The Science Activity Plan of PROBA-3/ASPIICS

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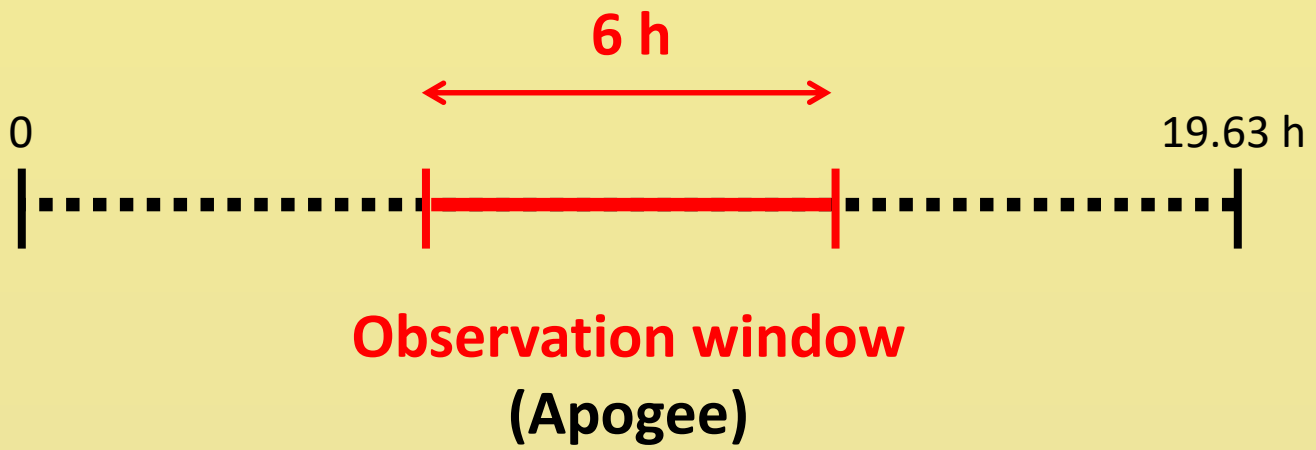
ASPIICS Science Objectives

				Cadence (s)	Bandpasses
Scientific Objectives	**Quiescent corona**	"What is the nature of the solar corona on different scales?"	Large scales	60	All
			Small scales	2	All
		"What processes contribute to the heating of the corona?" (waves)		2	WL (or only one filter)
		"What processes contribute to the solar wind acceleration?"	blobs	60	WL (All)
			jets	<2 s	WL (All)
	Eruptive corona	"What is the nature of the structures that form the CME?"		60	All
		"How do CMEs erupt and accelerate in the low corona?"		30	All
		"What is the connection between CMEs and active processes close to the solar surface?"		30	All
		"Where and how can a CME drive a shock in the low corona?"		30	All

“Coronagraph orbit”



Orbit allocation during the 2 years of the PROBA-3 mission

- 4-month commissioning ⇒ Year 1 has less orbits dedicated to observations

	Year 1	Year 2	Total
Commissioning orbits	146	0	146
Orbits with the Earth close to the field of view (no science operation planned)	33	33	66
Available orbits for regular operations	267	413	680
Total of orbits	446	446	892

- Guaranteed: 166 orbits for coronagraphy (fuel)

	Year 1	Year 2	Total
Orbits with instrument idle	207	307	514
Coronagraph orbits	60	106	166
Total	267	413	680

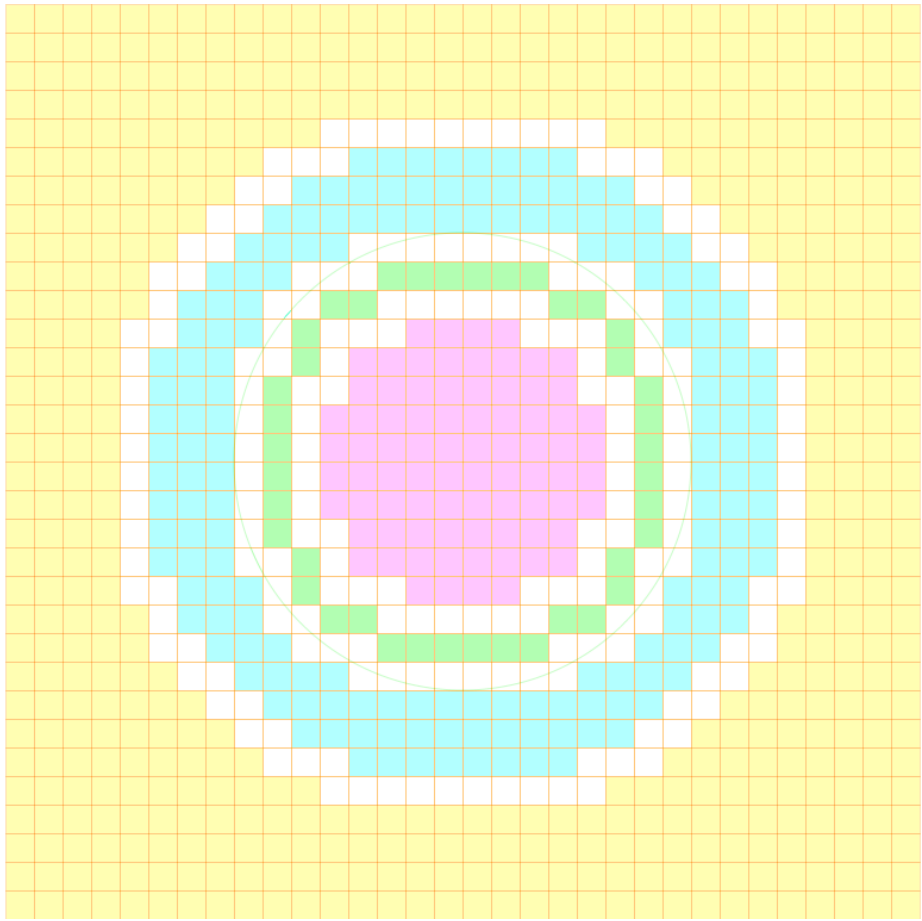
- Telemetry: average of 16 Gbits/week, with an irregular schedule (S/C visibility)

Filters

- 6 different filters slots in the filter wheel:
  1. Wide-band filter (“white light”)
  2. WBF with polariser, angle 1
  3. WBF with polariser, angle 2
  4. WBF with polariser, angle 3
  5. Green line filter
  6. He I D3 filter

Exposures and tile maps

- To cope with the large dynamic range of the corona, the same scene must be recorded with different exposures (typically, 3 exposures separated by factor 10)
- Tile maps: to download only the part of the FOV that is correctly exposed
- Optional: **quality flag** to discard tiles depending on a user-defined number of “correctly”-exposed pixels



A minimal set of observation programs to match as many science objectives as possible

1. “Full Set Synoptic”
   - A sequence of all filters, all exposure, to best observe the quiescent corona
   - < 4 min to complete, usually at beginning and end of each observation orbit

2. “Synoptic”
   - Only WBF @60 s cadence

3. “Waves”
   - One filter (usually WBF) @2 s, 4 s or 15 s cadence (adapting the number of exposures and thus the coverage in height)
   - Only ¼ FOV to compromise on detector readout time and TM volume

4. “CME-Watch”
   - All filters, almost all exposure times @30 s cadence (only every 5 minutes for polarisation)
   - Produce much more TM volume in 6 hours than can be downloaded in 1 week

Correspondence of observation programs to scientific objectives

Science objective	Typical observational target	Observation Programs			
		Synoptic	**CME-Watch** (Quicklook dateset)	**CME-Watch** (full-cadence dataset)	**Waves**
What is the nature of the solar corona on different scales?	large-scale dynamic events	Optimal	Sub-optimal		
	small-scale dynamic events	Sub-optimal		Sub-optimal	Optimal
What processes contribute to the heating of the corona and what is the role of waves?	oscillations and waves in loops/plumes	Sub-optimal		Sub-optimal	Optimal
What processes contribute to the solar wind acceleration?	interchange reconnection and blobs in the slow wind	Optimal	Sub-optimal		
	jets	Sub-optimal		Optimal	Sub-optimal
What is the nature of the structures that form the CME?	coronal cavities	Sub-optimal		Optimal	
How do CMEs erupt and accelerate in the low corona?	CMEs	Sub-optimal		Optimal	
What is the connection between CMEs and active processes close to the solar surface?	CMEs	Sub-optimal		Optimal	
Where and how can a CME drive a shock in the low corona?	fast CMEs	Sub-optimal		Optimal	

Science observations during Year 1 and 2

		# of coronagraph orbits		
		Year 1	Year 2	Total
Program	"Synoptic": 1 orbit observations, 3 orbits idle	49	0	49
	"Waves"	7	0	7
	"CME-Watch": about 2 orbits per week in Year 2	4 (test)	106	110
	Total	60	106	166

+ Full Set Synoptic at the beginning and end of each coronagraph orbit

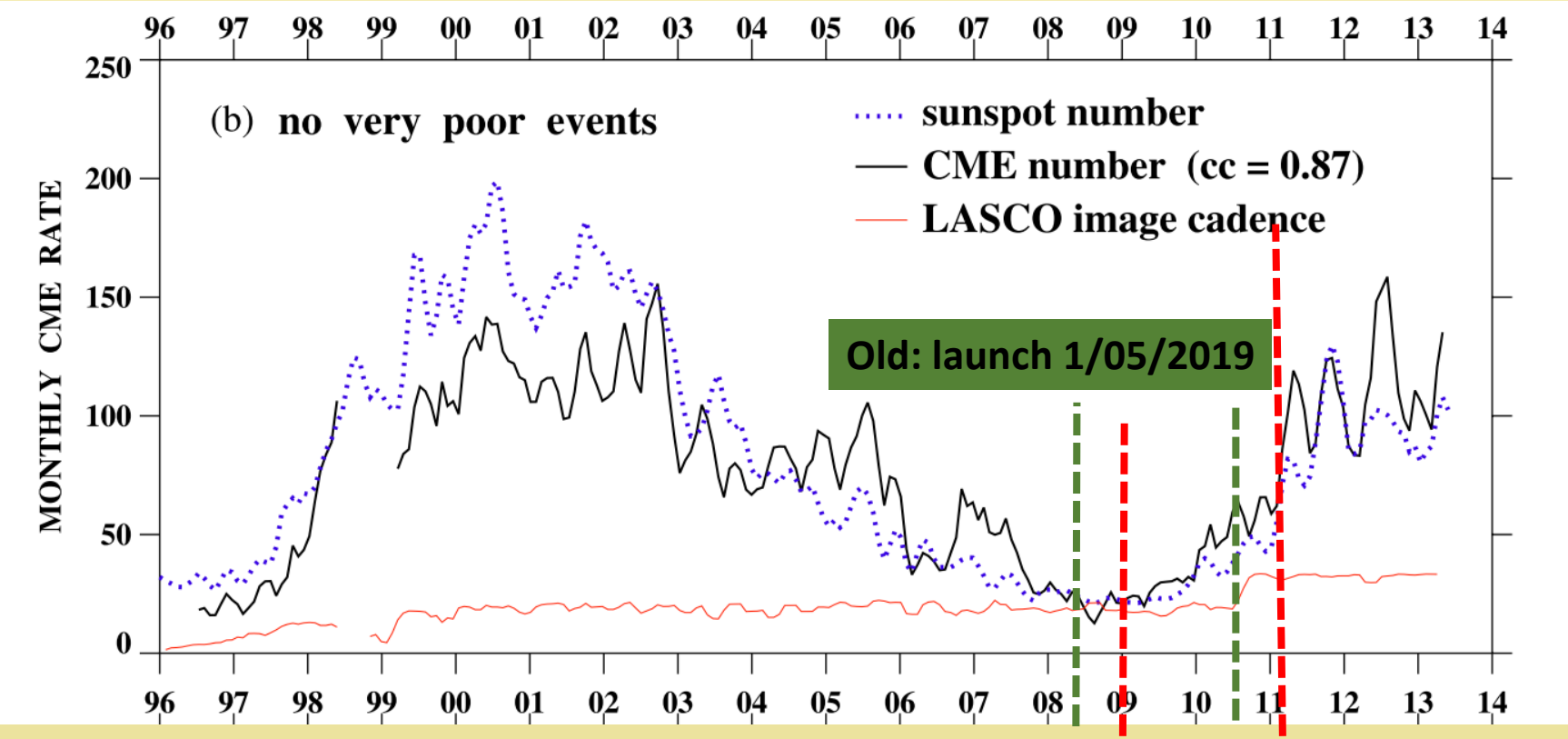
(Calibration not taken into account here)

Actual planning will be flexible

- Schedule is only indicative, will be modified according to several constrains depending on orbital mechanics (which will be known once the launch date is identified) and other operational aspects:
  - Actual schedule of telemetry coverage (visibility from the ground stations): will impact mostly the CME campaigns
  - Seasonal occultations (of the Sun by the Earth)
  - Trade-off with orbits devoted to other goals: FF manoeuvers, technology demonstration…
  - Earth and Moon being in the FOV: during 27 consecutive days (33 orbits) of each year, the Earth will be within 5° of the optical axis of ASPIICS and produce unacceptably large stray light levels
  - Activity of the Sun
  - Joint campaigns with other instruments
  - Special requests from Guest Investigators
  - Eclipses observed on ground (e.g. 04/12/2021)
  - Calibration
  - …

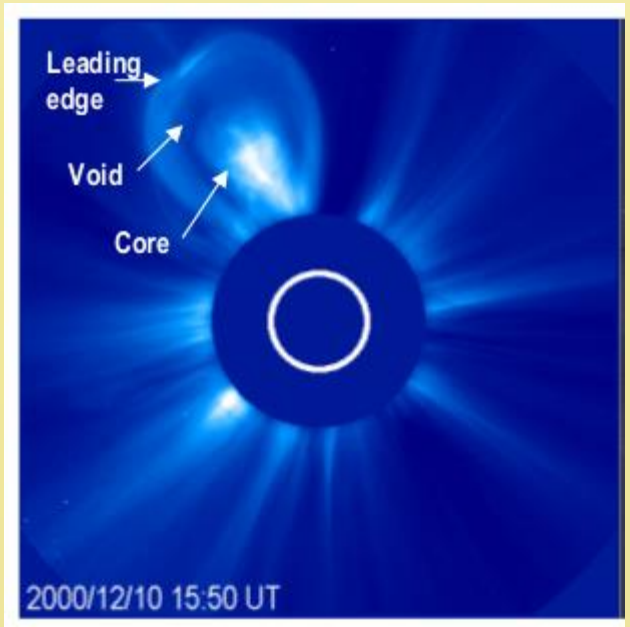
Estimation of CME rate: proxy using launch date -11 years

(Wang & Colaninno, 2014)

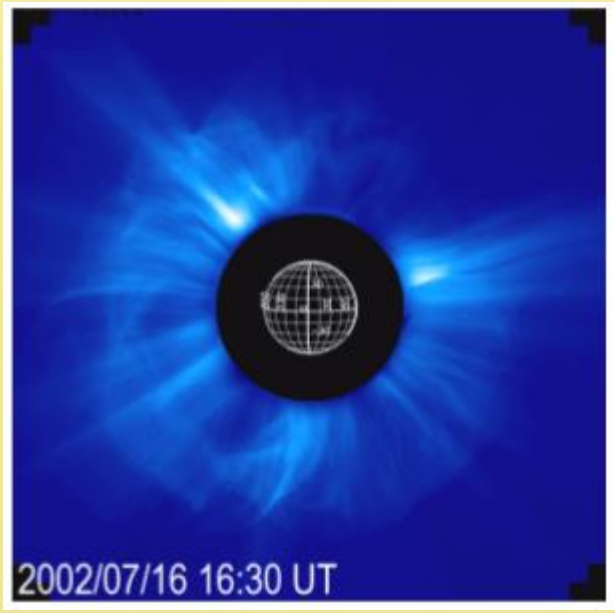


Structured CMEs

3-part limb CME



Full halo CME

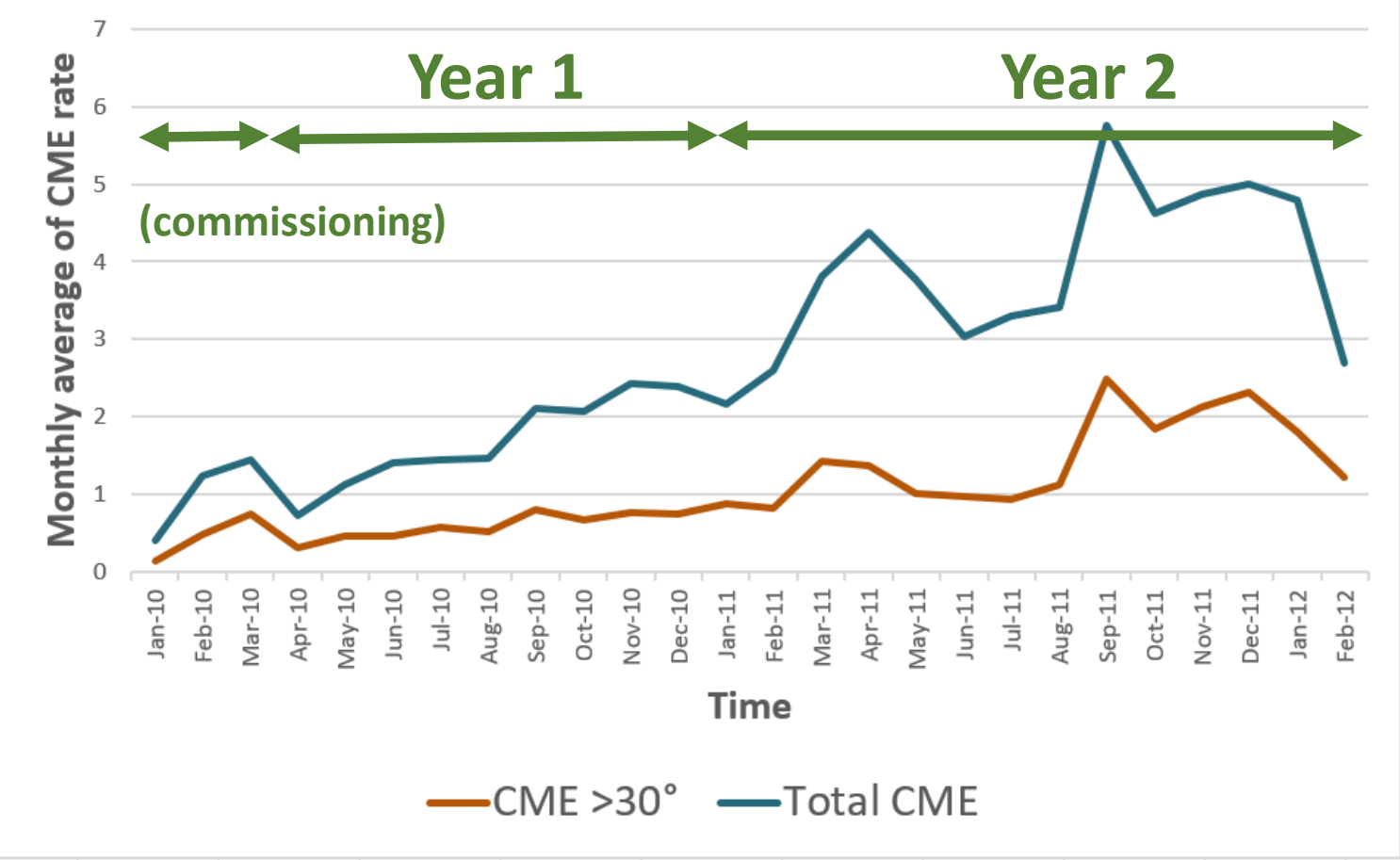


Source: Cremades, 2004, 2005 (Ph.D. thesis) – LASCO-C2

- Mostly useful for case study:
  - Structured, limb CMEs ⇒ source (AR, prominence, …) is close to the limb
  - some structured bright full halo CMEs (source is near disc centre)

⇒ 36% of the CMEs during the simulated mission are wider than 30° (CACTUS catalog)

Monthly average of CME rate during the simulated mission (CACTUS catalog)



- CMEs >30° (38 during Year 2): for case studies, minimum 1 paper per CME
- All kinds of CMEs (106): better for statistical studies and serendipity

Strategy for CME-Watch observations

- On average, 2 coronagraph orbits per week, but adapted to solar activity and presence of active regions at the West limb

- Old version of SAP:
  - launch 1/05/2019
  - 1 CME (all categories) out of 2 orbits of observation
  - CME event last 1 hour

- New version:
  - Launch 31/12/2020
  - 1 CME every coronagraph orbit!
  - CME event last 3 hours (latest analysis)
    $\Rightarrow$ 17.5 Gbits per event **on average**

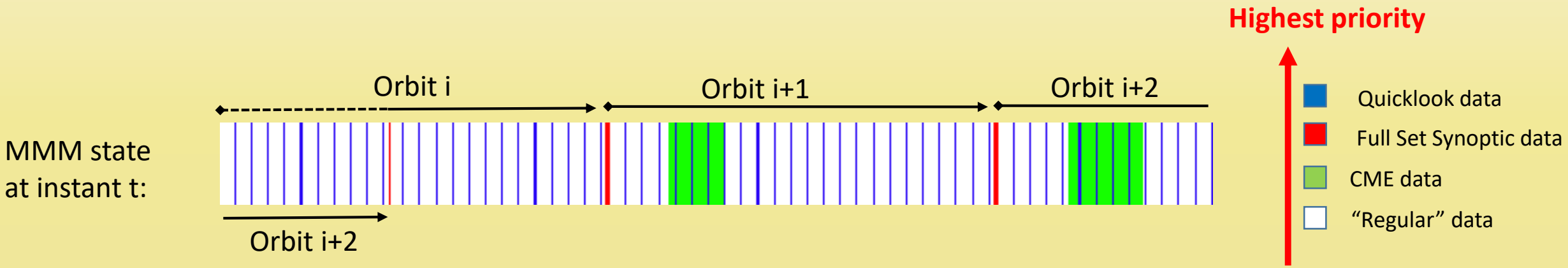
	CME >30°		All CMEs	
	Daily rate	Per 6h	Daily rate	Per 6h
Year 1	0.55	0.14	1.5	0.38
Year 2	1.4	0.36	3.8	0.97

- We download at full cadence (30 s) and all filters only the CME events, and "fill" the remaining TM with a regular cadence in WL images (≈Synoptic program) for the rest of the observing time interval

Selective downlink

- a necessity to accommodate the CME-Watch operations with the baseline telemetry allocation
  - 6 hours of CME-Watch observations produce ≈35 Gbits of data, twice a week ⇒ 70 Gbits
  - Only 16 Gbits/week can be downloaded
  - Granularity of the S/C mass memory: a complete memory sector of 24 Mbits must be downloaded
    - ⇒ cost of +30% in TM volume
    - ⇒ 1 hour of Synoptic (WL @60 s cadence) correspond to 1.42 Gbits

Selective downlink: a challenge for operations

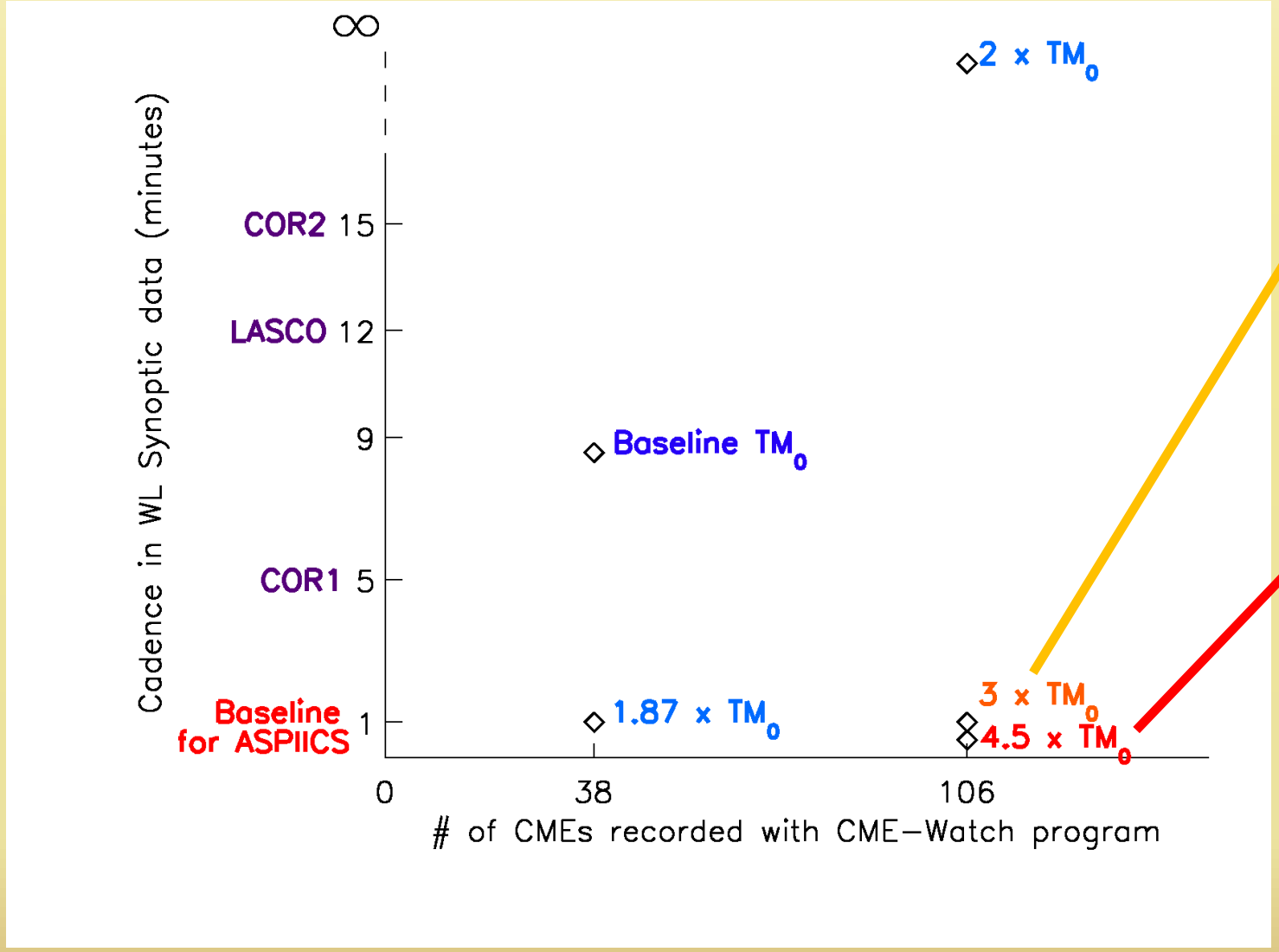


- Strategy:
  - a human operator will determine, from quicklook data, which time intervals are worth downloading for CME events
  - A ground-based automatic tool, using MMM TOC downloads, will determine which MMM sectors must be downloaded taking into priorities
- We are still not sure the selective downlink concept can be implemented on the S/C side

Science return (with baseline telemetry)

Target	Year 1			Year 2 (CME-Watch)
	Synoptic	CME-Watch	Waves	
Observations of the corona on the large scales	49×6 hours (at 1 min cadence in WL)	4×6 hours at 1 min cadence (Synoptic subset)		106×6 hours at 15 min cadence (Quicklook subset)
Observations of small-scale dynamics of the corona			7×6 hours in different structures and passbands	
Observations of waves in the corona	Transverse waves with periods < 2 min (49×6 hours)		Transverse waves and spectrum of compressible turbulence down to 4 s (7×6 hours)	
Solar wind acceleration profile (observations of blobs in the slow solar wind)	49 slow wind blobs (at 1-min cadence in WL)		Possibly 1 or 2 slow wind blobs (at high cadence)	106 slow wind blobs (at a cadence worse than that of older coronagraphs)
Observations of jets	Long-lived jets with moderate speed		Potentially a few fast and short-lived jets	
Observations of CMEs events	18-19 (1.5/day) (at 1-min cadence in WL)	1-2	2-3 (at a high cadence)	38 out of 106 (≈4/day)
Observations of structured CMEs	6-7 (at 1-min cadence in WL)	Possibly 1	Possibly 1	38 (1.4/day)

How can additional TM can help?



All CME events and 1 WL acquisition every 60 s (Synoptic) on the remaining time intervals

All data acquired during CME-Watch observations are downloaded <u>without selection</u>:

- Simplified operations: no need of selective downlink
- Most science objectives are covered with the same data set
- Open up to serendipitous discoveries

N.B: values are based on averages and estimations

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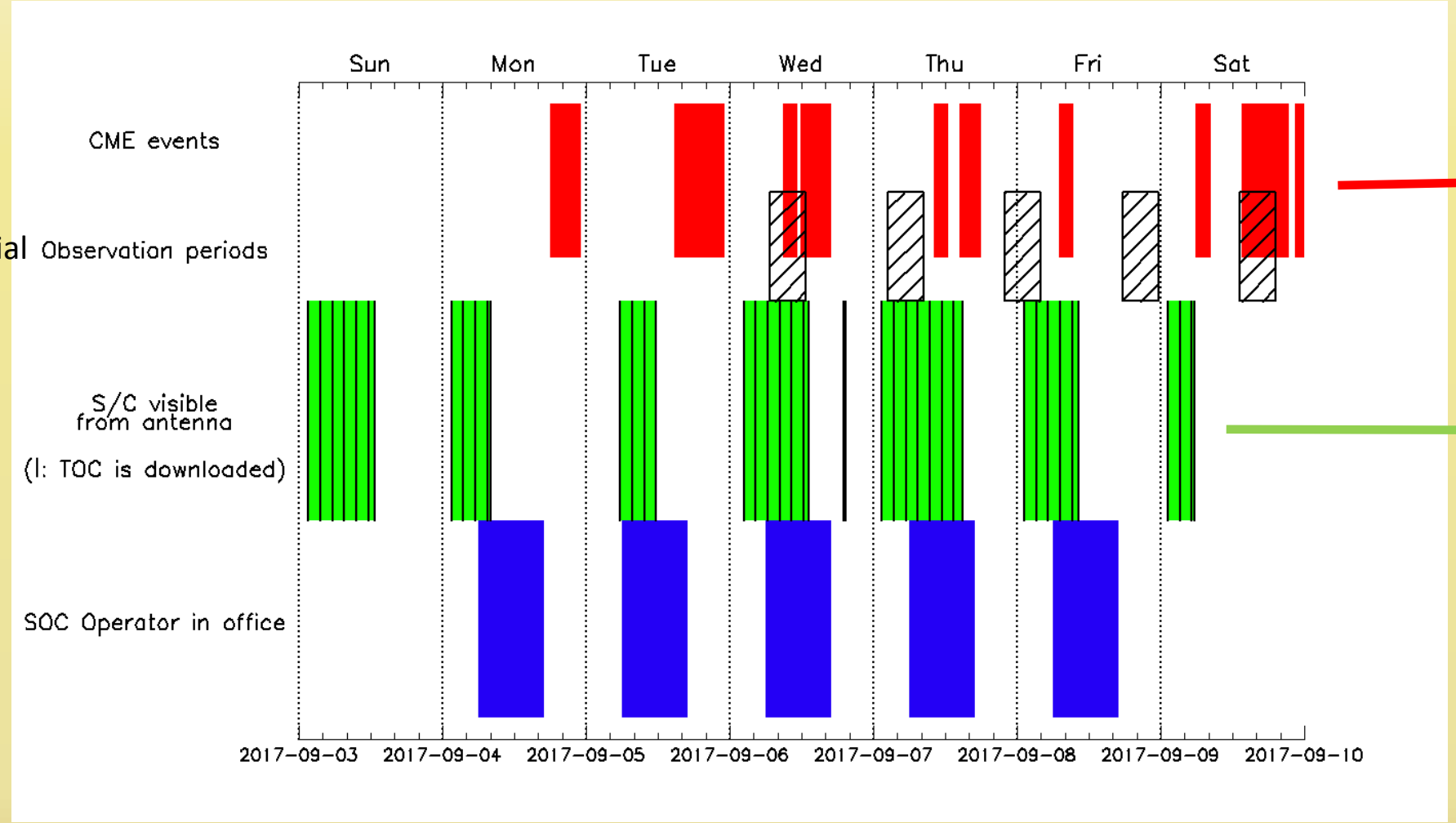
A simulated CME campaign (based on real observations of September 2017)



Real observations during September 2017

"Real" orbital parameters based on a launch in 2016

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Conclusions

- The scientific objectives can be met based on average and statistical parameters for CME events, weekly telemetry volume, etc.
- But irregularity of the Sun and of the S/C passes can lead to temporary bottlenecks that require adapting the science operations on short terms (~ days).
- CME campaign simulation demonstrates that planning of coronagraphic observations in periods of intense solar activity needs to be made on a very short-term scale (around 1 day).
- During Year 1, the baseline telemetry looks sufficient to fulfill the science objectives.
- During Year 2, the baseline telemetry is NOT sufficient to cover all the science objectives at the same time in the optimal way
- An increase of the baseline TM (16 Gbits/week *4.5) would avoid to make (human) choices that can have a strong impact on the science return, and avoid the need to implement the selective downlink on the S/C systems