Exploiting the transit timing capability of ARIEL high-precision photometry

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**Key points**

**ARIEL InfraRed Spectrometer (AIRS),** $R = 30 – 200$ between $1.95$ and $7.8 \ \mu m$.

**Chromatic light-curves from the spectra**

Fine Guidance Sensors (FGS), 3 photometric channels, between $0.5$ and $1.2 \ \mu m$ and low resolution NIR spectrometer at $1.2 – 1.95 \ \mu m$.

**High precision photometry at zero cost**

+ Cadence of up to $5 \ Hz$, simultaneously at multiple wavelengths.
+ Targeting bright stars will lead to high SNR light curves.
+ Uninterrupted observation of transit, out-of-transit and phase-curves.

**Fast sampling of the light curve**

- timing, ingress/egress, and second order effects (rings, moons, etc)

**IR photometry: smaller impact from limb darkening and stellar activity**
Transit Timing Variation (TTV)

Establish **planetary nature** of transiting planets

- multi-planet system characterisation
  - mass of the perturber (perturbers if more than one planets)
  - orbital **parameter determination** and degeneracy breaking

**architecture characterisation**: ~MMR, formation and evolution processes

complementary to RV for mass determination

\[ P \neq \text{const mutual interaction among planets} \]

Transit Timing Variation (TTV) w.r.t Linear Ephemeris

\[ T_{0,\text{lin}} = T_{0,\text{ref}} + P \times N \]

Agol+ 2005; Holman & Murray 2005
Transit Timing Variation (TTV)

KOI-142.01 – King of TTVs
close MMR 2:1
Nesvorný+ 2013

Kepler-9 – 2 transiting planets
close MMR 2:1 => anticorrelated TTV
Borsato+ 2014, 2019
set up ARIEL timing

ArielRad noise ppm/h for FGS 1 & 2 + noise floor 20 ppm

K2-24 b

Kmag = 9.18, M=1.07M☉, R=1.16R☉, Rp=5.4R⊕ (Neptune-size), P=20.89d

FGS1 noise 54 ppm/h

FGS2 noise 44 ppm/h

flux (only transit)

transit model with batman (Kreidberg 2015)
**K2-24 and the TTV baseline**

- **Petigura+ 2018**
- **min $\sigma_{T0,b} = 78s$**

![Graph showing TTV (days) over time with K2 & Spitzer observations](image_url)
K2-24 b

Kepler/K2: min $\sigma_{T0,b} = 78s$

$\sigma_{T0} = 35s$

batman (Kreidberg 2015) + emcee (Foreman-Mackey+ 2012)
**K2-24 b**

**FGS1**

**FGS2**

\[ \text{exposure} = 1.5s \Rightarrow \sigma_{T0} = 35s \]

\[ \text{exposure} = 30s \Rightarrow \sigma_{T0} = 35s \]

\[ \text{exposure} = 60s \Rightarrow \sigma_{T0} = 35s \]

**PHOTON-NOISE DOMINATED**

**batman (Kreidberg 2015) + emcee (Foreman-Mackey+ 2012)**

<table>
<thead>
<tr>
<th>exposure time / seconds</th>
<th>( \sigma_{T0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>35s</td>
<td>1.5s</td>
</tr>
<tr>
<td>35s</td>
<td>30s</td>
</tr>
<tr>
<td>35s</td>
<td>60s</td>
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K2-24 b ... what if ...

with one FGS channel of ARIEL we will obtain a transit time with an error of

\[ \sigma_{T0,b} \sim 53 \text{s} \]

that is still better than Kepler/K2-Spitzer, where

\[ \min \sigma_{T0,b} = 78 \text{s} \]
K2-24 Dynamical fit

synthetic Transit Times and Radial Velocities (realistic uncertainties and scatter)

dynamics with TRADES@https://github.com/lucaborsato/trades (Borsato+ 2014, 2019; Malavolta+ 2017)
K2-24 Dynamical fit

extended orbital integration to ARIEL launch (2028)

uncertainty on Transit Time greater than 3 hours

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dynamical fit with 1 Transit time from ARIEL of K2-24b

dynamics with TRADES@https://github.com/lucaborsato/trades (Borsato+ 2014, 2019; Malavolta+ 2017)
K2-24 Dynamical fit

dynamical fit with **1 Transit time** from ARIEL of K2-24b and **1 Transit time** of K2-24c

**planet b: transit times**

**planet c: transit times**

**1 Transits time** from ARIEL of K2-24b and **1 Transit time** of K2-24c

 dynamics with TRADES@https://github.com/lucaborsato/trades (Borsato+ 2014, 2019; Malavolta+ 2017)
K2-24 CHEOPS synergy

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take-home message

- **transit timing with ARIEL FGS1&2:** better precision (2x) than Kepler/K2
- **increase of the TTV baseline:** improvement of the orbital parameters (incl. masses) in known multi-planet systems
- **with ~10 ARIEL transits it is possible to independently detect TTV signals** allowing us to determine **planetary masses** with a precision better than 20% in the Earth-Neptune regime
- **synergy with CHEOPS** ⇒ ephemeris refinement
- this is part of the work within **WG High Cadence-Precision Photometry:**
  
  Luca Borsato, Gyula Szabo, Giampaolo Piotto, Valerio Nascimbeni, Robert Szabo, Kristián Vida, Amaury Triaud, Carole Haswell, Dave Waltham