Investigation of the brightest stars in the Cyg OB2 association

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Abstract

We present the results of investigation of most luminous stars belonging to the Cyg OB2 association using quantitative analysis of high-resolution spectra. Physical parameters derived using CMFGEN and TLUSTY codes allow us to estimate the mass and age of these stars. Also we discuss long-term star formation history in Cyg OB2.

Introduction

Cygnus OB2 (Cyg OB2) stellar association, discovered by Munch and Morgan in 1953 year, now is the leader in number of massive star among Galactic OB-associations. The interest of researchers to individual stars and to the association as a whole is not fading. A lot of articles dedicated to the investigation of stellar population of Cyg OB2, estimation of interstellar extinction, history of star formations have already been published and continue to appear.

Observational Data

We used the spectral data obtained on the Russian 6-m telescope of *Special Astrophysical Observatory (SAO RAS)* with NES and SCORPIO spectrographs, Echelle spectra from 1.5-m *Russian-Turkish telescope (RTT150)*, long-slit spectra from the archives of 4.2-m *William Herschel Telescope (WHT)* obtained with the ISIS. Moreover, we used the spectra obtained by the *Hubble Space Telescope (HST)* with the STIS spectrograph to investigate the objects in the UV range.

Modeling the dwarfs

We used the TLUSTY code by Lanz & Hubeny (2003) to model the atmospheres of Cyg OB2 #6, #16 and #21 dwarfs. The results of this modeling are listed in Table 1 and are displayed in Figure 1.

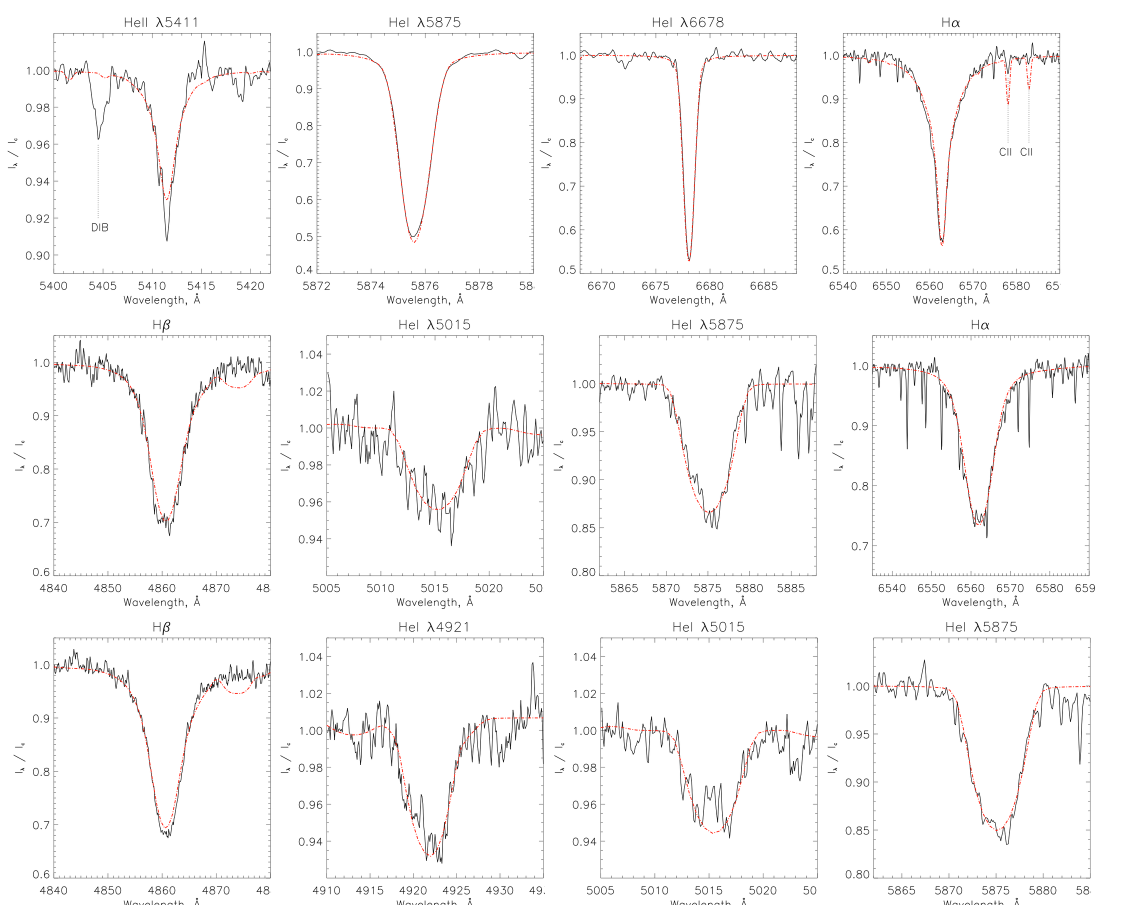

Figure 1: Comparison of the observed spectra (selected lines) with the best models. Top panel shows the spectrum of Cyg OB2 #21, middle – #6 and bottom – #16. The black line shows the observed profile, while the red line – the model.

Table 1: The resulted parameters and their standard deviations obtained for dwarf stars considered in this study

	Spec. class	T_{eff}, kK	log g	He/H	VsinI, km/s	V_{micr}, km/s	M_*, $M_\odot$	$\log(L_*/L_\odot)$	Age, Myr
6	O8 V	32.8	3.72	0.11	210	12	24 ± 5	5.1 ± 0.3	5.6 ± 1.3
16	O7.5 V	33.3	3.78	0.16	200	12	24 ± 5	5.1 ± 0.3	5.2 ± 1.4
21	B0 V	31.2	3.97	0.12	25	9	18 ± 2	4.7 ± 0.2	5.1 ± 1.6

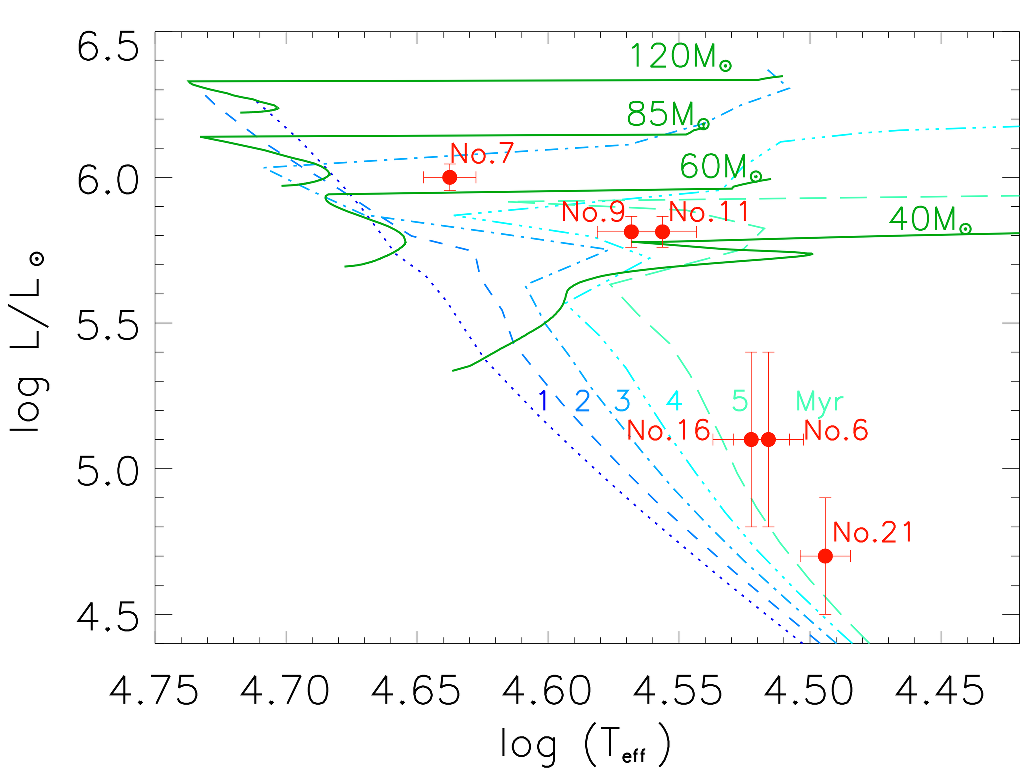

Figure 2: The determined positions of the stars in the Hertzsprung-Russell diagram. The evolution tracks and the stellar isochrones are taken from the Geneva library.

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Results of Ofc stars modeling

In 2010, Walborn et al. (2010) proposed to introduce new subclass Ofc to denote O-stars with comparable intensity of C III λλ4647, 4650, 4652 and N III λλ4634, 4640, 4642 lines. This phenomenon is often observed at spectral type O5 at all luminosity classes, but preferentially in some associations or clusters and not the others (Walborn et al., 2010). As of now, eighteen Galactic O-stars are classified as Ofc. Four of them are in Cyg OB2.

We modeled the spectra of #9 (O4.5 Ifc) and #11 (O5.5 Ifc) using the CMFGEN atmospheric modeling code (Hillier & Miller, 1998). Table 2 lists the parameters of the constructed models, calculated abundances of the basic elements are given in Table 3.

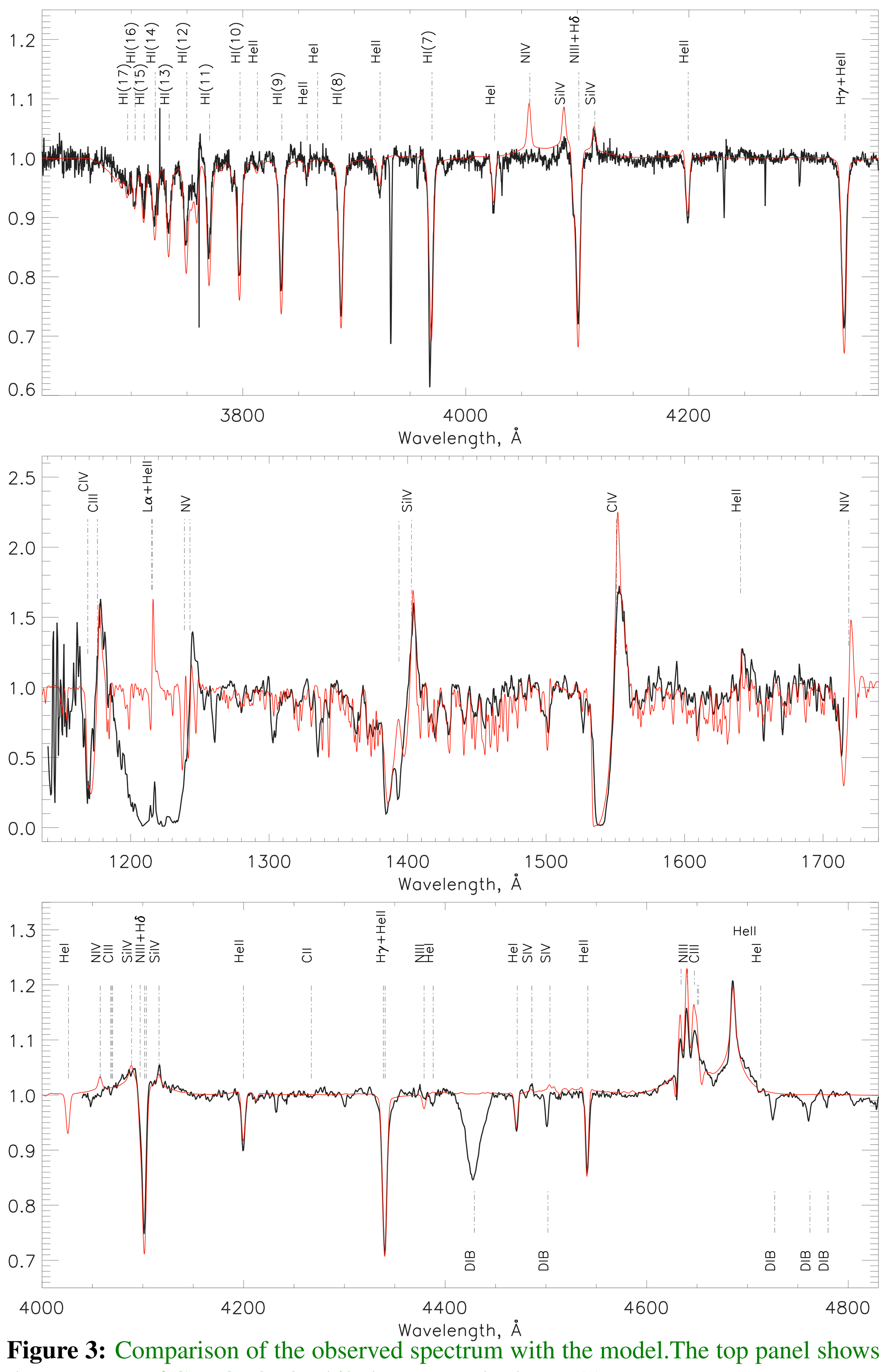

Figure 3: Comparison of the observed spectrum with the model.The top panel shows the spectrum of Cyg OB2 #9 while lower panels show #11.

Table 2: Atmospheric parameters of Cyg OB2 #9 and Cyg OB2 #11 .

	T_*, kK	R_*, $R_\odot$	T_{eff}, kK	$R_{2/3}$, $R_\odot$	L_*, $10^5 L_\odot$	$\dot{M}_{uncl}$, 10^{-6} $M_\odot yr^{-1}$	$\dot{M}_{cl}$, 10^{-6} $M_\odot yr^{-1}$	f_∞	V_∞, km s^{-1}	β
#9	37	20	36	21	6.5	3.9	1.1	0.08	1500	1.3
#11	35	22	34.4	22.7	6.5	6	1.7	0.08	2200	1.3

We found that in the atmospheres of the studied Ofc stars $He/H \approx 0.1$. It means that helium abundance within error limits is equal to initial helium abundance in the environment, that He/H did not change during the lifetimes of Cyg OB2 #9 and #11. In Cyg OB2 #11 nitrogen abundance is lower than the one for other "normal" O stars, while the carbon abundance is solar. In Cyg OB2 #9 the fraction of N is higher than in #9 and the fraction of C is lower. Cyg OB2 #9 is closer to "normal" O stars than #11. Probably, there is no mixing in atmospheres of Ofc stars that transports the products of CNO cycle from the core towards the stellar surface.

Table 3: The abundances of chemical elements.

Element	Cyg OB2 #9	Cyg OB2 #11	Sun
H	12	12	12
He	10.7 ± 0.15	10.85 ± 0.15	10.93 ± 0.01
C	8.08 ± 0.05	8.5 ± 0.09	8.39 ± 0.05
N	8.37 ± 0.03	8.28 ± 0.03	7.78 ± 0.06
O	8.18 ± 0.07	8.17 ± 0.07	8.66 ± 0.05
Fe	7.04 ± 0.09	7.14 ± 0.09	7.45 ± 0.05
Si	7.6 ± 0.07	7.81 ± 0.07	7.51 ± 0.04
S	6.54 ± 0.06	6.54 ± 0.06	7.14 ± 0.05

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History of star formation in Cyg OB2

Age of the association strongly depends on model of stellar evolution used to estimate it. Figure 4 shows the H-R diagram constructed by Comerón & Pasquali (2012) and two kind of isochrones. As we can see from the Figure 4, number of young objects in the association decreases when the new isochrones with rotation are used. The association became older by about 2 Myr. This result is just an illustration of how the measured quantity (in our case, the age of the star) may change when method of measurements changes.

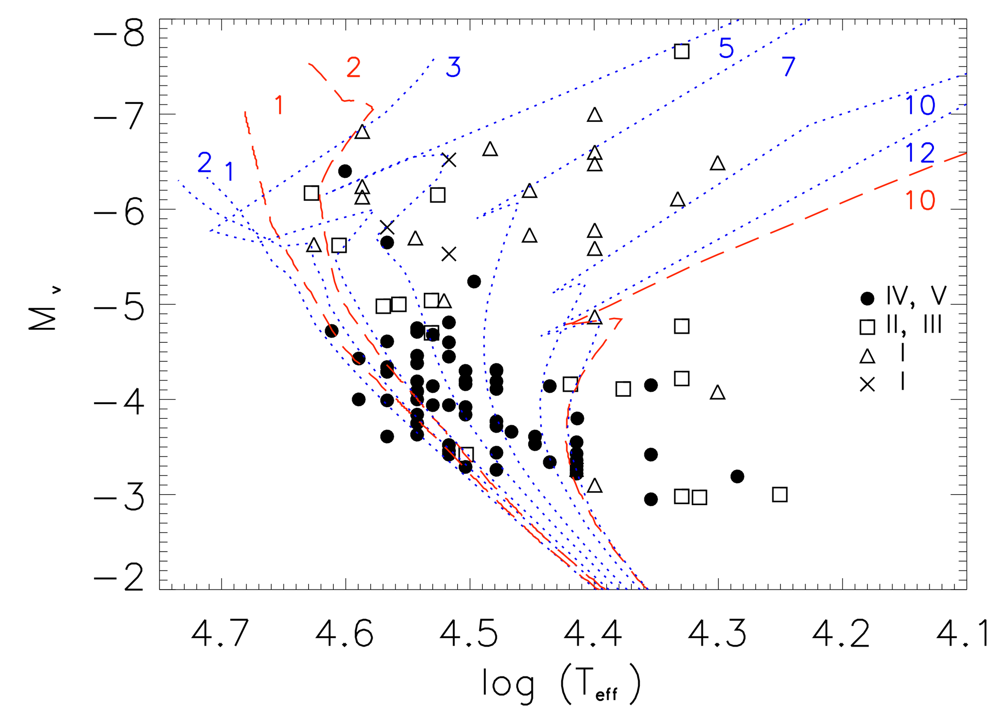

Figure 4: The H-R diagram for Cyg OB2 are created by Comerón & Pasquali (2012). Blue dotted lines are Geneva' isochrones (Ekström et al., 2012), while dashed red lines are isochrones from Lejeune & Schaerer (2001)

More interesting is to see how stars with different ages are located in space. We combined the data about stars (T_{eff} and M_V) published by Comerón & Pasquali (2012) with data from Kiminki et al. (2007). Using the H-R diagram and Geneva isochrones we determined the ages of 203 stars. Figures 5, 6 show spatial distribution of the stars up to B=16 mag with different ages. Stars older than 12 Myr are distributed quite uniformly in space. Number of stars with age 6-12 Myr is less than one of older stars, and they are mainly located in the eastern (or central) part of the association. Young stars stretched a narrow strip along the circle centered approximately on star #5. A void with coordinates α=308.18, δ=41.3 may be clearly seen. According to the Figures we can suggest that about 6 million years ago there was some event, which started new wave of star formation. Over the last 4 Myr more young stars formed in the eastern part than in the north-west one. Apparently it is related to larger amount of interstellar gas in this part of the association.

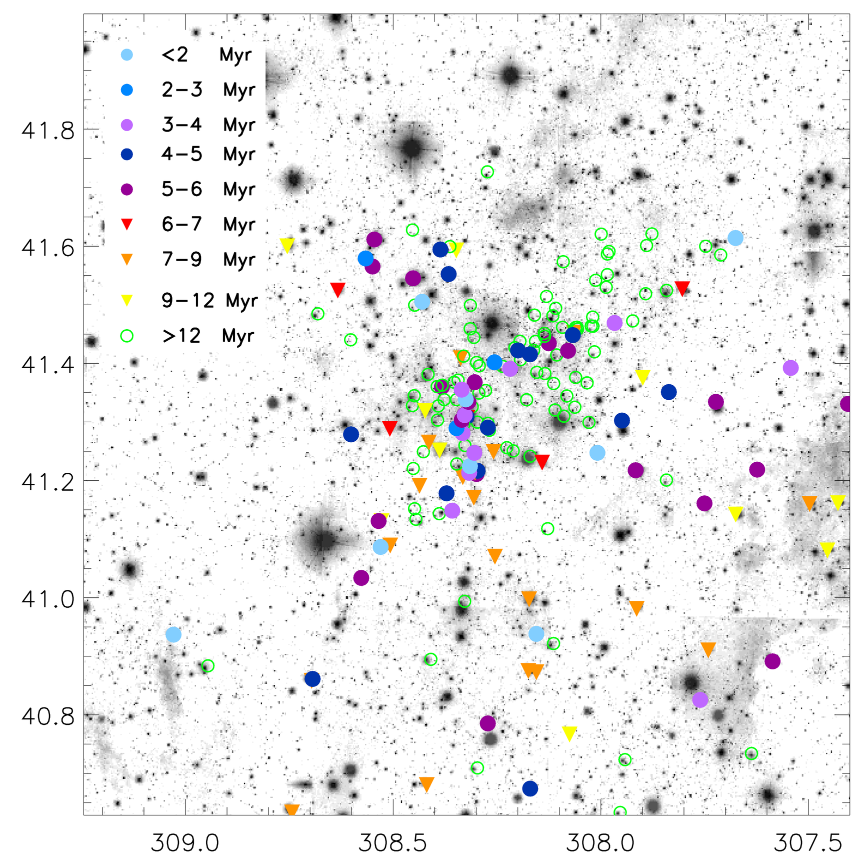

Figure 5: SDSS image of Cyg OB2.

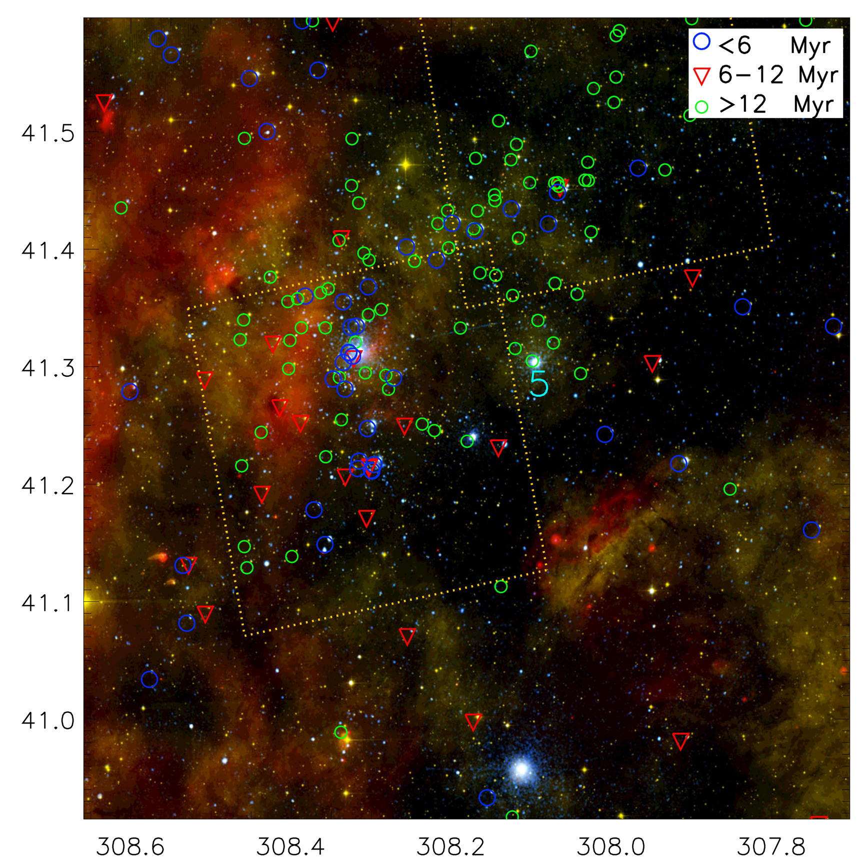

Figure 6: In this image, X-rays from Chandra (blue) have been combined with infrared data from NASAs Spitzer Space Telescope (red) and optical data from the Isaac Newton Telescope (orange). The 17′× 17′ fields of Chandra stydied by Wright et al. (2009) are shown as yellow squares.

Results are published in:
Maryeva, Zhuchkov & Malogolovets 2014, PASA, 31, 20
Maryeva, O. V. & Zhuchkov, R. Y. 2012, Astrophysics, 55, 371
Maryeva, Klochkova & Chentsov 2013, Astrophys. Bul., 68, 87
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