The HST Treasury Program on Eta Carinae

Proper Motions and Radial Velocities of Ejecta Around Eta Carinae from STIS 2-D Spectroscopy

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The complex nebula surrounding the central star of Eta Carinae represents distinct epochs of ejecta from several historically recorded events. We use HST/STIS CCD data to measure the proper motions and radial velocities of various parts of the inner ejecta within 1.5" of the central star and determine their expansion ages. Previous measures used broadband images. In contrast, our results use spectra and allow us to distinguish between differing components of the ejecta. The 2-D nature of STIS allows for both proper motion and radial velocity measurements.

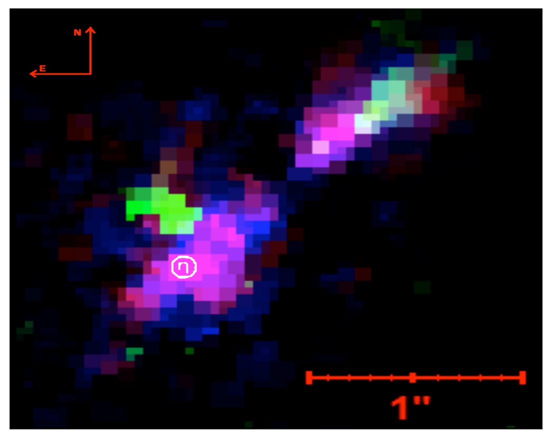

Fig B: Detected emission. Red = [Fe I] 4845; Green = Sc II 5032; Blue = [Ti II] 4918. The central star is marked by an η.

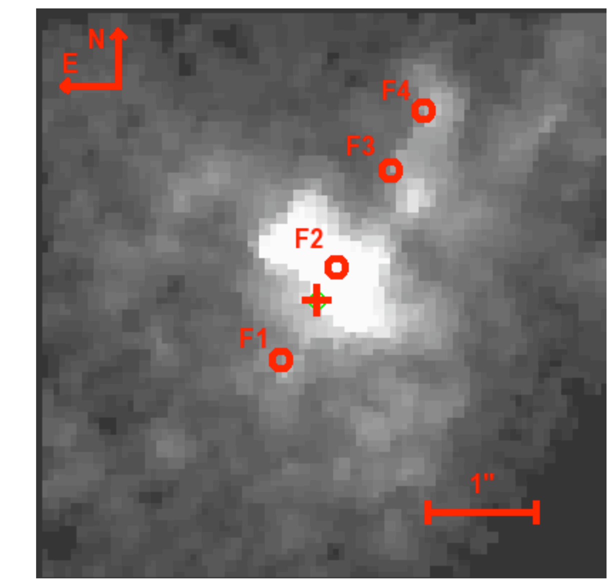

Figure 1: Continuum subtracted emission map at 4974.5 Å with features marked.

Radial Velocities

The Sr Region is an extended area NW of the star along the axis of the Homunculus nebula

with several unique emission features including [Sr II] (Hartman et al., 2004). This area is clearly visible in our maps of [Fe I] _4844, [Ti II] _4918, and Sc II _5032 (Fig B). Sr Region is in the equatorial plane (Fig A). Knowing the angle of the Homunculus axis with respect to the plane of the sky ($i = 40.7^{o}$) and the distance to η Car (D = 2250 pc), the date of origin for the emitting ejecta (T_0) is determined from the slope of the radial velocity with respect to the angular separation from the central star ($dV/d\varpi$):

$$T_0 = 2000. + \frac{4.74 \times \tan(i) \times D}{(dV/d\varpi)}$$

We measured the velocity of several strong emission lines with good S/N found exclusively in the Sr-Region spectrum in an HST/STIS slit placed along the axis of the Homunculus on 2001 March 13 (Fig C). The linear relation between velocity and position relative to the central star indicates that the material was ejected with different velocities at the same time. From the slope of this linear relation (and a few geometric assumptions discussed earlier) we find the date that the material was ejected.

Species	N	Avg Origin
Fe I	4	1839.5±3.3
Sc II	2	1839.2±2.4
Sr II	3	1840.9±9.4
Ti II	5	1833.6±8.7
Average	**14**	**1837.7±7.7**

Table A: Summary of ejection dates from radial velocities for the Sr Region.

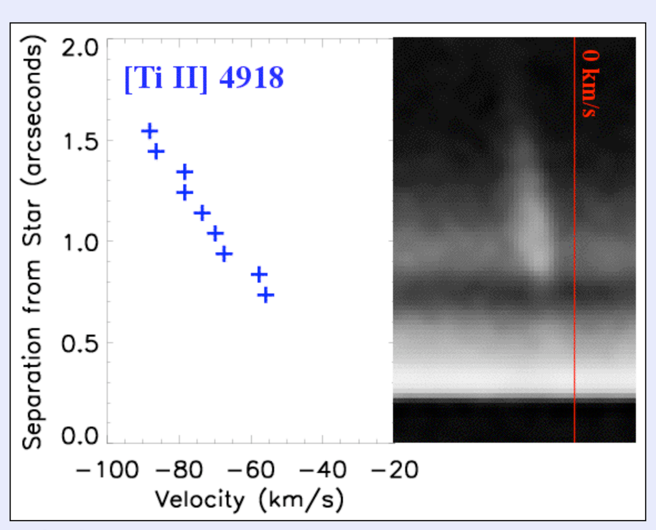

Fig C: Right Panel; a 2D spectrum from along the Homunculus axis. Left Panel; the velocity versus separation from the central star for the Sr Region.

The Sr Region was probably ejected from the central star during the Great Eruption circa 1840.

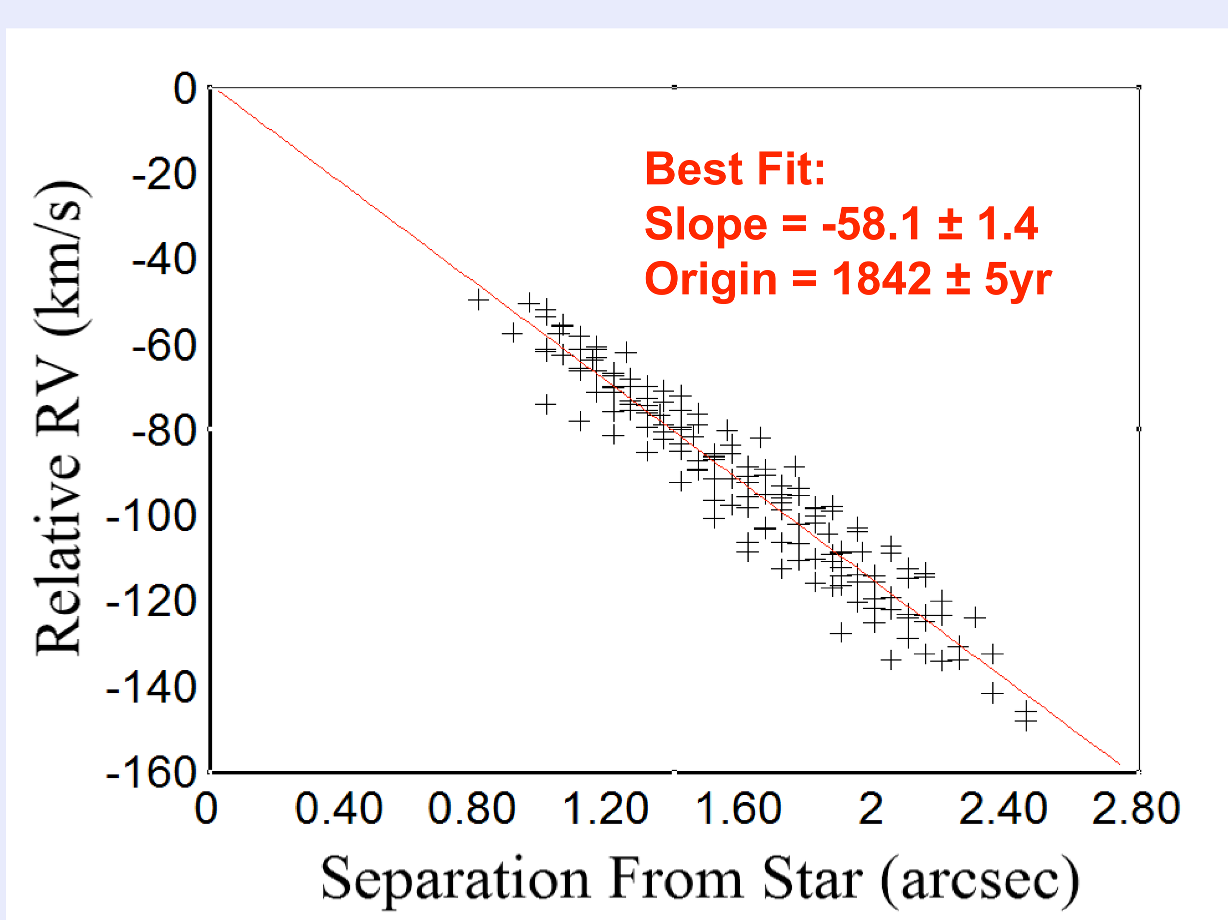

Fig D: A plot of all 156 data points from 14 spectral lines in the Sr Region shifted so that the best linear fit for each feature intercepts at zero.

References

Dorland et al, 2004, *AJ*, **127**, 1052

Hofman, K.H. and Weigelt, G., 1988, AA, **203**, L21

Smith et al, 2004, *AJ*, **605**, 405

Acknowledgments

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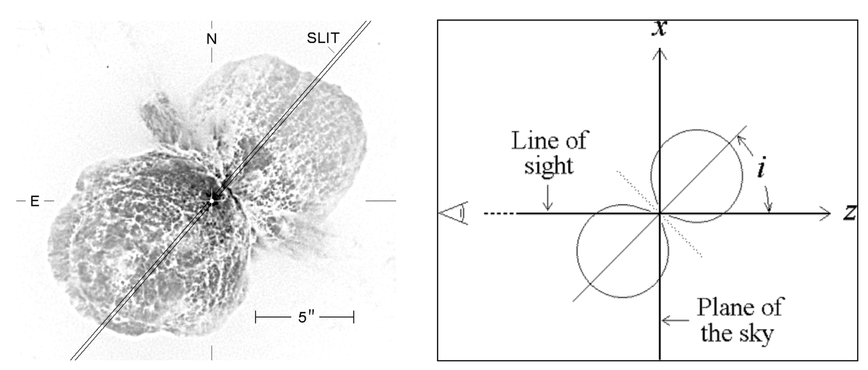

Fig A: Right: The 3D structure of the Homunculus nebula. Left: The slit position for the these data.

Date	Aperture	Position Angel	Used For
1998.204	52x0.1	-28.024	Proper Motion
1999.132	52x0.1	-27.968	Proper Motion
2000.208	52x0.1	-27.968	RV and Proper Motion
2003.229	52x0.1	-28.250	Proper Motion
1998.204	52x0.1	-28.350	Proper Motion

Table 1: Dates for data used in this analysis.

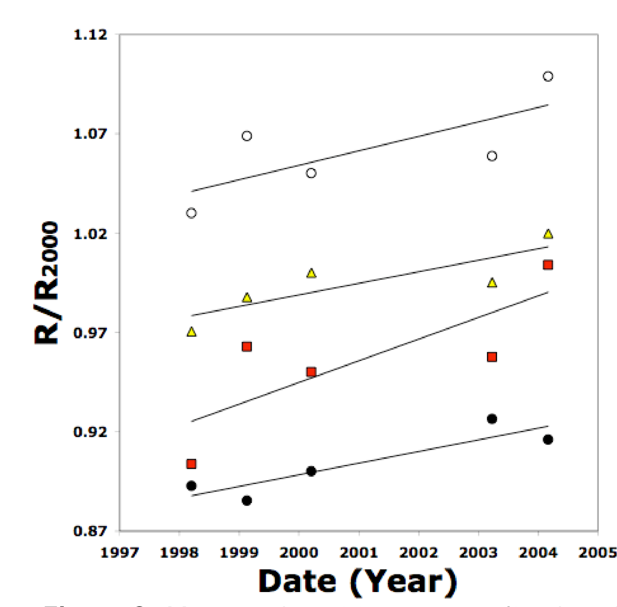

Figure 3: Measured positions, normalized to the 2000 measurement with arbitrary offset for clarity.

Weigelt "D" (f2)	Proper Motion (mas/yr)	+/-	Date of Origin	+/-	Instrument
This Work	2.93	1.02	1909	32	STIS
Smith (2004)	2.70	0.30	1908	12	FOC/WFPC2/ACS
Dorland (2004)	4.40	1.40	1934	24	WFPC2
Other features	**Proper Motion (mas/yr)**	**+/-**	**Date of Origin**	**+/-**	
f1	-2.93	0.63	1829	37	STIS
f3	6.42	1.86	1830	50	STIS
f4	11.35	4.58	1862	56	STIS
		Average	**1837**	**26**	

Table 1: Summary of results with comparison with previous work for the Weigelt "D" blob.

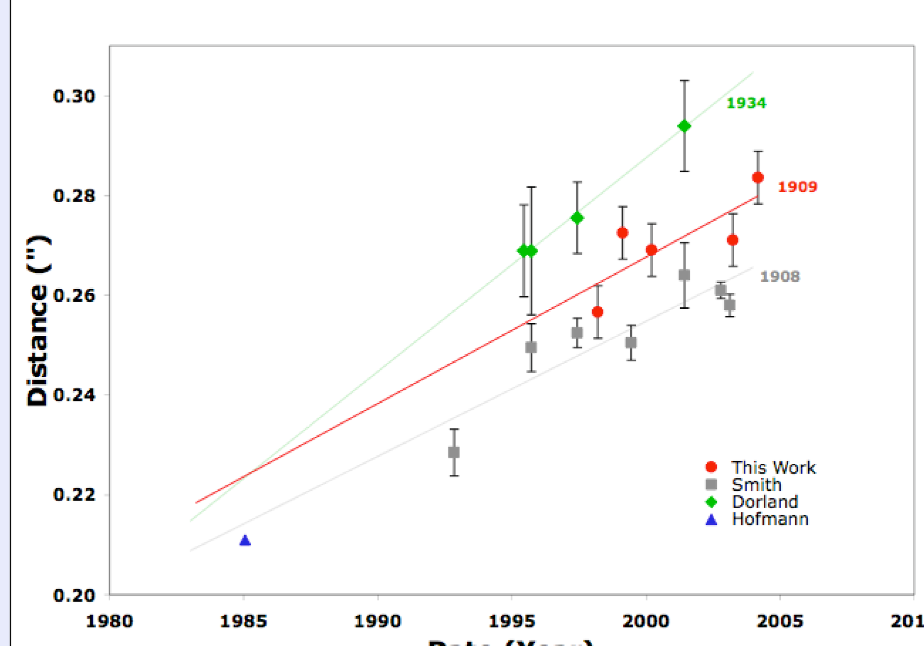

Figure 4: Comparison with previous work for the Weigelt "D" blob.

Proper Motions

We identified 15 bright lines in the 2-D STIS spectra centered around 4400 Å at the -28° position angle (Figure A). The spectra were from 5 epochs between 1998.2 and 2004.2. We performed cross-dispersion extractions 5 pixels in width (± 50 km/s or ± 0.7 Å) around each line to create spatial profiles. We also did extractions of the continuum and created a master median-combined profile which was subtracted from the individual profiles. The position of the central star (A) was determined using a cubic Chebyshev polynomial in IRAF and all profiles were offset such that A was at position zero.

We identified 4 measurable features (Figure 1 and Figure 2 top panel) in the spatial profile, referred herein as f1 through f4. f2 is also known as the Weigelt "D" blob. The other features are not specifically identified but are likely part of the inner ejecta.

For each epoch, the individual profiles were normalized to the brightest profile in a region centered on each feature and combined into a composite profile (Figure 2 middle panel). Because the spectrum does not run exactly along a single row in the image, each feature was sampled in a slightly different place in each of the 15 extractions. This creates a pseudo dithering. The impetus of this research was to explore the potential of such a method to create a high resolution composite profile for the features identified in the spatial profile.

The position of each feature was then determined using an iterative weighted centroid (Equation 1) and a linear fit was calculated for the position of each feature as a function of time (Figure 2 bottom panel and Figure 3). The fit gives both the proper motion and date of origin for each feature.

$$x_n = \frac{\sum_{x_{min}}^{x_{max}} Sxy}{\sum_{x_{min}}^{x_{max}} Sy}; S = 1 - 4\left(\frac{x - x_{n-1}}{x_{max} - x_{min}}\right)^2 \quad (1)$$

For the Weigelt "D" blob we find a date of ejection around 1910. For the other features we find ejection dates consistent with the Great Eruption circa 1840.

In Table 1 and Figure 4 we present our result alongside the results of Smith (2004), Dorland (2004) and Hofmann (1988). It is evident from the lack of overlap of the points in Figure 3 that there is uncertainty in what exactly is being measured. In this work we know that the material we are measuring has emission from FeII and [FeII]. The material being studied in previous work is likely a mix of emission and continuum sources. This question is complicated by the fact that we may be observing changes in illumination in addition to motion. The assumption that the material is preceding unaccelerated and can be fit linearly may also not be correct.

In future work we will be looking more closely at the Weigelt "C" and "D" blobs and explore improvements in our methods to more accurately date these this ejecta.

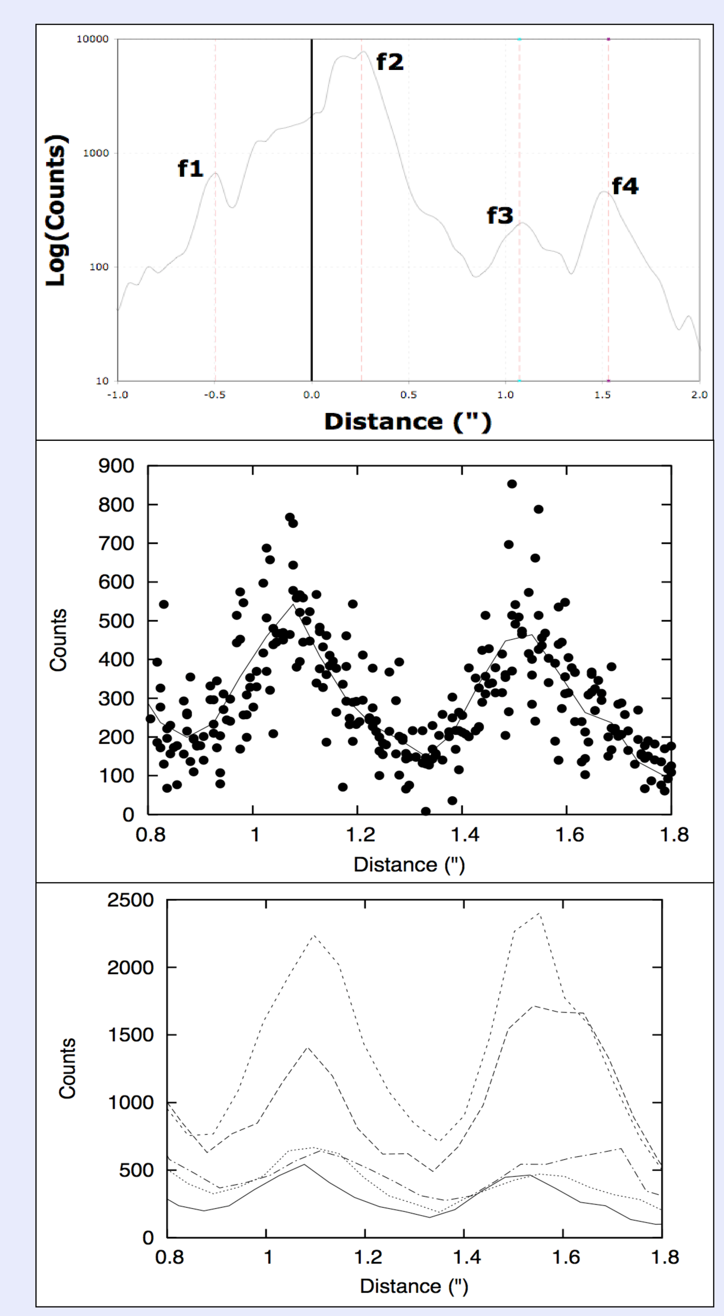

Figure 2: Top Panel: Example showing the features f1-f4. Middle Panel: Example of composite spatial profile. Bottom Panel: Example of the change in shape and position as a function of time of the spatial profiles.

This data is available at http://etacar.umn.edu/archive/spectra/