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To maximize the scientific return, we fully employ the flexibility offered by the JIRAM operational modes to efficiently plan observations of various Jovian targets, in spite of the harsh Jovian radiation environment and the spinning state of the Juno spacecraft. Moreover, the JIRAM observations are limited by the challenging pointing and timing scheme of the mission, which impose constraints on both the observation planning and instrumental commanding.

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09 January 2019

Dear Editor,

We wish to submit a new manuscript entitled “Juno/JIRAM: Planning and Commanding activities”. We confirm that this work is original and has not been published elsewhere nor is it currently under consideration for publication elsewhere. The purpose of this work is to describe in detail the activities of planning and commanding for the JIRAM instrument, on board the Juno spacecraft, a NASA mission to Jupiter. The paper should be of interest to readers in the areas of space instrumentation development and ground segment.

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Thank you for your consideration of this manuscript.

Sincerely

Raffaella Noschese

Juno/JIRAM: Planning and Commanding activities

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Abstract

In the context of space missions, where science is the most important goal, careful planning and detailed commanding are fundamental. The planning and commanding phases are activities whose complexity depends on the instrument characteristics, environmental constraints and scientific goals. The purpose of this work is to describe in detail these activities for the Jovian Infrared Auroral Mapper (JIRAM) on board the Juno spacecraft, a NASA mission to Jupiter.
To maximize the scientific return, we fully employ the flexibility offered by the JIRAM operational modes to efficiently plan observations of various Jovian targets, in spite of the harsh Jovian radiation environment and the spinning state of the Juno spacecraft. Moreover, the JIRAM observations are limited by the challenging pointing and timing scheme of the mission, which impose constraints on both the observation planning and instrumental commanding.

1 INTRODUCTION

JIRAM [1] is an imager/spectrometer onboard the NASA Juno spacecraft (S/C) [2]; the probe, launched on August 5th, 2011, arrived at Jupiter on July 4th, 2016, after a cruise of five years that included a flyby of the Earth-Moon system. JIRAM's main scientific goal is the Jovian atmosphere in order to determine its composition, to explore the dynamics and chemistry of the auroral regions and to study the hot spots through the troposphere; secondary goals, contingent on the existence of any fortuitous observing opportunities, include the observation of the three innermost Galilean moons (Io, Europa and Ganymede).

Since Juno is a spinning spacecraft, JIRAM was built with a de-spinning mirror designed to compensate for spacecraft rotation. A similar device was not implemented in the previous deep space spectrometers from which JIRAM derives its heritage, such as the Cassini VIMS-V, the Rosetta and Venus Express VIRTIS and Dawn VIR-MS instruments, which were operating aboard 3 axis-stabilized spacecraft. Juno is nominally rotating at 2 rpm, namely 12deg/s; the de-spinning mirror allows the target scene to remain stable in the instrumental Field-of-View (FOV) for up to 1.1 s.

In this paper we describe the planning and commanding processes implemented by the JIRAM team to successfully operate at Jupiter and obtain groundbreaking scientific observations. A brief description of the JIRAM instrument is reported in Section 3 (more details are reported in [1]). A description of the JIRAM observations and of the associated planning strategy is reported in Sections 4 and 5. In Section 6 the timelines for the most relevant targets observed during the mission detailed. Data volume estimation, an important operational constraint of the mission, is discussed in Section 7.

2 JIRAM INSTRUMENT DESCRIPTION

2.1 JIRAM INSTRUMENT

The JIRAM instrument [1] uses a dual-channel infrared (IR) imager and an imaging spectrometer sharing a common telescope and de-spinning unit (see Figure 1)

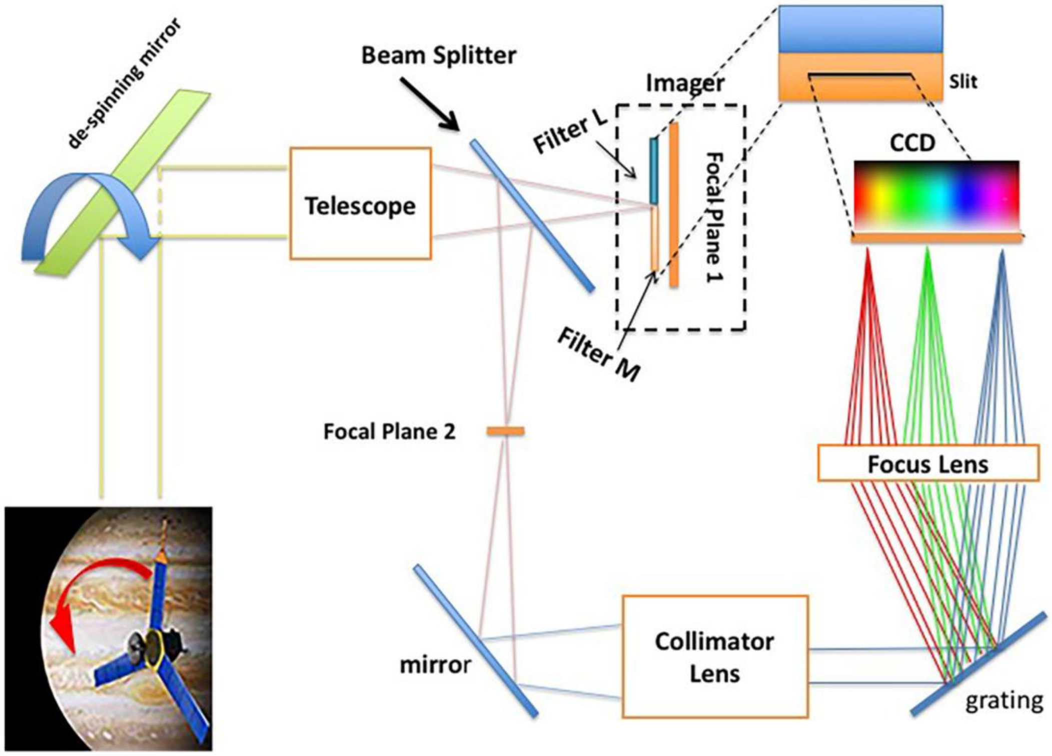

Figure 1 JIRAM optical scheme. The de-spinnig mirror rotates in the reverse direction of the rotation of the spacecraft to stop the image. The light, after entering the telescope, is splitted by 30 % on the focal plane 1 (imager) and the 70% on the Focal plane 2 (spectrometer). Regarding the spectrometer, the beam is deflected (mirror) and collimated on the grating; the grating separates the beam into different wavelengths and a then focalized on focal plane 2.

Such a configuration maximizes the scientific return in each phase of the mission by ensuring an equitable share of available resources, such as power and data rate. The JIRAM instrument makes use of its capabilities to perform:

- spectral imaging of the planet in the 2.0-5.0 µm interval of wavelengths with a spectral resolution better than 10 nm and
- simultaneous imaging in the L (spectral range 3.3−3.6 μm) and M (spectral range 4.5−5.0 μm) bands.

The two different channels composing the instrument front–end have a common Main Electronics Module (ME) and power supply (see Figure 2).

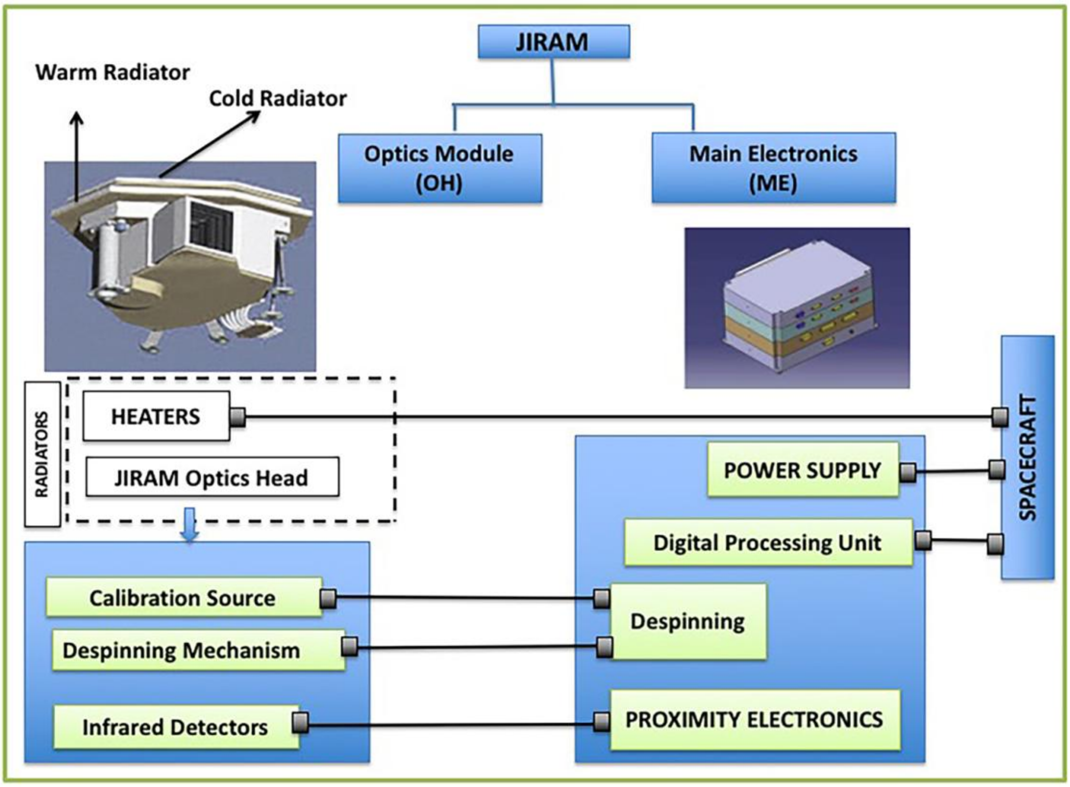

Figure 2: General block diagram of JIRAM. The instrument is constituted by the Optics Head (OH), the Electronic Unit and internal harness connecting the two units.

The ME contains the electronics that drive the Focal Plane Arrays (FPAs) and compensating mirror. It performs the acquisition of the science and housekeeping data, stores the data, performs data compression, and serves as an interface between the instrument and the spacecraft.

Both imager and spectrometer channels use the same HgCdTe detector type with a format of 270 × 438 pixels, 38-µm pixel pitch, 2 million e- full-well capacity. Data are recorded in a subset of these pixels (256 ×336 for the spectrometer and 256 × 432 for the imager).

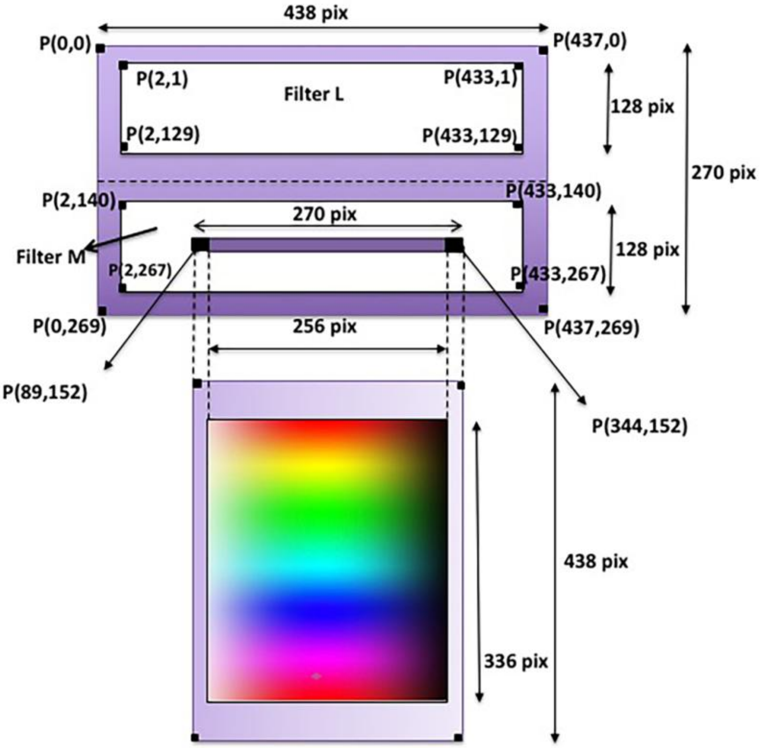

Figure 3: Layout of the JIRAM Detectors. Top panel: imager FOVs projected above the detector frame. Bottom panel: spectrometer channel detector. The position of the spectrometer FOV within the M channel FOV is shown in the top panel.

The JIRAM detectors are passively cooled down to operational temperatures of 80-90 K through a thermal harness connected to an external radiator. The detectors' optimal scientific performance (dark current) is guaranteed for T≤95 K. The compression algorithm does not work correctly at temperatures higher than 105 K due to increased noise. However, at these temperatures, the signal-to-noise ratio is typically too low to be scientifically useful. There are temperature limits, which, if reached, disable the usage of Calibration Lamps (170 K), Detectors (200 K), Motor Mirror (200 K), and Digital Processing Unit (DPU) (373 K). If the DPU temperature exceeds the limit, a SAFE ME transaction request will be sent to the spacecraft, commanding JIRAM to power off.

Focal planes are housed in two separate mechanical structures designed to:

1. maintain the correct alignment with respect to the optical bench,
2. thermally isolate the instrument housing with respect to the optical head mechanical structure and
3. hold the order-sorting filters on the spectrometer (SPE) detector and the L and M filters on the imager (IMG) detector.

The two filters of the imager are designed to address distinct scientific goals. The L-band filter is used primarily to study the Jovian aurora and environmental radiation ([3], [4], [5]), and to determine the infrared albedo of satellite surfaces. Images taken through the M-band filter are used to study morphology and dynamics of Jupiter's troposphere ([6], [7], [10]). Data from the JIRAM spectrometer, albeit more limited in spatial coverage, enable one to investigate Jupiter's atmospheric composition ([7] [8]), to determine the distribution, concentration and temperature of H_3^+ ions in the Jovian system [12] and to measure the surface temperature of Io [9]

2.2 JIRAM MODES

The onboard application software implements a number of system states (modes) as shown in Figure 4.
Each state is dedicated to the performance of specific actions. The transition from one state to another is commanded by the S/C by means of dedicated telecommands (TC). The states and their meaning for the application program are described below:

- Initialization mode (INI) is executed at the start-up or after any reset, when all preliminary operations for the nominal setting are executed.
- Software Maintenance mode (SWM) is commanded from INI to allow direct access to the onboard RAM and EEPROM memories that can be modified and checked to allow SW patching and parameter modification.
- Safe mode (SAF) is the entry state of the application program from the boot program. After the completion of the runtime environment and variable initialization, the application program will immediately communicate a mode change event to the S/C. All mandatory services are available (except some TCs of private services linked to the software maintenance and science operation). Periodic housekeeping (HK) is generated and sent to the S/C.
- Stand-by mode (STBY) is entered after switch on and when it is needed to change from one mode to another; the only performed activity is the periodic HK acquisition.
- Science mode (SCI) is the only mode in which the acquisition of science data occurs. The Science mode includes a number of sub-modes, organized in subgroups (for more details, see paragraph 5.3).
- Calibration mode (CAL) allows the instrument to perform the calibration sequence: the calibration sources are ON and the mirror motor is commanded to a fixed position.

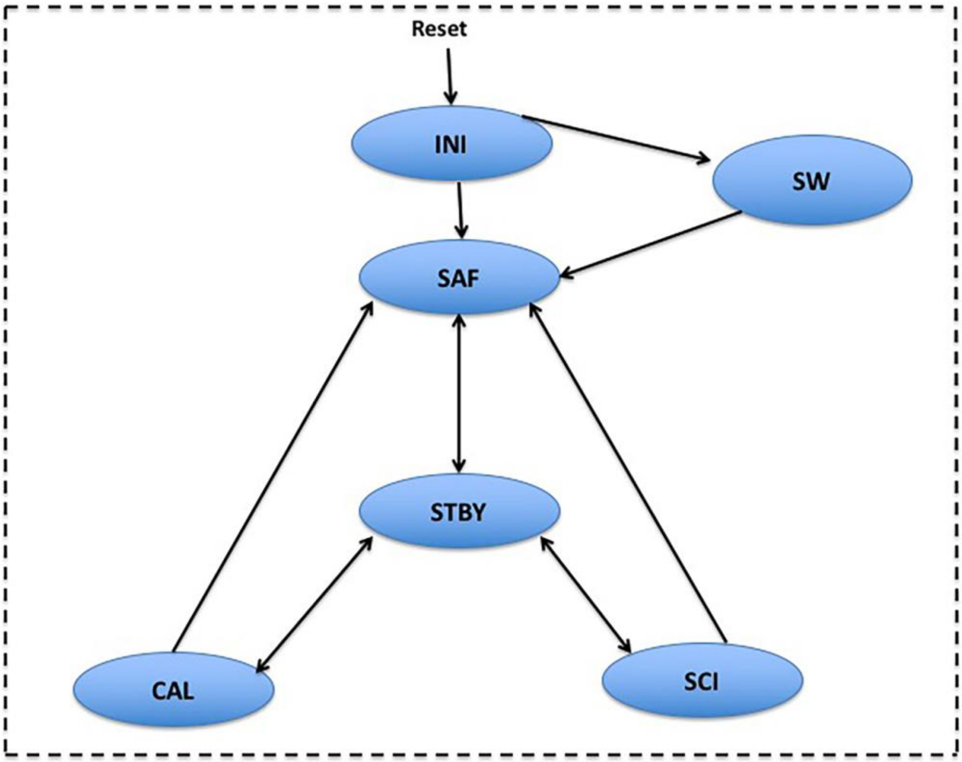

Figure 4: JIRAM operational modes and related transitions.

3 JIRAM PLANNING & COMMANDING DESCRIPTION

3.1 JIRAM SCIENCE PLANNING STRATEGY

Each orbit of the mission is divided into two planning sequences: a perijove sequence and an apojove sequence. Perijove sequences begin roughly one day prior to perijove and end one day before apojove. Apojove sequences pick up where the preceding perijove sequence leaves off and runs up until about one day before the following perijove. The JIRAM observation windows typically start 18 hours before perijove (PJ) and end 23 hours later. When Jupiter or its satellites are not in the FOV, JIRAM can be used for measuring background radiation.
Among Juno's various science investigations, JIRAM is a relatively straightforward instrument to operate. For example, there are no keep-out zones to which the instrument is subject that constrain when it can take data. And because it takes data in the near- to mid-infrared, JIRAM can take good data of science targets such as Jupiter and Io even when they are not illuminated by the Sun. The availability of resources such as power and data volume do not preclude simultanous operations of JIRAM with any of Juno's other instruments. The main factors that constrain the operability of JIRAM relate to the instrument's thermal environment, the Jovian radiation environment and, being body-mounted to a rotating spacecraft, spacecraft pointing.
As mentioned above, the instrument performance is guaranteed at detector temperatures <95 K. However, in practice, temperatures never greatly exceed this value by more than a few degrees K and does not effectively limit when JIRAM can

successfully obtain data. Likewise, the radiation does not limit the planning of data acquisition. At times radiation does degrade science data. But predicting precisely when radiation will impact observations to an unacceptable degree is difficult in the unpredictable Jovian radiation environment. Therefore, the JIRAM team does not attempt to plan around this.

It is spacecraft pointing and the orbital trajectory which mostly limit the data that JIRAM acquires. Being a spinning spacecraft, Juno maintains a constant attitude during a given perijove; changing attitudes at perijove is expensive from both an operational and resource standpoint. The bulk of Juno's Jupiter flybys are implemented in the GRAV attitude, which keeps the high-gain antenna pointed roughly at the Earth to enable ranging throughout the encounter. Other flybys incorporate a slight tilt to allow the Microwave Radiometer (MWR) instrument to observe the nadir point on Jupiter as the S/C rotates. Other custom orientations have been implemented as well. The principal difference from the perspective of JIRAM is the persistence of Jupiter in the JIRAM FOV.

When Juno arrived at Jupiter in July 2016, its orbit was roughly aligned along the dawn-dusk line and with a perijove latitude slightly north of the equator. As the spacecraft trajectory has evolved, the perijove latitude has shifted northward and the tilt of the orbit relative to the orbital plane of Jupiter has increased. The result is that Juno and JIRAM make ever quicker passes over the north pole of the planet with less time to observe, while the spacecraft provides an excellent platform to observe the south pole of Jupiter as Juno recedes away and towards apojove. This leads to greater coverage in the south compared to the north, as the number of footprints in Figure 6 suggests.

For each orbit JIRAM tries to observe Jupiter's auroras, to track and monitor the polar vortices and their evolution, and image Jupiter's moon Io to study the evolution of its volcanoes. In most cases, scientific objectives are not overlapping. For example, taking images of a satellite does not affect the observations of aurorae and atmosphere, because usually moons are visible in different time windows (some hours before or after perijove). In a few cases, the scientific team has to decide which scientific goal has precedence; this is the case, for example, when Juno is over the poles and one would like to observe the aurora or the cyclones, but can't do both at the same time, or in the rare cases when a moon opportunity happens at the same time that Jupiter is in the field of view. In this case, we follow the primary objectives of the Juno mission. Moon observations, for example, have lower priority because such science is not the primary goal of Juno.

3.2 PLANNING & COMMANDING PIPELINE

The JIRAM planning team participates in regular Science Planning Working Group (SPWG) meetings, which are held monthly, to discuss and prioritize possible science objectives for future sequences.

For each PJ, a Science Activity Plan (SAP), which specifies the instrument activities to occur during that interval of time and the resource distribution between the instruments, is generated and reviewed at the SPWG meeting. The JIRAM operations team then generates a Spacecraft Activity Sequence File (SASF), which contains the detailed commanding for instrument operations that is consistent with the SAP.

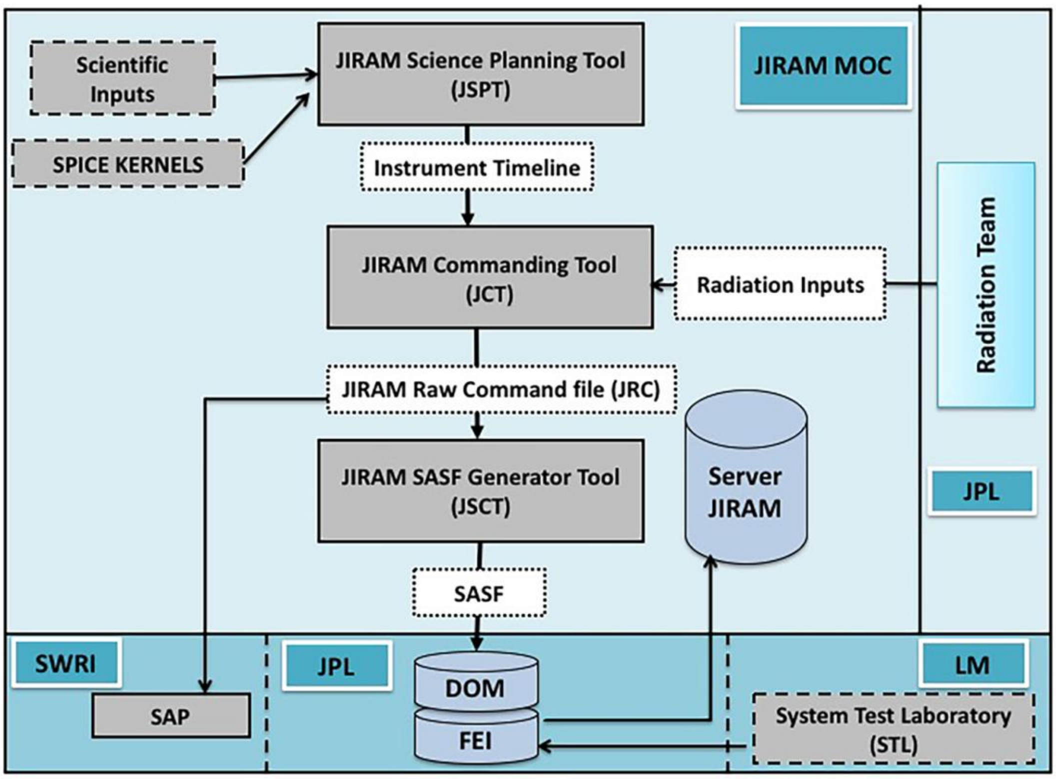

Figure 5: Planning & Commanding Pipeline. The image shows the uplink ground segment (JSPT, JCT,JSCT) and all bodies involved: SWRI for SAP, LM for STL, JPL for DOM, FEI and Radiations input; the tools of the ground segment of JIRAM were devoloped by JIRAM team in Matlab and have all a graphical interface.

In order to correctly plan and execute each sequence of science observations and allow for a variety of science targets and operational constraints, a complete Planning & Commanding Pipeline (see Figure 5) has been developed.
The first step of this chain involves the JIRAM Science Planning Tool (JSPT), the purpose of which is to allow the scientific team to visualize the observation opportunities during a given perijove and to plan the JIRAM observations based on the predicted trajectory (as encoded in the SPICE kernels), working on a common platform.

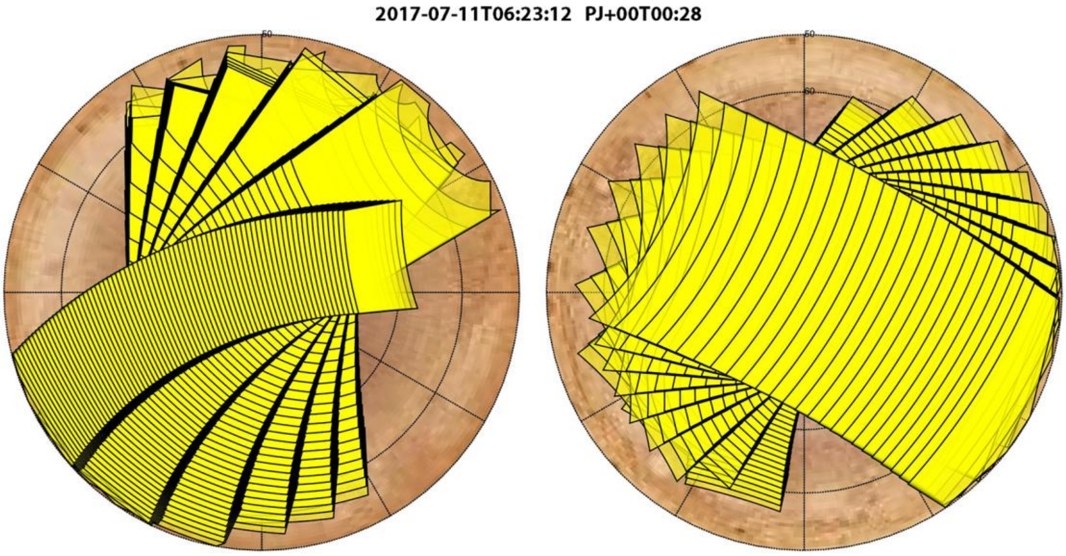

Figure 6: Simulation of Orbit 7- Imager filter L. Left: the coverage of the North Pole; right : the coverage of the South Pole. The overlapped yellow strips represent the predicted FOVs.

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The JSPT produces the time sequence of the JIRAM instrument activities and displays (in 2D and 3D) Juno's ground track on to Jupiter, as well as JIRAM's FOV (both imager and spectrometer) to verify the coverage (see Figure 6).
The next step is to process automatically process the output of the JSPT and the observation requests from the Radiation Monitoring team [5] with the JIRAM Commanding Tool (JCT) that implements procedures and algorithms, allowing the generation of the parameters used to configure the instrument. In particular, it takes into account both mission and instrument constraints:

- flight rules,
- data volume,
- data rate and
- hard partition size.

Nominal inputs to the Commanding Tool are the instrument timelines generated by the JSPT and validated within the Science Activity Plan file (SAP) at Southwest Research Institute (SWRI). The outputs of the JCT are the science parameters used to set the instrument and formalized in the JIRAM Raw Command file (JRC). The JRC file is then translated automatically into Spacecraft Activity Sequence File (SASF) format with the JIRAM SASF Generator Tool (JSGT) and delivered to the Distributed Object Manager (DOM) at JPL. Before the command sequence is transmitted to the S/C, the syntax and consistency of the content are checked and then integrated with the command sequences from Juno's other subsystems. The command sequence is then tested by Lockheed Martin (LM) on the System Test Laboratory (STL) against S/Cflight rules and for conflicts between subsystems.. The STL data are manually retrieved with a client-server application, "File Exchange Interface" (FEI), or queried by the JPL ground reception time. These data can also be automatically retrieved as soon as they are available through a subscription service. The check of the STL data allows us to verify commanding.

3.3 SCIENCE PLANNING CYCLE

The sequence development process typically starts 8-9 weeks before a given PJ. Science sequence development generally begins with "Pass 1", which lasts approximately two weeks and beings 4-5 weeks before sequence execution. Prior to this, the engineering team works through the engineering issues for that sequence. It is also during this period that the SPWG convenes to discuss the science activities in the sequence under development. It is in "Pass 1" that the SAP is officially approved and all subsystems generate their individual SASFs; "Pass 1" ends with the review of the STL run on the merged sequence product. After this period begins the "Pass 2" phase, which starts with the opportunity to correct any commanding errors uncovered during the "Pass1" phase. "Pass 2" generally lasts another two weeks and concludes with the uplink of the full background sequence. It is worth noting that if no problems arise during "Pass 1", "Pass 2" is bypassed, and the sequence is uplinked either during the nominally scheduled window or a few days prior.

4 SCIENCE OBSERVATIONS

During a single orbit, JIRAM can perform a sequence of different science observations depending on the details of the trajectory.

4.1 JUPITER SCIENCE OBSERVATIONS

For each orbit, the science team identifies the target areas to observe and optimizes the tilt angle to command for each acquisition in order to have the best coverage of the targets, the operational mode and the exposure time to be used, depending on the target to be studied. As stated above, the angular range of the de-spinning mirror limits the maximum exposure time to 1.1s.

The tilt angle, defined as the angle between the nadir direction and the direction to the target of interest in the sense of Juno's rotation, can be set as follows:

1. '0' tilt: the images are acquired with nadir pointing; i.e. the tilt angle is set to 0 deg with respect to nadir point (see simulation Figure 7 and Figure 8a)

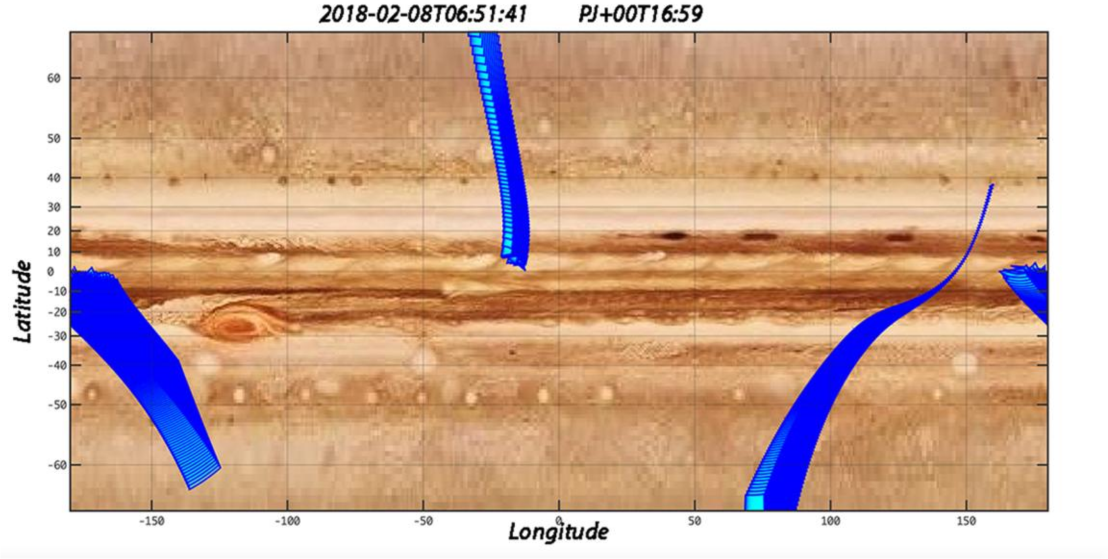

Figure 7: Observation PJ11 '0' tilt , simulated with JSPT,the blue strips are produced overlapping the predicted FOVs during the single orbit at each S/C revolution.

2. Fixed tilt : the images are acquired by setting the mirror at a fixed angle with respect to the nadir position.
3. Variable tilt (Figure 8b): in this case the combination of the movement of the S/C together with the variation of the tilt angle allows an extended coverage of the targets; this mode is used to scan both the polar and auroral areas.

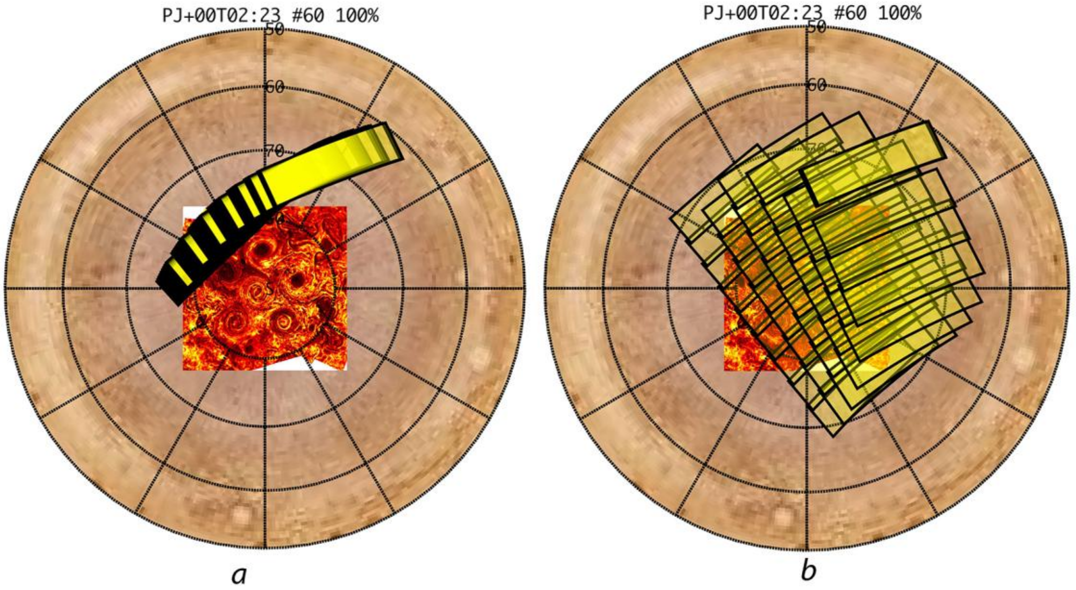

Figure 8: Simulation with JSPT, South Pole observation PJ13 Respectively a) with 0 tilt and b) with variable tilt. The overlapped yellow strips represent the predicted FOVs. The JSPT shows the apparent position of the polar cyclones observed by JIRAM during the first orbits [10]. This is a very useful capability during the planning process.

4.2 SATELLITE SCIENCE OBSERVATIONS

Occasionally, the trajectory around Jupiter allows serendipitous observation of the Galilean moons.

In such cases, we perform scans by manipulating the tilt angle in order to simultaneously acquire the targets with one or both filters of the imager and with the spectrometer. In Figure 9 is shown a simulated example of an observation of Ganymede, produced with JSPT and obtained with the following procedure. Since JIRAM's FOV is restricted to observations along the spin plane of Juno, JSPT uses SPICE software and the related mission kernels to estimate the time when the moon will be in a favorable position for the observation (i.e., when the moon crosses the spin plane of Juno). Then, the JSPT tool uses the same SPICE kernels to estimate the proper tilt angle needed to acquire the moon. This tilt is usually on the order of 90°, and the moon is often seen from above or below the poles. Even if the actual time of the observation has an uncertainty of about 30 seconds (we don't know in advance the orientation of the spacecraft, but we know that every 30 seconds the FOV of JIRAM will explore all the angles in the Juno spin plane). In summary, the JSPT's output is a time interval for the observation and a proper tilt angle for a given spacecraft orientation. In addition, JSPT is also used to evaluate the possibility to add a small additional tilt angle, slightly above or below the sub-spacecraft point on the target, in order to acquire spectra from different locations on the moon ("spectral cubes"). Since the moon is usually quite far from the spacecraft, these additional tilt angles are of the order of few minutes of arc.

As an example, Figure 9a shows the images of Ganymede acquired both with the spectrometer and the M filter of the imager ([10], [12]), while the Figure 9b shows the Ganymede observations managing the tilt in order to observe it also with both channels (L+M+ SPE).

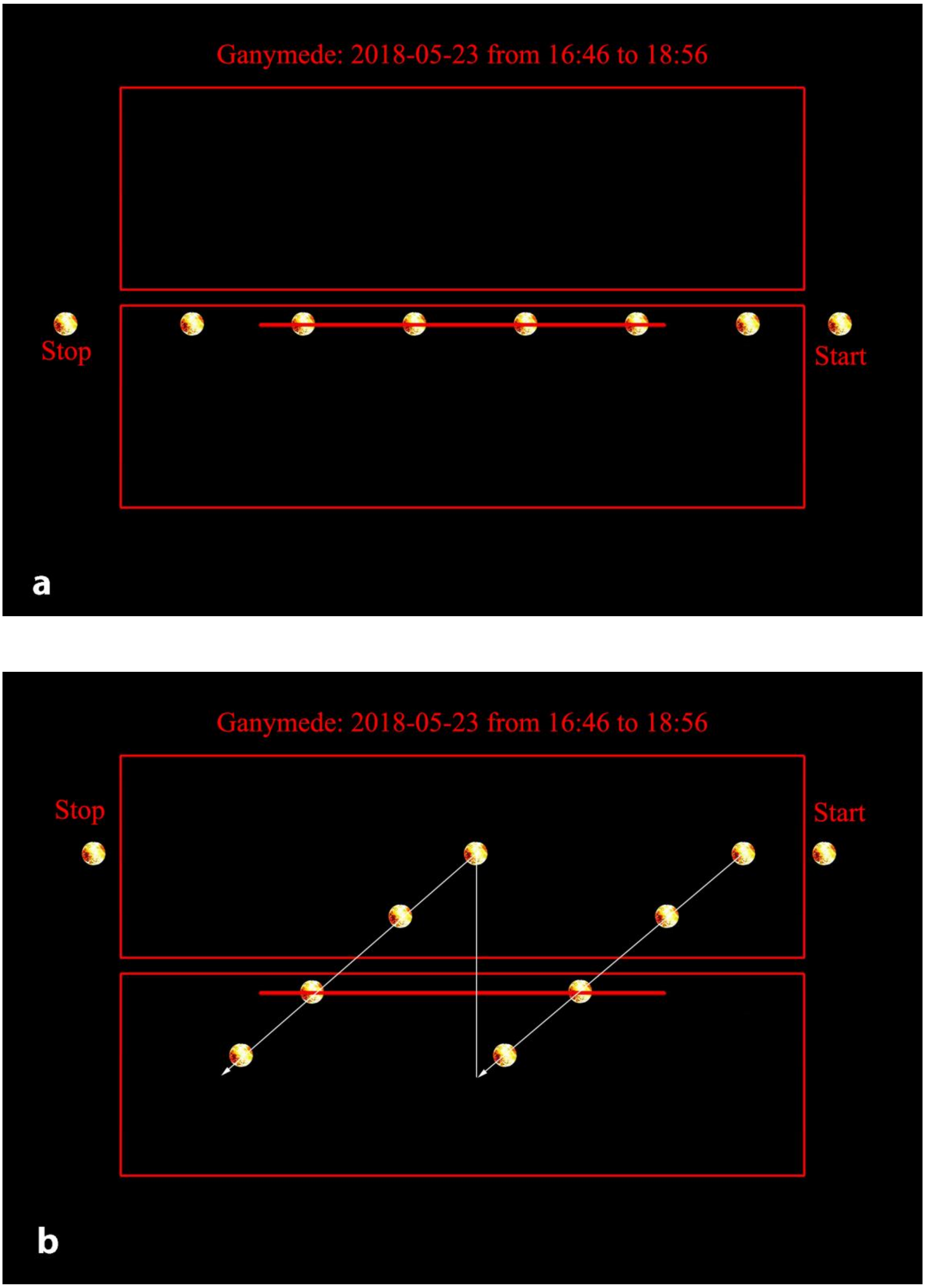

Figure 9: In Figure 'a' is reported a simulation of Ganymede prior to PJ13 with fixed tilt; in this case JIRAM acquires Ganymede with spectrometer and filter M. Using an appropriate variation of the tilt angle JIRAM can acquire Ganymede with both Imager (filter M and L) and spectrometer, as you can see in the Figure 'b'. Please note that in both images the satellite enters in the JIRAM FOV from right side (Start) and exits from left one

(Stop). In the Figure 9a the acquisitions are centered on the spectrometer while in the figure 9b we can see the apparent movement of the satellite in the JIRAM FOV generated by means of the mirror angle variation.

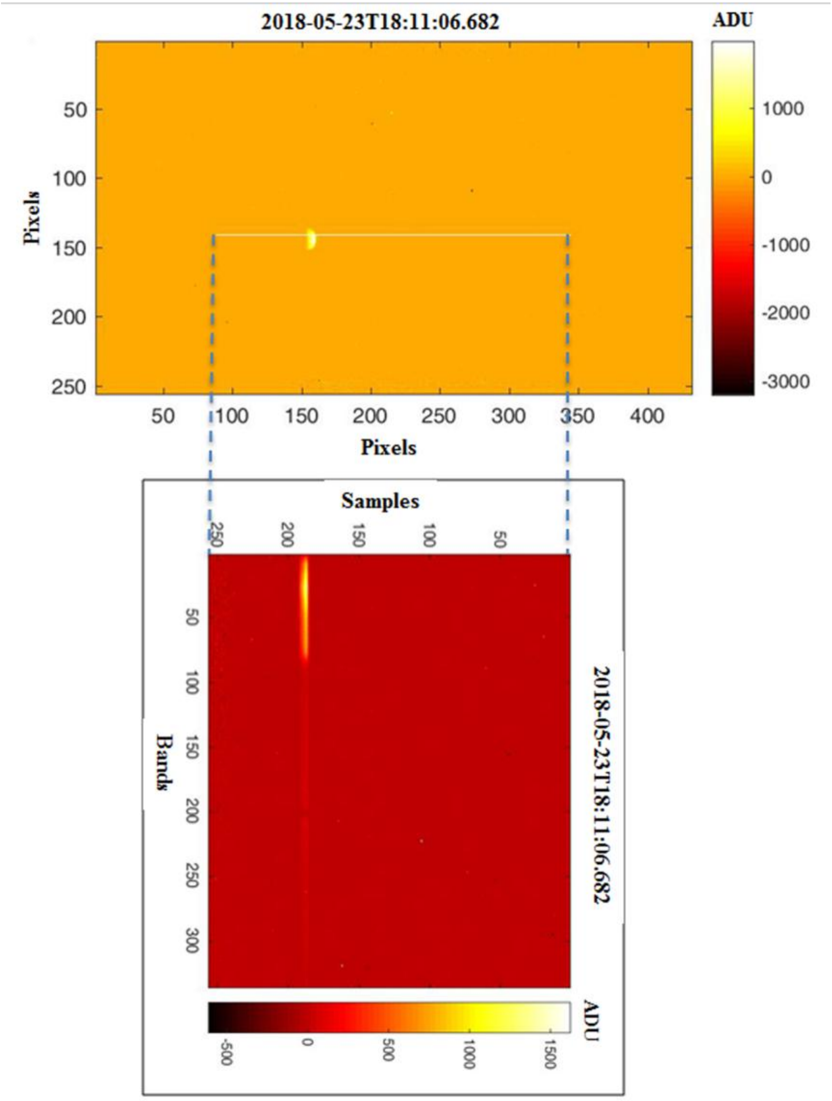

Figure 10: Ganymede observation, during PJ13, acquired by both the JIRAM Imager and Spectrometer. In the image are shown the simultaneus acquisitions of the Imager (top) and Spectrometer (down). Top: the M filter

4.3 RADIATION SCIENCE OBSERVATIONS

JIRAM is one of the first instruments to be used to monitor the environmental radiation at Jupiter; extremely harsh radiation intensities (>10 MeV) that characterize Jupiter's background conditions can affect the images acquired by JIRAM because of the potential for the detectors to detect penetrating charged particles.
This background radiation can degrade the quality of the standard observations. On the other hand, the amount of "hits" registered can be useful for estimating the levels

of radiation encountered. The analysis of the images contaminated by the radiation is discussed in [4].

4.4 Pointing Calibration Observations

During the first science orbit (JM0001), JIRAM was turned on for the first time after the insertion maneuver around Jupiter. In detail, JIRAM observed Aldebaran (α Tau) and the Hyades in order to perform the geometrical calibration of the instrument. Aldebaran was observed on 20 July 2016 by JIRAM, using an increasing offset of 0.0094169 deg (about ¾ pixel) for each image. These offsets were predicted by using the Juno reference trajectory (SPK kernel), the predicted SC orientation (CK kernel) and the Juno and JIRAM frame definition (frame kernels) [14]. The analysis of these observations was important because it allowed the JIRAM team to evaluate the difference between the reconstructed geometry (obtained with reconstructed kernels) and the predicted geometry for these observations. Examining these differences in each of the obtained images allowed the team to determine the Aldebaran centroid in the M band during this observation sequence. A significant outcome of this analysis was an improved knowledge of the pointing orientation of JIRAM.
Considering that Aldebaran is a very easy target, and the centroid is estimated by using ~10 pixels, we found that the position of the star in the images corresponds to the expected one, so the final error on the pointing is less than 1 pixel, once the improved knowledge of the JIRAM orientation is taken into account.

5 JIRAM Generic Timeline

Figure 11 shows a generic operations timeline that includes the science and radiation blocks, described in section 5, and also some technical blocks necessary for the execution of the sequence. The timeline for JIRAM is a sequence of TCs appropriately timed to achieve the scientific objectives defined during the planning phase.

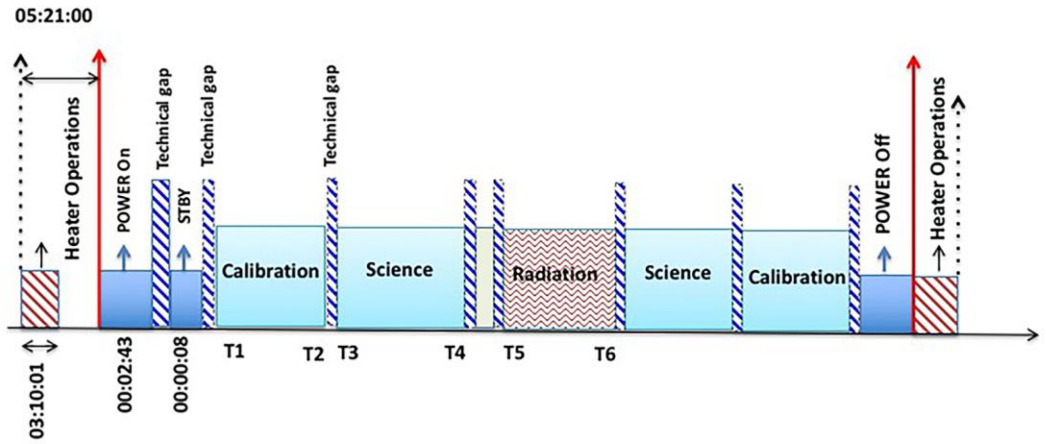

Figure 11: Generic Timeline

5.1 TECHNICAL BLOCKS

The Heater operations are a set of TCs to ensure the electronics and optical head temperatures are greater or equal to their turn-on temperatures before turning JIRAM on. These TCs are active 320 minutes before the power on.

5.2 CALIBRATION BLOCKS

The Calibration is inserted in the timeline immediately after the Power On and before Power Off, to verify that there are no changes in the radiometric and spectral response, defective pixels of the intrument. The Calibration Block consists of a sequence of TCs (see Figure 12):

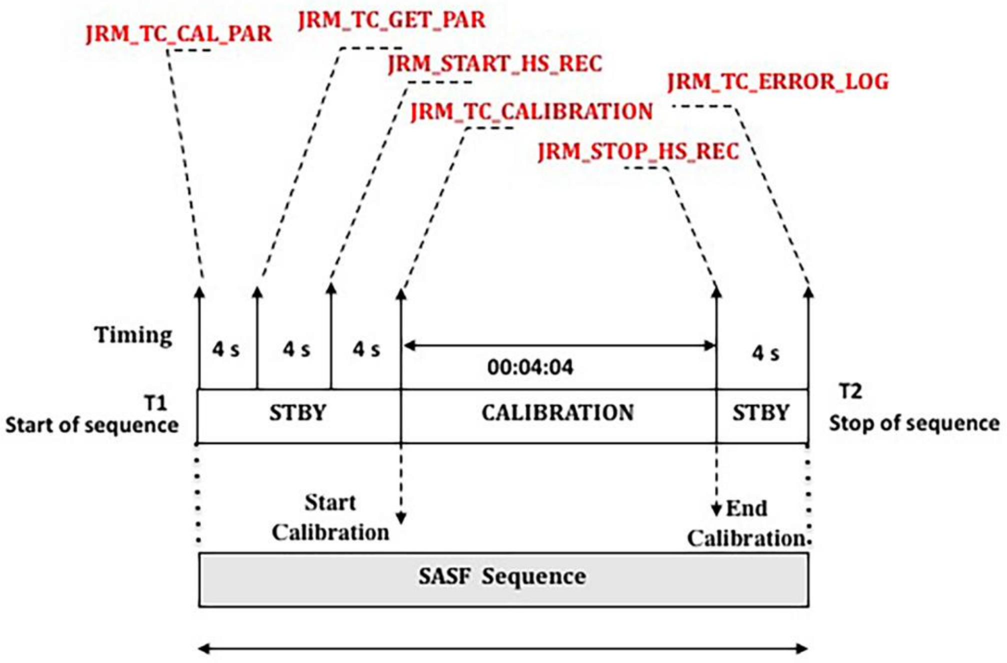

Figure 12: Calibration Sequence specifics and format.

- “JRM_TC_CAL_PAR” sets the parameters necessary to acquire images and spectra.
- “JRM_TC_GET_PAR” is a TC that enables the download of the copy of the instrument parameters inserted in the EEPROM.
- “JRM_START_HS_REC” enables the data recording
- “JRM_TC_CALIBRATION” starts the calibration phase
- “JRM_STOP_HS_REC” disables the data recording
- “JRM_TC_ERROR_LOG” enables the download of the related possible errors.

The calibration procedure provides a standard sequence of 6 measurements described in Table 1. The details of each of these steps are as follows:
1 - the detectors look at the internal calibration unit where the calibration sources are in the “off” state; the integration time is set in the “JRM_TC_CAL_PAR” and it is 6 ms for the imager and 140 ms for the spectrometer.
2 – the detector is acquired with an integration time of 20 µs
3 – one of the calibration sources is turned on and powered at a previously defined current level; same integration time as step 1
4 - the same calibration source is turned on and powered at another previously defined current level which is higher than that in step 3 to produce a different level of signal; integration time as in step 1
5 – repeat of step 1
6 – repeat of step 2.

Calibration Cycle:

Step	***Phase***
#1	Internal Background
#2	Readout Noise
#3a	Cal Source Stabilization
#3b	Cal Source Gain 1
#4a	Cal Source Stabilization
#4b	Cal Source Gain 2
#5	Internal background
#6	Readout noise

Table 1: JIRAM Calibration cycle

During each cycle (30 sec) JIRAM performs two acquisition (OFF-NADIR and NADIR see Figure 13) for each of the previous steps but only half of the collected 12 acquisitions are sent to the ground.

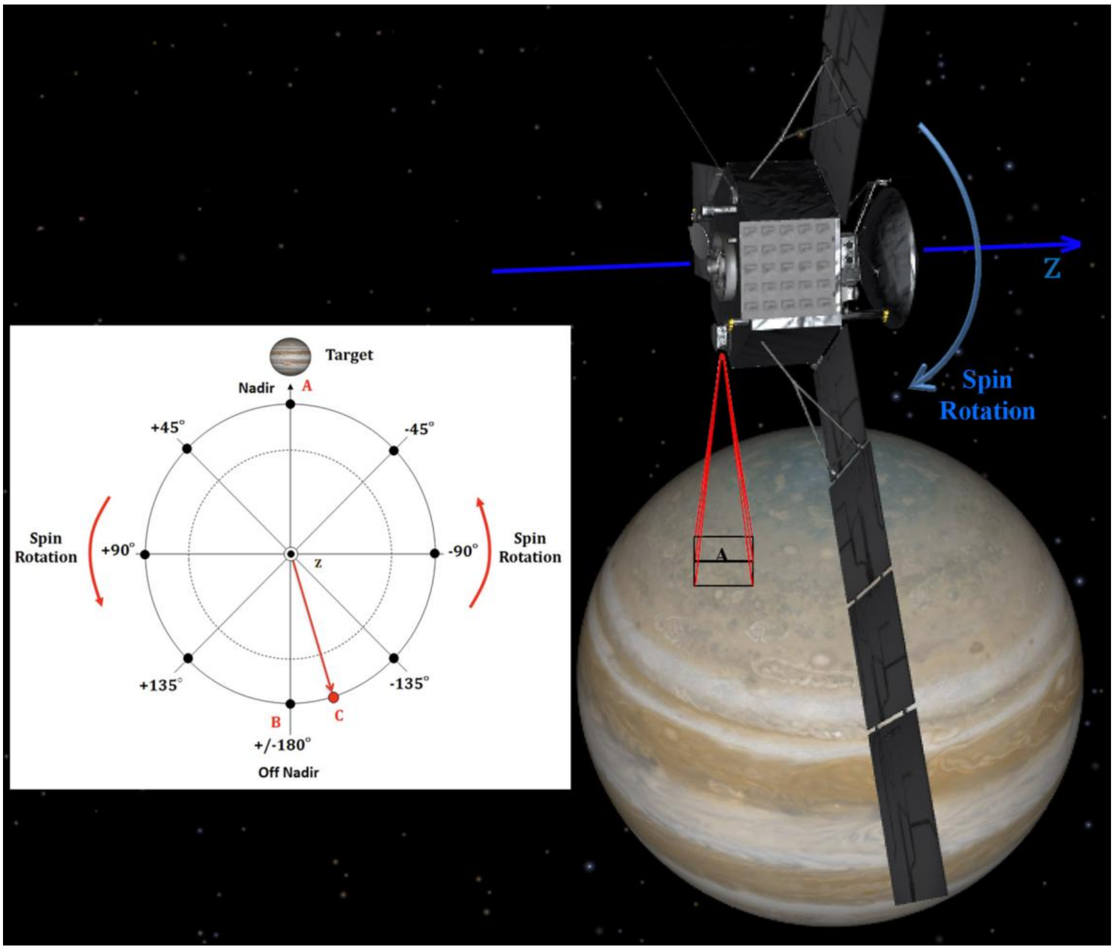

Figure 13: JIRAM(JRM) schematic observation geometry. The small image shows the position of the two acquisitions (A and B) performed in the nominal cycle of operation. The point “C” shows a generic position (see section 5.3.4). The inner panel shows the position, on Jupiter, of the acquisition “A” and the S/C spin rotation.

During the first step JIRAM acquires the background OFF-NADIR that is stored in the Buffer_A, and after 15 seconds the Readout Noise (RN) in the Buffer_B; the Readout Noise is subtracted if subtraction is enabled.

For the second step, the OFF-NADIR acquisition is not used; only the RN is sent to the ground.

For step 3b and 4b, the acquisition of Source 1 and Source 2, respectively, are stored on Buffer_A, and the RN is subtracted if it is enabled.

Steps 5 and 6 are the same as for step 1 and 2.

A scheme of the various combinations is reported in Figure 14.

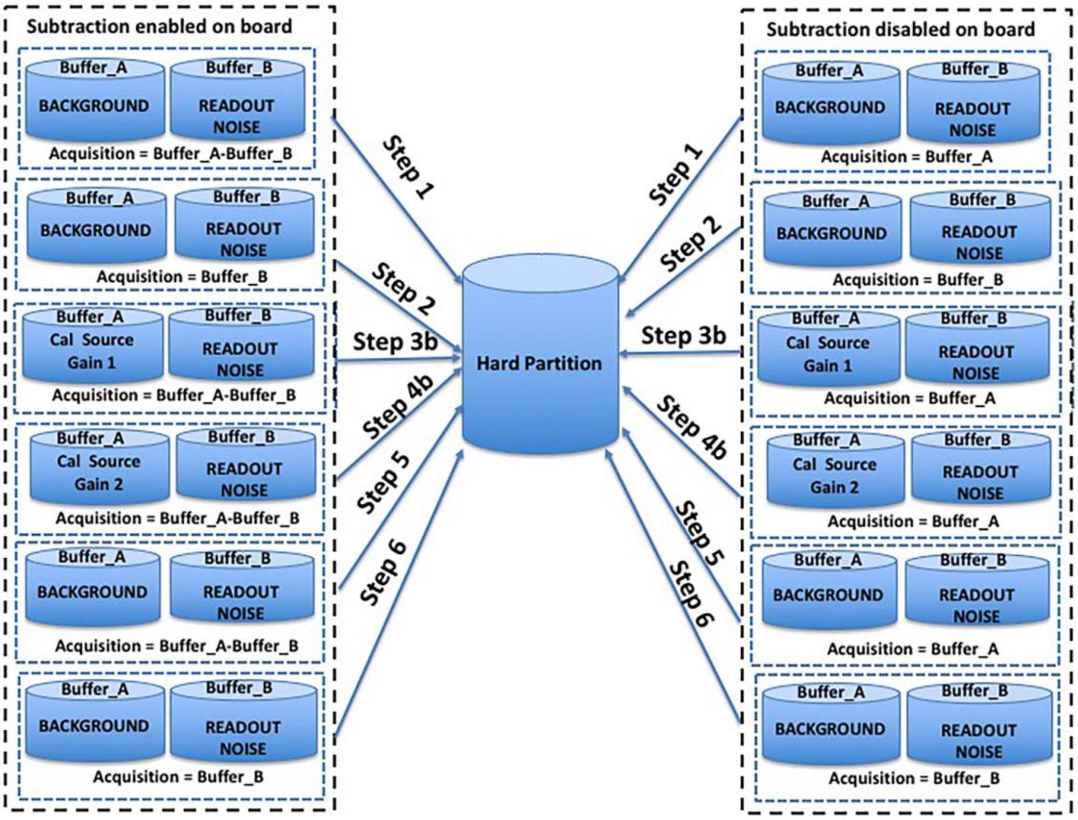

Figure 14: Details of the calibration cycle in case is enable or disable the subtraction on board.

5.3 SCIENCE BLOCK

In Science mode, the instrument performs a Science Session according to the parameters received in STBY. The Science Block includes the following sequence of TCs (Figure 15):

- “JRM_TC_SET_PAR” changes the default value of the onboard parameters
- “JRM_TC_SCI_PAR” sets the parameters that determine how the imager and spectrometer data are acquired: number of acquisitions, exposure time, operational modes, etc.
- “JRM_START_HS_REC” enables data recording
- “JRM_TC_SCIENCE” starts the science phase
- “JRM_TC_ERROR_LOG” enables the download of any potential related errors
- “JRM_STOP_HS_REC” disables data recording.

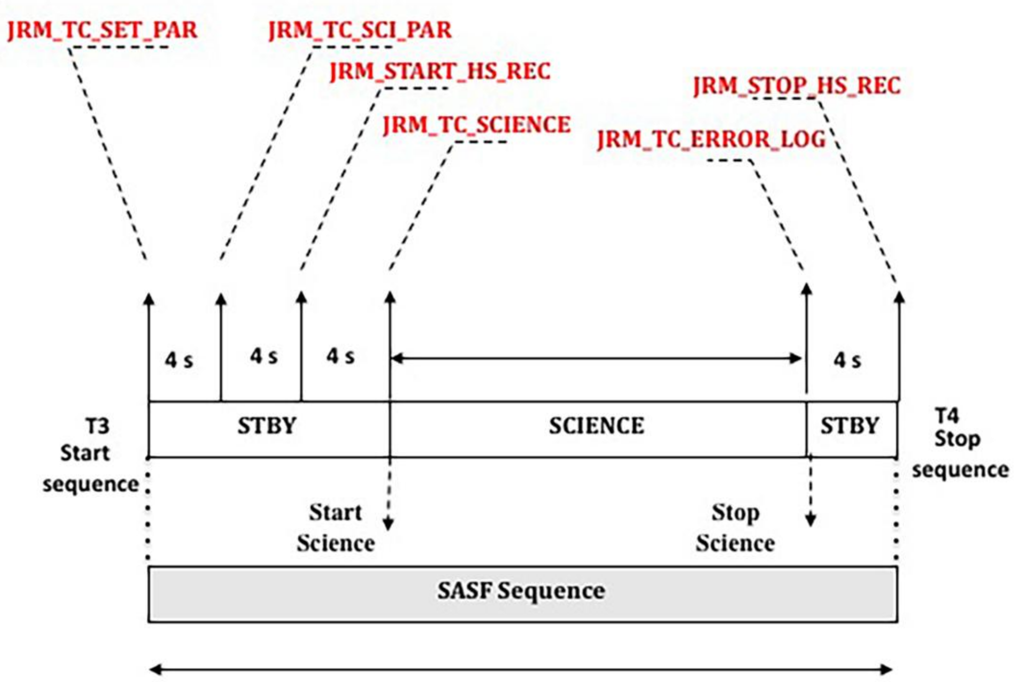

Figure 15: The figure shows the format of the science block: the TCs and the wait time required between successive TCs.

JIRAM can remain in SCI mode for a long time, depending on the parameters defined in JRM_TC_SCI_PAR. After this time it autonomously returns to STBY mode.

5.3.1 JIRAM SUBMODES

As mentioned in section 2.2, the Science mode is composed of several sub-modes that include both the imager and the spectrometer acquisitions.

For the Imager the possible sub-modes are:

I0	Imager is off
I1	acquires the entire focal plane (filter L and M)
I2	acquires only the part of focal plane with filter M.
I3	acquires only the part of focal plane with filter L

Table 2: Operational modes for Imager

For the Spectrometer the possible sub-modes are:

S0	Spectrometer is off
S1	acquires the entire focal plane

S2	spectral binning over 4 pixels.
S3	spectral binning over 16 pixels.

Table 3: Operational modes for Spectrometer

S2 and S3, whose main characteristic is to reduce the required data volume, have been tested but never used in flight during any routine observations, as the allocated data volume has always been sufficient to meet the needs of the observing plan.

5.3*.2* JIRAM Spacecraft Dynamics

A key step in planning the science observation is evaluating the duration of the acquisition. This involves utilizing Spacecraft Dynamics (SD), information provided by the spacecraft to its subsystems, which encodes attitude information. JIRAM receives SD every 2 seconds from the S/C, through the LSSL. The JIRAM instrument needs only three of the many parameters provided through SD for the correct start and duration of the acquisitions: the “Nadir Spin Phase Validity Flag”, the “Nadir Spin Phase” and the “Spin Rate”.

- Nadir Spin Phase Validity Flag:

  Depending on this flag, JIRAM software will use either the real spin phase of the S/C or an internally calculated one for the acquisition start. If the spin phase is invalid, JIRAM software uses the last valid value received for the spin phase and estimates its current value through the actual spin rate and onboard time (refreshed every two seconds via Juno).

- Spin Rate:

  It is used by JIRAM software to calculate the duration of each image acquisition cycle (the default is 30 seconds), and it is also used to calculate the exact time to start the acquisitions (for both off-nadir and nadir acquisitions).

- Nadir Spin Phase:

  It is necessary to calculate the exact moment at which to start each acquisition. Knowledge of the “angular distance” to the nadir position and the time necessary to reach the nadir is necessary to correctly calculate the start time for each acquisition.

After booting JIRAM will wait for the first transition and begins to send HK data every 2 sec. If the S/C time, provided by Spacecraft Dynamics, is available in the first transition, JIRAM will use it; otherwise the instrument will use an internal time (starting from 0). As soon as the S/C time is recovered, JIRAM is automatically re-synchronized.

5.3.3 JIRAM Acquisition Description

During the Science Block, JIRAM executes two acquisitions during each S/C rotation and stores them in two buffers; the first acquisition is set to -180° (off-nadir) relative to the direction to the target, the second is set to 0° (nadir) with respect to the target direction (see Figure 13).

The acquisitions can be as follows:

- Background: in this case the scanning mirror points at the calibration lamps that are switched off during the Science observation
- Readout Noise (RN)
- Dark: the scanning mirror points to the center of the field of view while JIRAM looks at deep space.
- Nadir Observation: the observation is executed while the JIRAM FOV is pointed at the target.

The observation mechanism is characterized as follows:

1. If the background repetition is set to a value ≥2 in the "JRM_TC_SCI_PAR", the acquisitions can be planned in two modes that can vary accordingly to the background subtraction settings.
   If the subtraction is enabled, JIRAM performs a first acquisition, background, stored in Buffer_A and a second acquisition, RN, stored in Buffer_B. Then it performs a subtraction between buffers A and B. Finally, JIRAM sends the data to the hard partition to await transmission to the ground. Since this particular acquisition is dedicated to the collection of the background, for the sake of simplicity, we refer to it as First Acquisition (FA hereafter).
   For the next set of rotations, until a new FA is acquired, JIRAM performs as a first acquisition the background, stored in Buffer_A, and the target observation, in Buffer_B; in this case, the subtraction is done between Buffer_B and Buffer_A. This sequence is identified as Science Acquisition (SA hereafter).
   If the subtraction is disabled, JIRAM will perform always the two observations but the subtraction between the buffers is not performed (see Figure 16).

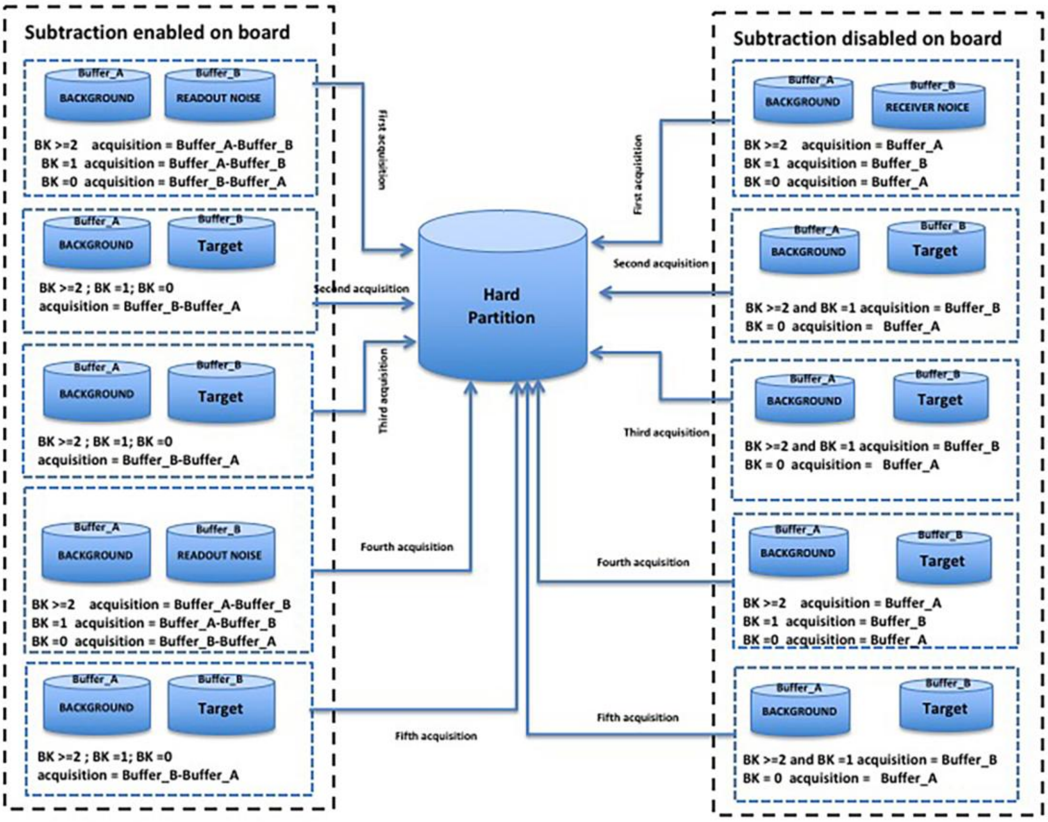

Figure 16: The acquisition dynamics for the possible case of the the background acquisition and in the cases where subtraction is disabled or enabled.

1. When the background repetition is set to a value of "0", the background is not sent to the ground (no FA sequence); only science is performed (see *Figure 16.*)

2. If the background repetition is set to a value of "1", there are no science acquisitions (no SA sequence); only background is sent to the ground (FA sequence) (see Figure 16).

5.3.4 JIRAM anomaly cases

Two anomalies may occur:

1) The S/C stops sending Spacecraft Dynamics information; in this case JIRAM uses the last ones received until the link with S/C is restored.
2) The Spacecraft Dynamics were never sent to JIRAM; this compromises the estimate of the spin rate of the S/C. In this case, JIRAM will perform a default science observation that consists of 120 acquisitions in mode I1_S3 (see table2 and 3) with an assumed duration of 30 sec per acquisition.

As of this writing, neither anomaly has occurred during operations.

Moreover, the acquisition duration can be set in order to disable the Spacecraft Dynamics; in this situation, the S/C spin rate will be evaluated starting from values set by the operator.
When the science TC starts, the first acquisition executed by JIRAM must be in position “B” (see Figure 12); if JIRAM is in position “C”, this means that it has already rotated beyond position “B”, so it is necessary to wait until the instrument returns to position B.

The following equation calculates the duration of a generic Science block:

$$Science\_Duration\_Sec = \mathbf{Spin\_Rate} * \left(N_{acq} + 1\right) + Technical\_Time + Tilt\_Time \qquad (1)$$

Where:

$N_{acq} + 1$ = number of acquisitions, taking into account the most unfavorable case, namely, that JIRAM is in position “C” (see Figure 13)

$Technical\_Time$ = the time necessary to perform the TCs when JIRAM is in standby before going into science mode (see Figure 11)

$Tilt\_Time = (N_{acq} - 1) * ({}^{Spin\_Rate}/_{360°}) * tilt$ = the amount of time required for the spacecraft to rotate from the nadir position to the planned observation orientation

5.3.5 RADIATION BLOCKS

Radiation science is performed with a set of 3 images, one image for each science block (see Figure 17) observing inside the instrument.
In particular, all of the acquisitions are commanded to following specifications:

- one second of exposure time,
- de-spinning mirror tilted into the instrument calibration source but with the calibration source OFF (a completely dark frame, not looking out into deep space),
- acquired filter M and L, even if interest is only for filter L and for spectrometer,
- onboard RN subtraction,
- no compression.

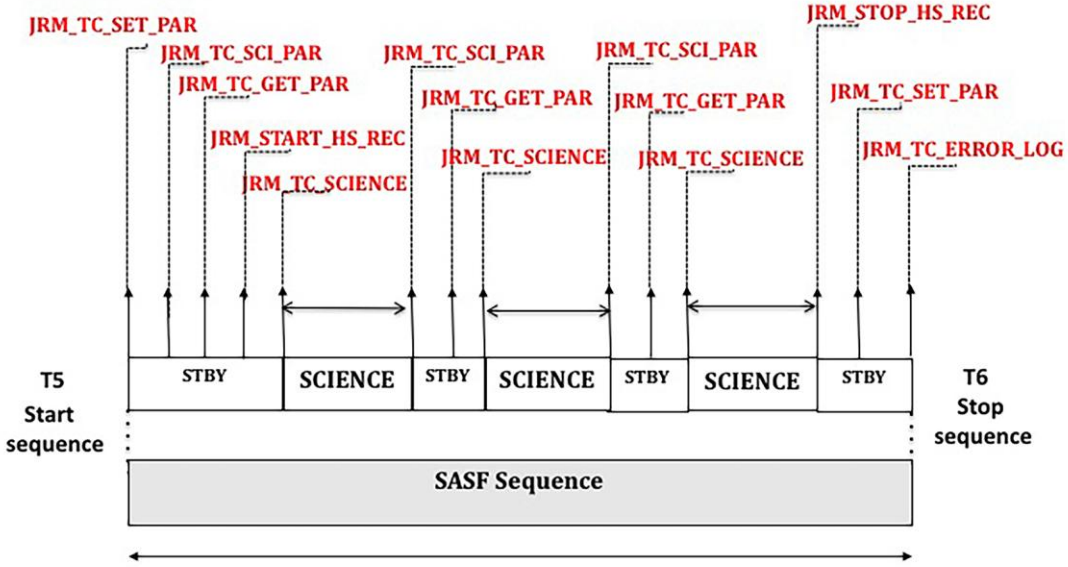

Figure 17: Science Radiation Sequence: JIRAM specifics and format.

6 DATA VOLUME ESTIMATION

During the planning phase, a key step is represented by the correct estimation of the data volume (DV) produced by the observations to avoid conflicts with other instruments or, in the worst case, the loss of scientific data.
It is necessary to consider the size of the instrument-specific Hard Partition (537 Mbit), where the data are stored during the observations, and the total storage capacity of the Soft Partition (4000 Mbit), where the data are transferred once JIRAM receives the TC "JRM_STOP_HS_REC" and where they remain until the downlink process occurs.
The formulas to estimate the DV are:

$$SCI\_DV\_bits = N_{acq} * 16 * \left\llbracket I\left(36 * N_p + \frac{pixels*432}{I\_Comp\_Factor}\right) + S\left(36 * N_p + \frac{pixels*336}{S\_Comp\_Factor}\right)\right\rrbracket \qquad (2)$$

$$CAL\_DV\_bits = N_{acq} * 6 * 16 * \left\llbracket I\left(36 * N_p + \frac{pixels*432}{I\_Comp\_Factor}\right) + S\left(36 * N_p + \frac{pixels*336}{S\_Comp\_Factor}\right)\right\rrbracket \qquad (3)$$

Where
I = 0 in operational mode I_0
I = 1 in operational mode I_1, I_2, I_3

S = 0 in operational mode S_0
S = 1 in operational mode S_1, S_2, S_3

N_{acq}: acquisition number

$N_p = \ number\ of\ packets$
$N_p = 3\ in\ operational\ mode\ I_2, I_3, S_2, S_3$

$N_p = 6$ *in operational mode* I_1, S_1

pixels =

- 256 in I_1, S_1
- 128 in I_2, I_3
- 64 in S_2
- 16 in S_3

The data compression is possible in order to reduce the data volume. Lossy compression is possible on imager data. The lossy compression reduces the images' data volume by a factor of 6. Lossless compression can be applied to spectra. The lossless compression would produce a compression of a variable factor that depends on the data itself. The average value is about 1.5. During routine operations, compression is disabled for both channels because, in practice, allocated data volume has always been sufficient. In each activity, the instrument produces about 2 Gbits of science packets and HK packets of 1824 bits in size; the activity cycle is expressed in seconds and can be changed from the default value that is set to 10 sec.

7 DISCUSSION

Imaging Jupiter in the infrared from a spinning spacecraft immersed in the harsh Jovian radiation environment is challenging at best. The JIRAM operations team has developed and implemented a successful and robust operations strategy that has allowed Juno to return infrared observations of the Jovian system of unprecedented quality and detail. This strategy allows the team to construct observation timelines that are robust to a 2.5% uncertainty in the spin rate of the spacecraft. This strategy and the action of the despinning mirror are key to obtaining stable images and spectra. It also allows the JIRAM team to incorporate radiation monitoring sequences into the observation timeline. Software built by the JIRAM operations team allows the team to plan future observation sequences, manage data volume and account for instrument flight rules and generate detailed command sequences that are used to operate JIRAM. It is these streamlined operations capabilities, in addition to the durability and capability of the instrument itself, that will be needed to insure continued successful operations at Jupiter.

Acknowledgments

The authors acknowledge the financial support from Italian Space Agency (ASI) for the Juno-JIRAM program through ASI-INAF agreement number 2016-23-H.0 and for the US authors, NASA. A special thank you is for Leonardo S.p.A who assisted us during these years. This paper is dedicated to the memory of Angioletta Coradini (1946-2011), Principal Investigator of JIRAM, who passed away before she could see the results achieved with JIRAM.

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Altieri, F., Fabiano, F., Piccioni, G., Stefani, S., Atreya, S. , Lunine, J. , Orton, G. , Ingersoll, A., Bolton, S., Levin, S., Connerney, J. , Olivieri, A. , Amoroso, M., 2017 Preliminary results on the composition of Jupiter's troposphere in hot spot regions from the JIRAM/Juno instrument,
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Table

Step	***Phase***
#1	Internal Background
#2	Readout Noise
#3a	Cal Source Stabilization
#3b	Cal Source Gain 1
#4a	Cal Source Stabilization
#4b	Cal Source Gain 2
#5	Internal background
#6	Readout noise

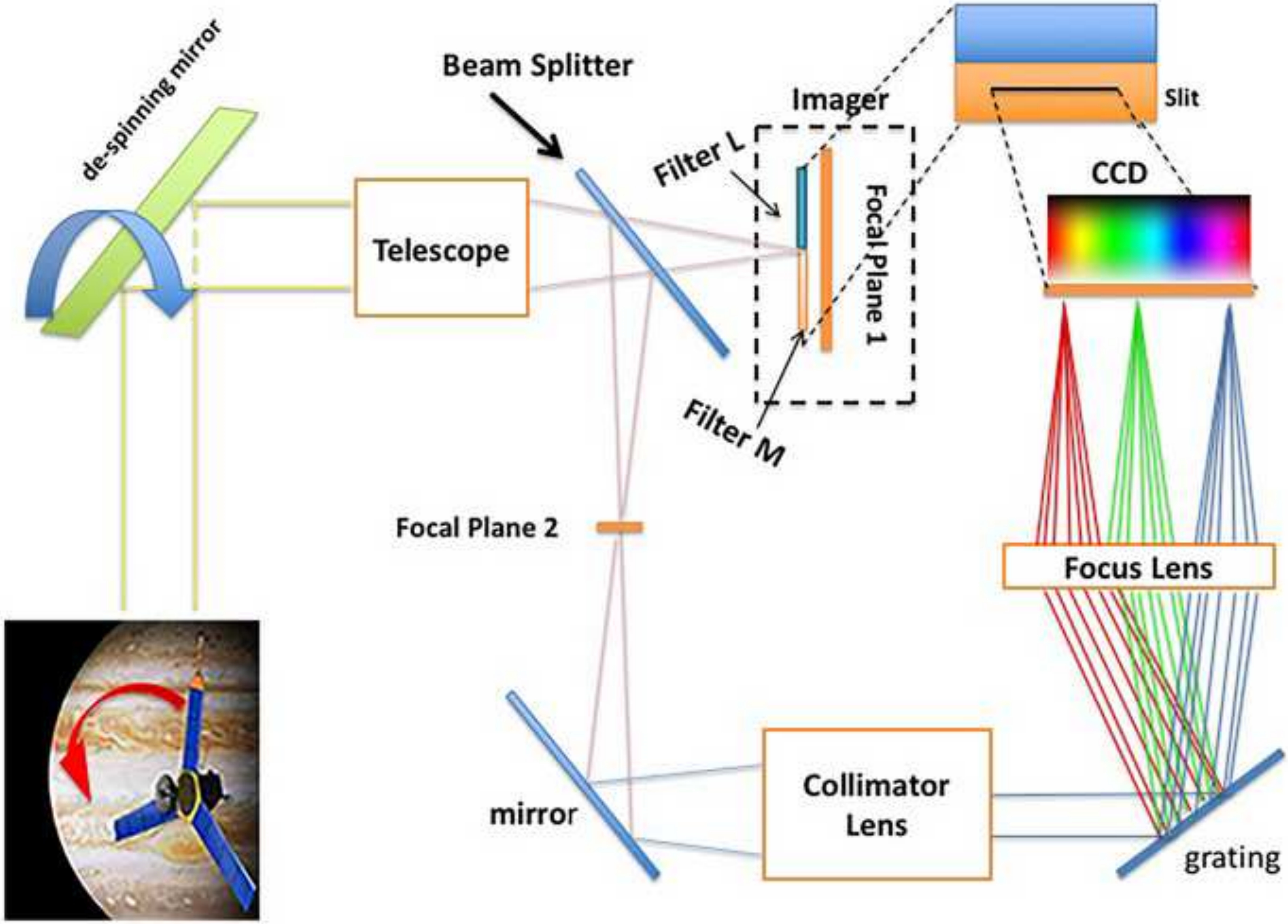
Table

I0	Imager is off
I1	acquires the entire focal plane (filter L and M)
I2	acquires only the part of focal plane with filter M.
I3	acquires only the part of focal plane with filter L

Table

S0	Spectrometer is off
S1	acquires the entire focal plane
S2	spectral binning over 4 pixels.
S3	spectral binning over 16 pixels.

Figure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Beam Splitter
Imager
Slit
Filter L
CCD
Telescope
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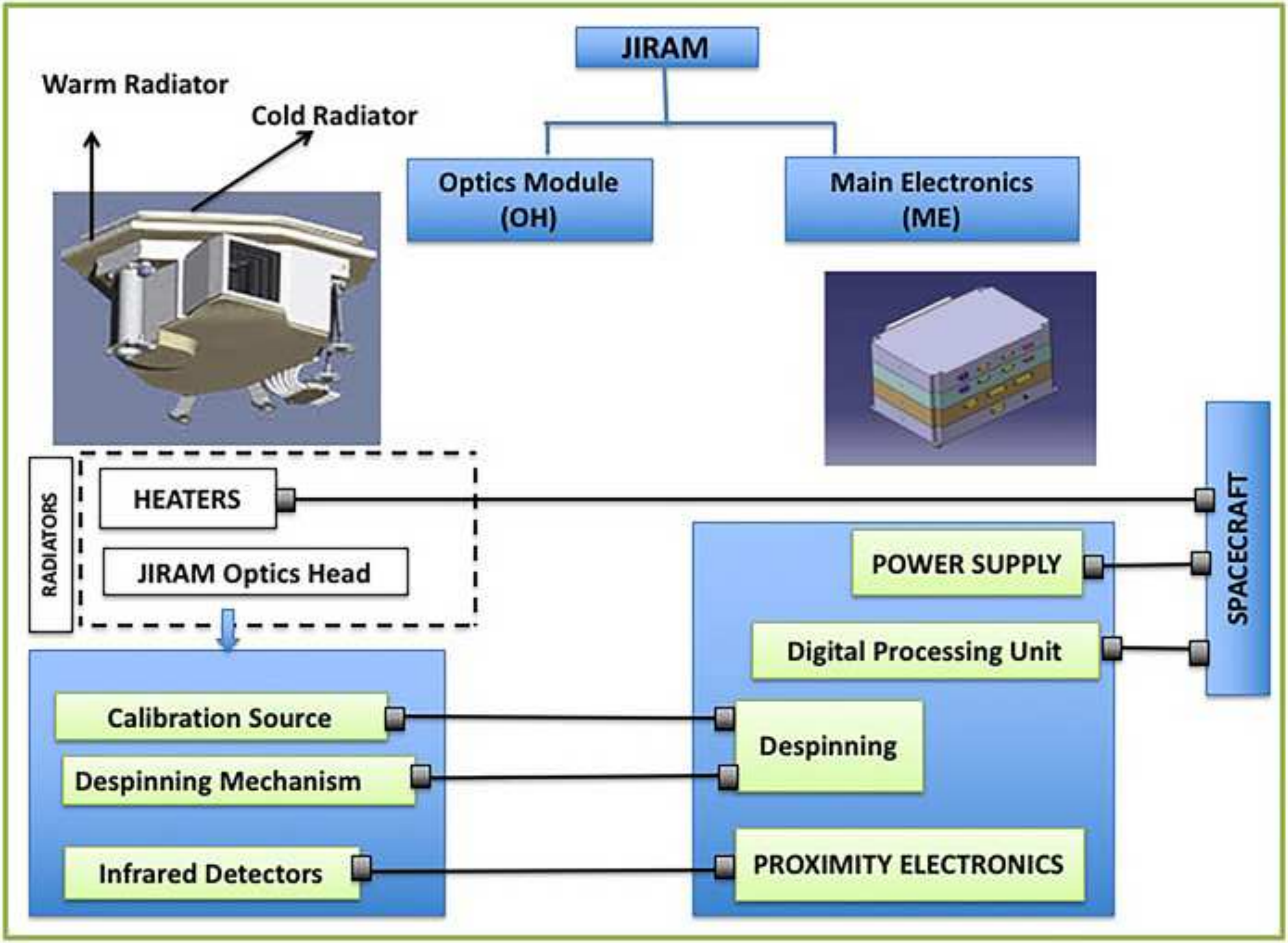
Filter M
Focal Plane 2
Focus Lens
mirror
Collimator Lens
grating

Figure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Warm Radiator
Cold Radiator
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Main Electronics (ME)
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HEATERS
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Digital Processing Unit
Calibration Source
Despinning Mechanism
Despinning
Infrared Detectors
PROXIMITY ELECTRONICS

Figure

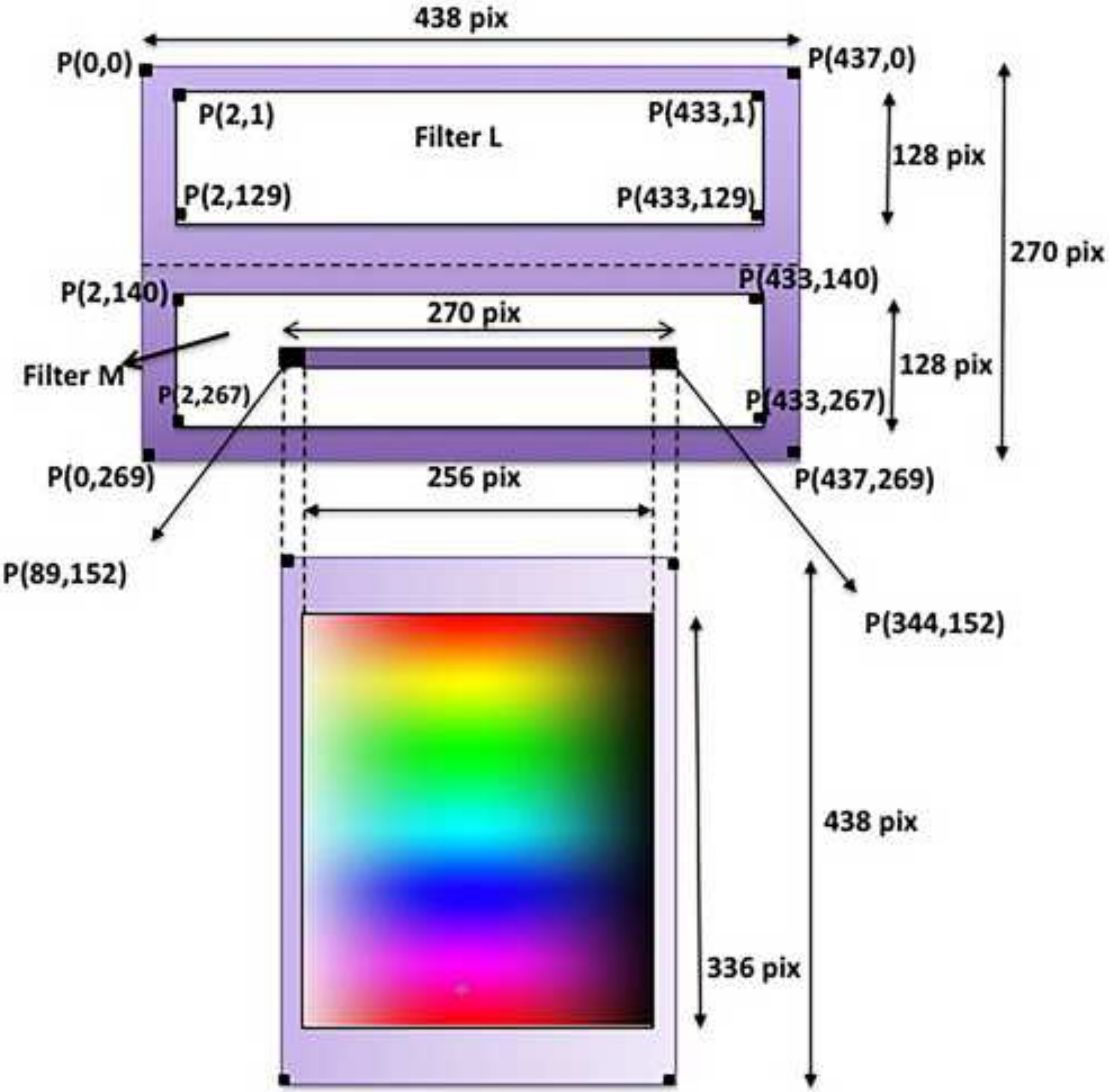
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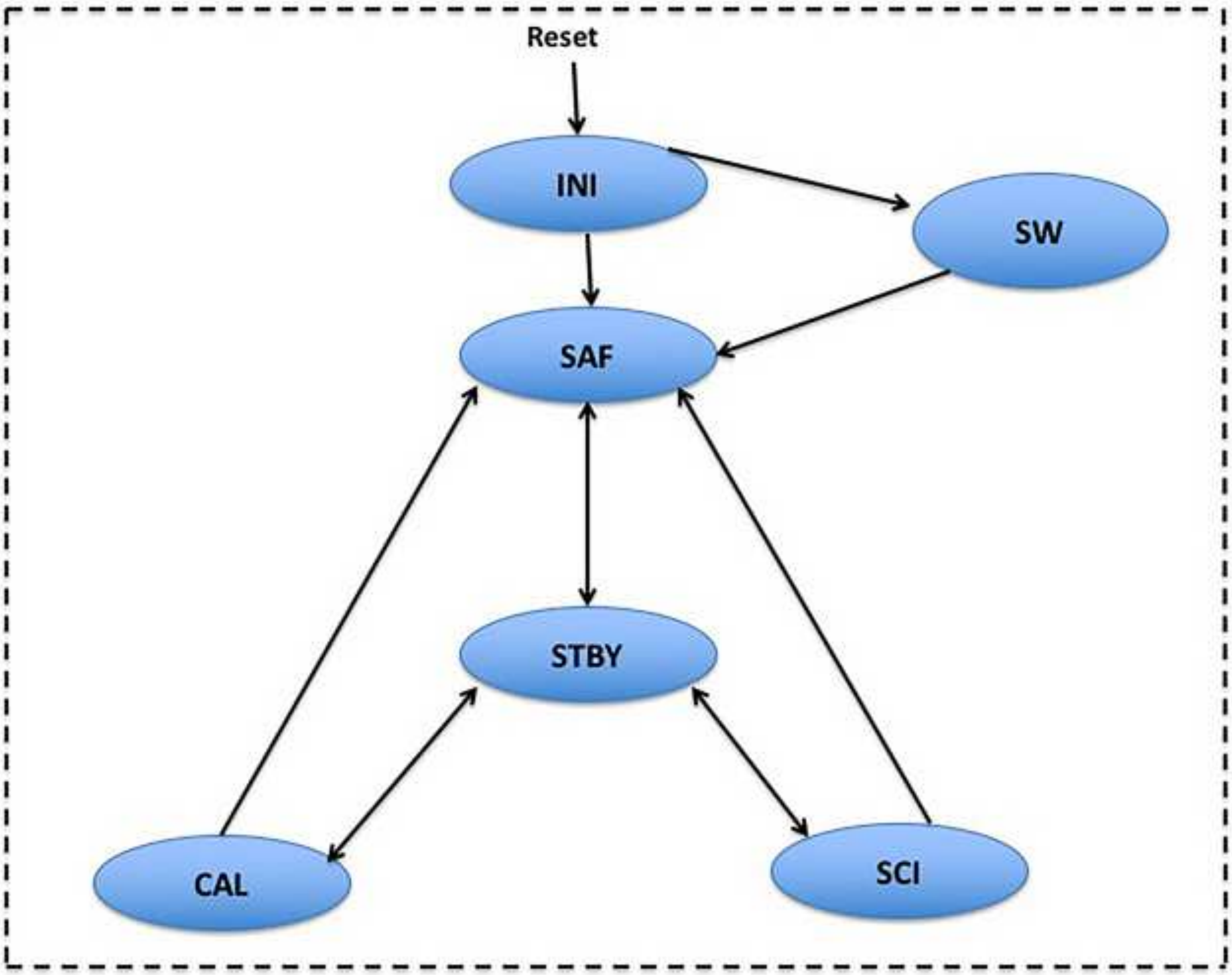
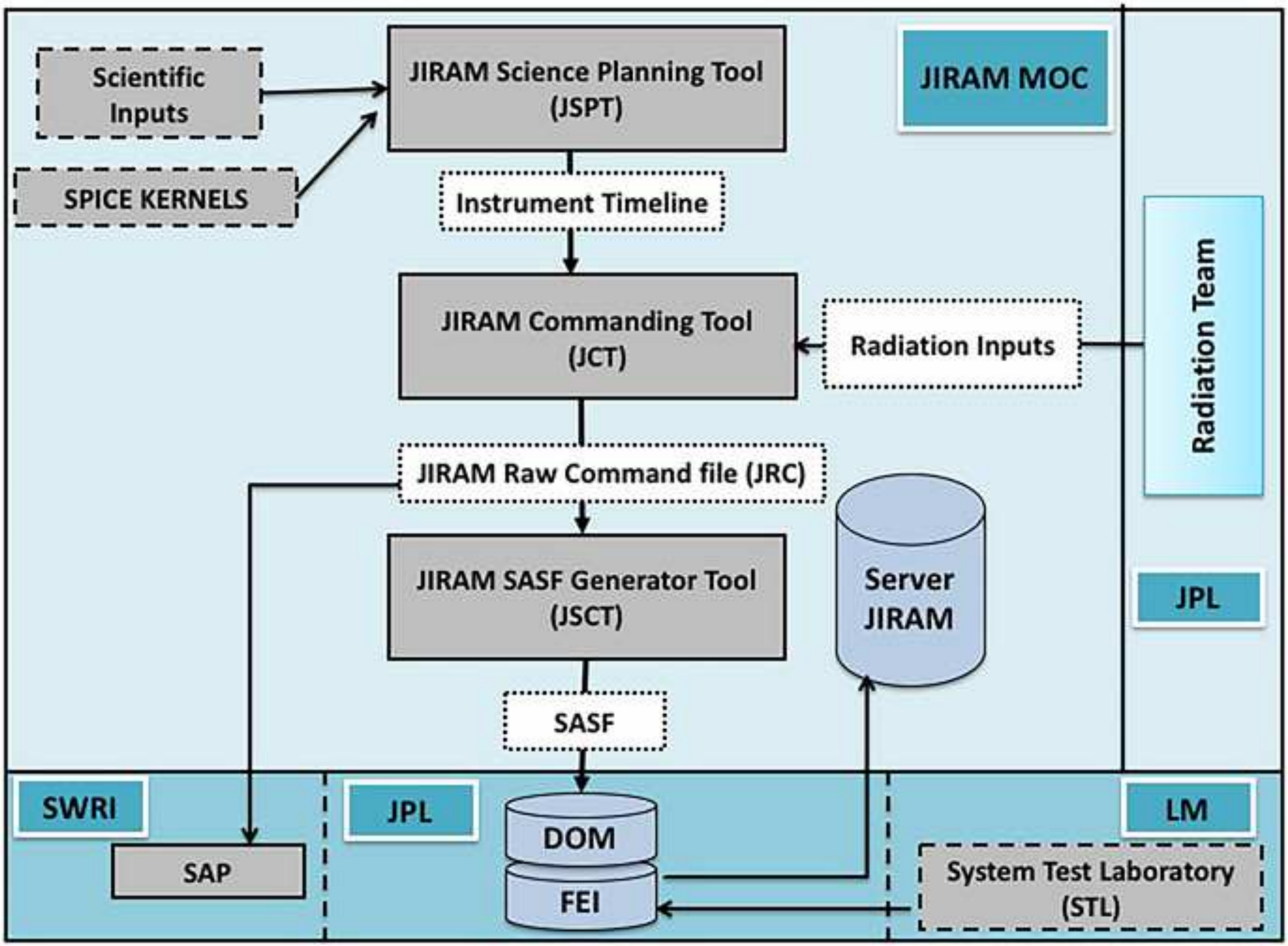
Figure



Figure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JIRAM MOC
Instrument Timeline
JIRAM Commanding Tool (JCT)
Radiation Inputs
Radiation Team
JIRAM Raw Command file (JRC)
JIRAM SASF Generator Tool (JSCT)
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SASF
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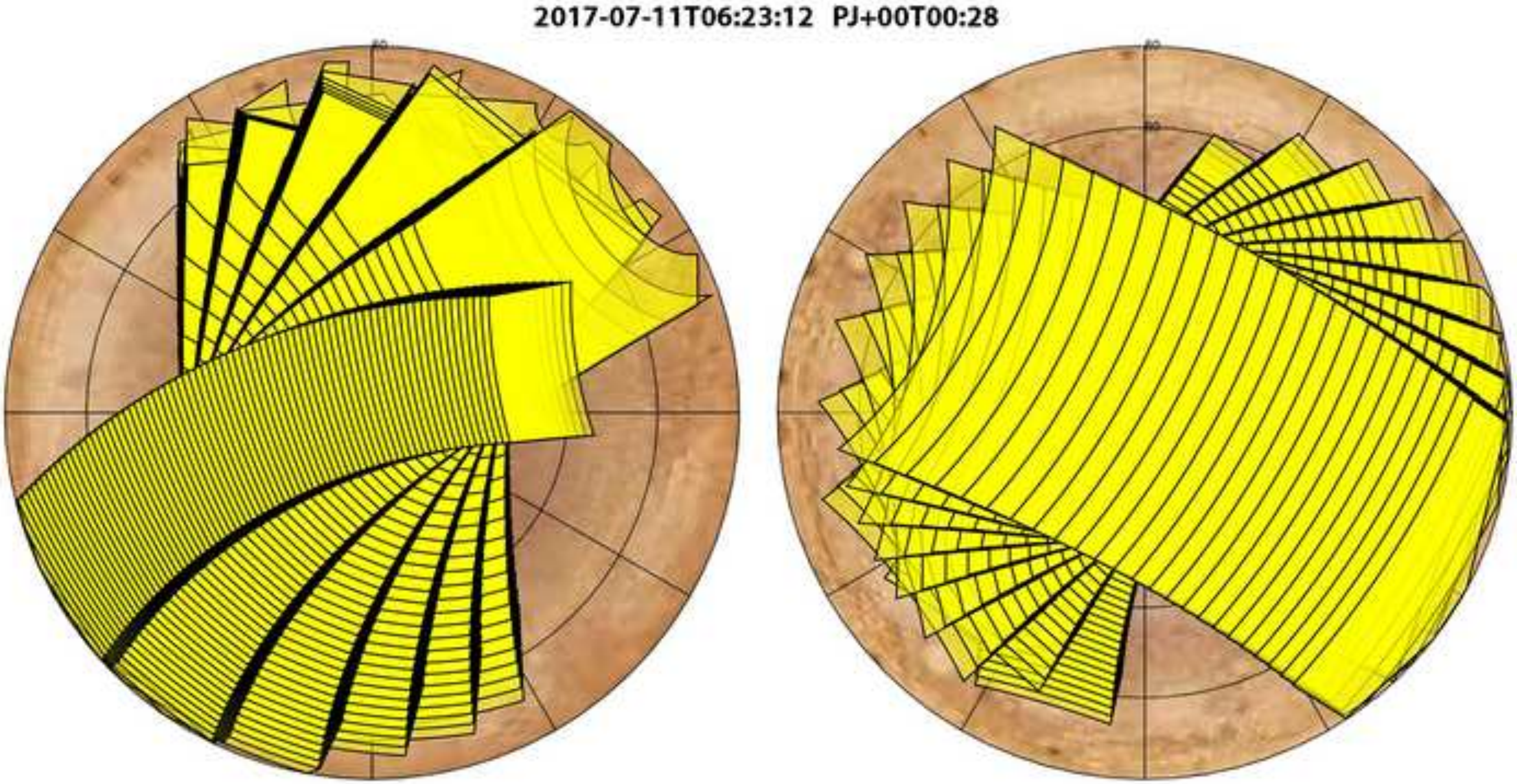
SAP
JPL
DOM
FEI
LM
System Test Laboratory (STL)

Figure



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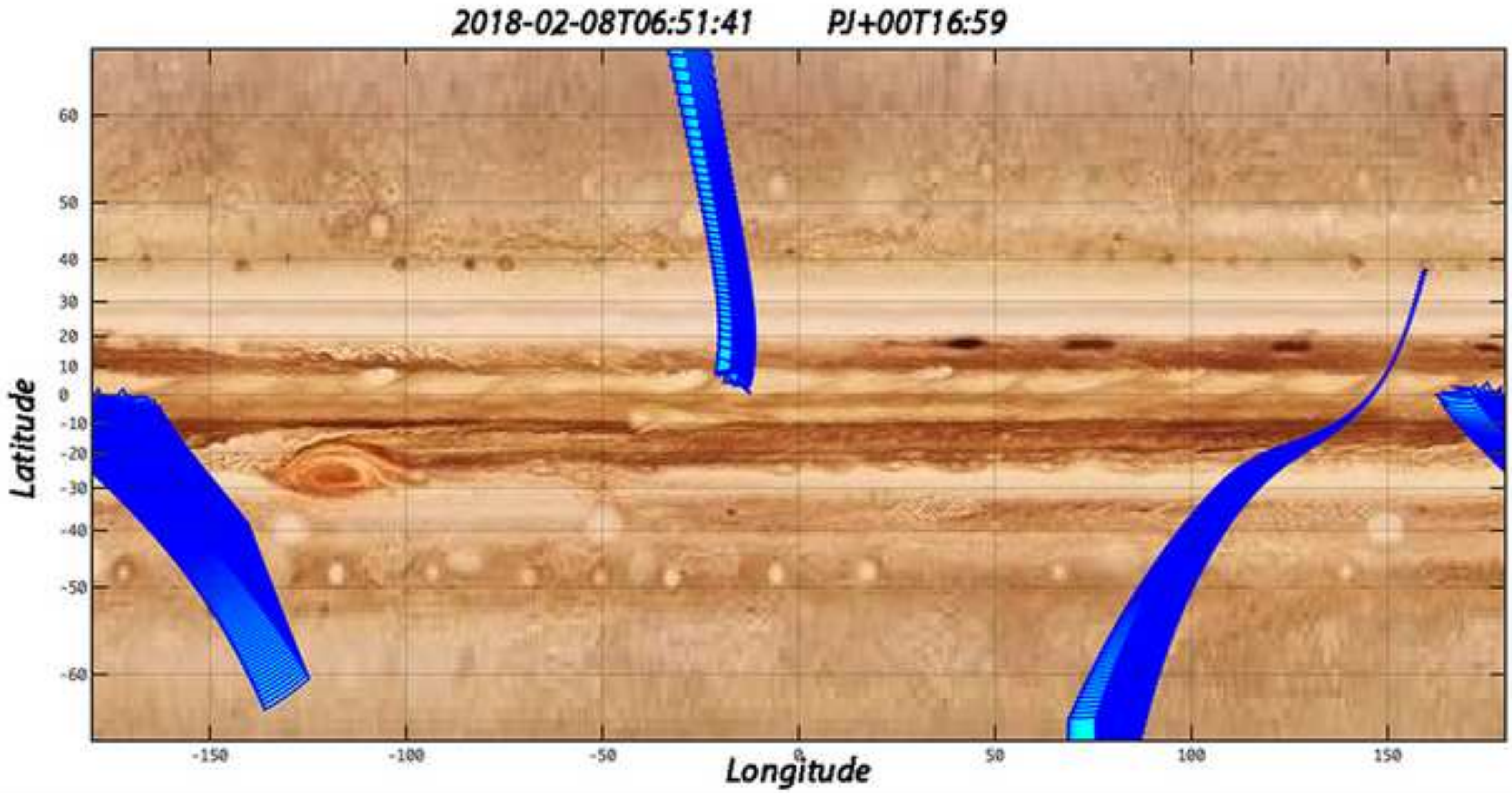
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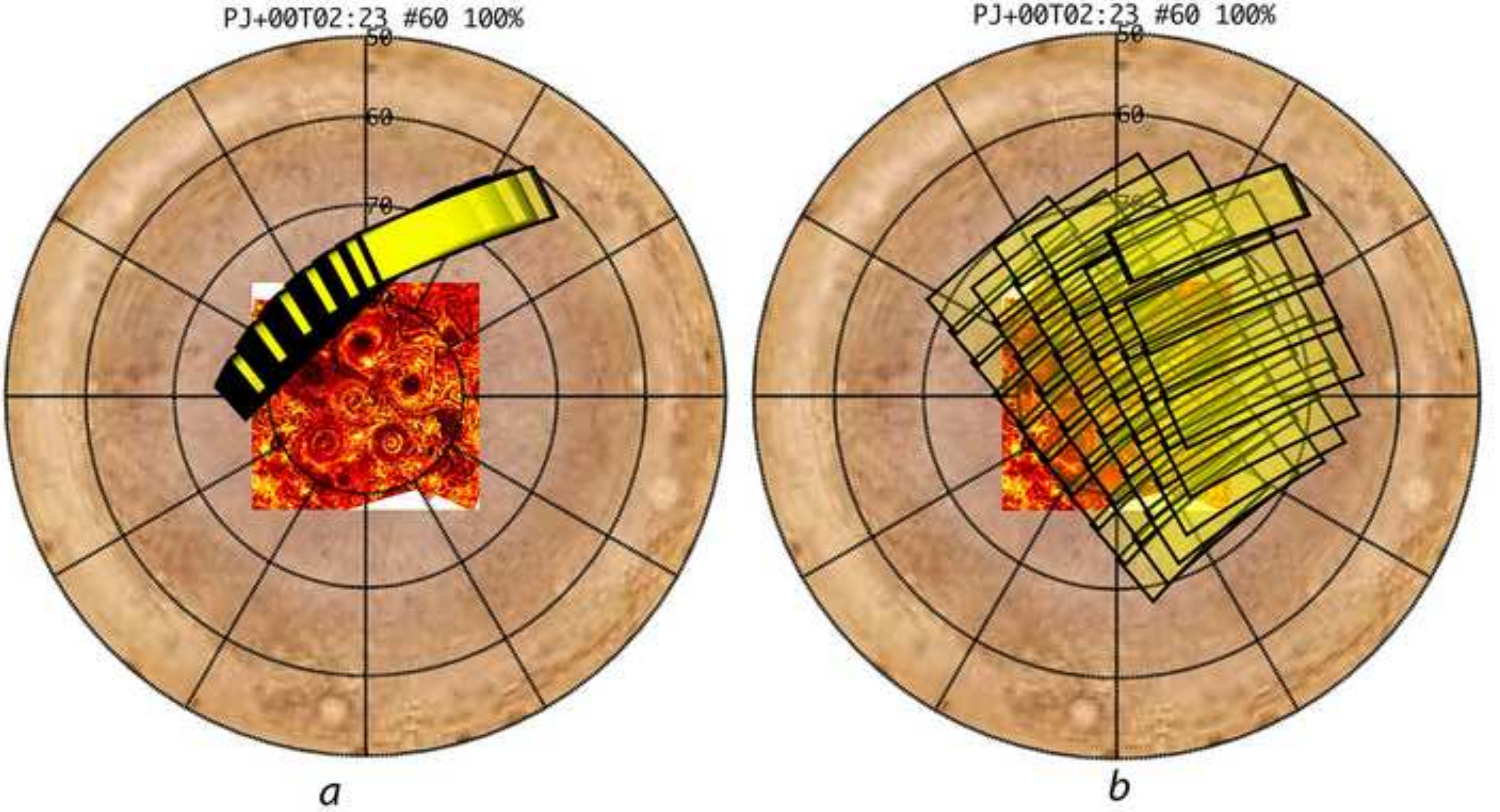
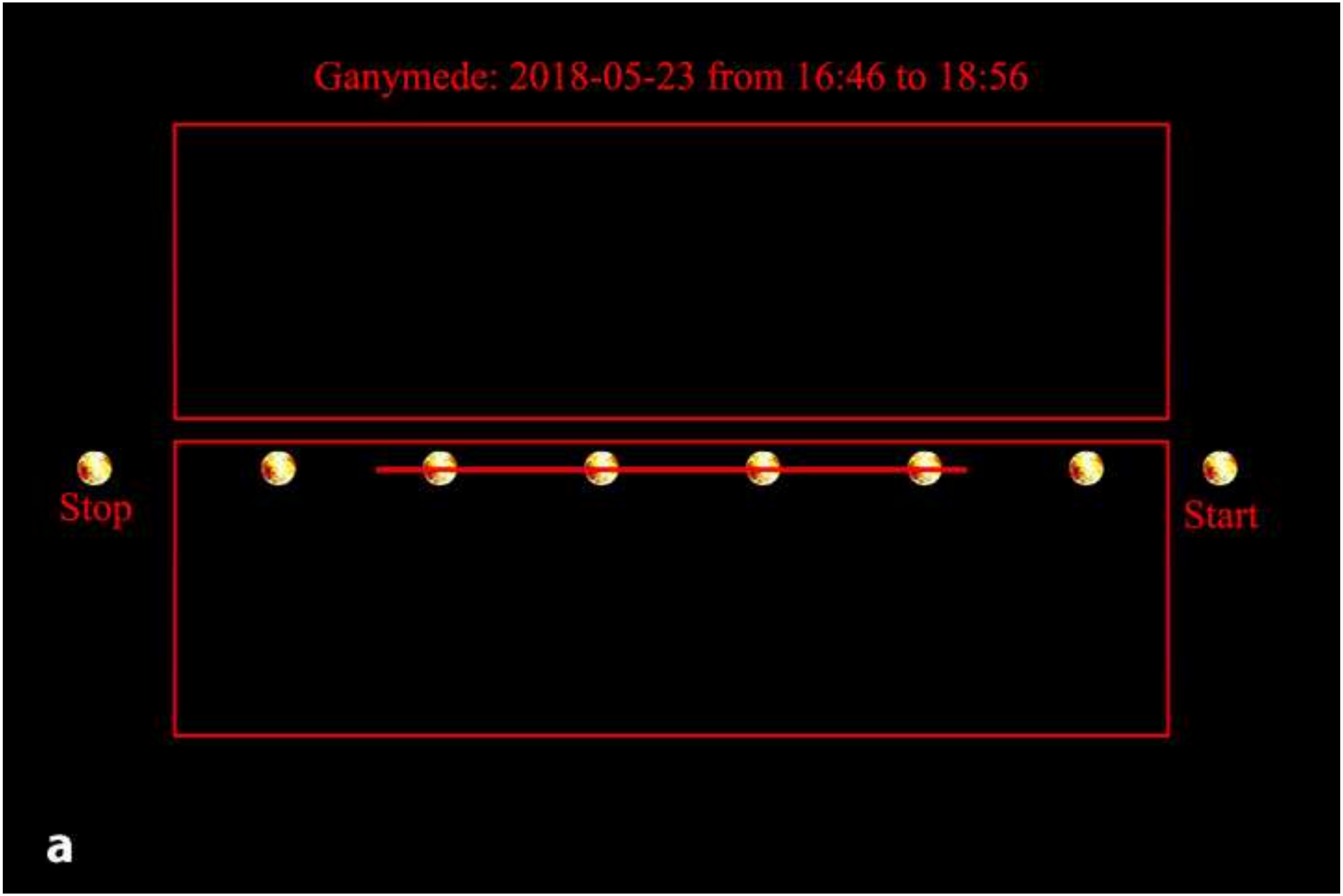
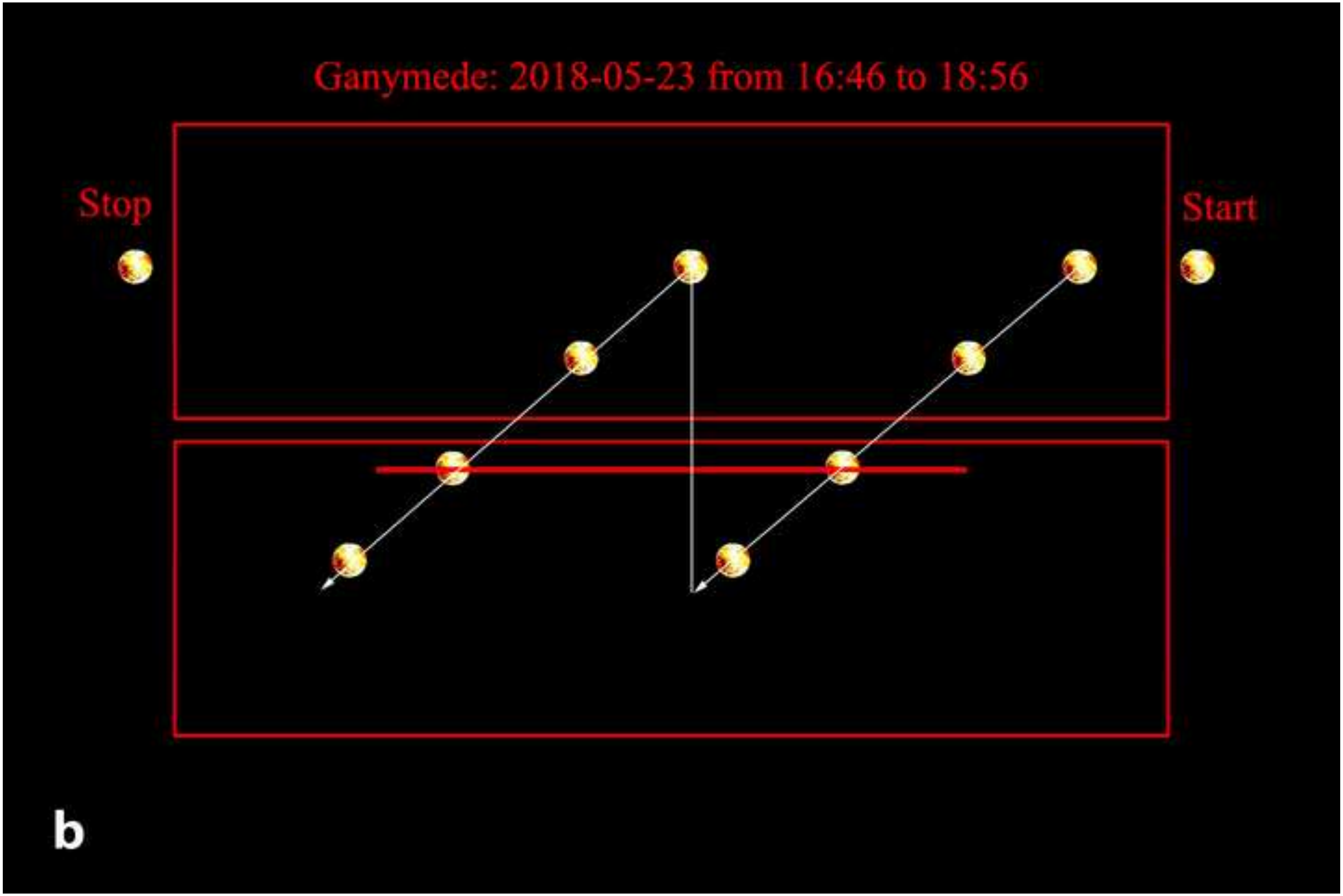
Figure



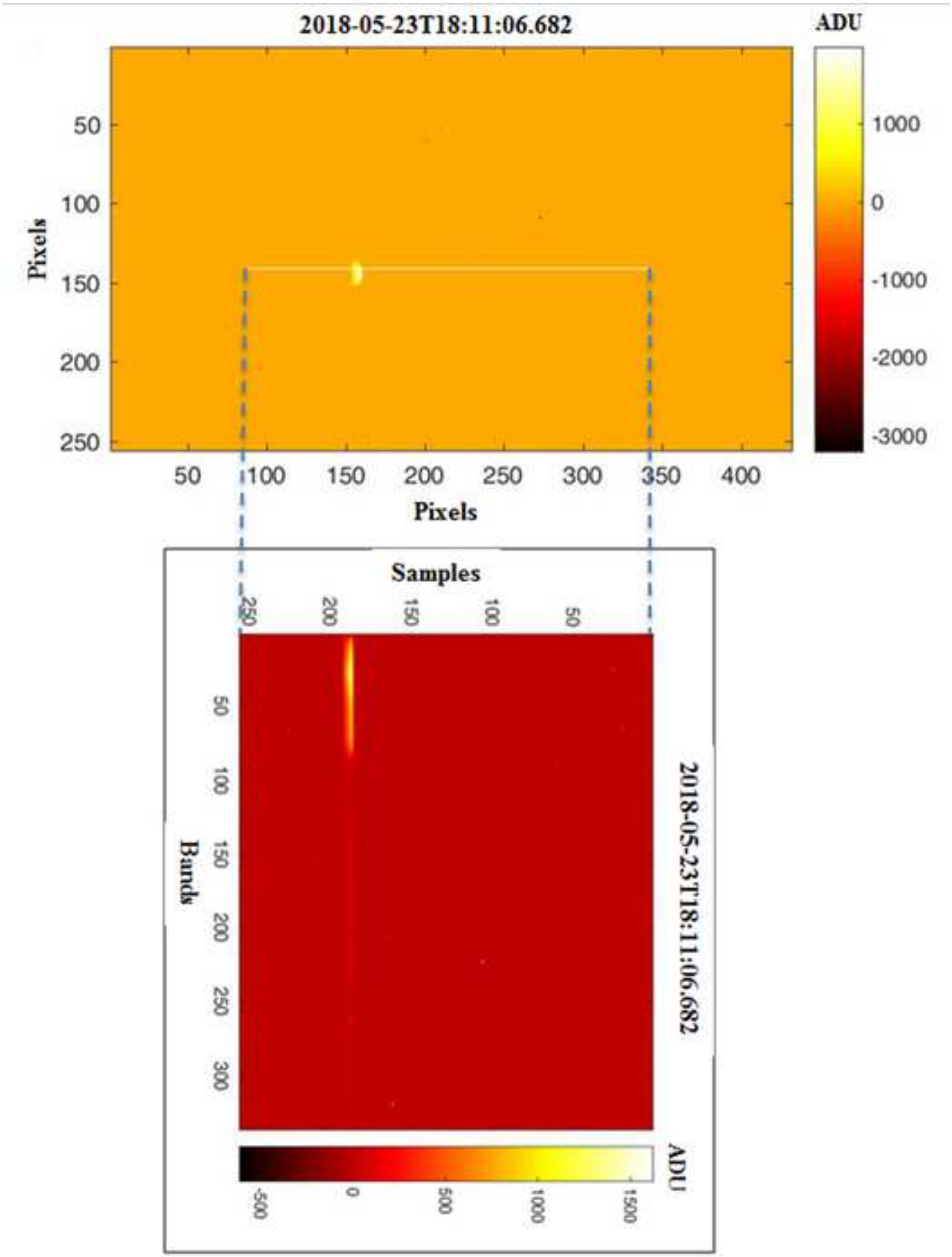
Figure



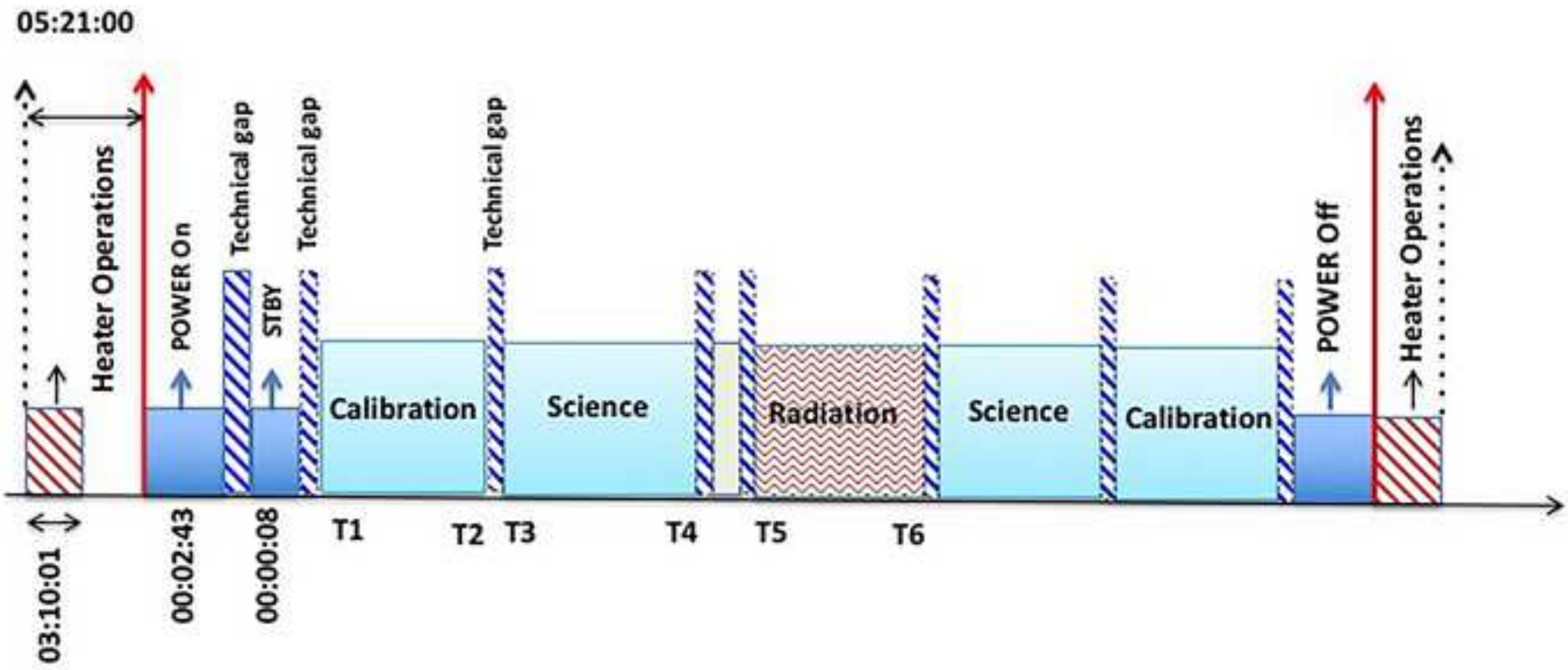
Figure



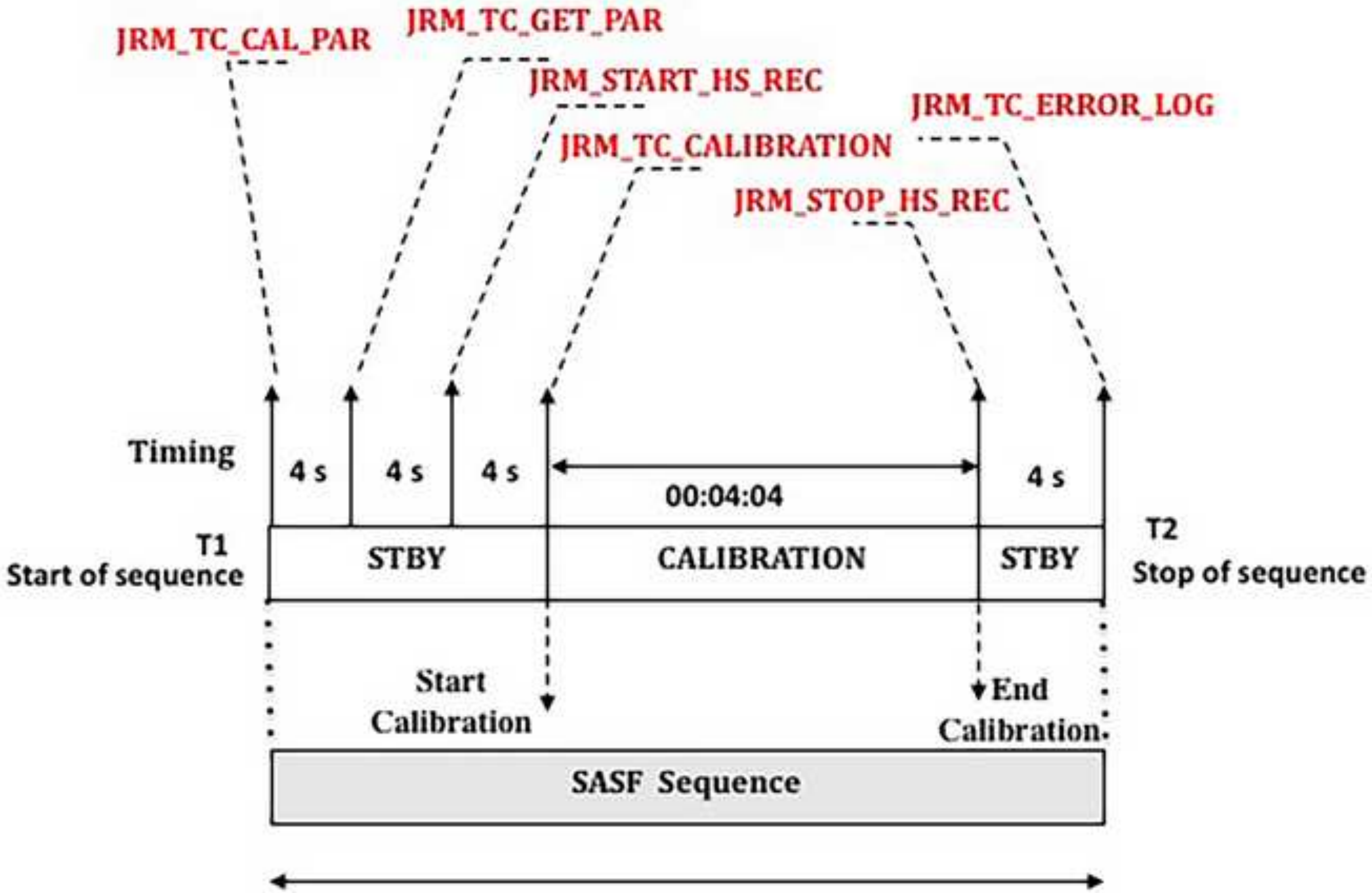
Figure


2018-05-23T18:11:06.682
ADU
Pixels
50
100
150
200
250
50
100
150
200
250
300
350
400
Pixels
1000
0
-1000
-2000
-3000
Samples
250
200
150
100
50
Bands
50
100
150
200
250
300
2018-05-23T18:11:06.682
ADU
-500
0
500
1000
1500

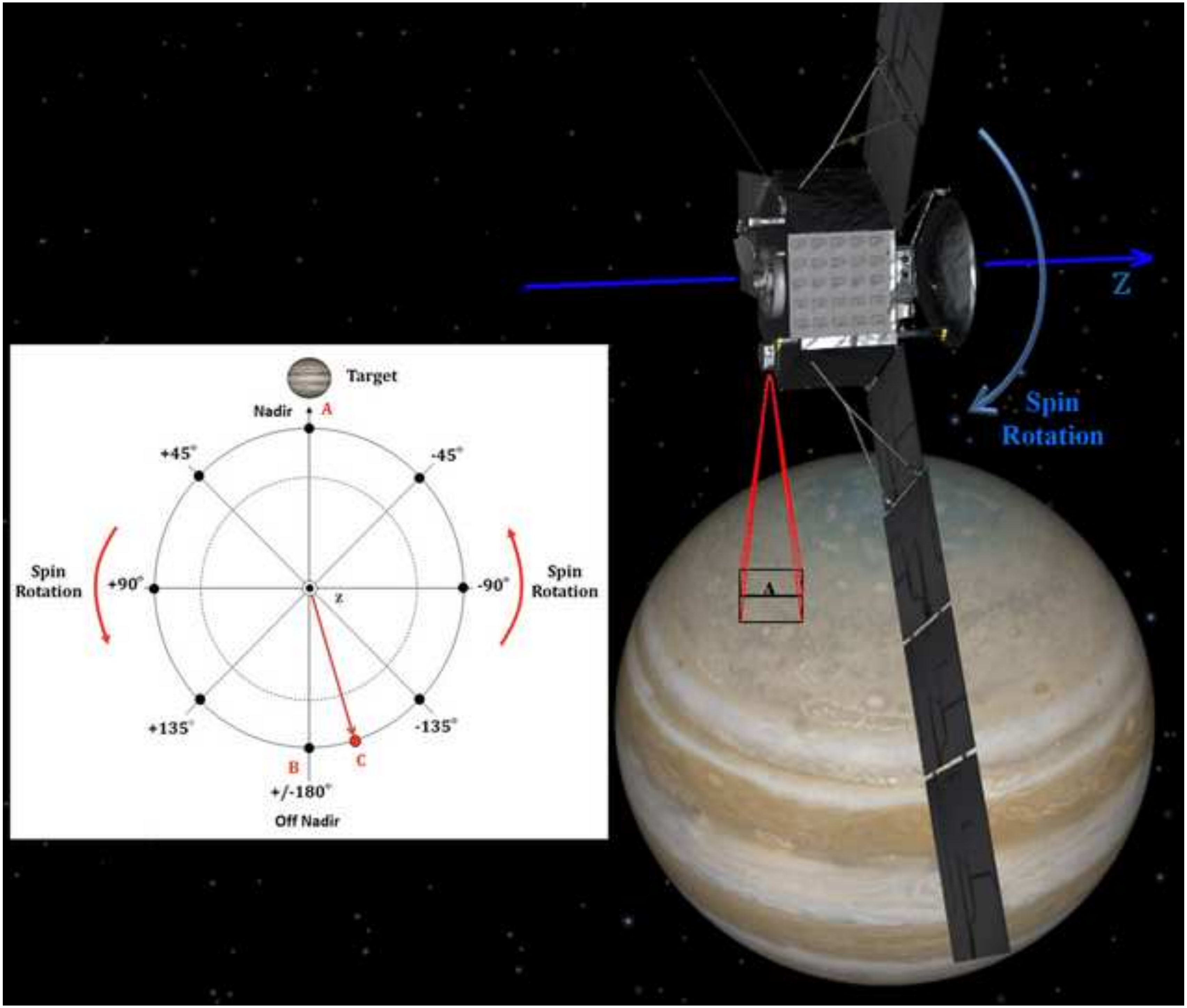
Figure


05:21:00
Heater Operations
POWER On
Technical gap
STBY
Technical gap
Technical gap
Calibration
Science
Radiation
Science
Calibration
POWER Off
Heater Operations
03:10:01
00:02:43
00:00:08
T1
T2
T3
T4
T5
T6

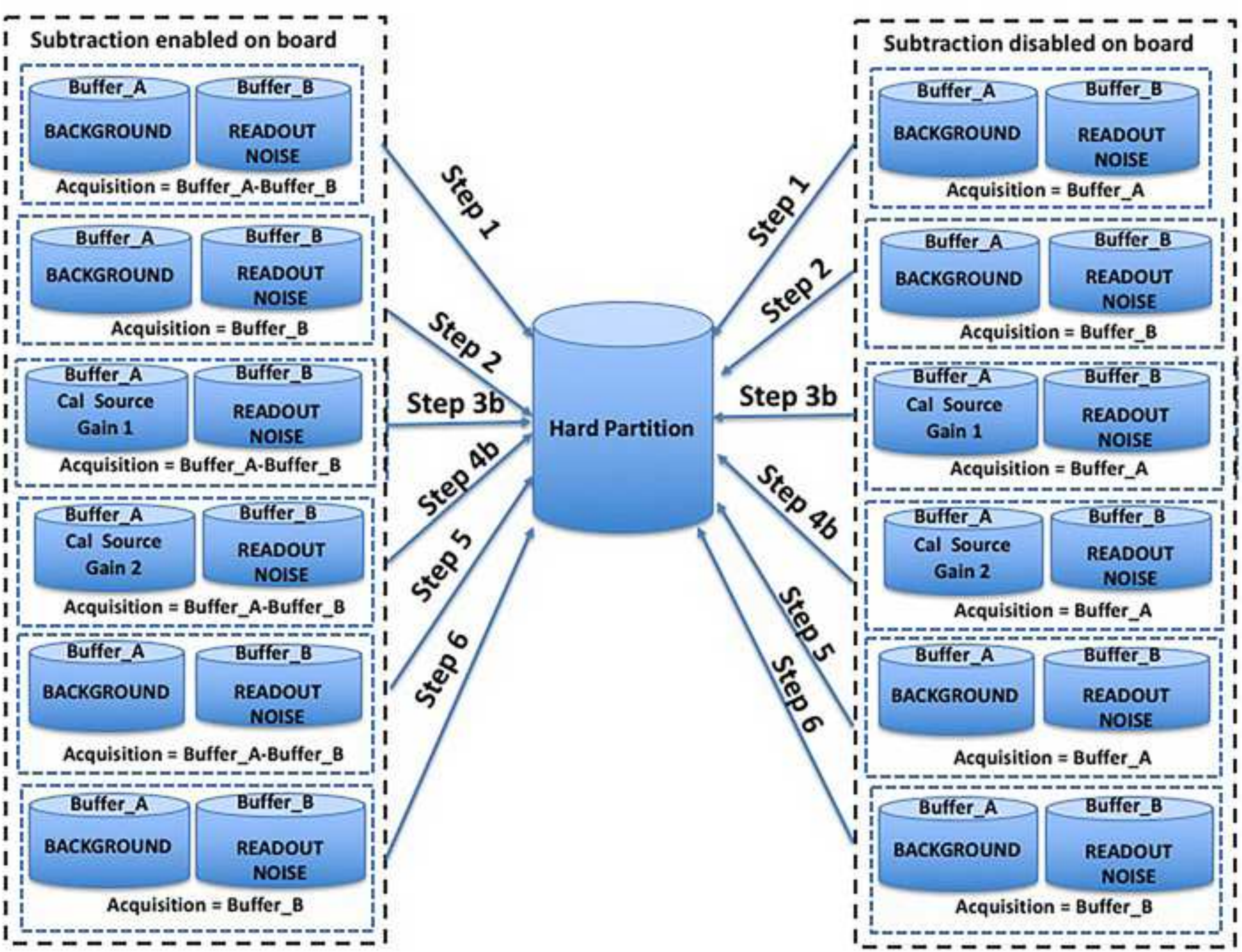
Figure


JRM_TC_CAL_PAR
JRM_TC_GET_PAR
JRM_START_HS_REC
JRM_TC_CALIBRATION
JRM_TC_ERROR_LOG
JRM_STOP_HS_REC
Timing
4 s
4 s
4 s
00:04:04
4 s
T1
Start of sequence
STBY
CALIBRATION
STBY
T2
Stop of sequence
Start
Calibration
End
Calibration
SASF Sequence

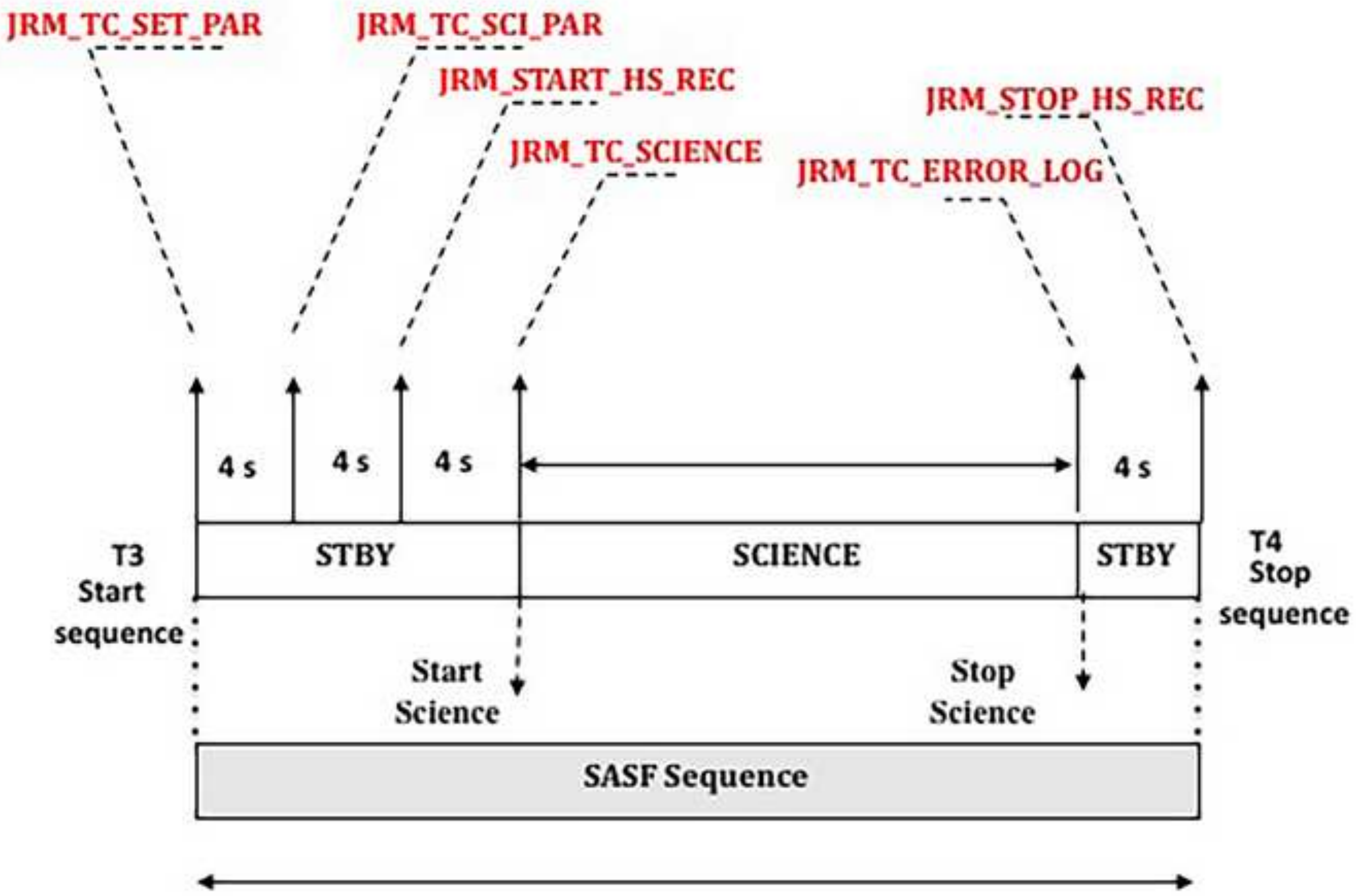
Figure


Target
Nadir
A
+45°
-45°
Spin Rotation
+90°
z
-90°
Spin Rotation
+135°
-135°
B
C
+/-180°
Off Nadir
Z
Spin Rotation
A

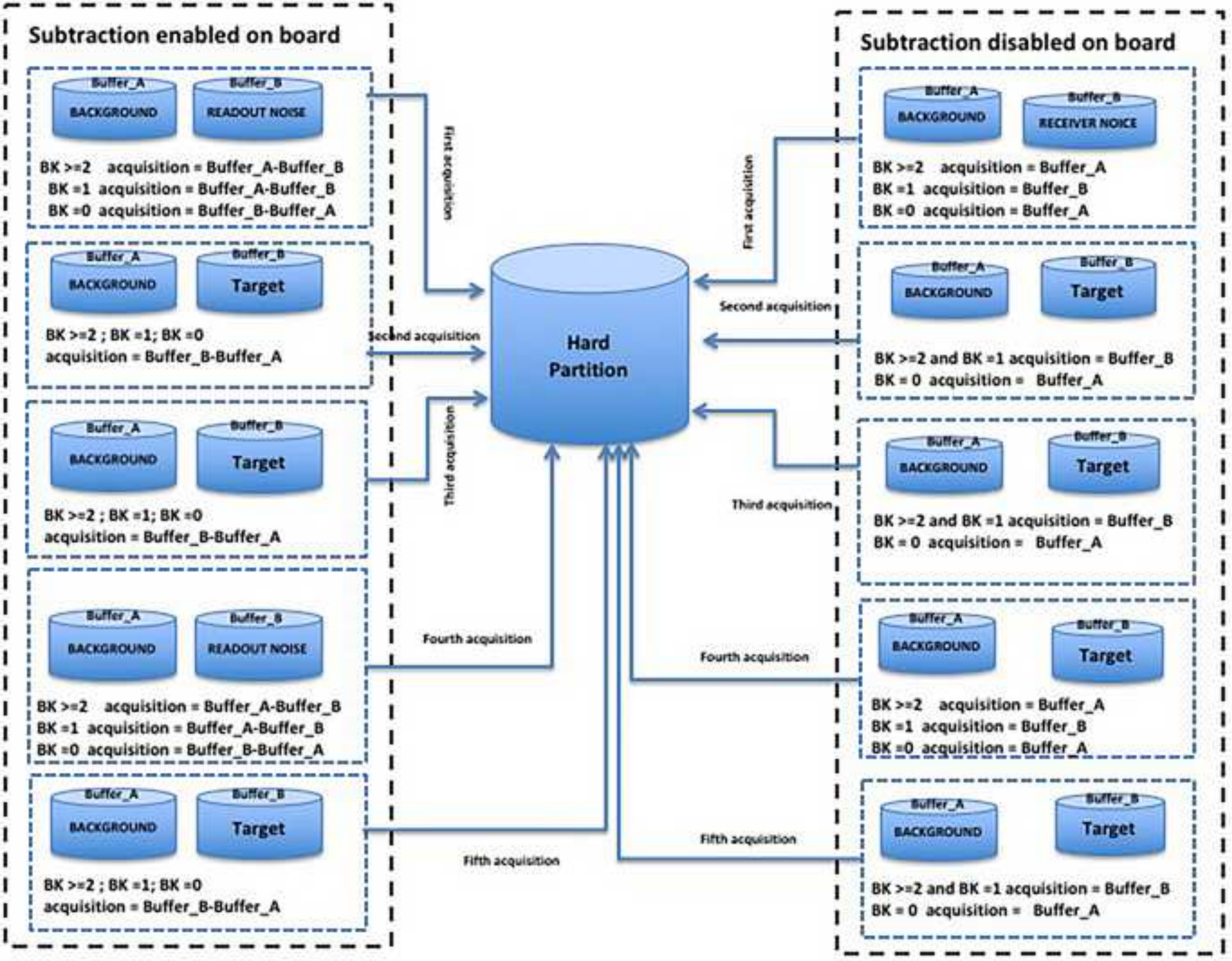
Figure


Subtraction enabled on board
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_A-Buffer_B
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_B
Buffer_A
Cal Source Gain 1
Buffer_B
READOUT NOISE
Acquisition = Buffer_A-Buffer_B
Buffer_A
Cal Source Gain 2
Buffer_B
READOUT NOISE
Acquisition = Buffer_A-Buffer_B
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_A-Buffer_B
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_B
Step 1
Step 2
Step 3b
Step 4b
Step 5
Step 6
Hard Partition
Step 1
Step 2
Step 3b
Step 4b
Step 5
Step 6
Subtraction disabled on board
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_B
Buffer_A
Cal Source Gain 1
Buffer_B
READOUT NOISE
Acquisition = Buffer_A
Buffer_A
Cal Source Gain 2
Buffer_B
READOUT NOISE
Acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
Acquisition = Buffer_B

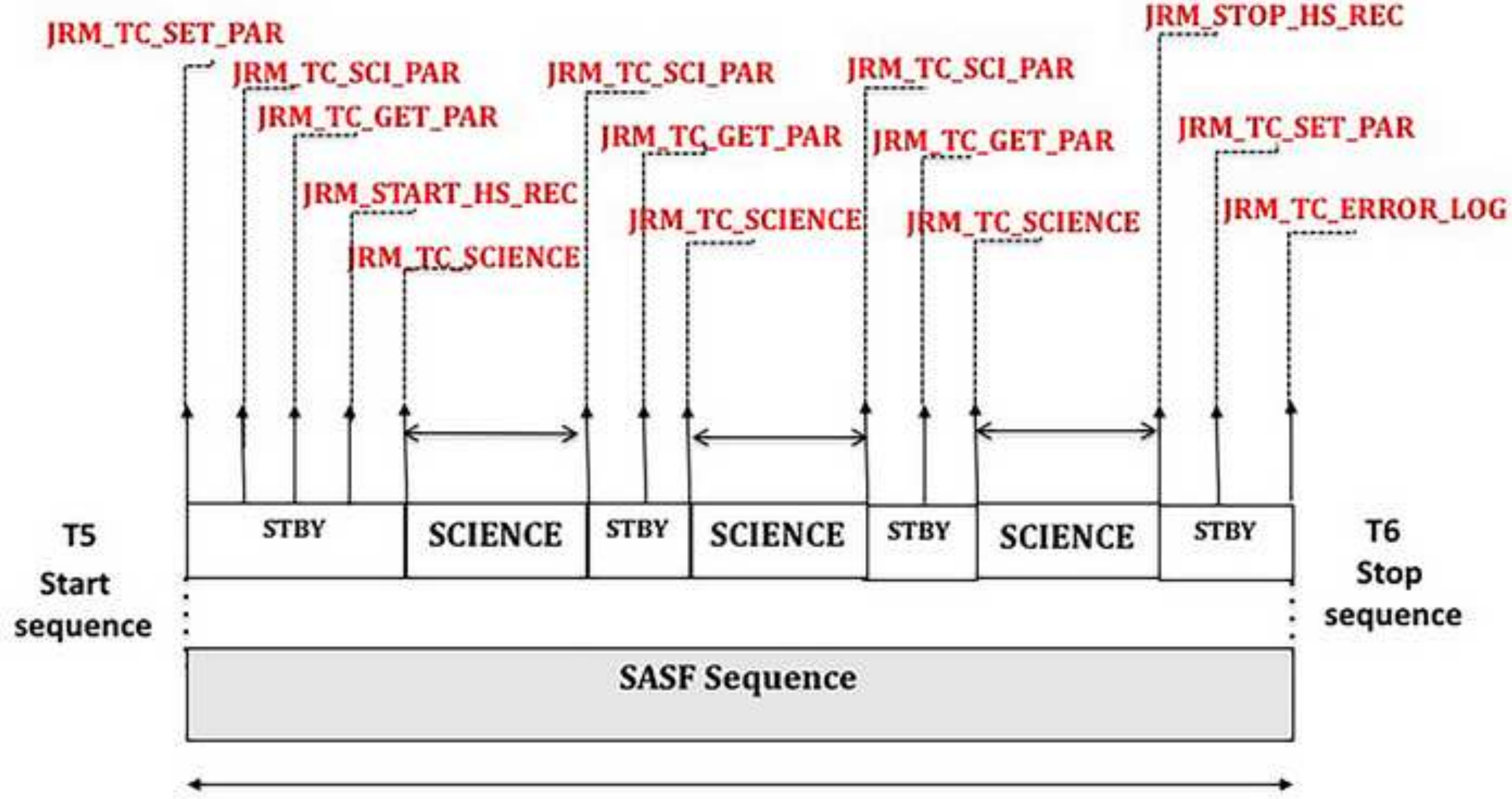
Figure


JRM_TC_SET_PAR
JRM_TC_SCI_PAR
JRM_START_HS_REC
JRM_TC_SCIENCE
JRM_TC_ERROR_LOG
JRM_STOP_HS_REC
4 s
4 s
4 s
4 s
T3
Start
sequence
STBY
SCIENCE
STBY
T4
Stop
sequence
Start
Science
Stop
Science
SASF Sequence

Figure


Subtraction enabled on board
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
BK >=2 acquisition = Buffer_A-Buffer_B
BK =1 acquisition = Buffer_A-Buffer_B
BK =0 acquisition = Buffer_B-Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 ; BK =1; BK =0
acquisition = Buffer_B-Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 ; BK =1; BK =0
acquisition = Buffer_B-Buffer_A
Buffer_A
BACKGROUND
Buffer_B
READOUT NOISE
BK >=2 acquisition = Buffer_A-Buffer_B
BK =1 acquisition = Buffer_A-Buffer_B
BK =0 acquisition = Buffer_B-Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 ; BK =1; BK =0
acquisition = Buffer_B-Buffer_A
First acquisition
Second acquisition
Third acquisition
Fourth acquisition
Fifth acquisition
Hard Partition
Subtraction disabled on board
Buffer_A
BACKGROUND
Buffer_B
RECEIVER NOICE
BK >=2 acquisition = Buffer_A
BK =1 acquisition = Buffer_B
BK =0 acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 and BK =1 acquisition = Buffer_B
BK = 0 acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 and BK =1 acquisition = Buffer_B
BK = 0 acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 acquisition = Buffer_A
BK =1 acquisition = Buffer_B
BK =0 acquisition = Buffer_A
Buffer_A
BACKGROUND
Buffer_B
Target
BK >=2 and BK =1 acquisition = Buffer_B
BK = 0 acquisition = Buffer_A
First acquisition
Second acquisition
Third acquisition
Fourth acquisition
Fifth acquisition

Figure


JRM_TC_SET_PAR
JRM_TC_SCI_PAR
JRM_TC_GET_PAR
JRM_START_HS_REC
JRM_TC_SCIENCE
JRM_TC_SCI_PAR
JRM_TC_GET_PAR
JRM_TC_SCIENCE
JRM_TC_SCI_PAR
JRM_TC_GET_PAR
JRM_TC_SCIENCE
JRM_STOP_HS_REC
JRM_TC_SET_PAR
JRM_TC_ERROR_LOG
T5
Start
sequence
STBY
SCIENCE
STBY
SCIENCE
STBY
SCIENCE
STBY
T6
Stop
sequence
SASF Sequence

Highlights

- We describe the in detail the activities of planning and commanding for JIRAM.
- We describe the observation strategy to construct robust observation timelines.
- We describe the timing of JIRAM science observation.