The Neil Gehrels Swift Observatory (Swift) is a rapid-reaction space observatory designed specially to gamma-ray burst astronomy. Yet its broad coverage from optical to gamma-ray waveband and flexible operations system has made noticeable contributions to multiple sciences, containing observations of this study with its Ultraviolet and Optical Telescope (UVOT). The seven broadband filters of UVOT covers 1800-6000 $\AA$, and provides a 17 arcmin square FoV with a plate scale of 1 arcsec/pixel and a point spread function of approximately 2.’’4 FWHM. The Microchannel Plate Intensified CCD can provide images of 2048 by 2048 pixels with photon counting operation mode.

In order to estimate water production rate of 2I/Borisov, we used UVW1 filter of UVOT (central wavelength 2600 \AA, FWHM 693 \AA) to obtain OH emission by removing continuum acquired from V filter (central wavelength 5468 \AA, FWHM 769 \AA). With both filters Swift/UVOT observed 2I/Borisov for three times respectively starting on 2019 September 27, November 1 and December 1 (Table 1), and every observation gathered about 7700 seconds of exposure for UVW1 filter and 3100 seconds for V filter. To minimize smearing caused by the comet’s motion (???), every observation was carried by eight short orbits and a snapshot were taken for each filter in every orbit. Every snapshot further consists of several approximately 200s exposures. Table 1 briefly summarizes the observing log.

To reduce the images, pixel coordinates of the comet’s nucleus in every exposure were first determined by corresponding celestial coordinates and Swift’s orbit [1 Horizon] before stack. As 2I/Borisov is an active moving object with extended coma, the inevitable contaminations from background stars should be removed carefully next. Regarding Swift provides a plate scale of 1 arcsec/pixel, we discarded exposures with stars in the central 20-pixel aperture (corresponding to about 30, 000 km in radius) or with extreme bright stars in the central 50-pixel aperture (corresponding to about 80, 000 km in radius). The left exposures were then aligned and co-added for every observation by the nucleus’ pixel coordinates to increase signal-to-noise (Fig.1). We further masked majority of pixels contaminated by detectable stars within the central 150-pixel aperture for every stacked image by visually checking.

We used V-band stacked images to calculate magnitudes of 2I/Borisov in this band and further derive Afr, a measure of solar radiation reflected from cometary dust grains. Assuming spherical symmetry of the coma, constant outflow velocity of the dust and no production or destruction of the dust after it leaves the nucleus […?], measure of Afr is independent on radius of used photometry aperture. In fact smaller apertures are more desirable to avoid the effect of propagation processes, while for Swift it is required to use apertures with radii of more than 5 pixels, which is comparable to Swift’s point-spread function [Dennis Garradd], thus we used 7 pixels in radius for calculation of Afr. For photometry, median values of surface brightness of unmasked pixels at the same radius were used to derive a surface brightness profile, by which a count rate within the given aperture can be estimated. We use mean values of count rates from multiple circular regions around the comet as background. These background regions should be in outer parts of the stacked images to avoid coma and also have similar scattered light from detectors as the aperture circling the comet […?]. Then magnitudes can be derived from Mag = ZP – 2.5\*log(CR) [Poole. ], and Afr can be determined by Afr = .. , where Msun = […?]. We normalized this calculated Afr to a phase angle of 0 deg with phase function by D. Schleicher, in order to account for different scattering efficiencies of dust grains observed from different phase angles.

Both UVW1 and V filter of Swift/UVOT contain reflect continuum of sunlight caused by cometary dust grains with superposed molecular emission bands. The UVW1 filter well encompasses strong features of 1-0, 0-0 and 1-1 bands of the OH [A2sigma-X2pi] vibrational transitions respectively at 2811 \AA, 3064 \AA and 3122 \AA. The V filter samples the bandhead of the delta v=0 Swan-band sequence of the C2 molecule.

To determine water production rate, we first calculated count rate attributed to OH content for every observation. If we assume the contribution from C2 emission is negligible in the band of the V filter for 2I/Borisov, this calculation can be carried out by

Where CROH, CRUVW1 and CRV are count rates respectively from OH emission, observed in the UVW1 and V-band filters, the term of alpha\*CRV is to estimate contribution from reflect continuum to the UVW1-band filter, and the removal factor alpha is the ratio of continuum count rates as measured with the two filter (alpha=0.9? for the un-reddened solar spectrum).

We converted the calculated count rate of OH to the corresponding flux according to,

Where the conversion factor beta can be estimated by an OH spectrum model. This spectrum can be convolved with effective area of the UVW1 filter to predict its count rate, and be integrated over wavelength to obtain flux, then beta can be assessed by the ratio of the spectrum’s count rate to its flux. An experimental OH spectrum measured for the comet xxx […] was used as a substitute of the model and the derived value is xxx. Next We used heliocentric velocity dependent fluorescence efficiency factor (g-factor) of OH transitions […] scaled by a rh-2 decrease to retrieve the number of OH molecules for every observation. Column density can also be determined in the same way by surface brightness.

Considering varying background in outer parts for every observation, we used 8,000 km (respectively corresponding to xx, xx and xx pixels for the three observations) as the radii of apertures to determine water production rates. Surface brightness profile within an aperture can be obtained as described above and thus the column distribution profile can be acquired. We compared the column distribution profile with vectorial model and empirically adjusted alpha in formula 1 (which represents to adjust the color of dust) so that the column density profile best matches vectorial model distribution, assuming that water productions is constant with time, that all water comes from the nucleus, and that there is no significant color gradient in the coma […]. Then the water production rate can be retrieved from the best fitted vectorial model.

画图

计算error

算结果

\subsection{Uncertainties}

% How do you do the data reduction?

1. find the center of comet (RA and DEC)

2. identify nearby stars in all individual frames and discard those frames

3. center and stack the images for V and UVW1

4. Subtract v-band from UVW1 band image using the relation CR$\_{OH}$ = CR\_UVW1 - $\alpha$ CR\_V

5. remove stars -> photometry: azimuthal median method, Flux conversion into magnitudes assuming .. (give formula) >> Table

6. Calculate Afr assuming ...

Production rates:

7. First assume zero reddening and then alpha is ...

8. count rate -> flux, Convert Surface brightness to N\_mol using fluorescence (r, rv) from Schleicher

9. Compare column distribution profile with vectorial model

10. Empirically determine alpha (which represents the color of the dust) so that Column density profile best matches vectorial model distribution, assuming Q(t) is constant, that all water comes from the nucleus, and that there is no significant color gradient in the coma.

\subsection{Uncertainties}

1. stochastical error (give \%)

2. calibration of Swift (zero point) and assumption of spectrum

3. coincidence loss?

4. broadband filters: is there much C2 in the v-band (we estimated XX%)

Additional systematic uncertainties are introduced by the as- sumption needed to derive water production rates from the mea- sured column densities (including. .... reddening, model, ....(give examples)). We therefore estimate the systematic uncertainty in the water production rates to be 25%.

Uncertainty: papers

from g-factor (papers), OH model, ARF (papers), Background v, solar spectra (papers), reddening, C2 v, zero point v, vectorial model (multiple aspects) v,