

# Spectroscopic abundance analysis of dwarfs in the young open cluster

## IC 4665

Z.-X. Shen<sup>1\*</sup>

B. F. Jones<sup>2</sup>, D. N. C. Lin<sup>2</sup>, X.-W. Liu<sup>1</sup>, H.-W. Zhang<sup>1</sup> and S.-L. Li<sup>1</sup>

Peking University<sup>1</sup>

UCO/Lick Observatory, University of California, Santa Cruz<sup>2</sup>



### I. Introduction

Properties of stars with planets (SWPs): the metal abundance of SWPs is on average about 0.25 dex larger than that of typical control sample stars (Laws et al. 2003) and the frequency of planets is a strong function of metallicity (Santos et al. 2004, Fischer et al. 2004).

Two possibilities: either planets form preferentially around stars which are intrinsically richer in heavy elements, or the overabundance of the central star is due to hydrogen deficient material enriching the stellar photosphere (Gonzalez 1997).

Open cluster stars: formed from the same cloud at almost the same time so they are believed to have homogeneous initial chemical composition. Therefore, it is a good way to test the accretion theory by detecting star-to-star differences in heavy element contents within a star cluster. Stars showing higher amounts of metals would have had to be enriched in some way, notably from H deficient material being accreted onto the stellar atmosphere sphere.

### II. Spectroscopic analysis

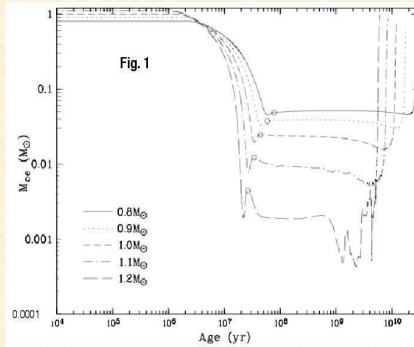
The samples: Keck spectra of dwarfs in the young open cluster IC 4665 (35 Myr; 430 pc);  $R \sim 60,000$ ;  $S/N \sim 30-120$

SME (Spectroscopy Made Easy, Valenti & Piskunov 1996): a tool that can be used to determine stellar and atomic parameters by marching observed spectra with synthetic spectra. Using a Kurucz model and a spectral line list (log gf and van der Waals damping constants), SME will create a synthetic spectrum. And then using a nonlinear least squares algorithm, it could solve for any subset parameters ( $T_{\text{eff}}$ , log g, radial and rotation velocities, micro- and macro-turbulence, element abundances, and atomic data). The atomic data is initially taken from VALD (Vienna Atomic Line Data-base), then solved using NSO solar spectrum (Kurucz et al. 1984) before determining the sample stellar parameters.

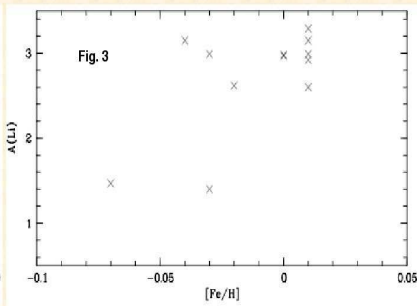
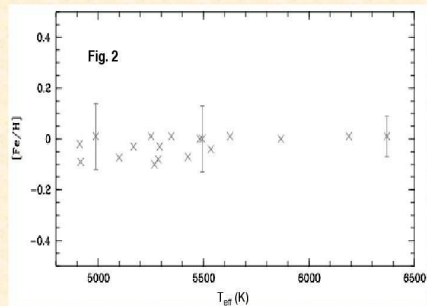
Results: The derived stellar parameters and element abundances are listed in Tab. 1 and Tab. 2, respectively.

### III. Discussions

Convective zone (CZ) and accretion: The accreted material is diluted inside the CZ. Thus stars which have different CZ masses will show different metal enrichment with the same amount of accreted material. The evolution of the CZ mass is calculated using Eggleton code and plotted in Fig. 1 for stars with different masses.



From Fig. 1, we see that just after the age of IC 4665 (30-40 Myr), the CZ mass becomes small and stable. For main sequence stars, the mass of CZ decreases with increasing stellar mass (i.e., increasing  $T_{\text{eff}}$ ). If accretion occurs, the enriched iron abundance is expected to increase with increasing  $T_{\text{eff}}$ . In Fig. 2, iron abundance  $[\text{Fe}/\text{H}]$  is plotted as a function of  $T_{\text{eff}}$ . A first order polynomial fit to the data has a slope consistent with zero  $10^{-5}$ , indicating that no correlations exist between  $[\text{Fe}/\text{H}]$  and  $T_{\text{eff}}$ . It is consistent with the results of Pinsonneault et al. (2001) for 55 Hyades (650 Myr) stars, Wilden et al. (2002) for 16 Pleiades (70 Myr) stars and Santos et al. (2004) for 98 SWPs. Heavy element accretion of larger than 4 earth masses is excluded for the two F stars.



### IV. Summary

We report the first detailed spectroscopic abundance analysis for the young open cluster IC 4665 for a sample of 18 F-K dwarfs. Stellar parameters and element abundances of Li, O, Mg, Si, Ca, Ti, Cr, Fe and Ni have been derived using the spectroscopic synthesis tool SME (Spectroscopy Made Easy). We find uniform iron abundance with a standard deviation of 0.04 dex, which is within our measurement uncertainties. No correlation is found between iron abundance and the mass of the stellar convective zone and between the Li abundance and the Fe abundance. In other words, no signature of accretion has been detected. Our results do not support the theory that the on the average higher metallicity of stars with planets than field stars is due to the pollution of metal-rich planetary material on the outer region of the central stars. It is more likely that planet formation is more efficient in environments of higher metallicity. On the other hand, it is possible that the bulk of the accreted material penetrates the thin convective zone into the deep stellar interior (e.g., Sandquist et al. 1998), or further mixing dilutes the surface metallicity enhancement when the metallicity differences between the inner and outer parts of a star exceeds a threshold (Vauclair 2004), and thus eludes detection by our current observations.

Tab. 1 Stellar parameters for stars in open cluster IC 4665

Name	V <sup>a</sup>	B-V <sup>a</sup>	$T_{\text{eff}}(\text{B-V})^b$ (K)	$T_{\text{eff}}(\text{SME})$ (K)	$\log g^c$ ( $\text{cm/s}^2$ )	$v_{\text{rad}}^d$ (Km/s)	$v_{\text{mac}}^d$ (Km/s)	$v_{\text{rot}}^d$ (Km/s)	$v_{\text{rot}}^d$ (Km/s)
P19	11.95	0.64	6308	6370	4.435	0.26	4.54	5.20	<10
P147	13.45	0.73	6027	6189	4.480	1.02	3.97	4.21	*
P297	12.93	0.75	5949	5867	4.503	1.25	3.85	13.6	15
P107	12.94	0.84	5626	5626	4.560	0.68	3.36	30.3	27
P150 <sup>f</sup>	13.08	0.86	5558	5535	4.572	1.62	3.35	26.6	25
P151	13.57	0.88	5493	5494	4.583	1.46	3.15	12.4	*
P60	13.43	0.88	5493	5483	4.583	1.27	3.15	9.83	13
P199	14.59	1.01	5100	5168	4.641	0.57	2.55	3.17	*
P75 <sup>f</sup>	13.70	0.89	5460	5347	4.465	1.60	3.10	14.10	16
P165	13.40	0.90	5428	5292	4.594	1.56	3.05	31.78	40
P267	14.83	1.04	5017	5286	4.650	0.43	2.41	1.92	*
P94	14.32	0.95	5274	5287	4.618	0.95	2.81	3.32	*
P71 <sup>f</sup>	13.68	0.92	5366	5251	4.604	1.55	2.96	14.62	17
P94	14.26	1.01	5100	5168	4.640	0.87	2.54	4.89	10
P100 <sup>f</sup>	14.37	1.06	4963	4913	4.654	1.46	0	16.92	21
P332	14.54	1.09	4884	4989	4.660	0.76	0	2.34	*
P349	14.65	1.11	4833	4917	4.662	0.57	0	3.89	*
P352	14.62	1.08	4911	5105	4.658	0.87	0	4.30	*

<sup>a</sup> Prosser, 1993; <sup>b</sup> Alonso et al., 1996; <sup>c</sup> Gray, 1992; The observation and analysis of stellar photospheres, p.365, equation (16.2); <sup>d</sup> For stars with  $T_{\text{eff}}(\text{B-V}) > 5000$ , equation from Fischer & Valenti (2003); for others, zero; <sup>e</sup> Prosser & Giampapa, 1994; <sup>f</sup> Variable star (The 73rd name-list of variable stars, 1997);

Tab. 2 Element abundances for stars in open cluster IC 4665

Name	Li	Li(MN) <sup>a</sup>	O	Mg	Si	Ca	Ti	Cr	Fe	Ni
Sun	1.12	*	8.83	7.54	7.51	6.32	4.98	5.63	7.46	6.21
P19	3.15	*	8.57	7.55	7.51	6.20	4.80	5.78	7.47	6.26
P147	2.60	*	8.91	7.55	7.52	6.31	4.97	5.64	7.47	6.20
P39	2.98	*	8.30	7.50	7.51	6.36	5.07	5.57	7.46	6.13
P107	2.99	3.0	9.34	7.50	7.38	6.32	4.89	5.55	7.47	6.12
P150	3.15	3.1	9.18	7.87	7.28	6.50	5.19	5.60	7.42	6.09
P151	2.97	*	9.00	7.77	7.53	6.45	5.07	5.54	7.46	6.12
P60	2.98	*	8.94	7.51	7.59	6.38	5.09	5.65	7.46	6.15
P199	1.47	*	9.05	7.53	7.45	6.14	5.52	5.55	7.39	6.35
P75	3.29	3.3	9.29	7.50	7.80	6.47	5.06	5.46	7.47	6.09
P165	2.99	3.1	9.06	7.38	7.35	6.48	5.23	5.68	7.43	6.15
P267	*	*	8.80	7.53	7.57	6.28	5.34	5.72	7.38	6.32
P94	*	*	8.98	7.42	7.37	6.13	5.36	5.78	7.36	6.33
P71	2.92	3.1	9.47	7.63	7.77	6.48	5.23	5.44	7.47	6.13
P94	1.40	2.1	8.63	7.52	7.45	6.46	5.14	5.56	7.43	6.14
P100	2.62	2.8	9.83	7.37	7.89	6.44	5.21	5.50	7.44	6.23
P332	*	*	9.79	7.70	7.82	6.10	5.30	5.52	7.47	6.55
P349	*	*	9.63	7.40	7.90	6.13	5.19	5.53	7.37	6.46
P352	*	*	9.46	7.64	7.71	6.19	5.29	5.44	7.39	6.44

<sup>a</sup> Martin & Nootes 1997;

A(Li) and  $[\text{Fe}/\text{H}]$ : Since Li is destroyed during Pre-main-sequence contraction, addition of only a small amount of hydrogen depleted material can lead to a large spread in Li abundance of stars in a cluster. If accretion is responsible for the high lithium, then stars with an enhanced lithium abundance would also have enhanced abundances of other metals. In Fig. 2, Li abundance A(Li) is plotted as a function of  $[\text{Fe}/\text{H}]$  to look for a correlation between the dispersion in the lithium abundance and the dispersion in the abundance of iron. Just as Wilden et al. (2002) found in Pleiades, We see no correlation between stars which have slightly higher iron abundance and stars which have exceptionally high lithium abundance in IC 4665.