

# Light Curves of Model Geostationary Satellites

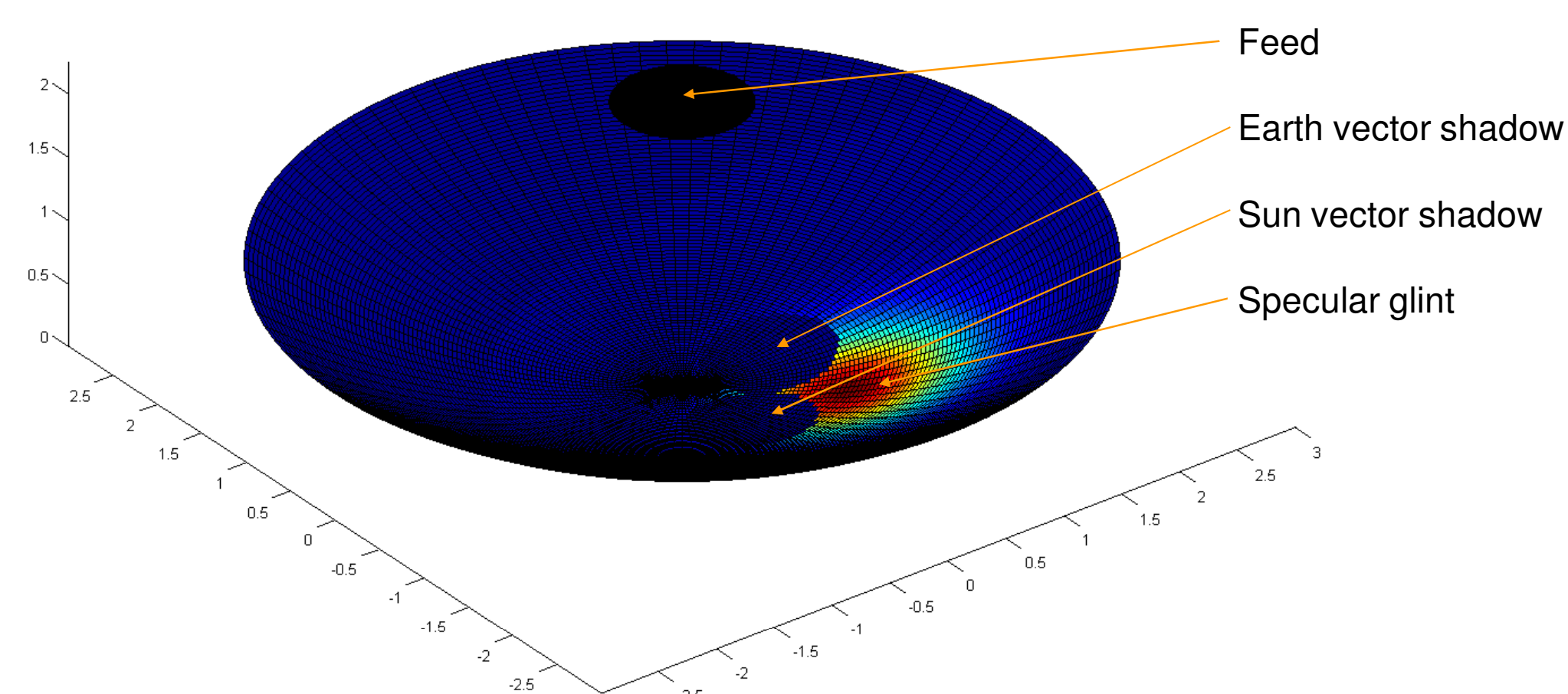
C2C Clayton Stanley and LtCol Jack Wetterer  
Physics 499, U. S. Air Force Academy

## Abstract

Geostationary satellites will reflect light from the Sun differently as viewed by an observer on Earth as the Sun-satellite-Earth angle changes during the night. The observed brightness as a function of time, or 'light curve', is a unique signature of the satellite – generated by the object's particular geometry, orientation, and reflectance. Further, if these parameters are previously known, an object's particular light curve can be generated by simulating its configuration in time and space. A bi-directional reflectance model accounting for diffuse and specular reflection was used to calculate simulated light curve signatures for various shaped objects in geostationary orbits while also accounting for rotation of various components (e.g. solar panels tracking the Sun) and self-shadowing (e.g. one component casting a shadow on another). These synthetic light curves are then compared to actual light curves of geostationary satellites taken at the USAFA Observatory

## Background

- All components were placed in geostationary orbit
- Three basic components were modeled to simulate satellite structure: A Sun-facing surface (e.g. solar panels), an Earth-facing surface (e.g. satellite bus), and a parabolic dish (e.g. communication array)
- Sitting at the focus of the parabolic dish is a small circular panel used to simulate the feed of the satellite antenna. This feed generates two shadows on the parabolic dish. These shadow locations are determined by the object's Earth-facing and Sun-facing vectors for each particular time period
- The satellite dish was modeled with and without black-feed. Here, this black-feed determines the reflectance of the receiver. With black-feed, the receiver will not reflect any light off its surface
- The bi-directional reflectance model calculated the intensity of light reflecting off a single facet. Afterwards, the total intensity was found by summing the  $n$  total contributions from each non-shadowed facet on a logarithmic scale. Each light-curve plot is in magnitudes (i.e.  $S = -2.5 \cdot \log(\text{total\_intensity})$ )



## Bi-Directional Reflectance Model

The result of the bi-directional reflection model is  $S$  which is proportional to the object's brightness.

Material properties are:

- $m$ : slope of facets
- $F_o$ : specular albedo
- $w$ : diffuse albedo

$R_d$  and  $R_s$  are the diffuse and specular bi-directional reflectance respectively

Reflectance model properties are:

- $D$ : facet slope distribution function
- $G$ : geometrical attenuation factor

$$n = \frac{1 + \sqrt{F_o}}{1 - \sqrt{F_o}}, F_o = w$$

$$c = \mathbf{V} \cdot \mathbf{H}$$

$$g = n^2 + c^2 - 1$$

$$F = \frac{(g-c)^2}{2(g+c)^2} \left\{ 1 + \frac{c(g+c-1)}{c(g-c)+1} \right\}$$

$$G = \min \left\{ 1, \frac{2(\mathbf{N} \cdot \mathbf{H})(\mathbf{N} \cdot \mathbf{V})}{\mathbf{V} \cdot \mathbf{H}}, \frac{2(\mathbf{N} \cdot \mathbf{H})(\mathbf{N} \cdot \mathbf{L})}{\mathbf{V} \cdot \mathbf{H}} \right\}$$

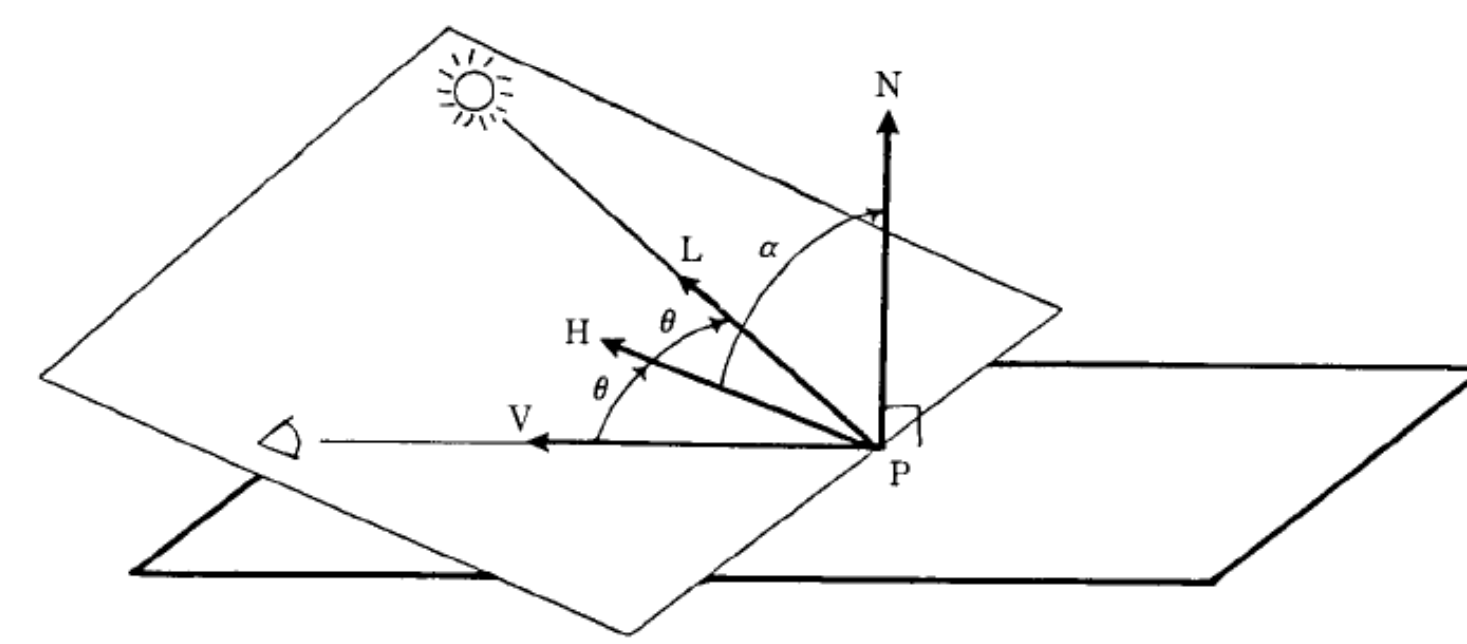
$$D = \frac{1}{m^2 \cos^4 \alpha} e^{-|\tan \alpha / m|^2}$$

$$R_s = \frac{DGF}{\pi(\mathbf{N} \cdot \mathbf{L})(\mathbf{N} \cdot \mathbf{V})}$$

$$R_d = w/\pi$$

$$S = (sR_s + dR_d)\pi(\mathbf{N} \cdot \mathbf{L})(\mathbf{N} \cdot \mathbf{V})$$

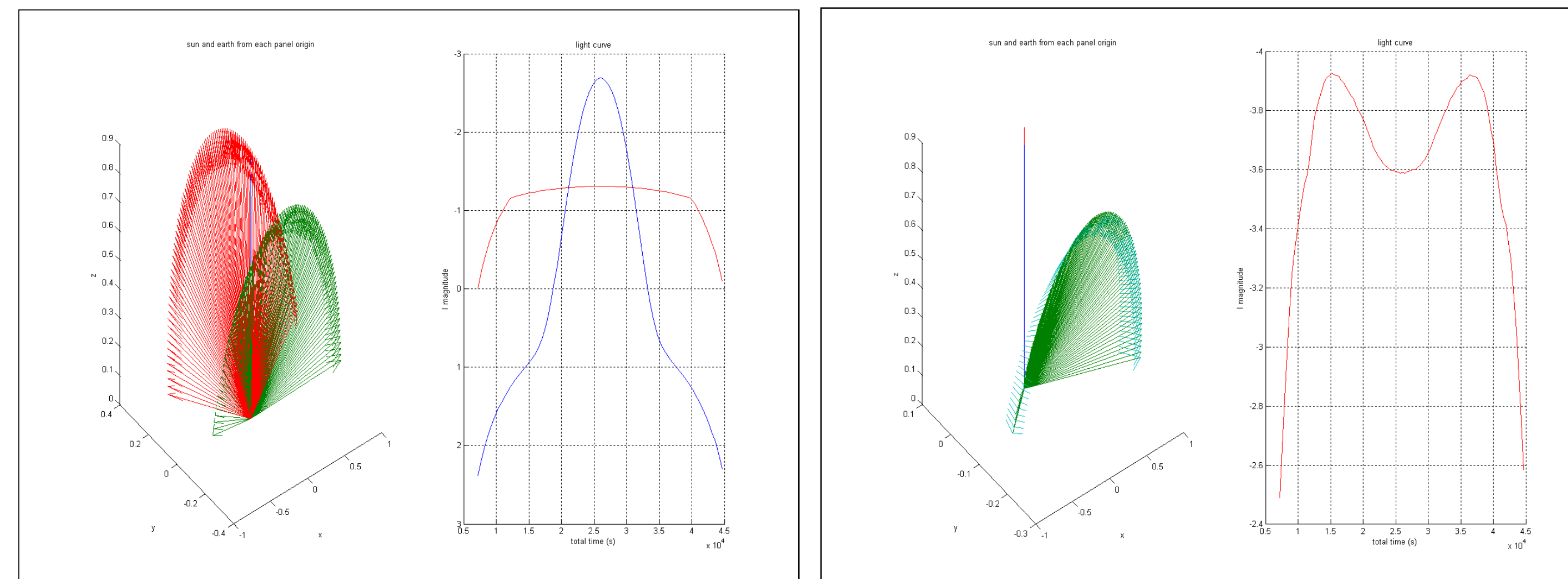
$$s + d = 1$$



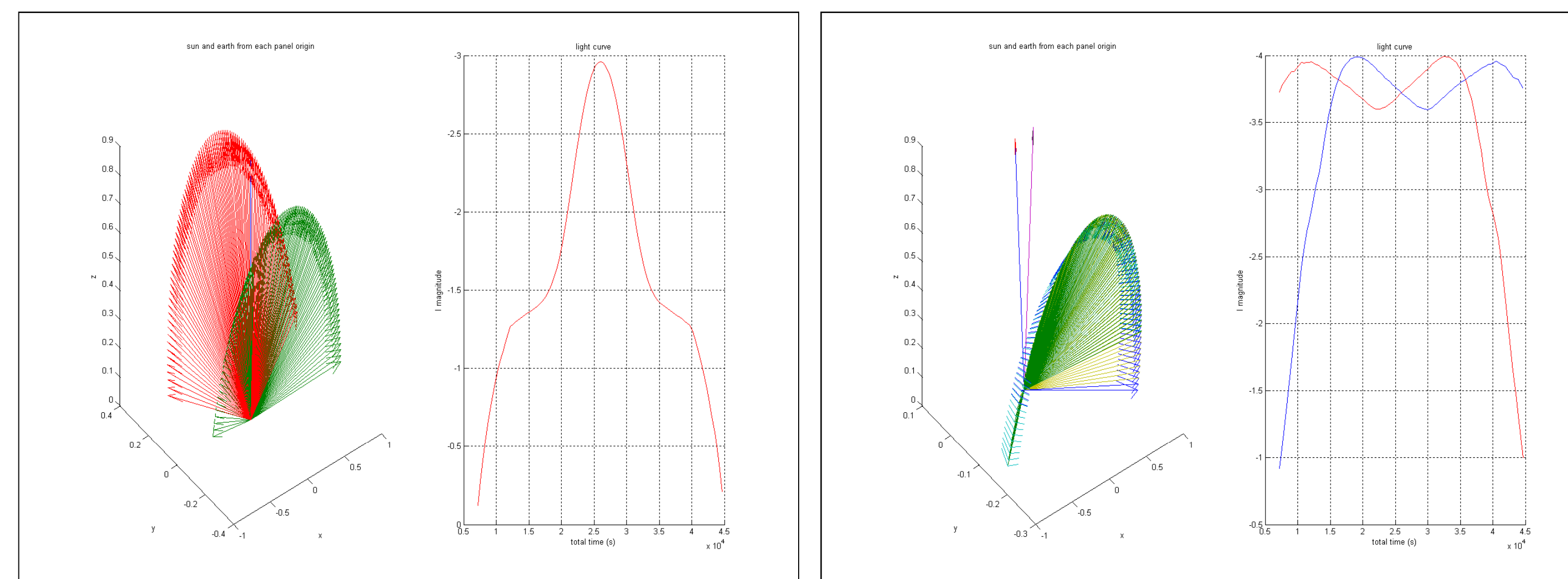
Ref. Fig. 2, Cook & Torrance, p. 9

## Simulated Data from Light-Curve Modeling

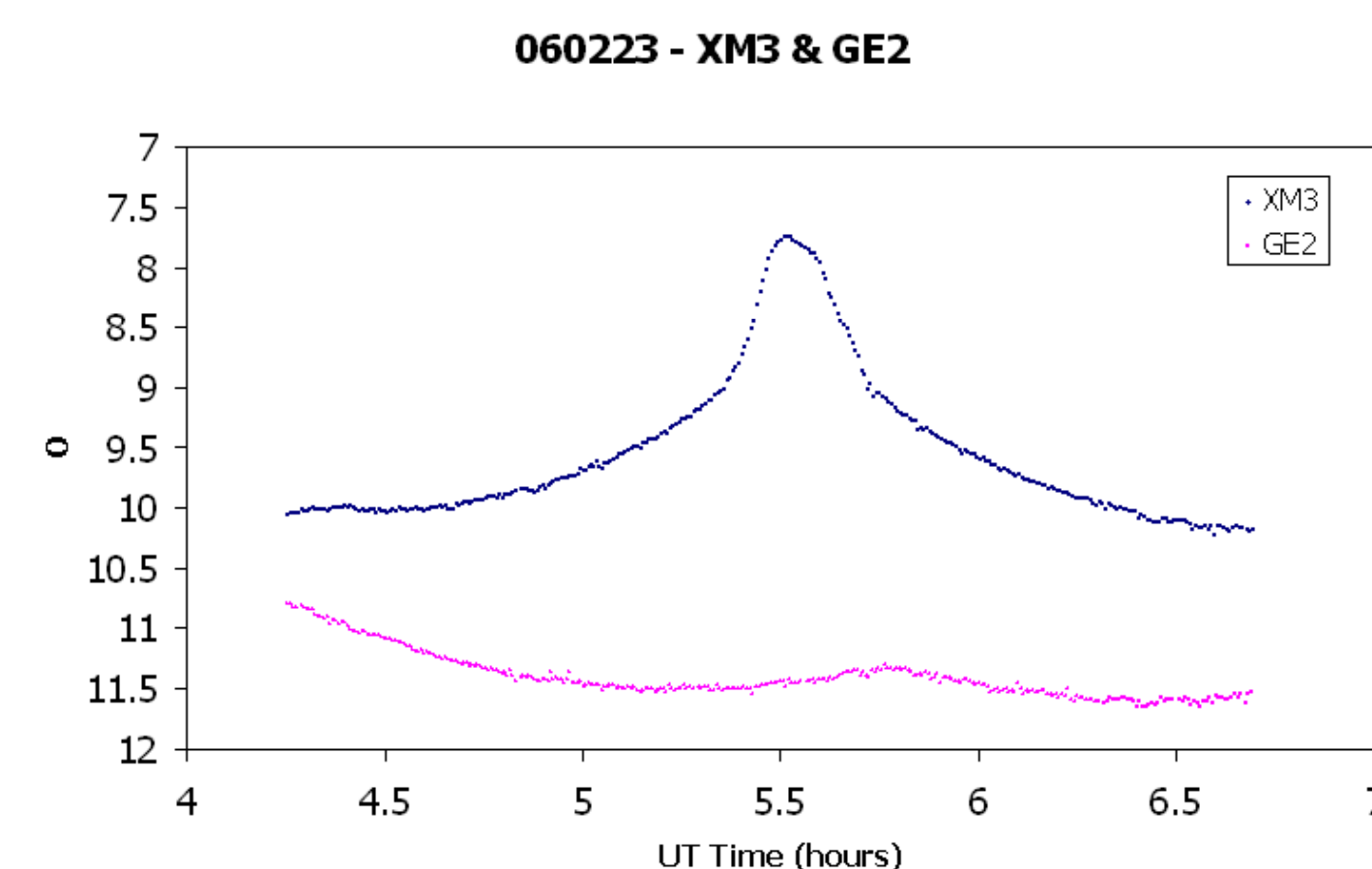
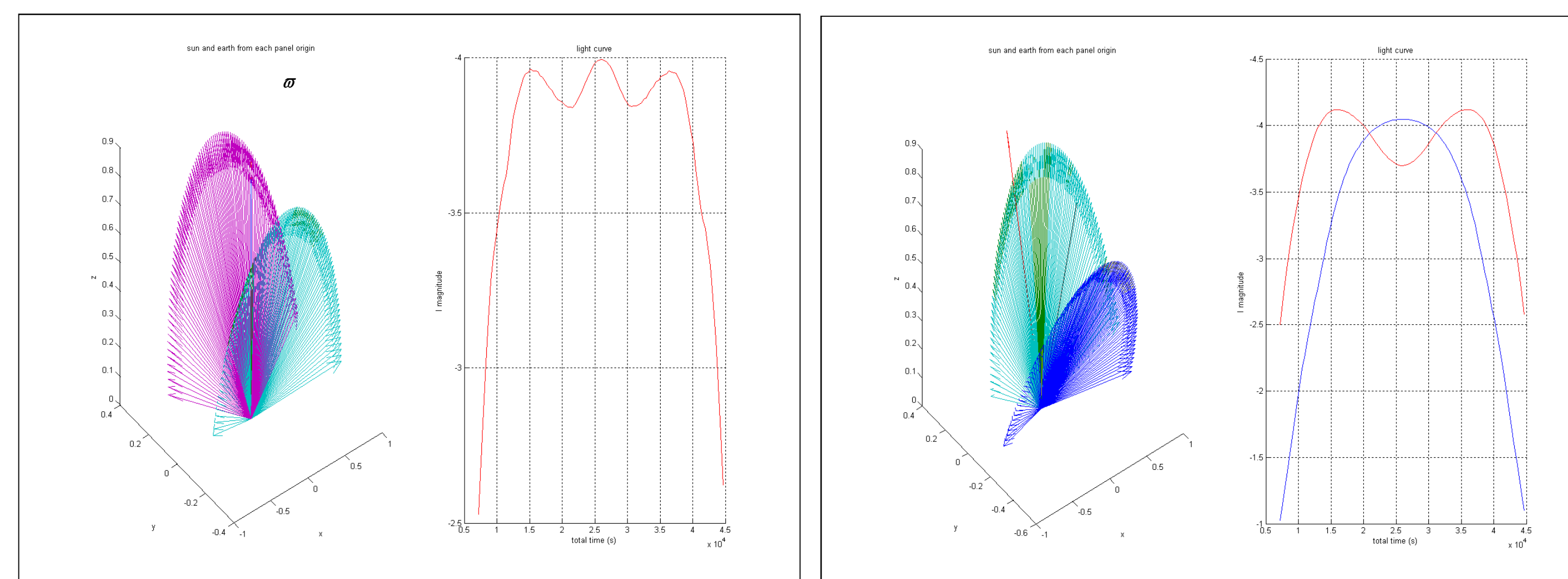
- Red Plot: Single panel facing Earth
- Blue Plot: Single panel facing Sun
- Parameters:
  - Sun:  $m=.15, w=.9, r=2/3, n=1$
  - Earth:  $m=.85, w=.9, r=1, n=1$



- Red Plot: Combination of two plots above: One Earth-facing panel and one Sun-facing panel
- Parameters: Same as used above



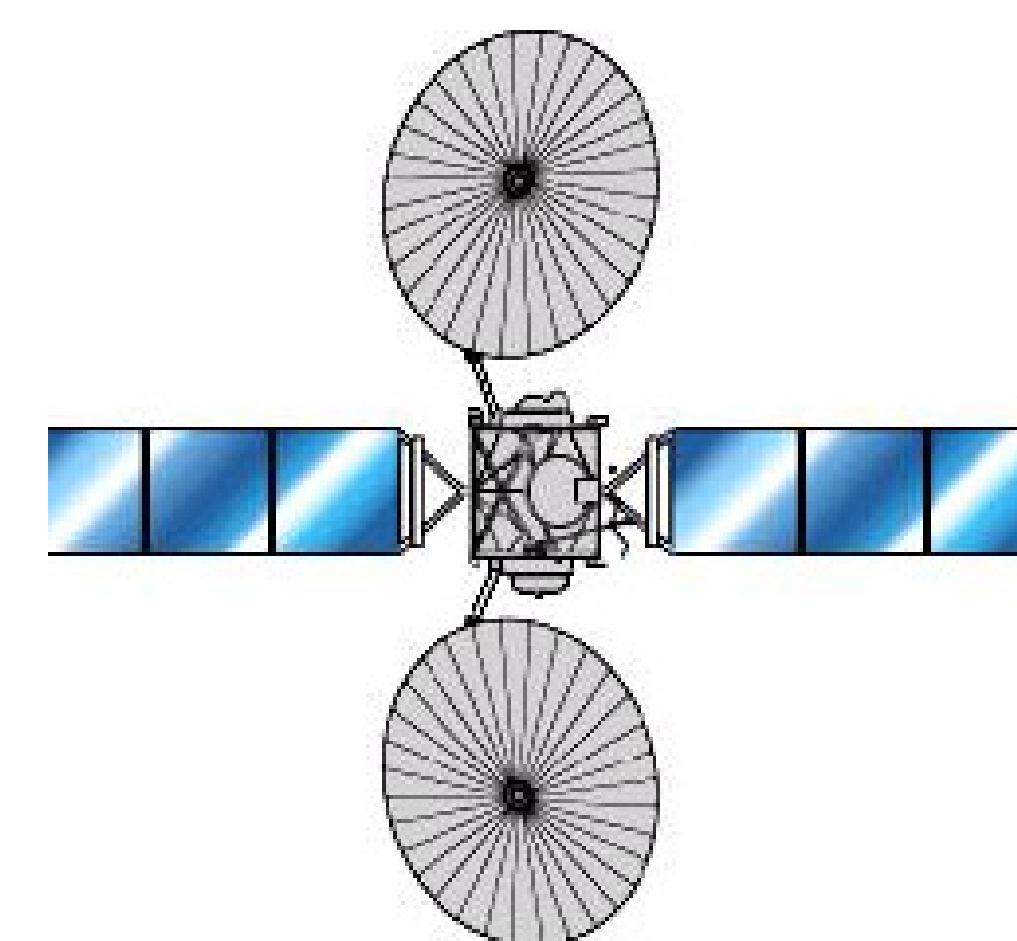
- Red Plot: One Earth-facing satellite dish without black-feed, one Sun-facing panel
- Parameters:
  - Dish:  $m=.15, w=.9, r=3, n=10,000$
  - Feed:  $m=.85, w=.9, r=1/2, n=1$
  - Solar Panel:  $m=.15, w=.6, r=4/5, n=1$



- Blue Plot: XM3 satellite; solar panel dominated; 41 cm telescope; USAFA observatory



- Red Plot: GE2 satellite; dish panel dominated; 41cm telescope; USAFA observatory



- Red Plot: One Earth-facing satellite dish with black-feed
- Parameters:
  - Dish:  $m=.15, w=.9, r=3, n=10,000$
  - Feed:  $m=.85, w=0, r=1/2, n=1$

- Red Plot: One Earth-facing satellite dish with black-feed and 8 degree RA offset
- Blue Plot: One Earth-facing satellite dish with black-feed and -8 degree RA offset
- Parameters:
  - Dish:  $m=.15, w=.9, r=3, n=10,000$
  - Receiver:  $m=.85, w=0, r=1/2, n=1$

- Red Plot: One Earth-facing satellite dish with black-feed and 20 degree DEC offset
- Blue Plot: One Earth-facing satellite dish with black-feed and -20 degree DEC offset
- Parameters:
  - Dish:  $m=.15, w=.9, r=3, n=10,000$
  - Receiver:  $m=.85, w=0, r=1/2, n=1$

## Summary

The specific light-curve for each configuration of the satellite depends greatly on the observer's location, satellite's geometry, and satellite's material makeup. For example, with a parabolic dish, the observer's location can cause the specular glint to shift into and out of the Earth and Sun shadow vectors. The satellite's geometry determines how much specular glint escapes from the receiver's shadow. Finally, the satellite's material makeup can stretch or raise the light-curve by modifying the object's  $m/w$  configuration or changing the relative area's of the object's panels.

## References

- Cook, Robert L & Kenneth E. Torrance. "A Reflectance Model for Computer Graphics." ACM Transactions: January 1982, p. 7-24.
- Kassalainen, M. & J. Toppa. "Optimization Methods for Asteroid Light-curve Inversion." Icarus: 2001, p. 24-36.