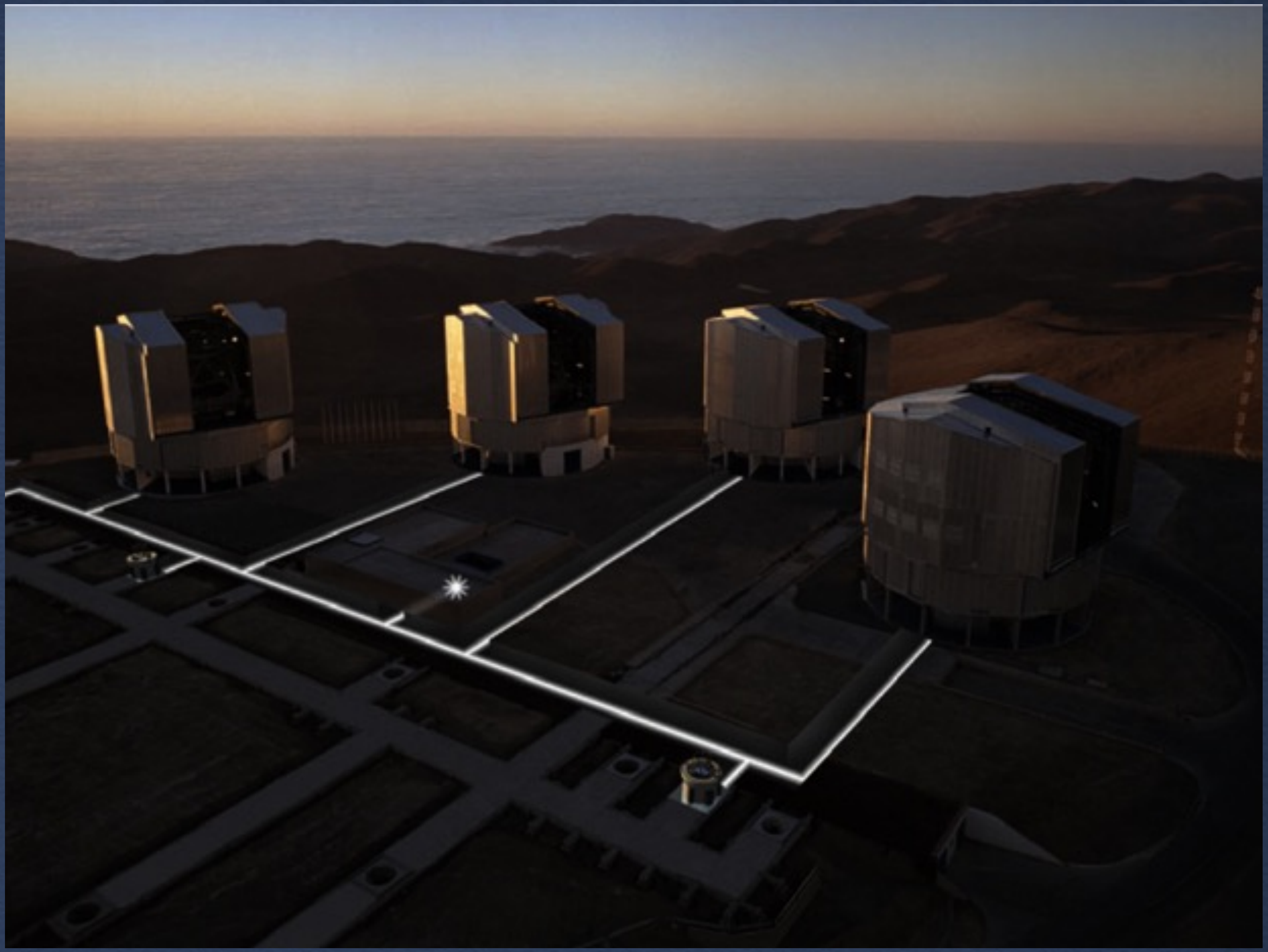
 

A pontosság bűvöletében: új fizikai felismerések ultraprecíz csillagászati megfigyelésekből

Kiss L. László, az MTA levelező tagja
Székfoglaló előadás, 2013. október 30.

(Optikai) csillagászat mért mennyiségei

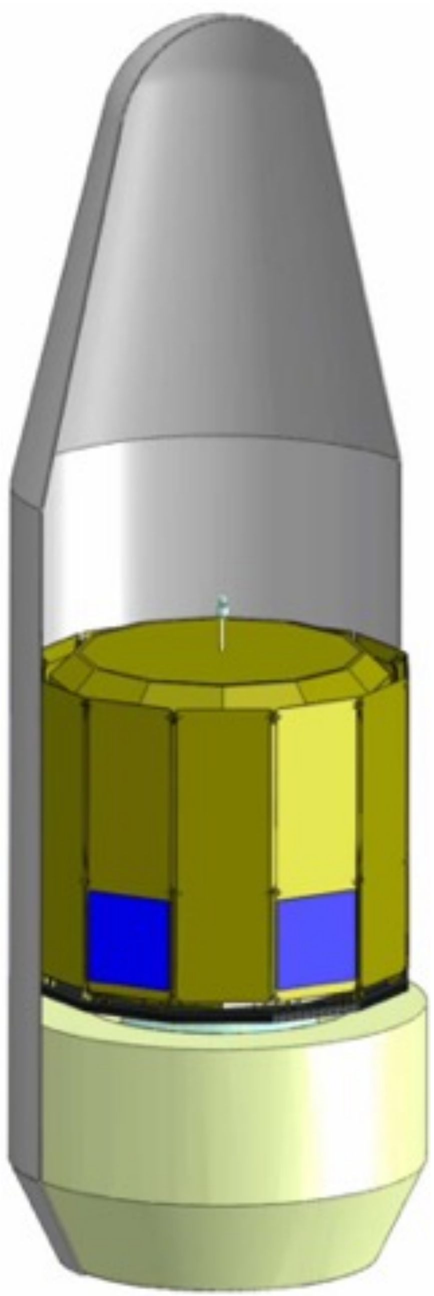
- **Égi irányok** - koordináták
- **Fényesség** - pontszerű és kiterjedt objektumok
- **Színkép** - folytonos és vonalas spektrumok
- **Sokaságok vizsgálata** - égboltfelmérések

A pontosság növelése új fizikai jelenségek felfedezéséhez vezethet!

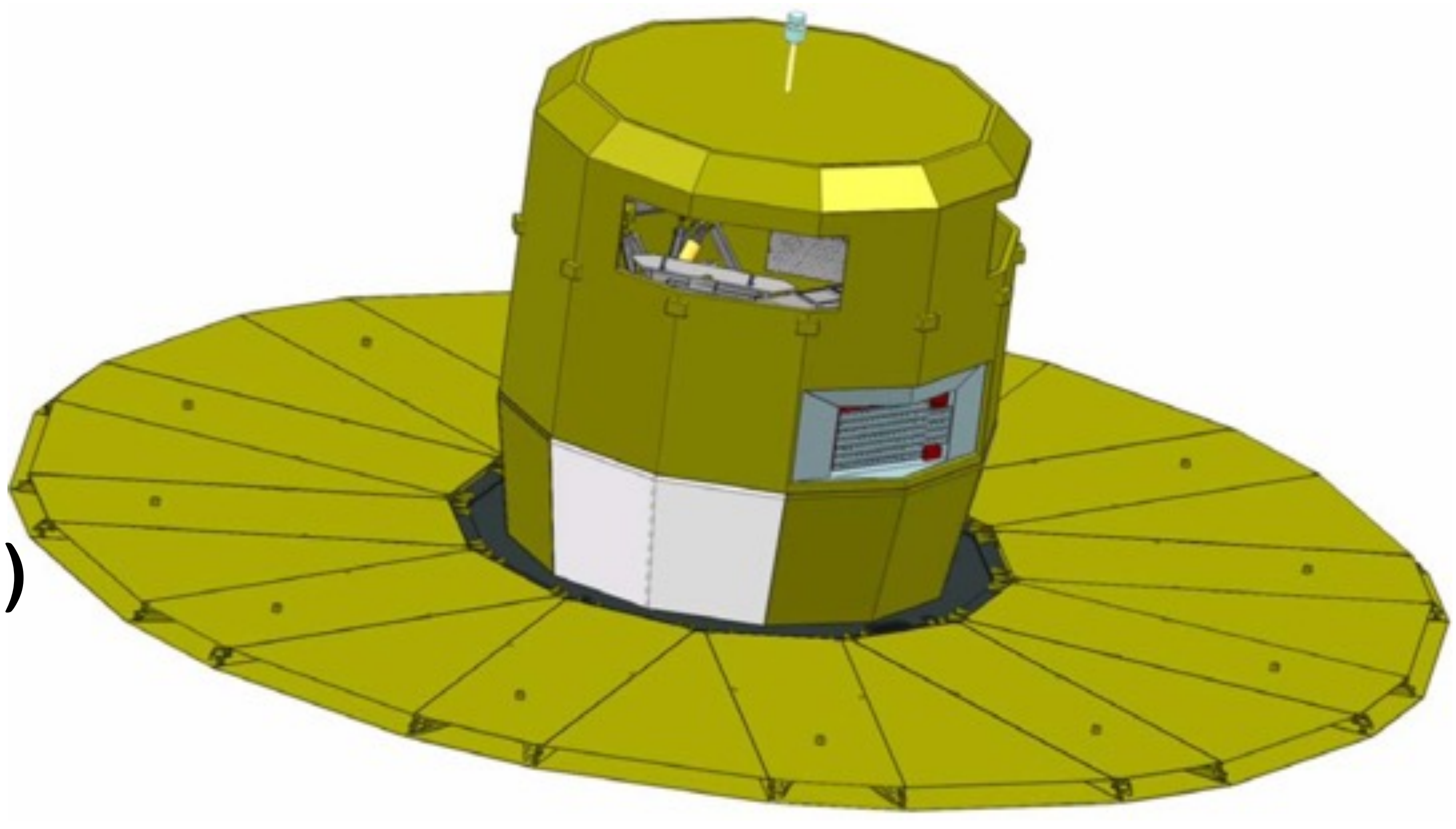
SZÖGMÉRÉS FEJLŐDÉSE

- 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 mas=4,8 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



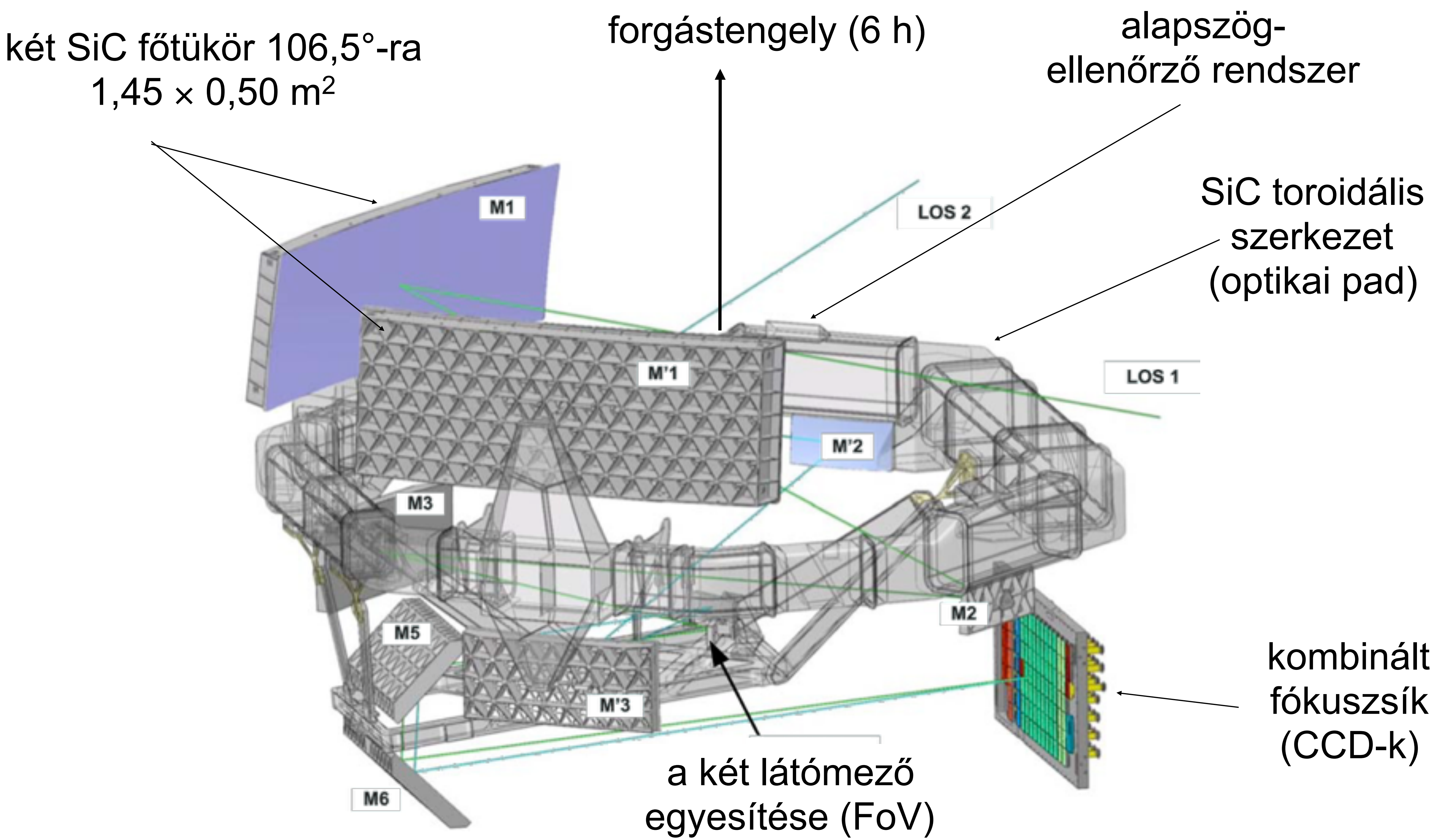
- kizárólag ESA-misszió
- indítás: 2013. december 20.
- 5 év működés (esetleg 1 év hosszabbítás)
- hordozórakéta: Szojuz–Fregat
- pálya: Lissajous-pálya az L2 pont körül
- adattovábbítás: 4–8 Mbps



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

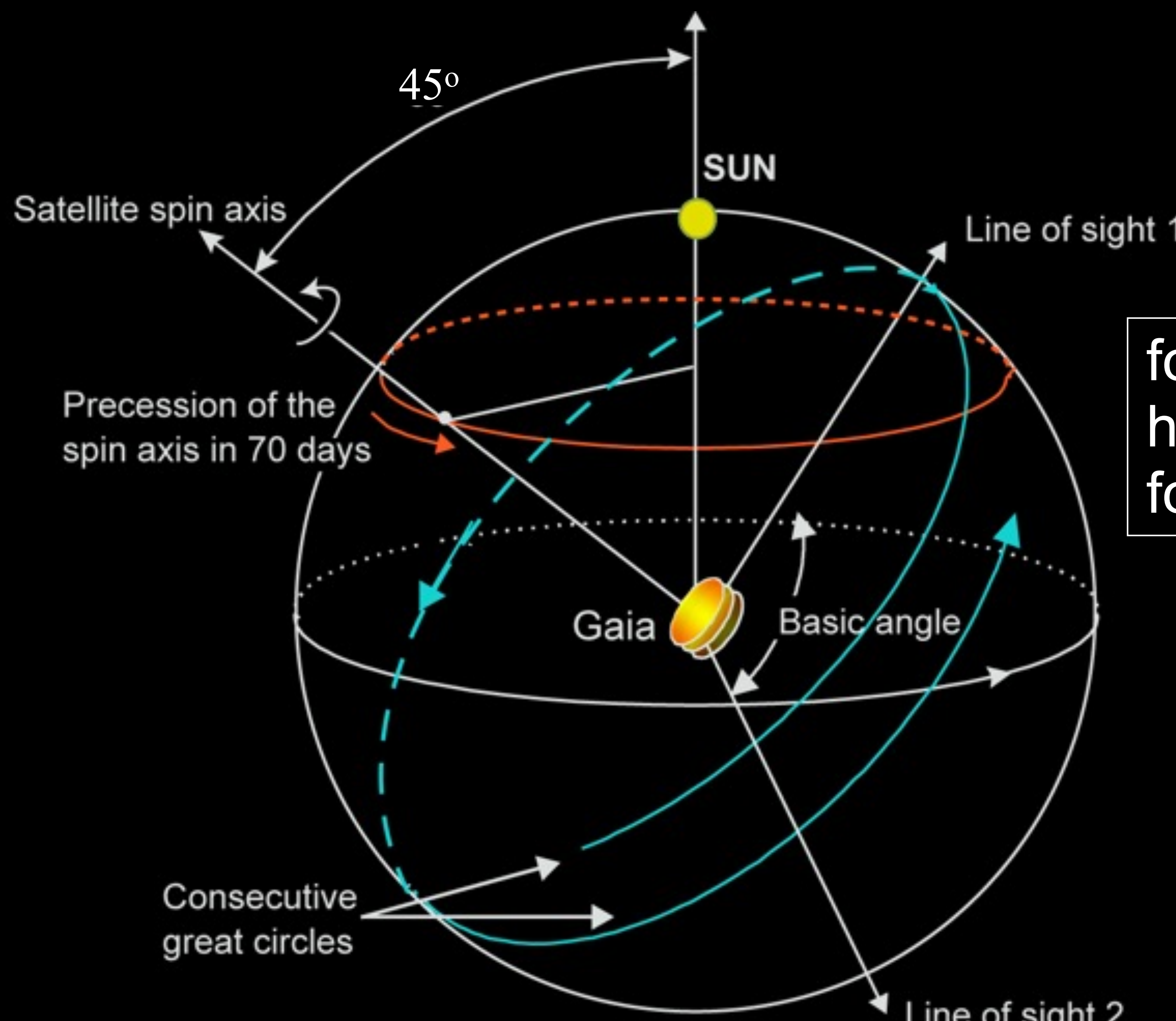
EADS-Astrium alapján

A távcső és a műszerek



EADS-Astrium alapján

Az égbolt szkennelésének elve



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

Forrás: Karen O'Flaherty

Gaia: teljes, pontos, mély

	Hipparcos	Gaia
Magnitúdóhatár	12	20 magnitúdó
Teljesség	7,3-9,0	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 es torzítatlan

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

Az égbolt szkennelése 5 éven át ⇒ 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

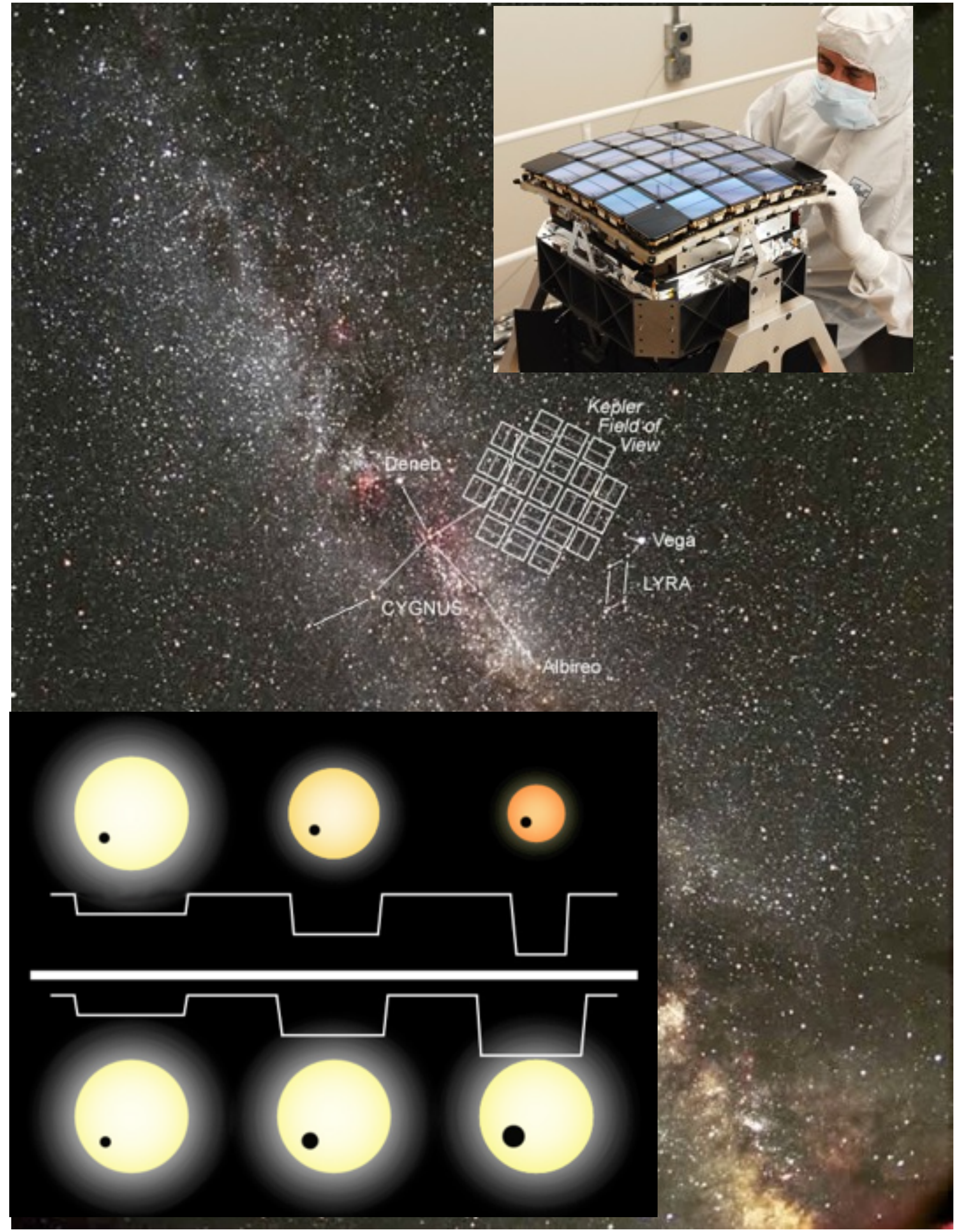
95 cm-es belépő nyílású Schmidt-távcső, látómezeje mintegy 100 négyzetfok, 42 CCD-ből álló mozaikkal

Fotometriai pontosság:

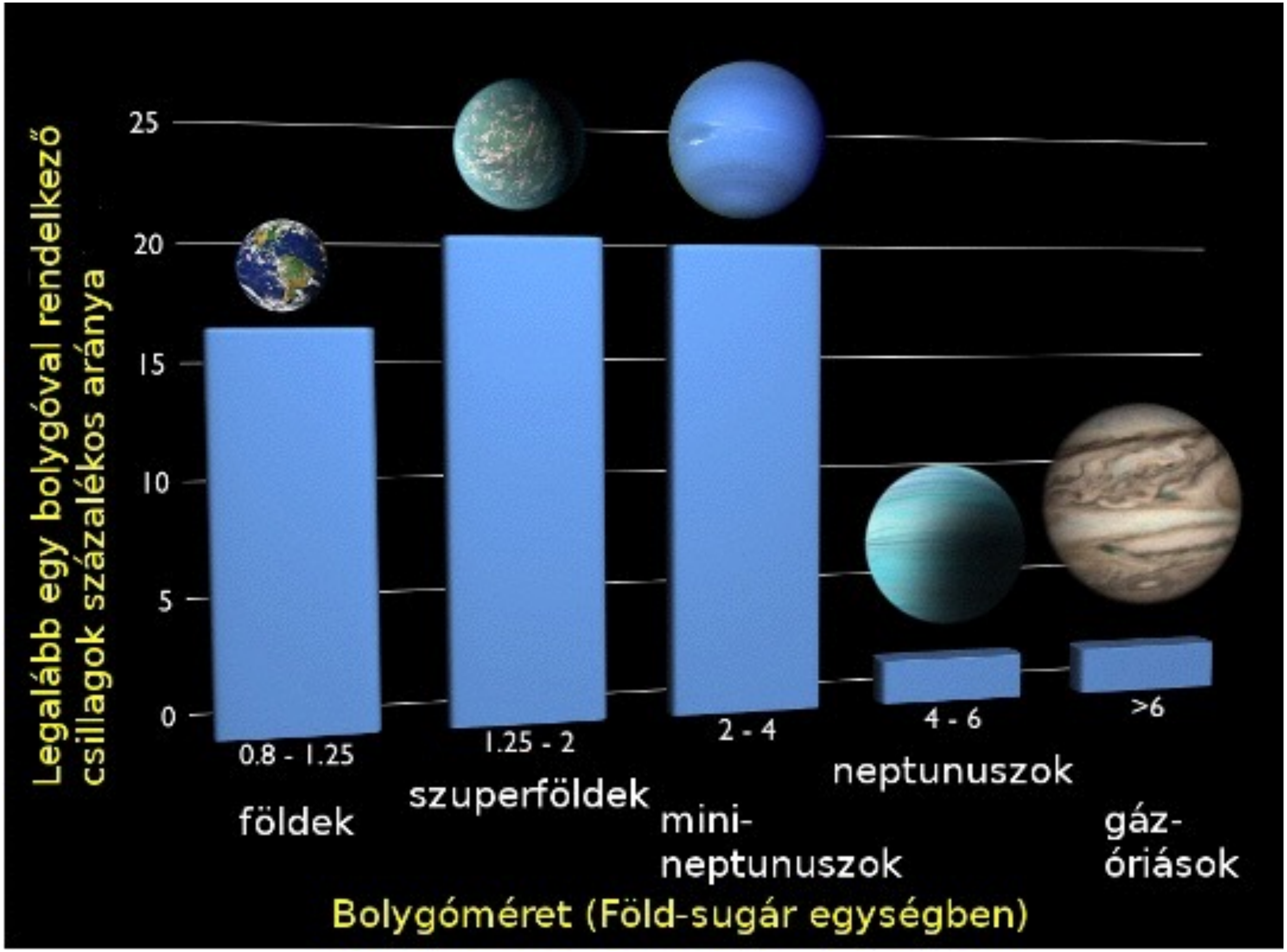
A zaj < 20 ppm 6,5 órányi mérés után egy 12 magn. Nap típusú csillagra

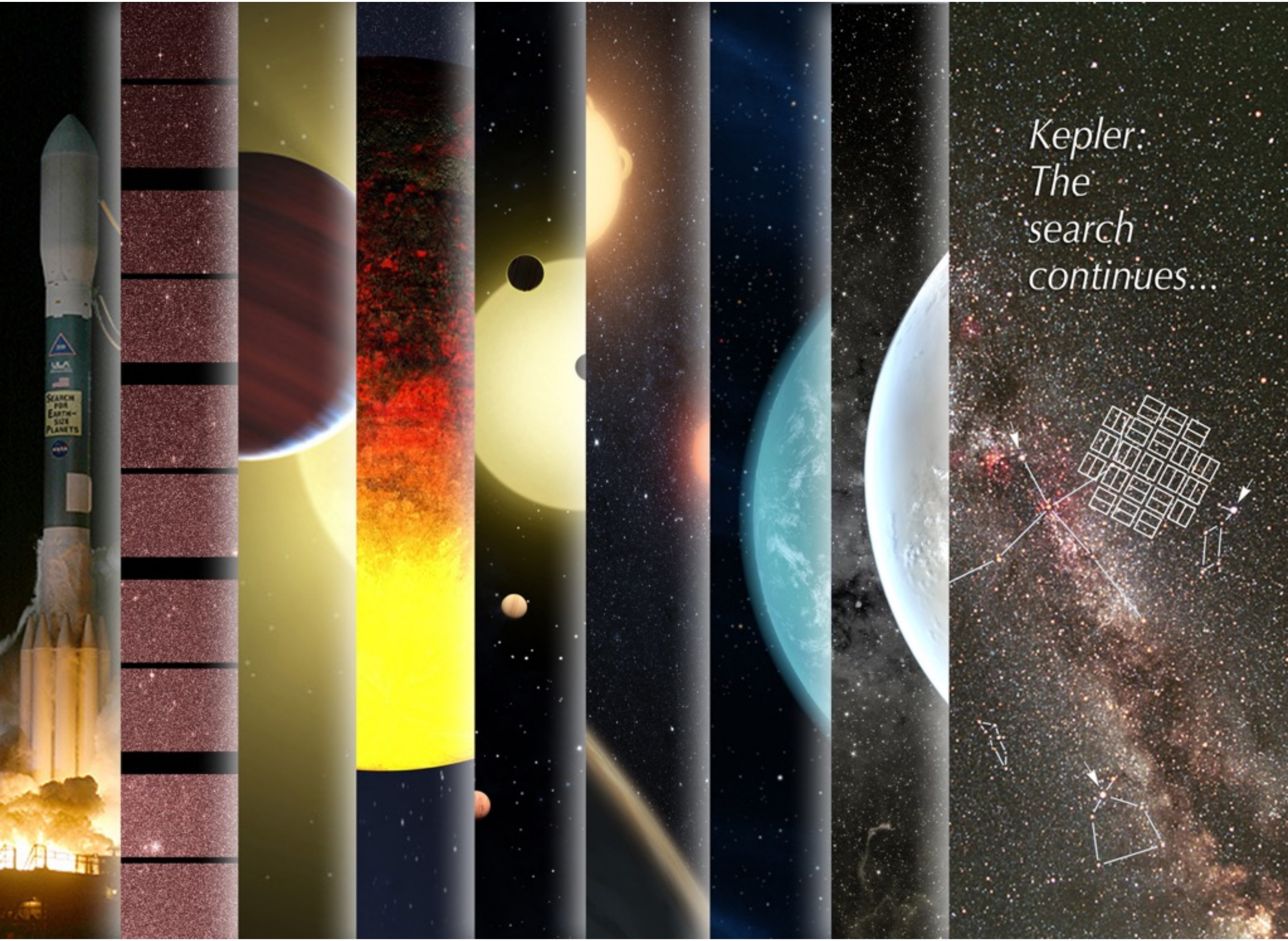
=> 4-szigma detektálás egy exoföld tranzitja esetén.

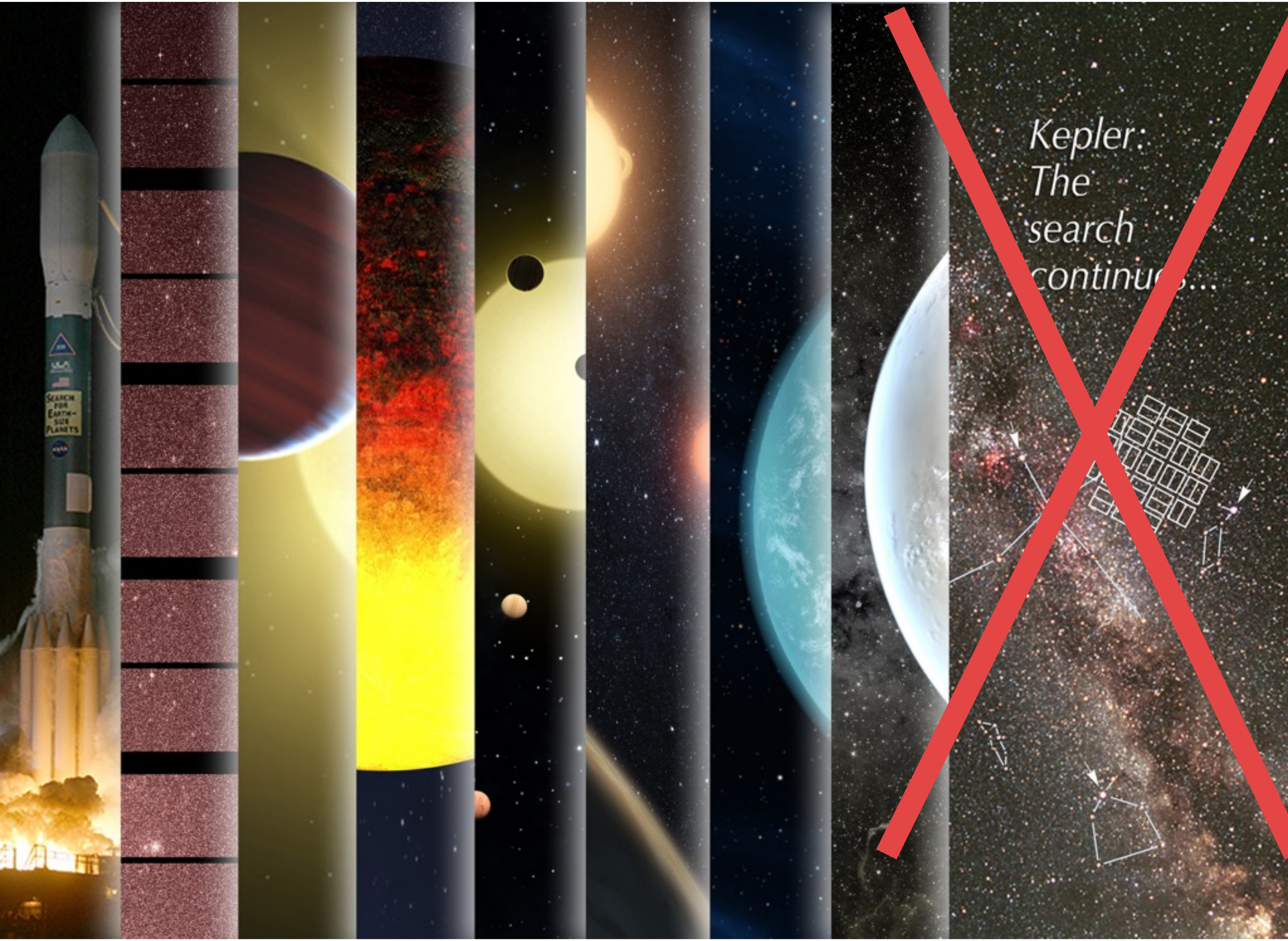
Heliocentrikus pálya, 2009-2013

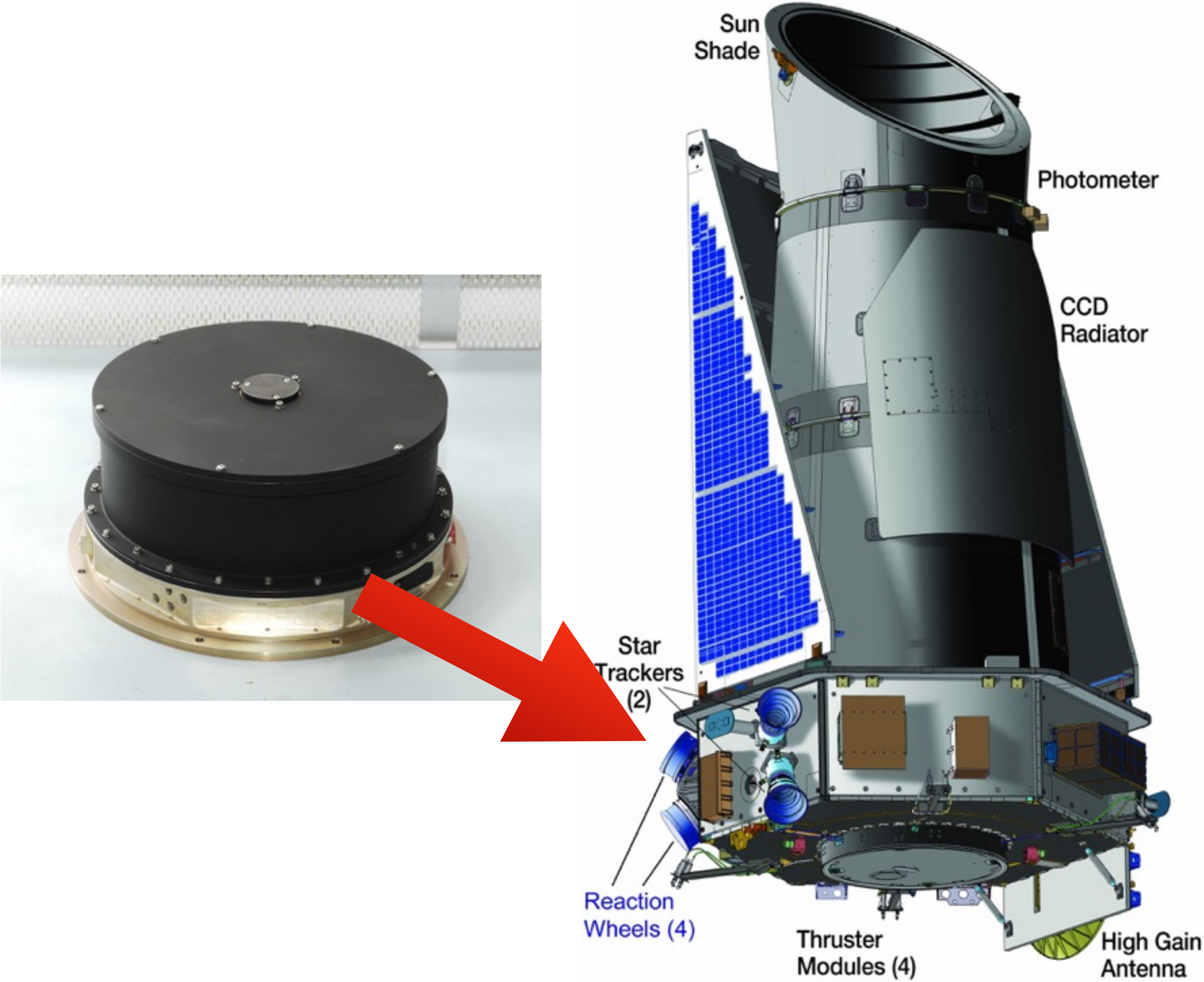


Rövidperiódusú bolygók gyakorisága




Kepler:
The
search
continues…
SEARCH FOR EARTH-SIZE PLANETS


Kepler:
The
search
continues...


Sun Shade
Photometer
CCD Radiator
Star Trackers (2)
Reaction Wheels (4)
Thruster Modules (4)
High Gain Antenna

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.* **482**, 883 (2008).
34. L. Girardi, M. A. T. Groenewegen, E. Hatziminaoglou, L. da Costa, *Astron. Astrophys.* **436**, 895 (2005).
36. 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 asteroseismology program of Kepler is being conducted by the Kepler Asteroseismic Science Consortium.

www.sciencemag.org/cgi/content/full/332
Materials and Methods
Figs. S1 to S3
References

16 December 2010; accepted 22 Februa
10.1126/science.1201827

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

A. Derekas,[1,2*] L. L. Kiss,[2,3] T. Borkovits,[4,5] D. Huber,[3] H. Lehmann,[6] J. Southworth,[7] T. R. Bedding,[3] D. Balam,[8] M. Hartmann,[6] M. Hrudkova,[6] M. J. Ireland,[3] J. Kovács,[9] Gy. Mező,[2] A. Moór,[2] E. Niemczura,[10] G. E. Sarty,[11] Gy. M. Szabó,[2] R. Szabó,[2] J. H. Telting,[12] A. Tkachenko,[6] K. Uytterhoeven,[13,14] J. M. Benkő,[2] S. T. Bryson,[15] V. Maestro,[3] A. E. Simon,[2] D. Stello,[3] G. Schaefer,[16] C. Aerts,[17,18] T. A. ten Brummelaar,[16] P. De Cat,[19] H. A. McAlister,[16] C. Maceroni,[20] A. Mérand,[21] M. Still,[15] J. Sturmann,[16] L. Sturmann,[16] N. Turner,[16] P. G. Tuthill,[3] J. Christensen-Dalsgaard,[22] R. L. Gilliland,[23] H. Kjeldsen,[22] E. V. Quintana,[24] P. Tenenbaum,[24] J. D. Twicken[24]

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,

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

over, almost all flares appea
shallower minimum of the BC
that this activity might be rel
pair.

We looked for optically resol
with a 1-m telescope [section
found none. We also obtained 3
optical spectra to measure the
tion of the A component (*6*) (fig
parameters for the wider system
that star A revolves on a circula
an orbital period twice the sepa
consecutive flat-bottomed min
curve (*6*). Long-baseline interfe
PAVO (Precision Astronomical
tions) beam combiner (*8*) at th
ter for High Angular Resolution
Array show that the angular

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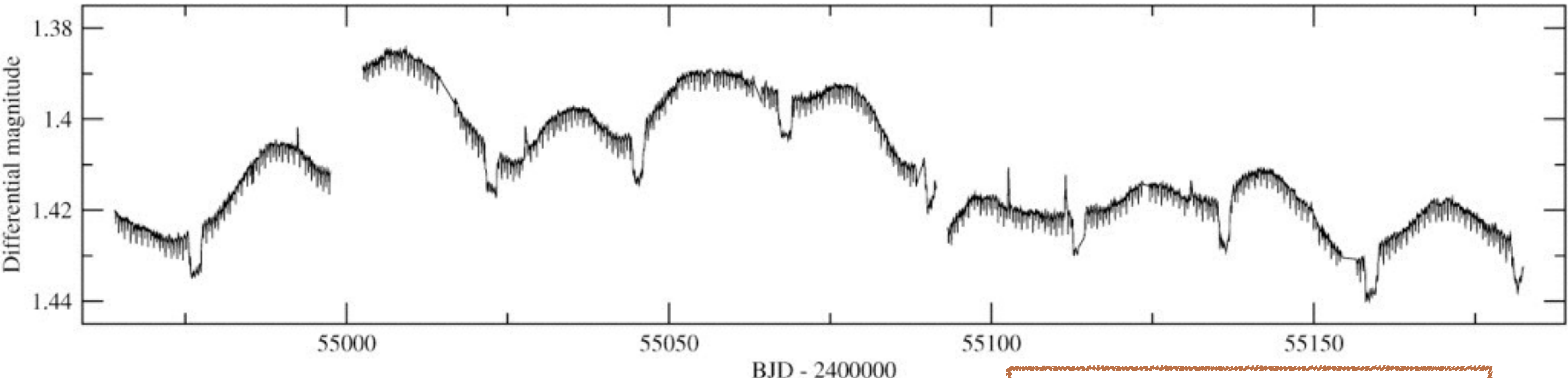
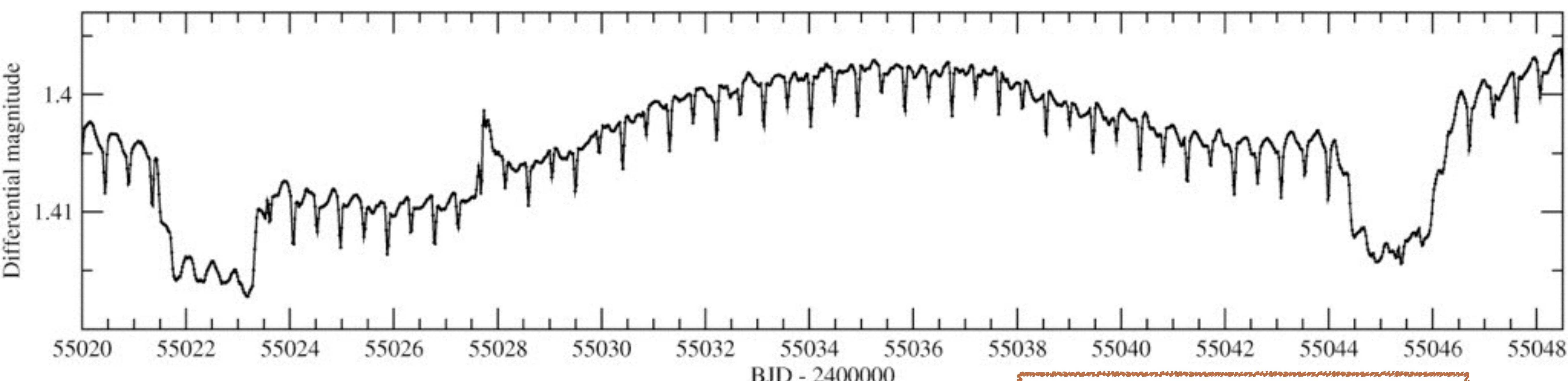
stitute for Astronomy, School of Physics,
Sydney, NSW 2006, Australia. [4]Baja Astr
H-6500 Baja, Szegedi út, Kt. 766, Hu
College, H-6500 Baja, Szegedi út 2, Hung
sternwarte (TLS) Tautenburg, Karl-Schwar
07778 Tautenburg, Germany. [7]Astrophy
versity, Newcastle-Under-Lyme ST5 5BG,
physical Observatory (DAO), Herzberg Institu

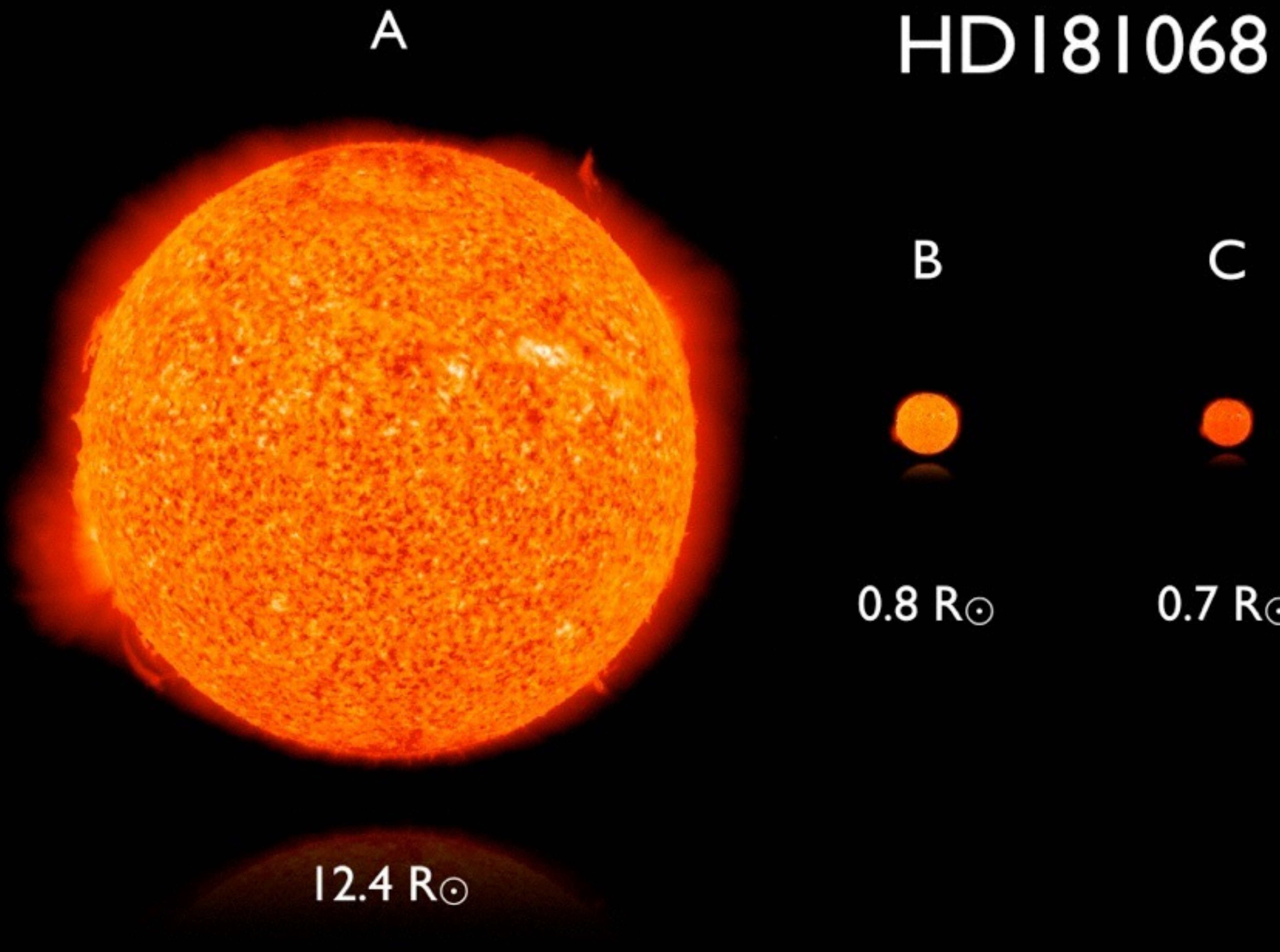
Trinity - triplán fedő hármascsillag



P(A-BC) ~ 45.52 nap



P(B-C) ~ 0.906 nap


A
HD181068
B
C
0.8 R☉
0.7 R☉
12.4 R☉

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **428,** 1656–1672 (2013) doi:10.1093/mnras/sts146

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. Szabó[2]

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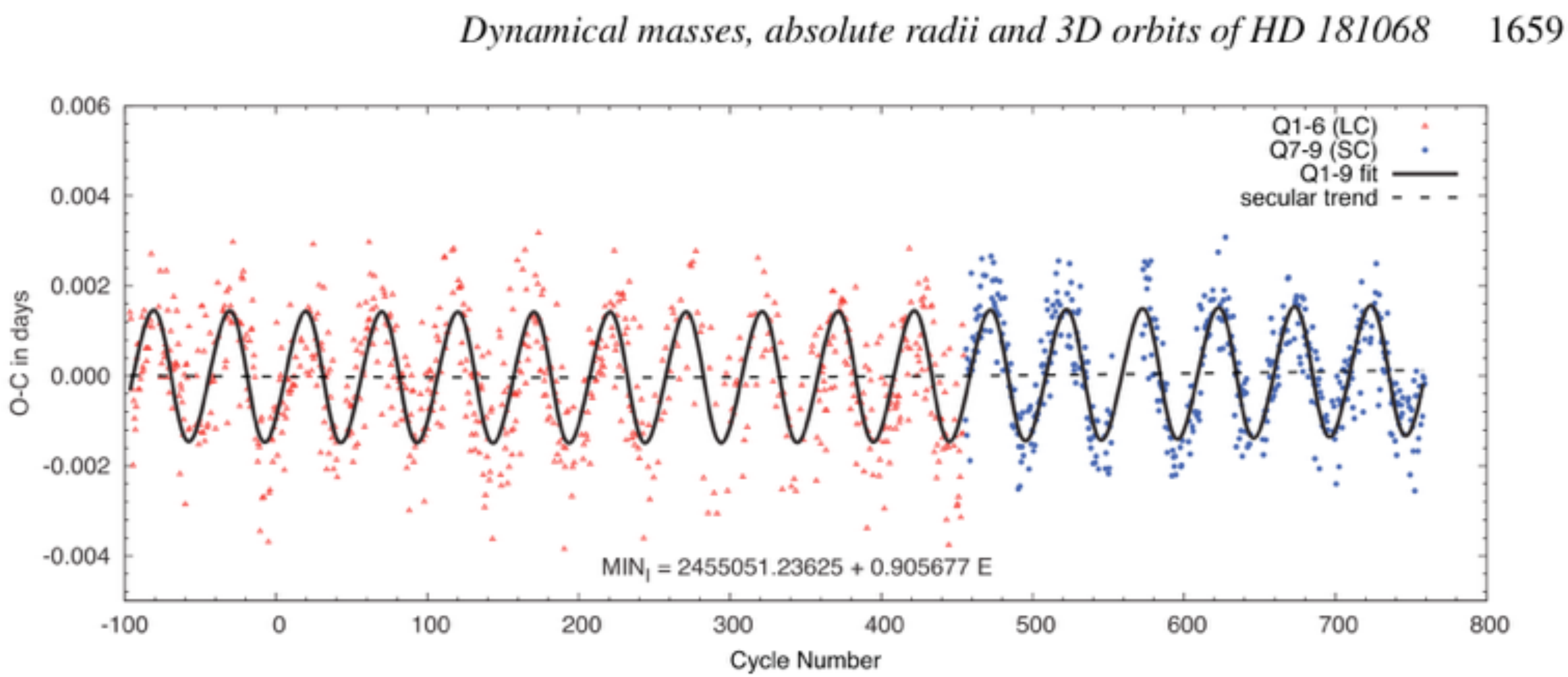
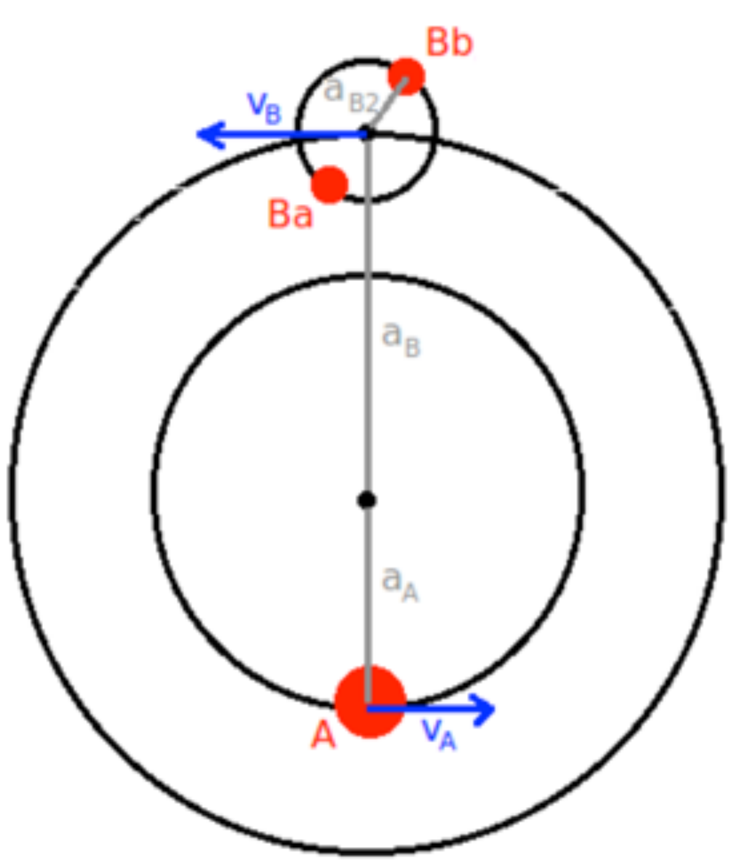
[3]*ELTE Gothard-Lendület Research Group, H-9700 Szombathely, Szent Imre herceg út 112, Hungary*
[4]*Sydney Institute for Astronomy, School of Physics, University of Sydney, NSW 2006, Australia*
[5]*Astronomical Department, Eötvös University, H-1118 Pázmány Péter stny. 1/A, Budapest, Hungary*
[6]*University of Vienna, Türkenschanzstrasse 17, 1180 Vienna, Austria*
[7]*NASA 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

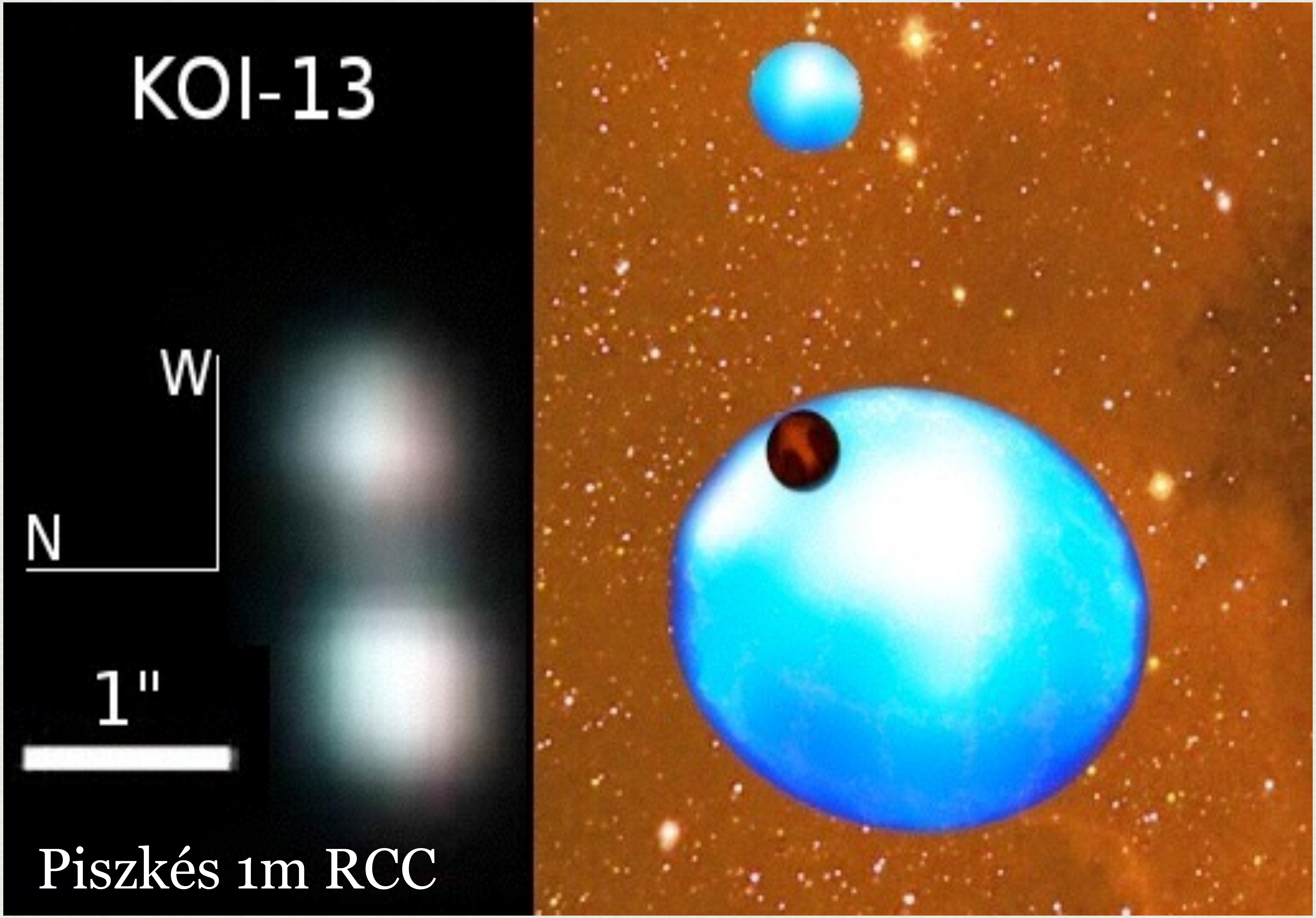




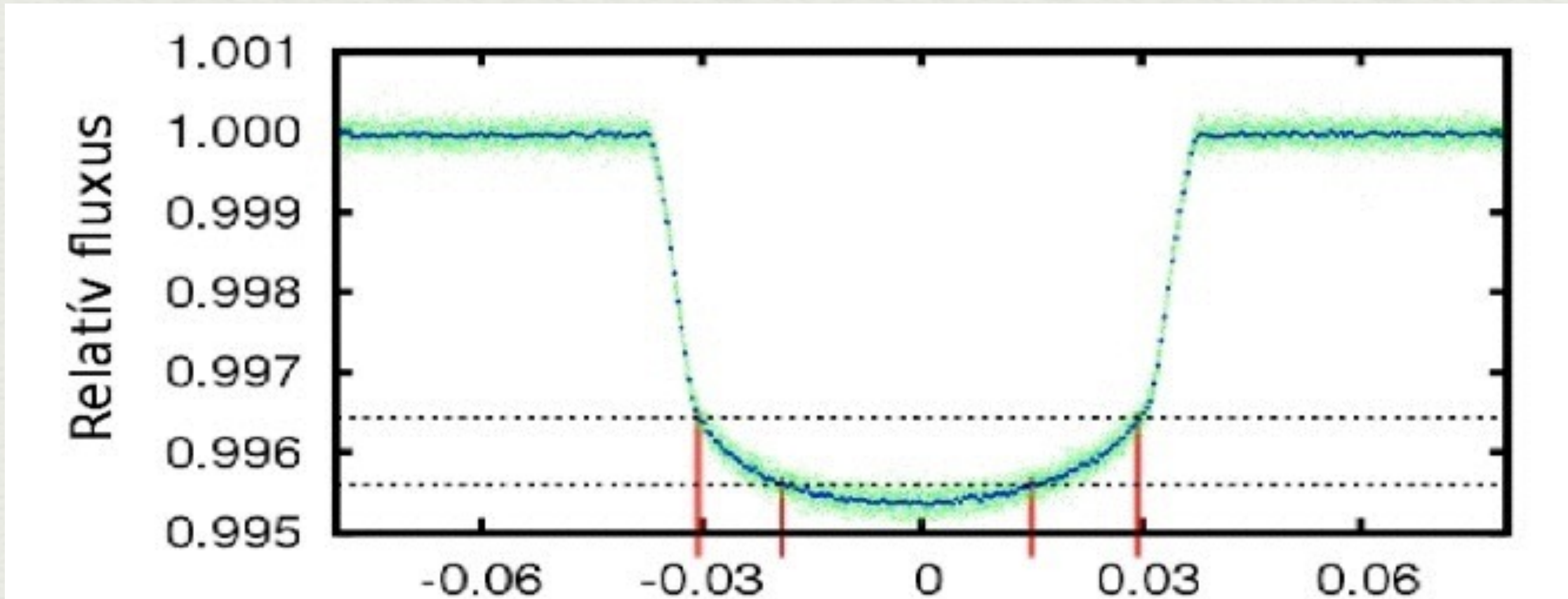
- Fényidő-effektus
- tömegmérés
- csillagfejlődési állapot
- Új tipusú rezgések: árapály-hatások által gerjesztett "normál" módusok

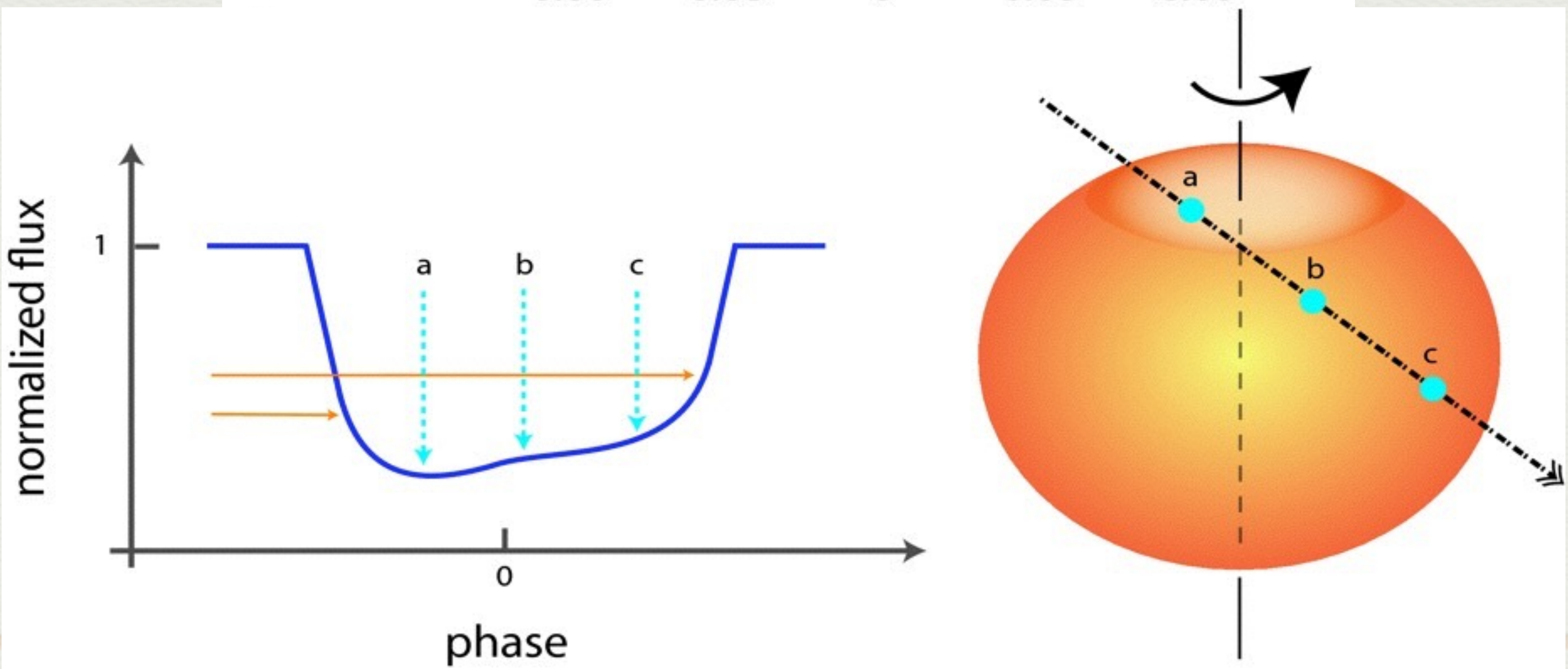
(Borkovits et al. 2013 MNRAS; Fuller et al. 2013 MNRAS)

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



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





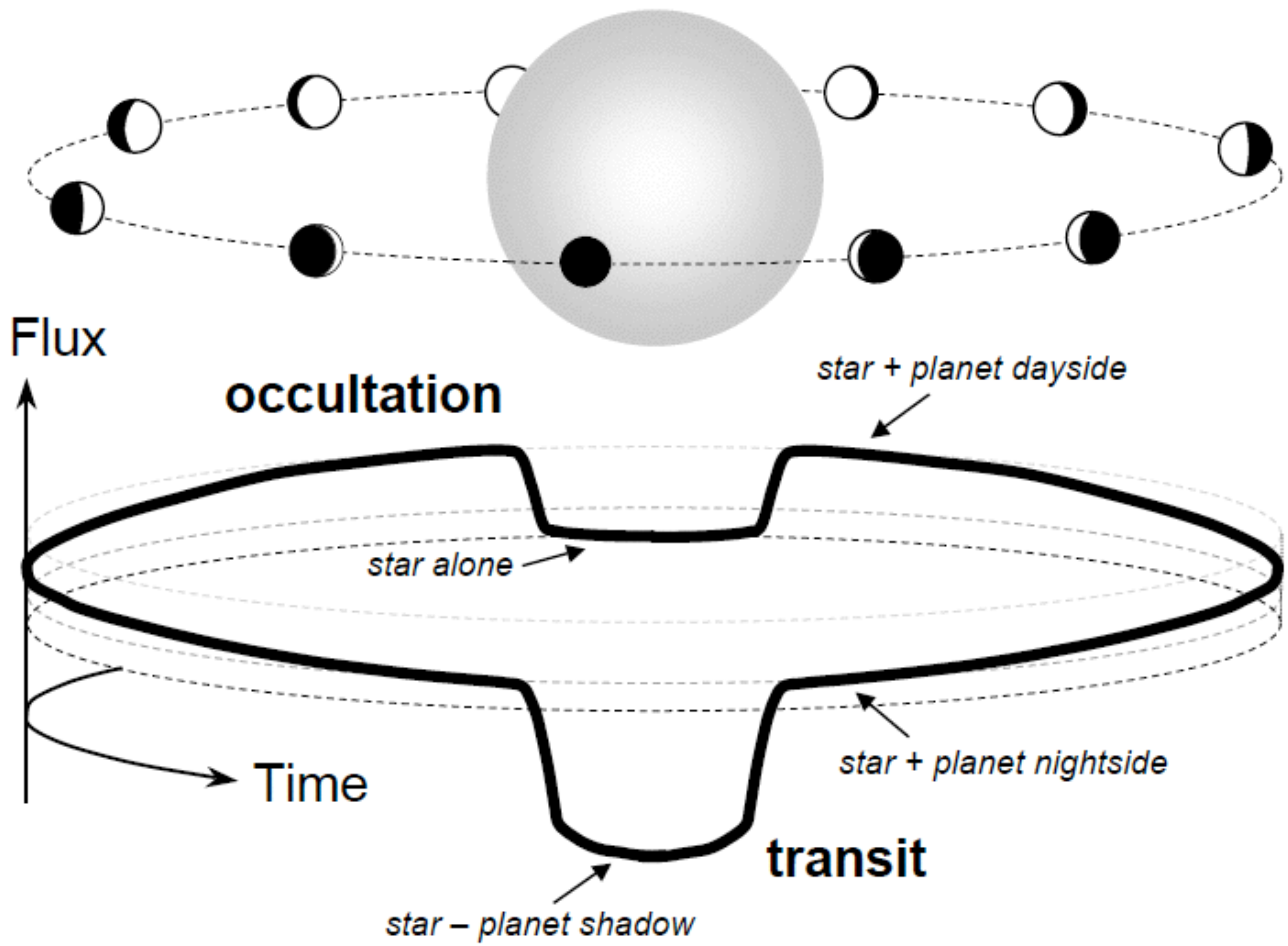


Fig. 1.— Illustration of transits and occultations. Only the combined flux of the star and planet is observed. During a transit, the flux drops because the planet blocks a fraction of the starlight. Then the flux rises as the planet's dayside comes into view. The flux drops again when the planet is occulted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

(Winn 2010)

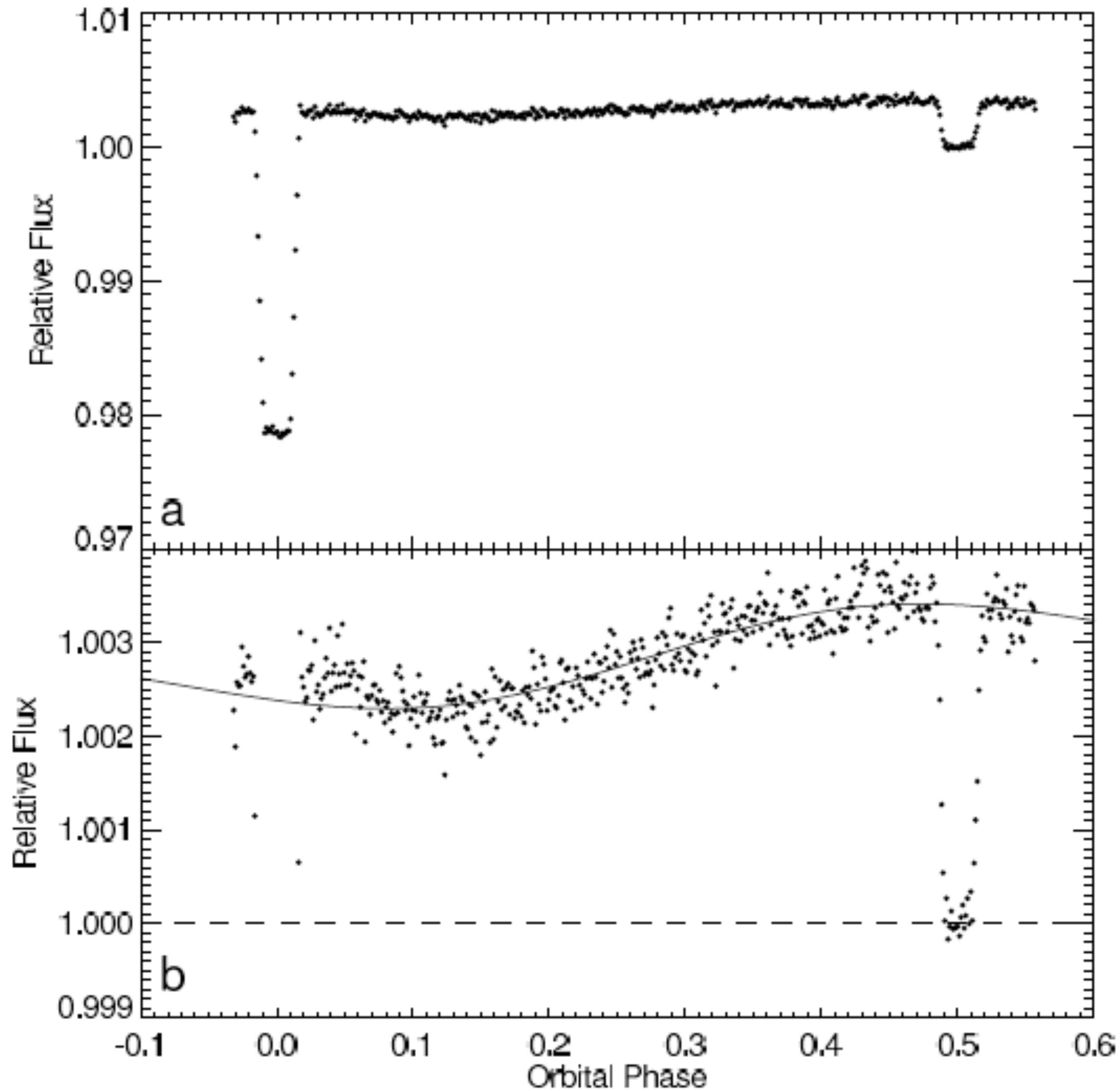


Fig. 11.— The combined 8 μm brightness of the K star HD 189733 and its giant planet, over a 33 hr interval including a transit and an occultation. The bottom panel shows the same data as the top panel but with a restricted vertical scale to highlight the gradual rise in brightness as the planet's dayside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

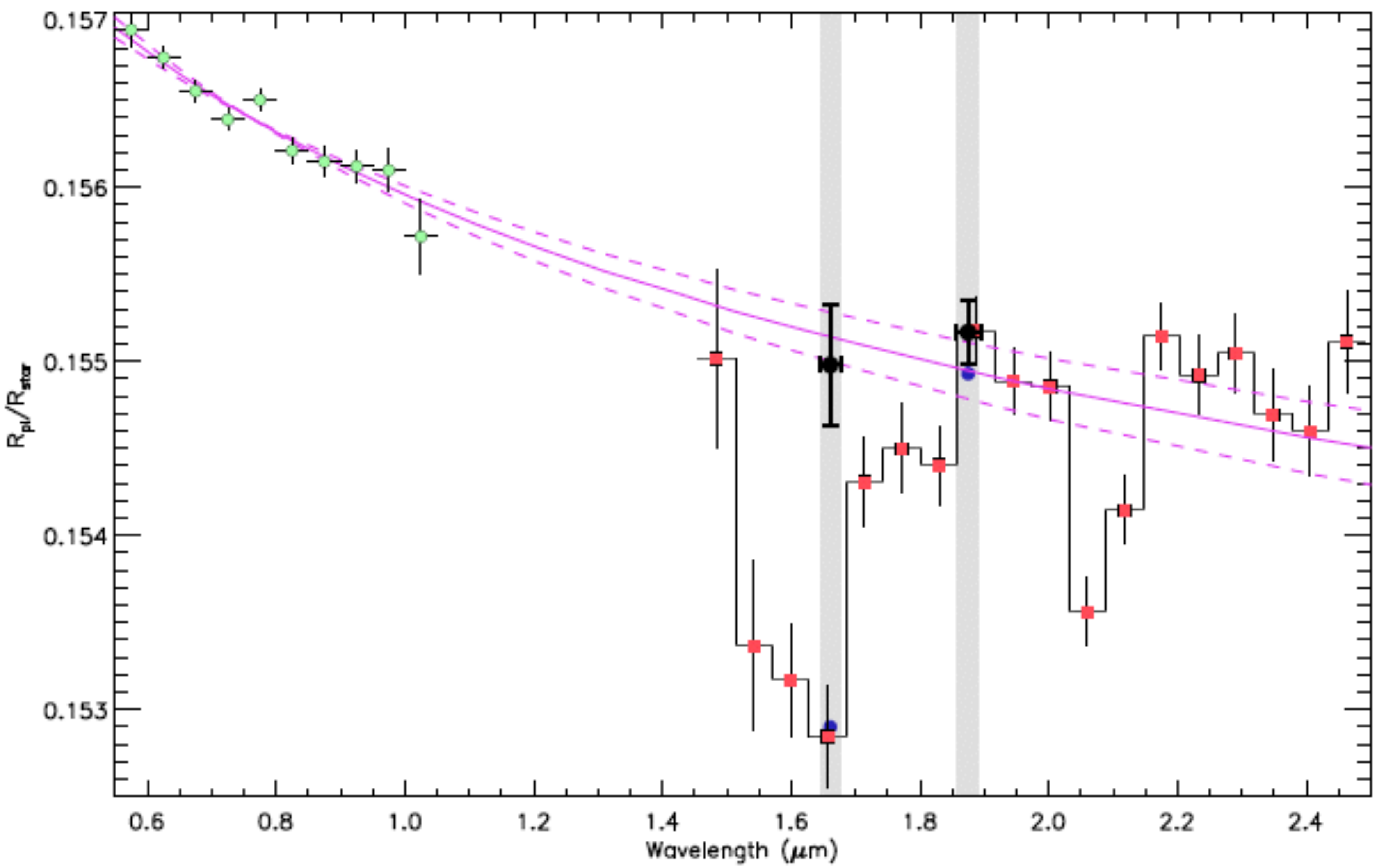
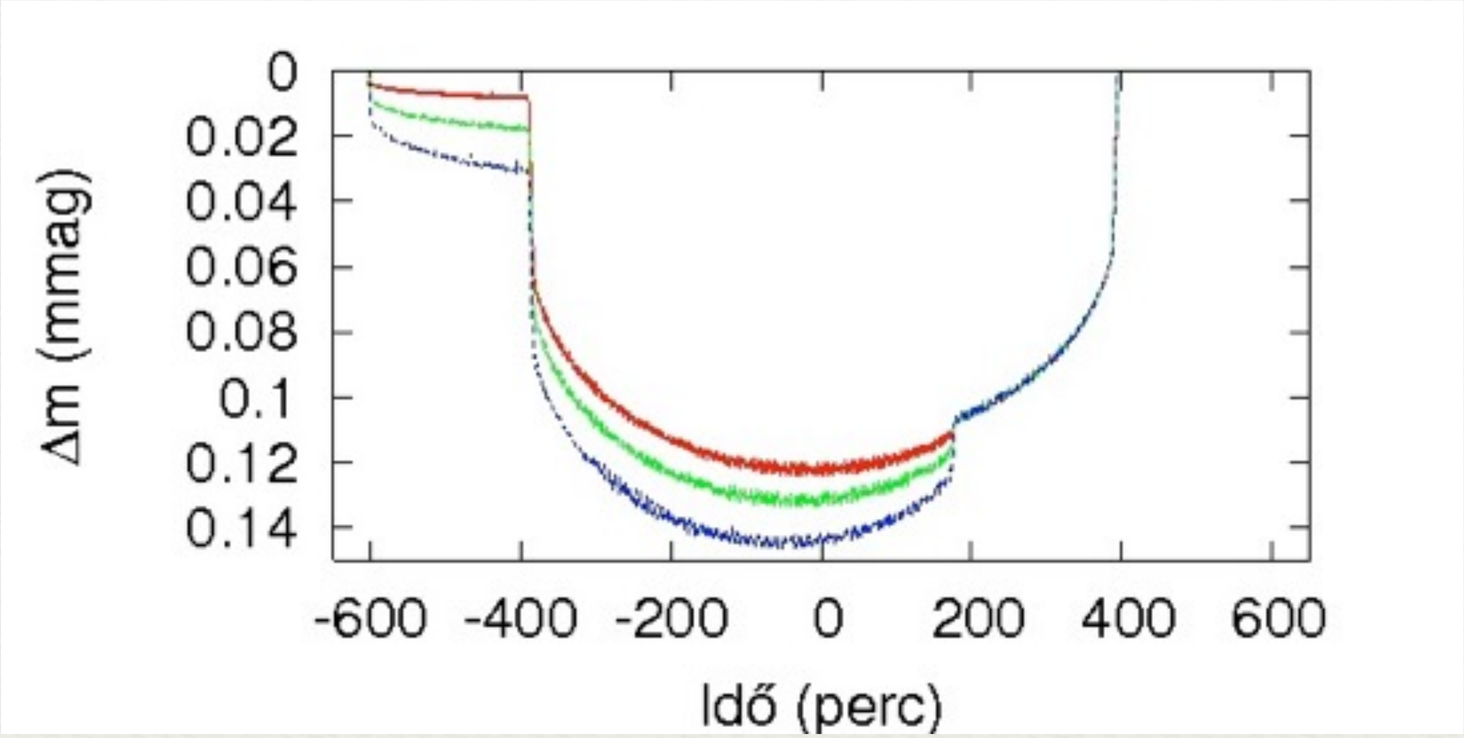
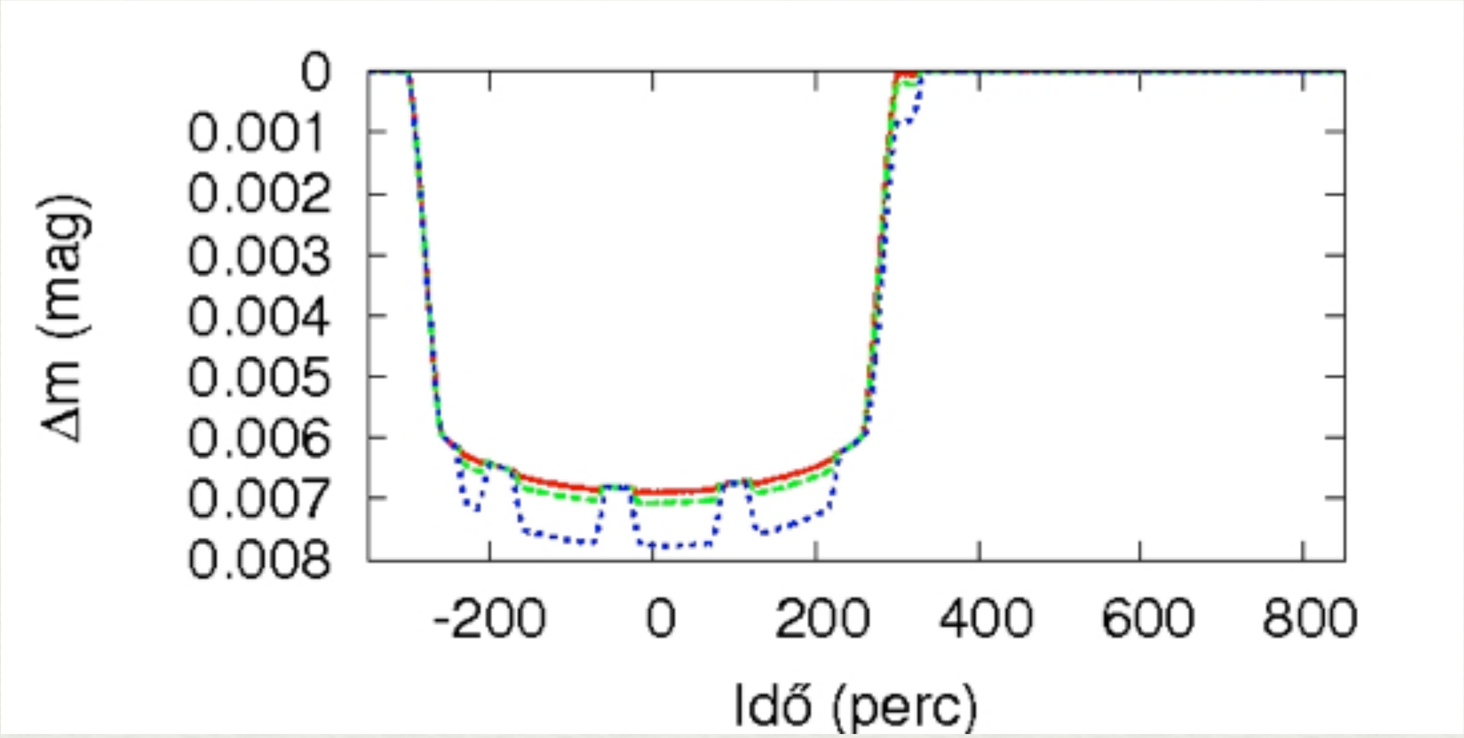
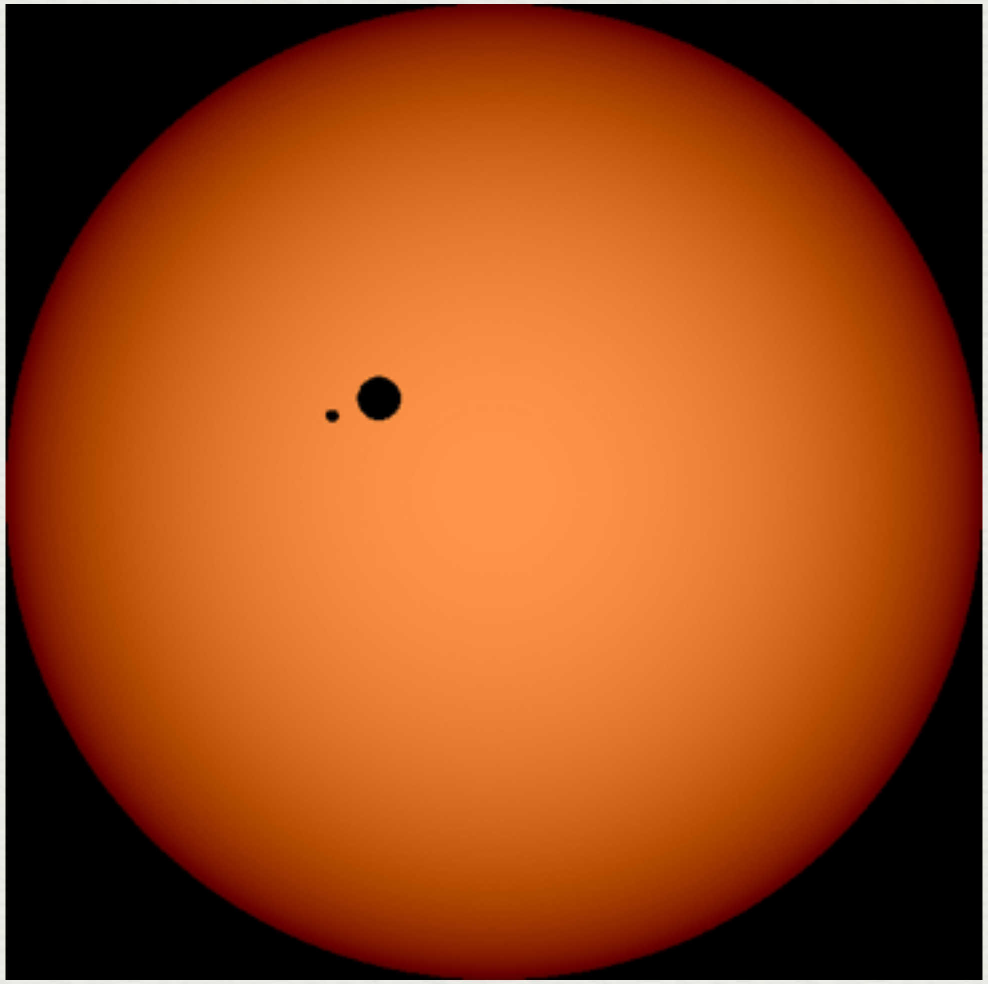


Fig. 12.— Transmission (transit) spectroscopy of the gas giant HD 189733b, using the *Hubble Space Telescope*. The symbols with errors bars are measurements of the effective planet-to-star radius ratio as a function of wavelength. The dip at 1.6 μm was interpreted as evidence for water, and the rise 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





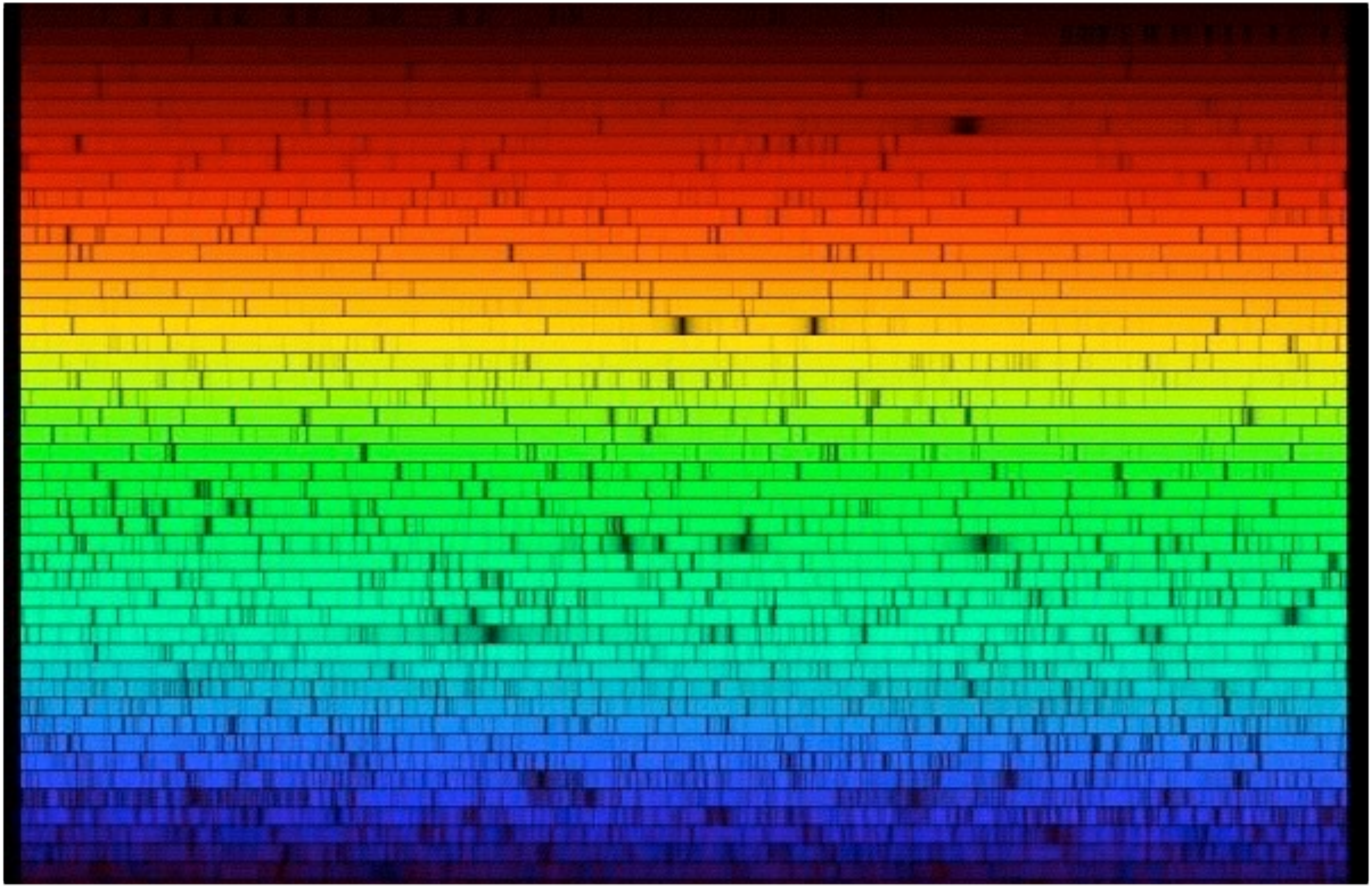


Lassan (fent) és gyorsan (lent) keringő hold (Simon A.)

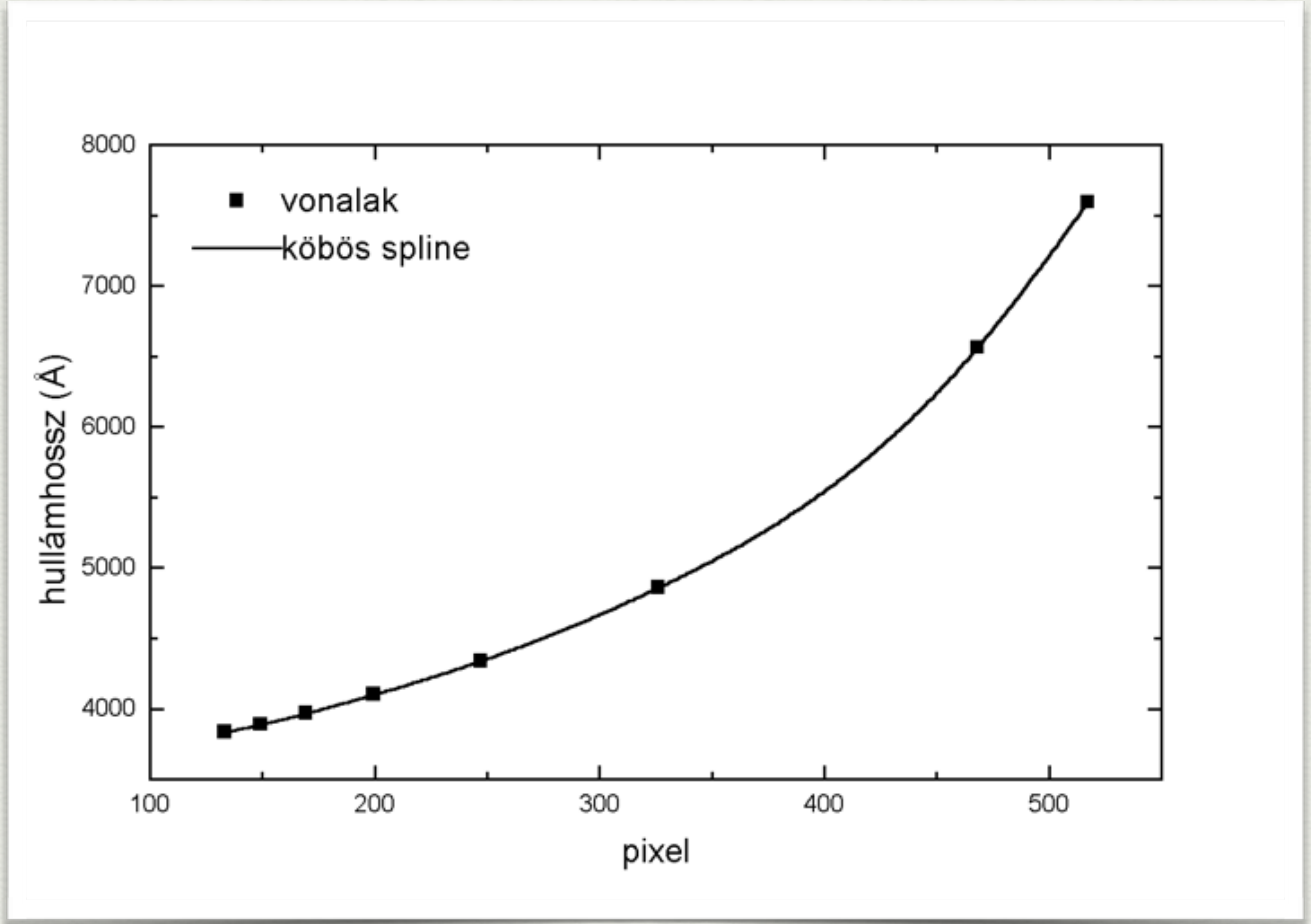
SPEKTROSZKÓPIAI FEJLŐDÉS: KOZMIKUS TRAFFIPAX

- 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 tipusú rezgések
  - 1- 10 cm/s: kozmológiai tesztek, exoföldek, exoholdak, ???

Színképvonalak - kozmikus traffipax

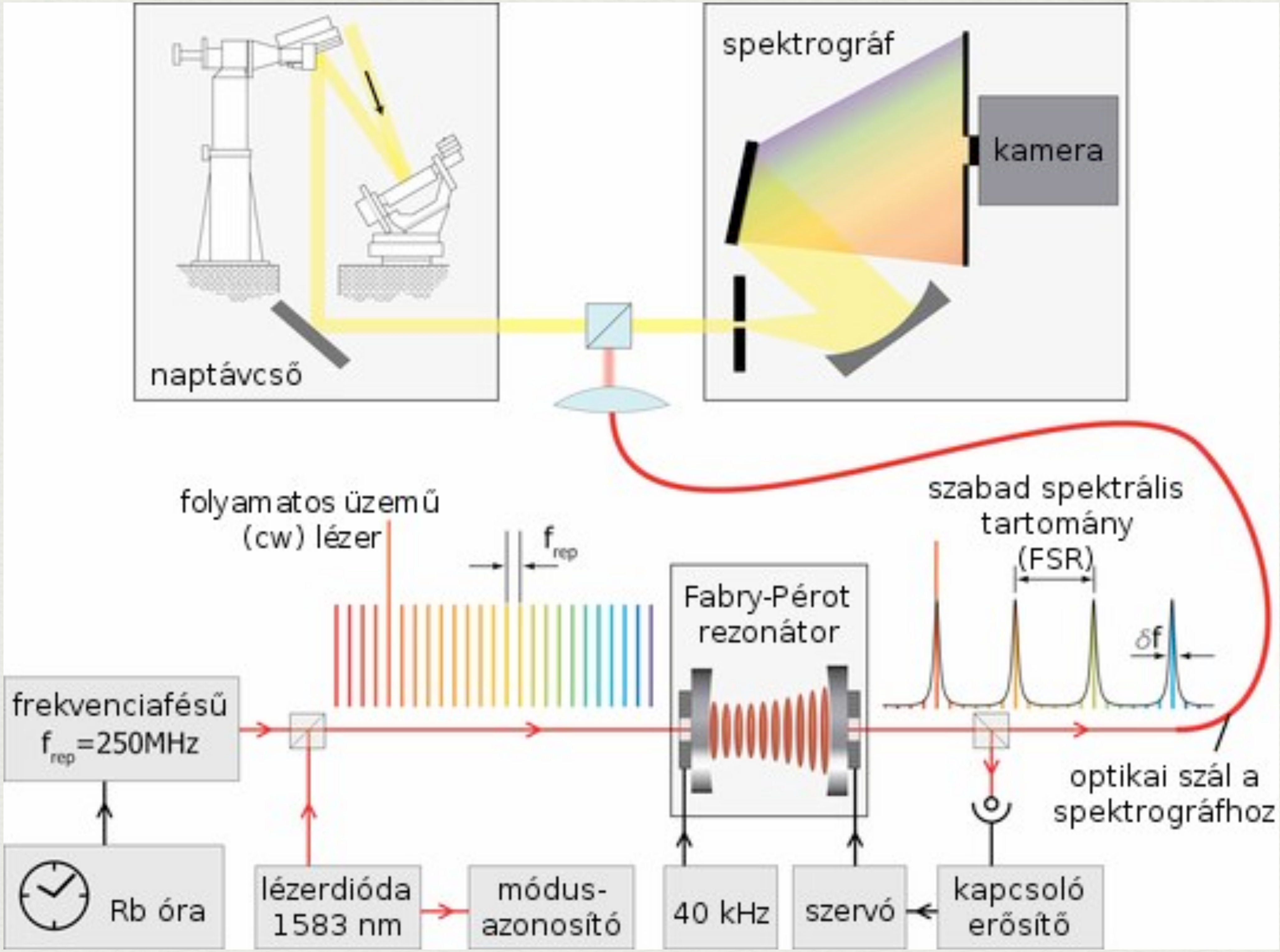


Hullámhossz-kalibráció: a pontosság kulcsa



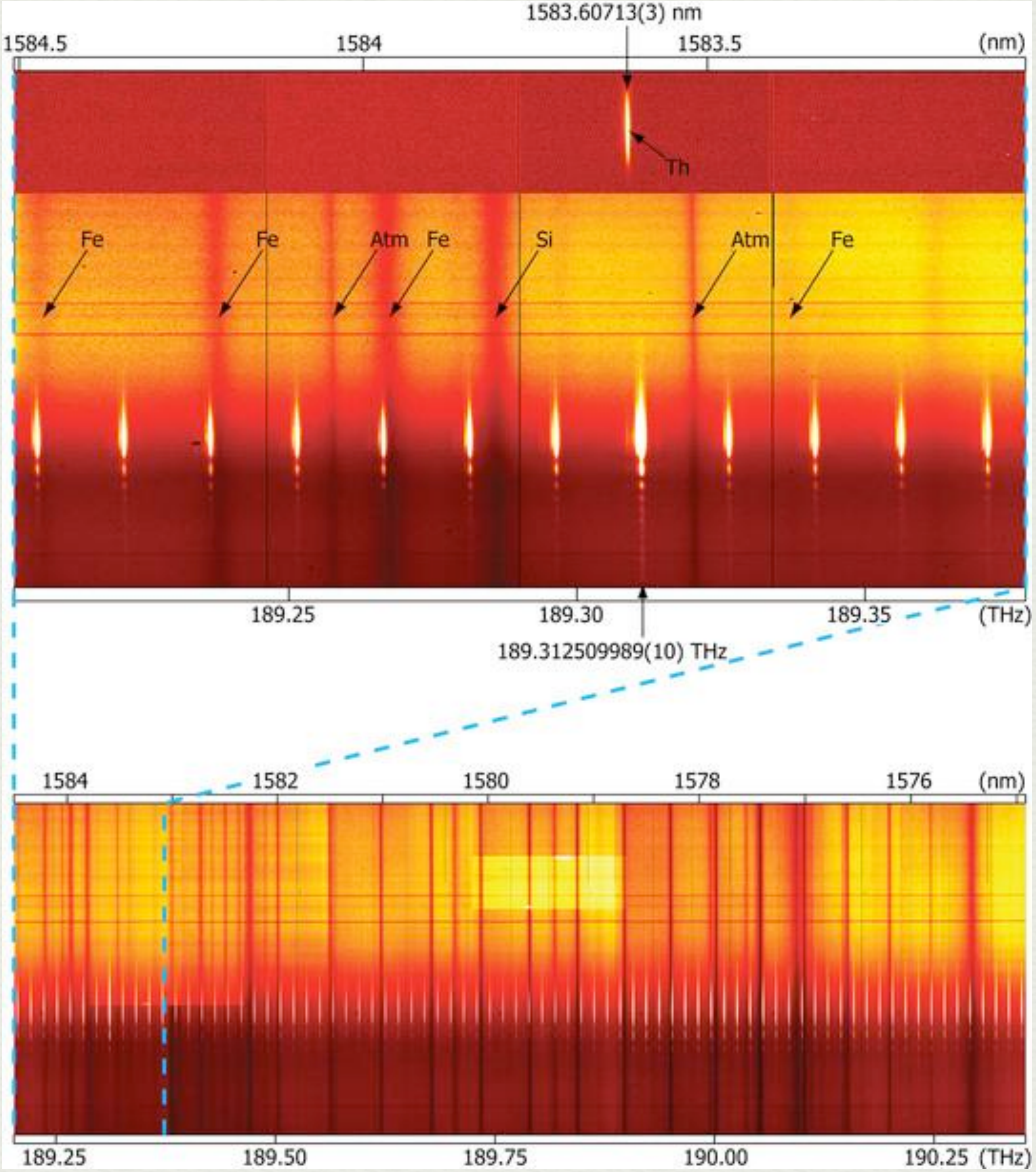
Egy jódcella

Lézerfésűk: továbblépés a cm/s pontosság irányába?

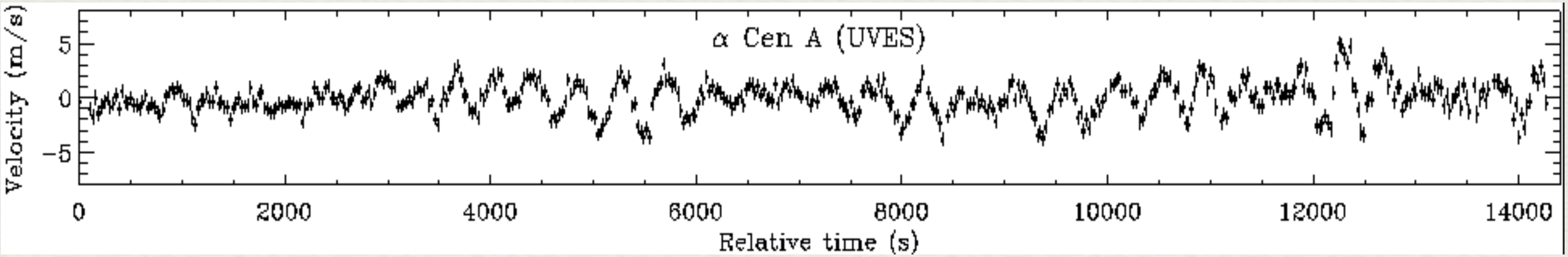


Steinmetz et al. 2008, Science

Napfény és a lézerfésű szimultán spektruma



Az alfa Cen A az UVES/VLT műszerrel



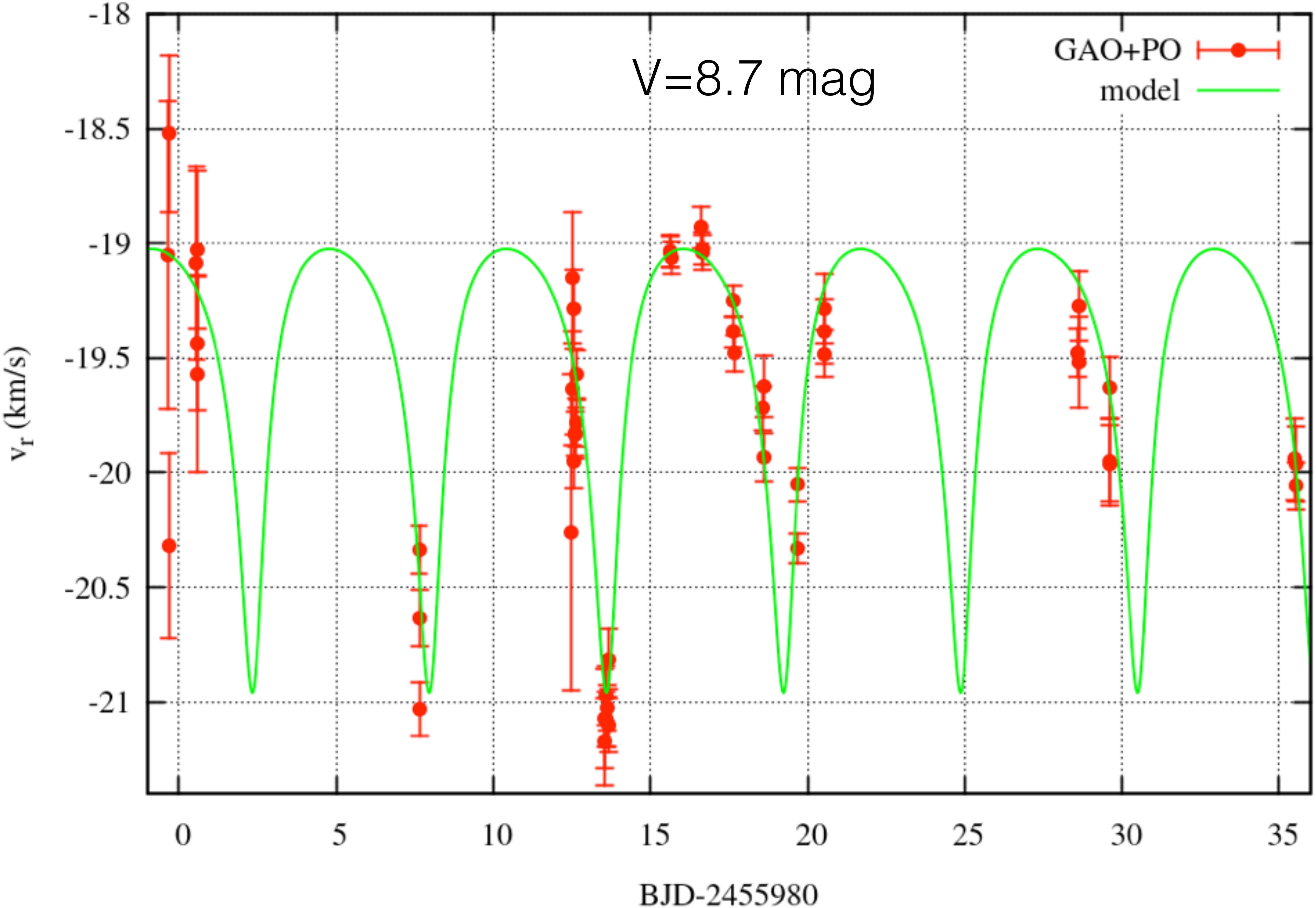
Pontosság: 50-70 cm/s. 3 s expozíciók, 8m-es távcső, a déli ég 3. legfényesebb csillaga

Butler et al. (2003)

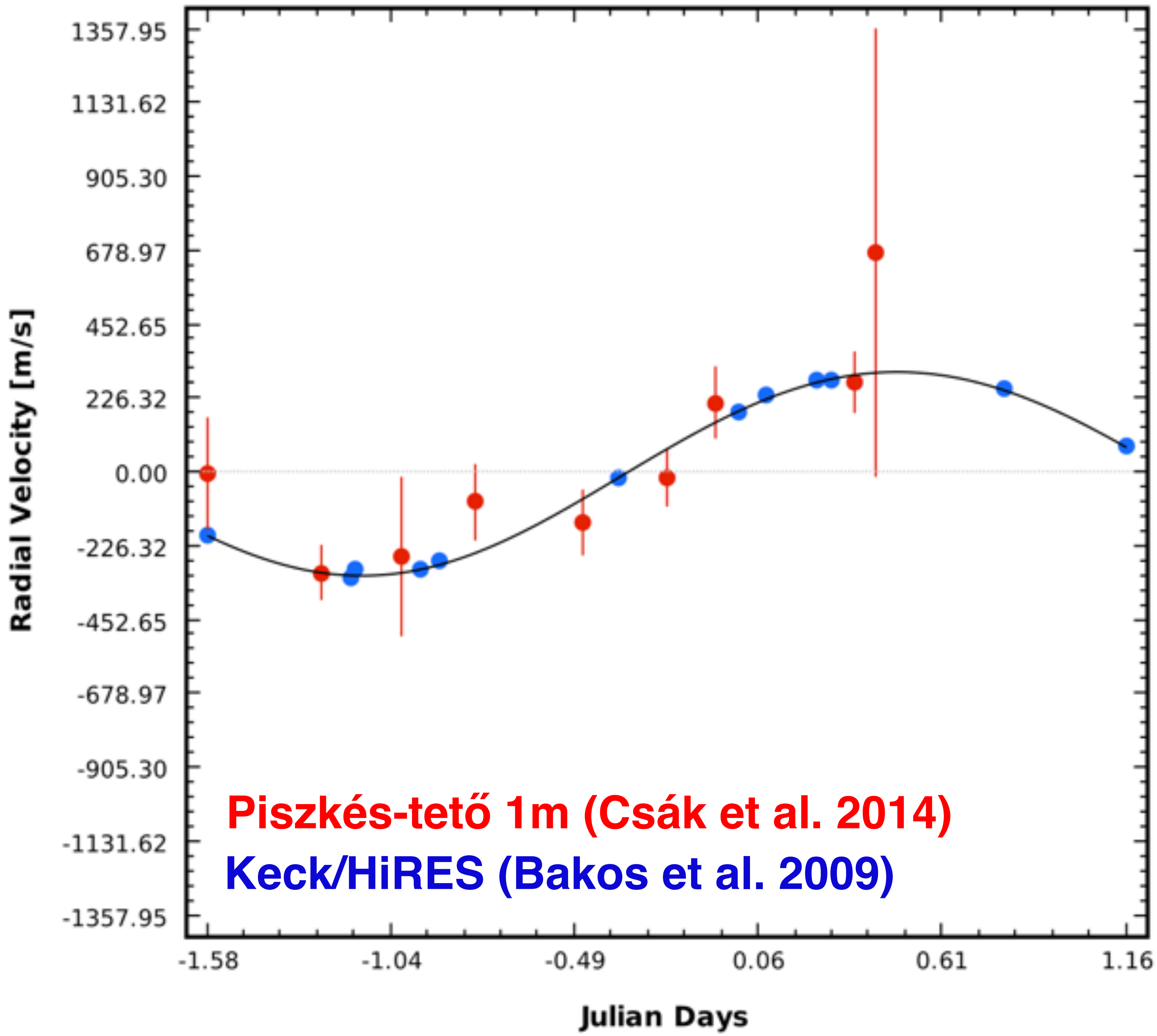
Pontosság: 10-50 cm/s. 10-20 perc expozíciók, 1-4m-es távcsövek, szabad szemmel látszó csillagok (kb. 6000)

Néhány csoport (2013)

HAT-P-2b (Csák et al. 2014)



HAT-P-22b (Csák et al. 2014)



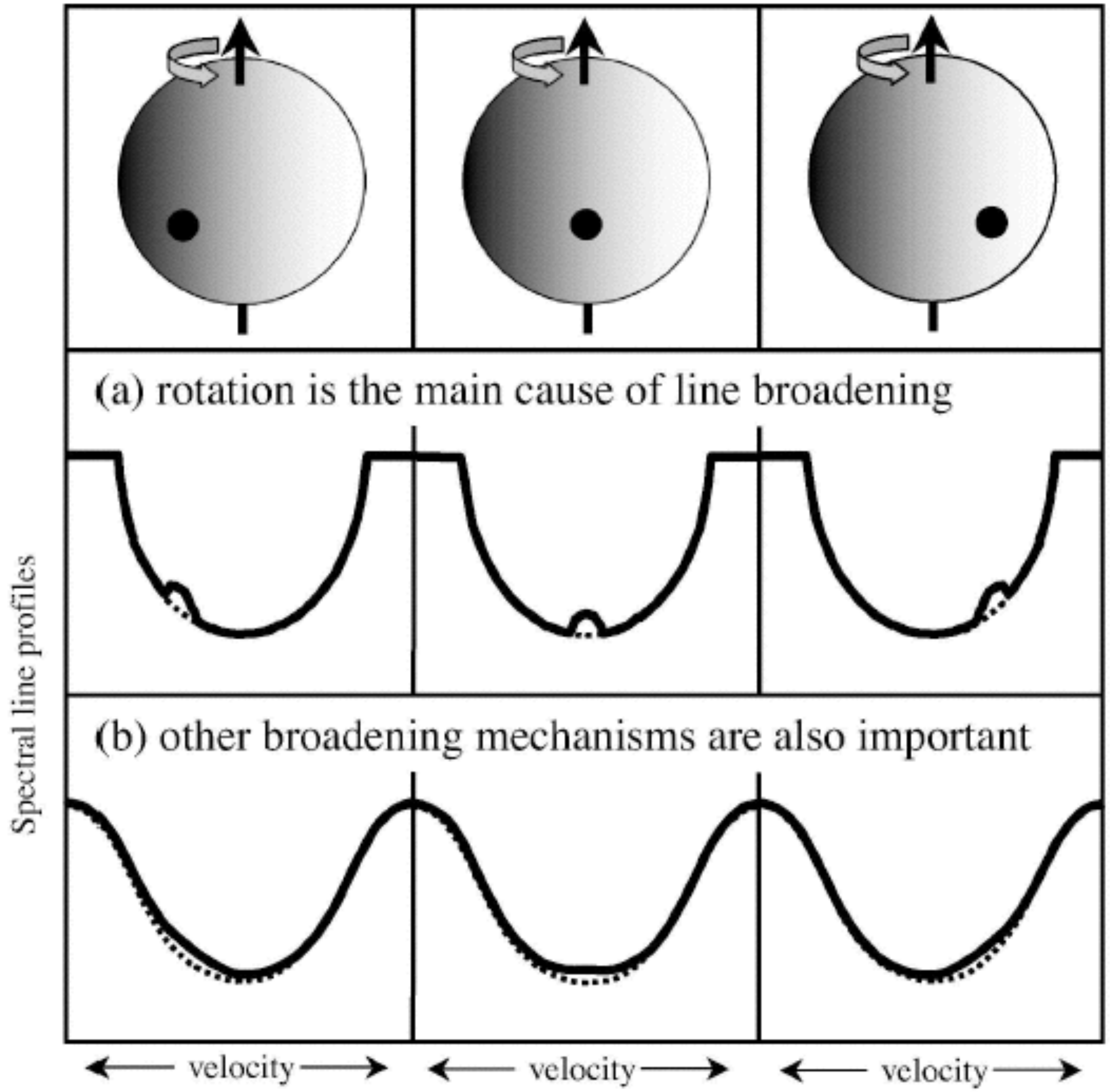


Fig. 5.— Illustration of the Rossiter-McLaughlin (RM) effect. The three columns show three successive phases of a transit. The first row shows the stellar disk, with the grayscale representing the projected rotation velocity: the approaching limb is black and the receding limb is white. The second row 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).

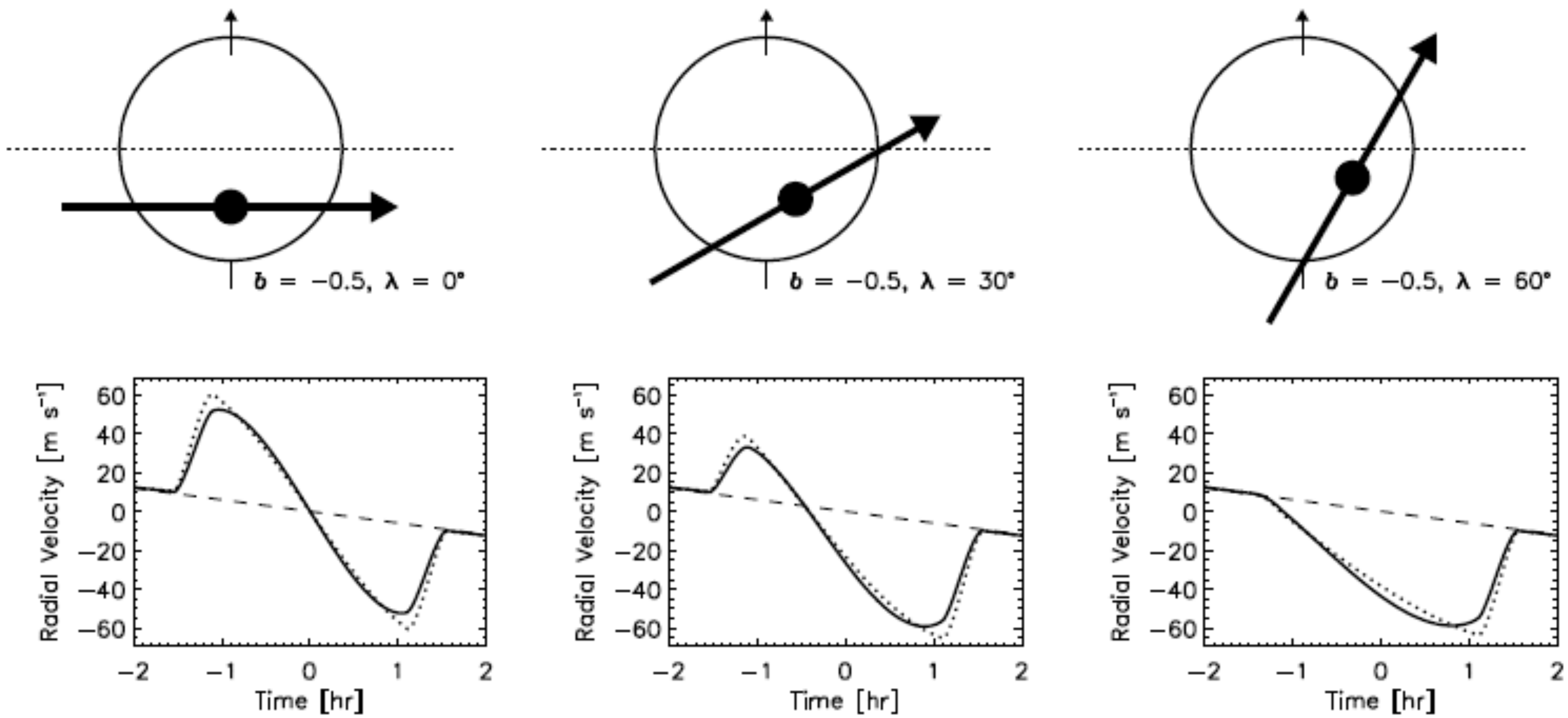


Fig. 6.— Using the RM effect to measure the angle λ between the sky projections of the orbital and stellar-rotational axes. Three different possible trajectories of a transiting planet are shown, along with the corresponding RM signal. The trajectories all have the same impact parameter and produce the 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).

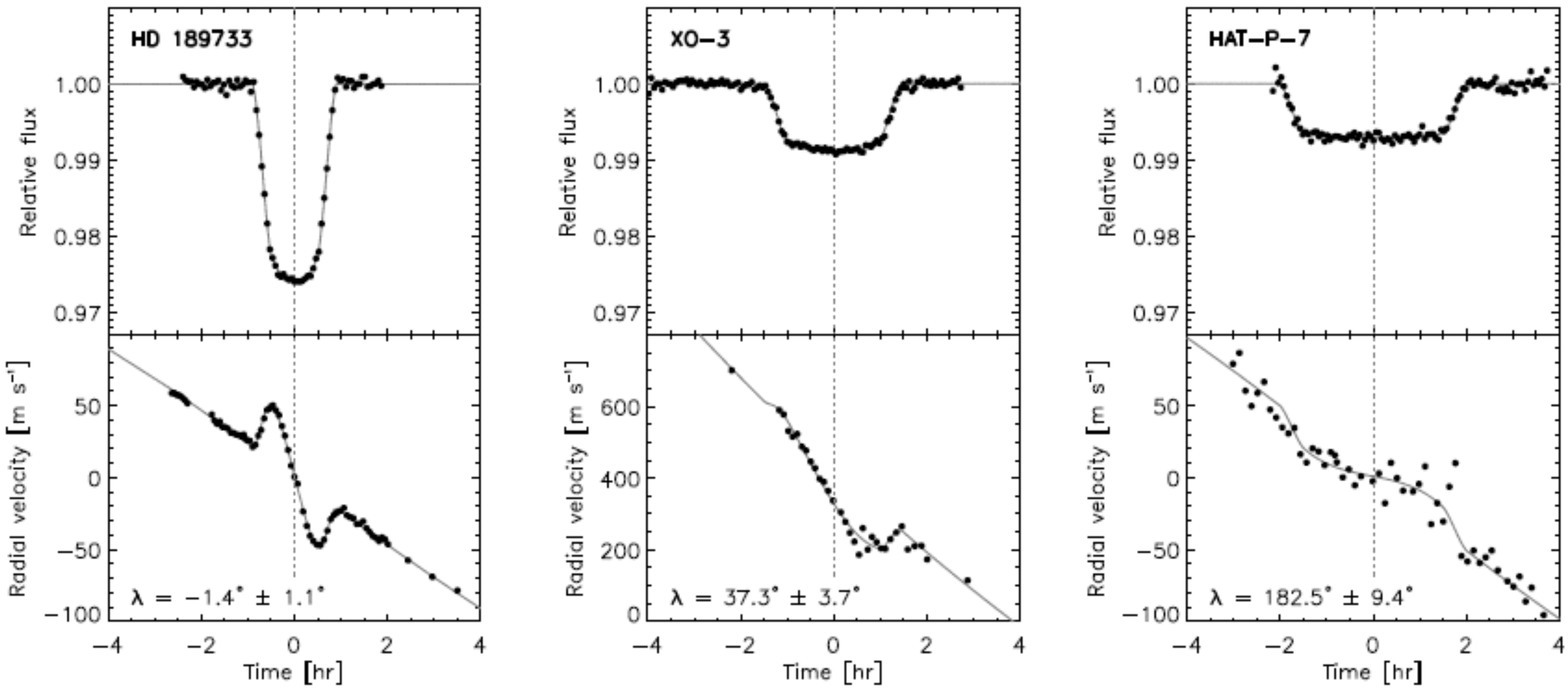


Fig. 14.— Examples of data used to measure the projected spin-orbit angle λ. The top panels show transit photometry, and the bottom panels show the apparent radial velocity of the star, including both orbital motion and the anomalous Doppler shift (the Rossiter-McLaughlin effect). The left panels show 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 spektroszkópiai felmérések: populációk elkülönítése, precíziós kozmológia

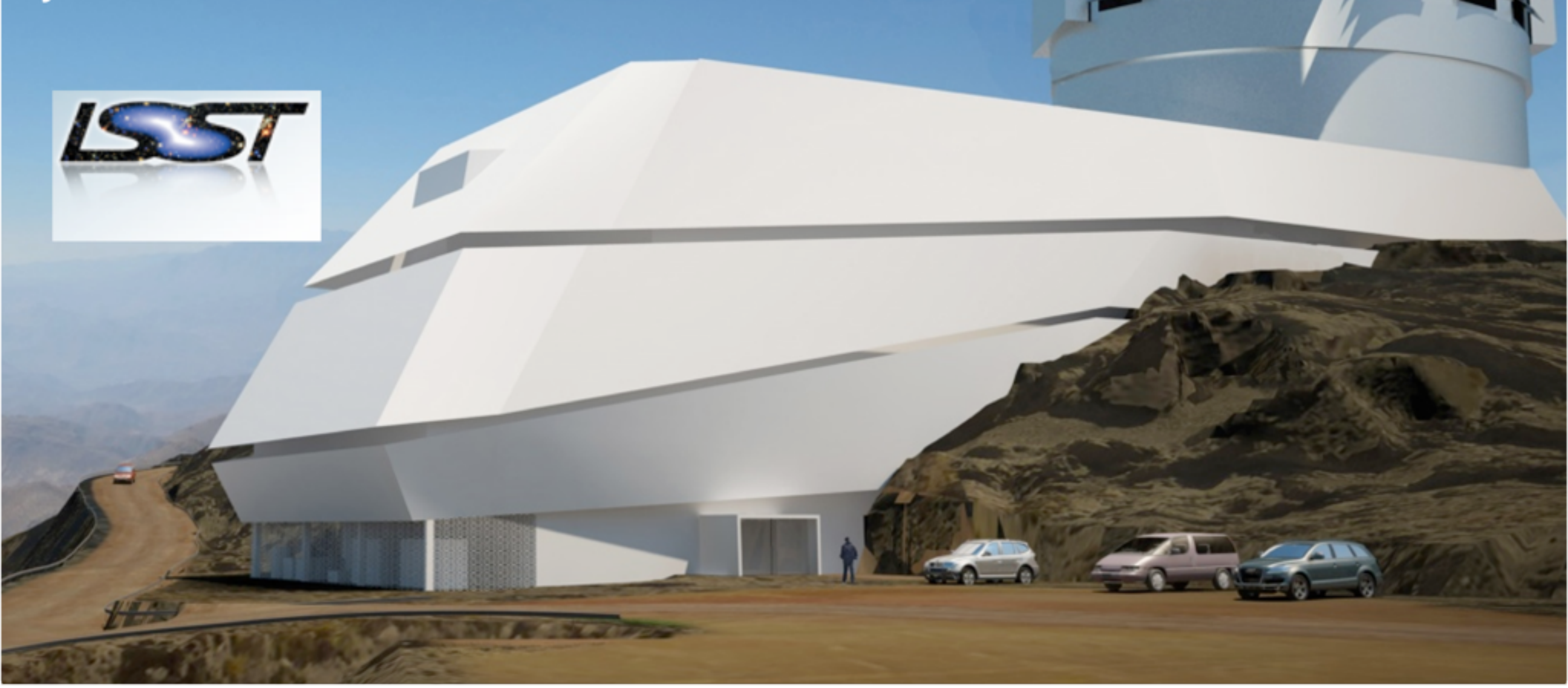
LSST: a digital color movie of the Universe

színes, digitális mozgókép 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

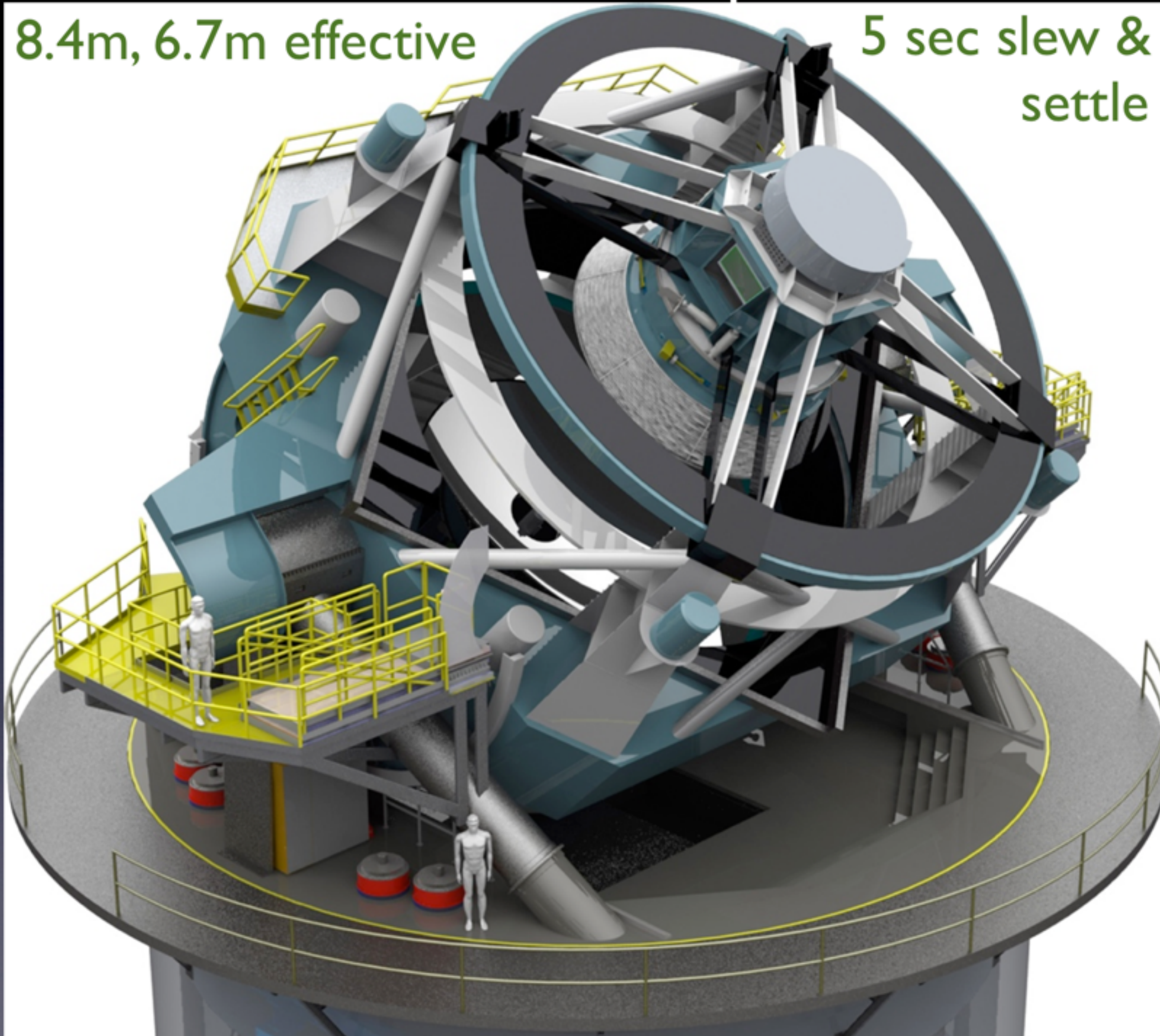
June 10, 2013



LSST Telescope

8.4m, 6.7m effective

5 sec slew & settle

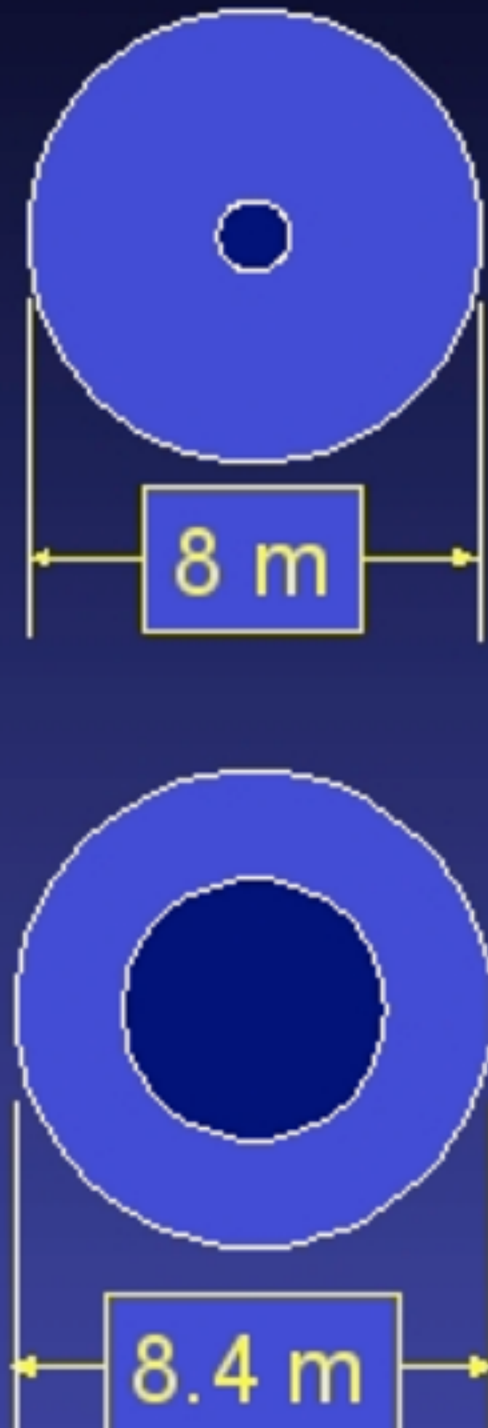


The field-of-view comparison: Gemini vs. LSST

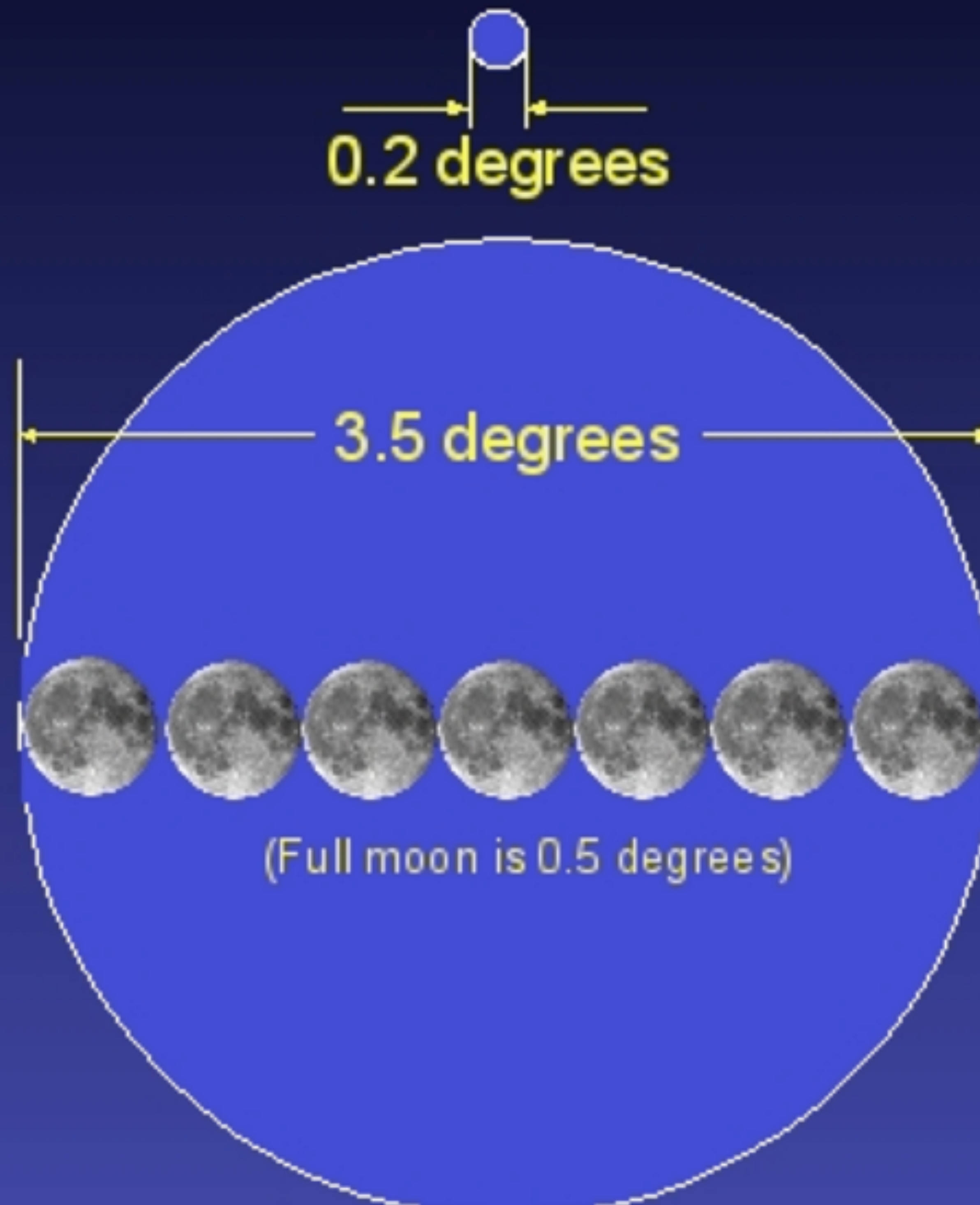
Gemini South Telescope

LSST

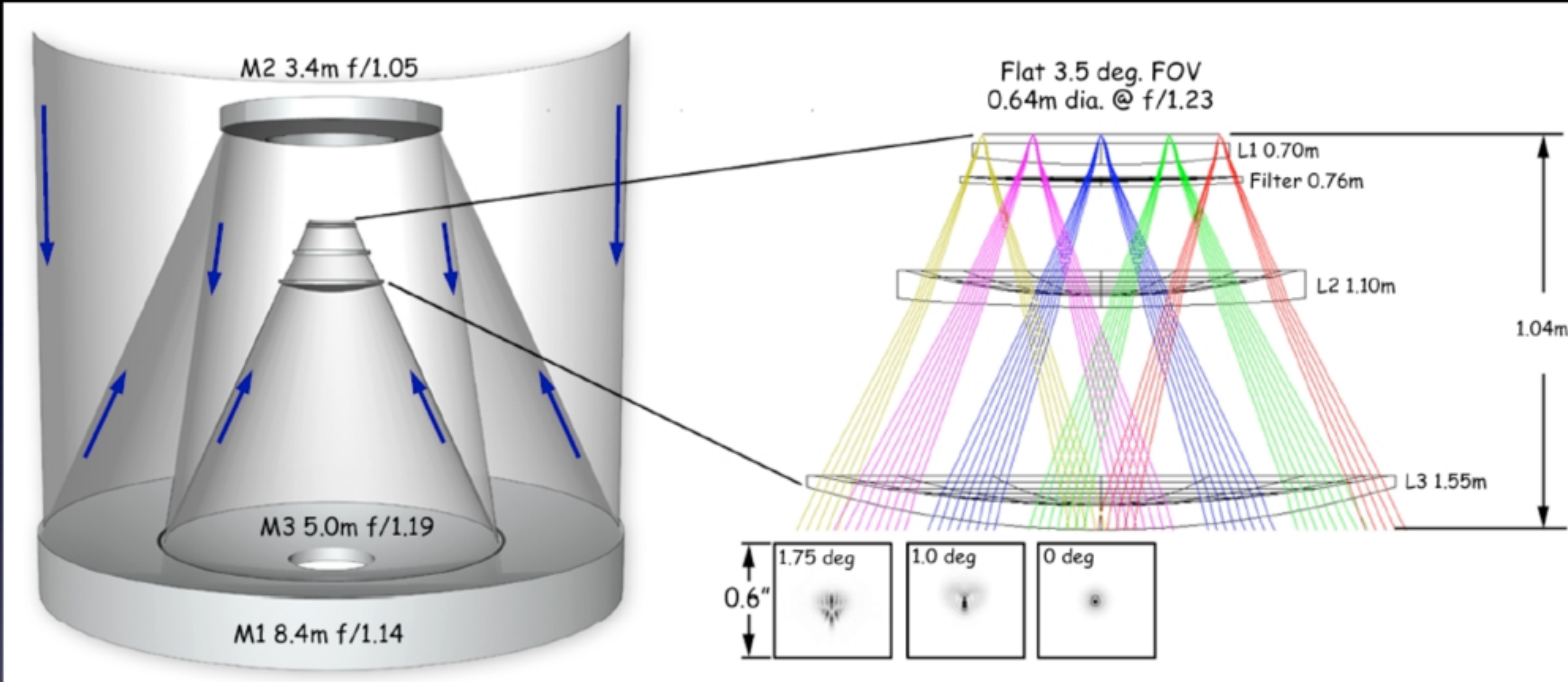
Primary Mirror Diameter



Field of View

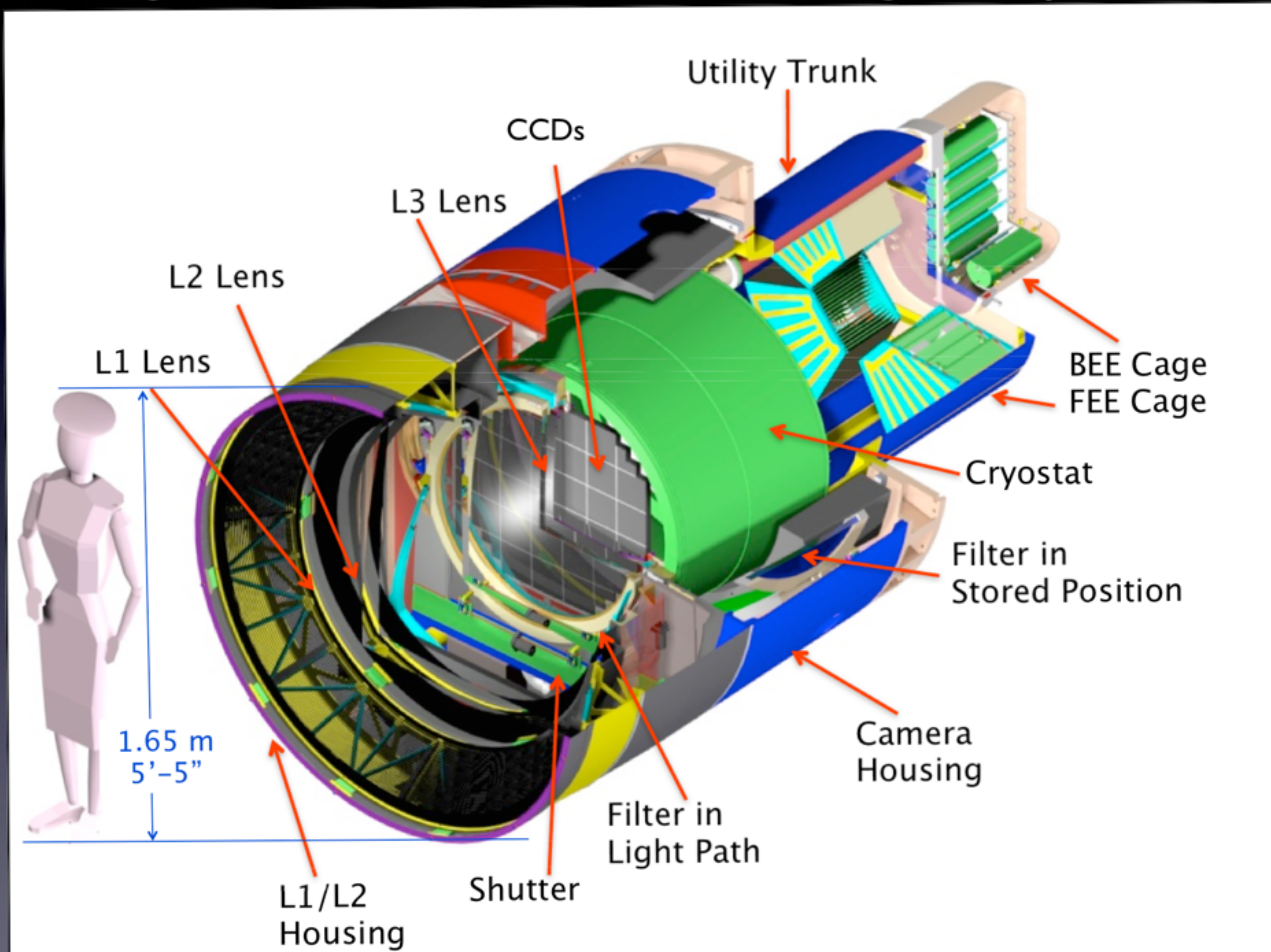


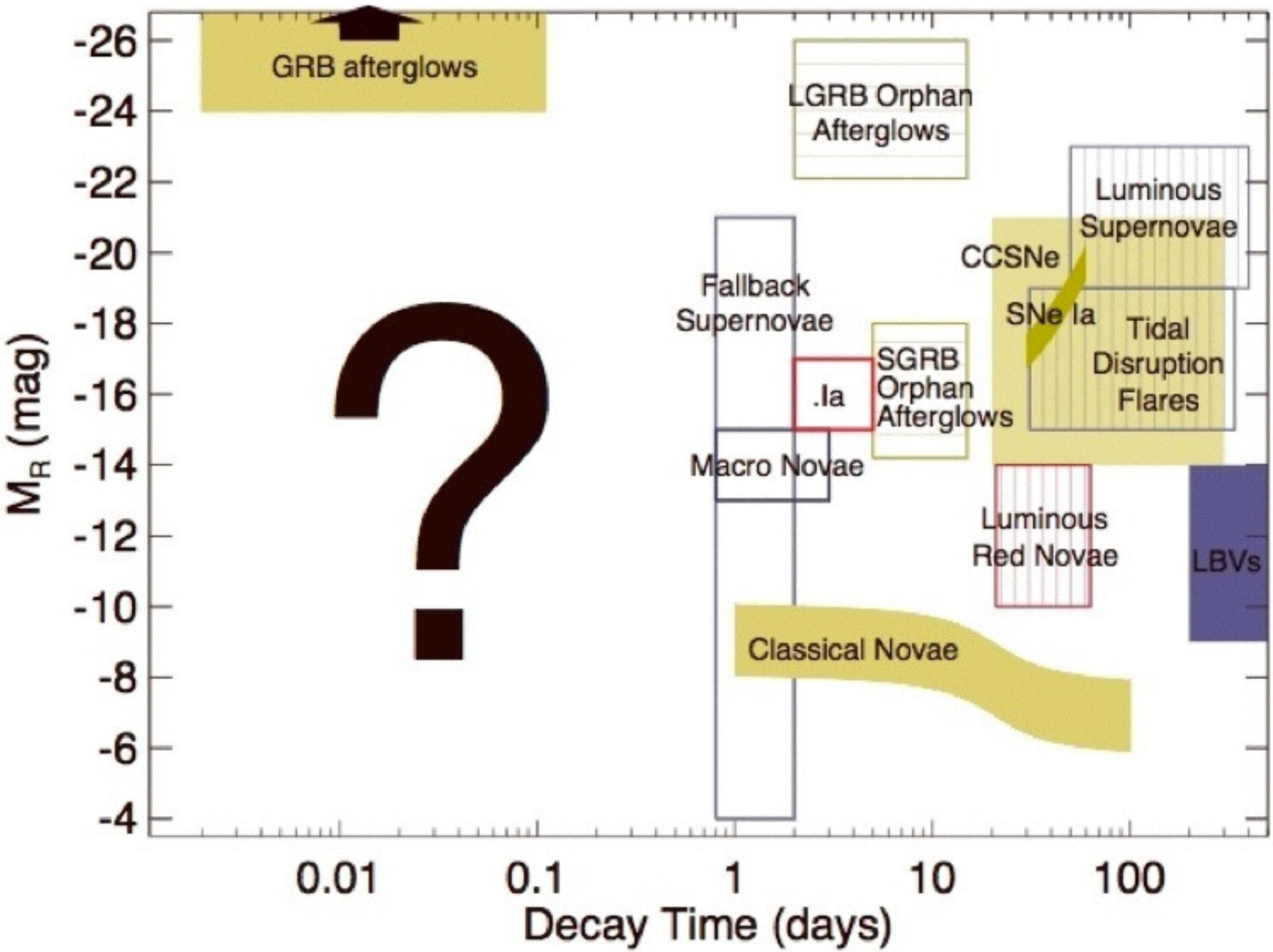
Optical Design for LSST



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




GRB afterglows
LGRB Orphan Afterglows
Luminous Supernovae
CCSNe
Fallback Supernovae
SNe Ia
Tidal Disruption Flares
SGRB Orphan Afterglows
.Ia
Macro Novae
Luminous Red Novae
LBVs
Classical Novae
?
-26
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
M_R (mag)
0.01
0.1
1
10
100
Decay Time (days)