Extragalactic gamma-ray background (EGB) radiation from dark matter annihilation

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Using the high-resolution Millennium-II simulation of cosmic structure formation, we have created the first full-sky maps of the gamma-ray radiation background expected from the annihilation of dark matter in extragalactic structures.

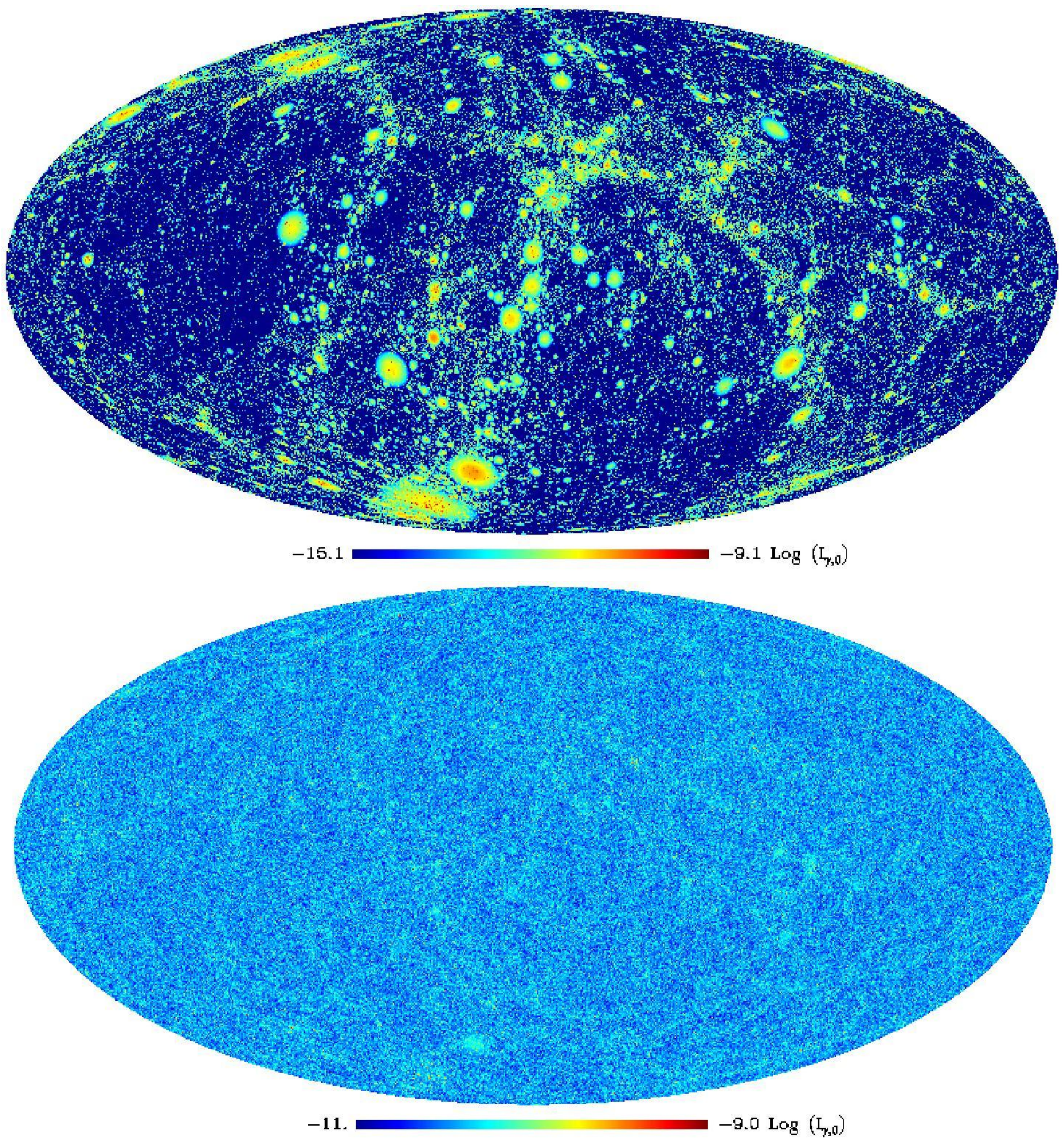


Fig. 1: Upper panel: A partial map showing the EGB produced by annihilation in nearby structures. Only sources within 68 Mpc from an observer, randomly located in the simulation box, are considered for the map. The color scale gives a visual impression of the values of the specific gamma-ray intensity for each pixel in the map; the red color corresponds to the highest values. The observed energy of the simulated map is 10 GeV.

Lower panel: The full gamma-ray sky map from annihilation containing sources up to z=10. The gamma-ray luminosity of dominant nearby halos clearly appearing in the map of the upper panel is outshined by a smoother radiation produced by distant halos, effectively emitting as point sources. In both maps only the contribution down to the smallest haloes resolved by the simulation (1 billion solar masses) is shown.

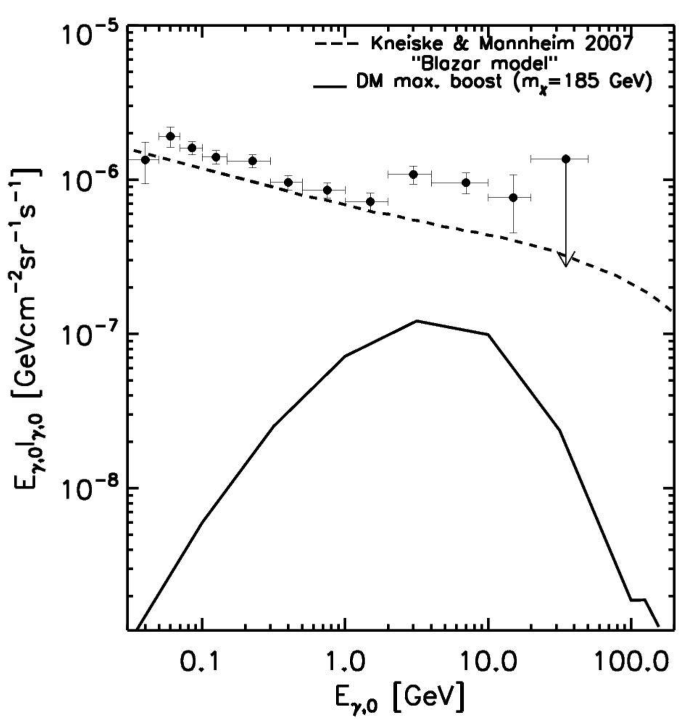
SUSY Dark Matter. The presence of dark matter has only been inferred through its gravitational effects. However, if dark matter is made of neutralinos, a new particle predicted by Supersymmetry, it would also interact, although very weakly, with ordinary matter, and it might be detected soon in laboratories on Earth. In addition, neutralinos can self-annihilate to produce ordinary particles like positrons, neutrinos and gamma-rays. If these byproducts of the annihilation are copious enough, they could be detected by satellites such as FERMI.

Galactic Halo. This gamma-ray radiation is produced most abundantly in high density regions. Thus, it seems best to look for it in very dense nearby regions, such as the center of our own Galaxy and/or the centers of its satellite galaxies. Actually, it turns out that the best prospects for detection in our Galaxy are obtained by looking slightly off-centre to avoid confusion of the signal with other sources of gamma rays residing at the Galactic center (Springel et al. 2008).

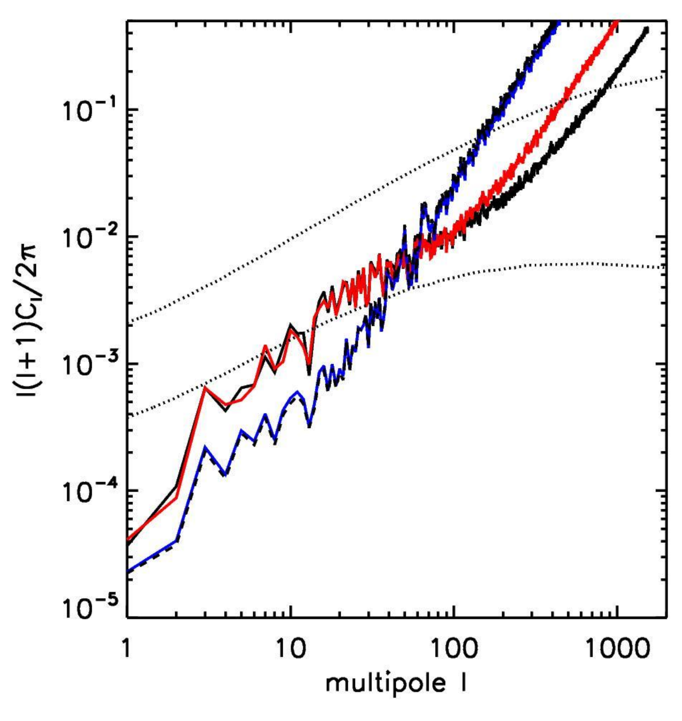
EGB. Gamma-rays are also produced in large quantities by annihilation in all the many halos and subhalos within our past light-cone, contributing to EGB radiation. Although the EGB also receives contributions from other sources, such as blazars and cosmic rays accelerated at structure formation shocks, the energy spectrum and angular power spectrum of the annihilation radiation have distinctive features that may open up effective ways for disentangling the signal.

Simulated maps. We used the state-of-the-art Millennium-II simulation to generate all-sky maps of the contribution of dark matter annihilation to the EGB. A special map-making procedure was developed that re-creates the past light cone of a fiducial galactic observer, taking into account the gamma-ray luminosity of all numerically resolved halos and their subhalos. The method also includes corrections for unresolved components as well as an extrapolation to the minimum mass for bound neutralino halos. The angular resolution of the created maps was chosen to be close to that of FERMI, approximately 0.115°.

Isotropic component. For most of the relevant energy range (0.1-30 GeV), the signal comes mainly from sources up to z=2. Several mechanisms have been proposed that may enhance the signal, such as the presence of highly dense "spikes" of dark matter formed around intermediate-mass black holes (with masses between a hundred and a million solar masses), or the so-called Sommerfeld enhancement, a quantum-mechanical focusing effect that increases the annihilation cross section (Zavala 2009b).



Anisotropic component. It can help to discriminate against other sources of gamma-rays. It depends in a unique way on the large-scale distribution of halos, on the distribution of subhalos within halos, and on the abundance and internal structure of halos as a function of time.



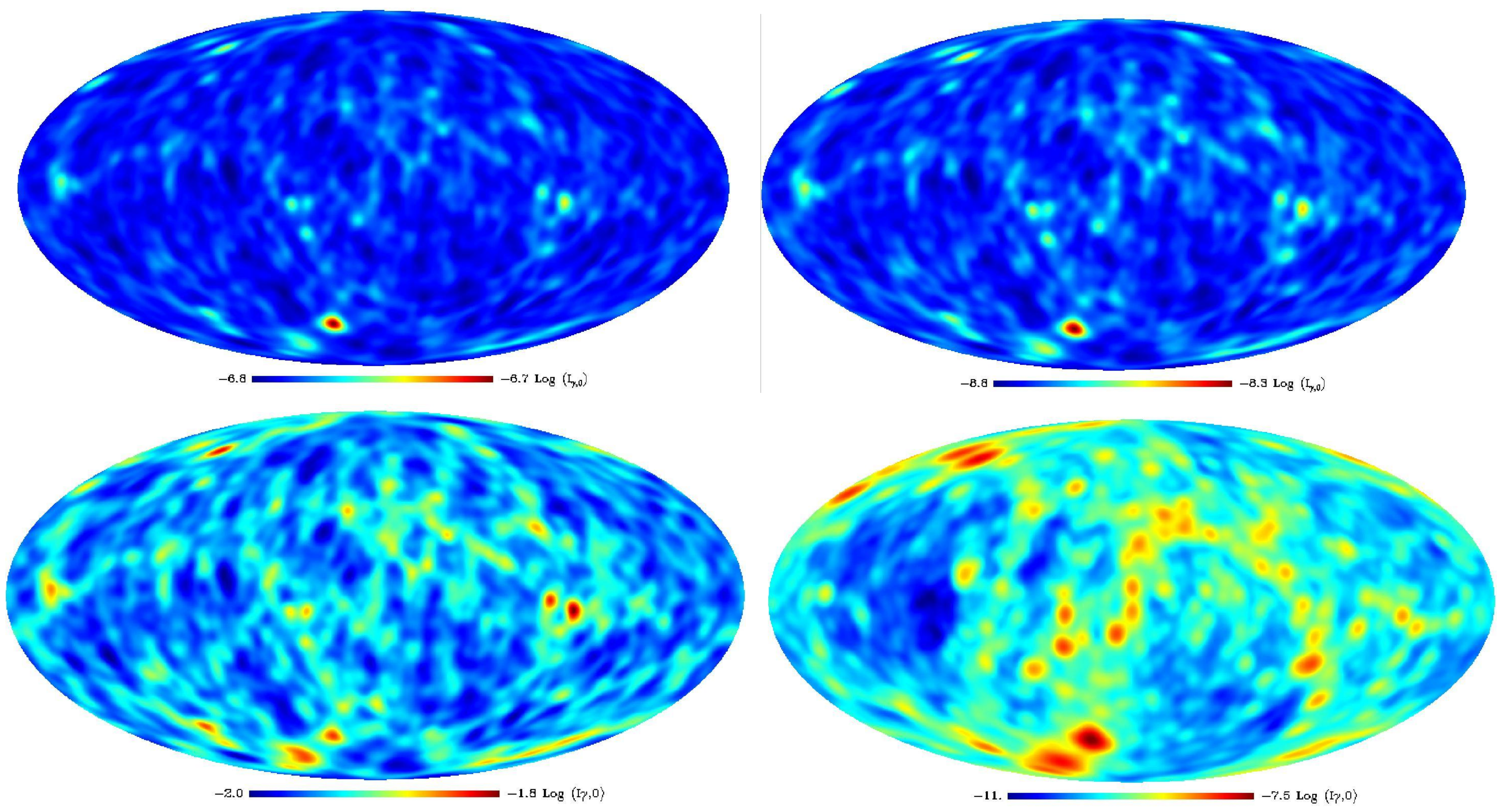


Fig. 2: Upper panel: Full-sky maps at energies 0.1 GeV and 32 GeV in the left and right, respectively. The maps were smoothed with a Gaussian beam with a FWHM of 5 degrees. At a single energy, a full-sky map is very smooth, nearby structures are only minimally visible.

Lower panel: Ratio of the maps in the upper panel (left) and a partial map containing only nearby structures within 68 Mpc for an observed energy of 0.1 GeV (right). Creating difference maps ("color" maps) using different energy channels greatly enhances the signal of nearby structures.

"Color Maps". The shape of the power spectrum depends on the observed energy. These maps can be used to enhance the signal of nearby dark matter structures.

References: Zavala et al. 2009a, arXiv: 0908.2428; Springel et al. 2008, Nature, 456, 73; Zavala et al. 2009b, arXiv: 0910.5221