Mimas and Enceladus: Formation and interior structure from astrometric reduction of Cassini images.

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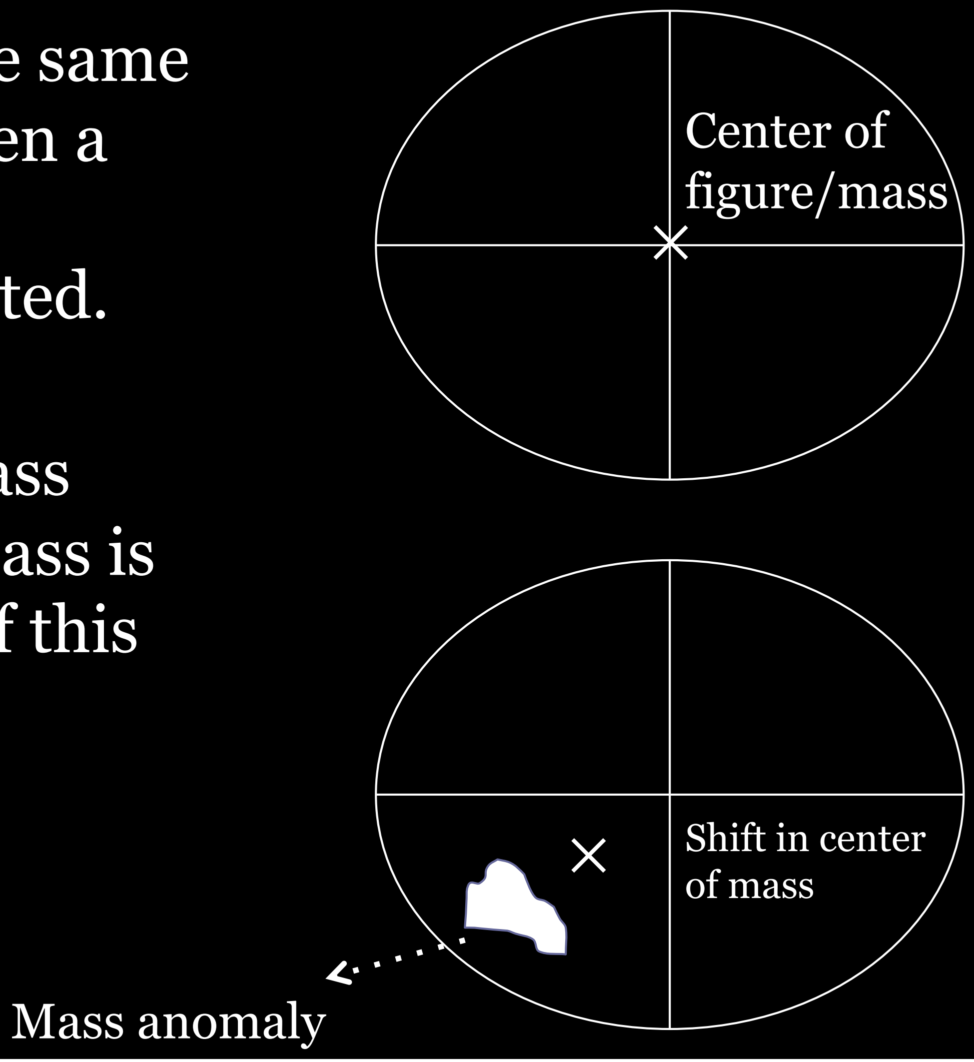
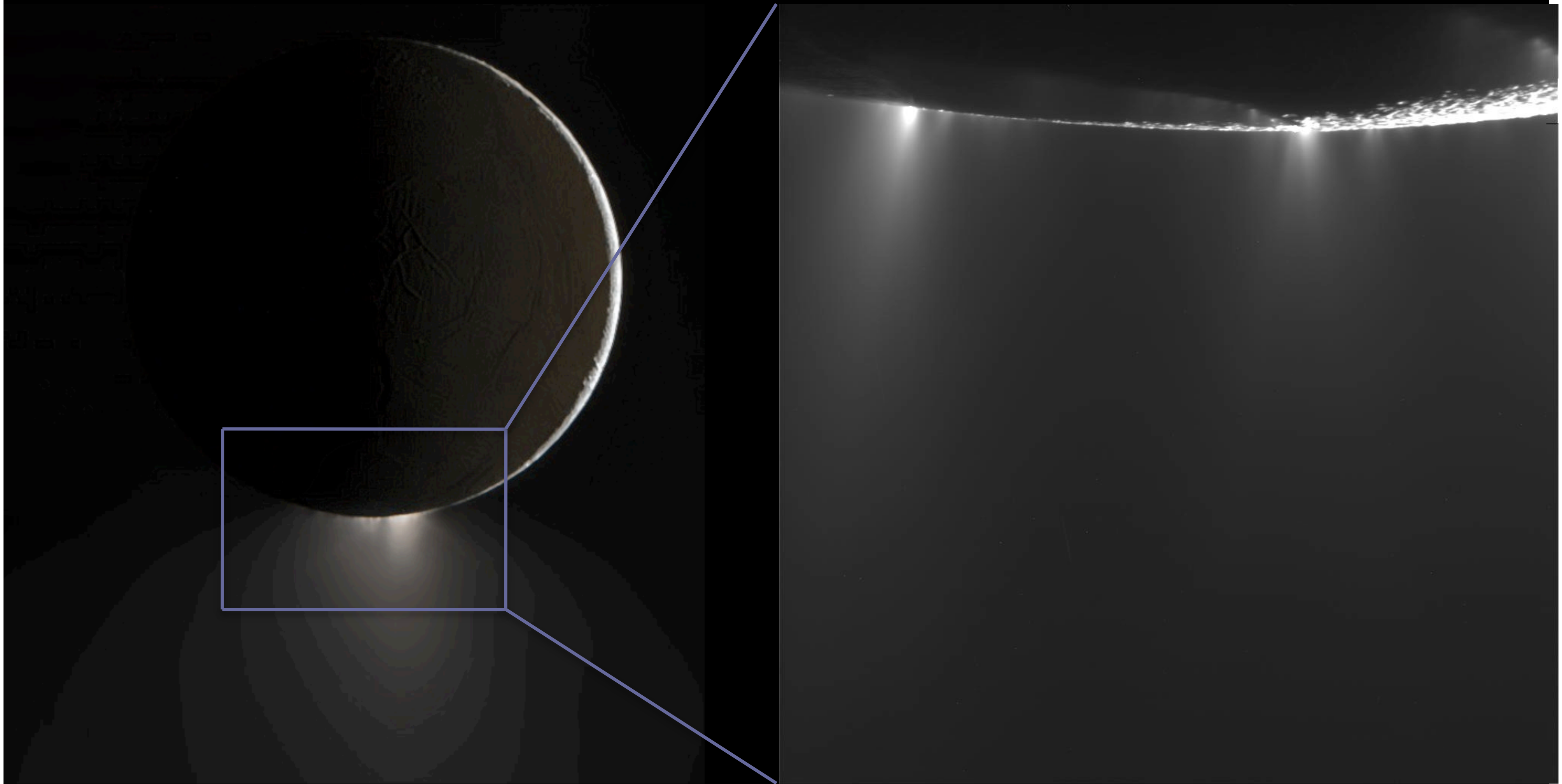
Center of Mass/Center of figure

- The center of figure is the same as the center of mass when a body is homogeneous or symmetrically diffirentiated.
- If the body contains a mass anomaly, the center of mass is shifted in the direction of this anomaly.



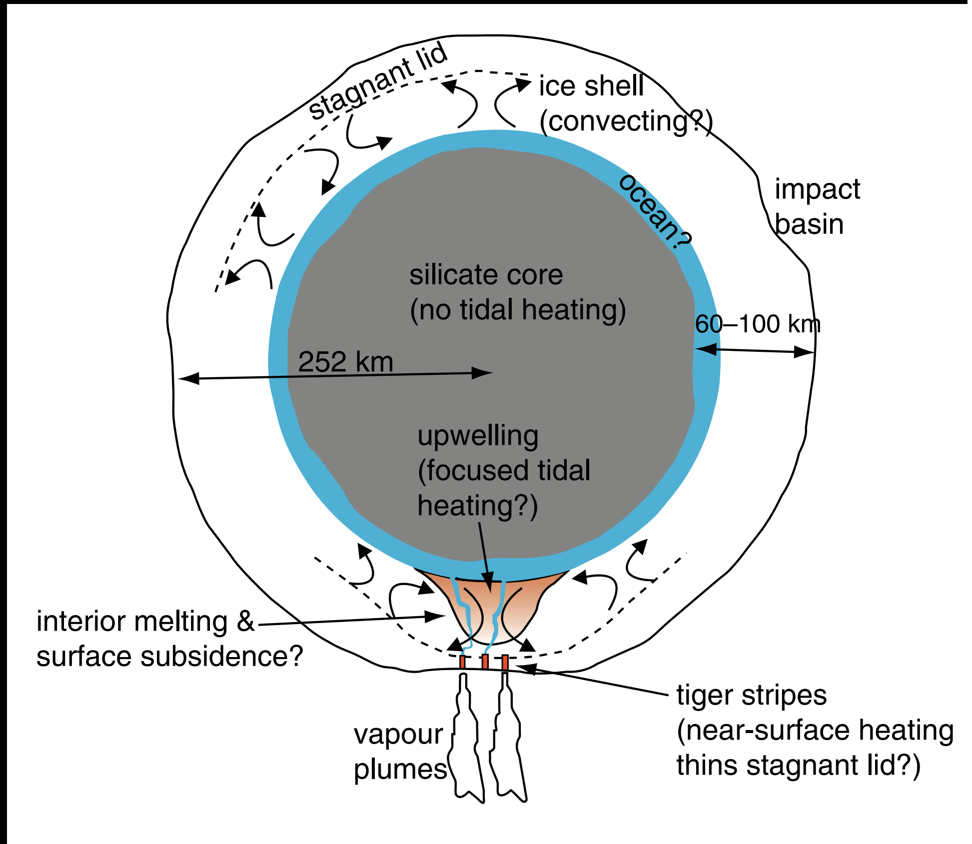
Water emission from Enceladus' south pole



Existing models

Nimmo & Pappalardo 2006 :

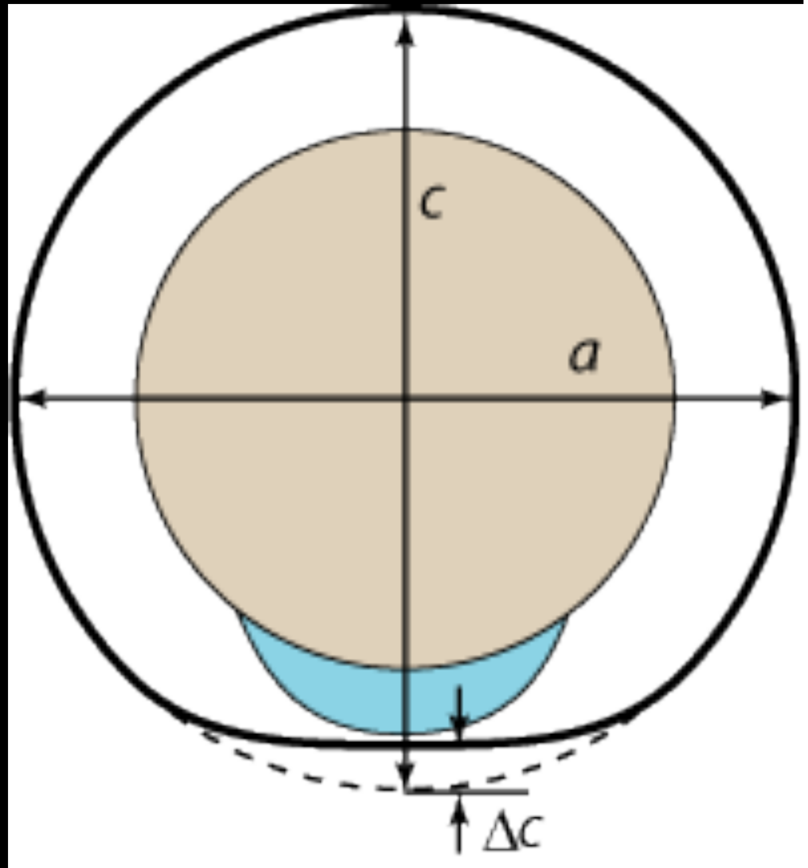
- Global ocean, with subsurface Ice melting localized in a specific region of the equator, caused by the tidal effects (?).
- Formation of a low density ice diapir resulting in a reorientation of the satellite's anomaly to the south pole.
- Because of this low density anomaly, the center of mass is shifted northward.



Existing models

Collins & Goodman 2007

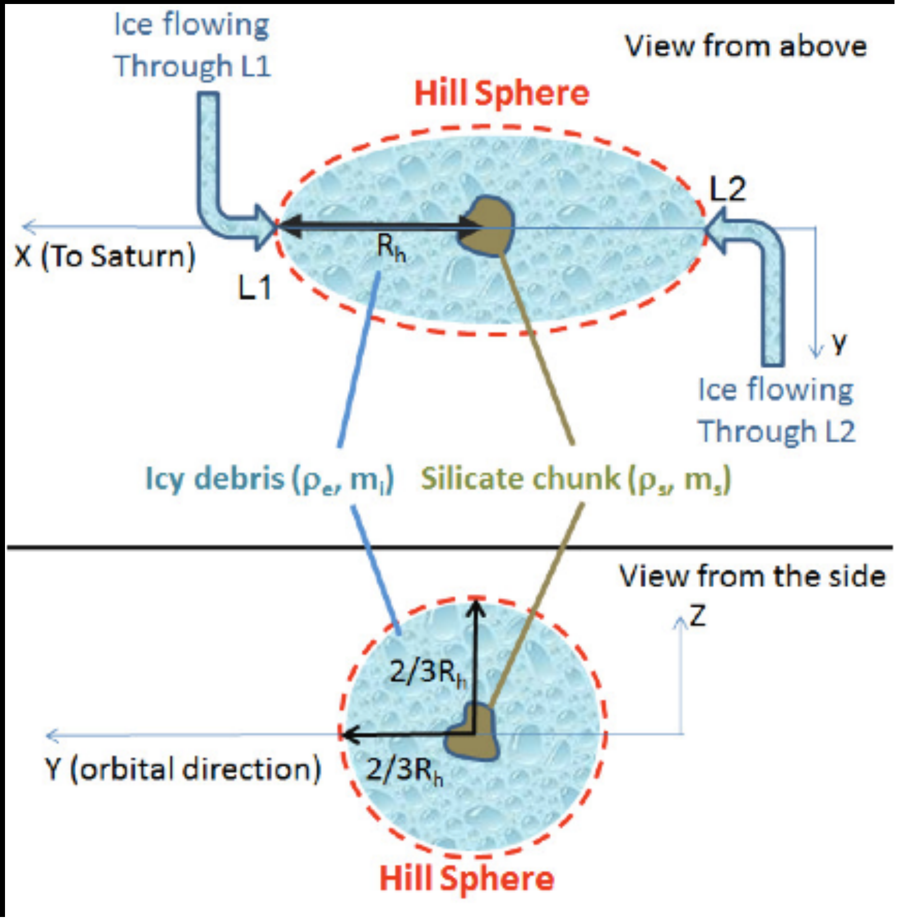
- No Global ocean, only a localized south polar sea.
- The density in this area is higher than it is in the rest of the ice shell.
- The center of mass is shifted southward.



Existing models

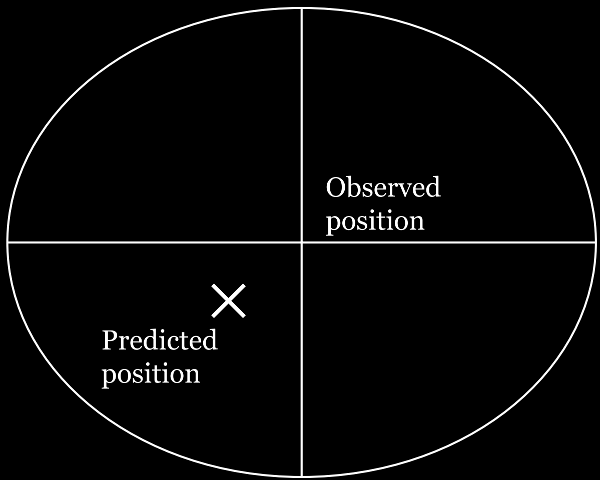
Charnoz et al. 2011

- The satellites core is formed by accretion of large silicate chunks (size 10-100 Km).
- This model could cause a shift in center of mass



Objective

- Astrometric reduction of the ISS-Cassini NAC images.
- Compare the satellite's observed center of figure position obtained from Astrometry to its center of mass position predicted by the ephemerides (sat317 and sat351).
- Discriminate between different models.



Astrometry

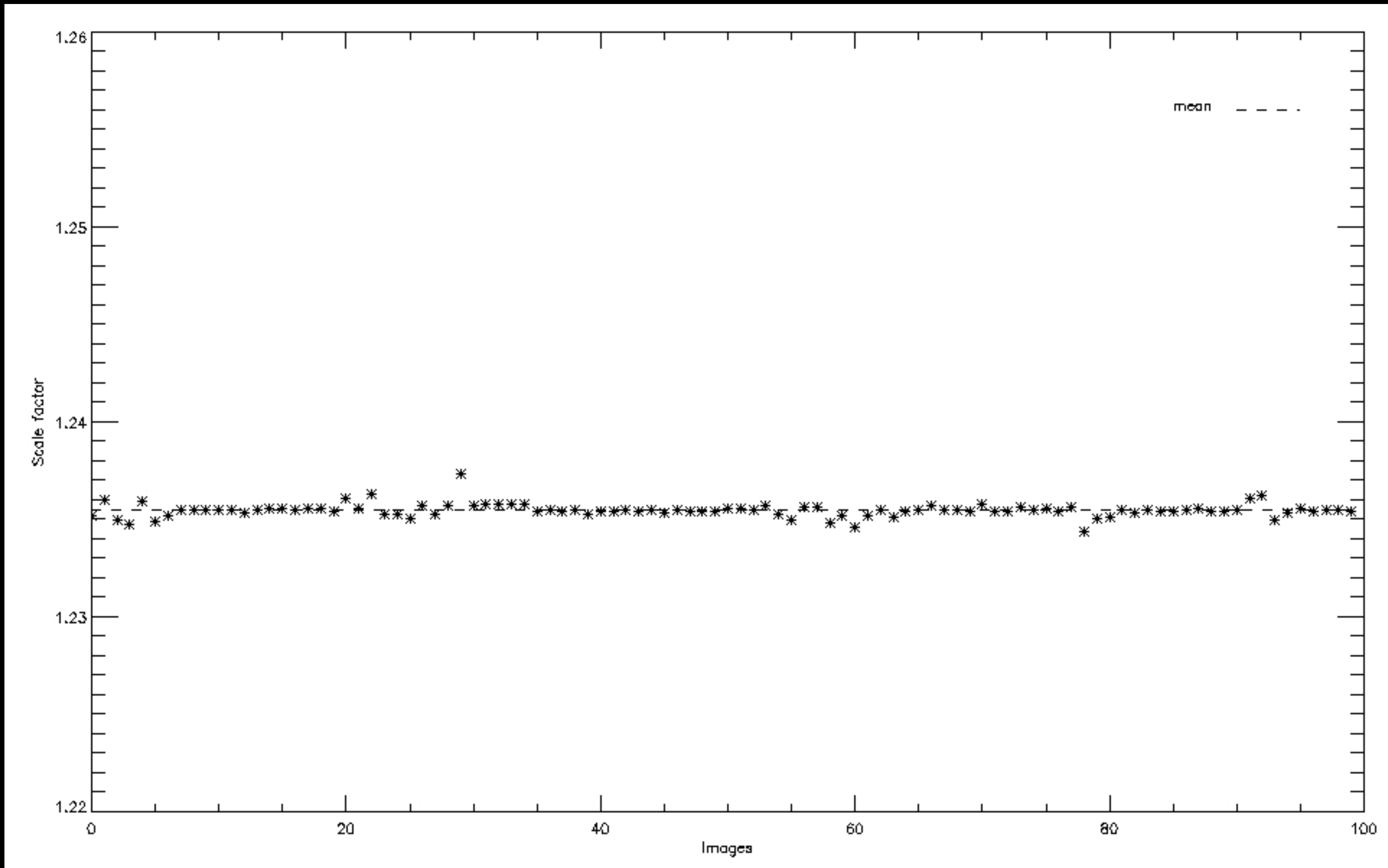
Algorithm used to convert a position from (RA,DEC) in radians to (sample, line) in pixels:

$$(\alpha,\delta) \xrightarrow[\text{projection}]{\text{gnomonic}} (X, Y)$$

$$s = 511.5 + (1/\rho)(X\cos\theta - Y\sin\theta) + \Delta s$$
$$l = 511.5 + (1/\rho)(X\sin\theta + Y\cos\theta) + \Delta l$$

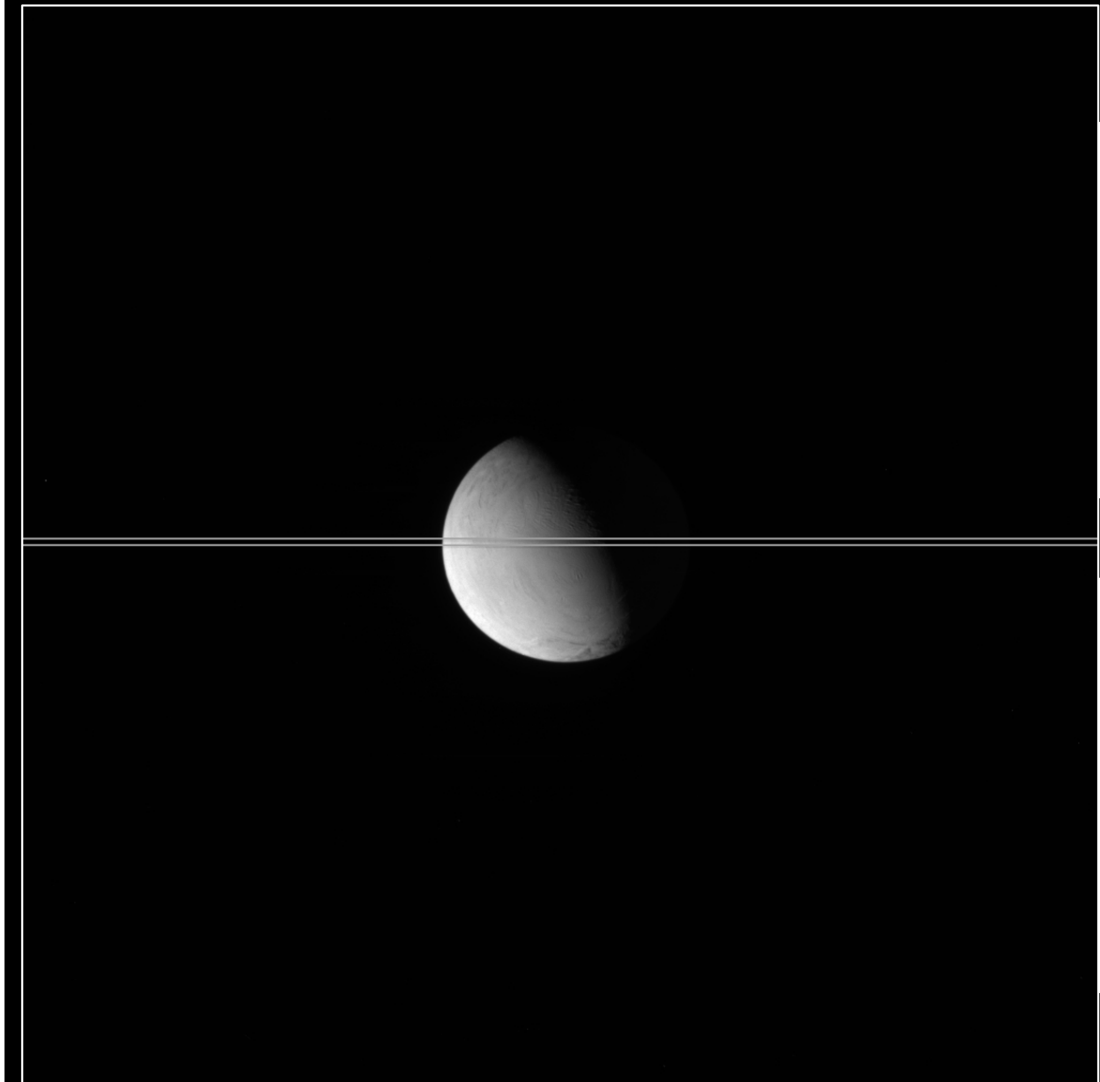
ρ : Scale factor (arcsec/ pixels)

Astrometry

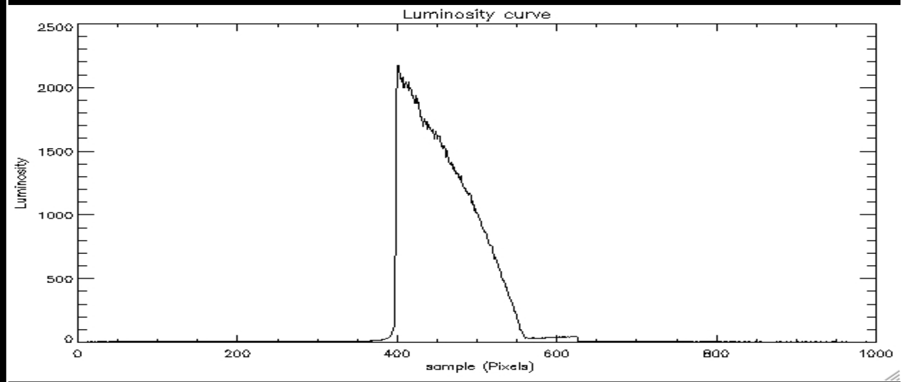


Scale factor = 1.2354 ± 10^{-4} arcsec/pixel
(based on 100 observations of stars clusters with 225 star per image)

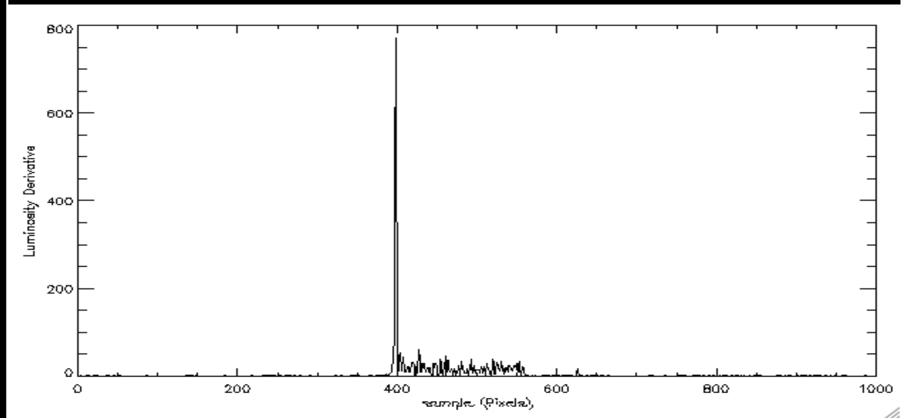
Finding the center of figure



Contour detection



Luminosity curve



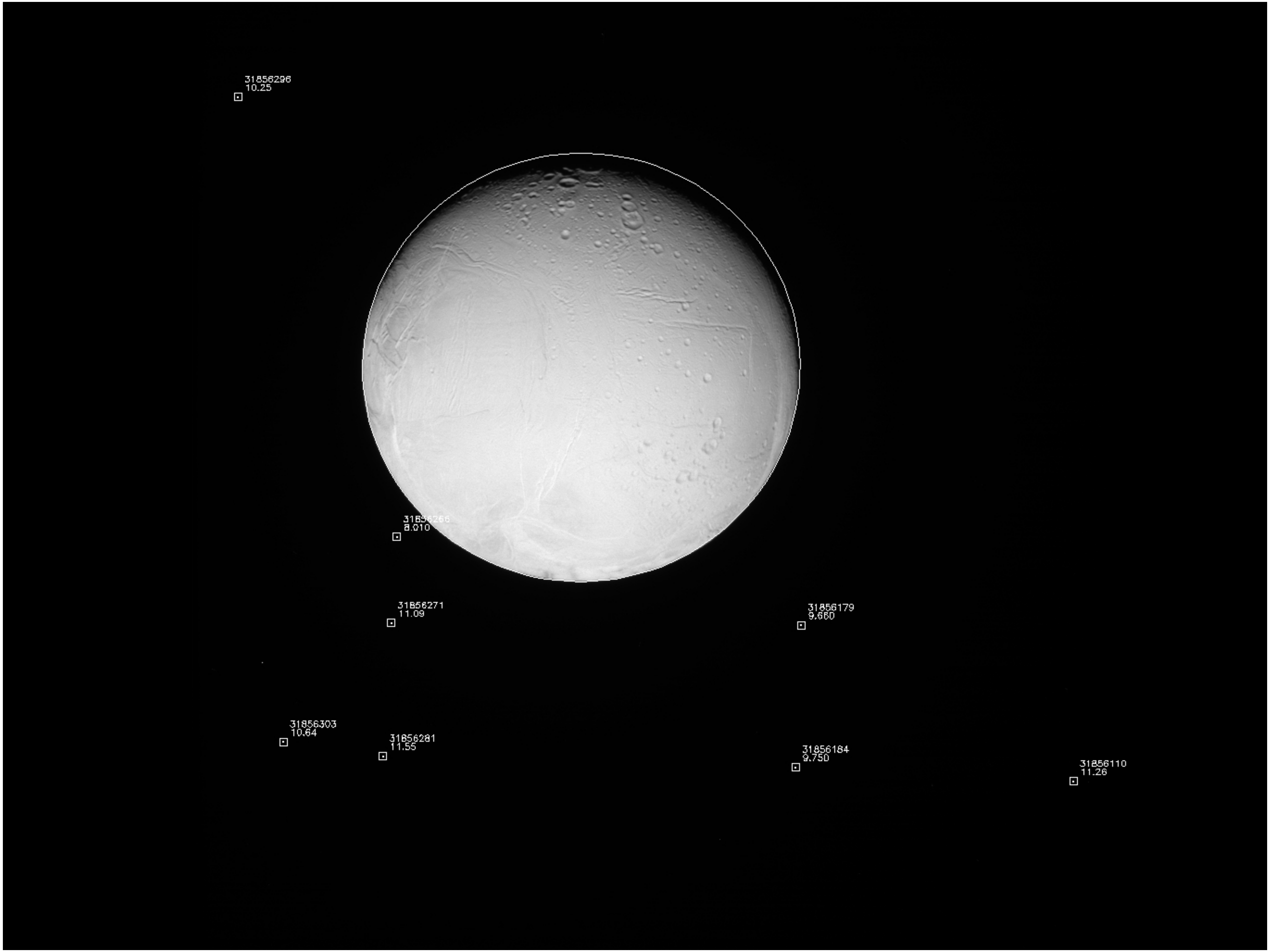
Derivative curve

Finding the center of figure

- Fit the cartesien equation parameters of an ellipse:
$f(x,y) = Ax^2+Bxy+Cy^2+Dx+Ey+F = 0$
to the bright part of the satellite, to finally obtain the ellipse parameters (X_c, Y_c, a, b, θ).

- In this work, a and b were fixed using the projection of the satellite's shape given by Thomas (2010). Thus, only three parameters are fitted at every limb fitting.

- UCAC2 catalogue was used for pointing correction.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10.64
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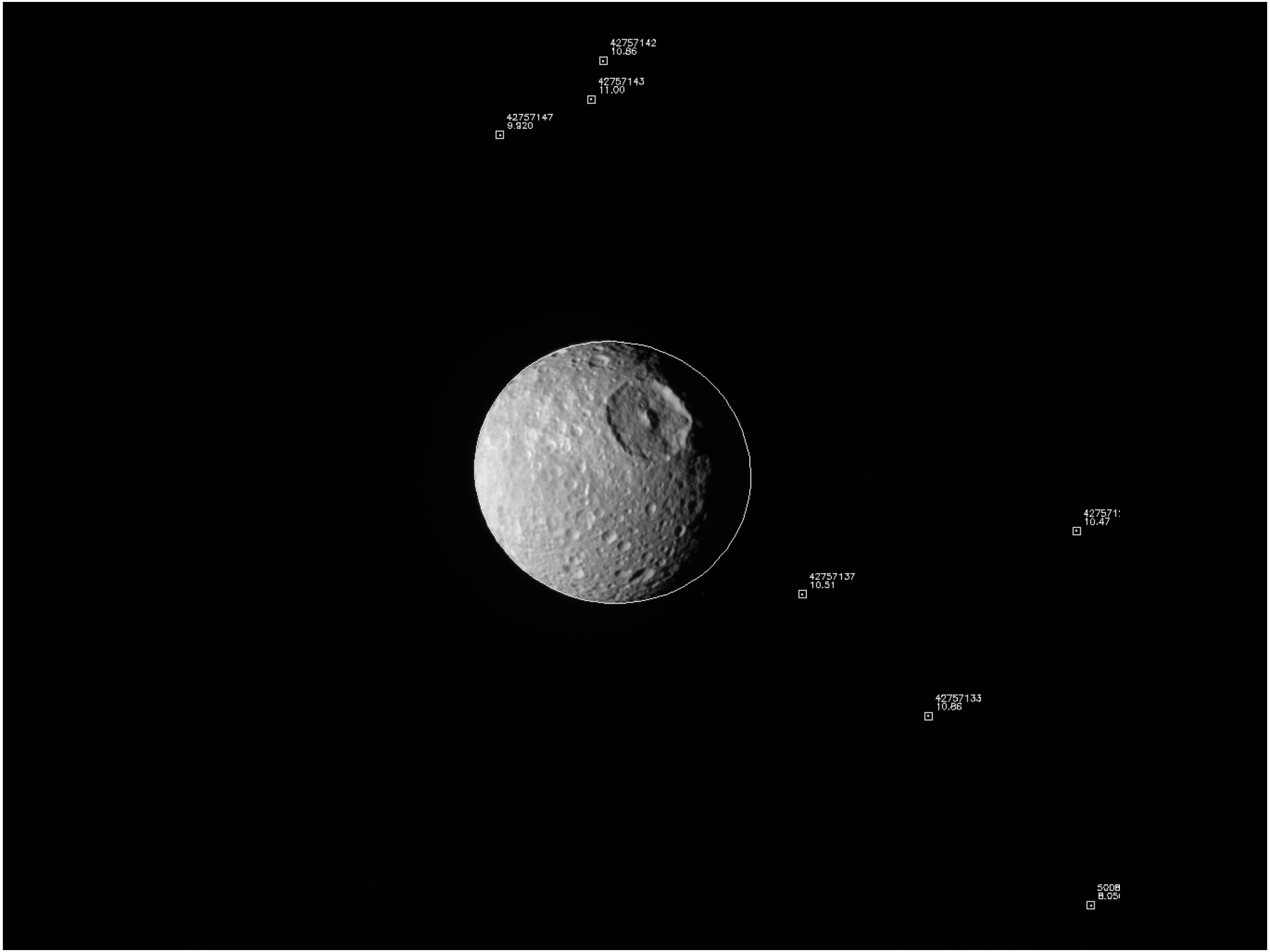
9.750
31856110
11.26



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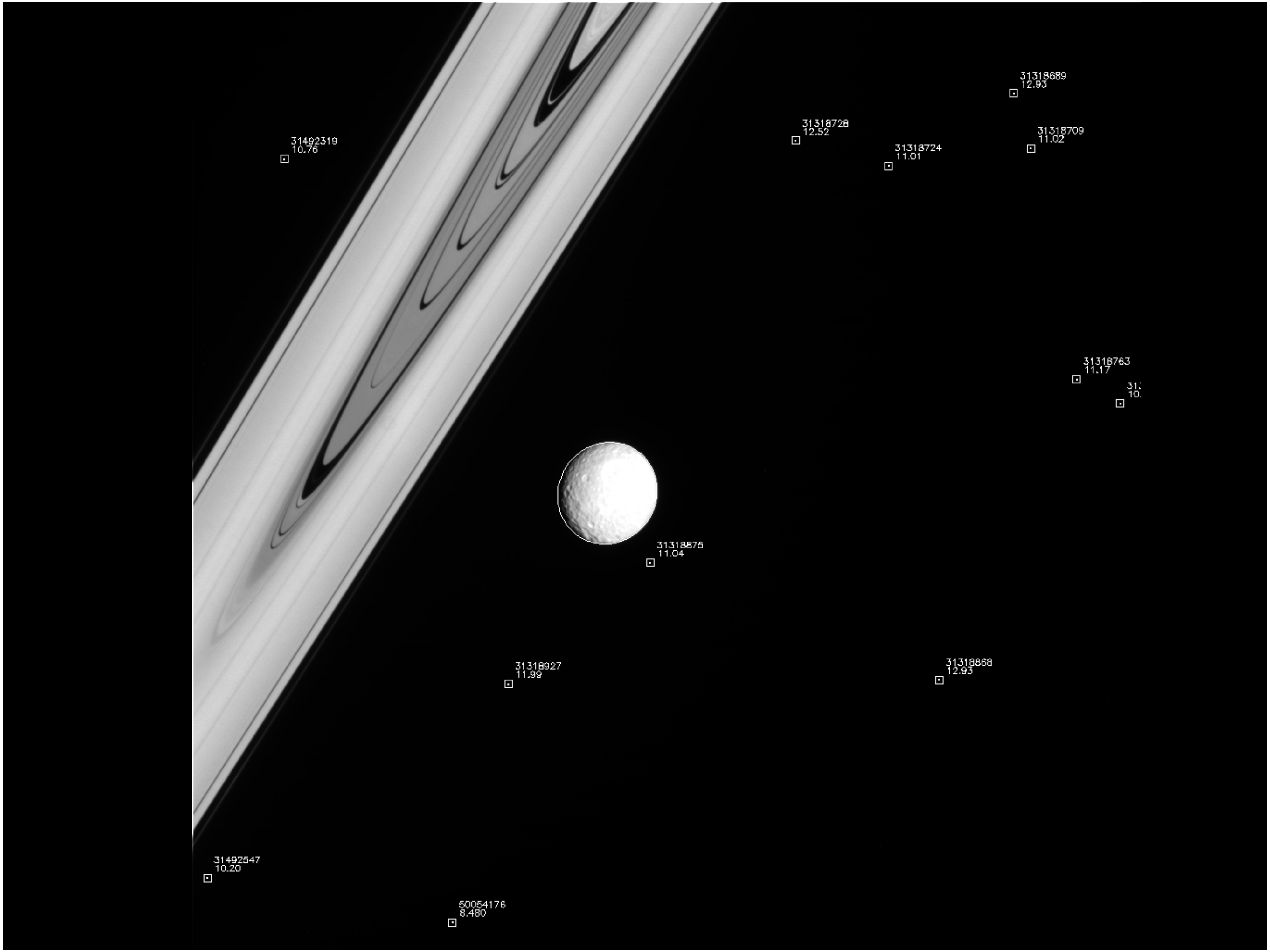
10.86
42757143
11.00
42757147
9.920
42757137
10.51
42757133
10.86
10.47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10.76
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11.04
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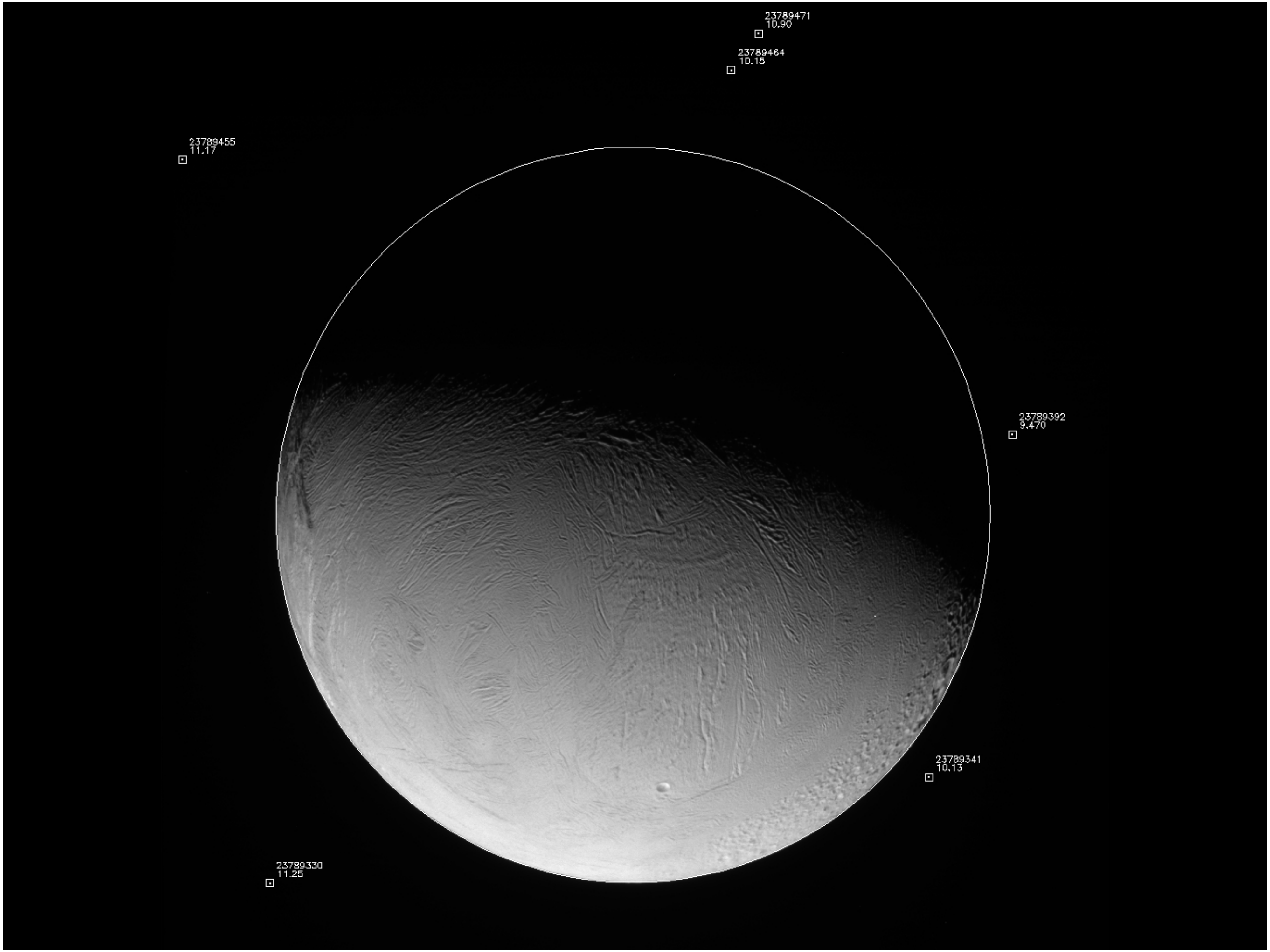
8.480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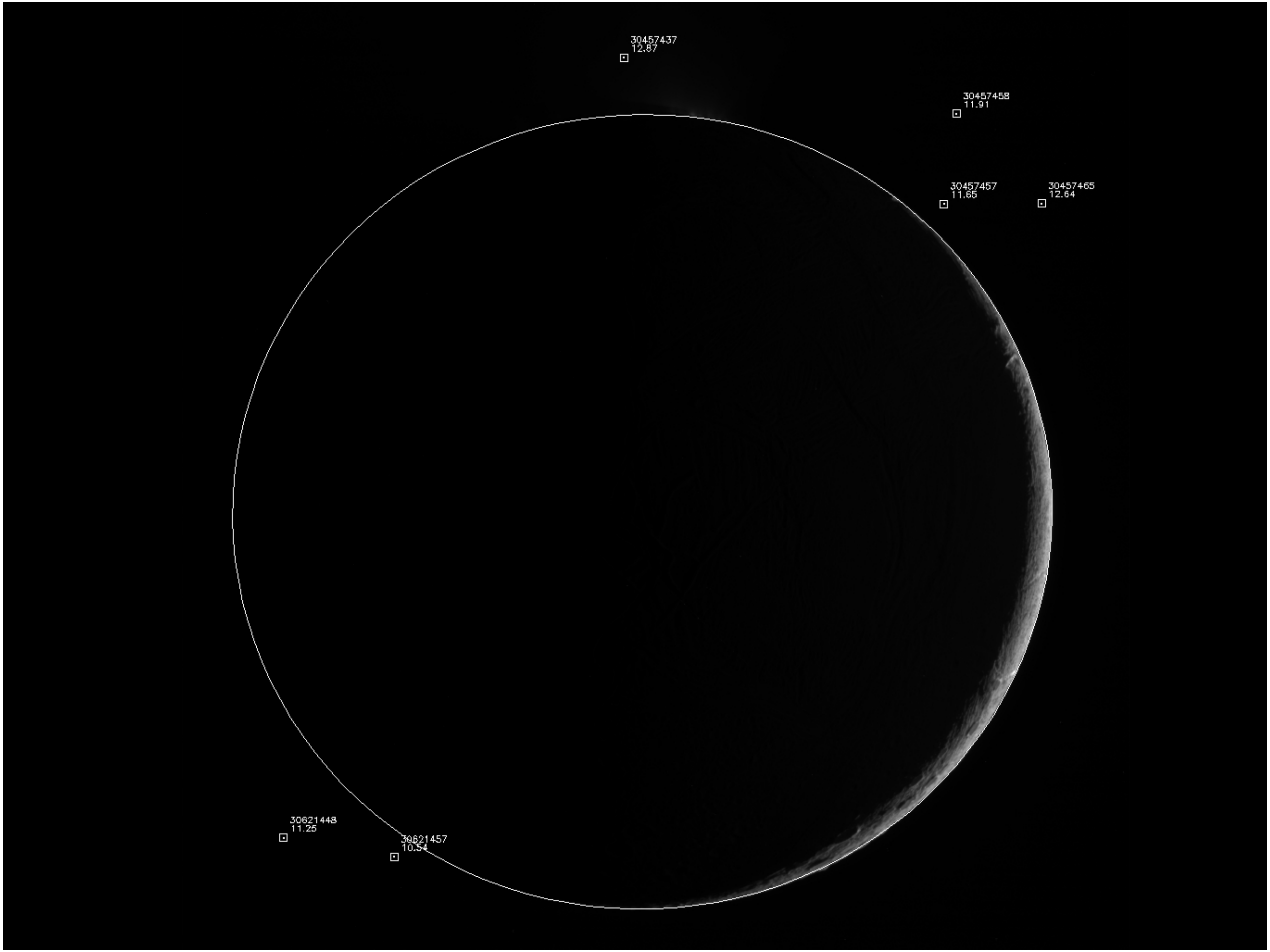
11.25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30457458
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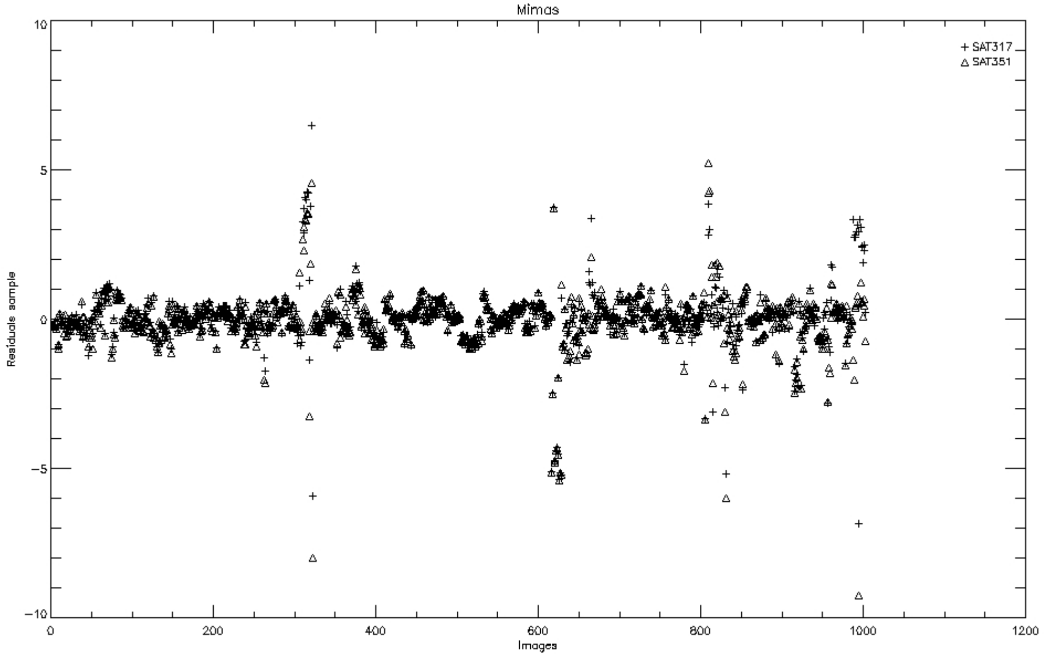
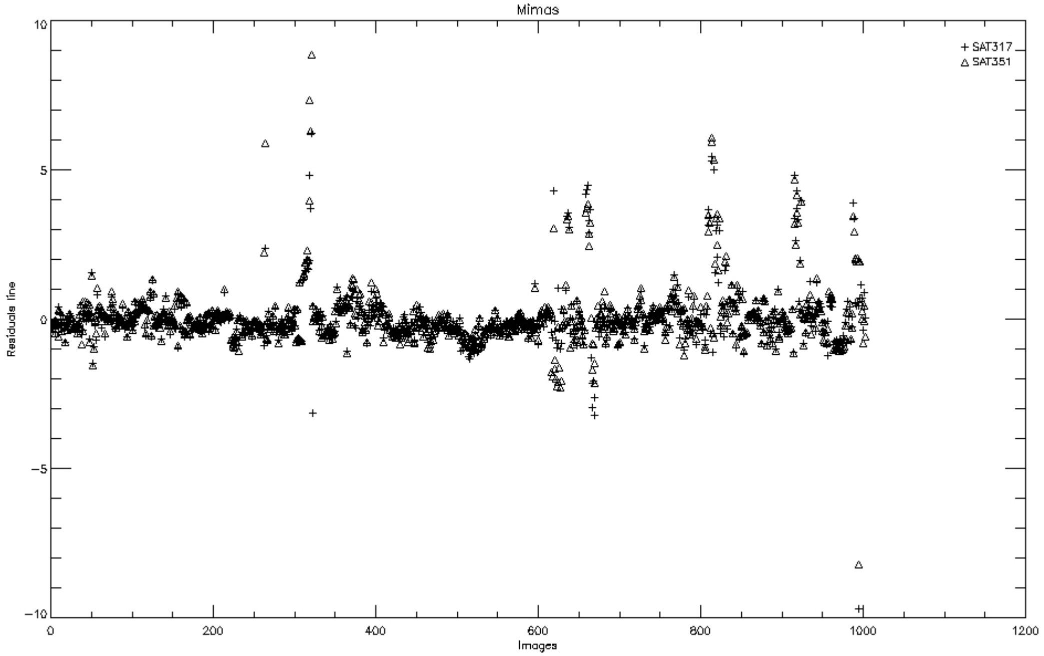
30457457
11.65
30457465
12.64
30621448
11.25
30621457
10.54

Residuals Mimas: (1006 images)

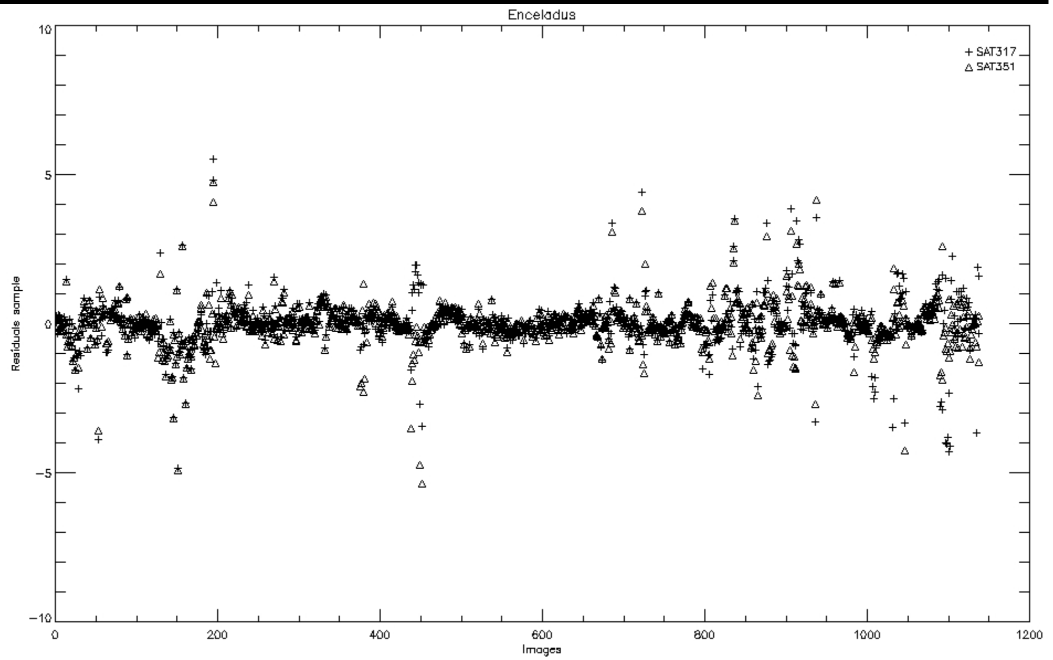
	SAT317	SAT351
$\langle O-C \rangle_{sample}$	2.69×10^{-2}	-5.34×10^{-2}
$\sigma_{\langle O-C \rangle sample}$	0.98	0.97
$\langle O-C \rangle_{line}$	2.10×10^{-2}	6.16×10^{-2}
$\sigma_{\langle O-C \rangle line}$	0.94	1.01

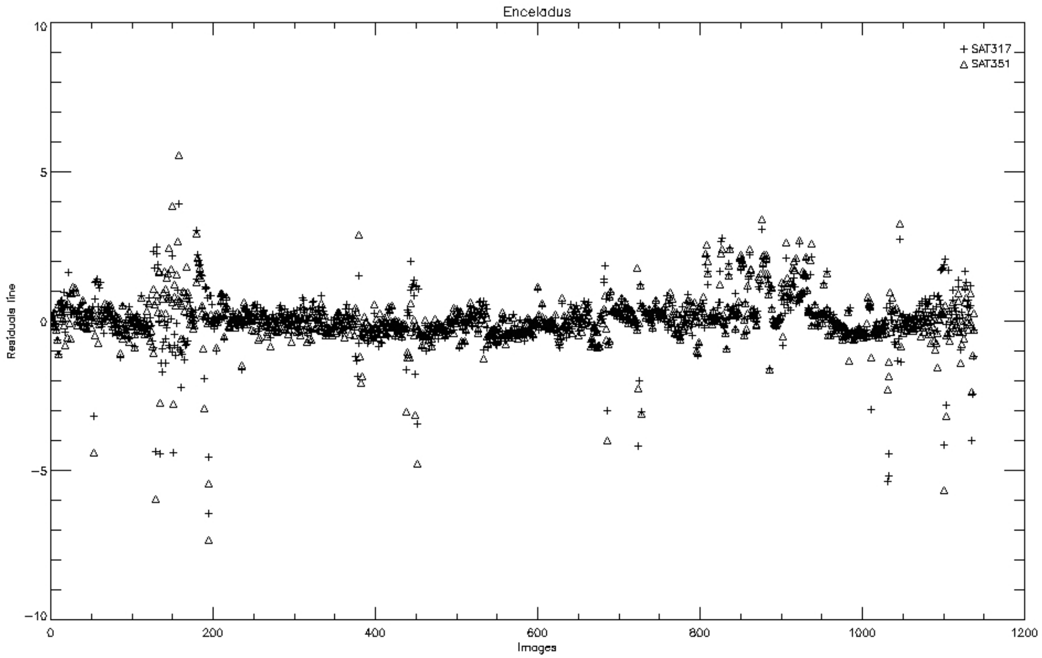




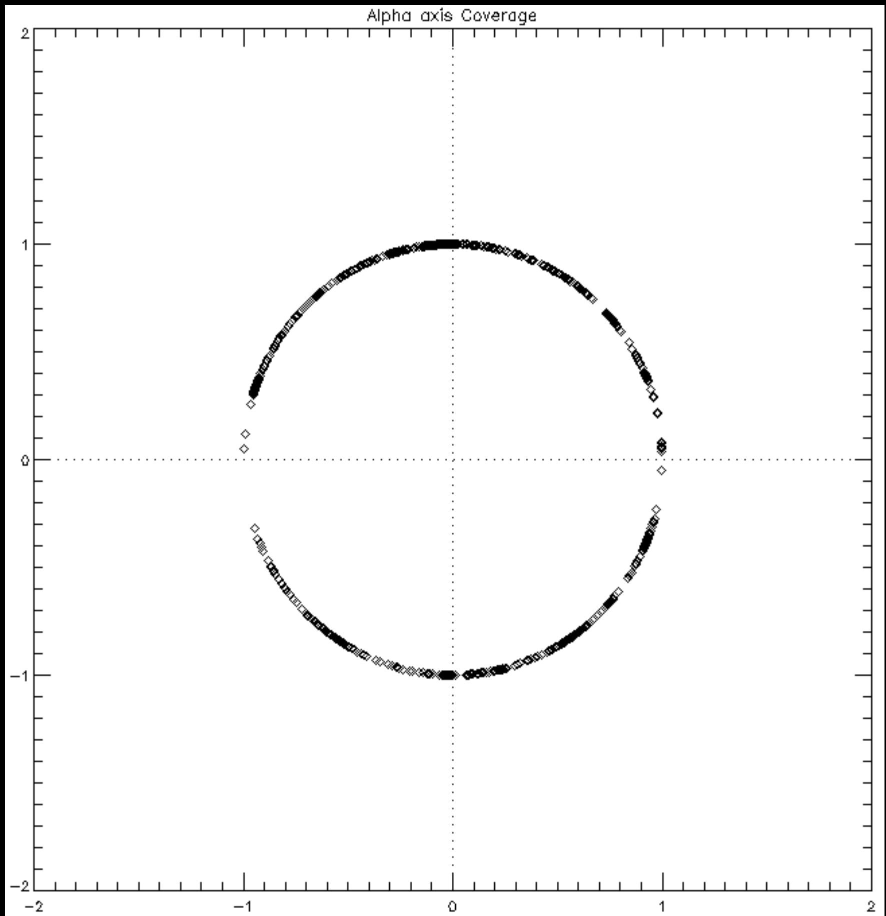
Residuals Enceladus:
(1141 images)

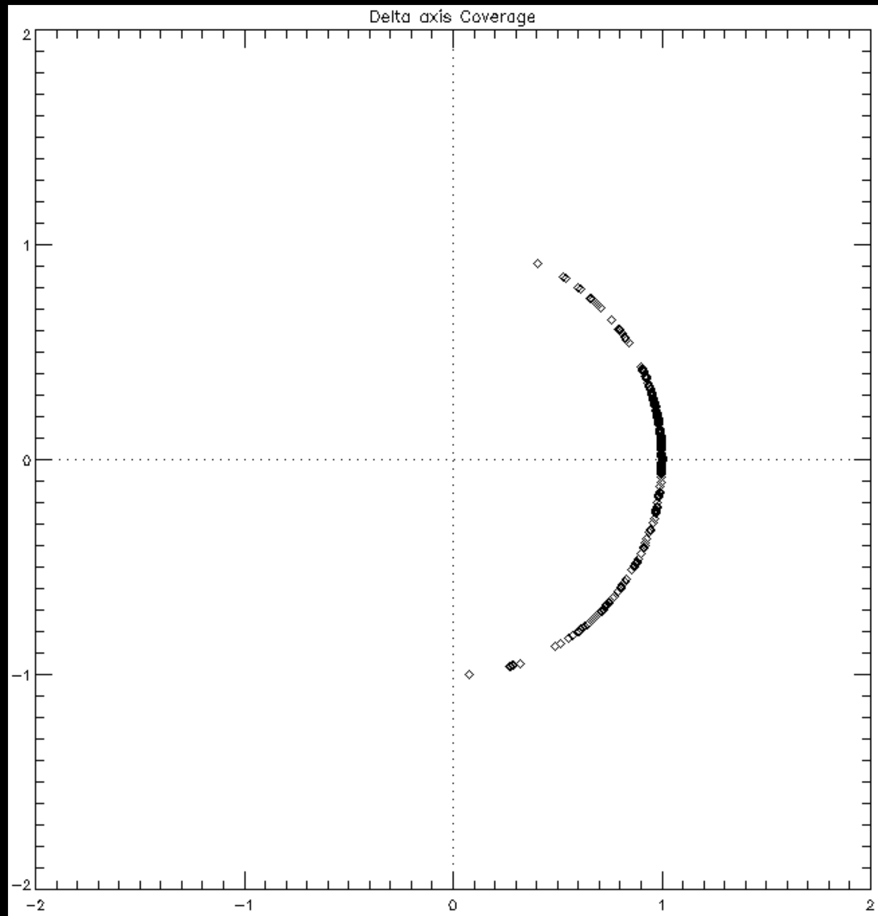
	SAT317	SAT351
$\langle O\text{-}C \rangle_{sample}$	2.71×10^{-2}	-2.69×10^{-2}
$\sigma_{\langle O\text{-}C \rangle sample}$	0.83	0.73
$\langle O\text{-}C \rangle_{line}$	6.72×10^{-2}	4.69×10^{-2}
$\sigma_{\langle O\text{-}C \rangle line}$	0.85	0.84



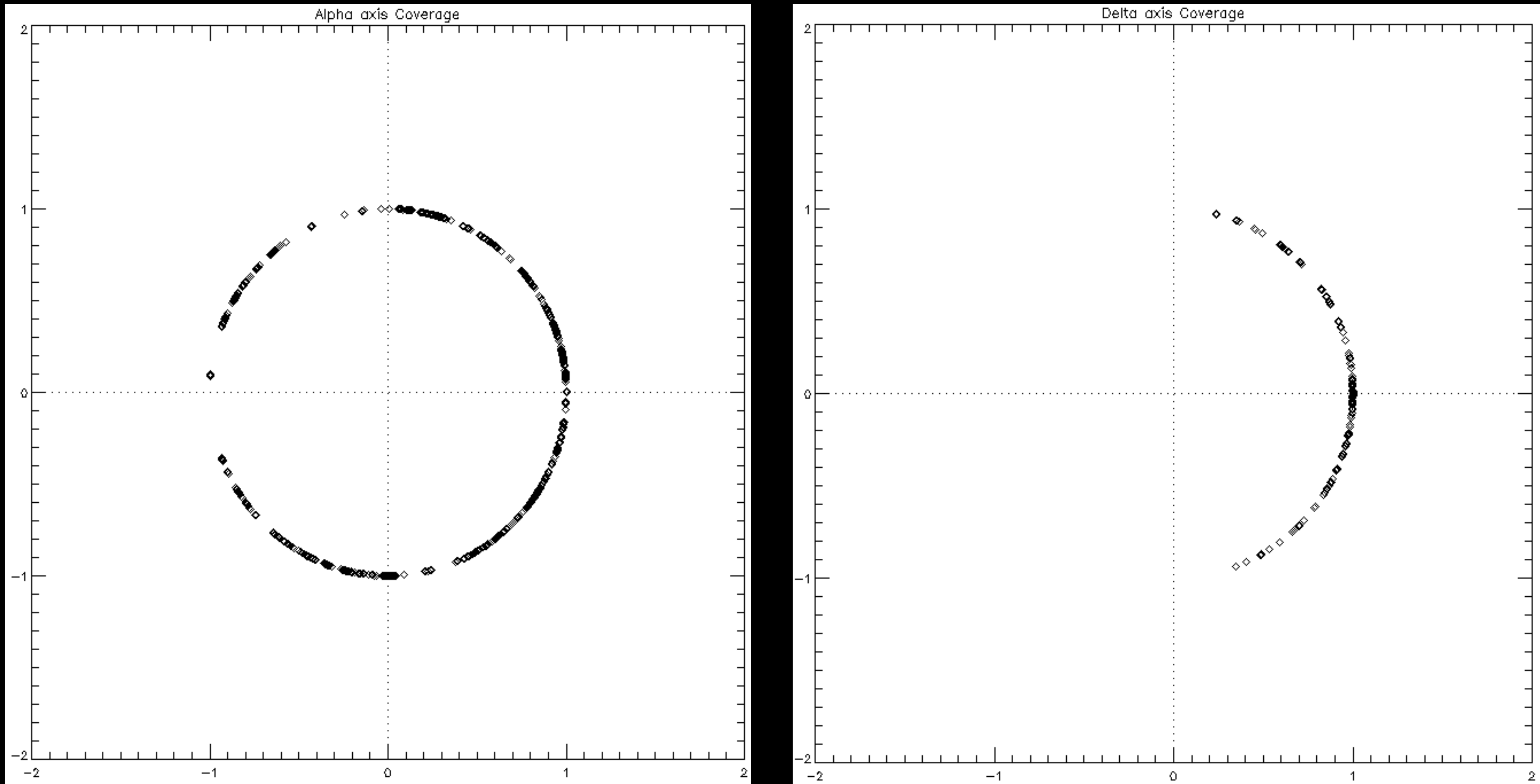


Coverage (Mimas)





Coverage (Enceladus)



COM/COF shift

Mimas:

Center of mass shift with SAT317 ephemeris:

X = 858 m ± 165 m
Y = -580 m ± 207 m
Z = 976 m ± 139 m

Center of mass shift with SAT351 ephemeris:

X = 734 m ± 163 m
Y = -535 m ± 210 m
Z = 925 m ± 134 m

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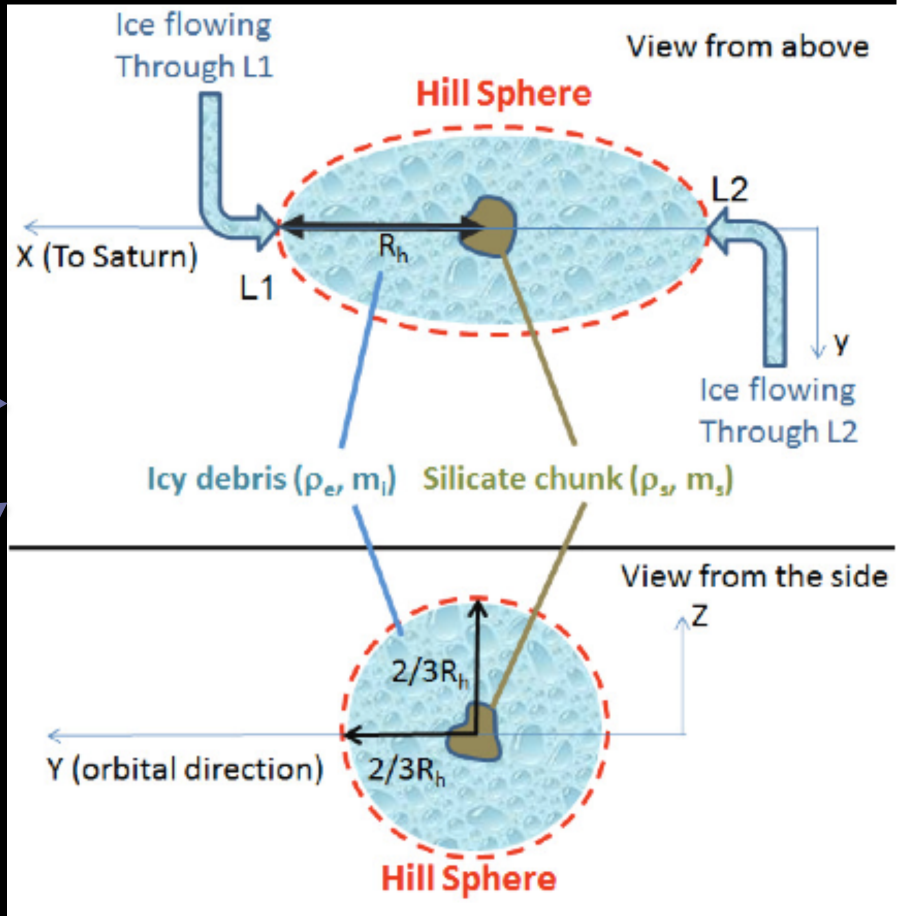
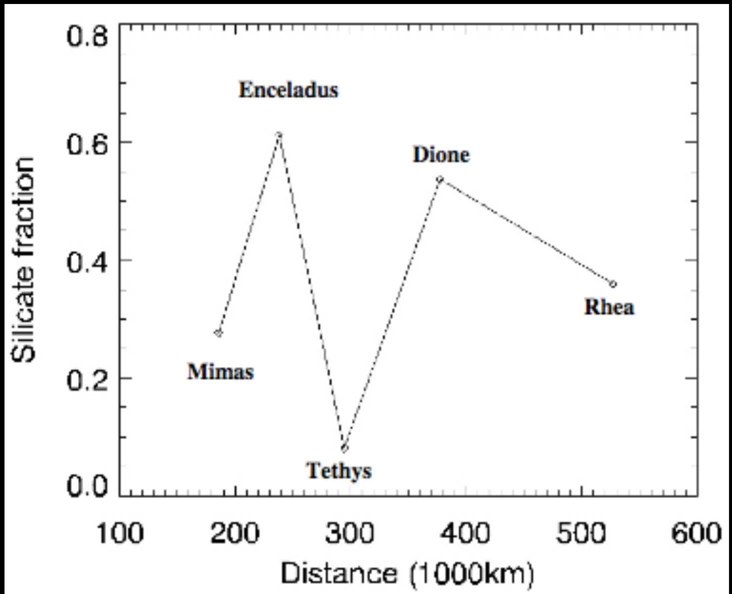
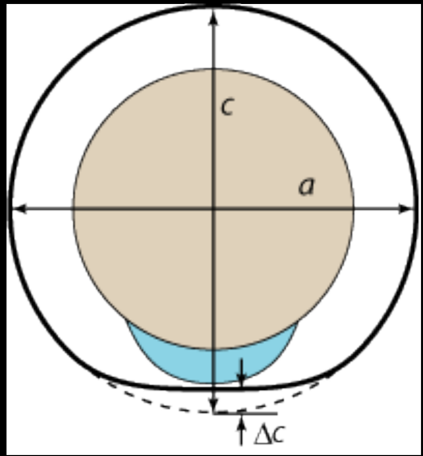


Charnoz et al. 2011

What are we expecting to observe on Enceladus ?

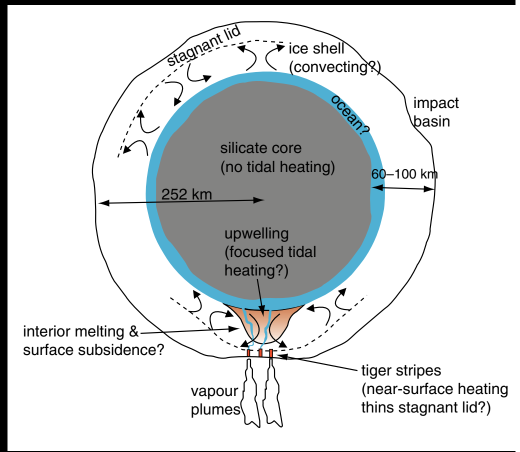
A more important shift ?





Southward ?

Northward ?



COM/COF shift

Enceladus:

Center of mass shift with SAT317 ephemeris:

X = -73 m ± 159 m
Y = -120 m ± 171 m
Z = - 5 m ± 132 m

Center of mass shift with SAT351 ephemeris:

X = -345 m ± 155 m
Y = -276m ± 170 m
Z = -136m ± 133 m

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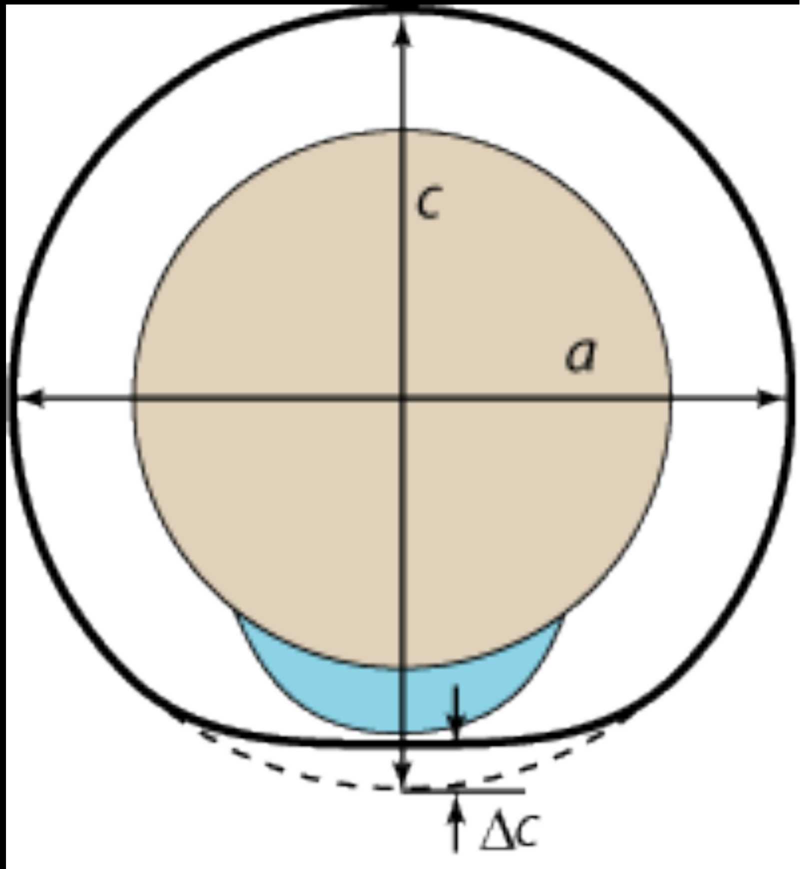
Disappointed ?

Don’t be..

- Collins and Goodman (2007) explained the observed south polar depression by Isostasy.
- Isostasy causes mass compensation within Enceladus’ interior.
- Center of Mass is back again at the center of figure and no shift is observed



Collins & Goodman 2007

Why Isostasy did not take effect on Mimas ?

Since tidal heating is way more important on Enceladus than on Mimas.
t_{relax}(Enceladus) < t_{relax}(Mimas)

And since Enceladus is older than Mimas. This latter, did not have enough time to relax and Isostasy did take effect on Mimas.

Summary

- We used astrometry to study the internal structure of Mimas and Enceladus.
- On Mimas we have detected a shift of the center of mass of about 800 meters in positive (X,Z) direction. Possible asymmetry in Mimas' core (closer to Charnoz et al. model).
- No shift in center of mass has been detected on Enceladus. Strong dissipation on Enceladus causes Isostasy in its interior, therefore mass compensation
- Next step: Fit NOE dynamical model to these observations adding the center of mass shift in the model.