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論文目次

論 文 内 容 要 旨

INTRODUCTION

Recent observational studies have revealed the ubiquity and critical role of dust in the circumstellar medium (CSM). For example, a significant amount of dust has been detected in the flow of stellar winds from highly luminous stars. The circumstellar region is found to be the main site for producing dust grains into the interstellar space. Our knowledge on dust formation process is, however, much fragmentary and limited at all and the improvement of dust formation theory is required. The variation of dust radius a is one of the key parameters which characterize the dust formation processes. Observational monitoring of a as a function of the time and location associated with the activity or dynamics of the central star system contributes to a quantitative understanding of the grain formation process.

We can use various probes in observational researches of CSM. Among those, the linear polarimetry often demonstrates its unique ability in certain fields of research, since the polarization is a vectorial quantity and is not dependent so much on the number density of the contributed particles when the scattering process is concerned to the polarization.

From the linear polarimetry, we can obtain information on both the characteristic distribution of CSM and the physical properties of the scattering particles including their 'size', simultaneously. It is valuable that the polarization brings such information of an object which is too far from us to be spatially resolved.

Generally speaking, the physical situation of CSM around a mass-losing star (evolved stars, cataclysmic variables, etc.) is subject to influences from the activity of the central star, and shows rapid variabilities. The ejected matter evolves rapidly due to the strong radiation. Therefore, frequent observation is necessary to trace the physical process properly.

In this thesis, we have selected three typical objects from a population of dust forming regions with taking into account the radiation field and time-scale of dust condensation process estimated for each sample, and made spectro- (and/or photo-) polarimetry in order to know about the distribution of CSM and to obtain evidence on the presence of dust grains and the size, if exist. Enough observations have successfully made at the Dodaira Observatory of National Astronomical Observatory of Japan (NAOJ) with either MCP (Multi-Channel Polarimeter) or HBS (an abbreviation of spectro-photo-polarimeter in Japanese). A part of the observations were carried out at the Okayama Astrophysical Observatory of NAOJ. The spectro-photo-polarimeter(HBS) developed by us has a polarimetric accuracy of $\Delta P \leq \sqrt{(P/50)^2 + (0.05)^2)}$ % and a spectral resolution of R=40-200 in the wavelength region of 4000-9000 Å. Isolation of each spectral feature (emission or absorption, line or band) from the continuum gives us direct information on the light source, intervening medium, and scattering matter itself. It enables us to research the physical properties and the distribution of CSM more precisely.

OBSERVATIONS

Our objects are (1) novae, (2) late-type WC stars, and (3) M-type giants. We have used MCP for the observation of (1) and HBS for others.

For a case study of (1), we use our extensive and high quality data from optical linear polarimetry and photometry of Nova Cassiopeiae 1993 (= V705 Cas). The light curve of V705 Cas is very similar to that of DQ Her, which is a typical dust forming nova. We have estimated and subtracted the interstellar polarization toward the nova, and derived the intrinsic component of polarization of the nova. The most dominant mechanism for the intrinsic polarization is considered to be the scattering by dust grains in the asymmetric nova ejecta. This suggests that these dust grains have been formed within several days from the outburst. We constructed a scattering cloud model and tried to explain the observed intrinsic polarization. We found the maximum grain size being almost constant and 0.10-0.15 μ m, and being almost model-independent. This tendency continued for about two months until the 'deep minimum' which is believed to be due to large-scale and rapid formation of optically thick cloud containing much larger (0.2-0.5 μ m) grains. The grains located nearby the star suffer the strong radiation from the hot central source (7000-30000K). Such grains do not seem to grow smoothly because of frequent sublimation.

As for the dust formation in the hostile environments, late-type WC Wolf-Rayet stars (WCLs) have been studied in recent years. WR stars are hot and luminous stars distinguished by their fast (1000-3000km s^{-1}) winds and lose their mass at a rate in excess of 10^{-4} - 10^{-5} M(Sun)/year. We observed five WCLs with HBS. The main aims are to find (a) evidence for any dense cloud near the photosphere and (b) the 'line effect' which directly indicates an asymmetric structure in the wind. The former is suggested by modeling the observed eclipsing-like variation in brightness, although the hot radiation may prevent condensation of nuclei in the region close to the photosphere (d ~ 0.4-4 AU). The latter is proposed in the grain formation theory as a necessary condition for the grain condensation. We have not found any positive result for (a) so far. On (b), our observation reveals that one of two

WC9s and one of two WC7s show line effects.

To examine the grain formation environments in late-type giants, we made spectro-photo-polarimetric study on a bright symbiotic star CH *Cyg* during the optical outburst in 1998. The observation was mainly carried out from 1997 December through 1998 August. This star is believed to be a multiple system which consists of at least two stars eclipsing each other: M6-7 giant and hot component (white dwarf or hot subdwarf). Polarization variation across Balmer emission lines and across TiO absorption bands were observed. We found that the incremental component of the flux due to the 1998 outburst was almost unpolarized as well as the Balmer emission lines, i.e., the polarized flux brings us the information on CSM around M giant, selectively. The material responsible for polarization contains two components: small (typically $< \lambda/10$) dust or molecules, and normal dust with a size up to $\sim 0.2\,\mu$m. It is suggested that a new cloud containing the former component was gradually formed preferentially along a direction with PA=50° which is almost orthogonal to the 1984 radio jet. If the direction of the jet coincides with the polar direction of the orbital plane, we may have observed the mass flow around the orbital plane.

DISCUSSION & CONCLUSION

We have derived typical radii of the grains formed around Nova V705 Cas and the M-type giant of CH *Cyg* system on the basis of our polarimetric data. We have also discussed some properties observed for late-type WC stars. Using the classical grain nucleation theory, we try to examine whether we have seen actual scene of the grain formation. Our strategy is as follows. The critical grain radius which maximize the Gibbs free energy of the spherical particle is found to be $0.00057\,\mu$m and $0.00137\,\mu$m for graphite and silicate, respectively. To form such nuclei around a star, the temperature at radiative equilibrium (between the energy of absorbed light and that of emitted radiation) must be below the condensation temperature (2000K for carbon dust and 1400K for silicate). This limits the minimum distance for the condensation site of nuclei from the central star, from which we can derive the density of the ambient gas if we know both the mass loss rate and the wind velocity in advance. Given the number density of the considered element, the grain formation rate can be calculated using the grain formation theory. We compare the grain growth rate (da/dt) derived from our polarimetry with that calculated above, and find that the former can be well explained. We conclude that we have really observed grain formation processes occurring in the CSM. It is also found that the rapid growth of grains ($\sim 0.1\,\mu$m in several days) around late-type WC stars seems possible provided that it occurs a compression of the wind density by ≥ 100 times compared with that for an isotropic one at the distance defined in the radiative equilibrium.

論文審査の結果の要旨

天文衛星からの赤外線観測など近年の観測的研究の進展により，星周媒質中には塵粒子が遍く存在して銀河物質の循環と進化に大きな役割を果たしていることが認識されるようになった。しかし，例えば強い輻射環境下にある恒星風中での塵粒子存在が観測的に示唆されているものの，それを説明できる理論はない。このように塵粒子形成に関する研究は理論的にも観測的にもまだ不十分な状況にある。

川端弘治は，星周物質の空間分布と塵粒子特性の研究に偏光観測がきわめて有効であることに着目し，自らが開発した偏光分光測光装置を用いて特徴的な星周環境を保持する天体の高精度観測を長期にわたって実施し，豊富な資料を得た。本論文はその成果をまとめ，星周塵粒子の形成史と空間分布を恒星活動と関連させて考察したものである。

本研究では，まず400-900nmの波長域を10nmの波長分解能と0.10-0.15%の測定精度で偏光分光する装置を開発した。ついで，粒子成長の時間尺度が異なる３種類の天体を選び，それらについて系統的な偏光分光測光観測を行った。著者はその結果に基づき，数時間から数日の時間尺度で数ヶ月以上にわたって光度変化を示す新星においては，恒星からの放出プラズマ内で塵粒子形成が新星爆発から１週間後には始まり，その後，塵粒子の成長が不安定となる段階を経て本格的な塵粒子形成に至るとの説を提唱した。観測される偏光測光量の時間変動はこの説により合理的に説明出来るものである。又，いくつかの晩期型ＷＲ星で非等方恒星風の存在を確認した。これは，極めて強い輻射環境下にある星周媒質中にも塵粒子形成を可能にする濃密な領域が存在することを示唆する。一方，連星をなすM型巨星においては，恒星活動に伴う塵粒子形成と星周物質の分布の時間変動を観測的に把握した。著者は，気相から固相への相変化の一次理論を自らの観測結果に適用し，形成期にある星周塵粒子の特性と進化および分布の特徴について，恒星活動・恒星系力学と関連づけて考察して，合理的な知見と今後の課題を明らかにした。

以上のように，本論文は，星周塵粒子の形成に関して貴重な観測事実を提供するとともに，凝結核形成理論の発展につながる手がかりを与えるものであり，著者が自立して研究活動を行うのに必要な高度の研究能力と学識を有することを示している。

よって，川端弘治提出の論文は，博士（理学）の学位論文として合格と認める。