J/ApJ/829/116 H-band spectroscopic analysis of 25 bright M31 GCs (Sakari+, 2016)

Infrared high-resolution integrated light spectral analyses of
M31 globular clusters from APOGEE.
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Abstract:
Chemical abundances are presented for 25 M31 globular clusters (GCs), based on moderately high resolution (R=22500) H-band integrated light (IL) spectra from the Apache Point Observatory Galactic Evolution Experiment (APOGEE). Infrared (IR) spectra offer lines from new elements, lines of different strengths, and lines at higher excitation potentials compared to the optical. Integrated abundances of C, N, and O are derived from CO, CN, and OH molecular features, while Fe, Na, Mg, Al, Si, K, Ca, and Ti abundances are derived from atomic features. These abundances are compared to previous results from the optical, demonstrating the validity and value of IR IL analyses. The CNO abundances are consistent with typical tip of the red giant branch stellar abundances but are systematically offset from optical Lick index abundances. With a few exceptions, the other abundances agree between the optical and the IR within the 1σ uncertainties. The first integrated K abundances are also presented and demonstrate that K tracks the α elements. The combination of IR and optical abundances allows better determinations of GC properties and enables probes of the multiple populations in extragalactic GCs. In particular, the integrated effects of the Na/O anticorrelation can be directly examined for the first time.

Description:
H-band spectra (1.51-1.69um) of the target clusters were obtained with the moderately high resolution (R=22500) APOGEE spectrograph on the 2.5m Telescope at Apache Point Observatory in 2011 and 2013. The details of the observations can be found in Majewski+ (2015arXiv150905420M) and Zasowski+ (2013AJ....146...81Z), including descriptions of the plates and fibers that were utilized for the observations.

The high-resolution optical abundances from Colucci et al. (2009, J/ApJ/704/385 and 2014ApJ...797..116C) are supplemented with new results for five globular clusters (GCs).
The new optical spectra were obtained in 2009 and 2010 with the High Resolution Spectrograph on the Hobby-Eberly Telescope at McDonald Observatory in Fort Davis, TX (R=30000; spectral coverage over ~5320-6290 and ~6360-7340Å in the blue and the red, respectively).

File Summary:

FileName	Lrecl	Records	Explanations
ReadMe	80	.	This file
table1.dat	80	25	Target list
table2.dat	55	25	Mean H-band abundances and random errors: Fe, C, N, and O
table3.dat	79	25	Mean H-band abundances and random errors: Na, Mg, Al, Si, Ca, and Ti
table7.dat	85	5	Observation information and derived isochrones for new optical data
table8.dat	57	134	Line list for optical abundances

See also:
V/143 : Revised Bologna Catalog of M31 clusters, V.5 (Galleti+ 2012)
J/AJ/151/144 : ASPCAP weights of 15 APOGEE chemical elements (Garcia+, 2016)
J/ApJS/221/24 : SDSS-III APOGEE H-band spectral line lists (Shetrone+, 2015)
J/ApJ/813/97 : M62 (NGC 6266) giant branch stars abundances (Lapenna+, 2015)
J/AJ/149/153 : Abundances of red giants in 10 GCs (Meszaros+, 2015)
J/MNRAS/434/358 : 4 Galactic globular clusters Fe line depths (Sakari+, 2013)
J/ApJ/773/L36 : NGC 5128 globular cluster abundances (Colucci+, 2013)
J/ApJ/746/29 : High-resolution GC abundances. IV. 8 LMC GCs (Colucci+, 2012)
J/AJ/143/14 : Lick indices of M31 globular clusters (Schiavon+, 2012)
J/AJ/141/61 : Star clusters in M31. II. (Caldwell+, 2011)
J/A+A/508/1285 : Metallicity estimates of M31 GCs (Galleti+, 2009)
J/A+A/507/1375 : HST/ACS VI data of M31 globular clusters (Perina+, 2009)
J/ApJ/704/385 : M31 integrated light abundances (Colucci+, 2009)
J/A+A/505/139 : Abundances of red giants in 17 GCs (Carretta+, 2009)
J/AJ/137/94 : Star clusters in M31 (Caldwell+, 2009)
J/AJ/133/2764 : M31 globular clusters structural parameters (Barmby+, 2007)

J/AJ/123/2490 : RV and [Fe/H] of M31 globular cluster system (Perrett+, 2002)

Byte-by-byte Description of file: table1.dat

Bytes	Format	Units	Label	Explanations
1- 4	A4	---	Bol	Cluster name
5	A1	---	---	[-]
6- 9	A4	---	SKHB	Other cluster name
11- 13	A3	---	f_Bol	Flag(s) on Bol (1)
15- 16	I2	h	RAh	Hour of right ascension (J2000) (2)
18- 19	I2	min	RAm	Arcminute of right ascension (J2000)
21- 24	F4.1	s	RAs	Arcsecond of right ascension (J2000)
26	A1	---	DE-	Sign of declination (J2000) (2)
27- 28	I2	deg	DEd	Degree of declination (J2000) (2)
30- 31	I2	arcmin	DEm	Arcminute of declination (J2000)
33- 36	F4.1	arcsec	DEs	Arcsecond of declination (J2000)
38- 42	F5.2	kpc	Rproj	[1.7/18.3] Pojected distance from the center of M31 (2)
44- 48	F5.2	mag	Vmag	[14/16.6] V-band magnitude (2)
50- 54	F5.2	mag	Hmag	[11.2/13.5] H-band magnitude (2)
56- 60	A5	---	Epoch	Observing epoch(s) (Clusters were observed in 2011 and/or 2013)
62- 63	I2	---	Nv	[3/11] Number of visits (3)
65- 69	F5.2	---	S/N	[7.9/65.8] Signal-to-noise ratio (4)
71- 76	F6.1	km/s	HRV	[-555/-54] Heliocentric velocity
78- 80	F3.1	km/s	e_HRV	[0.3/1] HRV uncertainty

Note (1): Flag as follows:
d = Some visits were affected by superpersistence (see text). The superpersistence regions are masked out, leading to lower S/N in the 1.51-1.62um region; some abundances are derived with unmasked spectra and have been flagged in subsequent tables.
e = All visits were affected by superpersistence. Spectral range of this cluster is limited due to superpersistence; see Section 2.2.
f = A background galactic component was subtracted during data reduction.
Note (2): Positions, projected distances from the center of M31, and magnitudes are from the Revised Bologna Catalog (Galleti+ 2012, V/143).
Note (3): Each visit is 66.6min of integration.

Note (4): Signal-to-noise ratios (S/Ns) are per pixel and represent the median value across the entire spectral range. There are approximately 2.06 pixels per resolution element in the blue, 2.27 in the green, and 2.66 in the red.

Byte-by-byte Description of file: table2.dat

Bytes	Format	Units	Label	Explanations
1- 4	A4	---	Bol	Globular cluster ID
6- 10	F5.2	---	[FeI/H]	[-1.9/-0.1] The H-band FeI abundance
12- 15	F4.2	---	e_[FeI/H]	[0.03/0.2] [FeI/H] uncertainty
17- 18	I2	---	NFeI	[2/13] Number of measured lines for [FeI/H]
20- 24	F5.2	---	[C/Fe]	[-0.6/-0.03] [C/Fe] abundance (5)
26- 29	F4.2	---	e_[C/Fe]	[0.04/0.2] [C/Fe] uncertainty
31	I1	---	NC	[1/5] Number of measured lines for [C/Fe]
33- 36	F4.2	---	[N/Fe]	[0.9/1.4] [N/Fe] abundance (5)
38- 41	F4.2	---	e_[N/Fe]	[0.04/0.2] [N/Fe] uncertainty
43	I1	---	NN	[1/8] Number of measured lines for [N/Fe]
45- 48	F4.2	---	[O/Fe]	[0.07/0.6] [O/Fe] abundance (5)
50- 53	F4.2	---	e_[O/Fe]	[0.03/0.8] [O/Fe] uncertainty
55	I1	---	NO	[1/5] Number of measured lines for [O/Fe]

Note (5): CNO abundances are determined from the CO, CN, and OH molecular lines in Smith et al. (2013ApJ...765...16S), assuming $^{12}C/^{13}C=6$ (see the text).

Byte-by-byte Description of file: table3.dat

Bytes	Format	Units	Label	Explanations
1- 4	A4	---	Bol	Globular cluster name
6- 9	F4.2	---	[Na/Fe]	[0.3/0.7]? H-band Na abundance
11- 14	F4.2	---	e_[Na/Fe]	[0.05/0.2]? [Na/Fe] uncertainty
16	I1	---	NNa	[1/2]? Number of measured lines for [Na/Fe]
18- 22	F5.2	---	[Mg/Fe]	[-0.2/0.5]? H-band Mg abundance
24- 27	F4.2	---	e_[Mg/Fe]	[0.05/0.2]? [Mg/Fe] uncertainty
29	I1	---	NMg	[1/4]? Number of measured lines for [Mg/Fe]
31- 34	F4.2	---	[Al/Fe]	[0.1/0.7]? H-band Al abundance
36- 39	F4.2	---	e_[Al/Fe]	[0.05/0.2]? [Al/Fe] uncertainty

41	I1	---	NAl	[1/2]? Number of measured lines for [Al/Fe]
43	A1	---	f_NAl	[a] Flag on NAl (6)
45- 48	F4.2	---	[Si/Fe]	[0.1/0.6] H-band [Si/Fe] abundance
50- 53	F4.2	---	e_[Si/Fe]	[0.05/0.2] [Si/Fe] uncertainty
55	I1	---	NSi	[1/5] Number of measured lines for [Si/Fe]
57- 60	F4.2	---	[Ca/Fe]	[0.2/0.5]? H-band [Ca/Fe] abundance
62- 65	F4.2	---	e_[Ca/Fe]	[0.05/0.4]? [Ca/Fe] uncertainty
67	I1	---	NCa	[1/4]? Number of measured lines for [Ca/Fe]
69- 72	F4.2	---	[Ti/Fe]	[0.2/0.5]? H-band [Ti/Fe] abundance
74- 77	F4.2	---	e_[Ti/Fe]	[0.07/0.2]? [Ti/Fe] uncertainty
79	I1	---	NTi	[1/3]? Number of measured lines for [Ti/Fe]

Note (6):
a = This H-band abundance was derived from at least one strong line with -4.7<REW -4.5, which may lead to systematic uncertainties of ~0.1dex (McWilliam+ 1995AJ....109.2757M).

Byte-by-byte Description of file: table7.dat

Bytes	Format	Units	Label	Explanations
1- 4	A4	---	Bol	Globular cluster ID
6- 45	A40	---	Date	UT dates of observation
47- 51	I5	s	Texp	[10565/16200] Exposure time
53- 55	I3	---	S/N	[120/250] 6000Å signal-to-noise ratio (1)
57- 62	F6.1	km/s	HRV	[-516/-120] Heliocentric radial velocity
64- 66	F3.1	km/s	e_HRV	[0.5/1] HRV uncertainty
68- 72	F5.2	km/s	sigma	[10.5/17] Velocity dispersion
74- 76	F3.1	km/s	e_sigma	[0.4/0.6] sigma uncertainty
78- 82	F5.2	---	[Fe/H]	[-1.7/-0.6] Isochrone metallicity
84- 85	I2	Gyr	Age	[11/14] Age

Note (1): S/N is per resolution element; there are 2.7 pixels per resolution element.

Byte-by-byte Description of file: table8.dat

Bytes	Format	Units	Label	Explanations
1- 8	F8.3	0.1nm	lambda	[5324/7326.2] Spectral line wavelength; Angstroms
10- 13	A4	---	El	Element and ionization state
16- 20	F5.3	eV	EP	[0/6] Excitation Potential
22- 27	F6.3	---	loggf	[-5.8/0.7] Log oscillator strength
29- 33	F5.1	10-13m	B006EW	[21/120]? B006 Equivalent width; milliAngstroms
35- 39	F5.1	10-13m	B063EW	[15/114.1]? B063 Equivalent width; mÅ
41- 45	F5.1	10-13m	B171EW	[26/143]? B171 Equivalent width; milliAngstroms
47- 51	F5.1	10-13m	B311EW	[13/149]? B311 Equivalent width; milliAngstroms
53- 57	F5.1	10-13m	B472EW	[11/118]? B472 Equivalent width; milliAngstroms

History:
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(End) Prepared by [AAS], Emmanuelle Perret [CDS] 15-Dec-2016