Astrophysical and Instrumental Noise Sources: Transits

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Why do we care about noise?

Take the example of the Kepler mission – the primary goal was determining the occurrence rate of Earth-like planets around sun-like stars.

That’s hard! Earth creates a 85ppm deep transit.

Mission design has to account for all the known sources of noise – error budget of 20ppm in 6.5h.

How big a telescope do we need to build?
How faint a star can we look at?
What kind of stars can we look at?
How expensive a detector do we need to buy?
What is the overall noise floor achievable?
Stars do stuff!

Spacecraft do stuff!

planet + star + space craft + detector = signal

Credit: Dan Foreman-Mackay, Davos
Overview

Telescopes do stuff!

Atmospheres do stuff!

Stars do stuff!

(Related to)

(Planets do stuff, too!)

Detectors do stuff!

Credit: Dan Foreman-Mackay, Davos
Stars do stuff...

**Flares**
- < 15 min
- < 1 m/s (only active M)

**Granulation**
- 15 min - 2 d
- a few m/s (Dumusque+ 11)

**Oscillations**
- Kjeldsen+ 95, Bouchy & Carrier 01, Butler+ 04, Bedding & Kjeldsen 07

**Magnetic Cycles**
- 1-20 m/s (Lovis+ 11)
- Makarov 10, Dumusque+ 11
- Dumusque+ 12, Meunier+ 13

**Stellar Signals**
- Lindegren & Dravins 03

**Active Regions**
- Saar & Donahue 97, Queloz+ 01
- Hatzes 02, Meunier+ 10,
- Boisse+ 11, Dumusque+ 11,
- Lanza+ 11, Aigrain+12,
- Boisse+ 12, Reiners+ 13,
- Dumusque+ 14, Haywood+ 14,
- Rajpaul+ 15, Haywood+ 16

**Gravitational Redshift**
- < 10 cm/s (Cegla+12)
- ~ 10 yrs
- 10 d - 10 yrs
- 10 - 50 d

Credit: Xavier Dumusque
Stars do stuff...

Oscillations (<15 minutes, <1%)

Granulation (15min - 2 days, <0.1%)

Magnetic activity - spots (2 days to weeks, <10%)
- flares (stochastic, <few%)

Pulsations (mins to yrs, <10s of %)

Eclipses (hrs to yrs, <50%)

Credit: NASA/SDO

Davenport et al. 2014

Molner+2014

Christiansen, PhD thesis, 2007

Credit: Arcetri Solar Physics Group/NSO

Paz - Chinchon+2015

Stars do stuff...
Different stars do different stuff...

Subgiant, giant stars;
Oscillations, pulsations

FGK dwarf stars;
Oscillations,
Granulation,
Spots

M dwarf stars;
Spots, flares

Christiansen+2012
Telescopes do stuff...

They typically have pointing jitter

- Intra-pixel variations, e.g. Spitzer, K2 (not Kepler!)

irachpp.spitzer.caltech.edu

Christiansen+2010
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Vanderburg+2016
Telescopes do stuff...

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• Intra-pixel variations, e.g. Spitzer, K2 (not Kepler!)
• Inter-pixel variations, e.g. EPOCh

Christiansen+2010
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• Inter-pixel variations, e.g. EPOCh

They experience thermal variations, e.g. Kepler

Smith+2012

Cadence Index
The atmosphere does stuff...

Essentially it changes transparency as a function of time, via:

- **Airmass** (colour-dependent extinction)
- **Humidity** (precipitable water vapour)
- **Variable sky background, cloud cover**

And the point spread function of the light also changes:

- **Seeing** (temperature, airmass, windspeed); similar effects to thermal changes

Often on similar timescales to transits

Generally affect all stars, can be treated with common mode models (PCA, SVD, etc).

Christiansen, PhD thesis, 2007

Berta+2012
Christiansen+2013
6.3 Video Crosstalk
6.4 Science Clock and Video Crosstalk into FGS
6.5 Start-of-Line Ringing
6.6 Undershoot
6.7 Aliased High Frequency Noise
6.8 Long Cadence Artifact Removal Pixels (ARPs)
Detectors do stuff...
Detectors do stuff...

3 years of data...

4 years of data...

372 days!

Tenenbaum+2014
Summary

There is a lot standing between you and a clean transit signal!

You can make clever choices in order to minimise/mitigate/isolate noise sources (or at least the timescales of those noise sources)
- Target selection
- Stability of instrument
- The more the merrier, for treating common mode systematics)

For remaining (and sometimes unavoidable) noise sources, exoplaneteers have been relying on increasingly sophisticated noise models (e.g. Gaussian process) – see rest of #sagan2016!