Intensive Coverage of the Eta Carinae Event in 2003

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Scientific category: HOT STARS
Scientific keywords: VARIABILITY, MASSIVE STARS, WINDS/OUTFLOWS/MASS-LOSS, EMISSION LINES, PECULIAR BINARY STARS
Instruments: STIS, WFPC2, NICMOS, ACS
Proprietary period: 0

Cycle 11 primary orbits:	39	Cycle 13 primary orbits:	5
Cycle 11 parallel orbits:	0	Cycle 13 parallel orbits:	0
Cycle 12 primary orbits:	28	Total all cycles primary orbits:	72
Cycle 12 parallel orbits:	0	Total all cycles parallel orbits:	0

Special Proposal Types: **Treasury**

Abstract

For a variety of reasons, HST can provide a *very* special and unique data set when η Car experiences its next spectroscopic event in mid-2003. Explaining the phenomenon is only part of the motivation. This star and its ejecta have unique characteristics that make them important for several branches of astrophysics; and when a spectroscopic event occurs, it's like varying the parameters in an experiment (or rather, set of experiments). The 2003 event will be the last chance in the forseeable future to obtain such a data set.

Eta Carinae has extreme parameters; it is mysterious in surprisingly basic ways; and HST/STIS can gather useful data on it at a terrific rate. As we explain below, the proposed data set will be valuable in several independent ways: It will help solve a specific set of current problems, it will constitute a large and unique archival data base for both stellar and nebular astrophysics, and it will be well-suited for educational uses.

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Total number of investigators: 16
Number of ESA investigators: 4 (indicated by * after name)

Observing Summary:

Target	RA	DEC	V	Configuration,mode,aperture spectral elements	Total orbits	Flags
ETA-CAR	10 45 3.62	-59 41 4.1	7.2	STIS/CCD SPECTRA G230MB(1713,1854,1995,2135,2276,2416, 2557,2697,2836,2976), G430M(3165,3423,3680,3936,4194,4451, 4706,4961,5216), G750M(5734,6252,6768,7283,7795, 8825,9336,9851)	18	CVZ,DUP
ETA-CAR	10 45 3.62	-59 41 4.1	7.2	STIS/CCD SPECTRA G230MB(1713,1854,1995,2135,2276,2416, 2557,2697,2836,2976), G430M(3165,3423,3680,3936,4194, 4451,4706,4961,5216), G750M(5734,6252,6768,7283,7795, 8825,9336,9851)	22	DUP
ETA-CAR	10 45 3.62	-59 41 4.1	7.2	STIS/FUV SPECTRA E140M	6	CVZ,DUP
ETA-CAR	10 45 3.62	-59 41 4.1	7.2	STIS/FUV SPECTRA E140M	3	DUP

Observing Summary:

Target	RA	DEC	V	Configuration,mode,aperture spectral elements	Total orbits	Flags
ETA-CAR-BCD	10 45 3.60	-59 41 3.9	7.2	STIS/NUV SPECTRA E230H(2513,2762)	10	CVZ,DUP
ETA-CAR-BCD	10 45 3.60	-59 41 3.9	7.2	STIS/NUV SPECTRA E230H(2513,2762)	3	DUP
ETA-CAR	10 45	-59 41	8	WFPC2 IMAGE F336W,F631N,F658N,F375N,F502N, F656N,F658N,F673N,F953N	6	DUP
ETA-CAR	10 45	-59 41	8	NIC1 IMAGE F108N,F113N,F164N,F166N,F187N,F190N	2	DUP
ETA-CAR	10 45	-59 41	8	ACS/HRC IMAGE F250W,F660N	2	DUP
				Grand total orbit request	72	

■ Scientific Justification

In May–August 2003, something strange will happen to η Carinae (Fig. 1). Its complex UV-to-near-IR spectrum will temporarily change while the X-rays peak and then plummet. The event is described below; we know *when* it will occur, but until suitable HST data are obtained we cannot know *why.* This is not merely a specialists' glitch in one variable star; circumstances have conspired to make it valuable for several branches of astrophysics. Moreover, *most of the observations proposed here are not likely to be feasible again during the next 20 years.* The resulting data set, large and diverse for the number of HST orbits required, will be a unique astrophysical resource. It will also be a hard-to-match demonstration of HST's best spatial resolution in complex spectroscopy and imaging.

Multiple, interrelated causes give this object its extraordinary role in modern astrophysics. (See reviews [1,2,3], which cite many references that we must omit here.)

• The most luminous stars are now known to exhibit decidedly non-textbook behavior, and η Car is the most extreme well-studied example, with its famous bipolar Great Eruption and subsequent history. It has $M > 120\,M_\odot$ and $L > 4{\times}10^6\,L_\odot$. The Great Eruption is the best known "supernova impostor" recognized so far. Aside from the physics of stellar structure and evolution *per se,* topics as remote as GRBs and the first galaxies require an improved understanding of very massive stars in this class. A few other known examples resemble η Car but they're much harder to study [4].

• This object occupies an extreme corner of parameter space for a different topic, stellar winds. A huge mass-loss rate (10^{-3} $M_\odot$ yr^{-1}) makes its non-spherical wind opaque.

• Unfamiliar phenomena have been discovered in the ejecta. They involve atomic excitation physics, radiative transfer, chemical evolution, and gas dynamics. The local radiation densities are orders of magnitude higher than in familiar types of nebulae. At various positions we observe several types of complex emission-line spectra and at least three of them are unlike any other known object [1,2a,2c,5,14]! They signify nebular excitation processes in conditions similar, e.g., to those in AGNs, but first recognized and easiest to study near η Car. Peculiar morphological structures in the ejecta are also noteworthy [7].

• Some of the most basic problems remain unsolved, including the Great Eruption. HST data have answered long-standing questions but also pose as many new ones – a sign of a frontier topic. Further progress requires specific new HST observations.

• It's hard to name another object that illustrates HST's resolution and data-gathering capacity as well. Excellent spatial resolution is both necessary and attainable for this target which is bright and complex, both spatially and spectrally. The oft-seen images of it came from WFPC2's high-resolution PC chip [7], not the wider field covered by most of the other famous HST pictures. Using FOS, GHRS, and STIS, this is the site of the highest angular resolution ever attained in spectroscopy of an intricate structure [2b,5].

In brief, the tag "η Car" now connotes a suprisingly broad active *topic,* not just one peculiar star. Theoretical work has been scarce so far, because the problems are novel.

Ground-based data are quite inadequate. Since ejecta with scales of $0.1''$ are very bright while our view of the star is dimmed by a localized dust patch, all ground-based spectroscopy includes a confused mixture of sources. Adaptive optics may fail to provide satisfying spectroscopy of such a difficult object in the near future, and anyway the UV is critical. Experience in the 1990s repeatedly confirmed the need for HST. We found amazingly intense anomalous UV Fe II emission $0.2''$ away from the star; a complicated Hα line shape ascribed to the star proved to be a smooth stellar wind profile contaminated by emission and absorption in nearby ejecta; the large-scale bipolar nebula contains fast and slow inner structures that are hard to explain; the shockingly large increase in apparent brightness of the central star in 1998–99 is known from HST data; plus other discoveries [1,2,5,7,14,11]. None of these was attained with ground-based instruments.

By 1996–97, HST FOS, GHRS, and WFPC2 data had revolutionized this topic [5,7] and STIS promised to do even better. Then a second, fortuitous revolution occurred. Occasionally in the past, high-excitation lines had briefly disappeared from the spectrum. (HST later showed that they originate in slow ejecta, but the root cause must be central.) In 1996 Damineli identified a *5.5-year recurrence period* for the puzzling "spectroscopic events" [8]. His discovery had two obvious implications: It was a clue to their nature, and it meant that, forewarned, we would be able to observe the next ones in late 1997 and mid-2003.

Though at least two review committees expressed skepticism, an event did indeed occur at the predicted time. The star's X-ray flux rose tremulously, peaked, and then crashed almost to zero in late November 1997 [2g,9]. Meanwhile ground-based observations like those shown in Fig. 1 were obtained [2,6,10]. Unfortunately the first STIS observations didn't occur until more than a month after onset (vertical line in Fig. 1), and then only in three narrow wavelength intervals [2b,2e]. (We anticipated the event and tried hard but failed to get the desired HST orbits.) Those first, minimal STIS results show that the event was not just an eclipse of one star or disk by another. An "iron curtain" of Fe II absorption temporarily hid much of the star's near-UV, hydrogen profiles changed, and He I emission nearly disappeared. Peculiar ejecta $0.2''$ away changed even more, probably because the star's UV flux had decreased. Judging from those and later results, similar observations a few weeks earlier would have been very interesting indeed, and would have strongly constrained models for the event and for the stellar parameters [1,2d,2h,10].

[A spectroscopic event is a multi-wavelength affair, but unfortunately we can't describe radio, IR, and X-ray aspects here [2,9]. Observing the hard X-rays with Chandra is especially desirable (Fig. 1) because in any model they come from the general region of the stellar wind; but only HST observations can separate the stellar wind from bright nearby ejecta.]

Apparently such an event lasts 3–6 months but the star continues to change subtly thereafter. Later STIS observations near times 1998.2, 1998.9, 1999.1, 2000.2, and 2001.2, with improved wavelength coverage, showed complex spectral evolution. We experienced a vivid warning of η Car's trickiness in 1998–99 when its apparent brightness tripled [11]. This was first noticed in STIS data, but a much smaller effect in ground-based photometry (dominated by ejecta) confirmed it. We think that some dust closest to the star was destroyed, but we don't know why; it wasn't a normal part of the 5.5-year cycle and it wasn't a normal LBV eruption. Eta Car fluctuates, but the last brightening this drastic occurred around

1940. Another Great Eruption – or worse! – may someday start the same way.

Spectral changes were more subtle (Figs. 2,3). Helium lines varied more after 1998 than simple binary orbit models predicted, and other strange things happened. This project has used a fairly modest amount of HST time – roughly 25 orbits in 4 years – but produced a huge volume of fascinating data. More than 2000 emission lines from the star and ejecta were observed in the STIS slit, spanning wavelengths 1700–10000 Å. Their spatial structures have led to discoveries such as an inner bipolar structure younger than the outer one, and a region with [Sr II] (strontium) emission lines [15]. Meanwhile a sophisticated wind model with an extreme mass-loss rate reproduces most (not all) features observed in 1998.2 near the end of the event [12]. However, the later ("normal"?) spectra seem more difficult to model, and non-spherical effects have not yet been included. For reasons noted below, our proposed observations will be useful for developing more ambitious models.

Thus the incomplete data on the 1997–98 event are extremely tantalizing, because the first STIS observations occurred well after the most critical period. We expect the 5.5-year spectroscopic cycle to give essential clues to the stellar parameters and thence to the basic instabilities and bipolar morphology. The most popular hypothesis invokes a companion star with a highly eccentric 5.5-year orbit. Maybe a spectroscopic event occurs near periastron when the second star either triggers an outburst of the primary or else moves into a circumstellar disk, suppressing the secondary's UV. For either of these to happen, the primary star must have certain characteristics of size, rotation, etc. – which are crucial for the fundamental problems: the instability, Great Eruption, and evolution. Ishibashi's X-ray-based orbit model predicts a brief orbital velocity peak that may be detectable at the time of the event (cf. [2h,10]). On the other hand, some binary interpretations of specific details contradict each other, and single-star alternatives may be available [1,2h]. If the star has a 5.5-year thermal/rotational/magnetic cycle – which seems possible – then this is a marvelous development for the physics of very massive stars in general. Simultaneously, certain emission lines in the ejecta – bizarrely intense Fe II λ2507 emission, for instance – are valuable for entirely different nebular processes that are easiest to study near η Car. They change dramatically during an event. (For those applications, observing the event is like varying the parameters in a laboratory experiment. Light-travel and cooling delay times times are typically 2 days in the dense gas $0.2''$ from the star.)

There is insufficient space here for us to describe all the competing scenarios, approaches, and physical arguments [1,2]; we can only note that STIS data on η Car provide many stellar and nebular diagnostics that are conventional and well-known [2a,2e,10,12,14], plus others that aren't [2a,2c,5,14]. The urgent point is that observations immediately before and during the next event – several weeks before the phase of our earliest 1998.0 STIS data – are badly needed. In summary: *The 5.5-year cycle is not yet understood, but further progress in this topic now appears to depend on it. The scientific connections are diverse and somewhat novel. The worst gap in our knowledge is a lack of HST spectroscopy just before and during an event.* Repeated (and fairly inexpensive) WFPC2-PC imaging during the event is also needed to explore variability within $3''$ of the star [2,7].

Given a period of 2023 $\pm$ 10 days $\approx$ 5.54 yr [2d,6,10], the next spectroscopic event will begin near the end of May 2003 (Fig. 1). So far we have needed only one or two sets of STIS observations per year to monitor the 5.5-year cycle. But in mid-2003, as Fig. 1 shows, the rate must greatly intensify.

Realistically, *this will probably be the last chance in the forseeable future to obtain the required spectroscopy.* The later 2009.0 event will be near the end of HST's lifetime and well past the design lifetime of STIS. STIS's data quality is gradually deteriorating, and since "side 1" electronics recently failed it now depends precariously on "side 2." HST/COS will be incapable of high spatial resolution. NGST will have no suitable instrument. Since no space-based instrument comparable to STIS is being planned now, none is likely to be in operation within the next 15 years at least, possibly much longer. A ground-based effort, though worthwhile, is inadequate for two reasons: UV is essential, and even at visual wavelengths, η Car is a difficult subject for adaptive optics spectroscopy. ($0.1''$ resolution is needed in a complex, wavelength-dependent high-contrast situation where, for instance, perceptible $0.2''$ wings would be unsatisfactory. In other words, this is a good challenge for experiments but success is not assured.) Moreover, we have already acquired STIS data through the current 5.5-year spectroscopic period, needed to connect the 1997 and 2003 events. The somber implication is that if these observations are not attempted in 2003, then some major questions may never be answered during the careers of most astronomers active today.

Since the "Description of Observations" section contains details, here we present only a sketch of our plan. The critical time extends into HST Cycle 12.

• *General remarks:* See Fig. 1. Adequate data through 2002 can be obtained with orbits already allocated (see below), and prudence requires some data in early 2003. Then the active period May–August 2003 must be sampled more intensively. How frequently? According to ground-based data, some line profiles or velocities have changed drastically in just a few days at a certain stage [2d,10]. If η Car is a binary, the current "best bet" orbit model predicts a brief 20-day orbital velocity peak, possibly detectable with STIS. Evidently, just two or three observations aren't sufficient. Maximal coverage, though, requires too many HST orbits. Our compromise plan includes just three "major" sets of observations during the event, supplemented by several minor (less complete) intervening sets. A few later observations will establish linkage with the 1998–99 STIS observations.

• *CCD slit spectroscopy:* Each "major" observation (preferably in late May, mid-June, and mid-July 2003) requires several HST orbits to sample the entire wavelength range 1700–10000 Å. Experience indicates that full wavelength coverage is merited on some occasions. (Among the 30 or so grating tilts, all but one or two are clearly useful for some problems in this complex spectrum. Moreover, archival value is a major consideration here.) We plan to observe both the star and the "Weigelt knots CD" about $0.2''$ away with the $0.1''$ slit. Each "minor" observation will use only a few grating tilts (the same subset each time) in, typically, 2 orbits.

• *STIS MAMA/echelle spectroscopy:* Some echelle observations are also needed. The few existing GHRS and STIS data on the star in the 1300–1800 Å range show a much wider range of ionization than one sees in any single spectral type [13]. This isn't merely due to a

companion star; most likely a very dense nonspherical wind is responsible. Since the far-UV spectrum represents different regions and parameters than that longward of 2000 Å, we want to see what changes occur. The best way to do that is with the FUV/E140M echelle which quickly gives a wide wavelength sample on just the star. The NUV/E230H echelle is useful for a very different purpose, concerning the Weigelt blobs. The most variable emission lines there are those excited by peculiar radiative mechanisms [14]. These lines are also narrower than more normal features in the same locations, a fact that is relevant to the mechanisms. The E230H echelle allows us to spectrally resolve the lines as they change.
• *Imaging:* Existing WFPC2 images show complex changes during the 5.5-year period, especially in the poorly-understood equatorial region of the bipolar structure [7]. Therefore we suspect that rapid variations will occur during the event. Existing IR images show a toroidal distribution of dust [2,3], and in some binary models an excitation decrease may sweep around the star. The light-travel-time delays in various parts of the ejecta range from a day to a few months. Our proposed mostly-narrow-band imaging with WFPC2 and NICMOS, repeated three times during the event, will monitor the morphological and ionization changes in regions not covered by the narrow STIS slit. (This was not attempted for the 1997 event.) ACS allows a UV image which may appear very different from existing WFPC2 pictures because peculiar emission lines dominate the 2000–3000 Å region.

The plan requires 39 HST orbits in Cycle 11, 28 in Cycle 12, and 5 in Cycle 13. This is an honest estimate of the most cost-effective size for the program, especially taking archival value into account (see below). The overall short-term plus long-term value is immense. STIS gathers data on η Car at a terrific rate, because the star is bright and a variety of intense emission-line regions occur along the slit. Including only the inner, high S/N ejecta, each complete 1700–10000 Å 2-dimensional spectrum is a 20000×400-pixel image which contains a larger fraction of meaningful, non-empty pixels than most astronomical spatial images do. Zethson identified 2500 distinct emission lines in our data sets! Consequently the volume of useful data from this project will be comparable to roughly 200 orbits' worth on normal faint targets; and the applications are diverse.

Last year we were allocated 7 orbits for Cycle 11, specifically as a precaution against "proposal-and-scheduling slippage" as the spectroscopic event approaches. They're obviously insufficient to cover the 2003 event, and last year's proposal stated that they were not intended for that purpose. Orbits requested here do not include the 7 already allocated.

A public archive

Since 1998 we have hoped to produce accessible data files of our continuing results, but the complicated nature of STIS data makes this a huge task. A Treasury project provides an opportunity. The 1998–2003 spectral record will constitute a large, definitely unique astrophysical resource that future researchers can use for several varieties of astrophysics. In a long-term view, note that η *Car will have changed significantly by the time that comparable observations become possible again 20 or more years from now.* We also remark that these data are useful for other STIS users, since they contain unusual indications of varying instrumental effects (see below).

STIS data reduction is notoriously tricky and the normal pipeline software has problems. Therefore we use greatly improved procedures developed by the STIS IDT (in some cases they used η Car as the test object, with its 2500 identified narrow lines). We must combine data from the 30 or so different grating tilts to produce a huge merged 2-dimensional 1700–10000 Å spectrogram for each major data set. Resulting files will be made available on the internet, with convenient viewing and measuring tools (rather then just referring the user to IRAF or IDL). We recognize that a typical user may be an impatient theorist developing models, not an observer accustomed to multiple reduction steps.

Education and Public Outreach

Eta Car is well known to be a wonderful object for E.P.O.; it looks spectacular, has impressive parameters, illustrates many varieties of physics, and evolves on a human timescale. Two-dimensional spectral images of STIS η Car data are appealing both pictorially and for educational projects in astronomy. In our experience, most people appreciate good scientific images which are not purely spatial – as many biologists, for example, will agree (and some journalists definitely have agreed). In this context the appeal of our project is obvious.

Among other activities, we will work with the Minneapolis Planetarium to prepare a major educational exhibit specifically on η Car and space astronomy. A new library and planetarium is scheduled to open in downtown Minneapolis in 2005. The planetarium director, Mr. Robert Bonadurer, has expressed enthusiasm and spectroscopy and imaging of η Car will probably form the opening exhibit. This is one local example and we expect others to develop.

Significance to Astronomy, and Reasons for a Treasury Project

As explained above, η Car's significance has several dimensions: It is the most massive well-studied star but its behavior has not been explained. Independently, it is a unique site for several exotic stellar, stellar-wind, nebular, and gas-dynamic phenomena.

This object and its 2003 event match the stated Treasury Program criteria *very* well. This proposal certainly "focuses on the potential to solve multiple problems with a single, coherent data set." We plan to provide "enhanced data products" as sketched above. These require and employ "new techniques for data reduction" – not just the STIS IDT procedures mentioned above, but also techniques for using time series of very large spectrograms (we may even make a movie). The Education and Public Outreach component is clearly appealing. But to us the most fundamental motivation, underlying all the others, is that this *"data set of lasting value ... should be obtained before HST ceases operations."* Not many years in the future, there will be no way to get data like these.

References: (Some entries contain more than one paper.)

[1] K. Davidson (2000), in *Cosmic Explosions,* AIP Conf. Proc. 522 (ed. S.S. Holt & W.W. Zhang), p. 421. – A brief, not-too-old review of η Car.
[2] J. Morse, R.M. Humphreys, & A. Damineli, eds. (1999), *Eta Carinae at the Millennium,* ASP Conf. Ser. 179. – Contains papers by many authors. Especially pertinent here:
. [2a] Hamann et al., p. 116 – Extraordinary compact ejecta.
. [2b] Gull et al., p. 144 – Early STIS data sets.
. [2c] Johansson & Zethson, p. 171 – Atomic physics near η Car.
. [2d] Damineli et al., p. 221 – The 5.5-year cycle.
. [2e] Davidson et al., p. 227 – Early STIS results on the star.
. [2f] McGregor et al., p. 236 – The 1997 event.
. [2g] Ishibashi et al., p. 266 – X-rays in 1997–98.
. [2h] Davidson, p. 304 – The binarity question.
[3] K. Davidson & R.M. Humphreys (1997), *Ann. Rev. Astr. Astrophys.* 35, 1. – General review of η Car as a broad topic, contains a large number of pre-1997 references.
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[9] X-rays during the 1997-98 event: M. Corcoran et al. (1998), *Ap.J.* 494, 381; K. Ishibashi et al. (1999), *Ap.J.* 524, 983; M. Corcoran et al. (2000), in *Cosmic Explosions,* AIP Conf. 522 (ed. Holt & Zhang), p. 431.
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[12] A wind model based on early STIS data: D.J. Hillier et al. (2001), *Ap.J.* 553, 837.
[13] Puzzling far-UV spectrum: D. Ebbets et al. (1997) *Ap.J.* 489, L161; H. Lamers et al. (1998) *Ap.J.* 505, L131.
[14] Exotic and unfamiliar nebular excitation processes first identified in the ejecta of η Car: S. Johansson et al. (1998), in *The Impact of GHRS on Atomic Physics,* ASP Conf.Ser. 143, p. 155; T. Zethson et al. (2001), *Astron.J.* 122, 322; K. Davidson (2001), in *Spectroscopic Challenges of Photoionized Plasmas,* ASP Conf. Ser. 247 (ed. Ferland & Savin), p. 455; Johansson & Letokhov (2001) *Science,* 291, 625; Johansson & Letokhov (2001) *Eta Carinae and Other Mysterious Stars,* ASP Conf. Ser. — (ed. Gull et al.), p. 283.
[15] Inner bipolar structure and other facets of existing STIS data:
http://hires.gsfc.nasa.gov/ bish/pub.html

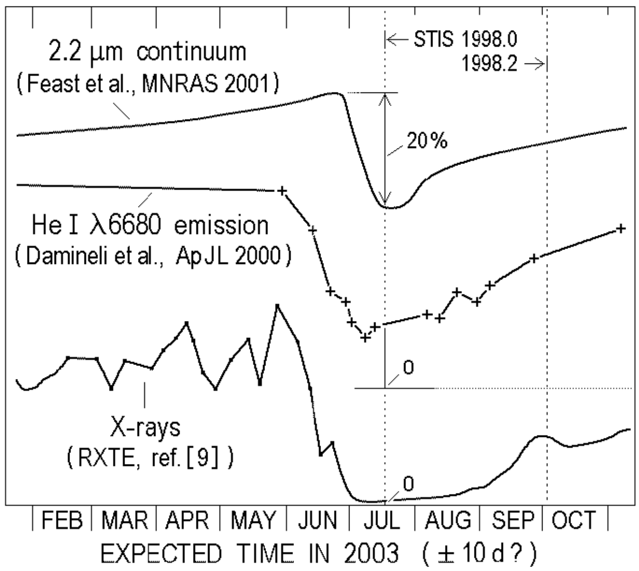
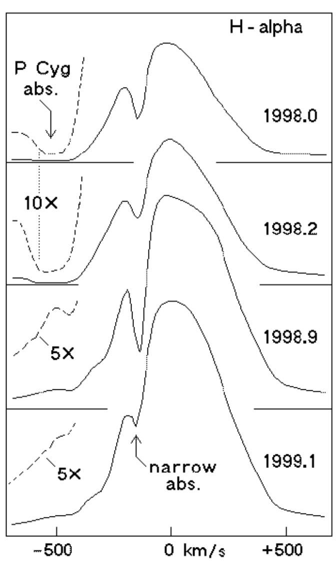


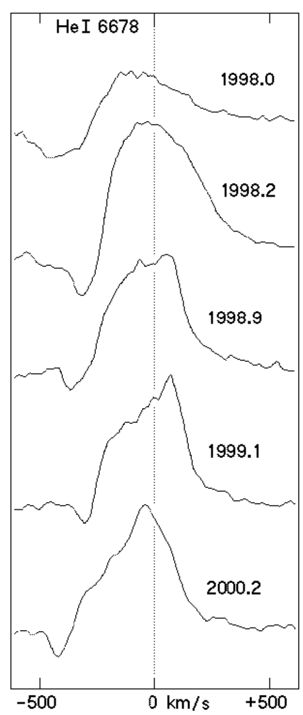
Fig. 1. Predicted time of the event: data from 1997–98, shifted 2023 days. These ground–based and RXTE observations represent an unresolved mixture of the stellar wind plus older ejecta; without HST we can't tell where the changes occurred or what they were. Two faint vertical lines show the phases of our 1998.0 and 1998.2 STIS observations. The first of these included only a minimal sample of wave–lengths and occurred after minimum had already been reached.



⬅ Fig. 2. H-alpha profile observed with STIS. Deep P Cyg absorption appeared only during the event; other changes in the profile occurred later in 1998--1999. In early 2000 (not shown) the profile resembled that for 1999.1 but had some differences.

Meanwhile, changes in the UV spectrum were quite dramatic but very complex.

Fig. 3. ➡
A helium line observed with STIS. Unlike Fig. 2, here the profiles are normalized relative to the underlying continuum; the line was weak in 1998.0 during the event. Since the change in shape appeared systematic from 1998.2 to 1999.1, the appearance in March 2000 came as a surprise. (In simple binary models the movement should have been quite slow during 1999-2001.)



Description of the Observations

• *General considerations:*
— In virtually all cases we know the exposure times from our previous observations of η Car. They range from a fraction of a second to several minutes. We obtain many exposures per orbit and overhead time is a serious factor.
— Experience shows that 1 HST orbit gives useful STIS/CCD wavelength coverage of η Car, 2 orbits are much better, and 4–4.5 normal orbits give complete 1700–10000 Å coverage. Given the STIS slit orientation in May–August 2003, the Weigelt blobs CD must be observed with a separate slit position which nearly doubles the required time. 9 normal orbits is therefore a realistic allowance for the STIS/CCD part of what we call a "major" (complete) observation set, and 2 orbits for a "minor" observation.
— Each FUV/E140M echelle observation of the star can be done in 1 orbit while NUV/E230H on the Weigelt blobs takes 2 orbits.
— A major observation set also includes WFPC2(PC) images with a number of filters, and several exposure times because the target has a huge range of surface brightness. This requires 2 orbits. The NICMOS story is similar and one orbit suffices for it.
— The main advantage of ACS for η Car is its F250W filter, but the small pixels are also useful. A suitable set of exposure times with F250W, F344N, and F660N takes an orbit. We plan to use NICMOS and ACS only twice.
— In summary, one full "major" set of observations takes about 15 orbits and a "minor" set needs 2 orbits. We can often economize, however, as noted below.
— η Car can be observed during most of the period May–August 2003, but during some critical weeks the visibility time per orbit is somewhat reduced.
— A complicating but valuable factor is CVZ. In the past we have found CVZ to be very effective for η Car, and several opportunities occur during mid-2003. These allow us to do a major observation set in less than 10 orbits rather than 15.
— The orbit budget described here does not include 7 orbits that have already been allotted for Cycle 11, intended for preparatory observations before the end of 2002.
— Plan details may need to be changed in light of later information. This may affect the division between HST Cycles 11 and 12.

• *HST Cycle 11 (see Fig. 1):*
(1) **3 CVZ orbits**: Preliminary observations sometime in February–April 2003. 2 STIS/CCD + 1 STIS/FUV orbits.
(2) **2 orbits**: Minor STIS/CCD observation set in early May, to ensure that we get some data before the event begins.
(3) **16 orbits**: Major observation set approximately May 17, near or slightly before onset of event. (8 CCD, 1 FUV, 3 NUV, 2 WFPC2, 1 NICMOS, 1 ACS orbits)
(4) **2 orbits**: Minor STIS/CCD observation set near the end of May.
(5) **7 CVZ orbits**: Semi-major STIS set in CVZ opportunity around June 3. (4 CCD, 1 FUV, 2 NUV)
(6) **7 orbits**: 2 separate minor STIS sets plus WFPC2 around June 20, time of most rapid

change. (4 STIS/CCD, 1 FUV, 2 WFPC2)
(7) **2 orbits**: "Prudent reserve" for unforeseen developments, and in case of scheduling difficulty with CVZ (probably STIS/CCD)
The total for HST Cycle 11 is therefore **39 orbits**, 10 of them CVZ.

• *HST Cycle 12:*
(1) **3 orbits**: Minor STIS observation set in early July. (2 CCD, 1 FUV).
(2) **8 CVZ orbits plus 4 others**: CVZ opportunity around July 29 provides good comparison with the earliest, 1998.0 data. Major STIS observations plus general imaging. These should be fairly close in time but need not be together. (4 STIS/CCD, 1 FUV, 3 NUV, 2 WFPC2, 1 NICMOS, 1 ACS)
(3) **8 CVZ orbits**: Near 2003 September 24, major observations with STIS but no imaging. Immediate aftermath of event. (4 CCD, 1 FUV, 3 NUV)
(4) **3 CVZ orbits**: In early 2004, to establish comparison with preceding 5.5-year period. (2 CCD, 1 FUV)
(5) **2 orbits**: Prudent reserve for unforeseen developments.
The total for HST Cycle 12 is **28 orbits**, 19 of them CVZ.

• *HST Cycle 13:*
It's wise to make one final set of observations in late 2004 or early 2005 to see how closely the next 5.5-year cycle is following its predecessor. A semi-minor STIS/CCD set plus echelle observations, **5 CVZ orbits** in cycle 13. (2 CCD, 1 FUV, 2 NUV)

Data reduction and archiving

We plan to assemble a public archive of these data, especially of the STIS/CCD two-dimensional spectra. Initial processing will use the STIS IDT software, which carries alignment,distortion corrections, special calibrations, and other details to a significantly more advanced level than the pipeline procedures used for most STIS work.

(Indeed some of the processing improvements were developed specifically in connection with η Car – because its spatially complex, dense emission line forest demands unusual effort while fortunately providing its own internal clues to distortions and other errors.)

The STIS record from 1998 through the 2003 event will constitute an archive that is rich in three dimensions: it is spectrally complex, it is spatially complex, and it shows major evolution in time. An archive should be easy to use, and shouldn't require a user (who may be an impatient theorist) to go through a series of reduction steps. One obstacle, harder than one might naively expect, is the need to merge 30 or so narrow grating-tilt wavelength samples to get a complete 1700–10000 Å spectrum. Experience shows that this is a non-trivial task, but feasible. (In 1999 we merged and spliced the our first two 1-d spectra of the star with complete wavelength coverage; files available on request.) First we will produce one-dimensional spectra of the star and other particular spatial locations, each with 20000 or more wavelength samples. Then we will develop techniques to merge the two-dimensional data sets in the same way (which is much harder). The result will be a roughly 20000×500-pixel spectral image for each "major" observing occasion from 1998 to 2003.

Lack of space precludes more details here, but since 1998 we have learned the main practical difficulties and various ways to cope with them. Of course the processed data will be publically available on the internet in both one- and two-dimensional forms. We also hope to provide suitable convenient viewing and analyzing tools, rather than merely referring the user to IRAF or IDL.

Special Requirements

These observations are time-critical for obvious reasons (Fig. 1). There is no need to make observations on any particular day, and the predictions are uncertain by ± 10 days. There is more than one reason to use CVZ opportunities, and on several occasions we have found it very suitable for η Car. For some purposes we can cut the required number of orbits by a factor of almost 2, and in our plan CVZ saves more than 20 orbits. Less well known, CVZ minimizes thermal changes within STIS, which were detected during our 1998.2 observations of η Car because the 2500 identified emission lines in the Weigelt blobs provided independent wavelength standards.

Coordinated Observations

We *will* plan supporting ground-based observations but they won't affect the HST plan. Chandra observations are also closely related in the same way. A workshop on the Homunculus Nebula (η Car ejecta) will be held in Washington State in July 2002. One full day will be devoted to discussing coordination of observations across the 2003.5 event.

Justify Duplications

We have been monitoring η Car and its ejecta for several years in order to follow its complex variability, especially related to the 5.5-year period.

Previous HST Programs

• Earlier HST FOS, GHRS, and WFPC2 programs:
GO 2338 "Spectroscopy of the η Car point sources." Pre-COSTAR FOS observations of Eta Car. Main results published in Davidson et al., AJ, 109, 1784 (1995).
GO 6041 "A Multifaceted investigation of Eta Carinae." Paper on GHRS spectroscopy published in Davidson et al., AJ, 113, 335 (1997). Data also reported in refs. 2, 5, 14 of the Scientific Justification. Other data combined with GO 6501, see below.
GO 6501 "Probing the Equatorial Ejecta of η Car," Imaging papers are Morse et al., AJ, 116, 2443 (1998) and Smith et al., AJ 120, 920 (2000). GHRS paper was Zethson et al., A & A, 344, 211 (1999). Other results published in ref. [2] of the Scientific Justification, and incorporated with later STIS work.

• The following programs were effectively one long-term project that culminates in this proposal. Resulting publications are listed together later below.
GO 7302 "STIS observations of η Carinae".

GTO 8036 (P.I. was T. Gull) "Observations of η Car: High Ionization and Internal Nebular Structure".
GO 8327 "STIS observations of η Car: the Central Star".
GTO 8348 (P.I. was T. Gull) "Eta Car, the Integral Nebula and the Homunculus".
GO 8619 "Critical spectroscopic variations in η Car".
GO 9083 (same title as 8619).
Data from 7302, 8327, and 8619 were obtained in 1998–2001. Those from 9083 have not been scheduled yet. 9083 includes 7 orbits to be used in Cycle 11 (see Description of Observations, above).

Papers from the above STIS programs, already published in refereed journals:
• Davidson, K., Gull, T.R., Humphreys, R. M., et many al. (1999) AJ, 118, 1777: "An Unusual Brightening Of η Carinae."
• Johansson, S., Zethson, T., Hartman, H., et al. (2000) A & A, 361, 977: "New Forbidden and Fluorescent Fe III Lines Identified in HST Spectra of η Carinae."
• Smith, N., Morse, J.A., Davidson, K., & Humphreys, R.M. (2000), AJ, 120, 920: "Recent Changes in the Near-UV and Optical Structure of η Carinae."
• Davidson, K., Ishibashi, K., Gull, T.R., et al. (2000) ApJ, 530, L107: "Eta Carinae: Testing a Binary Orbit Model with the HST/STIS."
• Zethson, T., Gull, T.R., Hartman, H., et al. (2001) AJ, 122, 322: "Sr II and [Sr II] Emission in the Ejecta of η Car."
• Hillier, D.J., Davidson, K., Ishibashi, K., & Gull, T.R. (2001) ApJ, 553, 837: "On the Nature of the Central Source in η Carinae."
• Davidson, K., Smith, N., Gull, T.R., et al. (2001) AJ, 121, 1569: "The Shape and Orientation of the Homunculus Nebula Based on Spectroscopic Velocities."
— We are currently (Sept. 2001) preparing several new papers on various aspects of the STIS data, including a general report on the star's spectral changes (Davidson et al.) and discovery of the small inner bipolar nebula (Ishibashi et al., see Scientific Justification ref. [15]).

• Recent conference proceedings book (2001): "Eta Carinae and Other Mysterious Stars: Hidden Opportunities of Emission Spectroscopy," ASP Conf. Ser. 242 (ed. Gull, Johannson, & Davidson). Thirteen papers in this book made use of our STIS data.

• A number of our STIS results first appeared in other conference proceedings, "Cosmic Explosions," AIP Conf. 522 (2000, ed. Holt & Zhang) and "Eta Carinae at the Millennium," ASP Conf. 179 (1999, ed. Morse et al.).

• Two Ph.D. theses: K. Ishibashi, University of Minnesota (1999) and T. Zethson, Universty of Lund (2001). The STIS data will also be a major component in at least two other Ph.D. theses now in preparation.

• In addition we have had a large number of poster papers and talks at AAS and other meetings.