SPRING network for real-time space weather predictions

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Solar Physics Research Integrated Network Group SPRING

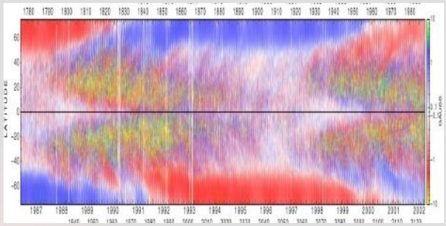
Objective: *Development of instrumentation for large field-of-view (Full disk) observations of the Sun with a network of solar telescopes to address variety of solar physics research problems.*

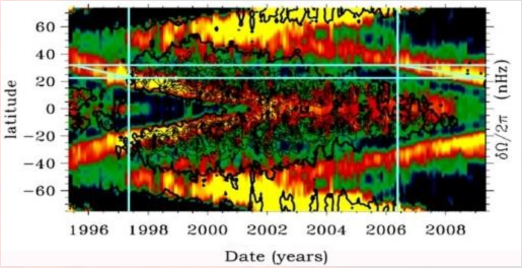
Technical Requirements: SPRING should provide multiwavelength

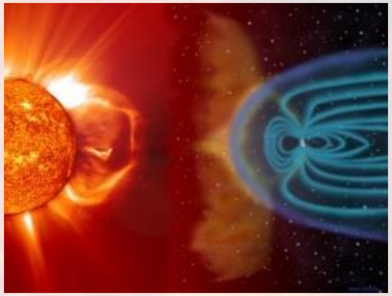
- Full-disk Doppler velocity images : Helioseismology (solar interior), atmospheric seismology
- Full-disk vector magnetic field images : Active Region Evolution, Flux emergence, Helicity injection, Flare research, Coronal field extrapolations, etc.
- Full-disk synoptic/context intensity images: H-alpha, Ca K, G-band, RGB continuum, etc.
- Provide the above data products in a variety of wavelengths, at a high cadence (≤ 60 seconds), at a spatial resolution of 1″ (0.5″ pixels), at least 90% of the time & for at least 25 years
- Complement space missions and large ground based telescopes : DKIST, EST, NLST etc.

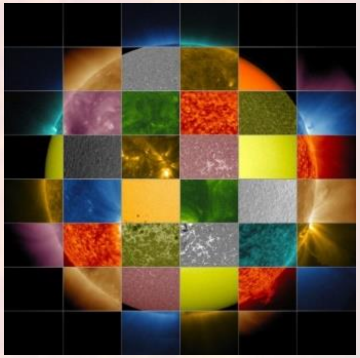
SOLARNET

Science Goals









- Evolution 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

- Evolution of the solar internal 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 high-resolution 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.
- Co-alignment of various ground and space based instruments.

*** Hill, F. *et al. Space Weather, 11, 392, 2013***
*** Elsworth, Y . *et al., Space Sci. Rev., 2015***

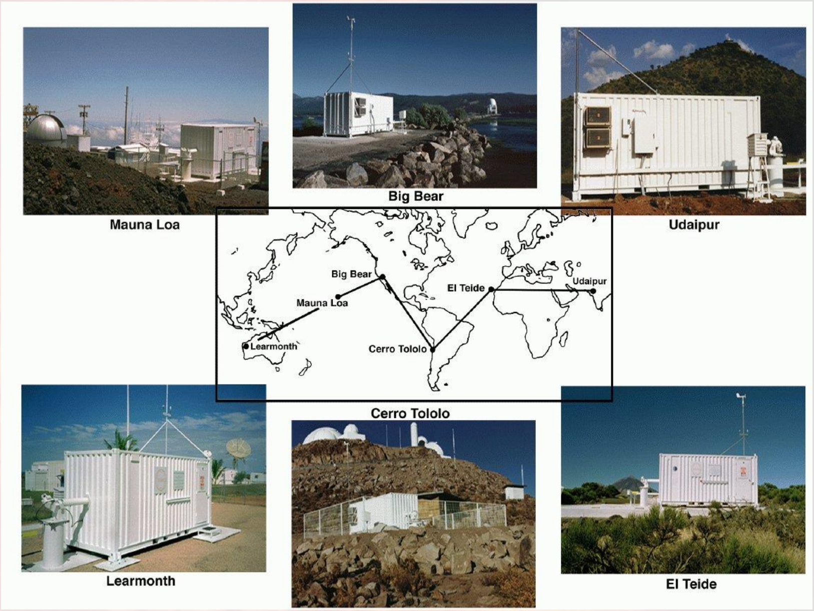
Existing ground based networks geared for space weather

-GONG was primarily designed for Helioseismology where uninterrupted long term time series are required for resolving the modes.

-GONG was upgraded and modified to provide space weather products such as

- continuous fulldisk H-alpha images at resolution of 10 seconds (funded by US Air Force)
- precise longitudinal magnetograms (10 minute averaged) Funded by NOAA space weather prediction center (SWPC).

GONG Network Operated by NSO



Why do we need new ground based networks?

Why new Network?

- GONG is 20 years old and its camera and electronics are aging
- GONG is optimized for global helioseismology not for space weather research.
- GONG lacks Vector Magnetograms which are essential for study of non-potentiality in Active regions.
- Reduced funds for GONG require more international efforts.

New network with broader scope which includes space-weather, synoptic studies, helioseismology and ground support/context imaging for future High-Res telescopes DKIST, EST, NLST etc. and space observations.

Why do we need ground based network for space-weather research when SDO exists?

- SDO provides excellent data for space weather research (Several Near realtime products) →Talk by Falconer et al.
- SDO also addresses helioseismology.
- SDO can also be long term.

What if SDO is hit by extreme space weather event and/or malfunctions?
Ground based network acts as a backup and can be upgraded, calibrated and maintained for long term.

Context Images for Ground and Space based Limited FoV Instruments

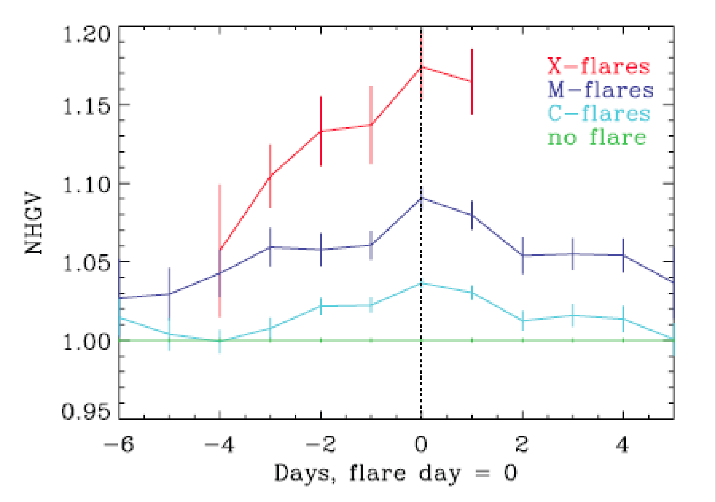
SPRING to provide context images (high resolution multi-wavelength filtergrams) for next generation high-res. telescopes.

Will also help as context for coordinated campaign observations by multiple telescopes.

SPRING for space weather research

Near-RT quantities provided by HMI for Active region Patch

Keyword	Description	Unit[1]	Formula[2]
USFLUX	Total unsigned flux	Mx	$\Phi = \sum \lvert B_z \rvert dA$
MEANGAM	Mean angle of field from radial	Degree	$\overline{\gamma} = \frac{1}{N}\sum \arctan\left(\frac{B_h}{B_z}\right)$
MEANGBT	Horizontal gradient of total field	G Mm^{-1}	$\overline{\lvert\nabla B_{tot}\rvert} = \frac{1}{N}\sum\sqrt{\left(\frac{\partial B}{\partial x}\right)^2 + \left(\frac{\partial B}{\partial y}\right)^2}$
MEANGBZ	Horizontal gradient of vertical field	G Mm^{-1}	$\overline{\lvert\nabla B_z\rvert} = \frac{1}{N}\sum\sqrt{\left(\frac{\partial B_z}{\partial x}\right)^2 + \left(\frac{\partial B_z}{\partial y}\right)^2}$
MEANGBH	Horizontal gradient of horizontal field	G Mm^{-1}	$\overline{\lvert\nabla B_h\rvert} = \frac{1}{N}\sum\sqrt{\left(\frac{\partial B_h}{\partial x}\right)^2 + \left(\frac{\partial B_h}{\partial y}\right)^2}$
MEANJZD	Vertical current density	mA m^{-2}	$\overline{J_z} \propto \frac{1}{N}\sum\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)$
TOTUSJZ	Total unsigned vertical current	A	$J_{z_{total}} = \sum \lvert J_z \rvert dA$
MEANALP	Characteristic twist parameter, α	Mm^{-1}	$\alpha_{total} \propto \frac{\sum J_z \cdot B_z}{\sum B_z^2}$
MEANJZH	Current helicity (B_z contribution)	G^2 m^{-1}	$\overline{H_c} \propto \frac{1}{N}\sum B_z \cdot J_z$
TOTUSJH	Total unsigned current helicity	G^2 m^{-1}	$H_{c_{total}} \propto \sum \lvert B_z \cdot J_z \rvert$
ABSNJZH	Absolute value of the net current helicity	G^2 m^{-1}	$H_{c_{abs}} \propto \lvert \sum B_z \cdot J_z \rvert$
SAVNCPP	Sum of the modulus of the net current per polarity	A	$J_{z_{sum}} \propto \left\lvert \sum^{B_z^+} J_z dA \right\rvert + \left\lvert \sum^{B_z^-} J_z dA \right\rvert$
MEANPOT	Proxy for mean photospheric excess magnetic energy density	erg cm^{-3}	$\overline{\rho} \propto \frac{1}{N}\sum\left(\vec{B}^{Obs} - \vec{B}^{Pot}\right)^2$
TOTPOT	Proxy for total photospheric magnetic free energy density	erg cm^{-1}	$\rho_{tot} \propto \sum\left(\vec{B}^{Obs} - \vec{B}^{Pot}\right)^2 dA$
MEANSHR	Shear angle	Degree	$\overline{\Gamma} = \frac{1}{N}\sum \arccos\left(\frac{\vec{B}^{Obs}\cdot\vec{B}^{Pot}}{\lvert B^{Obs}\rvert \lvert B^{Pot}\rvert}\right)$
SHRGT45	Fractional of Area with Shear > 45°		Area with Shear > 45° / HARP Area



Reinard et al (2010)

Local Helioseismology of Active regions can be used to derive Normalized Helicity Gradient Variance (NGHV) to predict flare probablity.

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.
- Azimuth disambiguation
- long term magnetic field records with improved spatio-temporal resolution.

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 (Finsterle et al 2014, Nagashima et al. 2009).
- Transportation of convective energy through solar atmosphere (Jefferies et al 2006).

….. more details in review article Elsworth et al. Space Sci. Review, 2015

Working Groups

Group 1 Synoptic magnetic fields

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

Pevtsov, Socas-Navarro, Schlichenmaier, Ermolli, Gosain, Sobotka, Borrero, Hasan, Schmidt

Group 2 Solar seismology

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

Jain, Leibacher, Del Moro, Erdelyi, Schou, Roth, Thompson, Hill, Hasan, Finsterle, Keys, Zaatri

Group 3 Transient events

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

Kucera, Gömöry, Jain, Gosain, Keys, ***Sobotka***, Polanec, (Zuccarello), Del Moro

Group 4 Solar Awareness

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

Pevtsov, Toufik, Del Moro, Scuderi, **Ermolli**, Davies, Finsterle, Hill, Thompson, Berrilli

Thanks!