ARRAKIHS

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

Action Dark Energy

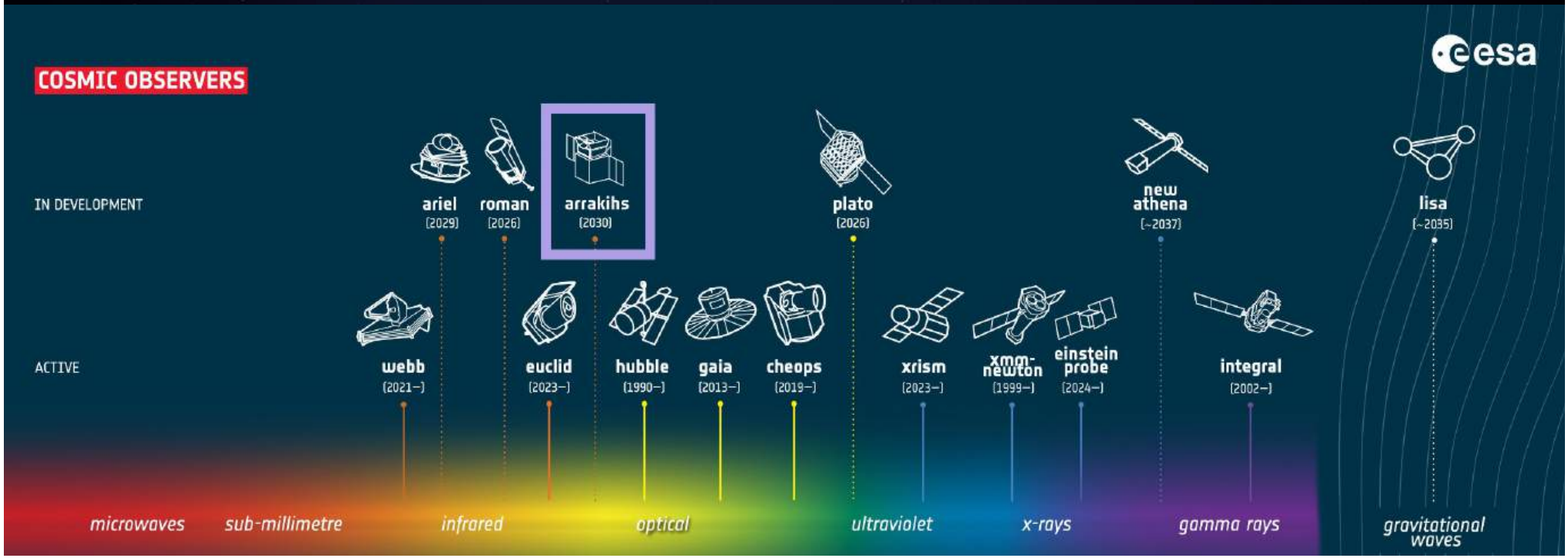
Institut Henri Poincaré (Paris), October 28-30, 2024

Rafael Guzmán, ARRAKIHS Mission Consortium Lead (IFCA & UF)

ARRAKIHS: ESA F2 Astrophysics Mission

ARRAKIHS

- ESA Fast Class Mission
- Call of opportunity Dec 2021
  - 19 F-class proposals submitted
  - Successfully passed phase 1 with 4 other missions
  - ARRAKIHS proposal *(Guzmán, Serrano + AMC)* selected as the F2 Mission in Nov 2022



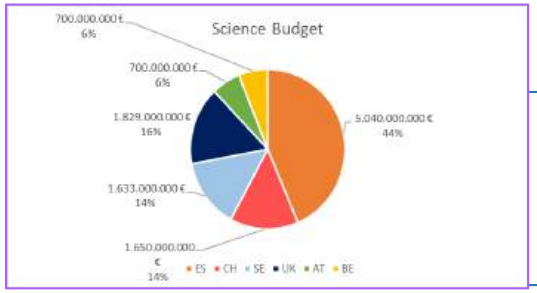
Consortium, Organization and Timeline

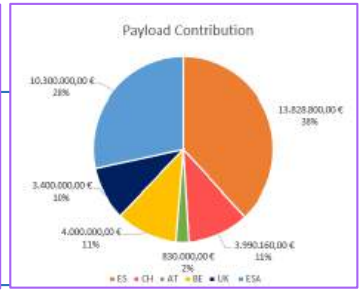
ARRAKIHS

ESA/F2-Mission (CoC 175M EUR)

CONSORTIUM (PAYLOAD + GROUND SEGMENT + SCIENCE)

	A/B	C/D/E	TOTAL	
Research Centers	3.691.000 €	13.801.000 €	17.492.000 €	
Industry	3.474.860 €	17.104.100 €	20.578.960 €	
			38.070.960 €	TOTAL





Over 160 scientists and engineers from over 20 research institutions and industrial partners worldwide.

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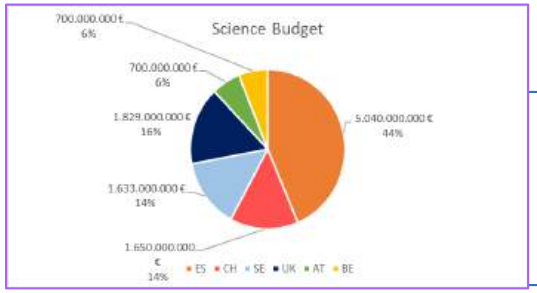

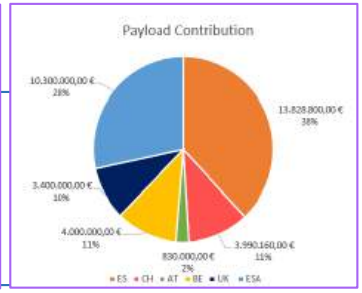

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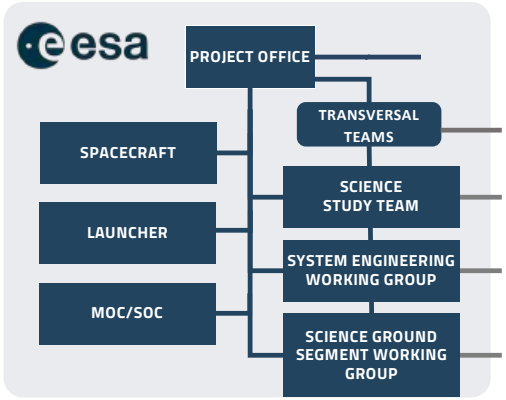
European Space Agency (ESA)

ARRAKIHS Mission Org.



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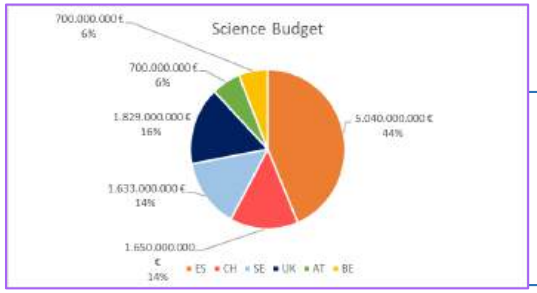

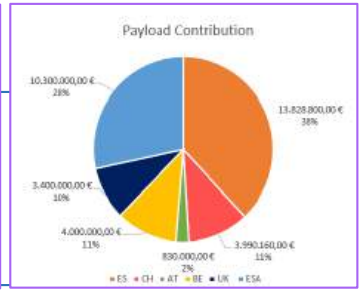

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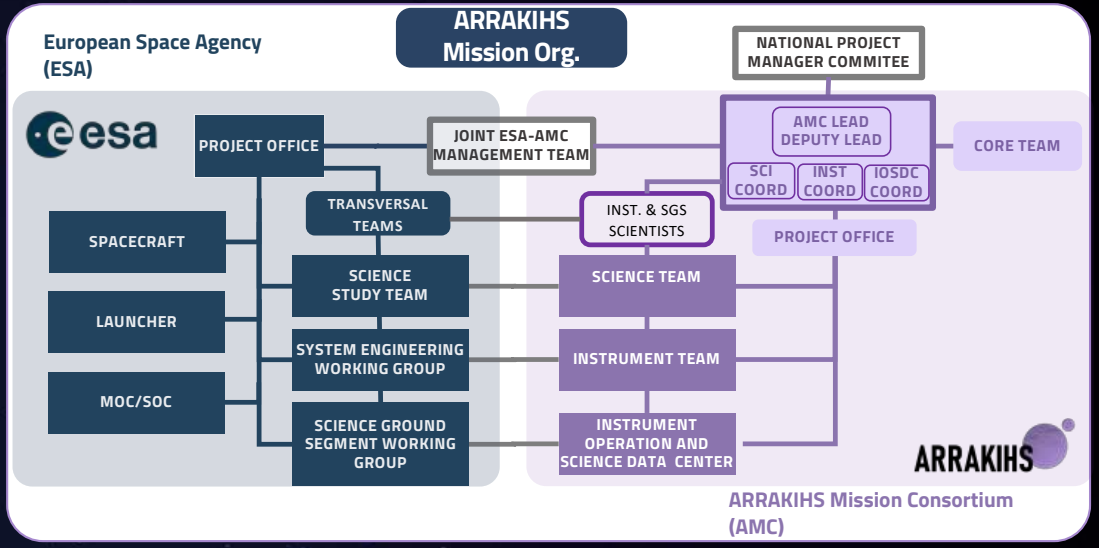

Consortium, Organization and Timeline

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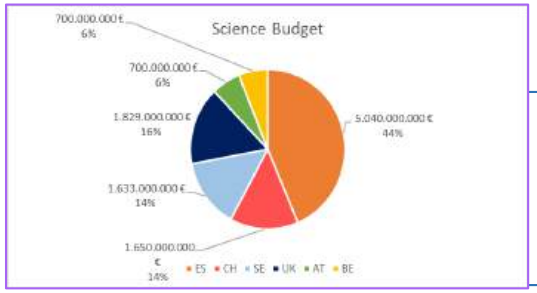
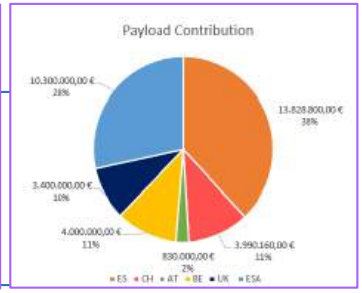
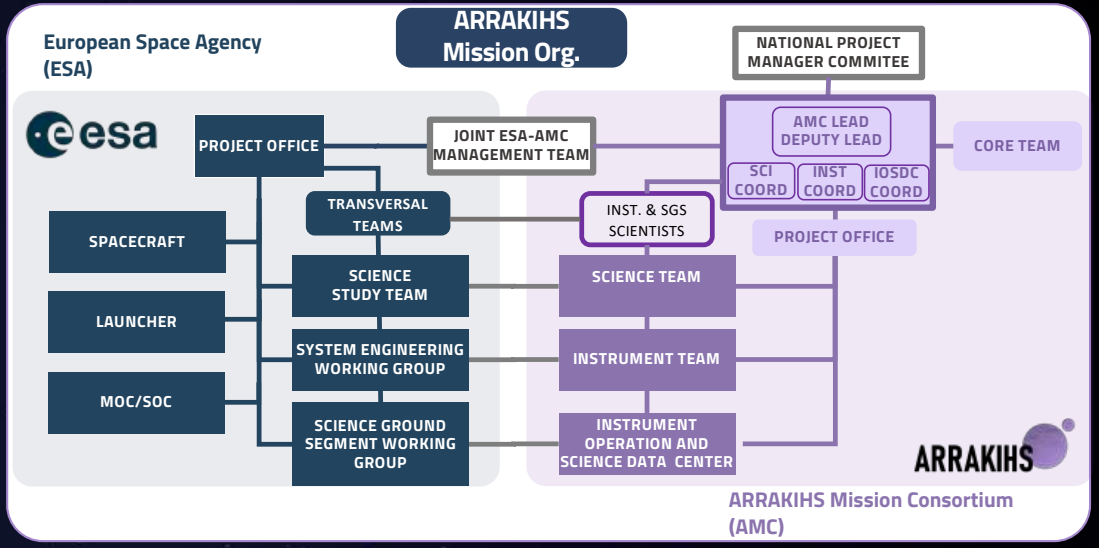
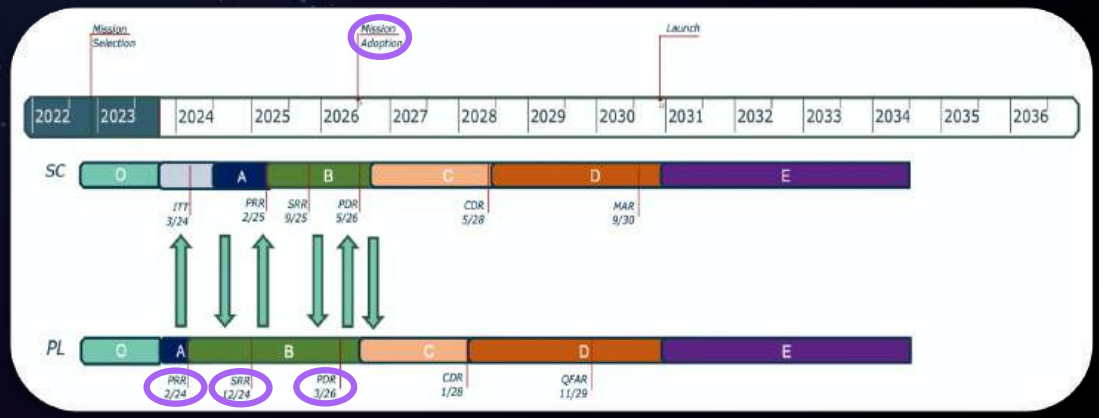




Over 120 scientists and engineers from over 20 research institutions and industrial partners worldwide.

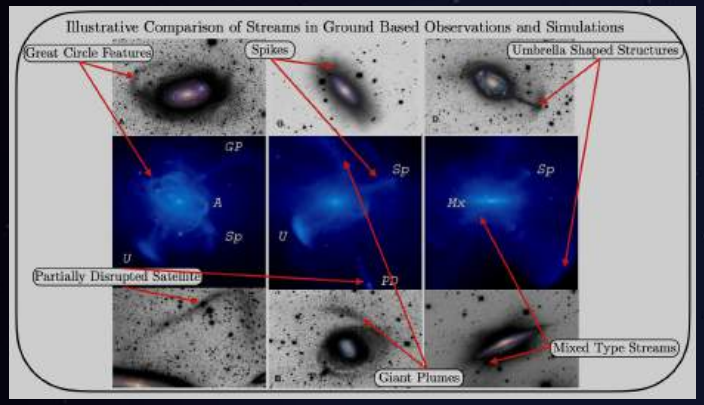




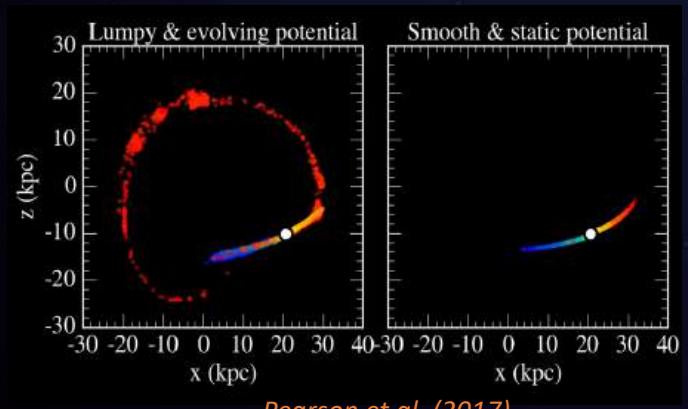
Science Goal: Resolve the Tensions with CDM at Galaxy Halo Scales

ARRAKIHS

1) Stellar Streams: Statistics and Shapes

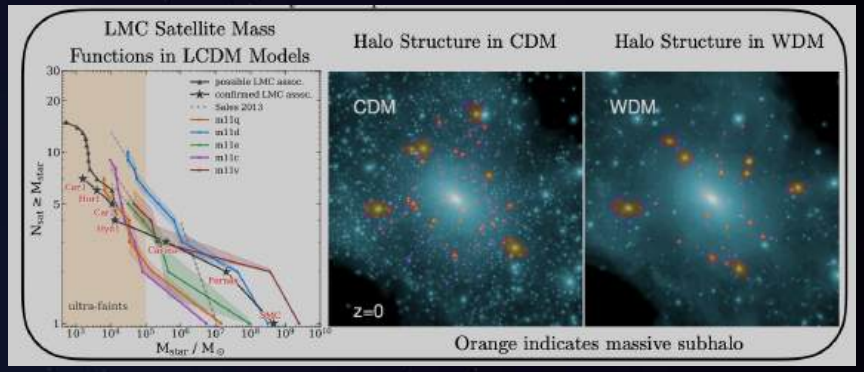


Martínez-Delgado et al. (2010, 2012, 2015, 2021)

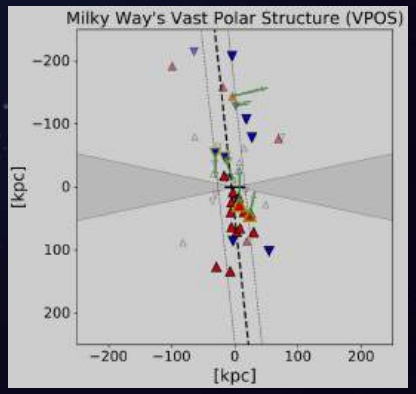


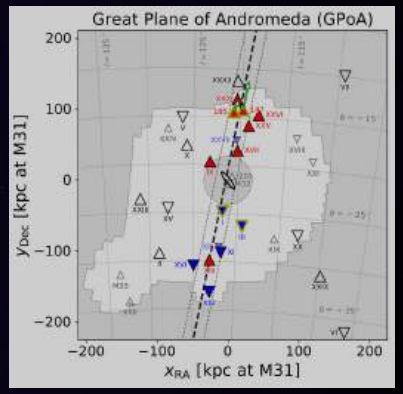
Pearson et al. (2017)

2) "Missing Satellites" and "Satellite Planes" problems:



Jahn et al. (2019)





Pawlowski (2021)

VIS+NIR Observations of MW-type Galaxy Halos at Ultra-Low SB

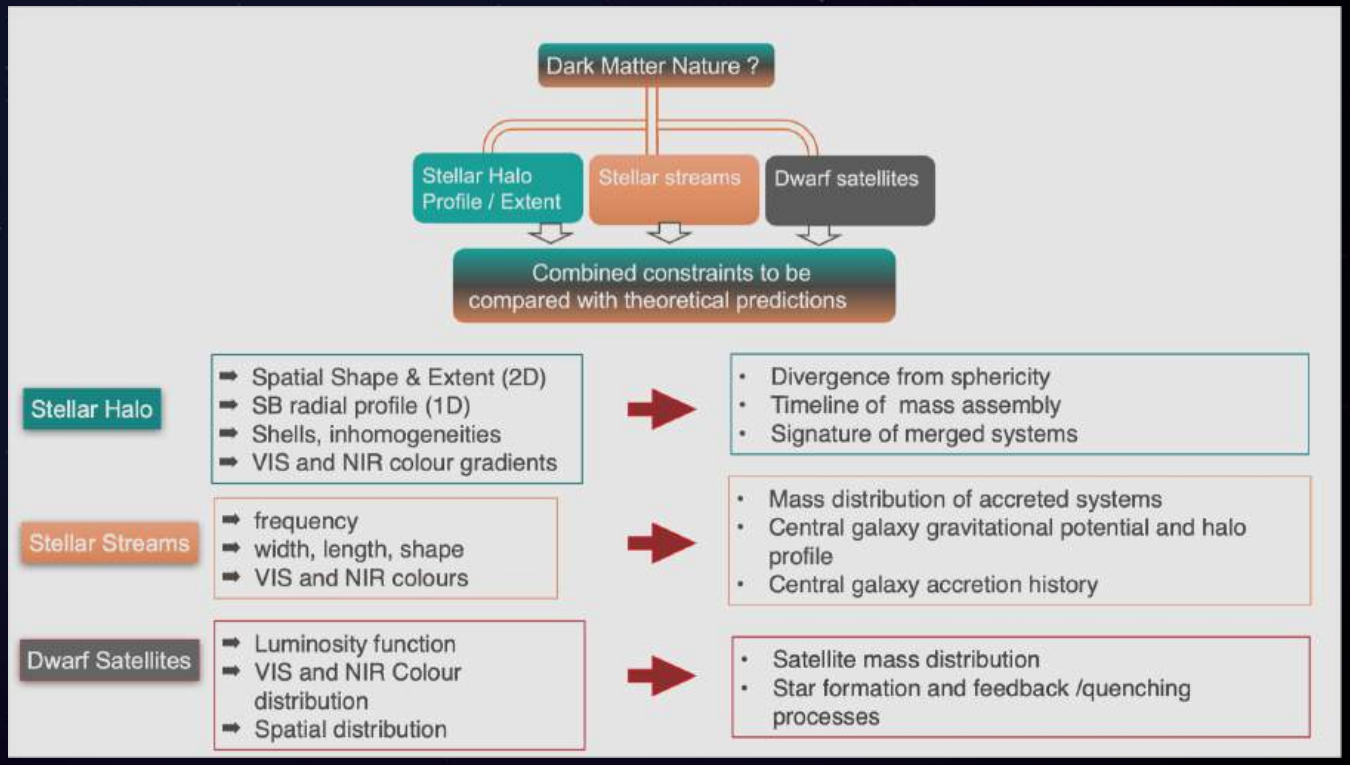
ARRAKIHS

Mission Statement: "ARRAKIHS will assess the significance of reported tensions between predictions of the Cold Dark Matter (CDM) cosmological model at galaxy halo scales, the current implementation of baryon physics (BP) in galaxy formation models and the observed properties of the haloes of the Milky Way (MW) and Andromeda galaxies. To test the predictions of the CDM+BP models, ARRAKIHS will obtain deep, simultaneous, visible and infrared imaging of a statistically representative sample of nearby haloes of MW-type galaxies in the local universe, down to unprecedented low surface brightness."

ARRAKIHS if the first mission specifically designed to explore the Ultra-Low SB features of the halos of MW-type galaxies through the optimization of:

(1) Instrument;
(2) Observational Strategy; and
(3) Image Processing Algorithms.

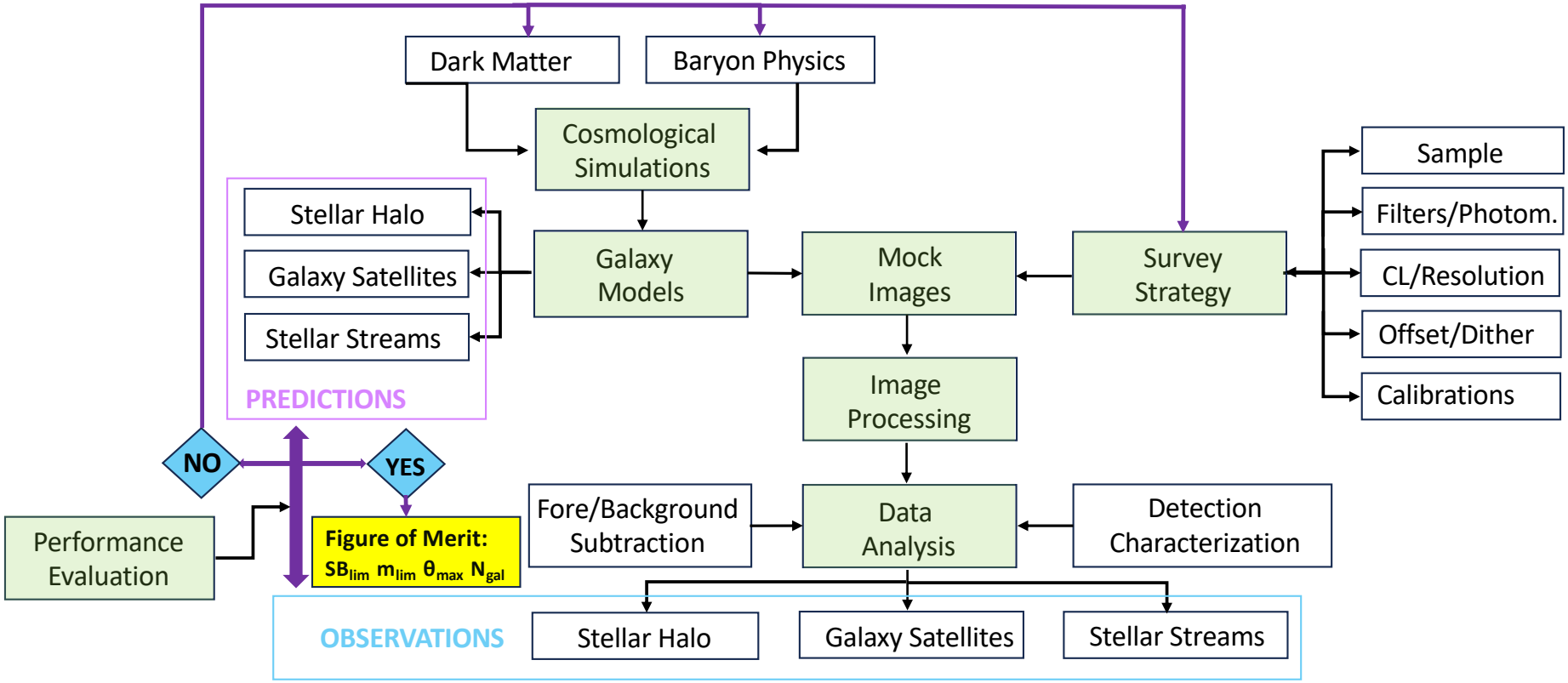
In addition, ARRAKIHS will run **extensive cosmological simulations** to provide state-of the art predictions on the Ultra-Low SB features of the halos of MW-type galaxies for different combinations of DM+BP.



SciRD: Guzmán, Jablonka, Isaac + AMC (2023)

Science Project Flow Chart

ARRAKIHS



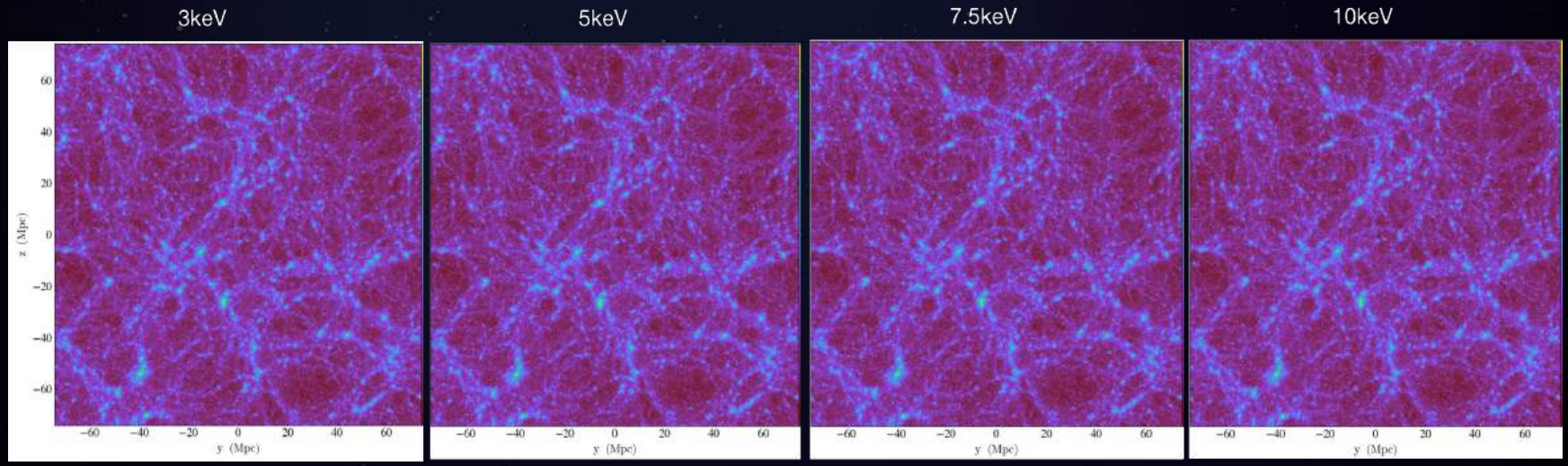
The "Harkonens" Cosmological Simulations

ARRAKIHS

Cosmological models HARKONENS (Horizon-ARraKihs ONset of Enlightening New Simulations):

1

50 cosmological zoom-in simulations (~30 pc) to resolve the formation of small satellites and the thickest streams, in six different dark matter flavours (3, 5, 7.5, 10, 30 keV, self-interacting) - Dark matter only first, with baryons later with the same cosmology (Planck+2018) using "Swift" and "Ramses" the fastest and more flexible codes available. We will rely on the cosmological box already simulated at intermediate resolution by the HorizonAGN group, and that has been extensively tested against observations.



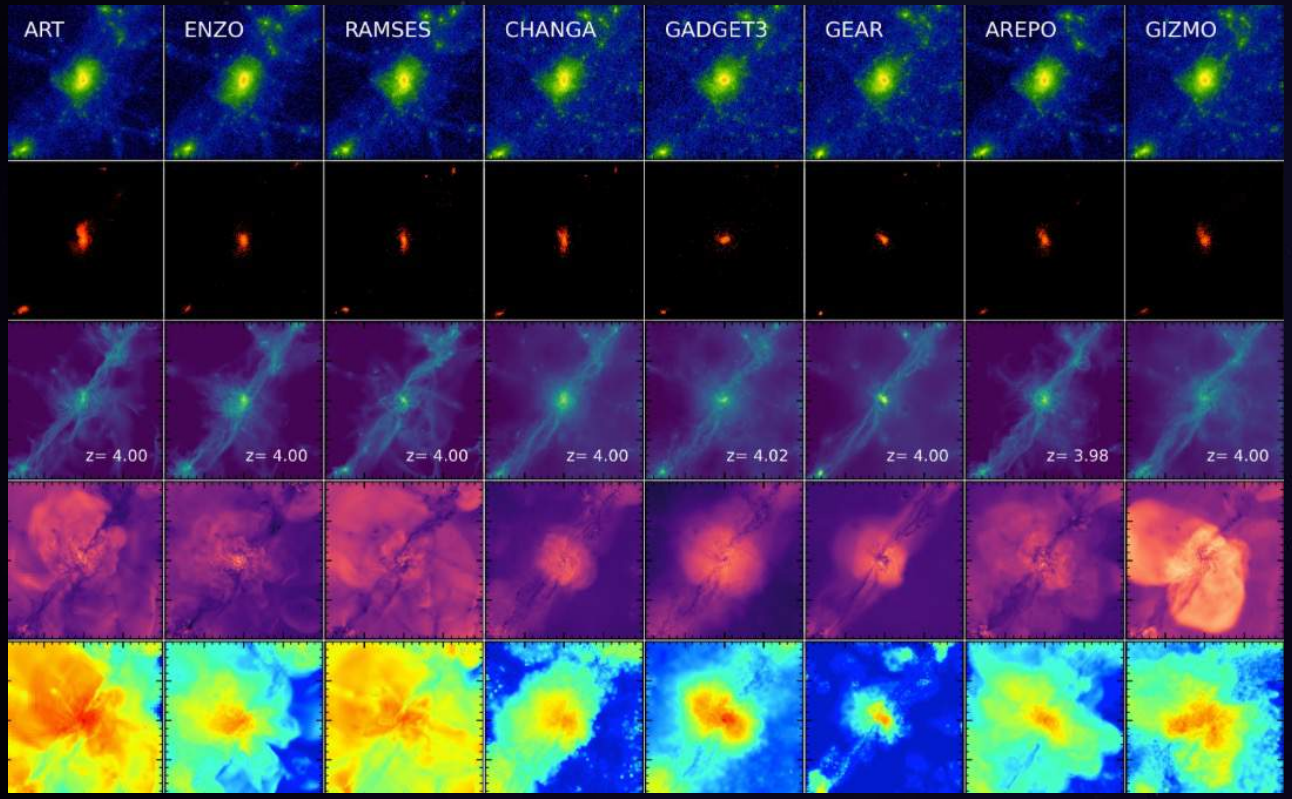
Dubois et al. 2016

The "Harkonens" Cosmological Simulations

ARRAKIHS

2

Two additional zoom-in simulations with the AGORA initial conditions will be ran. The AGORA halo has been ran already using all the most widely used numerical codes in the community. Thus a direct comparison will allow us to find out which parameters are code-dependent.



Roca-Fàbrega et al. 2024, 2021; Jung et al. 2024; Strawn et al 2023; Kim et al. 2014, 2016

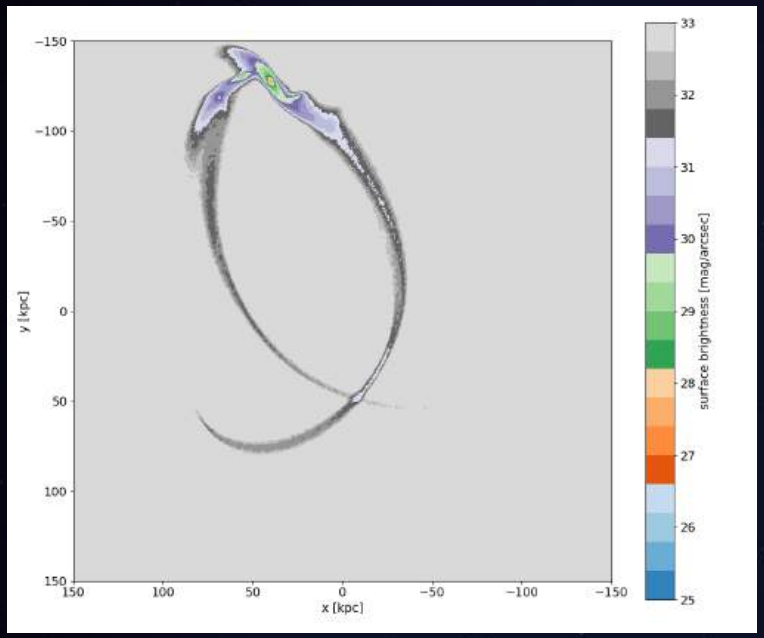
The AGORA CDM halo will be ran with small variations in the baryonic physics recipes to see the effect each has on the distribution and properties of satellites and streams, including:

- Stellar Feedback
- UV-background reionization
- Star Formation
- Cooling/Heating
- AGN feedback
- Magnetic fields

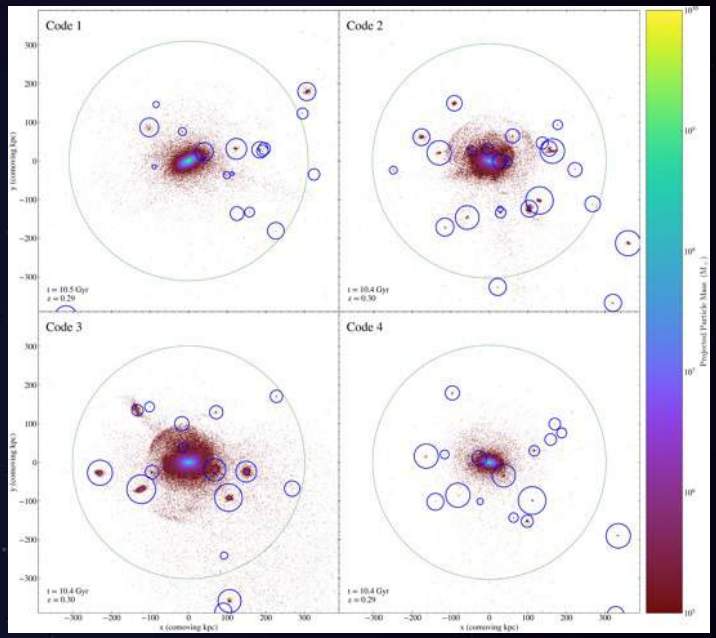
These models will also allow to determine the degeneracy between dark matter flavor and baryonic physics and their effect on the properties of the three halo observables in ARRAKIHS.

The "Harkonens" Cosmological Simulations

ARRAKIHS



Revaz, Erkal + AMC (2024)



Rodríguez-Cardoso + AMC (2024)

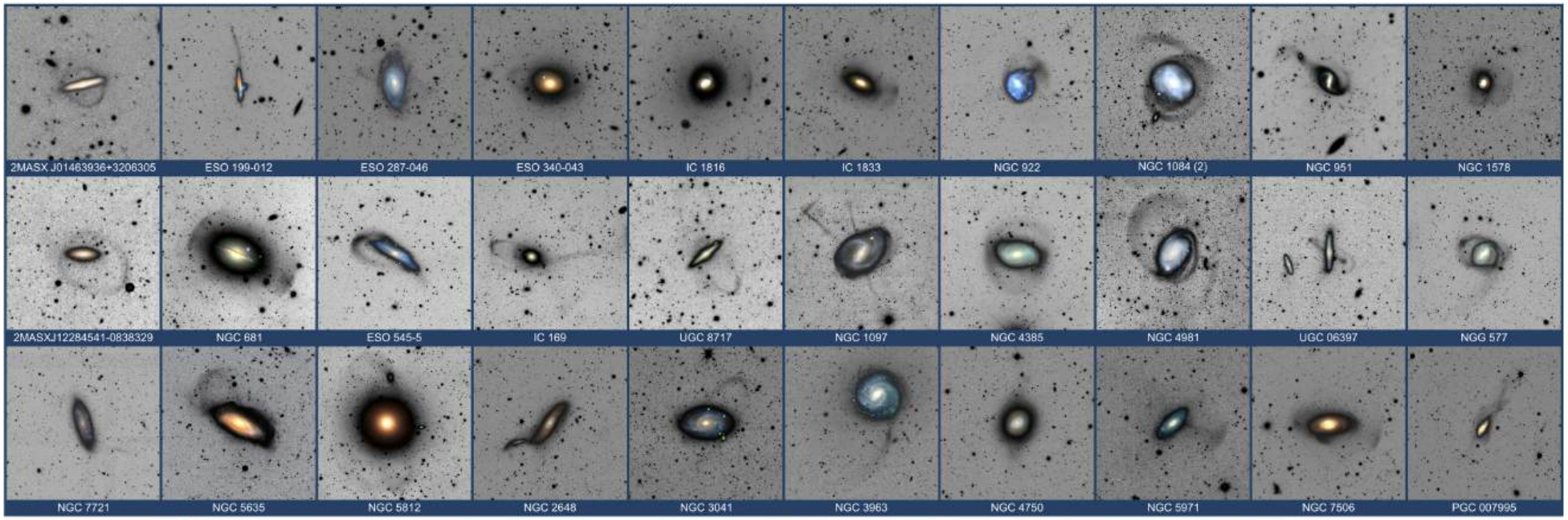
3

- The potential of the halos simulated in the zoom-in cosmological simulations with different dark matter flavors and baryonic physics will be extracted.
- Higher resolution halo models than in the cosmological models (~real stellar mass) will be run to resolve the thinnest stellar streams and the smallest satellites.
- The orbits of the satellites will be derived from the cosmological simulations
- Finally, we will inject the dwarfs to the frozen potential of the realistic halos, with a large number of particles and high spatial and temporal resolution.
- The properties of the three halo observables will be characterized from cosmological simulations and under different dark matter flavors and baryonic physics.

OVER 200M of CPU HOURS IN HPC (led by Sweden and Switzerland)

Ground Observations: SB_{lim} = 28.5 mag arcsec^{-2} in r-band

ARRAKIHS



STELLAR STREAM LEGACY SURVEY

Martínez-Delgado et al. (2023);
Miró-Carretero et al. (2024)

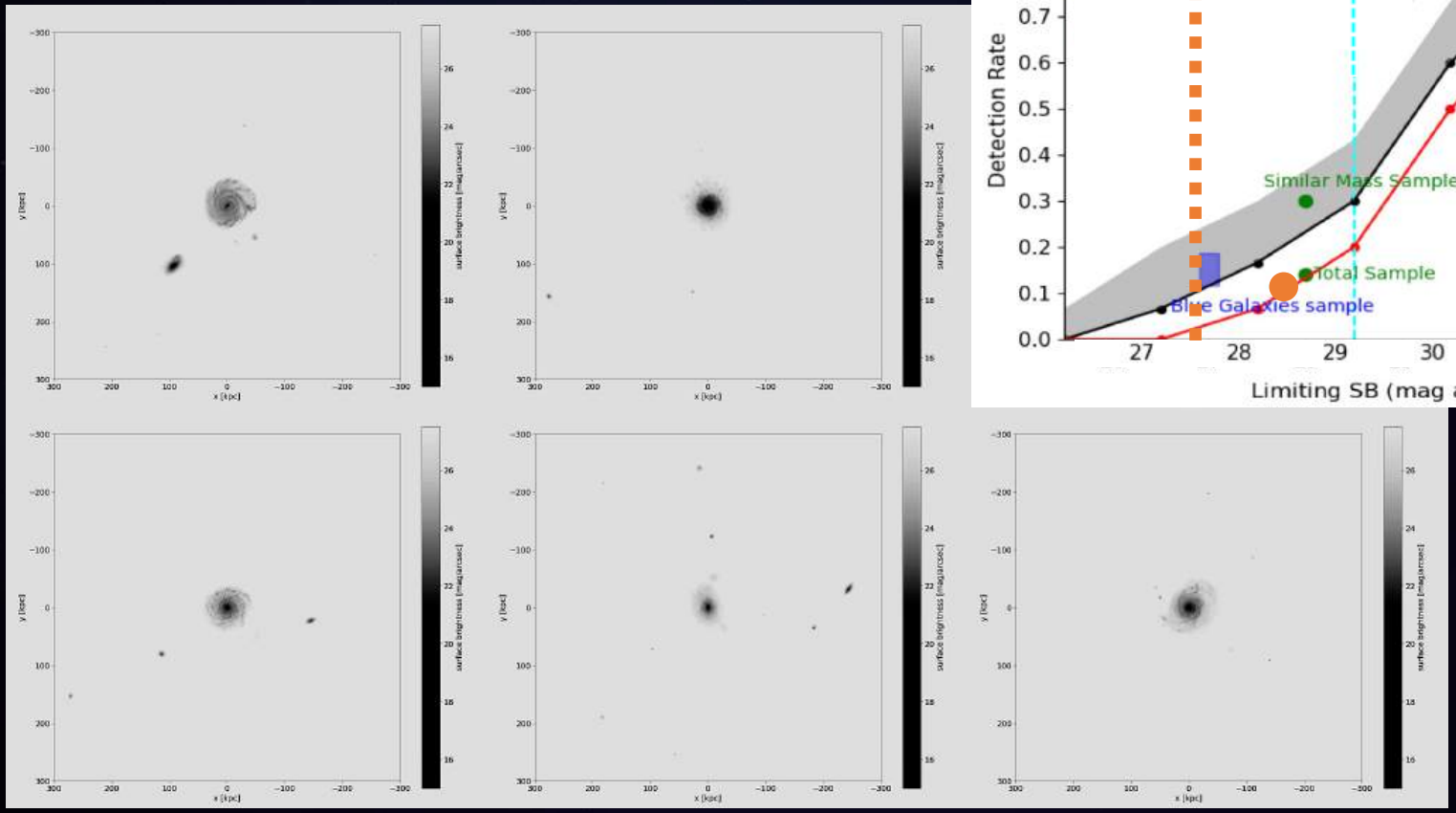
DARK ENERGY SPECTROSCOPIC INSTRUMENT

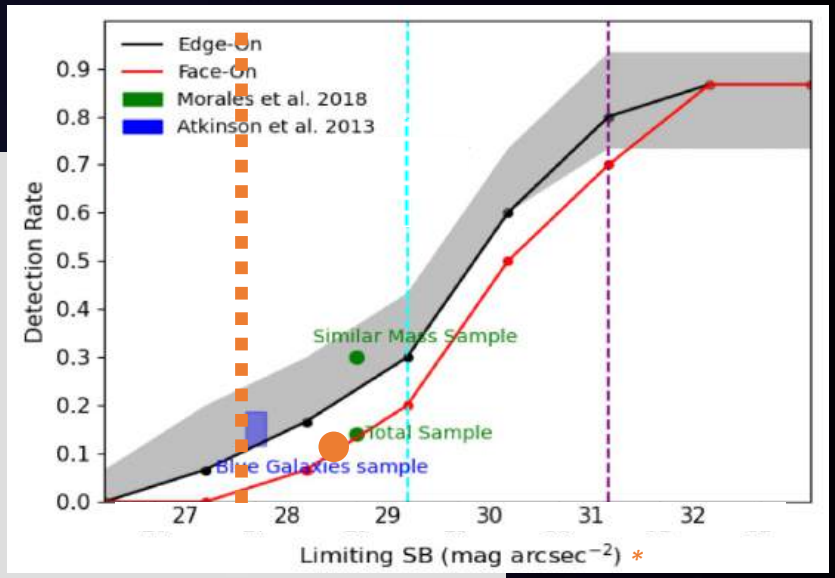
ARRAKIHS SB_{lim} = 31.5 mag (VIS), 30.5 mag (NIR)

ARRAKIHS

Miró-Carretero et al. (2024)
Vera-Casanova et al. (2022)

AMC (2024): SB_{lim} = 27.5 mag arcsec^{-2}





** SB_{lim} scaled to 100 arcsec^2*

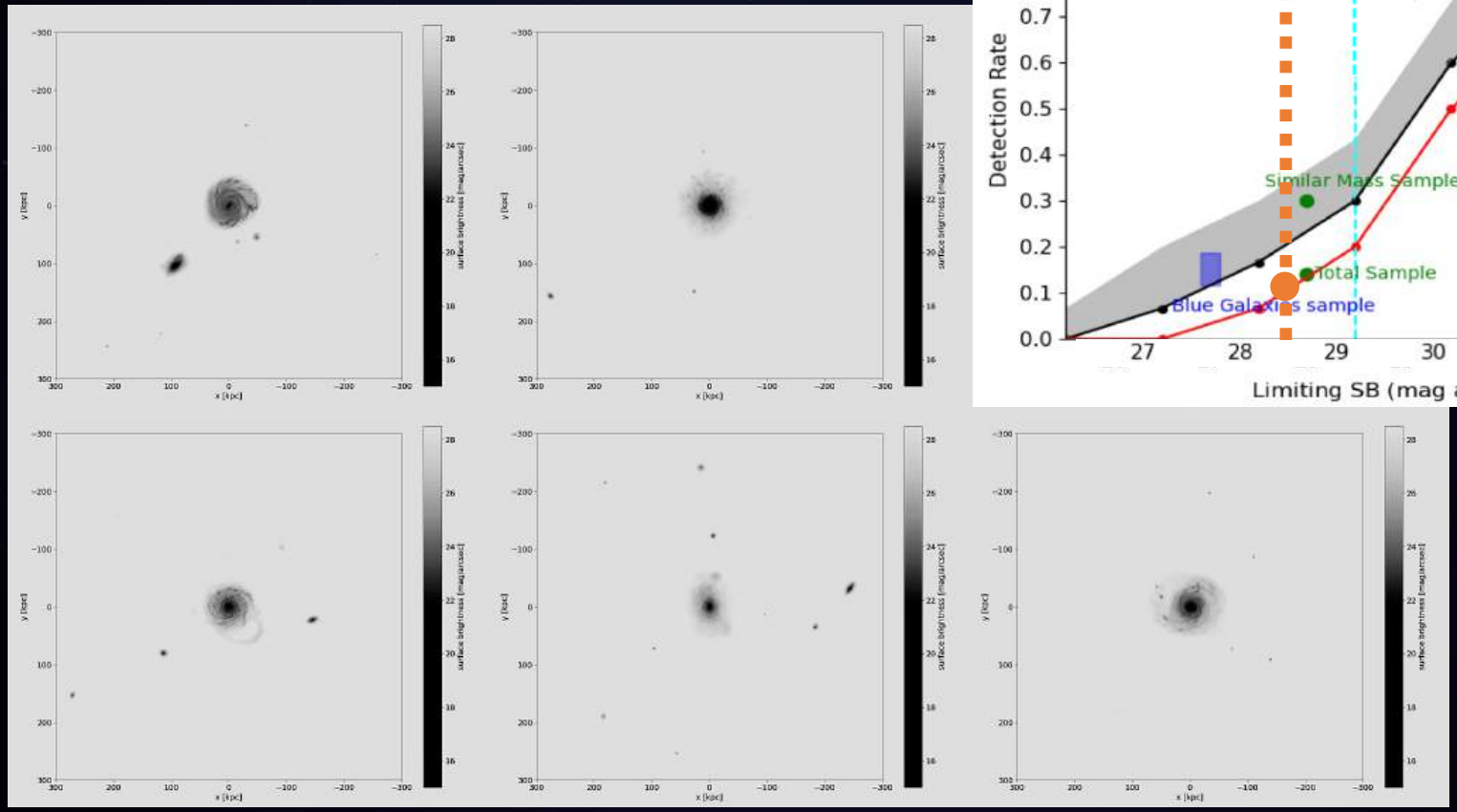
Revaz, Roca-Fábrega + AMC (2024)

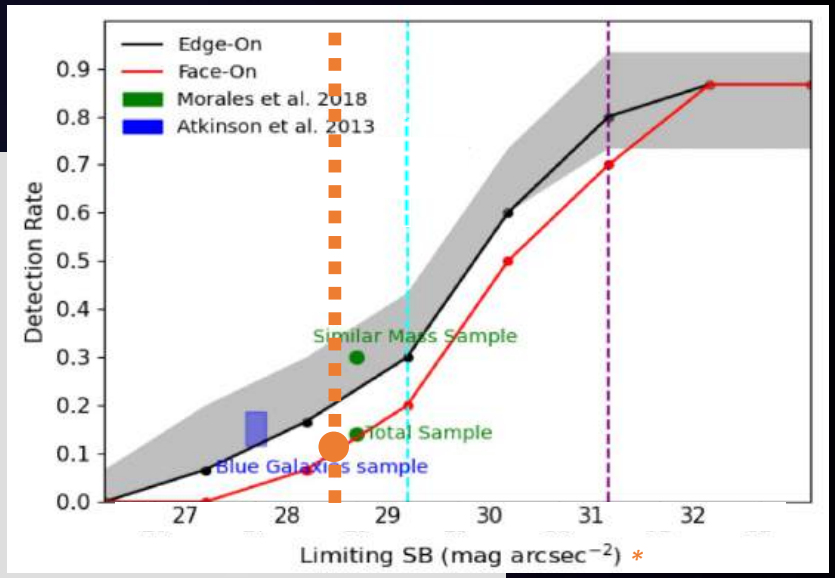
ARRAKIHS SB_{lim} = 31.5 mag (VIS), 30.5 mag (NIR)

ARRAKIHS

Miró-Carretero et al. (2024)
Vera-Casanova et al. (2022)

AMC (2024): SB_{lim} = 28.5 mag arcsec^{-2}





** SB_{lim} scaled to 100 arcsec^2*

Revaz, Roca-Fábrega + AMC (2024)

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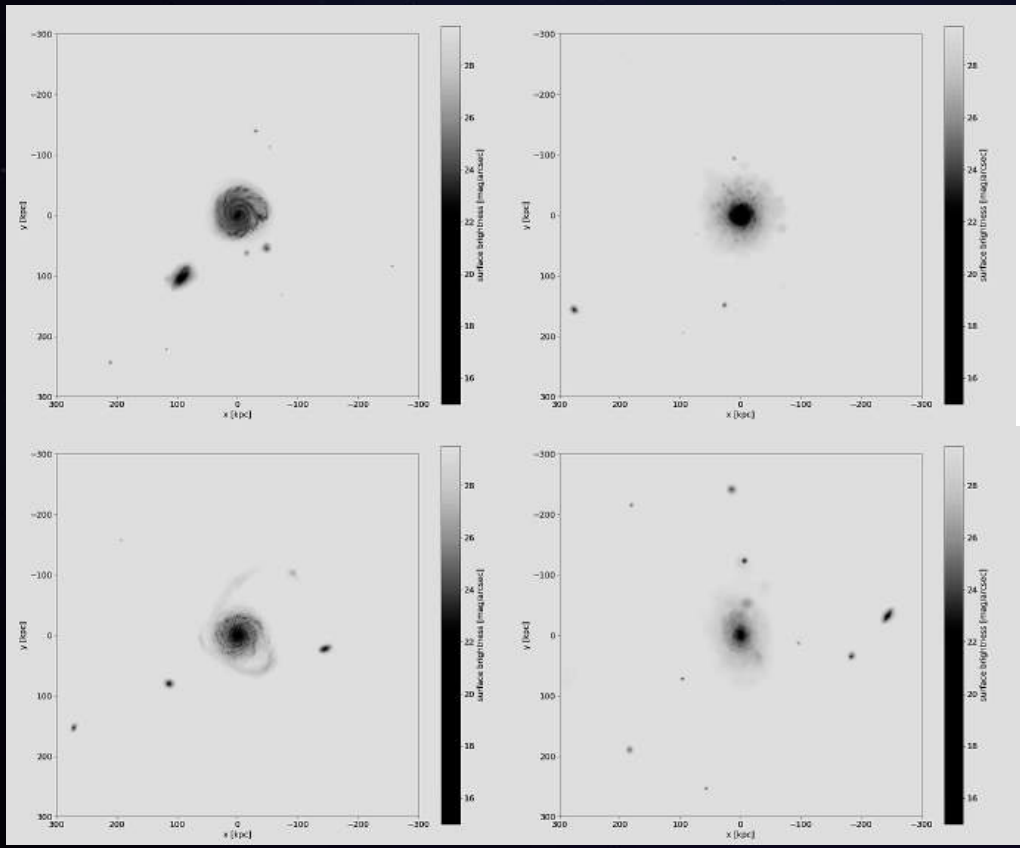
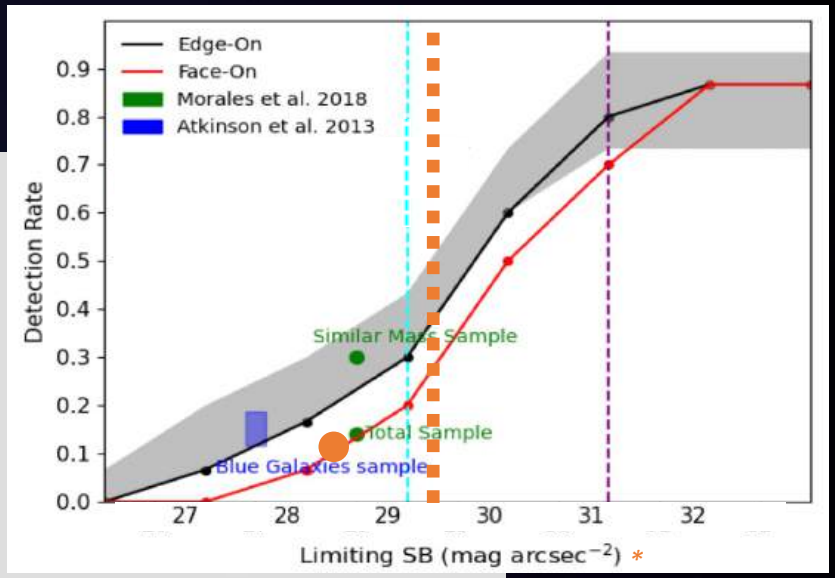
ARRAKIHS

Miró-Carretero et al. (2024)
Vera-Casanova et al. (2022)

AMC (2024): SB_{lim} = 29.5 mag arcsec^{-2}





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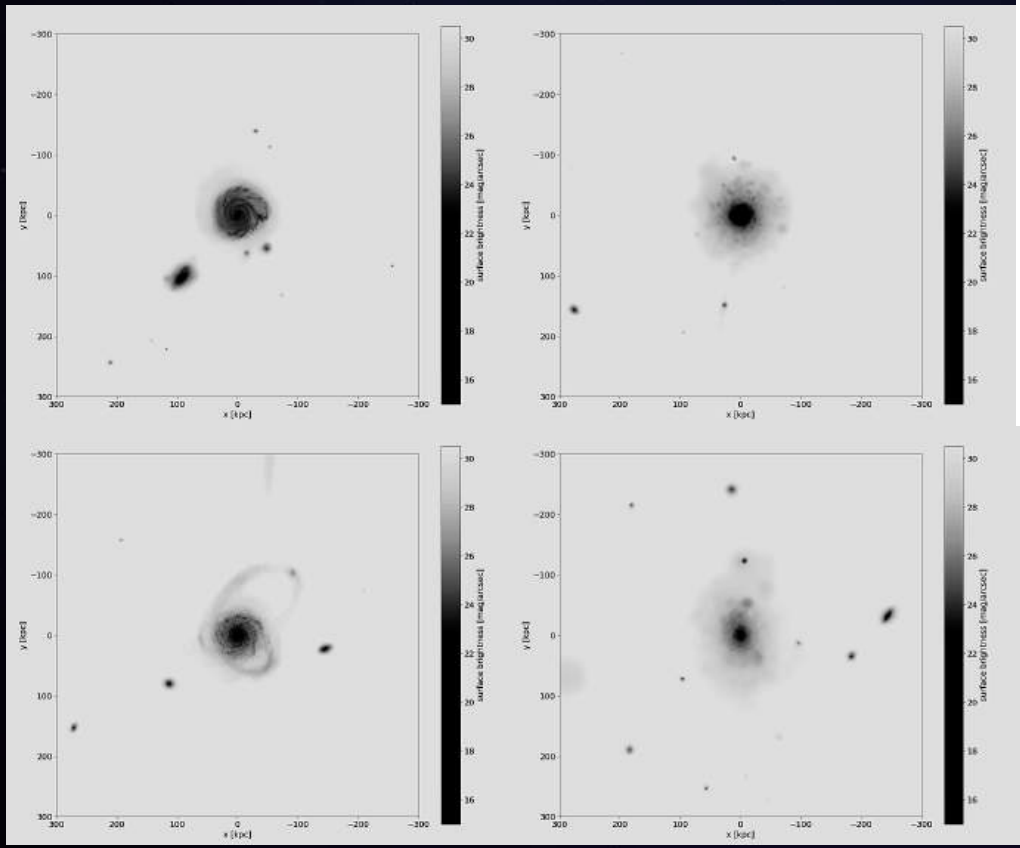
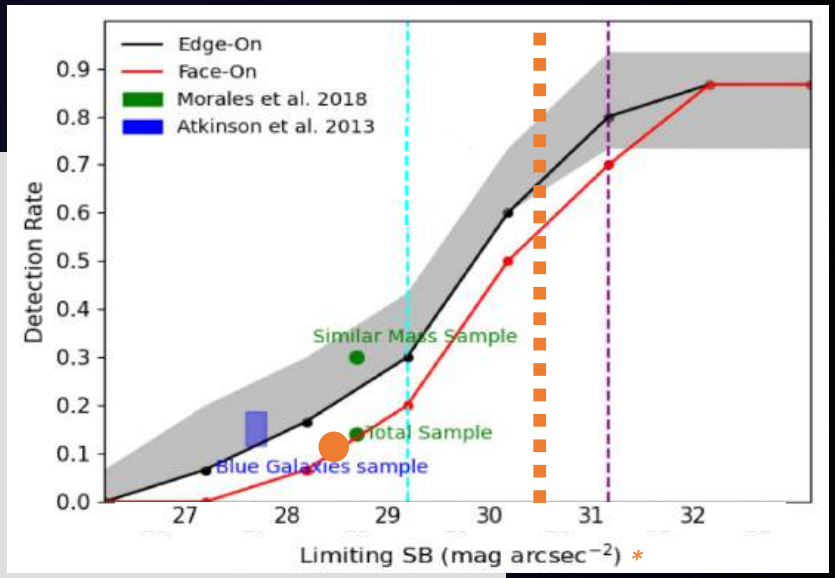
Vera-Casanova et al. (2022)

AMC (2024): SB_{lim} = 30.5 mag arcsec^{-2}





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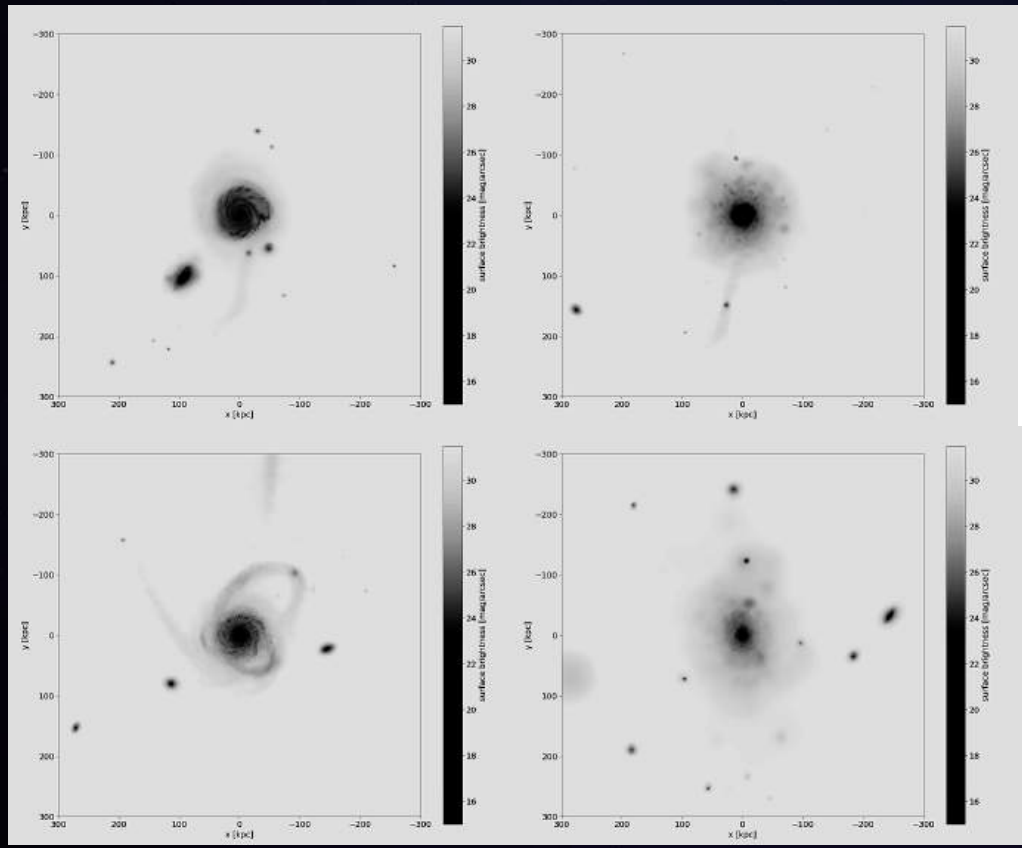
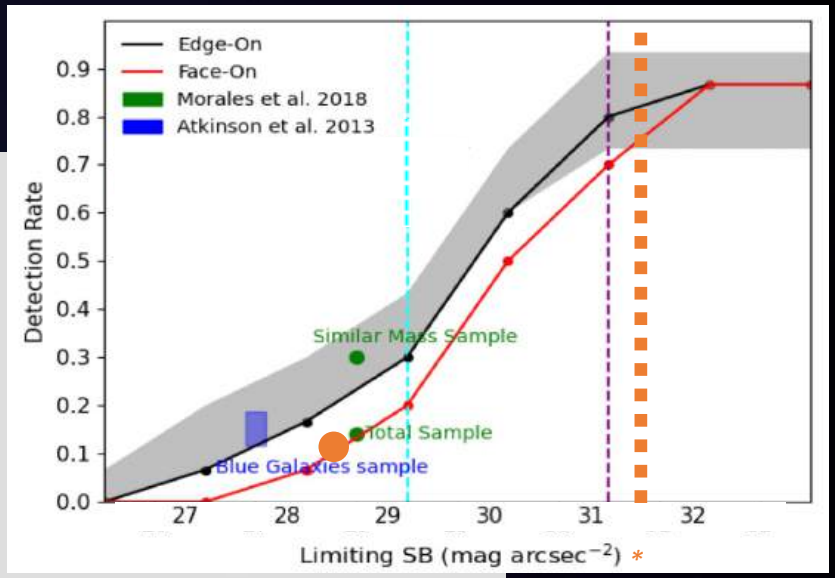
AMC (2024): SB_{lim} = 31.5 mag arcsec^{-2}





** SB_{lim} scaled to 100 arcsec²*

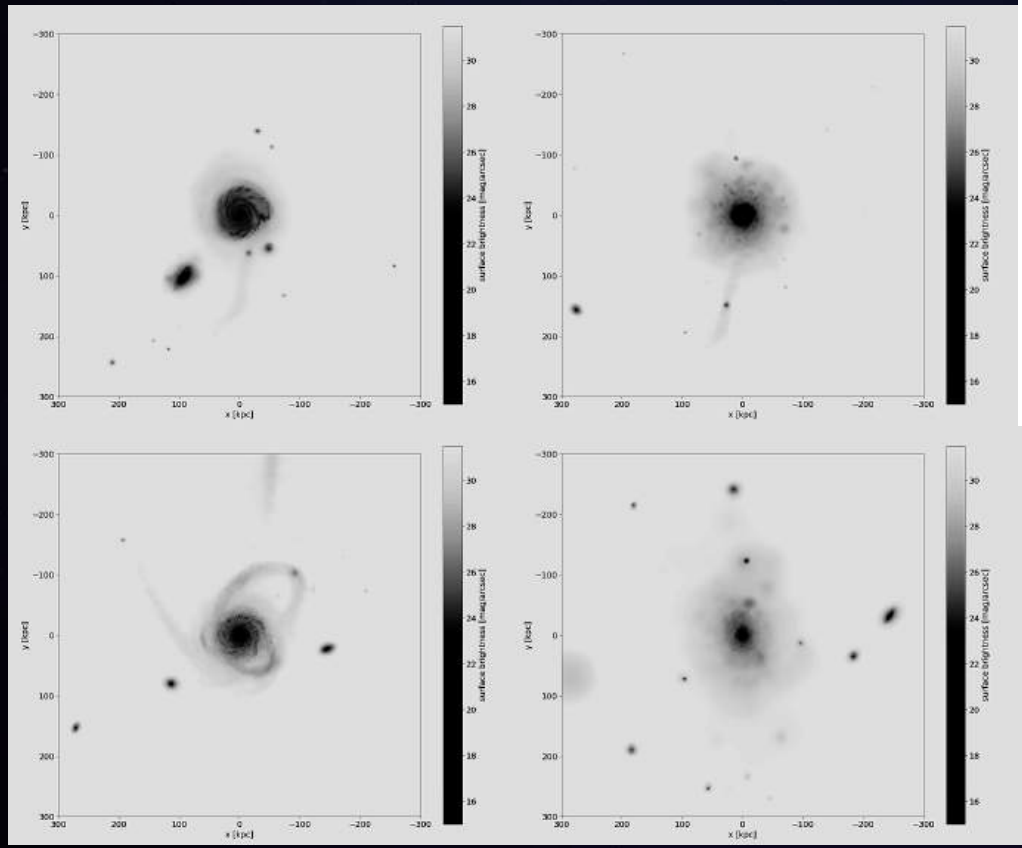
Revaz, Roca-Fábrega + AMC (2024)

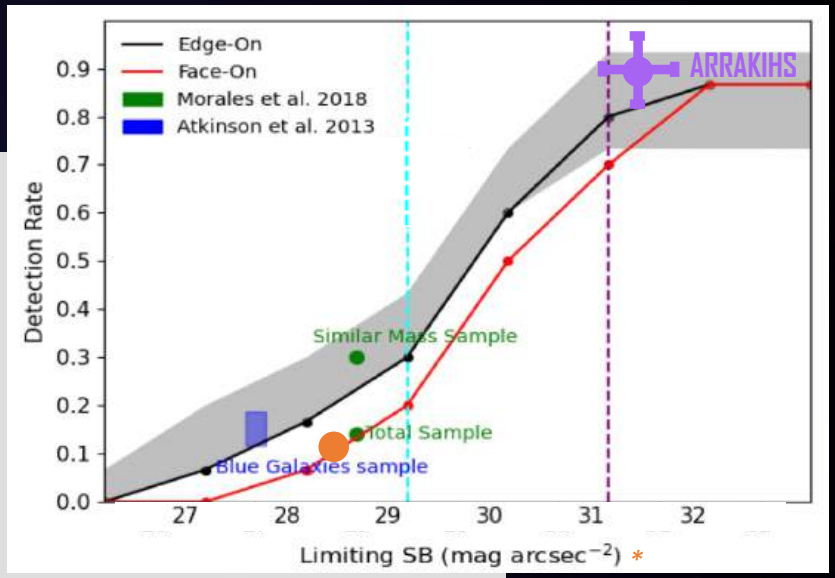
ARRAKIHS SB_{lim} = 31.5 mag (VIS), 30.5 mag (NIR)

ARRAKIHS

Miró-Carretero et al. (2024)
Vera-Casanova et al. (2022)

AMC (2024): SB_{lim} = 31.5 mag arcsec^{-2}





** SB_{lim} scaled to 100 arcsec^2*

Revaz, Roca-Fábrega + AMC (2024)

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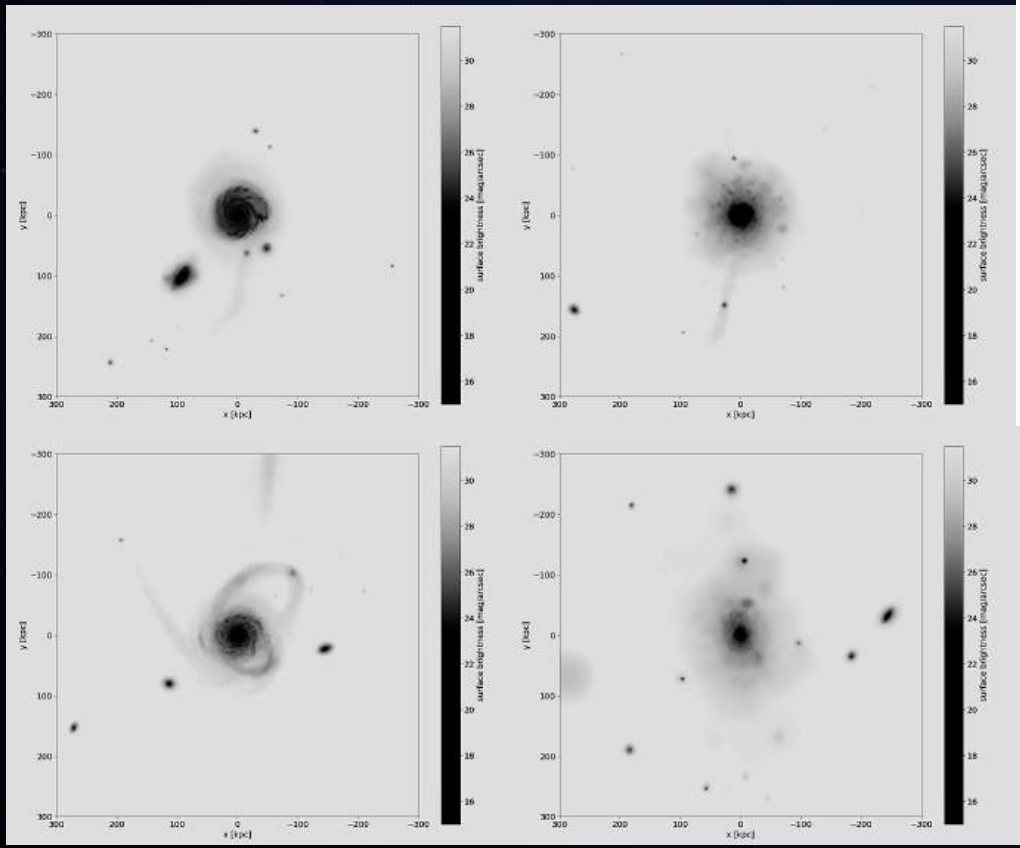
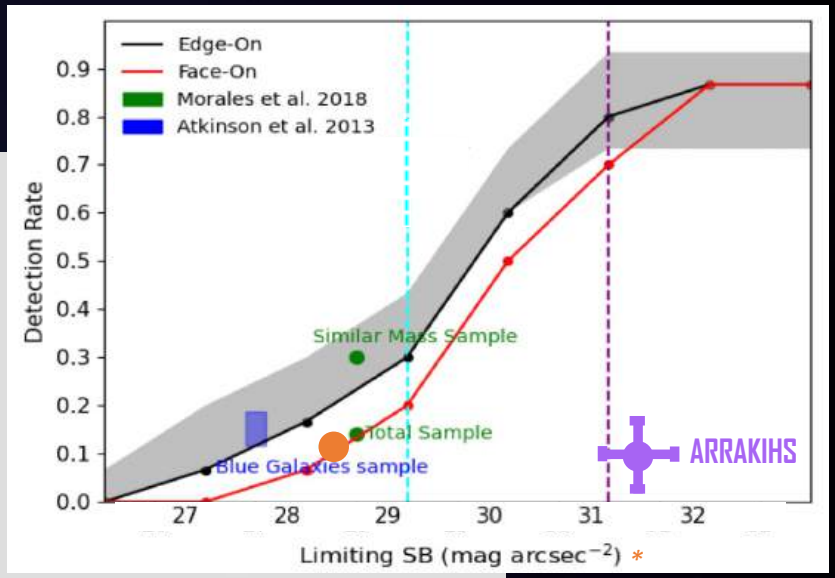
Miró-Carretero et al. (2024)
Vera-Casanova et al. (2022)

AMC (2024): SB_{lim} = 31.5 mag arcsec^{-2}





** SB_{lim} scaled to 100 arcsec²*

Revaz, Roca-Fábrega + AMC (2024)

Figure of Merit

ARRAKIHS

FoM: null test or S/N (SNR):

$$FoM = \chi^2_{SNR} = \sum_i \sum_j D_i \cdot C_{ij}^{-1} \cdot D_j$$

D = data vector (or difference with model predictions)

$$D = [f_1, f_2, \ldots, n_{sat}(m_1), n_{sat}(m_2), \ldots, halo_{\gamma 1}, halo_{\gamma 2}, halo_{r1}, \ldots]$$

C = covariance matrix (errors)

$$FoM = \chi^2_{SNR} = \frac{fN_{gal}}{\sqrt{fN_{gal} + (\sigma_f N_{gal})^2}}$$

Vera-Casanova:

$f \simeq 0.15\mu_{VIS} - 4.0$

$f \simeq 0.125\mu_{NIR} - 3.1$

VIS vs NIR: $\mu_{VIS} = \mu_{NIR} + 1$

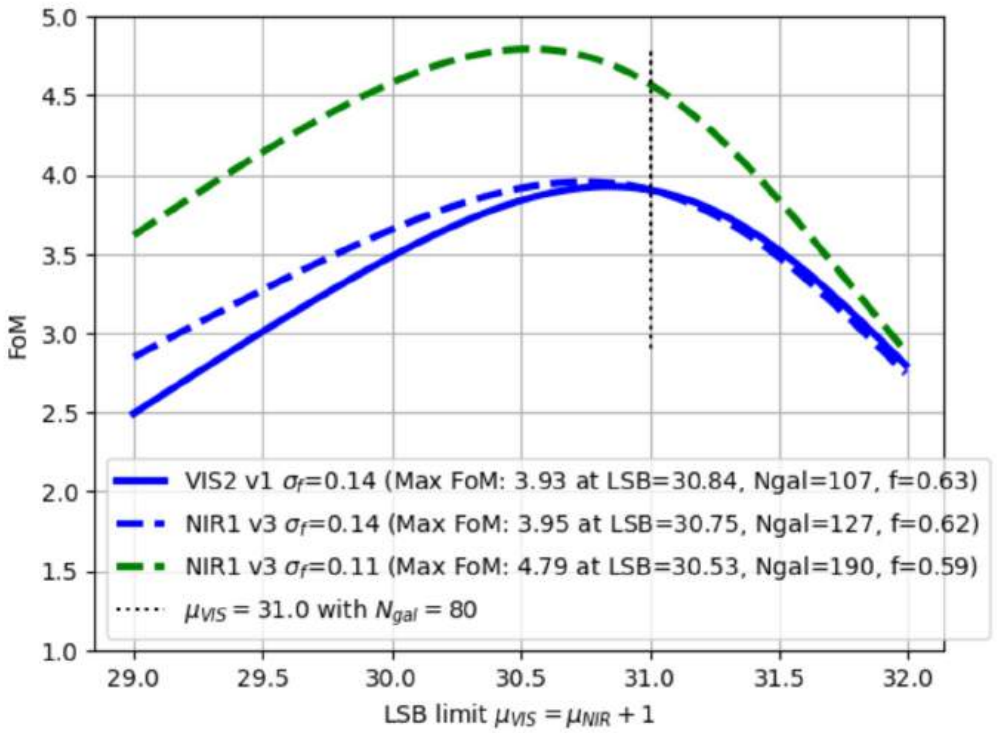
Speed:

$\mu \simeq \mu_{lim} - 1.25 \log_{10}(N_{gal}/80)$

@ Limit $\mu_{lim} = 30.5$

Uncertainties in σ_f:

- **Theoretical**: There are inherent uncertainties in the simulations and methods used to compare observations to LCDM predictions. Our target and requirement is to reduce this uncertainty to approximately 10% through extensive work with simulations.
- **Observational**: This includes uncertainties related to completeness, contamination, and other observational factors when measuring f. Target is another 10%



Payload Overview

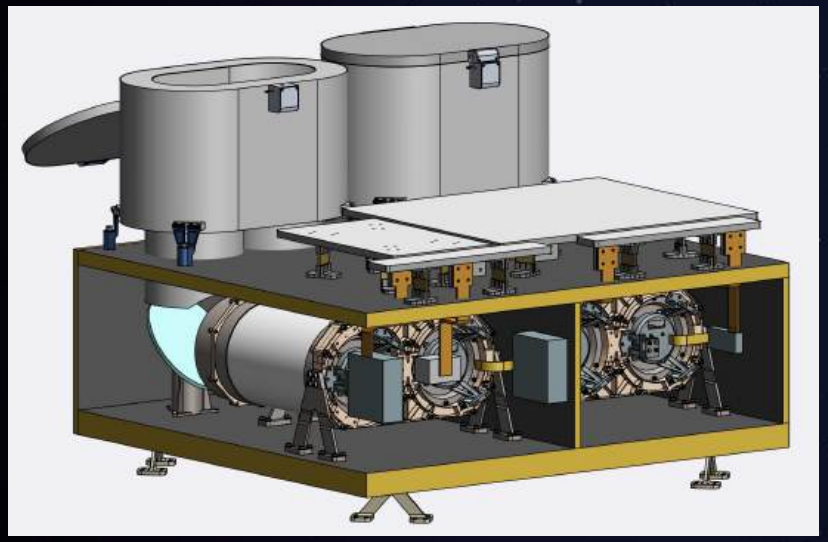
ARRAKIHS

SATLANTIS

OPTO MECHANICS

2x iSIM170

iPRR: Serrano, Guzmán, Prod'homme + AMC (2024)



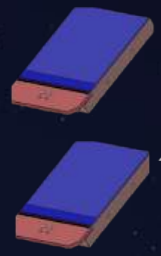
ELECTRONICS

SATLANTIS

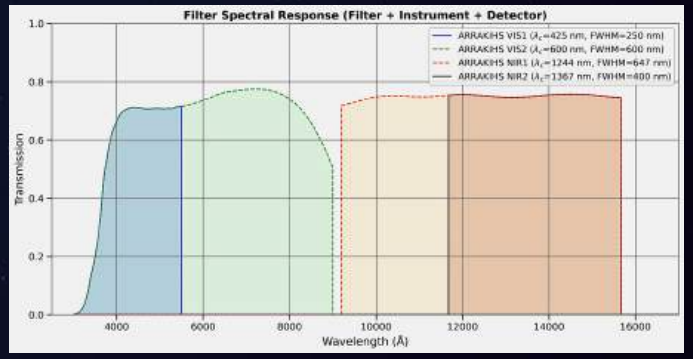
universität wien

TELEDYNE DALSA Everywhereyoulook™

2x CMOS-304



CDPU IWF



DETECTORS

TELEDYNE e2v Everywhereyoulook™

2x H2RG-10

KOEGL SPACE · POLITÉCNICA · University of Zurich

Thermo-Mech. Structure

IEEC CEFCA · LIDAX · HSLU

Detector & Filter Characterization

SATLANTIS · CEFCA

Payload Ground Tests

IFCA

Data Management & Analysis

CSL

Straylight & Baffles

Payload Overview

ARRAKIHS

SATLANTIS

OPTO MECHANICS

2x iSIM170

iPRR: Serrano, Guzmán, Prod'homme + AMC (2024)

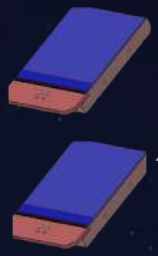
ELECTRONICS

SATLANTIS

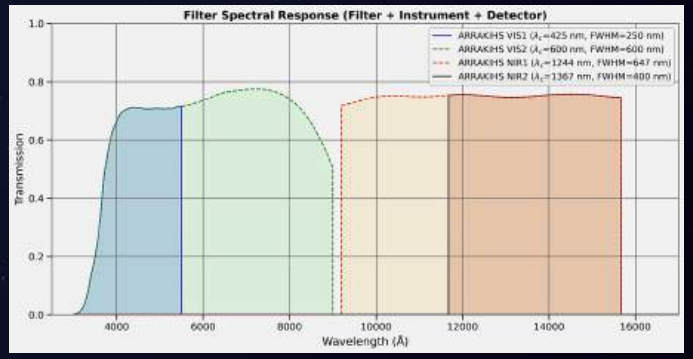
universität wien

TELEDYNE DALSA Everywhereyoulook™

2x CMOS-304



CDPU IWF



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KOEGL SPACE — POLITÉCNICA — University of Zurich

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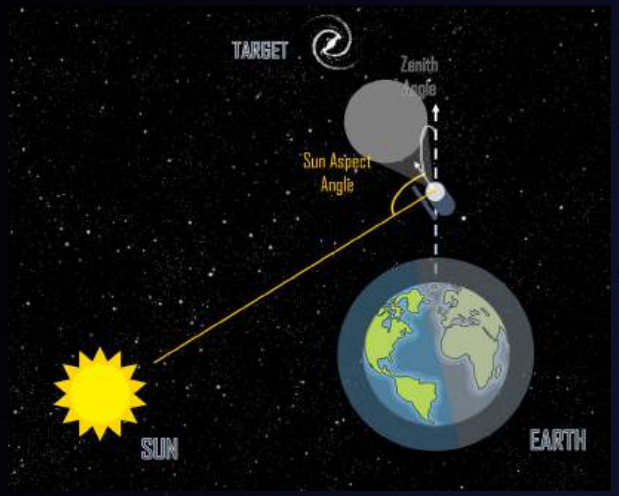
CONOPS & Mission Analysis

ARRAKIHS

AMC (2023)



CONOPS

iPRR: Camazón, Guzmán, Corral + AMC (2024)

Height: **800 Km**

Orbit: **Sun-Synchronous, 6am-6pm**

Field of Regard:

- **90º < Solar Angle < 130º**
- **0º < Zenith Angle < 60º**

Calibrations:

- **Darks, Flats**
- **Flux, PSF, Ghosts, etc.**

MISSION ANALYSIS

Sample: **226 MW-like galaxies** (ext-SAGA; Mao +2020)

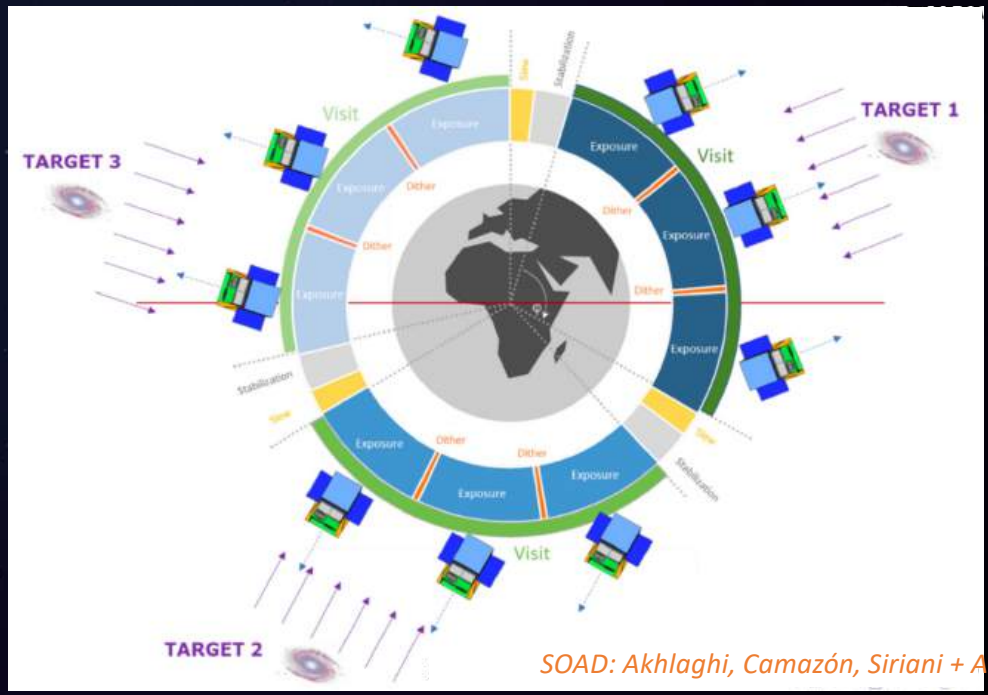
- $1 \leq M / 10^{10}$ Mo ≤ 5; $25 \leq d/\text{Mpc} \leq 50$
- Zodiacal Light ≥ 22 J-mag arcsec^{-2}
- E(B-V) < 0.1

Gómez-Flechoso + AMC (2024)

Total Observing time: ≥ **150 hrs/gal**

Single exposure time: ≤ **10 minutes**

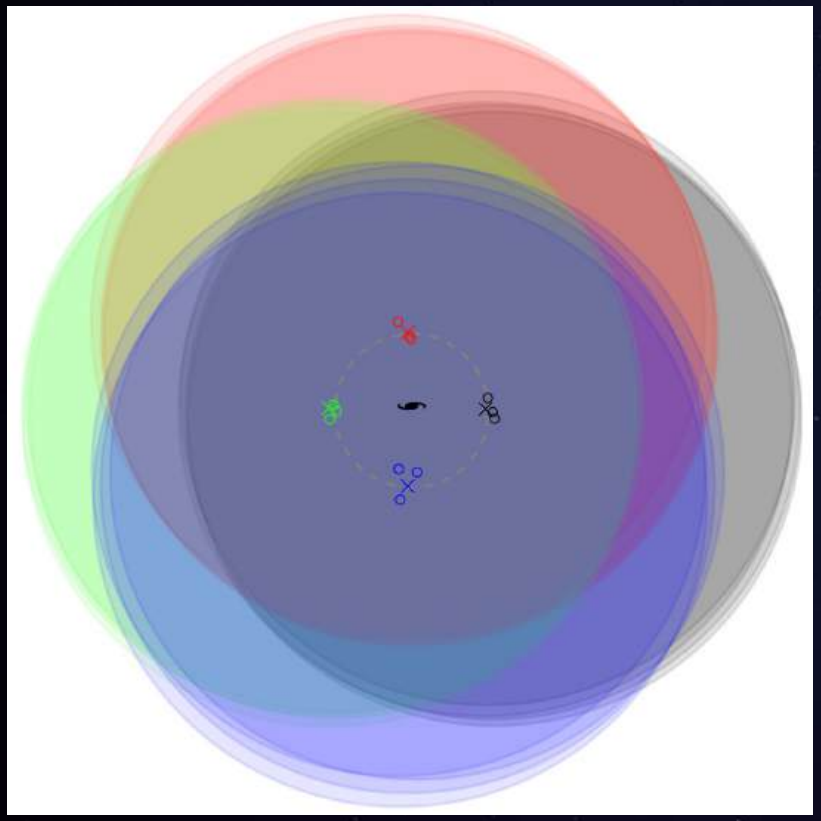
Camazón, Guzmán + AMC (2024)

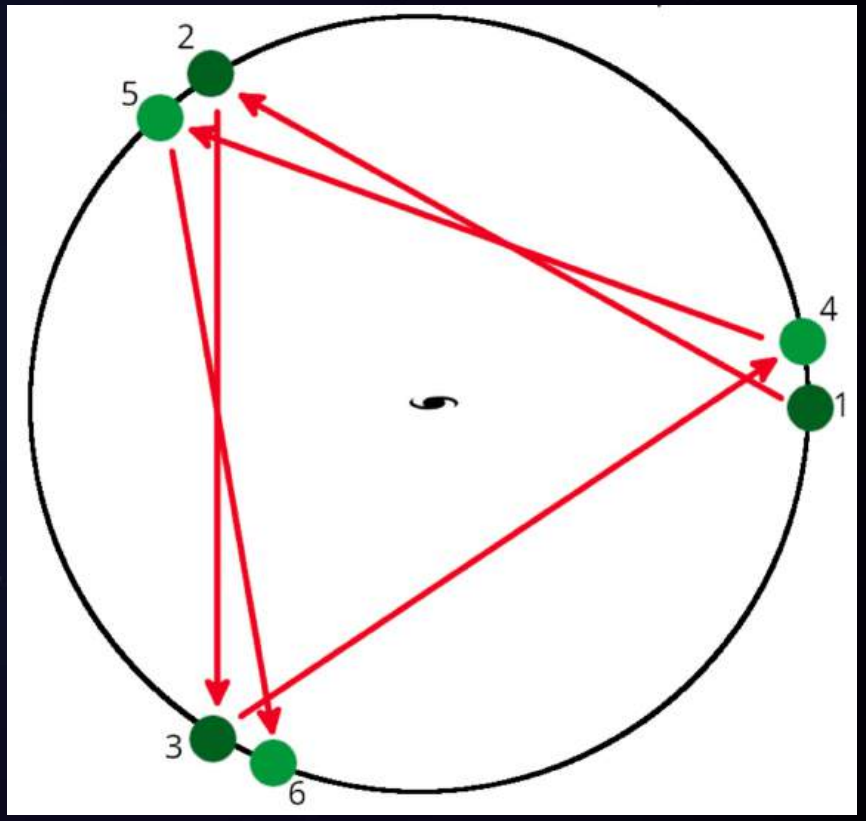


SOAD: Akhlaghi, Camazón, Siriani + AMC (2024)

Observational Strategy: Dithers & Offsets

ARRAKIHS

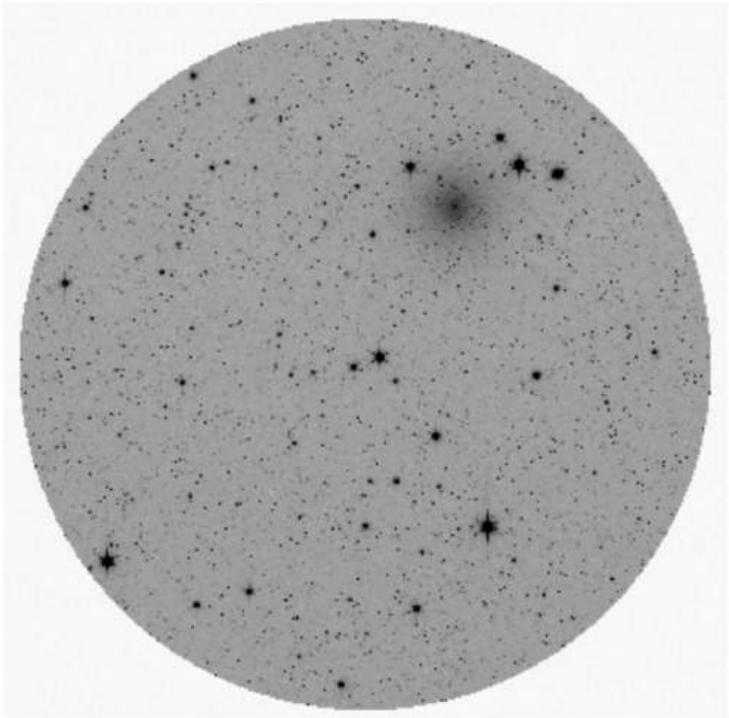


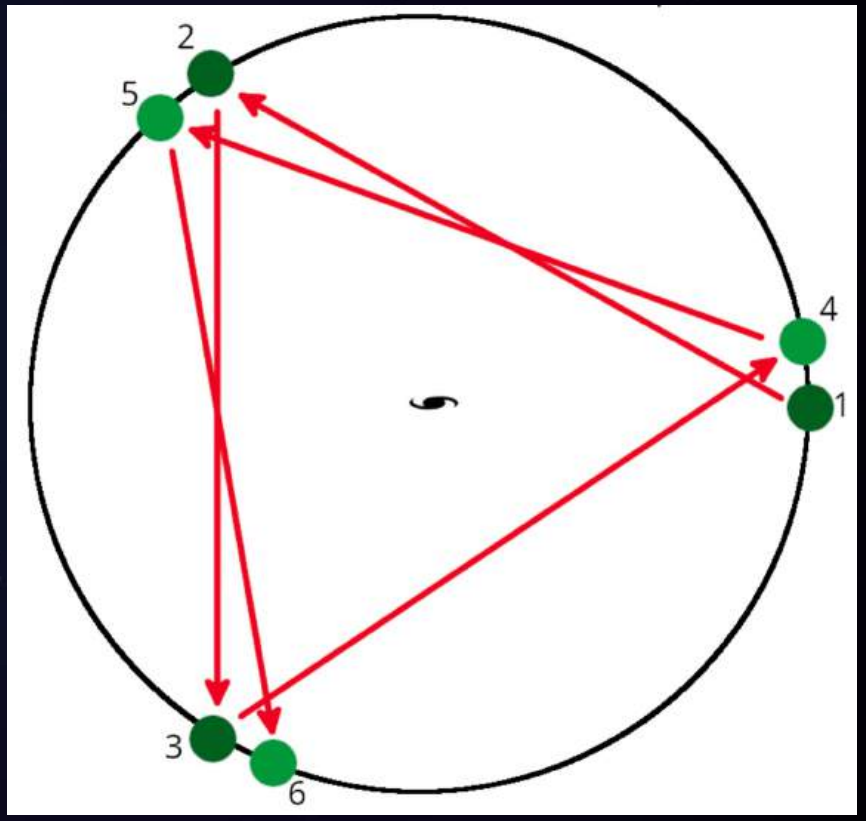


Akhlaghi + AMC (2024)

Observational Strategy: Dithers & Offsets

ARRAKIHS

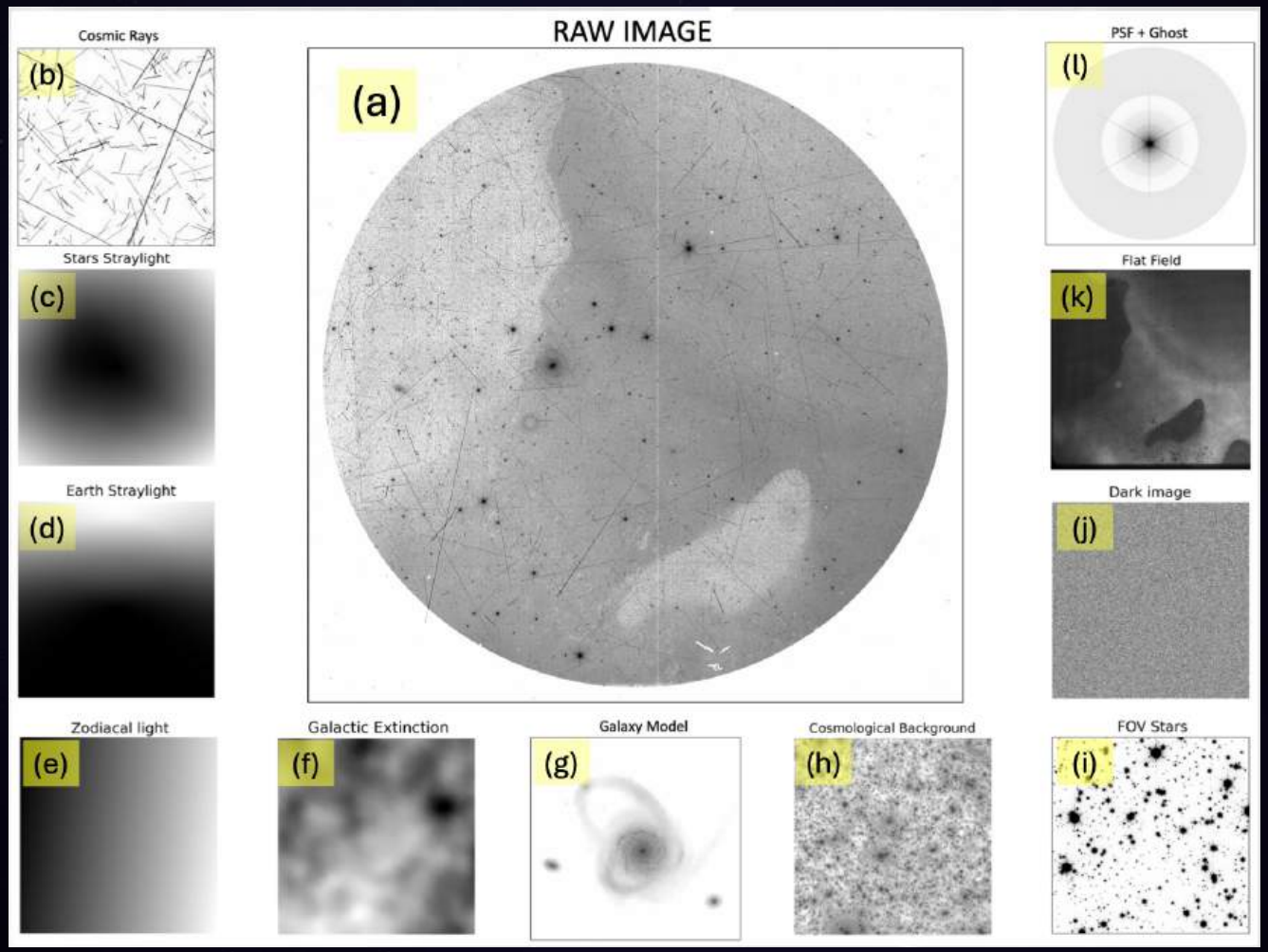




Akhlaghi, Camazón + AMC (2024)

The "ATREIDS" Mock End-to-End Simulations

ARRAKIHS



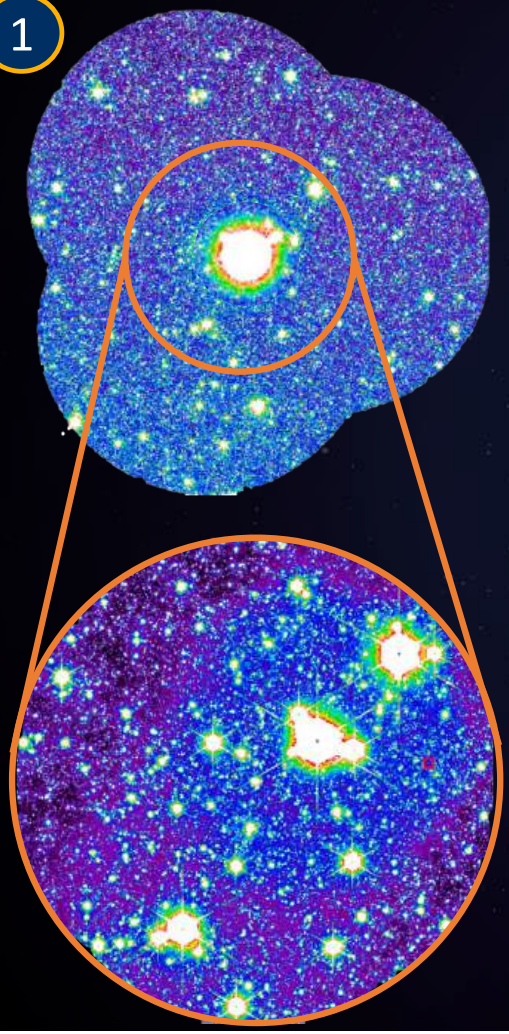
ARRAKIHS Telescope Realistic Exploration and Imaging Detection Simulations **(ATREIDS)**

Camazón, Guzmán + AMC (2024)

The "Harvestor" Image Processing Pipeline

ARRAKIHS

1



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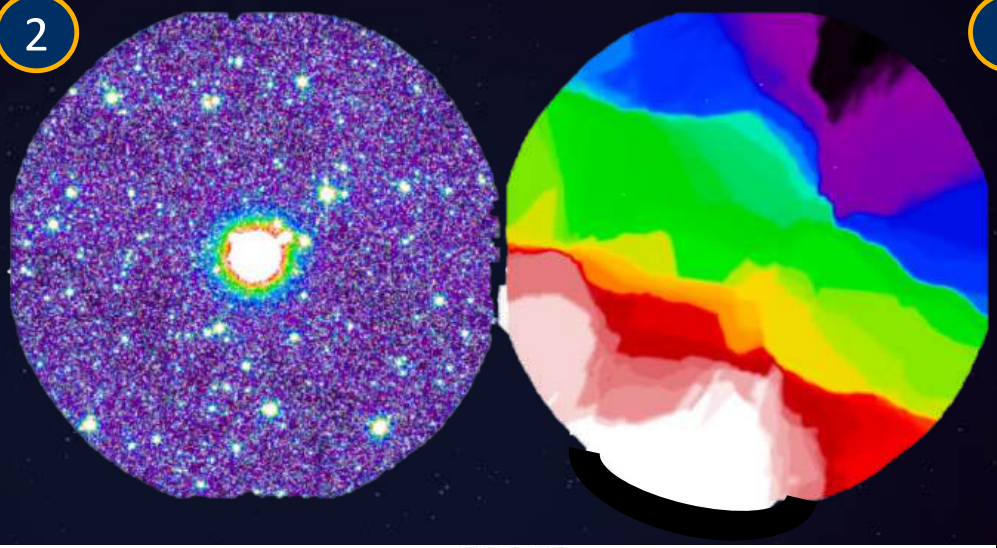
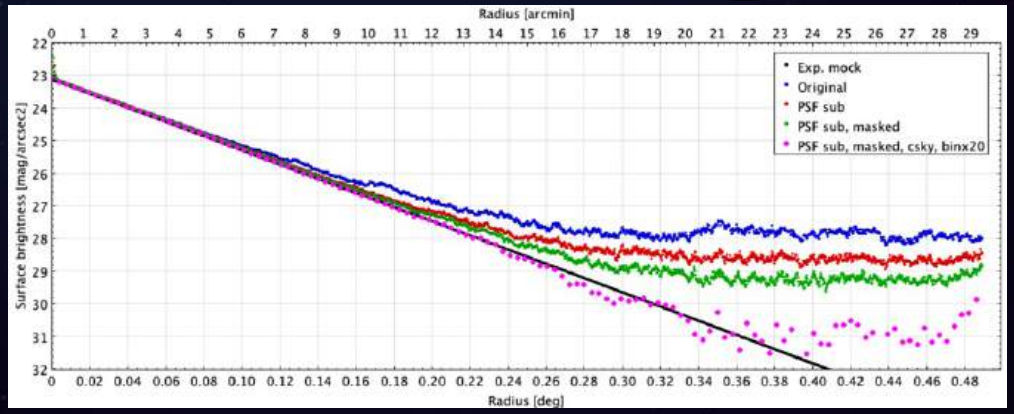
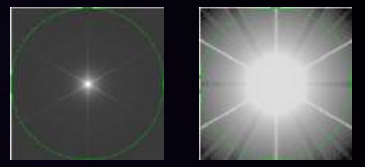




Akhlaghi, Infante + AMC (2024)

3



Infante + AMC (2024)

Infante-Sáinz & Akhlaghi (2024)

ARRAKIHS Processed Mock Simulations

ARRAKIHS

ARRAKIHS SB_{lim}

VIS1 =	31.36	mag/arcsec^2
VIS2 =	31.64	mag/arcsec^2
NIR1 =	31.02	mag/arcsec^2
NIR2 =	30.70	mag/arcsec^2

Akhlaghi, Camazón + AMC (2024)

Phase B: On-going Work for PDR

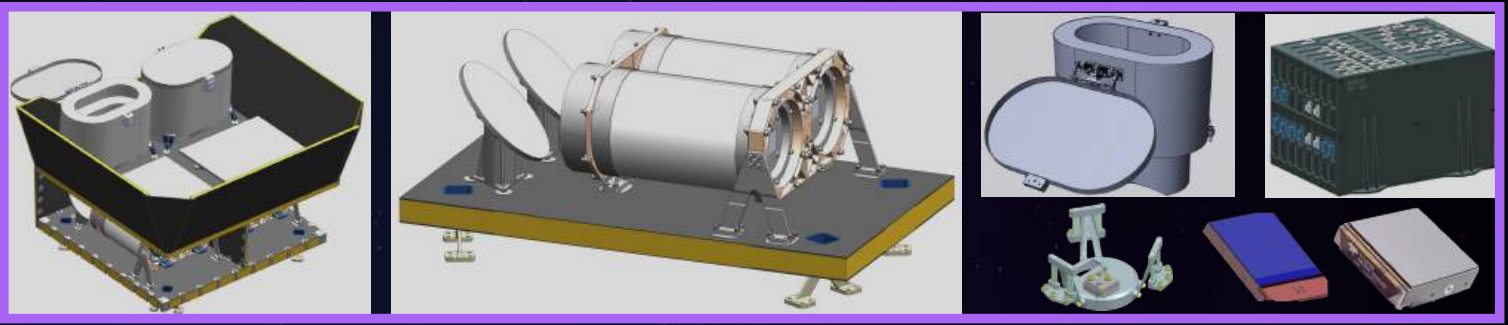
ARRAKIHS

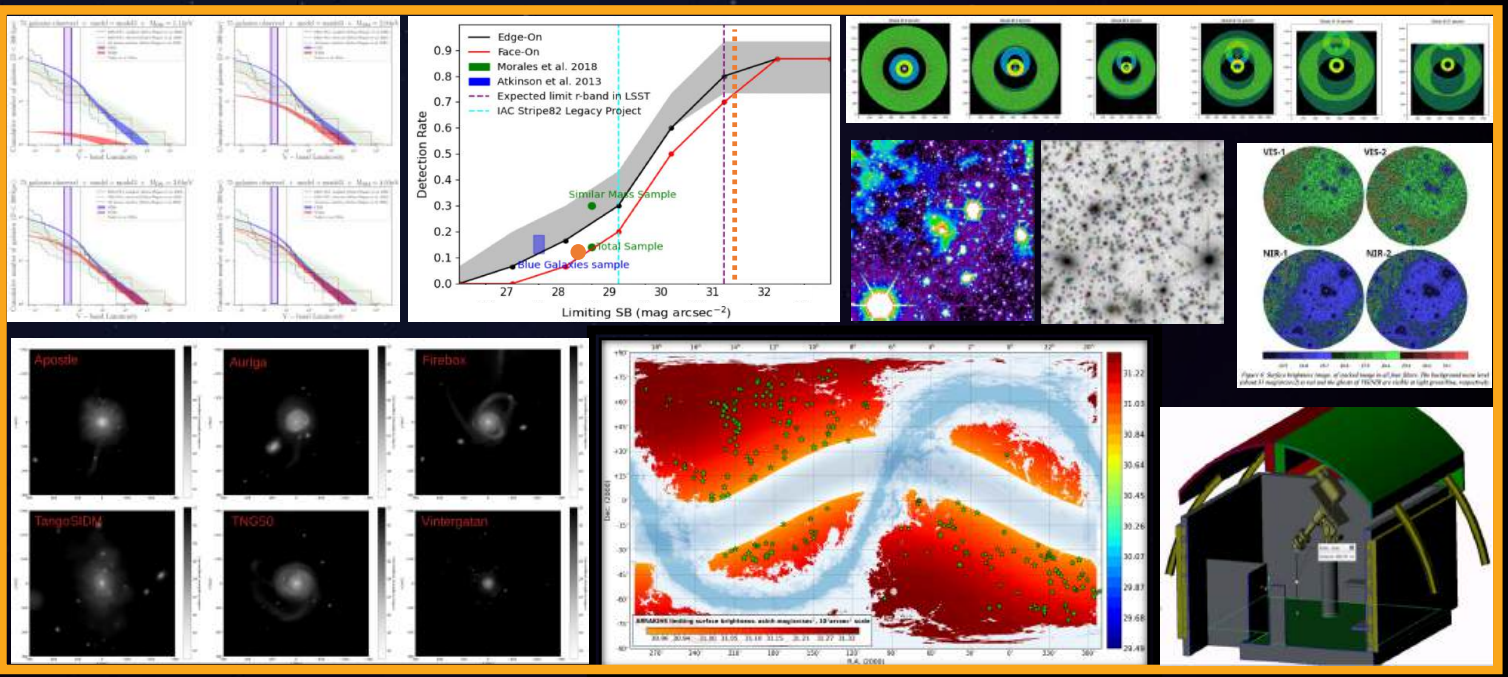
Instrumentation

- Straylight
- Pointing stability
- Thermal Stability
- Filters & Detectors

Science & SGS

- Statistical descriptor for CDM & BP models
- Mock images
- Data processing
- Cirrus subtraction
- Background galaxy subtraction
- CONOPS
- Mission Analysis
- Complementarity with Euclid
- On-ground demonstrator






ARRAKIHS
Thanks!
iFCA
CSIC
EPFL
CEFCA
IEEC
Institut d'Estudis Espacials de Catalunya
UNIVERSIDAD COMPLUTENSE MADRID
University of Zurich UZH
LUND UNIVERSITY
universität wien
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Rymdstyrelsen
Swedish National Space Agency
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
SERI

Phase B: On-going Work for PDR

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Akhlaghi, Camazón + AMC (2024)

ARRAKIHS

VIS1 = 31.36 mag/arcsec^2
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NIR1 = 31.02 mag/arcsec^2
NIR2 = 30.70 mag/arcsec^2

Hunt et al. value at 3 sigma (in 100 arcsec^2)
VIS = 30.5 – 1.19 ~ 29.3 mag/arcsec^2
Y = 29.2 – 1.19 ~ 28. mag/arcsec^2
J = 29.4 – 1.19 ~ 28.2 mag/arcsec^2
H = 29.4 – 1.19 ~ 28.2 mag/arcsec^2

Euclid

Jablonka + AMC (2024)

Phase B: On-going Work for PDR

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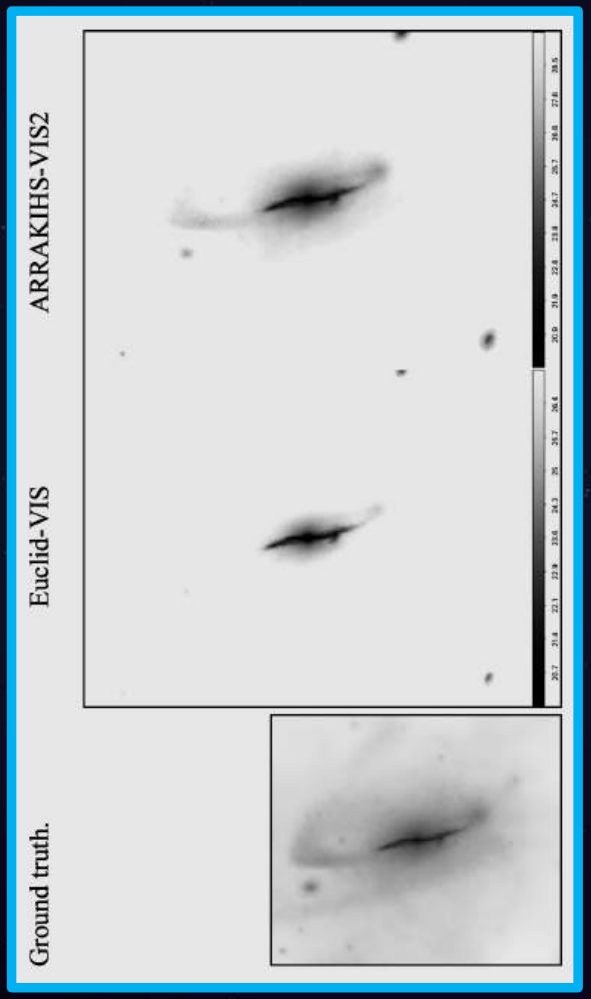
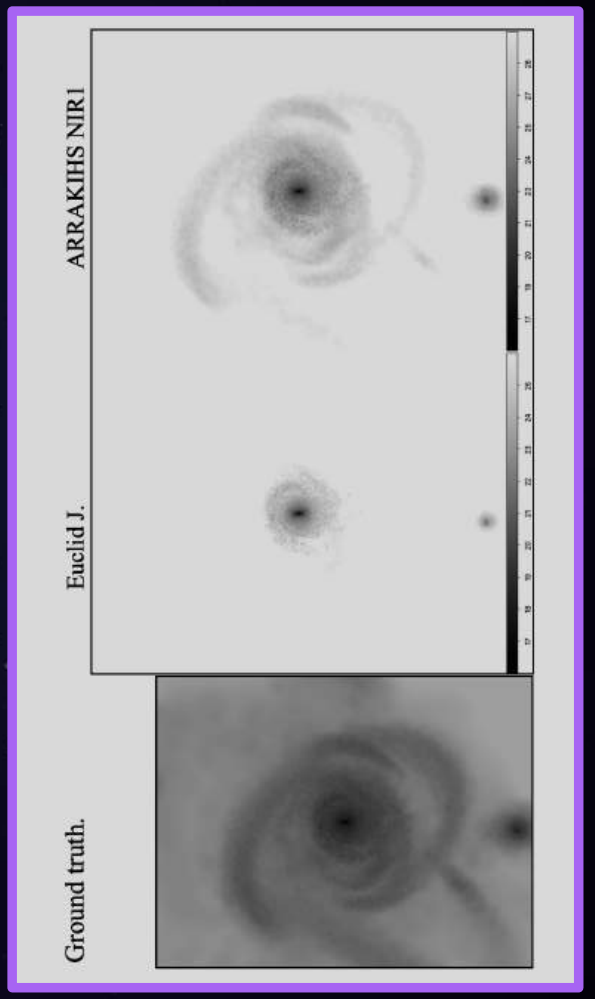
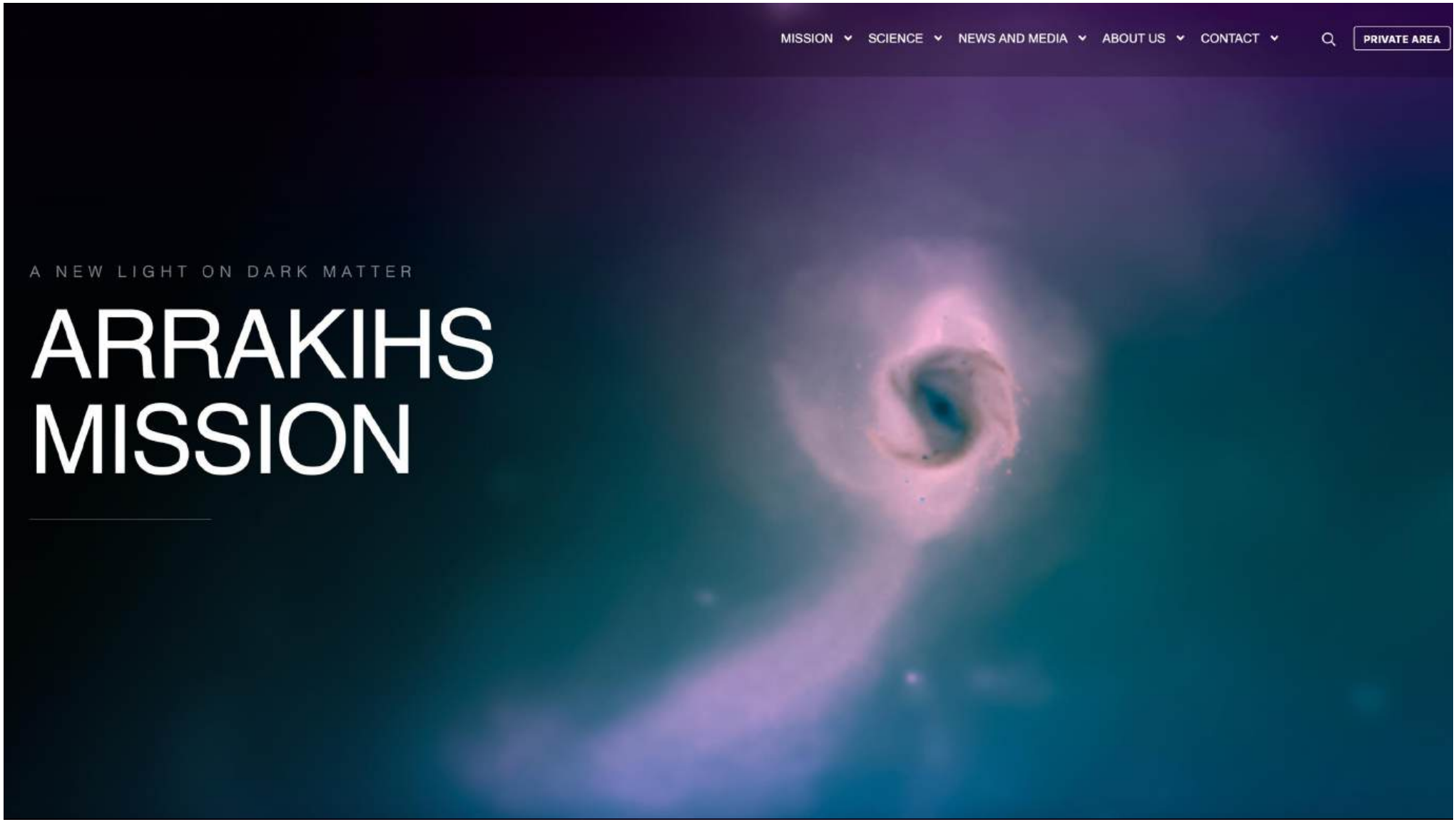




Jablonka + AMC (2024)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