OSEM Development Options

M.D. Hejduk, LZ Technologies
H.M. Cowardin, ESCG/Jacobs

September 17, 2012

OSEM Development Options

- **More elaborate technique**
  - Requires explicit material typing and shape determination for each survey object
- **More streamline technique**
  - Examines fragments from satellite explosion experiments in laboratory to develop relationship between photometric return and estimated size
- **JSC ODPO considering both**

Semi-Analytic OSEM

- **Described in oral presentation last week**
- **For each object, to estimate size the following would be required:**
  - Orbit determination
    - Requires follow-up tracking on multiple nights
    - Needed for object reacquisition at will
    - Needed to estimate area-to-mass ratio and thus separate some similar materials with similar colors
  - Four-color photometry to estimate material type and thus albedo
    - Requires 10-20 short tracks at different times
  - Open-aperture photometry to estimate object shape
    - Requires 20-40 short tracks at different times

Semi-Analytic OSEM Material Type Estimation

- **Material differentiation parameters/calculations**
  - B-R versus R-I separates the majority of tested material types
  - B-R versus B-V separates many of the remaining pairs that did not have a strong enough I-band return to calculate R-I
  - AGOM differences separate the remaining ambiguous cases
- **Problems**
  - Space reddening model needs to be developed
  - Additional laboratory work required
    - Four-color photometry of additional materials to complete needed portfolio
    - Albedo calculations for all materials in portfolio
  - Alignment between laboratory and telescope measurements
    - Historically not all that wonderful; additional calibration activities required

Semi-Analytic OSEM Shape Estimation

- **Hall et al. (2007): distinctive shape-dependent pattern to brightness-versus-phase intensity plots**
- **Identification of candidate shape can be effected by comparison to gallery of simulated shape responses**
  - 2007 study used two-dimensional Kolmogorov-Smirnov test
- **Proposed enhancements in present effort**
  - Examine just sliver (or slivers) of phase response
    - Reduces distribution-matching problem to single dimension
  - Use particular portion of CDF curve to reduce sensitivity to BRDF
- **Problems**
  - Needs more verification: shape gallery needs expansion, BRDF independence needs broader exercise, choice of “sliver” needs more investigation, entire phenomenon needs verification in laboratory
  - Shape confusion (e.g., cube and cylinder)
  - Somewhat large data requirements (40 measurements for two-sigma separation)

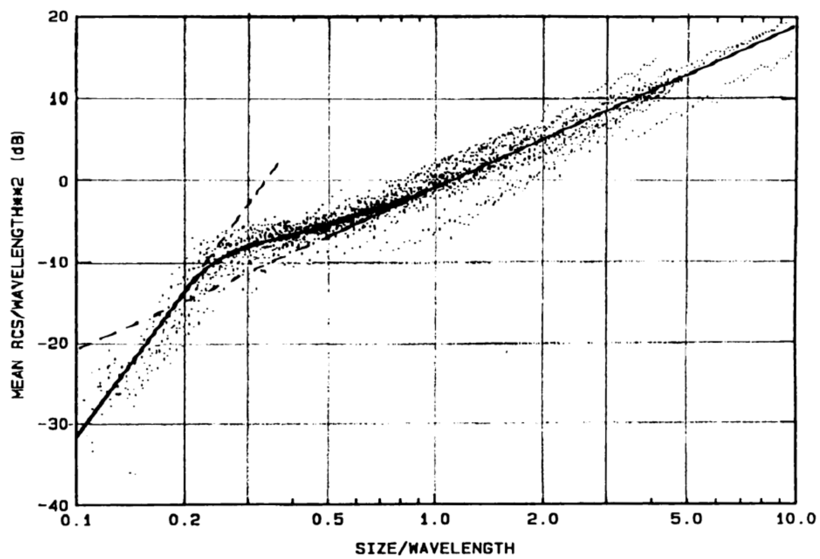
Semi-Analytic OSEM: Evaluation

- **Approach appears viable**
- **However, number of substantial outstanding items**
  - Significant laboratory investment
  - Significant verification activities with actual survey data required
  - Significant survey activities
    - Perhaps larger collections than expected
  - Space weathering effect modeling
- **Is there a more streamlined approach?**
  - Obviate at least some of the above outstanding items
  - Enable more efficient surveys

- **Possibility: OSEM modeled after JSC Radar SEM**

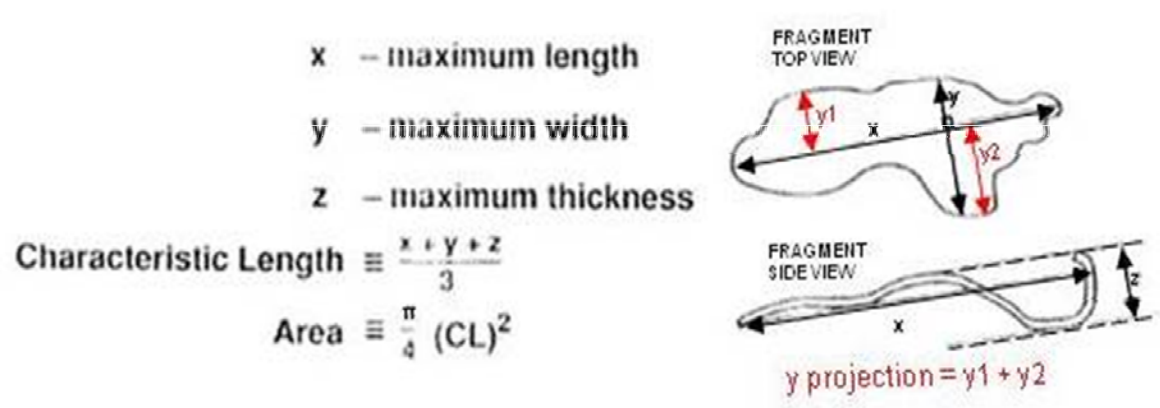
Radar OSEM: Basic Rubric

- **Simulated hyperkinetic destruction of satellite in vacuum chamber**
- **Collected pieces and subjected them to individual analysis**
  - "Observed" each piece with radar in special observation facility
  - Articulated full range of aspect angles and full range of radar frequencies
  - Recorded resultant RCS of each aspect/frequency configuration
- **Collected results and plotted in dimensionless format**
  - RCS / λ^2; size / λ
  - Results follow basic theory of Rayleigh, Mie, and optical regions



Size Estimation Possibilities

- **Single-number size value for each piece an average of three orthogonal axes**
  - Primary axis is longest segment that can be inscribed in the shape
  - Secondary axis is either the longest segment normal to the primary axis that can be inscribed in the shape or the longest “projected” orthogonal axis
  - Tertiary axis follows same rubric as for secondary



From Hill and Luna (2012)

- **Single number for object “size” always problematic; other potential options include object average/maximum projected area (for CA risk assessment)**

OSEM Fragment Source

- **Several recent satellite destruction experiments**
  - SOCIT 4 (1 ~1m functional payload; materials from early 90's)
  - Kyushu University (six ~30cm microsats; modern materials)
  - ESOC 2(1 rocket body; pressure explosion)
  - Additional experiments planned
- **Fragments for many of these in JSC possession**
  - Inventoried by shape, material, size
- **Verification of size scalability required**
  - In principle, optical response is scalable with size
    - Should be able to characterize one shape-material sample in laboratory and scale to multiple sizes
  - However soot collection and edge effects may negate scalability
    - Must verify scalability in laboratory
- **Inventory examination to yield shapes and materials of interest**
  - Governed by expected detectable size of surveys
- **Shape-material pairs to be examined in the laboratory**

OSEM Laboratory Activity

- **Each fragment examined in full suite of aspect and phase angles**
  - 10-degree increments in aspect (two-axis)
  - 5-degree increments in phase (some boundary limitations)
- **Radiometric measurements:**
  - Four-color photometry (BVRI)
  - Open-aperture photometry equivalent (perhaps V-band)
  - Spectroscopy, if time permits

OSEM Data Reduction

- **Envisioned optical approach would generate several functional relationships**
  - Size = *f* (open aperture)
  - Size = *f* (four-color photometry)
  - Size = *f* (open aperture, four-color photometry)
  - Size = *f* (open aperture, AGOM)
  - Size = *f* (open aperture, AGOM, four-color photometry)
- **Each would include an error analysis**
  - So each would return a size estimate and an estimation variance
  - Presumption is that more florid inputs (*e.g.,* color photometry) will return an estimate with a smaller estimation variance

Advantages/Disadvantages of Laboratory Approach

- **Advantages**
  - Easier to develop
  - Surveys simplified—less data required
  - Analogy with radar SEM maintained
- **Disadvantages**
  - Not as accurate: presumption is that selected fragments adequately represent debris population
  - Space reddening problem still requires solution

Back-up slides

- **Available telescopic data**
  - MODEST survey (Broad R filter)
    - *2002-2003 NASA Technical Report
    - *2004-2006 NASA Technical Report
    - *2007-2009 NASA Technical Report
  - Survey and chase using MODEST and CTIO 0.9-m
    - *AMOS 2007, Seitzer
  - Filter photometry data using single telescope MODEST/CTIO 0.9-m (BVRI)
    - *AMOS 2010, Seitzer
  - Synchronous photometry (MODEST in R and CTIO 0.9 m B)
    - *AMOS 2010, Seitzer
  - Magellan survey (fainter, smaller sizes)
    - *AMOS 2011, Seitzer
  - Magellan spectroscopy
    - *AMOS 2012, Seitzer