National Aeronautics and Space Administration

CHARACTERIZATION OF THE 2012-044C BRIZ-M UPPER STAGE BREAKUP

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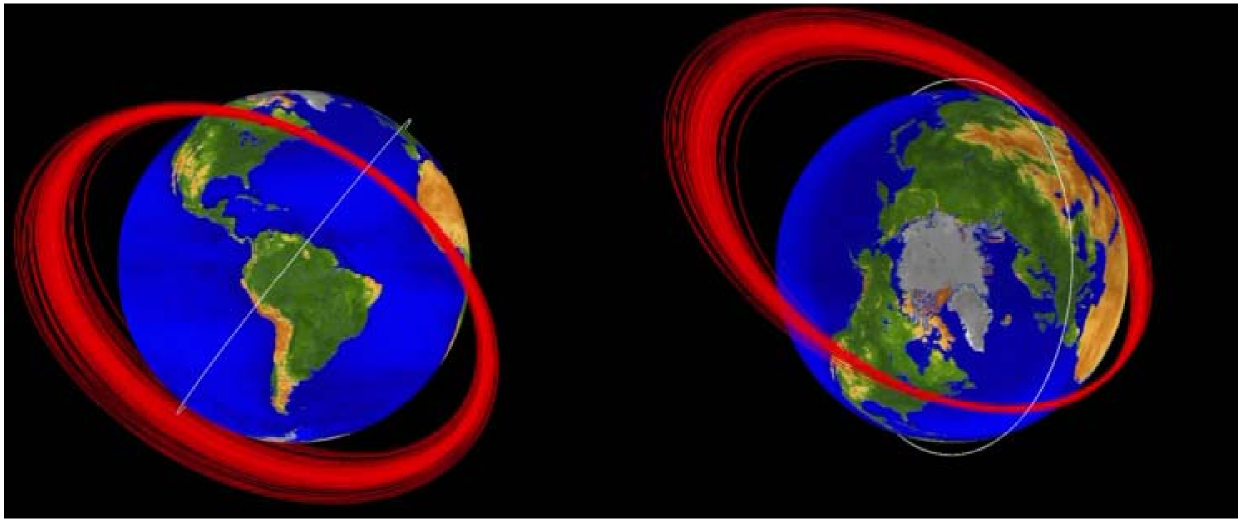
Breakup Background

- On 6 August, 2012, Russia launched two commercial satellites aboard a Proton rocket, and attempted to place them in geosynchronous orbit using a Briz-M upper stage (2012-044C, SSN 38746).
- The upper stage failed early in its burn and was left stranded in an elliptical orbit with a perigee in low Earth orbit (LEO).
- It broke up 16 October, creating a large cloud of debris with perigees below that of the International Space Station.
- The NASA Orbital Debris Program Office requested radar assets to characterize the extent of the debris cloud in sizes smaller than the standard debris tracked by the SSN.

Characterizing the Debris Cloud

- **The Space Surveillance Network (SSN) identifies the breakup and tracks the largest debris (> ~10 cm)**
- **NASA uses staring radars to statistically sample the smaller debris population**
  - **Lincoln Laboratory's HAX radar : > ~1 cm**
  - **Lincoln Laboratory's Haystack radar : > ~ 5 mm**
    - Not available due to upgrades
  - **NASA's Goldstone antenna : > ~ 2 mm**
    - Limited availability due to use by Deep Space Network
    - Was unable to get low-altitude passes during available times



NASA Breakup Model

- **In order to characterize an explosion, a breakup model needs to describe the initial cloud on the basis of:**
  - **Debris size distribution**
  - **Delta-velocity distribution**
  - **Ballistic coefficient distribution**
  - **Also would like to have information on shape and material type distribution, but these are much more difficult to obtain**

- **NASA Breakup Model**
  - **Based primarily upon empirical data**
    - Ground tests
    - Radar observations of on-orbit breakups
  - **Represents “typical” breakup**
    - Individual breakups can vary
    - Always in need of more data to validate/correct models

NASA Breakup Model

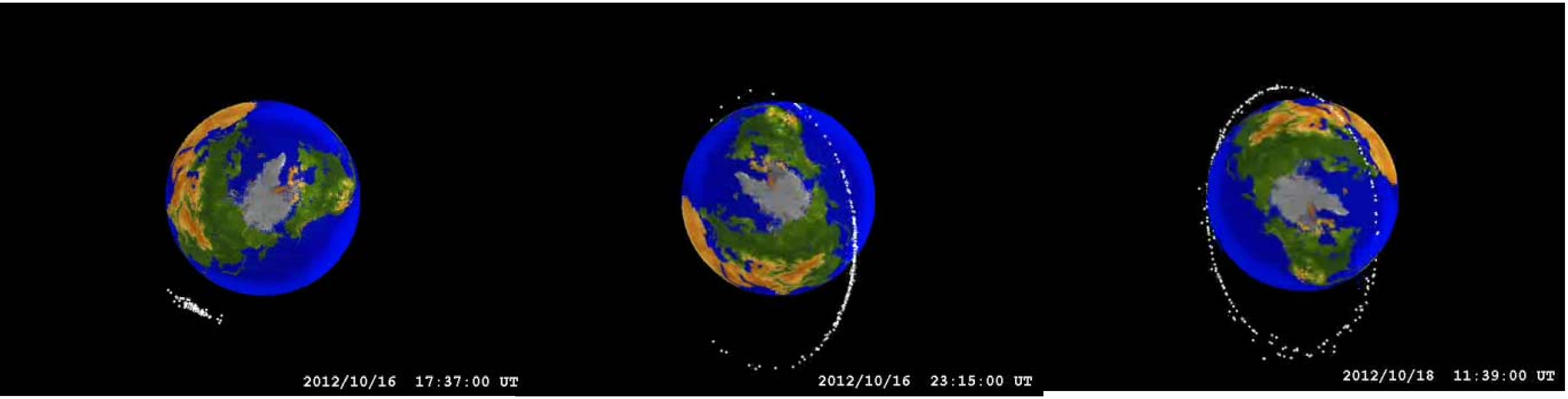
- **NASA uses a Monte Carlo approach that generates a set of N "characteristic" fragments**
  - **Individual debris objects are "created" at known breakup time**
    - Delta-velocity added to state vector of parent at time of breakup (provided by SSN)
  - **Each orbit is propagated independently**
  - **If the model is accurate, the ensemble of debris should mimic the actual cloud**

- **Separate models for explosion and collision**

- **Can use the model in a "reference" mode – calculate what the model predicts and compare to actual data**

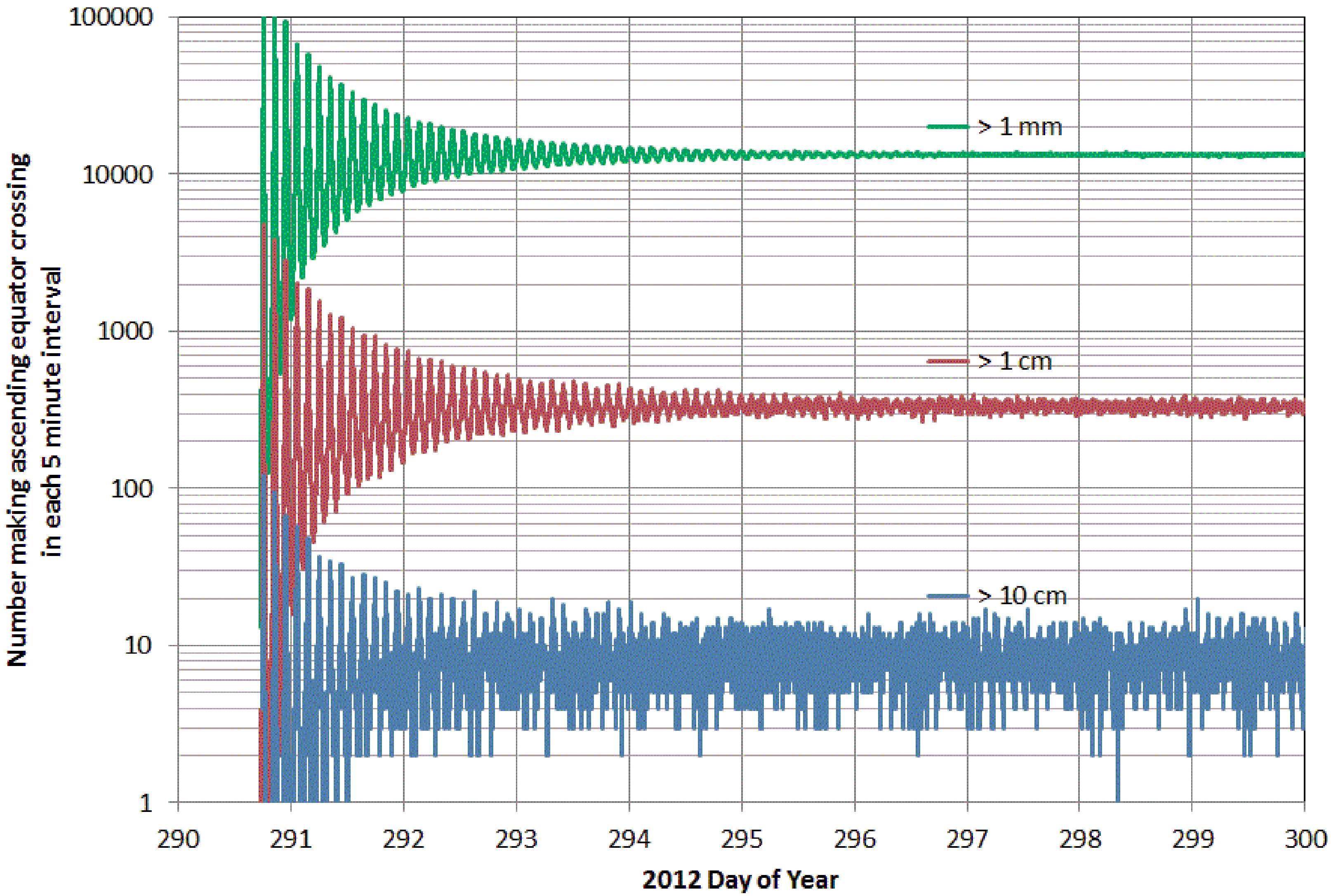
Anatomy of a Breakup

- **There are three phases of a breakup cloud:**
  - **The initial cloud, that is concentrated in space (Lasts hours to days)**
  - **The "ring" phase, where the debris mean anomalies are essentially randomized, but the cloud is still in an identifiable orbital plane (Lasts months to years)**
  - **The "background" phase, when the ascending nodes of the debris orbits become randomized**



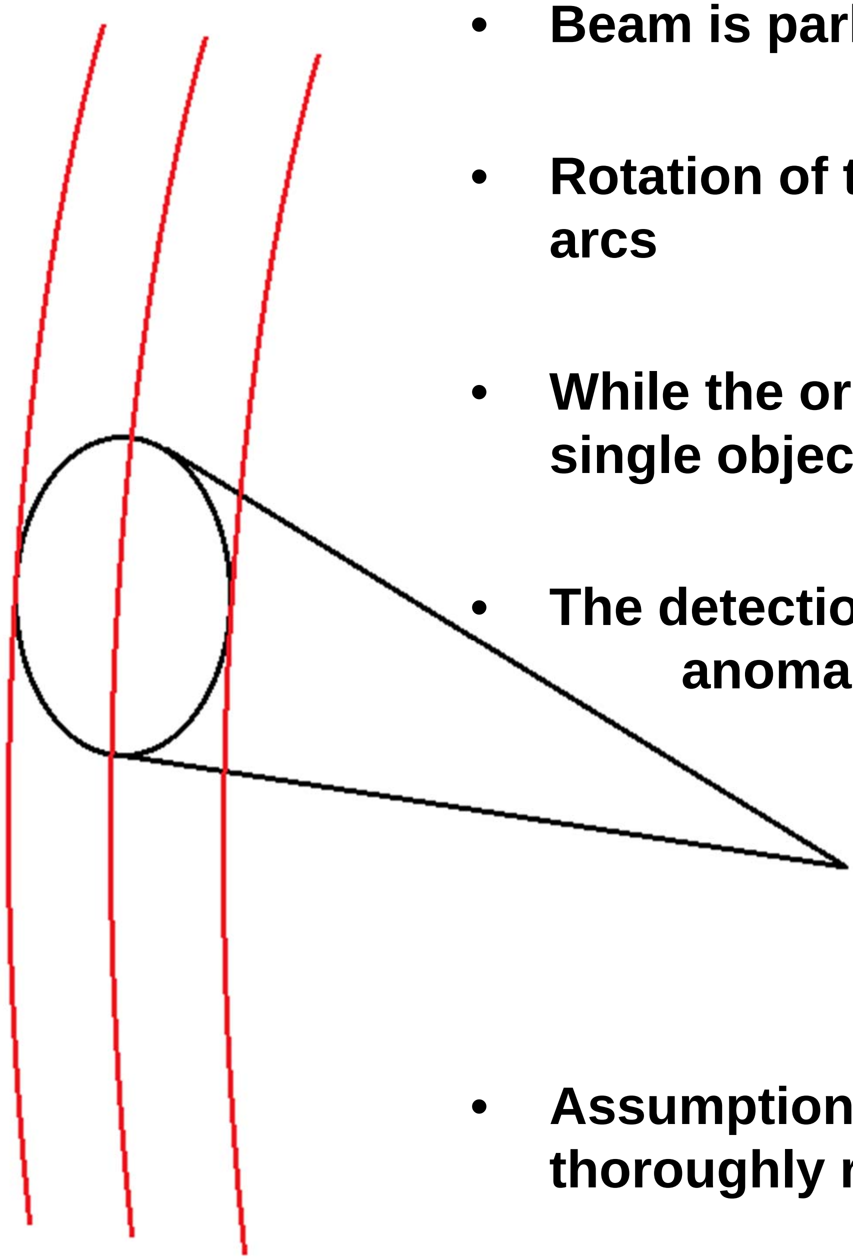
- **The time span of each phase is highly dependent on the parent orbit and where in the orbit that breakup occurred**

Evolution of BRIZ-M Breakup Cloud Based Upon Breakup Model Evolution



- **BRIZ-M mean anomaly is mostly randomized after a few days**

Beam Stare Strategy



- **Beam is parked at a particular elevation and azimuth**
- **Rotation of the Earth causes beam to sweep across orbit arcs**
- **While the orbit arc is in the beam, the rate of detection of a single object in that beam is once per orbit period**
- **The detection probability for an object with a random mean anomaly in the given orbit will be:**

$$\frac{\textit{Amount of time orbit arc is in beam}}{\textit{Period of orbit}}$$

- **Assumptions only apply once debris mean anomalies are thoroughly randomized**

Stare Modes

- **Normally, NASA uses the Haystack and HAX radars in a 75° East mode (75° elevation, 90° azimuth)**
  - **Operating off-vertical provides indication of orbit inclination by using Doppler**
- **However, because of the very low perigee of this breakup, much of cloud would pass too close to the HAX radar (closer than the nearest range bin) for some 75° elevation observations and times**
  - **Also, short-range observations can see smaller debris, but the count rate is lower because the beam is narrower at short ranges**
- **NASA developed several optimal viewing modes based on the model predictions for this breakup cloud and asked for HAX to observe these modes**
  - **A variety of observation modes were run from day 293-301**

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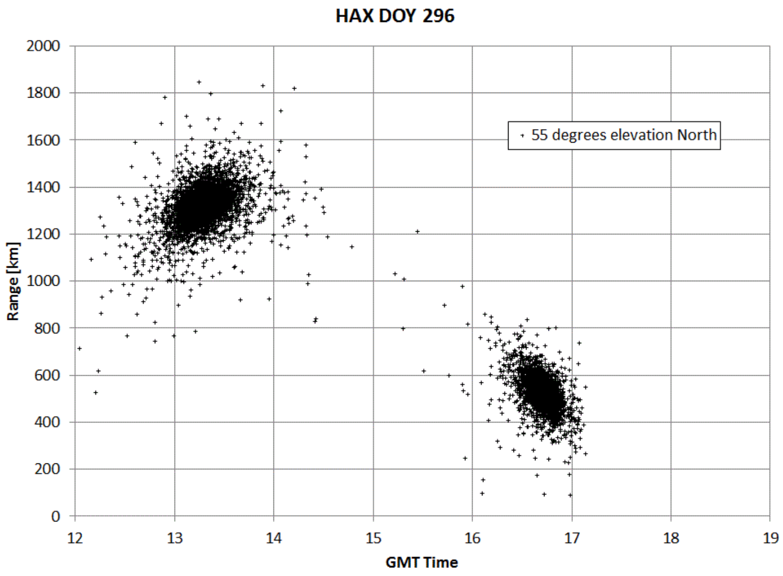
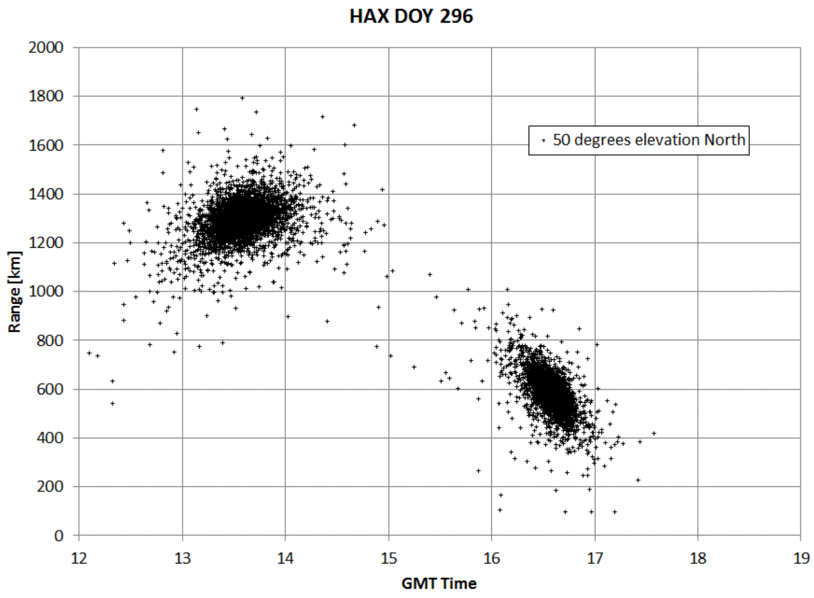
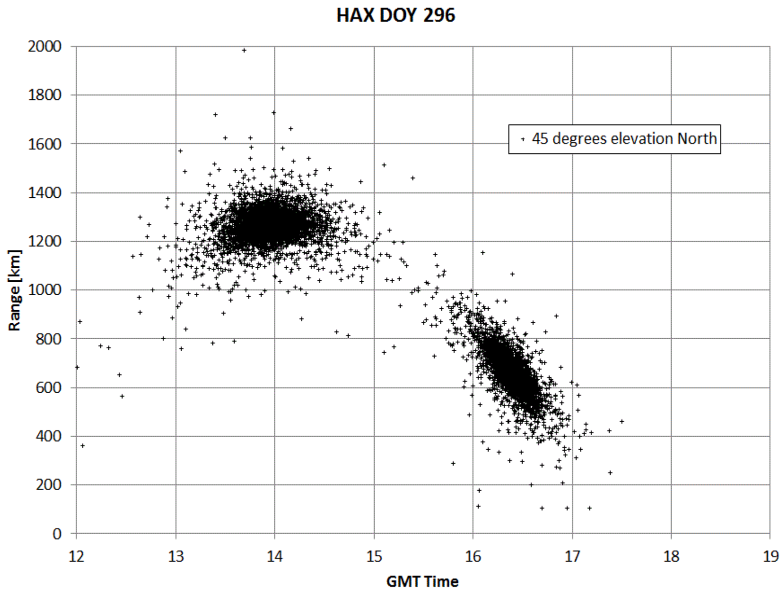
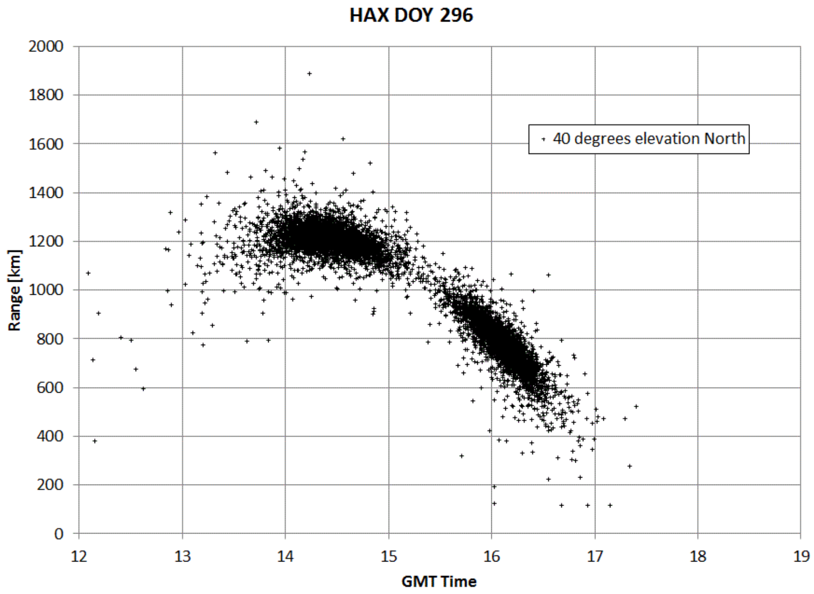
Probability Distribution







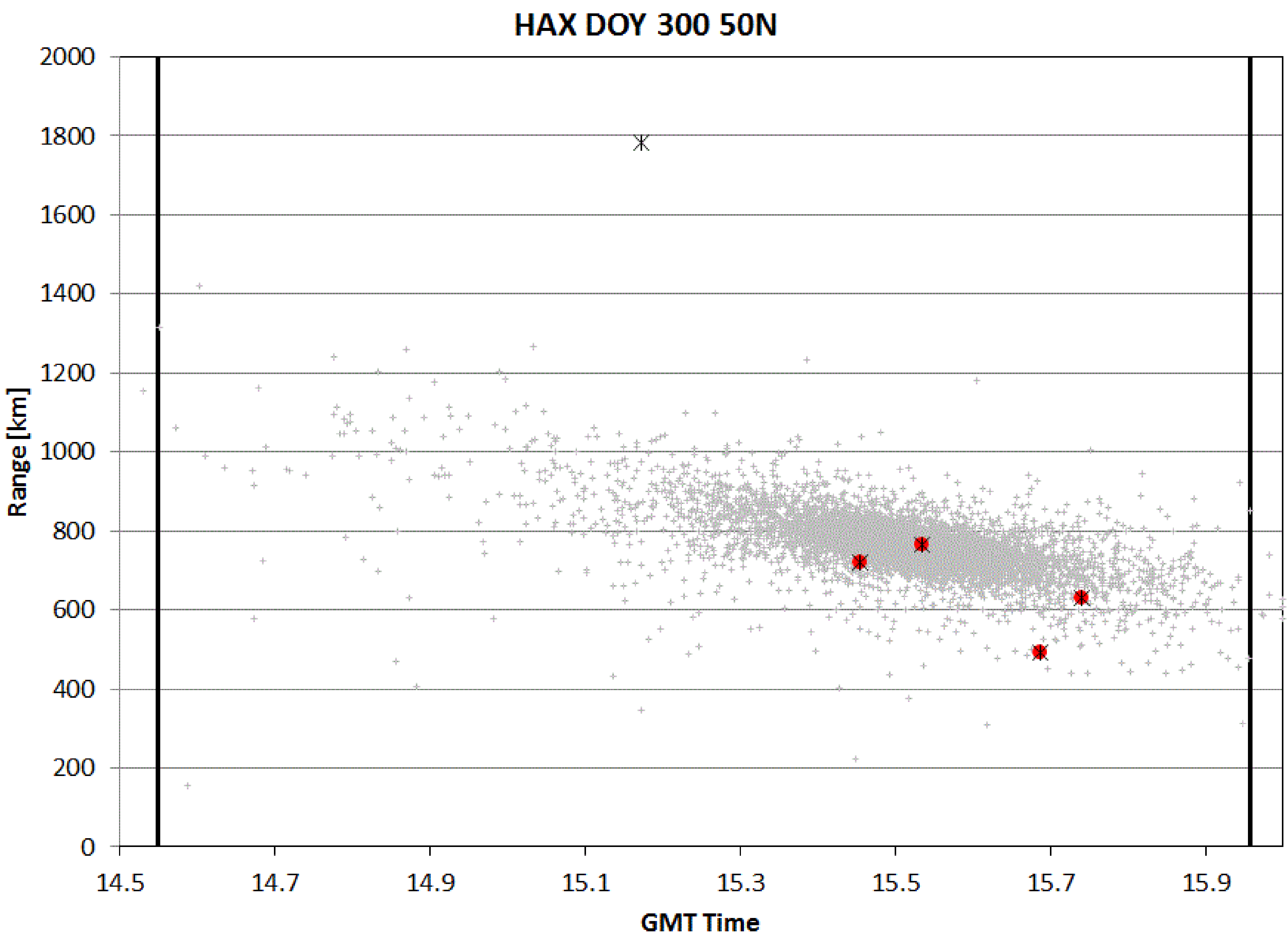


Candidate Identification

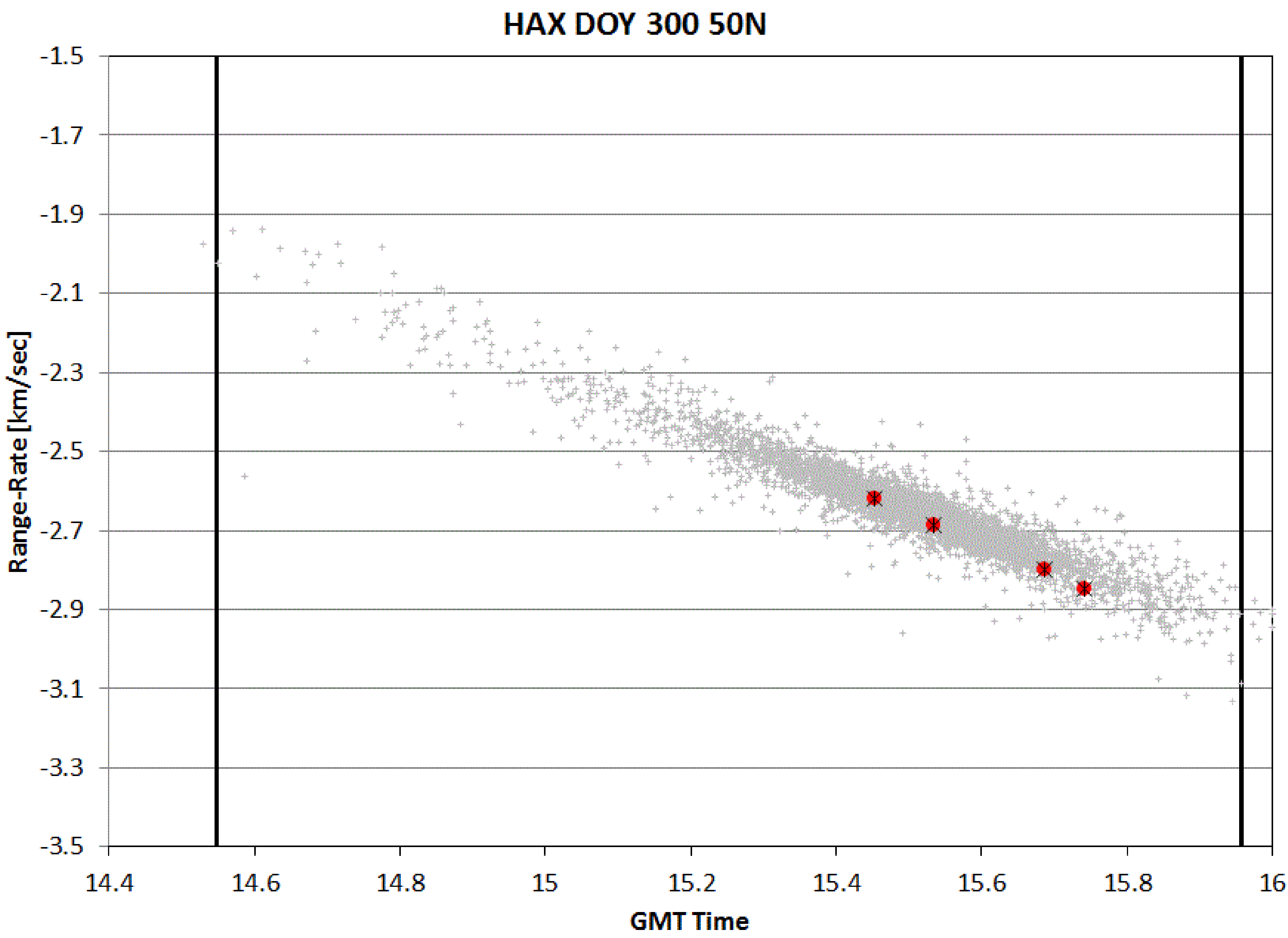
- **Potential cloud candidates identified by comparing both model and data patterns in three dimensions**
  - **Time**
  - **Range**
  - **Doppler Range-Rate**

- **In following graphs:**
  - **Grey points indicate the model predictions for all Monte Carlo cloud objects**
  - **Black stars represent HAX detections**
  - **Red dots represent detections assigned to the BRIZ-M cloud based on time/range/range-rate correlation**

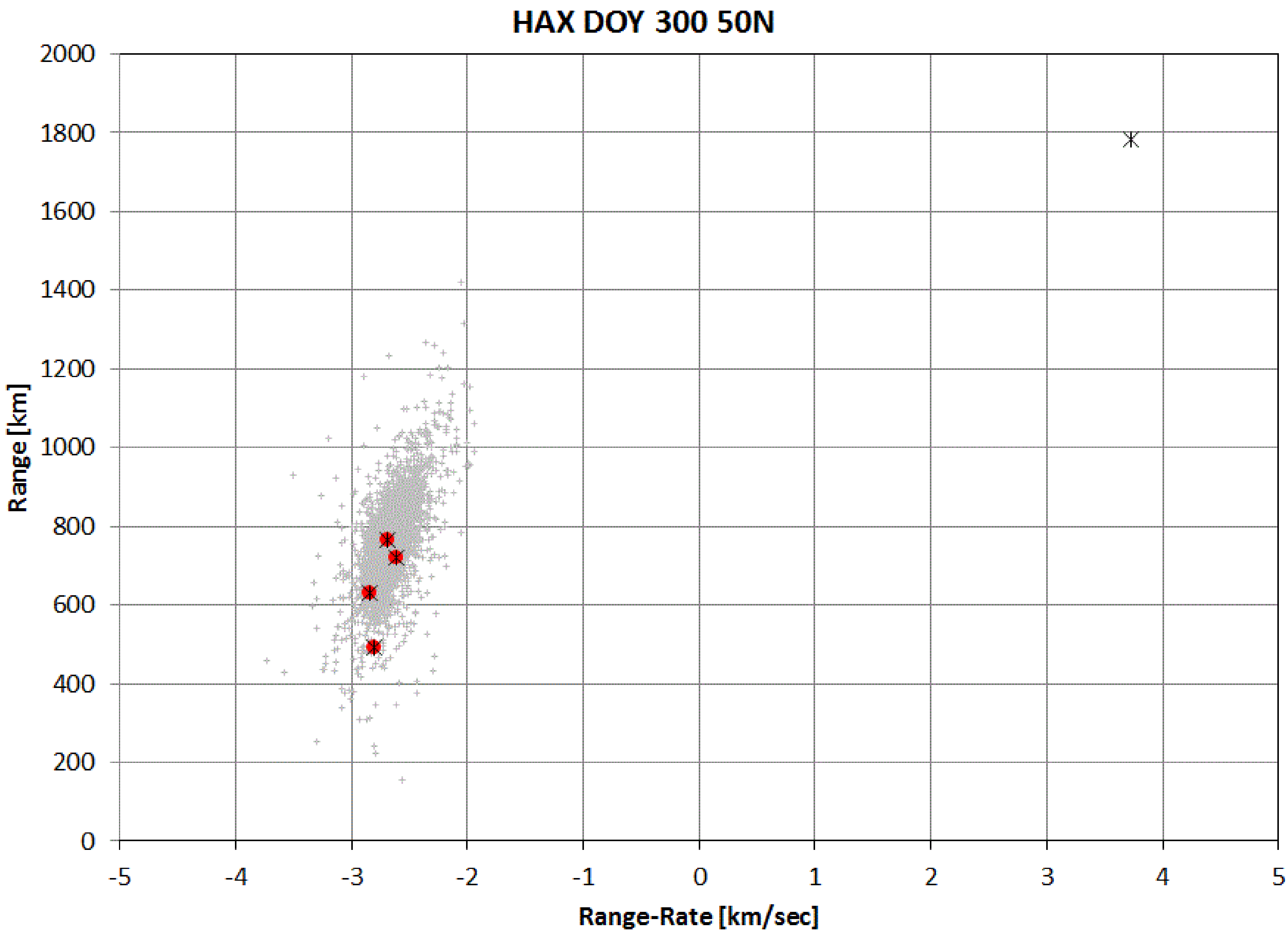
Candidate Identification



Candidate Identification

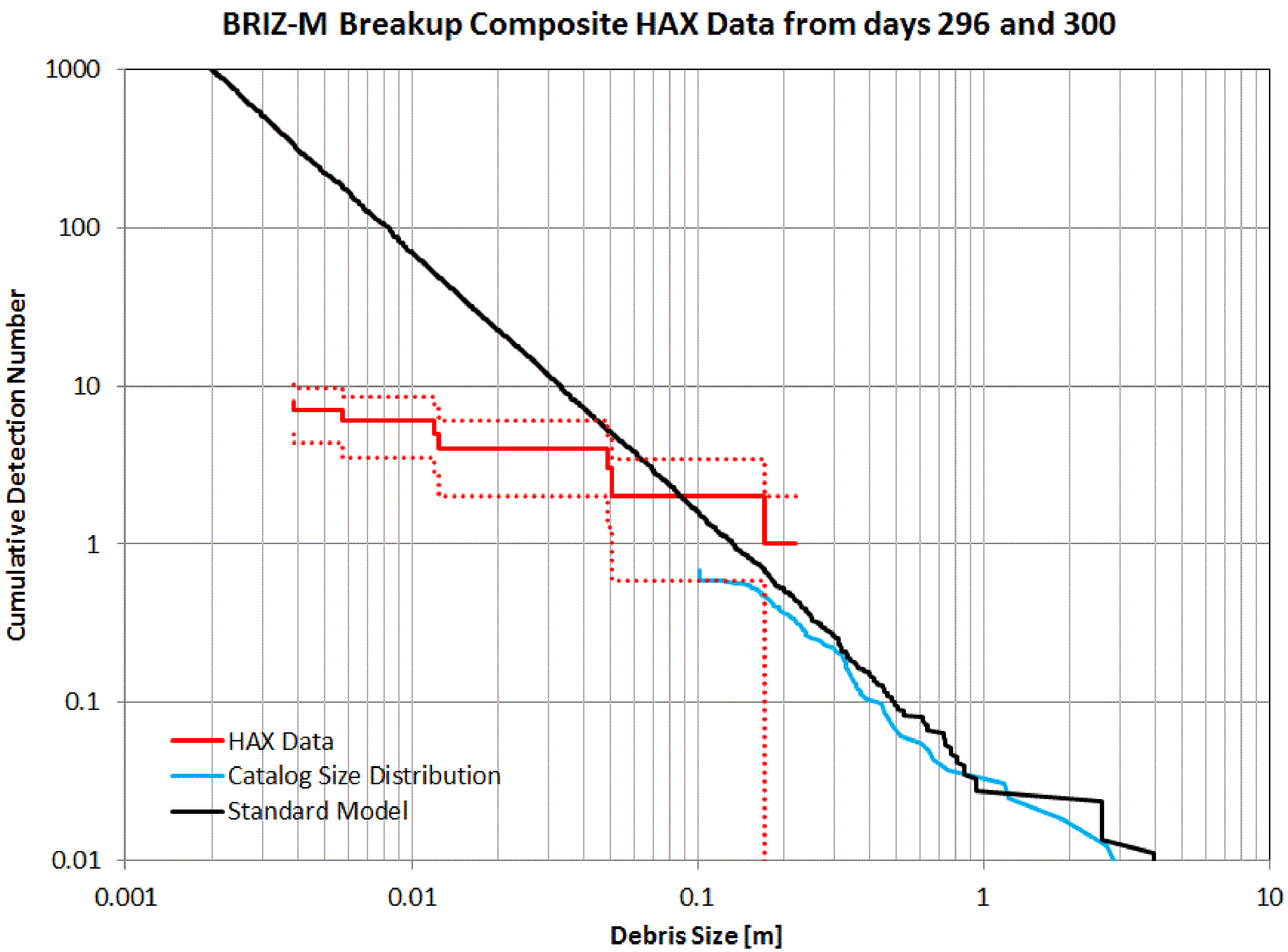


Candidate Identification



Size Distribution

- **Rate of detection of a particular size (RCS) is then compared to the model predicted population**



Conclusions

- **The NASA breakup model prediction was close to the observed population for catalog objects.**
- **The NASA breakup model predicted a larger population than was observed for objects under 10 cm.**
- **The stare technique produces low observation counts, but is readily comparable to model predictions.**
- **Customized stare parameters (Az, El, Range) were effective to increase the opportunities for HAX to observe the debris cloud.**
- **Other techniques to increase observation count will be considered for future breakup events.**