Searching for Cosmic Strings in the CMB

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Cosmic Strings

Cosmic strings as topological defects of space-time were introduced by Kibble (1976) and have been thoroughly discussed in cosmology over the past decades (cf. Zeldovich 1980; Vilenkin 1981; Vilenkin, Shellard 1994). The detection of defects in the modern universe would provide precious information on events in the earliest moments after the big bang. Their absence, on the other hand, would force a major revision of current physics teories about the energy scale of symmetry breaking or scenarios for phase transitions or both.

Among all possible types of such defects cosmic string are preferably arising in inflation scenarios and find support in modern theoretical physics. The great progress in cosmic string theory has been achieved within superstring theories, both in compactification models and in theories with extended additional dimensions. The main cosmic string parameter (i.e. the linear density μ) depends strongly on the underlying model and may vary over a wide range, even though some constrains can be obtained from superstring theory (Davis & Kibble 2005; Copeland et al. 2004; Majumdar 2005; Tye et al. 2005).However all cosmic strings, either classical strings, or F- and D-strings, share two properties which are model independent: the extremely long cosmological length and a negligibly small cross-section.

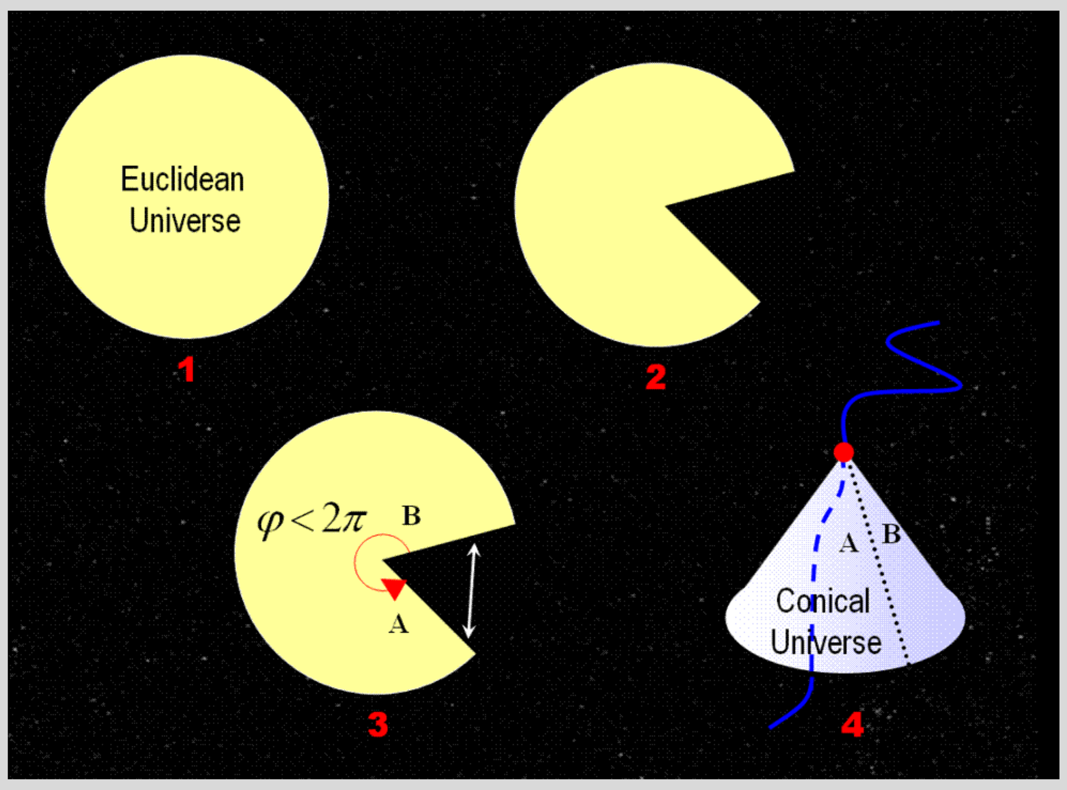

Fig. 1: Cosmic string in the Universe

Cosmic Strings and CMB

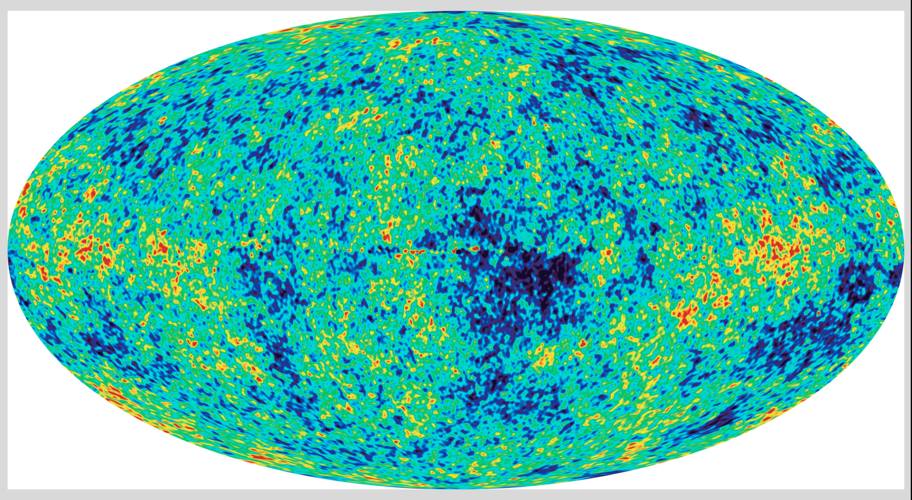

Fig. 2: Image of the CMB from WMAP data

A moving string would produce a step-like discontinuity in the CMB, so it will cause the temperature distribution to deviate from a Gaussian. This deviation could be detected analyzing data of the CMB (now from WMAP, in future from Planck).

Consider a cosmic string with mass per unit length μ, velocity β, and direction $\hat{\mathbf{s}}$, which is backlit by a uniform blackbody radiation background of temperature $\boldsymbol{T}$. Because of its deficit angle $\Delta = 8\pi G\mu$, there is a Doppler effect on one side of the string relative to the other, which causes a temperature step across the string of (Kaiser & Stebbins 1984; Gott 1985)

$$\frac{dT}{T} = 8\pi G\mu\gamma\beta\,\hat{\boldsymbol{n}}\bullet\left(\hat{\boldsymbol{\beta}}\times\hat{\mathbf{s}}\right)$$

where $\hat{\boldsymbol{n}}$ is the direction of the line of sight. It should be of the order of 10^{-5}, so that the S/N ratio (temperature fluctuations/CMB background) is very law, making complicated the detection of such variations.

Simulations

In order to study the effects of a cosmic string on the CMB, we have written a C++ code that generates a map of temperature fluctuations in presence of a straight cosmic string. The code uses the HEALPix package (see below), in order to generate the map and perform a multipole analysis, giving the following outputs: 1) a fits file containing the map of temperature (opportunely smoothed); 2) a TGA image of the map; 3) a_{lm}'s; 4) C_l's.

To define the string features, we used 3 parameters: the magnitude of its velocity (set *c=1*), its direction (angle between the velocity vector and the line of sight) and the distance between the observer and the string. By varying these parameters according to Tab. 1, we obtained different moving strings with their own signature of the CMB. In particular, to create a solid set of simulations, we exploited the features of the GRID computing (see the panel below). So it's been possible to generate 3040 simulations of a straight moving string and its effects on temperature distribution of the CMB. In Fig. 5 it's possible to see four examples of TGA images created by the software. Because of its close relation with HEALPix, this code can be easily interfaced with CMBFast and other tools for the CMB analysis.

β	k	ξ
0.0 ÷ 0.9	0 ÷ 180	0.0 ÷ 0.9
0.920		
0.940		
0.960		
0.980		
0.985		
0.990		
0.992		

Tab. 1: parameters used by simulations

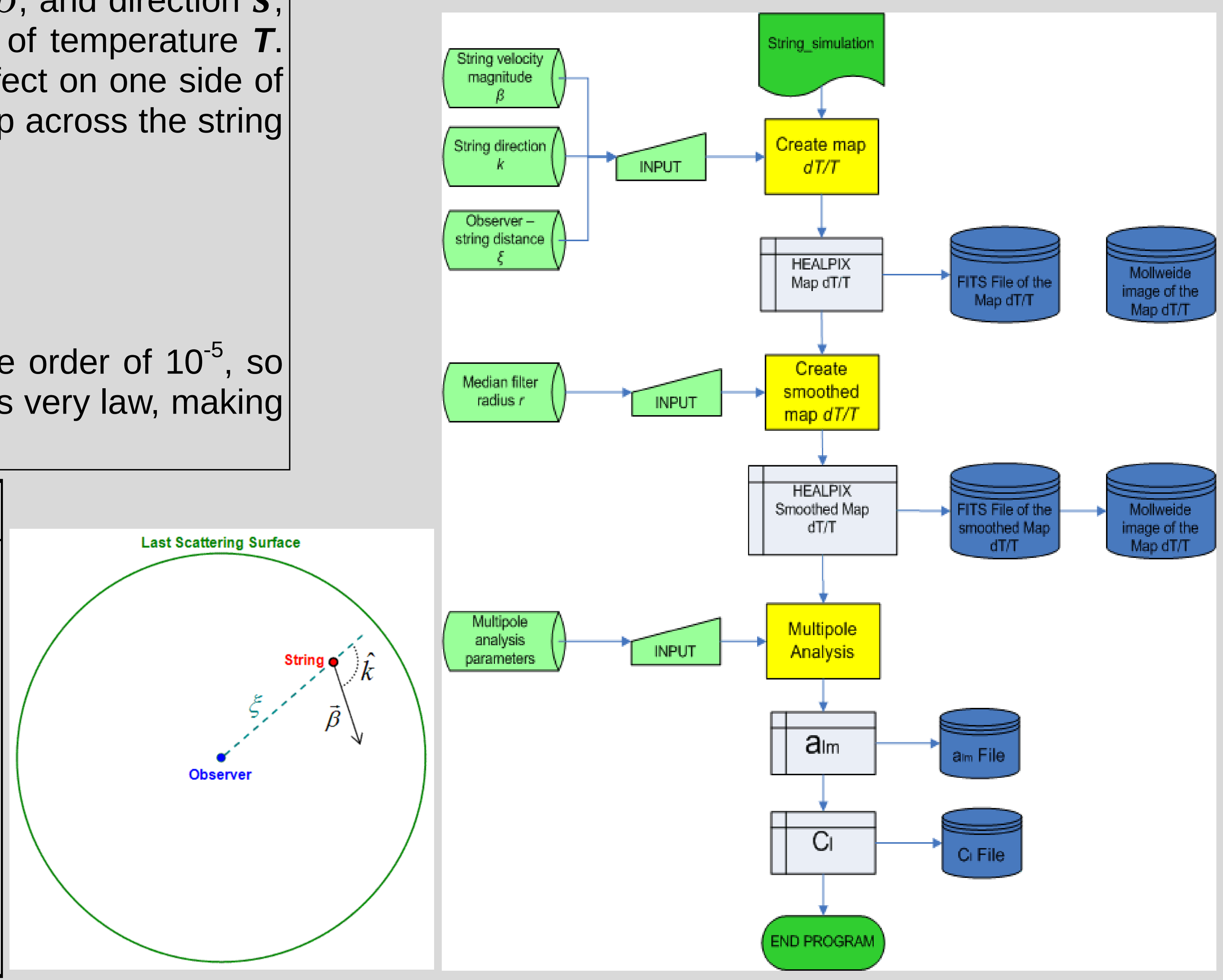

Fig. 3: left panel, representation of parameters used by simulations. On the right, flow-chart of the software simulating fluctuations of temperature due to a cosmic string

HEALPix

HEALPix – the Hierarchical Equal Area iso-Latitude Pixelization – is a versatile data structure with an associated library of computational algorithms and visualization software that supports fast scientific applications executable directly on very large volumes of astronomical data and large area surveys in the form of discretized spherical maps. Originally developed to address the data processing and analysis needs of the present generation of cosmic microwave background (CMB) experiments (e.g. BOOMERanG, WMAP), HEALPix can be expanded to meet many of the profound challenges that will arise in confrontation with the observational output of future missions and experiments, including e.g. Planck, Herschel, SAFIR, and the Beyond Ein-stein CMB polarization probe.

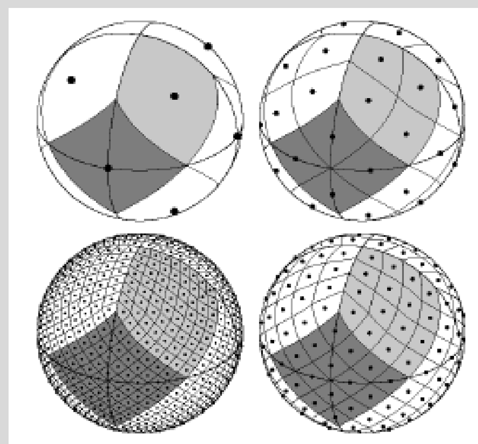

Fig. 4: Orthographic view of HEALPix partition of the sphere for different resolutions (Nside=1, 2, 4, 8)

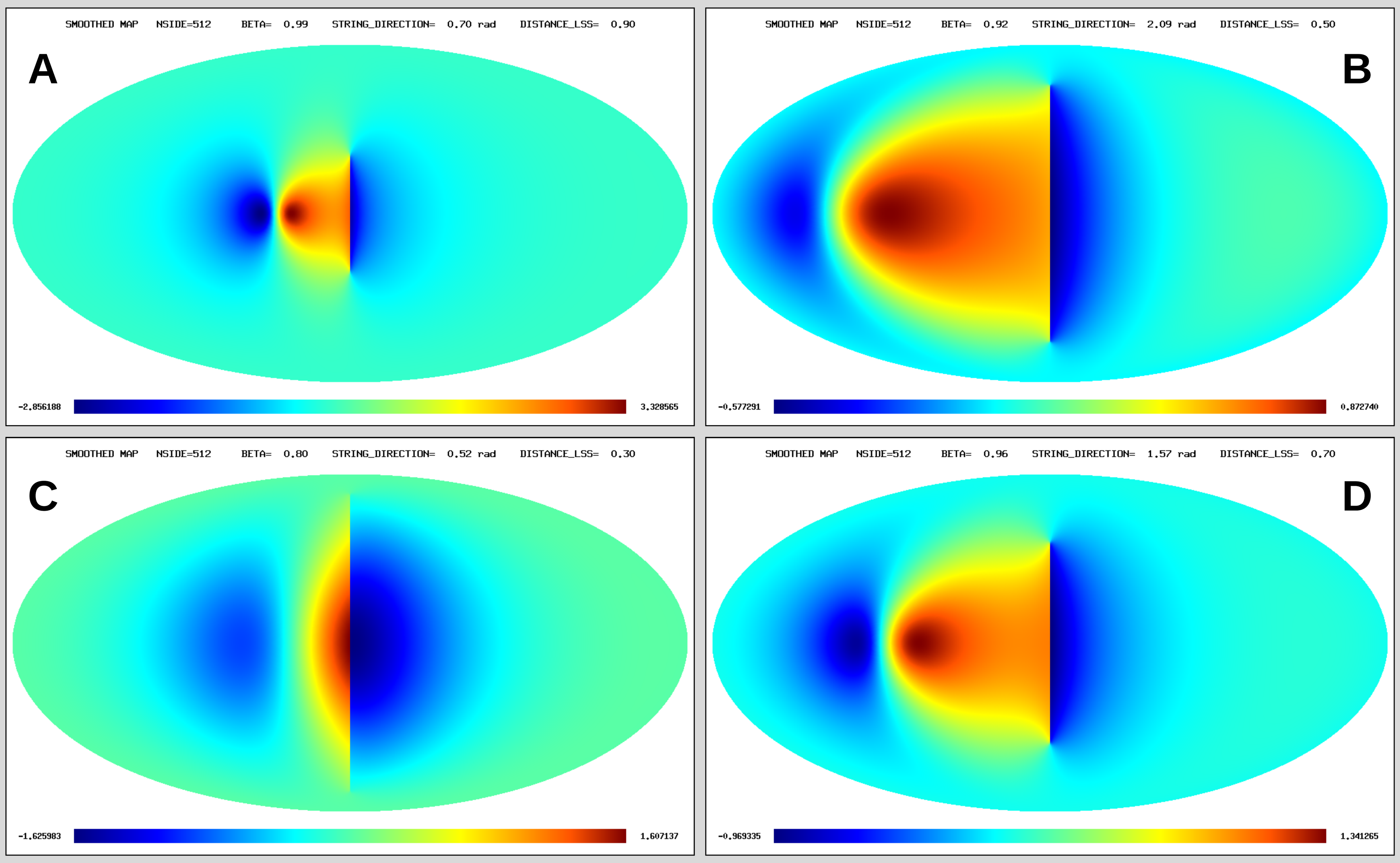

Fig. 5: Mollweide view of temperature distribution due to a straight cosmic string for different values of the parameters:
A) $\beta = 0.99, \hat{k} = 40°, \xi = 0.9$; **B)** $\beta = 0.92, \hat{k} = 120°, \xi = 0.5$; **C)** $\beta = 0.8, \hat{k} = 30°, \xi = 0.3$; **D)** $\beta = 0.8, \hat{k} = 30°, \xi . = 0.3$
Resolution of the map is fixed by *Nside=512.* These maps are calculated considering the amplitude *A=1* (no retardation)

GRID Computing

Grid computing is a special type of parallel computing founded on a highly decentralized infrastructure. It's able to allow the use of resources (generally CPU and storage) from different computers interconnected to a network (private, public or the Internet), by a wide number of users.

Users from different countries and institutes are organized in groups called Virtual Organizations (VO) and can use computational power and storage elements of a GRID distributed system. The GRID grants a coordinated and ensured access to shared resources as if they were on the same system.

Conclusions and future work

The described software is able to create HEALPix maps and perform multipole analysis of temperature distribution due to a straight cosmic string. It can be easily interfaced with CMBfast outputs in order to have simulations of the cosmic microwave background in presence of a string.

In the near future, the software will be upgraded in order to simulate more strings in different positions and sum their effects on the temperature of the CMB. It will also possible to simulate curved strings.

Then, using the GRID, it will be possible to generate an huge number of simulations, varying the parameters of the strings, as well as their number and relative position. This database could be useful to train (for instance by wavelet analysis) a neural network to find the signature of a cosmic string in the real data produced by WMAP and Planck.

A further step of this work will be to search statistical excess of gravitational lensing matching with the step-like discontinuity due to the string. The presence of a cosmic strings, in fact, would cause non-standard gravitational lensing, in which there is no deformation in the shape of the object. Therefore it would be possible to detect a strip of couple of identical objects along the trajectory of the string.

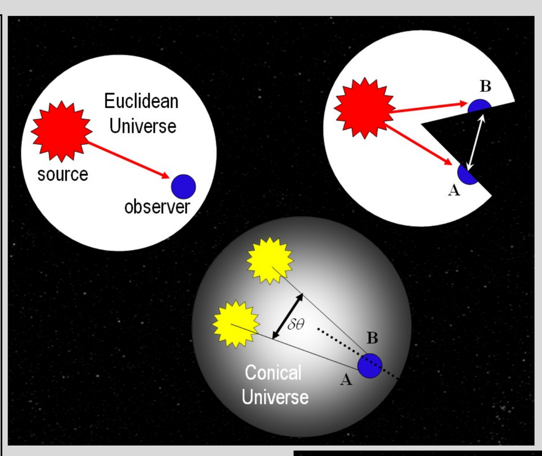

Fig. 7 (left panel): Gravitational lensing by a cosmic string. The observer sees two identical images of the same object.

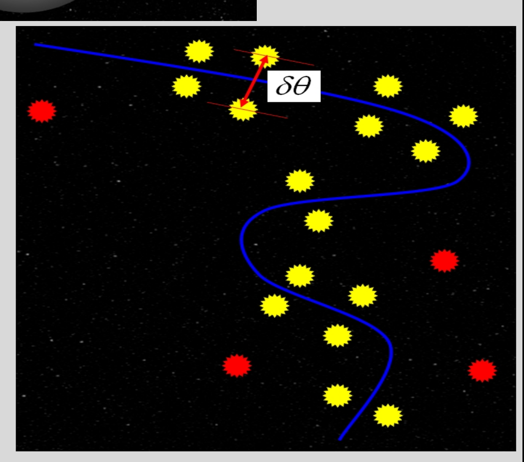

Fig. 8 (right panel): Strip of gravitational lenses along the trajectory of the cosmic string

PON S.Co.P.E. GRID

The S.Co.P.E. (Italian acronymic for high Performance, Cooperative and distributed System for scientific Elaboration) is a research project that aims at developing several applications in the field of fundamental research, which is one of its strategic objectives. The main spin off is the implementation of an open and multidisciplinar GRID infrastructure between the departments of University Federico II, distributed in Metropolitan scale in the city of Naples. 64 processors of the GRID infrastructure of PON S.Co.P.E. are been used to create simulations. In about 6 hours of CPU time 3040 simulations were generated and 18240 files were saved on a storage element of the grid:

6080 FITS files (maps smoothed and unsmoothed), 6080 TGA images, 3040 a_{lm}'s and 3040 C_l's files, for a total of about 100 GB of compressed data.

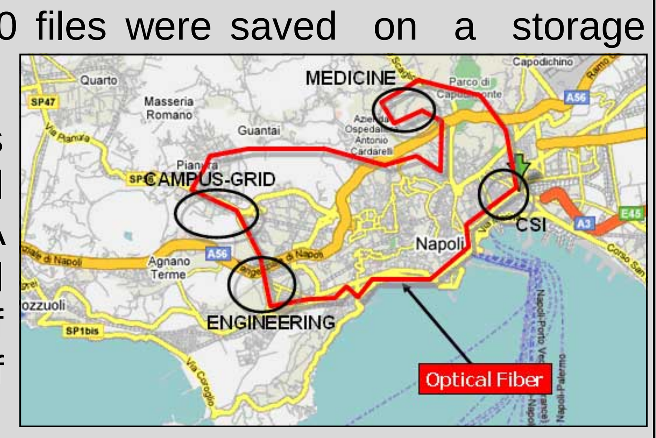

Fig. 6 : PON S.Co.P.E. GRID, Napoli (Italy)