Spectroscopic Observations of YY Orionis Stars at La Silla

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Trailblazing observations of stars in late stages of their initial formation were carried out some months ago by two astronomers from the Landessternwarte Heidelberg-Königstuhl, FRG, Drs. C. Bertout and B. Wolf. Spectroscopy with the ESO 1.5 m telescope on La Silla during twelve consecutive nights revealed dramatic spectral changes, and simultaneous photometric observations at the new observatory near San Pedro Martir, Baja California, Mexico, are now being reduced.

What are the YY Orionis Stars?

Back in 1961, M. F. Walker noticed that the T Tauri-like variable YY Orionis showed displaced absorption components located at the red edges of certain emission lines. At that time, ideas about the pre-main-sequence stellar evolution were still mostly of a qualitative nature, and no particular attention was paid to his discovery. In 1969, however, R. B. Larson published the first calculations of protostellar collapse, which indicated that the protostar grew by accretion of matter from the surrounding interstellar cloud. The model predicted that the new-born star would be imbedded in a free-falling envelope for as long as a million years (in the case of a 1 $M_\odot$ star). It also predicted that the star should be optically visible during a major part of this time.

In 1972, Walker suggested that YY Orionis was indeed such a protostar at the end of its hydrodynamic evolution. He based this supposition on the redward displacement of the absorption components of the Balmer emission lines, which indicate that the absorbing material has a recession velocity of at least 300 km s^{-1} with respect to the observer. This velocity is in good agreement with the end velocities of the infalling matter computed in theoretical collapse models for a 1 $M_\odot$ protostar. In the same paper, Walker reported the discovery of several other T Tauri-like stars showing line profiles similar to YY Orionis, and introduced the term "YY Orionis stars".

Like most of the T Tauri stars, each of the YY Ori stars has its own peculiarities, thus making it difficult to define clear-cut class characteristics. However, the basic properties of the YY Ori stars can be summarized as follows. They are T Tauri variables, and most of them possess a strong ultraviolet excess, defined by $U-B \lesssim 0$. Certain emission lines, in particular the hydrogen Balmer lines, sometimes exhibit a displaced absorption component at the red edge of the emission. Such line profiles are called YY Orionis profiles, or inverse P-Cygni profiles. In their other properties, YY Ori stars resemble T Tauri stars: their spectrum is often "veiled" by continuous emission in the blue and visual spectral ranges, so that it is often difficult to discern their photospheric late-type spectrum. Also, most YY Ori stars exhibit strong IR excess. YY Ori stars, like other T Tau stars, are aperiodic fast variables; large variations of the Balmer line profiles are recorded on time scales of hours to days, and variations of the continuum level and UV excess are indicated by photometric measurements. Examples of observed profile variations are given in the following sections.

One can easily understand the fascination that these stars exert on us. In the menagerie of young stellar objects, most of which show some evidence of mass loss rather than mass infall, and whose properties are still largely unexplained, the YY Ori stars are the only link between the observed pre-main-sequence evolution and today's pre-main-sequence evolutionary models. Detailed studies of these objects cannot only help us to gain insight into the early phases of stellar evolution, but can also be used to test the validity of proposed theoretical models.

A Search for "Bright" YY Ori Stars

The YY Ori stars listed by Walker (1972) are rather faint, with m_v between the 13th and 15th magnitude. Detailed spectroscopic investigations of these stars are therefore very difficult. In order to find additional and possibly brighter YY Ori stars, a spectroscopic survey is being carried out by several observers of the Heidelberg Observatory. Slit spectrograms of young emission-line stars suspected to belong to the YY Ori class are being taken.

The brightest YY Ori star so far, S Coronae Australis, was found by Appenzeller during his May 1976 observing run at the ESO 1.5 m spectroscopic telescope. This star was

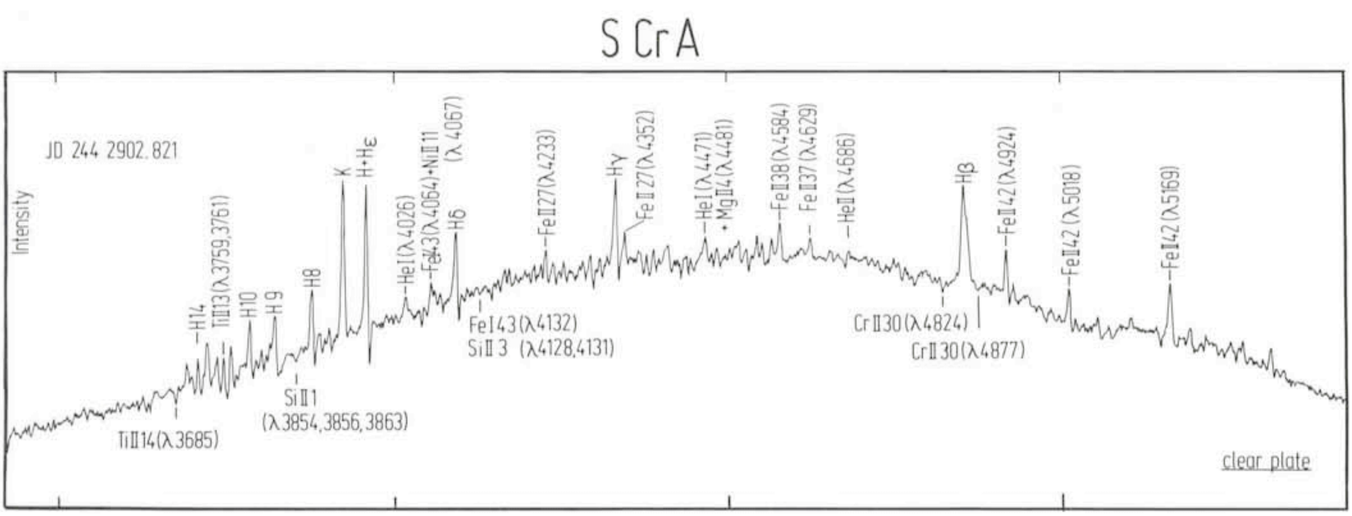

Fig. 1: *Intensity tracing of the spectrum of S CrA. The most prominent emission lines are identified. The inverse P Cygni of the higher Balmer lines (from Hγ on) and the strong Fe II lines are clearly discernible.*

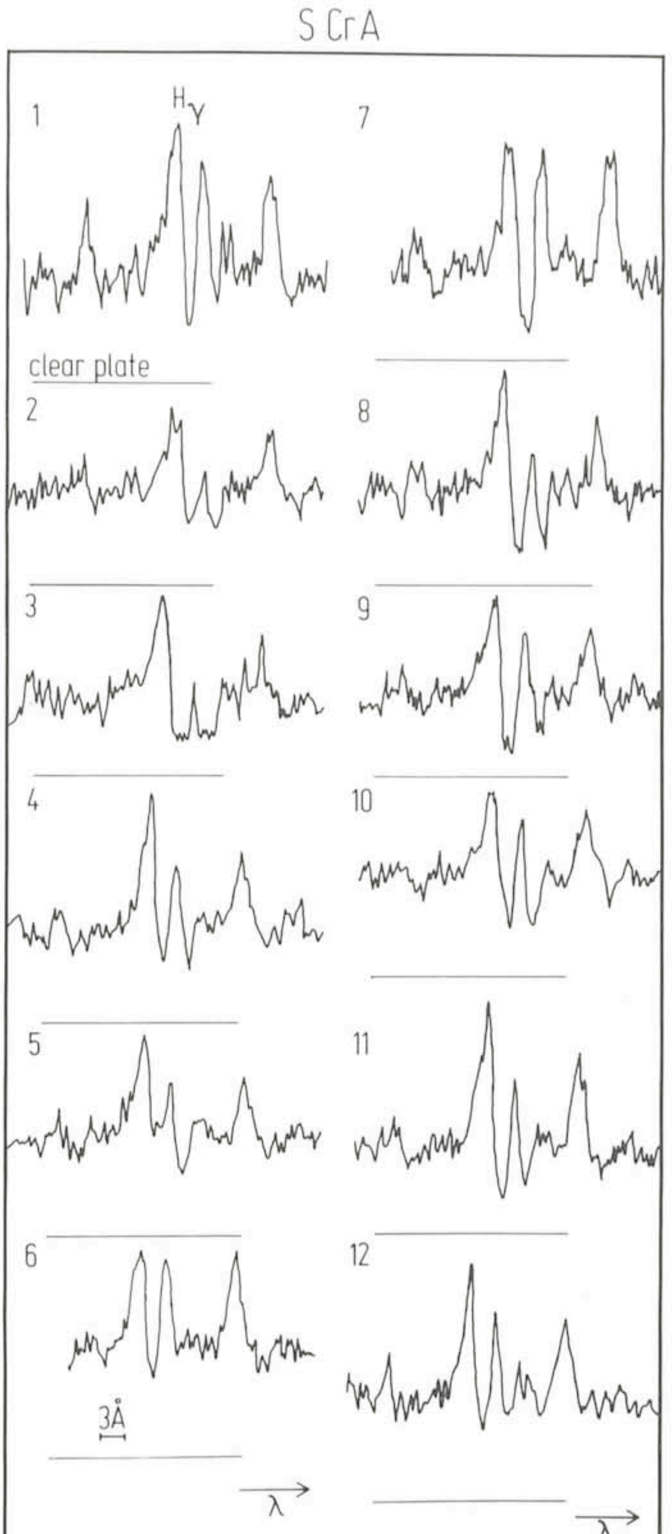

Fig. 2: *Intensity tracings of the Hγ profiles of high-dispersion (20 Å/mm) spectrograms of the YY Ori star S CrA. The coudé plates 1 to 12 were taken during twelve consecutive nights (one per night) between April 15, 1978 and April 27, 1978.*

known as a T Tauri-like variable, but apparently its prominent inverse P Cygni-line profiles had never been detected in earlier spectroscopic observations. S CrA, which is associated with the molecular cloud NGC 6729, has a mean visual magnitude of $11^{m}.5$; and its range of variations is $\Delta m_v \simeq 0.8$.

The spectrum of S CrA is described in detail in two papers (*Astron. Astrophys.* **54,** 713, and **58,** 163). In figure 1, we show the intensity tracing of an image-tube spectrogram of this star. In spite of the rather moderate resolution (about 3 Å), the inverse P Cygni profiles of the Balmer lines (except Hβ) and of the strongest Fe II lines are readily recognized. Besides the hydrogen Balmer series and the Fe II lines, prominent He I (λλ 4026, 4471) and He II (λ 4686) emission lines are present in the spectrum. The helium lines are undisplaced and never exhibit absorption com-

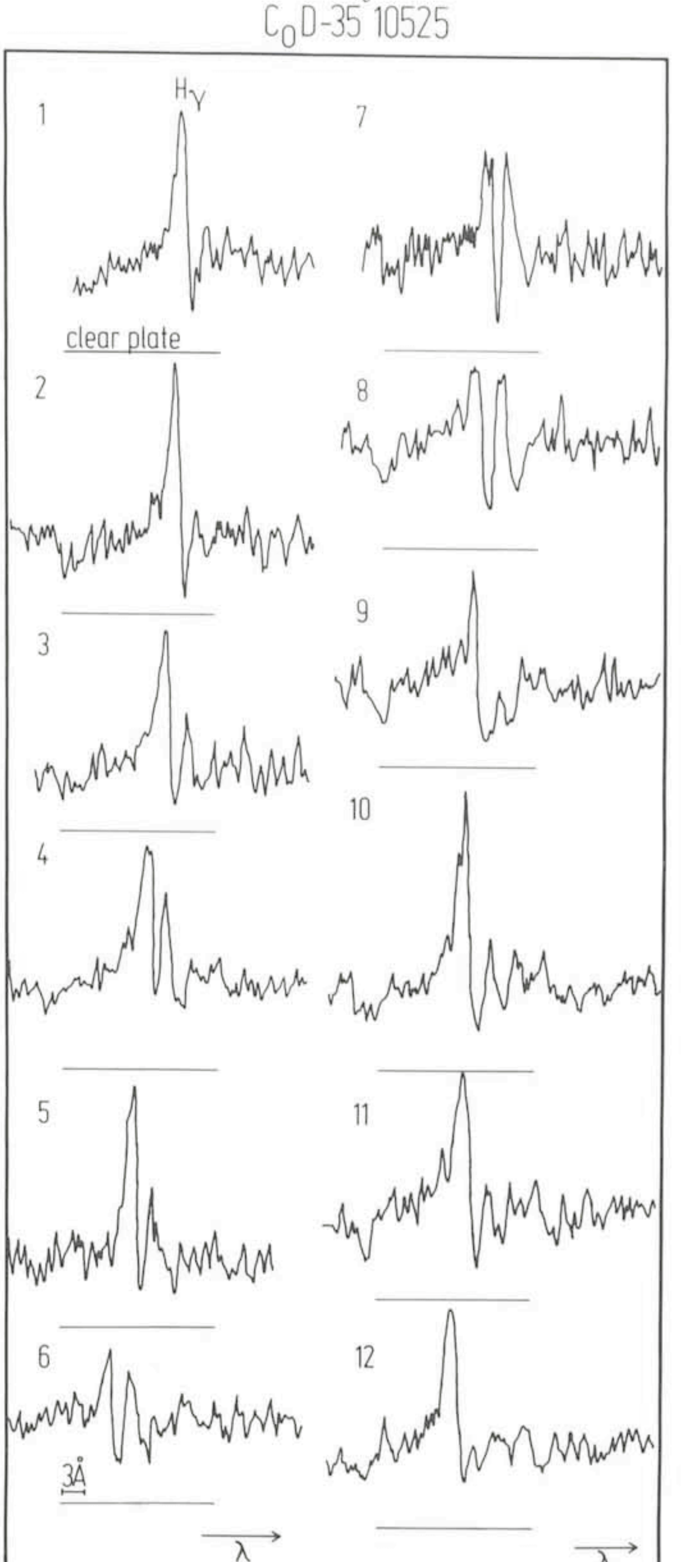

Fig. 3: *Same as for figure 2 for CD –35° 10525.*

ponents. Their occurrence is typical of YY Ori stars and requires excitation and ionization temperatures of about 30,000 to 50,000 °K.

The second in brightness among the YY Ori stars reported so far is CD −35° 10525, with an average brightness $V = 11^m.6$. This star is associated with the elongated interstellar dust cloud Barnard 228 in Lupus. The membership of CD −35° 10525 to the YY Ori subclass of the T Tauri variables was first established by Mundt and Wolf during an observing run in July 1977 at La Silla. The spectrum of CD −35° 10525, described in *Astron. Astrophys.* **63.** 289, is again characterized by inverse P Cygni-line profiles, especially of the Balmer lines. However, this star shows fewer emission lines in the blue spectral range than S CrA. For example, Fe II does not show up in emission. Also in contrast to S CrA, CD −35° 10525 exhibits absorption features characteristic of an underlying late-type spectrum of spectral type around M0.

Coudé Observations and Balmer Line Profile Variations

The apparent brightness of the newly-discovered YY Orionis stars described above allows for high dispersion spectroscopic observations even with medium-sized telescopes. Highly-resolved spectrograms are very desirable because they allow a detailed comparison of the observed line profiles with profiles calculated using theoretical protostar models. To our knowledge, the first coudé observations in the blue spectral range of a YY Ori star were carried out in August 1976 at La Silla, using the 1.5 m ESO spectroscopic telescope. These observations revealed the rather complex structure of the S CrA Balmer line profiles with (besides the red-displaced absorption at 300 km s^{-1}) two emission peaks separated by a slightly blue-shifted (about −30 km s^{-1}) central absorption. A comparison of these profiles with theoretical line calculations allowed Wolf, Appenzeller and Bertout to present a possible configuration of the outer layers of S CrA (*Astron. Astrophys.* **58,** 163).

In order to study the full range of profile variations of the Balmer lines and to relate these variations to the continuum variability, one needs high dispersion spectroscopy and simultaneous photometry. Since the broad photometric bands are contaminated by the emission lines, standard UBV photometry is not suitable to determine the continuum level exactly. What one needs here is narrow-band photometry. We therefore applied for observing time at the coudé ESO spectrograph at La Silla, and at the 1.5 m photometric telescope of the Mexican National Observatory located at San Pedro Martir, Baja California, in a joint programme with Dr. Luis Carrasco. The 13-colour medium narrow-band photometric system developed by Johnson and available at San Pedro Martir is well suited to our purposes.

Simultaneous Observations in Chile and in Mexico

Twelve half nights were allotted to our project by ESO. Thanks to the flexibility of the Mexican organization, Dr. Carrasco was able to obtain observing time during the same period. The spectroscopic coudé observations of S CrA and CD −35° 10525 were carried out by Wolf and the simultaneous photometric observations, extending from 3300 Å to 1μ, were made by Bertout and Carrasco, from April 15 to 27, 1978. Due to the catastrophic floodings which occurred in Baja California last winter, the San Pedro Martir Observatory had to be closed from February until our arrival. We are very much indebted to the technical team whose efforts kept the station in working order during our run.

Thanks to the excellent weather and seeing conditions at La Silla, we could take the best advantage of the allotted observing time. We could take one camera I spectrogram of each of our two programme stars each night, i. e. we obtained a complete series of 24 spectrograms with a dispersion of 20 Å/mm. Due to the unusual climatic conditions, the weather in Baja California was not as good as in Chile. However, six and a half of our twelve nights were photometric, so that we also obtained extensive data for our programme stars.

A first glance at the intensity tracings of the spectrograms gained during this last observing run readily shows the existence of strong spectral variations. The complex structure of the Balmer line profiles and the profile variations are illustrated by the intensity tracings of Hγ shown in figures 2 and 3 for S CrA and CD −35° 10525. Especially the red-shifted emission component shows dramatic changes even within two consecutive nights. In fact, it can be seen from these tracings that we never observed the same profile shape twice. Unfortunately, the simultaneous photometric observations are not yet completely reduced, so that we cannot say much about possible correlations between profile strengths and continuum level. However, it is already apparent that spectacular changes in the energy distribution occur.

Now the most difficult part of the work remains to be done. That is, we must try to understand what physical mechanism might be responsible for these variations. Doing that will probably require even more luck than we had in coordinating the simultaneous observations in Mexico and Chile without a telephone connection!

FIRST ANNOUNCEMENT OF A EUROPEAN WORKSHOP ON

"Astronomical Uses of the Space Telescope"

The European Space Agency (ESA) and the European Southern Observatory (ESO) are jointly organizing a Workshop on "Astronomical Uses of the Space Telescope". It will be held in Geneva, on the premises of CERN, on February 12–14, 1979. The purpose of the Workshop is to give the European astronomical community an occasion to discuss in depth possible scientific programmes in various astronomical areas. A preliminary list of topics includes: Star Formation, Globular Clusters, Magellanic Clouds, External Galaxies, Active Nuclei of Galaxies, Clusters of Galaxies, Cosmology. Attention will also be given to the problem of ground-based observations required before the launch in order to optimize the use of the ST.

Scientists wishing to participate and possibly present a short contribution related to the use of the ST for performing specific programmes should write as soon as possible to the following address:

Dr. M. Tarenghi
ESO-CERN
1211 Geneva 23
Switzerland

The maximum number of participants will be about 120 persons.