Ultraviolet and Infrared Correlation Studies in Orion

Article *in* Baltic Astronomy an International Journal · September 2015

DOI: 10.1515/astro-2017-0233

Sujatha N V
St. Xavier's College for Women, Aluva, India

Narayanankutty Karuppath
Amrita Vishwa Vidyapeetham

Baltic Astronomy, Vol. 24, p. 319-326

Ultraviolet and infrared correlation studies in Orion

Lakshmi S Bose[1] and N V Sujatha[2] and K Narayanankutty[3]

[1,3] *Amrita Vishwa Vidyapeetham, Amritapuri, Kollam, Kerala*

[2] *St. Xavier's College for Women, Aluva, Kerala*

Abstract. We have studied the variation of diffuse Ultraviolet (UV) radiation from the constellation of Orion using a set of eight All-Sky Imaging Surveys (AIS) of GALEX in the Far-UV and Near-UV and present here the preliminary results of the analysis. Different components of diffuse UV radiation from the region like Airglow, Zodiacal light, Dust Scattered Emission, H_2 Fluorescence, etc. were quantified and separated after removing the point sources from each of the fields. We then studied the dependence of individual UV components with parameters, such as solar activity, Sun angle and Infrared 100 micron intensity, etc., specific to each of the UV components. We did not find any positive correlation between diffuse-UV and IR-100 micron intensity, probably due to the high optical depth of the region or the entire dust column not contributing to the diffuse radiation. However we noticed the presence of an excess emission in addition to the dust scattered radiation in FUV which is clearly absent in NUV. This excess emission identified as H_2 Fluorescence is produced by Trapezium Stars from the molecular clouds. We also compare our results with that of the previous studies in the region with spectroscopic observations of Far Ultraviolet Spectroscopic Explorer (FUSE).

Key words: GALEX obseservations: Foreground & Background emmision: Correlation studies

1. INTRODUCTION

Carruthers & Opal (1977) first identified the Orion Nebula (M42), located at a distance of about 420 pc from the Earth, as one of the brightest diffuse sources in the ultraviolet (UV) sky due to the dust scattered radiation from bright Orion stars - well described and modeled by O′Dell (2001). Intense UV emission in this region has been observed by International Ultraviolet Explorer (Mathis et al. 1981, Murthy et al. 2005, France et al. 2005) and is presumed to be mainly due to forward scattering of starlight from the brightest Trapezium star θ^1 Ori C, by dust close to and in front of the star. It is also established that the scattering is not actually from the Orion nebula, which is defined as a region of ionized gas in front of the molecular cloud, but is rather from the neutral cloud in the same direction (Shalima et al. 2006). Previous observations of H_2 emission have been limited to weak transitions arising in UV. We present here an analysis of the high quality observations of Galaxy Evolution Explorer (GALEX) in the region of Orion, which has more accurate results for the variation of diffuse UV radiation.

GALEX, an orbiting space telescope, was launched into a nearly circular low-Earth orbit with a mean altitude of 690 km, an orbital inclination of 29°, and an orbital period of 98 minutes with ∼2100 sec orbital nights by a Pegasus XL launch in April 2003 by NASA. Using a 50 cm telescope, GALEX has obtained

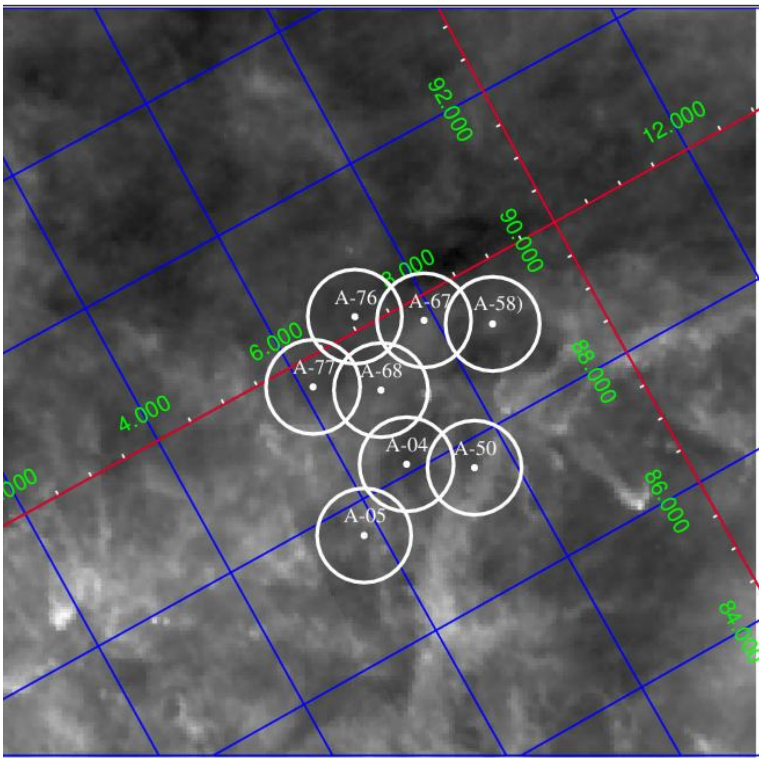

Fig. 1. GALEX field of view of 8 targets in Orion region in equitorial coordinates are over plotted as circles with diameter of 1.25 within 10° IRIS 100μm map.

over 45,000 observations covering about 80% of the sky in two ultraviolet bands (far-ultraviolet, FUV: 1350 − 1750 $\AA$ and near-ultraviolet, NUV: 1750 − 2850$\AA$) using a high-efficiency dichroic beam-splitter with $5'' - 7''$ resolution (FWHM) and $<1''$ astrometric accuracy. Detailed description about the mission and its calibration are given in Martin et al. (2005) and Morrissey et al. (2007) respectively. GR6/GR7 is the latest complete release of data and is available in FITS file format in the Space Telescope MAST archive.

Using spectroscopic FUSE data, Murthy et al. (1999) traced the diffuse emission from the region in FUV (905 − 1187$\AA$) and found the intensity to be as high as 3×10^5photons cm^{-2}sr^{-1}s^{-1}Å^{-1}. Such data can also be used to study the spectral properties of interstellar dust in the region and the origin of diffuse emission (Murthy et al. 2004). In 2006, the modeling of diffuse FUV spectrum of FUSE near M42 as starlight scattered by the interstellar dust from Trapezium stars in front of Orion nebula by Shalima et al. found that the brightest star in the region, θ^1 Ori C, alone can produce 65% of the total dust scattered radiation. Murthy et al. (2001) and Haikala et al. (1995) found that the diffuse FUV emission in the region is tightly correlated with IR 100 micron intensity.

2. OBSERVATIONS AND DATA ANALYSIS

A single GALEX observation is made up of number of visits and the standard

Table 1. Observations of Eight AIS GALEX targets nearer to Galactic Plane.

Tile Name	R.A (deg)	Dec (deg)	gl (deg)	gb (deg)	NUV exptime(s)	FUV exptime(s)
AIS-289-sg04	88.12	6.73	200.56	-9.86	224	224
AIS-289-sg05	87.56	5.78	200.62	-8.88	112	112
AIS-289-sg50	87.64	7.49	199.14	-9.91	112	112
AIS-289-sg58	89.20	8.63	198.90	-8.00	112	112
AIS-289-sg67	89.69	7.85	199.82	-7.95	93	93
AIS-289-sg68	89.15	6.91	200.40	-8.88	112	112
AIS-289-sg76	90.18	7.07	200.75	-7.91	93	93
AIS-289-sg77	89.63	6.14	201.31	-8.84	112	112

pipeline produces a single image per channel per visit by combining all observed events. Eight All Sky Survey (AIS) of GALEX observations of sky in Orion constellation were examined here. Observation details are tabulated in Table 1 and the GALEX FOV are marked in IRIS-100μm image in equatorial coordinates (Fig 1). The exposure time for the studied targets are of the order of a few hundreds both in FUV and NUV bands. The GALEX observed regions in the constellation are optically thick, and its variation is tabulated in Table 2. The bulk of the radiation in all of the GALEX images is the diffuse radiation which has two parts, foreground and background. The point sources are only a fraction (less than 7%) of the total signal. The diffuse background images were separated following the procedure described by Sujatha et al. (2009 2010) and re-binning the images into 2 arcmin resolutions. The diffuse UV data thus obtained for the region was studied after removing the edge effects by using only the central 1.15° of GALEX Field of View (FOV:1.25°). This data contains instrumental dark count, zodiacal light in NUV, airglow, dust scattered radiation, H_2 fluorescence in FUV, etc.

3. FOREGROUND EMISSION

nstrumental dark count in the GALEX observations is only about 5 photons cm^{-2}sr^{-1}s^{-1}Å $^{-1}$ (Sujatha et al. 2009). The contribution of airglow emission from Earths ionosphere is considered as negligible - less than 5% of the total radiation in the region - and therefore is ignored in this study. Zodiacal light - the sunlight scattered by interplanetary dust grains is one of the significant contributor to diffuse NUV and it depends upon angle from the Sun and distance from the ecliptic plane. Here we have estimated its contribution using the optical distribution of Zodiacal light by Leinert et al. (1998) assuming that the ratio between the zodiacal light and the solar spectrum is same at all wavelengths. We have found that its contribution to NUV observations of the region is of the order of 792$\pm$14 photons cm^{-2}sr^{-1}s^{-1}Å^{-1} as shown in Table 3. It should be re-emphasized that there is essentially no zodiacal light contribution to the FUV channel.

4. BACKGROUND EMISSION

The UV photons whose energy is higher than the Lyman limit, is absorbed in the $H_I I$ region, and the far UV radiation (6eV< Ephoton<13.6 eV) penetrates through the surface of the nearby molecular clouds. Major part of the observed diffuse background in any region is dust scattered radiation of starlight. However the contribution through fluorescent H_2 emission and hot line emissions are also significant in the molecular clouds. Sahnow et al. (2000) and Shalima et al.

Table 2. Variation of optical depth in each observation.

Tile Name	Optical depth
AIS-289-sg04	2.7 − 9.0
AIS-289-sg05	3.8 − 8.3
AIS-289-sg50	3.0 − 7.5
AIS-289-sg58	2.6 − 5.1
AIS-289-sg67	2.6 − 8.7
AIS-289-sg68	3.1 − 6.5
AIS-289-sg76	3.0 − 5.0
AIS-289-sg77	3.6 − 9.0

Table 3. Calculation of Zodiacal light contribution(PU) in NUV.

Tile Name	λ_{loc} (ecl)	β_{loc} (ecl)	λ_{sun}	β_{sun}	$\lambda_{loc} - \lambda_{sun}$	Zodiacal Light
AIS-289-sg04	267.81	-16.63	100.13	-0.0618	167.68	778.2
AIS-289-sg05	267.22	-17.57	100.13	-0.06164	167.08	764.8
AIS-289-sg50	267.33	-15.86	100.04	-0.06164	167.2	792.3
AIS-289-sg58	268.95	-14.75	100.03	-0.06186	168.91	812.4
AIS-289-sg67	269.44	-15.53	100.07	-0.06186	169.37	800.5
AIS-289-sg68	268.88	-16.47	100.12	-0.06186	168.76	782.0
AIS-289-sg76	269.94	-16.30	100.11	-0.06186	169.83	786.1
AIS-289-sg77	269.37	-17.24	100.16	-0.06186	169.21	772.4

(2006) already reported the presence of molecular hydrogen fluorescence in this region in FUV band. Here we have used the empirical formula, FUV_{excess} = FUV 0.8×NUV, derived by Sujatha et al. (2010) to estimate the excess emission (say, H_2 fluorescence) from the region in FUV. Note that FUV and NUV in the equation represent the dust scattered starlight in the corresponding bands.

5. CORRELATION STUDIES

Correlation studies of diffuse UV emissions and IR 100 micron intensity can provide a great insight into the region, components of diffuse radiation and its nature. rovide a great insight into the region, components of diffuse radiation and its nature. The preliminary correlation studies in this region were reported in NHOAA-2014(Lakshmi et.al 2014). It also enables easy identification and separation of excess emissions such as H_2 fluorescence or line emissions in any region. In Fig. 2 & 3, we plotted FUV NUV intensities against IR 100 micron intensity. Lack of correlation in these figures clearly indicate that the diffuse background in the region is composite and not due to the entire dust in the line of sight. Fig. 2 further points to the presence of excess FUV emission which might be mainly attributed to H_2 fluorescence. However we have found a good linear correlation between the signal in FUV and NUV bands (Fig. 4) and also between the FUV/NUV ratio and FUV (Fig. 5) which indicates the presence of excess emissions which is seen only in FUV and not in NUV. This is probably due to florescent emission from the Lyman band of molecular hydrogen or hot line emissions from the region in FUV. UV/IR vs. IR graphs is plotted in Fig. 6 & 7. The ratios drop off exponentially due t1o the increase of optical depth in UV region. The shape of the curve also follows the same path as that described in Murthy et.al (2001) in Orion using the

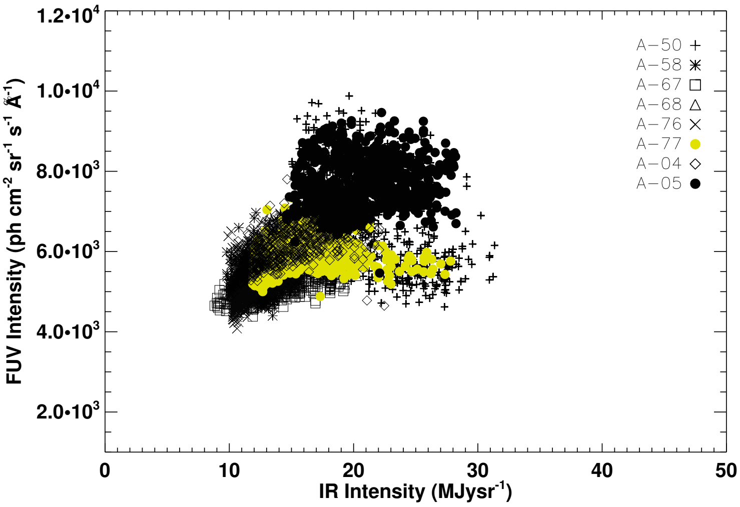

Fig. 2. Correlation of IRIS 100m intensity with diffuse FUV in Orion.

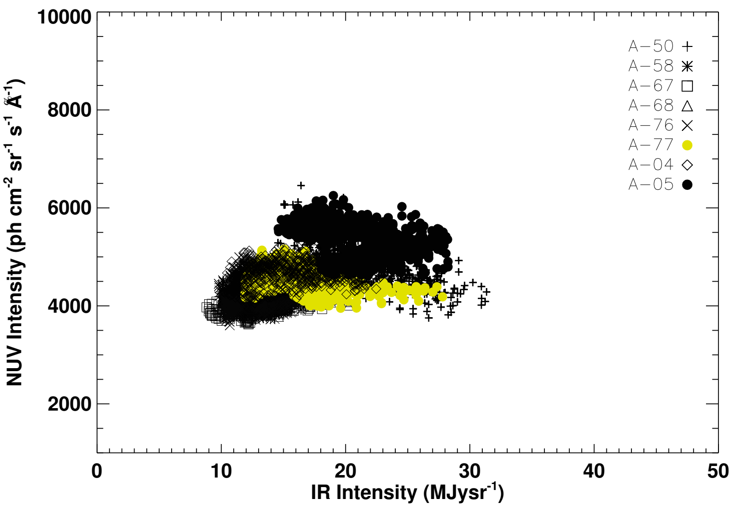

Fig. 3. Lack of correlation exists between NUV and IR intensity.

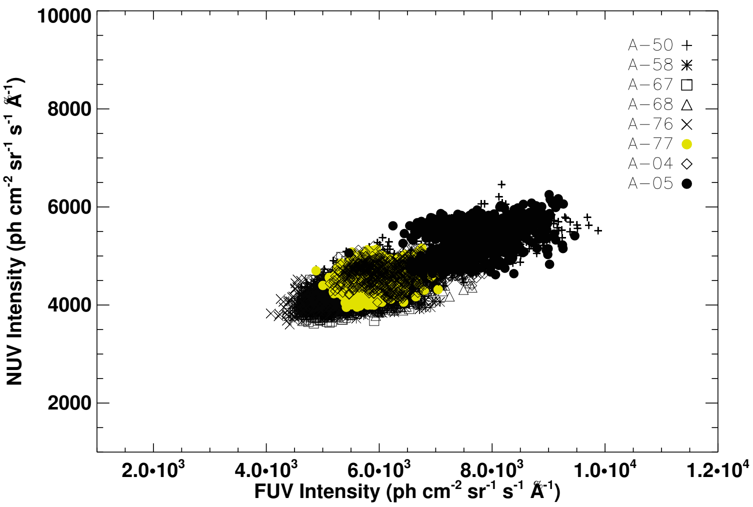

Fig. 4. Linear correlation between FUV and NUV.

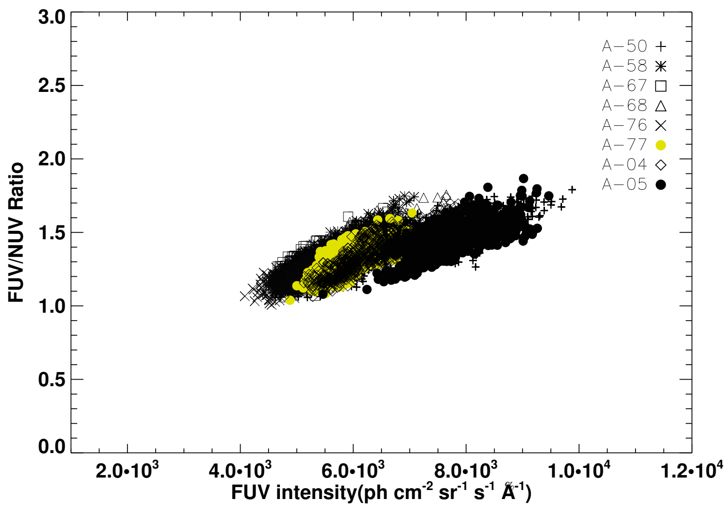

Fig. 5. it indicates the presence of H_2 fluorescence in this region.

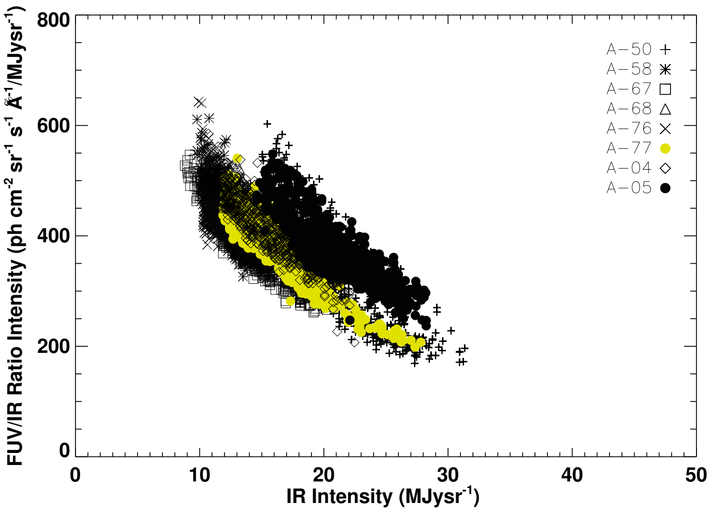

Fig. 6. The UV/IR ratio drop of exponentially with IR.

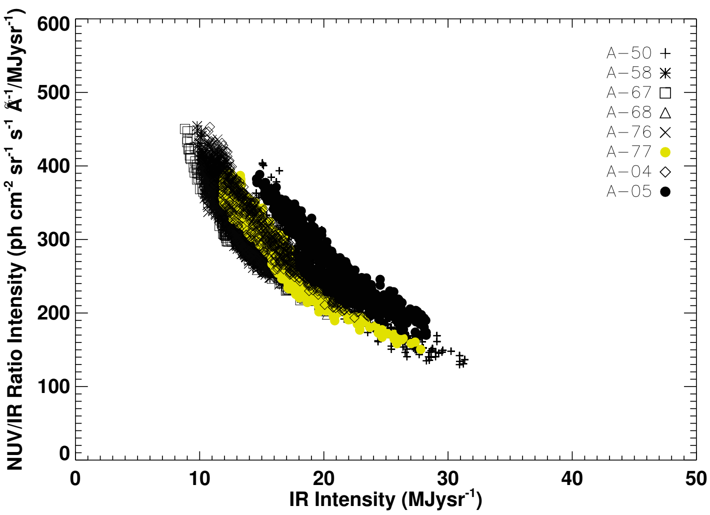

Fig. 7. it indicates rapid increase of optical depth in the region.

data from Midcourse Space Experiment (MSX) which has a resolution of 20″, ten times less than our data.

5. RESULT AND DISCUSSION

The FUV /FIR ratio follows an exponential curve across both regions, as would be expected for optically thick media. Interestingly, the FUV/FIR ratio in Orion follows exactly the same curve even though both the UV and IR values are higher by a factor of almost 200 due to the intense radiation field. We find that the total diffuse FUV and NUV emissions are not correlating with the IR100 micron intensity in the region (Fig. 2 & Fig. 3) indicating that the emissions are not from the total amount of dust in the region. Further correlation studies of diffuse UV emissions with neutral as well as molecular hydrogen column densities separately can verify the previous findings which indicate that the diffuse background emission is not from Orion nebula, but is rather from the neutral cloud in front of the nebula. We could also see that the FUV and NUV radiations are correlating well in the observed regions (Fig. 4). The higher scatter in FUV data than NUV (Fig. 2 & Fig. 3) indicates the presence of excess emission in FUV band. We found that an excess of 1000 - 4000 photon units in the FUV, possibily due to Lyman band emission from molecular hydrogen i.e., H_2 fluorescence in the region. These are preliminary results of our analysis and are in good agreement with previous results with FUSE and IUE observations.

6. ACKNOWLEDGEMENT

This research is based on data from NASA's *GALEX* GR6 and *Spitzer* DR1 program. *GALEX* is operated for NASA by California Institute of Technology under NASA contract NAS5-98034. *Spitzer Space Telescope* is operated by the Jet Propulsion Laboratory (JPL), California Institute of Technology (Caltech), under a contract with NASA. We acknowledge the use of NASA's Astrophysics Data System and also thank for NASA's Skyview facility[1] located at NASA Goddard Space Flight Centre. We acknowledge Prof. Jayant Murthy, IIA, Bangalore for his guidance and support.

REFERENCES

Cutri R. M., Skrutskie M. F., Van Dyk S. et al. 2006, Eplanatory Supplement to the 2MASS All Sky Data Release and Extended Mission Products.

Carruthers G. R., Opal C. B., 1977, ApJ, 217, 95

France, K. McCandliss, S. R. 2005, ApJ, 629, L97

Haikala, L.K., Mattila K., 1995, ApJ, 433, 33

Leinert, C, et.al.,1998, AAS,127,1

Martin, D. C., et al. 2005, ApJ, 619, L1

Mathis, J. S., Perinotto, M., Patriarchi, P., Shiffer, F. H 1981, ApJ, 249, 99

Murthy, J., Henry, R. C., Holberg, J. B. 1991, ApJ, 383, 198

Murthy, J., Henry, R. C., Shelton, R. L., Holberg, J. B. 2001, ApJ, 557, L47

Murthy, J., Hall, D., Earl, M., Henry, R. C., Holberg, J. B. 1999, ApJ, 522, 907

Murthy, J., Sahnow, D. J. 2004 ApJ, 615, 315

[1]http://skyview.gsfc.nasa.gov

Murthy J., Sahnow D. J., Henry R. C., 2005, ApJ, 618, 99
Morrissey. P, Barlow T.A, 2007, ApJ, 173:682-697
O′Dell C. R., 2001, ARAA, 39, 99
Sahnow, D. J. et al. 2000, ApJ, 538, L7
Shalima, P., Sujatha, N. V., Murthy, J., Henry, R. C., Sahnow, D. J. 2006, MNRAS, 367,1686
Sujatha, N. V., Murthy, J., Karnataki, A., Henry, R. C., Bianchi, L. 2009,ApJ, 692, 1333
Sujatha, N. V., Murthy, J., Suresh, R., Henry, R. C., Bianchi, L. 2010, ApJ, 723, 1549
Lakshmi S Bose, Sujatha, N.V., Narayanankutty, K., Proceedings of National Symposium New Horizons of Astronomy and Astrophysics NHOAA 2014