What triggered the early planet formation processes in HL Tau?

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abstract

T Tauri stars are surrounded by a circumstellar disk, hot plasma and dust. Their hot plasma emits x-ray. Some T Tauri stars host protoplanetary objects in their circumstellar disk, such as HL Tau. In this case, HL Tau system is a good example for stellar evolution and planet formation. With this purpose, this study discussed the question "What triggered the early planet formation processes in HL Tau system?".

1 Introduction

T Tauri stars are in the pre-main sequence phase of stellar evolution. These stars convert their own gravitational potential energy to light, but their cores do not have enough temperature for nuclear reactions like a main sequence star. T Tauri stars are surrounded by a circumstellar disk, hot plasma and dust. Some T Tauri stars host protoplanetary objects in their circumstellar disk, such as HL Tau (ALMA Partnership et al., 2015). HL Tau has protoplanetary objects, but its estimated age is less than 1 Myr. In this case, HL Tau system is a good example for stellar evolution and planet formation studies.

HL Tau is K5 star (White & Hillenbrand, 2004) and lies 140 pc away from the Sun (Kenyon et al., 1994; Rebull et al., 2004; Torres et al., 2009). HL Tau has a high extinction value in optic bands A_v=7^m.43 (White & Hillenbrand, 2004), because starlight scattered from its high density protoplanetary disk renders HL Tau nearly invisible in visual wavelengths. Therefore, HL Tau was observed in multiple wavelengths, especially in radio and NIR (near-infrared). NIR observations show that HL Tau is emitting bipolar jet outflows orthogonal to the disk plane (Wilner et al., 1996; Rodmann et al., 2006; Movsessian et al., 2007; Greaves et al., 2008).

In this study, protoplanetary disk properties of HL Tau via XMM-Newton and Chandra X-Ray observations are investigated, and formation of protoplanets in HL Tau's disk with the help of multi-wavelength observations are discussed.

2 Data Analysis

2.1 XMM-Newton Observations and Data Analysis

The *XMM-Newton* observation data of HL Tau was obtained from the public data archive. Obtained observations' obsIDs are: 0201,0501,0601,0801,0901,1101. In these observations their EPIC cameras were open in full-frame mode with the medium filters. Data have been processed with the standard SAS V14.0.0 pipeline system.

2.2 Chandra Observations and Data Analysis

The *Chandra ACIS* observation data of HL Tau was obtained from the public data archive of *Chandra*. The data were all reprocessed using the *chandra-repro* script in CIAO 4.8.2 and CALDB 4.7.1. Backgrounds were selected from the CCD with HL Tau in its frame for all *Chandra ACIS* observations. Obtained observations' obsIDs are: 1866, 5381, 11016.

3 Results

XMM-Newton data were not a good fit with phabs*apec model. This results may originate from angular resolution difference between two x-ray telescopes. *XMM-Newton* observations couldn't separate HL Tau from XZ Tau. Therefore, *XMM-Newton* spectrum of HL Tau was effected by XZ Tau and phabs*apec model didn't fit to the spectrum. We decided to use *Chandra* observations for study and analysis. The results are given in Table 1 and the best fitted spectrum is shown in Figure 1.

HL Tau is a T Tauri star inside its own dusty cloud. This cloud is formed of dust, grain, protoplanets, diffuse gas and hot plasma. Therefore, we used *phabs*apec* model for spectral analysis of both XMM-Newton and Chandra data. The Phabs model is for dust and grain in the cloud, and interstellar medium between HL Tau and the Sun, whereas the apec model is for diffuse gas and hot plasma emission. We analysed the spectrum with *Sherpa* and use *Xspec* models (*xsphabs*xsapec*).

Table 1: *Chandra ACIS* x-ray spectrum fitting results.

ObsID	nH_{in}	nH_{out}	T_{Plasma}	T_{err}	Z	Z_{err}	χ^2	ν	χ^2/ν
	$10^{22}cm^{-2}$	$10^{22}cm^{-2}$	keV	keV	$Z_\odot$	$Z_\odot$			
1866	0.156	3.72	2.90	-0.23	0.60	-0.18	86.24	85	1.01
5381	0.156	3.83	2.84	-0.19	0.75	-0.17	117.42	105	1.12
11016	0.156	3.17	3.20	-0.24	0.73	-0.19	89.63	93	0.96

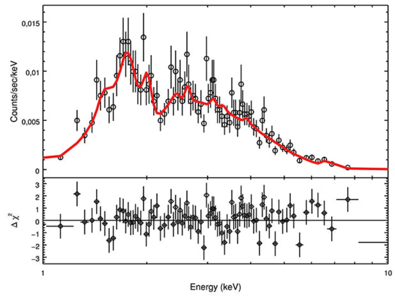

Figure 1: This graphic belong to ObsID 1866 observation spectrum. This spectrum fitted using phabs*apec model with *Sherpa*.

4 Discussion

Possibility of planet formation in HL Tau first teorical prediction leaded by Lin & Papaloizou (1986) as an explanation of axisymmetric rings. Gaps in the disk permited to estimate proplanet mass and recent simulation suggest mass of protoplanets sub-Jovian class (M_J) (Dipierro et al., 2015; Kanagawa et al., 2015; Tamayo et al., 2015; Jin et al., 2016). This simulations estimate planet formation with disk accretion models but HL Tau is younger than accretion process. Thus, planet accretion must be accrued with some other processes. In this section, we discuss every possible effects to planet formation process in HL Tau via results of our x-ray spectral analysis and multi-wavelengt results in literature.

4.1 Elemental Abundance Effect on Planet Formation

The first theoretical prediction of a possibility of planet formation in HL Tau was studied by Lin & Papaloizou (1986) as an explanation of axisymmetric rings. Gaps in the disk permitted to estimate protoplanets' mass and recent simulations suggest that the mass of protoplanets belong to the sub-Jovian class (M_J) (Dipierro et al., 2015; Kanagawa et al., 2015; Tamayo et al., 2015; Jin et al., 2016). These simulations estimate planet formation with disk accretion models, but HL Tau is younger than the suggested duration of the accretion process. Thus, planet accretion must be explained with some other processes. In this section, we discuss every possible effect to planet formation process in HL Tau taking our x-ray spectral analysis results and multi-wavelength observation results in literature into account.

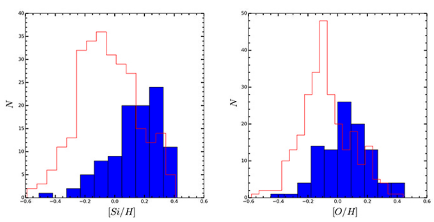

Figure 2: Blue histograms show the systems with planets, whereas red histograms show the systems without planets (Durmuş & Plevne, 2015).

4.2 Bipolar Jets

HL Tau and XZ Tau are also known as Herbig-Haro object. Mundt & Fried (1983) observed the first optical flows in HL Tau region. Mundt et al. (1989; 1990) studied these optic flows via imaging and spectroscopic observations and found bipolar jet emissions from both HL Tau and XZ Tau. Movsessian et al. (2007) estimated proper motion speed of jets of both HL Tau and XZ Tau using Fabry-Perót interferometry in Hα and [SII] 6716Å . Proper motions range from 200-220 km s^{-1} in HL Tau, and 125-146 km s^{-1} in XZ Tau. Moreover, Movsessian et al. (2007)'s study showed interactions of jets with each other and bow shocks in HL Tau.

5 Conclusion

This study aims to discuss possible answers of the question "What triggered the early planet formation processes in HL Tau?". We estimated the metallicity of HL Tau cloud in solar units 0.6$Z_\odot$. Planet formation processes progress easier in high metallicity media like HL Tau as Durmuş & Plevne (2015) suggested. Another trigger might be that high speed jets may create shockwaves from inside to outside in protoplanetary disks and these shockwaves may have triggered early planet formation in HL Tau. Or interaction jets between HL Tau and XZ Tau could create shockwaves from outside to inside in HL Tau's protoplanetary disk and these shockwaves might trigger planet formation. All of these scenarios might work in HL Tau and together they may have triggered the planet formation.

The future works will show more details and provide a lot of possible answers.

References

ALMA Partnership, Brogan, C. L., Pérez, L. M., et al., 2015, The 2014 ALMA Long Baseline Campaign: First Results from High Angular Resolution Observations toward the HL Tau Region, *Apjl*, 808, L3.

Dipierro, G., Price, D., Laibe, G., Hirsh, K., Cerioli, A., Lodato, G., 2015, On planet formation in HL Tau, *MNRAS*, 453, L73–L77.

Durmuş, D., Plevne, O., The effect of si and o element abundances on planetary formation, AbsiCon 2015, Chicago, 2015.

Greaves, J. S., Richards, A. M. S., Rice, W. K. M., Muxlow, T. W. B., 2008, Enhanced dust emission in the HL Tau disc: a low-mass companion in formation?, *MNRAS*, 391, L74–L78.

Jin, S., Li, S., Isella, A., Li, H., Ji, J., 2016, Modeling Dust Emission of HL Tau Disk Based on Planet-Disk Interactions, *Apj*, 818, 76.

Kanagawa, K. D., Muto, T., Tanaka, H., Tanigawa, T., Takeuchi, T., Tsukagoshi, T., Momose, M., 2015, Mass Estimates of a Giant Planet in a Protoplanetary Disk from the Gap Structures, *Apjl*, 806, L15.

Kenyon, S. J., Gomez, M., Marzke, R. O., Hartmann, L., 1994, New pre-main-sequence stars in the Taurus-Auriga molecular cloud, *AJ*, 108, 251–261.

Movsessian, T. A., Magakian, T. Y., Bally, J., Smith, M. D., Moiseev, A. V., Dodonov, S. N., 2007, Herbig-Haro jets in 3D: the HL/XZ Tauri region, *AAP*, 470, 605–614.

Mundt, R., Fried, J. W., 1983, Jets from young stars, *ApJl*, 274, L83–L86.

Rebull, L. M., Wolff, S. C., Strom, S. E., 2004, Stellar Rotation in Young Clusters: The First 4 Million Years, *AJ*, 127, 1029–1051.

Rodmann, J., Henning, T., Chandler, C. J., Mundy, L. G., Wilner, D. J., 2006, Large dust particles in disks around T Tauri stars, *AAP*, 446, 211–221.

Tamayo, D., Triaud, A. H. M. J., Menou, K., Rein, H., 2015, Dynamical Stability of Imaged Planetary Systems in Formation: Application to HL Tau, *Apj*, 805, 100.

Torres, R. M., Loinard, L., Mioduszewski, A. J., Rodríguez, L. F., 2009, VLBA Determination of the Distance to Nearby Star-Forming Regions. III. HP TAU/G2 and the Three-Dimensional Structure of Taurus, *Apj*, 698, 242–249.

White, R. J., Hillenbrand, L. A., 2004, On the Evolutionary Status of Class I Stars and Herbig-Haro Energy Sources in Taurus-Auriga, *Apj*, 616, 998–1032.

Wilner, D. J., Ho, P. T. P., Rodriguez, L. F., 1996, Subarcsecond VLA Observations of HL Tauri: Imaging the Circumstellar Disk, *Apjl*, 470, L117.

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