Bioverse and the Prospects for Observing Biosignatures with JWST and the ELTs

AJ, 165, 267
arxiv.org/abs/2304.12490
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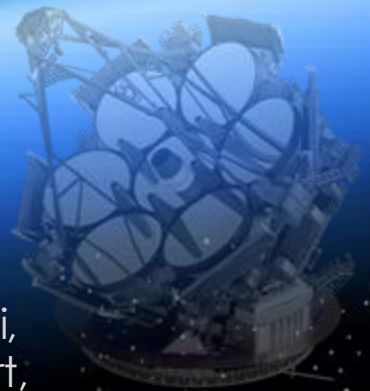
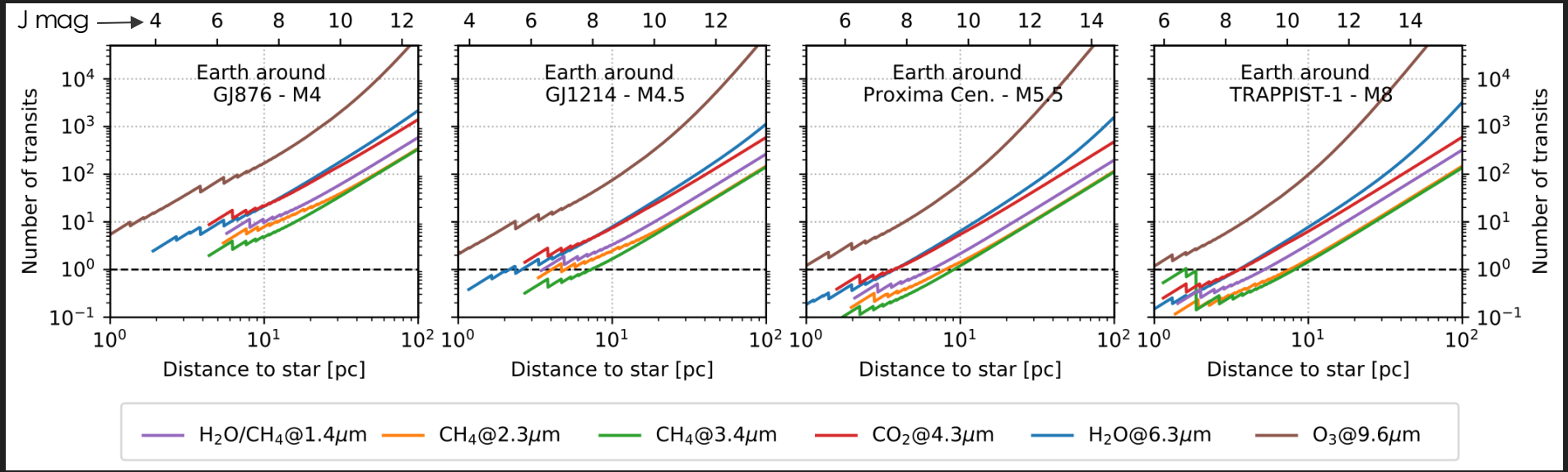
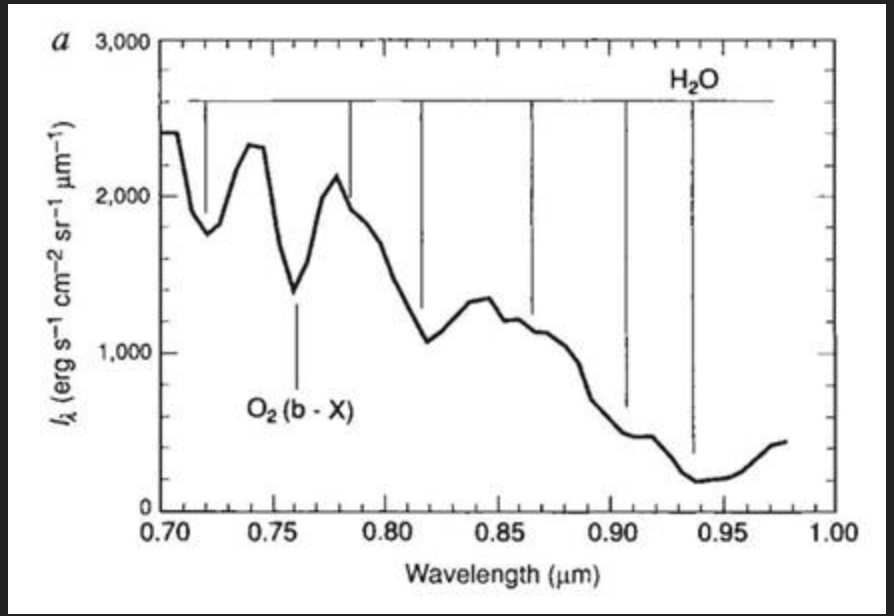


Kevin Hardegree-Ullman
Dániel Apai, Galen Bergsten, Ilaria Pascucci,
Mercedes López-Morales, Sebastiaan Haffert,
Markus Kasper, Martin Schlecker
ELT Science in Light of JWST – December 11, 2023

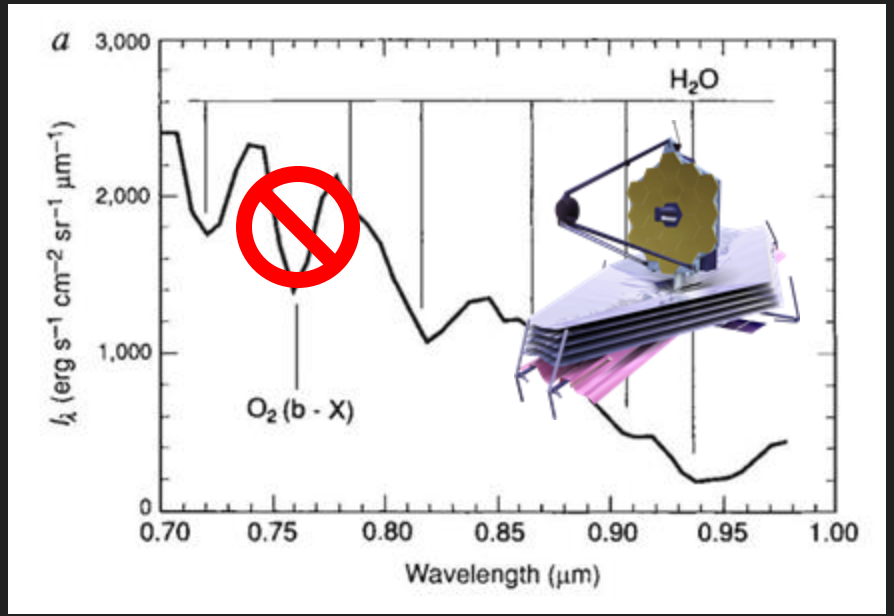
Observing biosignatures with JWST will be challenging



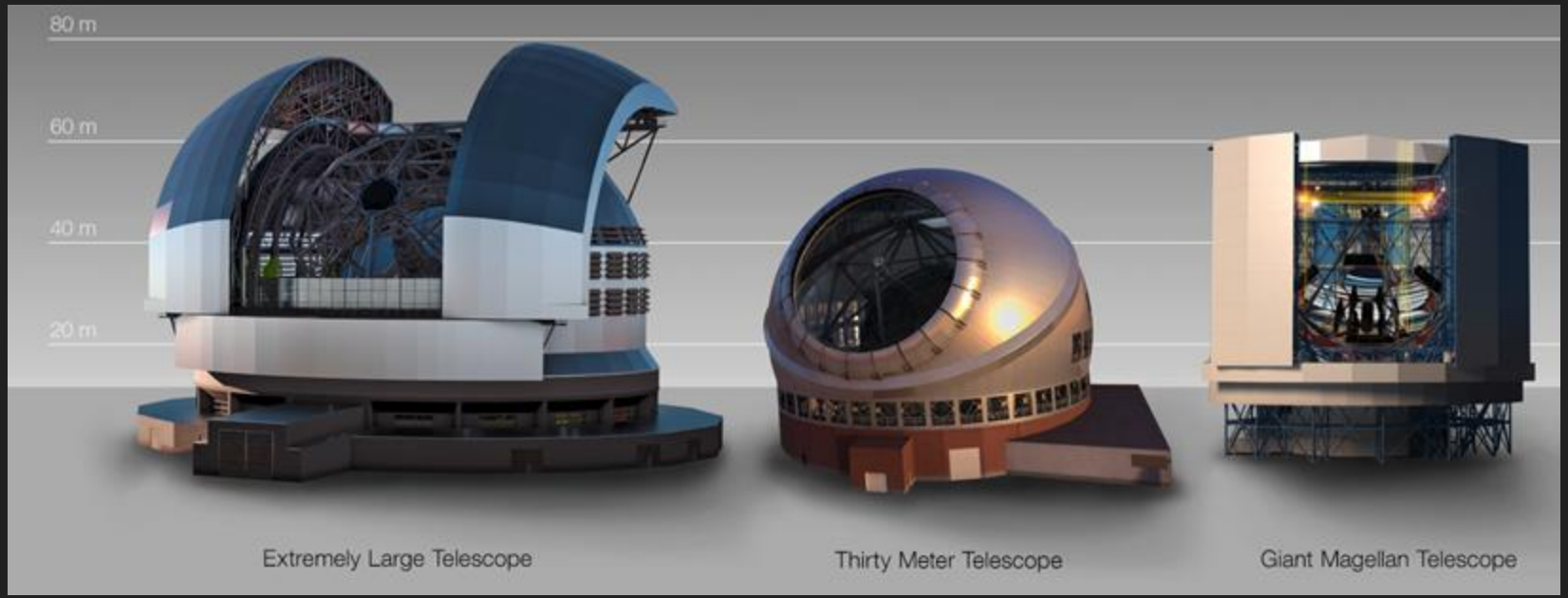
O_2 is a strong indicator of life on Earth



JWST is unlikely to detect O_2



Previous studies: Earth-like O_2 levels could be probed via transmission spectroscopy with ELTs



Previous studies did not fully consider:

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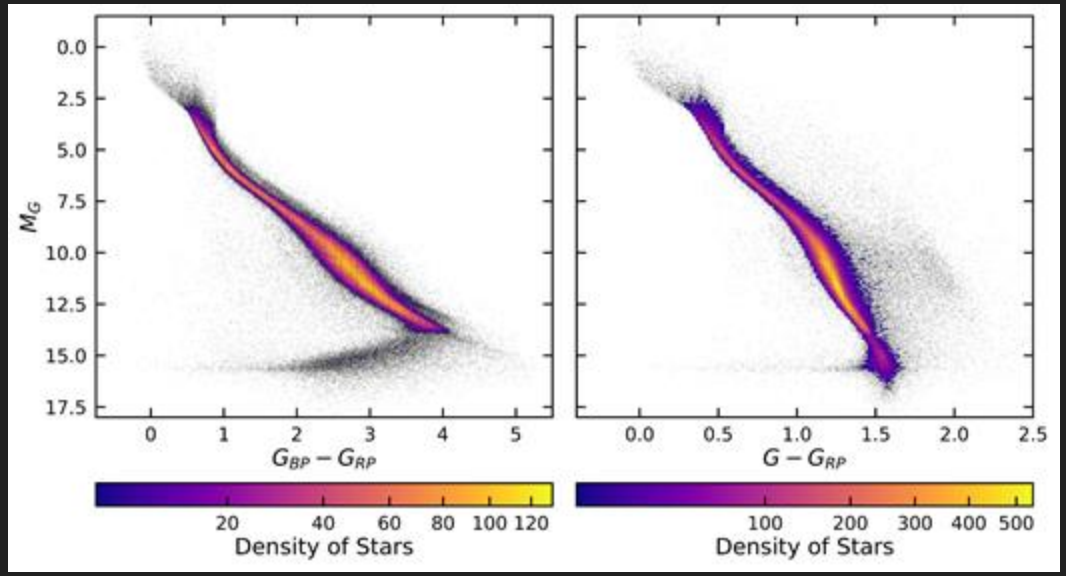
Previous studies did not fully consider:

- Realistic stellar sample



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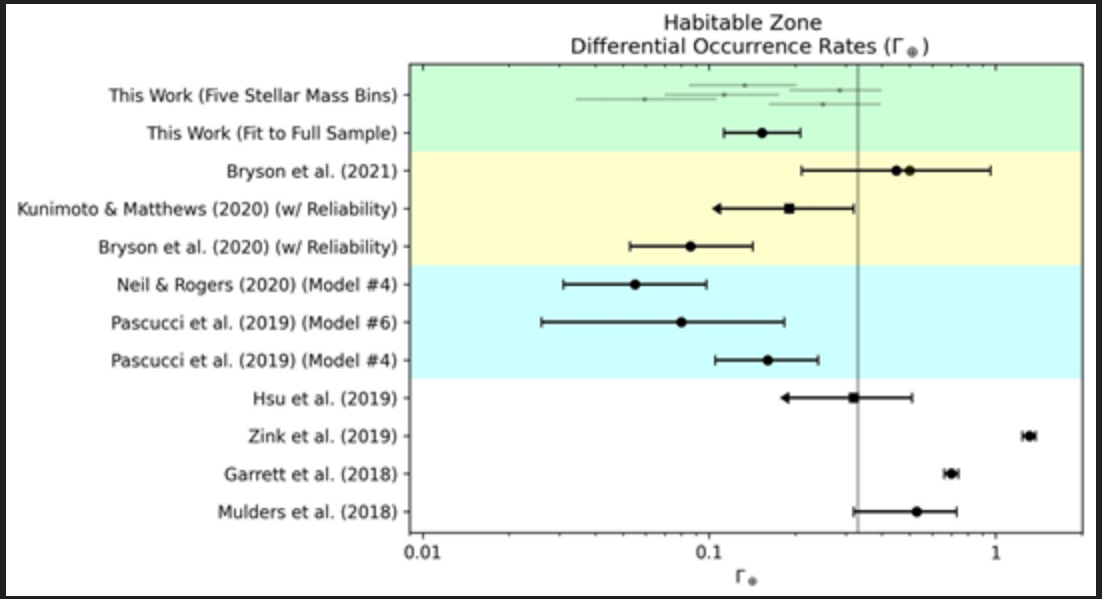
Previous studies did not fully consider:

- Realistic stellar sample
- Planet occurrence rates



Bergsten et al. (2022)

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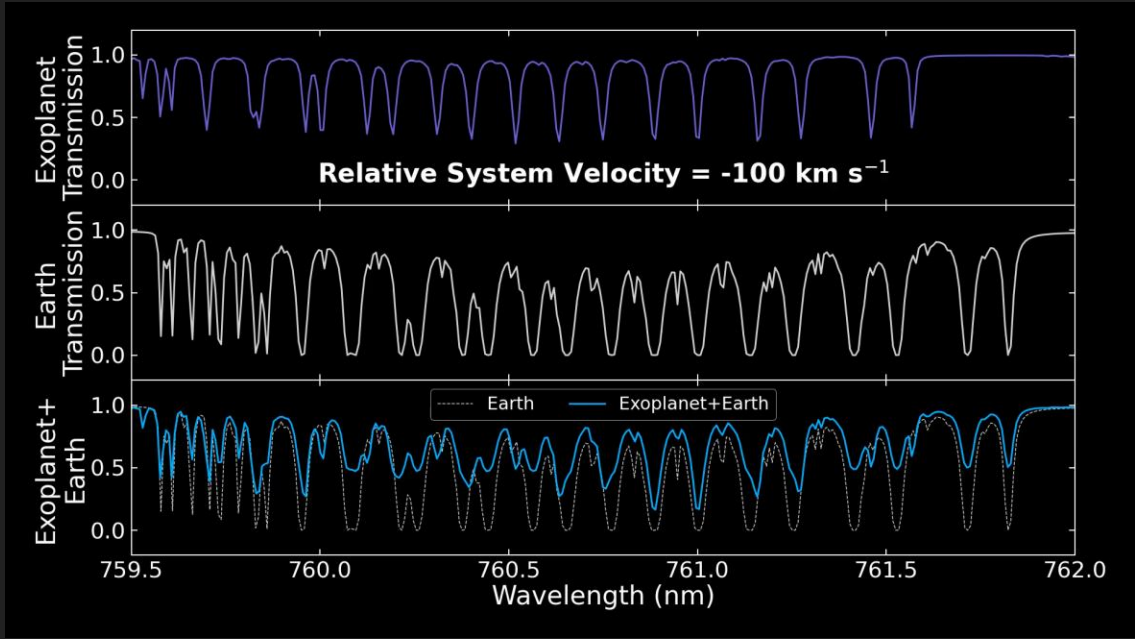
Previous studies did not fully consider:

- Realistic stellar sample
- Planet occurrence rates
- Relative system velocities



Lopez-Morales et al. (2019)

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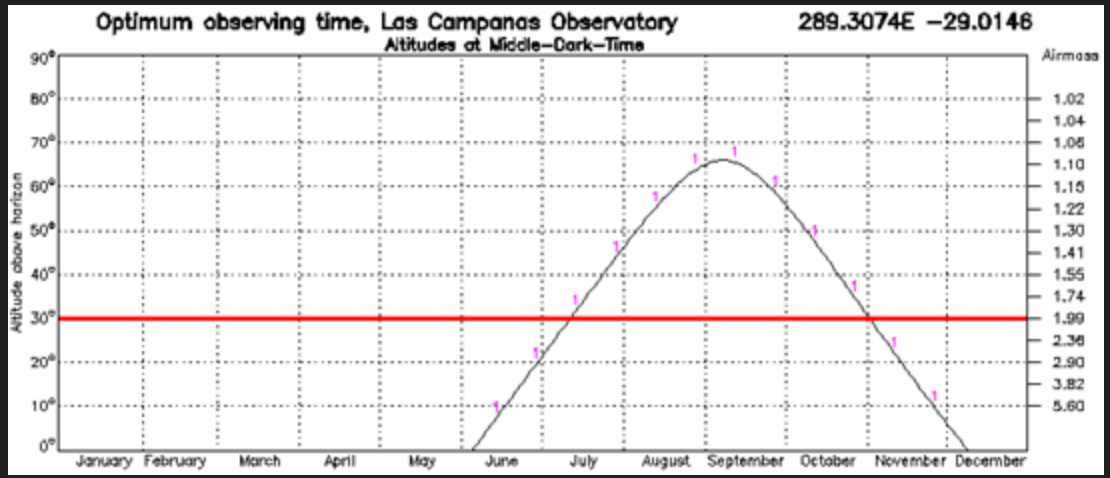
Previous studies did not fully consider:

- Realistic stellar sample
- Planet occurrence rates
- Relative system velocities
- Target observability



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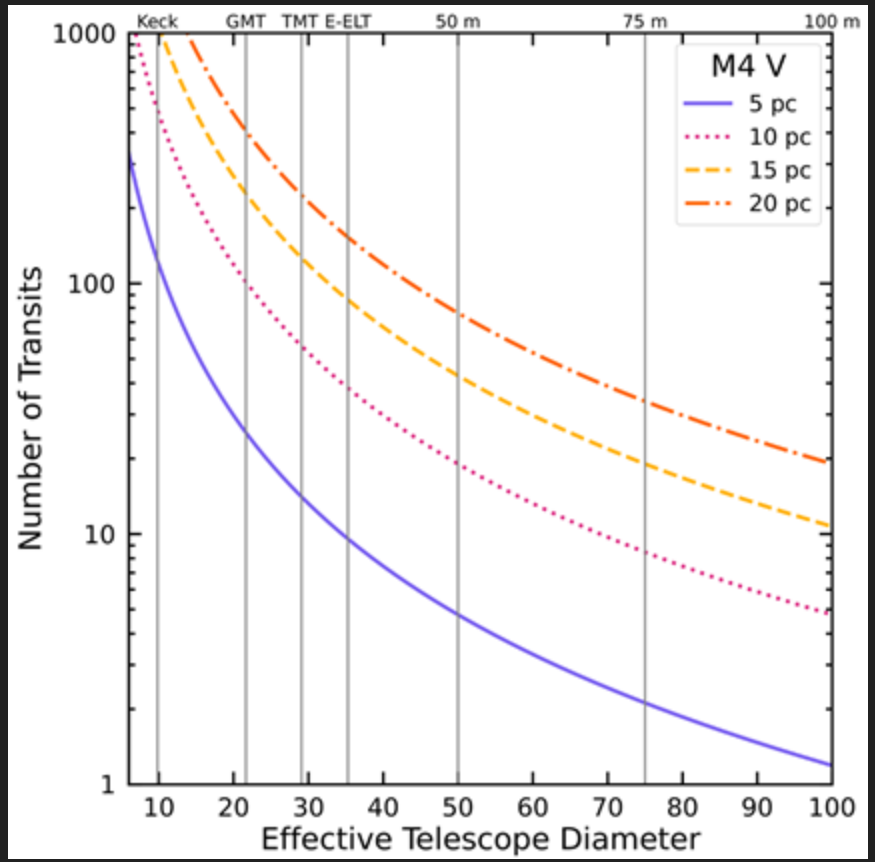
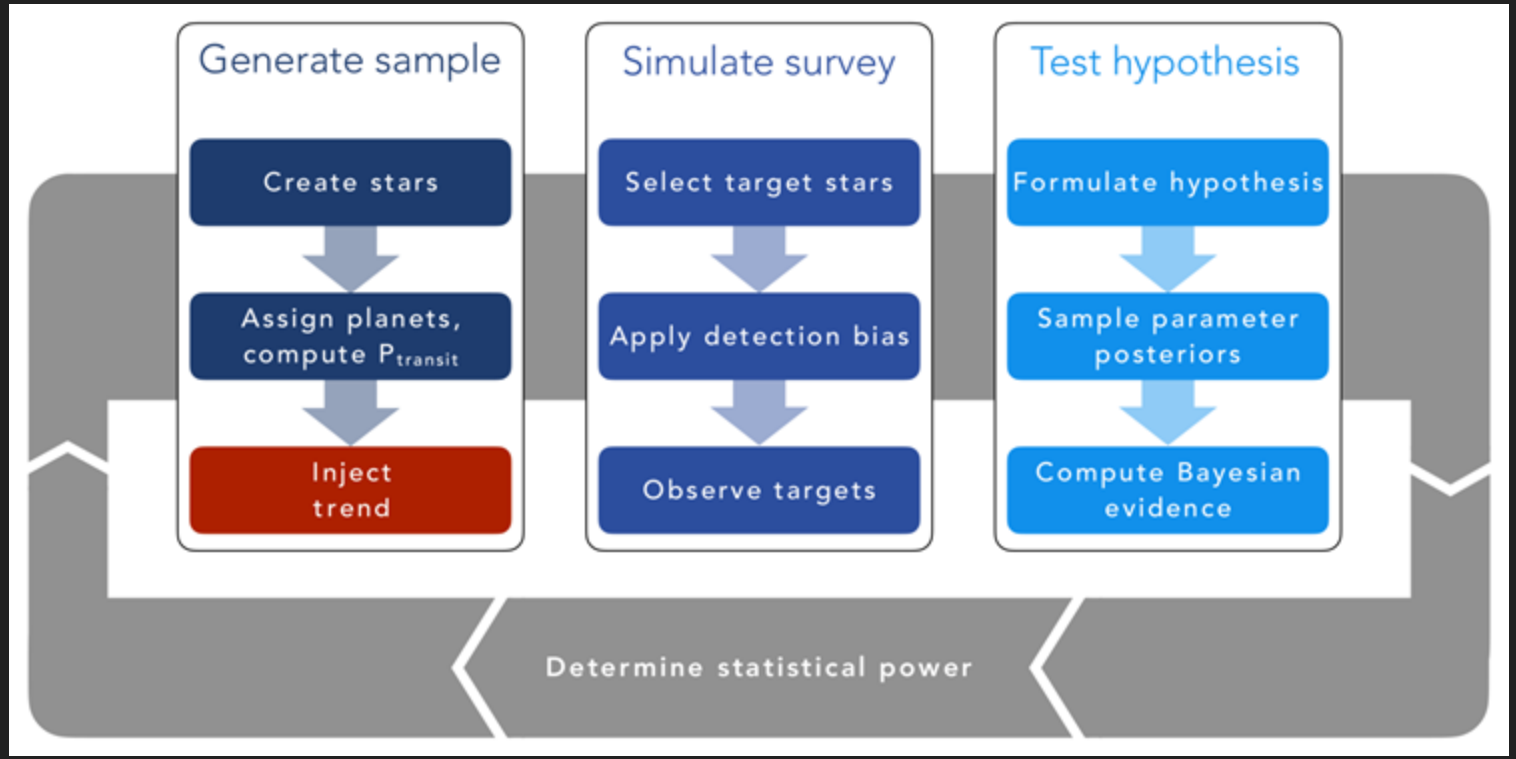
of transits to probe Earth-like O_2 levels with ELTs



- G-CLEF
- R=100,000
- White noise only
- 3σ detection

Bioverse: a statistical survey and testing framework

bioverse.readthedocs.io



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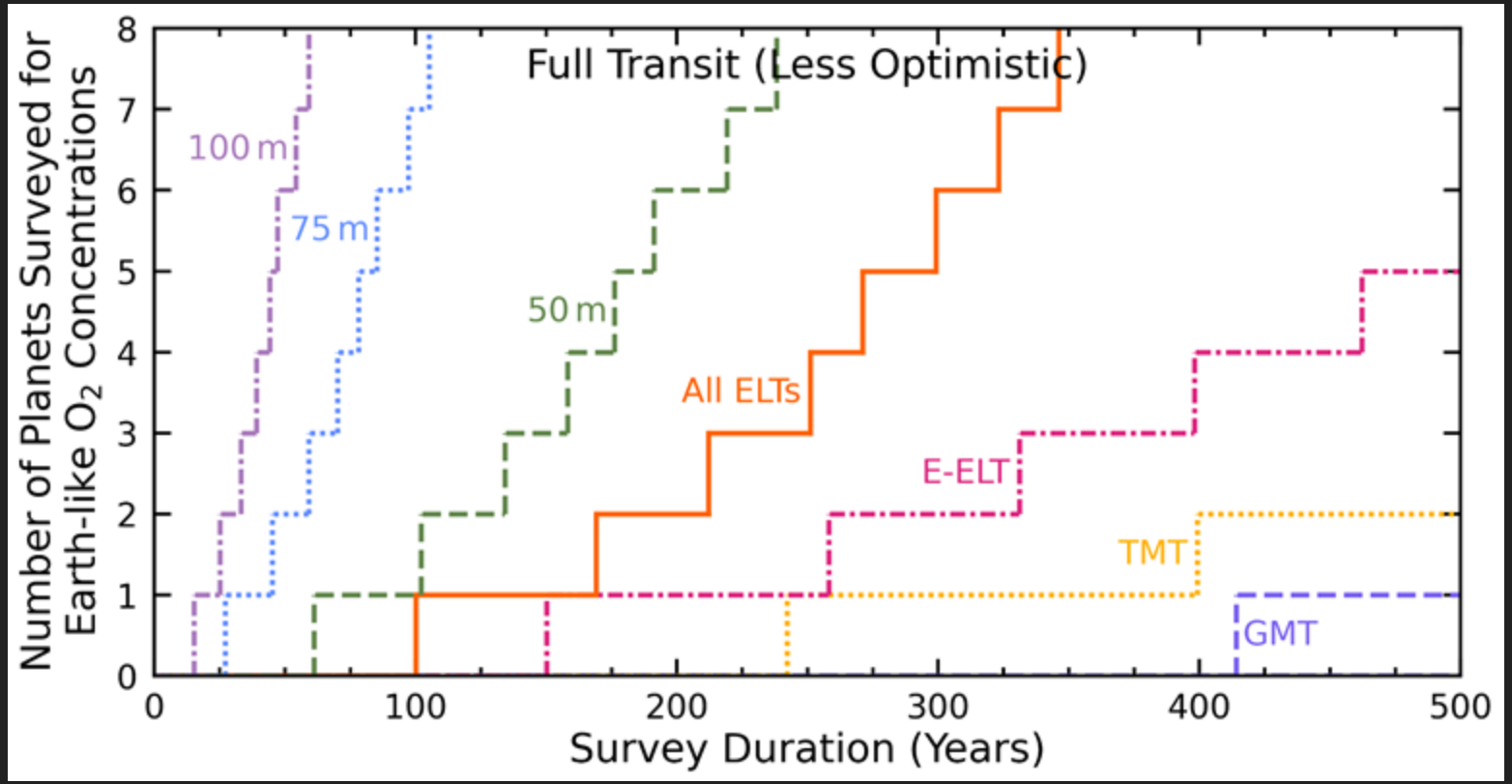
Bixel & Apai (2021), Hardegree-Ullman et al. (2023), Schlecker et al. (2023)

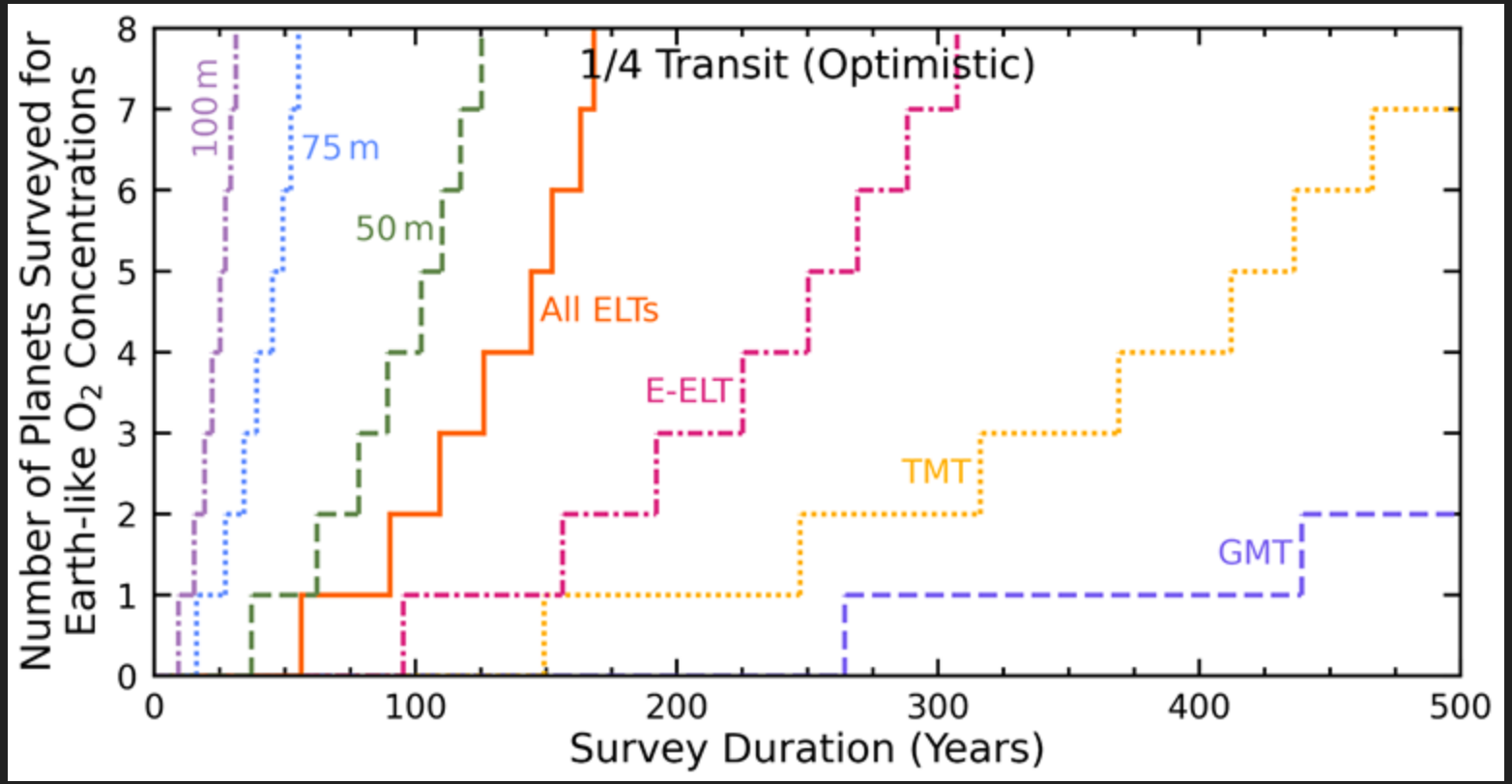
Bioverse Simulation

- Use $\eta_{\oplus}$ estimates for M dwarfs to generate HZ Earths
- Determine which Earths are transiting and if O_2 is observable at simulated times of transit
- Calculate how many years to probe Earth-like O_2 levels at 3σ
- Repeat 10,000x
- Sort each "universe" by years to probe O_2 and take median of first through N^{th} planets

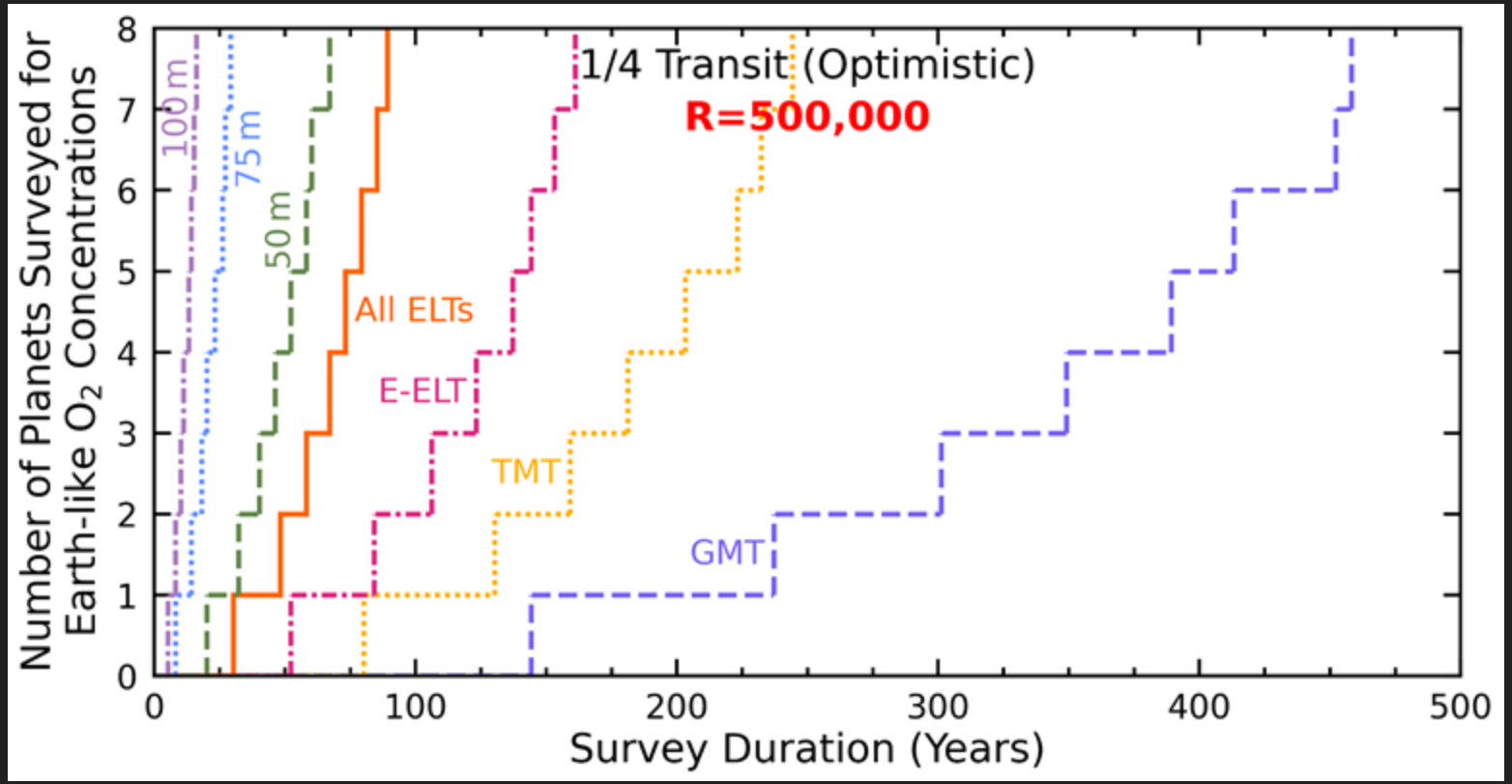
Bioverse simulations: probing Earth-like levels of O_2 on one HZ Earth-analog will take a **century**

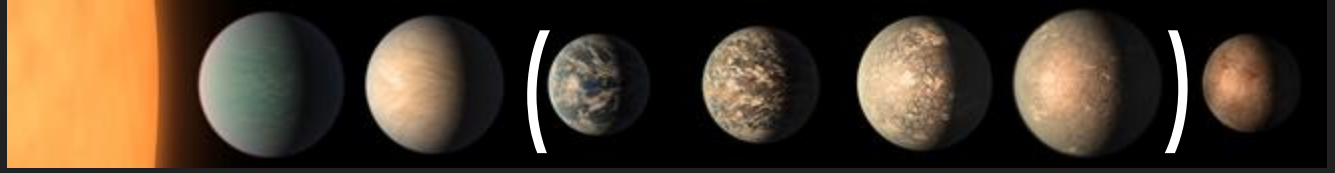


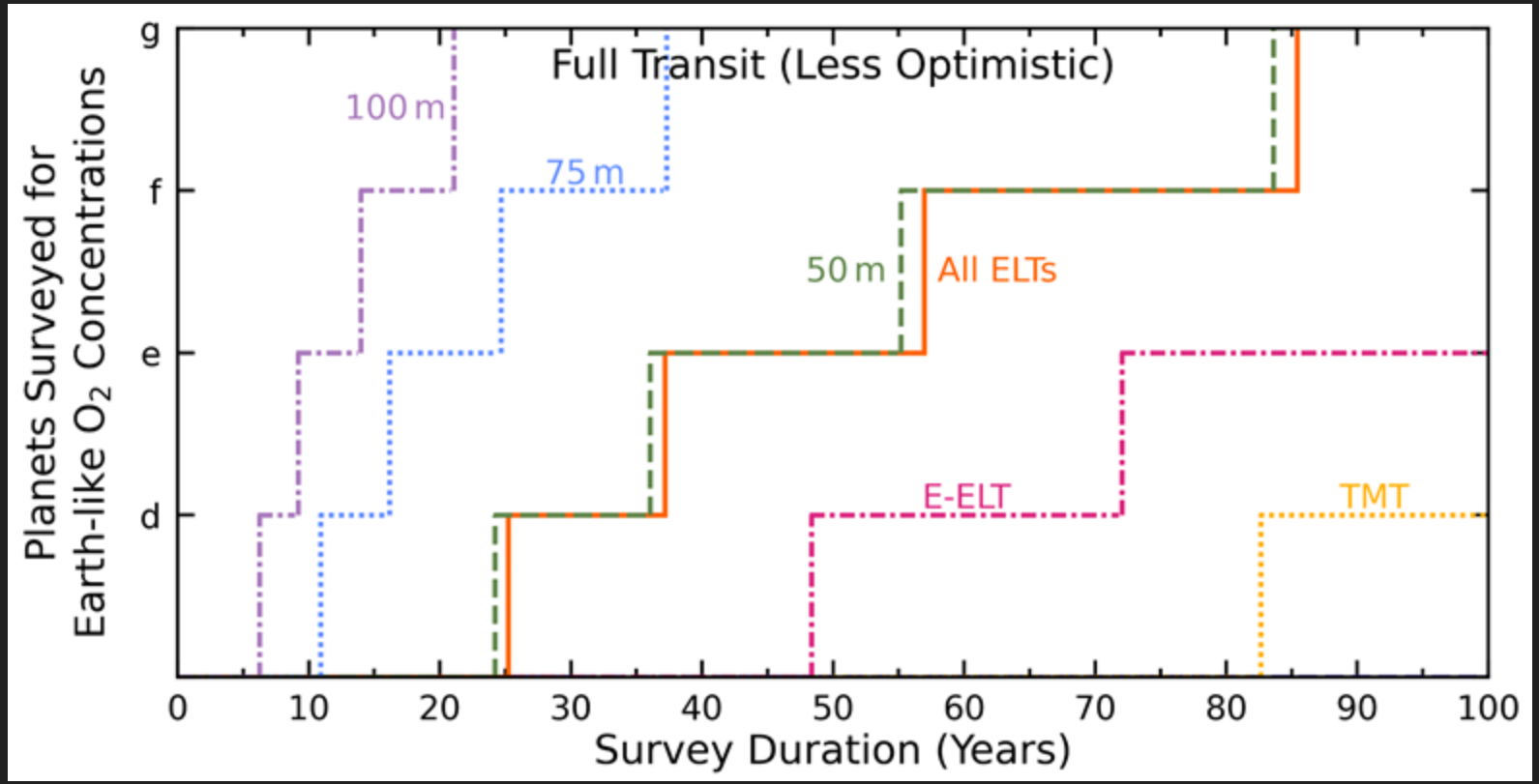
Partial transits reduce time by a factor of ~2

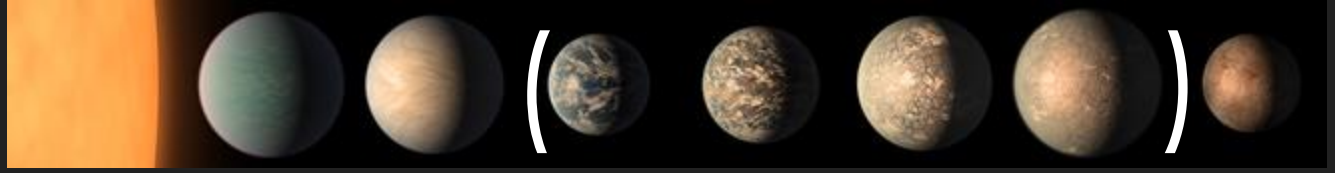


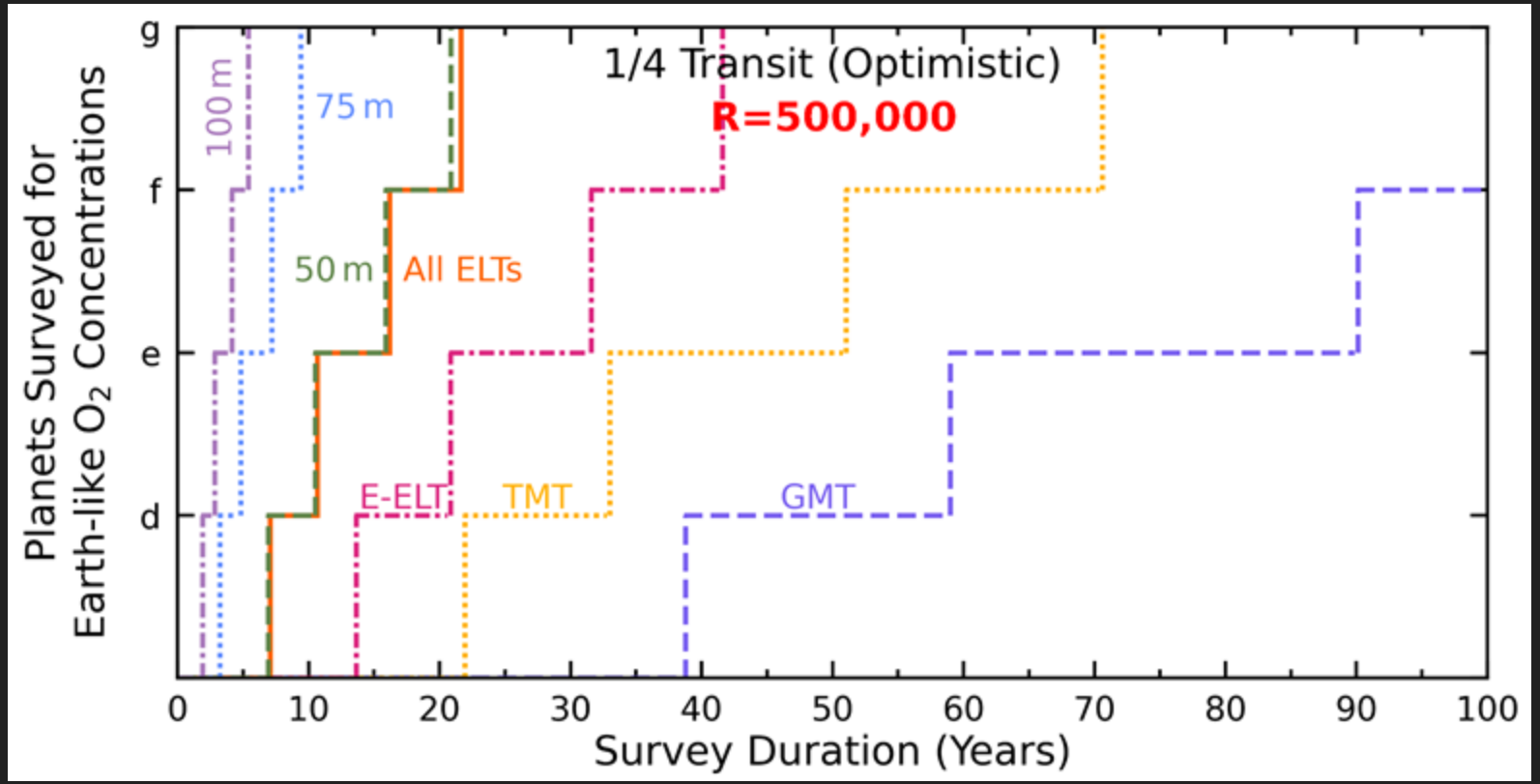
R=500,000 reduces time by a factor of ~2



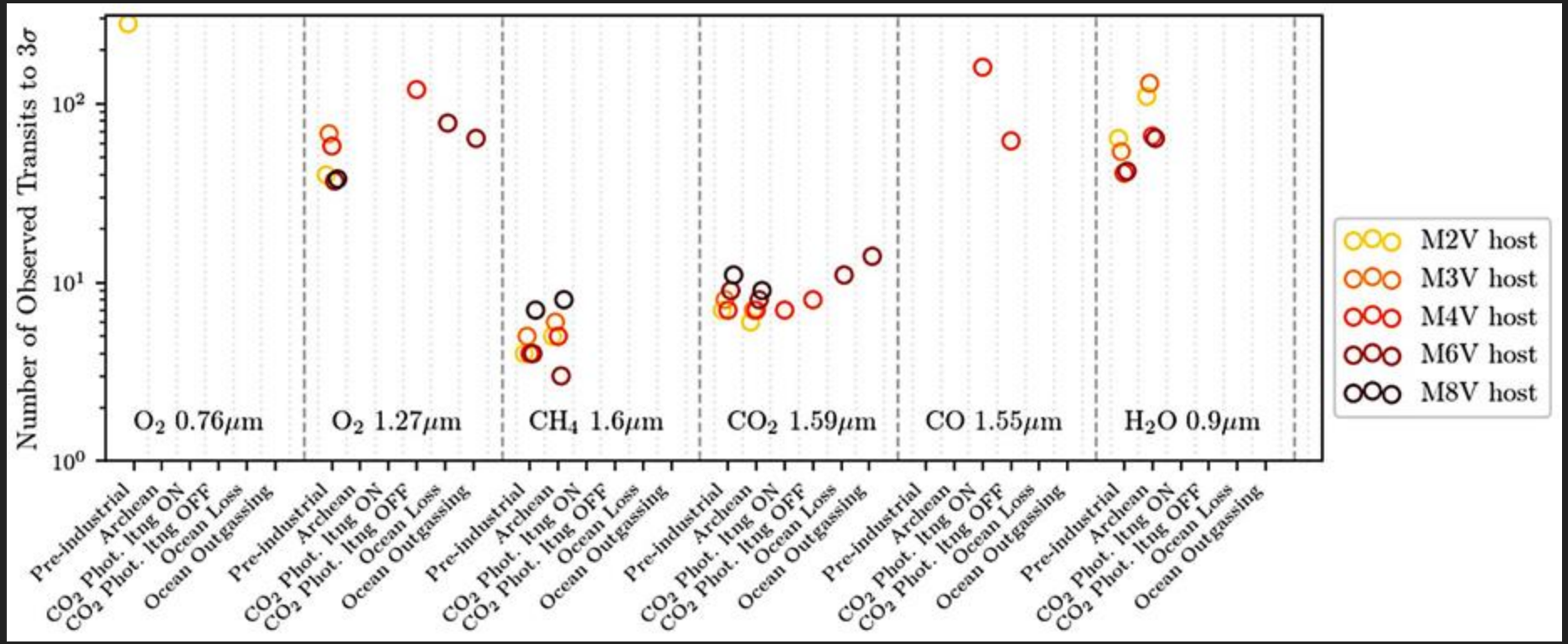



Full Transit (Less Optimistic)
100 m
75 m
50 m
All ELTs
E-ELT
TMT
Planets Surveyed for Earth-like O_2 Concentrations
g
f
e
d
0
10
20
30
40
50
60
70
80
90
100
Survey Duration (Years)

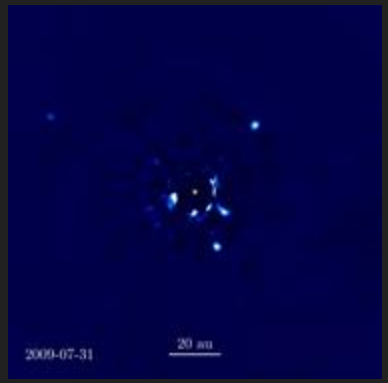



1/4 Transit (Optimistic)
R=500,000
100 m
75 m
50 m
All ELTs
E-ELT
TMT
GMT
Planets Surveyed for Earth-like O_2 Concentrations
g
f
e
d
0
10
20
30
40
50
60
70
80
90
100
Survey Duration (Years)

There's more to life than O_2

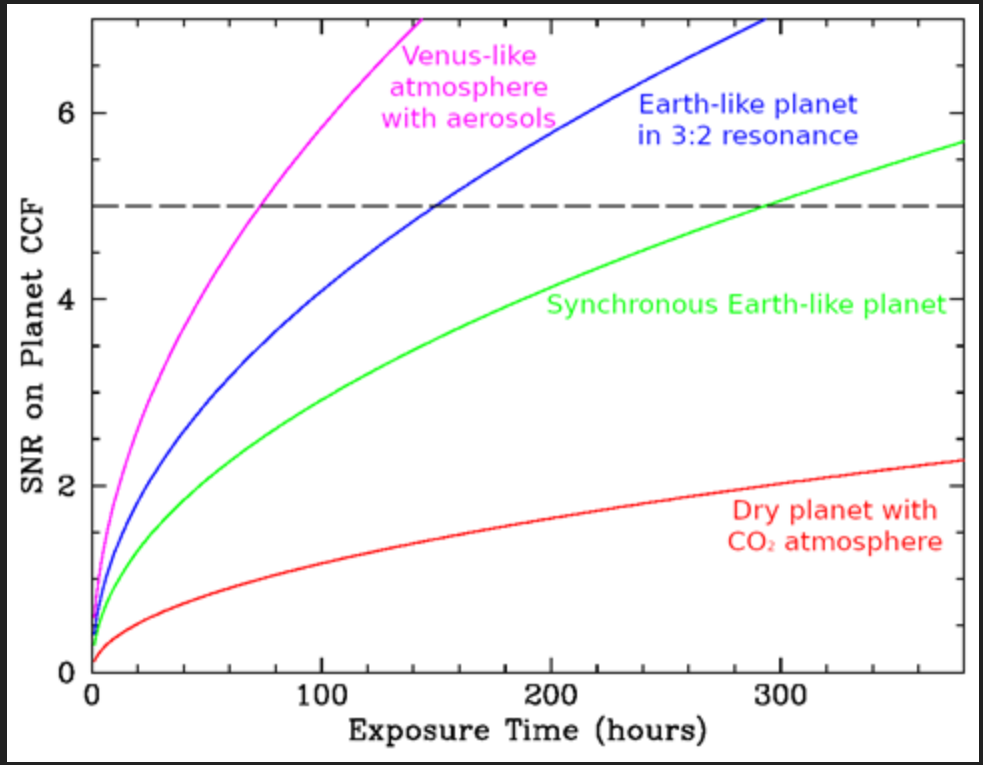


O_2 Options: Reflected Light Spectroscopy



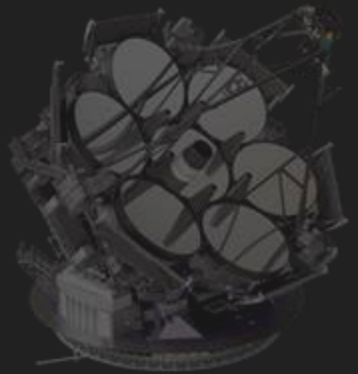
VLT (8.2m) SPHERE+ESPRESSO

- Proxima Centauri b
  - ~60 nights (~3 years) for 3.6σ O_2 detection



Conclusions

- JWST will detect atmospheres. ELTs are poised to tackle the biosignature challenge.
- Exo-Earth O_2 via transmission spectroscopy will be difficult. Reflected light is more promising.
- The Bioverse framework can be used to assess other molecules, methods (e.g. reflected light spectroscopy), and test hypotheses.



ALIEN EARTHS

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