



# Praktická astrofyzika

## Data z vesmírných fotometrických misí

Marek Skarka

12.12.2022

# The photometric method of detecting other planetary systems

Show affiliations

Borucki & Summers 1984, *Icarus*, 58, 121

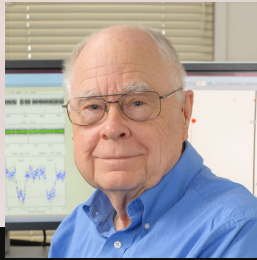
[Borucki, W. J.](#); [Summers, A. L.](#)

The photometric method detects planets orbiting other stars by searching for the reduction in the light flux or the change in the color of the stellar flux that occurs when a planet transits a star. A transit by Jupiter or Saturn would reduce the stellar flux by approximately 1% while a transit by Uranus or Neptune would reduce the stellar flux by 0.1%. A highly characteristic color change with an amplitude approximately 0.1 of that for the flux reduction would also accompany the transit and could be used to verify that the source of the flux reduction was a planetary transit rather than some other phenomenon. Although the precision required to detect major planets is already available with state-of-the-art photometers, the detection of terrestrial-sized planets would require a precision substantially

greater than the state-of-the-art and a spaceborne platform to avoid the effects of variations in sky transparency and scintillation. Because the probability is so small of observing a planetary transit during a single observation of a randomly chosen star, the search program must be designed to continuously monitor hundreds or thousands of stars. The most promising approach is to search for large planets with a photometric system that has a single-measurement precision of 0.1%. If it is assumed that large planets will have long-period orbits, and that each star has an average of one large planet, then approximately  $10^4$  stars must be monitored continuously. To monitor such a large groups of stars simultaneously while maintaining the required photometric precision, a detector array coupled by a fiber-optic bundle to the focal plane of a moderate aperture ( $\approx 1$  m), wide field of view ( $\approx 50^\circ$ ) telescope is required. Based on the stated assumptions, a detection rate of one planet per year of observation appears possible.



William Borucki



# Kepler

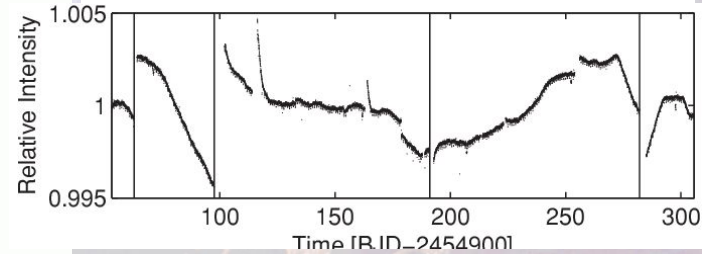
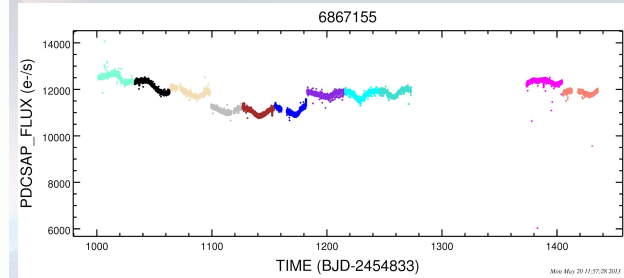
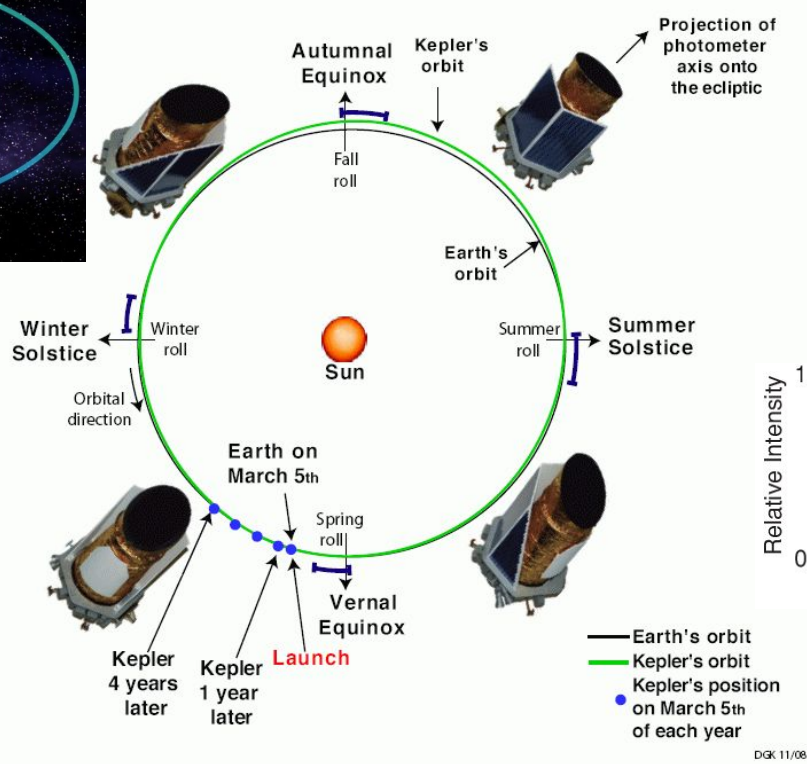
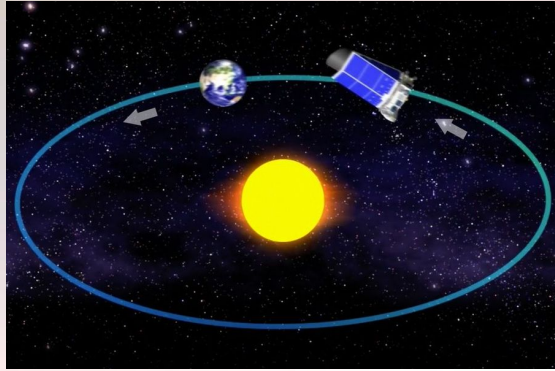
NASA



Provoz	květen 2009–říjen 2018 (došlo palivo)
Úkoly	Výskyt planet podobných Zemi Výskyt multiplanetárních systémů Statistika velikostí planet a jejich drah Vlastnosti mateřských hvězd
Dráha	Heliocentrická, 1 au, 372.5 dní
Strategie pozorování	1 (Cyg+Lyra)+19 polí (okolo ekliptiky), 4 roky + 19x80 dní
Rozměry a váha	1050 kg, 4.7x2.7 m
Optika	0.95m deska, 1.4m f/1 zrcadlo
Detektor	42 2kx1k CCD (94.6 Mpx)
Zorné pole	10.5°x10.5°
Kadence	1 nebo 30 minut
Přesnost na 15 mag	300 ppm/h
Rozlišení	4"/px
Objevených planet	~3200
Celkový počet objektů	530000, 8-16 mag

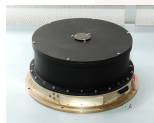
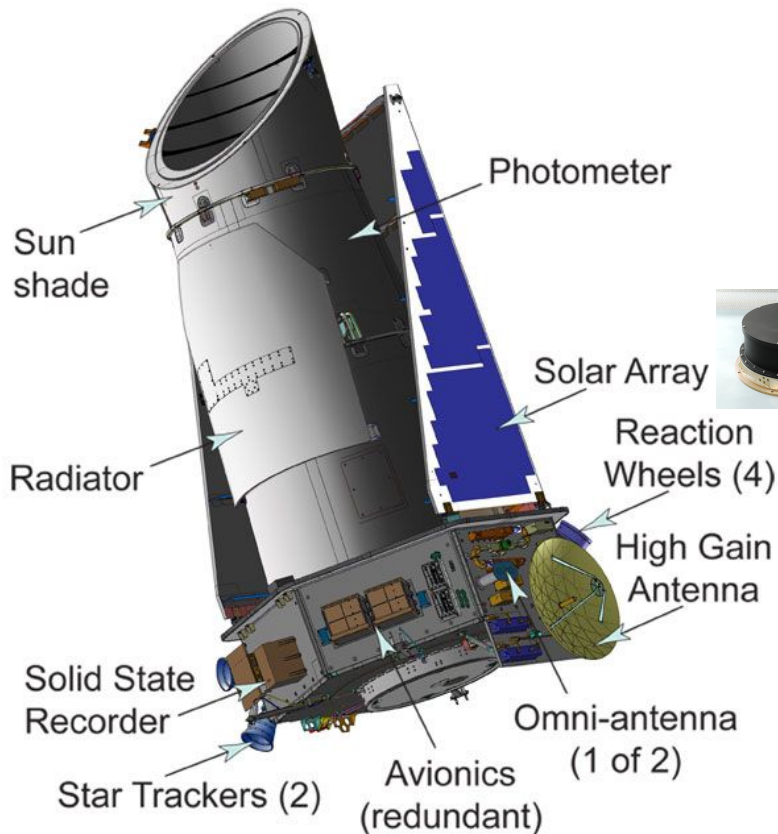
# Kepler - dráha

Primární 4-letá mise - nepřetržité pozorování jednoho pole => nemůže obíhat okolo Země -> oběh okolo Slunce



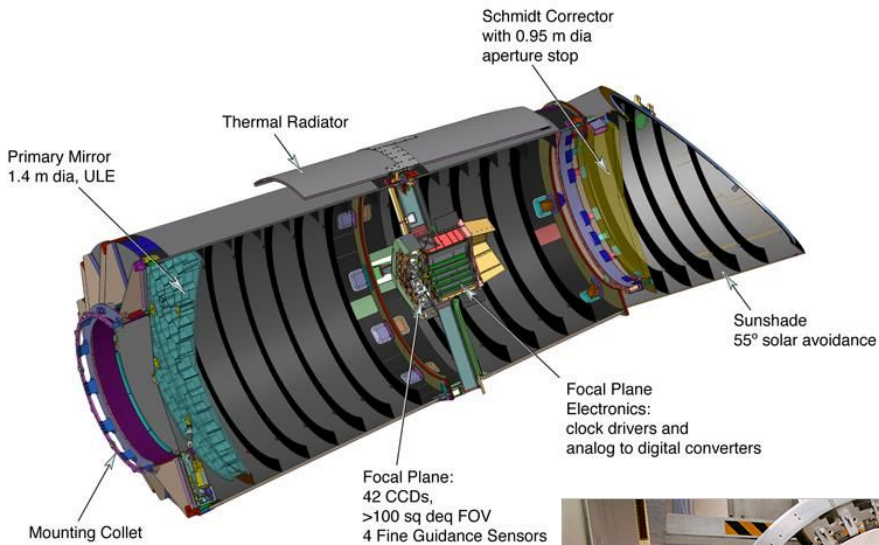
Každých 93 dní rotace o 90° - data rozdělena na tzv. Quarters + skoky v datech

# Kepler - dalekohled



Provoz	květen 2009-říjen 2018 (došlo palivo)
Úkoly	Výskyt planet podobných Zemi Výskyt multiplanetárních systémů Statistika velikostí planet a jejich drah Vlastnosti mateřských hvězd
Dráha	Heliocentrická, 1 au, 372.5 dní
Strategie pozorování	1 (Cyg+Lyra)+19 polí (okolo ekliptiky), 4 roky + 19x80 dní
Rozměry a váha	1050 kg, 4.7x2.7 m
Optika	0.95m deska, 1.4m f/1 zrcadlo
Detektor	42 2kx1k CCD (94.6 Mpx)
Zorné pole	10.5°x10.5°
Kadence	1 nebo 30 minut
Přesnost na 15 mag	300 ppm/h
Rozlišení	4"/px
Objevených planet	~3200
Celkový počet objektů	530000, 8-16 mag

# Kepler - dalekohled



Provoz	květen 2009-říjen 2018 (došlo palivo)
Úkoly	Výskyt planet podobných Zemi Výskyt multiplanetárních systémů Statistika velikostí planet a jejich drah Vlastnosti mateřských hvězd
Dráha	Heliocentrická, 1 au, 372.5 dní
Strategie pozorování	1 (Cyg+Lyra)+19 polí (okolo ekliptiky), 4 roky + 19x80 dní
Rozměry a váha	1050 kg, 4.7x2.7 m
Optika	0.95m deska, 1.4m f/1 zrcadlo
Detektor	42 2kx1k CCD (94.6 Mpx)
	10.5°x10.5°
	1 nebo 30 minut
	300 ppm/h
	4"/px
	~3200
	530000, 8-16 mag

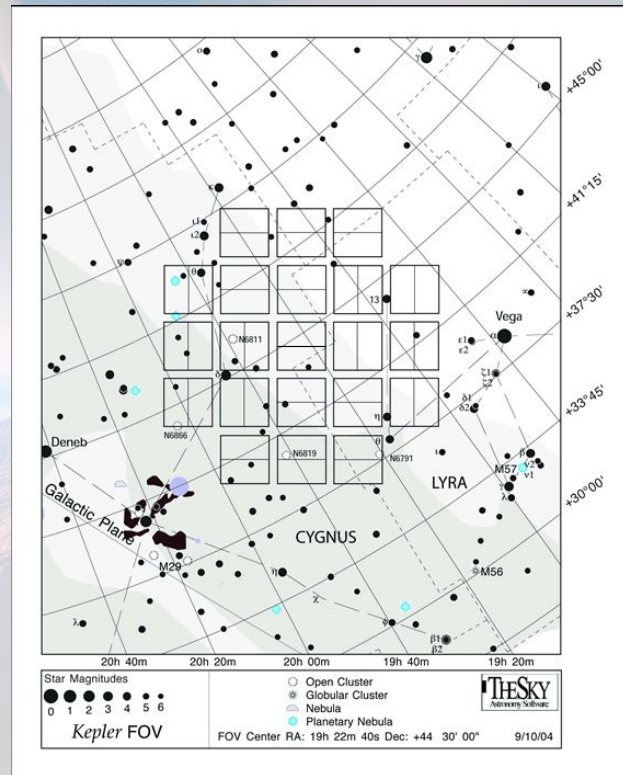
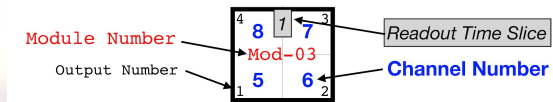
# Kepler - detektor



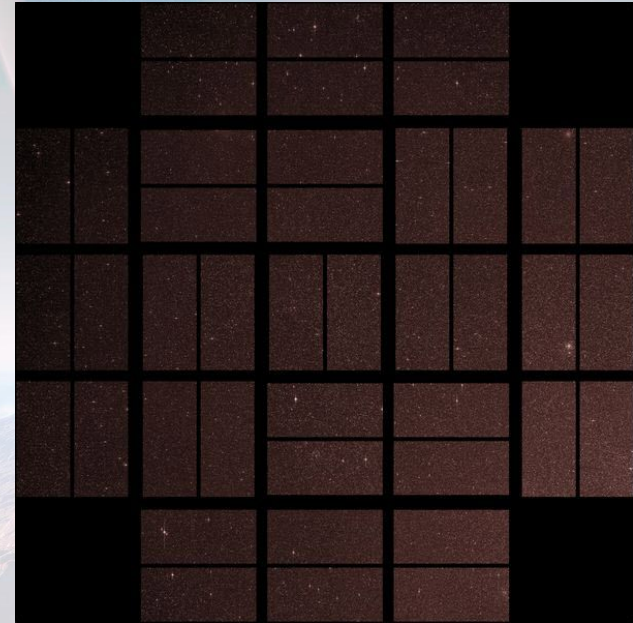
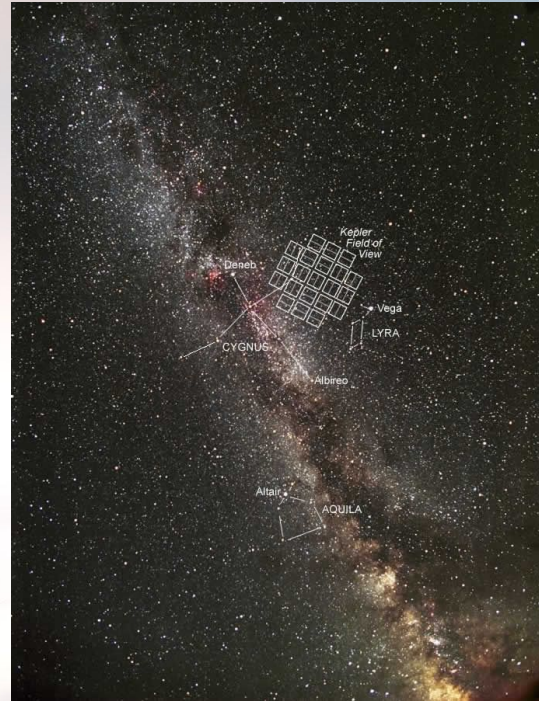
**Kepler Focal Plane Layout**

ECA-504	ECA-503	ECA-502	ECA-501	ECA-500
Mod-01 FGS2-CH1	4 4 3 Mod-02	4 8 7 3 Mod-03	12 3 11 Mod-04	Mod-05 FGS1-CH2
1	1 2	1 5 6 2	9 10 2	1
3 15 3 14 Mod-06	4 20 5 19 Mod-07	4 24 2 23 Mod-08	1 25 4 28 Mod-09	1 29 1 32 Mod-10
4 16 13 1	4 17 18 2	4 21 22 2	4 26 27 3	4 30 31 3
3 35 4 34 Mod-11	3 39 7 38 Mod-12	3 43 3 42 Mod-13	1 45 5 48 Mod-14	1 49 2 52 Mod-15
4 36 33 1	4 40 37 1	4 44 41 1	4 46 47 3	4 50 51 3
3 55 5 54 Mod-16	3 59 2 58 Mod-17	2 62 4 61 Mod-18	2 66 1 65 Mod-19	1 69 3 72 Mod-20
4 56 53 1	4 60 57 1	4 63 64 4	4 67 68 4	4 70 71 3
1	2 74 3 73 Mod-21	2 78 5 77 Mod-23	2 82 2 81 Mod-24	1 Mod-25
FGS2-CH2	3 75 76 4	3 79 80 4	3 83 84 4	FGS1-CH1

- 6s expozice, které se skládají do 1min a 30min
- vyčítají se jen předdefinované polohy (tzv. stamps)
- 3 moduly postupně odešly



# Kepler - detektor

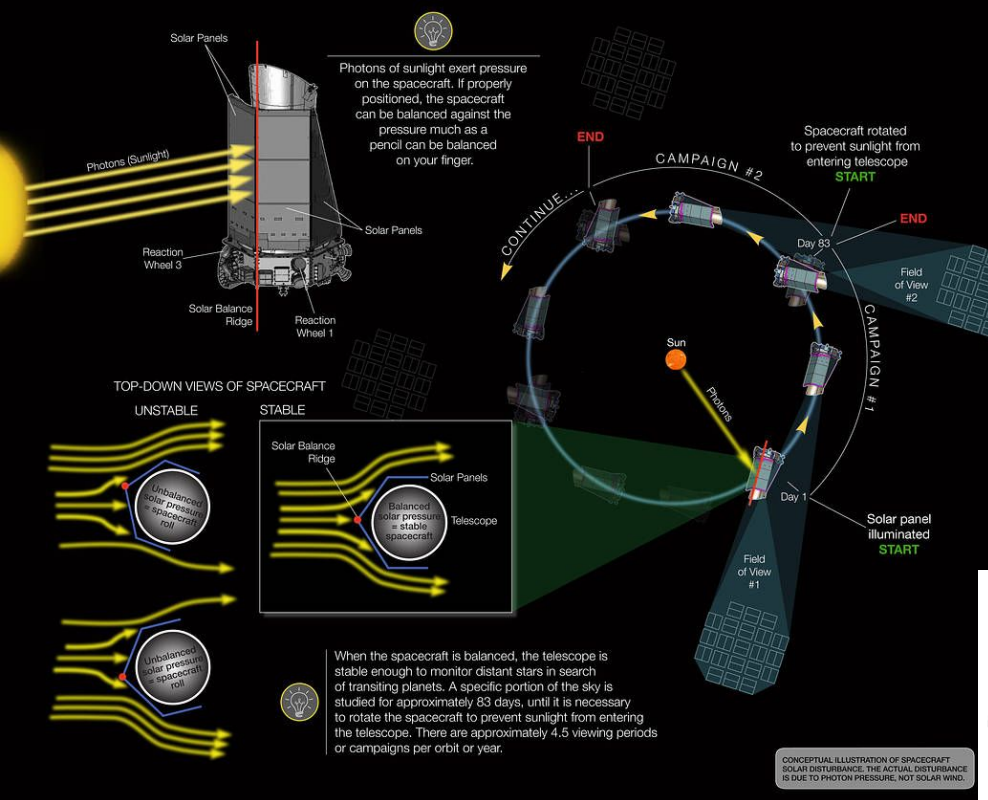


- 6s expozice, které se skládají do 1min a 30min
- vyčítají se jen předdefinované polohy (tzv. stamps)
- 3 moduly postupně odešly

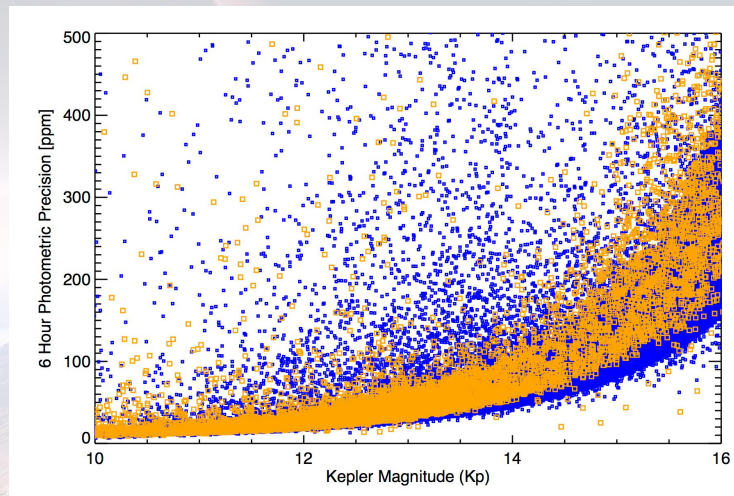


# Kepler - K2

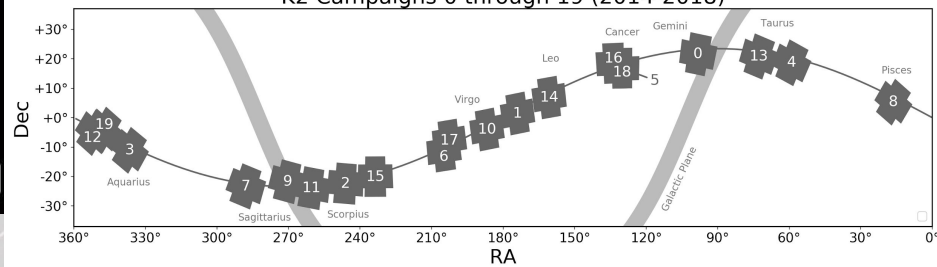
## Kepler's Second Light: How K2 Will Work



Po poruše druhého gyroskopu - náhradní mise od 2014, 19 polí okolo ekliptiky po ~80 dnech



K2 Campaigns 0 through 19 (2014-2018)

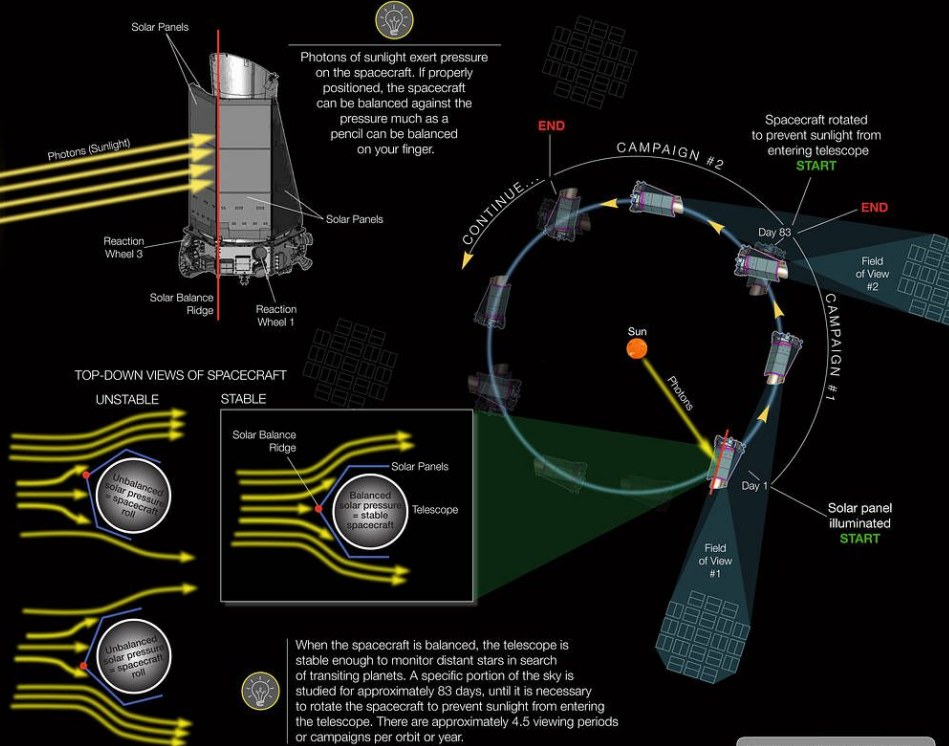


# Kepler - K2

## Kepler's Second Light: How K2 Will Work

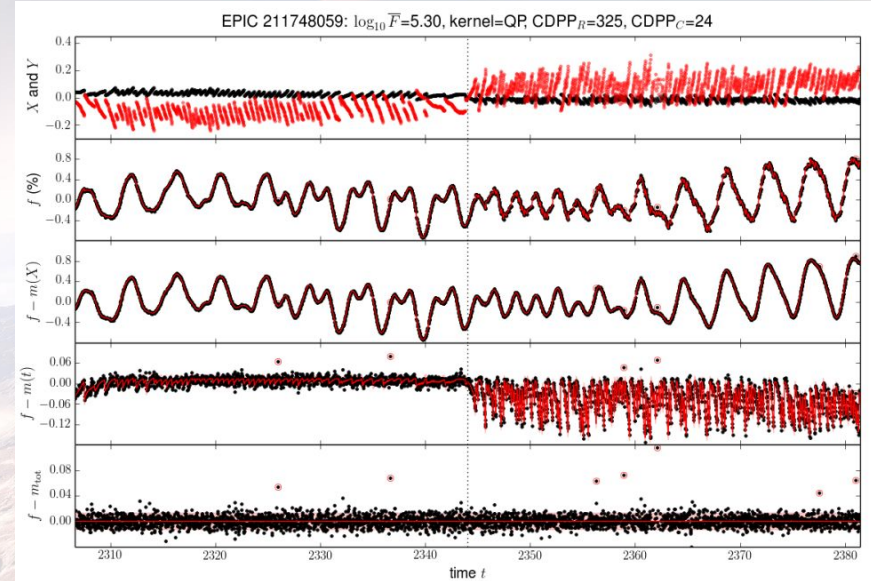


Photons of sunlight exert pressure on the spacecraft. If properly positioned, the spacecraft can be balanced against the pressure much as a pencil can be balanced on your finger.



CONCEPTUAL ILLUSTRATION OF SPACECRAFT SOLAR DISTURBANCE. THE ACTUAL DISTURBANCE IS DUE TO PHOTON PRESSURE, NOT SOLAR WIND.

Po poruše druhého gyroskopu - náhradní mise od 2014, 19 polí okolo ekliptiky po ~80 dnech



# TESS (Transiting Exoplanet Survey Satellite)



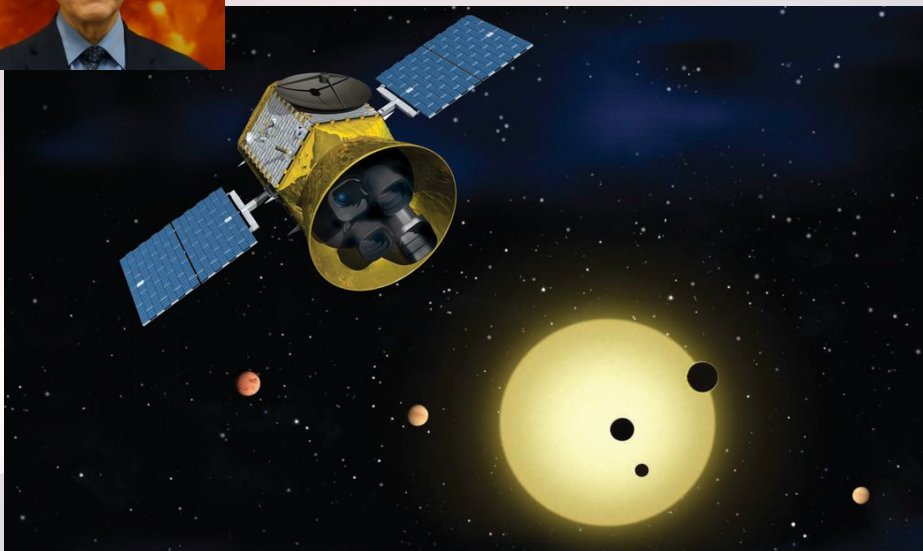
Massachusetts Institute of Technology (MIT) a Smithsonian Astrophysical Observatory (SAO); NASA

Start 18. dubna 2018, začátek měření 24.7.2018

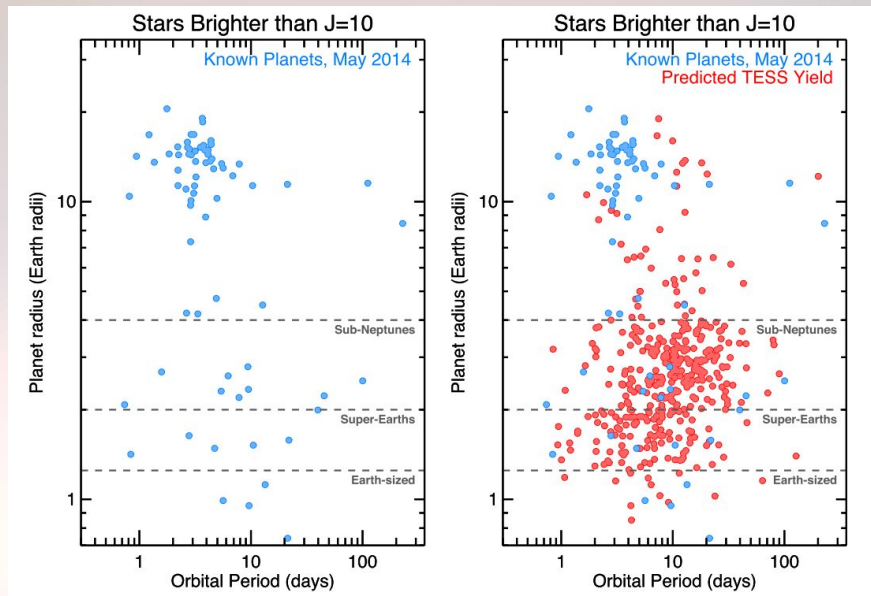
Provoz	duben 2018-
Úkoly	Exoplanety u jasných hvězd, F5-M5, asteroseismologie, kandidáti pro JWST
Dráha	Vysoká geocentrická, 13.7 dní
Strategie	x polí, 27.4-352 dní
Rozměry a váha	327 kg, 3.7x1.2x1.5 m
Optika	0.1m, f/1.4
Detektor	4x 2kx2k CCD (x4)
Zorné pole	4x24°x24°
Kadence	2 nebo 30 minut
Přesnost na 10 mag	200 ppm při 1-hodinové expozici
Rozlišení	21"/px
Objevených planet	268, 5931 kandidátů (listopad 2022)
Celkový počet objektů	200000 2min, 1 min, 10 <sup>9</sup> 30min, 3-15 mag

<https://tess.mit.edu/>

Ricker et al. 2014, SPIE, 914, 20



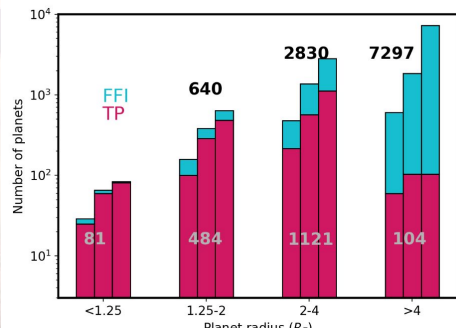
# TESS (Transiting Exoplanet Survey Satellite)



Start 18. dubna 2018, začátek měření 24.7.2018

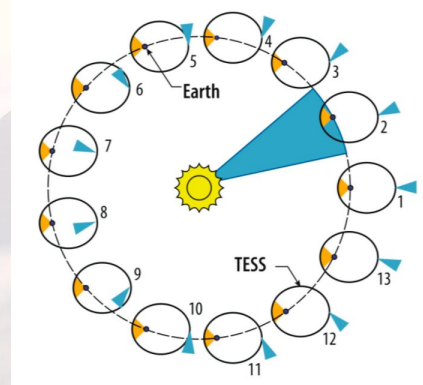
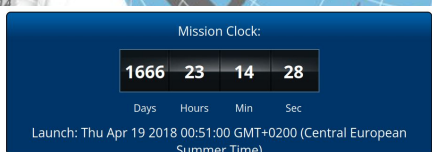
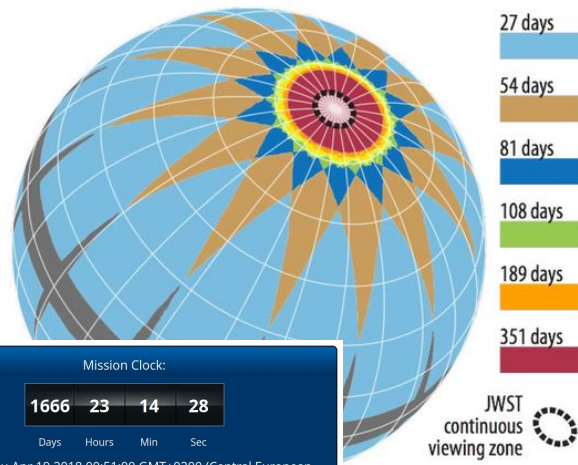
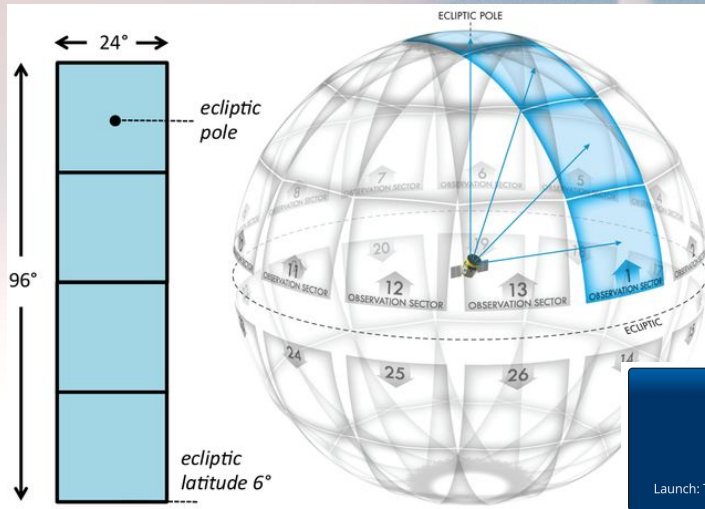
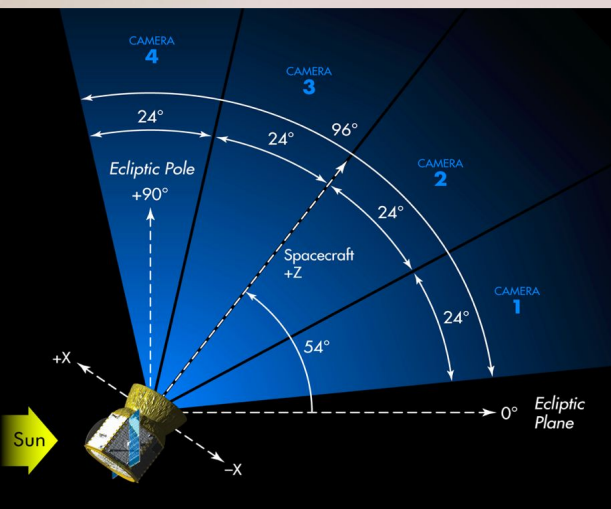
Provoz	duben 2018-
Úkoly	Exoplanety u jasných hvězd, F5-M5, asteroseismologie, kandidáti pro JWST
Dráha	Vysoká geocentrická, 13.7 dní
Strategie	x polí, 27.4-352 dní
Rozměry a váha	327 kg, 3.7x1.2x1.5 m
Optika	0.1m, f/1.4
Detektor	4x 2kx2k CCD (x4)
Zorné pole	4x24°x24°
Kadence	2 nebo 30 minut
Přesnost na 10 mag	200 ppm při 1-hodinové expozici
Rozlišení	21"/px
Objevených planet	268, 5931 kandidátů (listopad 2022)
Celkový počet objektů	200000 2min, 1 min, 10 <sup>9</sup> 30min, 3-15 mag

Ricker et al. 2014, SPIE, 914, 20

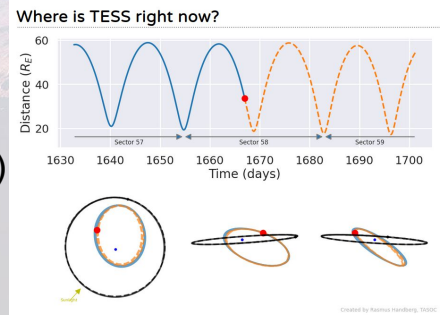


Huang et al. 2018, arXiv:1807.11129

# TESS - strategie

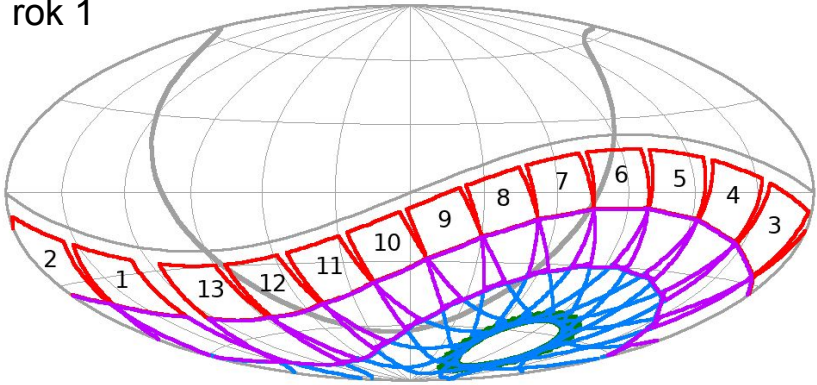


26 sektorů, každý 2x13.7 dne.  
Momentálně sektor 58 (69 celkem+?)

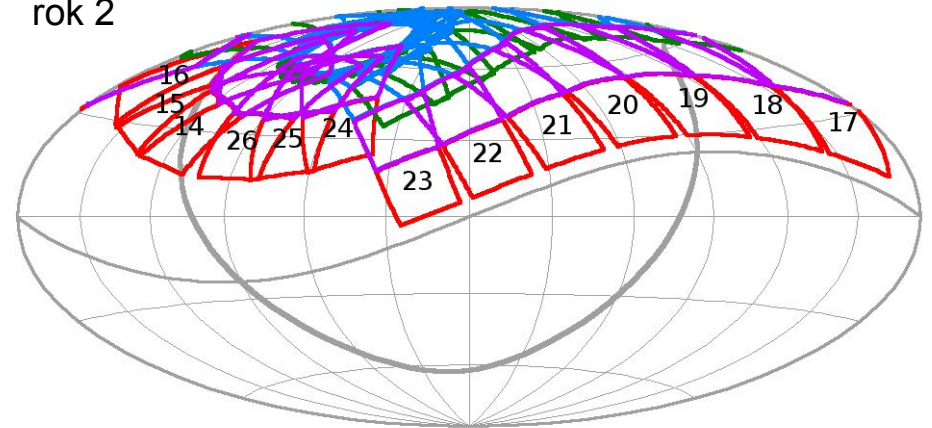


# TESS - strategie

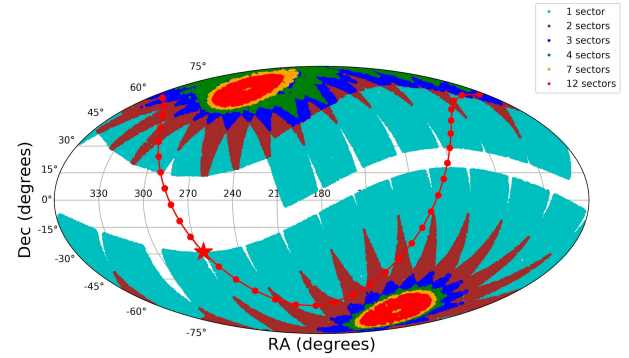
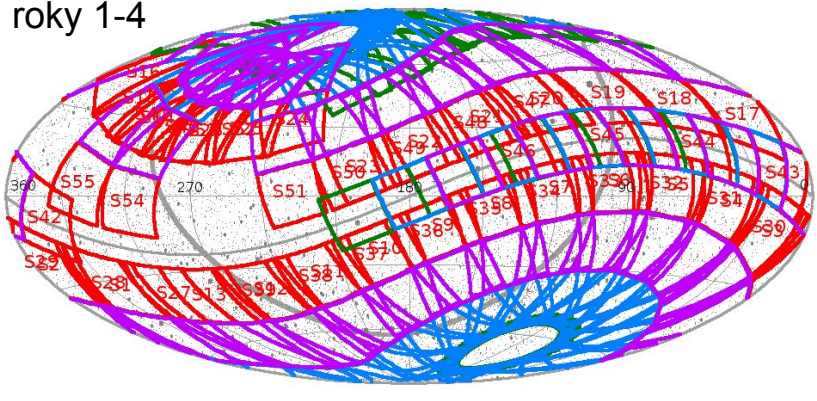
rok 1



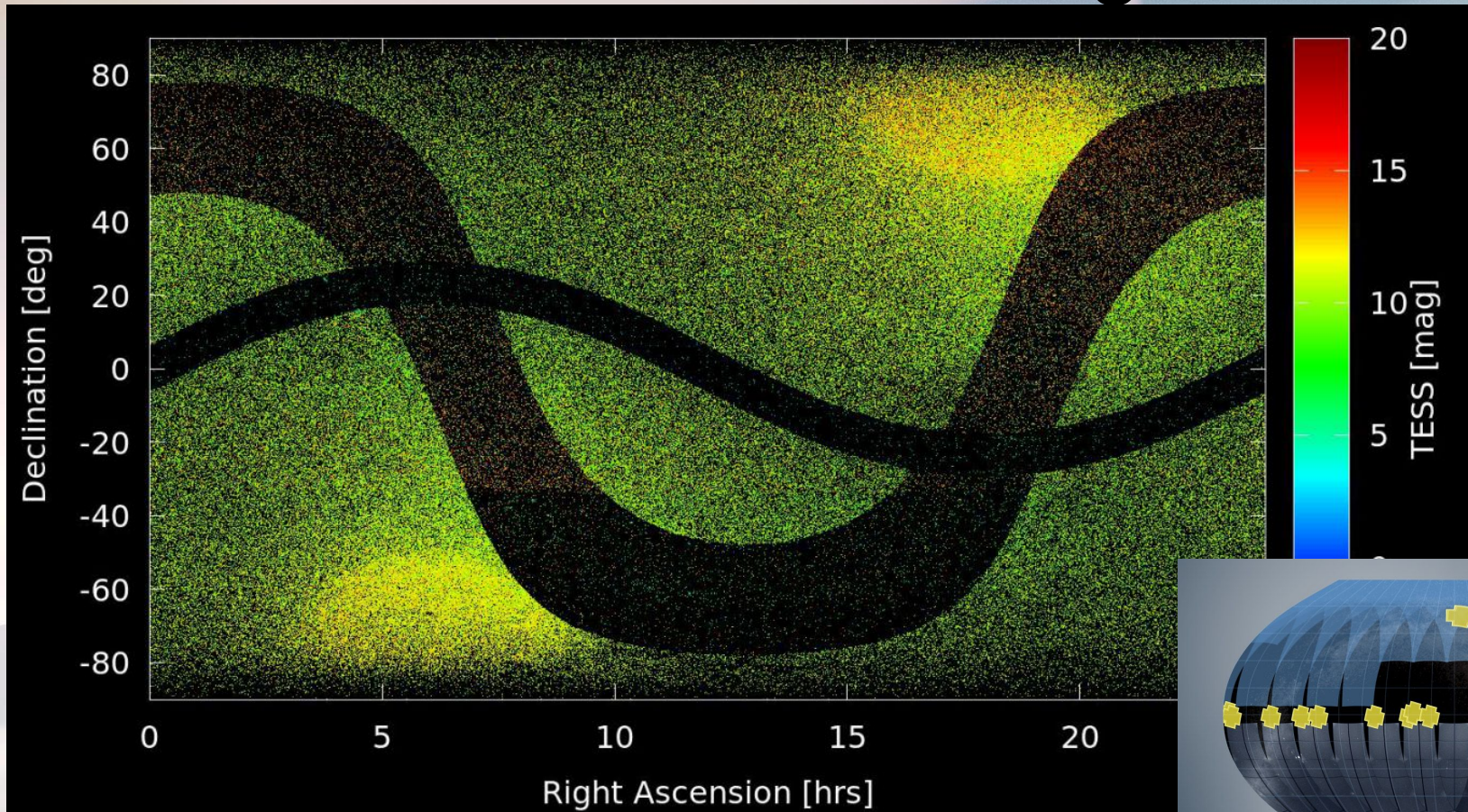
rok 2



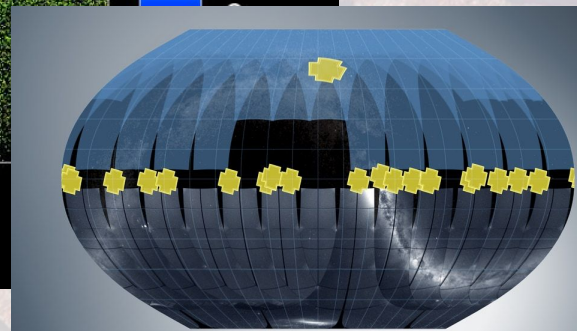
roky 1-4



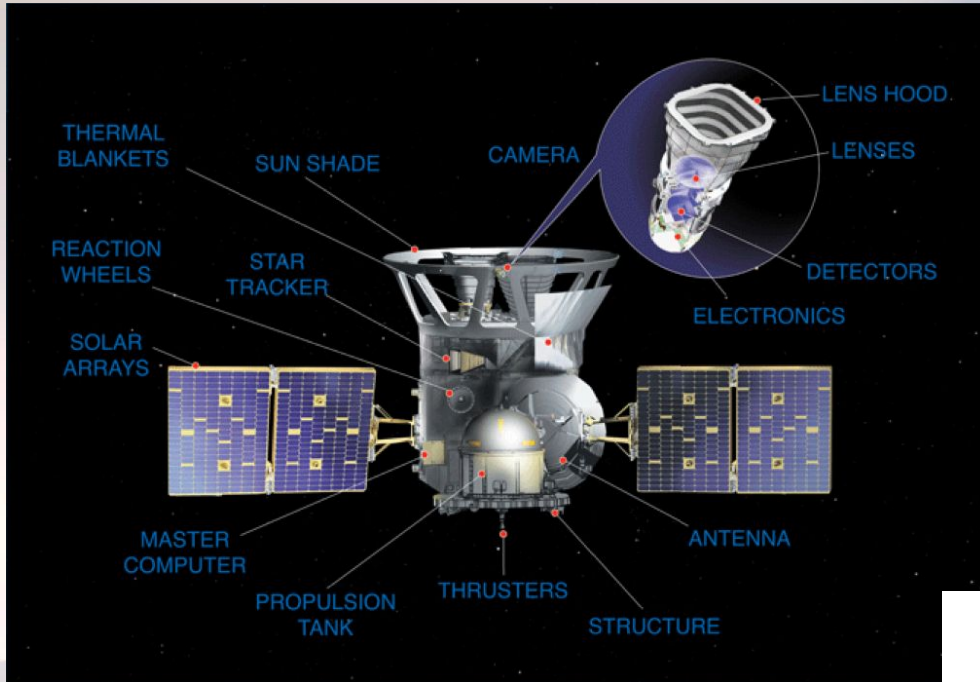
# TESS - strategie



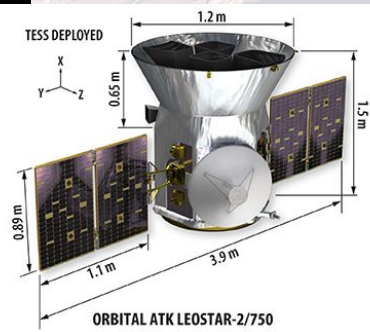
400x větší  
plocha než  
Kepler



# TESS - strategie

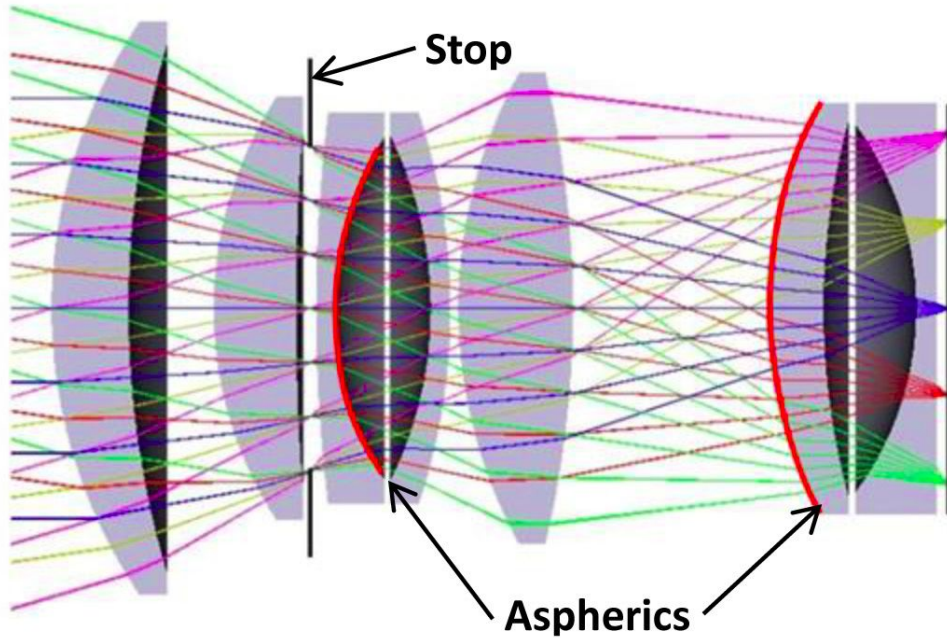


2x192 GB SSD  
Přenos 100 Mbit/s  
Pracovní výkon 290 W (415 W solární panely)  
Pracovní teplota  $\sim -75^{\circ}\text{C}$



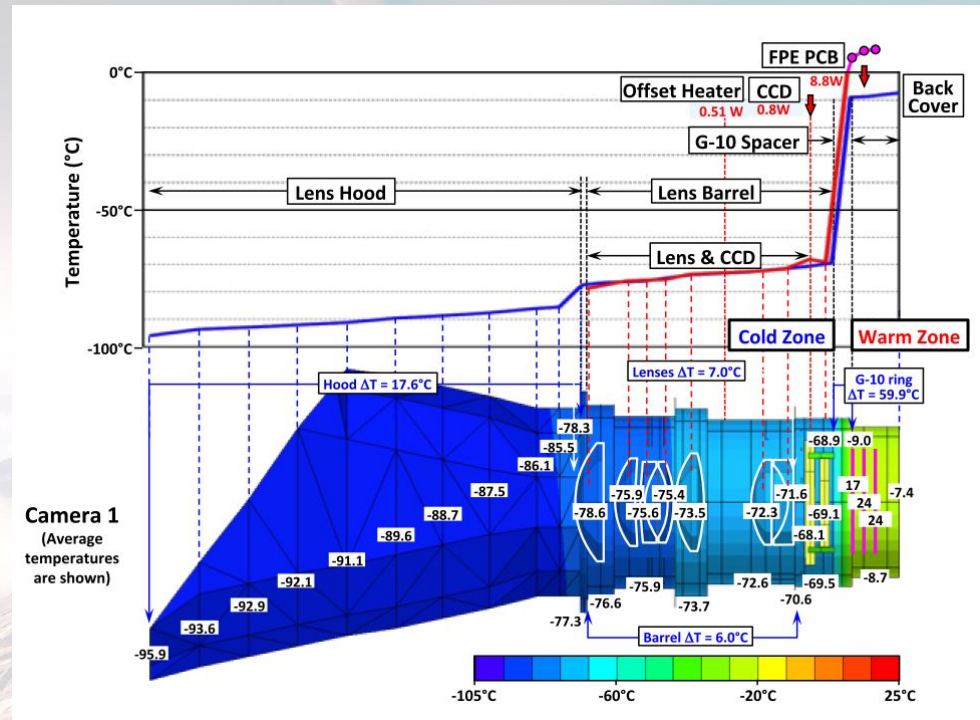
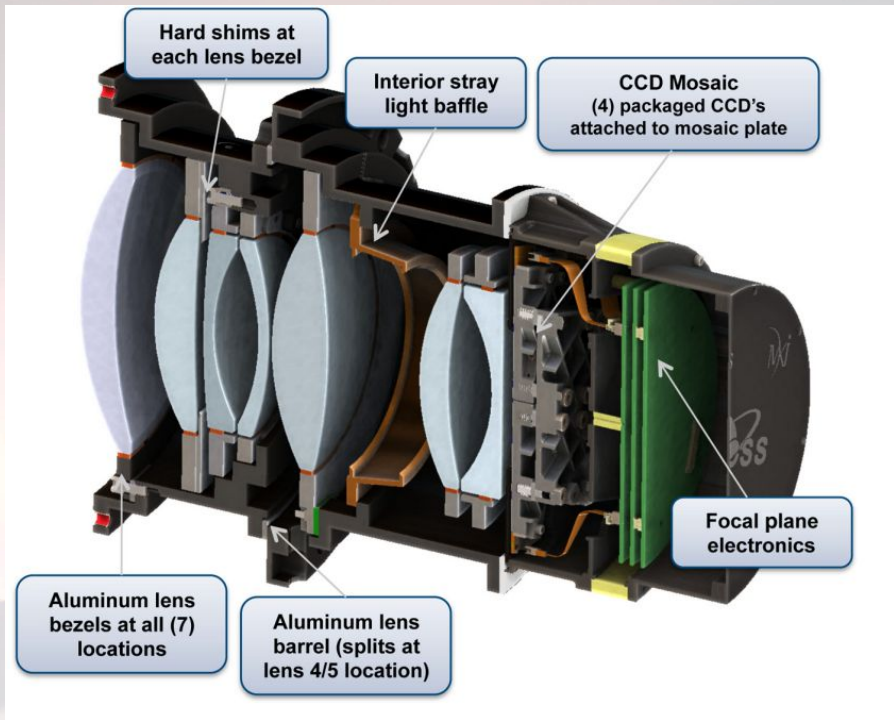


# TESS - parametry

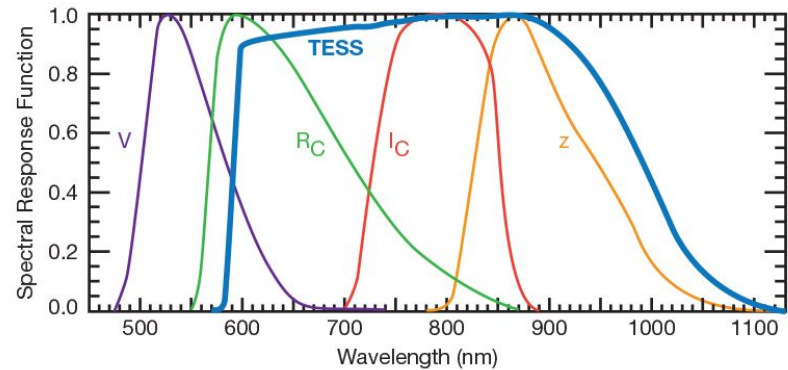
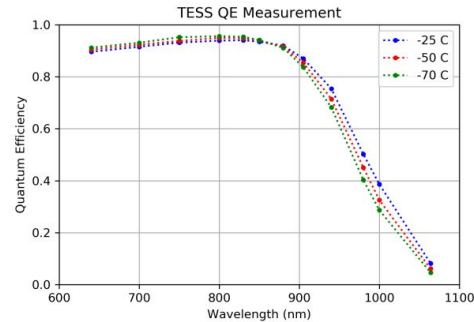
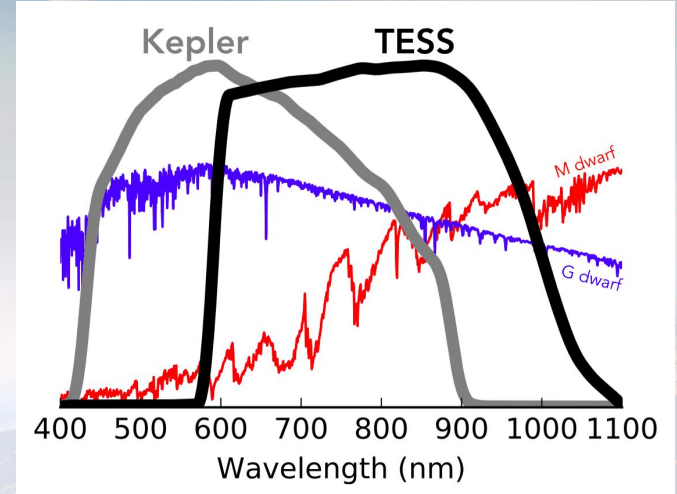
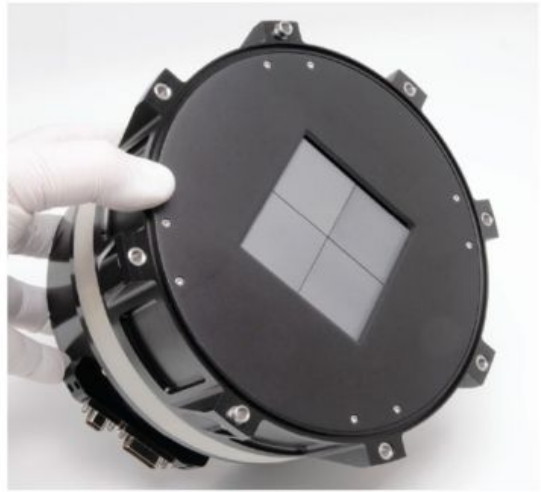
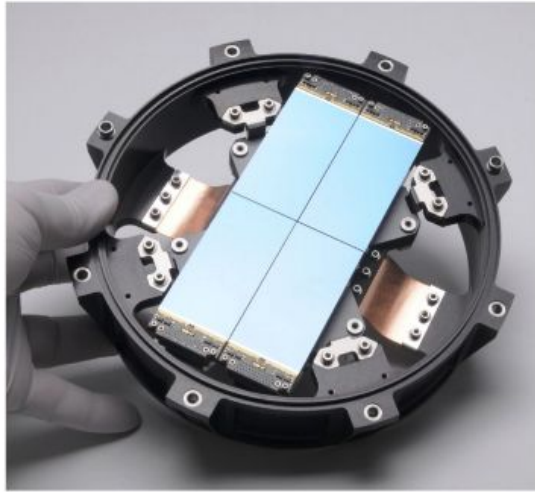


Parameter	Value
FOV	24° x 24°
FL, f/#	146 mm, f/1.4
EPD	105 mm
Wavelengths	600-1000 nm
CCD	2 x 2 detector arrays 4k x 4k pixels
Detector arrays	2048 x 2048 15 micron pixels
Transmittance	86.5% (with filter)
Mass	9.3 kg
Dimensions	17.0 cm diameter 21.1 cm long

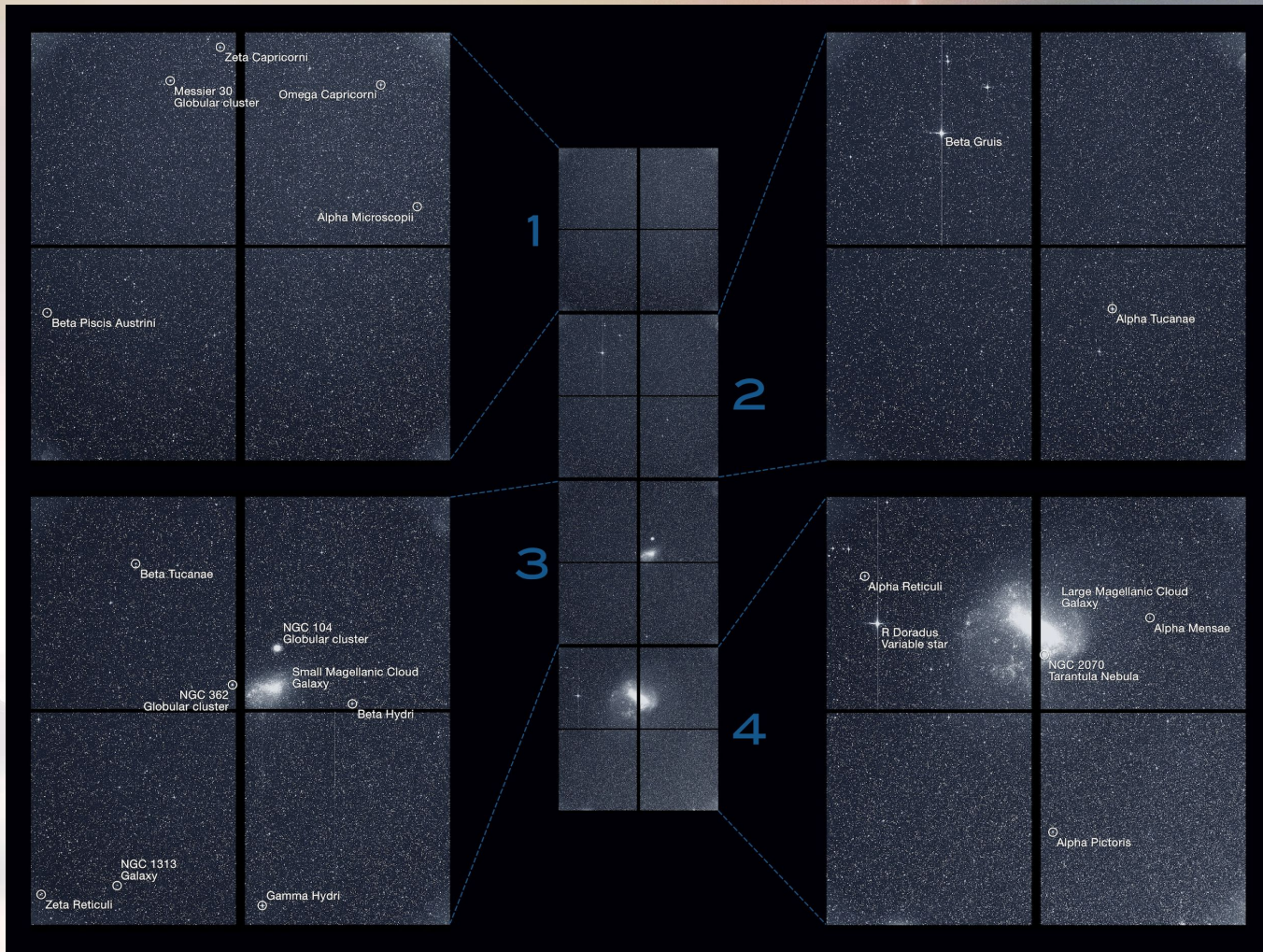
# TESS - parametry



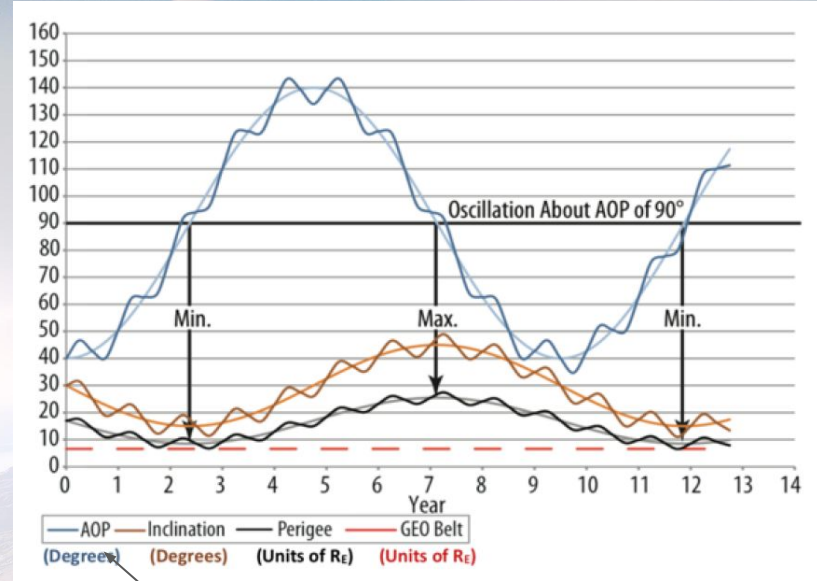
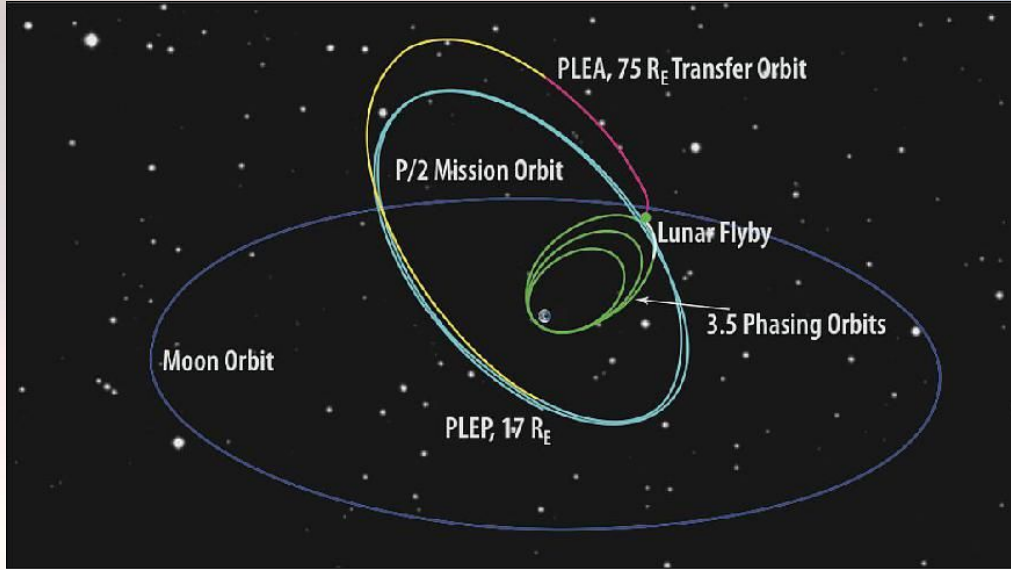
# TESS - parametry



# Sektor 1



# TESS - oběžná dráha



Argument perigea

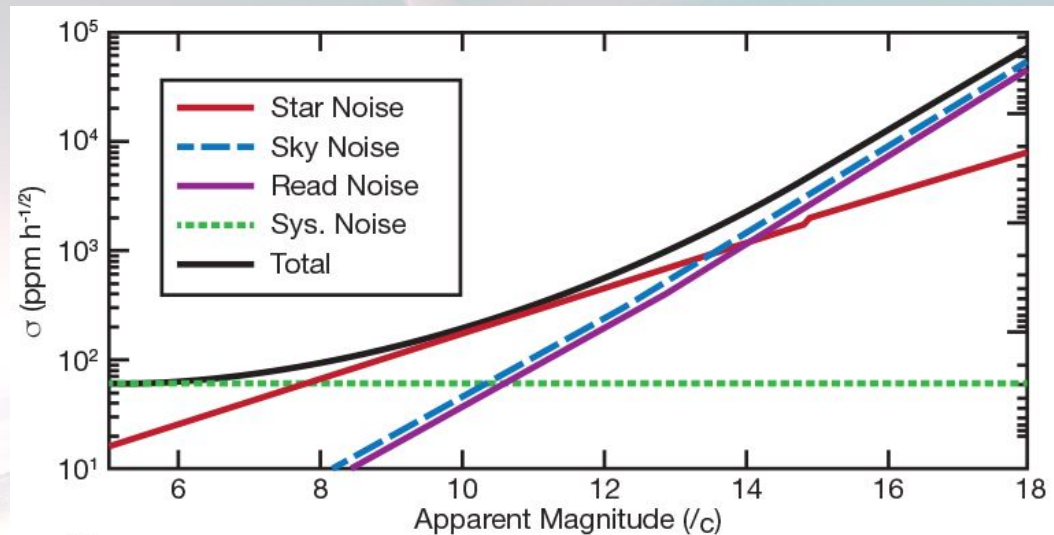
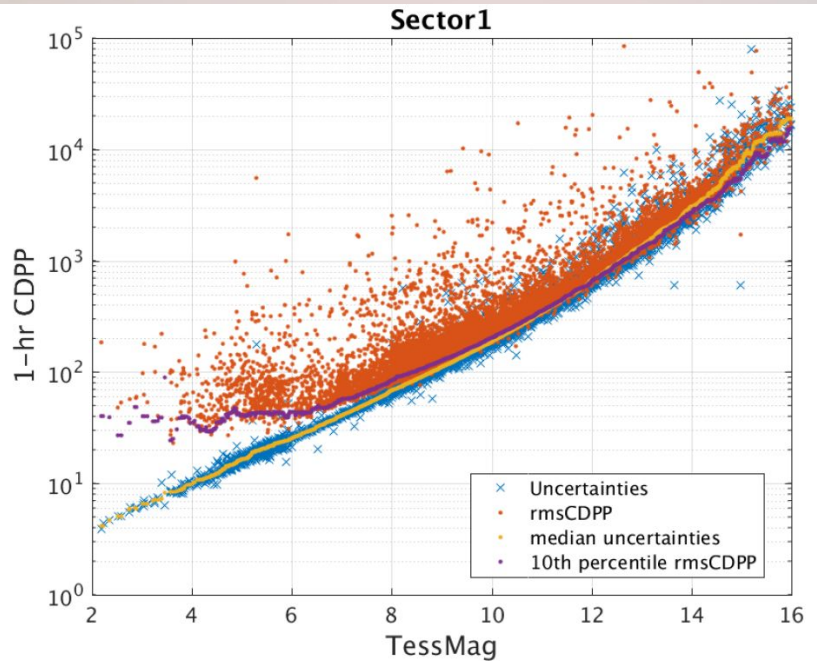
$P \sim 13.7$  d (2:1 rezonance s oběžnou dobou Měsíce)

$i = 37^\circ$

Stabilní po desetiletí bez nutnosti úpravy dráhy

Nad Van Allenovými pásy - málo zásahů nabitými částicemi

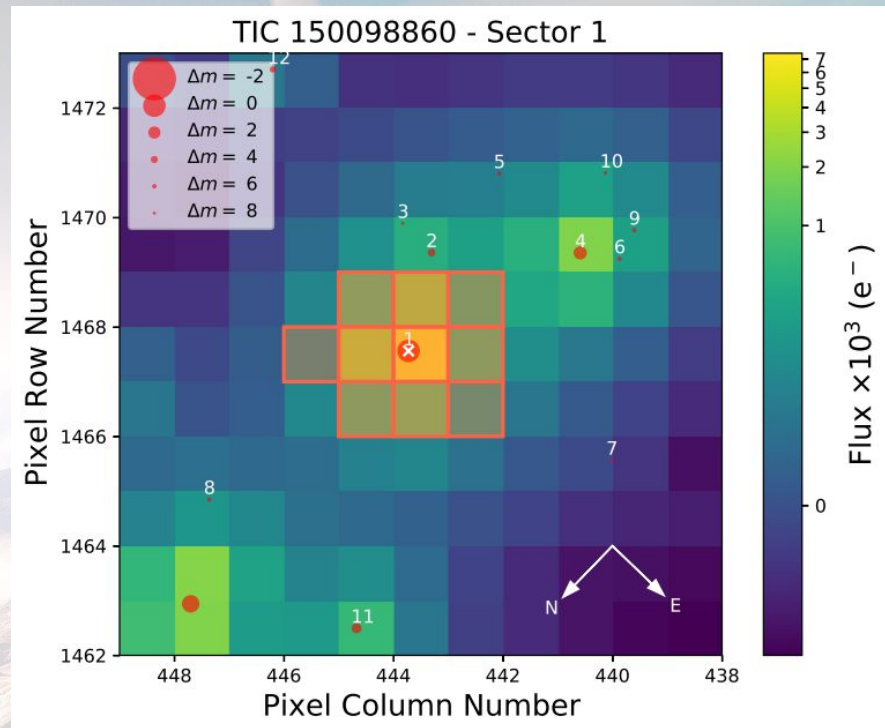
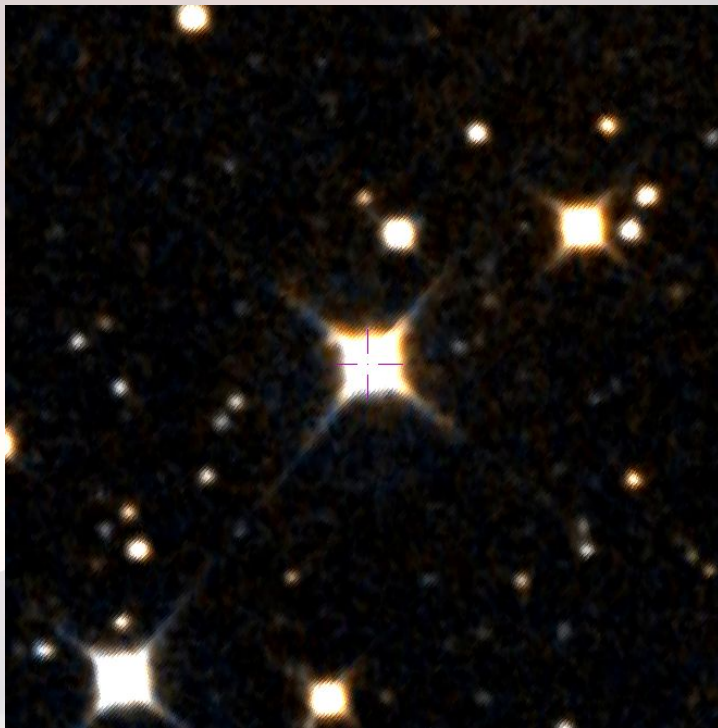
# TESS - data



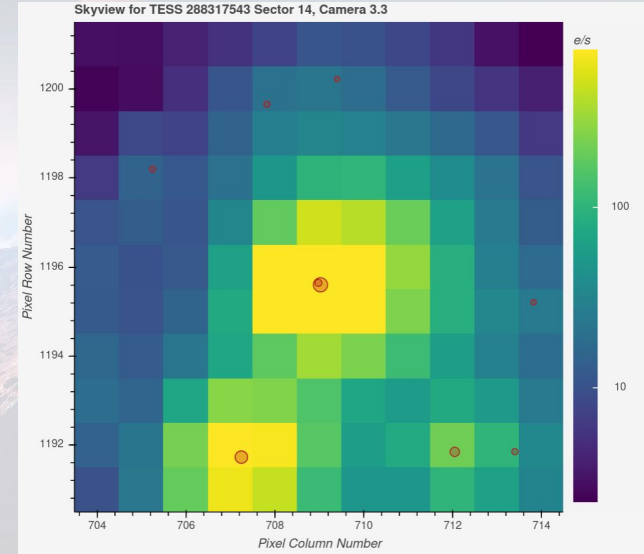
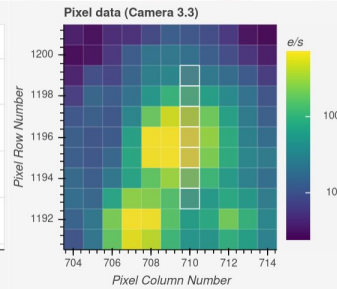
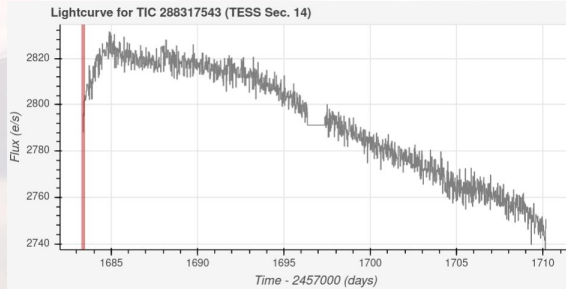
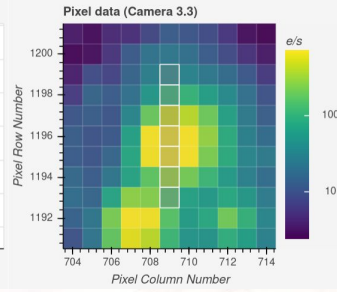
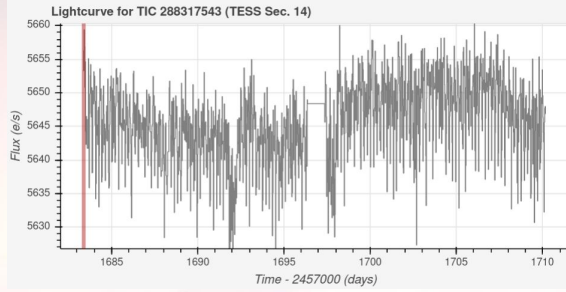
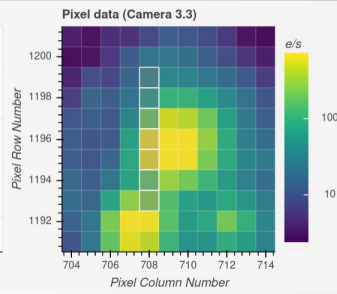
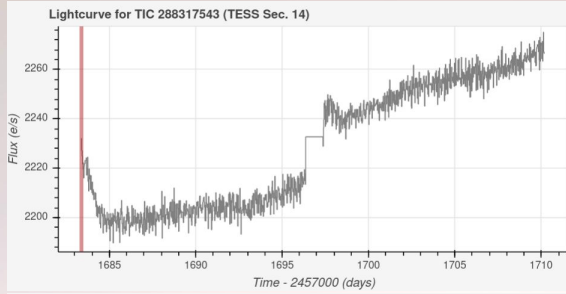
200 ppm pro  $I=10$  mag  
10 000 ppm  $I=16$  mag

# Blendy

TESS - 21"/px



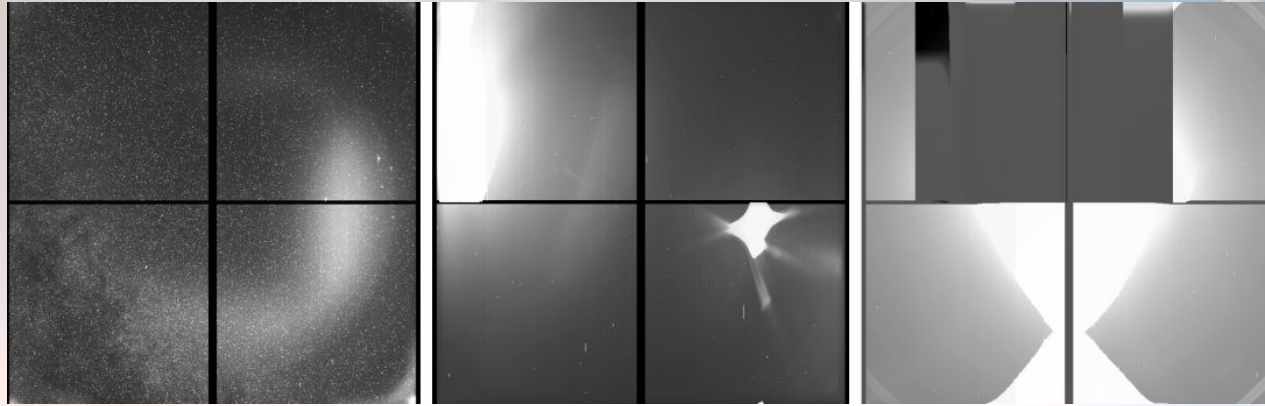
# Blendy



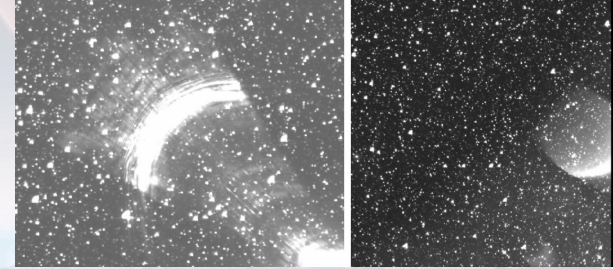


# Trendy v datech

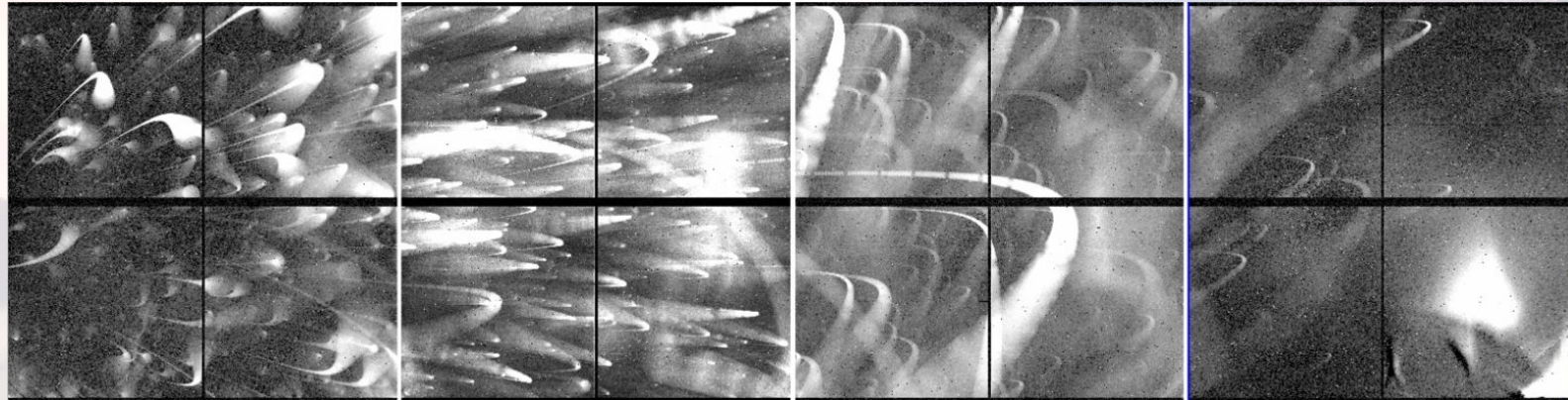
Rozptýlené světlo



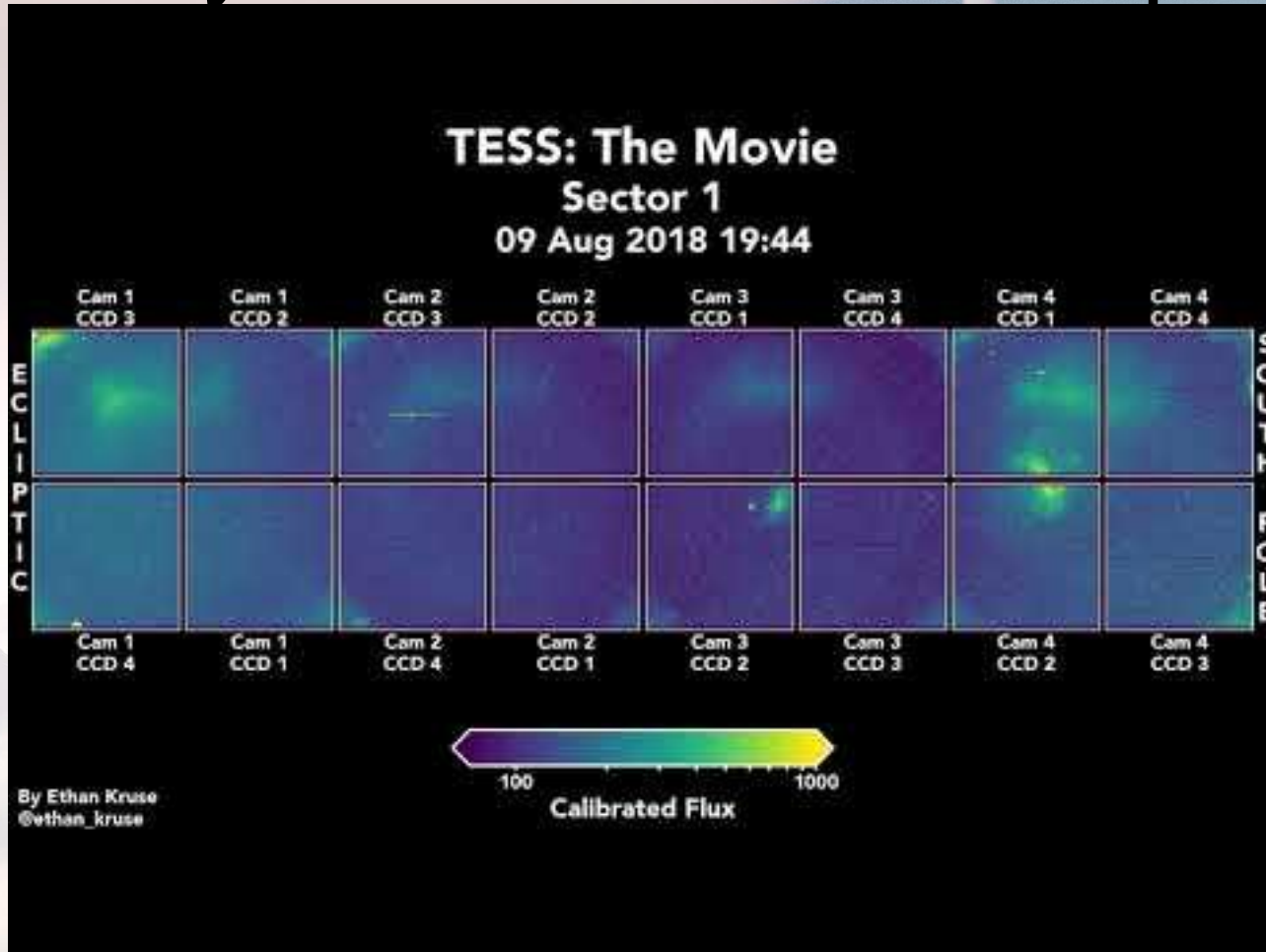
Příliš jasný objekt v blízkosti



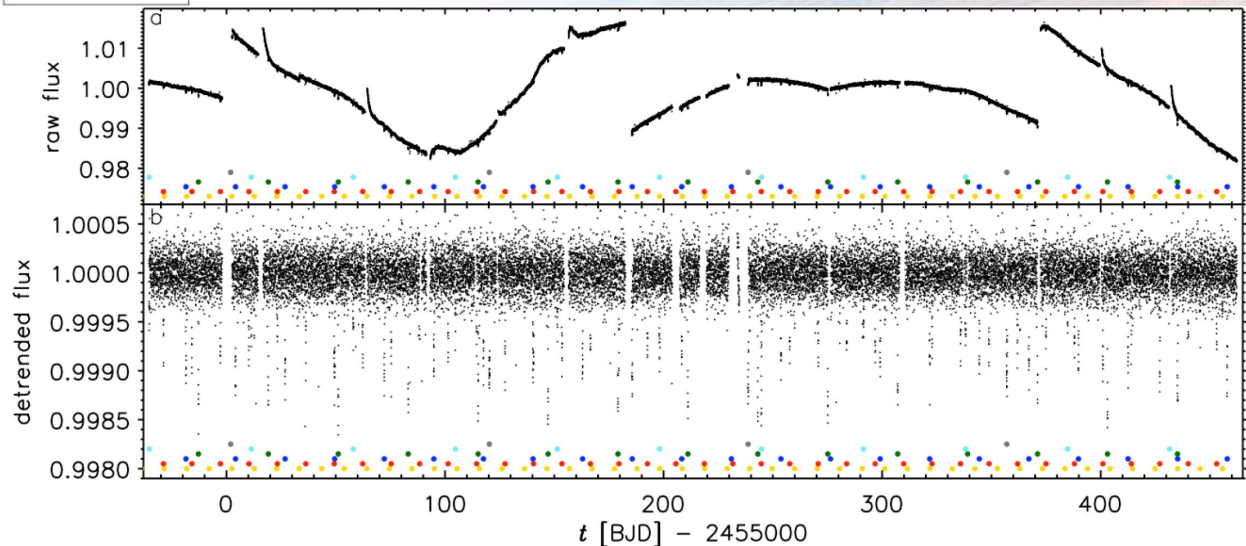
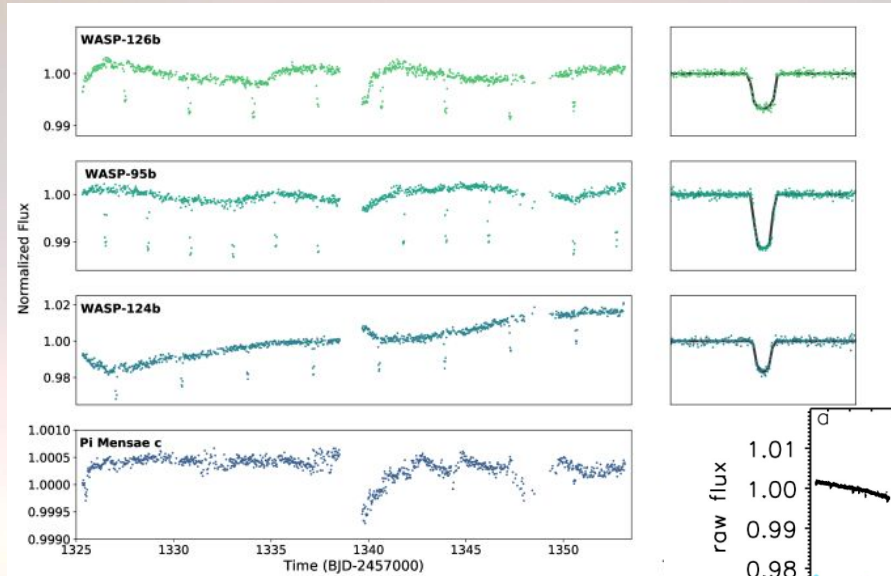
Impakty  
mikrometeoritů



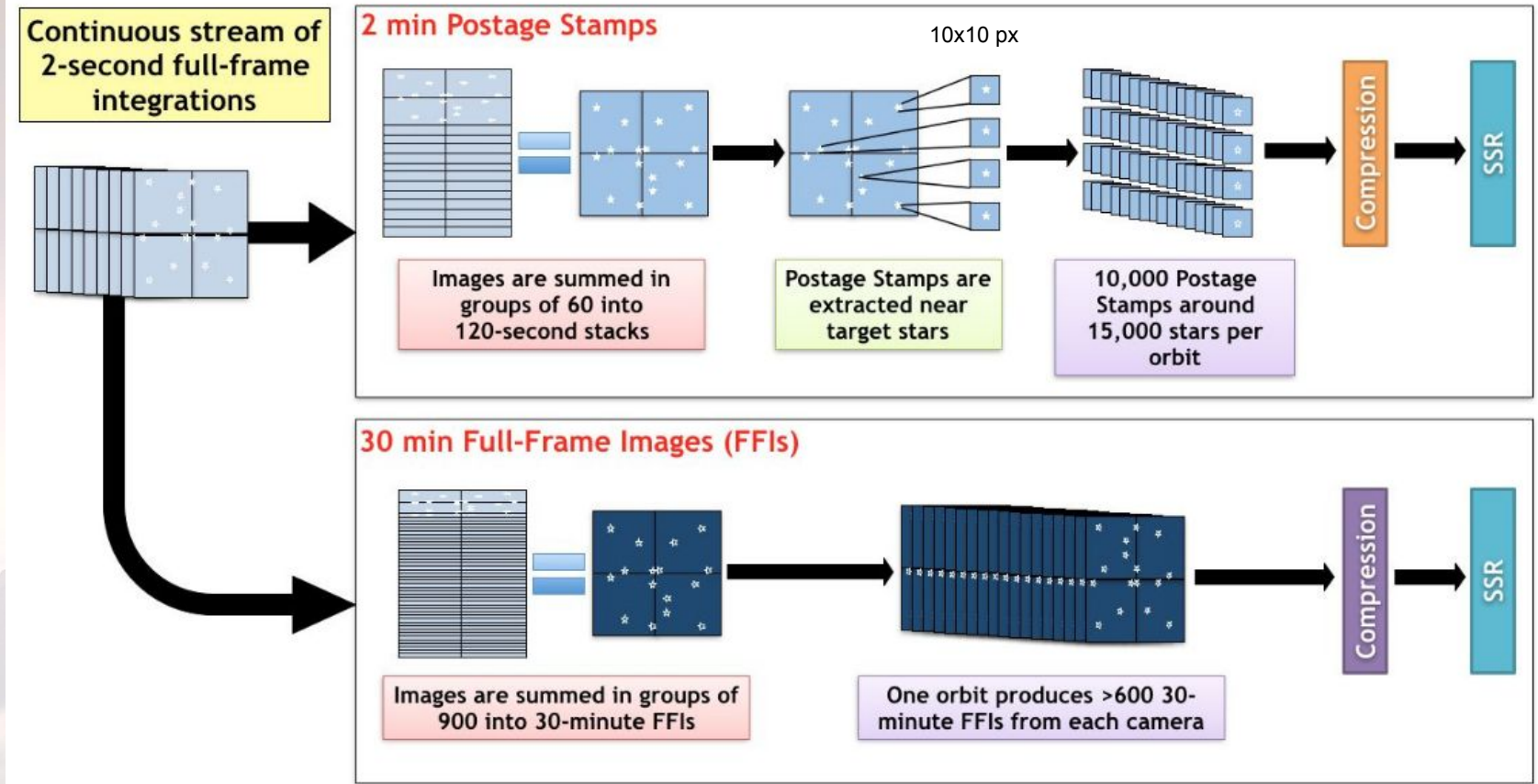
# Trendy v datech - variace pozadí



# Trendy v datech - změna orientace



# TESS - Zpracování dat



Stahování dat vždy v perigeu dráhy - díra v datech 4-16 hodin, od 2021 kadence 1 minuta a deset minut

# Datové produkty

SAP - simple aperture photometry

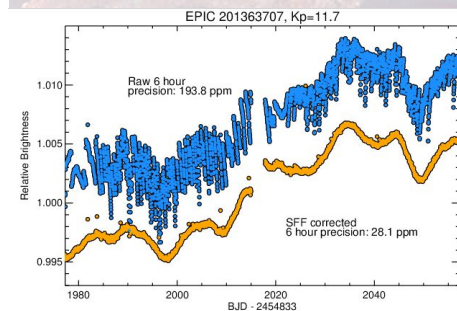
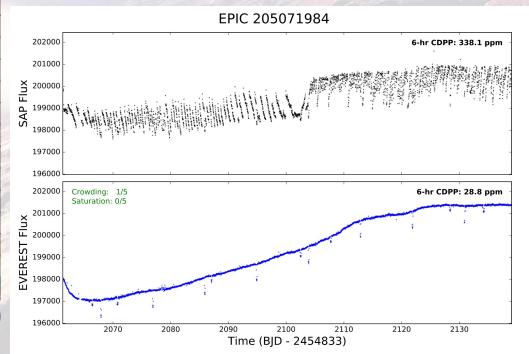
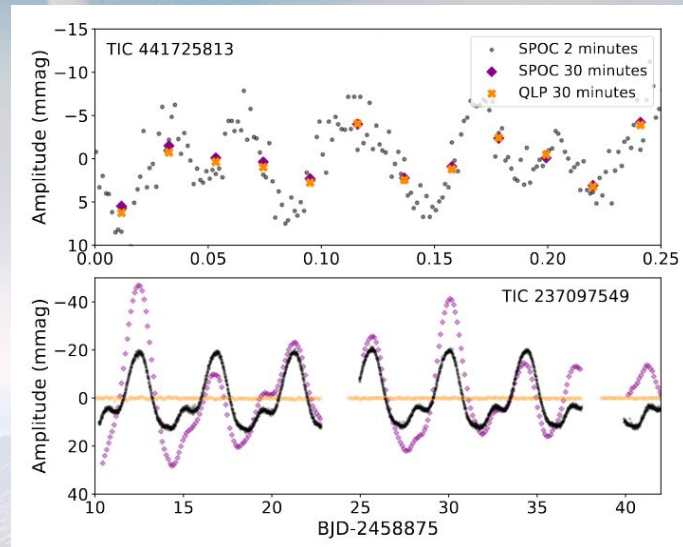
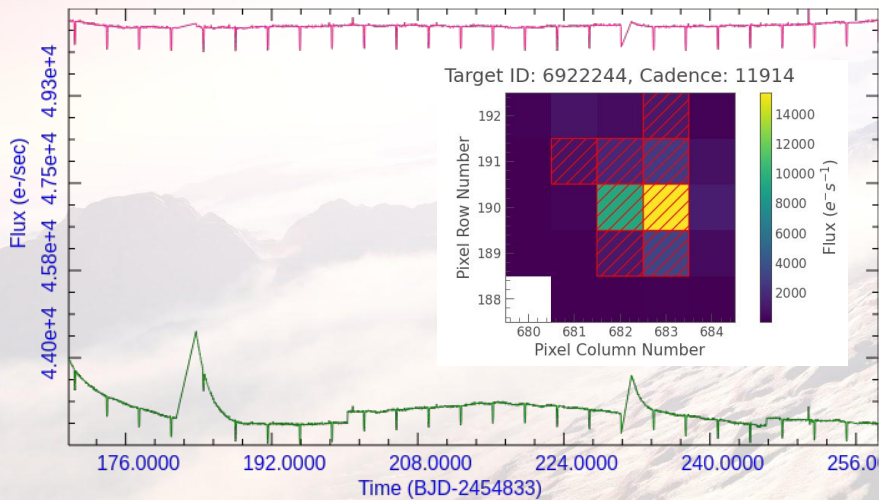
PDCSAP - Pre-conditioned SAP - bez trendů

TPF - target pixel file

High Level Science Products (HLSPs) -

EVEREST, K2SC, K2SFF (Kepler+K2)

QLP, SPOC, TASC (TESS)



# Datové produkty

<https://docs.lightkurve.org/index.html>

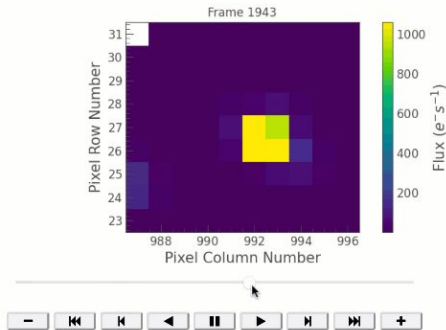
## Lightkurve

A friendly Python package for making discoveries with Kepler & TESS.

Lightkurve offers a user-friendly way to analyze time series data on the brightness of planets, stars, and galaxies. The package is focused on supporting science with NASA's Kepler and TESS space telescopes, but can equally be used to analyze light curves obtained by your backyard telescope. Lightkurve aims to lower barriers, promote best practices, reduce costs, and improve scientific fidelity by providing accessible open source Python tools and tutorials for time domain astronomy.

```
[4]: import lightkurve as lk
pixelfile = lk.search_targetpixelfile("Trappist-1")[1].download()
pixelfile.animate()
```

[4]:



<https://archive.stsci.edu/>



Barbara A.

MIKULSKI ARCHIVE FOR  
SPACE TELESCOPES

Maximizing the scientific accessibility & productivity of astronomical data.

The Mikulski Archive for Space Telescopes is an astronomical data archive focused on the optical, ultraviolet, and near-infrared. MAST hosts data from over a dozen missions like Webb, Hubble, TESS, Kepler, and in the future Roman.

TESS viewing tool

<https://heasarc.gsfc.nasa.gov/cgi-bin/tess/webtess/wtv.py>

# Úkoly

- Stáhnout dostupná data z TESS s různou kadencí (rutiny SPOC, TESS-SPOC, QLP, 1800, 120, 600 s expozice), sešít, normalizovat, převést na magnitudy, vykreslit celkový pohled a detailní pohled na kousek křivky ukazující základní charakteristiku změn (tranzit, pulzační cyklus apod.). V grafech ideálně porovnat křivky s různou kadencí a z různých rutin
- Diskutovat, jestli se jedná o blend, povaha proměnnosti

Buranský, Samuel      TIC 164173105 (TOI-1417)

Đuríšková, Michaela      TIC 164173105

Gazdoš, Jakub      TIC 335483600 (TOI-1480)

Honsová, Eliška      TIC 335483600

Kapusta, Vlastimil      TIC 468997317 (TOI-1986)

Pekárek, Tomáš      TIC 468997317

Pocar, Lukáš      TIC 458856474 (TOI-1978)

Rievajová, Tatiana      TIC 458856474

Soukup, Tomáš      TIC 97700520 (TOI-1013)

Šipková, Ema      TIC 97700520

Vanžurová, Alena      TIC 97700520