













the detector readout noise. The Software Bisque Taurus mount provides a slew/settle time between exposures of 3.0 seconds. The total dwell time for an image is thus 9.6 seconds.

The survey technique for this sensor is then to obtain an image, move in an optimum direction to the next image center and acquire another image, *et seq.*

The CONUS GEO belt mosaic requires 1020 images, and 9792 seconds (2.72 hours) to complete with one sensor. With focus and overlap overheads, this sensor can complete an imaging survey of the CONUS GEO belt in three hours. Thus, a single JTMA sensor, as currently configured can accomplish two full GEO belt surveys per clear night. This corresponds to a survey rate for a single-detector sensor, including observing overheads (e.g. focus) greater than 1000 square degrees per hour.

A simulation of a 40-image subset of a GEO Belt survey obtained from the JTMA test facility in New Mexico is shown in Fig. 4.

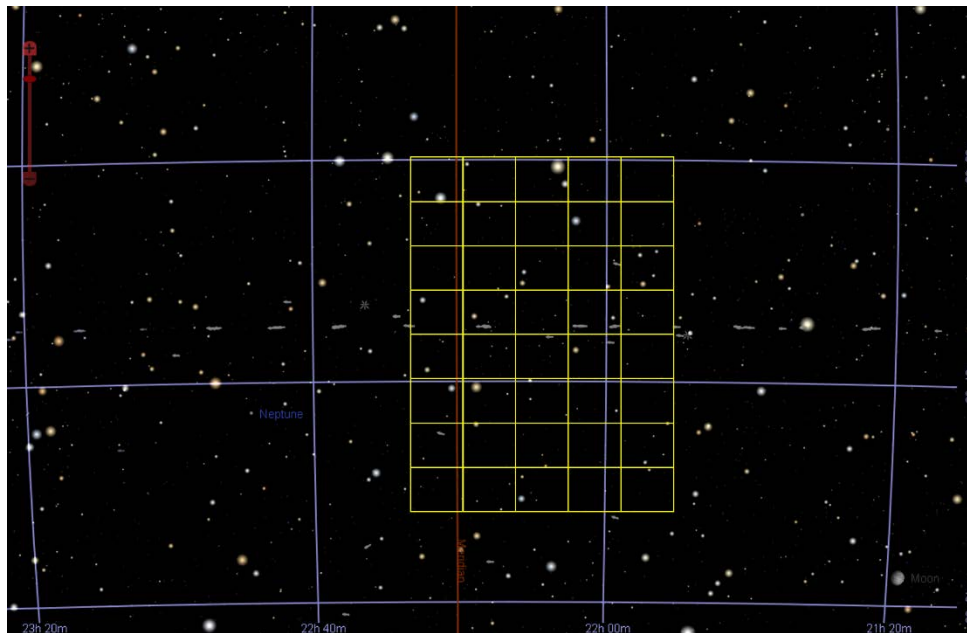


Fig. 4. 40 frames of a simulated survey of CONUS GEO from New Mexico using the sensor shown in Fig. 3. Each square subtends 3.53 square degrees on the sky and the 40-image subset covers 142 square degrees. This 4% segment of the CONUS GEO belt is acquired in 6.4 minutes, including telescope slew/settle time. A series of images across the middle of this image at declination  $\sim -5^\circ$  appear as “dashes.” These are the locations of GEO satellites in the mid-plane of the GEO belt as observed from latitude of  $+35^\circ$ . The observing sequence, starting at the northwest (upper right) image, is to proceed south, step east and then step north, *et seq.* This sensor surveys the sky to magnitude 17.5 or fainter at a rate greater than 1000 square degrees per hour.

There exist techniques to increase the survey rate based upon 300 mm – 500 mm diameter primary optics. A prime focus focal reducer (PFFR) designed by Ackermann has been fabricated, installed and tested on a C-14 telescope (Fig. 5). Using the interline transfer CCD detector this optical configuration yields a  $3.6^\circ \times 2.4^\circ$  field of view covering 8.6 square degrees on the sky, or 40% more sky area than the HyperStar PFC on the same telescope, and with markedly reduced vignetting. JTMA is conducting additional trade-space analyses and on-sky testing of survey capabilities of multiple telescopes, leading to future development of new complementary and supplementary sensors for the global surveillance system we envision.



Fig. 5. Ackermann-designed prime focus focal reducer mounted on a C-14 with prime focus corrector plate removed. The pupil for this unique system is on the first corrector lens, not, as is usual, at the primary mirror. This system produces a  $3.6^\circ \times 2.4^\circ$  FOV on a KAF16070 interline transfer CCD in a Finger Lakes Instruments camera.

Excellent optics design capability allows JTMA to optimally image and detect the information brought to the focal plane by an optical system.

- Edge-buttet mosaics of detectors can cover larger areas of the sky and obtain better angular resolution per pixel, as needed.
- For frame transfer CCD detectors time-delay and integrate readout provides optimal on-sky detection, especially for N-S scans, which are, by definition, on great circles on the sky.
- For detectors with significant readout structure at the edges, such as CMOS devices, sparse arrays with one detector-width “gaps” in the focal plane can prove efficient for some applications.

Other specialized configurations are enabled by very wide field optical systems, as well.

## 6. Summary

The optical survey operation described here produces uncued observations over large fractions of the sky. Here we’ve discussed GEO, in particular. With different observing strategies, but identical physical configurations, JTMA wide-field sensors can produce complete surveys to appropriately faint limiting magnitudes at satellite altitudes ranging from LEO to GEO and beyond, track transfer orbits, and perform neighborhood watch functions. The sensors are very versatile and easily configured to carry out these different missions.

There is no requirement that observations made with JTMA sensors be uncued! Sensors described here can be programmed to carry out targeted observations of objects, and those tasks are made easier and more secure because of the wide fields of view on all our sensors. With FOVs larger than two degrees (four square degrees on the sky), there will never be doubt about whether the target was just missed, as can happen with smaller FOV telescopes, or whether it really wasn’t where it was predicted to be!



In a recent interview, then Lt. Gen. Raymond described space surveillance as “a little data limited,” and he expressed the goal of “making sure we have the right data necessary to make decisions.”

We agree with these statements and add that the SoS effort cannot have the “right” data if it is data starved, and that adding information to any compilation of SoS data requires a systematic, planned approach. Mechanisms to achieve this are underway, under development, and being invented, re-invented or improved at this time. It is the goal of JTMA to provide a significant fraction of accurate SoS data that can be timely and straightforwardly integrated into the appropriate data bases. In fact, the logical thread running through the JTMA AMOS papers, from the outset of our involvement, is to contribute significantly to the optical portion of SoS data.

There are four significant statements embedded in this paper:

1. JTMA has developed techniques and sensors capable of synoptically surveying large areas of the sky with high fidelity, accuracy and known uncertainties.
2. JTMA can ultimately provide these data based upon a globally dispersed system of affordable, replicable sensors.
3. The primary, but not only, operational mode of our sensors is an uncued, wide-field survey.
4. Statements and ideas reported will be questioned until demonstrations are made and the results are known.

The most common query we expect concerns the use of wide-field surveillance. The anticipated first issue is that “we just aren’t used to doing it that way.” This is absolutely legitimate, and we invite our colleagues to discuss with us the issues we raise in these papers. That is, in fact, a primary purpose of AMOS and the inclusion of JTMA papers!

It is globally acknowledged that space surveillance systems track only a small fraction of objects known to be in Earth orbital space. Radar is excellent at surveying near-Earth space (LEO, and MEO), and somewhat less capable at larger ranges, primarily due to the  $1/R^4$  loss of transmitted power with distance. While queuing of radar observations occurs, it is inherently an uncued survey system because it is capable of detecting and tracking any object of appropriate angular size (physical size as a function of range). Thus, the concept of uncued observations is not unknown to the SoS community.

JTMA sensors are an excellent adjunct to radar at MEO, GEO and beyond, and in transfer orbit tracking. It is a useful adjunct at LEO (and beyond) because there is no significant instrumental modulation of detectivity over angle in the surveyed volume of the sky. (Except for clouds, of course.) In short, all SoS sensors are vital to continued observation in support of secure use of space. The optical capability we propose to implement will support current efforts, but the uncued, synoptic portion of the survey is capable of systematically building the catalog of tracked and identified Earth-orbiting objects for years to come.

Bringing space surveillance data bases current with inclusion of more of the untracked objects in Earth orbital space is daunting, but certainly not impossible. Thank goodness such a large fraction of the AMOS attendees are by nature, training, and mission, dauntless!

## **7. Acknowledgements**

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