FIP effect in RV Tauri Stars: A solar connection

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RV Tauri stars: Properties

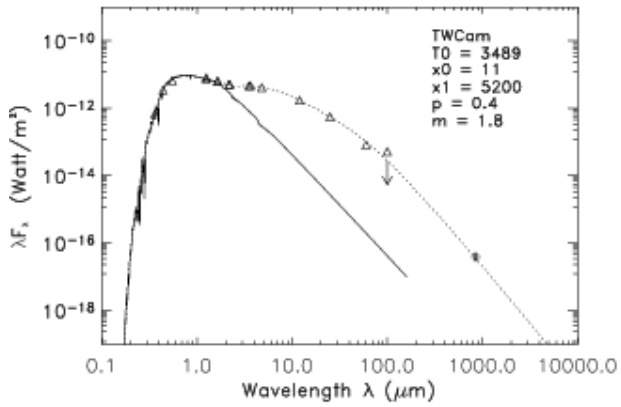
RV Tauri stars are of spectral type F5 – K2 supergiants

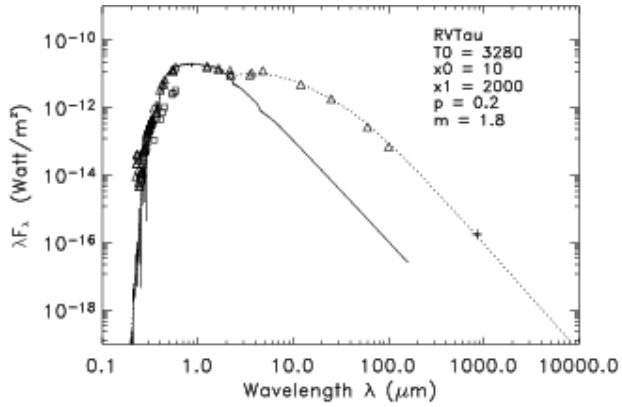
They are luminous (Mv = -4 for stars with period 50 days) and stars with periods 50 – 150 days have Mv = = -0.61 – 2.95 lop P + 5.49 <(V- R)>.

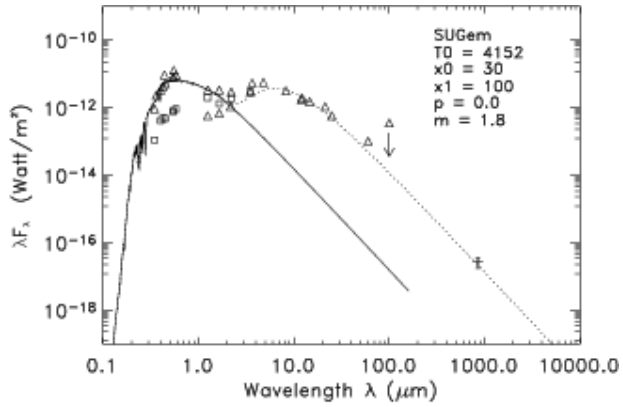
They show deep and shallow minima with periods ranging from 40- 150 days. They are found to have large amount of IR excess.

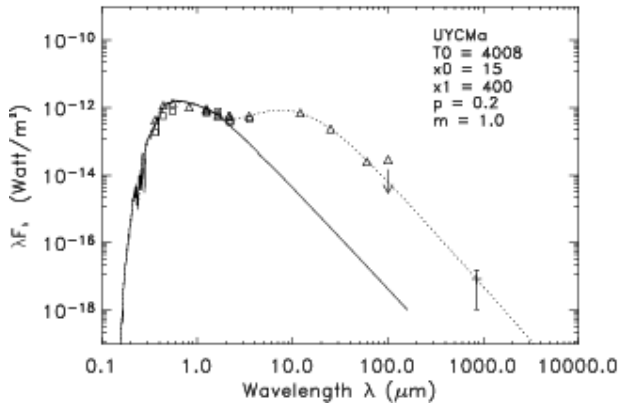
RV Tauri stars: Properties

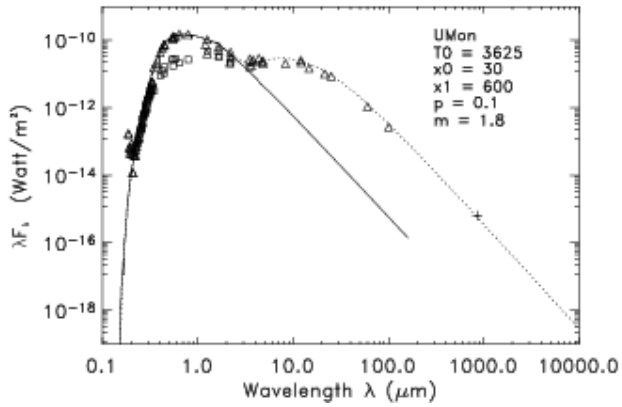
Several of the RV Tauri stars show IR excess. A few of them found to be binaries. Their exact evolutionary status is not known but post-AGB evolution is suspected.

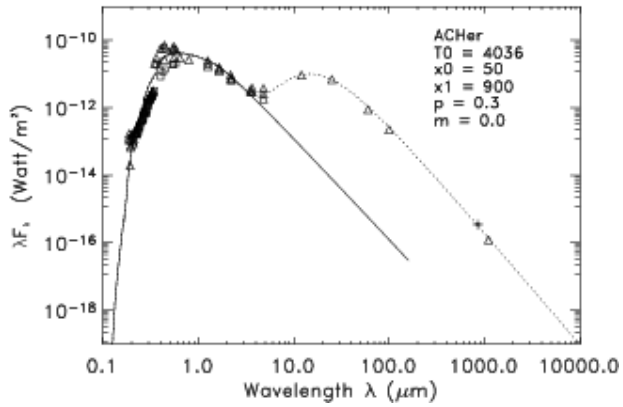




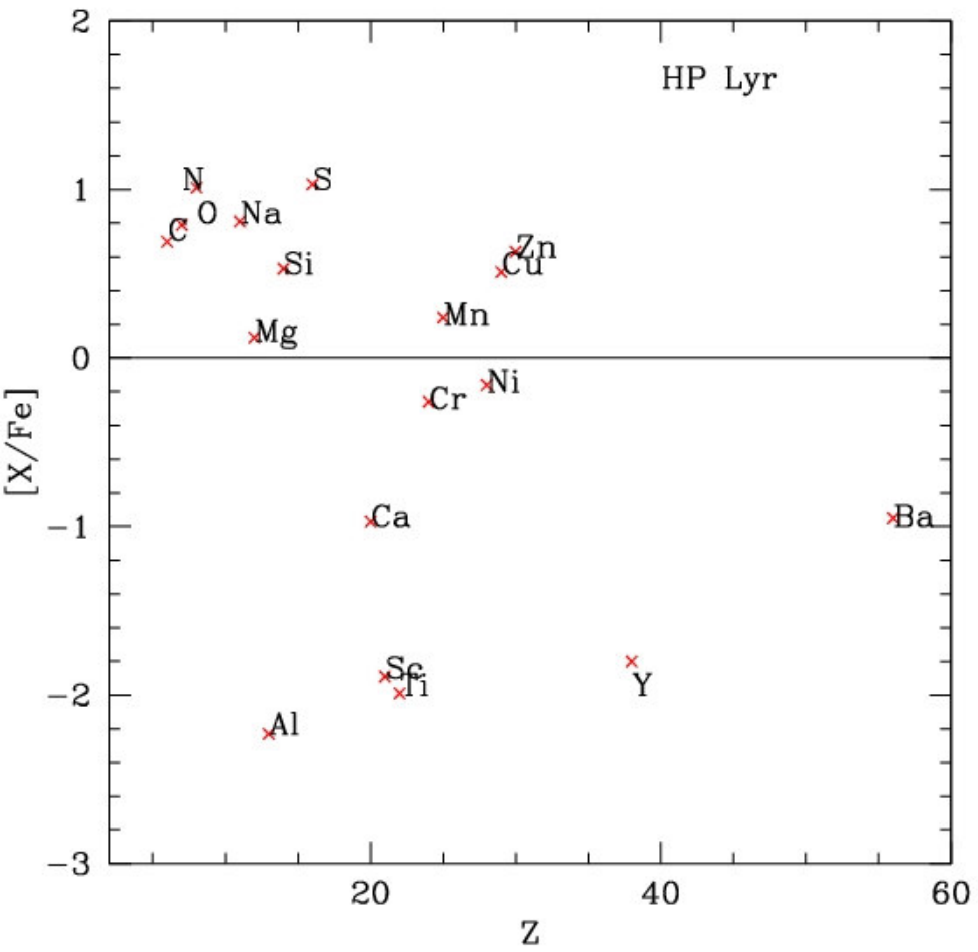








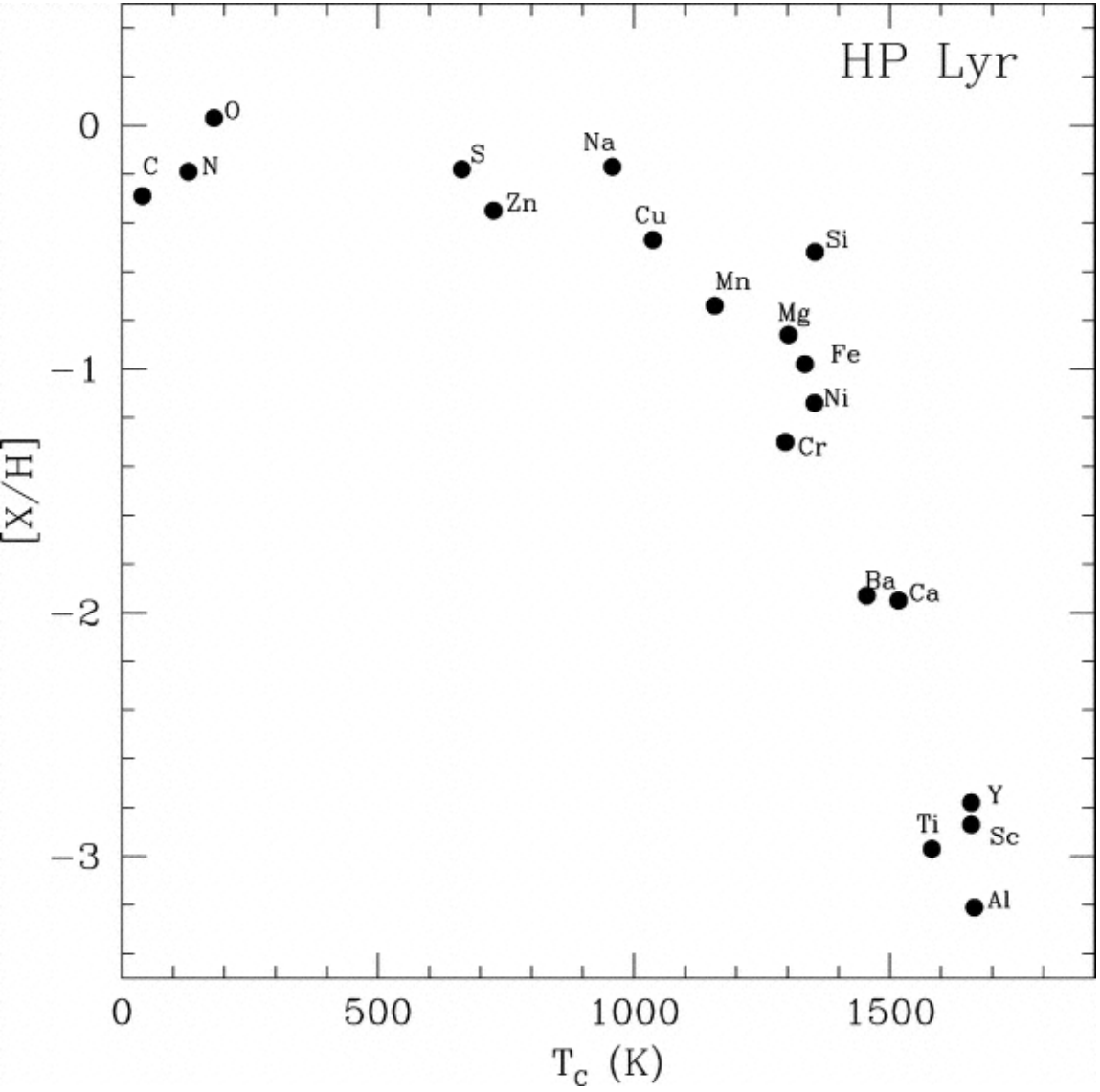
RV Tauri: abundances



RV Tauri stars with intrinsic metallicity [M/H] > -1.0 possess an abnormal surface abundance pattern that is quite different from either disk or halo or typical

Elements like S and Zn show signifi- cantly less deficiency compared to elements Fe, Ca etc.

RV Tauri stars: Abundances Vs. Tc

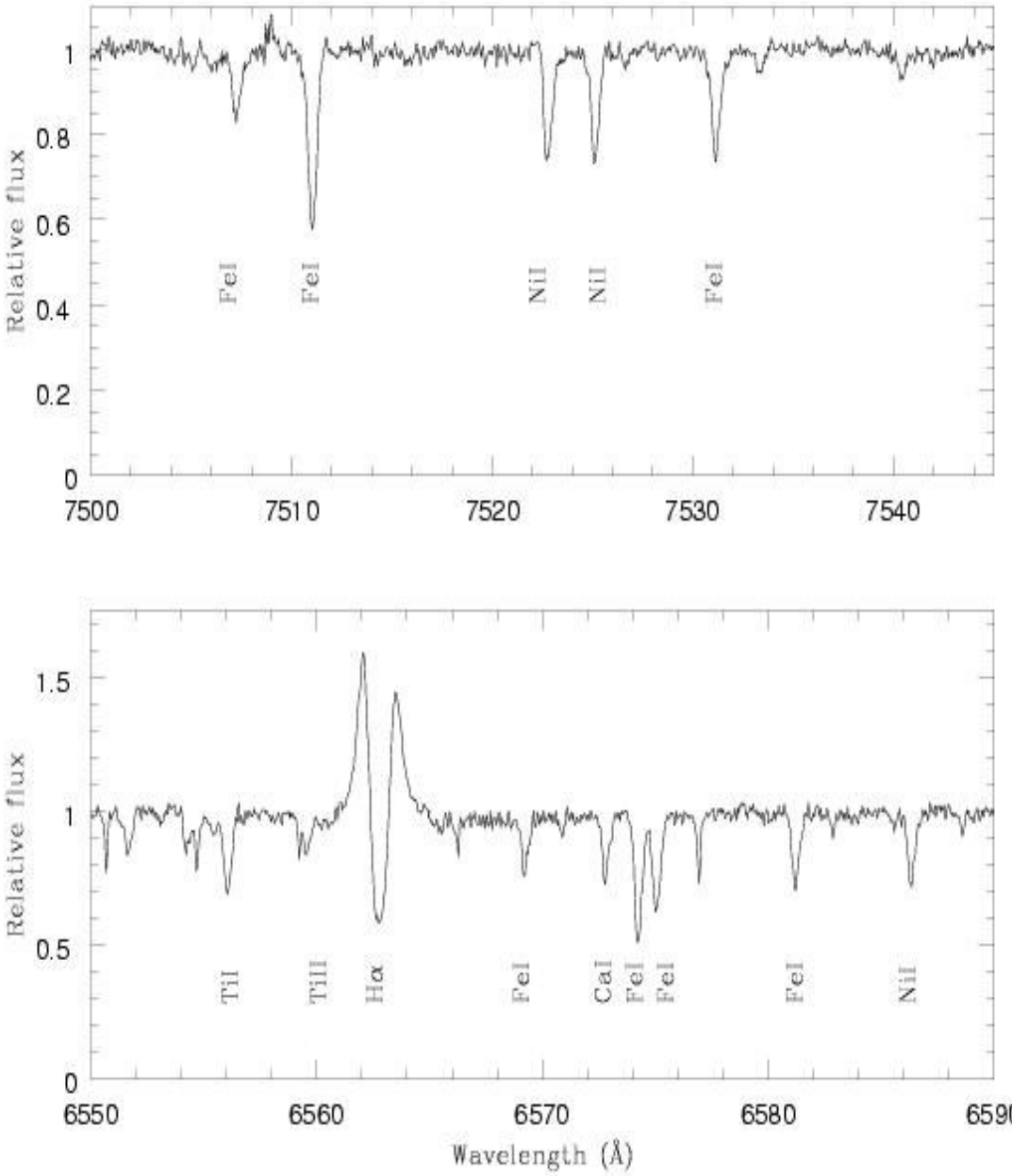


The elements that have conden- sation temperature, Tc > 1200 K are selectively depleted compared to lower Tc elements .

Adopted Tc for a given element is the temperature at which half the atoms in gaseous environment condense out of the gas phase (see Lodders 2003).

See e.g; Giridhar et al. 05

CE Vir: A new twist!

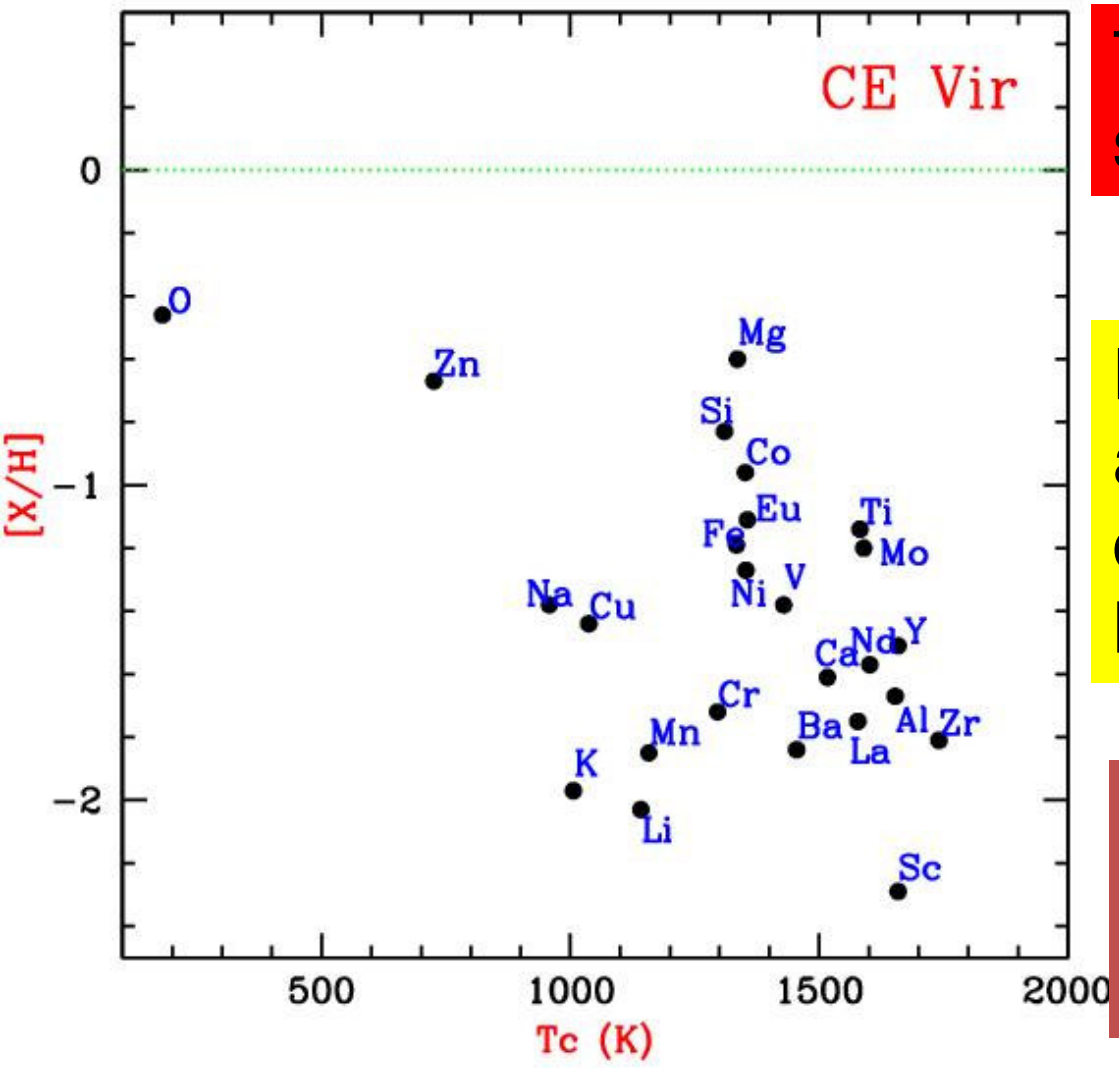


CE Vir is a SRd variable and one of the coolest members of the RV Tauri group.

It is also one of the just two stars in a sample of 21 RV Tauri stars with a strong Li line at 6707-A .

It's high galactic latitude and weak metallic lines suggestive of RV type "C".

CE Vir: A new twist!



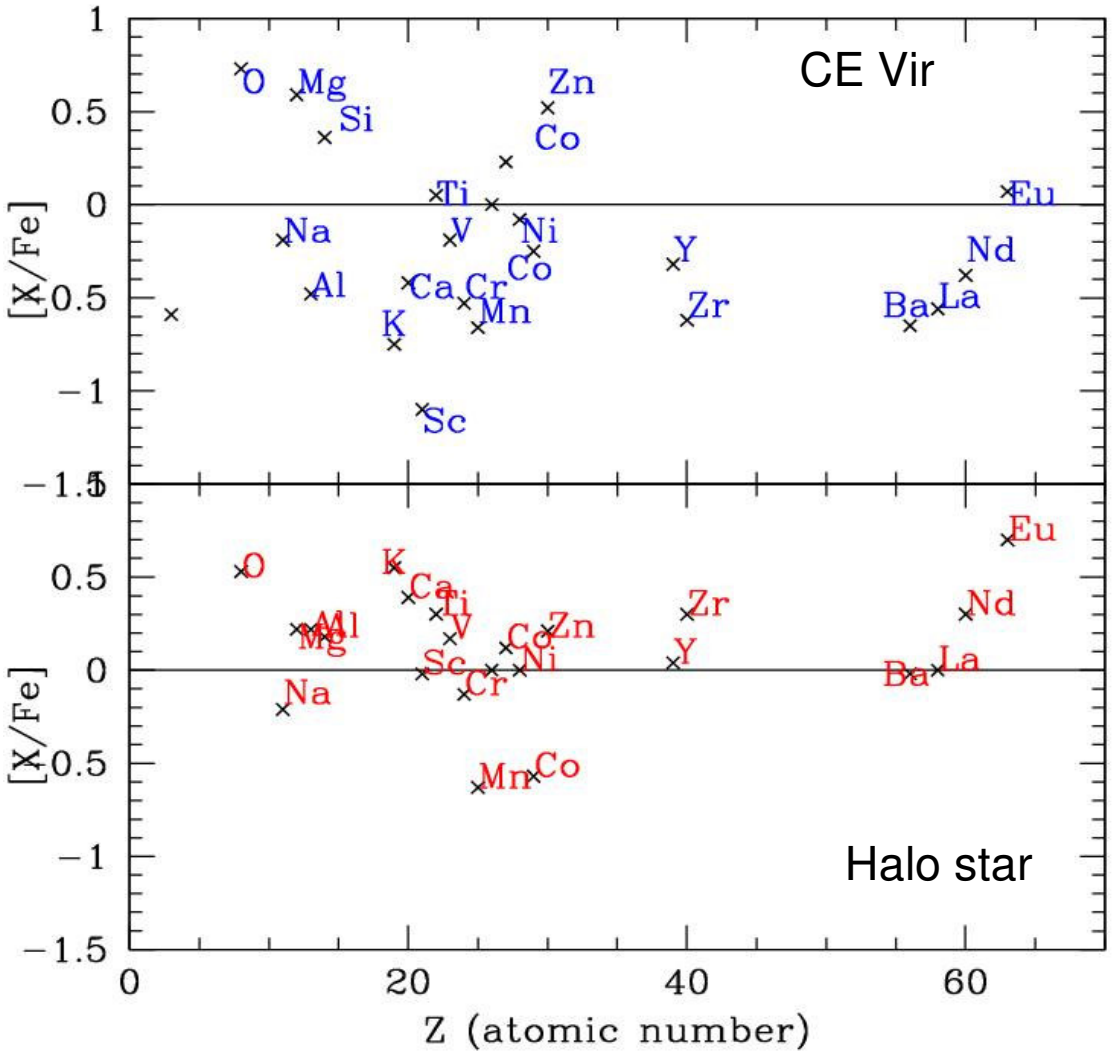
Trends in general seem to be similar to RV Tauri stars.

But elements like Na, Mn, K and and Li are more depleted compa- red to to Mg and Si having high Tc.

Trend is atypical of RV Tauri (warm or metal-poor), or post--AGB/AGB, or disk/halo star.

Rao & Reddy,

CE Vir: A new twist

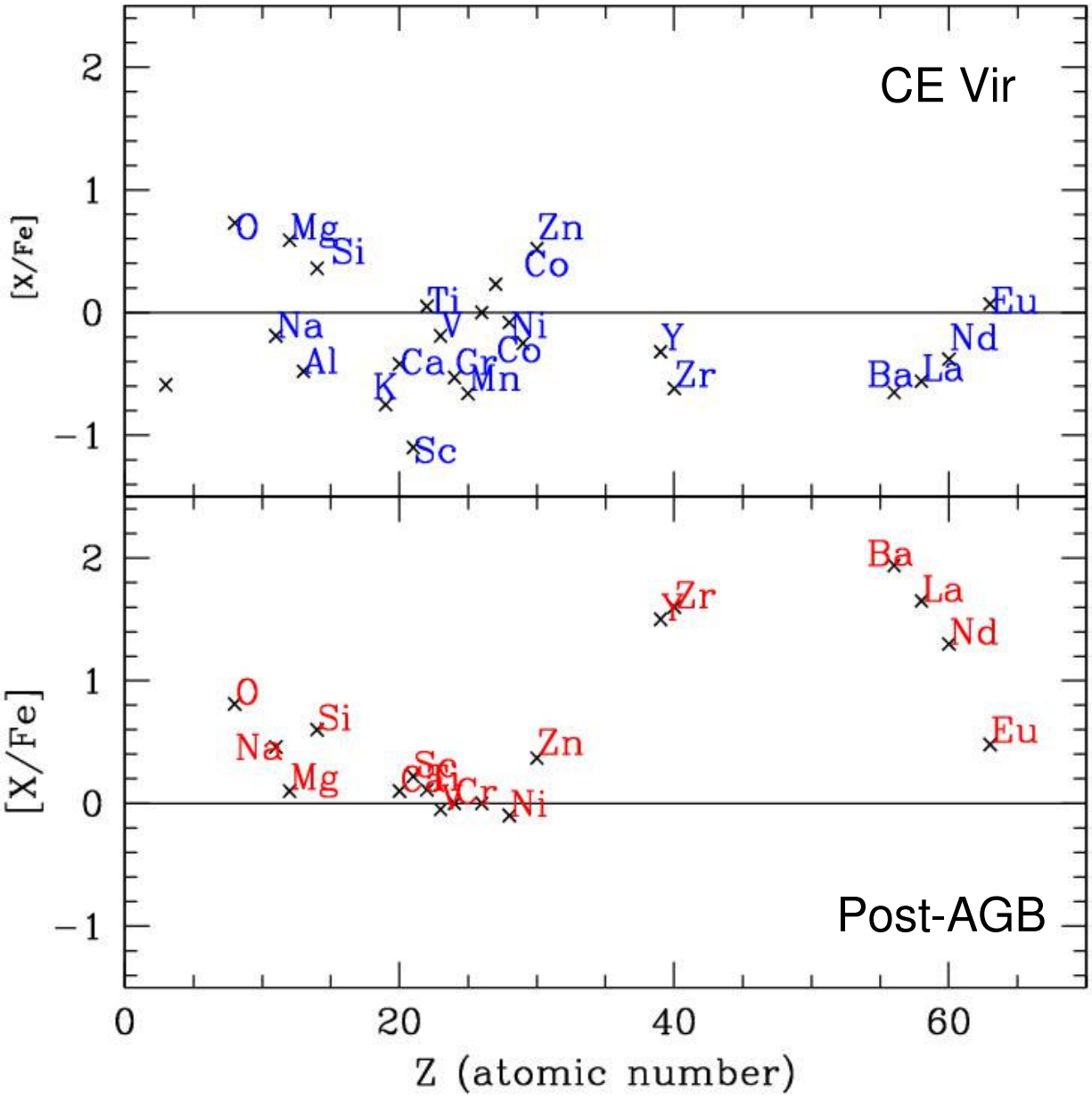


SNII: Mg, Si (alpha) fit into the Galactic chemical Evolution for a star of [M/H] = -1.0, but Ti, Ca (also alpha) do not.

SNI: Elements like Sc, V, Cr, Ni (Fe-peak elements) significanly lower compared to Fe.

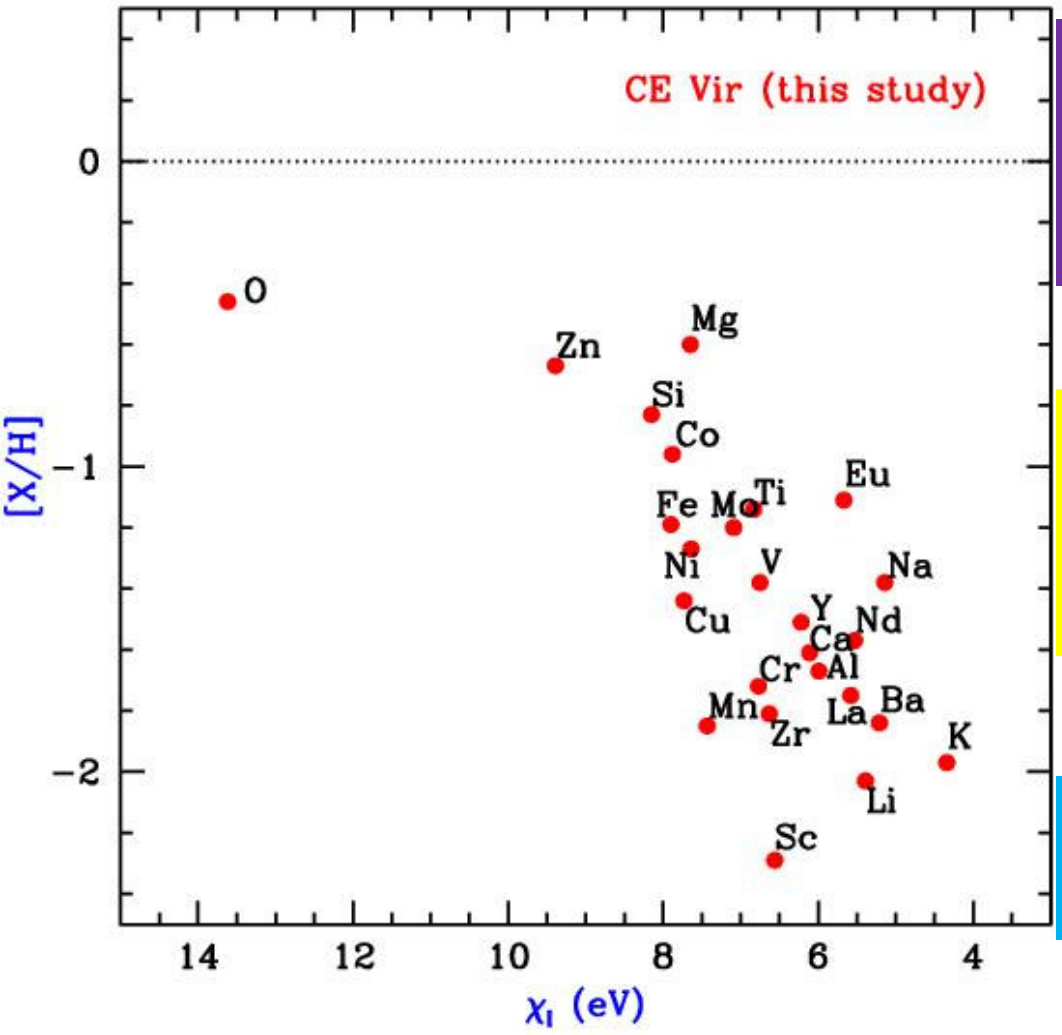
CE Vir at its [M/H] = -1.0 does not show expected composition of GCE.

CE Vir: A new twist



AGB nucleosynthesis: s-process elements like Y, Zr, Ba, La and Nd are deficient unlike for post-AGB stars

CE Vir: (Inverse) FIP effect



[X/H] ratios show a trend with FIP of the element. The lower the ionizat -ion potential higher the depletion.

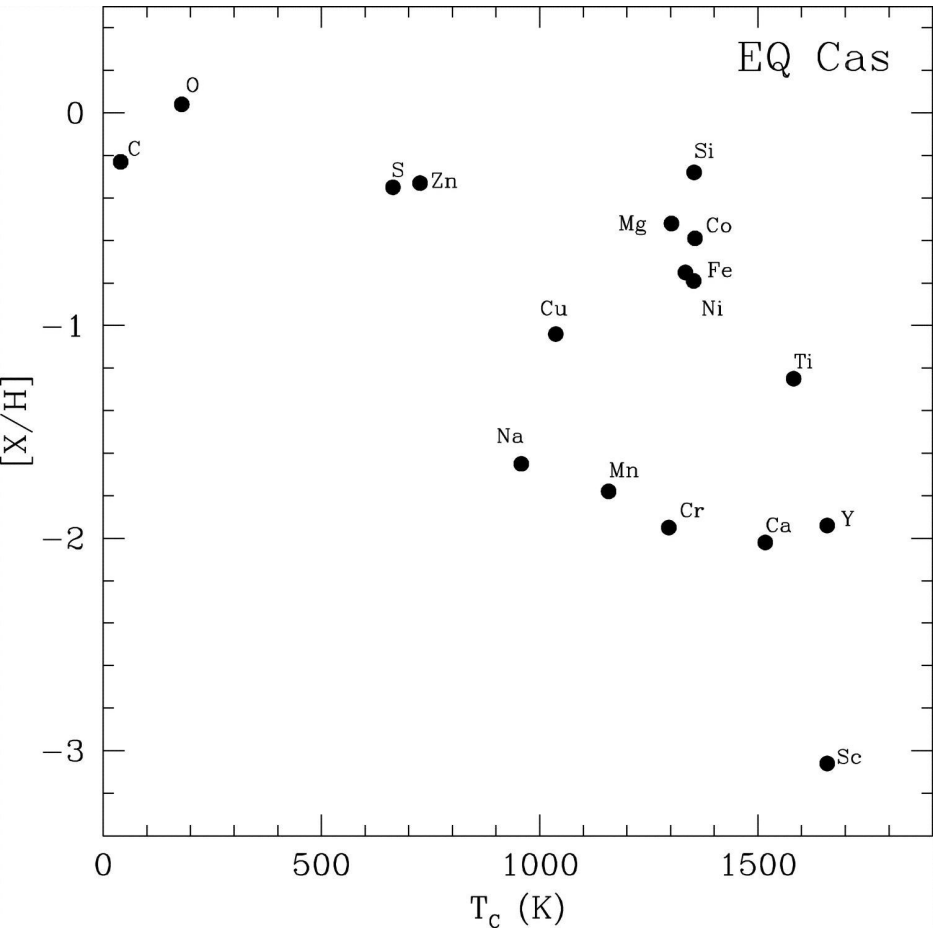
Note for an element with FIP below 8 eV depletion occurs. Now Na and Mn share this pattern.

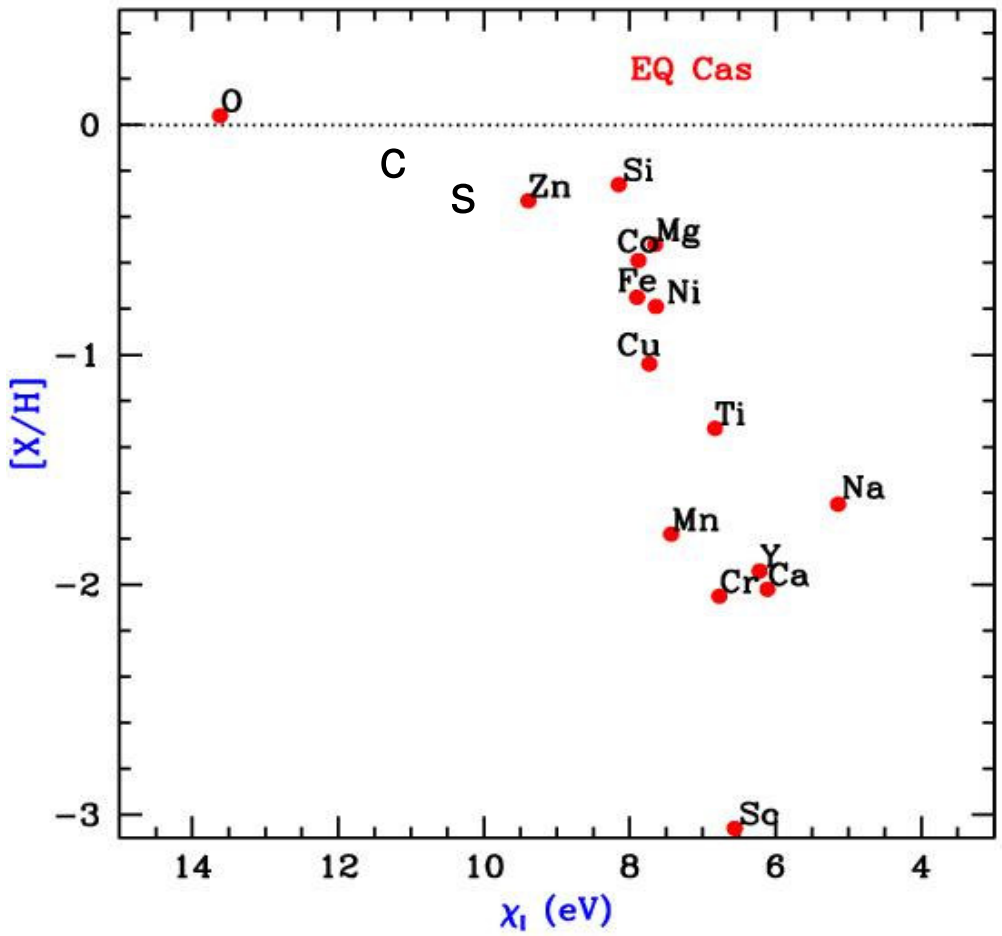
If this is true, undepleted Li must be ISM

Value of 3.3 suggesting Li production!

Rao & Reddy, 05

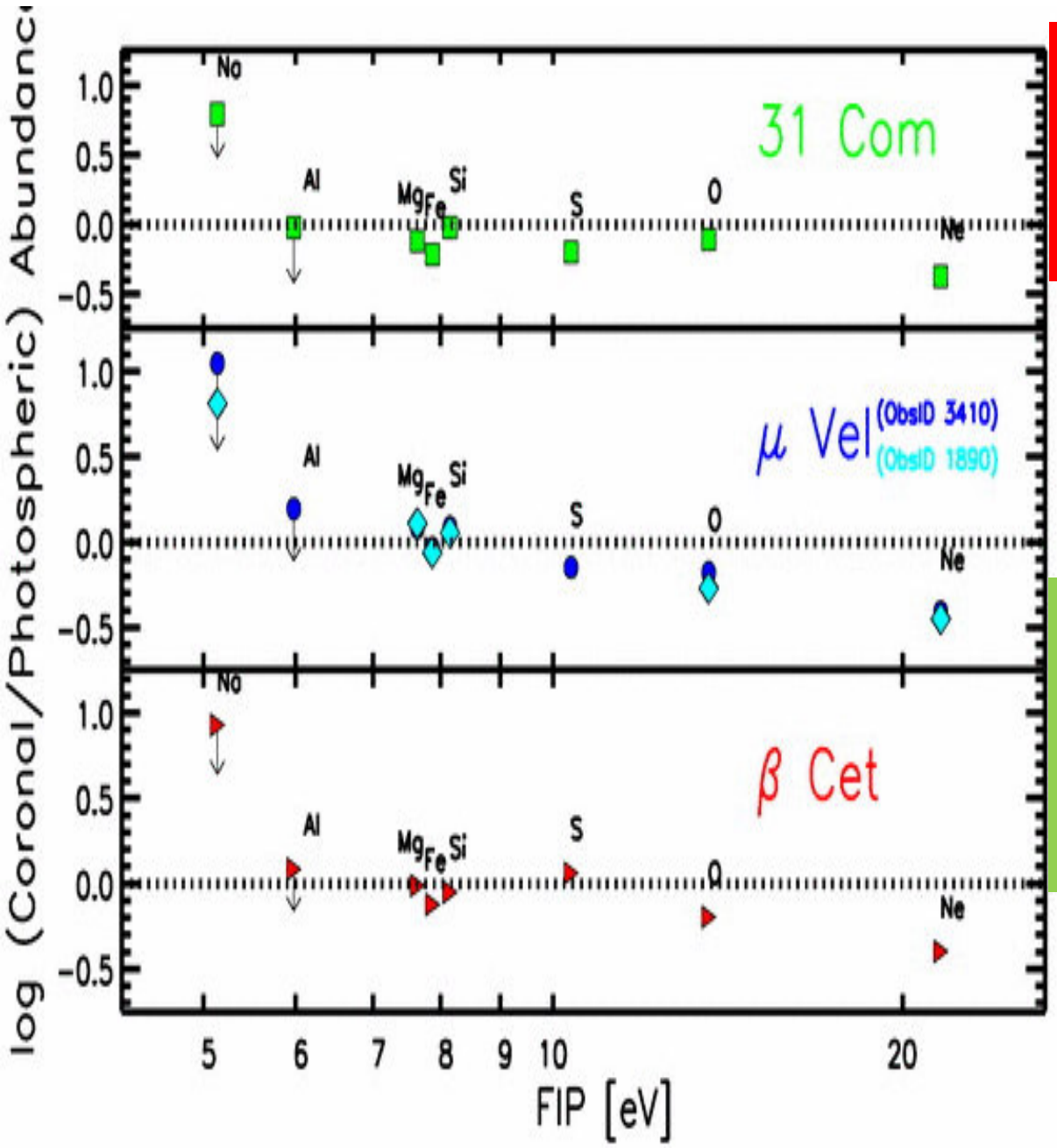
EQ Cas: one more (Inverse) FIP star!





Rao & Reddy, 05

FIP in Stellar Coronae



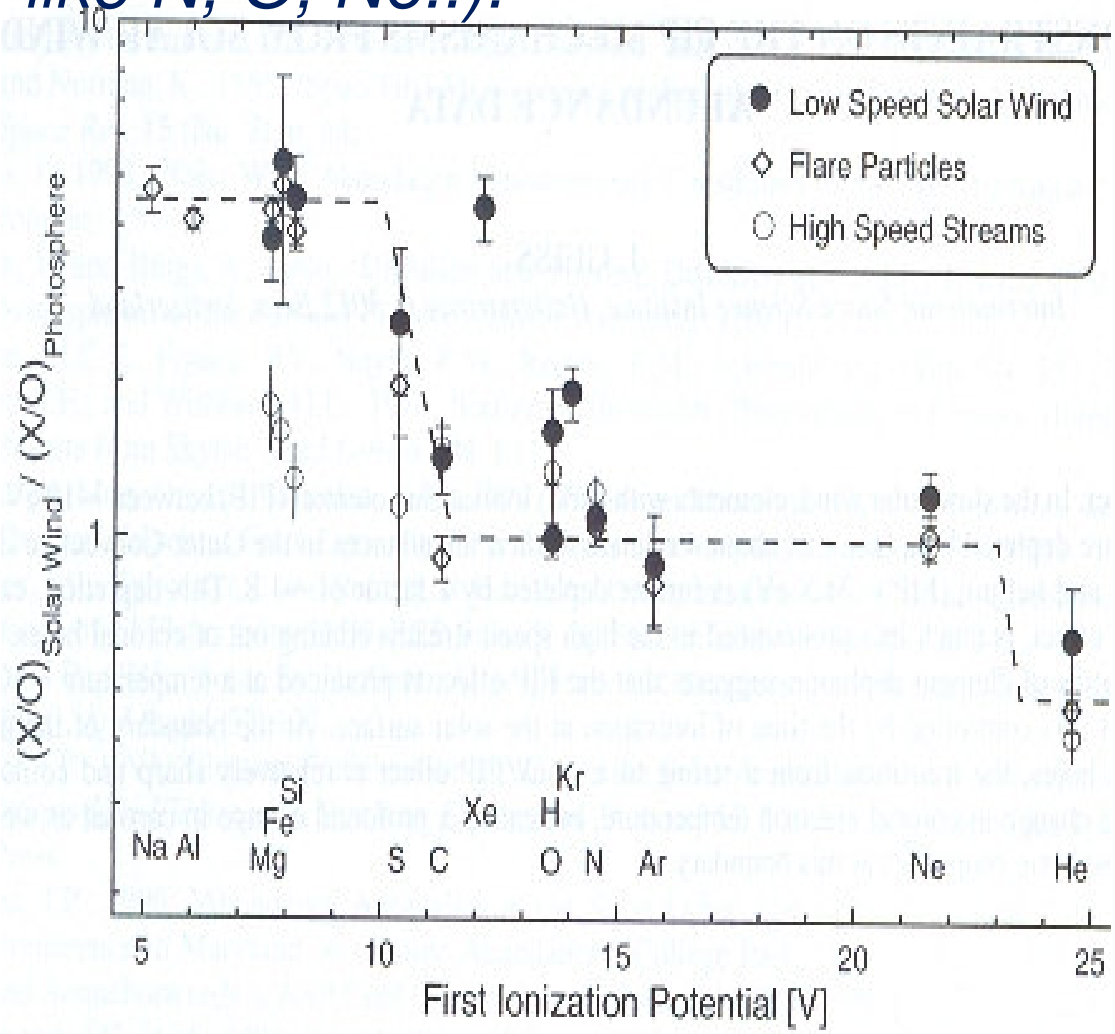
High resolution Chandra X-ray spectra reveals FIP in these G giants similar to

Abundances of high FIP elements are depleted more compared to lower ones with respect to their

Garcia-Alvarez et al. 2006

FIP in Solar wind

FIP effect: the enhancement of elements with low FIP (<=10 eV or so; Mg, Si, Fe etc) relative to those with high FIP (>=10 eV; like N, O, Ne..).



Elemental abundances as a function of FIP of the element in the low speed solar wind and in the high speed streams.

Note the enhancement of low FIP elements relative to high FIP elements.

See Geiss 1998

FIP in the solar corona

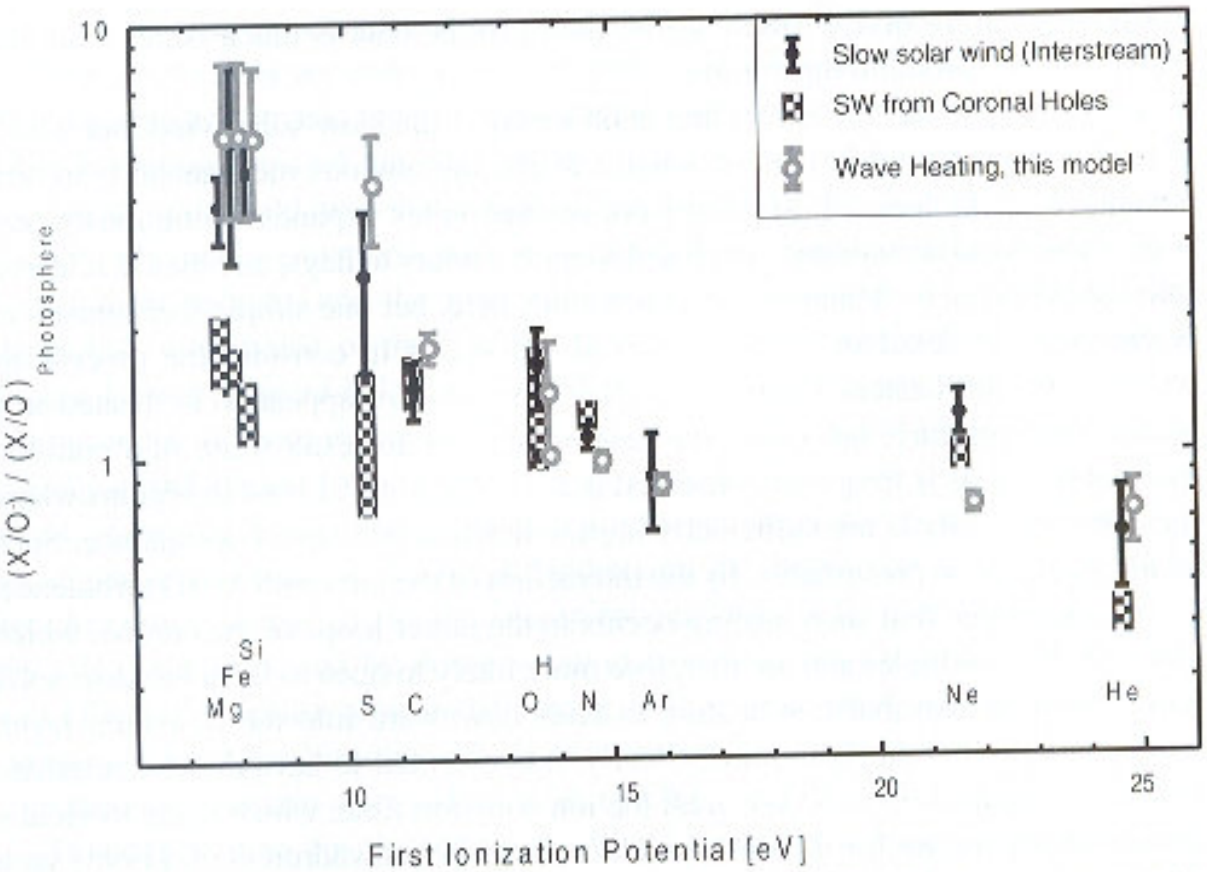
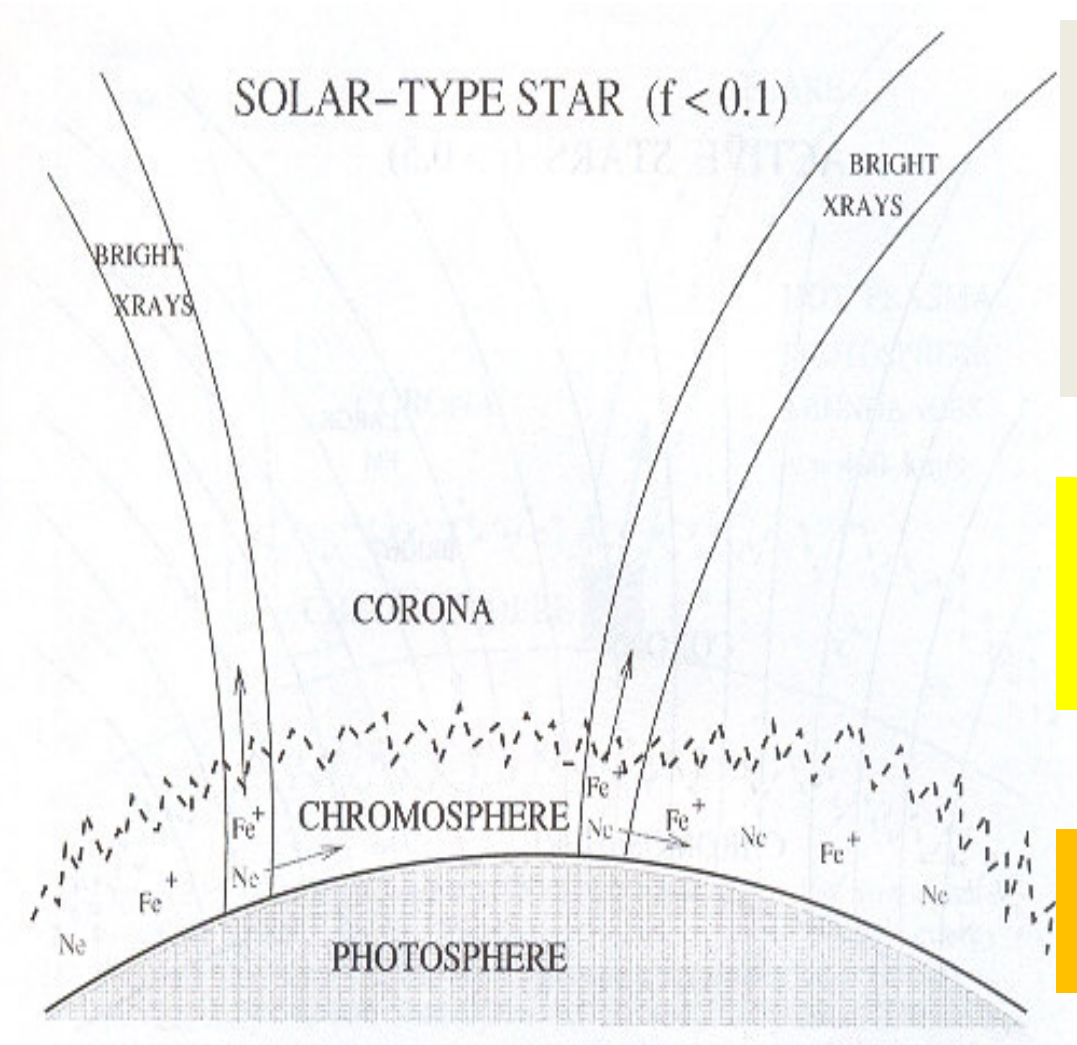


Figure 4. Solar wind abundance ratios, relative to their photospheric values, as a function of the first ionization potential. The measurements are compared with results from a FIP fractionation model described in the text. Figure adapted from von Steiger (1994).

FIP in the Sun



A schematic model for the atmosphere of the sun with magnetic fields covering small portions near the photosphere.

Low FIP elements like Fe are represented by Fe+ and high FIP elements by Ne. The neutral elements like Ne are not trapped in the field lines, but ionized lines like Fe+ are trapped.

Over the time abundances of low FIP elements are built-up in coronal loops which comes out as slow solar wind.

Similar mechanism may be operating in the two cool RV Tauri stars.

See a review by Drake 2004

Search for FIP stars among SRD variables

28 stars were selected with similar log g and Teff to that of CE Vir and EQ Cas.

So far only one star is found to have FIP effect: results yet to be published.

Reddy et al. 2008

FIP effect: magnetic field strength

IR observations help to detect magnetic field strengths in stars

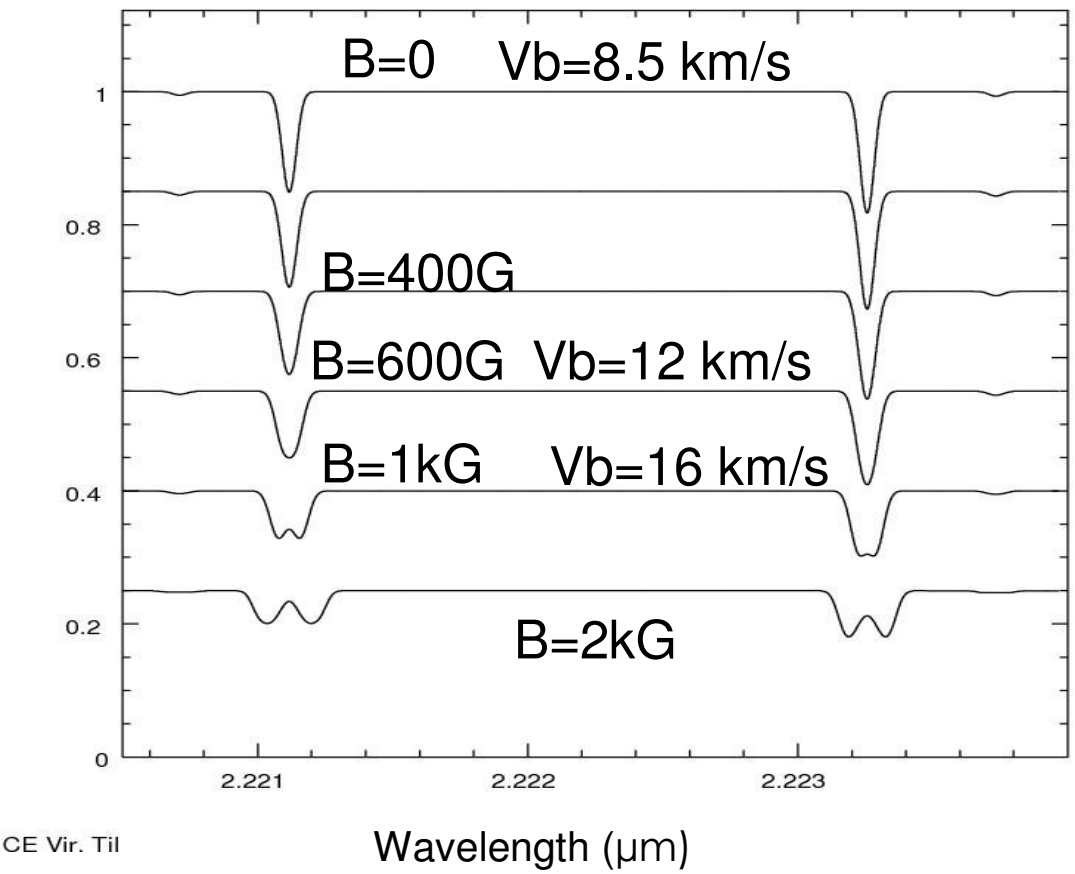
A few well resolved lines occur in the IR regions at 1. 56 micron (Fe I) and 2.2 micron (Ti I)

The Zeeman width $Vb = 10^{-4}\, g_{eff}\, \lambda\, B$ km/s for an optical line at 6000A for B =1KG and g (Lande factor) = 2.5 is around 2.6 km/s

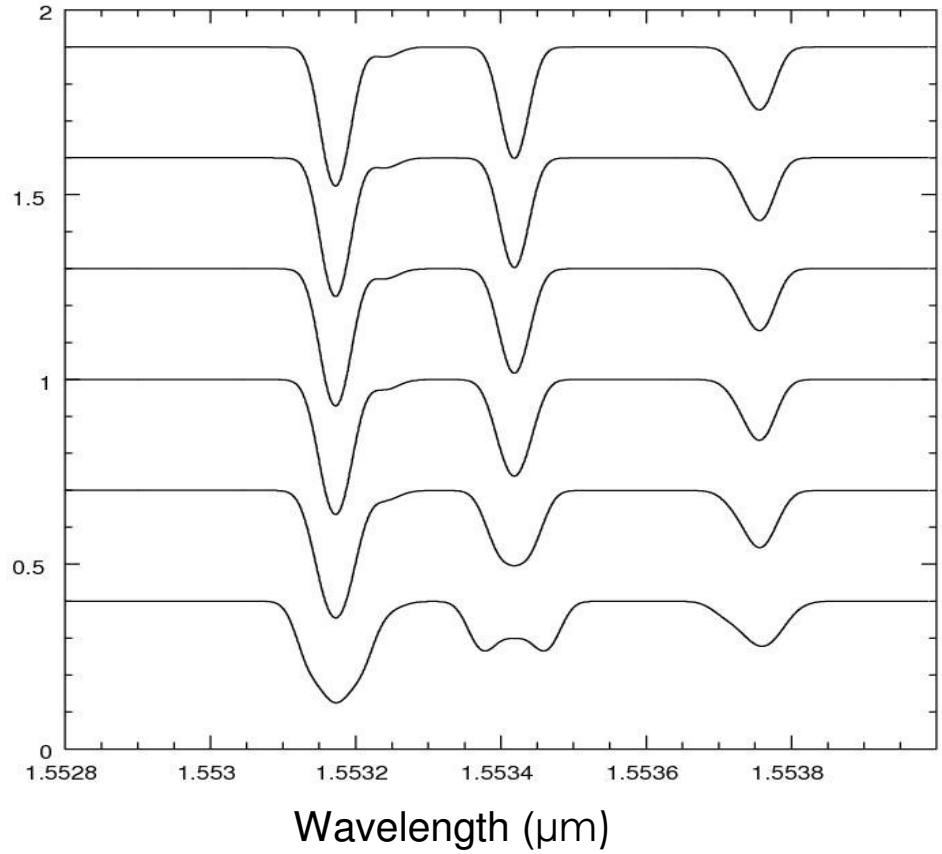
The Zeeman width $Vb = 10^{-4}\, g_{eff}\, \lambda\, B$ km/s for an IR line at 2.2μm for B =1KG and g=2.5 is around 9.4 km/s

(e.g; Sarr 1994)

Effect of Magnetic fields on spectral lines



CE Vir. TiI



Profiles are convolved with R=100,000 Gaussian profile, Vsini = 3 km/s, Vmacro=2km/s and for different values of magnetic field strengths (B).

Summary

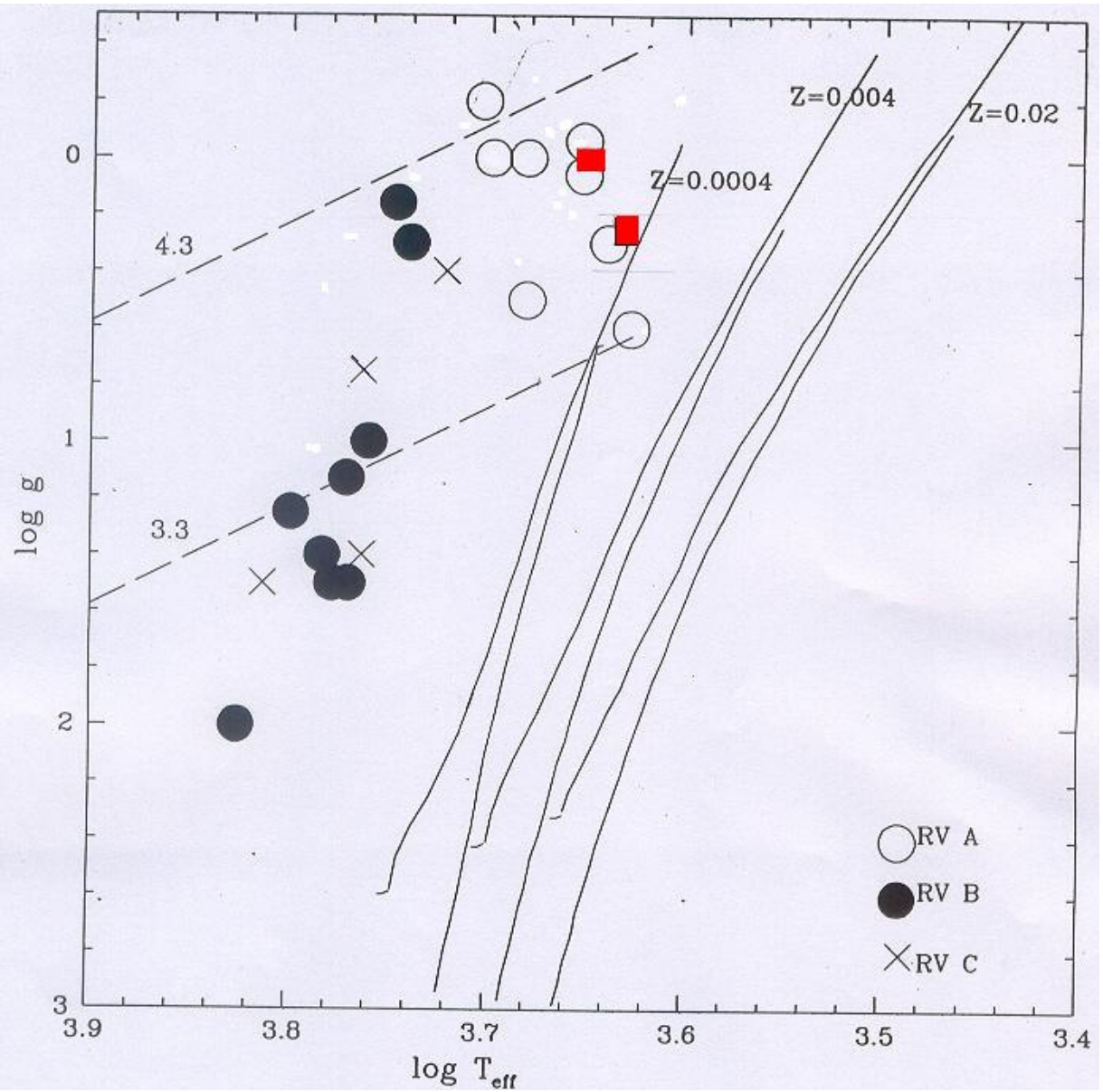
CE Vir and EQ Cas are the only two stars among 40 add RV Tauri stars to show (inverse) FIP effect .

Although the Sun and other stars show the FIP effect in their coronae and possibly in the winds, their photospheres are unaffected.

It is of great significance to trace in CE Vir and EQ Cas the presence of stellar wind or corona and its composition that might show FIP effect.

Understanding the FIP phenomenon on the photospheres of these stars is also relevant in understaning the composition of first stars which show very unusual chemical composition.

RV Tauri stars: HR diagram



RV Tauri stars: pulsations

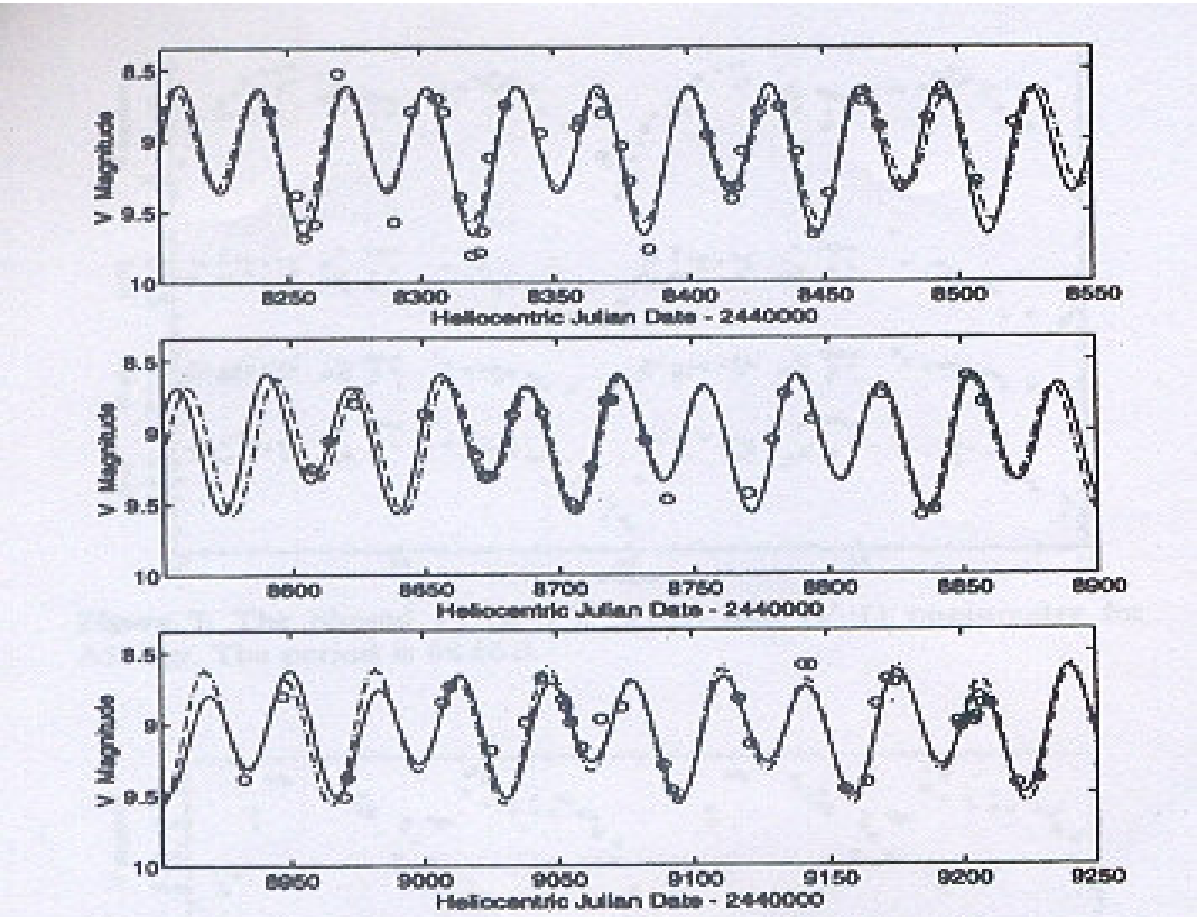


Figure 4. The synthetic light curves for the RU Cen V photometry. The fit to all the V photometry (dotted line) and the fit obtained from analysing each year of data individually (solid line) are compared with the harmonic fit (dashed line) obtained by fixing the second period at exactly twice the dominant 32.30-d period. Top to bottom: 1991, 1992, 1993.

They show deep and shallow
minima with periods