Arrakihs – ESA F2 mission

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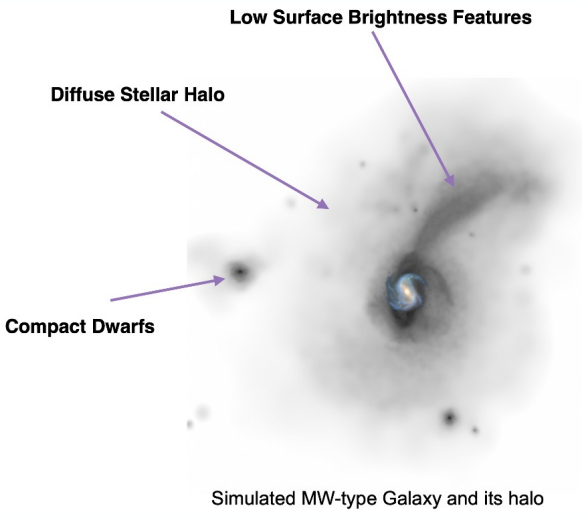
Arrakihs Science Goals

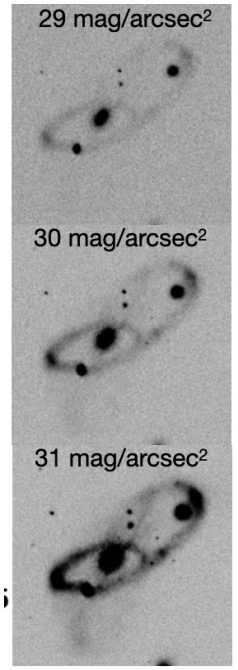
- Galaxies grow over time by merging with and absorbing smaller galaxies (hierarchical formation)
- The remains of these events are still present in the form of diffuse stellar halos, streams and compact dwarf galaxies. All these features are extremely faint.



Simulated MW-type Galaxy and its halo

Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Survey

- Study the properties of the accreted stellar mass of Low Surface Brightness Features and the Diffuse Stellar Halo
- in a statistically representative sample (80-100) of MW-type galaxies in the local universe (10-40 Mpc)
- Observing a region of at least 150kpc radius centered in each galaxy
- With deep SBL simultaneous observations in 4 filters at Surface Brightness < 30 mag/arcsec^2 in VIS and < 29 mag/arcsec^2 in NIR



To understand how the observable properties of the stellar outskirts in MW-like galaxies probe the assembly of dark matter halos and stellar mass of the central galaxy

ESA F-Class Mission

- Arrakihs is a **F**- (Fast track development) mission, different from Medium- or Large-class mission:
  - **Budget** constraints (~ 1/8 of L-class, < 1/3 of M-class).
  - **Reduced development time** (<8 yr from proposal selection to launch, ~ 1/2 of M-class).
  - Project to rely on re-use of existing and flight qualified solutions (P/L and PF, **TRL ≥ 6** at mission adoption = PDR)

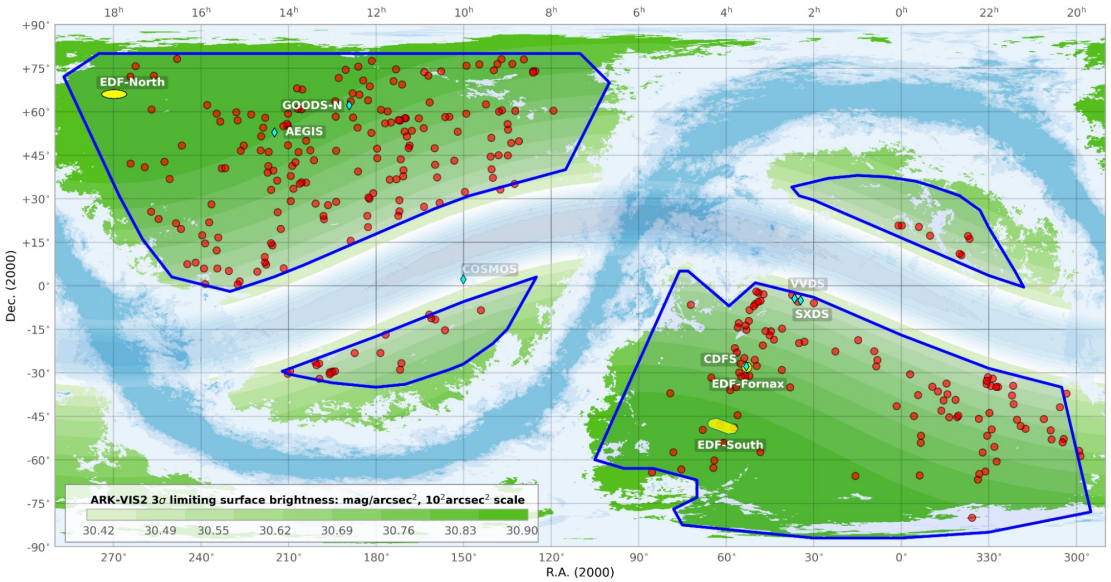
- After a selection process in 2 phases, the ESA Science Programme Committee (**SPC**) selected **ARRAKIHS** as **F2** mission in Nov 22.

- Lead Proposer: Prof. Rafael Guzmán, IFCA, Spain

- **Phase 0** completed in 2023
- Mission **adoption** is planned for June **2026**
- Targeting a **launch** in **2030**

Arrakhis Observation Strategy

- Science observations of individual galaxies will be made as a set of **10-minute exposures**, which will be combined on ground to achieve the required sensitivity and image quality.
- Each target in the survey will be observed for a total of **150 hours**, combining **900 exposures** of 10-minute integration time.
- After 3 years of science operations, the survey will include at least **80 target galaxies**.



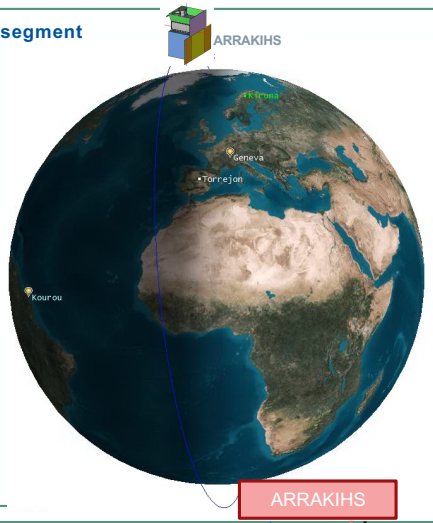
Sensitivity Map of Arrakihs
Red dots – Arrakihs target pool
Blue lines – Euclid wide survey
Yellow lines – other deep surveys

ARRAKIHS Mission Summary

Launch segment

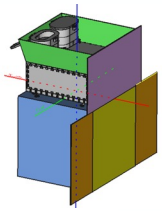
- **Launch** in **Q4-2030**
- Baseline scenario: **VEGA-C** launch from **Kourou**
- **Compatibility** with **small European launchers**

Space segment

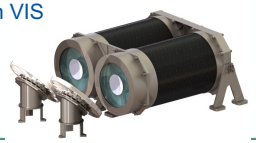


Orbit
- **Dawn-dusk SSO**
- Altitude: **700 km**
- Up to **60 deg off-pointing** towards Zenith
- Up to **40 deg off-pointing** towards Sun

Spacecraft
- 600 kg
- ~1.5 x 1.5 x 1.2m

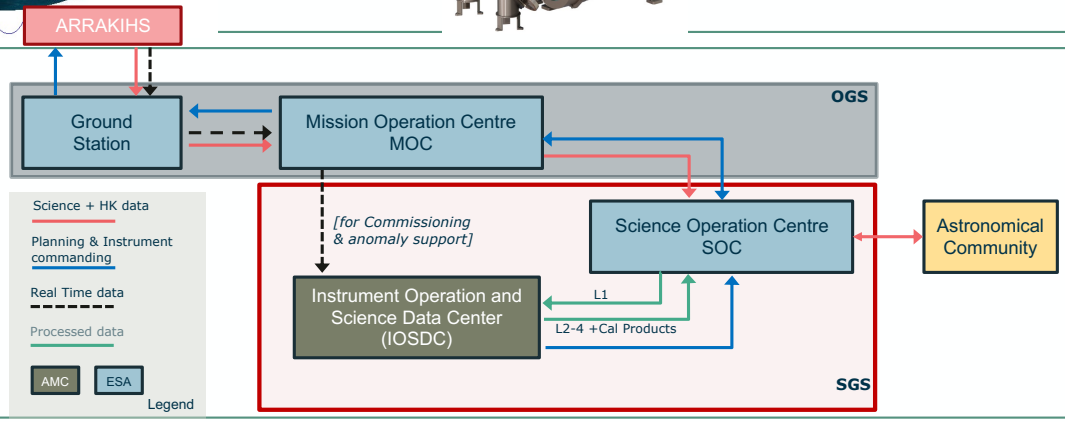


Payload
- 150 kg, 100 W
- 4 15-cm telescopes
- Observing in VIS and NIR



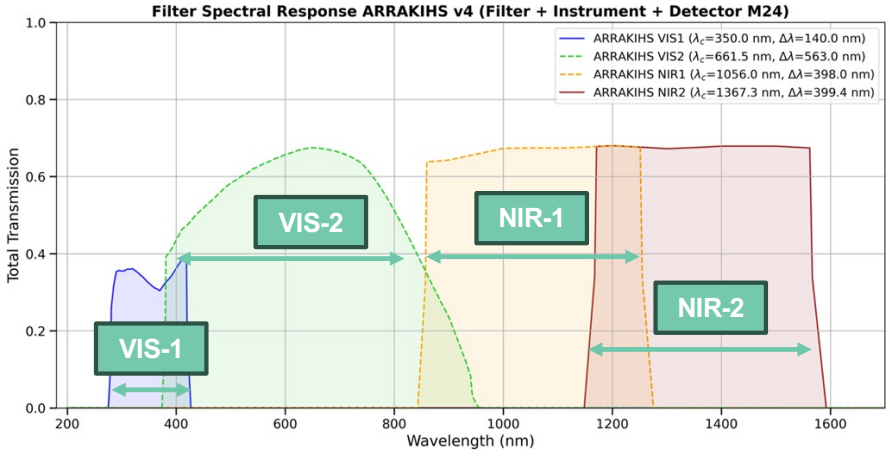
- **Downlink capability: 48.5 Gbits per day (limitations due to ITU category (Space Research)**
- **Compliance with latest Space Debris Mitigation: Re-entry within 5 years**

Ground segment



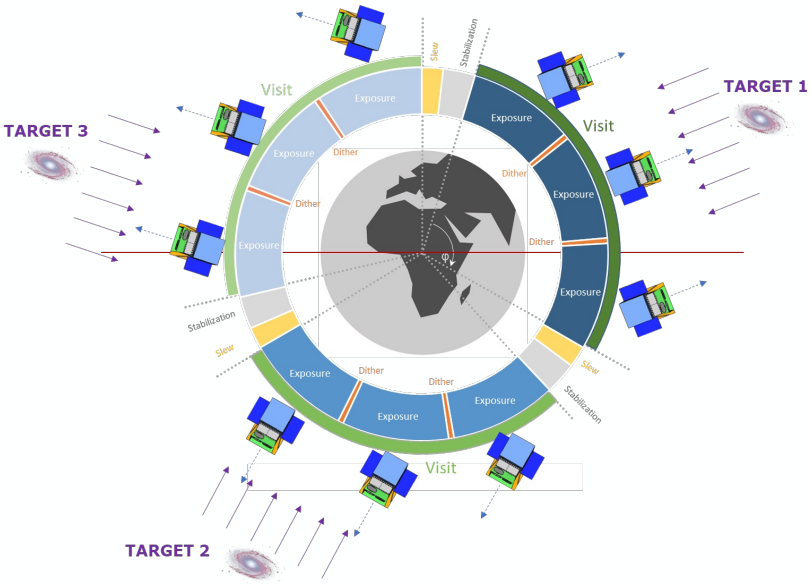
Payload

Arrakihs instrument overview	
Concept	Simultaneous imaging in 4 channels from 280 to 1600 nm Fine Guiding Systems thanks to NIR channels Passive cooling of detectors down to 150 K +/- 10 mK (NIR)
Budgets	Mass: 160 kg Power: average 100 W, peak 165 W Data: ~6 Gb /day Volume: Telescope and Camera Module (TCM) ~1x1x0.8 m, Electronics box: ~33x27x23 cm
Design features	4x Maksutov-Cassegrain f/10 150 mm telescopes: ~1.3° field of view per channel, >1.15° common, based on Satlantis iSIM170 Detectors: Te2v CIS304-33 (VIS), Teledyne H2RG 1.7 um cut-off (NIR) Light and stiff CFRP structure with 3 isostatic Ti bipods mount Straylight baffle based on COROT and CHEOPS
Performance	Photon-noise limited observations drive exposure durations of 10 mins and consecutively the VIS and NIR detector operating temperatures. Sensitivity: SNR > 3 at 30.5 mag/arcsec^2 (VIS2) Resolution EE50: better than 1.5 arcsec (VIS) and 2.7 arcsec (NIR) Pointing Relative Performance Error incl. FGS: 1 arcsec (3σ, 99.7%) over 10 minutes.

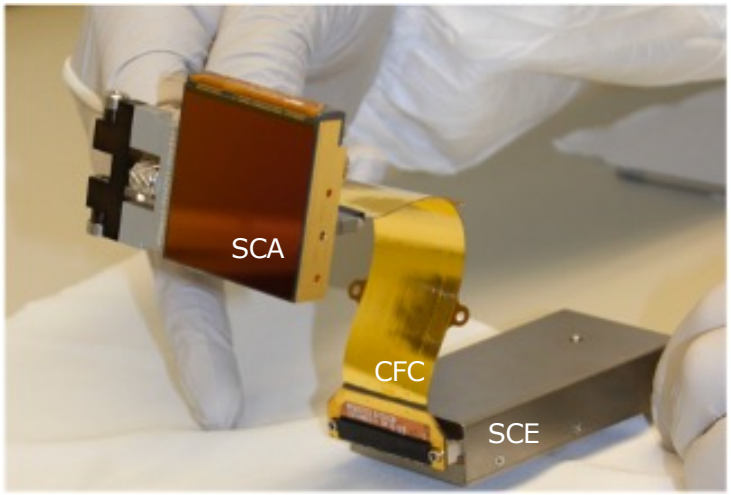


Observation strategy

- Science operations consist of observations of the science targets acquired simultaneously in the four bands of the Arrakihs instrument
- When pointed to a target galaxy, Arrakihs will acquire one or more consecutive images of the target, each with an exposure time of 10 minutes
- The **Sun** and **Earth angle constraints** determine which targets can be observed at any given time
  - Typically, 2 to 4 targets are observed per orbit
  - Each visit includes 1-3 dithered exposure



Arrakihs NIR detector system - I



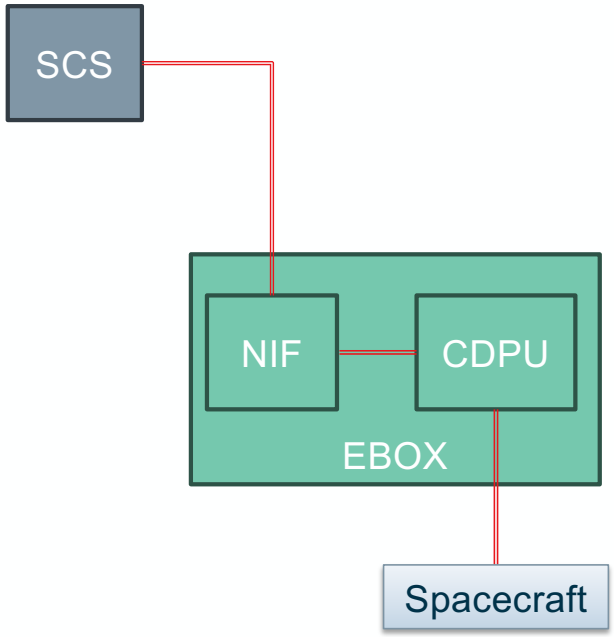
Expected performances at T=150K

Dark Current	0.05 e-/pix/sec
Read Noise.	30 e-
Total Noise	15 e- (Fowler-16, 10min integration)

Sensor Chip System (SCS)

- Sensor Chip Assembly (SCA)
  - Teledyne H2RG (2048x2028 - 18μm pixel)
    - No specific development
    - Cut-off (1.7μm) and AR coating tuned to Arrakihs need
    - H4RG RST recipe to minimize persistence
- Sensor Chip Electronics (SCE)
  - Teledyne sidecar ASICs
  - Re-use of non-hermetic packaging qualified for JPL NEO surveyor
  - Custom Firmware by Markury Scientific to support FGS operations
- Cold Flex Cable (CFC)

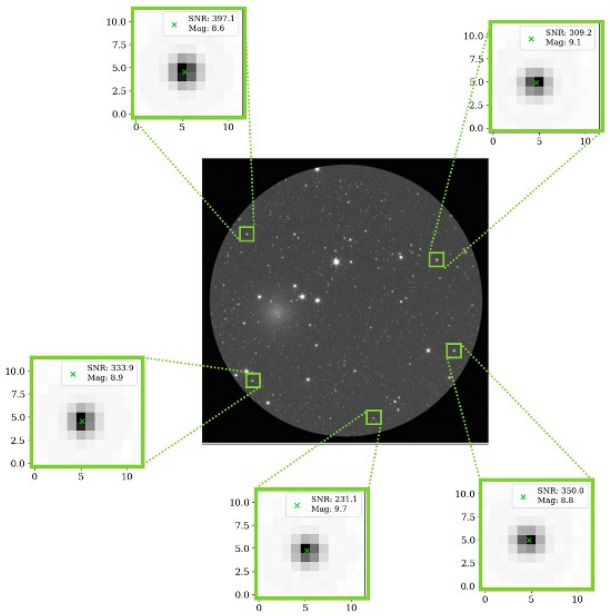
Arrakihs NIR detector system - II



- Near IR Interface Board (NIF) by IDEAS (NO)
  - Provides digital and analogue low noise voltage to ASIC
  - Manage communication (data and configuration) between ASICs and CDPU
  - Performs intermediate data processing (group averaging)
  - Extract and provide Region of Interests to the CDPU for FGS operations
- Control and Data Processing Unit (CDPU) by IWF (AT)
  - Monitor and operate the instrument (VIS+NIR)
  - Detector readout sequencing, timing and synchronization
  - Data processing, data compression
  - Housekeeping acquisition
  - FGS operations and real-time attitude feedback to S/C

FGS Operations - II

- Payload-in-the-loop concept

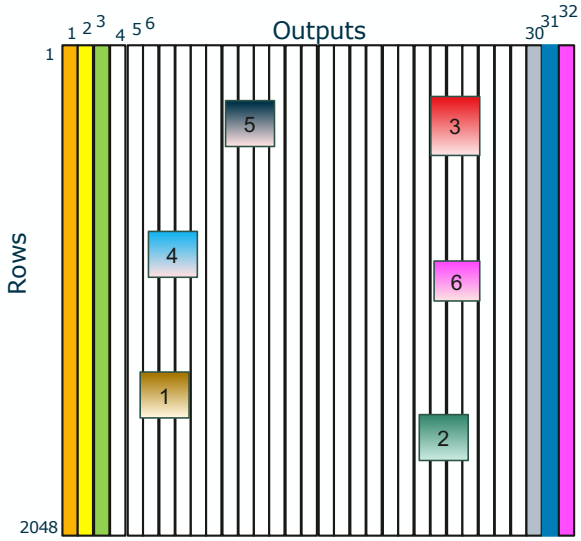


- During a science integration, every single read from NIR-1 is used to extract dedicated Region of Interests (ROIs) around ~25 Guide Stars (GS) in the FOV automatically selected during the acquisition phase.
- During the integration, these ROIs are transferred from the NIF to the CDPU which computes stellar centroid in the differential frames of the available ROIs and derives a pointing correction vector to pass to AOCS.
- Frequency of correction depends on the frame rate. Baseline is the 1.46 sec/frame clocking at 100 khz. Ongoing trade-off for increasing clocking rate of 200 khz.
- **PROBLEM**: Several GSs will however saturate during the 10 min exposure, and potentially deteriorate the pointing accuracy during the exposure

See Roman Zoufal's Poster : " Arrakihs FGS task and simulator"

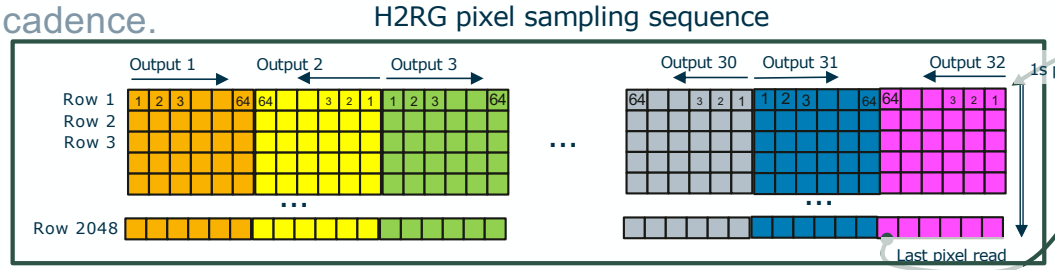
FGS Operations - II

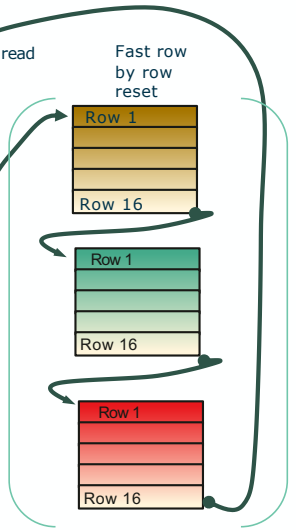
Solution: At the end of each full frame read, one or more ROIs are reset in rotation so that each ROI is reset at least once with a difference regular cadence.



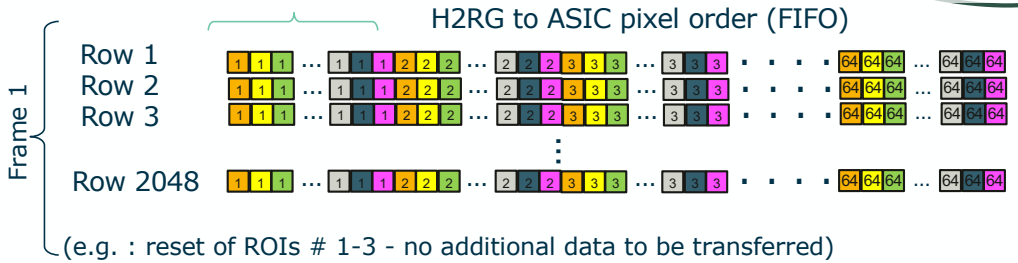
A dedicate ASIC firmware is necessary.
See Markus' talk

H2RG pixel sampling sequence

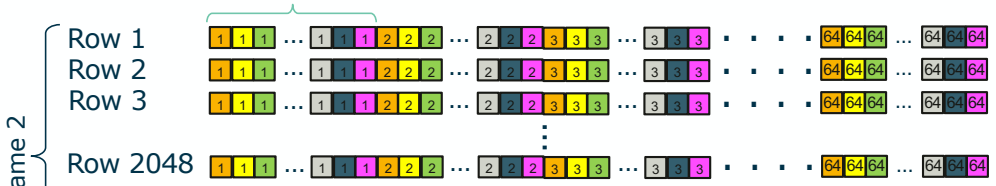




H2RG to ASIC pixel order (FIFO)



(e.g. : reset of ROIs # 1-3 - no additional data to be transferred)



(e.g. reset of ROIs #4-6 - no additional data to be transferred)

This activity becomes part a new frame Overhead "NFOH"

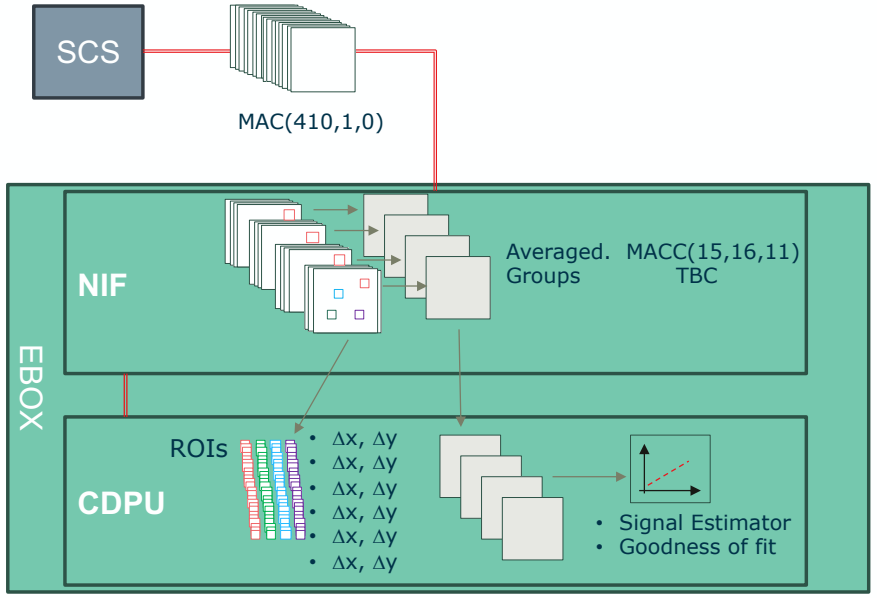
NIR on-board processing

Limited data budget requires data processing on board:

1. All frames are sent from the ASICs to the NIF
2. NIF extracts ROIs and send them to CDPU for FGS ops
3. NIF combines groups and send them to the CDPU
4. CDPU performs Euclid like processing
    1. Reference pixel correction
    2. Signal estimator [1]
    3. Goodness of fit calculation [2]

    } Kubik et al. 2016

5. CDPU package and compress [1] + [2] and send them to the S/C for downlink



Key requirements

For Arrakihs science these are major source of concern:

a) Stability of the system

b) Total noise (both from the instrument and scene)

c) Control of the systematics

- **Total noise on Level 3 (co-added images)**

  NIR1: ≤ 4 e- within a 100 arcsec^2 aperture area

  NIR2: ≤ 5 e- within a 100 arcsec^2 aperture area

Detector Specifications

Cut off. 1.7+/- 0.1 μm

Dark current* (@150K) EOL < 0.25 e-/pix/sec

FW* > 80 Ke-

Total Noise* (SCS) < 15e- RMS (BOL)

Read Noise* (SCS) < 30e- RMS (BOL)

Operability > 95%

*Persistence**: 3 e-/s after 5 minutes of a stimulus of 85% full well*

*Median value

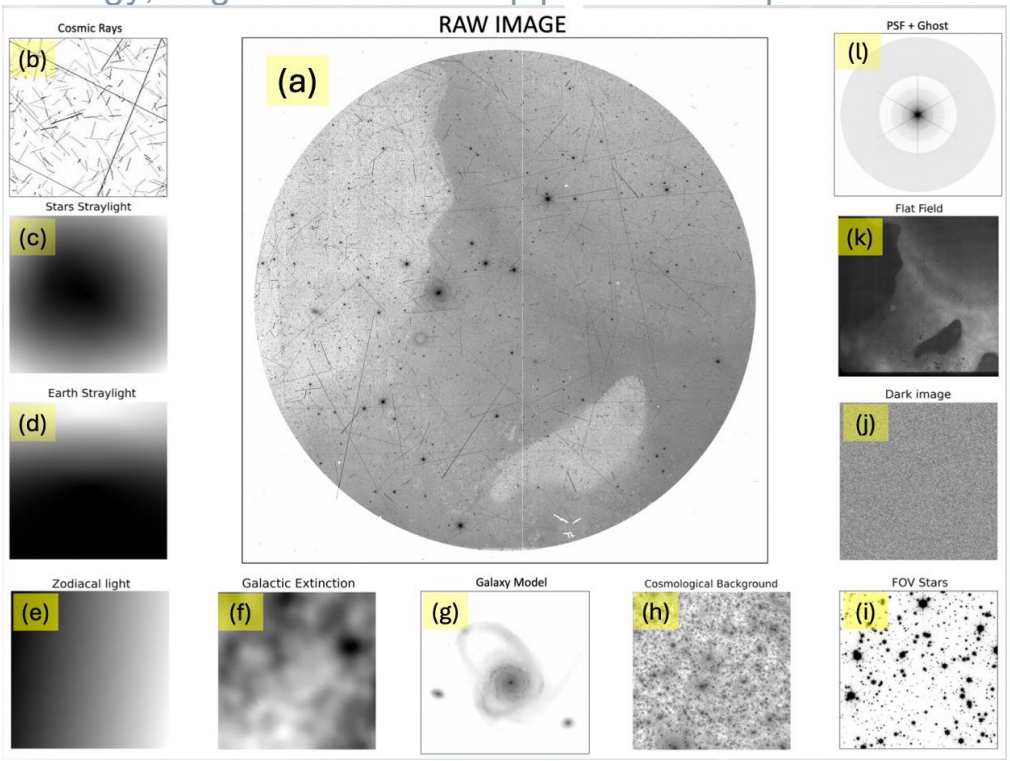
** ROMAN MCT grow recipe to minimize persistence

NIR Requirements vs. Current best estimates

Parameter	Requirement AD1	CBE (nego & KO slides)	Comment
SCA QE	0.5 @ 800, 1000 nm (95% > 0.3) 0.7 @ 1230, 1500 nm (95% > 0.5) <10% wavelength gradient	0.85 @ 1230 nm	
SCA cut-off	1.7 +/- 0.1 um		
SCA Qlin	80 ke- (5% departure from linearity)		
SCA dark current	BOL: 0.2 e-/pix/s EOL: goal 0.25 e-/pix/s	BOL: 0.05 EOL: ?	T < 150 K
SCA persistence	Req: 3 e-/pixel/s Goal: 0.2 e-/pixel/s	Values measured at T = 150 K show less than 0.5 e-/pixel/s for one device	5 mins after 85+/-5% full well illumination.
SCS readout noise	BOL: 30 e- rms EOL: TBD	EOL: less than 1e- increase	CDS
SCS total noise	BOL: 15 e- rms EOL: TBD	BOL: 10 EOL: less than 1e- increase	Fowler-16, 10 mins integration
SCS operability	Dark current < 0.75 e-/s/p (SCA) QE at 1230nm > 30% (SCA) Total noise < 27 e- (SCS)	Distributions have been shown, There is some margin.	95% of pixels
SCA offset channel to channel variation	7%	1% (measured at 120 K) but larger values measured	
SCS crosstalk	7%	Requirement based on measurement	Incl. IPC, diffusion (channels to channels < 0.1 %) – see req. for measurement method.
SCS gain	TBD	[1,2] e-/ADU	
Power dissipation	SCA < 2.7 mW SCE < 450 mW	SCA marginal Some margin for SCE	Requires SCA drain tuning Values confirmed for buffered mode and T = 150 K

Simulations

AMC is carrying out major end-to-end simulations to study impact of/mitigate systematics, optimize observation strategy, target selection and pipeline development



a) Final raw image simulating one 10min exp (1 of 900)
b) Cosmic rays
c) Out of FOW star straylight
d) Earth Straylight
e) Zodiacal Light
f) Galactic Extinction
g) Galaxy model
h) Cosmological background
i) Gaia FOV stars
j) Dark image
k) Flat field
l) PSF+Ghosts

H2RG Detector effects
are simulated with Pyxels.
When Arrakihs detector data will be available will be
Used by Pyxels to increase fidelity of the simulation

See Frederic Lemmel's Poster : " Pyxel 2.0"

Procurent and Calibrations

- Procurement campaign is ongoing. Prototype + EM/FM as two separate ESA contracts with Teledyne
- Acceptance and testing at ESTEC, IFAE (UAB) with support from IFCA (Santander)

- Prototype procurement:
  - Bare ROIC + ground-based sidecar - tested at ESTEC, now at IFAE for checkout of testing facility
  - **1.8** um cut off H2RG +1x Hybridized array + sidecar + CFC ('Engineering grade' model)
    - Currently tested and characterized at ESTEC with a prototype of the customized firmware

See Eloy Hernandez (here and SPIE in DK)

- EM/FM Procurement
  - EM (1) June 2026. Acceptance testing at ESTEC, Characterization at IFAE
  - FM (2+1) June 2027 Delivered directly to IFAE (Group lead by C. Padilla)

Summary and future steps

- In order to reach the faintest SBL, Arrakihs will push the control of systematics to the limit

- It will benefit from lesson learned from past, current and upcoming missions employing HxRG devices

Milestone	Date
Selection of Arrakihs as F2 mission	Nov 2022
Mission Definition Review	Sep 2023
Mission Requirements Consolidation Review	Jan 2026
PDR	Mar 2026 (Instrument), Jun 2026 (System)
Mission Adoption	Jun 2026
Phase 2 Prime Contractor Selection	Q3 2026
Phase 2 (C/D/E1) Industrial Kick-off	Jan 2027
Ground Segment Design Review	Dec 2027
CDR	Jan 2028 (Instrument), Jun 2028 (System)
Mission Design Review	Sept 2028
Instrument PFM Delivery	Jun 2029
QAR	Jun 2030
Launch	Dec 2030
In-Orbit Commissioning Review	Mar 2031

- Expected Mission Adoption (approval of schedule and costs) in June 2026

- Delivery of the Flight NIR detector is expected in Jun 2027

The timing of IRIS 2026 is perfect for Arrakihs !