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An Interactive Multi-instrument Database of Solar Flares

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Abstract

Solar flares are complicated physical phenomena that are observable in a broad range of the electromagnetic spectrum, from radio waves to γ-rays. For a more comprehensive understanding of flares, it is necessary to perform a combined multi-wavelength analysis using observations from many satellites and ground-based observatories. For an efficient data search, integration of different flare lists, and representation of observational data, we have developed the Interactive Multi-Instrument Database of Solar Flares (IMIDSF, https://solarflare.njit.edu/). The web-accessible database is fully functional and allows the user to search for uniquely identified flare events based on their physical descriptors and the availability of observations by a particular set of instruments. Currently, the data from three primary flare lists (*Geostationary Operational Environmental Satellites*, *RHESSI*, and HEK) and a variety of other event catalogs (*Hinode*, *Fermi* GBM, Konus-*WIND,* the OVSA flare catalogs, the CACTus CME catalog, the Filament eruption catalog) and observing logs (*IRIS* and Nobeyama coverage) are integrated, and an additional set of physical descriptors (temperature and emission measure) is provided along with an observing summary, data links, and multi-wavelength light curves for each flare event since 2002 January. We envision that this new tool will allow researchers to significantly speed up the search of events of interest for statistical and case studies.

Key words: catalogs – methods: data analysis – Sun: activity – Sun: flares – virtual observatory tools

1. Introduction

Among the many interesting heliospheric phenomena, solar flares and related events (coronal mass ejections (CMEs), solar energetic particles (SEPs), hard X-ray and gamma radiation) are of particular interest because they can cause problems for the terrestrial environment, such as initiating return currents and breaking power grids at high latitudes, disturbing the magnetosphere, and damaging satellite equipment. For a better understanding of solar flares and their prediction, it is crucially important to analyze multi-wavelength observations, as different physical processes are reflected at different energies. For example, in the standard flare model, hard X-ray radiation represents bremsstrahlung emission of accelerated particles, and carries information about acceleration processes associated with magnetic energy release. At the same time, observations of visible and ultraviolet spectral lines allow us to understand photospheric and chromospheric responses to the energy release.

Flare events are observed at different wavelengths by a variety of space- and ground-based instruments. Usually, flare lists are created for specific routinely observing instruments. Currently, the primary flare catalog is based on soft X-ray emission peaks (so-called X-ray flare classes) observed by the *Geostationary Operational Environmental Satellites* (*GOES*, Bornmann et al. 1996). The *GOES* X-ray instruments have observed solar activity for several decades, and created the largest database of solar flares. Another flare-observing instrument is the *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*, Lin et al. 2002), launched in 2002. *RHESSI* observes the X-ray radiation of flares in a wide range of energies, from 6 keV to >300 keV. The satellite detects the events and has its own flare list separate from the *GOES* flare list. Two instruments on board the *Solar Dynamics Observatory* (*SDO*) observe solar flares in EUV bands: the Extreme Ultraviolet Variability Experiment instrument (EVE, Woods et al. 2012) observes the EUV spectra of the integrated solar emission, and the Atmospheric Imaging Assembly (AIA, Lemen et al. 2012) instrument observes high-resolution images in several EUV bands. The flare data from both of these instruments are stored in independent data catalogs. In the EVE data, the flares are detected as enhancement of the EUV emission, and in the AIA data, the flare events are detected using image-processing algorithms (Martens et al. 2012) and are summarized in the Heliophysics Event Knowledgebase (Hurlburt et al. 2012). Some of these events are linked to the *GOES* database.

The Virtual Solar Observatory (VSO, http://sdac.virtualsolar.org/cgi/search) collects and accesses metadata from many space missions and ground-based observatories, allowing the user to search for available data for a particular time range. It also contains several flare and flare-related event catalogs (*SOHO*/LASCO CME catalog, *GOES* X-ray Catalog, *RHESSI* Flare list, etc.) The user can search for events with particular properties within each catalog, and request the corresponding data. However, VSO does not allow a detailed search based on flare parameters. The *RHESSI* browser (http://sprg.ssl.berkeley.edu/~tohban/browser/) allows users to look at *RHESSI* and *Fermi* data products, and to check the observational coverage of the detected flare events by the *Hinode* and *IRIS* satellites. However, this browser does not provide the ability to search for flares with particular properties.

Many problems in flare physics require analyses to be performed using data from a particular set of instruments, and/or for a sample of flares with particular characteristics. For

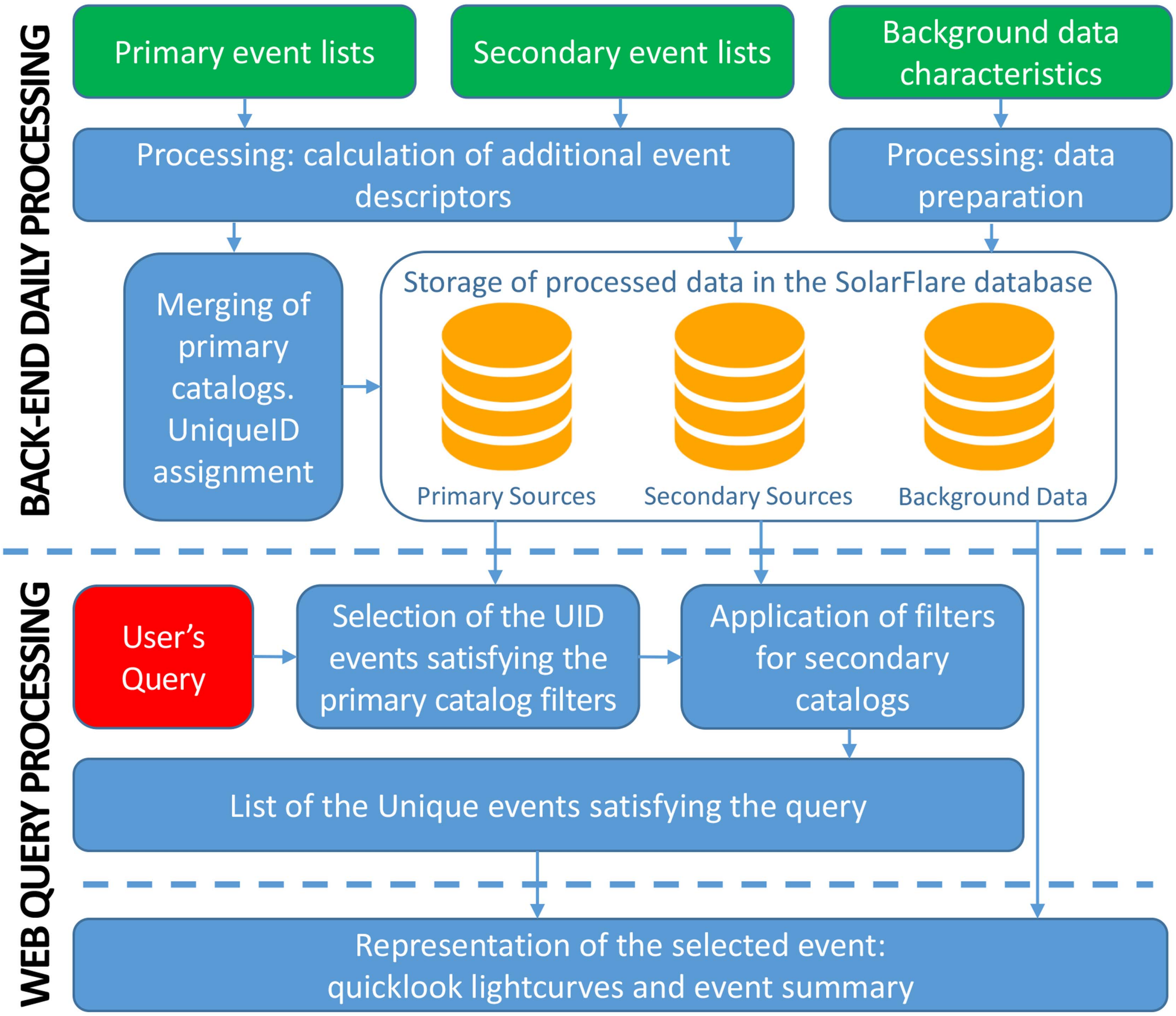

Figure 1. Schematic representation of the IMIDSF. The database stores the metadata from *GOES*, *RHESSI*, *SDO*, *SOHO*, *Hinode*, *IRIS*, *Fermi*, and other space-based and ground-based instruments, as well as some instrument-specific light curves.

example, one may try to find all events with *GOES* class ⩾C5.0 that were observed by *RHESSI*, or try to find the flares observed by the *IRIS* satellite in the EUV range, and by the Nobeyama radio telescope in the microwave range. To address these type of problems, we developed the Interactive Multi-Instrument Database of Solar Flares (IMIDSF).

This is not the first attempt to provide flare lists or event catalogs. For example, the Owens Valley Solar Array (OVSA, Hurford et al. 1984; Gary & Hurford 1990) legacy radio bursts database (Nita et al. 2004) allows event searches based on their physical parameter ranges, and the Solar Flare Finder tool (Milligan & Ireland 2017, http://hesperia.gsfc.nasa.gov/sff/), recently developed as a part of the Solar SoftWare package for Interactive Data Language (SSW IDL, Freeland & Bentley 2000), allows the selection of flaring events simultaneously observed by *GOES*, *RHESSI*, *SDO*/AIA, *Hinode*, *SDO*/EVE, and *IRIS*, and provides their data summaries. However, there is still room for a comprehensive solution that includes features such user-interactive filters, more convenient representations of the output set of events, and improved accessibility of the data via a search tool with minimum software requirements. We provide these and other new features in our newly developed database.

Figure 1 represents the basic structure of the database, and each block of this figure is explained in the following sections of this paper. In Section 2, we describe the flare and flare-related event lists, as well as actual data, which serve as daily input for our database. In Section 3, we explain the daily processing of the event lists and data: integration of the flares from different lists, calculation of additional event descriptors, preparation (smoothing) of the light curves. The processed data are stored in a MySQL database allowing convenient and fast interaction. In Section 4, we describe the web interface, the structure and logic of queries for our database, and the structure of the output data available to the user. A query example is also presented in this section. We present our conclusions in Section 5.

2. Data Collection and Storage

In this section, we describe the catalogs of events used as inputs. The complete and up-to-date list of integrated

Table 1
Event Catalogs Currently Implemented in the IMIDSF (https://solarflare.njit.edu/)

Source Name	Dates presented	Source web link
	Primary flare lists	
GOES flare list	2002 Jan—current time	ftp://ftp.swpc.noaa.gov/pub/warehouse/
RHESSI flare list	2002 Feb—current time	http://hesperia.gsfc.nasa.gov/hessidata/dbase/
HEK flare list	2010 Feb—current time	https://www.lmsal.com/isolsearch
	Secondary event catalogs	
IRIS observing logs	2013 Jul—current time	http://iris.lmsal.com/search/
Hinode flare catalog	2006 Nov–2016 Jul	http://st4a.stelab.nagoya-u.ac.jp/hinode_flare/
Fermi GBM flare catalog	2008 Nov—current time	https://hesperia.gsfc.nasa.gov/fermi/gbm/qlook/
Nobeyama coverage check	2010 Jan—current time	ftp://solar-pub.nao.ac.jp/pub/nsro/norp/xdr/
OVSA flare catalog	2002 Jan–2003 Dec	http://www.ovsa.njit.edu/data/
CACTus CME catalog	2002 Jan—current time	http://sidc.oma.be/cactus/
Filament eruption catalog	2010 Apr–2014 Oct	http://aia.cfa.harvard.edu/filament/
Konus-*WIND* flare catalog	2002 Jan–2016 Jul	http://www.ioffe.ru/LEA/Solar/index.html

event sources can be found via https://solarflare.njit.edu/datasources.html, and the current list is summarized in Table 1.

2.1. Primary Event Lists

The event lists are divided into "primary" and "secondary." The primary event lists represent daily updated lists of flares independently detected by the *GOES*, *RHESSI*, and *SDO*/AIA instruments. The secondary lists include partial flare lists, representing subsets of the primary lists, and catalogs of flare-related phenomena (such as filament eruptions or CMEs).

Each event in the primary lists is characterized by start, peak, and end times. In most cases, the event coordinates and the associated active region number are also reported. We use three primary event catalogs.

1. *GOES flare list*. The daily lists of events observed by the *GOES* satellites in the 1–8 Å channel are available from 2002 June to present. The reported characteristics include the *GOES* class, the X-ray peak flux during the event, and the information about the active region and coordinates of the event (not for all events). The daily lists are available at the NOAA website.
2. *RHESSI flare list.* The list of the flares observed by the *RHESSI* X-ray telescope from 2002 February to present. In addition to the usual descriptors (the flare times and position), the catalog contains the highest energy band in which the flares were observed, the number of counts during the flares, and a variety of observational quality flags.
3. *HEK SDO/AIA event list*. The events detected in the EUV images from the AIA/*SDO* instrument from February 2010 to present. The events reported in this catalog are characterized by a variety of different parameters (in addition to the common ones): the wavelength in which the event was detected, the coordinates in a variety of coordinate systems, peak fluxes, web links to quicklook images and movies, etc.

These three primary event lists are integrated into a single database, and unique identifiers (UniqueID) are prescribed for each event, as discussed in Section 3.

2.2. Secondary Event Sources

In addition to the primary event lists, the following secondary data sources are integrated into our catalog.

1. *Interface Region Imaging Spectrograph data* (*IRIS*, De Pontieu et al. 2014). *IRIS* obtains the slit-jaw UV images, as well as spectra of the Sun. The flare events are associated with *IRIS* observations based on the time and pointing stored in the form of instrument observing logs. The quicklook data web links allow users to select the events of interest.
2. *Hinode flare catalog* (Watanabe et al. 2012). The original catalog includes the events from the *GOES* flare list observed by the *Hinode* spacecraft. This catalog includes the availability of observations for each *Hinode* instrument, and quicklook data links.
3. *Fermi Gamma-ray Burst Monitor* (GBM, Meegan et al. 2009) solar flare catalog. The list of the flares observed by the *Fermi* GBM in the 8 keV–40 MeV energy range from 2008 November to present. This catalog includes the duration of the observed flares and the number of counts during the flares.
4. *Nobeyama Radio Polarimeter light curves* (Nakajima et al. 1994). The polarimetric measurements from Nobeyama Radio Observatory are available for almost every day, usually approximately 8 hours per day.
5. *OVSA legacy flare catalog* (Nita et al. 2004). This includes short-time summaries of events observed by the Ovens Valley Solar Array in the 1–18 GHz microwave range, from 2001 to 2003 only.
6. *Computer Aided CME Tracking (CACTus) catalog* (Robbrecht & Berghmans 2004; Robbrecht et al. 2009). This catalog collects records of CMEs detected by the LASCO/*SOHO* coronograph, and contains a variety of CME properties, including the onset time, principal angle, velocity, etc. The CME-flare event-matching algorithm currently implemented in our database is based on the following rule: the recorded CME onset time must lie within a predefined time interval relative to the flare start and end times, which can be interactively adjusted by the user by means of a "Search time interval" filter.
7. *Filament eruption catalog* (McCauley et al. 2015). The filament-flare event-matching is based on the time and

position of the eruptions. A variety of filament parameters are available. The catalog production was stopped on 2014 October 19.

8. *Konus-WIND flare catalog* (Aptekar et al. 1995; Pal'shin et al. 2014). The original catalog includes the events from the *GOES* flare list observed by the Konus-*WIND* spacecraft.

Our database is designed in such a way that it can support a continuously expanding number of input sources of different types. These include flare and flare-related event catalogs, and information about the observational coverage by different instruments.

2.3. Background Data Characteristics

The aim of the developed database is not only to collect and integrate the flare records from different sources, but also to provide users with an overview of the events they potentially want to study. The flare catalogs themselves already contain many useful quicklook links. For example, each HEK flare record contains the links to the quicklook movies and images obtained by AIA/*SDO*. Our approach is to contribute to the flare overview, and present additional data for each selected event.

Here is a summary of the time plots we provide for each event (if covered by the instrument):

1. *GOES X-ray light curves* (two channels 0.5–4 Å and 1–8 Å).
2. *Temperature and emission measure (EM) determined from the GOES X-ray data in a one-temperature approximation.*
3. *SDO/EVE ESP light curves* (four diode channels: 18, 26, 30, 36 nm).
4. *Nobeyama Polarimeter data* (six frequency bands, two polarizations: 1, 2, 3.75, 9.4, 17, 35 GHz, I and V polarizations for each frequency).

Each of the described sources is updated daily. The temperature (T) and EM for the events are computed using the Temperature and Emission measure Based Background Subtraction Algorithm (TEBBS, Ryan et al. 2012) described in Section 3. For the *SDO*/EVE ESP light curves, we apply 10 s averaging in order to obtain smoother profiles. The same approach is used for the Nobeyama Polarimeter data. These characteristics, which help describe the flare evolution, may provide useful information for selecting particular events for further detailed studies.

2.4. Data Storage and Queries

For quick access to the flare catalog information and other metadata derived from the observational data, we store the information in a MySQL database. Each catalog is created as a separate relation, and proper indexes are created to speed up the search. A web interface allows the user to query and visualize the results. A query can take from several seconds (for a typical one-month time period) to several minutes (for the entire time period and no active filters).

3. Data Enrichment and Processing

In addition to the routine daily updates of the event lists, we performprocessing to enrich the original data. First, we calculate physical descriptors of the events (coordinates, temperature and EM peaks, and their times for *GOES* events) which are in addition to the descriptors already stored in the original lists. Second, we match each event from each primary list with its counterparts in other primary lists, and assign a unique identifier (UniqueID) for each uniquely matched case. These procedures are described in this section.

3.1. Determination of Coordinates for the GOES Events

The *GOES* flare list reports the events detected from the integrated X-ray light curves and includes coordinates only for some events. However, in most cases, the NOAA active region number where the flare occurred is known and reported in the list, but without its coordinates. To estimate the coordinates of the event based on the active region number, we utilize the Solar Region Summary files. Such files are formed every day, half-an-hour after midnight, and report the current active regions, and their locations at 00:00 UT. Using these angular coordinates, we compute the position of the active region at the flare start time, assuming the Carrington rotation period $T \approx 27.3$ days, and taking into account the variations of the solar radius with time as a function of the Earth's position in its orbit.

3.2. Temperature and EM for GOES Events

Important physical properties derived from the *GOES* X-ray observations are temperature (T) and EM (Thomas et al. 1985; White et al. 2005). These parameters can be defined for each moment of time, and provide T and EM profiles for every flare. In our database, we characterize flares by the peak values of these parameters ($T_{\max}$ and $\mathrm{EM}_{\max}$), as well as by the times when these peak values are reached. To remove the background (non-flare) X-ray flux, we use the Temperature and Emission measure Based Background Subtraction (TEBBS) algorithm, initially proposed by Bornmann (1990) and improved by Ryan et al. (2012), based on the assumption that T and EM must grow during the flare impulsive phase. We have implemented in our database the algorithm proposed by Ryan et al. (2012). The corresponding GitHub repository is available for public access: https://github.com/vsadykov/TEBBS.git.

As mentioned above, the algorithm receives all the physically possible combinations of the background level, which provide growing T and EM curves after the flare start time. For each of these curves, we calculate the T and EM maximum values during the flare. The range of these values defines the physical interval for $T_{\max}$ and $\mathrm{EM}_{\max}$. To obtain "the best" curve representing the T and EM dynamics, we simultaneously minimize the deviation from the $T_{\max}$ and $\mathrm{EM}_{\max}$ median values for all curves, and choose the one corresponding to the minimum mean deviation. For the best estimate curve, we compute $T_{\max}$ and $\mathrm{EM}_{\max}$, and the corresponding time moments, and store them in our database, together with the possible physical intervals of $T_{\max}$ and $\mathrm{EM}_{\max}$. An example of the TEBBS calculations for a C3.9 class flare is presented in Figure 2.

3.3. UniqueID Assignment and Relation to the SOL ID

The three "primary" catalogs (the *GOES*, *RHESSI*, and HEK flare lists) of the database are updated on a daily basis. For every new flare event, we assign the UniqueIDs by integrating the information from these three sources.

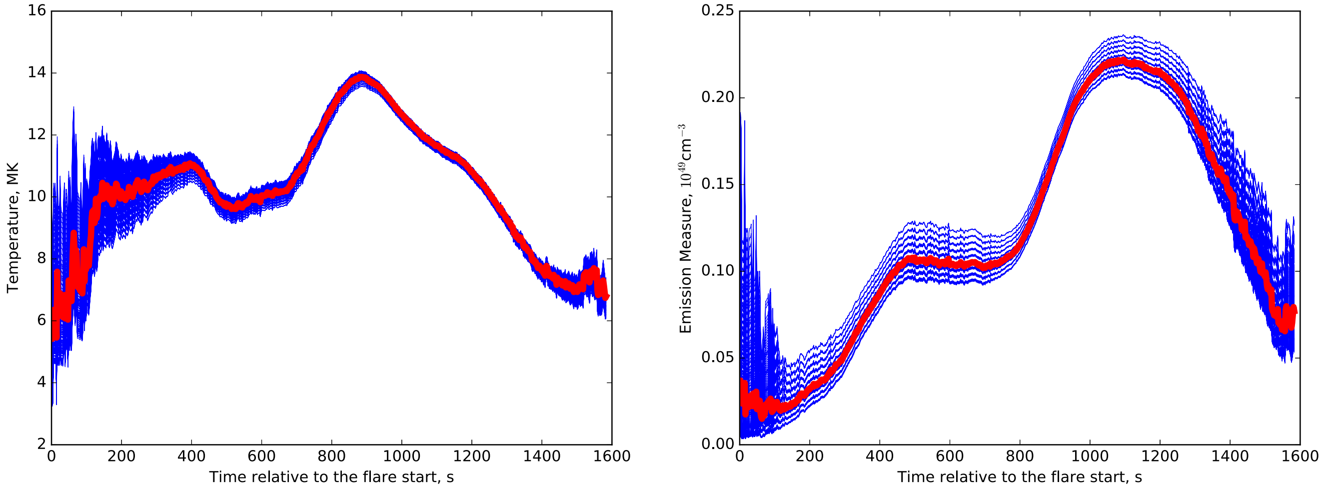

Figure 2. Example of the temperature (right panel) and EM (left panel) calculations using the TEBBS algorithm for the SOL2016-02-15T04:02:00 event (C3.9 class flare). The blue curves represent the physically possible temperature and EM solutions. The red light curves represent the best-estimate solution.

Each of the "primary" catalogs reports the events with their known start, peak, and end times. Also, the information about the event coordinates is provided or calculated as described above. This information is used to determine if the entries in these catalogs represent the same physical phenomenon, i.e., if they happened at the same time in the same place, or if they belong to different events.

To assign the UniqueID, we introduce the following hierarchy order: NOAA *GOES*, *RHESSI*, and the HEK flare list. This order means the following: if a flare event is reported by *GOES*, then it is labeled as a *GOES* event ("gev"). If an event is not in the *GOES* catalog, but reported by *RHESSI*, this event is labeled as a *RHESSI* event ("rhessi"). If an event is not reported by *GOES* and *RHESSI*, but is recorded as a flare in the HEK database, it is labeled as a HEK event ("hek"). The UniqueID consists of two parts: the name of the primary instrument that observed the flare, and its start time. For example, the *GOES* event observed at "yyyy-mm-dd hh:mm" gets the UniqueID "gev_yyyymmdd_hhmm00," while the *RHESSI* or HEK events are labeled "rhessi_yyyymmdd_hhmmss" and "hek_yyyymmdd_hhmmss," respectively (we add "00" to the *GOES* event UniqueIDs for compatibility with the UniqueIDs from other catalogs). In the case of events with the same start time but different locations (which was found for some HEK event only), we assign the UniqueID "hek_yyyymmdd_hhmmss_i," where "i" is an increasing integer, starting from 1 for each such case. The advantage of the event ID assignment procedure we adopted is that this classification can be easily extended for any number of flare-reporting instruments.

The procedure of the UniqueID assignment is as follows.

1. Query *GOES* flare list events for their coordinates and active region numbers. Then, sort the events according to their *GOES* X-ray class in descending order. For each event (hereafter parental event) assign the UniqueID "gev_yyyymmdd_hhmmss" according to the event. Then:
   (a) For each "gev" event, find all events in the *RHESSI* and HEK flare catalogs overlapping in time, from the start to end times, and obtain their coordinates and active regions. This is a list of candidate events corresponding to the parental event.
   (b) For each candidate event compare the coordinates and active regions with the parent event. The events are assigned the same UniqueID as the parent event if they have the same active regions and their locations differ by no more than $\delta = 250''$. This value was chosen experimentally, and it is approximately equal to the size of a large active region. If one of the compared events (parental or candidate) has missing coordinate and/or active region information, the corresponding condition is assumed to be satisfied.
2. Repeat the procedure for the events for which the UniqueID is still not assigned, using the *RHESSI* flare catalog. These events are sorted according to their energy range and their UniqueIDs are assigned in the form "rhessi_yyyymmdd_hhmmss."
3. Repeat the procedure for the remaining set of events for which the UniqueID is still not assigned, using the HEK register. The HEK register contains events overlapping in time (for example, reported for different *SDO*/AIA channels, or from different locations), thus the matching procedure is still needed. For the matched events, assign UniqueIDs "hek_yyyymmdd_hhmmss_i," where "i" represents a discriminatory index assigned only to those events characterized by the same start time but different locations.

The procedure of UniqueID assignment for new events is repeated on a daily basis. Nevertheless, a complication may happen if one of the events is reported with a delay of one day or more. If this is the case, the UniqueIDs of the events overlapping with such delayed events are deleted, and the UniqueID assignment starts for all the events with empty UniqueIDs.

The same UniqueID may be defined for several *GOES*, HEK, and *RHESSI* events. For all such overlappings, we keep the maximum and minimum values for each of the coordinates among all the matched events.

The last thing worth mentioning is how our UniqueIDs correspond to other event IDs. The Solar Object Locator (SOL), which, in its simplest form, contains only the event time, is one of the widely used identifiers. Because it is not documented whether the event time should correspond to the start, peak, or end time, for display purposes, we use the flare start time as a default reference time, but we also assign and maintain in the database the correspondence between our UniqueID and these three possible versions of the SOL IDs.

4. Query Structure and Processing

In this section, we discuss the structure of the query engine. This engine is the most important software component for the construction of the web ppplication, because it should be efficient, fast, and user-friendly. The current implementation retrieves and displays the final list of events in a convenient form, works fast, and is constructed in such a way that adding new catalogs does not require changing the code structure.

To perform a query, the user needs to fill out the request form on the web application site (the form is available at https://solarflare.njit.edu/webapp.html. In the request form, the user selects the desired time interval (including the ability to select the whole time range, starting from 2002 January 1), selects the position of the event on the solar disk, applying instrument-specific filters such as the event availability of the uniquely matched events in different catalogs, as well as ranges of various physical parameters, and executes the query by pressing the submit button. Alternatively, the user can load a previously saved query result.

4.1. Primary Catalogs, Filters, and the Appearance of the Additional Fields

The "primary" flare catalogs (*GOES*, *RHESSI*, and HEK flare records) are updated on a daily basis and have the flare records detected by their own algorithms. The descriptors of the primary catalogs are displayed independent of the user's selection of filters. For example, if the user is searching for all events listed in the *RHESSI* flare catalog, the output may have empty *GOES* or HEK fields. All fields will be populated only if the data availability filters in "primary" catalogs are selected.

The on-the-fly generation of additional search fields corresponding to specific event descriptors for the other catalogs depends upon user the selection. For example, let us consider the case of a user looking for the events listed in the *Hinode* catalog. In such cases, the descriptor fields related to the *Hinode* catalog (number of observed frames, corresponding quicklook link, etc.) will appear in the final table as additional columns. This strategy allows us to make the tables as short and informative as possible, based on the user's query. Almost each of the parameter fields may be tuned during the query: the filters allow not only the ability to check the appearance of the event in a certain catalog, but also to select events with particular physical characteristics.

The initially constructed table (based on the primary catalogs) is the backbone for the query: we simply discard from this table the event records that do not pass additionally selected filters. This allows us to check the selected filters one by one, without pulling them into one large query. This structure has one more advantage: we can add the filters for newly uploaded catalogs/lists without disturbing the working system. Adding a new event table would just require a new independent block in the query engine.

4.2. Results Table and Python Routine for Parsing

The final result of a query is presented in the form of a web table with moving headers. One can simply drag the table to the right to see the various characteristics of the events. For better performance, we currently restrict the number of events appearing in the table to 1000. However, full lists of events are available to download in the output file, which can be saved locally and reloaded anytime. We also added the possibility to sort the output table according to the flare characteristics. The sorting procedure represents another query to the server and includes all events, even if the number of events exceeds 1000. The user has the option to download the output table. In order to simplify the processing of the output file, we created a Python parser that reads the table and creates a structure corresponding to the events.

4.3. Detailed Visualization of a Selected Event

The main purpose of the created database is to integrate the entries from different catalogs, and to present a complete list of events satisfying a set of conditions specified by the user. However, from a practical perspective, it is very important to have a brief look at the event data, and decide whether a particular event is interesting for a case study or not. For this purpose, we created the ability to look at the event light curves derived from different instruments. To proceed onto the event page, one needs to select the event of interest from the summary table retrieved in the previous stage, and click the "Plot Data" button.

The main elements of this event page are the two dynamic graphs reflecting the behavior of several event light curves: X-ray fluxes, temperature and EM calculated for the *GOES* data using the TEBBS algorithm, light curves from the *SDO*/EVE/ESP instrument, and the Nobeyama Radio Polarimeter fluxes. The user can select which plot to display and scale it accordingly. For visualization, we are currently using the Google Charts tool.

The interactive web interface also allows the user to download all the displayed light curves. The downloaded file contains the *GOES* data with 2 s resolution, and the 10 s averaged Nobeyama and *SDO*/EVE/ESP data. In addition to the graphs, we also provide the user with an image of the flare generated from *SDO*/AIA 1600 Å data, and a detailed description of all overlapping events from the primary *GOES*, *RHESSI*, and HEK lists corresponding to the same UniqueID, as well as from the secondary event sources. In addition to the usual flare descriptors, the HEK database contains links to the flare quicklook images: we keep these links on our event summary page, which also can be downloaded.

In addition, the users are provided with the option of a similarity search mechanism (currently in its beta version) that allows automatic selection of similar events from the initial query table, based on some predefined and user-defined characteristics. Each such event characteristic is normalized, and if the associated fields are absent from the table for some of the events, they are replaced by the median values of the corresponding characteristic. The nearest neighbors of the selected event are determined based on the selected (predefined) characteristics using the Euclidean distance.

4.4. Example of a Query

To demonstrate the capabilities of the IMIDSF, here we provide an example of a multi-instrument query. Supposethe user wants to study the chromospheric evaporation processes that occurred during strong solar flares ($\geqslant$M1.0) in 2015 using the spatially resolved high-cadence multiline spectroscopic

Table 2
Results of the Sample Query (See the Text for Details)

SOL ID	Flare Class	*RHESSI* highest energy	*IRIS* raster mode and number of slit positions
SOL2015-03-10T23:46:00	M2.9	12–25 keV	coarse, 4-step
SOL2015-03-11T16:11:00	X2.1	25–50 keV	coarse, 4-step
SOL2015-03-11T18:37:00	M1.0	25–50 keV	coarse, 4-step
SOL2015-06-22T17:39:00	M6.5	100–300 keV	sparse, 16-step
SOL2015-08-27T04:48:00	M2.9	12–25 keV	coarse, 8-step
SOL2015-11-04T13:31:00	M3.7	50–100 keV	coarse, 16-step

observations performed by the *IRIS* satellite, and simultaneously analyze the energy released by precipitating accelerated electrons using *RHESSI* observations. Selecting the corresponding *GOES* filter, *GOES* class $\geqslant$M1.0; the *IRIS* filter, which expands the field of view by $100''$, $\geqslant$4 slit positions, $\geqslant 5''$ covered perpendicular to the slits with a cadence of $\leqslant$60 s; the availability of *RHESSI* observations; and the non-limb events (located not farther than $750''$ from the disk center to avoid strong projection effects); the query would return six records. Some descriptors of these flares are presented in Table 2. After such a query, the user could check the events manually, see the light curves for each event, proceed to the *IRIS* quicklook images and movies, and check how well the events were covered by the *IRIS* slit positions, etc.

5. Conclusion and Future Plans

We have created the IMIDSF that is available to the community at https://solarflare.njit.edu/. This database integrates a set of available solar flare lists and data in a convenient way and includes the following main features:

1. Integration of the flare events from different flare catalogs (*GOES*, *RHESSI*, HEK, *Hinode*, *Fermi* GBM, Konus-*WIND,* the OVSA flare catalogs): matching of events from the *GOES*, *RHESSI*, and HEK primary flare lists and assignment of UniqueIDs for flares. The queries provide “one flare—one result.” After the UniqueID assignment, the flare reports are integrated with secondary flare catalogs (*Hinode*, *Fermi* GBM, Konus-*WIND*, OVSA) and flare-related events (Filament Eruption catalog, CACTus CME catalog), depending on the user’s query.
2. A search of the flare events based on their physical descriptors (both those stored in the catalogs and calculated by our efforts) and the availability of observations (currently *IRIS* and Nobeyama observational filters are available). The search allows the users to select the events of interest based on the specified filters, get the integrated properties of the events in one table, download the results of the query, and visualize the processed light curves for each event.
3. A detailed look at the data (*GOES*, ESP/EVE, and Nobeyama light curves, and temperature and EM derived from *GOES* data) for a particular event, and a look at its summary containing quicklook links stored in the primary catalogs. This allows the user to form an initial opinion about the selected event, and to decide whether the event would be interesting for a case study.

The integrated catalog results generated by our database provide a tool to assist researchers who study solar flares using large data archives. The tool we have created allows the user to search for events with parameters of interest for various statistical studies, handling all the catalog-creation tasks, and at minimum provides a catalog to start from. Also, it provides a summary for each event, allowing researchers to understand if the particular event satisfies criteria for particular case studies. Finally, our web application allows access to such data independent of platform or software.

As far as we know, there are almost no examples of this kind of query engine for solar flares. In this case, our database really provides a unique overlook of the flare data. Currently, there are many filters, catalogs, and data processing modules already implemented in our database. However, our design allows further development of the instrumental logs and sources without distortion of the current schema. Further expansion of the sources is definitely in our plans. We also plan to increase the flexibility of the project by developing a true Web API that will allow users to receive the flare lists, apply different integration schema, and contribute to the database by adding their own records and data. We also plan to integrate the VSO API and generate data links for the stored flare events.

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