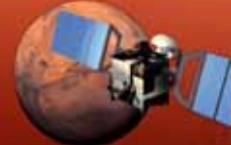




E X O M A R S

esa

mars express



Preliminary analysis of possible coordinated observations Mars Express – Trace Gas Orbiter

Alejandro Cardesín Moinelo, Bernhard Geiger, Marc Costa
and MEX/TGO Science Operations Centres



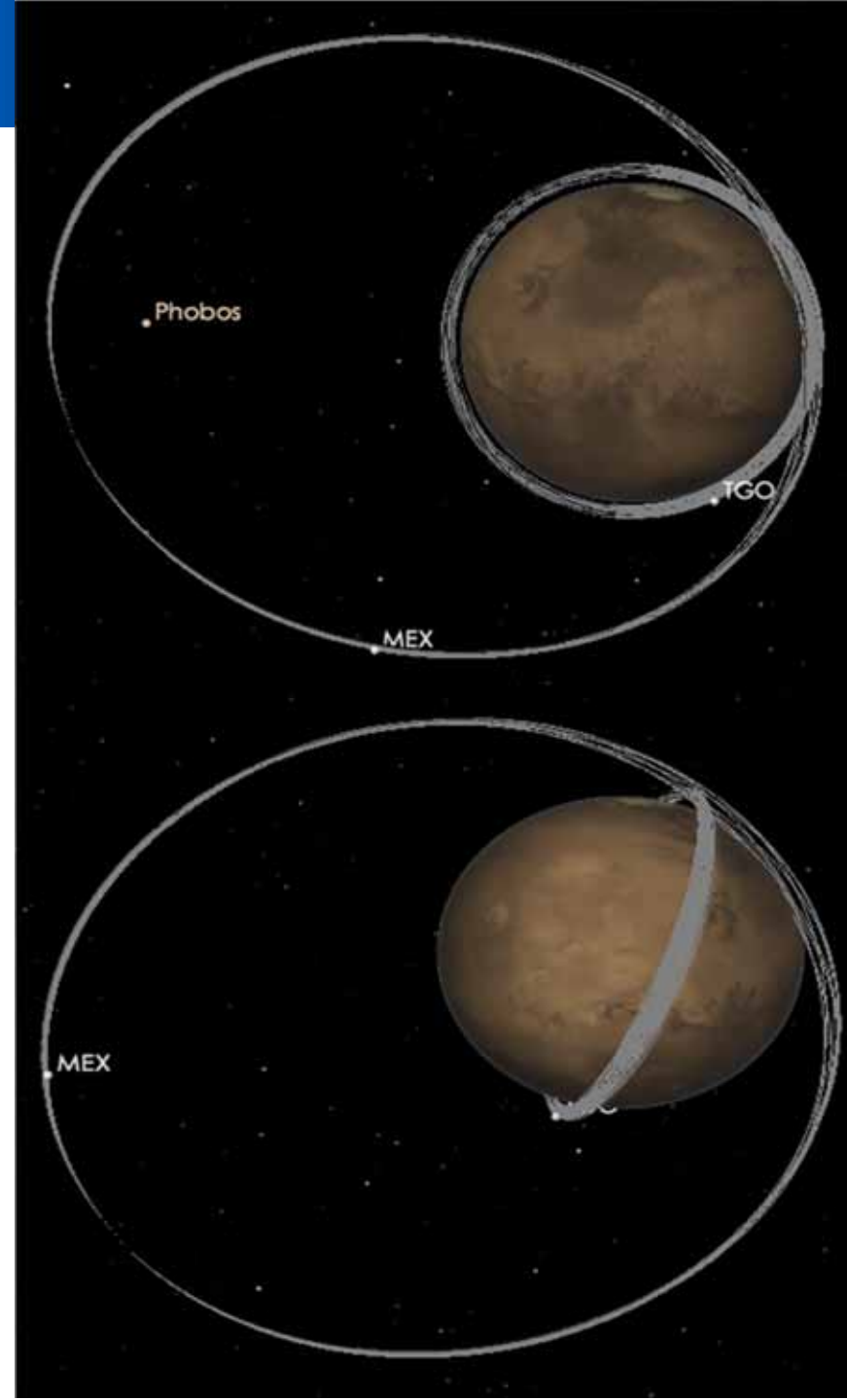
MEX-TGO Meeting,
Madrid 1 March 2018, ESAC

❑ Mars Express

- Elliptical orbit: 350 x 10,000km
- Polar orbit : 87°
- Period: ~7h
- Slow precession: ~20month cycle

❑ Trace Gas Orbiter

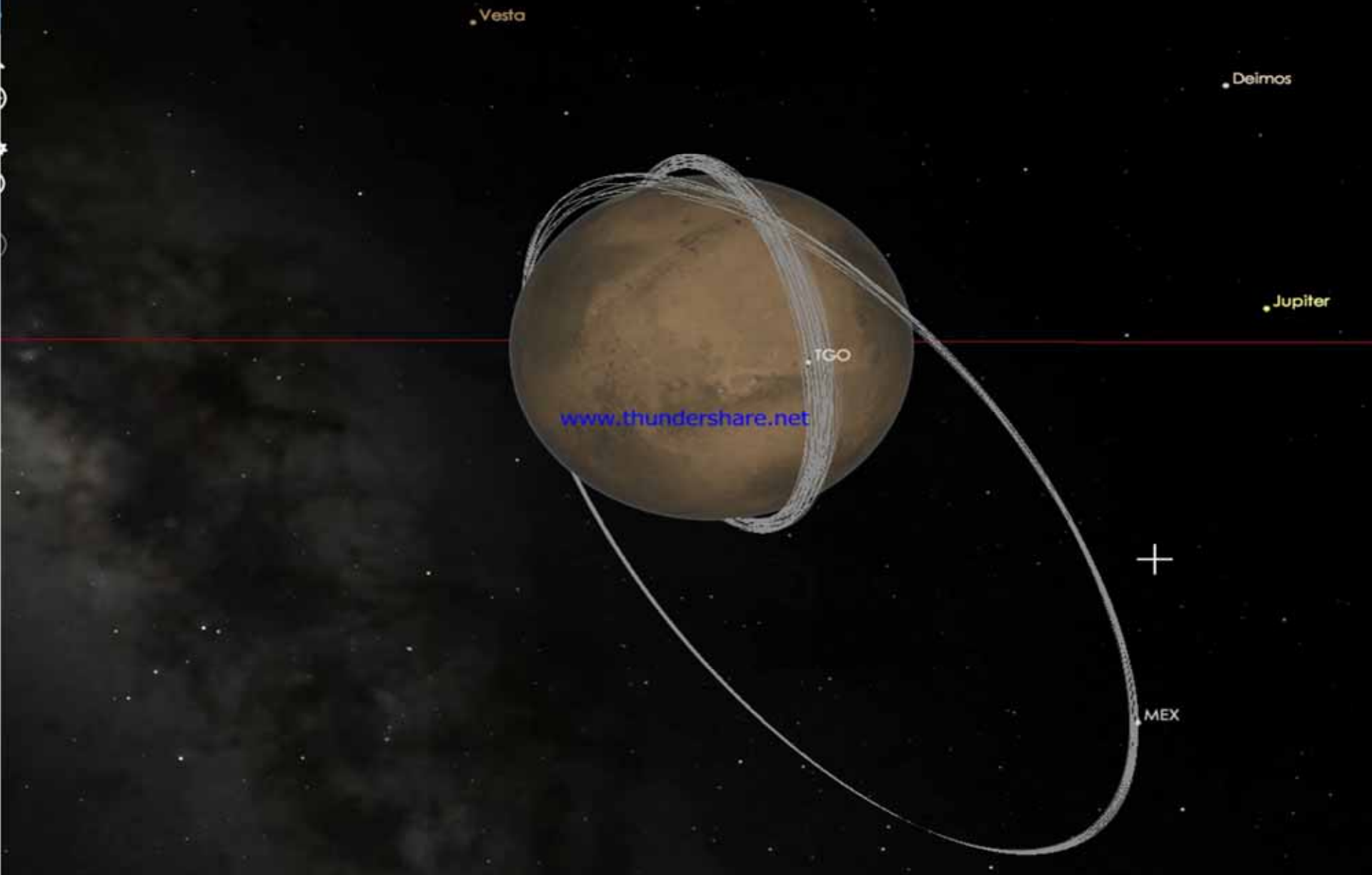
- Circular Orbit: ~400km
- High Inclination 74°
- Period: ~2h
- Fast node regression: ~7 week cycle



Mars

Distance: 18,678.5 km
Radii: [3,397 3,397 3,375] km

2018-Apr-11 22:10:41 UTC
1,000x time

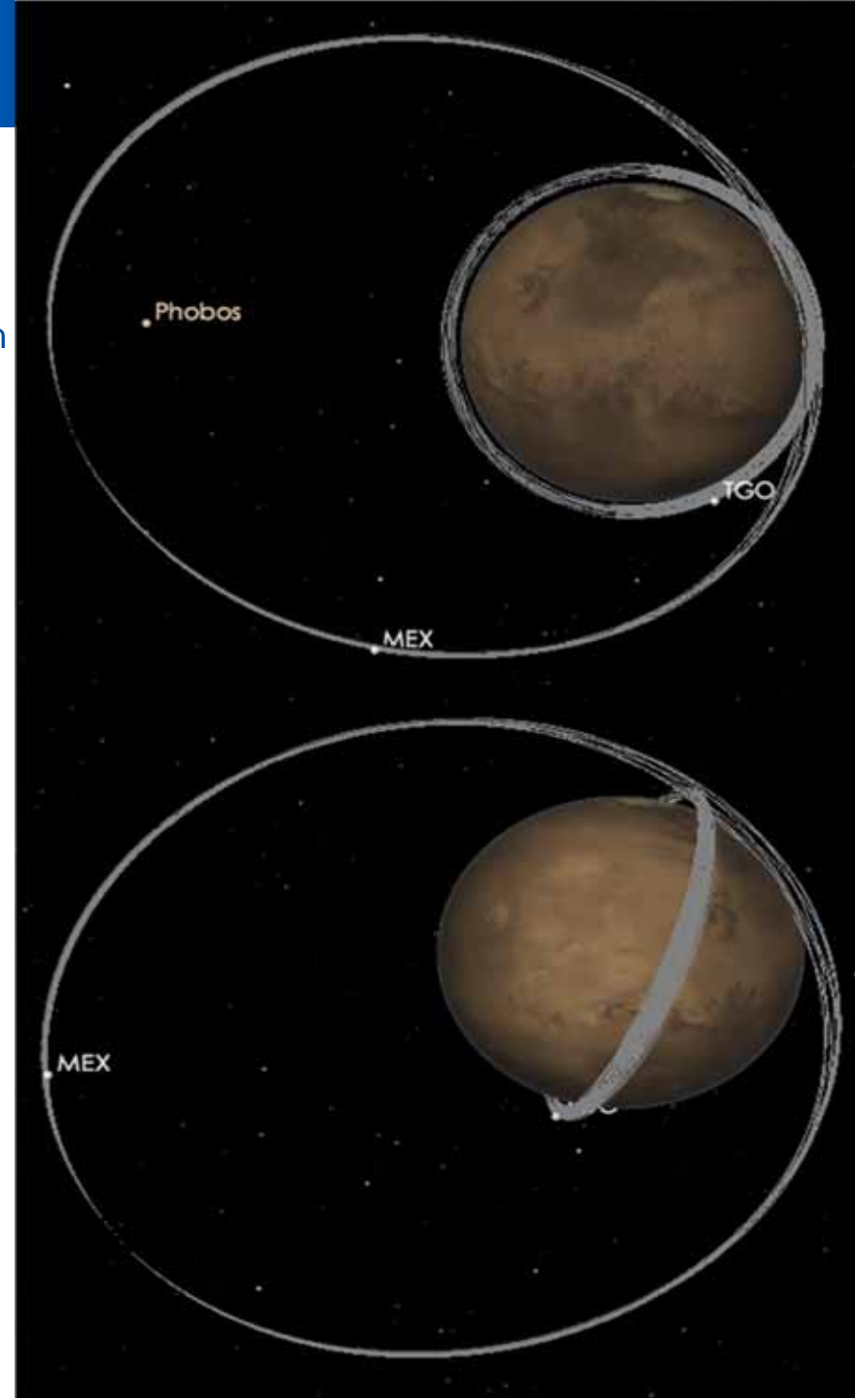


❑ Mars Express

- Very stable/slow changing seasons
 - Illumination at pericenter varies with precession
 - Very slow seasonal variation (3~6 months)
- Variable distances
 - Pericenter high res. / Apocenter context
- Pointing flexibility (inertial, nadir, limb, ...)
- Science limited by geometry/constraints:
 - SPICAM 1~2 obs. per orbit
 - Total 2~3 pointings per orbit (duty 25-60%)

❑ Trace Gas Orbiter

- Dynamic short observing seasons
 - Weekly basis, based on node regression
 - Full surface + local time coverage ~monthly (except poles)
- Continuous monitoring
 - Duty cycle >75% (tbc)
- Basically 2 pointings “only”: Nadir / Sun Occ



Possible Coordinated Observation “Types”

- ❑ **Simultaneous observations:** same time + latitude + longitude + local time
 - Useful for cross-calibrations
 - Are they possible??? (weekly/monthly/yearly?, nadir / sun occs ?)

- ❑ **Quasi-simultaneous observations (time diff. <10min, <1h ???)**
 - Surface driven:
 - Same latitude / longitude
 - Different local time (~1h/h, max illumination diff. <15deg/h, important at terminator)
 - Sun illumination driven:
 - Same latitude / local time
 - Longitude variation: 15deg/h (~900km/h, ~15km/min at equator)
 - Useful for comparison
 - Climatology, dynamics, etc...
 - Longitude independent features (e.g. upper atmosphere)

- ❑ **Non-simultaneous seasonal observations**
 - Same season (LS) + latitude + local time + longitude
 - Common, limited only by each SC geometry (e.g. MEX distance)

GOAL: Full global coverage: Season + Local Time + Latitude + Longitude

Preliminary Analysis Computations

- ❑ **All calculations based on preliminary orbits NOT CONFIRMED**
- ❑ **Only evolution trends are valid, all detailed values may change**
 - New MEX trajectory now available (2 weeks ago)
 - Confirmed TGO trajectory expected early March 2018
 - Everything can change depending on last maneuver

Sun Occultations

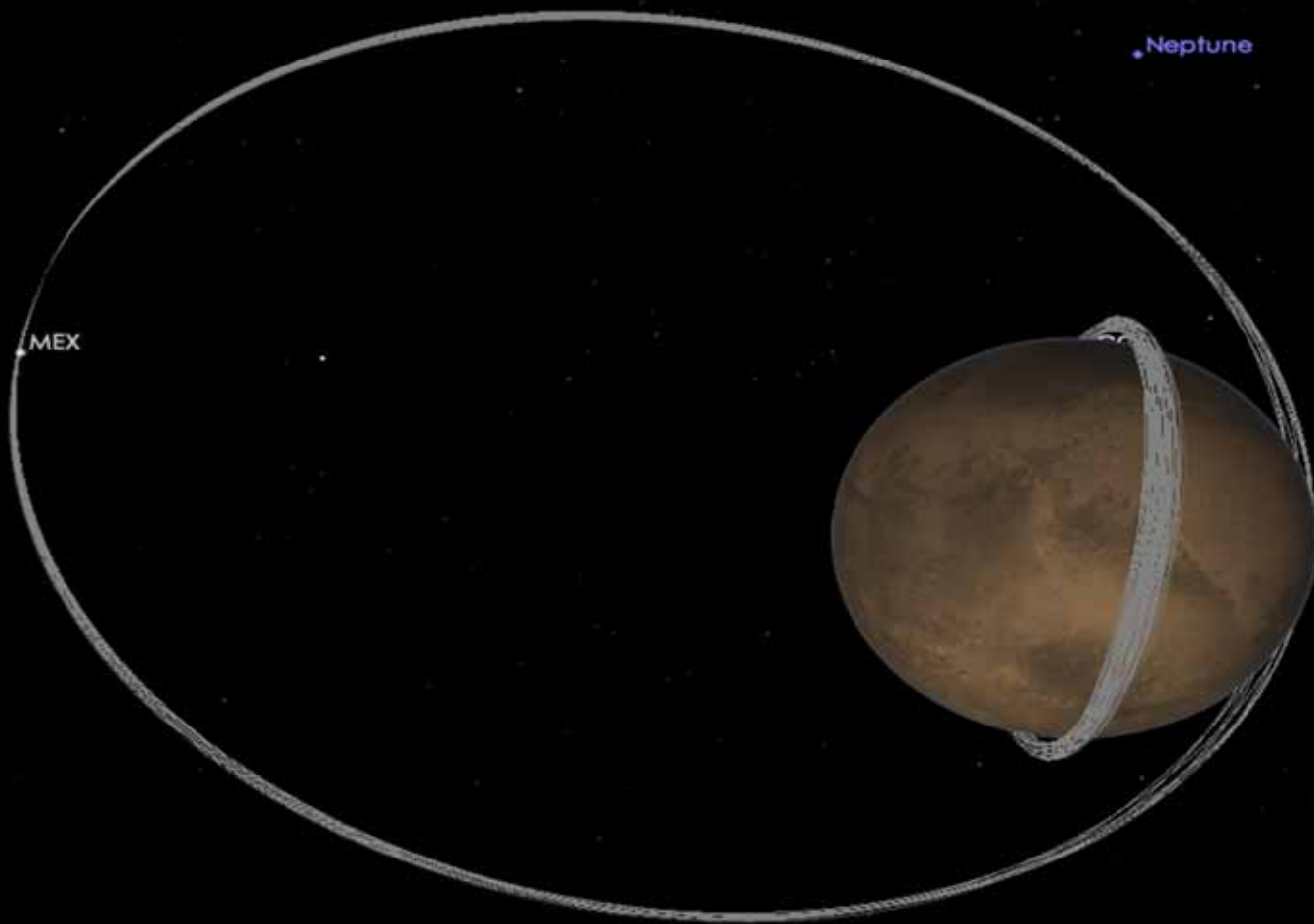
2018-Sep-19 06:59:09 UTC
-1,000,000x time (paused)

Astroea

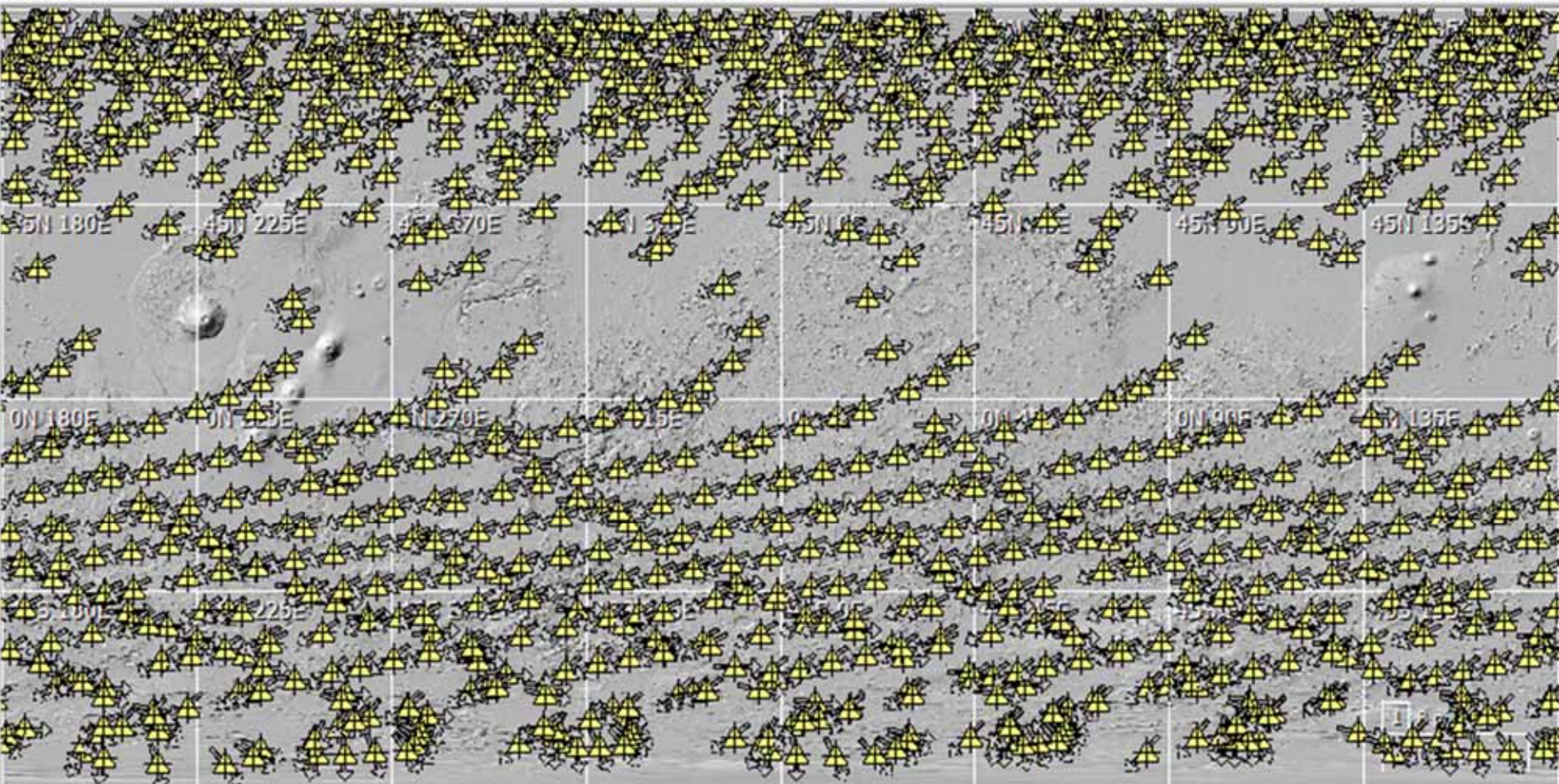
Neptune

MEX

Phobos

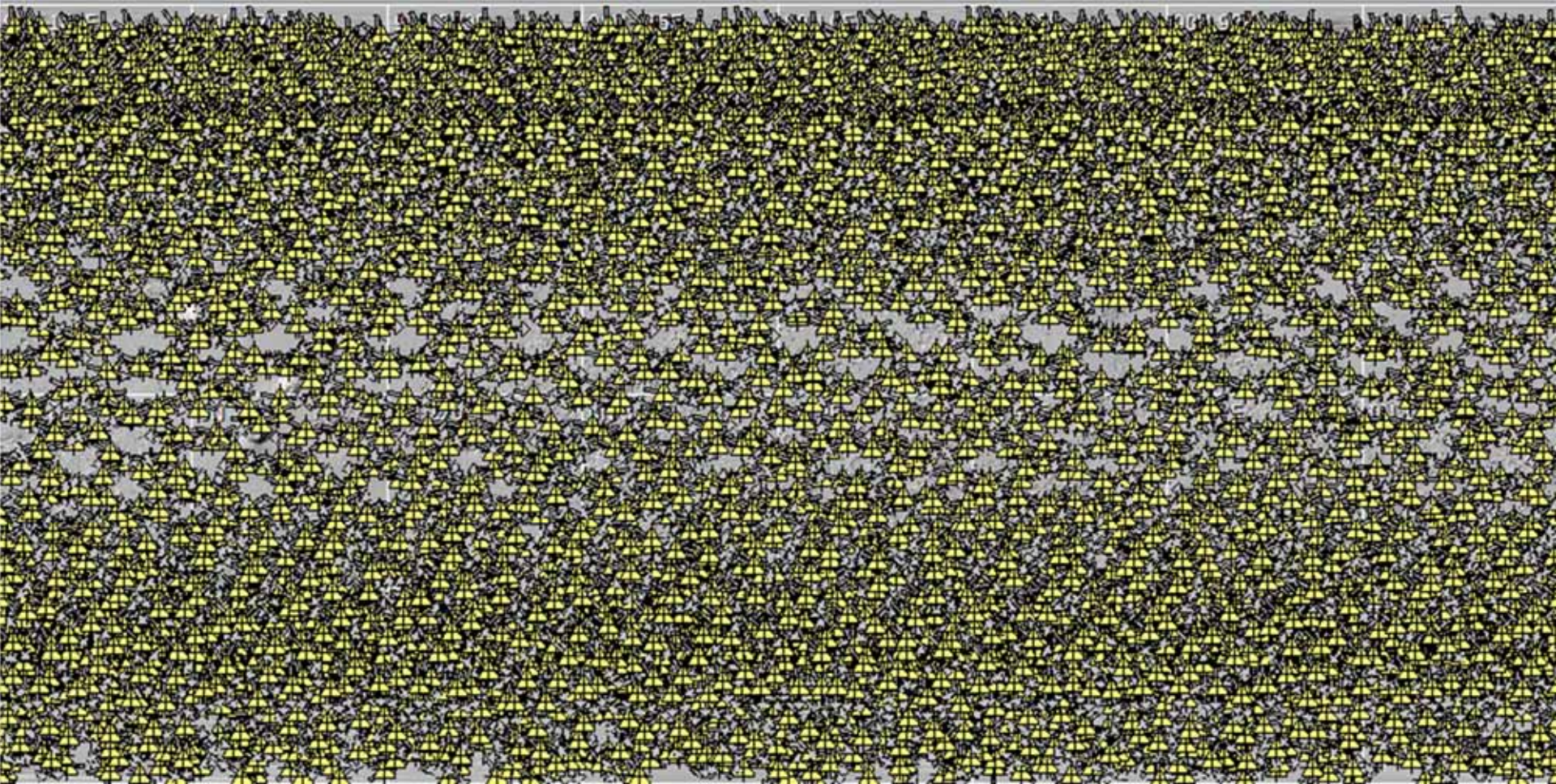


MEX Sun Occultations (2018)



* SPICAM typically only 10~20% of all possible sun occultations (tbc)

TGO Sun Occultations (2018)



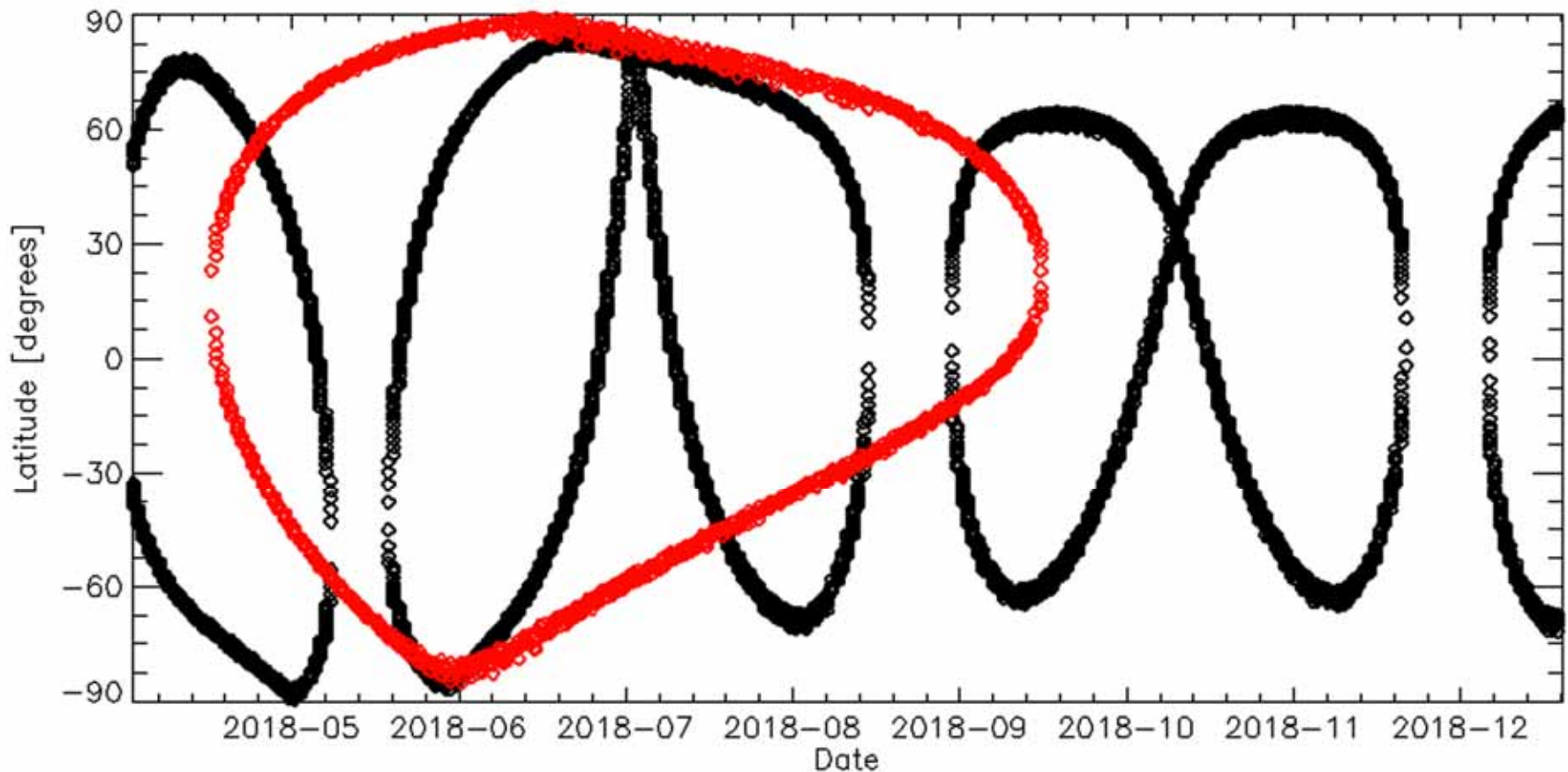
* **ALL OCCULTATIONS WILL BE USED**

* ACS/NOMAD share

Sun Occultations 2018 (April-December)

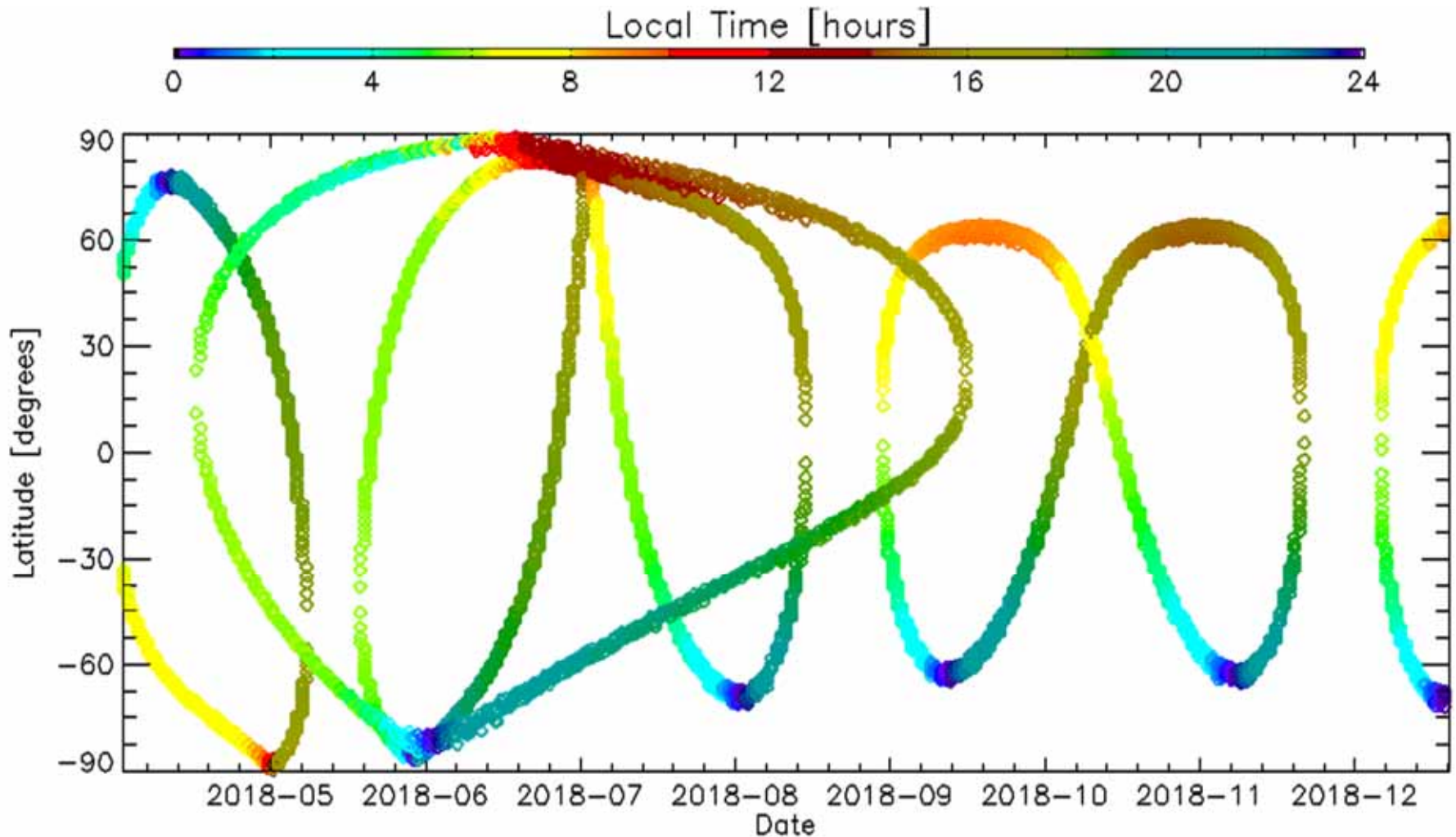
□ TGO

□ MEX

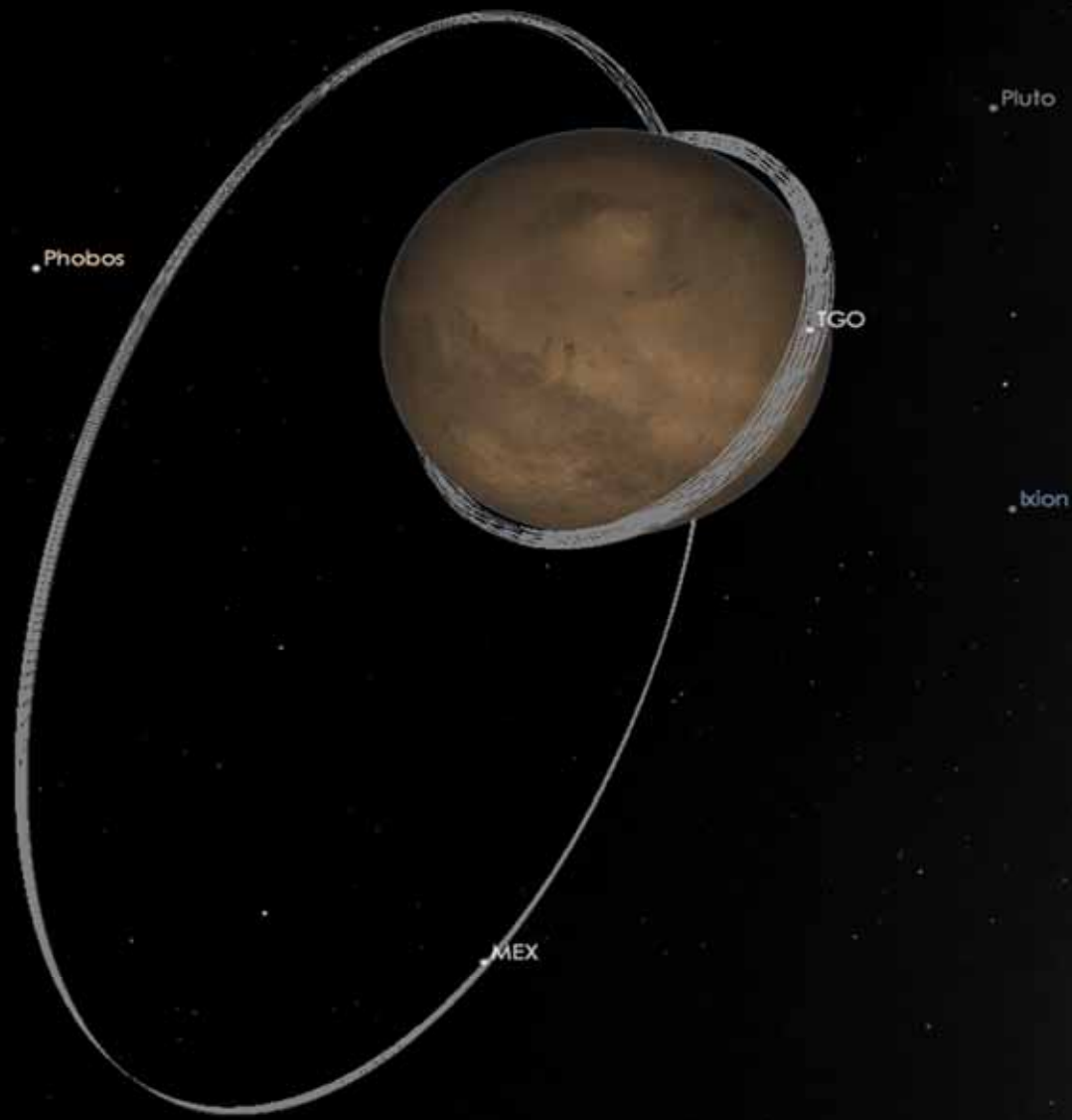


Sun Occultations 2018 (April-December)

Local Time



2018-Jul-20 05:09:09 UTC
1,000,000x time (paused)



Phobos

Pluto

TGO

Deimos

MEX

Sun Occultations coincidences MEX/TGO

South Pole

North Pole

Lower Latitude →

UTC Date	Time	Latitude	Longitude	Local Time	Time diff	Lat diff	Long diff	Local Time diff
23-May-18	00:02:00	-70	282	05:28:12	00:11:30	5	6	00:34:37
24-May-18	17:35:31	-78	30	05:05:23	00:19:21	-2	-6	00:06:00
26-May-18	18:22:20	-81	35	04:54:30	00:04:18	-1	5	00:25:32
29-May-18	09:14:00	-85	170	03:04:25	00:18:22	-4	-7	00:10:35
29-May-18	22:59:10	-85	319	02:26:48	00:08:27	-5	-4	00:08:46
30-May-18	12:45:45	-79	111	01:56:57	00:01:25	5	8	00:33:29
17-Jun-18	19:43:48	89	256	06:49:13	00:08:18	8	-3	00:04:40
28-Jun-18	13:08:32	85	187	12:44:04	00:09:52	0	8	00:40:15
29-Jun-18	03:03:29	82	341	12:32:09	00:19:39	-2	-1	00:13:12
01-Jul-18	03:51:00	82	351	12:41:27	00:05:33	-1	-4	00:09:02
01-Jul-18	17:40:09	86	165	13:44:24	00:04:09	4	7	00:32:07
02-Jul-18	07:35:02	85	316	13:22:25	00:13:52	3	0	00:12:22
04-Jul-18	22:13:20	80	126	13:40:00	00:01:26	-4	5	00:20:13
05-Jul-18	12:06:37	84	284	13:40:32	00:08:07	5	-4	00:09:19
08-Jul-18	02:51:20	79	82	13:17:17	00:07:56	-3	-5	00:11:23
08-Jul-18	16:38:22	80	238	13:05:40	00:01:52	1	-6	00:20:41
09-Jul-18	06:33:08	83	43	13:39:35	00:11:28	3	-2	00:02:34
11-Jul-18	07:28:40	80	55	14:05:18	00:13:39	-3	-1	00:09:32
11-Jul-18	21:13:50	79	215	14:07:28	00:03:56	-2	7	00:31:02
13-Jul-18	00:59:36	82	168	13:59:35	00:15:36	4	-9	00:19:16
14-Jul-18	12:05:50	76	19	14:12:30	00:19:01	-3	6	00:44:05
15-Jul-18	01:51:00	77	182	14:27:57	00:09:31	-4	8	00:41:16
18-Jul-18	06:28:30	76	148	14:47:51	00:16:28	-5	5	00:36:04
18-Jul-18	20:13:40	75	307	14:43:54	00:07:06	-6	3	00:20:31
25-Jul-18	19:13:40	71	34	15:01:47	00:11:15	-8	4	00:25:11
01-Aug-18	18:14:10	69	126	15:39:05	00:16:10	-8	9	00:50:05
19-Aug-18	16:57:40	-22	5	18:40:25	00:08:06	4	-6	00:16:15

2018-Jul-08 16:38:20 UTC
10,000x time (paused)

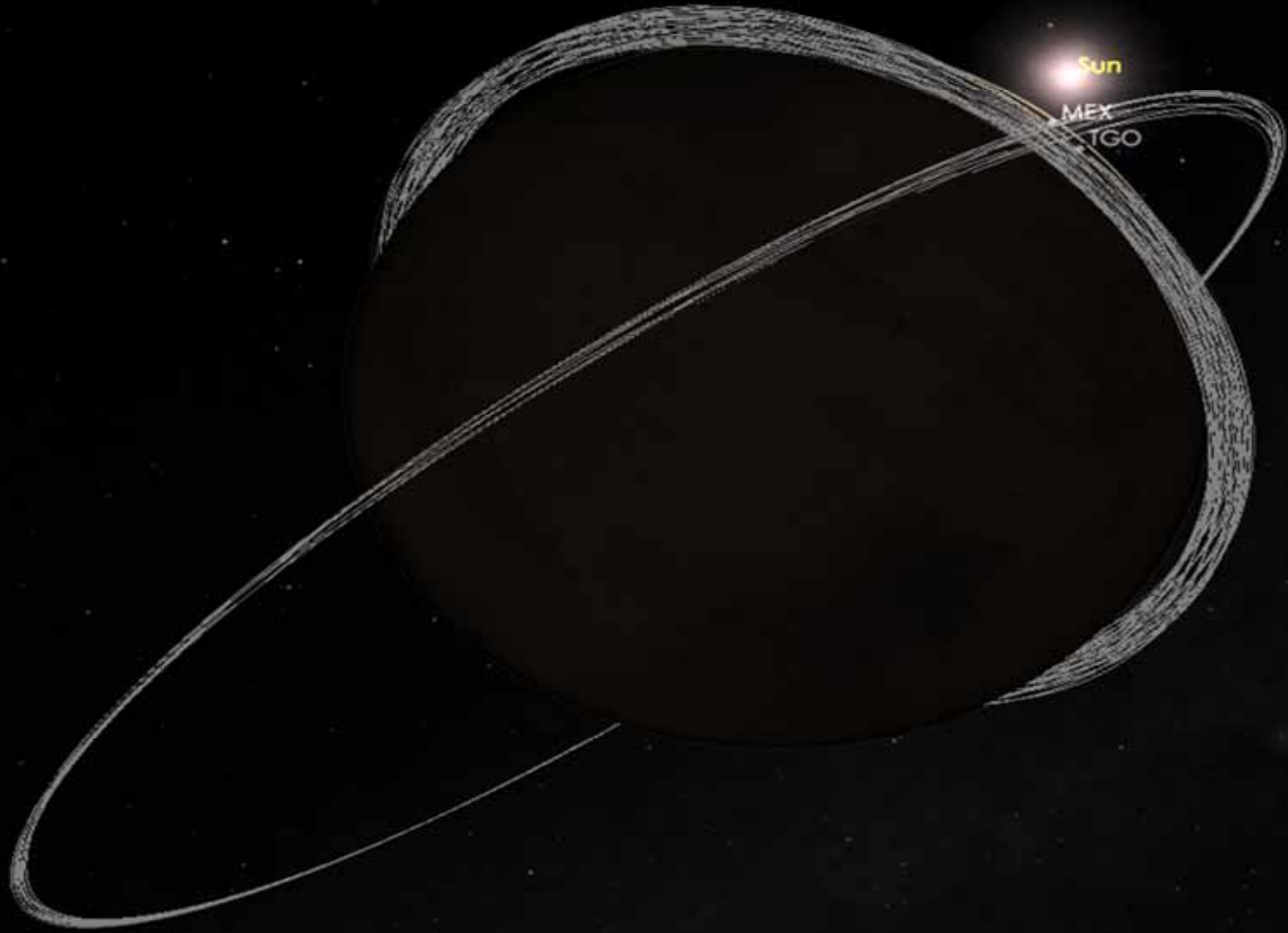
Earth

Mercury

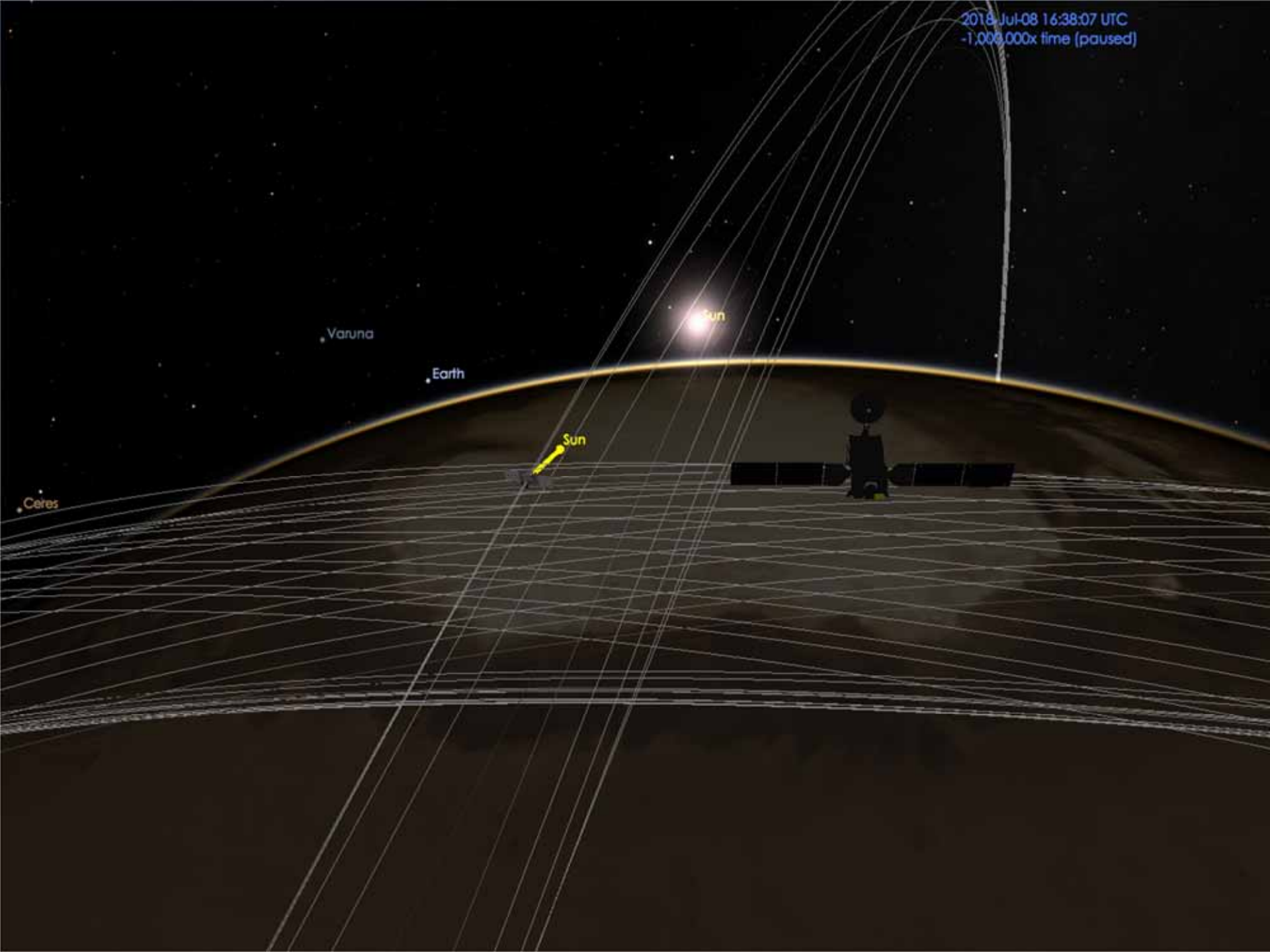
Sun

MEX

TGO



2018 Jul-08 16:38:07 UTC
-1,000,000x time (paused)



Varuna

Earth

Sun

Sun

Ceres

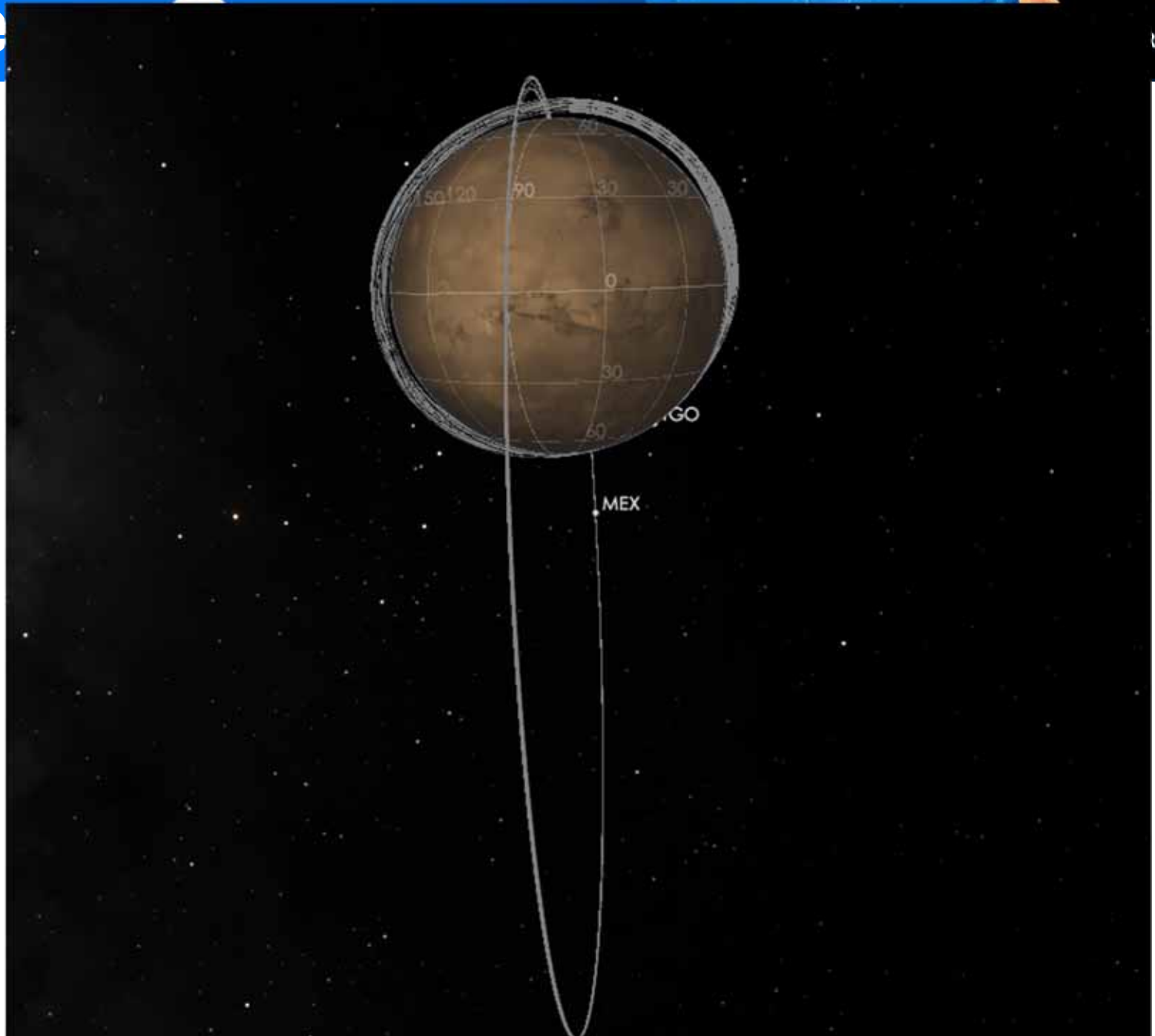
Sun Occultation Possible Coordinated Observations

- ❑ **Simultaneous observations:** (time + latitude + longitude + local time)
 - Some cross-calibrations are possible!!!
 - Mostly on poles, few also possible at lower latitudes (tbc)
 - Interpretation maybe complex though...
 - different angles, distance, velocity, resolution, etc

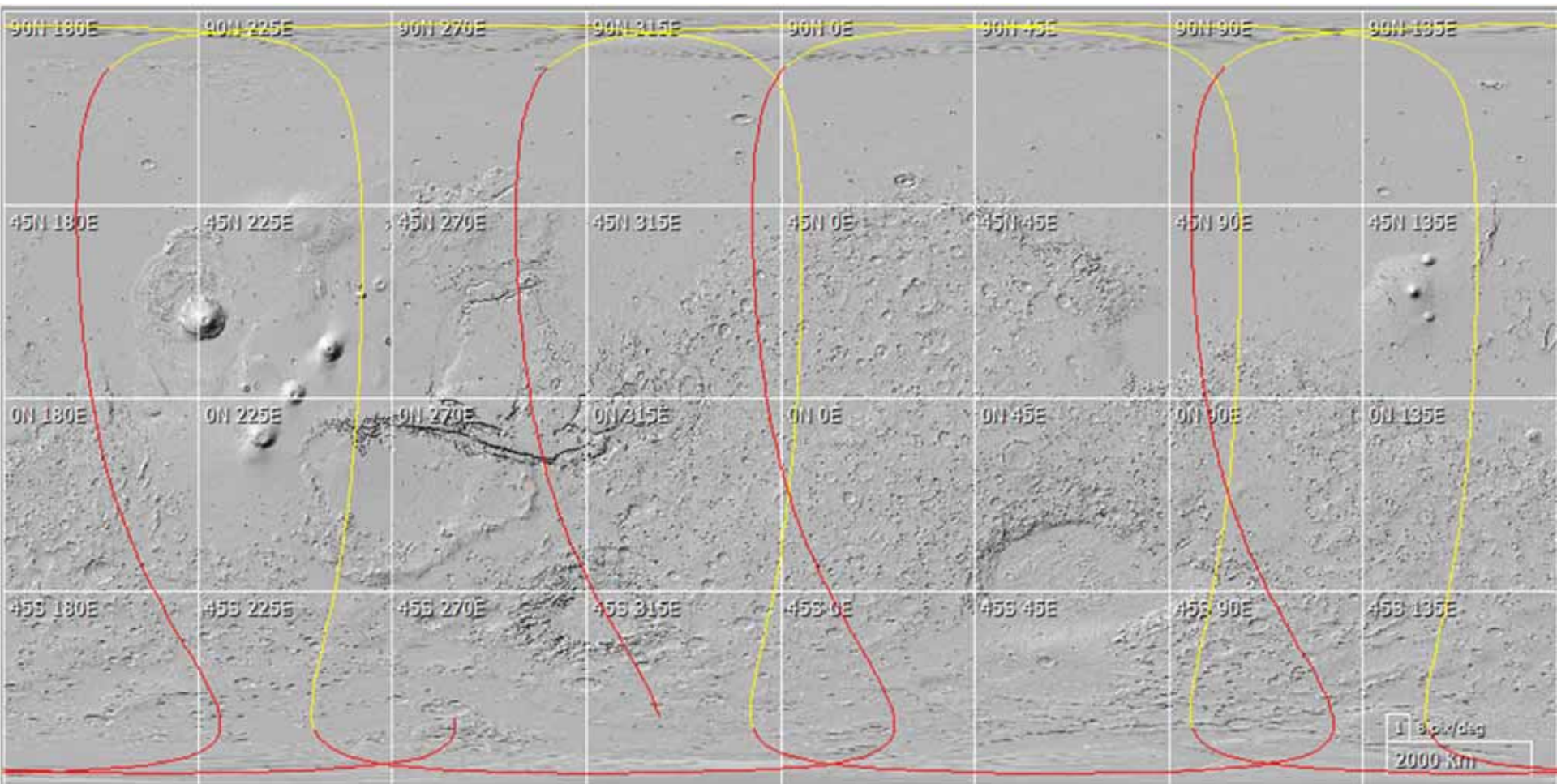
- ❑ **Quasi-simultaneous observations** (time diff. <10min, <1h???)
 - Same Lat/LocalTime but not necessarily same surface longitude
 - TGO occs. cross MEX occs. every few weeks (but maybe on other side)
 - Limited by few MEX occultation seasons (~twice per Martian year)

- ❑ **Non-simultaneous seasonal coverage** (LS + lat + long + local time)
 - MEX only some seasons (but has a long 14year archive)
 - TGO covers most latitudes for all seasons

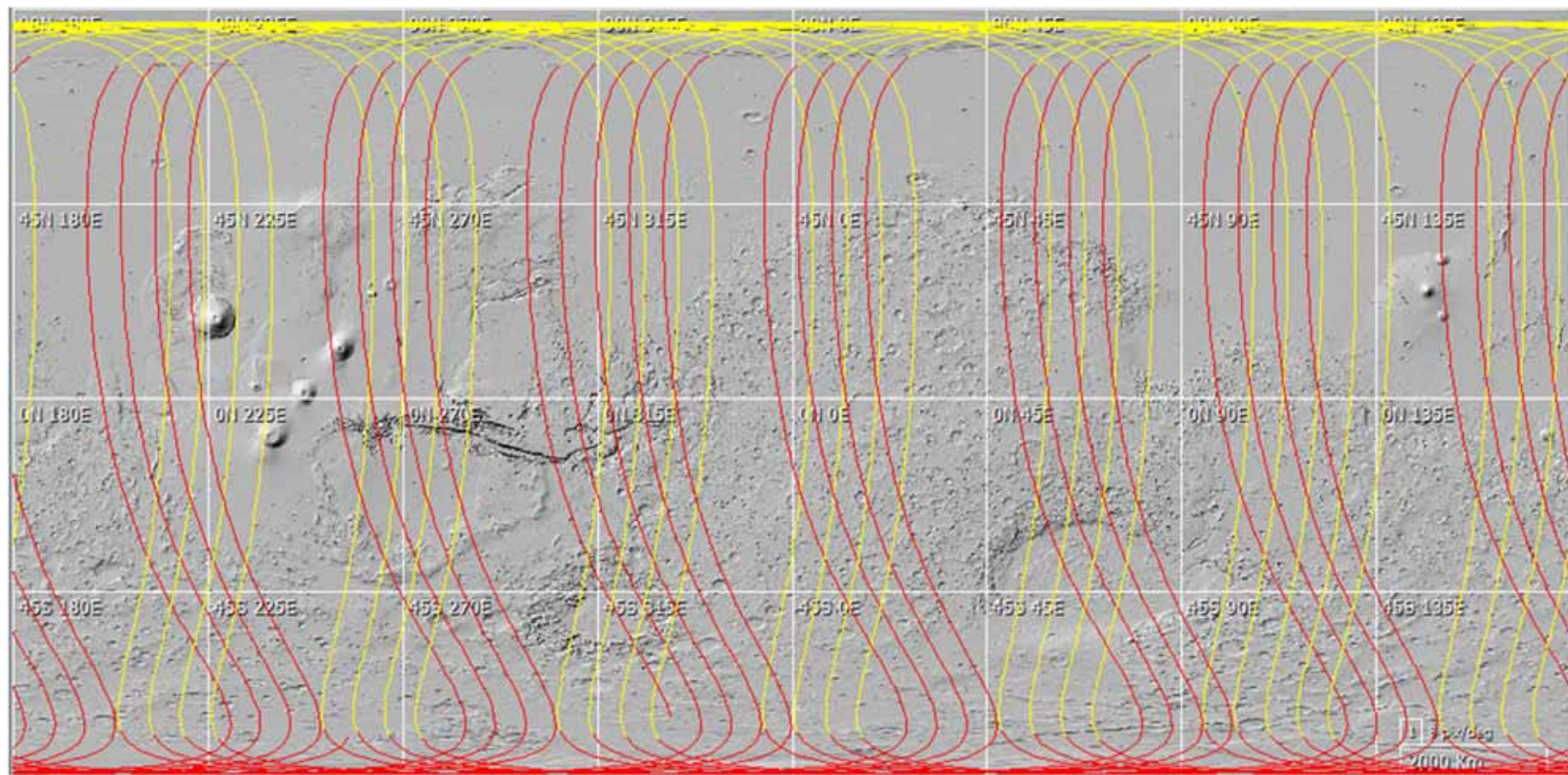
Nadir analysis



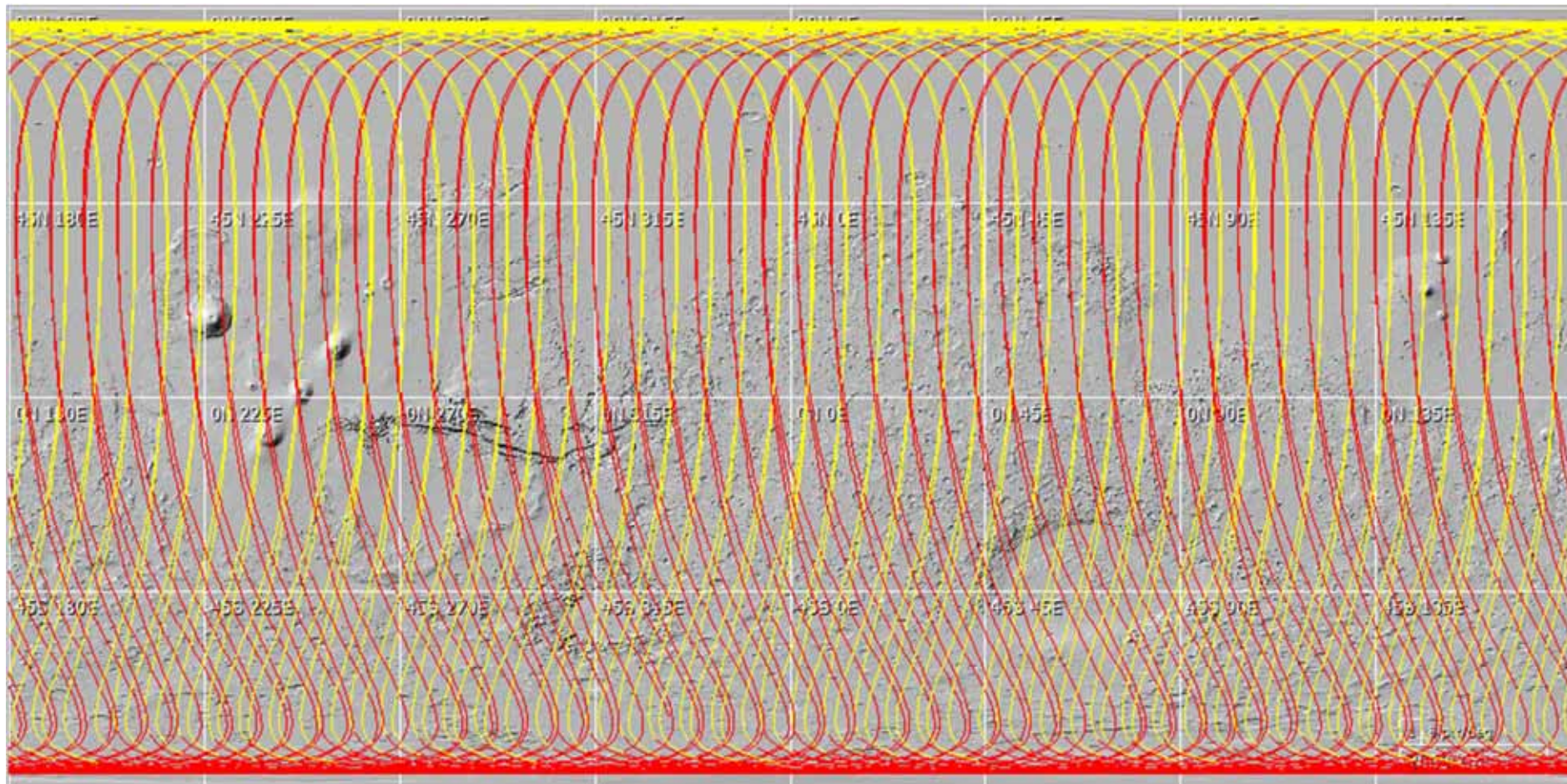
MEX Nadir surface coverage (1 day)



MEX Nadir surface coverage (1 week)

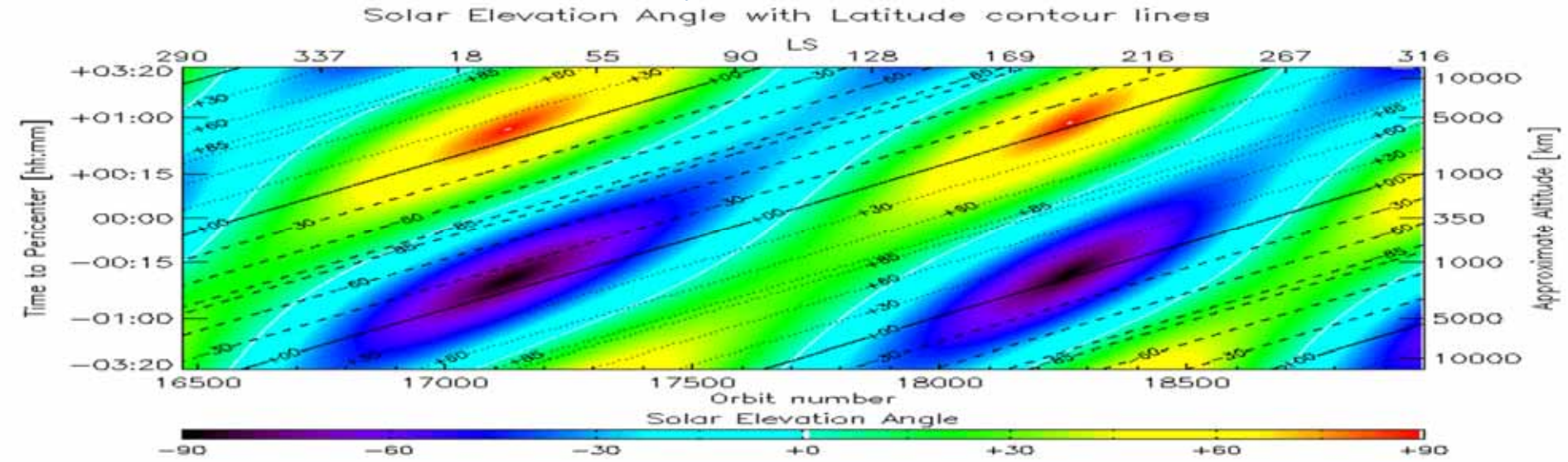


MEX Nadir coverage (4weeks)

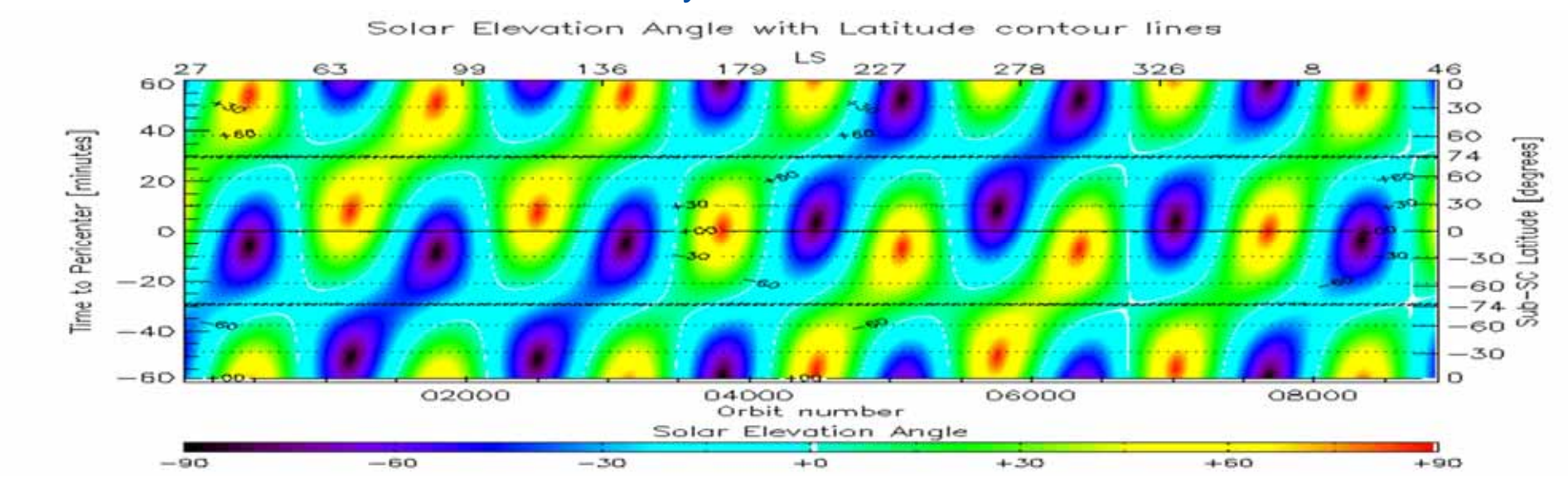


- **Sub-SC illumination changes very slowly**
- **Limited by MEX distance (pericenter/apocenter)**

Mars Express nadir illumination for 2 years

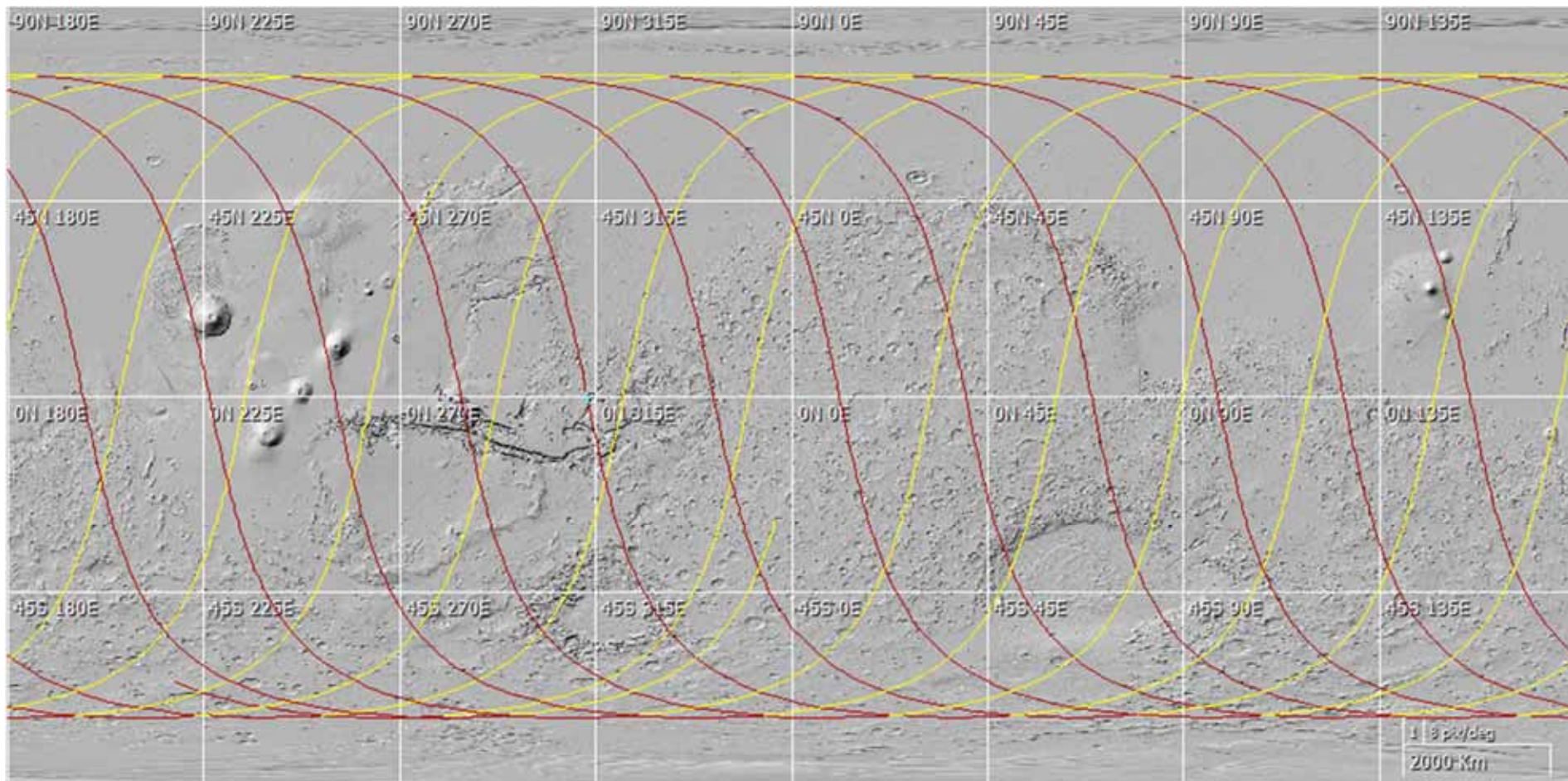


ExoMars TGO nadir illumination for 2 years

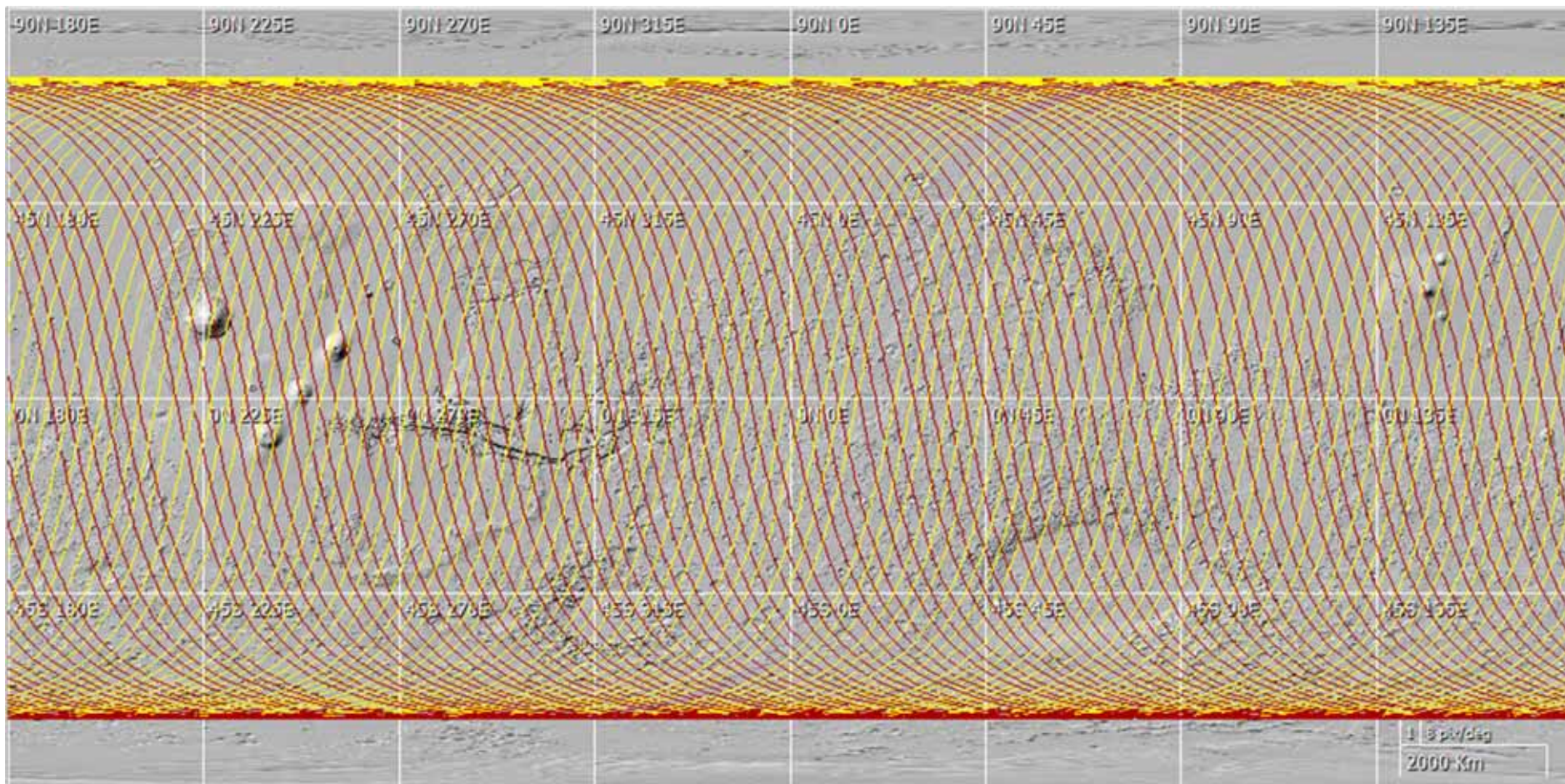


*different periods are shown

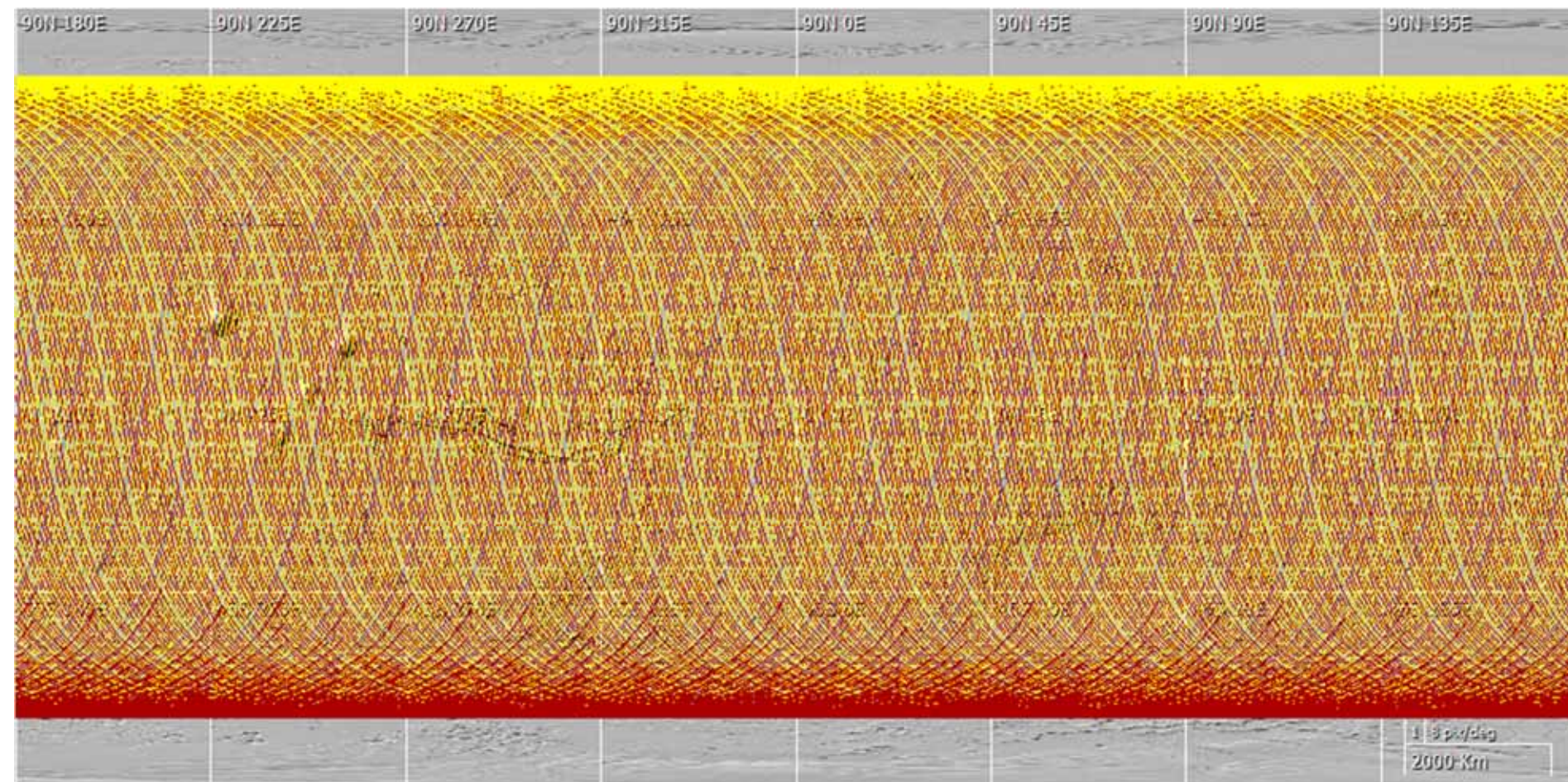
TGO Nadir surface coverage (1 day)



TGO Nadir surface coverage (1 week)

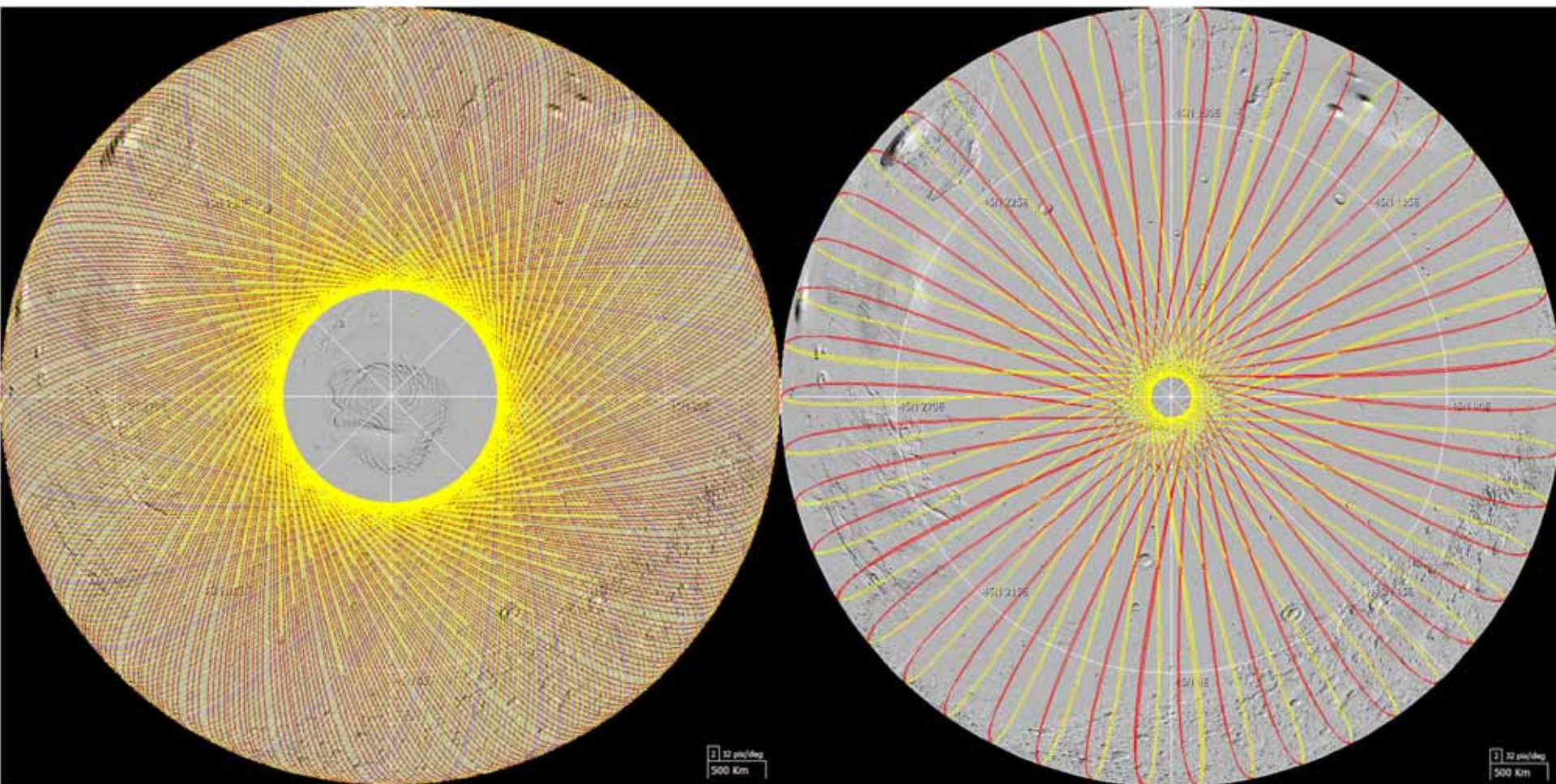


TGO Nadir surface coverage (4weeks)

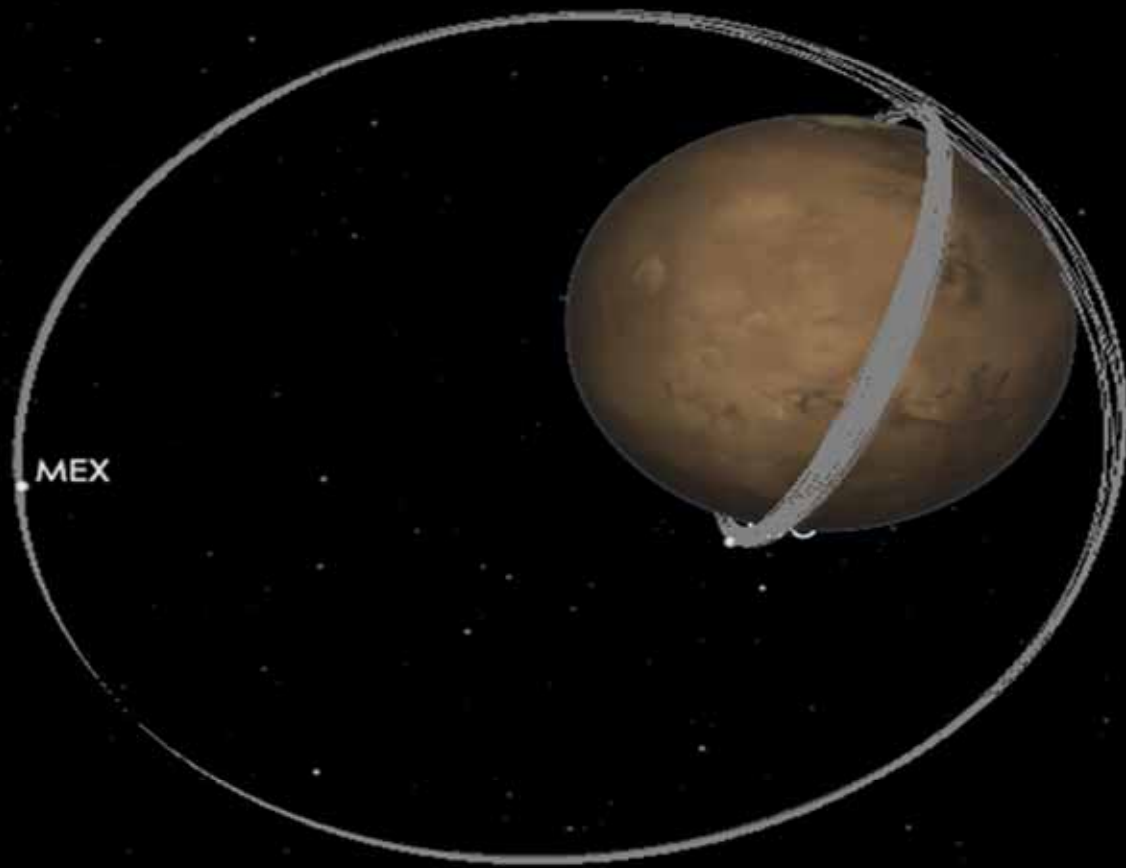


- Sub-SC illumination changes quickly with orbit regression
- Constant altitude, global coverage (limited by Sun Occultation gaps... TBC at LTP)

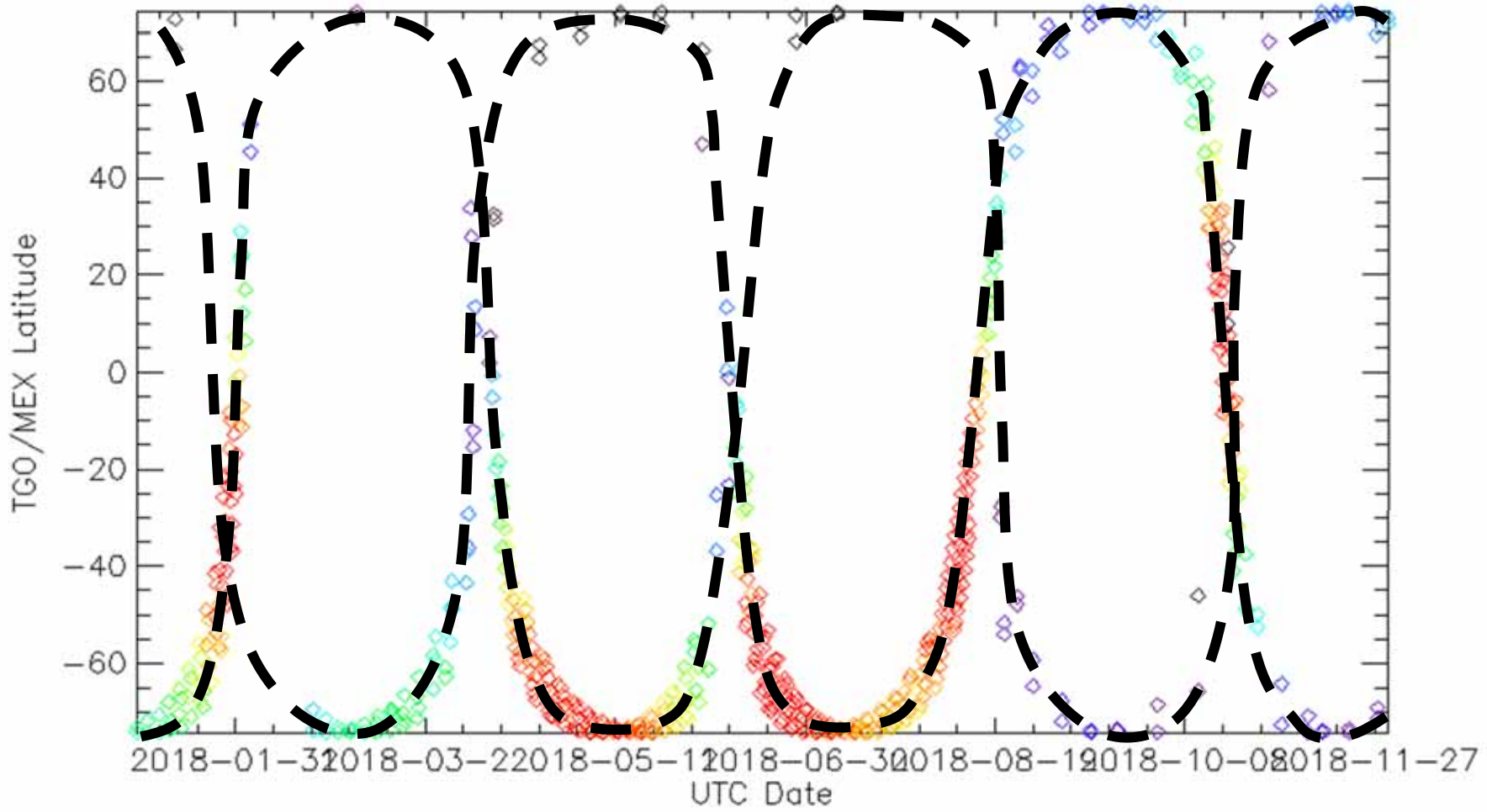
TGO vs MEX Polar coverage (4weeks)



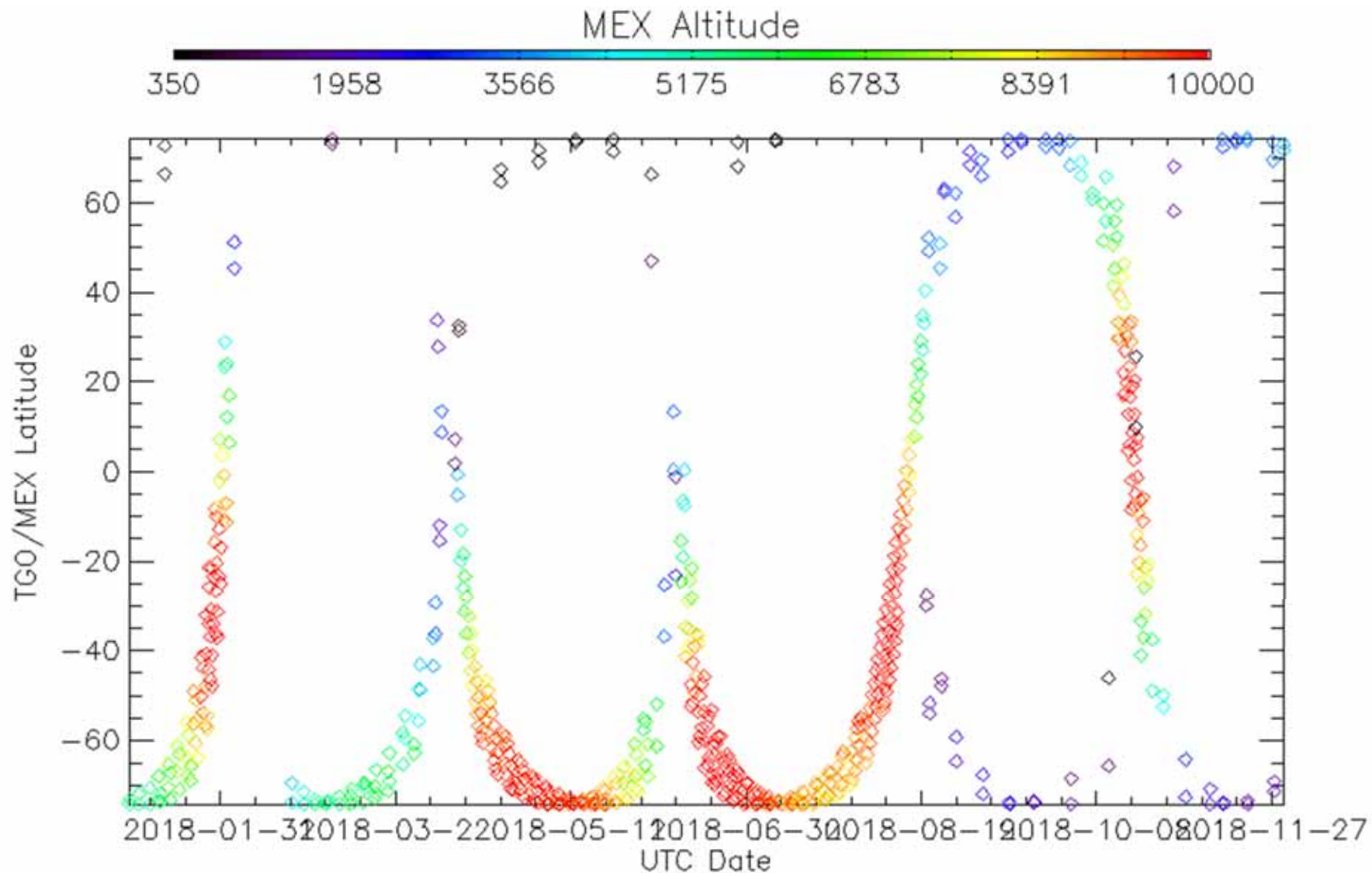
TGO - MEX orbit crossing points



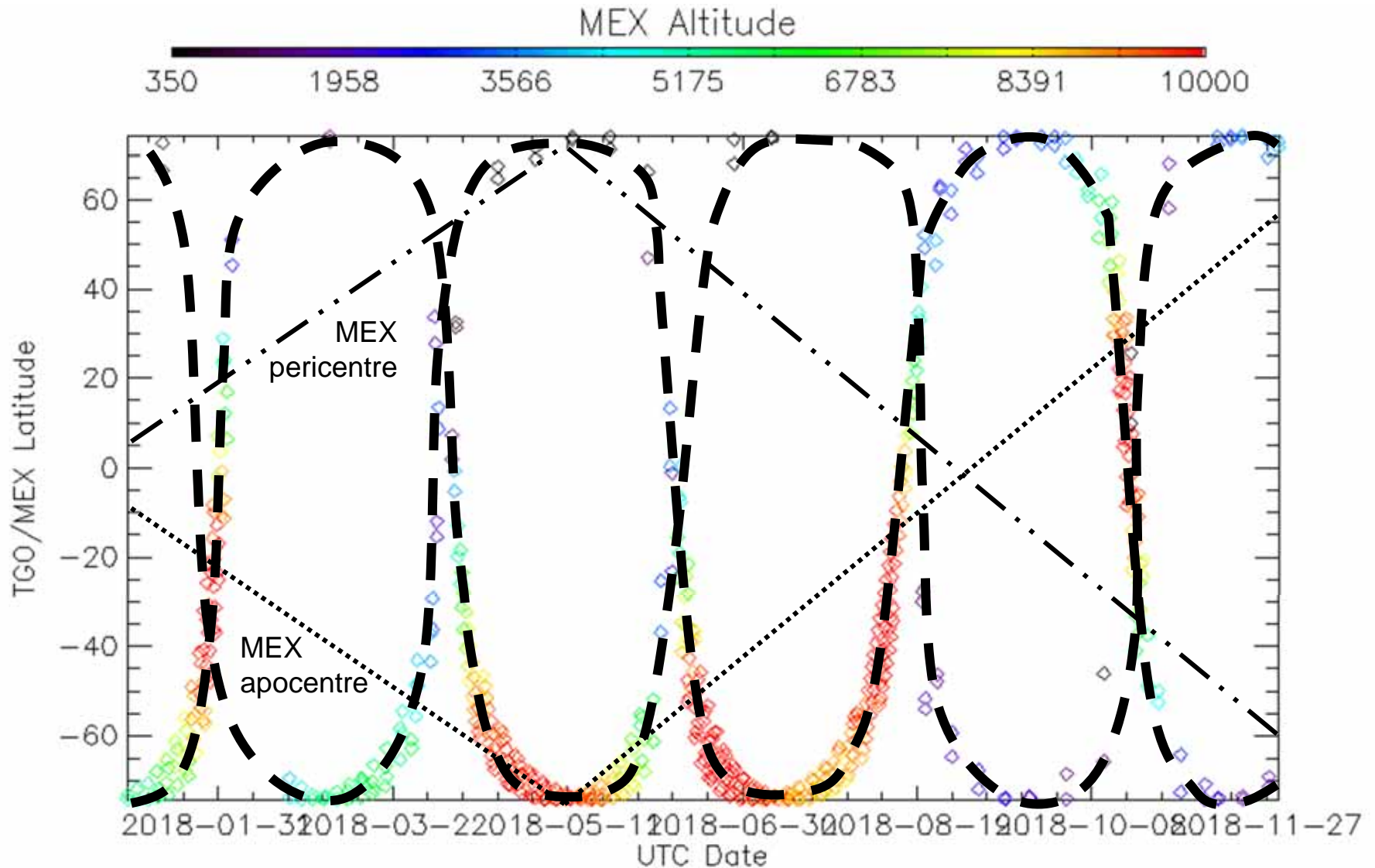
MEX-TGO 2018 orbit crosses



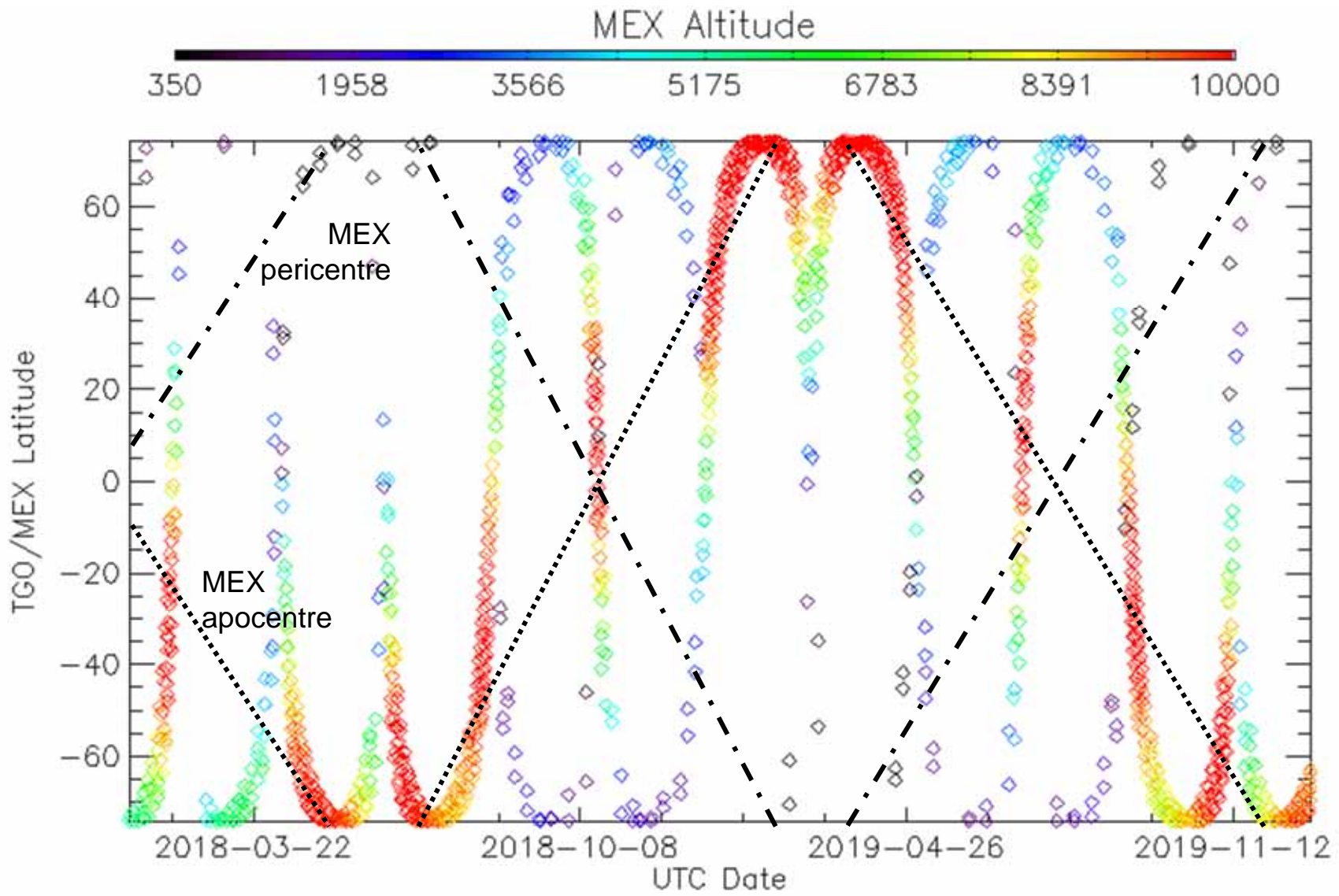
MEX-TGO 2018 Nadir (<5deg)



MEX-TGO Nadir 2018 (<5deg)

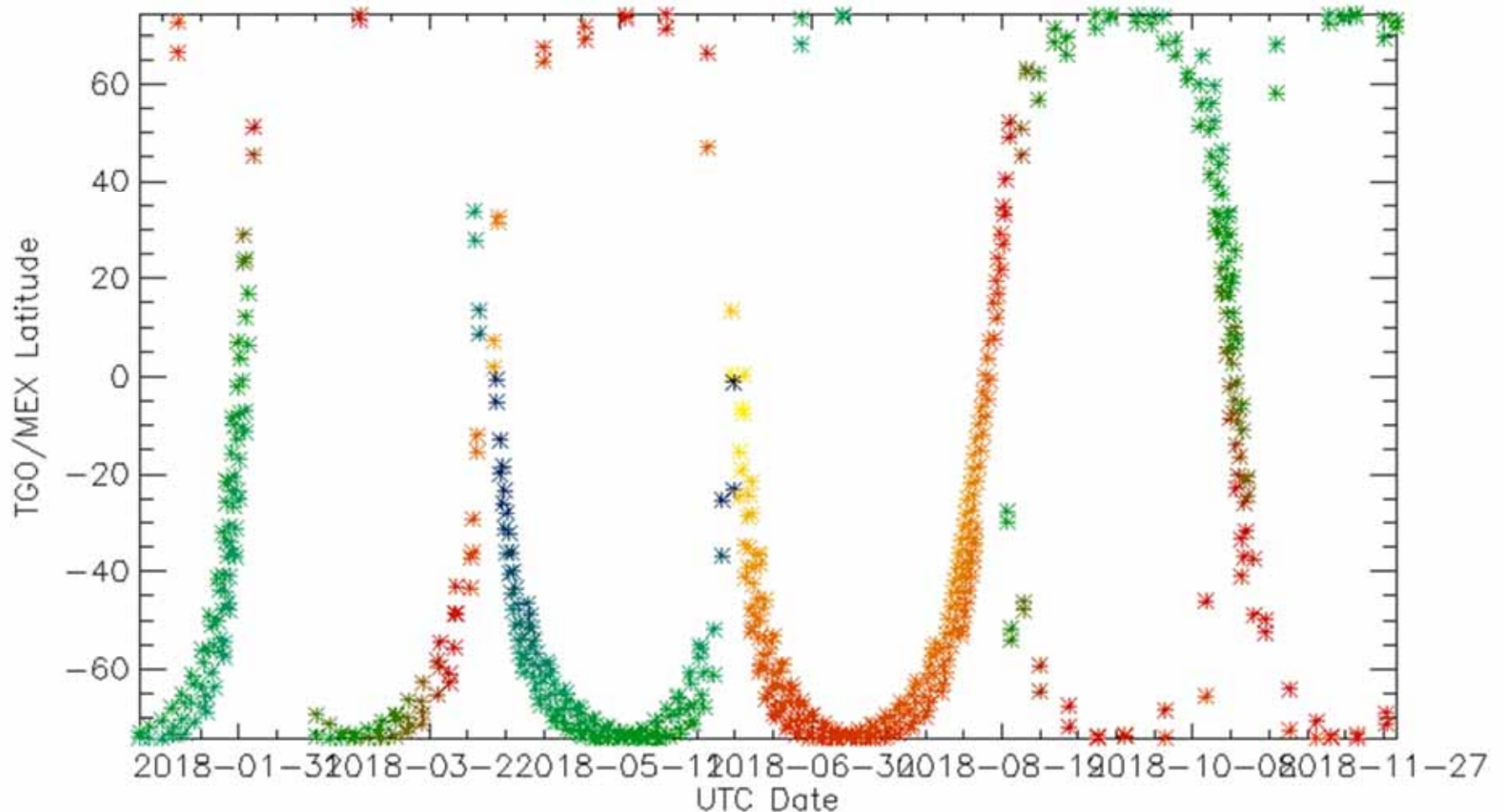


MEX-TGO Nadir 2018-2019 (<5deg)

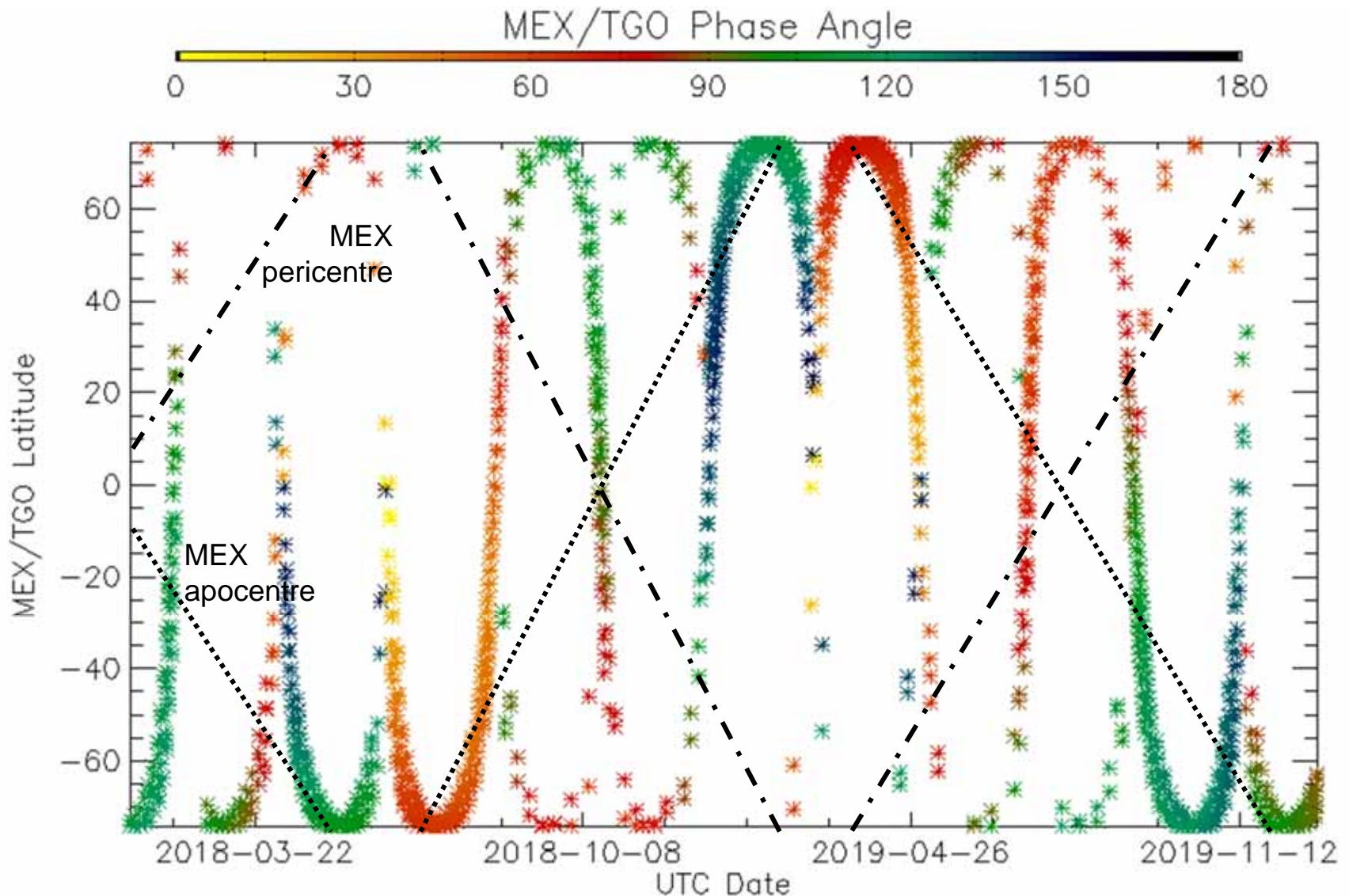


MEX-TGO Nadir 2018 (<5deg)

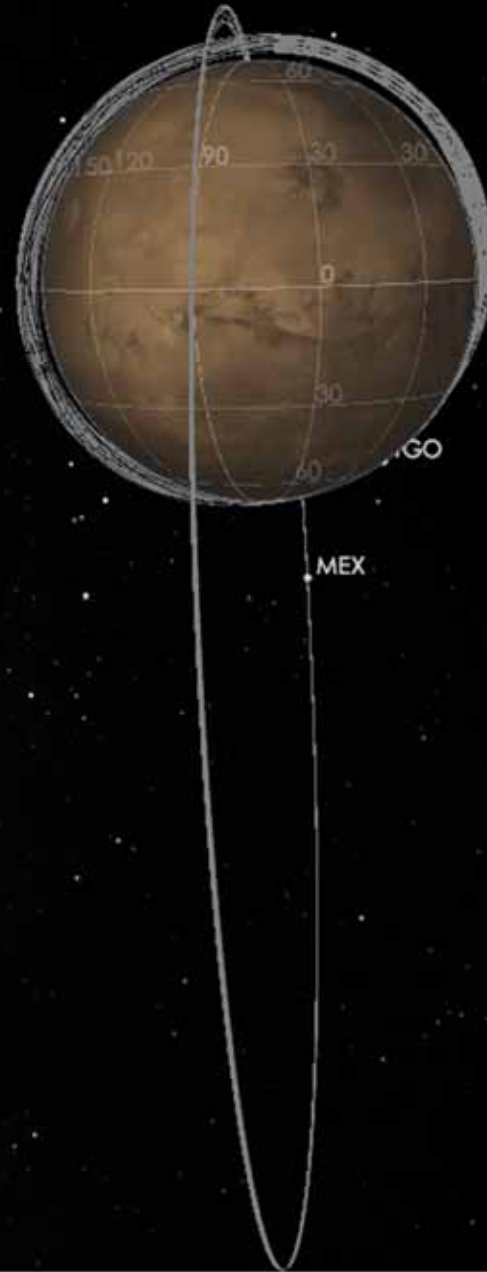
TGO/MEX Phase Angle



MEX-TGO Nadir 2018-2019 (<5deg)



MEX-TGO Orbit “perpendicular”

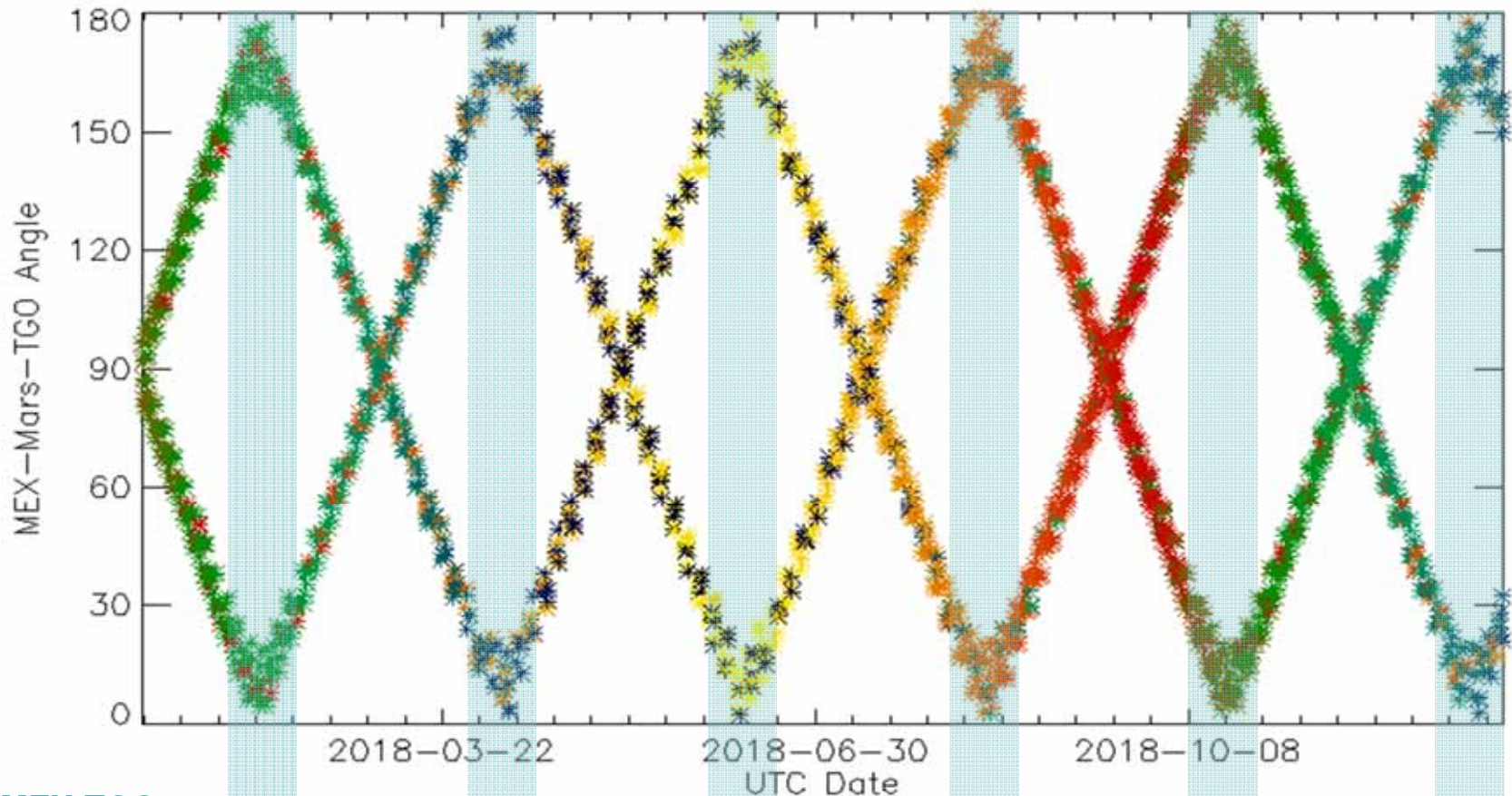


MEX-TGO Orbit "alignment"



MEX-TGO Orbit Plane Angles (at Equator Crossings)

MEX Phase Angle



MEX-TGO
“Orbit Alignment”
Seasons

Nadir Possible Coordinated Observations

- **Simultaneous observations:** (time + latitude + longitude + local time)
 - Nadir cross-calibrations are possible regularly (different distances)
 - All latitudes/longitudes covered (except poles)
 - Interpretation maybe complex (distance, velocity, resolution, etc)

- **Quasi-simultaneous observations (time diff. <10min, <1h???)**
 - TGO-MEX crosses every orbit, always 2 crossing points
 - Orbit “alignment” seasons every few months
 - Limited mostly by MEX apocenter distance

- **Non-simultaneous seasonal coverage (LS + lat + long + local time)**
 - Limited only by MEX pericenter illumination seasons
 - TGO covers most latitudes/illuminations for all seasons

MEX / TGO Planning

TGO / MEX Planning Cycles

❑ Long Term Planning (6-month cycles)

- Starts ~6 months in advance
 - MEX only SOWG high level agreements
 - TGO observation share and LTP timeline
- Definition of combined observation campaigns
- Computation of combined observation opportunities
- Agree long term priorities

❑ **Medium Term Planning** (4-week cycles)

- Starts ~12 weeks before execution, during 4 weeks
 - TGO maybe 10 weeks (TBC)
- Confirmation of observations and pointing (based on LTP agreements)
- TGO and MEX planning can be done almost in parallel
 - Confirmation of specific opportunities (from LTP calculations)
 - 4 weeks to iterate between missions

❑ **Short Term Planning** (1-week cycles)

- Only late parameter updates

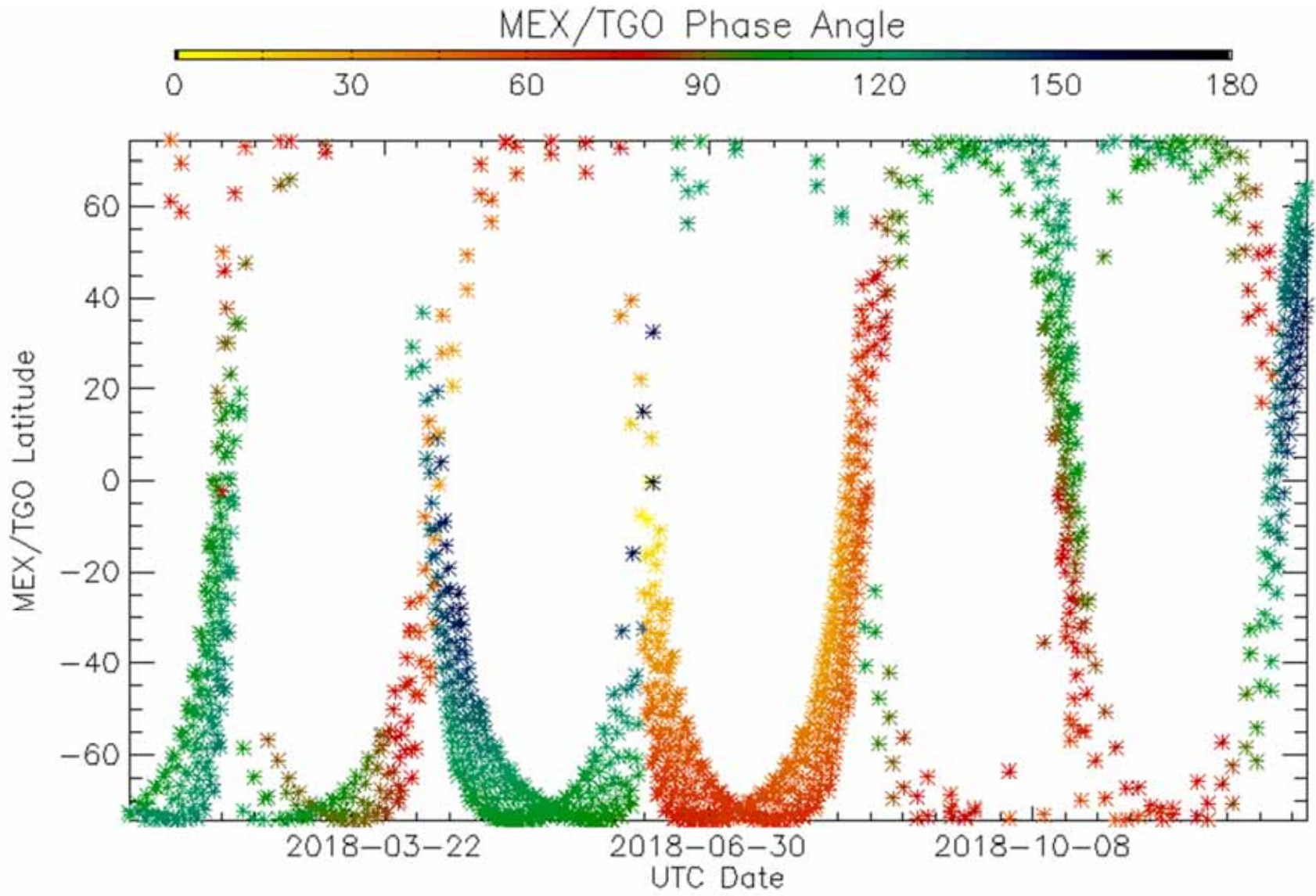
ExoMars Planning Schedule: Milestones and Cycles

▲ Aerobraking exit (mid April)
 ◆ FD product (orbit) delivery (T-4w)
 ◆ Sci com. 1 PTR & POR delivery (T-2w)
 ◆ Sci com. 2 PTR & POR delivery (T0)
 ◆ Sci com. 3 PTR & POR delivery (T+2w)
 ◆ Nom. Science PTR delivery (T+4w)
 ◆ Nominal science start (T+6w)

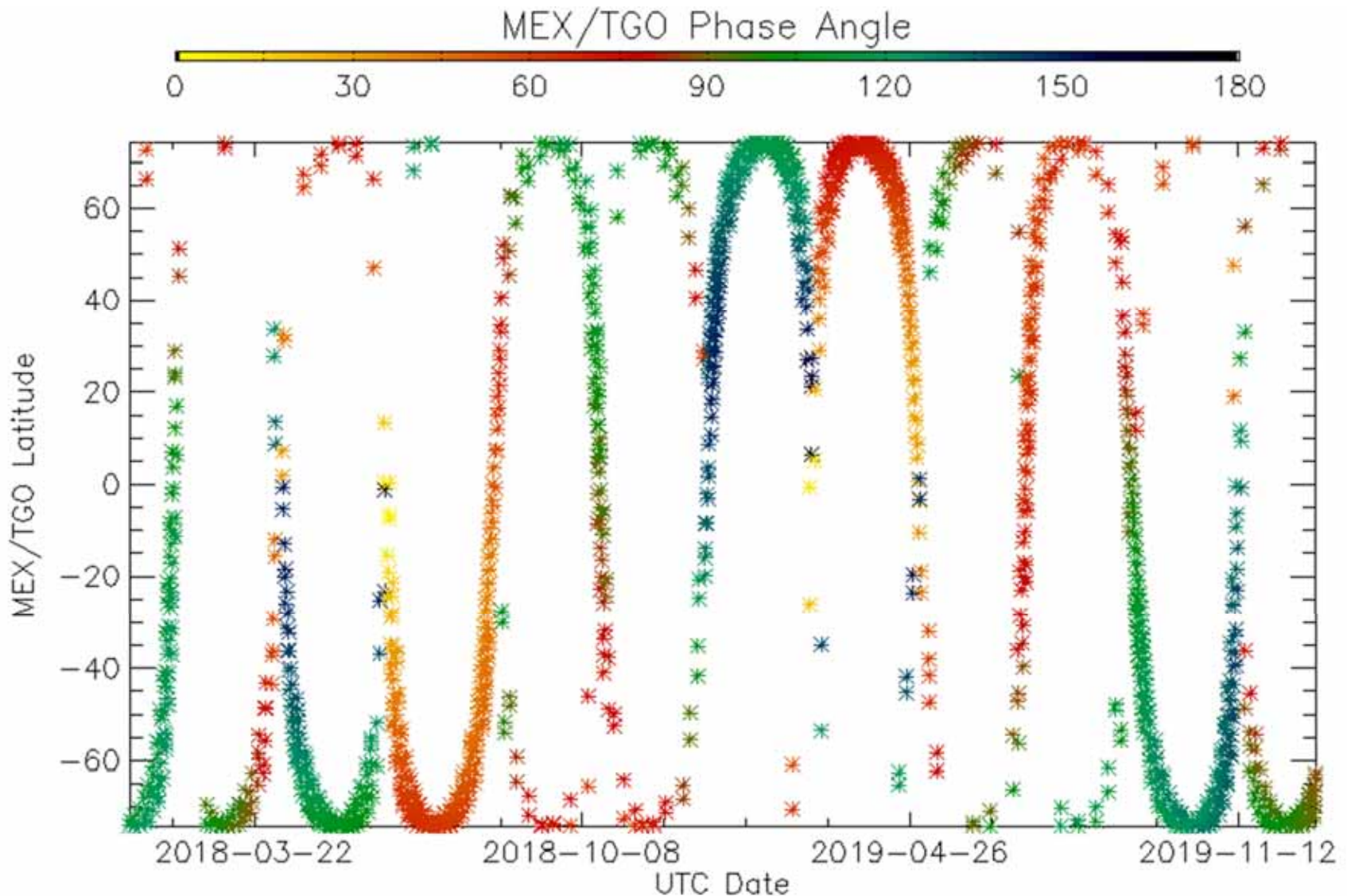
Est. Date	April				May				June				July				August				September				October							
Week	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20				
SOC + Pls Sci. Comm.	CVP preparation				MTP 1		MTP 2		MTP 3																							
SOC + Pls MTP #n									MTP 4		MTP 5		MTP 6				MTP n				MTP n+1				MTP n+2							
MOC/FD activities	Aero-braking		Orbit Deter.						MTP 1		MTP 2		MTP 3		MTP 4		MTP 5				MTP 6				MTP n				MTP n+1			
SOC + Pls STP CP#	E	N	E	N	C	C	C	C	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22		
On-board Execution			Eng. Act. (PDOR to MOC)		Mars CVP (POR via SOC, No PTR)				Sci. Com. MTP 1		Sci. Com. MTP 2		Sci. Com. MTP 3		Nominal Science MTP 4				Nominal Science MTP 5				Nominal Science MTP 6				...					
Pointing	NADIR Power Optimised								Science Pointings plus Relay Slots																							

END

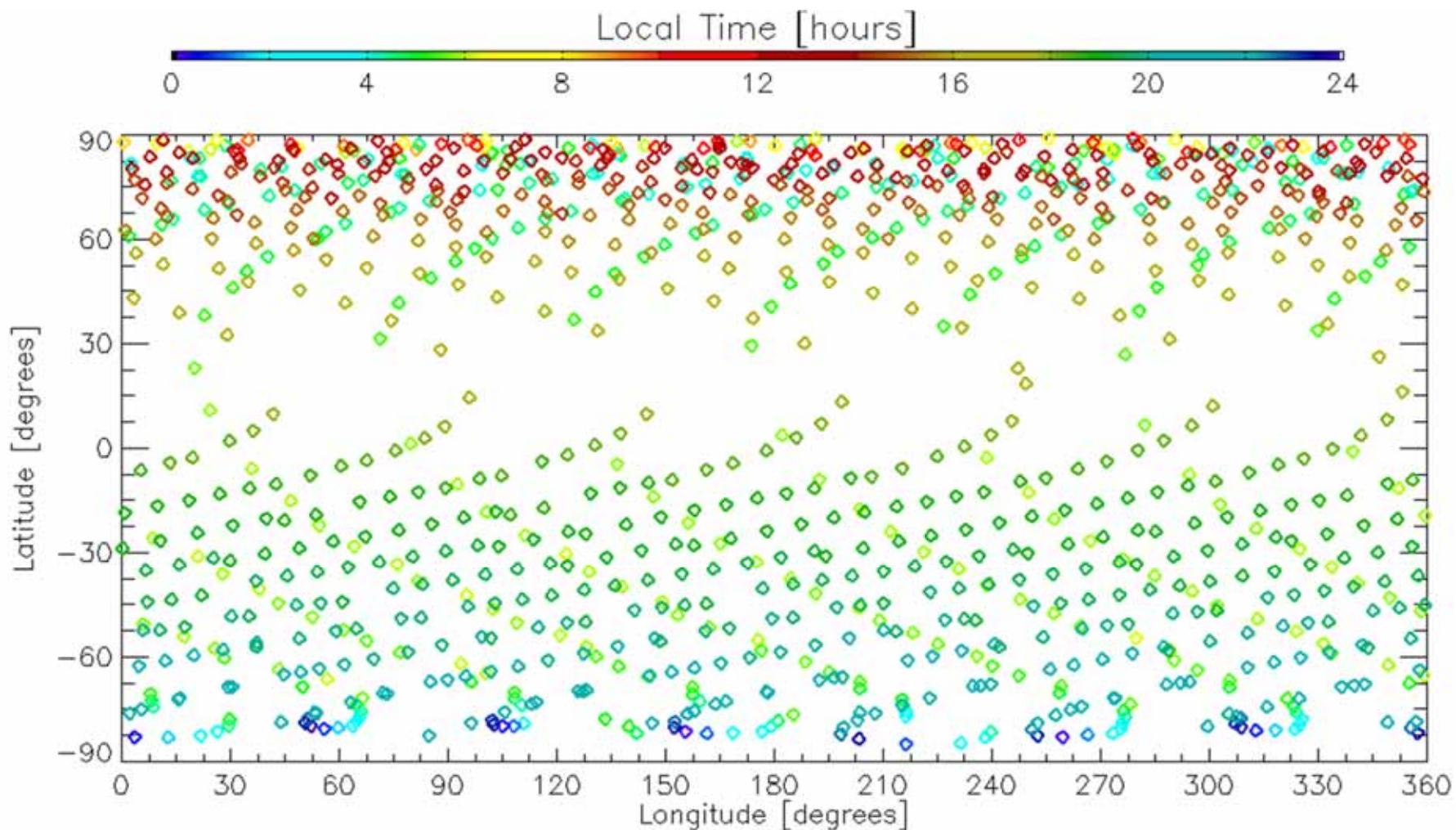
MEX-TGO Nadir 2018 (<10deg)



MEX-TGO Nadir 2018-2019 (<10deg)



MEX Sun Occultations 2018 (Local Time)



TGO Sun Occultations 2018 (Local Time)

