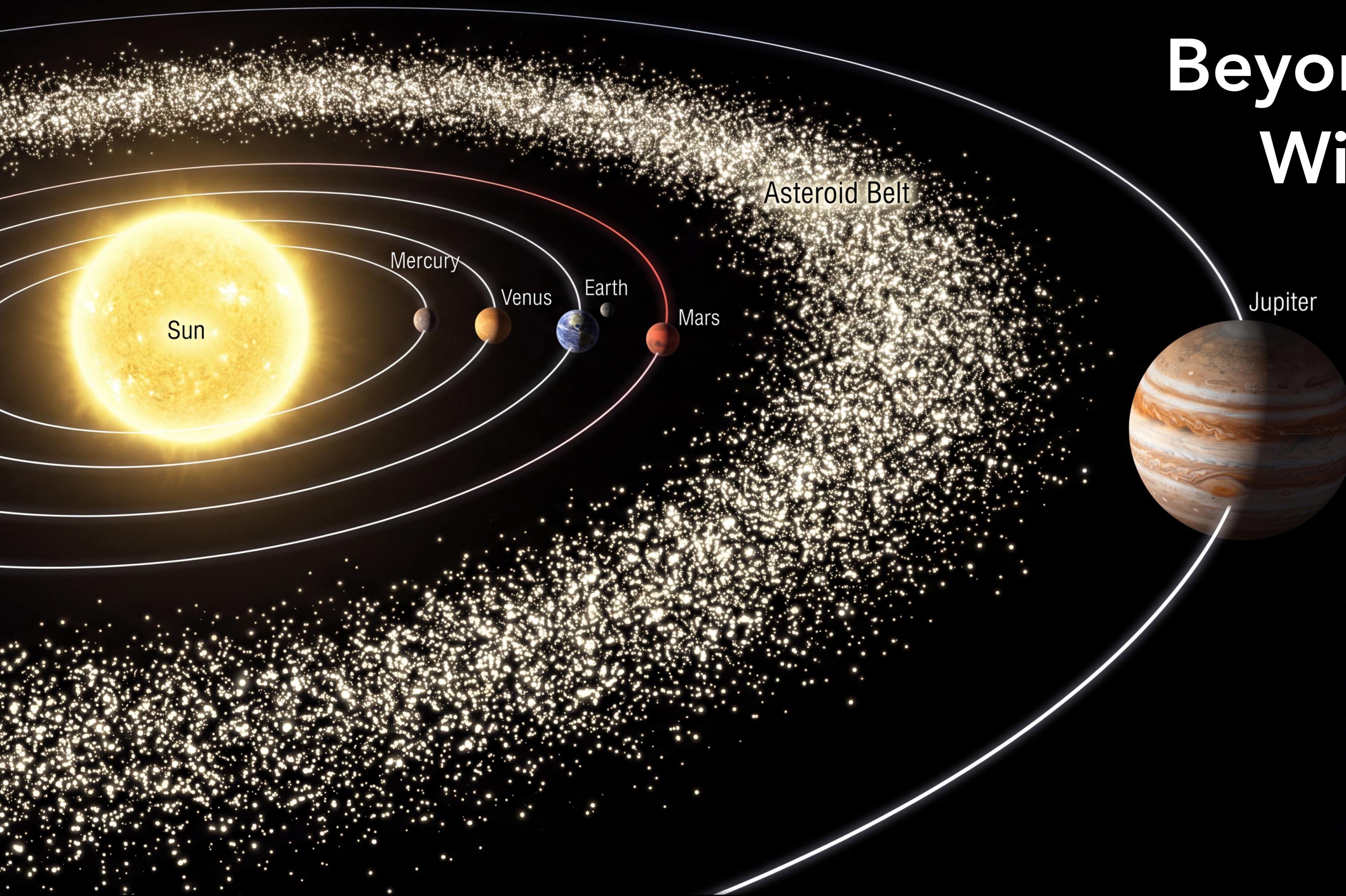


Beyond Zodi Mid-Infrared Wide-Field Surveyor



Gary Melnick
Center for Astrophysics |
Harvard & Smithsonian

in collaboration with

E. Egami, A. Wong, J. Leisenring (Steward Observatory, University of Arizona), M. Ashby, S. Willner, J. Hora, H. Smith, V. Tolls (CfA | Harvard & Smithsonian), P. Stahl, C. Hopkins, S. Cheney, T. Lis (NASA Marshall Space Flight Center), A. Inoue (Waseda University), Y. Harikane (University of Tokyo)

Talk Outline: Key Takeaways

- 1) *Enormously* reduced natural infrared foreground (and sensitivity gains) for an observatory beyond 3 AU

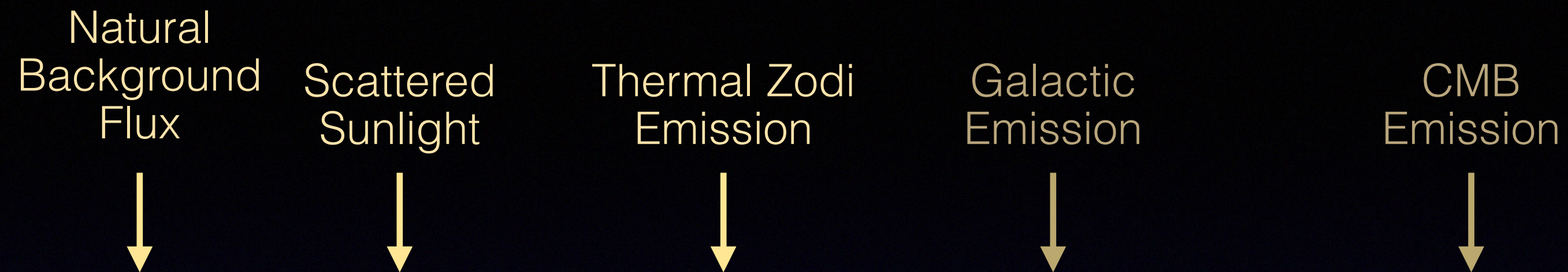
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- 2) Sample projects that would benefit from lower IR backgrounds
 - Wide-area (10-1000 deg²) census of $z \geq 10$ galaxies
 - Direct measurement of the 2-10 μm diffuse cosmic IR background
 - Ultra-low surface brightness imaging of galaxies searching for fossil evidence of past interactions

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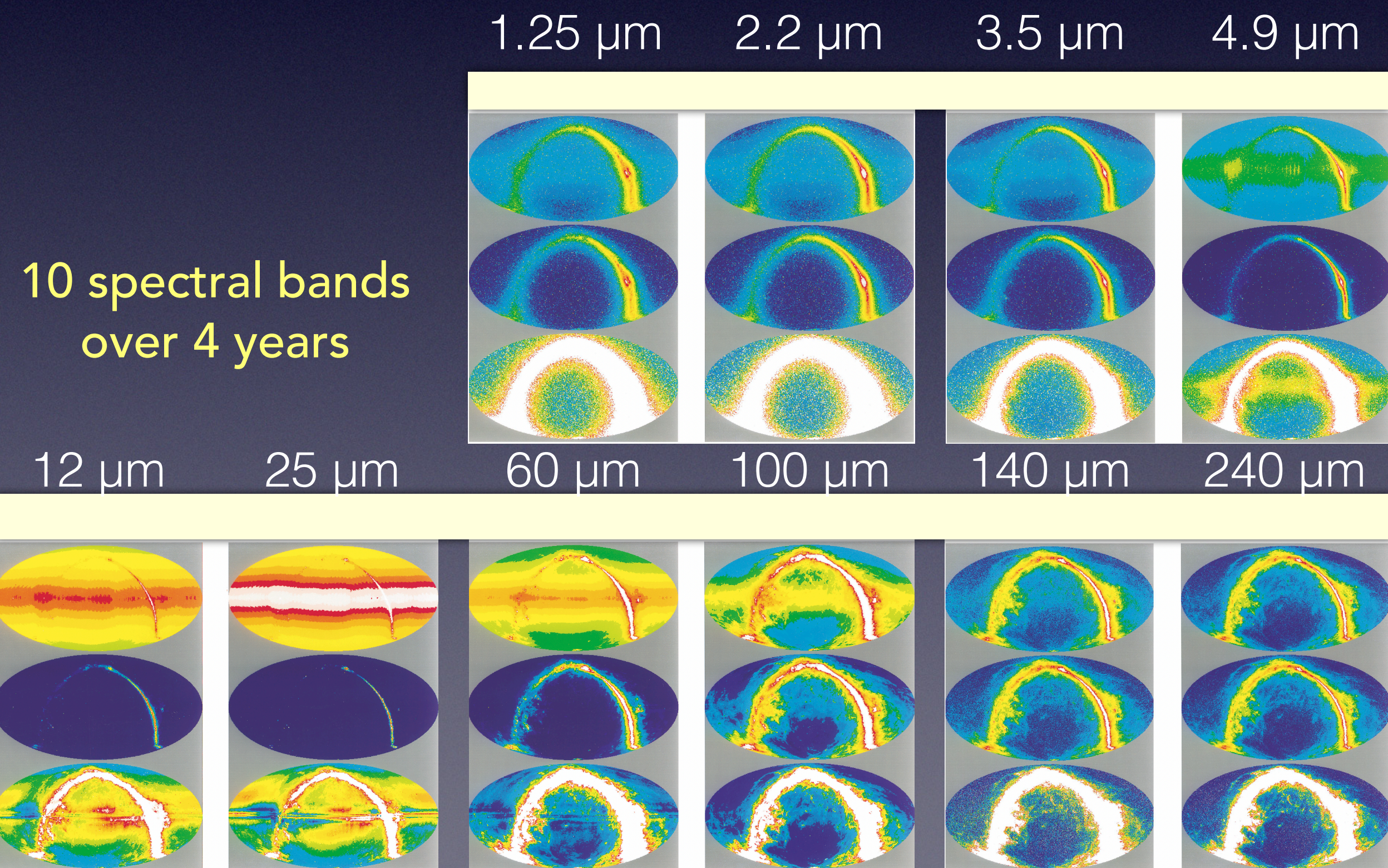
Natural Infrared Foreground (Zodiacal Light)



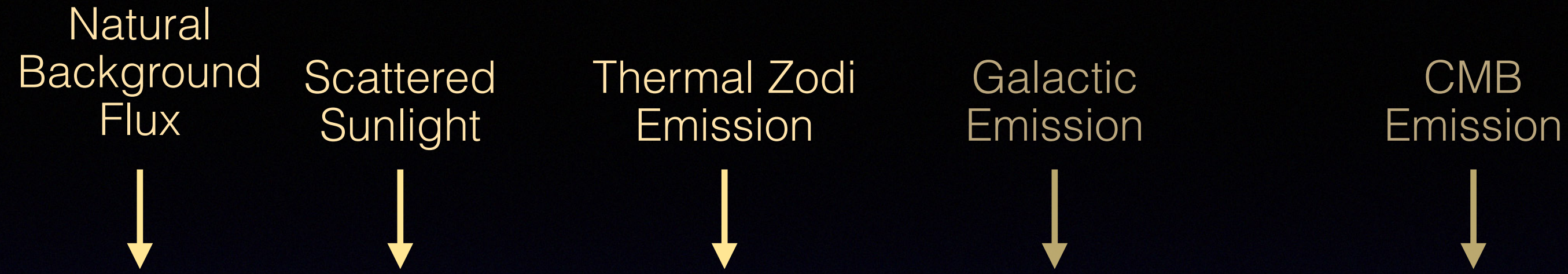
$$I_{\lambda} = \epsilon_S B_{\lambda}(T_S) + \epsilon_Z B_{\lambda}(T_Z) + \epsilon_G B_{\lambda}(T_G) + \epsilon_{CMB} B_{\lambda}(T_{CMB})$$



Diffuse Infrared Background Experiment (DIRBE)



Natural Infrared Foreground (Zodiacal Light)



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THE *COBE* DIFFUSE INFRARED BACKGROUND EXPERIMENT SEARCH FOR THE COSMIC INFRARED BACKGROUND. II. MODEL OF THE INTERPLANETARY DUST CLOUD

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M. G. HAUSER,⁶ S. H. MOSELEY,¹ N. P. ODEGARD,³ R. F. SILVERBERG,¹ AND E. L. WRIGHT⁷

Received 1998 January 7; accepted 1998 June 22

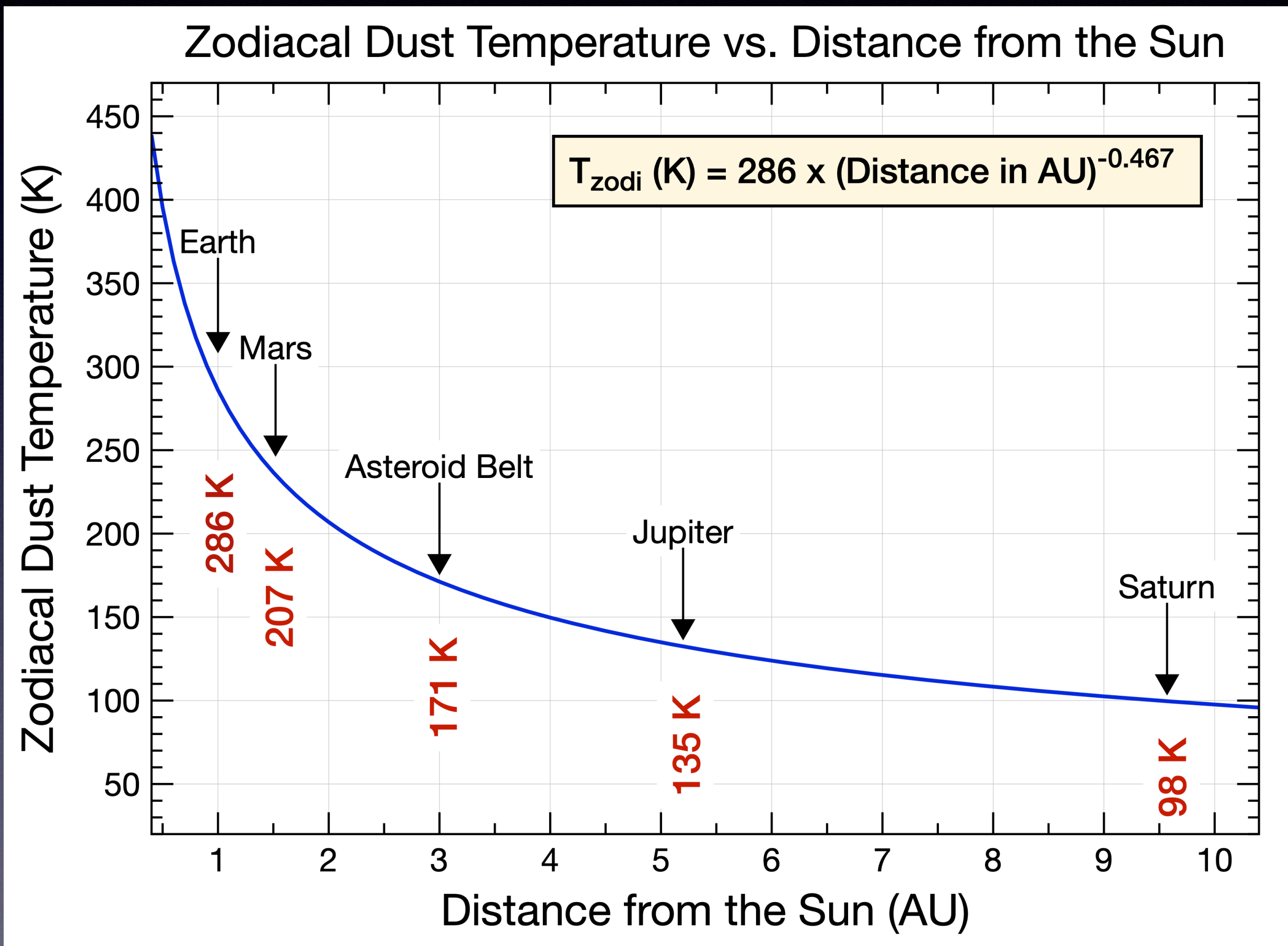
ABSTRACT

The *COBE* Diffuse Infrared Background Experiment (DIRBE) was designed to search for the cosmic infrared background (CIB) radiation. For an observer confined to the inner solar system, scattered light and thermal emission from the interplanetary dust (IPD) are major contributors to the diffuse sky brightness at most infrared wavelengths. Accurate removal of this zodiacal light foreground is a necessary step toward a direct measurement of the CIB. The zodiacal light foreground contribution in each of the 10 DIRBE wavelength bands ranging from 1.25 to 240 μm is distinguished by its apparent seasonal variation over the whole sky. This contribution has been extracted by fitting the brightness calculated from a parameterized physical model to the time variation of the all-sky DIRBE measurements over 10 months of liquid He cooled observations. The model brightness is evaluated as the integral along the line of sight of the product of a source function and a three-dimensional dust density distribution function. The dust density distribution is composed of multiple components: a smooth cloud, three asteroidal dust bands, and a circumsolar ring near 1 AU. By using a directly measurable quantity that relates only to the IPD cloud, we exclude other contributors to the sky brightness from the IPD model. High-quality maps of the infrared sky with the zodiacal foreground removed have been generated using the IPD model described here. Imperfections in the model reveal themselves as low-level systematic artifacts in the residual maps that correlate with components of the IPD. The most evident of these artifacts are located near the ecliptic plane in the mid-IR and are less than 2% of the zodiacal foreground brightness. Uncertainties associated with the model are discussed, including implications for the CIB search.

Subject headings: cosmology: observations — diffuse radiation — infrared: general —
infrared: solar system — interplanetary medium

Zodiacal Emission Depends on 3 Factors:

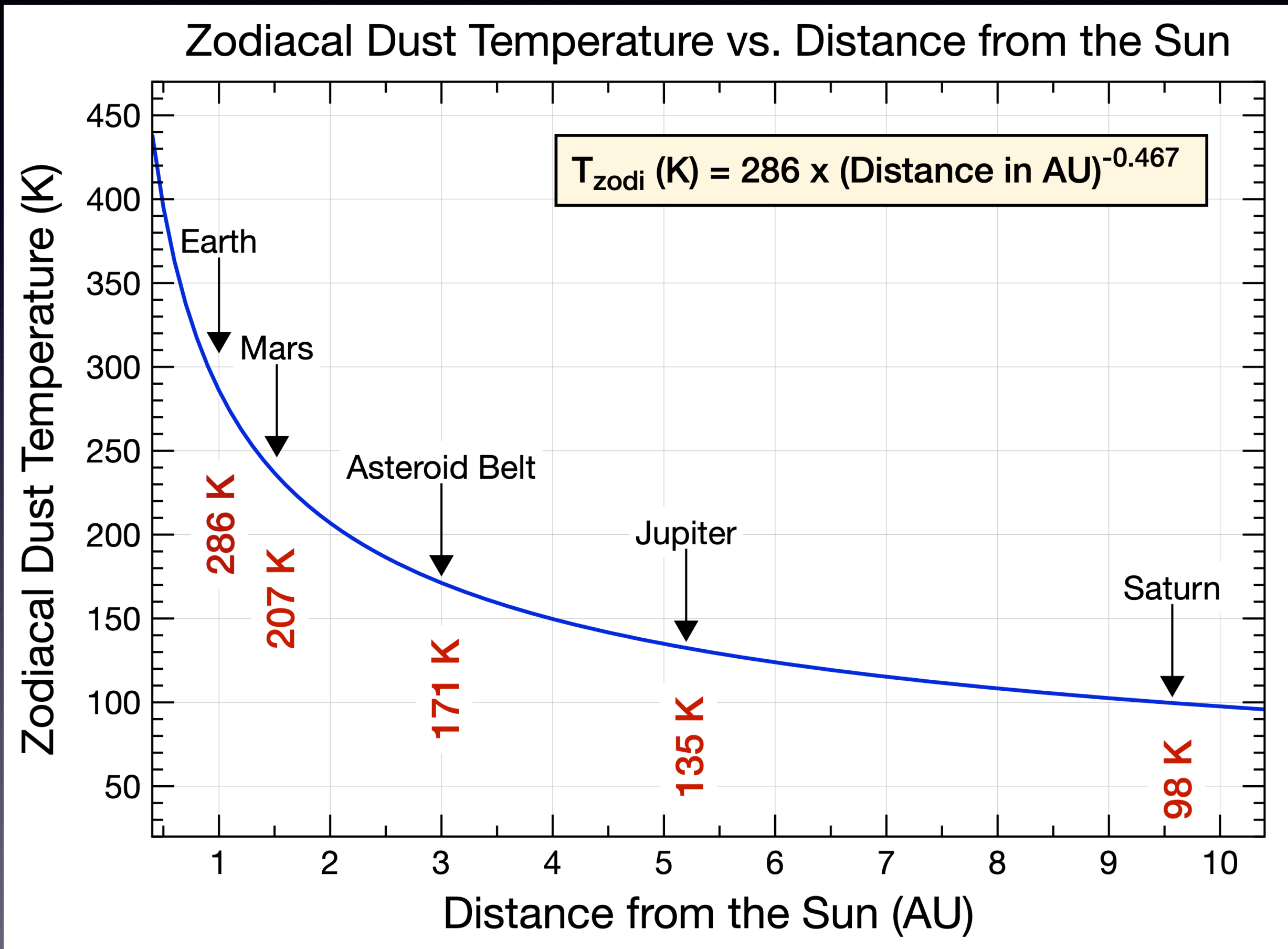
#1. Dust temperature vs. Sun distance



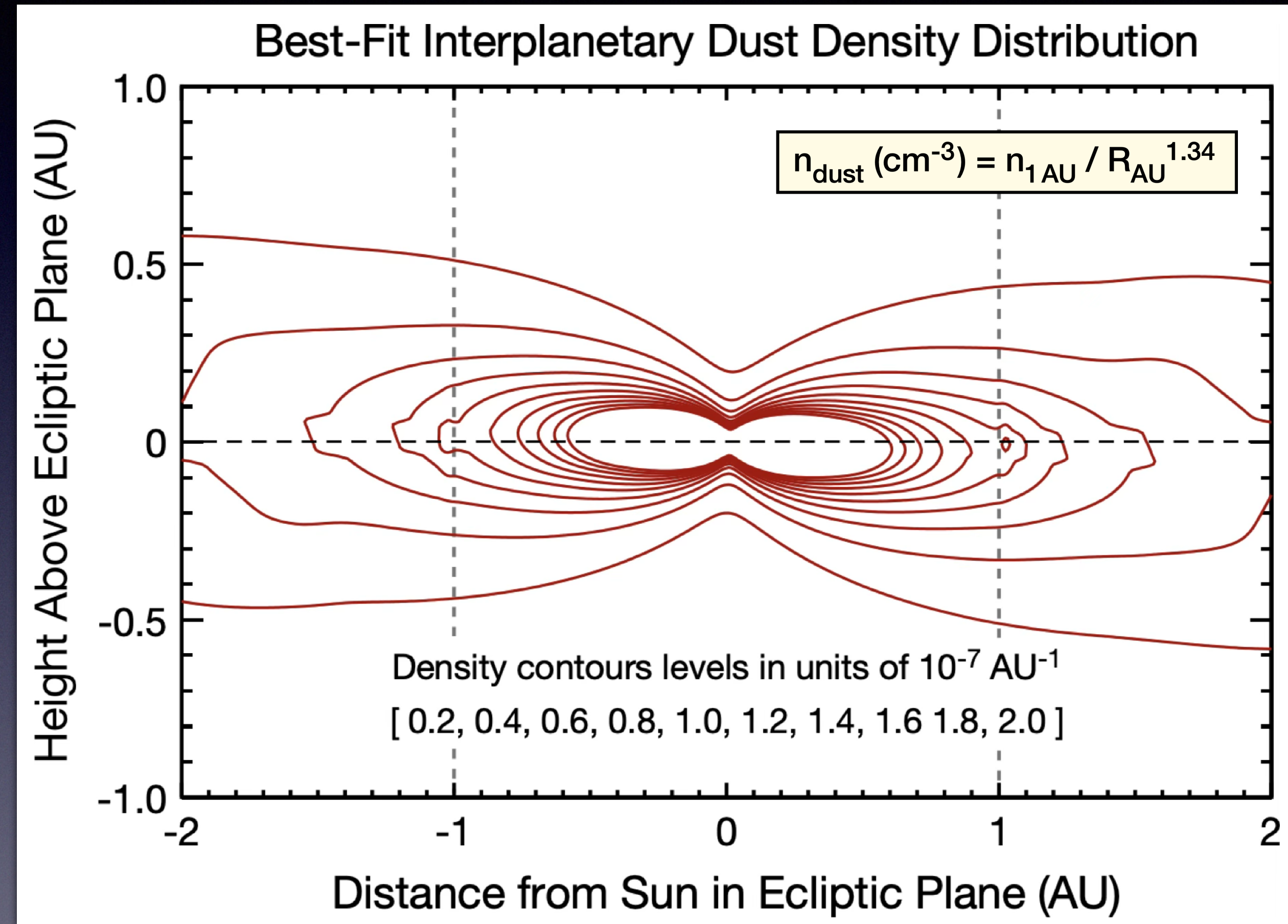
Kelsall et al. 1998

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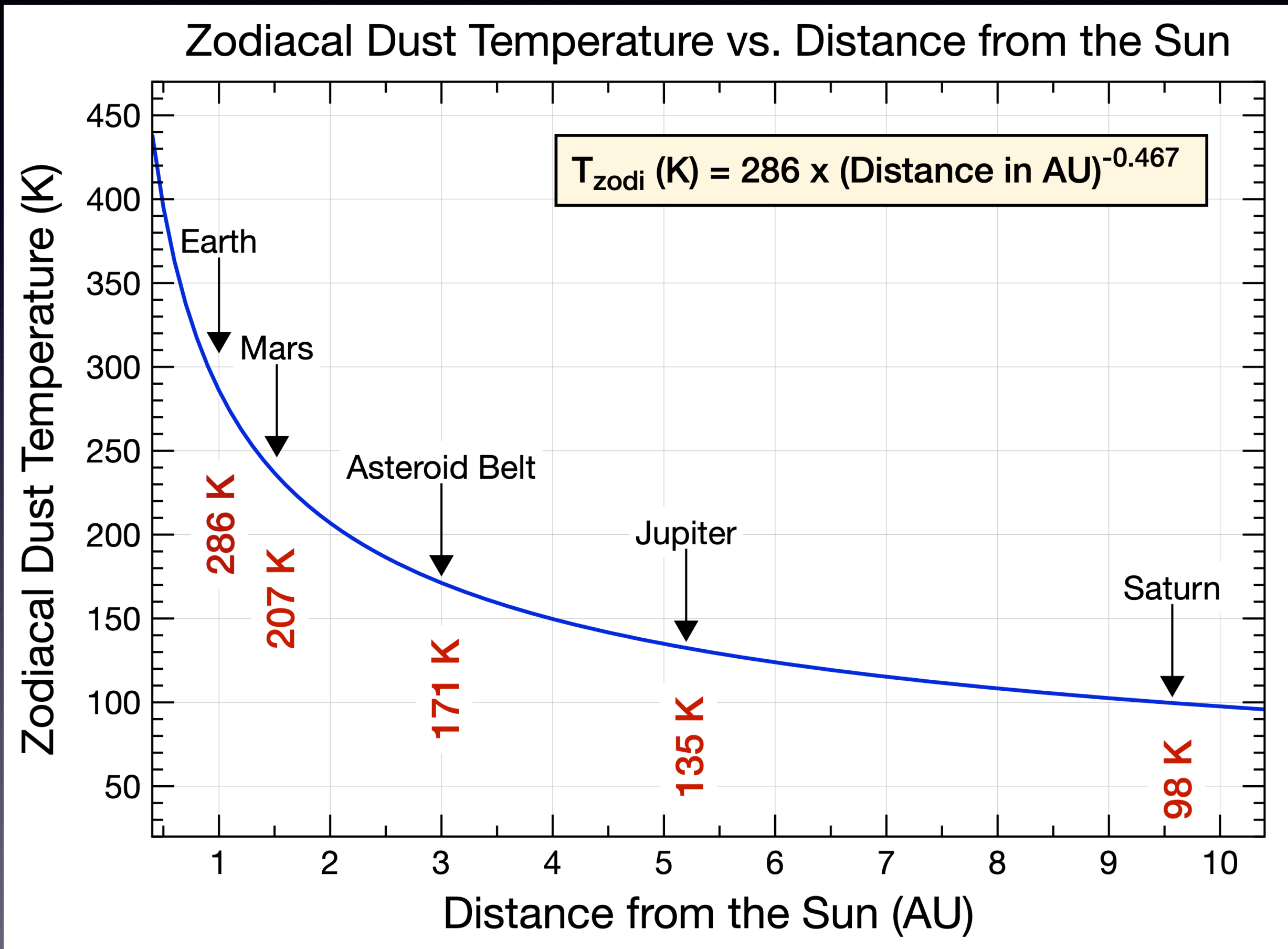


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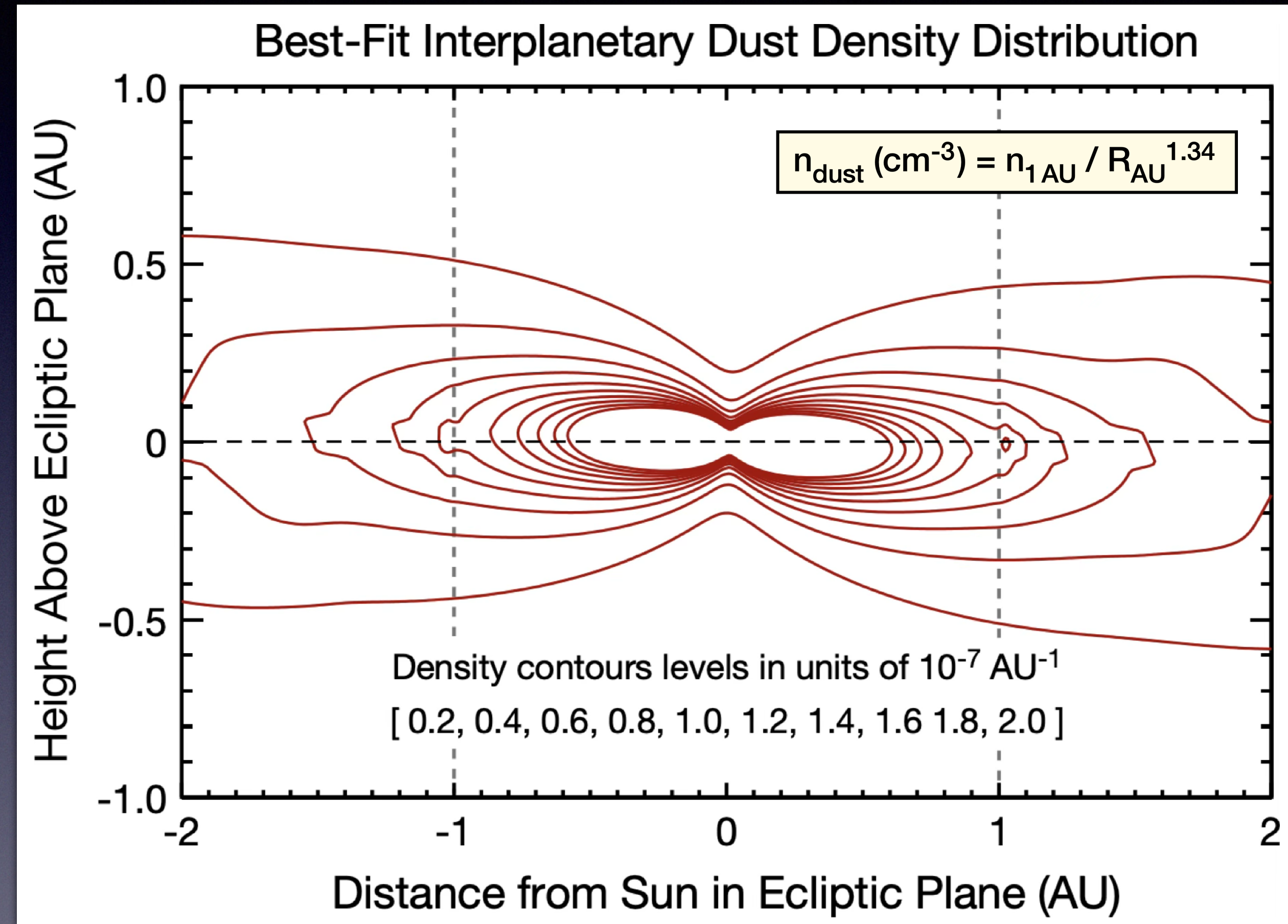
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Kelsall et al. 1998

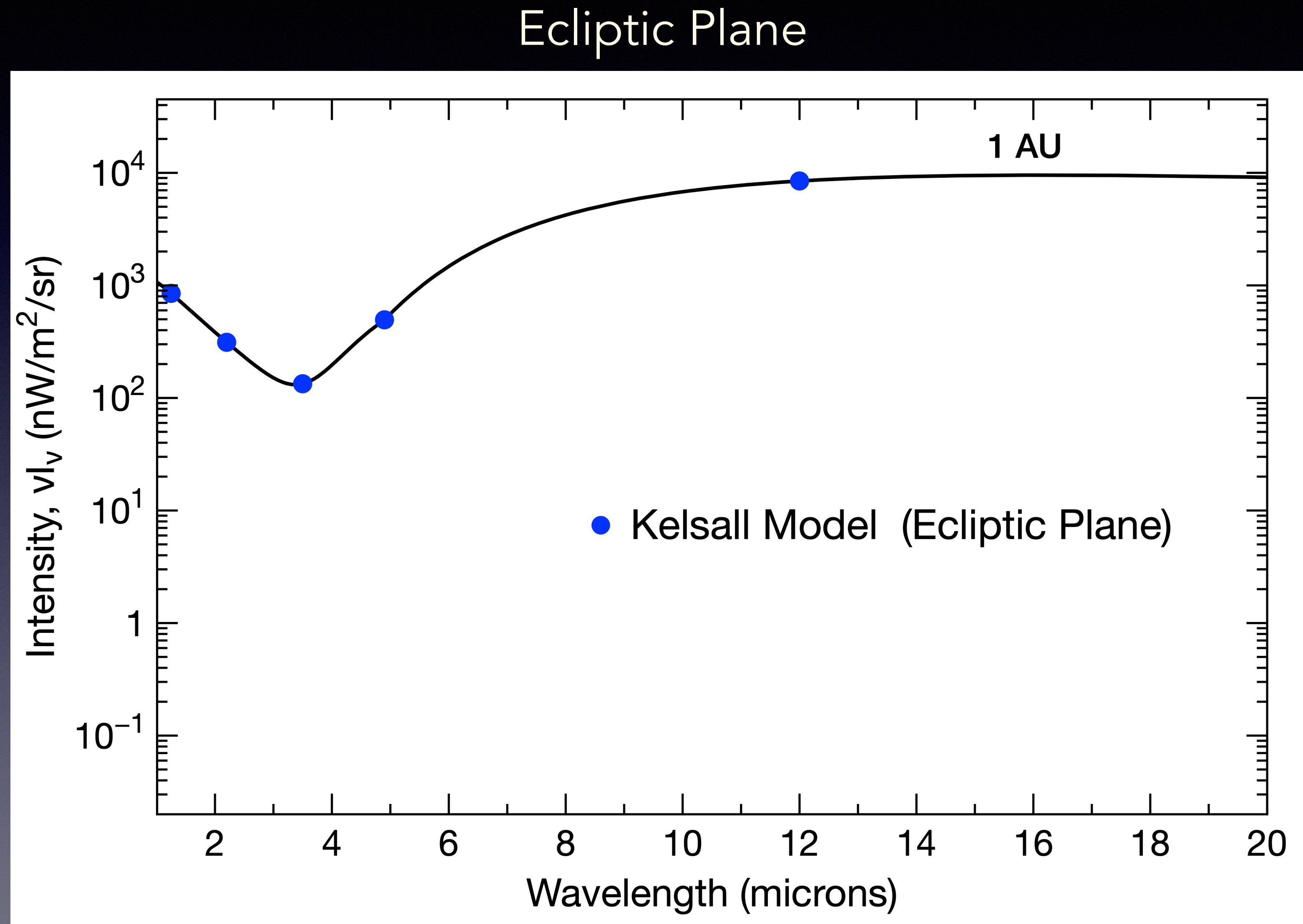
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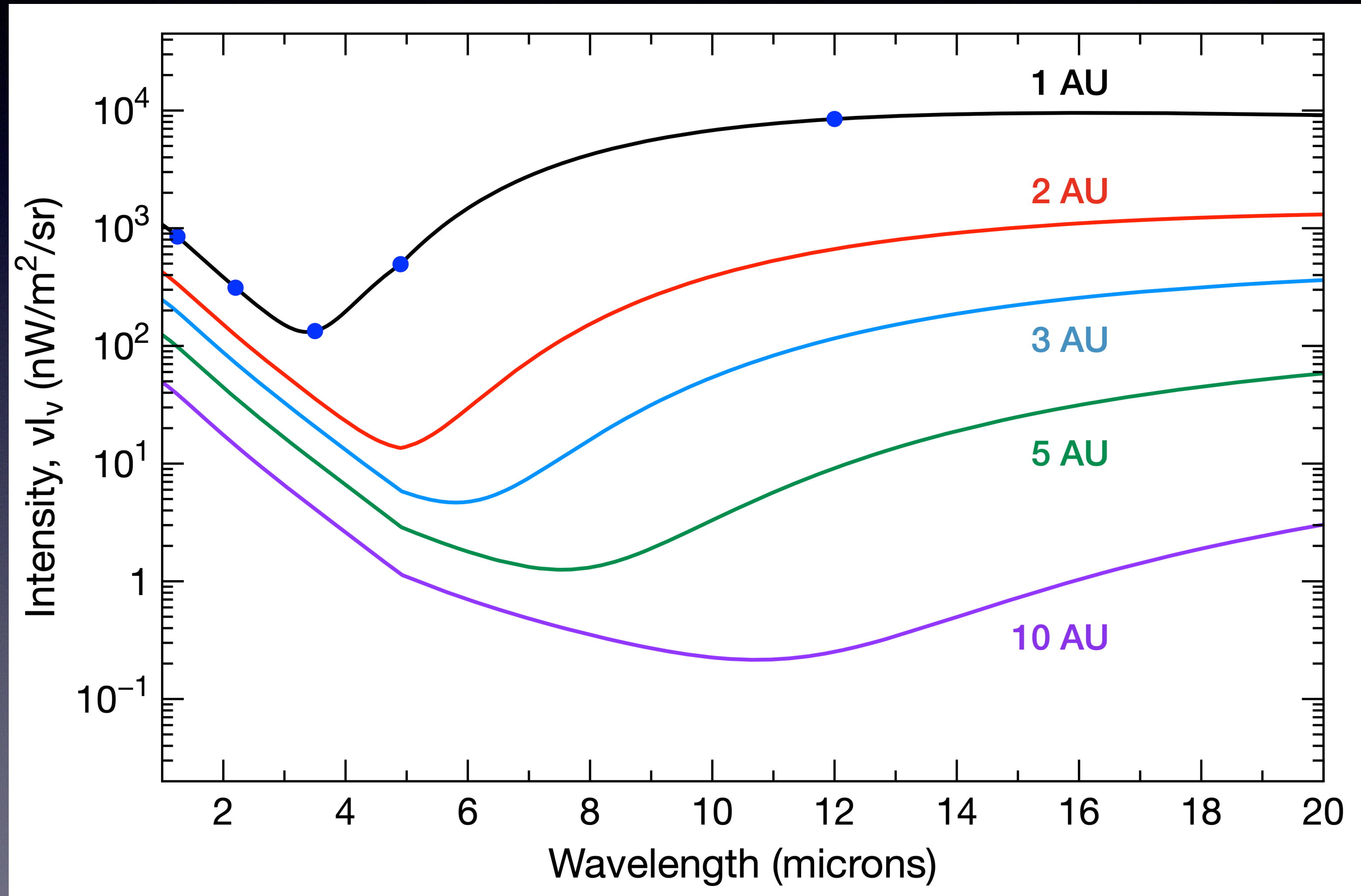
#3. Ecliptic latitude

Natural Infrared Background vs. Distance from the Sun

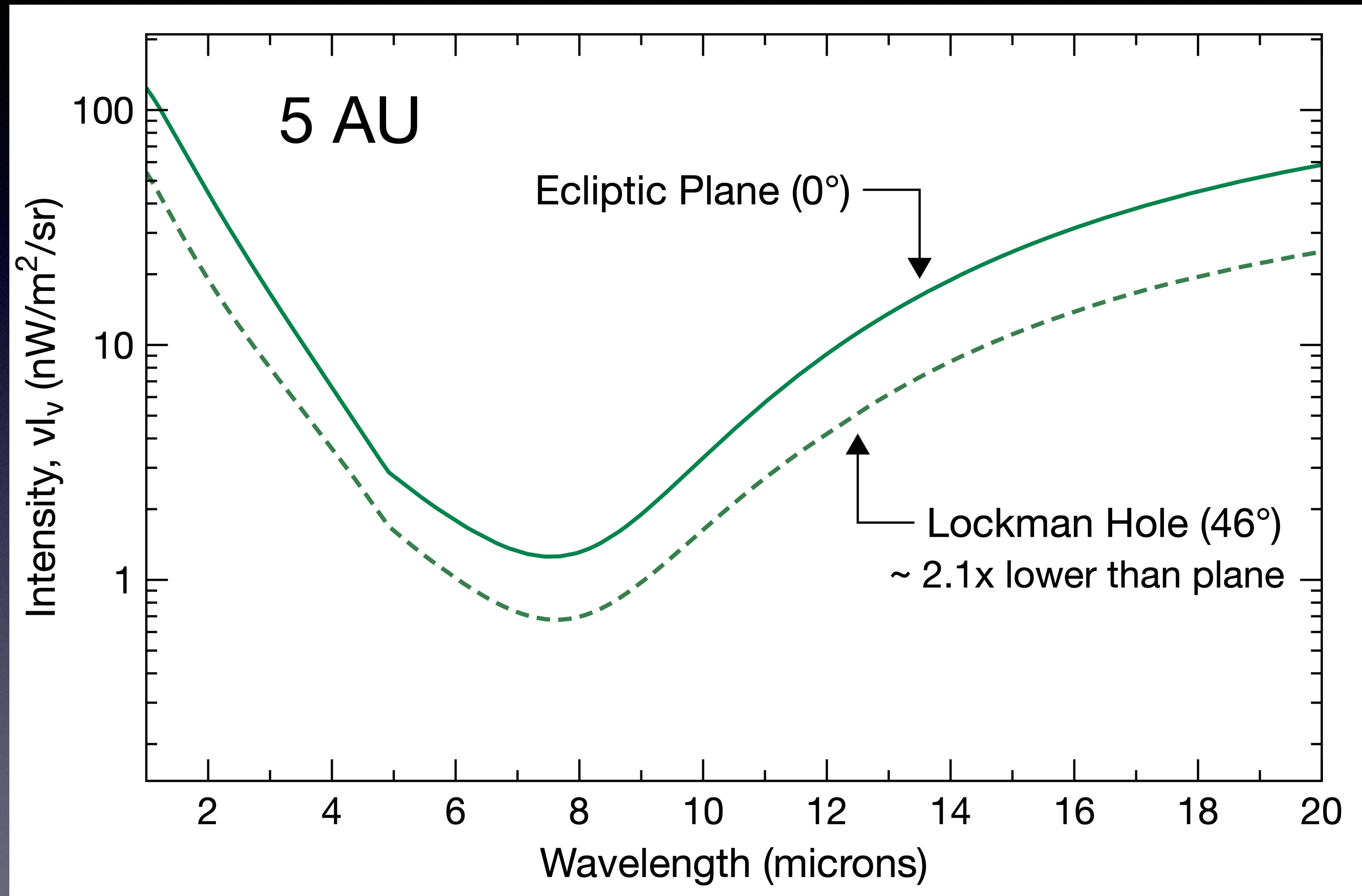


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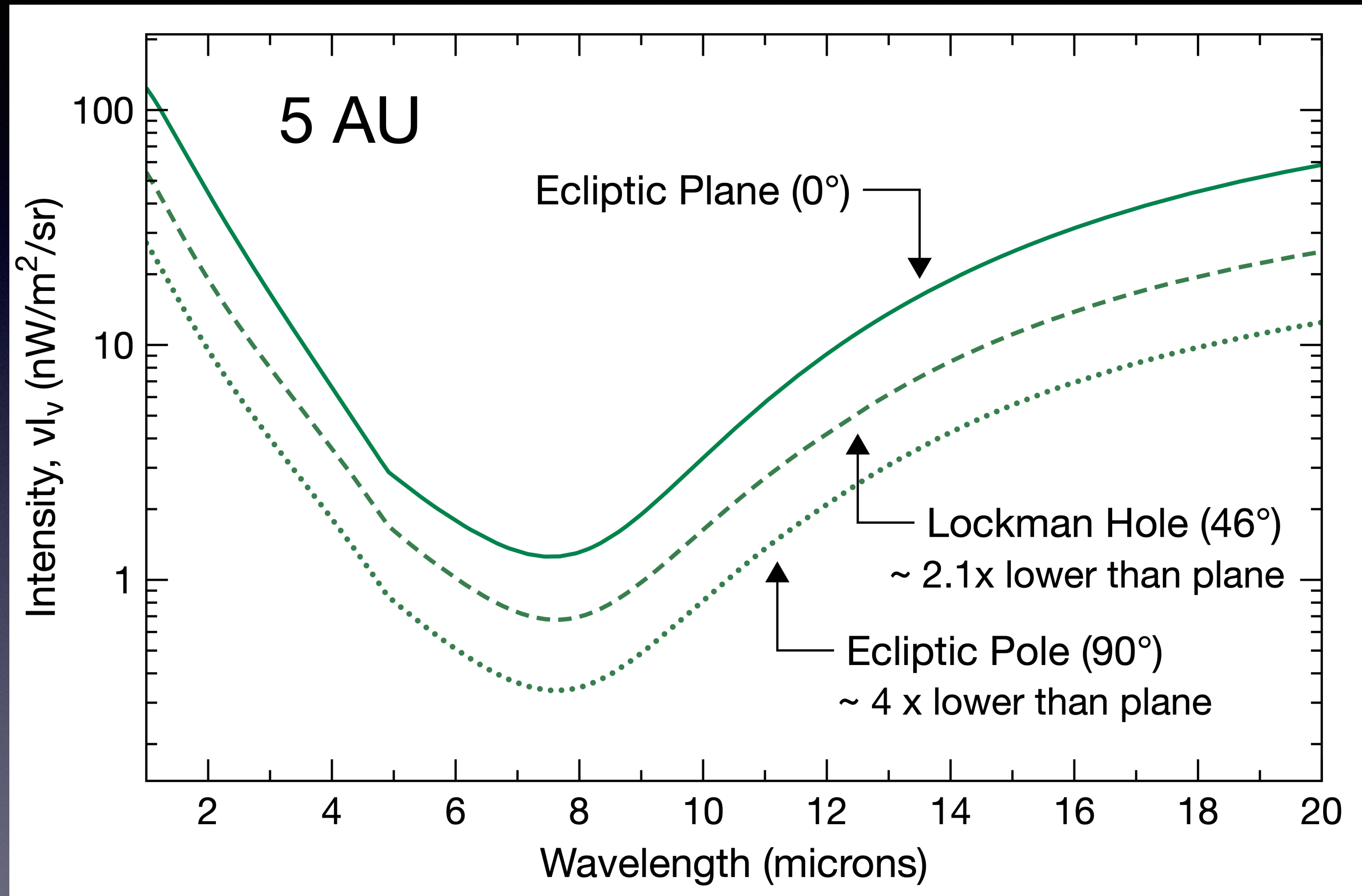
Ecliptic Plane



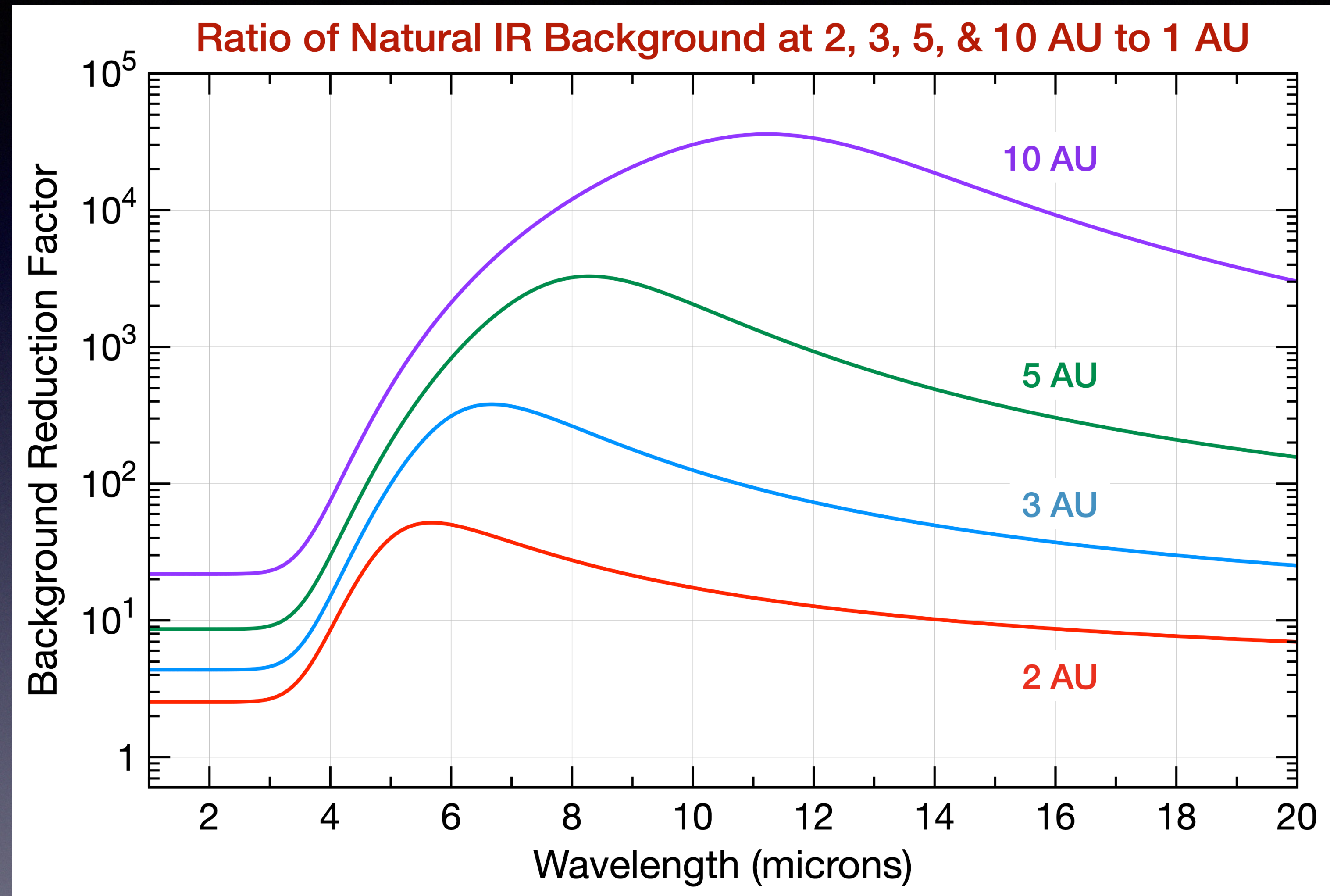
Higher Ecliptic Latitudes Result in Even Lower Zodi Backgrounds



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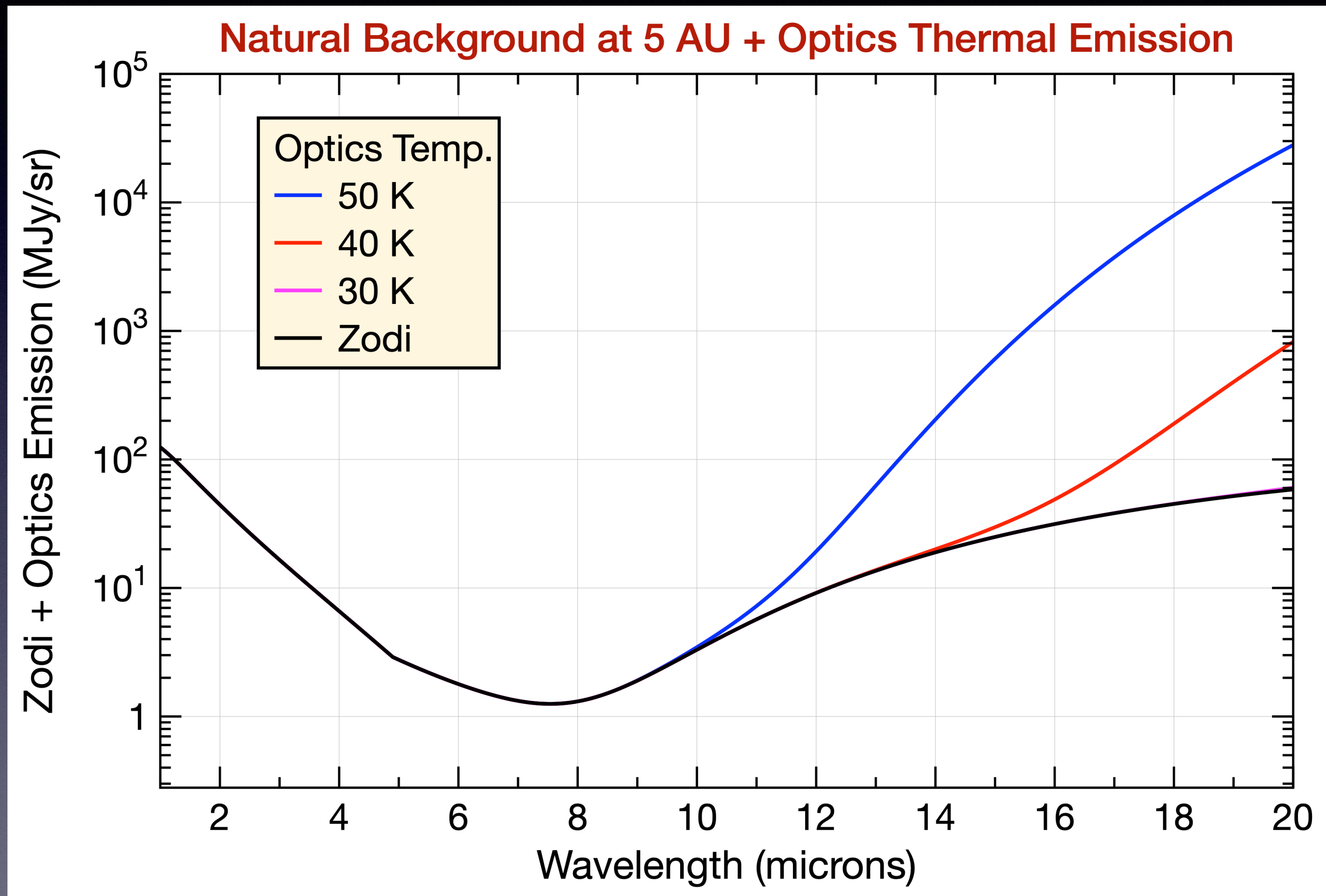


Enormous Gains in Sensitivity Can Be Realized Relative to 1 AU

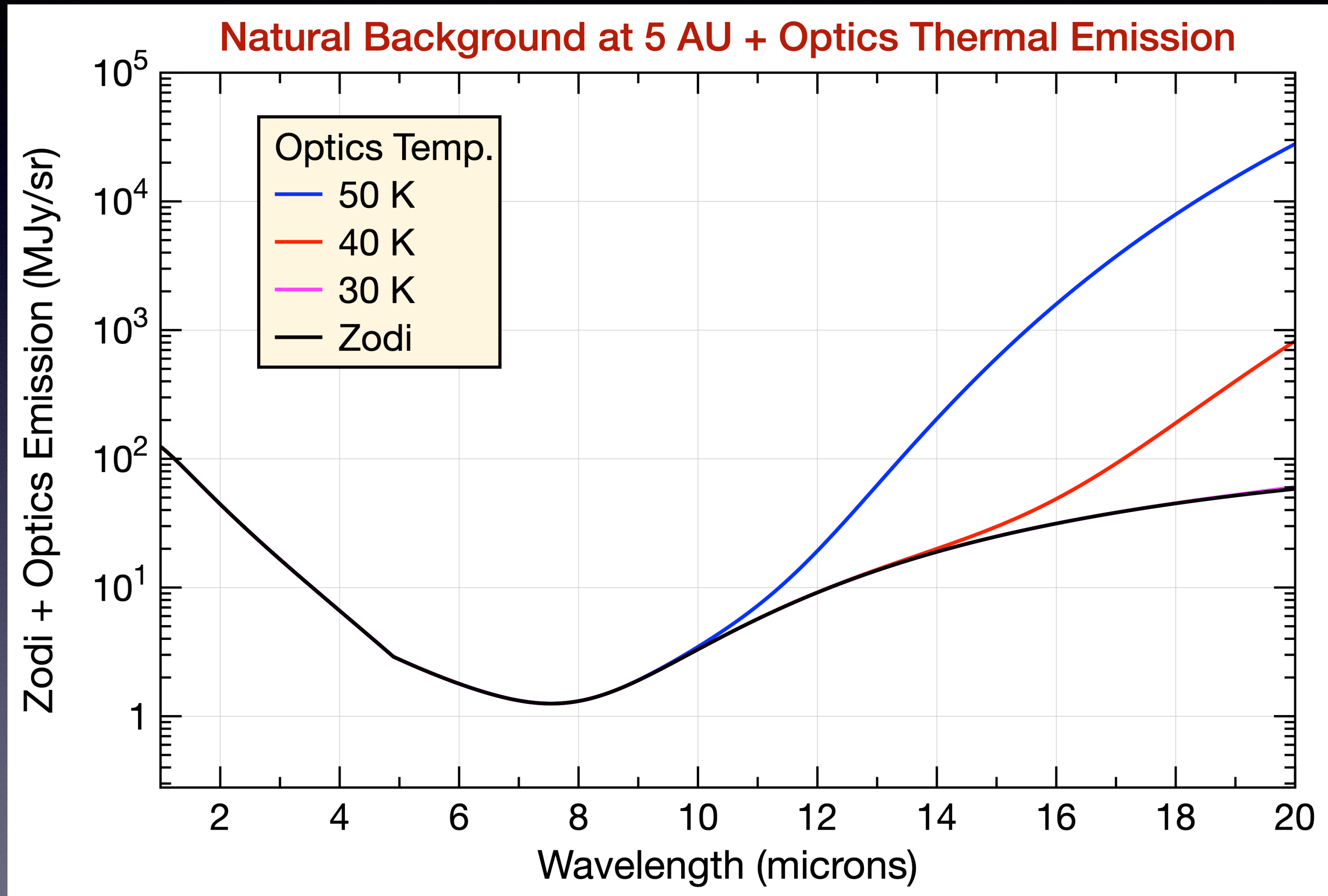


Gains of 10^2 - 10^3 should be easily achievable with the possibility of 10^4

Observatory Remains Background Limited to at Least $\lambda = 14 \mu\text{m}$ With Telescope Optics at $T \leq 40 \text{ K}$

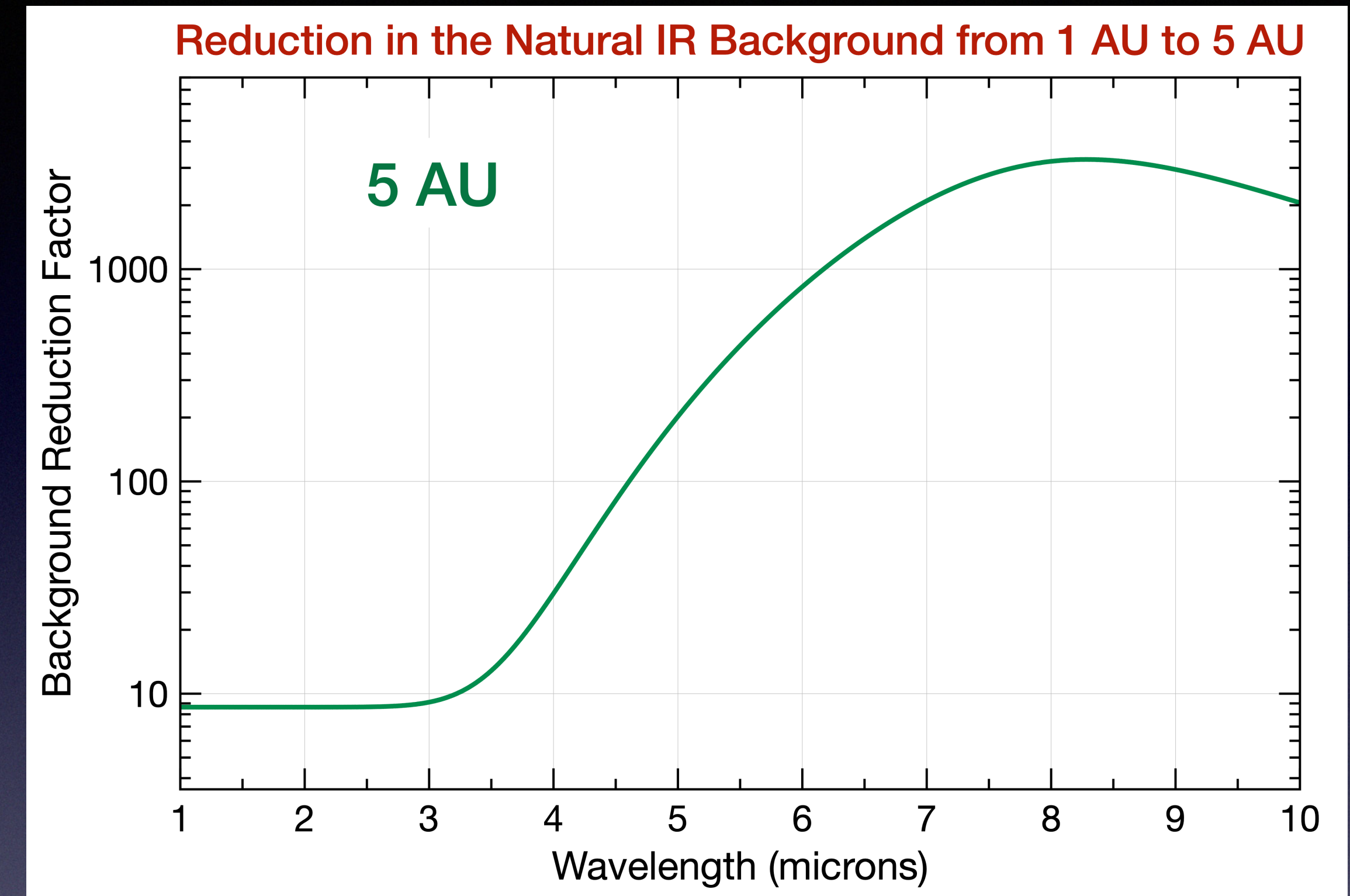


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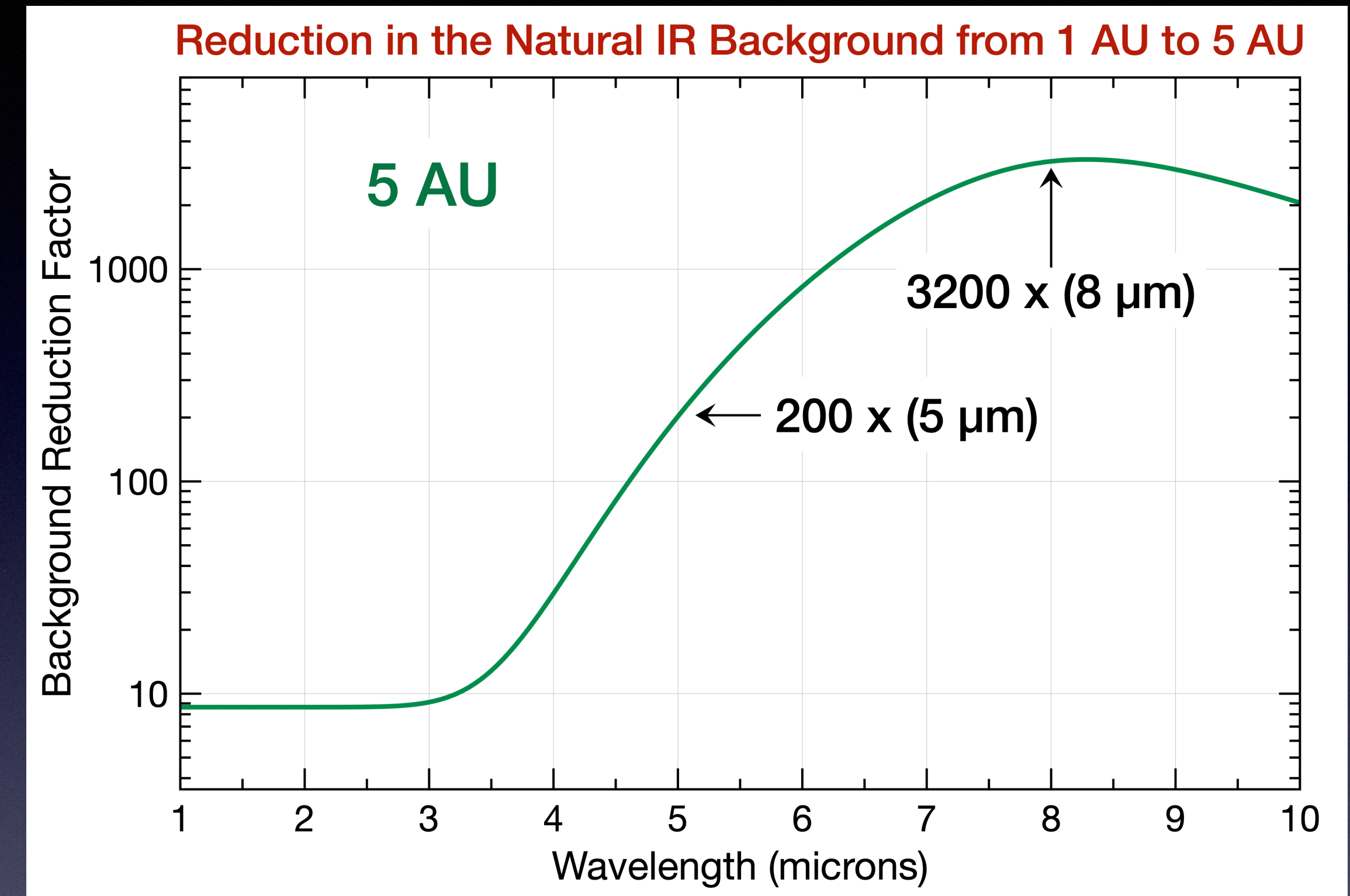


JWST primary & secondary mirrors operate passively at $\sim 44 \text{ K}$ & 29 K , respectively, at 1 AU

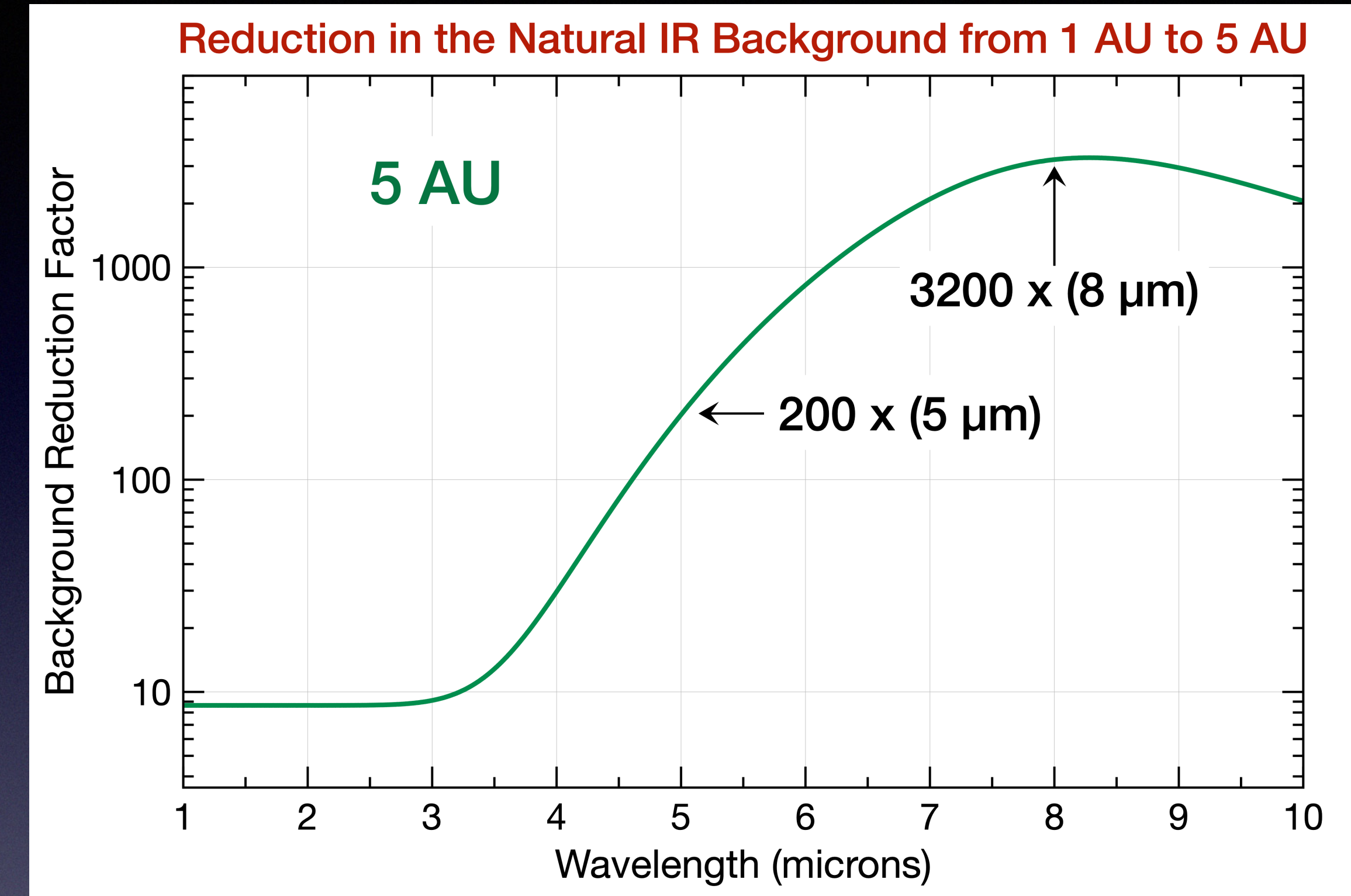
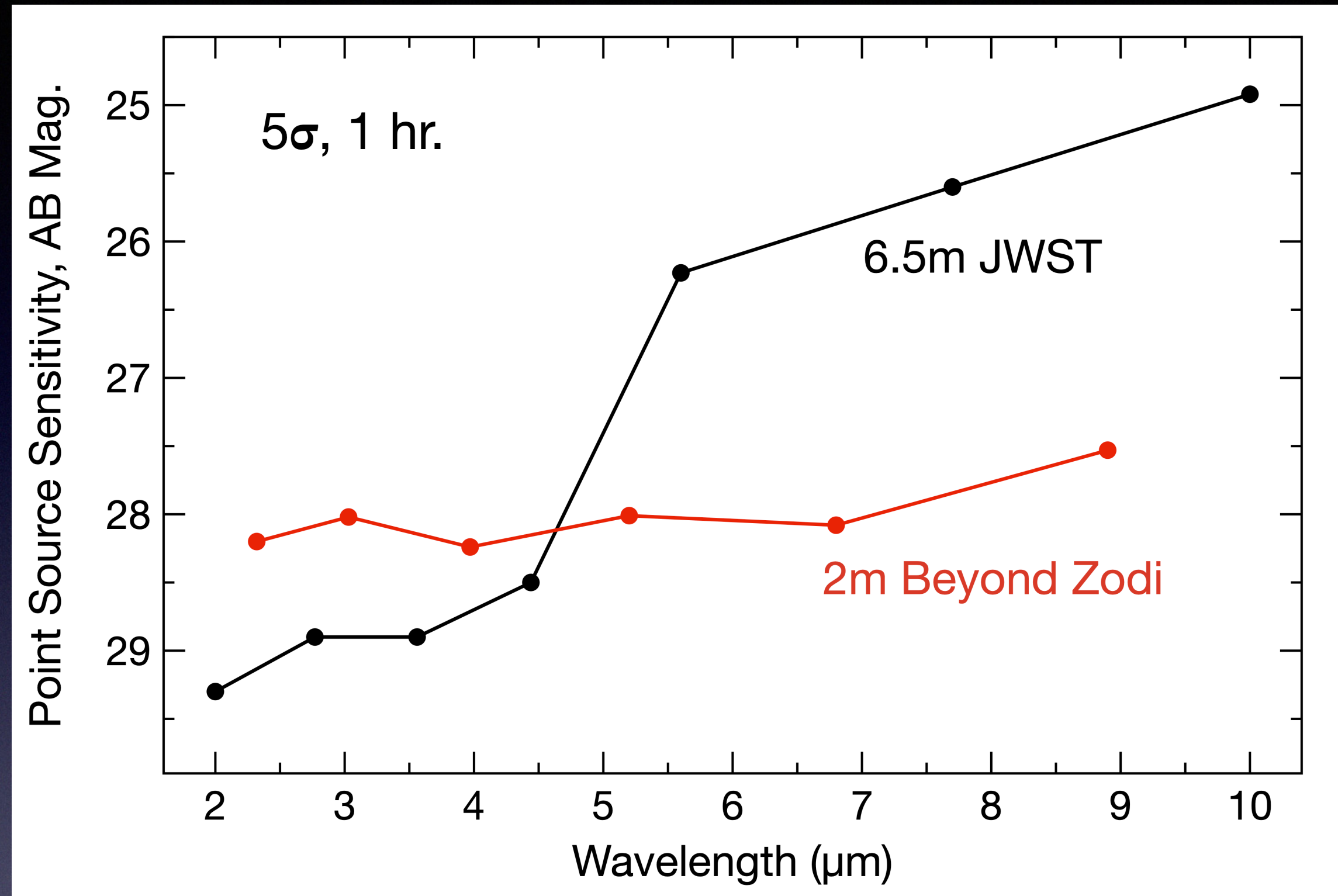
Greatly Reduced Background Allows a 2m Telescope To Exceed the Capabilities of JWST



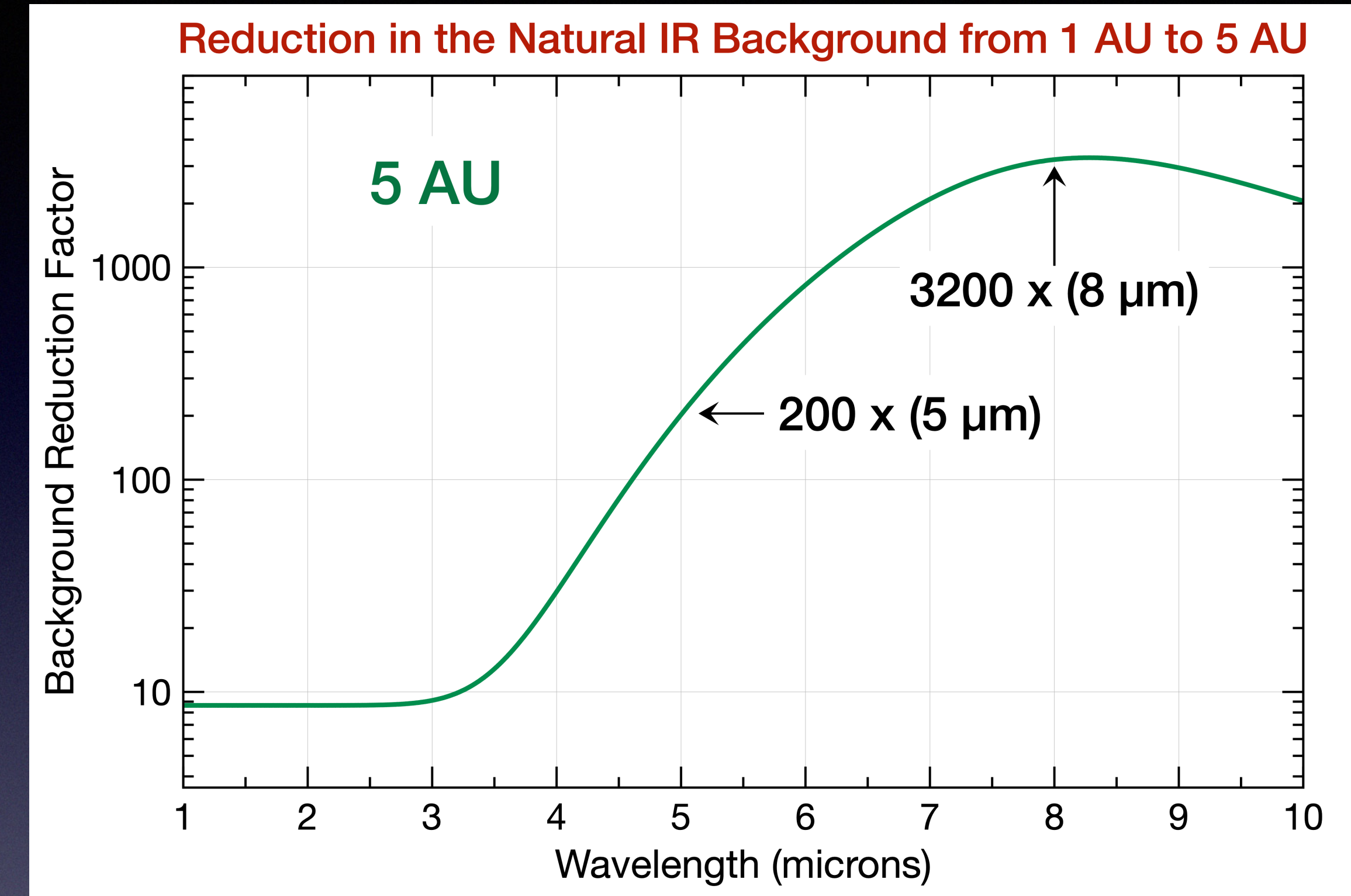
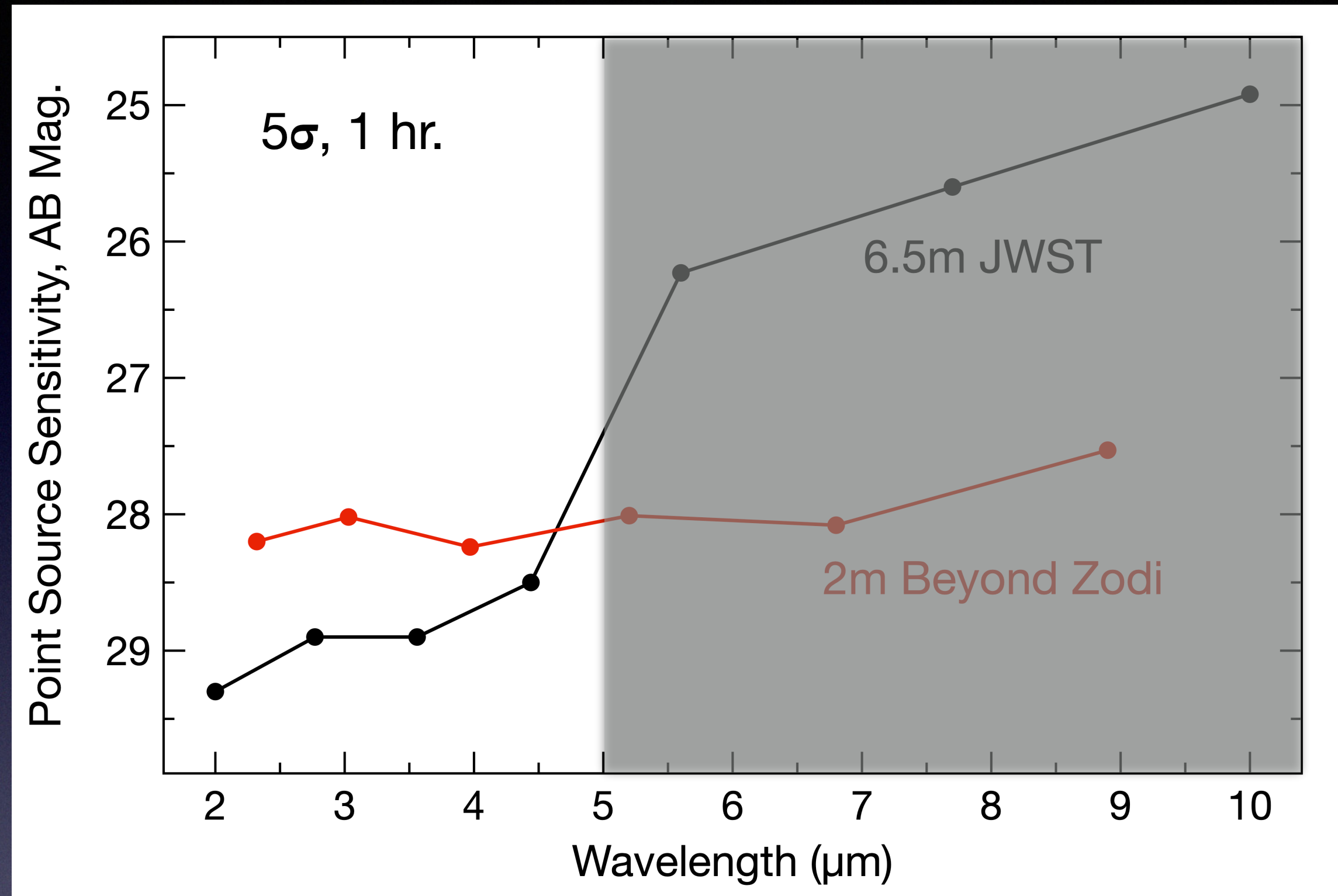
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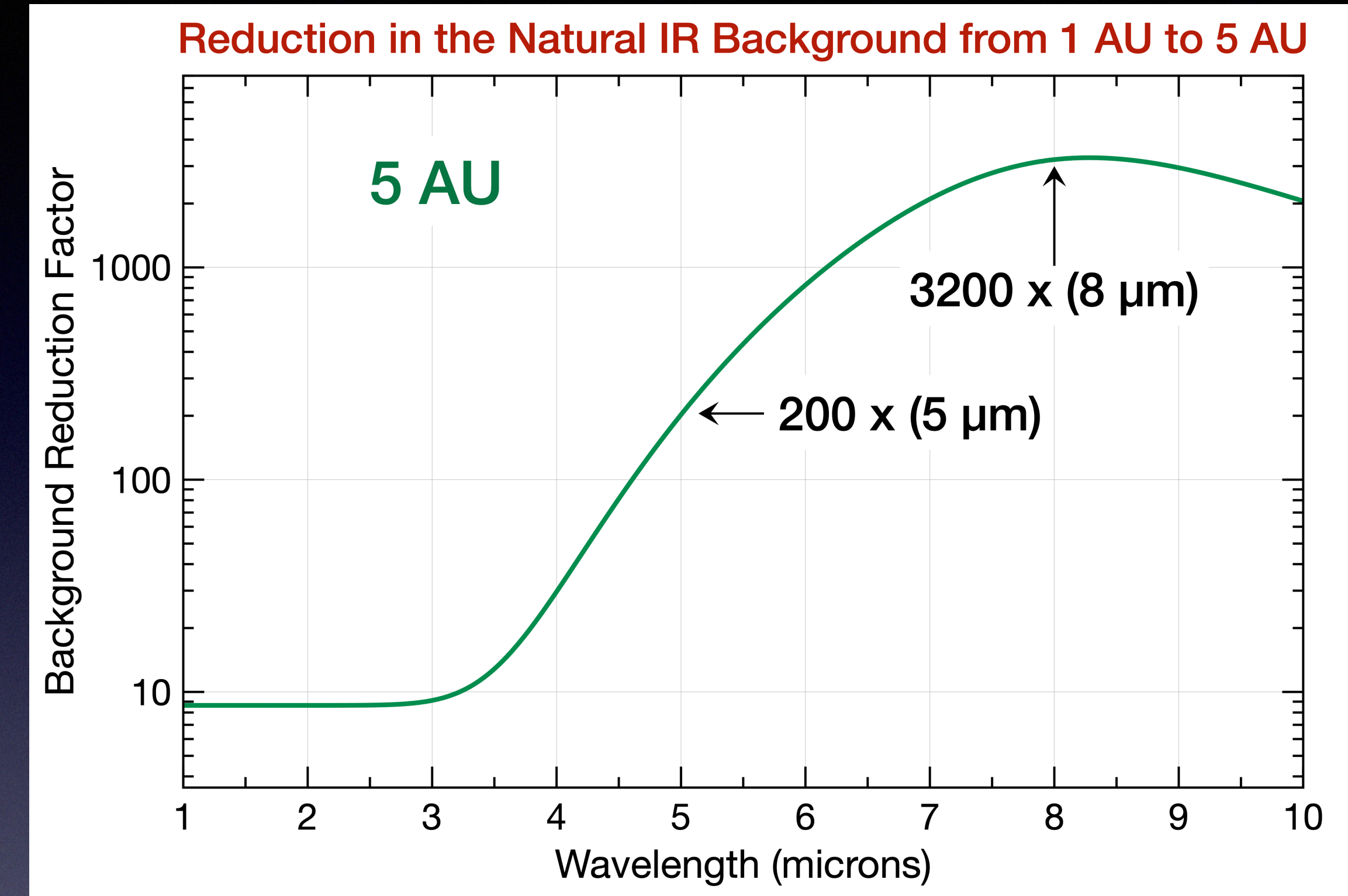
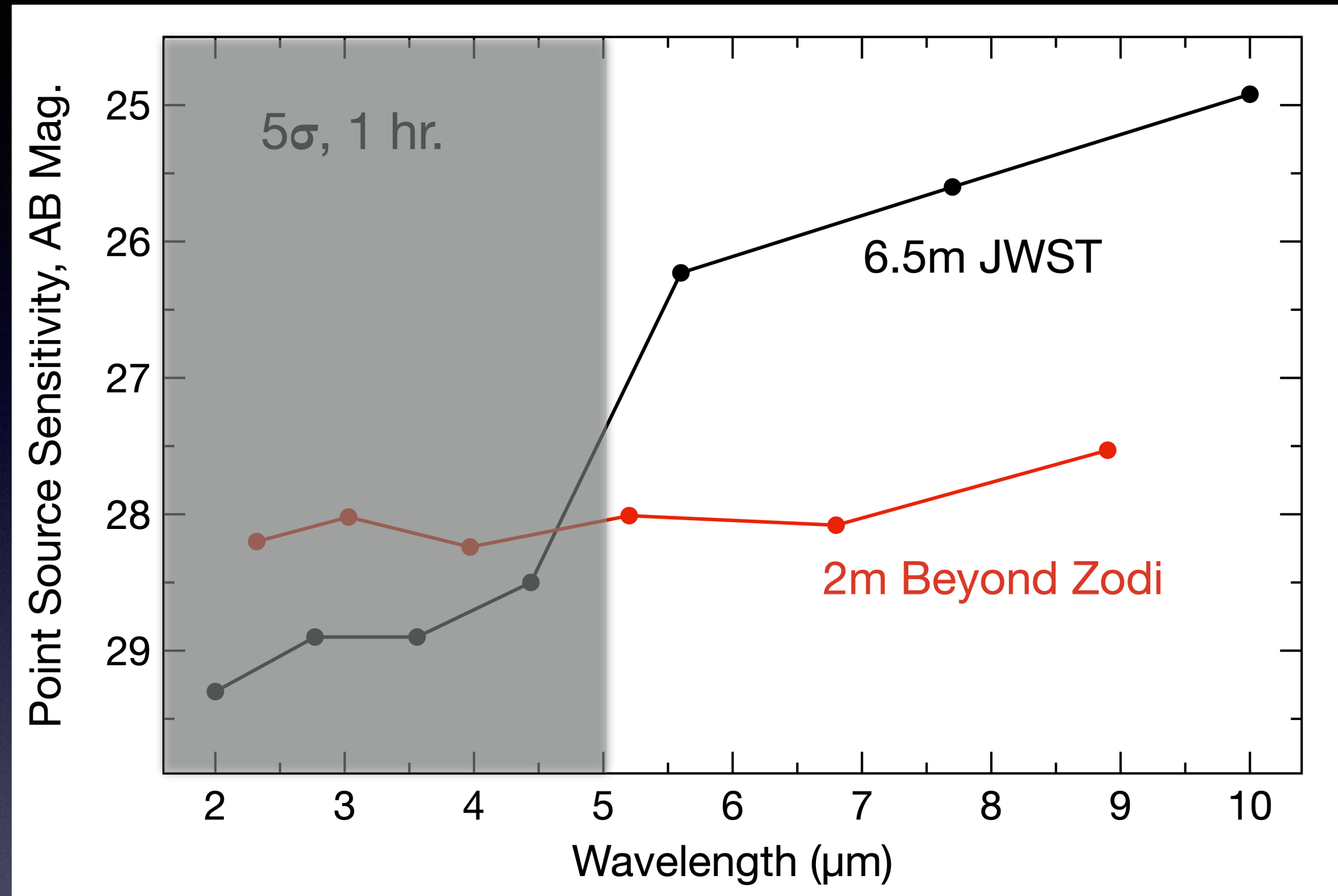


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At 5 AU: • Between 2 and 5 μm , the Beyond Zodi Mid-IR Wide-Field Surveyor offers comparable sensitivity to JWST with the agility to survey much larger areas

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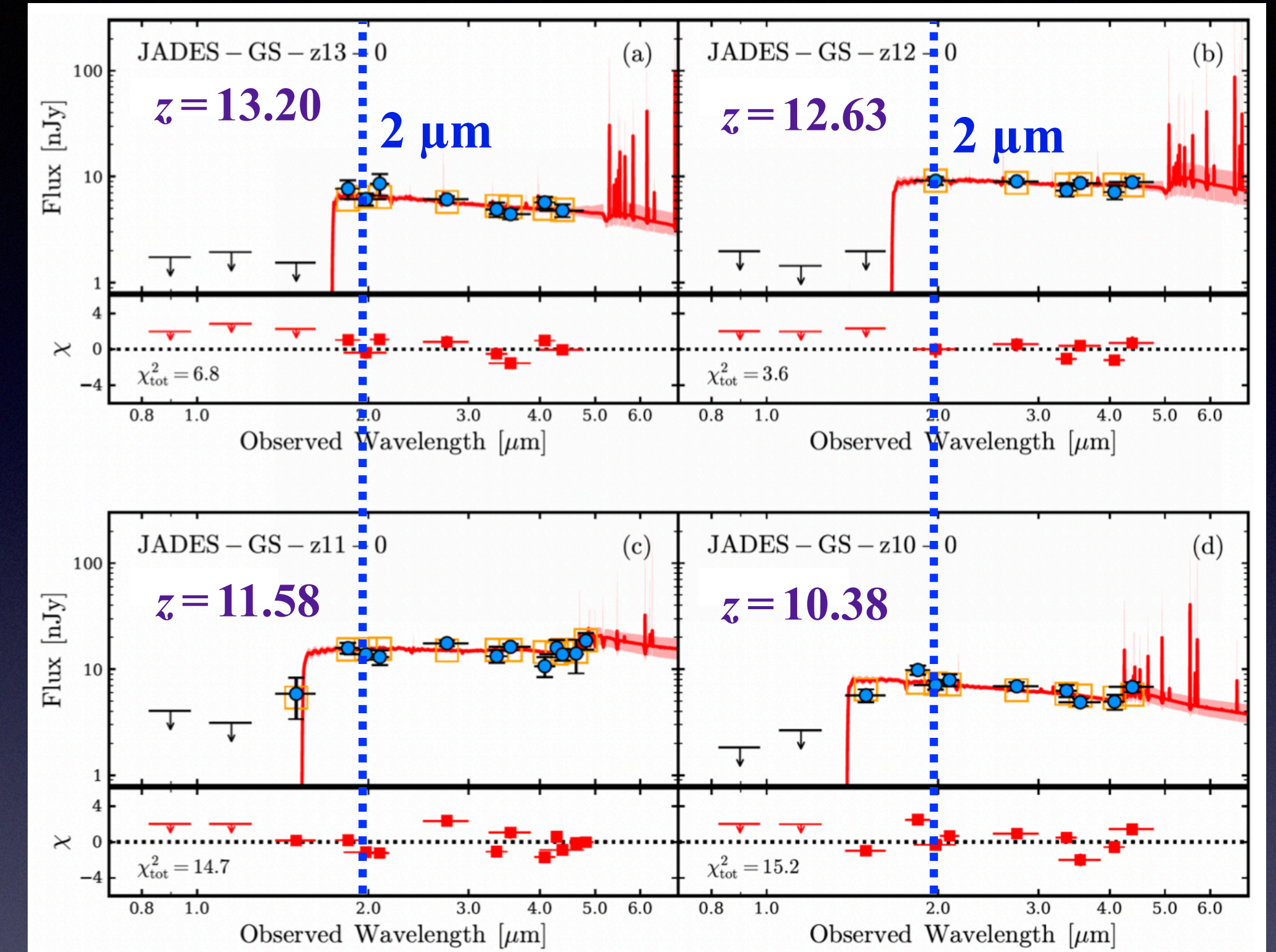
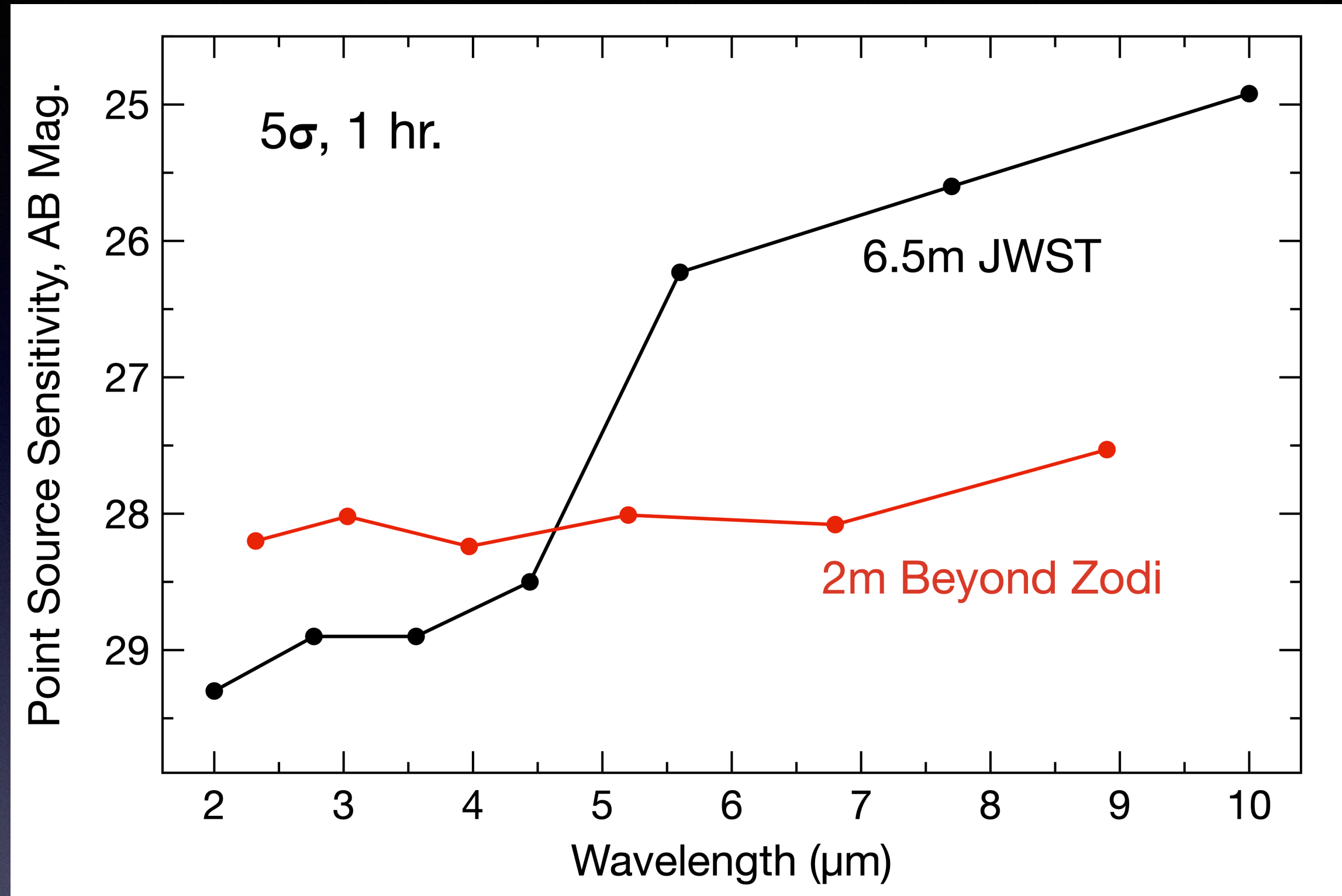


- At 5 AU:
- Between 2 and 5 μm , the Beyond Zodi Mid-IR Wide-Field Surveyor offers comparable sensitivity to JWST with the agility to survey much larger areas
 - Between 5 and 10 μm , the Beyond Zodi Mid-IR Wide-Field Surveyor offers the same agility with much greater sensitivity than JWST

What are a few of the science projects enabled by a highly sensitive, agile near- and mid-infrared observatory?

Wide-area (10-1000 deg²) census of $z \geq 10$ galaxies

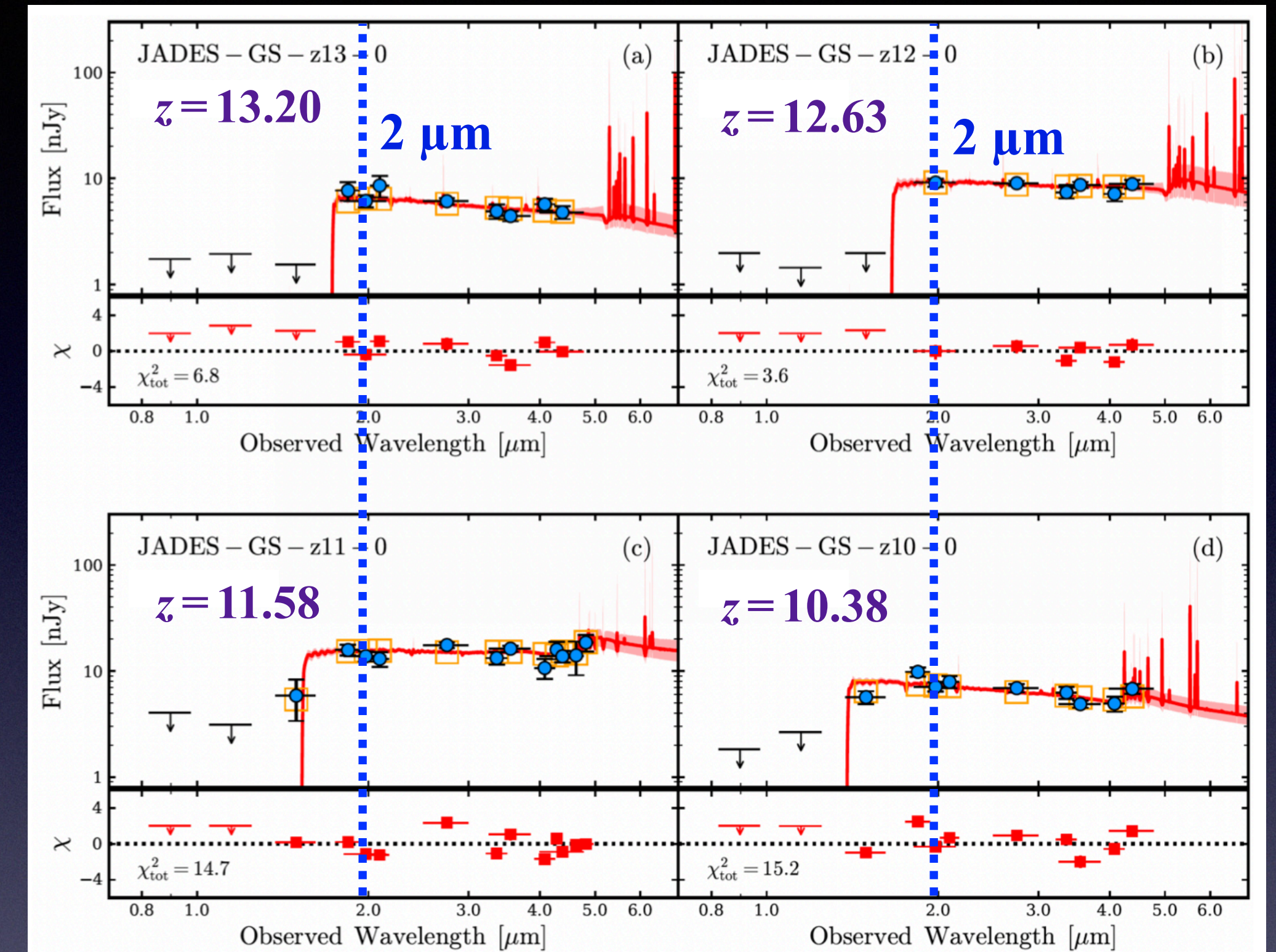
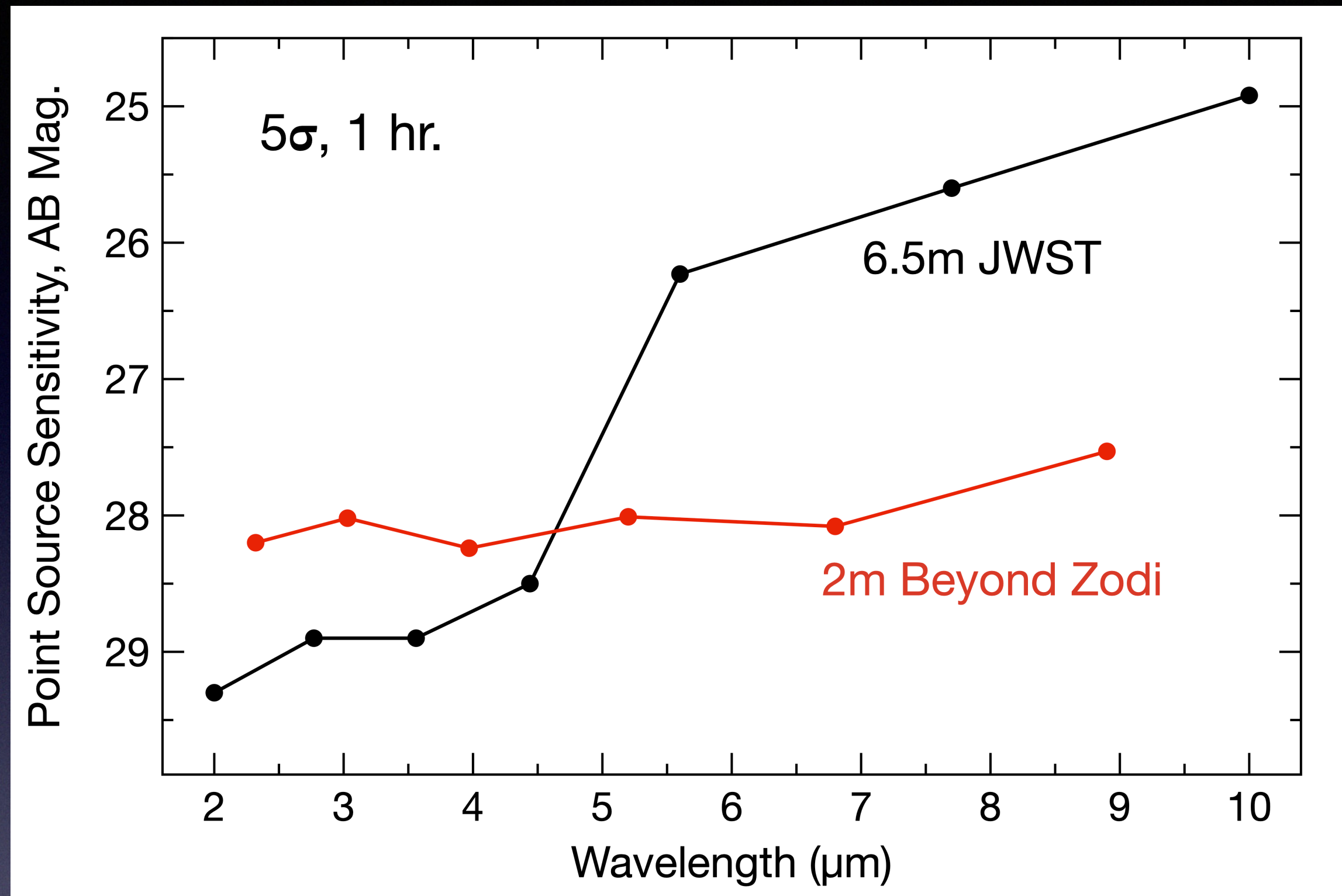
Robertson et al. 2023



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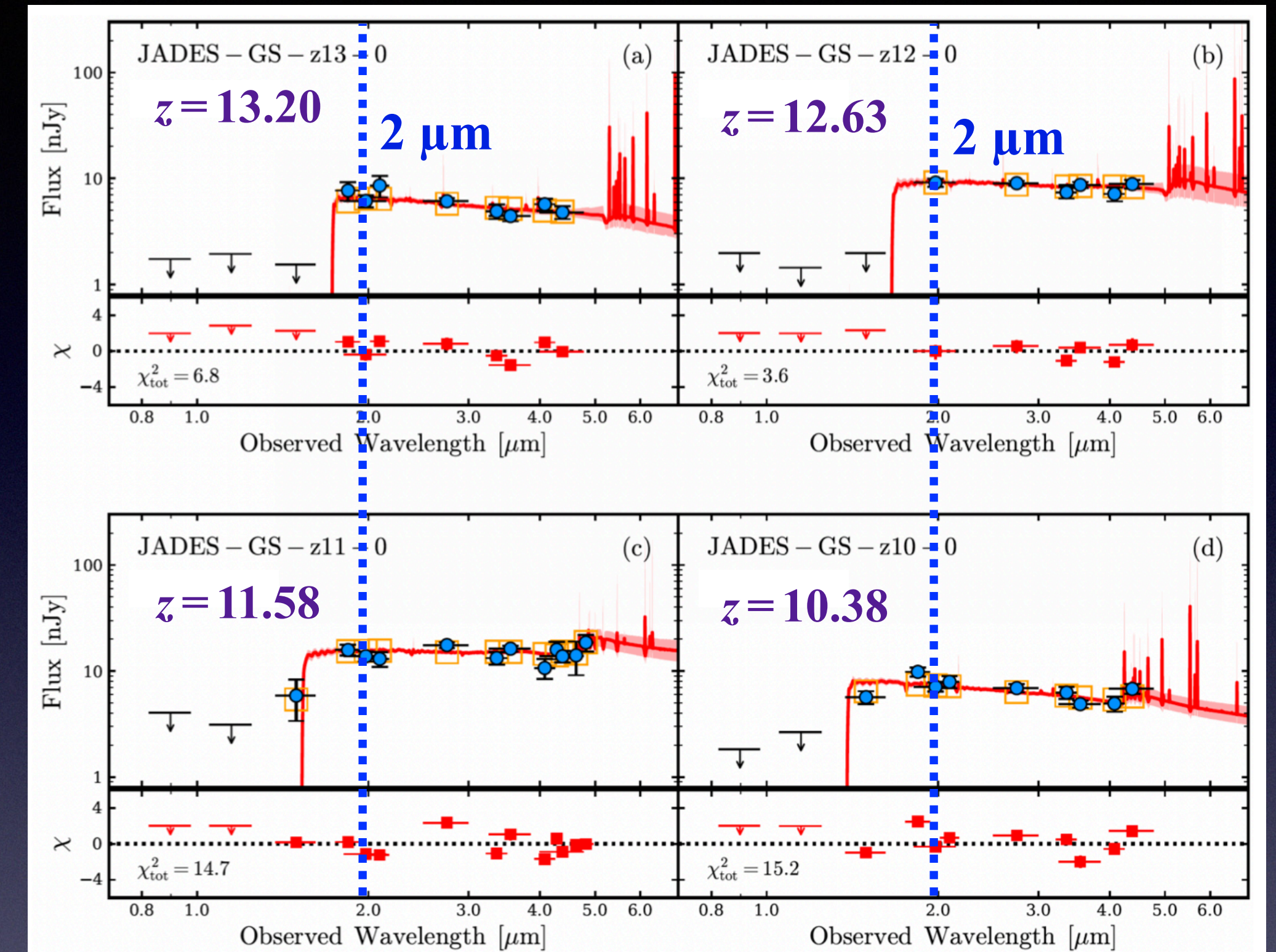
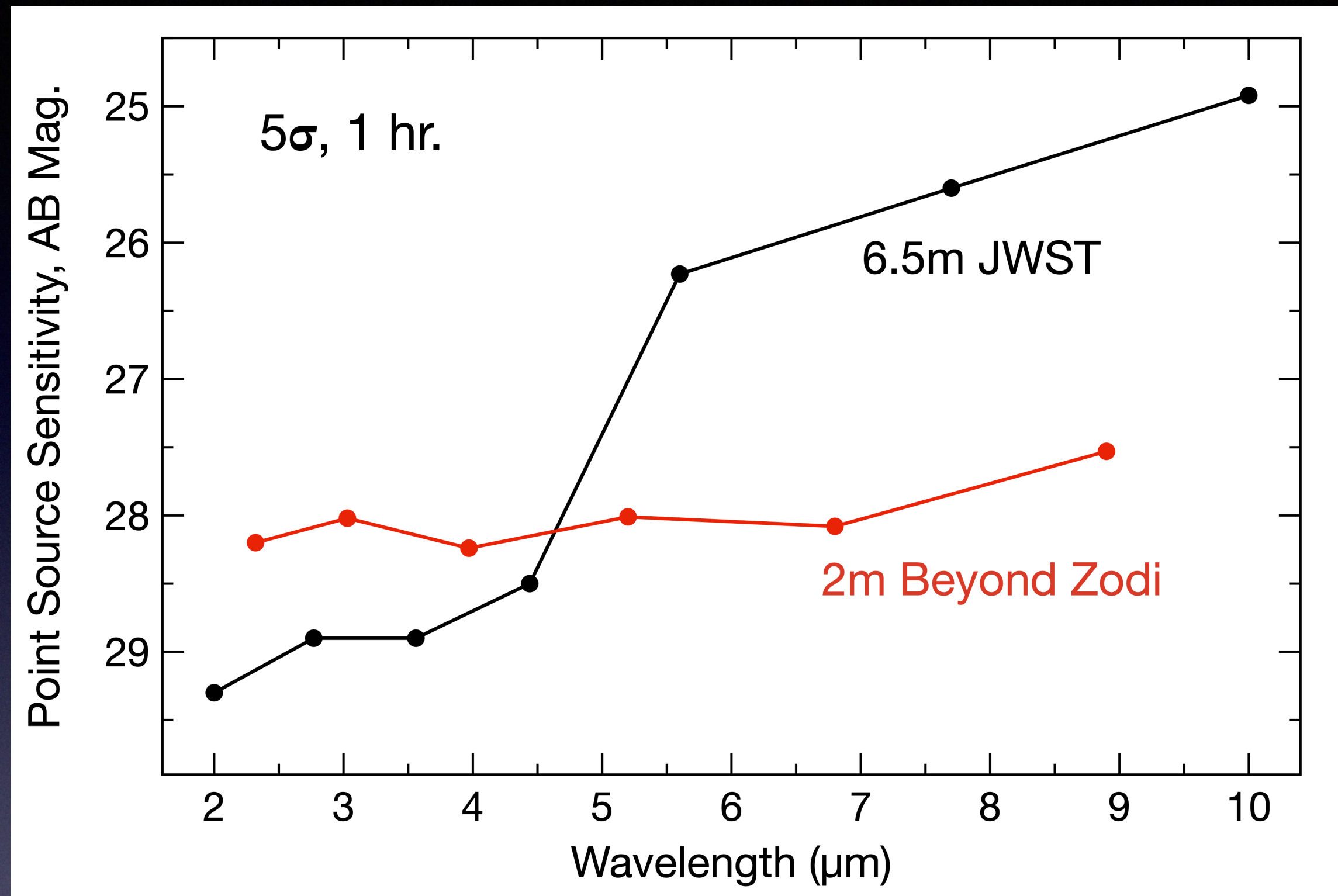
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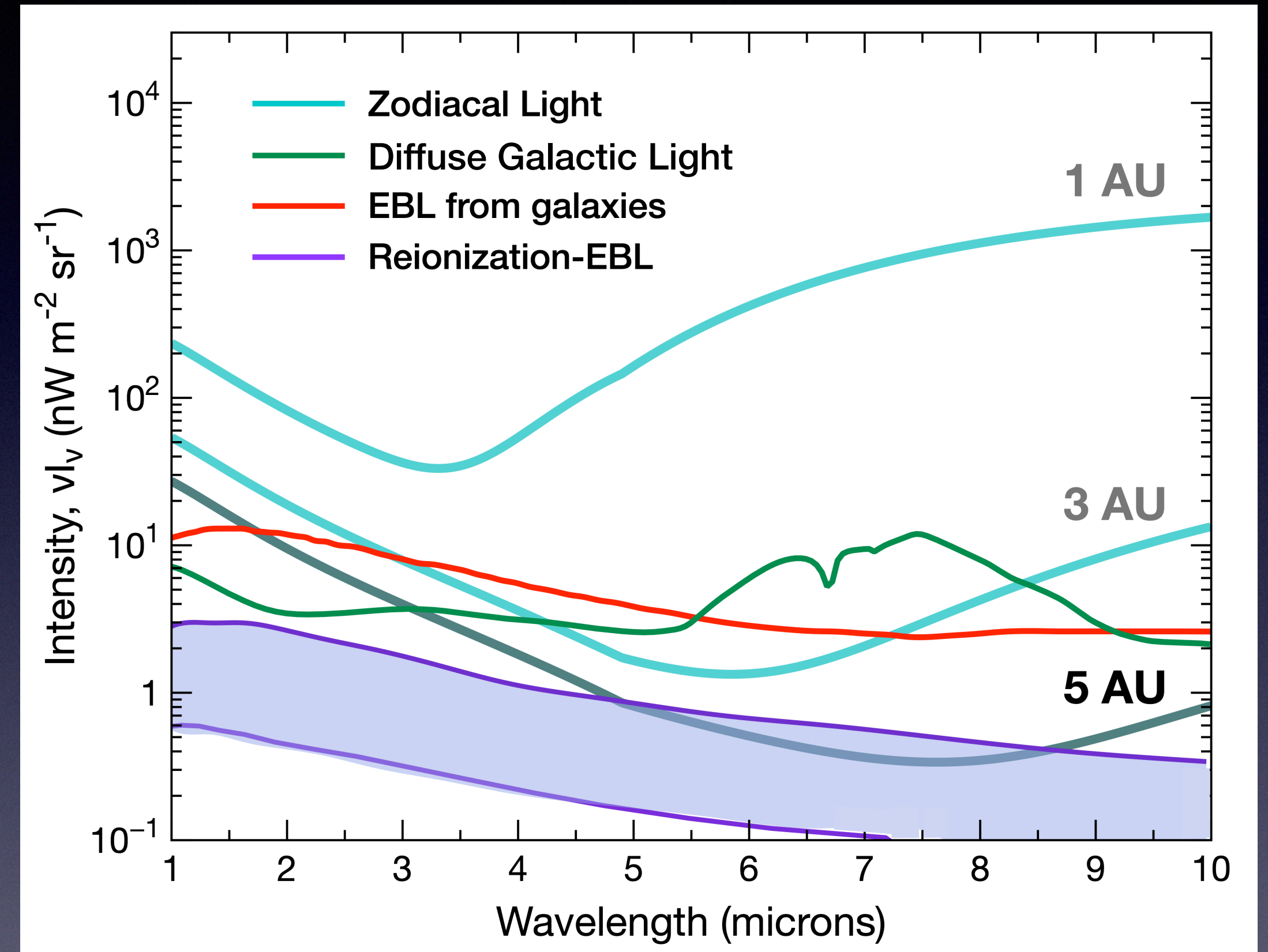


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- To probe luminous galaxies at $z > 13$, we need a Roman-like survey telescope, but covering $> 2 \mu\text{m}$
- The added sensitivity of the Beyond-Zodi Mid-IR Surveyor will allow either (or both) a high- z survey to greater depth or a larger-area survey to the same depth as at 1 AU, while providing stellar masses (by observing rest-frame B band or longer) out to $z = 14$ compared to $z = 4$ for Roman

Faint and Diffuse Extragalactic Background Light

Adapted from Bock et al. 2012

- A faint, diffuse IR background at $\sim 1\text{--}10\ \mu\text{m}$ contains light from sources in the Epoch of Reionization (EoR) and beyond that are too faint to be individually detected (e.g., Pop-III stars and primordial black holes).
- However, direct intensity measurements of the extragalactic background light (EBL) at 1 AU are difficult because the zodi is 1000x brighter.
- At 5 AU, the zodiacal background at $2\text{--}10\ \mu\text{m}$ is sufficiently reduced to enable *direct measurements* of the EBL from galaxies and the diffuse Galactic light (DGL), and possibly to probe emission from the EoR.

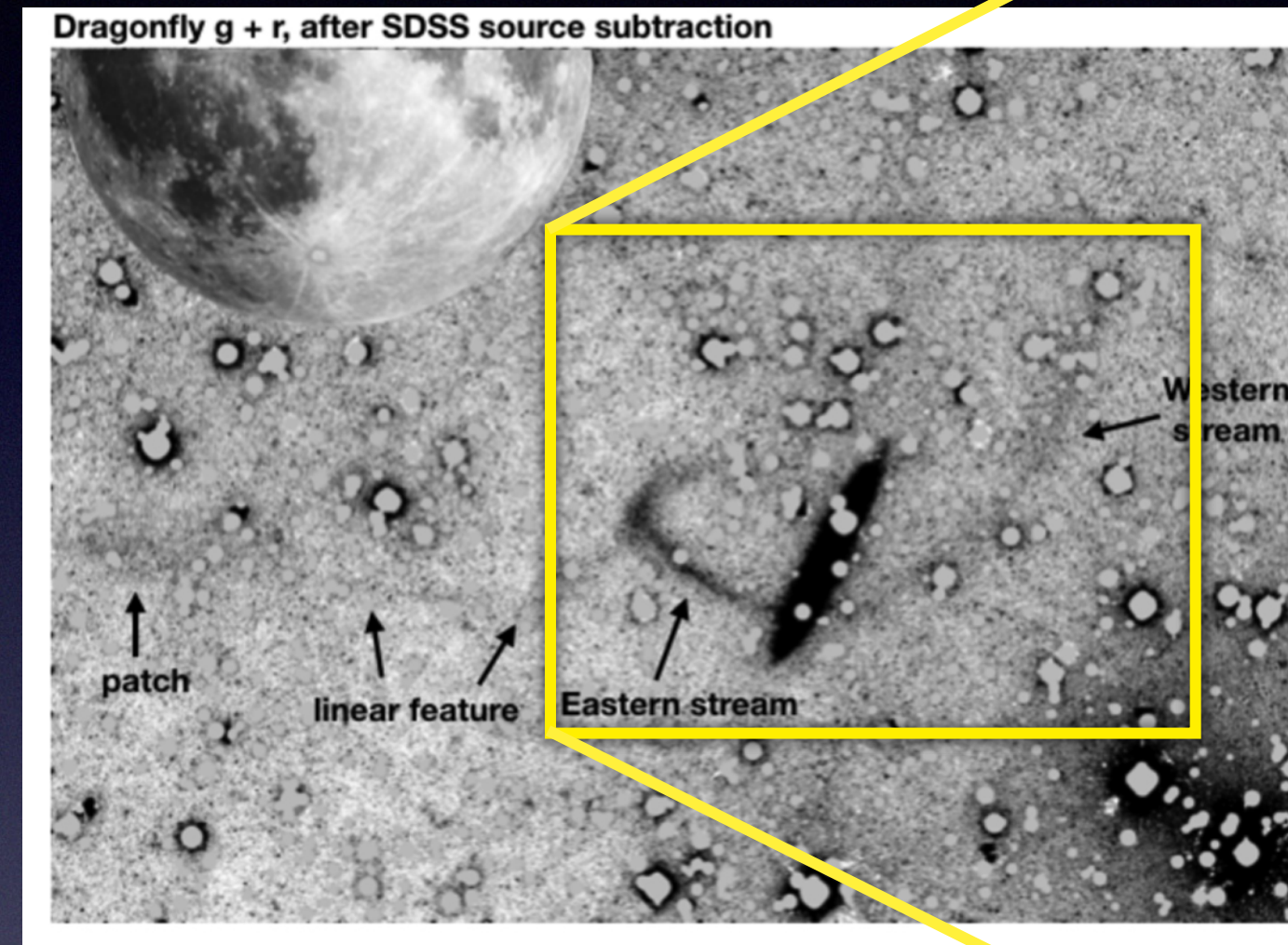


Ultra-Low Surface-Brightness Halos and Tidal Tails

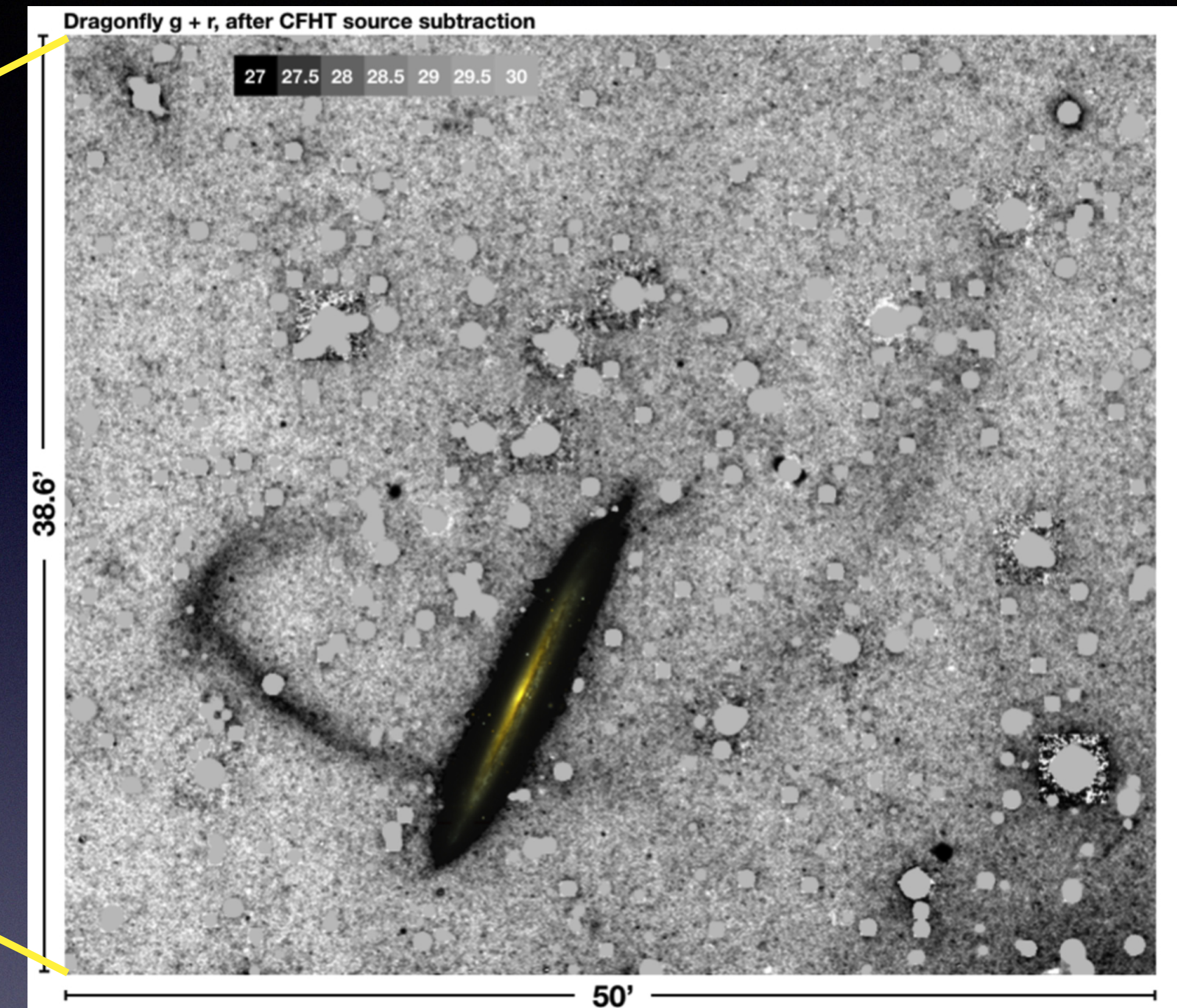
At $z < 1$, ULIRGs are major mergers; at $z > 1$, that doesn't seem to be true.

Many $z > 1$ ULIRGs are believed to be isolated, gas-rich systems with vigorous star formation, but is there evidence of past mergers?

NGC 5907
($D = 17$ Mpc)



van Dokkum 2019 ApJL



If the “non-merger ULIRGs” are the result of mergers, faint tidal tails should reveal the evidence.

To have emission proportional to stellar mass, we want to observe $1.6 - 2 \mu\text{m}$ in the rest frame, which Euclid and Roman cannot do, and to image large areas, which is difficult for JWST.

Challenges of Operating an Astrophysics Observatory Beyond 3 AU:

Data Downlink Rate & Power

Two Main Challenges: Data Downlink Rate & Power

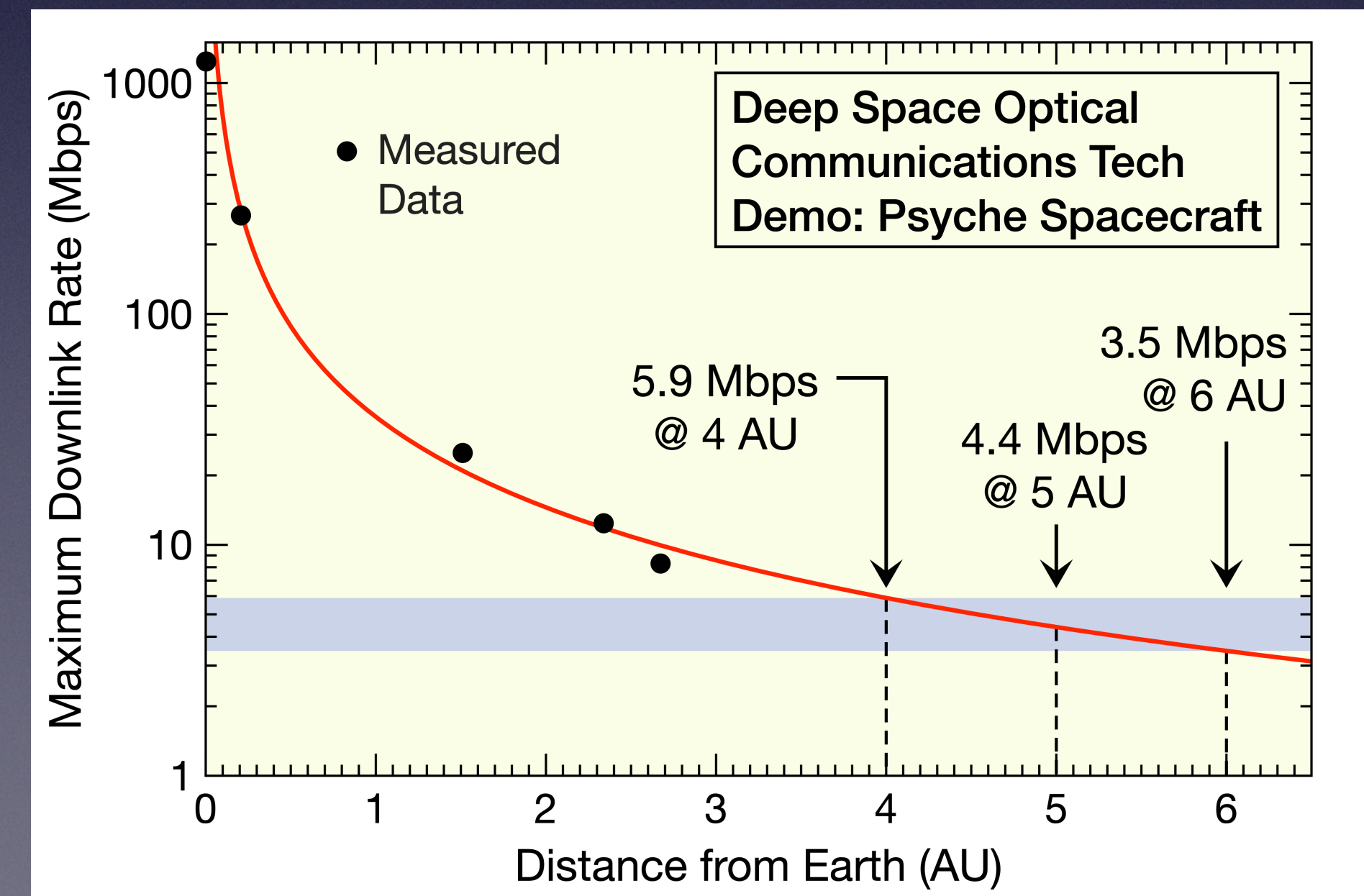
Data generation rate (worst case):

$(4 \times 4096^2 \text{ pixels} \times 16 \text{ bits}) + (4 \times 2048^2 \text{ pixels} \times 16 \text{ bits}) = 1.34 \text{ Gbits/readout}$

300 sec. integrations + 20 sec. slew & settle = 270 readouts/day

Total data generated/day = 362 Gbits/day

Time to downlink 1 day of data @ 4.4 Mbps = 0.48 days (w/2x data compression)



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Solar Arrays Have Been Used Out to 5 AU

