PROBLEMS OF STAR FORMATION THEORY AND PROSPECTS OF SUBMILLIMETER OBSERVATIONS

D. Z. Wiebe, M. S. Kirsanova, B. M. Shustov, Ya. N. Pavlyuchenkov
Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia

Astronomy Reports, in press

Abstract

We consider current state of star formation theory and requirements to observations in millimeter and submillimeter ranges which are necessary for resolution of the most actual problems of the physics of star formation. Two key features of star-forming regions which define observational requirements to their studies, are relatively low energy of processes that take place there and smallness of corresponding spatial scales. This is especially true for the objects in the latest stages of “pre-stellar” evolution, that is, hot cores, hyper- and ultracompact HII regions, and protoplanetary disks. Angular resolution, sensitivity, and spectral coverage in existing projects of ground-based and space telescopes of submillimeter and millimeter range are not completely adequate to necessary requirements. To obtain detailed information on star-forming regions as well as on individual protostars it is necessary to employ a space-based interferometer.

1 INTRODUCTION

By the end of twentieth century the overall picture of star formation process in dense interstellar clouds became fully formed. Contraction (collapse) of protostellar clumps is initiated by gravitation and external pressure; thermal pressure, rotation of the clumps and magnetic field counteract contraction. Thus, general scenario of star formation is defined by a complex interaction of these factors. However, many fundamental problems of star formation remain unsolved. For instance, the mechanisms that stimulate the collapse of low-mass prestellar cores remain unclear. Even more enigmatic is formation of massive stars. Apparently, more complex processes, like competitive accretion and merger of protostellar fragments are involved in the latter process in addition to spherical and disc accretion.

For the later evolutionary stages, when the planetary systems form, the number of unsolved problems is none the less. There are still no unique solutions for the problems of the nature of angular momentum transfer in the protoplanetary discs, their physical and chemical structure, the role of mixing in the formation of chemical and mineralogical composition of protoplanetary matter (including protosolar nebula).
Table 1: Atomic and molecular lines in the 10 mkm to 2 cm range which are used for the study of star formation regions.

| Molecule | Lines       | Radiation mechanism & Specific problem                                                                                                                                 |
|----------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| H$_2$O   | 22 GHz      | Maser emission, Studies of protostellar discs, astrometry                                                                                                                |
| CH$_3$OH | 25 GHz      | Maser and thermal emission, Astrometry, determination of physical conditions in protoplanetary discs and regions of massive star formation                                  |
| NH$_3$   | 24 GHz      | Thermal emission, Tracer of physical conditions in the dense gas, especially in the late stages of the evolution of prestellar cores                                      |
| CS       | 49 GHz      | A tracer of physical conditions in the dense gas                                                                                                                     |
|          | 98 GHz      |                                                                                                                                                                     |
|          | 147 GHz     |                                                                                                                                                                     |
|          | 244 GHz     |                                                                                                                                                                     |
| HCN      | 89 GHz      | A tracer of physical conditions in the dense gas                                                                                                                     |
|          | 266 GHz     |                                                                                                                                                                     |
| HCO$^+$  | 89 GHz      | Tracer of physical conditions in the dense gas, including ionization degree                                                                                           |
|          | 268 GHz     |                                                                                                                                                                     |
| HNC      | 91 GHz      | A tracer of physical conditions in the dense gas                                                                                                                     |
|          | 272 GHz     |                                                                                                                                                                     |
| N$_2$H$^+$| 93 GHz      | Tracer of physical conditions in the dense gas, especially in the late stages of the evolution of prestellar cores and the regions of massive star formation                |
| CO       | 115 GHz     | The main tracer of the presence of diffuse molecular gas                                                                                                               |
|          | 230 GHz     |                                                                                                                                                                     |
| H$_2$CO  | 140 GHz     | Tracer of physical conditions in the dense gas                                                                                                                     |
| NO       | 150 GHz     | Tracer of physical conditions in the dense gas                                                                                                                     |
|          | 250 GHz     |                                                                                                                                                                     |
| H$_2$D$^+$| 372 GHz     | Tracer of physical conditions in the dense gas, especially, of the kinematics of the central regions of prestellar cores                                             |
| C        | 492 GHz     | Tracer of physical conditions in diffuse gas, PDR-regions, ultracompact HII regions                                                                                 |
|          | 809 GHz     |                                                                                                                                                                     |
| C$^+$    | 1.9 THz     | A tracer of physical conditions in diffuse gas, PDR-regions, ultracompact HII regions                                                                               |
| Si$^+$   | 8.6 THz     | A tracer of physical conditions in the protoplanetary discs                                                                                                           |
| H$_2$    | 10.7 THz    | A tracer of physical conditions in the protoplanetary discs                                                                                                           |
| Fe$^+$   | 11.5 THz    | A tracer of physical conditions in the protoplanetary discs                                                                                                           |
| S        | 12.0 THz    | A tracer of physical conditions in the protoplanetary discs                                                                                                           |
| Fe$^+$   | 12.5 THz    | A tracer of physical conditions in the protoplanetary discs                                                                                                           |
Table 2: Requirements to the angular resolution in observations of different stages of star formation

| Stage                           | Typical distance | Typical scale | Angular resolution (10 diagrams per object) |
|--------------------------------|------------------|---------------|--------------------------------------------|
| Prestellar cores               | 140 pc           | 0.1 pc        | 15″                                        |
| Hot cores, UCHII*              | 2–4 kpc and more | 0.1 pc        | <1″                                        |
| protostellar objects           | 400 pc           | 0.01 pc       | 0.5″                                       |
| Outer regions of the discs     | 100 pc           | 1000 a.u.     | 1″                                         |
| Inner regions of the discs,    | 100 pc           | 100 a.u.      | 0.1″                                       |
| brown dwarfs discs             |                  |               |                                            |

These uncertainties are related, first, to the low energetics of the transformation of gas into stars, especially in its initial stages, which makes impossible studies of this process in the visual wave range. For instance, in the prestellar cores the temperature does not exceed 10 K and it is only slightly higher at the periphery of protostellar objects, protoplanetary and more evolved debris discs. Therefore, a significant fraction of their radiation is emitted in submillimeter and millimeter wave ranges. However, these wave ranges are very informative — the spectral range from 100 mkm to 20 mm contains thousands of lines of many dozens of interstellar molecules (table 1) which, in the absence of observed emission of molecular hydrogen, are the only source of information on composition, temperature, and kinematics of molecular clouds and star formation regions. Second, prestellar and, especially, protostellar objects are rather compact, but at the same time their structure is complex and its study demands high angular resolution (table 2). Just for this reason there is world-wide growing interest to construction of sensitive detectors for millimeter and submillimeter wavebands, including interferometers.

Of course, the main expectations are related to the submillimeter interferometric system ALMA (located in the Atacama desert in Chile) which will consist of several tens of 12-m antennas with the maximum distance between them of 12 km [1]. A somewhat lower scale project works successfully already. It is submillimeter interferometer SMA [2] in Hawaii (USA) which consists of eight 6-m antennas. However, capabilities of the best of existing and planned ground-based instruments for the studies in millimeter and submillimeter ranges are limited by disturbances created by the Earth atmosphere. In the submillimeter range there are only several transparent windows in the Earth atmosphere, with transmittance factor that does not exceed 60% even in the Earth regions with the best astroclimate [3]. To some extent this problem will be solved with the launch of the space-born infrared telescope “Herschel”, but its spatial resolution will be limited by its relatively small 3.5-m dish. More, in the long wavelength band “Herschel” will be sensitive up to 670 mkm only (ALMA will be sensitive up to 1 cm). Therefore, this telescope Will be unable to observe both the coldest clouds and many astrophysically interesting molecular lines, including, for instance, the lines associated with low-level rotational

---

1 http://www.eso.org/projects/alma/specifications/ FreqBands.html.
transition of the CO molecule.

A prerequisite to substantial increase in our knowledge of star formation would be construction of an extra-atmospheric submillimeter telescope which would conjoin sensitivity and spectral resolution with high angular resolution (which would mean possibility of its usage in the regime of an interferometer). It is by no means unimportant that location of the telescope in the space would allow homogeneous observations both in northern and southern celestial hemispheres. Space telescope “Millimetron” which is a part of the Russian Federal Space Programme may become such an instrument. In Russia, problems of star formation are studied in most of astronomical research centers (see, for instance, the collection of works edited by Wiebe and Kirsanova [3]). For this reason, high demand for observations by submillimeter telescope is expected from Russian scientists working in this field of astrophysics. In the present paper we describe some of the problems for which space-born submillimeter observatory will give crucially important results and justify some of requirements to its parameters.

2 THE STRUCTURE OF MOLECULAR CLOUDS, INITIAL CONDITIONS FOR STAR FORMATION

Molecular clouds have complex structure which is associated with chaotic motions in them. Most of modern researchers think that the structure and evolution of molecular clouds, in particular, parameters of star formation in them (efficiency, mass function, kinematics of their cores) are defined by turbulence [4]. Apart of structural features, important role of turbulence is indicated by different scale relations in the observed parameters of molecular clouds (“velocity dispersion–size”, “density–size”). However, parameters of turbulence — its outer scale and dissipation scale and sources of excitation — are still unclear. For the studies of molecular gas in our and other galaxies the CO(1–0) lines are used traditionally, applying so called X-factor, which is the ratio of column density H$_2$ and integral intensity of the CO(1–0) line. However, CO(1–0) line is not always suitable for solution of this problem. In some regions its emission is optically thick and, with increase of number density of molecular hydrogen, X-factor loses its informativity. In other cases, relative abundance of CO molecules along the line of sight is varied. As a result, an uncertainty in the determination of the abundance of H$_2$ -molecules that exceeds and order of magnitude appears [5, 6].

Submillimeter range space interferometer with a wide bandwidth will allow to solve this problem. For the studies of the structure and kinematics of the gas in diffuse clouds and less dense regions of the nearest molecular clouds it would be useful to observe high-excitation lines of the CO-molecule (Fig. 1) and its isotopologues, appended by observations of the lines with visible hyper-fine splitting C and C$^+$. At present, such observations are successfully used for the studies of emitting regions in our and other galaxies. However, to carry out such observations for a more wide range of conditions, including ones in the cooler regions of molecular clouds and at larger distances from the Sun, a larger sensitivity is necessary (up to several mJ for observations both in
Figure 1: Maximum brightness in units of $T_R$ (panels to the left) and optical thickness (panels to the right) for CO(1–0)-lines (upper row) and CO(4–3)-lines (lower row) as a function of kinematic temperature and column density of molecules in a homogeneous medium with density $n(\text{H}_2) = 100 \, \text{cm}^{-3}$. Practically independent of temperature, optical thickness 1 for CO(1–0) line is achieved at column density $10^{15} \, \text{mol./cm}^2$, while for CO(4–3) line it is achieved at $3 \times 10^{16} \, \text{mol/cm}^2$. Thus, CO(4–3) lines allow to penetrate “deeper” into dense regions of molecular clouds, but their brightness is by an order of magnitude lower than the brightness of CO(1–0) lines.
Simultaneous observations of CO, C, and C\(^+\) in the clouds that do not show star formation activity (for instance, in Maddalena cloud [7]), as well as in the clouds with reduced abundance of molecular hydrogen, allow tracing CO formation process and measurement of the ratios \(^{12}\text{C}/^{13}\text{C}\) and \(^{12}\text{CO}/^{13}\text{CO}\) for a large range of galactocentric distances, determination of the nature of the penetration of UV-radiation into molecular clouds, derivation of the dependence of X-factor on external conditions. The studies of CO in the submillimeter range may be appended by observations of the CO transitions in the ultraviolet range [6] by the space-born observatory “Spectrum -UV” (also known as “World Space Observatory” — Ultraviolet”).

High sensitivity will also allow mapping the thermal emission of the dust in these regions and studying the structure of magnetic field in them, by observations of dust emission by a wide band polarimeter. At present, ground-based instruments allow determination of polarization of dust emission in dense clouds only. The structure of magnetic field recovered from these polarimetric observations of the thermal dust emission does not correlate with the structure of magnetic field in the surrounding less dense matter recovered from observations of the thermal molecular lines and stellar radiation passing through the matter. The latter is also polarized due to interaction with the ensemble of dust particles aligned by magnetic field. Polarimetric observations of dust emission in the rarefied regions of molecular clouds will allow to resolve this controversy.

There exists still unresolved problem of relation between mass function of prestellar clumps and stellar initial mass function. Existing millimeter and submillimeter range instruments allow already to map formation regions of high- and low-mass stars [8, 9]. For large enough viewing field of the bolometers matrix (not less than 10’ and, desirably, up to 30’), a sensitive space-born submillimeter telescope would allow to carry out an in-depth mapping of star formation regions and to study mass function of dense clumps, encompassing not only low-mass stars but also sub-stellar objects (proto-brown-dwarfs, planetars, i. e. isolated objects of planetary mass). High sensitivity of the instrument will allow to study star formation regions at large galactocentric distances and reveal possible connection of the parameters of the mass function of prestellar objects (of so called initial mass function ”— IMF) with the gradient of chemical composition in the Galaxy and with its structure. For instance, observations of objects at different Galactic longitudes would allow to reveal possible variations of the parameters of IMF (in particular, relative distribution of formation regions of high- and low-mass stars) with position of molecular clouds respective to the Galactic spiral wave.

3 PRESTELLAR CORES

One of the main sources of information on the physical conditions in the protostellar objects are their spectra in a wide range of wavelengths (spectral energy distribution, SED). In essence, just SED became the basis for of the currently accepted system of classification of these objects. Note, for class –1 objects (starless cores) and class 0 ones (objects in the very initial evolutionary stages in which central IR-source is present) the maximum of SED is located just in the submillimeter and millimeter ranges. Location of the telescope in
the cosmic space will allow for the first time to construct SED of starless cores without discontinuities caused by existence of atmospheric transparency windows. Detailed shape of the spectrum will allow to answer at least two important questions. The first of them is related to the evolutionary state of a specific core. Up to now, the cores were classified as starless or protostellar ones on the base of presence or absence of the central radiation source. Relative number of of starless and prestellar serves as the basis for the estimate of the lifetimes in respective evolutionary stages. Though, for instance, observations of the starless core L1014 by space-born infrared telescope “Spitzer” revealed that this core has a weak compact inner source, discovered due to excess of radiation at wavelengths shorter than 70 mkm [10]. Theoretical spectrum of this system has a rather complex shape [10, Fig. 3], but its reliability is based on several observational points only which are obtained by different instruments. Space submillimeter telescope will allow to discover compact inner sources (future stars or substellar objects) with even lower luminosity and in earlier evolutionary stages, and will provide significantly more detailed and homogeneous spectra extending from far IR to millimeter range for verification of theoretical models.

The properties of dust grains in starless and protostellar objects still remain an important unsolved problem. Since the shape of the dependence of absorption coefficient on the frequency of radiation changes with with the size of grains, the growth of the latter is reflexed in the slope of the long-wavelenght spectrum. Construction of detailed spectra will, in particular, to find at which stage of the evolution of a protostellar object coagulation of the grains which finally leads to formation of dust clumps — the embryo of future planets — begins.

Observations of high-excitation lines in prestellar cores will bring no less information then their observations in the diffuse medium. Strong molecular lines which are traditionally used for the studies of dense clumps in the molecular clouds are a bad tracer of physical conditions in their most dense regions where where formation of a protoplanet as such have already occurs or already occured. Like in the case of the diffuse medium, this is related to the effects of radiation transfer and chemical evolution. Due to high abundance of CO-molecules in the envelope of a prestellar core, even lines of isotopologue C$^{18}$O are optically thick in transitions (1–0) and (2–1). Therefore, most convenient seem to be high-excitation lines of this isotopologue [11], as well as the lines of isotopologue C$^{17}$O. This is especially actual for the study of “chemically young” cores, which are currently actively searched for. It is beyond doubt that in the next few years a large number of such cores will be discovered, but without a high-sensitivity instrument their large-scale investigation will be impossible.

In the more evolved cores, the effects of freeze-out are strong. Due to them the molecules that are usually observed in the central regions of prestellar cores are bound in the ice mantles of dust grains. Since for the theory of star formation kinematics of just these regions is most interesting, one will be forced to use for their study low-abundance molecules (with relative abundance of molecular hydrogen $10^{-9}$ and less) and/or new molecules (or transitions). In this respect, molecules containing nitrogen are most promising, including not only traditional NH$_3$, N$_2$H$^+$, HCN [12], but also less known ones, like NO [13] and HNO. Figure 2 shows theoretical radial distributions of the absolute number densities of molecules CO, CS, and HNO in the starless core L1544
Figure 2: Number density of some molecules in the model of starless core L1544 at the age of 2 Myr. The parameters of the model are as follows: adhesion coefficient $\alpha = 0.3$, intensity of UV-illumination in the units of interstellar background $I = 0.2$, the rate of ionization by cosmic rays $\zeta = 10^{-17}$ s$^{-1}$.

computed by the model described in [11]. It is seen that the number density of CO almost does not change along the profile of the core, while the number density of CS on average even slightly decreases to the center. Emission of these molecules is generated in the envelope of the core mainly and, therefore, it is a bad tracer of conditions in the central region of the core. On the other hand, number density of HNO molecules in the envelope is minor, but it substantially increases to the center. Also, as it was discovered recently, it is convenient to use the lines of H$_2$D$^+$ and other deuterized molecules for the studies of the kinematics of central regions of starless cores [14]. These molecules also emit in the submillimeter range.

It is important to note that the width of spectral lines of starless cores usually does not exceed several 100 m/s. Therefore, for their observations one needs a high spectral resolution, which enables the accuracy of determination of radial velocities of the order of 10 m/s (not less than 50 m/s). For observations of nitrogen-rich molecules, the long-wave limit of high-resolution spectrometer must be not less than 15 mm.
4 PROTOSTELLAR OBJECTS

With a well-thought choice of molecules and transitions for the studies of starless cores, it will be possible to obtain unique results even if space telescope will be used in one-mirror regime. However, investigations of more advanced stages of star formation will require a significantly higher angular resolution which may be achieved in the interferometer regime. Resolution of “space antenna – ground antenna” interferometer will allow to study the inner structure of protostellar objects at distances up to several kpc from the Sun. It will become possible, for instance, to estimate directly from observations the scale of the region in which the bipolar outflow is generated and to find whether it is due to the wind of a young star in its immediate vicinity or to the more powerful wind that encompasses protostellar disc and contributes to the angular momentum loss. There will appear also a possibility to study connection between outflows and continuing accretion onto a protostar at scales less than 1 a.u.

The detailed investigation of the kinematics and molecular composition of the vicinities of young massive stars is necessary for solution of the problem of their formation. Observations by space telescope in the interferometric regime with high resolution will allow to study the structure of distant regions of high-mass star formation, to perform a comparative analysis of high- and low-mass protostellar objects. Even now, observations of molecular lines from high-mass formation regions made by ground-based telescopes in the millimeter and submillimeter ranges revealed their complex structure [15], but for quantitative interpretation of these observations by chemo-dynamical models a significantly higher angular resolution is necessary.

Currently, quite actual are observations of immediate vicinities of protostars of different masses. In particular, the question about evolutionary connections between hot cores, hypercompact regions of ionized hydrogen, and ultracompact regions of ionized hydrogen remains unanswered, it is unknown whether they represent subsequent stages of the region that surrounds a young massive star. Evolution of different fronts in the matter surrounding massive stellar objects ”— shocks, ionization and dissociation (of H₂-molecule) fronts, evaporation one ”— are of large interest, but due to insufficient sensitivity and angular resolution of modern instruments even the question about presence of dust in the vicinity of young stars (in the compact regions of ionized hydrogen) remains unanswered.

Detailed observations of molecular composition of protostellar objects with high angular resolution are necessary for the studies of the details of evaporation of ice mantles of dust grains close to protostellar objects. According to current notions, chemical reactions in these mantles result in formation of very complex molecules, including the simplest organic ones. Observations of molecular spectra of the above mentioned regions will allow to explore the problem of possibility of nascence of organic molecules and their further propagation through the cosmic space, which is of extreme importance for problem of the origin of life. In particular, it is necessary to learn whether these complex molecules desorb (volatilize) from ice mantles without simultaneous destruction and what is their lifetime before destruction by short-wave stellar radiation.
Molecular maser emission is an irreplaceable tracer of the physical conditions and processes in the star formation regions. It has a large potential for separation of different stages of evolution of young stellar objects. This is due to high sensitivity of the parameters of maser emission to the parameters of the medium in which it is generated. The main maser transitions which are observed in star formation regions belong to the molecules of water (H$_2$O), hydroxide (OH), and methanol ((CH$_3$OH). Already at present Russian researchers are actively studying physical conditions in the interstellar medium using maser emission, in particular, that of methanol (see the papers published by V. I. Slysh group from Astro-Space center of Lebedev Physical Institute and by A. M. Sobolev group from Ural State University, e.g., [16, 17]). Maser sources (spots) have angular dimensions of fractions of an arcsecond (down to a thousandth and less). Therefore, for their studies one needs interferometers. High angular resolution of the “ground–space” interferometer and possibility of observations in several spectral ranges will allow to study the most important questions of the theory of formation of masers:

- Which stages of the evolution of young stellar objects are accompanied by appearance of maser emission?
- What is the morphology of the regions of maser emission?
- Where in space maser emission is generated respective to a young stellar object?

The most suitable for interferometric observations are class I water and methanol masers (with frequencies 84, 95, and 104 GHz). In particular, they were discovered in a young stellar object IRAS 16547-4247 [18].

One more problem which may be solved by observations of masers is determination of distances. The measurements of trigonometric parallaxes of the sources of water and methanol maser emission allows to determine the distances to the Galactic star formation regions avoiding all uncertainties related to restricted capabilities.
of the kinematic method (uncertainty “close-large distance” for the sources from the inner galactic regions, necessity of usage of rotation curve). The parallaxes of maser sources allow to determine distances to the sources up to several kpc from the Sun, still unattainable for optical and infrared instruments. Measured distances will allow to determine positions of star formation regions in the Galaxy and their concentration to the spiral arms and, hence, to find out the role of spiral structure in the star formation process. For instance, the distance to the high-mass stars formation complex W3 in the Perseus spiral arm was measured using parallaxes of the methanol maser sources. It is $2 \pm 0.1$ kpc [19, 20]. Determination of distances to the regions of star formation in distant outer Galactic regions (galactocentric distances up to 15 kpc) will allow to construct a precise rotation curve for the Galaxy. The first steps in this study are made already for the star formation region S269 located at 5 kpc from the Sun [21]. A sensitive space submillimeter interferometer would significantly expand the possibilities for solution of this fundamental astronomical task.

Observations of masers also allow to learn how their number changes depending on galactocentric distance. In Fig. 3 we show distribution of class II methanol masers in the galaxy according to Sobolev et al. [22]. It is seen that the number of masers increases at galactocentric distances that correspond to the positions of spiral arms. Observations by space instrument will allow to study Galactic distribution of the other type masers, in particular, to find out, whether their number depends not only on the presence of molecular gas, but also on its metallicity (in connection with existence of Galactic gradient of chemical composition).

It is important to note that all above mentioned studies require a possibility of interferometric spectral observations.

6  CIRCUMSTELLAR DISKS

The final stage of the evolution of a low-mass protostellar object is a T Tauri star surrounded by gas-dust disk. Radiation of these disks is of large interest for numerous reasons.

- First, according to current notions, just in them planetary systems similar to the solar one occurs.
- Second, the studies of relatively close protoplanetary disks will allow to investigate a fundamental physical problem ”— the mechanisms of angular momentum transfer in the accretion discs.
- Third, the processes of mixing associated with the transfer of angular momentum in the protoplanetary discs may explain the peculiarities of chemical and isotopical composition of the solar system.
- Finally, in the inner regions of the discs dust grains retain ice mantles with complex molecular composition. The presence of the mantles influences both the processes of grains coagulation (the growth of the planetesimals) and the chemical composition of the embryos of planets which are born in this process.
Angular resolution of modern instruments is insufficient for full-scale studies of protoplanetary discs. Currently, interferometric studies do not allow to obtain the images of objects of interest. When interferometric system ALMA will be put into operation, it will become possible to study the structure of discs in general, but investigation of the details of the structure, in particular, of the regions cleared of the matter by young planets (existence of which is a signature of an important stage in the evolution of planetary systems) requires an instrument with a higher angular resolution.

The studies of SED in the inner regions of protoplanetary discs will be possible even in the one-mirror regime of the work of space telescope. Under condition of high sensitivity it will allow to follow distribution of matter at large distances from the central star and to determine the parameters of the growth of grains to larger dimensions than it is possible by present-day instruments. Observations of different transitions and molecular isotopologues will allow to investigate the vertical structure of the discs, their chemical and thermal structure, to study efficiency of mixing [23], as well as possibility of layered accretion.

A possibility for the similar studies of brown dwarfs discs will appear. At present, the studies of brown dwarfs attract a large attention due to uncertainties existing in the scenarios of their formation. An important stage in the finding out of their origin became investigations of gas-dust discs around them. As it is shown by observations, while in general discs of brown dwarfs and of low-mass stars have similar physical structure, the discs of the former are less dense. As a result, they are more transparent for ionizing radiation (for X-rays and for cosmic rays) and this determines another chemical structure. In particular, theoretical calculations [24] show that column densities for majority of observed molecules in the discs of brown dwarfs are by 1 to 2 orders of magnitude lower than in more massive discs. In addition, indirect data give an evidence that the discs of brown dwarfs are more compact [25]. As a result, existing ground-based telescopes allowed to obtain observational data not only on molecular lines but also on thermal dust emission only for several such discs in the close vicinity of the Sun. It is quite possible that the operation of high-sensitivity space telescope will not simply expand our knowledge about brown dwarfs, but also will change our notions about peculiarities of chemical reactions in protoplanetary discs in general.

7 CONCLUSION

Currently, several projects of millimeter and submillimeter range telescopes are already implemented or developed. The problems related to different stages of star formation take an important place in their programmes. However, the sensitivity of ground-based instruments is naturally limited by atmospheric absorption. A submillimeter telescope in the space, even operating in the one-mirror would allow to carry out extremely important investigations both of close and distant star formation regions (thanks to high sensitivity) and will allow to solve a lot of enigmas of star formation not only in the vicinity of the Sun but also in a more extended region of the Galaxy. To some extent this goal will be achieved by “Herschel” project, but the angular resolution
of ‘Herschel’ will be not high enough to solve many fundamental problems of star formation theory. In this respect, capabilities of the “Earth–Space” interferometer will be unbeaten and will allow to obtain highly valuable information on the structure of the star formation regions and protostellar (young stellar) objects that is unavailable by other means.

8 ACKNOWLEDGMENTS

The authors acknowledge A. M. Sobolev and A. B. Ostrovskij for their comments on observations of masers. This study was supported by the Program of state support of leading scientific schools (project code -4820.2006.2). DZW also acknowledges President of the Russian Federation grant for support of young Doctors of Science (project code -4815.2006.2).

References

[1] M. Tarenghi, Astrophys. and Space Sci. (2008, in press).
[2] P. T. P. Ho, J. M. Moran, and K. Y. Lo, Astrophys. J. (Letters) 616, L1 (2004).
[3] Star Formation in the Galaxy and Beyond ....
[4] J. Ballesteros-Paredes, R. S. Klessen, M.-M. Mac Low, and E. Vazquez-Semadeni, in: Protostars and Planets V, eds B. Reipurth, D. Jewitt, K. Keil (Univ. Arizona Press, Tucson, 2007), p. 63.
[5] T. A. Bell, E. Roueff, S. Viti, and D. A. Williams, Monthly Not. Roy. Astron. Soc. 371, 1865 (2006).
[6] E. B. Burgh, K. France, and S. R. McCandliss, Astrophys. J. 658, 446 (2007).
[7] R. J. Maddalena and P. Thaddeus, Astrophys. J. 294 , 231 (1985)
[8] F. Motte, S. Bontemps, P. Schilke, et al., Astron. and Astrophys. (2008, in press).
[9] J. K. Jorgensen, D. Johnstone, H. Kirk, and Ph. C. Myers, Astrophys. J. 656, 293 (2007).
[10] Ch. H. Young, J. K. Jorgensen, Y. L. Shirley, and J. Kauffmann, Astrophys. J. Suppl. Ser. 154, 396 (2004).
[11] Ya. Pavlyuchenkov, Th. Henning, and D. Wiebe, Astrophys. J. (Letters) 669, L101 (2007).
[12] L. Pirogov, I. Zinchenko, A. Lapinov, et al., Astron. and Astrophys. Suppl. Ser. 109, 333 (1995).
[13] M. Akyilmaz, D. R. Flower, P. Hily-Blant, et al., Astron. and Astrophys. 462, 221 (2007).
[14] F. F. S. van der Tak, Roy. Soc. of London Trans. Ser. A 364 (1848), 3101 (2006).
[15] L. Pirogov, I. Zinchenko, P. Caselli, and L. E. B. Johansson, Astron. and Astrophys. 461, 523 (2007).
[16] S. V. Kalenski, V. G. Promyslov, V. I. Slysh, P. Bergman, A. Winnberg, ARep, 50, 4, 289 (2006)
[17] A. M. Sobolev, D. M. Cragg, S. P. Ellingsen, et al., in: Astrophysical Masers and their environments, Proc. IAU Symp. No. 242 (2008).
[18] M. A. Voronkov, K. J. Brooks, A. M. Sobolev, et al., Monthly Not. Roy. Astron. Soc. 373, 411 (2006).
[19] Y. Xu, M. J. Reid, X. W. Zheng, and K. M. Menten, Science 311, 54 (2006).
[20] K. Hachisuka, A. Brunthaler, K. M. Menten, et al., Astrophys. J. 645, 337 (2006).
[21] M. Honma, T. Bushimata, Y. K. Choi, et al., Publs Astron. Soc. Pacif. (2008, in press).
[22] A. M. Sobolev, A. B. Ostrovskii, M. S. Kirsanova, et al., in: Massive star birth: A crossroads of Astrophysics, Proc. IAU Symp. No. 227 (Cambridge: Cambridge Univ. Press 2005), p. 174.
[23] D. Semenov, D. Wiebe, and Th. Henning, Astrophys. J. (Letters) 647, L57 (2006).
[24] A. Scholz, R. Jayawardhana, and K. Wood, Astrophys. J. 645, 1498 (2006).