# Hot-Am stars as intermediary objects to the HgMn and Am stars

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**Abstract.** We describe the early results of an investigation into the spectral characteristics of the hottest Am stars (A0 - A2) in an attempt to link the HgMn and Am classes of chemical peculiarity. A limited sample of hot-Am stars was searched for the presence of lines from the very heavy elements platinum and mercury, as well as a search for lines from the rare-earth elements in HgMn stars. Our analysis of the strong optical platinum and mercury lines in the spectrum of the HgMn star HR 7775 has detected isotopic shifts that are different from those found at ultraviolet wavelengths and, in the case of mercury, vary with ionization stage.

**Key words:** Stars: abundances – Stars: chemically peculiar

## 1. Introduction

The creation of stellar groupings by spectral characteristics is an often necessary first step in being able to explore underlying physical processes. The descriminating, or classification, criteria are often chosen arbitrarily from available observational data and without regard for the physical mechanisms which create them. Thus, a single physical process may be responsible for the variation of spectral characteristics over a great range of temperature or luminosity. In some sense, the warm chemically peculiar stars may be overclassified. Various subclasses exist which are loosely arranged by temperature or enhanced element, but they are now beginning to loose their identity and purpose as additional elements and spectral regions are explored.

We describe here the analysis procedure and early results of a project that has been undertaken to ascertain the extent of common spectral properties amongst warm chemically peculiar star groups. Our motivation is to test the theoretical hypothesis that diffusive element separation in the stellar atmosphere acts throughout the HgMn and Am star temperature range to create the abundance and isotopic anomalies observed (Michaud 1991). The concept that the Am and HgMn stars may be a related sequence can be traced back to Smith (1974) and perhaps even earlier, and has since been reiterated by others. However, an insufficient amount of evidence has been produced to either prove or disprove this assertion.

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The well accepted, but perhaps arbitrary, boundary at spectral type B9.5/A0 separates the HgMn stars from the realm of the cooler, metallic-lined A (Am) stars. The classical Am stars are usually limited to spectral types later than A3. More recently the term *hot-Am* star has found its way into the literature, representing those stars within the A0 - A3 subclasses whose spectra display a certain degree of Am star spectral characteristics, most notably an apparent deficiency of calcium and/or enhancements of iron-group element lines. We are particularly interested in exploring the A0 - A2 stars for signs of an extension of the HgMn phenomenon to cooler temperatures as well as the B8 - A0 stars as an extension of the Am star phenomenon to hotter temperatures.

## 2. Defining intermediary objects

If we are to recognize objects exhibiting both the HgMn and Am star phenomena we must first consider the defining qualities of each of these classes. Let us start by ignoring their classic definitions, as these were set up in an era that predates satellite ultraviolet observations, and is solely based upon the blue optical region. However, the first and second ions dominate the spectrum for late-B through mid-A type stars, with most of their strongest transitions occurring at ultraviolet wavelengths. Therefore, our thinking regarding the classification of peculiarity, and its implication for the responsible physical processes, must be expanded to include the clues found at ultraviolet wavelengths.

For the cooler HgMn stars the defining characteristics must include the great line strength enhancements of the very heavy elements (VHE) Pt, Au, and Hg. Abundance anomalies for other elements, such as P, Ga, Mn, Tl, and Bi, have either been identified for a subgroup of stars or have yet to be thoroughly investigated. From a variety of studies it can be stated that the iron-group element abundances can be enhanced by up to 1 dex, which is also typical of the iron-group elements among the Am stars. The identification of rare-earth element (REE) lines in HgMn stars has, up to now, received little attention. Guthrie (1985) noted the likely occurrence of lines from Nd II, Nd III, and Pr III in the spectrum of HR 7775, but "no other rare earths were found in HR 7775, and no rare earth lines were detected in any of the other Hg-Mn stars".

For the Am stars the relative weakness of calcium and scandium lines compared to those of iron, along with the presence of the REE are notable characteristics. Abundance enhancements for the heaviest elements (Pt, Au, Hg) have not been identified in Am stars at optical wavelengths, which has lead to the general belief that these elements are not enhanced above solar-system levels.

From these simplistic characterizations we have chosen to search for the presence of REE lines in HgMn stars and VHE lines in Am stars as indicators of a common, albeit continuously varying, physical process that connects these two stellar groups. Other common spectral properties are already known, i.e. the abundance levels for light elements (He, C, N, O) and iron-group elements, for example. The literature provides few explicit examples of stars that display spectrum features common to both groups.

## 3. Observational data

Optical region spectral observations of HgMn, hot-Am, and Am stars were made at the 2.6-m Nordic Optical Telescope during 1996 November. The SOFIN echelle spectrograph was operated at a resolving power of R = $\Delta\lambda/\lambda = 80000$, with a single grating setting at blue wavelengths including the lines Pt II 4046, 4061, 4288, Au II 4052, Hg I 4358, and Hg II 3984 Å. Each spectral observation consists of partial data from 14 contiguous orders. Typical signal-to-noise levels in the primary orders of interest were in excess of 100:1 and in some cases as large as 200:1. Details of the observations and data reduction will be presented in a later publication. We have supplemented the optical data with ultraviolet IUE satellite high-dispersion spectra when available.

## 4. The analysis procedure

The detection and analysis of platinum and mercury lines in Am stars depends critically upon the use of synthetic spectra due to the crowded nature of the line spectrum in the blue spectral region. The Hg II $\lambda$3984 line is further complicated by being blended with the lines Fe I $\lambda$3983.7 and Cr I $\lambda$3983.8 Å. The presence of an absorption feature at 3984 Å can be traced from the HgMn stars through the Am stars, but the relative contributions of the mercury, iron, and chromium lines varies with temperature and abundance. Other mercury and platinum lines have their own blending concerns. For example, the strongest optical Pt II line, at $\lambda$4046 Å, is blended with a weak line of Hg I. Our line data for the platinum and mercury transitions accounts for their complicated hyperfine and isotopic structures, both from recent wavelength measurements with the Lund Fourier Transform spectrometer (Wahlgren et al. 1998a) and literature sources (Engleman 1989, Kalus et al. 1998).

We have determined the influence of blending lines by analysing the spectra of 68 Tau and $\theta$ Leo. From IUE spectra of Hg II $\lambda$1942 one sees that these stars have only weak, if any, contribution from mercury. Therefore, we do not expect to see the intrinsically weaker, optical region lines of mercury (or platinum). The rotational velocity and the abundances of Fe I and Cr I were determined from optical lines possessing experimentally determined oscillator strengths. These abundances were then used to evaluate the f-values of the blending lines to the optical region platinum and mercury lines.

After establishing the atomic-line data we proceeded to synthesize the spectra of the HgMn and Am stars. Model atmospheres were computed from the code ATLAS9 based upon stellar atmospheric parameters derived from the uvby photometric calibration of Moon & Dworetsky (1985). The synthetic spectrum program SYNTHE and the atomic line data of Kurucz (1993) were used to compute the synthetic spectra, with the exception of alterations that we have made for the heavy element line data, the hyperfine structure of Y II 3982 Å, and the $gf$-value for Fe I $\lambda$3983.7 Å (O'Brien et al.1991).

## 5. Early results

The presence of rare-earth elements has previously been noted in the spectra of the cool, HgMn stars $\chi$ Lupi (Wahlgren et al. 1994) and HR 7775 (Wahlgren et al.1998a) at optical wavelengths. We therefore speculate that other, if not all, cool HgMn stars also display REE lines. Although it is difficult to assess the exact abundance levels for the REE from their third spectra, due to a lack of oscillator strength data, an abundance enhancement on the order of 1 to 2 dex is obtained from lines of the singly-ionized state. This enhancement level is similar to that found in Am stars.

Our high-resolution optical spectra have enabled us to study the isotopic shifts in the platinum and mercury lines found in the spectrum of the HgMn star HR 7775. Observations of isotopic shifts represent important tests of diffusion theory. We were unable to satisfactorily fit the observed mercury lines with synthetic spectra that were computed assuming a mercury isotopic mixture based upon the q-formalism of White et al.(1976). By trial and error selection we were able to identify a difference in the isotopic mixture between Hg II 3984 Å and Hg I 4358 Å, where the former presents a mixture of $^{202}$Hg : $^{204}$Hg = 40:60 and the latter line a terrestrial-like mixture. For each of the three Pt II lines an essentially similar isotope mixture of $^{195}$Pt : $^{196}$Pt : $^{198}$Pt = 10:60:30 provided good fits to the observed features. However, this platinum isotope mixture is different from that obtained from ultraviolet transitions by Kalus et al.(1998). The potential significance of this difference lies in the excitation energies of the transitions studied and the possibility that their isotopic variations (for Pt and Hg) are depth dependent in the stellar atmosphere. This would provide strong evidence for the effects of diffusion. Further details are presented by Wahlgren et al.(1998a).

Our optical region search for VHE in hot-Am stars (Sirius, o Peg, HR 3383, $\alpha$ Gem) has not yielded positive identifications. The spectrum of HR 3383 did show promise for a mercury enhancement in the Hg II $\lambda$3984 line at the detection limit. However, further analysis showed that the enhancement could be reproduced with an abundance variation of 0.05 - 0.10 dex for iron and chromium. The calculations show that for the hot-Am stars a mercury abundance enhancement of [Hg/H] = + 3 dex would be easily noticeable in the 3984 Å feature, with a minimum detection limit set at approximately [Hg/H] = + 2.5 dex. As a further check on the possibilty of a mercury enhancement in HR 3383, the IUE high-dispersion spectrum was investigated. The Hg II $\lambda$1942 line is present in HR 3383 at a strength nearly identical to that found in Sirius ([Hg/H] = + 1.5, Wahlgren et al. 1998b). The three stars Sirius, HR 3383, and o Peg (Wahlgren et al. 1993) all display the Hg II $\lambda$1942 line at a mercury enhancement of 1 - 1.5 dex. This value is remarkable for two reasons. First, if the abundance enhancement level for the Am stars only approaches a level of +1.0 to +1.5 dex, then by virtue of the difference in oscillator strength of approximately 1.7 dex between the strong Hg II lines at 1942 and 3984 Å, we would not expect to notice the presence of enhanced mercury at optical wavelengths. Thus, the B9.5/A0 boundary for the HgMn stars would be applicable as a classification criterion at *optical* wavelengths. Secondly, the solar system abundances for platinum and mercury are poorly defined, the latter only from s-process systematics. This therefore raises the question of whether the abundance of platinum and mercury in hot-Am stars is a reflection of the galactic abundance at a later epoch of star formation than that of the sun, or the result of a reduced degree of diffusion relative to the HgMn stars.

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