Visualizing Solar Image Data with J/Helioviewer and Event Searching with HEK

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The Helioviewer Team
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The HEK Team
Visualizing Solar Image Data

Motivation

- Solar observatories generate huge amount of data
  SOHO (1995): 0.2 GB/day
  SDO (2010): 1.4 TB/day
  ATST (estimated average): ~12 TB/day
- Data covers wide ranges of length and time scales
- Many different data products available
Visualizing Solar Image Data

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Goals

• Enable efficient data browsing and visualization
• Link data to knowledge bases and automated feature recognition algorithms
• Support data-driven modeling
Solar Dynamics Observatory

• **Payload:**
  - **Atmospheric Imaging Assembly (AIA)**
    - Full-disk images in 10 channels, up to 12 sec cadence, 16 MPixel
  - **Helioseismic & Magnetic Imager (HMI)**
    - (Vector) Magnetograms, Dopplergrams, Intensitygrams, 16 MPixel
  - **Extreme UV Variability Instrument (EVE)**
    - EUV irradiance ($\lambda=0.1$-105 nm), 0.1 nm spectral resolution, every 20 sec

SDO returns ~50 times more data than any previous space science mission!
Large Data Volumes: The Challenge

- **SDO:**
  - ~4 PB for 5-year mission: costly to store
  - Equivalent to 2-3 TV channels
  - Can be delivered to <6 sites from JSOC

- **ATST:**
  - Data generation ~4.5 PB/year
  - ATST/VBI after speckle processing: ~10^6 images/day (SDO/AIA: ~60,000 /day)
  (figures courtesy of K. Reardon)
Science with SDO: Why browse tools are essential

Example:
Long range magnetic couplings between solar flares and coronal mass ejections observed by SDO and STEREO
(C. Schrijver & A. Title, JGR 116, 2011)

• Shows that coupling of flares and eruptive events spans > 180° in longitude
• Data used for this study:
  • SDO/AIA+HMI, STEREO EUVI
• Data volume (compressed):
  • 800 GByte
• Download time @ 3 Mbit/s:
  • 25 days

Need to know what’s in the data before downloading in full science quality!
Science with SDO: Why browse tools are essential

AIA takes 16MP images in 10 channels, every 12 sec, 24/7

Challenges:

• Data access & distribution
• Search
• Visualization
Science with SDO: Why browse tools are essential

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• Visualization

Solution:

• With JPEG 2000: Can compress 4k × 4k image to 1 MB
• 10 channels at 36 sec cadence → 24 GB/day = 8.8 TB/year
• Can keep comprehensive data set of browse data online for entire mission (science data: only few months)
The ESA/NASA Helioviewer Project

**Front-Ends**

- **JHelioviewer** - Java/OpenGL application
- **Helioviewer.org** - Web application

**Back-End**

*Helioviewer Server:*

- **JP2Gen** - FITS-to-JPEG 2000 processing pipeline
- **JPIP Server** - JPEG 2000 Interactive Protocol streaming server
- **Dynamo** - JPEG 2000 archive index, tiling engine, etc.
JHelioviewer

What is JHelioviewer?

- Client-server solution for browsing large data volumes, using
  - JPEG 2000 compression
  - JPIP for interactive streaming
  - OpenGL for fast rendering

Why use it?

- Interactively play & overlay time series of high-res images with arbitrary cadence
- Perform basic image processing on-the-fly
- Connect to event databases, overlay markers
- Export to common movie formats
- Request SDO science data
Example: Combine SDO + SOHO Data

SDO/AIA: 0-1.3 $R_{\text{sun}}$
LASCO/C2: 2-6 $R_{\text{sun}}$
LASCO/C3: 3.7-32 $R_{\text{sun}}$
Example: Combine SDO + SOHO Data

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What is JPEG 2000?

JPEG 2000 = wavelet-based compression standard

Advantages:

• **Multi-resolution**
  Images at different resolutions are automatically created during wavelet compression

• **Random image access**
  Selected parts + quality layers can be accessed remotely

• **Flexible file format**

• **Well-suited for archives**
Remote Image Access via JPIP

- JPIP = JPEG 2000 Interactive Protocol
- Provides a client–server architecture for interactively transmitting image data over networks
- Can request arbitrary parts and quality levels of image series

Müller et al., Computing in Science & Engineering (2009)
JHelioviewer User Interface
JHelioviewer User Interface

Layer Manager

Layer Manager window with two selected layers:
- AIA 171 2010/12/06 12:36:00
- AIA 304 2010/12/06 12:35:56
JHelioviewer User Interface

Layer Manager

Add Layer

- Start Date: 2010/12/06
- Start Time: 00:59:36
- End Date: 2010/12/06
- End Time: 21:54:00
- Time Step: 30 min
- Observatory: SDO
- Instrument: AIA
- Detector/Measurement: 171 Å
JHelioviewer User Interface

Adjustments

- Selected Layer: AIA 304
- Quality: 8/8
- Opacity: 100%
- Sharpen: 0%
- Gamma: 1.0
- Color: SDO-AIA 304 Å
- Channels: Red, Green, Blue
JHelioviewer User Interface

Features/Events

- HEK (36/72)
  - Coronal Cavity (2/4)
  - Filament Eruption (10/20)
  - Filament (18/36)
  - Flare (4/8)
  - Other (2/4)
JHelioviewer User Interface
JHelioviewer Features

- Serving AIA images at 36s cadence
- Feature tracking
- Knowledgebase integration
- Plugin architecture
- RGB channel mixer
- Radial opacity filter
- Versatile movie export
- Save & load states
- SDO Cut-Outs data service
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Helioviewer Project: Coming Soon...

Server-Side

• New API and back-end database structure to handle more complex data types such as spectral data (old API will still be supported for backwards compatibility)
• Hinode XRT and TRACE images
• Temperature maps (generated by Iain Hannah, U. Glasgow)

Helioviewer.org

• More flexible image selection options; support for more complex data products
• Generation of science data download scripts based on user selection
Helioviewer Project: Coming Soon...

JHelioviewer 3D
Space Weather Helioviewer

- 2-year ESA GSTP Project (2013-15) to add space weather capabilities to J/Helioviewer
- Led by Royal Observatory of Belgium (F. Verstringe, B. Bourgoignie, B. Nicula, D. Berghmans, C. Marqué, V. Delouille)

Incorporate new datasets

3D support:
- Rotate the image freely
- Overlay multiple images at their true location (SOHO)
- Hide/unhide outer corona
- Solar grids
- Show magnetic fieldlines

Switch to difference images

Space weather events
- Tag timelines with events
- Indicate events on disk

Plot space weather relevant timeline data

Show spectral radio image data

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References & affiliations
(1) Royal Observatory of Belgium
(2) www.JHelioViewer.org
(3) www.HelioViewer.org

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Space Weather Events
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Helioviewer API

In order to facilitate third-party application developers who wish to use content from and interact with Helioviewer.org, a number of Application Programming Interfaces (APIs) have been developed, offering access to a variety of components used by Helioviewer.

http://www.helioviewer.org/api/

Use Cases

• Catalog of AIA images and movies based on RHESSI flare list (in development, Iain Hannah, U. Glasgow)
• Public outreach web application on the science of sunspots (US PBS NOVA TV show)
• Institut d’Astrophysique Spatiale, Paris: SDO data browse tool uses Helioviewer API to deliver images (http://medoc-sdo.ias.u-psud.fr/sitools/client-user/IAS_SDO_DATA/project-index.html)
Helioviewer Servers

- Main Helioviewer Server at NASA GSFC
- Additional servers have been installed at:
  - Montana State University
    - Project on content-based image retrieval services
  - Royal Observatory of Belgium
    - Space Weather JHelioviewer development, substitute server during recent US government shutdown
  - Institut d’Astrophysique Spatiale (IAS)
    - IAS uses Helioviewer Server for their SDO/AIA data browse tool
- Long-term goal: A distributed system of publicly accessible Helioviewer Servers
Student Involvement

- Most of JHelioviewer has been coded by students
- Open source approach is key
- All source code available at https://launchpad.net/helioviewer
The Heliophysics Event Knowledgebase (HEK)

What is HEK?

- Heliophysics Events Registry (HER)
  - Tells you what features and events have been found on the Sun
- Heliophysics Coverage Registry (HCR)
  - Tells you what data sequences are available (AIA, HMI, SOT, XRT, TRACE and more).

HEK is the integrated system which
- directs scientists to the data they need without blindly downloading TBs of images, and
- allows users to report new features/events and to contribute information on existing ones (hence “knowledge”).


HEK Event-Searching

You can search the HEK in different ways:

• Using visual browse tools (iSolSearch, Helioviewer.org, JHelioviewer)

• Using the Web API (http://www.lmsal.com/hek/api.html)

• Using SolarSoft IDL

• Using SunPy
HEK Event-Searching with iSolSearch

http://www.lmsal.com/isolsearch
HEK Event-Searching with SolarSoft/IDL

• Uses the SolarSoft *Ontology* package:

```
IDL> ssw_upgrade,/ontology,/spawn/loud
```

• A simple example: Query the HEK for all flares that occurred between \( t_{\text{Start}} \) and \( t_{\text{End}} \):

```
IDL> tstart = '2011/08/09 07:23:56'
IDL> tend = '2011/08/09 12:40:29'
IDL> result = ssw_her_query(ssw_her_make_query(tstart,tend,/flare))
```

• And then look up the corresponding SDO/AIA data using VSO:

```
IDL> aia=vso_search(inst='aia',event=result.fl[0])
```
HEK Event-Searching with SunPy

What is SunPy?

- SunPy ([http://sunpy.org](http://sunpy.org)) is a community-developed, free and open-source software library for solar physics
- HEK module was developed by Austrian student Florian Mayer as part of ESA’s “Summer of Code in Space” programme
HEK Event-Searching with SunPy

• Same example as above, now using SunPy:

```python
>>> from sunpy.net import hek
>>> client = hek.HEKClient()

>>> tstart = '2011/08/09 07:23:56'
>>> tend = '2011/08/09 12:40:29'
>>> result = client.query(hek.attrs.Time(tstart, tend), hek.attrs.EventType(event_type))
```
Conclusions

• The Helioviewer Project enables users to navigate and explore petabyte-scale data archives

• The torrent of data from SDO has started to transform the way research in solar physics is done - good exercise for ATST!

• The Heliophysics Event Knowledgebase provides means to efficiently identify and access relevant data for research

• Helioviewer Project + SunPy are open source – share and enjoy

http://helioviewer.org
http://jhelioviewer.org
http://sunpy.org
http://www.lmsal.com/hek