

# Air Force Research Laboratory

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*Lead ~ Discover ~ Develop ~ Deliver*

## **Object Handoff: From Survey Telescope to Follow-up Telescope**



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Paul W Kervin, DRIV, AFRL/RDSMA

Directed Energy Directorate

Air Force Research Laboratory

Kihei, Hawaii, USA

**U.S. AIR FORCE**

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# Outline



- **Brief description of MCAT**
- **Survey telescopes**
- **Initial orbit estimation using short-arc data**
- **Raven telescope locations**



# Meter-Class Autonomous Telescope (MCAT)



- **Collaboration between NASA and Air Force Research Laboratory**
- **Improve knowledge of the debris environment in under-sampled orbit regimes**
  - Low Inclination / high eccentricity
  - Near geosynchronous



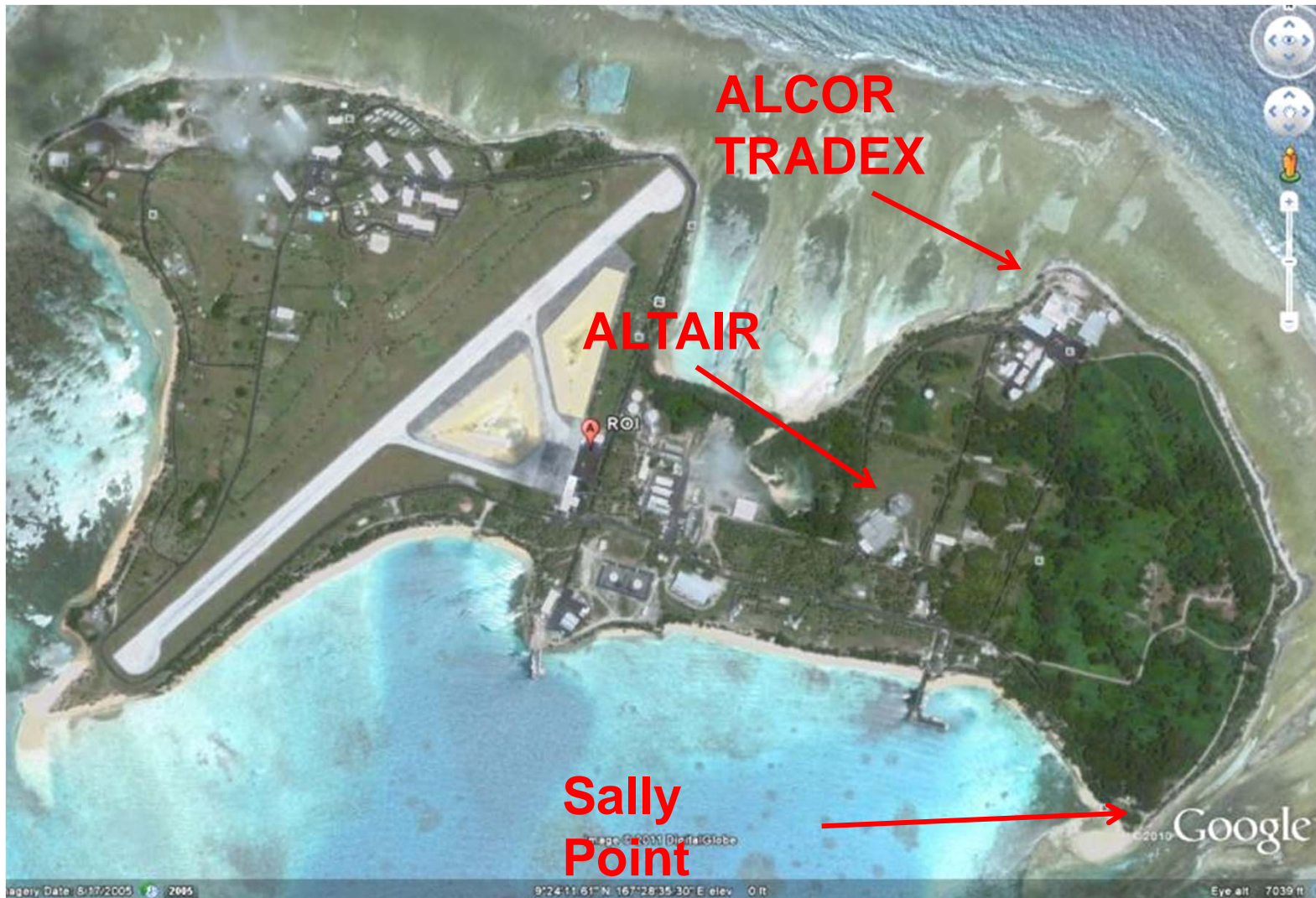


# MCAT Operations

- **Will initially operate as an independent sensor performing blind searches**
  - Orbit rate track during twilight for low inclination / low altitude / high eccentricity debris
  - Geo observations similar to MODEST
- **However, future plan for more complex operations**
  - Follow-up or simultaneous operations with the 14" scope on Roi-Namur
  - Task specific objects



# Roi-Namur



Slide courtesy of NASA: Status of the Meter Class Autonomous Telescope, Gene Stansbery et al





# Ascension Island



Slide courtesy of NASA: Status of the Meter Class Autonomous Telescope, Gene Stansbery et al



# Survey Telescopes



- **What is purpose of survey?**
  - Determine statistical nature of the population
  - or
  - Catalog the newly-detected objects
  - or
  - Both
- **What happens when new object is detected?**
  - Survey telescope continues survey, no follow up
  - or
  - Survey telescope breaks off survey to follow up
  - or
  - Survey telescope continues survey (makes statistics a little cleaner) and hands off new object to follow-up telescope
  - Choice depends on
    - Nature of survey
    - Quality of survey telescope and follow-up telescope



# Survey Telescopes



- **Survey telescopes usually optimized for search**
  - **Wide field of view (FOV) to search large volumes**
  - **Large aperture to detect faint objects**
  - **Achieving both simultaneously is difficult (expensive)**
  - **Examples**
    - **Panoramic Survey and Rapid Response System (Pan-STARRS)**
      - **1.8 meter aperture, 7 square degree FOV**
    - **Meter-Class Autonomous Telescope (MCAT)**
      - **1.3 meter aperture, 1 square degree FOV**
- **Compare with**
  - **Raven-class telescope**
    - **0.4-meter aperture, 0.1 square degree FOV**
  - **AEOS telescope**
    - **3.6-meter aperture, 0.003 square degree FOV**





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**Raven looks like a  
search telescope**



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**Raven looks like a follow-up telescope**



# Orbit estimation using short-arc optical data



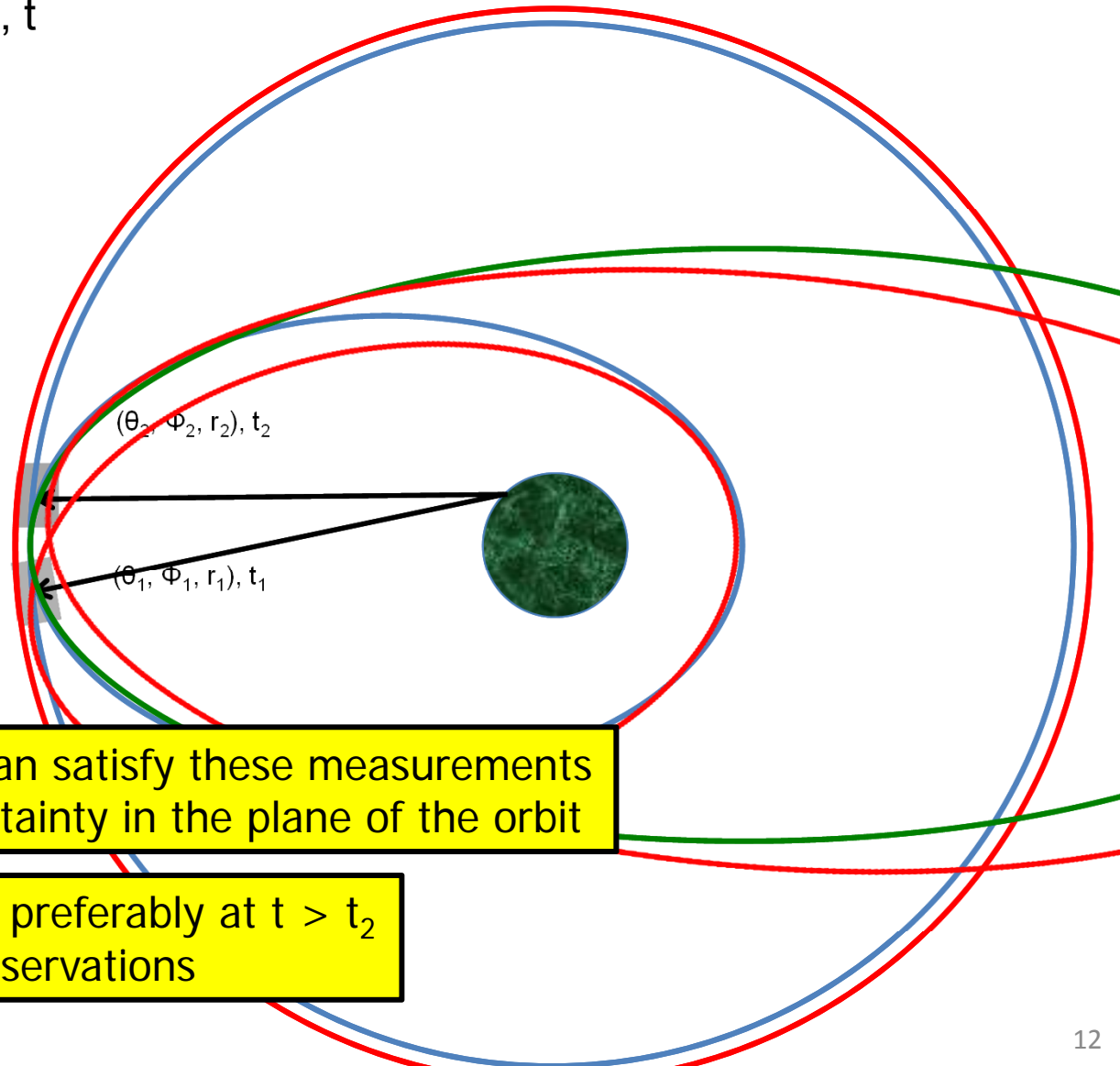
- **Concept of Operations determines length of observation**
- **Duration of observation will be short compared to orbital period**
  - **Typical observations from 15 seconds to 5 minutes**
  - **Orbital periods from 90 minutes to ~24 hours**
  - **Very little of orbit is actually sampled**
- **Many orbits can be consistent with short observations**
- **Particularly true for optical (angles-only) observations**



# Orbit Uncertainty with Measurement Errors Angles plus Range



Observations include:  $(\theta, \Phi, r), t$



**Problem:** Even more orbits can satisfy these measurements  
There is now uncertainty in the plane of the orbit

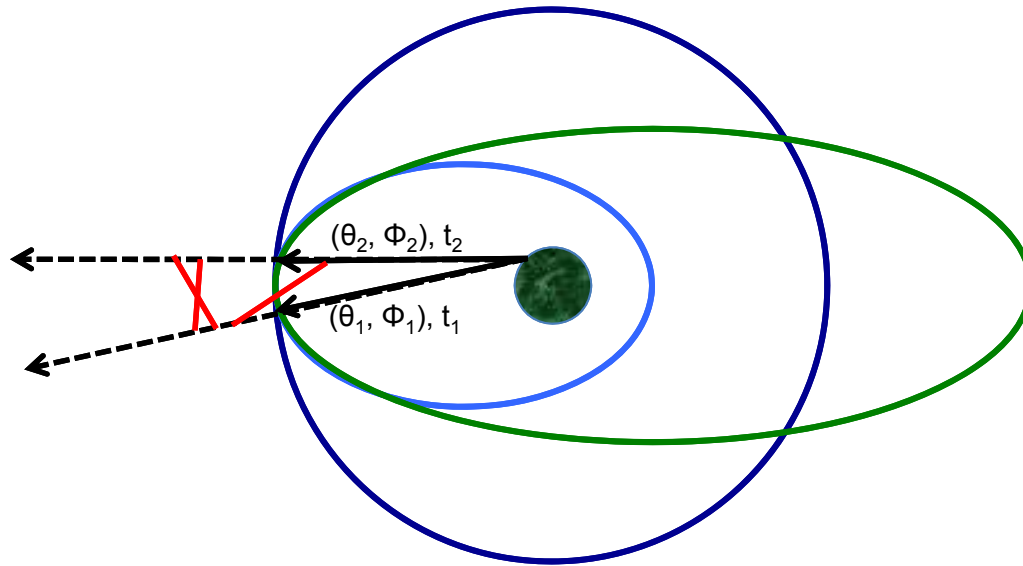
**Solution:** More observations, preferably at  $t > t_2$   
Higher accuracy observations



# Orbit Uncertainty Angles Only



Observations include:  $(\theta, \Phi, \textcolor{red}{r}), t$



Problem: MANY more orbits can satisfy these measurements

Solution: More observations, preferably at  $t > t_2$

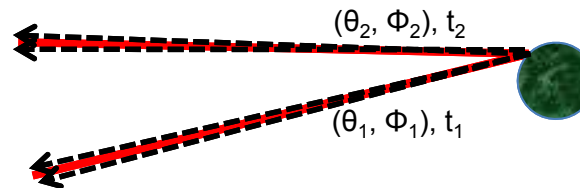




# Orbit Uncertainty with Measurement Errors Angles Only



Observations include:  $(\theta, \Phi, \neq), t$

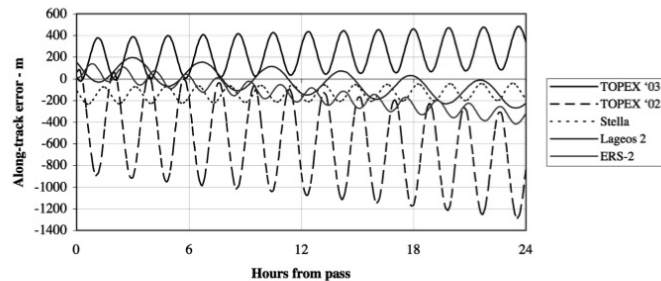


- Dramatic increase in number of possible orbits
  - Including uncertainty in orbital plane
- Does angular rate help?
  - Observed vectors are topocentric
  - Can't determine geocentric vectors without range
  - Angular rate is really the projected angular rate in the plane perpendicular to the line of sight
- Circular orbit is often assumed for initial guess
  - May be fairly reasonable assumption for near-geo orbits
  - A bad assumption for high-eccentricity orbits

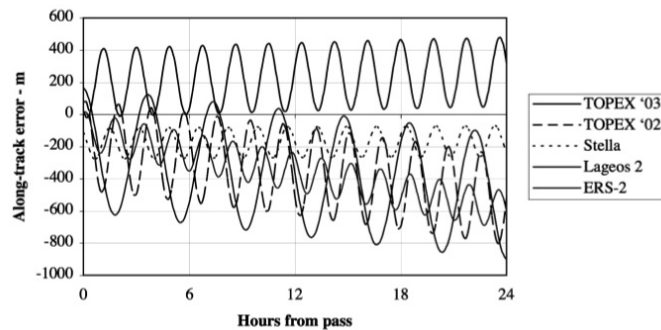


# Observations and Error Growth

- Solution: make more observations
  - When?
  - Where?
- What about error growth?



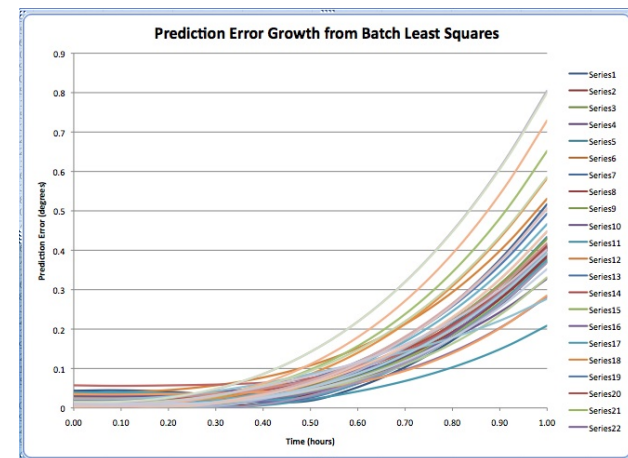
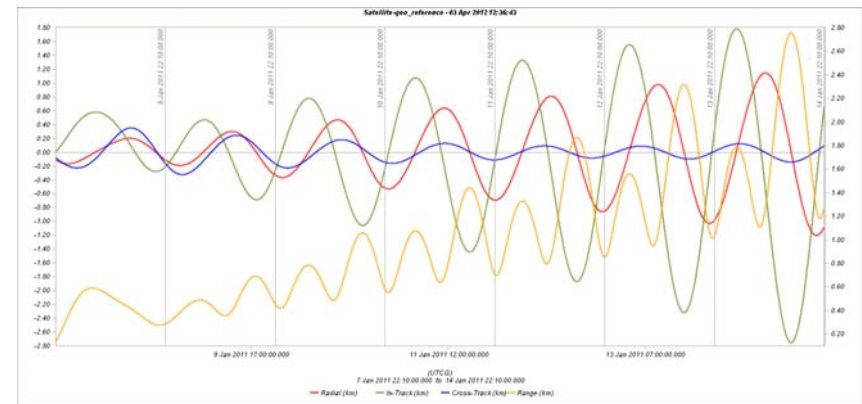
**Fig. 10 Orbit update along-track prediction error using PCE differences as the uncertainty.**



**Fig. 11 Orbit update along-track prediction error using calculated uncertainty.**

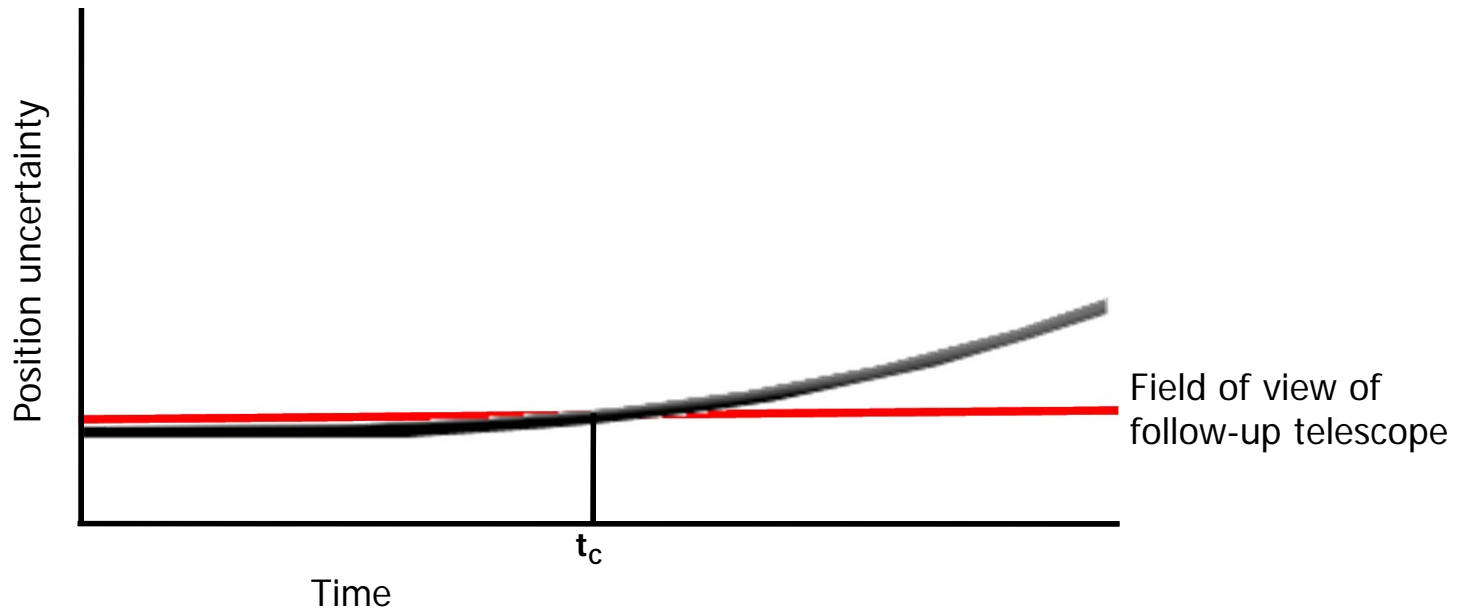
Angles-Only Orbit Updates for Low-Earth-Orbit Satellites

Chris Sabelfeld  
Air Force Research Lab, Kirtland AFB, NM 87117  
Kurt T. Althoff  
Space & Astronautics, College Station, Texas 77843-3147  
David Russell  
University of Colorado Boulder, Colorado 80509  
1998-02-01/2008





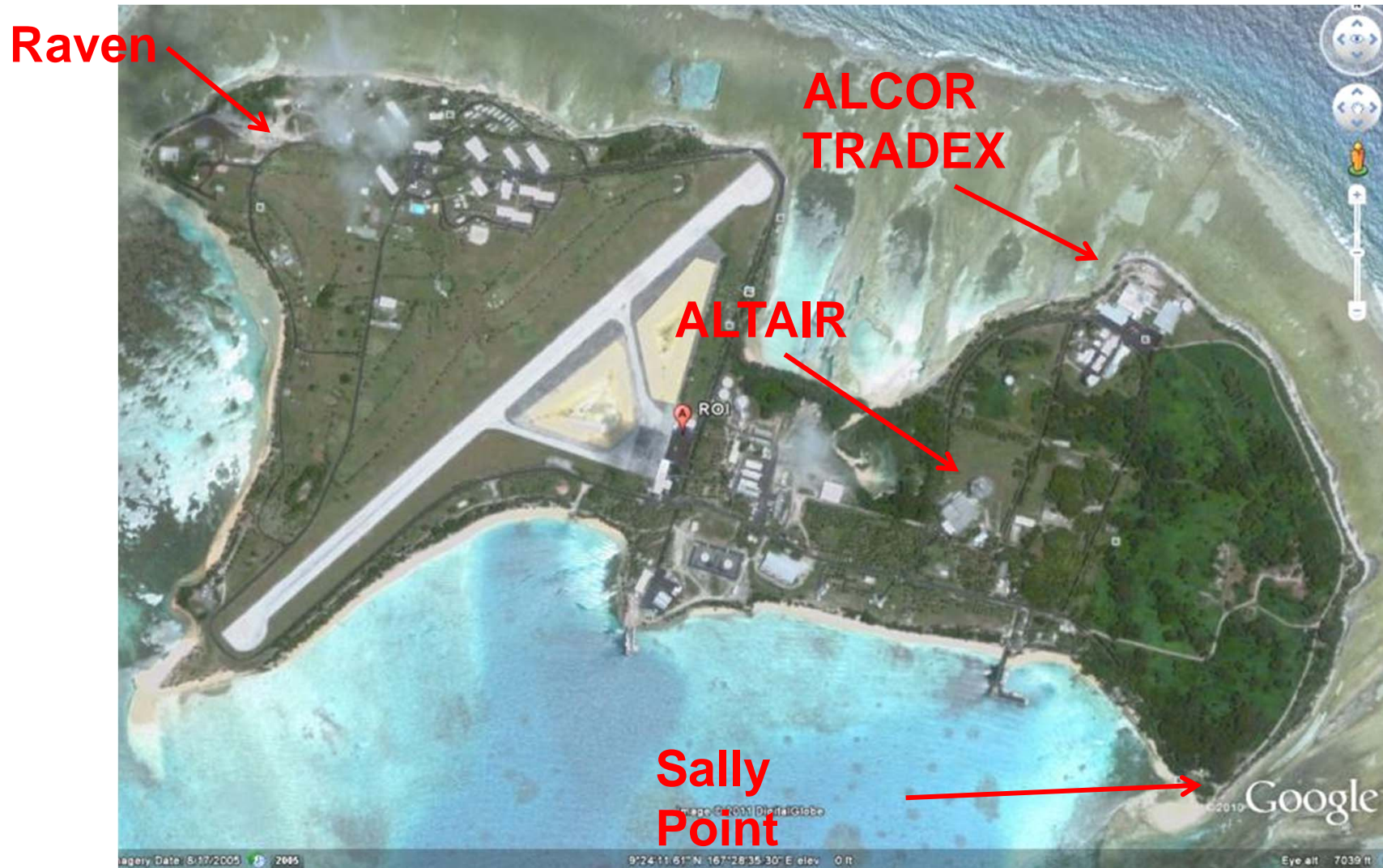
# Generic Error Growth



- $t_c$ , critical time, is usually measured in minutes
- Very dependent on type of orbit and quality of observations
- Follow-up telescope should be physically near the survey telescope



# Roi-Namur



Slide courtesy of NASA: Status of the Meter Class Autonomous Telescope, Gene Stansbery et al





# Raven Telescopes



- **What it is**
  - **A paradigm: Commercial off-the-shelf (COTS) solutions**
  - **Goal-driven: What is the mission, what is desired data product?**
  - **Deliverable: Cost-effective COTS-based optical systems**
- **What is is not:**
  - **A specific telescope/mount/sensor combination**







# Raven Telescope Locations





# Comments



- **Many object orbits can be consistent with optical short-arc observations**
- **Refining the orbit takes additional observations**
- **Rapid follow up is critical for orbit determination**
- **Follow up must be done rapidly**