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The Brazilian Science Data Center (BSDC)

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Astrophysics and Space Science are becoming increasingly characterised by what is now known as "big data", the bottlenecks for progress partly shifting from data acquisition to "data mining". Truth is that the amount and rate of data accumulation in many fields already surpasses the local capabilities for its processing and exploitation, and the efficient conversion of scientific data into knowledge is everywhere a challenge. The result is that, to a large extent, isolated data archives risk being progressively likened to "data graveyards", where the information stored is not reused for scientific work.

Responsible and efficient use of these large data-sets means democratising access and extracting the most science possible from it, which in turn signifies improving data accessibility and integration. Improving data processing capabilities is another important issue specific to researchers and computer scientists of each field. The project presented here wishes to exploit the enormous potential opened up by information technology at our age to advance a model for a science data center in astronomy which aims to expand data accessibility and integration to the largest possible extent and with the greatest efficiency for scientific and educational use. Greater access to data means more people producing and benefiting from information, whereas larger integration of related data from different origins means a greater research potential and increased scientific impact.

The project of the BSDC is preoccupied, primarily, with providing tools and solutions for the Brazilian astronomical community. It nevertheless capitalizes on extensive international experience, and is developed in full cooperation with the ASI Science Data

Center (ASDC), from the Italian Space Agency, granting it an essential ingredient of internationalisation. The BSDC is Virtual Observatory-complient and part of the "Open Universe", a global initiative built under the auspices of the United Nations.

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1. Motivation: A view from Blazar Astrophysics

We would like to start by providing some concrete motivation for the development of a large-scale, globally integrated astronomical database such as proposed here. It is widely recognised that Astrophysics and Space Science are prime examples of international collaborative research. Today's observation of the cosmos involve expensive satellite and often large ground-based facilities, and special geographic conditions are required for the installation of modern telescopes. Individual facilities, while certainly valuable, are of limited utility when working alone, as the combination of data from a number of instruments, forming what astronomers call a multi-frequency, or multi-messenger[a] view of the celestial sources, is nowadays mandatory for progress in research. In many areas, the unfolding of the cosmic drama happens at timescales that range from the extremely short (even for human standards), requiring fast integration and communication between facilities around the globe, to the extremely long, demanding the build up of extensive catalogues of source populations which in turn requires sustained observational efforts over decades. The study of blazars, for which we are developing specific analysis and data handling software tools, are perhaps the simplest, and at the same time one of the richest examples to illustrate the concept and potential of a data center like the BSDC, and will be used as a example in this document. The concept of the BSDC, of a web-based, "science-ready" data center, is readily extensible to other fields, not only of astrophysics, but of science in general, and could be of broader interest and usefulness to other communities.

Almost fifty years ago it was suggested, and now it is commonly accepted, that supermassive black holes (SMBHs), with masses between 10^6-10^{10} $M_\odot$, are present at the nucleus of every Galaxy with stellar bulges [1]. A small fraction of these SMBHs are being fed with sufficient quantities of gas so that an accretion disk is formed around them. Radiative emission from these systems is comparable to the gross starlight output of the entire host galaxy, thanks to the large efficiency of the accretion process in converting matter to radiation, this being the fundamental mechanism by which the so-called active galactic nuclei, or AGN, shine [2]. For some AGN, the accretion process may be accompanied by the bulk acceleration of particles at ultra-relativistic energies into collimated jets of plasma extending for thousands of light-years away from the central engine [3]. AGN and their associated

[a]That is, combining, other than usual electromagnetic carriers, information derived from neutrino, cosmic-rays and even gravitational-wave observations.

jets are the most luminous persistent sources of radiation in the Universe, emitting over the entire electromagnetic spectrum. Their action is fundamental within the models of evolution of galaxies and large-scale structure in the Universe.

Blazars are a small sub-set of AGNs, distinguished by extreme observational properties, such as the presence of superluminal motion in high-resolution radio maps, and highly variable non thermal emission over the entire spectrum.[4] In blazars, such properties result from the fact that the plasma jets are pointing at a direction close to our line of sight, which amplifies the emission's relativistic effects [5]. Multi-frequency observations of blazars provide, therefore, a clear view of the physics and evolution of relativistic particles accelerated by the AGN.

The spectral energy distribution (SED) of blazars displays two broad humps (see Fig. 1). Radiation associated to the low-frequency part of the SED is firmly established as synchrotron emission from relativistic electrons interacting with the jet's magnetic field. The nature of the high-energy hump, peaking in the range from X- to gamma-rays, is attributed to two intrinsically different mechanisms: In a purely leptonic scenario, emission is due to inverse-Compton scattering of soft photons by the energetic electrons [6], whereas in lepto-hadronic models a component from proton-synchrotron radiation[7] or photo-hadronic interaction [8] may be present.

The fact that a same population of relativistic particles is responsible for emission in the low and high-energy humps means that the entire SED of blazars is correlated, requiring joint multi-instrument data to be studied, over 20 orders of magnitude in energy. The kpc-scale sizes of the sources, contrasted with particle acceleration and cooling timescales as short as few hours or less, means that temporal analysis should span four orders of magnitude, from sub-hour to several years. Such observational characteristics clearly demonstrate the need for large integrated databases to provide the required data services which are beyond any individual group's capabilities to acquire and analyse. More recently, not only EM information such as shown in Fig. 1, but also multi-messenger data, is becoming increasingly relevant in the field of blazar astrophysics, demanding, for example, software tools and data-services for cross-matching blazar catalogues and high-energy neutrinos and cosmic ray sky maps [9].

Such "data-intensive" characteristics present in blazar studies are common to a number of fields within and beyond astrophysics, illustrating the global relevance of a model for an open access, science and web-ready data center.

2. The Concept of the BSDC

The BSDC is a space science data center which aims, primarily, to serve the interests and necessities of the Brazilian community of astronomy and astrophysics. It is the National branch of a broader international project, building upon the experience and being developed in strict collaboration with ASDC, the science data center of the Italian Space Agency (ASI), where the concept of a science data center of this

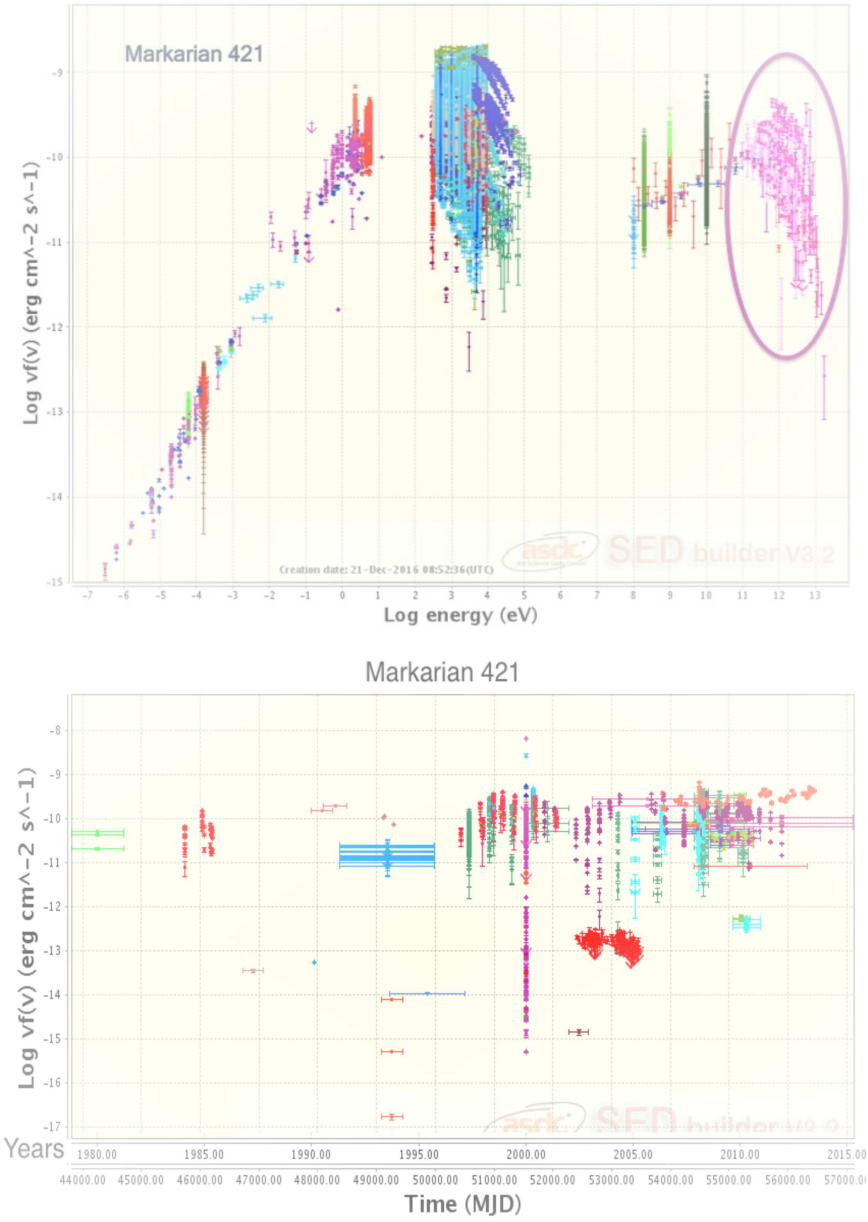

Fig. 1. Example of a data set. (Top panel) The spectral energy distribution (SED) for the prototypical blazar Mkn 421, plotted in the traditional energy flux representation (νF_ν vs. ν), and showing the extent of the source's emission from radio to TeV gamma-rays. The marked VHE gamma-ray points are provided by the BSDC database, in cooperation with the MAGIC Collaboration. (Bottom panel) The ligth-curve of Mkn 421, with data collected since 1980, showing the presence of variability in all timescales, from decades to days. The plots are made up of data from a dozen catalogues spanning more than 30 years, and collected by over 10 different instruments. The plots are produced with the SEDBuilder tool available online from ASDC (see Ref. [9]).

kind was originally advanced[b]. The BSDC is being built at the Brazilian Center for Research in Physics (CBPF), at Rio de Janeiro, within the framework of the International Center for Relativistic Astrophysics Network (ICRANet). It will be fully operational as an open access online data service in 2017.

More than an online data repository, the BSDC is a portal for multi-source data integration and access, and an online platform for research and education, containing software tools for data mining, visualisation, as well as data inspection and analysis. Not a simple data provider, its goal is to enable, promote and actively conduct collaborative data-intensive scientific research, whose success is measured in scientific impact and papers rather than Terabytes. It is focused therefore on astrophysics and space science applications characterised by "big data". The BSDC is built over two conceptual pillars, essential for its goals of integration and accessibility.

The fundamental notion behind the BSDC model is that of a "science-ready" database, that is, an on-line service providing access to scientific data in a form that can be directly used in professional scientific publications, without the need of any specific knowledge about the instrumentation that produced it. As in the case of blazars, data-intensive research requires information that is usually collected in complex ways, involving multiple instruments and techniques that no single group can individually master, or even guarantee its direct access to. Raw data repositories, even if open access, are thus limited in terms of direct scientific applications, requiring the knowledge of specialists to be analysed. Nevertheless, for most of the regular scientific applications, quality standard data products are enough, and providing direct access to such products cuts through an expensive and limiting intermediary to reaching the final scientific objective of the experiments.

The purpose of the BSDC is therefore to provide final data products that can be directly used in scientific applications by a very broad fraction of the academic community, and easily integrated with other data-sets from multiple sources. This allows for a truly global and democratic distribution and accessibility of the data, even by people or groups away from the centres where data is produced. By guaranteeing broad and easy integrability of related data from different origins, it also increases the scientific impact of individual data-sets, specially from small and medium-sized facilities and observatories which in isolation cannot compete with world-class centres, but become relevant when integrated to those.

The second conceptual pillar of the BSDC is that the database and all related tools must be "web-ready", that is, flexible and efficiently accessible for manipulation entirely over the web, guaranteeing robustness, stability and universality of the data services. This notion of web-readiness, combined with the numerous mobile platforms for web access today make the BSDC a real tool for "citizen science", meaning that it allows for first hand access to scientific data not only by scientists

[b]For a detailed presentation of the ASDC itself, please see the following document by Paolo Giommi [9] and visit the ASDC website at www.asdc.asi.it.

but to any interested citizen, as an expected return of society's investment in science. To this purpose the BSDC is being built in full coordination with the United Nations "Open Universe" initiative (see below for more detail).

The construction and operation of such a data center is a prime opportunity for the formation and training of high-level human resources specialised in data technology, an essential skill in today's scientific environment. It also serves as a center for the development of applied data science research, at a scale potentially unrivalled in Brazil at the moment.

2.1. *Current Activities at BSDC*

Since the start of our activities in early 2016, the BSDC has already produced a few data products. Among them, we can cite access to two on-line astronomical catalogues, produced by Brazilian authors, on the fields of blazar astrophysics [10], and white dwarf stars [11], along with virtual observatory (VO) remote query services of these same tables. Discussions are ongoing with specific groups in Brazil for the future integration of software products and other databases from National instruments and research within the BSDC, as soon as the center is fully operational in 2017. Likewise, discussions have been initiated within a BRICS Working Group on Astronomy[c] about an integrated expansion of the BSDC model to the BRICS community, given the especial relevance of this model to countries which are currently developing their national data infrastructure in science.

Since the BSDC is developed in collaboration with the ASDC and is fully integrated to it, specific functionalities and databases available in each center are readily available for the other. In addition to products and services related to the Brazilian community, the BSDC shall also specialise in fields where expertise is not already available within the ASDC. Two examples are the construction of a database of ground-based very-high-energy gamma-ray data from multiple observatories around the globe (see example of data from a recent collaboration with data from the MAGIC Collaboration[d] in Figure 1), and a platform for optical polarimetric data, focused on blazar observations, both of which are services currently under development.

3. The Open Universe Initiative

The "Open Universe"[e] is a recent project aimed at greatly expanding the availability and accessibility to space science data, extending the potential of scientific discovery to new participants in all parts of the world. A very wide range of communities

[c]Please, see the contents of the 2nd BRICS Astronomy Workshop, held in Ekateringburg (Russia) in 2016, on the theme of "Astronomical Data and Computation" at http://astro.brics.urfu.ru/en/astrodata2016/.
[d] https://magic.mppmu.mpg.de.
[e]For more information, please refer to the proposal document for the "Open Universe" initiative, at www.unoosa.org/oosa/en/oosadoc/data/documents/2016/aac.1052016crp/aac.1052016crp.6_0.html.

will benefit from Open Universe: professional scientists, teachers and students, and potentially any citizen interested in space science. The initiative was proposed by Italy and approved by the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in June 2016. A first workshop dedicated to the discussion of the Open Universe concepts will be held in Italy on 10-12 April 2017. The BSDC is part of the "Open Universe", and the initiative is fully supported by Brazil.

4. Conclusions

In this document we have presented the BSDC project, part of an international initiative for the development of an open access, online science data center aimed at enabling and actively conducting astrophysics and space-science data-intensive research, through the integration of data and data handling tools in a single, VO-complient web platform.

The BSDC is unique in its kind and extent in Brazil, being totally integrated and functioning in strictly collaboration with the ASDC. It is also part of a global initiative fostered and developed under the auspices of the United Nations, which will bring together science and education oriented data centres into a worldwide framework to expand availability of and accessibility to open source science data.

The BSDC is open to collaboration with any interested group, specially those associated to Brazilian astrophysics and space science activities, and will be fully available for online access early in 2017 as a platform integrated to the ASDC. Activities are also being conducted in order to expand the model for groups in other BRICS countries, through the ICRANet framework.

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