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SUMMIT
SOFIA UNIVERSITY MARKING MOMENTUM FOR INNOVATION AND TECHNOLOGICAL TRANSFER

SOFIA UNIVERSITY - MARKING MOMENTUM FOR INNOVATION AND TECHNOLOGICAL TRANSFER

National Recovery and Resilience Plan
OF THE REPUBLIC OF BULGARIA

Study of High-luminosity Objects in the Field of Galaxies from the Local Volume

Introduction

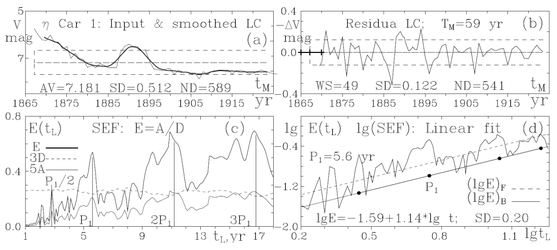
- The current survey covers objects (stellar and non-stellar) with the highest luminosity that are present in the field of galaxies from the Local Volume (falling within a radius of ~11 Mpc from the Sun).
- All scientific results obtained in this study are related to the acquisition of new fundamental knowledge through observations, astronomical images processing, data analysis and interpretation of the results.

Project Guidelines

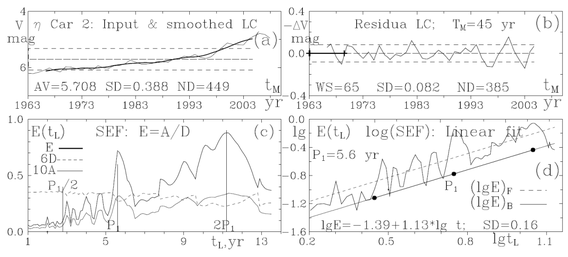
- Globular clusters (GC) are high-luminosity objects in the Milky Way (Harris 2010, arXiv, 1012, 322) and M31 galaxy (Agar & Barmby 2013, AJ, 146, 135). Ellipticity is their important structural parameter that shows a correlation with their luminosity, size, metallicity, age, etc. There are indications that GC associated with X-ray sources have smaller ellipticity, which indicates their dynamical evolution, due to the loss of angular momentum and the slowing down of their rotation due to the evaporation of stars (Baumgardt et al., 2022, MNRAS, 510, 3531).
- High luminosity stellar objects in galaxies are the massive and rare luminous blue variables (LBV). They are characterized by variability on different time scales. The largest changes in their brightness are associated with spontaneous ejections of solar mass over tens of years, but smaller changes in brightness over weeks and months are also recorded. The study of these objects is crucial for understanding the physics and evolution of these massive stars, as well as for the various mechanisms responsible for their variability.
- Another high luminosity stellar objects in galaxies are the transients such as novae (classical, recurrent, dwarf). These objects are important for studying the physics of the explosions in these systems and their physical characteristics, as well as their use as distance indicators in the Universe (Kasliwal et al. 2011, *ApJ*, 735, 94). The study of recurrent novae, especially those with short periods, is important because of their association with type Ia supernovae (Hachisu et al. 1999, ApJ, 519, 314). Due to the unpredictability of these transients, their detailed study is very difficult.
- Quasars are the objects with the highest known luminosity in the Universe. They are powered by the accretion of matter into supermassive black holes at the centers of distant galaxies (Lynden-Bell 1969, Nature, 223, 690). Their study in the fields of nearby galaxies is important because they set a fixed reference frame for astrometric measurements, allow the absorption in intervening galactic discs to be determined, and probe the kinematics and chemical composition of the galactic medium.

Periods in the Historical Light Curve of the LBV star η Car

Periods in the historical light curve (LC) of η Car (Fernández-Lajús et al. 2009) using Structure Eminence Function (SEF) are derived. The analysis is performed on two selected parts (1 and 2) from the residual LC - the difference between the uniformly resampled and large scale trend removed LC.



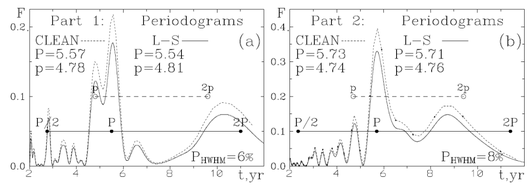
SEF method (Georgiev 2023, BAJ, 38) reveals the repeating structures with maximum internal amplitudes and the corresponding time lengths, i.e. periods or quasi-periods. Larger counterpart QPs 2P, 3P, etc., as well as shorter ones like P/2 are also identified.



Results:

- Detected major photometric period is 5.6 ± 0.1 yr in the time intervals 1867–1926 (Part 1) and 1963–2008 (Part 2). This result corresponds well to the system's orbital period of 5.54 yr, derived by Damineli et al. (2008).
- A minor period of 4.8 yr, better pronounced in the Part 1, is also detected.

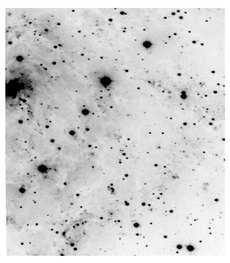
The considered LC parts are also analyzed with the CLEAN and Lomb-Scargle periodogram methods (see figures below). Parts 1 and 2 contain the average major periods of 5.56 and 5.72 yr, respectively. The average minor periods have 4.80 and 4.75 yr, respectively. The results coincide with the results obtained by the SEF method.

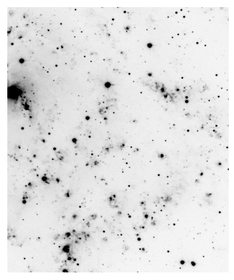


Our Goals

- Determine unmeasured structural parameters of GCs in the Milky Way and M31 galaxy, and search for a relationship with their X-ray luminosity.
- Follow, analyze, and physically interpret the changes in brightness of LBVs and other variables through optical light curves and spectra. Measure the amplitude of brightness variation on arbitrary time scales and show the presence of potential quasi-periodicity.
- Detection and photometric classification of novae and recurrent novae in nearby galaxies (M31, M33, M81, etc.). Determining the spatial distribution of different types in different galaxies (Williams et al. 2016, ApJ, 817, 143) and their progenitors.
- Discovery and spectral confirmation of unknown quasars and search for periodic quasars in the field of M31. Also, obtaining their redshifts through the prominent broad emission lines.

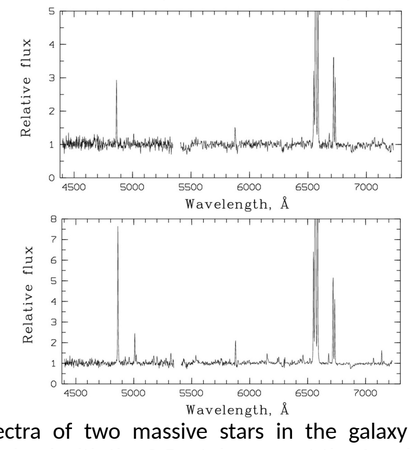
Search and Study of the Brightest stars in IC342 Galaxy





Selected fields from the images of IC 342 obtained with the 2m telescope at NAO Rozhen in filter B (top) and Hα (bottom).

Based on archival images from the Hubble Space Telescope and images from the 2m telescope at Rozhen Observatory (Bulgaria), candidates for massive stars in IC342 were selected. Spectral observations of 24 out of 27 selected stars were carried out using the 6m BTA telescope of the SAO RAS and the 3.5m Apache Point telescope (USA).



Spectra of two massive stars in the galaxy IC 342 obtained with the 3.5m telescope at the Apache Point Observatory. **Above** - object F7.1 – spectroscopically classified as a B[e] supergiant and **below** - object F7.3 - classified as a luminous blue variable (LBV).

Results from the spectral analysis:

- 12 O9-A5 supergiants and young compact clusters;
- 7 WR stars or compact clusters, containing WR stars;
- 2 LBV in cold condition; 1 B[e] supergiant;
- 1 compact supernova remnant; 1 star from the MW.

Novae in M31

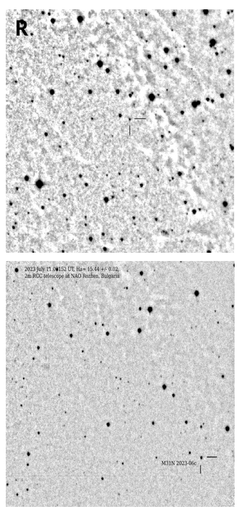
Astronomical observations of M31 galaxy in the BRHα optical filters with 2m RCC and 50/70 cm Schmidt telescopes at NAO Rozhen, Bulgaria, were conducted. Novae search in M31 galaxy was performed.

Results:

A transient object with variable brightness was discovered on 2023 June 23.9939 UT with the 50/70 cm Schmidt telescope at Rozhen NAO. (ATel #16095), https://www.astronomerstelegram.org/?read=16095).

The strong rise in 24 hours and the color of the transient lead to the conclusion that this is a nova candidate in M31.

- 2023 June 23.9939 UT; R=18.81 ± 0.07 mag (5x300 sec)
- 2023 June 24.9979 UT; R=17.64 ± 0.03 mag (5x300 sec)
- 2023 June 25.0021 UT; B=17.97 ± 0.03 mag (3x300 sec)

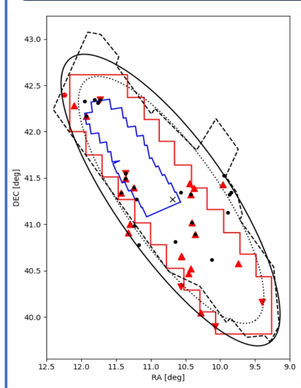


The object was subsequently classified as a nova based on Hα narrow-band observations with the focal reducer FoReRo2 at the 2m telescope at NAO Rozhen (ATel #16127), https://www.astronomerstelegram.org/?read=16127.

- 2023 July 11.00152 UT: Ha=15.44±0.02 (3x300s);
- 2023 July 11.00993 UT: R=18.16±0.03 (3x120s).

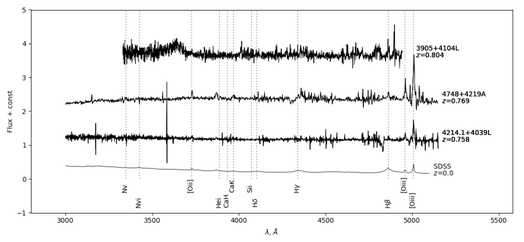
Additional R-band observations show that the object is slowly fading in brightness.

QSOs behind the Disk of M31 Galaxy



Map of known quasars behind the disk of M31 until 2019 (triangles) and 2023 (circles).

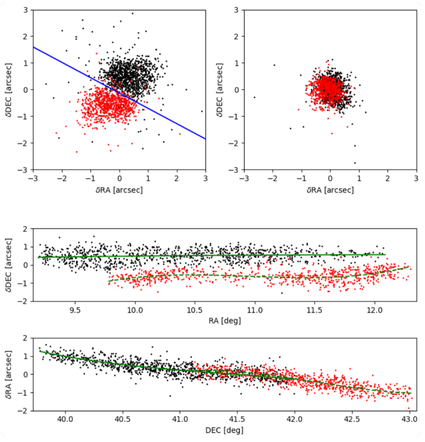
Spectra of 3 quasars at redshift z≈0.8 in the field of M31 galaxy obtained with the Apache Point Observatory 3.5m telescope (middle) and the Xinglun Observatory 4m telescope (top and bottom in the figure below) are shown.

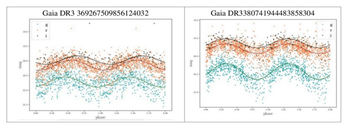


Refining the coordinates of IR point sources from the Spitzer mission (2017) for more accurate optical identification of quasar candidates behind the disk of M31.

Obtained results:

- A spectral analysis of 32 quasar candidates was performed, of which 22 objects were confirmed as quasars.
- A list of 183 candidates with known spectroscopic redshift was prepared.
- Among 336 quasars, 11 objects behind the disk of M31 with a periodic variation in brightness were found.

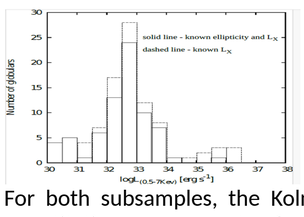




Properties of Milky Way Globular Clusters with X-ray Sources

Statistical comparison of 89 Milky Way globular clusters (GC) with different integral X-ray luminosity is performed. Main clusters' parameters are collected from literature.

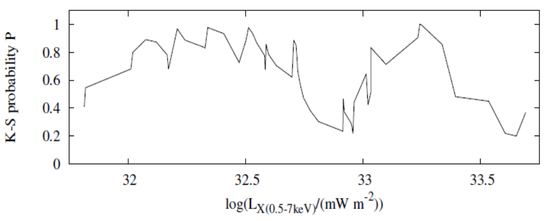
- The clusters integral X-ray luminosities have been estimated by the average X-ray fluxes of individual sources detected in Chandra, XMM-Newton, Swift, Beppo-Sax.



X-ray luminosity function (solid line) within 2 core radii for all 89 GCs (72 GCs has known ellipticity - dashed line) was used to create samples of high- and low-luminosity clusters (18 and 71 clusters, respectively).

For both subsamples, the Kolmogorov-Smirnov (K-S) test was applied to make a quantitative assessment of the statistical distinguishability of them, for the parameters ellipticity, eccentricity of the orbit and number of intermediate mass black holes.

- Confidence level of statistically different ellipticity, by K-S test, between a sample with high- and with low X-ray luminosity (see figure in the right).



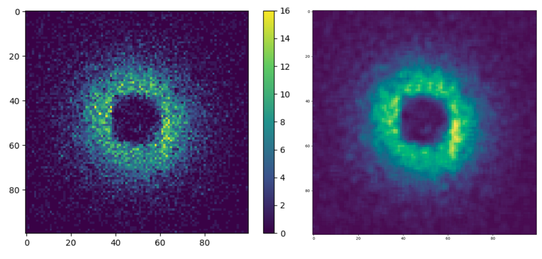
Results:

- The high X-ray luminosity clusters have lower ellipticity and higher eccentricity compared to the low X-ray luminosity clusters, but at significantly lower confidence levels of 80%.
- The test results show that at a confidence level of 99.9%, the high X-ray luminosity clusters have fewer black holes with intermediate mass than the low X-ray luminosity clusters.

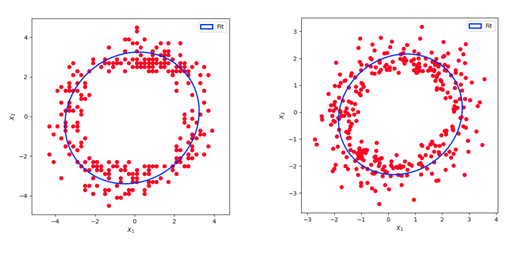
Conclusion

- Within the framework of the project, the active study of high-luminosity stars in galaxies from the Local Volume continues, as well as the active search and study of the properties of novae (classical and recurrent) in the nearby galaxies M31, M33, M81.
- Ongoing studies are focused on determining previously unmeasured structural parameters (ellipticity, position angle, center, etc.) for globular clusters and searching for correlations with their X-ray luminosity.
- Research continues on the discovery of previously unknown quasars, confirmation of their nature through spectral observations and the search for periodic changes in their luminosity.

Ellipticity of the Globular Cluster M2



Maps of the true stellar density (left) and 3x3 boxcar averaged stellar density (right) in the 20'x20' field centered at the globular cluster M2. The colored wedge shows the densities based of the BV photometry of Lee et al.(1999). The maps will be used to derive precise ellipticity, position angle and center coordinates. North is to the top, East is to the right and coordinates are in pixel units.



Results from ellipse fitting of the space distribution of the pixels (red dots) with the highest stellar density (left) and real stars (right) within a certain photometric color-magnitude intervals in field of the globular cluster M2. North is to the top, East is to the left and coordinates are in armin units.

Research field:

Astronomy and Astrophysics

Head of the research group

Assoc. Prof. Antoniya Valcheva

Members of the group

Assoc. Prof. Petko Nedialkov
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