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Morning Rock Clouds and Clear Evening Skies: The Bizarre Weather of WASP-94A b as Seen by JWST

Space * Astronomy

Introduction: Breaking the 1D Exoplanet Paradigm with JWST

Characterizing exoplanetary atmospheres has long been hindered by high-altitude aerosols that mute molecular absorption features in transmission spectroscopy.[1][9] Earlier observatories lacked the precision to resolve planetary limbs, forcing astronomers to model the terminator as a uniform 1D annulus.[9][10] Yet tidally locked hot Jupiters experience extreme day-night irradiation gradients that drive 3D atmospheric circulation and equatorial super-rotating jets.[1][2]

Using the James Webb Space Telescope (JWST), Johns Hopkins University astronomers applied limb-resolved spectroscopy to map WASP-94A b, an inflated hot Jupiter ~690-700 light-years away.[1][11] Published in Science, their observations isolated the planet's morning and evening terminators: the morning limb is choked by opaque magnesium silicate rock clouds, whereas the evening limb is completely clear -- resolving a systemic 100-fold metallicity bias in 1D exoplanet retrievals.[1][7]

The WASP-94 Binary Architecture and Retrograde Dynamics

WASP-94 is a wide F-star binary (WASP-94A and WASP-94B) in which both stars host hot Jupiters, providing a rare testbed for orbital evolution.[4] WASP-94A b is an inflated gas giant (0.445-0.456 MJup, 1.72 RJup) orbiting at 0.055 AU every 3.95 days (Teq = 1,508 K).[4][6] Rossiter-McLaughlin measurements show a ~123 deg spin-orbit obliquity, indicating a retrograde orbit driven by high-eccentricity migration or Kozai-Lidov scattering from WASP-94B.[4][5]

| Parameter | | WASP-94A b (Primary) | | WASP-94B b (Companion) | | Unit |

| Planetary Mass | | 0.445 to 0.456 | | Minimum 0.618 | | Jupiter Masses [4] |

| Planetary Radius | | 1.35 to 1.72 | | Unknown (Non-transiting) | | Jupiter Radii [4] |

| Orbital Period | | 3.95 | | 2.008 | | Days [4] |

| Semi-Major Axis | | 0.055 | | 0.0335 | | Astronomical Units (AU) [4] |

| Equilibrium Temperature | | 1508 | | Unconstrained | | Kelvin [6] |

| Host Star Type | | F8V | | F9V | | Spectral Class [4] |

Limb-Resolved Spectroscopy and JWST Data Reduction

With a scale height corresponding to ~262 ppm in transit depth, WASP-94A b enables limb-resolved spectroscopy by separating transit ingress (morning limb) from egress (evening limb).[6][10] JWST Cycle 3 observations combined NIRISS/SOSS (0.6-2.8 m, 246 ppm precision) and NIRSpec/G395H (2.8-5.1 m) to probe water vapor (H2O), carbon dioxide (CO2), CO, and H2S.[1][3][7]

| Instrument | | Mode / Grating | | Wavelength Range | | Target Molecules / Features |

| JWST NIRISS | | SOSS | | 0.8 to 2.8 microns | | H2O, aerosols, metastable Helium [1][7] |

| JWST NIRSpec | | G395H | | 2.8 to 5.1 microns | | CO2, CO, H2S, CH4 limits [3] |

| Ground (HARPS / NTT) | | Echelle / EFOSC2 | | Optical | | CaII H&K, Sodium, Rayleigh slope [5][6] |

Independent reductions via Eureka!, FIREFLy, and Fu pipelines were fitted with the catwoman asymmetric semi-circle model and dynesty nested sampling, measuring a broadband morning transit depth of 1.176% versus 1.078% on the evening limb (2.8).[3][7][12]

The Magnesium Silicate Cloud Cycle and 3D Circulation

The morning limb spectrum is flat (11 cloud opacity), whereas the evening limb displays deep absorption bands (10 H2O).[7] At ~1,500 K, water and ammonia stay gaseous; the morning overcast consists of condensed magnesium silicate (forsterite).[1] Nightside cooling condenses silicate droplets near millibar pressures, which thermodynamic updrafts loft to 0.01 mbar before eastward jets carry them across the morning terminator.[2][9] Intense dayside stellar and solar radiation heats the evening limb by ~450 K (above the 280 K 3 threshold), evaporating the rock clouds before sunset -- a cycle replicated by 3D Met Office Unified Model GCMs coupled with PICASO 1.5D retrievals.[1][8][9]

Resolving the 100-Fold Metallicity Bias and Protoplanetary Origins

In planetary meteorology, applying a 1D spherical model to a blended transit spectrum lets the cloudy morning continuum dilute evening gas absorption troughs.[9][10] Standard retrievals misinterpret muted features in a hydrogen-dominated envelope as a compact, hyper-metallic atmosphere.[1][7]

| Retrieval Model Type | | Assumed Geometry | | Inferred Metallicity [M/H] | | Elemental Abundance | | Validity |

| 1D Spherical Model | | Blended Terminator | | +1.937 +/- 0.073 | | ~100x Solar | | Biased (5-sigma error) [1][7] |

| 1.5D Limb-Resolved | | Asymmetric Limbs | | +0.31 +/- 0.32 | | ~2x to 5x Solar | | Accurate (Jupiter-like) [1][10] |

Evening-limb detections of H2O (10), CO2 (11), CO (3), and H2S (2.5) -- plus methane upper limits -- yielded a sub-stellar carbon-to-oxygen ratio of C/O = 0.49+0.08-0.13 (stellar 0.68 +/- 0.10), confirming icy planetesimal accretion beyond the water snow line.[3][13] A 1.083 m metastable helium core also revealed active XUV-driven escape, while >5 limb asymmetries found on WASP-39 b and WASP-17 b establish an "asymmetry horizon" across hot gas giants.[1][2][7]

Conclusion: A Multi-Dimensional Era for Exoplanet Characterization

Isolating WASP-94A b's silicate-cloud morning from its clear evening mapped an extrasolar weather cycle and corrected a 100-fold metallicity error in 1D

retrievals, proving that multi-dimensional modeling is essential for exoplanet characterization.

Updates... (Nov 18, 2026): Aligned attribution for the JWST NIRSpec/G395H molecular and C/O measurements directly to Ahrer et al. (2025) in Monthly Notices of the Royal Astronomical Society and updated sources to primary peer-reviewed DOIs (including Fu et al., 2025, The Astrophysical Journal Letters; Ahrer et al., 2022, 2024, 2025).

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