THEORETICAL STUDIES OF CHROMOSPHERES AND WINDS IN COOL STARS

Grant NAGW-100

Semiannual Report No. 2

For the period 1 April 1981 through 30 September 1981

Principal Investigator

Dr. A. K. Dupree

November 1981

Prepared for
National Aeronautics and Space Administration
Washington, D.C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

The NASA Technical Officer for this grant is Dr. Edward J. Weller, Code SC-7, Headquarters, National Aeronautics and Space Administration, Washington, D.C. 20546.

THEORETICAL STUDIES OF
CHROMOSPHERES AND WINDS
IN COOL STARS

Grant NAGW-100

Semiannual Report No. 2

For the period 1 April 1981 through 30 September 1981

Principal Investigator

Dr. A. K. Dupree

November 1981

Prepared for
National Aeronautics and Space Administration
Washington, D.C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The NASA Technical Officer for this grant is Dr. Edward J. Weller, Code SC-7, Headquarters, National Aeronautics and Space Administration, Washington, D.C. 20546.

A paper entitled "Wave-Driven Winds from Cool Stars. I. Some Effects of Magnetic Field Geometry" by Hartmann and MacGregor is being submitted to *Ap. J.* This work investigated the effects of magnetic field divergence on isothermal wind solutions. It was found that while wave damping is still required to produce low wind velocities, the divergence effects can produce further reductions in the terminal velocities, helping to bring the theory into better agreement with observations. It was also noted that the opening of magnetic field lines may assist the non-linear development and subsequent damping of Alfven waves required by the theory.

We have pursued the question of radiative losses through study of plane- parallel chromospheres for low-gravity stars. A sample of these calculations, including losses from H, H-, Ca II, and Mg II is shown in Fig. 1. It can be seen that the cooling laws for the chromosphere of the supergiant star ϵ Gem do not differ greatly from the solar law, although there are differences at ~ 6000K due to ionization effects.

These results have encouraged us to adopt a rough standard law for the computation of stellar winds using the Hartmann - MacGregor theory. Using this cooling law, and using standard stellar evolutionary calculations we have produced a systematic exploration of wind velocities and temperatures in the HR diagram, adopting an initial magnetic field $B_o = 3$ gauss uniformly. The results of this are shown in Fig. 2. One finds that cool winds with temperatures <100,000K are not possible for log $g \geq 2$. This is in rough agreement with observations of the onset of stellar coronal and transition-region activity, and the disappearance of cool circumstellar shells.

The predicted wind velocities are ~ 1.5 to 2 x larger than observed, particularly for the most luminous cool stars. However, we feel this agreement is not bad, considering the probable importance of magnetic field geometry, and the uncertainties in assigning masses to M supergiants.

The wind temperature structure can be analyzed in more detail with the PANDORA computer program. We have calculated the ionization balance for the wind of α Ori (M2 Iab), in which the temperature is predicted to peak at around 6000K. With an estimate of the nonspherical effects in the radiative transfer solution, it is possible to predict the electron density and consequently the radio-free-free excess emission from the wind from various models. As seen in Fig. 3, it is possible to account for the observed radio excess emission of α Ori in this fashion.

With S. Edwards we have also combined the wind calculations with PANDORA solutions in order to compute hydrogen line profiles for T Tauri stars. We find that reasonable agreement with observation can be obtained with mass loss rates 10^{-1} to 10^{-2} of previous optical estimates. The reason for the discrepancy lies in the large wave amplitudes present, which provide line broadening far in excess of local expansion velocities.

Work is continung on the spherical transfer solution method necessary to place the foregoing PANDORA results on a more quantitative basis. A major objective of this research is to be able to determine the formation of spectral lines in expanding spherical atmospheres in a physically realistic way, taking into account the effects of optical thickness, departures from LTE, and partial frequency redistribution.

Most of the computer program development necessary for such calculations has been successfully carried out, and the remaining work should be finished by November 1981.

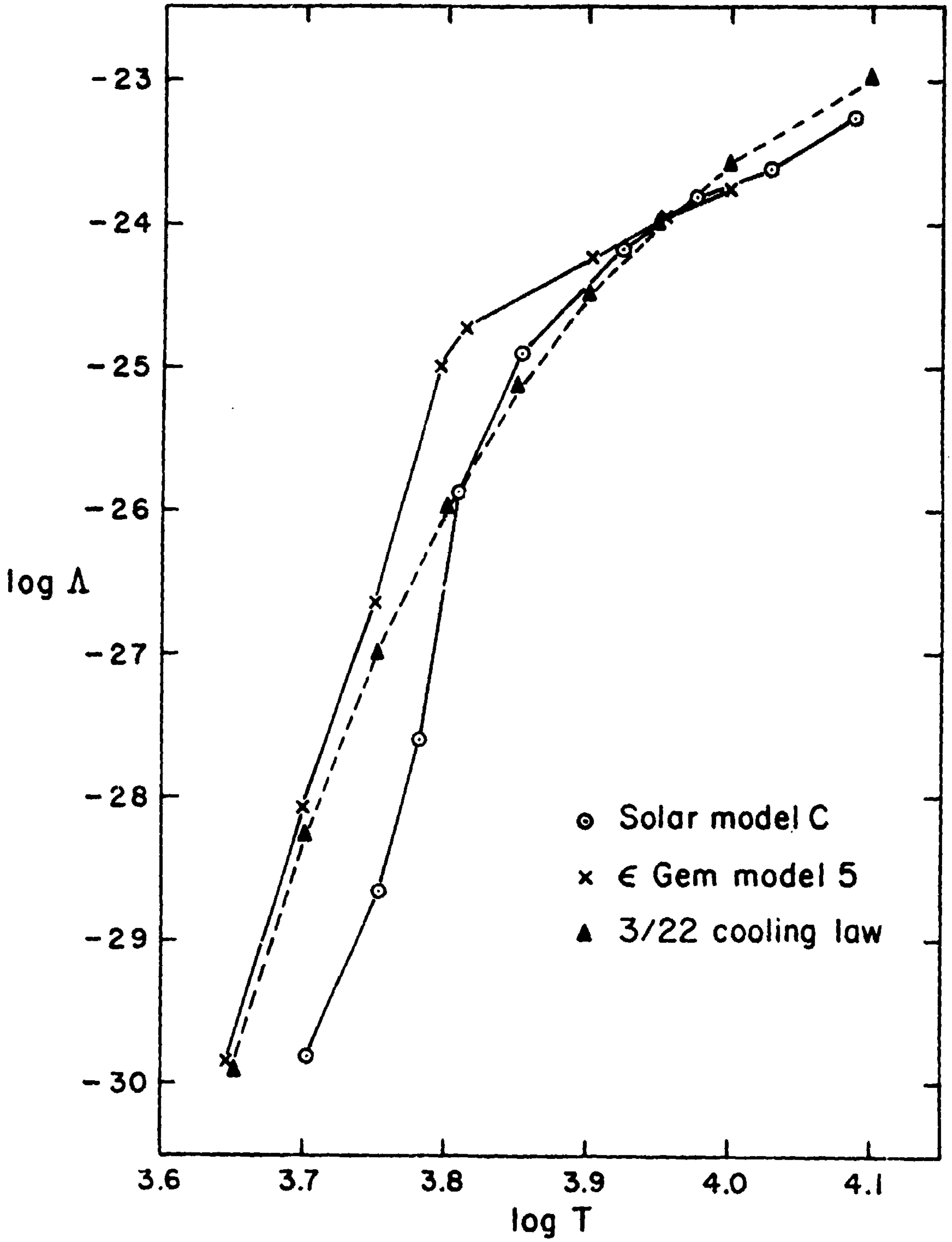

Fig. 1. Comparison of radiative cooling laws (in erg cm^{-3} s^{-1}) for the sun and for ε Gem with two rough cooling laws adopted for purposes of wind dynamical calculations.

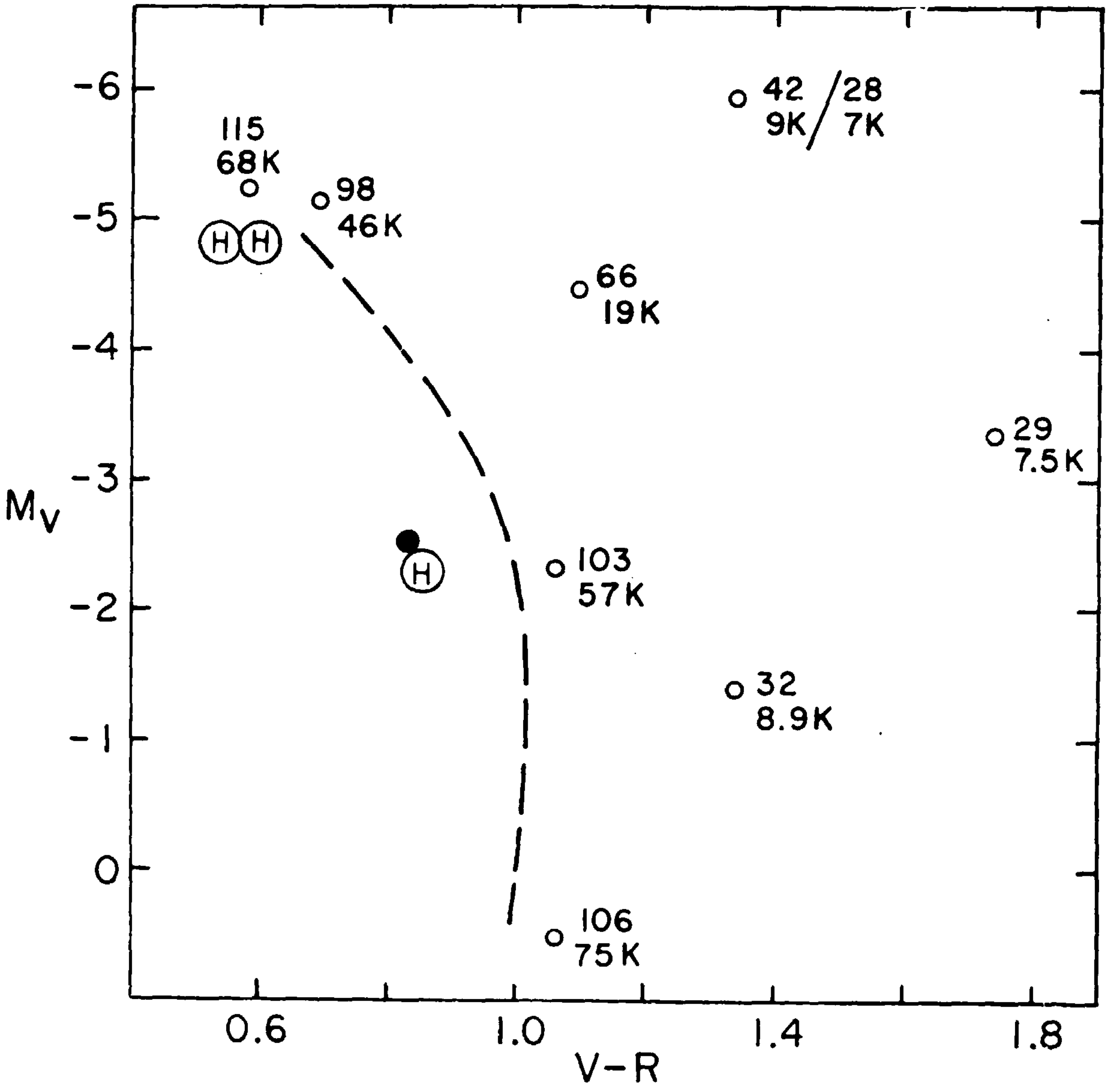

Fig. 2. HR diagram of wind results. The upper figure is the wind velocity in km s^{-1}; the lower label is the maximum wind temperature in $^{o}K/1000$. The dashed line is the approximate limit of cool winds ($T < 100{,}000K$); the solid symbol is a model for which no cool wind exists; and the circled H's represent hybrid stars, positioned near the observed circumstellar shell boundary.

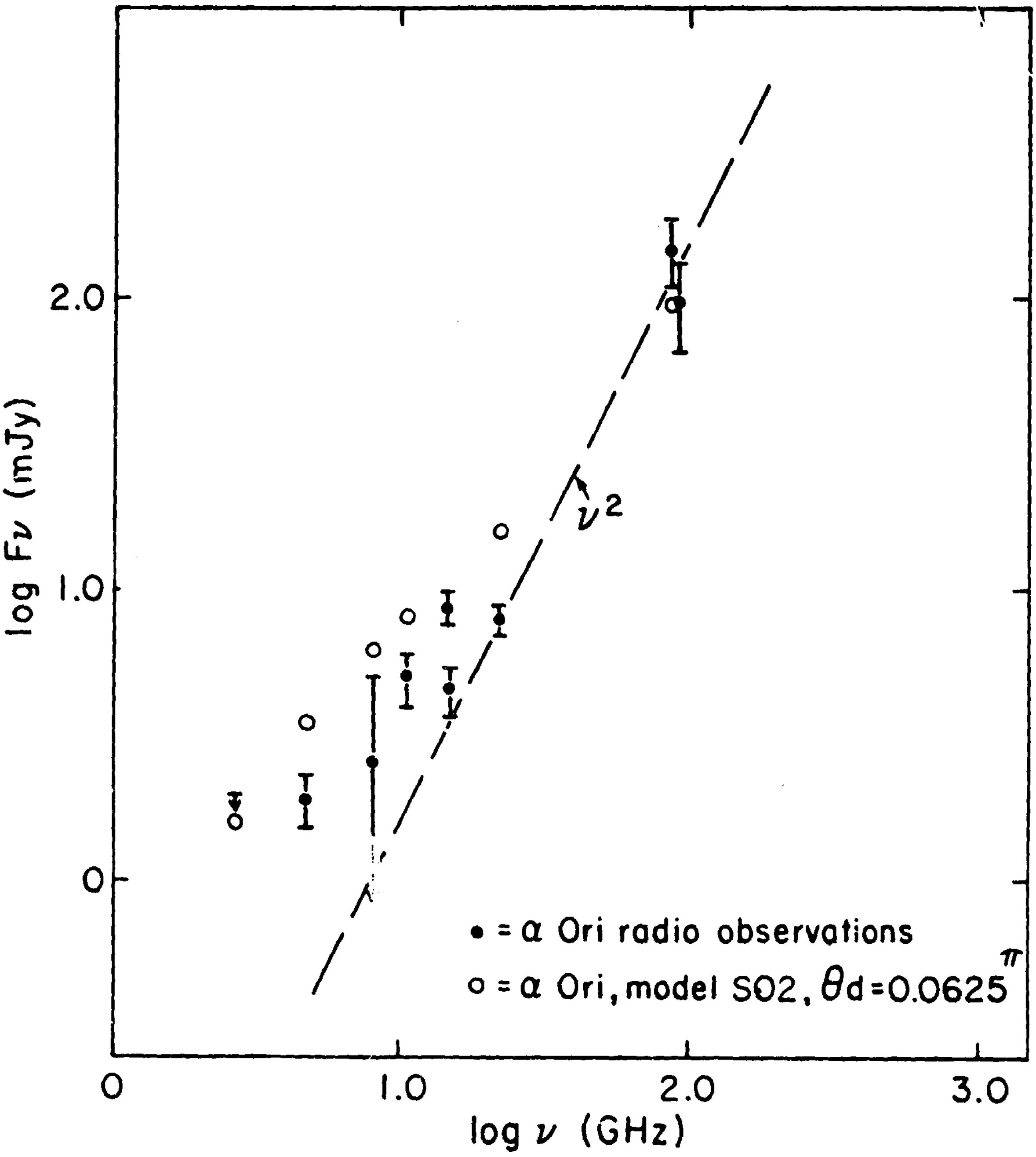

Fig. 3. Comparison of observed α Ori radio fluxes with those predicted by a model wind with $M = 10^{-6}$ $M_{\odot}$ yr^{-1} and T ~ 6000K.