

Multiwavelength and Spectroscopic Classification of Four Astronomical Sources

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ABSTRACT

We present a multiwavelength and spectroscopic analysis of four unidentified astronomical sources. For each object, we combine optical and infrared photometry, Gaia astrometry when available, multiwavelength imaging, Gaia H–R diagram placement when meaningful, and optical spectra obtained with the FAST spectrograph. The sources display a wide range of physical properties. Object A is a very red luminous star whose colors, infrared brightness, and optical spectrum are consistent with a late-type M giant, possibly located in the inner Galactic halo. Object B is a Galactic emission-line source with strong H α emission and infrared excess, most consistent with a young stellar object or classical T Tauri-like star. Object C is a blue-white stellar source with strong Balmer absorption lines and is best interpreted as an A-type star, likely somewhat evolved relative to a main-sequence dwarf. Object D lacks measurable Gaia parallax or proper motion and exhibits a narrow emission-line spectrum. Its emission features are consistent with redshifted H α , H β , [O III], and [O II] at $z \approx 0.039$, indicating that it is most likely an external star-forming or starburst galaxy. These classifications demonstrate how combining photometric colors, astrometry, spectral diagnostics, and multiwavelength morphology allows physically distinct astronomical sources to be identified.

Keywords: stars: late-type — stars: pre-main sequence — stars: emission-line — galaxies: starburst — techniques: spectroscopic — astrometry

1. INTRODUCTION

Astronomical source classification relies on combining several complementary forms of observational evidence. Photometry provides information about the color and approximate temperature of a source, while multiwavelength imaging can reveal whether the source emits primarily in the ultraviolet, optical, infrared, or across a broad spectral range. Astrometric measurements, especially from Gaia, are useful for distinguishing nearby Galactic stars from distant or extragalactic sources. Spectroscopy provides the most direct physical diagnostic because the presence, absence, and relative strength of absorption and emission lines can reveal stellar temperature, evolutionary state, accretion activity, or redshift.

In this work, we analyze four unidentified astronomical objects using available catalog photometry, Gaia astrometry, multiwavelength images, Gaia H–R diagram placement when meaningful, and optical spectra. The purpose is to infer the physical nature of each object using as much of the available data as possible. The analysis emphasizes not only the final classification, but

also the reasoning that connects the observations to the interpretation.

The four sources represent different astrophysical categories. Some are best understood as Galactic stars, while one is more consistent with an extragalactic emission-line galaxy. This variety makes the data set useful for demonstrating the role of color, distance, proper motion, spectral features, and redshift in astronomical classification.

2. DATA

For each object, the available data include sky coordinates, catalog magnitudes, Gaia parallax and proper motion when available, multiwavelength images, Gaia H–R diagram information, and FAST optical spectra. The photometric measurements include Johnson-like B and V magnitudes and Gaia-like blue, broad-band, and red magnitudes. These values allow approximate color indices such as $B - V$ and $B_P - R_P$ to be estimated.

The comparison spectra were obtained from publicly available spectral atlases and astronomical reference pages. One of the comparison spectrum for Object A was taken from the Digital Spectral Classification Atlas (Gray 2000). The comparison spectra used for Objects

A, B and C were taken from the FAST Spectral Atlas (Berlind et al. 2003). The comparison spectrum for Object D was taken from Keel’s starburst galaxy spectral examples (Keel 1996). These comparison spectra were used to compare continuum shape, absorption features, and emission-line behavior with standard or representative astronomical sources.

The Gaia parallax, when reliable, is converted to distance using

$$d = \frac{1000}{\varpi}, \quad (1)$$

where d is the distance in parsecs and ϖ is the parallax in milliarcseconds. This direct inversion is only meaningful when the parallax uncertainty is small compared with the measured parallax. When the fractional uncertainty is large, the inverse-parallax distance is not treated as reliable.

Absolute magnitude is estimated using the distance modulus,

$$M = m - 5 \log_{10} \left(\frac{d}{10} \right), \quad (2)$$

where M is absolute magnitude, m is apparent magnitude, and d is distance in parsecs.

The spectra are used to identify major stellar or galactic features. Important diagnostic features include the hydrogen Balmer series, which is especially strong in A-type stellar spectra, and molecular absorption bands that become prominent in cool late-type stars (Gray & Corbally 2009). For emission-line sources, $H\alpha$ at 6563 Å, $H\beta$ at 4861 Å, [O III] at 5007 Å, and [O II] at 3727 Å are particularly useful for identifying accreting young stars and star-forming galaxies (Kenyon & Hartmann 1995; Baldwin et al. 1981). For an extragalactic source, the redshift is calculated using

$$z = \frac{\lambda_{\text{obs}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}}, \quad (3)$$

where λ_{obs} is the observed wavelength and λ_{rest} is the rest-frame wavelength.

3. METHODS

The analysis follows a consistent procedure for all four objects. First, the broad photometric colors are used to estimate whether the source is blue, intermediate, or red. Blue colors suggest a hot stellar photosphere, while red colors may indicate a cool star, dust reddening, or infrared excess. Second, Gaia astrometry is examined. A reliable parallax and measurable proper motion usually indicate a Galactic source, while the lack of Gaia astrometry can suggest that the object is faint, extended, confused, or extragalactic.

Third, the Gaia H–R diagram is used when the object has sufficient stellar astrometric information. For stellar sources, the H–R diagram provides a consistency check between color, luminosity, and the proposed spectral classification. For objects without reliable Gaia astrometry or objects that are not best interpreted as individual stars, the H–R diagram is not physically meaningful.

Finally, the optical spectra are inspected for diagnostic features. Stellar absorption-line spectra are compared with expected spectral behavior for different stellar types. Strong Balmer absorption is characteristic of A-type stars, while red continua and molecular absorption bands are associated with late-type M stars (Gray & Corbally 2009). Strong $H\alpha$ emission can indicate accretion or chromospheric activity in young stellar objects, including classical T Tauri stars (Kenyon & Hartmann 1995). Narrow nebular emission lines such as $H\alpha$, $H\beta$, [O III], and [O II] are also common diagnostics for star-forming galaxies and other emission-line galaxies (Baldwin et al. 1981).

4. ANALYSIS AND RESULTS

4.1. Object A

4.1.1. Observed Properties

Object A is located at approximately $\text{RA} = 148.4^\circ$ and $\text{Dec} = -1.8^\circ$. Its catalog magnitudes are approximately $B = 16.4$ and $V = 14.5$, with Gaia-like values $B_P = 15.1$, $G = 12.1$, and $R_P = 10.7$. The measured parallax is

$$\varpi = 0.019 \pm 0.110 \text{ mas}, \quad (4)$$

and the proper motions are

$$\mu_\alpha = -3.7 \pm 0.2 \text{ mas yr}^{-1}, \quad (5)$$

$$\mu_\delta = -0.5 \pm 0.2 \text{ mas yr}^{-1}. \quad (6)$$

The optical colors are very red:

$$B - V \approx 16.4 - 14.5 = 1.9, \quad (7)$$

$$B_P - R_P \approx 15.1 - 10.7 = 4.4. \quad (8)$$

The multiwavelength images of Object A are shown in Figure 1. The source is faint at shorter wavelengths and becomes much brighter toward the infrared, consistent with the very red colors measured from the catalog photometry.

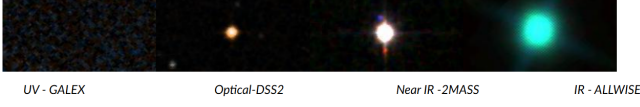


Figure 1. Multiwavelength images of Object A.

4.1.2. Astrometric Interpretation

A formal inverse-parallax estimate gives

$$d = \frac{1000}{0.019} \approx 5.3 \times 10^4 \text{ pc.} \quad (9)$$

However, this value is not reliable because the uncertainty is much larger than the measured parallax. The parallax is statistically consistent with zero, so the distance cannot be securely determined from simple parallax inversion. The measurable proper motion, however, supports a Galactic interpretation rather than an extragalactic one.

If the formal distance is used only as an approximate scale, the implied absolute magnitude is

$$M_G = 12.1 - 5 \log_{10} \left(\frac{52600}{10} \right) \approx -6.5. \quad (10)$$

Although this value is highly uncertain, it would place the source among luminous cool stars.

4.1.3. Spectral Classification

The FAST spectrum of Object A is shown in Figure 2. The spectrum rises strongly toward red wavelengths and has a red continuum, also with a sequence of broad molecular absorption structures. This overall shape is characteristic of a cool M-type stellar atmosphere.

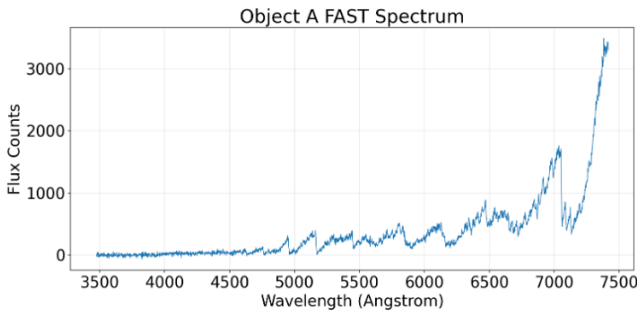


Figure 2. FAST optical spectrum of Object A.

The comparison spectrum in Figure 3 is an M5 III giant template from the Digital Spectral Classification Atlas. Among the comparison spectra considered, this M5 III spectrum provides the most reasonable match to Object A because both spectra show a strongly rising red continuum and many broad absorption-band structures across the optical red wavelength range near $\sim 6150 \text{ \AA}$,

$\sim 6650 \text{ \AA}$, and $\sim 7050 \text{ \AA}$. Although the exact subtype cannot be determined precisely from this comparison alone, the similarity supports a late M-type giant classification (Gray 2000; Gray & Corbally 2009).

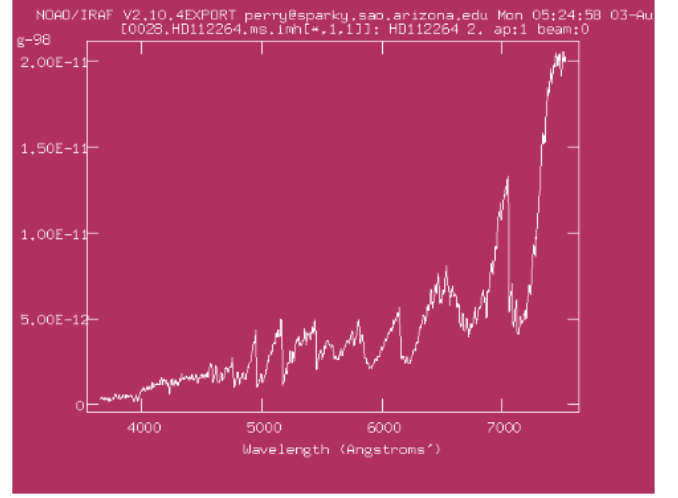


Figure 3. M5 III giant comparison spectrum from the Digital Spectral Classification Atlas (Berlind et al. 2003).

The M-giant temperature sequence in Figure 4 provides an important check on the TiO interpretation. In the sequence, TiO molecular absorption bands become increasingly strong from earlier M giants toward later M giants. The labeled TiO bandheads near $\sim 4760 \text{ \AA}$, $\sim 4950 \text{ \AA}$, $\sim 5167 \text{ \AA}$, and $\sim 5448 \text{ \AA}$ correspond to broad absorption structures that are also visible and consistent in the Object A FAST spectrum. This supports the interpretation that the repeated dips in Object A's spectrum are part of the TiO molecular absorption expected in a cool M-type giant atmosphere (Gray & Corbally 2009).

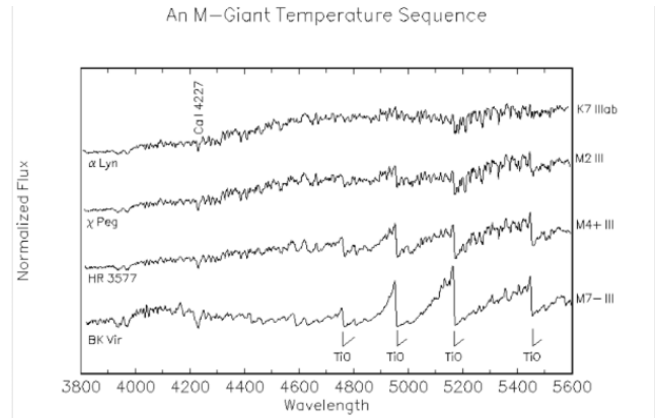


Figure 4. M-giant temperature sequence showing TiO molecular absorption bands (Gray 2000).

Because late M-type spectra can look broadly similar in low-resolution optical data, the exact subtype should be treated as approximate. The M5 III comparison appears to provide the closest visual match among the available templates, while the strength of the red continuum and TiO molecular bands suggests a generally late M-type classification. Therefore, the spectrum supports classifying Object A as an M-type giant, approximately in the mid-to-late M giant range.

4.1.4. Gaia H-R Diagram Interpretation

The Gaia H-R diagram provides an additional consistency check for Object A, as shown in Figure 5. Using the formal parallax inversion gives an extremely large distance of approximately 5.3×10^4 pc and an estimated absolute magnitude of $M_G \approx -6.5$. However, because the parallax uncertainty is much larger than the measured parallax, this absolute magnitude should not be treated as a precise luminosity measurement.

Even with this uncertainty, the very red color of Object A, with $B_P - R_P \approx 4.4$, places it on the cool red side of the Gaia H-R diagram. If it is luminous, as suggested by its apparent brightness and red giant-like spectrum, it would fall in the red giant or asymptotic giant branch region rather than on the main sequence. Therefore, the H-R diagram supports the luminosity-class part of the interpretation: Object A is more consistent with a luminous red giant than with a nearby red dwarf. Together with the M-type spectral features and TiO molecular absorption bands, this is consistent with the interpretation that Object A is an late M-type giant (Gray 2000; Gray & Corbally 2009; Berlind et al. 2003).

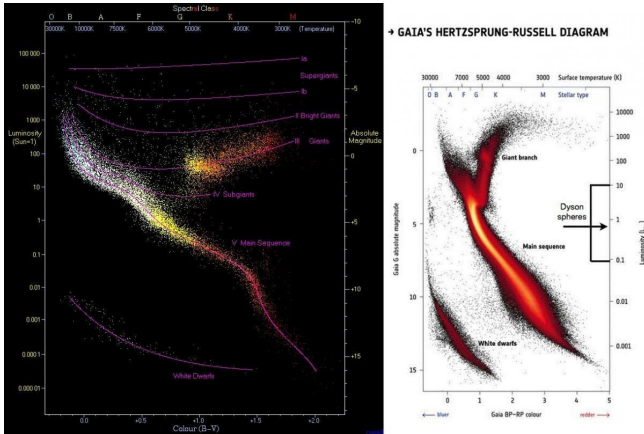


Figure 5. Gaia H-R diagram for Object A.

4.1.5. Interpretation

Object A is best classified as a late-type red giant, approximately M5 III. This classification is supported

by its very red color, infrared brightness, measurable proper motion, H-R diagram consistency, and similarity to late-type giant comparison spectra (Gray 2000; Gray & Corbally 2009). Its uncertain parallax prevents a precise distance measurement, but the available evidence strongly supports a Galactic late-type giant interpretation. The source may plausibly lie in the inner halo, although this conclusion is limited by the large parallax uncertainty.

4.2. Object B

4.2.1. Observed Properties

Object B is located at approximately RA = 80.1° and Dec = -5.8°. Its magnitudes are approximately $B = 13.3$, $V = 12.3$, $B_P = 12.7$, $G = 12.1$, and $R_P = 11.3$. The parallax is

$$\varpi = 2.493 \pm 0.039 \text{ mas}, \quad (11)$$

with proper motions

$$\mu_\alpha = 1.15 \pm 0.08 \text{ mas yr}^{-1}, \quad (12)$$

$$\mu_\delta = -1.29 \pm 0.06 \text{ mas yr}^{-1}. \quad (13)$$

The color indices are

$$B - V \approx 13.3 - 12.3 = 1.0, \quad (14)$$

$$B_P - R_P \approx 12.7 - 11.3 = 1.4. \quad (15)$$

Figure 6 shows that Object B is detected in the optical and infrared. This imaging behavior is consistent with a Galactic stellar source and may suggest infrared excess or circumstellar material, although the imaging alone is not sufficient for a definitive classification.



Figure 6. Multiwavelength images of Object B.

4.2.2. Distance and Luminosity

Because the parallax uncertainty is small, the distance estimate is reliable:

$$d = \frac{1000}{2.493} \approx 401 \text{ pc}. \quad (16)$$

Using $G \approx 12.1$, the absolute magnitude is

$$M_G = 12.1 - 5 \log_{10} \left(\frac{401}{10} \right) \approx 4.1. \quad (17)$$

This luminosity is consistent with a Galactic stellar source and is not consistent with a luminous giant.

4.2.3. Spectral Properties

The FAST spectrum of Object B is shown in Figure 7. The defining spectral feature is strong H α emission near 6563 Å. Additional emission is likely present near H β at 4861 Å. This is not the spectrum of a normal main-sequence star dominated by absorption lines. Strong Balmer emission, especially strong H α , is commonly associated with active or accreting young stellar objects, including classical T Tauri stars (Kenyon & Hartmann 1995).

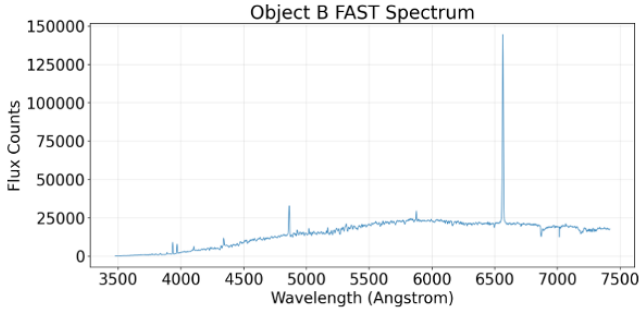


Figure 7. FAST optical spectrum of Object B.

The comparison spectrum in Figure 8 was obtained from the FAST Spectral Atlas. Its strong emission-line behavior provides a useful comparison for Object B and supports the interpretation that Object B is a young emission-line stellar source (Berlind et al. 2003; Kenyon & Hartmann 1995).

4.2.4. Gaia H-R Diagram Interpretation

For Object B, the Gaia parallax is reliable, so its position on the H-R diagram can be interpreted more confidently. As shown in Figure 9, with $d \approx 401$ pc and $G \approx 12.1$, the estimated absolute magnitude is $M_G \approx 4.1$. Combined with its moderate color, $B_P - R_P \approx 1.4$, Object B would lie near or slightly above the lower main sequence on a Gaia H-R diagram.

This location is consistent with a low-mass or intermediate-temperature Galactic star, the combination of its Galactic distance, moderate luminosity, red color, infrared brightness, and emission-line spectrum supports the interpretation of Object B as a young stellar object or classical T Tauri-like star (Berlind et al. 2003; Kenyon & Hartmann 1995).

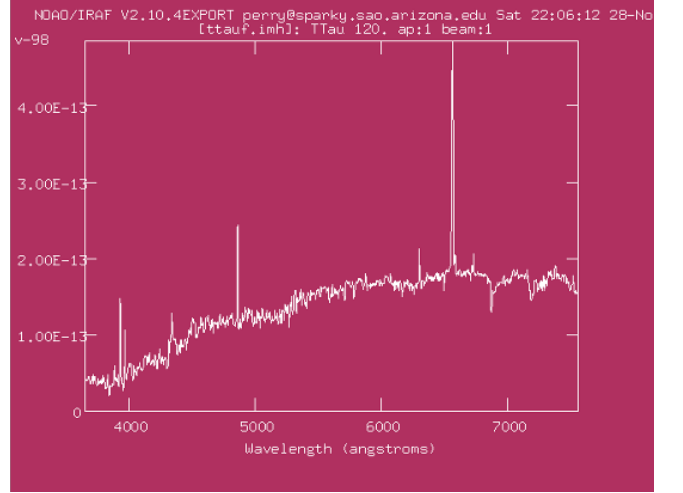


Figure 8. Pre-Main Sequence (PMS) Stars T Tau comparison spectrum from the FAST Spectral Atlas (Berlind et al. 2003).

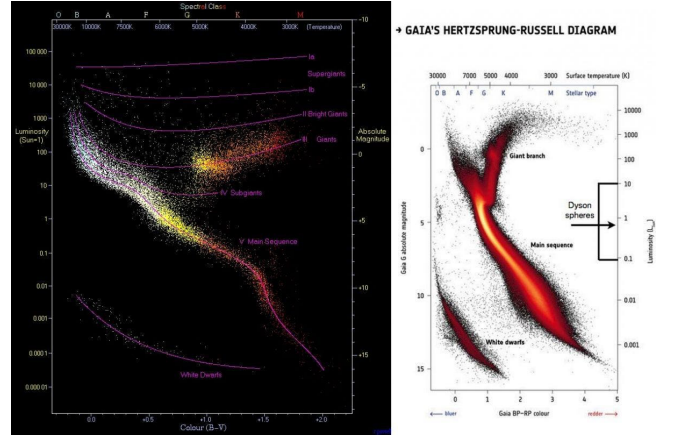


Figure 9. Gaia H-R diagram for Object B.

4.2.5. Interpretation

Object B is most consistent with a young stellar object, likely a classical T Tauri-like star. This classification is supported by its reliable Galactic distance, measurable proper motion, moderate red color, infrared brightness, H-R diagram location, and especially strong H α emission (Berlind et al. 2003; Kenyon & Hartmann 1995). The source is therefore not simply classified by photospheric temperature; its emission-line behavior indicates active circumstellar or accretion-related processes.

4.3. Object C

4.3.1. Observed Properties

Object C is located at approximately RA = 77.5° and Dec = +10.0°. It is much brighter than the other sources, with approximate magnitudes $B = 7.7$,

$V = 7.7$, $B_P = 7.6$, $G = 7.6$, and $R_P = 7.6$. Its parallax is

$$\varpi = 2.43 \pm 0.11 \text{ mas}, \quad (18)$$

and the proper motions are

$$\mu_\alpha = 1.20 \pm 0.19 \text{ mas yr}^{-1}, \quad (19)$$

$$\mu_\delta = -0.33 \pm 0.12 \text{ mas yr}^{-1}. \quad (20)$$

The colors are approximately

$$B - V \approx 0.0, \quad (21)$$

$$B_P - R_P \approx 0.0. \quad (22)$$

The multiwavelength images in Figure 10 show that Object C is bright in the optical and ultraviolet. This is consistent with a relatively hot stellar photosphere and agrees with its nearly zero color index.



Figure 10. Multiwavelength images of Object C.

4.3.2. Distance and Absolute Magnitude

The parallax gives

$$d = \frac{1000}{2.43} \approx 412 \text{ pc}. \quad (23)$$

Using $G \approx 7.6$, the absolute magnitude is

$$M_G = 7.6 - 5 \log_{10} \left(\frac{412}{10} \right) \approx -0.5. \quad (24)$$

This is brighter than expected for a typical A-type main-sequence dwarf.

4.3.3. Spectral Classification

Figure 11 shows that Object C has a blue continuum and strong absorption lines from the hydrogen Balmer series. Important features include $H\delta$ at 4102 Å, $H\gamma$ at 4340 Å, $H\beta$ at 4861 Å, and $H\alpha$ at 6563 Å. Strong Balmer absorption is one of the key defining features of A-type stellar spectra (Gray & Corbally 2009). The near-zero color index and blue-white continuum are therefore consistent with an A-type stellar classification.

The comparison spectrum in Figure 12 shows the same main diagnostic behavior: a blue continuum with strong Balmer absorption lines. This comparison supports the interpretation that Object C is an A-type star (Berlind et al. 2003; Gray & Corbally 2009).

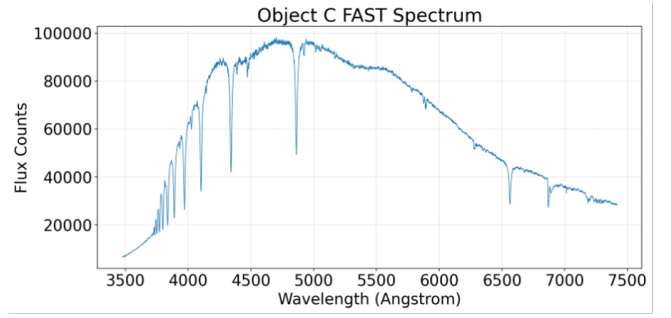


Figure 11. FAST optical spectrum of Object C.

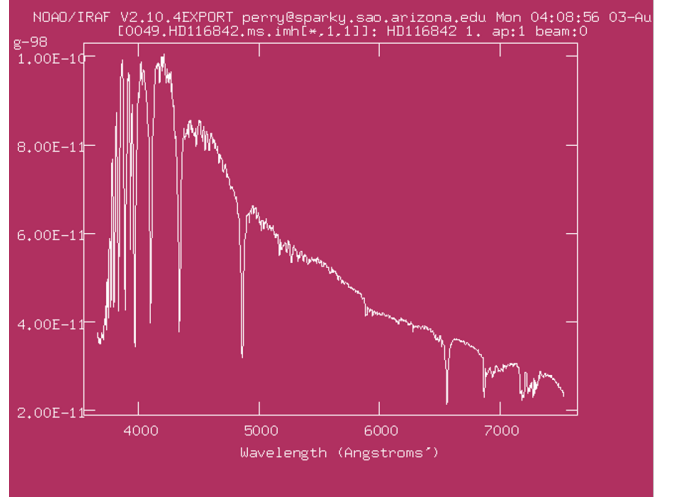


Figure 12. A-type stellar comparison spectrum from the FAST Spectral Atlas (Berlind et al. 2003).

4.3.4. Gaia H-R Diagram Interpretation

Object C has a reliable parallax and therefore can be placed meaningfully on the Gaia H-R diagram. As shown in Figure 13, its estimated distance is $d \approx 412$ pc, and with $G \approx 7.6$ its absolute magnitude is approximately $M_G \approx -0.5$. Its color is very blue, with $B_P - R_P \approx 0.0$.

This position places Object C on the hot, luminous side of the H-R diagram. A normal A-type main-sequence star would be blue, but the estimated absolute magnitude is brighter than expected for a typical A-type dwarf. Therefore, the H-R diagram suggests that Object C may be somewhat evolved or more luminous than a main-sequence A star. This supports the interpretation of Object C as an A-type giant or slightly evolved A-type star (Berlind et al. 2003; Gray & Corbally 2009).

4.3.5. Interpretation

Object C is best classified as an A-type star. Its color is close to zero, its optical spectrum is dominated by Balmer absorption, its comparison spectrum matches the expected behavior of an A-type stellar spectrum,

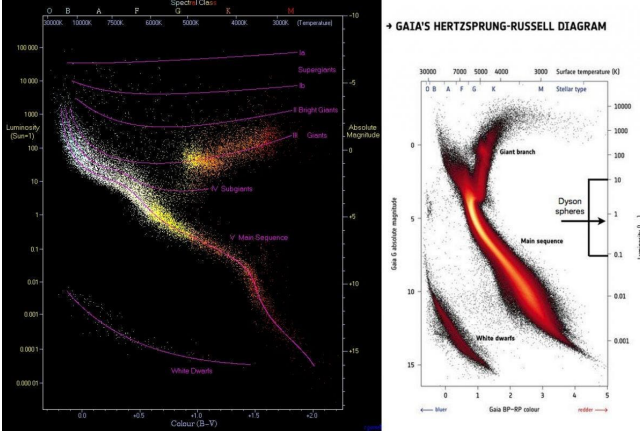


Figure 13. Gaia H-R diagram for Object C.

and its H-R diagram position places it on the hot, luminous side of the diagram (Berlind et al. 2003; Gray & Corbally 2009). Its absolute magnitude suggests that it may be more luminous than a main-sequence A dwarf. Therefore, an A-type giant or slightly evolved A-type star is the most reasonable interpretation.

4.4. Object D

4.4.1. Observed Properties

Object D is located at approximately $RA = 37.8^\circ$ and $Dec = -9.8^\circ$. Its magnitudes are approximately $B = 16.7$, $V = 15.9$, $B_P = 17.3$, $G = 17.9$, and $R_P = 16.3$. Unlike the first three objects, it has no available Gaia parallax or proper motion.

The approximate colors are

$$B - V \approx 16.7 - 15.9 = 0.8, \quad (25)$$

$$B_P - R_P \approx 17.3 - 16.3 = 1.0. \quad (26)$$

The multiwavelength images in Figure 14 show a faint source. Unlike the previous objects, Object D does not have Gaia astrometric information that would support a nearby stellar interpretation. The imaging and catalog properties therefore motivate a closer examination of its spectrum.

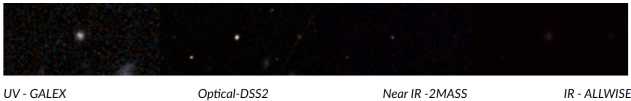


Figure 14. Multiwavelength images of Object D.

4.4.2. Emission-Line Spectrum and Redshift

The FAST spectrum of Object D is shown in Figure 15. It is dominated by narrow emission lines.

This behavior is more characteristic of an emission-line galaxy than a normal stellar photosphere. Strong nebular emission lines such as $H\alpha$, $H\beta$, $[O III]$, and $[O II]$ are commonly used to identify and analyze star-forming galaxies and other emission-line galaxies (Baldwin et al. 1981).

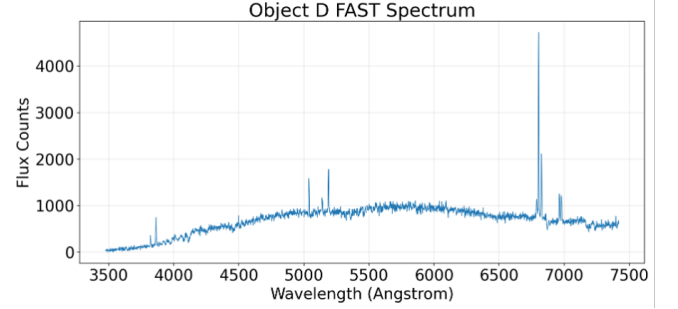


Figure 15. FAST optical spectrum of Object D.

A strong line appears near 6820 Å. If this line is identified as $H\alpha$ with rest wavelength 6563 Å, then the redshift is

$$z = \frac{6820 - 6563}{6563} \approx 0.039. \quad (27)$$

This redshift predicts the observed wavelengths of several other common galaxy emission lines:

$$[O II] 3727(1+z) \approx 3872 \text{ Å}, \quad (28)$$

$$H\beta 4861(1+z) \approx 5050 \text{ Å}, \quad (29)$$

$$[O III] 5007(1+z) \approx 5202 \text{ Å}. \quad (30)$$

These predicted wavelengths match the observed emission features reasonably well. Therefore, the spectrum is naturally explained as that of a redshifted emission-line galaxy.

The comparison spectrum in Figure 16 was obtained from Keel's starburst galaxy spectral examples. Its strong nebular emission-line appearance is similar to Object D and supports an extragalactic star-forming or starburst-galaxy interpretation (Keel 1996; Baldwin et al. 1981).

4.4.3. Gaia H-R Diagram Consideration

Object D cannot be meaningfully placed on a Gaia stellar H-R diagram because it has no available Gaia parallax or proper motion. In addition, its spectrum is dominated by narrow emission lines rather than by a stellar photospheric continuum. The Gaia H-R diagram is designed for stellar sources with reliable colors and distances, so applying it to Object D would not provide a physically meaningful stellar classification.

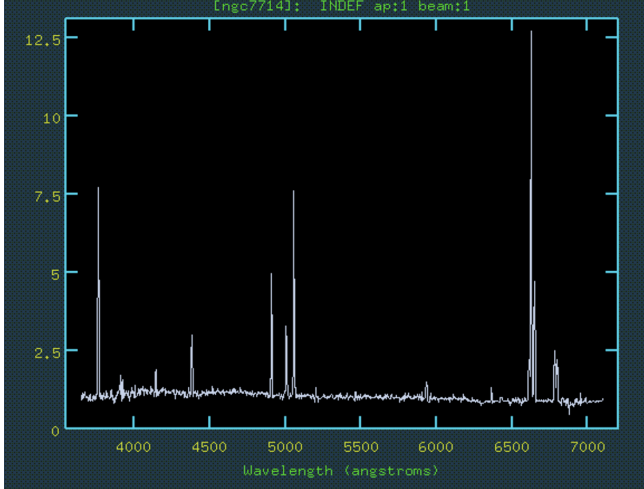


Figure 16. Starburst galaxy comparison spectrum from Keel’s spectral examples (Keel 1996).

4.4.4. Interpretation

Object D is not well explained as a normal Galactic star. The absence of Gaia parallax and proper motion, the faint optical magnitude, and the narrow emission-line spectrum all support an extragalactic interpretation. Its emission features are consistent with redshifted $H\alpha$, $H\beta$, [O III], and [O II], which are common in star-forming and starburst galaxies (Baldwin et al. 1981; Keel 1996). The measured redshift of approximately $z \approx 0.039$ therefore suggests that Object D is most likely a star-forming or starburst galaxy.

5. DISCUSSION

The four objects illustrate how different observational diagnostics contribute to classification. Object A and Object C are both stellar sources, but their colors and spectra are very different. Object A is extremely red and luminous, with spectral properties typical of a late M giant, including a red continuum, multiple TiO molecular absorption bands and late-type spectral structure (Gray 2000; Berlind et al. 2003; Gray & Corbally 2009). Object C is blue-white and shows strong Balmer absorption, making it consistent with an A-type star (Berlind et al. 2003; Gray & Corbally 2009). Object B is also Galactic, but its classification depends more strongly on emission-line activity than on a normal photospheric spectrum. Its strong $H\alpha$ emission and infrared brightness are most consistent with a young stellar object or classical T Tauri-like star (Berlind et al. 2003; Kenyon & Hartmann 1995).

The Gaia H–R diagram provides an important cross-check for the stellar sources. Object A lies on the very red side of the diagram, consistent with a cool late-type giant, although its luminosity is uncertain because of the

unreliable parallax. Object B falls near the lower main sequence or possible pre-main-sequence region, which is consistent with a young stellar interpretation when combined with its $H\alpha$ emission. Object C occupies the hot and luminous part of the diagram, supporting an A-type classification and suggesting that it may be more evolved than a typical A-type dwarf. Object D is excluded from the H–R diagram analysis because it lacks reliable Gaia astrometry and is better interpreted as an extragalactic emission-line galaxy.

Object D is physically distinct from the first three sources. Its lack of Gaia astrometry and narrow emission-line spectrum indicate that it is not a typical Galactic star. The line identifications produce a self-consistent redshift, which strongly supports an extragalactic classification. The likely emission lines are the same lines commonly seen in star-forming galaxies: $H\alpha$, $H\beta$, [O III], and [O II] (Baldwin et al. 1981; Keel 1996).

The main uncertainties differ from object to object. For Object A, the largest uncertainty is the distance, because the parallax is too small and uncertain for reliable inversion. For Object B, the broad classification as a young emission-line object is strong, but more detailed classification would require additional information such as infrared colors, equivalent width of $H\alpha$, and environmental context. For Object C, the A-type classification is secure, but the exact luminosity class is less certain. For Object D, the extragalactic interpretation is strong if the proposed line identifications are correct; higher-resolution spectroscopy would allow more precise redshift and line-ratio measurements.

6. CONCLUSION

We classified four astronomical sources using photometry, Gaia astrometry, multiwavelength imaging, Gaia H–R diagram placement when meaningful, and optical spectroscopy.

1. Object A is best classified as a late-type M giant, approximately M5 III. Its very red color, infrared brightness, cool-star spectrum, strong red continuum H–R diagram consistency, and TiO molecular bands absorption similarity to late M type giant comparison spectra support this conclusion (Gray 2000; Berlind et al. 2003; Gray & Corbally 2009). Its distance remains uncertain because the Gaia parallax has a large fractional uncertainty.
2. Object B is most consistent with a young stellar object or classical T Tauri-like star. Its reliable Galactic parallax, infrared brightness, approximate H–R diagram position, and strong $H\alpha$ emission indicate an active emission-line stellar

source (Berlind et al. 2003; Kenyon & Hartmann 1995).

3. Object C is best classified as an A-type star. Its nearly zero color index, blue continuum, strong Balmer absorption lines, comparison spectrum, and hot luminous H–R diagram position support this classification (Berlind et al. 2003; Gray & Corbally 2009). Its luminosity suggests that it may be somewhat evolved.
4. Object D is most likely a redshifted emission-line galaxy, possibly a starburst galaxy. Its narrow emission lines are consistent with H α , H β , [O III], and [O II] at $z \approx 0.039$ (Baldwin et al. 1981; Keel 1996). It is not placed on the Gaia H–R diagram because it lacks reliable Gaia astrometry and is not best interpreted as a stellar source.

Overall, the analysis demonstrates that robust astronomical classification requires combining several inde-

pendent types of evidence. Photometric colors provide a first estimate of source temperature or reddening, Gaia astrometry separates nearby Galactic objects from distant sources, the Gaia H–R diagram provides an additional consistency check for stellar sources, and spectroscopy provides the strongest physical diagnostics through absorption lines, emission lines, and redshift measurements.

- 1 This work was completed as part of an astrophysics
- 2 laboratory project. The analysis made use of multiwave-
- 3 length imaging, Gaia astrometric information, catalog
- 4 photometry, FAST optical spectra, and Gaia H–R dia-
- 5 gram information provided for the mystery-object clas-
- 6 sification exercise. The comparison spectra used in this
- 7 work were obtained from publicly available online spec-
- 8 tral atlases and astronomical reference pages.

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