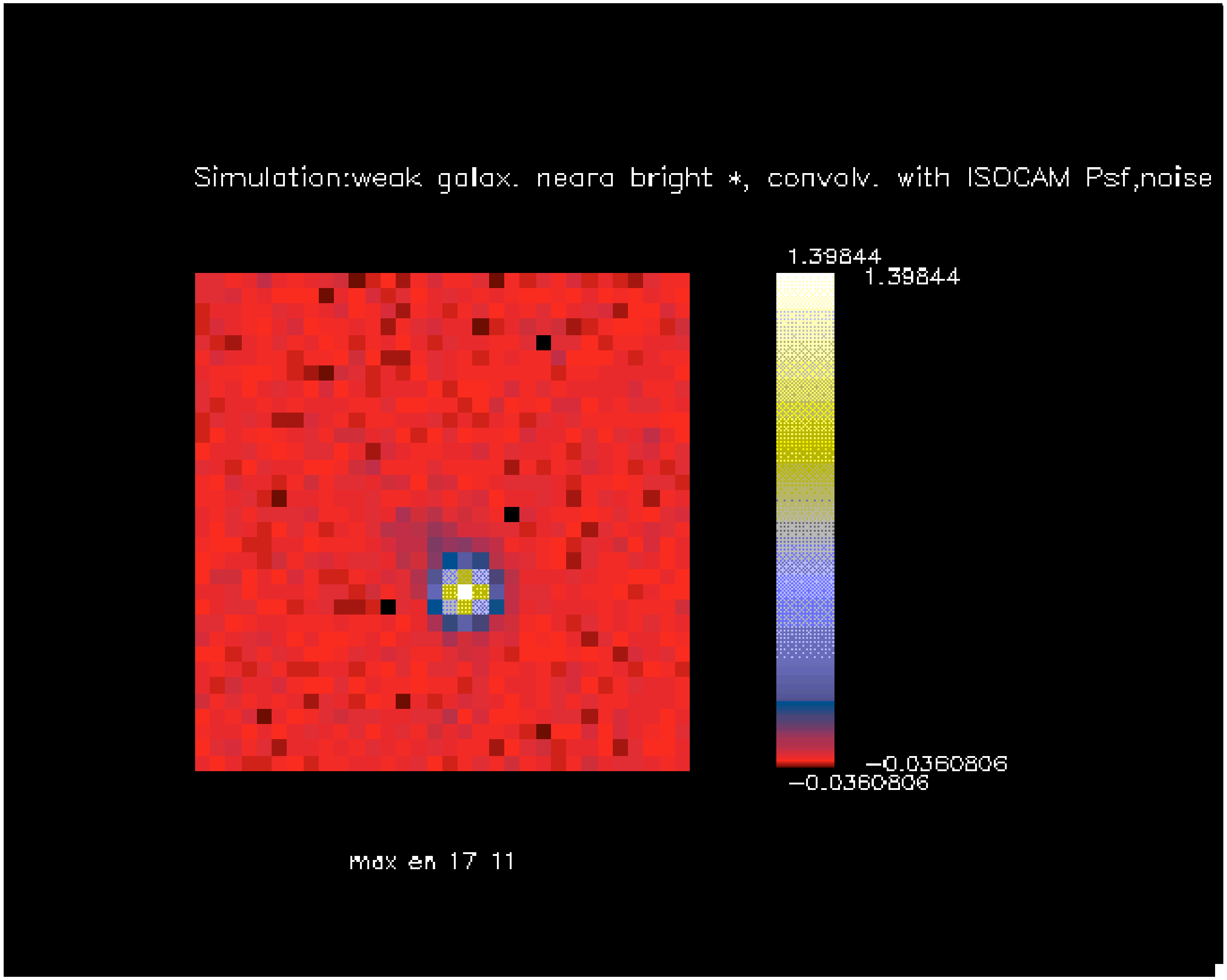



Galaxy M51

Search for exo-planet in infrared images: Deconvolution



$$s = P * \tilde{s} + N$$


Simulation:weak galax. neara bright *, convolv. with ISOCAM Psf,noise
1.39844
1.39844
-0.0360806
-0.0360806
max en 17 11

$$\min \quad \text{Complexity\_penalty}(\tilde{s}), \quad \text{subject to} \quad \tilde{s} \subset C$$

Where C is the set of vectors which obey the linear constraints:

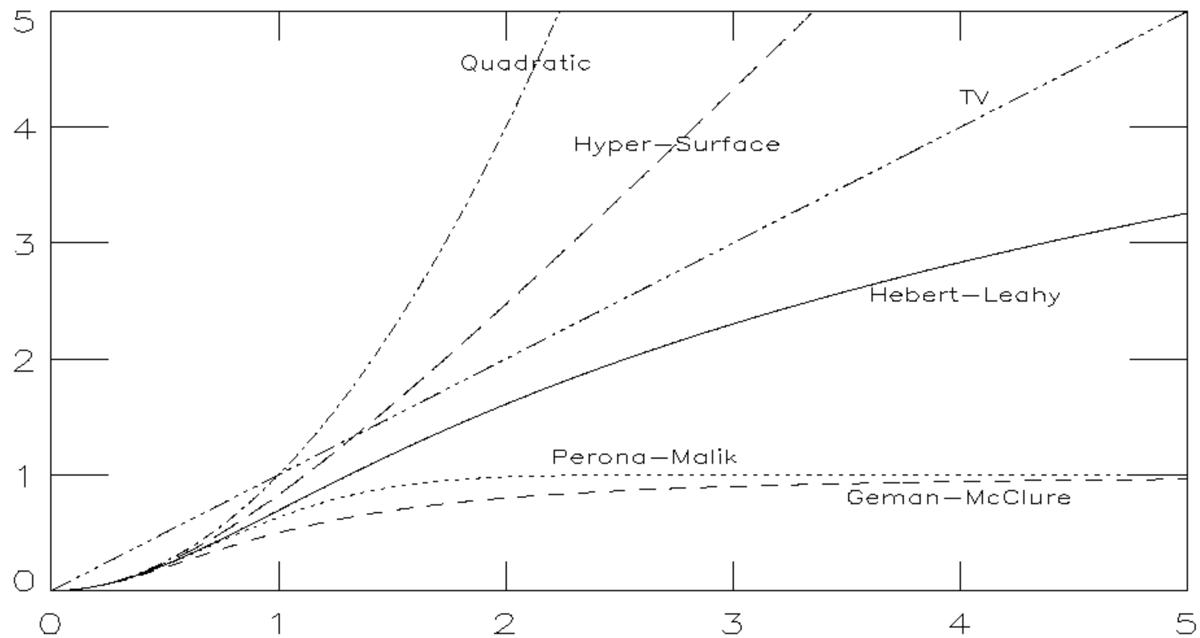
$\tilde{s} > 0,$ positivity constraint

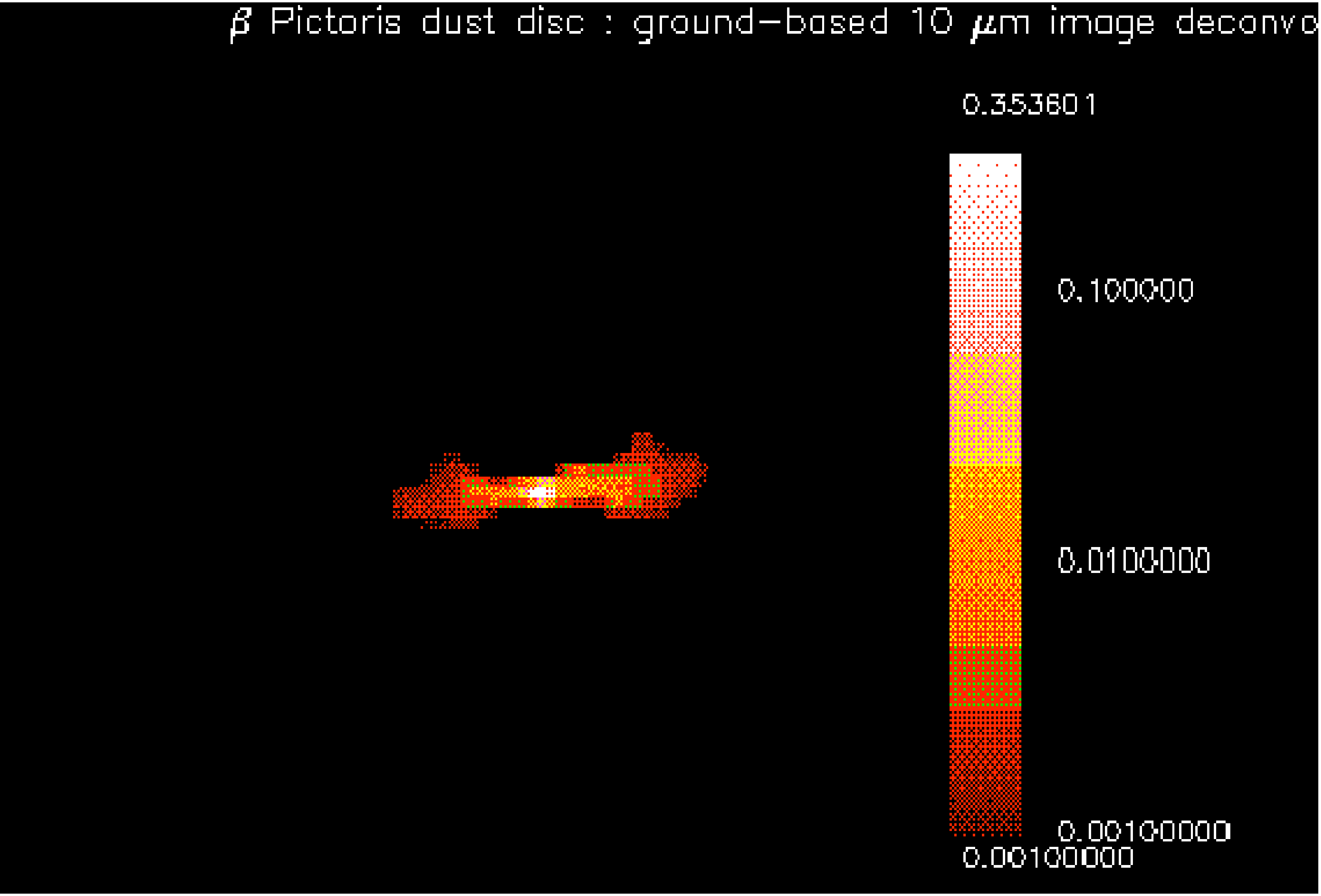
$\left|\left(W[s] - W[P * \tilde{s}]\right)_l\right| \leq e, \quad if \left(W[s]\right)_l$ is significant

$$Complexity\_Penalty = \sum_{j,k} \varphi(w_{j,k})$$

Examples of ϕ functions:

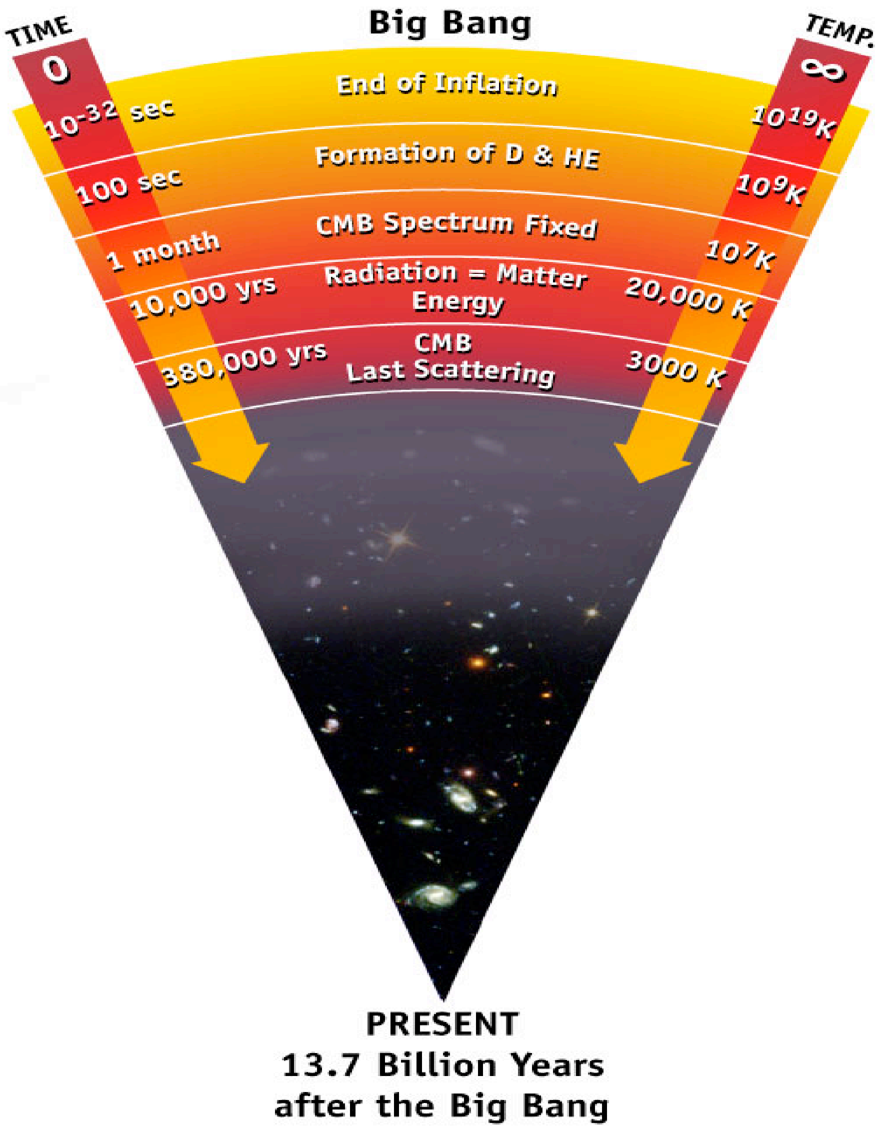
1. $\phi_q(x) = x^2$: quadratic function.
2. $\phi_{TV}(x) = \mid x \mid$: Total Variation.
3. $\phi_2(x) = 2\sqrt{1 + x^2} - 2$: Hyper-Suface (Charbonnier et al, 1997).
4. $\phi_3(x) = x^2/(1 + x^2)$ (Geman and McClure, 1985) (Non convex .
5. $\phi_4(x) = 1 - e^{-x^2}$ (Perona and Malik, 1990).
6. $\phi_5(x) = \log(1 + x^2)$ (Herbert and Leahy, 1989).

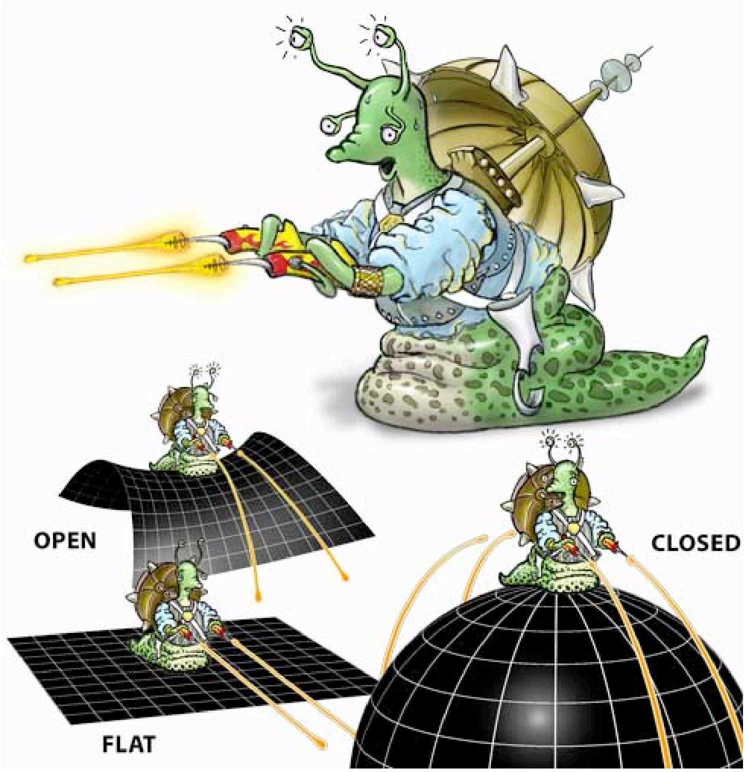


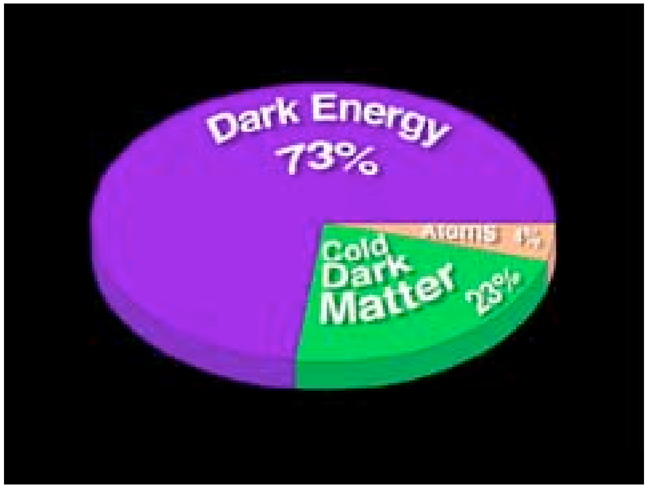


β Pictoris dust disc : ground-based 10 μm image deconvo
0.353601
0.100000
0.0100000
0.00100000
0.00100000

COSMOLOGY


TIME
0
Big Bang
TEMP.
∞
End of Inflation
10^{-32} sec
10^{19}K
Formation of D & HE
100 sec
10^{9}K
CMB Spectrum Fixed
1 month
10^{7}K
Radiation = Matter Energy
10,000 yrs
20,000 K
CMB Last Scattering
380,000 yrs
3000 K
PRESENT
13.7 Billion Years after the Big Bang


OPEN
CLOSED
FLAT


Dark Energy 73%
Atoms
Cold Dark Matter 23%

2004: The current situation:
The triumph of dark stuff in cosmology

Visible matter cannot account for dynamics; ***dominated*** by DM

Cosmic energy budget:

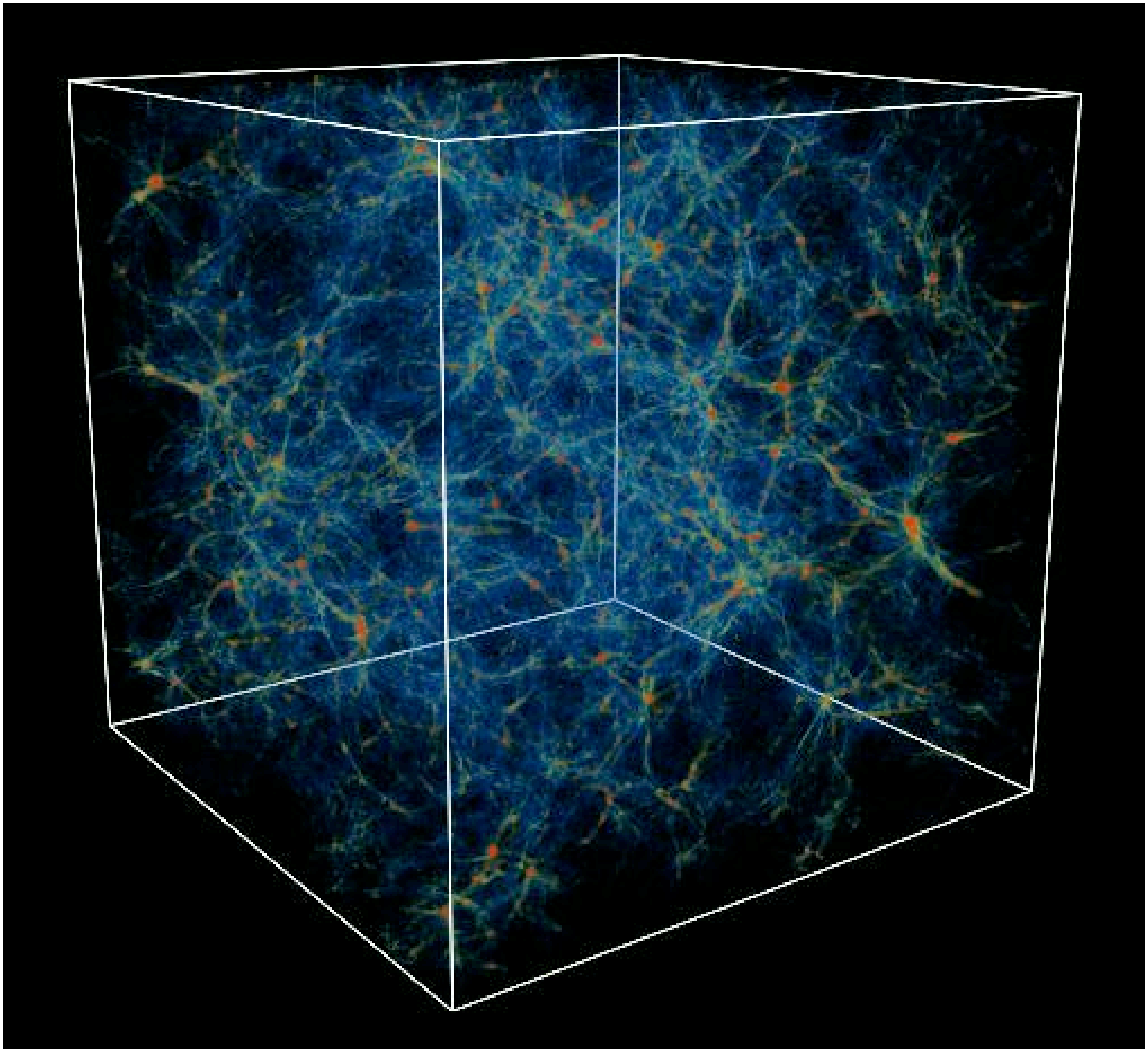
$\Omega_{visible} \sim 0.004$

$\Omega_{baryon} \sim 0.04$

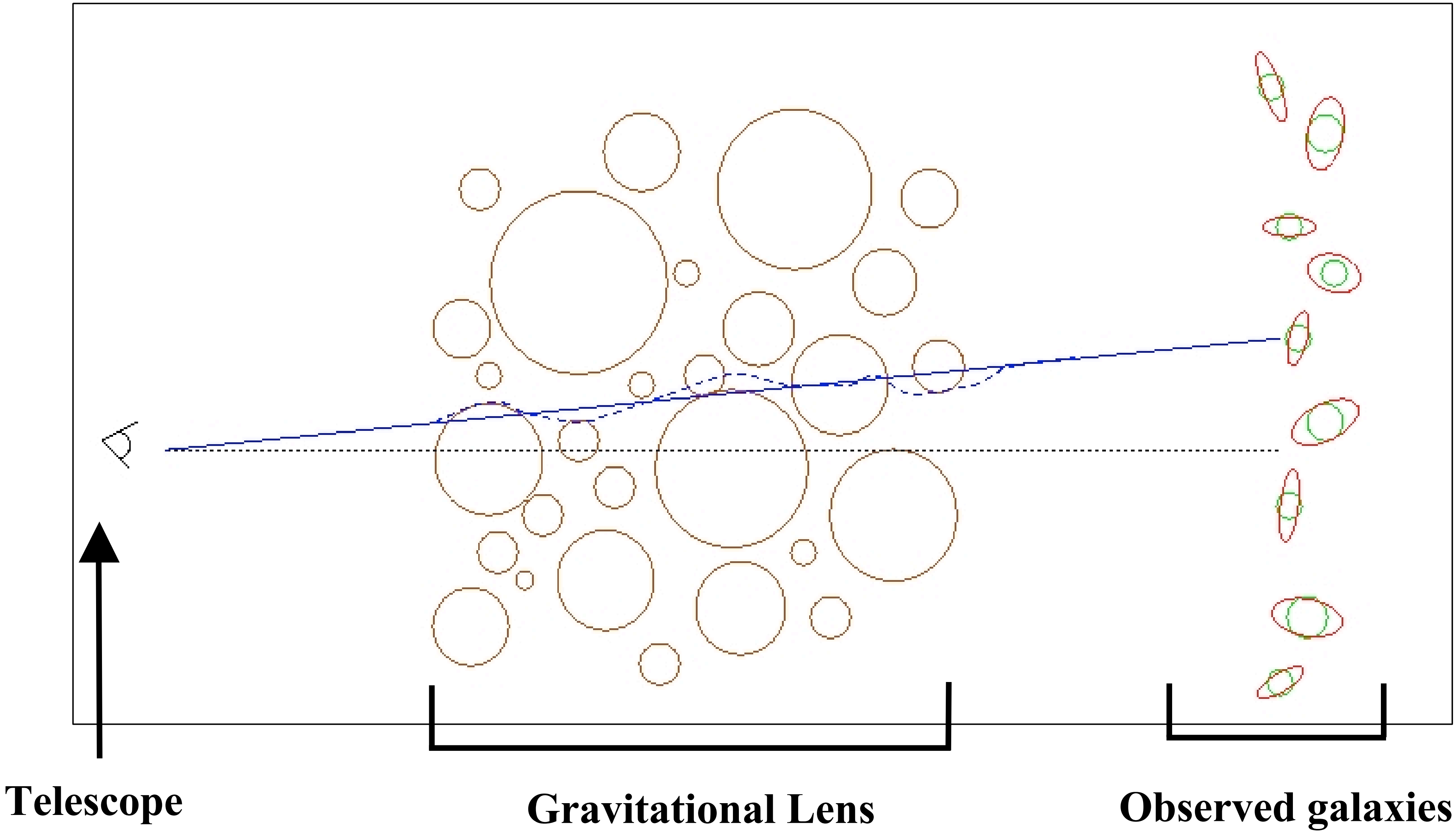
$\Omega_{dark\ matter} \sim 0.3$

$\Omega_{dark\ energy} \sim 0.7$

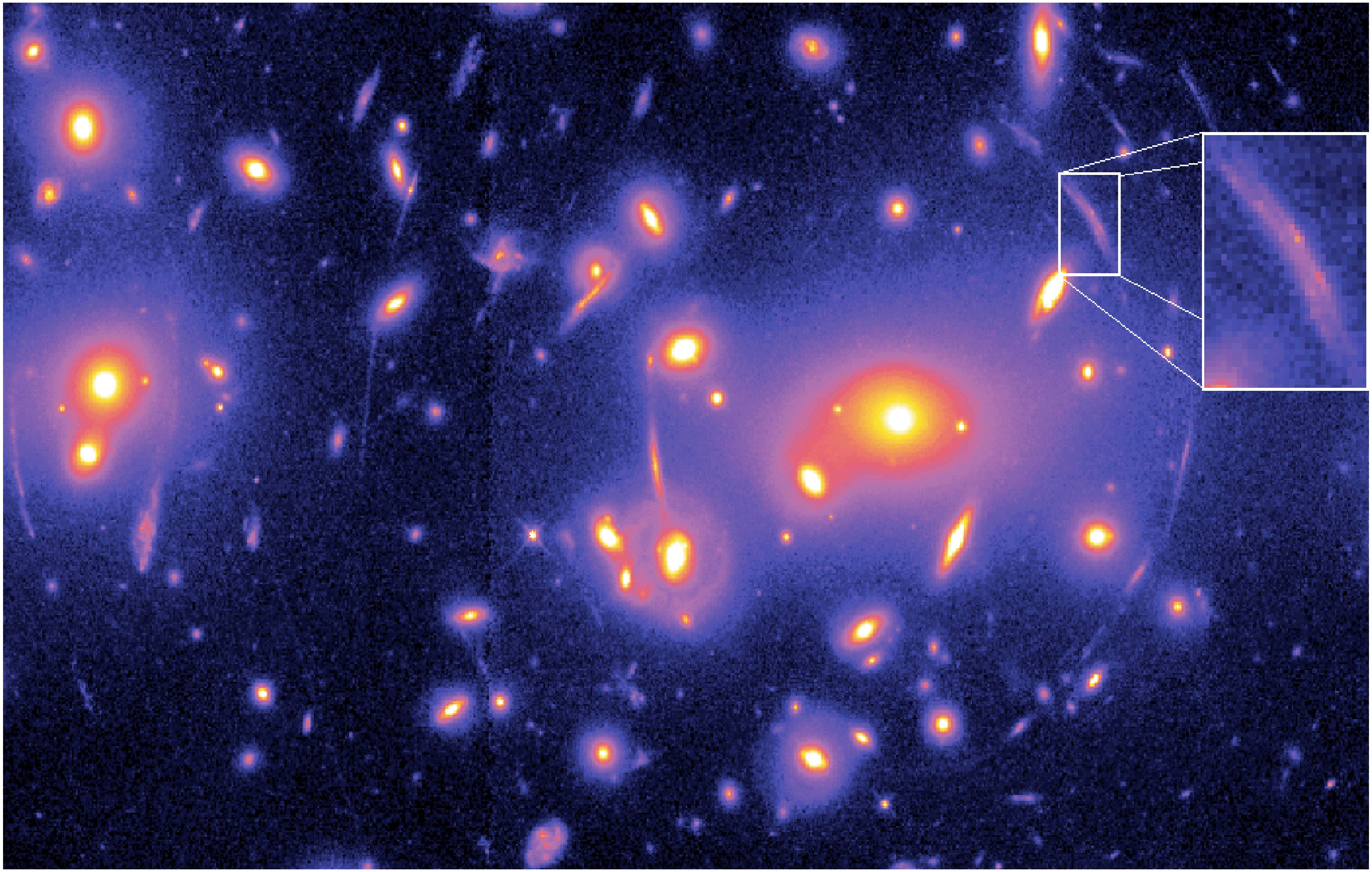
Dark matter/energy, once accepted, works extremely well on large scales.



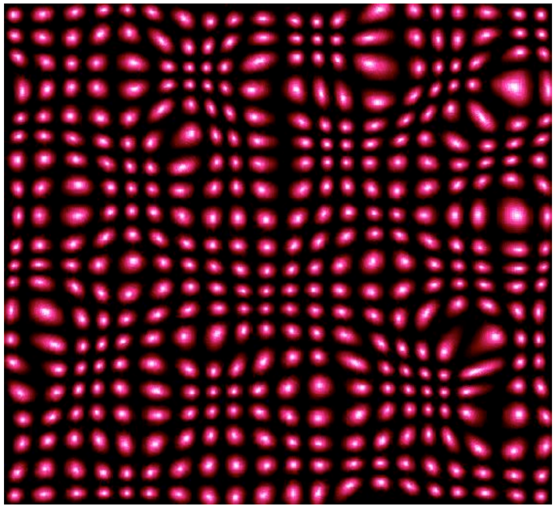
Weak Gravitational Lensing



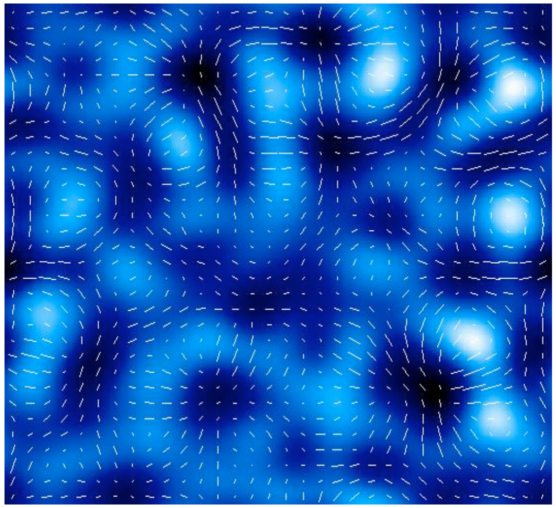
Lentilles Gravitationnelles Fortes



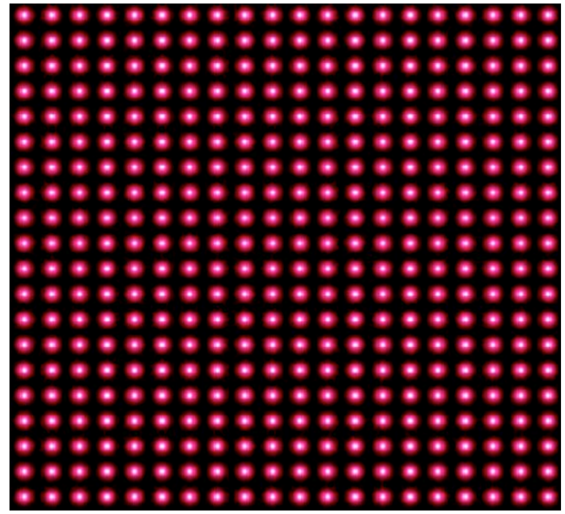
Weak Gravitational Lens



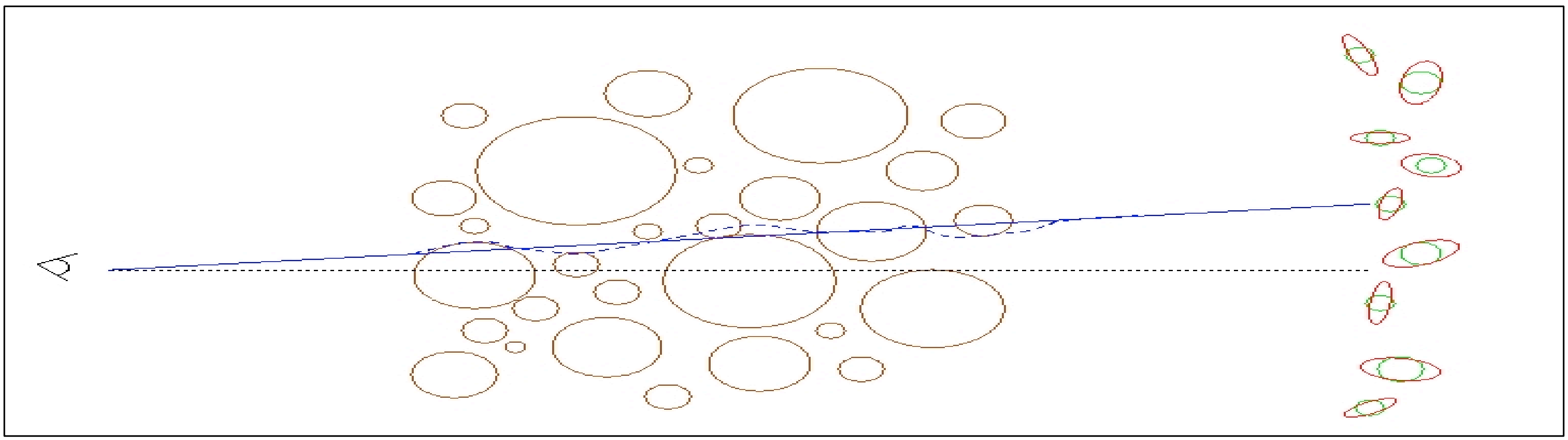
Observation



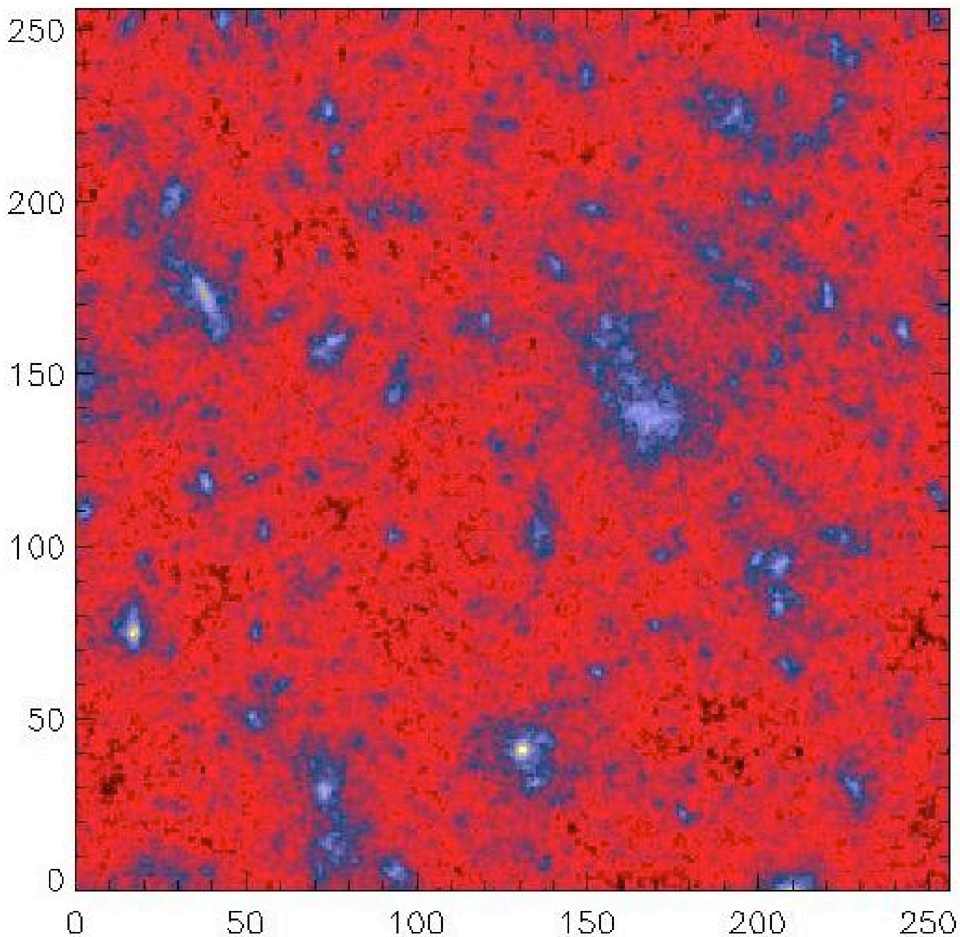
Dark Mass Map

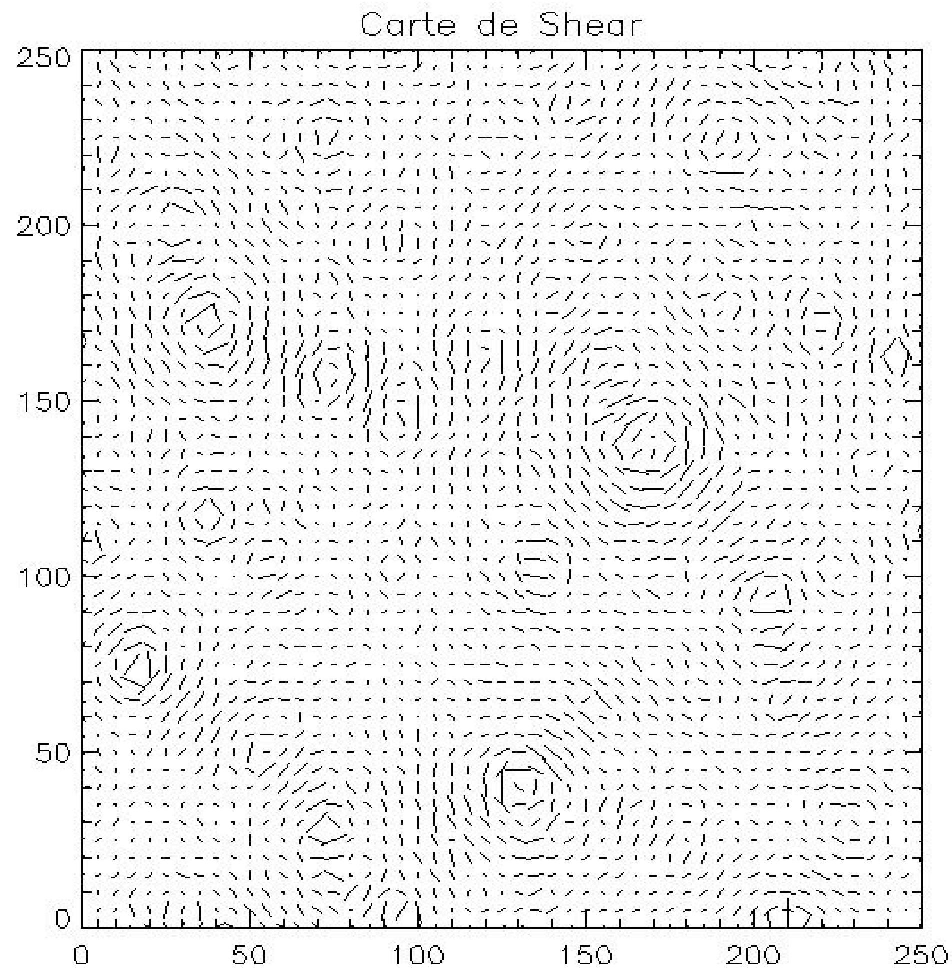


Original field of galaxies

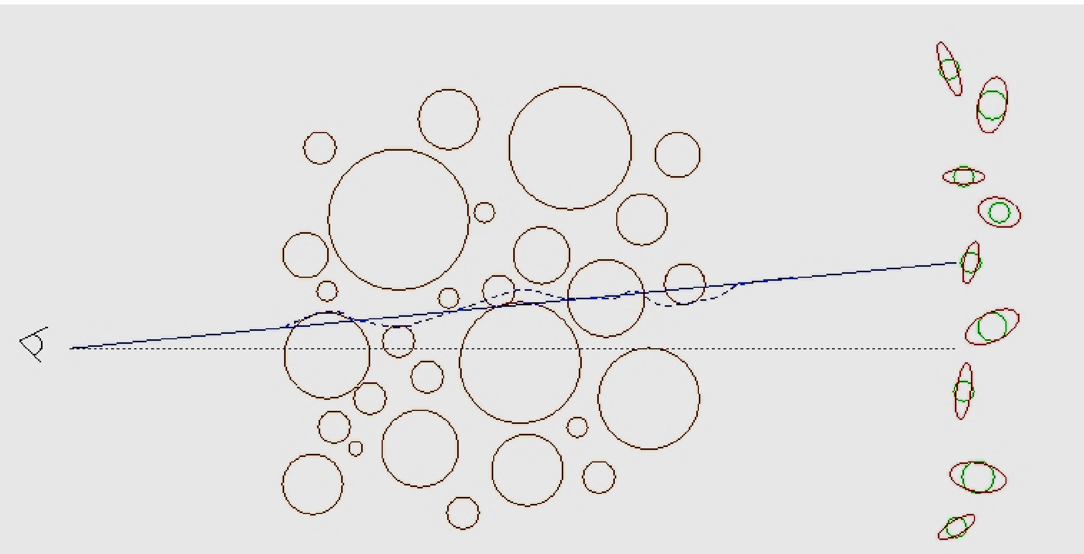


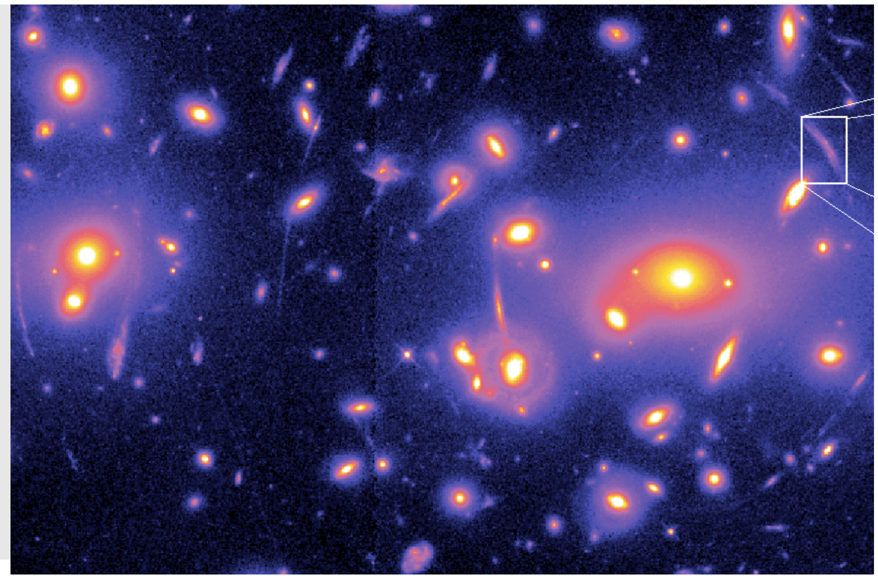
Simulated Mass Map & Related Shear Mass Map





Weak Lensing by Large-Scale Structure





Distortion Matrix: $$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial\theta_i \partial\theta_j}$$

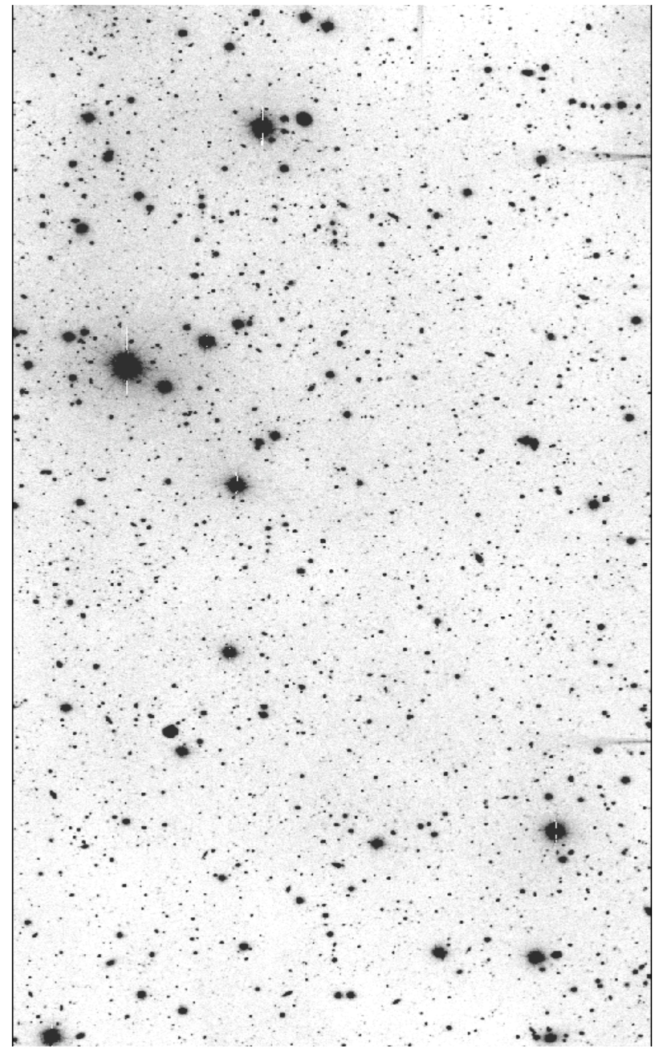
Theory

→ **Direct measure of the distribution of mass in the universe, as opposed to the distribution of light, as in other methods (eg. Galaxy surveys)**

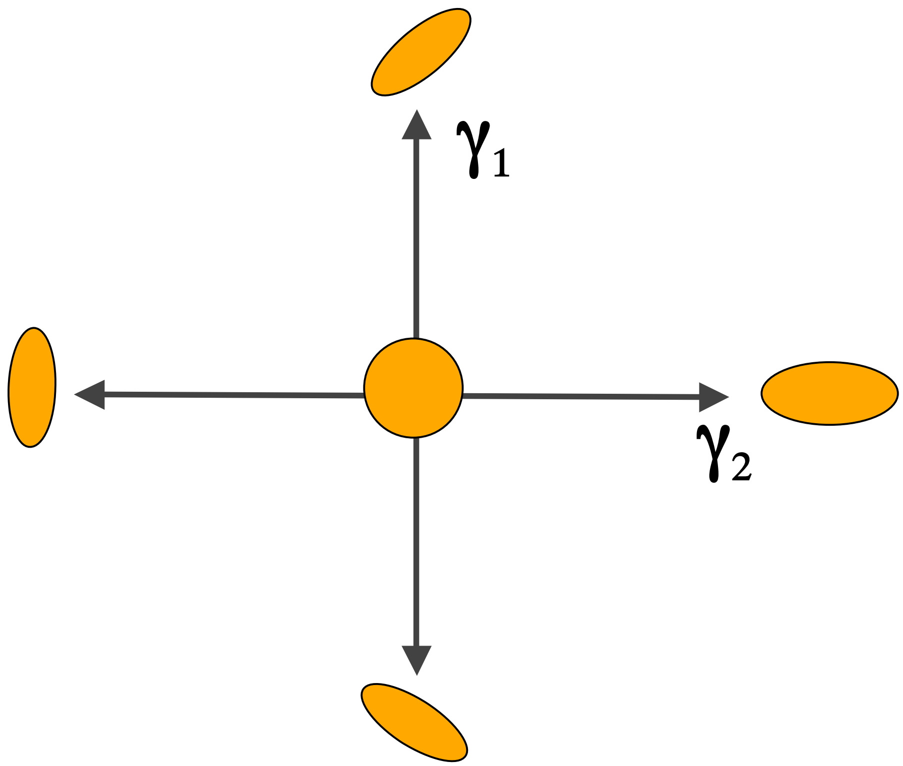
Deep Optical Images

William Herschel Telescope
La Palma, Canaries

16’x8’
R<25.5
30 (15) gals/sq. arcmin



Relation between the shear map (γ_1, γ_2) and the dark matter map κ



Relation in Fourier space:

$$\hat{\kappa} = \hat{P}_1 . \hat{\gamma_1} + \hat{P}_2 . \hat{\gamma_2}$$

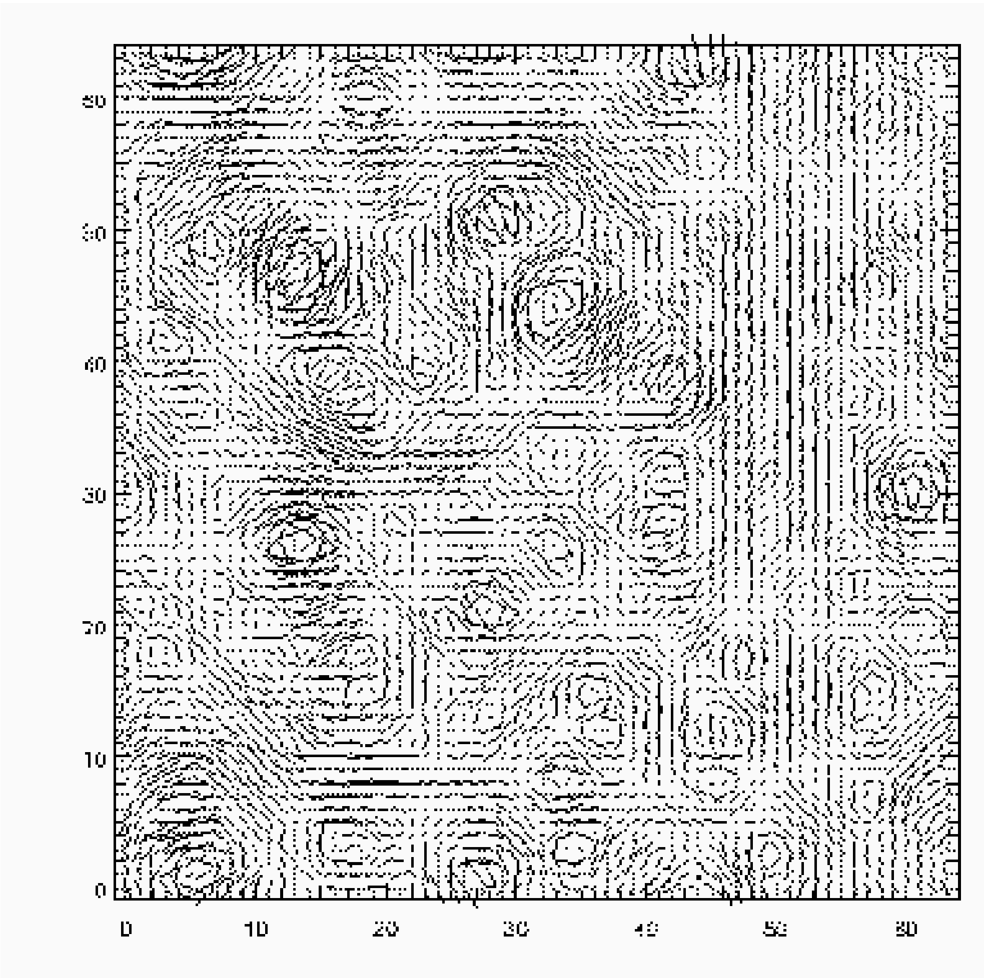
with :

$$\hat{P}_1(k_1, k_2) = \frac{k_1^2 - k_2^2}{k^2}$$

$$\hat{P}_2(k_1, k_2) = \frac{2 k_1 k_2}{k^2}$$

Scientific Promise of Weak Lensing

From the statistics of the shear field, weak lensing provides:

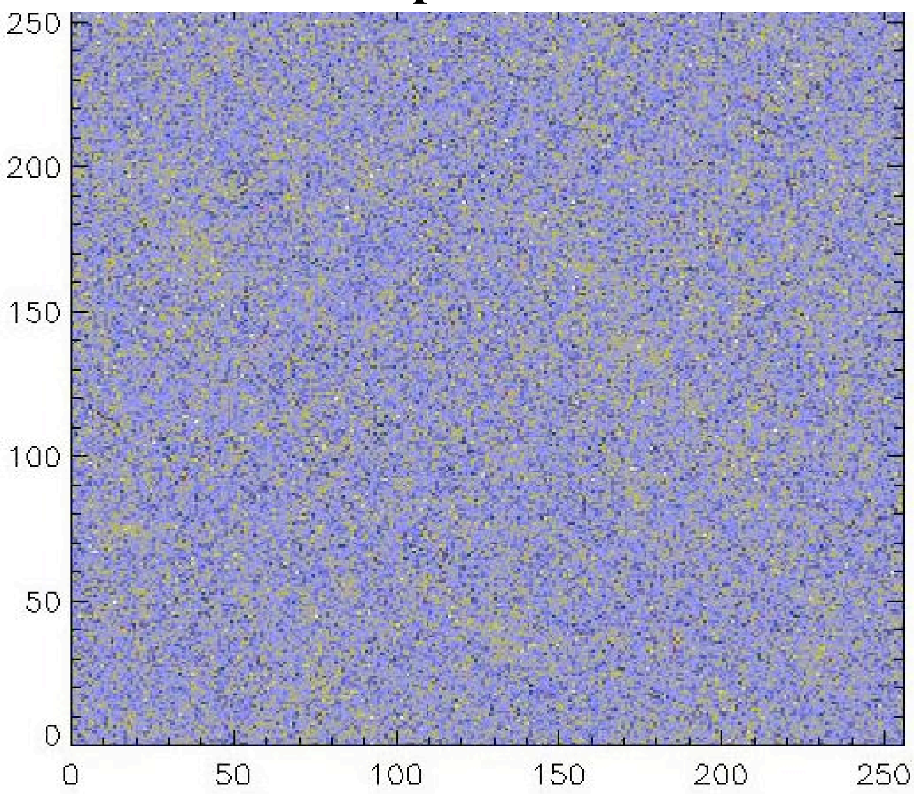


1x1 deg

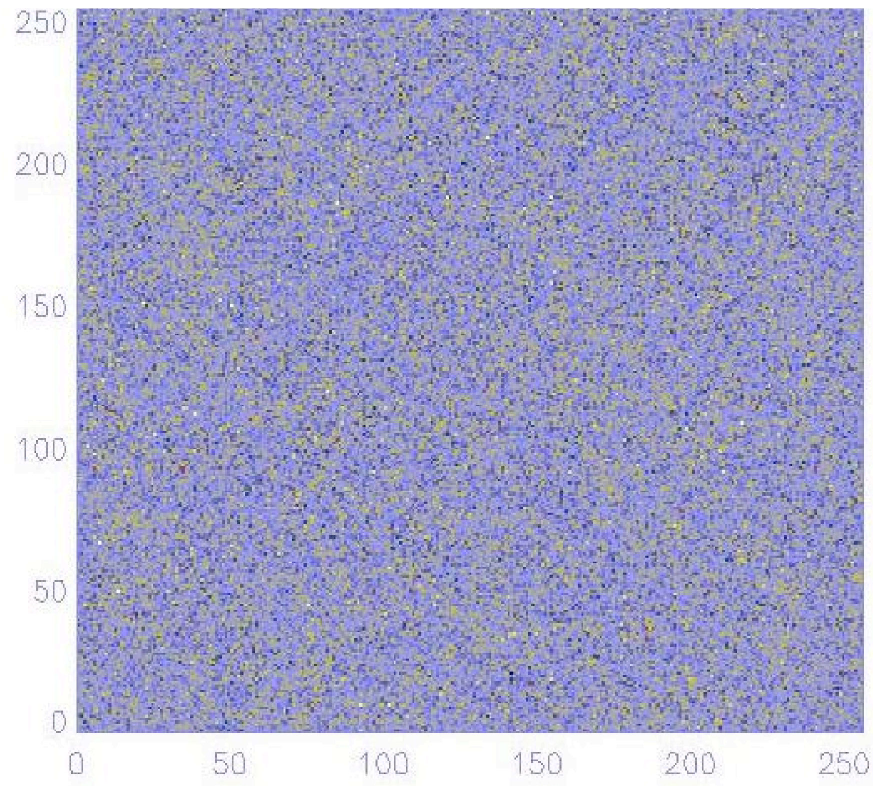
- **Mapping of the distribution of Dark Matter on various scales**
- **Measurement of cosmological parameters, breaking degeneracies present in other methods (SNe, CMB)**
- **Measurement of the evolution of structures**
- **Test of gravitational instability paradigm**
- **Test of General Relativity in the weak field regime**
- **a mass-selected cluster catalog**

Problem :
maps are very noisy

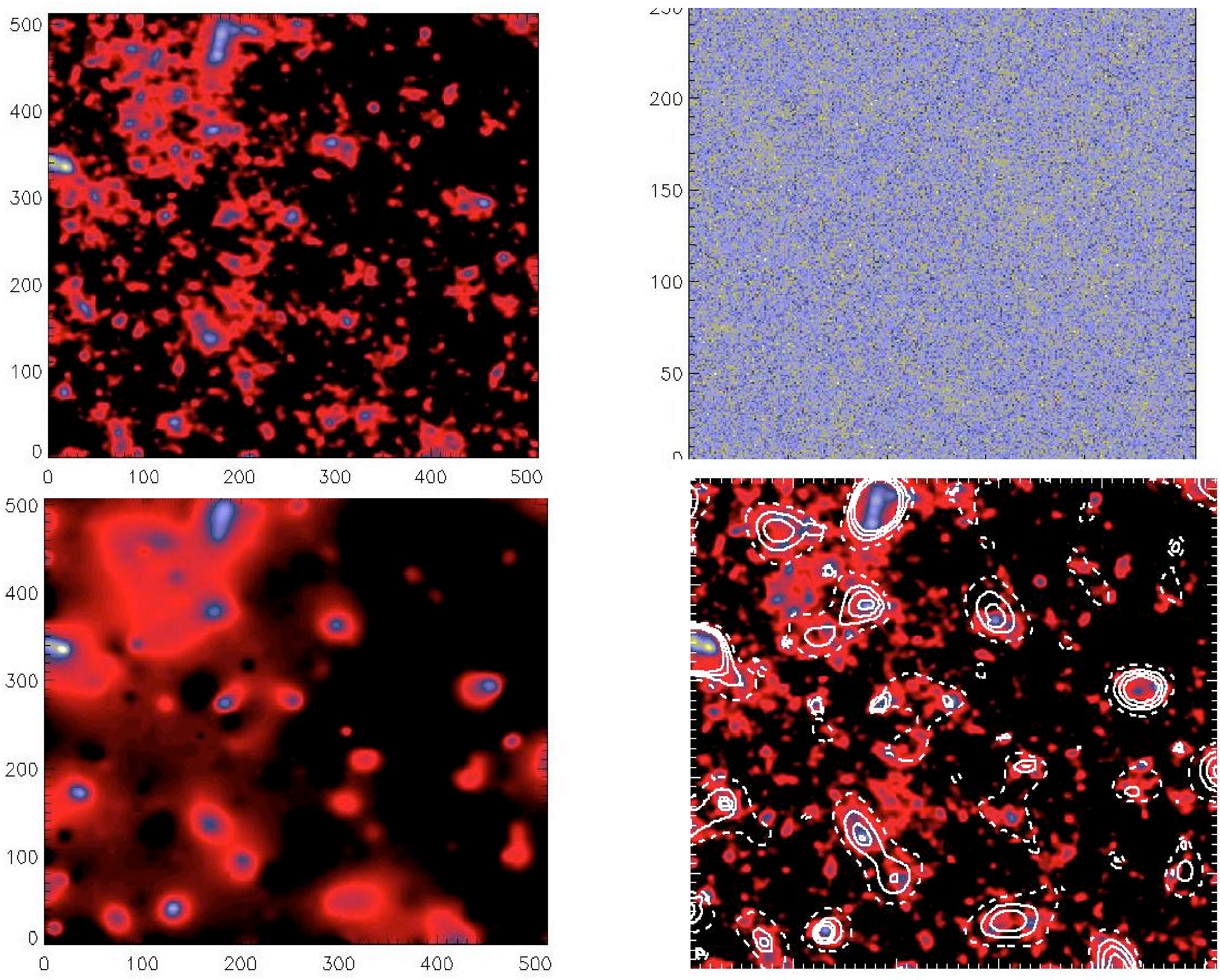
Simulated spatial observation



Simulated on ground observation



Reconstructed Dark Matter Map



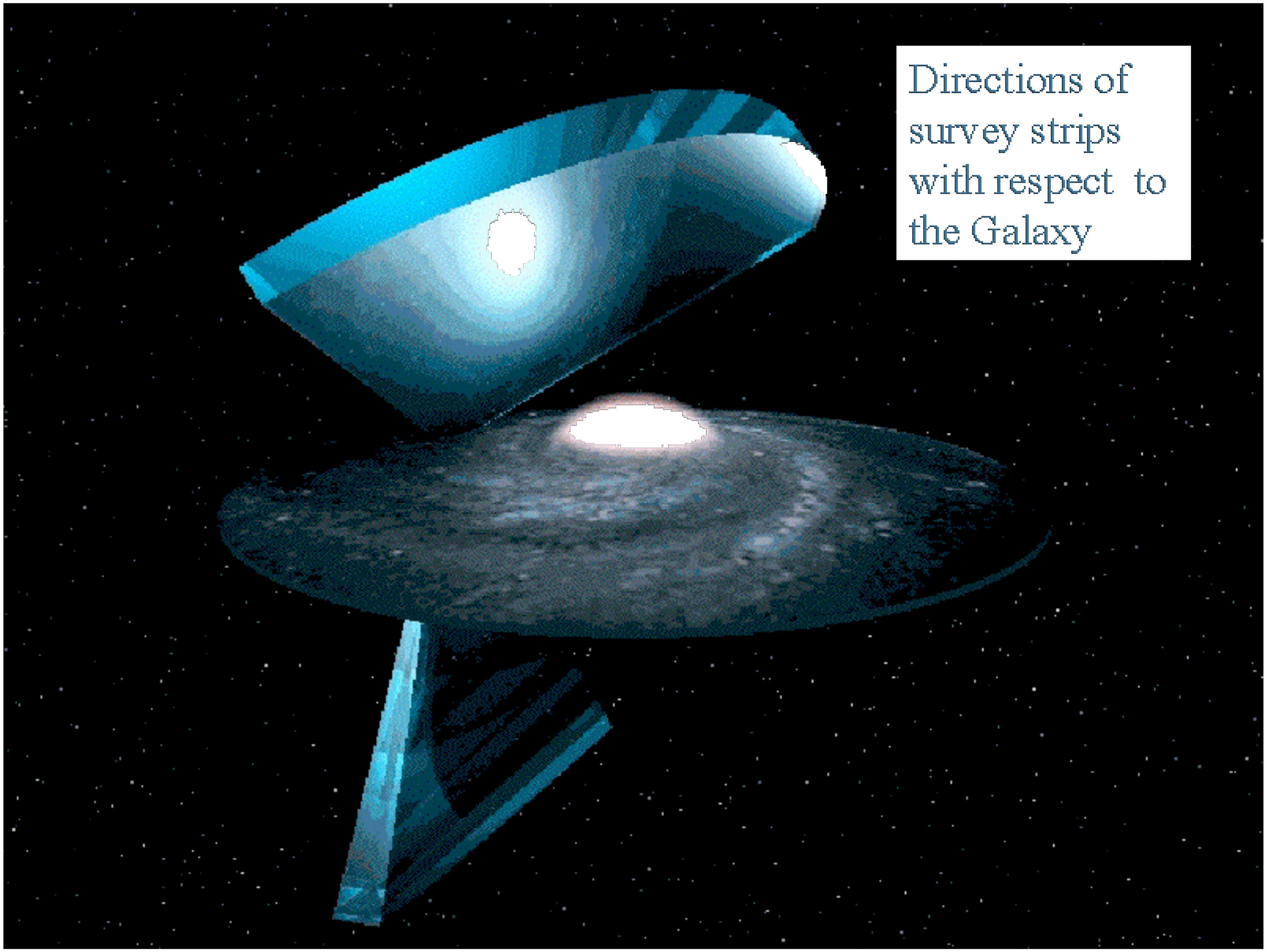
Analysis of catalog of galaxies

The spatial distribution of galaxies allows us to:

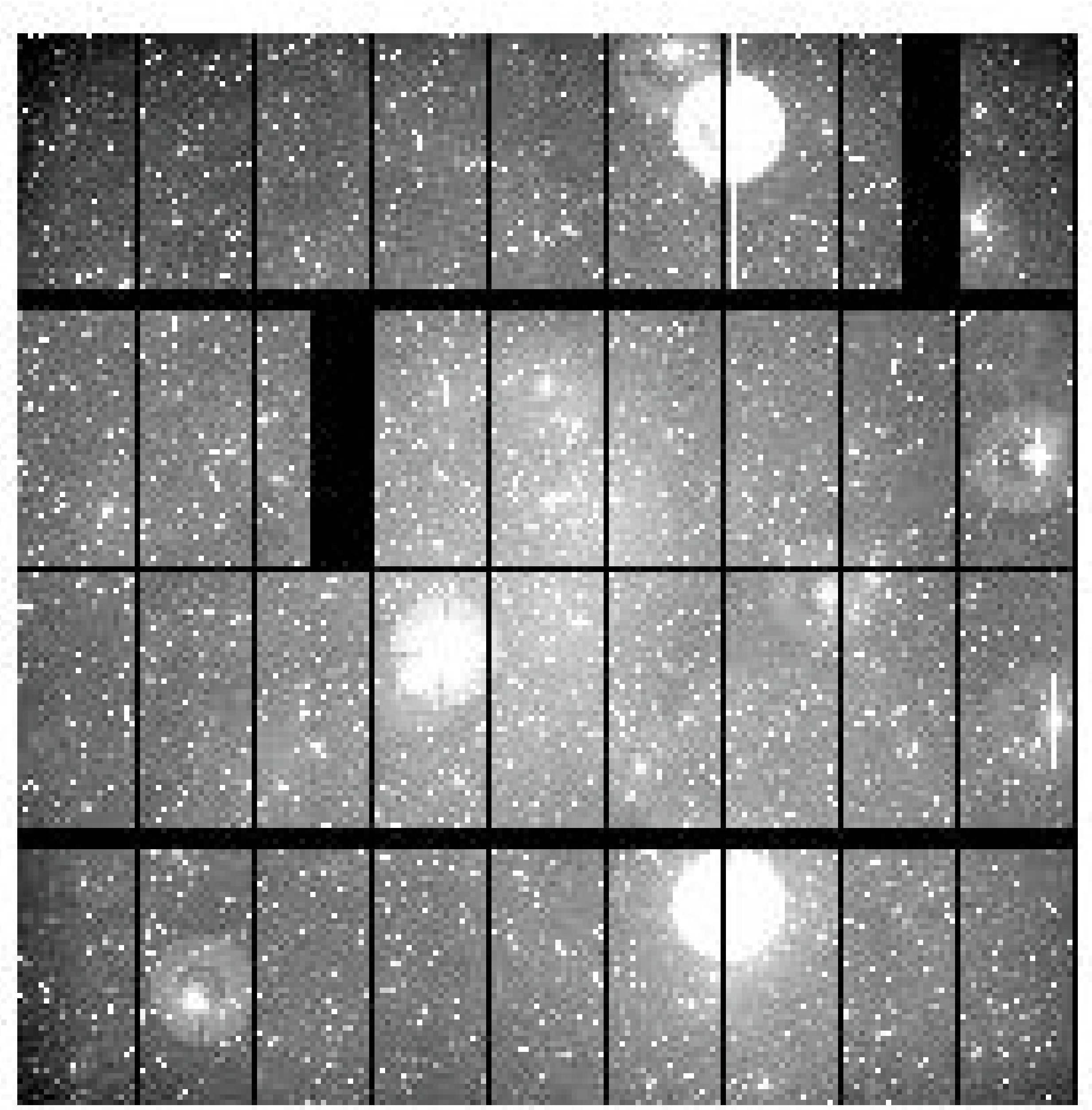
. Check and constraint the cosmological models.

. Study the formation of large scale structures.

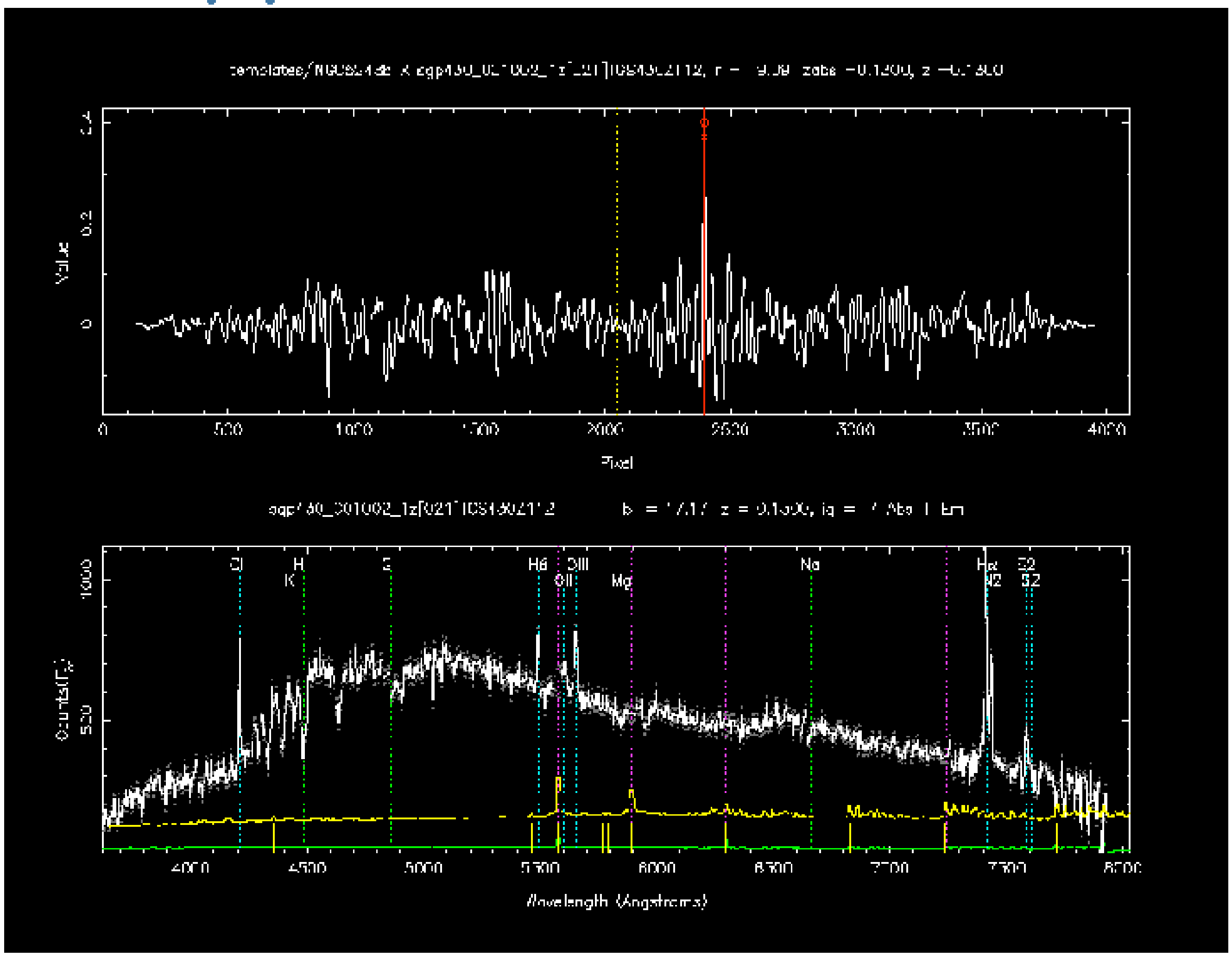
2dF Galaxy Redshift Survey



MEGACAM RAW IMAGE



Data pipeline: real-time redshifts



To map out the universe:

1) Measure redshifts of lots of galaxies: $\mathbf{z = \Delta\lambda / \lambda}$

2) Calculate speed from redshift: $\mathbf{V = c\, z}$

3) Calculate distance from Hubble Law: $\mathbf{V = H\, d}$

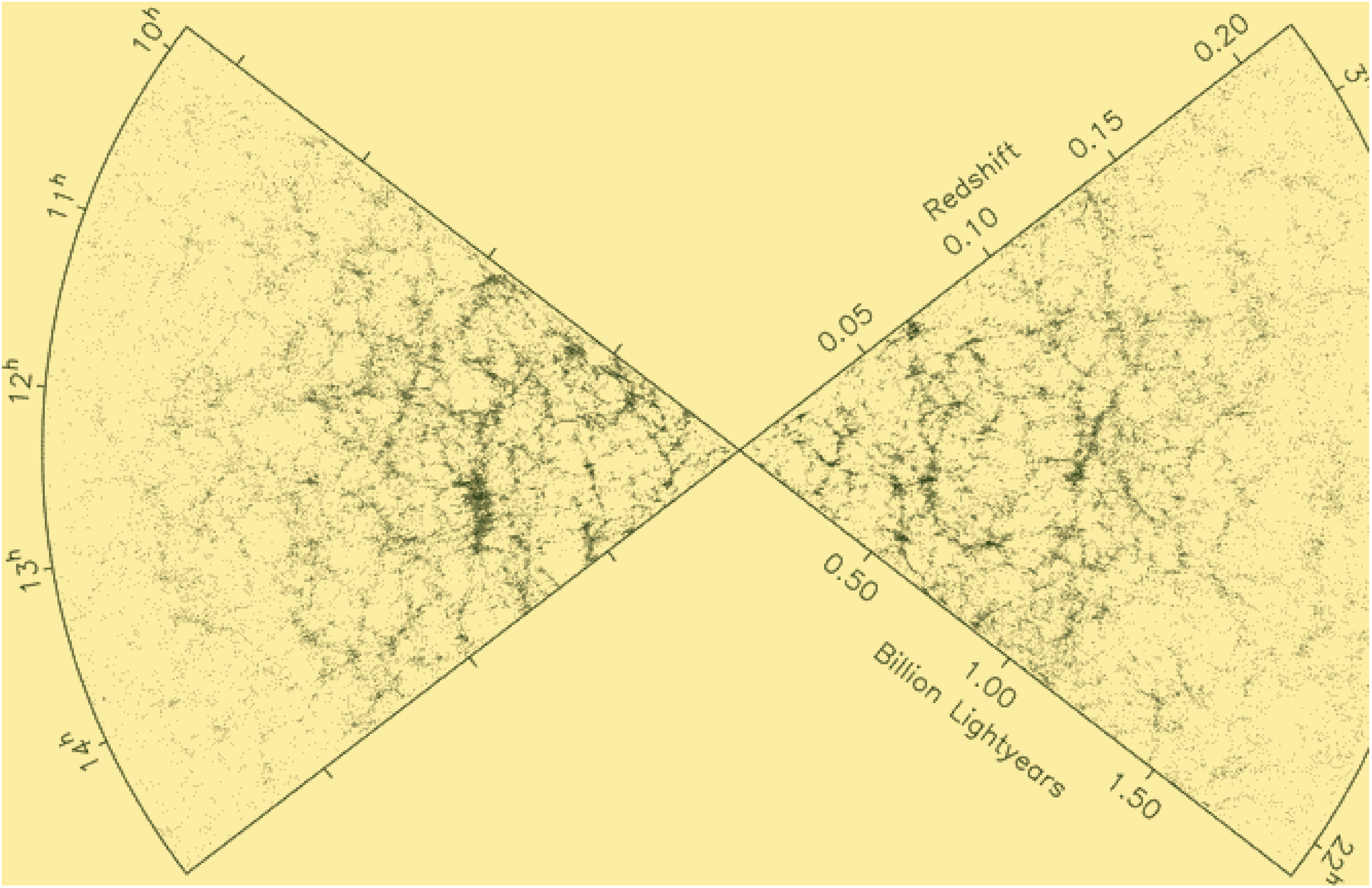
V = velocity (in km/s)
d = distance (in megaparsec = 3.08 10^19 km)
H = Hubble constant (around 70 km/s per Mpc)

4) make a map of direction vs. distance

lots of structures

- bubbles and voids
- some structures more than 10 Mpc long
- voids at least that wide across

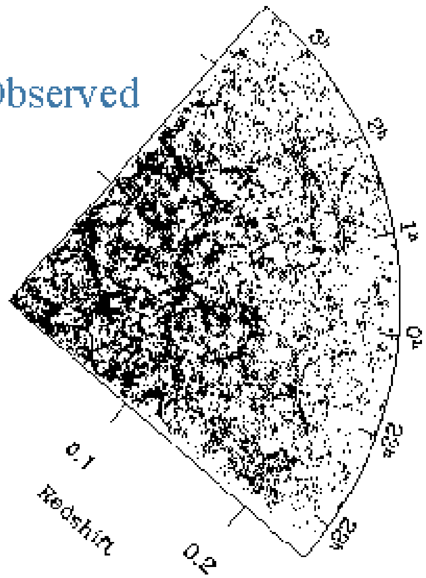
How do you form such huge things?



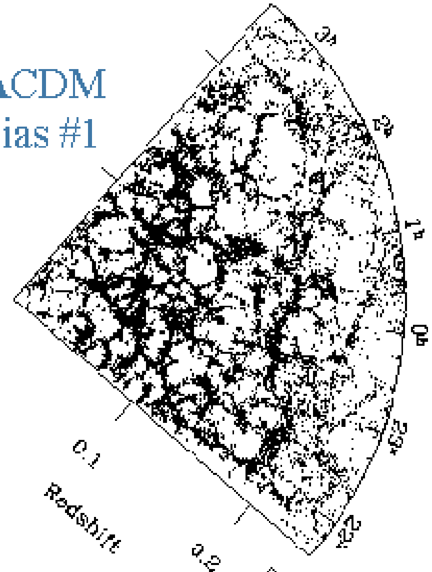
10h
11h
12h
13h
14h
0.05
0.10
0.15
0.20
Redshift
0.50
1.00
1.50
Billion Lightyears
22h

Models vs observations

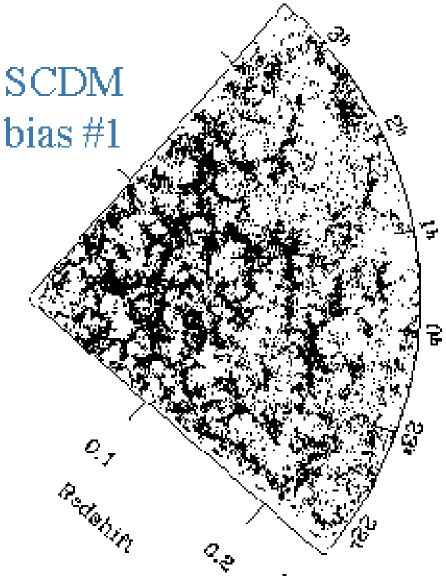
Observed



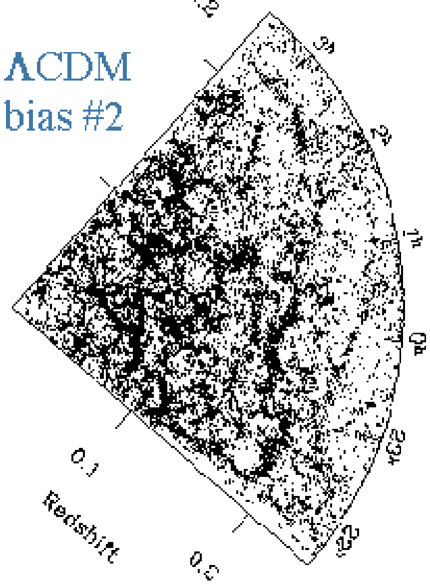
ΛCDM
bias #1



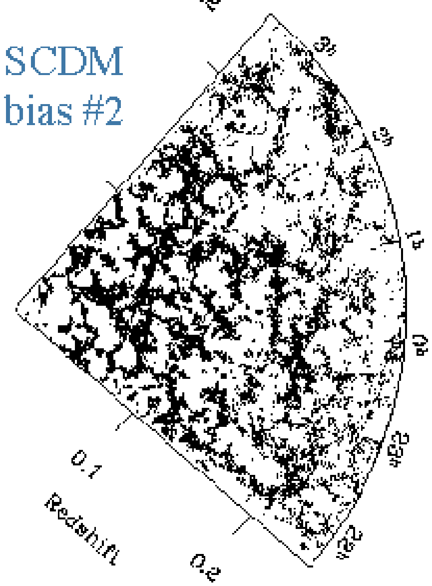
SCDM
bias #1



ΛCDM
bias #2



SCDM
bias #2



Methods

.Two or three point correlation function

. Genus curve

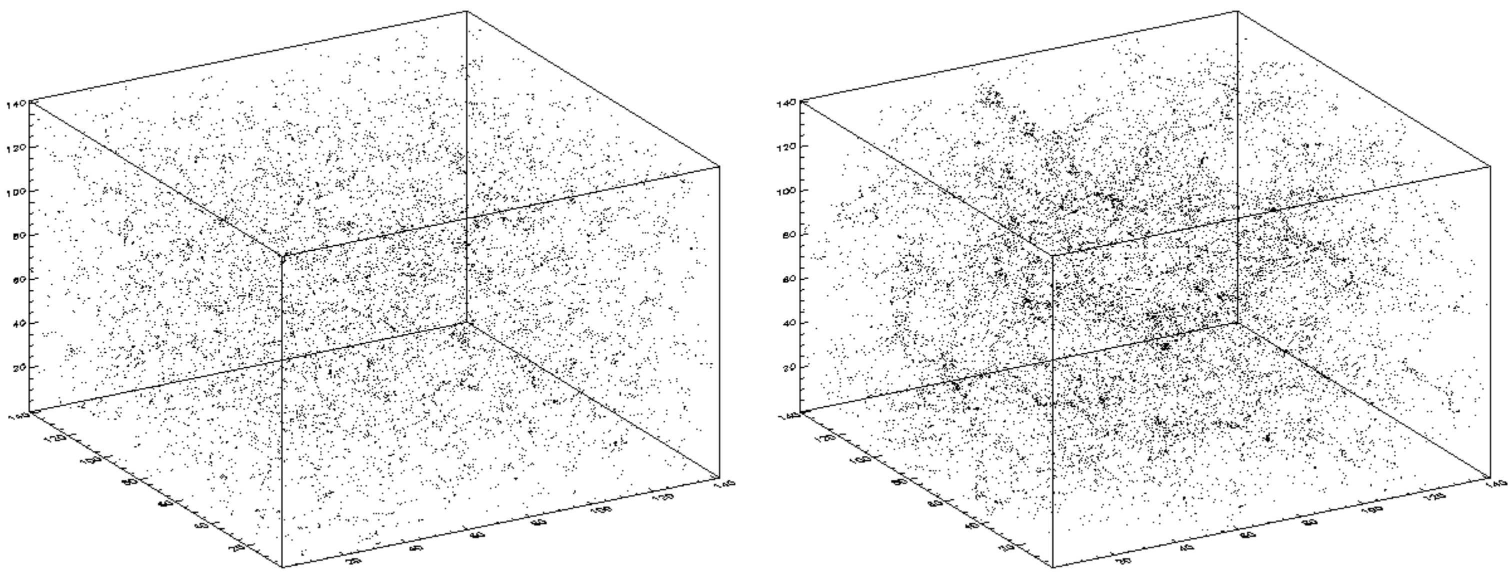
. Voronoi Tessellation

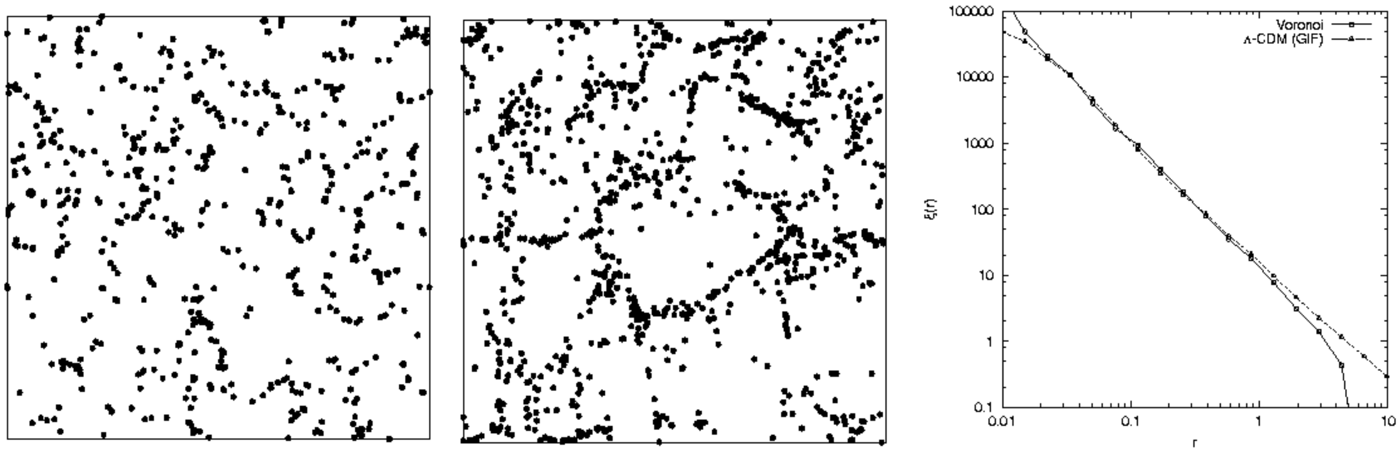
. Minimal spanning trees

. Power spectrum

. Fractals

Simulations




Voronoi
Λ-CDM (GIF)
ξ(r)
r
100000
10000
1000
100
10
1
0.1
0.01
0.1
1
10

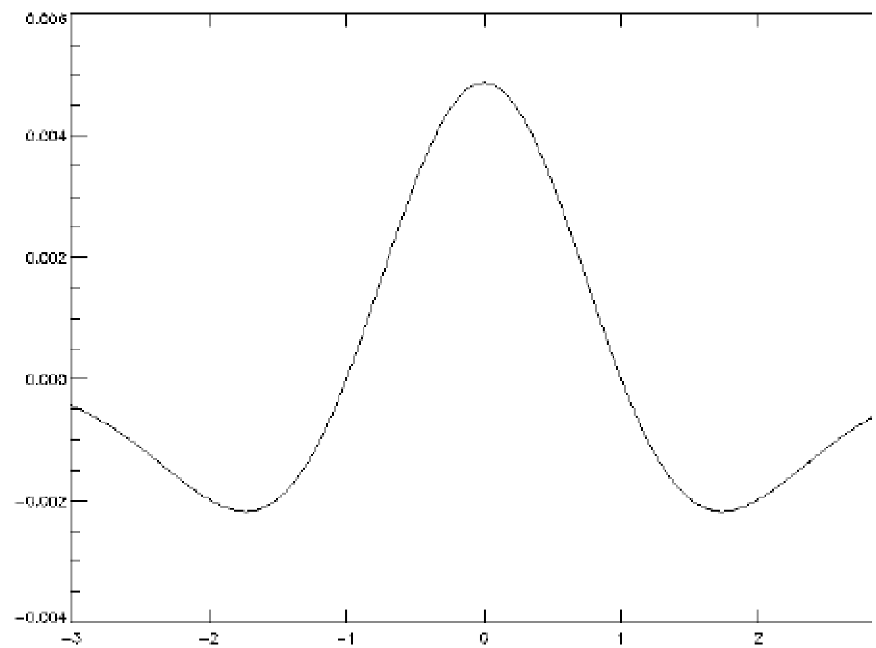
GENUS FUNCTION

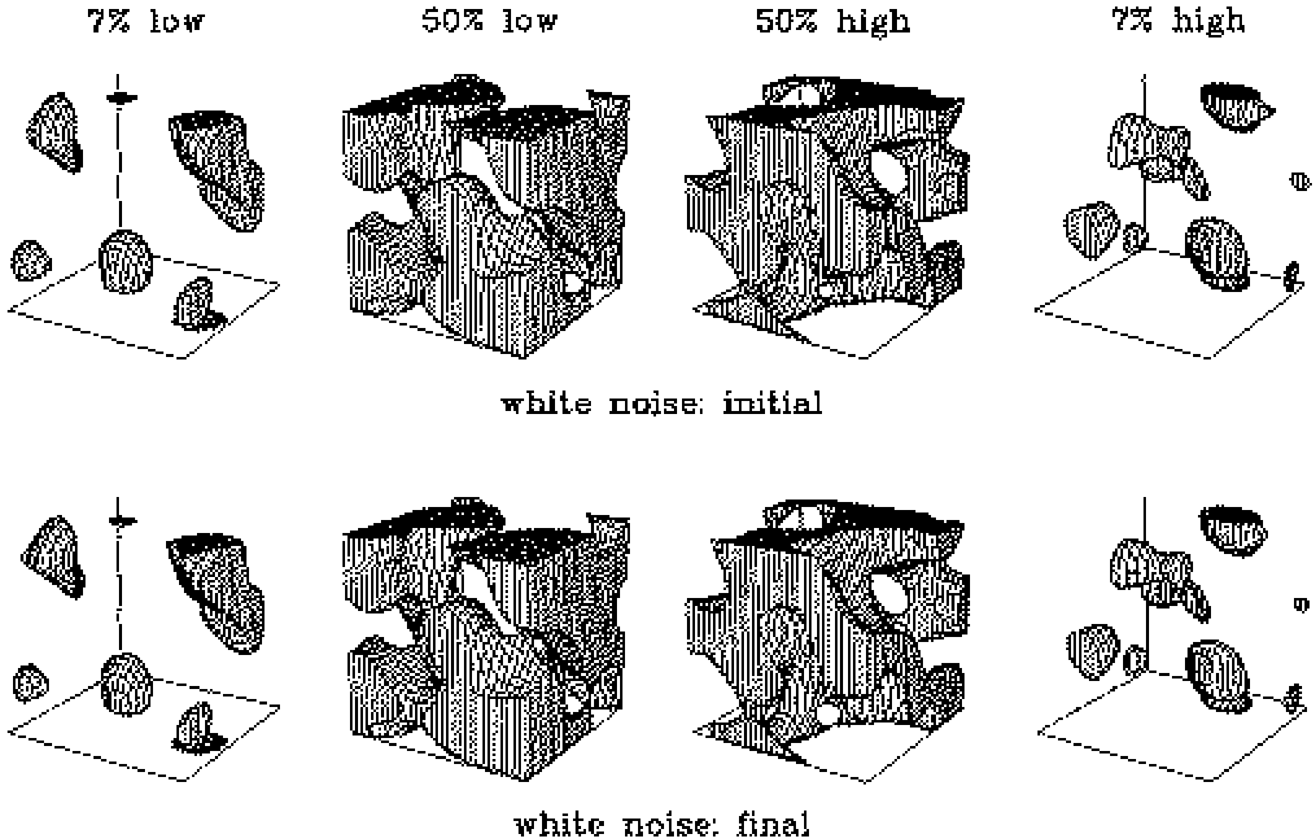
The genus of a surface G is

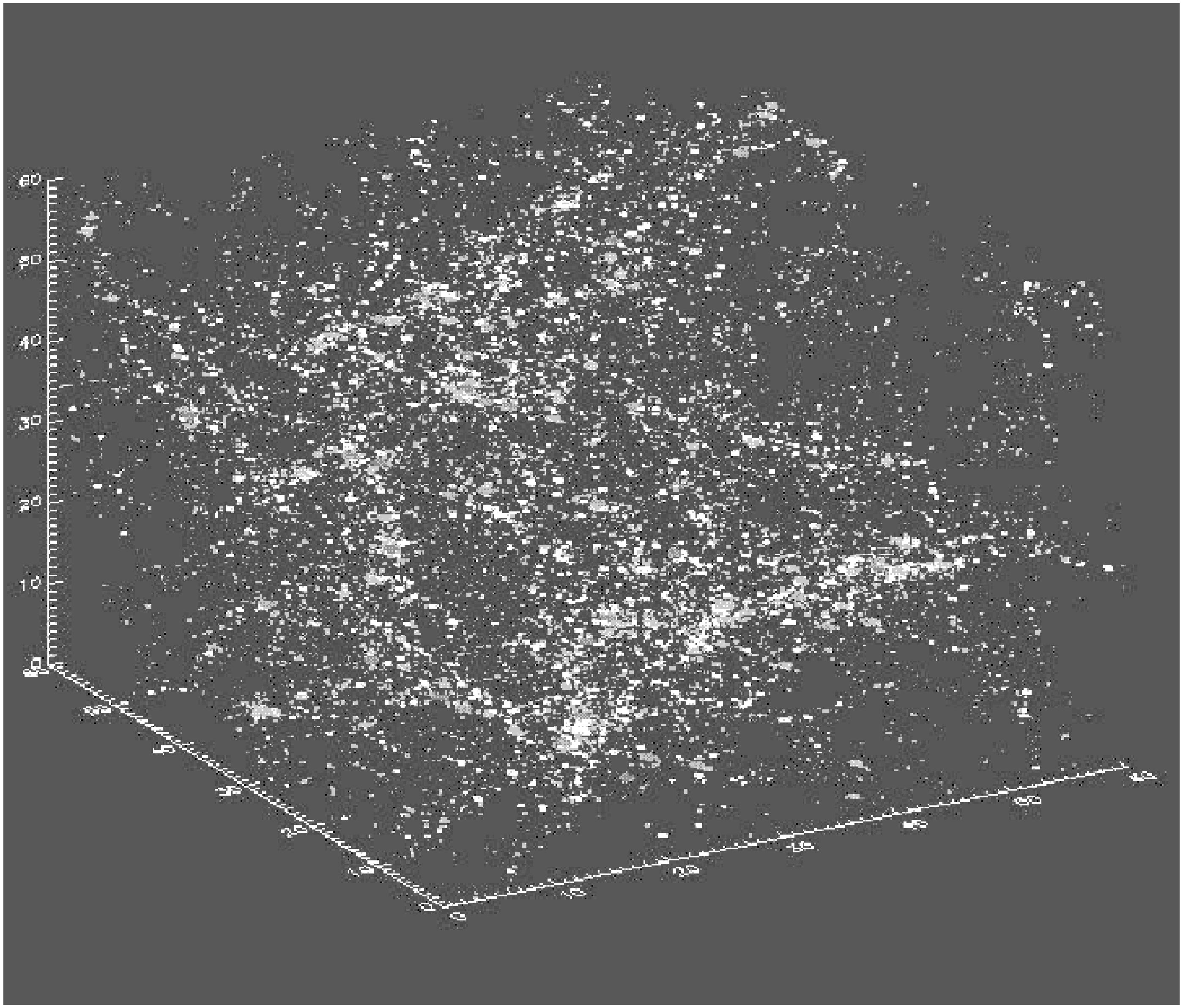
G(T) = (number of holes) - (number of isolated regions) + 1

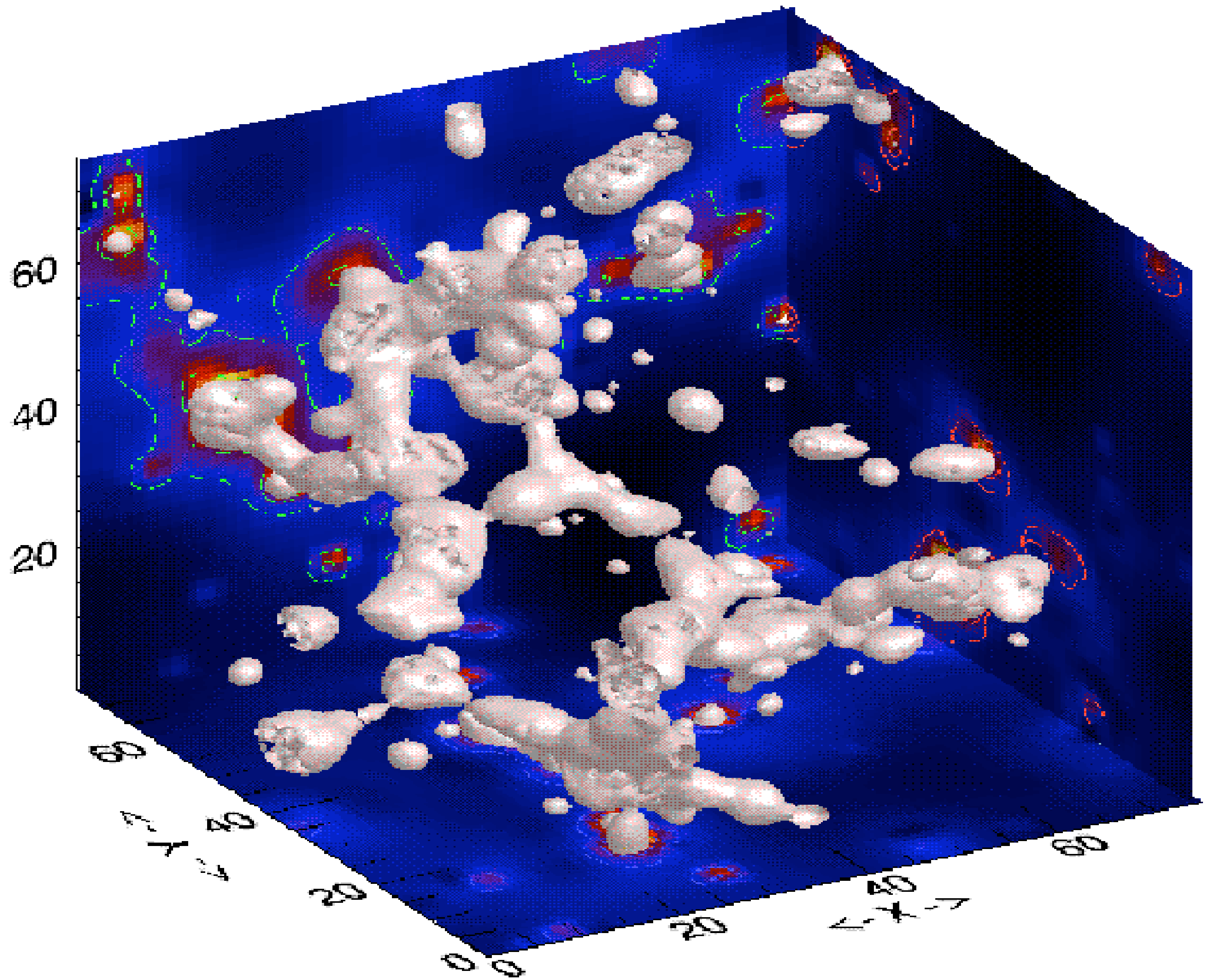
- Convolve the data by a Gaussian
  - Threshold all values under a threshold level T
  - G(T) = (number of holes) - (number of isolated regions) + 1

For a Gaussian field, the genus curve is:




7% low
50% low
50% high
7% high
white noise: initial
white noise: final


60
50
40
30
20
10
0



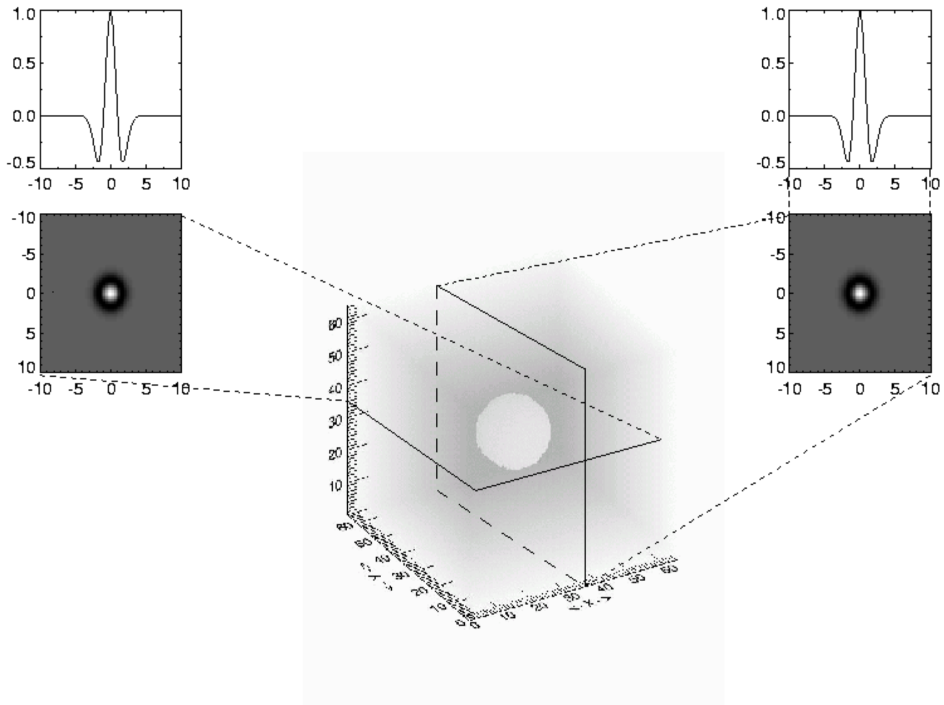
60
40
20
60
40
<-Y->
20
0
0
20
40
<-X->
60

3D MULTISCALE TRANSFORMS

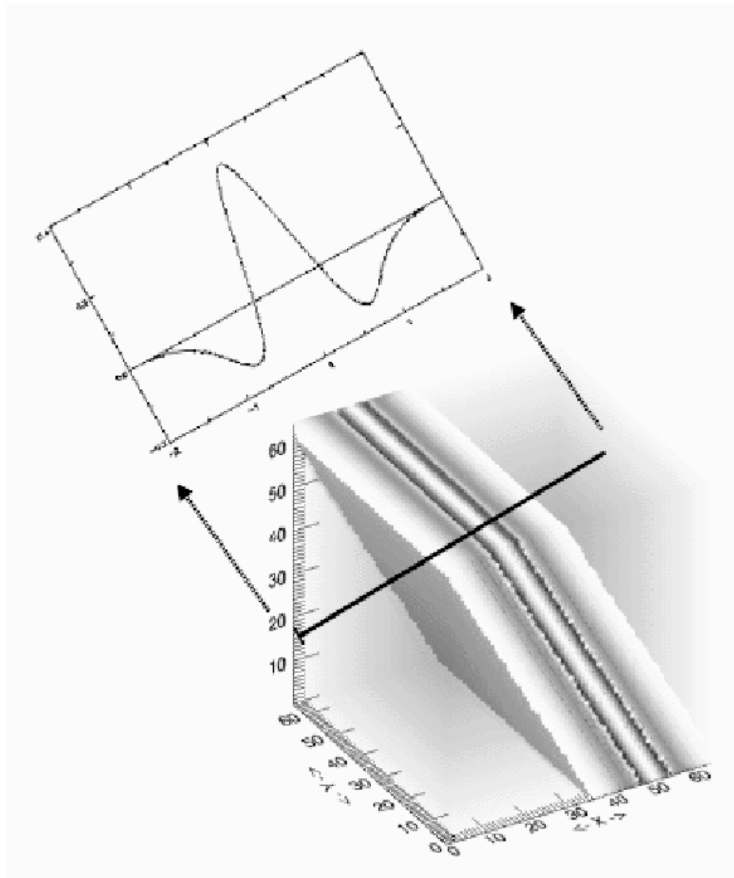
1) **3D WAVELET TRANSFORM: Isotropic Structures**
2) **3D RIDGELET TRANSFORM: Sheet like Structures**
3) **3D BEAMLET TRANSFORM: Filaments**

=> Statistical information extraction.

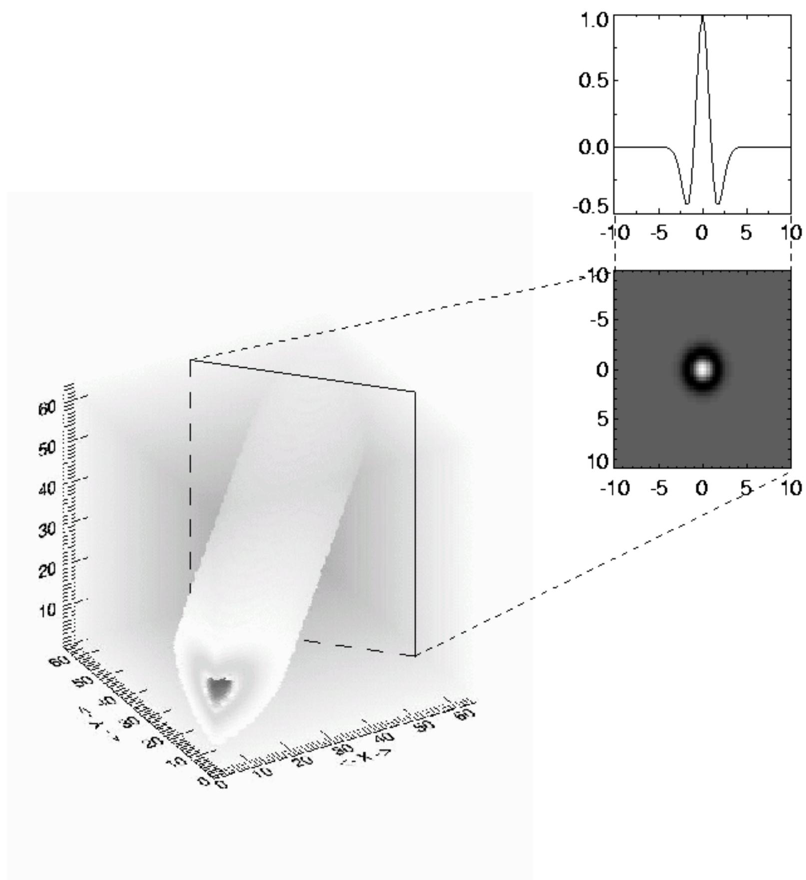
3D Wavelet Function

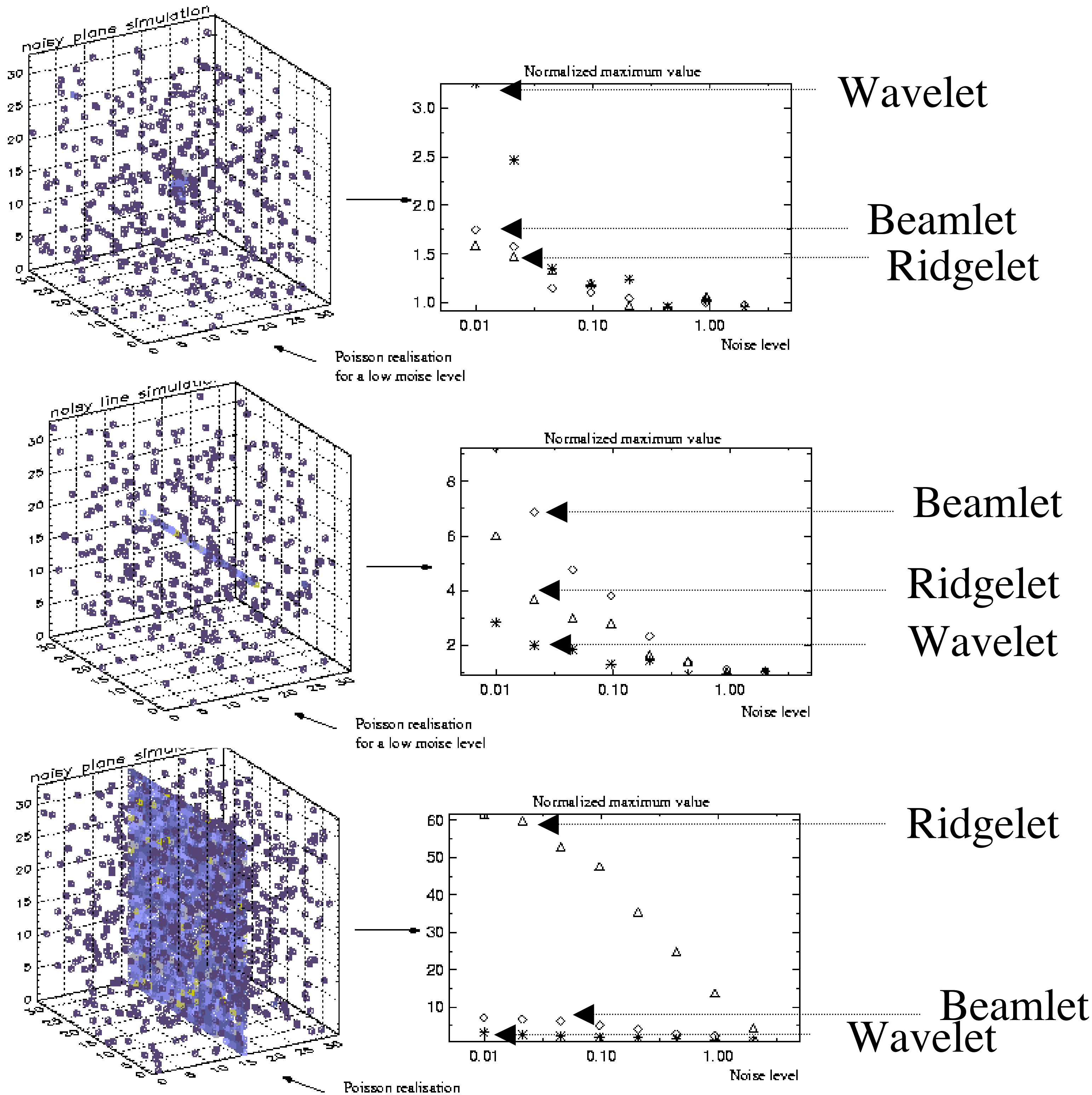


3D Ridgelet Function

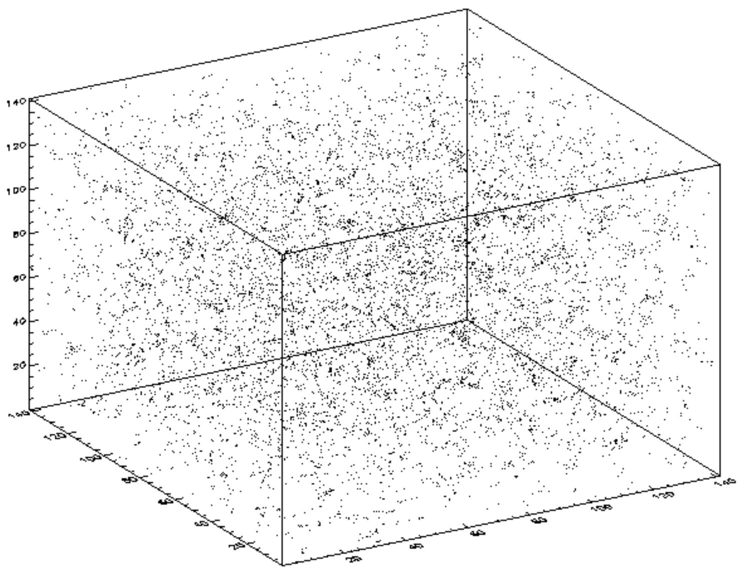


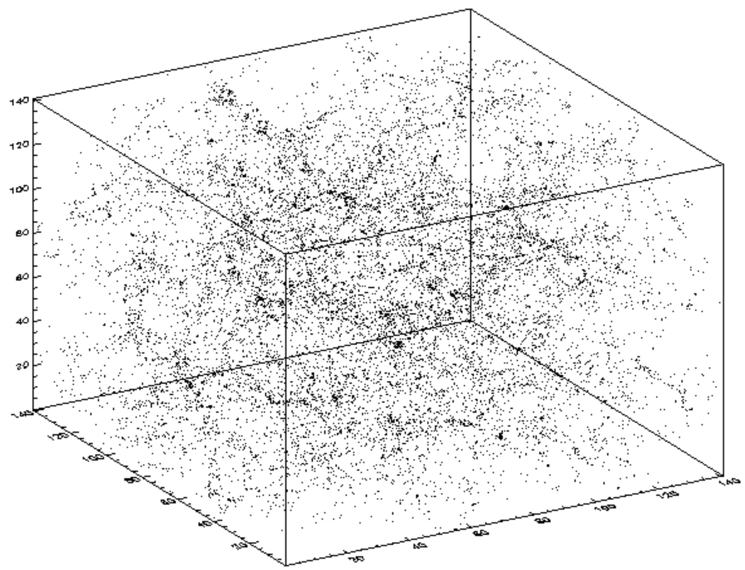
3D Beamlet Function



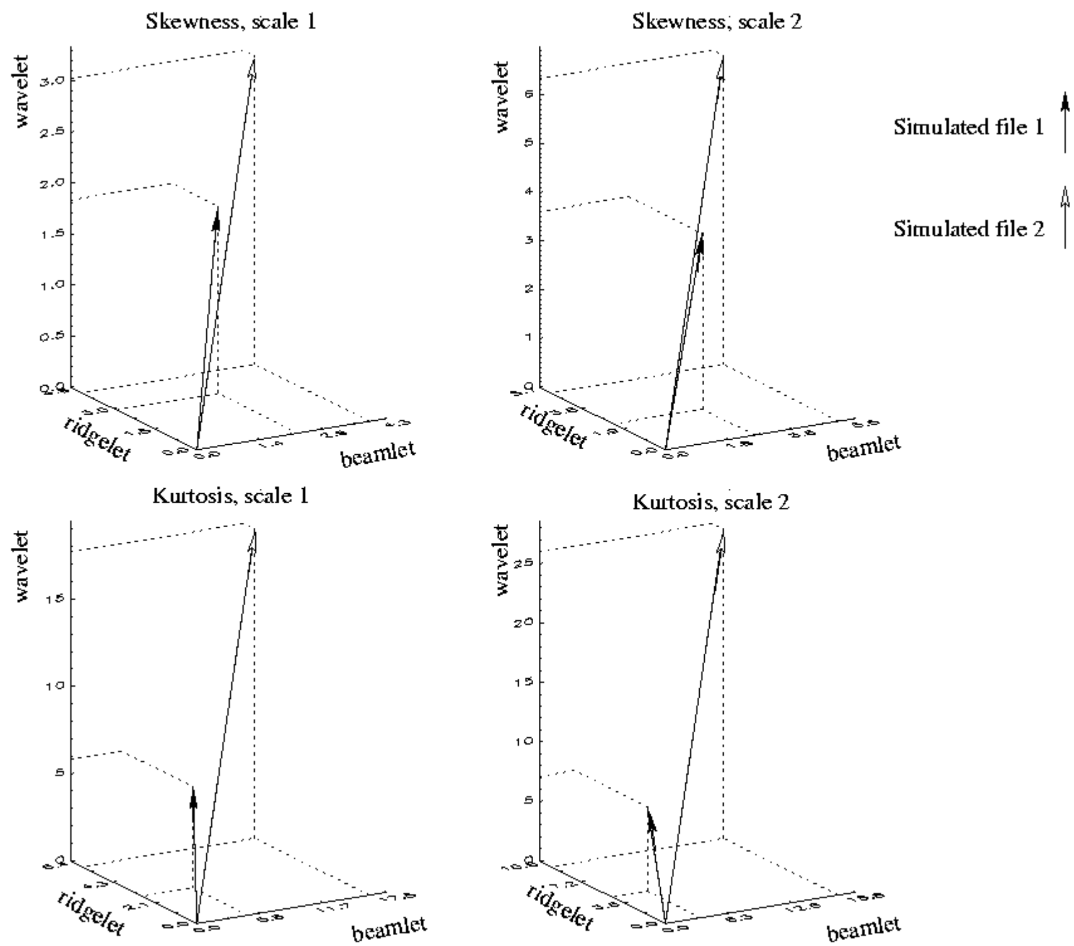

noisy plane simulation
Normalized maximum value
Noise level
Poisson realisation
for a low moise level
Wavelet
Beamlet
Ridgelet
noisy line simulation
Normalized maximum value
Noise level
Poisson realisation
for a low moise level
Beamlet
Ridgelet
Wavelet
noisy plane simulation
Normalized maximum value
Noise level
Poisson realisation
Ridgelet
Beamlet
Wavelet

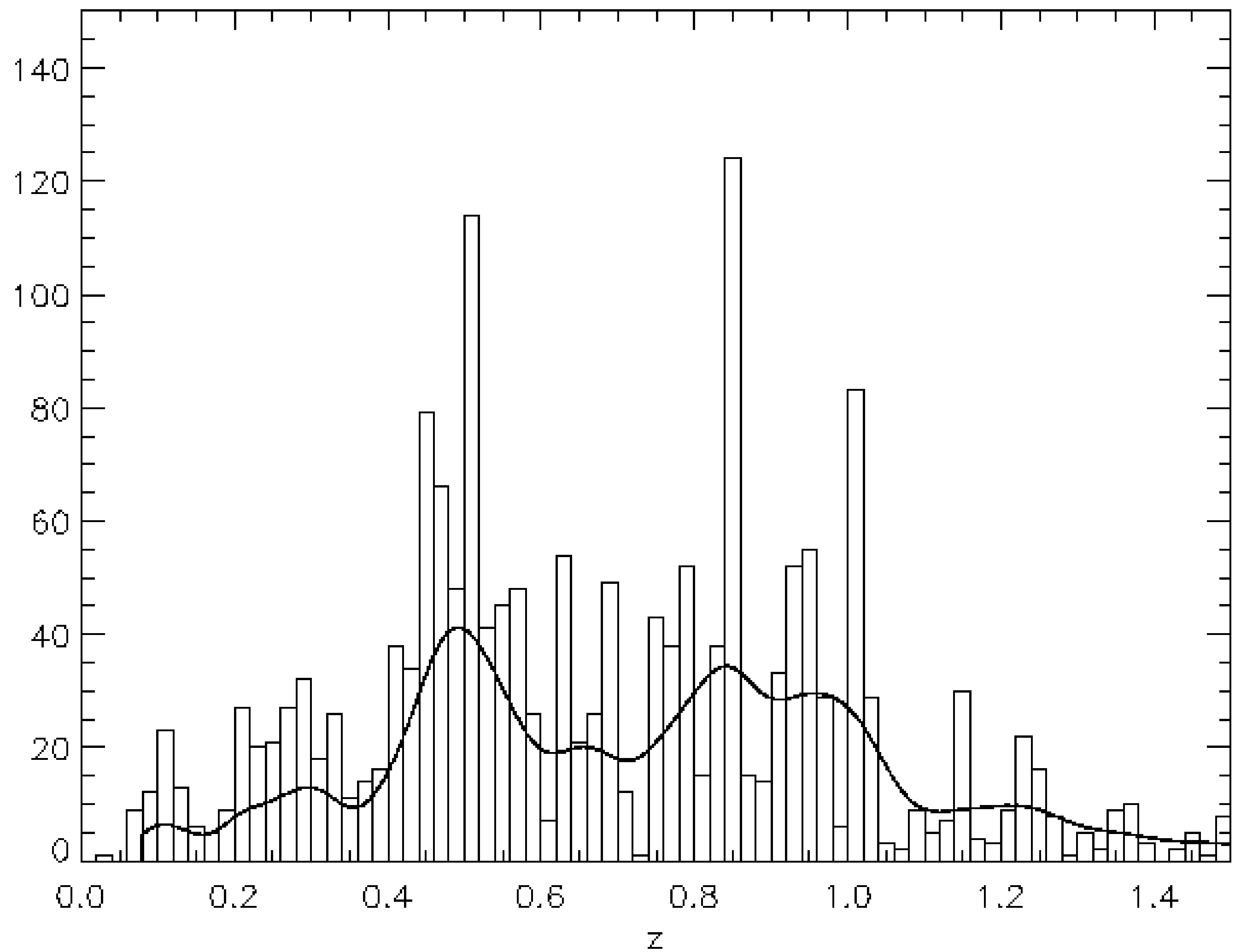
Simulations



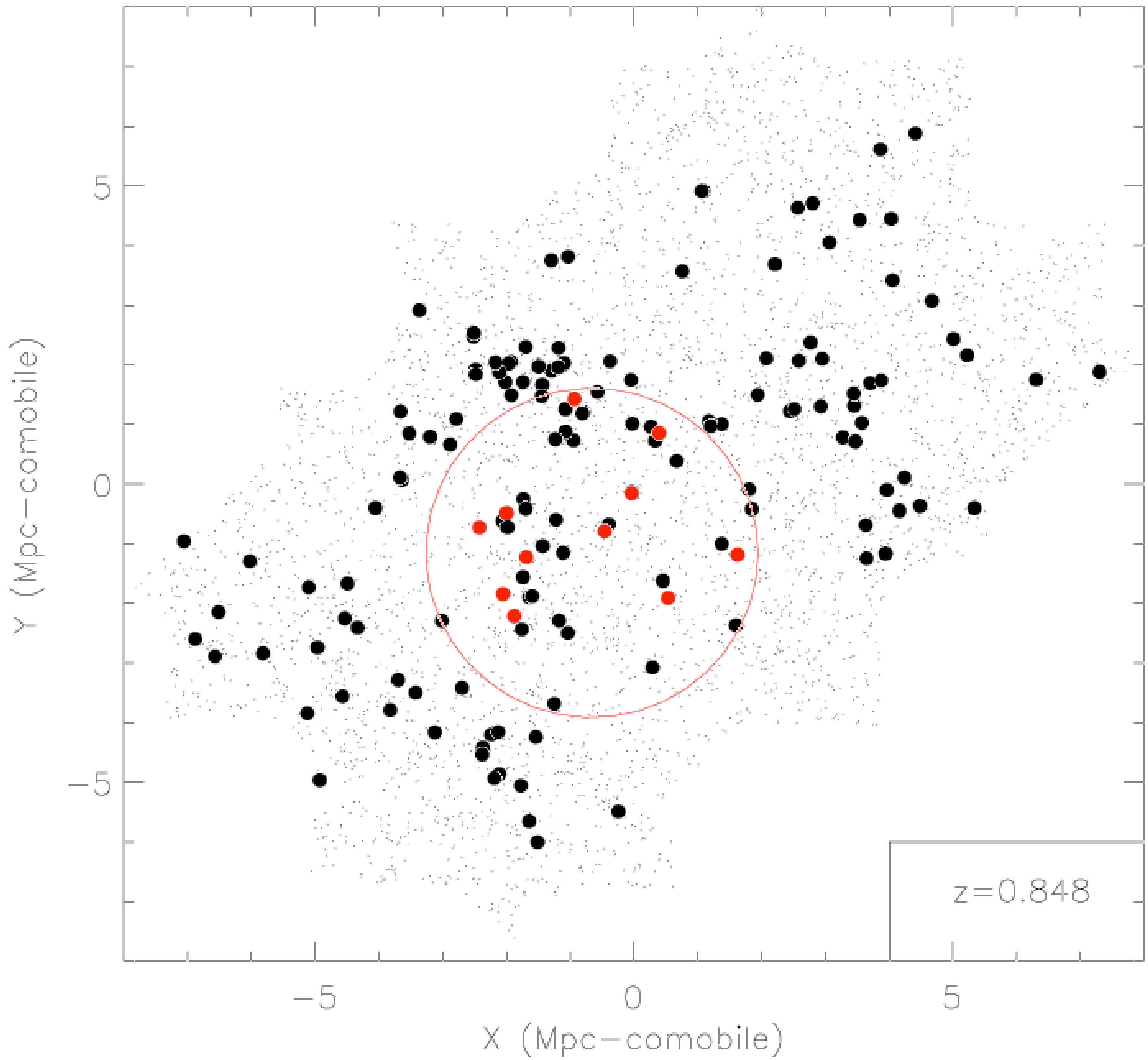


Skewness and Kurtosis

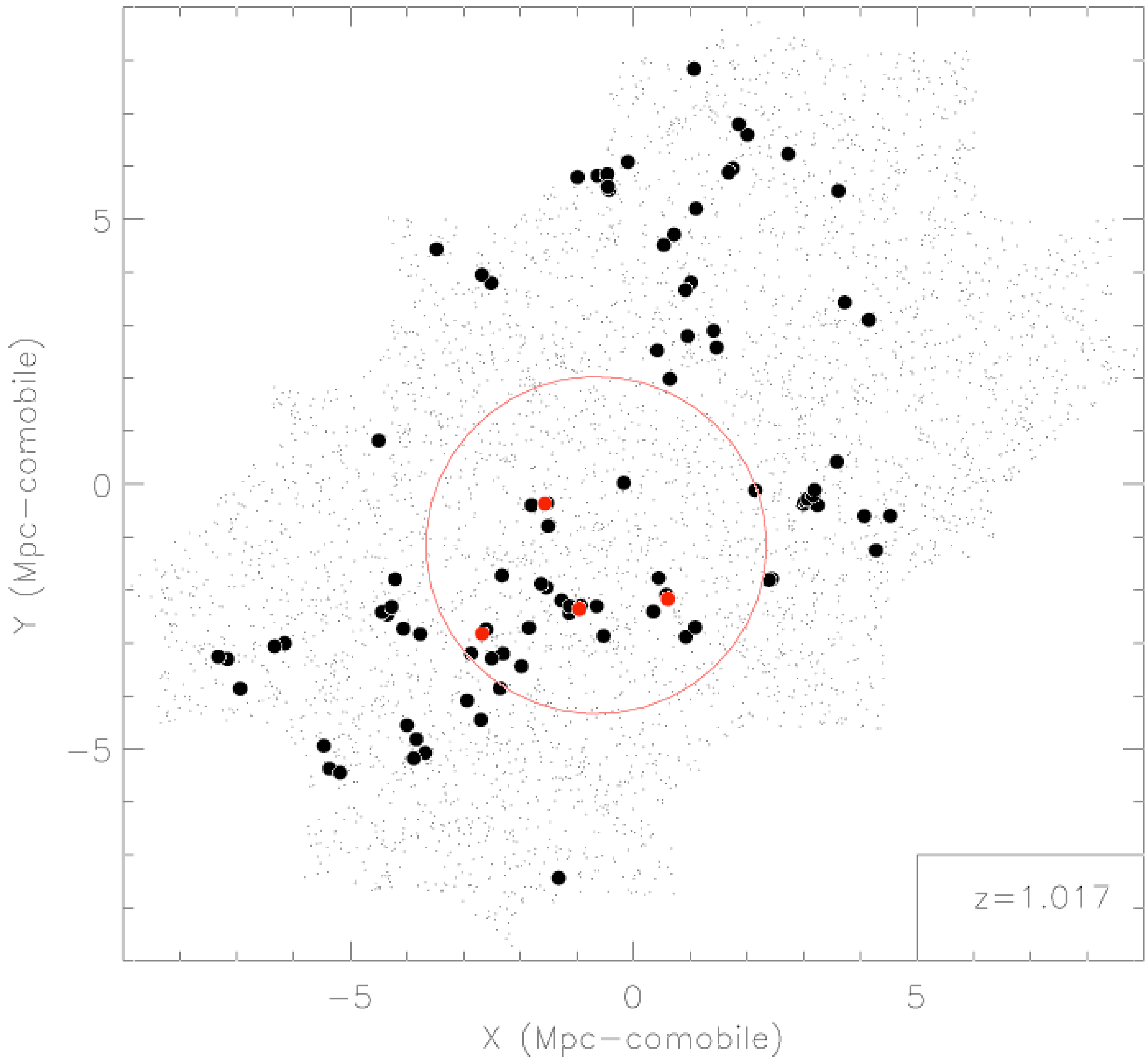




140
120
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
z

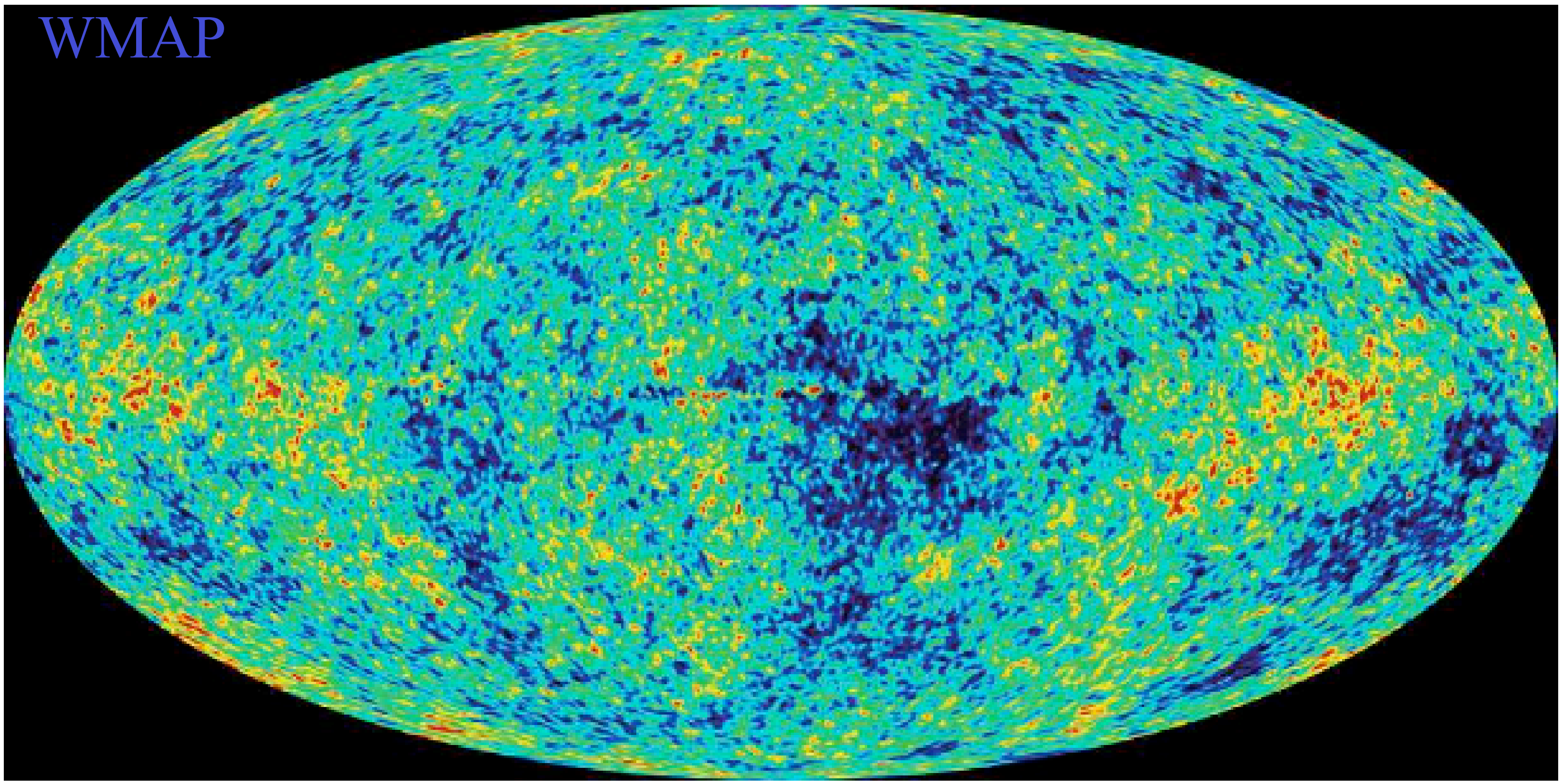


z=0.848
Y (Mpc−comobile)
X (Mpc−comobile)
5
0
−5
−5
0
5

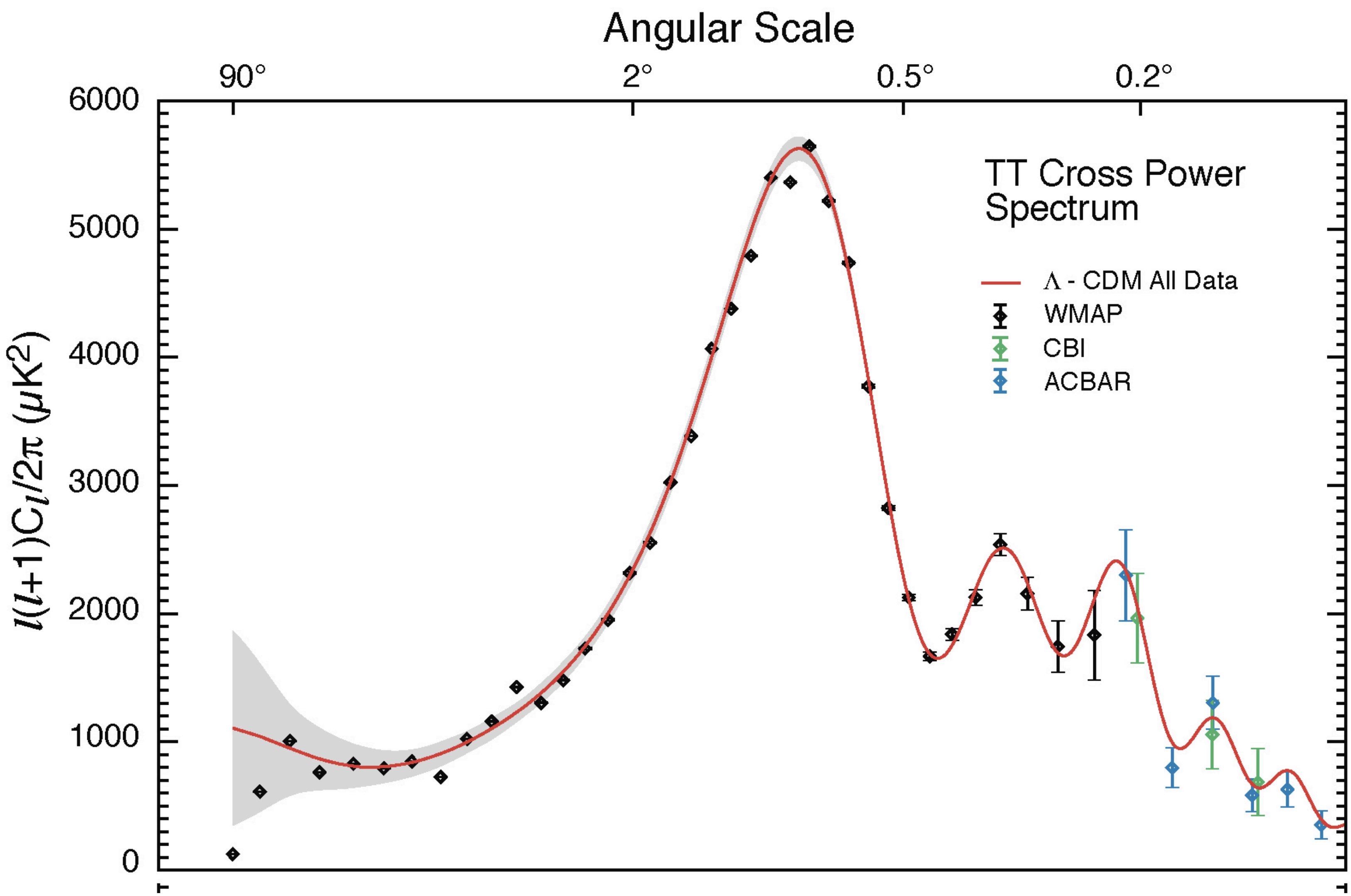


Y (Mpc−comobile)
X (Mpc−comobile)
5
0
−5
−5
0
5
z=1.017

Cosmic Microwave Background



The Cosmic Microwave Background (CMB) is a relic radiation (with a temperature equals to 2.726 Kelvin) emitted 13 billion years ago when the Universe was about 370000 years old.

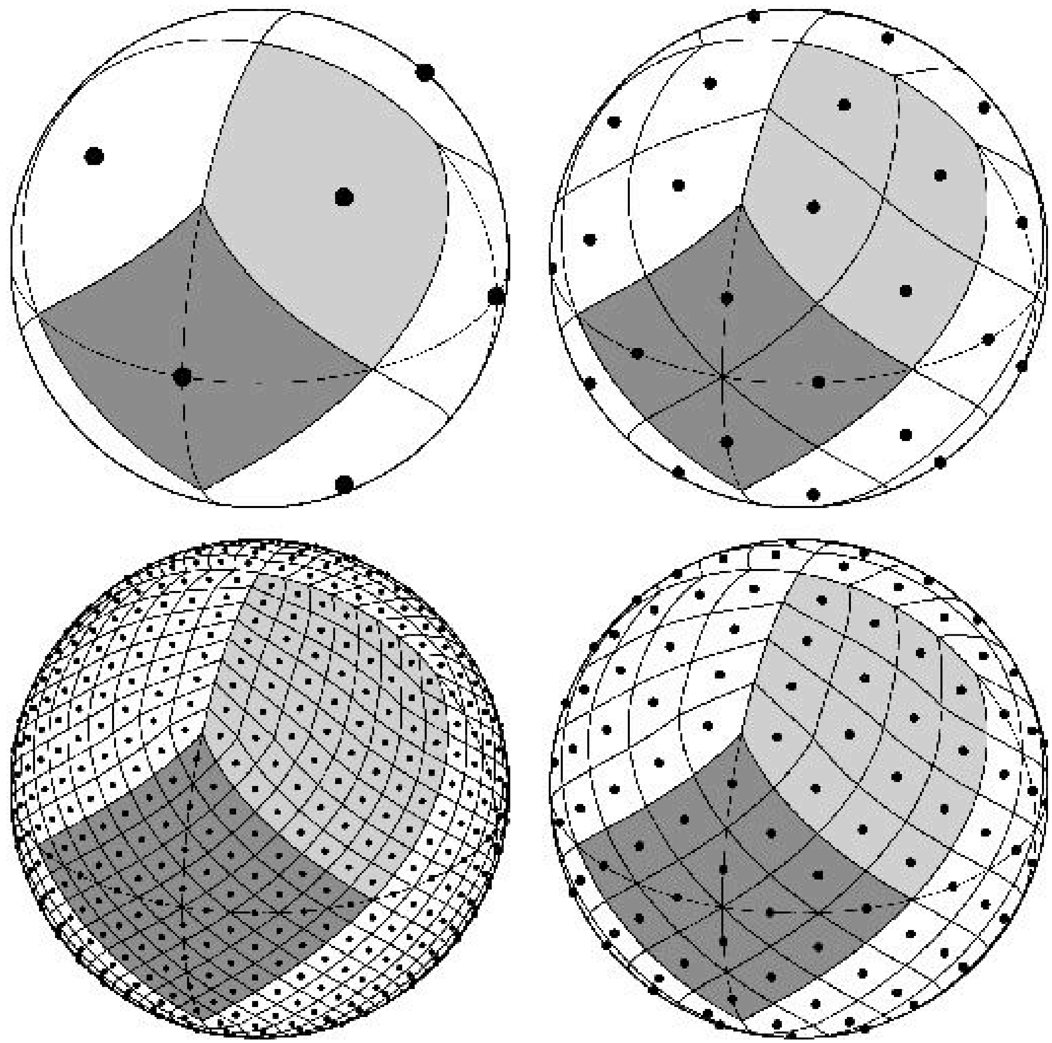


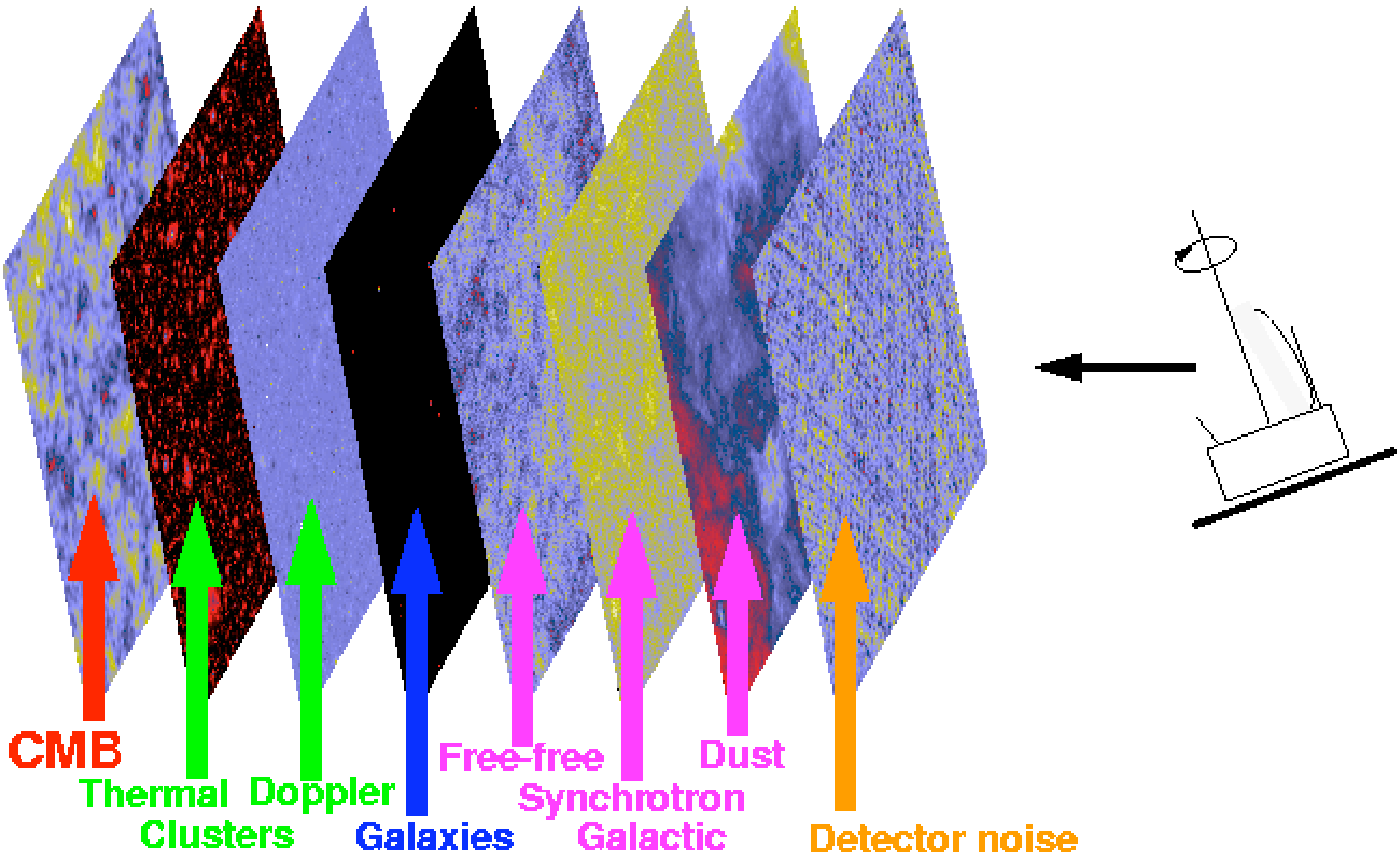
Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
TT Cross Power Spectrum
Λ - CDM All Data
WMAP
CBI
ACBAR

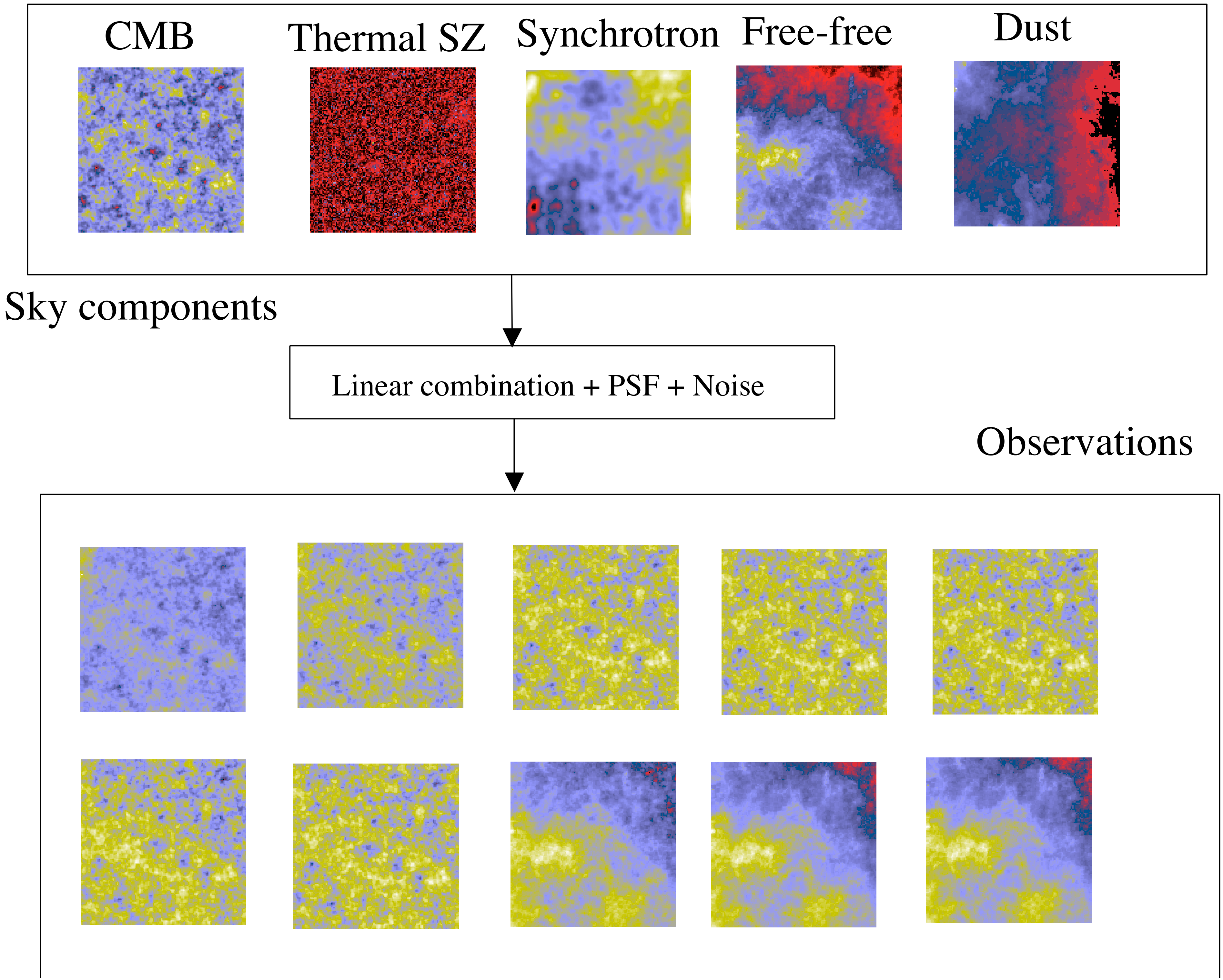
Healpix

K.M. Gorski et al., 1999, astro-ph/9812350,
http://www.eso.org/science/healpix

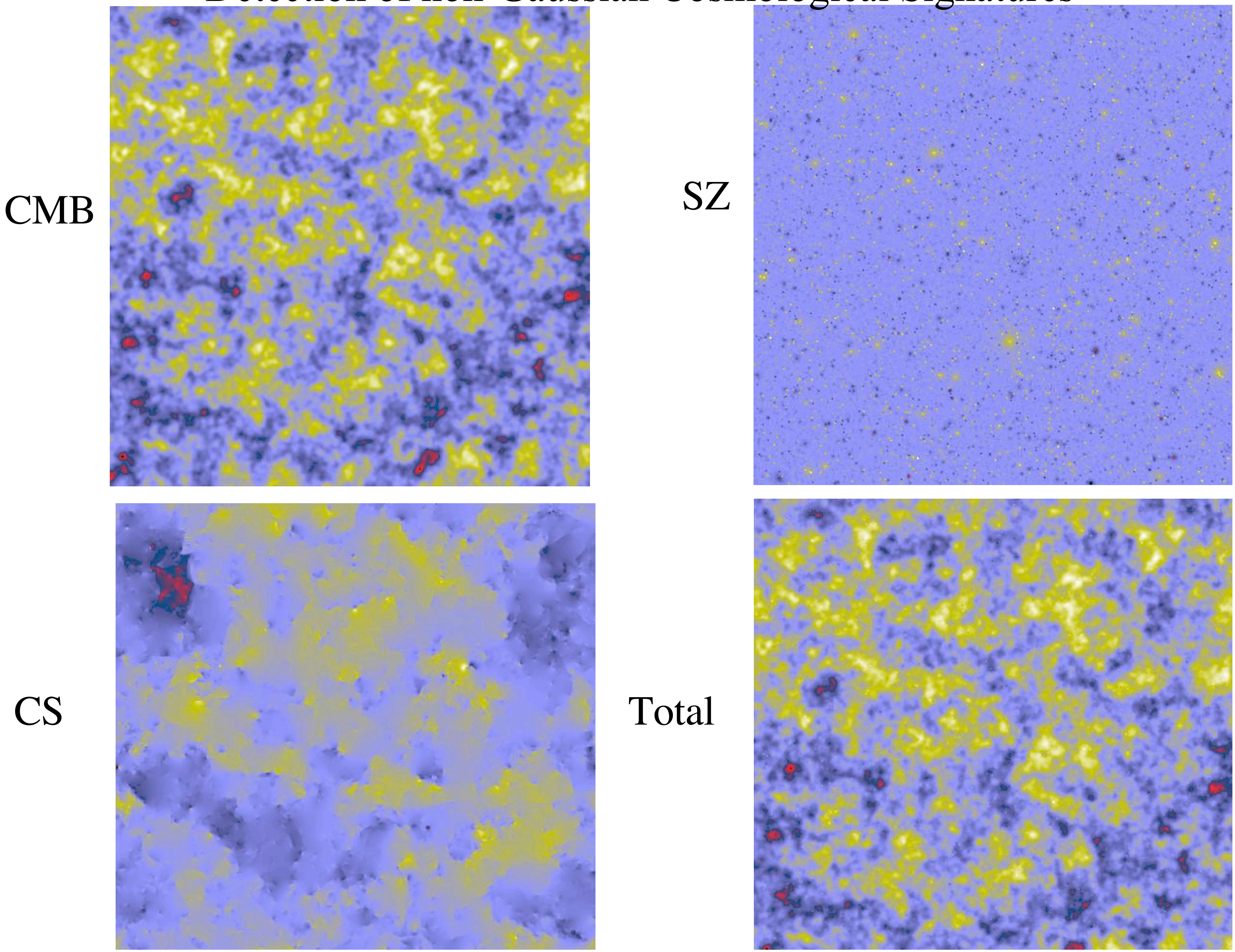
- Pixels = Rhombus
- Same Surfaces
- For a given latitude : regularly spaced
- Nbr of pixels :12*nside^2
- Includeds in the software:
  - Anafast
  - Synfast

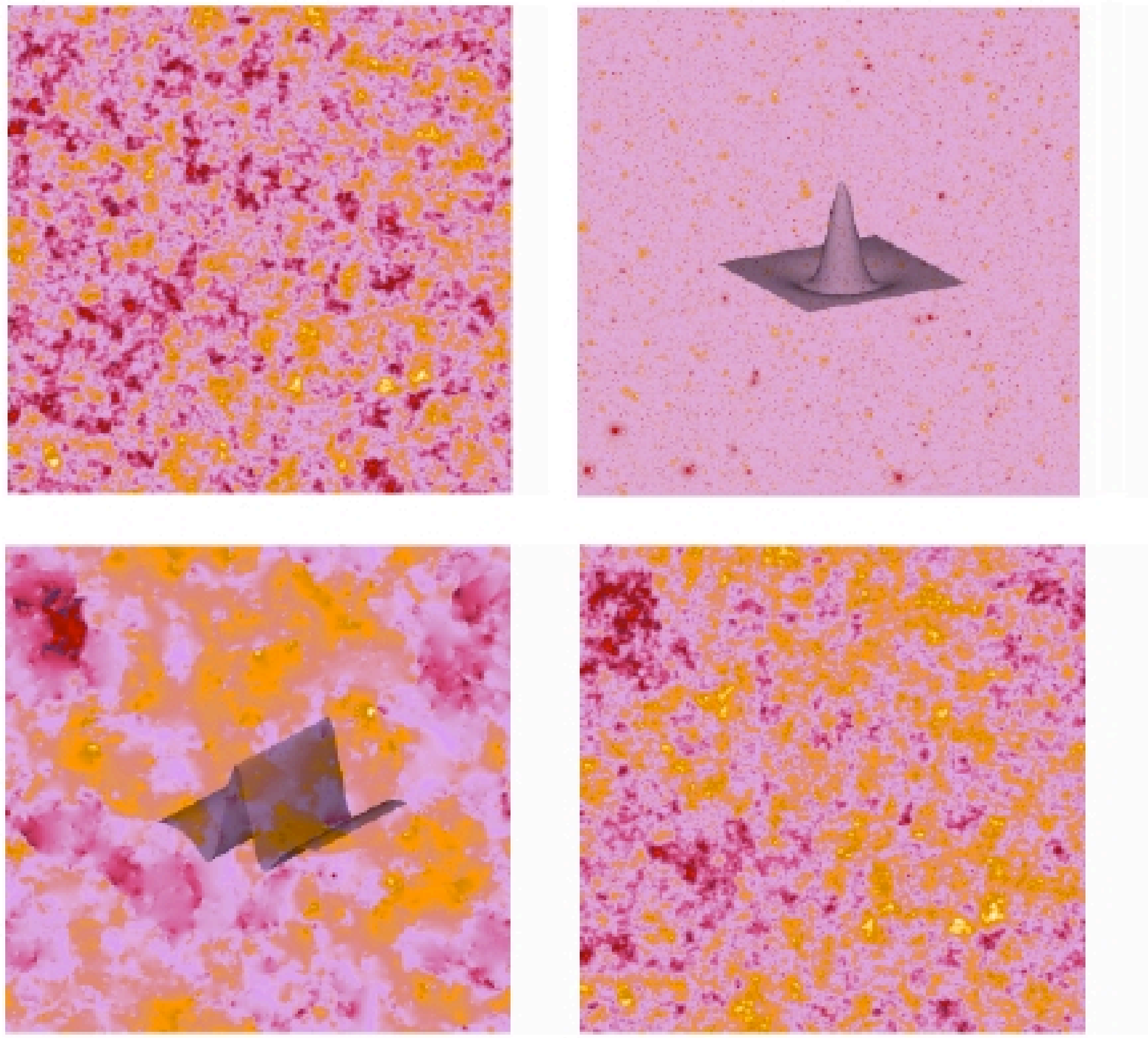



CMB
Thermal
Clusters
Doppler
Galaxies
Free-free
Synchrotron
Galactic
Dust
Detector noise


CMB
Thermal SZ
Synchrotron
Free-free
Dust
Sky components
Linear combination + PSF + Noise
Observations

Detection of non-Gaussian Cosmological Signatures





Results

• **Curvelets are NOT sensible to KSZ and sensitive to cosmic string**

	Bi-orthogonal WT	Ridgelet	Curvelet
CMB+KSZ	1106.	0.1	10.12
CMB+CS	1813.	5.7	198.
CMB+CS+KSZ	1040.	5.9	165.

Detecting cosmological non-Gaussian signatures by multi-scale methods, *Astron. and Astrophys., 416, 9--17, 2004* .

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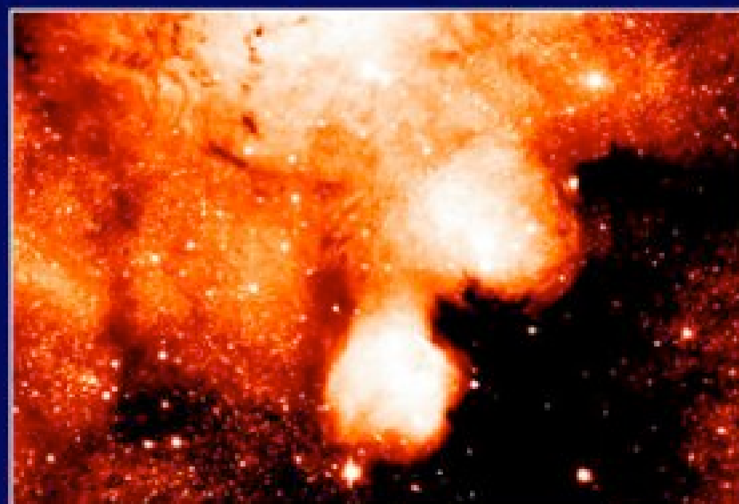
Jean-Luc Starck
Fionn Murtagh

Astronomical Image and Data Analysis



Springer