THE AGES OF STARS

IAU SYMPOSIUM No. 258

COVER ILLUSTRATION: A star-spangled banner

Top left: $\sim 10^5$-10^6 year-old stars forming in dense molecular gas on the edge of an H II region illuminated by a $\sim 10^{6.5}$ year-old massive O-type star. *Top right:* $\sim 10^8$ year-old B-type stars in the Pleiades open cluster illuminating reflection nebulae. *Bottom right:* A $\sim 10^{10}$ year-old globular cluster – a metal-poor stellar city. *Bottom left:* Site of the 258th IAU symposium – "The Ages of Stars" – the Inner Harbor of Baltimore, Maryland, USA – illuminated by a $10^{9.66}$ year-old G2V star.

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THE AGES OF STARS

PROCEEDINGS OF THE 258th SYMPOSIUM OF THE INTERNATIONAL ASTRONOMICAL UNION HELD IN BALTIMORE, MARYLAND, USA OCTOBER 13–17, 2008

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Preface

How old is that star?

That is one of the most difficult questions to answer in Galactic astrophysics. Of the fundamental properties that determine the state of a star (mass, composition and age, primarily), we can directly and accurately measure many stars' masses and then estimate the mass of a single star of the same spectral types. Similarly, stars directly reveal their compositions to us through their spectra. Many significant and interesting questions remain in studying the masses and compositions of stars, yet one can say that those subjects are well enough understood to know what the important questions are.

Age is another matter all together. We know a precise and accurate age for exactly one star: the Sun, and that age comes not from the Sun itself, but rather from studying solar system material in the laboratory, something we can do for no other star. For other stars, ages are inferred indirectly in one way or another. For example, in clusters we can assume a single composition and age and then fit an isochrone to the ensemble. Other age estimates can be derived from context, by drawing a connection among a group of stars or by applying some other constraint. For example, space motions can be used to estimate when in the past a young group of stars were in closest proximity, a likely time of formation. Or if we find a number of stars that share the same space motion, we presume a common origin so that an evolved star among them limits the age, just as for a bona fide cluster.

Stellar ages lie at the heart of much of astrophysics, and stellar evolution is all about time and how stars change with time. We wish to determine time-scales for physical processes such as angular momentum loss, nucleo-synthetic processing, changes in magnetic fields, and the like, or we wish to compare objects or groups of objects at different stages in their lives. Stellar and galactic evolution cannot be understood without some consideration of ages. If we could pin ages on individual stars we could determine the Galaxy's star formation history and we could understand the physics of low-mass stars much better. The well-studied spin-down of stars like the Sun and the concomitant decline of observed activity indices makes it possible to estimate rough ages for individual stars, but the scarcity and remoteness of older clusters makes calibrating and testing the activity-age (or rotation-age) relation problematic.

Age has been a slippery enough topic that it has been poorly examined in and of itself over the years. Only two international meetings have specifically addressed the ages of stars, in 1972 and 1989, a generation ago. The topic has come up in other contexts but has never been the focus of an IAU Symposium, which is truly amazing given the fundamental importance of age.

Yet now is an appropriate time to examine the problem of stellar ages in detail. We now understand models of stars and systems of stars much better than even a decade ago. Our understanding of the physics that goes into those models has greatly improved, including such aspects as opacities, nuclear reaction rates, diffusion, effects of rotation and gravity waves, and the influence of magnetic fields. At the same time, observations have tested the models, including now the detection of white dwarf cooling sequences in globulars and an open cluster, and evidence for multiple generations of stars within some clusters. At the other end of the age scale, we want to understand the mechanisms and duration of planet formation, but the stars around which we find circumstellar material have highly uncertain ages. We would like to be able to tell if the youngest star clusters and associations undergo multiple waves of formation, or if higher-mass stars form at

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different times from those of lower mass. So many aspects of stellar evolution beg for accurate ages!

This symposium brought together astronomers from the around the world to discuss the current state of the problem of estimating ages of individual stars and of populations, where the advances are now being made, and what the near future offers.

Some of the questions that we addressed included:

(*a*) What is the current state of our knowledge of stellar ages and how can we improve on that?

(*b*) How do we calibrate ages of systems and ensembles of stars, and what limits our ability to do so?

(*c*) What are current limits in the input physics for stellar models?

(*d*) How well can observations be matched to the models? How well can we model real spectra?

(*e*) How well do we, in fact, know the ages of ensembles and systems of stars? What limits the accuracy and precision of calculating and fitting isochrones for all kinds of stars at all stages of evolution? In other words, how well can we test and calibrate our models? To what extent does internal evolution within clusters limit us (e.g., blue stragglers)?

(*f*) What evidence is there for age spreads within systems and ensembles? How well does the lithium depletion boundary at the low end of the main sequence tell us ages?

(*g*) How good are ages of ensembles determined from tracing back kinematics?

(*h*) Can the morphology of the horizontal branch be used to determine ages?

(*i*) What do binary star systems tell us about ages and how can they help test models?

(*j*) Can we reach a point where we can reliably measure an accurate age for a single star in the field? How well does the nascent field of asteroseismology offer an independent means of determining ages?

These subjects then led to the essential question of the symposium: how well can we estimate the age of a single star or of groups of stars such as populations in nearby (resolved) stellar systems? Ages of stars can then be applied to some key astrophysical questions:

(*a*) How old are the primary components of our Galaxy; the thick disk and the thin disk; and over what span of time did they form? For instance, stars of the thick disk can be selected kinematically and from abundances of their alpha elements, but we need better and independent estimates of their ages.

(*b*) Over what span of time do stars within a cluster form?

(*c*) How old are the stars that have planets? In addition to the effect recently shown, in which metal- rich stars tend to be more likely to have planets, is there an age effect?

(*d*) How about the ages of stars with observed debris disks or other circumstellar material?

(*e*) Can we establish a well-defined comparison sample for the Sun, based on mass and age, so that we have a context for understanding long- and short-term changes in solar luminosity and activity?

(*f*) Are clusters, especially old ones, in fact representative of stars in the field? Or have they managed to survive as clusters because of different initial conditions?

(*g*) How well can we derive the star formation histories of composite systems such as the Local Group galaxies?

(*h*) How well can we extend our experience in our Galaxy to more distant realms, such as the halo of Andromeda, and what do we learn about the Milky Way as a result?

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Address by the SOC & LOC

Dear colleagues,

No meeting of this kind just happens without the assistance and support of many people and organizations. The Scientific Organizing Committee, listed on page xiii, provided critical guidance on the content of the symposium and potential speakers, which was invaluable. The Local Organizing Committee gave freely of their time to make the meeting the success it was, both in the program and the execution. Finally, many individuals at the Space Telescope Science Institute provided the support we can sometimes take for granted, and their willingness to assist in an unusual undertaking made all the difference. I particularly wish to thank Darlene Spencer and Catherine Riggs, who put in many hours and provided the keel to keep our ship steady.

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- Space Telescope Science Institute
- International Astronomical Union
- U.S. National Science Foundation
- Las Cumbres Observatory Global Telescope Network

D.R. Soderblom, SOC Chair, 15 October 2008

Thoughts on IAU 258 (with apologies to Edgar Allan Poe)

Sitting in a lecture dreary, pondering convective theory
From some vast and vacuous volume of astrophysics lore,
As I nodded, nearly napping, suddenly there came a rapping
As if the audience were clapping, begging of the speaker "More!"
Then I made a quick decision: all I had to do was listen,
Listen up and nothing more.

Lost amidst the storm and fury, delivered to that eager jury
Was the answer to this story, story that the stars foreswore.
Somewhere in that stellar history lay the answer to the mystery,
Mystery of the stellar ages, ages we'd not known before.
Could it be companion planet, orbiting in a field magnetic?
Or if not this, then how much more?

Elegantly he spun a theory connecting cluster's metallicity
Through the oscillating iron's penetrating to the core.
Utilizing new fiducials (calibration's ever crucial),
CMD are most unusual: take a look at Messier four
Sir, said I, unto the speaker, "Is it this or something deeper?"
Quoth the speaker, "Of such data - we need more."

Lithium in circulation's symptom of the star's rotation,
Rotation seen as modulation of the stellar spots before.
Does convective overshooting coupled with magnetic heating
Cause horizontal branch's splitting, splitting into three or four?
When we find a clear dependence relating ages to abundance
Then all is done in Baltimore.

Fred M. Walter
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