ngGONG -- The Next Generation GONG –
A New Solar Synoptic Observational Network

A White Paper for the Astro2020 Decadal Survey

Type of activity: Ground-based project
Proposing team: AURA/NSO, HAO

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Key Science Goals and Objectives: The Sun (Figure 1) is the only star that currently can be observed with spatial and temporal resolution adequate to investigate key physical processes that must exist on all stars. Many stellar phenomena that are now well known were first observed on the Sun, including star spots, magnetic fields, activity cycles, rotation, flares, coronal mass ejections (CMEs), radio bursts, coronae, chromospheres, and stellar winds. More recently, the technique of helioseismology that allows us to probe the solar interior with acoustic oscillations has been extended to the more distant stars in the field of asteroseismology and has provided an additional 200 parameters per star to constrain stellar structure and evolution (Aerts, Christian-Dalsgaard & Kurtz 2010). Helioseismology observations were also a key component in the resolution of the solar neutrino problem and resolved the last uncertainty about the validity of nuclear generation of stellar energy.

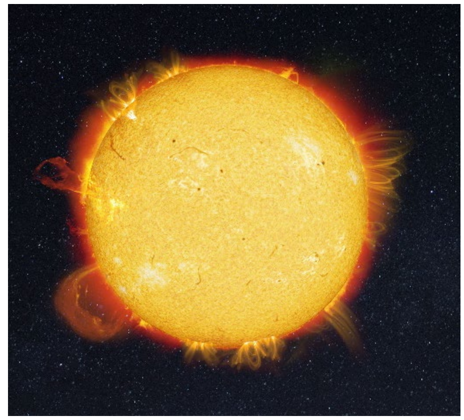

Fig. 1 -The Sun, the closest star and an archetype for all stars.

The Sun also creates a radiation environment that immerses all bodies in the solar system. It is now clear that the impact of a central star on the constantly changing radiation environment of its astrosphere and stellar system, known as space weather in the solar context (Figure 2), must play a significant role in determining the habitability of exoplanets. A prime example is the stripping of the Martian atmosphere by the solar wind and CMEs (Jakosky 2017). The field of space weather has increased in societal importance due to its adverse effects on modern technology.

This white paper describes ngGONG, a next-generation solar observational network based on experience with the NSF GONG (Global Oscillation Network Group) facility operated by the National Solar Observatory (NSO). GONG is a set of six identical solar observing stations distributed geographically around the world in California, Hawaii, Australia, India, Spain, and Chile. (Figure 3) Deployed in 1995, GONG was originally intended to be a source of Doppler velocity data for helioseismology (the study of solar oscillations) but has since also become an important provider of solar magnetic field and H-α intensity observations for space weather forecasts and research (Hill 2018). As mentioned above, space weather has become an increasingly important area of research for society since it can adversely impact technological systems that have become integrated with daily living. Examples of these systems are GPS, HF radio communications, cell phones, satellites, airline routing, astronaut safety, power grids, and military operations. The development of autonomous vehicle technology

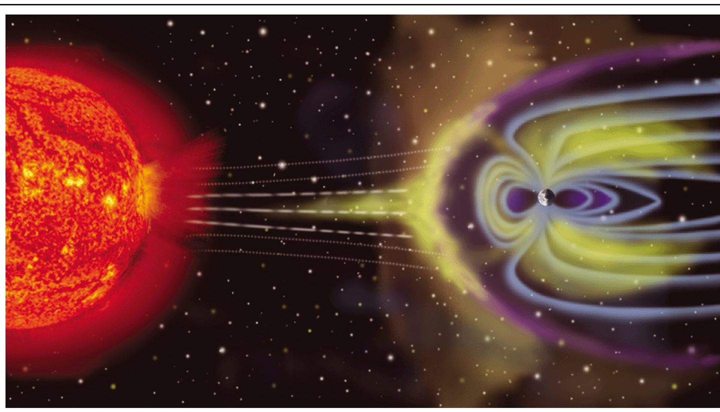

Fig. 2 Space weather is the study of the dynamic radiation and particle environment that is created by the central star and that interacts with the stellar system bodies. The Earth, on the right, is protected by a magnetic field, but exoplanets may not be so lucky.

will also need to take account of space weather events. While GONG is delivering essential space weather data, *it was not originally designed for that role and has some significant disadvantages in its instrumentation.* Given our increased knowledge of the causes (Chen, 2017) and effects (Schrijver, 2015) behind solar storms there is a need for a next-generation solar observing network, or ngGONG, that considers space weather requirements from its inception.

The primary advantage of a network is the continuity of the observations. GONG, with its carefully selected sites, observes the full disk of the Sun with a median daily duty cycle of 0.91, which means that good observations are typically obtained 91% of a 24-hour day. This greatly increases the probability that significant solar events (e.g. flares or coronal mass ejections) will be captured compared to what can be observed from a single ground-based site with a typical 24-hour daily duty cycle of 0.3 to 0.4. This is vital for space weather research that needs continual data to drive forecasts of unforeseen events. Some of the space weather research aspects are discussed in a companion Astro2020 science white paper (Martinez Pillet et al. 2019) The temporal continuity also enables the production of high-quality acoustic spectra of the Sun's oscillations for helioseismic probing of the solar interior. These spectra are important for comparisons in asteroseismology and ultimately may play a role in studies of exoplanet habitability.

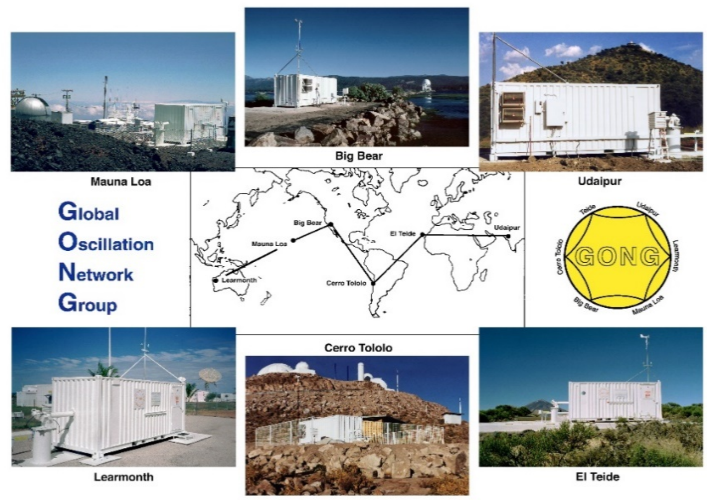

Fig. 3: The GONG network, operating since 1995.

It is important that solar synoptic observations cover a time period of decades so that several 11-year sunspot activity cycles can be observed, and their properties statistically characterized. Currently we are entering only the 25th cycle of systematically observed sunspot numbers since the mid eighteenth century. Observations of sunspot numbers are plagued with systematic errors and are not obviously physically meaningful. There have been only seven cycles since it was realized that the Sun can affect our technology, five cycles since the start of space exploration, and two cycles since the beginning of continual helioseismic observations. These small numbers of sampled cycles make it challenging to derive any useful conclusions about the behavior of the Sun. We now are aware that the strength of the magnetic fields at the solar poles is correlated with the sunspot number amplitude of the next activity cycle (e.g. Pesnell & Schatten 2018) (Fig 4). Helioseismology has shown that the timing of the migration towards the solar equator of a zonal east-west flow known as the torsional oscillation is correlated with the time that the sunspot number rapidly increases (Howe et al. 2018) (Fig 5). These two indicators of the properties of the next activity cycle are useful for long-term planning of the mitigation of space weather events, but data must be available to estimate the future cycle properties. As an example, the Maunder activity minimum of the late seventeenth century was poorly observed due to the lack of systematic sunspot observations.

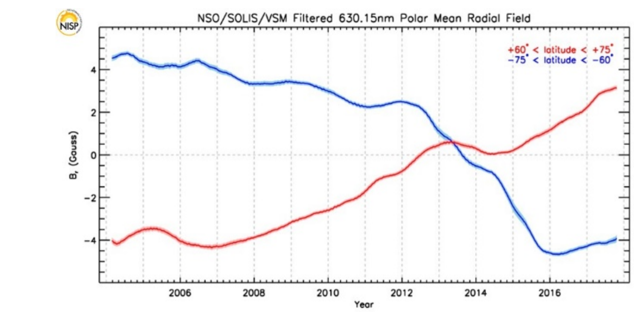

Fig. 4: The Sun's polar magnetic field strength as a function of time in the north (red) and south (blue). The polarity reversal for cycle 25 is the crossing mid-way through 2013.

Full-disk synoptic observations are also needed to extract the maximum scientific return of the large high-resolution solar telescopes such as the DKIST (Daniel K Inouye Solar Telescope) nearing completion in Hawaii. A typical high-resolution field of view of 5 arc-min represents 3.5% of the visible solar disk area. Since adjacent active regions are usually connected via their magnetic fields, it is vital to have spatial context observations in order to fully understand the high-resolution data. In addition, it is known that flares can generate waves that trigger other flares at very long distances and other times, increasing the need for continual temporal coverage of the full disk.

Space-based observations are also used for solar synoptic programs. The most prominent of these missions are the ESA/NASA SOHO (Solar and Heliospheric Observatory), launched in 1995, and NASA's SDO (Solar Dynamics Observatory), launched in 2010. Note that there currently no plans for a successor to SDO, making the development of a new ground-based solar synoptic facility essential in the next decade. While space-based observations are free of the problems caused by the Earth's atmosphere, there are several advantages of a ground-based network versus a space-based platform for continual solar observations:

1. A ground system is estimated to cost 15 to 25% of an equivalent space system.
2. A ground system is much more accessible than a space system, so it can be maintained in the event of failure and can be upgraded with new technology.
3. A ground system has access to a much higher data transmission bandwidth than space telemetry rates.
4. A ground system is much less vulnerable than a space system to the effects of space weather.

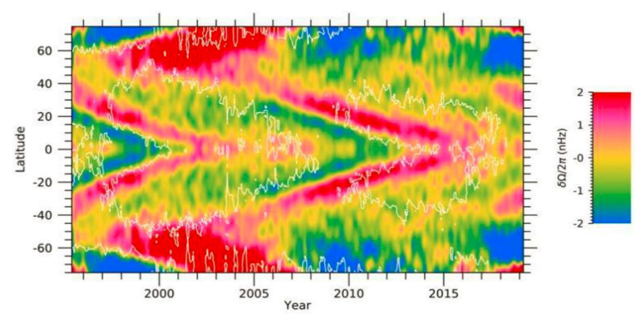

Fig. 5 – The torsional oscillation at a depth of 7 Mm in the Sun appears as a zonal east-west flow with respect to the background solar rotation. It has two branches, poleward and equatorward and the rate of migration of these branches is highly correlated with the timing of the solar activity cycle. Note the extremely weak poleward flow for the upcoming cycle 25.

Virtually all solar observatories that work below radio wavelengths obtain data on three basic physical quantities: the magnetic field on the Sun; the velocity of the solar plasma; and the intensity of the emitted light. Of these, it can be argued that the magnetic field is the most important but all three are needed for full understanding of solar physics. The magnetic field (Fig 6) is the basic driver of solar activity and space weather. It is constantly changing on time scales of milliseconds to decades and controls most events such as flares and CMEs. Magnetic fields in the photosphere can be extrapolated into the corona, and the resulting coronal hole distribution is used to forecast the solar wind speed. This prediction is then combined with space observations of CMEs to provide a forecast of the geomagnetic storms that cause the aurorae and induce ground currents that can cause large-scale power failures such as the Quebec blackout of 1989. The physics of the generation and cyclic behavior of the solar magnetic field remains one of the most significant scientific questions about the Sun (Cameron, 2015).

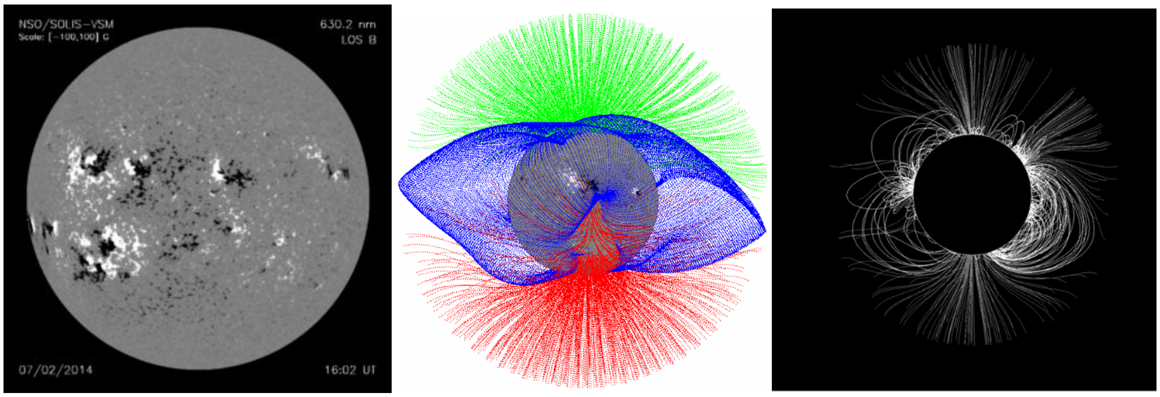

Fig. 6: Three representations of the solar magnetic field. Left: a magnetogram, an image of the line-of-sight solar photospheric magnetic field obtained by polarimetry in the Fe I 630.1 nm line. Strong fields are shown as black and white, weak fields are grey. Center: the magnetic field in the solar corona extrapolated as a potential field from the photospheric observations. Green and red lines are open to the galaxy; blue lines are closed on the solar surface. Right: Extrapolated fields for the eclipse of Aug 2017.

The motions of the solar plasma generate the Sun's magnetic field via a dynamo mechanism. The velocity is typically estimated either from the Doppler shift of solar spectral lines or from tracers such as sunspots. There are several large-scale global flows visible on the surface (Fig 7), such as differential rotation, meridional flow, and torsional oscillation. These flows govern cycle characteristics, and variations in them are correlated with solar cycle amplitude and timing. Smaller-scale flows, primarily convection in the form of granulation and supergranulation, influence active region dynamics by transporting magnetic field.

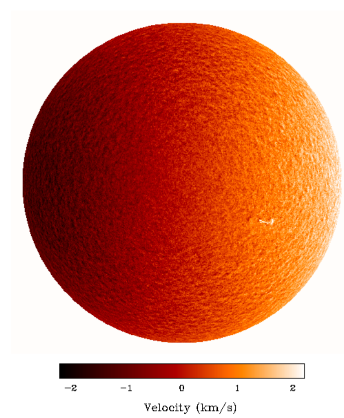

Fig. 7: A Doppler velocity image showing differential rotation and supergranulation.

The total intensity of the emitted light over various wavelength bands is analyzed for many purposes. The intensity at a specific wavelength provides an estimate of the temperature of the solar atmosphere integrated over a range of heights. Magnetic field lines can be traced as bright features in the corona and chromosphere. Two very useful wavelength bands are H-α (656.4 nm) and He I 1083.0 nm. The H-α images (Fig 8) clearly show flare kernels and filaments; both are major factors in the generation of space weather with erupting filaments being a source of CMEs. The He I images (Fig 9) are proxies for coronal x-rays, and show the coronal holes that affect the solar wind.

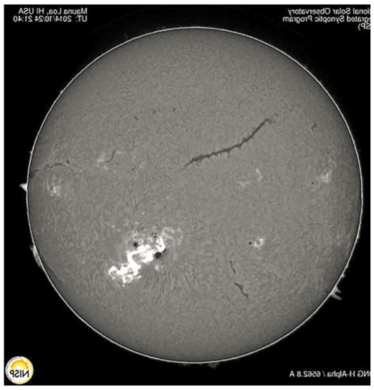

Fig. 8 – An intensity image in H-α showing a bright flaring region and a large filament.

Since the myriad of absorption lines detected in the solar spectrum are formed over different height ranges, multi-wavelength observations can be combined to infer the magnetic field, velocity, and temperature of the solar atmosphere as a function of height. This allows the development of a comprehensive physical model of the solar atmospheric conditions under various scenarios. This improves the extrapolation of the magnetic field into the corona where it is currently impossible to directly measure the field strength. In addition multi-wavelength observations are needed to make progress on the development of helioseismic probing below sunspots, as discussed below.

The original purpose of GONG was to obtain data for helioseismology, which requires long (months to years) time series of Doppler velocity data as continuously as possible to measure the frequencies of the acoustic oscillations that are trapped in the internal solar temperature gradient. This data is the only method we have of probing the solar interior, and ngGONG would continue these measurements. Global helioseismology decomposes the large-scale velocity field over the entire Sun into spherical harmonics to infer, among other things, the depth profile of differential rotation (Fig 10). The frequencies of the global modes evolve over the course of the solar cycle and comparison of these changes seen in different modes provides information about the depth and latitude of the cycle-related variations in the solar interior.

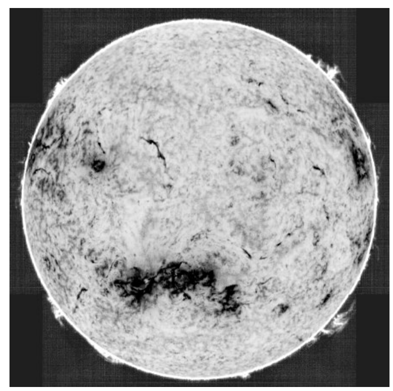

Fig. 9 – An intensity image in He I 1083.0 nm. This negative image is a proxy for coronal x-rays, polar coronal holes are visible as large light areas at the top and bottom.

Local helioseismology analyzes the velocity field within selected areas. The localized analysis has the potential to infer the structure and dynamics of the plasma below sunspots, but there is a problem due to the transformation of the acoustic waves into various MHD modes when an inclined magnetic field is encountered. This greatly changes the phases of the waves and produces inaccurate results if the waves are assumed to be purely acoustic in nature. One solution to the issue is to observe both the wave field and the background magnetic field as a function of height using multi-wavelength data and then compute the phase shifts. These observations would be carried out by ngGONG.

The solar oscillations can also be used to create images of the magnetic activity on the invisible far side of the Sun that is oriented away from Earth (Fig 11) (Lindsey & Braun 2017). This is useful for an early indication of the existence of large active regions that could appear on the Earth-facing side as much as two weeks after detection. This information is valuable for space weather forecasts, and these maps would be generated by ngGONG.

The solar corona is the hot tenuous outer atmosphere of the Sun that can be considered to extend throughout the solar system. CMEs are easily detected in time series of coronal images and can cause strong geomagnetic storms in particular if the CME contains a southward pointing magnetic field with respect to the Earth (Kilupa 2019). We currently have no synoptic observations that help us model data-driven propagation in the Heliosphere of magnetized CMEs. ngGONG will provide such data.

Observations of CMEs are thus critical for space weather forecasting specifically the so-called Halo CMEs seen as annular brightness increases over the circumference of the Sun indicating an Earth-directed event. Currently, Halo-CMEs are only observed from space and its detection from the ground would lead to a much more reliable characterization of these processes. Observing the corona from the ground is challenging but possible (Fig 12) since it requires extremely dark daytime skies with very low scattering.

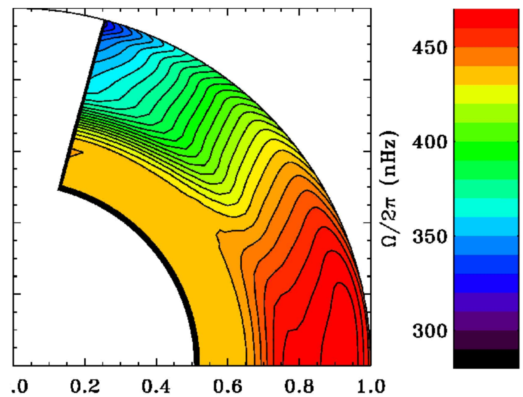

Fig. 10 – Helioseismic estimate of the Sun's internal rotation. Note that differential rotation persists from the surface to the bottom of the convection zone, where it is replaced by solid- body rotation.

In summary, ngGONG would obtain the following data:

- Full-disk vector magnetic field measurements at a resolution of 2048 X 2048 pixels every 30 minutes in at least two spectral lines with 20 spectral samples across each line.
- Full-disk Doppler velocity measurements at a resolution of 2048 X 2048 pixels every 60 seconds in at least three spectral lines with 10 spectral samples across each line.
- Full-disk intensity measurements at a resolution of 2048 X 2048 pixels every 10 seconds in H-α at three spectral points and every 5 minutes in He I 1083.0 nm.
- White-light coronal images (polarized brightness) at a resolution of 2048 X 2048 pixels every 10 minutes extending to 4-6 solar radii.

These data would be processed to produce helioseismology products, far-side maps, vector magnetograms, and intensity time series. The inclusion of coronal imaging may also be part of ngGONG, but the impact on site selection and cost must be carefully evaluated.

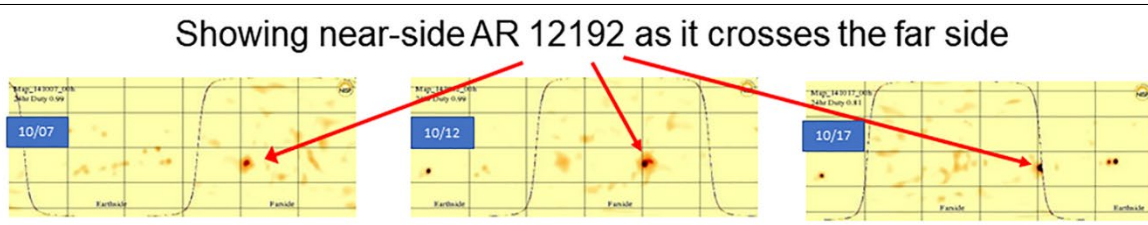

Fig. 11 – Maps of strong magnetic fields on the solar far-side estimated from phase shifts of acoustic modes

Technical Overview: The selection of the sites for ngGONG is a crucial decision that must be made early in the program. There is now a considerable body of experience derived not only from GONG, but also from the USAF SOON (Solar Optical Observing Network), and BiSON, the Birmingham Solar Oscillation Network operated by the University of Birmingham, UK. These programs indicate that a minimum of three sites is needed to obtain reasonably continuous data with a duty cycle of 75%, but that six sites are much better providing a duty cycle of 90 to 95%. In any event, the sites must be properly distributed in longitude to reduce periodic data gaps as much as possible. Periodic gaps produce many spurious features in the solar acoustic spectrum. If ngGONG includes a coronagraph, the number of candidate sites is greatly reduced due to the stringent requirement for dark daytime skies with a brightness less than 10^{-9} of the solar disk. However, not all sites need to have the same set of instruments so, with a six-site system perhaps three would have a coronagraph. As a starting point, it is assumed that the current

GONG sites will continue as components of nsGONG with the possibility of the Indian site currently in Udaipur moving to the high Himalayas near Ladakh where the skies are very clear.

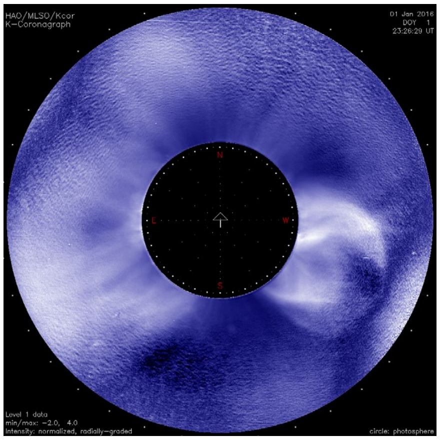

Fig. 12 - Calibrated white light image of a CME in the corona on Jan 1, 2016.

Each site would have multiple instruments with a light feed mounted on a pier to reduce the effects of ground-layer seeing (Fig. 13). The height of the pier could be reduced with the addition of a ground-layer adaptive optics (GLAO) system. A trade-off study between the pier height and the GLAO system would be carried out during the development phase. The light would be routed down to the support building at the base, which would house the instrumentation in a stable thermal environment with a constant gravity vector, the data processing hardware, and other equipment. The light feed would be a 50-cm telescope with a design based on that of the European Solar Telescope with the advantages that it is polarization-free and compensates for image rotation.

The instrumentation for ngGONG would consist of a magnetograph, a Dopplergraph, two or more intensity filtergraphs, and a coronagraph system. For the magnetograph, there are basically two options for the spectral analyzer – a spectrograph, or a filter-based system such as a Fabry-Perot or a Lyot filter. It is now evident that the spatial flatness of the background magnetic field in the data (the so-called magnetic zero point) strongly influences the quality of the solar wind forecasts for space weather. The magnetic field data from GONG suffer from a substantial and variable instrumental background, since GONG was designed for Doppler velocity measurements, not magnetic fields. The measurement of the background instrumental magnetic field can be simply accomplished by producing a magnetogram in the continuum, which can then be subtracted from a magnetogram created using a spectral line. This is more easily accomplished with a spectrograph than with a filter-based system. In addition, in order to improve the extrapolation of the magnetic field into the corona and to provide boundary conditions for models of the magnetic field in CMEs, the measurements should produce vector data that provides the direction as well as the strength of the field. Thus, ngGONG would include a vector spectromagnetograph (VSM) like that in the SOLIS instrument operated by NSO (Fig 14).

Fig. 13 – A concept of an ngGONG site. The telescope would be mounted on a pier to reduce ground-layer seeing; the cost of the pier will be traded-off with a ground-layer adaptive optics (GLAO) system.

The Dopplergraph, an instrument to measure the velocity of the solar plasma, needs to have a multi-wavelength capability that observes the spectral line profile as discussed above. As with the magnetograph, the basic instrumental design choice is between a spectrograph and a filter-based system. The spectrograph can observe several wavelengths simultaneously but must be scanned spatially across the image, which takes time. A filter system observes all spatial points simultaneously but must be scanned in wavelength. Since wavelength scanning with a filter system is much faster than spatial scanning with a spectrograph, and the cadence needed for helioseismology must be less than 60 seconds, a filter-based system, such as a Fabry-Perot, would be used for the ngGONG Doppler velocity instrument.

The filter systems to produce intensity images would be relatively simple. The H-α system should be tunable in wavelength to the line wings so that the velocity of erupting filaments that are frequently associated with CMEs could be measured. The He I 1083.0 nm system and any other wavelengths could be designed in several ways, such as Fabry-Perot or Lyot.

The inclusion of a coronagraph in ngGONG would increase the complexity of the facility since coronagraphs require specialized dedicated light feeds. In addition, two types of coronagraphs are required if the field of view is to cover the height range of 1.05 to 6 solar radii in the images, as is needed to detect halo CMEs that are traveling along the Sun-Earth line. This then needs an internally-occulted device that will cover 1.05 to 3 solar radii, and an externally-occulted instrument to view from 2.5 to 6 solar radii.

Fig. 14 – The vector spectromagnetogrpah (VSM) for the NSO SOLIS instrument set. A similar device would be a component of ngGONG.

An important consideration is the choice of spectral lines for the measurements. For the magnetograph, two spectral lines in the IR provide photospheric and chromospheric coverage, the Fe I line at 1564.8 nm and the He I line at 1083.0 nm. For the Doppler velocity instrument, the spectral lines could be one or both of the two heritage lines currently in use by GONG and HMI, namely Ni I 676.8 and Fe I 617.3 nm. A non-magnetically sensitive line with Lande g=0 is also needed, the Fe I 709.0 or the Fe I 553.4 nm lines have been used for this purpose. Ten spectral points across each line would be adequate for the helioseismology applications. The intensity filtergraphs will operate at H-α and He I 1083.0 nm. Coronagraphs operate in polarized white light.

It is desirable to automate ngGONG as much as possible, but this is an area that requires substantial research and development. During the development of GONG, a much simpler system than ngGONG, it was determined that it would be far easier and less costly to forego automation triggered by environmental sensors and instead to strengthen the equipment to withstand moisture and thermal stresses. The only automation in the present system is the daily sequence of image acquisition, calibration sequence, tracking, and system shutdown at the end of the day. One required task that is difficult to automate is the cleaning of the entrance window on the light feed, which needs to avoid damaging the optics as well as thoroughly cleaning it without leaving residue. A study of the application of machine learning to the challenge of automating ngGONG would be carried out during the development phase.

The data rate of a single ngGONG site will be substantial. The drivers are the spatial resolution of the detectors, the cadence of the observations, the number of spectral lines, and the number of samples cross the spectral lines. For the parameter values listed above, the data rate per site for a 12-hour perfectly clear day of 16-bit magnetograms would be 31 GB/day, 173 GB/day for the velocity images, and 105 GB/day for the intensity data giving a total of 309 GB/day per site. At the current approximate global average internet speed of 8 Mbits per second, it would take nearly 3.5 days to return one day of data causing a permanently growing backlog of data. To deal with this, ngGONG will have a substantial data processing and storage system at each site. The system will compute the relevant space weather data products that comprise a much smaller data volume and return those quantities in near real time to forecasters. The raw data accumulates at the rate of 10 TB per month in this example and will be stored at the site for at least six months. After that, it will either be discarded or transported via physical disks to the ngGONG data center. Machine learning could be developed here as well to select which data to discard at what time.

Organization, Partnerships, and Current Status: In addition to its research role as an NSF facility, ngGONG would provide data to the agencies that have space weather operational forecast centers. These agencies are the Space Weather Forecast Center (SWPC) administered by the National Oceanic and Atmospheric Administration (NOAA); the 557th Weather wing of the US Air Force (USAF), and the Community Coordinated Modeling Center (CCMC) at NASA/Goddard. It is thus important that these agencies are substantially and financially involved in the planning, designing, construction, and operation of ngGONG if it is to succeed as both a research and operational data source. This means that the scientific and technical requirements must satisfy the needs of all participating agencies. Perhaps even more challenging is developing a set of operational policies and procedures that satisfies all agencies. This is particularly important for the USAF, which has specific requirements for security. It is probable that an oversight board will be required to ensure timely resolution of challenges. The negotiation of a management and funding plan for ngGONG that involves Federal agencies with specific requirements is arguably the biggest obstacle to its progress. There is also considerable interest by the international community to participate in the construction and operations of the network, from the existing GONG partners to countries such as Japan that also has experience in solar synoptic observations.

The nominal operation of ngGONG could be done much as the current GONG is operated. In this scenario, a single organization, such as the NSO, would be responsible for the monitoring and maintenance of technical systems as well as the data processing at both the sites and a central data storage and distribution system. Experience with GONG, which is a simple system compared to ngGONG, has taught us that it is essential for network sites to be located at places where there is expert staff that is familiar with operating astronomical instrumentation and who can help with trouble shooting.

Currently, ngGONG is unfunded. A development proposal was prepared by the NSO and HAO for the recent (Feb, 2019) NSF MRI opportunity, but the project was not invited to submit a step 2 proposal mainly due to the lack of inclusion of ngGONG in the last Decadal Survey. This was not possible, since ngGONG was only conceived around 2017, about five years after the last survey. This points out a deficiency in the survey process – ten years between surveys is too long for the pace of scientific innovation.

Schedule: ngGONG would take three years to develop a detailed design to get to FDR, and then an additional three years to construct and deploy. It is anticipated that ngGONG would operate for at least 25 years to cover a full 22-year Hale cycle including the polarity reversal of the global solar magnetic field.

Cost Estimates: Preliminary cost and schedule estimates were carried out by NSO and HAO for a development proposal submitted to the NSF Mid-Scale Research Infrastructure (MRI) program Step 1 call in February 2019. The estimated development cost for nsGONG, including the two coronagraphs, from that proposal was $13.8M baselined to FY2020. A separate study in October 2018 carried out by NSO and HAO for the Air Force Research Laboratory of the costs to construct nsGONG produced a per-site estimate of $14.2M to $18.2M. For six sites, the total construction cost is estimated to be $85.2M to $109.2M, making ngGONG a large ground-based project. Annual operation costs are estimated to be $1M per site. Ideally, funding for all phases of the project would come from an inter-agency partnership involving the NSF, NOAA, USAF, and NASA.

Summary: ngGONG is

- A multi-agency multi-site multi-wavelength solar observing facility
- A path for scientific progress in solar & stellar physics and exoplanet habitability
- A program important for the NSF, NOAA, NASA, and the USAF space weather efforts
- A source of data for solar research and space weather operations
- A geographically distributed network of 3 to 6 solar synoptic observing systems
- A replacement for GONG (Global Oscillation Network Group)
- A consistent source of multi-wavelength measurements of solar magnetic field, Doppler velocity, and intensity
- A continual source of helioseismology data and observations of the sunspot cycle
- A source of context observations for high-resolution solar telescopes
- A challenge to machine learning for observatory automation and data culling
- A distributed computing system
- A coronal observing system possibly limited to a subset of the sites

ngGONG is a program that bridges the two realms of research and operations. Both realms require substantial amounts of input data for progress to be made understanding the physics of the Sun, stars and exoplanet habitability (Garrafo, 2017); and to develop predictive capabilities for the space weather that can wreak havoc in our lives. There are four Federal agencies that need the data: NSF, NOAA, NASA, and the USAF, all with different but overlapping needs and requirements for the data. For long-term stability of this vital data source, it would be best if all four agencies participated in financially supporting the development and operation of ngGONG. This need (opportunity?) for high-level Federal agency cooperation, along with ideas of how to achieve it, could provide Astro2020 with a novel focus topic that is relevant to other projects. In addition, ngGONG contains some cyber challenges that could exploit machine learning, and its contributions to space weather are also relevant for exoplanet habitability studies.

We encourage Astro2020 to endorse the importance of understanding our Sun as the local stellar archetype. Specifically, we encourage Astro2020 to specifically endorse the need for a next-generation global solar monitoring system like ngGONG. Such a system will provide significantly improved understanding of the effects of a star and its space weather on a habitable planet (Earth) and an inhabited planetary system (our own). In the long run, such information will help us understand the probability and possibility of life on planets around other stars.

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