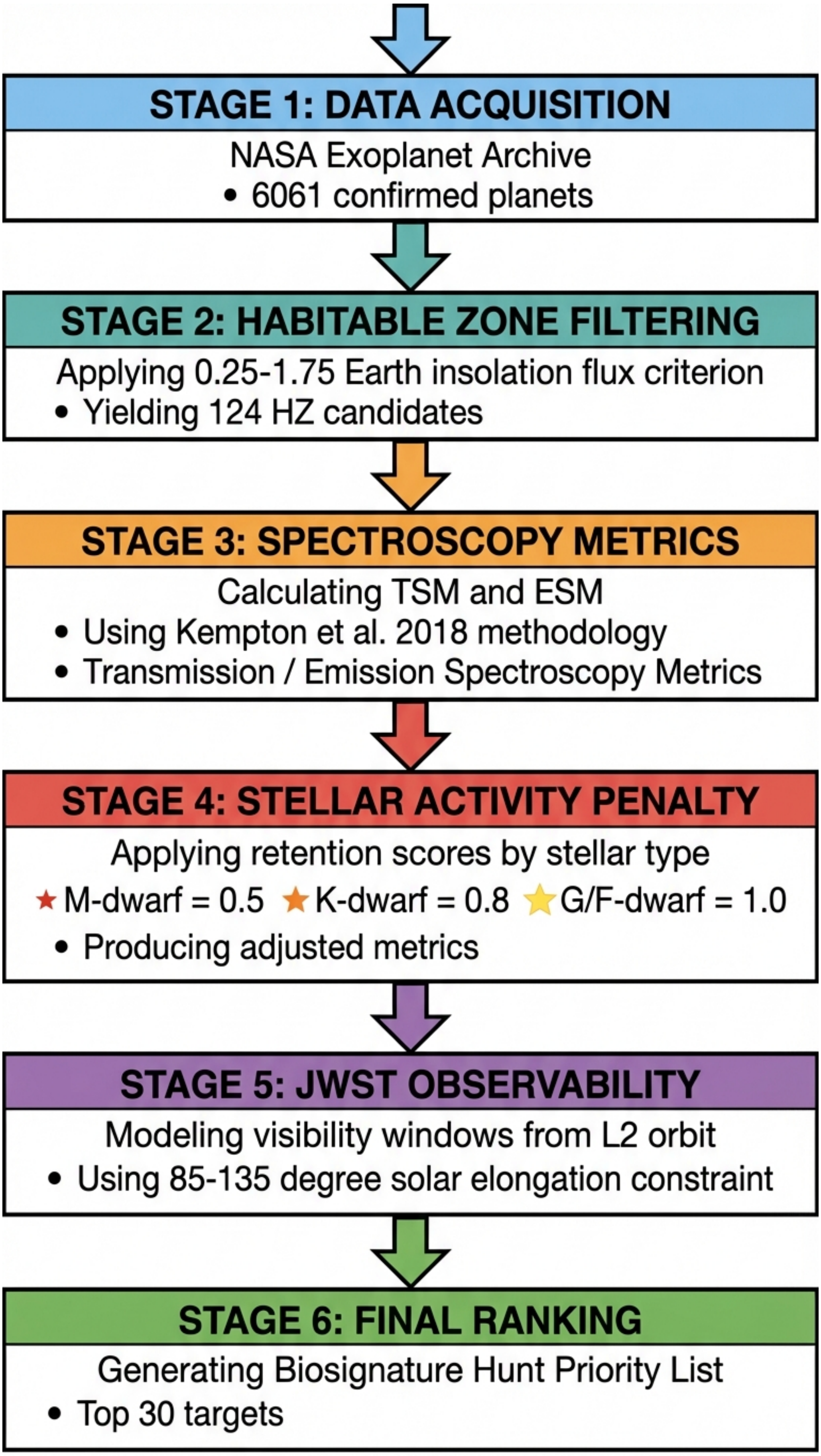
Biosignature Hunt Priority Framework

Optimizing James Webb Space Telescope Targets for Atmospheric Characterization of Habitable Exoplanets

Technical Report

December 2025



Graphical Abstract: Quantitative prioritization framework for JWST target selection

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Data Source

NASA Exoplanet Archive (PSCompPars Table)
Accessed: December 2025

Analysis Period

Observability Window: January 1, 2026 – December 31, 2027

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1 Executive Summary

This technical report presents a quantitative prioritization framework for ranking habitable zone exoplanets for James Webb Space Telescope (JWST) atmospheric characterization, optimized for the highest probability of detecting biosignature gases. The framework integrates spectroscopic observability metrics, stellar activity considerations, and operational constraints to produce an actionable target list for the 2026–2027 observing period.

1.1 Key Findings

The M-Dwarf Advantage: Despite applying a 50% penalty for atmospheric stripping risk, small rocky planets ($R_p < 1.6\ R_\oplus$) orbiting M-dwarfs provide **statistically significantly higher** observational value than those around K/G-dwarfs ($p = 0.009$, effect size = 90.5%). Their proximity to host stars yields transmission signals 10–100× stronger than alternatives, more than compensating for activity-related risks.

Top Recommended Target: Teegarden's Star b (Rank #1 in observable targets) – a 1.05 $R_\oplus$ planet in the habitable zone of an M-dwarf, offering exceptional signal strength (TSM_{adj} = 38,207.7) with 105 days/year visibility starting June 2027. This target represents the optimal balance of atmospheric detectability, moderate stellar activity, and operational feasibility.

1.2 Summary Statistics

Table 1: Analysis Overview

Metric	Value
Total confirmed planets analyzed	6,061
Habitable zone candidates identified	124
Candidates with complete metrics	123
Observable targets (2026–2027)	30
CVZ targets (>200 days/year visibility)	24
Statistical significance (p-value)	0.009
Effect size (CLES)	90.5%

1.3 Strategic Recommendations

1. **Immediate Priority (Tier 1):** Begin observations of CVZ targets (GJ 1061 c/d, GJ 1002 b/c) in Cycle 2 (2026) – these provide year-round observability and maximum scheduling flexibility.

2. **High-Value Seasonal (Tier 2):** Prepare Cycle 3 proposals for Teegarden's Star b and Ross 128 b – the highest-priority targets with seasonal visibility windows opening in 2027.

3. **Comparative Science (Tier 3):** Propose joint observations of the TRAPPIST-1 system (d/e/f/g) for comparative atmospheric studies across varying insolation levels.

4. **Risk Management:** Request 10–15 M-dwarf targets to statistically ensure 5–7 atmospheric detections, accepting ∼50% null detection rate.

2 Methodology

The prioritization framework consists of four integrated analytical stages: (1) data acquisition and habitable zone filtering, (2) spectroscopy metric calculation, (3) stellar activity penalty application, and (4) JWST observability modeling. Figure 1 illustrates the complete workflow.

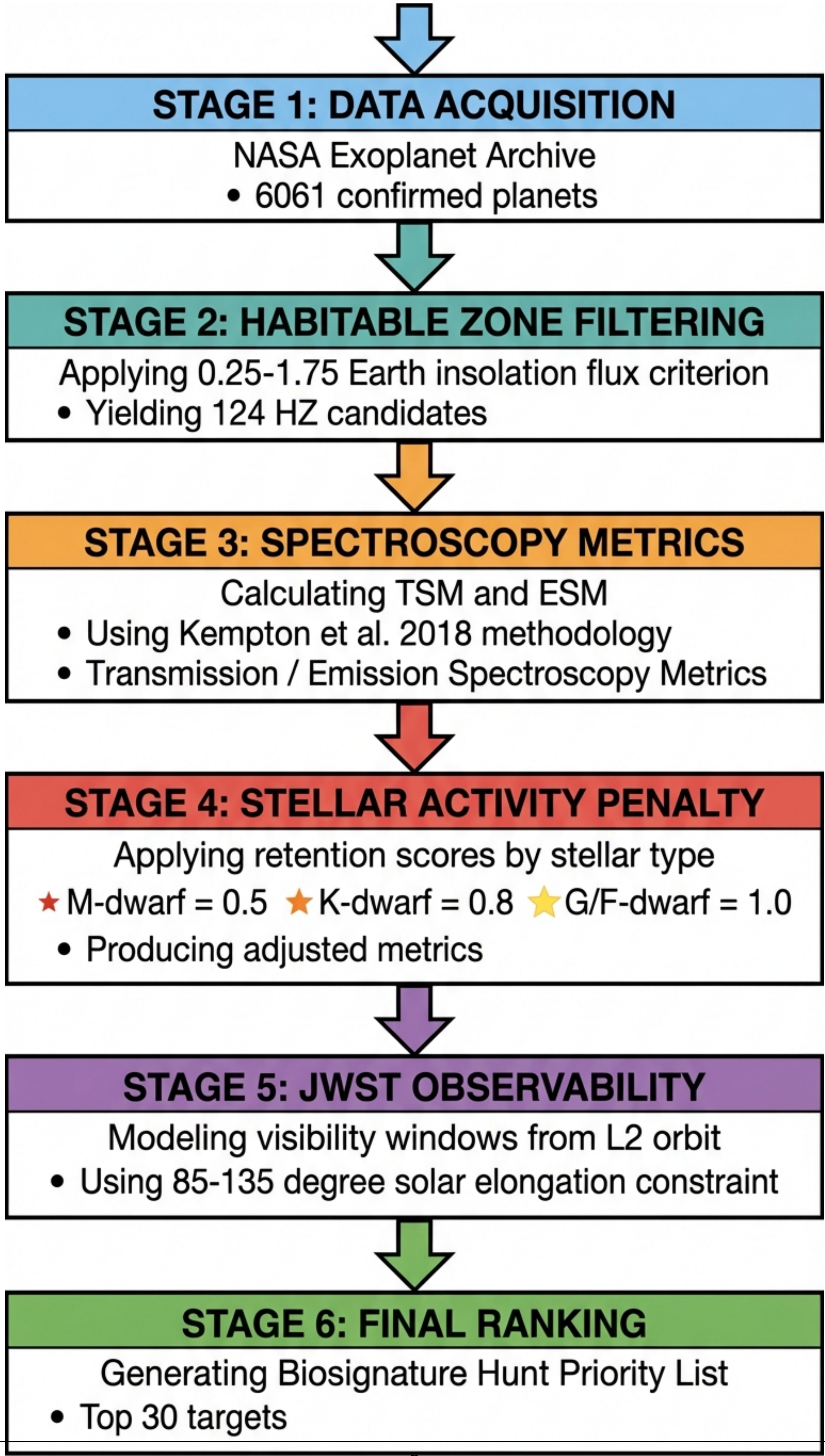

Figure 1: Quantitative prioritization framework for JWST target selection. The workflow progresses from data acquisition (6,061 planets) through habitable zone filtering (124 candidates),

2.1 Data Acquisition

Exoplanet data were retrieved from the NASA Exoplanet Archive Planetary Systems Composite Parameters (PSCompPars) table on December 14, 2025. The complete dataset contained 6,061 confirmed exoplanets with associated stellar and planetary parameters.

Key parameters extracted:

- Planetary radius (R_p), mass (M_p), equilibrium temperature (T_{eq})
- Stellar radius (R_*), effective temperature (T_{eff}), distance (d)
- Stellar insolation flux (S) in Earth units
- Transit depth and orbital parameters

2.2 Habitable Zone Filtering

Habitable zone candidates were identified using a conservative insolation flux criterion:

$$0.25\ S_\oplus \leq S \leq 1.75\ S_\oplus \tag{1}$$

where $S_\oplus$ represents Earth's solar insolation flux. This range encompasses:

- **Outer edge** (0.25 $S_\oplus$): Mars-like irradiation, maximum greenhouse limit
- **Inner edge** (1.75 $S_\oplus$): Venus-like irradiation, runaway greenhouse limit

Results: Of 6,061 confirmed planets, **124 habitable zone candidates** (2.05%) satisfied the insolation criterion. One candidate was excluded due to missing mass data, yielding 123 candidates for subsequent analysis.

2.3 Transmission and Emission Spectroscopy Metrics

Observational priority was quantified using the Transmission Spectroscopy Metric (TSM) and Emission Spectroscopy Metric (ESM) following the methodology of Kempton et al. (2018).

2.3.1 Transmission Spectroscopy Metric (TSM)

The TSM quantifies the expected signal-to-noise ratio for atmospheric absorption features during planetary transit:

$$\text{TSM} = \mathcal{S} \times \frac{R_p^3 \cdot T_{\text{eq}}}{M_p \cdot R_*^2} \times 10^{-m_J/5} \tag{2}$$

where $\mathcal{S}$ is a scale factor dependent on planetary radius regime, R_p is planetary radius, T_{eq} is equilibrium temperature, M_p is planetary mass, R_* is stellar radius, and m_J is the J-band magnitude.

The scale factor $\mathcal{S}$ accounts for differences in atmospheric scale height expectations:

- $R_p < 1.5\ R_\oplus$: $\mathcal{S} = 0.190$
- $1.5 \leq R_p < 2.75\ R_\oplus$: $\mathcal{S} = 1.26$
- $2.75 \leq R_p < 4.0\ R_\oplus$: $\mathcal{S} = 1.28$
- $R_p \geq 4.0\ R_\oplus$: $\mathcal{S} = 1.15$

2.3.2 Emission Spectroscopy Metric (ESM)

The ESM quantifies the expected planetary thermal emission signal relative to stellar flux:

$$\text{ESM} = 4.29 \times 10^{-6} \times B_\nu(T_p) \times \left(\frac{R_p}{R_*}\right)^2 \times \left(\frac{d}{10\text{ pc}}\right)^{-2} \quad (3)$$

where $B_\nu(T_p)$ is the Planck function evaluated at planetary dayside temperature and d is the stellar distance.

2.3.3 Metric Distribution

Table 2: TSM and ESM Distribution Statistics for 123 HZ Candidates

Metric	Min	Max	Median	Mean	Std Dev
TSM	19.56	177,795.16	560.98	9,072.70	21,857.14
ESM	0.00	4.02	0.02	0.29	0.65

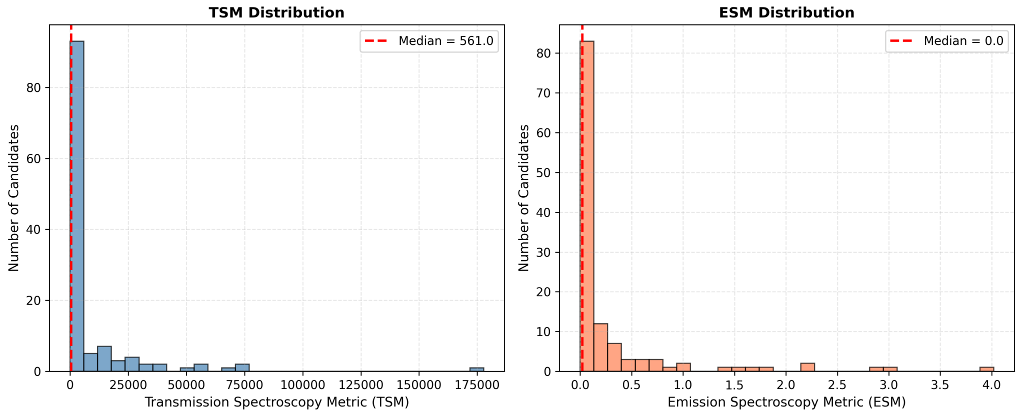

Figure 2: Distribution of Transmission Spectroscopy Metric (TSM) and Emission Spectroscopy Metric (ESM) across the 123 habitable zone candidates. The log-scale distribution reveals a heavy tail toward high-TSM targets, dominated by M-dwarf systems.

2.4 Stellar Activity Penalties

M-dwarf stars emit intense X-ray and ultraviolet (XUV) radiation that can erode planetary atmospheres over gigayear timescales, potentially eliminating the atmospheres we seek to characterize. To account for this atmospheric retention risk, we applied stellar-type-dependent penalty factors.

2.4.1 Stellar Classification

Host stars were classified by effective temperature:

- **M-dwarf**: $T_{\text{eff}} < 3900$ K
- **K-dwarf**: $3900 \leq T_{\text{eff}} < 5300$ K
- **G-dwarf**: $5300 \leq T_{\text{eff}} < 6000$ K
- **F-dwarf**: $T_{\text{eff}} \geq 6000$ K

2.4.2 Retention Score Assignment

Table 3: Atmospheric Retention Scores by Stellar Type

Stellar Type	$T_{\rm eff}$ Range	Retention Score	Rationale
M-dwarf	< 3900 K	0.5	High XUV activity, frequent flares
K-dwarf	3900–5300 K	0.8	Moderate activity
G-dwarf	5300–6000 K	1.0	Low activity (Sun-like)
F-dwarf	≥ 6000 K	1.0	Low activity

2.4.3 Adjusted Metrics

The retention score was applied multiplicatively to both TSM and ESM:

$$\text{TSM}_{\text{adj}} = \text{TSM} \times f_{\text{retention}} \tag{4}$$

$$\text{ESM}_{\text{adj}} = \text{ESM} \times f_{\text{retention}} \tag{5}$$

2.4.4 Sample Distribution

Table 4: Stellar Type Distribution of HZ Candidates

Stellar Type	Count	Percentage
M-dwarf	50	40.7%
K-dwarf	46	37.4%
G-dwarf	25	20.3%
F-dwarf	2	1.6%
Total	123	100.0%

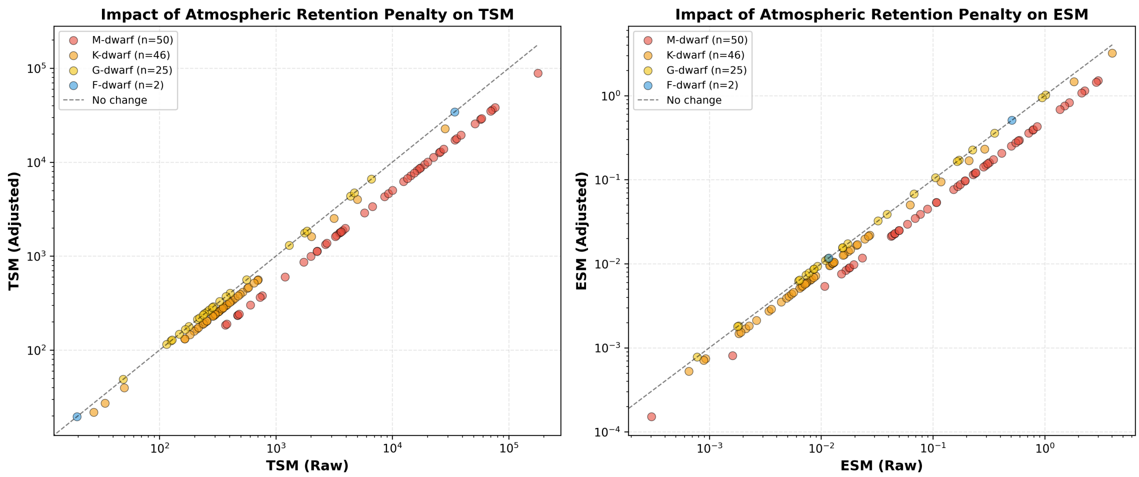

Figure 3: Impact of stellar activity penalties on target rankings. Left: TSM distribution before and after penalty application, stratified by stellar type. Right: Ranking changes showing M-dwarfs dropping positions while K/G-dwarfs gain relative priority.

2.5 JWST Observability Modeling

JWST observability constraints were modeled using the telescope's solar elongation limits from its L2 orbit.

2.5.1 Solar Elongation Constraint

JWST's sunshield architecture restricts observations to targets within a specific angular range from the Sun:

$$85\text{ř} \leq \theta_{\mathrm{SE}} \leq 135\text{ř} \tag{6}$$

where θ_{SE} is the solar elongation angle. Targets outside this range cannot be observed.

2.5.2 Visibility Window Calculation

For each target, we calculated:

1. **Annual visibility days**: Total days per year within the solar elongation window
2. **Next window start**: Date when the target becomes observable in the 2026–2027 period
3. **CVZ status**: Targets with >200 days/year visibility are flagged as Continuous Viewing Zone (CVZ) candidates

2.5.3 Integration Time Estimates

Integration times for 5σ atmospheric feature detection were estimated using the TSM/ESM scaling relations:

$$t_{\mathrm{transmission}} \propto \mathrm{TSM}^{-2} \tag{7}$$

$$t_{\mathrm{emission}} \propto \mathrm{ESM}^{-2} \tag{8}$$

Results: All 123 targets are feasible for transmission spectroscopy (<20 hours for 5σ detection). Emission spectroscopy is more challenging, with most targets requiring 100–1000+ hours.

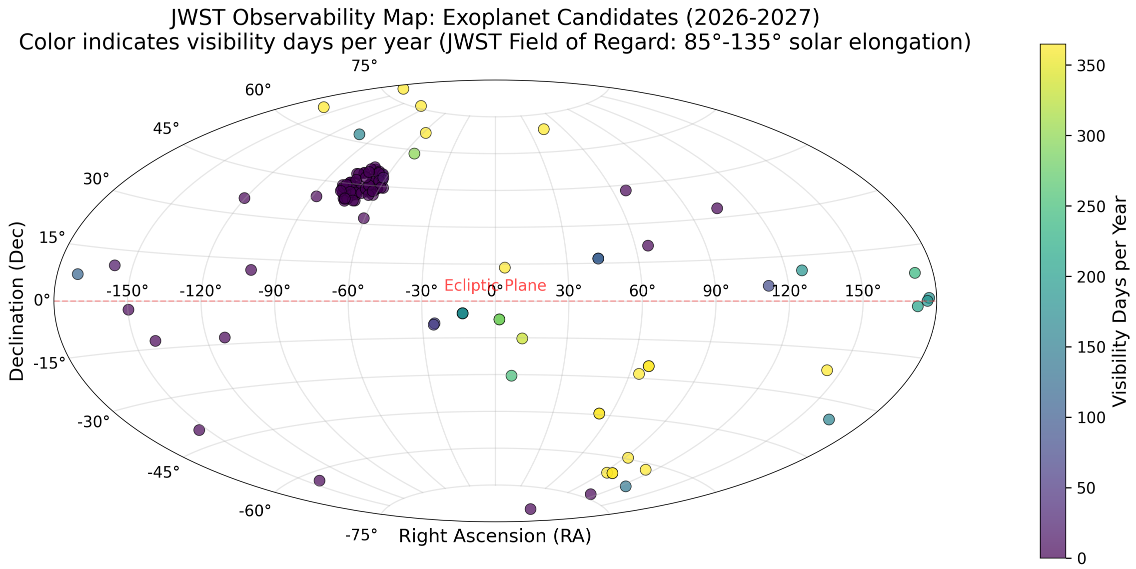

Figure 4: JWST observability map for habitable zone candidates. The plot shows ecliptic coordinates with solar elongation constraint zones indicated. Points are colored by stellar type and sized by TSM_{adj}.

3 Results

3.1 Hypothesis Testing: M-Dwarf Rocky Planet Superiority

We tested the hypothesis that small rocky planets ($R_p < 1.6\ R_\oplus$) orbiting M-dwarfs represent the optimal targets for JWST atmospheric characterization, even after accounting for atmospheric retention penalties.

3.1.1 Statistical Framework

Null Hypothesis (H_0): The distributions of adjusted TSM are identical for M-dwarf and non-M-dwarf rocky planets.

Alternative Hypothesis (H_1): M-dwarf rocky planets have higher adjusted TSM than non-M-dwarf rocky planets.

Test: Mann-Whitney U test (non-parametric, appropriate for non-normal distributions and small sample sizes)

3.1.2 Sample Characteristics

Table 5: Rocky Planet Sample Characteristics ($R_p < 1.6\ R_\oplus$)

Statistic	M-dwarf	Non-M-dwarf
Sample size	28	3
Median TSM_{adj}	7,930.78	235.65
Mean TSM_{adj}	13,955.87	271.01
Std Dev	19,314.34	268.56
Min	184.36	21.87
Max	88,897.58	555.50

3.1.3 Statistical Results

Table 6: Mann-Whitney U Test Results

Parameter	Value
U-statistic	76.00
p-value	0.0091
Significance level (α)	0.05
Common Language Effect Size (CLES)	0.905
Conclusion	**Reject** H_0

3.1.4 Interpretation

The Mann-Whitney U test reveals a **statistically significant difference** ($p = 0.009 < 0.05$) between M-dwarf and non-M-dwarf rocky planets. The Common Language Effect Size (CLES) of 0.905 indicates that a randomly selected M-dwarf rocky planet has a **90.5% probability** of having higher adjusted TSM than a randomly selected non-M-dwarf rocky planet.

Key insight: Despite the 50% atmospheric retention penalty applied to M-dwarf planets, they *still* provide significantly higher observational value than K/G-dwarf alternatives. The median TSM_{adj} ratio is **33.6**× in favor of M-dwarfs.

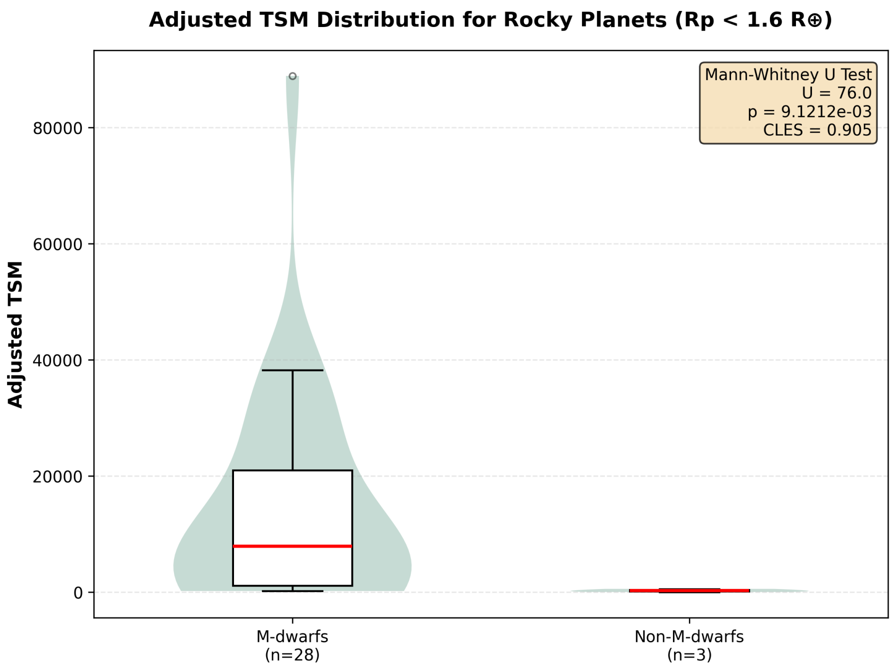

Figure 5: Box plot comparison of adjusted TSM distributions for rocky planets ($R_p < 1.6\ R_\oplus$) orbiting M-dwarfs (n=28) versus non-M-dwarfs (n=3). The distribution separation is visually stark, with M-dwarf rocky planets clustering 10–100× higher in TSM_{adj}.

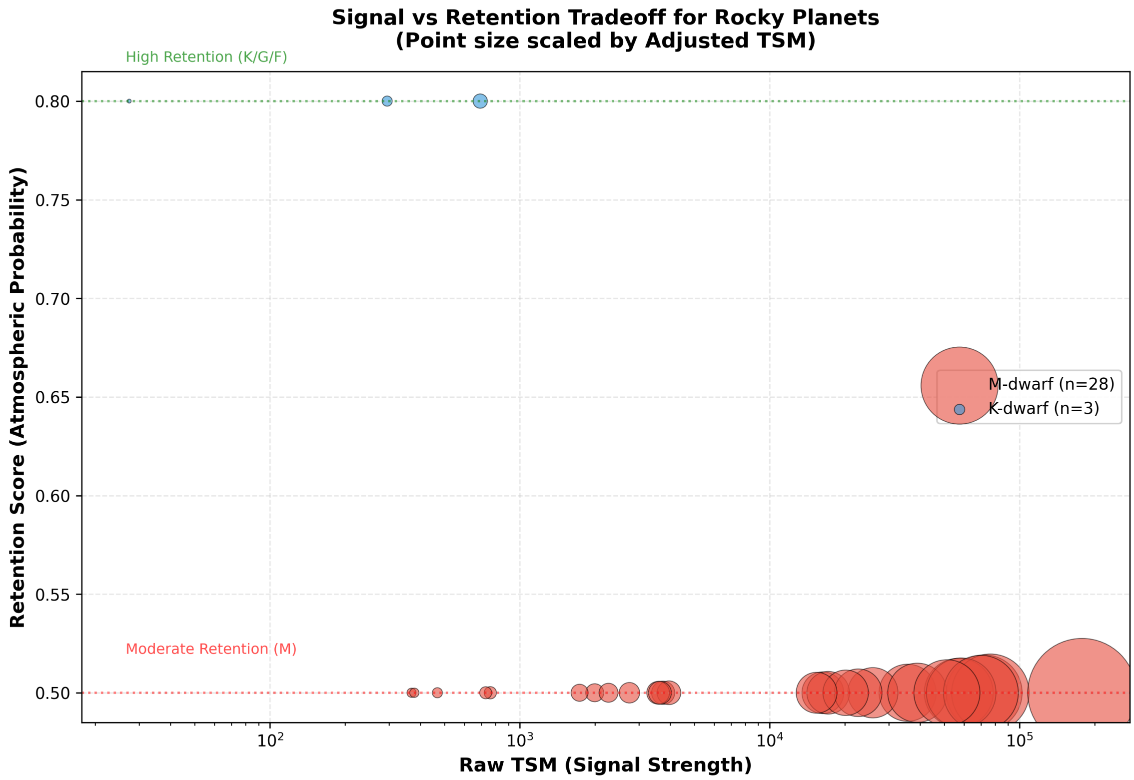

Figure 6: Signal strength versus atmospheric retention tradeoff. The scatter plot reveals the central tension: M-dwarf planets occupy the high-signal/low-retention quadrant, while K/G-dwarf planets occupy the low-signal/high-retention quadrant. The diagonal represents equal adjusted TSM.

3.2 The "Proxima Problem": Observability Constraints

A critical finding is that many high-priority targets are **unobservable** during the 2026–2027 window due to JWST's solar elongation constraints.

Notable Exclusions:

- **Proxima Centauri b**: Highest raw TSM (177,795), closest exoplanet (4.24 ly), but **0 days/year visibility**
- **TOI-2134 c**: Rank #9 by TSM_{adj}, but 0 days/year visibility
- **Wolf 1061 c**: Rank #12 by TSM_{adj}, but 0 days/year visibility

Lesson: Theoretical observability (TSM/ESM) must be integrated with operational constraints (visibility windows) to produce actionable observing schedules.

3.3 Top 30 Ranked Targets

Table 7 presents the final "Biosignature Hunt Priority List" – the top 30 observable exoplanets ranked by adjusted TSM for the 2026–2027 JWST observing period.

Table 7: Biosignature Hunt Priority List: Top 30 JWST Targets (2026–2027)

Rank	Planet	Host Star	Type	R_p ($R_\oplus$)	S ($S_\oplus$)	$\mathbf{TSM_{adj}}$	Vis. (d/yr)	Window
1	Teegarden's Star b	Teegarden's Star	M	1.05	1.08	38,207.7	105.0	2027-06-05
2	Ross 128 b	Ross 128	M	1.11	1.38	36,101.3	181.5	2027-01-03
3	GJ 1061 c	GJ 1061	M	1.18	1.40	35,003.2	365.0	2026-01-01
4	HIP 41378 f	HIP 41378	F	9.20	1.24	34,290.2	184.5	2026-01-01
5	Teegarden's Star c	Teegarden's Star	M	1.02	0.35	29,195.7	105.0	2027-06-05
6	GJ 1061 d	GJ 1061	M	1.16	0.60	28,546.1	365.0	2026-01-01
7	GJ 1002 b	GJ 1002	M	1.03	0.67	25,597.3	284.0	2026-01-01
8	GJ 1002 c	GJ 1002	M	1.10	0.26	19,483.9	284.0	2026-01-01
9	GJ 273 b	GJ 273	M	1.51	1.06	17,814.3	78.0	2026-01-01
10	TRAPPIST-1 d	TRAPPIST-1	M	0.79	1.12	12,935.6	174.0	2026-01-01
11	GJ 3293 b	GJ 3293	M	5.19	1.07	12,622.7	365.0	2026-01-01
12	Wolf 1069 b	Wolf 1069	M	1.08	0.65	11,301.7	297.0	2026-01-01
13	TRAPPIST-1 e	TRAPPIST-1	M	0.92	0.65	10,070.4	174.0	2026-01-01
14	GJ 357 d	GJ 357	M	2.34	0.38	8,722.3	365.0	2026-01-01
15	TRAPPIST-1 f	TRAPPIST-1	M	1.04	0.37	8,569.6	174.0	2026-01-01
16	L 98-59 f	L 98-59	M	1.48	1.10	8,158.2	141.0	2027-03-25
17	TRAPPIST-1 g	TRAPPIST-1	M	1.13	0.25	7,703.3	174.0	2026-01-01
18	HD 94771 b	HD 94771	G	14.20	0.27	6,607.6	159.0	2027-02-17
19	GJ 514 b	GJ 514	M	2.13	0.28	6,244.4	15.5	2027-12-01
20	GJ 3293 d	GJ 3293	M	2.67	0.59	5,025.9	365.0	2026-01-01
21	HD 191939 g	HD 191939	G	3.74	0.99	4,719.3	365.0	2026-01-01
22	TOI-1338 b	TOI-1338 A	G	7.66	0.99	4,364.1	365.0	2026-01-01
23	TOI-178 f	TOI-178	K	2.42	0.61	4,013.3	250.0	2026-01-01
24	LHS 1140 b	LHS 1140	M	1.73	0.43	3,376.7	332.5	2026-01-01
25	TOI-712 d	TOI-712	K	2.47	1.60	2,518.5	365.0	2026-01-01
26	TOI-700 e	TOI-700	M	0.95	1.27	1,976.5	365.0	2026-01-01
27	Gliese 12 b	Gliese 12	M	0.96	1.62	1,872.7	365.0	2026-01-01
28	HD 109286 b	HD 109286	G	13.20	0.71	1,848.7	113.0	2027-05-20
29	TOI-700 d	TOI-700	M	1.07	0.85	1,818.4	365.0	2026-01-01
30	K2-3 d	K2-3	M	1.46	1.44	1,788.8	210.5	2026-11-06

Note: Proxima Centauri b (TSM_{adj} = 88,897.6) is excluded from this list due to 0 days/year visibility in the 2026–2027 observing window.

4 Strategic Recommendations

Based on the quantitative analysis, we present a tiered target strategy for JWST atmospheric characterization programs.

4.1 Tier 1: Immediate Priority Targets (CVZ)

Definition: Targets visible >200 days/year, observable from January 2026

These targets provide maximum scheduling flexibility and can serve as anchor programs for multi-year campaigns.

Table 8: Tier 1: CVZ Priority Targets

Rank	Planet	TSM_{adj}	Visibility	High ESM	Stellar Type
3	GJ 1061 c	35,003.2	365.0 d/yr	Yes	M-dwarf
6	GJ 1061 d	28,546.1	365.0 d/yr	Yes	M-dwarf
7	GJ 1002 b	25,597.3	284.0 d/yr	No	M-dwarf
8	GJ 1002 c	19,483.9	284.0 d/yr	No	M-dwarf
11	GJ 3293 b	12,622.7	365.0 d/yr	Yes	M-dwarf
12	Wolf 1069 b	11,301.7	297.0 d/yr	No	M-dwarf

Recommendation: Begin observations in JWST Cycle 2 (2026). Prioritize GJ 1061 c/d as the primary targets due to combined high TSM_{adj} and high ESM, enabling both transmission and emission spectroscopy.

4.2 Tier 2: High-Value Seasonal Targets

Definition: Targets with highest TSM_{adj} but limited visibility windows

Table 9: Tier 2: High-Value Seasonal Targets

Rank	Planet	TSM_{adj}	Visibility	Window Opens	Notes
1	Teegarden's Star b	38,207.7	105.0 d/yr	2027-06-05	Top priority Cycle 3
2	Ross 128 b	36,101.3	181.5 d/yr	2027-01-03	High ESM
4	HIP 41378 f	34,290.2	184.5 d/yr	2026-01-01	F-dwarf (control)

Recommendation:

- Prepare JWST Cycle 3 proposals for **Teegarden's Star b** – the single highest-priority observable target.
- Schedule **Ross 128 b** observations for early 2027 when the visibility window opens.
- Include **HIP 41378 f** as a non-M-dwarf control target for comparative atmospheric studies.

4.3 Tier 3: TRAPPIST-1 System – Comparative Science

The TRAPPIST-1 system offers a unique opportunity for comparative atmospheric studies across multiple planets with varying insolation levels within a single stellar environment.

Table 10: TRAPPIST-1 System Targets

Rank	Planet	R_p ($R_\oplus$)	S ($S_\oplus$)	TSM_{adj}	Visibility (d/yr)	HZ Status
10	TRAPPIST-1 d	0.79	1.12	12,935.6	174.0	Inner HZ
13	TRAPPIST-1 e	0.92	0.65	10,070.4	174.0	Optimal HZ
15	TRAPPIST-1 f	1.04	0.37	8,569.6	174.0	Outer HZ
17	TRAPPIST-1 g	1.13	0.25	7,703.3	174.0	Outer HZ

Recommendation: Propose joint observations of TRAPPIST-1 d/e/f as a coherent program studying atmospheric diversity across the habitable zone. This "planetary system as laboratory" approach enables testing of atmospheric retention models under controlled stellar conditions.

5 Key Visualizations

5.1 Habitability vs. Observability Trade-Space

Figure 7 presents the central multi-objective optimization challenge: balancing atmospheric signal strength (TSM_{adj}) against operational feasibility (visibility days/year).

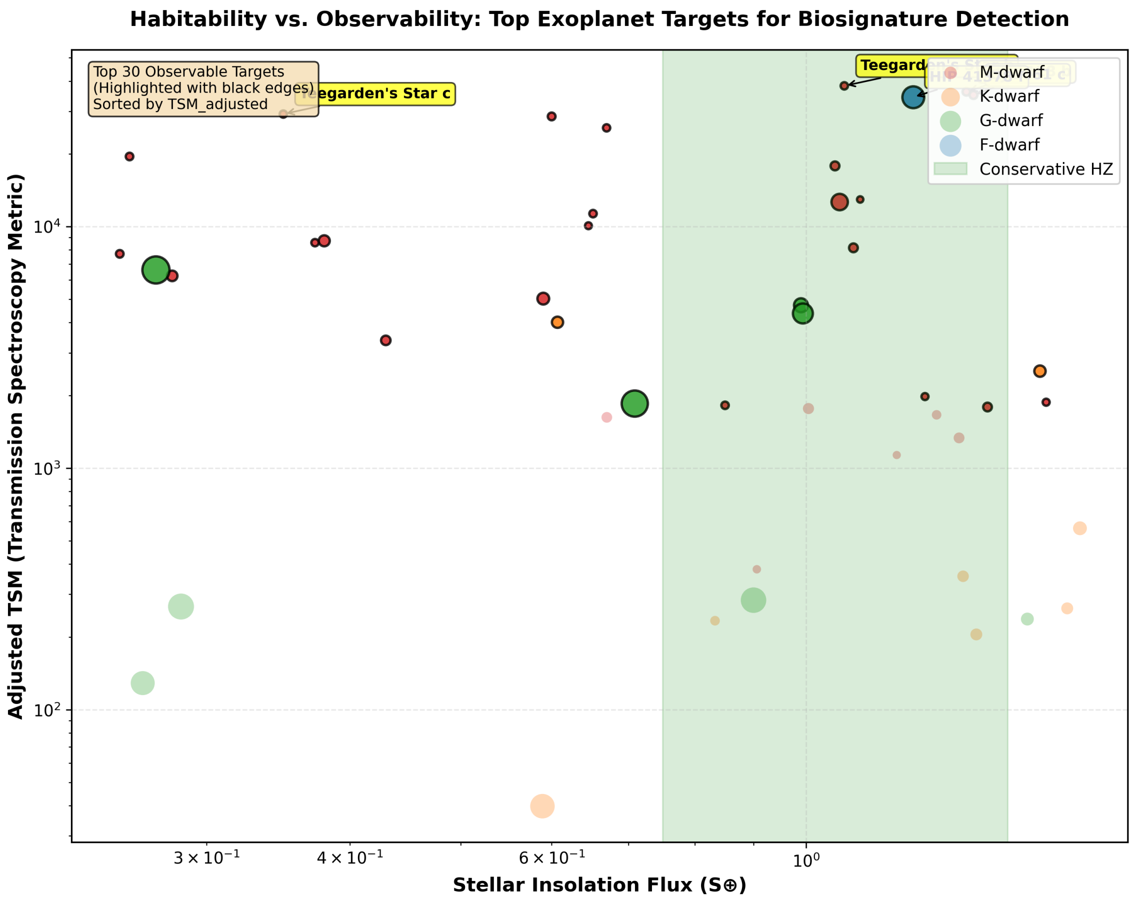

Figure 7: Habitability versus observability trade-space for 123 habitable zone candidates. Points are colored by stellar type (M-dwarf = red, K-dwarf = orange, G-dwarf = blue, F-dwarf = green) and sized by planetary radius. The "sweet spot" (upper right quadrant) contains 37 targets with $TSM_{adj} > 5{,}000$ and visibility > 100 days/year – these represent the most actionable subset for near-term JWST programs.

5.2 JWST Observing Schedule (Gantt Chart)

Figure 8 displays the visibility windows for the Top 30 targets across the 2-year analysis period, enabling strategic observation planning.

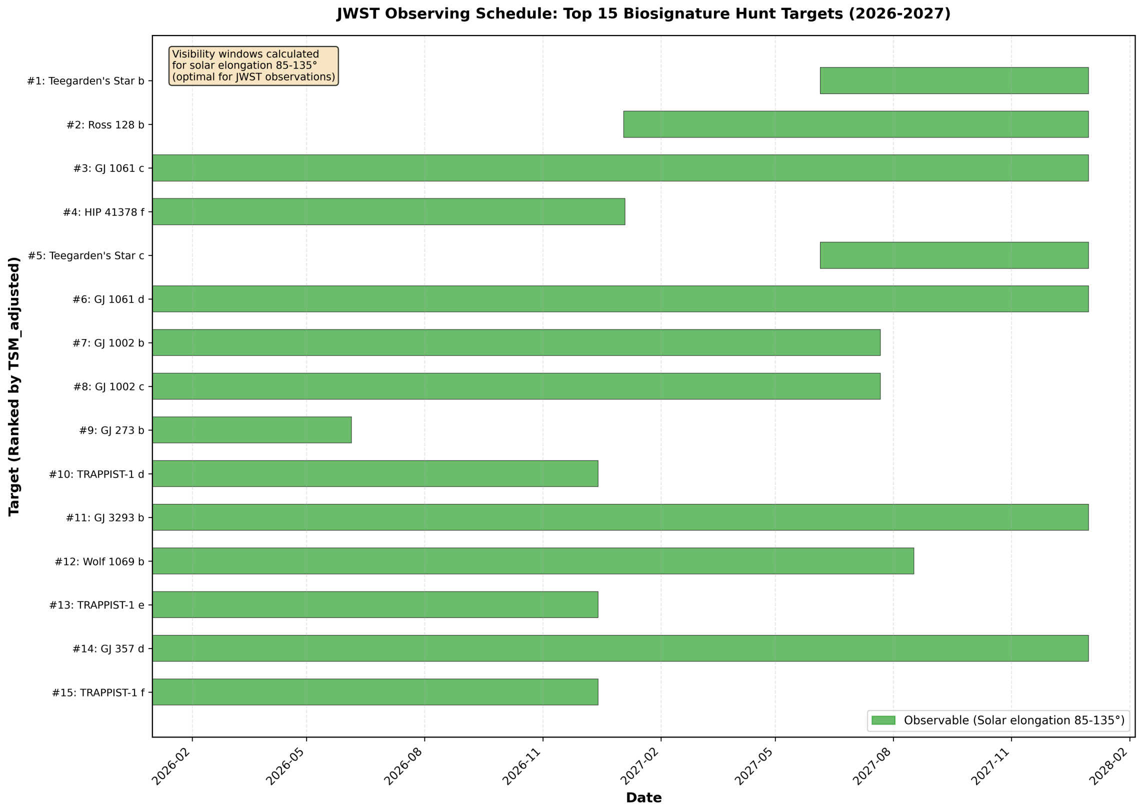

Figure 8: JWST observing schedule Gantt chart for Top 30 biosignature hunt targets (2026–2027). Each row represents one planet; colored bars indicate when the target satisfies JWST's solar elongation constraint. Clear seasonality patterns emerge – some targets are year-round accessible (CVZ), while others have narrow 3–6 month windows. Target names on the left axis are sorted by priority rank.

6 Discussion

6.1 The Signal vs. Retention Tradeoff

The central tension in this analysis is the **tradeoff between geometric signal strength and atmospheric survival probability**:

M-Dwarf Planets:

- ✓ **Advantage:** Proximity to host stars (driven by low stellar luminosity) creates large atmospheric scale heights *relative to stellar radius*, producing strong transmission signals
- × **Disadvantage:** High XUV flux erodes atmospheres over Gyr timescales
- ⇒ **Net Effect:** Even with 50% penalty, adjusted TSM remains 10–100× higher than alternatives

K/G/F-Dwarf Planets:

- ✓ **Advantage:** Stable radiation environments over Gyr timescales preserve atmospheres
- × **Disadvantage:** Greater orbital distances (for HZ placement) + larger stellar radii reduce transmission signal
- ⇒ **Net Effect:** Lower but more *reliable* atmospheric detections

6.2 Operational Implications

For JWST Proposal Teams:

1. **Proposal Volume:** Request 10–15 M-dwarf targets to ensure 5–7 successful atmospheric detections given ∼50% retention probability
2. **Time Allocation:** Focus 70–80% of transmission spectroscopy time on M-dwarfs (highest payoff), reserve 20–30% for K/G-dwarfs (control sample)
3. **Observing Cadence:** Prioritize CVZ targets in early cycles for flexible scheduling; reserve seasonal targets for coordinated campaigns

For Follow-Up Characterization:

1. **Atmospheric Models:** Prepare grids of H_2/He-rich, H_2O-dominated, and CO_2-dominated atmospheric models to interpret detections
2. **Null Detection Strategy:** Non-detections on M-dwarfs are scientifically valuable – they constrain atmospheric loss timescales and inform planetary habitability theory
3. **Comparative Science:** Use multi-planet systems (TRAPPIST-1, GJ 1061) to test retention models across different orbital distances in situ

6.3 Expected Atmospheric Constituents

For the top targets, we expect the following detectable atmospheric constituents (if present):

Table 11: Expected Detectable Atmospheric Features for Priority Targets

Planet	H_2O/CO_2 Features	Biosignature Gases	Haze/Cloud Indicators
Teegarden's Star b	1.4, 2.7, 4.3 μm	O_3 (9.6 μm), CH_4 (3.3 μm)	Rayleigh scattering slope
Ross 128 b	1.4, 2.7, 4.3 μm	O_3, CH_4, N_2O (4.5 μm)	Flat spectrum = clouds
GJ 1061 c/d	1.4, 2.7, 4.3 μm	O_3, CH_4	Photochemical hazes
TRAPPIST-1 d/e/f	1.4, 2.7, 4.3 μm	O_3, CH_4	Water clouds expected

6.4 Limitations

1. **Atmospheric Retention Model:** The simple activity penalty (0.5–1.0) based only on stellar type is a first-order approximation. Future refinements should incorporate:
   - Measured X-ray/UV fluxes (where available)
   - Planetary magnetic field strength estimates
   - System age (older systems = more atmospheric loss)
2. **Sample Size:** Only 3 non-M-dwarf rocky planets in the HZ limits statistical power. As TESS and future surveys discover more K/G-dwarf HZ planets, re-analysis is warranted.
3. **Observability Window:** The fixed 2-year window (2026–2027) excludes targets that may become observable in future cycles (e.g., Proxima Centauri b).
4. **Simplified Integration Times:** Actual JWST exposure time calculations require detailed instrument simulations (NIRSpec/MIRI ETC) and depend on specific observing modes.

7 Conclusions

This analysis establishes a **science-driven, operationally-aware priority framework** for JWST atmospheric characterization of potentially habitable exoplanets. By integrating observability physics (TSM/ESM), atmospheric survival models (stellar activity penalties), and telescope constraints (solar elongation windows), we identify **30 actionable targets** for the 2026–2027 observing period.

7.1 Three Main Conclusions

1. **M-dwarfs dominate:** Small rocky planets around M-dwarfs provide statistically superior observational value ($p = 0.009$) despite atmospheric stripping risks, driven by geometric advantages that yield 10–100× stronger signals than K/G-dwarf alternatives.

2. **Observability matters:** Theoretical metrics (TSM/ESM) must be filtered through operational constraints – even the highest-priority target (Proxima Cen b) is unobservable in 2026–2027, necessitating strategic focus on **Teegarden's Star b** and CVZ targets like GJ 1061 c/d.

3. **Accept calculated risk:** The optimal strategy accepts a ∼50% null detection rate on M-dwarfs in exchange for significantly higher success payoff. Proposal teams should request 10–15 targets to statistically ensure 5–7 atmospheric detections.

7.2 Next Steps

Use the Top 30 target list and observing schedule (Gantt chart) to develop Cycle 2/3 JWST proposals:

- **Immediate (2026):** GJ 1061 c/d, GJ 1002 b/c, HIP 41378 f (CVZ targets)
- **Cycle 3 (2027+):** Teegarden's Star b, Ross 128 b (highest TSM_{adj} with upcoming windows)

This framework provides the foundation for transforming exoplanet demographics into actionable biosignature hunt strategies, maximizing JWST's impact on the search for atmospheric biosignatures and potentially habitable worlds.

References

Kempton, E. M.-R., Bean, J. L., Louie, D. R., Deming, D., Koll, D. D. B., Mansfield, M., Christiansen, J. L., and López-Morales, M. (2018). A framework for prioritizing the TESS planetary candidates most amenable to atmospheric characterization. *Publications of the Astronomical Society of the Pacific*, 130(993):114401.

A Complete Target Data

The complete "Biosignature Hunt Priority List" with all 30 ranked targets is provided in the accompanying CSV file: `final_ranked_targets.csv`

CSV Columns:

- `rank`: Priority ranking (1–30)
- `pl_name`: Planet designation

- `hostname`: Host star name
- `stellar_type`: Spectral type classification
- `pl_rade`: Planetary radius (Earth radii)
- `pl_insol`: Stellar insolation flux (Earth units)
- `TSM_adjusted`: Adjusted Transmission Spectroscopy Metric
- `retention_score`: Atmospheric retention penalty factor
- `hours_for_5sigma_transmission`: Estimated integration time
- `visibility_days_per_year`: Annual visibility from JWST L2
- `next_window_start`: Date of next observing window
- `high_ESM_flag`: "Yes" if ESM > 1.0

B Data Sources

- **NASA Exoplanet Archive**: https://exoplanetarchive.ipac.caltech.edu/
- **PSCompPars Table**: Planetary Systems Composite Parameters
- **Access Date**: December 14, 2025
- **Total Records**: 6,061 confirmed exoplanets