

Centi Astro-Space Activities “Worlds Beyond”

Mystery Driven Lesson

Topic: EXOPLANET K2-18 b

Activity Pack Structure

- **Part 1: Student Worksheets (The Narrative Inquiry)**
 - **Log 1:** The Alert from Dr. Mara Ellison (Story Hook & Observatory Control setting).
 - **Data Drop 1:** The Mismatched Chemistry (CH₄ & CO₂ spectral peaks/dips).
 - **Data Drop 2:** The Biosignature Whisper (2.72 μm DMS feature & high error bars).
 - **Data Analysis:** Hypothesis Matrix comparison (Model A: Hycean Ocean, Model B: Mini-Neptune, Model C: Unmodeled Science).
 - **Claim, Evidence, Reasoning (CER) Sheet:** Final voting & argument construction.
- **Part 2: Educator Facilitation Guide**
 - **Implementation Roadmap:** Step-by-step timing and classroom setup.
 - **Grade-Level Scaffolding:** Adaptations for Middle School, High School, and Introductory College.
 - **Answer Keys & Discussion Prompts:** Sample student responses and guidance on handling "Structured Uncertainty."
 - **Standards & Core Education Requirements:** NGSS, AP, and higher-ed alignment mapping placed at the very end.

Scaffolding Breakdown in the Educator Guide

Middle School (MS) Adaptation

- **Worksheet Focus:** Qualitative observation and pattern matching.
- **Teacher Strategy:**
 - Direct students to focus on the big visual elements of the charts (e.g., matching the named peak labels like CH₄ and CO₂ directly to Model A, B, or C).
 - Reframe the three models into plain-language concepts: *Water World (A)*, *Gas World (B)*, and *Unknown World (C)*.
 - Skip deep error bar calculations; focus on whether a peak is "tall" or "small."

High School (HS) Baseline

- **Worksheet Focus:** Quantitative spectral analysis, gas ratios, and habitability limits.
- **Teacher Strategy:**
 - Students complete the worksheet as written, analyzing the specific wavelength values (3.3 μm , 4.3 μm , and 2.72 μm).
 - Students evaluate how methane-to-carbon dioxide ratios constrain atmospheric models.
 - Students construct a full Claim, Evidence, and Reasoning (CER) argument comparing the competing models.

Introductory College Adaptation

- **Worksheet Focus:** Signal-to-noise ratio evaluation, error bar interpretation, and unmodeled physics.
- **Teacher Strategy:**
 - Instruct students to scrutinize the 2.72 μm DMS region specifically through statistical significance (error bar overlap with the continuum).
 - Require students to critique Model C as an example of "unmodeled science" vs. systematic measurement noise.
 - Expand the CER section into a written peer-review rebuttal arguing why current data cannot definitively confirm a biosignature.

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Mystery Driven Lesson

Topic: EXOPLANET K2-18 b

STUDENT INVESTIGATION WORKSHEET: EXOPLANET K2-18 b

Mission Control ID: ASTRO-2026-K218b

Student Name: _____ **Date:** _____

Section 1: Narrative Log 1 — The Alert from Dr. Mara Ellison

FACILITIES RECORD — DEEP SPACE SPECTROSCOPY DIVISION

Source: Dr. Mara Ellison, Senior Exoplanet Researcher

Target System: K2-18 b (Red Dwarf Star System, 124 Light-Years Away)

Transmission Status: Incoming Urgent Alert

"Team, we have a situation with the latest James Webb Space Telescope (JWST) NIRSpec transmission data for sub-Neptune exoplanet K2-18 b. Initial transit measurements were expected to show a standard hydrogen-rich envelope. However, our preliminary reduction reveals an unexpected atmospheric anomaly.

We are seeing prominent carbon-based features that contradict baseline gas-giant models, along with a tentative, low-confidence signal right where we'd expect to see Dimethyl Sulfide (DMS)—a compound tied directly to marine biological activity on Earth. The data is noisy, and the error bars are substantial, but we cannot rule out an active biosignature without deeper analysis.

I am handing off the data fragments directly to your team. Examine the light curves, evaluate the competing models, and determine what this data is actually telling us."

Initial Briefing Questions

- 1. Identifying the Anomaly:** Based on Dr. Ellison's log, what two distinct features in the data make K2-18 b an unusual target compared to standard gas planets?
 - Feature A (Chemical Balance):**

 - Feature B (Potential Biosignature):**

- 2. Initial Predictions:** Before looking at the raw spectrum, why must researchers exercise caution when analyzing tentative signals with large error bars?

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Student Name: _____ Date: _____

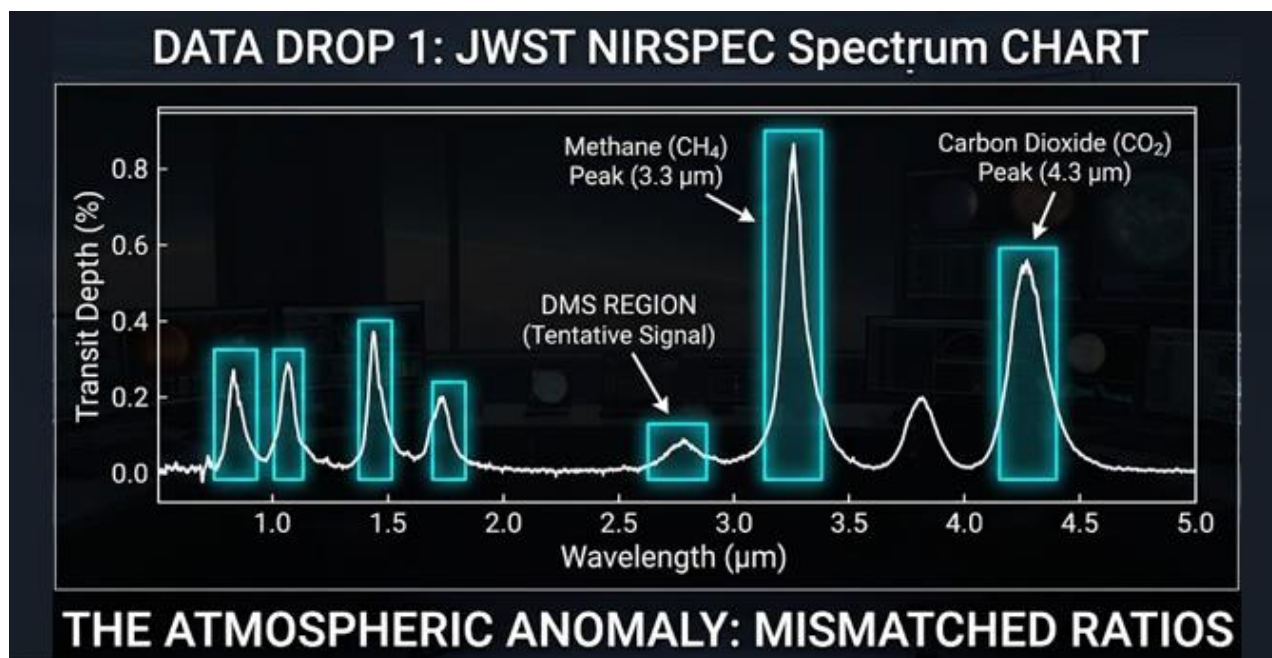
Section 2: Data Drop 1 — The Mismatched Chemistry (CH_4 & CO_2)

DATA TRANSMISSION RECORD — JWST NIRSpec Instrument

Target: K2-18 b Transmission Spectrum

Spectral Region: $0.6\ \mu\text{m}$ — $5.0\ \mu\text{m}$ (Near-Infrared)

Observation Note: In transmission spectroscopy, starlight passing through the planet's atmosphere gets absorbed by specific gases. On the transit depth chart, these absorption events appear as high visual peaks (representing starlight blocked or "dipped" by the atmosphere).



Data

Analysis Tasks

1. Spectral Feature Identification:

Locate the two primary spectral peaks on the transit depth graph above and record their values:

- **Peak 1 Wavelength:** $3.3\ \mu\text{m}$ → **Gas Identified:** _____ (CH_4)
- **Peak 2 Wavelength:** $4.3\ \mu\text{m}$ → **Gas Identified:** _____ (CO_2)

2. Chemical Ratio Analysis:

Standard gas-giant planets (like Jupiter or Neptune) are expected to show strong absorption features for **Ammonia** (NH_3). However, K2-18 b exhibits strong CH_4 and CO_2 peaks with a notable **absence of** NH_3 .

What physical environment does this specific chemical combination suggest?

- ☐ **Option A:** A standard gas giant planet with deep hydrogen gas layers and no liquid water.
- ☐ **Option B:** A planet with a water ocean underneath a hydrogen-rich atmosphere (a Hycean world) where ammonia has been dissolved into the ocean.
- ☐ **Option C:** An airless rocky planet with no atmosphere to absorb starlight.

3. Evidence-Based Reasoning:

In 1–2 sentences, explain how the presence of carbon gases (CH_4 and CO_2) combined with the depletion of ammonia (NH_3) supports your choice above:

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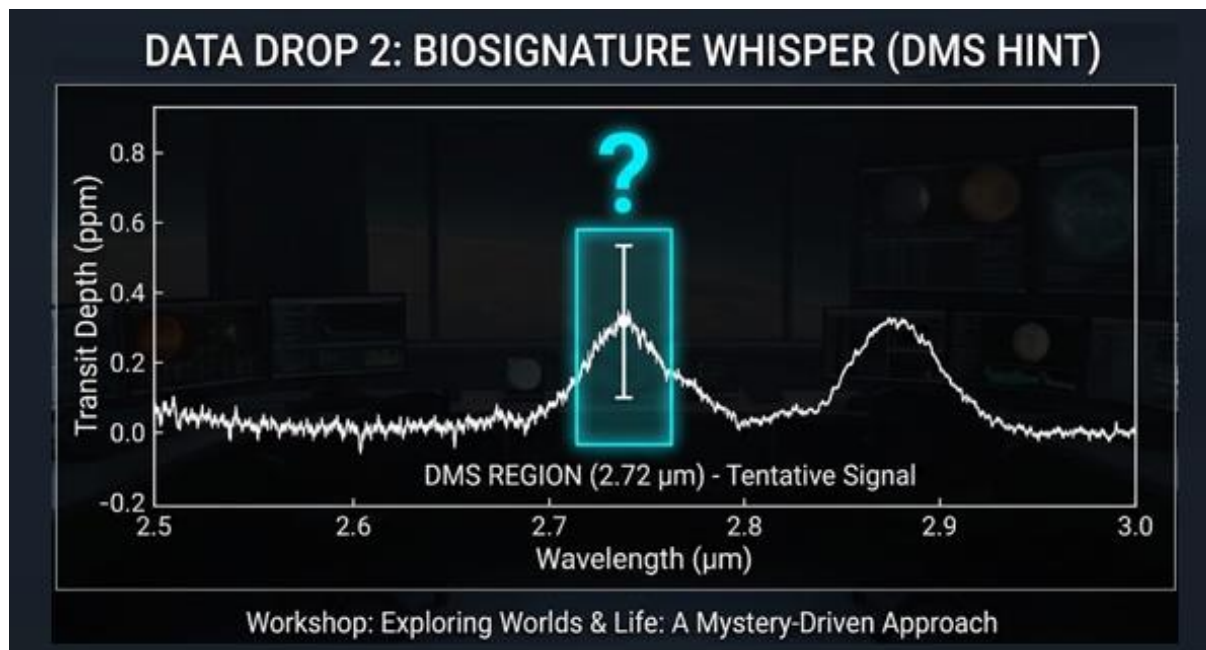
Section 3: Data Drop 2 — The Biosignature Whisper (DMS Hint at $2.72\ \mu\text{m}$)

DATA TRANSMISSION RECORD — JWST High-Precision Analysis

Target Region: Near-Infrared Spectrum ($2.5\ \mu\text{m} - 3.0\ \mu\text{m}$)

Target Molecule: Dimethyl Sulfide (DMS — $\text{C}_2\text{H}_6\text{S}$)

Context: On Earth, Dimethyl Sulfide is produced almost exclusively by marine life (phytoplankton) and escapes into the atmosphere. Finding DMS on an exoplanet could be a potential biosignature, but low signal-to-noise ratios require extreme caution before jumping to conclusions.



Data

Evaluation Questions

1. Reading the Signal:

Look at the target box around $2.72\ \mu\text{m}$ on the spectrum above.

- What is the approximate height of the candidate feature above baseline?
~ _____ ppm
- What is the reported error bar uncertainty for this specific region?
 $\pm$ _____ ppm

2. Evaluating Statistical Significance:

Compare the height of the signal (~ 35 ppm) to the size of the error bar (± 45 ppm).

When the error bar is larger than the signal itself, what does this tell scientists about the detection?

- [] **Option A:** The detection is 100% confirmed, and alien marine life definitely exists on K2-18 b.
- [] **Option B:** The feature is a tentative "whisper" that could easily be instrumental noise or a data artifact rather than real gas absorption.
- [] **Option C:** The data proves that no atmosphere exists around the planet.

3. Critical Thinking — Biological vs. Abiotic Sources:

Suppose future observations confirm that DMS gas is truly present in K2-18 b's atmosphere. Why must scientists investigate alternative (non-biological) chemical pathways before declaring the discovery of extraterrestrial life?

This video provides valuable background on the James Webb Space Telescope's analysis of K2-18 b, including details on the candidate DMS signal and the scientific caution needed when interpreting potential biosignatures.

Signs of Life on K2-18b? What JWST Found 124 Light-Years Away

https://www.youtube.com/watch?v=XXm_S9PzwE8&t=22s

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Student Name: _____ Date: _____

Section 4: Hypothesis Matrix Analysis (Evaluating Models A, B, and C)

RESEARCH BRIEFING — COMPETING ATMOSPHERIC MODELS

Scientists use computer models to match observed spectroscopic data against theoretical planetary environments. Below are three leading hypotheses for sub-Neptune exoplanet K2-18 b. Compare the physical features of each model against the observed JWST data fragments.

Model Evaluation Matrix

Evaluated Feature	Model A: Hycean Ocean World	Model B: Mini-Neptune / Gas Giant	Model C: Unmodeled Science / Noise
Physical Structure	Thin H ₂ -rich envelope over a liquid water ocean.	Deep gas envelope with no solid/liquid surface.	Unknown / Non-standard atmospheric physics or instrument noise.
Methane (CH ₄) & CO ₂	Matches: Plentiful carbon gases in upper atmosphere.	Partial: Carbon gases present, but ratios usually differ.	Matches: Carbon gases detected, but model incomplete.
Ammonia (NH ₃) Depletion	Matches: Ammonia readily dissolves into liquid ocean water.	Fails: Should show strong Ammonia absorption peaks.	Unclear: Depletion could be driven by unexpected photochemistry.
2.72 μ m DMS Signal	Possible: Potential marine biosignature	Fails: Cannot produce marine	Matches: Signal is instrumental noise or

Evaluated Feature	Model A: Hycean Ocean World	Model B: Mini-Neptune / Gas Giant	Model C: Unmodeled Science / Noise
	or photochemical artifact.	biosignatures without an ocean.	unmodeled stellar activity.

Hypothesis Analysis Questions

1. Comparing Evidence:

Which model best explains the combination of strong methane (CH_4), strong carbon dioxide (CO_2), and missing ammonia (NH_3)?

- ☐ **Model A: Hycean Ocean World**
- ☐ **Model B: Mini-Neptune / Gas Giant**
- ☐ **Model C: Unmodeled Science / Noise**

2. Identifying Strengths and Weaknesses:

- What is the strongest piece of evidence supporting **Model A**?
- What is the strongest argument for adopting **Model C** instead of declaring a discovery?

3. Synthesizing Models:

Why is it scientifically risky to completely rule out Model C when analyzing brand-new astronomical data with high error bars?

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Section 5: Claim, Evidence, Reasoning (CER) & Final Vote

SCIENTIFIC SYNTHESIS — FORMULATING YOUR VERDICT

Science is an iterative process of building arguments grounded in observed data. Review all the data drops, consider the error bars, and evaluate the hypothesis matrix before rendering your final team assessment.

1. Claim, Evidence, Reasoning (CER) Framework

- **CLAIM:** State your conclusion regarding the nature of exoplanet K2-18 b's atmosphere.

(Which hypothesis—Model A, B, or C—is most plausible based on current data?)

- **EVIDENCE:** Provide at least two specific spectral data points or observations that support your claim.

(Reference specific wavelengths, detected or missing chemical species, or error bar values.)

- *Evidence Item 1:*

- *Evidence Item 2:*

- **REASONING:** Explain the scientific logic connecting your evidence to your claim.

(How do physical atmospheric processes or instrument limitations justify your conclusion?)

2. Mission Control Final Vote

Cast your individual ballot based on your analysis:

- ☐ **MODEL A (Hycean World):** The data supports a water ocean beneath a hydrogen envelope; the DMS feature warrants priority follow-up.
- ☐ **MODEL B (Mini-Neptune):** The planet is a standard gas giant; anomalous features are driven by non-biological atmospheric chemistry.

- [] **MODEL C (Unmodeled Science / Noise):** High error bars and potential instrument artifacts mean current data is inconclusive; more JWST transit time is required.

3. Next Scientific Steps

If NASA granted your team 50 additional hours of JWST observation time, what specific measurement would you prioritize to resolve the remaining uncertainty?

Centi Astro-Space Activities “Worlds Beyond”

Mystery Driven Lesson

Topic: EXOPLANET K2-18 b

EDUCATOR FACILITATION GUIDE: EXOPLANET K2-18 b

Module Title: Exploring Worlds & Life: A Mystery-Driven Approach

Target Audience: Middle School, High School, and Introductory College STEM Educators

Implementation Roadmap & Classroom Setup

Total Recommended Duration: 50–60 Minutes (Single Class Period or Block Session)

Required Materials:

- **Student Worksheets:** Printed copies of Sections 1–5 (one per student or pair).
- **Slide Deck Visuals:** Slides 4, 5, 6, and 7 displayed on a main classroom screen.
- **Digital Access:** Computer/tablet with internet connection (optional for video stream).

Suggested Lesson Timeline

Time	Phase	Activity & Teacher Guidance
00:00–00:10	1. The Hook	Display Slide 4 (Dr. Mara Ellison Log): Read Narrative Log 1 aloud. Introduce the mystery setting at Mission Control and have students complete Section 1 of the worksheet.
00:10–00:20	2. Data Drop 1	Display Slide 5 (CH₄ & CO₂ Spectrum): Walk students through Section 2. Emphasize reading the 3.3 μm and 4.3 μm absorption peaks and discussing the missing ammonia (NH ₃).
00:20–00:30	3. Data Drop 2	Display Slide 6 (2.72 μm DMS Region): Direct attention to Section 3. Highlight the error bars

Time	Phase	Activity & Teacher Guidance
		around the candidate feature. Address how measurement uncertainty impacts scientific conclusions.
00:30– 00:45	4. Sensemaking	Display Slide 7 (Hypothesis Matrix): Group students into small teams (2–4) to evaluate Models A, B, and C in Section 4. Facilitate peer discussion on trade-offs between hypotheses.
00:45– 00:60	5. Voting & Debrief	Student Synthesis: Have students complete the Section 5 CER framework individually or as a team, cast their final Mission Control vote, and share responses.

Classroom Setup & Physical Arrangement

- **Collaborative Stations:** Group desks into teams of 3 to 4 students. Designate each group as a "Mission Control Analysis Team."
- **Data Projection:** Ensure the transmission spectrum charts (Slides 5 and 6) remain prominently displayed on screen during data analysis phases so students can visually cross-reference their worksheets.
- **Facilitation Tip:** Encourage "Structured Confusion" during Data Drop 2. RESIST giving students a straight "yes" or "no" answer on whether DMS exists. Emphasize that real scientific data frequently contains ambiguity.

EDUCATOR FACILITATION GUIDE: EXOPLANET K2-18 b

Module Title: Exploring Worlds & Life: A Mystery-Driven Approach

Grade-Level Scaffolding & Tiered Adaptations

This single worksheet is designed to scale across multiple education tiers without requiring separate printouts. Use the following adaptations to tailor the facilitation, discussion depth, and assessment expectations to your specific student population.

Middle School (MS) Adaptation — Qualitative Observation & Pattern Matching

- **Focus Area:** Visual chart reading, basic gas identification, and introduce the concept of "ocean vs. gas world."
- **Facilitation Modifications:**
 - **Section 1:** Read Dr. Ellison's alert together as a class. Define key terms like *light-year*, *atmosphere*, and *telescope*.
 - **Section 2:** Guide students visually on Slide 5. Have them circle the tall $3.3\ \mu\text{m}$ (CH_4) and $4.3\ \mu\text{m}$ (CO_2) peaks on their worksheet. Frame ammonia (NH_3) simply as "the missing ingredient that should be there."
 - **Section 3:** Reframe the $2.72\ \mu\text{m}$ DMS feature using a simple physical metaphor: *"If you try to hear a quiet whisper in a noisy hallway, how sure are you about what was said?"*
 - **Section 4 & 5:** Simplify the models to *Water World (A)*, *Gas World (B)*, and *Inconclusive/Noise (C)*. Allow students to write 1–2 sentence CER responses focusing on qualitative observations.

High School (HS) Baseline — Quantitative Spectroscopy & Habitability Limits

- **Focus Area:** Wavelength-to-gas correlation, atmospheric chemical equilibrium, and signal uncertainty.
- **Facilitation Modifications:**
 - **Section 1 & 2:** Complete as written. Expect students to independently identify wavelengths and correlate the missing NH_3 with atmospheric dissolution into a liquid ocean envelope.
 - **Section 3:** Have students quantitatively evaluate signal strength vs. error bar height. Prompt discussion on why a ~ 35 ppm signal with a ± 45 ppm uncertainty range cannot be claimed as a definitive discovery.

- **Section 4 & 5:** Expect full CER arguments. Student reasoning must integrate chemical ratios (CH_4/CO_2 vs. missing NH_3), physical structure parameters of sub-Neptunes, and the statistical limitations of NIRSpec transit spectroscopy.

Introductory College Adaptation — Signal-to-Noise Ratio & Unmodeled Physics

- **Focus Area:** Statistical significance (σ -levels), photochemical modeling, and peer-review rigor.
- **Facilitation Modifications:**
 - **Section 1 & 2:** Challenge students to critique the assumptions of the "Hycean" classification. Have them evaluate how solar metallicity and stellar flare activity from M-dwarf host stars affect methane and carbon dioxide formation pathways.
 - **Section 3:** Instruct students to analyze the $2.72\ \mu\text{m}$ region through a formal Signal-to-Noise Ratio (SNR) lens. Address how stellar spot contamination and instrument systematics can mimic narrow molecular absorption features.
 - **Section 4 & 5:** Treat Model C as a core scientific outcome rather than a "fail-safe." Require students to draft their CER as a peer-review rebuttal, explaining why current JWST transit data lacks the statistical confidence ($\geq 5\sigma$) required to claim an authentic biosignature.

Answer Keys & Tiered Student Responses

Section 1: Narrative Log 1 — Initial Briefing

1. Identifying the Anomaly:

- **Feature A (Chemical Balance):** Strong carbon-bearing gases (CH_4 and CO_2) combined with an unexpected absence of ammonia (NH_3).
- **Feature B (Potential Biosignature):** A tentative signal at $2.72\ \mu\text{m}$ corresponding to Dimethyl Sulfide (DMS).

2. Initial Predictions (Caution with Noise):

- **MS Tier:** "If the error bars are big, it means the telescope isn't sure. It could just be a mistake or extra noise instead of a real gas."

- **HS Baseline:** "Scientists must be cautious because when error bars are larger than the feature itself, the signal might just be random instrument noise or background stellar activity."
- **College Tier:** "High measurement uncertainty reduces statistical significance ($\text{SNR} < 3\sigma$). Claiming a detection without resolving error bars leads to false-positive biosignature reports."

Section 2: Data Drop 1 — The Mismatched Chemistry

1. Spectral Feature Identification:

- **Peak 1** ($3.3\ \mu\text{m}$): Methane (CH_4)
- **Peak 2** ($4.3\ \mu\text{m}$): Carbon Dioxide (CO_2)

2. Chemical Ratio Analysis:

- **Correct Answer: Option B** (A planet with a liquid water ocean underneath a hydrogen-rich atmosphere—a Hycean world—where ammonia has dissolved into the ocean).

3. Evidence-Based Reasoning:

- **MS Tier:** "Ammonia dissolves easily in water. If K2-18 b has a giant ocean, the ammonia gets pulled out of the air and trapped in the water, leaving methane and carbon dioxide behind."
- **HS Baseline:** "In a hydrogen gas world, ammonia should be abundant. The missing ammonia alongside CH_4 and CO_2 suggests that a global liquid ocean is absorbing soluble nitrogen gas."
- **College Tier:** "Under thermochemical equilibrium in a hydrogen-dominated atmosphere, NH_3 should dominate. Its depletion, paired with high CH_4/CO_2 abundance, implies ocean-atmosphere interactions where soluble nitrogen species are scrubbed into an underlying aqueous reservoir."

Section 3: Data Drop 2 — The Biosignature Whisper

1. Reading the Signal:

- **Signal Height:** $\sim 35\ \text{ppm}$
- **Uncertainty Range:** $\pm 45\ \text{ppm}$
-

2. Evaluating Statistical Significance:

- **Correct Answer: Option B** (The feature is a tentative "whisper" that could easily be instrumental noise or a data artifact).

3. Critical Thinking (Abiotic vs. Biotic DMS):

- **MS Tier:** "Even if DMS is real, non-living things like volcanoes or chemical reactions in space might make it without needing living organisms."
- **HS Baseline:** "Scientists must test non-biological pathways because unknown atmospheric reactions or UV radiation from the host star could generate DMS abiotically."
- **College Tier:** "Alternative photochemistry must be ruled out. Photolytic reactions on sulfur-bearing species or stellar flare-driven synthesis can yield trace organic sulfides without biological catalysts."

Section 4: Hypothesis Matrix Analysis

1. Comparing Evidence:

- **Selected Model: Model A** (Hycean Ocean World) best explains the combined CH_4/CO_2 presence and NH_3 depletion.

2. Strengths and Weaknesses:

- **Strongest Support for Model A:** The concurrent detection of CH_4 and CO_2 with depleted NH_3 matches the theoretical profile of a Hycean atmosphere over a liquid ocean.
- **Strongest Support for Model C:** The $2.72\ \mu\text{m}$ DMS candidate feature has low statistical confidence ($< 3\sigma$) and falls completely within the measurement uncertainty noise.

3. Synthesizing Models:

- **MS Tier:** "If we ignore Model C, we might jump to conclusions and think we found alien life when it was really just a glitch in the telescope graphics."
- **HS Baseline:** "Dismissing Model C creates confirmation bias. Early exoplanet data often contains unmodeled starspots or calibration noise that look like real planet signals."
- **College Tier:** "Rejecting the null hypothesis (Model C) prematurely fails scientific rigor. Systematic noise, stellar contamination, and baseline fitting

errors frequently mimic narrow absorption bands at low signal-to-noise ratios."

Section 5: Claim, Evidence, Reasoning (CER) Framework

- **MS Tier Sample:**

- **Claim:** K2-18 b is a water world (Model A).
- **Evidence:** We saw big peaks for methane ($3.3\ \mu\text{m}$) and carbon dioxide ($4.3\ \mu\text{m}$), but no ammonia.
- **Reasoning:** The missing ammonia proves it dissolved into an ocean, but the DMS signal is too noisy to prove life.

- **HS Baseline Sample:**

- **Claim:** K2-18 b is best categorized as a Hycean candidate world (Model A), though biosignature claims are unconfirmed (Model C).
- **Evidence:** JWST data displays 180 ppm transit depth for CH_4 ($3.3\ \mu\text{m}$) and 120 ppm for CO_2 ($4.3\ \mu\text{m}$), with missing NH_3 . The $2.72\ \mu\text{m}$ feature has a signal height of ~ 35 ppm with an error bar of ± 45 ppm.
- **Reasoning:** Ammonia depletion fits liquid ocean dissolution. However, because the measurement error exceeds the DMS feature height, the data cannot confirm biological activity.

- **College Tier Sample:**

- **Claim:** The current spectroscopic data supports a sub-Neptune with an ocean-atmosphere boundary (Model A), but potential biosignatures remain statistically inconclusive (Model C).
- **Evidence:** High spectral significance for CH_4 and CO_2 accompanied by NH_3 suppression below equilibrium limits. The DMS candidate at $2.72\ \mu\text{m}$ yields an $\text{SNR} < 1$.
- **Reasoning:** Ocean-atmosphere exchange accounts for nitrogen scrubbing. However, an $\text{SNR} < 1$ fails 5σ detection thresholds, making systematic noise or unmodeled stellar contamination the most statistically defensible explanation for the $2.72\ \mu\text{m}$ signal.

STANDARDS & CORE EDUCATION REQUIREMENTS

Next Generation Science Standards (NGSS) — Middle & High School

- **MS-ESS1-2 / MS-ESS1-3 (Earth's Place in the Universe):** Analyze and interpret data to determine scale properties and characteristics of objects in space.
- **HS-ESS1-2 (Earth's Place in the Universe):** Construct an explanation based on astronomical evidence obtained through spectral analysis of distant celestial bodies.
- **HS-PS4-5 (Waves and Electromagnetic Radiation):** Evaluate information about how information transmitted via light (spectroscopy) is used to determine chemical compositions of remote systems.
- **Science and Engineering Practices (SEP):**
 - *Analyzing and Interpreting Data:* Evaluating spectral light curves and error bars.
 - *Constructing Explanations and Designing Solutions:* Formulating CER statements from observations.
 - *Engaging in Argument from Evidence:* Evaluating competing atmospheric models.

Advanced Placement (AP) & Introductory College Alignment

- **AP Environmental Science / AP Chemistry:**
 - *Topic 3.1 / Chemical Equilibrium:* Solution chemistry, gas solubility, and Henry's Law (ammonia dissolving into planetary oceans).
 - *Molecular Spectroscopy:* Light-matter interactions, infrared vibrational absorption modes of carbon compounds (CH₄, CO₂).
- **Introductory Astronomy / Astrobiology (Higher Ed):**
 - *Exoplanet Detection Techniques:* Transmission spectroscopy, transit depth calculations, and stellar contamination.
 - *Biosignature Criteria:* Distinguishing biotic signals from abiotic photochemistry; evaluating Signal-to-Noise Ratios (SNR) and statistical confidence thresholds (σ -levels).

Permission is granted to educators to modify this lesson to fit the needs of students with proper attribution to **Christopher S. Centi, Centi Astro-Space Activities**

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