PRIDE – JUICE Interface Scenario

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JIVE, Dwingeloo
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juice

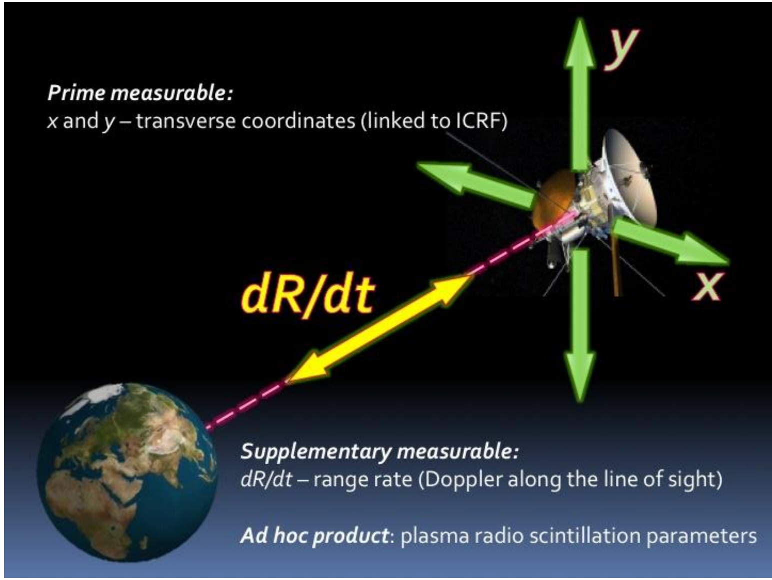
JIVE

Objectives

- To provide engineering interface between the PRIDE science component and the JUICE project.
- To brief the current opportunities/scenarios available for the PRIDE.
- To exploit synergies with other JUICE instruments.
- To discuss on potential imminent plans for PRIDE-JUICE development.

PRIDE Measurables

- <u>Transverse positioning (in ICRF) – main deliverable</u>
  - *S/C differential lateral position with the accuracy of 100-10 uas (1σ) over integration time 60-1000 s ➔ ephemerides of Jovian system.*
- Range rate Doppler – *ad hoc*
  - *<u>Supplementary</u> multi-static Doppler range-rate measurements with an accuracy of no worse than 0.015 mm/s (1σ) at 60 s integration time.*
- Radio Occultations
  - *<u>Supplementary</u> multi-static measurements of occultation radio signal for characterisation of the ionosphere and neutral atmosphere.*
  - *Qualitative characterisation of the occulting limb roughness.*
- Other ad-hoc opportunities
  - *IPS plasma diagnostics*
  - *Synergy with DtE science data delivery via "smart telecom"*



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3GM & PRIDE

	Observables		Responsibility		Comments
Investigation	3GM	PRIDE	3GM	PRIDE	
Moons gravity field	V_R, R				
Ganymede shape		L			Joint with GALA.
Ephemerides of the moons	V_R, R	L			
Ephemerides in the Solar System	V_R, R	L			
Radio-occ atmospheres	Bending angle, phase	Bending angle, phase			PRIDE support for deep atmospheric occultations at Jupiter.
Radio-occ ionospheres/ exospheres	Bending angle, phase	Bending angle, phase			
Radio occ surfaces	-	Diffraction pattern			Surface roughness, dielectric constant etc.
Bi-static radar	Reflected signal	Reflected signal			Uplink bistatic, dual polarisation.
Rings science	Phase, diffraction				Feasibility tbd
Jovian plasma, Io torus	Phase	Phase	tbd	tbd	Feasibility tbd

Responsibilities of the 3GM and PRIDE experiments. Red and blue shading means leading and complementary roles respectively.

JUICE Top Level Science Requirements Matrix

Goals	Science objectives		Measurements
Exploration of the habitable zone: Ganymede, Europa, and Callisto	Characterise Ganymede as a planetary object and possible habitat	Characterise the extent of the ocean and its relation to the deeper interior	Moons gravity field
		Characterise the ice shell	Moons gravity field and shape
		Determine global composition, distribution and evolution of surface materials	
		Understand the formation of surface features and search for past and present activity	
		Characterise the local environment and its interaction with the jovian magnetosphere	Radio-occultation in the moons atmospheres and ionospheres
	Explore Europa's recently active zones	Determine the composition of the non-ice material, especially as related to habitability	
		Look for liquid water under the most active sites	
		Study the recently active processes	
	Study Callisto as a remnant of the early jovian system	Characterise the outer shells, including the ocean	Moons gravity field and shape
		Determine the composition of the non-ice material	Bi-static radar
		Study the past activity	
Explore the Jupiter system as an archetype for gas giants	Characterise the Jovian atmosphere	Characterise the atmospheric dynamics and circulation	
		Characterise the atmospheric composition and chemistry	
		Characterise the atmospheric vertical structure	Radio occultation in the Jovian atmosphere and ionosphere
	Explore the Jovian magnetosphere	Characterise the magnetosphere as a fast magnetic rotator	
		Characterise the magnetosphere as a giant accelerator	
		Understand the moons as sources and sinks of magnetospheric plasma	Radio-occultation in the moons atmospheres and ionospheres
	Study the Jovian satellite and ring systems	Study Io's activity and surface composition	
		Study the main characteristics of rings and small satellites	Ephemerides of the moons and in the Solar system (?), ring science.

Science objectives covered by 3GM and PRIDE experiments are highlighted in green

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Science Observation Scenarios

Remote Sensing (RS) | Geophysics (GP) | Particles and Fields (PF)

SATELLITES

1. Satellite Stellar and Solar Occultations
2. Satellite Aurorae, Exospheres and Aurorae
3. Satellite Surface Imaging and Spectroscopy
4. Satellite Gravity& Geodesy
5. Satellite Topographic Mapping
6. Radar Sounding of Satellite Subsurfaces
7. Satellite Magnetospheric Characterisation
8. Satellite Ionospheric Characterisation
9. Remote Sensing of Io

MAGNETO SPHERE

10. Characterising Jupiter's Magnetosphere
11. Jupiter Auroral studies
12. Jovian Radio Emissions
13. Jupiter global Imaging & spectroscopy

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14. Jupiter Regional Imaging
15. Jupiter Limb Observations
16. Jupiter Stellar/ Solar Observations
17. Jupiter radio Occultations
18. Satellite Ephemerides

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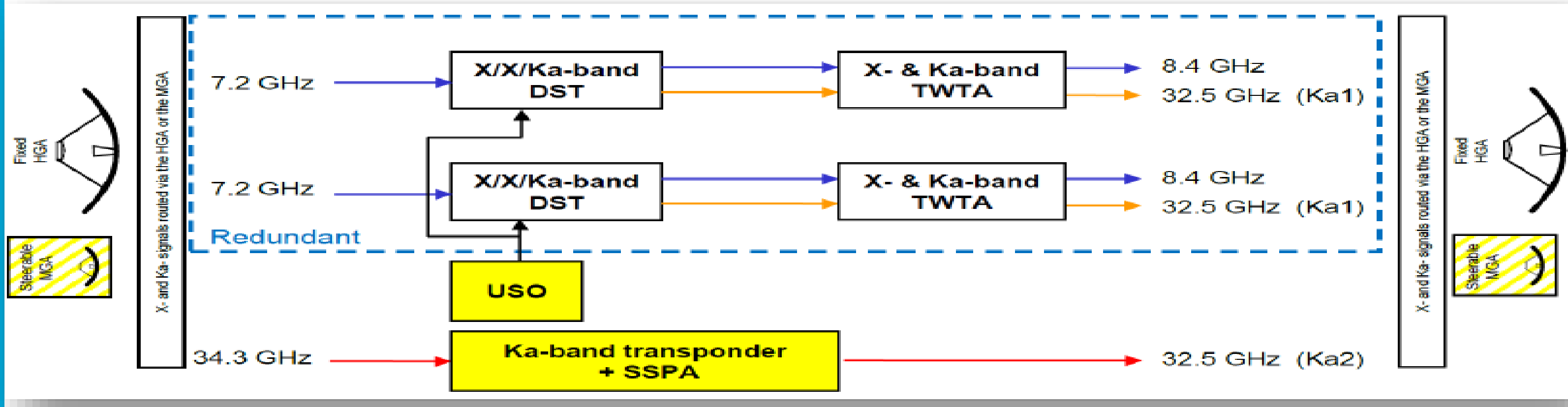
3GM Operating Modes



3GM Modes: Gravity and Atmospheric Science

G1: Gravity with KaT only
G2: Gravity with full multilink
(when full plasma rejection is required)
G3: Gravity with incomplete multilink
(partial plasma rejection. No X/Ka link)

O1: Occultation with downlink only
(X band and Ka band signals from USO)
O2: Occultation with uplink only
O3:Occultation with both downlink and uplink

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USO

Phase	Date	Duration (days)	USO running	Phase
1	2029-06-01	359	Never	1
2	2030-05-26	120	15 days, 18:51:12	2
3	2030-09-23	37	28 days, 12:11:31	3
4	2030-10-30	276	5 days, 4:51:22	4
5	2031-08-02	488	463 days, 17:14:25	5
6	2032-12-02	151	127 days, 3:51:47	6
7	2033-05-02	152	Never	7
End	2033-10-01			End
Total		**1583**	**640 days, 9:00:17**	**Total**

USO must be activate 1 month before occultation (30 days (before occ) until the end of occ)

WG1 Main Segments/ Opportunities

Main Segments in Phase 2

Energy reduction

- *3 Ganymede flybys* (C/A 401 km, 502 km, 3807 km) - 2G2, 3G3, 4G4
- *1 Callisto flyby* (C/A 791 km) - 5C1

"The priority in phase 2 will be the 'characterisation of Ganymede as a planetary object and possible habitat' and Callisto as a remnant of the early Jovian system"

WG	Phase	Subphase	Start time	Stop time	Duration (min)	Cases	Ops mode	Priority	Comments
Flybys									
			2G2 flyby (401 km, c/a 2030-151T09:15:01)						
1	1	2.2	-8h from 2G2 CA	+8h from CA	960	4, 18	DLA	High	3GM MGA observations. Gravity field
			3G3 flyby (3807 km, c/a 2030-208T14:21:03)						
1	1	2.2	-8h from 3G3 CA	+8h from CA	960	4, 18	DLA	High	3GM MGA observations: gravity field
			4G4 flyby (502 km, c/a 2030-244T08:41:30)						
1	1	2.2	-8h from 4G4 CA	+8h from CA	960	4, 18	DLA	High	3GM MGA observations: gravity field
			5C1 flyby (791 km)						
1	1	2.2	-8h from 5C1 CA	+8h from CA	960	4, 18	DLA	High	3GM MGA observations. Gravity field and tides

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WG1 Main Segments

Main Segments in Phase 3

Europa Phase

•***2 Europa flybys*** ***(C/A: 403 km)*** **- 6E1 and 7E2**

"The priority in phases 3 and 4 will be to 'Explore Europa's recently active zones' and to study Callisto as a remnant of the early Jovian system"

WG	Phase	Subphase	Start time	Stop time	Duration (min)	Cases	Ops mode	Priority	Comments
Flybys									
			6E1 flyby (403 km, c/a 05-OCT-2030_10:57:17)						
1	3	3.2	-8h from CA	+8h from CA	960	4, 18	DLA	High	3GM MGA observations: gravity field
			7E2 flyby (403 km, c/a 19-OCT-2030_16:48:04)						
1	3	3.4	-8h from 2G2 CA	+8h from CA	960	4, 18	DLA	High	3GM MGA observations: gravity field

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WG1 Main Segments

Main Segments in Phase 4

High latitudes phase

- ***9 Callisto flybys*** ***(C/A: 7x 199 km, 409 km, 2008 km)***
  8C2, 9C3, 10C4, 11C5, 12C6, 13C7, 14C8, 15C9 and 16C10

"The priority in phases 3 and 4 will be to 'Explore Europa's recently active zones' and to study Callisto as a remnant of the early Jovian system"

WG	Phase	Subphase	Start time	Stop time	Duration (min)	Cases	Ops mode	Priority	Comments
			Flybys						
			8C2 flyby (409 km, c/a 31-OCT-2030_08:26:01)						
1	4	4.2	-8h from CA	+8h from	960	4, 18	NLA	High	3GM MGA observations: gravity field and tides
			9C3 flyby (199 km, c/a 14-DEC-2030_13:18:30)						
1	4	4.10	-8h from CA	+8h from	960	4, 18	NLA	High	3GM MGA observations: gravity field and tides
			10C4 flyby (199 km, c/a 31-DEC-2030_05:50:30)						
1	4	4.14	-8h from CA	+8h from	960	4, 18	NLA	High	3GM MGA observations: gravity field and tides
			11C5 flyby (199 km, c/a 16-JAN-2031_22:16:13)						
1	4	4.18	-8h from CA	+8h from	960	4, 18	NLA	High	3GM MGA observations: gravity field and tides
			12C6 flyby (2008 km, c/a 02-FEB-2031_14:45:35)						
1	4	4.22	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			13C7 flyby (199 km, c/a 27-APR-2031_01:05:28)						
1	4	4.32	-8h from CA	+8h from	960	4, 18	NLA	High	3GM MGA observations: gravity field and tides
			14C8 flyby (199 km, c/a 13-MAY-2031_17:23:59)						
1	4	4.36	-8h from CA	+8h from	960	4, 18	DLA	High	3GM MGA observations: gravity field and tides
			15C9 flyby (199 km, c/a 30-MAY-2031_09:52:51)						
1	4	4.40	-8h from CA	+8h from	960	4, 18	DLA	High	3GM MGA observations: gravity field and tides
			16C10 flyby (199 km, c/a 16-JUN-2031_02:22:05)						
1	4	4.44	-8h from CA	+8h from	960	4, 18	DLA	High	3GM MGA observations: gravity field and tides

WG1 Main Segments

Main Segments in Phase 5

Low energy or Transfer to Ganymede

11 Satellite Flybys **- *8 Ganymede and 3 Callisto***

17G5, 18G6, 22G7, 23G8, 24G9, 25G10, 26G11, 19C11, 20C12, 21C13

"The priority in phase 5 will be the 'characterization of Ganymede as a planetary object and possible habitat' and Callisto as a remnant of the early Jovian system"

WG	Phase	Subphase	Start time	Stop time	Duration (min)	Cases	Ops mode	Priority	Comments
			Flybys						
			17G5 flyby (807 km, c/a 26-AUG-2031_19:16:36)						
1	5	5.7	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			186G flyby (3855 km, c/a 10-SEP-2031_02:05:45)						
1	5	5.10	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			19C11 flyby (357 km, c/a 26-SEP-2031_21:55:32)						
1	5	5.14	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			20C12 flyby (6209 km, c/a 13-OCT-2031_13:12:13)						
1	5	5.18	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			21C13 flyby (787 km, c/a 11-JAN-2032_17:44:04)						
1	5	5.20	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			22G7 flyby (27782 km, c/a 02-FEB-2032_23:21:30)						
1	5	5.22	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			23G8 flyby (27409 km, c/a 07-APR-2032_09:48:15)						
1	5	5.23	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			24G9 flyby (19262 km, c/a 13-MAY-2032_08:58:03)						
1	5	5.14	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			25G10 flyby (33235 km, c/a 04-JUN-2032_03:39:58)						
1	5	5.14	-8h from CA	+8h from	960	4, 18		High	3GM MGA observations: gravity field and tides
			26G11 flyby (32825 km, c/a 24-JUL-2032_15:31:53)						
1	5	5.14	-8h from CA	+8h from	960	4, 18	DLA	High	3GM MGA observations: gravity field and tides
			27G12 flyby (26903 km, c/a 22-AUG-2032_23:07:51)						
1	5	5.14	-8h from CA	+8h from	960	4, 18	DLA	High	3GM MGA observations: gravity field and tides

WG2 Main Segments

Main Opportunities for WG2

1. Flybys of Europa, Ganymede, and Callisto down to a distance of about 1500 km
2. Distant flybys of Europa, Ganymede, and Callisto for exospheric studies and astrometric observations
3. Distant observations and monitoring of Io
4. Characterisation and astrometric observations of the inner satellites at distances below 1,000,000 km
5. Characterisation and astrometric observations of the irregular satellites at distances below 10,000,000 km
6. GCO5000
7. Occultation Opportunities (Ionospheric Characterisation)

Main segments in Phase 2

- Three flybys of Ganymede & One flyby Callisto
- Science objectives related to Io, the small satellites and the ring system
  - 5 opportunities to observe Io, 3 of which at distance closer than 450,000 km.
  - Favourable opportunities to observe some of the largest among the small inner satellites of Jupiter (Thebe and Amalthea), and some of the outer irregular satellites (Themisto, Himalia, Leda, Elara, 55066)
- Explore the Jupiter system as archetype of gas giants
- No occultation opportunities (i.e., the Earth being occulted to the S/C by Ganymede or Callisto)

(future evolution of the trajectory may provide occultation opportunities)

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WG2 Main Segments

Main Segments in Phase 3

Phase 3 ("Europa phase") time range: **2030-09-28T02:17** to **2030-10-26T20:31**

- Two close Europa flybys and distant observations of Io (1) and minor satellites.
- No occultation opportunities (i.e., the Earth being occulted to the S/C by Europa)

Main Segments in Phase 4

Phase 4 (" moderate inclination phase") time range: **2030-10-26T20:31 to 2031-06-25T20:56**

- Nine flybys of Callisto: 3 dayside low altitude, 1 dayside high altitude and 5 nightside low altitude
- Distant observations of Europa(4), Ganymede(5), Io (4)and other minor satellites
- 3GM Occultation's : 3 out of 9 Callisto flybys (8C2, 9C3 and 11C5), provide occultation opportunities
  - 8C2 occurring on 31 October 2030 provides the longest occultation arc (~17 minutes, covering the C/A period and part of the egress phase)
  - 9C3 and 11C5 provide shorter occultation's (10 and 5 minutes respectively, both in the egress phase)

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WG2 Main Segments

Main Segments in Phase 5

Phase 5 time range (low energy phase or Transfer to Ganymede): **2031-06-25T20:56 to 2032-08-24T12:56**

It features several opportunities relevant to WG2, most notably:

- 8 flybys of Ganymede: 1 nightside low altitude and 1 nightside high altitude. All other opportunities are distant encounters in the altitude range ~19,000-33,000 km, where most of the nightside is seen
- Three flybys of Callisto: 2 low altitude (one nightside and one dayside) and 1 nightside high altitude
- Distant observations of Io, Europa, and minor satellites
- The longest opportunities to observe Jupiter’s ring system at high phase angle and low elevation
- 3GM Occultation's : Ganymede flybys (17G5 & 18G6), as well as Callisto flybys (19C11 & 20C12), provide occultation opportunities
    - Ganymede flyby 17G5 --> 20 min, around C/A
    - Ganymede flyby 18G6 --> 22 min, around C/A
    - Callisto flyby 19C11 --> 34 min, inbound phase
    - Callisto flyby 20C12 --> 93 min, inbound phase

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WG4

The prime segment request for WG4 can be summarized as:

1. Perijove segments
2. Phase angle segments
3. Inclined segments
4. Monitoring segments
5. Synergistic science segments
6. Event-driven segments (e.g., radio/solar/stellar occultation's, impacts, storms)

Phases

Phase 2 : Three flybys of Ganymede and one flyby Callisto & ***4 Jupiter perijoves***

Phase 3 : ***2 equatorial dayside perijoves*** (rather like Phase 2), they provide the highest spatial resolution for Jupiter observations of the entire mission

Phase 4 : High latitude phase of the mission , 9 Callisto flybys (from 8C2 to 16C10), and ***13 Jupiter perijoves***

Phase 5 : Transfer of the spacecraft to Ganymede following two subphases ***- the Ganymede - Callisto ladder, and the low energy endgame***. It will last for 433 days, and consists of ***31 perijove opportunities.*** This phase has generally higher phase angles at closer proximity to Jupiter

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WG4: 3GM Occultation's Opportunities

3GM radio occultation's are used to probe the electron content of the upper atmosphere and the composition/structure of the neutral atmosphere

- **Phase 2:** No 3GM occultations
- **Phase 3:** Immediately following Europa flybys, two 3GM occultations on
  - October 7th 2030 and
  - October 24th 2030
- **Phase 4:** No 3GM occultations
- **Phase 5:** 21 3GM occultations before GOI

3GM Occultations during Phase 5

	Ingress time	Jupiter Distance	Longitude	Latitude	Egress time	Jupiter Distance	Longitude	Latitude
1	2031 OCT 09 19:01:45.0	14,784	276,77	-39,447	2031 OCT 09 21:18:51.0	14,973	10,16	-39,125
2	2031 OCT 28 08:18:23.0	14,888	329,63	-37,825	2031 OCT 28 10:40:01.0	15,11	60,605	-37,558
3	2031 NOV 15 21:56:33.0	15,206	9,9563	-39,034	2031 NOV 16 00:26:52.0	15,572	95,423	-42,423
4	2032 JAN 20 03:22:55.0	19,686	124,16	-56,285	2032 JAN 20 05:24:18.0	19,77	225,6	-55,605
5	2032 FEB 05 13:43:27.0	15,363	222,29	-38,718	2032 FEB 05 16:12:58.0	15,321	309,36	-37,257
6	2032 FEB 18 15:34:34.0	15,347	0,1477	-36,115	2032 FEB 18 18:09:33.0	15,322	84,276	-34,666
7	2032 MAR 02 17:23:03.0	15,278	139,25	-32,73	2032 MAR 02 20:02:51.0	15,248	220,87	-30,672
8	2032 MAR 15 13:11:18.0	15,36	135,8	-30,776	2032 MAR 15 15:58:28.0	15,308	213,22	-28,074
9	2032 MAR 28 11:02:18.0	15,49	57,769	-28,315	2032 MAR 28 13:54:39.0	15,447	132,29	-25,588
10	2032 APR 10 09:30:00.0	15,475	317,16	-26,194	2032 APR 10 12:25:37.0	15,444	29,891	-23,484
11	2032 APR 23 07:44:00.0	15,474	224,4	-24,45	2032 APR 23 10:42:10.0	15,451	295,74	-21,757
12	2032 MAY 06 05:37:17.0	15,38	143,72	-22,134	2032 MAY 06 08:38:05.0	15,327	213,62	-19,01
13	2032 MAY 18 03:36:29.0	15,456	209,63	-20,624	2032 MAY 18 06:42:21.0	15,394	276,56	-17,573
14	2032 MAY 30 01:56:03.0	15,459	262,9	-20,187	2032 MAY 30 05:02:23.0	15,396	329,58	-17,145
15	2032 JUN 10 23:55:12.0	15,397	328,19	-19,461	2032 JUN 11 03:01:57.0	15,294	34,66	-16,112
16	2032 JUN 21 15:43:45.0	15,826	47,987	-18,258	2032 JUN 21 18:59:52.0	15,715	108,83	-15,203
17	2032 JUL 02 09:57:32.0	15,805	39,89	-18,566	2032 JUL 02 13:13:20.0	15,671	100,92	-15,429
18	2032 JUL 12 09:04:49.0	16,035	4,9261	-15,239	2032 JUL 12 12:29:41.0	15,876	60,579	-12,617
19	2032 JUL 22 08:58:22.0	16,115	302,15	-15,934	2032 JUL 22 12:23:20.0	15,951	357,71	-13,297
20	2032 AUG 01 08:59:02.0	16,145	235,24	-16,682	2032 AUG 01 12:23:33.0	15,978	291,04	-14,029
21	2032 AUG 11 09:04:37.0	16,162	165,62	-17,387	2032 AUG 11 12:28:40.0	15,991	221,67	-14,716

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Earth Occultation by Jupiter (seen from Juice)

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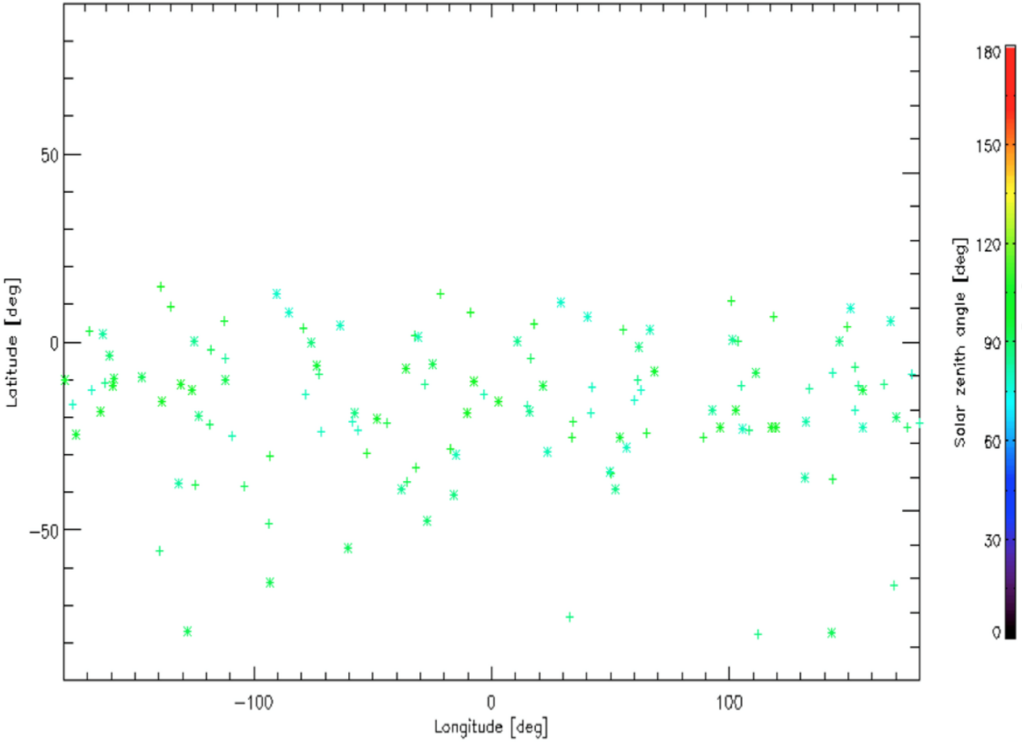
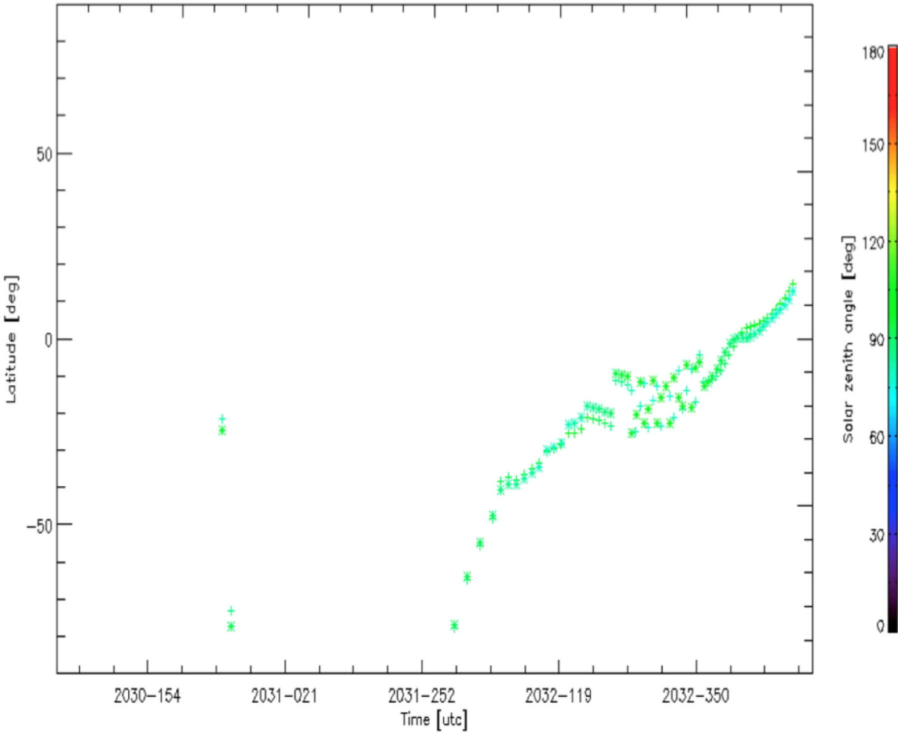
Body-fixed Latitude-Longitude-illumination coverage



Temporal coverage of Jupiter-Earth occultation's.



(https://www.cosmos.esa.int/web/juice/)

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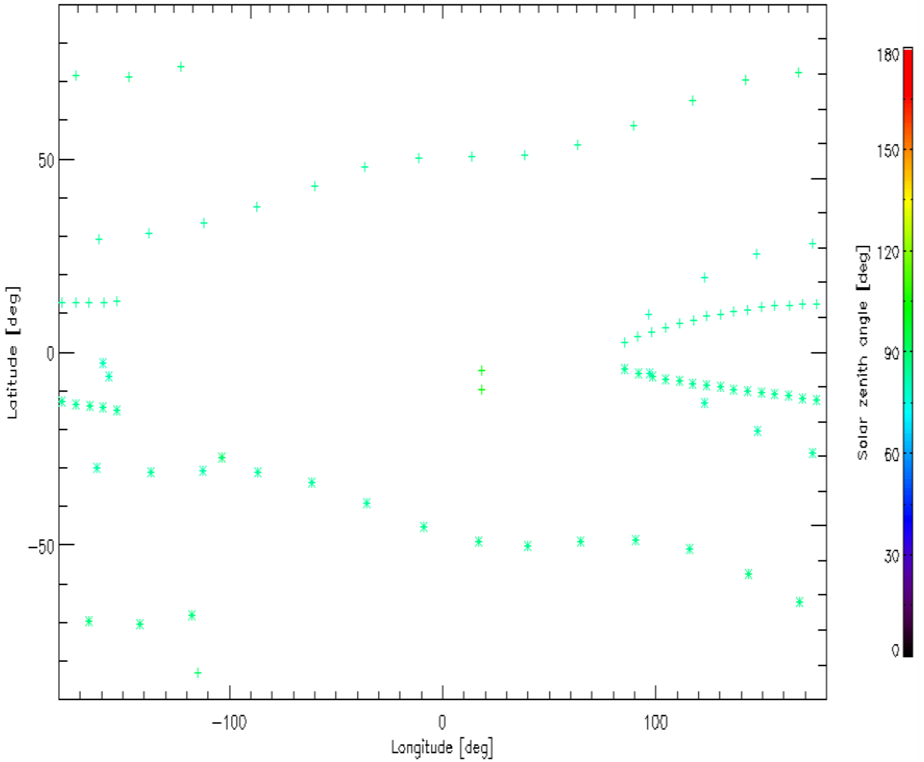
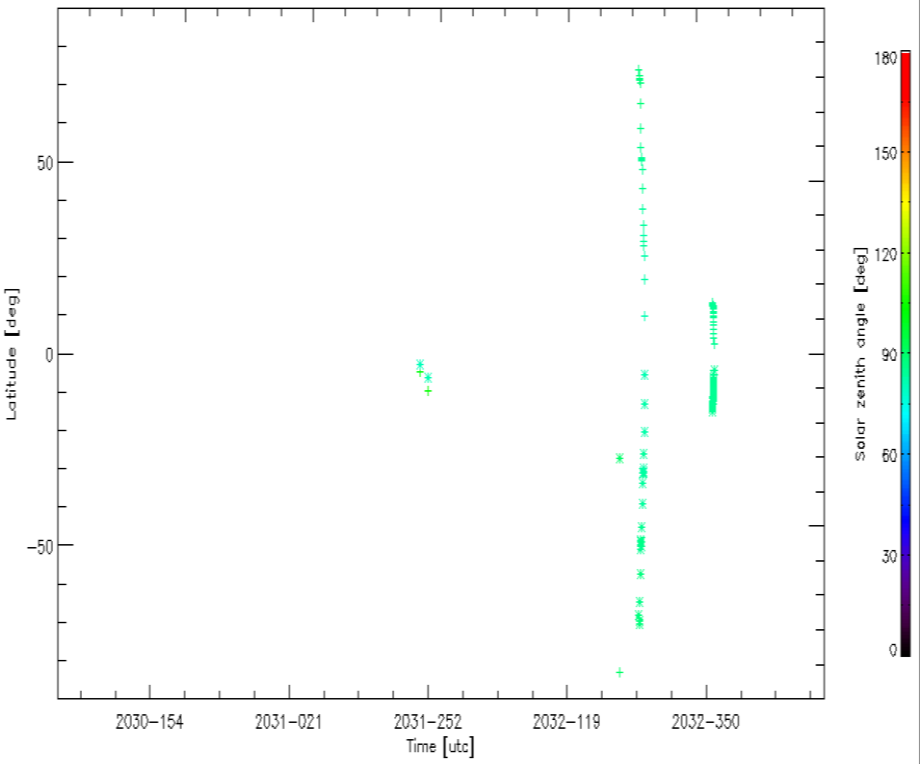
Earth Occultation by Ganymede (seen from Juice)

Body-Fixed Latitude-Longitude-Illumination Coverage



Distribution of Occultation's with time



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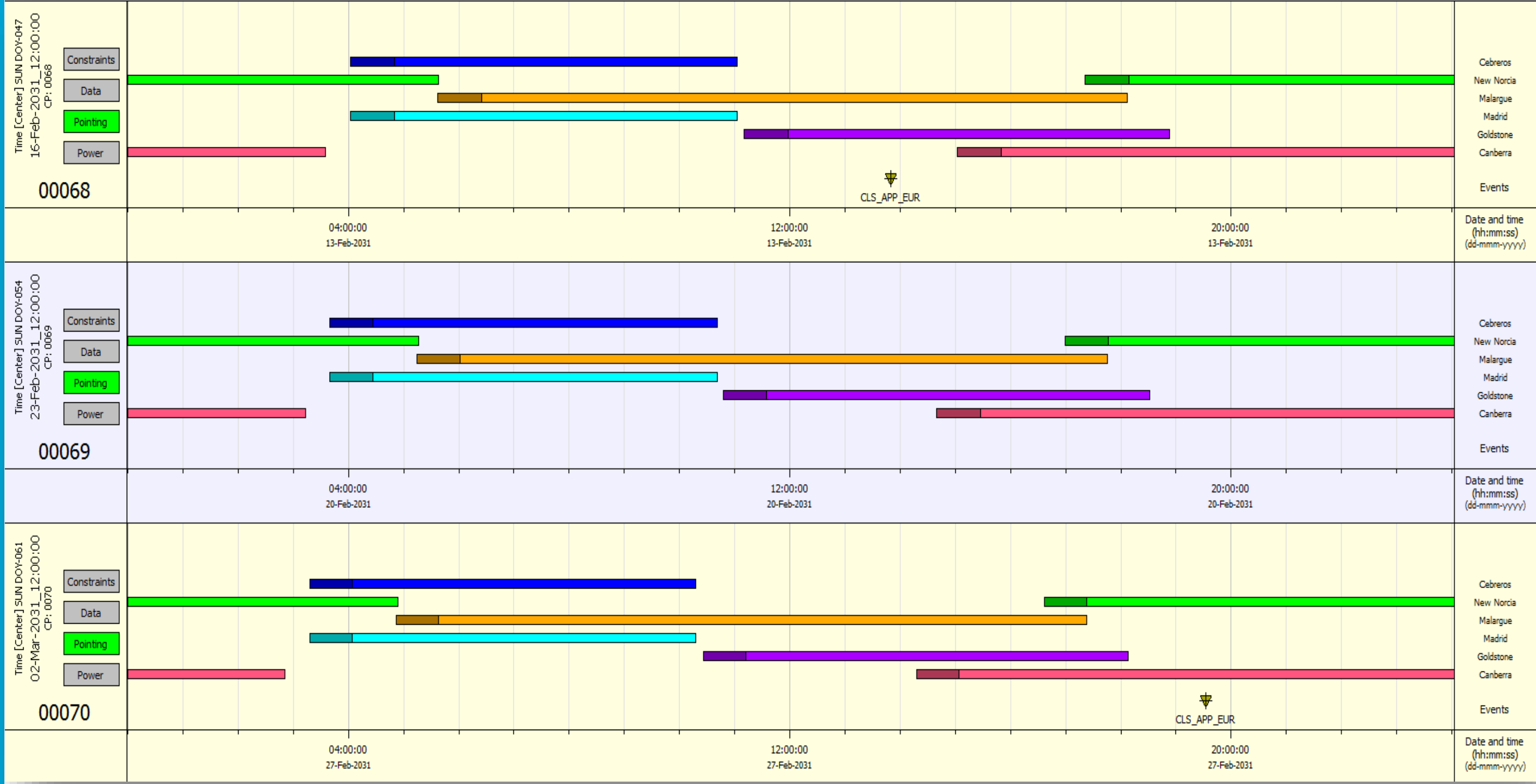
Ground Station Visibility (examples)



Southern Antennas ~12h:
Malargue, New Norcia, Canberra
Northern Antennas ~7h:
Cebreros, Madrid, Goldstone

ESTRACK Malargue (12h) + DSN Canberra (12h) / 2 hour overlap
→ up to 22 hours of coverage
ESTRACK Cebreros (7h) + DSN Goldstone (7 h) / 0 hour overlap
→ up to 14 hours of coverage
ESTRACK New Norcia (12 h) + DSN Goldstone (7h) / x hour overlap
→ up to 18 hours of coverage (*X band only) / 7h Ka band.

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Conclusions and Future Plans

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Conclusions

1. Identified the different opportunities for PRIDE in synergy with 3GM (Spacecraft tracking & atmospheric science).
2. Explored the GS/downlink visibilities from the timeline tool (*Malargue visibility events – SOC)*.
3. Confirmation from 3GM team/WG's on the instrument modes/occultations/ opportunities (*main occultation and eclipse events-calculated with SOLab eFinder - SOC*).

Major activities in 2019-20 for JUICE

1. PRIDE ops scenarios for all relevant mission segments/sequences (in cooperation with all WG's and SWT) for eg: cruise phase science.
2. Continuation of the catalogue densification.
3. Data archive of useful PRIDE dataset
4. Ka-band functionality: tests and developments.
5. Synergy between PRIDE, 3GM and other instruments (GALA and JANUS) and reformulate the responsibilities.

Thank you!