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RESEARCH ARTICLE

An approximation to determine the source of the WOW! Signal

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Abstract

In this paper it is analysed which of the thousands of stars in the WOW! Signal region could have the highest chance of being the real source of the signal, providing that it came from a star system similar to ours. A total of 66 G and K-type stars are sampled, but only one of them is identified as a potential Sun-like star considering the available information in the Gaia Archive. This candidate source, which is named 2MASS 19281982-2640123, therefore becomes an ideal target to conduct observations in the search for techno-signatures. Another two candidate stars have a luminosity error interval that includes the luminosity of the Sun, and 14 candidates more are also identified as potential Sun-like stars, but the estimations on their luminosity were unknown.

Contents

1. Introduction

As of October 2020, the WOW! Signal remains the strongest candidate SETI signal (Charbonneau, 2018). It has been suggested that the signal was produced by hydrogen clouds from Comets 266/P Christensen and P/2008 Y2 (Paris and Davies, 2015). However, this hypothesis has been dismissed by the scientific community, and the source of the signal remains unknown (SETI Institute, 2017).

Despite the WOW! Signal never repeated, the key aspect was its duration. The signal lasted for 72 seconds, but since this was the maximum amount of time that the Big Ear radio telescope was able to observe, it is likely that the signal would have lasted longer.

The main problem, however, is that the signal never repeated. Follow-up observations of the area conducted by many observatories during several years never detected another signal (Gray and Ellingsen, 2002). Nonetheless, the fact that the signal never repeated, does not necessarily rule out that it was produced by extraterrestrial intelligence.

In fact, if we analyse the history of (the few) radio signals that humanity have sent to several targets in the hope of contacting a civilization, none of those transmissions had a long duration or were repeatedly sent for a long time (The Staff at the National Astronomy and Ionosphere Center, 1974). An extraterrestrial civilization could have opted to behave in a similar manner.

Few attempts have been made to determine the exact location of the WOW! Signal due to the difficulty involved. Despite it was detected in just one of the two feed horns of the radio telescope, the data was processed in a way that does not allow us to determine which of the feed horns actually received the signal.

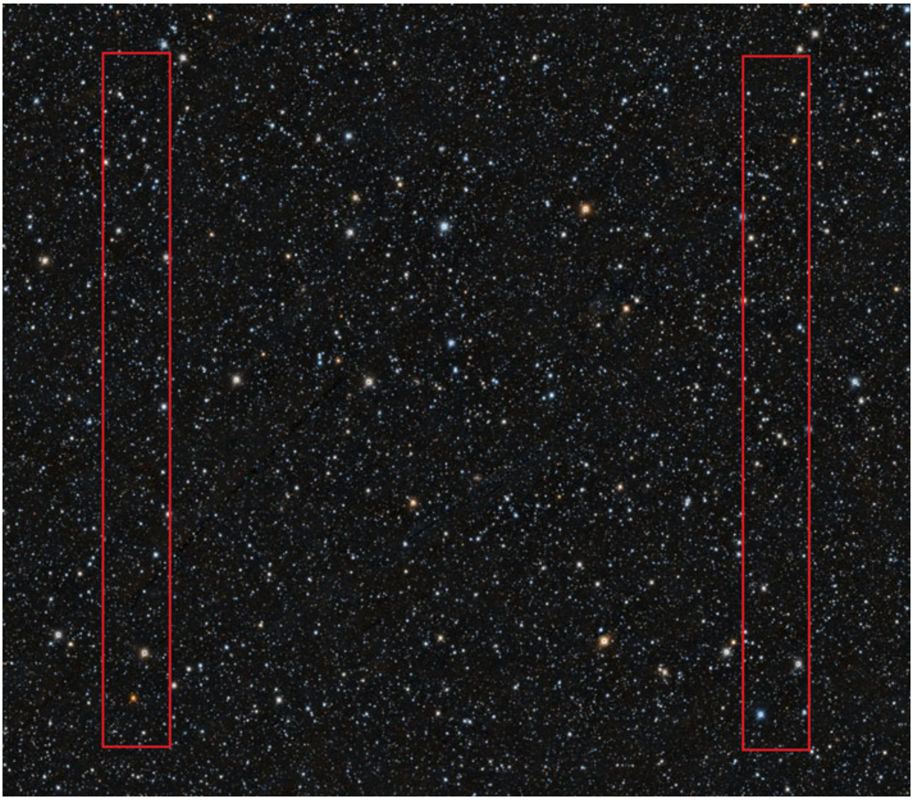

Figure 1. *In red, the two regions where the WOW! Signal could have originated*
Source: Pan-STARRS/DR1

The other reason that makes difficult to determine the exact source is the high uncertainly in declination: 20 arcminutes. The following image shows an approximation of the two sections of the sky that could contain the source of the signal, each of them with thousands of stars.

The coordinates of the signal are RA: 19h25m31s ± 10s (for the positive horn), 19h28m22s ± 10s (for the negative horn), and DEC: $-26°57' \pm 20'$, both in J2000 equinox (Ehman, 1997).

A 2002 study conducted by Robert Gray and Simon Ellingsen concluded that no emissions resembling the WOW! Signal were detected over a bandwidth of 2.5 MHz (Gray and Ellinsen, 2002). Other authors such as Wheeler (2014) also examined whether the transmission was an artificial signal. More recently, Harp *et al.*, (2020) determined that no point-like features were found inside WOW! Signal region, although one point-like feature was detected about 1/3° away.

In this article an attempt is made to create a list of the possible sources of the signal assuming that, if it was produced by an extraterrestrial civilization, their exoplanet could be similar to Earth.

2. Methodology

In order to create a list of possible sources, the Gaia Archive and its Gaia DR2 database are used. For the positive horn, the RA interval was set between 19:25:21 and 19:25:41. For the negative horn, it was set between 19:28:12 and 19:28:32. The DEC interval was set between -27.2833 (-27:16:59.8) and -26.6167 (-26:37:0.12) for both horns.

To filter an optimistic sample of stars that range from intermediate K to G type, several parameters were added. Radius_val (estimated radius of the star) was set between 0.83 and 1.15, teff_val (estimated temperature) was set between 4,450 and 6000 Kelvin, and lum_val (estimated luminosity) was set between 0.34 and 1.5 (Weidner, 2010). A conservative sample of candidate sources only

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include potential Sun-like stars with a teff_val between 5730 and 5830. Despite the effective temperature of G-type stars is considered to be between 5,200 and 6,000 Kelvin (Weidner, 2010), the conservative sample included a much smaller range of values: only those stars with an estimated temperature 50 degrees below that of the Sun and 50 degrees above. The limit of 50 degrees was chosen based on the (Cox, 1999) attribution of a temperature of 5,830 K to G2V stars, the exact type of star that the Sun is. The difference between this temperature and the temperature of the Sun – 5,778 K – is 52 K.

G-type stars were selected due to the fact that the Sun is a G-type star, with a temperature of 5,778 Kelvin, and the only type of life we have found orbits this type of star. K-type stars were also selected because they are considered likely to host super-habitable planets, that is, planets more habitable than Earth, but not necessarily with similar flora and fauna (Heller *et al.*, 2012). However, the sample only included the upper half of K-type stars in terms of radius and temperature, and it excluded F-type stars due to the fact that the smaller the star, the more X-radiation it emits, and the bigger the star, the more UV radiation is emitted; both factors are considered detrimental for life as we know it (Andreoli, 2020). For this same reason, and due to a generally higher rate of star flares that can erode atmospheres (France *et al.*, 2020), red dwarf stars were also excluded.

3. Optimistic sample of candidate sources

For the positive horn, the following list extracted from the Gaia Archive shows a total of 38 candidates that were found.

source_id	ra deg	dec deg	parallax mas	phot_g_mean_mag mag	teff_val K	radius_val solRad	lum_val solLum
6765764507112448256	291.4078244106725	-27.25103348064761	0.6617190537184244	15.817942	5338.75	1.0674632	0.8339861
6765765258727494400	291.3880678944634	-27.232111134776794	0.745458633122556	16.440039	4985.6665	0.8412172	0.3939163
6765764507112457472	291.4050378881666	-27.242314482415665	0.8690020759734415	15.33458	5208.98	1.0768784	0.7691992
6765765469185193856	291.3405777082392	-27.231619063047397	0.6119436180636963	15.834018	5791.3335	0.95350605	0.92141634
6765765159947515264	291.3498168952102	-27.262044885229212	4.132132545543122	11.953611	5473.5	0.9562914	0.73949575
6765776258143127296	291.3894525946542	-27.076231480909186	1.039794636307421	15.3299265	5282.663	0.8720368	0.53355104
6765774986832739456	291.4063064229606	-27.143010661715195	1.489180692281826	14.933055	4979.0	0.84579146	0.39608628
6765776395582109184	291.3549437124267	-27.071737100248757	1.2561866682267304	14.481471	5354.0	1.03361	0.79090005
6765776322562322432	291.3802140337682	-27.067936288917686	0.548376333515173	15.986092	5672.0	1.0384039	1.0054771
6765967023410285824	291.3471247775688	-26.937616985335993	0.8856357690749613	14.837008	5739.6665	1.0633346	1.1055572
6765967882403793920	291.3407598229724	-26.87675246899194	0.834710615463235	15.204329	5321.6665	1.1310799	0.9244254
6765966576733650176	291.3815830436253	-26.948958807736112	0.6433463227673782	16.145773	5100.5	1.0541036	0.67750466
6765965850879999232	291.36090333085394	-26.994445033634367	0.5845269379581346	15.975662	5324.0	1.13112	0.92611355
6765966542373897984	291.4161831365087	-26.93292040204237	2.233219284845393	13.188023	5360.0	1.0520328	0.8230239
6765965820819385088	291.3477417977837	-27.011847032815247	0.7358897849096999	15.778309	5643.3335	0.86113155	0.677605
6765966817251822976	291.4062167740024	-26.91715196942292	0.8671629077437688	15.4946165	5597.8447	0.8479383	0.6360725
6765966370575194368	291.3993763620409	-26.966779530092996	1.9262678052195197	14.305581	5008.5864	0.8598932	0.41922235
6765966576733648768	291.37296675485896	-26.959119803252666	0.9686262433653223	14.830159	5374.5	1.131444	0.96230567
6765966503715392256	291.4024104176108	-26.944489145141773	2.2952767970537167	12.569741	5914.5	1.0923635	1.3155313
6765970940420526080	291.34271484185274	-26.851809389087308	1.015469282933235	14.987729	5309.6724	1.0327581	0.76377034
6765967813684287616	291.35558214834754	-26.8975149203459	0.7729907465387106	15.615973	5348.0	0.9988009	0.7352214
6765966576733650816	291.3791057796132	-26.95007259508542	0.8129311982244052	15.814709	4993.0	1.0249876	0.58827204
6765995194097657728	291.39061240901964	-26.774968594519052	0.7900374481004636	16.382814	4922.0	0.8422995	0.37514076
6765991418824567296	291.37685980536037	-26.852073066964092	1.1644933594104796	14.982484	5093.495	0.998458	0.6045301
6765991384464827648	291.36886654958215	-26.861500548892298	0.6195416137772571	16.585733	5202.6665	0.851454	0.4785431
6765996400986745856	291.3605625401642	-26.719099268419004	0.5490298668754247	16.114515	5334.6665	1.1243402	0.92239994
6765998084613926400	291.40933867337293	-26.669647247919453	1.0428271108018765	15.674025	4867.0	0.91072005	0.41928554
6765991040867405568	291.3959560903157	-26.88825362294387	0.9275737800195296	15.949698	4889.0	0.891221	0.40883276
6765994579920532224	291.37891647634257	-26.803075768824147	0.6165501479055495	15.979432	5374.5	1.0470474	0.8240994
6765996023029593472	291.3685770130869	-26.750913371240294	0.7499241878171775	15.627783	5162.0	1.1145408	0.7946184
6765994648640031104	291.33770132924815	-26.818556732487767	0.6723169607891949	15.748095	5332.0	1.0882161	0.8623538
6765994339402347136	291.3522928418148	-26.852118591986823	0.7348805803778272	16.118809	4870.0	1.051287	0.560084
6765996882023035392	291.4096869651997	-26.731824228151872	0.5614153597745786	15.911455	5452.0	1.1477177	1.0485479
6765997633639271552	291.399361758971	-26.732110164267503	0.7219073480322802	16.138458	5339.5	0.8439137	0.5215466
6765996126108802816	291.38633280833335	-26.741936856548573	1.1596343970316858	15.29579	5107.935	0.86186033	0.4555646
6765990284953127808	291.41888355191026	-26.90546674512369	1.0200372317532642	15.25953	5086.6636	1.006677	0.6112334
6765991143946632064	291.3971991733755	-26.86656692552351	1.6675611560931494	14.08374	5312.75	0.9523269	0.65094507
6766010316680810880	291.40816971816764	-26.634124358309908	0.5060977859031384	16.258465	5733.0	0.96940476	0.9146033

Figure 2. *List of G and early-to-mid K type stars in the WOW! Signal region, positive feed horn*
Source: ESA

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source_id	ra deg	dec deg	parallax mas	phot_g_mean_mag mag	teff_val K	radius_val solRad	lum_val solLum
6765736057248561280	292.1006411084745	-27.21261451522549	0.6770301939417982	15.823268	5769.5	0.87326604	0.76127326
6765743066636007296	292.09496370141426	-26.99746405912848	0.851001741594187	15.519336	5400.25	0.9272313	0.65875864
6765741314288690304	292.060361979927	-27.0593914881932	1.6625818516315762	14.252357	5144.3335	0.9551288	0.5756189
6765730319172282240	292.0560940194295	-27.224607313260446	0.6585505506342175	15.246085	5827.0195	1.1461735	1.3645244
6765742615659064320	292.0929014486811	-27.04707574266142	0.5619097663211164	16.100163	5774.6665	0.9244046	0.8561041
6765742856177287296	292.0868209180845	-27.031051726628903	1.1606470433537	14.985551	5230.0	0.93771935	0.59271675
6765740111697782016	292.09474860429157	-27.108498876731172	0.6230461047113127	16.299883	5234.28	0.95176905	0.6126121
6765735228318190080	292.12287647730295	-27.22957020598409	0.6959928922176472	16.41032	4993.0	0.91000867	0.4636946
6765730353532007808	292.07902880171923	-27.21720126238249	1.1529966721926206	14.469317	5424.5	1.0984589	0.94124174
6765742894836663296	292.0759513968115	-27.030785816974635	0.6098307913751307	16.160534	5499.3335	0.92362803	0.70295763
6765740042978281600	292.1265748541325	-27.10483117369423	0.7224034322118007	16.033098	5072.115	1.0025636	0.59934235
6765790345636231552	292.05900196055336	-26.960555365946902	5.99738492568554	10.847295	5438.6665	1.1128556	0.9762072
6765790379995741568	292.1087982137261	-26.97226361335549	0.6850750555485354	15.4897785	5871.3335	0.9688844	1.0050453
6765790861032086912	292.0930345124132	-26.915360128567457	0.6568770612523586	16.530819	4838.0	0.9899087	0.48366922
6765791548226860032	292.0526515365629	-26.92236323264193	0.5711494805445938	16.207207	5220.0	1.0906745	0.7957325
6765790581857735424	292.1253427521075	-26.944584694882142	0.6072714874748856	16.341255	5171.467	0.98649144	0.62709934
6766173662876487040	292.1018977249007	-26.703533903204548	0.8196983473427807	15.744305	5295.955	0.9085708	0.5850452
6766185860583649280	292.07907228629284	-26.65468402891079	0.8343066865491464	15.039279	5727.6934	1.0330772	1.0348547
6766170570500493184	292.0538562962534	-26.818120313593298	1.16983605540771	15.3357725	4952.4927	0.9067327	0.44560352
6766170364342062720	292.0638655786175	-26.824618062756596	0.5808766874796816	15.902043	5872.9	0.9445489	0.9562116
6766174040833637248	292.09353773619483	-26.664311851782127	1.3169351714788855	13.793874	5763.25	1.1457651	1.3048353
6766174075193374464	292.1042995558813	-26.655675199554384	1.3838029577182769	14.053238	5342.5	1.1486186	0.9683326
6766185791864654720	292.082562206216	-26.670163196643735	1.8108125151055896	13.3890915	5783.0	0.9965662	1.0007366
6766167237604777728	292.0821866791453	-26.865065174203693	0.6077678961151007	16.136177	5231.75	1.05332	0.7488647
6766167271964515456	292.09507515404727	-26.861305154776026	0.946032078198879	15.3182125	5293.3335	0.9590382	0.6505543
6766167271964515712	292.0928906903116	-26.856928874197855	1.0494598017362597	14.216689	6000.0	1.085432	1.3756406
6766166962726868864	292.10542793511127	-26.89363989479729	0.6353080864011327	15.979972	5447.0	0.9848016	0.7691689
6766166206812624000	292.1162400523931	-26.901633336763922	0.8649620494184755	15.2424755	5457.8867	1.0112089	0.8174752

Figure 3. *List of G and early-to-mid K type stars in the WOW! Signal region, negative feed horn*
Source: ESA

With the parallax values is possible to know how far each star is. The higher the parallax, the closer the star. Out of the 38 stars, the closest one seems to be source_ID: 6765765159947515264, with a parallax of 4.132 milliarcseconds, which is around 242 parsecs, or 789 light years. For the negative horn, the following list extracted from the Gaia Archive shows a total of 28 candidates that were found.

In this sample, the closest star appears to be source_ID: 6765790345636231552, with a parallax of 5.997 milliarcseconds, which is around 166 parsecs, or 544 light years. The fact that all the stars in both samples are farther than 500 light years away is consistent with Claudio Maccone estimations that the closest communicative civilization is no closer than 500 light years away (Maccone, 2010).

Maccone points out that the distance in which the existence of a communicative civilization is more likely is 1,933 light years away, which is 592 parsecs, equivalent to a parallax of 1.68 millarcseconds. In the sample of the positive feed horn, the star (apparently a G-type) closer to that distance is source_id: 6765741314288690304, located 1,961 light years away. This star has an estimated temperature 634 Kelvin lower than the Sun, a radius 5% lower, and a luminosity 43% lower.

In the sample of the negative horn, the star (apparently a K-type) closest to that distance is source_id: 6765991143946632064, located 1,955 light years away. This star has an estimated temperature 466 Kelvin lower than the Sun, a radius 5% lower, and a luminosity 35% lower.

4. Conservative sample of candidate sources

If we introduce the interval values corresponding to Sun-like stars stars in the Gaia Archive, no stars are found in the positive horn beam. If we introduce the same intervals for the negative horn beam, only one Sun-like star is found: source_id: 6766185791864654720, with a RA of 292.082562206216 (19:28:19.8), and a DEC of -26.67016319664373 (26:40:12.6).

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The star, which is named as 2MASS 19281982-2640123 in the 2MASS archive, has an estimated temperature of 5,783 Kelvin, a radius of 0.9965662 solar radii, and a luminosity 1.0007366 times that of the Sun. It has a parallax of 1.81 milliarcseconds, which is 552 parsecs, or 1,801 light years.

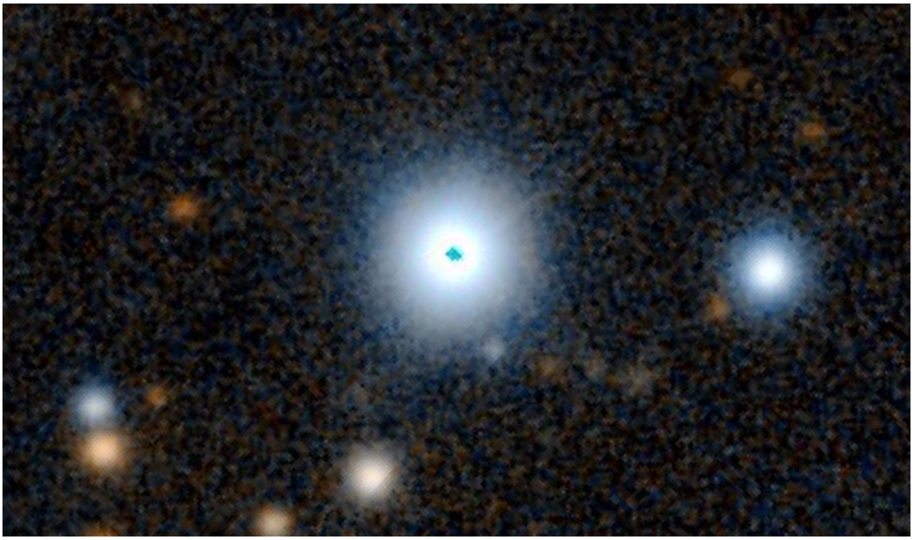

Figure 4. *2MASS 19281982-2640123, the star with the temperature, radius, and luminosity most similar to the Sun found in the WOW! Signal region, based on data from to the Gaia Archive.*
Source: PanSTARRS/DR1

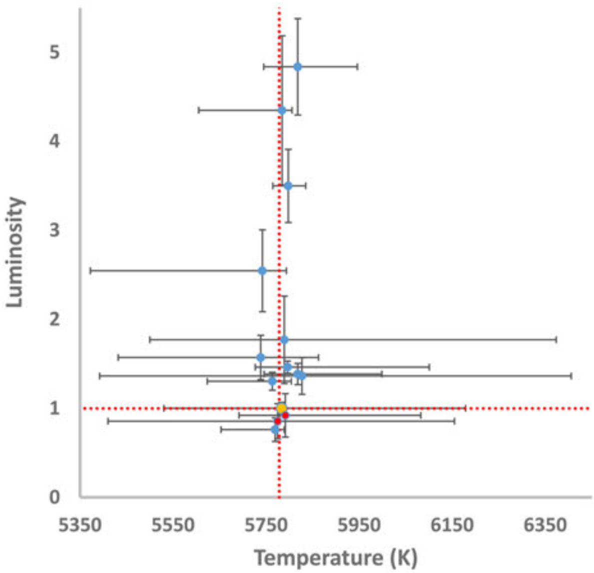

Figure 5. *Candidate stars with estimated temperatures between 5,730 and 5,830 K – Error shown for both luminosity and temperature – Vertical red line corresponds to Solar luminosity, and the horizontal red line to Solar temperature – Yellow dot corresponds to 2MASS 19281982-2640123, red dots to 2MASS 19252173-2713537 and 2MASS 19282229-2702492 (below).*

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2MASS 19281982-2640123 could be, therefore, the only Sun-like star found among the thousands of stars located in the WOW! Signal region. The location of this star has a RA error / difference of 2.2 seconds and a DEC difference of 17 arcminutes with respect to the signal (Ehman, 1997).

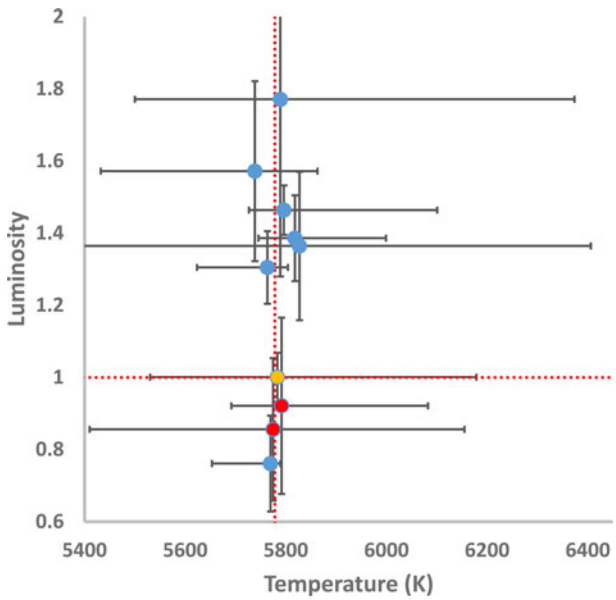

Figure 6. *This is figure 5 zoomed in on the candidates with a luminosity more similar to the Sun.*

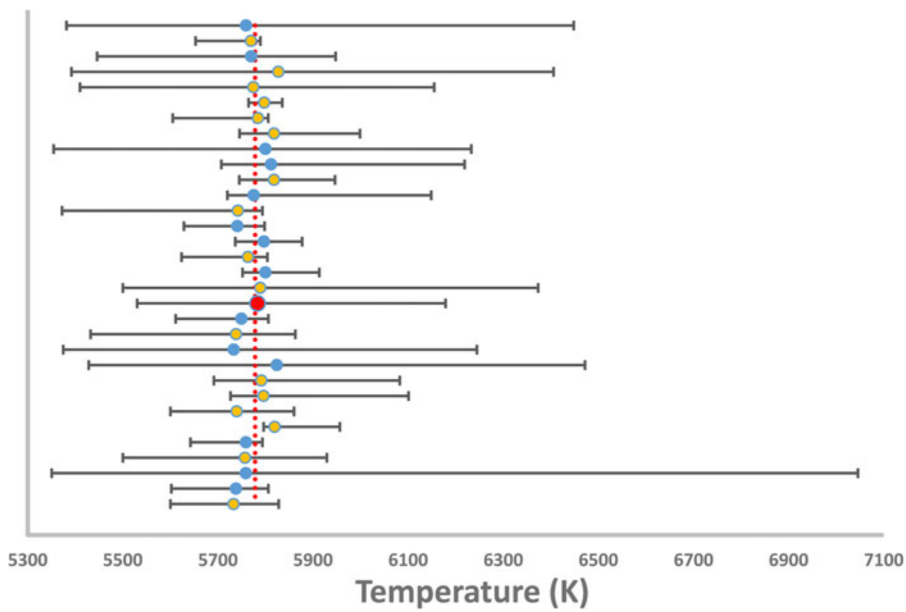

Figure 7. *All conservative candidate stars with estimated temperatures between 5,370 and 5,830 K, including errors – Vertical red line corresponds to Solar temperature – Red dot is 2MASS 19281982-2640123, yellow dots are the stars with known temperature and luminosity, and blue dots are the stars with only known temperature in the Gaia Archive.*

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There are also two more conservative candidates with estimated temperatures similar to the Sun, and with the luminosity of the Sun falling within the interval of their estimated luminosity lower and upper errors. The first one is source_id 6765765469185193856, which corresponds to 2MASS 19252173-2713537, with an estimated temperature of 5,791 K and a luminosity of 0.92 Solar lum. The second one is source_id 6765742615659064320, which is 2MASS 19282229-2702492, with an estimated temperature of 5,774 K and luminosity of 0.85.

Apart from the three candidates mentioned above, in the Gaia Archive another 14 potential Sun-like stars in the WOW! Signal region were found. However, there is no available data about their luminosity and radius.

Some of the stars without known luminosity could be potential Sun-like stars. The most interesting ones are those with an estimated temperature similar to the Sun, and a low error in this parameter. They are source_id 6766167787361134720 (2MASS 19283011-2649582), source_id 6766167168886391296 (2MASS 19282778-2652013), and source_id 6765739355783521280 (2MASS 19281550-2709296).

5. Conclusions

In this paper several candidate sources for the WOW! Signal have been suggested. In the region ranging from 19h25m31s ± 10s to −26°57′ ± 20′, and 19h28m22s ± 10s to −26°57′ ± 20′, a total of 66 G and K-type stars were found in the Gaia DR2 archive. Out of this sample, two stars are close to the celestial distance with the highest chance of having a communicative civilization, according to Maccone's mathematical estimations.

With the available data, the only potential Sun-like star in all the WOW! Signal region appears to be 2MASS 19281982-2640123. Despite this star is located too far for sending any reply in the form of a radio or light transmission, it could be a great target to make observations searching for techno-signatures such as artificial light or satellite transits.

However, more information such as metallicity, age, and presence or not of stellar companions is needed in order to determine that 2MASS 19281982-2640123 is indeed a Sun-like star. Moreover, another two candidate stars have an error interval of their luminosity that covers the luminosity of the Sun, and three candidates more among 14 are also identified as potential Sun-like stars, but the estimations on their luminosity were unknown.

It is also important to mention that the signal could have come from any of the 66 G and K-type stars, a star that only meets one or two of the parameters set for the optimistic sample (in the WOW! Signal region, a total of 550 stars with a temperature between 4,450 and 6,000 K were found, but no information about their luminosity and radius is available), stars that are not included in the Gaia Archive, a star that is too dim to image with current technology, an extragalactic source, or any other origin.

In any case, since all these stars are located in the same part of the sky, it is ideal to search for techno-signatures in the whole region where the WOW! Signal could have come from.

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