

**Computational issues in
Astrophysics,
Cosmology & Astrobiology**

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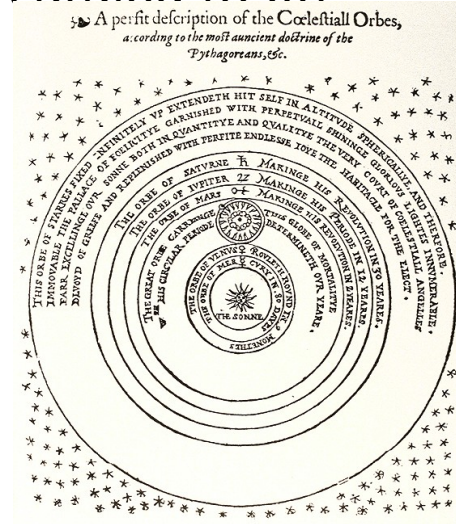
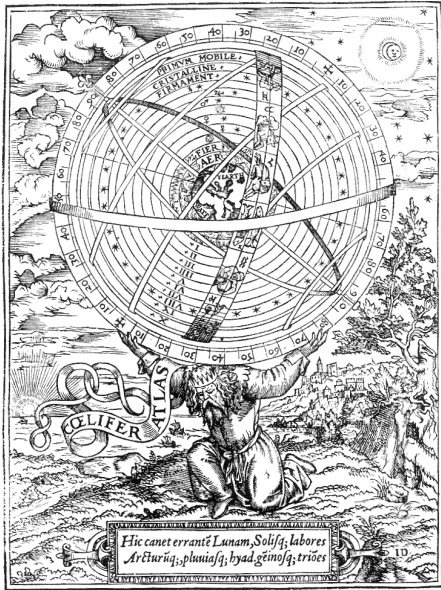


1. **Astronomy and Computation – old friends**
 - databases
 - data processing
 - image visualization
 - simulations
 - the Virtual Observatory experience
2. **High Performance Computing – the FoF example**
 - the parallel *Friends-of-Friends* algorithm
 - a computational Grid for Astrophysics (Brazil-Mexico)
3. **Turbulence and LSS evolution**
 - Virgo Consortium intermediate scale
 - Millennium Simulation
 - SDSS observational data
4. **Astrobiology and Bioinformatics**
 - “*in silico*” techniques for identifying extremophiles

Astronomy and Computation – old friends (databases)

Hipparkhos (Nicaea, 190 b.C.) – abacus:

trigonometry, eclipses, etc
 celestial position of *Spica* (over 144 years)
 Earth's precession (equinoxes movement)
 star catalog (850)



Large catalogs of stars:

Babylonians, Chinese, Arabs, ...

Bayer (☐ Cen), **Flamsteed** (61Cygni), ...

Henry Draper (HD), **SAO**, **GSC**, ...

and nebulae:

Messier (M31), **Herschel**, ...

• **NGC**, **IC**, ...

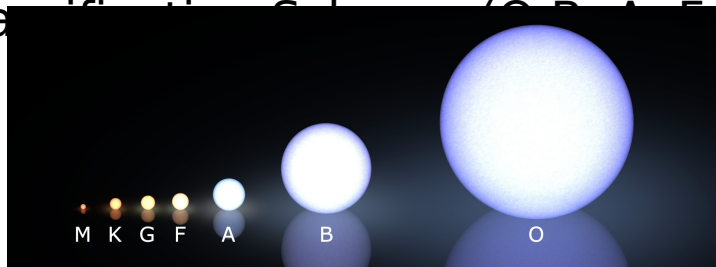
Astronomy and Computation – old friends (data processing)

“computer-women”:

1910-1920 – Harvard College Observatory:

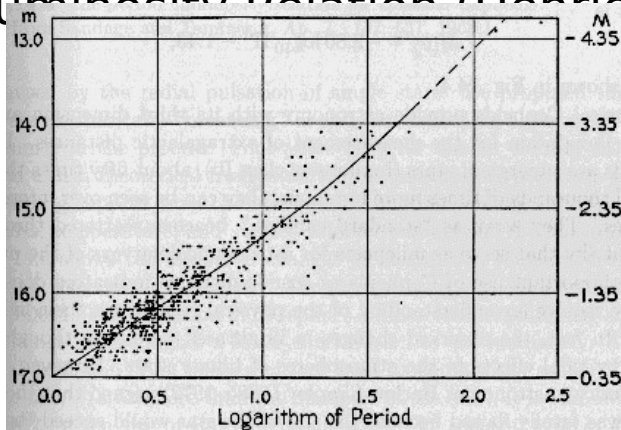
Amelia Fleming, Antonia Maury, Henrietta S. Leavitt, and others

- HD catalog
- Harvard Classification Scheme (O, B, A, F, G, K, M)



“Edward C. Pickering’s Harem”

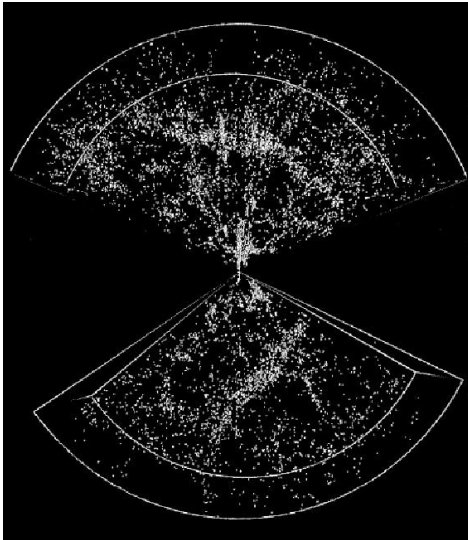
• Period-Luminosity Relation (Henrietta S. Leavitt)



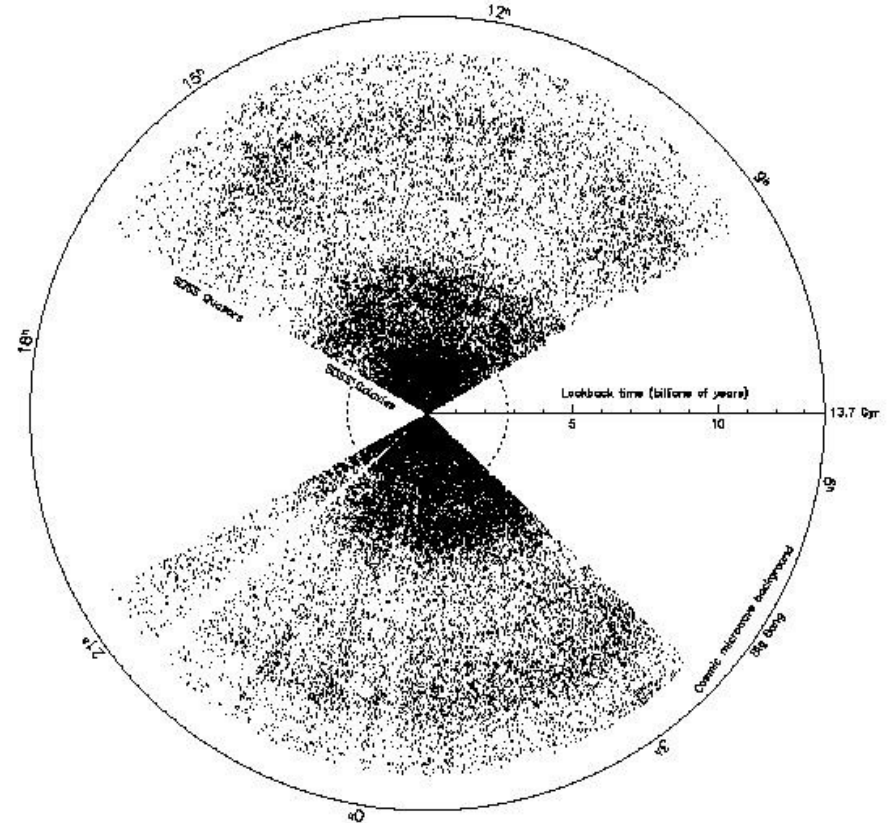
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Astronomy and Computation - old friends (more databases)

Cosmology - the Universe is much bigger, and so are the numbers...

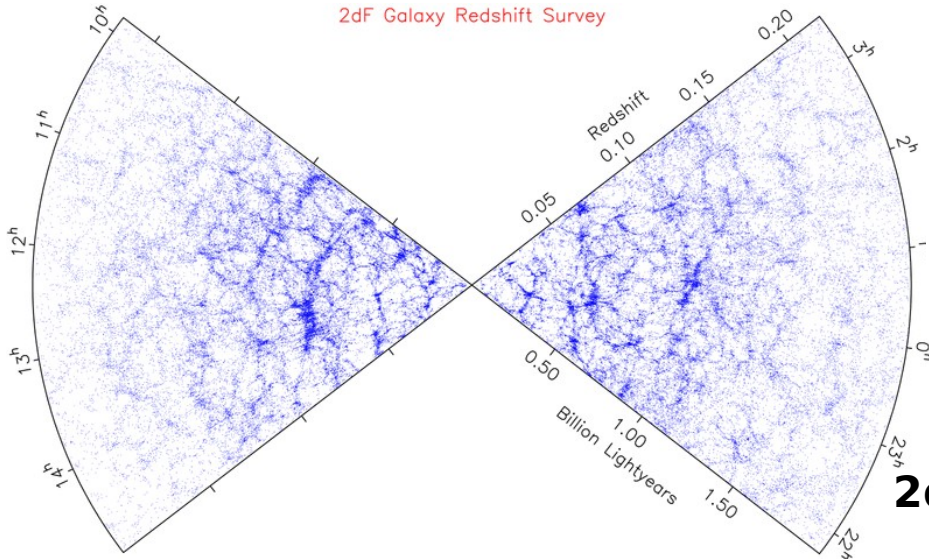


CfARS (1989)
+SSRS (1994):
38,000 galaxies



SDSS (2009): 930,000 galaxies
120,000 quasars

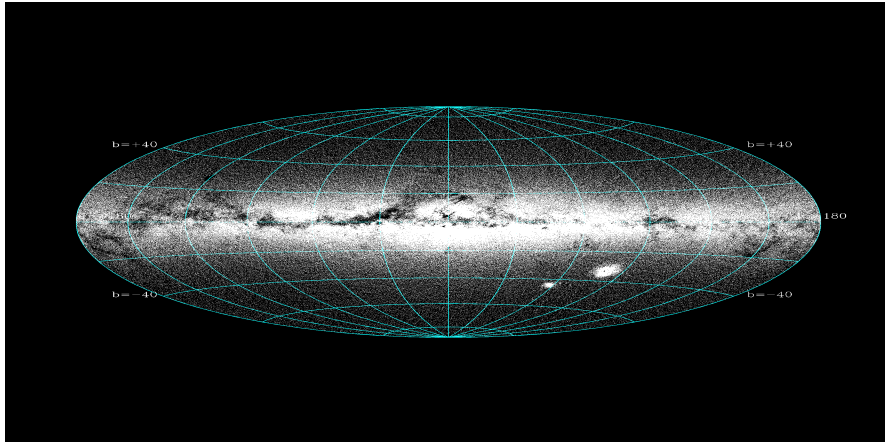
2dF Galaxy Redshift Survey



2dFGRS (2001): 221,000 galaxies

Astronomy and Computation - old friends (image visualization and processing)

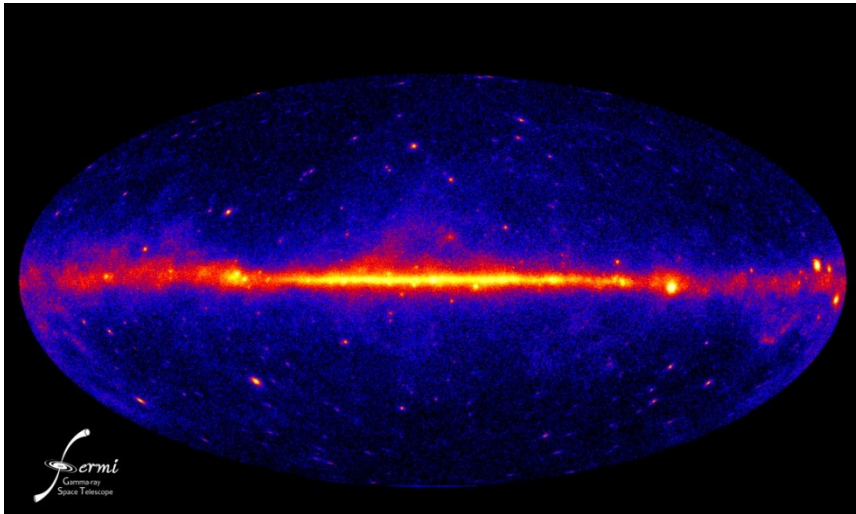
Photometry and Spectroscopy:



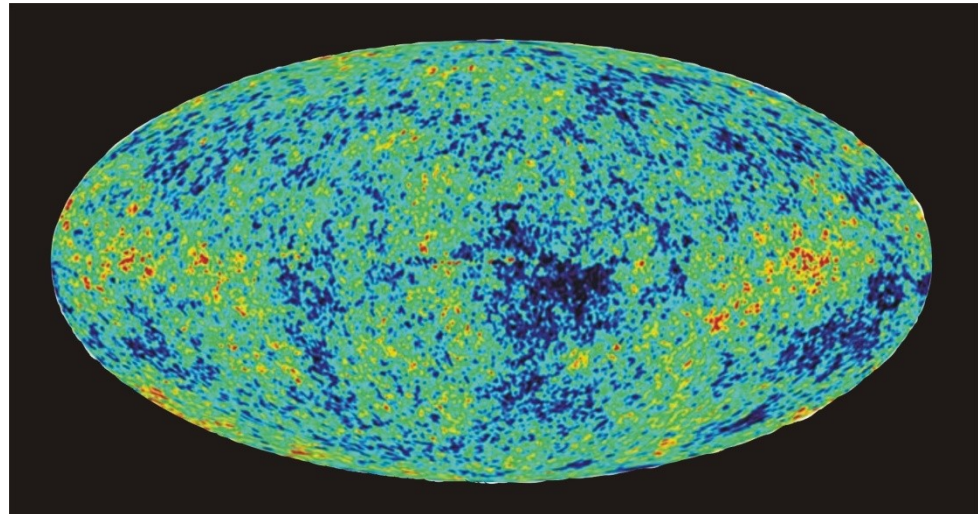
SuperCOSMOS (2001): optical



2MASS (2006): near infrared



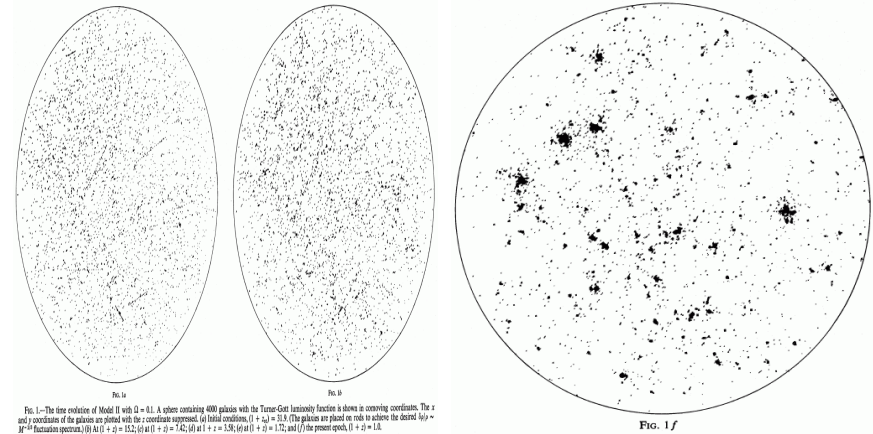
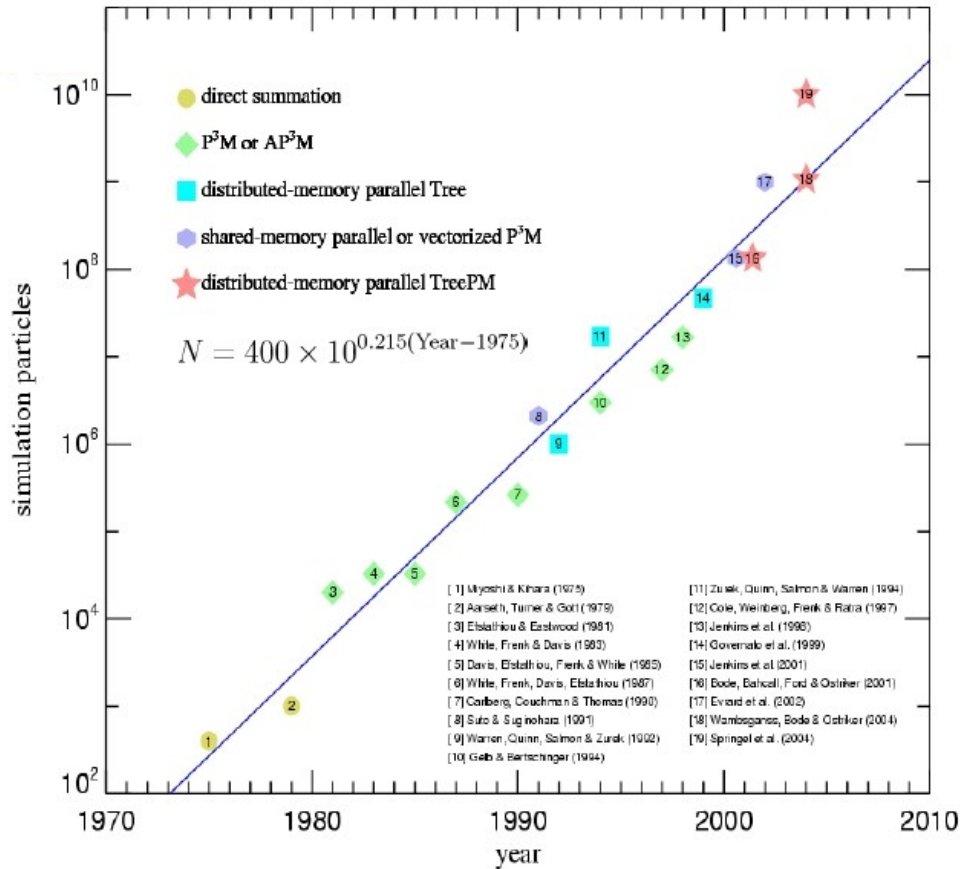
Fermi (2010): gamma-rays



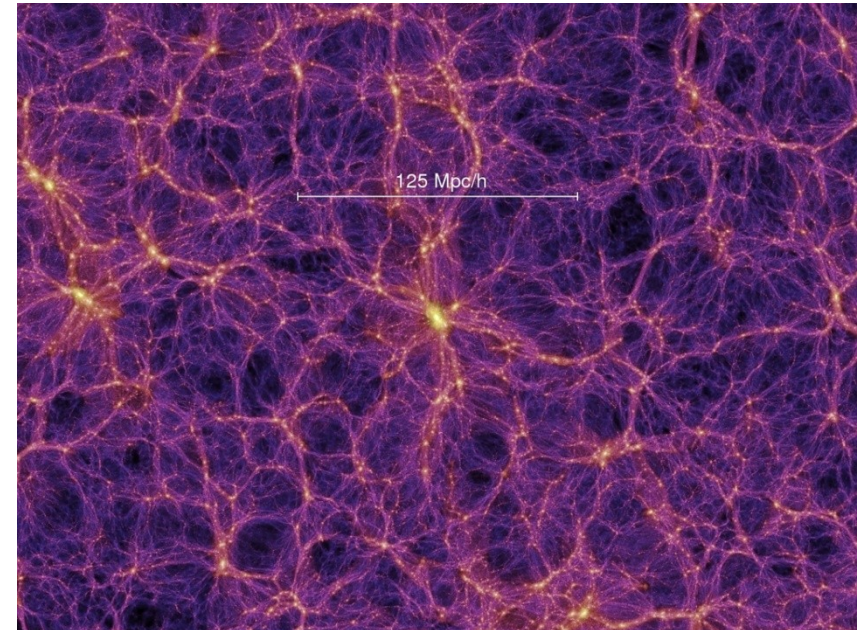
WMAP (2005): microwave

Astronomy and Computation – old friends (simulations)

The Universe in a box:



Aarseth et al. (1979): 4,000 particles



Millennium (2005): 1010 particles

The Virtual Observatory experience

Large Astrophysical Databases:

NASA Extragalactic Database (**NED**)

<http://nedwww.ipac.caltech.edu/>



HyperLEDA

<http://leda.univ-lyon1.fr/>



Centre de Données astronomiques de Strasbourg (**CDS**)

<http://cdsweb.u-strasbg.fr/>



International Virtual Observatory Alliance (IVOA):

<http://www.ivoa.net/>

Armenia, Australia, Brazil, Canada, China, Europe, France, Germany, Hungary, India, Italy, Japan, Korea, Russia, Spain, UK and USA

Objectives:

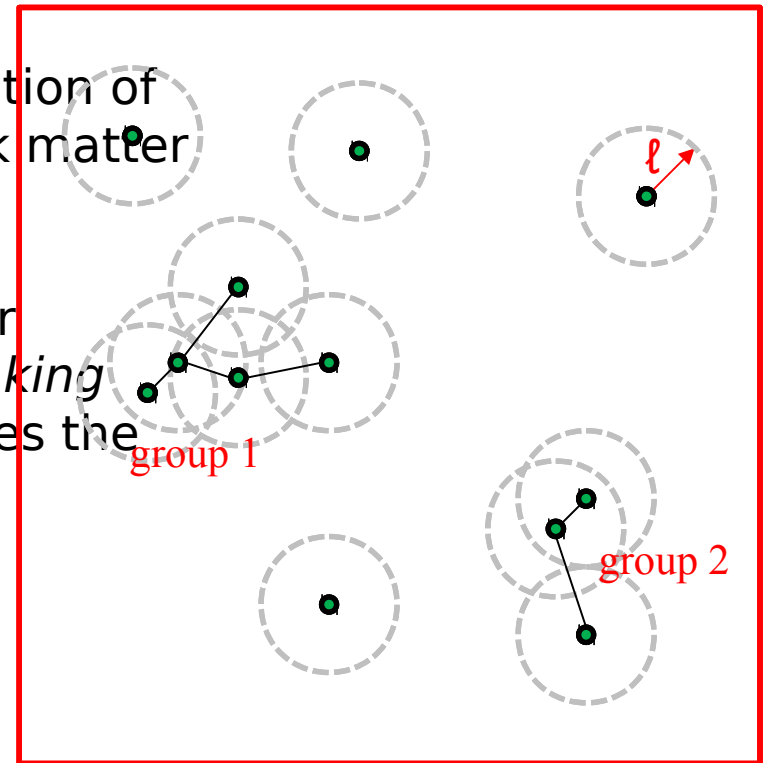
- maintenance and distribution of astronomical data
- development of mining, visualizing and analyzing tools



High performance computing: the FoF algorithm example

The “Friends-of-Friends” percolation algorithm:

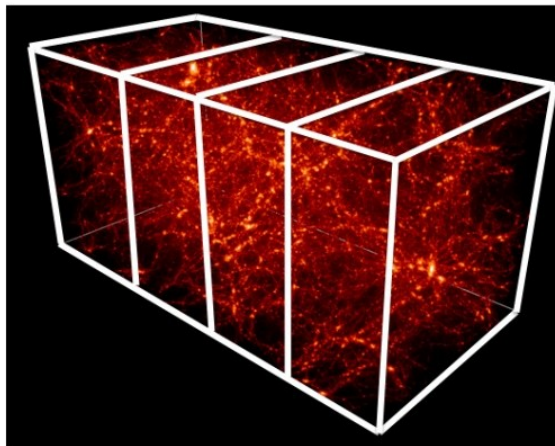
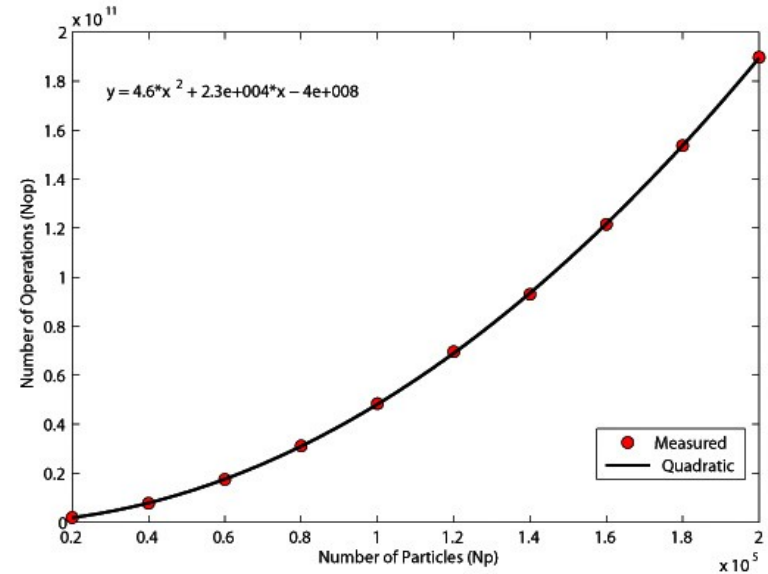
- For detecting overdensities in a distribution of points (groups of stars, galaxies, dark matter particles, etc.)
- Groups together particles that have pair separations smaller than a chosen *linking length*, ℓ (usually referred to as b times the mean inter-particle separation).



High performance computing: the FoF algorithm example

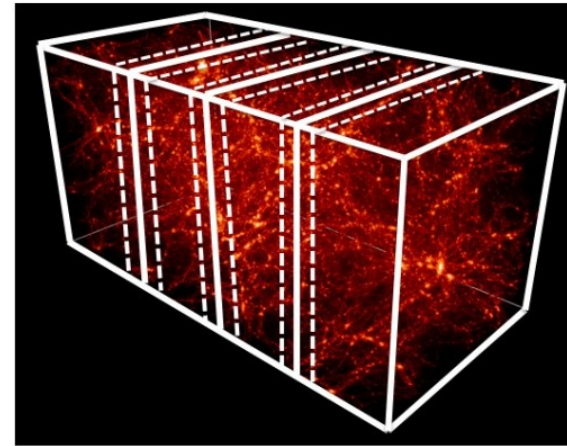
Parallel processing:

- time consuming: complexity $\sim O(N^2)$
- model: Single Instruction, Multiple Data (SIMD) \Rightarrow domain decomposition
- post processing



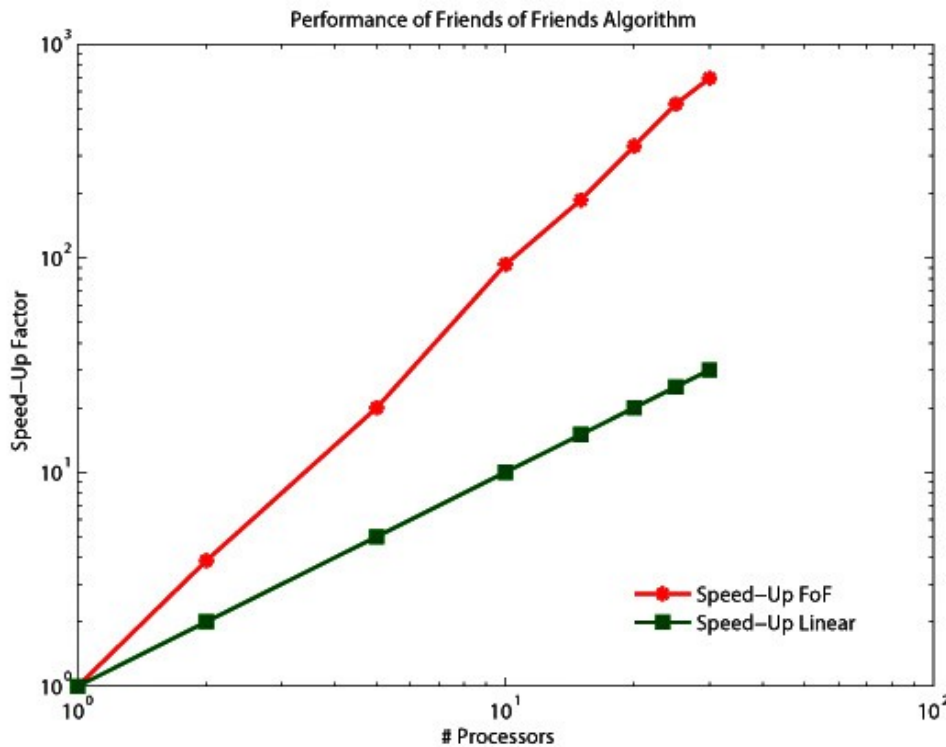
(a)

Post-Processing



(b)

High performance computing: the FoF algorithm example



Performance:

- $N = 2\,245\,649$ particles

- **Speed-up:**

$$S(N,p) = T_{\square}(N) / T_{\square}(N,p)$$

- " superlineal

- **Efficiency:**

$$E(N,p) = S(N,p) / p$$

- excellent

Rocha-Ruiz, R.; Campos-Velho, H.; Caretta, C.A. 2010b, in preparation.

Supercomputers, clusters and grids

A computational grid for Astrophysics:

- Middleware: **OurGrid** (Andrade et al. 2003):

- MyGrid* grid coordinator
 - OurGrid Peer* job distributor
 - Worker* working unit

- Grid nodes (**poster 38**):
 - Lab. Associado de Computação e Matemática Aplicada (INPE, Brazil)
 - Divisão de Astrofísica (INPE, Brazil)
 - Departamento de Eletrônica e Computação (UFES, Brazil)
 - Departamento de Astronomia (UG, Mexico)

North and South America



Turbulence-like patterns in LSS evolution

Virgo Cons. (intermediate scale):

$L = 239.5 h^{-1} \text{ Mpc}$

$M = 6.86 \times 10^{10} h^{-1} M_{\odot}$

$N = 1.7 \times 10^7 = 2563$

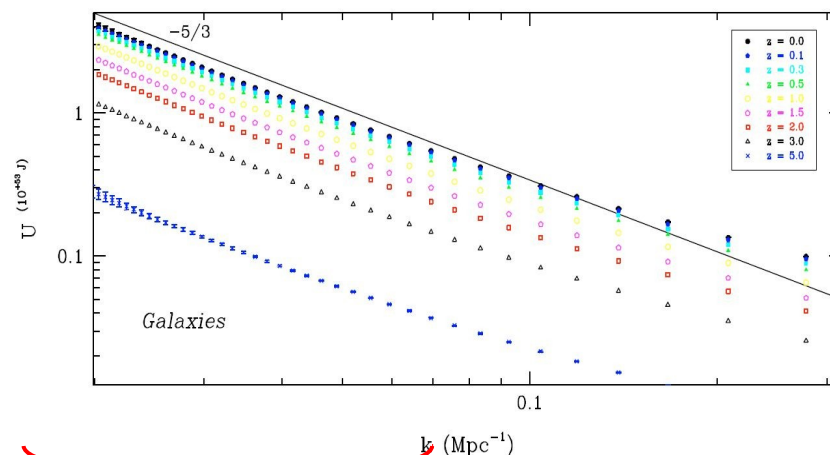
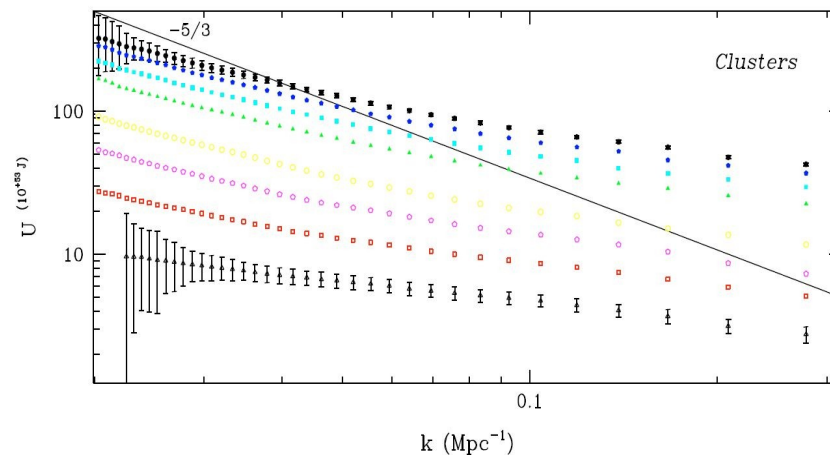
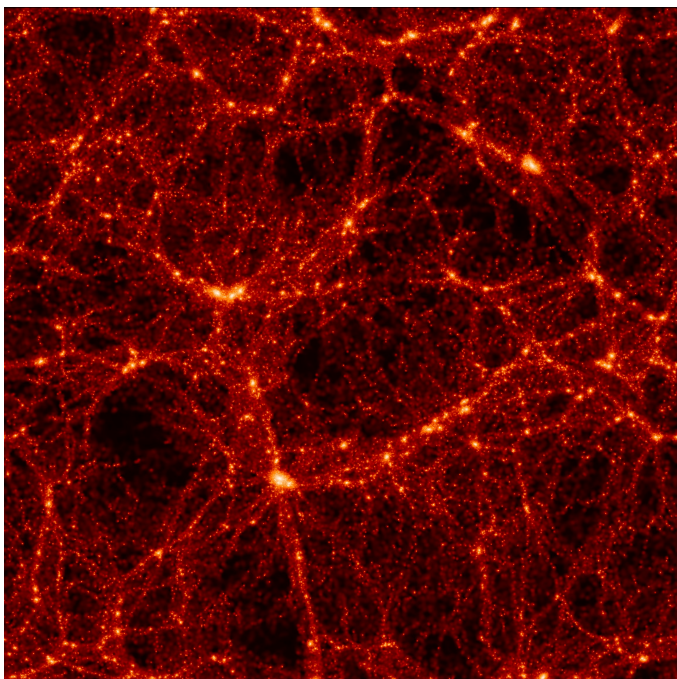


Fig. 6. Gravitational energy spectra for cluster-sized haloes (above panel) and galaxy-sized haloes (below panel), for the sampled redshifts. A reference $-5/3$ power law is plotted as a solid line.

15 - 50 h^{-1} Mpc

FoF:	b	l	f	
Npart	$M(M_{\odot})$			
Galaxies	0.1	0.10	1300	2 -
150	1×10^{11}			
Clusters	0.2	0.18	180	>100
	7×10^{12}			

Caretta, C.A.; Rosa, P.R.; Campos-Velho, H.F.; Ramos, F.M.; Makler, M. 2008, A&A 487, 445

Turbulence-like patterns in LSS evolution

A conservative turbulent-like mechanism?

- computational statistical analysis: extreme value theory

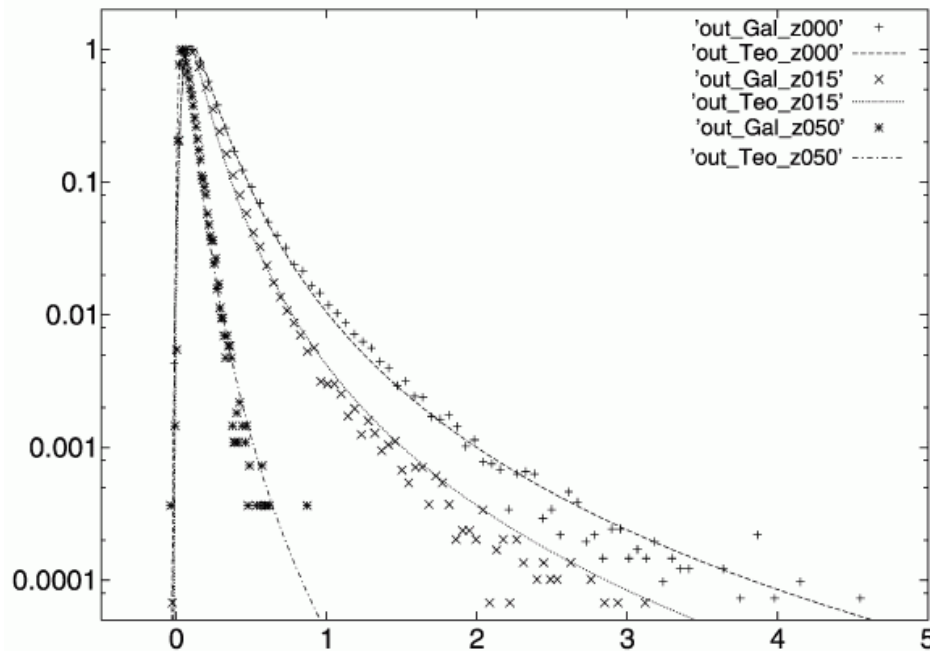


Fig. 2. Empirical and theoretical (GEV model) rescaled energy histograms, for redshifts $z = 0, 1.5$ and 5.0 .

- Generalized Extreme Value Distribution (**GEV**):

$$F(x) = \exp\left\{\left[1 - \left(1 + \frac{x}{\tilde{\sigma}}\right)^{-1/\tilde{\alpha}}\right]\right\}$$

- x \square rescaled gravitational energy

- the good fit indicates:
rare, intense events are present

(galaxy-sized halos)

similar to chaotic

advection

(also non-dissipative)

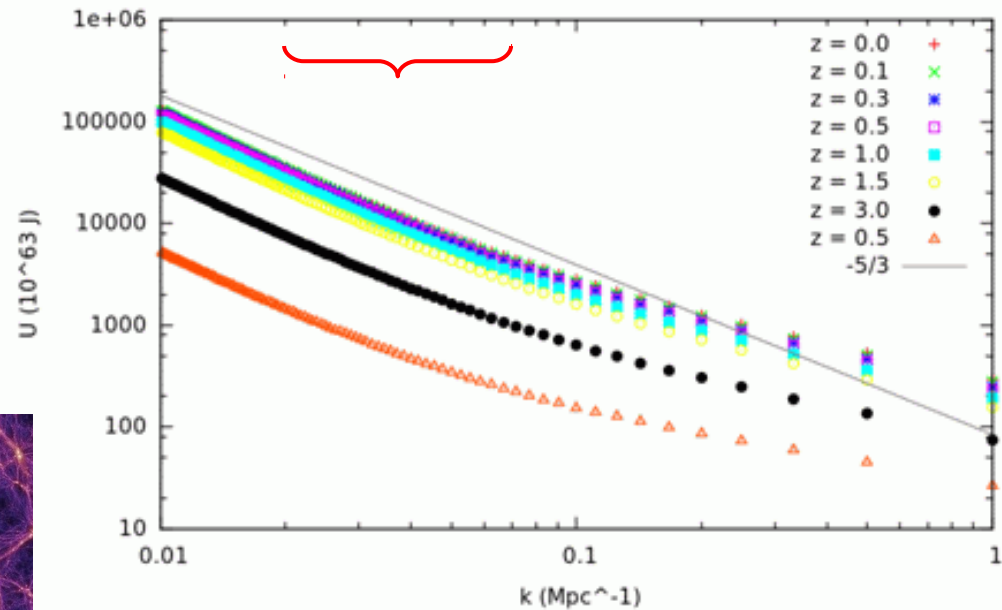
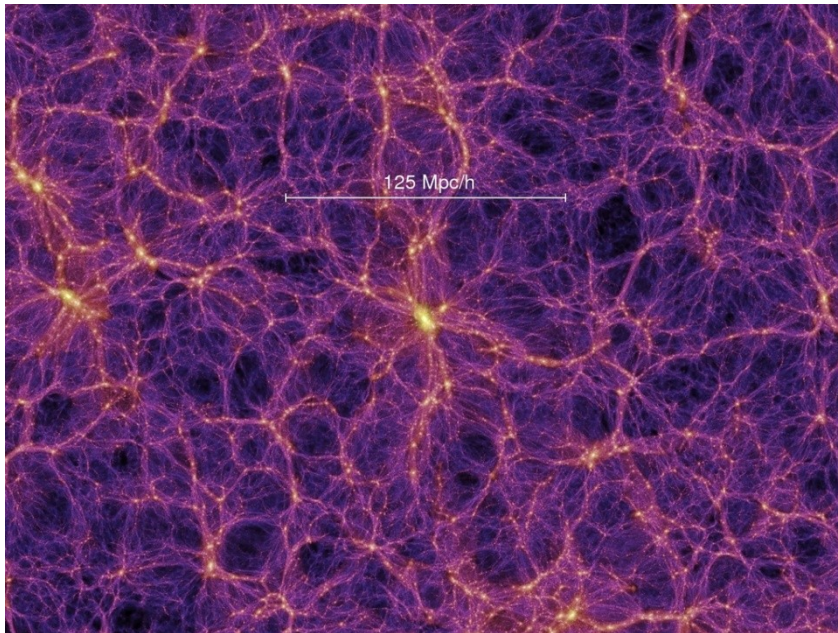
Turbulence-like patterns in LSS evolution

Millennium Simulation:

$L = 500 h^{-1} \text{ Mpc}$

$M = 8.6 \times 10^8 h^{-1} M_{\odot}$

$N = 1.0 \times 10^{10} = 21603$



Rocha-Ruiz, R.; Campos-Velho, H.; Caretta, C.A. 2010a, WorCap.

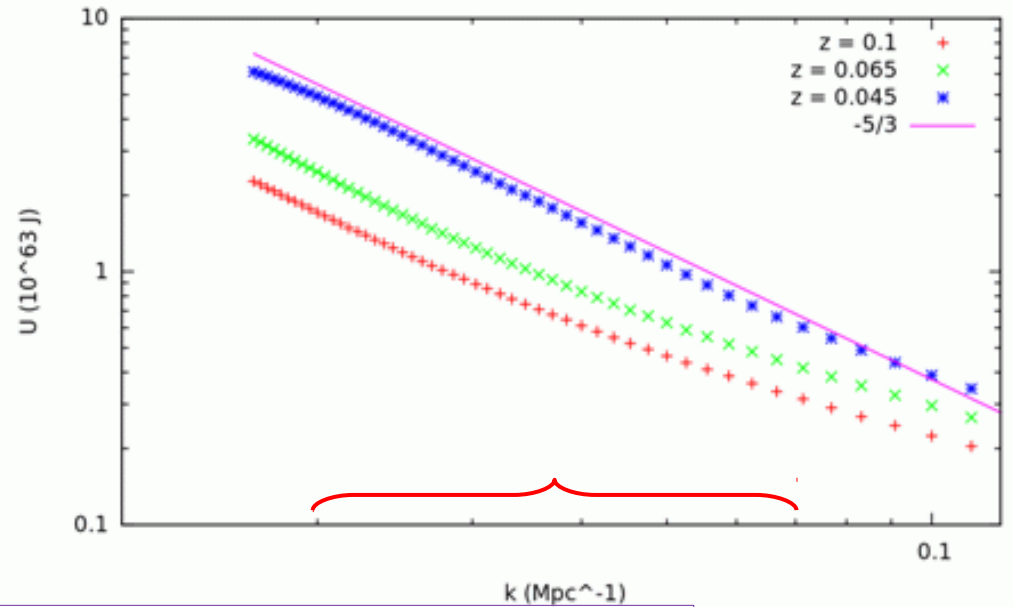
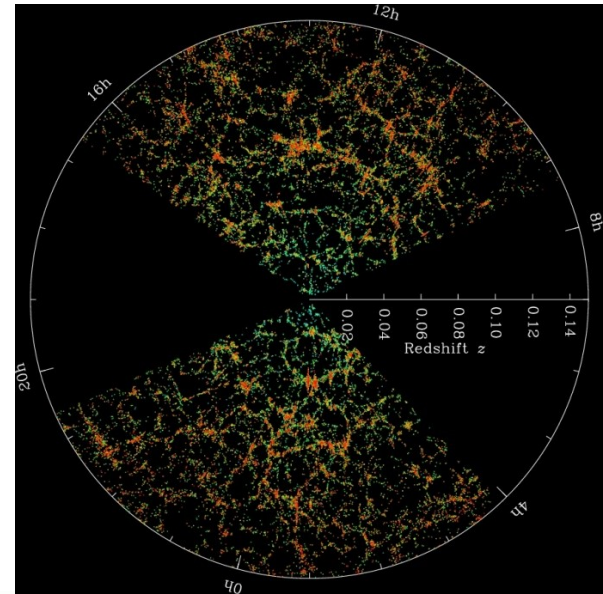
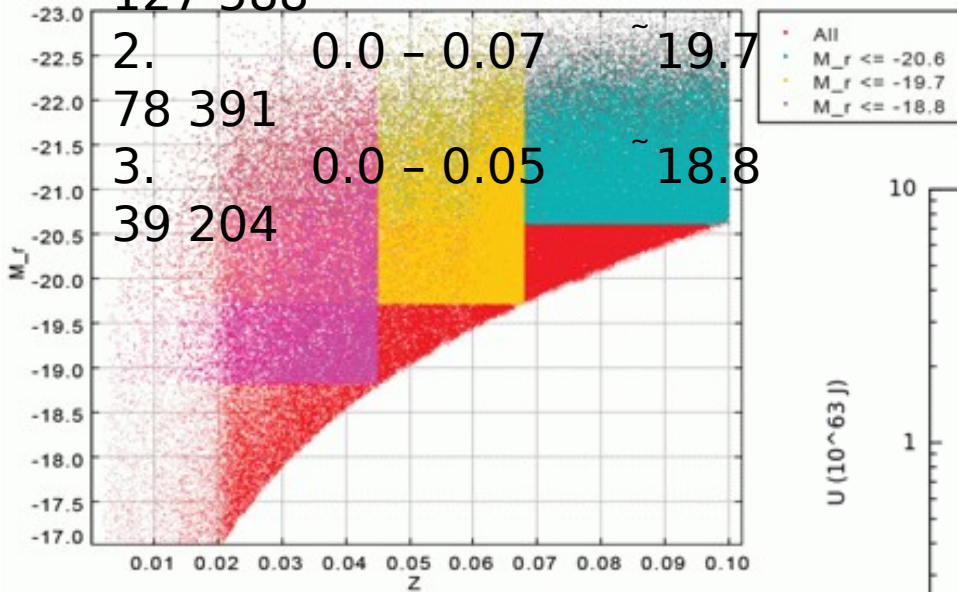
Turbulence-like patterns in LSS evolution

Sloan Digital Sky Survey (SDSS):

DR7: 930 000 galaxies (9 380 deg²)

□ z Mr □

N	z	Mr
1. 127 588	0.0 - 0.10	~ 20.6
2. 78 391	0.0 - 0.07	~ 19.7
3. 39 204	0.0 - 0.05	~ 18.8

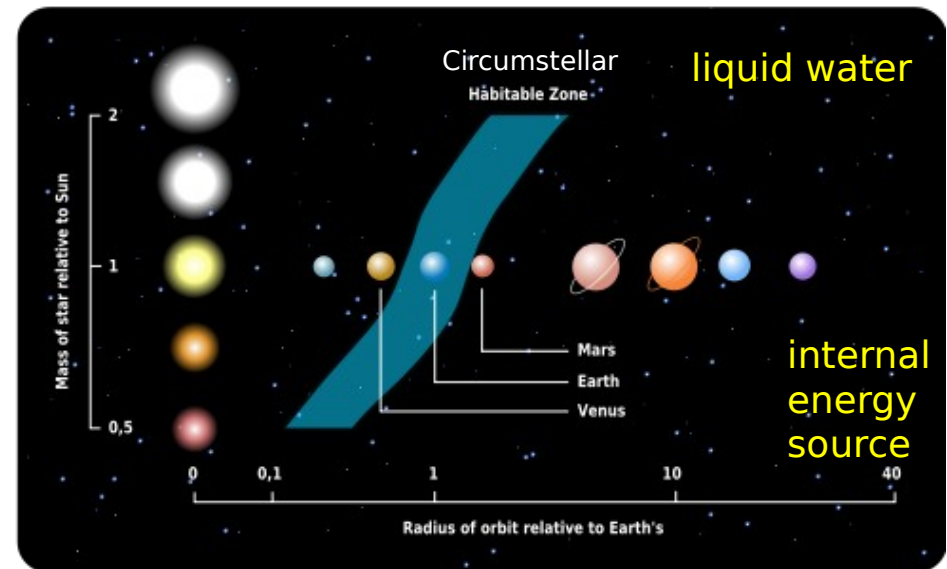
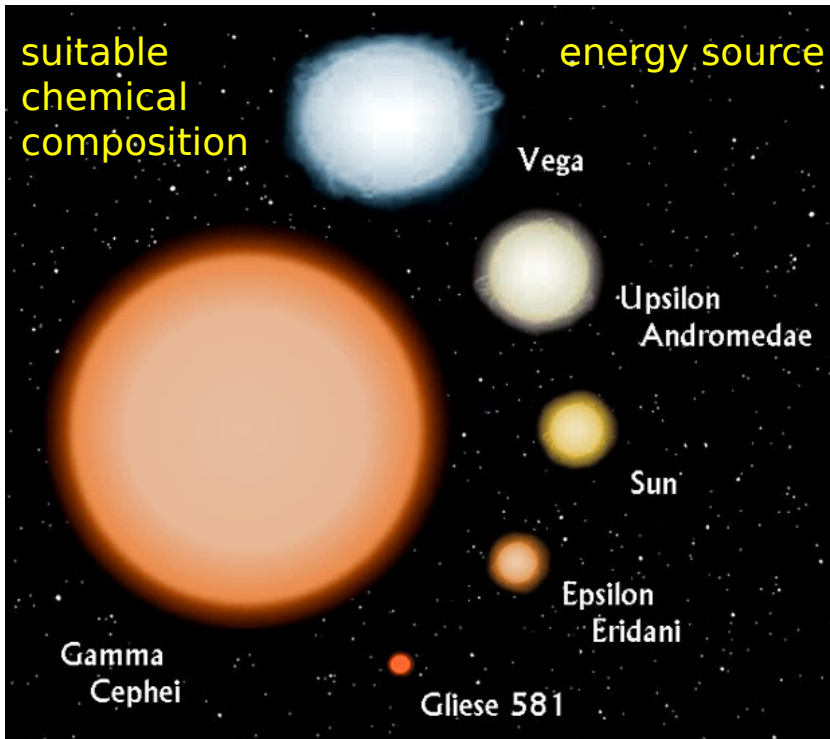
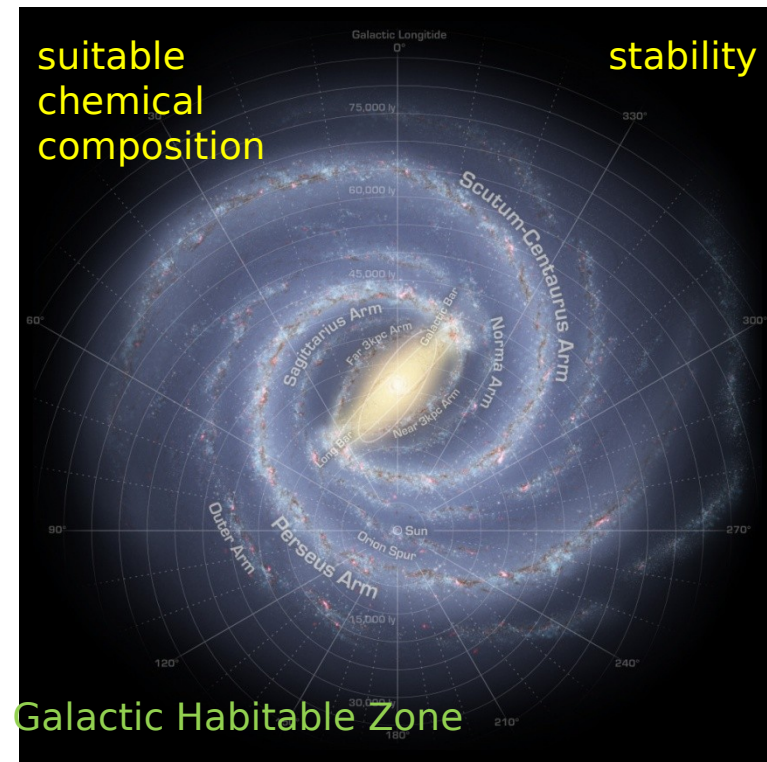


Rocha-Ruiz, R.; Campos-Velho, H.; Caretta, C.A. 2010a, WorCAp.

Astrobiology (or Exobiology)

Search for extraterrestrial life:

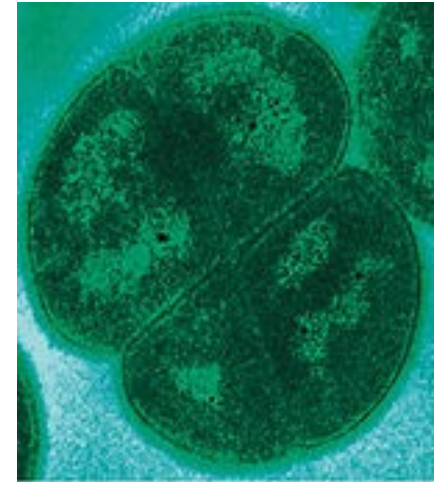
- Where in the Galaxy?
- In which kind of stars?
- In which kind of planets/satellites?
- Under which physical conditions?



Terrestrial extremophile organisms

Extreme conditions:

- **temperature** (*hyperthermophiles*: 80–115 °C; *psychrophiles*: < 15°C)
- **desiccation** (*xerophiles*)
- **pH** (*acidophiles*: 0.7–4.0; *alkalophiles*: 8–12.5)
- **salinity** (*halophiles*: 15–38% NaCl)
- **pressure** (*piezophiles*: < 130 MPa; *barophiles*)
- **oxygen** (*anaerobes*, *aerobes*)
- **radiation**
- **vacuum**
- **chemical extremes**
- etc



Pyrococcus furiosus



Leptospirillum ferrooxidans



Thermus aquaticus



Deinococcus radiodurans

Extreme sites in Mexico



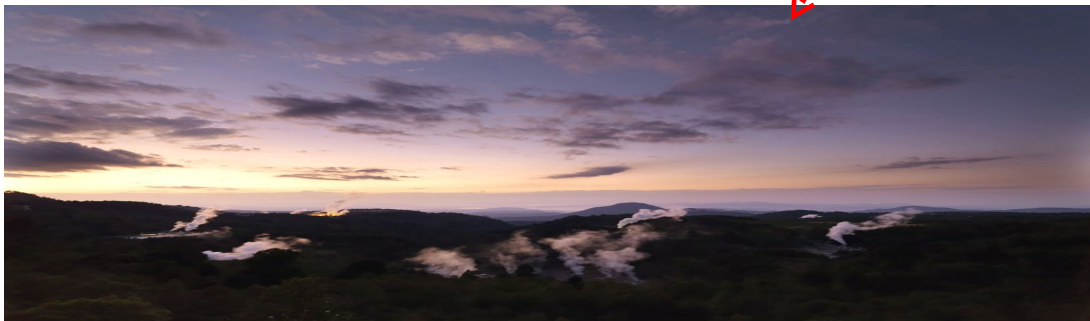
Esteros hipersalinos



2006 © Hern Nalini Morzaría Luna
www.cedointercultural.org



Desierto de Sonora



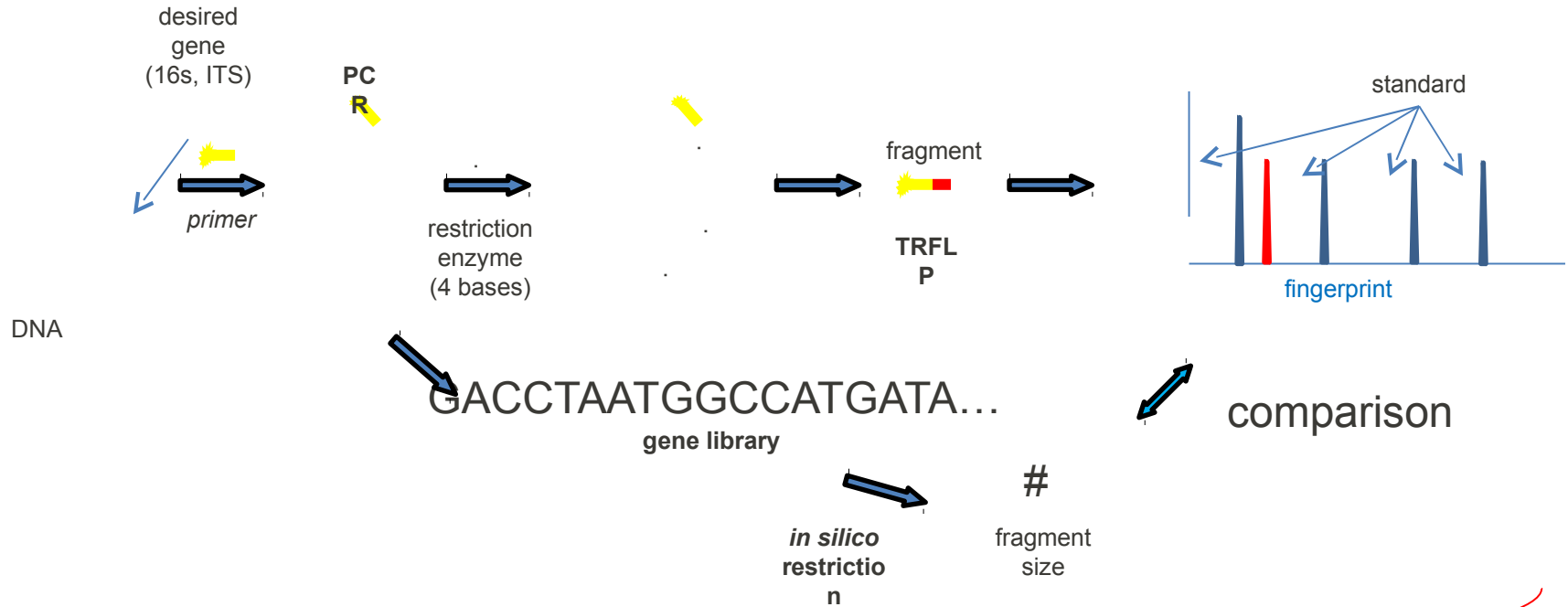
Zona volcánica (geothermal sites and volcanoes)



Cenotes (Chicxulub)

Studying extremophiles: *in silico* biological reactions

Bioinformatics: *in silico* restrictions



Applied to DNA of a community (independent of culture technique)

Piñón-Castillo, H. et al. 2010, J. Applied Microbiology, accepted
Brito, E.M.S. et al. 2010, submitted

A dense field of galaxies in various colors and orientations against a black background. The galaxies are scattered across the frame, with some appearing as bright, multi-colored points and others as elongated, faint structures. The colors range from bright yellow and orange to deep blue and green. The overall appearance is that of a rich, multi-wavelength galaxy survey.

**Gracias
Obrigado
Thank you**