Friss eredmények a (változó)csillagászatból

Kiss L. László akadémikus
MTA CSFK KTM CSI

Tata, 2015. október 3.

A legfényesebb exobolygós csillag…

A&A 580, A31 (2015)
DOI: 10.1051/0004-6361/201425519

Astronomy & Astrophysics

Long-lived, long-period radial velocity variations in Aldebaran: A planetary companion and stellar activity⋆,⋆⋆

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Table 1. Stellar parameters of α Tau.

Parameter	Value
Spectral type	K5III
m_V [mag]	0.85
M_V [mag]	-0.65 ± 0.041
$B - V$ [mag]	1.520 ± 0.005
Parallax [mas]	48.94 ± 0.77
Distance [pcs]	20.43 ± 0.32
Mass [$M_\odot$]	1.13 ± 0.11
R_* [$R_\odot$]	45.1 ± 0.1
Age [Gyr]	6.6 ± 2.4
$T_{\rm eff}$ [K]	4055 ± 70
[Fe/H] [dex]	-0.27 ± 0.05
$\log g$ [dex]	1.2 ± 0.1

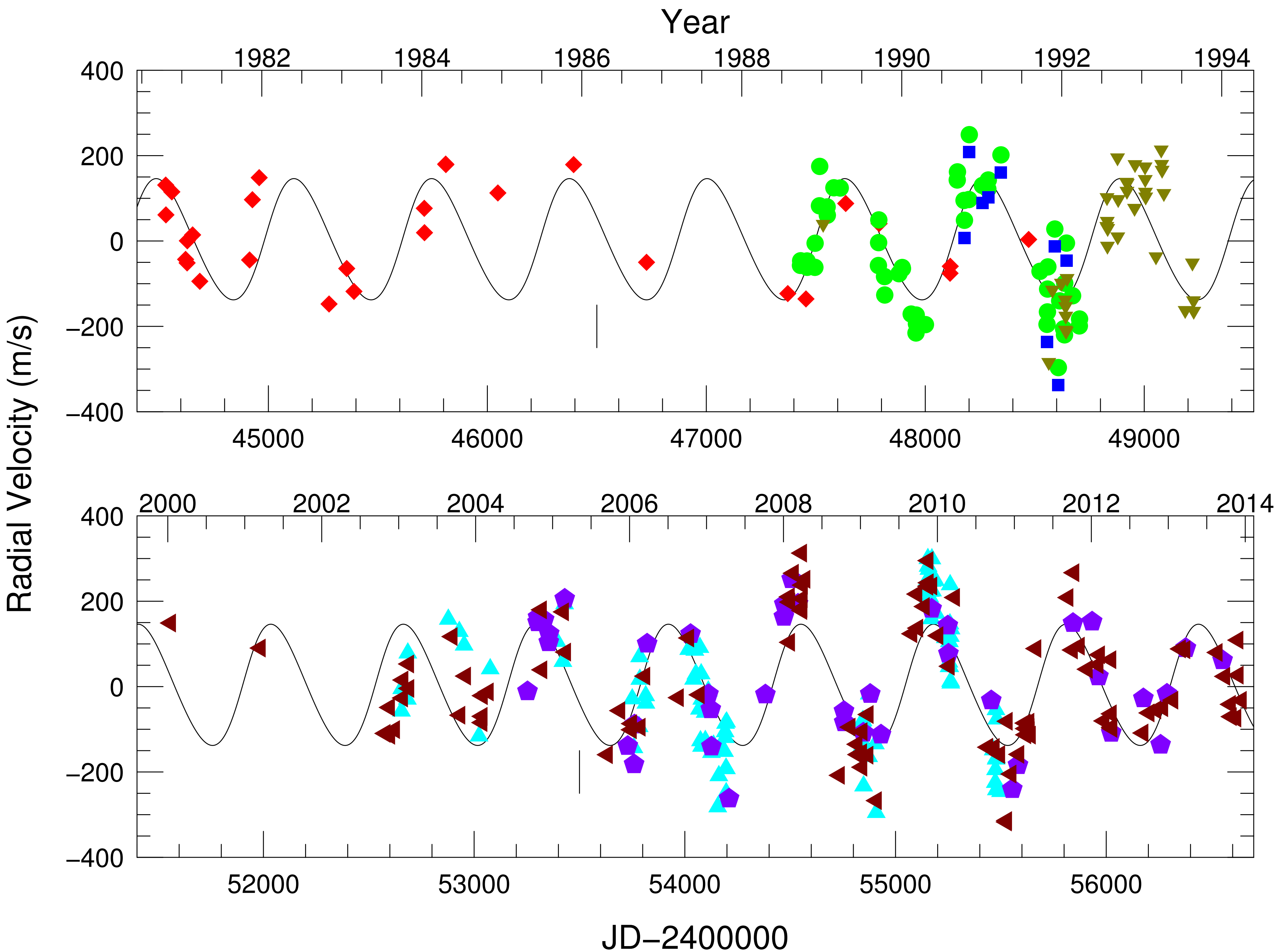

Fig. 2. Radial velocity measurements for α Tau from the seven data sets: CFHT (diamonds), DAO (inverted triangles), McD-2.1 m (circles), McD-CS11 (squares), McD-Tull (sideways triangles), TLS (triangles), and BOAO (pentagons). Zero point corrections have been applied to the individual data sets before plotting (see text). The curve represents the orbital solution (see Table 10). The vertical dash represents the peak-to-peak variations of the stellar oscillations.

Table 10. Orbital parameters for the companion to α Tau.

Parameter	Value
Period [d]	628.96 ± 0.90
$T_{\text{periastron}}$ [JD]	2 451 297.0 ± 50.0
K [m s^{-1}]	142.1 ± 7.2
e	0.10 ± 0.05
ω [deg]	287 ± 29
$f(m)$ [$M_\odot$]	$(1.84 \pm 0.28) \times 10^{-7}$
$m \sin i$ [M_{Jup}]	6.47 ± 0.53
a [AU]	1.46 ± 0.27

Table 11. Periods derived from RV residuals and activity indicators.

Quantity	Period (d)	K ($\mathrm{m\,s^{-1}}$)
RV residuals: Epoch 3	521 ± 11	95 ± 10
RV residuals: Epoch 2	526 ± 82	132 ± 30
RV residuals: Epoch 1-3	534.7 ± 1.7	91.2 ± 9.0
Ca II K S-index	521 ± 10	N/A
Hα EW	520 ± 23	N/A
Hα FWHM	526 ± 10	N/A

Duplán fedő ötöscsillag

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Astronomy & Astrophysics

The doubly eclipsing quintuple low-mass star system 1SWASP J093010.78+533859.5★

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ABSTRACT

Our discovery of 1SWASP J093010.78+533859.5 as a probable doubly eclipsing quadruple system, containing a contact binary with $P \sim 0.23$ d and a detached binary with $P \sim 1.31$ d, was announced in 2013. Subsequently, Koo and collaborators confirmed the detached binary spectroscopically, and identified a fifth set of static spectral lines at its location, corresponding to an additional non-eclipsing component of the system. Here we present new spectroscopic and photometric observations, allowing confirmation of the contact binary and improved modelling of all four eclipsing components. The detached binary is found to contain components of masses 0.837 ± 0.008 and 0.674 ± 0.007 $M_{\odot}$, with radii of 0.832 ± 0.018 and 0.669 ± 0.018 $R_{\odot}$ and effective temperatures of 5185^{+25}_{-20} and 4325^{+20}_{-15} K, respectively; the contact system has masses 0.86 ± 0.02 and 0.341 ± 0.011 $M_{\odot}$, radii of 0.79 ± 0.04 and 0.52 ± 0.05 $R_{\odot}$, respectively, and a common effective temperature of 4700 ± 50 K. The fifth star is of similar temperature and spectral type to the primaries in the two binaries. Long-term photometric observations indicate the presence of a spot on one component of the detached binary, moving at an apparent rate of approximately one rotation every two years. Both binaries have consistent system velocities around -11 to -12 km s^{-1}, which match the average radial velocity of the fifth star; consistent distance estimates for both subsystems of $d = 78 \pm 3$ and $d = 73 \pm 4$ pc are also found, and, with some further assumptions, of $d = 83 \pm 9$ pc for the fifth star. These findings strongly support the claim that both binaries – and very probably all five stars – are gravitationally bound in a single system. The consistent angles of inclination found for the two binaries ($88.2 \pm 0.3°$and $86 \pm 4°$) may also indicate that they originally formed by fragmentation (around 9–10 Gyr ago) from a single protostellar disk, and subsequently remained in the same orbital plane.

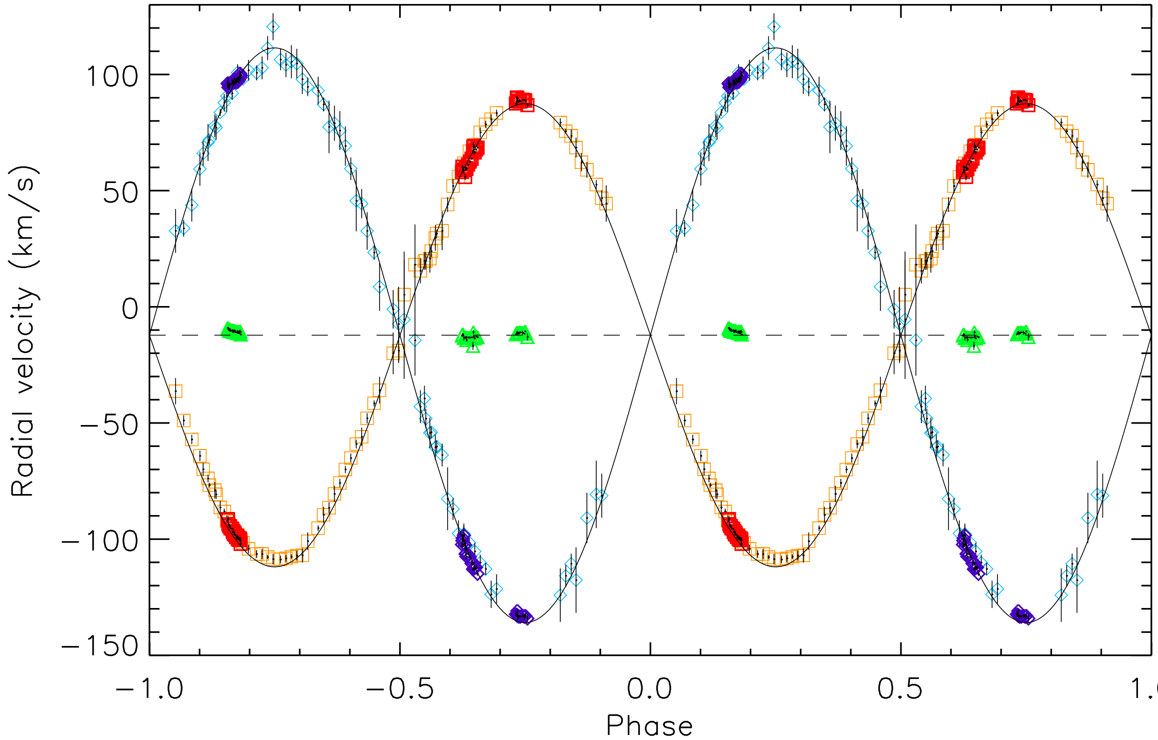

Fig. 4. Radial velocity curves for J093010A. The primary's measurements are indicated by squares, the secondary by diamonds and the third component by triangles. Data from Koo et al. (2014) is in fainter print (orange and light blue in the online version of the paper) and our new results are in bold print (red, dark blue and green). Phase-folding uses Koo et al.'s primary minimum time of HJD 2 456 346.78443 and our optimum period. PHOEBE model fits are overplotted (solid black curves) and the location of the modelled system velocity is shown by the dashed line.

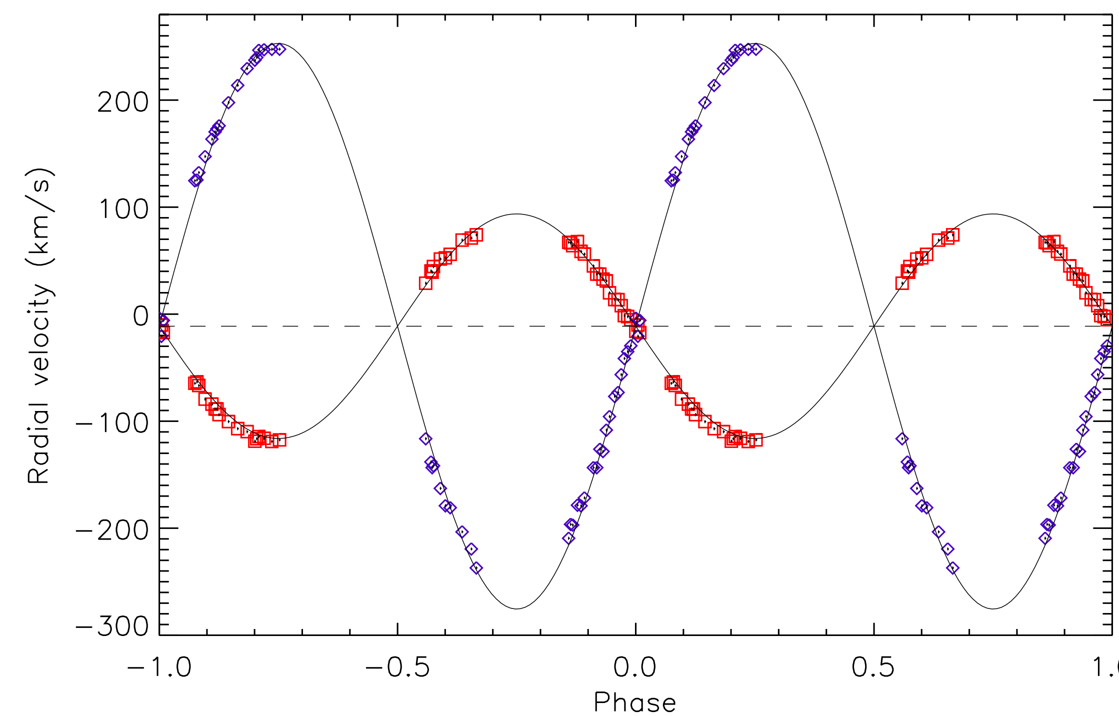

Fig. 7. Radial velocity curves for J093010B, based on our WHT observations. The primary is shown with red squares and the secondary with blue diamonds; uncertainties are generally smaller than the symbol size. Phase-folding uses HJD 2 456 288.8780, found by PHOEBE modelling of radial velocity and light curves simultaneously, and our optimum period. The dashed line shows the location of the (modelled) system velocity.

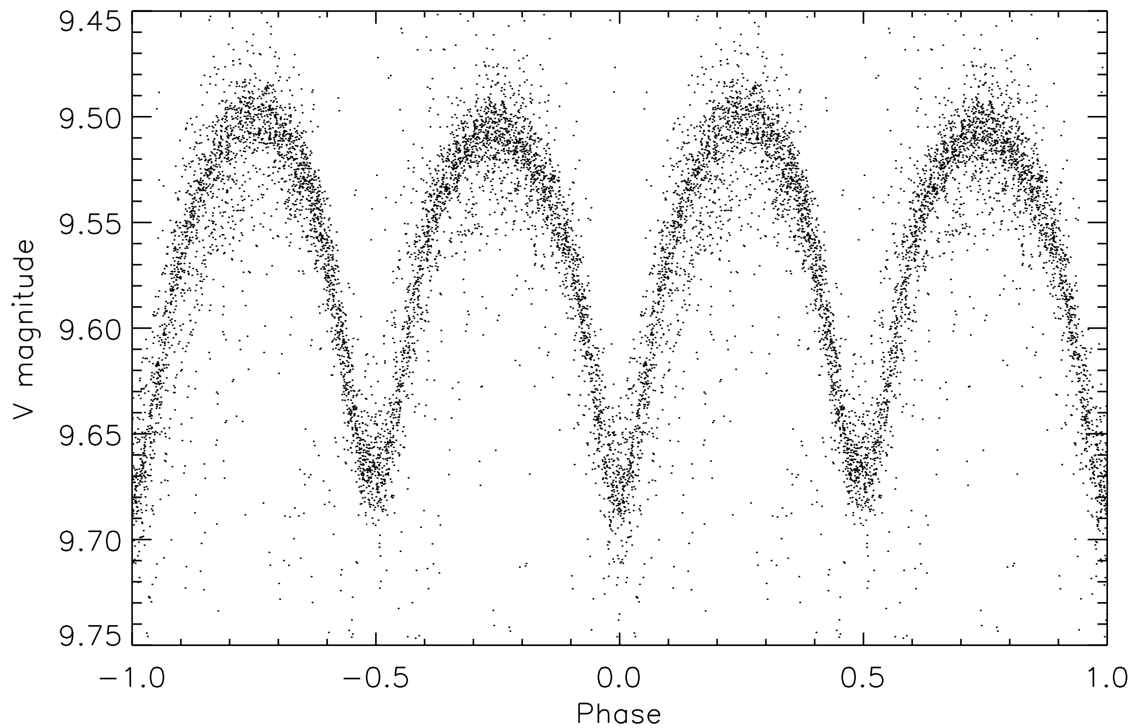

Fig. 10. SuperWASP folded light curve for J093010B, converted to *V* magnitudes. The maximum magnitude is that of the quintuple system as a whole.

This bright, close, highly unusual star system, containing a very short-period contact eclipsing binary, and a triple system including a low-mass detached eclipsing binary, would doubtless repay further investigation.

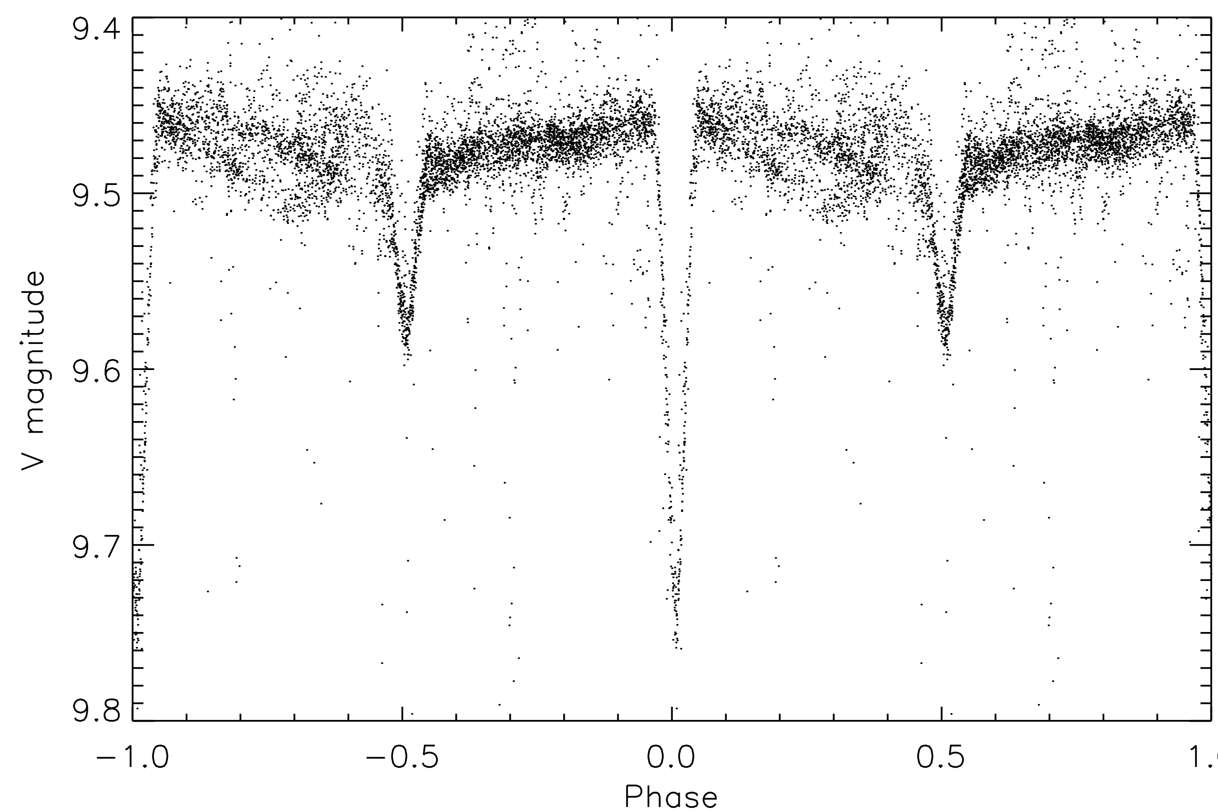

Fig. 11. SuperWASP folded light curve for the detached binary in J093010A, converted to *V* magnitudes. The maximum magnitude is that of the quintuple system as a whole.

“Sirály1”

The Astrophysical Journal, 808:179 (9pp), 2015 August 1 doi:10.1088/0004-637X/808/2/179

A NEW sdO+dM BINARY WITH EXTREME ECLIPSES AND REFLECTION EFFECT

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ABSTRACT

We report the discovery of a new totally eclipsing binary (R.A. $= 06^{\mathrm{h}}40^{\mathrm{m}}29^{\mathrm{s}}.11$; decl. $= +38^\circ 56' 52''.2$; $J = 2000.0$; $R_{\mathrm{max}} = 17.2$ mag) with an sdO primary and a strongly irradiated red dwarf companion. It has an orbital period of $P_{\mathrm{orb}} = 0.187284394(11)$ day and an optical eclipse depth in excess of 5 mag. We obtained 2 low-resolution classification spectra with GTC/OSIRIS and 10 medium-resolution spectra with WHT/ISIS to constrain the properties of the binary members. The spectra are dominated by H Balmer and He II absorption lines from the sdO star, and phase-dependent emission lines from the irradiated companion. A combined spectroscopic and light curve analysis implies a hot subdwarf temperature of $T_{\mathrm{eff}}(\mathrm{spec}) = 55{,}000 \pm 3000$ K, surface gravity of $\log g$ (phot) $= 6.2 \pm 0.04$ (cgs), and a He abundance of $\log(n\mathrm{He}/n\mathrm{H}) = -2.24 \pm 0.40$. The hot sdO star irradiates the red dwarf companion, heating its substellar point to about 22,500 K. Surface parameters for the companion are difficult to constrain from the currently available data: the most remarkable features are the strong H Balmer and C II-III lines in emission. Radial velocity estimates are consistent with the sdO+dM classification. The photometric data do not show any indication of sdO pulsations with amplitudes greater than 7 mmag, and Hα-filter images do not provide evidence for the presence of a planetary nebula associated with the sdO star.

Key words: binaries: eclipsing – stars: fundamental parameters – stars: low-mass – subdwarfs

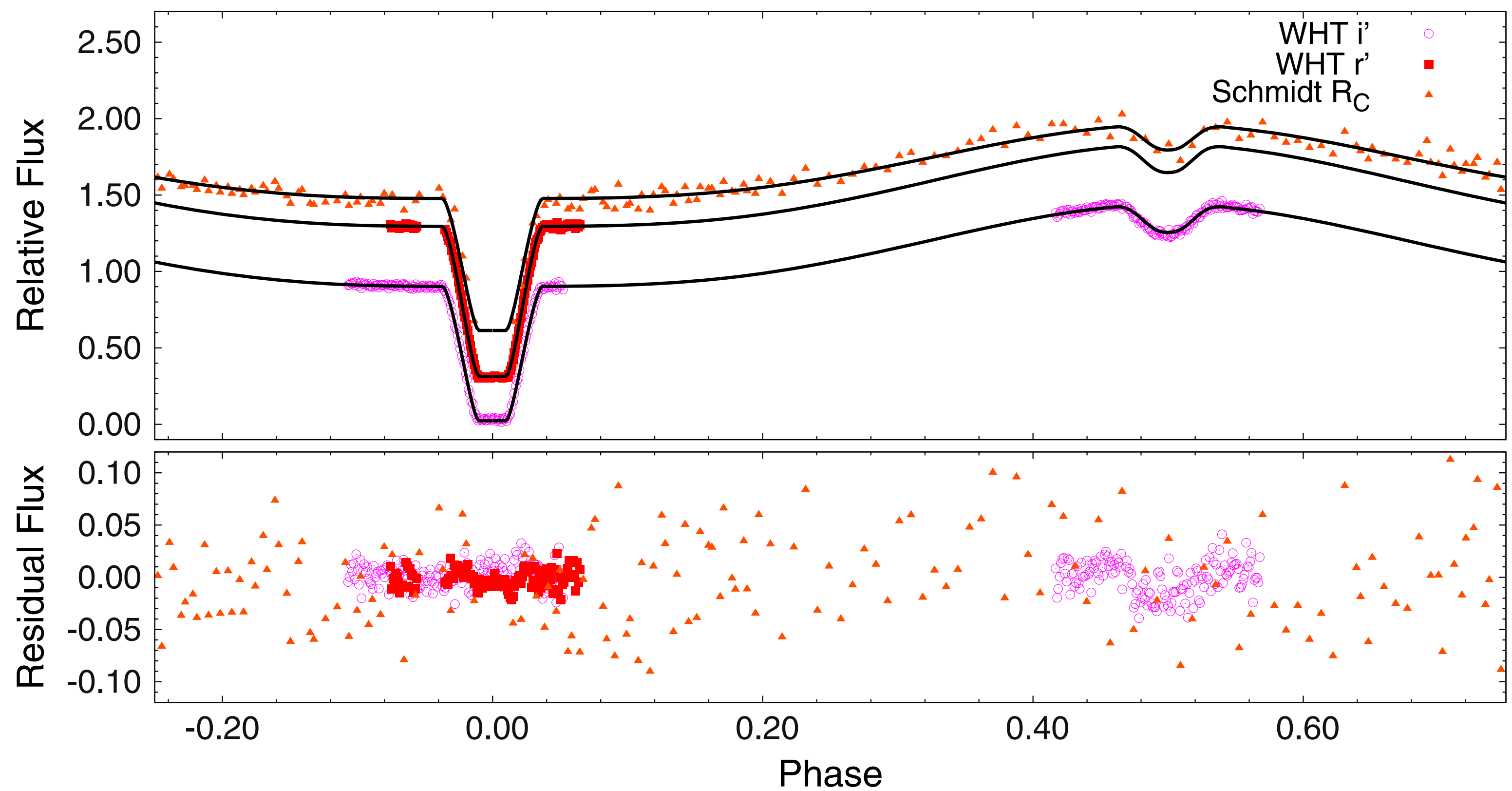

Figure 5. Observed light curves and solutions with their residuals for the Sloan i', r' (WHT), and R_C (Piszkéstető Observatory) passband measurements.

The Astrophysical Journal, 808:179 (9pp), 2015 August 1 Derekas et al.

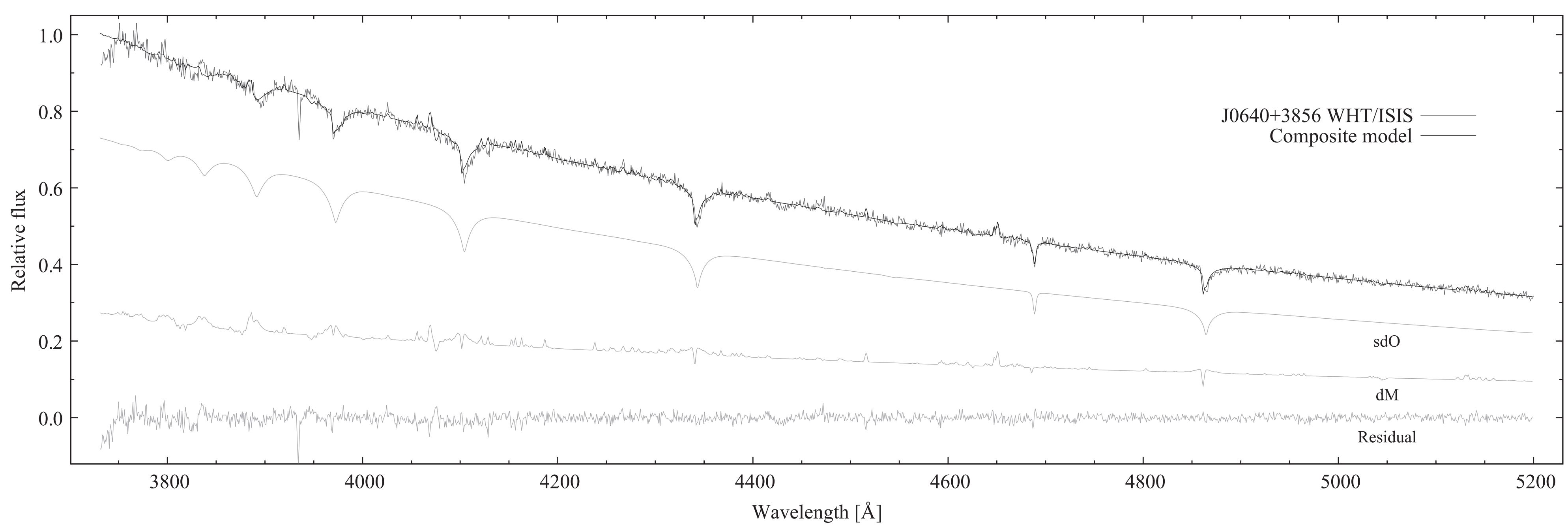

Figure 2. Spectral decomposition of the WHT/ISIS spectrum at $\varphi = 0.647$. The spectral features can be described with the superposition of a 55,000 K sdO star and an irradiated dM companion heated to ~22,500 K.

Cefeida összeolvadt kettőscsillagból

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DOI: 10.1051/0004-6361/201526716

Astronomy & Astrophysics

Letter to the Editor

The strange evolution of the Large Magellanic Cloud Cepheid OGLE-LMC-CEP1812

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ABSTRACT

Classical Cepheids are key probes of both stellar astrophysics and cosmology as standard candles and pulsating variable stars. It is important to understand Cepheids in unprecedented detail in preparation for upcoming *Gaia*, *James Webb* Space Telescope (JWST) and extremely-large telescope observations. Cepheid eclipsing binary stars are ideal tools for achieving this goal, however there are currently only three known systems. One of those systems, OGLE-LMC-CEP1812, raises new questions about the evolution of classical Cepheids because of an apparent age discrepancy between the Cepheid and its red giant companion. We show that the Cepheid component is actually the product of a stellar merger of two main sequence stars that has since evolved across the Hertzsprung gap of the HR diagram. This post-merger product appears younger than the companion, hence the apparent age discrepancy is resolved. We discuss this idea and consequences for understanding Cepheid evolution.

Key words. binaries: eclipsing – stars: evolution – stars: variables: Cepheids – stars: late-type

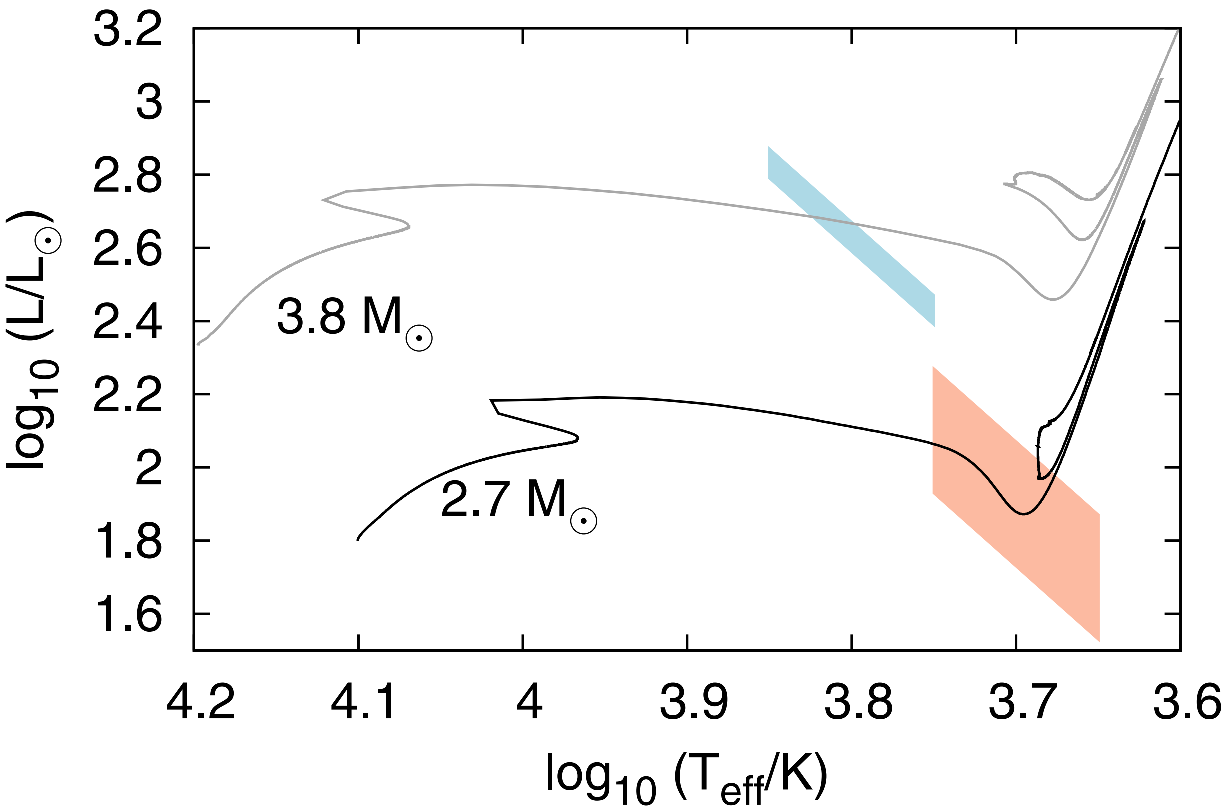

Fig. 1. Hertzsprung-Russell diagram showing stellar evolution models with initial masses $M_1 = 3.8\ M_\odot$ (gray) and $M_1 = 2.7\ M_\odot$ (black) along with regions consistent with the radius of the Cepheid, $R_{\rm Cepheid} = 17.4 \pm 0.9\ R_\odot$ (blue) and that of the red giant companion, $R_{\rm RG} = 12.1 \pm 2.3\ R_\odot$ (red).

Given the masses and radii of the two stars in the binary system, we computed stellar evolution models with initial masses, $M_1 = 3.8$ and $M_2 = 2.7\ M_\odot$. The stellar evolution tracks are plotted in Fig. 1 along with the regions of the Hertzsprung-Russell diagram consistent with the measured radii. Stellar evolution models appear to fit the measured stellar masses and radii. However, the models suggest that the Cepheid has an age of about 175 Myr while the red giant star's age is between 420 and 450 Myr. Pietrzyński et al. (2011) noted that the stellar ages

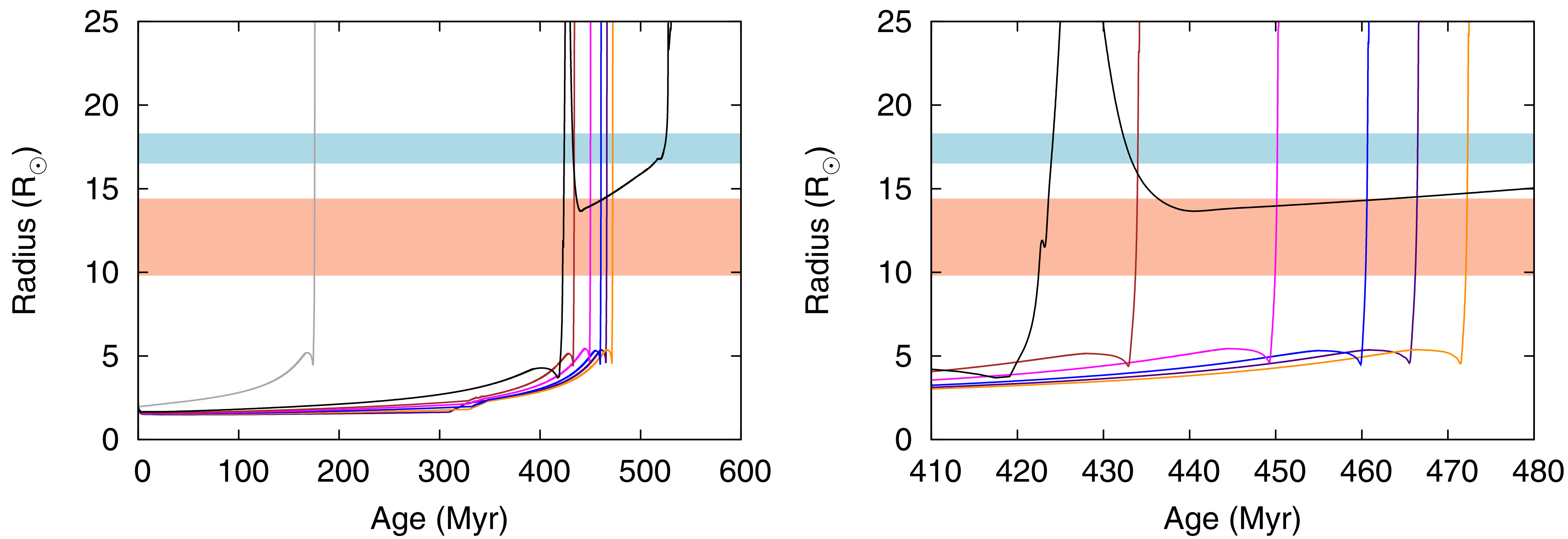

Fig. 2. *Left*: stellar radii as a function of age for stellar evolution models with initial mass M_1 = 3.8 (gray) and M_2 = 2.7 $M_\odot$ (black), along with stellar merger models with progenitor initial masses 2.1 (violet), 2.2 (orange), 2.3 (blue), 2.4 (pink) and 2.5 $M_\odot$ (brown). The blue and red colored regions represent the measured Cepheid and red giant companion radii, respectively. *Right*: a closer view of the stellar radius as a function age consistent with the current age of the red giant.

Kepler 1: Pulzáló-kitörő fehér törpék

The Astrophysical Journal Letters, 810:L5 (6pp), 2015 September 1 doi:10.1088/2041-8205/810/1/L5

A SECOND CASE OF OUTBURSTS IN A PULSATING WHITE DWARF OBSERVED BY *KEPLER*

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ABSTRACT

We present observations of a new phenomenon in pulsating white dwarf stars: large-amplitude outbursts at timescales much longer than the pulsation periods. The cool ($T_{\mathrm{eff}} = 11{,}060$ K), hydrogen-atmosphere pulsating white dwarf PG 1149+057 was observed nearly continuously for more than 78.8 day by the extended *Kepler* mission in *K2* Campaign 1. The target showed 10 outburst events, recurring roughly every 8 day and lasting roughly 15 hr, with maximum flux excursions up to 45% in the *Kepler* bandpass. We demonstrate that the outbursts affect the pulsations and therefore must come from the white dwarf. Additionally, we argue that these events are not magnetic reconnection flares, and are most likely connected to the stellar pulsations and the relatively deep surface convection zone. PG 1149+057 is now the second cool pulsating white dwarf to show this outburst phenomenon, after the first variable white dwarf observed in the *Kepler* mission, KIC 4552982. Both stars have the same effective temperature, within the uncertainties, and are among the coolest known pulsating white dwarfs of typical mass. These outbursts provide fresh observational insight into the red edge of the DAV instability strip and the eventual cessation of pulsations in cool white dwarfs.

Key words: stars: evolution – stars: general – stars: individual (PG 1149+057) – stars: oscillations – stars: variables: general – white dwarfs

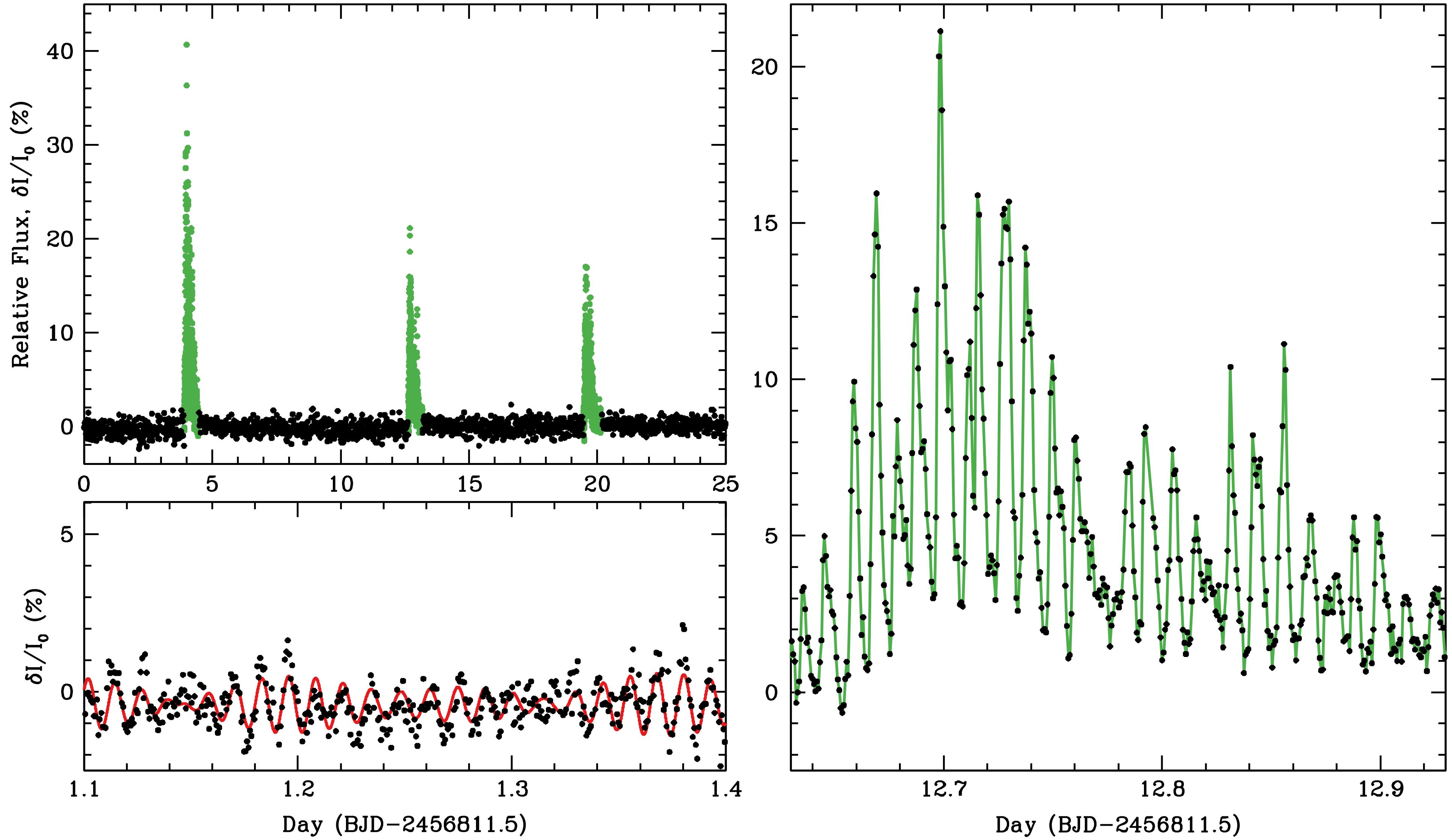
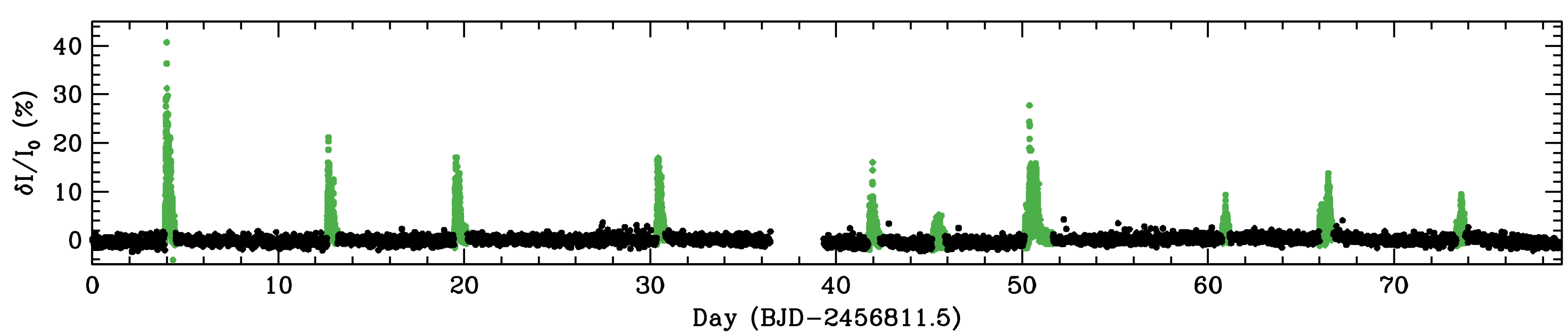


Figure 1. Representative portions of the *K2* Campaign 1 light curve of the pulsating white dwarf PG 1149+057. The top left panel shows the first 25 days of observations; three outburst events are denoted in green. The bottom left panel shows 7.2 hr of data on the second day of *K2* observations; the white dwarf pulsations are clearly visible, and underplotted is a best-fit to the three highest-amplitude signals (with periods of 1145.7, 998.1, and 1052.8 s). The right panel shows 7.2 hr during the second outburst, with points connected in green.



Kepler 2: Exotrójaik statisztikus detektálása

The Astrophysical Journal, 811:1 (5pp), 2015 September 20 doi:10.1088/0004-637X/811/1/1

A STATISTICAL SEARCH FOR A POPULATION OF EXO-TROJANS IN THE *KEPLER* DATA SET

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ABSTRACT

Trojans are small bodies in planetary Lagrangian points. In our solar system, Jupiter has the largest number of such companions. Their existence is assumed for exoplanetary systems as well, but none have been found so far. We present an analysis by super-stacking $\sim 4 \times 10^3$ *Kepler* planets with a total of $\sim 9 \times 10^4$ transits, searching for an average Trojan transit dip. Our results give an upper limit to the average Trojan transiting area (per planet) that corresponds to one body of radius <460 km with 2σ confidence. We find a significant Trojan-like signal in a sub-sample for planets with more (or larger) Trojans for periods >60 days. Our tentative results can and should be checked with improved data from future missions like *PLATO 2.0*, and can guide planetary formation theories.

Key words: minor planets, asteroids: general – planets and satellites: general

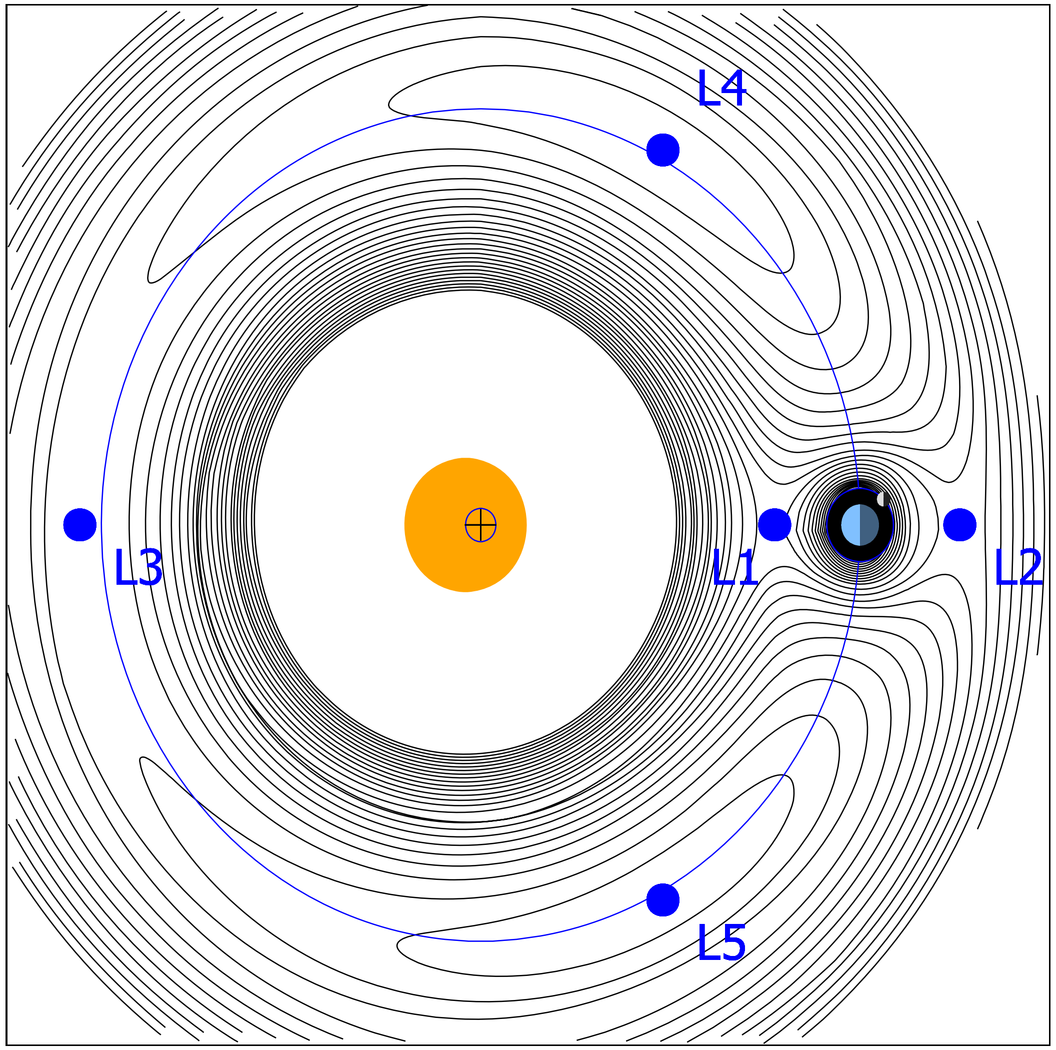

Figure 1. Lagrangian points L4 and L5 are 60° from the planet.

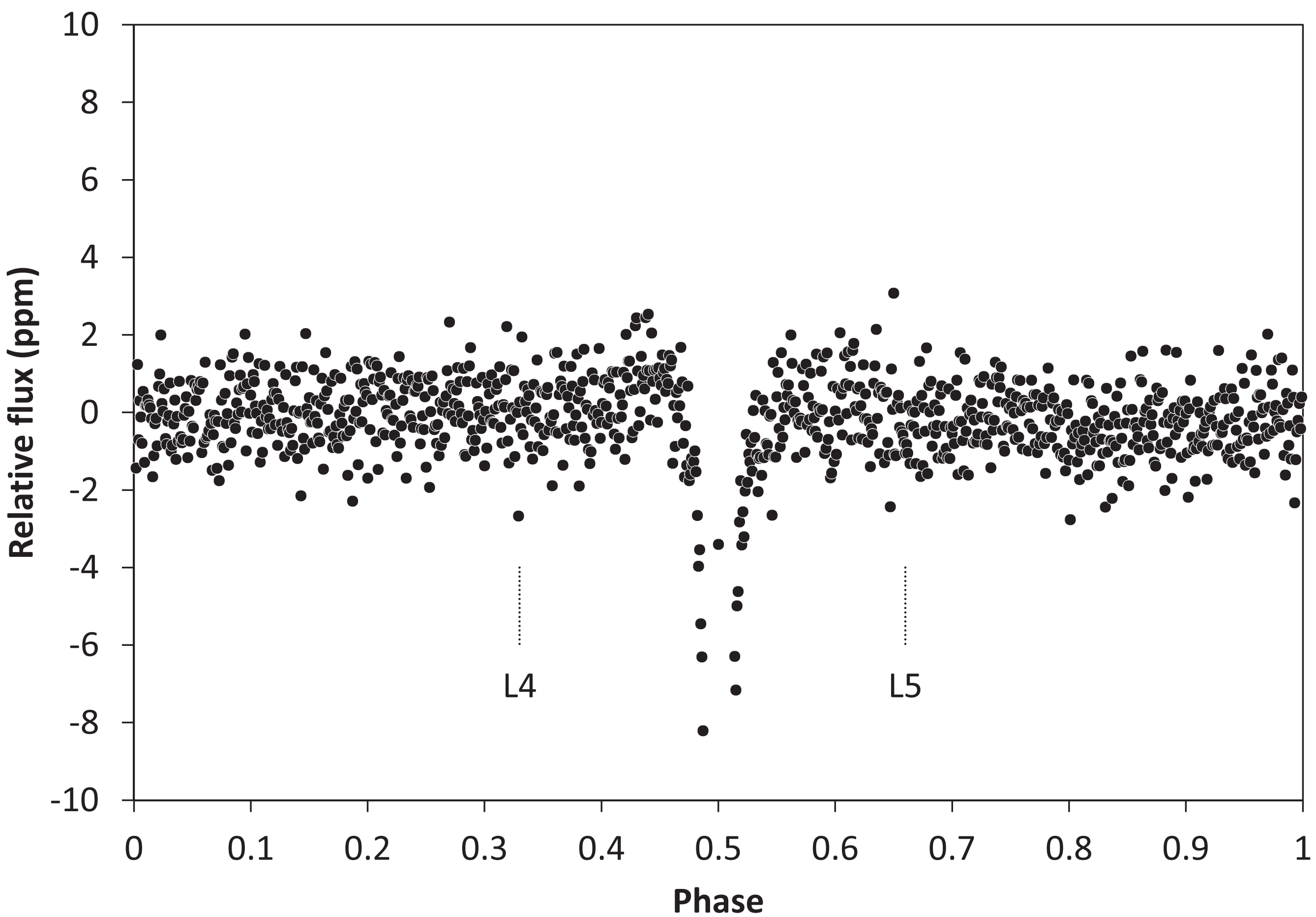

Figure 2. Initial super-stack shows no significant dips at the Lagrangian points.

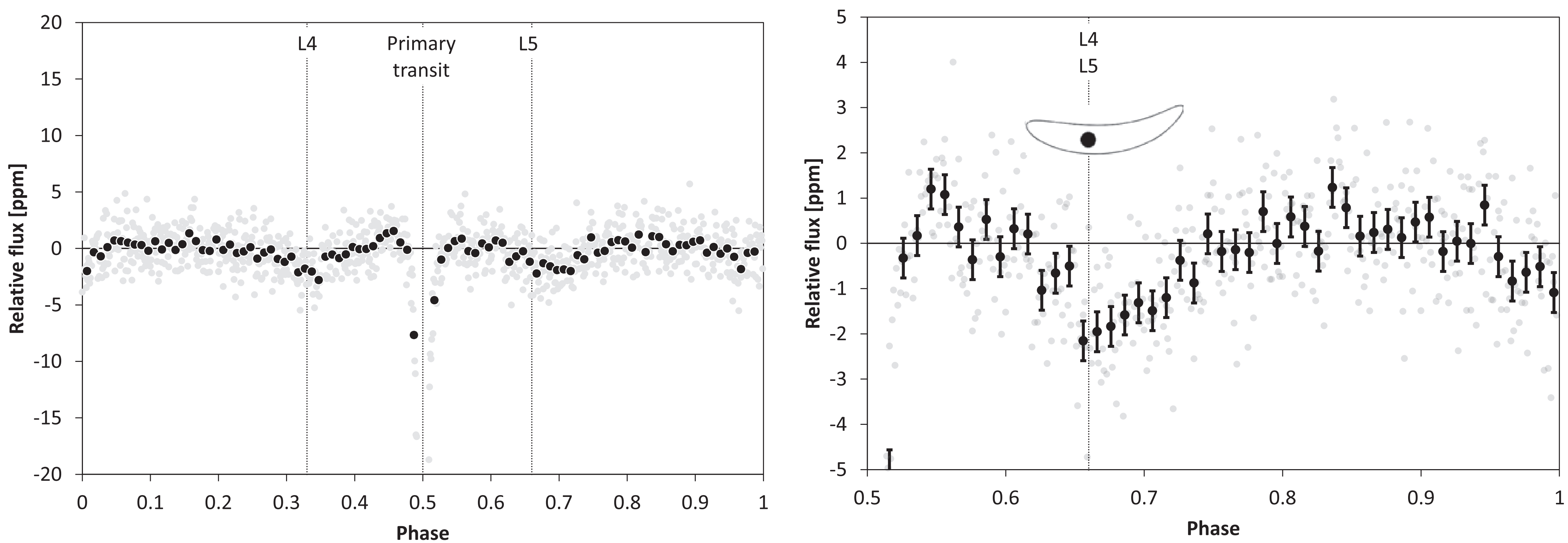

Figure 3. Sub-sample super-stack in normal (left) and double symmetric (right) phase fold, with expected orbit size shown for reference. Note the different vertical axes. The gray dots are 1000 bins over phase space, and the black dots with error bars (right) are 100 bins for better visibility.

M31N 2008-12a: egy éves periódusú RN az Andromeda-ködben

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Astronomy & Astrophysics

A remarkable recurrent nova in M31: Discovery and optical/UV observations of the predicted 2014 eruption⋆,⋆⋆

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ABSTRACT

The Andromeda Galaxy recurrent nova M31N 2008-12a had been caught in eruption eight times. The inter-eruption period of M31N 2008-12a is ∼1 yr, making it the most rapidly recurring system known, and a strong single-degenerate Type Ia supernova progenitor candidate. Following the 2013 eruption, a campaign was initiated to detect the predicted 2014 eruption and to then perform high cadence optical photometric and spectroscopic monitoring using ground-based telescopes, along with rapid UV and X-ray follow-up with the *Swift* satellite. Here we report the results of a high cadence multi-colour optical monitoring campaign, the spectroscopic evolution, and the UV photometry. We also discuss tantalising evidence of a potentially related, vastly-extended, nebulosity. The 2014 eruption was discovered, before optical maximum, on October 2, 2014. We find that the optical properties of M31N 2008-12a evolve faster than all Galactic recurrent novae known, and all its eruptions show remarkable similarity both photometrically and spectroscopically. Optical spectra were obtained as early as 0.26 days post maximum, and again confirm the nova nature of the eruption. A significant deceleration of the inferred ejecta expansion velocity is observed which may be caused by interaction of the ejecta with surrounding material, possibly a red giant wind. We find a low ejected mass and low ejection velocity, which are consistent with high mass-accretion rate, high mass white dwarf, and short recurrence time models of novae. We encourage additional observations, especially around the predicted time of the next eruption, towards the end of 2015.

Key words. galaxies: individual: M31 – novae, cataclysmic variables – stars: individual: M31N 2008-12a

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Astronomy & Astrophysics

A remarkable recurrent nova in M 31: The predicted 2014 outburst in X-rays with *Swift* ⋆

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ABSTRACT

Context. The M 31 nova M31N 2008-12a was recently found to be a recurrent nova (RN) with a recurrence time of about one year. This is by far the fastest recurrence time scale of any known RN.
Aims. Our optical monitoring programme detected the predicted 2014 outburst of M31N 2008-12a in early October. We immediately initiated an X-ray/UV monitoring campaign with *Swift* to study the multiwavelength evolution of the outburst.
Methods. We monitored M31N 2008-12a with daily *Swift* observations for 20 days after discovery, covering the entire supersoft X-ray source (SSS) phase.
Results. We detected SSS emission around day six after outburst. The SSS state lasted for approximately two weeks until about day 19. M31N 2008-12a was a bright X-ray source with a high blackbody temperature.
Conclusions. The X-ray properties of this outburst are very similar to the 2013 eruption. Combined X-ray spectra show a fast rise and decline of the effective blackbody temperature. The short-term X-ray light curve showed strong, aperiodic variability which decreased significantly after about day 14. Overall, the X-ray properties of M31N 2008-12a are consistent with the average population properties of M 31 novae. The optical and X-ray light curves can be scaled uniformly to show similar time scales to those of the Galactic RNe U Sco or RS Oph. The SSS evolution time scales and effective temperatures are consistent with a high-mass WD. We predict the next outburst of M31N 2008-12a to occur in Oct.–Dec. 2015.

Key words. galaxies: individual: M 31 – novae, cataclysmic variables – X-rays: binaries – stars: individual: M31N 2008-12a

Table 1. Observed eruptions of M31N 2008-12a.

$t_{\mathrm{max,\,optical}}$[a] (UT)	$t_{\mathrm{max,\,X-ray}}$[b] (UT)	Time since last eruption (days)[c]	Source	References
	1992 Feb. 05		X-ray (ROSAT)	1
	1993 Jan. 11	341	X-ray (ROSAT)	1
	2001 Sep. 08		X-ray (*Chandra*)	2
2008 Dec. 26			Optical	3
2009 Dec. 03		342	Optical (PTF)	4
2011 Oct. 23.49		689 (∼368/337[†])	Optical	4, 5, 6, 7
2012 Oct. 19.72		362.2	Optical	7, 8, 9
	<2012 Nov. 06.45		X-ray (*Swift*)	10
2013 Nov. 28.60		405.1	Optical (iPTF)	4, 7, 11, 12
	2013 Dec. 05.9 ± 0.2		X-ray (*Swift*)	4, 10
2014 Oct. 03.7 ± 0.1		309.1	Optical (LT)	7
	2014 Oct. 13.6		X-ray (*Swift*)	13

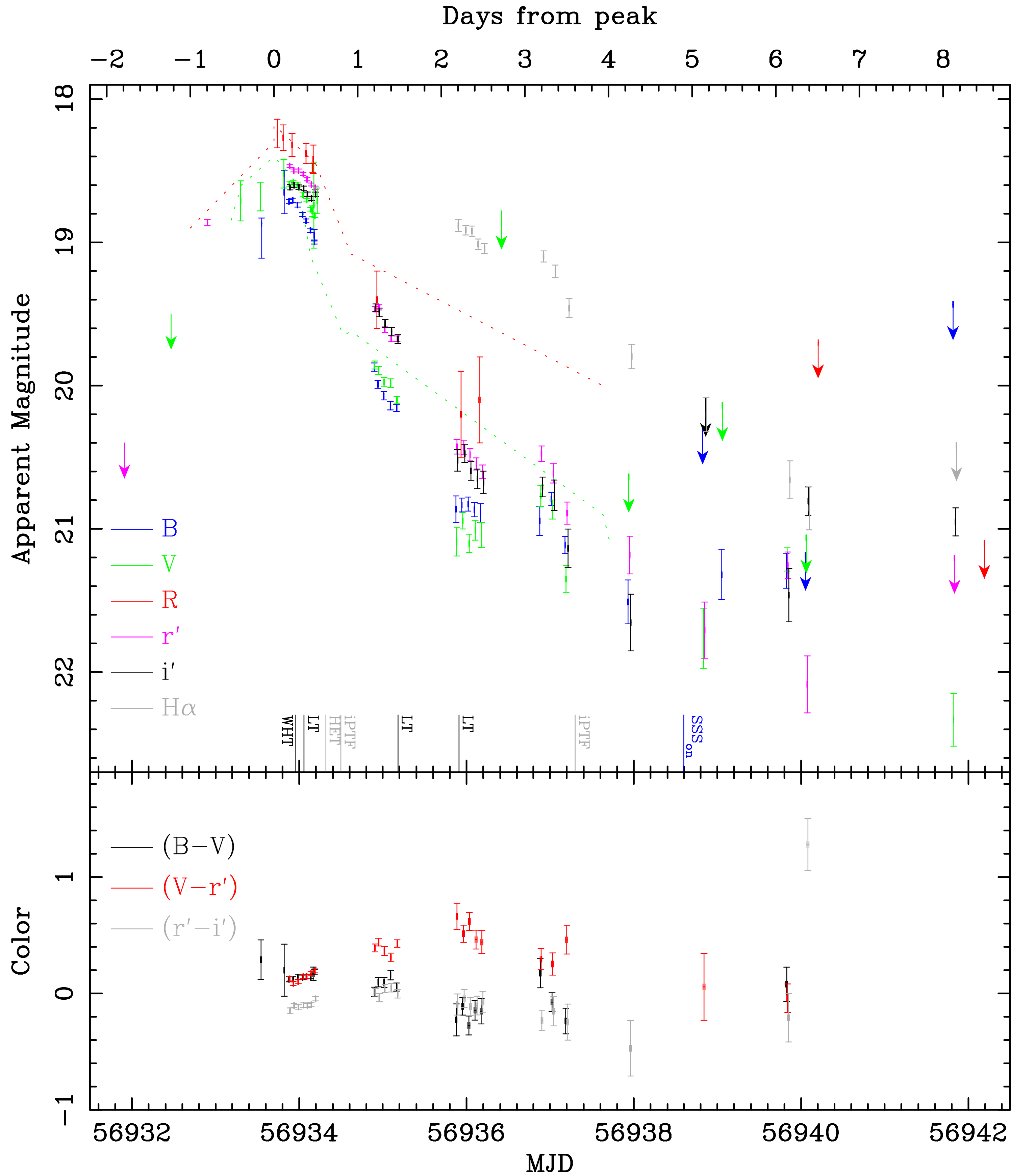

Fig. 1. Ground-based optical photometry of the 2014 eruption of M31N 2008-12a, all data are taken from Table 6. Epochs of optical spectra from the 2014 eruption (black lines), 2012 eruption (grey line), and the SSS behaviour (blue lines) are shown for informational purposes. *Top panel*: optical light curve; the dotted lines indicate a template light curve based on the *V*- (green) and *R*/*r*′-band (red) observations of the 2008, 2011, 2012, and 2013 eruptions, and we assume t_{max} = 56 933.7 (MJD) or 2014 Oct. 3.7 UT (see discussion in Sect. 4.1 and DWB14). *Bottom panel*: colour evolution of the 2014 eruption of M31N 2008-12a.

Egy kis sci-fi a végére…

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SETI VIA LEAKAGE FROM LIGHT SAILS IN EXOPLANETARY SYSTEMS

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ABSTRACT

The primary challenge of rocket propulsion is the burden of needing to accelerate the spacecraft's own fuel, resulting in only a logarithmic gain in maximum speed as propellant is added to the spacecraft. Light sails offer an attractive alternative in which fuel is not carried by the spacecraft, with acceleration being provided by an external source of light. By artificially illuminating the spacecraft with beamed radiation, speeds are only limited by the area of the sail, heat resistance of its material, and power use of the accelerating apparatus. In this paper, we show that leakage from a light sail propulsion apparatus in operation around a solar system analogue would be detectable. To demonstrate this, we model the launch and arrival of a microwave beam-driven light sail constructed for transit between planets in orbit around a single star, and find an optimal beam frequency on the order of tens of GHz. Leakage from these beams yields transients with flux densities of Jy and durations of tens of seconds at 100 pc. Because most travel within a planetary system would be conducted between the habitable worlds within that system, multiply transiting exoplanetary systems offer the greatest chance of detection, especially when the planets are in projected conjunction as viewed from Earth. If interplanetary travel via beam-driven light sails is commonly employed in our galaxy, this activity could be revealed by radio follow-up of nearby transiting exoplanetary systems. The expected signal properties define a new strategy in the search for extraterrestrial intelligence (SETI).

Key words: extraterrestrial intelligence – space vehicles

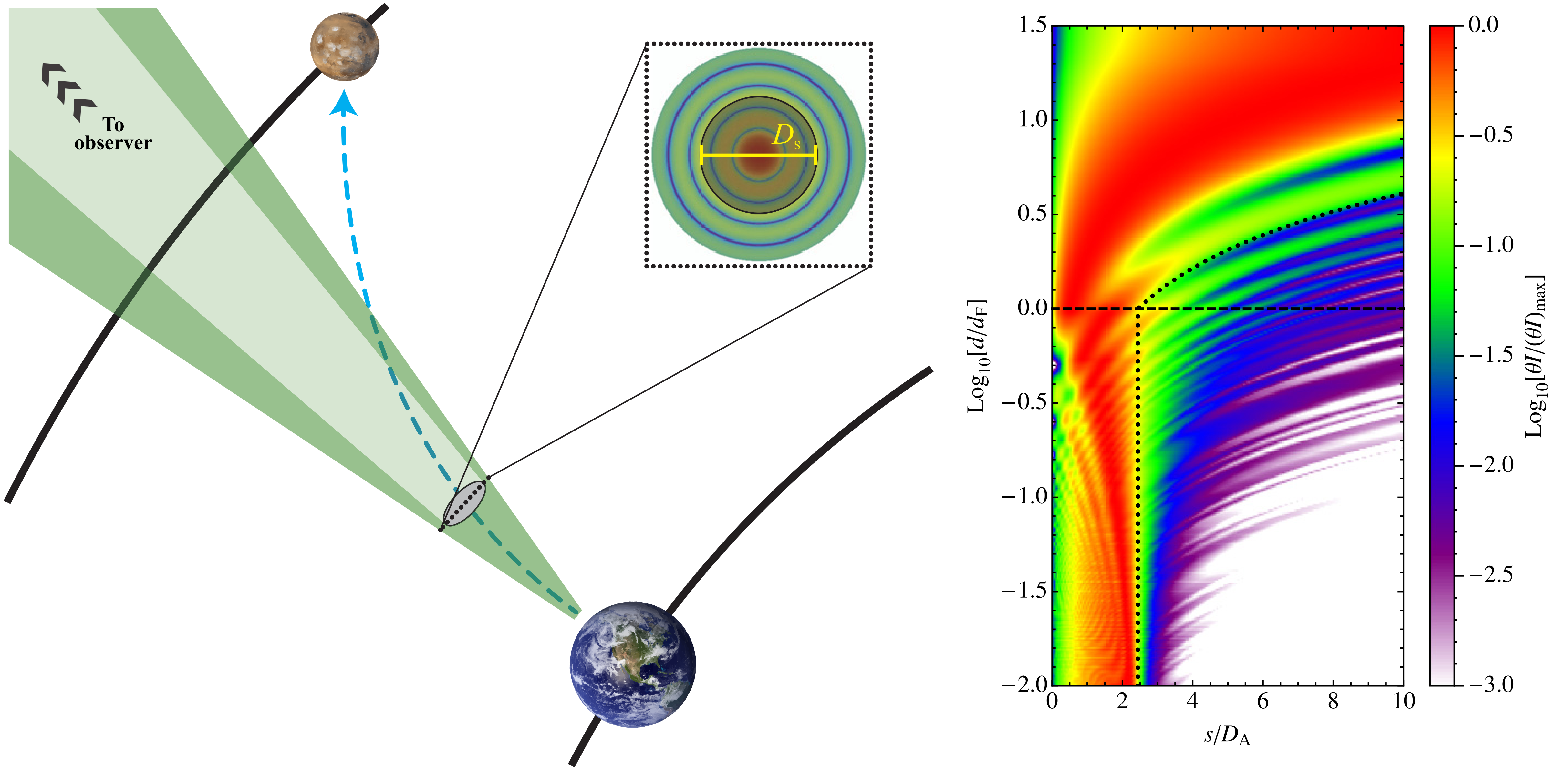

Figure 1. Left panel: diagram showing the leakage likely for a light sail system developed for Earth–Mars transit. The path of the light sail is shown by the dashed cyan arrow, whereas the beam profile is shown by the green area. The inset shows the logarithm of the intensity $\log I$ within the beam profile, which we have presumed to be in the Fraunhofer regime (Born & Wolf 1999; Kulkarni et al. 2014). Right panel: cylindrical profile of the intensity pattern incident upon the sail, where the cylindrical radius s is scaled to D_A and the radial distance d is scaled to d_F. The dashed line shows $d = d_F$, whereas the dotted line shows the region within which most of the intensity is directed.

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STATISTICAL SIGNATURES OF PANSPERMIA IN EXOPLANET SURVEYS

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ABSTRACT

A fundamental astrobiological question is whether life can be transported between extrasolar systems. We propose a new strategy to answer this question based on the principle that life which arose via spreading will exhibit more clustering than life which arose spontaneously. We develop simple statistical models of panspermia to illustrate observable consequences of these excess correlations. Future searches for biosignatures in the atmospheres of exoplanets could test these predictions: a smoking gun signature of panspermia would be the detection of large regions in the Milky Way where life saturates its environment interspersed with voids where life is very uncommon. In a favorable scenario, detection of as few as $\sim$25 biologically active exoplanets could yield a 5σ detection of panspermia. Detectability of position-space correlations is possible unless the timescale for life to become observable once seeded is longer than the timescale for stars to redistribute in the Milky Way.

Key words: astrobiology – planets and satellites: atmospheres

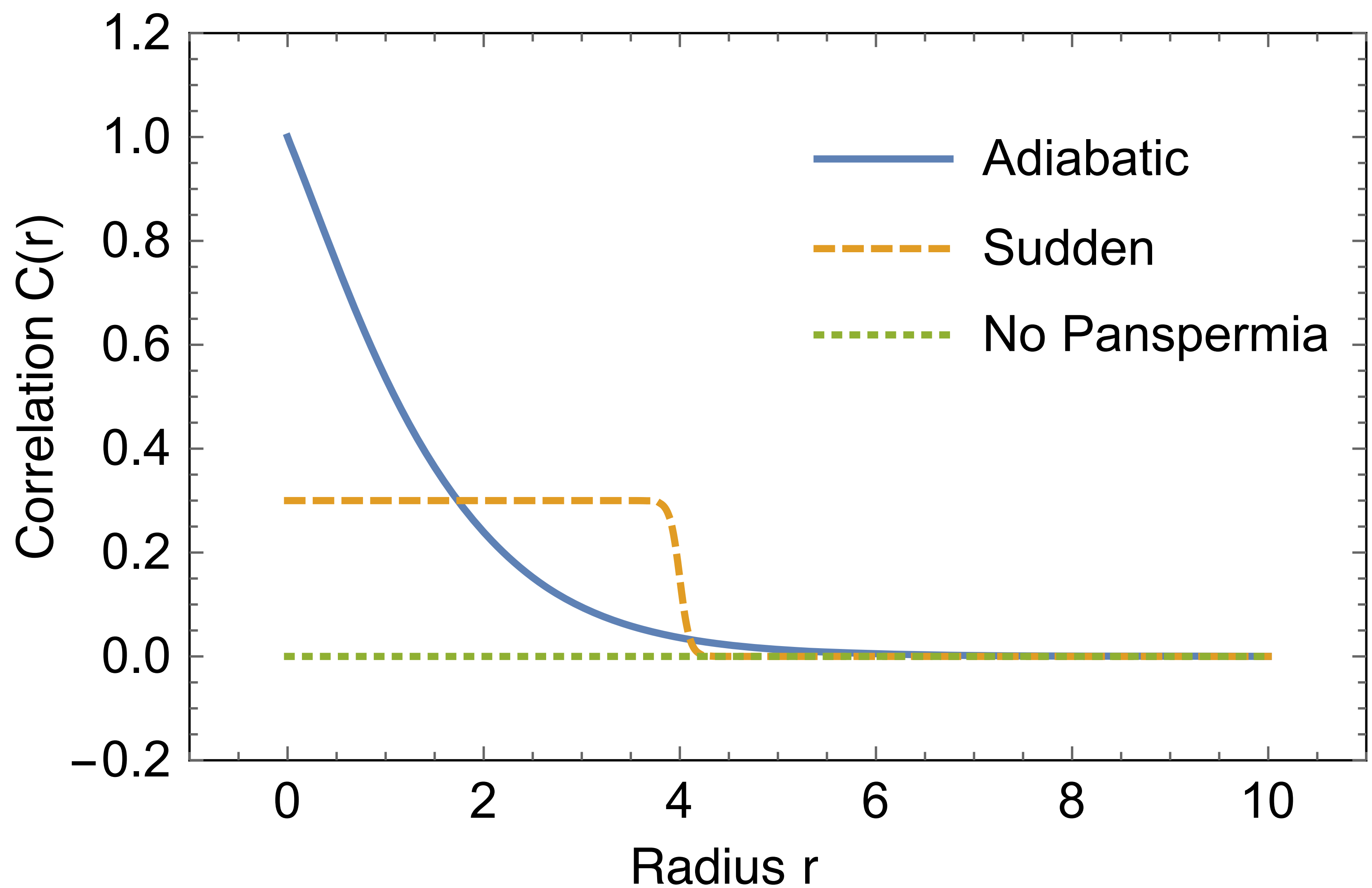

Figure 2. Schematic plot of the spherically averaged correlation function $C(r)$ as a function of radius r during the panspermia phase transition for two different panspermia scenarios and the no panspermia scenario. In the adiabatic regime, life can percolate in addition to spontaneously arising. In the sudden regime, life arises once and then begins to percolate. Both correlation functions define a characteristic scale radius ξ which reflects the time elapsed t since the first life started percolating. In the case where no panspermia occurs, the reduced correlation function is exactly zero, so a measurement of $\mathcal{C}(r) > 0$ (see Equation (5) for a definition) would be compelling evidence for panspermia.

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Astronomy & Astrophysics

Letter to the Editor

Application of the mid-IR radio correlation to the Ĝ sample and the search for advanced extraterrestrial civilisations⋆

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ABSTRACT

Wright et al. (2014, ApJ, 792, 26) have embarked on a search for advanced Karadashev Type III civilisations via the compilation of a sample of sources with extreme mid-IR emission and colours. The aim is to furnish a list of candidate galaxies that might harbour an advanced Kardashev Type III civilisation; in this scenario, the mid-IR emission is then primarily associated with waste heat energy by-products. I apply the mid-IR radio correlation to this Glimpsing Heat from Alien Technology (Ĝ) sample, a catalogue of 93 candidate galaxies compiled by Griffith et al. (2015, ApJS, 217, 25). I demonstrate that the mid-IR and radio luminosities are correlated for the sample, determining a k-corrected value of $q_{22} = 1.35 \pm 0.42$. By comparison, a similar measurement for 124 galaxies drawn from the First Look Survey (FLS) has $q_{22} = 0.87 \pm 0.27$. The statistically significant difference of the mean value of q_{22} for these two samples, taken together with their more comparable far-IR properties, suggests that the Ĝ sample shows excessive emission in the mid-IR. The fact that the Ĝ sample largely follows the mid-IR radio correlation strongly suggests that the vast majority of these sources are associated with galaxies in which natural astrophysical processes are dominant. This simple application of the mid-IR radio correlation can substantially reduce the number of false positives in the Ĝ catalogue since galaxies occupied by advanced Kardashev Type III civilisations would be expected to exhibit very high values of q. I identify nine outliers in the sample with $q_{22} > 2$ of which at least three have properties that are relatively well explained via standard astrophysical interpretations e.g. dust emission associated with nascent star formation and/or nuclear activity from a heavily obscured AGN. The other outliers have not been studied in any great detail, and are deserving of further observation. I also note that the comparison of resolved mid-IR and radio images of galaxies on sub-galactic (kpc) scales can also be useful in identifying and recognising artificial mid-IR emission from less advanced intermediate Type II/III civilisations. Nevertheless, from the bulk properties of the Ĝ sample, I conclude that Kardashev Type III civilisations are either very rare or do not exist in the local Universe.

Key words. astrobiology – galaxies: general – galaxies: star formation – radio continuum: galaxies – infrared: general

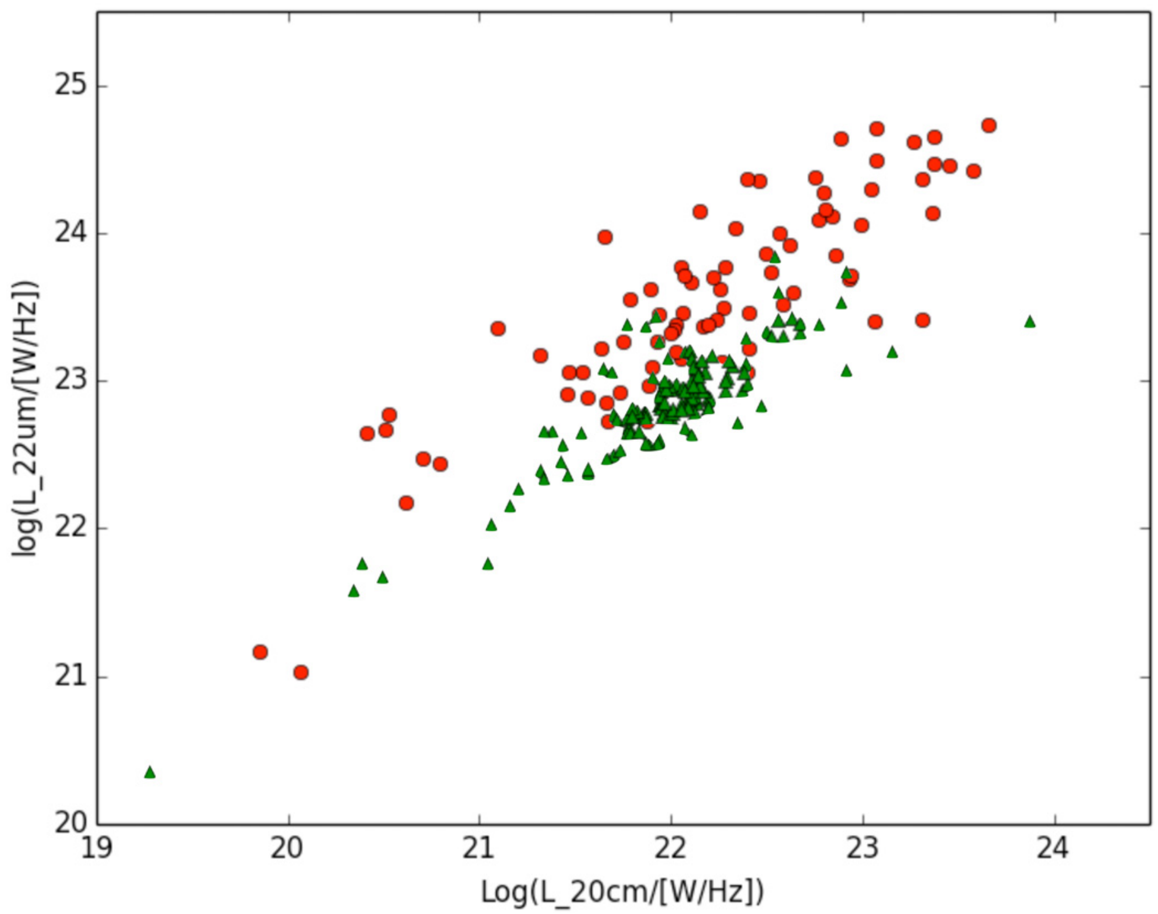

Fig. 1. k-corrected 22 μ mid-IR luminosity ($L_{22\,\mu}$, W/Hz), plotted against the 20 cm radio luminosity ($L_{20\text{ cm}}$, W/Hz) for the Ĝ (red circles) and FLS (green triangles) samples.

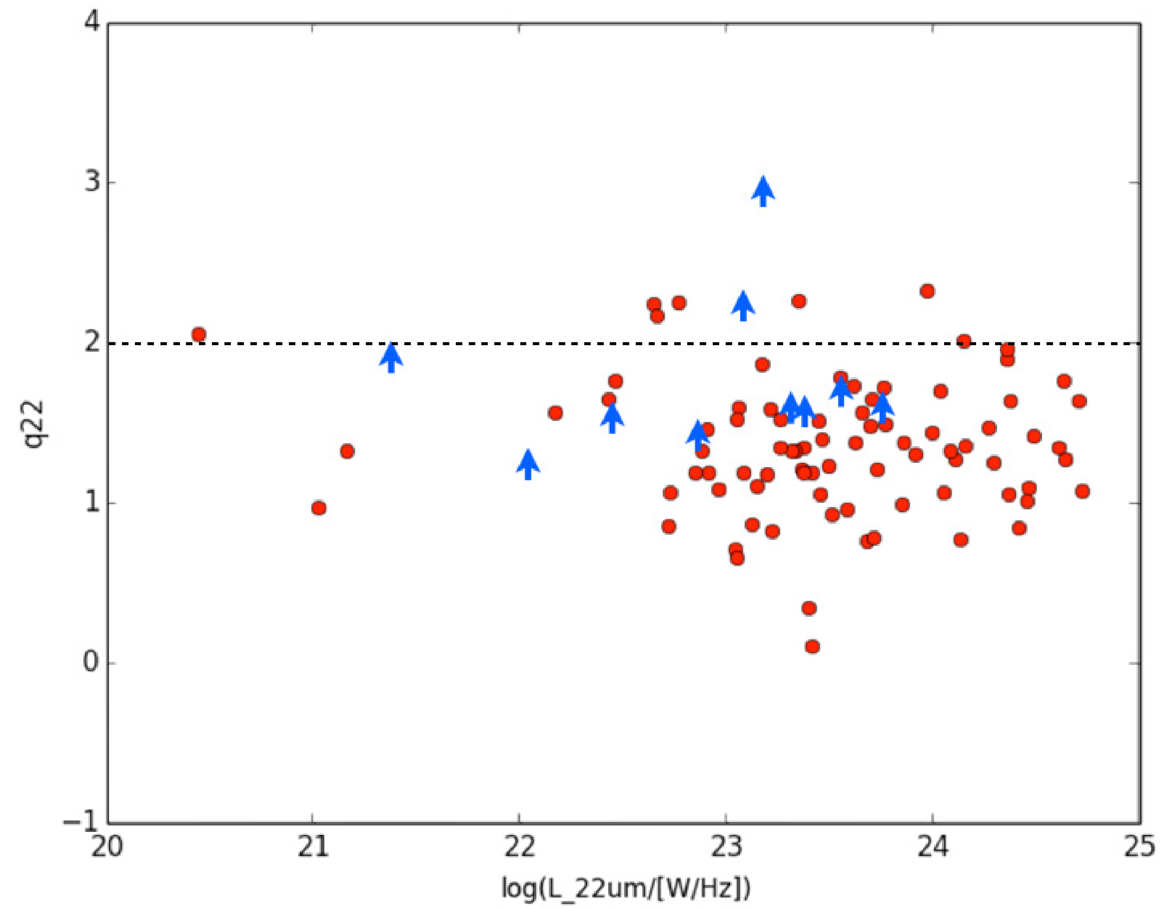

Fig. 2. k-corrected values of q_{22} plotted against the 22 μ mid-IR luminosity ($L_{22\,\mu}$, W/Hz) for the Ĝ sample (red filled circles). Above the dashed line, lie the 9 outliers from the sample with $q_{22} > 2$. Sources not detected in the NVSS radio survey show lower limits for q_{22}, and are presented as arrows.

SOVIET ASTRONOMY—AJ VOL. 8, NO. 2

TRANSMISSION OF INFORMATION BY EXTRATERRESTRIAL CIVILIZATIONS

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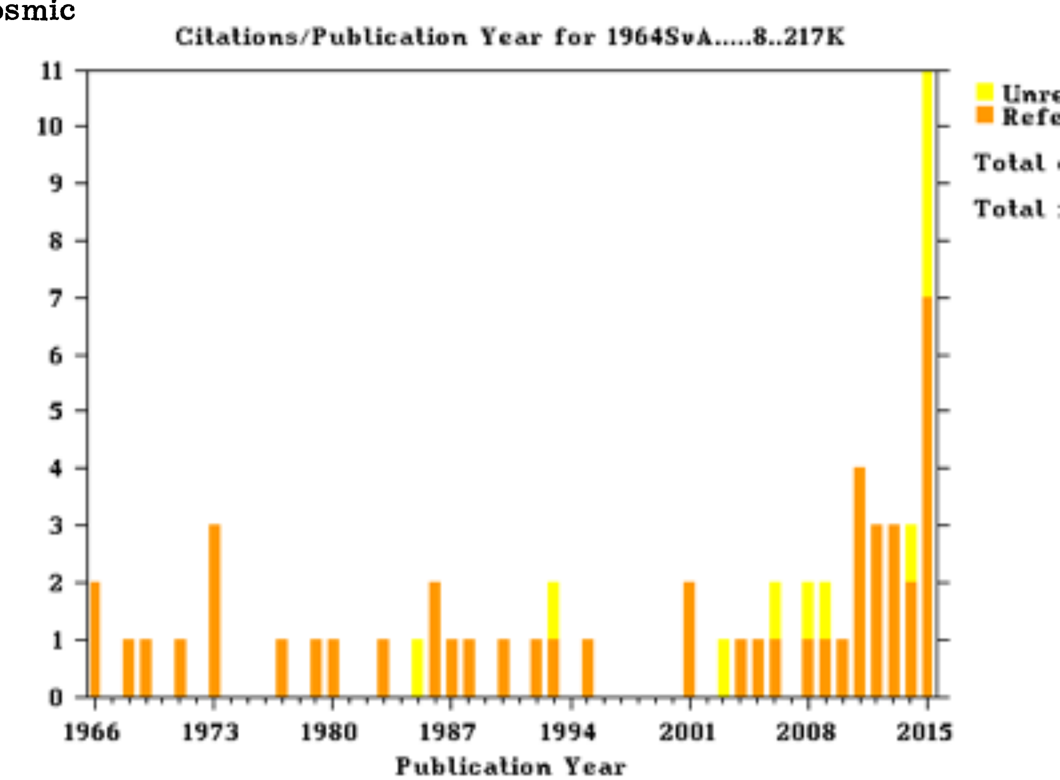
The protracted duration of signal propagation is a determining factor in the one-way transmission of information through space. Reliable reception, or any reception at all, of signals by unknown subscribers necessarily requires an isotropic emission. The optimum signal spectrum for transmitting the maximum amount of information in the presence of quantum noise and the background of cosmic radio-frequency emission has been calculated. It is shown that a civilization located at any distance in the universe and in possession of power on the order of $L_\odot \approx 4 \times 10^{33}$ erg/sec or more, which it is capable of transmitting in a coded isotropic radio-frequency signal, may be detected by conventional radio astronomical techniques. The expected distinguishing properties of artificial sources of cosmic radio-frequency emission are enumerated. It is speculated that even some sources
to us today (notably CTA-21 and CTA-102) may be artificial radio sources.

I – technological level close to the level presently attained on the earth, with energy consumption at $\approx 4 \times 10^{19}$ erg/sec.

II – a civilization capable of harnessing the energy radiated by its own star (for example, the stage of successful construction of a "Dyson sphere" [6]); energy consumption at $\approx 4 \times 10^{33}$ erg/sec.

III – a civilization in possession of energy on the scale of its own galaxy, with energy consumption at $\approx 4 \times 10^{44}$ erg/sec.




THE TRUTH IS OUT THERE