The HST Treasury Program on Eta Carinae

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GENERAL RELEASE NOTES FOR GEMINI GMOS SPECTRA

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(If you use information or advice from this memo, please acknowledge it and the net site `http://etacar.umn.edu/` in any resulting publications; thanks)

1. Introduction

In 2008, we were granted long-term status to observe Eta Car with the Gemini Multi-Object Spectrograph (GMOS) on the Gemini-South telescope (P.I. K. Davidson). This includes DD time during the 2007A semester and an intensive set of observations taken before, during, and after the 2009.0 spectroscopic event. This data release includes data generated through January 2010.

For general information on GMOS see: `http://www.gemini.edu/node/10625`

If you use the GMOS spectra from this archive in a publication, please cite us in the text and include the following acknowledgment or equivalent wording:

> Based on observations (P.I K. Davidson, `http://etacar.umn.edu`) obtained at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under the cooperative agreement with the National Science Foundation on behalf of the Gemini partnership: the NSF (US), the National Research Council (Canada). CONICYT (Chile), the Australian Research Council (Australia), Ministério da Ciência e Tecnologia (Brazil), and SECYT (Argentina)

2. File Naming Convention

The file naming conventions for the HST Treasury Project archive are described in detail in Gray (2005). The *instrument code* for Gemini-South GMOS data is "g" and the date code and observation number follow the usual conventions.

3. Key Differences Between the GMOS and STIS Data

Users of the Eta Car archive may already be familiar with HST/STIS data. There are several critical differences between the STIS and GMOS data that all users should be keenly aware of.

1. **Spatial Resolution**: The Gemini/GMOS data have significantly worse spatial resolution than the HST/STIS data. At Gemini-South, seeing-limited resolution varies between 0.5 and 2.0 arcseconds (compared with 0.05 arcseconds for the HST). Furthermore, the quality of the spatial resolution in the GMOS spectra may vary greatly from night-to-night as well as from exposure-to-exposure on the same night.

2. **Spectral Resolution**: Gemini/GMOS (R = 3700–4400) has a spectral resolution that is about half the spectral resolution of the STIS/CCD covering the same wavelengths.

3. **Air vs. Vacuum**: The wavelength scale of Gemini/GMOS is calculated at the index refraction of air at sea level while the HST/STIS is calibrated in vacuum. This was the choice of the Gemini Observatory.

4. **Atmospheric Absorption**: Spectra from the Gemini/GMOS are subject to atmospheric absorption. At longer wavelengths there are several prominent terrestrial molecular bands.

5. **Differential Atmospheric Refraction**: Gemini/GMOS observations are not corrected for atmospheric refraction. The majority of the GMOS observations were not obtained at the parallactic angle. As a result, the effective slit center shifts with respect to the wavelength as one moves along the spectrum. Section 4.3 of this report explains how the slit centers have been corrected for differential atmospheric refraction *at the central wavelength (CENWAVE)* of the spectrum. The position of the slit can differ by more than 0.50 arcseconds as one proceeds along the spectrum, particularly in the bluest spectra. Use `http://www.gemini.edu/sciops/instruments/gmos/itc-sensitivity-and-overheads/atmospheric-differential-refraction` and Filippenko (1982) to for relevant information and formulae.

4. Data Reductions

The data were processed using the standard IRAF data pipeline for Gemini/GMOS observations (`http://www.gemini.edu/sciops/data/dataSoftware.html`). A few additional steps were taken in post-processing of the 2D-spectra:

1. Excess CCD rows above and below the recorded spectrum were trimmed from the archived data.

2. The [SCI] array was moved into the second FITS HDU position (after the primary header) to match the file format of other data in the archive.

3. Several FITS keywords were added to the data in post processing to facilitate indexing (see Section 4.1).
4. The wavelength scale of the spectra were corrected to the heliocentric reference frame (see Section 4.2).
5. The TEXPTIME keyword, which records exposure length, was corrected to reflect the actual length of the exposure.
6. The actual slit position was calculated accounting for possible slit position errors and differential atmospheric refraction (see Section 4.3).
7. Bad or suspect wavelength calibrations have been identified, corrected, and flagged (see Section 4.4).

The details are given below.

4.1 FITS Keywords Added For Archiving

The following are keywords added to the primary header of the data files during post-processing.

ACQDCOFF The value of the DECOFFSE keyword when the acquisition target (ACQREF) was centered on the slit.

ACQP_OFF The value of the P_OFFSET keyword when the acquisition target (ACQREF) was centered on the slit.

ACQQ_OFF The value of the Q_OFFSET keyword when the acquisition target (ACQREF) was centered on the slit.

ACQRAOFF The value of the RAOFFSET keyword when the acquisition target (ACQREF) was centered on the slit.

ACQREF The target used during acquisition. "A" denotes the central star. "S1" and "S2" denote reference stars defined in the Phase II proposal that are used to perform blind offsets.

ACQWAVE The effective wavelength of the filter that was used to center the slit during target acquisition.

APERTURE The length and width of the slit. The GMOS slits used are 300 arcseconds long and either 0.75, 0.50, or 0.25 arcseconds wide.

CENWAVE The central wavelength of the recorded spectrum (in Å).

DRPMNWAV The offset in P due to differential atmospheric refraction at MINWAVE calculated relative to CENWAVE. Users must be aware that the effective slit position may change dramatically with wavelength from one end of the spectral order to another. This keyword is provided to help assess the likelihood that further user-applied corrections are need.

DRPMXWAV The offset in P due to differential atmospheric refraction at MAXWAVE calculated relative to CENWAVE. Users must be aware that the effective slit position may change dramatically with wavelength from one end of the spectral order to another. This keyword is provided to help assess the likelihood that further user-applied corrections are need.

FILENAME The name of the dataset in the Treasury Project archive.

INTEND_P The P offset (arcseconds) with respect to the central star that was intended for the slit according to the Phase II proposal. This includes any errors introduced in the blind offset.

INTEND_Q The Q offset (arcseconds) with respect to the central star that was intended for the slit according to the Phase II proposal. This includes any errors introduced in the blind offset.

MAXWAVE The maximum wavelength of the recorded spectrum (in Å).

MINWAVE The minimum wavelength of the recorded spectrum (in Å).

OPT_ELEM The grating used for the spectrum.

P_ACTUAL The P offset (arcseconds) of the slit at the central wavelength of the spectrum with respect to the central star. This includes and accounts for the effects of atmospheric refraction and error in the blind offset.

PARAANGL The parallactic angle (degrees) of the observation. The angle is measured as defined by the north celestial pole, the object, and the local zenith (positive in the clockwise direction, Smart (1960)).

Q_ACTUAL The Q offset (arcseconds) of the slit at the central wavelength of the spectrum with respect to the central star. This includes and accounts for the effects of atmospheric refraction and error in the blind offset.

ROOTNAME The name of the observation that the spectrum has been assigned in the Gemini Science Archive (`http://www2.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/gsa/`).

TARGNAME The name of the target the slit covers. If the P_ACTUAL is within 0.50 arcseconds of the star the target is "ETA-CAR-A" otherwise the target is "ETA-CAR-HOM" ("HOM" for Homunculus).

TEXPTIME The duration of the exposure in seconds. This has been corrected for a known issue with the GMOS data.

TEXPSTRT The Modified Julian Date (MJD) when the exposure was begun.

The following are keywords added to the [SCI] header of the data files during post-processing. The [SCI] header immediately follows the primary header in all Treasury Project data files.

CD2_2 The size of a GMOS CCD pixel in degrees (2.091E-05 degrees). This is a standard WCS keyword supplied to define the cross-dispersion coordinate system.

CDELT2 The size of a GMOS CCD pixel in degrees (2.091E-05 degrees). This is a standard WCS keyword supplied to define the cross-dispersion coordinate system.

CRPIX2 The row number in the array that corresponds with the center of the slit on the cross-dispersion axis.

CRVAL2 The value of the reference pixel along the cross dispersion axis. In all the data this has been set to zero.

DEC_APER The declination of the slit center. This includes the effects of the blind offset and atmospheric refraction at the central wavelength of the spectrum (see Section 4.3). This absolute position assumes that the declination of the central star is -59.684472 degrees. This is a nominal value; the true position has never been measured with high precision.

PA_APER The position angle of the slit aperture (degrees) measured from north through east.

RA_APER The Right Ascension of the slit center. This includes the effects of the blind offset and atmospheric refraction at the central wavelength of the spectrum (see Section 4.3). This absolute position assumes that the Right Ascension of the central star is 161.265083 degrees (see remark for DEC_APER, above).

RVHELIO If this keyword = 1 then the wavelength scale of the data has been converted to the heliocentric frame of reference. If it is 0 then the wavelength scale remains in the rest-frame of the GMOS spectrograph at the time of the observation (see Section 4.2).

RVHELIOC The value of the correction to convert from the rest-frame of the GMOS spectrograph to the heliocentric reference frame. The conversion takes the form of multiplying CRVAL1 and CD1_1 by a factor of $(1 + RVHELIOC/c)$ where c is the speed of light (see Section 4.2).

4.2 Correction to Heliocentric Reference Frame

The standard IRAF reduction pipeline for GMOS data outputs a wavelength scale in the rest-frame of the spectrograph. We converted this scale to the heliocentric rest-frame. The correction factor for each spectrum was calculated using the IRAF procedure noao.rvcorrect. Those correction factors are recorded in RVHELIOC. The correction is applied by multiplying the terms of the wavelength scale in the WCS (CRVAL1 and CD1_1) by a factor of $(1 + RVHELIOC/c)$ where c is the speed of light. If this correction has been applied then the keyword RVHELIO is set equal to 1.

4.3 Actual Slit Positions

The slit positions are typically discussed as offsets with respect to the central star. Those offsets can be given in RA and Dec or P and Q. P is in the direction parallel to the dispersion axis of the slit. Q is in the direction parallel to the cross-dispersion (spatial) axis of the slit. More detailed documentation of the P/Q coordinate system can be found at:

`http://www.gemini.edu/sciops/observing-with-gemini/phase-ii-and-s/w-tools/observing-tool/science-program-editor/offset-ite`

No atmospheric dispersion corrector is installed on the Gemini-South GMOS. Consequently, the GMOS spectra are all affected by atmospheric refraction. The remedy is to orient the slit at the parallactic angle (so that a line drawn along the cross-dispersion axis is perpendicular to the horizon). It would not have been possible to plan our observing sequence to compensate all of the spectra for atmospheric dispersion, although it could have been minimized.

The Gemini-South target acquisition procedure for Eta Car used either direct acquisition or blind offset depending on observing conditions. Errors in the blind offset together with atmospheric refraction cause the actual placement of the slit to differ from the intended position. The INTEND_P and INTEND_Q keywords include the effects of errors in the blind offset.

To help the end-users of our data determine the actual placement of the GMOS slit we have calculated the effects of the blind offset and atmospheric refraction and included those in the slit positions recorded by the keywords P_ACTUAL, Q_ACTUAL, RA_APER, and DEC_APER.

We used the atmospheric refraction model of Filippenko (1982) to calculate the slit position at the central wavelength of the spectrum (given by the CENWAVE keyword). We also provide data in additional keywords (PARAANGL and ACQWAVE) to help the end user calculate additional effects of atmospheric refraction on the slit position.

The slits have also been corrected for the effect of atmospheric refraction due to the difference in hour angle. The OIWFS guider sets the tracking rate for the telescope. After aquisition it is tracked at a rate corrected for differential refraction at the effective wavelength of the OIWIFS. The telescope is *not* tracked at a rate that compensates for differential refraction at the wavelength of the spectrum. At a later time the relative position between the slit and the guider observed at their respective wavelengths will have changed (much as the apparent shape of the Sun distorts as it approachs the horizon at sunset). The parallactic angle also changes with hour angle so that this effect must be treated as a two-dimensional vector that is misaligned with the effect due to difference in wavlength between the acquisition and the observation.

Note that we have corrected the slit position for atmospheric refraction *at the central wavelength of the spectrum.* That effect changes as one moves along the dispersion axis to other wavelengths. In every spectrum, but particularly in the bluest spectra (where the effect of atmospheric refraction is most pronounced), the effective position of the slit can change by more than the width of the slit (0.5 arcseconds) over the length of the spectrum. *If your work relies on knowing the actual slit position, you* **must** *use the equations in Filippenko (1982) and the data we have provided in the header to calculate further corrections in the slit position at your wavelength of interest!*

The data for re-calculating the contribution of the blind offset to the actual slit placement are included in the keywords ACQREF, ACQRAOFF, and ACQDCOFF.

For indexing purposes the intended slit positions/offsets requested in the Phase II observing proposal are included in keywords INTEND_P and INTEND_Q.

4.4 Bad Wavelength Calibrations

A wavelength calibration error has been identified in some of the observations taken on January 21, 2009 (date code gJ05). The observations that were taken with a central wavelength (CENWAVE) of 430 nm were not correctly calibrated by the standard IRAF pipeline (file numbers 0230 through 0290). The cause of the error is uncertain. These observations were already uniquely distinguished by a problem with the flat-field calibration.

We re-calibrated the wavelength scale for each of those spectra by measuring the shift of features in the overlap between those spectra and ones at the same slit position on the same date taken with a central wavelength of 520 nm. Shifts on the order of 1.2 Å were applied to each spectrum to correct their wavelength scales.

As a precaution, the comments for the CRVAL1 header keyword have been clearly flagged "**BAD WAVECAL**" so that users are aware that there was an issue with the wavelength calibration for those files that has been corrected.

References

Gray, M. 2005, "Naming Convention for Data Files," HST Eta Car Treasury Project Technical Memo, 3[1]

Filippenko, A. V. 1982, PASP, 94, 715.

Smart, W.M. 1931, Textbook on Sperical Astronomy, 4th ed. (1960) (Cambridge: Cambridge University Press), p. 49.

[1] http://etacar.umn.edu/treasury/techmemos/pdf/tmemo003.pdf