spectroscopy/

1. Introduction

In October 2013, comet ISON spectra were taken on two 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
2013-10-01	2-m HCT
2013-10-17	2.34-m VBT

HCT telescope HFOSC spectra were taken in Grism 7 only; the description of the instrument and reduction procedure is in Section 3 and 3.1-3.2, respectively. VBT telescope OMR spectra were taken in grating **300 l/mm**. The description of the instrument and the reduction procedure is 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/October01

Raw/:

File	Object	Exposure (sec)	Grism
wj010077.fits	FeAr	20.000	Grism 7
wj010078.fits	bias snspec	0.000	None
wj010087.fits	FeAr	20.000	Grism 7
wj010088.fits	bias snspec	0.000	Grism 7
wj010089.fits	bias snspec	0.000	None
wj010101.fits	Comet Ison	1200.000	Grism 7
wj010102.fits	FeAr	40.000	Grism 7
wj010103.fits	Halogen	6.000	Grism 7
wj010104.fits	Bias speco	0.000	Grism 7

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

Derived/

`*oct_ison_spectrum.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.

'oct_ison_continuum.tab' 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.

'oct_continuum_subtracted.tab' 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.

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

2.2. Spectroscopy/October17

Raw/:

File	Object	Exposure (sec)	Comment
17obi1.fits	bias_spec	0.00	spectroscopic bias
17obi2.fits	bias_spec	0.00	spectroscopic bias
17obi3.fits	bias_spec	0.00	spectroscopic bias
17obi4.fits	bias_spec	0.00	spectroscopic bias
17obi5.fits	bias_spec	0.00	spectroscopic bias
17obi6.fits	bias_spec	0.00	spectroscopic bias
17ofear1.fits	Fe-Ar lamp	50.00	wavelength comparison source
17ofear2.fits	Fe-Ar lamp	50.00	wavelength comparison source
17ofear3.fits	Fe-Ar lamp	500.00	wavelength comparison source
17ofear4.fits	Fe-Ar lamp	100.00	wavelength comparison source
17ofene1.fits	Fe-Ne lamp	50.00	wavelength comparison source
17ofene2.fits	Fe-Ne lamp	50.00	wavelength comparison source
17oflat1.fits	Halogen lamp	2.00	flat-field source
17oflat2.fits	Halogen lamp	3.00	flat-field source
17oflat3.fits	Halogen lamp	5.00	flat-field source
17oflat4.fits	Halogen lamp	10.00	flat-field source
17oflat5.fits	Halogen lamp	15.00	flat-field source
17oflat6.fits	Halogen lamp	20.00	flat-field source
17oison1.fits	Comet ISON	1800.00	comet
17oobj1.fits	HR3454	30.00	solar-type star
17oobj2.fits	HR3454	40.00	solar-type star

Processed/

17o_masterbias.fits	bias_spec	0.00	Master Bias
17o_masterflat.fits	Flat	9.045717	Master Flat

17o_normflat.fits	Flat	9.045717	Normalized Master Flat
17ofear1_tb.ms.fits	Fe-Ar lamp	0.05	for HR3454 wavelength calibration
17ofear2_tb.ms.fits	Fe-Ar lamp	0.05	for comet wavelength calibration
17ofear3_tb.ms.fits	Fe-Ar lamp	0.5	for comet wavelength calibration
17ofear4_tb.ms.fits	Fe-Ar lamp	0.1	for comet wavelength calibration
17ofene2_tb.ms.fits	Fe-Ne lamp	0.05	for comet wavelength calibration
17ofene2_tbw.ms.fits	Fe-Ne lamp	0.05	for comet wavelength calibration
17oison1_tbfw.ms.fits	Comet ISON	1800.00	wavelength-calibrated comet spectrum
17oobj1_tbfw.ms.fits	HR 3454	30.00	wavelength-calibrated HR3454 spectrum
17oobj2_tbfw.ms.fits	HR 3454	40.00	wavelength-calibrated HR3454 spectrum

Derived/

`17oct_ison_spectrum.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.

3. HFOSC CCD characteristics and Reduction procedure

The data was taken on 2013-10-01 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 2048×2048 pixels with a pixel scale of 0.296"/pix and a field of view (FOV) of ~10×10 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 W×L	Dispersion Å/px	Range Å	Resolution Å
Gr7/ HCT	500×3500	1°.92×11'	1.45	3800--6840	10
Gr 8/HCT	500×3500	1°.92×11'	1.45	5800--8300	10

3.1 Reduction Procedure.

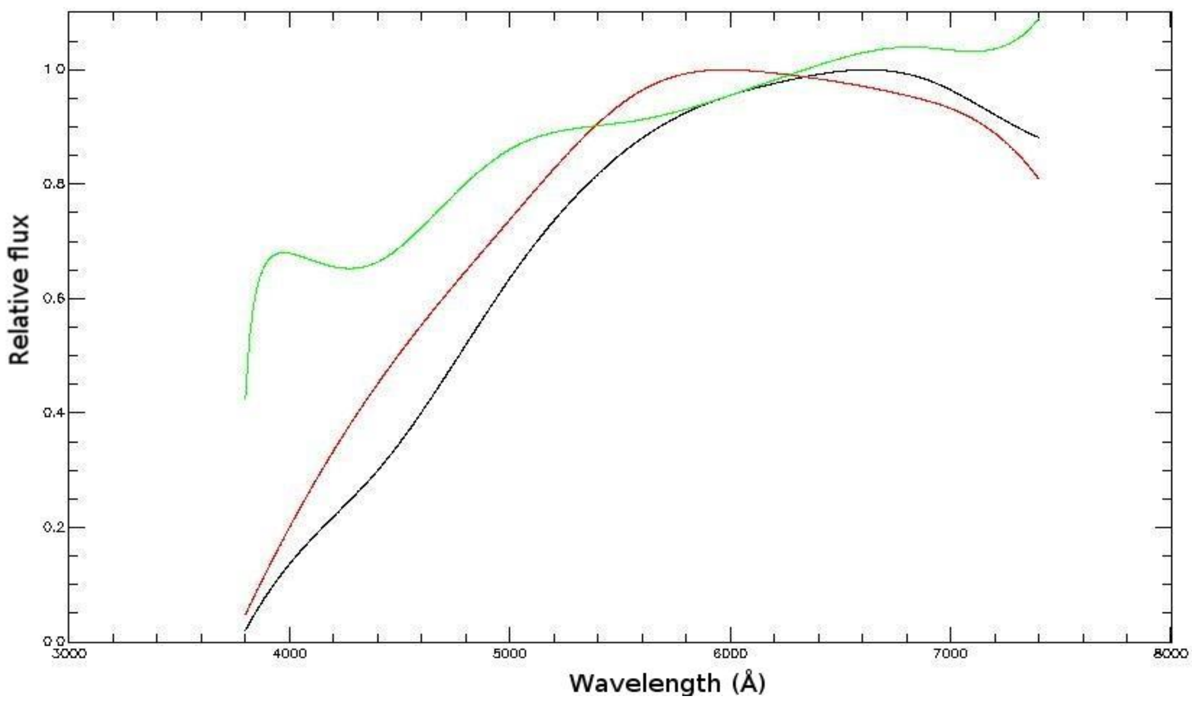
The spectroscopic data analysis was performed using standard routines of the IRAF software by bias subtraction and flat-fielding using the halogen lamp spectra. Multiple spectroscopic flats and biases taken on two dates: **2013-09-29** and **2013-10-01**, were used to construct the Master Flat. The gain and readout noise on each of these nights were calculated using the photometric sky flats (with average count/pixel = 30,000 to 40,000) and biases taken on the same night by the IRAF utility *findgain*. As the HCT/*HFOSC* has several regions of bad pixels/hot pixels and other flaws, an average value of these parameters, determined from sections of the CCD with no bright field stars or hot/bad pixels, was used in the subsequent analysis. The position of the slit on the CCD is fixed and does not change from night to night. For each night, the multiple spectroscopic biases were combined using the IRAF utility *zerocombine* (an average value is taken for each pixel, after using a minmax algorithm for cosmic-ray rejection). The combined Master Bias was subtracted from each halogen lamp spectrum. The latter were then combined using IRAF utility *flatcombine* (average combine with an average sigma clipping factor of +/- 3 to reject cosmic rays), to give a spectroscopic Master Flat. A response function of type spline3, order 25, was fitted to the segment of this Master Flat from which useful spectroscopic data would be extracted (i.e lines 200 to 3000 along the dispersion axis). The IRAF utility *response* used this response function to produce the final, normalized spectroscopic Master Flat.

1-D spectra were obtained using the *apall* function in IRAF with multispec format. This algorithm allows us to (*a*) track and make a polynomial fit to the dispersion axis on the CCD, (*b*) extract a 1-D target spectrum from a region +/- 10 pixels around the optocenter (maximum of light) at each point on the dispersion axis, (*c*) estimate the local background at each point along the dispersion axis, and (*d*) to subtract the modelled background from the raw spectrum. The local background here was obtained by a single polynomial fit to two regions, each 50 pixels wide, located +/- *Y* pixels on either side of the dispersion axis.

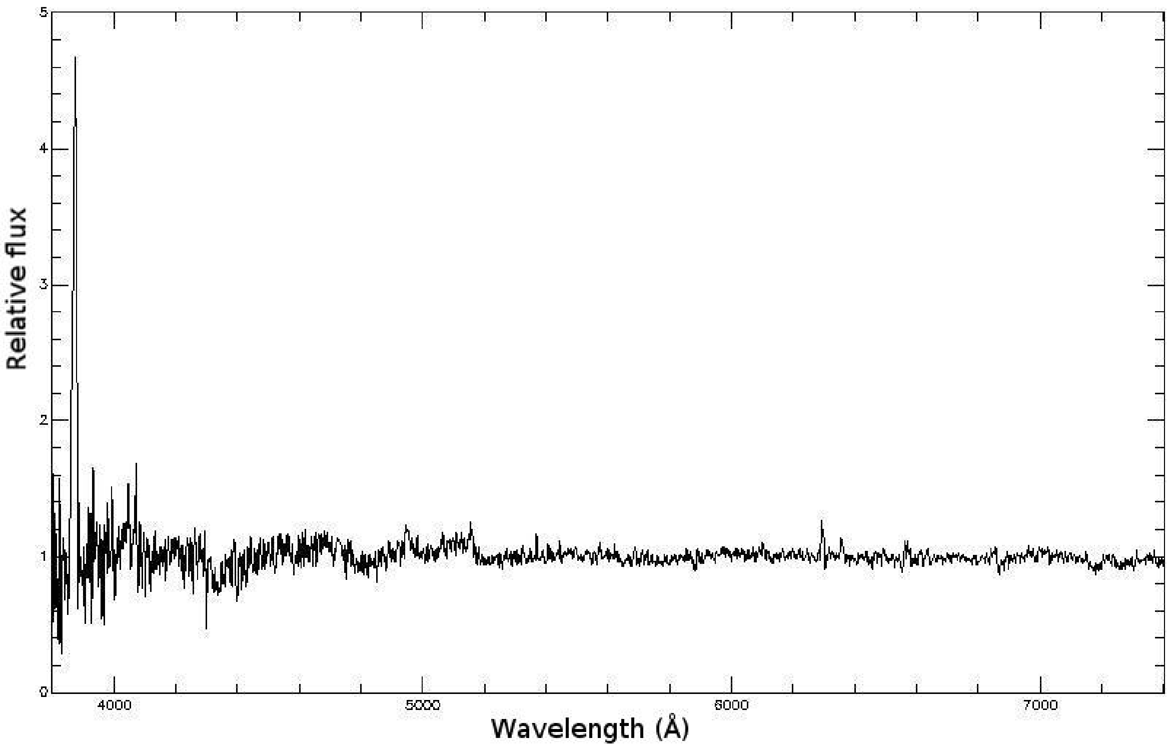
3.2 Derived Spectra.

Each 1-D spectrum was then wavelength calibrated using a Fe-Ar arc spectrum. The wavelength-calibrated comet spectrum was fitted with a 3rd order polynomial function in IRAF using the *continuum function* to obtain the spectrum of the comet continuum. Comet continuum was then normalized by dividing by the maximum value to obtain the normalized continuum. To obtain the continuum-subtracted relative comet flux, first the wavelength-calibrated comet spectrum was divided by the spectrum of the continuum, and then the normalized continuum was subtracted from the result. Both the continuum and the continuum-subtracted data were used for data analysis. Reduction of the solar analog star HD195034 spectrum, observed on **2014-05-31**, followed the same reduction routine. The reflectance spectrum was obtained by dividing the normalized comet continuum with the normalized solar analog continuum.

First figure shows the variation of reflectance 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 with wavelength.



4. OMR Spectrograph

The data was taken on 2013-10-17 using medium resolution Optometrics Research Spectrograph (OMR) mounted the 2.34-m Vainu Bappu Telescope (VBT) of the Vainu Bappu Observatory (VBO) on the IIA, located about 160 km from Bangalore in Kavalur, Tamil Nadu. 2.34-m VBT telescope has a Tek 1K×1K liquid-nitrogen cooled CCD (pixel size 24 μm) with the 6.7"/mm plate scale in Cassegrain mode, and the FOV of 2.5×3.7 arcmin. Camera focal length is 150 mm, and the collimator focal length is 1000 mm, which gives the Reduction factor: R- factor = 1000/150 = 6.7. The readout noise and gain of the CCD are 12.6 e and 6 e/ADU, respectively.

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 40 μm and a maximum width of 950 μm. OMR has a guide CCD which views the slit assembly and helps to centre the object on the slit. The desired slit height may be achieved by moving the decker using the 'decker' switch. Full slit corresponds to 25 mm. The position of the decker can be checked on the guide CCD. For example, for two pixel resolution (2×24= 48 μm) , the slit width can be kept as 48×6.7= 321 μm , which corresponds to 2.15 arcs of the sky. Slit width can be changed to any width following the above rule.

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.
Available gratings are:

1. 150 l/mm with R~21.2 and 8.0. Dispersion is ~10 Å/px.
2. 300 l/mm with R~10.6 and 4. Dispersion is 5 Å/px.
3. 600 l/mm with R~5.3 and 2.0. Dispersion is Å/px.
4. 1200 l/mm with R~2.7 and 1.0. Dispersion is Å/px.

It has two wavelength comparison sources: Fe-Ne and Fe-Ar, and one flat-field lamp: 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-Ar or 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).

4.2 Derived Spectra.

Spectra of objects and comparison frames were extracted using the ***apall*** function with multispec format. Each 1-D spectrum was then wavelength calibrated using a Fe-Ar or Fe-Ne arc spectrum.

The figure represents the variation of relative comet flux with wavelength.