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The Italian solar data archives: national and European perspectives

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Abstract. We discuss the present status of the solar data archives geographically distributed in the Italian Astronomical Observatories of the National Institute for Astrophysics (INAF). In particular, we describe the national project SOLARNET (SOLAR NETwork) aimed at federating all the Italian solar archives as a distributed database, the first step toward an Italian Virtual Solar Observatory (IVSO), and the European Grid for Solar Observations (EGSO) project, which is under implementation to construct the basis for a large solar archive federation based on the Grid architecture to provide the scientific user with advanced resources such as a solar feature catalogue.

Key words. astronomical data bases: miscellaneoussolar databases – Sun: general

1. Introduction

Solar space- and ground-based observatories operate complex sets of instruments, which work at different wavelengths and produce inhomogeneous 1-D, 2-D, 3-D and 4-D datasets (Messerotti 1997). These datasets are stored in many solar data archives distributed all over the world managed by different systems and with different user interfaces for data search and retrieval. The full exploitation of the data information content in scientific research can be achieved only through an advanced DataBase Management System (DBMS) capable to cope with inhomogeneous, distributed datasets via a common user interface (Reardon 1998; Messerotti 2000). In Sect. 2 we outline the SOLARNET (SOLar NETwork) project aimed to federate the Italian solar data archives as a first step toward the above operational requirements. The status of the Italian solar data archives is detailed in Sect. 3.

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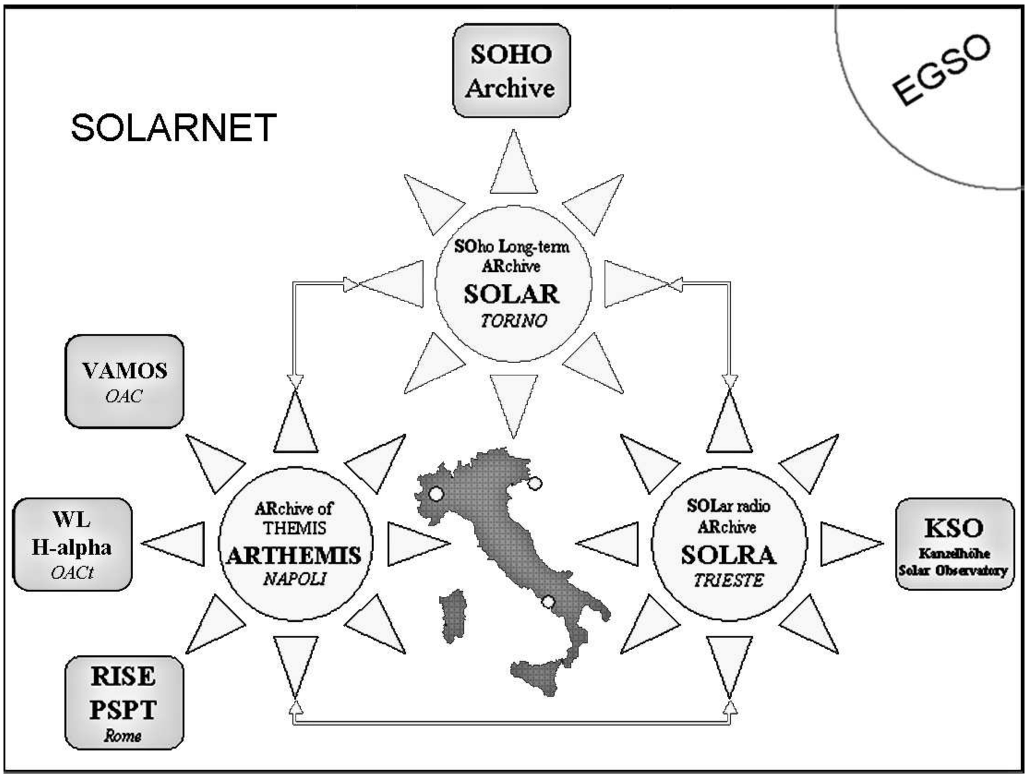

Fig. 1. SOLARNET: the federation of Italian solar data archives.

The European Grid of Solar Observations (EGSO) project (Bentley 2002), an advanced project of archive federation, is described in Sect. 4. The conclusions are drawn in Sect. 5.

2. SOLARNET

Modern archiving techniques allow an efficient data management through a Relational DataBase Management System (RDBMS). Data descriptors are organized in tables, whose row and column elements identify respectively records and fields. Key indices interrelate the information stored in different tables and allow to efficiently locate the data by querying a catalogue, which stores all the relevant information about the data tables and their organization in the archive, i.e. metadata and pointers to the physical data location. Typically the catalogue query is formulated in the Structured Query Language (SQL) via the Graphical User Interface of an intermediate translation software (middleware) which takes care of result display and data retrieval both onsite or in a distributed environment.

In this framework it was conceived and developed SOLARNET, the network of the federated Italian solar data archives (Fig. 1):

1. SOLAR, the SOho Long-term ARchive operated by the INAF-Osservatorio Astronomico di Torino (OATo).
2. ARTHEMIS, the ARchive of THEMIS operated by the INAF-Osservatorio Astronomico di Napoli (OANa), which hosts also the data of the INAF-Osservatorio Astronomico di Roma

(OARm) and of the INAF-Osservatorio Astrofisico di Catania (OACt).
3. SOLRA, the SOLar Radio Archive operated by the INAF-Osservatorio Astronomico di Trieste (OATs), which acts also as a gateway to the data of the Kanzelhöhe Solar Observatory (KSO; Villach, Austria).

The goal of SOLARNET is to allow to query all the linked archives via a unified World-Wide Web (WWW) Graphical User Interface (GUI) in a user-transparent way (Fig. 2). Therefore SOLARNET is a Distributed Database (DD), an architecture simpler than the more advanced Data Grid (DG), that links multiple data collections by managing data entities across distributed repositories, i.e. allows collective data search and retrieval.

This is the first step toward the realization of an Italian Virtual Solar Observatory (IVSO), which interconnects the distributed resources and maps the available solar data in a searchable unified catalogue and in an ancillary solar feature catalogue to help the scientists in placing more advanced, topic-specific queries. Therefore SOLARNET can act as a test-bed for the larger and more advanced project EGSO, a 3-year project funded by the EU under the Information Scientific Technologies Programme, that will lay the foundations of a Worldwide Virtual Solar Observatory (WWVSO) (Hill 2000; Gurman 2002).

As a consistent modelling is based on a multi-instrument multi-wavelength approach, this requires data search and retrieval capabilities to be complemented by data analysis capabilities in a distributed environment. Such features can be provided by a Virtual Data Grid (VDG) architecture. In fact, a VDG manages the data collection and allow data processing via the Grid protocols by combining the operational characteristics of a Data Grid with those of a Computational Grid. The Grid architectures now under development can in principle incorporate data processing in

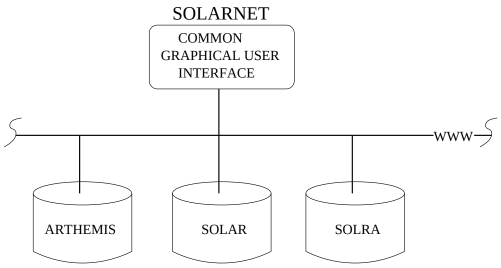

Fig. 2. SOLARNET as a Distributed Database.

addition to data management and act as VDG's as final advanced goal.

3. The Italian solar data archives

3.1. SOLAR

SOLAR (Cora et al. 2000; Antonucci et al. 2001; Cora et al. 2003) is one of three long-term European archives of SOHO, which mirror the NASA Goddard Space Flight Center (GSFC) SOHO primary short-term archive (Dimitoglou et al. 2001) and are aimed to store and preserve SOHO data for 10 years after the end of the mission. The other two mirror archives are located at the Rutherford Appleton Laboratory (UK) and at the Multi-Experiment Data Operation Centre (MEDOC) of the Institute dAstrophysique Spatiale (France).

Each site has implemented the archive using *the same software* but *different hardware platforms.*

SOLAR has been operating since March 2002 and is reachable on the WWW[1].

3.1.1. General description

SOLAR is an astrophysical database and belongs to the class of Scientific and Statistical DataBases (SSDBMS). It provides a system to store and retrieve observations from SOHO solar and heliospheric instruments and information gathered during simultaneous observations (campaigns)

[1] `http://solar.to.astro.it`

with ground-based observatory experiments. The database operates as a catalogue: it does not store the actual scientific observations but information about the data (metadata) along with pointers that link each catalogue entry with the actual observation. An Oracle RDBMS is used to store the catalogue information and C routines are used to extract metadata from FITS file headers. Routines developed in Oracle's native programming language (PL/SQL) populate the database tables.

3.1.2. Data structure and data types

As a typical RDB, SOLAR consists of Tables of highly structured Records with fixed-length Fields. Keywords and Fields are defined on the base of the Keywords fixed by the instrumental scientific teams.

SOLAR stores the following types of datasets and data products:

1. Calibrated Scientific Data: the observational data of 12 instruments working on board SOHO.
2. Summary Data: a simple collection of daily observations of the instruments.
3. Software: packages developed by the instrumental teams to reduce and analyze the observations.

3.1.3. Remote archive access

Efficient methods are needed for disseminating large amounts of digital data generated by space missions. Hence the SOHO Archives adopted the WWW as the platform to disseminate mission information and allow access for data retrieval. The GUI developed in JAVA by the MEDOC team (Fig. 3) allows to build very complex operations within a single query. An alternative non-JAVA web-enabled interface was also developed by the ESA team at GSFC and provides catalogue search and retrieval facilities. The WWW interface allows a multi-step query process in which queries are progressively refined. At the end

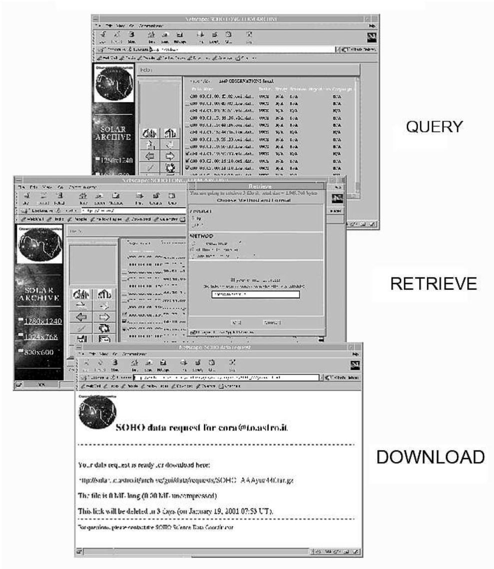

Fig. 3. The WWW GUI developed by MEDOC to access SOHO archives.

the user decides to either save the information related to the requested data files or retrieve them. In such a case the requested observations are compressed into a cache area and then made available for downloading via a temporary web address, specific to the request.

3.1.4. Data storage and architecture

SOLAR is provided with a flexible storage and retrieval system capable to manage approximately from 1.7 TB up to 2.75 TB of non-compressed data (Fig. 4). The hardware architecture is based on three servers connected via a Fiber Channel (FC) line at 1 GBps in a Private Network. The main server hosts the RDBMS and is connected through a SCSI bus to a 254 GB RAID disk array dedicated to the storage of the RDBMS software and the SOLAR catalogue data. A 1.05 TB DLT Library is connected to the server over the FC line and is used to backup the entire system. It is planned to use a hierarchical storage management software to increase the global

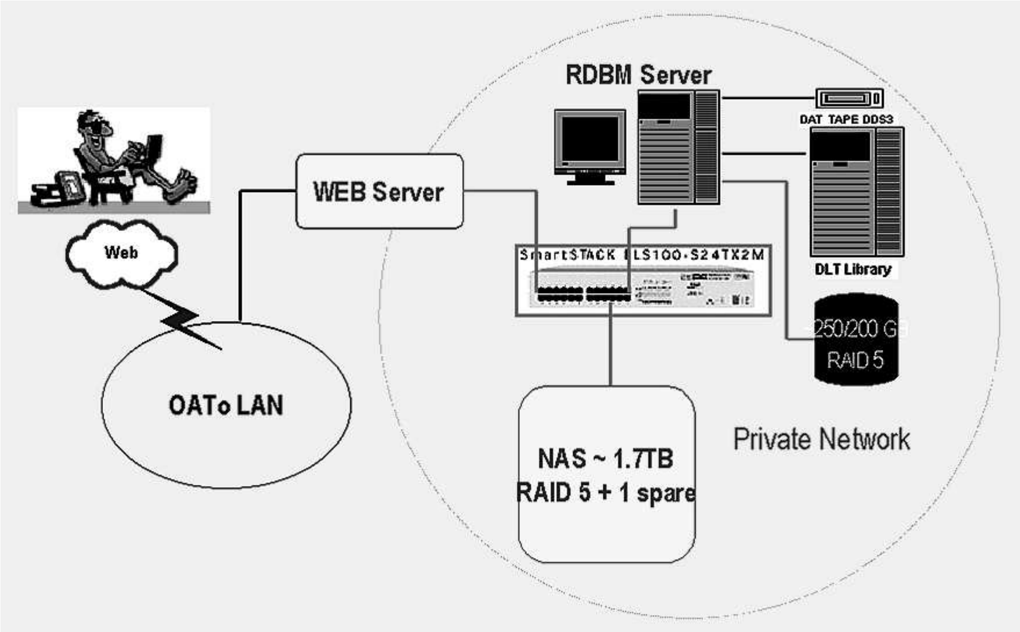

Fig. 4. Scheme of the SOLAR system architecture.

amount of the available file system space, allowing the migration of files from the local or NAS (Network Attached System) file systems to the DLT Library. This hybrid solution will expand the available storage space from 1.7 TB of pure, on-line data by 1.05 TB of near-on-line data for a total accessible capacity of 2.75 TB. The actual observation files (in FITS format) are stored on a NAS. The third server is a web server (HTTP).

3.2. ARTHEMIS

ARTHEMIS (Reardon et al. 1997) is the archive initially developed for the storage and management of the THEMIS data and later extended to allow the access to the Italian solar datasets in the visible band.

3.2.1. The original project

Originally the project was aimed to construct a database for the IPM (Italian Panoramic Monochromator) mounted on THEMIS.

Relevant characteristics referred to the year 1996 are: a. the archive access and query system are managed via a WWW GUI; b. a commercial Relational Data Base Management System (Oracle) is used; c. the stored data are high spatial and spectral resolution images taken in the visible band.

Pros of such a configuration are those typical of an RDBMS system and the fact that it is was designed to be homogeneous with BASS 2000 (BAse de donneés Solaire Sol 2000), which archives and distributes French ground-based solar observations provided by various instruments such as THEMIS, and with the SOHO archive.

The cons lie in the need of having an archive scientist, i.e. a specialist, both in the design and in the development and maintenance phases.

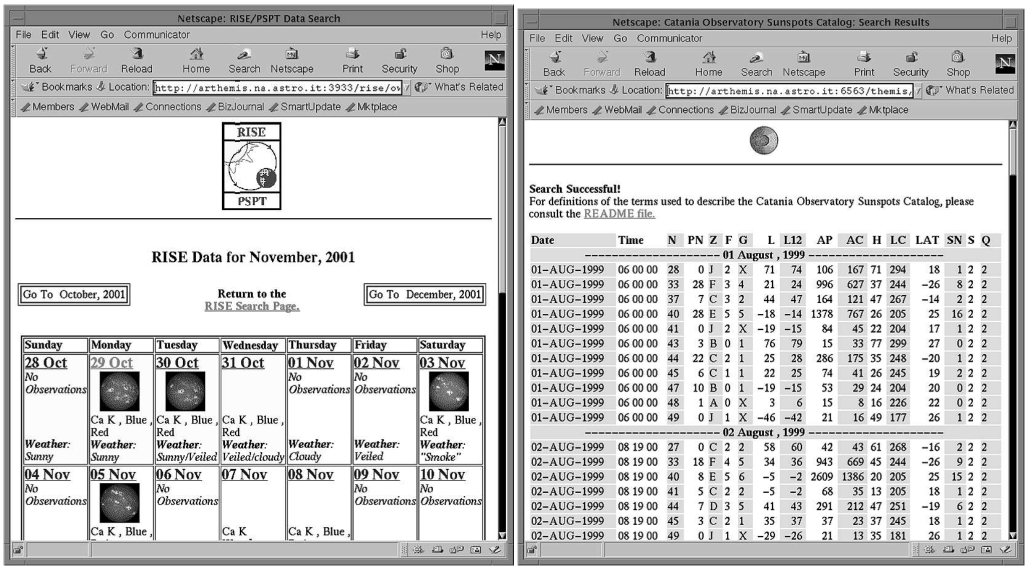

Fig. 5. Sample result pages from ARTHEMIS queries: INAF-OARm RISE/PSPT data (left panel) and INAF-OACt optical data (right panel).

3.2.2. Recent developments

In the framework of the co-financed project SOLARNET, started in 1999, two major archive extensions were carried out:

1. The incorporation of the Italian ground-based data in the visible band from:
   - The RISE/PSPT (Radiative Inputs from the Sun to Earth/Precision Solar Photometric Telescope) operated by the INAF-Osservatorio Astronomico di Roma: full-disk images in the Visible, Blue, Red and CaII K (Fig. 5, left panel).
   - The equatorial spur operated by the INAF-Osservatorio Astrofisico di Catania: sunspot data from 1974 to 2000 and full-disk Hα images (Fig. 5, right panel).
   - The VAMOS (Velocity and Magnetic Observations of the Sun) operated by INAF-Osservatorio Astronomico di Napoli: full-disk images in KI (7699 Å) (Intensity, Velocity, Longitudinal Magnetic Field).
2. The setting up as a node of SOLARNET.

3.2.3. Operational status

At present the IPM catalogue is not accessible via WWW. In fact in its most advanced form it was developed on a Linux platform, faster than the original one (Digital Unix), but software licensing policies are now forcing the migration to the original platform or the use of an open source DBMS on a Linux platform, which appears to be the better option.

3.3. SOLRA

SOLRA (SOLar Radio Archive) (Messerotti & Zlobec 2001) stores and manages the high time resolution radiopolarimetric data acquired daily by the Trieste Solar Radio System (TSRS), a set of two multichannel solar radiopolarimeters that perform a continuous surveillance of the coronal radio activity for Space Weather (SpW) applications, available in near real-time on the WWW[2].

3.3.1. TSRS system architecture

TSRS operates at 6 fixed frequencies in the metric and in the decimetric band. The system is entirely PC-based with three major subsystems: 1. the high speed digital acquisition, common to both radiopolarimeters; 2. the near real-time data processor; 3. the data archive server. The subsystems communicate via a fast intranet (LAN) behind a hardware firewall unit. The access to the Wide Area Network (WAN) is managed by a PC running an Apache web server under Linux, which is located outside the firewall to assure a reasonable level of protection.

3.3.2. Data flow and architecture

At the start of each daily observing run ancillary and calibration data are stored in a log file onto the buffer disk of the acquisition machine. Then during the whole day the continuously acquired data are processed and stored at 10-minutes time intervals according to predefined steps (Fig. 6):

1. Analog radio data are converted into digital ones by the acquisition machine at a routinary sampling rate of 1000 Hz and temporarily stored onto the local buffer disk in a proprietary binary raw format.
2. The near-real time processor machine:
   a. downloads the digital data from the acquisition machine.
   b. unpacks the binary data files.
   c. applies a calibration routine to convert signal levels into Solar Flux Units (1 SFU = 10^{-22} W Hz^{-1} m^{-2}).
   d. generates: 1. a synoptic multichannel graph which depicts the time evolution of radio flux and polarization at all frequency channels; 2. a series of solar radio indices computed as the mean radio flux value over each 1-minute time interval. All such data products are locally stored onto separate files as graphics images and text values to be used in Space Weather applications.
   e. generates FITS files from the high time resolution raw data, compliant with the SOHO file name and FITS keyword standard, properly organized in a local directory tree.
   f. copies the FITS files and the SpW products to a high capacity NAS for redundancy and to make available online the most recent, not yet permanently archived data.
   g. transfers the Space Weather data products to the web server machine for publication in near real-time on the dedicated web server.
   h. runs scripts to automatically update the archive catalogue and to perform data file management and housekeeping.

The data are organized according to a relational tabular structure homogeneous with that of the other solar archives to facilitate integration and federation. The archive management is carried out by the main server, which runs a commercial RDBMS (MS SQL Server 2000) under MS Windows 2000 Pro Server operating system. A CD/DVD Juke-Box Unit connected with the archive server can host up to 200 DVD's for a total online capacity of 940 GB.

Both raw and processed data are compressed and permanently stored on optical supports (CD-R and DVD-R).

3.3.3. Data products and data volume

Uncalibrated raw radio data files are permanently stored but not indexed nor accessible through the archive, as they are not directly usable but need a specific custom processing and calibration.

[2] `http://radiosun.ts.astro.it`

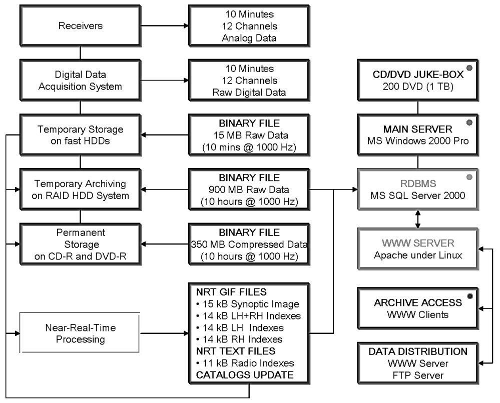

Fig. 6. The TSRS data flow.

The following products (Fig. 7) are indexed, searchable and available for download via FTP or HTTP:

a. Calibrated high time resolution radio data: a FITS file contains 10 minutes of 1000 Hz sampling rate recordings at 6 observing frequencies in both circular polarization modes.
b. Calibrated low time resolution radio data: a daily binary file, which contains the 1-sec averaged solar radio flux values at all frequencies, and a daily binary file, which contains the 1-sec maximum solar radio flux values.
b. Synoptic multichannel radio graphs: a daily GIF/PNG graphic file, i.e. the last radio graph of the series generated on-the-fly every 10 minutes and published on the WWW in near real-time.
c. Radio indices graphs and values: daily GIF/PNG graphic files, generated similarly to the synoptic graph, and a daily text file with the correspondent numerical values in ASCII format.
d. Radio maxima graphs and values: same as the previous item but referred to the maximum radio flux detected over each 1-minute interval.

The total uncompressed data volume to date is 213 GB (80 GB, compressed), stored on 130 CD-R and 18 DVD-R.

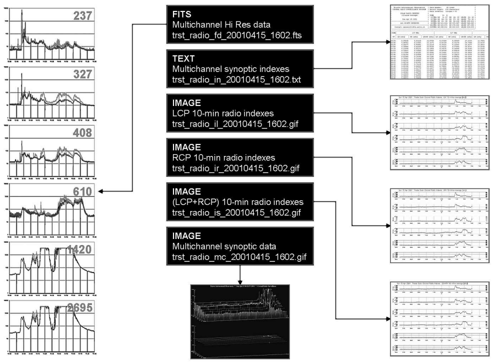

Fig. 7. TSRS data products.

The typical daily uncompressed data volume is 900 MB (350 MB, compressed) for a routinary sampling rate of 1000 Hz, i.e. 0.5-2 CD-R per day depending on data compression level and sampling rate and 1-3 DVD-R per week.

The expected maximum online data volume is 940 GB correspondent to 7.5 years of 1000 Hz radio data compressed to 40% the original file size.

4. The EGSO project

The European Grid of Solar Observations[3] (Bentley 2002) is a Grid test-bed based on solar data resources, which represents a step toward a virtual solar observatory. The project is funded by the European Commission through Information Society Technology (IST) Programme of the Fifth Framework (Grid Test Bed, Digital Collections) and the primary objectives are respectively:

– Federate solar data archives across Europe (and beyond!).
– Create tools to select, process and retrieve distributed and heterogeneous solar data (including data mining).
– Provide mechanisms to produce standardized observing catalogues for space and ground-based observations.
– Produce catalogues of solar features through automatic feature recognition.

[3] http://www.egso.org/

– Explore application of Grid technologies to distributed data analysis.

Funded partners with Solar Data [SD] and Information Technology [IT] expertise are: - University College London: Mullard Space Science Laboratory (UCL-MSSL) [SD]; - University College London: Computer Science Department (UCL-CS) [IT]; - Rutherford Appleton Laboratory (RAL) [IT]; - University of Bradford [IT]; - INAF-Osservatorio Astronomico di Torino (OATo), di Napoli (OANa) e di Trieste (OATs) [SD]; - Politecnico di Torino [IT]; - Institut d'Astrophysique Spatiale (IAS) [IT]; - Observatoire de Paris-Meudon [SD].

No cost partners are: - University of Applied Sciences, Switzerland [IT]; - NASA Solar Data Analysis Center (NASA-SDAC) [SD]; - National Solar Observatory (NSO-NOAO) [SD]; - Astrium [IT].

The project coordinator is Bob Bentley (UCL-MSSL). To enlarge the reach and utility of the Grid, collaborations are in progress with other projects and consortia such as: Virtual Solar Observatory (USA); SpaceGRID (ESA); GRIDSTART (IST Cluster); and AstroGrid (UK), as well as the Space Weather and astronomical communities.

4.1. The Grid architecture

Many resources, such as processors, data repositories, software packages, storage devices, etc., are geographically distributed among different sites. All such resources can be made available to the users through a grid architecture, which maps them by realizing large scale sharing and extended connectivity in a flexible, user-driven mode to transparently provide collective access. In fact, a new generation grid architecture combines both a computational and a data grid. This allows high performance computation and data management and analysis via the concurrent distributed resources, which are arranged and communicate in a virtual grid infrastructure through a coomon middleware (see Fig. 8).

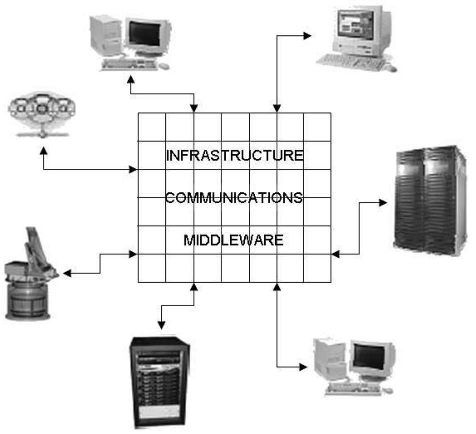

Fig. 8. Data, storage and computational resources mapped in a Grid architecture.

4.2. Combining solar datasets

Locating and obtaining solar data is a key problem in today solar research. In fact there are more than 100 ground-based and space-based solar observatories, which manage their own data sets in proprietary archives with no common metadata standards, no uniform means of access and a limited analysis software framework (SolarSoft). Large (100's of GB) datasets are continuously produced with many images (thousands per day) for an overall data volume of 10's of TB, but little automatic feature extraction from data sets is available.

In modelling the solar phenomenology combining multiple datasets is often essential for understanding the physical processes involved. Fundamental aspects in this sense are the relationship between wavelength and height of formation in the solar atmosphere, as well as the vast range of timescales, which span from 10^1 to $10^8 s$. Hence the goal of the scientist is to get the full coverage of a solar phenomenon in 5 dimensions for an quantitative description suitable to provide adequate experimental inputs to the theoretical model. Moreover an extended multi-dimensional superset allows broader statistical studies and crosscorrelation of specific physical parameters. This can be achieved only by combining the solar data sets, i.e., by making them fully searchable in a unified way.

The solution is therefore the construction of a Data Grid to interconnect the datasets: the joining of distributed systems so that their individual resources can be transparently shared among users at different nodes. EGSO will tackle the problem of creating an information grid with heterogeneous datasets. The grid will provide a framework onto which additional datasets, catalogues, and analysis routines can be attached.

4.3. The scientist's viewpoint

The scientist typically operates according to the following stages:

A. Identify suitable observations in coordinated campaigns, by serendipity or data mining.
B. Locate data, which are widely scattered and whose volume is ever increasing.
C. Process the data, by running standard reduction routines and reducing the data volume.
D. Perform data mining, by performing searches on the data and applying specialized algorithms to distributed datasets.

4.4. The designers's viewpoint

To accomplish the scientist's operational requirements the designer has to follow the corresponding guidelines in developing the system architecture:

A. Create a Unified Catalogue of Solar Observations. This requires a common metadata standard to be agreed upon and the development of new user interfaces.
B. Develop a robust data retrieval system, which needs to be able to deal with issues of availability, multiple data sources, caching, etc. and to be provided with a user authentication system to allow access to proprietary datasets.
C. Provide automatic data processing capabilities, which requires common software like SolarSoft and other data reduction routines carried out on remote machines.
D. Realize a Computational Grid, which allows user-uploaded code to run on the grid (and handles the relevant security issues) and favors the generation of Solar Features Catalogues.

This results in an advanced data search and retrieval system as outlined in Fig. 9.

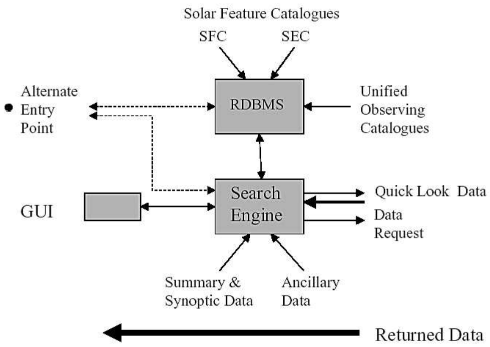

Fig. 9. Advanced data search and retrieval scheme.

4.5. EGSO development key items

The major key items involved in the development of EGSO can be summarized as follows.

A. Construction of an unified catalogue
   1. Define metadata standards (including FITS keywords, coordinate systems, etc.) that can be applied to all datasets. A common description is needed to aid search and reduction procedures. A possible difficulty in ensuring the community participation is expected in this phase.
   2. Create a catalogue of solar observations based on this meta-

data standard, which: will separate data description from data location information; will be managed in XML (eXtended Markup Language), RDBMS or OO (Object Oriented) database; will not be centralized but organized in distributed fragments; will create abstraction layer over large, legacy databases.

3. Populate catalogue by importing existing lists of solar observations into the new format: existing, complete catalogues can be imported easily; well-defined standard will allow easy insertion of additional datasets in future.

B. Enabling an efficient data access

Write middleware that will allow transparent queries of the entire "virtual" catalogue distributed throughout the data grid: must be able to determine the best location of all fragments in the grid; must be able to cope with the duplication of smaller catalogue fragments to improve the Quality of Service (QoS).

C. Enabling an advanced data mining

1. Create query and visualization tools that will allow complex searches and extend into data mining: allow iterative searching; use synoptic images to provide context during search; allow searches based on solar features and heliographic position.
2. Define procedures to allow data to be pre-reduced at source: do subset selection to reduce data volume; Perform initial data reduction to ease load on end user.
3. Build mechanism by which users can upload their own software to remote machines to perform customized processing on selected portions of remote datasets: allows more flexibility; can allow more complex, *data-based*, queries.

D. Grid operation monitoring

1. Write tools to monitor operation of data grid and optimize its configuration: data mirroring, load balancing, QoS measurements; dynamic classification of data usefulness and demand; monitor data use metrics for distributed, replicated datasets.
2. Provide for security and access controls: proprietary and open datasets will be combined in same grid; remote execution of user-supplied procedures!

E. Extraction of additional information

Produce algorithms that can automatically identify solar features in existing datasets: Solar Filaments, Active Regions, Coronal Mass Ejections (CME), etc.; can be fed back into catalogue to provide additional query options.

4.6. EGSO implementation plan

The implementation of EGSO will occur in 4 phases:

- Phase I: Define Project requirements.
- Phase II: Architectural Design of EGSO.
- Phase III: Creation of Middleware, Observation Catalogue, Feature Catalogue.
- Phase IV: Integration and Final Product Delivery.

Six Work Packages are involved in the development:

- WP0 Project Control and Dissemination (87 person/months - 5 deliverables).
- WP1 System Definition and Integration (187 person/months - 6 deliverables).
- WP2 Federate Data Archives (125 person/months - 4 deliverables).
- WP3 Search and Visualization Tools (91 person/months - 2 deliverables).
- WP4 Unified Observing Catalogue (58 person/months - 4 deliverables).
- WP5 Solar Feature Catalogue (119 person/months - 4 deliverables).

5. Conclusions

Solar datasets from ground-based and space-based instrumentation constitute a highly inhomogeneous, distributed virtual data repository, quite complex to search by the final scientific user. The Italian solar data archives are federated as a national distributed database in SOLARNET to allow the user to place a complex query over all the federated nodes in a transparent way. SOLARNET is a first step toward an Italian Virtual Solar Observatory and a test-bed for the European Grid of Solar Observations project. In fact, the Grid technology is asserting itself as the architecture of choice in providing a distributed operating environment for data management. EGSO will provide the framework for a true Virtual Solar Observatory: the definition of standards and grid architecture will be the essential foundation on which to build and develop to cope with future complex requirements.

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