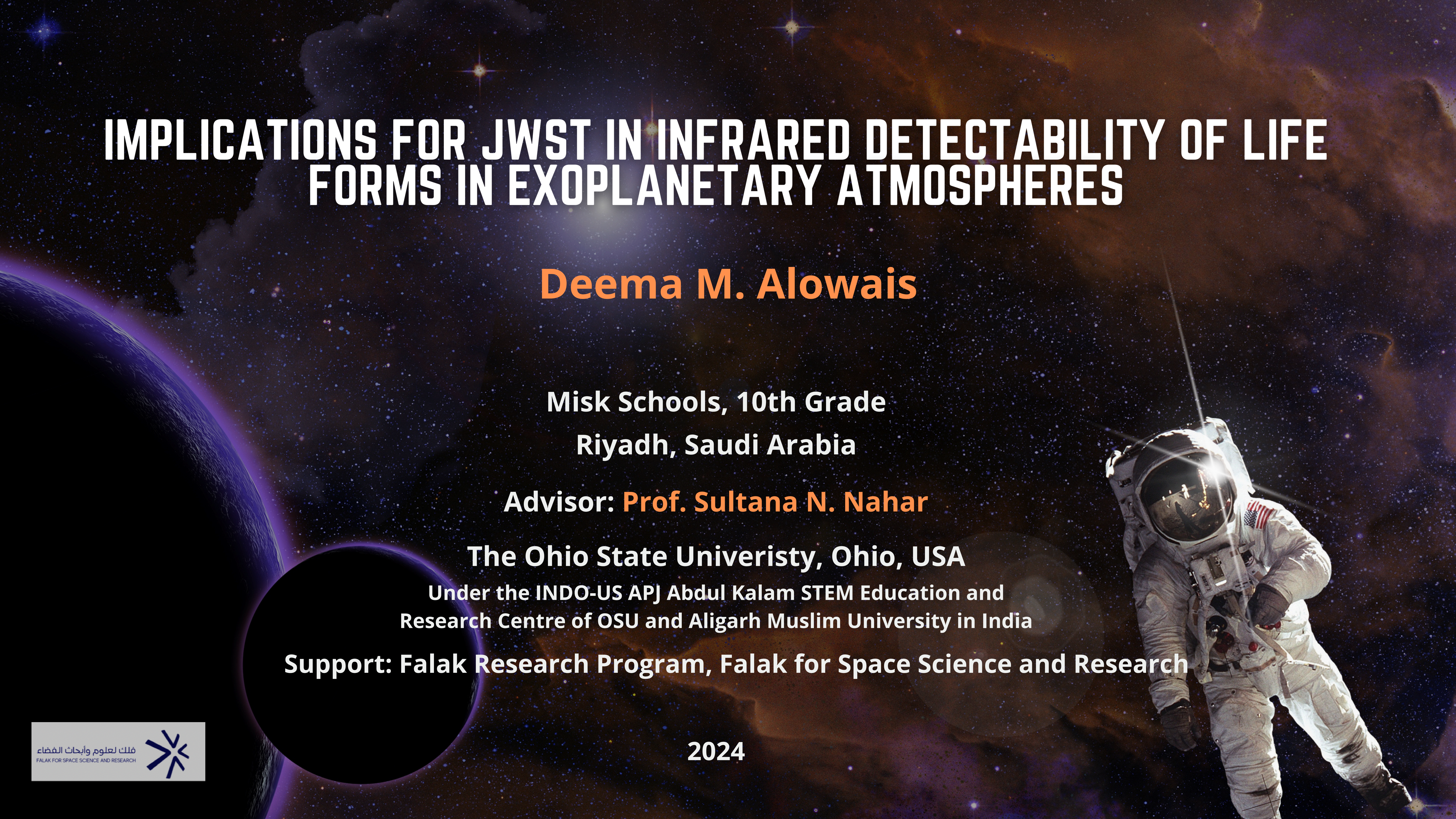
IMPLICATIONS FOR JWST IN INFRARED DETECTABILITY OF LIFE FORMS IN EXOPLANETARY ATMOSPHERES
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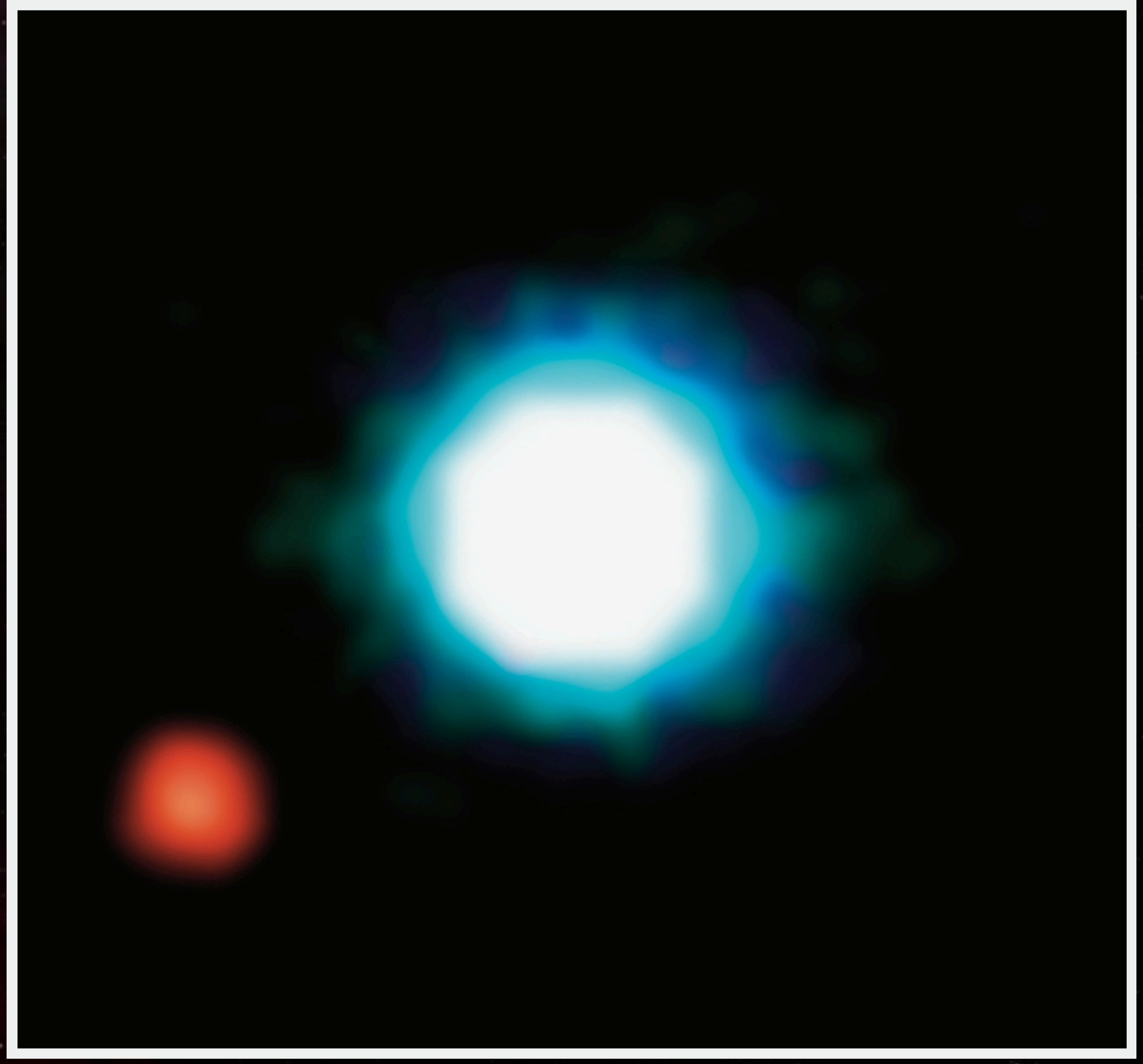
EXOPLANETS

Exoplanets are planets that orbit stars outside our solar system. Since their discovery in the early 1990s, thousands of exoplanets have been identified, many with diverse characteristics. These planets vary greatly in size, composition and distance from their stars, ranging from gas giants larger than Jupiter to rocky planets similar in size to Earth.

Studying exoplanets helps scientists understand the formation and diversity of planetary systems, as well as the potential for life elsewhere in the universe.



METHODOLOGIES: I) DETECTION OF EXOPLANETS

- **Transit Method**
  - Detects periodic dips in a star's brightness when a planet passes in front of it. The amount of dimming reveals the planet's size and distance from the star. Used by telescopes like Kepler to discover thousands of exoplanets.

- **Radial Velocity (Doppler Method)**
  - Measures a star's slight wobble caused by the gravitational pull of an orbiting planet. The wobble shifts the star's light spectrum, allowing scientists to estimate the planet's mass and orbit.

- **Direct Imaging**
  - Captures images of exoplanets by blocking out the star's light. Useful for detecting large planets far from their stars, although it's a challenging technique that requires advanced instruments like the James Webb Space Telescope.

- **Gravitational Microlensing**
  - Detects planets by observing the bending and magnifying of a star's light when a planet passes between a distant star and Earth. Particularly effective for finding planets in distant or faint star systems.

METHODOLOGIES: II) SPECTROSCOPY OF ATOMIC / MOLECULAR LINES

Spectroscopy is a powerful method used in astronomy to detect and analyse the composition of distant objects by examining the light they emit, absorb or reflect. In the context of exoplanet studies, spectroscopy allows scientists to study the atmospheres of these planets by observing the starlight that passes through or reflects off their atmospheres. As light interacts with the gases in the atmosphere, specific wavelengths are absorbed, leaving behind distinct patterns known as absorption lines.

These absorption lines are formed when atoms or molecules within a gas absorb photons at specific energies, corresponding to the difference between two energy levels in an atom or molecule. When a photon with just the right amount of energy interacts with an electron, the electron jumps from a lower energy level to a higher one, leaving a "gap" in the spectrum at that specific wavelength. Each gas, such has a unique set of energy levels, resulting in a distinct spectral signature that allows scientists to identify its presence.

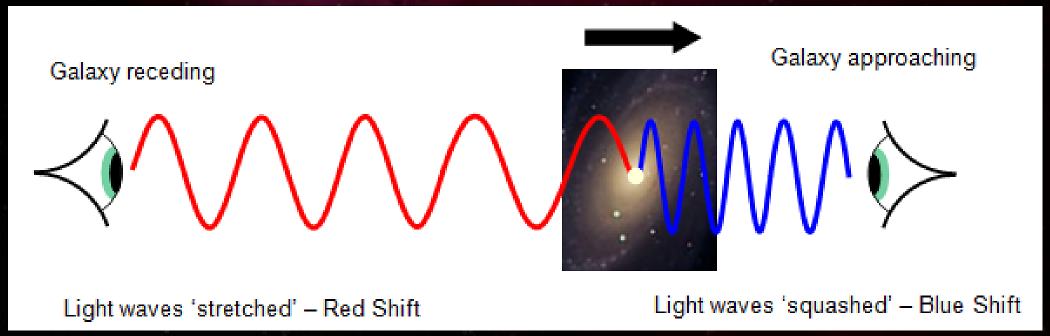
By using instruments like the James Webb Space Telescope (JWST), which can capture light in the infrared spectrum, spectroscopy can detect these biosignatures even at great distances. This method is crucial for determining the chemical makeup of exoplanet atmospheres and assessing their potential habitability, offering valuable insights into the possibility of life beyond Earth.

METHODOLOGY III): Z-REDSHIFT

Redshift is a key concept in astrophysics that refers to the stretching of light waves as objects move away from the observer, typically due to the expansion of the universe. This phenomenon is similar to the Doppler effect with sound, where an ambulance siren sounds lower in pitch as it moves away from you. With light, however, as an object recedes, its light waves are stretched to longer wavelengths, shifting the light toward the red end of the spectrum. This effect is most commonly observed with distant galaxies and celestial objects, which are moving away from us as the universe expands.

In astronomy, redshift is crucial for understanding distant objects, such as galaxies or exoplanets. As light travels through the expanding universe, it gets redshifted. For objects billions of light-years away, the light that originally might have been in the ultraviolet (UV) or visible spectrum shifts into the infrared (IR) region by the time it reaches us.

For instance, many atmospheric gases—such as methane (CH_4), carbon dioxide (CO_2), and water vapour (H_2O)—have distinct absorption features in the UV or visible wavelengths. As the planet emitting or absorbing these wavelengths moves away from us, those features are redshifted into the IR, which falls within the observational range of instruments like the James Webb Space Telescope (JWST).



METHODOLOGY IV) Z-REDSHIFT

The degree of redshift is often represented by the variable z, which quantifies how much the light has been stretched:

$$z = \frac{\lambda_{\text{obs}} - \lambda_{\text{em}}}{\lambda_{\text{em}}}$$

- λ_{obs} is the wavelength of the light as we observe it (after redshift).
- λ_{em} is the original wavelength of the light when it was emitted from the source.

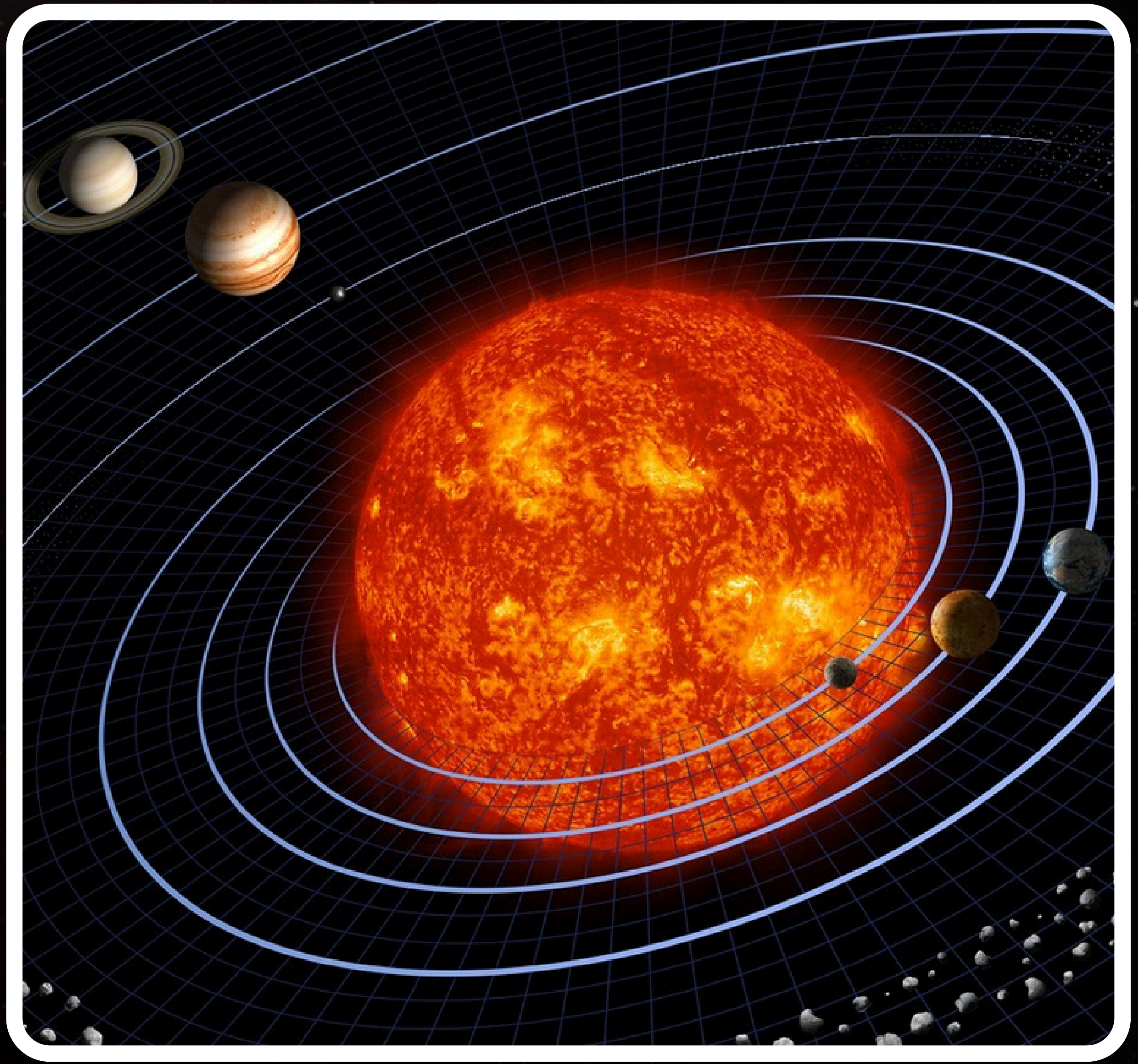
For example, if the redshift value (z) is 1, this means the light's wavelength has doubled since it was emitted. If z=2, the wavelength has tripled, and so on.

A rearranged version of the equation, with observed wavelength as the subject, is as the following:

$$\lambda obs = \lambda em(z+1)$$

PRESENT RESEARCH INTEREST: HABITABLE EXOPLANETS AND LIFE FORM

Biosignatures are indicators of past or present life that can be detected remotely, such as gases like oxygen or methane, or even patterns of light absorption linked to biological activity. Detecting biosignatures in exoplanet atmospheres is challenging due to false positives, where non-biological processes mimic life's signals, and the vast distances involved, which make detailed analysis difficult. Advanced instruments like the James Webb Space Telescope are required for such studies.



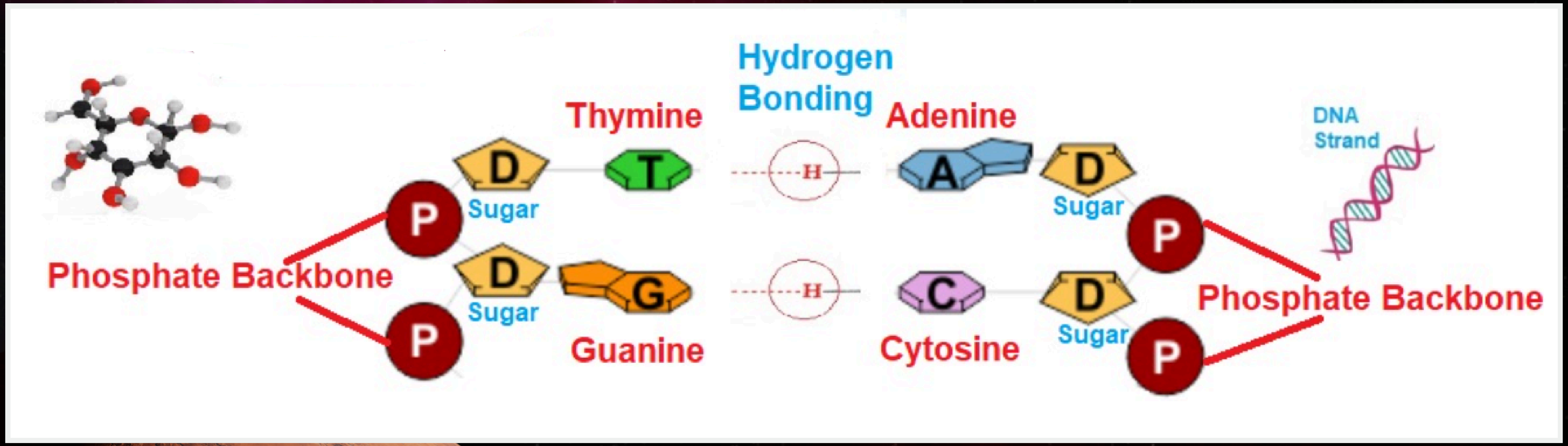
For a planet to be considered habitable, it must lie within the "habitable zone" — the region around a star where conditions allow liquid water to exist. Factors include the right atmospheric composition, a stable climate, and a protective magnetic field. For instance, Earth is habitable because it orbits at an optimal distance from the Sun, has abundant water, and an atmosphere rich in oxygen and nitrogen that supports life. The discovery of Proxima b, an exoplanet in the Alpha Centauri system, has intrigued scientists as it lies in its star's habitable zone. However, questions about its atmosphere and water presence remain unresolved.

Key biosignatures like oxygen (O_2), essential for life on Earth, could suggest biological processes on other planets, while methane (CH_4) and water (H_2O) are also critical indicators. Methane, produced by both biological and geological processes, and water, a fundamental requirement for life, are essential clues when assessing planetary habitability.

PRESENT RESEARCH INTEREST: BIOSIGNATURE COMPOUNDS: PHOSPHORUS, CO2, H2O, CH4

Phosphorus (P) is a key element for life as we know it, playing a crucial role in biological processes, including the formation of DNA, RNA and energy-carrying molecules like ATP. As a potential biosignature, the presence of P in an exoplanet's atmosphere or surface could indicate the chemical building blocks necessary for life.

P is rare in the universe compared to elements like carbon (C) or O_2, making its detection particularly significant. It's often delivered to planetary surfaces via geological processes or meteorite impacts. If phosphorus is found alongside other biosignatures such as H_2O, O_2 and CH_4, it strengthens the argument for potential biological activity. Although challenging to detect directly in exoplanet atmospheres, the identification of phosphorus, particularly through advanced telescopes like the James Webb Space Telescope (JWST), would be a major step forward in the search for extraterrestrial life.



PROBLEM STATEMENT: HABITABLE EXOPLANETS & SIGNS OF LIFE

The detection of atmospheric gases on distant exoplanets is crucial for understanding their habitability and the potential presence of biosignatures. However, as light from these planets travels through space, it becomes redshifted, moving absorption features of key gases such as ozone (O_3), nitric oxide (NO), chlorine (Cl_2) and sulfur dioxide (SO_2) from the ultraviolet (UV) and visible spectra into the infrared.

The James Webb Space Telescope (JWST) is designed to observe in the infrared range, making it a promising tool for detecting these redshifted features. However, it is unclear how much redshift would affect the detectability of these gases and whether JWST can effectively identify them at varying redshift values.

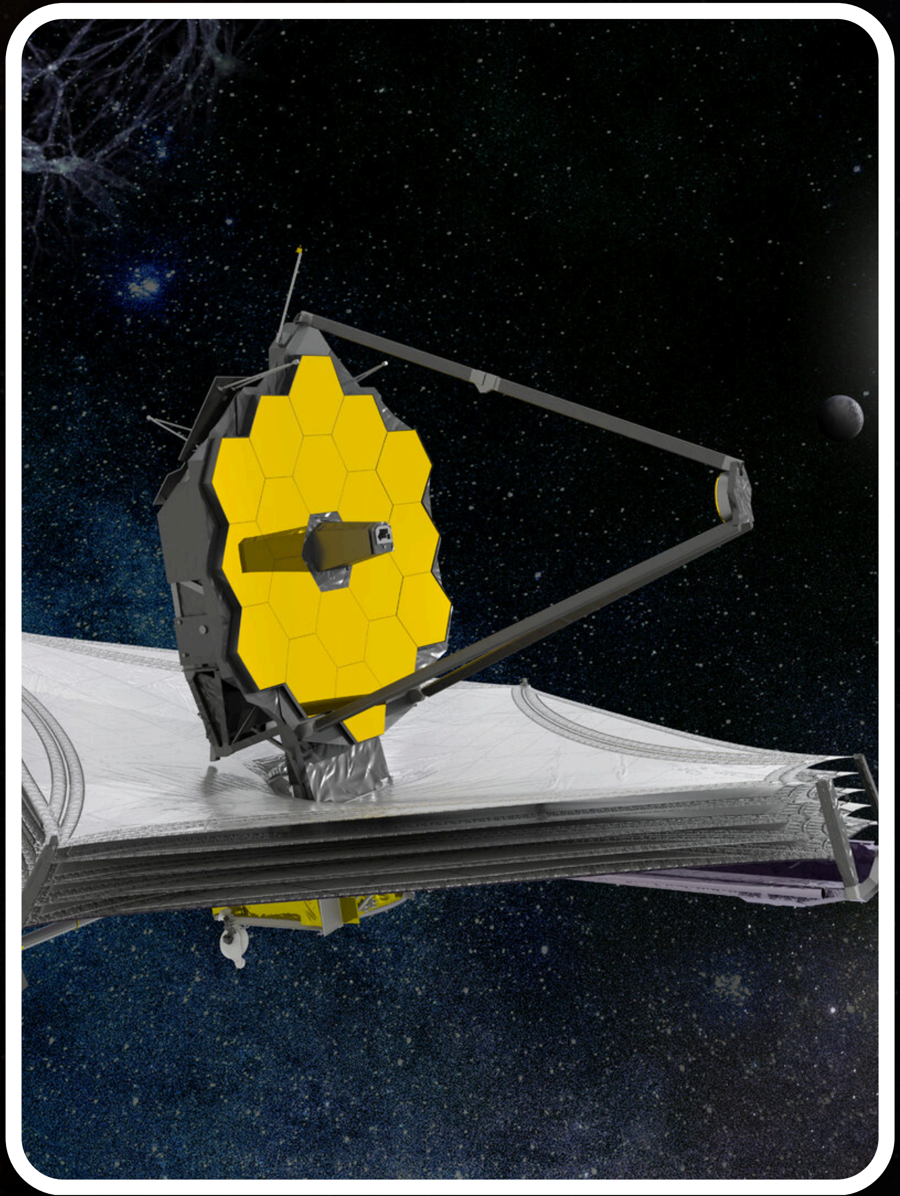
The problem this research addresses is:

- How can we detect redshifted lines of gases outside the infrared spectrum (e.g. P)?
- How can we predict biosignature elements / compounds that have been redshifted?

By answering these questions, we aim to determine the extent to which JWST can detect biosignatures on distant exoplanets and assess the telescope's potential for advancing the search for life beyond Earth.

PRESENT RESEARCH INTEREST: DETECTIBILITY BYJAMES WEBB SPACE TELESCOPE (JWST)

The James Webb Space Telescope (JWST), launched in December 2021, is the most advanced space observatory to date, focusing on infrared observations across a wavelength range of 0.6 to 28.5 micrometers. Its infrared capabilities allow it to detect objects that are too faint or distant for telescopes like the Hubble Space Telescope. JWST's large 6.5-meter primary mirror, coated with a thin layer of gold to maximize reflection of infrared light, enables it to collect more light, allowing it to observe distant and faint objects with remarkable precision. Positioned far from the Sun, approximately 1.5 million kilometers away at the second Lagrange point (L2), JWST is shielded from solar radiation, allowing its instruments to remain cool and sensitive to infrared signals.



One of JWST's most significant features is its ability to analyse exoplanet atmospheres. Its Near Infrared Camera (NIRCam) and other instruments can detect biosignatures like water vapour (H_2O), methane (CH_4), and oxygen (O_2) by analyzing starlight that passes through these atmospheres. By simulating how redshift moves gas absorption features from the UV and visible spectra into the infrared, scientists can predict which gases JWST will detect at different redshift values. For example, methane normally absorbs at 230 nm, but at a redshift of z=4, it shifts to 1150 nm, falling within NIRCam's detection range. Water vapor, which absorbs around 1.4 µm and 2.7 µm, and carbon dioxide (CO_2), with a strong band near 4.26 µm, remain detectable even at higher redshift values, up to z=2.

These capabilities make JWST a critical tool in the search for habitable exoplanets and the detection of potential signs of life beyond Earth. By studying how gases' absorption features shift with redshift, JWST provides unprecedented insights into the atmospheres of distant worlds, helping us assess the feasibility of detecting life on exoplanets.

PHOSPHORUS I TABLE OF TRANSITION VALUES AND WAVELENGTHS

I'm selecting the wavelength **2149.145 Å** as it has the highest transition probability of **3.18×10^{8} s^{-1}** *(Ref. NIST Table).*

Phosphorus I (P I): *λem = 2149.145 Å,*

	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs (Å)	4298.	6447	8596.	10746	12895	15044	17193	19342 .	21491	23641	25790	27939	30088

Phosphorus I (P I): *λem =2136.17 Å,*

	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs (Å)	4272	6408	8544	10680	12817	14953	17089	19225	21361	23497	25634	27770	29906

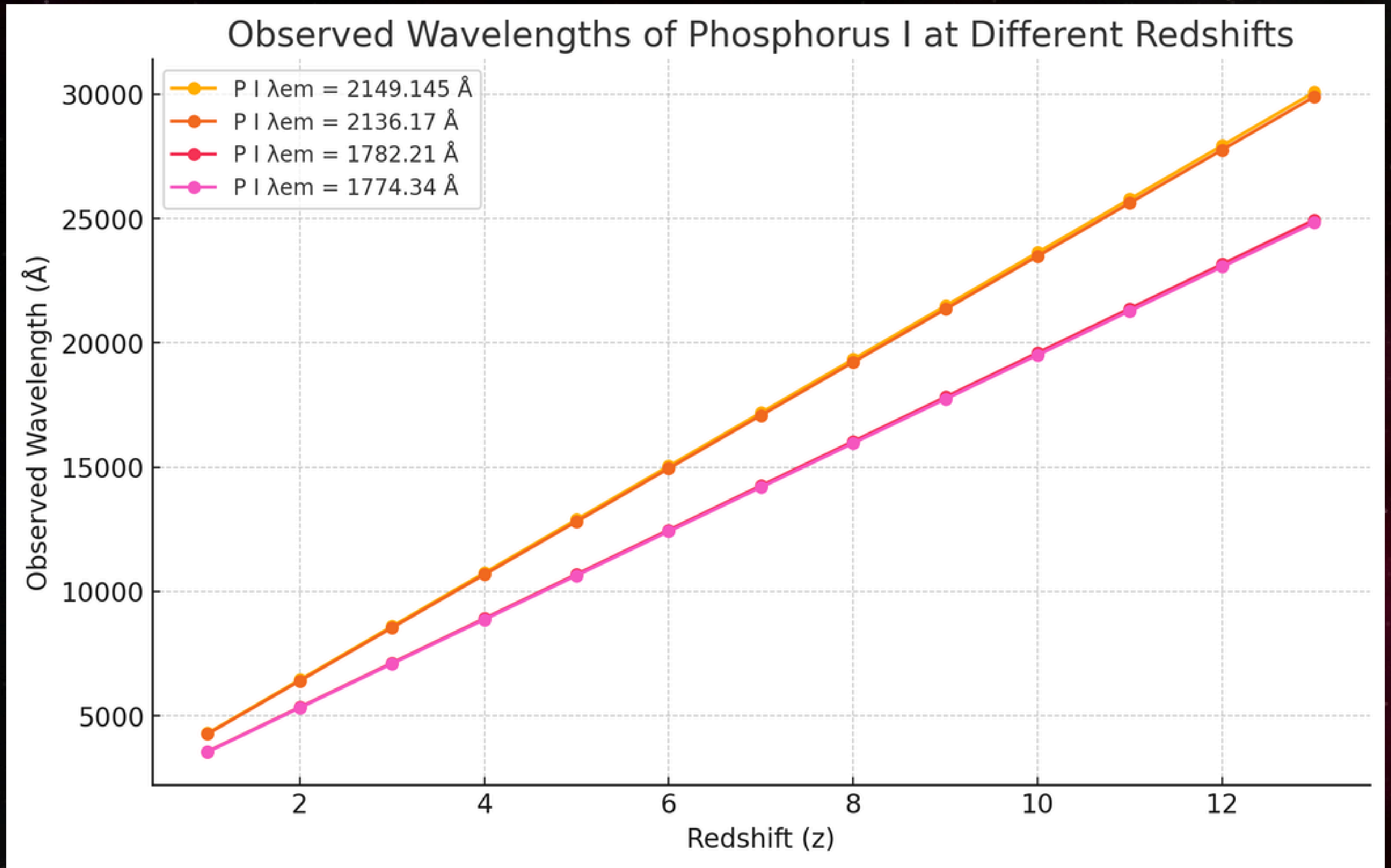
Phosphorus I (P I): *λem = 1782.21 Å,*

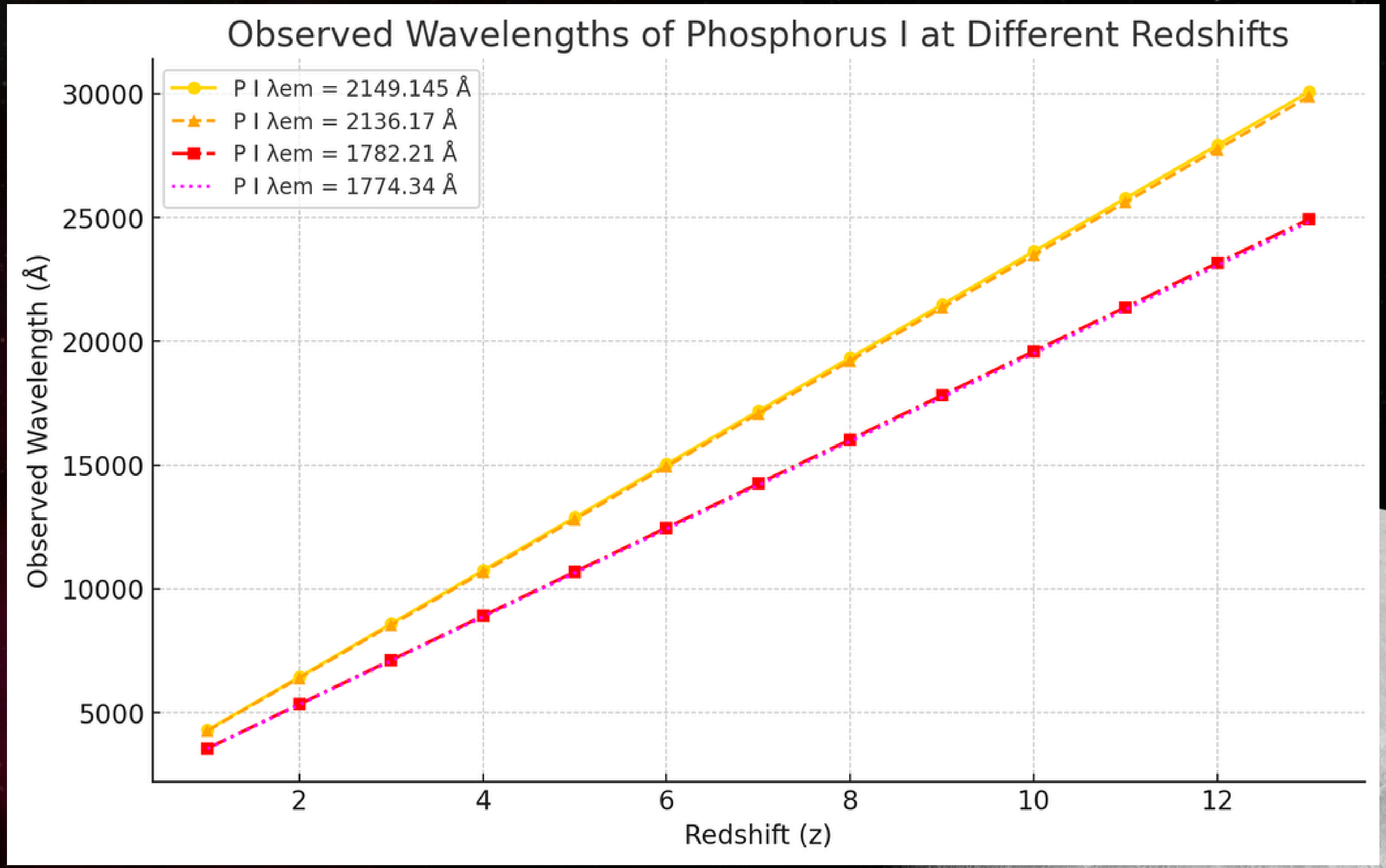
	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs (Å)	3564	5346	7128	8911	10693	12475	14257	16039	17822	19604	21386	23168	24950

Phosphorus I (P I): *λem = 1774.34 Å,*

	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs (Å)	3549	5323	7097	8872	10646	12420	14194	15969	17743	19517	21292	23066	24840

PHOSPHORUS I TABLE OF TRANSITION VALUES AND WAVELENGTHS





METHANE TABLE OF TRANSITION VALUES AND WAVELENGTHS

I'm selecting the wavelength **33,000 Å** as it has the highest transition probability of 1 × 10^4 s^{-1}

Water Vapour (H_2O): *λem = 14000 Å*

	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs (Å)	28000	42000	56000	70000	84000	98000	11200 0	12600 0	14000 0	15400 0	16800 0	1820 00	19600 0

WATER VAPOUR TABLE OF TRANSITION VALUES AND WAVELENGTHS

I’m selecting the wavelength 14000 Å This is based on a strong near-infrared absorption band of water vapour, which is a commonly referenced feature in atmospheric studies

Water Vapour (H_2O): *λem = 14000 Å*

	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs (Å)	28000	42000	56000	70000	84000	98000	11200 0	12600 0	14000 0	15400 0	16800 0	1820 00	19600 0

CARBON DIOXIDE TABLE OF TRANSITION VALUES AND WAVELENGTHS

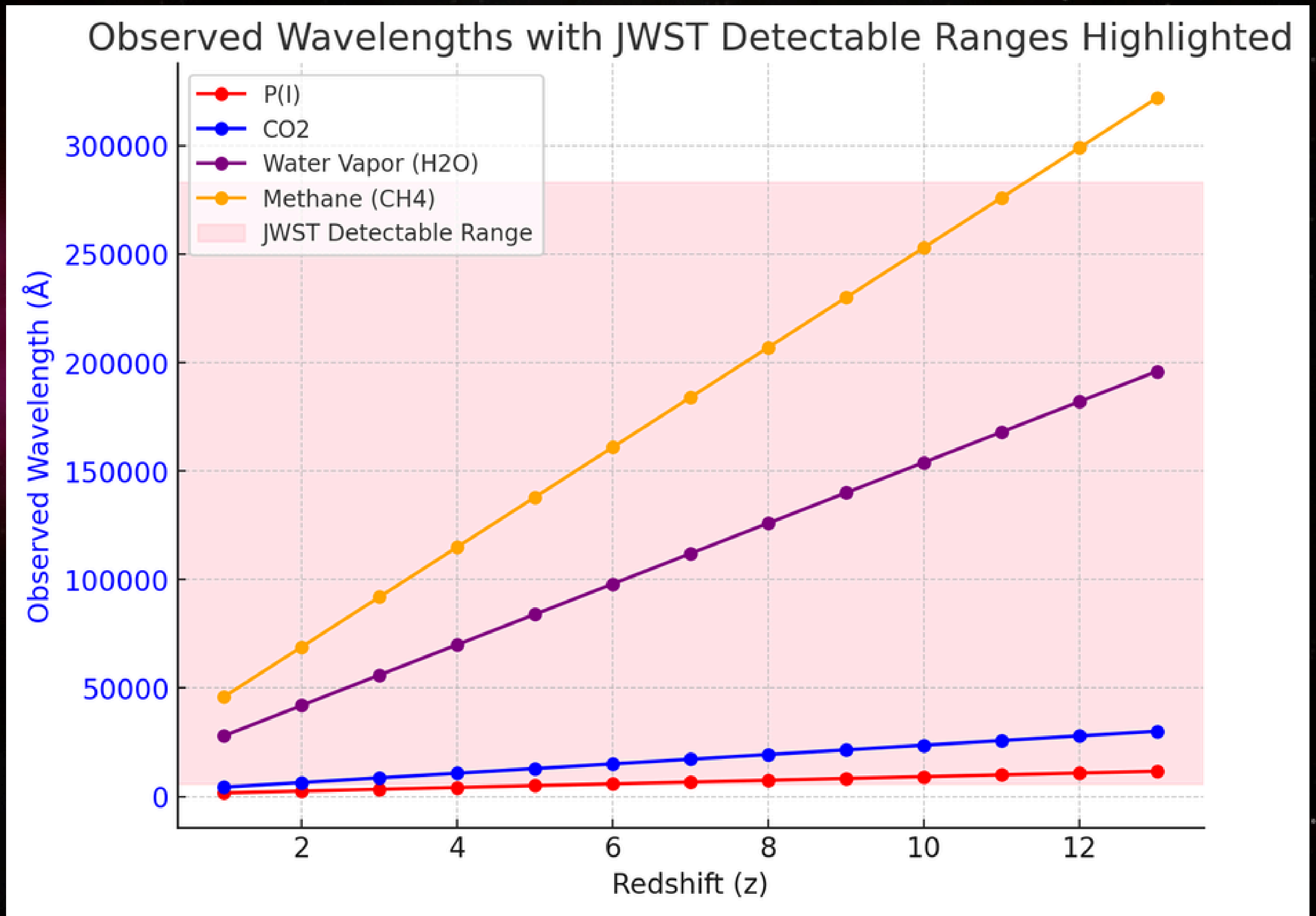
I'm selecting the wavelength **832.045 Å** – it has the highest transition probability of **1.6 × 10^9 s^{-1}** *(Ref. NIST table)*

Carbon Dioxide (CO_2): *λem = 832.045 Å*

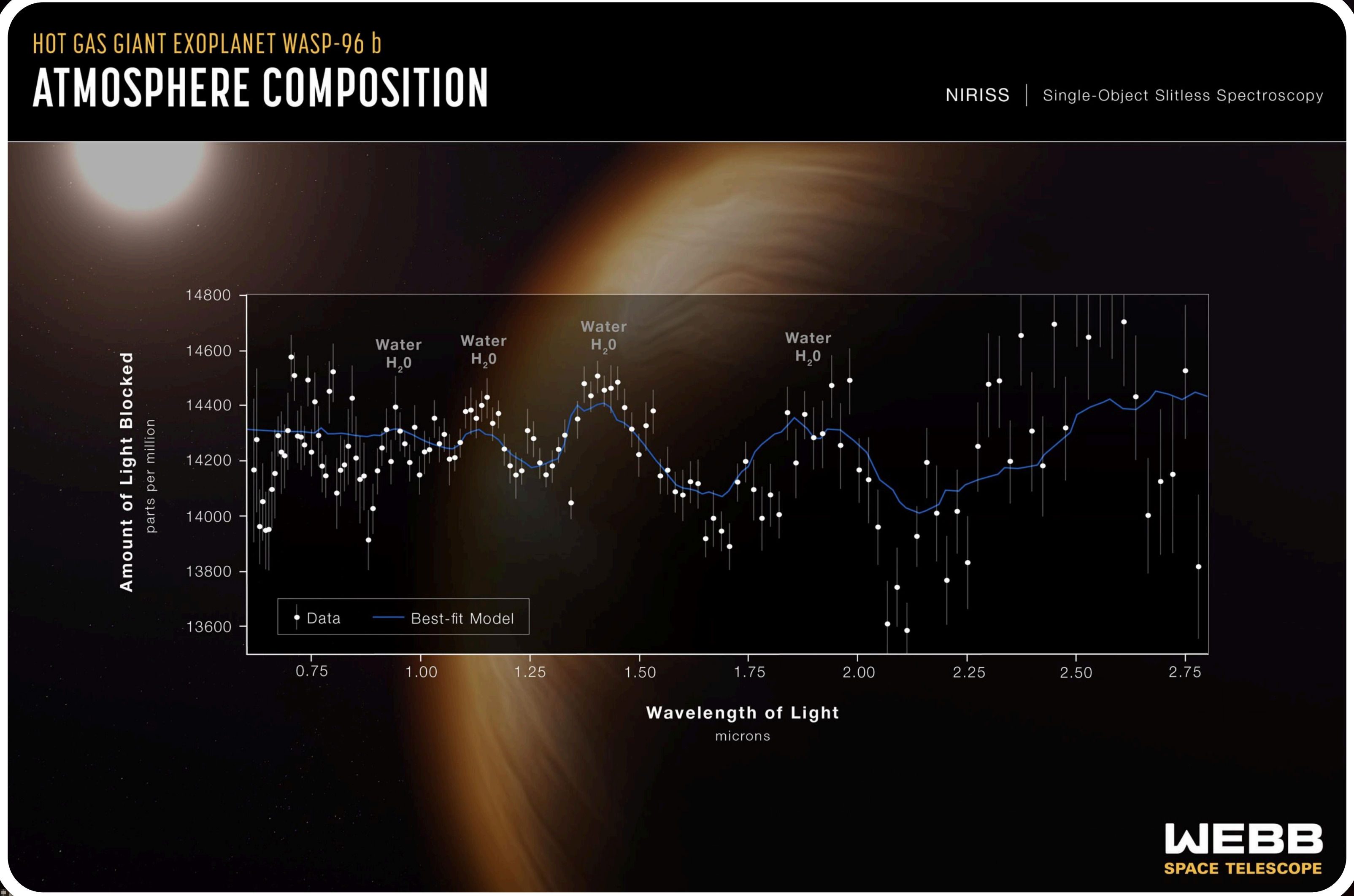
	z=1	*z=2*	*z=3*	*z=4*	*z=5*	*z=6*	*z=7*	*z=8*	*z=9*	*z=10*	*z=11*	*z=12*	*z=13*
Λobs	1664.09	2496.135	3328.18	4160.225	4992.27	5824.315	6656.36	7488.405	8320.45	9152.495	9984.54	10816.585	11648.63

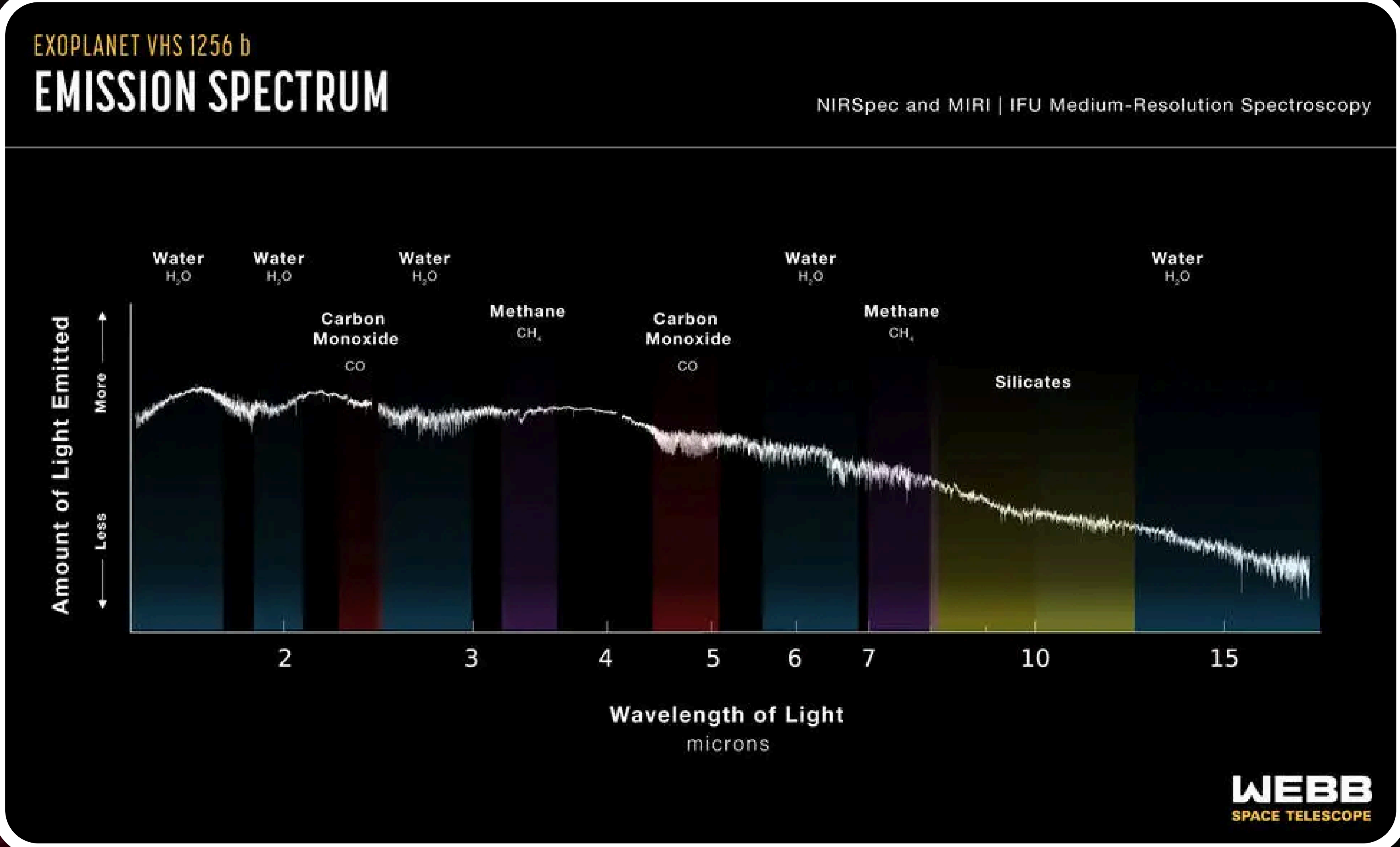
INVESTIGATION FOR DETECTION OF ELEMENTS: P I, CO2, H2O, CH4

- Pink covers the area of detection by JWST
- H2O (purple) and CH4 (gold) have the highest probability of detection by JWST
- CO2 (blue) and P I (red) have the lowest probability of detection by JWST



PROOF FOR CH4 AND H20





CONCLUSION

In this research project, we explored how redshift affects the detectability of key atmospheric gases : phosphorus (P I), carbon dioxide (CO_2), water vapour (H_2O), and methane (CH_4) in exoplanetary atmospheres using the James Webb Space Telescope (JWST). By modelling how the absorption features of these gases shift at various redshift values, we identified which gases are likely to fall within JWST's detectable range and at what redshifts. The analysis shows that H_2O and CH_4, with their infrared absorption features, are detectable by JWST even at lower redshifts and remain observable as redshift increases. In contrast, P I and CO_2, which have absorption lines outside JWST's range, only become detectable at higher redshifts as their wavelengths shift into the infrared spectrum.

This graph illustrates how different gases respond to redshift and how their detection windows align with JWST's capabilities. For exoplanets at higher redshifts, gases like P I and CO_2 become detectable as their absorption lines shift into the infrared range, while H_2O and CH_4 are more easily detectable even at lower redshift values. These findings have significant implications for studying exoplanet habitability and searching for biosignatures. Understanding which gases are detectable at varying redshift conditions can guide observational strategies for JWST and future telescopes.

Moving forward, I will enhance this research by investigating variations in the wavelengths of phosphorus (P I), refining the model, and incorporating real observational data to further improve our understanding of potential signs of life on distant worlds.

THANK YOU

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