Search for Flares in M Dwarf (GJ 3147) using Polarimetric Data

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Abstract

Flare detection in M-dwarf stars using polarimetry offers a unique perspective on understanding the underlying physical processes driving these energetic events. M dwarf stars, being highly active, exhibit flares that release substantial amounts of energy in various wavelength ranges. In this study, we present an innovative approach for flare detection in M dwarf stars by harnessing polarimetric observations.

Polarimetry involves measuring the polarization properties of light, which can provide valuable insights into the magnetic fields and geometry associated with flaring regions. We leverage polarimetric data obtained from ground-based telescope (1.04-m Sampurnanand Telescope) equipped with sensitive polarimeter. Our methodology focuses on analyzing the temporal in polarization signals during flaring events.

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Chapter 1

Introduction

1.1 Introduction

Late-type stars with magnetic activity exhibit surface irregularities that can result in fluctuations in their spectral lines and light curves. The uneven arrangement of magnetic regions on the surfaces of late-type dwarfs can also generate a wide-range linear polarization . Consequently, it is anticipated that the polarization of the combined stellar light will vary in conjunction with the stellar activity phenomenon.

Dominique Francois Jean Arago conducted the initial polarization measurements in optical wavelengths during the early 19th century. Nevertheless, it wasn't until the late 1960s that optical polarimetry gained widespread popularity as a method for astrophysical observations. This transformation was facilitated by the increased adoption of sensitive photoelectric detectors like photomultiplier tubes (PMTs) and charge-coupled devices (CCDs) in optical photometry and spectroscopy.

PMTs and CCDs have significantly improved the signal-to-noise ratio (S/N) for measuring optical polarization, even when dealing with low fluxes from astronomical objects. CCD cameras, being panoramic or multi-cell detectors, enable the simultaneous measurement of polarization in multiple elements of an image or spectrum. The introduction of these new detectors has led to the development of powerful polarization devices and innovative techniques for polarization measurements. (4)

1.2 Optical Polarimetry

Optical polarimetry in astronomy is the study of the polarization of optical (visible) light emitted or scattered by celestial objects. This technique allows astronomers to gain valuable insights into various astronomical phenomena, including the characteristics of light sources, the presence of magnetic fields, and the properties of interstellar and intergalactic matter.

To perform optical polarimetry, specialized instruments called polarimeters are used, which are equipped with polarizing elements that can measure the polarization state of incoming light. The data obtained from polarimeters are then analyzed to determine the degree and angle of polarization of the observed light, providing valuable information about the physical processes and properties of the celestial objects under study.

Currently, optical polarimetry has become a well-established observational tool, widely utilized on both small and large optical telescopes to study a diverse range of astrophysical objects, spanning from planets to active galaxies. Notably, at the EWASS 2018 meeting, it was highlighted that since the year 2000, approximately 4000 refereed publications on optical polarimetry have been published, underscoring the significant impact and prevalence of this field of research.

1.3 M-Dwarfs

An M-dwarf, also known as a red dwarf, is a type of main-sequence star that belongs to the smallest and coolest category of stars. These stars are the most abundant in the universe, making up about 70% of all stars.

Active M-dwarfs are M-dwarf stars that exhibit heightened levels of magnetic activity compared to typical M-dwarfs. This increased activity is often characterized by strong magnetic fields and a variety of phenomena, including flares and stellar spots (similar to sunspots on the Sun). These active events can release significant amounts of energy, leading to dramatic changes in brightness and emission across the electromagnetic spectrum.

Previously studies has been done on different magnetically acitve M dwarfs like for example **WOLF 359**, an M6.5 dwarf was studied by H.T Lin et al (3), they detetcted optical flares in the star using optical polarimetry.

1.4 Our Target Star

This project focuses on the detection and confirmation of a flare in the M dwarf star GJ3147. By combining the utilization of IRAF tasks and Python scripts, we aim to unravel the mysteries surrounding this celestial event and gain deeper insights into the behavior of M dwarf stars. Our Target star, GJ3147 (RA: 02 17 10.0181389739, DEC:+35 26 32.541896954), is an active red dwarf which falls in the category of eruptive variables.

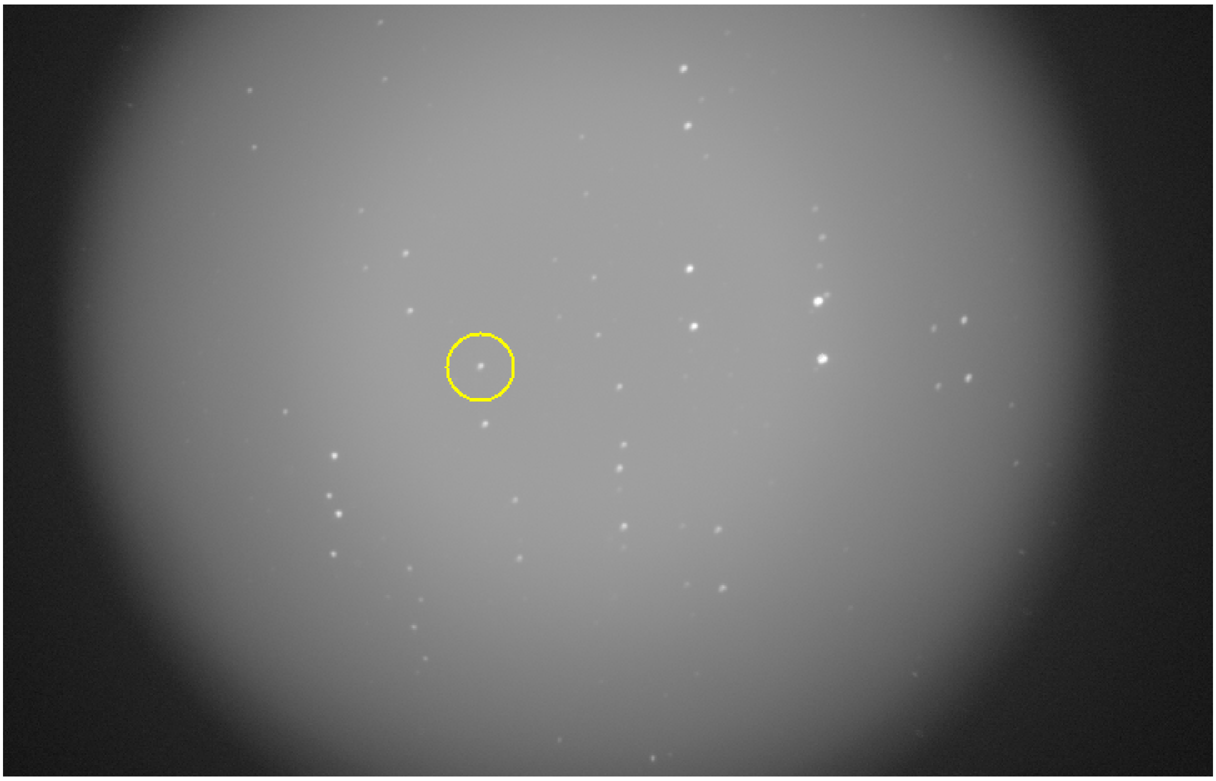

FIGURE 1.1: Marked picture of Target star GJ 3147

1.5 Study Objective

The main objective if this study is to use the polarization parameters to confirm the presence of the flare in the target star GJ 3147. The data for the project is taken from Sampurnanand Telescope (104 cm) located on Manora Peak, Nainital. The data was taken between 11 Nov. 2021 to 17 Nov. 2021.

Chapter 2

Dataset parameters

The primary dataset for our investigation was obtained from the Sampurnanand Telescope (104 cm) during the period of 13th to 17th November 2021, specifically in the R band. The imaging process utilized a CCD camera with a resolution of 1024×1024 pixels. Each individual pixel on the CCD corresponds to an angular size of 1.73 arcsec. The entire field of view covered by the CCD is approximately 8 arc-min in diameter when observing the sky. The CCD has a readout noise of 7.0 eand a gain of 11.98 e/ADU. In the case of linear polarimetry, the retarder (Half-wave plate) was rotated at intervals of 22.5 degrees between exposures. As a result, one polarization measurement was obtained from every four exposures, specifically at retarder positions of 0 degrees, 22.5 degrees, 45 degrees, and 67.5 degrees. Each frame contains ordinary and extraordinary images of a single source. The exposure time was taken as 90 sec and 60 sec.

2.1 Procedure

All the data taken from the sampurnanand Telescope is pre processed using Python scripts, PyRAF and IRAF. Following steps were taken to process the data-

- The raw data from Sampurnanand Telescope is in form of 3D array which is then converted into 2D array using the **imcopy** task of IRAF.
- The bias frames from that particular day are consolidated using **zerocombine** task of PyRAF. Median is taken using all the bias frames.
- This consolidated bias is then removed from all the frames using **imarith** task of IRAF.
- All the frames are then cleaned by removing the cosmic rays from the frames using the **cosmicrays** task of PyRAF.
- All the frames are aligned using a python script.
- A coordinate file is created of the target star with some refernce stars.
- Then **Phot** task is performed on the pre processesd frames to produce mag files.
- The value of flux is taken from the mag file and then further used to calculate the polarization value and angle.

2.1.1 Polarization value calculation

Calculation of the polarization value and angle is performed using the following relations (1)-

$$R(\alpha) = \frac{\frac{I_0}{I_E} - 1}{\frac{I_0}{I_E} + 1} = P\cos(2\theta - 4\alpha) \tag{2.1}$$

$$P = \sqrt{p^2 + q^2} \tag{2.2}$$

Where P is the degree of polarization and θ is the polarization angle, I_0 and I_E are the intensities of the ordinary and extraordinary sources respectively. p and q are the normalised stokes parameter. These can be defined as R(0) and R(22.5) respectively. For converting the magnitudes from the mag. file to intensities following relation is used

$$\frac{I_0}{I_E} = 2.512^{(m_E - m_0)} \tag{2.3}$$

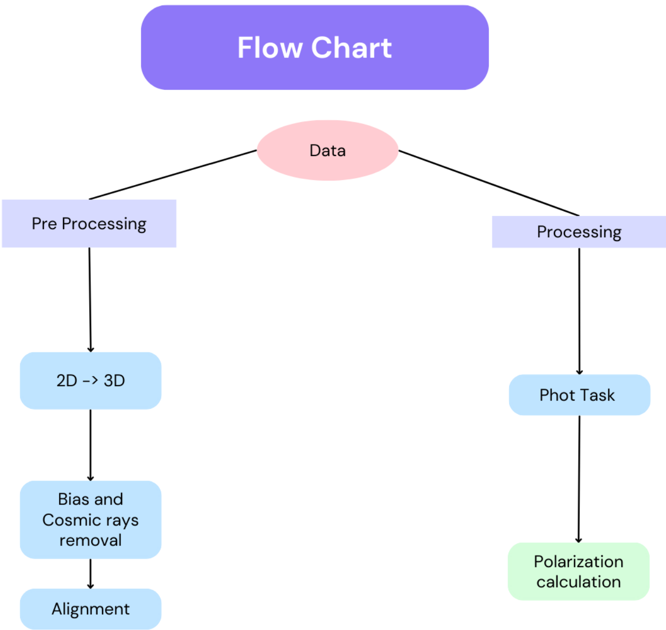

FIGURE 2.1: Flow chart of the procedure

2.1.2 Polarization angle calculation

The polarization angle is calculated for the frames of target star. To calculate this, following relation was used-

$$\theta = 0.5 \arctan(q/u) \tag{2.4}$$

Where q and u are the stokes parameter for the target star.

Chapter 3

Analysis and Conclusion

3.1 Analysis

The degree of polarization and corresponding angle of the target star in R filter is given in table 1. Table 2 contains normalised stokes parameters(p & q) for the target star. We have plotted polarization of the target star in R band with the Julian Day(JD).

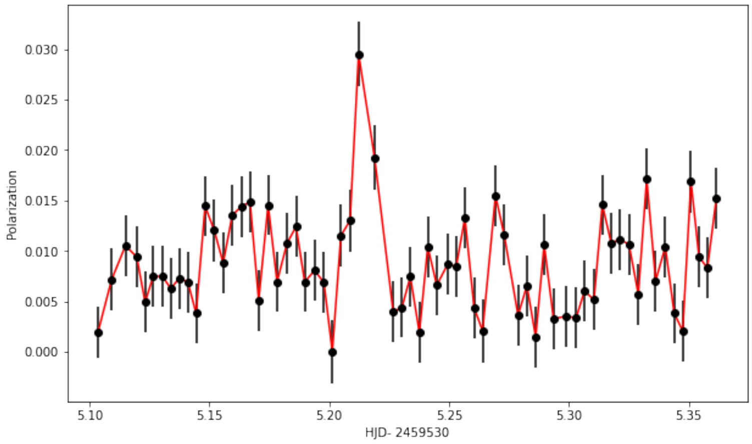

FIGURE 3.1: R band polarimetric lightcurve of GJ3147 on 16^{th} Nov. 2021

The distinguishable peak in the figure 1 between 5.20 and 5.25 JD shows the presence of a flare in the target star on 16 Nov. To confirm this detection of the flare in our target star we plotted the varation of stokes parameter with time on the same day (figure 2).

The plot of the stokes parameter also shows the presence of peak in the values of the p and q at the same JD as the figure 1. The peaks in figure confirms the presence of a flare in the target star.

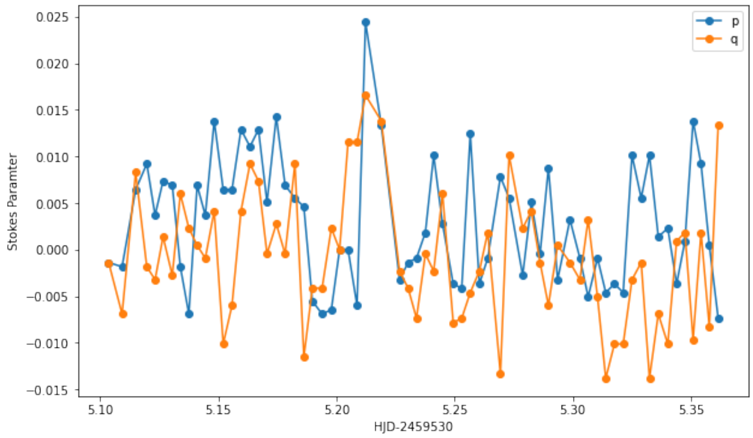

FIGURE 3.2: Stokes parameters of GJ3147 on 16^{th} Nov. 2021

3.1.1 Flare Energy

The energy released by a flare can vary widely depending on the characteristics of the star and the specific flare event. Flares in M dwarf stars, for example, are known to be particularly energetic. The energy released by a flare is often estimated by integrating the flare's emission over time and across different wavelengths.

Initially, the flux values of the observed light curve, represented as $f(t)$, are adjusted by subtracting the detrended quiescent stellar count. This is achieved by employing a linear fit to the flux measurements outside of the event region. The resulting adjusted light curve is then normalized by dividing it by the detrended quiescent stellar count within the spectral filter, denoted as f_0. To estimate the released energy based on this normalized light curve, we adopt the $\Delta f/f_0$ ratio, calculated as $(f(t) - f_0)/f_0$. This methodology follows the equivalent duration method originally described by Gershberg in 1972.

The total flare energy is estimated from the bolometric luminosity of the star multiplied by the equivalent duration:

$$E_{flare} = \alpha L_* \int \frac{\Delta f}{f_0} dt \tag{3.1}$$

where α is the constant accounting for the correction for the blackbody assumption and the filter response. Taking the stellar temperature as 2900 K, α of 0.11 for the standard Johnson–Cousins R filter, $L_* = 1.25 * 10^{-3} L_\odot$ leads to the derivation of the flare energy, E_{flare} released in an event. Note that this method assumes the flare temperature to be constant throughout the event, and the behavior of the flare is the same in all spectral bands.

On plugging in the values, the energy of the flare released from the GJ3147 M Dwarf is :

$$E_{flare} = 1.73 * 10^{31} erg$$

A standard flare in the M Dwarf releases energy in between $10^{31} - 10^{34}$erg while in case of fast rotators this energy can go up to 10^{35}erg .

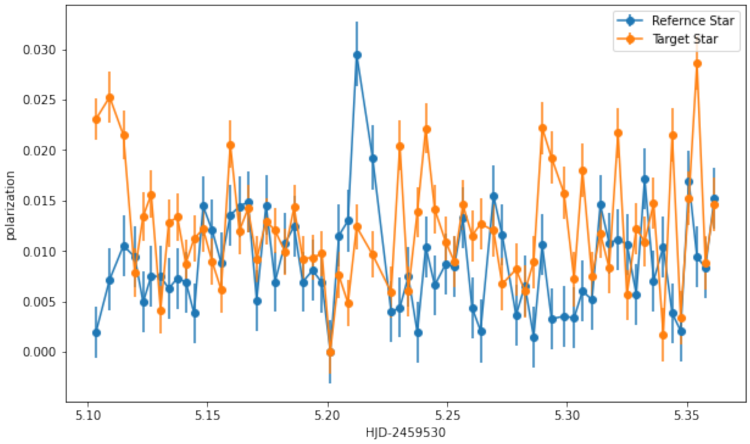

FIGURE 3.3: Comparison of GJ 3147 and a reference star on 16^{th}Nov.

3.1.2 Polarization Angle

The polarization angle is calculated for the frames of target star. To calculate this, following relation was used-

$$\theta = 0.5 \arctan(q/u) \tag{3.2}$$

Where q and u are the stokes parameter for the target star.

JD	Polarization %	Pol. Error %	Pol. Angle	Pol. Angle error
2459535.1037	0.1954	0.2520	22.5111	0.6448
2459535.1094	0.7149	0.3058	7.4695	0.2139
2459535.1151	1.0502	0.3060	18.9469	0.1457
2459535.1198	0.9393	0.3047	-39.3643	0.1622
2459535.1233	0.4896	0.3026	-24.4190	0.3090
2459535.1267	0.7497	0.3045	39.7096	0.2031
2459535.1306	0.7440	0.3023	-34.1160	0.2031
2459535.1340	0.6264	0.3017	-8.5557	0.2409
2459535.1376	0.7282	0.3012	-35.8000	0.2068
2459535.1411	0.6923	0.3020	43.1142	0.2181
2459535.1446	0.3798	0.3007	-38.0006	0.3959
2459535.1483	1.4424	0.3012	36.6680	0.1044
2459535.1521	1.2009	0.3032	-16.2439	0.1262
2459535.1558	0.8798	0.3039	-23.5721	0.1727
2459535.1597	1.3544	0.3004	36.1079	0.1109
2459535.1634	1.4387	0.3009	25.1094	0.1046
2459535.1670	1.4851	0.3025	30.1419	0.1019
2459535.1707	0.5087	0.3007	-42.4236	0.2956
2459535.1746	1.4541	0.2997	39.5421	0.1030
2459535.1783	0.6923	0.3008	-43.1142	0.2172
2459535.1825	1.0741	0.2999	15.4897	0.1396
2459535.1862	1.2400	0.3001	-10.9064	0.1210
2459535.1898	0.6908	0.2987	26.5781	0.2162
2459535.1939	0.8056	0.3000	29.5325	0.1862
2459535.1979	0.6846	0.3031	-35.1903	0.2214
2459535.2014	0.0000	0.3150	-0.2253	4.8016
2459535.2049	1.1513	0.3067	0.0000	0.1332
2459535.2087	1.2977	0.3103	-13.7444	0.1196
2459535.2123	2.9502	0.3164	27.9193	0.0536
2459535.2190	1.9215	0.3219	22.0254	0.0838
2459535.2267	0.3962	0.2991	27.2446	0.3775
2459535.2303	0.4369	0.2984	9.2221	0.3415
2459535.2339	0.7426	0.2980	3.5643	0.2006
2459535.2376	0.1899	0.2999	-38.0006	0.7896
2459535.2411	1.0390	0.3010	-38.6167	0.1449
2459535.2449	0.6594	0.2974	12.3938	0.2255
2459535.2494	0.8653	0.2992	12.6069	0.1729
2459535.2530	0.8454	0.2973	14.6863	0.1758
2459535.2566	1.3259	0.3018	-34.8552	0.1138
2459535.2605	0.4345	0.3043	29.0116	0.3502
2459535.2640	0.2060	0.3121	-13.2891	0.7576
2459535.2694	1.5480	0.3007	-15.1975	0.0971
2459535.2730	1.1541	0.3019	14.3126	0.1308
2459535.2788	0.3597	0.2980	-25.1096	0.4143
2459535.2825	0.6545	0.3002	25.3677	0.2293

FIGURE 3.4: Data from 16^{th} Nov.

3.2 Conclusion

- The analysis of the polarization data from 16^{th} November confirms the detection of a flare in the target star GJ 3147.
- A peak in the polarization plot confirms the presence of the flare.
- The energy of the flare is $1.73 * 10^{31} erg$ which lies in the standard flare energy range.

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