



Automated star–galaxy segregation using spectral and integrated band data for TAUVEV/ASTROSAT satellite data pipeline

Archana Bora^{a,c,*}, Ranjan Gupta^a, Harinder P. Singh^b, K. Duorah^c

^aIUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India

^bDepartment of Physics and Astrophysics, University of Delhi, Delhi 110 007, India

^cDepartment of Physics, Gauhati University, Guwahati 781 014, India

ARTICLE INFO

Article history:

Received 20 March 2009

Accepted 25 March 2009

Available online 5 April 2009

Communicated by P.S. Conti

PACS:

95.75.Fg

98.52.Cf

Keywords:

Methods: data analysis

Space vehicles: instruments

Astronomical data bases: miscellaneous

Galaxies: fundamental parameters

Stars: fundamental parameters

Ultraviolet: general

ABSTRACT

We employ an Artificial Neural Network (ANN) based technique to develop a pipeline for automated segregation of stars from the galaxies to be observed by Tel-Aviv University Ultra-Violet Experiment (TAUVEX). We use synthetic spectra of stars from UVBLUE library and selected International Ultraviolet Explorer (IUE) low-resolution spectra for galaxies in the ultraviolet (UV) region from 1250 to 3220 Å as the training set and IUE low-resolution spectra for both the stars and the galaxies as the test set. All the data sets have been pre-processed to get band integrated fluxes so as to mimic the observations of the TAUVEV UV imager. We also perform the ANN based segregation scheme using the full length spectral features (which will also be useful for the ASTROSAT mission). Our results suggest that, in the case of the non-availability of full spectral features, the limited band integrated features can be used to segregate the two classes of objects; although the band data classification is less accurate than the full spectral data classification.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

The TAUVEV (Tel-Aviv University Ultra-Violet Experiment) is a collaborative UV imaging experiment between the Indian Institute of Astrophysics (IIA, Bangalore, India) and the Tel-Aviv University, Israel. TAUVEV will have three UV imaging telescopes of 20-cm area which will obtain UV images of the sky in the spectral region of 1250–3220 Å with five different band filters. Each telescope has a field of view (FOV) of about 54' and an angular resolution of about 6'–10', depending on the wavelength. It will be placed into a geostationary orbit as part of the Indian Space Research Organization's (ISRO's) GSAT-4 mission.

In its life time the satellite is expected to collect data of about 10^6 celestial sources (Brosch, 1998) of both point sources (stars, QSO's etc.) as well as extended sources like nebulae, galaxies, clusters etc. With such a huge data set there is a call for automatizing the segregation of the point sources from other non-point-like sources. Different machine learning algorithms governed by some

'learning rule' serves this purpose and they are now routinely used in astronomy for different classification problems. There are three major learning paradigms for machine learning algorithms: supervised learning, unsupervised learning and reinforcement learning, each corresponding to a particular learning task. Some examples of such machine learning algorithms are Artificial Neural Network (ANN), support vector machines, difference boosting neural network, self-organized maps (SOM) etc.

Odewahn et al. (1992) pioneered the use of ANN based scheme for automated segregation of stars and galaxies based on point-spread function (PSF) fitting. Mähönen and Hakala (1995) used SOM based neural network using the CCD images directly. Mähönen and Frantti (2000) also introduced another method based on fuzzy set reasoning. Philip et al. (2002) used the difference boosting neural network for the star–galaxy classification of NOAO Deep Wide Field Survey (NDWFS). Qin et al. (2003) also demonstrated the use of spectra for the same purpose using RBF neural network, in the wavelength range of 3800–7420 Å. In this paper, we propose the use of ANN with integrated flux measurements in different bands, in case of non-availability of full spectra, to separate objects (stars and galaxies) with different spectral energy distributions. The wavelength of concern in the present work is the UV range

* Corresponding author. Present address: Department of Physics, Gauhati University, Guwahati 781 014, India. Fax: +91 20 25604699.

E-mail addresses: archana@iucaa.ernet.in, abora.80@gmail.com (A. Bora).

(1250–3200 Å). We also classify the two types of objects using corresponding full spectral informations and present a comparison between the two schemes (i.e. using band data and full spectral data).

It is to be noted here that the integrated flux approach has already been used to classify stellar objects into different spectral types and to estimate the colour excess for the hot stars (Bora et al., 2008). However, while doing the classification in the above mentioned work, it was assumed that the separation of the stellar objects from other celestial objects have been done apriori by some other method. Thus with the incorporation of the proposed scheme both the tasks of star–galaxy segregation and star classification can be performed with the band integrated flux to be available from the TAUVE X satellite.

2. Network architecture

In this section, we very briefly review the basics of ANN and describe the network structure used in the present work. The neural network considered here is the supervised learning network, with a back-propagation algorithm (Gulati et al., 1994, 1997a,b; Singh et al., 1998). The network consists of three layers, i.e. (i) input layer, (ii) hidden layer and (iii) output layer. Patterns are presented to the network for learning at the input layers which are subsequently communicated to the hidden layer. The hidden layer interconnects the input and the output layers and can have several nodes with a particular transfer function. The actual processing is done in the hidden layer via weighted connections and the outputs are rendered at the output layers (Bailer-Jones, 2002; Bailer-Jones et al., 2002). We have used two hidden layers of 64 nodes each with a Sigmoid function as the transfer function. The scheme requires a training session where the ANN output and the desired output get compared after each iteration and the connection weights get updated till the desired minimum error threshold is reached. At this stage, the network training is complete and the connection weights are considered frozen. The next stage is the testing session in which the test patterns are fed to the network and output is the classification of the objects as star or galaxy.

3. Data for training and testing

In the following, we describe the data sources for the stellar and galaxy spectra, and the generation of the train and the test sets for the network.

3.1. The sources for stellar and galaxy spectra

- (i) *The stellar data set:* We have used the UVBLUE fluxes (Rodríguez-Merino et al., 2005) for generating the training sets for stellar spectra with solar type stars with $[M/H] = 0$ (<http://www.bo.astro.it/~eps/uvblue/uvblue.html>). The references Allen (2000); Böhm-Vitense (1981); Johnson (1966); Ridgway et al. (1980); Alonso et al. (1999) and Bertone et al. (2004) provide the necessary information for matching the parameter space of UVBLUE to spectral-types. The UVBLUE library source provides the sets of theoretical fluxes (based on Kurucz model atmospheres) in the UV region. The test spectra were taken from the IUE low-resolution spectra: reference atlas, normal stars, ESA SP-1052 by Heck et al. (1984) which contains 229 low-dispersion flux calibrated spectra of O to K spectral type at a resolution of 6 Å obtained by the IUE satellite.
- (ii) *The galaxy data set:* For galaxy spectra we have used the UV-optical spectra of 99 Nearby Quiescent and Active Galaxies

available online on http://www.stsci.edu/ftp/catalogs/nearby_gal/sed.html (Storchi-Bergmann et al., xxxx). The spectra covers the wavelength range 1200–3200 Å with a resolution of 5–8 Å.

Although an extended grid of synthetic galaxy spectra are available in the wavelength range 2500–10,500 Å with zero-redshift (Fioc and Rocca-Volmerange, 1997), there is no such grid in the range of our interest (1200–3200 Å). So, we chose a subset of the galaxies from the above mentioned database as the train set, keeping the rest for the test set. The selection of the galaxy subset for the training session is based on the following general observations related to the galaxy spectra:

The spectra of galaxies of different morphological types reveal that the Elliptical and the S0 galaxies essentially have no star-formation activity and the spectra of these two types look quite similar. By contrast, the Sc spirals and the Irr galaxies have a spectrum dominated by emission lines. On the other hand the Sa and the Sb galaxies form a kind of transition between these early-type galaxies and Sc galaxies (Schneider, 2006). Depending on these spectral distributions we prepare a list of 16 galaxies spanning over all the above mentioned types as the training sample. The remaining 69 galaxies are then used as the test set. All these galaxies considered in the train set and in the test are at the low red-shift regions.

It is to be mentioned that the TAUVE X detectors being virtually noiseless and also with little or no stray light in parts of the orbit, its detection will be limited only by photon statistics (Brosch, 1998; Safonova et al., 2008) and so the effect of noise on the data is not taken into account.

3.2. Generation of the train and the test sets

While making the train and the test sets, one has to ensure that the number of spectral fluxes at the respective wavelengths and the starting, ending wavelengths are identical. Also the spectral resolution of the two sets needs to be the same. This has been achieved by first trimming the spectra in the range of 1250–3200 Å at 40 data bins and then convolving the IUE star/galaxy spectra with appropriate Gaussian functions to bring down their resolution to 50 Å. The resolution of UVBLUE spectral types have also been degraded to a resolution of 50 Å using the relevant codes provided on the UVBLUE library web site (<http://www.bo.astro.it/eps/uvblue/go.html>).

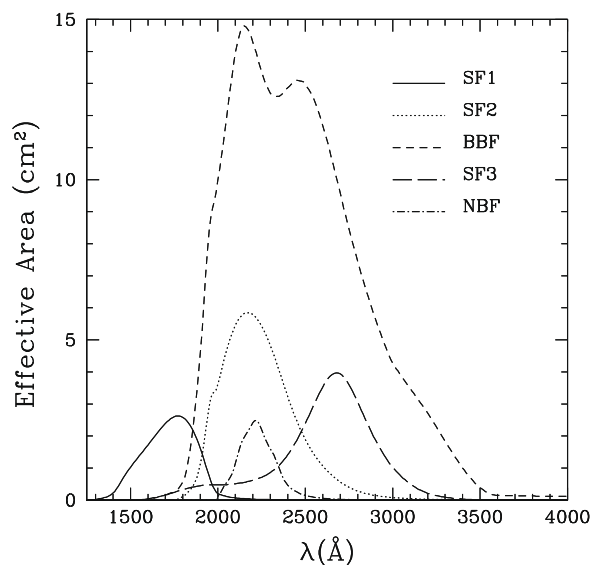


Fig. 1. Filter response of the five filters of TAUVE X.

The details of the procedure adopted for generating the band integrated train and test sets is described below with reference to the TAUVE X filter response. For the TAUVE X mission, the observations will be available from 1250 to 3220 Å spectral region using filters, namely BBF, SF1, SF2, SF3 and NBF3, in five UV bands. Fig. 1 shows the total response of each of the TAUVE X filters in units of Effective Area cm² and their approximate characteristics are summarized in Table 1.

The spectra are degraded to same resolution and rebinned to a common spectral range and then the fluxes are processed via a common flux integration programme provided at the TAUVE X tool site to form two sets of band data (each having five fluxes corresponding to the four TAUVE X bands).

We have also obtained two sets of fluxes (with 50 Å resolution and 40 data bins covering the spectral region of 1250–3220 Å) aimed at preparing the ANN tools for another Indian scientific mission satellite ASTROSAT (<http://www.rri.res.in/astrosat/>) which will have gratings to provide slitless spectra for spatially resolved stars. It will also prepare us for the future GAIA mission (<http://gaia.esa.int/science-e/www/area/index.cfm?fareaid=26>). For this the spectra are normalized to unity with respect to the maximum flux in each spectrum before sending to the network. Fig. 2 and Fig. 3, shows the block diagram for creating the UVBLUE train sets and the IUE test sets for the star while Fig. 4 shows the flow chart for creating the IUE train and the test sets for the galaxy.

Table 1
TAUVE X filters specifications.

Filter	Wavelength (Å)	Width (Å)	Normalized transmission (%)
BBF	2300	1000	80
SF1	1750	400	20
SF2	2200	400	45
SF3	2600	500	40
NBF3	2200	200	30

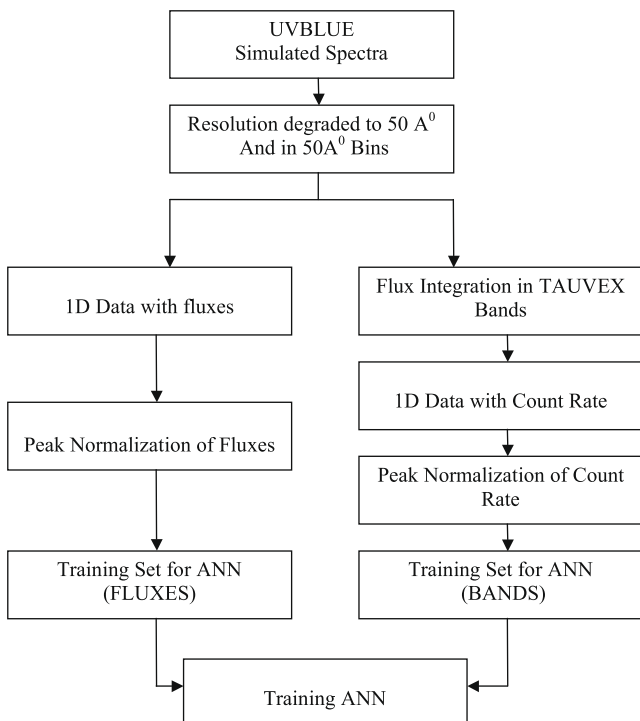


Fig. 2. A block diagram showing the flow chart for creating the ANN train set for star with UVBLUE simulated sources.

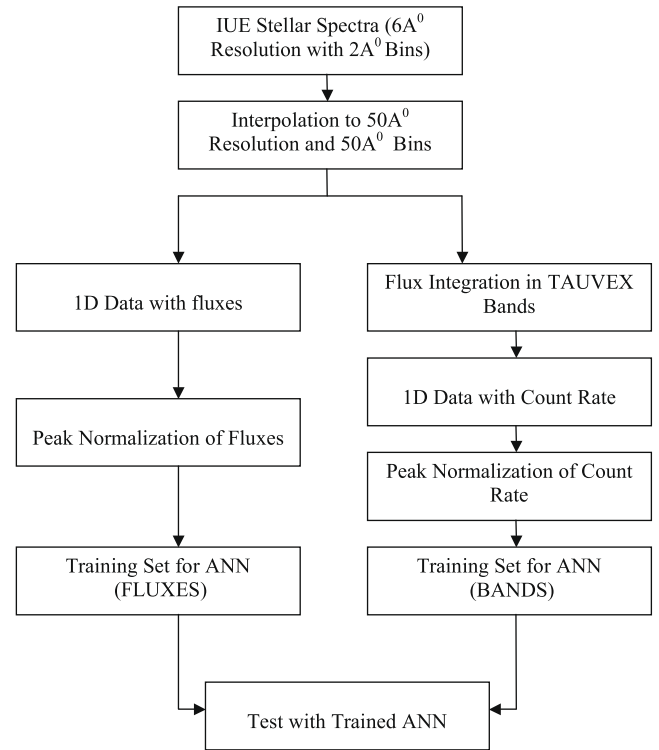


Fig. 3. A block diagram showing the flow chart for creating the ANN test set for stellar sources.

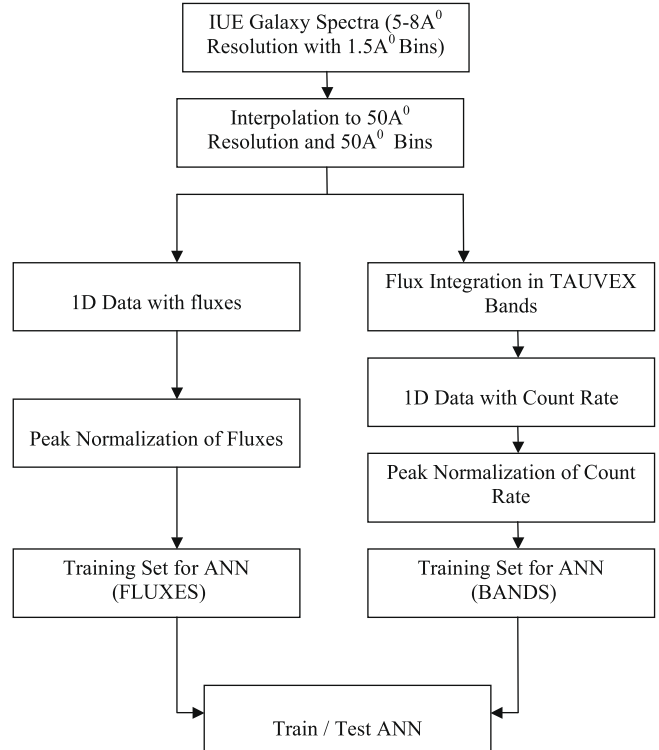


Fig. 4. A block diagram showing the flow chart for creating the ANN train/test set for galaxy.

In the current work, we have neglected the effect of red-shift on the galaxy spectra and this will be incorporated in a future upgrade of the software which is being developed.

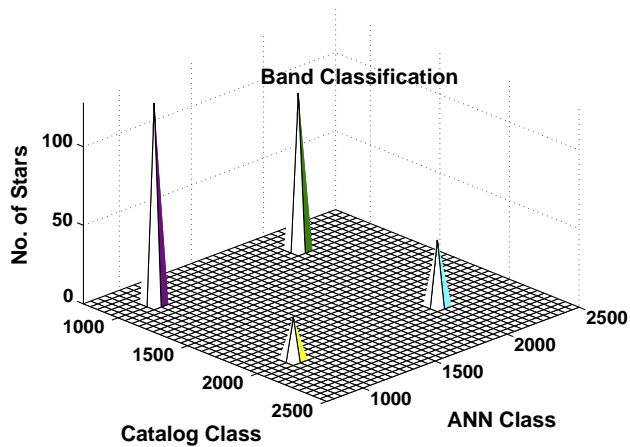


Fig. 5. Scatter plot of classification of 229 IUE stars and 69 galaxies using Band data (class-code: 1000-stars; 2000-galaxy).

4. Results of the classification

4.1. Band data

Separating the stellar objects from the galaxies using the five TAUVE data points only as the classification features, is a challenging job. However, the use of all the available informations in the five filters enable us to classify 170 (128 stars and 42 galaxies) objects correctly out of a sample of 297 stars plus galaxies, yielding the success rate of classification as 57%. The scattered 3D plot of the classification is shown in Fig. 5. In these three dimensional scatter plots, the two axes in the horizontal plane denote the catalog and ANN classes, and the vertical axis in the plots gives the

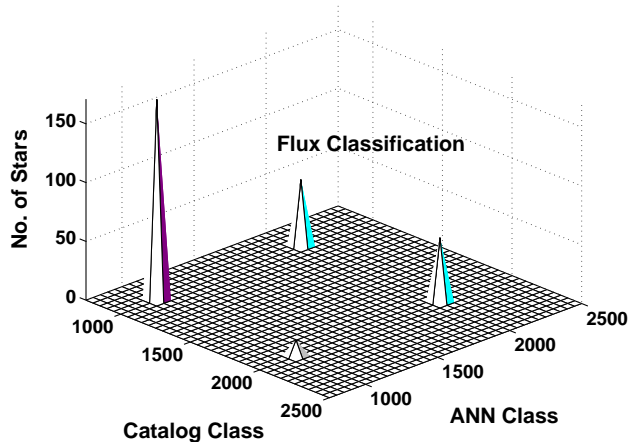


Fig. 6. Scatter plot of classification of 229 IUE stars and 69 galaxies using Flux data (class-code: 1000-stars; 2000-galaxy).

Table 2
Classification and results.

Classification scheme	Results
Band	Star: 128/228 Galaxy: 42/69
Flux	Star: 171/228 Galaxy: 55/69

number of stars present for a particular class. In the plot stars are labeled as 1000 while galaxies are labeled as 2000.

4.2. Flux data

The classification results with the full spectral features excel the result with the band integrated features, which is to be expected as the full spectra will always have more information as compared to the band data. The network classifies 226 objects correctly, (171 being stars and 55 being galaxies) out of a sample of 297 stars and galaxies, yielding the success rate of classification as 76%. The scattered 3D plot of the classification is shown in Fig. 6. The result of both the band classification and the flux classification is summarised in Table 2.

5. Conclusions

Generally stars are separated from the galaxies by PSF fitting and this has been extensively done in the optical region of the electro magnetic spectrum. The extension of applicability of the neural network based scheme to the UV region has been less prevalent mainly because of non-availability of abundant data in this region. The present work demonstrates that the ANN can be successfully employed to separate stars from galaxies in the UV region too. We have shown that the tool developed by us can successfully classify the two classes of objects using both their full spectral information as well as their photometric data. The success rate is 76% when using the Flux data. Automatizing the separation of star and galaxy using only few photometric data is indeed a challenging job to perform. The result of our analysis shows that with our ANN tool this can be achieved with a success rate of 57%. Thus, even with the limitation of data from just five photometric bands, the ANN can be used to classify the point sources from the extended sources like galaxies/AGNs etc. There is a good chance for improving the classification results with larger data sets to be available from the upcoming satellite missions TAUVE/ASTROSAT/GAIA etc.

Acknowledgements

This work is supported by a research grant from Indian Space Research Organization under its RESPOND scheme. A.B. would like to thank Prof. S. Ravindranath for suggesting useful references that helps to understand the galaxy spectra.

References

- Allen, 2000. *Astrophysical Quantities*, fourth ed., Springer-Verlag, New York.
- Alonso, A., Arribas, S., Martinez-Roger, C., 1999. *A&S* 140, 261.
- Bailer-Jones, C.A.L., 2002. In: Gupta, R., Singh, H.P., Bailer-Jones, C.A.L. (Eds.), *Automated Data Analysis in Astronomy*. Narosa, New Delhi, p. 83.
- Bailer-Jones, C.A.L., Gupta, R., Singh, H.P., 2002. In: Gupta, R., Singh, H.P., Bailer-Jones, C.A.L. (Eds.), *Automated Data Analysis in Astronomy*. Narosa, New Delhi, p. 51.
- Bertone, E., Buzzoni, A., Rodriguez-Merino, L.H., Chavez, M., 2004. *AJ* 128, 829.
- Bora, A., Gupta, R., Singh, H.P., Murthy, J., Mohan, R., Duorah, K., 2008. *MNRAS* 384, 449.
- Brosch, N., 1998. *Physica Scripta – Supplement T* 77, 16.
- Böhm-Vitense, Erika, 1981. *Ann. Rev. Astron. Astrophys.* 295, 318.
- Fioc, M., Rocca-Volmerange, B., 1997. *A&A* 326, 950.
- Gulati, R.K., Gupta, R., Gothoskar, P., Khobragade, S., 1994. *ApJ* 426, 340.
- Gulati, R.K., Gupta, R., Rao, N.K., 1997a. *A&A* 322, 933.
- Gulati, R.K., Gupta, R., Singh, H.P., 1997b. *PASP* 109, 843.
- Heck, A., Egret, D., Jaschek, M., Jaschek, C., 1984. *ESA SP-1052*, IUE lowdispersion spectra reference atlas. Part 1. Normal Stars, ESA SP-1052.
- Johnson, H.L., 1966. *Ann. Rev. Astron. Astrophys.* 4, 193.
- Mähönen, P., Hakala, P., 1995. *ApJ* 452, L77.
- Mähönen, P., Frantti, T., 2000. *ApJ* 541, 261.
- Odewahn, S.C., Stockwell, R.L., Pennington, R.L., Humphreys, R.M., Zumach, W.A., 1992. *Astron. J.* 103, 318.
- Philip, N.S., Wadadekar, Y., Kembhavi, A., Joseph, K.B., 2002. *A&A* 385, 1119.
- Qin, D.M., Guo, P., Hu, Z.U., Zhao, Y.H., 2003. *Chin. J. Astron. Astrophys.* 3, 277.

- Schneider, P., 2006. Extragalactic Astronomy and Cosmology: An Introduction. Springer-Verlag, Berlin, Heidelberg.
- Ridgway, S.T., Joyce, R.R., White, N.M., Wing, R.F., 1980. ApJ 235, 126.
- Rodriguez-Merino, L.H., Chavez, M., Bertone, E., Buzzoni, A., 2005. ApJ 626, 411 (UVBLUE).
- Safonova, M., Sivaram, C., Murthy, J., 2008. Astrophys. Space Sci. 318, 1.
- Singh, H.P., Gulati, R.K., Gupta, R., 1998. MNRAS 295, 312.
- Storchi-Bergmann, T., Calzetti, D., Kinney, A.L., A Database of UV-Optical Spectra of Nearby Quiescent and Active Galaxies, (<http://www.stsci.edu/ftp/catalogs/nearby_gal/sed.html>).