"The universe is based on simple physics. Given our knowledge of basic physical data and straightforward logic, we can simulate the whole universe and everything in it, including ourselves. Our understanding is only statistical, of course. We cannot predict individual objects. We did not discover through our simulations that there are races who do not use common sense or logic to look at the universe, but who are capable, nevertheless, of travelling from planet to planet, destroying as they go."

Once the Vegans met us, they realized that their idyllic, introverted planet was open to rape and pillage by people like us from all over the galaxy, and that they need protection. We are their Swiss Guards. Starfleet Command is funding basic research here with the intent of quickly bringing us up to Vegan level in atomic and nuclear physics and then in simulation and modelling. It will be a great day when we progress to the point where we can find a mistake in the cubes or we can add our own work to them. We will throw a giant party. Perhaps at that time, through our brash exploration, where we strive to see and to visit the stars, we will be able to offer some gift to the Vegans.

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[Postscript

After going through this gedanken exercise I was able to find an explanation for white dwarf cooling:

Because of downward diffusion by gravitational settling, the center of a white dwarf is filled with heavy elements that continue to produce nuclear reactions as the white dwarf cools. The center is not degenerate. The nuclear reactions are electron captures that change protons to neutrons and fissions when there are too many neutrons for stability. The energy produced is partly in neutrinos that can escape, but the remainder increases the pressure and temperature and slowly inflates the white dwarf by a factor of 30 or so until it looses degeneracy. It then looks like a hot subdwarf, has a large temperature gradient, and radiates like mad. It also has a hot wind. The star loses a significant amount of energy and cools back to a cooler degenerate white dwarf. The cycle repeats until the nuclear reactions at the center become too weak to matter. Thus white dwarfs cool rapidly because of heating episodes.]

heated that an emergency meeting of the Society was called that lasted a whole week. It resulted in research guidelines that we have followed and prospered under ever since.

"The guidelines are that basic physics — atomic and nuclear data, energies and cross-sections — must be fixed by theory and experiment before proceeding to simulations and modelling. Instead of wasting effort and the wealth of our people on calculations that cannot be trusted, physicists must first work to fill in the basics. This does not rule out exploratory calculations that can suggest routes to follow in more detail, but it does rule out extravagant claims about minor or negligible accomplishments. Funding and jobs are not based on such claims. They are based on whether the Physical Society thinks a physicist is a good scientist and has hope of producing something, not on actual or immediate production. Conformity is not expected or encouraged.

"The second guideline is that in any calculation or experiment, physicists must demonstrate that the physics is resolved in space and time. There is no point in wasting our wealth on meaningless, low-resolution work (unless it is exploratory). If more resolution is required physicists must build better equipment or bigger, faster computers.

"People help each other. Physicists help each other. Scientists are supported by the state because basic science benefits everyone.

"All known atomic physics is recorded in one cube and all known nuclear physics is recorded in another cube. Almost everything is known since they are such easy subjects. We have given copies of the cubes to Starfleet Command as a gift. These cubes provide the fundamental background input to all of our astrophysics modelling. Whenever someone finds a significant mistake or finds significant new data, new cubes are distributed and we have a party. We work on laboratory and computational astrophysics in parallel. In a specific case one may be better than another. None of our physics is adjustable or has free parameters.

"For stars the physics is straightforward 3-dimensional-time-dependent-radiation-nuclear-magnetohydrodynamics unless all the particle velocities are too small for nuclear reactions to take place, as in a stellar photosphere, in which case 3-dimensional-time-dependent-radiation-magnetohydrodynamics may be used.

"We have some information derived from observation. We observe the sun (Vega). Imaging transform spectrographs developed for laboratory work are installed on seven-meter telescopes to monitor the solar spectrum over the fuzzy disk at high resolution and high signal-to-noise. We determine radial velocities to $\Delta\beta = 10^{-9}$. We determined our orbit around the sun. Perturbations allowed us to determine the existence of several other planets because they are large or nearby. The planetary orbits lie in a plane. The elemental abundances at the surface of the sun are different from the abundances in the earth. The explanation is that the sun and planets formed in a disk and that there was element segregation in the disk. We also observe very energetic cosmic rays with still different abundances. The cosmic rays must be generated in very large scale magnetic fields remote from us. We observe large neutrino fluxes and neutrino bursts.

computer had found an adequate match in their library of model stars so that they would not have to make new calculations. She gave me a cube recording of the whole evolution of the star from gas cloud to black dwarf. She put the cube in a player that produced a three dimensional space-time image as a black cylinder. When I specified an instant of time along the axis the projection became a sphere (when the star was a sphere). When I specified a point in the sphere it presented the values of all physical variables at that point. To retrieve the data I would write a little program that generates the space-time coordinates of interest. Starfleet Command rewrote the data in a format that I could read at home. They kept the cube. She said that normal density was 2^{40} mass points per time step and that the time step was adjusted to match any significant changes. When the time step or resolution was not enough to resolve the physics on their normal computers they would run on the central government computers at 2^{50} mass points and whatever time step was needed. She stated that none of their modelling was accepted unless it could be shown that the physics was numerically valid. The cube she gave me did not show the full 2^{50} resolution calculations continuously but only highlights to give an impression of the statistics. In between the calculation was smoothed to the lower resolution.

[It occurred to me later that, of course, this solar model would have been one of the first calculations the Vegans made after meeting the initial Starfleet ship and that Starfleet must have had this calculation all along. Also that Starfleet would have given our observational data to the Vegans to get the Vegan interpretation, and that Starfleet is not revealing that interpretation.]

Then I told her about my interest in Population II white dwarfs. She asked whether a textbook would suffice and I said yes. A few seconds later another cube appeared that was a chapter from a stellar evolution textbook. It described Population II white dwarf evolution from white to black for all possible masses. It had space-time cylinders with programs to play the cylinders to illustrate specific points. The answer to my question is that the white dwarfs cool faster than we thought. Starfleet Command kept that cube as well.

Since the whole interview thus far had taken only ten minutes I decided to try her patience and to ask her to describe how the Vegans do astrophysics without seeing the stars.

"Cretin human! It is obvious!"

"But it would help me just to hear you present the argument. I presume that a great deal of it must be having self confidence that you are working in the correct way and that you can solve a problem. It is partly psychological, not just logic."

"I admit some value to your statement. Everything that matters is not written in books.

"Two hundred eleven years ago there was a great debate. It started at the annual Physical Society banquet. Everyone was pleasantly drunk, but for some reason the leading theoretician wanted to have an argument and she started to complain that computer modellers and "hackers" were not doing real science, which was true, but it was bad manners to discuss it at a banquet. The argument got so

		52	.83789			124	.05787		
		53	.09501					76 Os	184 .00018
		54	.02365	51	Sb	121	.57362		186 .0158
						123	.42638		187 .016
25	Mn	55	1.0000						188 .133
				52	Te	120	.0009		189 .161
26	Fe	54	.058			122	.0257		190 .264
		56	.9172			123	.0089		192 .410
		57	.022			124	.0476		
		58	.0028			125	.0710	77 Ir	191 .373
						126	.1889		193 .627
27	Co	59	1.0000			128	.3173		
						130	.3397	78 Pt	190 .000127
28	Ni	58	.6827						192 .0078
		60	.2610	53	I	127	1.0000		194 .329
		61	.0113						195 .338
		62	.0359	54	Xe	124	.00121		196 .252
		64	.0091			126	.00108		198 .0719
						128	.0219		
29	Cu	63	.6917			129	.2734	79 Au	197 1.0000
		65	.3083			130	.0435		
						131	.2169	80 Hg	196 .001504
30	Zn	64	.4863			132	.2650		198 .09968
		66	.2790			134	.0976		199 .16873
		67	.0410			136	.0794		200 .23096
		68	.1875						201 .13181
		70	.0062	55	Cs	133	1.0000		202 .29863
									204 .06865
31	Ga	69	.60108	56	Ba	130	.00106		
		71	.39892			132	.00101	81 Tl	203 .29524
						134	.02417		205 .70476
32	Ge	70	.205			135	.06592		
		72	.274			136	.07854	82 Pb	204 .0194
		73	.078			137	.1123		206 .1912
		74	.365			138	.7170		207 .2062
		76	.078						208 .5831
33	As	75	1.0000	57	La	138	.00089		
34	Se	74	.0088			139	.99911	83 Bi	209 1.0000
		76	.090						
		77	.076	58	Ce	136	.0019	90 Th	232 1.0000
		78	.236			138	.0025		
		80	.497			140	.8848	92 U	235 .00720
		82	.092			142	.1108		238 .99275

Her inputter swallowed the numbers. After 3 minutes she reported that the

										162	.2551
13	Al	27	1.0000	43	Tc	99	1.0000			163	.2490
										164	.2819
14	Si	28	.9223	44	Ru	96	.0552				
		29	.0467			98	.0188	67	Ho	165	1.0000
		30	.0310			99	.127				
						100	.126	68	Er	162	.0014
15	P	31	1.0000			101	.170			164	.0161
						102	.316			166	.336
16	S	32	.9502			104	.187			167	.2295
		33	.0075							168	.268
		34	.0421	45	Rh	103	1.0000			170	.149
		36	.0002								
				46	Pd	102	.0102	69	Tm	169	1.0000
17	Cl	35	.7577			104	.1114				
		37	.2423			105	.2233	70	Yb	168	.0013
						106	.2733			170	.0305
18	Ar	36	.00337			108	.2646			171	.143
		38	.00063			110	.1172			172	.219
		40	.99600							173	.1612
				47	Ag	107	.51839			174	.318
19	K	39	.932581			109	.48161			176	.127
		40	.000117								
		41	.067302	48	Cd	106	.0125	71	Lu	175	.9741
						108	.0089			176	.0259
20	Ca	40	.96941			110	.1249				
		42	.00647			111	.1280	72	Hf	174	.00162
		43	.00135			112	.2413			176	.05206
		44	.02086			113	.1222			177	.18606
		46	.00004			114	.2873			178	.27297
		48	.00187			116	.0749			179	.13629
										180	.35100
21	Sc	45	1.0000	49	In	113	.043				
						115	.957	73	Ta	180	.00012
22	Ti	46	.080							181	.99988
		47	.073	50	Sn	112	.00973				
		48	.738			114	.00659	74	W	180	.0013
		49	.055			115	.00339			182	.263
		50	.054			116	.14578			183	.143
						117	.07672			184	.3067
23	V	50	.00250			118	.24217			186	.286
		51	.99750			119	.08587				
						120	.32596	75	Re	185	.3740
24	Cr	50	.04345			122	.04632			187	.6260

63 Eu	-11.53	64 Gd	-10.92	65 Tb	-11.94	66 Dy	-10.94	67 Ho	-11.78
68 Er	-11.11	69 Tm	-12.04	70 Yb	-10.96	71 Lu	-11.28	72 Hf	-11.16
73 Ta	-11.91	74 W	-10.93	75 Re	-11.77	76 Os	-10.59	77 Ir	-10.69
78 Pt	-10.24	79 Au	-11.03	80 Hg	-10.95	81 Tl	-11.14	82 Pb	-10.19
83 Bi	-11.33	84 Po	-20.00	85 At	-20.00	86 Rn	-20.00	87 Fr	-20.00
88 Ra	-20.00	89 Ac	-20.00	90 Th	-11.92	91 Pa	-20.00	92 U	-12.51
93 NP	-20.00	94 Pu	-20.00	95 Am	-20.00	96 Cm	-20.00	97 Bk	-20.00
98 Cf	-20.00	99 Es	-20.00						

Fractional isotopic abundances:

1 H	1	.999966	35 Br	79	.5069	59 Pr	141	1.0000	
	2	.000034		81	.4931				
						60 Nd	142	.2713	
2 He	3	.000142	36 Kr	78	.00339		143	.1218	
	4	.999858		80	.0222		144	.2380	
				82	.1145		145	.0830	
3 Li	6	.075		83	.1147		146	.1719	
	7	.925		84	.5711		148	.0576	
				86	.1742		150	.0564	
4 Be	9	1.0000							
			37 Rb	85	.72165	62 Sm	144	.031	
5 B	10	.199		87	.27835		147	.150	
	11	.801					148	.113	
			38 Sr	84	.0056		149	.138	
6 C	12	.9890		86	.0986		150	.074	
	13	.0110		87	.0700		152	.267	
				88	.8258		154	.227	
7 N	14	.99634							
	15	.00366	39 Y	89	1.0000	63 Eu	151	.478	
							153	.522	
8 O	16	.99762	40 Zr	90	.5145				
	17	.00038		91	.1122	64 Gd	152	.0020	
	18	.00200		92	.1715		154	.0218	
				94	.1738		155	.1480	
9 F	19	1.0000		96	.0280		156	.2047	
							157	.1565	
10 Ne	20	.9299	41 Nb	93	1.0000		158	.2484	
	21	.00226					160	.2186	
	22	.0679	42 Mo	92	.1484				
				94	.0925	65 Tb	159	1.0000	
11 Na	23	1.0000		95	.1592				
				96	.1668	66 Dy	156	.00056	
12 Mg	24	.7899		97	.0955		158	.00096	
	25	.1000		98	.2413		160	.0234	
	26	.1101		100	.0963		161	.1891	

and humans cannot survive on the surface of the planet, so all intercommunication is through a space station operated by Starfleet Command that orbits the planet. The space station reminds me of the one in Lem's novel "Solaris". The Vegans themselves are not interested in the space station. They think it is a necessary evil. There is no physical contact between the two races. Each race has a separate part of the station. The meeting room is holographic. The Vegans travel up so they can talk in real time, with body language and arguing. the way physicists are supposed to, instead of having to cope with the orbital time delays from the ground.

Starfleet Command offered to fly me to that space station to interview a Vegan astrophysicist who would come up from the surface. It is a two week round trip from here to Vega. Information about and from Vega is generally classified because Starfleet Command gains a military advantage by using real Vegan astrophysics instead of our primitive sort. There is also the consideration of the impact on morale here if everything we are doing is shown to be a waste of time. The strategy Starfleet Command has adopted is to slowly leak information into the scientific community so that we can "grow" into it. Thus they were willing to let me bring back the morsels that I describe here.

"I would like a check on our understanding of the evolution of our sun, partly as a test of our overall astrophysical capabilities."

"You came all the way here for that? What are the parameters?"

"One solar mass, one solar radius, one solar luminosity, solar composition, and 4.56 billion years old."

She did not appreciate my humor. I gave her the real numbers as follows:
Mass: 1.197×10^{57} nucleons;
Luminosity: equivalent to 1.03×10^{56} photons from the second level to the first level of hydrogen per lifetime of the second level;
Radius: 1.315×10^{19} radii of the first level of hydrogen;
Age: $6.76 \times 10^{+25}$ lifetimes of the second level of hydrogen;
Rotation velocity: 6.23×10^{-15} radians per lifetime of the second level of hydrogen;
Fractional elemental abundances in base 10 logarithms:

1	H -0.0405	2	He -1.0506						
3	Li -10.88	4	Be -10.89	5	B -9.44	6	C -3.48	7	N -3.99
8	O -3.11	9	F -7.48	10	Ne -3.95	11	Na -5.71	12	Mg -4.46
13	Al -5.57	14	Si -4.49	15	P -6.59	16	S -4.83	17	Cl -6.54
18	Ar -5.48	19	K -6.82	20	Ca -5.68	21	Sc -8.94	22	Ti -7.05
23	V -8.04	24	Cr -6.37	25	Mn -6.65	26	Fe -4.37	27	Co -7.12
28	Ni -5.79	29	Cu -7.83	30	Zn -7.44	31	Ga -9.16	32	Ge -8.63
33	As -9.67	34	Se -8.69	35	Br -9.41	36	Kr -8.81	37	Rb -9.44
38	Sr -9.14	39	Y -9.80	40	Zr -9.54	41	Nb -10.62	42	Mo -10.12
43	Tc -20.00	44	Ru -10.20	45	Rh -10.92	46	Pd -10.35	47	Ag -11.10
48	Cd -10.18	49	In -10.58	50	Sn -10.04	51	Sb -11.04	52	Te -9.80
53	I -10.53	54	Xe -9.81	55	Cs -10.92	56	Ba -9.91	57	La -10.82
58	Ce -10.49	59	Pr -11.33	60	Nd -10.54	61	Pm -20.00	62	Sm -11.04

VEGAN ASTROPHYSICS, A GEDANKEN EXPERIMENT

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ABSTRACT

There is another approach to astrophysics that is much more productive than our current methods.

I. QUESTIONS

The halo is filled with 10 to 14 billion year old Population II white dwarfs. I was wondering what they look like. I decided that their evolution must depend on how much abundance stratification there is due to diffusion, on the strength of the magnetic field, and on how much mass loss there is. If the mass loss is significant the atmosphere has to be continuously replaced by evaporating the degenerate interior. I talked to my colleague Andrea Dupree about mass loss. She said that mass loss has not been observed, that the rate has to be small because the gravity is high, and that a small rate is not observable. All of which made sense but did not rule out that mass loss could affect the evolution. I looked up white dwarf cooling in textbooks. The discussions seemed to be at the 1950s back-of-the-envelope level with uniform polytropes. At IAU Symposium 189 in Sydney, Gilles Chabrier reviewed a much more sophisticated model with crystallization of cores containing only C and O. We need modelling with rotation and diffusion as well. Have people just assumed there were no complications and therefore have not looked for them? That thought made me wonder how much we really know about anything in astrophysics, and how much are we taking for granted. It is difficult for us to determine what we are taking for granted. I decided to find a completely independent astrophysics and to find out what it says about (a star like) the sun, which presumably we know something about, and what it says about old Population II white dwarfs.

II. ANSWERS

I went to Starfleet Command and asked for help. They said the Vegans on planet Vega-5 (the Vegans call it "Earth" in Vegan) orbiting Vega ("Sun" in Vegan) are the best astrophysicists. Their atmosphere is hazy and warm. The only star that is visible is Vega itself as a fuzzy ball. Except for ultra-high-resolution, ultra-high-signal-to-noise spectra of Vega, Vegan astrophysics is produced by thinking and by laboratory work. That gives the Vegans a tremendous advantage over us.

Large ships cannot land on Vega-5 because they destabilize the atmosphere,

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