Title
Place of Bohdan Paczynski in the Astronomical History

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Place of Bohdan Paczyński in the Astronomical History

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Abstract. From first paper (1958) to last (probably not yet published), Bohdan Paczyński contributed a truly remarkable number of ideas to a wide range of astronomical subfields. The current discussion attempts to provide an overview of his work and its impact, focusing on some aspects not emphasized in other presentations, including a few ideas that did not entirely pan out. I note also a number of awards, quotes, and other items that reflect his place in our collective folklore.

1. Introduction

To a generation of stellar evolutionists, he was "The Paczyński Code," though by the time of his death, Bohdan Paczyński was even better known as a very early, persistent advocate for the extragalactic origin of gamma ray bursts and as the father and godfather of several projects that have succeeded in finding gravitational lensing of stars by other stars (some with planets) and in setting firm upper limits to the numbers of dark lenses in the galactic halo. And there was yet another community who, if asked, "Where did you first learn about binary star evolution?" would say, "From the Paczyński review article (1971 ARA&A 9, 183)." Notice that references to his papers have been run into the text as well as listed with the references by other authors at the end of this proceeding.

The presentation that this proceeding summarizes began and ended with linguistic notes. Polish, like other Slavic languages, has no articles (a, an, the), and Paczyński remarked that, very early, he had learned roughly how many to put into each paragraph, but not where they should go. Thus my title has a slight Polish accent. We first met at the 1969 Stony Brook summer school on stellar structure and evolution (Chiu & Muriel 1972), where participants ran versions of his code non-stop for several days, and then carried home copies for their own use. We collaborated on several papers published in 1969-73, reflecting work done partly at the Institute of Theoretical Astronomy, Cambridge (where he visited briefly in the summer of 1970 - Fig. 1), and partly between California and Warsaw, with communication via airmail letters that had turn-around times of several weeks (due to reading, one supposes, by officials in both countries). We last met briefly at the June 2006 AAS meeting in Calgary, where he delivered the Russell Lecture (picture not reproduced, since he had aged much more gracefully than I).

Figure 1. Late summer 1970 staff photo of the Institute of Theoretical Astronomy, Cambridge. Second row from the top, left to right: three women secretarial staff, Nick Butler, Arthur Wolfe, Giancarlo Setti, Paczyński, P.C. Waylen, Douglas Gough, and Fisher Dilke. Front row, left to right: Stephen Hawking, Virginia Trimble, Martin Rees, Lodewijk Woltjer, Fred Hoyle, Jayant Narlikar, Donald Clayton, W.L.W. Sargent, William A. Fowler, Geoffrey Burbidge, Gary Steigman, and Phil Solomon. Sharp eyes and good memories may also spot, among others, Ed Salpeter, Douglas Heggie, Peter Eggleton, Joe Silk, Ron Ekers, Klaus Fricke, James Felton, John Sutton, Jean Audouze, Paul Davies, Vahe Petrosian and Dick Manchester (not in that order)

How did he get so much done? In a commentary on employment issues in England that appeared in a 10 September 2007 issue of a London paper, the editorialist said, "Until I started employing Poles, I had forgotten how much work one person could do in a day." He also managed always to be at the front end of the bandwagon, remarking on one occasion, "Well, once upon a time, everything was due to magnetic fields; then everything was due to black holes, and now everything is supposed to be mass transfer in close binaries." He had, by then, moved on beyond all three, having made marks on each.

Paczyński is the only astronomer ever to have scored a clean sweep of all the major awards of the Royal Astronomical Society - the Eddington Medal in 1987, the George Darwin Lectureship in 1995, and the Gold Medal in 1999. From the American Astronomical Society, he picked up only the Heineman Prize (1992), the Rossi Prize (2000), and the Russell (2006, for which his name is misspelled in the 2007 AAS directory). Why not the Warner Prize? In 1975 when he turned 35, the US did not yet know what it was missing (though that year's winners, Patrick Palmer and Ben Zuckerman, are also very impressive astronomers!).

Other honors began with an IAU Invited Discourse at the 1979 Montreal General Assembly, where the other two speakers were S. Chandrasekhar and G. Herzberg. All three titles (General Relativity in Astronomy, Molecular Spectroscopy in Astronomy, and Stellar Evolution and Close Binaries) would be plausible IDs for the upcoming 2009 GA. Along the way, Paczyński also swept up major awards from Germany, Poland, and the United States and memberships in their academies of science. Also, minor Planet 11755 is named for him.

In contrast, he undertook relatively few of the standard "support" roles within the astronomical community, serving as director of the Astronomical Institute in Warsaw for about a year (1976-77), between the terms of Piotrowski and Smak, and as vice-president (1973-76) and president (1976-79) of Commission 35 (C35; Stellar Constitution) of the International Astronomical Union, as part of an east-west oscillation (Alla Massevitch, Leon Mestel, Paczyński, Roger Tayler). Neither task appears on his most recent CV, and the major duty of the commission president, the preparation of a report of the significant astronomical advances during the triennium, was, BP later cheerfully recalled, carried out by Tayler.

2. The Early Career

Acta Astronomica began publication in 1921, with early papers in German, French, and English, and three volumes complete to 1938. It resumed with volume 4 in 1948. Poland adhered to the IAU starting in 1922 and paid the seventh-largest dues assessment, after the USA, France, Britain, Japan, Spain, and Italy (with a dozen other countries from Australia to Switzerland being assessed smaller amounts). In other words, neither BP nor his teachers were the first Polish astronomers! They were, however, among the most prolific. Up to 1980 the astronomers with the largest numbers of papers in Acta were Banachiewicz (member of the initial IAU delegation), Paczyński, Piotrowski, Smak, and Szafinec.

Some astronomers begin looking seriously at the sky very early and decide on scientific careers as a result. Others come to astronomy or even to science only at college age or beyond. Paczyński definitely belonged to the first class, observing variable stars from age 14 and publishing at 18 (Acta Astron. 8, 48, with Warsaw University students J. Ginter and A. Wernik in 1958). The nickname Bep, though used most typically by American colleagues, dates from that period (Dziembowski 2007, q.v. for much additional early information). A back-formation is responsible for his occasionally being cited as B.E. Paczyński, and to the question, "Did Bep have a middle name?" I can say only, "Why would he need one?". The first star he observed officially, by the Nijland-Blashko method on JD 2,434,975, was SW Lac, an eclipsing B8V pair whose light curve varies.

Paczyński's second paper (Acta Astron. 12, 206, 1962) incorporated his master's thesis on the ratio of polarization to absorption of starlight near the galactic plane at $l^{II} = 122 - 168^o$ (though he gave l^I first - 45 years ago is a long time). Using data from a catalogue by William Hiltner (co-discoverer of interstellar polarization with John Hall), he concluded that variations of the ratio were a result of differences in the density of the ISM and that depolarization was negligible. I have not checked whether this conclusion still stands; in any case it was some years before he returned to magnetic phenomena.

Fresh degree in hand, Bep took up a 1962-63 fellowship, in effect as a night assistant at Lick Observatory, by the end of which he had pretty much decided he was meant to be a theorist. His first Lick paper (PASP 75, 278, 1963) reported UBV photometry of $2.1937 Ceti$. It flared from $V = 14$ to 11 in the fall of 1962, but is not to be found under that name in the Russian Variable Star Catalogue, though recourse to the footnotes brings one to a supposed Paczyński paper (AJ 68, 637W, 1963) not listed on his CV. Sorting this out is left as an exercise for the reader (Kholopov et al. 1985). Over the next three years, there were 13 papers on observations of binary and pulsating variable stars, four representing Lick data in collaboration with George Preston, George Herbig, and Joe Smak (and well represented in the chapter by Preston). A stray bit of data from that period appeared in Table 4 of Herbig et al. (2004) and was called to my attention by Herbig.

The PhD dissertation, completed under Stefan Piotrowski and published in 1964 (Acta Astron. 14, 157), dealt with interstellar absorption as deduced from star counts. The idea is a classic one (Bok & Reilly 1947, used it to identify what they called Barnard globules) in use down to the present (even by me on one occasion to hunt for dust belonging to the Crab Nebula), and Paczyński developed the underlying mathematics in great detail. It is his paper with the most equations (205 of them) but almost entirely uncited and unknown. Among all the dishonorable reasons you might think of for this is the fact that he never published again on the topic and so did not cite the paper himself. In addition, methods for locating dust and estimating its quantity that depend on colors and spectral types of stars largely took over from pure counting (Lynds & Wickramasinghe 1968).

3. Evolution of Close Binaries

Then, unheralded outside Warsaw, came a sudden flowering. At very nearly the same time in the mid-1960's, there were three independent efforts to understand the evolution of close binary systems, in order to account quantitatively for the origin of Algol systems (where the less massive star is more evolved) and other phenomena unique to interacting stars. Paczyński's interest was perhaps partly catalyzed by his co-recognition (with Preston, Herbig, and Smak, ApJ 141, 617, 1965) that nova-like variables were short-period eclipsing binaries. The other two efforts, approaching from slightly different directions, were skippered by Miroslav Plaveç at Ondrejov (Prague) and Rudolf Kippenhahn in Germany. All three spoke at a 1966 colloquium in Uccle, Belgium (Dommanget 1967) and began publishing in their "home" journals (respectively Acta Astron. , Zs. f. Ap., and Bull. Astron. Inst. Czech.) in 1967. Paczyński's presentation focused on resolving the Algol paradox, which arguably was co-discovered by his C35 predecessor (Parenago & Masevich 1951).

Relations among the theorists (despite disagreements from the beginning regarding, for instance, what difference it would make if some mass and/or angular momentum left the systems, contrary to the initial assumptions that were required for existing computational equipment to be able to complete the calculations, especially east of the Elbe) seem to have been peaceable, and this remained so through later encounters, for instance at the 1969 IAU Colloquium 6 in Elsinore, Denmark, whose paper proceedings (Gyldenkerne & West 1970) are on my desk and whose actual proceedings are a very vivid memory (it was the first, though not the last, conference at which I was the only woman at the table, and a gate-crasher at that). In 1966, Paczyński began publishing the detailed results of his calculations (Acta Astron. 16, 231) in a series of five papers, of which the most cited (Acta Astron. 17, 1) appeared in 1967, when he also received his docent (habilitation) degree. Paper III (Acta Astron 17, 7) is joint with the first of his slightly younger collaborators, Janusz Ziółkowski.

In contrast to this peaceable progress, fire broke out when theory touched observations. The 1967 IAU General Assembly (like the 2006 one) took place in Prague. Paczyński spoke, concentrating on the origins of Wolf-Rayet stars, and Anne Underhill responded with a vigor not entirely encapsulated in the printed proceedings (Perek 1968). Her attitude was that nothing could be said about the surface composition of the stars, that the strong C and N lines were a non-equilibrium ionization effect, that they were probably pre-, not post-main sequence, and that post-MS mass transfer, revealing a processed interior, was not an acceptable scenario (see Underhill 1968, or indeed a large fraction of her publications during the rest of her career).

Bep never lost his love for binary stars. Speaking somewhat skeptically at a 1994 conference on dark matter (APS Conf. Ser. 336, 10, 1995), he called gravitational lensing only a good tracer of DM and the virial theorem, applied to galaxies and clusters, a poor one. "The best" tracer was dynamical methods with dynamical time less than the span of observations — binaries, in other words. And, quite late in life, he remarked that although the MACHO and OGLE programs he had inspired were officially directed at detecting dark matter, in his view the most exciting thing coming out was the large samples of variable stars, especially binaries. Some additional binary ideas appear in Sections 6 & 7.

4. Evolution of Single Stars and the Paczyński Code

The title of the first paper in this series (1970, Acta Astron. 20, 47, subtitled "Stellar Evolution from Main Sequence to White Dwarf or Carbon Ignition") must have puzzled those who were not aware he had previously evolved binary stars (twice as hard, one might have supposed). The code was developed largely while Bep was at JILA, 1968-69, but designed with an eye for running with limited computational facilities. The first was always the most-cited of the six papers, which is as much laziness by the citers as anything, I suspect. The later ones, published in 1970-71, were subtitled "Core Helium Burning in Population I Stars" (1970 Acta 20, 195), "Stationary Shell Sources" (1970 Acta 20, 287), "Helium Stars" (1971 Acta 21, 1), "Carbon Ignition in Population I Stars" (1971 Acta 21, 271), and "Model Nuclei of Planetary Nebulae" (1971 Acta 21, 417). All are single author papers, and the single result most often cited is the unique correlation between core mass and luminosity of evolved, intermediate mass ($\sim 3 - 7M_{\odot}$) stars.

Paczyński's own publications, based on gradually improving versions of the code, continue to about 1978, gradually moving into other journals: "Carbon Ignition in Degenerate Stellar Cores" (1972, Astrophys. Lett . 11, 53), "Thermal Stability of Pure Carbon Stars" (1973, A&A 26, 291), and "Helium-Shell Flashes in Population I Stars" (1974, ApJ 192, 483), for instance. He also at this stage published a few papers with students and other slightly younger collaborators, though this was never his dominant mode. Examples include, "On the Origin of Planetary Nebulae and Mira Variables" with J. Ziółkowski (1968 Acta 18, 225); work on helium stars with Virginia Trimble (hereafter: VT) (1971 BAAS 3, 9; 1973, A&A 22, 9); several papers in the group "Linear Series of Stellar Models" with M. Kozłowski (1972, Acta 22, 315), with Kozłowski and K. Popova (Acta 23, 263, 1973), and with M. Rozyczka (Acta 27, 213, 1977); exploring the URCA process in carbon burning (Acta. 24, 1, 1974, with E. Ergma); and several considerations of shell flashes (1975 Liege Colloquium Proceedings, p. 335, with I.J. Christy-Sackmann; 1978 ApJ 222, 604, with A. Zytkow). For a bit more about his collaborators in this period, see Trimble (2007).

Bep encouraged anyone who had attended the 1969 Stony Brook summer school to take home a copy of the codes for main sequence modeling and evolution. This became, according to Princeton professor James E. Gunn (who is much more knowledgeable about such matters than I), the first example ever, at least in astrophysics, of open-source coding. You could read it line by line and change lines if you dared. A simplified version of the Paczyński code remains available to this day on a disk inside the back cover of a standard text on stellar interiors (Hansen et al. 2004).

In addition to the "open source" aspects and Bep's extraordinary generosity in sharing the fruits of his labors, two other aspects of the code led to its being very widely used for many years. First, it was modular in nature. Opacities, equations of state, and nuclear energy generation rates were calculated by separate programs and stored in tables that ranged over the temperature, density, and composition regimes one would expect to need. The main programs then pulled numbers from these tables, rather than calculating the auxiliary variables as they went. Part of the motivation for this was to fit as much science as possible onto a small computer. Indeed, the IBMs of the time had to be asked for double precision to prevent numerical discontinuities from mimicking physical ones (for instance, sending massive red giants looping back blueward when a shell source hits a change in mean molecular weight). This is perhaps a sufficiently hidden place to confess that real blue swings of this sort appeared in the tracks of massive Population II stars (1973 A&A 25, 35 with B. Zimmerman and VT), but by the time of SN 1987A, this had been forgotten even by us, so we were as surprised as anyone else by the blue progenitor.

Second of the additional merits of the code was its extraordinarily good documentation, hand-written for HB7 available at Stony Brook, but typed in Warsaw in February, 1970 for the subsequent HB8 iteration. Figures 2-4 show a few characteristic pages from each. Even the subroutine names were transparent. GOB, for instance, Generated Outer Boundary conditions, and there were pages of advice on what to do if the Henyey part of the code refused to converge (loosening tolerances and adding zones as a rule) and when to give up. A typical output mode provided only things you might want to plot (surface temperature and luminosity; central temperature, density, and composition) for each time step, but the complete interior structure (Fig. 5, from runs at the Institute of Theoretical Astronomy) for every 50th time step or thereabouts. Bep appeared as co-author on only a very small fraction of the papers that derived from his code, and an intense culling of the acknowledgments sections of publications from 1970 to about 1990 would be required to identify them all.

By 1978 Paczyński had turned his attention primarily to accretion disks for X-ray binaries, cataclysmic variables, and active galactic nuclei. Of his collaborators from that period, I am most grateful to B. Muchotrzeb (1982 Acta 32, 1), who, in an instant flash of generosity, allowed me to introduce her talk at a conference using her married name (Czerny), which I could pronounce. She later used it exclusively, and we now serve together on a Commission of IUPAP.

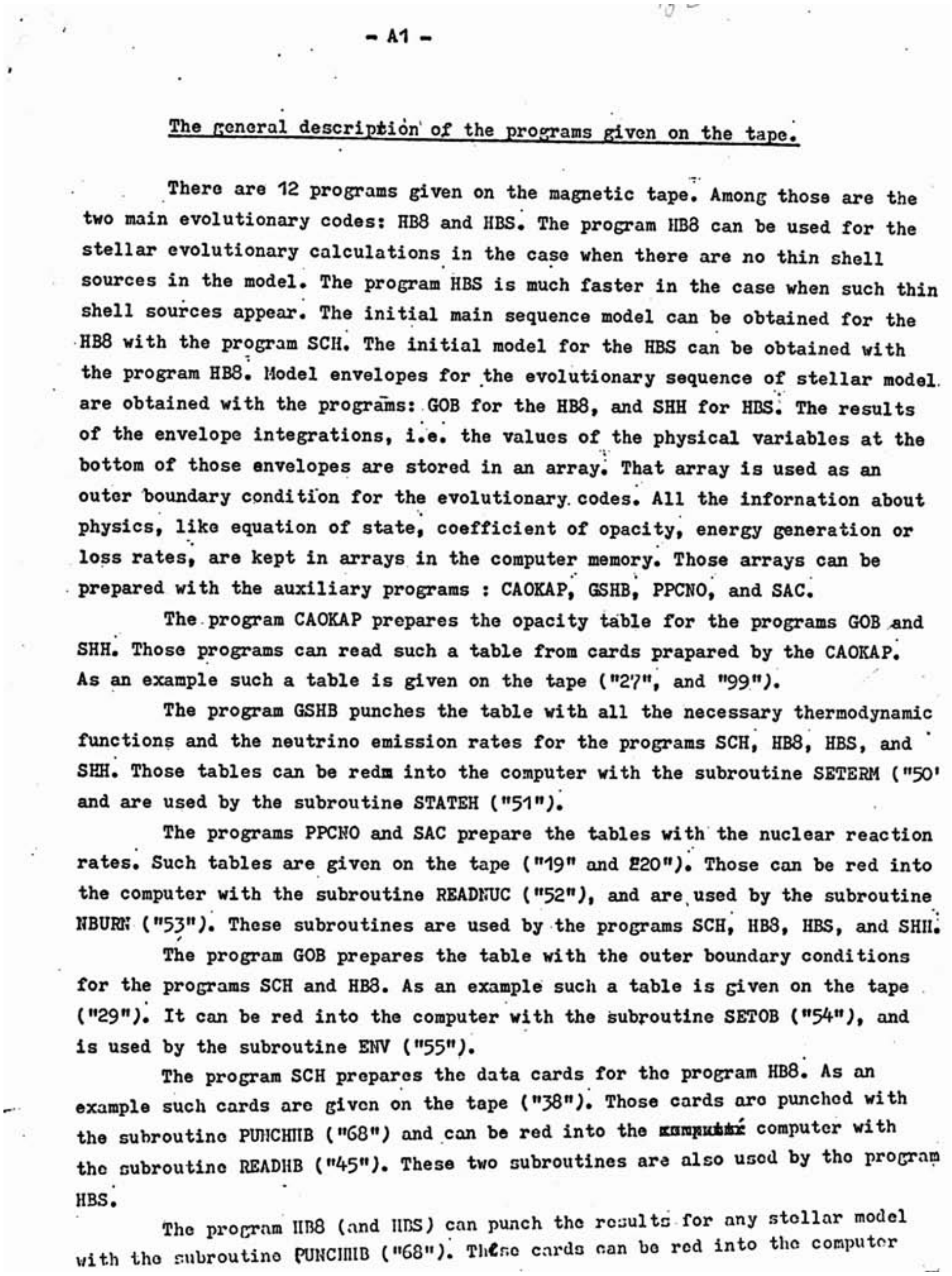
5. Even Homer Nods

We here touch briefly on several ideas that did not pan out, though they are not all completely unique to Paczyński:

- Explanations of the solar neutrino problem that rest on non-standard solar physics: a metal-depleted core (1988 ApJ 326, 392 with R. Sienkiewicz and S. Ratcliff) or extra mixing (1990 ApJ 349, 641 with R. Sienkiewicz and J.N. Bahcall). Neutrino oscillation has scored an 11th round knock-out on this one.

- The 600 km/sec dipole in the CMB as at least partly a cosmological effect of asymmetric expansion vs. a local Doppler displacement (1990 ApJ 364, 341, with T. Piran). Though possible at the time, this has since been ruled out by WMAP data according to cosmologists at the Princeton meeting.

- The X-ray source 1E 2259+586 as a white dwarf with a 7 sec rotation period, strong magnetic field, and emission by a pulsar-like mechanism (1990 ApJ 365, L9). It turned out to be a neutron star with still stronger field belonging to the class of anomalous X-ray pulsars.



- A1 -

The general description of the programs given on the tape.

There are 12 programs given on the magnetic tape. Among those are the two main evolutionary codes: HB8 and HBS. The program HB8 can be used for the stellar evolutionary calculations in the case when there are no thin shell sources in the model. The program HBS is much faster in the case when such thin shell sources appear. The initial main sequence model can be obtained for the HB8 with the program SCH. The initial model for the HBS can be obtained with the program HB8. Model envelopes for the evolutionary sequence of stellar model are obtained with the programs: GOB for the HB8, and SHH for HBS. The results of the envelope integrations, i.e. the values of the physical variables at the bottom of those envelopes are stored in an array. That array is used as an outer boundary condition for the evolutionary codes. All the infornation about physics, like equation of state, coefficient of opacity, energy generation or loss rates, are kept in arrays in the computer memory. Those arrays can be prepared with the auxiliary programs : CAOKAP, GSHB, PPCNO, and SAC.

The program CAOKAP prepares the opacity table for the programs GOB and SHH. Those programs can read such a table from cards prapared by the CAOKAP. As an example such a table is given on the tape ("27", and "99").

The program GSHB punches the table with all the necessary thermodynamic functions and the neutrino emission rates for the programs SCH, HB8, HBS, and SHH. Those tables can be redm into the computer with the subroutine SETERM ("50' and are used by the subroutine STATEH ("51").

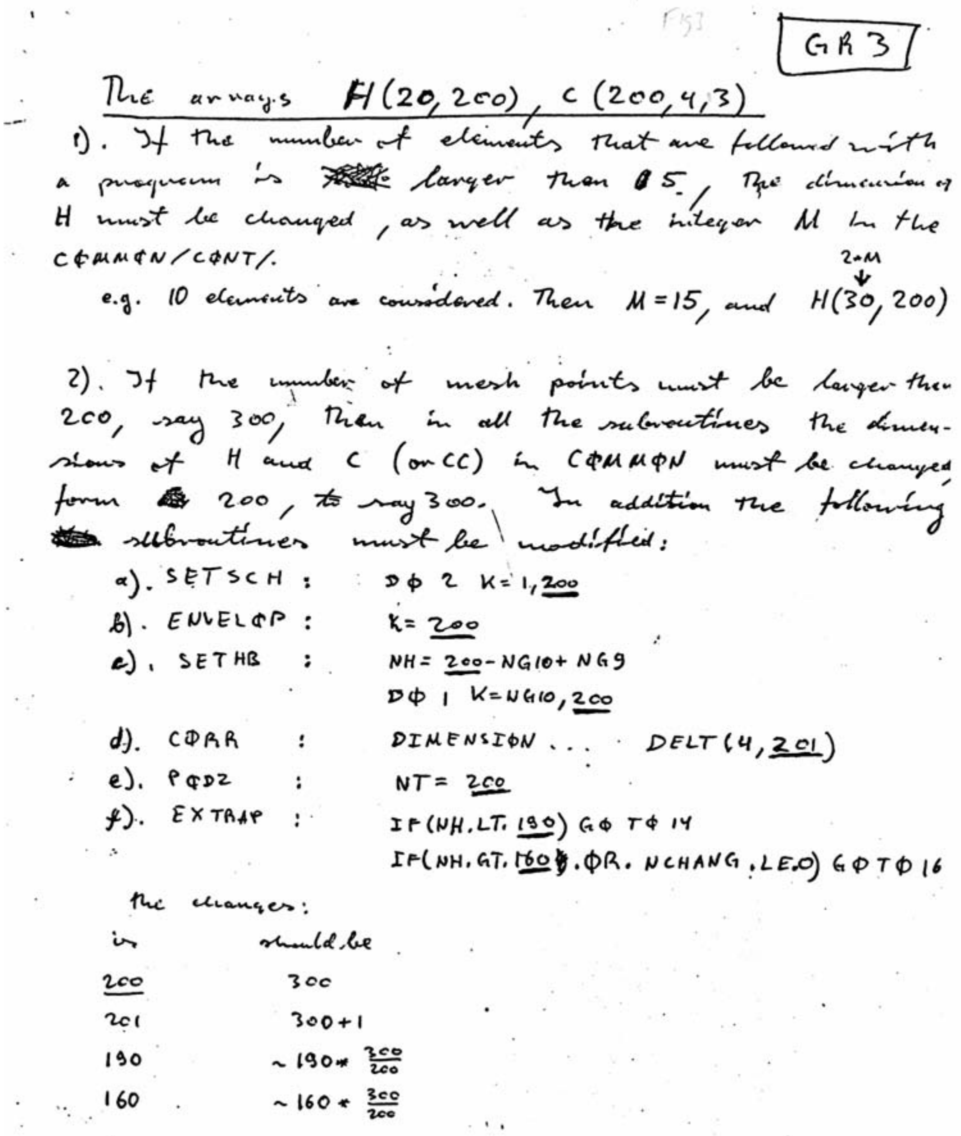
The programs PPCNO and SAC prepare the tables with the nuclear reaction rates. Such tables are given on the tape ("19" and "20"). Those can be red into the computer with the subroutine READNUC ("52"), and are used by the subroutine NBURN ("53"). These subroutines are used by the programs SCH, HB8, HBS, and SHH.

The program GOB prepares the table with the outer boundary conditions for the programs SCH and HB8. As an example such a table is given on the tape ("29"). It can be red into the computer with the subroutine SETOB ("54"), and is used by the subroutine ENV ("55").

The program SCH prepares the data cards for the program HB8. As an example such cards are given on the tape ("38"). Those cards are punched with the subroutine PUNCHHB ("68") and can be red into the computer with the subroutine READHB ("45"). These two subroutines are also used by the program HBS.

The program HB8 (and HBS) can punch the results for any stellar model with the subroutine PUNCHHB ("68"). These cards can be red into the computer

Figure 2. First page (of 50) of the February, 1970, documentation of the most widely distributed early version of the structure (SCH) and evolution (HB8) codes.



GR 3

The arrays H(20, 200), C(200, 4, 3)

1). If the number of elements that are followed with a program is larger than 5, the dimension of H must be changed, as well as the integer M in the CØMMØN/CØNT/.

e.g. 10 elements are considered. Then M = 15, and H($\overset{2*M}{\downarrow}$30, 200)

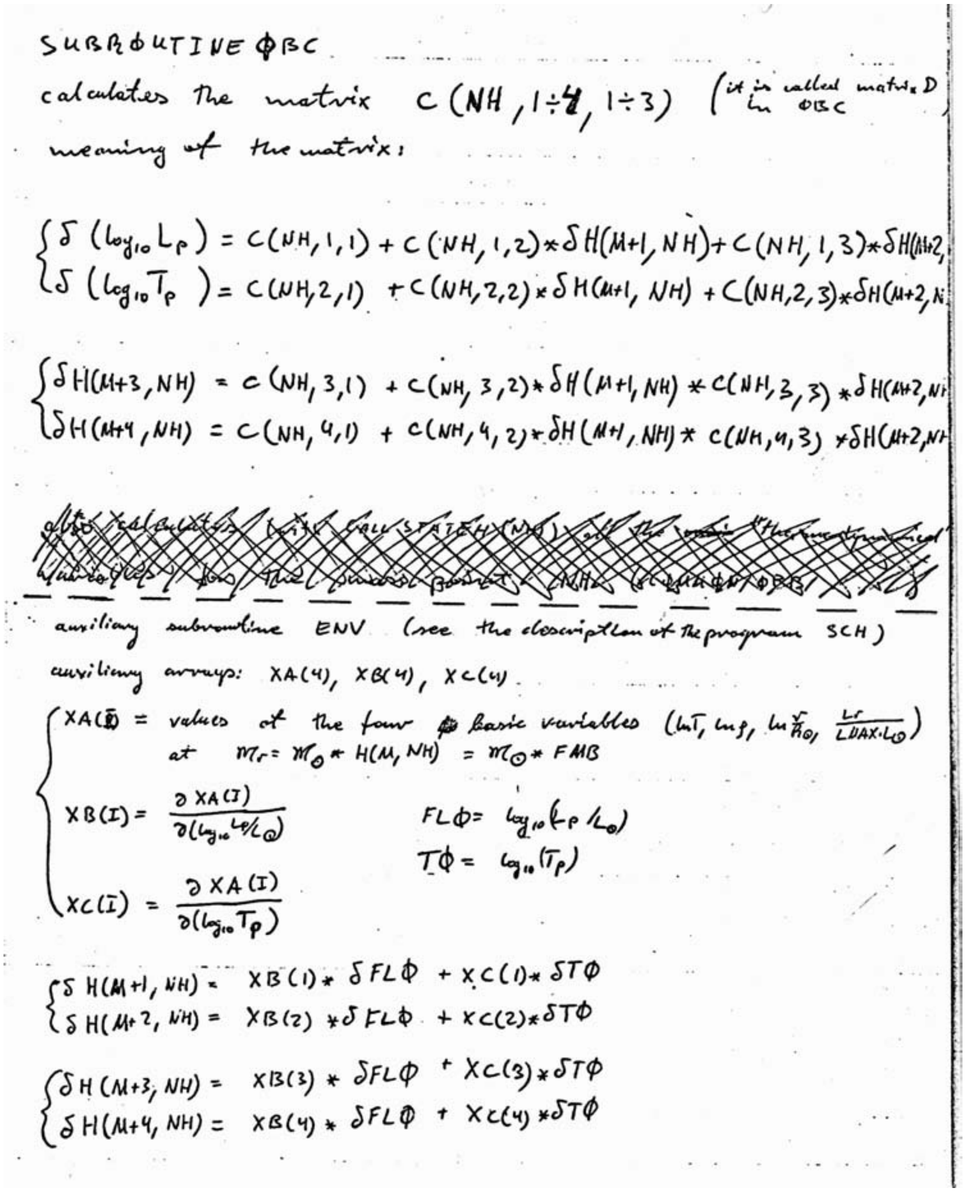
2). If the number of mesh points must be larger than 200, say 300, then in all the subroutines the dimensions of H and C (or CC) in CØMMØN must be changed form 200, to say 300. In addition the following subroutines must be modified:

```
a). SETSCH  :   DØ 2 K=1,200
b). ENVELØP :   K= 200
c). SETHB   :   NH= 200-NG10+NG9
                DØ 1 K=NG10,200
d). CØRR    :   DIMENSIØN ...   DELT(4,201)
e). PØDZ    :   NT= 200
f). EXTRAP  :   IF(NH.LT.190) GØ TØ 14
                IF(NH.GT.160.ØR.NCHANG.LE.0) GØTØ 16
```

the changes:

is	should be
200	300
201	300+1
190	$\sim 190 * \frac{300}{200}$
160	$\sim 160 * \frac{300}{200}$

Figure 3. A page of the hand-written documentation for SCH and HB7 explaining what to do if you need to add more zones to your stellar interior. This example is from the JILA, 1969, version.



SUBRØUTINE ΦBC

calculates the matrix C(NH, 1÷4, 1÷3) (it is called matrix D in ΦBC

meaning of the matrix:

$$\begin{cases} \delta(\log_{10} L_p) = C(NH,1,1) + C(NH,1,2)*\delta H(M+1,NH) + C(NH,1,3)*\delta H(M+2, \\ \delta(\log_{10} T_p) = C(NH,2,1) + C(NH,2,2)*\delta H(M+1,NH) + C(NH,2,3)*\delta H(M+2,N \end{cases}$$

$$\begin{cases} \delta H(M+3,NH) = C(NH,3,1) + C(NH,3,2)*\delta H(M+1,NH) * C(NH,3,3) * \delta H(M+2,N \\ \delta H(M+4,NH) = C(NH,4,1) + C(NH,4,2)*\delta H(M+1,NH) * C(NH,4,3) * \delta H(M+2,N \end{cases}$$

~~also calculates (with CALL STATEH(NH)) all the [illegible] thermodynamical variables for the [illegible] point NH (see MAIN ΦBC)~~

auxiliary subroutine ENV (see the description of the program SCH)

auxiliary arrays: XA(4), XB(4), XC(4)

$$\begin{cases} XA(I) = \text{values of the four basic variables } \left(\ln T, \ln \rho, \ln \frac{r}{R_\odot}, \frac{L_r}{LMAX \cdot L_\odot}\right) \\ \qquad \text{at } \mathcal{M}_r = \mathcal{M}_\odot * H(M,NH) = \mathcal{M}_\odot * FMB \\ XB(I) = \dfrac{\partial XA(I)}{\partial(\log_{10} L_p/L_\odot)} \\ XC(I) = \dfrac{\partial XA(I)}{\partial(\log_{10} T_p)} \end{cases}$$

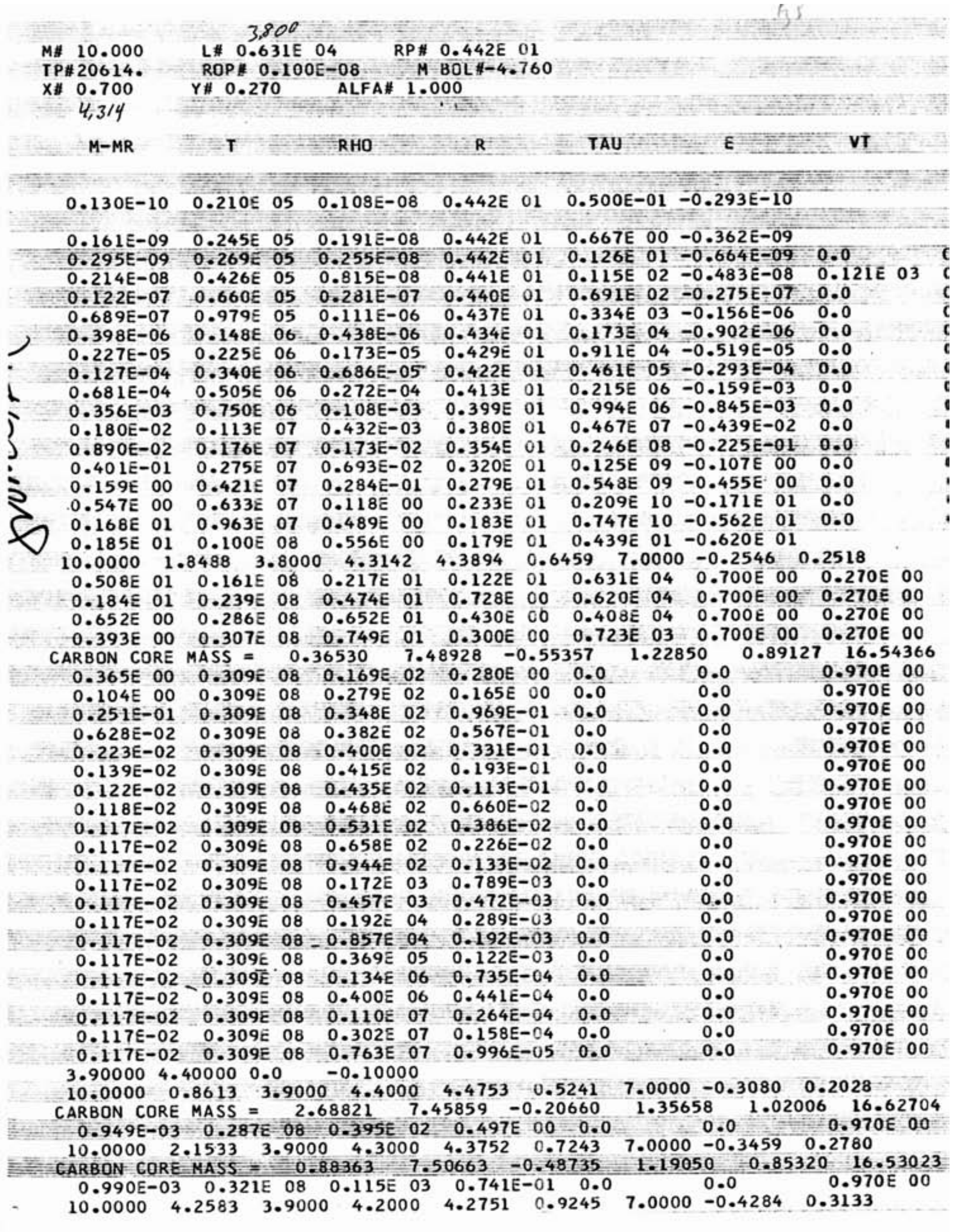
$FL\Phi = \log_{10}(L_p/L_\odot)$

$T\Phi = \log_{10}(T_p)$

$$\begin{cases} \delta H(M+1,NH) = XB(1) * \delta FL\Phi + XC(1) * \delta T\Phi \\ \delta H(M+2,NH) = XB(2) * \delta FL\Phi + XC(2) * \delta T\Phi \end{cases}$$

$$\begin{cases} \delta H(M+3,NH) = XB(3) * \delta FL\Phi + XC(3) * \delta T\Phi \\ \delta H(M+4,NH) = XB(4) * \delta FL\Phi + XC(4) * \delta T\Phi \end{cases}$$

Figure 4. Another page from the earlier documentation, showing that the programmer sometimes changed his mind about what went where.



```
                      3,800
 M# 10.000        L# 0.631E 04        RP# 0.442E 01
 TP#20614.        ROP# 0.100E-08        M BOL#-4.760
 X# 0.700        Y# 0.270        ALFA# 1.000
    4,314

      M-MR          T          RHO          R          TAU          E          VT


    0.130E-10   0.210E 05   0.108E-08   0.442E 01   0.500E-01 -0.293E-10

    0.161E-09   0.245E 05   0.191E-08   0.442E 01   0.667E 00 -0.362E-09
    0.295E-09   0.269E 05   0.255E-08   0.442E 01   0.126E 01 -0.664E-09  0.0
    0.214E-08   0.426E 05   0.815E-08   0.441E 01   0.115E 02 -0.483E-08  0.121E 03
    0.122E-07   0.660E 05   0.281E-07   0.440E 01   0.691E 02 -0.275E-07  0.0
    0.689E-07   0.979E 05   0.111E-06   0.437E 01   0.334E 03 -0.156E-06  0.0
    0.398E-06   0.148E 06   0.438E-06   0.434E 01   0.173E 04 -0.902E-06  0.0
    0.227E-05   0.225E 06   0.173E-05   0.429E 01   0.911E 04 -0.519E-05  0.0
    0.127E-04   0.340E 06   0.686E-05   0.422E 01   0.461E 05 -0.293E-04  0.0
    0.681E-04   0.505E 06   0.272E-04   0.413E 01   0.215E 06 -0.159E-03  0.0
    0.356E-03   0.750E 06   0.108E-03   0.399E 01   0.994E 06 -0.845E-03  0.0
    0.180E-02   0.113E 07   0.432E-03   0.380E 01   0.467E 07 -0.439E-02  0.0
    0.890E-02   0.176E 07   0.173E-02   0.354E 01   0.246E 08 -0.225E-01  0.0
    0.401E-01   0.275E 07   0.693E-02   0.320E 01   0.125E 09 -0.107E 00  0.0
    0.159E 00   0.421E 07   0.284E-01   0.279E 01   0.548E 09 -0.455E 00  0.0
    0.547E 00   0.633E 07   0.118E 00   0.233E 01   0.209E 10 -0.171E 01  0.0
    0.168E 01   0.963E 07   0.489E 00   0.183E 01   0.747E 10 -0.562E 01  0.0
    0.185E 01   0.100E 08   0.556E 00   0.179E 01   0.439E 01 -0.620E 01
   10.0000   1.8488   3.8000   4.3142   4.3894   0.6459   7.0000 -0.2546   0.2518
    0.508E 01   0.161E 08   0.217E 01   0.122E 01   0.631E 04   0.700E 00   0.270E 00
    0.184E 01   0.239E 08   0.474E 01   0.728E 00   0.620E 04   0.700E 00   0.270E 00
    0.652E 00   0.286E 08   0.652E 01   0.430E 00   0.408E 04   0.700E 00   0.270E 00
    0.393E 00   0.307E 08   0.749E 01   0.300E 00   0.723E 03   0.700E 00   0.270E 00
  CARBON CORE MASS =    0.36530    7.48928   -0.55357    1.22850    0.89127  16.54366
    0.365E 00   0.309E 08   0.169E 02   0.280E 00   0.0          0.0          0.970E 00
    0.104E 00   0.309E 08   0.279E 02   0.165E 00   0.0          0.0          0.970E 00
    0.251E-01   0.309E 08   0.348E 02   0.969E-01   0.0          0.0          0.970E 00
    0.628E-02   0.309E 08   0.382E 02   0.567E-01   0.0          0.0          0.970E 00
    0.223E-02   0.309E 08   0.400E 02   0.331E-01   0.0          0.0          0.970E 00
    0.139E-02   0.309E 08   0.415E 02   0.193E-01   0.0          0.0          0.970E 00
    0.122E-02   0.309E 08   0.435E 02   0.113E-01   0.0          0.0          0.970E 00
    0.118E-02   0.309E 08   0.468E 02   0.660E-02   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.531E 02   0.386E-02   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.658E 02   0.226E-02   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.944E 02   0.133E-02   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.172E 03   0.789E-03   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.457E 03   0.472E-03   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.192E 04   0.289E-03   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.857E 04   0.192E-03   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.369E 05   0.122E-03   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.134E 06   0.735E-04   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.400E 06   0.441E-04   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.110E 07   0.264E-04   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.302E 07   0.158E-04   0.0          0.0          0.970E 00
    0.117E-02   0.309E 08   0.763E 07   0.996E-05   0.0          0.0          0.970E 00
   3.90000 4.40000 0.0      -0.10000
   10.0000   0.8613   3.9000   4.4000   4.4753   0.5241   7.0000 -0.3080   0.2028
  CARBON CORE MASS =    2.68821    7.45859   -0.20660    1.35658    1.02006  16.62704
    0.949E-03   0.287E 08   0.395E 02   0.497E 00   0.0          0.0          0.970E 00
   10.0000   2.1533   3.9000   4.3000   4.3752   0.7243   7.0000 -0.3459   0.2780
  CARBON CORE MASS =    0.88363    7.50663   -0.48735    1.19050    0.85320  16.53023
    0.990E-03   0.321E 08   0.115E 03   0.741E-01   0.0          0.0          0.970E 00
   10.0000   4.2583   3.9000   4.2000   4.2751   0.9245   7.0000 -0.4284   0.3133
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Figure 5. Part of a 15-inch wide page of print-out (remember the green lines?) showing the interior of a $10M_{\odot}$, Pop I composition star that has reached the stage of having a carbon core taking up 36.5% of the mass of the star. The columns show fractional mass from surface inward, temperature, density, and radius of the zone, and radiative opacity (notice that the core is isothermal). Columns hanging off the edge include various gradients of thermodynamic interest. Scholars worried about the need for archive-quality paper should notice that these sheets of cheap Xerox and computer paper are still in very good condition 36 years after being shipped back from Cambridge. Of the folks in Figure 1, I believe that (Oct. 2007), all but Fowler, Hoyle, Salpeter, and Paczyński are still living, which probably also means something.

- Multi-shelled planetary nebulae as the result of sequential shell-flashes in AGB stars, arising from the paper by BP and I.J. Christy-Sackmann mentioned above. This is probably true, but not for the PN shells identified by VT and IJ S-C in 1977 (Trimble & Sackmann 1978). The goal of the project was a new, independent distance scale for PNe, based on the correlation of time between shell flashes and the luminosity of the star concerned. Curiously, the result made superficial sense and tended to support the larger of two scales then under consideration.

6. Ideas Probably Mentioned Elsewhere

The first half-dozen of these are largely astronomical, the later ones less so.

- The Alcock-Paczyński test for non-zero cosmological constant (Nature 281, 358 1979). This uses lensed QSOs, of which there were about three known then (dozens now), but you need 100 or more. In the same time frame, however, William H. McCrea said that he could think of no way of measuring Λ decoupled from the other cosmological parameters.

- Violation of the Russell-Vogt theorem (that mass and chemical composition uniquely determine stellar luminosity and radius), or at any rate the demonstration that it does not apply when there are composition discontinuities, first by showing that a red giant and a white dwarf + PN are separated only by a run-away instability (IAU Symp. 34, p. 396, 1968, with Ziółkowski) and later in the series of papers on "Linear Series of Stellar Models" (1972 Acta 22, 163 and others).

- Gravitational lensing in multiple contexts. This was fully covered in other presentations, including the curious detail that BP seems to have recognized one of those blue arcs retro-posed on a cluster of galaxies as a lensed image of something behind before the observers did.

- Extragalactic GRBs. You might not think that there was anything further to be said about these either. And this is true once BP entered the fray. But of the first 30 published GRB models (Nemiroff 1994), eight involved things happening outside the Milky Way, most often in or around supernovae or neutron stars, though there were also white holes. Indeed, Colgate (1968) was arguably a prediction of GRBs. He had in mind shock break-out from core-collapse SNe, and in light of recent associations of GRBs with Type Ic supernovae, one is inclined to say (indeed BP was inclined to say) that Colgate had been essentially correct, though he backed off from the prediction for some years. Then, the GRB cosmos was silent after 1975 (AGN and white hole models from Prilutski and Narlikar respectively) until the 1986 Paczyński paper, when the cosmological models gradually picked up again, with more white holes and (Eichler et al. 1989) neutron star mergers, until they begin to dominate after the first BATSE data arrived. Curiously, Paczyński said at one point that he had been led to cosmological models by believing an early report of a low-flux turn-over of log N-log S that was later disbelieved. My own view is that the data on this from R.S. White's balloon group were already to be trusted in 1978 (White et al. 1978).

- Clean (detached spectroscopic, eclipsing) binaries as the only real way to measure distances apart from parallax. The others (based on standard candles and angular diameter effects) are mere "distance indicators". This was a statement at a 1996 Space Telescope conference that was, of course, devoted largely to "distance indicators."
- One person can make a journal worth reading twice. First, Acta Astronomica with the binary and single star evolution papers, and, more than 20 years later, with OGLE papers.
- The Allies had no business letting Russia push Poland westward to exclude Wilno.
- Climbing stairs is good preparation for climbing the Grand Canyon, if you climb enough of them (preferably, said BP, when you are alone in the house).
- And there must surely be lessons to be gained from Paczyński's interactions with Polish and US astronomy and astronomers on optimal ways of encouraging the development of astronomy in other non-prosperous countries, though "first find a genius" may not be terrible helpful advice.

7. Ideas Probably Not Mentioned Elsewhere

The first half-dozen or so of these come from the realm of binary stars. You might suppose that it would have been obvious to anyone reading BP's initial papers (or indeed those from the other two groups) that, by the time the initially more massive star in a massive binary experiences a supernova explosion, it has become the less massive star, so that isotropic mass ejection cannot unbind the system. It was not, however, obvious to Gott, Gunn & Ostriker (1970) in their discussion of "Runaway Stars and the Pulsars Near the Crab Nebula." Nor was it obvious to me when I mentioned that paper to Paczyński shortly after publication to be rewarded with a slowly shaking head and, "It won't work." VT: "Why not?" BP: "Mass transfer in close binaries." By the time the rebuttal (Trimble & Rees 1971) had been submitted and published, Bep was in the acknowledgments rather than an author. I suspect this happened to him very often, and other astronomers have provided other examples. His generosity is an idea mentioned elsewhere!

That gravitational radiation can dominate the evolution of close binary stars (1967 Acta 17, 287) was an idea so far in advance of its time that even Paczyński had to rediscover it (1981 ApJ 248, L27, with Sienkiewicz) before it could be used to explain the period distribution of cataclysmic binaries (1983 ApJ 268, 825, also with Sienkiewicz).

Binary formation from a disk around a single core appears in the 1971 Annual Reviews article (1971 ARA&A, 9, 183).

The need for extreme loss of angular momentum to get from two main sequence stars to the CVs and their precursors, like V471 Tau, surfaces in IAU

Symp 73, 75 (1976), and though the name for the process was initially in doubt, they were common envelop binaries by the time the proceedings appeared. I had voted for yang and yin stars. So thoroughly incorporated is the idea into the community that systems like V 471 Tau are quite often called pre-novae, though obviously it will be some sizable number of megayears before we can be sure.

I have not found in print the suggestion that FK Comae stars are likely to be merger products, but I first heard it from Bep at a time and with sufficient persuasiveness that when Lick Observatory finally changed its policy in 1981 (under the then-new Kraft regime) to allow astronomers from non-astronomical campuses (of which UCI was then one) to apply for Lick time, the first things I asked to look at were spectra of FK Comae and FU Ori stars, which Bep had said a little earlier (QJRAS 17, 31, 1976) were essentially powered by excretion disks. It rained most of the time, and my main memory of the observing run is the outstanding support services, including home-cooked Italian food, provided by night assistant Rem Stone.

Another idea I heard first from Bep but have not tried to trace to a particular publication is binary white dwarfs (of total mass in excess of the Chandrasekhar mass and orbit period short enough for gravitational radiation to bring the stars together in a Hubble time) as the progenitors of Type Ia supernovae. It came in a phone call dating back to about 1981, during which he asked whether any of the white dwarfs for which Greenstein & Trimble (1967) had tried to measure gravitational redshifts had shown highly variable velocities. Well, so it would seem, said I, though we left those out of the tables and average values. An interesting enough question that my second Lick proposal was to do multiple spectra of the same few white dwarfs. The weather was fine, but the 40" telescope was not a hefty-enough light-gatherer for the spectra to be of much use. Later work by many others showed (a) our variable stars were all cases where Jesse had kicked the spectrograph or something and (b) such systems, if any exist, are very rare indeed.

A number of aspects of accretion disks studied by Paczyński appear in other chapters of this volume. I note here only a few of the earliest papers: "A Model of X Per" (A&A 40, 351, 1975 with Ziólkowski); "Disk Structure in U Gem" (1977 IAU Colloq. 42, 313, with J. Madej); and a quick series of models of self-gravitating disks in Acta (1978, v. 28, pp. 91, 111, 241, 253, the second with M. Jaroszyński). Two of the key ideas were the use 'of (geometrically as well as optically) thick disks to collimate jets and permit luminosities in excess of the Eddington limit (1980 Acta 30, 1, with Jaroszyński and M. Abramowicz) and the Paczyński-Wiita potential (1980 A&A 88, 23), which can allow you to model X-ray binaries and other fairly relativistic systems without the full mechanism of general relativity.

At a time when the community was only rather reluctantly accepting that black holes (objects with sizes close to the Schwarzschild radius) exist in astronomical systems—just before the bandwagon took off—Paczyński set an upper limit to the black hole mass in the quasar 4C11.50A (1974 Nature 249, 329) and a lower limit to the black hole mass in X-ray binary Cyg X-1 (1974 A&A 34, 161). Like the Alcock-Paczyński test for the cosmological constant, using pulsars around the black hole in $SgrA^*$ to probe space-time geometry (IAU Symp.

84, 401, 1979, with Trimble) requires more and different astronomical objects from the ones in the inventory then or now.

8. Idiosyncrasies, Quotes, and Other Oddments

Among the things Paczyński liked were mountains, binary stars, and girls (in that order); Annual Reviews (because of the simplicity of citing its articles compared to edited books in general); email when it was new (though he was also responsible for the concept that one email in 7 goes down a black hole, leaving no trace; you may wish to call this the Paczyński constant); good wine, not so good wine; and LSST and PanSTAARS (each in some ways an outgrowth of the MACHO and OGLE and ASAS programs), which were in development near the end of his life.

Neither Dziembowski (2007) nor Trimble (2007) has managed to compile a complete list of Bep's students (though both have partial lists). This should be done.

Gresham's law is that bad money drives good out of circulation. The Princeton meeting provided an interesting example of Gresham's law of phonology. Some languages have, and others do not, the sound of the "h" in Bohdan (or ch in the Scots "loch" or in Hebrew "chai" as approximations). English does not, and American speakers used either Bep or "Boe-dan" (as if the first syllable rhymed with toe); however, so did some speakers whose first languages have some sort of "ch" sound, and it was in this context that at the end of the talk I asked those participants who were native speakers of Polish to say loudly together Bep's standard telephone greeting, "Is here Bohdan Paczyński."

Some of his remarks were eternal verities of wide applicability. For instance, concerning Polish passports as stochastic processes rather than products, he concluded that for many officials with low-level jobs, the only fun they have is the arbitrary power of saying yay and nay. May this console you in your encounters with the three scariest bureaucracies in the US today — the Internal Revenue Service, the Department of Motor Vehicles, and the Transportation Safety Agency.

Other remarks were context dependent, like "Sorry for Polish" (even when spoken to fellow countrymen) and, when a joke had made no impression, "It's all right. I have no sense of humor in Polish either." This was clearly false, as illustrated by discussion remarks from Ralph Wijers.

Finally some were utterly context dependent: (1) on the beach of Long Island close to the Stony Brook campus, "Let me tell you what I think about stellar evolution." (2) somewhere around 2 AM near the end of a very long social event connected with a Cambridge summer school, in response to the suggestion that a particular colleague was a very rare example of someone who does absolutely first class science while still remaining a pleasant, normal human being, "It is 2 o'clock in the morning. We have been eating and drinking since 6 p.m., and X is still talking about galaxies. Do you think that is normal?".

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Bohdan Paczyński in 1993. Photo by Denise Applewhite, courtesy of Princeton University, Office of Communications.