

ENTROPY OF EXOPLANETS: DETECTION METHODS IN THE CONTEXT OF ACTA UNIVERSI

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THEORETICAL BASIS

The exoplanet AU entropy equation:

$$H_{AU} = \int S(v, t) \cdot \tau(v, d) dv dt$$

where:

$\tau(v, d)$ is the transmission of the interstellar medium at frequency v and distance d

METHODS FOR DETECTING AU ENTROPY

1. INDIRECT METHODS

1.1. Spectral analysis (analogous to biosignatures)

Principle: measurement of information complexity of spectral lines

$$H = - \sum p_i \log_2 p_i$$

(Shannon entropy over the line intensity distribution)

Habitability criteria based on spectral entropy:

Planet	H (bit)	Note
Earth	12.3 ± 0.5	biosphere + atmosphere
Venus	4.1 ± 0.3	dense homogeneous atmosphere
Mars	3.8 ± 0.2	thin atmosphere, dust

Telescope capabilities:

Telescope	Resolution R	Limit H (bit)	Distance (pc)
JWST	1000-3000	~10	10
ELT / HIRES	~100,000	~8	30
LUVOIR	~50,000	~9	40

1.2. Time variability analysis

Principle: entropy of brightness time series

$$S = \lim (1/T) \cdot H (\text{brightness range over time } T)$$

Typical values of the entropy of variability:

Planet Type	S (bit / hour)
Dead planet	1-3
Live planet	4-8
Technogenic	6-12

Photometry Missions:

Mission	Accuracy	Cadence
PLATO	10^{-6}	25 s
TESS	10^{-4}	2 min
CHEOPS	10^{-5}	1 s

1.3. Phase curve analysis

Surface characteristic	H (bit)
Homogeneous	2-3
Continental	4-6
Technogenic	7-10

2. DIRECT METHODS (AU-SPECIFIC)

2.1. Low-frequency AU spectroscopy

Detector Type	Frequency Range	Sensitivity	Temperature	Approximate cost
Superconducting Quantum Interferometers (SQUID)	0.1-100 Hz	10^{-18} Tl/ $\sqrt{\text{Hz}}$	4 K	\$1-10 million
Atomic interferometers	10-3-10 Hz	10^{-11} g/ $\sqrt{\text{Hz}}$	300 K	\$0.1-1 million
Cryogenic bolometers	0.01-1000 Hz	10^{-19} W/ $\sqrt{\text{Hz}}$	0.1 K	\$5-20 million

2.2. AU-correlation interferometry

Configuration	Base	Resolution	Sensitivity	Cost
Ground Network (10 stations)	1000 km	0.001 " @ 1 GHz	10^{-21} W / m ²	~\$100 million
Space Interferometer	100,000 km	10^{-6} "	10^{-24} W / m ²	~\$1 billion

2.3. Quantum entangled detectors

Technology	Sensitivity
NV-centers in diamond	10^{-5} Tl/ $\sqrt{\text{Hz}}$
Quantum dots	10^{-8} K / $\sqrt{\text{Hz}}$
Superconducting qubits	10^{-10} eV/ $\sqrt{\text{Hz}}$

SPACE MISSIONS FOR AU DETECTION

Mission	Period	Target	Orbit / base	Sensitivity	Cost
AU-SCOPE	2030-2035	AU-Entropy map 100 nearest exoplanets	L2	10^{-22} W / m ²	\$500 million
AU-NET	2035-	Network of 6	Heliocenter.,	10^{-25} W / m ²	\$1 billion

Mission	Period	Target	Orbit / base	Sensitivity	Cost
	2040-2040	microsatellites	base 1 million km		
AU-PROBE	2040-2050	Direct measurements of nearest exoplanets	Interstellar probe, 0.1-0.2 c	—	\$10-100 billion

EXAMPLES OF EXOPLANETS TO OBSERVE

Planet	Star	Distance (pc)	T _{eq} (K)	Forecast Φ _{AU}	Priority
Proxima b	Proxima Centauri	1.3	234	10 ⁶ – 10 ⁸	★★★★★★
TRAPPIST-1e, TRAPPIST-1		12.4	251	10 ⁵ – 10 ⁷	★★★★★☆
LHS 1140 b	LHS 1140	12.5	230	10 ⁵ – 10 ⁷	★★★★★☆
b Teegarden	Teegarden	12.5	274	10 ⁵ – 10 ⁷	★★★★☆☆
Kepler-186f	Kepler-186	182	188	10 ⁴ – 10 ⁶	★★★☆☆☆
Kepler-442b	, Kepler-442	342	233	10 ⁴ – 10 ⁶	★★☆☆☆☆

TECHNOLOGICAL CHALLENGES — sensitivity targets

Technology	Current	Goal 2030	Goal 2040	Fundamental limit
SQUID	10 ⁻¹⁸ TL/√Hz	10 ⁻²⁰	10-22	10 ⁻²⁴
Bolometers	10 ⁻⁹ W/√Hz	10-21	10-23	10 ⁻²⁵
Qubits	10 ⁻¹⁰ eV/√Hz	10-12	10 ⁻¹⁴	10 ⁻¹⁶
Atomic interferometers	10-11 g/√Hz	10-13	10 ⁻¹⁵	10 ⁻¹⁷

Comparison table: AU entropy vs Biosignatures

Parameter	Biosignature parameter (2025-2026 state)	AU-entropy (according to Acta Universi)
What you're looking for	Gases / molecules / imbalances produced by life (O ₂ , O ₃ , CH ₄ , DMS, N ₂ O, CO ₂ +CH ₄ of balance, etc.)	Information complexity / entropy in the AU field (spectral, time, phase, low-frequency)
Physical Basis	Atmospheric Chemistry + Photochemistry + Geochemistry + Biogeochemistry	Hypothetical universal AU field (possibly related to dark energy / information physics)
Signal type	Spectral lines (IR, UV, visible range), Chemical imbalance	Shannon entropy (H), time entropy (S), phase curve complexity, low-frequency fields
Frequency / wavelength	range 0.3-20 microns (mostly IR + visible)	Optical / IR (indirect) + extremely low frequencies 10-3-1000 Hz (direct)
Basic detection methods	Transit / Emission / Direct image spectroscopy (JWST, ELT, ARIEL, HWO)	Indirect: spectral / time / phase analysis Direct: SQUID, bolometers, atomic interferometers, quantum sensors

Parameter	Biosignature parameter (2025-2026 state)	AU-entropy (according to Acta Universi)
Current technological maturity	is High (JWST already provides data, many publications 2024-2026)	Low (theoretical stage + laboratory prototypes, missions offered from 2030+)
Sensitivity to biological activity	is Medium-high (but there are many false positive results-abiosignatures)	Potentially very high (if the AU hypothesis is correct — - responds to any complexity / organization)
Sensitivity to technogenic activity	Low-medium (only if the civilization changes the atmosphere significantly)	High (H ~ 7-10 bits for technogenic phase curves, S ~ 6-12 bits / hour)
Resistance to distance	Drops as 1/d ² (photon flux)	Falls as low as 1/d ² (AU entropy flux), but requires huge areas / very sensitive detectors
False Positives A	lot (geochemistry, photochemistry, volcanism, comets, etc.)	Unknown (depends on the nature of the AU field), but could theoretically be smaller (entropy is harder to fake)
False negative results	are high (life without oxygen, without DMS, subsurface life, etc.)	High (if life does not create a sufficient AU anomaly)
Examples of values for the Earth	O ₂ ~21%, CH ₄ ~1.8 ppm O ₃ , N ₂ O; imbalance CO ₂ -CH ₄ -O ₂	Nsems ≈ 12.3 ± 0.5 bits (range) S ~ 4-8 bits/hour (time series) H ~ 4-6 bits (phase curve)
Examples of values for dead planets	H_Venera ≈ 4.1 bits, H_Mars ≈ 3.8 bits	S ~ 1-3 bits / hour, H ~ 2-3 bits (homogeneous surface)
The nearest priority targets	are Proxima b, TRAPPIST-1 e/f/g, K2-18b, LHS 1140 b, and others.	Proxima b (★ ★ ★ ★ ★), TRAPPIST-1e, LHS 1140 b, Teegarden b
A realistic date for the first serious attempts	is already underway (JWST 2022-2026+), ARIEL ~2029, HWO / ELT 2030s	2030-2035 (AU-SCOPE), 2035-2040 (AU-NET)
The main current limitations	are Abiotic false positives, low SNR for Earth-like planets, 3D atmospheric effects	Detector sensitivity is 4-6 orders of magnitude lower than required, huge mission costs
The potential advantage	is well theoretically developed, there is JWST data, international missions	Can detect any complex organization (life + technology), possibly even non-carbon life

Summary of comparison results (as of February 2026)

Biosignatures today is the leader in terms of maturity

- JWST is already actively looking for gases (CH₄, CO₂, DMS, DMDS, etc.), there are high-profile (but controversial) candidates, for example K2-18b (2025).
- The method relies on well-known physics and chemistry → clear false positives and negative results.
- The main problem is **a lot of abiotic simulators** and the complexity of unambiguous interpretation (especially for sub-Neptunes and hazy planets).

AU entropy is a radically different approach

- It does not look for specific molecules, but **for the level of organization / complexity** (Shannon entropy as a measure).
- Theoretically, it can be **much more universal**: it detects life of any type (not only oxygen, not only surface), as well **as man-made activity** at a much higher level of significance.
- But in practice, it is still **very far from being implemented** — it requires technologies that are now at the prototype level (SQUID, cryogenic bolometers, quantum sensors), and huge investments (hundreds of millions to billions of dollars).

Which approach is more promising in the next 10-15 years?

- **2026-2035**-biosignatures will dominate (JWST, ELT, ARIEL, PLATO, Roman).
- **2035-2050** — if the AU hypothesis is confirmed at least in laboratory / theoretical works, then AU methods can become the second (and possibly more powerful) search channel.
- The most realistic scenario is **a combined approach**: first, candidates are found by biosignatures (or photometry / phase curves), and then they are tested for AU entropy using specialized missions.

Combining **classic biosignatures** and **AU entropy** in a single mission is a powerful and logical step. It allows you to first filter out promising targets based on the chemical characteristics of life, and then check them for fundamental complexity and organization through the AU field.

Here is a realistic concept for such a hybrid mission based on your document and current plans (HWO, ARIEL, PLATO, and low-frequency observatory concepts like GO-LoW).

Why the combination is profitable

- **Biosignatures** produce specific molecules ($O_2 + CH_4$, O_3 , DMS, etc.), but suffer from false positives (abiotic processes) and false negatives (life without oxygen).
- **AU-entropy** measures information complexity (spectral, temporal, phase, and low-frequency), which is potentially more universal and sensitive to any organized system (including man-made ones).
- **Synergy**: Bio-data → priority goals → deep AU analysis. This increases confidence in detecting life and reduces the risk of false alarms.
- **Economy**: One platform, shared systems (cryogenics, power supply, communications, precision guidance).

Proposed mission: AU-BioScope (AU-SCOPE extension)

Dates: 2032-2038 (first launch under your roadmap 2030-2035).

Orbit: L2 (Sun-Earth) - minimum interference, stable temperature, like JWST.

Weight/Cost: ~\$700-900 million (basic AU-SCOPE \$500M + biomodule and integration).

Target: 50-150 nearest Earth-like exoplanets (up to 20-30 pc), with priority of Proxima b, TRAPPIST-1e, LHS 1140 b.

Instrumental composition (hybrid payload)

Module	Range / Type	Main task	Communication with methods	Example of an analog / Technology
High-resolution spectrometer	0.3-20 microns (UV-Vis-IR), R = 50,000-100,000	Biosignatures (O ₂ , CH ₄ , H ₂ O, etc.) + spectral AU-entropy (H)	Indirect AU + biosignatures	ELT / HIRES + HWO coronagraph + IFS
High-precision photometry	Wide optical, 10-60 s cadence	Time entropy S (t) + phase curves	Indirect AU (variability)	PLATO / CHEOPS
AU-low-frequency block	0.001-1000 Hz	Direct AU-spectroscopy and correlations	Direct AU-	SQUID method + atomic interferometers + bolometers
Correlation interferometer	Multiple antennas / sensors on rods or small companion	satellites Spatial correlations AU-fields	Direct AU	Mini-version AU-NET
Quantum sensors	NV centers, qubits	Ultra-high sensitivity to weak	Direct AU fields (entangled detectors)	Laboratory prototypes 2025-2030

Key point: The main telescope (4-6 m mirror with coronagraph/starshade) works in optics/IR for biosignatures and indirect AU entropy. Low-frequency unit — a separate module on the same platform (or 2-3 small satellites in the formation for interferometry).

Observation protocol (multi-stage pipeline)

1. Screening (fast mode)

- Photometry + low-resolution spectroscopy → detection of transits, phase curves, and basic biosignatures.
- Calculation of the preliminary AU entropy (H and S).

2. Priority goals (deep mode)

- High-resolution spectroscopy → accurate biosignatures + spectral entropy.
- Long-term monitoring (days-weeks) → time entropy S and phase curves.
- Simultaneous activation of the AU low-frequency unit → search for a direct AU signal.

3. Correlation analysis

- Mapping: high bio-complexity + high AU-entropy → strong candidate for life.
- If the AU signal is strong, but there are no biosignatures → possible non-carbon or technogenic activity.

Advantages of such a mission

- **Scientific power** is the first tool in history that searches for life through two independent channels at once (chemistry + information).

- **Efficiency** — the same goals are observed by all methods simultaneously → save time and resources.
- **Flexibility** — you can start with already known candidates from JWST/ELT/ARIEL.
- **A technological bonus** is the development of cryogenic systems, quantum sensors and interferometry for two tasks at once.

Key challenges and solutions

- **Different ranges** (Optics vs Hz) → solution: modular design, different subsystems on a common platform.
- **AU sensitivity** → start with the nearest targets (≤ 10 pc) and large effective areas (spaced sensors).
- **Data and processing** → machine learning for real-time entropy calculation + joint analysis of bio-and AU-data.
- **Cost** → use ready-made developments of HWO (optics) + your AU technologies.

This fits perfectly into your roadmap: AU-SCOPE 2030-2035 gets a biomodule, and by 2035-2040 it is moving to a full-fledged AU-NET with combined capabilities.

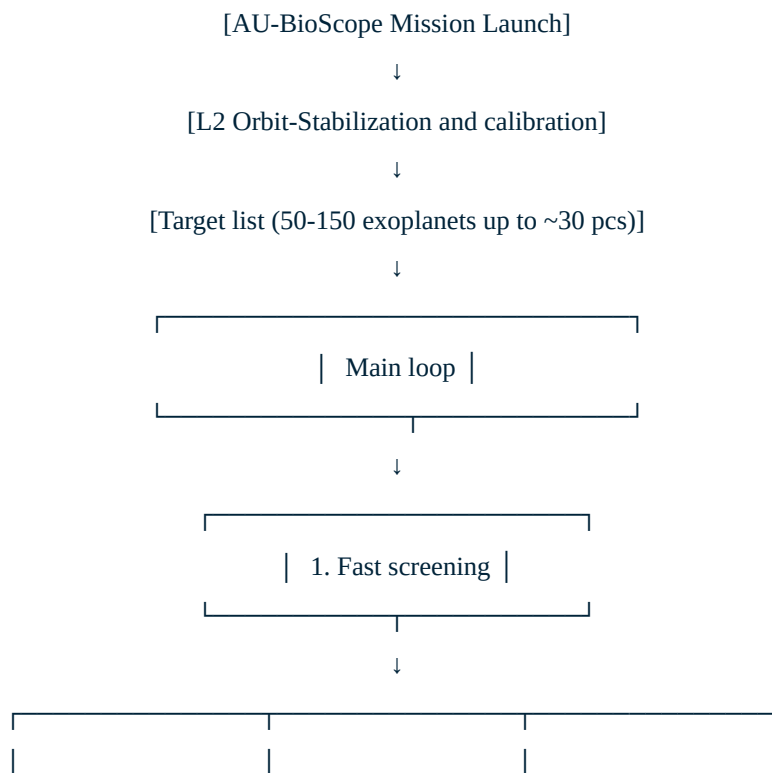
Here is a text representation **of the flowchart** of the AU-BioScope mission (a hybrid mission to search for biosignatures and AU entropy of exoplanets).

I made it in two versions:

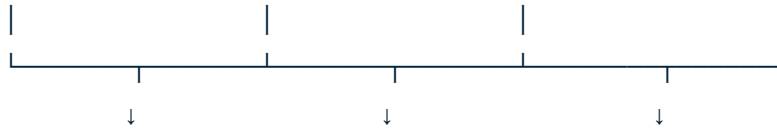
1. Simple linear sequence (easy to read)
2. More structured hierarchical flowchart-style flowchart (in markdown format)

1. Simple linear flow chart of the mission (general process)

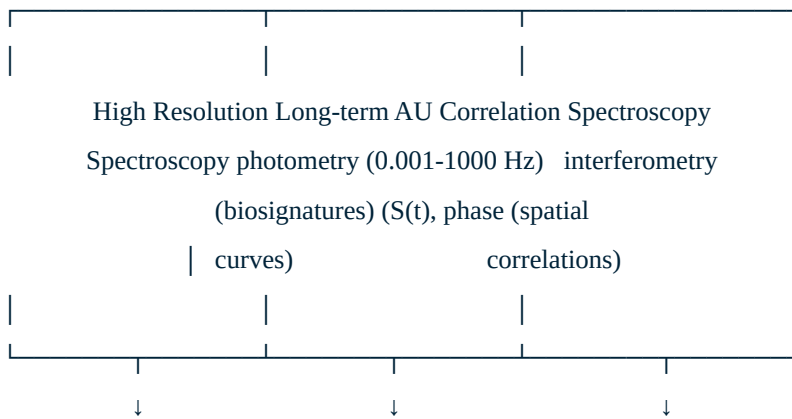
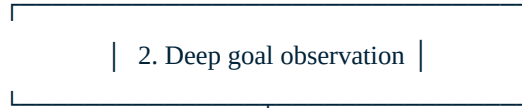
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Photometry Low Resolution AU-Low Frequency Test
(TESS/PLATO-like) spectroscopy transit monitoring



Identifying candidates with anomalies

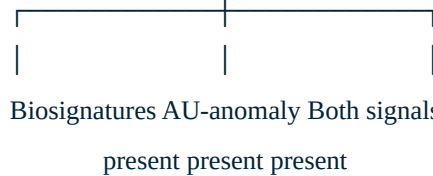


High Resolution Long-term AU Correlation Spectroscopy
Spectroscopy photometry (0.001-1000 Hz) interferometry
(biosignatures) (S(t), phase (spatial
curves) correlations)

Data collection across all channels (bio + AU)



Collaborative analysis (ML + statistical methods)



Strong candidate Very strong candidate



[Publication / Further study]

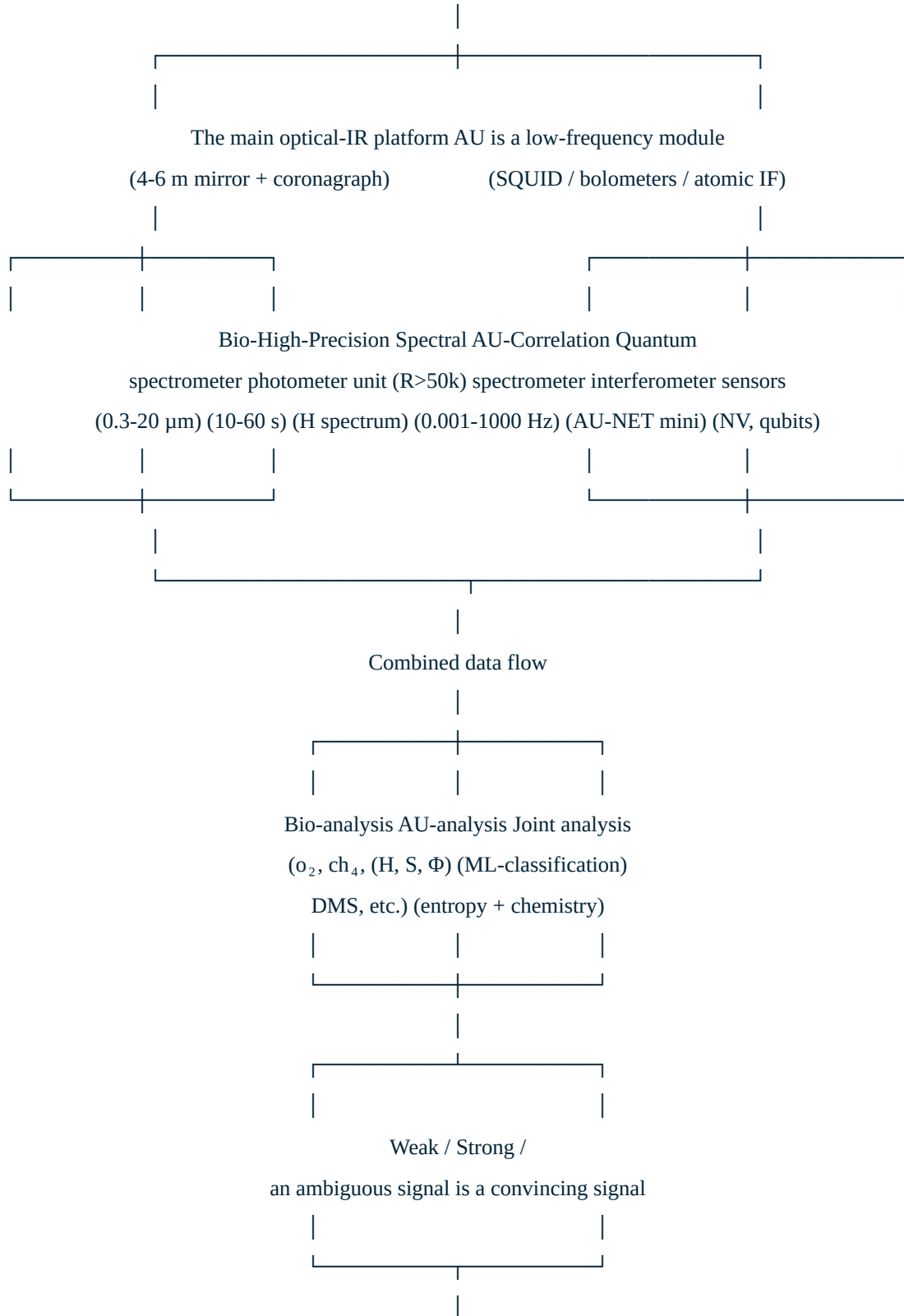


[Move to the next goal]

2. Hierarchical flowchart (more visual structure)

text

AU-BioScope (L2, 2032–2038)





Short text description for the presentation / article

Flowchart of the AU-BioScope mission observation process

1. **Phase 1 - Screening** Fast photometry + low-resolution spectroscopy + initial AU monitoring
→ selection of 10-20% of the most promising targets.
2. **Phase 2-Deep investigation** High resolution spectroscopy (biosignatures + spectral entropy)
Long-term photometry (time entropy + phase curves) Direct AU spectroscopy and correlation interferometry
3. **Phase 3 - Data integration** Collaborative analysis: correlation between the level of biochemical dissipation and the level of AU entropy Machine learning for classification: dead planet / biological activity / possible technogenic activity
4. **Output** a ranked list of candidates with confidence levels and recommendations for follow-up observations (ground-based or future missions)

Phase 2: Deep goal observation

(Deep Characterization Phase)

The goal of the phase

is to obtain high-quality, multi-channel data on a single priority exoplanet with sufficient duration and sensitivity to reliably estimate:

- availability of classic biosignatures
- level of spectral, time, and phase entropy
- presence and characteristics of a direct AU signal (if the technology allows it to be registered)

Typical cycle duration per target

is 14-120 days (depending on priority, orbital period of the planet, and available observation time)

Main subphases and operating modes

Subphase no	Duration	Basic Tools	Basic measured values	Target Accuracy / SNR	Note / Feature	
2.1	High-precision of 1-3 transits (usually 6-30 hours each) observation	High-resolution spectrometer (R ≥ 50,000-100,000)	Spectrum during transit (transmission)	SNR ≥ 20-50 per pixel in continuum	Measurement of molecular bands O ₂ , O ₃ , CH ₄ , CO ₂ , H ₂ O, possible DMS/DMDS	
.2	Day-side emission spectroscopy	≥ 20-60 hours total	Same spectrometer +	Emission spectrum (thermal +	SNR ≥ 10-30 in the key	Search for thermal radiation and

Subphase no		Duration	Basic Tools	Basic measured values	Target Accuracy / SNR	Note / Feature
			coronagraph / starshade	reflected light)	bands	reflected light
2.3	Full phase curve	≥ 1-2 full orbits	High-precision photometry + spectrometer	Brightness as a function of phase angle, spectral phase curves	$\Delta F/F \sim 10^{-6} - 10^{-7}$, time stability	H ₂ phase entropy calculation, asymmetry search
2.4	Long photometric monitoring	10-60 days continuously or with high occupancy	High-precision photometry (10-120 s cadence)	Time series of brightness outside the transit	Noise < 20-50 ppm for 1 hour	Calculation of time entropy S(t), search for non-stationary processes
2.5	AU-low-frequency spectroscopy	In parallel with 2.3 and 2.4 (continuously)	AU-low-frequency block (SQUID / bolometers / atomic IF)	Power spectrum in the range of 0.001-1000 Hz	Sensitivity 10 ⁻²¹ -10 ⁻²³ W / m ² / √Hz	Search for narrow-band and broadband AU signals
2.6	Correlation interferometry	20-100 hours of integration	AU-correlation interferometer (2-4 elements)	Spatial-temporal correlations of the AU field	Sensitivity 10 ⁻²³ -10 ⁻²⁵ W / m ²	for immediate targets only (≤ 5-10 pc)
2.7	Quantum-sensitive measurements	If possible (10-50 hours)	Quantum sensors (NV centers, qubits, etc.)	Ultra-sensitive measurements of magnetic / gravitational / thermal fluctuations	10 ⁻¹⁴ -10 ⁻¹⁶ eV/√Hz or new equivalent	Experimental mode, testing new technologies

Sequence and concurrency of modes

A typical strategy for observing a single target (for example, for a planet with a period of ~10-40 days):

1. First 1-3 orbits

- Main focus: 2.1 (transit) + 2.2 (emission) + 2.3 (start of phase curve)
- Parallel: Enabled AU-low frequency monitoring (2.5)

2. Next 1-3 orbits

- Main focus: phase curve completion (2.3) + long-term photometric monitoring (2.4)
- In parallel: AU spectroscopy (2.5) + beginning of correlation interferometry (2.6) if the target is closer than 10 pc

3. Final stage (if resources are available)

- Additional 20-50 hours of quantum-sensitive measurements (2.7)
- Repeated transits / emissions to increase SNR

Key data quality parameters (target values)

- **Biosignatures**
 - Detection of O₂ at the level of 10-20% (Earth-like case) → SNR ≥ 15-25 in the 0.76 μm band
 - Detection of CH₄ at 1-5 ppm → SNR ≥ 10-20 v 3.3 μm
 - Unbalance detection (O₂ + CH₄ simultaneously) → priority attribute
- **Spectral AU entropy**
 - Target: H ≥ 10-12 bits (Earth-like level)
 - Required estimation accuracy H: ±0.5-1.0 bits
- **Time entropy**
 - Target: S ≥ 4-6 bps (biological activity)
 - Required accuracy: ±0.5-1 bit / hour
- **Phase entropy**
 - Target: H_{phase} ≥ 4.5-6 bits (non-uniform surface with continents / biomass)
 - Required accuracy: ±0.3-0.7 bits
- **Direct AU stream** (very ambitious)
 - Objective: Detection of flow ≥ 10⁻²²-10⁻²⁴ W / m² in key frequency bands

Transition criteria for phase 3 (integration and classification)

Phase 2 is considered successful if at least one of the following conditions is met:

- At least one transit + one complete phase curve with high quality was obtained
- Achieved SNR ≥ 10-15 in key biosignature bands
- ≥ 20-30 days of continuous AU monitoring were performed
- Is there at least a preliminary estimate of the spectral and / or temporal entropy

If at least one of the channels (bio or AU) receives a strong positive signal, the target is transferred to the "high priority" category for repeated observations or additional resources.