Conjunction Assessment Space Weather Needs

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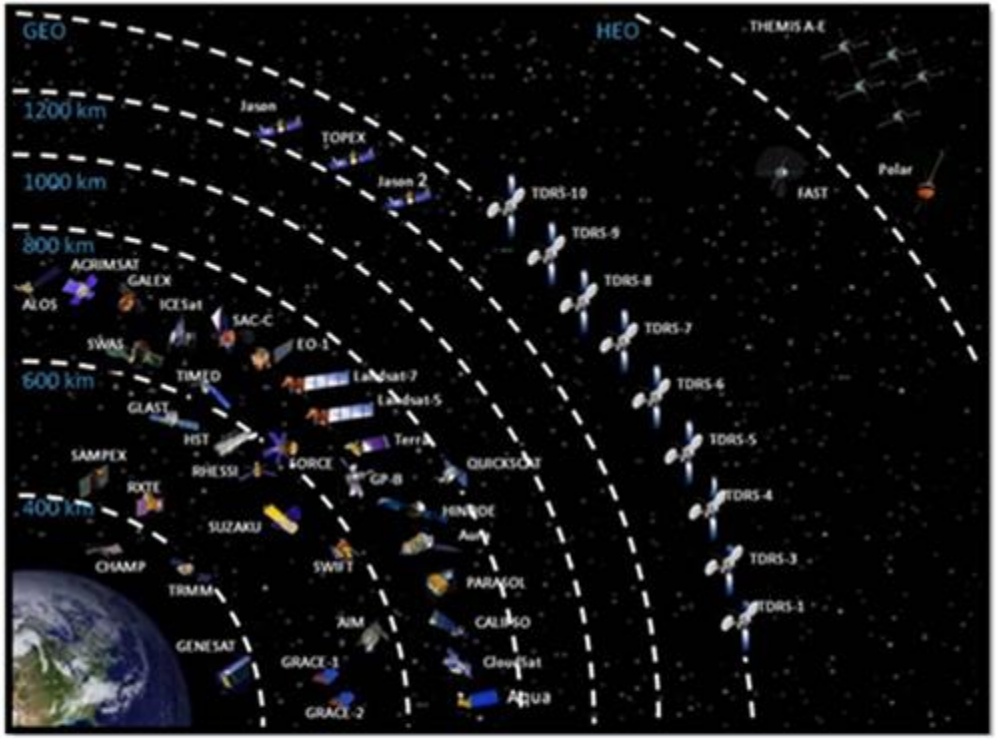
NASA Robotic Conjunction Assessment Risk Analysis (CARA)

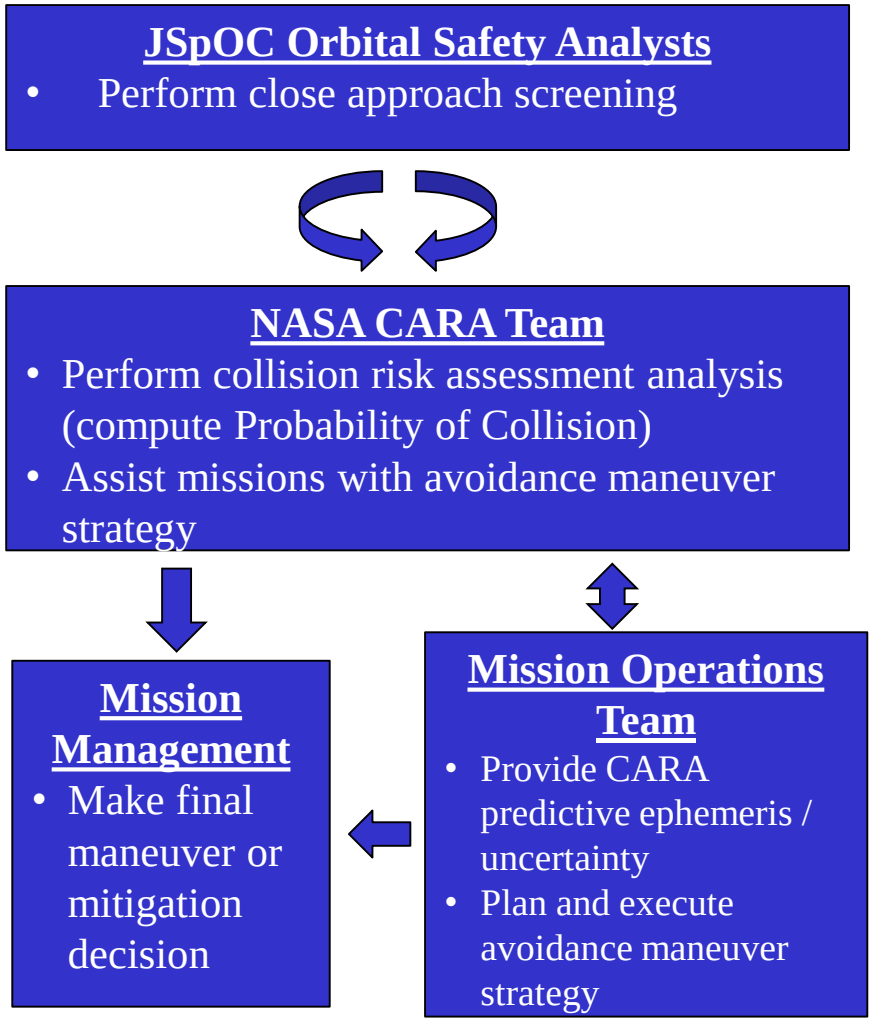
- CARA provides support to all operational NASA robotic missions
- Supports **67** missions, including
  - Earth Science Constellation
  - TDRSS
  - Hubble Space Telescope
- As well as a service to other agencies
  - NOAA for POES satellites
  - USAF for SBSS and DMSP satellites



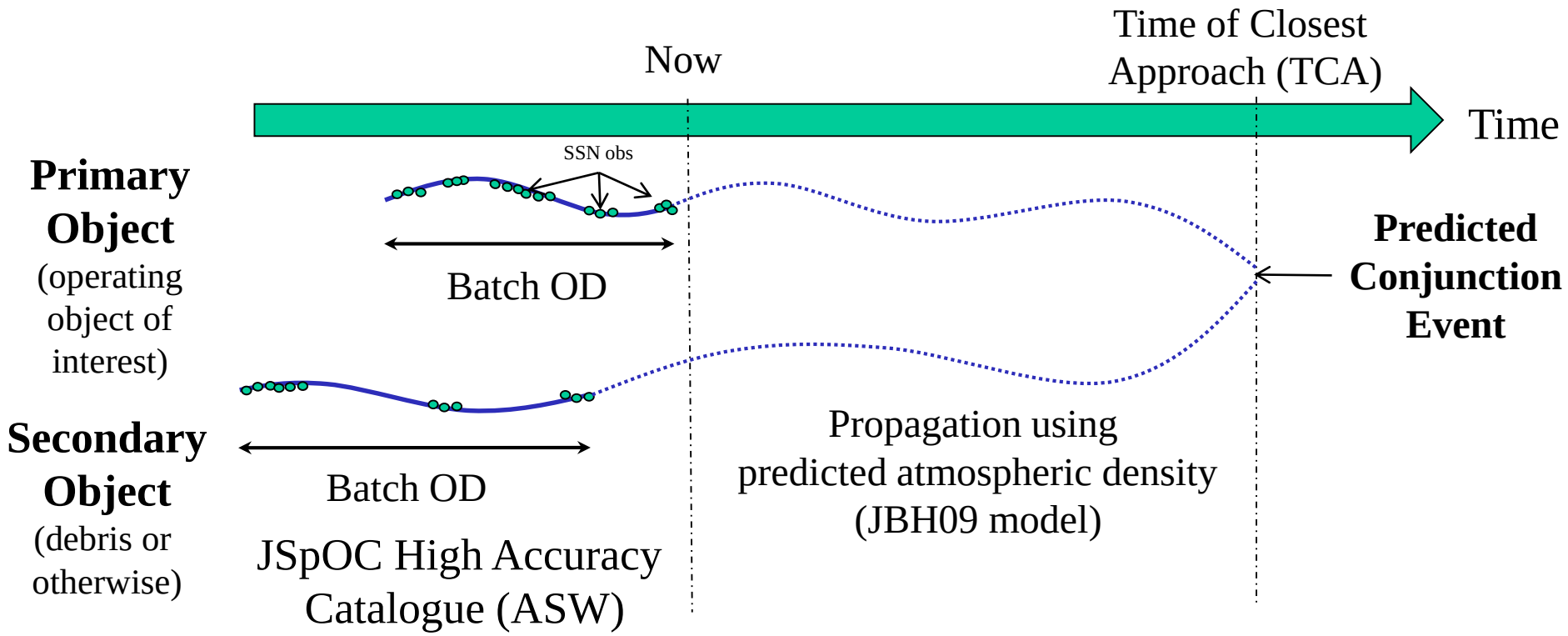
The Conjunction Assessment Risk Analysis mission at NASA GSFC is to protect NASA robotic assets from threats posed by other space objects while operating in the space environment through ensuring domain expertise, a robust concept of operations, and an operationally-responsive system to meet the expanding needs of the mission area

NASA Robotic Conjunction Assessment Risk Analysis (CARA)

- ***Conjunction Assessment Risk Analysis (CARA):*** Process of analyzing a conjunction event to determine the associated risk to the asset
- ***Conjunction***: Local minimum in the difference between the position components of two trajectories (closest point of approach)
- ***Time of Closest Approach (TCA):*** Epoch at which two objects in a conjunction are closest to each other.
- ***Probability of collision (Pc):*** One of the primary metrics used to indicate risk.

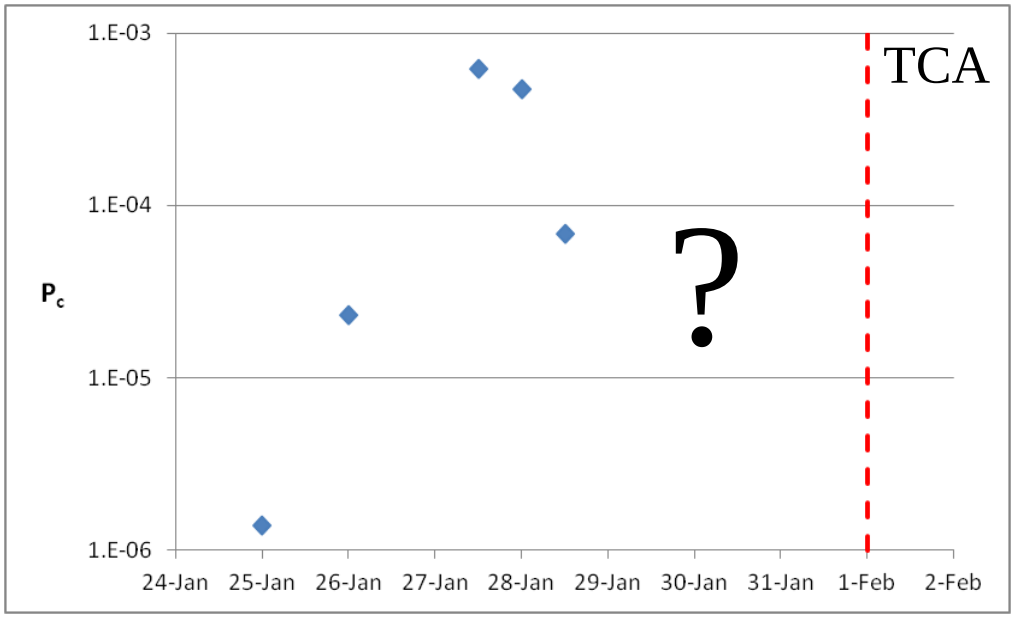


Accurate Propagation Requires Durable Atmospheric Density Estimates



- **Considerable amount of propagation**
  - This propagation requires atmospheric density estimation
  - Incorrect density predictions result in incorrect conjunction data

Accurate Conjunction Analysis Requires Space Weather Event Compensation



- **25 Jan**: First identification of possible conjunction with TCA on 1 Feb
- **27-28 Jan**: P_c increases to level of concern before starting to fall (looking safer)
- **29 Jan**: Alert of a Coronal Mass Ejection (CME) heading for Earth on 31 Jan

  - Would like to know if (and how) CME will impact conjunction event
  - Does the new space weather prediction make this event safer or riskier?
  - Might performing a maneuver make the conjunction event worse?

Jacchia-Bowman-HASDM-2009 (JBH09) Atmospheric Density Model

- **Default drag model used for ASW propagation at the JSpOC**
  - Updates/enhancements to many of the internal empirical models
  - Employs DCA for optimized performance during fit-span
- Went operational at the JSpOC on 3 June 2013
- **Accuracy Improvements over HASDM:**
  - Updated usage of solar and geomagnetic indices
    - Uses 11 solar indices instead of 3
    - Addition of Disturbance storm time (Dst) geomagnetic index
  - New equations for modeling variations and temperature profile
  - Accepts 6-day predictions of solar indices and employs them for propagations up to 6 days
  - Includes solar storm compensation feature
  - Improves accuracy of predictions up to 72 hours by 20-45%

JBH09 Advantages and Disadvantages

- **Advantages**
  - More capable than predecessors
  - Allows longer prediction times
  - Includes solar storm compensation
- **Disadvantages**
  - No output statement of uncertainty
    - Cannot take account of model error in conjunction analysis error budgeting
  - Still an empirical, rather than physics-based, model
    - Will always be limited in prediction and solar storm compensation

CARA Approach

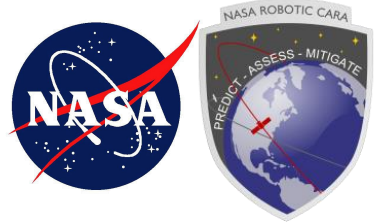
- Let the atmospheric model do the work
  - HASDM 2 / JBH09 actively models solar events
  - Frequent OCM generation, even in the absence of tracking, can model situation nicely (due to three-hour space weather index updates)
- Identify effects of model error on conjunction risk through a brute-force Pc trade space
  - Sensitivity of Pc to changing atmospheric density

Needed from Space Weather Community: JBH09 Error Profiling

- Uncertainties for non-perturbed (neutral) density prediction errors
- Uncertainties for space weather event compensation activities
- Knowing these will allow proper error bounds to be put on probability of collision (Pc) calculations for satellite conjunctions
  - Will better inform mitigation decisions

Needed from Space Weather Community: Space Weather Event Compensation

- JBH09 space weather event compensation, although a step forward, is still just a beginning
  - Addresses coronal mass ejection (CME) events only
  - Subject to inherent limits of empirical models
- For NASA conjunction assessment to work well in all circumstances, really need much better density predictions during solar events
  - Would allow more reliable and earlier resolution of conjunction events
- Probably requires a physics-based model



BACKUP

Predicting Dst

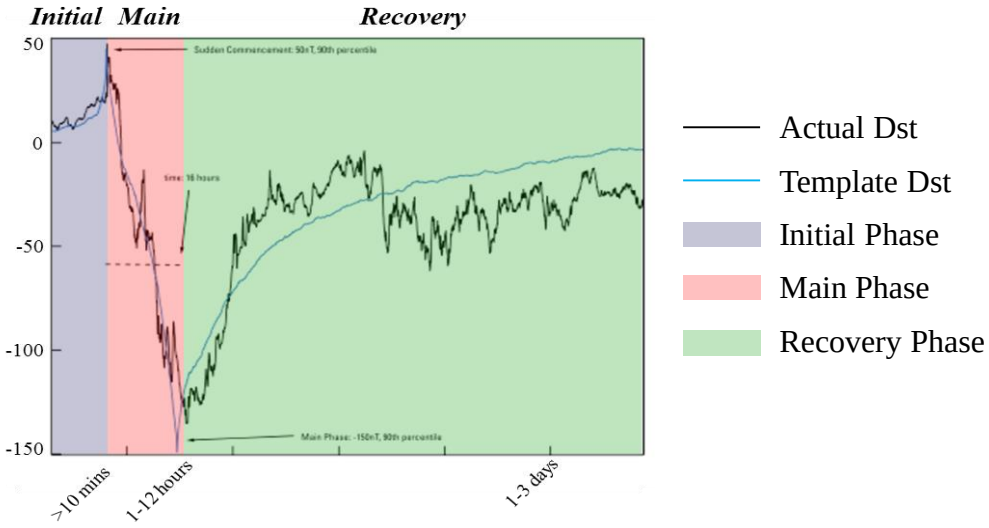
- In quiescent periods, typical averaging prediction techniques used
- For storm-related Dst prediction:
  - Heliolocation determines whether storm actually headed to Earth in a manner likely to be absorbed
  - Velocity estimate allows storm start time estimate
  - Predicted intensity allows storm severity to be assessed
- Many organizations perform this prediction
  - Rice University Space Institute—"A" stream for JSpOC
  - **Anemomilos model**—"B" stream for JSpOC and current main source
  - NOAA WSA-Enlil model—to be integrated into JSpOC also; will handle CIR as well as CME events

JBH09 Solar Storm Modeling (1 of 2)

- **Typical storm dynamics**
  - Initial peak in Dst indicates storm's beginning — can persist for several hours
  - "Main sequence" indicated by decrease in Dst with time until minimum reached (typically 1 – 12 hrs)
  - Recovery period (time to return to ambient Dst levels) — can be several days
- **Uses predicted Dst dataset to find storm inflection points**
  - Identifies major phases described above
  - Uses templating equations to construct anticipated storm behavior

JBH09 Solar Storm Modeling (2 of 2)

- Typical JBH09 Storm Profile Template:



- Storms can also follow/overlap
  - Morphology more difficult in such cases