SPEARNET: A Global Network for Transmission Spectroscopy of Hot Transiting Exoplanets

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In collaboration with

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EXOPLANET OBSERVATION STATS

TRANSITING EXOPLANETS TO DATE

4,300+

The transit method is the most successful discovery technique, accounting for about **75%** of the ~5,600+ total confirmed exoplanets.

OBSERVABLE BY 2M CLASS TELESCOPE

2,000 – 2,500

Targets accessible to 2-meter class professional telescopes.
These instruments can follow up on almost all targets from TESS and K2 (typically stars brighter than mag 14–15).

OBSERVABLE HOT JUPITERS

500+

Virtually all known transiting Hot Jupiters are observable by 2m telescopes.
Their large size blocks 1-2% of starlight, creating deep signals detectable even by amateur astronomers.

ATMOSPHERES STUDIED

150 – 200

Planets studied via **transmission spectroscopy**. While thousands exist, only a fraction have characterized atmospheres. This number is rising rapidly with JWST.

STUDIED VIA TRANSIT TIMING (TTV)

150+

TTVs allow us to weigh planets in compact multi-planet systems.
This method has provided mass measurements for over 150 planets and discovered **~40 non-transiting** companions.

THE ERA OF TRANSITING EXOPLANETS

Cumulative Growth

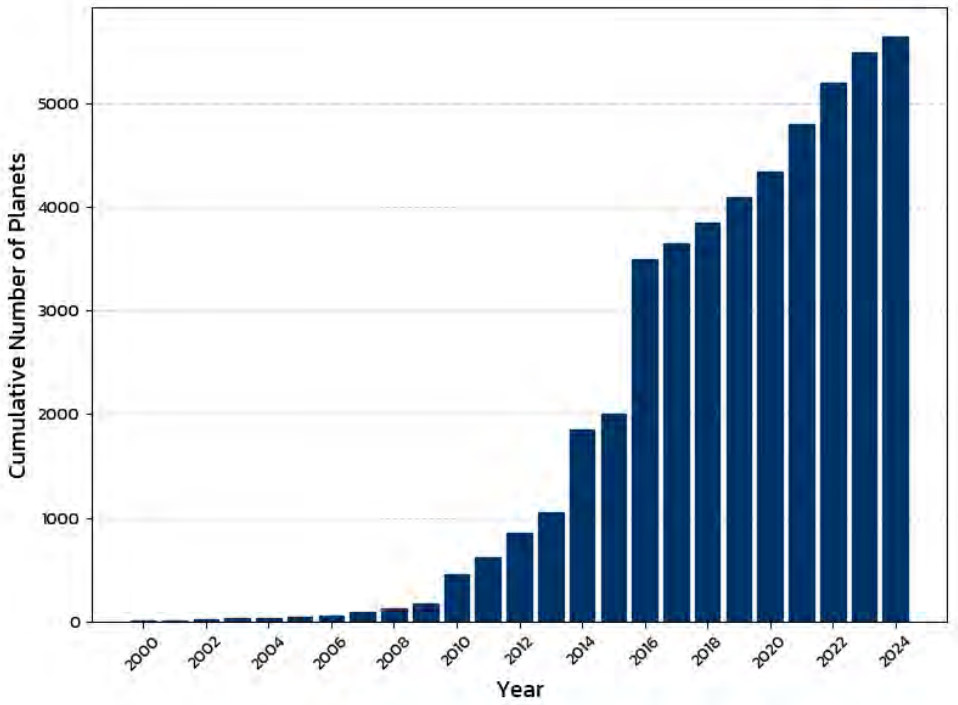
From **<2,000** planets in 2014 to over **5,600+** in 2024. The transit method now accounts for **75%** of all confirmed discoveries, largely driven by the Kepler telescope n 2016.

Discovery Powerhouses

Kepler: Revolutionized the field with 2,700+ confirmed planets.
TESS: Scanning the whole sky; 7,000+ candidates (TOIs) found around bright, nearby stars

Future Survey Missions

PLATO (2026): Targeting Earth-analogs in habitable zones.
ARIEL (2029): First dedicated atmospheric survey of ~1,000 worlds.




KEPLER


TESS


PLATO


ARIEL

GLOBAL NETWORK OF 0.5–2.5M TELESCOPES

Worldwide 0.5-2.5 telescopes

There are **hundreds** of meter-class professional telescopes (0.5m – 2.0m) distributed globally. While individually modest, collectively they form a massive, 24-hour continuous monitoring network essential for time-domain astronomy.

SPEARNET Telescope

The **SPEARNET telescope** leverages this global distribution to perform transmission spectroscopy of hot transiting exoplanets.

Thailand:	Thai National Telescope (TNT)
Chile:	Cerro Tololo Inter-american Observatory (TRT-CTO)
USA:	Sierra Remote Observatories (TRT-SRO)
China:	Gao Mei Gu Observatory (TRT-GAO)
Australia:	Springbrook Observatory (TRT-SBO)
India:	Devasthal Optical Telescope (DOT)

Observation Capability

These instruments are perfectly suited for observing 1-2% transit depths of Hot Jupiters around stars brighter than mag 14, complementing space missions like TESS.





GROUND-BASED OBSERVATION ROUTINE

01

Telescope Selection

Select suitable telescope and instrument

02

Target Selection

Select suitable transiting exoplanet candidates based on visibility.

03

Observation Plan

Define exposure times, filters, and cadence.

04

Observe

Execute data acquisition and monitor environmental conditions.

05

Data Reduction

Calibration (Bias, Dark, Flat) and differential photometry.

06

Fitting Light Curve

Model the transit dip to extract physical parameters.

07

Final Analysis

Analyze Transit Timing Variations (TTV) & Transmission Spectroscopy.

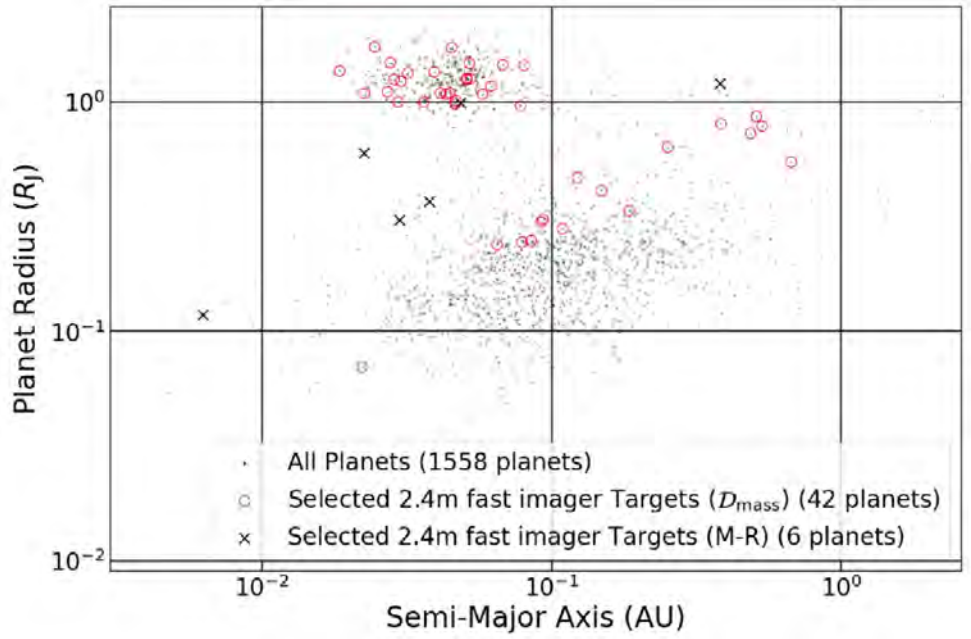
TARGET SELECTION STRATEGY

Optimizing Observations with a Decision Metric

Morgan et al. (2019)
MNRAS 468, 79

Exoplanet Atmosphere Target Decision Metric

To maximize the scientific return of a telescope network by objectively pairing the best targets to the most suitable telescope assets, enabling robust population studies.



Decision Metric

$$D \propto F_*^{0.4} R_p^{(3-n)} a^{-0.25} d^{-0.2}$$

Host Brightness
Photon flux drives S/N

Transit Duration (t_{14})
Longer integration time

Temperature (T_{eq})
Atmospheric scale height

Transit Depth (δ)
Planet-to-Star ratio

FILTER SELECTION STRATEGY

Optimizing Ground-Based Observations for Hot Jupiters

Morgan et al. (2019)
In prep

Recursive Feature Elimination

Using **Recursive Feature Elimination (RFE)** with Random Forest models trained on synthetic spectra. The study iteratively removed the least informative filters from a set of 10 (Johnson-Cousins & SDSS) to find the optimal subset.

The "Anchor" Filters

V and u' are consistently the most important across all planet sizes. Located in the blue-optical region, they probe the atmospheric continuum free of major molecular opacity, providing a stable baseline for R_p measurement.

Probing Absorption

Red-optical filters (**r', i', z'**) rise in importance for larger planets (R_p > 1.2 R_J). This correlates with increasing scale heights and stronger **TiO/VO absorption** features characteristic of hot atmospheres.

Key Result: 5 Filters ~ Full Set

Reducing observations to just the top 5 filters retains predictive accuracy.

Filter Importance Ranking by Planet Radius



See Poster SE22-P

TRANSITFIT

Multi-Instrument Exoplanet Transit Fitting Package

Hayes et al. (2024)
MNRAS 527, 493

Multi-Dimensional Fitting

Simultaneously fits data from **multiple telescopes**, epochs, and wavelengths. Ideal for combining sparse ground-based data with space-based observations.

Coupled Limb Darkening

Uses LDTK and PHOENIX atmosphere models to **couple limb-darkening coefficients** across wavelengths, improving retrieval accuracy for transmission spectroscopy.

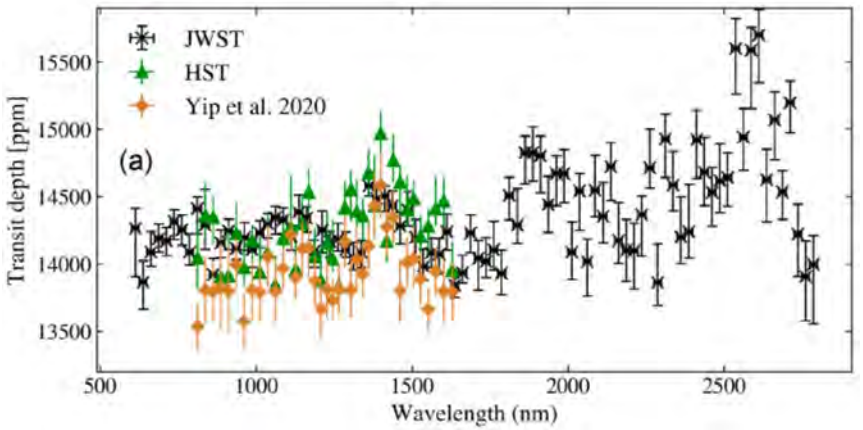
Simultaneous Detrending

Performs **simultaneous detrending** and normalization alongside parameter fitting. Supports custom functions to handle complex systematics (e.g., HST ramps).

Robust Retrieval

Built on **Python 3**, utilizing batman for light curve modelling and dynesty (Nested Sampling) for robust parameter estimation and error analysis.

WASP-96b



WASP-96b: Combined JWST (NIRISS) & HST fitting

- **WASP-127b (SPEARNET):** Improved broadband optical results using ground-based network data.
- **WASP-43b (HST):** Successfully removed complex instrumental systematics using custom detrending functions.
- **TESS Science:** Updated ephemeris for WASP-91b and ruled out TTV signatures in WASP-126b.

OPTIMIZING EXOPLANETARY ATMOSPHERE RETRIEVAL

Unsupervised Machine Learning for Informed Priors

Hayes et al. (2020)
MNRAS 494, 4492

Computational time

Standard retrieval methods (e.g., Nested Sampling) are computationally expensive. In the era of large surveys like **TESS** and **ARIEL**, we face an "asset-starved" regime where rapid characterization is critical.

Unsupervised Machine Learning

Instead of using uniform (uninformed) priors, use **Unsupervised Machine Learning** to classify spectra and generate **Informed Priors**. This narrows the parameter space search significantly.

01

Compression

Use **PCA** to compress synthetic spectra grid (PLATON) into essential components.

02

Classification

Apply **k-means clustering** in PCA space to identify discrete spectral classes.

03

Retrieval

Use the parameter distribution of the identified class as the **Prior** for Nested Sampling.

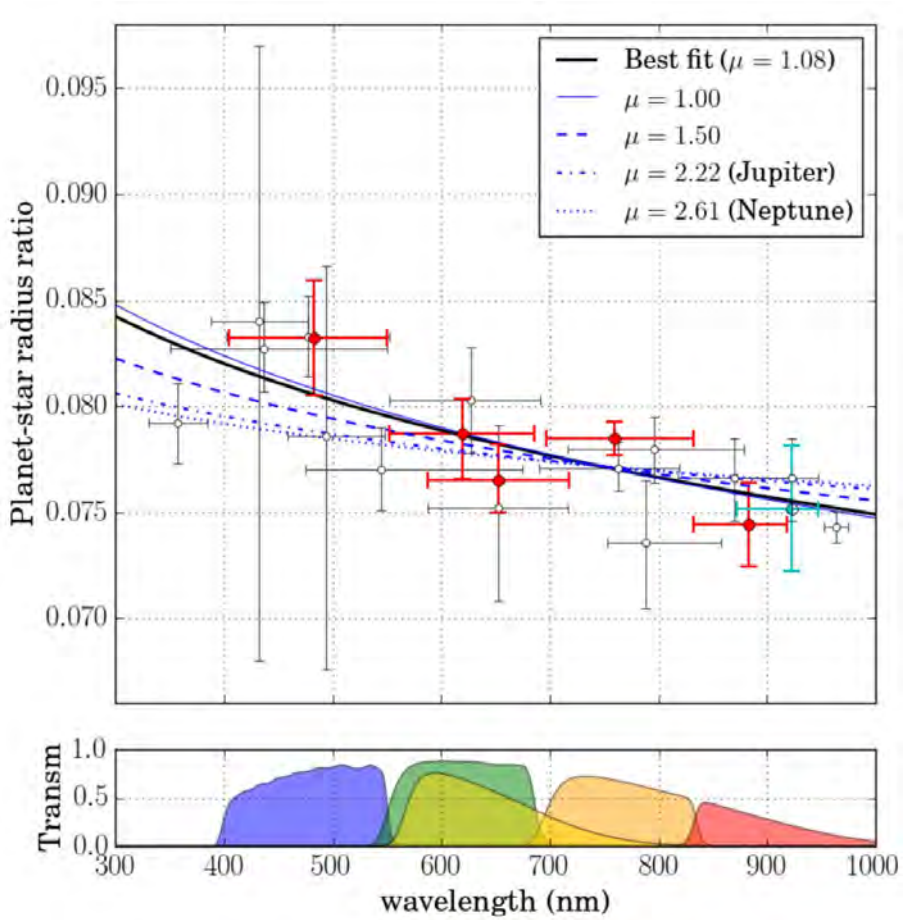
2x Faster

Computational Efficiency with Negligible Accuracy Loss

GJ 3470B: BLUE SKY EXOPLANET

Strong Rayleigh Scattering Slope

Awiphan et al. (2016)
MNRAS 463, 527



Transit Timing Variations (TTV)

No significant TTV signal was detected (O-C residuals consistent within 2σ).

Constraint: Rules out the presence of a nearby massive companion (e.g., Hot Jupiter with P < 10 days).

Transmission Spectroscopy

Combined with literature data, the transmission spectrum reveals a strong **Rayleigh scattering slope** in the optical.

This indicates a low mean molecular weight (μ=1.08), consistent with an **H/He-dominated atmosphere** obscured by high-altitude haze.

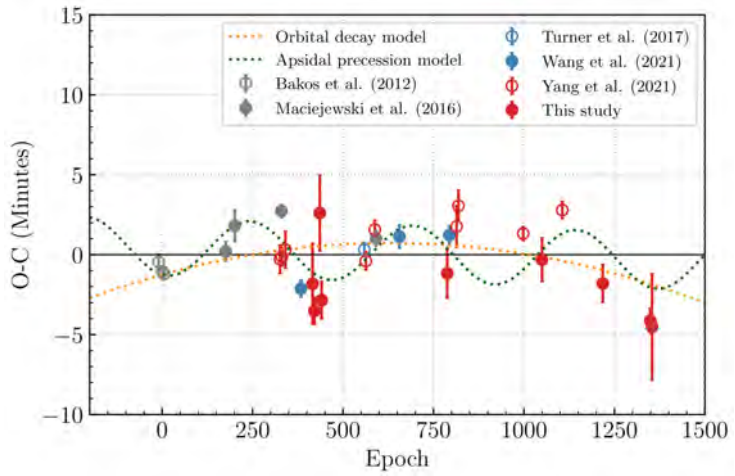
HAT-P-37B: CLOUDY ATMOSPERE

Possible 3rd body near 1:2 resonance with cloudy atmosphere

A-thano et al. (2022)
AJ, 163, 77

Timing Variations (TTV)

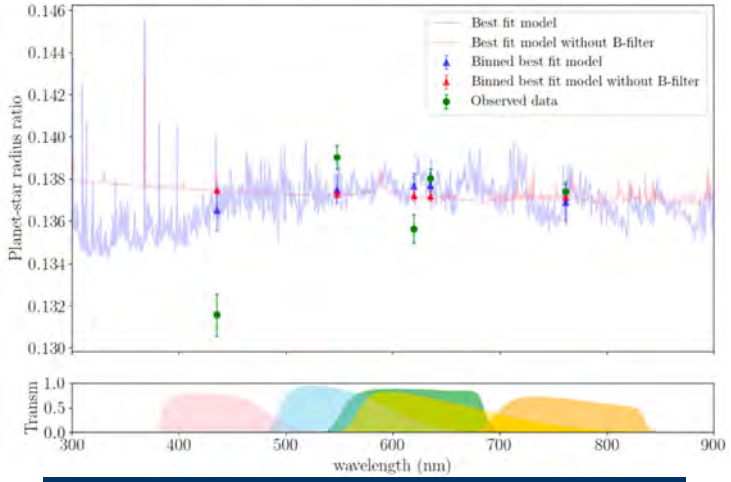
- Detected a TTV signal amplitude of 1.74 min
- Suggests a possible **3rd body** near 1:2 resonance.
- Predicted companion: Sub-Earth mass 0.06 Earth Mass
- **Constraints:** Ruled out any Saturn-mass planets with periods < 6 days.



TTV O-C Diagram Analysis

Atmosphere

- Broadband transmission spectroscopy using **B, V, R, r', i'** filters.
- Results favor a (flat spectrum) cloudy model.
- Notable **anomaly in B-band** transit depth, potentially indicating stellar activity or instrumental noise rather than clear Rayleigh scattering.

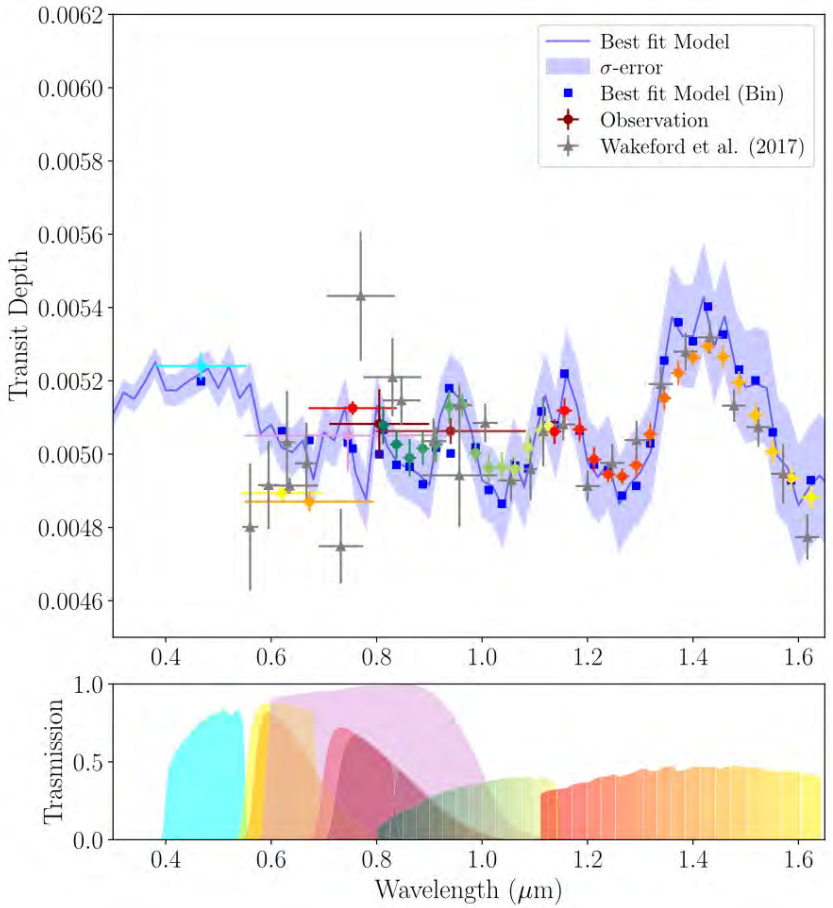


Broadband Transmission Spectrum

HAT-P-26B: H_2O ABSORPTION FEATURES

Possible 3rd body with water detection

A-thano et al. (2023)
AJ, 166, 223



Transit Timing Variations

Analyzed 33 transits over a 7-year baseline.

- Detected TTV amplitude: **1.98 ± 0.05 min**.
- Periodicity: ~222 epochs (0.0045 cycles/period).
- **Hypothesis:** Potential presence of a third body (~0.02 M_{Jup}) near 1:2 mean-motion resonance.

Atmospheric Retrieval

Transmission spectroscopy performed using TauREx 3 on combined datasets.

- **Water Detection:** Clear H2O absorption features (**2.4%**).
- **Temperature:** Derived atmospheric temperature of **590 K**
- **Composition:** Likely cloud/haze-free ($P_{cloud} > 10^3$ Pa) with no strong evidence for metal hydrides.

WASP-11B / HAT-P-10B: STONG RAYLEIGH SCATTERING SLOPE

Transit Timing & Transmission Spectroscopy

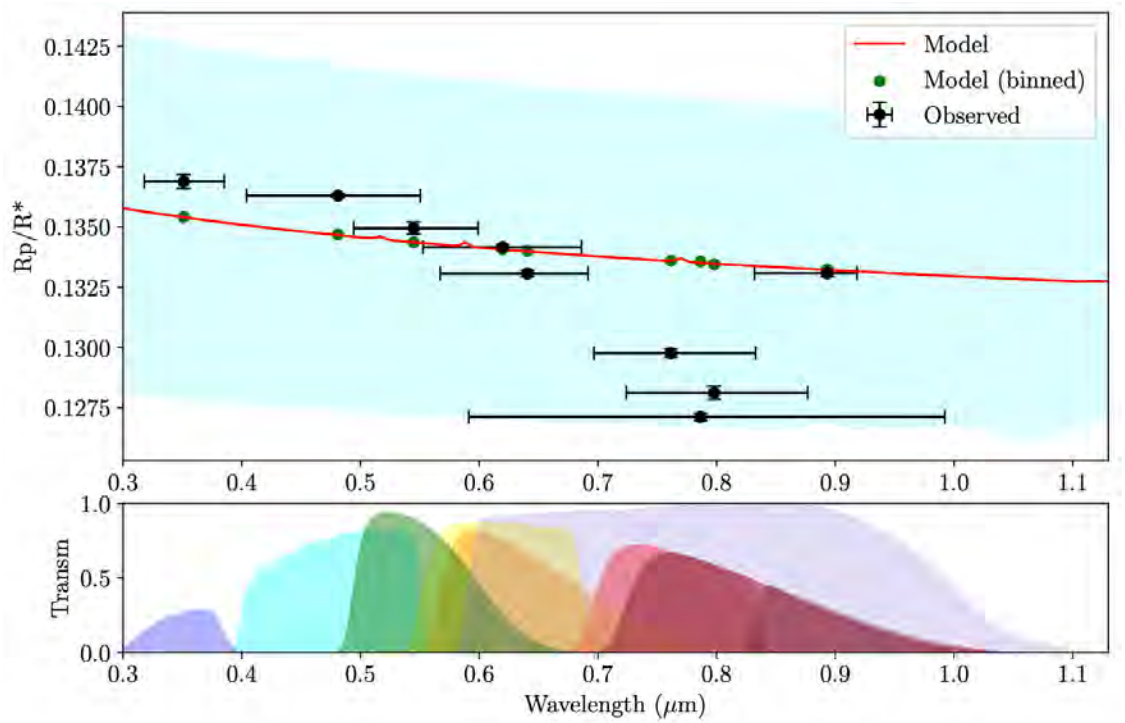
A-thano et al. (2025)
Submitted to AJ

Timing Analysis

Updated linear ephemeris. No significant evidence of **orbital decay** ($dP/dE = -6 \times 10^{-10}$) or Transit Timing Variations (TTVs), ruling out nearby massive companions.

Atmospheric Result

Multi-band optical transmission spectroscopy reveals a **strong Rayleigh scattering slope**. This may indicate a hazy atmosphere or stellar activity contamination.



WASP-43B: A DECADE OF OBSERVATIONS

Transit Timing & Transmission Spectroscopy Results

A-thano et al. (2025)
Submitted to AJ

Extensive Dataset

35 new transit light curves from the ground-based SPEARNET network, combined with archival data from TESS, HST, JWST, and 109 published ground-based curves.

Timing Analysis

Analyzed **188 mid-transit times**. No significant Transit Timing Variations (TTVs) were found. Orbital decay rate measured at -3×10^{-11} days/orbit, showing no strong evidence for decay.

Atmospheric Result

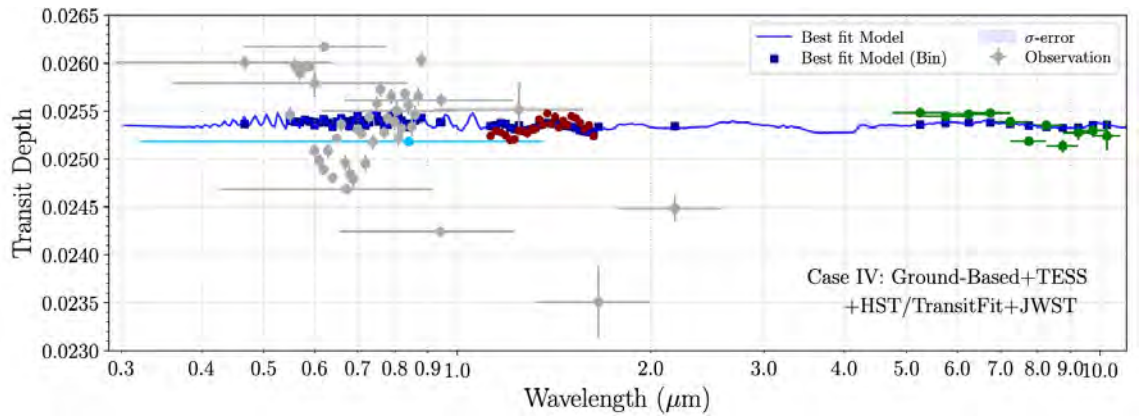
Combined multi-band analysis indicates a cooler planetary temperature of **~400 K** with water abundance $\log_{10}(H_2O)$ = -2.8 - -2.1%.

SPEARNET
Ground-based Network

HST WFC3
Near-IR Spectroscopy

TESS
High-Cadence Photometry

JWST MIRI
Mid-IR Spectroscopy



Combined Transmission Spectrum Model (Optical to Mid-IR)

See Poster SE20-C

CONCLUSIONS

Global Network Value

SPEARNET demonstrates that a heterogeneous network of **0.5–2.4m telescopes** can effectively contribute to high-precision exoplanet science, providing critical long-baseline monitoring and optical continuum constraints.

Toolkit Innovation

Development of **TransitFit** and ML-driven target/filter selection strategies allows for homogeneous analysis of diverse datasets, optimizing resource allocation in the "asset-starved" era.



Global Coverage



Robust Analysis



Long Baselines

"Ground-based follow-up is essential for maximizing the scientific return of current and future space missions like TESS, JWST, and ARIEL."