Update on TIRA mission requirements

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TIRA CDR MEETING

Updates

- Version 2.4 of the HERA Mission Requirements were distributed on the 28th of October.
    - Consistency checked and small updated made on both documents (HERA & TIRA MRD).

- Requirements on Temp are verified using a developed thermal model.
    - Consistency checked and The geometry was updated based on the latest SPICE kernels.

- Release of SPICE Kernel Dataset Version (v0.5.1) with addition of TIRA Sensor (20/09/2019)
    - Operations & Data volume updated.
    - TIRA FOV erroneous

- HERA Operations Telecon 2019-10-30 (The geometry was updated based on the latest SPICE kernels.)
    - The use of the thermal camera for GNC needs to be clarified. In particular, the data volume from TIRA navigation is currently not considered.
    - Jesús organizes a splinter meeting on the topic of imaging during close flybys (TIRA would like to be present)
    - Evaluation of the phase angle distribution in the current trajectories: They are ok for AFC. TIRA would like to get into the nightside (currently implemented only after the closest flyby).
    - During closest approach to Didymoon Hera will point to the moon.
    - Dart impact location (Assumed on the farside in this presentation) _MK to find out the DART impact location.

TIRA Science Objectives & Requirements

Checked consistency with update MRD & minor modifications are made, requirements verified, Operations an data volume updated

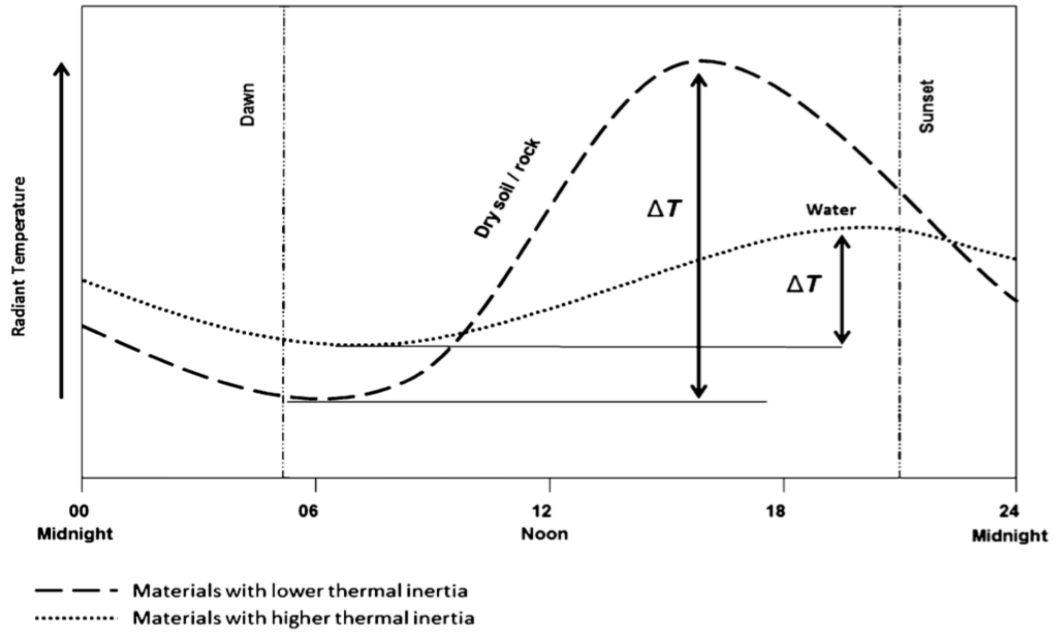
#	Priority	Objective	Description	Reference
TIRA_SO1	Primary	Surface properties & materials:	Discriminate between different possible surface properties of Didymoon (e.g. bare rock versus granular surfaces) that have great influence on the momentum transfer efficiency of a kinetic impactor.	D3, D6 from AD2
TIRA_SO2	Primary	Global thermo-physical properties & Orbital and spin state evolution	Determine the thermal inertia and other relevant global thermo-physical properties of the asteroid surface that contribute to the orbit/rotation evolution, in particular Yarkovsky and YORP effects.	D4 from AD2
TIRA_SO3	Secondary	Subsurface properties & materials	Characterize the subsurface material exposed by the DART impact.	D9, D10 from AD2

Requirements

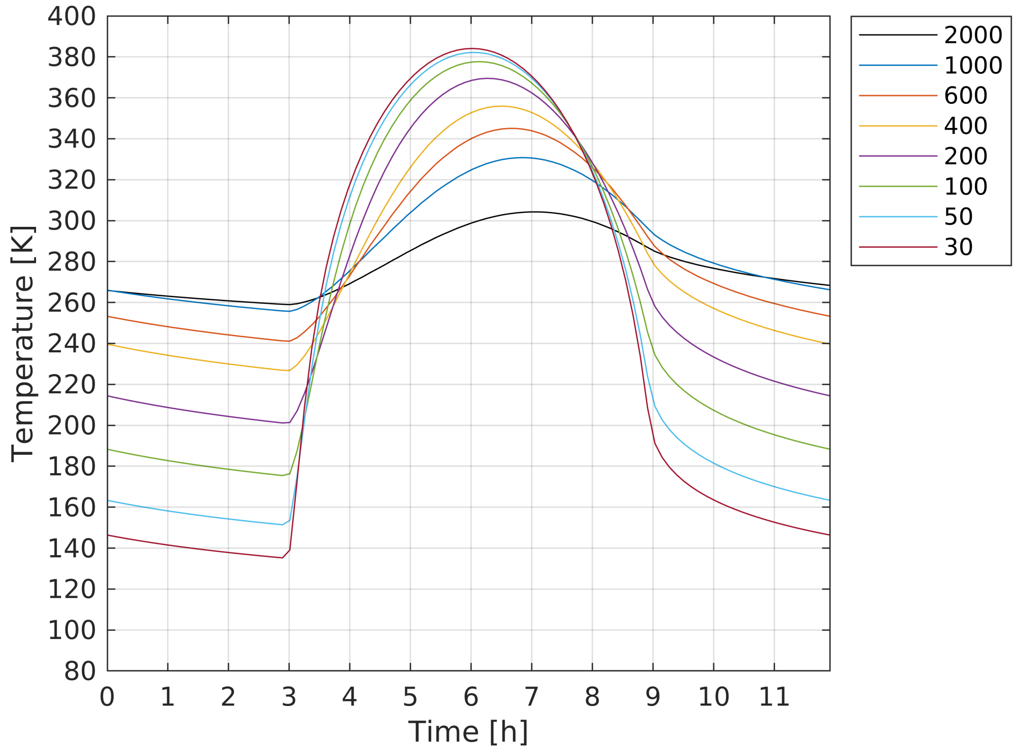
#	
TIRA_SCI_REQ001	TIRA shall enable the retrieval of the surface temperature with an accuracy of < 5K over the range of 200K <T<400K
TIRA_SCI_REQ002	TIRA shall have spatial resolution < 3m from 10 km at 8 µm .

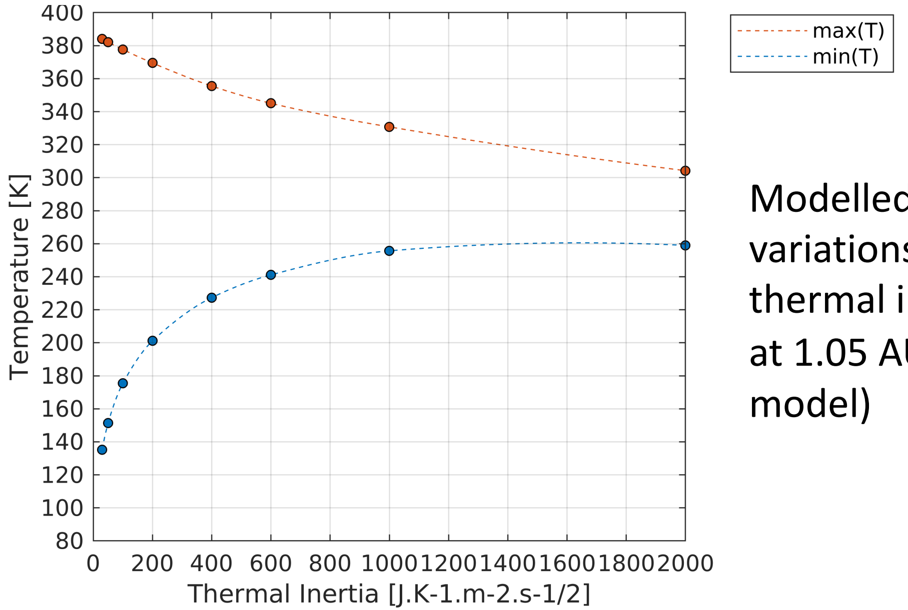
#	
TIRA_TEC_REQ001	TIRA shall retrieve images at a frequency > 1 frame/s
TIRA_TEC_REQ002	TIRA shall have a spatial resolution < 3m from 10 km at 8 ⍰m
TIRA_TEC_REQ003	TIRA shall have a FOV > 5.5°x5.5° to have the whole Didymoon for Centre-of-brightness determination in proximity operations.

Thermal Inertia



Kuenzer, C. & Dech, S. Thermal infrared remote sensing: sensors, methods, applications. (2015).





Modelled surface temperature variations as a function of thermal inertia on Didymoon at 1.05 AU (ROB Thermal model)

Maximum and minimum surface temperatures ΔT, and their position allows to to determine the thermal inertia (Noon & Dawn)

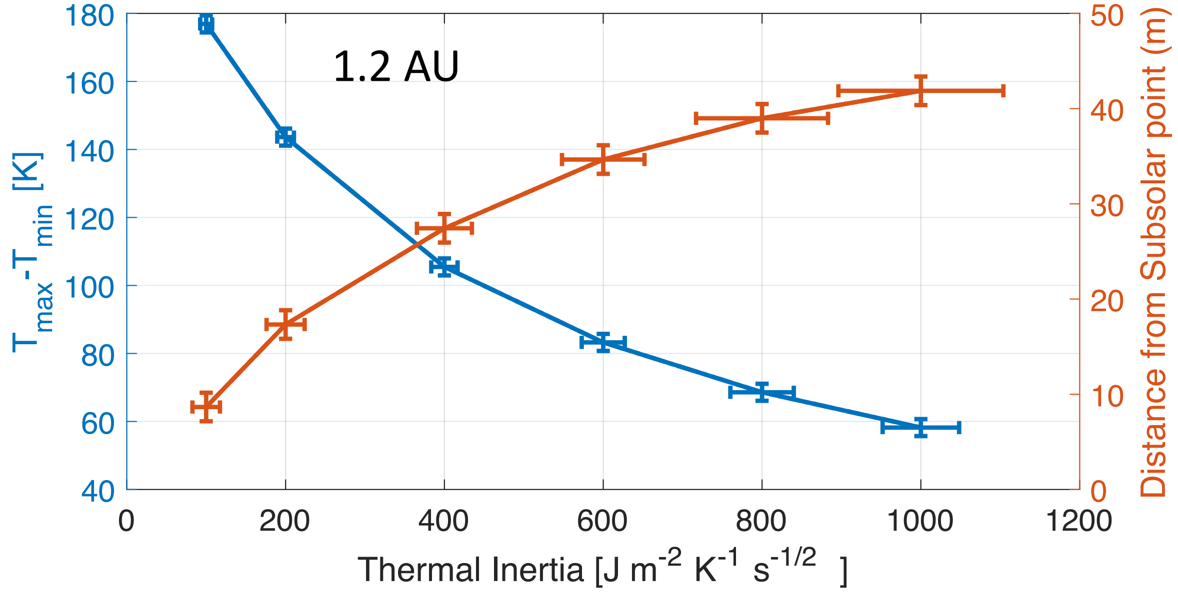
Uncertainty in Thermal Inertia

- A simple estimate of the uncertainty in thermal inertia can be made by calculation of $\frac{\partial \Gamma}{\partial \Delta T}$ or $\frac{\partial \Gamma}{\partial \Delta \lambda}$ from simulations (Neglecting all other error sources).

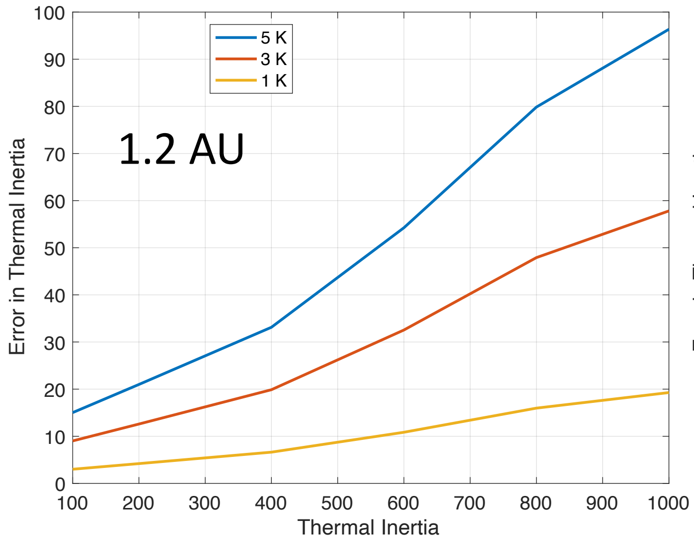
- The retrievals at closer distances to Sun with larger ΔT will improve the thermal inertia determination.

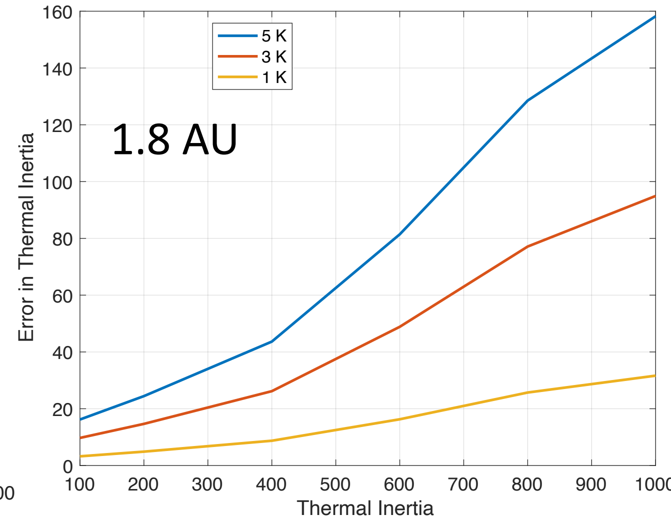
- Knowledge of absolute T better than 5 K, allows to determine the thermal inertia with an uncertainty ~20-160 J m^{-2} $s^{-0.5}$ K^{-1} ; Sufficient to distinguish between fine dust (30 J m^{-2} $s^{-0.5}$ K^{-1}), coarse sand 400 J m^{-2} $s^{-0.5}$ K^{-1} and for bare rock (>1000 J m^{-2} $s^{-0.5}$ K^{-1}) .

- NETD 0.3 K does not give directly the uncertainty in ΔT. Assuming a factor ten as a rule of thump, 3 K can be achievable. Current TIR instrument of JAXA is reported to have NETD @230 K=0.3 and an absolute accuracy of 3 K.



Error in Thermal Inertia for uncertainty of 5 K in temperature 1.2 AU





Effect of surface Emissivity

- Didymos' main body is categorized as S-type consistent with the presence of silicates
- Most of the emissivity features in TIR region are produced by silicate minerals.
- A rule of thumb a 0.01 emissivity error leads to a temperature error of 0.5–1 K. Actually, the emissivity-induced error depends on the object temperature and the emissivity of the object.

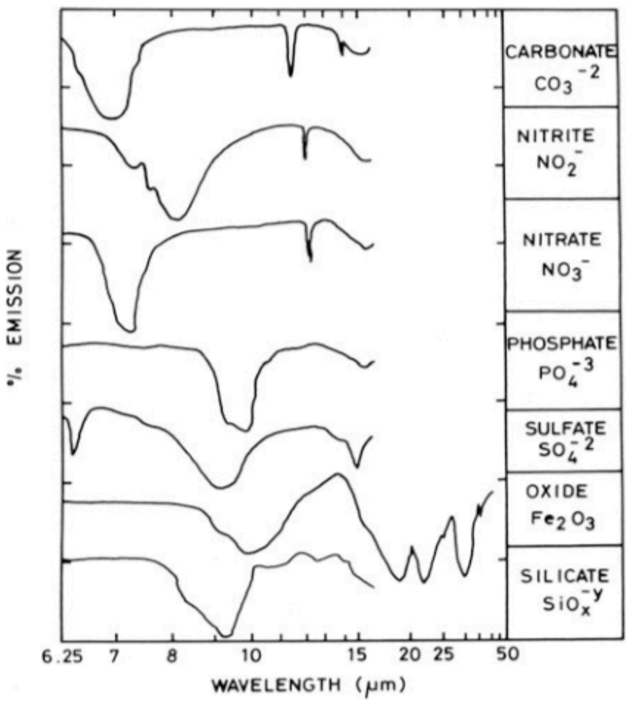
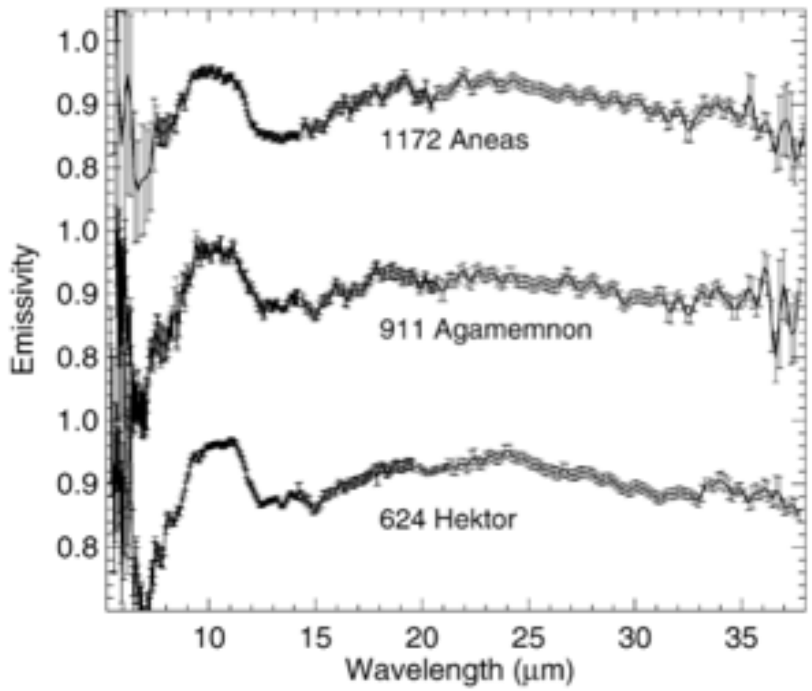


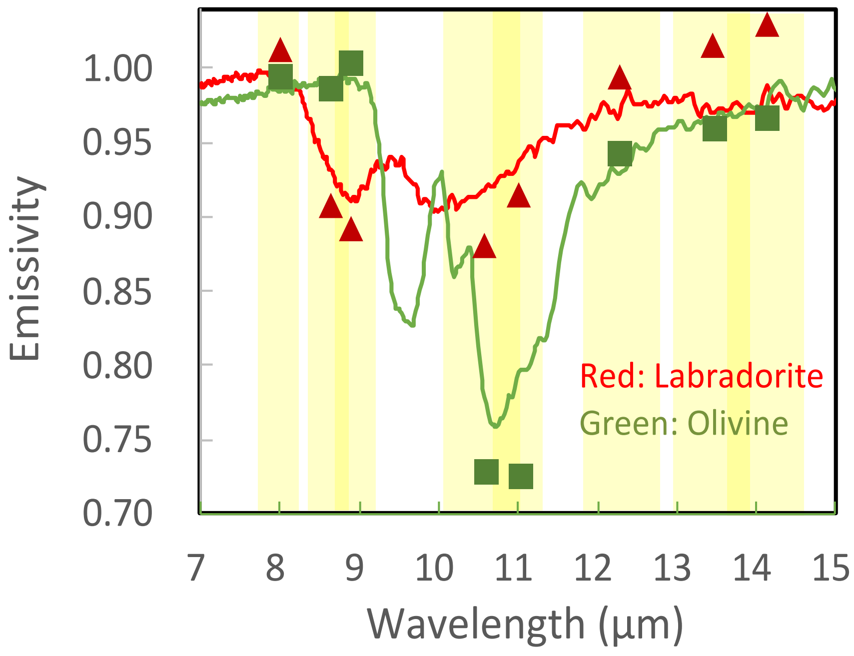
Fig. 3.9 Thermal infrared spectra of the major anionic mineral groups. (generalized) (data in all figures are reflectance spectra converted to emission spectra using Kirchoff's law) (Christensen et al. 1986)



The emissivity spectra of Trojan asteroids from Earth based measurements (Campins et al 2015)

Effect of surface Emissivity

- Without filters brightness temperatures (emissivity*Tsurface) can be sufficient to determine the global Thermal Inertia, if the emissivity does not.
- Additional filters covering region 8–9 µm and 9–12 µm (Exact number of filters and bandwith are TBD) would allow to identify silicate minerals
- Observations **with at least 2 bandwidth** help to separate the emissivity and surface temperature.



Proposed filters (8) for the TIRI instrument (Okada & Fukihara, AIDA meeting 2019)

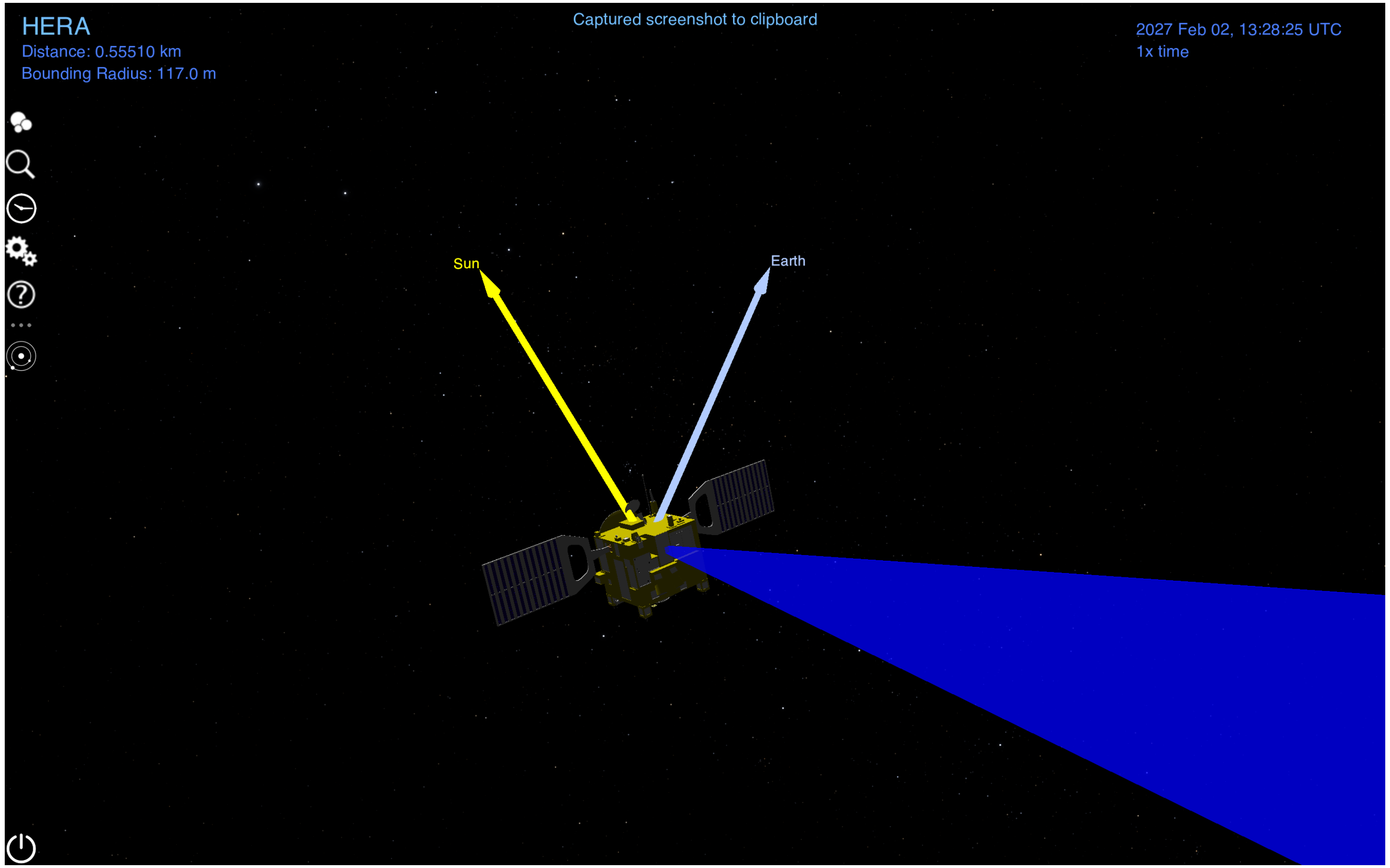
From HERA MRD :

→ **D9: If it provides spectral information,** comparison of the overall spectrum with that of the crater may allow to distinguish effects of space weathering.

→ **D10: If it provides spectral information,** TIR will contribute to the spectral identification of Didymos by measuring a low resolution spectrum of the 10 µm region. A spatial resolution of 10 m is required to distinguish between different surface regions on Didymos

Operations

- SPICE Kernel Dataset Version (v0.5.1) with addition of TIRA Sensor configuration
  - (FOV of TIRA is erroneous 9.8x7.4 instead of 7.39x5.34)



Operational Requirements

- SO1-SO2:
  - Imaging the whole surface with maximum surface temperature difference (Noon & Dawn / low & high phase angles) from single images.
  - The global coverage with best spatial resolution at each mission phase.
  - Closest to the Sun to increase the surface temperature difference between day and night.
  - Observations from different viewing geometries /solar distances whenever possible.

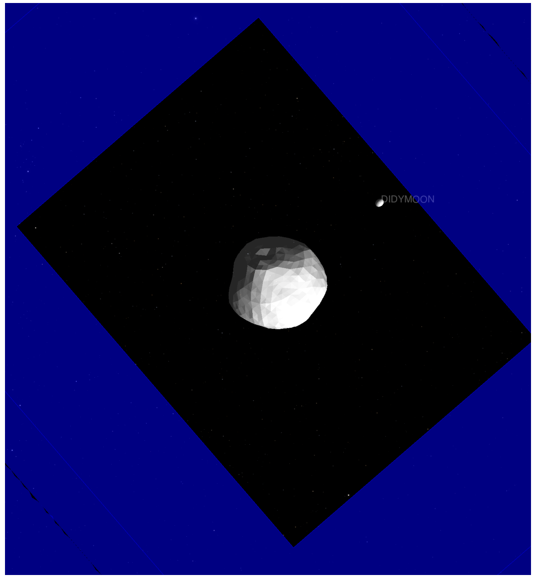
- SO3:
  - Imaging of the impact crater
  - Observation of maximum & minimum surface temperature (Noon & Dawn / low & high phase angles).
  - Spatial resolution better than 3m (goal < 1 m)
  - Observations from different viewing geometries /solar distances whenever possible.
  - Additional observations of regions of interests whenever possible.

- TN1 &TN2
  - The resolution of the images shall be such that surface landmarks can be identified
  - TBC with HERA (See notes of Operations telecon)

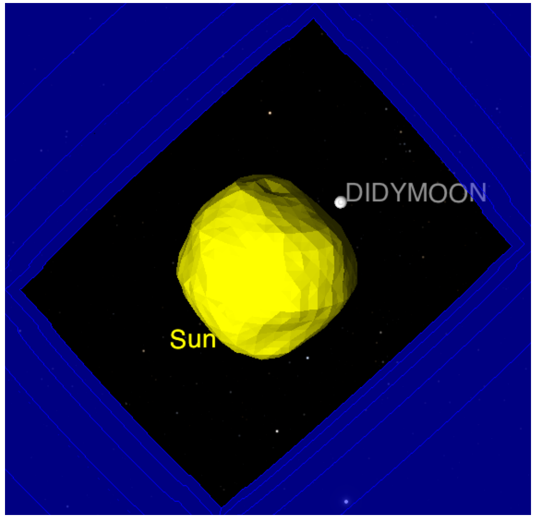
- Others
  - No specific limits of phase incidence and emission angles (other than coverage of max/min temp).
  - Whenever available measurements co-aligned and with AFC

Mission Phases

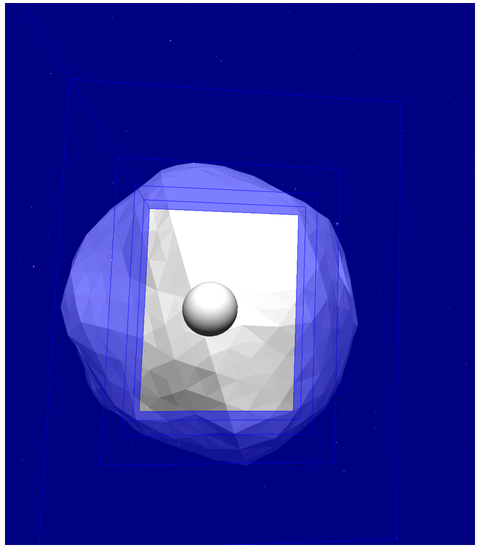
Phase	start	Distance from Sun	Min Flyby Distance (km)	Resolution	Num flyby
ECP	28/01/2027	1.0-1.1	20	< 5m (30 pix)	4 @ < 21 km
DCP1	25/02/2027	1.1-1.3	8.8	< 3m (60 pix)	4 @ < 10 km
DCP2	28/03/2027	NA	NA	NA	NA
DCP3	25/04/2027	1.4-1.7	0.8	<0.3m	4 @< 5km



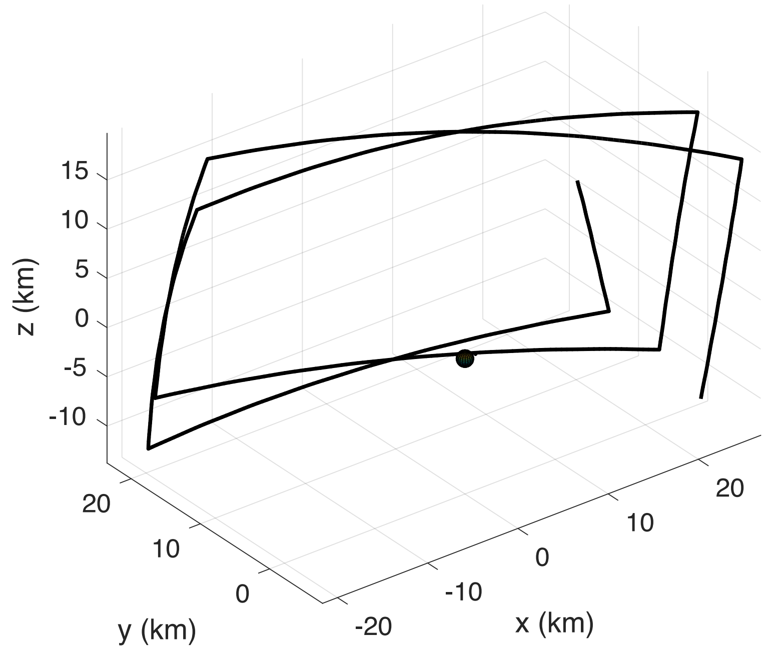
ECP



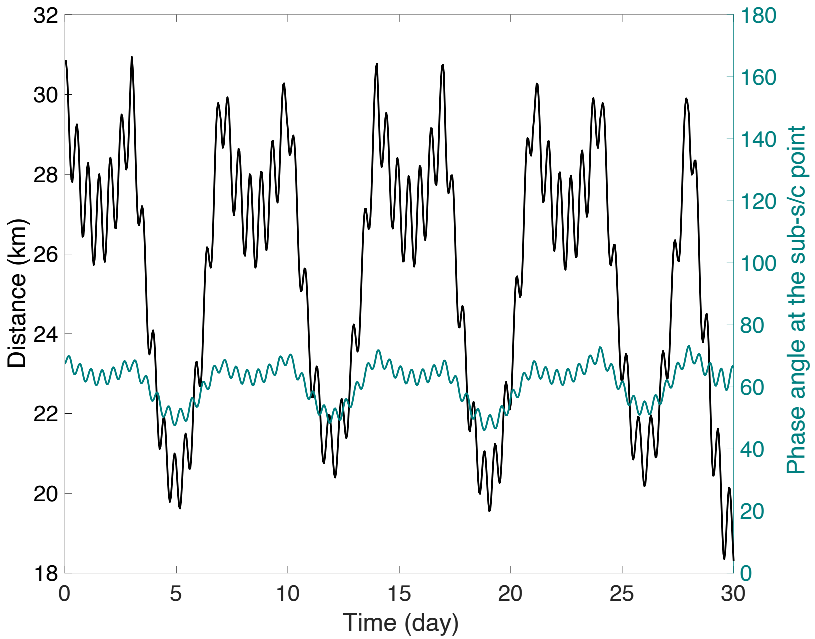
DCP1


DCP3

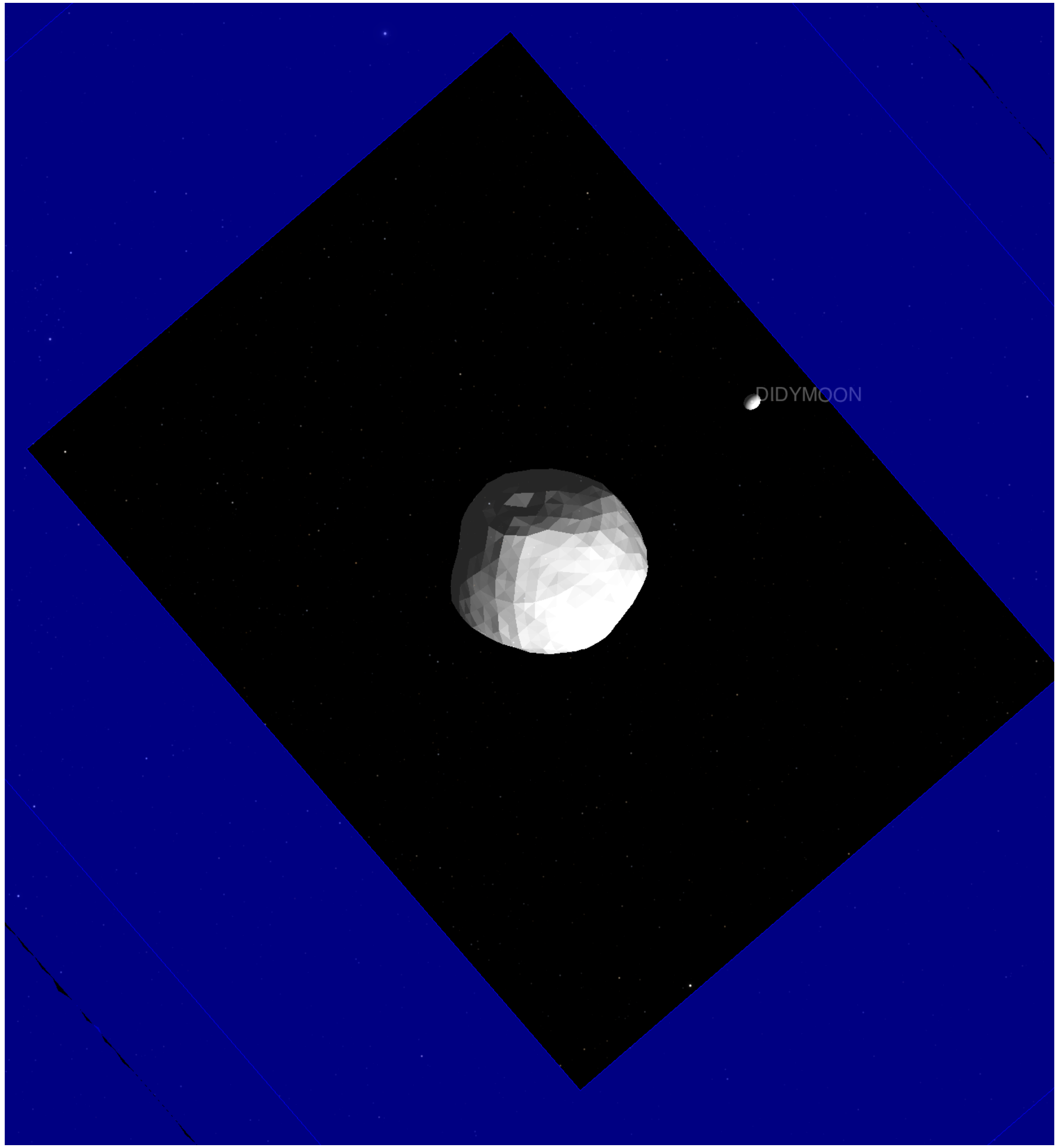
ECP



z (km)
15
10
5
0
-5
-10
20
10
0
y (km)
-20
-10
0
10
20
x (km)

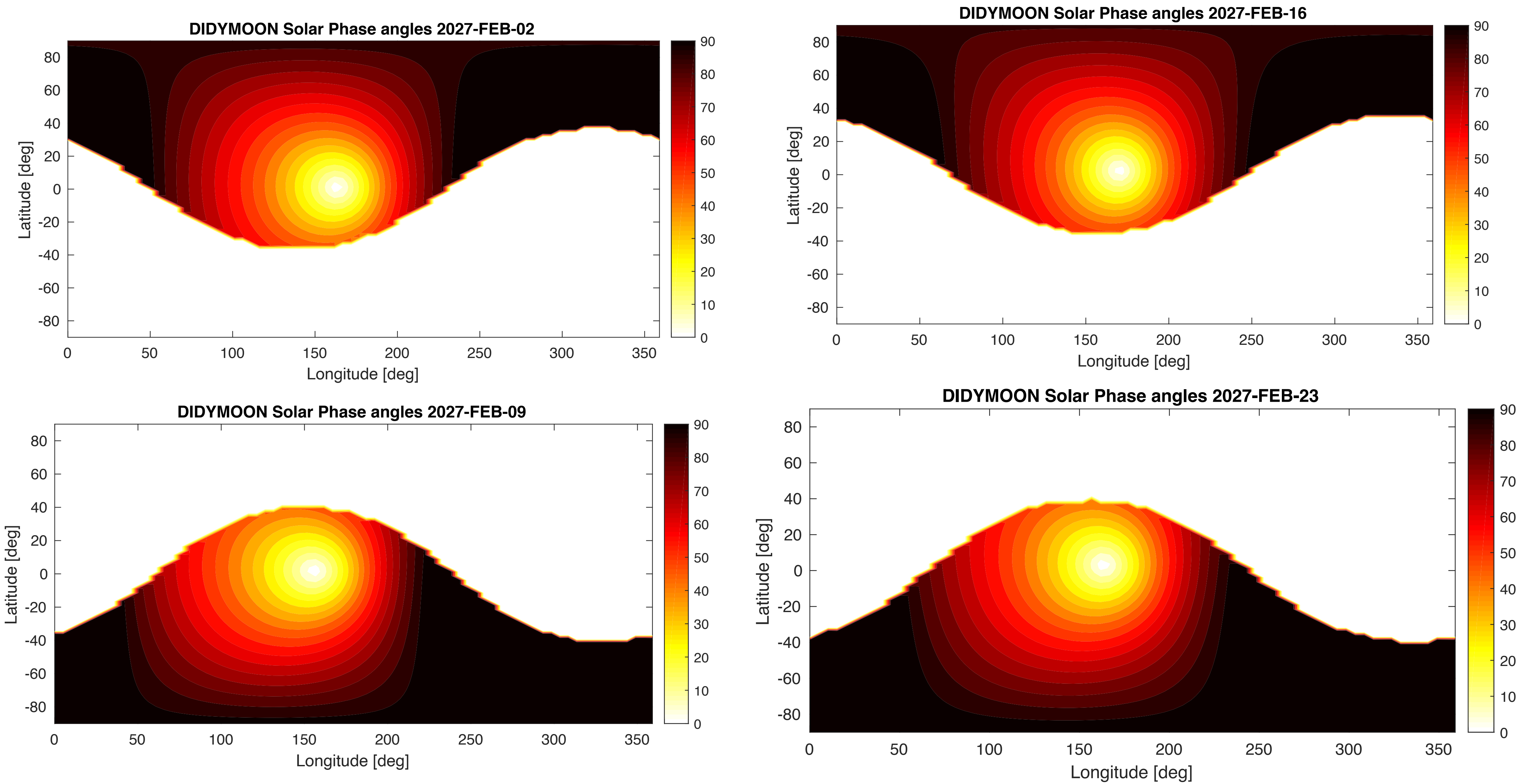


Distance (km)
32
30
28
26
24
22
20
18
Phase angle at the sub-s/c point
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Time (day)

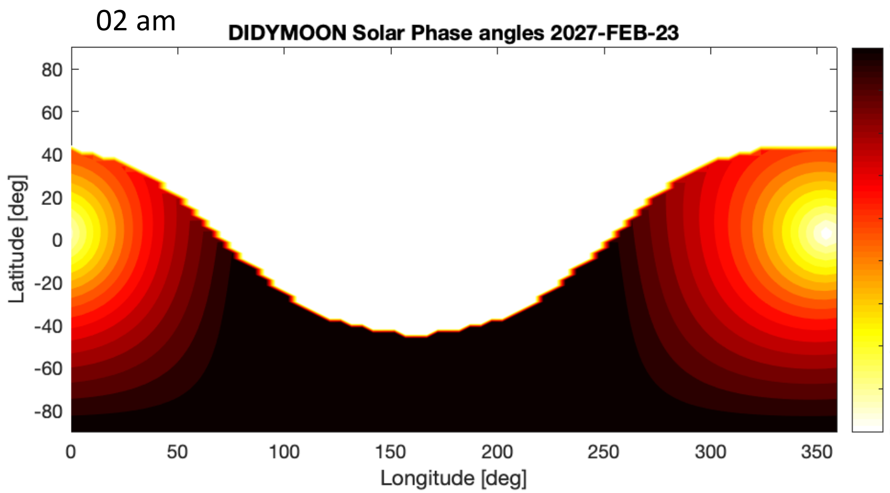


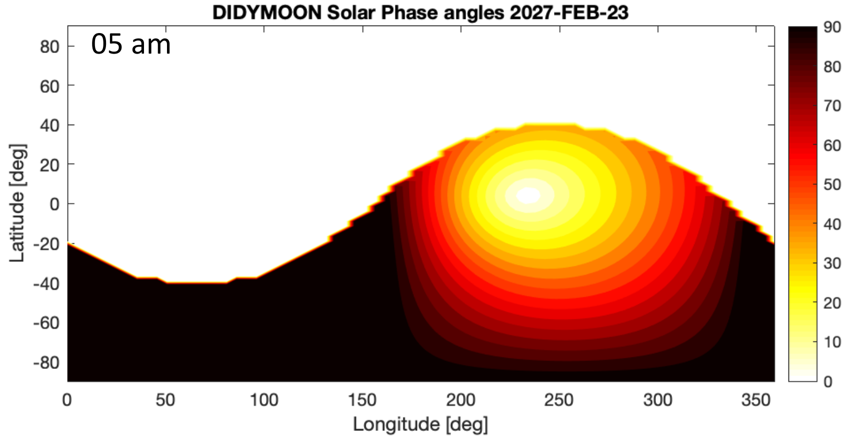
DIDYMOON

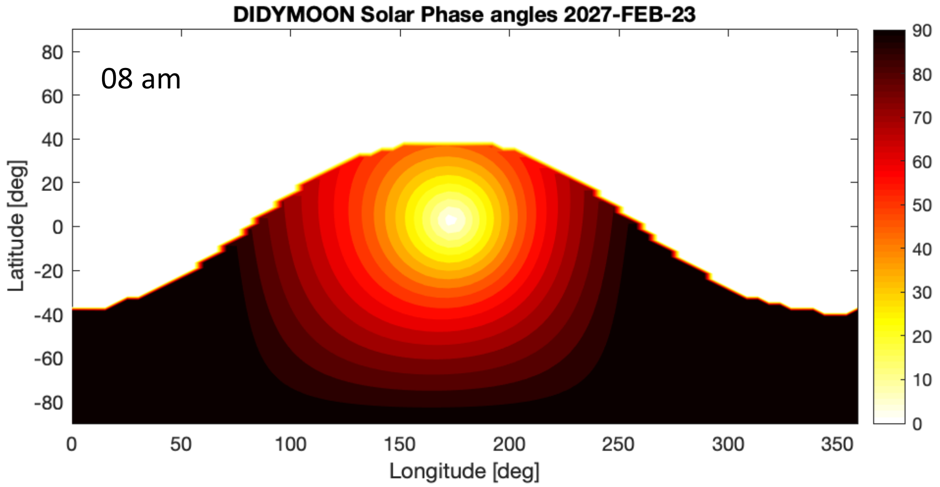
Solar Phase Angles and Visibility at Closest flybys during ECP

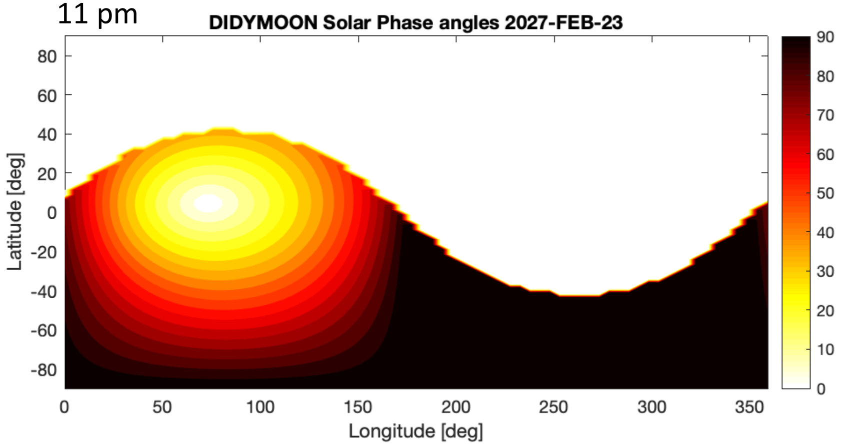


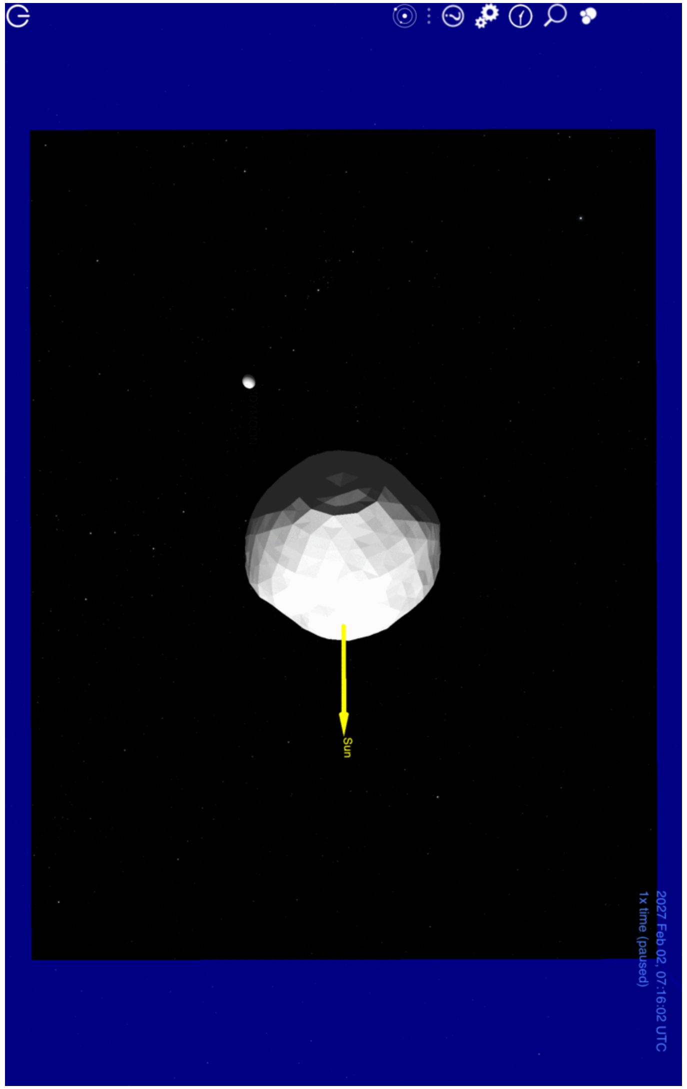
Solar Phase Angles and Visibility around flybys of 09/03/2027







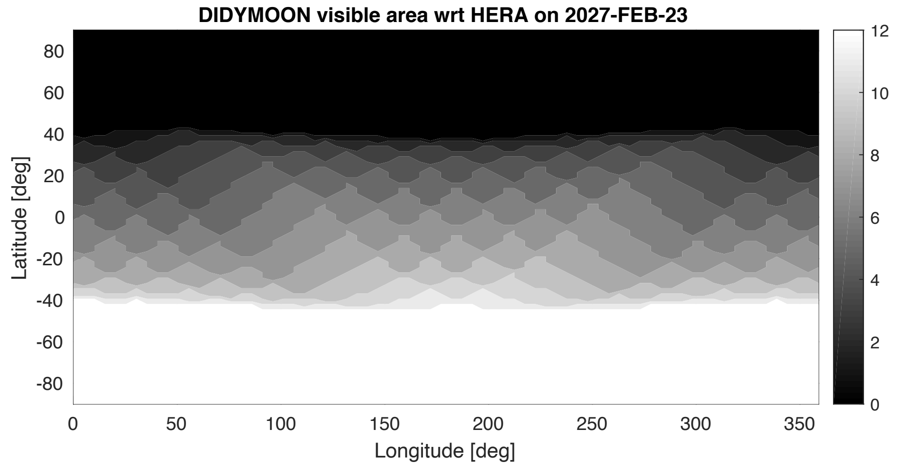


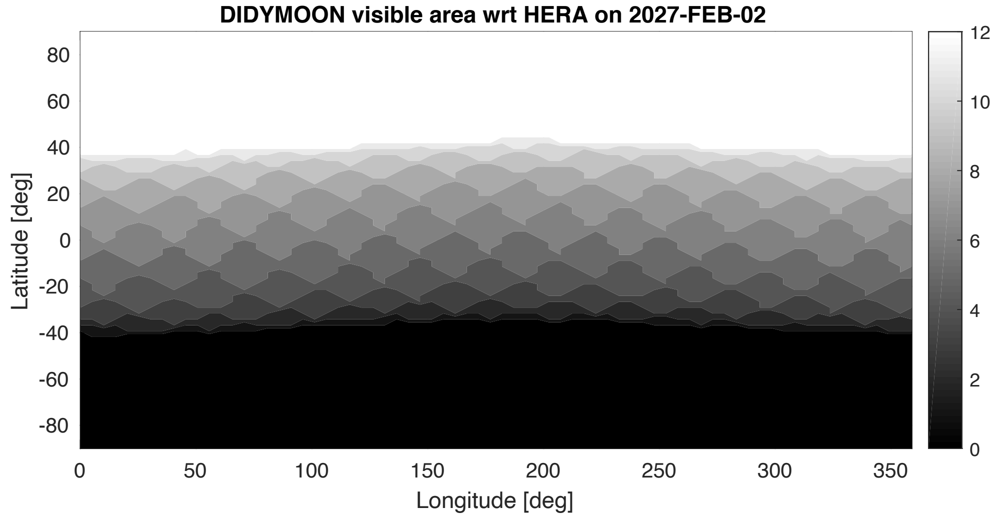


ECP

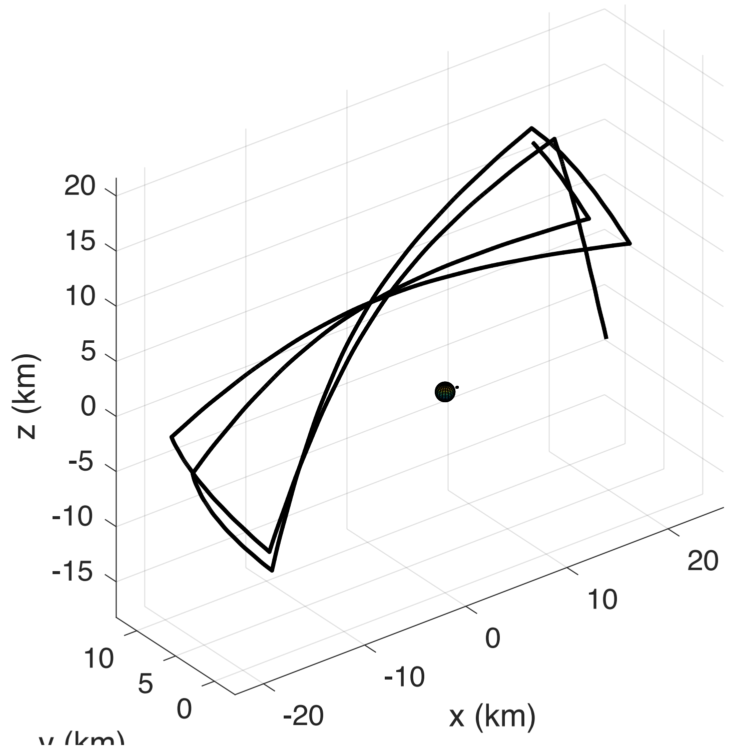
- Highest temp contrast, lowest spatial resolution (~ 5m) among the phases
- SPA ~ 60 at subsolar point, visibility of poles
- 12 images along the orbit during at least two flybys to cover all surface & solar phase angles : 24 measurements x 3 (with calibration) =72 images.

→ Give total surface coverage & rough global TI

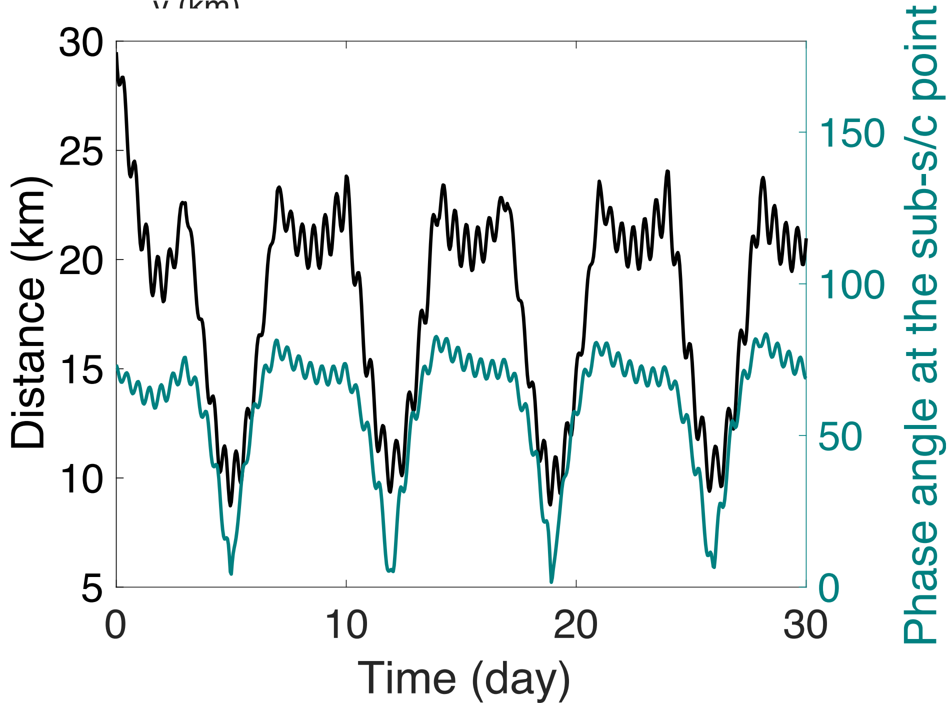




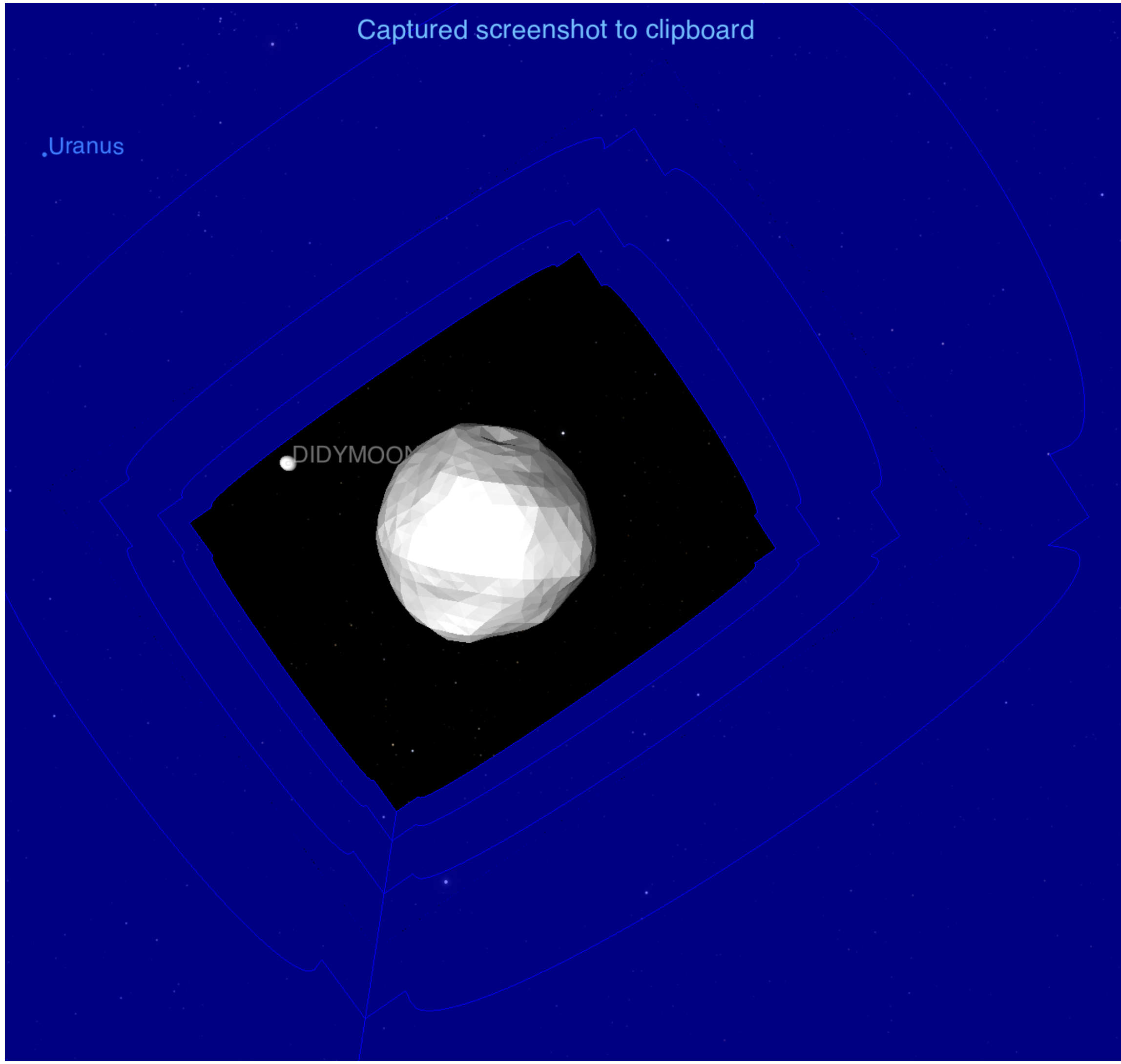
DCP1



z (km)
x (km)
y (km)

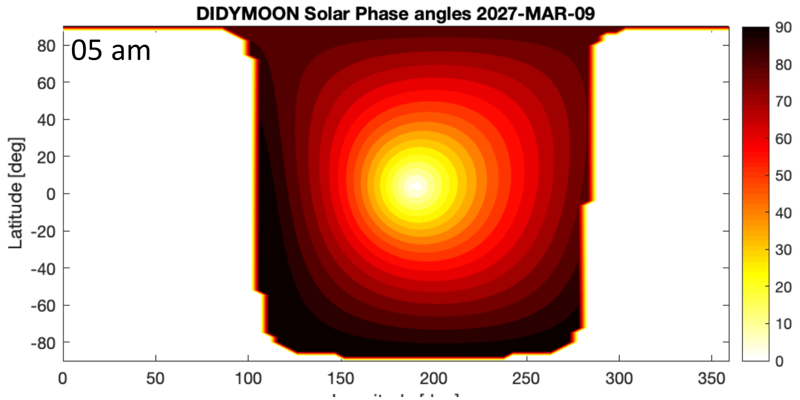


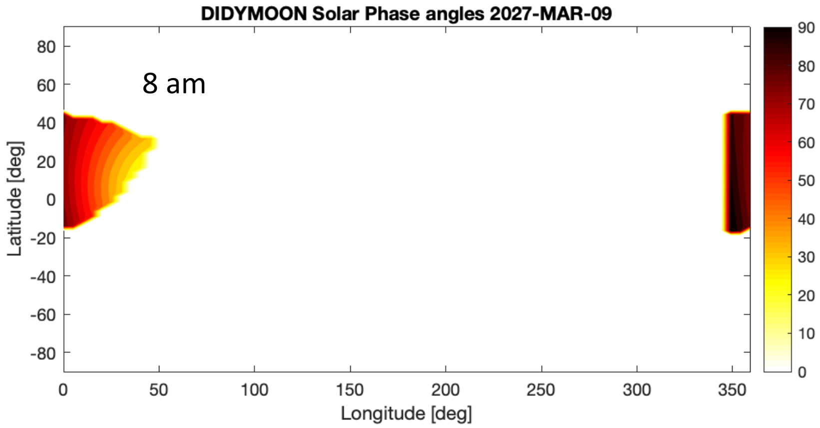
Distance (km)
Phase angle at the sub-s/c point
Time (day)

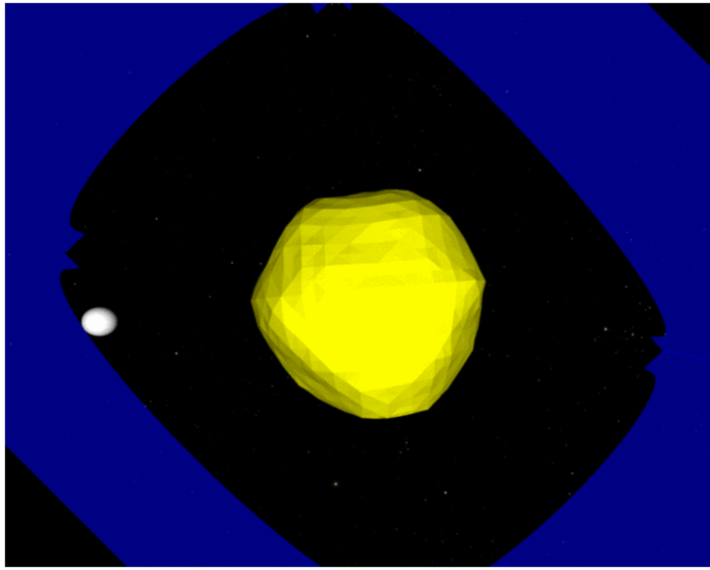


Captured screenshot to clipboard
Uranus
DIDYMOON

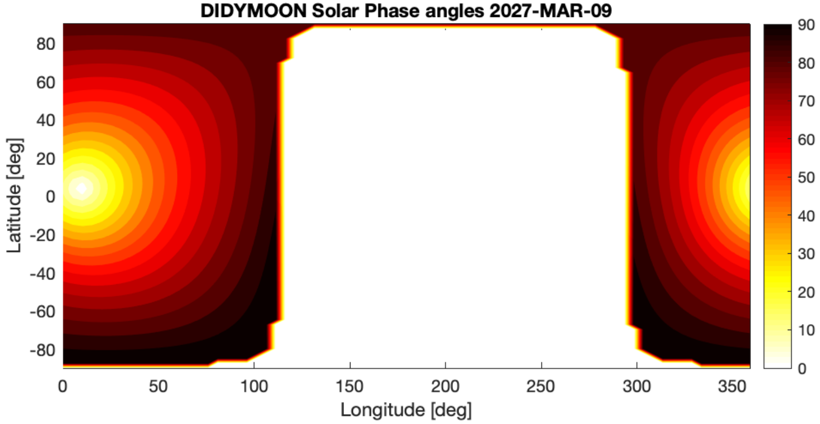
Solar Phase Angles and Visibility around flybys of 09/03/2027



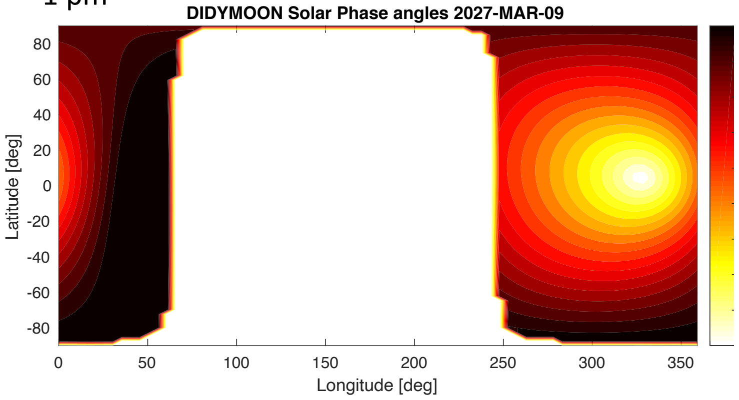




11 am



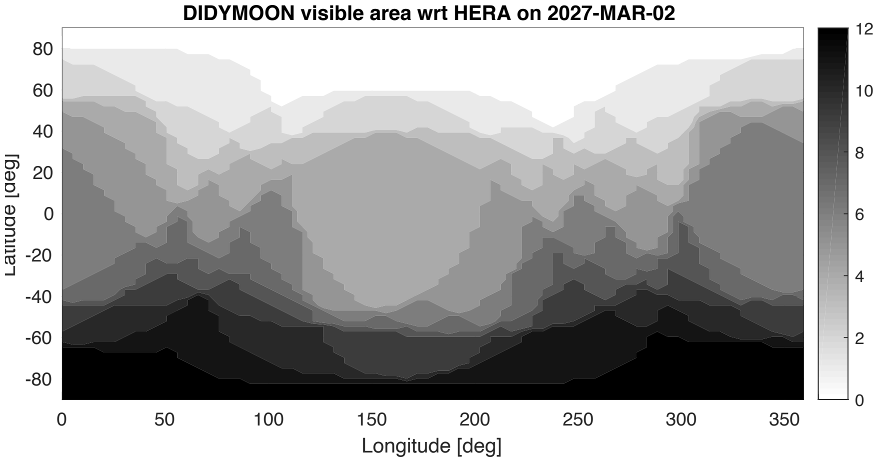
1 pm

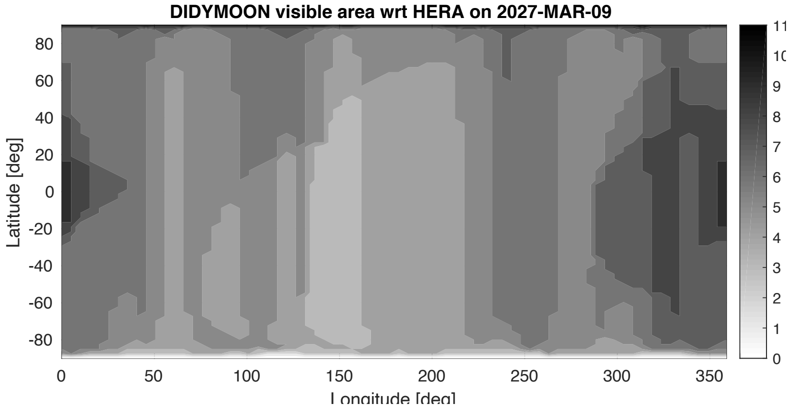


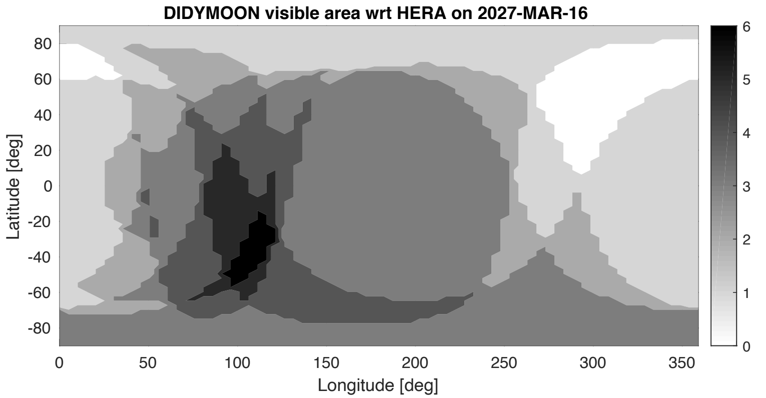
DCP 1

- Good spatial resolution (~ 3m) but eclipsed by HERA.
- 0 <SPA< 70 at subsolar point, can see mostly the day.
- Images around the closest flybys during at least one orbit to cover all Solar phase angles : 24 measurements x 3 (with calibration) =72 images

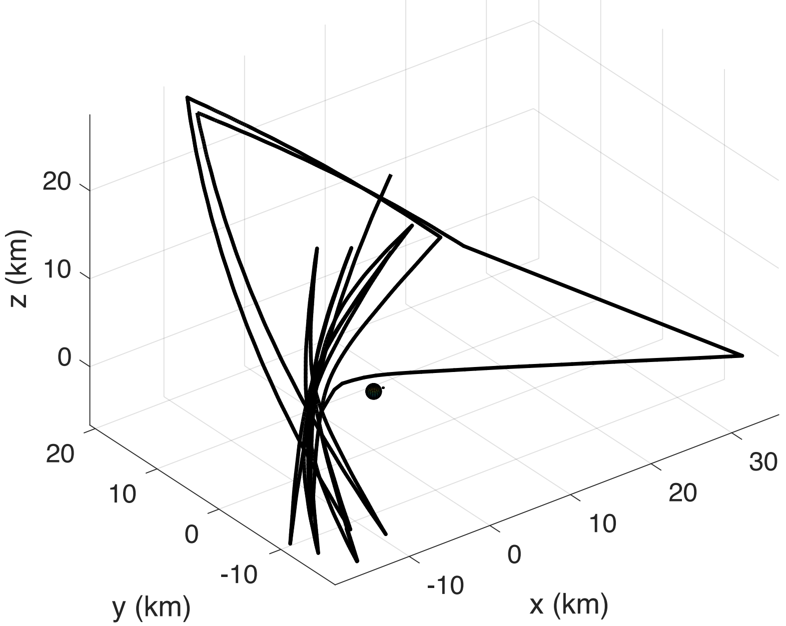
→ Give mainly day side, observation of terminal line and dawn whenever possib;e



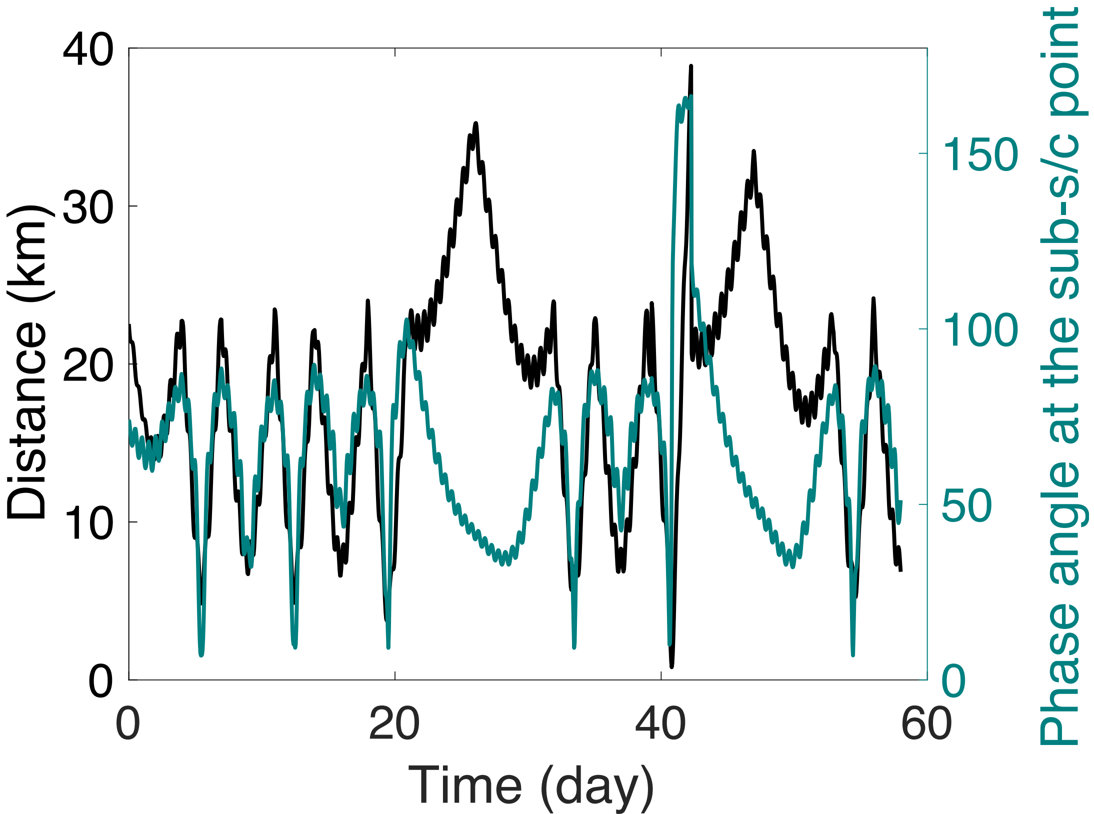




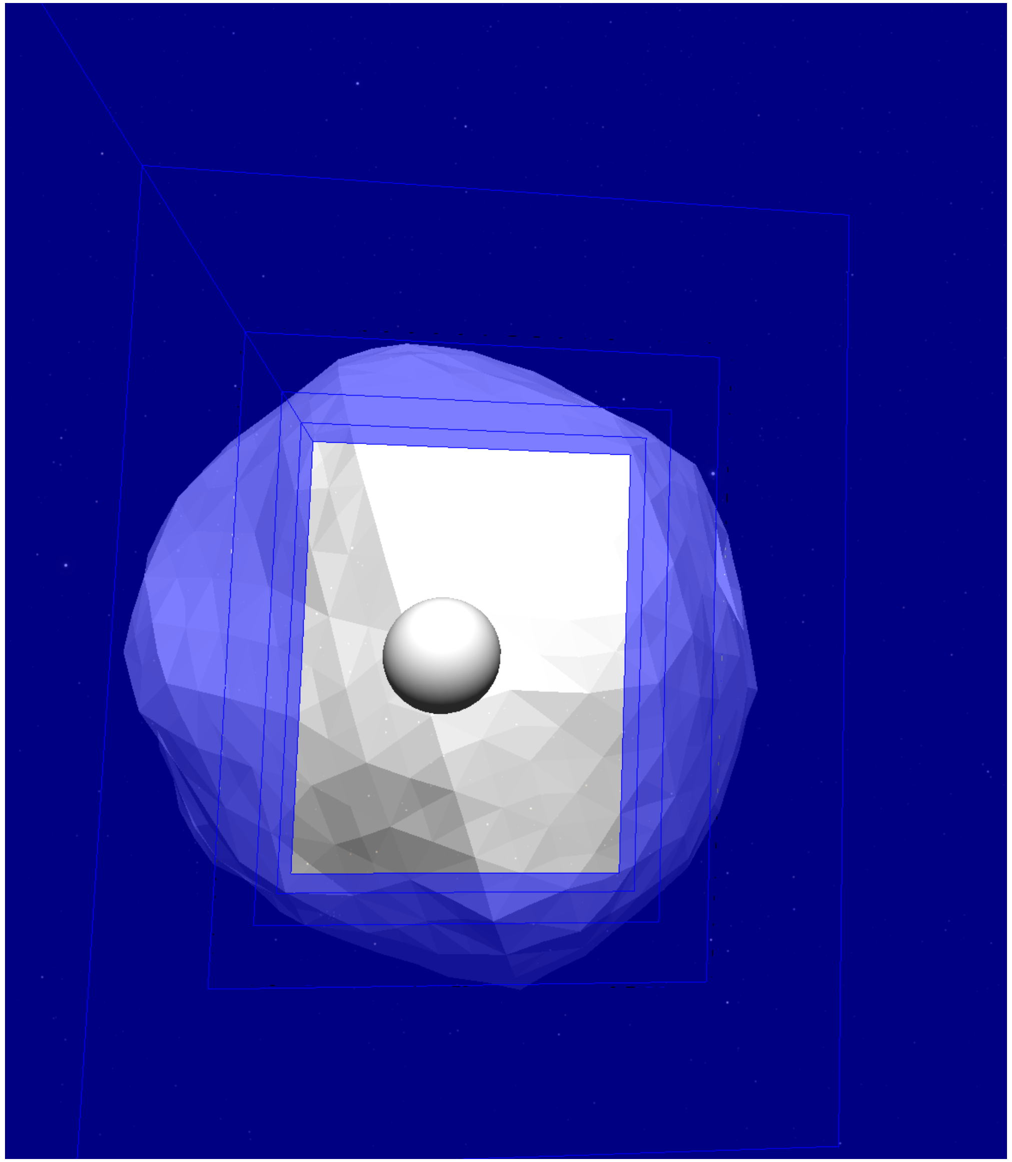
DCP3



z (km)
20
10
0
20
10
0
-10
y (km)
-10
0
10
20
30
x (km)

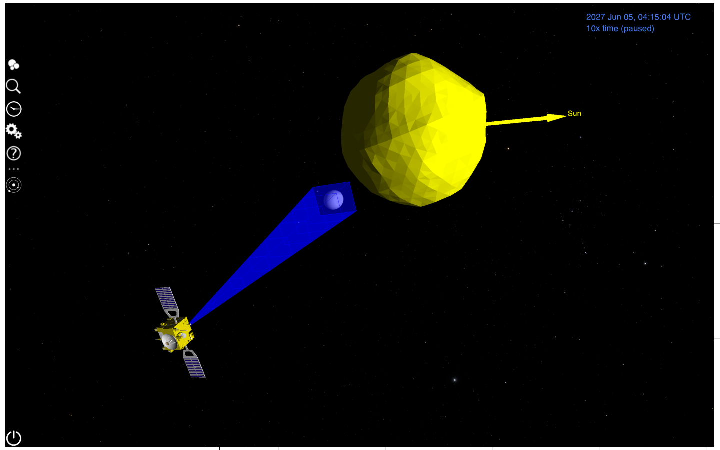


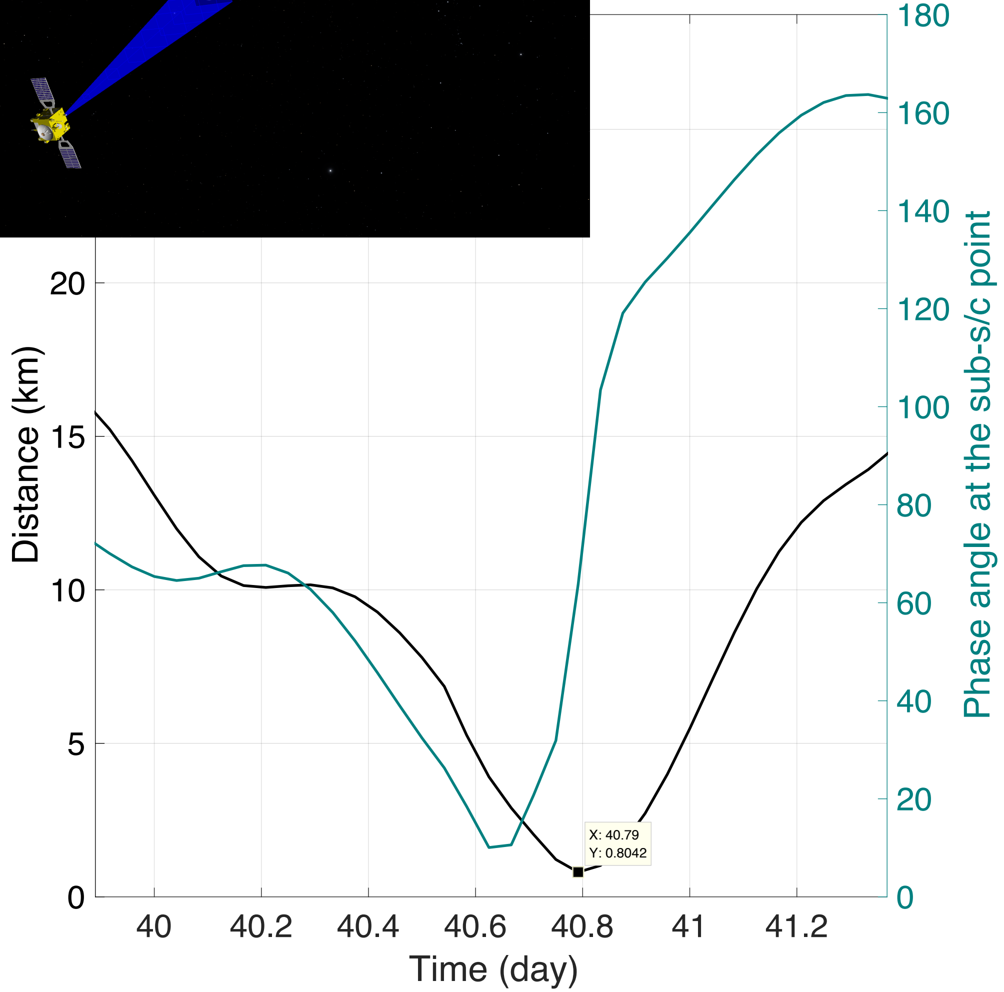
Distance (km)
Phase angle at the sub-s/c point
Time (day)
40
30
20
10
0
150
100
50
0
0
20
40
60



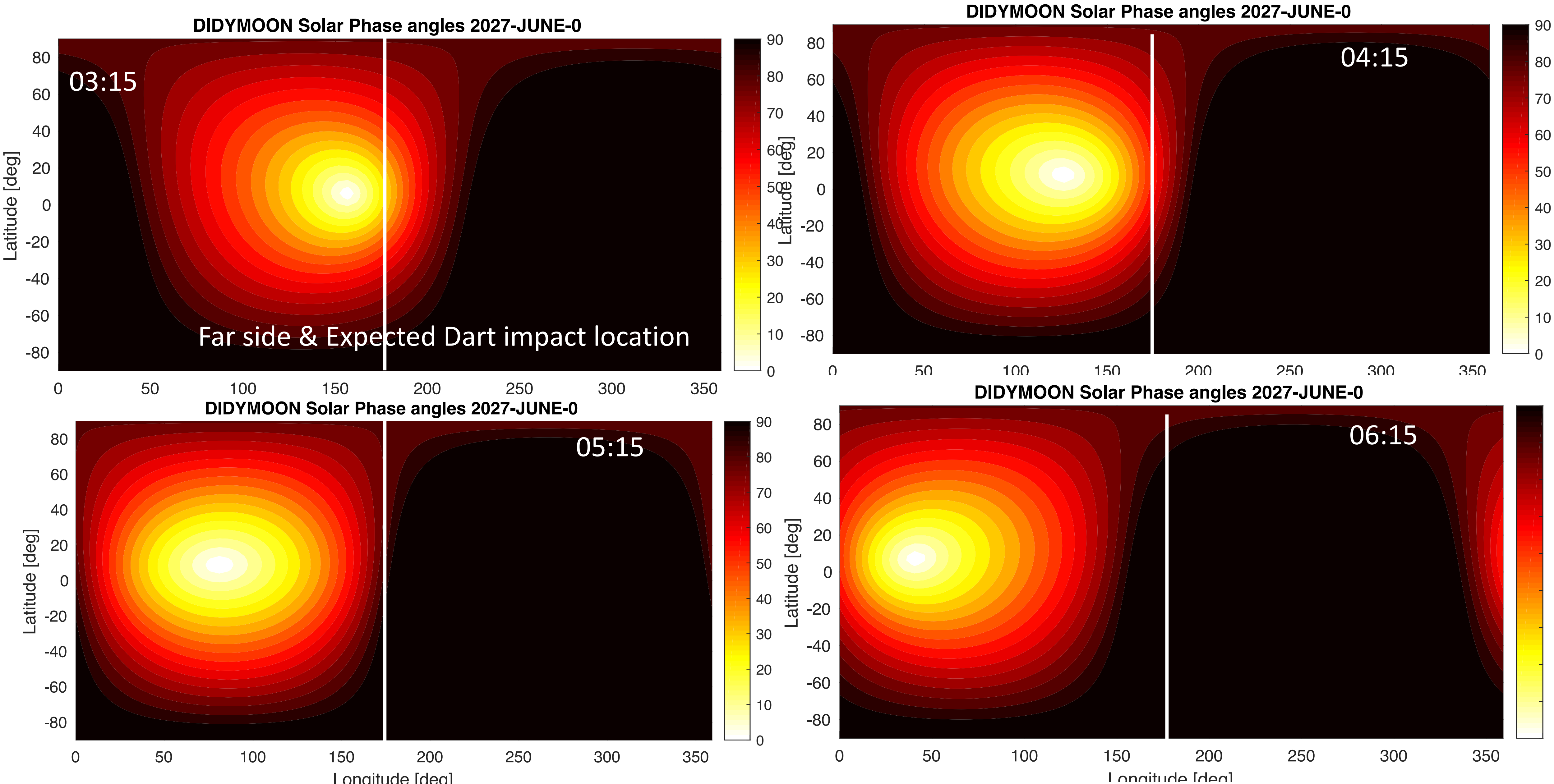
DCP 3

- Only 4 flyby with less than 5 km.
- Closest approach 0.8 km @ 1.6 AU
- 10 <Phase angle < 120 at subsolar point, can see more night side then the day
- The Dart crater is expected to be visible at closest passage at far side
- Cover phase angle variation over impact
- Focus on close flybys : minimum (3+3+3+12) x 3 (with calibration) =63 images.





SPA during closest approach (04:15 UTC)



Data Volume

Updated Data Volume

	ECP	DCP1	DCP2	DCP3	ELP	Total (GB)
Images	72	72		62	62	
bit/ pixel	16	16		16	16	
pixels	786432	786432		786432	786432	
Mbit	905.97	905.97		780.14	780.14	**3.37**

Allocated Data Volume (HERA MRD v4.2)

For data volume considerations, we assume that TIR rides along with AFC on D2, D3/6, D5, and D10.
One image corresponds to 1024 * 768 pixels *16 bits/pixel = 12.6 Mbits.
D2: 62 images, corresponding to 780 Mbits
D3/D6: 151 Mbits (4 images per flyby * 3 flybys)
D5: 113 Mbits (same as D2)
D10: Same as D2 (780 Mbits), as there are no filters.

Allocated Data Volume (HERA MRD v1.3)

	ECP (Mb/day)	DCP#1 (Mb/day)	DCP#2 (Mb/day)	DCP#3 (Mb/day)	ELP (Mb/day)	Total (Gb)
Duration (day)	*30*	*30*	*30*	*45*	*30*	*165*
AFC	*1 frame/30 min (32 h/day) 14 bit/pixel (no compression)*	*1 frame/h (ROSETTA) No windowing/no compression*	*No windowing/ no compression*	*No windowing/ no compression*	*No windowing/ no compression*	
Navigation	**469.8**	**234.9**	**234.9**	**234.9**	**234.9**	**45.8**
"Hot redundancy" 1 AFC for navigation 1 AFC for science	*D1: 2936 Mb D3: 910 Mb D6: 1761 Mb*	*D1: 2936 Mb D6: 1761 Mb D9: 8631 Mb*	*D4: 9450 Mb*	*D1: 2936 Mb D2: 440 Mb D5: 440 Mb*	*As DCP#3*	
AFC data volume	5607	13328	9450	3816	3816	36.0
Science	**186.9**	**444.3**	**315.0**	**84.8**	**127.2**	**36.0**
TIRI 1024 X 768 pixel 12 bit/pixel No filters	*585.105408*	*585.105408*	*0*	*226.492416*	*226.492416*	1.6
TIRI	**19.5**	**19.5**	**0.0**	**5.0**	**7.5**	**1.6**
PALT	*Out of range (TBC) HK only*	*16 h measurements*	*16 h measurements*	*16 h measurements*	*16 h measurements*	
ge	**0.0**	**7.2**	**7.2**	**7.2**	**7.2**	**1.0**
esat	*HK only*		*16 h comms @ 200 kbit/s is too conservative*	*AFC + TIR + PALT???*		
	0.0	**0.0**	**322.2**	**97.0**	**141.9**	**18.3**
AL (per day)	**676.2**	**705.9**	**879.3**	**428.9**	**518.8**	
AL SCIENCE DATA VOLUME						**102.7**

- Difference with HERA MRD due to assumed bit/pix and # of images at each phase including calibration images.
- GNC images not considered in data volume
- 2 Calibration images for each science image
- Rastering not in data volume
- The close flyby and DCP3 must be evaluated more detailed with attitude information.
- Images on Didymain have not yet been evaluated