

CHEMICAL ENRICHMENT OF THE GALACTIC AND INTRA-CLUSTER MEDIUM

Cesare Chiosi

The program deals with the problem of chemical evolution of the interstellar medium in galaxies (our own included) and the intracluster medium in clusters of galaxies. The subject of chemical evolution was started long ago and ever continued. The program splits in two parts:

(1) The chemical evolution of galaxies

Studies in this areas date back to the late seventies with the first formulation of the so-called infall model (Chiosi 1980) ever since adopted in the international literature on models for the chemical enrichment of the solar vicinity, the Galactic Disk, the galaxies in general. Over the years the subject has been repeatedly addressed depending on novelties from the theory of stellar yields and the growing interest toward semi-empirical models mimicking the chemical history in galaxies of different morphological type. The work done in the past five years is a continuation along this tradition however with important significant improvement in particular the multizone fully coupled description of radial flows of gas across the Galactic Disk (Portinari & Chiosi 2000).

(2) The chemical evolution of the intracluster medium

The subject is relatively new. It stems from (i) the study of the consequence of a variable IMF on chemical yields and the possibility that the IMF in the range of Massive stars may vary with the galaxy mass (steeper in low mass galaxies) and the redshift of galaxy formation (flatter at increasing redshift); (ii) the fact that previous studies on the subject did not tighten up the abundance of metals and of gas together but treated them separately will inconclusive results. The model we have proposed consider a galaxy cluster as whole and in analogy to the case of the interstellar medium it consider the galaxies and their yields of elements are responsible for the gas consumption and chemical enrichment. The results, although not fully satisfactory, are on the right track. Finally, the problem is addressed of the most plausible stellar IMF compatible with the amounts of metals and gas in a galaxy cluster showing that the classical Salpeter law is not compatible with the data.

Project 1: THE CHEMICAL EVOLUTION OF GALAXIES

(1) Marigo P. *Chemical yields from low- and intermediate-mass stars: Model predictions and basic observational constraints.* (2001). *Astronomy and Astrophysics*, vol. 370, pp. 194-217

In this work we analyse the role of low- and intermediate-mass stars in contributing to the chemical enrichment of the interstellar medium. First we present new sets of stellar yields basing on the results of updated evolutionary calculations, which extend from the ZAMS up to the end of the AGB phase (Girardi et al. 2000; Marigo et al. 1999a). These new yields, that present a significant dependence on metallicity, are then compared to those of other available sets (Renzini & Voli 1981; van de Hoek & Groenewegen 1997). The resulting differences are explained in terms of different model assumptions - i.e. treatment of convective boundaries, mass loss, dredge-up, hot-bottom burning - and further discussed on the basis of important empirical constraints which should be reproduced by theory - i.e. the initial-final mass relation, white dwarf mass distribution, carbon star luminosity function, and chemical abundances of planetary nebulae. We show that present models are able to reproduce such constraints in a satisfactory way.

(2) Portinari L. & Chiosi C. *On radial gas flows, the Galactic Bar and chemical evolution in the Galactic Disc.* (2000). *Astronomy & Astrophysics*, vol. 355, pp. 929-948

We develop a numerical chemical model allowing for radial flows of gas, with the aim to analyse the possible role of gas flows in the chemical evolution of the Galactic Disc. The dynamical effects of the Galactic Bar on the radial gas profile of the Disc are especially addressed.

Previous studies on this topic

(i) On star formation and chemical evolution in the Galactic disc. Portinari L., Chiosi C. 1999. *Astronomy & Astrophysics*, 350, pp.827-839

The abundance gradients and the radial gas profile of the Galactic disc are analysed by means of a model for the chemical evolution of galaxies. As one of the major uncertainties in models for galaxy evolution is the star formation (SF) process, various SF laws are considered, to assess the response of model predictions to the different assumptions. Only some SF laws are successful in reproducing the metallicity gradient, and only if combined with a suitable infall timescale increasing outward (inside-out formation scenario). Still, it is difficult to reproduce at the same time also the observed gas distribution; we therefore suggest further improvements for the models.

(ii) Galactic chemical enrichment with new metallicity dependent stellar yields. Portinari L., Chiosi C., Bressan A. 1999. *Astronomy & Astrophysics*, vol. 334, pp. 505-539

New detailed stellar yields of several elemental species are derived for massive stars in a wide range of masses (from 6 to 120 $M_{\odot}$) and metallicities ($Z = 0.0004, 0.004, 0.008, 0.02, 0.05$). Our calculations are based on the Padova evolutionary tracks and take into account recent results on stellar evolution, such as overshooting and quiescent mass-loss, paying major attention to the effects of the initial chemical composition of the star. We finally include modern results on explosive nucleosynthesis in SNe by Woosley & Weaver (1995). The issue of the chemical yields of Very Massive Objects (from 120 to 1000 $M_{\odot}$) is also addressed. Our grid of stellar yields for massive stars is complementary to the results by Marigo et al. (1996, 1998) on the evolution and nucleosynthesis of low and intermediate mass stars, also based on the Padova evolutionary tracks. Altogether, they represent a complete set of stellar yields of unprecedented homogeneity and self-consistency. Our new stellar yields are inserted in a code for the chemical evolution of the Galactic disc with infall of primordial gas, according to the formulation first suggested by Talbot & Arnett (1971, 1973, 1975) and Chiosi (1980). As a first application, the code is used to develop a model of the chemical evolution of the Solar Vicinity, with a detailed comparison to the available observational constraints.

Project 2: THE CHEMICAL EVOLUTION OF THE INTRA-CLUSTER MEDIUM

(1) Chiosi C. *Gas and iron content of galaxy cluster.* (2000). *Astronomy & Astrophysics*, vol. 364, pp. 423-442

Up to now, many theoretical studies aimed at reproducing the total amount of iron and gas in the intra-cluster medium meet the embarrassing situation, in which if the iron content is reproduced, the gas is not. More precisely, at given iron mass, too little gas and too high Fe abundance in turn are obtained as compared to the observational data. Large dilution by primordial gas is then invoked to get rid of the difficulty. In this paper we present a new approach to this problem. Basic ingredients of the present analysis are: (i) The adoption of multi-zone models of elliptical galaxies in the framework of the super-nova driven galactic wind scheme. They yield a more realistic description of the galactic ejecta in which the effects of gradients in star formation and chemical enrichment are taken into account. (ii) The stellar initial mass function is let vary with the physical conditions of the star forming medium. More

precisely, the typical mass scale of the initial mass function increases with the gas temperature. Since no cooling process exists decreasing the temperature of a galaxy's gas below the limit set by the current value of the cosmic background radiation, it immediately follows that the stellar initial mass function of proto-galaxies whose stellar activity began at high red-shift (when the CBR temperature was higher than the present-day mean temperature of molecular clouds) is different from the one in galaxies which did the same but at lower red-shift. Because of this, at given galaxy mass the ejecta are expected to depend on the red-shift. (iii) Finally, the basic assumption is made that at any time (red-shift) the mass distribution of proto-galaxies follows the Press-Schechter law holding for Dark Matter, however with masses comprised between suitable minimum and maximum values, $M_{L}^{\min}$ and M_{L}^* , respectively, that are also varying with time and/or red-shift. This is equivalent to assume a sort of continuously varying mass function for galaxies as well. When the same input physics (stellar initial mass function and galactic ejecta) is adopted, the new method recovers previous results in literature. However, when the above three ingredients are let work simultaneously, the total amount of iron and gas are reasonably matched, a point of major difficulty in previous studies. The absolute abundance of Fe and abundance ratio [O/Fe] are fully compatible with the observational determinations. However, even in this case some dilution (up to about 20%) by primordial gas (never cycled through galaxies) seems to be required. This is less than the older estimates of 65% to 90%. Finally, a simple model for the evolution of the intra-cluster medium abundances as a function of the red-shift is presented and compared with the observational data for clusters at high red-shift (up to $z \approx 0.5$).

(2) Moretti A., Portinari L., Chiosi C. *Chemical evolution of the intra-cluster medium.* (2003). *Astronomy & Astrophysics*, vol. 408, pp. 431-453

The high metallicity of the intra-cluster medium (ICM) is generally interpreted on the basis of the galactic wind scenario for elliptical galaxies. In this framework, we develop a toy model to follow the chemical evolution of the ICM, formulated in analogy to chemical models for individual galaxies. The model computes the galaxy formation history (GFH) of cluster galaxies, connecting the final luminosity function (LF) to the corresponding metal enrichment history of the ICM. The observed LF can be reproduced with a smooth, Madau-plot like GFH peaking at $z \sim 1-2$, plus a "burst" of formation of dwarf galaxies at high redshift. The model is used to test the response of the predicted metal content and abundance evolution of the ICM to varying input galactic models. The chemical enrichment is computed from "galactic yields" based on models of elliptical galaxies with a variable initial mass function (IMF), favouring the formation of massive stars at high redshift and/or in more massive galaxies. For a given final galactic luminosity, these model ellipticals eject into the ICM a larger quantity of gas and of metals than do standard models based on the Salpeter IMF. However, a scenario in which the IMF varies with redshift as a consequence of the effect of the cosmic background temperature on the Jeans mass scale appears to be too mild to account for the observed metal production in clusters. The high iron-mass-to-luminosity-ratio of the ICM can be reproduced only by assuming a more dramatic variation of the typical stellar mass, in line with other recent findings. The mass in the wind-ejected gas is predicted to exceed the mass in galaxies by a factor of 1.5-2 and to constitute roughly half of the intra-cluster gas.

(3) Portinari L., Moretti A., Chiosi C., & Sommer-Larsen J. *Can a "Standard" Initial Mass Function Explain the Metal Enrichment in Clusters of Galaxies?* (2004). *The Astrophysical Journal*, vol. 604, issue 2, pp. 579-595

It is frequently debated in literature whether a "standard" initial mass function (IMF)-meaning an IMF of the kind usually adopted to explain the chemical evolution in the local solar neighbourhood-can account for the observed metal enrichment and iron mass-to-light ratio in clusters of galaxies. We address this problem by means of straightforward estimates that should hold independently of the details of chemical evolution models. It is crucial to compute self-consistently the amount of mass and metals locked-up in stars by accounting for the stellar mass-to-light ratio predicted by a given IMF. It then becomes clear that a "standard"

solar neighbourhood IMF cannot provide enough metals to account for the observed chemical properties in clusters: clusters of galaxies and the local environment must be characterized by different IMFs. Alternatively, if we require the IMF to be universal, in order to explain clusters such an IMF must be much more efficient in metal production than usually estimated for the solar vicinity. In this case, substantial loss of metals is required from the solar neighbourhood and from disk galaxies in general. This ``non-standard" scenario of the local chemical evolution would challenge our present understanding of the Milky Way and of disk galaxy formation.

Personnel:

Cesare Chiosi (PO),
Alessandro Bressan (Astron.A),
Paola Marigo (R),
Laura Portinari (Post-doc),
Alessia Moretti (Post-doc)

Collaborations:

EARA collaboration, MPA (Garching, Germany)
Osservatorio Astronomico di Padova (INAF),
TAC Copenhagen (Denmark),

Research products:

From NASA-ADS, referred to all the 4 programmes presented:
117 refereed articles
151 proceedings (mainly refereed)
by the following authors: Chiosi, Marigo, Cararo, Girardi, Nasi, Bertelli, Salasnich, Piovan, Tantalo, Pasetto, Vallenari, Moretti, Portinari, Ragaini.