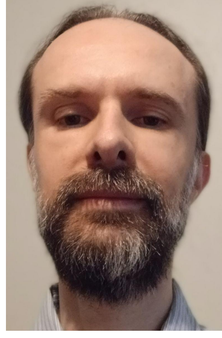
OVERCOMING STELLAR ACTIVITY IN THE ANALYSIS OF TRANSIT AND ECLIPSE TIMING VARIATIONS OF WASP-52 b: UPDATES TO ORBITAL AND SYSTEM PARAMETERS AND EPHEMERIDES



2026 Sagan Summer Workshop – July 20-24, 2026

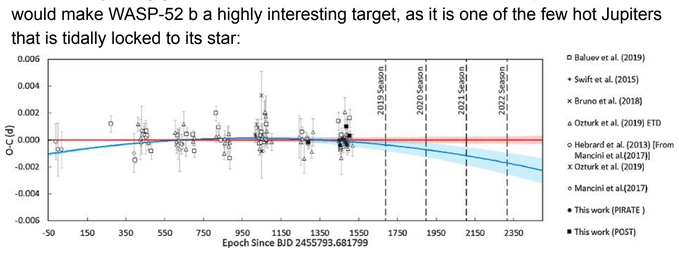
Andre O. Kovacs – Center for Radio Astronomy and Astrophysics Mackenzie (CRAAM)

Collaborators: Kyle A. Pearson – Jet Propulsion Laboratory (JPL) – CalTech; + 39 others

1. CONTEXT:

The exoplanet WASP-52 b is a hot Jupiter orbiting a K2V-type star. In the discovery paper, Hébrard et al. (2013) identified signs of a possible ~+40 m s^{-1} drift over a 15-month period in radial velocity data from the SOPHIE and CORALIE spectrographs, indicating the possible presence of an additional massive component pulling the system toward us.

Furthermore, more recently, Salisbury et al. (2021) identified signs of possible orbital decay using ground-based observational data and literature ephemerides; this would make WASP-52 b a highly interesting target, as it is one of the few hot Jupiters that is tidally locked to its star:



Currently, more than 10 years of ground-based photometric observation data are available from citizen science projects—specifically NASA Exoplanet Watch, the Exoplanet Transit Database (ETD), and the ExoClock Project (Kokori et al. 2023)—along with more recent radial velocity observations obtained via the HARPS spectrograph (HARPS RVBank v2 database; Perdelwitz et al. 2024) and space-based transit observation data from NASA missions such as the James Webb Space Telescope (JWST) (transits and eclipses), Hubble Space Telescope (HST) (transits), Spitzer (phase curves), and TESS (transits), in addition to various literature publications containing ephemeris data.

2. DATA:

Citizen Science Databases:

- Heterogeneous data sources (citizen scientists from all around the world):
  - NASA Exoplanet Watch (https://exoplanets.nasa.gov/exoplanet-watch/results/)/AAVSO Exoplanet Database (154 ttrânsitos) (Zellem et al. 2023);
  - Exoplanet Transit Database (ETD; http://var2.astro.cz/EN/tresca/index.php?lang=en) (70 transits);
  - ExoClock project (39 trânsitos) (Kokori et al. 2023);
  - Telescopes from >150mm & <1m (>6" & <39") in aperture; CCD and CMOS sensors; Cousins Rc e Ic photometric filters, and Clear filter;
  - Data reduction software: AstroImageJ (Collins et al. 2017), EXOTIC (EXOplanet Transit Interpretation Code; Zellem et al. 2020), HOPS (HOlomon Photometry Software; Tsiaras 2019), etc;

POST e OpenScience Observatories (Salisbury et al. 2021):

- Private Observatory POST (3 transits):
  - 0.4m (15.75") telescope in aperture; CCD sensor; Johnson V and Cousins Rc photometric filters;
  - Data reduction software: AstroImageJ (Collins et al. 2017);
- Open University's OpenScience Observatories (OSO) (6 transits):
  - COAST: 0.35m (13,78") telescope in aperture; CCD sensor; Cousins Rc photometric filter;
  - PIRATE: 0.45m (17,72") telescope in aperture; CCD sensor; Johnson B and Cousins Rc photometric filters;
  - Data reduction software: AstroImageJ (Collins et al. 2017);

Space Data:

- TESS: sector 83 (14 transits)
- JWST NIRISS/SOSSo1 GR700XD (1 trânsito): Program GTO 1201 (P.I. David Lafreniere);
  - Data reduction software: Eureka! pipeline (Bell et al. 2022);

Ephemerides Data:

- HST STIS/G430L and G750L (3 transits: Program GO-14767 (P.I. David K. Sing);
  - Data reduction and fitting software: STIS pipeline (Allen et al. 2024);
- Spitzer IRAC/CH1 and CH2 (3 phase curves – eclipses & transits): Program 13038 (P.I. Kevin B. Stevenson);
  - Data reduction and fitting software: Spitzer IRAC pipeline from JPL (Swain et al. 2025);
- JWST NIRSpec/PRISM Clear (1 eclipse): Program GTO 1224 (P.I. Stephan Birkmann);
  - Data reduction and fitting software: Eureka! pipeline (Bell et al. 2022);
- Literature (7 transit times):
  - Hébrard et al. 2013;
  - Baluev et al. 2015;
  - Mancini et al. 2017 (starspot);
  - Chen et al. 2017;
  - Ivshina & Winn 2022;
  - Bruno et al. 2018;
  - Cegla et al. 2023 (starspot);

Radial Velocity Data:

- SOPHIE & CORALIE: discovery paper (Hébrard et al. 2013);
  - Data reduction software: Sophie and CORALIE pipelines;
- HARPS: HARPS RVBank v2 (Perdelwitz et al. 2024);
  - Data reduction software: SERVAL pipeline;

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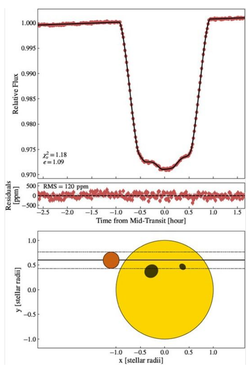
3. CHALLENGES:

The star WASP-52 is known to be active, resulting in 'bumps' in the light curve during its exoplanet's transits due to contamination from starspots on its surface—as illustrated in the adjacent figure, generated by Fournier-Tondreau et al. (2025) for the JWST NIRISS/SOSS observations.

In general, spot occultations by the transiting exoplanet occurring near the transit midpoint can affect the determination of transit depth, appearing as transit depth variations (TDVs), whereas spot occultations near the times of ingress or egress can affect the determination of contact times, appearing as transit duration variations (TTVs).



4. DATA HOMOGENIZATION:

Transits:

- Ground-based and space-based observations (105 ground-based transits and 15 space-based transits):
  - Detrending and readjustment of observations using the development version of EXOTIC (Zellem et al. 2023);
  - Cut-off criterion (stellar contamination check): outlier removal via 3-sigma clipping; removal based on a 10-minute deviation from the transit center and a 3-sigma deviation in transit depth;
  - Deduplication: based on the lowest data dispersion;

Eclipses:

- Eclipse observations (1 eclipse):
  - Reduction and fitting of the data from JWST NIRSpec/PRISM (NASA Exoplanet Archive), using the Eureka! pipeline (Bell et al. 2024);

Phase Curves:

- Space Observations (3 transits and 6 eclipses):
  - Reduction and fitting of the data from Spitzer IRAC (NASA Exoplanet Archive), using the JPL pipeline (Swain et al. 2025);

Radial Velocity Data:

- From Literature (3 instruments):
  - Deduplication: no grouping of data per night;

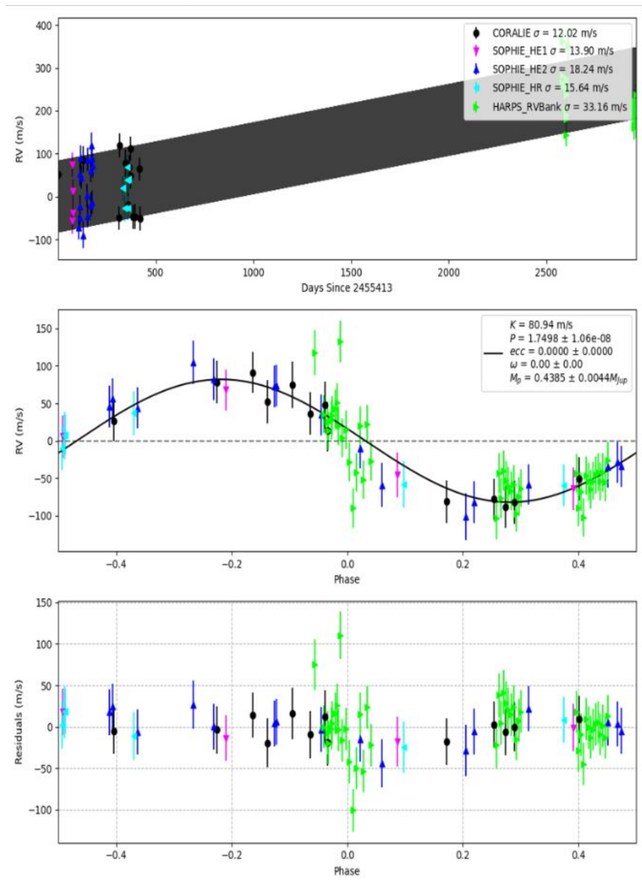
Ephemerides:

- Retain only observations free from significant contamination by starspot crossing events;

5. RADIAL VELOCITY MODEL FITTING:

Radial Velocity Analysis (according to Noguer et al. 2024):

- Modified EXOTIC code:
  - Radial velocity model: kepmodel (Delisle 2016), s+leaf (stellar jitter) (Delisle et al. 2020, 2022) & trend model;
  - Dynamic Nested Sampling: UltraNest (Buchner 2016);

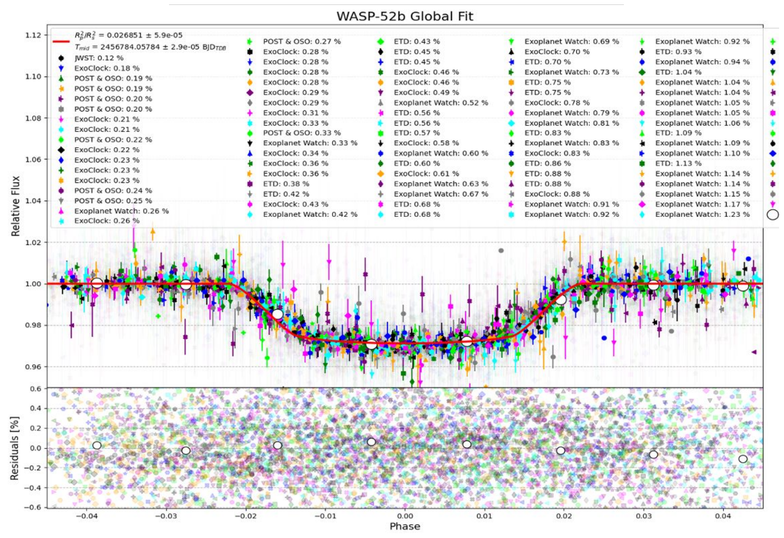


6. GLOBAL MODEL FITTING:

Simultaneous Joint Analysis (according to Pearson et al. 2022):

- Modified EXOTIC code:
  - Transit model: EXOTIC (Zellem et al. 2023);
  - Radial velocity model: kepmodel (Delisle 2016), s+leaf (stellar jitter) (Delisle et al. 2020, 2022) & trend model;
  - Ephemerides model: linear model;
  - Dynamic Nested Sampling: UltraNest (Buchner 2016);

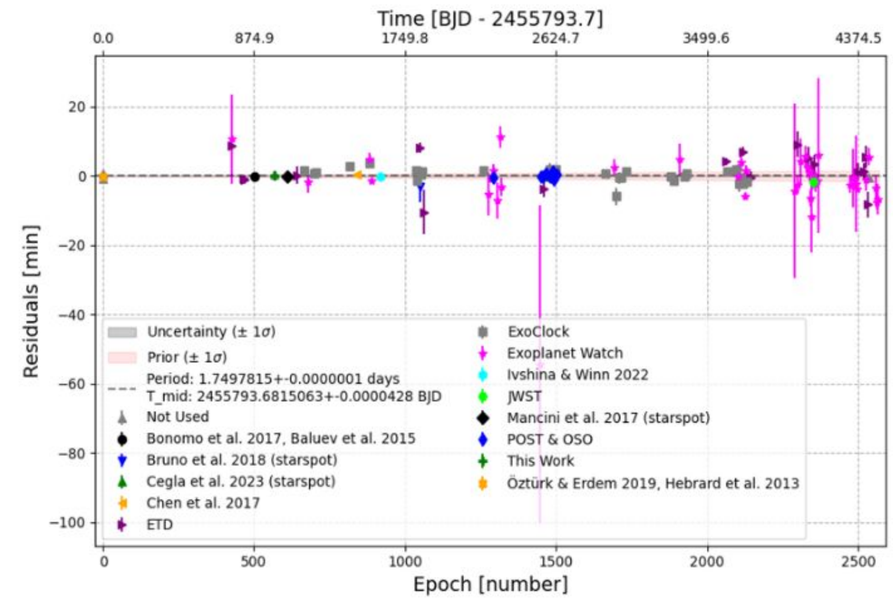
$$\mathcal{L}_{\text{Joint}} = \mathcal{L}_{\text{RV}} + \mathcal{L}_{\text{Transit}} + \mathcal{L}_{\text{Mid-transit}} + \mathcal{L}_{\text{Mid-eclipse}}.$$

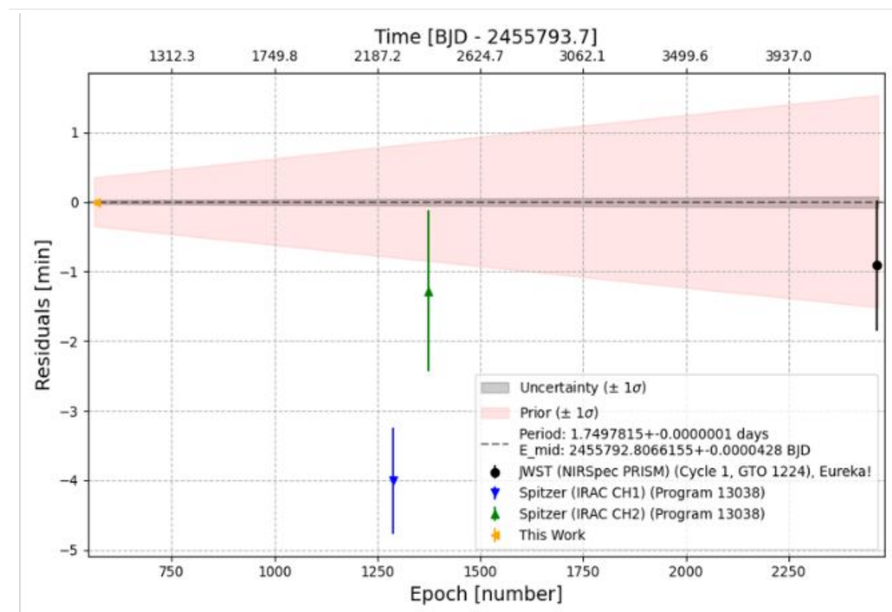


7. ORBIT DECAY MODEL ADJUSTMENT:

Timing Variation Analysis (according to Nediyedath et al. 2023):

- Modifies EXOTIC code:
  - Transit and eclipse ephemerides (120 transits used to adjust the global model, plus HST & Spitzer and literature);
  - Linear and quadratic ephemerides models;
  - Dynamic Nested Sampling: DYNASTY (Speagle 2020);
  - Outlier detection: Mixture Model (Gaussian distribution) (Hogg et al. 2010, https://doi.org/10.5281/zenodo.15856);
  - BIC: in favor of the linear ephemerides model;

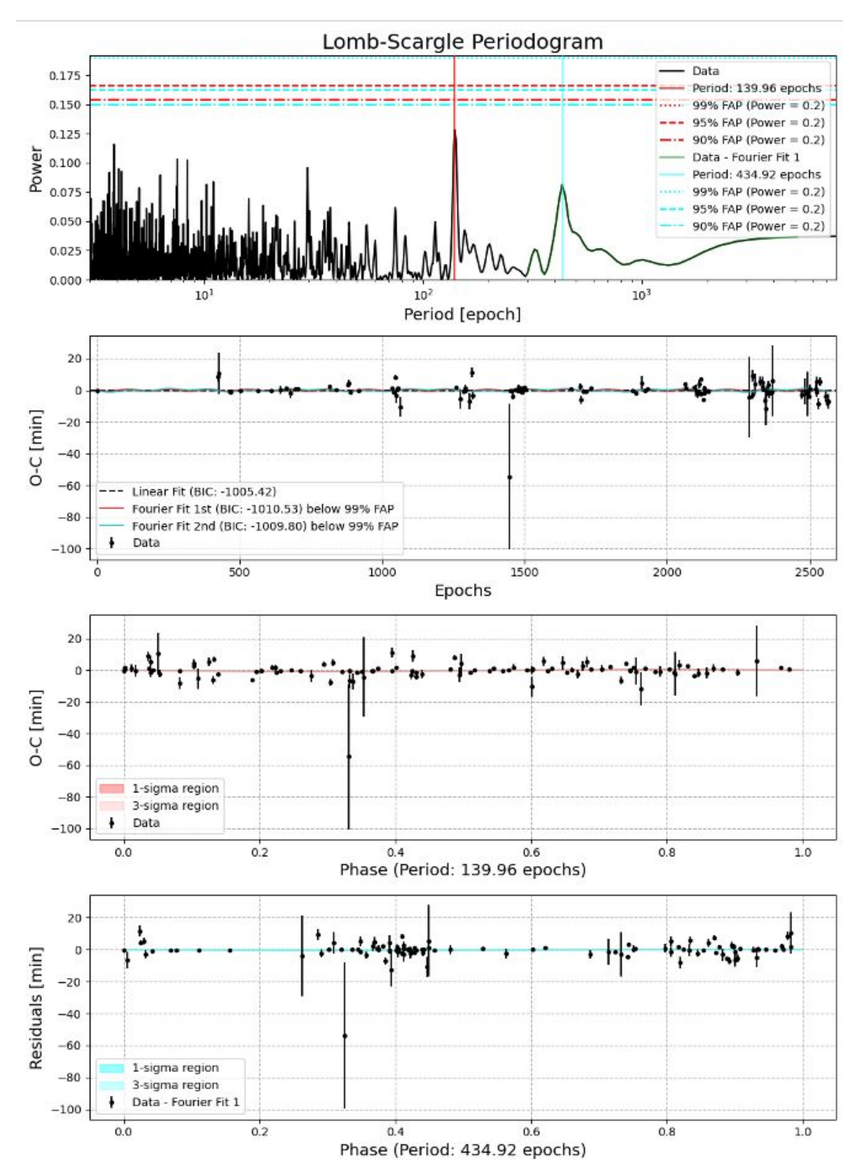




8. SEARCH FOR ADDITIONAL COMPONENT:

Timing Variation Analysis (according to Nediyedath et al. 2023):

- Modified EXOTIC code:
  - Search for perturbations caused by a possible additional planet in the system;
  - O-C: mid-transit times;
  - Periodogram (FAP): no significant signal detected for an additional planet;



CONCLUSIONS:

This study presents the most comprehensive analysis of the exoplanet WASP-52 b to date, incorporating over 100 light curves from transit and eclipse observations made by various ground- and space-based telescopes, alongside radial velocity data from multiple instruments and literature-based ephemerides. This diversity of data sources necessitated preliminary work to homogenize the data and to filter out measurements heavily affected by stellar activity or systematic instrumental errors.

First, by incorporating the most recent radial velocity data from the HARPS instrument, we confirmed the system's acceleration toward us (an upward trend in the fitted model)—consistent with the findings of Hébrard et al. (2013)—which may indicate the presence of a massive third body in the system.

However, contrary to the findings of Salisbury et al. (2021), we were unable to confirm orbital decay for the exoplanet, nor did we detect any signs of perturbation attributable to a potential additional planet in the system.

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CONTACT:

Andre Kovacs, andre.kovacs@gmail.com

Member of the American Association of Variable Star Observers (AAVSO) – observer code KADB