SN1998eq Analysis Status Report

presented by Greg Aldering
Apr 9, 2001

1 Introduction

Here I examine the latest progress that has been made in analyzing the HST and Keck photometry of SN1998eq. I want to make it very clear that much of what I will present is based on extensive work done by Shane Burns on the NICMOS end and Rob Knop and Alex Conley on the WFPC2 end.

There are two levels of analysis which have been pursued. In the first, we hoped to use the NICMOS rest-frame B-band brightness of SN1998eq to set a limit on the possible amount of SN evolution and/or intergalactic dust. The idea is that if we assume SN1998eq is a normal Type Ia which is unextinguished by dust or dimmed by evolution, then it should be no fainter than the faint end of the stretch-corrected SN Ia distribution. At the 1σ level, this would translate to as little as 0.10—0.12 magnitudes fainter than our favorite cosmology. The advantage of this approach is that we need not perform an extinction correction, e.g., based on the measured $U - B$ color excess. Of course if SN1998eq *does* suffer extinction, then the constraint will not be very powerful.

The second level of analysis would try to perform the extinction correction using the $U - B$ color excess. This step would be needed to actually include SN1998eq in a new measurement of Ω_M, Ω_Λ.

This memo is organized as follows: I first examine the NICMOS data and show that SN1998eq was a non-negligible host contribution. I then discuss NICMOS aperture photometry measurements done by Shane Burns and WFPC2+Keck rest-frame U-band photometry and associated lightcurve fit performed by Rob Knop. Finally, some discussion of the next steps in the analysis is presented.

2 NICMOS image analysis

I obtained a *DRIZZLE*'d image of the Nov 18, 1998 NICMOS F110W observations of SN1998eq from Shane Burns. From this image, it is apparent that

SN1998eq has a substantial host galaxy. Note that the presence of a host is not readily apparent from individual NICMOS or WFPC2 images.

In order to estimate the impact of this host on our photometry, I modeled the scene as a delta-function plus an underlying circularly symmetric exponential disk centered on the delta-function. This scene was convolved with a PSF generated by Shane Burns, and further blurred with a $0''.067 \times 0''.067$ box filter in order to model the observed image. The pre-blurred PSF was calculated using TinyTim assuming a blackbody spectral energy distribution peaking at 1.1 μm. (The PSF is sensitive to the object spectrum at the level of a few percent due to the variation in diffraction over the very broad bandpass of the F110W filter). The box filter width was chosen to give a reasonably good match to the SN, as the original PSF was clearly too strongly peaked. Physically, the box filtering operation would mimic registration errors of roughly ± 0.5 pixels in the original NICMOS images. All pixels within $1''.52$ of SN1998eq were included in the fit; pixels at larger radii were included to better constrain the disk model. (This is appropriate if a circularly symmetric centered exponential disk is a good match to the host galaxy, but will be less than optimal for obtaining a good SN brightness measurement if the host is not well described by such a model.)

Fig. 1 shows the *DRIZZLE*'d NICMOS F110W image, while Fig. 2 shows the model and Fig. 3 shows the difference between the data and the model. The best-fit was obtained for a SN flux of 0.104 DN/sec, and an exponential disk having a central surface brightness of 0.0004 DN/pixel/sec and an exponential scale-length of $0''.08$. For this initial study, the noise was taken to be constant across the image, which would be appropriate for sky- or readout-noise dominant ed data. Accordingly, the noise was taken to be the measured dispersion of pixel values in a blank-sky region. The resulting fit gives $\chi^2/DOF = 1.3$. As shown in the next section, this is higher χ^2/DOF is consistent with the observed versus expected scatter amongst individual photometry points, indicating that the uncertainties have been underestimated (perhaps due to correlated noise). I should caution that there could be a significant correlation between the disk scale length and my choice of the blurring kernel, since the fit is likely to add more disk light if the blurring kernel was too conservative. Also, by centering SN1998eq on the disk in this model, it is probable that the maximum amount of disk light has been incorporated.

Using the standard STScI NICMOS photometry cookbook procedures (NICMOS handbook version December 1999, chapter 5), the SN counts can

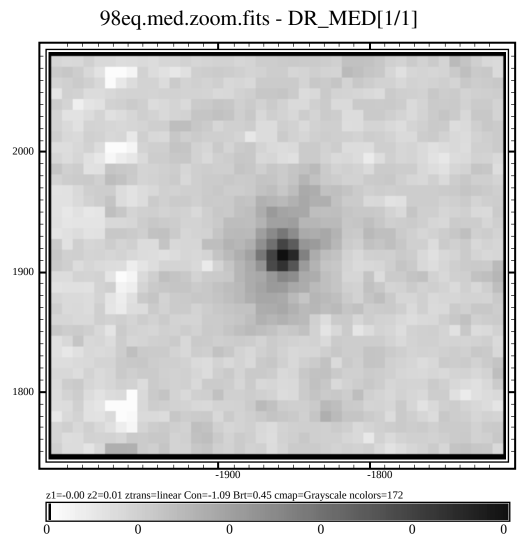

Figure 1: The *DRIZZLE*'d NICMOS F110W image of SN1998eq constructed by Shane Burns from the four orbits of observation taken Nov 18, 1998.

be converted to a J-band magnitude on the Vega=0 system of $J = 24.69$. Based on the lightcurve fits (see below), these observations occurred 12.8 restframe days after maximum light if $s = 1$. Using Peter's value of $J = 23.79$ mag for a $s = 1$ Ia at peak at $z = 1.2$ in our favorite cosmology, along with our standard B-band template, I estimate that the expected brightness of SN1998eq at this lightcurve phase is $J = 24.66$, in good agreement with the observed value. If instead I assume $s = 1.15$, as suggested by the lightcurve fits, then $J = 24.2$ would be expected. In this case it is possible that either SN1998eq suffers extinction or the host-galaxy contribution has been overestimated[1]. A radial profile of the data, the best-fit model, the PSF-convolved SN, and the PSF-convolved disk is shown in Fig. 4.

3 NICMOS photometry

Shane Burns performed aperture photometry on the 12 individual images obtained from four orbits of NICMOS observations on Nov 18, 1998. These images consisted of $2 \times 1026 + 512$ seconds per orbit. Shane used an aperture

[1] since we know our cosmology can't be wrong!

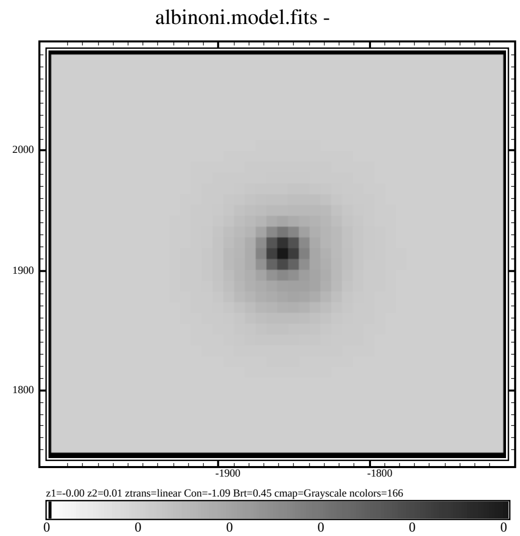

Figure 2: Best-fit model of the NICMOS F110W data obtained by assuming an underlying circularly symmetric exponential disk centered underneath SN1998eq.

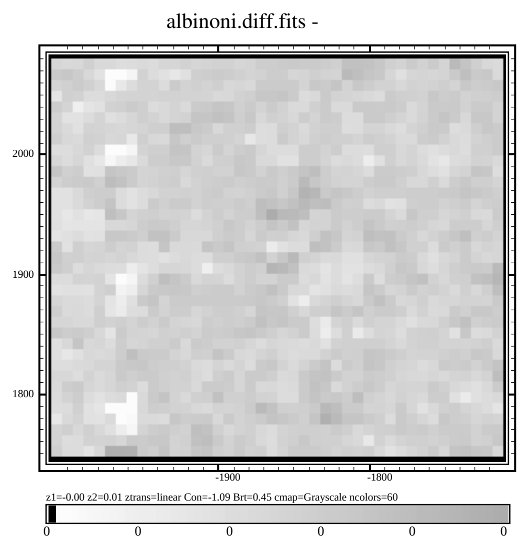

Figure 3: Difference between the NICMOS F110W data and the best-fit model.

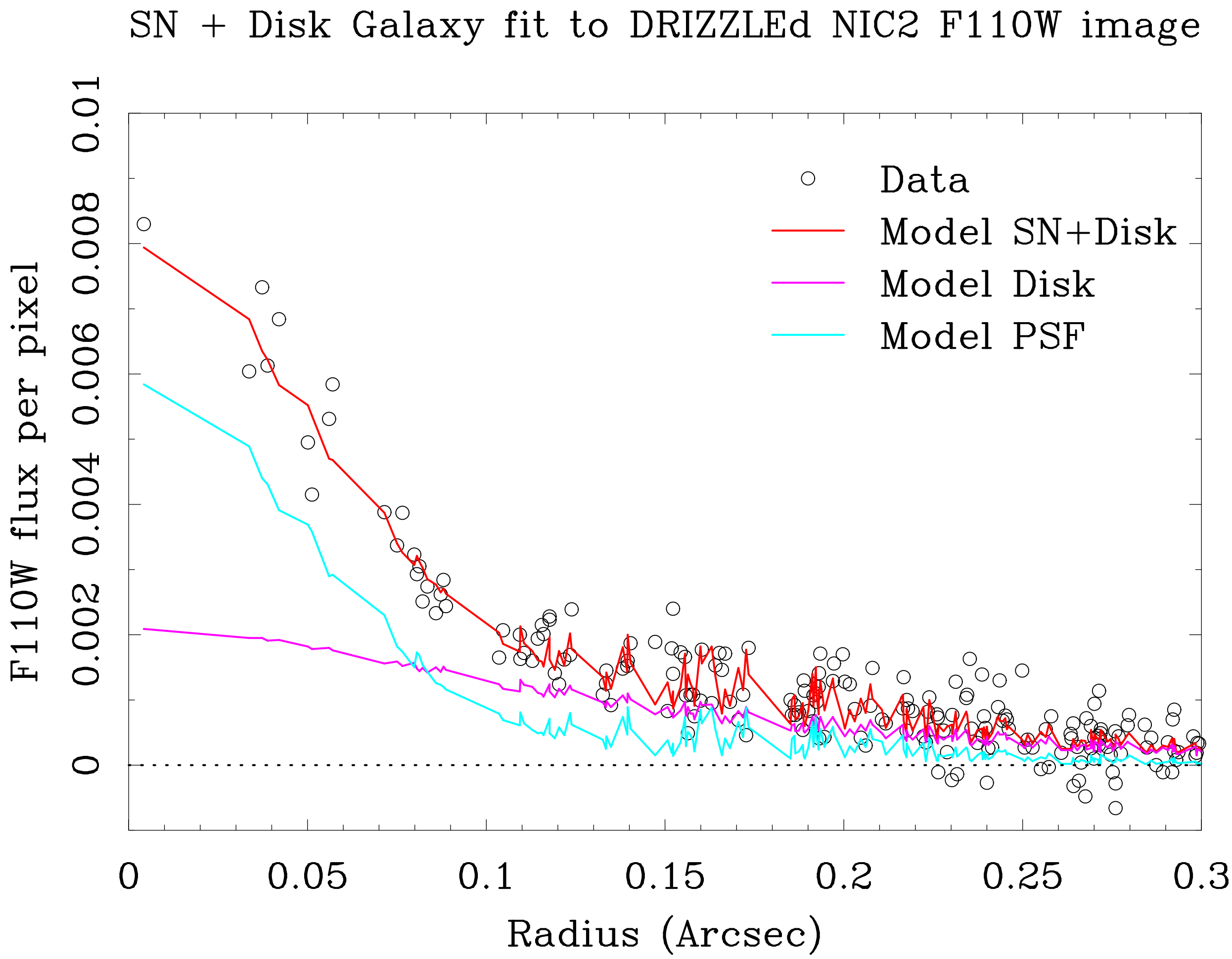

Figure 4: Radial profile showing the data, the model, and the SN and disk model components. Note that the model components are shown after they have been convolved by the blurred TinyTim PSF. Note that the pupil mask is decentered in the NIC2 camera, causing asymmetric diffraction features which appear as glitches in the radial profile.

with a diameter of 4 pixels. Sky reference was measured using the median in a 20 pixel-wide annulus whose inner edge was located 10 pixels ($0\farcs76$) from SN1998eq. The counts in the photometry aperture were scaled to the counts that would have been obtained in a $1''$ (13.3 pixel) diameter aperture using a TinyTim PSF. A further correction of $1.15\times$ is applied to obtain the total flux in an infinite aperture. These counts can be converted to f_ν, f_λ, or Vega magnitudes using header keywords. See the March 10, 2001 report by Shane for further details.

I took Shane's measured fluxes for SN1998eq from the 12 individual NICMOS images and calculated χ^2 versus J-band magnitude. A parabolic fit gives 24.004 ± 0.038, but with $\chi^2/DOF = 1.3$. So, conservatively, we achieved an uncertainty of $0.038\sqrt{1.3} = 0.043$. This corresponds to $S/N = 23.0$. If I apply the $\sqrt{1.3}$ factor to the individual uncertainties quoted by Shane, then $S/N \sim 7.3$ in 1026 seconds. The NICMOS ETC says that at 24.00 mag an exposure of 1024 seconds should give $S/N = 7.8$. (Thus, some correction to the NICMOS ETC estimates should be applied in further proposals.)

Of course the presence of significant host galaxy light, as demonstrated above, means that these aperture photometry measurements overestimate the flux from SN1998eq itself. The S/N for SN1998eq will be decreased in proportion to the fraction of host light in the measurement aperture.

4 Restframe U-band Lightcurve Fitting

Rob Knop obtained photometry from ground-based Keck I-band images from the reference image, the search image, and a final reference image using standard SCP procedures. Note that the Keck I-band photometry could be improved by approximately $\sqrt{2}$ if a deeper final reference image were obtained.

Rob also measured WFPC2 F814W photometry, which is still *very preliminary*. PSF-fitting was employed, using a PSF calculated using TinyTim and then convolved with a charge diffusion kernel obtained (long ago) from Andy Fruchter. To crudely account for galaxy light, a plane was fit to approximate the local background. The PSF+plane model was fit over a 9×9 pixel ($0\farcs45 \times 0\farcs45$) region centered on the nominal position of SN1998eq. The parameters $(\langle x\rangle_i, \langle y\rangle_i, f_i^{SN}, f^{Bkg}, \partial f^{Bkg}/\partial x, \partial f^{Bkg}/\partial y)$ were fit to the $i = 1, .., 4$ images. The fit gives $\chi^2/DOF = 1.08$, and is shown in Fig. 5. The uncertainties on f_i^{SN} used in the lightcurve fit include the marginalized uncertainties on the

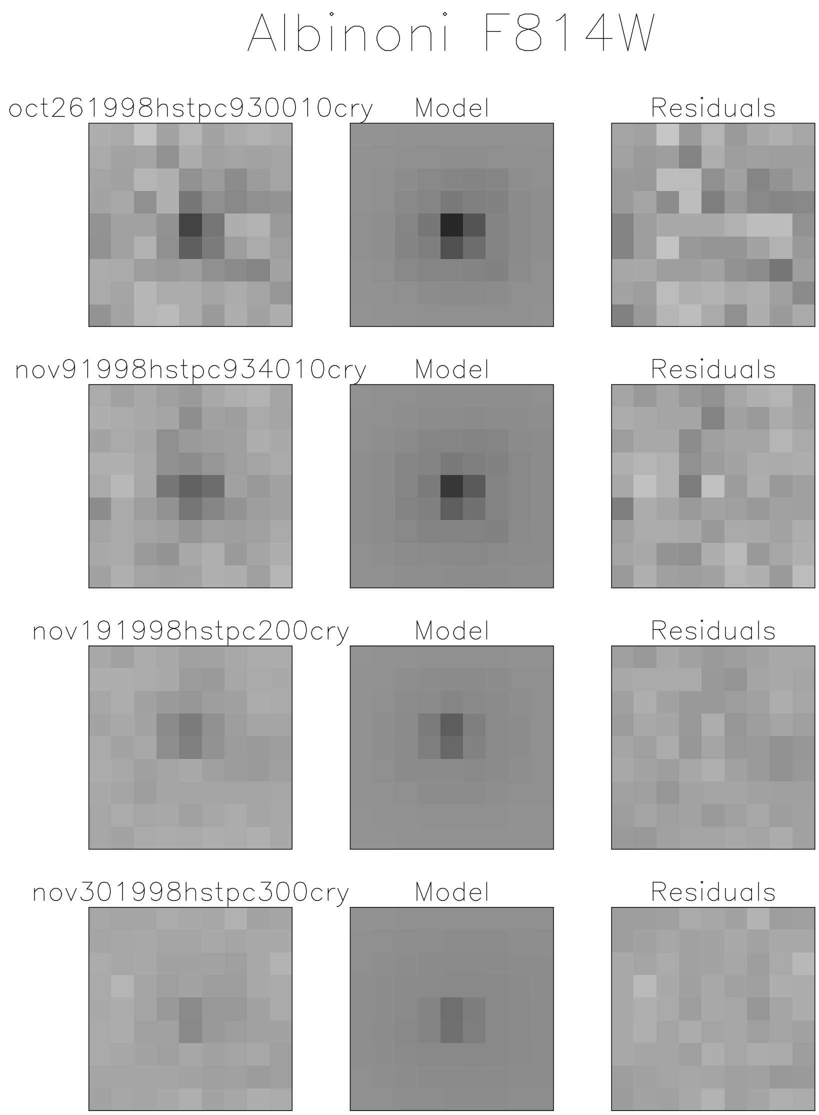

Figure 5: Rob Knop's PSF+plane fit to the HST WFPC2 F814W images. The left column shows the data, the middle column shows the model, and the right column shows the difference between the two.

other fitting parameters. However, the 4 photometry points don't yet include the correlated errors due to covariance with the background fit parameters.

CTE corrections were applied, but incorrectly, so they must be redone. First, the background sky had already been subtracted from the images Rob photometered, so the incorrect sky brightness (i.e., roughly zero) was used in the standard Whitmore CTE correction formula. Second, the correction was performed based on the sum of the fluxes of the individual images, however, the CTE correction is supposed to be applied to the individual images. These two effects work in opposite directions, but certainly don't cancel!

The results of the lightcurve fits are given in Figs. 6 and 7. Noticed that in the unedited fit (Fig. 6) there is a suggestion of a scale difference between the Keck aperture photometry and the WFPC2 PSF photometry. Indeed, the Keck data alone give χ^2 per datum of ~ 1.9 relative to the best-fit lightcurve. There is no χ^2 problem for the edited fit Fig. 7), however, all the Keck points are above the best-fit by about 5%. Since WFPC2 CTE corrections are about this size, proper CTE corrections may remove this discrepancy.

Note that according to these fits, SN1998eq was on the rise during the reference run. So I think that a ground-breaking paper comparing the risetime of SN1998eq with that of nearby SNe Ia is urgently needed [2].

5 Future Work

Since SN1998eq is contaminated by host-galaxy light, it is crucial that final reference images be obtained. I am in the process of incorporating final WFPC2 F814W reference images into our Cycle 9 RPS2. In theory these observations could be obtained next month, depending on how flexible the HST calendar is at this point. We cannot obtain a NICMOS final reference images until a early next year at best. I suggest, however, that the WFPC2 F814W image may provide sufficient guidance concerning the shape of the host galaxy that an adequate model for NICMOS F110W can be constructed. A very deep ground-based final reference image is also desirable; I estimate that a minimum of one hour on Keck with good ($0.''7$) seeing is highly desirable. (Unfortunately, SN1998eq will not be observable from the ground until late June.)

Given the data we currently have, the overall impact the final results on SN1998eq will have is unclear. Rob's edited lightcurve fit indicates that

[2] NOT!

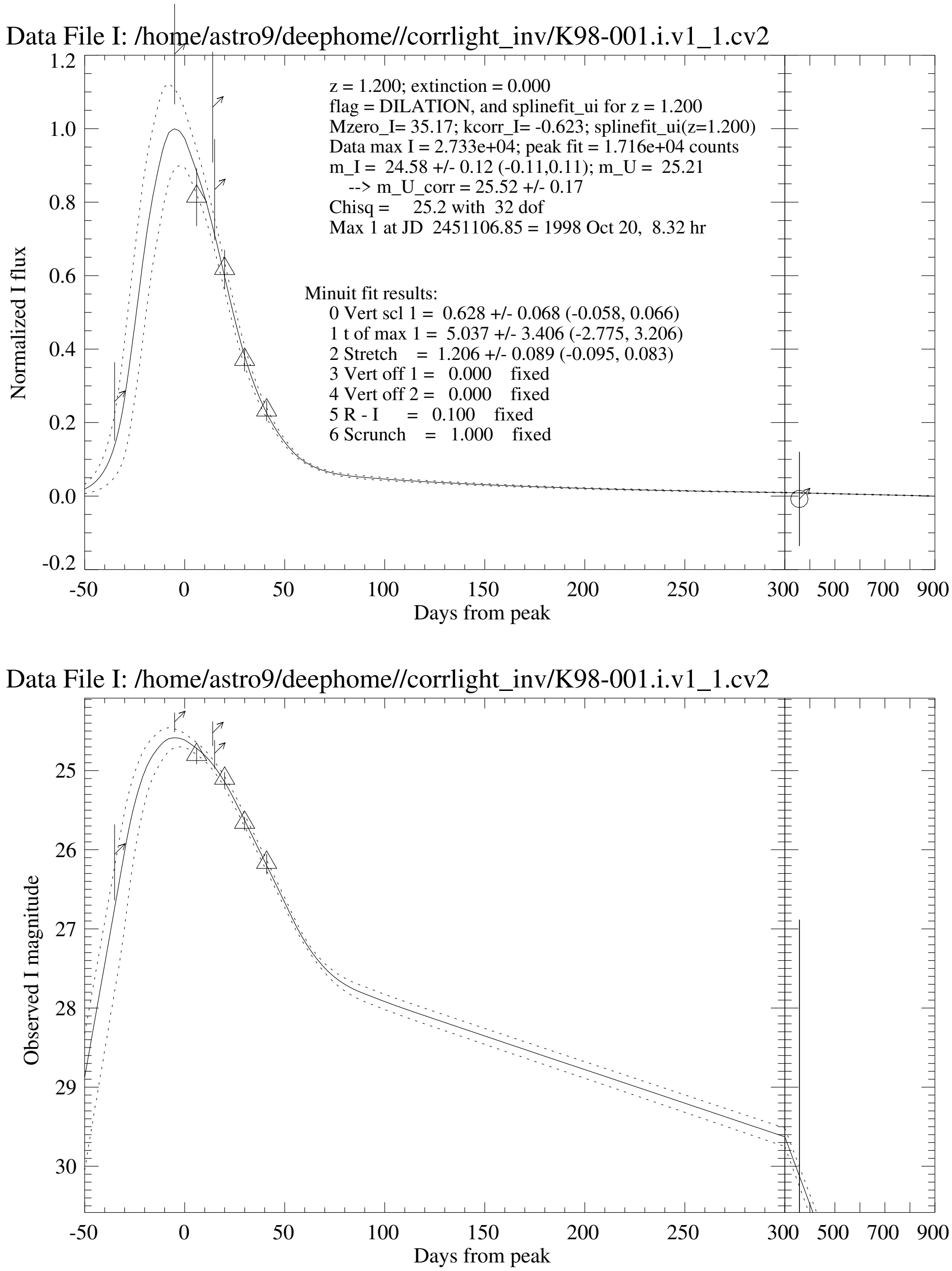

Figure 6: Rob Knop's *SNMINUIT* fit to the Keck I-band and all the WFPC2 F814W photometry. A Keck I-band observation has been used as a final reference.

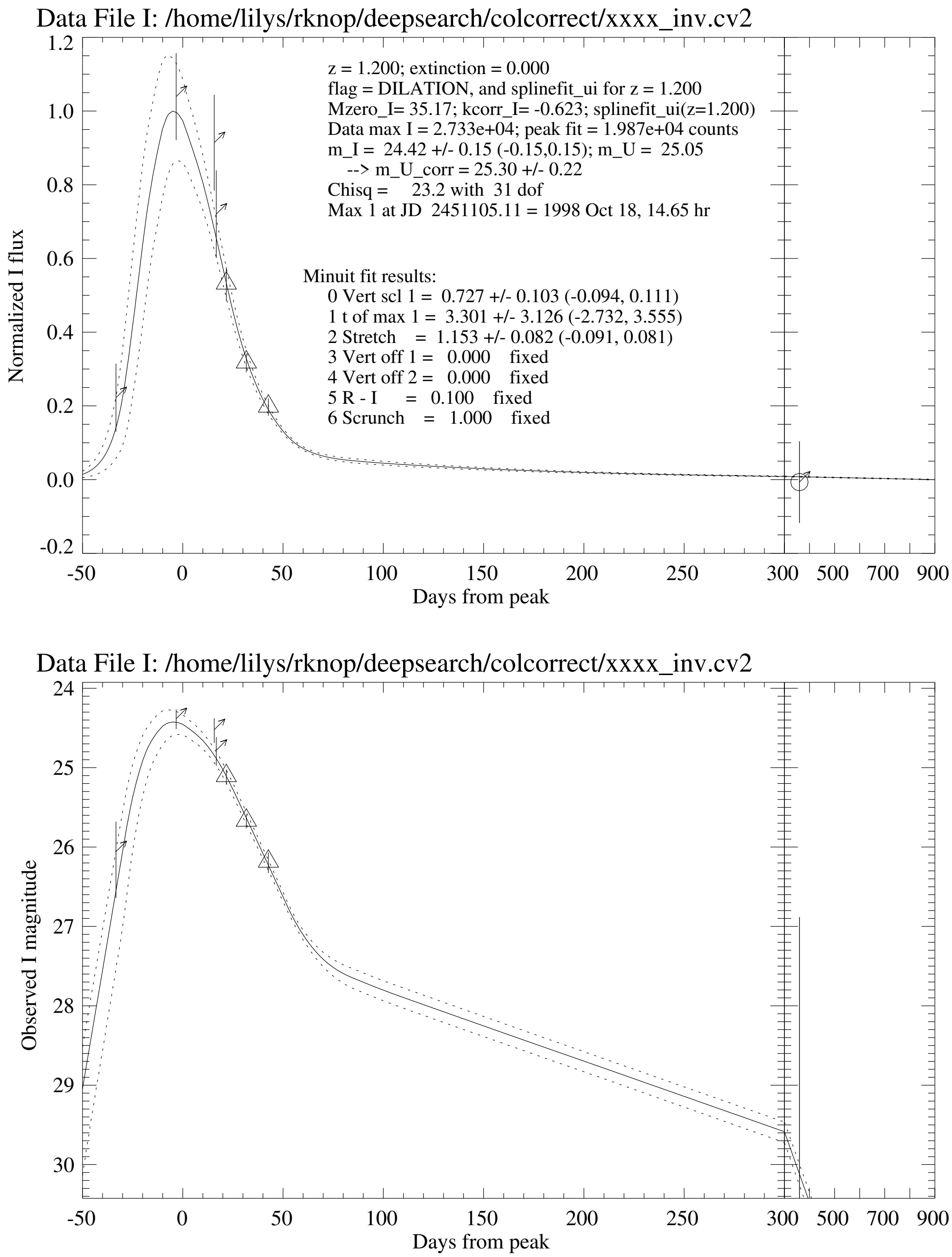

Figure 7: The same as the previous figure except that one WFPC F814W point has been rejected because it may be contaminated.

m_U^{corr} is uncertain by ± 0.22 mag. If we renormalize the uncertainties in the fit according to the $\chi^2/DOF = 23/31$, the uncertainty would be reduced to ± 0.19 mag. If a much better reference image for the Keck I-band can be obtained, it is possible that the stretch uncertainty (which is currently the same size as the raw flux uncertainty) would drop considerably because the pre-max and max photometry would improve. The photometry in NICMOS seems potentially very good, although after a best-effort correction for host-galaxy light SN1998eq may be slightly dimmer than expected. SN1998eq is about as bright as expected in the WFPC2 data.

Given that there are still a number of aspects of the analysis which need fixing, I think there is considerable hope for achieving a solid result from the SN1998eq photometry. Some work has also been done on the rates from the SN1998eq search and the interpretation of the SN199eq spectrum, which may be to sufficient to yield additional papers.