Absolute Radiometric Calibration Using a Solar Reflector in Near-Geosynchronous Orbit

Richard J. Rudy, Ray W. Russell, Dan J. Mabry, Andrea M. Gilbert, Paul V. Anderson, David J. Gutierrez (The Aerospace Corporation)
and
Stephen Schiller (Raytheon Intelligence, Information and Services)

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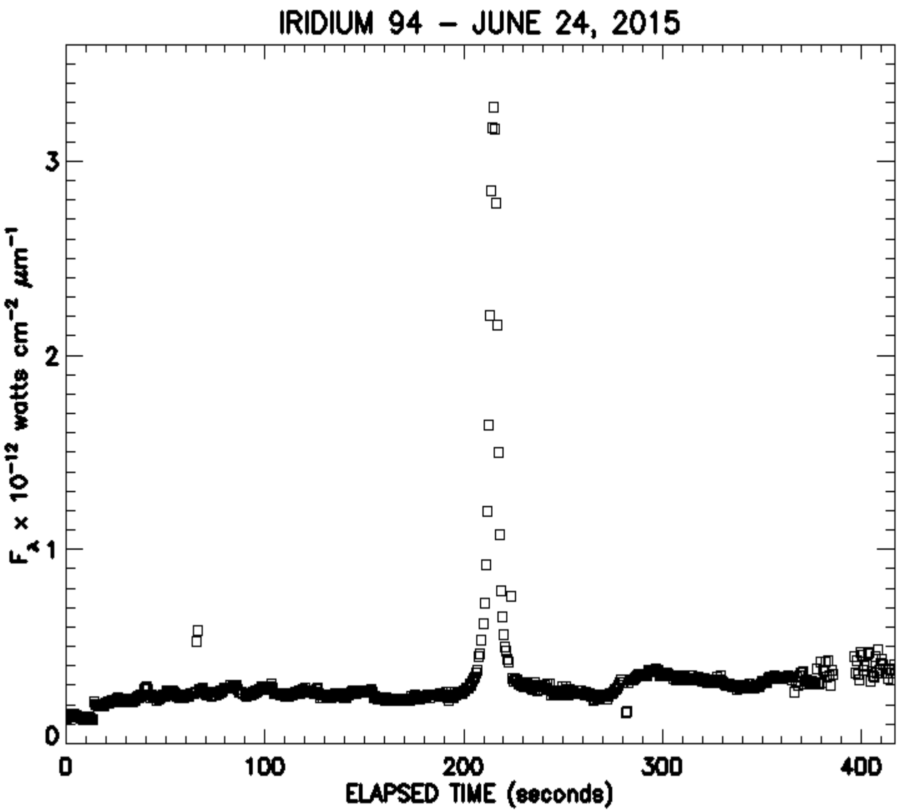
Solar Reflections off Satellites are Observable from Earth

- Iridium flares are solar reflections off antennae
- Iridium flares are the most common and can reach magnitude -9.5
- Antennae are flat with areas of ~ 2 meters^2
- Reflections are short lived and cover only about 10 km on the ground



Flares are unsuitable for radiometric calibration

Convex mirrors produce specific irradiances and FOVs

- Brightness ~ radius^2
- Field of View ~ 1/radius^2
  - *Field of view needs to exceed 0.5 degrees on a side to allow for reflection of the entire solar disk*
- Brightness depends also on observer-to-reflector distance and reflector-to-sun distance
- Example reflector:
  - *Size: 0.5 meter on a side*
  - *Radius of curvature: 10 meters*
  - *Apparent brightness at GEO location as seen from earth: Vmag = 7.6*
  - *Diameter (at earth's surface) illuminated by CalSat: >1000 km*

Convex mirrors are not as bright as flat mirrors but have controllable brightness and much larger fields of view (FOVs)

Convex mirrors have been used for calibration

- V. Zanoni, M. Pagnutti, R. Ryan, D. Helder, W. Lehman, S. Roylance & G. Snyder, 2004. "The Joint Agency Commercial Imagery Evaluation (JACIE) team and Product Characterization Approach," In ***Post-launch Calibration of Satellite Sensors,*** International Society for Photogrammetry and Remote Sensing, Vol. 2, pp 135-141.

- D. Helder, T. Choi & M. Rangaswamy, 2004. "In-Flight Characterization of Spatial Quality using Point Spread Functions," In ***Post-launch Calibration of Satellite Sensors,*** International Society for Photogrammetry and Remote Sensing, Vol. 2, pp 149-170.

- S. J. Schiller and J. F. Silny, 2010, "The Specular Array Radiometric Calibration (SPARC) method: a new approach for absolute vicarious calibration in the solar reflective spectrum", Proceedings of SPIE Vol. 7813, 78130E .

- S.J. Schiller, J. Silny and M. Taylor, 2012. Conference on Characterization and Radiometric Calibration for Remote Sensing, Utah State University Eccles Conference Center, Logan, Utah, August 28, 2012, CALCON Technical Conference, "The Specular Array Radiometric Calibration (SPARC) Technique As A Vicarious Methodology For Accurate Intersensor Calibration", Published on CD.

Schiller et al (2010, 2012) have used simple, convex, safety and truck side-view mirrors for calibration and characterization of satellite sensors

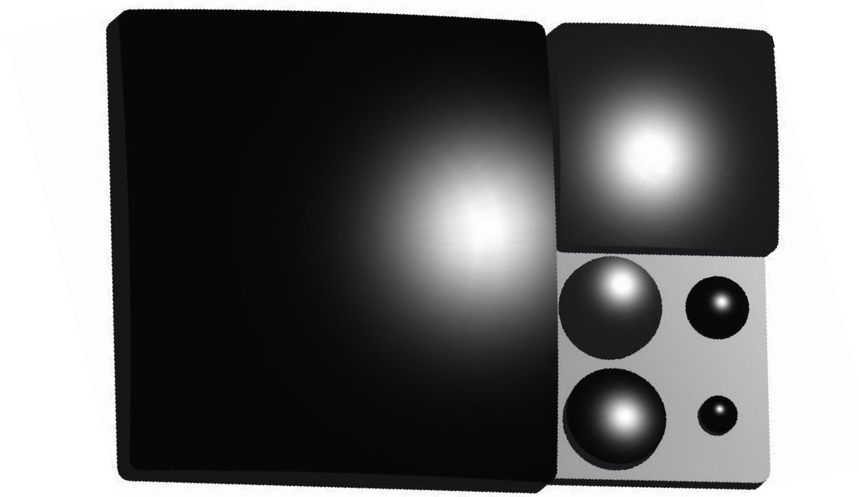
Convex mirrors have been used to illuminate satellite sensors

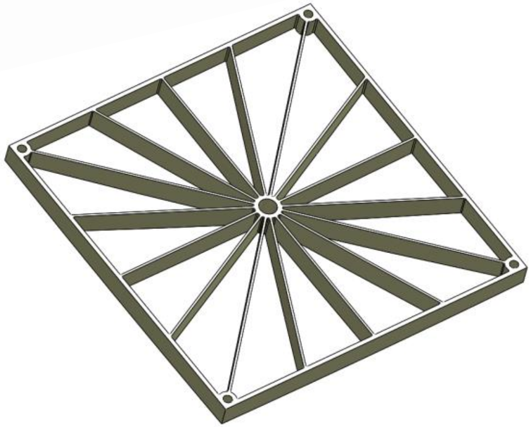
The Calibration Satellite (CalSat)

- Satellite with convex reflector(s) near GEO can illuminate ground-based observatories and sensors in LEO orbits
- Reflector(s) are simple, very broad band, and bright
- Absolute calibration accuracy limited by knowledge of sun
- Sub GEO orbit results in changing satellite longitude that allows for near global use
- Attitude control requirements for CalSat are modest (0.1^{o})

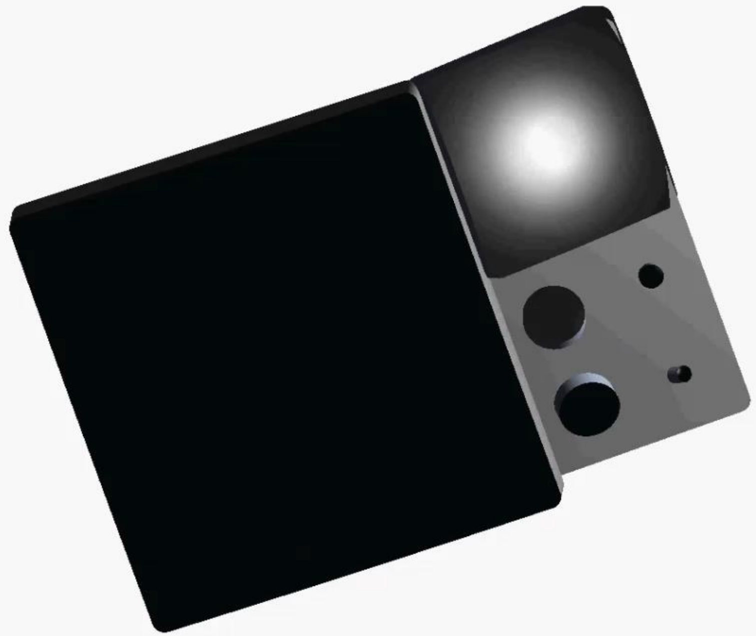
CalSat Reflector(s)

- Multiple reflectors in x10 brightness differences can cover 7.5 or 10 Mags of brightness range
- Tilting reflectors with respect to each other keeps fields-of-view from overlapping
- Largest (0.5x0.5m)and brightest reflector can be light-weighted for very low mass





CalSat Reflector(s) cont.



CalSat Reflector(s) Characteristics

- Reflectors in factor of 10 brightness increments:
  - *Vmag = 7.6, 10.1, 12.6 etc.*
- Material: Aluminum (light-weighted)
- Fabrication: Diamond turning with possible post polishing
- Surface Treatment: Protected silver
  - *One mirror with aluminum surface for UV calibration*
- Monitoring:
  - *Temperature (radius changes with temperature)*
  - *Reflectance*
  - *Surface non-uniformity*
- Weight of principal reflector (0.5 x 0.5 m): ~ 4 kg

CalSat Characteristics & Components

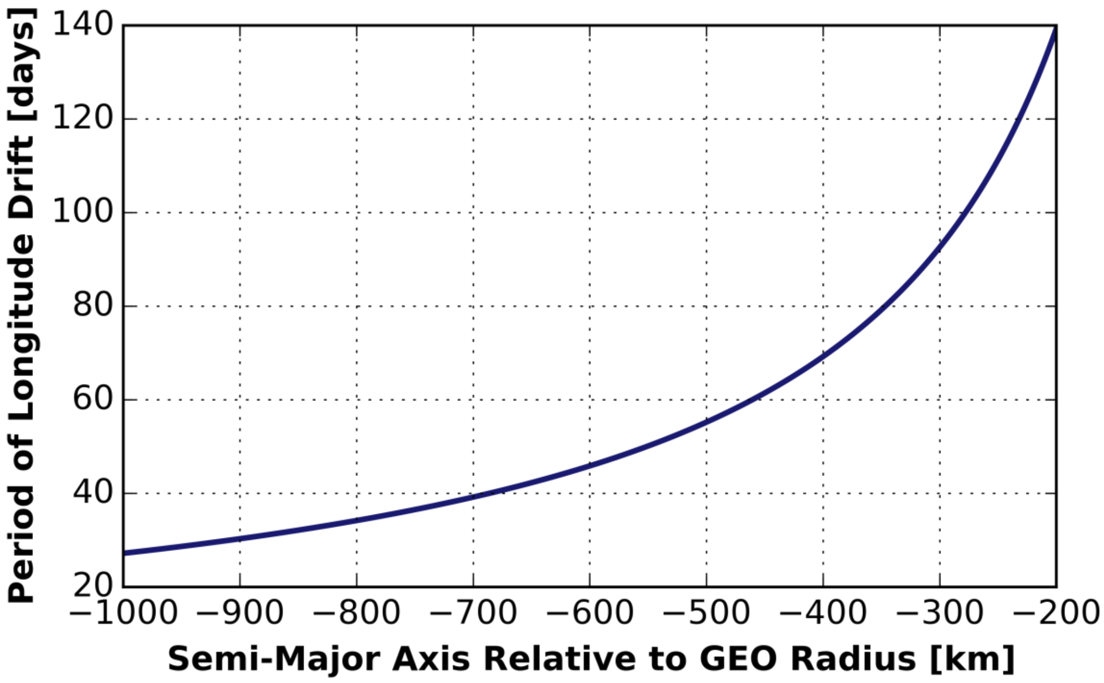
- Satellite (bus, solar panels, reaction wheels, etc.)

- Payload
  - *Reflector, or panel of reflectors*
  - *Reflectance monitor*
  - *Attitude control and position and altitude knowledge*
  - *Communication*
    - Very small bandwidth required to monitor reflector temperature and reflectance

CalSat has a very simple, mostly passive payload

Orbit Considerations: Viewing Opportunities

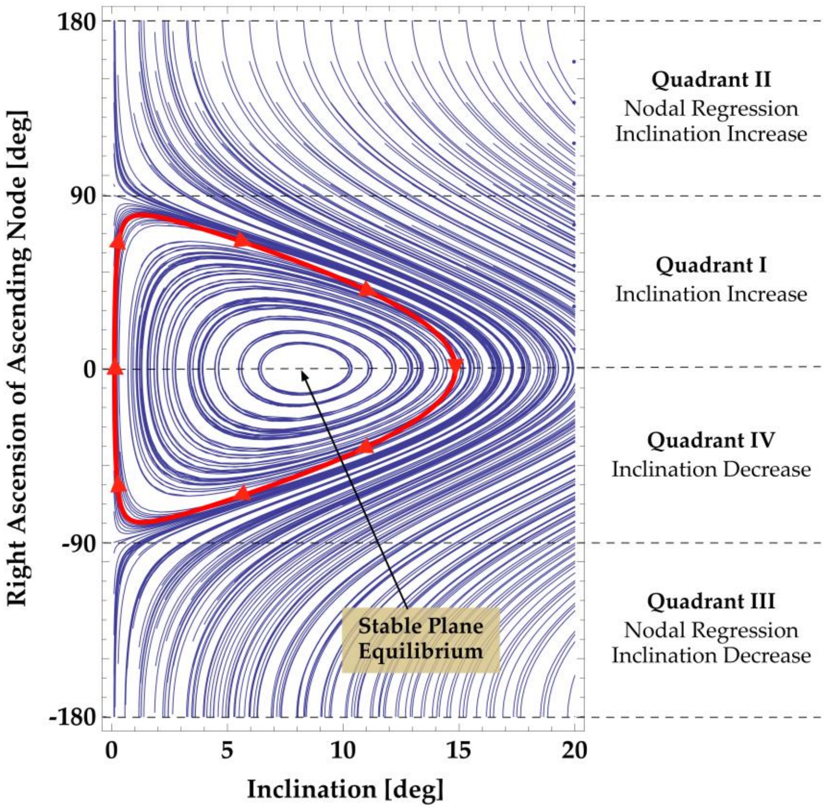
- Orbit below GEO continually changes CalSat's longitude, making it periodically viewable to almost all ground-based sites



Keep out distance above/below GEO is 250 km

Orbit Considerations: Station Keeping

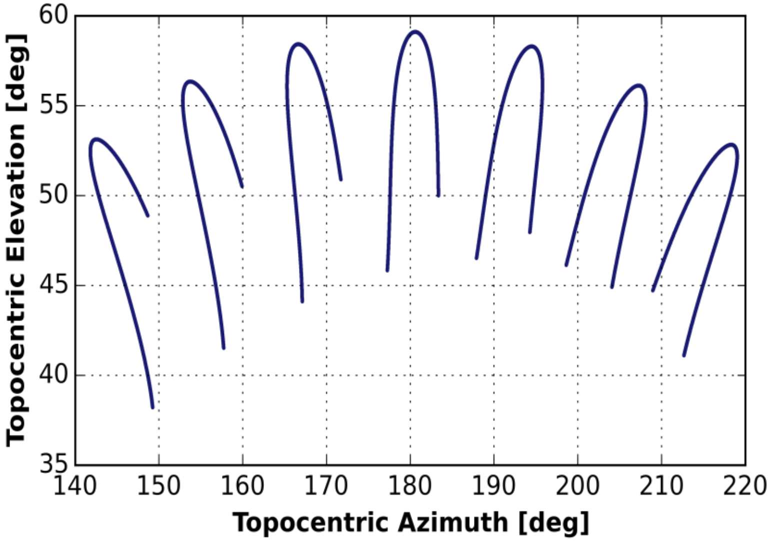
- North-South station keeping to maintain true equatorial orbit is energetically costly: Δvelocity ~ 47 m/sec yearly
- An orbit inclined by 7.5º to the equatorial plane will be relatively stable but will display 15º of apparent latitude drifts over a day

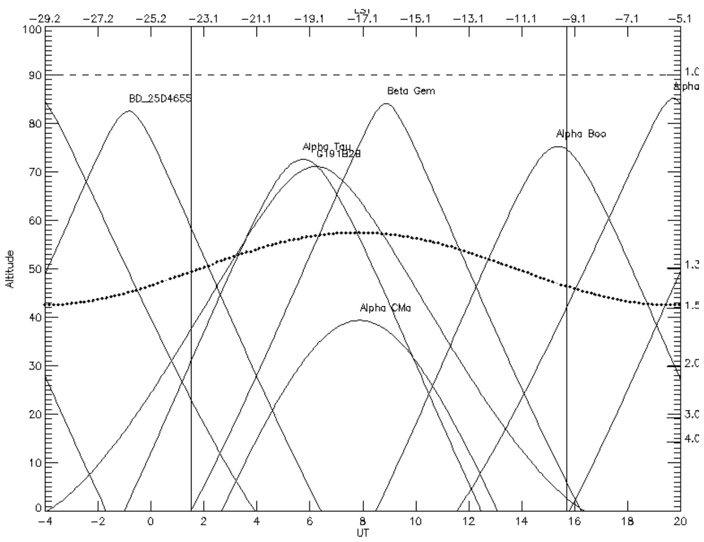


Proposed orbit requires little or no Δvelocity

Orbit Considerations: Viewing

- Orbit 500 km below GEO gives repeated viewing of CalSat for a given ground site for about one week period every 2 months





CalSat visibility from Los Angeles for one week period. Each loop segment represents CalSat's apparent location for one night (sunrise to sunset). Figure on right shows visibility of CalSat and selected HST and infrared calibration stars for a single night when CalSat is optimally placed.

CalSat contributions to absolute irradiance uncertainty

Effect	Error (%)
Reflector radius	0.005
Overall reflectance	0.2
Surface reflectance non-uniformity	0.1
Reflectance angular dependence	0.05
Sun-satellite distance	0.002
Observer-satellite distance	0.01
TOTAL (rms)	0.22

CalSat's absolute irradiance at top of atmosphere is limited by knowledge of solar spectral radiance but should be < 1% for most wavebands

Other Considerations

- Contamination
  - *Contamination and/or space-weathering changes to the reflectance can be tracked by monitoring a representative witness sample*
  - *Non-uniformities across a given reflector's surface can be evaluated remotely by varying the CalSat's attitude within the reflector's field of view*
- Background removal
  - *"Background" refers to other parts of the CalSat and of a possible host vehicle viewable by the observer (e.g., spacecraft bus, solar panels)*
  - *Background levels limit the faintest reflector that can be used*
  - *Chopping technique whereby satellite orientation is changed slightly to turn the illumination of the observatory site on and off can remove this background.*

Summary

- CalSat is simple, low weight, low power facility for improving the absolute radiometric calibration of stellar sources from the UV to the far IR
- CalSat's accuracy is limited primarily by knowledge of the sun's spectral radiance
- CalSat's changing longitude and equatorial centered latitude make it observable to almost all ground-based observatories
- CalSat is viewable for LEO observatories (HST, WISE)
- CalSat is not viewable for observatories at the L2 Lagrangian point (Herschel, Planck, JWST) <u>but</u>, subject to the challenges of station keeping at L2, those observatories could deploy their own CalSats

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