Imaging Science Requirements for a Uranus Flagship Mission

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Background: Voyager 2 Image of Uranus (NASA Image Release PIA00143)

Goals of this talk

- Review process to determine imaging instrument requirements.
- Focus on:
  - Field of View
  - Resolution
  - Number of instruments
- Use Decadal UOP Mission Design as an example

Imaging Science Objectives

Uranus Atmospheric Science
- Cloud Morphology/Evolution, Vertical Structure
- Wind Measurements
- Cloud/Haze Aerosol Properties
- Energy Balance

Satellite Interiors
- Shape reflects internal density structure / oceans
- Rotational State/Libration

Magnetospheric Interactions
- Aurora Dynamics
- Response to Solar Wind
- Auroral footprints of Satellites

Satellite Origins
- Identify/Map Origin Markers, e.g. organics
- Reveal how moons formed (in circumplanetary disk, rings, ejecta of giant impacts…)

Rings and Small Moons
- Search for small moons
- Determine particle composition & size distribution
- Understand collisional history
- Reveal fine scale structures
- Characterize current dynamical state

Satellite Geology
- Topography / Stereo Imaging
- Crater distribution/morphology
- Tectonic & Cryovolcanic Features
- Geologic History
- Resurfacing / Thermal Evolution

Measurement Requirement Summary (From UOP Decadal Study)

Uranus:

- Imaging: 50 km/pix
- VIS/NIR*: 500 km/pix

Rings/Small Moons:

- Imaging: 0.1 km/pix
- VIS/NIR*: 1 km/pix

Major Satellites:

- Imaging: 0.5 km/pix
- VIS/NIR*: 3 km/pix

- *VIS/NIR is an Imaging Spectrometer
- *7 nm spectral resolution is sufficient (Cassini VIMS-like)

Determining Imaging Science Instrument Requirements

Instrument Performance
- Field of View (FOV)
- Resolution
- Wavelength Range
- How many / Which filters?
- Spectral Resolution

How many imaging instruments?
- Wide Angle Camera
- Narrow Angle Camera
- VIS/NIR Mapping Spectrometer

Scope of this presentation: ~300 nm – 5 µm, see next talk by Becker et al. for UV observations – synergy and overlap with UV instrument should also be explored.

Decadal UOP Study Notional Instruments
- Narrow Angle Camera
  - Heritage: New Horizons LORRI
    - Resolution: 10 µrad/pix
    - FOV: 10 mrad (0.6 deg)
    - Panchromatic / 5 filters?
- Wide Angle Camera
  - Heritage: Lucy L'Ralph MVIC
    - iFOV: 50 µrad/pix
    - FOV: 8.3×0.85 degree
    - 5 Filters in 400 nm – 1000 nm
- NIR Imaging Spectrograph
  - Heritage: Lucy L'Ralph LEISA
    - iFOV: 250 µrad/pix
    - FOV: 4.6×3.2 degree
    - 1472 Channels in 1.0 – 5.0 µm

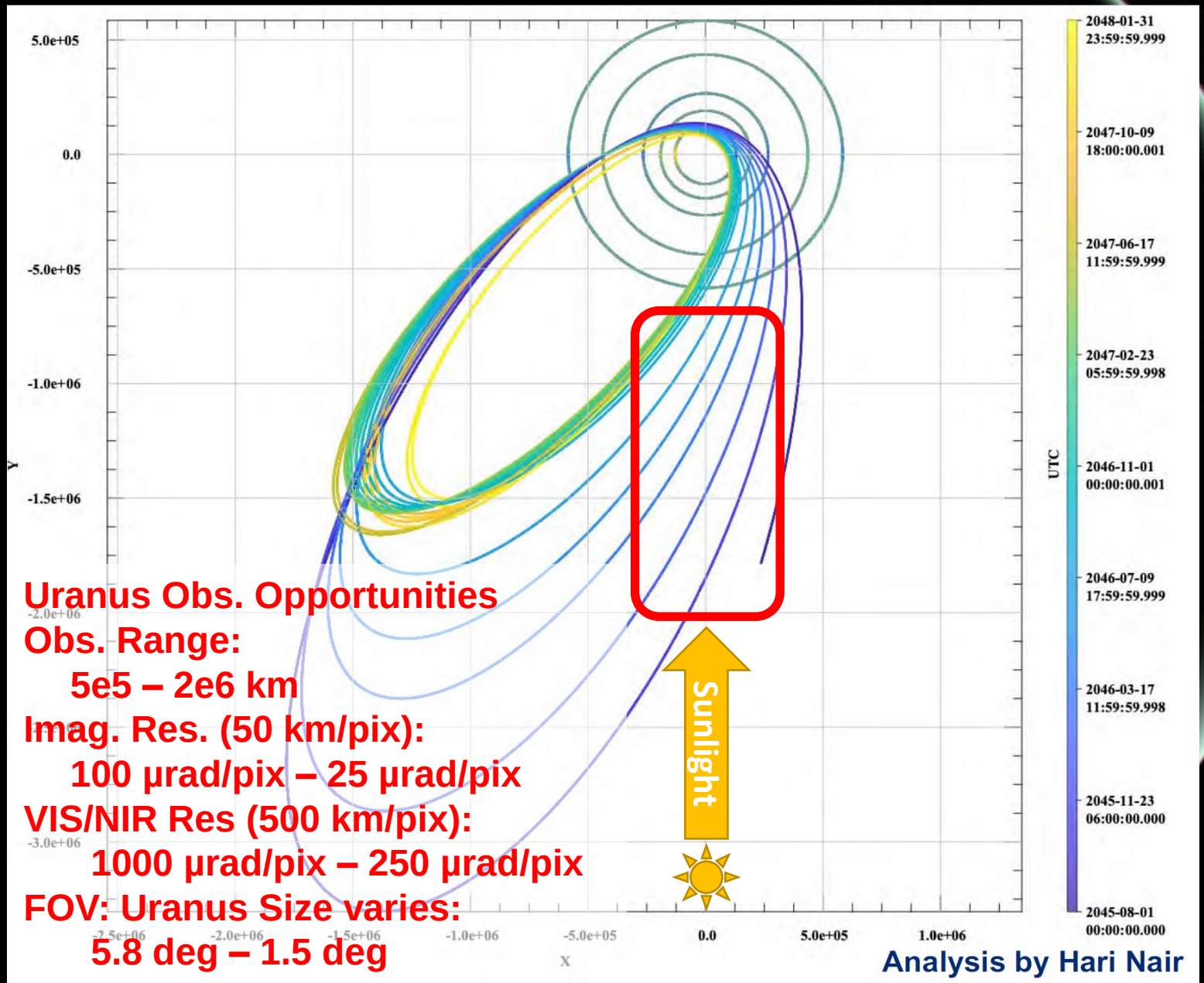
From Simon et al. (2021, UOP Decadal Report)

Uranus Imaging Opportunities (Based on Decadal UOP orbits)

Decadal UOP Orbits:

- Good: low phase angle imaging opportunities for wind measurements
- Good: Global mapping (w/ wind) with 30-hour imaging coverages (x2 rotations), which cannot be done near periapsis

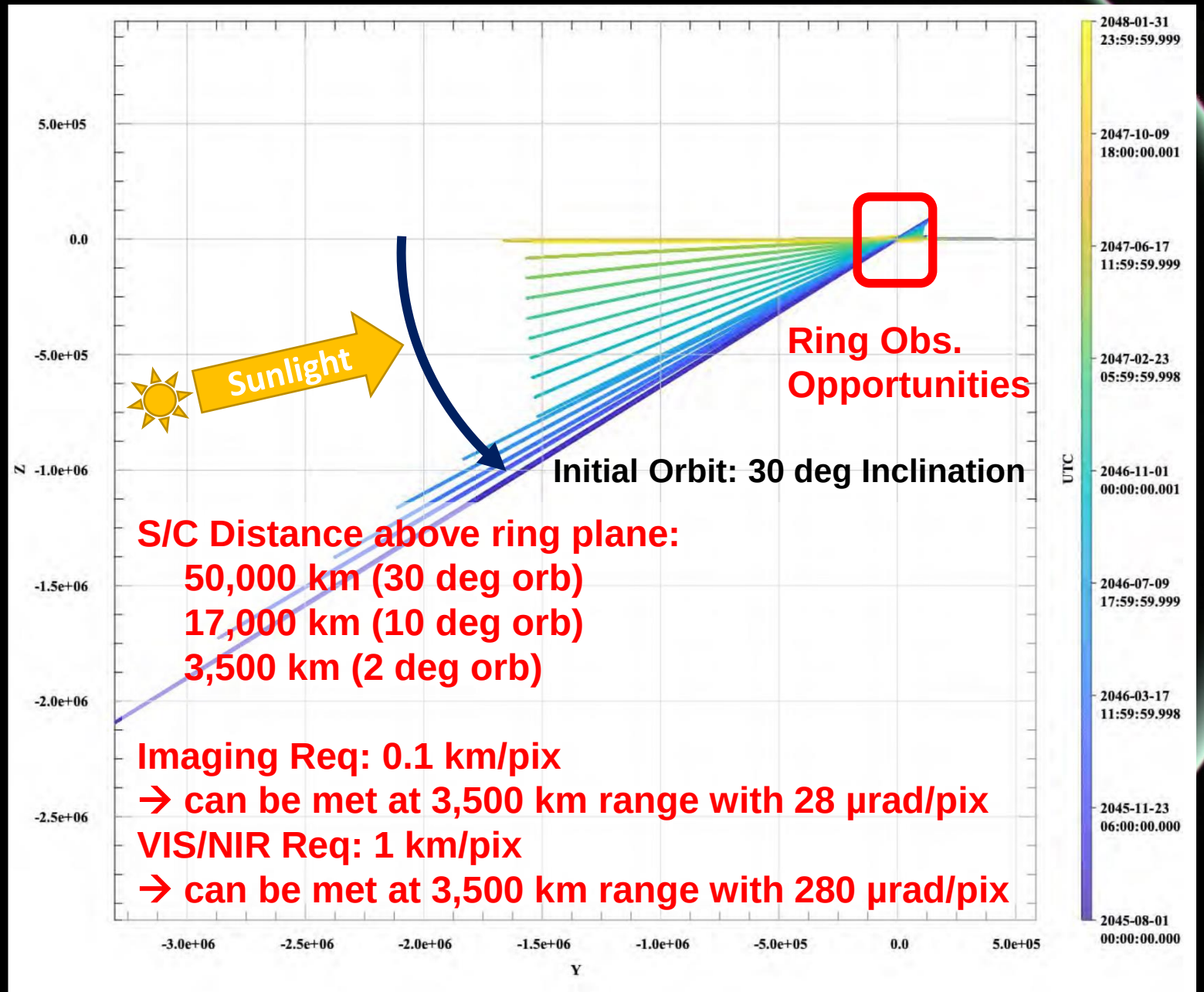
- Not great: Limited views of the night side may affect aurora imaging, energy balance measurements, lightning search …



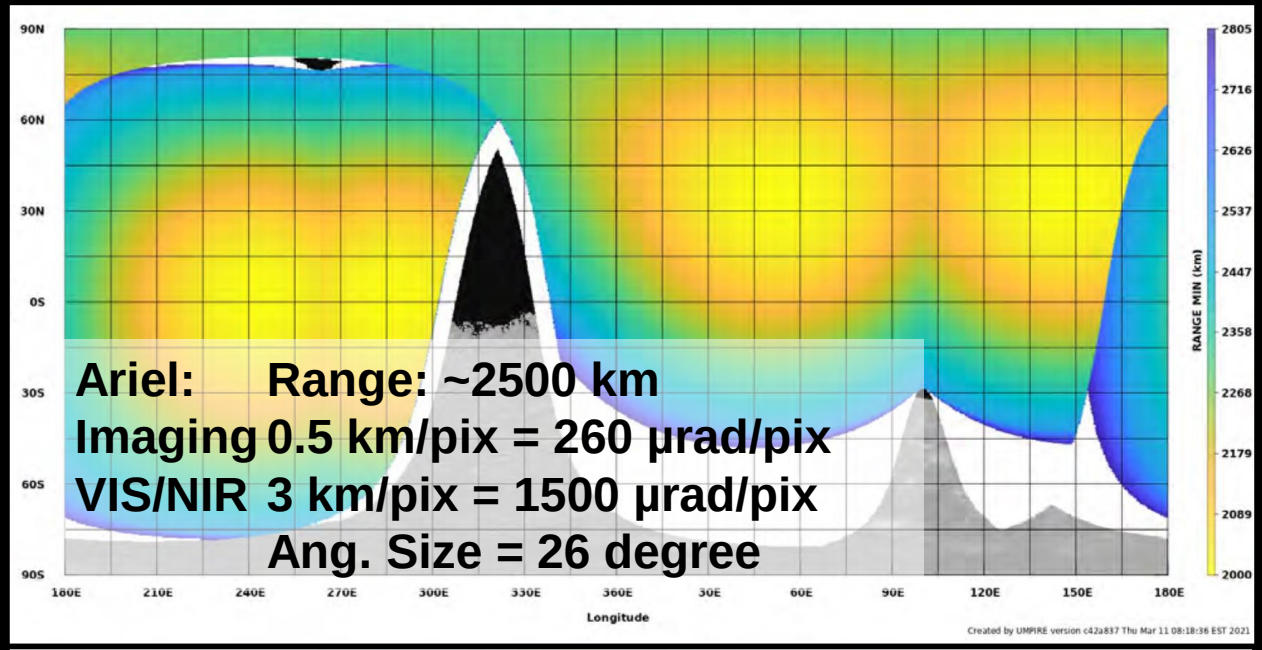
Rings Imaging Opportunities (Based on Decadal UOP orbits)

Data Volume Concern?

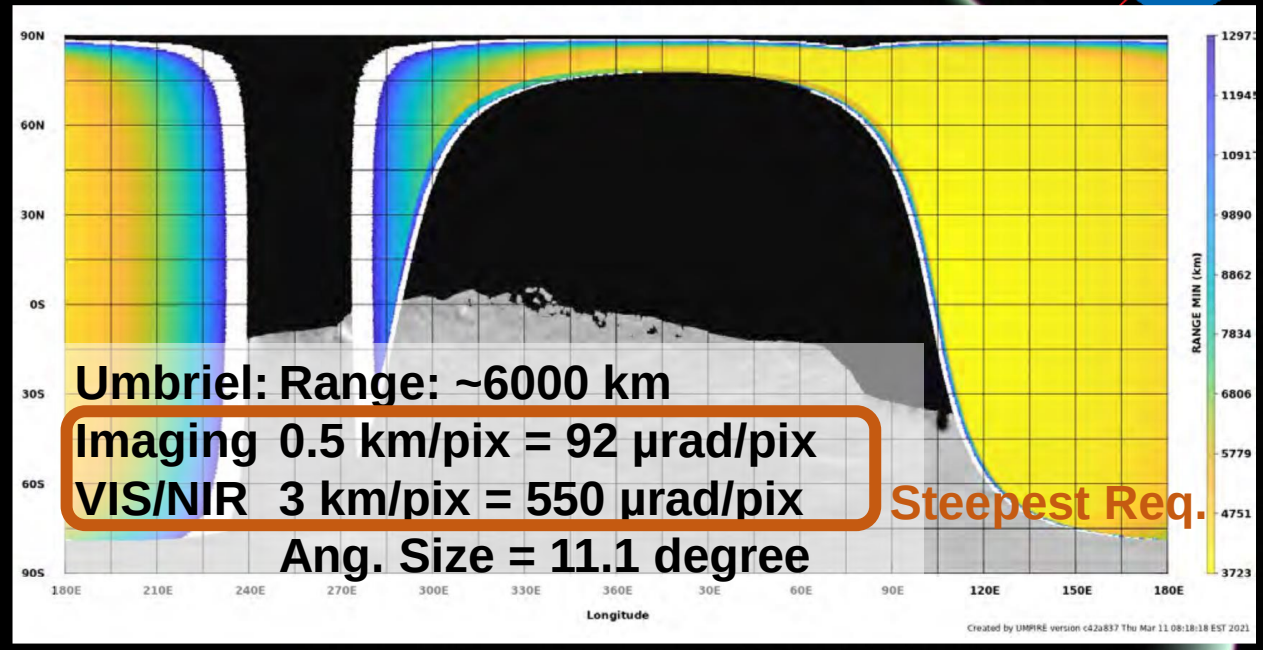
- Req. to map the entire ring system to 500,000 km from center of planet at 0.1 km/pix resolution will require ~157 TB of data! (assuming 16 bit/pix)
- Mapping at 1 km/pix will require ~1.6TB.



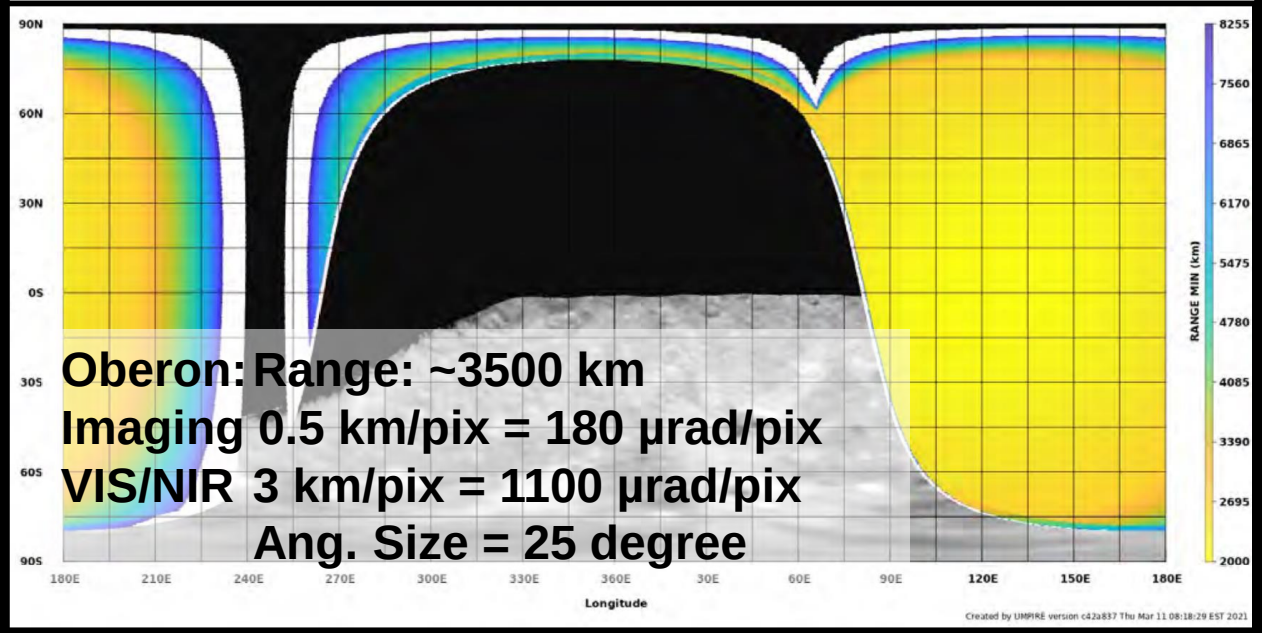
Major Satellites – Flyby Ranges in UOP Decadal Orbits



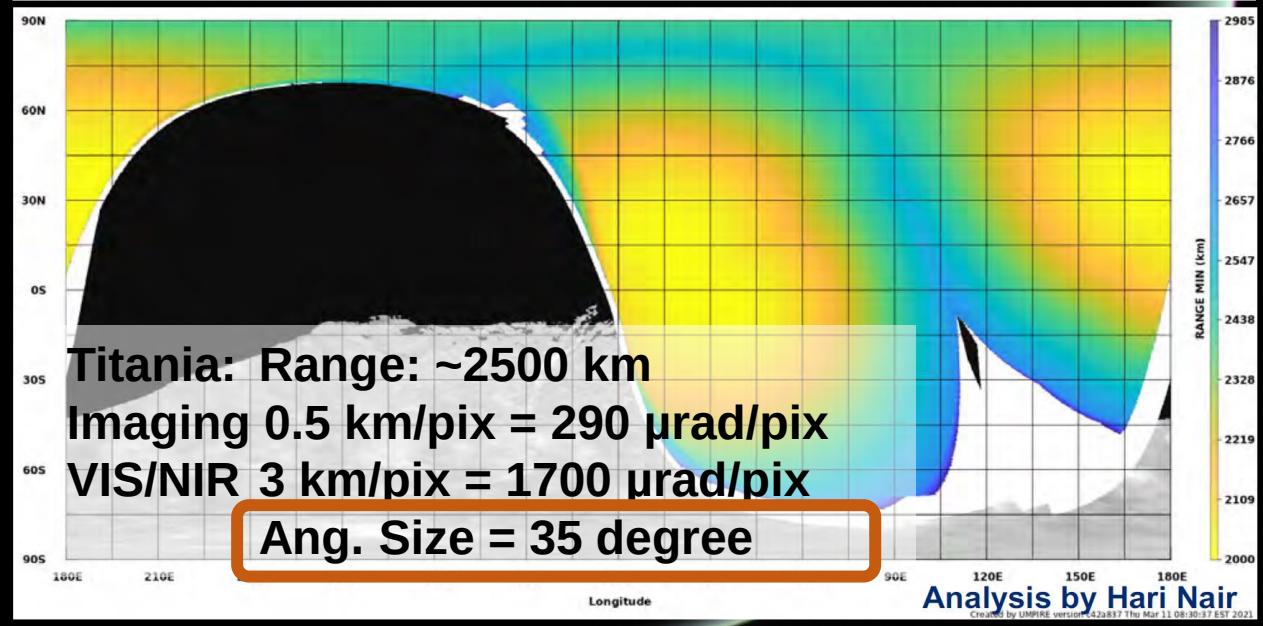
Ariel: Range: ~2500 km
Imaging 0.5 km/pix = 260 µrad/pix
VIS/NIR 3 km/pix = 1500 µrad/pix
Ang. Size = 26 degree



Umbriel: Range: ~6000 km
Imaging 0.5 km/pix = 92 µrad/pix
VIS/NIR 3 km/pix = 550 µrad/pix
Steepest Req.
Ang. Size = 11.1 degree



Oberon: Range: ~3500 km
Imaging 0.5 km/pix = 180 µrad/pix
VIS/NIR 3 km/pix = 1100 µrad/pix
Ang. Size = 25 degree



Titania: Range: ~2500 km
Imaging 0.5 km/pix = 290 µrad/pix
VIS/NIR 3 km/pix = 1700 µrad/pix
Ang. Size = 35 degree

Analysis by Hari Nair

Synthesizing Resolution and FOV Req's for Different Targets

Uranus:

- Imager Res: 25 µrad/pix (50 km/pix from 2e6 km)
- VIS/NIR Res: 250 µrad/pix (500 km/pix from 2e6 km)
- FOV: 3 degree (1/2 Uranus in FOV at 500,000 km range)

Rings and Small Moons:

- Imager Res: 28 µrad/pix (0.1 km/pix from 3500 km)
- VIS/NIR Res: 280 µrad/pix (1 km/pix from 3500 km)

Major Satellites:

- Imager Res: 92 µrad/pix (0.5 km/pix from 6000 km)
- VIS/NIR Res: 550 µrad/pix (3 km/pix from 6000 km)
- FOV: >10 degree (<4x4 mosaic to cover 40 deg^2)

NAC:

- Resolution <25 µrad/pix
- FOV: >3 degree

WAC:

- Resolution <92 µrad/pix
- FOV: >10 degree

VIS/NIR:

- Resolution: 250 µrad/pix
- FOV: >10 degree
- Spec. Res: 7 nm

Comparison with Notional Instruments and Cassini Instruments

This Talk

NAC:

- Resolution <25 µrad/pix
- FOV: >3 degree

WAC:

- Resolution <92 µrad/pix
- FOV: >10 degree

VIS/NIR Imaging Spectrograph:

- Resolution: 250 µrad/pix
- FOV: >10 degree
- Spec. Res: 7 nm

Decadal UOP Study Notional Instruments

NAC:

- Heritage: New Horizons LORRI
- Resolution: 10 µrad/pix
- FOV: 0.6 deg
- Panchromatic / 5 filters?

WAC:

- Heritage: Lucy L'Ralph MVIC
- iFOV: 50 µrad/pix
- FOV: 8.3×0.85 degree
- 5 Filters in 400 nm – 1000 nm

VIS/NIR Imaging Spectrograph:

- Heritage: Lucy L'Ralph LEISA
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From Simon et al. (2021, UOP Decadal Report)

Cassini

ISS NAC

- Resolution: 6 µrad/pix
- FOV: 0.35 deg
- 24 filters in 200 nm – 1050 nm

ISS WAC

- iFOV: 60 µrad/pix
- FOV: 3.5 degree
- 18 Filters in 380 nm – 1050 nm

VIMS

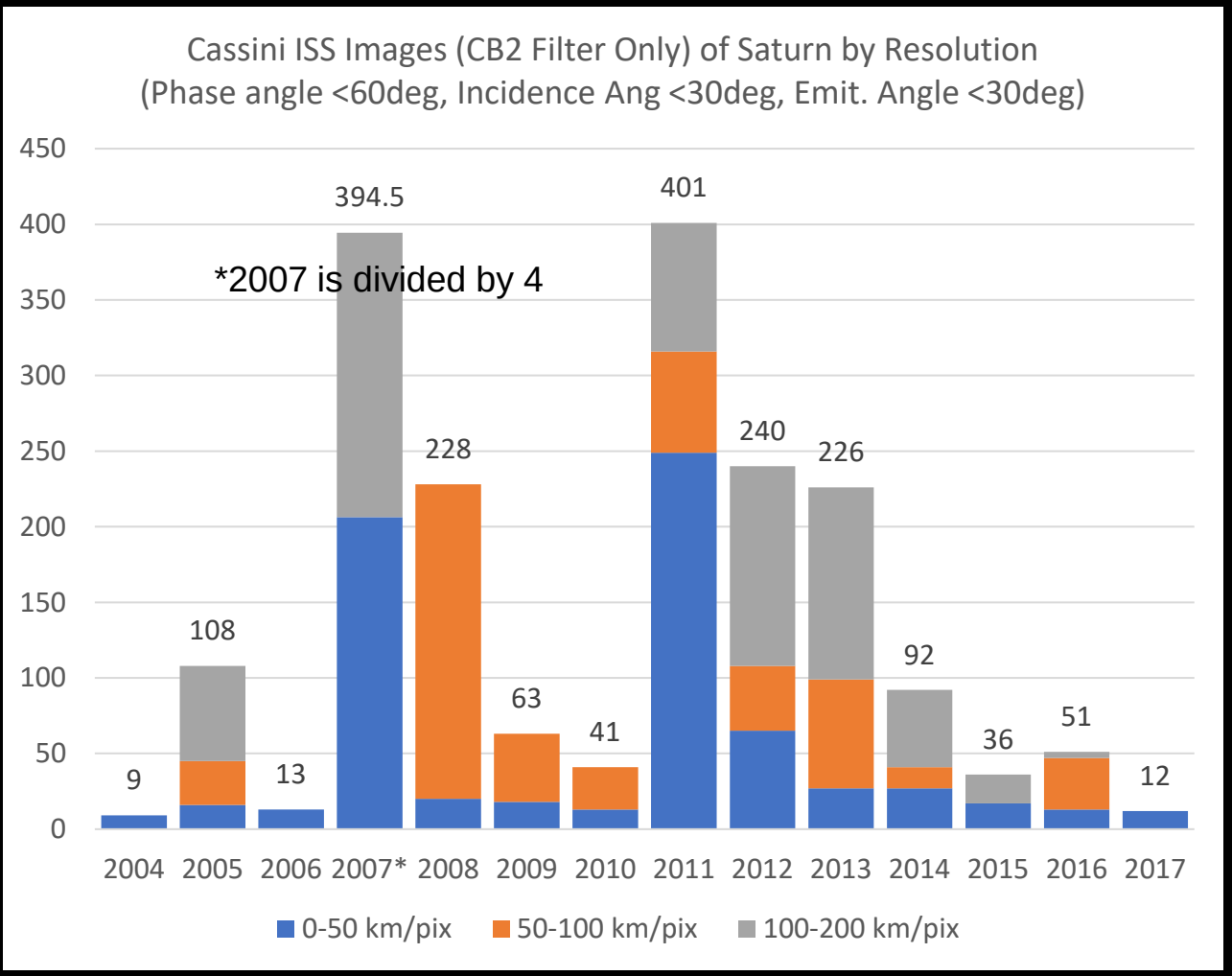
- iFOV: 500 µrad/pix
- FOV: 3.5 degree
- 352 Channels in 300 nm – 5.1 µm
- Spec. Res.:
  - 7.3 nm in VIS
  - 16.6 nm in IR

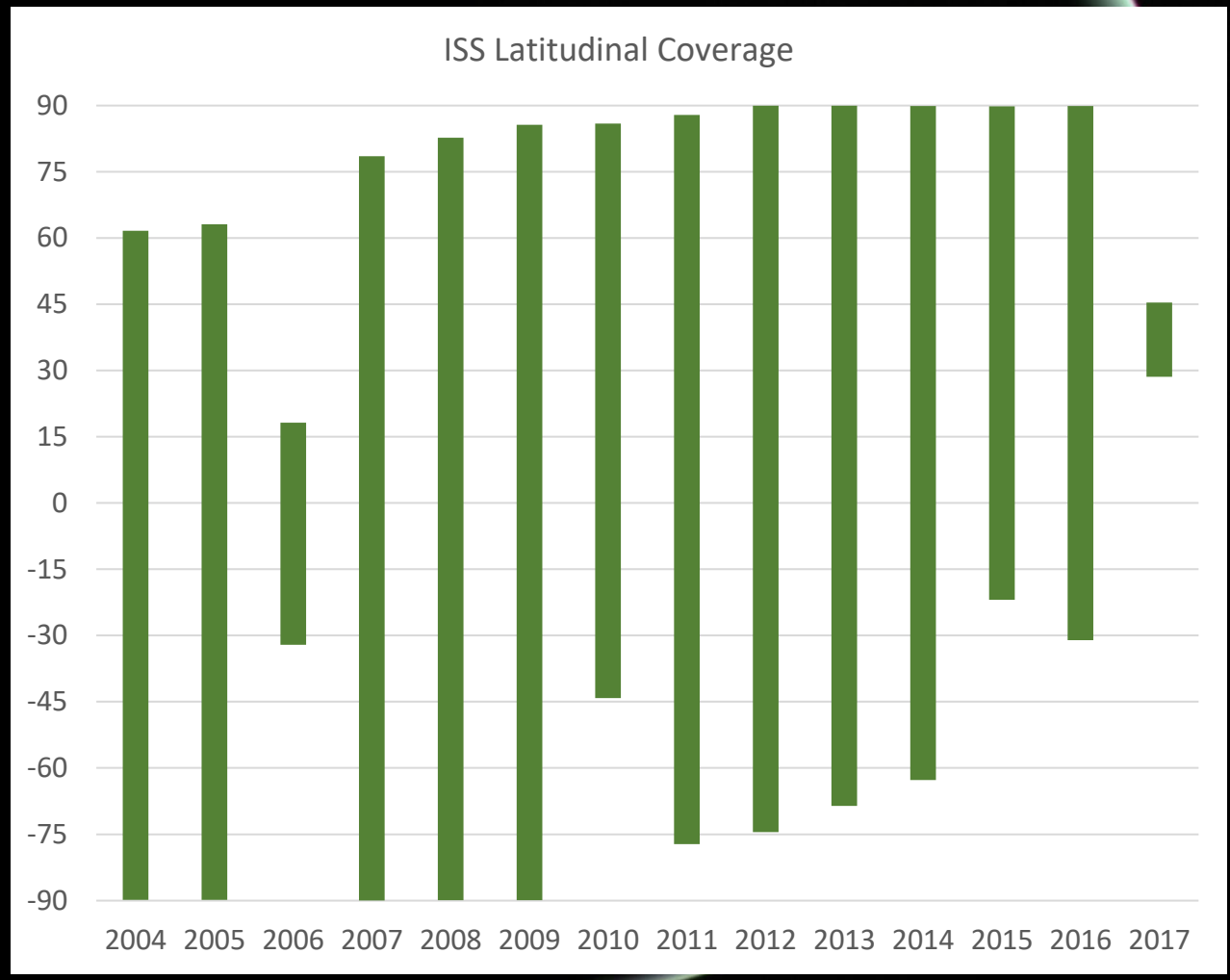
Leverage Cassini Experience

Example: Low Phase-angle Imaging Coverage for Saturn's Dayside

Flagship Challenge: Finding best balance of science across all disciplines

New Discoveries may change plans!





Closing Thoughts

- Imaging Instrument Requirements
  - Spatial and spectral requirements depend on evolving science
  - Resolution and FOV may need to be updated for Orbits & Flyby designs
  - Repeating exercise to determine instrument req is useful in building experience
- Orbit Design Considerations:
  Sci Objectives may require incompatible optimal Phase/Emission/Incidence Angles
  - e.g. for Uranus atmospheric dynamics, apoapsis needs to be on dayside of Uranus, while aurora and energy balance measurements require night-side measurements.
  - Add orbits that give better views of the night side?
  - Higher inclination orbits to gain better views of Uranus high-latitude and rings?
- Lessons from Cassini:
  - Challenge: Finding the best balance of mission science across all disciplines
  - May need to adopt to new Discoveries (e.g. Enceladus plumes, Great Storm of 2010-2011)
  - “Flagship missions offer an incredible array of opportunities, both expected and unexpected!”
- Technology Development Needs
  - We need a good solution to accommodate more filters
    - Atmospheric measurements alone need at least 6 narrow-band filters
  - Fantasy: Can we combine NAC+WAC+VIS/NIR in a single instrument?
    - Resolution <25 µrad/pix
    - FOV 10 > degree
    - Hyperspectral Imaging Capability