Cassini ISS Astrometry by the Astronomy Unit at Queen Mary, University of London - An Overview

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Cassini Imaging (so far)

- Since start of mission:
  - 306305 images (incl. ~26000 from Jupiter)
  - ~17000 hours
- QMUL contribution:
  - 34269 images (11.2 %)
  - ~1470 hours (8.7 %)

Observation time-span (Saturn) 2004-2012

ISS Sequence Design at QMUL

- SATELLITE ORBITS (‘SATELLORB’) 12262
- MUTUAL EVENTS 4246
- SATELLITE SEARCH 923
- F RING 12032
- OTHER 4806

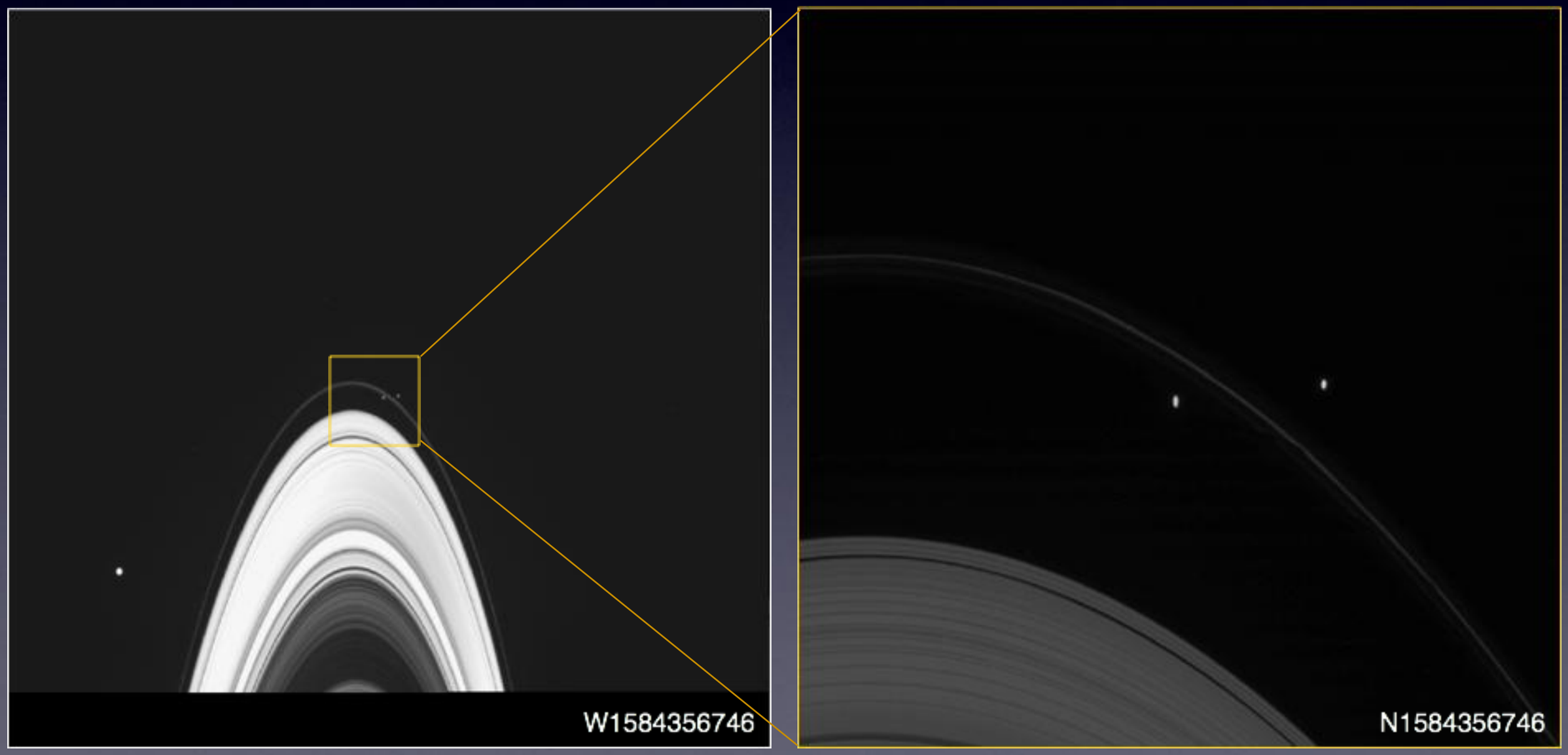
Cassini Imaging Science Subsystem

Wide Angle Camera (WAC)

1024 x 1024 12-bit CCD
200 mm focal length refractor
FOV 3.5 deg (12.3 arcsec /pixel)
18 filters on 2 wheels

Narrow Angle Camera (NAC)

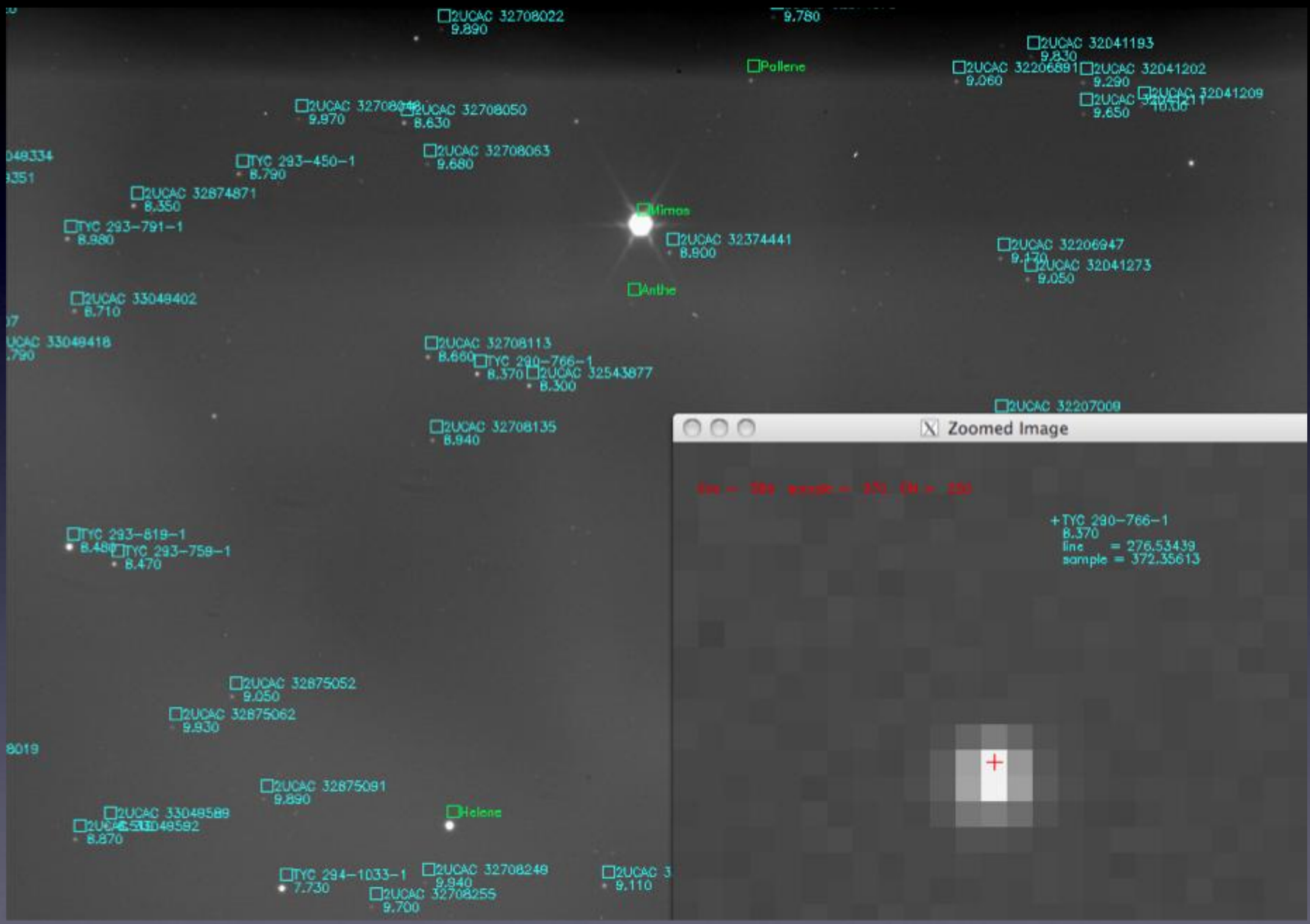
1024 x 1024 12-bit CCD
2000 mm focal length reflector
FOV 0.35 deg (1.23 arcsec /pixel)
24 filters on 2 wheels

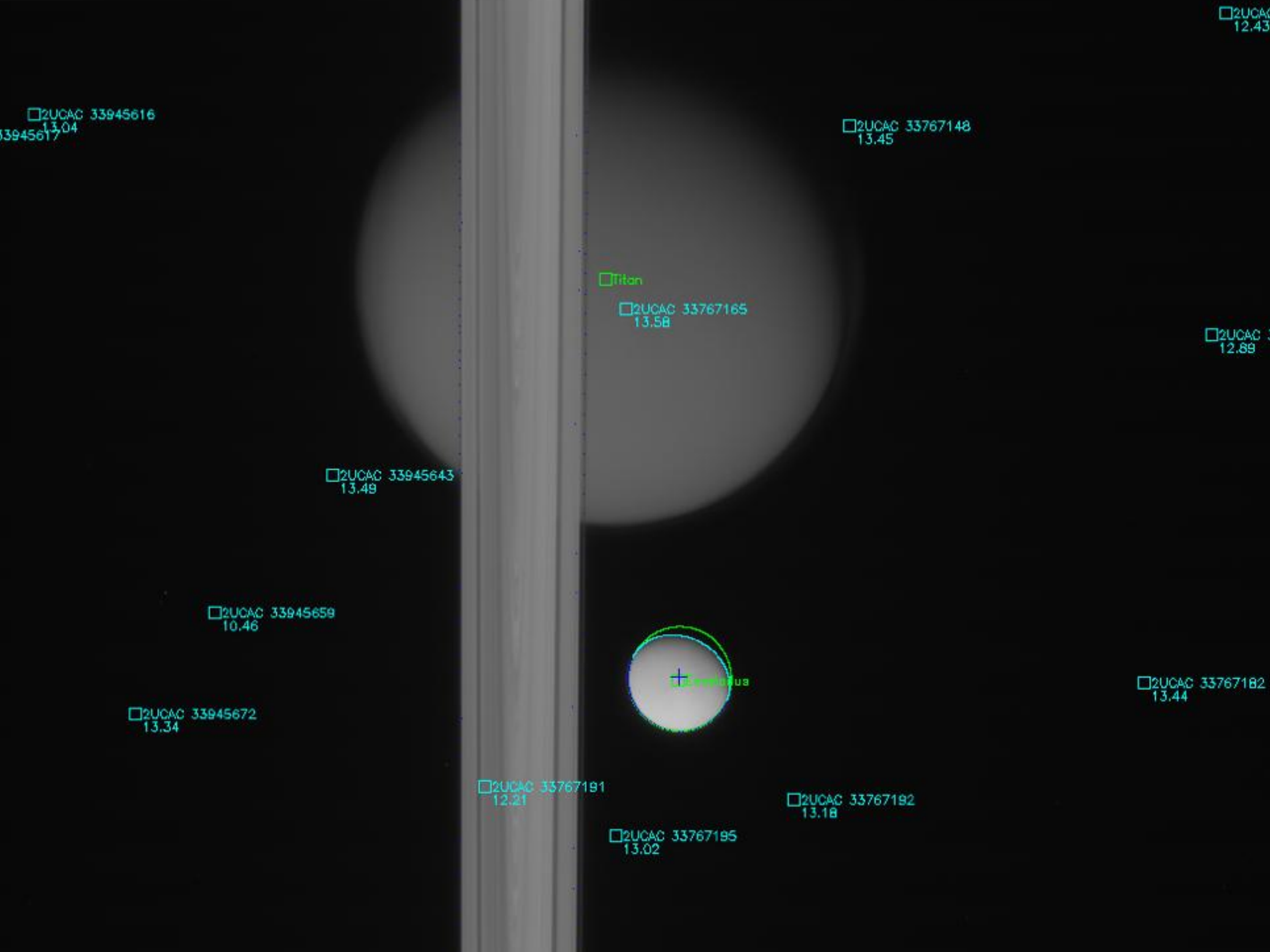


Astrometry

- CAVIAR software package (QMUL).
- Camera pointing correction.
- UCAC2/Tycho2 catalogues.
- Nearest pixel, centroid or limb-fitting.
- Raw images.

Camera Pointing Correction

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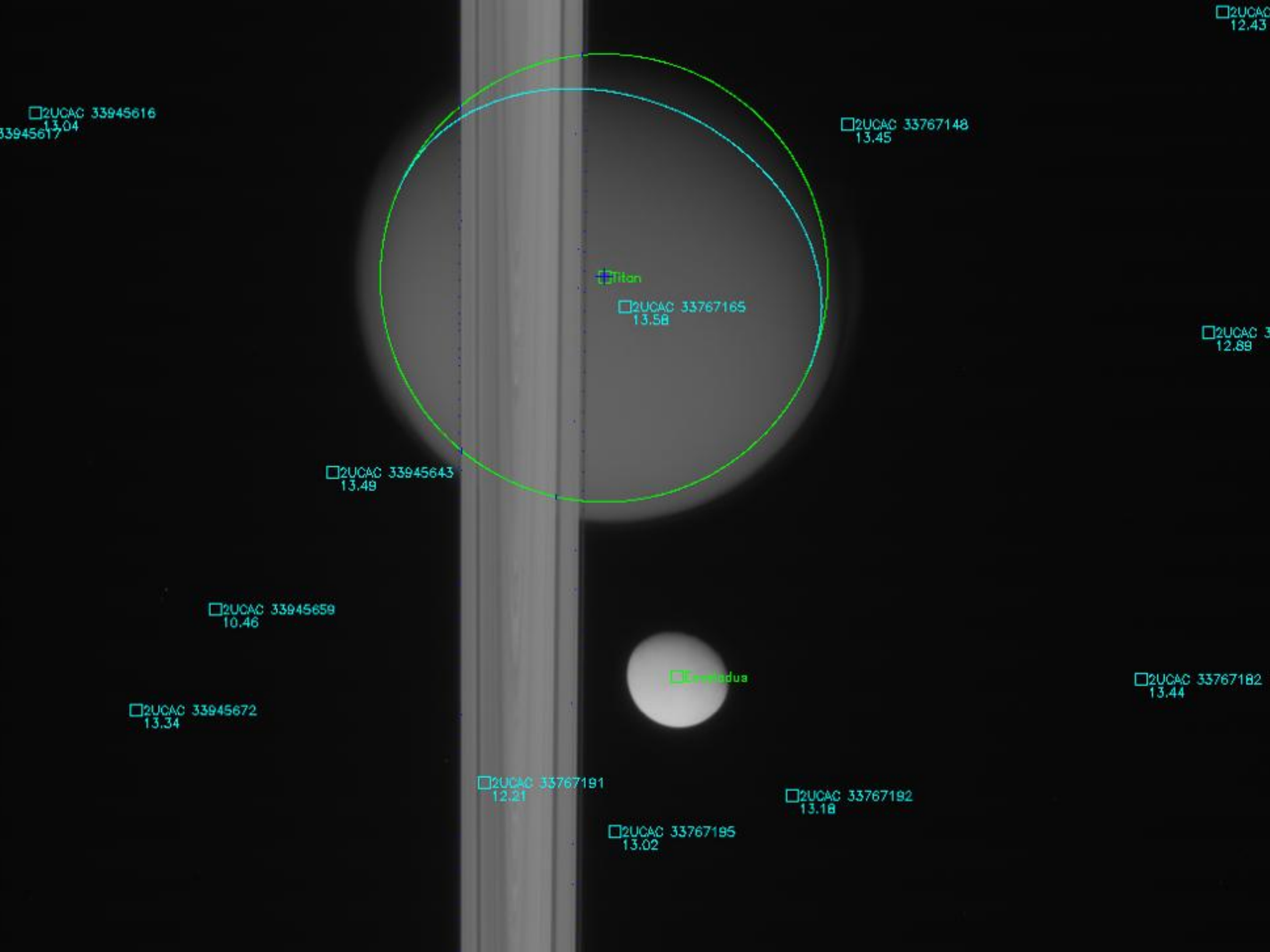
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2UCAC 33767191
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2UCAC 33767192
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2UCAC 33767195
13.02

Image Projection Algorithm

1. Given α and δ, the right ascension and declination, respectively, of the pole of the primary body in the J2000 frame (Table 2), rotate the position vector of the target satellite from the planetocentric to the J2000 frame:

$$\mathbf{S}_{t-\tau} = \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix} = \begin{pmatrix} -\sin\alpha & \cos\alpha & 0 \\ -\cos\alpha\sin\delta & -\sin\alpha\sin\delta & \cos\delta \\ \cos\alpha\cos\delta & \sin\alpha\cos\delta & \sin\delta \end{pmatrix} \begin{pmatrix} s_x \\ s_y \\ s_z \end{pmatrix}. \tag{A.1}$$

2. Compute the pointing vector $\mathbf{p}_t$ from the Cassini spacecraft to the target satellite in the J2000 frame:

$$\mathbf{p}_t = \mathbf{S}_{t-\tau} - \mathbf{A}_{t-\tau}. \tag{A.2}$$

$\mathbf{A}_{t-\tau}$ and $\mathbf{S}_{t-\tau}$ are the position vectors of the spacecraft and target satellite, respectively, in the J2000 frame, at the one-way light-time-corrected observation time (note that this expression includes light-time and stellar aberration corrections: see, for example, Seidelmann (1992, p. 133)). The position vector for the spacecraft may be obtained from the tour kernel (Table 2) using the SPICE *spkpos* routine.

3. Rotate the unit pointing vector from the J2000 frame to the camera-body frame using the C-matrix:

$$\hat{\mathbf{P}}_t = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix} = \mathbf{C}\hat{\mathbf{p}}_t, \tag{A.3}$$

where

$$\mathbf{C} = \mathbf{R}_3(\phi)\mathbf{R}_1(90^\circ - \delta)\mathbf{R}_3(90^\circ + \alpha) \tag{A.4}$$

and α, δ, and ϕ are, respectively, the nominal right ascension, declination and twist angles for the camera optical axis, in degrees (see Table 1), and $\mathbf{R}_i$ is the 3×3 rotation matrix about the ith axis.

4. Transform from the camera body frame into image coordinates (s, l), where s is sample and l is line, via the projection (following Owen, 2003):

$$\begin{pmatrix} s \\ l \end{pmatrix} = \sigma \begin{pmatrix} K_x & K_{xy} \\ K_{yx} & K_y \end{pmatrix} \begin{pmatrix} x + \Delta x \\ y + \Delta y \end{pmatrix} + \begin{pmatrix} s_0 \\ l_0 \end{pmatrix}, \tag{A.5}$$

where

$$\begin{pmatrix} x \\ y \end{pmatrix} = \frac{f}{P_z} \begin{pmatrix} P_x \\ P_y \end{pmatrix}, \tag{A.6}$$

$$\begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} = \begin{pmatrix} xr^2 & xy & x^2 \\ yr^2 & y^2 & xy \end{pmatrix} \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \end{pmatrix} \tag{A.7}$$

and

$$r^2 = x^2 + y^2. \tag{A.8}$$

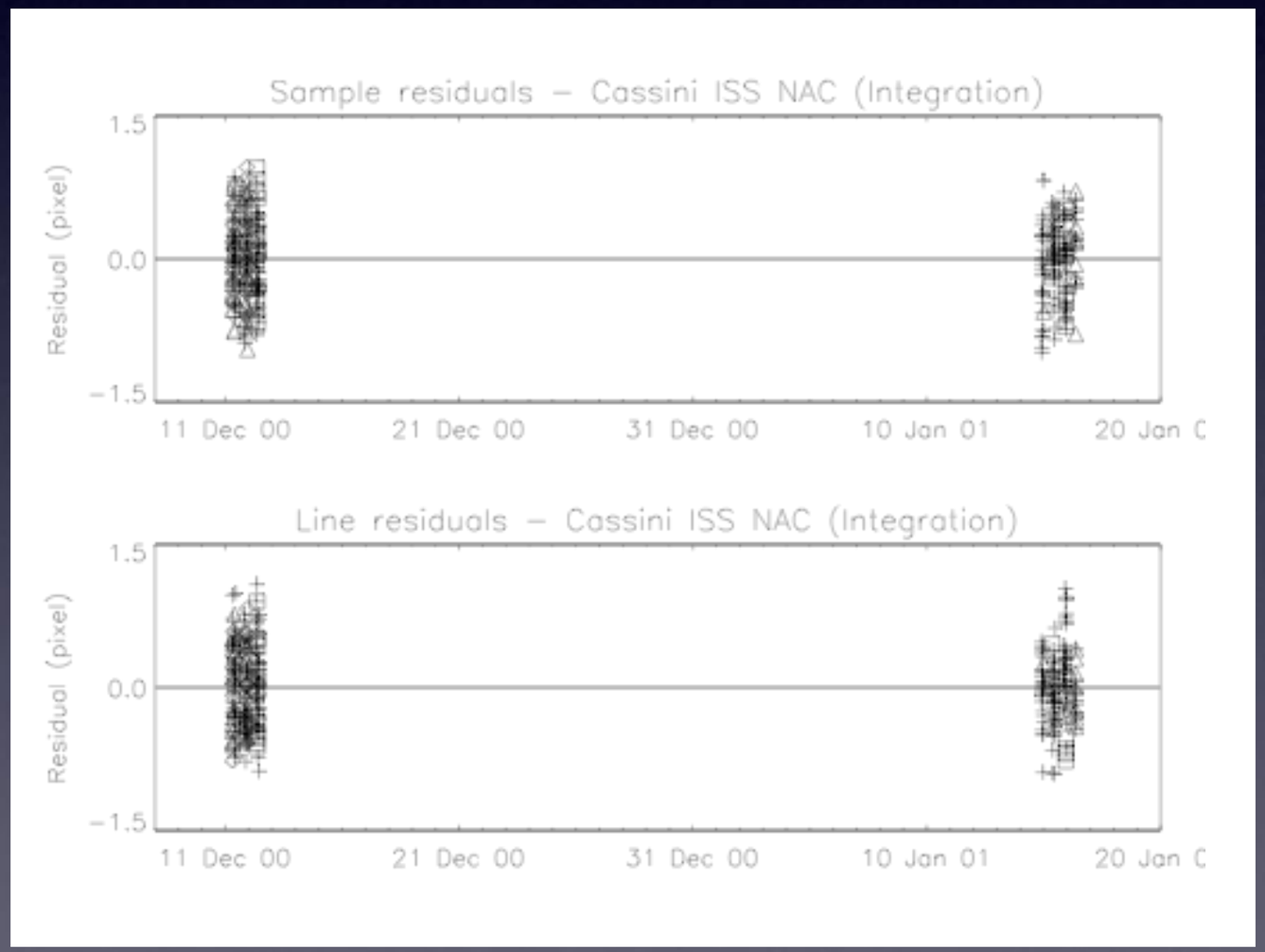
Table 3
JPL Cassini NAC calibration results (Owen, 2003)

Parameter	Value	Units
f	2002.703	mm
ϵ_1	8.28	$\times 10^{-6}$ mm^{-2}
ϵ_2	5.45	$\times 10^{-6}$ mm^{-1}
ϵ_3	−19.67	$\times 10^{-6}$ mm^{-1}
K_x	83.33333	samples/mm
K_{xy}	0.0	samples/mm
K_{yx}	0.0	lines/mm
K_y	83.3428	lines/mm

Owen (2003), Cooper et al. (2006)

Inner Satellites of Jupiter

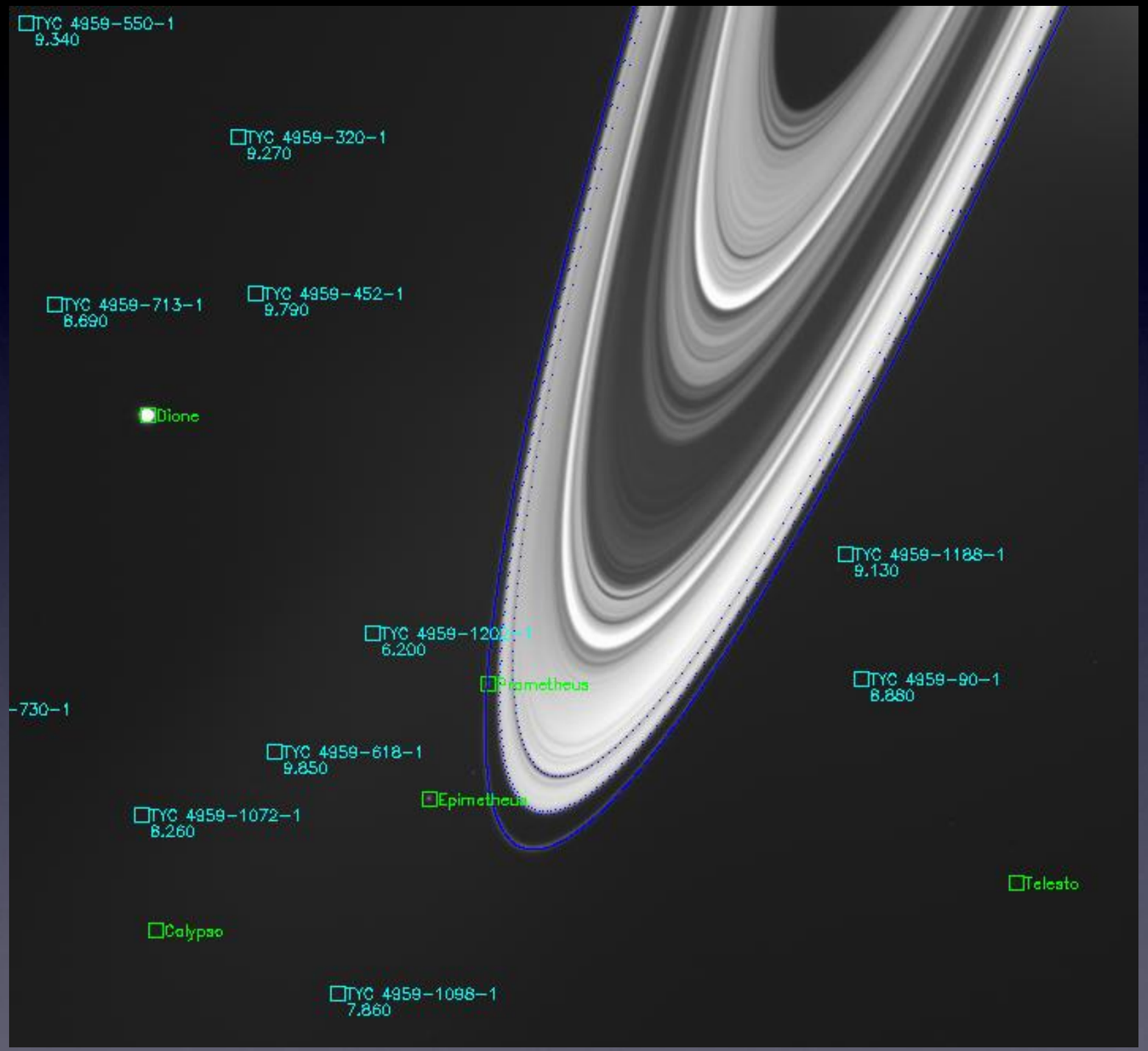
- Amalthea (239), Thebe (50) (Cooper et al. 2006)
- Metis (28), Adrastea (23) (unpublished)



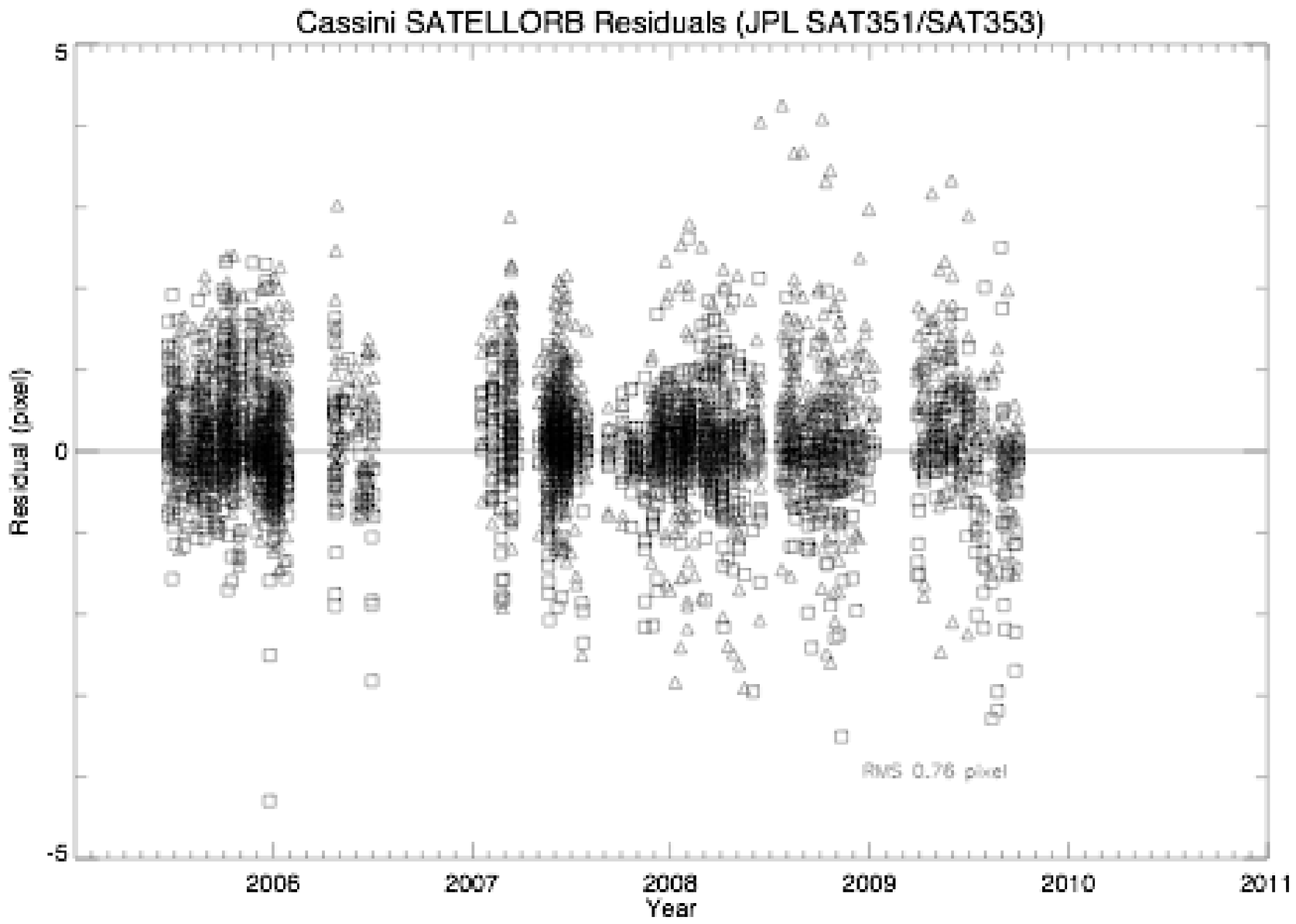
Observations using images from Dec 2000 and Jan 2001

SATELLORB Observations

- Emphasis on the small inner satellites (‘The Rocks’)
- ~2000 individual measurements since 2004
- Observation requests up to 2013
- Further observations anticipated from 2013 to end-of-mission in 2017
- Astrometric data reduction is ongoing



MIMAS	601	27
ENCELADUS	602	19
TETHYS	603	20
DIONE	604	19
RHEA	605	8
TITAN	606	0
HYPERION	607	2
IAPETUS	608	0
PHOEBE	609	2
JANUS	610	216
EPIMETHEUS	611	237
HELENE	612	127
TELESTO	613	136
CALYPSO	614	147
ATLAS	615	143
PROMETHEUS	616	223
PANDORA	617	202
PAN	618	127
METHONE	632	120
PALLENE	633	117
POLYDEUCES	634	59
DAPHNIS	635	35
ANTHE	649	49



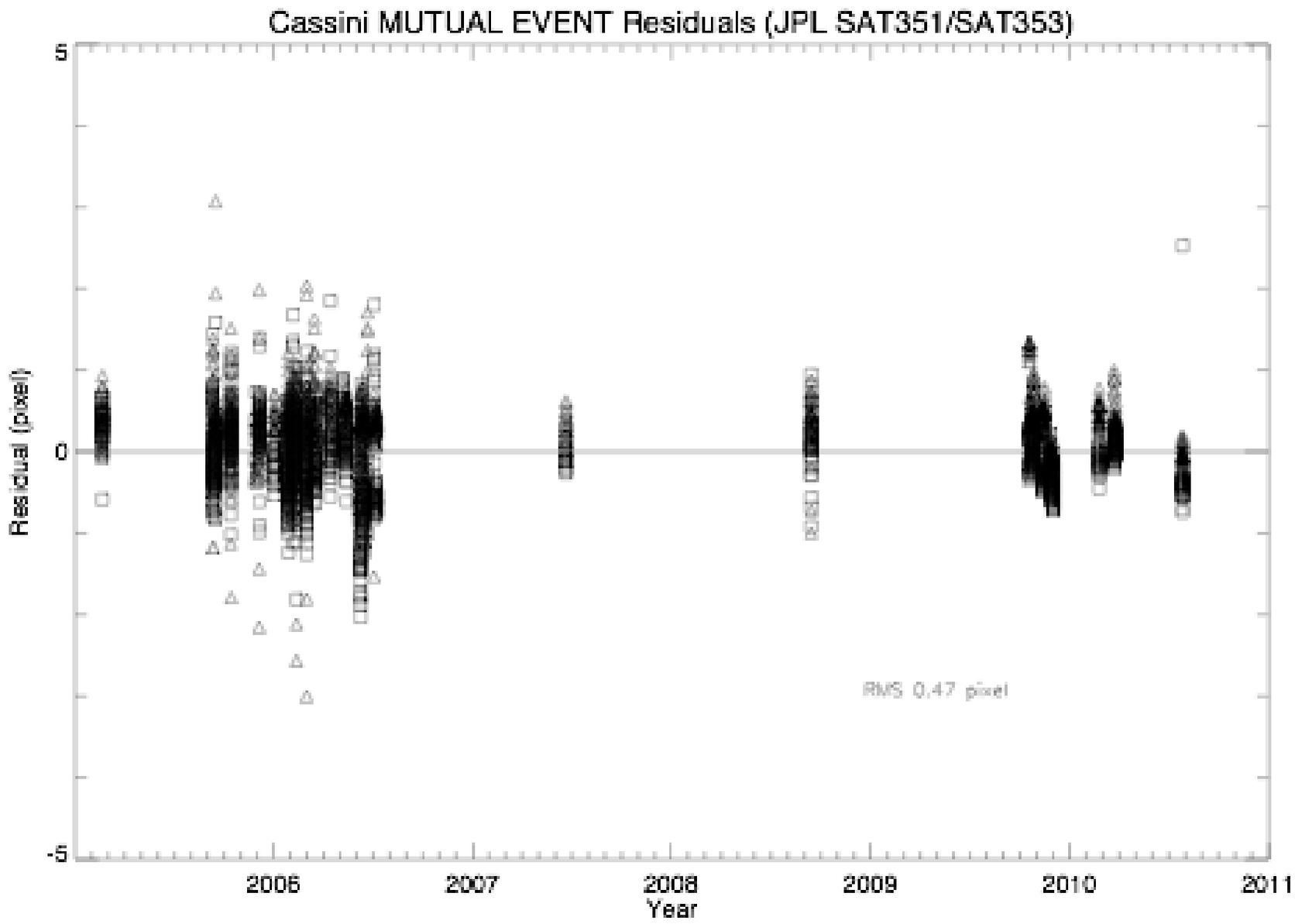
Cassini ISS Mutual Event Observations

- 176 events observed since June 2004 (total ~3500 images)
- Planning in-place for 11 future events up to 2013
- Further observation requests from 2013 to end-of-mission in 2017
- Targets so far include all major satellites except Iapetus, and numerous small satellites
- Astrometric data reduction is ongoing

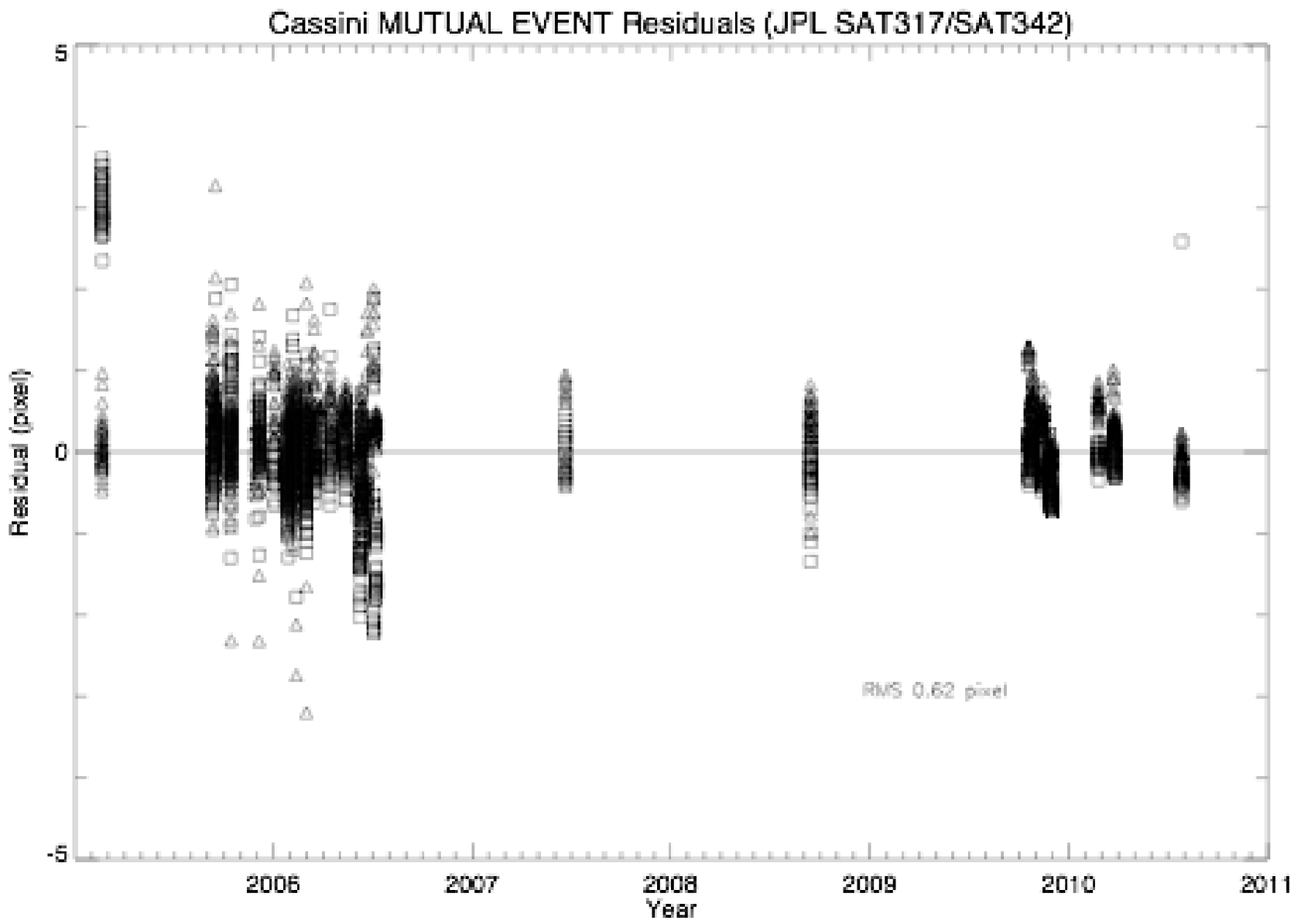
Dione/Rhea Mutual Event

February 2005

MIMAS	601	154
ENCELADUS	602	417
TETHYS	603	345
DIONE	604	467
RHEA	605	482
TITAN	606	0
HYPERION	607	0
IAPETUS	608	0
PHOEBE	609	0
JANUS	610	18
EPIMETHEUS	611	10
HELENE	612	60
TELESTO	613	8
CALYPSO	614	0
ATLAS	615	0
PROMETHEUS	616	0
PANDORA	617	0
PAN	618	0
METHONE	632	0
PALLENE	633	0
POLYDEUCES	634	0
DAPHNIS	635	0
ANTHE	649	0



MIMAS	601	154
ENCELADUS	602	417
TETHYS	603	345
DIONE	604	467
RHEA	605	482
TITAN	606	0
HYPERION	607	0
IAPETUS	608	0
PHOEBE	609	0
JANUS	610	18
EPIMETHEUS	611	10
HELENE	612	60
TELESTO	613	8
CALYPSO	614	0
ATLAS	615	0
PROMETHEUS	616	0
PANDORA	617	0
PAN	618	0
METHONE	632	0
PALLENE	633	0
POLYDEUCES	634	0
DAPHNIS	635	0
ANTHE	649	0

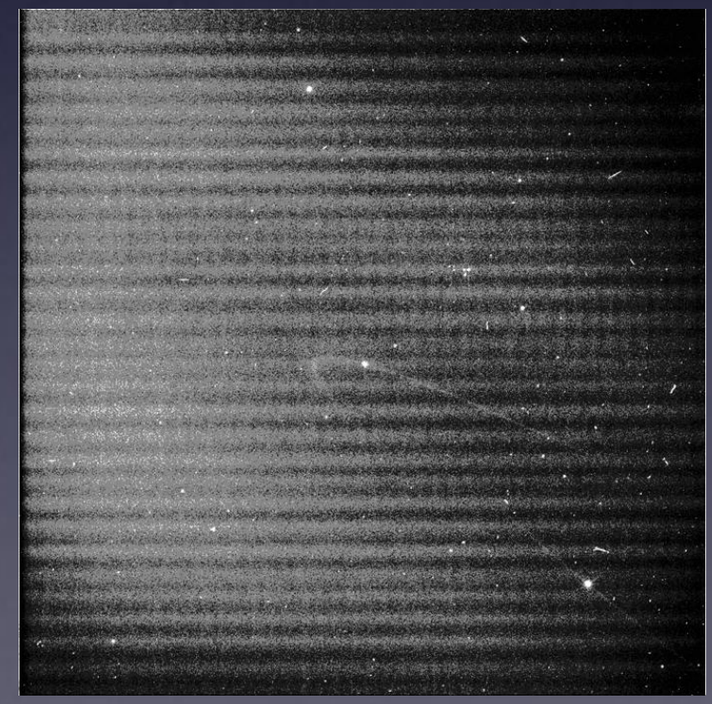


Satellite Discoveries

Polydeuces
(L5 co-orbital of
Dione)

Anthe

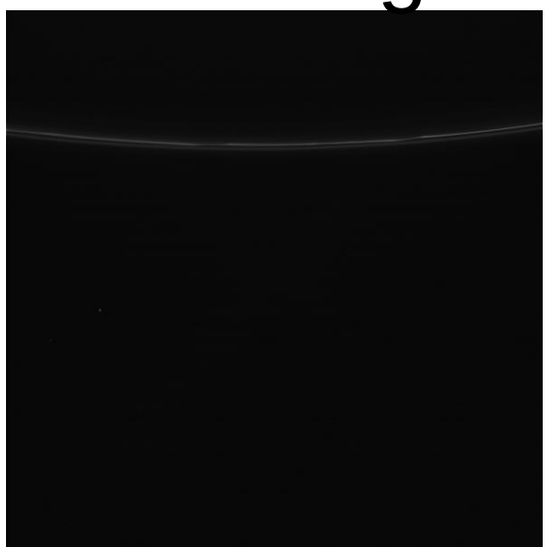
Discovered in June 2007

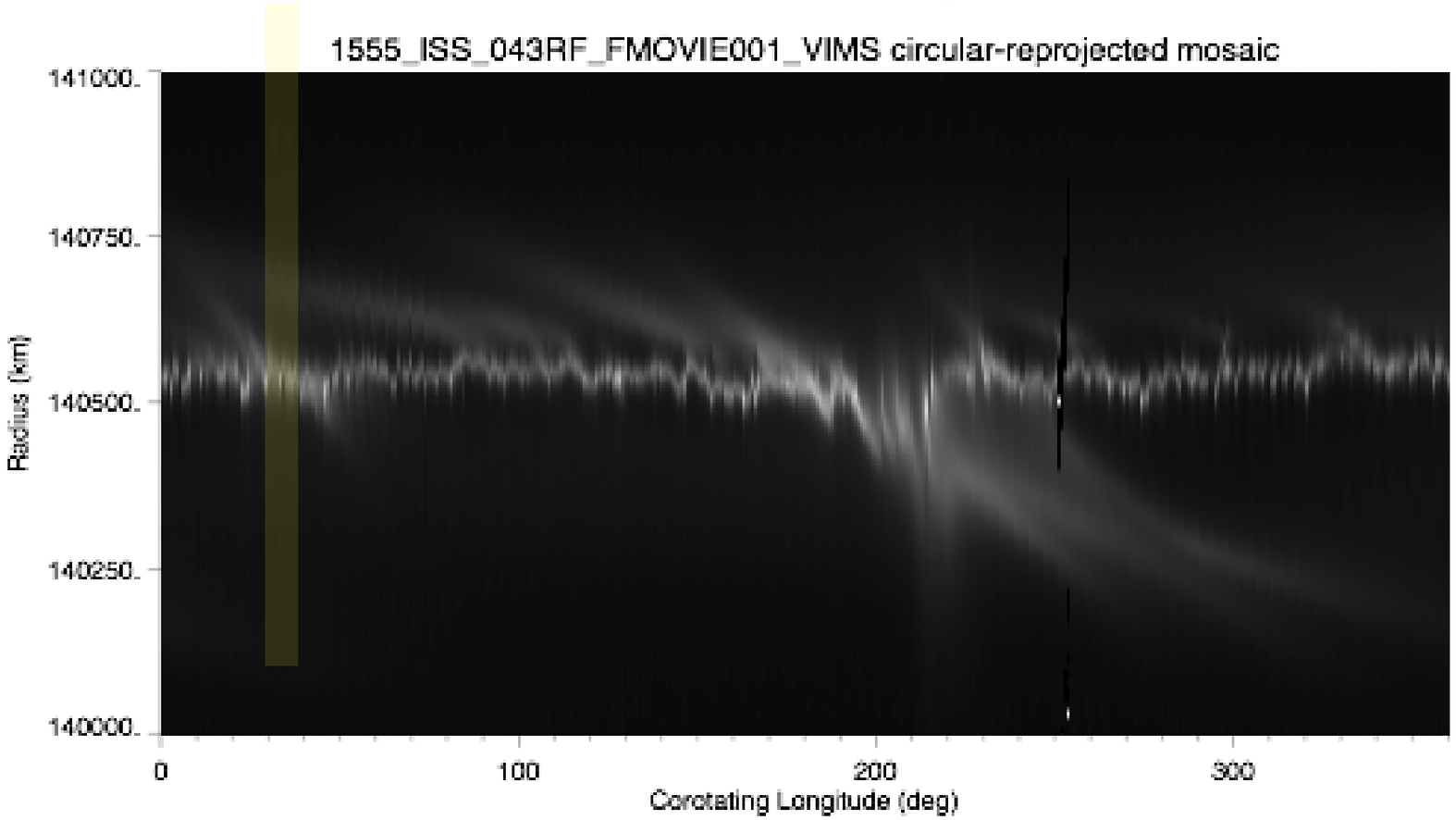


Recovered in Oct 2007

SATURN’s F Ring

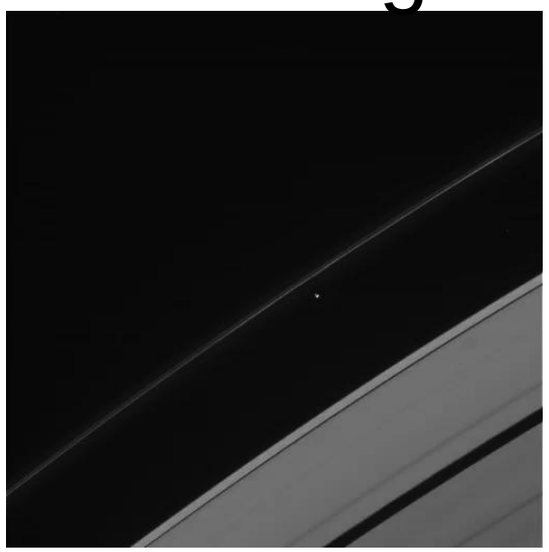
Raw images

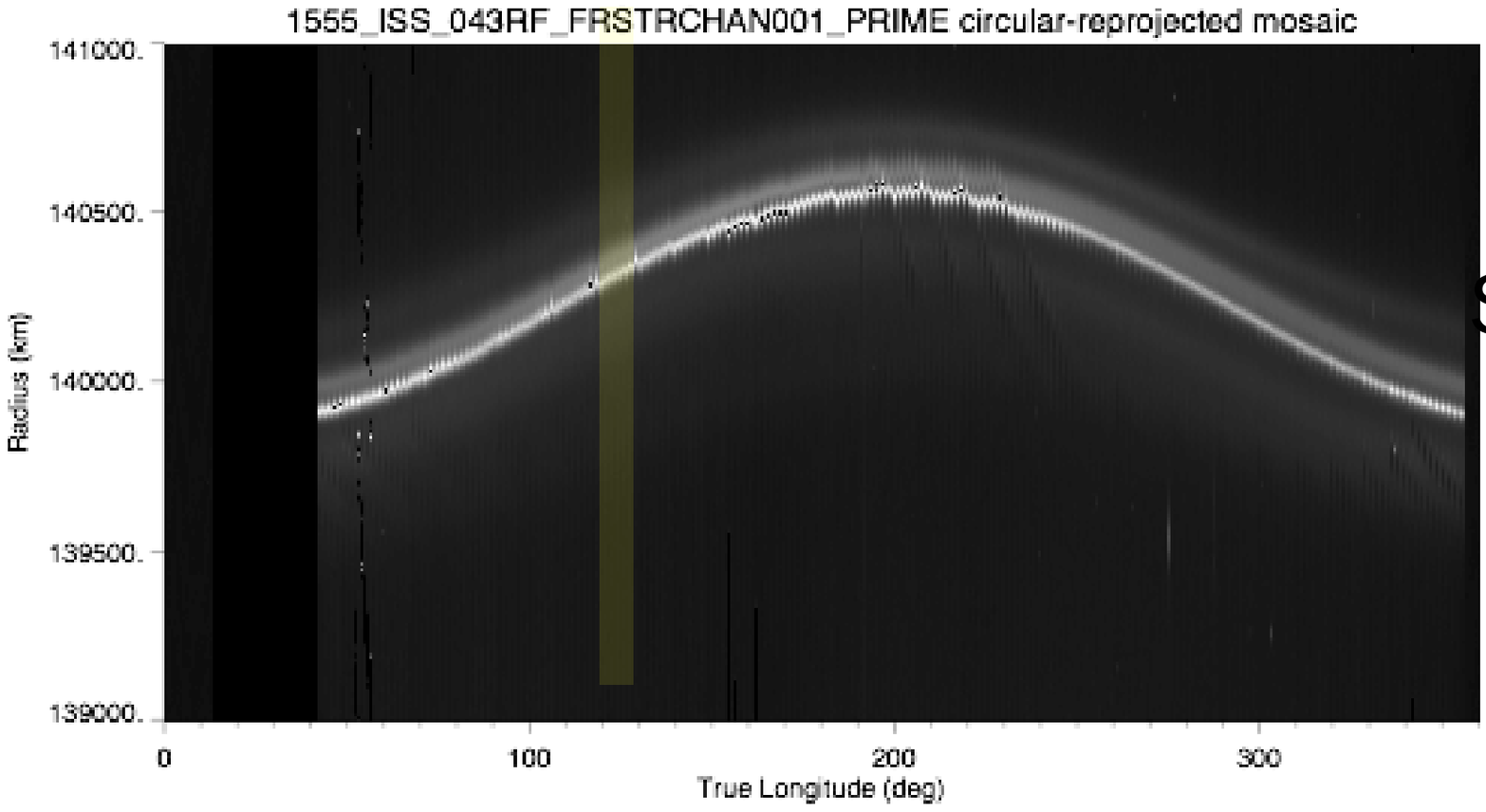




FMOVIE

Raw images

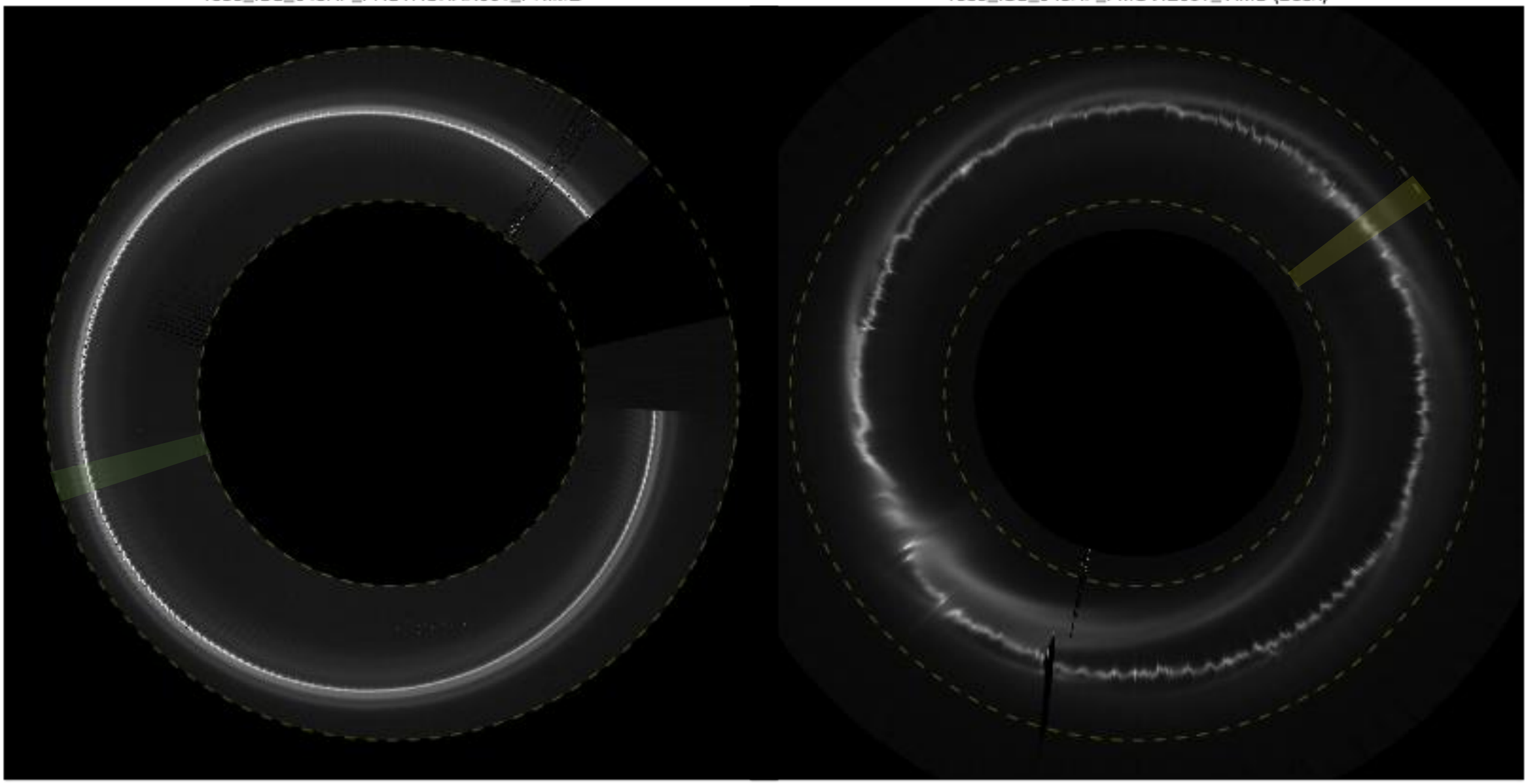




Streamer-Channel Movie

1555_ISS_043RF_FRSTRCHAN001_PRIME

1555_ISS_043RF_FMOVIE001_VIMS (Bosh)



Streamer/Channel Movie

FMOVIE

Publication and Archiving

- Observations of Amalthea and Thebe : Cooper et al (2006)
- Observations of Polydeuces : Murray et al (2005)
- Observations of Anthe : Cooper et al (2008)

- Plans for an online archive of ‘raw’ astrometric data for easy reprocessing using new star catalogues such as GAIA
  - Satellite and star positions, pointing information