Star Formation in Early-Type Galaxies
ASP Conference Series, Vol. 163, 1999
J. Cepa and P. Carral, eds.

Panel Discussion: Star Formation in Early-Type Galaxies

G.R. Knapp, L. Binette, R. Bower, E. Brinks, P. Goudfrooij, G. Hau, R.W. Pogge, L.M. Young

A panel discussion on past and current star formation in early-type galaxies was held on the second day of the conference. The panelists were Luc Binette, Elias Brinks, Paul Goudfrooij, Lisa Young, George Hau, Rick Pogge and Richard Bower, and the moderator was Jill Knapp. There was enthusiastic participation by the audience. Luc Binette opened the discussion by describing the data on the sources of ionization in the warm gas in elliptical galaxies, and Paul Goudfrooij followed by discussing what the metallicity of warm gas (HII regions) in elliptical galaxies has to say about the origin of that gas.

Discussion

Luc Binette: Much of the work on abundances and star formation in early-type galaxies has been done on so-called 'cooling flow' galaxies. The problem with this term is that it is an interpretation, not necessarily correct, rather than a description. It is better to discuss these phenomena in terms of what we *observe*, namely the properties of early-type galaxies in clusters. What is the origin of the warm gas in these systems, and what is its composition? Is there ongoing star formation? What is the source of ionization for the warm gas?

A spectroscopic survey of such systems by Heckman et al. (1989) finds that the line ratios agree better with shock ionization models than with photoionization models. On the other hand, consideration of the old stellar population in elliptical galaxies (Binette et al. 1994, 1996) finds that it produces sufficient UV photoionization to produce the observed Hα luminosities from the warm gas component. Is the source of warm ionized gas, and of the ionization, different in cluster and field elliptical galaxies?

Paul Goudfrooij: A problem with models in which star formation depends on the accretion of gas from some external source is that such gas, whether it originates from mergers or from some other external source, is likely to be unprocessed or underprocessed; and yet all indications are that the ionized regions in elliptical galaxies have, as do the stars, metallicities higher than solar. We should be careful, though: [NII] is not a good species for measuring metallicity. Observations of HII regions in spiral galaxies also show that the abundance of [NII] is often higher than solar. This species is produced by secondary enrichment; is there a better indicator of metallicity?

Paul Eskridge: Indeed! N/O is enhanced in the Magellanic clouds, whose metallicity is only 1/5 solar!

Goudfrooij: The straightforward interpretation of these observations is that the star forming gas in cluster ellipticals originates in gas stripped from spiral galaxies, i.e. gas whose metallicity is already high.

However, perhaps the higher metallicities are a by-product of the merger or accretion process. Another candidate for the donor of high metallicity gas is the dwarf galaxies which appear to be forming in tidal tails, for example in the NGC 4038/39 system. Duc & Mirabel (1994) have observed the spectra of such dwarf galaxies, which they suggest are forming in the tidal tails made by the current mergers. Spectroscopy of these systems shows that they are much more metal rich than are their isolated counterparts (gas-rich dwarfs in the field). For isolated dwarfs, O/H decreases smoothly with decreasing blue luminosity. Star forming dwarfs in tidal tails, on the other hand, have abundances completely different from this relationship, with O/H approaching solar values for systems which are of very low luminosity. This is a possible origin for the metal-rich gas in elliptical galaxies.

Tom Oosterloo: Yes, but the dwarfs are formed from the galaxies which are merging, and therefore should have the metallicities of large spirals. Further, what about the remaining gas in the tails? Wouldn't it also be part of the new galaxy, and lower the overall abundance?

Goudfrooij: Sure, the remaining gas will be accreted too, but the dwarfs are found at the *ends* of the tidal tails and so will be around for a long time as separate entities, producing greater metal enhancement.

Eskridge: Remember that we're only able to measure abundances in material dense enough to form HII regions; we have no idea about the metallicities of the lower density gas. For example, the gas in the outer regions of a spiral galaxy is the easiest to strip away, but is also the most metal poor. There are several external sources from which an elliptical galaxy could accrete cold gas, but it's very likely that such events preferentially accrete lower metallicity gas.

Markus Kissler-Patig: This seems no problem for either high or low metallicities, since we hardly know if only the stripped gas (low metallicity) or the whole satellite galaxy (higher metallicity) will fall in.

Brigitte Rocca-Volmerange: When you model the stellar populations and the resulting spectra and colors of isolated elliptical galaxies in detail, you find that the central regions present no problem; the colors are very red, and a closed model, with a passively-evolving stellar population, does a fine job. But we observe color gradients in elliptical galaxies, and the global color of the galaxy is bluer than the central color. To explain this, especially the far-UV data, you need an open model, with the addition of gas as the galaxy evolves.

Richard Bower: Can't you reproduce the color gradients by metallicity gradients?

Rocca-Volmerange: No, this doesn't work. The evolutionary model needs infall to explain the metallicity and stellar populations consistently.

Bower: Why isn't the cold gas we see today in elliptical galaxies the accumulated ejecta from evolved stars, as discussed long ago by Faber & Gallagher (1976). And if it's not, where did that gas go?

Michael Loewenstein: If you integrate the stellar mass loss from an $L_\star$ elliptical galaxy over a Hubble time, you get 10^{11} $M_\odot$ of gas! Thus internal sources are more than adequate to support the needed ongoing star formation: the amount, heating, composition and ionization of the gas are all OK. So we're really back to the old question: what happens(ed) to that 10^{11} $M_\odot$ of gas? It's far more than is seen at the present epoch in hot gas, which dominates the gas content for most elliptical galaxies.

It's interesting in this context that polar rings often have high metallicities (see the discussion by P. Eskridge later in this conference). Did the bulk of the internal gas production, like the bulk of the star formation, take place early in the galaxy's history? Are the outer rings seen in many S0s the remains of that expelled gas which never formed a disk? The trouble is that the kinematics of a galaxy do not tell its history.

Binette: Observations of high-redshift radio galaxies, in which the polarization of the light correlates with the extinction of Lyα, show that these systems are surrounded by huge amounts of dust, and it's likely that they ejected this dust. These observations suggest that the metallicity in quasars is 5 times solar - -

Bower: It doesn't take very much dust to extinguish Lyα - -

Binette: - - so the suggestion is that, if quasars and radio galaxies are the progenitors of the luminous elliptical galaxies we see today, their metallicity has been *decreasing* with time. What happened to all those metals?

Jesús Gonzalez: There's no real problem with metallicity. The stars in giant cluster ellipticals have high metallicities, higher than that of the surrounding X-ray gas - so continued infall of lower metallicity gas can account both for the metallicity gradients and the overall decrease with time of a system's metallicity.

George Hau then took the floor to discuss mergers and the formation of elliptical galaxies.

George Hau: I'd like to discuss the formation of elliptical galaxies from the merging of spirals at low redshift, and argue that this process is not important for producing present day elliptical galaxies. Recent mergers are often invoked to explain two interesting structural properties of many elliptical galaxies - shells and decoupled cores, which are found in some 50% of nearby elliptical galaxies. However, while shells are young features, they can also be excited by flybys of other galaxies (including ellipticals!), while apparently kinematically decoupled cores may be nothing of the sort, with the observational signatures actually produced by triaxial streaming in the inner regions of the galaxies (Statler 1991). Thus we need not invoke actual mergers at all to explain these features, which is just as well, because the enhanced Mg/Fe abundance ratios in present-day elliptical galaxies show that ellipticals are *not* formed at the present day by the merging of spirals.

Bender and Surma (1992) have argued that decoupled cores are old. Thus, if present day merging is important for producing decoupled cores in present-day ellipticals, where are the young decoupled cores? Kojima and Noguchi (1997) have modeled star formation in mergers, and their models show that no central starburst is produced. What about E+A galaxies? These need not involve a starburst, but rather truncation, i.e. continuous star formation which is truncated. Finally, elliptical galaxies have more globular clusters than do spirals, so are unlikely to be the result of merging spirals.

Gonzalez: I agree. Recent mergers can't explain all elliptical galaxies. However, if you put the epoch of most major mergers back to high redshift, there will be no problem with the Mg/Fe abundances. However, regardless of when the merger took place, the formation process(es) for elliptical galaxies must still create metallicity gradients.

Hau: On the other hand, shells are young systems, so their presence in some elliptical galaxies must mean that the merging, or interaction, was recent.

Goudfrooij: Carollo et al. (1993) show that the metallicity gradients in elliptical galaxies increase with luminosity up to some luminosity, but that above this there's no dependence on luminosity. So mergers would work perfectly well in this case.

Bower: Simulations of merging show that violent relaxation is complete in the merged system. In other words, the material that starts out in the center of a galaxy ends up in the center of a galaxy. Thus there is no need to create metallicity gradients in mergers; if they're present in the parent galaxies before merging, they'll be there after the merger has produced the new galaxy.

Richard Bower then began his discussion by being controversial.

Bower: The stars in early-type galaxies are old!

But what does this mean? What do we mean by old stars? Formed more than 8 Gyr ago, more than 10? A more tricky question is what do we mean by early-type galaxies? Is the description of early-type galaxies as galaxies dominated by their bulge components adequate? Do we rather mean galaxies without young stellar disks? How about galaxies without current star formation? ...but if that's the case then is the statement that these systems contain old stars just tautology?

We need to be really careful when looking at how morphology interacts with star formation history: they're certainly not independent. Maybe a more workable definition would be that early-type galaxies are galaxies which are not forming stars and lie in clusters. Then at least we'd know exactly what my opening sentence means.

Lisa Young objected:

Lisa Young: The only systems for which we really *know* the star formation history and can measure ages are those for which we can resolve the stellar HR diagram. The elliptical galaxies in the Local Group, for example the dwarf spheroidal galaxies and the four elliptical galaxy companions of M31, are all morphologically speaking proper elliptical galaxies - their overall morphology shows a smooth light distribution. However, the stellar populations of these nearby dwarf elliptical galaxies have a wide variety of star formation histories (Smecker-Hane 1997). Some of the dwarf spheroidals have predominantly old stars (about 10 Gyr). Some are made up mostly of intermediate-age stars (a few Gyr old). Some— Carina is the most dramatic example— have had multiple episodes of star formation activity from 10 Gyr ago until only 1 Gyr ago. We even find young massive stars (100 Myr old) in NGC 185, NGC 205, and the Fornax dwarf spheroidal, and possibly others (e.g. Stetson et al. 1998; Lee 1996; Lee et al. 1993; Peletier 1993). These are clear examples that star formation has happened recently in early-type galaxies, and sometimes the *majority* of the star formation has happened recently. But with the current data on elliptical galaxies, for which you have only global luminosities, spectra, colors and color gradients, you have very little information on the details of their star formation histories. They could be just the same as dwarf elliptical galaxies in terms of having a variety of star formation histories. So how do I know that other ellipticals don't also have a lot of young stars?

Bower: Good question! So the dwarf Es must be oddballs: remember that their formation is easily disrupted by a few supernova events. Let's understand the 'real' galaxies first – what we desperately need is a coherent paradigm. So why do we think they're old? The homogeneity of cluster galaxies is strongly suggestive of a very uniform formation process, but that argument is indirect. Better evidence comes from comparing line indices and colors in clusters (but the data are rather limited) and from the evolution of the slope and zero-point of the color-magnitude (Kodama & Arimoto 1998; Bower et al. 1998; Kodama et al. 1998) or fundamental plane (Pahre et al. 1998) relations.

Kissler-Patig: Small elliptical galaxies are much more influenced by their surroundings. But for large elliptical galaxies, just look at the globular clusters. These clusters are *old.* If large elliptical galaxies were of mixed ages, then so would be their globular clusters, and they're not. So large elliptical galaxies are old. That's great. I've no problem with that.

Bower: Well, I'm not sure I agree: everything would be fine if it weren't for the Butcher-Oemler effect. Looking back in time, we see lots of blue galaxies in the cores of rich clusters. Something has to happen to these objects, they can't escape from the clusters, so their relicts must be hanging around in rich clusters like the Coma cluster at the present day. At least some of the stars in some 'early-type' galaxies (I like my last definition) must have been formed in the last 4 Gyr. But in the field we have so little data, the whole question seems to still be completely open.

Eskridge: The globular cluster systems in some nearby early-type galaxies seem to have a range of ages.

Kissler-Patig: Yes, but in the most luminous galaxies, like M87, the properties of the globular cluster systems show these major epochs of star formation occurred a long time ago.

Elias Brinks: I've a question for Markus - what do the properties and history of globular clusters have to do with star formation at the present epoch?

Kissler-Patig: Because galaxies which experience massive star formation, as in merger events, are forming globular clusters now. Thus globular clusters track the star formation history of a galaxy.

Brinks: Excuse me? Are you saying that the clusters which are forming today are globular clusters? I don't think so!

Kissler-Patig: Clusters dissipate, it is true. But if a cluster survives for many Gyr, who cares what you call it now? It will become something we call a globular cluster! It's also worth pointing out in this context that globular clusters are not destroyed in mergers - take the system around the old merger system NGC 5018, for example.

Rick Pogge: The star-forming knots seen in systems like NGC 1275 by HST are called globular clusters, but this is something of an extrapolation! Do you know that any low mass stars are forming in these systems at all? Because a large number of low mass stars are an essential property of a globular cluster.

Kissler-Patig: Big HII regions don't have low mass star formation going on?

Pogge: In some of the large star formation regions in the Galaxy (M17 and M16 come to mind), most of what you see are the high-mass stars. There's little evidence that these regions are forming low mass stars, or that they will evolve into globular clusters. Those data come from IR observations, and are still preliminary as far as I know. The suggestion is that lots of high-mass star formation can choke off low-mass star formation.

Bower: *Could* giant ellipticals have a huge range in star formation history? The data for galaxies in clusters say not, at least as far as recent history goes - the color-magnitude and fundamental-plane relationships are really tight. But if you look back to higher z, beyond 0.5, you see a range of galaxy colors and hence of star formation histories. So to produce the tight CM and FP relationships, which you see in clusters today, the stellar evolution since this epoch must be passive.

Gonzalez: The evidence fairly strongly suggests that high luminosity elliptical galaxies have different star formation histories from low-luminosity ellipticals, and that cluster ellipticals have different star formation histories from field ellipticals. Giant ellipticals get through all their gas easily, while small ellipticals have less dissipation and much longer star formation timescales, and hence tend to have bluer colors.

Mike Pahre: In yesterday's sessions, the talks and discussions focused on the narrow range of properties among elliptical galaxies as evidenced by the fundamental plane (FP) and the color-magnitude relation (CMR). The assumption yesterday was that galaxies following these relations are the "normal" ellipticals, while those deviating from the tight relations are the "peculiar" ellipticals. In today's sessions, on the other hand, we have seen a much wider range of properties discussed: the neutral and ionized gas content and their distributions, the mid-IR colors, dust lanes, etc. Jill Knapp went so far as to suggest that the diverse properties of the ISM of such ellipticals are the norm, while the narrow range of properties exhibited by cluster ellipticals make them the "peculiar" galaxies.

These are two very different perspectives on elliptical galaxies. The problem is that we are not always talking about the *same* elliptical galaxies: the cluster ellipticals (in the FP and CMR studies) show a remarkable uniformity, while the field ellipticals (ISM studies) show a larger range in their properties. It seems to me that both sides of this debate need to look at the galaxies that the other people are observing. A complete understanding of these issues will be essential in order to determine what fundamental properties define an "elliptical" or an "early-type" galaxy.

The discussion ended up by getting into gas in early-type galaxies and its origin. Elias Brinks discussed elliptical galaxies, and Rick Pogge the S0s, which had been almost ignored up to this point.

Brinks: Twenty years ago, elliptical galaxies had no gas! Now they do. This isn't rapid evolution of the galaxies! It shows how our thinking has evolved.

Stellar evolution models and observations show that there is lots of mass loss from evolved stars in elliptical galaxies, but we do not observe this gas- -

Ginevra Trinchieri: Yes we do! It's all in hot gas, seen via its X-ray emission.

Brinks: But what *is* the source of the gas we observe in elliptical galaxies? I'm confused! The X-ray emitting gas isn't as much as you'd expect, and besides there are *several* sources of the gas: AGB star mass loss, primordial gas, infall of expelled gas, cooling flows, and capture of gas-rich satellites! In large galaxies, you detect the bulk of the gas by its X-ray emission, but what about smaller galaxies?

Goudfrooij: The small galaxies can't retain gas.

Brinks: Claude Carignan just sent me a beautiful new result - he and his colleagues have detected HI around the Sculptor dwarf spheroidal galaxy using the Australia Telescope (this paper has just appeared in astro-ph - see Carignan et al. 1998). The HI is in two clouds forming a partial ring around the galaxy. In this regard it is very similar to the HI configurations seen in low-luminosity late-type dwarf galaxies, which appear to have begun significant star formation only recently, and which now have a central stellar galaxy surrounded by a ring of HI. Our thinking about the nature of the dwarf spheroidals has changed a lot recently. I expect that so will our thinking about elliptical galaxies.

Pogge: S0s. Remember them? Their properties are hard to pin down, because the morphological definition of this class of galaxies is something of an afterthought: they have disks, so are not ellipticals, but the disks have no structure, so they are not spirals. The present day S0s may therefore be descended from several different kinds of galaxy.

S0s also have a wide range in the amounts of interstellar gas they contain and in its distribution. I'd like to argue that the cold gas in these systems is (mostly) intrinsic. There are several lines of evidence: (1) the distribution of $M(HI)/L_B$ is narrower than seen in elliptical galaxies but not as narrow as found in early-type spirals; (2) when you see dust or $H\alpha$ (HII regions) in S0s, the distribution follows the light, unlike what is seen in ellipticals, except for polar ring galaxies and 'train wrecks' (the systems remaining after major mergers); (3) the gas return times from AGB stars and planetary nebulae are reasonable (cf. Faber and Gallagher 1976); and (4) the metallicities of the HII regions are 1–2 times solar, consistent with the stars we see.

Indeed, in near-infrared images, Sa galaxies look like S0s. I would maintain that the properties of most S0s lie between those of spirals and ellipticals, and that the ISM in S0s is mostly intrinsic and evolves with the galaxy. It is interesting that many lines of evidence point towards the ISM in elliptical galaxies having a significant component of intrinsic gas also.

Acknowledgments. We thank Patricia Carral, Jordi Cepa and colleagues at the University of Guanajuato for putting together this most enjoyable and informative meeting.

References

Bender R. & Surma P. 1992, A&A 258, 250

Binette L., Magris C.G., Stasinska G. & Bruzual G. 1994, A&A 292, 13

Binette L., Wilson A.S. & Storchi-Bergmann T. 1996, A&A 312, 365

Bower R.G., Kodama T. & Terlevich A. 1998, MNRAS (in press; astro-ph/9805290)

Carignan C., Beaulieu S., Côté S., Demers S. & Mateo M. 1998, AJ (in press; astro-ph/9807222)

Carollo C.M., Danziger I.J. & Buson L. 1993, MNRAS 265, 553

Duc P.A. & Mirabel I.F. 1994, A&A 289, 83

Faber S.M. & Gallagher J.S. 1976, ApJ 204, 365

Heckman T.M., Baum S.A., van Breughel W.J.M. & McCarthy P. 1989, ApJ 338, 48

Kodama T. & Arimoto N. 1998, MNRAS (in press; astro-ph/9806029)

Kodama T., Arimoto N., Barger A.J. & Aragon-Salamanca A. 1998, A&A (in press; astro-ph/9802245)

Kojima M. & Noguchi M. 1997, ApJ 481, 132

Lee M.G. 1996, AJ 112, 1438

Lee M.G., Freedman W.L. & Madore B.F. 1993, AJ 106, 964

Pahre M.A., de Carvalho R.R. & Djorgovski S.D. 1998, AJ (in press; astro-ph/9806326)

Peletier R.F. 1993, A&A 271, 51

Smecker-Hane T. 1997, in Star Formation—Near and Far eds. S. Holt & L. G. Mundy (AIP: New York), 571.

Statler T.S. 1991, AJ 102, 882

Stetson P.B., Hesser J.E. & Smecker-Hane T. 1998, PASP 110, 533

Part 4. Hot Gas and Star Formation