The Magdalena Ridge Observatory Interferometer: Geostationary Target Imaging Capabilities.

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ABSTRACT

The Magdalena Ridge interferometer (MROI) is an optical interferometer that is currently (summer, 2010) in the construction phase. Almost all of the design work has been completed and the majority of the subsystems are being assembled. When completed, the array will consist of 10 fully transportable 1.4m telescopes to support multiple configurations with baselines from 7.5m to 350m to give sub-milliarc second angular resolution. We assess the potential imaging capability of the Interferometer with regard to geosynchronous targets. We conclude that a significant proportion of the GEO targets may be accessible and that it may be possible to routinely extract key diagnostics with 7x7 pixel image and could distinguish 70cm features on a 5-meter satellite, or 30cm features on a 2-meter satellite.

MAGDALENA RIDGE OBSERVATORY INTERFEROMETER (MROI)

The MROI project is an international consortium between New Mexico Institute of Mining and Technology (NMT) and the Astrophysics Group of the Cavendish Laboratory at the University of Cambridge in the UK. The MROI offices are located on the campus of New Mexico Tech in Socorro, NM and the observatory site is located on the Magdalena Mountains, about 48 km (30 miles) west of Socorro, at an elevation of 3230 meters (10600 ft) above sea level.

MROI is a world-beating, high-sensitivity optical/near-infrared interferometer which will comprise an array of up to ten 1.4-meters unit telescopes (UT) arranged in an equilateral “Y” configuration. Each of these UTs will send a collimated beam of starlight to a laboratory facility located close to the center of the array, the Beam Combining Facility (BCF). The UTs will be re-locatable amongst a discrete set of 28 foundation pads, giving baseline lengths from 7.5 meters to 350 meters. The interferometer will deliver hundred (100) times the angular resolution of the Hubble Space Telescope and ten (10) times that of the Thirty Meter Telescope (TMT).

With regard to the sensitivity, MROI has fifty to a hundred (50 - 100) times greater sensitivity than the current best optical and infra red interferometers such as the Keck, CHARA and VLTI. In addition, MROI will be more efficient than the existing interferometers with an ability to create twenty to a hundred (20 - 100) times more images per night. Another distinguishing feature is that the images that MROI produce are model independent.

It is also worth noting that in addition to providing a tool for professional astronomers, a core mission of the MROI is to provide a tool for the defense community to support space situational awareness.

IMPLICATIONS OF KEY DESIGN FEATURES FOR GEO IMAGING

The MROI comprises up to 10 fully transportable 1.4m telescopes which enable multiple array configurations which means that the optimal resolution for the target of interest can be selected. The minimum baseline is 7.5m and the maximum is just short of 350m which enable sub-milliarcsecond angular resolution. MROI operates in the visible and IR, from 600nm to 2400nm (RIJHK bands) which provides a number of useful additional features. For example, the array resolution can be adjusted by factor of four - without relocating any of the telescopes - by simply changing the observing wavelength, or alternatively, structures that have very different albedos in the optical and near infrared can be detected very straightforwardly through differential color imaging. These extra diagnostic capabilities will be valuable both from a scientific and operational perspective.

The implementation of separate fringe tracking and science beam combiners results in improved sensitivity and automated end-to-end alignment ensures a high-level of efficiency in the imaging operation. The light beam itself travels from each telescope through single-stroke delay lines to beam combiners in vacuum which ensures minimum coherence loss.

The fact that the MROI delivers 100x the angular resolution of the Hubble Space Telescope and 10x that of TMT means that it will offer an unprecedented capability for model-independent imaging of targets in geostationary orbits. For example, even a perfectly adaptively corrected 30m-class telescope will only provide 1m resolution for geosynchronous targets - the MROI can in principle reach 10cm resolution at the same 1 micron wavelength. The increased sensitivity of the MROI, as compared to existing first- and second-generation interferometers, is also a key feature. The MROI will be able to image satellites as faint as magnitude 14 in the near-infrared H band: as a comparison, no existing interferometer can image targets fainter than H = 10.

The larger number of telescopes in the array, up to 10, will enable quicker imaging than any existing interferometer, enabling up to 100 times the number of images per night achieved by interferometers. Furthermore, those images are reliable model independent images of faint and complex targets whereas to date, imaging on interferometers has been confined to bright targets or confined to fitting *a priori* models.

The field of view of the telescopes of the MROI array is an approximately 120 degree cone. This means that the MROI will be able to image targets in the GEO belt from approx. the 64 degree West slot to the 150 degree West slot. There are currently 102 known satellites in the GEO belt between these longitudes.

All of these key design characteristics result in the MROI being a potentially powerful tool for imaging both military and commercial geosynchronous satellites.

ABILITY OF THE MROI TO “SEE” GEO TARGETS

Based on data from Payne (1998) and Payne et al (2006) we estimate that 50% of GEO satellites are brighter than K=12.5 magnitude. Some examples of photometry of GEO satellites are provided in Figure 1 below. These J-band measurements reveal two classes of targets. The first of these show a characteristic brightening and then fading of apparent magnitude with increasing longitude, with excursions of as much as 2.5 mag (equivalent to a factor of 10). A second class show much less variation in brightness, presumably due to a smaller contribution to the total brightness from large highly reflective solar panel-type structures that are altering their orientation with respect to the sun as a function of time. Importantly, in this survey of Sanchez, even the faintest targets had mean J-band magnitudes of approximately 11. The larger datasets of Payne and colleagues (1998, 2006) suggest that perhaps 50% of all GEO satellites will be visible with the MROI in the K-band, assuming the typical red colors seen by Sanchez which imply a median K magnitude of 12.5.

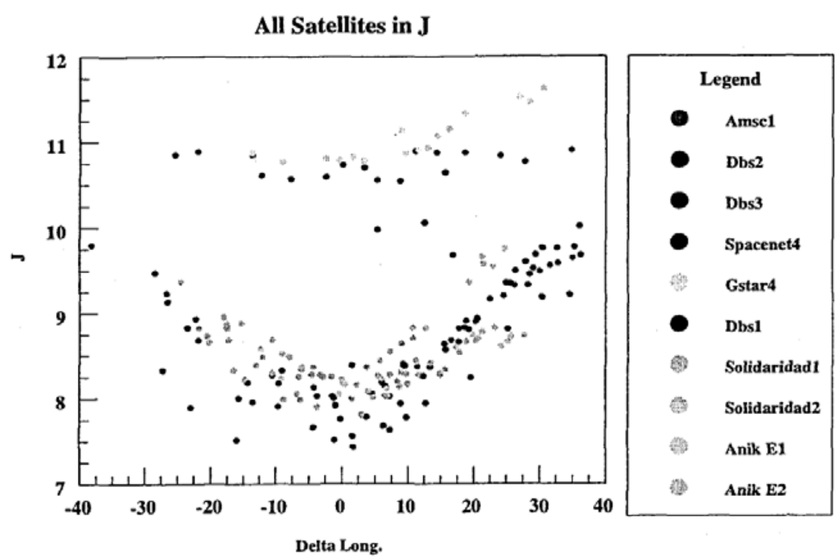


Fig.1. Measurements of infrared magnitudes of a number of GEO satellites from Sanchez et al (2000). In the H-band (1.6 micron wavelength) the objects were measured to be approximately 0.3-0.8 magnitudes brighter. The MROI with, an H-band limiting magnitude of 14, should be able to track fringes on all these targets, providing they have significant amounts of compact (<5m) structure.

While the MROI will certainly be able to detect targets with a K magnitude of 12.5, the more important question is whether it will be able to “image” such targets. The ability of a ground-based interferometer to image a target depends crucially on how resolved the target is on the baselines being measured, and the design of the MROI has specifically allowed for faint source imaging. Notably:

1. It has a fringe tracker, which monitors the atmospheric disturbances on the shortest nearest neighbor baselines, that has been designed to operate at a flux level corresponding to K=13, i.e. 0.5 magnitudes fainter than the median flux levels expected.
2. It is likely that a reasonable fraction of targets will be compact enough to give high contrast fringes on the short fringe tracker baselines. At GEO, the term “compact” would imply that >50% of the light comes from a region less than 5 meters across.

More extended sources could also be imaged successfully if they were correspondingly brighter, but some of the structure on scales above ~10 meters might be “washed out” due to over-resolution by the longest interferometer baselines. In addition, even fainter targets might be accessible if they observable in the H-band (where the fringe tracker sensitivity is somewhat better), provided they were more compact.

In summary, we expect that overall a significant proportion of the GEO population is likely to be accessible. These targets would be observable even when they are not “glinting” - allowing the whole target to be inspected without being blinded by the “glare” of a glint. Furthermore multi-color data would allow characterization of the targets.

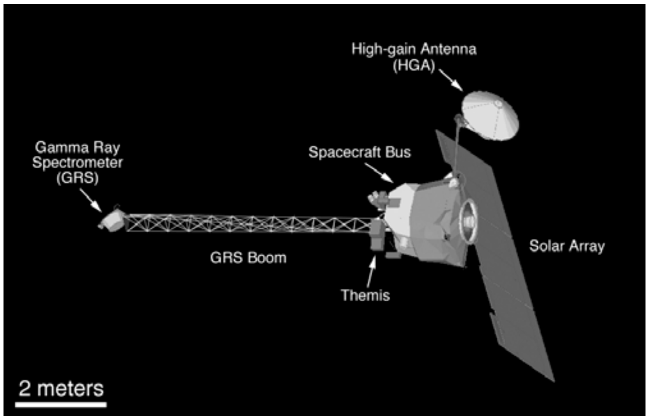
One key feature of the MROI that underpins these unique capabilities is the use of a large number of array elements - up to 10 - simultaneously. Not only does this allow for robust monitoring and correction of the atmospheric perturbations (this leads to diffraction limited resolution), but it compensates for the inability to use Earth Rotation Synthesis to fill in the Fourier (uv) plane when targeting GEO objects. The need to secure quasi-complete Fourier plane coverage in a “snapshot”
is key when attempting to create images of time varying GEO targets, and the MROI with its 10 telescopes is unique in being able to collect such a high density of Fourier visibility and closure phase measurements in such a rapid manner.

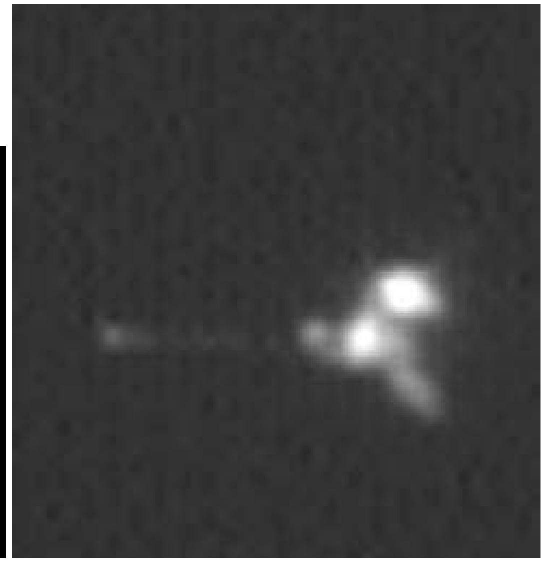
WHAT KIND OF IMAGING WILL BE POSSIBLE WITH THE MROI?

With the full 10-telescope complement of the MROI it will be possible to make 7x7 pixel images routinely. Depending on the precise array layout being used, these could distinguish for example 70cm features on a 5-meter satellite, or 30cm features on a 2-meter satellite. The first phase of deployment of the MROI with 6 telescopes would have a similar angular resolution but would be less able to separate out complex image structure.

In both cases, simultaneous imaging in multiple spectral channels to give a “hyperspectral” image cube would be available. This would typically provide between 5-70 channels across either the 1.2-1.3 micron, 1.5-1.8 micron, or 1.9-2.4 micron wavebands.

For a subset of targets it may be possible to extract key diagnostics on features as small as 10cm, depending on the image structure and brightness. However, before this can be confirmed further studies including realistic simulations of satellite appearances at multiple infrared wavelengths will need to be underataken. We expect to initiate such studies in the near term so as to permit more detailed predictions of the likely diagnostic capabilities (contrast ratios etc) to be made.





Figs 2 & 3. An idea of the type of imaging which may be possible with MROI. Figure 2 shows an artist's rendition of the 2001 Mars Odyssey orbiter and Figure 3. Shows an actual image of the orbiter as taken by the Mars Global Surveyor from a range of 90 km. The resolution of the lower image is comparable to that which could be obtained from MROI at GEO range (36,000km). The orbiter's size would qualify it as a "compact" object at GEO. Images courtesy NASA.

CONCLUSIONS

We have outlined the capabilities of the MROI and have concluded that it offers an unprecedented new capability in GEO imaging. The MROI capitalizes both on significantly enhanced sensitivity as compared to existing ground based interferometer arrays and also on significantly higher (10x) resolution as compared to an AO corrected 30m telescope. The Magdalena Ridge Observatory interferometer leverages on the designs of earlier arrays but combines their design knowledge with state of the art sensitivity and a step change in the number of array telescopes which are combined together (from 2 or 3 to 10). It is this unique large number of telescopes, coupled with its high sensitivity, that allows snapshot imaging of GEO target.

REFERENCES

Payne 1998. "Target selection database" Schafer Corporation

Payne et al 2006. "Electro-Optical Signatures Comparisons of Geosynchronous Satellites" Aerospace Conference, 2006 IEEE

Sanchez et al 2000. "Photometric measurements of deep-space satellites", SPIE 4091, 164.

ACKNOWLEGEMENTS

Magdalena Ridge Observatory (MRO) is funded by Congressional appropriation which is administered by the Naval Research Laboratory (Agreement No. N00173-01-2-C902). The MRO Interferometer is hosted by New Mexico Institute of Mining and Technology (NMT) at Socorro, NM, USA, in collaboration with the University of Cambridge (UK).