



VVV-WIT-12 and Its Fashionable Nebula: A 4 yr Long-period Young Stellar Object with a Light Echo?

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Abstract

We report the serendipitous discovery of VVV-WIT-12, an unusual variable source that seems to induce variability in its surrounding nebula. The source belongs to the rare objects that we call WITs (short for What Is This?) discovered within the VISTA Variables in the Vía Láctea (VVV) survey. VVV-WIT-12 was discovered during a pilot search for light echoes from distant supernovae in the Milky Way using the near-IR images of the VVV survey. This source has an extremely red spectral energy distribution, consistent with a very reddened ($A_V \sim 100$ mag) long-period variable star ($P \sim 1525$ days). Furthermore, it is enshrouded in a nebula that changes brightness and color with time, apparently in sync with the central source variations. The near-IR light curve and complementary follow-up spectroscopy observations are consistent with a variable young stellar object illuminating its surrounding nebula. In this case the source periodic variation along the cycles produces an unprecedented light echo in the different regions of the nebula.

Unified Astronomy Thesaurus concepts: [Variable stars \(1761\)](#); [Stellar oscillations \(1617\)](#); [Galaxy stellar content \(621\)](#); [Sky surveys \(1464\)](#)

1. Introduction

A few previously unclassified variable sources that we call “WIT” objects—short for What Is This?—have been discovered by the VISTA Variables in the Vía Láctea (VVV) survey (Minniti et al. 2010). These represent a wide variety of extreme or rare astrophysical phenomena, including a very reddened novae or supernova or a protostellar collision (VVV-WIT-01; Lucas et al. 2020), an extragalactic radio source violently variable in the near-IR (VVV-WIT-04; Saito et al. 2019b), another Tabby star or Mamajek object (VVV-WIT-07; Saito et al. 2019a) and a giant star that blinked (VVV-WIT-08 Smith et al. 2021).

In year 2012 we started a pilot search for light echoes in the near-IR images of VVV survey. Light echoes occur when the interstellar dust acts as a mirror reflecting the light of a very bright transient event like a supernova (SN; Patat 2005; Patat et al. 2006; Rest et al. 2008, 2011). We made RGB color images using observations in the K_s band acquired in three different epochs from 2010 to 2012. Very few candidates were detected, probably because the time span was short. However, one of these candidates showed a nebula with changing colors, around a strongly variable point source that we named VVV-WIT-12 (see Figure 1).

It is not clear if VVV-WIT-12 produces a light echo or the mere illumination of the gaseous nebula by a strong variable source. Since this object defies classification, we labeled it as one of our WIT objects. This discovery is relevant because the Vera Rubin Observatory (former LSST) will start operations soon, enabling a massive search for light echoes from ancient SNe in the Milky Way (Li et al. 2022). Such searches have the potential to discover and monitor the evolution of other unusual objects like VVV-WIT-12.

2. Observations and Archive Data

VVV-WIT-12 is located in the Galactic plane within VVV tile b341, in the direction of the bulge. Its equatorial coordinates are R.A./decl. (J2000) = 17:17:20.29, $-36:08:43.9$; corresponding to Galactic coordinates $l, b = 350.7080, +1.0259$ deg. The target is embedded in a compact nebula that lies within the large RCW126 (GUM20) H II region complex (Dubout-Crillon 1976).

The parallax and VVV K_s -band light curve of VVV-WIT-12 was obtained from VIRAC2 (Smith et al. 2018; L. C. Smith et al. 2023, in preparation). There is a total of 203 well-sampled epochs, spanning by 3418 days (~ 9.4 years), from 2010 April 18 to 2019 August 27. The parallax is $\omega = 2.5 \pm 1.5$ mas, $PM_{RA} = -0.03 \pm 0.33$ mas yr⁻¹, and $PM_{DEC} = -0.30 \pm 0.33$ mas yr⁻¹. Both the parallax and proper motions are consistent with zero, indicating a distant object. Based on VIRAC2 data, Molnar et al. (2022) classified this object as a long-period variable (LPV), reporting a period of $P = 292$ days. Indeed, our VIRAC2 light curve looks nearly sinusoidal, but

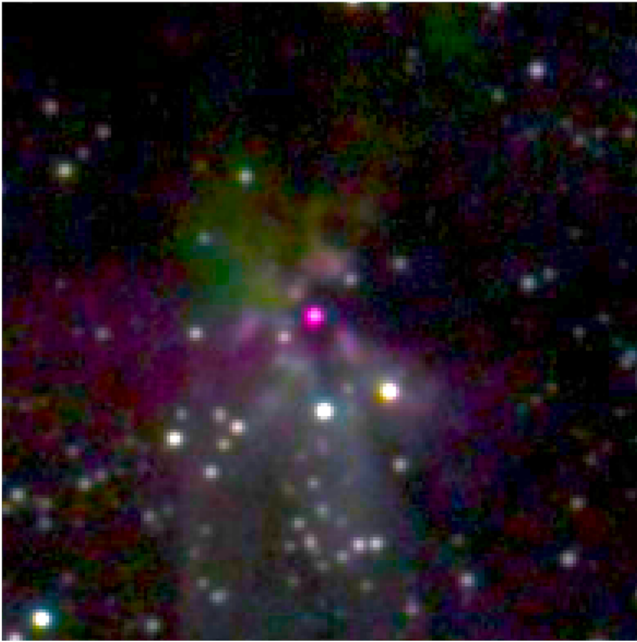


Figure 1. Composite VVV-WIT-12 K_s -band image made using three different epochs: years 2010 (red), 2011 (green), and 2012 (blue). This is the discovery image for VVV-WIT-12, that shows the variation of the central source as well as the nebula. The image is $67''$ on a side, centered in VVV-WIT-12 at R.A./decl. (J2000) = 17:17:20.29, $-36:08:43.9$ ($l, b = 350.7080, +1.0259$ deg), and oriented along Galactic coordinates. Sources that are nonvariable in the near-IR should look white, while variable sources are colored differently. The point source was brighter in 2010 and the nebula changed brightness in different parts along the epochs.

with a much longer period of $P = 1525 \pm 30$ days, resembling an LPV (see Figure 2).

Despite having acquired many observations with the other VVV filters (*ZYJH*), the central point source is not detected in any of these shorter wavelengths in order to establish if color variations are in sync with the light curve. However, this nondetection allows us to estimate the color limits using the limiting magnitudes for the VVV tile b341 (Saito et al. 2012). In particular, the extreme $(H - K_s) > 5.0$ mag suggests very high optical extinction, $A_V \sim 100$ mag. The mean extinction toward this field, considering a $5'$ field of view, is $A_V = 23.28$

mag ($A_{K_s} = 2.69$ mag) using the Schlafly & Finkbeiner (2011) extinction maps. However, the source is indeed located in a dense and dark part of the nebula, and a total extinction $A_V \sim 100$ mag is not unrealistic. Such high extinction is also confirmed by the spectral energy distribution (SED) of the point source, shown in Figure 3, which is rather extreme (see Appendix C for details about the SED data). We tried to fit the SED using a variety of stellar spectra libraries available at VOSA (Bayo et al. 2008), and Robitaille et al. (2007) and Baraffe et al. (2015) stellar models; however, the results are inconclusive since none of the models resulted in a reasonably good fit to the data. For instance, adopting the aforementioned extinction and distance, the SED models suggest this source is likely to be a massive young stellar object (YSO). Limiting ourselves to the range 2 to $22 \mu\text{m}$ (K_s from VVV plus W1 to W4 from WISE) the SED can be fitted to the Robitaille et al. (2007) model grid with a deeply embedded, class 0 or class I YSO model, but model parameters should be treated with caution due to the presence of a massive cloud core that dominates the far-IR SED and the unusual nature of the system. The difficulty in matching the SED with YSO models arises because in the archival data the photometry was taken at different epochs, thus at different phases, and with different apertures (see Appendix C).

The VVV images of this region show that the vicinity resembles an active star formation region (SFR), being rich with interstellar clouds, compact cores, YSOs, and young star clusters, as example of DB121 and DB123 which have distances measured by Soares et al. (2008) as $D = 1.6$ kpc. Assuming the same distance for VVV-WIT-12 and its nebula yields a size of about 0.2 pc for the whole illuminated nebular region ($30''$). While this is a safe assumption, the confirmation of the distance needs further observations.

Archive search at the VVV-WIT-12 position revealed additional measurements at longer wavelengths. In particular, (NEO)WISE data (Wright et al. 2010; Mainzer et al. 2011) covers a longer baseline than VVV, from 2010 March 12 to 2022 August 21, but with a sparser cadence. The W1-band light curve presents a periodicity of ~ 4 yr with an amplitude $A_{W1} = 1.1$ mag, in agreement with the VVV observations (see Figure 2). Such a long period is toward the upper end of what is seen in LPVs, and we note that YSOs can also be periodic too.

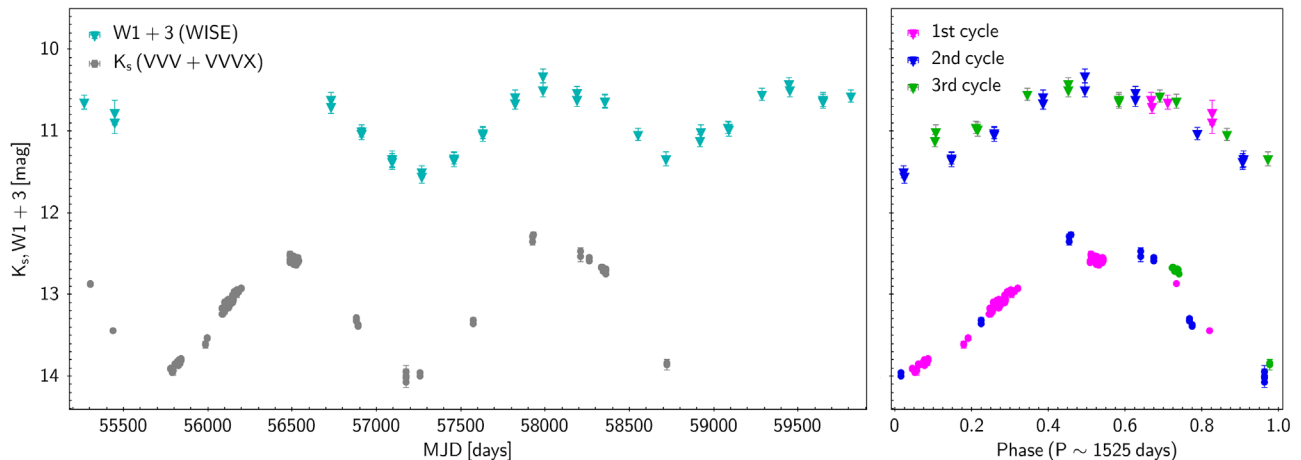


Figure 2. Left panel: light curve of VVV-WIT-12 covering years 2010–2022. Gray points represent the K_s -band observations from VVV/VVVX, and cyan points represent the W1-band observations from WISE (arbitrarily shifted by 3 mag). Right panel: VVV-WIT-12 light curves phased using $P = 1525$ days. The different cycles are color coded as labeled to show the amplitude changes. While the minimum light seems to be the same in the two cycles observed with the K_s -band, the maximum is about 0.3 mag brighter in the second cycle, indicating a possible eruption.

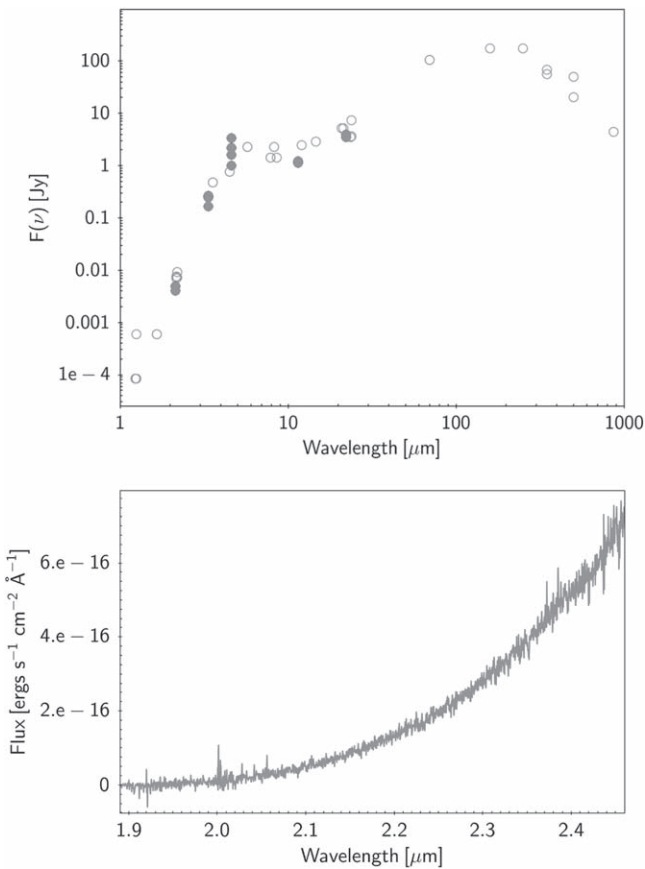


Figure 3. Top: spectral energy distribution (SED) of VVV-WIT-12 covering 1–1000 μm , obtained with the Vizier photometry viewer (<http://vizier.cds.unistra.fr/vizier/sed/>). Solid circles mark the data points from VVV and WISE within the range 2 to 22 μm (see Section 2). Bottom: near-IR spectrum of the VVV-WIT-12 stellar source, acquired with the TripleSpec spectrograph at the SOAR telescope in Chile, on 2023 June 11 (JD 2460106, corresponding to $\phi = 0.17$ cycles, see the right panel of Figure 2). This shows that the source is very red, with a featureless steadily rising continuum, lacking strong near-IR emission lines. Data appearing in the SED are described in Appendix C.

The amplitude is variable in the K_s -band based on three cycles. The first and second cycles show observed peak-to-peak amplitudes of $A_{K_s} \sim 1.4$ and 1.7 mag, respectively.

The surrounding nebula changes its brightness and $J - K_s$ color during the period of observations (Figure 4; see details in Appendix A). In year 2015 the northern part appears redder than in 2010, while the opposite occurred with the southern part, which became bluer. Scattered light from two regions located on bright nebular patches at opposite sides of VVV-WIT-12 shows the same periodic behavior as the central source, confirming that the scattered light is indeed an echo of the source (see Figure 5). The red curve shows a substantial lag (about half a period), which may indicate that it is caused by back scattering off dust more distant than the source. In this case, if we take the 2.1 yr lag as the light-travel time from the source to the back side of the nebular cavity, it would yield a distance of about 0.32 pc. On the other hand, the blue curve is in phase with central source, which is interesting since the forward scattered light also has to travel an extra distance compared to the direct light. However, this consideration only holds for single scattering. Because of the dense environment and the large extinction toward the source, this will likely not

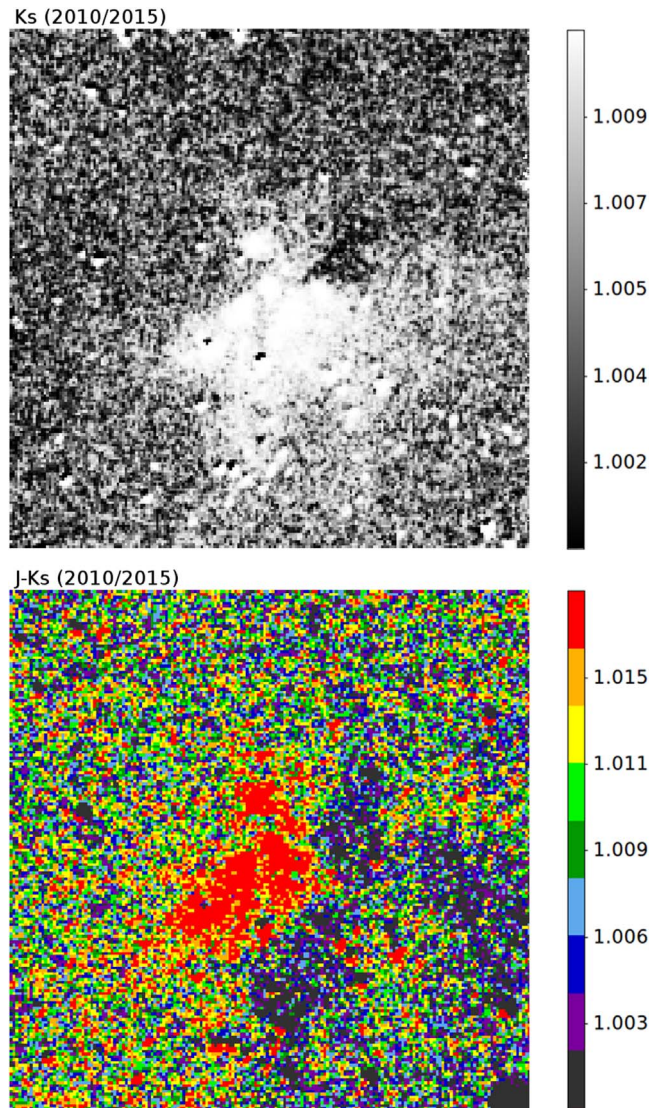


Figure 4. Top: composite K_s -band image made using a year 2010 image (with VVV-WIT-12 near phase $\phi \sim 0.75$ cycles) divided by a year 2015 ($\phi \sim 0.05$ cycles). The nebula varies in the K_s band, appearing brighter in the first epoch. Bottom: composite J/K_s image showing the spatial variation of the near-IR nebular color. Also, the color variations cover different places than the brightness variations. In both panels the field of view is $67''$ on a side, oriented along Galactic coordinates, with longitude increasing to the left and latitude toward the top, and covers the same field as Figure 1. The color scale has been stretched to emphasize the changes. A horizontal bar shows the relative intensity in each case.

be the case here. Perhaps the blue region has a lower optical depth so that the light can more easily leak toward us.

The scale of the variations across the nebula is relevant, and we take $30''$ as a representative scale, fully contained within Figure 1, that covers $1.1'$ on a side. We use $30''$ because this is the total size of the region that varies in brightness and color. Assuming a distance $D = 1.6$ kpc, $30''$ corresponds to 0.24 pc. In this case, the fluctuating region would be 40 times smaller than the size of the Orion nebula for example. The light-travel time throughout a region of this size would be about 0.8 yr. If the source is more distant, e.g., located within the bulge at $D = 8$ kpc, then this region would be larger, $30'' = 1.2$ pc. This is a large scale for brightness variations, considering that it cannot be attributed to gas motions because that would require superluminal velocity. Instead, the preferred explanation is that

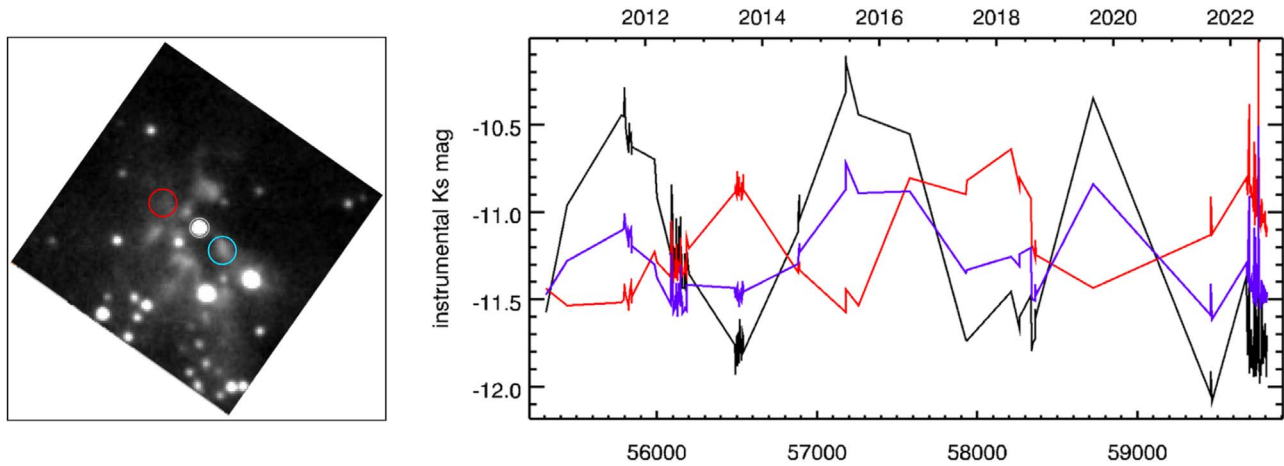


Figure 5. Variability of the scattered light from two regions of the VVV/VVVX K_s images. Left: the emission was integrated inside the circular blue and red masks. A smaller mask was also placed on the object. The image orientation is the same as in Figures 1 and 4. Right: the resulting light curves for the three regions covering the same epochs as Figure 2. All curves show the same periodicity behavior, but the red curve presents a substantial lag with respect to the point source, while the blue curve is in phase with VVV-WIT-12. Time in the x -axis is shown in years (top) and MJD (bottom).

the nebula changes as it is being illuminated by the variable central source. We estimated the range of luminosity variation for the point source using the lowest and highest values of fluxes in the near-IR/mid-IR bands, assuming the distance of 1.6 kpc and no extinction correction. This yields $\Delta L = 657 \pm 71 L_{\odot}$ and $800 \pm 56 L_{\odot}$, where the errors were derived by using the photometric errors as lower/upper bounds.

Spectroscopic follow-up of the central source (VVV-WIT-12) was secured on 2023 June 11 (JD 2460106, corresponding to $\phi = 0.17$ cycles according to the ephemeris used to phase fold our light curves) with the TripleSpec spectrograph¹² at the SOAR Telescope (Wilson et al. 2004; Herter et al. 2008). The spectrum (Figure 3) shows that the source is very red, with a featureless steadily rising continuum, lacking strong near-IR emission lines. The feature seen at $\sim 2.0 \mu\text{m}$ is the residual of the removal of a very strong telluric line. Such featureless but very red spectra are typical of some YSOs (Contreras Peña et al. 2020; Guo et al. 2022). However, a very dusty Mira cannot be discarded, as they may also exhibit a similar spectral behavior.

3. Discussion

As with most VVV-WIT objects discovered, we still do not know what is this. Not only is the source variable, but also the surrounding nebulosity changes brightness and shape. Given the long period and the classification as an LPV, initially we considered two possibilities: (i) an LPV that illuminates the encircling interstellar medium (ISM) inhomogeneously through thick dust clouds in its atmosphere, or (ii) an LPV that is coming out from behind an unrelated interstellar cloud.

The LPV hypothesis is discarded by examining the magnitudes. The expected magnitude for an LPV with $P = 1525$ days is $M_{K_s} \sim -11$ mag (e.g., Macri 2017). If the object is located at $D = 1.6$ kpc, its distance modulus would be

$m - M_0 = 11.02$ mag. Therefore its apparent unreddened magnitude should be about 0 mag, which is inconsistent with the observed magnitude of $K_s = 13.2$ mag. A possible exception might have a rare case of J -type carbon star, which is fainter than other AGB stars, reaching $M_K \sim -2.5$ mag (Abia et al. 2020). However, these objects are rather blue, inconsistent with the observed colors and the SED that is rising to the near-IR.

We also note that the observed geometry for the nebular changes is inconsistent with the spherically symmetric picture that a light echo would produce, as seen for example in historical SNe remnants and η Carina (Rest et al. 2005). This suggests that the dust configuration surrounding VVV-WIT-12 causes a light echo that is by far more complex than those of SNe. In principle, the dust distribution could be characterized based on the phase lag of the scattered light, but this detailed 3D modeling is beyond the scope of this paper.

Considering now that VVV-WIT-12 is a YSO because of its luminosity and spectrum as well as the long-term oscillatory pattern, as seen in other YSOs in the mid-IR (e.g., Park et al. 2021, and references therein), attributed to either variable extinction or a cyclical change in accretion rate, there are a few other alternatives to explain the observations: (i) the light echo from a periodic YSO, or (ii) the progressive illumination of the ISM by the precessing disk of a YSO, or (iii) an orbiting clump of material that blocks the light path of the variable source. Even though at present the YSO option remains as the most reasonable hypothesis, we are unable to confirm this without further observations.

4. Conclusions

We have discovered VVV-WIT-12, a very reddened ($A_V > 100$ mag) periodic variable source with $P = 1525$ days, that has a smooth red continuum and that is located inside a nebula that changes in brightness and color with time. The real nature of the source is still unknown, but based on the extensive near-IR imaging and spectroscopic observations, our preferred explanation is a periodically variable YSO with a light echo.

In particular, massive light echo searches are being planned for the Vera C. Rubin Observatory (Li et al. 2022), taking

¹² TripleSpec instrument covers the wavelength range ~ 0.80 – $2.47 \mu\text{m}$ with a resolving power of $R \sim 3500$. The spectra were reduced using a modified version of the IDL-based SpexTool and the SOAR-TS4 pipeline was used to remove the telluric lines by conducting an A-B position pattern (Cushing et al. 2004). The star HIP 86098 was used as the telluric standard for the flux calibration.

Table 1
VVV-WIT-12 K_s -band Variability Data

MJD (days)	K_s -band (mag)
55305.31399078	12.882 ± 0.014
55305.31435675	12.872 ± 0.012
55437.11724679	13.440 ± 0.015
55437.11768706	13.448 ± 0.010
55779.09640132	13.906 ± 0.014
55779.09682943	13.911 ± 0.019
55791.14535418	13.954 ± 0.013
55791.14572990	13.956 ± 0.017
55796.03104124	13.936 ± 0.053
55796.03145355	13.923 ± 0.046
55804.09243890	13.855 ± 0.013
55804.09283343	13.871 ± 0.016
55822.03137893	13.835 ± 0.014
55822.03181434	13.839 ± 0.015
55822.04318502	13.851 ± 0.015
55822.04358429	13.849 ± 0.018
55823.01212277	13.840 ± 0.021
55823.01254251	13.814 ± 0.017
55826.99329101	13.869 ± 0.021
55826.99370021	13.869 ± 0.026
55829.07088450	13.821 ± 0.028
55829.07126727	13.802 ± 0.015
55838.01804222	13.821 ± 0.018
55838.01843721	13.837 ± 0.028
55842.00936837	13.786 ± 0.016
55842.00976777	13.809 ± 0.015
55842.02231214	13.797 ± 0.012
55842.02272759	13.788 ± 0.015
55843.00842881	13.807 ± 0.022
55843.00881339	13.812 ± 0.017
55984.32586264	13.614 ± 0.041
55984.32623896	13.605 ± 0.031
55999.28517953	13.537 ± 0.019
55999.28555562	13.526 ± 0.019
56084.20270002	13.240 ± 0.010
56084.20316717	13.238 ± 0.013
56086.22350249	13.168 ± 0.011
56086.22399201	13.179 ± 0.009
56091.17856161	13.230 ± 0.021
56091.17908462	13.238 ± 0.023
56099.27448288	13.189 ± 0.027
56099.27495279	13.207 ± 0.027
56101.13757731	13.148 ± 0.013
56101.13805174	13.157 ± 0.022
56102.21649852	13.089 ± 0.014
56102.21698412	13.100 ± 0.018
56112.07114756	13.159 ± 0.017
56112.07158345	13.157 ± 0.017
56113.98610091	13.136 ± 0.027
56113.98648592	13.133 ± 0.015
56114.98102135	13.072 ± 0.014
56114.98143780	13.074 ± 0.015
56115.98474485	13.110 ± 0.023
56115.98515314	13.105 ± 0.024
56120.04092490	13.069 ± 0.018
56120.04145048	13.067 ± 0.012
56121.12187599	13.159 ± 0.029
56121.12243938	13.167 ± 0.029
56121.97479523	13.061 ± 0.019
56121.97517811	13.074 ± 0.020
56123.01474560	13.164 ± 0.026
56123.01514024	13.145 ± 0.022
56124.06170449	13.121 ± 0.014

Table 1
(Continued)

MJD (days)	K_s -band (mag)
56124.06210611	13.154 ± 0.013
56125.04530593	13.123 ± 0.023
56125.04569999	13.110 ± 0.019
56126.15988966	13.144 ± 0.018
56126.16028760	13.145 ± 0.013
56129.13860467	13.103 ± 0.014
56129.13901743	13.100 ± 0.013
56132.03022292	13.097 ± 0.015
56132.03062791	13.107 ± 0.014
56133.02148136	13.086 ± 0.011
56133.02186186	13.087 ± 0.015
56134.01105021	13.099 ± 0.043
56134.01146314	13.065 ± 0.038
56144.99923930	13.076 ± 0.012
56144.99963643	13.069 ± 0.013
56145.06523432	13.081 ± 0.016
56145.06561676	13.078 ± 0.013
56145.14724240	13.063 ± 0.014
56145.14764321	13.068 ± 0.014
56146.15497943	13.098 ± 0.024
56146.15537408	13.092 ± 0.019
56147.08220646	13.013 ± 0.017
56147.08260093	13.004 ± 0.016
56151.16657051	13.063 ± 0.038
56151.16695293	13.066 ± 0.026
56158.03083614	12.962 ± 0.012
56158.03126193	12.981 ± 0.018
56158.06806029	12.987 ± 0.012
56158.06845358	12.976 ± 0.018
56171.97870177	12.989 ± 0.015
56171.97914848	12.998 ± 0.016
56172.05053745	12.943 ± 0.012
56172.05096107	12.953 ± 0.012
56173.00648989	12.995 ± 0.037
56173.00688473	12.984 ± 0.029
56173.10230482	12.966 ± 0.018
56173.10269927	12.957 ± 0.016
56184.02361554	12.959 ± 0.019
56184.02402129	12.948 ± 0.014
56185.08016956	12.966 ± 0.026
56185.08055668	12.963 ± 0.033
56197.99238377	12.934 ± 0.017
56197.99277893	12.925 ± 0.011
56486.05191910	12.613 ± 0.010
56486.05232836	12.588 ± 0.019
56488.21161727	12.582 ± 0.022
56488.21203659	12.567 ± 0.021
56489.09005584	12.526 ± 0.026
56489.09049970	12.501 ± 0.026
56497.12600446	12.566 ± 0.018
56497.12642201	12.547 ± 0.017
56501.04456267	12.529 ± 0.015
56501.04497836	12.564 ± 0.017
56502.07928420	12.528 ± 0.008
56502.07970634	12.522 ± 0.017
56511.00270899	12.563 ± 0.014
56511.00311435	12.638 ± 0.013
56512.05194052	12.545 ± 0.022
56512.05239296	12.549 ± 0.012
56512.15321218	12.533 ± 0.011
56512.15364685	12.537 ± 0.010
56513.00073429	12.585 ± 0.013
56513.00114849	12.578 ± 0.022

Table 1
(Continued)

MJD (days)	K_s -band (mag)
56513.09750733	12.582 ± 0.011
56513.09793096	12.597 ± 0.012
56514.02949870	12.559 ± 0.025
56514.02992590	12.584 ± 0.039
56522.08995637	12.643 ± 0.015
56522.09035346	12.638 ± 0.014
56522.98801717	12.580 ± 0.016
56522.98842534	12.594 ± 0.013
56523.08986704	12.610 ± 0.014
56523.09029174	12.598 ± 0.016
56524.10995656	12.594 ± 0.017
56524.11036344	12.595 ± 0.015
56525.00600829	12.591 ± 0.009
56525.00643632	12.592 ± 0.015
56525.10749755	12.597 ± 0.012
56525.10789068	12.572 ± 0.016
56526.01769841	12.608 ± 0.013
56526.01810583	12.621 ± 0.014
56526.13782058	12.621 ± 0.008
56526.13820470	12.614 ± 0.010
56527.03777189	12.621 ± 0.021
56527.03819244	12.620 ± 0.016
56535.99104194	12.546 ± 0.021
56535.99147113	12.567 ± 0.015
56536.06409385	12.609 ± 0.023
56536.06451513	12.608 ± 0.015
56536.12114000	12.592 ± 0.014
56536.12153927	12.571 ± 0.018
56536.98901042	12.574 ± 0.019
56536.98944144	12.573 ± 0.025
56537.03435051	12.561 ± 0.010
56537.03477811	12.566 ± 0.014
56537.08520569	12.567 ± 0.016
56537.08559973	12.572 ± 0.014
56538.05154343	12.588 ± 0.010
56538.05195734	12.592 ± 0.013
56881.05502514	13.285 ± 0.014
56881.05544981	13.291 ± 0.018
56881.15602101	13.315 ± 0.017
56881.15640352	13.327 ± 0.010
56890.10222876	13.373 ± 0.020
56890.10264517	13.380 ± 0.016
56890.16151307	13.389 ± 0.014
56890.16192479	13.382 ± 0.018
57178.28608468	13.995 ± 0.037
57178.28647014	13.951 ± 0.035
57178.33491099	14.012 ± 0.050
57178.33531670	14.070 ± 0.059
57178.37275000	14.019 ± 0.058
57178.37315627	13.947 ± 0.069
57259.00702552	13.954 ± 0.011
57259.00838138	13.994 ± 0.014
57576.21099736	13.311 ± 0.033
57576.21138467	13.357 ± 0.022
57926.32108585	12.290 ± 0.034
57926.32144990	12.357 ± 0.046
57933.31940204	12.267 ± 0.035
57933.31975150	12.270 ± 0.033
58210.33530629	12.535 ± 0.061
58210.33569310	12.473 ± 0.045
58263.23436190	12.585 ± 0.011
58263.23471955	12.588 ± 0.018
58264.18160133	12.550 ± 0.017

Table 1
(Continued)

MJD (days)	K_s -band (mag)
58264.18197642	12.553 ± 0.022
58335.02426649	12.664 ± 0.015
58335.02466130	12.673 ± 0.013
58339.08740732	12.678 ± 0.015
58339.08777100	12.667 ± 0.017
58346.06097997	12.717 ± 0.022
58346.06134360	12.713 ± 0.016
58359.00003648	12.701 ± 0.019
58359.00039320	12.682 ± 0.015
58360.02341993	12.700 ± 0.020
58360.02382860	12.709 ± 0.026
58362.99737906	12.752 ± 0.017
58723.07908335	13.842 ± 0.045
58723.07946611	13.857 ± 0.060

advantage of a median of 815 images scheduled for every position of the sky, reaching $g \sim 24.5$ mag, $r \sim 24.0$ mag. These searches will use artificial intelligence tools like automated deep convolutional neural networks to make many important light echo discoveries from past SNe, especially across the Milky Way plane (Rest et al. 2005). Our work suggests that these massive light echo explorations may be contaminated by variable objects like the one presented here. However, these light echo searches will allow us to discover and classify VVV-WIT-12 analogs, and to study their time evolution. Also, not less important, these searches would open the door for other serendipitous discoveries.

In conclusion, VVV-WIT-12 appears to be a very rare long-period YSO that acts as a cosmic beacon flashing its surrounding nebula. This is worthy of further study, and suggested future observations are near-IR spectroscopy of the nebula to confirm its nature, and more continuous monitoring of the variability of this interesting object.

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Table 2
Data from VizieR Photometry Viewer Presented in the SED of Figure 3

Filter (name)	Telescope	Frequency (GHz)	Flux (Jy)	Flux Error (Jy)	Separation (arcsec)	Catalogue (VizieR code)
<i>J</i>	2MASS	241960	8.33E-5	...	0.80	I/297/out
<i>J</i>	2MASS	239830	8.50E-5	...	0.03	II/246/out
<i>J</i>	2MASS	239830	5.88E-4	...	0.03	II/246/out
<i>H</i>	2MASS	181750	5.94E-4	...	0.03	I/297/out
<i>K_s</i>	VISTA	140500	0.00485	2.0E-5	0.24	II/376/vvv4
<i>K_s</i>	VISTA	140500	0.00491	2.0E-5	0.27	II/348/vvv2
<i>K_s</i>	VISTA	140500	0.00491	2.0E-5	0.18	II/337/vvv1
<i>K_s</i>	VISTA	140500	0.00398	0.00107	0.27	II/364/virac
<i>K_s</i>	2MASS	138550	0.00748	5.1E-4	0.55	J/AJ/149/64/archive
<i>K_s</i>	2MASS	138550	0.00687	4.7E-4	0.55	J/AJ/149/64/archive
<i>K_s</i>	2MASS	136890	0.00904	1.9E-4	0.03	II/246/out
<i>K_s</i>	2MASS	136890	0.00724	4.9E-4	0.03	II/246/out
W1	WISE	89490	0.166	0.002	1.14	II/365/catwise
W1	WISE	89490	0.241	0.0	1.02	II/363/unwise
W1	WISE	89490	0.255	0.005	0.80	II/328/allwise
W1	WISE	89490	0.261	0.006	0.54	II/311/wise
3.6	Spitzer/IRAC	84449	0.472	0.025	0.19	II/293/glimpse
4.5	Spitzer/IRAC	66724	0.763	0.095	0.19	II/293/glimpse
W2	WISE	65172	1.0	0.02	1.14	II/365/catwise
W2	WISE	65172	1.58	0.0	1.02	II/363/unwise
W2	WISE	65172	3.32	0.23	0.80	II/328/allwise
W2	WISE	65172	2.21	0.07	0.54	II/311/wise
5.8	Spitzer/IRAC	52311	2.32	0.06	0.19	II/293/glimpse
8.0	Spitzer/IRAC	38083	1.45	0.08	0.19	II/293/glimpse
A	MSX	36207	2.27	0.09	0.48	V/114/msx6_gp
S9W	AKARI	34819	1.4	0.06	1.65	II/297/irc
W3	WISE	25934	1.23	0.02	0.80	II/328/allwise
W3	WISE	25934	1.11	0.02	0.54	II/311/wise
C	MSX	24715	2.5	0.14	0.48	V/114/msx6_gp
D	MSX	20464	2.91	0.18	0.48	V/114/msx6_gp
21 μm	Hi-GAL	14276	5.28	0.33	3.38	J/MNRAS/471/100/hcatalog
E	MSX	14048	5.28	0.33	0.48	V/114/msx6_gp
W4	WISE	13571	3.90	0.09	0.80	II/328/allwise
W4	WISE	13571	3.52	0.09	0.54	II/311/wise
24	Spitzer/MIPS	12663	3.53	0.0	0.77	II/368/sstsl2
24 μm	Hi-GAL	12491	7.43	0.1	3.38	J/MNRAS/471/100/hcatalog
24 μm	Hi-GAL	12491	3.71	0.07	3.38	J/MNRAS/471/100/hcatalog
70 μm	Hi-GAL	4282.8	105.0	5.0	3.38	J/MNRAS/471/100/hcatalog
70 μm	Hi-GAL	4282.8	105.0	5.0	3.38	J/MNRAS/471/100/hcatalog
160 μm	Hi-GAL	1873.7	173.0	3.0	3.38	J/MNRAS/471/100/hcatalog
250 μm	Hi-GAL	1199.2	175.0	6.0	3.38	J/MNRAS/471/100/hcatalog
350 μm	Hi-GAL	856.55	68.1	2.7	3.38	J/MNRAS/471/100/hcatalog
350 μm	Hi-GAL	856.55	56.7	2.2	3.38	J/MNRAS/471/100/hcatalog
500 μm	Hi-GAL	599.59	49.5	2.7	3.38	J/MNRAS/471/100/hcatalog
500 μm	Hi-GAL	599.59	20.1	1.1	3.38	J/MNRAS/471/100/hcatalog
870 μm	Hi-GAL	344.59	4.35	...	3.38	J/MNRAS/471/100/hcatalog

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Appendix A Analysis of the Nebula

To inspect the variability of the scattered light across the surrounding nebula, we analyze the VVV/VVVX images taken at different epochs. In a first step, we selected K_s -band images taken near to maximum/minimum of the VVV-WIT-12 light curve, according to the $P = 1525$ ephemeris: a K_s -band image taken on 2010 April 18, at phase $\phi \sim 0.75$; and a K_s -band image from 2015 August 15, at phase $\phi \sim 0.05$. Then we

divided the 2010 image by the 2015, creating a composite K_s -band image with the differences. As presented in Figure 4, the nebula changes in brightness, appearing brighter in the first epoch, when the VVV-WIT-12 is closer to the maximum ($\phi \sim 0.75$). We then repeated the same steps as above using J - and K_s -band images taken in sequence at those nights (in 2010 and 2015). A composite J/K_s image was created by dividing the J band by the K_s band, and finally dividing the 2010 J/K_s image by the 2015 J/K_s . This shows the spatial variation of the near-IR nebular color, which cover different places than the brightness variations. After all the divisions, the net differences both in brightness and color are $\sim 1\%$ – 2% , but consistent

across all the nebula. In Figure 4 the color scale has been stretched to emphasize the changes.

Since our first analysis using two epoch showed variations in brightness and color across the nebula, we made use of a set of K_s -band images taken along the VVV/VVVX campaign, ranging from 2010 April to 2019 August. We selected two regions located on bright nebular patches at opposite sides of the point source to place two circular masks of 6 pixel radius in order to integrate the emission, after subtracting the background. A third and smaller mask of 4 pixel radius was also placed on the position of the point source (VVV-WIT-12), for simultaneous monitoring (see the left panel of Figure 5). The extracted magnitudes (instrumental, i.e., not photometrically calibrated) were combined with the MJD to create a resulting light curve for both masks placed on the nebula simultaneously with the central point source. In extracting the magnitudes, the uncertainty is in the range of $\sigma_{K_s} \approx 0.2$ mag. The light curves for the two regions (blue and red) were arbitrarily shifted to approximately match the mean level of the point source (black light curve), as presented in the right panel Figure 5. All curves show the same periodicity behavior, but the red curve presents a substantial lag with respect to the point source, while the blue curve is in phase with VVV-WIT-12.

Appendix B VIRAC2 K_s -band Light Curve











Here we present all the VIRAC2 photometric measurements of the central source VVV-WIT-12 used to build the light curve presented in Figure 2. These data listed in Table 1 comprise 203 K_s -band data points. The source is relatively bright, and the typical photometric errors are very small (~ 0.02 mag).

Appendix C Archival Data from VizieR SED

Table 2 presents archival data from VizieR Photometry Viewer (VizieR SED),¹³ presented in Figure 3. Wavelength coverage ranges from 1 to 1000 μm . In the near-IR we allowed 1'' maximum separation from VVV-WIT-12 coordinates as R. A./decl. (J2000) = 17:17:20.29, -36:08:43.9. In the mid-IR and far-IR we relaxed the allowed separation to 5'' because of the lower resolution of the instruments at these longer wavelengths. The archival data came from several different catalogs under the CDS VizieR database. The full information and metadata for each catalog can be found by accessing the VizieR Photometry Viewer service² with the VVV-WIT-12 coordinates and then selecting the desired catalog. We caution that the archival data have been taken at different epochs—thus at different phases for VVV-WIT-12—as well as depending on

the aperture/spatial resolution the flux measurements can include some contamination from the surrounding nebula to the central source.

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¹³ <http://vizier.cds.unistra.fr/vizier/sed/>