Correlation between exoplanet and star metallicity

Laith.M.Karim and Ahmed.A.Abdulhameed

Layth_karim@yahoo.com ahmedmajeed_81@yahoo.com
Department of Astronomy, College of Science, University of Baghdad

Abstract

The metallicity [Fe/H] for several stars accompanied by Extra-solar planets were calculated and plotted as a function of stars mass (M_*). Results showed that masses of Extra-solar planets stars are well correlated with their metallicity .This relation could be explained by the equation: Y=-0.0045x + 0.065. The metallicity limit is found to be in the range of (0.18 to 0.3), relative to the mass limit in the range of (0.76 to 1.44) M_{Sun}.

This criteria is a good tool that can be used by observers who are aiming for detecting Extra-solar planets.

Key words
Astronomy
Astrophysics
exoplanets

Article info
Received: Feb. 2010
Accepted: Aug. 2011
Published: Dec. 2011

العلاقة بين نجوم الكواكب الخارجية وعامل معدنيتها

ليث محمود كريم و احمد عبد المجيد عبد الحميد

قسم الفلك، كلية العلوم، جامعة بغداد

الخلاصة:

تم حساب ورسم عامل المعدنيه [Fe/H] لعدد من النجوم مرتبطه بها كواكب خارجية (Extra-solar planets) كدالة لكتلة النجوم (M_*). النتائج بينت ان هنالك علاقة خطيه بين كتلة نجوم تلك الكواكب وعامل معدنيتها. هذه العلاقة يمكن ان تعطى بالصيغة: Y=0.0045X+0.065
ان حدود المعدنية وجدت في حدود المديات (٠,١٨ الى ٠,٣) نسبة الى حدود الكتلة ضمن المدى (٠,٧٦ الى ١,٤٤) من كتلة الشمس.

Introduction

Extra-solar planets, or Exoplanets, are planets beyond the Solar System orbiting a star other than the Sun. Wobbling movement of stars, resulted from an effect of a companioned (unseen) object, this object is unseen planet. Many methods have been used to detect these planets, but the vast majority has been detected through radial velocity observations [1, 2, 3, 4].

According to the International Astronomical Union (IAU) definition of "planet," a planet must orbit a Star. The working definition for Extra-solar planets was established in 2001 and updated in 2003 [5, 6].

Claims about detection of Extra-solar planets have been made from the middle of 19th century. Some of the earliest involve the binary star 70 Ophiuchi. In 1855, Jacob reported that orbital anomalies made it "highly probable" that there was a planetary body in this system [7]. In the 1890s, Thomas stated that the orbital anomalies proved the existence of a dark body in the 70 Ophiuchi systems with a 36-year period around one of the stars [8]. However, Moulton later published a paper proving that a three-body system with those orbital parameters would be highly unstable [9].

In 1916, an article appeared that dealt with a small discovery, insignificant star that show a large proper motion.[10] The purpose of the article was to alert the astronomical world that indeed, Barnard(HD 21185) detected a unique find, which is a star with a proper motion larger than any star that had been studied previously [11,12]. In 1969 van de Kamp published an article, stated that two planets revolving around Barnard's Star, that one of the planets revolved around the star every 26 years while the other every 12 years. The companions seemed to have masses 1.1 and 0.8 the mass of Jupiter [13]. In 1975, van de Kamp published yet another article, stated that the masses of the two planets were determined to be 0.4 Jupiter masses and 1.0 Jupiter masses. In addition, the period for the two planets, 22 years and 11.5 years respectively [14]. Astronomers Gatewood and Eichhorn examined photographic plates for Barnard's star taken with a 20-inch refractor and the 30-inch Thaw refractor. They were unable to detect any wobble in the proper motion of Barnard's Star [15]. In 1995 Gatewood suggested that brown dwarfs (more massive than Jupiter by greater than 10 masses, but not massive enough to glow as a star) could not exist around Barnard's Star [16]. Although work on Barnard's Star has increased well over a half century, but no definitive confirmation by the astronomical community as a whole has been established.

Recently confirmation of Exoplanets discoveries was made by many authors using new methods of detection. The first published discovery to have received subsequent confirmation was made in 1988 by astronomers [17]. Their radial-velocity observations suggested that a planet orbited the star Gamma Cephei. The following years, additional observations were published that supported the reality of the planet orbiting Gamma Cephei [18]. While Walker work in 1992 raised uncertain statement of confirmation [19]. In 1992, radio astronomers Wolszczan and Frail announced the discovery of planets around pulsar, (PSR 1257+12) [20]. This discovery was quickly confirmed.

In 1995, Mayor and Queloz announced the first definitive detection of Extra-solar planets orbiting an ordinary main-sequence star (51 Pegasi). This discovery was made a great approach in the modern era of Extra-solar planets discovery. Technological advances, most notably in high-resolution spectroscopy, led to the detection of many new Extra-solar planets at a rapid rate. Several Extra-solar planets were eventually also detected by observing the variation in a star's apparent luminosity as a planet passed in front of it [21].

In 1996, Researchers announced that they have found the first planetary system that similar to our solar system, 41 light years away [22]. The system centers on sun-like star (55 Cancri) which lies in the Cancer constellation. Then after, the number reached to five planets orbiting this star [23]. In 1998, Researchers found first planet that orbits around a red dwarf star (Gliese 876). It orbits closer to the star than Mercury is to the Sun. More planets have subsequently been discovered closer to the star [24]. In 1999, the first multiple-planetary systems to be discovered around a main sequence star (HD 209458). It contains three planets, all of which are Jupiter-like. Planets b, c, d were announced in 1996, 1999. Their masses are 0.687, 1.97, and 3.93 M_J; they orbit at 0.0595, 0.830, and 2.54 AU respectively [25]. In 2001, Astronomers using the Hubble Space Telescope and studied the physical properties of HD 209458 b [26]. In 2002, Fischer and Valenti have studied the metallicity of star with Extra-solar planets. This is a very important method to be added to the physical properties of exoplanets stars [27]. In 2003, using information obtained from the Hubble Space Telescope, a team of scientists led by Sigurdsson confirmed the oldest Extra-solar planet yet. The planet is located in the globular star cluster M4, about 5,600 light years from Earth in the constellation Scorpius. This is the only planet known to orbit around a stellar binary; one of the stars in the binary is a pulsar and the other is a white dwarf. The planet has a mass twice that of Jupiter, and is estimated to be 1.3 billion years old [28]. In 2005, a third planet orbiting the red dwarf star (Gliese 876) was announced. With a mass estimated at 7.5 times that of Earth (M_E)[29]. In 2006, astronomers announced the discovery of (OGLE-2005-BLG-390L) [30]. This star has one known planet, which was discovered using gravitational microlensing technique. It is considered as one of the smallest known extra-solar planets around a main sequence star, possibly rocky, with a mass around 5.5 M_E [30]. In 2009, Fischer et al announced the discovery of five Extra-solar planets revolving around the star (HD 196885Ab) [31]. The number of discovered Extra-solar planets increasing and reach by now to 422. It is necessary to find a criteria for observing stars that probably having planets revolving around them. Metallicity correlation with masses of star is the method presented in this paper for making such a criteria.

2-Data preparation and samples selection:

Data were taken from catalogues which we got from authors [32]. These catalogues contain much information about stars parameters, including data for confirmed Extra- us with all parameters needed. The chosen stars for this paper, are investigated for the correlation between the metallicity [Fe/H] and mass of the sample stars. Results show a population correlation between these two parameters, with a linear result given by the solar planets. We worked on confirmed Extra-solar planets data, so that we attempt to make criteria about stars accompanied with planets. This criteria will be used to confirm the presence of Extra-solar planets. From these data, 360 stars have been chosen as they provided equation Y=-0.0045X+0.065 and as shown in figure-1. The sample then reduced to the number grabbed in the square of the figure, the sum of 259 stars.

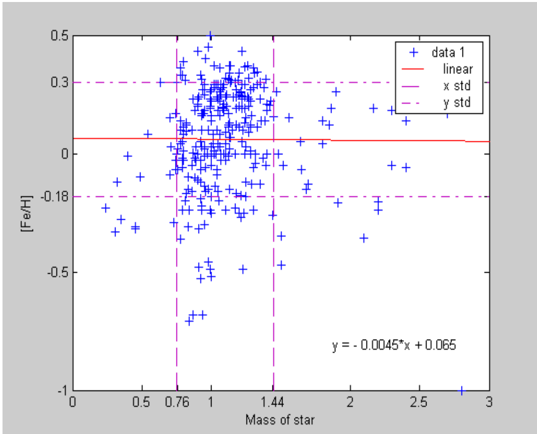

Fig.1: The correlation between the metallicity and the mass of the sample star.

From this figure the limit of masses to be taken, are of the range between $0.76 <= M_s <= 1.44$. This range is adopted in this work in looking for stars having such values of masses, which could be accompanied with planets.

The next step is to find out another correlation for the sample, like, the visual magnitude and distance with masses of stars. This is done and plotted as shown in figure-2 and figure-3.

Figure-2 shows a correlation of 280 stars grabbed in the square between visual magnitude and masses of stars with a linear relation given by the equation: Y=-2.1X+10.While figure -3, shows a correlation of 316 stars grabbed in the square between distance and masses of stars with a linear relation given by the equation: $Y=1.5*10^{2x}-39$.

The related stars in common between those three figures are of the sum 197 stars, and further calculation will be done.

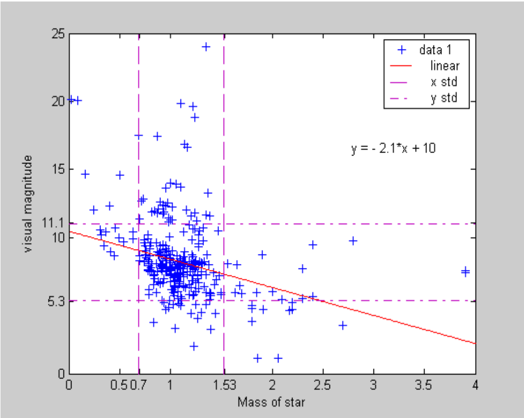

Fig.-2: The correlation between the visual magnitude and the mass of the sample star.

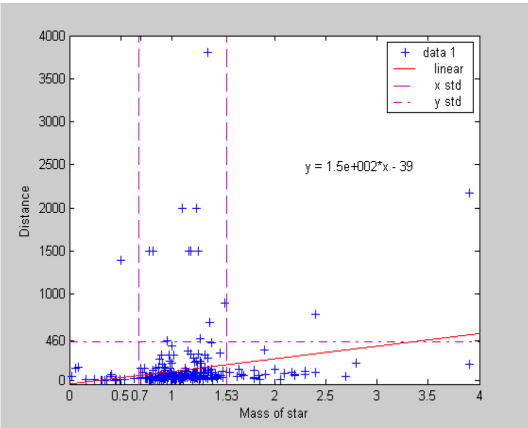

Fig.-3: The correlation between the distance and the mass of the sample star.

3-Calculation and results:

The metallicity for any stars is expressed by "[Fe/H]", which represent the proportion of star's iron abundance divided by star's hydrogen abundance compared to that for the sun. The formula for the logarithm is given by [33]:

$$[Fe/H] = \log_{10}(N_{Fe}/N_H)_{Star} - \log_{10}(N_{Fe}/N_H)_{Sun} \text{ --------- } (1)$$

Where N_{Fe} and N_H is the number of iron and hydrogen atoms per unit of volume respectively. By this formulation, stars with a higher metallicity than the sun have a positive logarithmic value, while those with a lower metallicity than the sun have a negative value. For these purposes, available spectra for some of related stars are obtained via online, taken from Elodie Archive [34]. Spectra show the intensity of each star plotted as a function of their wavelength, and as shown in figure 4-1 to figure 4-11. These spectra show the absorption lines of hydrogen and iron, and their relative intensities. Spectra were investigated and the values of $[N_H]$ and $[N_{Fe}]$ have been produced, then the values for [Fe/H] have been calculated using equation 1. Results are as shown in table-1, which present as well as these results, a comparison with results obtained by authors.

Table 1: Value of $[N_H]$ and $[N_{Fe}]$ obtained from spectra sample, and the calculated [Fe/H] values of this work compared with values obtained by authors:

Star's name	Relative absorption intensity		Calculated [Fe/H]	
	N_H	N_{Fe}	Authors result[32] [Fe/H]	This work [Fe/H]
HD 210277	3400	3000	0.19	0.14
HD 195019(1)	6000	4000	0.08	0.02
HD 195019(2)	2200	1800	0.08	0.1
HD 222582	500	300	-0.01	-0.02
HD 168433	3000	2000	0.03	0.02
HD 92788	600	500	0.24	0.11
HD 198874	360	360	0.14	0.198
HD 132406(1)	1600	1700	0.18	0.22
HD 132406(2)	2200	2000	0.18	0.156
HD 164922(1)	1600	1500	0.17	0.169
HD 164922(2)	2100	2000	0.17	0.176
HD 187123(1)	2000	1900	0.16	0.175
HD 187123(2)	4000	3800	0.16	0.175
HD 187123(3)	5600	5000	0.16	0.148
HD 118203	2100	1800	0.1	0.13
HD 1461 b	16000	15000	0.19	0.169

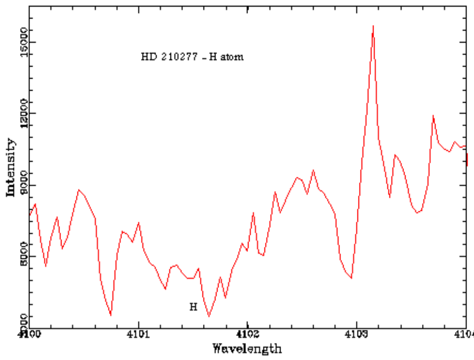

Fig. 4-1-a: absorption line of hydrogen at λ=4101.6 A^0.

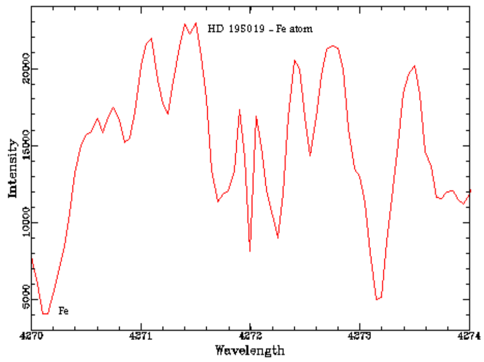

Fig. 4-2-b: absorption line of iron at λ=4270.2 A^0.

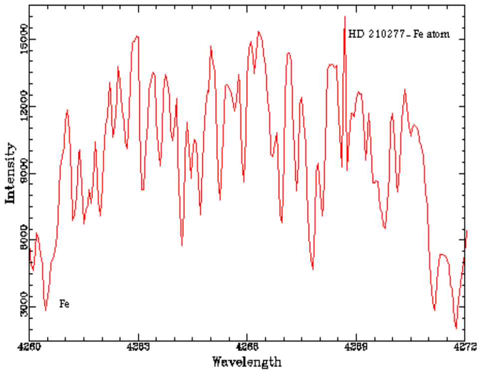

Fig. 4-1-b: absorption line of iron at λ=4260.5 A^0.

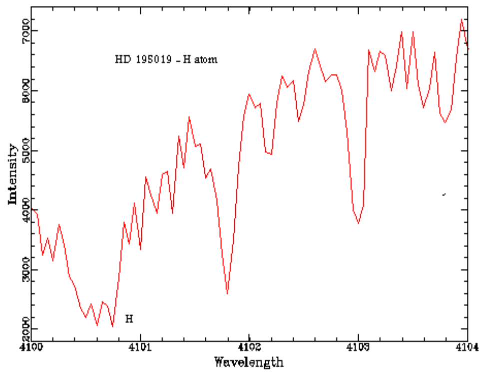

Fig.4-2-c: absorption line of hydrogen at λ=4100.6 A^0.

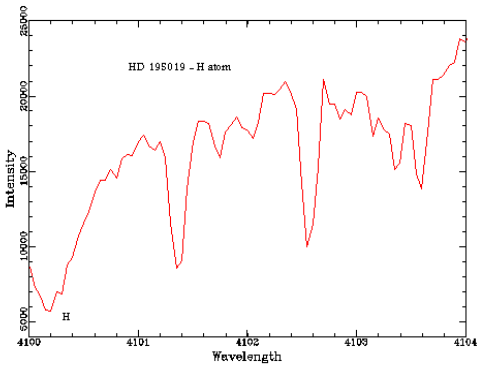

Fig. 4-2-a: absorption line of hydrogen at λ=4100.2 A^0.

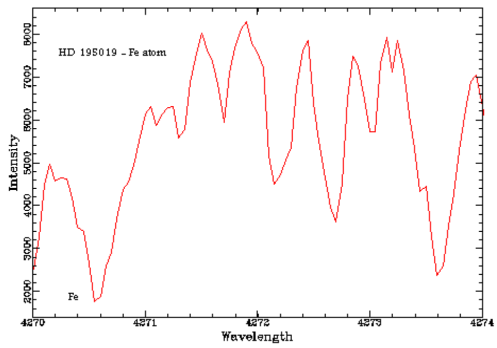

Fig. 4-2-d: absorption line of iron at λ=4270.6 A^0.

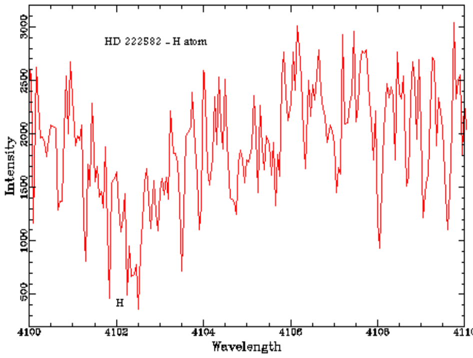

Fig. 4-3-a: absorption line of hydrogen at λ=4102.1 A^0.

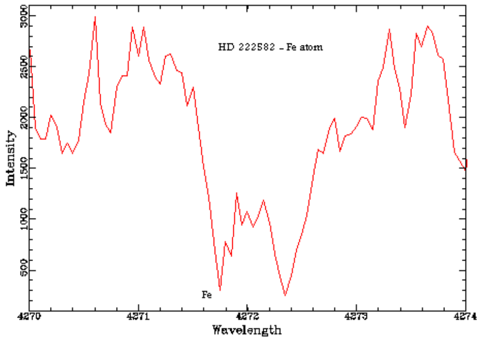

Fig. 4-3-b: absorption line of iron at λ=4271.8 A^0.

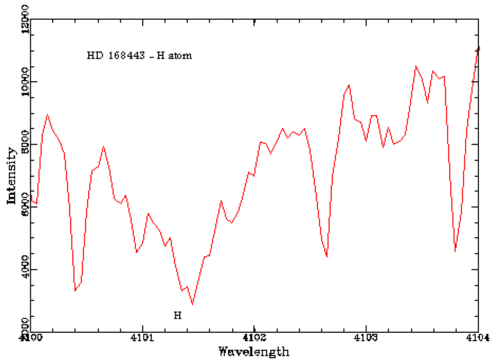

Fig.4-4-a: absorption line of hydrogen at λ=4101.5 A^0.

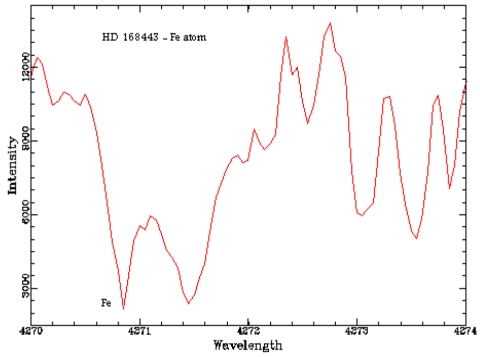

Fig. 4-4-b: absorption line of iron at λ=4270.8 A^0.

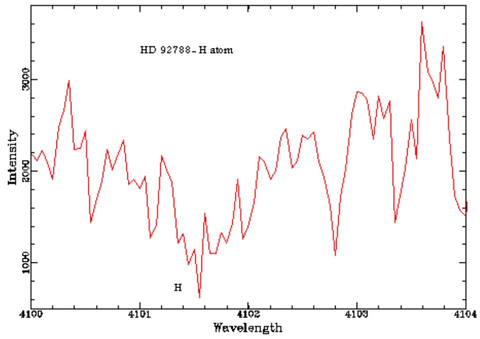

Fig. 4-5-a: absorption line of hydrogen at λ=4101.6 A^0.

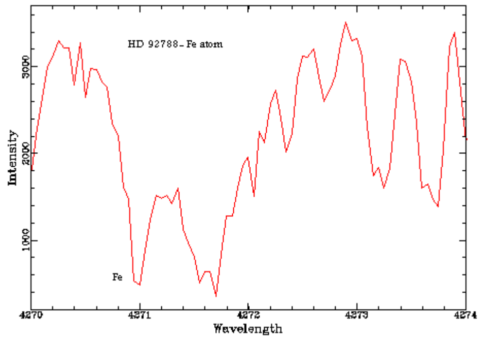

Fig. 4-5-b: absorption line of iron at λ=4271 A^0.

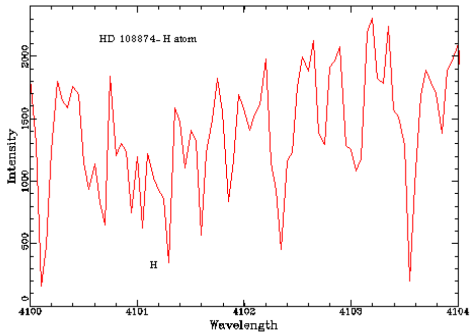

Fig. 4-6-a: absorption line of hydrogen at λ=4101.3 A^0.

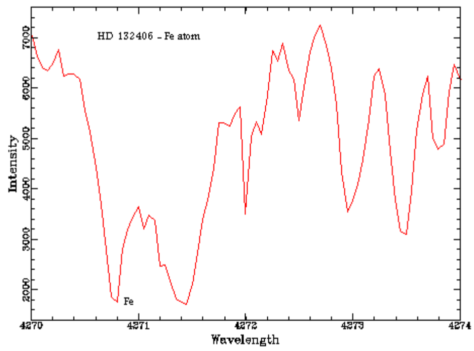

Fig. 4-7-b: absorption line of iron at λ=4270.8 A^0.

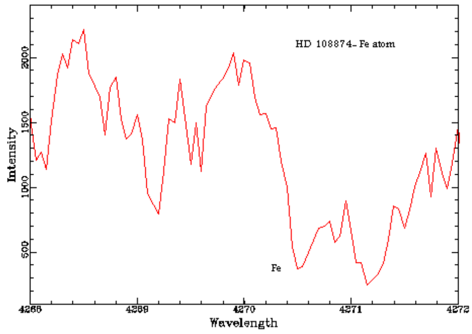

Fig. 4-6-b: absorption line of iron at λ=4270.5 A^0.

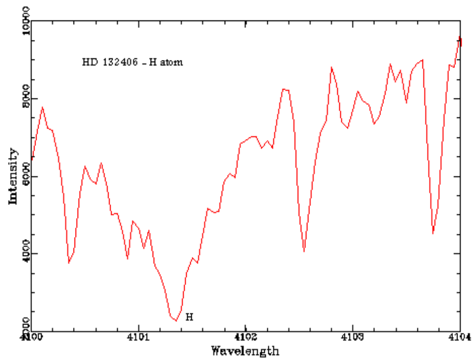

Fig.4-7-c: absorption line of hydrogen at λ=4101.3 A^0.

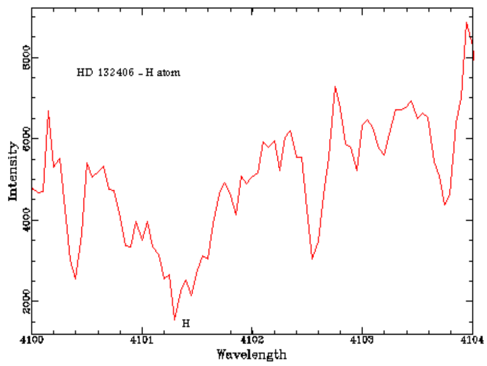

Fig. 4-7-a: absorption line of hydrogen at λ=4101.3 A^0.

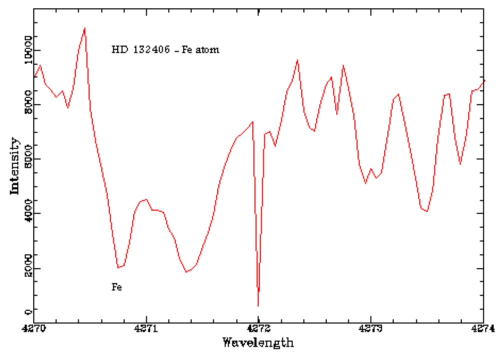

Fig. 4-7-d: absorption line of iron at λ=4270.8 A^0.

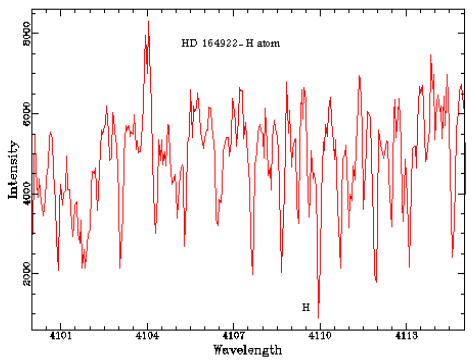

Fig. 4-8-a: absorption line of hydrogen at λ=4110 A^0.

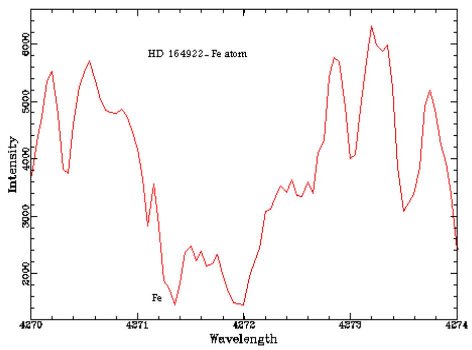

Fig. 4-8-b: absorption line of iron at λ=4271.4 A^0.

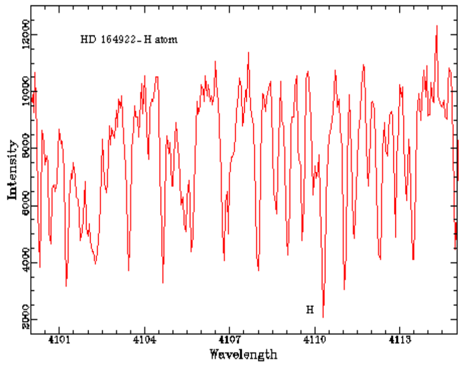

Fig. 4-8-c: absorption line of hydrogen at λ=4110.1 A^0.

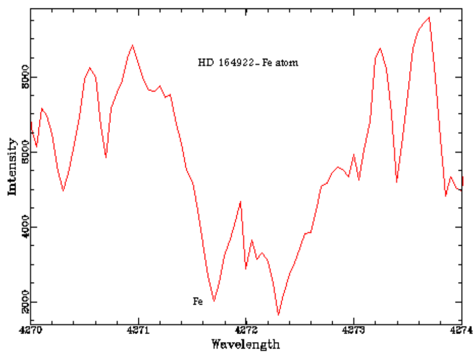

Fig. 4-8-d: absorption line of iron at λ=4271.7 A^0.

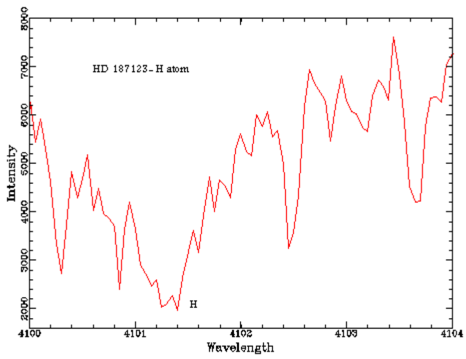

Fig. 4-9-a: absorption line of hydrogen at λ=4101.4 A^0.

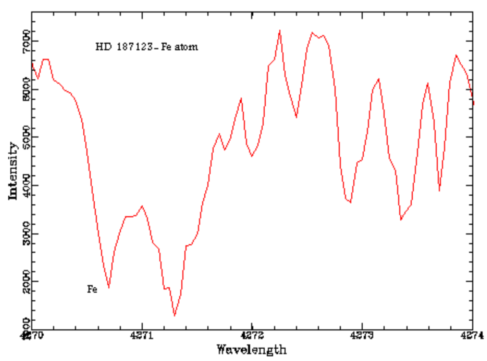

Fig. 4-9-b: absorption line of iron at λ=4270.7 A^0.

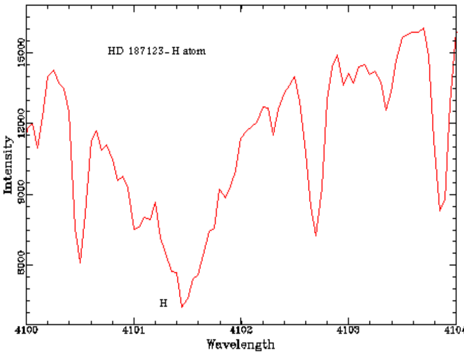

Fig. 4-9-c: absorption line of hydrogen at λ=4101.5 A^0.

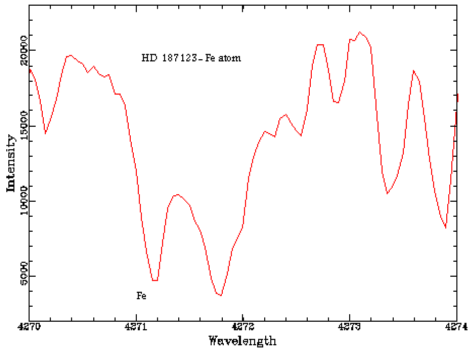

Fig. 4-9-f: absorption line of iron at λ=4271.2 A^0.

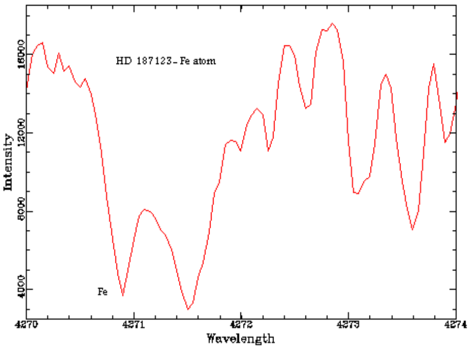

Fig. 4-9-d: absorption line of iron at λ=4270.9 A^0.

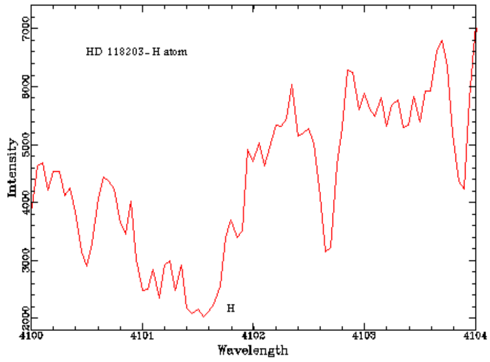

Fig. 4-10-a: absorption line of hydrogen at λ=4101.6 A^0.

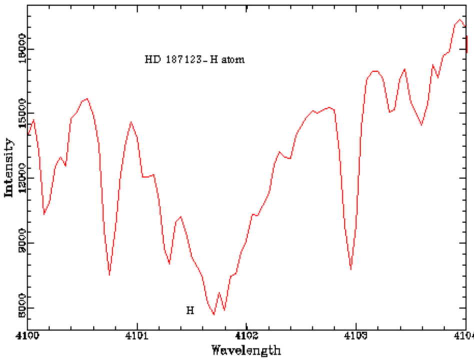

Figure 4-9-e: absorption line of hydrogen at λ=4101.7 A^0.

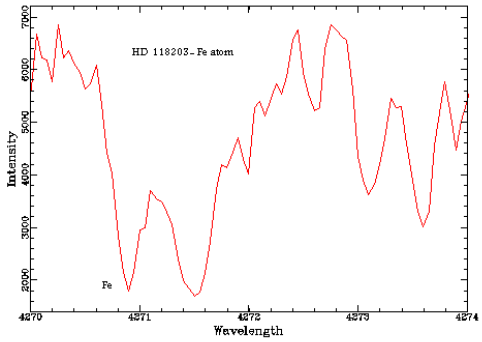

Fig. 4-10-b: absorption line of iron at λ=4270.9 A^0.

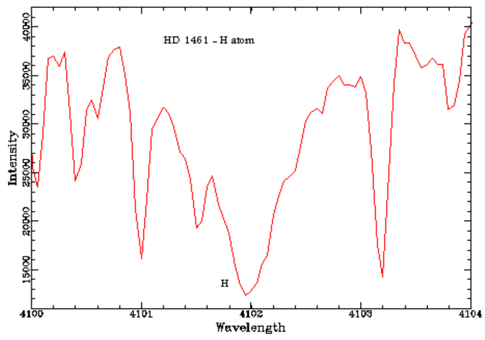

Fig. 4-11-a: absorption line of hydrogen at λ=4101.9 A^0.

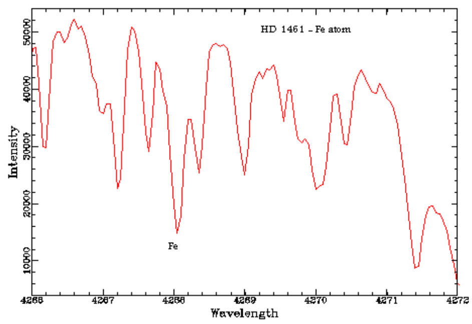

Fig. 4-11-b: absorption line of iron at λ=4268 A^0.

4-Discussion and conclusion:

Selecting star as a programmed sample preparation for observation needs a criteria for choosing such star. In this paper the criteria worked on is to find the correlation between metallicity [Fe/H] of stars with their masses, as it is a good tool to determine whether a star can be observed with a planet revolving around it or not. Wobbling phenomena was a tool for this purpose, but not enough to decide or confirm the presence of such planets. Therefore another tool for confirmation is the metallicity weight of a star.

It is clear from figures tabulated that star with masses range between (0.7 to 1.53) Jupiter mass are the candidate stars that participate in the sample chosen for the purpose of identification of extra_solar planets. Getting spectra for the proposed sample needs an access to data-bank resources or otherwise direct observations, the idea that getting such spectra needs extra efforts.

The result for overall sample of 360 stars showed a good correlation for the metallicity with stars masses according to the equation of correlation given by: Y=-0.0045X+0.065. The reduced sample for more specific results, of 11 selected stars which listed in table-1, showed a good agreement with results obtained by authors. Calculated metallicity has an average value of 0.18 for this work in comparison with that produced by authors of the value: 0.14, with deviation ± 0.04. We conclude that the criteria put in this paper for considering metallicity correlation with masses of stars is a good tool in deciding for observing Extra-solar planet revolving around stars planned by astronomers.

References:

1. M. Pätzold, Rauer, H., Astrophysical. Journal (2002) 568, L117.
2. S. Ida, Lin, D. N. C., Astrophysical. Journal (2004) 604, L 388.
3. S. N. Raymond,; Mandell, A. M.; Sigurdsson, S., Science (2006) 313, L1413.
4. J. C. Armstrong,; Larson, S. L.; Astron. Soc., (2007) 38, L105.
5. "Working Group on Extra-solar Planets (2003): Definition of a "Planet"". IAU position statement. www.space.com
6. R.R. Brit, "Why Planets Will Never Be Defined". (2006). www.space.com
7. W.S. Jacob, "On Certain Anomalies presented by the Binary Star 70 Ophiuchi". Monthly Notices of the Royal Astronomical Society (1855) 15. L228.
8. J. J. Thomas "Researches on the Orbit of F.70 Ophiuchi and on a Periodic Perturbation in the Motion of the System Arising from the Action of an Unseen Body". The Astronomical Journal. (1896) 16: p17.
9. Sherrill, Thomas J. "A Career of controversy: the anomaly OF T. J. J. " Journal for the history of astronomy (1999) (30).

10. E.E. Barnard, "A small star with large proper-motion." The Astronomical Journal (1916) 24. L3. P 181.
11. Croswell, Ken. "Does Barnard's Star have planets?" Astronomy (1988) 16. L3. PP 6-17, Pg. 13.
12. Illingworth, Valerie, Ed. The Facts on File Dictionary of Astronomy, 3rd Ed. New York: Facts on File, Inc., (1994). Pg.354.
13. Van de Kamp, P.."Alternate dynamical analysis of Barnard's Star." The Astronomical Journal (1969) 74. L6: PP.757-9.
14. P.Van de Kamp, "Astrometric study of Barnard's Star from plates taken with the Sproul 61-cm refractor." The Astronomical Journal (1975) 80. L8: PP 658-61.
15. G.D. Gatewood, and Heinrich, E., "An unsuccessful search for a planetary companion of Barnard's Star (BD + 4 degree3561)." The Astronomical Journal (1973) 78. L8 :PP 769-776,
16. G.D.Gatewood, "A study of the astrometric motion of Barnard's Star." Astrophysics and Space Science (1995) 223(1-2): pp 91-101.
17. B. Campbell, Walker, G. A. H.; Yang, S. "A search for substellar companions to solar-type stars". Astrophysical Journal, Part 1 (1988) 331: pp 902 – 921.
18. A. T.Lawton, Wright, P. "A planetary system for Gamma Cephei?" British Interplanetary Society, Journal (1989) 42: pp 335 – 336.
19. G. A. H.Walker,; Bohlender, D. A.; Walker, A. R.; Irwin, A. W.; Yang, S. L. S.; Larson, A. "Gamma Cephei - Rotation or planetary companion?" Astrophysical Journal, Part 2 (1992), L396 (2): L91 – L94.
20. A. Wolszczan; Frail, D. A."A planetary system around the millisecond pulsar PSR1257+12". Nature (1992) 355: L145 – 147.
21. M. Michel. Didier, Q."A Jupiter-mass companion to a solar-type star". Nature (1995) 378: L355– 359.
22. Marcy et al. "A planet at 5 AU around 55 Cancri". Astrophysical Journal (2002) 581 (2), pg: 1375–1388.
23. Fisher and 21 co Author's. "Five planets orbiting 55 Cancri". Astrophysical journal (2008) 675, p 790.
24. J. N. Wilford, "New Planet Detected Around a Star 15 Light Years Away". The New York Times (1998).
25. B. Edgar, Watzke, M; Rasmussen, C. "Multiple planets discovered around Upsilon Andromedae". Extra-solar planets (1999) 415, 617, 303: 338 – 6747, 495 – 7463, 497 – 8611.
26. Charbonneau et al. "Detection of an Extra-solar Planet Atmosphere". Astrophysical Journal (2002) 568 (1): L377 – 384.
27. D.A. Fisher, Valenti. "Metallicity of stars with Extra-solar planets". ASP Conference series (2002) 259.
28. S. Sigurdsson, Richer, H.B., Hansen, B.M., Stairs I.H., and Thorsett, S.E., "A Young White Dwarf Companion to Pulsar B1620-26: Evidence for Early Planet Formation". Science (2003) 301 (5630): pp193-196.
29. Rivera et al. "A 7.5 Me Planet Orbiting the Nearby Star GJ 876". Astrophysical Journal (2005) 634 (1):L625 – 640.
30. Beaulieu et al. "Discovery of a cool planet of 5.5 Earth masses through gravitational microlensing". Nature (2006) 439 (7075): L437–440.
31. D. Fisher, and 11 co Author's. "Five planets and an independent confirmation of HD 196885Ab from lick observatory". Astrophysical journal (2009) 703(2), pp 1545-1556.
32. J. Schnider, "Interactive Extra-solar planets Encyclopedia", The Extra solar planets Encyclopedia version 2.02, (2009) Paris observatory.
33. J.C. Bond, Lauretta, D.s, "Beyond the iron peak: r-and s-process elemental abundances in stars with planets". Astrophysical journal (2008) 682. p 1234. Moultaka et al., PASP, (2004) 116, pp 693-698.