JOINT COMMISSION MEETINGS ON

STELLAR ABUNDANCES AND STELLAR ROTATION

(Commissions 29, 36, 45)

Chairman M. Hack

STELLAR ATMOSPHERES AND CHEMICAL COMPOSITIONS OF GALAXIES

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ABSTRACT:
The chemical compositions of external galaxies are usually found from their HII regions or composite absorption line spectra of their nuclei. In the Magellanic Clouds, however, individual stars are observable, but objects heretofore studied necessarily have been luminous Ia supergiants which border on the brink of instability. The image photon counting system on the Anglo-Australian Telescope makes it possible to observe fainter, more stable Ib supergiants. Energy distributions and Balmer line profiles for these stars can be fitted with theoretical predictions by Kurucz. A joint effort by J.E. Ross and B.J. O'Mara of the University of Queensland, Bruce Peterson of the Anglo-Australian Observatory, and a group at the University of California, Los Angeles to analyze three Ib supergiants suggests that metals of the iron group are depleted by a factor of 2-3.5 with respect to the normal chemical composition of our own galaxy. * * *

A knowledge of chemical compositions of external galaxies is important. To derive luminosities in galaxies in remote clusters by comparing them with objects in nearby clusters of presumably known distance we should know the rates at which colors and absolute magnitudes of involved stars change with time. Aside from dynamical evolution effects, galaxies suffer modifications because of changing stellar luminosity functions. The luminosity of every star that contributes to a galaxy's total brightness is a function of its mass, age, angular momentum, and chemical composition. Hence, the brightness and color of a galaxy at any epoch is influenced by its chemical evolution

What we want to do is to compare chemical compositions of other galaxies with our own, both with respect to lighter elements formed in the carbon-nitrogen-oxygen cycle, on the one hand, and those such as iron that are formed in more spectacular events such as supernova detonations, on the other.

Certain important light elements are observable in HII regions; these can be studied in remote as well as nearby galaxies. Efficient

Patrick A. Wayman (ed.), Highlights of Astronomy, Vol. 5, 811–815.

devices such as the image dissector scanner (IDS) and the image photon counting system (IPCS) reach much fainter emission lines than heretofore. Background "noise" from unresolved stars smothers faint lines; stellar absorption may affect Balmer lines. Simple formulae for extrapolating total elemental abundances from ionic concentrations have been justified, or sometimes replaced by theoretical models. The most advanced of these are the self-consistent models constructed by Searle and Shields (1978) for M101. Here the theoretical stellar energy fluxes, which fix the ionizing radiation fields in HII regions, are calculated from stellar atmospheres of the same chemical composition as the nebular gas itself. In many galaxies, the metal/H ratio appears to decline with distance from the center. Alas, all systems that show this effect are so remote that individual stars are unobservable.

Nuclear and integrated spectra of galaxies have been observed intensively. One assumes appropriate luminosity functions, sundry chemical compositions, etc., and predicts colors, flux distributions, and line intensities. As an example, we cite Ms. Faber's (1972) model for the M31 nuclear region, which suggests many very metal-rich giant stars.

The great opportunity offered by the Magellanic Clouds is that we can compare results from both HII regions and supergiants and assess chemical composition differences over a wide range in atomic number. High dispersion spectroscopy probably never can be pushed beyond the Clouds, but for fainter stars therein and for other members of the local group we may be able to use Stromgren's narrow band pass filters. By this technique, McNamara (1979) found no evidence for metal deficiency in Classical Cepheids of the Large Magellanic Cloud (LMC).

Recent analyses of HII regions in the LMC agree better than some spectroscopic analyses of a given star (see Table 1). Aller et al. (1979) used the method of model nebulae; the other investigators used simple extrapolation procedures to get elemental abundances from ionic concentrations. For own own galaxy, we use three diverse samples: Orion Nebula (the best studied HII region), a B2.5V star, γ Pegasi, and the sun, the composition of which pertains to an earlier epoch of the interstellar medium. No reliable solar helium abundance is available. The solar neon abundance is adopted from solar cosmic ray data by Biswas (1975) and some results by Acton et al. (1975). The last column of Table 1 is Δ log N(LMC)/N(galaxy). Although a depletion factor of 2-3 appears valid for O, Ne, S, and Ar, that of N is greater. In the LMC, He shows evidence of less stellar processing (Peimbert and Torres-Peimbert [1974]).

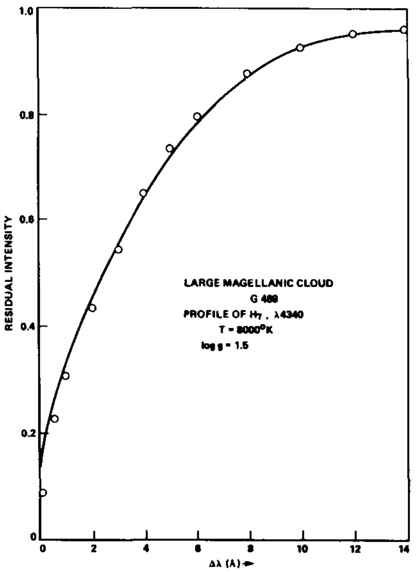
The pioneering efforts of Przybylski (1971, 1972) and of subsequent workers all involved luminous Ia stars on the brink of instability. Comparable stars in our galaxy, e.g., Deneb (A2Ia) or Rigel (B8Ia) have complex atmospheric motions and shell ejection (Paddock [1935]; Lamars et al. [1978]; Kondo et al. [1975]). In his theoretical study of F-type supergiants, Osmer found both temperature and pressure inversions in subphotospheric layers. In such supergiants, assumptions of plane parallel layers, LTE, and simple kinematics do not seem justified.

Table 2

Comparison of Abundances in G421 and G489 With Solar Values
(Effective Temperature = 8000°K, log g = 1.5 for G421 and G489)

	^{I}log A			Δ (Sun - Star)	
Ion	G421	G489	Sun	G421	G489
FeI	6.76 ± 0.54	7.00	7.50	0.7	0.5
FeII	6.84 ± 0.53	7.00	7.50	0.7	0.5
TiII	4.27 ± 0.34	4.53	5.05	0.8	0.5
CrII	5.07 ± 0.40	5.40	5.71	0.7	0.3
VII	4.4 ± 1.4	4.4	4.02	-0.4	-0.2
ScII	2.28 ± 0.14	2.6	3.04	0.8	0.4
MnI	4.64 ± 0.33	5.4	5.42	0.6	0.0
SrII	1.05 ± 0.05?		2.90	1.8:	

galactic star is too luminous. The spectrum of G447 is strange. It shows prominent lines of helium, CII λ4267, MgII λ4481, and strong CaII H and K lines with displaced components that are too broad for a shell feature. The Kurucz models for T = 8000°K, log g = 1.5 seemed to fit the energy distributions and Balmer profiles well for G421 and G489 (see Figs. 1, 2). Although ionization balance for Fe in G489 fits T = 7500, log g = 1.5 best, the errors are large and the ionization temperature may be as high as 8500°K. As compared with the sun, the



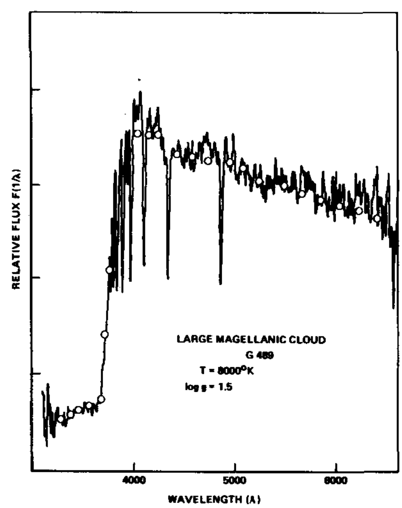


Fig. 1. Flux Distribution in G489.
Fig. 2. (Left) H Line Profile in G489.
Circles indicate theoretical values, solid lines indicate the observations.

https://doi.org/10.1017/S1539299600004780 Published online by Cambridge University Press

Table 1

Comparison of Large Magellanic Cloud HII Regions With Our Own Galaxy
log A = log N(element)/N(H) + 12.00

	Large Magellanic Cloud					Our Galaxy				
El	AKC	PEFW	D	PTP	Adopt	Orion	γ Peg	Sun	Adopt	Δ
He	10.94		10.89	10.90	10.91	11.00	10.96		11.00	0.09
N	7.02	6.88	6.80	7.10	6.90	7.76	7.82	7.94	7.8	0.9
O	8.43	8.39	8.43	8.58	8.43	8.75	8.66	8.34	8.75	0.32
Ne	7.77	7.61	7.64	7.94	7.74	7.90	8.54	8.1	8.0	0.26
S	6.90	6.8	7.15		6.9	7.41	7.23	7.2	7.4	0.5
Ar	6.35	6.35	7.10		6.35	6.7	6.7	6.0	6.7	0.35

AKC: Aller, Keyes, and Czyzak (1979)
PEFW: Pagel, Edmunds, Forsbury, and Webster (1978)
D: Dufour (1975)
PTP: Peimbert and Torres-Peimbert (1974)
Orion: Peimbert and Torres-Peimbert (1977)
γ Peg: Peters (1976)
Sun: Ross and Aller (1976), except for Ne

From a discussion of then-available analyzes by Przybylski (1971), by Wares et al. (1968), and by Wolf (1972) for the LMC and by Osmer (1973), Przylbylski (1972) and Wolf (1973) for the SMC, van den Bergh (1975) concluded that although SMC stars showed a small metal deficiency, those in the SMC were strongly deficient. Fry and Aller (1975), using a spectral synthesis method on R59, a G4Ia LMC supergiant, concluded it to be deficient in iron-group metals. Wolf (1973), however, argued for essentially solar abundances in both the LMC and SMC. His conclusions cannot be reconciled with HII region data (Table 1), with studies of evolutionary tracks (Hagen et al. [1974]), or with short-period cut-offs in Cepheids (Robertson [1973]).

The basic trouble seems to be that Ia stars have unstable atmospheres, not amenable to interpolation by usual or even unusual theoretical models. It is better to choose stars of higher surface gravities, smaller radii, and lower luminosities: Ib stars with M = -6 or even -3.5 or -4 are preferable to M = -8 supergiants. The Anglo-Australian telescope equipped with IPCS enables one to get reasonably high spectral resolution and good energy distributions for such stars. In December, 1978, B.J. O'Mara, J.E. Ross, and Bruce Peterson obtained data for the LMC stars G421, G447, and G489 of spectral classes A2Ib, B8Iab, and A2Ib, respectively. HD 92207 was chosen as comparison star.

At UCLA, we employed a fine analysis curve of growth program due to J.E. Ross together with Kurucz's (1979) grid of LTE model atmospheres. The Balmer profiles and energy fluxes for HD 92207 did not match theoretical predictions; the Balmer lines were too narrow and shallow. This iron depletion in G489 drops from a factor of 8 at 7500°K to 1.7 at 8500 but a solar iron abundance would require temperatures and gravities that would not fit the Kurucz models. The G421 data likewise admit a higher temperature and therefore a lower metal depletion. We emphasize the preliminary character of the results given in Table 2. Assigning the greatest weight to G489 and to Fe, Ti, and Cr (which have the most lines), we find a mean depletion factor of about 2-3.5, comparable with that found for O, Ne, S and Ar. Further work is underway.

We are grateful for help provided by UCLA research students who analyzed individual stars, viz.: J. Weiland and R. Downes (G421), R. Ciardullo and A. Shafter (G447), J. Becker and P. Etzel (G489). C.D. Keyes supervised handling programs in the UCLA campus computing network which supplied a helpful allotment of time. We are grateful to the director and staff of the Anglo-Australian Observatory and to the UCLA research committee for travel support.

REFERENCES

Acton, L.W., Catura, P.C., and Joki, E.G.: 1975, Astrophys. J. 195, L93.
Aller, L.H., Keyes, C.D., and Czyzak, S.J.: 1979, Proc. N. Acad. Sci. 76, 1525.
Biswas, S.: 1975, Bull. Astr. Soc. India 3, Nr. 4.
Dufour, R.: 1975, Astrophys. J. 195, 315.
Faber, S.: 1972, Astron. Astrophys. 20, 361.
Fry, M. and Aller, L.H.: 1975, Astrophys. J. Suppl. 29, 55.
Hagen, G.L. and van den Bergh, S.: 1974, Astrophys. J. 189, L103.
Kondo, Y., Morgan, T.H., and Modisette, J.: 1975, Astrophys. J. 198, L37.
Kurucz, R.L.: 1979, Astrophys. J. Suppl. 40, 1.
Lamars, H., Stalio, R., and Kondo, Y.: 1978, Astrophys. J. 223, 307.
McNamara, D.B.: 1979, paper given at Astron. Soc. Pacific meeting.
Osmer, P.S.: 1973, Astrophys. J. 184, L127.
Osmer, P.S.: 1972, Astrophys. J. Suppl. 24, 255.
Paddock, G.: 1935, Lick Observatory Bulletin, 17, 99.
Pagel, B.E., Edmunds, M.G., Forsbury, R., and Webster, B.L.: 1978, Mon. Not. Roy. Astr. Soc. 184, 569.
Peimbert, M. and Torres-Peimbert, S.: 1974, Astrophys. J. 193, 327.
Peimbert, M. and Torres-Peimbert, S.: 1977, Mon. Not. Roy. Astr. Soc. 179, 217.
Peters, G.D.: 1976, Astrophys. J. Suppl. 30, 551.
Przylbylski, A.: 1971, Mon. Not. Roy. Astr. Soc. 152, 197.
Przylbylski, A.: 1972, Mon. Not. Roy. Astr. Soc. 159, 155.
Robertson, J.W.: 1973, Astrophys. J. 185, 817.
Ross, J.E. and Aller, L.H.: 1976, Science 191, 1223.
Searle, L. and Shields, G.A.: 1978, Astrophys. J. 222, 821.
van den Bergh, S.: 1975, Ann. Rev. Astron. Astrophys. 13, 217.
Wares, G.W., Ross, J.E., and Aller, L.H.: 1968, Astrophys. and Space Sci. 2, 244.
Wolf, B.: 1972, Astron. Astrophys. 20, 275.
Wolf, B.: 1973, Astron. Astrophys. 28, 335.