KRISTIANSTAD
UNIVERSITY

Learning in Science and
Mathematics
The LISMA group

Project based Astrophysics with Role Playing

Andreas Redfors, Kristianstad University, Sweden

Paper presented at:

GIREP 2006 – Modeling in Physics and Physics Education
August 20 – 25, 2006, Amsterdam, NL

www.hkr.se/lisma
Kristianstad University · 291 88 Kristianstad · Ph +46 44-20 30 00 · Fax +46 44-12 96 51

Work presented at the GIREP conference 2006.

Project based Astrophysics with Role Playing

Andreas Redfors Kristianstad University Sweden, Andreas.Redfors@mna.hkr.se

Abstract

A teaching sequence in astrophysics for future science teachers that incorporates both explicit discussions of the nature of scientific models and the role of these models in explanations has been developed and tested. The goal was to promote meaningful learning in Physics. The lectures were combined with lab and project work. During the lectures the students formed groups in the classroom, thus enhancing discussions. A semi-structured role-play was used to report on the project. The students impersonated different experts, with different perspective of the phenomenon. The students expanded on the descriptions of the roles in their own way in their group work, thus adding theoretical perspectives of the phenomenon at hand – stellar birth, life and death. The teaching was well received by the students and we found that it elicited meaningful learning.

Introduction

A central feature of physics teachers' competence is the ability to illuminate and explain the objects of teaching. Hence, student teachers need to develop their view on the relationship between scientific theories and the real world, i.e. the epistemology of their subject matter. The teacher education at Kristianstad makes this possible since the 4.5 year education mixes subject matter and professional development.

A teaching sequence that incorporates both explicit discussions of the nature of scientific models and the role of these models on scientific explanations has been developed. The goal for such teaching is to elicit meaningful learning in Physics, e.g. Viennot (2001). Meaningful learning is interpreted as reaching an understanding of the physics models based on an ability to distinguish between the world of models and the real world, and an awareness of limitations and usefulness of models for different phenomena. It is crucial that students are given the opportunity to discuss and work with different models for one specific phenomenon. This will make it possible for the student to separate the world of models from the real world and it makes it clear that there are several different scientific models for a given phenomenon, not one correct model that gives the right answer.

The teaching sequence is based on a social-constructivist perspective on learning, i.e. that learning occurs within individuals, but has a strong connection to social context and content. To achieve meaningful learning of new theories in Physics, i.e. that students can combine and use both the learnt theoretical perspective and previous experiences in new situations. This requires a substantial effort by the students. Thus, the students need to be interested and motivated. The motivation of students is paramount and it can be increased if the teaching takes the knowledge of the students as a starting point. David Ausubel (1968) states in his book.

> ”If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly” (s VI).

A prerequisite for the teaching of physics is that the teacher realizes the importance of theoretical models in Physics, and their role in the inter-play between Physics and the real world (Coll, France & Taylor, 2005; Crawford & Cullin, 2004; Justi, & van Driel, 2005). We believe that a teaching sequence that incorporates both explicit discussions of the nature of models and their role in explanations of phenomena can be very successful. The goal of such teaching is to provide opportunity for meaningful learning of physical phenomena (Viennot, 2001; Viennot, 2003). Hence, meaningful learning is taken to mean the ability to distinguish between the world of models and the real world, the recognition of the limitations of models, and the coexistence of several theoretical models for a given phenomenon. Different models are used in different circumstances. It is crucial that students are given the opportunity to work with several different models for a given phenomenon. This will make it possible for students to discern that there is more than one model to use, and that this is acceptable within Physics. There is neither one correct model, nor one correct answer. It will also make it easier for the student to recognize that the world of models and the real world are separated (Giere, 1997).

Marton and Booth (1997) stress the importance of variation in learning using *variation theory*. The consequences of *variation theory* for teaching are further developed in a more recent book chapter (Marton, Runesson & Tsui, 2004), where an individual perspective on learning is emerging, and both individuals and content are claimed to be crucial. There are no general recipes for teaching – it depends on the object of teaching, the context and the learners, i.e. what is taught, where it is taught and to whom.

The teaching sequence recognizes the need to vary the presentation of the learning object (Marton, Runesson & Tsui, 2004) and it is based on the fact that research has shown that learning in physics can be seen as the acquisition of more and more explanatory models for a given phenomenon. That the learner does not substitute old mental models with new ones, rather he accumulates models. Kärrqvist (1985, chap 10), Thornton (1995) and Taber (1998) and Redfors & Ryder (2001) all find that students use several different mental models when they talk about real world phenomena. Hence, we do not believe that learners exchange old mental models for new ones instead learning can be described as a growing complexity based on some basic elements, e.g. diSessa (1993). We think that to understand something is to be able to explain it and the mental models used in explanations are conjured up – depending on the context – as the explanation starts. Thus several different ways of explaining phenomena are available simultaneously, and use of mental models in explanations often become context dependent, e.g. Redfors and Ryder (2001).

Several studies have reported on use of multiple explanations, e.g. Kärrqvist (1985, chap 10), Thornton (1995), Taber (1998), Tytler (1998), Petri and Niedderer (1998), Marton and Booth (1997), Eskilsson (2001, kap. 18). Kärrqvist (1985), in her study of students' explanatory models of electric circuits, defines hierarchical levels of models and she finds that students in general progress towards more advanced models as the teaching continues. However, she also sees that students revert to less advanced models late in the course in their explanations, and that they after a while use the advanced models again. According to Kärrqvist (1985) this could be explained by the fact that problems elicit student use of advance explanatory models differently.

Taber (1998) shows how one student use three different explanatory models of chemical binding in related contexts. His conclusion is that students have several parallel conceptual frameworks, and that the students use the framework they find most fitting in a given situation. Petri and Niedderer (1998) find in their case study of a single student and his mental models of atoms that he has several simultaneously accessible explanatory models for a single context.

Marton and Booth (1997) state that learning can be seen as gaining more ways of looking at the world, i.e. more explanatory models become accessible. Old ideas are not changed into new ones – they remain and are simultaneously available. Eskilsson (2001, s. 184) talk about it in terms of spontaneous and more considered answers. The spontaneous ones come first, but can be changed by students who are prompted during an interview situation. Redfors och Ryder (2001) finds students explanatory models heavily context dependent and Redfors and Niedderer (2004) takes this a step further and describes students' use of mental models with an analogy to quantum mechanical wave functions, where the expectation values of the coefficients give a measure on which explanatory model to expect. We suggest that this is a useful metaphor for the learning process, i.e. the eigenfunctions are small constituents and the coefficients are determined at the time of the explanation. Thus, the coefficients will be strongly context dependent and can change quickly, which give an impression of coexisting parallel mental models.

Helldén (2000) finds in a longitudinal study that many students year after year use the same core ideas in their explanations. He has found a personal context that follows the educational context year after year. He thinks that great opportunities arise for students if they get to discuss their personal contexts and core ideas in class. This also gives the class several perspectives and different ways of looking at a phenomenon, which according to Marton and Booth (1997) is crucial for learning.

Hence, there are several important aspects of learning to take into account when teaching is planned and enacted. The social aspect makes it important to also include opportunities for students to discuss and learn from peers in small groups. However, this process can be significantly enhanced by the presence of a tutor who can guide the students and challenge emerging ideas (Vygotsky, 1996; Eskilsson, 2001).

The teaching sequence

We have developed and implemented a research based teaching sequence in a mathematically and theoretically quite advanced course in astrophysics. The author was the teacher and it was a student centered approach. The course was a part of the Swedish secondary science teacher program. The program is 4½ years long and comprises everything, subject theory, teaching and learning theory and practice teaching (Redfors & Eskilsson, 2003). In the second to last semester the students take elective science courses and one of their choices was this course in astrophysics. It was a 5 week course and there were two teachers involved. The author was teaching the second part of the course, which is focused here. It was mathematically the most advanced course for the student teachers in their education. Therefore, the teaching was structured to encourage student and group activity and it was designed to promote qualitative thinking rather then mathematical problem solving. The aim was for the students to be able to use the mathematically formulated models from the first part of the course in qualitative explanations and discussions.

The teaching sequence was in part based on *contrastive teaching* (Schecker & Niedderer, 1996) and we had interactive lectures and lab-work, but alongside these, the students worked in groups with a project. According to Schecker and Niedderer (1996) it is important that the project work runs alongside other activities and that time is explicitly allocated to work with it. They have also found that if students get to work with a problem formulated by themselves, the learning process will be improved. The project needs to be strongly connected to the course content, i.e. the theoretical framework from lectures and lab-work should be contextualized in the project. In our case the project was reported in form of a semi structured role-play, see Appendix A.

The lectures

The lectures were not traditional instead we worked according to the following principle. The students were divided into groups, and they were sitting with their group in the classroom. To have the students sit with their group members augments discussions in the class (Mazur, 1997). It is also quick and convenient to change between group and full class activities. The groups were used during lectures and in the project work. For the lab-work the students were paired.

A typical lecture would start with the teacher giving an introduction to the material (often a chapter of the course book). The introduction served as an *advance organizer* (Novak, 1998) for the students who thereafter discussed and prepared the rest of the lecture in their groups. The *advance organizer* was in this case a general description of the content of the chapter, which was set in the astrophysical framework of the course. The students were given the opportunity to make connections between the new material and their previous knowledge, especially from earlier parts of the course. The *advance organizer* also helped them to see the logical structure of the content in the chapter. After this initial part of the lecture the content was divided up and given to the groups who were given time to discuss their part. The teacher was circling in the room as a resource for the groups. Taking part in discussions and challenging student ideas. The lecture continued with the student groups lecturing their part of the content for the rest of the class. Hence, the students themselves had to discuss all details, and they were helped to keep their presentations linked to the introduction of the teacher, thus giving the overall lecture a logical structure and making the introduction a true *advance organizer*. These sessions led by students were profitable for both lecturing and listening students. The lecture was concluded by a general discussion generating questions that were kept unanswered for contemplation until the next lecture that was started by addressing them.

The lab-work

The teaching sequence also contained lab-work. It was a semi-structured task. They worked with simulated observations of stellar spectra, and were asked to establish ways to categorize the different stars of an open cluster according to spectral classes. The students worked in pairs during this lab, thus they had mostly different companions compared to lectures and project. In the instruction sheet we had inserted open questions (heads-on) that the two students should discuss with each other as they worked with the analysis. The questions were situated in the lab-context.

Role playing

Drama in science education can be of different sorts Ødegaard (2003) discusses this in an article on drama in upper secondary school. It can be impulsive, conjured in a moment, i.e. students are improvising. Drama can also be structured, based on a manuscript, or it can be something in between, semi-structured. An example of this is the role playing we have done in this course, with described role-characters that students were asked to extend through improvisation. Furthermore, Ødegaard (2003) states that it was found in a survey (Christofi & Davies, 1991) that over 70% of the pupils are positive to drama, but that hardly any science teacher uses it, upper secondary teachers not at all. Ødegaard (2003) discusses pros and cons for drama and concludes that it is an unused resource for science teaching with great potential for all age groups. Ødegaard (2003) discusses three different perspectives on drama activities in science, based on Sjøberg (2000), namely the understanding of

- science concepts
- the scientific process and the nature of science
- the culture of science and its social processes.

We have developed a semi-structured role playing scenario primarily focusing the first two perspectives above. We have focused on the role of astrophysical models and in doing so the first two perspectives come to dominate. We have elaborated on an existing structure described elsewhere (Francis, 2005; Francis & Byrne, 1999) in the group based project. The students were given short description of different experts required to understand the process of star formation, see appendix A. They were asked to extend the description of the experts in their preferred direction. The task given to the student was formulated like this.

> There are many giant gas clouds in space. They have diameters of about 10^{16} m, and masses of around 3×10^{30} kg. They contain chemical elements needed to form a sun and its planets. Your task is to figure out how a star with a planetary system can develop from these clouds. Below there are nine experts described in short. Your group will elaborate on them and make comprehensive descriptions of the experts. Based on these your group will write the "star and planetary system formation" story and submit. Remember to relate your story to observational evidence of today.
>
> Your group will submit one story. However, on your oral exam you will individually act in the role playing and I will decide who plays which role. You will be expected to show that you have acquired expertise in all nine areas.

All the experts included are needed to understand and explain the complex phenomenon of star formation, i.e. there were experts on

- condensation
- observations
- gravitation
- meteorites
- planets
- stones and minerals
- rotation
- stars
- stellar evolution.

Hence, it was a semi-structured drama (Ödegaard, 2003) with defined roles for the students. However, the students were given the opportunity to develop the descriptions of the roles in any direction they chose, thus an ownership developed that stimulated the learning process.

They submitted their extended role descriptions in the form of a complete story in writing, group by group. The students played several different roles at the oral examination. They discussed the general process and specific questions from the teacher.

Examination

The basis for the examination of the second part of the course was the student performance during lectures and lab-work. The written material was the lab-reports and the report of the project. The final examination was the oral role-playing, where the students played several different roles. The students were evaluated normatively against correct scientific arguments based on the role character perspective.

Results

The teaching sequence was evaluated through teacher observations, written questionnaires to the students and group discussions.

The lectures

The teacher (the author) made notes after each lecture. The most noteworthy observation was the way in which the students "came alive" when they got the chance to take charge of the teaching and prepare the remaining part of the lecture. They based their work on the information given at the start of the lecture, and on that from previous parts of the course. They read the material and worked to make a comprehensive presentation, including the new material. They did this in an engaged way and they taught their part interactively, which added to all students understanding. Their preparatory work, including discussions in the group, seemed fruitful for their learning.

The lectures were also evaluated after completion of the course by a questionnaire with open response questions that cover the whole course, not only the part discussed in this article. The questionnaire is presented in Appendix B. The students were also given the opportunity to discuss in groups their answers to the questions, and this added to the individual answers.

The students enjoyed the teaching sequence and they highlighted the importance of following the course literature closely, since it was difficult to read. They appreciated the discussions in the groups during the lectures, and deemed them to be fruitful. They concluded that discussions with peers, with supervision, was a good learning opportunity, which they reckoned to be powerful.

The lab-work

The lab was found interesting and stimulating for the students. They got insights into the work of classifying that astronomers do. Some said it brought interesting questions to focus and that it was a useful part of their learning experience. Also here the role of supervisor was fruitful with frequent opportunities to challenge the student pairs and help them with additional questions and herd them to greater depths of understanding.

The role-playing project

The project work was really appreciated and it was considered by the students to give a nice overview of the course content, at the same time as it was an application of the newly learnt material. Furthermore they appreciated that it was not strongly controlled, but let them take the initiative and develop their work according to their wishes. The students took the questions posed seriously, and brought the descriptions of the different experts to a more advanced level. They did this enthusiastically.

During the group discussion in the evaluation process the importance of the project work is further stressed. It worked to increase interest and it helped to put new knowledge into context. They thought the examination through role-playing was an interesting experience and they considered it to be a good learning opportunity. Finally they were a bit surprised that we had been able to work this way in an advanced course.

Discussion

To be able to discuss with peers in groups has in several cases been found fruitful for learning, see for instance a book on the subject by Mazur (1997). In the teaching sequence we report on here we made a similar experience. Group discussions were central and they constituted a significant role in student engagement. The students were forced to engage with the new theory and make sense of it together, when they in groups were reading and discussing to prepare and continue the lecture. Especially, since they were asked to restructure the material and present it to the other groups during the last part of the lecture. The student led lecturing was a central part of the success.

It seems that student learning really was improved by the project work they all did alongside the lectures and labs. An ongoing project like this where students get to engage and expand into areas chosen by them was effective, just as it has been reported on earlier (Schecker & Niedderer, 1996;

Novak, 1998). The project becomes a direct application and it trains students to use new knowledge in new contexts. We like to conclude that there are good reasons for students to be given the opportunity to discuss in groups and challenge peer ideas in a project. The project needs to be closely interrelated with the course content and it shall require use of the new theory presented in the course. Also of importance is that students get to define or expand on the project tasks themselves. A certain degree of ownership increases the motivation to work with the project. In this we agree with (Schecker & Niedderer, 1996). It was clear to us that the project work made significant advances as we penetrated the theoretical content in the lectures.

The role-playing as an examination was really interesting and it proved to be possible, or even easy, to distinguish different performances. We could evaluate individually and grade students accordingly. The students appreciated this kind of examination and they considered it to be a valuable learning opportunity, an example of *Peer Instruction* (Masur, 1997). Since we let the students play different roles during the examination we made different perspectives visible and this brought the discussion to greater depths. We could also through comments probe students understanding further as they were accommodating to and including new perspectives in their remarks. Hence, we are in agreement with Ödegaard (2003) in finding role-playing interesting and we see a lot of possibilities to expand the use of it in higher education.

List of references

Ausubel, D. P (1968). *Education Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston.

Christofi, C. and Davies, M. (1991). Science through drama. *Education in Science* 141, 28-29.

Coll, K. R., France, B. andTaylor, I. (2005). The role of models/and analogies in science education: implications for research. *International Journal of Science Education* 27, 183-198.

Crawford, B. A. and Cullin, M. J. (2004). Supporting prospective teachers' conceptions of modelling in science. *International Journal of Science Education* 26, 1379 – 1401.

DiSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, 10, 105-225.

Eskilsson, O. (2001) En longitudinell studie av 10 – 12 åringars förståelse av materiens förändringar [A Longitudinal Study on 10-12-Year-Olds´ Conceptions of The Transformations of Matter], Göteborg. *Studies in Educational Science* 167, Acta Universitatis Gothoburgensis.

Francis, P. (2005). Using Role-Playing Games to Teach Astronomy: An Evaluation. T*he Astronomy Education Review*, 4(2).

Francis, P. and Byrne, A.P. (1999). Use of Role-Playing Exercises in Teaching Undergraduate Astronomy and Physics. *Publications of the Astronomical Society of Australia* 16, 206.

Giere, R. N. (1997) *Understanding Scientific Reasoning* 4:th ed. Orlando: Harcourt Brace, (pp 24-35).

Helldén, G. (2000, April 24-28, 2000). *To Identify Personal Context And Continuity Of Human Thought As Recurrent Themes In A Longitudinal Study Of Students' Understanding Of Ecological Processes*. Paper presented at the Annual Meeting of the American Educational Research Association , April 24-28, 2000, New Orleans.

Justi, R. and van Driel, J. (2005). The development of science teachers' knowledge on models and modelling: promoting, characterizing, and understanding the process. *International Journal of Science Education* 27, 549-573.

Kärrqvist, C. (1985). *Kunskapsutveckling genom experimentcentrerade dialoger i ellära*., Göteborgs Universitet, Göteborg.

Marton, F. and Booth, S. (1997). *Learning and Awareness*. Mahwah, New Jearsey: Lawrence Earlbaum Associates.

Marton, F., Runesson, U. and Tsui, A. B. M. (2004). The space of learning. In: Marton, F. & Tsui, A. B. M. (Eds), *Classroom discourse and space of learning* (pp 1-72). N.J.: Lawrence Erlbaum.

Masur, E. (1997) *Peer Instruction*. Upper Saddle River NJ: Prentice Hall.

Novak, J. D. (1998). *Learning, Creating and using Knowledge -- Concept maps as facilitative tools in Schools and Corporations*. Mahwah, New Jersey: Lawrence Erlbaum Assoc. Publishers.

Petri, J., and Niedderer, H. (1998). A Learning Pathway in High-School Level Quantum Atomic Physics. *International Journal of Science Education*, 9, 1075-1088.

Redfors, A. and Eskilsson, O. (2003). Secondary Teacher Education in Science and Mathematics at Kristianstad. Paper presented at the 3-paper symposium *Structures of science teacher education programs in Europe: Differences and similarities*. Org. Borghi, L. and Redfors, A. at The fourth International Conference of the European Science Education Research Association, ESERA, August 19 - 23, 2003, Utrecht, Netherlands.

Redfors, A. and Niedderer, H (2004). Cognitive Developement in a Learning Process about Electric Circuits. I E.K. Henriksen och M. Ødegaard (red). *Naturfagenes didaktikk – en disiplin i forandring?* Det 7.

nordiske forskersymposiet om undervisning i naturfag i skolen, s 399 – 413, Kristiansand: Høyskoleforlaget.

Redfors, A. and Ryder, J. (2001). University physics students' use of models in explanations of phenomena involving interaction between metals and radiation. *International Journal of Science Education*, 23, 1283-1301.

Schecker, H. and Niedderer, H. (1996), Contrastive teaching: A strategy to promote qualitative conceptual understanding of science. In Treagust, D. F. , Duit, R. , Fraser, B. J (Eds): *Improving teaching and learning in science and mathematics*, Teachers College Press, New York.

Sjøberg, S. (2000). *Naturvetenskap som allmänbildning - en kritisk ämnesdidaktik*. Lund: Studentlitteratur.

Taber, K. S. (1998). An alternative conceptual framework from chemical education. *International Journal of Science Education*, 20(5), 597-608.

Thornton, R. (1995). Conceptual dynamics -- Changing student views of Force and Motion. In Bernardini, C., Tarsitani, C. and Vicentini, M. (Eds.), *Thinking physics for teaching* (pp 157-183). New York: Plenum Press.

Tytler, R. (1998). The nature of students' informal science conceptions. *International Journal of Science Education*, 20, 901-927.

Viennot, L. (2001). *Reasoning in Physics. The part of common sense*. Netherlands: Kluwer Academic Publishers.

Viennot, L. (2003). *Teaching Physics*. Netherlands: Kluwer Academic Publishers.

Vygotsky, L. S. (1996). *Thought and language* (A. Kozulin, Trans.): MIT Press.

Ödegaard, M. (2003) Dramatic Science. A Critical Review of Drama in Science Education. *Studies in Science Education* 39 75-1001.

Appendix A. Project work (Swedish)

Se Francis (2005) for English versions of role-playing exercises.

Problemet

Det finns många jättelika gasmoln i rymden. De har en diameter av ca 10^{16} m, en massa av cirka 3×10^{30} kg. De är sammansatta av alla grundämnen som vi finner i stjärnor och planeter. Ditt uppdrag är att fundera ut hur en stjärna med tillhörande planetsystem kan utvecklas ur ett av dessa moln. Nedan finner du ett antal expertbeskrivningar som du skall **komplettera** och utgå ifrån när du gör din slutgiltiga berättelse om bildningen av en stjärna med planetsystem. Kom ihåg att beskriva de observationella grunder som finns idag.

Ni skriver en gemensam berättelse gruppvis. På **redovisningsdagen den 5 juni** så är mitt förslag att ni redovisar berättelsen som ett rollspel och att jag som lärare bestämmer vilken som spelar vilken roll och när byten av roller sker.

Kondensationsexperter

Många astronomer tenderar att glömma bort existensen av fasta föremål, antagligen beroende på att nästen hela det observerbara universum består av gas och strålning. Du, däremot är expert på fasta kroppar och hur de formas i stora gasmoln. Kanske var du fascinerad av meteoriter när du var barn och bestämde dig för att ta reda på hur de formerats, eller kanske var det bilder av virvlande "dammkorn" i universum (små korn av fast material som flyter runt i det interstellära mediet) som fick dig intresserad av detta forskningsfält. Du arbetar mycket i labbet och använder elektronmikroskop för att studera små interstellära korn som samlats in genom rymdfärder.

Du vet att alla gasmoln som innehåller en rimlig mängd tyngre material, t ex kol och kisel, kommer att formera små klumpar. Molekyler kommer helt enkelt att träffa på varandra och ibland häftas ihop. Detta är en mycket mycket långsam process då de flesta interstellära moln har så låg densitet att atomer och molekyler nästan aldrig "träffas". Formationen av små "gruskorn" kommer därför att ta mer än 10^{10} år.

Men om ett gasmoln trycktes ihop till en storlek av bara ~ 10^{13} m eller mindre, så skulle densiteten bli tillräckligt hög för att det skulle uppstå små korn i gasen. Atomer skulle träffa på dessa små korn och vissa skulle fastna på dem och genom detta skulle kornen långsamt växa till sig. Processen skulle ta ca 10^5 år, men gasmolnen skulle mot slutet formera små "klumpar" av ett sandkorns storlek (~1 mm). När ~ 10^5 år gått har de flesta av de tyngre elementen använts för att formera korn (som kan bli klumpar) och kondensationsprocessen upphör.

Observationsexperter

Du är experimentellt inriktad och gillar att observera. Du tycker att teoretikerna bara snackar när de genom sina modeller beskriver hur stjärnor och planeter formeras. Du bestämmer dig för att själv observera några näraliggande gasmoln och försöka *se* hur stjärnor och planeter formeras genom att observera strålning från dessa moln.

Du använder *Hubble Space Telescope* och observerar några näraliggande jättemoln. I samtliga finner du kompakta regioner med "ny-födda" stjärnor. Anmärkningsvärt nog så var nästan alla av dessa nyfödda omgivna av roterande diskar av gas och korn som hade i medeltal en diameter av ca 10^{13} m.

Vad betyder detta? Du vet inte säkert. 10^{13} m är en storlek motsvarande vårt solsystem, så du tänker dig att dessa roterande diskar skulle kunna ha med planetformation att göra.

Gravitationsexperter

Du är en gravitationsexpert. Det betyder att du är väldigt betydelsefull eftersom gravitationen är den universums dominerande kraft. Gravitationen beskrivs också matematiks väldigt vackert och du började antagligen jobba inom detta område eftersom du gillar matematiska härledningar och för att du är duktig på att lösa ekvationer. Du sitter på ditt kontor och beräknar banor och dynamik för satelliter, planeter, stjärnor och galaxer.

Gravitationen gör att allting attraheras av allting annat, speciellt attraheras olika delar i ett stort gasmoln av varandra. Så om inga andra krafter fanns så skulle molnens olika delar accelereras mot varandra. Om inget stoppade dem så skulle molnet krympa ihop till ett svart hål med massan cirka 3 x 10^{30} kg på cirka 3 x 10^{6} år.

Ett sådant svart hål skulle attrahera andra svarta hål och efter ca 10^{11} år skulle det ha svalt alla närbelägna stjärnor och andra svart hål och bara bli mer och mer massivt.

Meteoritexperter

Du är en speciell typ av astronom eftersom du kan ta på det du studerar och hantera det med händerna. Du är specialist på meteoriter: stenklumpar som fallit ner på jorden. Du letar igenom torra Antarktiska dalar och andra ställen för att hitta meteoriter. När du hittat dem så studerar du dem i ditt laboratorium.

Du koncentrerar dig för tillfället på en viss typ av meteoriter som kallas *chondriter*. Dessa verkar komma ifrån vårt solsystems tidigaste tid, ca 4.6 miljarder år sedan. Solen och dess planeter hade just börjat formera sig. Märkligt nog verkar de flesta av dessa meteoriter vara bildade av tusentals små millimeterstora korn. Kornen sitter rätt så löst ihop. Det verkar som det vid denna viktiga tid för solsystemets vidkommande har funnits stora moln av små korn som legat i banor runt solen. Kanske har de kletats ihop och bildat dessa meteoriter.

Andra meteoriter består av solid sten och de kanske en gång varit chondriter, men de verkar ha smält ihop någon gång, kanske via kollisioner med något större...

Planetexperter

Du har dedicerat ditt liv till att studera andra planeter. Många lyckliga timmar har du använt ditt teleskop och studerat samt räknat kratrar på Merkurius, vulkaner på Mars och berg och dalar på Venus.

Du har fascinerats av att alla äldre kroppar i solsystemet har väldigt ärriga ytor. Du vet till exempel att de största delarna av månen dateras till solsystemets första dagar (genom datering med joniserande strålning av månstenar från Apollo-resorna). Du vet också att månen fått mycket stryk och att varje kvadratmeter är täckt av kratrar efter nedfallande meteoriter.

Så mycket meteoriter finns det inte nuförtiden. Istället inser du att under solsystemets första dagar så måste det ha funnits massor av meteoriter som konstant regnade ner från himlen. Vissa av dem var jättestora eftersom det finns kratrar som har en diameter på flera tusen kilometer.

Frågan är var alla dessa klumpar (meteoriter i banor runt solen) kom från och vart de tog vägen?

Stenexperter

Stenar flyger omkring i hela solsystemet. Vi kallar dem för meteoriter. Många slår ner på jorden. De flesta av dem brinner upp i atmosfären, men några landar på jordytan och kan bli studerade. Du är expert på teorierna kring dessa fascinerande stenobjekt. Kanske började ditt intresse för meteoriter när du var student och valde mellan att studera geologi eller astronomi ...

Du är speciellt intresserad av vad som händer när du har ett stort antal små korn inom en liten volym i rymden t ex 10^{13} m i diameter eller mindre. Om kornen är för små, mindre än 0.1 mm, så kommer de nästan aldrig att vidröra varandra och molnet kommer att förbli ett moln av korn. Men, om kornen är lite större så kommer någonting väldigt annorlunda att inträffa. Kornen kommer att börja träffa på varandra och de kommer att klistra sig ihop så att de ganska snabbt växer i storlek.

När de har blivit klumpar om några meters storlek så kommer processen a snabbas upp eftersom attraktionen via gravitation kommer in i bilden och ger fler kollisioner. Stenklumparna blir större och större och efter så där en tusen år så kan de vara många kilometer i diameter och du börjar kalla dem asteroider. Kollisionerna fortsätter och blir mer våldsamma eftersom klumparna är så stora och de färdas med en fart av tiotals km/s, Snart är dock alla klumpar "insugna" till de större enheterna som nu kan vara tusentals kilometer stora och situationen lugnar ner sig. Viktigt i detta sammanhang är också vilka riktningar klumparna färdas i.

Dessa stora enheter kan ge upphov till så mycket gravitationskraft att deras centrala delar övergår i vätskefas och de blir mer och mer sfäriska till formen. Är de stora nog kan de "suga till" sig kringliggande gas och skapa sig en atmosfär.

Rotationsexperter

Allting i universum roterar. Jorden roterar runt sin axel, alla planeter rör sig runt solen i banor och solsystemet rör sig runt Vintergatans centrum. Trots detta så bortser många astronomer från rotation när de gör sina beräkningar. Men inte du, du är rotationsexpert och du älskar att åka på konferenser och påpeka vikten av rotation för de som redovisar beräkningar där den approximerats bort.

De stora gasmolnen roterar, precis som allting annat i universum. Detta beror antagligen på att gasen kommer från stjärnor som i sin tur roterade. Rotationen hos dessa moln är mycket långsam och påverkar inte vad som hände och sker inne i molnet.

Men, fysiken lagar säger att om en kropp dras samman så ökar rotationshastigheten, typ isprinsessor. Om ett gasmoln blir större så kommer det att rotera ännu långsammare, men om det krymper kommer det att rotera snabbare och snabbare i takt med att det krymper.

Detta är inte viktigt så länge som molnet förblir stort, men om någonting påverkar molnet så att det krymper en faktor 1000 (till en storlek av 10^{13} m), så skulle det förstås rotera 1000 gånger snabbare. Denna rotation skulle skapa centrifugal krafter som skulle krympa molnet ytterliggare. Det skulle plattas ut och formas till en roterande skiva kring en central ansamling av gas. Den centrala ansamlingen skulle väga bort emot 2 x 10^{30} kg och resten av gasen skulle rotera i en ganska tät gasskiva runt omkring.

Stjärnexperter

Nästan allting du ser på stjärnhimlen är stjärnor, enstaka eller i grupp. Du är stjärnexpert och det börjar bli lite speciellt inom astronomivärlden. Många astronomer tycker att vi redan kan allt om stjärnor och att det inte längre är ett intressant område. Du vet att detta inte är sant och att det är endast de basal principerna om stjärnor som vi förstår. Varje stjärna är speciell och unik och värd att studera. Du kommer att hitta något speciellt hos varje stjärna bara du observerar noga. Dessutom är det otroligt viktigt att förstå stjärnor väl om man skall kunna gå vidare och studera resten av universum. Du fördelar din tid mellan att ta upp spektra av olika typer av ovanliga stjärnor och att köra datorsimuleringar av olika typer av kärnreaktioner i dessa stjärnors centrala delar.

Vilket gasmoln som helst kontraherar till en stjärna om det blir varmt och tätt nog för att fusionsreaktioner skall kunna äga rum. Det behövs ett ganska tätt gasmoln med en total massa av ungefär 10^{29} kg för att få ingång fusion. Denna massa måste vara sammanpressad till en volym med högst radien 10^{9} m. När fusionen börjar och väte "förbränns" till helium så frigörs mycket energi. Strålningen från stjärnan kan då beskrivas med hjälp av kärnprocesserna. Vidare så kommer strålningen att "blåsa bort" flyktigt material från det närmast området, ca 10^{12} m bort från den nyfödda stjärnan.

Stjärnutvecklingsexperter

Du har alltid fascinerats av att stjärnors liv faktiskt går att beskriva och att det finns både analytiska och numeriska modeller som kan användas för att beräkna hur stjärnor beter sig och förändras. Detta trots att en stjärnas liv är oändligt långt i förhållande till en forskares aktiva tid. Hur är det egentligen möjligt, kan man fråga sig, men du har alltid en förklaring tillhands. Beskrivningar av stjärnors utveckling kan utgå från $\log T - \log\rho$ diagram, HR-diagram eller andra modellbeskrivningar och du är förtjust i alltihopa.

Stjärnan i detta exempel kommer att vara mycket lik vår sol och den kommer att lysa i cirka 10^{10} år, tills den blir utan kärnbränsle i kärnan. I det här läget kommer den att svälla till en röd jättestjärna med storlek d ~ 10^{11} m och sedan kollapsa till en vit dvärg med ett par tusen kilometers diameter. Den vita dvärgen kommer att fortsätta att stråla i miljarder år medan den svalnar.

En annan sak som fascinerar dig är stjärnors massor och deras betydelse för utvecklingen. Massan är en avgörande faktor för stjärnans utveckling och det brukar du påpeka, inte minst när det gäller olika typer av slutstadier och "dödsryckningar". Vilka storlekar och massor kan man tänka sig för de gas- och stoftmoln som ger upphov till stjärnor av andra masstyper än solens?