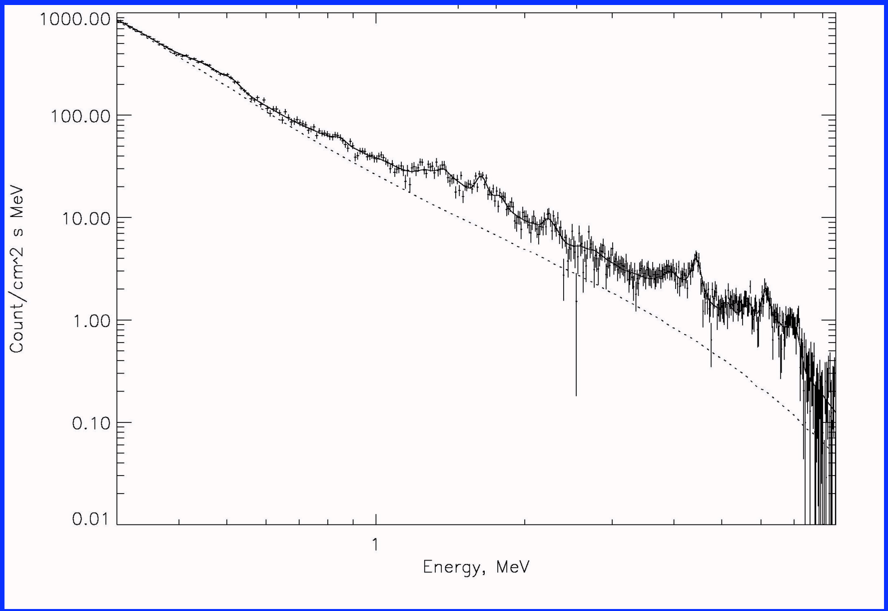
Using Gamma Rays to Measure Accelerated Ions and Electrons and Ambient Composition

Gerald Share[1,2], Ronald Murphy[2], Benz Kozlovky[3], and Juergen Kiener[4]

[1] UMD, [2]NRL, [3]Tel Aviv Univ, [4]Univ. Paris Sud

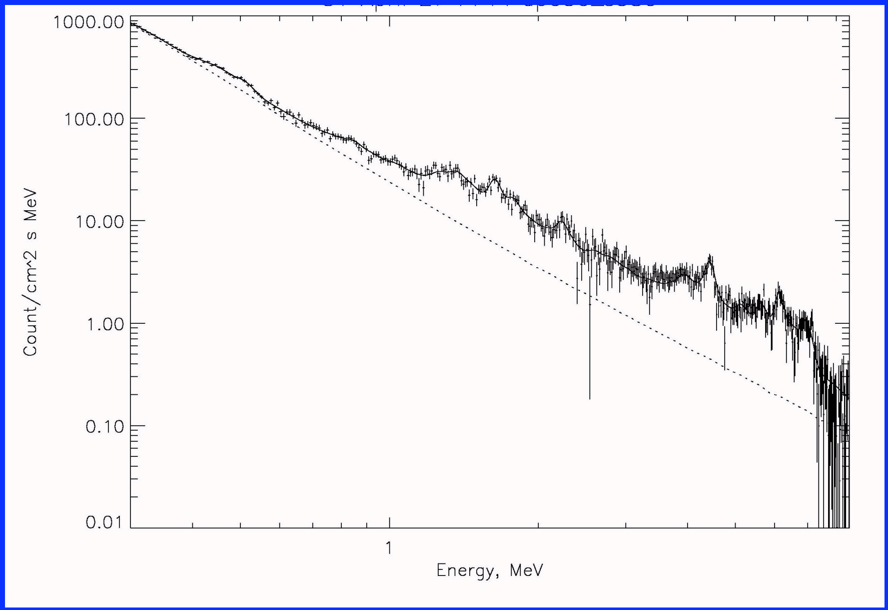
Supported under NASA Grants NNX07AH81G, NNX07AO74G, and NNG06GG14G.

We have re-evaluated the SMM instrument response using a Monte Carlo calculation in lieu of the original quasi-empirical response. Two fits to the 1981 April 27 spectrum are shown below; both are acceptable but the fit with PL*Exp is favored. The latter compensates for the unresolved nuclear continuum that extends above 10 MeV



Fit with PL + PL x exp:

chi2/dof 1.008 (50% probability)



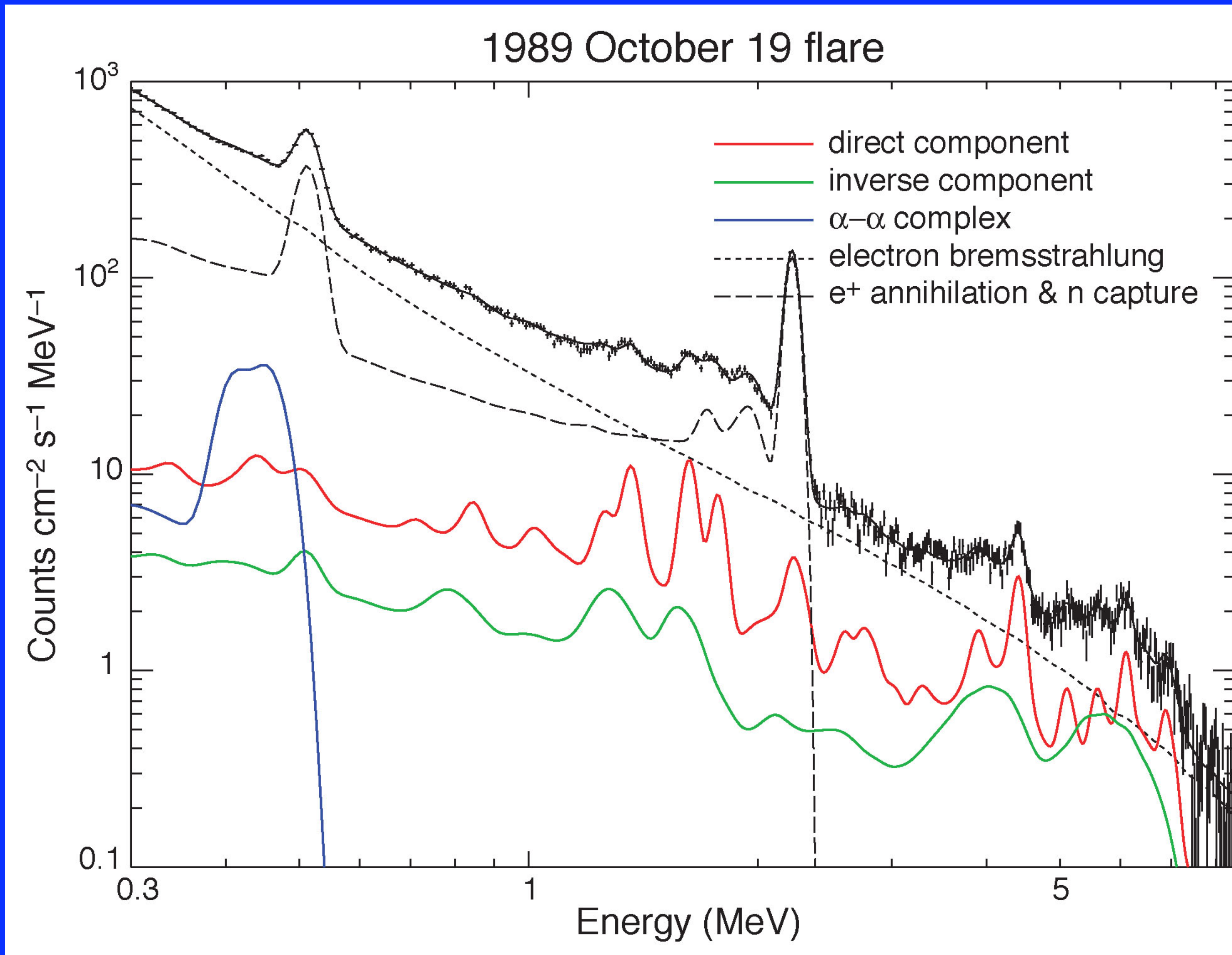
Fit with PL + PL

chi2/dof 1.053 (20% probability)

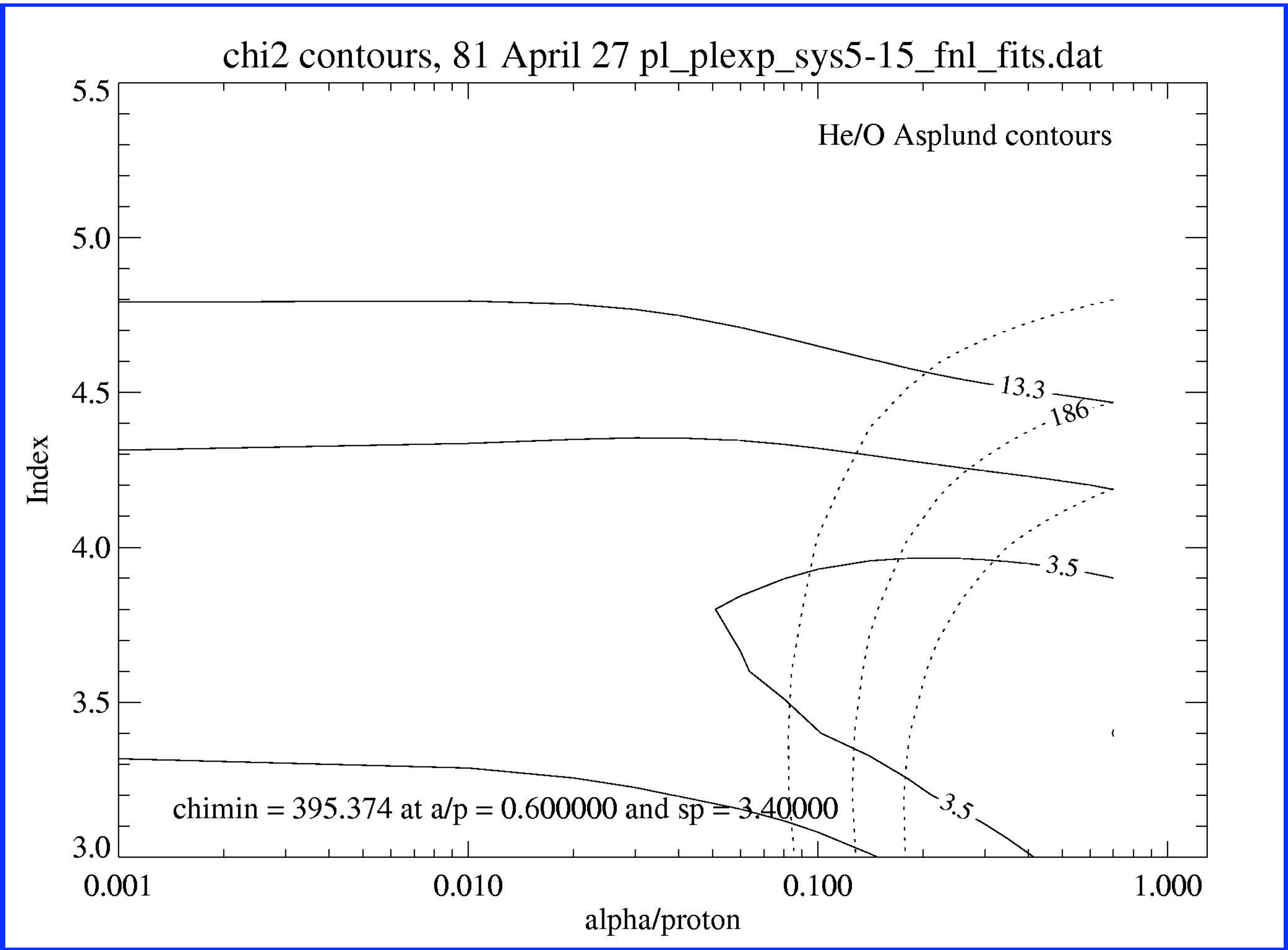
We fit the flare spectra with the pl + plexp, 0.5, 2.2 MeV, α – ^{4}He lines, a solar Compton-scattered 2.2 MeV continuum, individual line templates for p, α interactions on C, N, O, Ne, Mg, Si, and Fe, individual line templates for accelerated C, N, O, ^{3}He, and a combined template (coronal composition normalized to Fe) for Ne, Mg, Si, and Fe on H and He.

We have included a 5% systematic in the data >1 MeV and a 15% systematic between 1.9 and 2.4 MeV to account for the strong 2.2 MeV line and its back scatter peak that are not adequately represented by the detector response function.

These nuclear line templates were calculated for heliocentric angle of the flare and for various values of α/p and spectral index (assuming the same index for all accelerated particles; no significant difference found when allowing the alphas and protons to have different indices.)

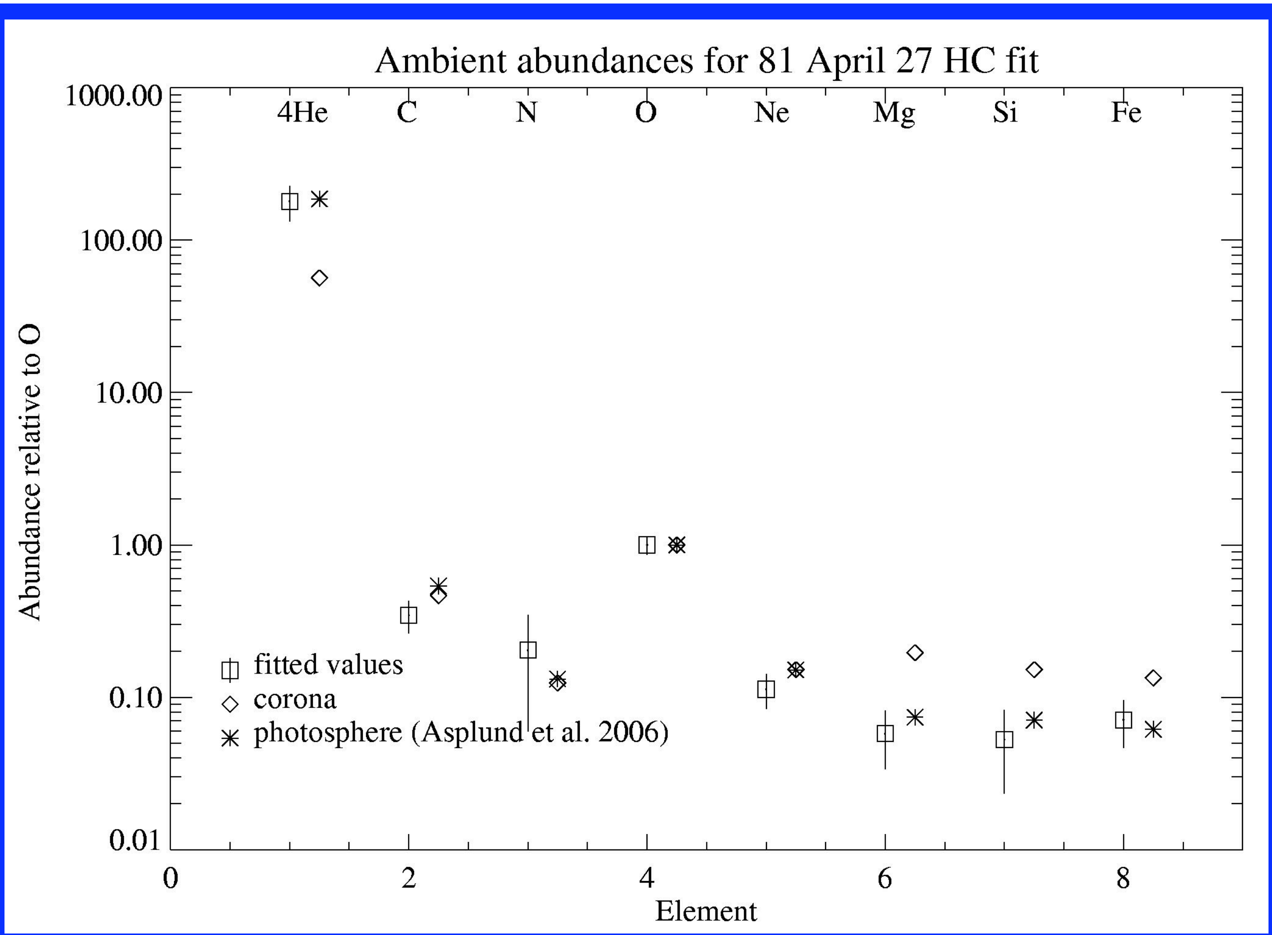


Fits to the 1989 October 19 flare showing the total fit, bremsstrahlung, direct interaction (i.e. accelerated p and α on ambient elements), inverse interaction (i.e. heavy ions on ambient elements), α-4He, and 0.511/2.223 MeV line components and Compton-scattered 2.2 MeV line.

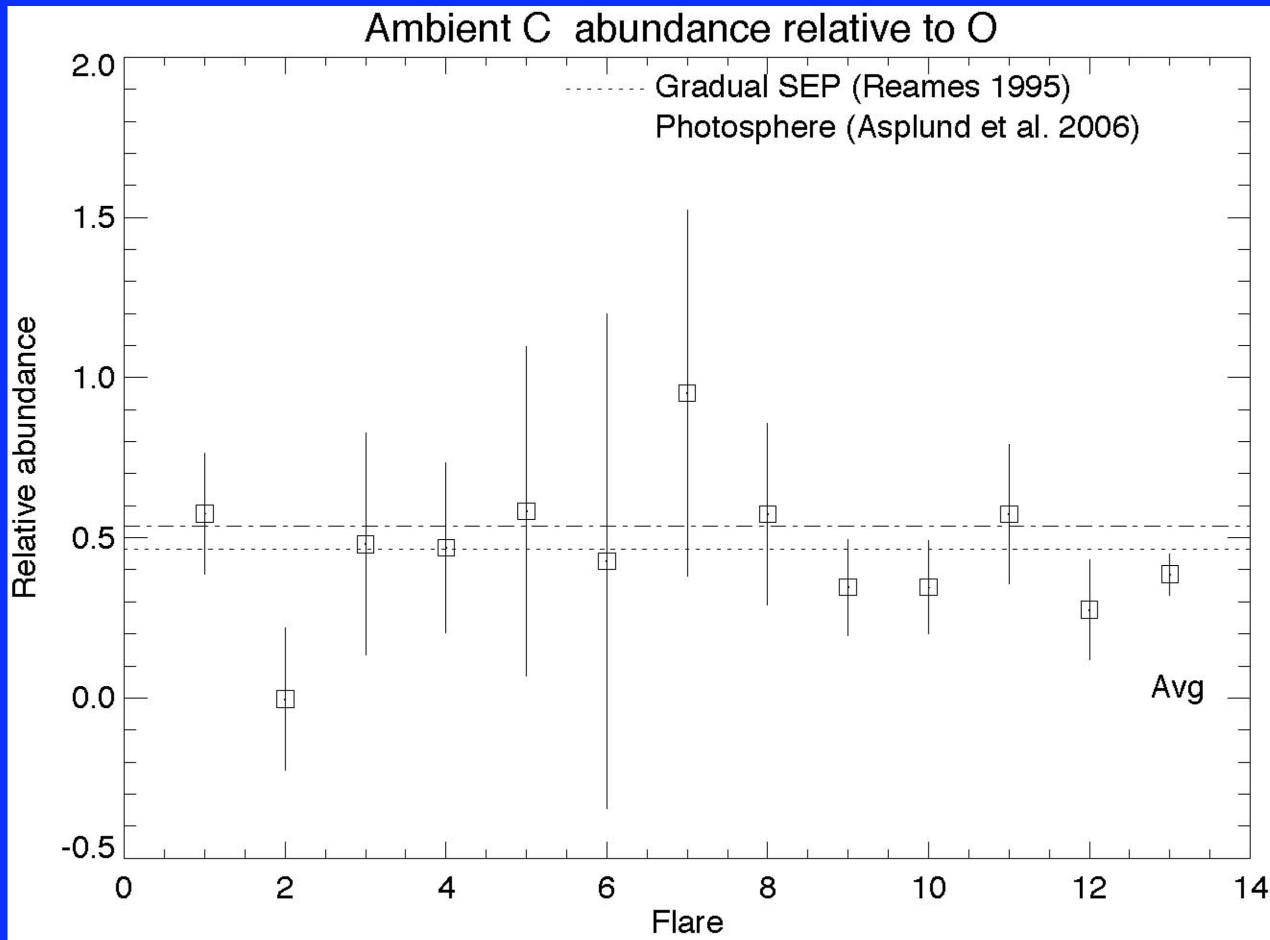


1981 April 27 chi2 contour plots for spectral index and α/p ratio. From Monte Carlo studies a $\Delta\chi^2$ = 3.5 has a 68% probability.

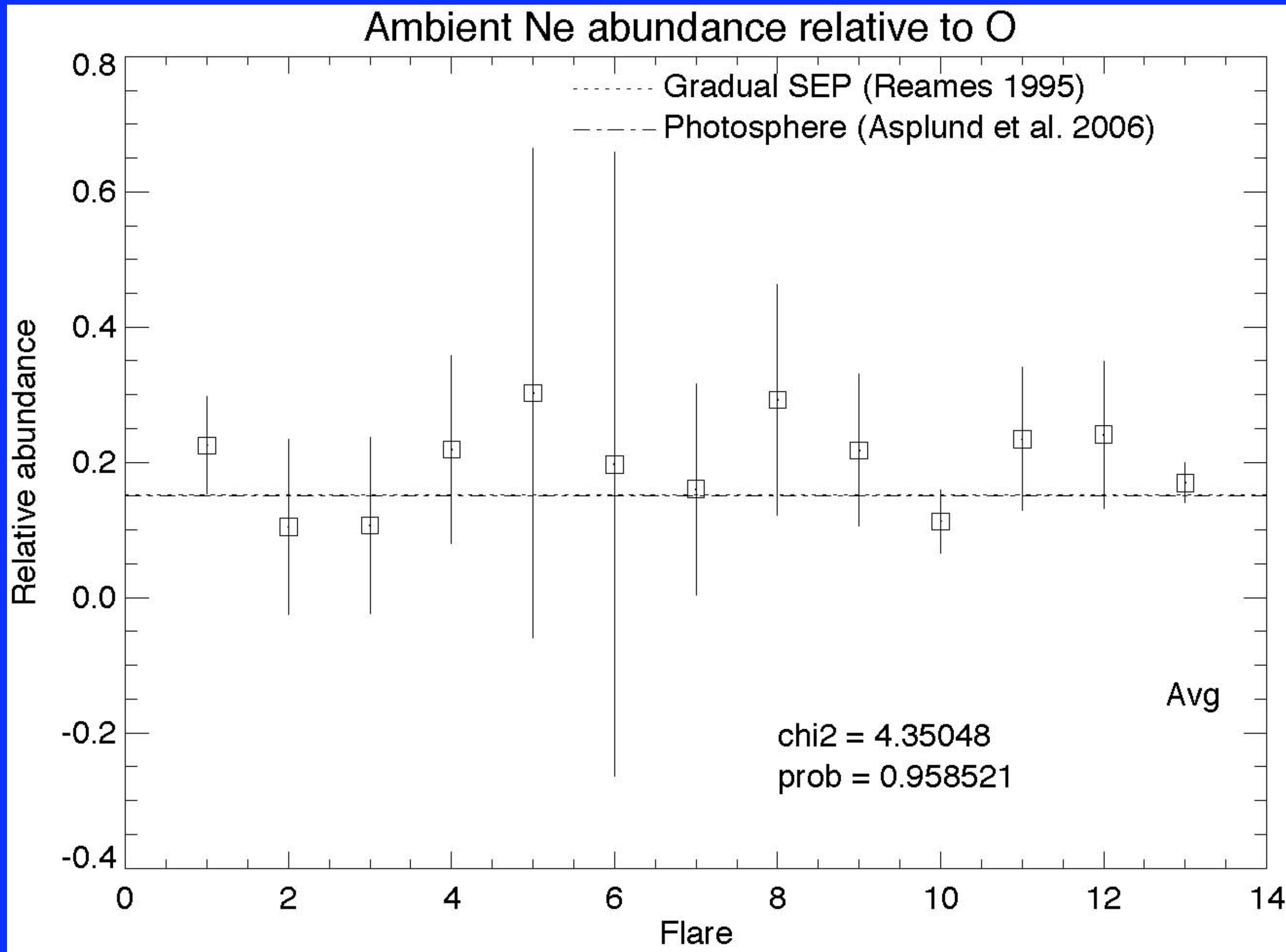
Curve marked 186 shows the indices and α/p ratios consistent with photospheric He/O (Asplund abundances) for the flux measured in the α-^{4}He fusion lines (the other dotted curves show the 1 sigma statistical uncertainty in the line measurement).



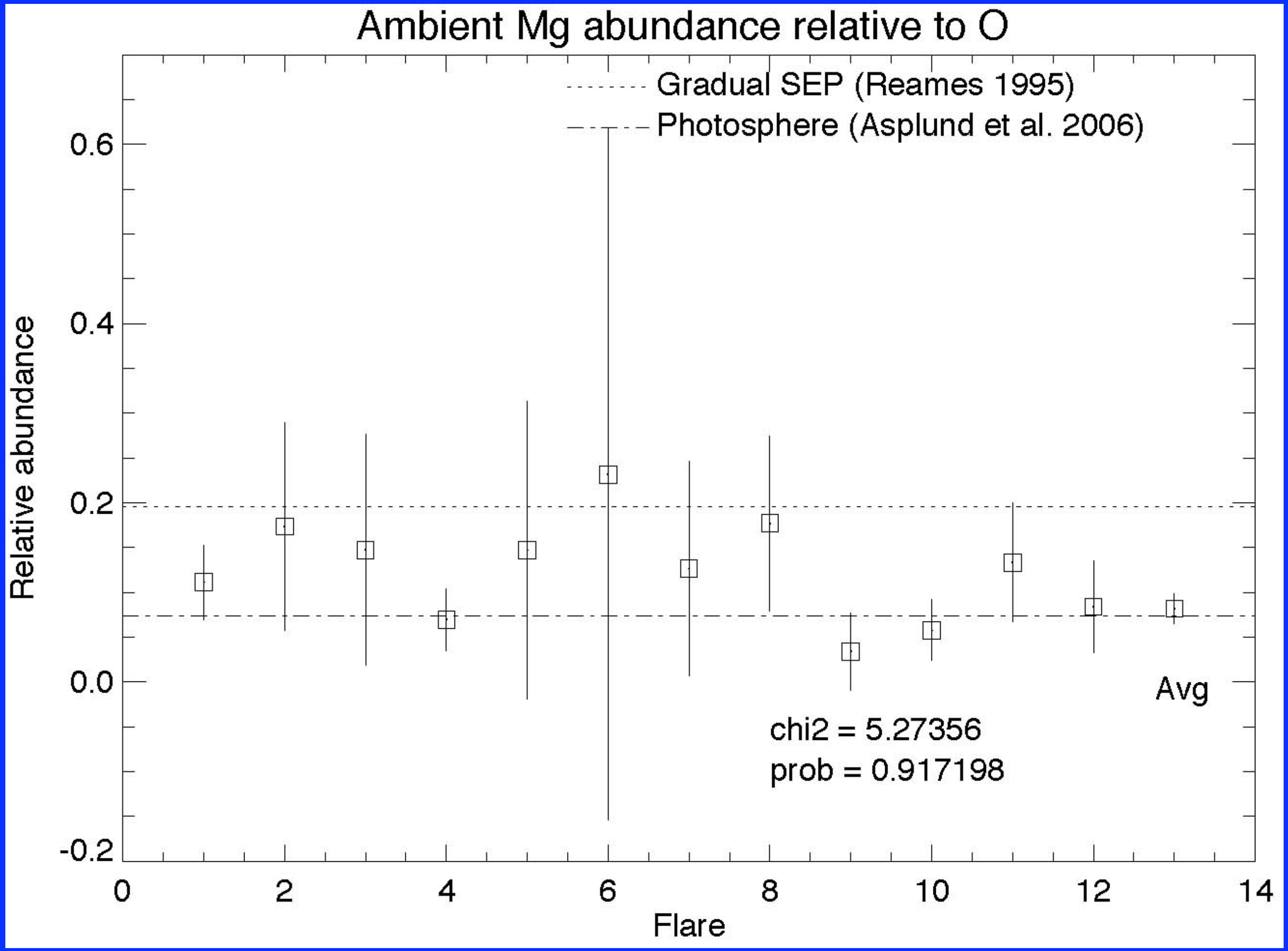
In order to estimate the ambient abundances (normalized to O) for the flare we use the parameters for the best fitting α/p ratio and spectral index consistent with the Asplund photospheric He/O. C/O ratio just below photospheric and coronal values; Ne/O is ~12% (note this is lower the value adopted by Ramaty et al.,) the low FIP elements do not appear to be significantly enhanced over photospheric values.



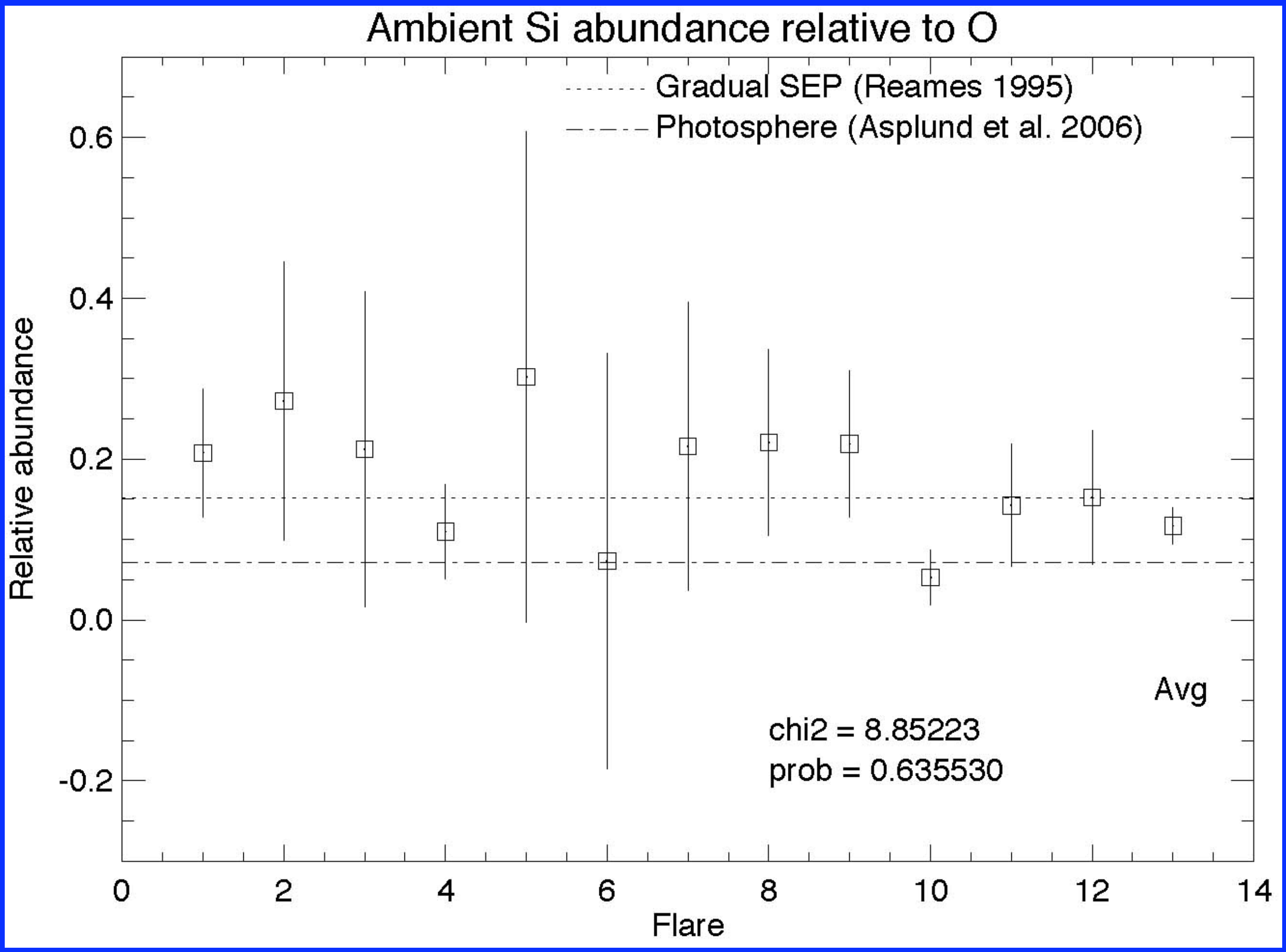
The ambient C abundance relative to O for twelve SMM flares (errors include +- 1 sigma range in Asplund He/O). The average ratio appears to be below coronal and photopheric abundances but may be consistent when uncertainties in both the abundances and our measurements are fully taken into account.



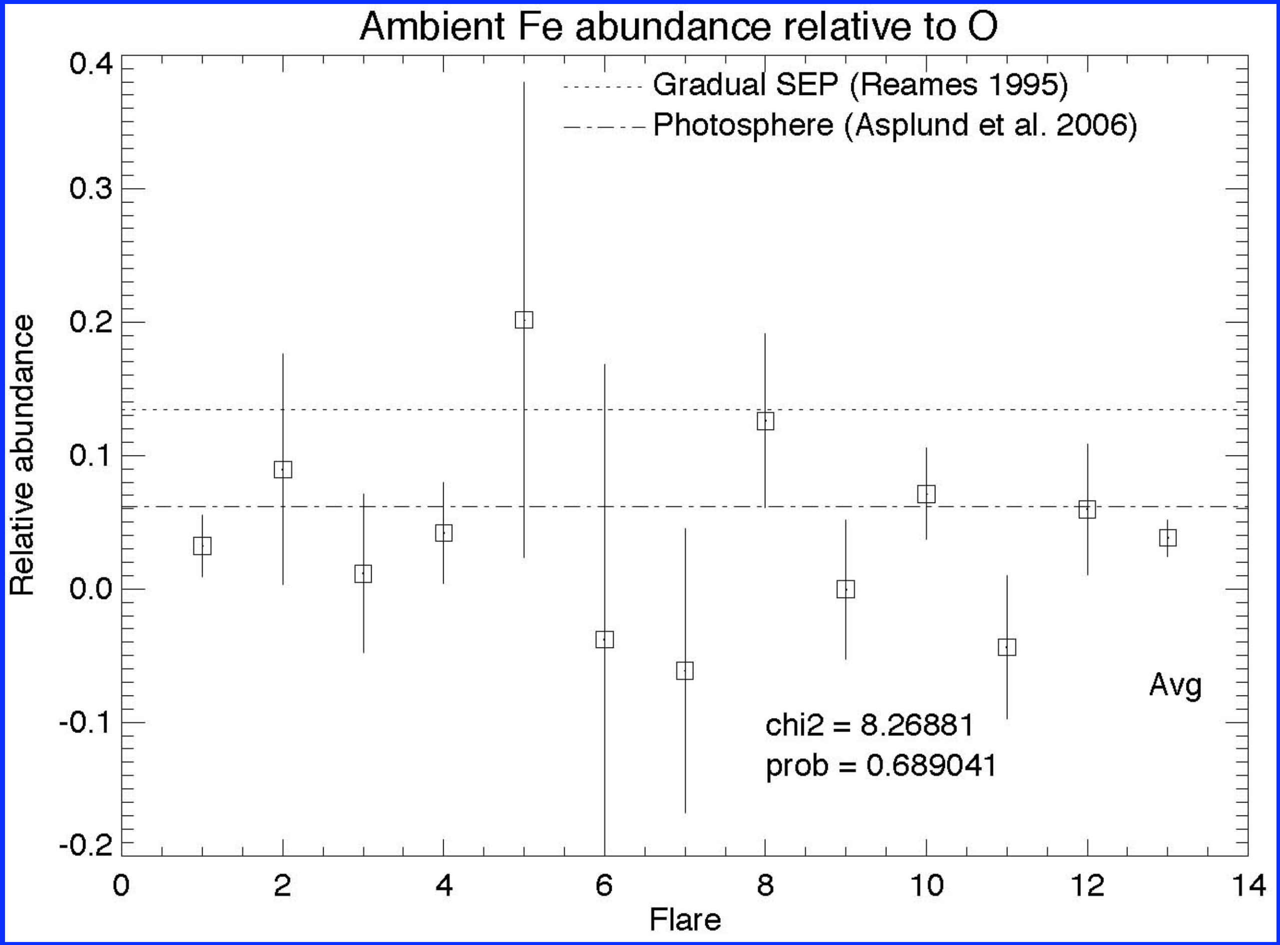
The ambient Ne abundance relative to O for twelve SMM flares. The average ratio appears to be consistent with a value between 15 and 20%, consistent with adopted photospheric and coronal abundances.



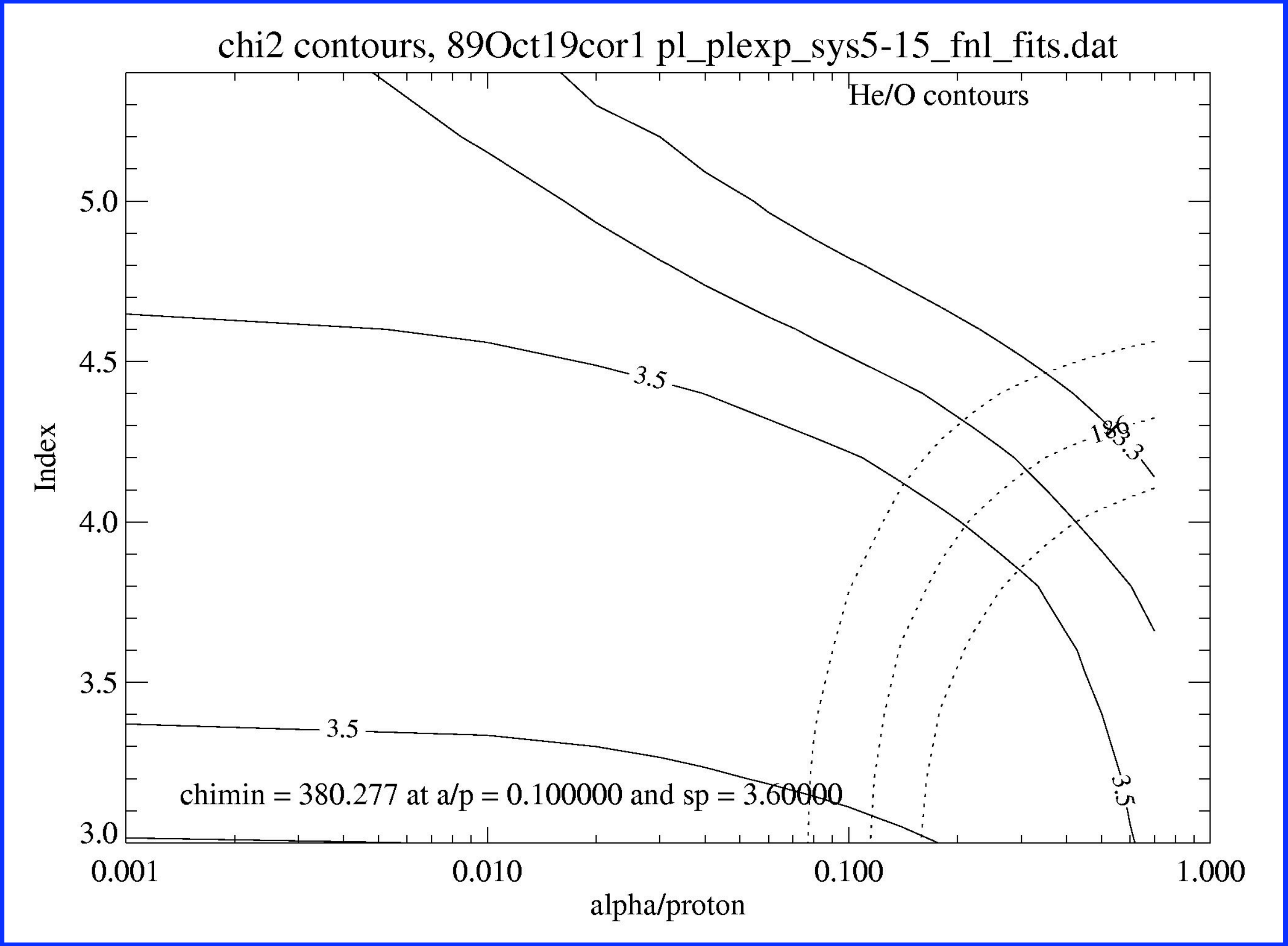
The ambient Mg abundance relative to O for twelve SMM flares. The average ratio appears to be consistent with photospheric values but is not consistent with coronal abundances as determined by gradual SEP measurements.



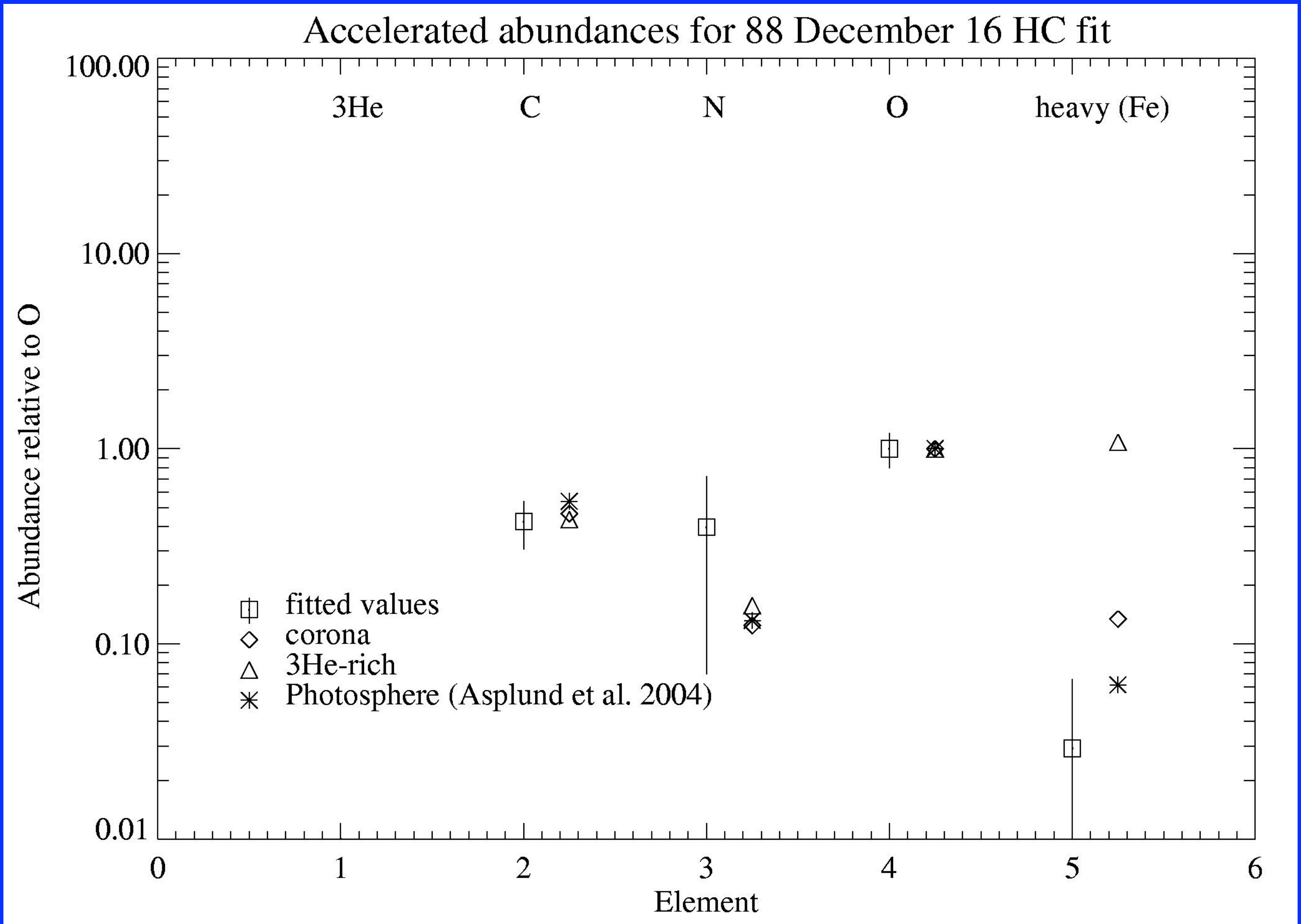
The ambient Si abundance relative to O for twelve SMM flares. The average ratio is in between photospheric and coronal values. It is important to note that the line is near the instrumental backscatter peak of the neutron- capture line which could affect the measurement.



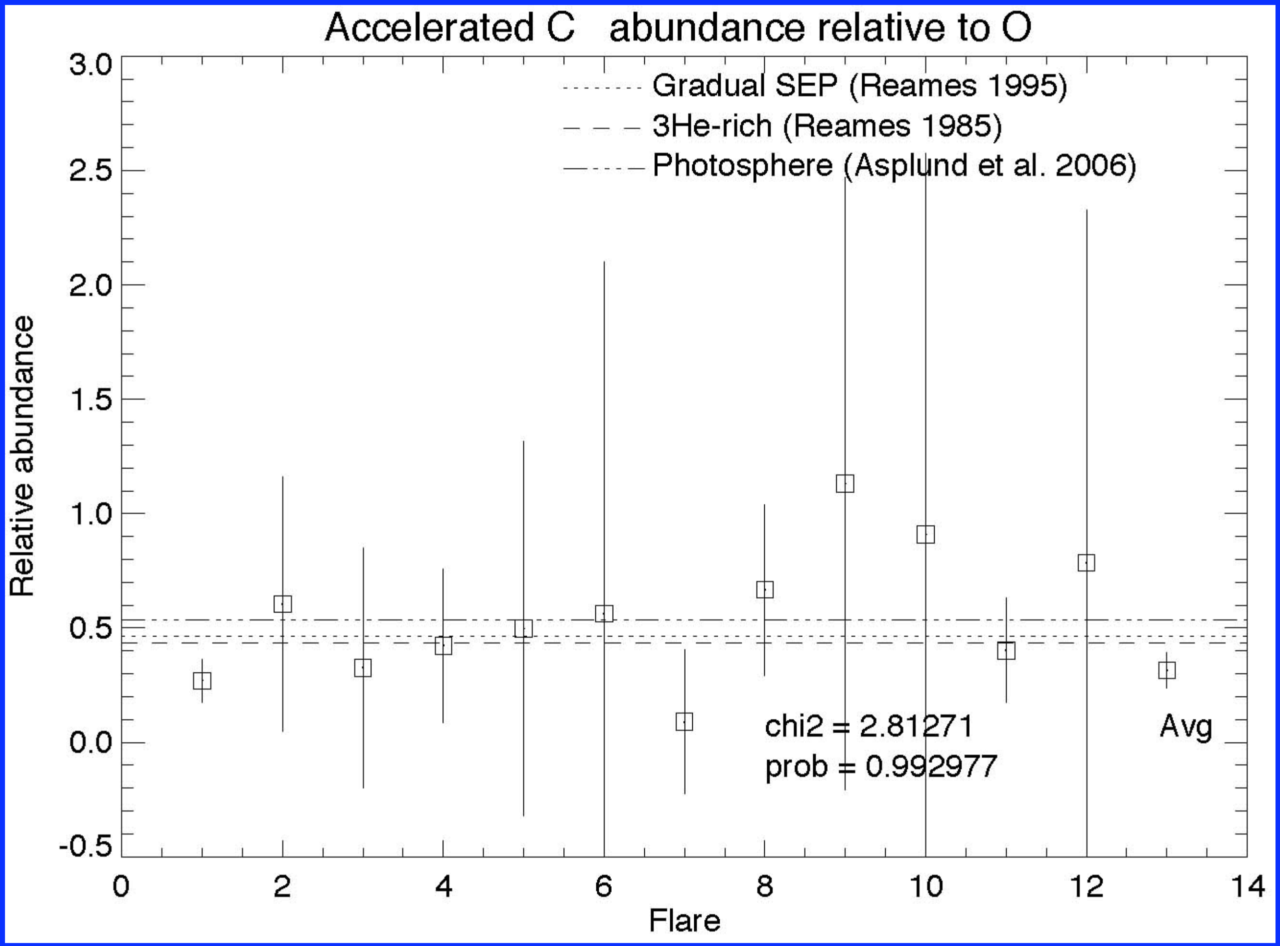
The ambient Fe abundance relative to O for twelve SMM flares. The average ratio appears to be consistent with photospheric values and not consistent with that found in the corona. There is therefore no consistent evidence for a FIP effect in the ambient medium where the ions interact.



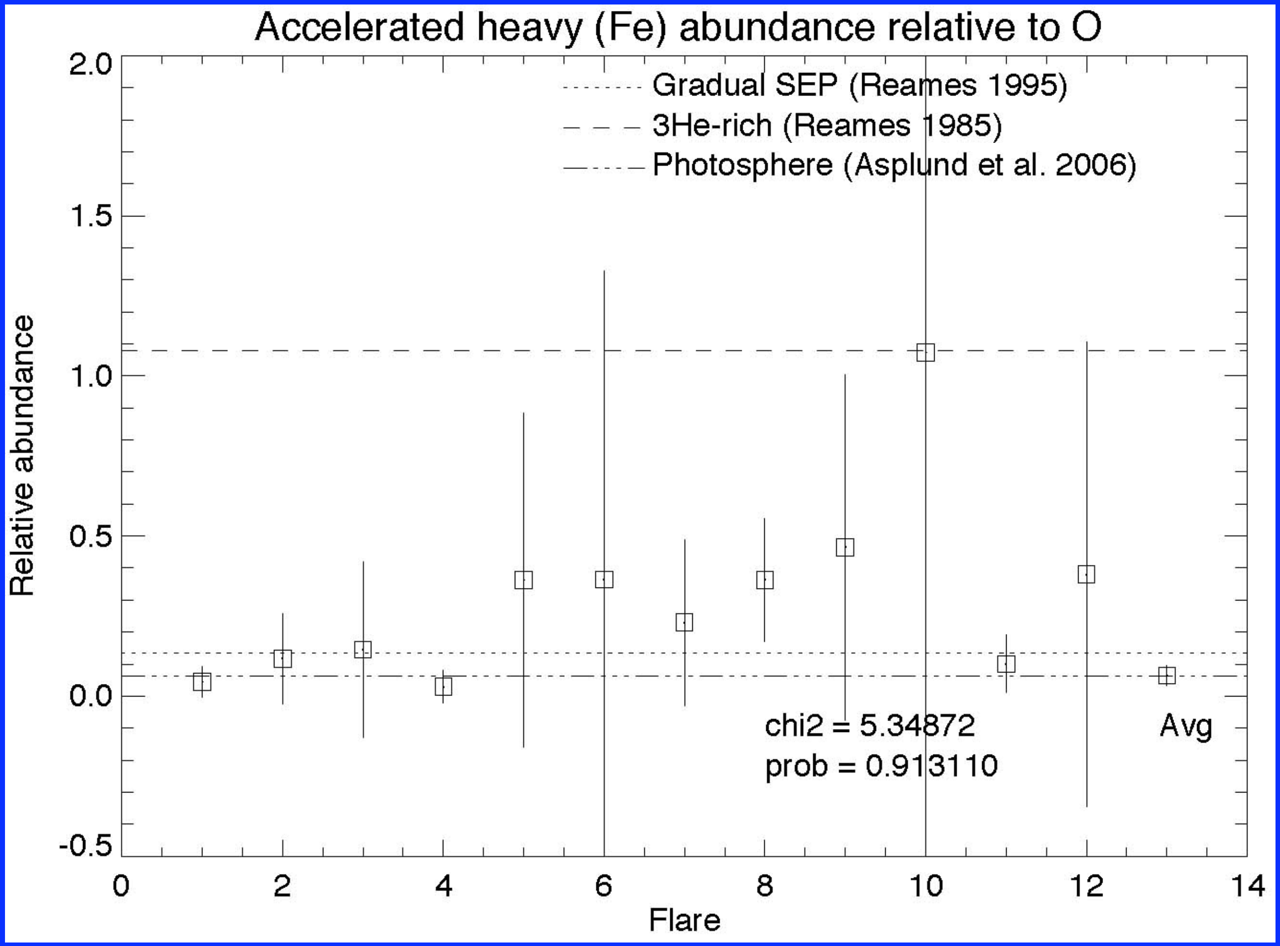
Results of our fits on the 1989 October 19 flare at heliocentric of 30°. The He/O ratio (dotted curves) consistent with the Asplund et al. photospheric abundance is consistent with the chi^2 contours from our fits. The accelerated ion spectrum is consistent with a power law with index between ~3.2 and 4.2.



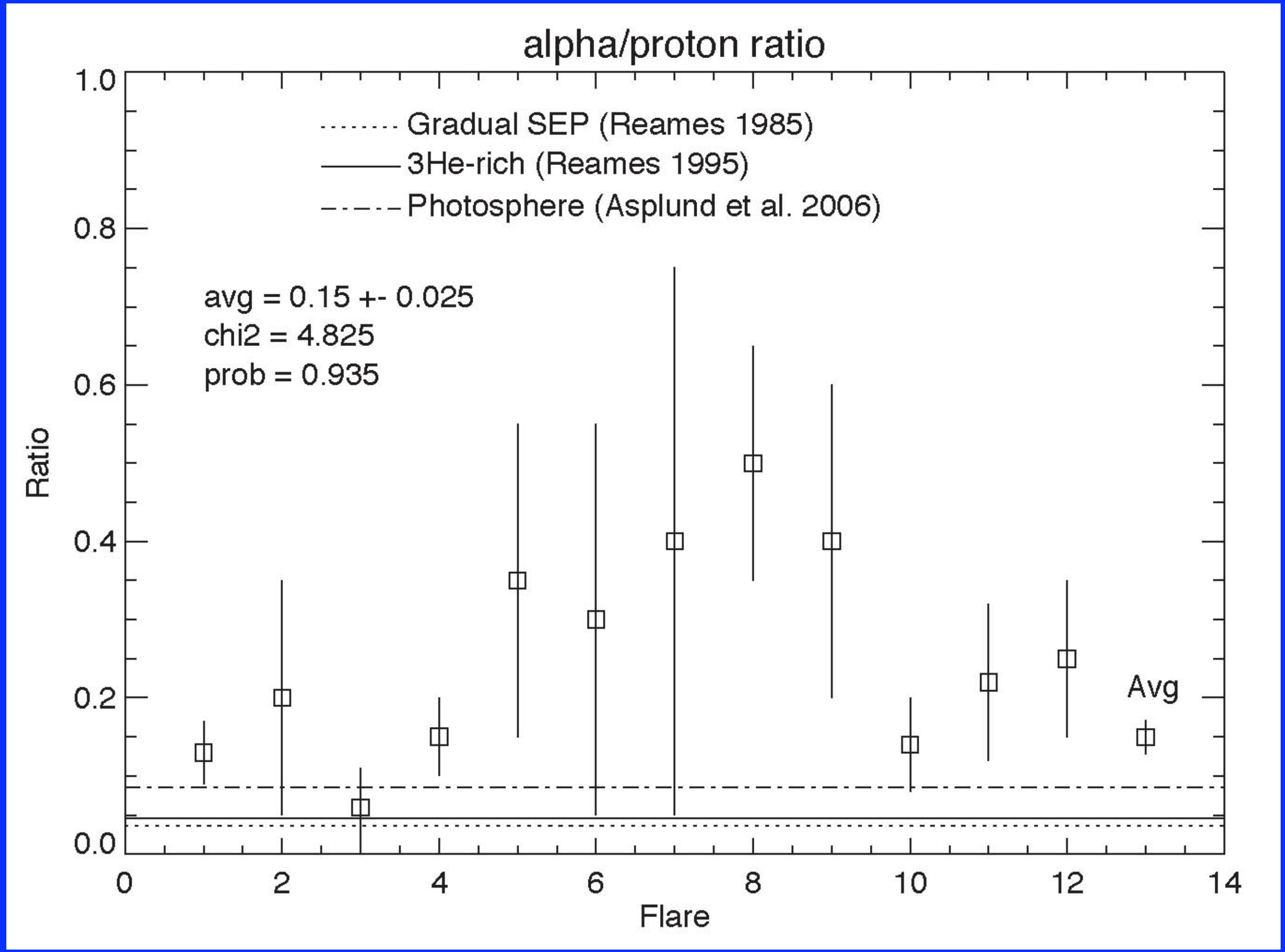
We obtained the accelerated abundances relative O for the 88 December 16 flare; the uncertainties are larger than for the ambient abundances. C/O is consistent with photospheric value; the heavy nuclei (Ne, Mg, Si, and Fe) also have a combined abundance consistent with what is found in the photosphere. It appears to be inconsistent with impulsive SEPs.



The accelerated C abundance relative to O for twelve SMM flares. The average ratio appears to be somewhat below the photospheric, coronal, and impulsive SEP abundances.



The accelerated heavy (combined Ne, Mg, Si, S, and Fe abundance normalized to Fe) relative to O for twelve SMM flares. The average ratio appears to be consistent with photospheric and coronal values but not with the strong enhancement found in impulsive SEP events.



We have roughly estimated the accelerated alpha/proton ratios for the 12 flares from using acceptable ranges of He/O from Asplund. The average ratio is 0.15, about a factor of two above He/H in the photosphere.

Current Status of our Studies

Fit 12 SMM spectra with bremsstrahlung, 0.511/2.2 MeV lines, and nuclear templates developed from empirical measurements and TALYS using a new instrument response. Abundances determined by assuming Asplund He/O.

Average ambient Mg and Fe abundance ratio consistent with photospheric abundances while ambient Si abundance appears to be between photospheric and corronal. No consistent low FIP enhancement.

The average Ne/O abundance in the lower chromosphere has been measured directly for the first time with a value of 0.15-0.20.

Average accelerated heavy ion (Ne, Mg, Si, and Fe)/O abundance ratio consistent with corona and photosphere but not impulsive SEPs.

The average accelerated alpha/proton ratio (~0.15) is elevated.

These conclusions may be revised as we continue our studies and modify uncertainties in our measurements and include uncertainties in the solar models

Measured Compton Scattered 2.2 MeV Line at the Sun from 1989 October 19 Flare

Scattered Flux (>300 keV)/2.223 MeV Line Flux = 0.9 +- 0.1

Calculated ratio for the continuum >200 keV ~1.2

This is the first measurement of the 2.223 MeV Compton scattered flux.

Other well-measured flares give similar ratios.