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The DAMPE space mission(*)

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Summary. — The DArk Matter Particle Explorer (DAMPE) is a satellite-based cosmic-ray experiment that has been operational for almost 8 years. Since its launch in December 2015, it is continuously collecting data on high-energy cosmic particles with very good statistics and particle identification capabilities, thanks to a large geometric factor and a good energy resolution. In this contribution some of the latest results are presented and discussed.

1. – The DAMPE instrument

The DArk Matter Particle Explorer (DAMPE) [1] is designed to investigate several scientific fields, such as gamma-ray astronomy, observation of cosmic-ray spectra up to hundreds of TeV, and search for indirect signatures of dark matter. The instrument consists of four sub-detectors: a plastic scintillator detector (PSD), devised to discriminate charged particles from gamma rays and to measure their absolute charge; a silicon-tungsten tracker-converter (STK), used to perform the track reconstruction and convert photons in $e^{\pm}$ pairs; a bismuth germanium oxide (BGO) calorimeter with a total depth of 32 radiation lengths, designed to measure the energy of the particles and separate hadronic from electromagnetic showers; finally, a neutron detector (NUD), which allows a better discrimination between electromagnetic and hadronic particles.

2. – Gamma-ray observations

DAMPE is capable of detecting gamma rays in a wide energy range, from ~2 GeV to 10 TeV, with an effective acceptance of about 0.18 m^{2}sr. Over the past years, the understanding of the instrument response has been improved significantly and the entire gamma-ray sky has been covered 15 times since the start of the mission, with more than 300 thousands gamma rays collected (see fig. 1a). The study of the gamma-ray physics conducted by DAMPE includes different topics, such as the observation of transient sources, the study of the Galactic Centre, and the search for dark matter signatures in

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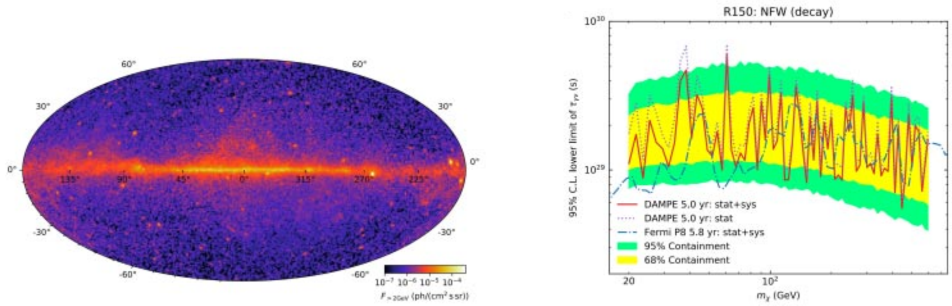


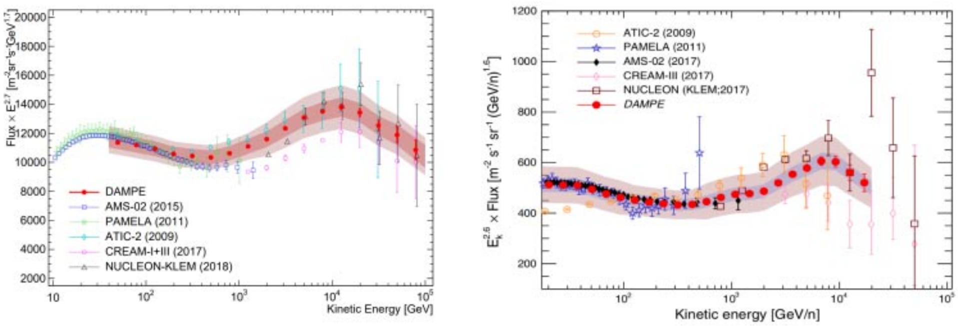
(a) (b)

Fig. 1. – Gamma-ray observations with the DAMPE instrument: (a) map of the integrated gamma-ray flux above 2 GeV derived with 7.2 years of data [2]; (b) constraints on dark matter decay lifetime derived from the gamma-ray line search [3].

the diffuse gamma-ray spectrum [2]. The excellent energy resolution of DAMPE, thanks to its thick calorimeter, allows for high sensitivity in the search for spectral lines possibly produced by annihilation or decay processes of dark matter particles in the Galaxy. Five years of DAMPE data were used to search for spectral lines from 10 to 300 GeV, and the constraints on the annihilation cross section or decay lifetime are presented in ref. [3]. Most of the results are comparable to the *Fermi*-LAT limits and, as it can be seen in fig. 1b, the DAMPE constraints on the decay lifetime are even stronger by a factor of $\sim$2 for dark matter with mass $\leq$100 GeV, demonstrating the potential of the high-energy-resolution observations on dark matter detection.

3. – Galactic cosmic-ray measurements

3$\cdot$1. *Proton and helium energy spectra.* – Proton and helium ions represent the most abundant primary cosmic-ray nuclei. Thanks to the large acceptance and good calorimetric features of the DAMPE detector, their study allows probing the highest energies that can be reached by cosmic-ray direct measurements. The data collected from January 2016 to June 2018 have been used to compute the cosmic-ray proton spectrum from 40 GeV to 100 TeV (see fig. 2a) [4]. The result confirms the presence of a hardening around a few hundreds GeV observed by previous experiments [5, 6], and reveals a softening at $\sim$14 TeV with a significance of 4.7σ. Similar spectral features have also been found in the helium flux in the energy range from 70 GeV to 80 TeV, obtained using the data collected from January 2016 to June 2020 (see fig. 2b) [7]. Also in this case, the result confirms the hardening at $\sim$1.3 TeV also found by previous experiments [6, 8], and provides a strong evidence of a softening at $\sim$34 TeV with a high significance of 4.3σ. When combined with the proton spectrum, this result suggests that the observed spectral features are consistent with a charge-dependent hypothesis, although a dependence on particle mass cannot be ruled out because of the uncertainties. In order to have more details about the behaviour of the cosmic-ray flux at the highest energies that can be reached with direct measurements, the proton+helium analysis has been recently performed, and the combined spectrum has been calculated up to hundreds TeV (see fig. 3) [9]. The result is in agreement with the previously reported individual proton and helium spectra, confirming the hardening and softening features with the unprecedented



(a) (b)

Fig. 2. – Proton (a) [4] and helium (b) [7] energy spectra measured by the DAMPE instrument, compared with the results of the previous experiments. The error bars represent the statistical uncertainties, while the inner and outer bands denote the systematic uncertainties from the analysis and the total systematic uncertainties.

significance of 6.6σ. Moreover, the significantly larger combined statistics allows reaching higher energies with low background, suggesting a hint of a new spectral hardening above 100 TeV and establishing a link between space- and ground-based experiments.

3˙2. *B/C and B/O ratios.* – Boron nuclei are believed to be secondary cosmic rays, since they are mainly produced through spallation of heavier primaries, such as carbon and oxygen, via collisions with the interstellar medium. Therefore, the study of secondary over primary ratios provides a unique probe to investigate the cosmic-ray propagation mechanisms inside the Galaxy. The direct measurement of boron-to-carbon (B/C) and boron-to-oxygen (B/O) flux ratios in the energy range from 10 GeV/n to 5.6 TeV/n has been performed using 6 years of data collected by DAMPE (see fig. 4) [10]. The results are well consistent with the previous measurements [11] and allow a precise measurement of both the ratios above 1 TeV/n. Their energy dependence can be fitted by a broken

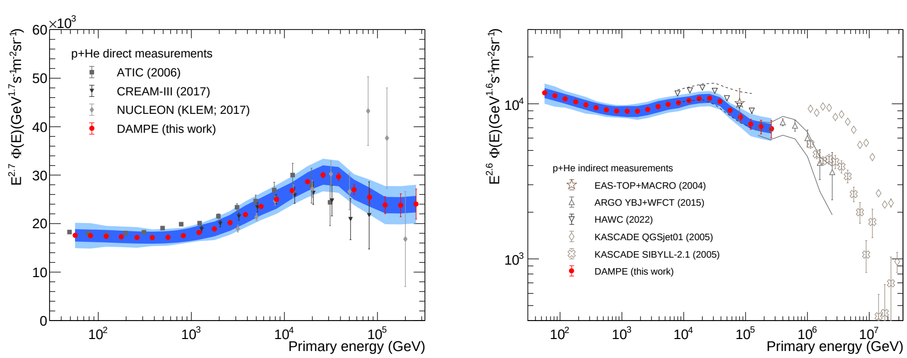
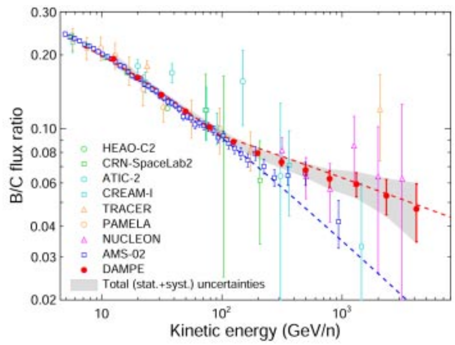


Fig. 3. – p+He spectrum measured with the DAMPE detector, compared with direct (left) and indirect (right) measurements. The statistical uncertainties are represented by error bars, while the continuous bands represent the systematic uncertainties on the analysis (inner band) and the total systematic uncertainties (outer band). More details in ref. [9].



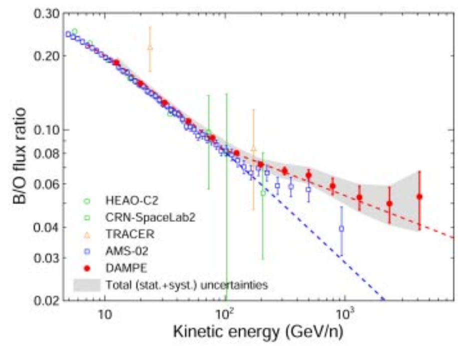


Fig. 4. – Boron-to-carbon (left) and boron-to-oxygen (right) flux ratios as a function of the energy per nucleon measured by the DAMPE instrument. The error bars represent the statistical uncertainty, while the shaded bands denote the total uncertainty (sum in quadrature of the statistical and systematic uncertainties). More details in ref. [10].

power-law model, suggesting the existence of a spectral hardening at about 100 GeV/n with a significance greater than 4σ. This features may imply a change of the turbulence properties of the interstellar medium, or may be the results of more complicated propagation effects of cosmic rays. Therefore, an improvement in the measurement of the B/C, B/O, and the other secondary-to-primary ratios is necessary to solve the fundamental questions about the origin and propagation mechanisms of cosmic rays in the Galaxy.

3˙3. *Heavier nuclei and ongoing analyses*. – Other analyses are currently ongoing for the study of the individual spectra of boron, carbon and oxygen, as well as other cosmic-ray species, from the secondaries lithium and beryllium to the heavier primaries such as neon, magnesium and silicon, up to iron [12-14]. Such analyses must confront various challenges, including background contamination and fragmentation inside the detector. These obstacles can effectively be addressed by employing machine learning-based methods to enhance track reconstruction and improve background rejection [15].

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