Conference Highlights

The Outer Edges of Dwarf Irregular Galaxies: Stars and Gas[1]

[1]Workshop held in Flagstaff, AZ, USA on October 10–11, 2002. Proceedings are available on-line at http://www.lowell.edu/Workshops/Lowell02/ .

1. Introduction

The outer edges of dwarf irregular galaxies have been an area of interest for about 40 years. Its origin can be traced back at least to Sandage's (1962) discussion of the outer parts of IC 1613, which, on Baade's deep red photographic plates, showed an envelope of faint red stars that extended outwards significantly beyond the main parts of the galaxy. Scattered reports of the properties of other dwarf galaxies followed at a low rate until the recent work of Hunter and her collaborators highlighted the importance of the edges of irregular galaxies, both because of their importance in illuminating the evolution of the galaxies and because of the sensitivity of their properties to the nature of the intergalactic medium. Recent research in this area has flourished, as the Workshop clearly demonstrated.

2. The Outer Gas

Distribution: Eric Wilcots pointed out that dwarf irregular galaxies can have three different types of HI envelopes, which were described as extended smooth, extended chaotic, and starless clumps. For example, the HI outer envelope of IC 10 has a very extended, clumpy counter-rotating structure, involving a possibly infalling gas cloud of 10^7 $M_\odot$.

David Strickland showed some results from detailed feedback models of SN-produced outflows, mostly for larger disk galaxies, but he included a discussion of the shell-like structures in the outer excited gas of NGC 1569. Sally Oey described her calculations showing how ionizing photons escape from irregular galaxy disks, demonstrating how the rate of escape depends on the porosity of the interstellar medium.

The outer gas in galaxies sometimes includes bridges between galaxy pairs and some interesting new results for the Magellanic bridge was presented by Erik Muller. The western part of the bridge has been mapped at high resolution and is found to have a chaotic and filamentary structure. There are 163 HI shells, similar to those in the SMC, but on average smaller and less energetic. Eon-Chang Sung et al. showed what may the largest HI bridge of all: a 130 kpc-long bridge between two Blue Compact Dwarf (BCD) irregulars.

Sylvie Beaulieu described the detection of HI in the outer parts of two dSph galaxies in nearby groups, and Daniela Calzetti described the ionized gas in starburst galaxies.

In a report on some remarkably deep searches for CO in the outer parts of irregular galaxies, Fabian Walter showed that the outer parts of some are rich in molecules. For example, IC 10 has several clouds in distant regions as well as in the center. Its H_2 mass is $\sim 10^6$ $M_\odot$ and the conversion factor is like the Galactic value.

Stéphanie Côté reviewed recent results on the distribution of dark matter in dIm galaxies based on Fabry-Perot 2-d velocity fields, showing that they are dark matter dominated.

Abundances: Do dwarf irregular galaxies have abundance gradients such that the outer edges are even lower in metals abundance than the central areas? The answer to this question was touched on by a few talks and posters, but there was more new information regarding the abundances in irregulars in general, especially with relation to the question of their possible primordial nature. Starburst irregulars were featured in two such studies. Daniela Calzetti showed results of HST narrow-band imaging, which provided line ratios in four starbursters. Alessandra Aloisi revealed the results of FUSE spectra of IZw18, which allowed analysis of lines of Fe, Ar, Si, O, N, C, P, and H. She revealed the fact that the abundances of species are ten times lower in HI regions than in HII regions. The data best fit multi-burst models; the gas is not primordial and IZw18 is not in its first starburst.

3. The Outer Stars

Distribution: Deidre Hunter reported on the distribution of the outer stars in two irregular galaxies, detecting stellar light down to values as faint as 29 magnitudes per square second. "There is no edge yet." Yutaka Komiyama showed some surprising results based on a widefield camera attached to the Suburu telescope. He found that the distribution of the outer stars in NGC 6822 goes far beyond the traditional borders of the optical image and is similar in distribution and extent to HI distribution. Ralf-Jürgen Dettmar used very deep images of disk galaxies to demonstrate that the apparent "edges" are actually not cut-offs, but demarcate a steeper exponential distribution of starlight. Studying many irregular galaxies, Igor Drozdovsky concluded that most are thick disks.

Star Formation Histories: An exhaustive review by Carme Gallart included the fact that the outer parts of irregular dwarfs are dominated by an older population, but also an intermediate population extends far from the center. She showed recent remarkable new LMC data that support this. Sebastian Hidalgo demonstrated the fact that the Phoenix dwarf has a smooth gradient of age outward. Ted Wyder, reporting on an HST study of NGC 6822, showed detailed star formation histories for five regions across the bar of the galaxy, including two outer areas. All showed star formation at all times since formation, though the outer areas had relatively lower recent activity levels. Arna Karick reported on a survey of the irregular dwarfs in the Fornax cluster, with the intriguing suggestion that star formation activity is preferentially located on the "leading edges" of some of the galaxies, which are presumably falling into the cluster.

Inside the outer edges: Patricia Knezek reported on a study of three extreme Cen A Group dwarfs. Vincent McIntyre showed some impressive HI maps of NGC 4214's HI shells. Some of the outer ones have star formation at their edges. In Caroline Simpson and collaborators' study of DDO 88, it was found that the galaxy has an inner HI ring, neither expanding or contracting, while the object is otherwise a normal irregular galaxy. Janice Lee did an analysis of a sample of Hα-selected dwarfs, which provided an HI mass function for galaxies, the first of its type. Jan Palouš developed expanding shell models and determined the mass spectrum of shell fragments. Javier Alonso-García showed *HST* results for two contrasting dwarfs in the M81 group, one with a mixture of old and young stars and one with only old or intermediate age stars. Violet Taylor measured color gradients in 100 irregular and peculiar galaxies, finding that most are redder in their outer regions, in agreement with results from CM diagrams of nearer Irr galaxies. Matthew Walker showed the results of measurements of over 200 stars in and in the direction of the Fornax dwarf galaxy (not an irregular at the present, but in the past). Membership is demonstrated for 160 stars according to their radial velocities; the velocity profile is nearly flat.

Formation and Evolution: In deriving a model for the formation of low mass irregular galaxies ($< 10^8$ M$_\odot$), Massimo Ricotti calculated the effects of radiative feedback in the early universe; his simulations agree with many of the observed properties of dwarfs. In related theoretical analyses, Gerhard Hensler described extensive results from chemodynamical models, including such items as formation, star formation self- regulation, chemical peculiarities, mixing time scale, and infall of gas. Stephen Murray reported on numerical simulations of dwarfs forming near a massive galaxy. In related simulations carried out by Chris Fragile it was shown that the degree of enrichment by supernovae depends on the smoothness of the ISM; if the ISM is porous, most of the enriched gas is lost from the galaxy core. Arif Babul nicely demonstrated how increasingly-complete modeling is showing details of dwarf galaxy evolution, including how SN-driven outflows from dwarfs can pollute the IGM. Sergey Mashchenko demonstrated a model for dwarf galaxies in which the UV radiation from spirals ionizes the ISM of orbiting dwarfs cycling through plane of the spiral, causing periodic star formation episodes.

Blue Compact Dwarfs: BCD galaxies as a class were examined in detail by several attendees. Walter Koprolin reported that an old stellar population could be detected underlying the brighter, young component. The structure of this underlying population was described by Nicola Caon, who said that most can be fit to an exponential law, including Mrk 35, though two in his sample could not. Finally, Eon-Chang Sung and his collaborators searched BCD galaxies for new super-star clusters and found several of these highly-luminous young products of rampant star formation.

4. Related Issues

Spiral Galaxies: Very deep HI maps of 10 spiral galaxy edges were described by Thijs van der Hulst, who concluded that UV metagalactic radiation may ionize the outer gas, but current simple models need refinement. Annette Ferguson analyzed the outer disks of spirals, finding them to be surprisingly metal-rich and 5–10 Gyr old. She showed some faint M31 star counts that cover 30 square degrees and show structure at remarkably large distances. René Walterbos reported on a study of HII regions in M81's outer disk, including some in the vast M81 HI envelope. The abundances correlate with distance from M81's center. Stephen Odewahn reported on UV-optical colors of a large sample of galaxies, including analysis of the star formation history distributions. Martin Bureau modeled NGC 2915's starless outer spiral structure.

Low Surface Brightness Galaxies: In a survey of Low Surface Brightness (LSB) galaxies, Gaspar Galaz and colleagues found that in general the star formation rate is low and there exist both color and age gradients; all have an old component and some show bulges in K-band images. Michael Pohlen and R.-J. Dettmar investigated the structure of LSB spirals, including UGC 7321, finding that they have the same structure as normal surface brightness galaxies, except for the depressed overall brightness levels.

In other related fields, Lyle Hoffman and Ed Salpeter reported on the discovery of 10^4 $M_\odot$ "mini-HVCs," while Jay Lockman, also using the new GBT, described the discovery that the Galactic halo HI is resolved into clouds. J. O'Brien showed an unusual galaxy that has a bar in a non-nucleated pure disk. Andrew Odell demonstrated the effectiveness of a intemediate-band photometry of galaxies, mostly ellipticals in clusters, for determining ages and metallicities. Finally, Javier Alonso-García reported the excellent news that the first RR Lyrae variables have now been detected in the elliptical companion of M31, M32.

5. Concluding Discussion Session

The Workshop ended with a lively interchange on several topics that had been raised during the course of the meeting. The first question put before the attendees was "To what extent have the stars in the far outer regions of dwarf irregular galaxies formed there and to what extent have they migrated there from inner regions of the galaxy?" Discussion concluded that, on the one hand, the rotation of the galaxy makes it difficult to move stars radially outward. On the other hand, such motions are easier if the gravitational potential has been disturbed. A change in the potential can occur if the galaxy is perturbed by galaxy interactions, or depending on the dark matter content, if an extreme starburst results in the gas being blown out of the center and into the outer parts.

But, could stars form out there? Observational evidence suggests that models for the formation of gas clouds due to gravitational instabilities in the disk fail in irregulars generally and especially so in the outer parts. It was suggested that the thermal phase of the gas might be more important, but such models also generally fail for dIm disks. It was suggested that gas disk instabilities suggested to explain the formation of holes seen in the outer HI disks of some irregulars could result in interstices with higher column densities that might be able to form stars. Another idea was that the outer gas could be, for whatever reason, in gas clouds too small to be detected in current interferometric observations, and stars might be forming without massive stars so that star-forming regions are not detectable in current Hα surveys. Since some extended HI disks around irregulars are found to be highly structured and others are very smooth, it was suggested that there might be a difference in the star formation in the outer regions of these two sets of galaxies. Perhaps this difference could be seen in the surface brightness profile or the colors in the extreme outer parts of the galaxies.

The second question posed was "What are the parallels between the outer parts of spirals and irregulars, and between these regions and LSB galaxies?" The outer parts of spirals are still more metal-rich than most irregulars. While magnetic pressure may dominate the ISM pressure in the outer parts of spirals, less is known about the magnetic field in irregulars. Spirals also show a strong decrease in the fraction of cold neutral medium vs warm neutral medium outside the star-forming disk. We were reminded that spirals have more shear due to differential rotation in their outer parts than do irregulars. Azimuthally-averaged surface brightness profiles of both LSB and dIm galaxies show a break in the slope, with the outer parts declining in surface brightness more steeply than the inner parts; the cause of this break is not known. The outer parts of both spirals and irregulars show low-density gas with faint populations of old and intermediate-age stars.

A third question that was raised was "Is there any real evidence for significant accretion onto galactic disks?" Accretion is predicted by cosmological and chemical evolution models, and is proposed as the source of X-ray emission around galactic halos. IC 10, for example, is interacting with a gas cloud that is believed to be falling into it. High velocity clouds are seen around our Galaxy, but massive ones have not been found around other galaxies. The X-ray emission convincingly appears to result from massive star feedback. The participants were hard pressed to think of solid observational evidence for significant external accretion.

REFERENCES

Sandage, A. 1962, in Problems of Extragalactic Research, ed. G. C. McVittie (New York: Macmillan Co.), p 359

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