spectroscopy/

1. Introduction

In May 2013, comet ISON spectra were taken on three dates, using HFOSC instrument on 2-m HCT telescope of Indian Astrophysical Observatory, Hanle, and OMR instrument on 2.34-m VBT telescope of Vainu Bappu Observatory, Kavalur:

DATE-OBS	Telescope
2013-05-01	2-m HCT
2013-05-02	2.34-m VBT
2013-05-15	2-m HCT

HCT telescope HFOSC spectra were taken in Grisms7 and 8; the description of the instrument and data reduction are in Sections 3 and 3.1, respectively. VBT telescope OMR spectra were taken in grating 600 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/May01

Raw/:

File	Object	Exposure (sec)	Grism
we010022.fits	Comet Ison	1200.0	Grism 7
we010024.fits	Comet Ison	1800.0	Grism 8
we010026.fits	FeAr	26.0	Grism 7
we010027.fits	FeAr	12.0	Grism 8
we010028.fits	bias_spec	0.0	
we010029.fits	bias_spec	0.0	
we010042.fits	FeAr	13.0	Grism 7
we010043.fits	bias_snspec	0.0	
we010044.fits	bias_snspec	0.0	
we010061.fits	FeAr	13.0	Grism 7
we010062.fits	bias_snspec	0.0	
we010063.fits	bias_snspec	0.0	
we010066.fits	FeNe	7.0	Grism 8
we010067.fits	FeAr	3.0	Grism 7
we010068.fits	bias_snspec	0.0	
we010069.fits	bias_snspec	0.0	
we010092.fits	HZ 44	600.0	Grism 7
we010093.fits	HZ 44	600.0	Grism 8
we010094.fits	FeNe	6.0	Grism 8
we010095.fits	FeAr	3.0	Grism 7
we010096.fits	bias_snspec	0.0	
we010097.fits	bias_snspec	0.0	
we010098.fits	bias_snspec	0.0	

Processed

File	Object	Exposure (sec)	Grism
CometGr7_spectrum.fits	Comet Ison	1200.00	Grism 7
ContinuumGr7.fits	Comet Ison	1200.00	Grism 7
Continuum_subCometGr7.fits	Comet Ison	1200.00	Grism 7
MasterFlat.fits	Halogen lamp	6.000051	Grism 7
SolarAnalogGr7.fits	HD195034	5.00	Grism 7
StandardGr8.fits	HZ 44	600.00	Grism 8

Derived/

ison_spectrum.txt' 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.

'ison_continuum.txt' is the text file of comet continuum obtained from the comet spectrum in Grism 7. The first column is the wavelength in angstrom, the second column is the normalised continuum flux of the comet.

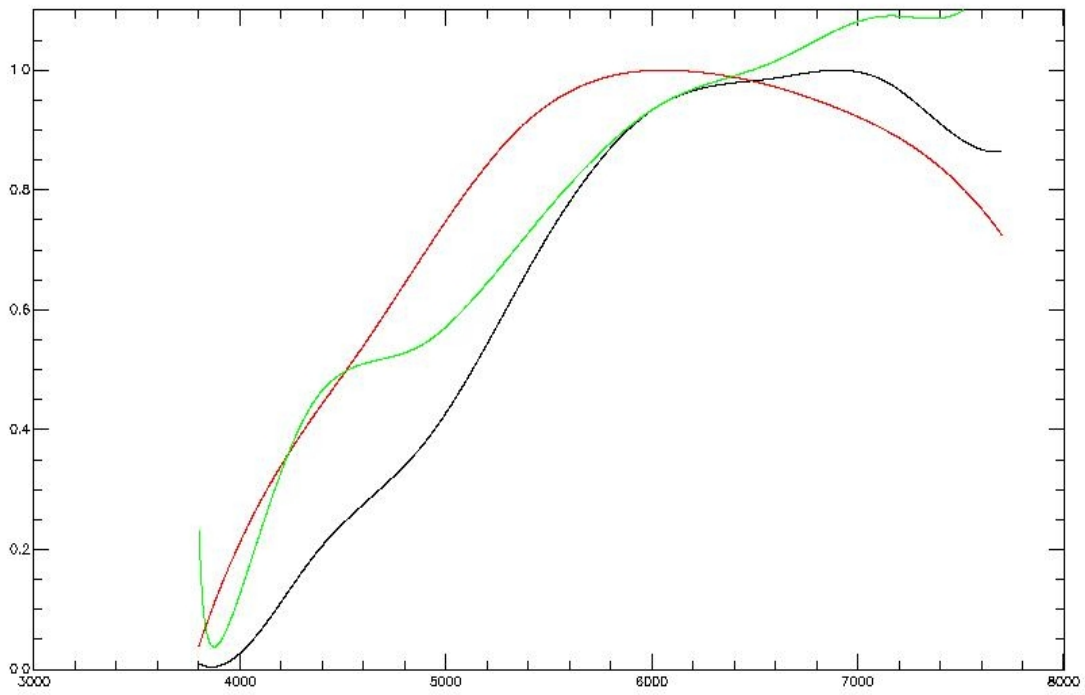
'ison_continuum_subtracted.txt' is the text file of the continuum-subtracted spectrum of the comet. The first column is the wavelength in angstrom, the second column is relative normalized flux.

'solar_analog.txt' is the text file of solar analog star HD195034 spectrum. The first column is the wavelength in angstrom, the second column is the relative flux of the solar analog.

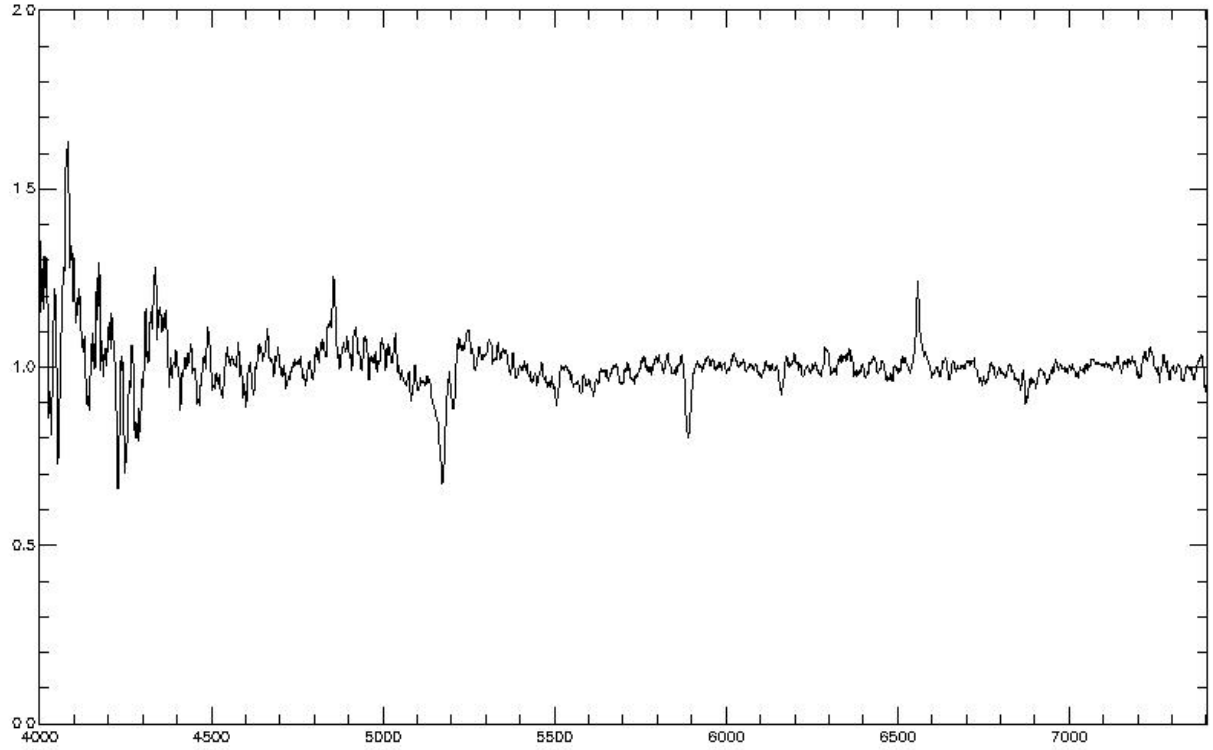
'solar_continuum.txt' is the text file of solar continuum obtained from the solar analog star HD195034 spectrum. The first column is the wavelength in angstrom, the second column is the normalised flux of the solar analog.

'albedo.txt' is the text file of the albedo of the comet. The first column is the wavelength in angstrom, the second column is the albedo value. The albedo is obtained by dividing the comet continuum with that of a solar continuum, obtained from the solar analog star HD195034 spectrum.

First figure shows the variation of albedo with wavelength. Black line: normalised continuum of ISON spectrum; Red line: normalised continuum of solar spectrum; Green line: normalised ratio of both.



Second figure represents the variation of relative continuum-subtracted comet flux (y-axis) with wavelength (x-axis).



2.2. Spectroscopy/May02

Raw/:

File	Object	Exposure (sec)
2mybia1.fits	spec bias	0.00
2mybia2.fits	spec bias	0.00
2mybia3.fits	spec bias	0.00
2mybia4.fits	spec bias	0.00
2mybia5.fits	spec bias	0.00
2mybia6.fits	spec bias	0.00
2mybia7.fits	spec bias	0.00
2mycom1.fits	Fe-Ne lamp	1.67
2mycom2.fits	Fe-Ne lamp	1.67
2mycom3.fits	Fe-Ne lamp	1.67
2mycom4.fits	Fe-Ne lamp	1.67
2myflat1.fits	Halogen flat	2.00
2myflat2.fits	Halogen flat	2.00
2myflat3.fits	Halogen flat	1.00
2myflat4.fits	Halogen flat	1.00
2myobj1.fits	Comet ISON	300.00
2myobj2.fits	Comet ISON	1800.00
2myobj3.fits	Comet ISON	1200.00
2myobj4.fits	HIP57198 star	600.00
2myobj5.fits	HD100889 standard	60.00

2.3. Spectroscopy/May15

Raw/:

File	Object	Exposure (sec)	Grism
we150018.fits	Ison Comet	600.000	Grism 7
we150020.fits	Ison Comet	1200.000	Grism 7
we150021.fits	Fe-Ar	35.000	Grism 7
we150028.fits	bias_snspec	0.000	
we150029.fits	bias_snspec	0.000	
we150034.fits	bias_snspec	0.000	
we150035.fits	bias_snspec	0.000	
we150038.fits	bias_snspec	0.000	
we150055.fits	bias_snspec	0.000	
we150056.fits	bias_snspec	0.000	
we150071.fits	bias_snspec	0.000	
we150072.fits	bias_snspec	0.000	

Processed

File	Object	Exposure (sec)	Grism
fb_ison.fits	Ison Comet	600.000	Grism 7
wfb_ison.ms.fits	Ison Comet	600.000	Grism 7
15m_masterflat.fits	Halogen	6.000051	Grism 7

Derived/

No derived spectra (see Sec. 3.1).

3. HFOSC CCD characteristics and Reduction procedure

The data was taken using the Himalayan Faint Object Spectrograph and Camera (HFOSC) mounted on the 2.0 m HCT of the Indian Astrophysical Observatory (IAO) of the Indian Institute of Astrophysics (IIA), located at 4500 m above the sea level, Hanle, Leh, Ladakh, India.

HFOSC is equipped with a Thompson CCD of 2048 x 2048 pixels with a pixel scale of 0.296”/pix and a field of view of ~10 x 10 arcmin. The readout noise, gain and readout time of the CCD are 4.87 e, 1.22 e/ADU, and 90 sec, respectively. Spectroscopy was performed using a slit width of 1.92 arcsec, and grisms 7 and 8 with resolution $\lambda/\Delta\lambda$ = 1330 for Gr7, and 2190 for Gr8, and bandwidth coverage of 0.38–0.64 μm and 0.58–0.84 μm, for Grisms 7 and 8, respectively. All the spectra are provided here were taken in the *sn-spec* mode. In this mode, the data is binned by a factor of two, along the cross-dispersion axis. For faint, and extended faint objects, this allows for a higher S/N in each pixel, but compresses the dimension of the object along the slit by a factor of two.

Details of the grisms used are as follows:

Instrument/ Telescope	Frame size (px)	Slit Dimension (WxL)	Dispersion Å/px	Range Å	Resolution Å
Gr7/ HCT	500 x 3500	°.92×11’	1.45	3800-6840	10
Gr 8/HCT	500 x 3500	°.92×11’	1.45	5800-8300	10

3.1 Reduction Procedure.

Spectra was extracted using the *apall* function with multispec format. The spectroscopic data analysis was performed using standard routines of the IRAF software by bias subtraction and flat fielding using halogen lamp. The halogen lamps taken on 2013-09-29 were used to create a Master flat which was used in all HFOSC data reductions. One-dimensional spectra were obtained using the *apall* function in IRAF. The region of interest for extracting the spectrum was considered to be 10 pixel around the optocenter (maximum of the light). Each 1-D spectrum was then wavelength calibrated using a Fe-Ar arc spectrum. Continuum subtraction was then carried out on the wavelength-calibrated spectra. Both the continuum (3^{rd} order polynomial fit) and the continuum-subtracted spectra were used for data analysis. Reduction of solar analog stars spectra, observed on 2014-05-31, also followed the same routine. The wavelength-calibrated comet spectra are fitted with a 3^{rd} order polynomial function in IRAF using the continuum-function. The extracted spectra are only for Grism 7, because SNR for Grism 8 spectra were very low. In addition, we have extracted the spectra only from May 01 data, as on May 15 the signal was not very good; hence we only present the calibrated spectral fits files: flat-fielded and bias-subtracted (fb_ison.fits), and wavelength-calibrated (wfb_ison.fits); and the same halogen flat (masterflat.fits) we have used for all the HCT reductions.

4. 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, and one flat-field: Tungsten-Halogen quartz lamp.

4.1. 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.