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A database of charged cosmic rays*

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ABSTRACT

Aims. This paper gives a description of a new online database and associated online tools (data selection, data export, plots, etc.) for charged cosmic-ray measurements. The experimental setups (type, flight dates, techniques) from which the data originate are included in the database, along with the references to all relevant publications.

Methods. The database relies on the MySQL5 engine. The web pages and queries are based on PHP, AJAX and the jquery, jquery.cluetip, jquery-ui, and table-sorter third-party libraries.

Results. In this first release, we restrict ourselves to Galactic cosmic rays with $Z \leq 30$ and a kinetic energy per nucleon up to a few tens of TeV/n. This corresponds to more than 200 different sub-experiments (i.e., different experiments, or data from the same experiment flying at different times) in as many publications.

Conclusions. We set up a cosmic-ray database (CRDB) and provide tools to sort and visualise the data. New data can be submitted, providing the community with a collaborative tool to archive past and future cosmic-ray measurements.

Key words. astroparticle physics – solar neighborhood – cosmic rays – astronomical databases: miscellaneous

1. Introduction

Since the discovery of cosmic rays (CR) a century ago, instrumental capabilities have steadily improved. A large variety of types of experiments (balloon- or satellite-borne experiments, those flown on a shuttle, those installed on the International Space Station, or ground-based experiments) and techniques have been used (nuclear emulsions, drift chambers, Cerenkov counters, spectrometers, etc.) to refine our knowledge of the CR composition and spectrum.

The presence of heavy $Z < 30$ (Freier et al. 1948a,b) and extremely heavy $Z \geq 30$ elements (Fowler et al. 1967; Blanford et al. 1969) in the cosmic radiation were among the main discoveries related to Galactic CR nuclei, which culminated with the discovery of a few $Z > 90$ events (Fowler et al. 1970; O'Sullivan et al. 1971; Price et al. 1971). Isotopes and, in particular, the radioactive CR clocks were identified with more or less difficulties due to their decreasing abundance and mass separation with increasing atomic number: ^{10}Be (Webber et al. 1973c), ^{36}Cl (Young et al. 1981), ^{26}Al (Webber 1982), and ^{54}Mn (Webber et al. 1979). The CR leptons were identified in the early 60's with the first measurement of electrons – also called negatrons at that time – (Earl 1961; Meyer & Vogt 1961) and of the positron fraction (de Shong et al. 1964; Hartman et al. 1965; Agrinier et al. 1965; Daniel & Stephens 1965b). Anti-protons are $\sim 10^{-4}$ times less abundant than protons and were only observed in the late 70's (Bogomolov et al. 1979; Golden et al. 1979). Anti-deuterons, which are expected to be yet another factor $\sim 10^{-4}$ below (Chardonnet et al. 1997), are still to be detected: the best limit is given by the BESS balloon (Fuke et al. 2005; see also Abe et al. 2012a for limits on anti-helium), and is still three orders of magnitude above what is required to reach the expected astrophysical production. This level could be within reach of the AMS-02 detector on the International Space Station (Arruda et al. 2008; Choutko & Giovacchini 2008) and/or the GAPS balloon-borne experiment (Aramaki et al. 2012). We note that other milestones in CR studies are the discovery of the γ-ray diffuse emissions that were reported first by Kraushaar et al. (1972) and studied by the contemporary *Fermi*-LAT instrument (Ackermann et al. 2012b), and the first evidence of high-energy CRs from extensive air showers (Auger et al. 1939), which are currently studied at the *Pierre Auger* Observatory (e.g., Abraham et al. 2010).

In the last twenty years, a lot of effort has been devoted in measuring the CR composition at higher energy ($\gtrsim$TeV). Very accurate isotopic data were also provided in the low energy range $\sim$100–500 MeV/n (Voyager 1 and 2, *Ulysses*, and ACE), over an extended period of time. The recently installed AMS-02 experiment on the International Space Station (May 2011) has started to provide impressive measurements in the GeV/n–TeV/n range (Aguilar et al. 2013). Interestingly, most of the even oldest CR measurements are not outdated yet. Indeed, many instruments are designed to focus on specific CR species: neither all instruments have the isotopic resolution capabilities nor have all species been measured repeatedly. Some old experiments are also useful when one wishes to inspect a possible charge-sign dependence (22 year cycle) of the Solar modulation effect as a function of the Sun polarity, as first proposed by Clem et al. (1996) and further studied in Clem & Evenson (2002). For all these reasons, we believe it is worth providing an archival database of CR measurements to the community.

The CR data are the backbone of Galactic CR propagation studies (e.g., Jones et al. 2001; Maurin et al. 2001; Strong et al. 2007; Evoli et al. 2008). In the last twenty years, anti-protons

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and positron fraction measurements have also become a strong probe for dark matter indirect searches (e.g., Porter et al. 2011; Lavalle & Salati 2012). A database would therefore be useful to any researcher in these fields but also to CR experimentalists, who wish to compare their data to previously published ones. Another independent effort to provide a CR database was presented in Strong & Moskalenko (2009). We present a contextualised and more complete version of the data here[1], along with many user-friendly interfaces and tools to use them.

The paper is organised as follows: Sect. 2 describes the database content; Sect. 3 describes the website and available tools. We conclude and comment on possible improvements of the database in Sect. 4. Appendix A provides the rules to combine CR quantities from a given experiment (e.g., to form quantity A/B from A and B fluxes), and Appendix B gives a summary list of all the experiments/references contained in this first release.

2. Content of the database

In this section, we first describe the information gathered in the database and the data themselves. We then present how this information is organised in a MySQL framework[2].

2.1. Definitions

The CR data are connected to experiments, analyses, and publications. The first step for creating the database is to define what an experiment is. Then, the need to define a sub-experiment arises because i) an experiment may consist of several detectors; or ii) an instrument may have flown several times, or over distinct periods. Data from a sub-experiment often involve several CR species, the analyses of which are published in one or several papers. For the sake of clarity, the following keywords/definitions are used in the database:

Experiment. Name associated with the instrument (CREAM, AMS). To identify unnamed balloons, we use the syntax Balloon (YYYY), and a further distinction is made if a balloon was flown several times: a comma-separated list of years Balloon (1966,1967) is used if the data were analysed and published for each flight; a plus-separated list Balloon (1967+1968) is used if the data resulted from the combined analysis of the flights[3].

Sub-experiment. Sub-detector name or experiment name concatenated with the flight number and data taking period (YYYY/MM) with start and stop dates separated by a hyphen for durations over a month[4]: Balloon (1972/07), CREAM-I (2004/12-2005/01), CREAM-II (2005/12-2006/01), and *Ulysses*-HET (1990/10-1997/12).

Cosmic-ray quantity. Combination (sum, ratio, etc.) of measured CR species[5]. It can be an elemental (e.g., C), isotopic (e.g., ^{1}H), or leptonic (e.g., e^-) flux, or any ratio of these quantities such as B/C, ^{10}Be/Be, $e^+/(e^- + e^+)$, etc. The keyword SubFe is used for the group $Z = 21-23$, but no other charge group is defined for now.

Energy axis. Detectors often measure the CR total energy $E_{\rm tot}$ or rigidity $\mathcal{R} = pc/Ze$ (p is the momentum, Z the charge, c the speed of light, and e the electron charge). Data are also very often presented as a function of the kinetic energy $E_{\rm k} = E_{\rm tot} - m$ (m is the CR mass) or the kinetic energy per nucleon $E_{\rm k/n} = E_{\rm k}/A$ (A is the atomic number). In the database, we allow four representations of the energy unit and axis: [GeV] for $E_{\rm tot}$, [GV] for $\mathcal{R}$, [GeV] for $E_{\rm k}$, and [GeV/n] for $E_{\rm k/n}$.

Publication. Refereed or non-refereed reference (i.e., journal or conference proceedings) providing CR quantity data from (sub-)experiments. A publication is usually attached to a single (sub-)experiment, and it contains different CR measurements, but there are a few exceptions. Over time, some of these publications may be superseded by newer analyses: a specific entry of the database allows us to keep track of deprecated analyses and references.

Data. The CR quantity measurement and uncertainties at one or several energy bins (see Sect. 2.2 for a complete description).

Because the combinations of CR quantities are themselves CR quantities, this introduces a subtleties in the choice of how to handle the database. One could be tempted to fill the database with all useful combinations of data (e.g., the often used B/C ratio) from published quantities (e.g., B and C fluxes). However, the number of combinations that can be formed is large (for $Z < 30$, as many elements and about a hundred isotopes can be combined), and the procedure to combine the errors on the measurements is not always sound. For these reasons, we decided to fill the database with the published quantities only. We leave the task of extracting the most complete dataset (for a given CR quantity) to the DATA EXTRACTION tab interface (Sect. 3.2), which combines the data found directly in the database and those obtained by looking for all combinations of data leading to this quantity (see Sect. 3.2 and also Appendix A for a discussion of the priority rules and criteria to decide how and when to form new quantities and evaluate their uncertainties).

2.2. Data description and units

The structure of a CR data entry (energy, energy range, measurement and uncertainties) for any measured quantity is as follows:

$\langle E \rangle$ "Central" energy given in the publication (unit is [GeV] if the energy axis is $E_{\rm tot}$ or $E_{\rm k}$, [GV] for $\mathcal{R}$, and [GeV/n] for $E_{\rm k/n}$). If only the bin range (see below) is given in the publication, the geometric mean $\langle E \rangle = \sqrt{E_{\rm min} E_{\rm max}}$ is used.

Bin range Energy range (same unit as $\langle E \rangle$). If only $\langle E \rangle$ is given in the publication, $E_{\rm min} = E_{\rm max} = \langle E \rangle$.

Value Measured CR quantity in unit of $[(\langle E \rangle\,{\rm m^2\,s\,sr})^{-1}]$ if this is a flux, or unitless if this is a ratio. The data correspond to top-of-atmosphere (TOA) quantities, which is modulated by the Sun's activity.

[1] The data were gathered independently of the data presented in the Strong & Moskalenko (2009) database https://sourceforge.net/projects/cosmicraydataba

[2] The descriptions correspond to CRDB V2.1, which was the version at the time of re-submission of the paper.

[3] The naming convention chosen for the experiment and the sub-experiment ensures the many unnamed balloons flown before the 90's to be uniquely defined.

[4] Some of the start and stop dates for balloon flights are not given in the publication and were taken from the StratoCat database of stratospheric balloons launched worldwide since 1947 (http://stratocat.com.ar/globos/indexe.html). For long-lived instruments, we do not include the excluded time periods (within the start and stop dates) in the database based on the analysis quality criteria (solar flares, high solar activity, instrument stability, etc.) because they are never given in the publication.

[5] A CR must be a stable species with respect to the confinement time in the Galaxy, with an effective lifetime $\gtrsim$kyr (note that the electronic capture decay mode is suppressed because CR nuclei are fully stripped of e^- above ~0.1 GeV/n).

Stat Err Statistical error (same unit as Value).
Syst Err Systematic error (same unit as Value); this is set to 0 if not given in publication.

In the database, these values must be filled for each data point from the published data. Whenever available, we used the values given in the publication tables. However, most publications provide none, and the data had to be retrieved from the plots (using the DataThief III software[6]).

2.3. Solar modulation description

A flight period for a given instrument is uniquely associated to a Solar activity period. For each sub-experiment of the database, a unique modulation level thus can be attached. In practice, its determination depends primarily on the choice of the (unknown) Solar modulation model. It also depends on the assumption made for the unknown interstellar (IS) flux and on the set of data used for its calculation. At least three different model-dependent approaches exist: the modulation potential given in the experimental papers is very often determined from an assumed ad-hoc local interstellar spectrum (LIS), which is modulated to match the data. Another widely used approach is to take a demodulated spectrum from another publication and modulate it to match the data. Another strategy is to rely on the worldwide network of neutron monitor data that gives an indirect estimation of the Solar modulation level (Usoskin et al. 2002, 2005, 2011).

2.3.1. Sets of modulation levels in the database

As there is no consensus yet regarding how to proceed best, we provide several sets of values (of the modulation parameters) in the database and the underlying assumptions made for their determination. The two sets introduced in CRDB V2.1 are

1. *From publication*: in this set, the solar modulation values are directly taken from the publications. This set is not *homogeneous*, since each value relies on IS fluxes and Solar modulation models (see below), which differ from one publication to another. We note that the underlying hypotheses are not always provided and that only a small fraction of the publications offers a modulation value at all.
2. *NM [Uso11]*: the modulation levels in this set (ϕ in the Force-Field approximation) are based on the NM data analysis of Usoskin et al. (2011). Monthly average values in the period July 1936 – December 2009 are interpolated for the flight dates of each sub-experiment. The ensemble of values forms a *homogeneous* set of ϕ for all sub-experiments, because each value is based on the same modelling.

It is very important to pursue the efforts towards the determination of homogeneous sets of modulation parameter values: (1) because these values are routinely used *as is* by cosmic-ray physicists for CR propagation studies (and also in the context of indirect dark matter detection) and (2) because assessing which is the correct modulation model requires to disprove simple models. Systematic studies of CR data on several decades are mandatory to achieve this goal. Indeed, as underlined in Maurin et al. (2014), there is a degeneracy between the IS flux and the solar modulation level: assuming the wrong IS flux lead to a shift of all determined ϕ values. Combining the results of direct fits to CR data and the use of NM data should provide more robust (and homogeneous) determinations of ϕ time series (Maurin et al. 2014). As progress is made along this line (Ghelfi et al., in prep.), new sets of values will complement the two above.

2.3.2. Ingredients: Modulation model, IS flux, and data

The modulation level for any set and any sub-experiments is associated to assumptions regarding the ingredients of its calculation. To avoid too much complexity, a few general categories were created for each ingredient:

– *Modulation models and values*[7]
  1. *N/A*: No modulation model in the publication;
  2. *Diffusion/convection*: model used in early CR data publications with the free parameter η (Parker 1958a,b; L'Heureux et al. 1972);
  3. *Force-Field approximation*: widely used model with one free parameter ϕ_{FF} (Gleeson & Axford 1967, 1968; Perko 1987; Caballero-Lopez & Moraal 2004)
  4. *Spherically Symmetric solution*: model with a single effective[8] free parameter ϕ_{1D} (Fisk & Axford 1969; Fisk 1971; Beatty et al. 1993);
  5. *Sign-charge dependent*: 3D models have plenty of parameters to describe the tilt angle, the current sheet, anisotropic diffusion, etc. (Jokipii & Kopriva 1979; Potgieter & Moraal 1985; Potgieter 2013). For simplicity, we use the same category for all of them.

– *IS fluxes*
  1. *N/A*: if unknown or if ϕ not calculated;
  2. *LIS flux hypothesis*: if taken from another study;
  3. *LIS flux fitted*: if taken from a fit on CR data;
  4. *Leaky-Box calculation*: if taken from a Leaky-Box model calculation (e.g., Garcia-Munoz et al. 1987);
  5. *GALPROP calculation*: if taken from a GALPROP[9] run (Strong & Moskalenko 1998);
  6. *Monte Carlo Diffusion*: if taken from a Monte Carlo propagation run (e.g., Webber & Rockstroh 1997).

– *Data*
  1. *N/A*: if unknown or if ϕ not calculated;
  2. *CR data from the publication*: if ϕ is determined from the published set of CR data;
  3. *CR data from another publication*: if ϕ is based on another published set of CR data;
  4. *Neutron Monitor (NM) data*: if ϕ from NM data.

Examples of how these informations are organised and displayed in CRDB are given in the next sections.

2.4. Database structure description

The database engine is MySQL5, hosted at the Laboratoire de Physique and Cosmologie (LPSC) on a backed up server. The structure and keys are shown in Fig. 1 (keys in exp, subexp, and publi were discussed in Sect. 2.1, those in data are found in Sect. 2.2, and those in ref_modulation_type in Sect. 2.3). Each

[6] http://datathief.org

[7] For the time being, only one parameter value per Solar modulation model is allowed. If no value is provided in the publication or if a 3D model is used, the value is set to 0.

[8] The parameter ϕ is related to the Solar wind velocity V_w, the spatial-dependent diffusion coefficient $\kappa(r)$, and the Solar cavity boundary R_0 by $\phi = (1/3)\int_1^{R_0} V_w/\kappa(r)\,dr$. We note, however, that this formula depends on assumptions made on the wind spatial dependence and the diffusion coefficient rigidity dependence.

[9] http://galprop.stanford.edu

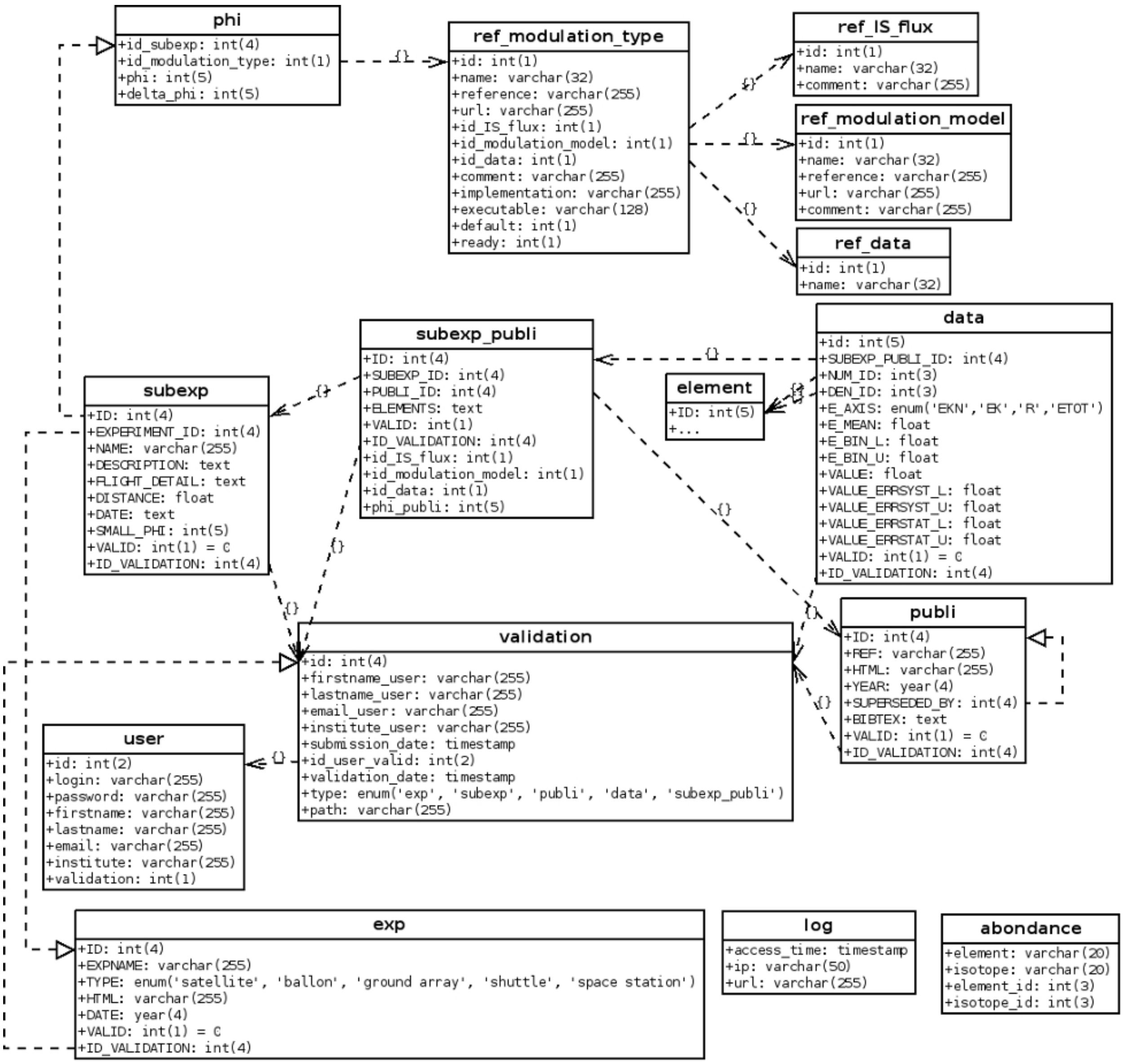


Fig. 1. Tables and keys of the database MySQL structure (see text for details).

entry in a table is associated with a unique identifier. These identifiers are used to link elements from one table to another (for example, several sub-experiments can be linked to a single experiment). For completeness, all tables of Fig. 1 are briefly described below:

- *exp* Name, type, web site (if available), and flight date.
- *subexp* Link to which the experiment belongs, name, description of the apparatus, flight details (launch place and the number of flights for balloons), flight dates, distance to the Sun [AU], and Solar modulation level [MV].
- *publi* Bibliographic reference, web link, publication year, BibTeX[10] entry (taken from the Astrophysics Data System ADS[11]), and link to other publications (if more recent analyses exist).
- *subexp_publi* Bridge table linking entries from publi to one or several entries of subexp.
- *phi* Solar modulation level and error for the sub-experiment.
- *ref_modulation_type* Bridge table linking entries from phi to entries in the three tables below.
- *ref_IS_flux* List/description of IS flux categories.
- *ref_modulation_model* List/description of Solar modulation models.
- *ref_data* List/description of data used to calculate ϕ.
- *element* Name, mass, atomic number, charge, etc. for CR quantities (isotopes, elements, $\bar{p}$, e^-, and e^+).
- *data* Type (flux or ratio of element), energy axis, energy, bin range, value, statistic and systematic errors.
- *abondance* Association of each element to its most abundant isotope to allow (approximate) conversions between different energy axes (since V1.2).
- *user* Contact details of administrators (persons authorised to change and validate submitted data).
- *log* Statistics of the number of the users (since V1.2).
- *validation* Contact details of persons submitting new data (see Sect. 3.3 for the New Data interface), validation date and Identity of the person (user) who validated the data.

[10] http://www.bibtex.org

[11] http://cdsads.u-strasbg.fr

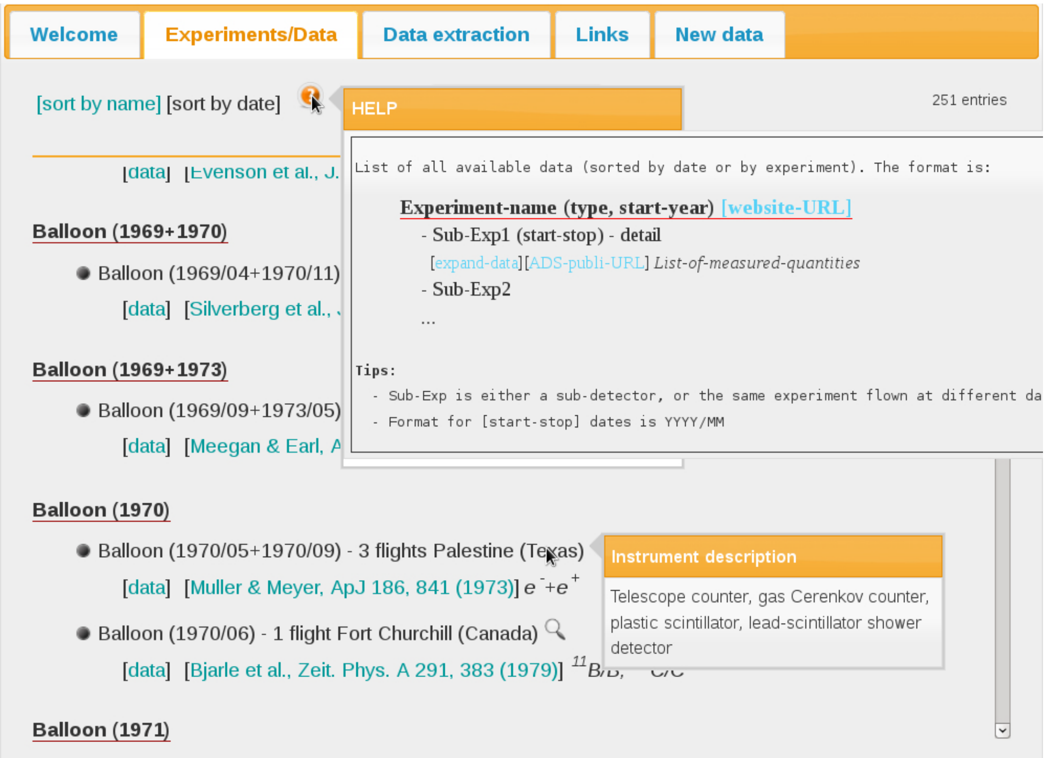


Fig. 2. Snapshot of the EXPERIMENTS/DATA tab content (Sect. 3.1). The help box is activated by clicking on the [question mark] icon and a picture of the instrumental setup (not shown) pops-up when clicking on the [magnifying glass] icon. The *Instrument description* box appears for a mouse-over action on the sub-experiment name. A click on [data] pops-up a new window with the data entries and a summary of all the (sub-)experiment/publication informations (not shown).

3. Website, interfaces, and example plots

The CR database website (http://lpsc.in2p3.fr/crdb) is hosted by the LPSC laboratory website and is based on a LAMP solution[12]. Authentication uses the `https` protocol to ensure a good level of confidentiality. (Only administrators use their own credentials to access protected areas.) All web pages are written using the PHP (Hypertext PreProcessor) language, with a global structure made in AJAX (Asynchronous JavaScript and XML). The third-party libraries jquery, jquery-ui, jquery.cluetip, and table-sorter are also used.

The website is based on tabs, in which the user is guided by help boxes (identified by [question mark] icons). We give below a brief description of the implemented tabs:

Welcome Quick description and organisation of the database, log of the latest changes, and link to download the database content formatted for the USINE[13] propagation code.

Experiments/Data List of available data sorted by experiment names or dates. A list of experiment acronyms is given.

Data extraction Main interface to retrieve data in ASCII files, ROOT[14] macros and plots, and BIBTEX references for the selection.

Admin Shown for authenticated users only: internal checks of the database content and validation of submitted data.

Links Standard useful (here GCR-related) web links.

New Data Interface to submit new data which will appear in the database after validation by authorised users.

As underlined previously, native data (i.e., data directly from publications) are listed and accessed from EXPERIMENTS/DATA (Sect. 3.1). In the DATA EXTRACTION tab (Sect. 3.2), native data and matching combinations of native data are combined to provide the most complete list of data found for user-selected quantities/criteria. Adding new data is possible from the NEW DATA tab (Sect. 3.3).

3.1. Data access from EXPERIMENTS/DATA tab

Figure 2 shows a snapshot of the EXPERIMENTS/DATA tab (and some enabled actions within this tab). The list of published data is ordered by experiment name or date. For each experiment, the list of sub-experiments is shown and sorted by start time[15]. The publication references related to this sub-experiment are then listed, along with the quantities measured (older analyses/publications of the same data are indicated). The most useful actions/pop-up informations available for the user are as follows:

- experiment description (name, type, official web page);
- sub-experiment description (name, data periods[16], instrument description [mouse-over] name, experimental setup picture [magnifying glass] icon);

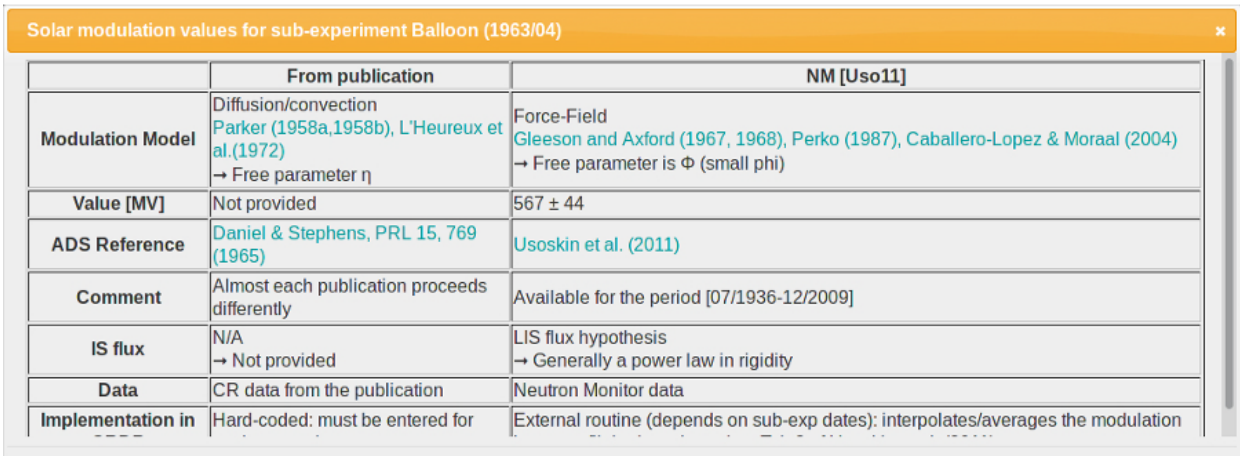
[12] The acronym LAMP refers to a stack of free open source softwares: Linux operating system, Apache HTTP server, MySQL database software, and PHP.

[13] http://lpsc.in2p3.fr/usine

[14] http://root.cern.ch

[15] We refer the reader to Sect. 2.1 for the definition of what is meant by experiment, sub-experiment, publication, etc., and to Sect. 2.4 for the structure of the data in the MySQL frame.

[16] Full details of the flight dates are given clicking on [data]. The start and stop time format is YYYY/MM/DD-hh:mm:ss. A new line is used for each flight.



Solar modulation values for sub-experiment Balloon (1963/04)

	From publication	NM [Uso11]
Modulation Model	Diffusion/convection Parker (1958a,1958b), L'Heureux et al.(1972) → Free parameter η	Force-Field Gleeson and Axford (1967, 1968), Perko (1987), Caballero-Lopez & Moraal (2004) → Free parameter is Φ (small phi)
Value [MV]	Not provided	567 ± 44
ADS Reference	Daniel & Stephens, PRL 15, 769 (1965)	Usoskin et al. (2011)
Comment	Almost each publication proceeds differently	Available for the period [07/1936-12/2009]
IS flux	N/A → Not provided	LIS flux hypothesis → Generally a power law in rigidity
Data	CR data from the publication	Neutron Monitor data
Implementation in	Hard-coded: must be entered for	External routine (depends on sub-exp dates): interpolates/averages the modulation

Fig. 3. Snapshot of the Solar modulation values for a given sub-experiment (after clicking on [data], see Fig. 2, then [Parameters]).

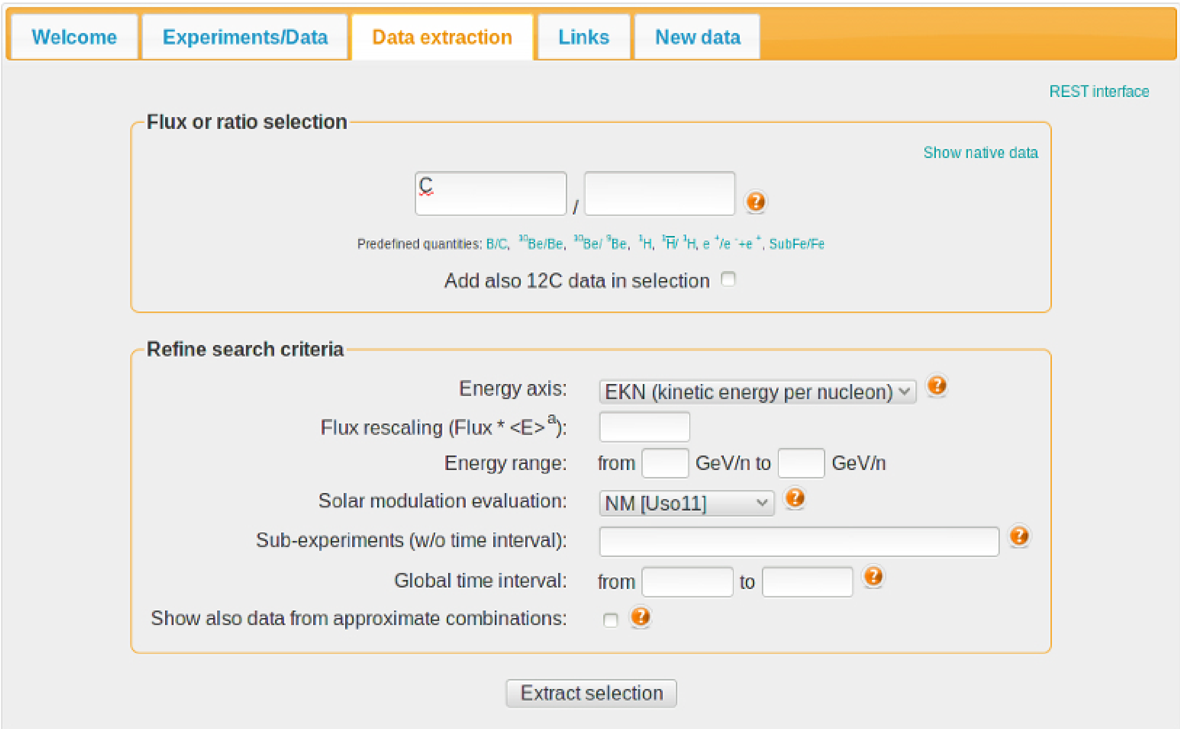


Fig. 4. Snapshot of the DATA EXTRACTION tab interface. In the *upper panel*, a CR quantity is chosen by means of selection boxes (auto completion enabled). In the *lower panel*, more search criteria are possible (energy range, list of experiments or sub-experiments, time period, etc.). The selector [Solar modulation evaluation] allows the user to choose which set of ϕ values (see Sect. 2.3) is displayed. A tick box allows to add in the search the data points obtained from combinations of "native" data (see Appendix A). Clicking on the [Extract selection] button pops up the results, as shown in the example Fig. 5.

– data for each publication (from a sub-experiment). A click on [data] (see Fig. 2) pops-up a window (not shown in the examples): its upper half summarises all the information on the sub-experiment (contained in the database) and gives the ADS link of the reference. The lower half shows the data (see Sect. 2.2 for their format): ratios are sorted first and fluxes second. (One can jump directly to the data of interest clicking on one of the quantities suggested in the upper half panel.) In the upper half panel, clicking on [Solar modulation: Parameters] pops up a new window with the sub-experiment modulation values, as shown in Fig. 3. [Solar modulation: Parameters]).

By default, CR data for nuclei and anti-nuclei are given as a function of kinetic energy per nucleon, whereas leptons are given as a function of the kinetic energy. Whenever the energy axis for a given dataset is given as a function of rigidity, the flag "Rigidity" (in red colour and in brackets) is added after the data.

3.2. Selection and tools from DATA EXTRACTION tab

Figure 4 shows a snapshot of the selection interface within the tab. A mandatory step is the quantity selection (Flux or ratio selection), for which a few predefined choices are proposed. For a ratio, both the numerator and denominator selection boxes must

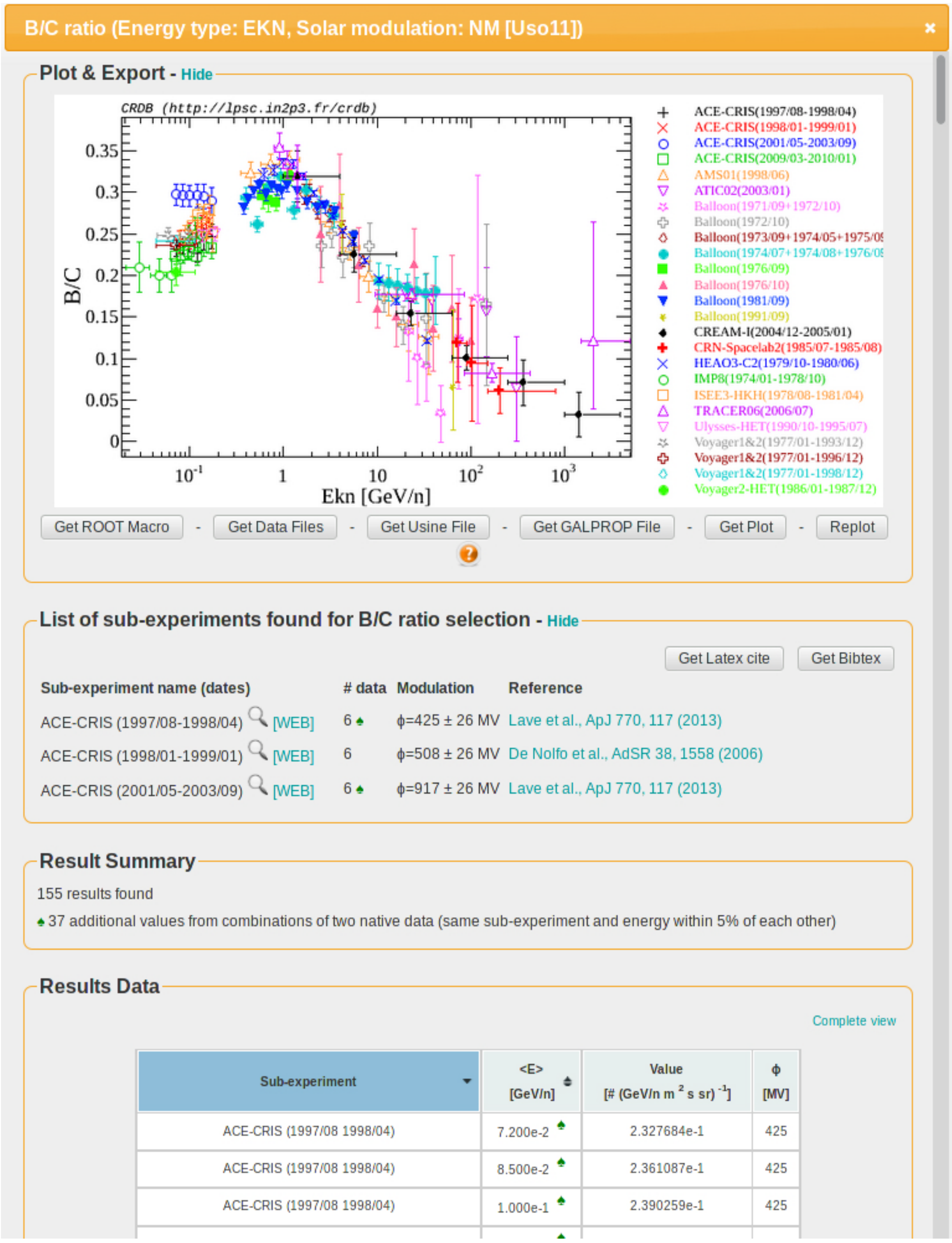


Fig. 5. Snapshot of the result of the DATA EXTRACTION operation. This pop-up window appears after the selection step shown in Fig. 4 is completed. Buttons, links, and tables give access to raw data and plots, see text for details.

be filled (auto completion is enabled). The other optional selection criteria (Refine search criteria) are:

- *Energy axis*: to be selected among EKN, EK, R or Etot[17];
- *Flux rescaling*: multiplies the flux values and errors by $\langle E\rangle^a$ (useful for presentation purpose);
- *Energy range*: restricts the energy range allowed;
- *(Sub-)Experiment names*: list of comma-separated names (partial names allowed, e.g., CREAM, BESS);
- *Time interval*: selects only experiments falling into the selected period (format is YYYY/MM);
- *Show also data from combinations*: tick box to add in the search the data points obtained from combinations of "native" data (see Appendix A).

Hitting the [Extract Selection] button pops-up a new window with the data extracted from the user selection. This is shown in Fig. 5, which is organised in three panels (click on [hide]/[show] to collapse/expand each panel):

1. *Plots and exports for the selection*:
   - Export selected data in various formats: [Get Data Files], [GET USINE/GALPROP File] provide a tar-ball of ASCII files containing the data (one file per sub-experiment) and a USINE- or GALPROP-compliant file (i.e., input for these propagation codes) respectively;

[17] As already said, most data are published in EKN for nuclei and anti-nuclei and EK for leptons (very few data are published on several energy axes). For elements, a conversion to move from one energy axis to another is implemented, since V1.2. The result is approximate, since a unique A, Z, and m must be assumed for all isotopes of this elements. (We use the most abundant isotope, which is a very good approximation for some elements.)

   - Exports plots: [Get ROOT Macro] and [Plot] provide a ROOT executable C++ file to re-generate and/or modify the plot[18] and a high-resolution image `database_plot.png` respectively;
   - [Replot] (since V1.2): new panel to change the plot (size, *y*-axis range, select only a subset of sub-experiments, etc.).
2. *List of experiments found for the selection*: summary of the data sorted by (sub-)experiment (name, publication, number of data, etc.). The [Get Bibtex] and [Latex cite] buttons provide a BIBTEX file (bibtex.bib) to be included in the references, and the text to cite this selection in the LATEX document[19]. As for the EXPERIMENTS/DATA tab (Sect. 3.1), links to the experiment website and the ADS publication are provided.
3. *Data for the selection*: data in a table (see Sect. 2.2 for the content description) sorted by experiment name or energy. An asterisk denotes the data obtained by combinations of native data of the database (see Appendix A).

With the default search criteria (i.e., none), we note that all analyses of a CR quantity by the same instrument show up in the result as long as they correspond to different data taking (or analysed) periods (i.e., different sub-experiments). For most of the time, these data are independent, but the analysed periods overlap in a few cases. It happens, for instance, for the Voyager data (launched in 1977 and still taking data). In that case, it is up to the user to decide, which data sets are relevant for her/his analysis, and exclude it using the "Sub-Experiment" or "Global Time interval" selection boxes (see Fig. 4).

3.3. New data from the ADD DATA tab

This tab allows anyone to interactively enter new data. This is an essential part of the database as it provides the community with the possibility to contribute to the completion of the database (either by adding data from new instruments, or adding missing data from older experiments).

Submitting new data consists of two parts: as shown in Fig. 6 (top panel), the first part concerns the submitter identification (contact details). The second part (same figure, middle and bottom panel) is data submission. Four steps must be passed in order. For the first three steps (experiment, sub-experiment, and publication), the submitter is left with the choice of selecting her/his entry among those already in the database, or to add a new entry ([Insert new] button): the latter action pops-up a new window in which the submitter is guided, where help boxes are provided for each item, to fill the necessary information, which match the keys of the database structure as described in Sect. 2.4 (see also Fig. 1). Each time a new entry is submitted, the submitted element becomes available for further submissions, though it does not appear yet in the database (i.e., in EXPERIMENTS/DATA and EXTRACT DATA tabs).

Once the three previous steps are completed, the last action is the submission of the CR data (see bottom panel of Fig. 6). A template file for the required format (and units) of the data is provided (see Sect. 2.2). Only one CR quantity at a time (with as many energy bins as desired) can be submitted. Before the final submission of the data, the [Data graphical check] button pops-up a summary of the uploaded file, along with a plot of the submitted data for a last visual inspection. At this stage, the submission process can still be cancelled if any mistake is spotted.

For each submitted entry (experiment, sub-experiment, publication, and data), an email is sent to the administrators of the database content[20]. Validation tools from the ADMIN tab are then

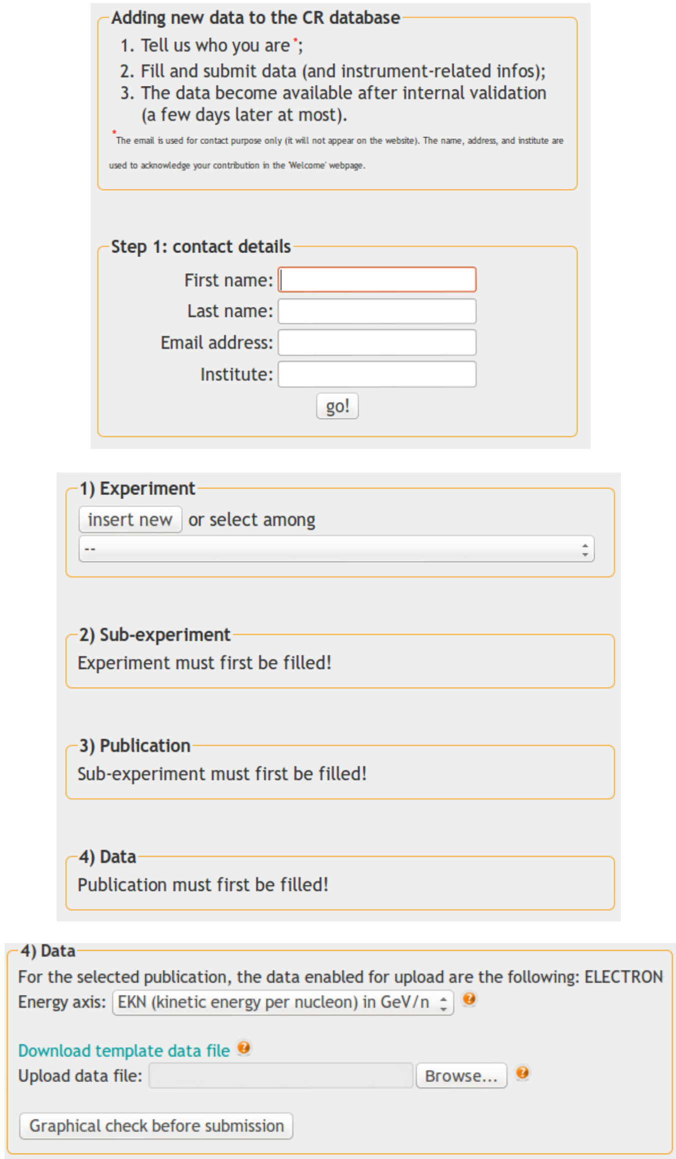


Fig. 6. Snapshots of the user interfaces in the ADD DATA tab. The first stage for adding new data is the submitter identification (*upper panel*). The ordered four-step submission process comes next (*middle panel*). The user has to either select among existing entries or insert a new one (this pops-up a window with fields to fill), which does not work for the fourth step that concerns the CR data. The latter must be filled one CR quantity at a time (and must belong to the list of quantities declared at the publication step): the *bottom panel* shows the state of the panel once this step is reached with the energy axis to select, the data file to upload, and the [Graphical check before submission]. We note that help buttons exist for most of the fields to fill at all steps.

[18] Based on the ROOT library http://root.cern.ch. To execute, type `root database_plot.C` (the data are hard-coded). The errors displayed correspond to the quadratic sum of statistical and systematic uncertainties.

[19] These files are useful to quickly prepare scientific manuscripts based on LATEX and BIBTEX. Appendix B and the references of this paper were prepared with the full list of references retrieved from the [Get Bibtex] and [Latex cite] buttons in the WELCOME tab.

[20] For now, the only authorised persons are the developers of the database. Any person wishing to get involved in further developments of the database is welcome to contact us.

used (format check, completeness, etc.) to authorise the addition in the database (pending validation, the data are inserted in the database with a "not validated" flag and do not appear on the web site).

4. Conclusions and future improvements

We have developed a database of charged CRs (http://lpsc.in2p3.fr/crdb) that includes e^-, e^+, $\bar{p}$, and nuclide data up to $Z = 30$ for energies below a few TeV/n. Each CR data is linked to a description of the instrument that measured it (flight dates, picture of the experiment setup, techniques used, etc.) and to the ADS reference in which it was published: this first release contains more than 200 experiments and 200 publications. The data can be extracted according to a selection on the CR quantity, the energy range, the experiments, and the epoch of measurement: ASCII files, ROOT macros, plots, and BibTeX for the corresponding publications are then readily available. Since CRDB V1.3, we have also implemented (on request) a REST interface[21].

The possibility to add new data by means of a user-friendly interface enables the database to be a collaborative tool for the CR community, provided enough people take an interest, use it, and help expand it. New data will be added as new results become available (We encourage experimentalists to submit their data once they become public.). The database could also be extended to a larger energy domain (data from ground-based detectors $\gtrsim$TeV/n data) or to heavier species ($Z > 30$). Time series, such as low-energy proton, helium, and electron data with a monthly or finer time resolution from long-lived high-precision instruments (e.g., AMS-02) could also be very interesting inputs for Solar modulation studies.

We welcome any help to further develop the database. Comments, questions, suggestions, and corrections[22] can be addressed to crdatabase@lpsc.in2p3.fr.

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Appendix A: Forming a new combination of data from "native" data in the database

The CR experiments provide measurements over several energy bins. The elementary brick of information in GCR physics is the isotopic flux. However, isotopic identification is rarely achieved even in contemporary experiments, and published results are often ratios of elements (e.g., B/C) and elemental fluxes (e.g., B, C).

Flux measurements suffer from many systematics (energy-dependent acceptance, dead time, rigidity cut-off in the Geomagnetic field, etc.) that mostly factor out from the ratio of species close in charge. As a result, uncertainties of published ratios are smaller than if calculated by quadratically combining the errors on the fluxes. Obviously, published ratios should always be preferred if provided in the publication. However as underlined in Sect. 2.1, only the most used ratios are generally published (e.g., B/C).

In this Appendix, we detail how "native" data are searched for and combined to lead to the user-selected quantity (Appendix A), as it is for fluxes or ratios. We then discuss the necessary rules to calculate the uncertainties from the "native" data uncertainties (Appendix A). We note that the data can only be combined if coming from the same sub-experiment. (Otherwise, they would correspond to different Solar modulation periods and suffer from different systematics.) Obviously, the benefit of adding extra data (for a CR quantity) to a CR analysis must also always be weighted against using only the "native" and more accurate data found in the same energy range. A check box in the selection interface (shown in Fig. 4) enables or disables the search for these data. We did not systematically check how many extra data points are obtained in this way, but the algorithm finds some. These data are singled out by an asterisk in the result panel (shown in Fig. 5).

A.1. Priority rules to form new quantities

The database extraction tool (Extract data tab) is designed to return the most complete set of data for a given CR quantity $Q^{\rm searched}$. It needs a set of rules to browse through the database content and retrieve the queried quantity. The search is prioritised as follows (We use the superscript *native* to indicate quantity in the database.):

1. look directly for the queried quantity $Q^{\rm native}$;
2. if Q is a flux, search for all i for which the pair $(Q/Q_i)^{\rm native}$, $(Q_i)^{\rm native}$ exist. The new data obtained are $Q^{\rm combo} = \cup_i \left\{(Q/Q_i)^{\rm native}/(Q_i)^{\rm native}\right\}$;
3. if CR quantity is a ratio $Q = Q_{\rm num}/Q_{\rm denom}$, search for
   - $Q^{\rm combo} = Q^{\rm native}_{\rm num}/Q^{\rm native}_{\rm denom}$;
   - $Q^{\rm combo} = \cup_i \left\{(Q_{\rm num}/Qi)^{\rm native}/(Q_{\rm denom}/Q_i)^{\rm native}\right\}$;
   - $Q^{\rm combo} = \cup_i \left\{(Q_{\rm num}/Qi)^{\rm native} \times (Q_i/Q_{\rm denom})^{\rm native}\right\}$.

To be complete, more complex combinations should be implemented (addition and subtraction of isotopic fraction of an element, addition of group of charges, etc.). These combinations require a more complex query that remains to be implemented (it is under development).

Another subtlety is that valid combinations are restricted to data points of similar energy ranges. As underlined in Sect. 2.2, sometimes only the "central" energy bin of the data point is available. Moreover, values extracted from published plots (using DataThief) cannot match exactly one another. For these reasons, we relax the constraint of a perfect energy match and use instead

- *data point that haves only a "central" value*: we demand this value to be i) within the energy range, or ii) within 20% of the "central" value of the data point it is combined to;
- *data point that have an energy range*: we demand an overlap of the energy ranges of the data points to be combined.

A.2. Rules to calculate uncertainties

For all experiments, the default rule is that relative errors are quadratically summed whenever combinations of CR data are formed. In this first release, the only exception concerns

[21] An example of call using a command line in an xterm is given by *wget "http://lpsc.in2p3.fr/crdb/rest.php?num=C&energy_type=EKN" --output-document=file*. For a list of parameters, click on [REST interface] (Fig. 5).

[22] Despite our best efforts, many data published in CR conferences (e.g., ICRC) are probably missing, and many typos and errors probably remain to be corrected.

HEAO-3 data (Engelmann et al. 1990), where the authors provide tables for the oxygen flux and for the relative fluxes (to O). The rules to calculate uncertainties depends on the charge proximity of the combined elements. The original text, which is spread over the original publication, is reproduced below:

- *"In Table 5 [...] the standard error is given with each flux value. This error includes the statistical error and, in the case of the last two energy channels, the systematic error."*
- *"The spectrum of any element between $Z=4$ and $Z=28$ can be obtained by multiplying the oxygen flux values of Table 5 by the corresponding abundance ratios given in Table 2. The relative errors on these two numbers shall be quadratically summed to get the error on the flux derived by this way."*
- *"For widely different charges Z_1 and Z_2, a reasonable estimate of the error on the abundance ratio is the quadratic sum of the errors on both type of nuclei Z_1 and Z_2 (for example, the total error on Fe/O ratio is ~5.2%). For nearly adjacent charges, an upper limit of the systematic error is given by the difference between the systematic errors on each element (for example, the error on B/C is ~0.4%)."*

Appendix B: List of experiments and publications

We provide below a sorted list of experiments (unnamed balloons appear first), sub-experiments, and associated publications present in the database first release[23].

- Balloon (1963/04): Daniel & Stephens (1965a)
- Balloon (1964,1965,1966)
  - Balloon (1964/07): L'Heureux (1967)
  - Balloon (1965/06+1965/07): L'Heureux (1967)
  - Balloon (1966/06): L'Heureux & Meyer (1968)
- Balloon (1965/07+1965/08+1966/06): Hartman (1967); Fanselow et al. (1969); Fanselow (1968)
- Balloon (1965,1966,1967,1968)
  - Balloon (1965/07): Bleeker et al. (1965)
  - Balloon (1966/08): Bleeker et al. (1970)
  - Balloon (1967/08): Bleeker et al. (1970)
  - Balloon (1968/07): Bleeker et al. (1970)
- Balloon (1965,1966,1968,1969,1971+1972)
  - Balloon (1965/07): Webber et al. (1973a)
  - Balloon (1965/07+1966/07): Beedle & Webber (1968); Webber & Chotkowski (1967)
  - Balloon (1966/07): Webber et al. (1973a)
  - Balloon (1968/07): Webber et al. (1973a)
  - Balloon (1969/07): Webber et al. (1973a)
  - Balloon (1971/07+1972/07): Webber et al. (1973a)
- Balloon (1966/03): Anand et al. (1968)
- Balloon (1966/09): Danjo et al. (1968)
- Balloon (1966,1967)
  - Balloon (1966/07): Earl et al. (1972)
  - Balloon (1966/09): Earl et al. (1972)
  - Balloon (1967/07): Earl et al. (1972)
- Balloon (1967/06+1967/07): Israel & Vogt (1968)
- Balloon (1967/07): Agrinier et al. (1969)
- Balloon (1967/11+1968/06): Fanselow et al. (1971)
- Balloon (1968/05): Anand et al. (1973)
- Balloon (1968/06): Scheepmaker & Tanaka (1971)
- Balloon (1968/07): Beuermann et al. (1969)
- Balloon (1968+1969…1999+2001): Nishimura et al. (1980, 1985); Kobayashi (1999); Nishimura et al. (2001); Kobayashi et al. (2012)
- Balloon (1968-1975,1977,1979,1982,1984,1987,1990,1992,1994)
  - Balloon (1968/06+1968/07): Fulks (1975); Hovestadt et al. (1971); Schmidt (1972)
  - Balloon (1969/06+1969/07): Fulks (1975); Hovestadt et al. (1971); Schmidt (1972)
  - Balloon (1970/06+1970/07): Fulks (1975); Hovestadt et al. (1971); Schmidt (1972)
  - Balloon (1971/06+1971/07): Fulks (1975); Hovestadt et al. (1971)
  - Balloon (1972/07): Fulks (1975); Hovestadt et al. (1971)
  - Balloon (1973/07): Caldwell et al. (1975)
  - Balloon (1974/07): Caldwell et al. (1977)
  - Balloon (1975/07): Caldwell et al. (1977)
  - Balloon (1977/07): Evenson et al. (1979)
  - Balloon (1979/08): Evenson & Meyer (1984)
  - Balloon (1982/08): Evenson & Meyer (1984)
  - Balloon (1982/10): Garcia-Munoz et al. (1986)
  - Balloon (1984/09): Garcia-Munoz et al. (1986)
  - Balloon (1987/08): Evenson et al. (1995)
  - Balloon (1990/08): Evenson et al. (1995)
  - Balloon (1992/08): Evenson et al. (1995)
  - Balloon (1994/08): Evenson et al. (1995)
- Balloon (1969/04+1970/11): Silverberg et al. (1973)
- Balloon (1969/09+1973/05): Meegan & Earl (1975)
- Balloon (1970/05+1970/09): Muller & Meyer (1973)
- Balloon (1970/06): Bjarle et al. (1979)
- Balloon (1971/05): Apparao (1973)
- Balloon (1971/09+1972/10): Juliusson (1974)
- Balloon (1971,1972)
  - Balloon (1971/07): Webber et al. (1973a)
  - Balloon (1971/07+1972/07): Webber et al. (1973a)
  - Balloon (1972/07): Webber et al. (1973a)
- Balloon (1972/07): Webber & Schofield (1975); Webber et al. (1987)
- Balloon (1972/07): Daugherty et al. (1975)
- Balloon (1972/10): Freier et al. (1977); Orth et al. (1978)
- Balloon (1972/11+1973/05): Buffington et al. (1974, 1975)
- Balloon (1973/06): Ishii et al. (1973)
- Balloon (1973/08): Fisher et al. (1976); Hagen et al. (1977); Leech & Ogallagher (1978)
- Balloon (1973/09+1974/05): Dwyer (1978)
- Balloon (1973/09+1974/05+1975/09+1975/10): Dwyer & Meyer (1987)
- Balloon (1974/07+1974/08): Hartman & Pellerin (1976)
- Balloon (1974/07+1974/08+1976/09): Lezniak & Webber (1978)
- Balloon (1975/09+1975/10): Minagawa (1981)
- Balloon (1975/10): Prince (1979); Hartmann et al. (1977)
- Balloon (1975/12): Bogomolov et al. (1979)
- Balloon (1976/05): Golden et al. (1984, 1987)
- Balloon (1976/10): Simon et al. (1980)
- Balloon (1977/05): Buffington et al. (1978)
- Balloon (1977/07): Webber & Yushak (1983)
- Balloon (1977/09): Webber & Kish (1979); Webber (1982)
- Balloon (1980/10): Tang (1984)
- Balloon (1981/04): Jordan (1985)
- Balloon (1981/09): Webber et al. (1985a,b)
- Balloon (1984/04): Mueller & Tang (1987)
- Balloon (1987/05+1988/05+1989/05+1991/05): Ichimura et al. (1993)
- Balloon (1989/05+1991/05): Kamioka et al. (1997)
- Balloon (1989/09): Hatano et al. (1995)
- Balloon (1990/07): Bogomolov et al. (1995)
- Balloon (1991/09): Buckley et al. (1994)
- ACE
  - ACE-CRIS (1997/08-1998/04): George et al. (2009)
  - ACE-CRIS (1997/08-1998/12): Wiedenbeck et al. (1999)
  - ACE-CRIS (1997/08-1999/07): Yanasak et al. (2001)
  - ACE-CRIS (1998/01-1999/01): de Nolfo et al. (2006)
  - ACE-CRIS (2001/05-2003/09): George et al. (2009)
  - ACE-SIS (1997/08-1999/07): Yanasak et al. (2001)
- AESOP
  - AESOP94 (1994/08): Clem et al. (1996)
  - AESOP97+98 (1997/09+1998/08): Clem et al. (2000)
  - AESOP99 (1999/08): Clem & Evenson (2002)
  - AESOP00 (2000/08): Clem & Evenson (2002)
  - AESOP02 (2002/08): Clem & Evenson (2004)
  - AESOP06 (2006/08): Clem & Evenson (2009)
- ALICE
  - ALICE (1987/08): Hesse et al. (1996)
  - ALICE (1987/08+1987/08): Esposito et al. (1992)
- AMS-01
  - AMS01 (1998/06): Alcaraz et al. (2000a); AMS Collaboration et al. (2000, 2002); Xiong et al. (2003); Aguilar et al. (2010, 2011)
  - AMS01-BremsstrahlungPhotons (1998/06): AMS-01 Collaboration et al. (2007)
  - AMS01-singleTrack (1998/06): Alcaraz et al. (2000b); AMS Collaboration et al. (2002)
- ATIC
  - ATIC01&02 (2001/01+2003/01): Chang et al. (2008)
  - ATIC02 (2003/01): Panov et al. (2008, 2009)
- BESS
  - BESS93 (1993/07): Moiseev et al. (1997); Wang et al. (2002)
  - BESS94 (1994/07): Myers et al. (2003)
  - BESS95 (1995/07): Matsunaga et al. (1998); Myers et al. (2003)
  - BESS97 (1997/07): Orito et al. (2000); Myers et al. (2003); Shikaze et al. (2007)
  - BESS98 (1998/07): Sanuki et al. (2000); Maeno et al. (2001); Myers et al. (2003); Shikaze et al. (2007)
  - BESS99 (1999/08): Asaoka et al. (2002); Shikaze et al. (2007)
  - BESS00 (2000/08): Asaoka et al. (2002); Shikaze et al. (2007)
  - BESS-TeV (2002/08): Haino et al. (2004, 2005); Shikaze et al. (2007)
  - BESS-PolarI (2004/12): BESS Collaboration et al. (2008)
  - BESS-PolarII (2007/12-2008/01): Abe et al. (2012b)
- BETS
  - BETS97&98 (1997/06+1998/05): Torii et al. (2001)
  - BETS04 (2004/01): Yoshida et al. (2008)
- CAPRICE
  - CAPRICE94 (1994/08): Boezio et al. (1997, 1999, 2000)

[23] The list and BibTeX references were obtained from the Get all BibTeX entries and LaTeX cite links in the Welcome tab.

  - CAPRICE98 (1998/05): Boezio et al. (2001a,b); Mocchiutti & Wizard/Caprice Collaboration (2003); Boezio et al. (2003); Papini et al. (2004)
- CREAM
  - CREAM-I (2004/12-2005/01): Ahn et al. (2008); Yoon et al. (2011)
  - CREAM-II (2005/12-2006/01): Ahn et al. (2009, 2010)
- CRISIS (1977/05): Freier et al. (1980); Young et al. (1981)
- CRN-Spacelab2 (1985/07-1985/08): Swordy et al. (1990); Mueller et al. (1991)
- CRRES (1990/07-1992/10): Duvernois et al. (1996a)
- *Fermi*
  - *Fermi*-LAT (2008/06-2011/04): Ackermann et al. (2012a)
  - *Fermi*-LAT (2008/06-2009/06): Ackermann et al. (2010)
- H.E.S.S. (2004/10-2007/08): Aharonian et al. (2008, 2009)
- HEAO3-C2 (1979/10-1980/06): Ferrando et al. (1988); Engelmann et al. (1990)
- HEAT
  - HEAT94 (1994/05): Barwick et al. (1995, 1997, 1998)
  - HEAT95 (1995/08): Barwick et al. (1997); DuVernois et al. (2001)
  - HEAT94&95 (1994/05+1995/08): Barwick et al. (1997); DuVernois et al. (2001)
  - HEAT-pbar (2000/06): Beach et al. (2001); Beatty et al. (2004)
- HEIST (1988/08): Gibner et al. (1992)
- IMAX92 (1992/07): Mitchell et al. (1996); Reimer et al. (1998); Menn et al. (2000); de Nolfo et al. (2000)
- IMP
  - IMP1 (1963/11-1964/05): Cline et al. (1964)
  - IMP3 (1965/06-1965/12): Hsieh et al. (1971)
  - IMP3 (1965/07-1966/03): Fan et al. (1968)
  - IMP4 (1967/06-1967/10): Hsieh et al. (1971)
  - IMP5 (1969/06-1969/09): Hsieh et al. (1971)
  - IMP7 (1972/09-1972/12): Teegarden et al. (1975)
  - IMP7 (1972/10-1976/10): Garcia-Munoz et al. (1979)
  - IMP7 (1973/05-1973/08): Garcia-Munoz et al. (1975)
  - IMP7&8 (1972/09-1975/09): Garcia-Munoz et al. (1977)
  - IMP7&8 (1973/02-1977/09): Guzik (1981)
  - IMP7&8 (1974/01-1980/05): Garcia-Munoz et al. (1981)
  - IMP8 (1974/01-1977/11): Beatty et al. (1985)
  - IMP8 (1974/01-1978/10): Garcia-Munoz et al. (1987)
- ISEE
  - ISEE3-HIST (1978/08-1978/12): Mewaldt et al. (1980b,a, 1981); Mewaldt (1986)
  - ISEE3-HKH (1978/08-1979/08): Wiedenbeck & Greiner (1980)
  - ISEE3-HKH (1978/08-1980/05): Wiedenbeck & Greiner (1981a,b)
  - ISEE3-HKH (1978/08-1981/04): Wiedenbeck (1983); Krombel & Wiedenbeck (1988); Leske (1993)
  - ISEE3-MEH (1978/08-1979/02): Evenson et al. (1979)
  - ISEE3-MEH (1978/08-1984/04): Kroeger (1986)
  - ISEE3-MEH (1979/02-1980/03): Evenson et al. (1981)
  - ISEE3-MEH (1980/03-1981/03): Evenson et al. (1981)
- ISOMAX (1998/08): Hams et al. (2004)
- JACEE (1979+1980+1982...1990+1994+1995): Asakimori et al. (1998)
- MASS
  - MASS89 (1989/09): Webber et al. (1991); Golden et al. (1994)
  - MASS91 (1991/09): Hof et al. (1996); Bellotti et al. (1999); Basini (1999); Grimani et al. (2002)
- MUBEE (1975/09+1978/08+1986/07+1987/07): Zatsepin et al. (1993)
- OGO5
  - OGO5 (1968/04-1968/05): Burger & Swanenburg (1974)
  - OGO5 (1968/04-1969/04): L'Heureux et al. (1972)
  - OGO5 (1968/06-1968/10): Fulks (1975)
  - OGO5 (1969/06-1969/07): Fulks (1975); Burger & Swanenburg (1974)
  - OGO5 (1970/06-1970/07): Fulks (1975); Burger & Swanenburg (1974)
  - OGO5 (1971/05-1971/08): Fulks (1975)
  - OGO5 (1971/07-1971/08): Burger & Swanenburg (1974)
  - OGO5 (1972/06): Fulks (1975)
  - OGO5 (1972/06-1972/07): Burger & Swanenburg (1974)
- PAMELA
  - PAMELA (2006/07-2008/02): Adriani et al. (2009a)
  - PAMELA (2006/07-2008/06): Adriani et al. (2009b)
  - PAMELA (2006/07-2008/12): Casolino et al. (2011); Adriani et al. (2010, 2011a)
  - PAMELA (2006/07-2010/01): Adriani et al. (2011b)
- Pioneer
  - Pioneer8&9 (1967/12-1969/04): Webber et al. (1973b)
  - Pioneer10-HET (1972/03-1973/03): Teegarden et al. (1975)
  - Pioneer10-HET (1985/04-1988/11): Webber & McDonald (1994)
- RICH-II (1997/10): Diehl et al. (2003)
- RUNJOB (1995+1996+1997+1998+1999): Derbina et al. (2005)
- SMILI
  - SMILI-I (1989/09): Beatty et al. (1993)
  - SMILI-II (1991/07): Ahlen et al. (2000)
- SOKOL (1984/03-1984/04): Ivanenko et al. (1993)
- TRACER
  - TRACER03 (2003/12): Ave et al. (2008)
  - TRACER06 (2006/07): Obermeier et al. (2011, 2012)
- Trek-MIR (1991/06-1992/12): Westphal et al. (1996)
- TS93 (1993/09): Golden et al. (1996)
- Ulysses
  - Ulysses-KET (1990/10-1991/02): Rastoin et al. (1996)
  - Ulysses-HET (1990/10-1995/07): Duvernois & Thayer (1996); Duvernois et al. (1996b); Connell & Simpson (1997); Duvernois (1997); Thayer (1997)
  - Ulysses-HET (1990/10-1996/12): Simpson & Connell (1998)
  - Ulysses-HET (1990/10-1997/12): Connell (1998); Connell et al. (1998); Connell (1999)
  - Ulysses-KET (1992/07-1992/10): Rastoin et al. (1996)
  - Ulysses-KET (1993/07-1993/10): Rastoin et al. (1996)
  - Ulysses-KET (1994/07-1994/10): Rastoin et al. (1996)
- Voyager
  - Voyager1-HET (1977/10-1977/11): Webber & Yushak (1983)
  - Voyager1-HET-Aend (1977/10-1977/11): Webber & Yushak (1983)
  - Voyager1-HET (1994/01-1994/09): Seo & McDonald (1995)
  - Voyager1-HET (2010/01-2010/03): Caballero-Lopez et al. (2010)
  - Voyager2-HET (1986/01-1987/12): Ferrando et al. (1991)
  - Voyager2-HET (1987/01-1987/12): Seo et al. (1994)
  - Voyager2-HET (2010/01-2010/03): Caballero-Lopez et al. (2010)
  - Voyager1&2 (1977/01-1991/12): Lukasiak et al. (1994b)
  - Voyager1&2 (1977/01-1993/12): Lukasiak et al. (1994c); Webber et al. (1996)
  - Voyager1&2 (1977/01-1996/12): Lukasiak et al. (1997b,a); Webber et al. (1997)
  - Voyager1&2 (1977/01-1998/12): Lukasiak (1999)
  - Voyager1&2 (1986/01-1989/12): Lukasiak et al. (1994a)
  - Voyager1&2-HET (1987/01-1987/12): Webber & Higbie (2009)

References

Abe, K., Fuke, H., Haino, S., et al. 2012a, Phys. Rev. Lett., 108, 131301
Abe, K., Fuke, H., Haino, S., et al. 2012b, Phys. Rev. Lett., 108, 051102
Abraham, J., Abreu, P., Aglietta, M., et al. 2010, Phys. Lett. B, 685, 239
Ackermann, M., Ajello, M., Atwood, W. B., et al. 2010, Phys. Rev. D, 82, 092004
Ackermann, M., Ajello, M., Allafort, A., et al. 2012a, Phys. Rev. Lett., 108, 011103
Ackermann, M., Ajello, M., Atwood, W. B., et al. 2012b, ApJ, 750, 3
Adriani, O., Barbarino, G. C., Bazilevskaya, G. A., et al. 2009a, Nature, 458, 607
Adriani, O., Barbarino, G. C., Bazilevskaya, G. A., et al. 2009b, Phys. Rev. Lett., 102, 051101
Adriani, O., Barbarino, G. C., Bazilevskaya, G. A., et al. 2010, Phys. Rev. Lett., 105, 121101
Adriani, O., Barbarino, G. C., Bazilevskaya, G. A., et al. 2011a, Science, 332, 69
Adriani, O., Barbarino, G. C., Bazilevskaya, G. A., et al. 2011b, Phys. Rev. Lett., 106, 201101
Agrinier, B., Koechlin, Y., Parlier, B., et al. 1965, in International Cosmic Ray Conference, 1, 331
Agrinier, B., Koechlin, Y., Parlier, B., et al. 1969, Nuovo Cimento Lettere, 1, 53
Aguilar, M., Alcaraz, J., Allaby, J., et al. 2010, ApJ, 724, 329
Aguilar, M., Alcaraz, J., Allaby, J., et al. 2011, ApJ, 736, 105
Aguilar, M., Alberti, G., Alpat, B., et al. 2013, Phys. Rev. Lett., 110, 141102
Aharonian, F., Akhperjanian, A. G., Barres de Almeida, U., et al. 2008, Phys. Rev. Lett., 101, 261104
Aharonian, F., Akhperjanian, A. G., Anton, G., et al. 2009, A&A, 508, 561
Ahlen, S. P., Greene, N. R., Loomba, D., et al. 2000, ApJ, 534, 757
Ahn, H. S., Allison, P. S., Bagliesi, M. G., et al. 2008, Astropart. Phys., 30, 133
Ahn, H. S., Allison, P., Bagliesi, M. G., et al. 2009, ApJ, 707, 593
Ahn, H. S., Allison, P. S., Bagliesi, M. G., et al. 2010, ApJ, 715, 1400
Alcaraz, J., Alpat, B., Ambrosi, G., et al. 2000a, Phys. Lett. B, 490, 27
Alcaraz, J., Alpat, B., Ambrosi, G., et al. 2000b, Phys. Lett. B, 484, 10
AMS Collaboration, Alcaraz, J., Alpat, B., et al. 2000, Phys. Lett. B, 494, 193
AMS Collaboration, Aguilar, M., Alcaraz, J., et al. 2002, Phys. Rep., 366, 331
AMS-01 Collaboration, Aguilar, M., Alcaraz, J., et al. 2007, Phys. Lett. B, 646, 145
Anand, K. C., Daniel, R. R., & Stephens, S. A. 1968, Phys. Rev. Lett., 20, 764
Anand, K. C., Daniel, R. R., & Stephens, S. A. 1973, in International Cosmic Ray Conference, 1, 355
Apparao, K. M. V. 1973, in International Cosmic Ray Conference, 1, 126
Aramaki, T., Chan, S. K., Hailey, C. J., et al. 2012, Nucl. Instr. Meth. Phys. Res. A, 682, 90
Arruda, L., Barão, F., & Pereira, R. 2008 [arXiv:0801.3243]
Asakimori, K., Burnett, T. H., Cherry, M. L., et al. 1998, ApJ, 502, 278
Asaoka, Y., Shikaze, Y., Abe, K., et al. 2002, Phys. Rev. Lett., 88, 051101
Auger, P., Ehrenfest, P., Maze, R., Daudin, J., & Fréon, R. A. 1939, Rev. Mod. Phys., 11, 288
Ave, M., Boyle, P. J., Gahbauer, F., et al. 2008, ApJ, 678, 262
Barwick, S. W., Beatty, J. J., Bhattacharyya, A., et al. 1997, ApJ, 482, L191
Barwick, S. W., Beatty, J. J., Bower, C. R., et al. 1995, Phys. Rev. Lett., 75, 390
Barwick, S. W., Beatty, J. J., Bower, C. R., et al. 1998, ApJ, 498, 779
Basini, G. 1999, in International Cosmic Ray Conference, 3, 77
Beach, A. S., Beatty, J. J., Bhattacharyya, A., et al. 2001, Phys. Rev. Lett., 87, A261101

Beatty, J. J., Garcia-Munoz, M., & Simpson, J. A. 1985, ApJ, 294, 455
Beatty, J. J., Ficenec, D. J., Tobias, S., et al. 1993, ApJ, 413, 268
Beatty, J. J., Bhattacharyya, A., Bower, C., et al. 2004, Phys. Rev. Lett., 93, 241102
Beedle, R. E., & Webber, W. R. 1968, Canad. J. Phys. Suppl., 46, 1014
Bellotti, R., Cafagna, F., Circella, M., et al. 1999, Phys. Rev. D, 60, 052002
BESS Collaboration, Abe, K., Fuke, H., et al. 2008, Phys. Lett. B, 670, 103
Beuermann, K. P., Rice, C. J., Stone, E. C., & Vogt, R. E. 1969, Phys. Rev. Lett., 22, 412
Bjarle, C., Herrström, N.-Y., Jonsson, G., & Kristiansson, K. 1979, Z. Phys. A, 291, 383
Blanford, G. E., Friedlander, M. W., Klarmann, J., et al. 1969, Phys. Rev. Lett., 23, 338
Bleeker, J. A. M., Burger, J. J., Scheepmaker, A., Swanenburg, B. N., & Tanaka, Y. 1965, in International Cosmic Ray Conference, 1, 327
Bleeker, J. A. M., Burger, J. J., Deerenberg, A. J. M., et al. 1970, in International Cosmic Ray Conference, 1, 209
Boezio, M., Carlson, P., Francke, T., et al. 1997, ApJ, 487, 415
Boezio, M., Carlson, P., Francke, T., et al. 1999, ApJ, 518, 457
Boezio, M., Carlson, P., Francke, T., et al. 2000, ApJ, 532, 653
Boezio, M., Barbiellini, G., Bonvicini, V., et al. 2001a, Adv. Space Res., 27, 669
Boezio, M., Bonvicini, V., Schiavon, P., et al. 2001b, ApJ, 561, 787
Boezio, M., Bonvicini, V., Schiavon, P., et al. 2003, Astropart. Phys., 19, 583
Bogomolov, E. A., Lubyanaya, N. D., Romanov, V. A., Stepanov, S. V., & Shulakova, M. S. 1979, in International Cosmic Ray Conference, 1, 330
Bogomolov, E. A., Vasilyev, G. I., Yu, S., et al. 1995, in International Cosmic Ray Conference, 2, 598
Buckley, J., Dwyer, J., Mueller, D., Swordy, S., & Tang, K. K. 1994, ApJ, 429, 736
Buffington, A., Orth, C. D., & Smoot, G. F. 1974, Phys. Rev. Lett., 33, 34
Buffington, A., Orth, C. D., & Smoot, G. F. 1975, ApJ, 199, 669
Buffington, A., Orth, C. D., & Mast, T. S. 1978, ApJ, 226, 355
Burger, J. J., & Swanenburg, B. N. 1974, J. Geophys. Res., 79, 1533
Caballero-Lopez, R. A., & Moraal, H. 2004, J. Geophys. Res., Space Physics, 109, 1101
Caballero-Lopez, R. A., Moraal, H., & McDonald, F. B. 2010, ApJ, 725, 121
Caldwell, J., Evenson, P., Jordan, S., & Meyer, P. 1975, in International Cosmic Ray Conference, 3, 1000
Caldwell, J. H., Evenson, P., Jordan, S., & Meyer, P. 1977, in International Cosmic Ray Conference, 11, 203
Casolino, M., de Santis, C., de Simone, N., et al. 2011, Astrophys. Space Sci. Trans., 7, 465
Chang, J., Adams, J. H., Ahn, H. S., et al. 2008, Nature, 456, 362
Chardonnet, P., Orloff, J., & Salati, P. 1997, Phys. Lett. B, 409, 313
Choutko, V., & Giovacchini, F. 2008, in International Cosmic Ray Conference, 4, 765
Clem, J. M., & Evenson, P. A. 2002, ApJ, 568, 216
Clem, J., & Evenson, P. 2004, J. Geophys. Res., Space Physics, 109, 7107
Clem, J., & Evenson, P. 2009, J. Geophys. Res., Space Physics, 114, 10108
Clem, J. M., Clements, D. P., Esposito, J., et al. 1996, ApJ, 464, 507
Clem, J. M., Evenson, P., Huber, D., et al. 2000, J. Geophys. Res., 105, 23099
Cline, T. L., Ludwig, G. H., & McDonald, F. B. 1964, Phys. Rev. Lett., 13, 786
Connell, J. J. 1998, ApJ, 501, L59
Connell, J. 1999, in International Cosmic Ray Conference, 3, 33
Connell, J. J., & Simpson, J. A. 1997, ApJ, 475, L61
Connell, J. J., Duvernois, M. A., & Simpson, J. A. 1998, ApJ, 509, L97
Daniel, R. R., & Stephens, S. A. 1965a, Phys. Rev. Lett., 15, 769
Daniel, R. R., & Stephens, S. A. 1965b, in International Cosmic Ray Conference, 1, 335
Danjo, A., Hayakawa, S., Makino, F., & Tanaka, Y. 1968, Canad. J. Phys., 46, 530
Daugherty, J. K., Hartman, R. C., & Schmidt, P. J. 1975, ApJ, 198, 493
de Nolfo, G. A., Barbier, L. M., Christian, E. R., et al. 2000, in Acceleration and Transport of Energetic Particles Observed in the Heliosphere, eds. R. A. Mewaldt, J. R. Jokipii, M. A. Lee, E. Möbius, & T. H. Zurbuchen, AIP Conf. Ser., 528, 425
de Nolfo, G. A., Moskalenko, I. V., Binns, W. R., et al. 2006, Adv. Space Res., 38, 1558
Derbina, V. A., Galkin, V. I., Hareyama, M., et al. 2005, ApJ, 628, L41
de Shong, J. A., Hildebrand, R. H., & Meyer, P. 1964, Phys. Rev. Lett., 12, 3
Diehl, E., Ellithorpe, D., Müller, D., & Swordy, S. P. 2003, Astropart. Phys., 18, 487
Duvernois, M. A. 1997, ApJ, 481, 241
Duvernois, M. A., & Thayer, M. R. 1996, ApJ, 465, 982
Duvernois, M. A., Garcia-Munoz, M., Pyle, K. R., Simpson, J. A., & Thayer, M. R. 1996a, ApJ, 466, 457
Duvernois, M. A., Simpson, J. A., & Thayer, M. R. 1996b, A&A, 316, 555
DuVernois, M. A., Barwick, S. W., Beatty, J. J., et al. 2001, ApJ, 559, 296
Dwyer, R. 1978, ApJ, 224, 691
Dwyer, R., & Meyer, P. 1987, ApJ, 322, 981
Earl, J. A. 1961, Phys. Rev. Lett., 6, 125
Earl, J. A., Neely, D. E., & Rygg, T. A. 1972, J. Geophys. Res., 77, 1087
Engelmann, J. J., Ferrando, P., Soutoul, A., Goret, P., & Juliusson, E. 1990, A&A, 233, 96
Esposito, J. A., Christian, E. R., Balasubrahmanyan, V. K., et al. 1992, Astropart. Phys., 1, 33
Evenson, P., & Meyer, P. 1984, J. Geophys. Res., 89, 2647
Evenson, P., Meyer, P., & Nandkumar, R. 1979, in International Cosmic Ray Conference, 1, 462
Evenson, P., Krawczyk, L., Moses, D., & Meyer, P. 1981, in International Cosmic Ray Conference, 10, 77
Evenson, P., Huber, D., Patterson, E. T., et al. 1995, J. Geophys. Res., 100, 7873
Evoli, C., Gaggero, D., Grasso, D., & Maccione, L. 2008, J. Cosmol. Astropart. Phys., 10, 18
Fan, C. Y., Gloeckler, G., Simpson, J. A., & Verma, S. D. 1968, ApJ, 151, 737
Fanselow, J. L. 1968, ApJ, 152, 783
Fanselow, J. L., Hartman, R. C., Hildebrad, R. H., & Meyer, P. 1969, ApJ, 158, 771
Fanselow, J. L., Hartman, R. C., Meyer, P., & Schmidt, P. J. 1971, Ap&SS, 14, 301
Ferrando, P., Engelmann, J. J., Goret, P., Koch-Miramond, L., & Petrou, N. 1988, A&A, 193, 69
Ferrando, P., Lal, N., McDonald, F. B., & Webber, W. R. 1991, A&A, 247, 163
Fisher, A. J., Hagen, F. A., Maehl, R. C., Ormes, J. F., & Arens, J. F. 1976, ApJ, 205, 938
Fisk, L. A. 1971, J. Geophys. Res., 76, 221
Fisk, L. A., & Axford, W. I. 1969, J. Geophys. Res., 74, 4973
Fowler, P. H., Adams, R. A., Cowen, V. G., & Kidd, J. M. 1967, Roy. Soc. London Proc. Ser. A, 301, 39
Fowler, P. H., Clapham, V. M., Cowen, V. G., Kidd, J. M., & Moses, R. T. 1970, Roy. Soc. London Pro. Ser. A, 318, 1
Freier, P., Lofgren, E. J., Ney, E. P., & Oppenheimer, F. 1948a, Phys. Rev., 74, 1818
Freier, P., Lofgren, E. J., Ney, E. P., et al. 1948b, Phys. Rev., 74, 213
Freier, P., Gilman, C., & Waddington, C. J. 1977, ApJ, 213, 588
Freier, P. S., Young, J. S., & Waddington, C. J. 1980, ApJ, 240, L53
Fuke, H., Maeno, T., Abe, K., et al. 2005, Phys. Rev. Lett., 95, 081101
Fulks, G. J. 1975, J. Geophys. Res., 80, 1701
Garcia-Munoz, M., Mason, G. M., & Simpson, J. A. 1975, ApJ, 202, 265
Garcia-Munoz, M., Mason, G. M., & Simpson, J. A. 1977, ApJ, 217, 859
Garcia-Munoz, M., Simpson, J. A., & Wefel, J. P. 1979, ApJ, 232, L95
Garcia-Munoz, M., Simpson, J. A., & Wefel, J. P. 1981, in International Cosmic Ray Conference, 2, 72
Garcia-Munoz, M., Meyer, P., Pyle, K. R., Simpson, J. A., & Evenson, P. 1986, J. Geophys. Res., 91, 2858
Garcia-Munoz, M., Simpson, J. A., Guzik, T. G., Wefel, J. P., & Margolis, S. H. 1987, ApJS, 64, 269
George, J. S., Lave, K. A., Wiedenbeck, M. E., et al. 2009, ApJ, 698, 1666
Gibner, P. S., Mewaldt, R. A., Schindler, S. M., Stone, E. C., & Webber, W. R. 1992, ApJ, 391, L89
Gleeson, L. J., & Axford, W. I. 1967, ApJ, 149, L115
Gleeson, L. J., & Axford, W. I. 1968, ApJ, 154, 1011
Golden, R. L., Horan, S., Mauger, B. G., et al. 1979, Phys. Rev. Lett., 43, 1196
Golden, R. L., Mauger, B. G., Badhwar, G. D., et al. 1984, ApJ, 287, 622
Golden, R. L., Mauger, B. G., Horan, S., et al. 1987, A&A, 188, 145
Golden, R. L., Grimani, C., Kimbell, B. L., et al. 1994, ApJ, 436, 769
Golden, R. L., Stochaj, S. J., Stephens, S. A., et al. 1996, ApJ, 457, L103
Grimani, C., Stephens, S. A., Cafagna, F. S., et al. 2002, A&A, 392, 287
Guzik, T. G. 1981, ApJ, 244, 695
Hagen, F. A., Fisher, A. J., & Ormes, J. F. 1977, ApJ, 212, 262
Haino, S., Sanuki, T., Abe, K., et al. 2004, Phys. Lett. B, 594, 35
Haino, S., Abe, K., Fuke, H., et al. 2005, in International Cosmic Ray Conference, 3, 13
Hams, T., Barbier, L. M., Bremerich, M., et al. 2004, ApJ, 611, 892
Hartman, R. C. 1967, ApJ, 150, 371
Hartman, R. C., & Pellerin, C. J. 1976, ApJ, 204, 927
Hartman, R. C., Meyer, P., & Hildebrand, R. H. 1965, J. Geophys. Res., 70, 2713
Hartmann, G., Mueller, D., & Prince, T. 1977, Phys. Rev. Lett., 38, 1368
Hatano, Y., Fukada, Y., Saito, T., Oda, H., & Yanagita, T. 1995, Phys. Rev. D, 52, 6219
Hesse, A., Acharya, B. S., Heinbach, U., et al. 1996, A&A, 314, 785
Hof, M., Menn, W., Pfeifer, C., et al. 1996, ApJ, 467, L33
Hovestadt, D., Meyer, P., & Schmidt, P. J. 1971, Astrophys. Lett., 9, 165
Hsieh, K. C., Mason, G. M., & Simpson, J. A. 1971, ApJ, 166, 221
Ichimura, M., Kogawa, M., Kuramata, S., et al. 1993, Phys. Rev. D, 48, 1949

Ishii, C., Kobayashi, T., Shigihara, N., et al. 1973, in International Cosmic Ray Conference, 5, 3073
Israel, M. H., & Vogt, R. E. 1968, Phys. Rev. Lett., 20, 1053
Ivanenko, I. P., Shestoperov, V. Y., Chikova, L. O., et al. 1993, in International Cosmic Ray Conference, 2, 17
Jokipii, J. R., & Kopriva, D. A. 1979, ApJ, 234, 384
Jones, F. C., Lukasiak, A., Ptuskin, V., & Webber, W. 2001, ApJ, 547, 264
Jordan, S. P. 1985, ApJ, 291, 207
Juliusson, E. 1974, ApJ, 191, 331
Kamioka, E., Hareyama, M., Ichimura, M., et al. 1997, Astropart. Phys., 6, 155
Kobayashi, T. 1999, in International Cosmic Ray Conference, 3, 61
Kobayashi, T., Komori, Y., Yoshida, K., et al. 2012, ApJ, 760, 146
Kraushaar, W. L., Clark, G. W., Garmire, G. P., et al. 1972, ApJ, 177, 341
Kroeger, R. 1986, ApJ, 303, 816
Krombel, K. E., & Wiedenbeck, M. E. 1988, ApJ, 328, 940
Lavalle, J., & Salati, P. 2012, Comptes Rendus Physique, 13, 740
Leech, H. W., & Ogallagher, J. J. 1978, ApJ, 221, 1110
Leske, R. A. 1993, ApJ, 405, 567
Lezniak, J. A., & Webber, W. R. 1978, ApJ, 223, 676
L'Heureux, J. 1967, ApJ, 148, 399
L'Heureux, J., & Meyer, P. 1968, Canad. J. Phys. Suppl., 46, 892
L'Heureux, J., Fan, C. Y., & Meyer, P. 1972, ApJ, 171, 363
Lukasiak, A. 1999, in International Cosmic Ray Conference, 3, 41
Lukasiak, A., Ferrando, P., McDonald, F. B., & Webber, W. R. 1994a, ApJ, 426, 366
Lukasiak, A., Ferrando, P., McDonald, F. B., & Webber, W. R. 1994b, ApJ, 423, 426
Lukasiak, A., McDonald, F. B., & Webber, W. R. 1994c, ApJ, 430, L69
Lukasiak, A., McDonald, F. B., & Webber, W. R. 1997a, in International Cosmic Ray Conference, 3, 389
Lukasiak, A., McDonald, F. B., & Webber, W. R. 1997b, ApJ, 488, 454
Maeno, T., Orito, S., Matsunaga, H., et al. 2001, Astropart. Phys., 16, 121
Matsunaga, H., Orito, S., Matsumoto, H., et al. 1998, Phys. Rev. Lett., 81, 4052
Maurin, D., Donato, F., Taillet, R., & Salati, P. 2001, ApJ, 555, 585
Maurin, D., Cheminet, A., Derome, L., Ghelfi, A., & Hubert, G. 2014, Adv. Space Res., accepted [arXiv:1403.1612]
Meegan, C. A., & Earl, J. A. 1975, ApJ, 197, 219
Menn, W., Hof, M., Reimer, O., et al. 2000, ApJ, 533, 281
Mewaldt, R. A. 1986, ApJ, 311, 979
Mewaldt, R. A., Spalding, J. D., Stone, E. C., & Vogt, R. E. 1980a, ApJ, 235, L95
Mewaldt, R. A., Spalding, J. D., Stone, E. C., & Vogt, R. E. 1980b, ApJ, 236, L121
Mewaldt, R. A., Spalding, J. D., Stone, E. C., & Vogt, R. E. 1981, ApJ, 251, L27
Meyer, P., & Vogt, R. 1961, Phys. Rev. Lett., 6, 193
Minagawa, G. 1981, ApJ, 248, 847
Mitchell, J. W., Barbier, L. M., Christian, E. R., et al. 1996, Phys. Rev. Lett., 76, 3057
Mocchiutti, E., & Wizard/Caprice Collaboration 2003, in International Cosmic Ray Conference, 4, 1809
Moiseev, A., Yoshimura, K., Ueda, I., et al. 1997, ApJ, 474, 479
Muller, D., & Meyer, P. 1973, ApJ, 186, 841
Mueller, D., & Tang, K.-K. 1987, ApJ, 312, 183
Mueller, D., Swordy, S. P., Meyer, P., L'Heureux, J., & Grunsfeld, J. M. 1991, ApJ, 374, 356
Myers, Z. D., Seo, E. S., Abe, K., et al. 2003, in International Cosmic Ray Conference, 4, 1805
Nishimura, J., Fujii, M., Taira, T., et al. 1980, ApJ, 238, 394
Nishimura, J., Fujii, M., Yoshida, A., et al. 1985, in International Cosmic Ray Conference, ed. F. C. Jones, 9, 539
Nishimura, J., Kobayashi, T., Komori, Y., et al. 2001, Adv. Space Res., 26, 1827
Obermeier, A., Ave, M., Boyle, P., et al. 2011, ApJ, 742, 14
Obermeier, A., Boyle, P., Hörandel, J., & Müller, D. 2012, ApJ, 752, 69
Orito, S., Maeno, T., Matsunaga, H., et al. 2000, Phys. Rev. Lett., 84, 1078
Orth, C. D., Buffington, A., Smoot, G. F., & Mast, T. S. 1978, ApJ, 226, 1147
O'Sullivan, D., Price, P. B., Shirk, E. K., et al. 1971, Phys. Rev. Lett., 26, 463
Panov, A. D., Sokolskaya, N. V., Adams, Jr., J. H., & et al. 2008, in International Cosmic Ray Conference, 2, 3
Panov, A. D., Adams, J. H., Ahn, H. S., et al. 2009, Bull. Russ. Acad. Sci., Phys., 73, 564
Papini, P., Piccardi, S., Spillantini, P., et al. 2004, ApJ, 615, 259
Parker, E. N. 1958a, Phys. Rev., 110, 1445
Parker, E. N. 1958b, Phys. Rev., 109, 1874
Perko, J. S. 1987, A&A, 184, 119
Porter, T. A., Johnson, R. P., & Graham, P. W. 2011, ARA&A, 49, 155
Potgieter, M. 2013, Liv. Rev. Sol. Phys., 10, 3
Potgieter, M. S., & Moraal, H. 1985, ApJ, 294, 425
Price, P. B., Fowler, P. H., Kidd, J. M., et al. 1971, Phys. Rev. D, 3, 815
Prince, T. A. 1979, ApJ, 227, 676
Rastoin, C., Ferrando, P., Raviart, A., et al. 1996, A&A, 307, 981
Reimer, O., Menn, W., Hof, M., et al. 1998, ApJ, 496, 490
Sanuki, T., Motoki, M., Matsumoto, H., et al. 2000, ApJ, 545, 1135
Scheepmaker, A., & Tanaka, Y. 1971, A&A, 11, 53
Schmidt, P. J. 1972, J. Geophys. Res., 77, 3295
Seo, E. S., & McDonald, F. B. 1995, ApJ, 451, L33
Seo, E. S., McDonald, F. B., Lal, N., & Webber, W. R. 1994, ApJ, 432, 656
Shikaze, Y., Haino, S., Abe, K., et al. 2007, Astropart. Phys., 28, 154
Silverberg, R. F., Ormes, J. F., & Balasubrahmanyan, V. K. 1973, J. Geophys. Res., 78, 7165
Simon, M., Spiegelhauer, H., Schmidt, W. K. H., et al. 1980, ApJ, 239, 712
Simpson, J. A., & Connell, J. J. 1998, ApJ, 497, L85
Strong, A. W., & Moskalenko, I. V. 1998, ApJ, 509, 212
Strong, A. W., & Moskalenko, I. V. 2009, [arXiv:0907.0565]
Strong, A. W., Moskalenko, I. V., & Ptuskin, V. S. 2007, Ann. Rev. Nucl. Part. Sci., 57, 285
Swordy, S. P., Mueller, D., Meyer, P., L'Heureux, J., & Grunsfeld, J. M. 1990, ApJ, 349, 625
Tang, K.-K. 1984, ApJ, 278, 881
Teegarden, B. J., von Rosenvinge, T. T., McDonald, F. B., Trainor, J. H., & Webber, W. R. 1975, ApJ, 202, 815
Thayer, M. R. 1997, ApJ, 482, 792
Torii, S., Tamura, T., Tateyama, N., et al. 2001, ApJ, 559, 973
Usoskin, I. G., Alanko, K., Mursula, K., & Kovaltsov, G. A. 2002, Sol. Phys., 207, 389
Usoskin, I. G., Alanko-Huotari, K., Kovaltsov, G. A., & Mursula, K. 2005, J. Geophys. Res., Space Physics, 110, 12108
Usoskin, I. G., Bazilevskaya, G. A., & Kovaltsov, G. A. 2011, J. Geophys. Res., Space Physics, 116, 2104
Wang, J. Z., Seo, E. S., Anraku, K., et al. 2002, ApJ, 564, 244
Webber, W. R. 1982, ApJ, 252, 386
Webber, W. R., & Chotkowski, C. 1967, J. Geophys. Res., 72, 2783
Webber, W. R., & Higbie, P. R. 2009, J. Geophys. Res., Space Physics, 114, 2103
Webber, W. R., & Kish, J. 1979, in International Cosmic Ray Conference, 1, 389
Webber, W. R., & McDonald, F. B. 1994, ApJ, 435, 464
Webber, W. R., & Rockstroh, J. M. 1997, Adv. Space Res., 19, 817
Webber, W. R., & Schofield, N. J. 1975, in International Cosmic Ray Conference, 1, 312
Webber, W. R., & Yushak, S. M. 1983, ApJ, 275, 391
Webber, W. R., Kish, J., & Rockstroh, J. M. 1973a, in 2, 760
Webber, W. R., Lezniak, J. A., & Damle, S. V. 1973b, J. Geophys. Res., 78, 1487
Webber, W. R., Lezniak, J. A., Kish, J., & Damle, S. V. 1973c, Ap&SS, 24, 17
Webber, W. R., Kish, J., & Simpson, G. 1979, in International Cosmic Ray Conference, 1, 430
Webber, W. R., Kish, J. C., & Schrier, D. A. 1985a, in International Cosmic Ray Conference, 2, ed. F. C. Jones, 16
Webber, W. R., Kish, J. C., & Schrier, D. A. 1985b, in International Cosmic Ray Conference, 2, ed. F. C. Jones, 88
Webber, W. R., Golden, R. L., & Mewaldt, R. A. 1987, ApJ, 312, 178
Webber, W. R., Golden, R. L., Stochaj, S. J., Ormes, J. F., & Strittmatter, R. E. 1991, ApJ, 380, 230
Webber, W. R., Lukasiak, A., McDonald, F. B., & Ferrando, P. 1996, ApJ, 457, 435
Webber, W. R., Lukasiak, A., & McDonald, F. B. 1997, ApJ, 476, 766
Westphal, A. J., Afanasyev, V. G., Price, P. B., et al. 1996, ApJ, 468, 679
Wiedenbeck, M. E. 1983, in International Cosmic Ray Conference, 9, 147
Wiedenbeck, M. E., & Greiner, D. E. 1980, ApJ, 239, L139
Wiedenbeck, M. E., & Greiner, D. E. 1981a, ApJ, 247, L119
Wiedenbeck, M. E., & Greiner, D. E. 1981b, Phys. Rev. Lett., 46, 682
Wiedenbeck, M. E., Binns, W. R., Christian, E. R., et al. 1999, ApJ, 523, L61
Xiong, Z., Chen, H., Yang, C., et al. 2003, J. High Energy Phys., 11, 48
Yanasak, N. E., Wiedenbeck, M. E., Mewaldt, R. A., et al. 2001, ApJ, 563, 768
Yoon, Y. S., Ahn, H. S., Allison, P. S., et al. 2011, ApJ, 728, 122
Yoshida, K., Torii, S., Yamagami, T., et al. 2008, Adv. Space Res., 42, 1670
Young, J. S., Freier, P. S., Waddington, C. J., Brewster, N. R., & Fickle, R. K. 1981, ApJ, 246, 1014
Zatsepin, V. I., Zamchalova, E. A., Varkovitskaya, A. Y., et al. 1993, in International Cosmic Ray Conference, 2, 13