spectroscopy/

1. Introduction

In November 2013, comet ISON spectra were taken on five dates, using OMR instrument on 2.34-m VBT telescope of Vainu Bappu Observatory, Kavalur:

DATE-OBS

2013-11-08
2013-11-09
2013-11-11
2013-11-12
2013-11-13

VBT telescope OMR spectra were taken in grating **300 l/mm** only. The description of the instrument and the reduction procedure are in Sections 4 and 4.1, respectively.

2. Description of the dataset

This dataset contains the following subdirectories with data in the directories:

2.1. Spectroscopy/November08

Raw/:

File	Object	Exposure (sec)
8nbia1.fits	bias	0.00
8nbia2.fits	bias	0.00
8nbia3.fits	bias	0.00
8nbia4.fits	bias	0.00
8nbia5.fits	bias	0.00
8nbia6.fits	bias	0.00
8nbia7.fits	bias	0.00
8ncom1.fits	Fe-Ne lamp	0.1
8ncom2.fits	Fe-Ne lamp	0.1
8ncom3.fits	Fe-Ne lamp	0.1
8ncom4.fits	Fe-Ne lamp	0.1
8ndflat1.fits	Halogen lamp	1.00
8ndflat2.fits	Halogen lamp	2.00
8ndflat3.fits	Halogen lamp	3.00
8ndflat4.fits	Halogen lamp	4.00
8ndflat5.fits	Halogen lamp	5.00
8ndflat6.fits	Halogen lamp	6.00
8ndflat7.fits	Halogen lamp	10.00
8ndflat8.fits	Halogen lamp	10.00
8nobj1.fits	HR3982	30.00
8nobj2.fits	HR3982	8.00
8nobj3.fits	HR3951	60.00
8nobj6.fits	Comet ISON	1800.00
8nobj7.fits	Comet ISON	600.00

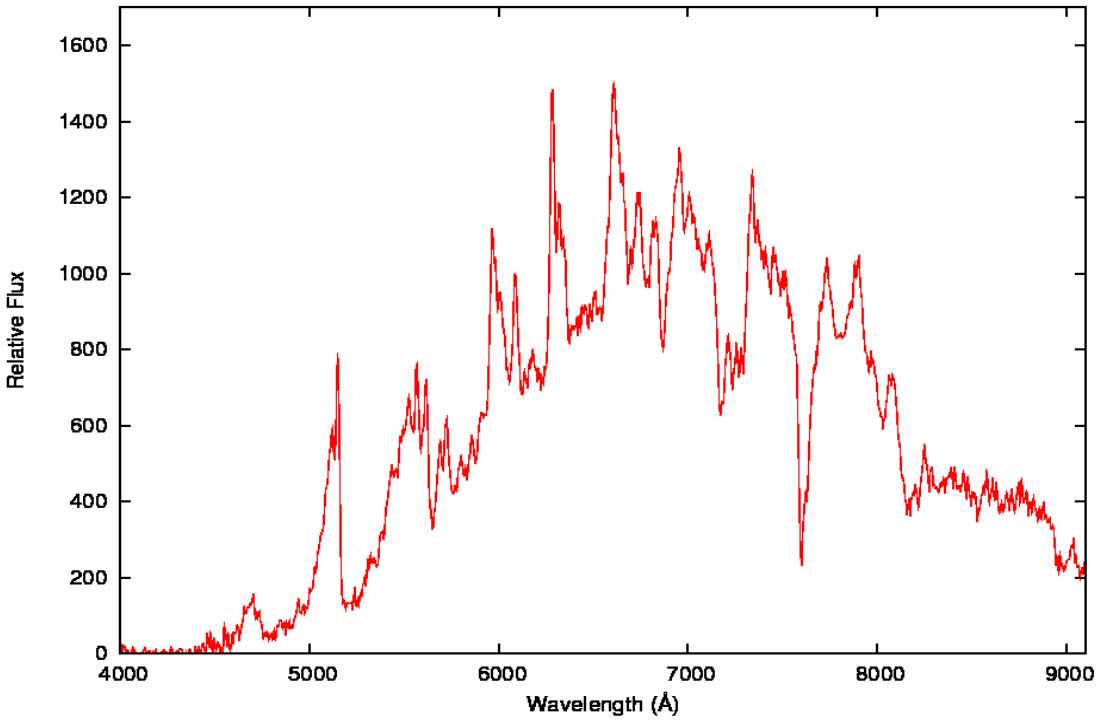
Processed/

File	Object	Exposure (sec)	Remark(s)
Files for CCD processing:			
8n_masterbias.fits	bias	0.00	MasterBias
8n_masterflat.fits	Halogen lamp	5.218185	MasterFlat
8n_nmasterflat.fits	Halogen lamp	5.218185	normalized MasterFlat
Extracted Spectra:			
8ncom1_tb_ms.fits	FeNe lamp	0.1	lamp datacube used for HR3982
8ncom2_tb_ms.fits	FeNe lamp	0.1	lamp datacube used for HR3951
8ncom4_tb_ms.fits	FeNe lamp	0.1	lamp datacube used for comet ISON
Wavelength-calibrated spectra:			
8nov2013_HR3951_60s.fits	HR3951	60.00	solar type star datacube
8nov2013_HR3982_30s.fits	HR3982	30.00	telluric standard star datacube
8nov2013_HR3982_8s.fits	HR3982	8.00	"
8nov2013_ison_1800s.fits	comet ISON	1800.00	comet single spectrum
8nobj6_tbfw.ms.fits	comet ISON	1800.00	comet datacube

Derived/

Only one spectrum out of two was extracted, as 8nobj7.fits with exposure of 600 sec has too low S/N. *`8nov2013_ison.tab'* is the text file of wavelength-calibrated comet spectrum. The first column is the wavelength in angstrom, the second column is the relative flux of the comet.

Figure represents the variation of the relative comet flux (y-axis) with the wavelength (x-axis).



2.2. Spectroscopy/November09

Raw/

File	Object	Exposure (sec)
9nbia1.fits	bias	0.00
9nbia10.fits	bias	0.00
9nbia2.fits	bias	0.00
9nbia3.fits	bias	0.00
9nbia4.fits	bias	0.00
9nbia5.fits	bias	0.00
9nbia7.fits	bias	0.00
9nbia8.fits	bias	0.00
9nbia9.fits	bias	0.00
9nco3.fits	Fe-Ne lamp	0.05
9nco4.fits	Fe-Ne lamp	0.05
9ncom1.fits	Fe-Ne lamp	0.05
9ncom2.fits	Fe-Ne lamp	0.05
9ndft1.fits	halogen lamp	2.00
9ndft2.fits	halogen lamp	4.00
9ndft3.fits	halogen lamp	6.00
9ndft4.fits	halogen lamp	8.00
9ndft5.fits	halogen lamp	10.00
9nobj1.fits	HR3982	15.00
9nobj2.fits	HR3982	5.00
9nobj3.fits	HR3982	5.00
9nobj4.fits	HR 3951	50.00
9nobj5.fits	HR 3951	50.00
9nobj6.fits	comet ISON	2400.00

Processed/

File	Object	Exposure (sec)	Remarks

Files for CCD processing:

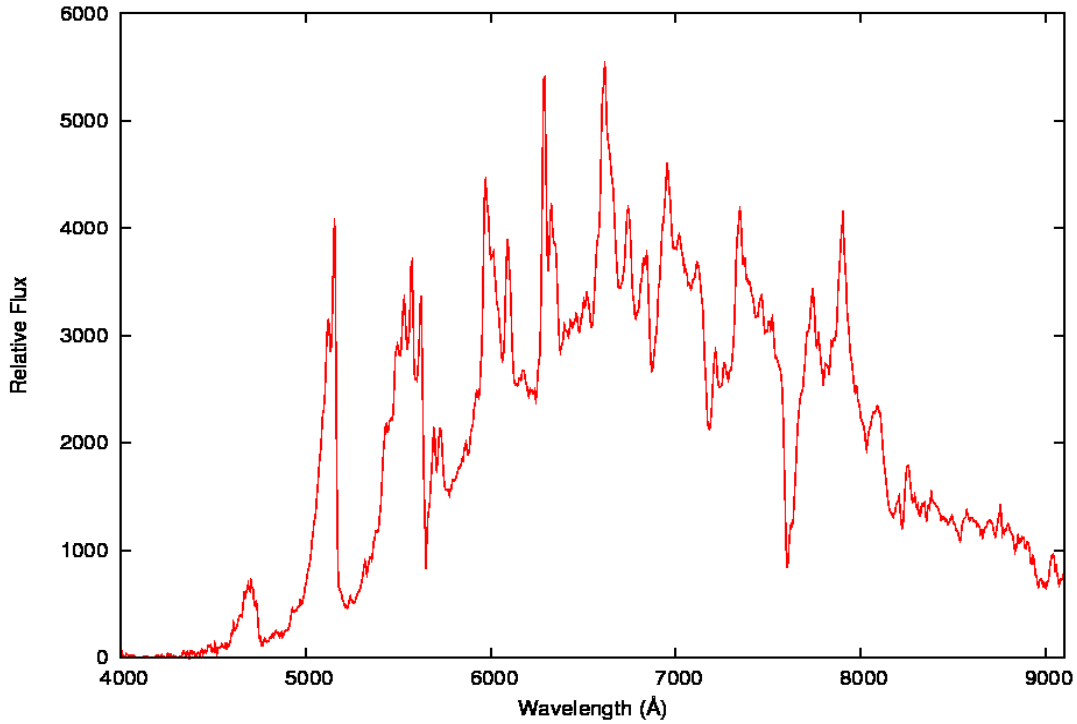
9n_masterbias.fits	bias	0.00	MasterBias
9n_masterflat.fits	Halogen lamp	6.092116	MasterFlat
9n_nmasterflat.fits	Halogen lamp	6.092116	normalized MasterFlat

Wavelength-calibrated spectra:

9ncom2_tbw_ms.fits	FeNe lamp	0.05	lamp datacube used for HR3951
9nco4_tbw_ms.fits	FeNe lamp	0.05	lamp datacube used for comet
9nobj4_tbfw.ms.fits	HR3951	50	solar-type star datacube
9nov2013_hr3951_50sec.fits	HR3951	50	solar-type star datacube
9nov2013_ison_2400sec.fits	Comet ISON	2400.00	comet datacube
9nov2013_ison.fits	Comet ISON	2400.00	comet single spectrum

Derived/

`9nov2013_ison.tab' is the text file of wavelength-calibrated comet spectrum. The first column is the wavelength in angstrom, the second column is the relative flux of the comet.



2.3. Spectroscopy/November11

Raw/

File	Object	Exposure (sec)
11nbia1.fits	bias	0.00
11nbia2.fits	bias	0.00
11nbia3.fits	bias	0.00
11nbia4.fits	bias	0.00
11nbia5.fits	bias	0.00
11nbia6.fits	bias	0.00
11nbia8.fits	bias	0.00
11nbia9.fits	bias	0.00
11ncom1.fits	Fe-Ne lamp	0.05
11ncom2.fits	Fe-Ne lamp	0.05
11ncom3.fits	Fe-Ne lamp	0.05
11ncom4.fits	Fe-Ne lamp	0.05
11ncom5.fits	Fe-Ne lamp	0.05
11ndft1.fits	halogen lamp	2.00
11ndft2.fits	halogen lamp	4.00
11ndft3.fits	halogen lamp	6.00
11ndft4.fits	halogen lamp	8.00

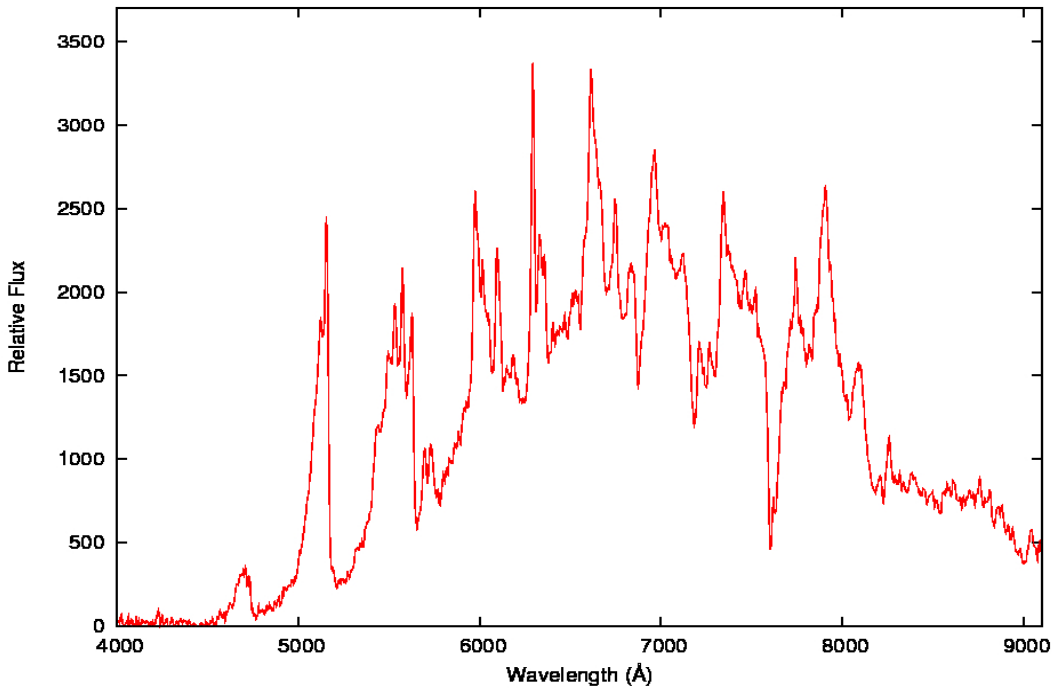
11ndft5.fits	halogen lamp	10.00
11ndft6.fits	halogen lamp	12.00
11nobj1.fits	HR3454	40.00
11nobj2.fits	HR3951	40.00
11nobj3.fits	comet ISON	2400.00

Processed/

File	Object	Exposure (sec)	Remark(s)
Files for CCD processing:			
11n_masterbias.fits	bias	0.00	MasterBias
11n_masterflat.fits	Halogen lamp	7.042886	MasterFlat
11n_nmasterflat.fits	Halogen lamp	7.042886	normalized MasterFlat
Extracted Spectra:			
11ncom1_tb_ms.fits	FeNe lamp	0.05	lamp single spectra:
11ncom2_tb_ms.fits	FeNe lamp	0.05	used for HR3951
11ncom3_tb_ms.fits	FeNe lamp	0.05	used for HR3951
11ncom4_tb_ms.fits	FeNe lamp	0.05	used for comet
11nobj2_tbf.ms.fits	HR3951	40.00	solar-type star datacube
Wavelength-calibrated spectra:			
11nobj3_tbfw.ms.fits	comet ISON	2400.00	comet datacube
11nov2013_ison.fits	comet ISON	2400.00	comet single spectrum

Derived/

'*11nov2013_ison.tab*' is the text file of wavelength-calibrated comet spectrum. The first column is the wavelength in angstrom, the second column is the relative flux of the comet.



2.4. Spectroscopy/November12

Raw/:

File	Object	Exposure (sec)
12nbia1.fits	bias	0.00
12nbia2.fits	bias	0.00
12nbia3.fits	bias	0.00
12nbia4.fits	bias	0.00
12nbia5.fits	bias	0.00
12nbia6.fits	bias	0.00
12nbia7.fits	bias	0.00
12nbia8.fits	bias	0.00
12nbia9.fits	bias	0.00
12nbia10.fits	bias	0.00
12ncom1.fits	Fe-Ne lamp	0.05
12ncom2.fits	Fe-Ne lamp	0.05
12ncom3.fits	Fe-Ne lamp	0.05
12ncom4.fits	Fe-Ne lamp	0.05
12ndft1.fits	Halogen lamp	2.00
12ndft2.fits	Halogen lamp	4.00
12ndft3.fits	Halogen lamp	6.00
12ndft4.fits	Halogen lamp	8.00
12ndft5.fits	Halogen lamp	10.00
12nobj2.fits	HR3951	60.00
12nobj3.fits	HR3951	120.00
12nobj4.fits	HR3684	300.00
12nobj5.fits	Comet ISON	1200.00

Processed/

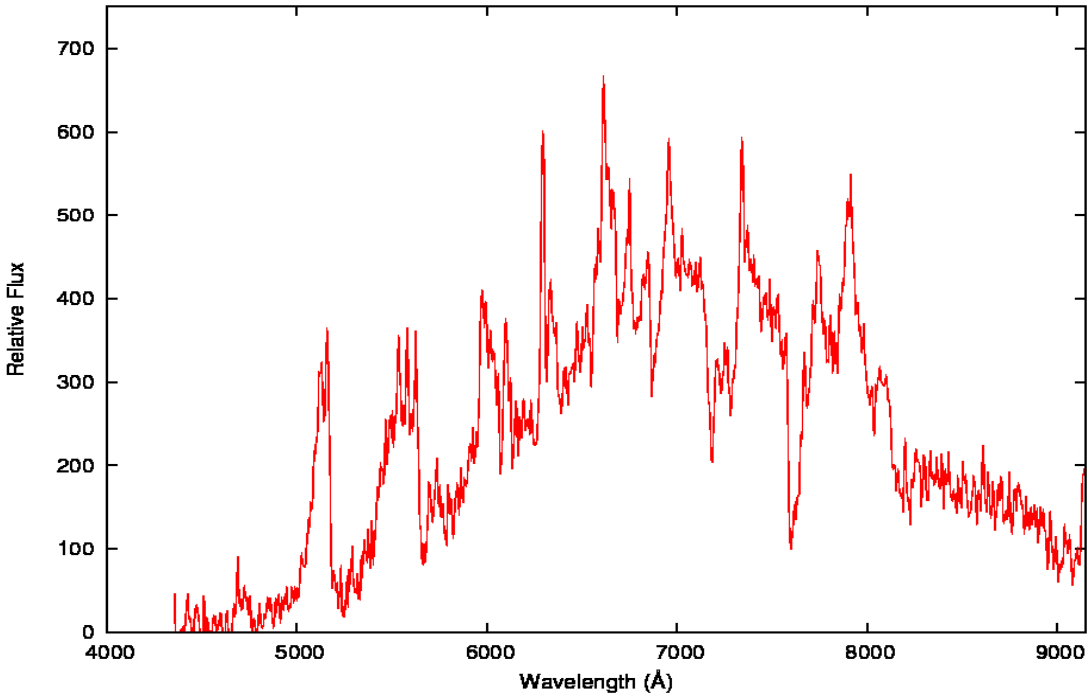
File	Object	Exposure (sec)	Remarks
Files for CCD processing:			
12n_masterbias.fits	bias	0.00	MasterBias
12n_masterflat.fits	Halogen lamp	5.993605	MasterFlat
12n_nmasterflat.fits	Halogen lamp	5.993605	normalized MasterFlat
Extracted Spectra:			
12ncom1_tb_ms.fits	FeNe lamp	0.05	lamp datacube
12ncom2_tb_ms.fits	FeNe lamp	0.05	lamp datacube
12ncom3_tb_ms.fits	FeNe lamp	0.05	lamp datacube
12ncom4_tb_ms.fits	FeNe lamp	0.05	lamp datacube
12nobj2_tbf.ms.fits	HR3951	60.00	solar-type star datacube
12nobj3_tbf.ms.fits	HR3951	120.00	solar-type star datacube

Wavelength-calibrated spectra:

12ncom4_tbw_ms.fits	FeNe lamp	0.05	lamp datacube used for comet
12nobj5_tbfw.ms.fits	comet ISON	1200.00	comet datacube
12nov2013_ison.fits	comet ISON	1200.00	comet single spectrum

Derived/

'*12nov2013_ison.tab*' is the text file of wavelength-calibrated comet spectrum. The first column is the wavelength in angstrom, the second column is the relative flux of the comet.



2.5. Spectroscopy/November13

Raw/:

File	Object	Exposure (sec)
13nbia1.fits	bias	0.00
13nbia2.fits	bias	0.00
13nbia3.fits	bias	0.00
13nbia4.fits	bias	0.00
13nbia5.fits	bias	0.00
13nbia6.fits	bias	0.00

13nbia7.fits	bias	0.00
13nbia8.fits	bias	0.00
13nbia9.fits	bias	0.00
13nbia10.fits	bias	0.00
13ncom1.fits	Fe-Ne lamp	0.05
13ncom2.fits	Fe-Ne lamp	0.05
13ncom3.fits	Fe-Ne lamp	0.05
13ncom4.fits	Fe-Ne lamp	0.05
13ndft1.fits	Halogen lamp	2.00
13ndft2.fits	Halogen lamp	4.00
13ndft3.fits	Halogen lamp	6.00
13ndft4.fits	Halogen lamp	10.00
13ndft5.fits	Halogen lamp	10.00
13ndft6.fits	Halogen lamp	10.00
13nobj1.fits	HR4354	40.00
13nobj2.fits	HR3982	5.00
13nobj3.fits	HR3951	30.00
13nobj4.fits	HR3951	60.00
13nobj5.fits	Comet ISON	1800.00
13nobj6.fits	Comet ISON	900.00

Processed/

File	**Object**	**Exposure (sec)**	**Remarks**

Files for CCD processing:

13n_masterbias.fits	bias	0.00	MasterBias
13n_masterflat.fits	Halogen lamp	19.73036	MasterFlat
13n_nmasterflat.fits	Halogen lamp	19.73036	normalized MasterFlat

Extracted Spectra:

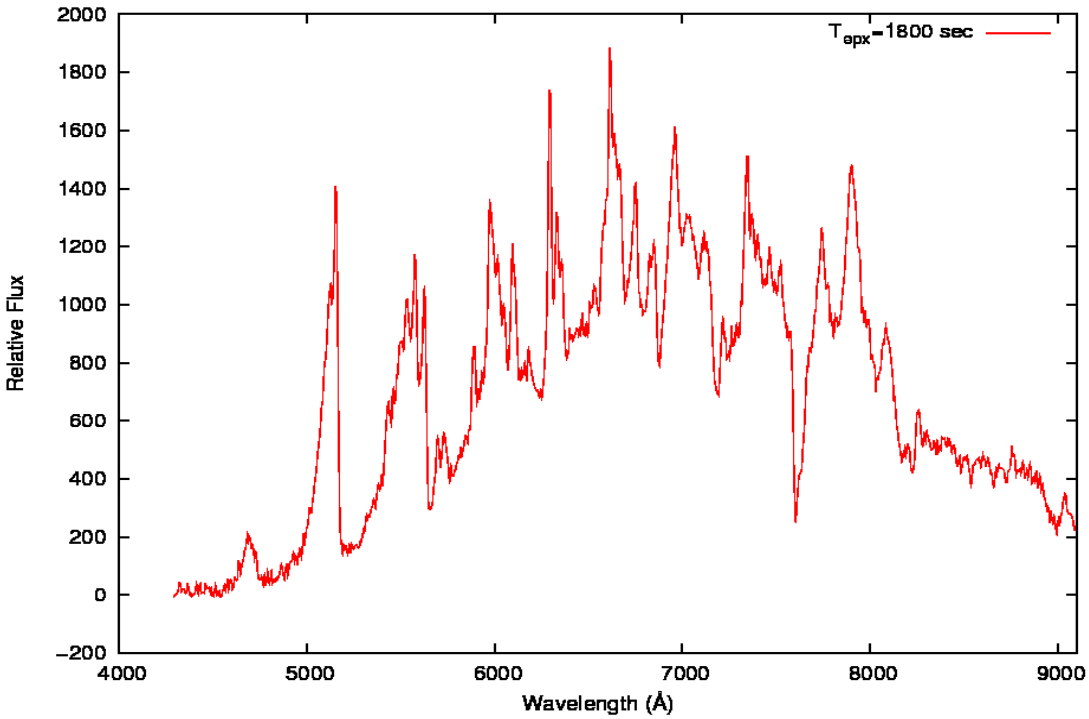
13ncom1_tb_ms.fits	FeNe lamp	0.05	lamp datacube
13ncom2_tb_ms.fits	FeNe lamp	0.05	lamp datacube
13ncom3_tb_ms.fits	FeNe lamp	0.05	lamp datacube
13ncom4_tb_ms.fits	FeNe lamp	0.05	lamp datacube
13nobj2_tbf.ms.fits	HR3982	5.00	telluric standard star datacube
13nobj3_tbf.ms.fits	HR3951	30.00	solar-type star datacube
13nobj4_tbf.ms.fits	HR3951	60.00	solar-type star datacube

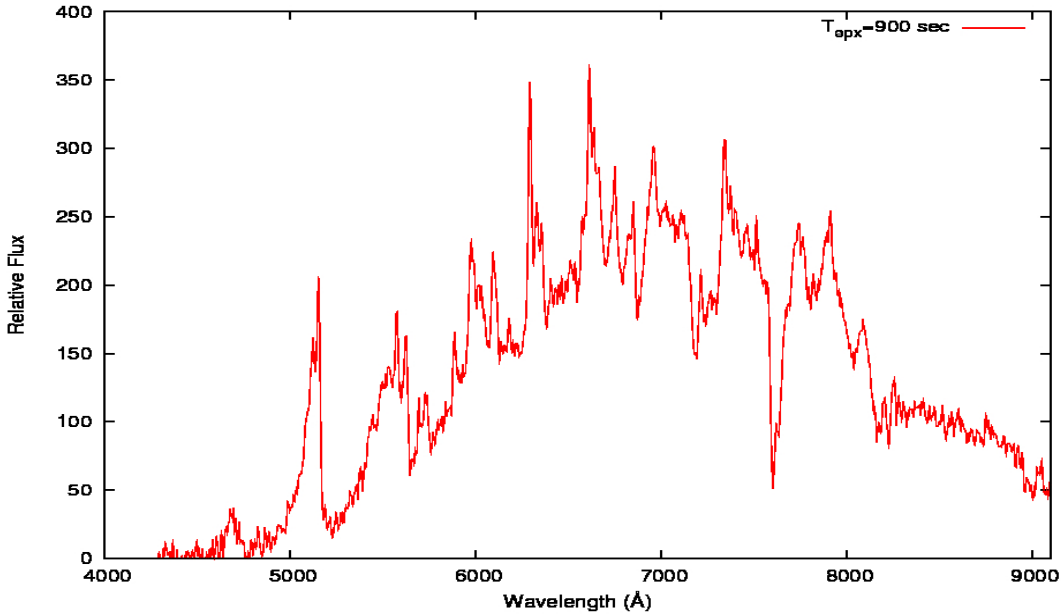
Wavelength-calibrated spectra:

13ncom4_tbw_ms.fits	FeNe lamp	0.05	lamp datacube used for comet
13nobj5_tbfw.ms.fits	Comet ISON	1800.00	comet datacube
13nobj6_tbfw.ms.fits	Comet ISON	900.00	comet datacube
13nov2013_ison_1.fits	Comet ISON	1800.00	comet single spectrum
13nov2013_ison_2.fits	Comet ISON	900.00	comet single spectrum

Derived/

'*13nov2013_ison_1.tab*' and '*13nov2013_ison_2.tab' are* the text files of wavelength-calibrated comet spectrum. The first column is the wavelength in angstrom, the second column is the relative flux of the comet. Below are the plots of the spectra, first plot is for 1800 sec, and the second plot is for 900 sec.





3. OMR Spectrograph

2.34-m VBT telescope has a Tek 1Kx1K liquid-nitrogen cooled CCD with the pixel size of 24 μm, pixel scale of 6.7"/mm in Cassegrain mode, and a field of view of 2.5'x3.7'. The readout noise and gain of the CCD are 12.6 e and 6 e/ADU, respectively. Camera focal length = 150 mm, Collimator focal length = 1000 mm, which gives the Reduction factor: R- factor = 1000/150 = 6.7.

OMR spectrograph (designed and built by the Optomechanics Research Inc., Vail, Arizona, USA) is positioned at the Cassegrain F/13 focus of the VBT. It has a 25-mm long slit with a minimum width of 50 μm and a maximum width of 900 μm. There is a set of four gratings which can be manually changed as per requirement. Short and long camera focii are available, both with clear aperture of 100 mm, with focal length 150 mm and 450 mm, respectively.

Gratings available are:
150 l/mm with resolution ~ 300. Dispersion is ~10 Å/px
300 l/mm with resolution ~ 600. Dispersion is 5 Å/px
600 l/mm with resolution ~ 1200. Dispersion is 2.5 Å/px
1200 l/mm with resolution ~ 2500. Dispersion is 1.2 Å/px

It has two wavelength comparison sources: Fe-Ne and Fe-Ar lamps, and one flat-field: Tungsten-Halogen quartz lamp.

3.1. Reduction Procedure.

All frames are trimmed. After trimming all files are with extensions _t (like 17nft1_t.fits). Then using the ***imstat*** task, the mean and standard deviation of trimmed bias frames were found, and files with large standard deviation were removed. For Masterbias frames, all trimmed bias frames were combined using the task ***zerocombine***.

Bias correction is applied to all frames of comparison (Fe-Ne lamps), flats (halogen lamp) and object frames using the Masterbias frame by task **CCDPROC**. Now all these files are with appendage _tb (like 19nob1_tb.fits) (`t' for trimmed and `b' for bias-subtracted).

All trimmed and bias-subtracted flats were combined (*_tb.fits) using the task ***flatcombine*** to make the Masterflat frame. The master flat frame is **normalized** using a task called ***response*** in the ***specred*** package to give the normalized file: nmasterflat.fits (`n' before masterflat.fits stands for normalized). This normalized flat frame (nmasterflat.fits) is used for flat-field correction of object frames using the task **CCDPROC**. Now the flat fielded object frames are with _tbf (like 19nob1_tbf.fits ) (here `t' - trimmed ,`b' - bias subtracted , `f' – flat-fielded).

Spectra of objects and comparison frames were extracted using the ***apall*** function with multispec format. The IRAF utility apall has the option "Extras" which can be set to **yes** or **no**. If set to **yes**, it produces the spectral cube, with the raw, sky and sigma/variance spectra.

Thus, in this format, it is possible to create a datacube, saving each processing step in a separate layer hat can be used later for analysis. We have used 4 layers, where the first layer will have a cleaned spectrum; the second layer will have a raw spectrum, the third layer – extracted background; and the fourth layer – sigma/variance of the extracted background that can be used to estimate the error of the signal.