Summary of the Second "Three-Islands" Euroconference: What have we learned? Where are we going? And some lessons from the past

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Abstract.
The study of clusters and associations of stars, which presumably have common ages, abundances, and histories, provides an excellent data base for testing theories of stellar evolution, physical processes in stars, and the interactions of stars with their nascent clouds, circumstellar disks, and binary companions. This second of the "Three Islands" Euroconferences discussed all of these issues in depth. I will summarize the conference first through a series of revealing quotes to provide the flavor of the meeting, and then highlight nine of the major issues discussed by several speakers to show how far we have come in the last few years and the unsolved problems that deserve further study. Hopefully, at future meetings we will learn of the solutions to these problems. Finally, we can learn from the first astronomer to study clusters, Gallileo Galilei, an appreciation for the awe of discovery.

Gallileo: ... Come on. I am going to show you something else. [He leads Sagredo to the telescope.]

Sagredo: I don't know that I want to look again.

Gallileo: This is one of the brighter nebulae of the Milky Way. What do you see?

Sagredo: But it is made up of stars — countless stars.

Gallileo: Countless worlds.

(later in the play)

Old Cardinal: I am informed that Mr. Galilei transfers mankind from the center of the universe to somewhere in the outskirts. Mr. Galilei is therefore an enemy of mankind and must be delt with as such. Is it conceivable that God would trust this most precious fruit of His labor to a minor, frolicking star? Would he have sent His Son to such a place? How can there be people with such twisted minds that they believe what they're told by the slave of a multiplication table? *Bertolt Brecht (1966)*

1. Introduction

The Second "Three-Islands" Euroconference on Stellar Clusters and Associations: Convection, Rotation, and Dynamos has finally reached an end. After four days of stimulating review talks, oral and poster presentations of exciting new results, numerous discussions, tours, wine, food, and companionship in this beautiful setting, what can we conclude from it all? What have we learned? Where are we headed? What guidance can we take from the past? Summarizing such a rich meeting in a reasonably comprehensive and honest way is a nearly impossible task. Now that we recognize this, let's proceed.

2. Some Revealing Quotes

The true flavor of a meeting cannot be appreciated from a bland summary of the each speaker's conclusions. To appreciate this flavor one should hear what, in our unguarded moments, we actually said. So, I begin my summary with some of the more revealing direct quotes with the context and speaker identified.[1] I do hope that I have not misquoted anyone.

Johannes Andersen: "This will be a clean observational paper because I have cleaned the fingerprints from the projector." [This is an excellent way to begin any talk.]

Constantine Deliyannis: [Referring to the difficulties in explaining the "Boesgaard gap" in the lithium abundance in Hyades age F dwarfs,] "...and you can sit on the data for a long time."

Robin Jeffries: "I don't know. I'm just an observer." [This insight was presented perhaps as a justification for not indicating which of several competing speculations is his favorate explanation for why the lithium depletion in PMS stars does not fit standard mixing theory.]

Constantine Deliyannis: [referring to Robin Jeffries' excellent review of lithium depletion in clusters] "I agree with everything you have said. I have never been at a meeting where this has happened before."

Francesca D'Antona: "We have introduced a second parameter. This is a failure." [This was said as she was trying to explain lithium depletion patterns in premain sequence stars.]

Constantine Deliyannis: [since significant mass loss in F dwarfs is probably inconsistent with the observed lithium depletion patterns] "I will kill the mass loss in a different way I assure you."

John Stauffer: "I will start by trashing the classical methods." [This was the introduction to his review of the lithium test for dating young clusters.]

John Stauffer: "I do not want people to treat these new ages as gospel." [This was a warning that there could be systematic errors in using lithium equivalent widths to date young clusters.]

[1] In my oral presentation I asked the audience to identify the speaker for each quote. (The speaker, of course, was asked not to identify himself.) The audience was right about 80% of the time, indicating that we remember the more outrageous statements far better than the logically correct but bland conclusions. This may be useful guidance for future speakers.

Georges Meynet: [when discussing the instabilities that can result from the inward transfer of angular momentum by meridinal circulation in rapidly rotating stars] "We have to struggle against gravity."

Sylvie Vauclair: "Stars are very complex." [Perhaps we should be reminded of this more often. She said this when discussing the need for a mechanism to suppress mixing in the solar core to be consistent with helioseismic data.]

Guenter Rüdiger: "There is no hope, but let us try." [This was Guenter's sobering introduction to the difficult topic of turbulent mixing between the base of a convective zone and a radiative core.]

Hans Zinnecker: "The IMF cutoff risks turmoil." [This newspaper headline (obviously written for a different purpose) was prominently displayed to call our attention to the possible implications of an observational low mass cutoff of the initial mass function in clusters and the field.]

Sydney Barnes: [before listing the various explanations for why stars in clusters of different ages have rotation rates that disagree with the simple angular momentum evolution from the birth line] "Here is a list of culprits so you know where to place the blame."

Ian Bonnell: "We have difficulty understanding how stars form, clusters are more difficult." [He was referring to the problems in explaining early mass segregation, few wide binaries, and the formation of very massive stars in young rich clusters.]

Keith MacGregor: "Whoever works the fastest wins." [This was the single nontechnical explanation concerning internal angular momentum transport in the talk with the highest rate of technical jargon.]

Chris Johns-Krull: "Magnetic fields are a theoretician's Swiss army knife." [This may be the explanation for why some observers make the great effort to measure stellar magnetic fields.]

Joergen Christensen-Dalsgaard: "Think about spaghetti. Magnetic fields will do the same on the Sun." [Is this MHD for dummies?]

Andrea Dupree: [upon forgetting the point she was trying to make] "My philosophy vanished."

Sofia Randich: "More data are needed. I know that I am not the only person to say this." [This was the understatement of the meeting.]

3. What Have We Learned?

There are a number of issues that appeared very significant to me because they are being intensively studied and because they call attention to important unanswered questions that typically involve uncertainties in the physical processes that occur in stars. I present these issues in the form of questions.

3.1. Are stars in a cluster all formed at the same time?

Johnson presented evidence for an age spread of about 15 Myr in several of the young clusters in the LMC. On the other hand, Preibisch found that the stars in the Upper Scorpius association fit a 5 Myr isochrone in the H-R Diagram with very little age spread. He presented a detailed sequence of events for star formation in the Scorpius-Centaurus association in which the shock wave from a supernova in Upper Centaurus-Lupus passed through the Upper Scorpius cloud about 5 Myr ago, triggering a burst of star formation. The strong winds of the massive stars in Upper Scorpius then dispersed the molecular cloud, halting the star formation. Stauffer cautioned us that it is difficult to infer age spreads in clusters from the location of stars in the H-R diagram because is often not known whether stars are in fact binaries. It will be interesting to pursue Preibisch's hypothesis that the type of shock triggering star formation may play a critical role in determining whether star formation occurs at one time or over a range of times.

3.2. What are the distances to the nearby clusters and associations?

Hipparcos distances are generally accepted as the best available, but there is a major problem with the Hipparcos distance to the Pleiades. Main sequence fitting and lithium-based distance determinations place the Pleiades further away than measured by Hipparcos parallaxes, whereas similar clusters like Praesepe appear to have distances in agreement with Hipparcos. Van Leeuwen argued that there is no evidence for systematic errors in the Hipparcos distance to the Pleiades, and Robichon and Pinsonneault were skeptical that errors in the assumed metallicity, reddening, and helium abundance could modify the distance estimates to be in agreement with the Hipparcos distance to the Pleiades.

In my opinion, one of the most interesting talks on the conference was Valls-Gabaud's presentation on the eclipsing double-lined spectroscopic binary HD 23642, which is located in the Pleiades cluster. There is enough information about this system to derive its distance independent of Hipparcos. His preliminary distance is $121 \pm 4.2(1\sigma)$ pc, whereas the Hipparcos distance to this binary system is 118 ± 3 pc. This agreement indicates that the Hipparcos distance to the Pleiades is probably correct, and thus the discrepancy with the main sequence fitting must be due to some problem with the theoretical models or the assumed parameters for the Pleiades used in the models. Stauffer pointed out that if the Hipparcos distance to the Pleiades is correct, then the Pleiades age from the lithium test for the brown dwarfs increases from 125 Myr to 140 Myr.

3.3. Can mass segregation in clusters be used to study the history of clusters and the origin of field stars?

Andersen presented the evidence for the concentration of more massive stars in the cores of some clusters like the Hyades but not in others like IC 4651. He suggested that the degree of mass segregation depends upon whether "dangerous" encounters with other clusters and molecular clouds have occured in the past, and Mathews added that the strength of the Galactic tidal field also plays an important role. Old clusters typically have lost their low mass stars by evaporation. Hodgkin presented evidence for mass segregation in the Pleiades and showed that the core radius for brown dwarf candidate stars is about 3 pc whereas 8 pc is predicted for a fully relaxed cluster of the Pleiades mass. Thus the Pleiades cluster in not yet relaxed.

In his numerical simulations of star formation in gas clouds, Bonnell found that massive stars usually form near the center before mass segregation processes have time to operate because densities are highest at the center of gas clouds and the gravitational potential of the cloud funnels gas to the center. This accretion of gas leads to significant core contraction and may explain the presence of high mass stars in the core of the Trapezium cluster. One problem is that radiation pressure works against the formation of very massive stars, but tidal captures in dense clusters can lead to massive star binaries with small separations and few wide binaries. The inclusion of angular momentum and magnetic fields in these calculations is needed to make them more realistic. If the general conclusions of these models are correct, then the study of binary separations in field stars can predict the origin of these stars. Scally and Zinnecker concluded that most field stars are born in dense star forming regions like Orion because there are relatively few wide binaries in the field. The few wide binaries among the field stars likely indicate that a small fraction of the field stars are born in low density star forming regions like Taurus.

3.4. In what ways does rapid rotation change stellar evolution?

Meynet reminded us that since rapidly rotating high mass stars are cooler at the equator than at the poles, the temperature difference generates meridional circulation that transfers angular momentum to the interior and can lead to instabilities in the interior at high rotation rates. The different interior structure for rapid rotators compared to slowly rotating stars produces much larger He/H and N/C ratios in the surface layers before the star leaves the main sequence. This may explain the blue supergiants seen in the LMC, including perhaps the progenator to SN1987A, and also the Wolf-Rayet stars. An important observational consideration is that rapidly rotating stars will appear to lie in a different location in the H-R diagram depending upon whether they are viewed pole-on or equator-on. This can broaden the empirical upper main sequence of clusters and complicate the fitting to theoretical evolutionary tracks.

3.5. How can uncertainties in the prescription for convection change stellar evolution?

The 50-year search for a stellar convection theory that includes the essential physics and has predictive power is yielding prescriptions that go beyond the old mixing length model and include overshooting. D'Antona showed that the inclusion of overshooting in stellar models leads to evolution tracks for giants that now make the inferred ages of the oldest globular clusters younger than the age of the universe. Without the inclusion of overshooting the clusters would appear to be 3 Gyr older and, indeed, older than accepted ages for the universe. We can now sleep at night without embarrasing calls from the media concerning the latest "crisis of cosmology."

Is convection the missing "second parameter" that could explain the lithium depletion patterns in premain-sequence stars? D'Antona admitted that this approach is a "failure." Bertelli and D'Antona said that estimates of the age of the Pleiades from the turnoff of stars at the top of the main sequence depend crucially on the amount of convective overshooting. The age of the Pleiades using one popular prescription for convection lies in the range 80–120 Myr, but this is uncertain as the prescription lacks physical justification and the amounting of convective overshoot may depend on the uncertain metallicity.

3.6. What roles can mixing play in our understanding of phenomena in clusters?

Mixing of different atomic species must occur inside stars when convection or circulation patterns induced by rotation or thermal gradients are present, but the importance of mixing and possible stabilization processes are matters of some dispute. The helioseismology results require that mixing occur near the tachocline between the core and convective envelope of the Sun, according to Christensen-Dalsgaard, but the mixing must be suppressed in the core (Vauclair). In clusters younger than about 1 Gyr there is a good correlation of the abundances of beryllium and lithium, which is not predicted by standard models without mixing since Li is destroyed at lower temperatures than Be. The inclusion of rotation-induced mixing processes in main sequence stars, as described by Deliyannis, naturally explains the correlation. From his observational perspective, Jeffries concluded that mixing is the most plausible explanation for why standard models do not explain the observed depletion of lithium with age in solar-type stars.

3.7. What roles can metallicity play in our understanding of phenomena in clusters?

Mermilliod described several ways in which uncertainties in the metallicity of cluster stars could lead to uncertainties in cluster age determinations. One way occurs when one transfers stars from the empirical $L_{\rm bol}$ vs (B–V) plane to a theoretical H-R diagram containing the theoretical isochrones. This process requires knowledge of [Fe/H], which could be uncertain by 0.1–0.3 dex. U-band photometry or some other empirical measure of metallicity may help in the conversion of (B–V) to $T_{\rm eff}$. However, Gratton argued that high resolution spectroscopy is needed to determine the metal abundance of stars because low resolution spectroscopy or multicolor photometry makes the interstellar reddening correction and rotation difficult to separate from metal abundances. Since the isochrones themselves depend on [Fe/H], age determinations from the location of stars at critical turning points on the isochrones depends on metallicity. Clusters, however, may not have uniform abundances. For example, Gratton showed that there is a 0.6 dex variation in the oxygen abundance with position in Orion, perhaps due to pollution by a supernova explosion. Bertelli asked but could not answer the question of whether the overshoot parameter in the prescription for convection should depend on metallicity. Deliyannis and Jeffries asked whether metallicity is a parameter that may partially explain the lithium depletion morphology of clusters. Clearly, we must have accurate abundance determinations for many stars in a cluster to constrain the cluster age and evolution.

3.8. What roles can interactions of stars with circumstellar disks play in our understanding of phenomena in clusters?

A popular model for the distribution of rotational periods in pre-main sequence stars is that circumstellar disks regulate the stellar rotation rate. When magnetic fields connect the star to a disk, the disk acts as a brake on the stellar rotation rate with the important parameters being the accretion rate and the inner radius of the disk. According to the model, as the disk loses mass the brake is no longer effective, and the stellar rotation accelerates as the star contracts to the main sequence and acquires additional angular momentum from accretion. Early observations of Orion stars supported this model by showing a bifurcation in rotation periods. Stassun refuted this intuitive model, however, by showing that a much larger data set of 254 Orion stars shows no bifurcation and the absence of a correlation between rotation and infrared measures of the amount of material in disks. This new data set provides a challenge to those who enjoy modelling the evolution of pre-main sequence stars.

3.9. What roles can magnetic fields play in our understanding of phenomena in clusters?

When all other explanations fail, astronomers often speculate that magnetic fields may somehow explain the discrepancies between observations and theory. I have compiled a partial list of the problems for which speakers at the conference have proposed that magnetic fields may provide the answers. Unfortunately, there were presented few detailed theoretical models that included magnetic fields. D'Antona suggested that the low lithium abundance in the Sun may be due to the suppression of convection by magnetic fields, but Jeffries suggested that magnetic fields may reduce the lithium depletion in young solar-type stars. Since magnetic fields were invoked to explain opposite behavior of the lithium abundances, both explanations are unlikely to be right. Barnes suggested that the nagging problem of why some stars arrive on the main sequence as fast rotators may somehow be due to saturation of the stellar magnetic fields during the pre-main sequence phase when disk locking controls the stellar rotation rate. The need to explain the inferred sound speed in the solar tachocline inferred from helioseismology data led MacGregor to propose that gravity waves propagate through a strong horizontal magnetic field in the shear layer to alter the sound speed. Johns-Krull argued that in T Tauri stars where strong magnetic fields cover nearly the entire surface, standard photospheric models do not apply, the prescription for convection is likely wrong, and the metal abundances could be very inaccurate. Since some RS CVn systems have very large surface coverage by star spots, about 50% in the case of II Peg according to Rodonò, very active evolved stars may have the same analysis problems. I look forward to a future meeting where these speculations about magnetic fields are replaced by detailed MHD models that show quantitatively how the atmospheric and interior structures of stars are changed by magnetic fields and the observable consequences of these changes.

4. Guidance from the Past

Like many topical workshops, this conference has concentrated on recent observational and theoretical research, but there is an all too human tendency to ignore or perhaps even be unaware of important insights of previous researchers that have guided the study of stars in clusters from the inception of the field. The first viewgraph shown at this meeting was a picture of Gallileo Galilei, who is famous for his courageous support of the then heretical Copernican view that the Earth is not the center of the universe. One of his lesser known accomplishments is that he began the study of star clusters and associations. With the newly invented telescope, then called a "monocular," he made an important discovery that initiated the research field that led to this meeting in Mondello. Nearly 400 years ago when he pointed his telescope at the Milky Way, Gallileo discovered to his great amazement that the nebulae are very different from what theoreticians for more than 2000 years believed them to be. From that point forward, astronomy has been an observation-driven rather than a theory-driven science. I would like to give a taste of what he experienced by including in this summary selected portions of the "Sidereus Nuncius"[2] published in 1610. Note the underlined portions to which I will refer at the end of this section.

"With the monocular it is possible to see a huge number of stars beyond the 6th magnitude that are not visible to the naked eye. This is rather <u>unbelievable:</u> it is possible, in fact, to see more stars than the total of those which belong to the other six magnitudes. The strongest of these stars, which we can call of 7th magnitude (the first of those not visible), with the help of the monocular appear to be as strong and luminous as the 2nd magnitude stars observed by a naked eye. And to testify their <u>unbelievable</u> number, I want to show you the drawings of two constellations, so that from these examples you can have an idea of the others."

"In the first drawing I have chosen to show the entire Orion, but the number of stars is so large that I delay this enterprise to a later occasion. In fact there are more than 500 stars 1-2 degrees around those already known. For this reason the drawing shows 80 recently observed stars close to the three already known as the Belt and to the six of the Sword. We have saved <u>their relative distances</u> the most accurately as it was possible. We have drawn the known old stars large with a double line contour, and the other, not visible stars, small with a single line. We attempted to keep also their <u>difference in magnitude</u>."

"In the second example we have drawn the six stars in Taurus called Pleiadi (I say six, because the seventh is generally not visible), close to which there are more than 40 invisible stars in a small portion of the sky. Not one of these stars is more than half a degree away from one of the six majors. We have drawn 36 of these, and, as in the case of Orion, we have retained their distances, magnitudes and the distinction between old and new ones."

"We have also observed the Milky Way, which is so well observable through the monocular <u>that all the discussions, the troubles that philosophers had for</u>

[2] I refer the reader to the URL http://www.liberliber.it/biblioteca/g/galilei/index.htm where the original Latin text, an Italian translation, and Gallileo's drawings can be found. I thank Dr. Isabella Pagano for the English translation.

many centuries, stop after this reasonable experience, and we are free of sterile disputes. The Galaxy, in fact, is a cluster of an uncountable number of stars. Everywhere the monocular is pointed, you can immediately see a large number of stars, of which most are bright, while others are so many and so small that they cannot be distinguished one from the other."

"And since not only in the Galaxy do we see that white milky paleness like a white cloud, but also in a number of small areas of similar color bright in several parts of the sky. When we point the monocular towards one of these areas, we see a dense CLUSTER of stars. Moreover (what a great surprise!) the stars called NEBULOSAE by the astronomers are groups of small stars marvellously spread out. These objects are fairly visible because they are small as consequence of their huge distance, and their white cloud appearance is the result of the superposition of the stars' light rays. They are not a dense portion of the sky that reflects the Sun and stars light, as believed up to now! We have observed some of these nebulae and we show the drawings of two."

"In the first drawing the Head of Orion Nebula is shown, in which we count 21 stars. The second drawing represents the Nebula called PRESEPE, which is not only one star, but there are more than 40 stars. Other than the "Donkeys" (the two major stars), we have observed 36 stars, whose positions are the following:"

These sections of the "Sidereus Nuncius" demonstrate the surprise, amazement, and awe that Gallileo felt when he saw what no human being had ever seen before. Many of us in our work also discover new phenomena or theoretical models that explain data for the first time. Do we also communicate our amazement and awe in our publications of these new results, or do present our results without the excitement that they deserve? Gallileo set a good example. Some of the speakers at this meeting did convey their excitement in what they have discovered, but others did not. Gallileo also called attention to the central role that observations play in our field of research, since theory without strong guidance from observations often leads in unproductive directions. It is rare that theory predicts new phenomena that are later observed. Perhaps inadvertantly, Gallileo prepared the groundwork for later studies by carefully measuring the relative distances and brightnesses of the stars that could be useful for later proper motion and photometric studies. Finally, from his observations that many "milky" portions of the sky are really clusters of stars, one might conclude that all such areas are star clusters. Gallileo does not make this argument, and indeed he makes no mention of the Orion Nebula which he must have seen and which is an HII region rather than a star cluster. Thus one must be careful about making broad generalizations before one understands the physics.

5. Final Thoughts

As we return to our observatories and research laboratories, we should keep in the front of our minds the data driven nature of our research. Theory is important for placing diverse observations into context, and models with predictive power can be tested by future observations. However, models are no better than their physical approximations that can only be tested by their ability to explain diverse sets of observations. When studying clusters it is easy to be lulled by the agreement of a model with one type of observation, but the real test of a model is whether it can explain a broad range of observations. It is likely that such simple approximations as homogeneous ages and abundances for all stars in a cluster are not valid. It is also likely that our approximations for convection, mixing, angular momentum evolution, and interactions of stars with disks are overly simplified. As Johns-Krull emphasized, when strong magnetic fields cover most of a star's atmosphere, standard photospheric models do not apply, the prescription for convection is likely wrong, and the metal abundances could be very inaccurate.

As the Old Cardinal said, "How can there be people with such twisted minds that they believe what they're told by the slave of a multiplication table?" If the physical assumptions in our computer codes are adequate and the models explain a wide range of data, then we can believe such "slaves." And, like Gallileo, we must share our surprise, amazement, and awe.

Acknowledgments. I wish to thank NASA for support through grant H-04630D to NIST and the University of Colorado. I also thank the organizers of the conference for the excellent program and environment that they have created.

References

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