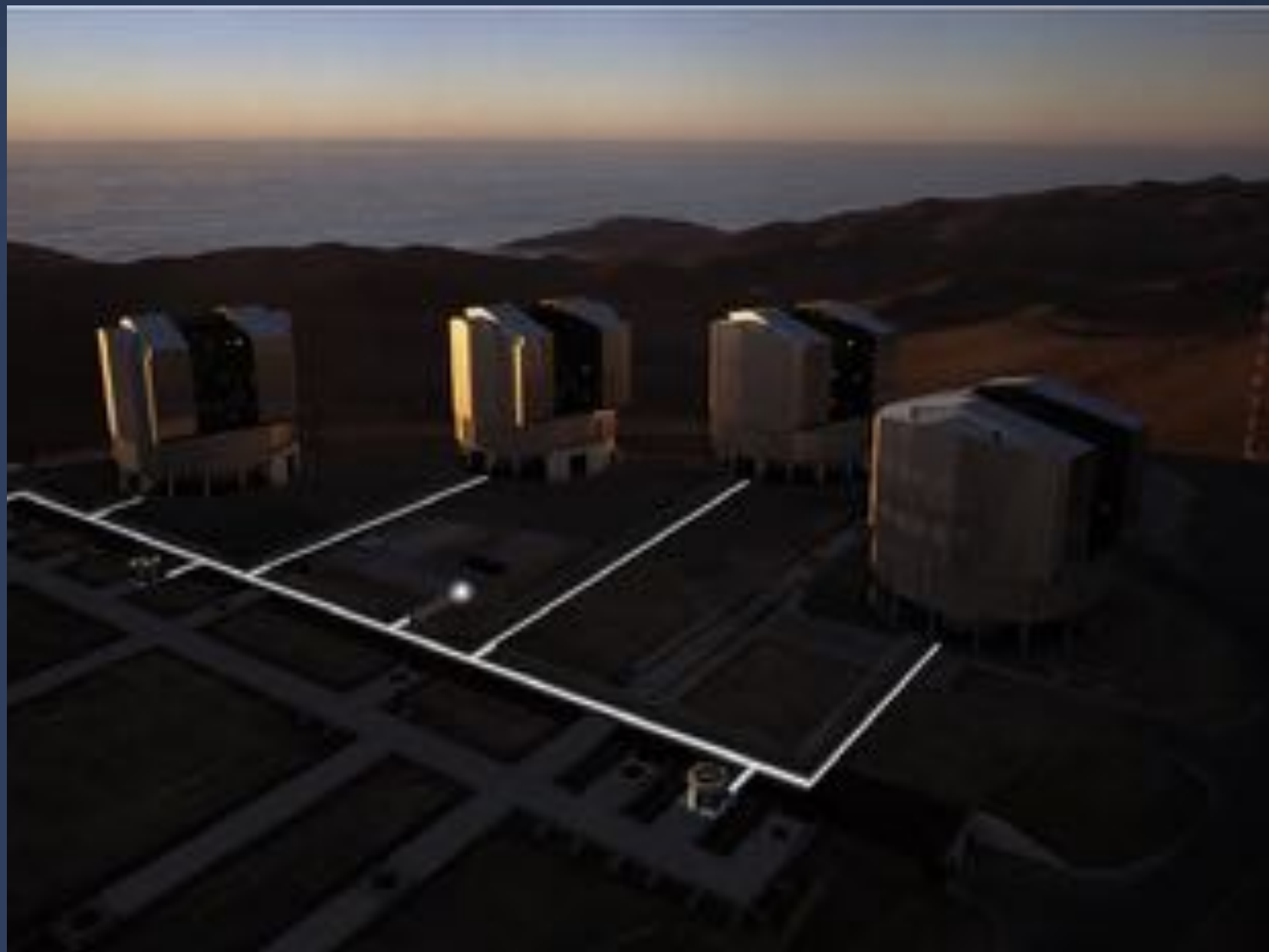




(Optikai) csillagászat mért mennyiségei

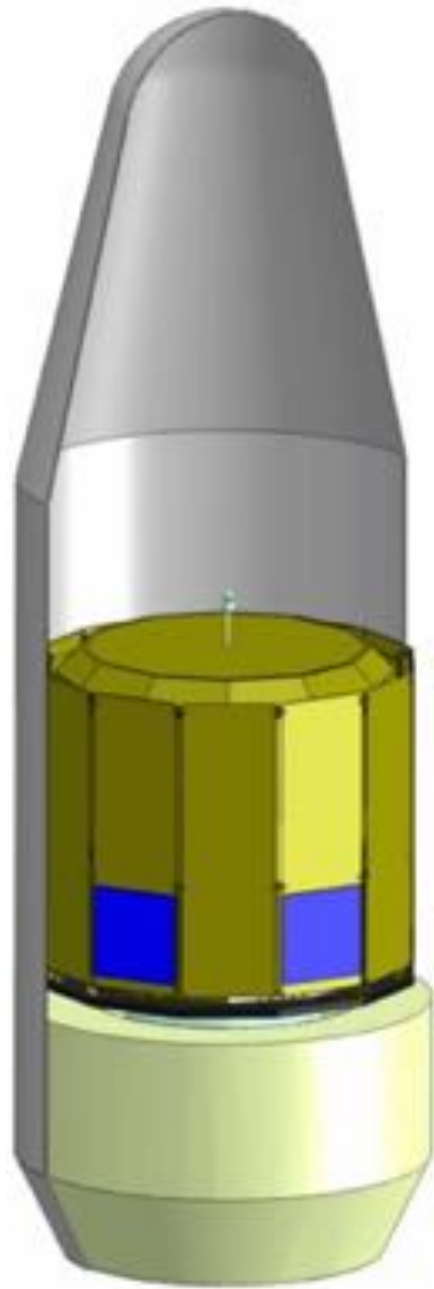
- **Égi irányok** - koordináták
- **Fényesség** - pontszerű és kiterjedt objektumok
- **Színkép** - folytonos és vonalas spektrumok
- **Sokaságok vizsgálata** - égboltfelmérések

A pontosság növelése új fizikai jelenségek felfedezéséhez vezethet!

SZÖGMÉRÉS FEJLŐDÉSE

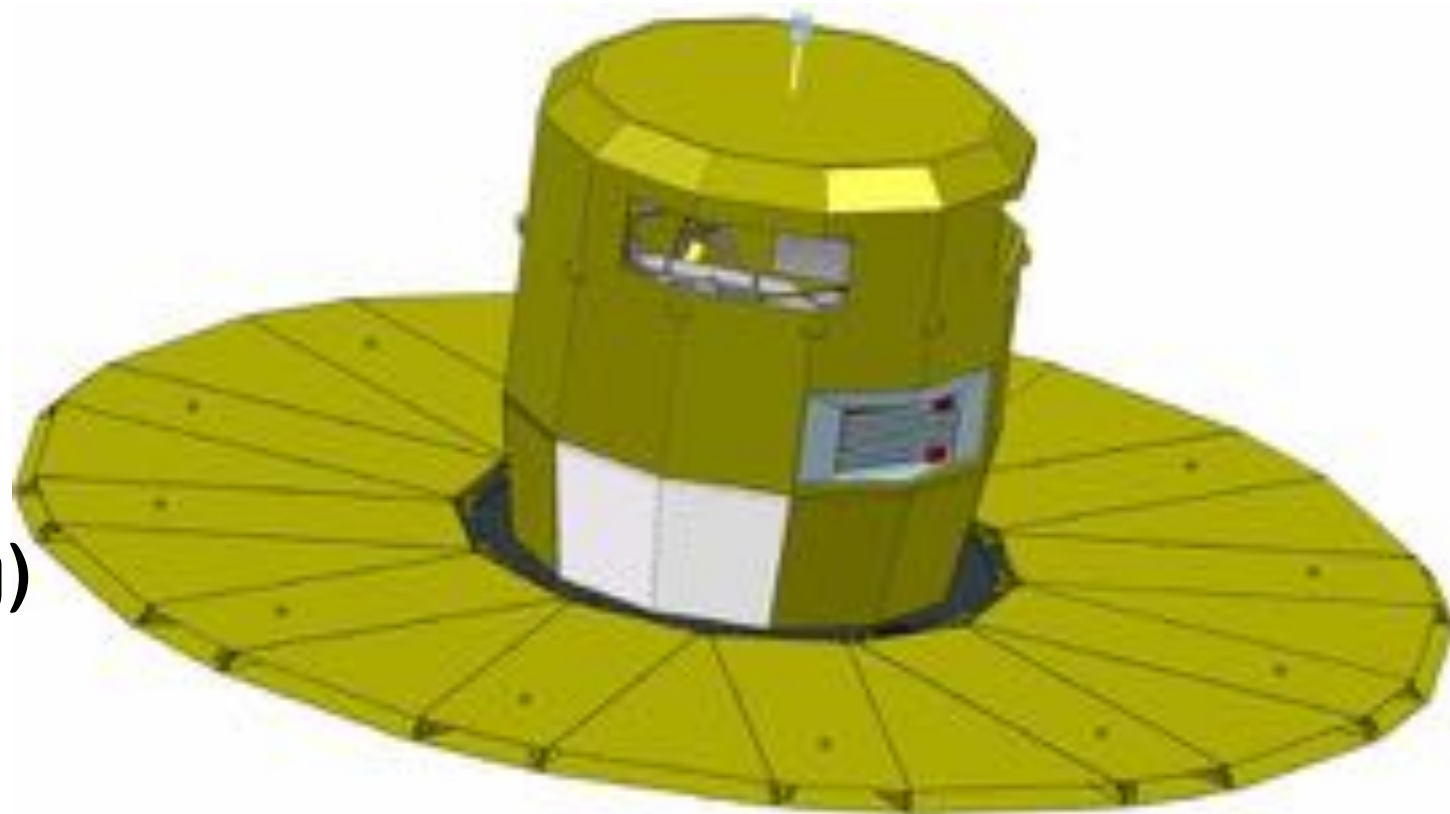
- Nagyságrendi ugrások:
 - 1 ívperc: szabadszemes mérések, csillagkatalógus, sajátmozgás, bolygókoordináták, felső becslések parallaxisokra
 - 1 ívmásodperc: kettőscsillagok, Naprendszer mérete, kis égitestek pályaszámítása
 - 0,1- 0,001 ívmásodperc ($1 \text{ mas} = 4,8 \text{ nrad}$): csillagok parallaxisa, bolygók asztrometriai hatása
 - 0,1-0,001 mas: csillagok & exobolygók felszíni részletei, exoholdak, Tejútrendszer és közeli galaxisok térbeli feltérképezése, ??????

Gaia: asztrometriai űrobszervatórium

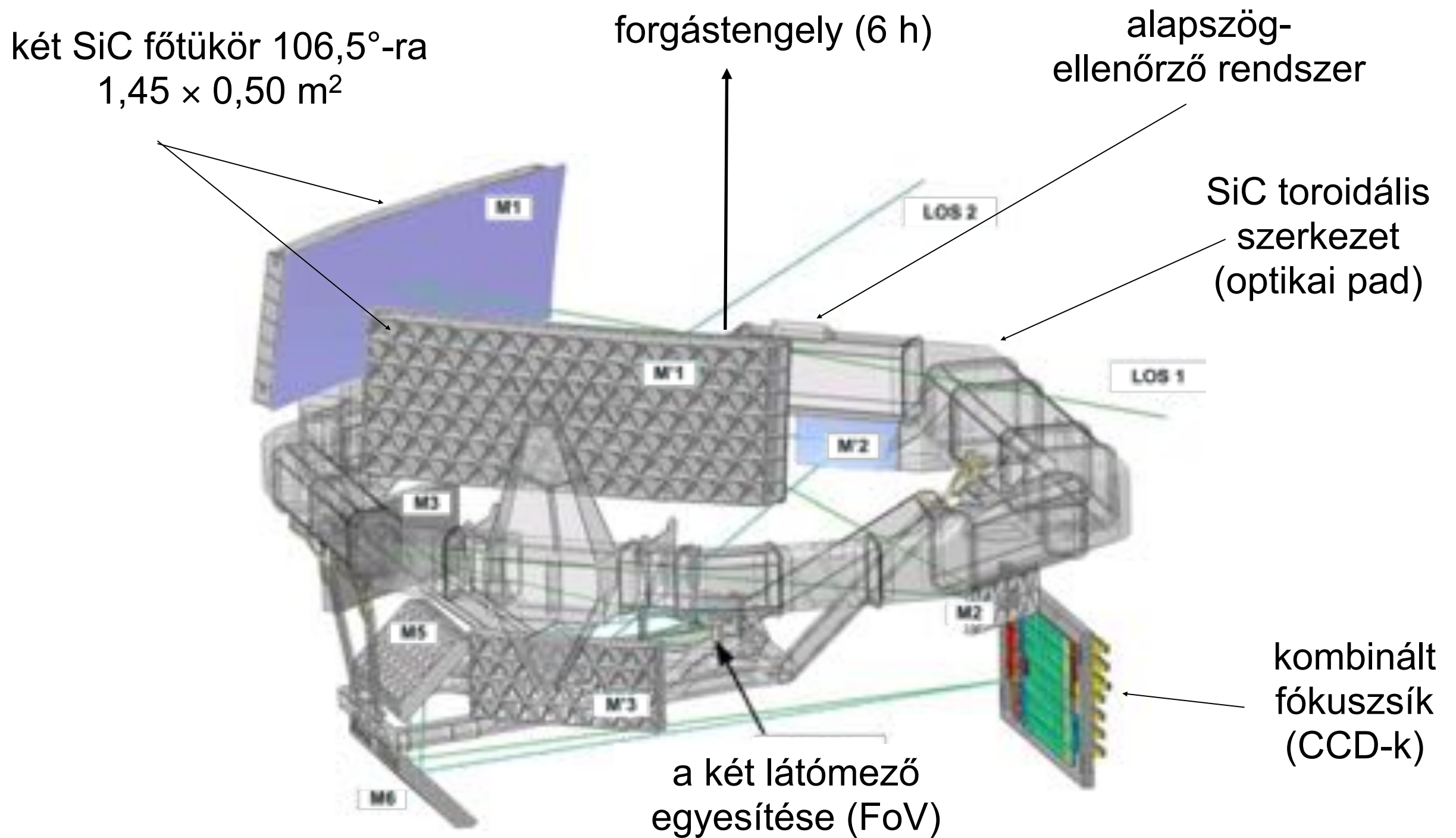


- kizárólag ESA-misszió
- indítás: **2013. december 20.**
- 5 év működés (esetleg 1 év hosszabbítás)
- hordozórakéta: Szojuz–Fregat
- pálya: Lissajous-pálya az L2 pont körül
- adattovábbítás: 4–8 Mbps

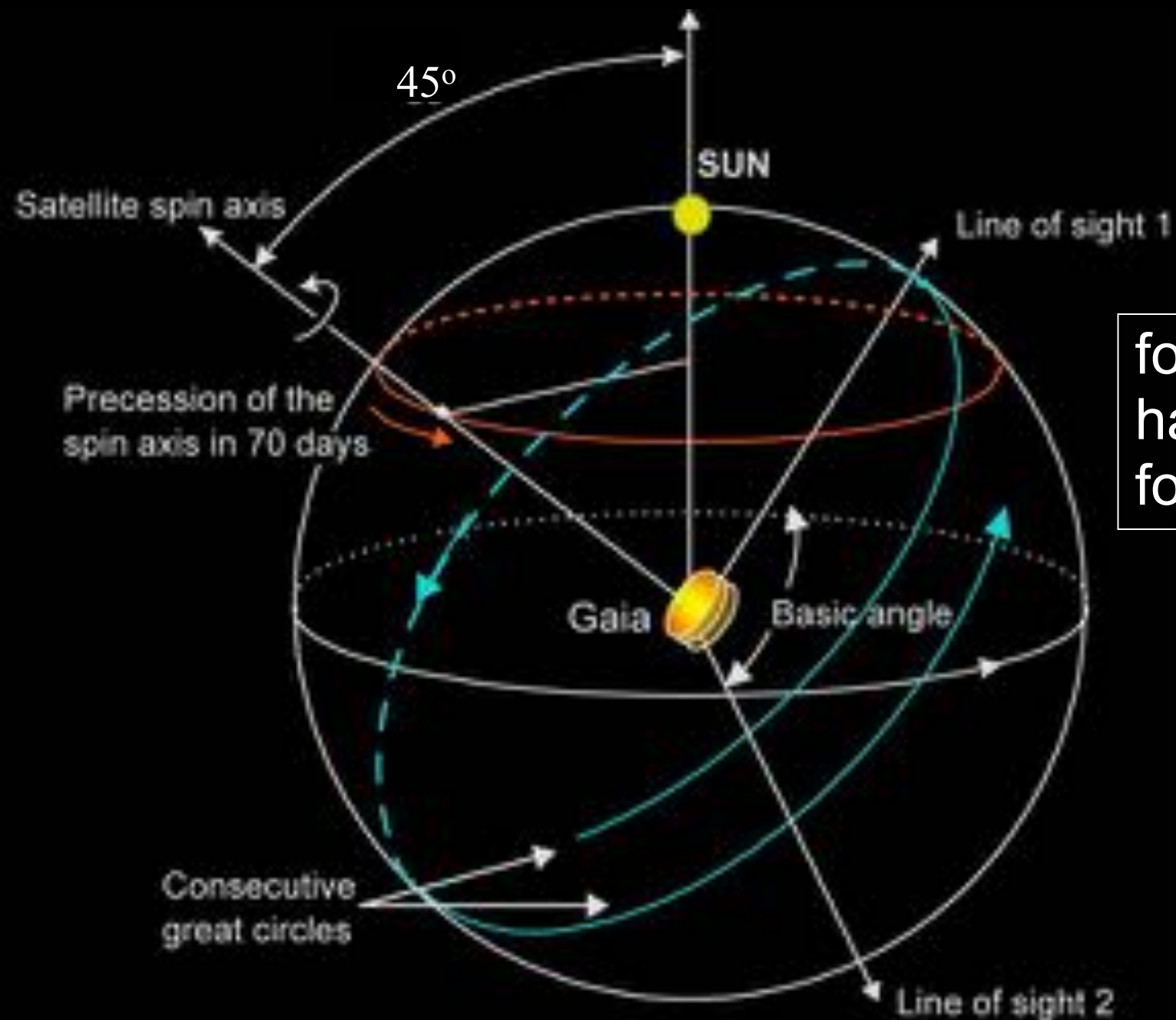
- tömeg: 2120 kg (hasznos 743 kg)
- teljesítmény: 1631 W
(hasznos 815 W)



A távcső és a műszerek



Az égbolt szkennelésének elve



forgástengely: 45° a Naphoz;
haladás: 60 ívmásodperc s^{-1} ;
forgási periódus: 6 óra

Gaia: teljes, pontos, mély

	Hipparcos	Gaia
Magnitúdóhatár	12	20 magnitúdó
Teljesség	7,3-9,8	20 magnitúdó
Fényes határ	0	6 magnitúdó
Objektumok száma	120 000	26 millió V = 15 m-ig, 250 millió V = 18 m-ig 1000 millió V = 20 m-ig
Effektív távolsághatár	1 kpc	50 kpc
Kvazárok	1 (3C 273)	500000
Galaxisok	nincs	1000000
Pontosság	0,001 ívmásodperc	7 mikroívmásodperc V = 10 m 10-25 mikroívmásodperc V = 15 m 300 mikroívmásodperc V = 20 m
Fotometria	2-színfotometria (B és V)	alacsony diszp. spektrum V = 20 m-ig
Radiális sebesség	nincs	15 km/s V=16-17 m-ig
Megfigyelési program	előre kiválasztva	teljes és torzítatlan

A pontosság 2 nagyságrendet javul, az érzékenység 4 nagyságrenddel jobb, a vizsgált csillagok száma 4 nagyságrenddel több.

Az égbolt szkennelése 5 éven át $\Rightarrow$ parallaxisok és sajátmozgások.

FOTOMETRIAI FEJLŐDÉS

- Nagyságrendi ugrások:
 - 1 magnitúdó: Mirák, (szuper)nóvák
 - 0,1-0,01 magnitúdó: geometriai és fizikai (pulzáló, eruptív és kataklizmikus) változócsillagok
 - 0,001 magnitúdó (1 mmag): fedési exobolygók - forró jupiterek
 - 0,1-0,001 mmag: Nap típusú csillagrezgések, exoholdak, exoföldek, ???????

Kepler-űrtávcső

A Kepler célja Föld típusú, lakható bolygók felfedezése a fedési módszerrel

Szimultán észlelt több mint 150 ezer csillagot

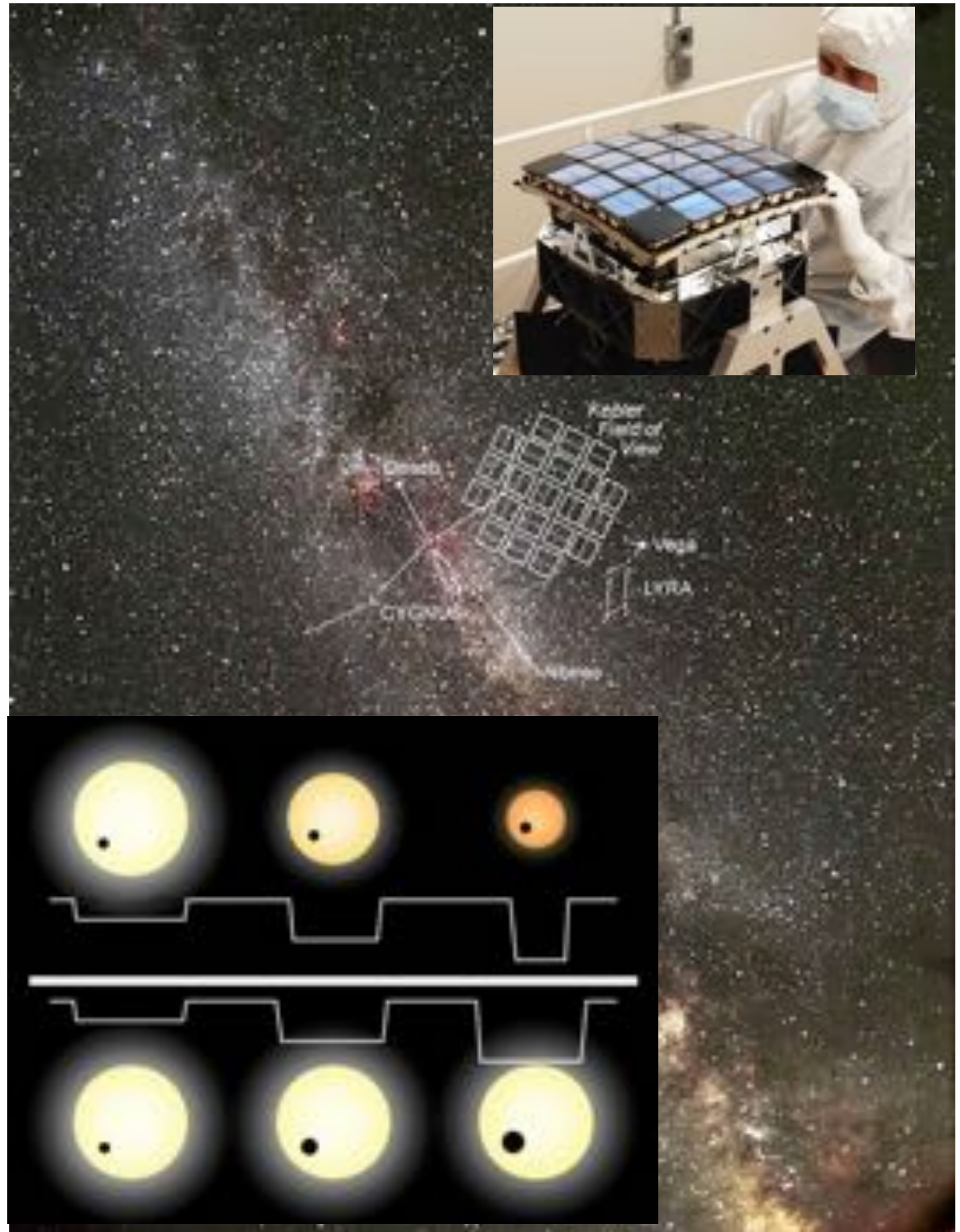
95 cm-es belépő nyílású Schmidt-távcső, látómezeje mintegy 100 négyzetfok, 42 CCD-ből álló mozaikkal

Fotometriai pontosság:

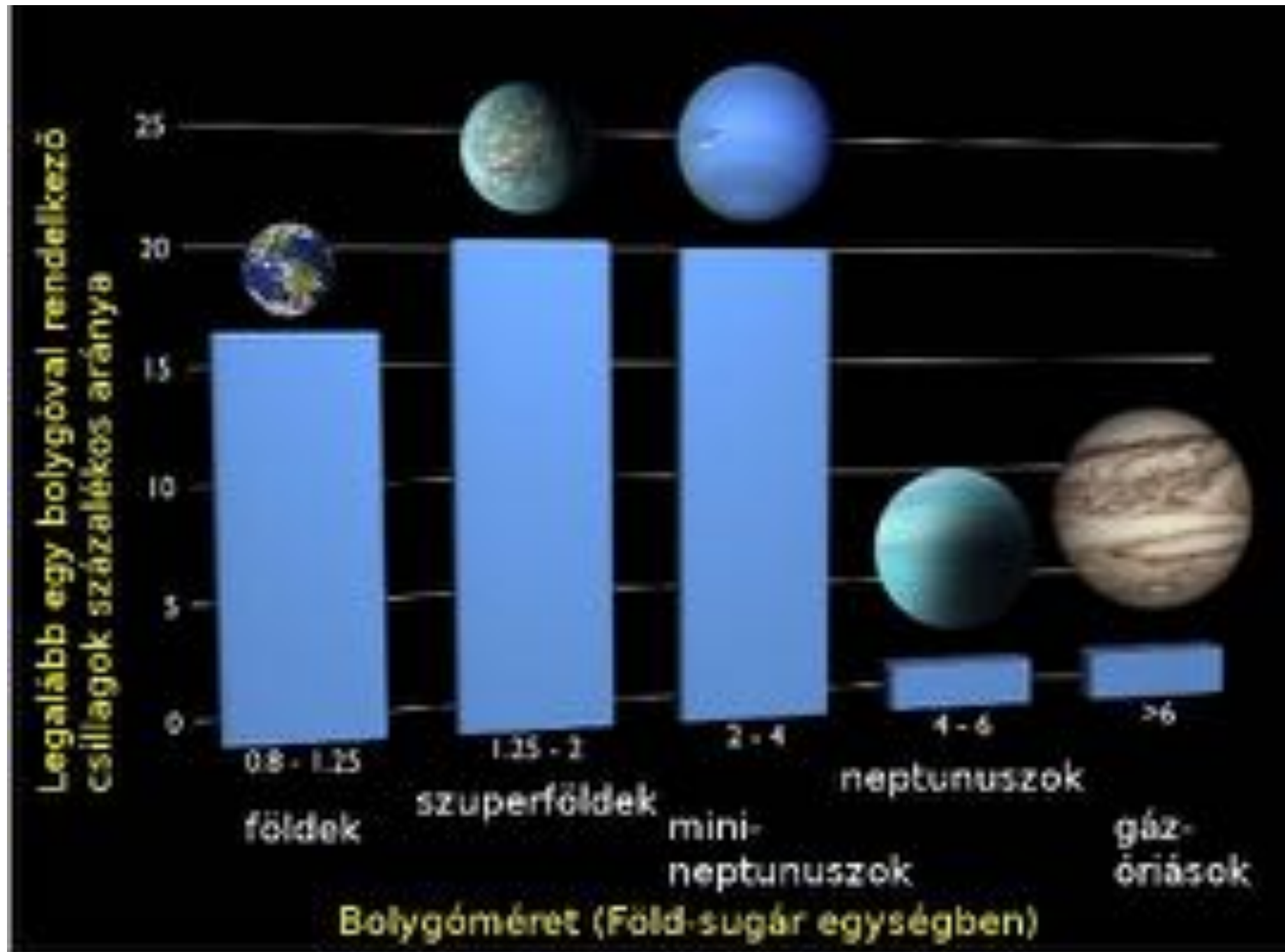
A zaj < 20 ppm 6,5 órányi mérés után egy 12 magn. Nap típusú csillagra

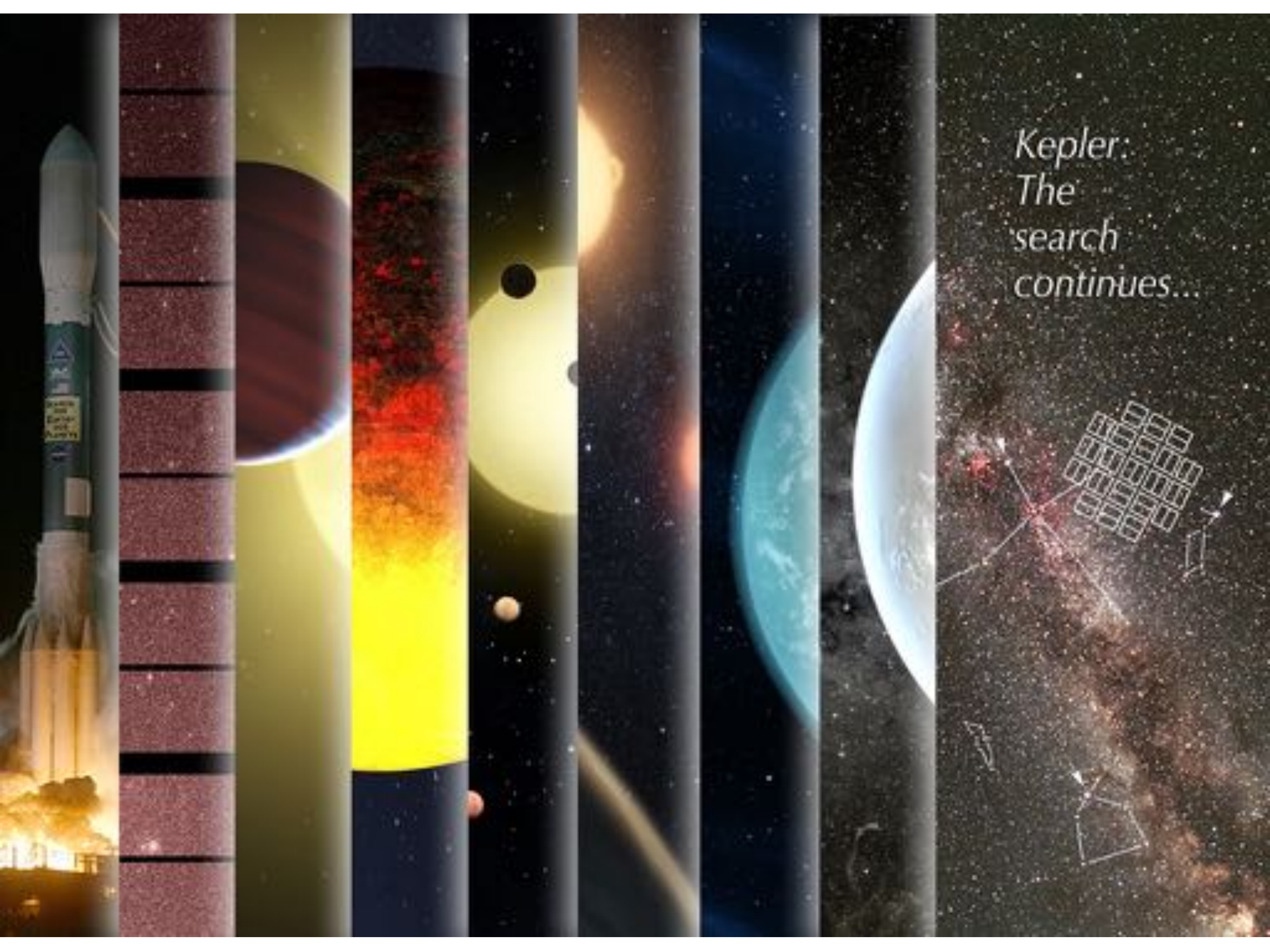
=> 4-sigma detektálás egy exoföld tranzitja esetén.

Heliocentrikus pálya, 2009-2013



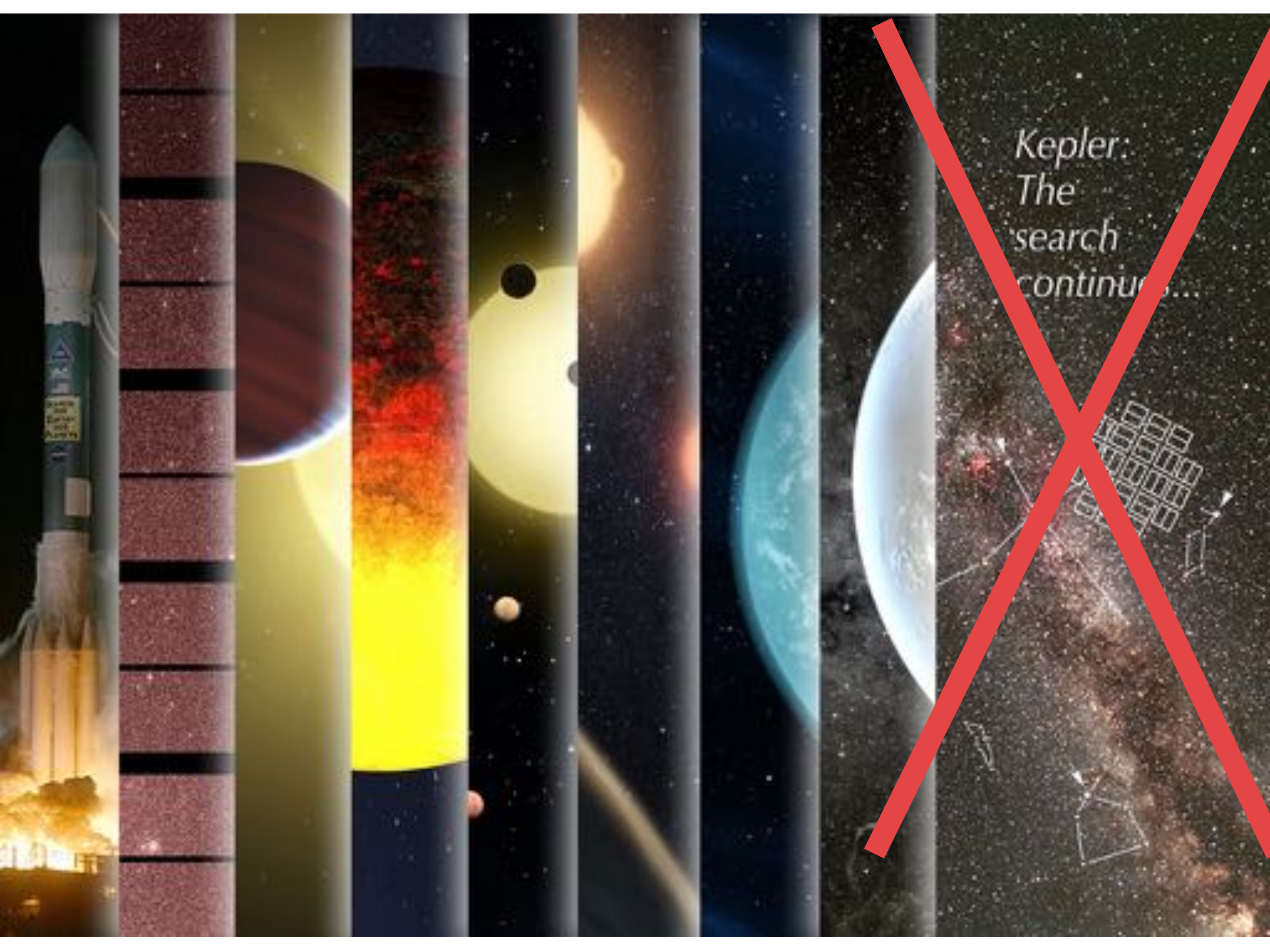
Rövidperiódusú bolygók gyakorisága





*Kepler:
The
search
continues...*



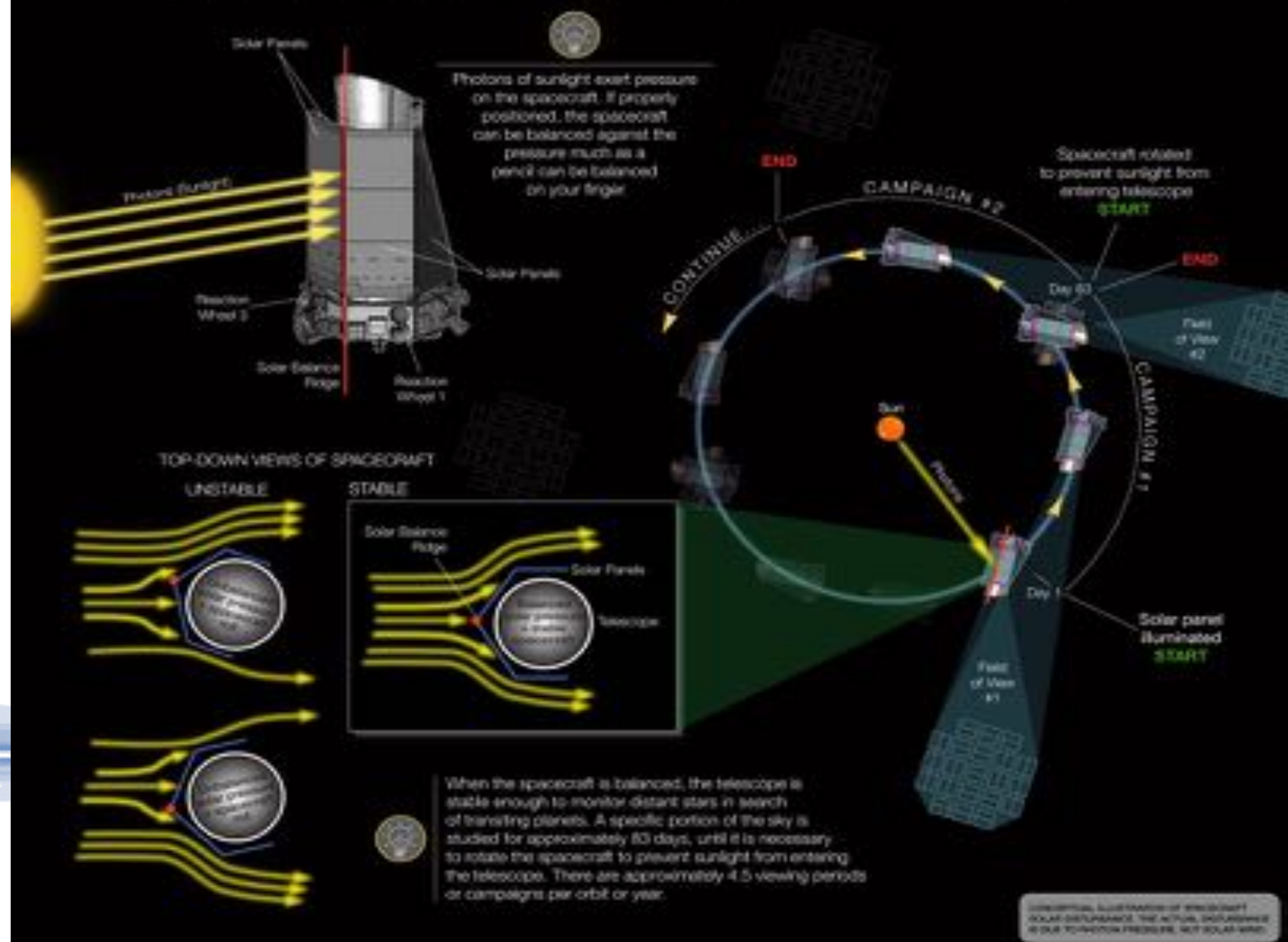


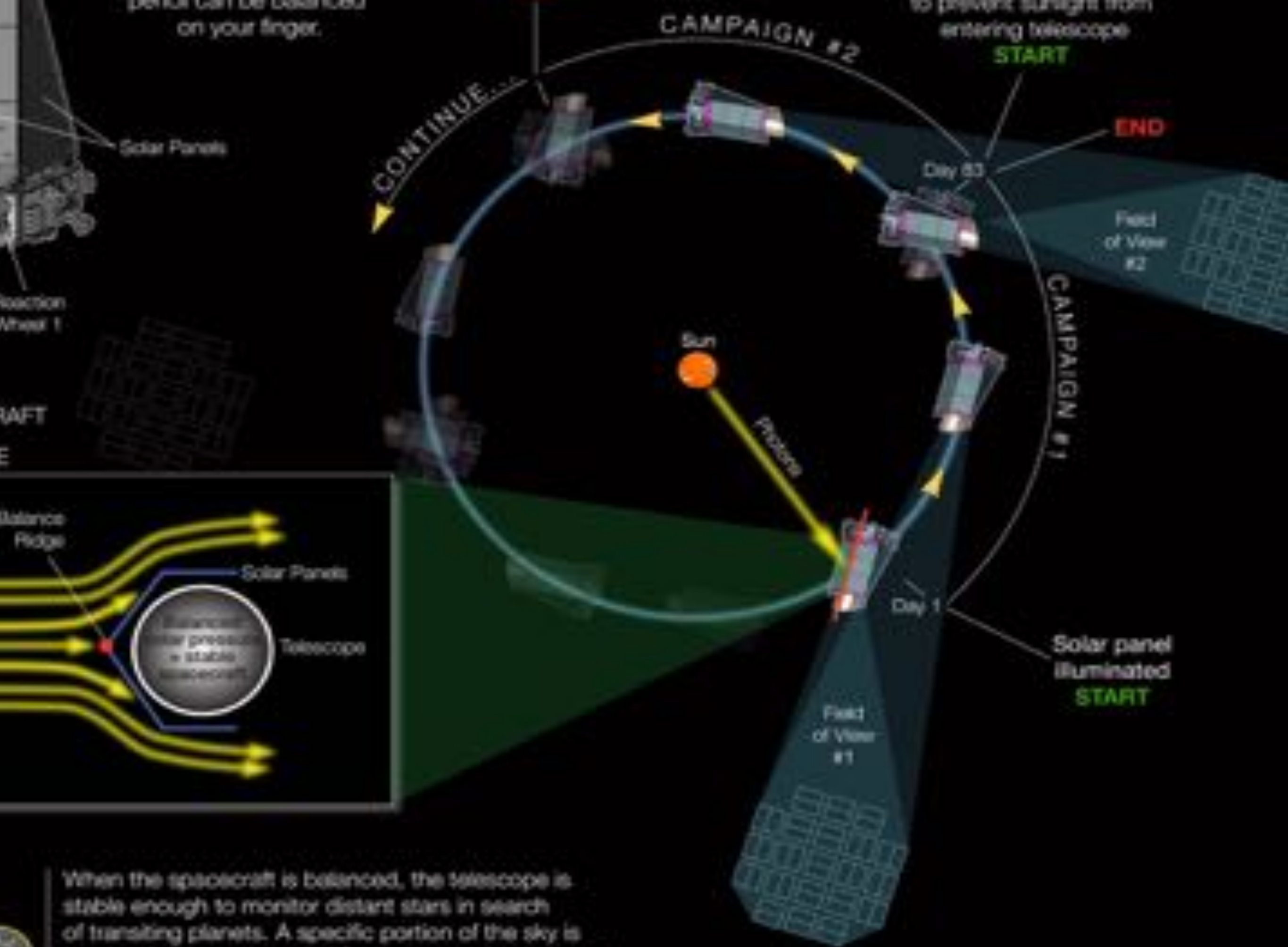
Kepler:
The
search
continues...





Kepler's Second Light: How K2 Will Work





When the spacecraft is balanced, the telescope is stable enough to monitor distant stars in search of transiting planets. A specific portion of the sky is studied for approximately 83 days, until it is necessary

- Working Group Report no. 4, Paris, 2008).
32. G. Torres, J. Andersen, A. Giménez, *Astron. Astrophys. Rev.* **18**, 67 (2010).
33. P. Marigo et al., *Astron. Astrophys.* **442**, 881 (2005).
34. L. Girard, M. A. T. Groenewegen, E. Hatzidimitriou, L. de Costa, *Astron. Astrophys.* **436**, 895 (2005).

35. Kepler is a NASA discovery class mission, which was launched in March 2009 and whose funding is provided by NASA's Science Mission Directorate. The authors thank the entire Kepler team, without whom these results would not be possible. The astrometry program of Kepler is being conducted by the Kepler Astrometric Science Consortium.

www.nature.com/scientificdata/

Materials and Methods

Figs. S1 to S3

References

16 December 2010; accepted 22 February 2011

HD 181068: A Red Giant in a Triply Eclipsing Compact Hierarchical Triple System

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Hierarchical triple systems comprise a close binary and a more distant component. They are important for testing theories of star formation and of stellar evolution in the presence of nearby companions. We obtained 218 days of Kepler photometry of HD 181068 (magnitude of 7.1), supplemented by ground-based spectroscopy and interferometry, which show it to be a hierarchical triple with two types of mutual eclipses. The primary is a red giant that is in a 45-day orbit with a pair of red dwarfs in a close 0.9-day orbit. The red giant shows evidence for tidally induced oscillations that are driven by the orbital motion of the close pair. HD 181068 is an ideal target for studies of dynamical evolution and testing tidal friction theories in hierarchical triple systems.

The Kepler space mission is designed to observe continuously more than 10^5 stars,

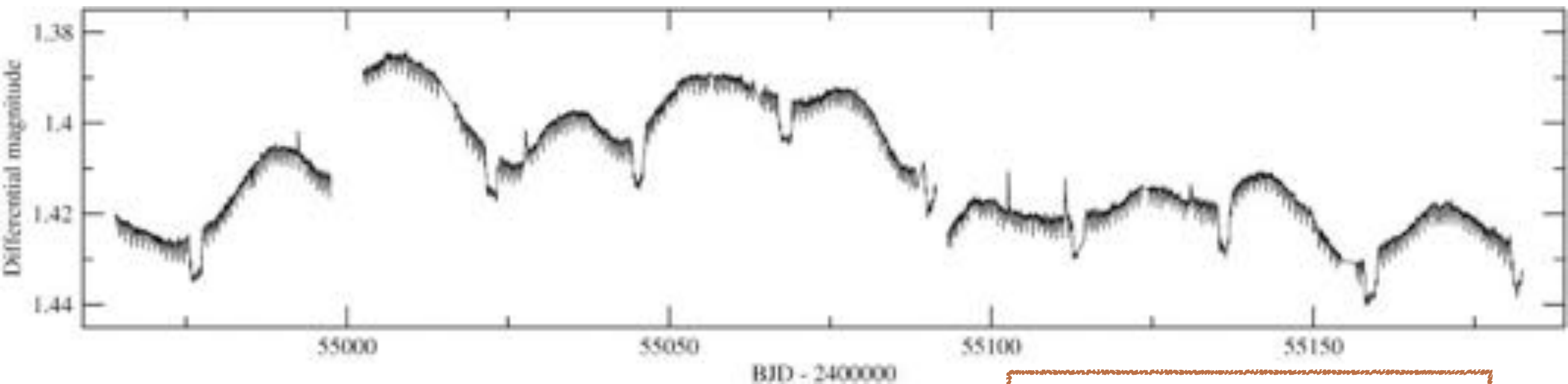
so that when the BC pair is in front of A, their mutual eclipses do not change the total amount

over, almost all flares appear at the shallower minimum of the BC that this activity might be related to.

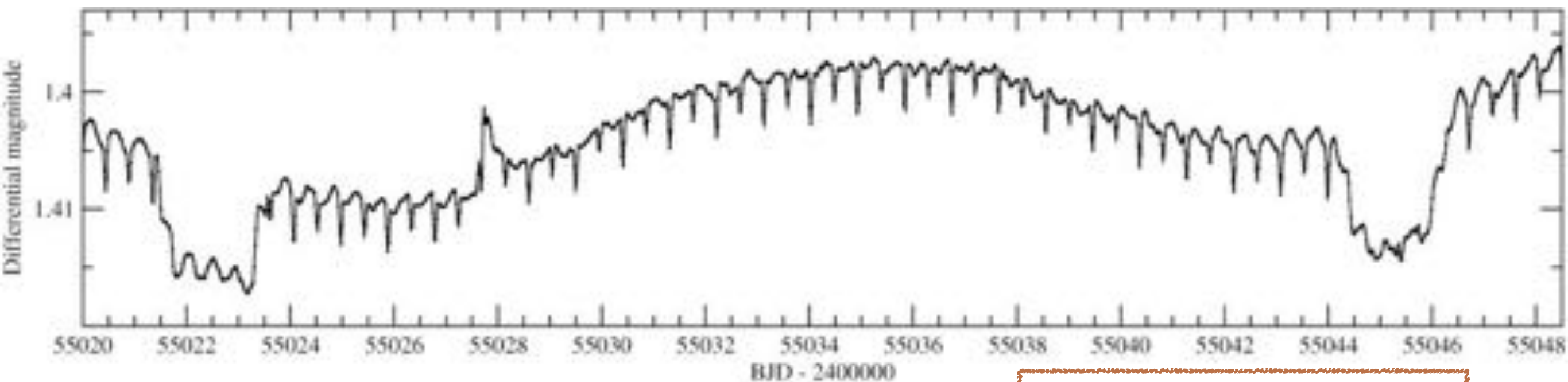
We looked for optically resolved eclipses with a 1-m telescope [section 3.1] and found none. We also obtained 3 optical spectra to measure the position of the A component (6) (Fig. 1). Parameters for the wider system show that star A revolves on a circular orbit with an orbital period twice the separation of the BC pair. The light curve shows consecutive flat-bottomed minima (6). Long-baseline interferometry (PAVO (Precision Astronomical Observations) beam combiner (8) at the Interferometer for High Angular Resolution Array show that the angular

¹Department of Astronomy, Eötvös University, H-1125 Budapest, Post Office Box 67, Hungary. ²Kölköly Observatory, Hungarian Academy of Sciences, H-1525 Budapest, Post Office Box 67, Hungary. ³Institute for Astronomy, School of Physics, Sydney, NSW 2006, Australia. ⁴Baja Astronomical Observatory, H-6500 Baja, Szeged út, 13, 766, Hungary. ⁵College, H-6500 Baja, Szeged út 2, Hungary. ⁶German Astrophysical Observatory (TAO), H-6500 Baja, Szeged út 2, Hungary. ⁷Department of Astronomy, University of Sydney, Sydney, NSW 2006, Australia. ⁸Baja Astronomical Observatory, H-6500 Baja, Szeged út, 13, 766, Hungary. ⁹College, H-6500 Baja, Szeged út 2, Hungary. ¹⁰German Astrophysical Observatory (TAO), H-6500 Baja, Szeged út 2, Hungary. ¹¹Department of Astronomy, University of Sydney, Sydney, NSW 2006, Australia. ¹²Baja Astronomical Observatory, H-6500 Baja, Szeged út, 13, 766, Hungary. ¹³College, H-6500 Baja, Szeged út 2, Hungary. ¹⁴German Astrophysical Observatory (TAO), H-6500 Baja, Szeged út 2, Hungary. ¹⁵Department of Astronomy, University of Sydney, Sydney, NSW 2006, Australia. ¹⁶Baja Astronomical Observatory, H-6500 Baja, Szeged út, 13, 766, Hungary. ¹⁷College, H-6500 Baja, Szeged út 2, Hungary. ¹⁸German Astrophysical Observatory (TAO), H-6500 Baja, Szeged út 2, Hungary. ¹⁹Department of Astronomy, University of Sydney, Sydney, NSW 2006, Australia. ²⁰Baja Astronomical Observatory, H-6500 Baja, Szeged út, 13, 766, Hungary. ²¹College, H-6500 Baja, Szeged út 2, Hungary. ²²German Astrophysical Observatory (TAO), H-6500 Baja, Szeged út 2, Hungary. ²³Department of Astronomy, University of Sydney, Sydney, NSW 2006, Australia. ²⁴Baja Astronomical Observatory, H-6500 Baja, Szeged út, 13, 766, Hungary.

Trinity - triplán fedő hármascsillag



$P(A-BC) \sim 45.52$ nap



$P(B-C) \sim 0.906$ nap

A

HD 181068

B

C



0.8 $R_{\oplus}$

0.7 $R_{\oplus}$

12.4 $R_{\oplus}$



Dynamical masses, absolute radii and 3D orbits of the triply eclipsing star HD 181068 from *Kepler* photometry

T. Borkovits,^{1,2,3*} A. Derekas,^{2,4} L. L. Kiss,^{2,3,4} A. Király,^{2,5} E. Forgács-Dajka,^{5,6}
I. B. Bíró,¹ T. R. Bedding,⁴ S. T. Bryson,⁷ D. Huber^{4,7} and R. Szabó²

¹Baja Astronomical Observatory, H-6500 Baja, Szegedi út, Kt. 766, Hungary

²Konkoly Observatory, MTA CSFK, H-1121 Budapest, Konkoly Thege M. út 15–17, Hungary

³ELTE Gothard-Lendület Research Group, H-9700 Szombathely, Szent Imre herceg út 112, Hungary

⁴Sydney Institute for Astronomy, School of Physics, University of Sydney, NSW 2006, Australia

⁵Astronomical Department, Eötvös University, H-1118 Pázmány Péter stry. 1/A, Budapest, Hungary

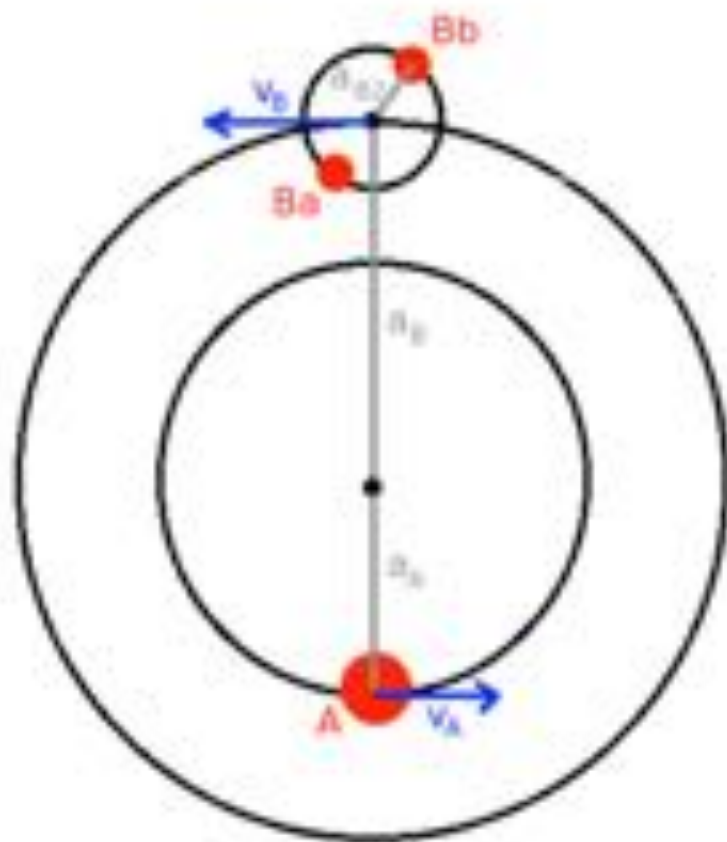
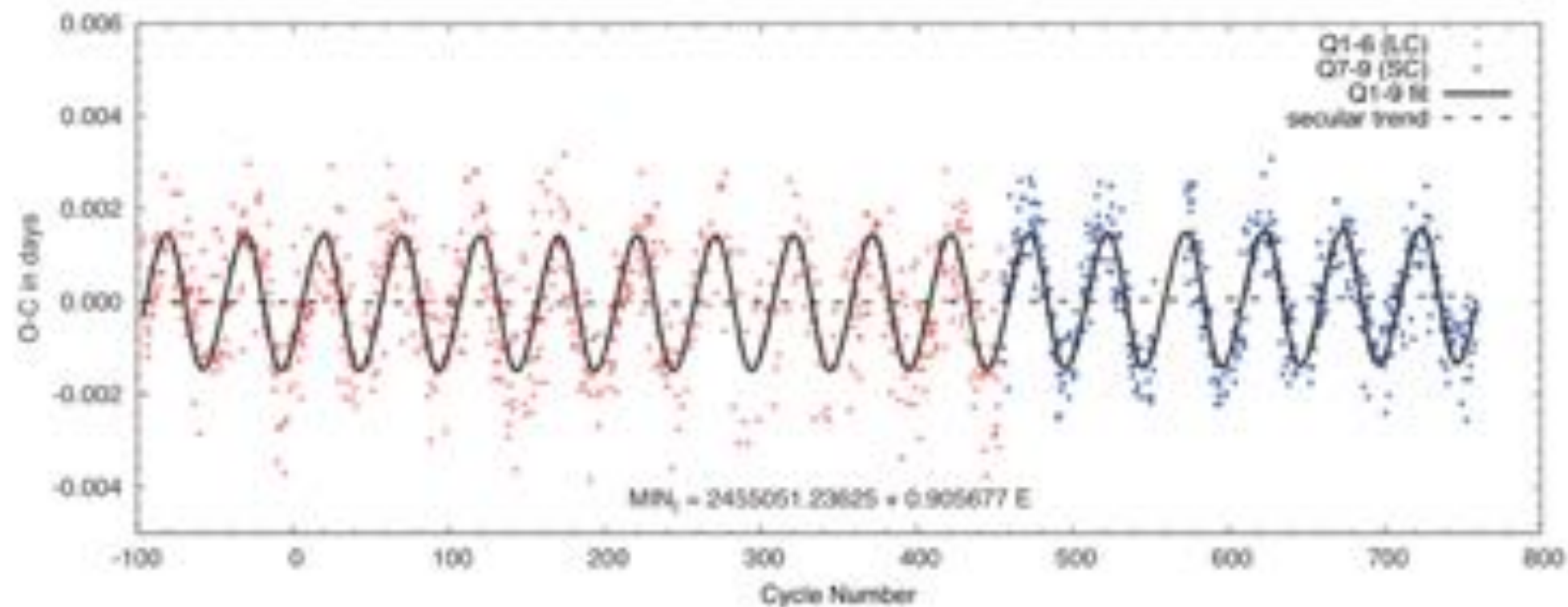
⁶University of Vienna, Türkenschanzstrasse 17, 1180 Vienna, Austria

⁷NASA Ames Research Center, Moffett Field, CA 94035, USA

Accepted 2012 October 3; Received 2012 October 3; in original form 2012 September 12

ABSTRACT

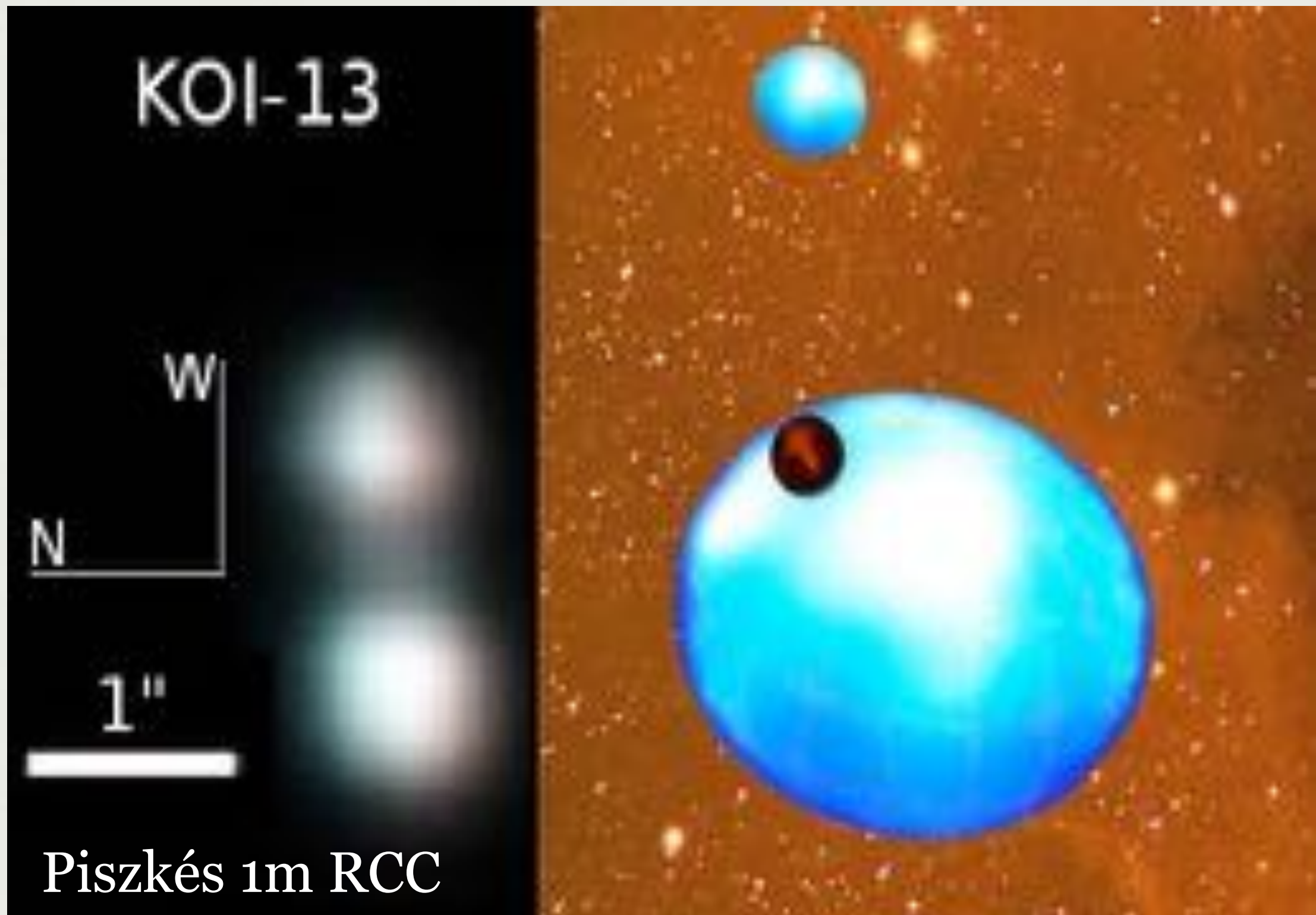
HD 181068 is the brighter of the two known triply eclipsing hierarchical triple stars in the *Kepler* field. It has been continuously observed for more than 2 yr with the *Kepler* space telescope. Of the nine quarters of the data, three have been obtained in short-cadence mode, that is one point per 58.9 s. Here we analyse this unique data set to determine absolute physical parameters (most importantly the masses and radii) and full orbital configuration using a sophisticated novel approach. We measure eclipse timing variations (ETVs), which are then combined with the single-lined radial velocity measurements to yield masses in a manner equivalent to double-lined spectroscopic binaries. We have also developed a new light-curve synthesis code that is used to model the triple, mutual eclipses and the effects of the changing tidal field on the stellar figures and the relativistic Doppler boosting. By combining the stellar



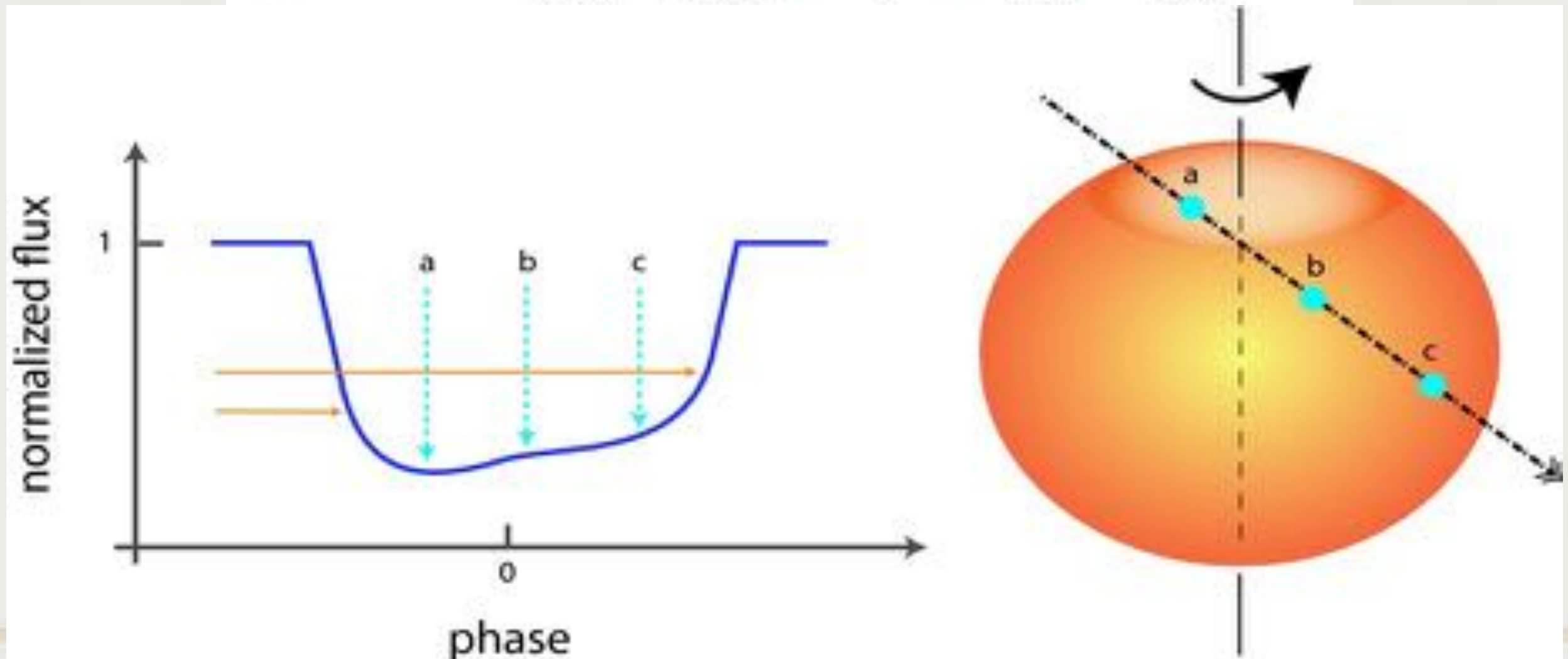
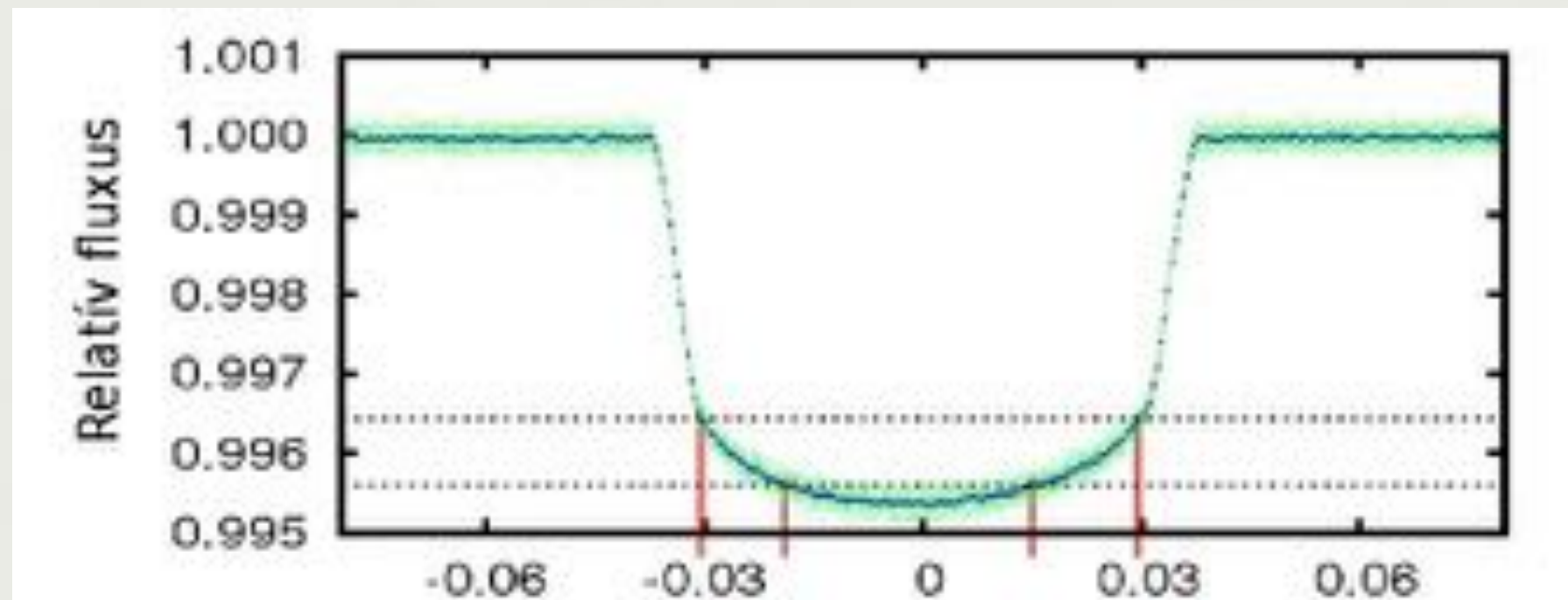
- Fényidő-effektus
- tömegmérés
- csillagfejlődési állapot
- Új típusú rezgések: árapály-hatások által gerjesztett "normál" módusok

(Borkovits et al. 2013 MNRAS;
Fuller et al. 2013 MNRAS)

Kepler-13 (=KOI-13)
(Szabó et al. 2011, 2012, 2013)



Pályadőltség detektálása tisztán fotometriából (Szabó et al. 2011, 2012, 2013)



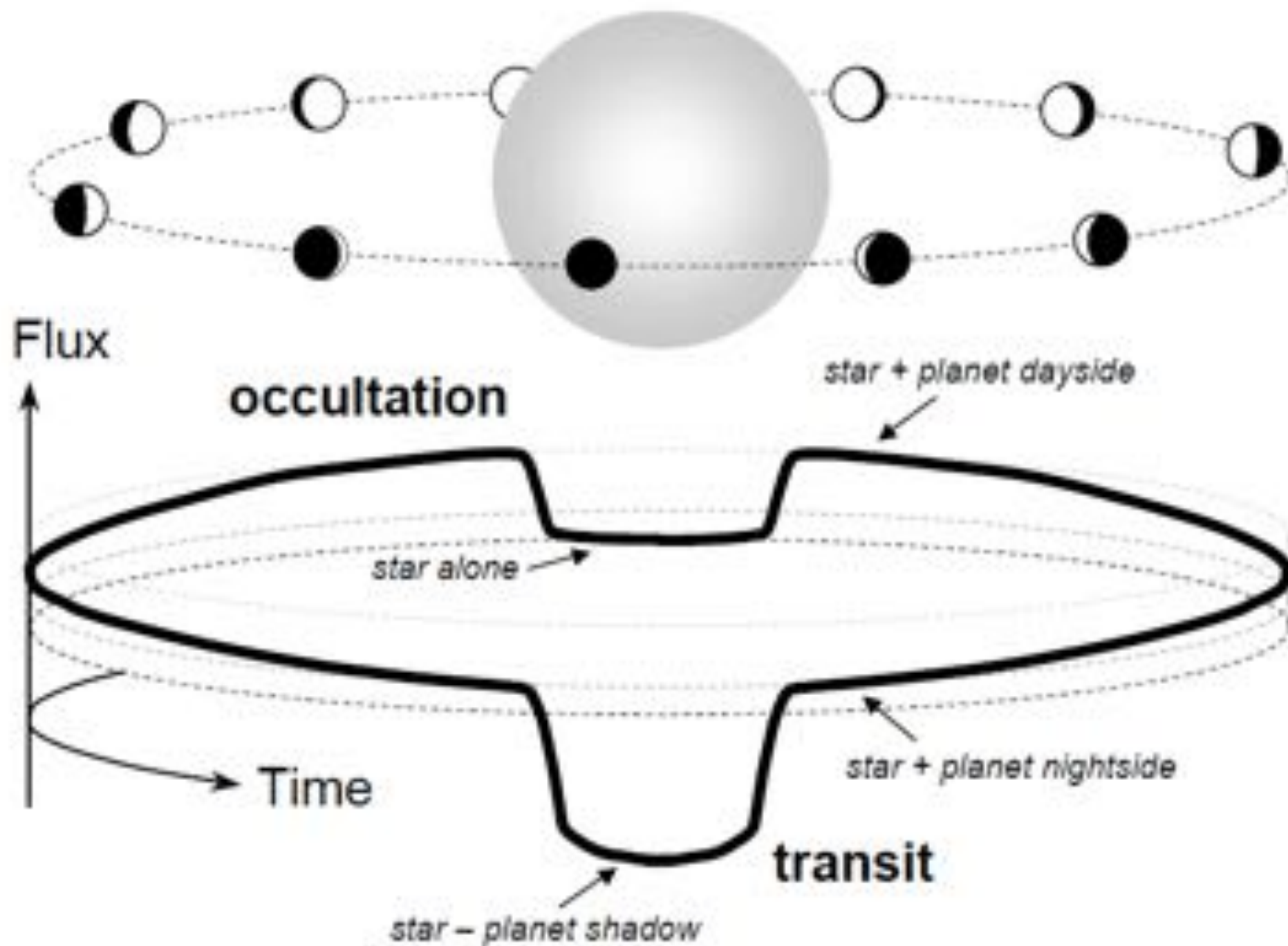


Fig. 1.— Illustration of transits and occultations. Only the combined flux of the star and planet is observed. During a transit, the flux drops because the planet blocks a fraction of the starlight. Then the flux rises as the planet's dayside comes into view. The flux drops again when the planet is occulted by the star.

(Winn 2010)

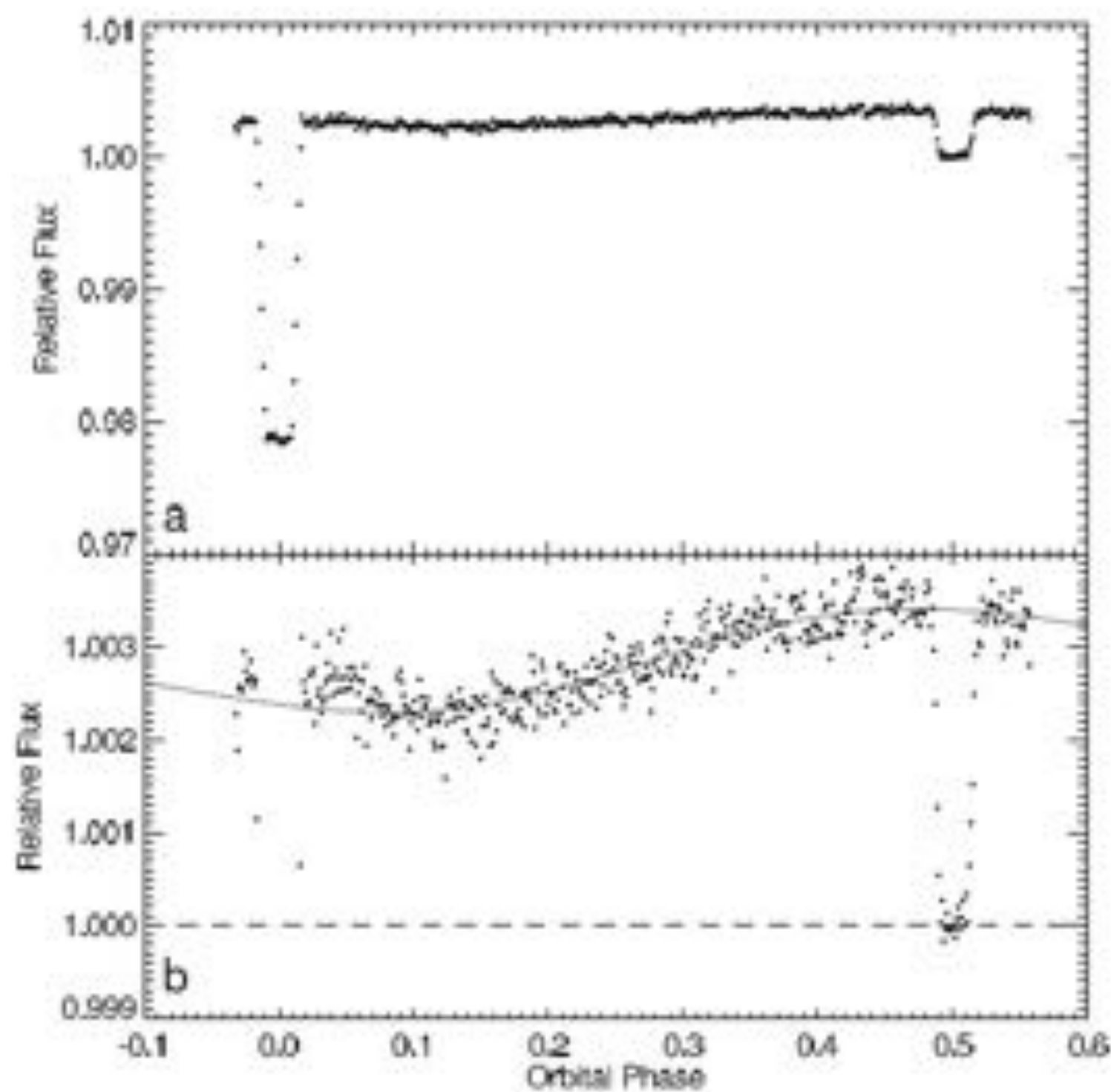


Fig. 11.— The combined $8\ \mu\text{m}$ brightness of the K star HD 189733 and its giant planet, over a 33 hr interval including a transit and an occultation. The bottom panel shows the same data as the top panel but with a restricted vertical scale to highlight the gradual rise in brightness as the planet's dayside comes into view. The amplitude of this variation gives the temperature contrast between the dayside (estimated as $1211 \pm 11\ \text{K}$) and the nightside ($973 \pm 33\ \text{K}$). From Knutson et al. (2007b).

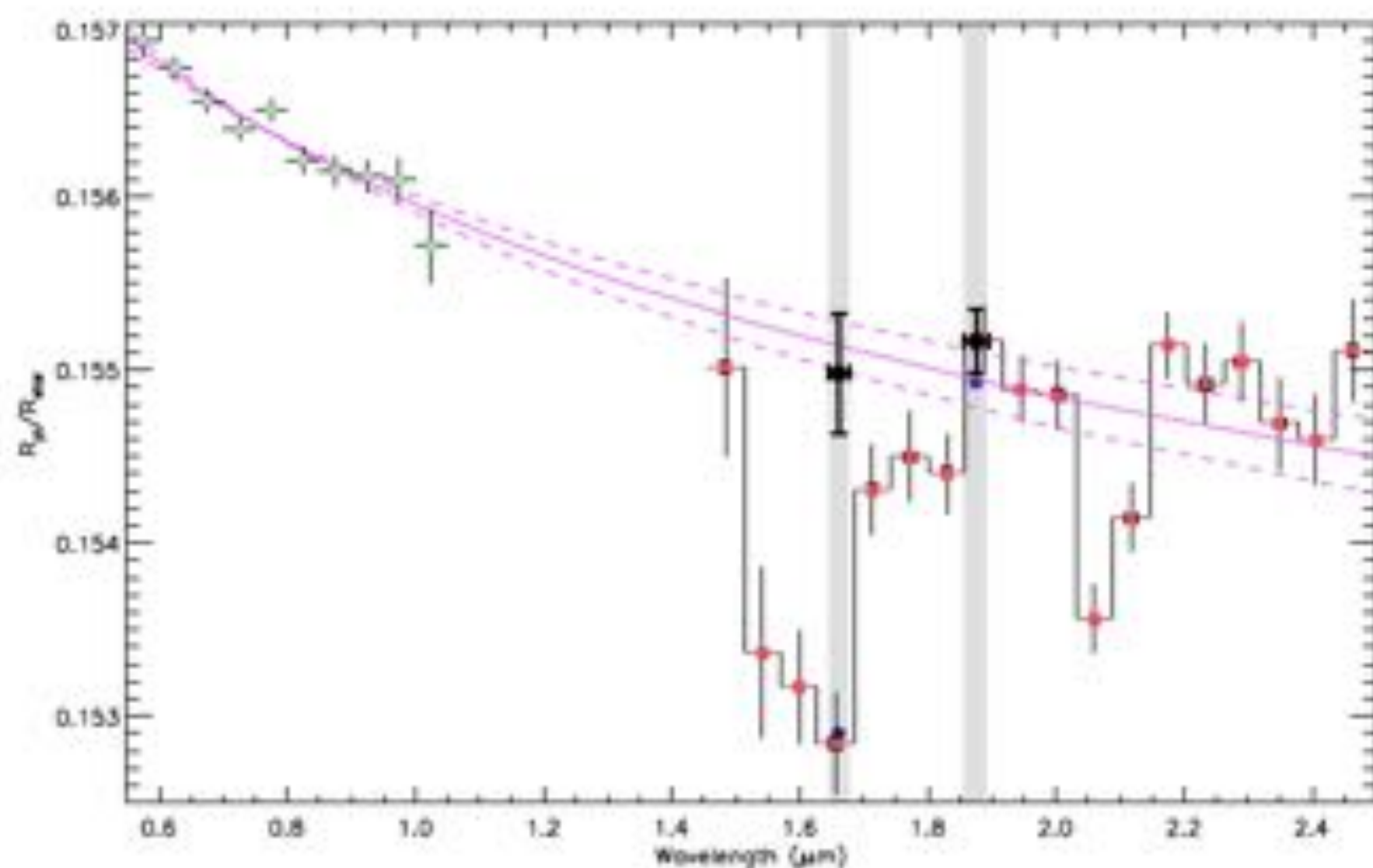
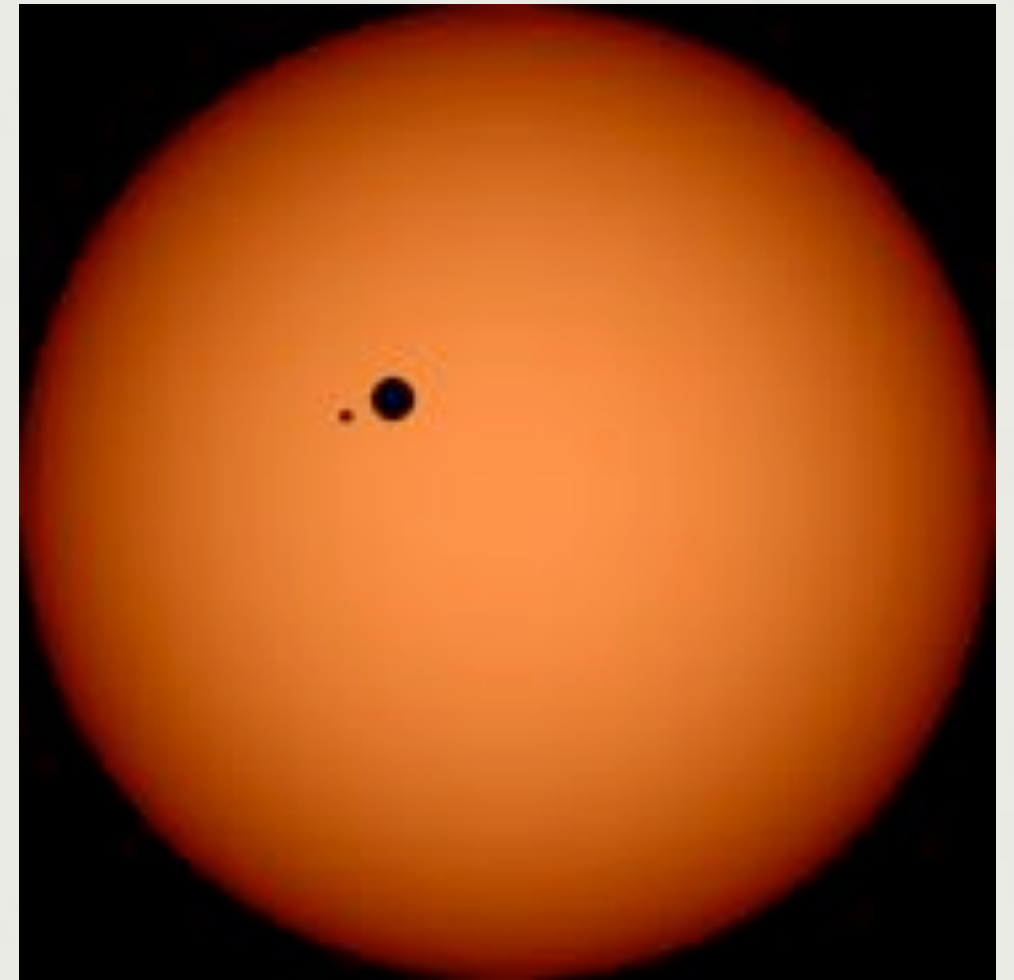
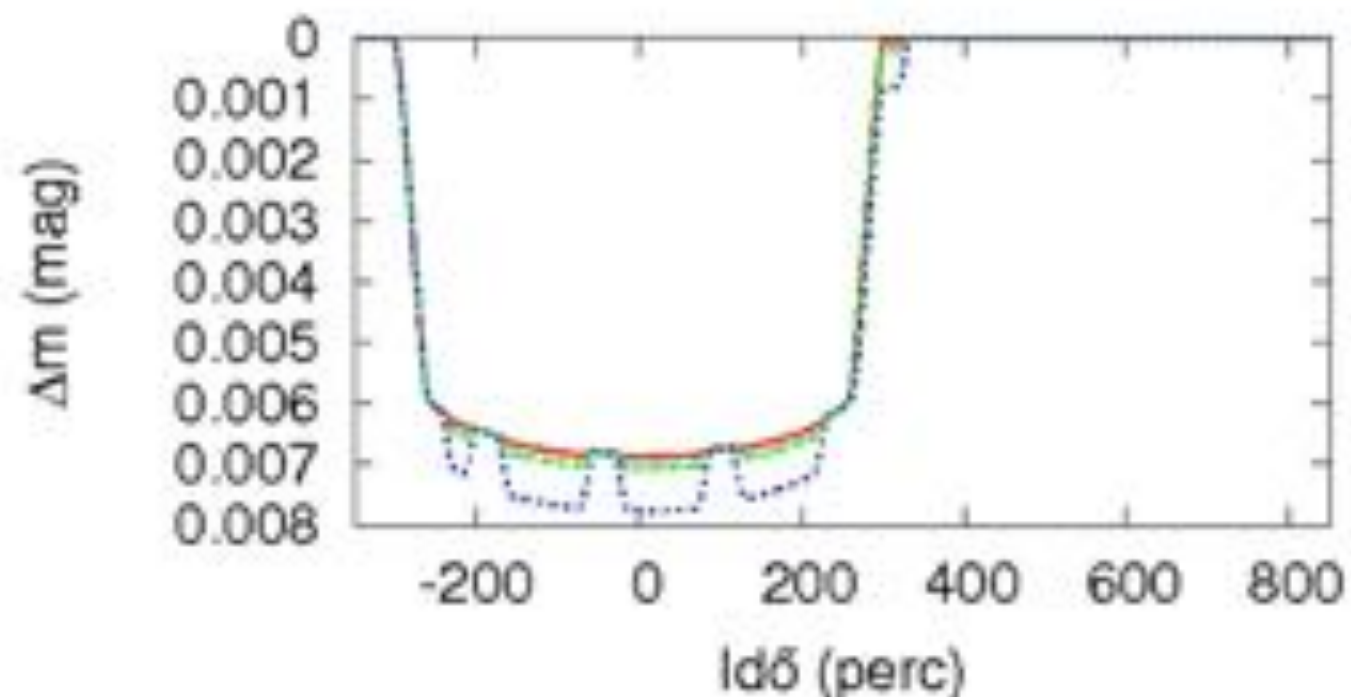
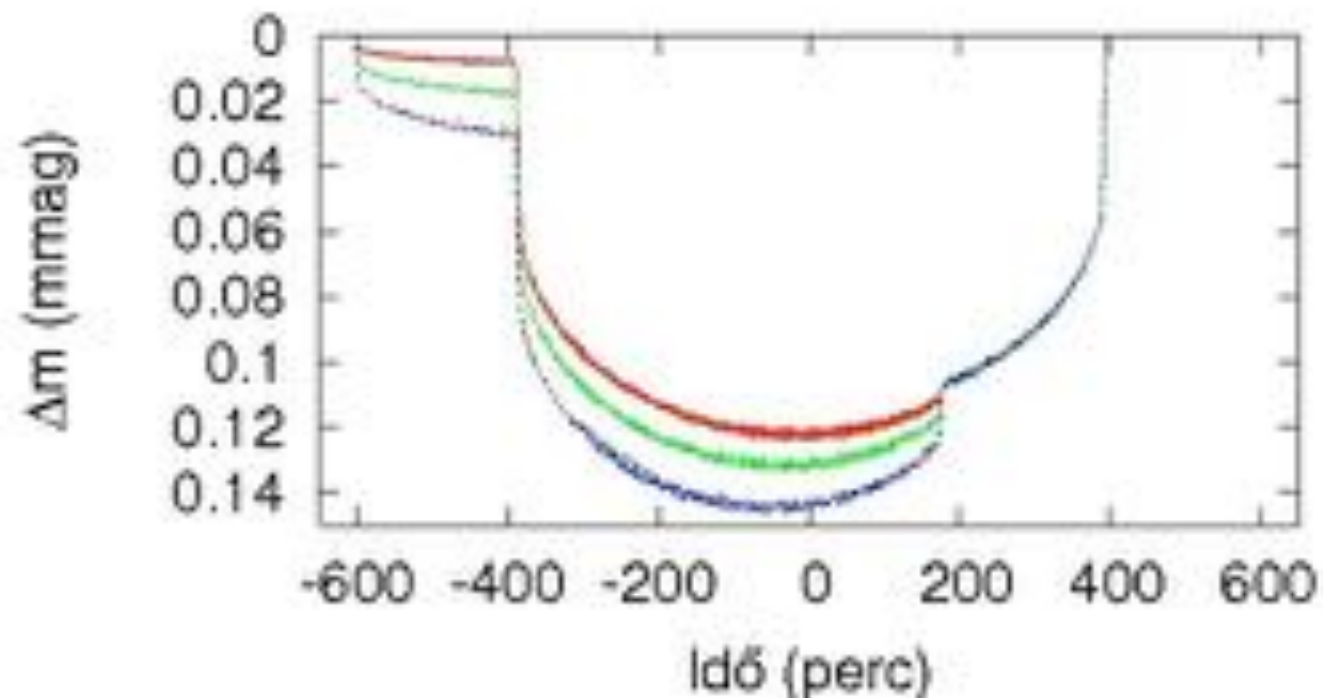


Fig. 12.— Transmission (transit) spectroscopy of the gas giant HD 189733b, using the *Hubble Space Telescope*. The symbols with errors bars are measurements of the effective planet-to-star radius ratio as a function of wavelength. The dip at 1.6 μm was interpreted as evidence for water, and the rise at 2.1 μm as evidence for methane (Swain et al. 2008). However, subsequent observations at 1.7 μm and 1.9 μm , shown with darker symbols and gray bands, disagree with the earlier results and are consistent with a Rayleigh scattering model (solid and dashed curves). From Sing et al. (2009).

Tranzit rendszerek holddal - exoholdak

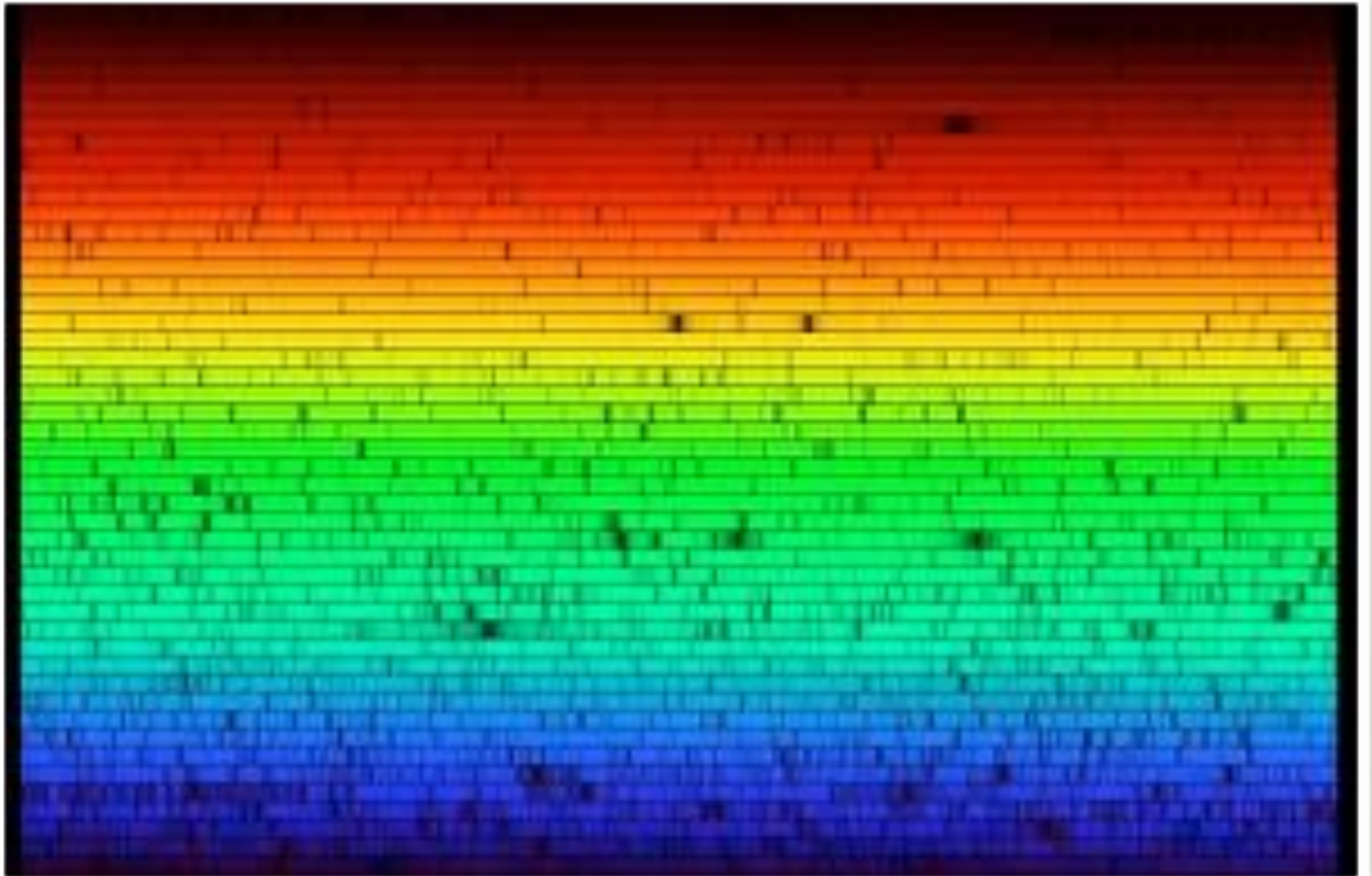


Lassan (fent) és gyorsan (lent) keringő hold (Simon A.)

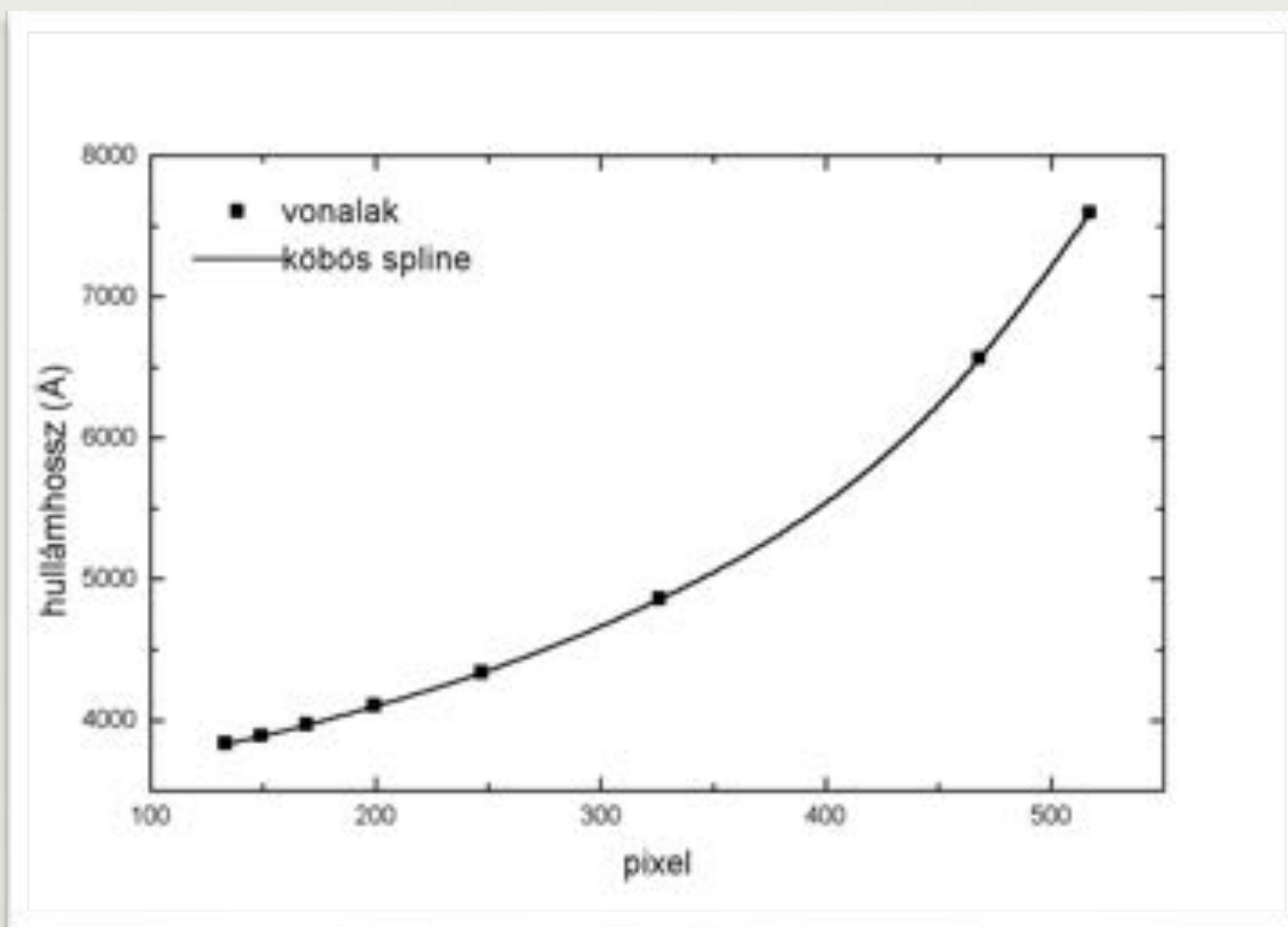
SPEKTROSZKÓPIAI FEJLŐDÉS: KOZMIKUS TRAFFIPAX

- Nagyságrendi ugrások:
 - 10 km/s: szoros kettőscsillagok, galaxisok vöröseltolódása
 - 1 km/s: kettőscsillagok tömegei, klasszikus pulzáló csillagok, sötét anyag gravitációs hatása
 - 1-100 m/s: exobolygók (szuperföld-Neptunusz-Jupiter), Nap típusú rezgések
 - 1- 10 cm/s: kozmológiai tesztek, exoföldek, exoholdak, ???

Színképvonalak - kozmikus traffipax



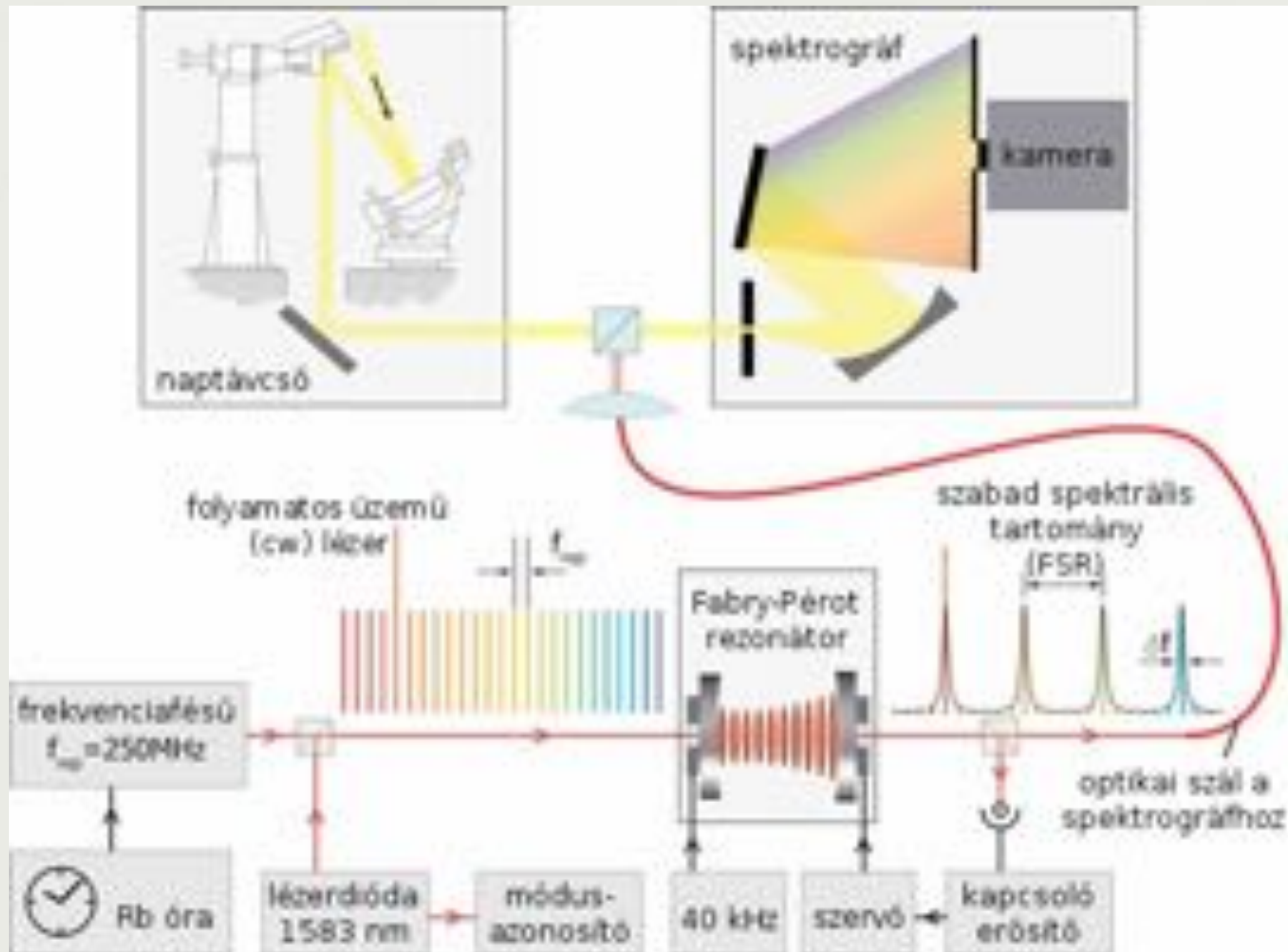
Hullámhossz-kalibráció: a pontosság kulcsa



Egy jódcella

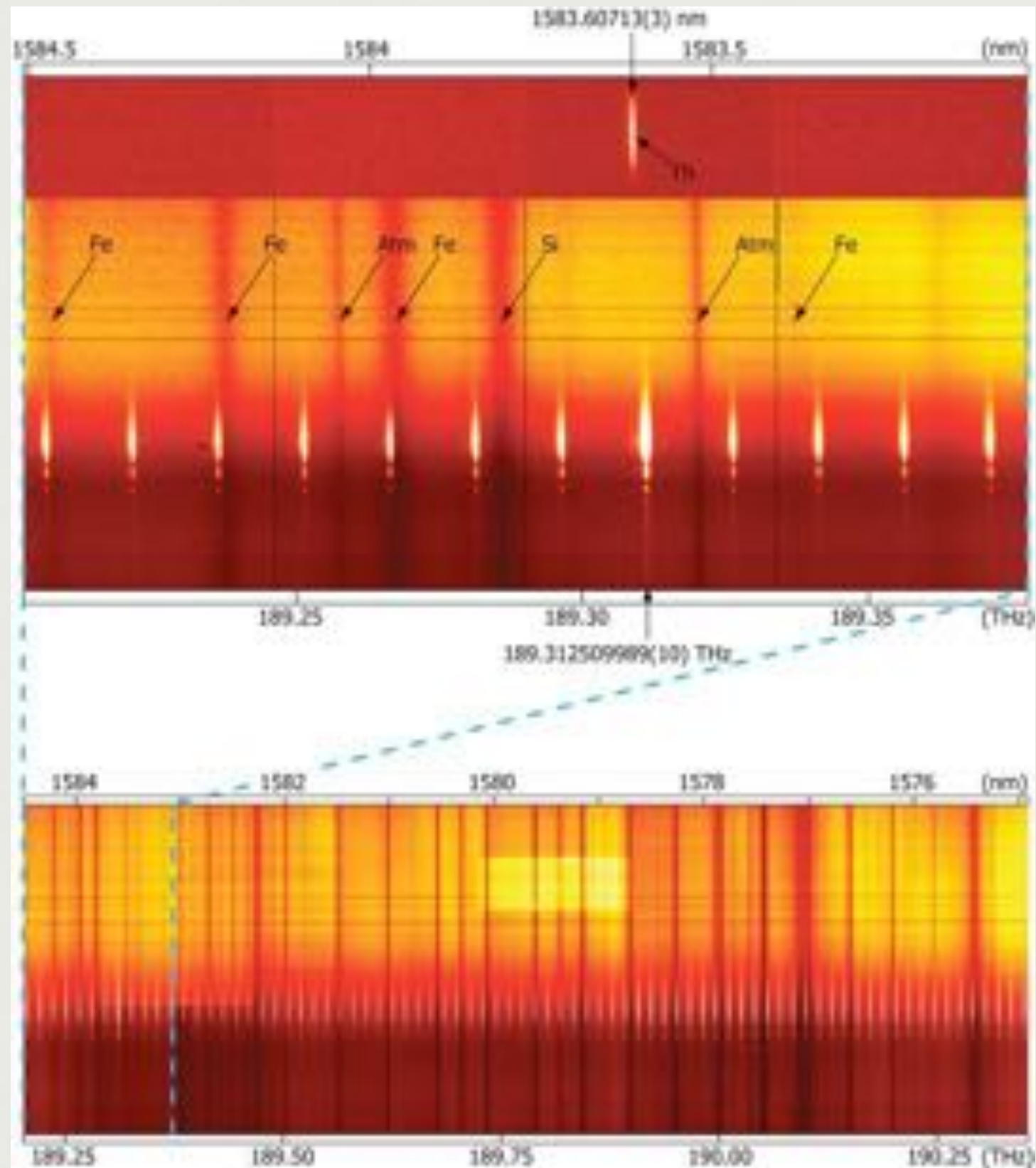


Lézerfésűk: továbblépés a cm/s pontosság irányába?

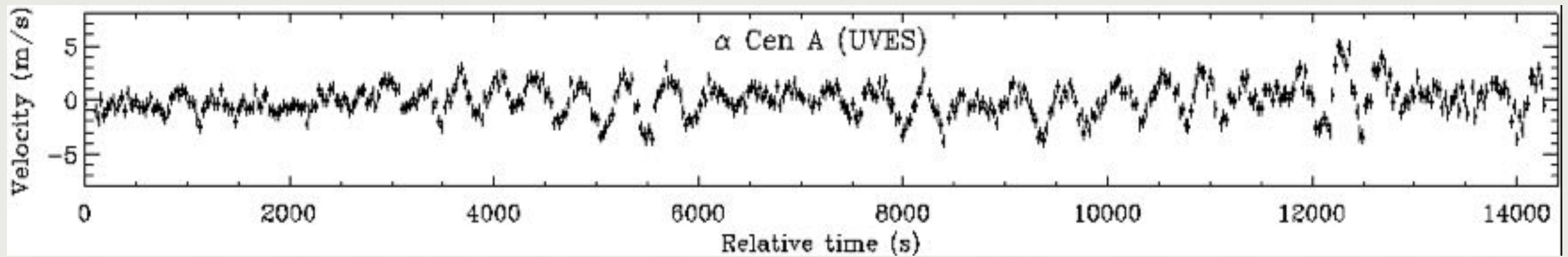


Steinmetz et al. 2008, Science

Napfény és a lézerefésű szimultán spektruma



Az alfa Cen A az UVES/VLT műszerrel



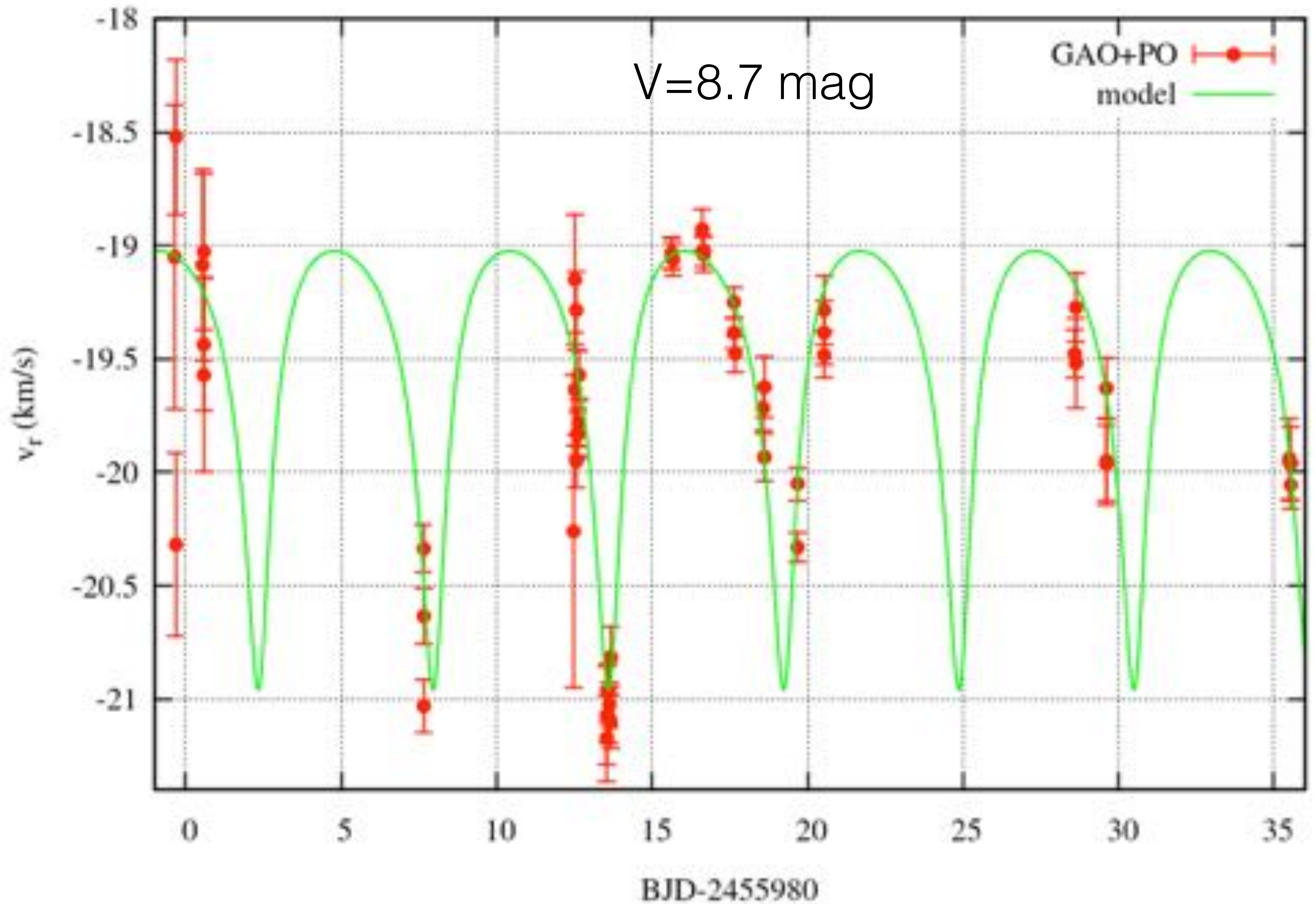
Pontosság: 50-70 cm/s. 3 s expozíciók, 8m-es távcső, a déli
ég 3. legfényesebb csillaga

Butler et al. (2003)

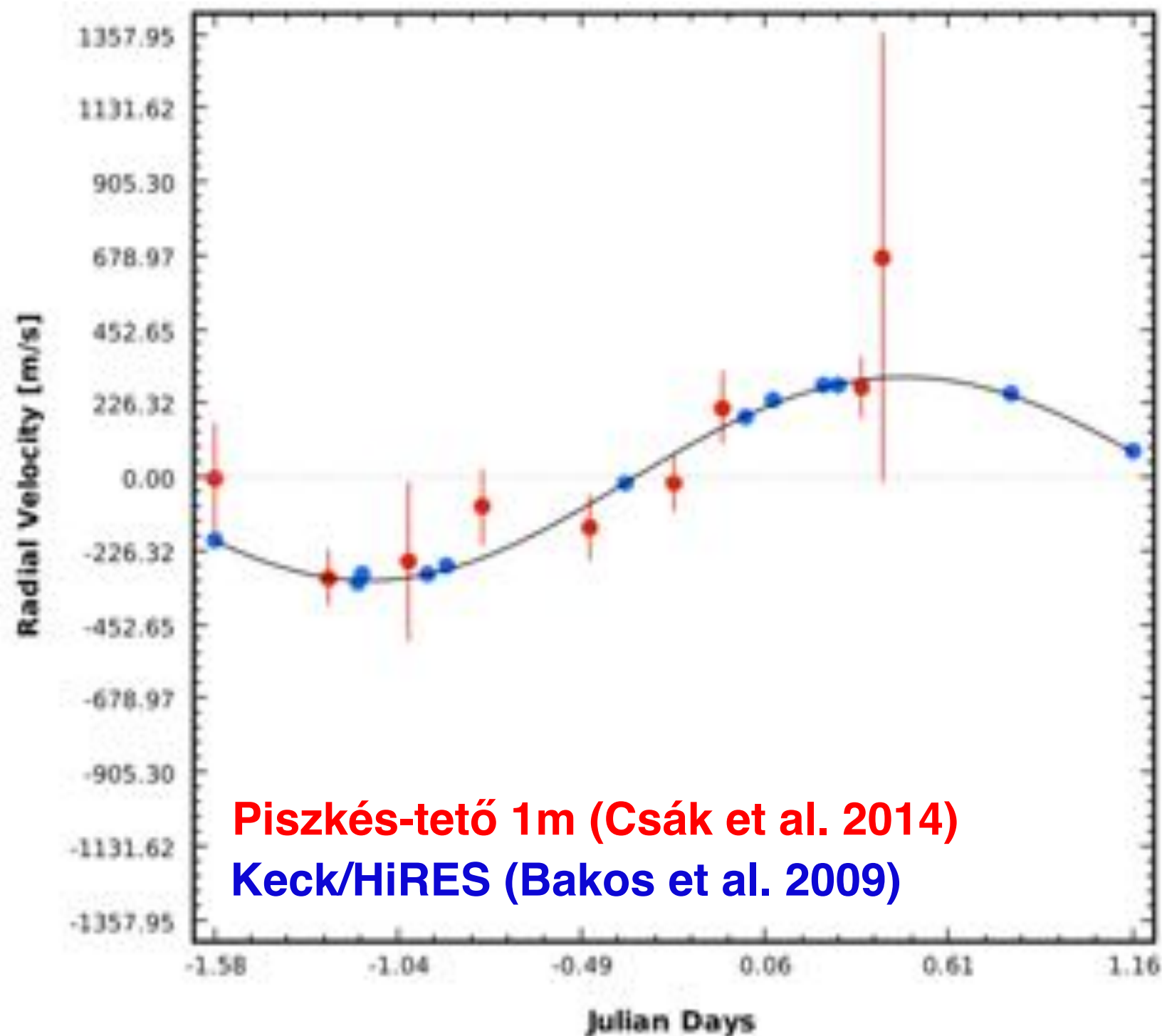
Pontosság: 10-50 cm/s. 10-20 perc expozíciók, 1-4m-es
távcsövek, szabad szemmel látszó csillagok (kb. 6000)

Néhány csoport (2013)

HAT-P-2b (Csák et al. 2014)



HAT-P-22b (Csák et al. 2014)



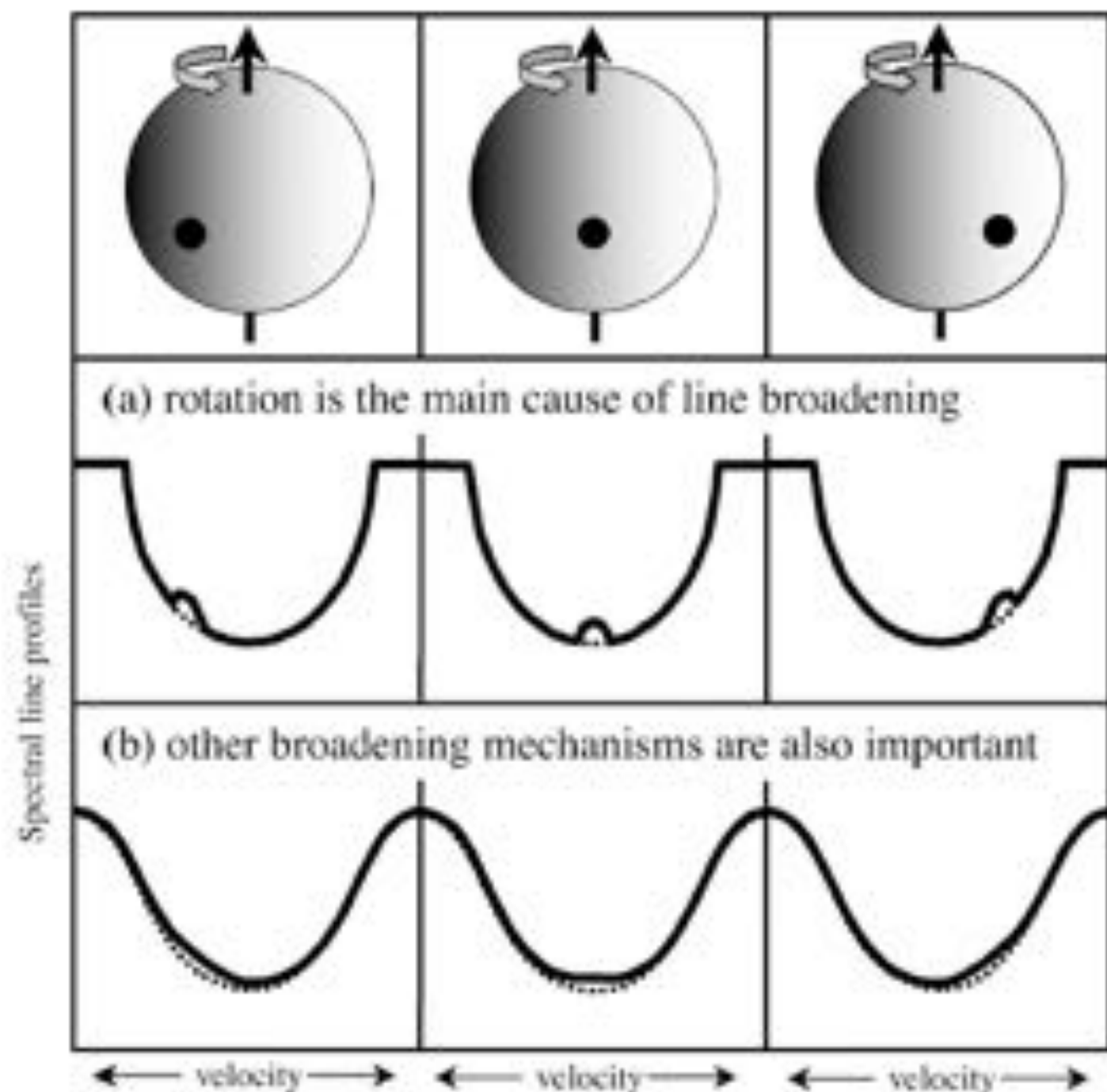


Fig. 5.— Illustration of the Rossiter-McLaughlin (RM) effect. The three columns show three successive phases of a transit. The first row shows the stellar disk, with the grayscale representing the projected rotation velocity: the approaching limb is black and the receding limb is white. The second row shows the corresponding stellar absorption line profiles, assuming rotation to be the dominant broadening mechanism. The “bump” occurs because the planet hides a fraction of the light that contributes a particular velocity to the line-broadening kernel. The third row shows the case for which other line-broadening mechanisms are important, here the RM effect is manifested only as an “anomalous Doppler shift.” Adapted from Gaudi & Winn (2007).

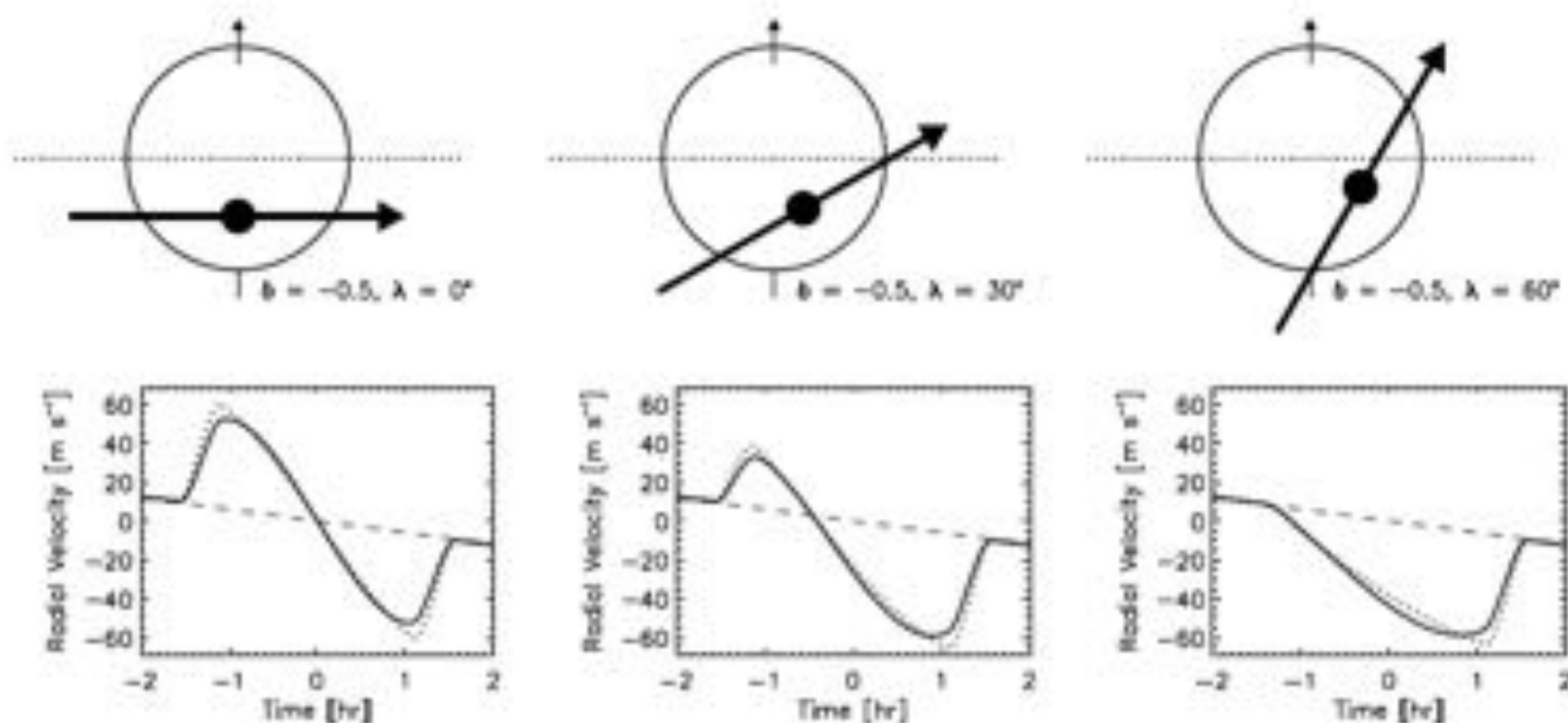


Fig. 6.— Using the RM effect to measure the angle λ between the sky projections of the orbital and stellar-rotational axes. Three different possible trajectories of a transiting planet are shown, along with the corresponding RM signal. The trajectories all have the same impact parameter and produce the same light curve, but they differ in λ and produce different RM curves. The dotted lines are for the case of no limb darkening, and the solid lines include limb darkening. From Gaudi & Winn (2007).

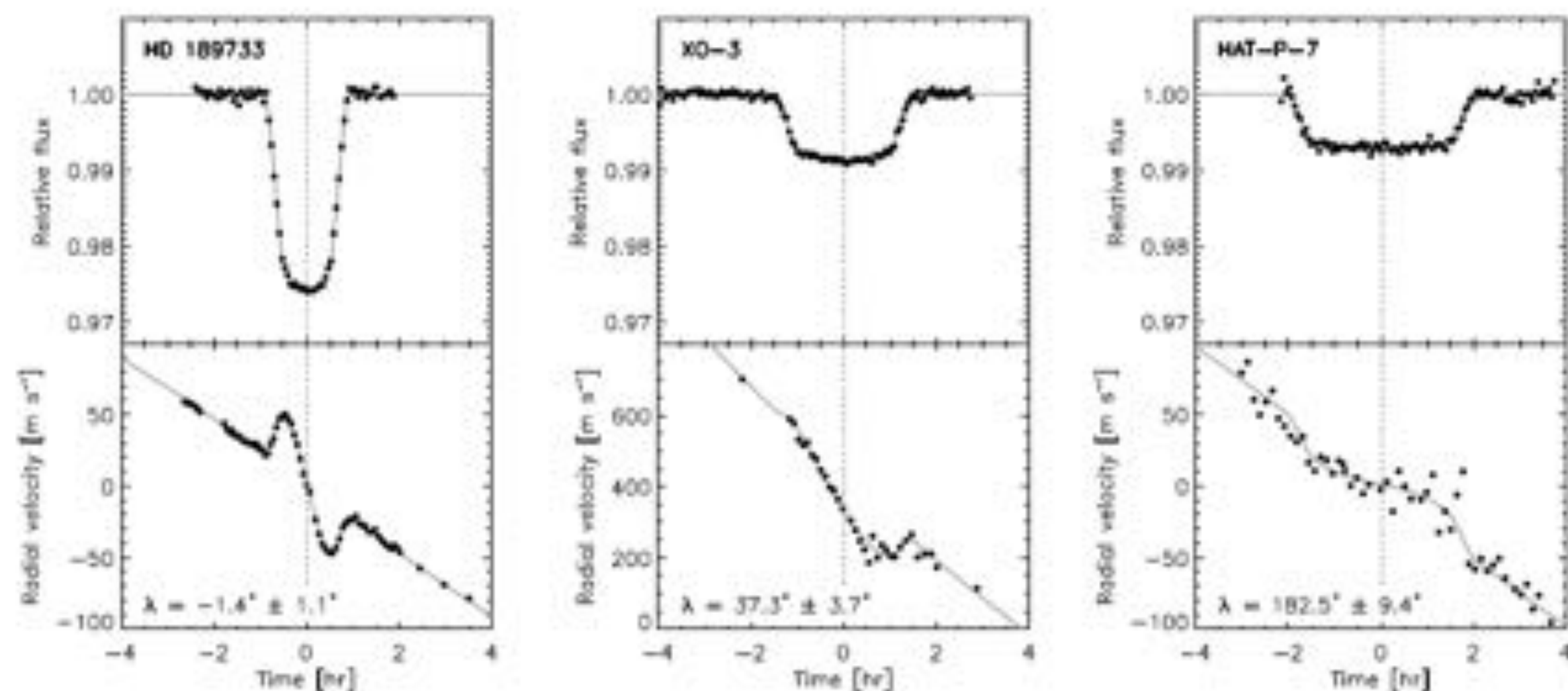


Fig. 14.— Examples of data used to measure the projected spin-orbit angle λ . The top panels show transit photometry, and the bottom panels show the apparent radial velocity of the star, including both orbital motion and the anomalous Doppler shift (the Rossiter-McLaughlin effect). The left panels show a well-aligned system and the middle panels show a misaligned system. The right panels show a system for which the stellar and orbital “north poles” are nearly *antiparallel* on the sky, indicating that the planet’s orbit is either retrograde or polar (depending on the unknown inclination of the stellar rotation axis). References: Winn et al. (2006, 2009a,b).

ÉGBOLTFELMÉRÉSEK

- Nagyságrendi ugrások:
 - 5000 csillag: szabad szemmel látszó égbolt
 - 100 ezer csillag: távcsöves, vizuális felmérés - a Tejútrendszer szerkezete
 - 10 millió csillag: fotografikus felmérés, égbolt homogén határfényességű lefedése
 - 1 milliárd csillag: digitális felmérés - a Tejútrendszer 1%-a
 - Pánkromatikus és spektroszkópai felmérések: populációk elkülönítése, precíziós kozmológia

LSST: a digital color movie of the Universe

színes, digitális mozgóképek az Univerzumról

Željko Ivezić, LSST Project Scientist

University of Washington and
Konkoly Observatory

Research Centre for Astronomy and Earth Sciences
Hungarian Academy of Sciences, Budapest

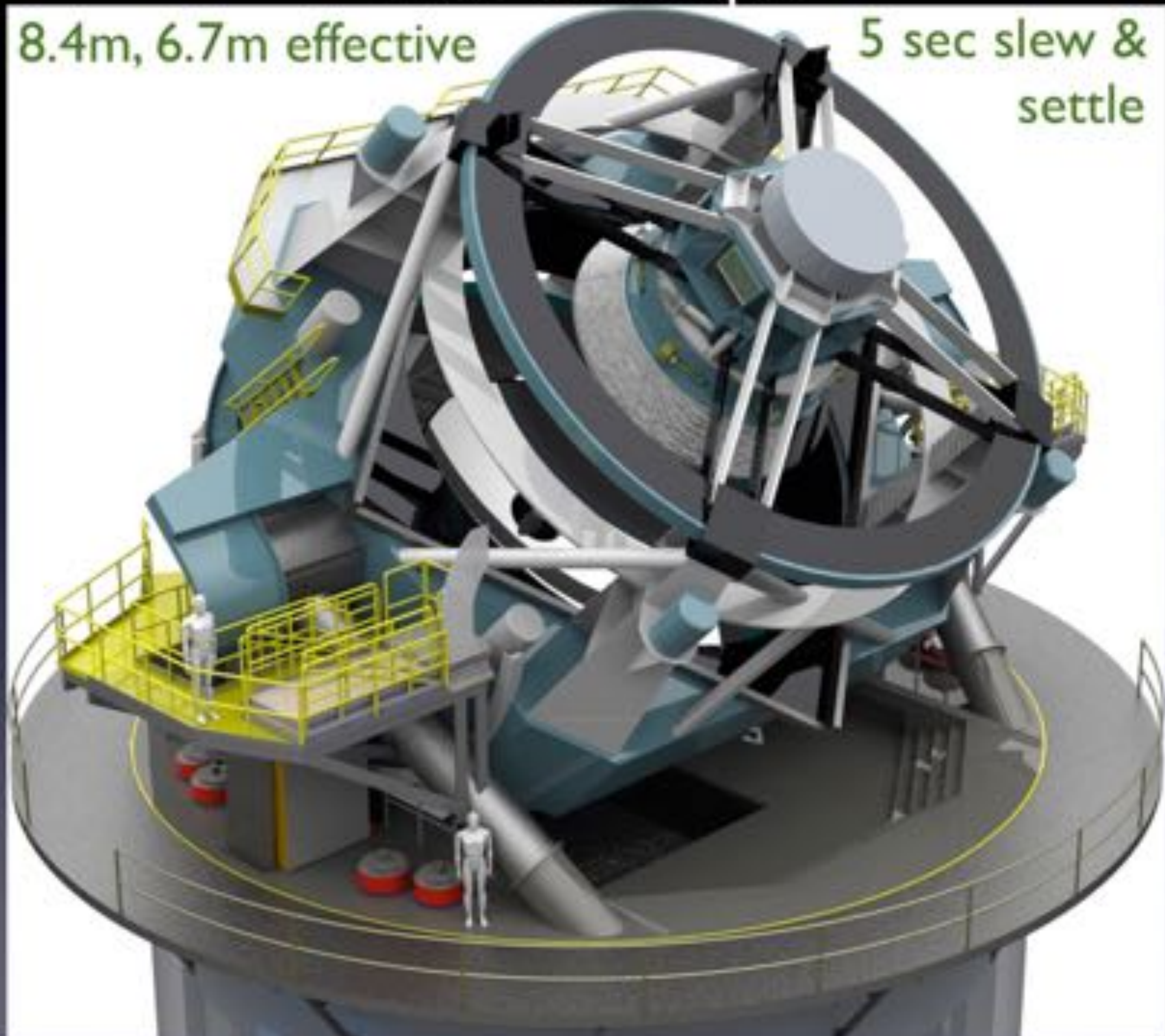
June 10, 2013



LSST Telescope

8.4m, 6.7m effective

5 sec slew &
settle



The field-of-view comparison: Gemini vs. LSST

Primary Mirror
Diameter

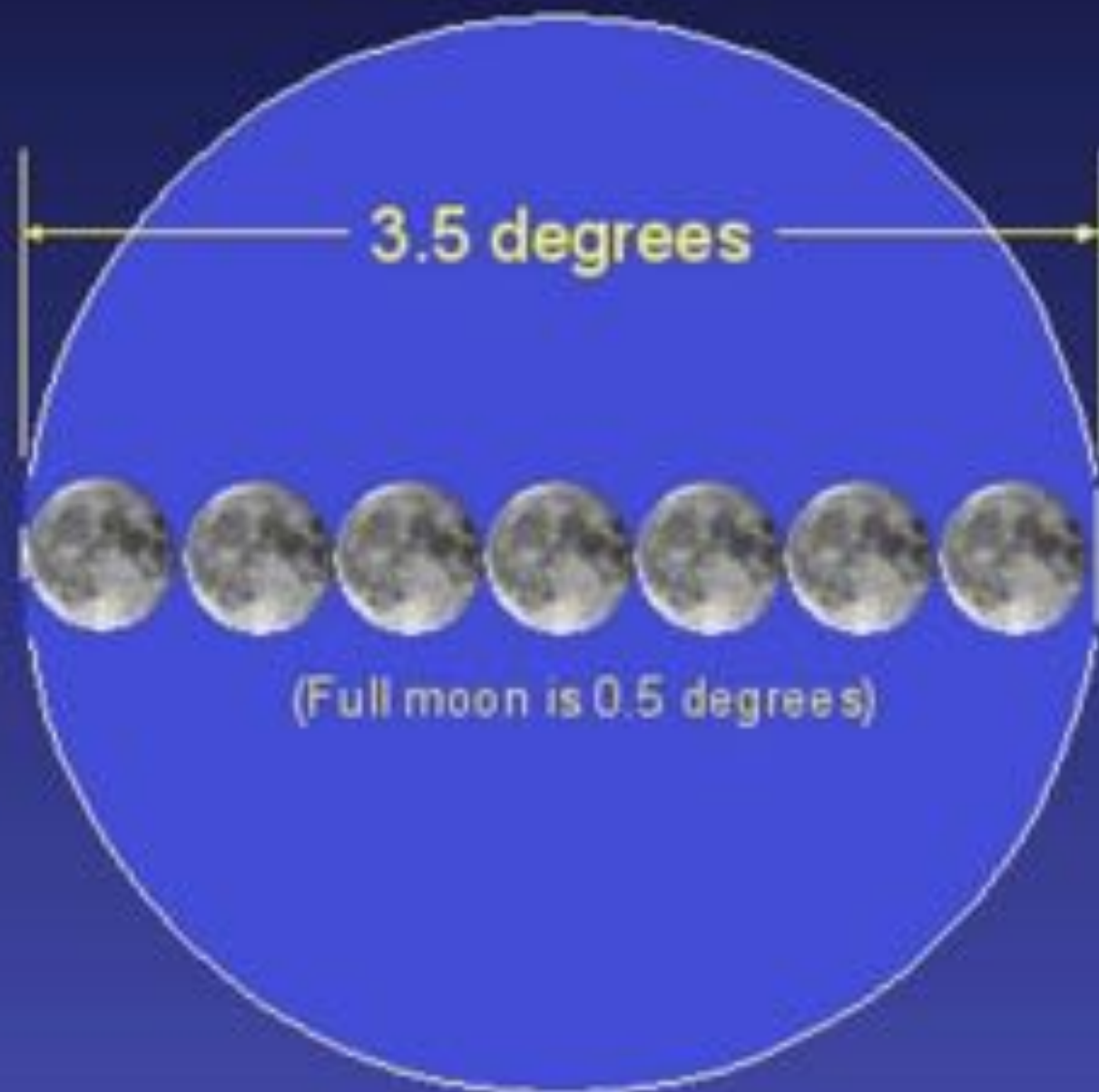
Field of
View



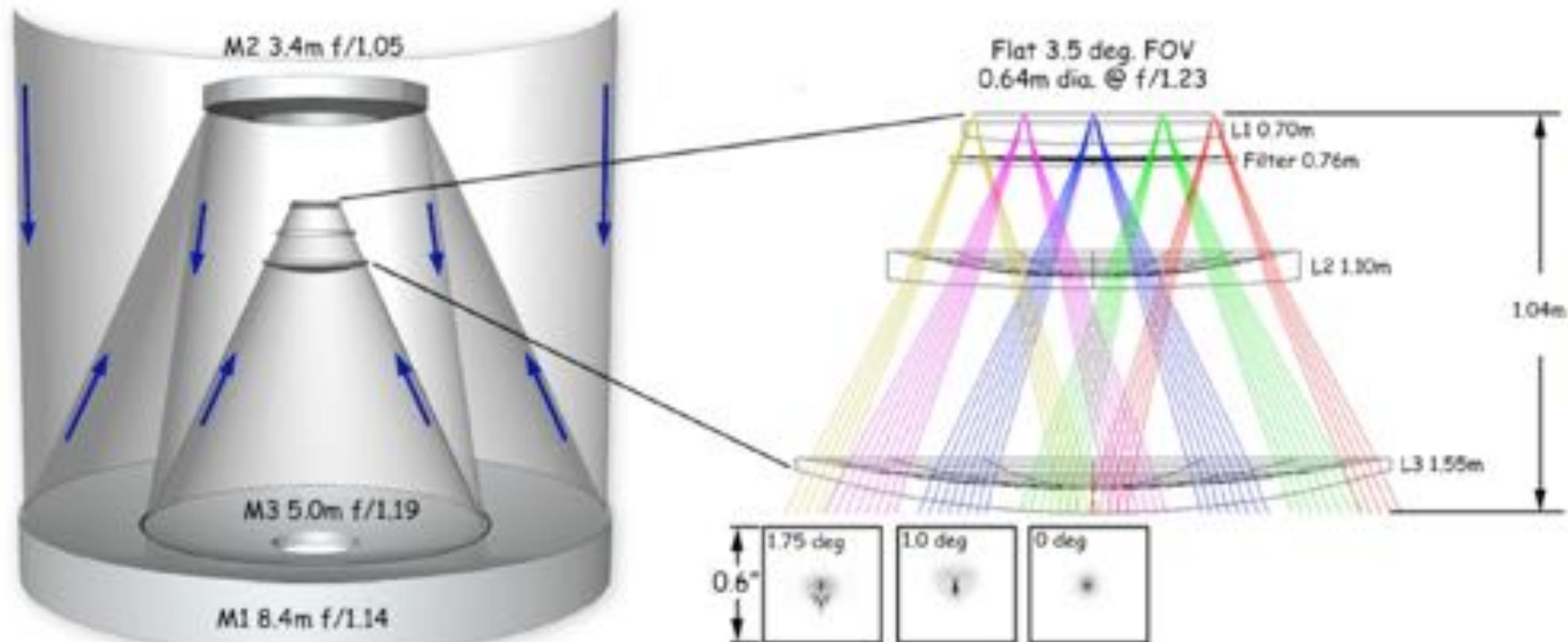
Gemini South
Telescope



LSST



Optical Design for LSST



Three-mirror design (Paul-Baker system)
enables large field of view with excellent image quality:
delivered image quality is dominated by atmospheric seeing

The largest astronomical camera: 2800 kg, 3.2 Gpix

