Diffuser-Assisted Time Series Exoplanet Photometry with ARCTIC

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Abstract

ARCTIC has been a workhorse in the field of exoplanet followup photometry, contributing to several recent discoveries. The instrument's remarkable diffuser element, which broadens the source PSF into a wide, tophat-like profile, has pushed ground-based photometry to sub-millimagnitude precision. We summarize the instrument's noise performance, show a fitted transit light curve, and offer our best observing practices for future observations.

The Pipeline

Flat field

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Shift-stabilize

↓

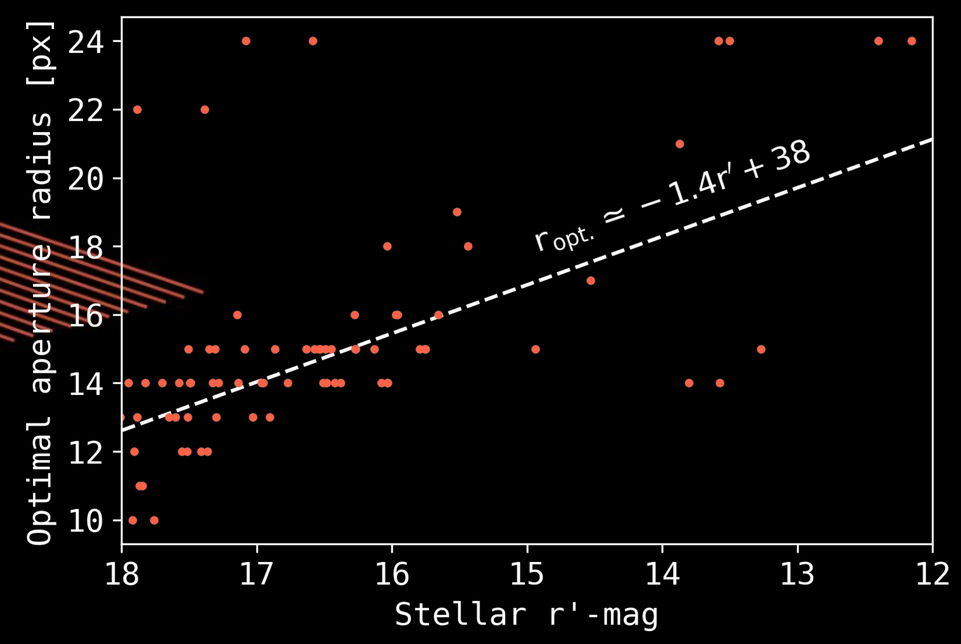
Find sources

↓

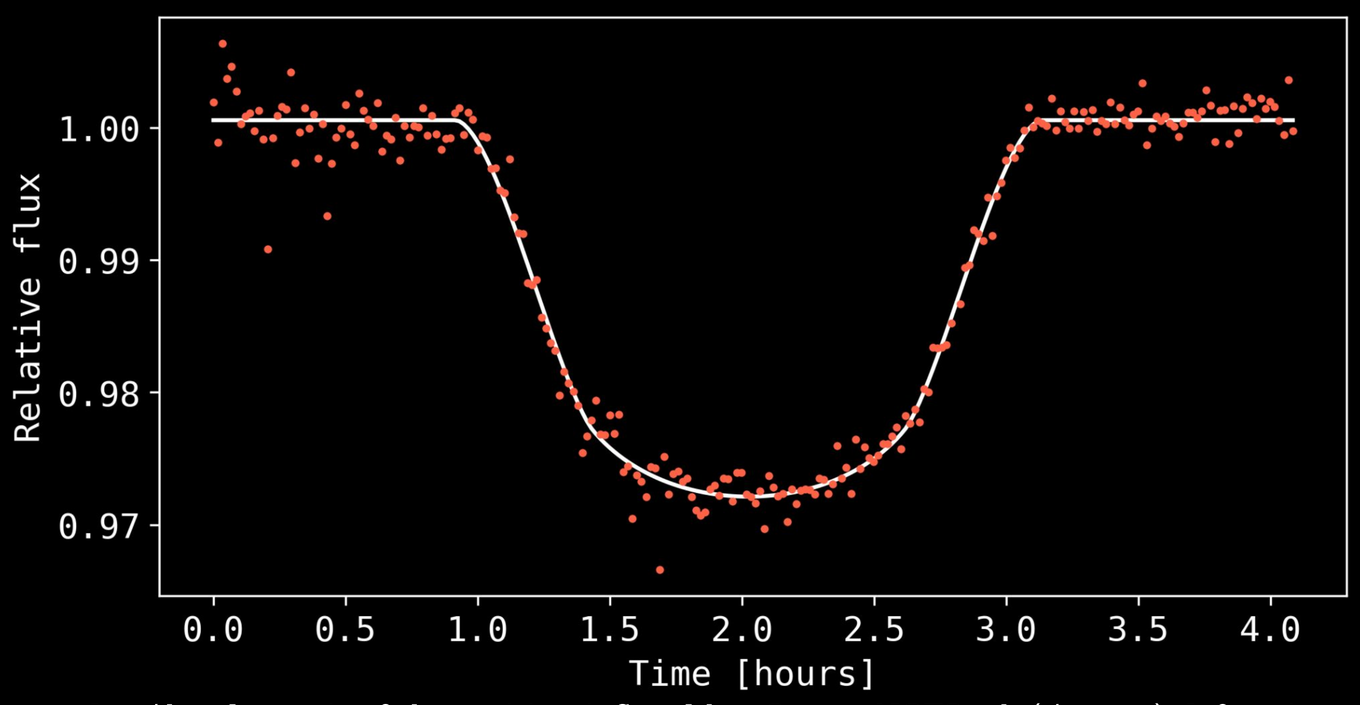
Aperture photometry

↓

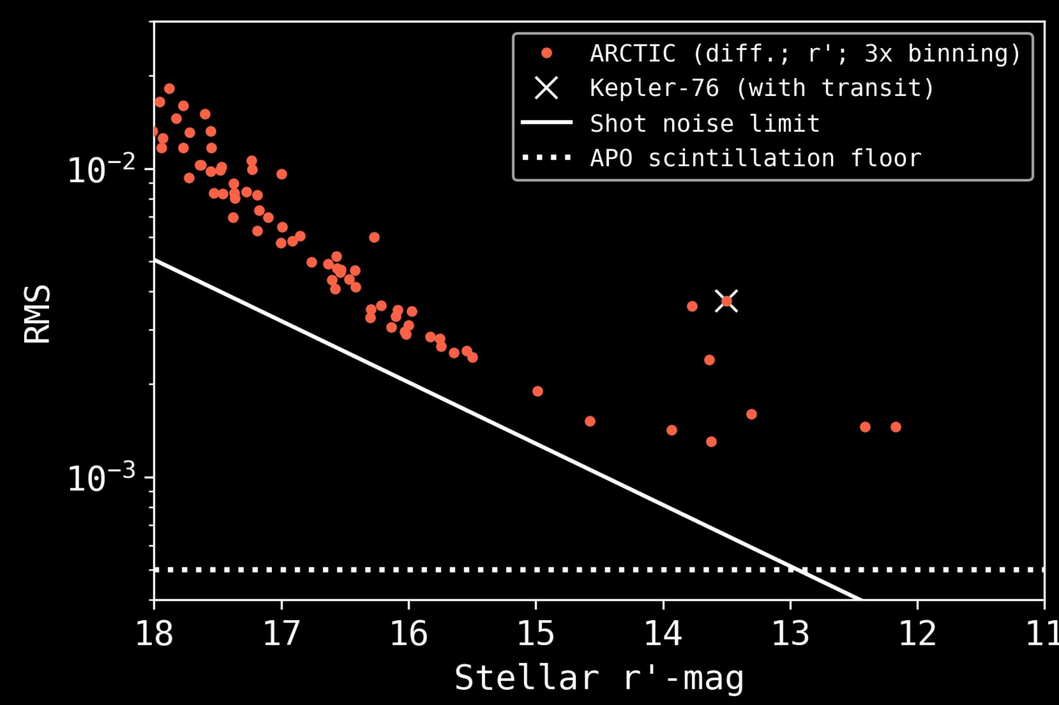
Systematics detrending



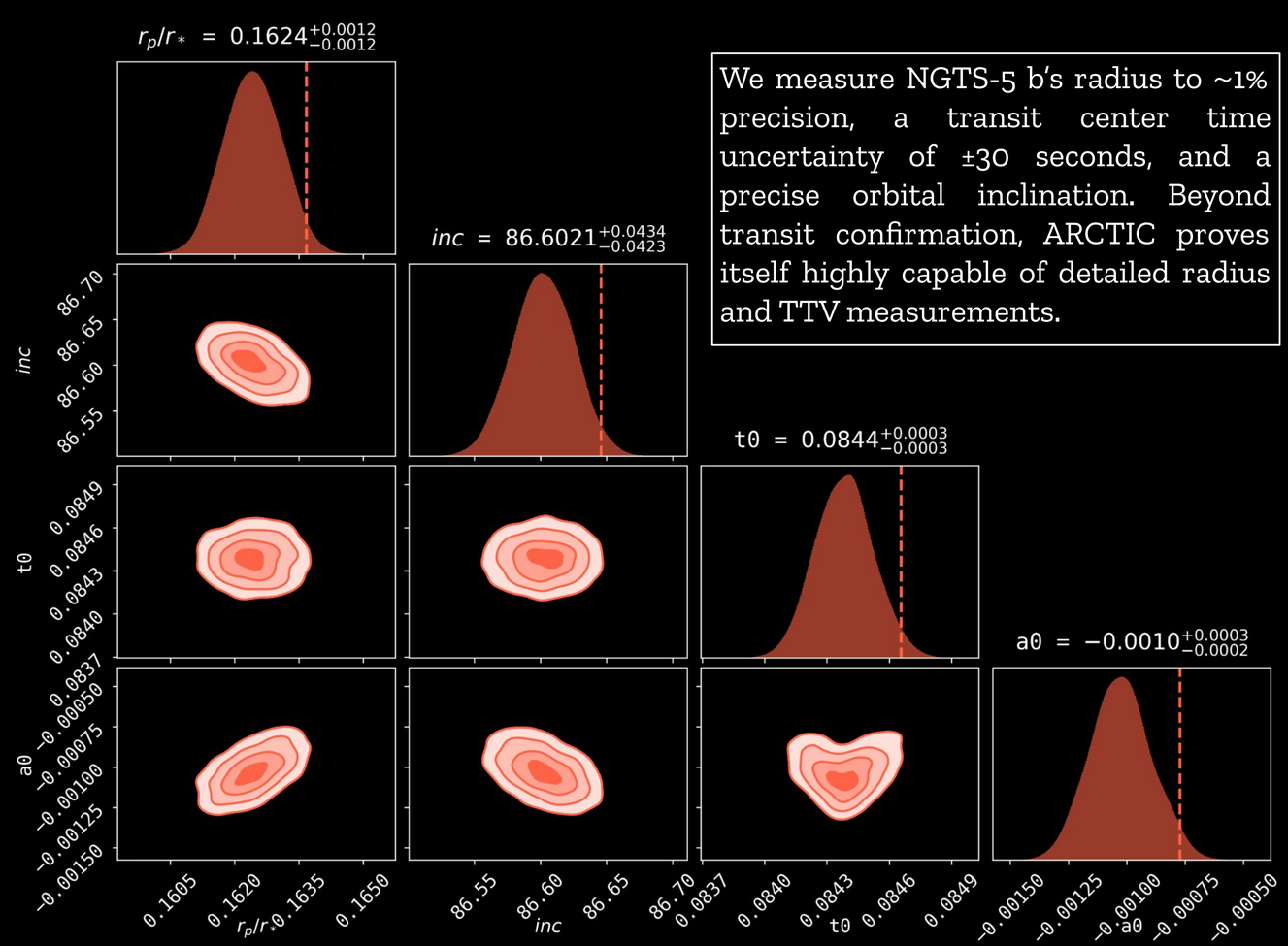
We perform aperture photometry on the dense starfield surrounding the hot Jupiter host Kepler-76. We find that the aperture radius should be optimized for the target's magnitude to achieve a lower RMS. This observation used 3x binning and 30s exposure times with the r′ filter.



An r′-band transit of the exciting inflated hot-Saturn NGTS-5 b (r′ = 13.5). A fortuitous bright nearby reference star enabled a systematics-free photometric light curve. We use a nested sampler to fit the planet's radius, orbital inclination, and time of transit, along with a scalar vertical offset. We find that this single transit improves upon the discovery paper's system constraints (Eigmüller et al., 2019).



The unbinned magnitude-RMS relation for a single night of observations with 30s exposure times. Stars brighter than 15th magnitude routinely achieve near-mmag precision. The shot noise limit and APO's scintillation noise floor are shown. Brighter stars deviate from the shot noise trend due to red-noise systematics, which can be largely detrended given a reference star of similar color and magnitude.



We measure NGTS-5 b's radius to ~1% precision, a transit center time uncertainty of ±30 seconds, and a precise orbital inclination. Beyond transit confirmation, ARCTIC proves itself highly capable of detailed radius and TTV measurements.

ARCTIC Precise Time Series Best Practices

- Take ~100+ flats at ~40k counts per pixel
- Study the flat field as you acquire your target and be sure to position it on clean pixels
- Dome flats are preferable to sky flats (only the high-order variations in the flat impact our photometry)
- Maximize the number of reference stars with similar color and magnitude in your FOV; allocate ~10 minutes to nudge and rotate your FOV around
- 3x or 2x binning is fine; use the "LL" amplifier in fast readout mode
- You don't need darks or biases, I promise
- Guide on a bright star
- Both g′ and r′ have the highest throughput and fairly few telluric lines, but most stars are brighter in r′
- Short, 20-60 second exposure times are ideal
- Thank your tech and Beware of Moths