Kiepenheuer-Institut für Sonnenphysik

The Solar Physics Research Integrated Network Group – SPRING

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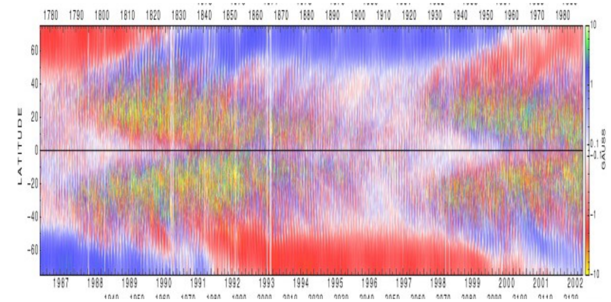
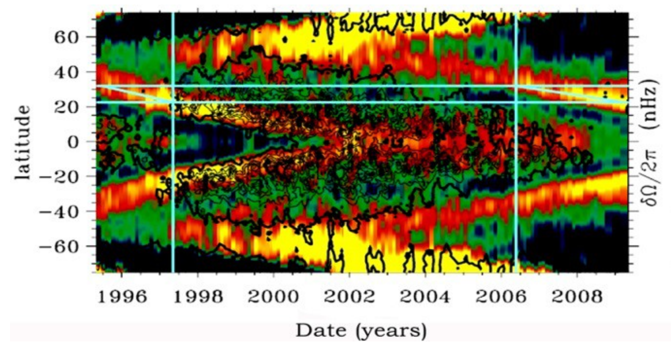
Synoptic Ground-based Solar Observations for Space Weather
Nice, October 18, 2016

The Need for Synoptic Observations of the Sun

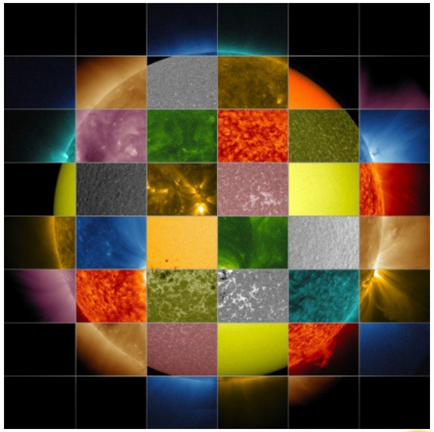
- **Long term monitoring of the solar magnetic fields**
  - to understand solar dynamo
  - evolution with solar cycle (polar and active region fields)
  - Active region evolution for space weather studies
  - surface flows via feature tracking





- **Long term monitoring of velocity fields**
  - subsurface flows via helioseismology
  - solar cycle variations and relationship to solar dynamo
  - Flows beneath emerging flux regions and active regions for space weather studies

- **Context imaging for next generation high-res telescopes such as DKIST and EST**
  - Large scale effects (flares, filament eruptions) of small scale events such as flux emergence.



* Hill, F. *et al. Space Weather, 11, 392, 2013*

* Elsworth, Y . *et al., Space Sci. Rev., 2015*, *193,137*

Big Questions

- What is the origin of the solar activity cycle?
- What is the structure, dynamics, and energetics of the solar atmosphere?
- How does the Sun drive space weather?
- What are the signatures of solar activity?

Detailed questions for a synoptic network

- What is the magnetic field in the chromosphere and photosphere?

SPRING is part of SOLARNET

Solarnet is an Integrated Activity (IA) funded by the European Union's Capacities Programme under Framework Programme 7:

Work Programme includes:

- *Networking Activities (NAs)*
- *Transnational Access and Services (TAS)*
- *Joint Research Activities*
  - Tools for innovative data handling
  - Advanced instrumentation development
  - Wavefront control: turbulence characterization and correction
  - **Synoptic observations:**
    Solar Physics Research Integrated Network Group (SPRING)

Coordinator of Solarnet: Manolo Collados (IAC)

Project Duration: April 2013 – March 2017

Synoptic observations: Solar Physics Research Integrated Network Group (SPRING)

Objective: Development of instrumentation for large field-of-view observations of the Sun with a network of solar telescopes in support of observations with existing high-resolution solar telescopes (either isolated or in a coordinated way).

Technical Requirements / Future synoptic telescopes should provide

- Full-disk Doppler velocity images
- Full-disk vector magnetic field images
- Full-disk intensity images
- Measurements of quantities relevant for space weather

- Provide the above data products in a variety of wavelengths
- Provide the above data products at a high cadence (≤ 60 seconds)
- Provide the above data products at a spatial resolution of 1” (0.5” pixels)
- Provide the above data products at least 90% of the time
- Provide the above data products for at least 25 years
- Complement space missions

Participants:

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SPRING Activity – Three Working Phases

1. **Science requirement study**
   - describe the supporting data required by high-resolution observing programs
   - the scientific objectives to be achieved by high-quality synoptic observations
   - study of the relation with other existing ground-based solar observation networks

Science Requirement Document (SRD) is available on http://www.science-media.org/paperPage.php?v=251

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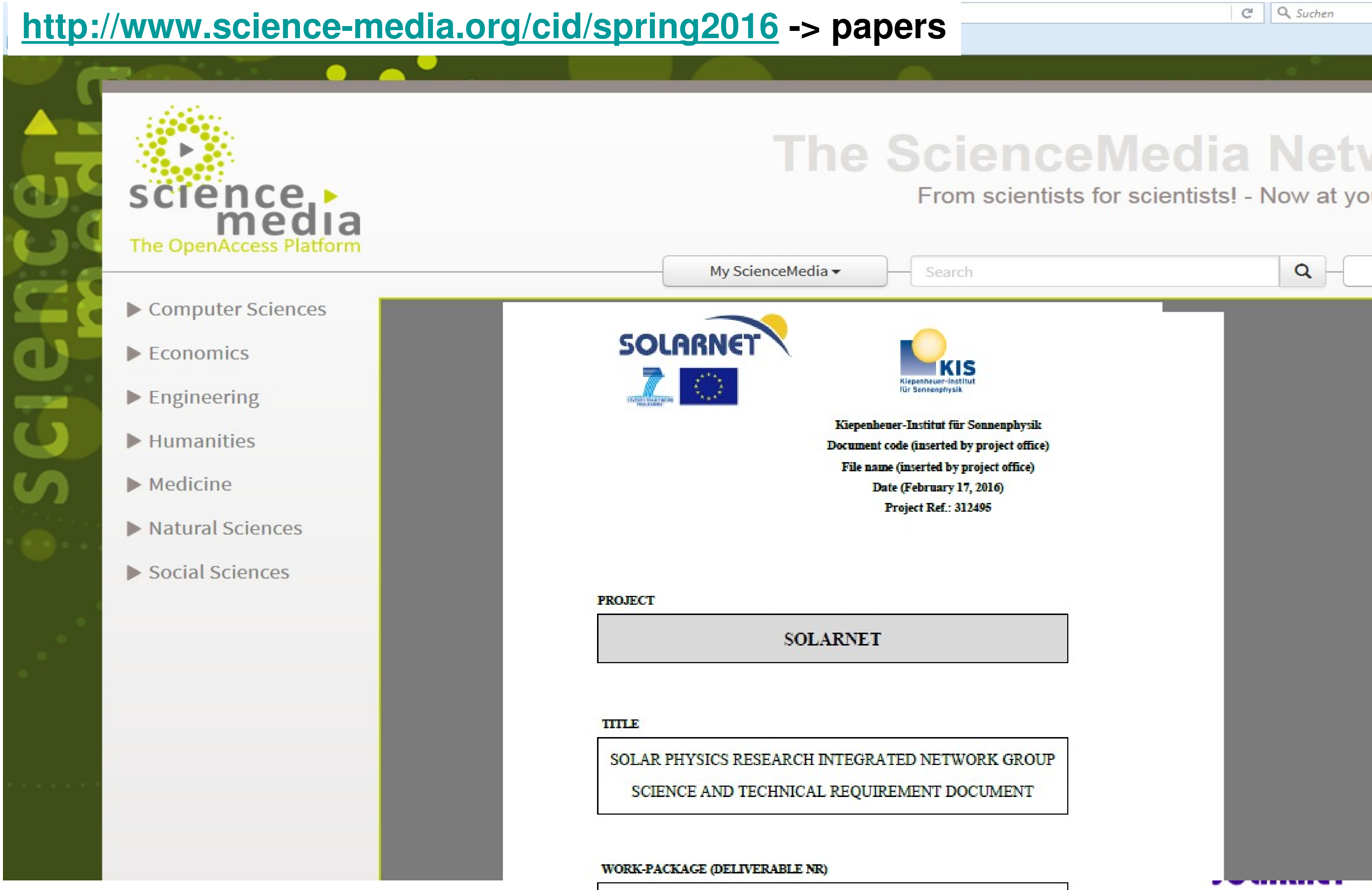
Science Requirement Document

http://www.science-media.org/cid/spring2016 -> papers



Working Groups

Group 1: Synoptic magnetic fields

- Sunspots (problems with cool atmospheres)
- Active regions
- Quiet Sun magnetism
- Synoptic Hanle Observations

Head: A. Pevtsov

Group 2: Solar seismology

- Waves (solar interior)
- MHD waves (magnetoseismology)
- Velocity field inside and on the Sun

Head: R. Jain

Group 3: Transient events

- Flow of energy through the solar atmosphere (3,2)
- Transient events
  (flares, prominences, CMEs)

Head: M. Sobotka

Group 4: Solar Awareness

- TSI / SSI
- Space Weather (4,3)
- Space Climate
- Sun-as-a-star

Head: I. Ermolli

Workshops

Synoptic Network Workshop, 22. – 24.04.2013, Boulder, USA
1st SPRING Meeting, 25. – 28.11.2013, Titisee, Germany
2nd SPRING Meeting, 25. – 28.11.2015, Tatranska Lomnica, Slovakia
3rd SPRING Meeting, 15.-17.05.2016, Boulder, USA

Instruments Wishlist

- Vector Magnetograph
- Broad band imager
- Disk-integrated spectrograph (high spectral resolution)
- Multi-lambda-helioseismic-Doppler-imager-and-magnetic-field
- Multi-lambda-vector-magnetometer
- Irradiance device (resolved)

Expected Improvements: Magnetometry

Multi-line high-resolution magnetic observations of the Sun

Several Advantages:

- 3-D magnetic topology of active region magnetic fields
- Improved coronal field extrapolations due to force-free behavior in upper layers of solar atmosphere.
- First ground based continuous vector magnetometry for near real time space weather predictions.
- Flare related changes in magnetic fields and electric currents in the chromosphere.
- Long-term magnetic field records with improved spatio-temporal resolution.

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Expected Improvements: Helioseismology

Multi-line high-resolution Doppler observations of the Sun

Several Advantages:

- Improved accuracy and precision of helioseismic mapping, in vicinity of active regions (Hill 2009).
- Reduction in systematic errors (i.e., improved accuracy) (Baldner & Schou 2012)
- Also, multi-height observations are useful for seismic mapping of solar atmosphere (Wisniewska et al. 2016, Finsterle et al. 2014, Nagashima et al. 2009).
- Transportation of convective energy through solar atmosphere (Jefferies et al 2006).

….. more details in the review by Elsworth et al., 2015, Space Sci. Review, 193, 137

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SPRING Activity – Three Working Phases

2. Feasibility study

2.1 Instrument design concepts

Definition of technical requirements for the instrument, based on scientific goals

Definition of alternatives of instruments concepts

To be studied:

- Adaptive optics or other image stabilizing/enhancement technology
- Observations in at least the following spectral lines: Ni I 6768, Fe I 6301/2, Na D, H-α, Ca K, Ca H, He10830,Fe I 6173 and Fe I 1.5 micron.
- High-speed image post-processing / High-speed real-time data access
  ? first concepts to provide line-of-sight magnetic field and velocity maps
- Location of telescopes for setting up a network mode **? BiSON/GONG experience**
- Possible instruments concepts:
  Filtergraph, Spectrograph and Interferometer, each one with different options
  ? under study

2.2 Operational concepts

Develop operational ideas (remote operations, data pipelining, delivery of real-time data to operating telescopes)

Narrow-band & Broad-band Filtergrams

Existing instruments:

SOLIS FDP, CHROTEL, Kanzelhöhe, NAOJ, Kodaikanal, HAO, GONG

Goal: Improve spatial resolution for these images

Options:

1. Implement Fast Image stabilization (with SOLIS FDP)
2. Explore fast camera (4kx4k at 200 fps)
3. Use existing 2kx2k @ 200 fps, fast cameras for acquiring broadband filtergrams and apply reconstruction methods such as speckle imaging, MOMFBD and Phase-diversity.

- Post processing methods need to be developed for highly parallelized (for near real-time) processing of iso-planatic patches over the fulldisk.

 Feasibility is currently being explored at NSO and KIS.

Filtergraph v/s Spectrograph

1. Cadence and spatial resolution requirements make it clear that **filtergraph is a suitable choice**

- **Advantages:**
  - Cadence of data can be higher for filtergraph at the cost of spectral resolution.
  - Spatial resolution can be better due to use of post processing techniques.

- **Disadvantages:**
  - Spectral degradation due to seeing variations during scans.

  Solution: Simultaneous broadband imaging can be used to reconstruct the spatial variations in the scans via reconstruction methods such as destretching.

2. Spectrograph systems give instantaneous spectra
   However: Time-varying seeing ? Spatial degradation during long scan times,

   Post facto techniques cannot be applied
   Non simultaneity of fulldisk rules out usage for helioseismology

Filtergraph Approach to SPRING

1. Michelson Interferometer: Examples: GONG, MDI, HMI

Advantage: large FoV, stable, compact

Disadvantage: Not suitable for multi-wavelength work as proposed in SPRING

2. Lyot type filters: Examples: UBF, Chromag

Advantage: large FoV, high contrast

Disadvantage: Requires lot of Calcite, Dual beam polarimetry not possible, slow tunability, low transmission for narrow passbands

3. Magneto-optical-filter : Examples : MOTH, GOLF

Advantage: stability, large FoV

Disadvantage: Not suitable for multi-wavelength work as required in SPRING

4. Fabry-Perot Interferometer: Examples: IBIS, CRISP

Advantage: Large wavelength range, rapid tunability, high transmission

Disadvantage: Field dependent passband shift, ghost reflections, long term drifts.

Filtergraph Concept (Feasibility)

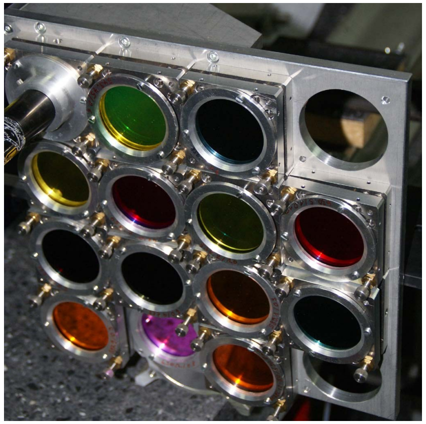
Demonstration Instrument at Vacuum Tower Telescope

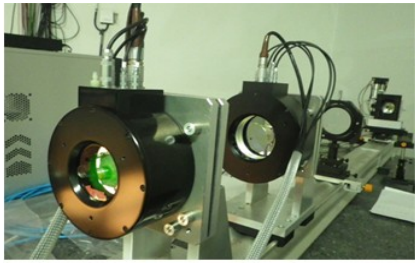
HELioseismic Large Region Interferometric DEvice (HELLRIDE, Staiger 2011)

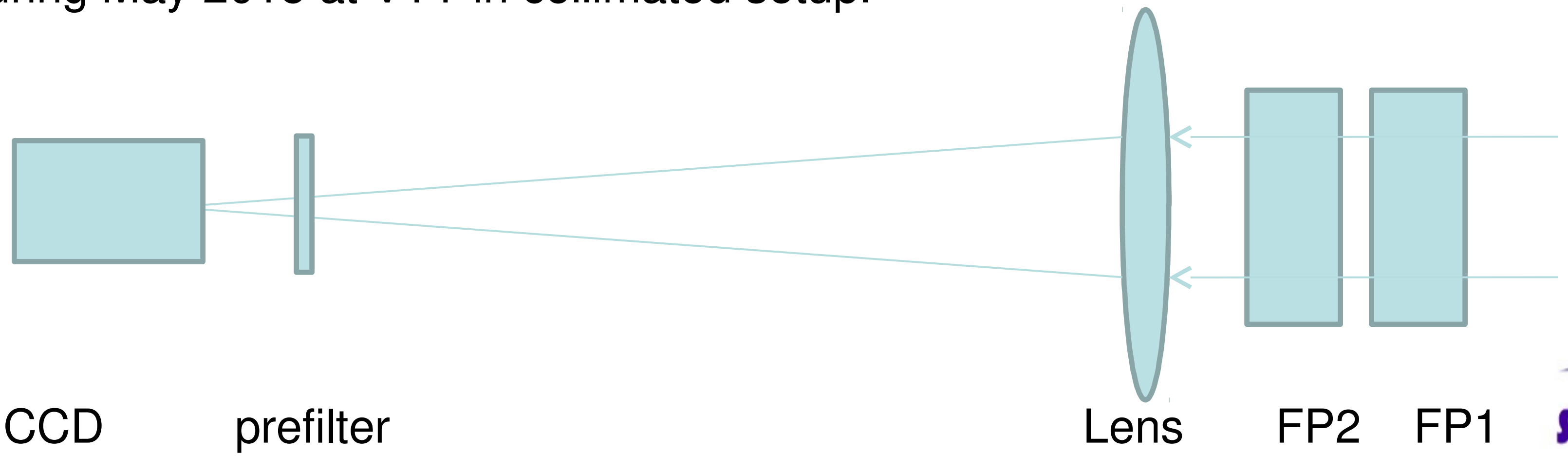
Dual Etalon system designed for multi-line observations over 100 arcsec FoV

The fast prefilter positioning system is used for minimizing the dead-time between subsequent spectral scans.

HELLRIDE was tested for feasibility of fulldisk measurements during May 2015 at VTT in collimated setup.







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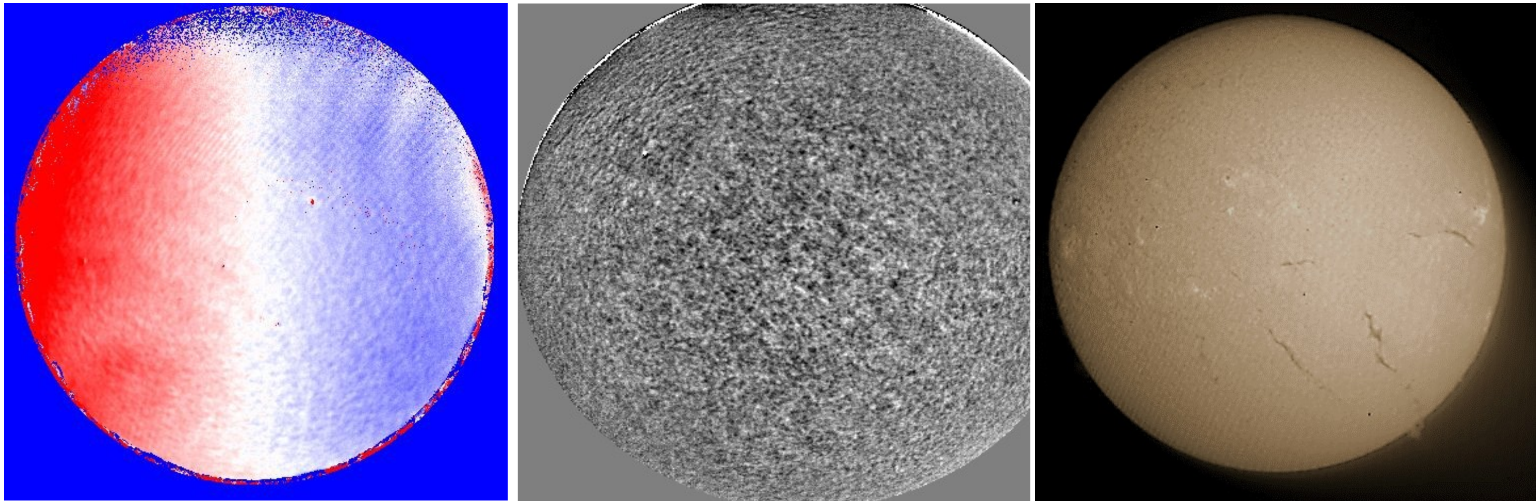
Filtergraph (Feasibility)



- Sample preliminary HELLRIDE observations of fulldisk with Fe 6302 line
- Long time series possible: instrument stable enough.

Future tests in the next weeks:

- Implement a diffuser + lens system to obtain flat-fields
- Online spectral drift monitoring system: using Laser
- Simultaneous white-light camera for image restoration.
- Polychromatic Polarimeter: to obtain LOS/vector magnetic and velocity maps in various lines.

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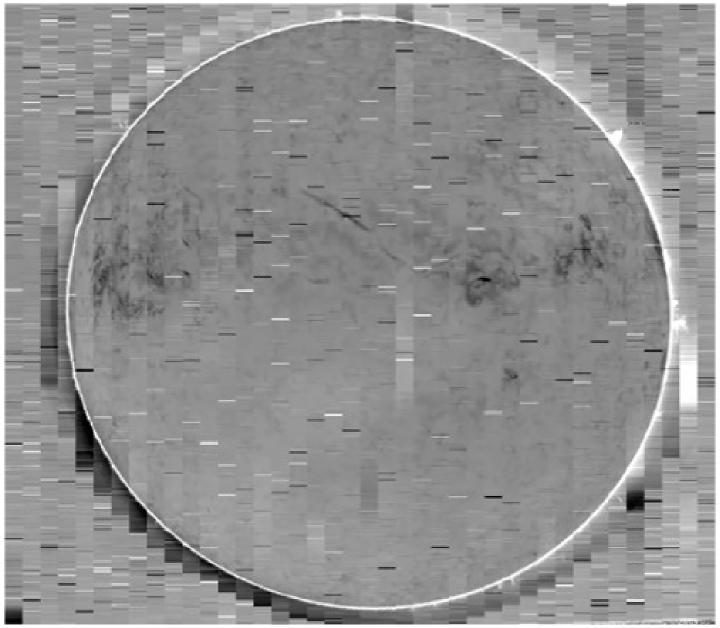
Spectrograph (Feasibility)

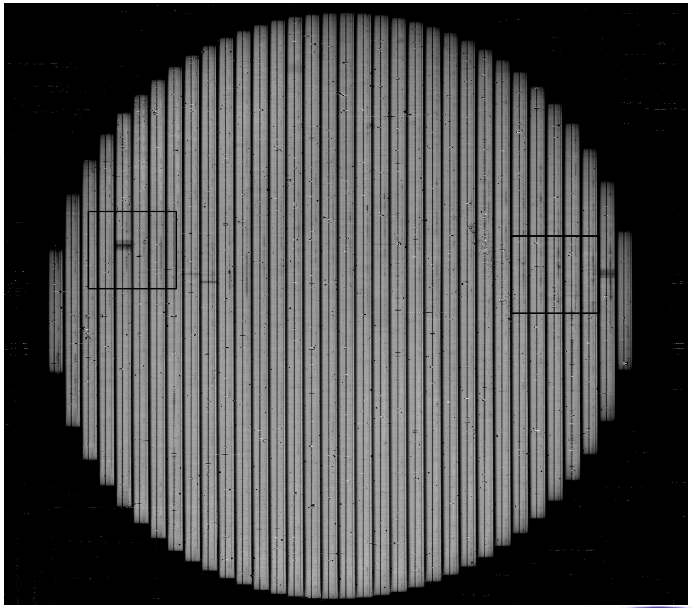
- **Slit spectropolarimeter:** e.g. SOLIS/VSM
  - Cadence is ~20 minute for full disk vector magnetogram with single slit.
  - Multiple-slit design can be implemented for improved cadence

Haosheng Lin from IFA, Hawaii carried out multi-slit demo. Observations with NSO DST for Stokes-I in He 10830, achieving cadence of 1 minute with 35 slits.

Reconstructed Line Core Image



Sample 35-Slit Full Disk Spectral Image



3. Development and operation study

3.1 Trade-off analysis

Combination of instruments and cameras

Camera set-up and development, particularly in large format and high cadence

Select less than 3 instrument concepts to be detailed and cost estimated

3.2 Network operation and data delivery to high-resolution telescopes

Network operation and performance and on-line data access

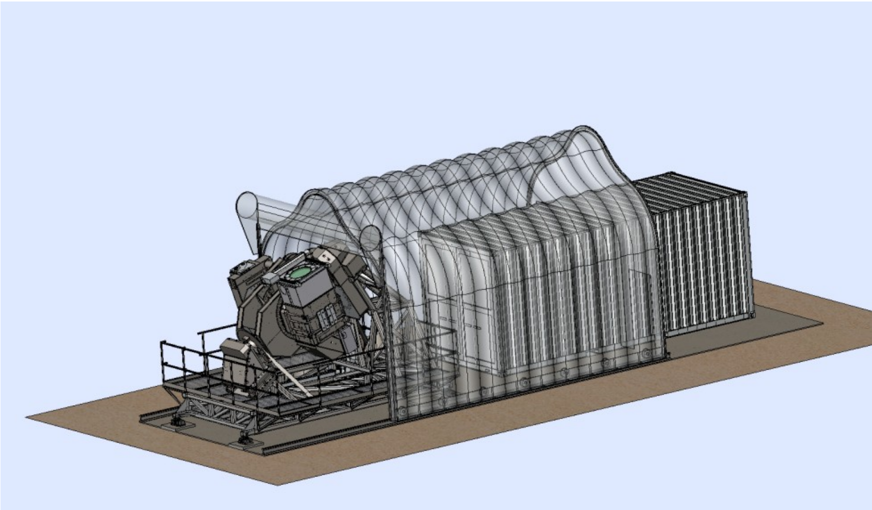
Deepening on the studies on data processing and merging, including automated control, data pipelines processing on clusters of CPUs or possible use of Graphical Processing Units and data delivery
? **being explored**

Final Deliverable

Final proposed instrument concepts and operational plan to be delivered end of March 2017

Will contain a summary of our results with our suggestion on how to set up a new synoptic network

+ Collection of technical studies that lead to our conclusions



Summary:
Invitation to Contribute to Discussion & Work

Discussion of possible plans for a future full-disk telescope and a platform to carry multiple instruments has become a world-wide effort

- **Physics**
  - Big questions ? What are the physical quantities to be measured?
  - Multiple-wavelength observations ? What can be learned from them?

- **Requirements**
  - Spatial resolution
  - Temporal resolution
  - Selection of wavelengths ? How to observe them with one setup?

- **Instrumentation**
  - Several instruments at one telescope vs. several telescopes at one observatory
  - Need for a network
  - Joint ground and space observations