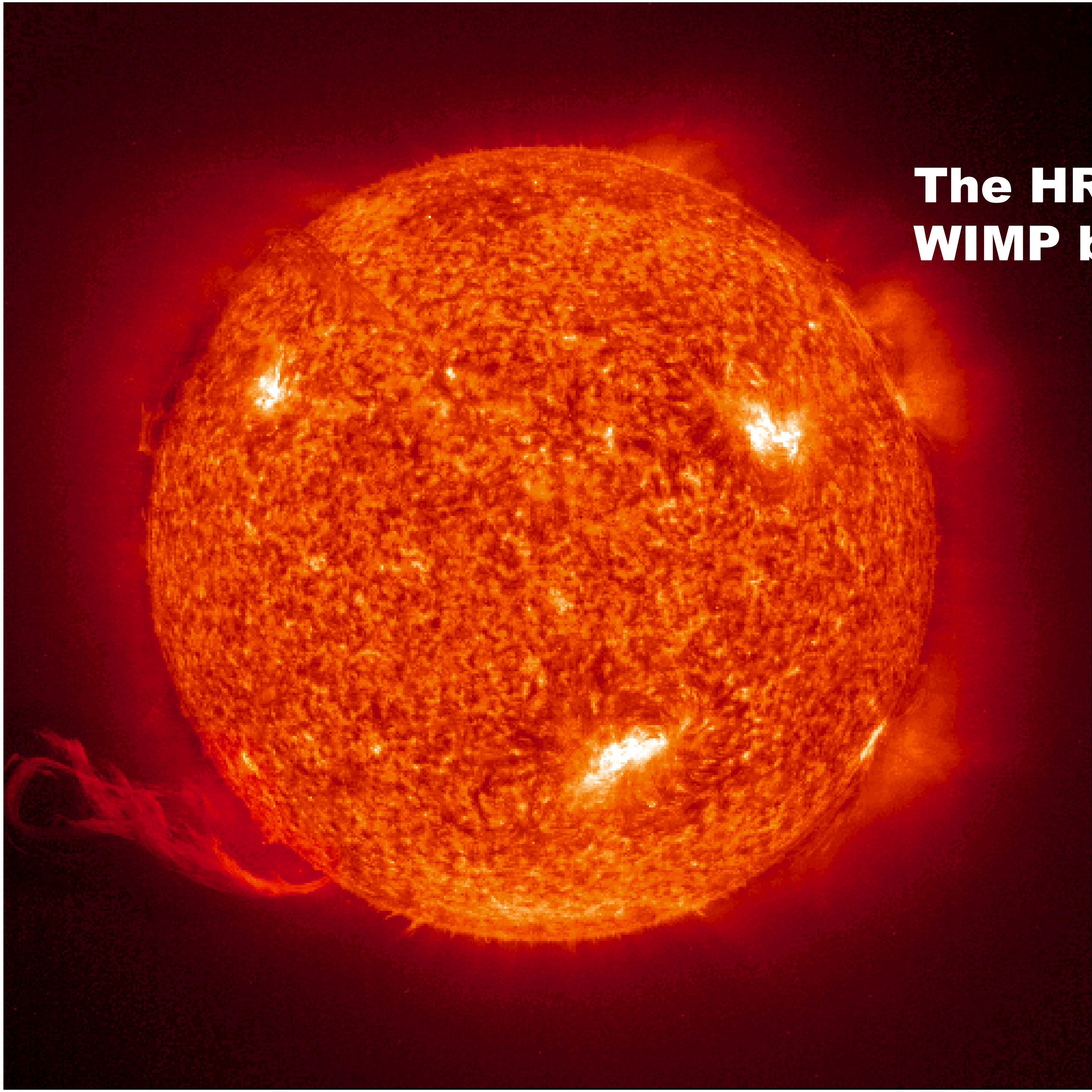
The HR diagram of WIMP burning stars



Malcolm Fairbairn

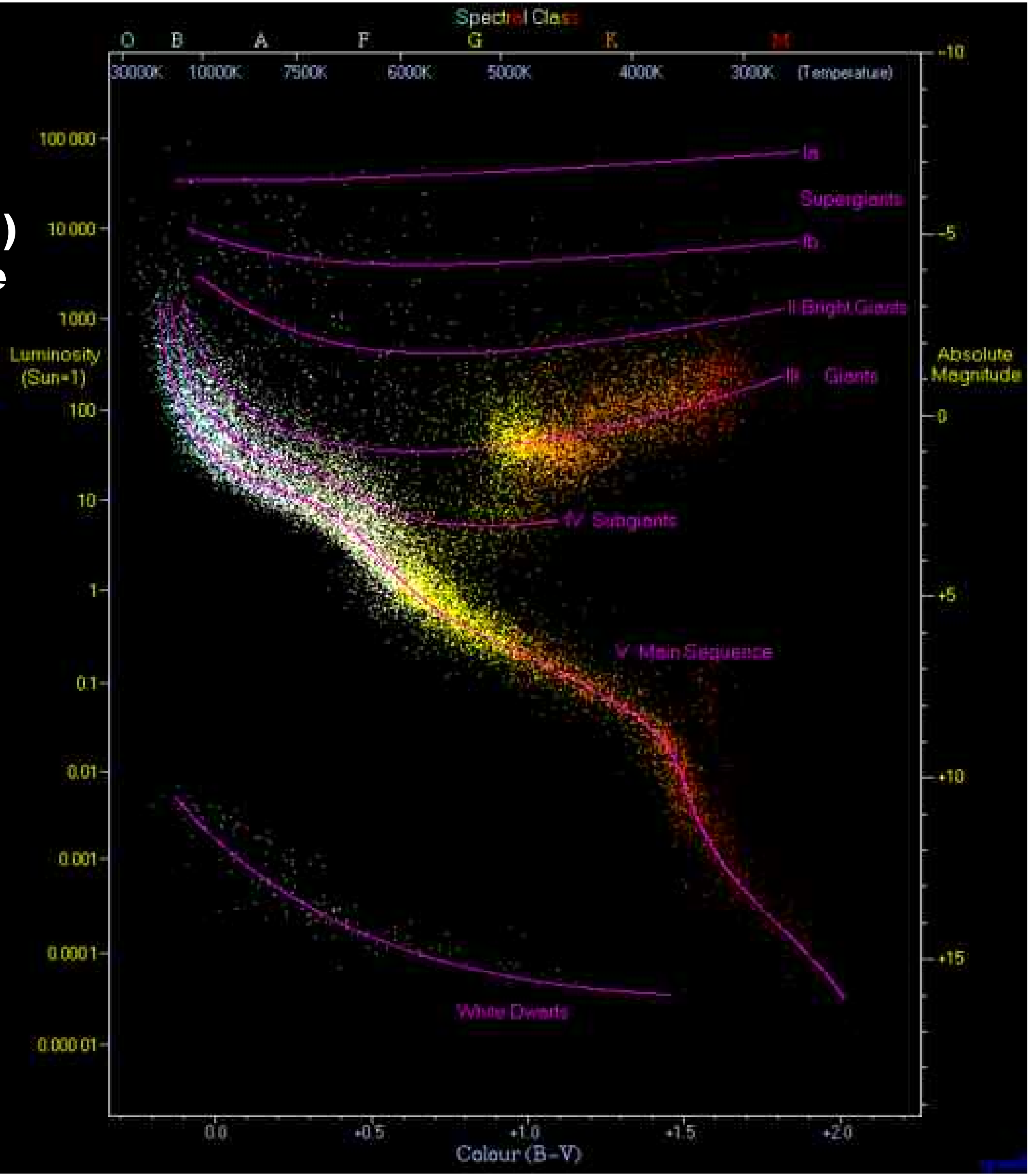
CERN

See also related work:-

e.g. Bouquet, Salati, Silk, Raffelt, ... 1980s-1990s

Moskalenko and Wai 2006

HR (Hertzsprung-Russell) luminosity-temperature diagram



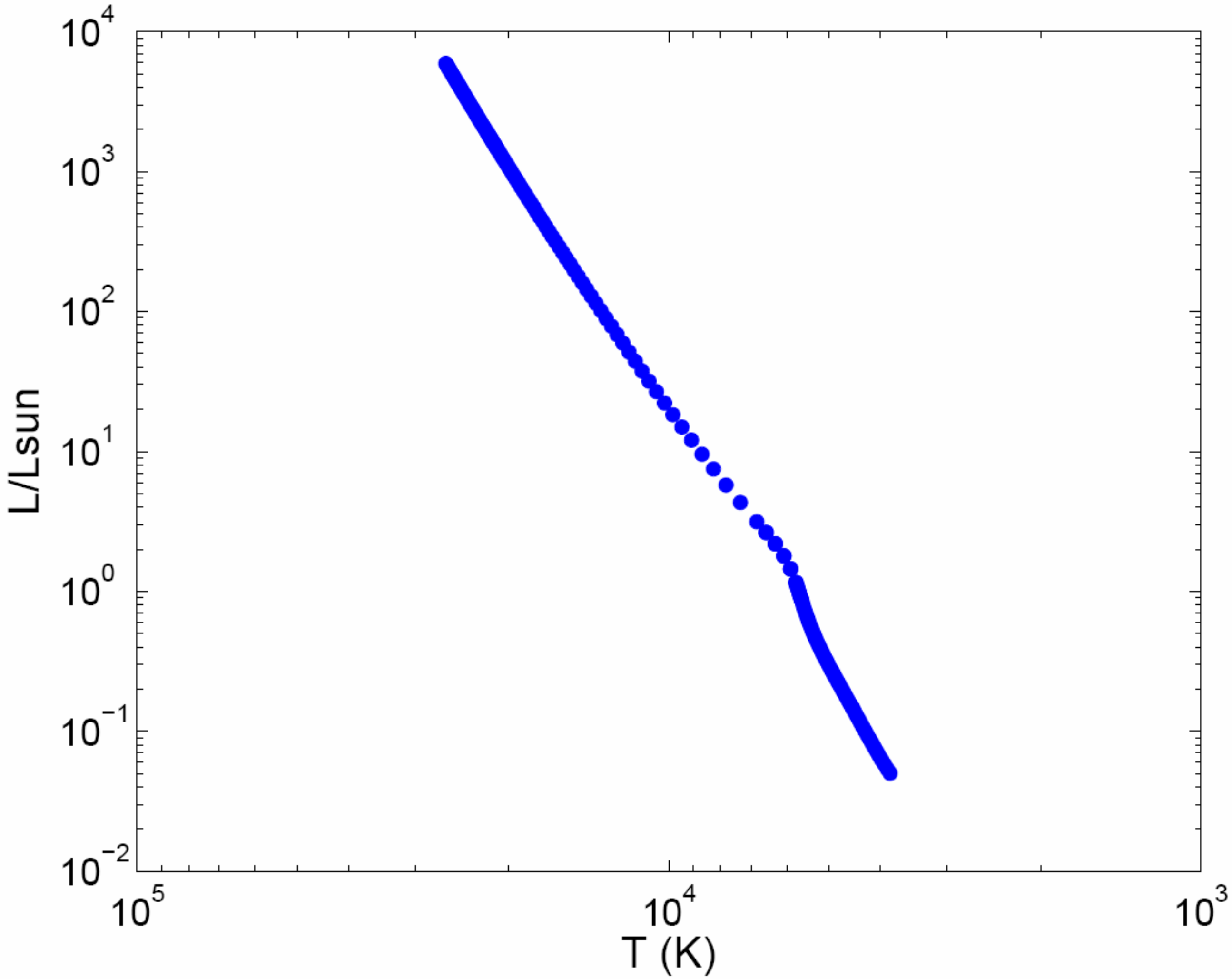
Hertzsprung-Russell diagram from computer

$$\frac{dM_r}{dr} = 4\pi r^2 \rho$$

$$\frac{dP}{dr} = -\frac{GM_r}{r^2}\rho$$

$$\frac{dL_r}{dr} = 4\pi r^2 \epsilon \rho$$

$$\frac{dT}{dr} = -\frac{1}{4\pi r^2 \lambda} L_r$$



Capture of dark matter onto stars

capture rate $$\Gamma_c = \left(\frac{8\pi}{3\pi}\right)^{1/2} \frac{\rho_\chi \bar{v}}{m_\chi} \left[\zeta + \frac{3v_{esc}^2}{2\bar{v}^2}\right] \sigma_{eff}$$

See e.g. Griest and Seckel 1988

where $$\sigma_{eff} = min\left(\sigma_{si} \sum_i \frac{M_*}{m_p} \frac{x_i}{A_i} A_i^4 \quad , \quad \pi R_*^2\right)$$

dark matter forms thermal core within the star of radius $r_{th} \sim \left[\frac{9kT}{8\pi G \rho_c m_\chi}\right]^{1/2}$

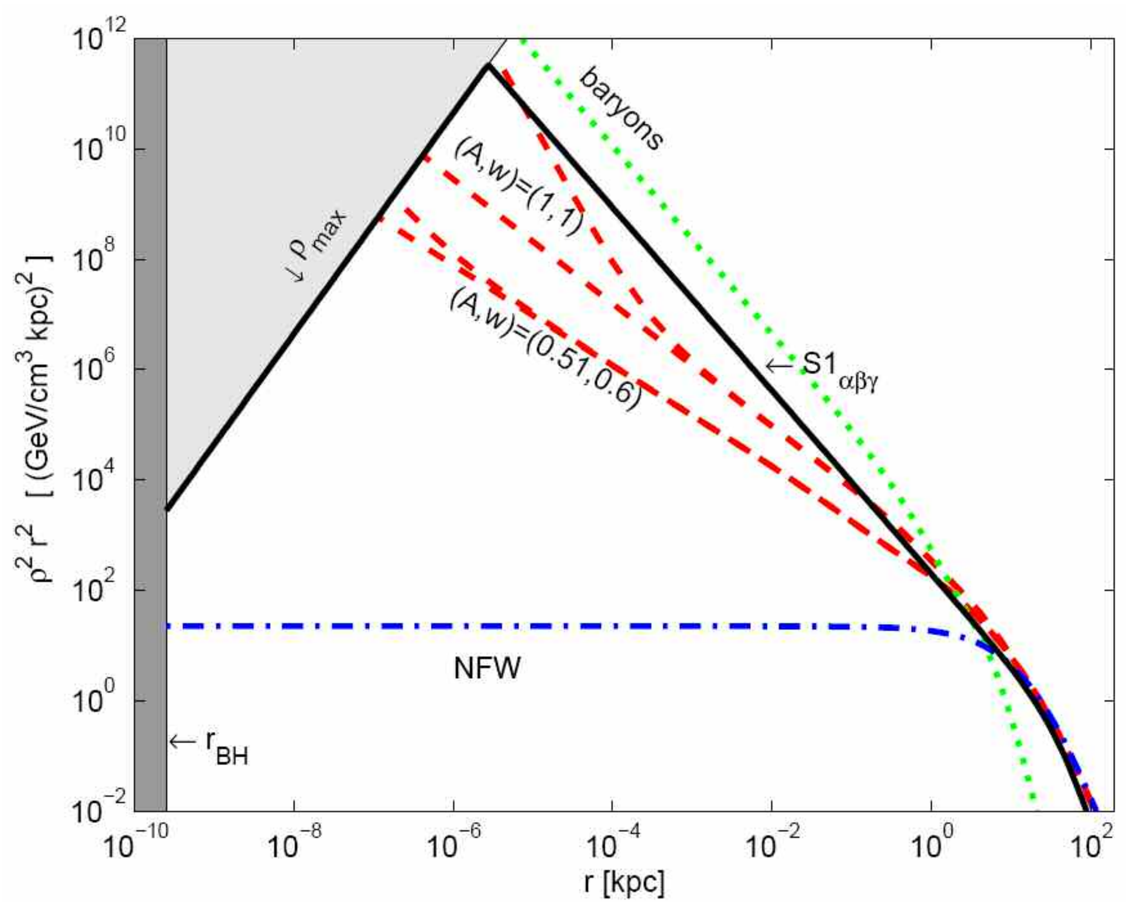
annihilation rate inside the core given by $\Gamma_a = \frac{1}{2} \frac{N^2 \langle \sigma v \rangle}{\frac{4}{3}\pi r_{th}^3}$

Number in core evolves as $\frac{dN}{dt} = \Gamma_c - \Gamma_a$ and equilibrium is reached when $\Gamma_c = \Gamma_a$

Dark matter density

$$\Gamma_c = \left(\frac{8\pi}{3\pi}\right)^{1/2} \frac{\rho_\chi \bar{v}}{m_\chi} \left[\zeta + \frac{3v_{esc}^2}{2\bar{v}^2}\right] \sigma_{eff}$$

For bigger effect, need bigger density



Simulations predict high densities in the centre of the galaxy and baryonic contraction plus the black hole may increase this.

M. Gustafsson, M.F. and J. Sommer-Larsen

Possible enhancement at the centre of the galaxy due to black hole

Gondolo and Silk 1999 Bertone and Merritt 2005

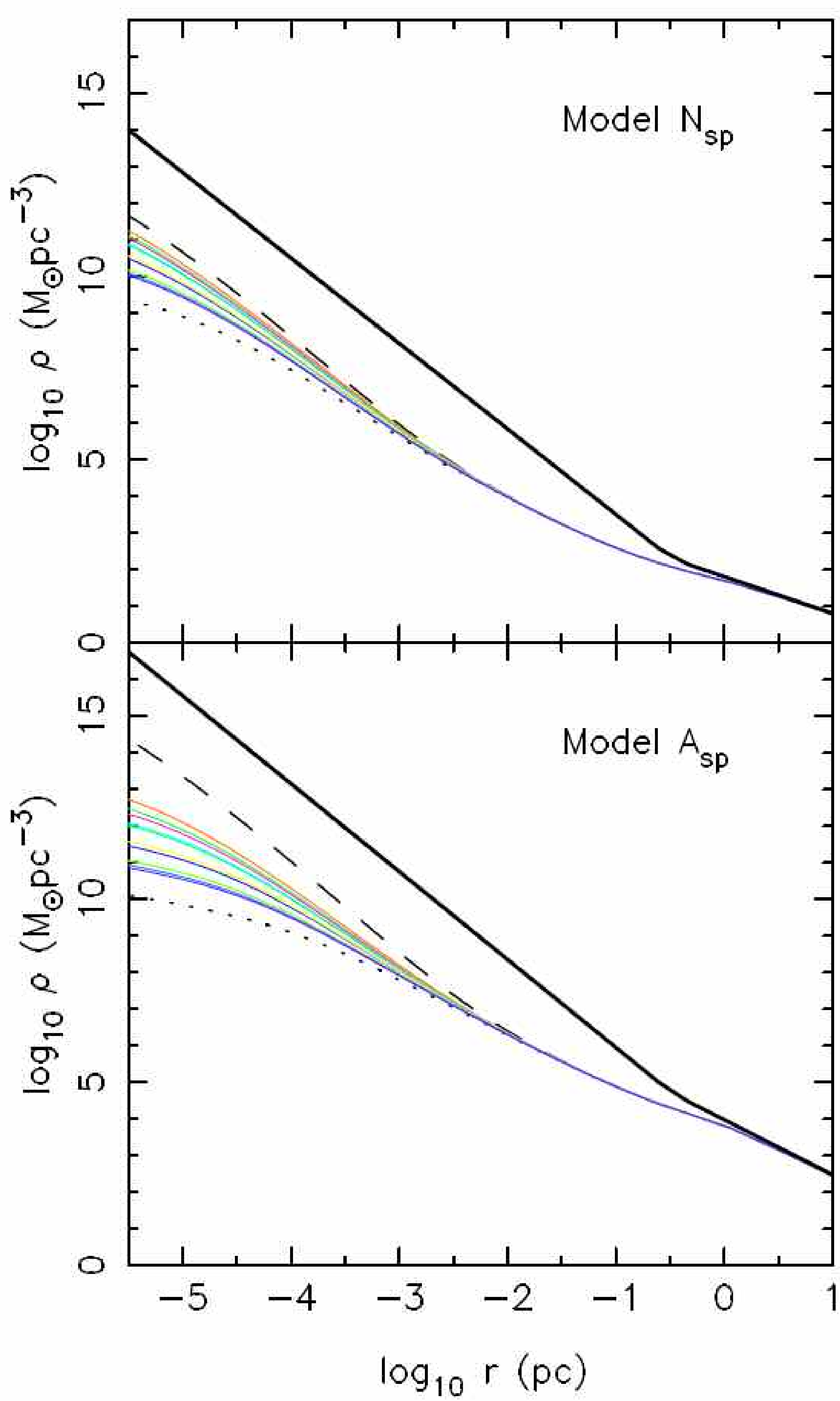
$f(\mathbf{r}, \mathbf{v}, t)$ = mass density of dark matter particles in phase space

$$\frac{\partial f}{\partial t} = \frac{1}{4\pi^2 p} \frac{\partial}{\partial E}\left[D_{EE}\frac{\partial f}{\partial E}\right] - f(E,t)\nu_{\rm coll}(E) \;\; - f(E,t)\nu_{\rm lc}(E)$$

Diffusion in mom. space due to gravitational heating by stars

DM self annihilation and actual collisions with stars

DM falling into Black hole



Solution of diffusion equation show that initial spikes die down over time

Bertone and Merritt 2005

we find interesting things start to happen around

$$\rho = 10^8 \text{ GeV cm}^{-3}$$

Effect of composition on capture

Also need to take into account chemical composition of star

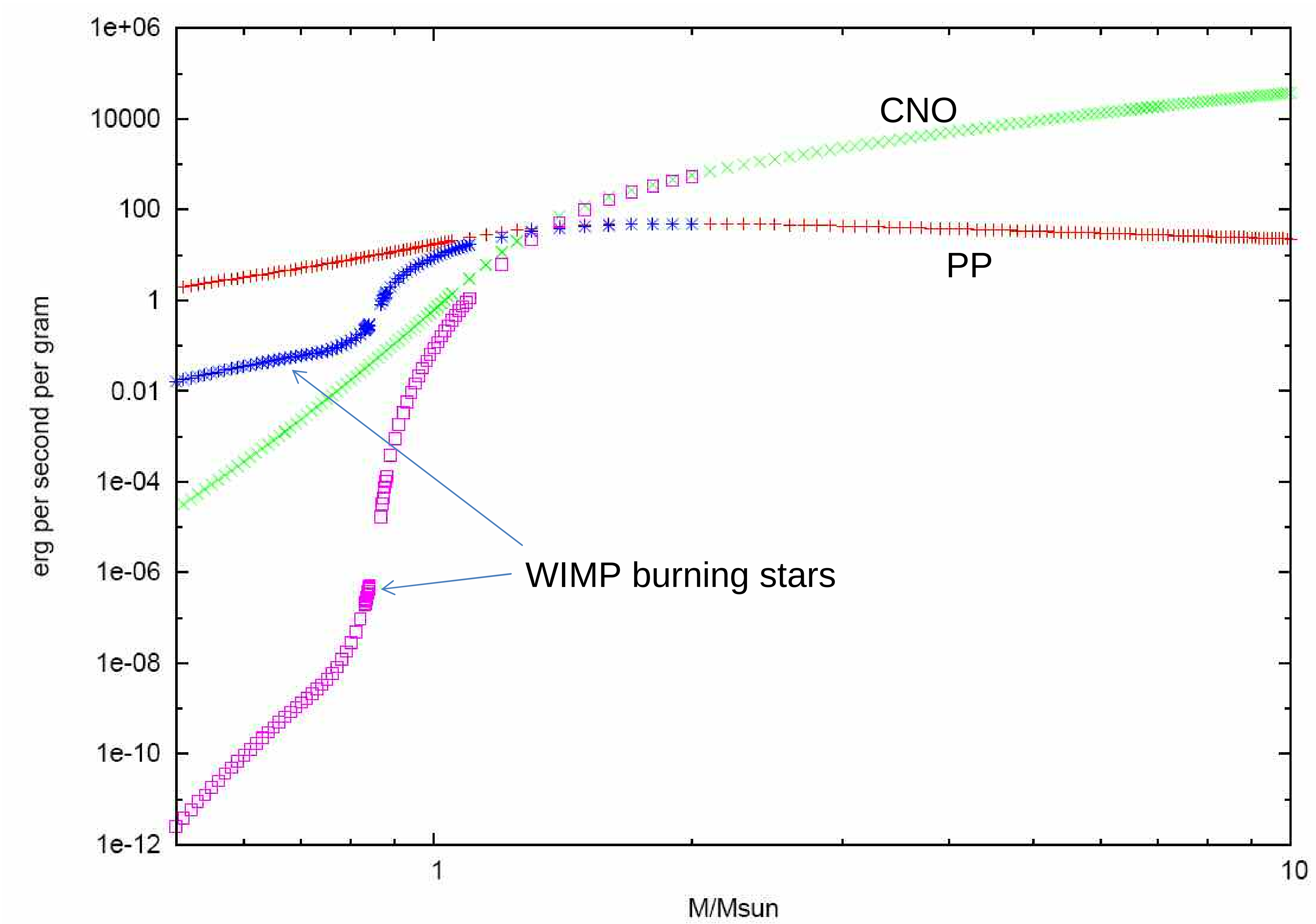
$$\sigma_{si} \sum_i \frac{M_*}{m_p} \frac{x_i}{A_i} A_i^4$$

For the solar composition, this yields extra factor 216

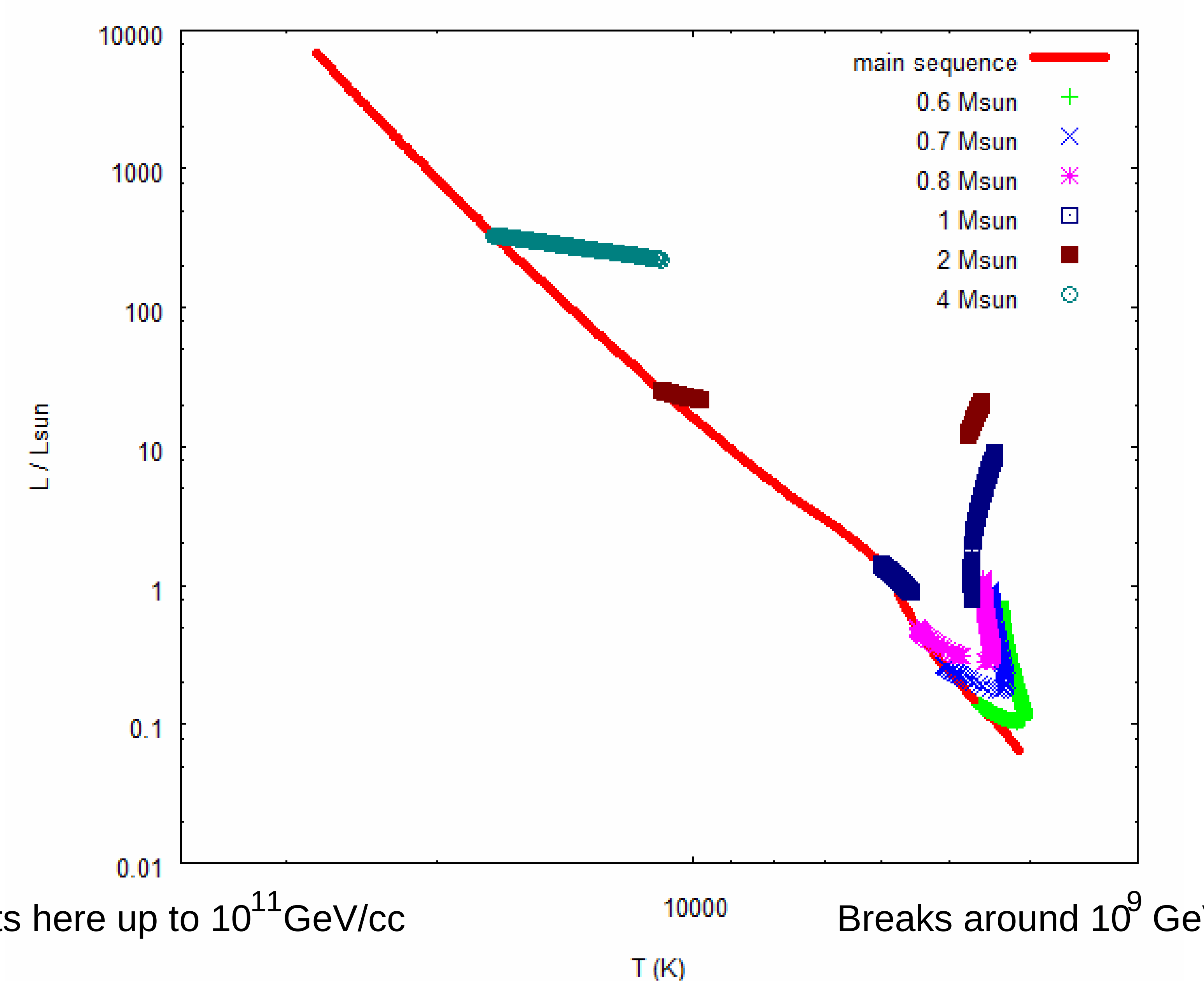
Table 1. Element abundances in the present-day solar photosphere and in meteorites (C1 chondrites). Indirect solar estimates are marked with [..]

	Elem.	Photosphere	Meteorites		Elem.	Photosphere	Meteorites
1	H	12.00	8.25 ± 0.05	44	Ru	1.84 ± 0.07	1.77 ± 0.08
2	He	[10.93 ± 0.01]	1.29	45	Rh	1.12 ± 0.12	1.07 ± 0.02
3	Li	1.05 ± 0.10	3.25 ± 0.06	46	Pd	1.69 ± 0.04	1.67 ± 0.02
4	Be	1.38 ± 0.09	1.38 ± 0.08	47	Ag	0.94 ± 0.24	1.20 ± 0.06
5	B	2.70 ± 0.20	2.75 ± 0.04	48	Cd	1.77 ± 0.11	1.71 ± 0.03
6	C	8.39 ± 0.05	7.40 ± 0.06	49	In	1.60 ± 0.20	0.80 ± 0.03
7	N	7.78 ± 0.06	6.25 ± 0.07	50	Sn	2.00 ± 0.30	2.08 ± 0.04
8	O	8.66 ± 0.05	8.39 ± 0.02	51	Sb	1.00 ± 0.30	1.03 ± 0.07
9	F	4.56 ± 0.30	4.43 ± 0.06	52	Te		2.19 ± 0.04
10	Ne	[7.84 ± 0.06]	-1.06	53	I		1.51 ± 0.12
11	Na	6.17 ± 0.04	6.27 ± 0.03	54	Xe	[2.27 ± 0.02]	-1.97
12	Mg	7.53 ± 0.09	7.53 ± 0.03	55	Cs		1.07 ± 0.03
13	Al	6.37 ± 0.06	6.43 ± 0.02	56	Ba	2.17 ± 0.07	2.16 ± 0.03
14	Si	7.51 ± 0.04	7.51 ± 0.02	57	La	1.13 ± 0.05	1.15 ± 0.06
15	P	5.36 ± 0.04	5.40 ± 0.04	58	Ce	1.58 ± 0.09	1.58 ± 0.02
16	S	7.14 ± 0.05	7.16 ± 0.04	59	Pr	0.71 ± 0.08	0.75 ± 0.03
17	Cl	5.50 ± 0.30	5.23 ± 0.06	60	Nd	1.45 ± 0.05	1.43 ± 0.03
18	Ar	[6.18 ± 0.08]	-0.45	62	Sm	1.01 ± 0.06	0.92 ± 0.04
19	K	5.08 ± 0.07	5.06 ± 0.05	63	Eu	0.52 ± 0.06	0.49 ± 0.04
20	Ca	6.31 ± 0.04	6.29 ± 0.03	64	Gd	1.12 ± 0.04	1.03 ± 0.02
21	Sc	3.05 ± 0.08	3.04 ± 0.04	65	Tb	0.28 ± 0.30	0.28 ± 0.03
22	Ti	4.90 ± 0.06	4.89 ± 0.03	66	Dy	1.14 ± 0.08	1.10 ± 0.04
23	V	4.00 ± 0.02	3.97 ± 0.03	67	Ho	0.51 ± 0.10	0.46 ± 0.02
24	Cr	5.64 ± 0.10	5.63 ± 0.05	68	Er	0.93 ± 0.06	0.92 ± 0.03
25	Mn	5.39 ± 0.03	5.47 ± 0.03	69	Tm	0.00 ± 0.15	0.08 ± 0.06
26	Fe	7.45 ± 0.05	7.45 ± 0.03	70	Yb	1.08 ± 0.15	0.91 ± 0.03
27	Co	4.92 ± 0.08	4.86 ± 0.03	71	Lu	0.06 ± 0.10	0.06 ± 0.06
28	Ni	6.23 ± 0.04	6.19 ± 0.03	72	Hf	0.88 ± 0.08	0.74 ± 0.04
29	Cu	4.21 ± 0.04	4.23 ± 0.06	73	Ta		-0.17 ± 0.03
30	Zn	4.60 ± 0.03	4.61 ± 0.04	74	W	1.11 ± 0.15	0.62 ± 0.03
31	Ga	2.88 ± 0.10	3.07 ± 0.06	75	Re		0.23 ± 0.04
32	Ge	3.58 ± 0.05	3.59 ± 0.05	76	Os	1.45 ± 0.10	1.34 ± 0.03
33	As		2.29 ± 0.05	77	Ir	1.38 ± 0.05	1.32 ± 0.03
34	Se		3.33 ± 0.04	78	Pt		1.64 ± 0.03
35	Br		2.56 ± 0.09	79	Au	1.01 ± 0.15	0.80 ± 0.06
36	Kr	[3.28 ± 0.08]	-2.27	80	Hg		1.13 ± 0.18
37	Rb	2.60 ± 0.15	2.33 ± 0.06	81	Tl	0.90 ± 0.20	0.78 ± 0.04
38	Sr	2.92 ± 0.05	2.88 ± 0.04	82	Pb	2.00 ± 0.06	2.02 ± 0.04
39	Y	2.21 ± 0.02	2.17 ± 0.04	83	Bi		0.65 ± 0.03
40	Zr	2.59 ± 0.04	2.57 ± 0.02	90	Th		0.06 ± 0.04
41	Nb	1.42 ± 0.06	1.39 ± 0.03	92	U	<-0.47	-0.52 ± 0.04
42	Mo	1.92 ± 0.05	1.96 ± 0.04				

Central nuclear energy generation rates



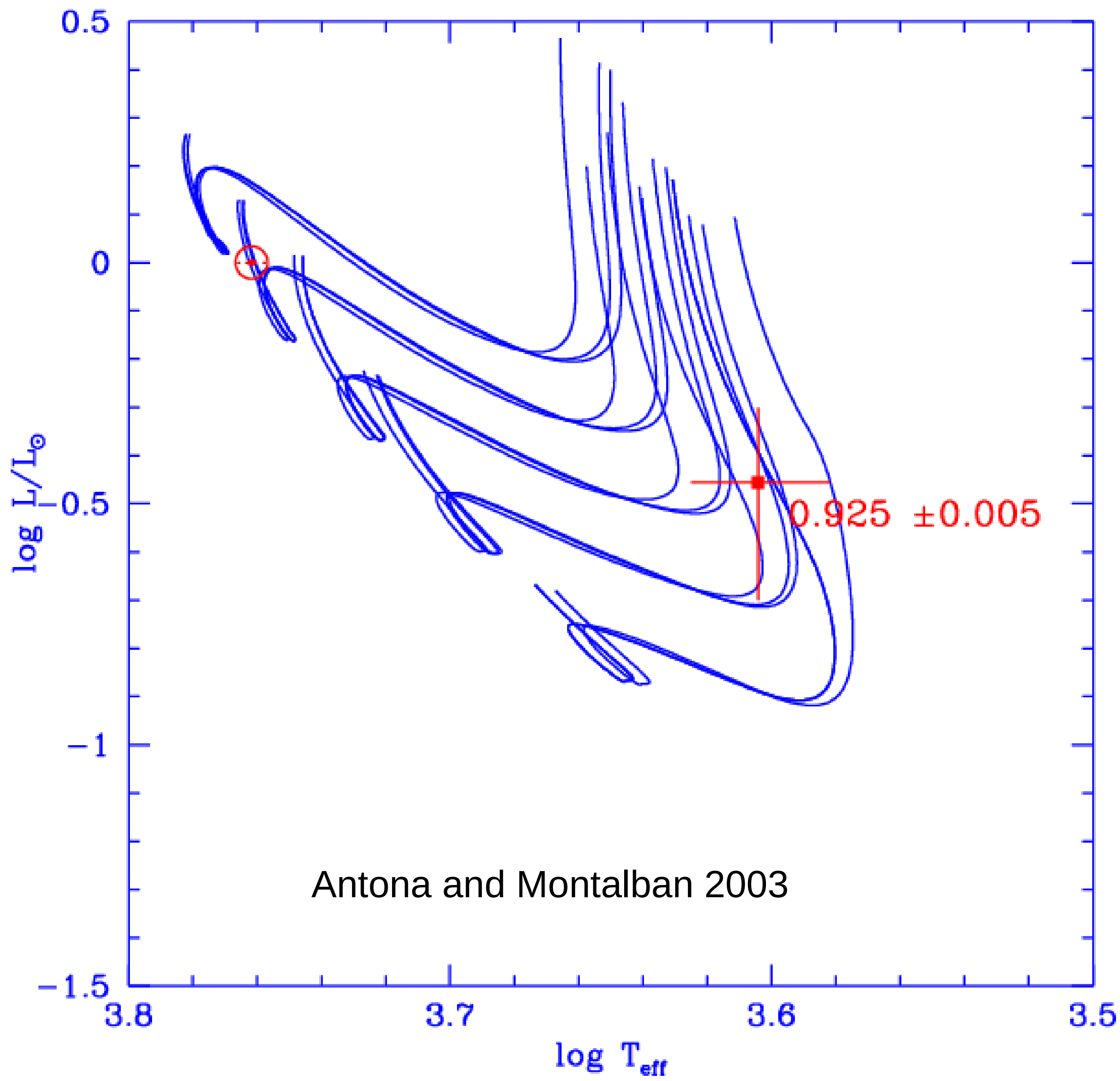
The HR diagram of WIMP burning stars



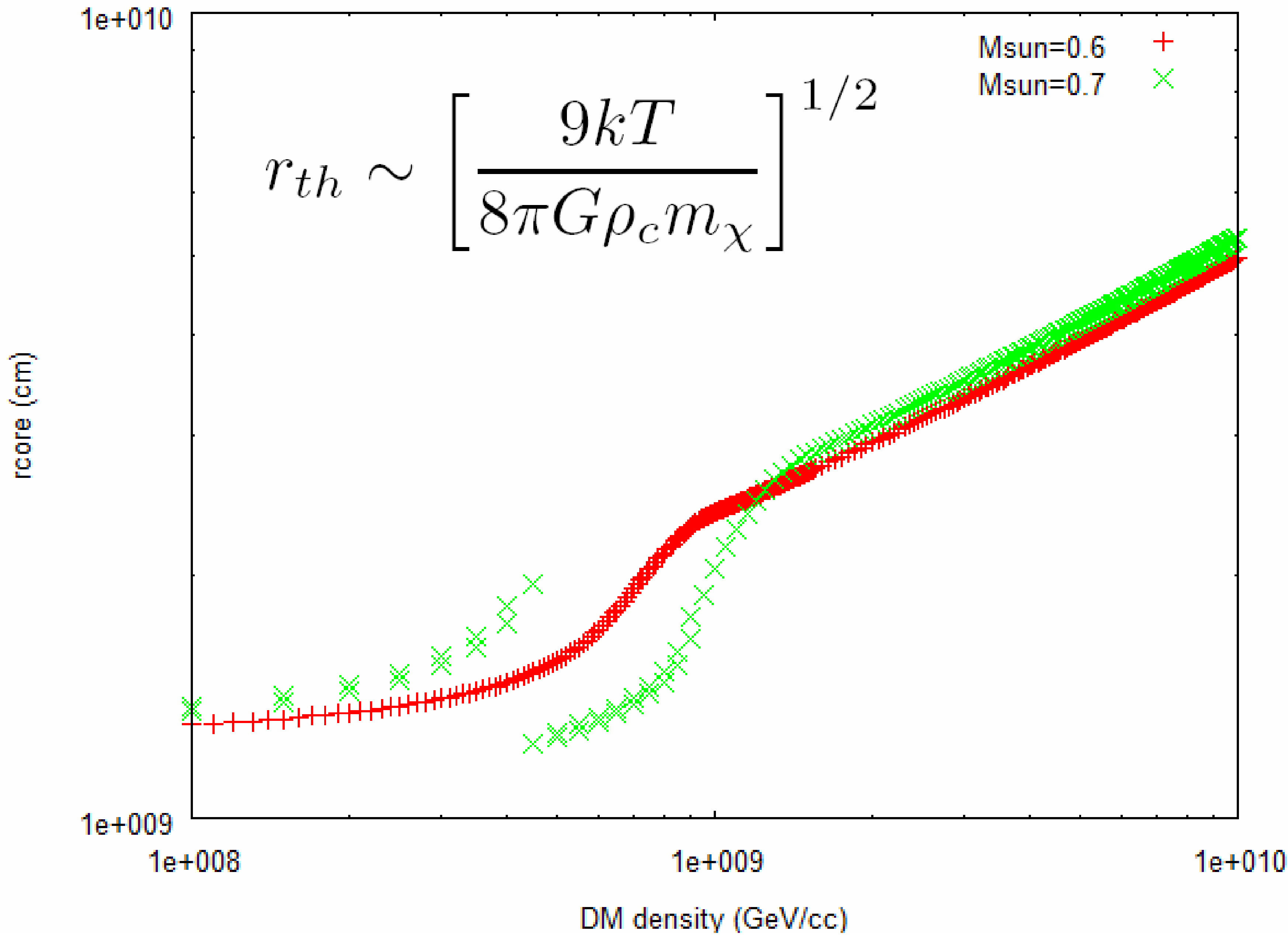
Plots here up to 10^{11} GeV/cc

Breaks around 10^{9} GeV/cc

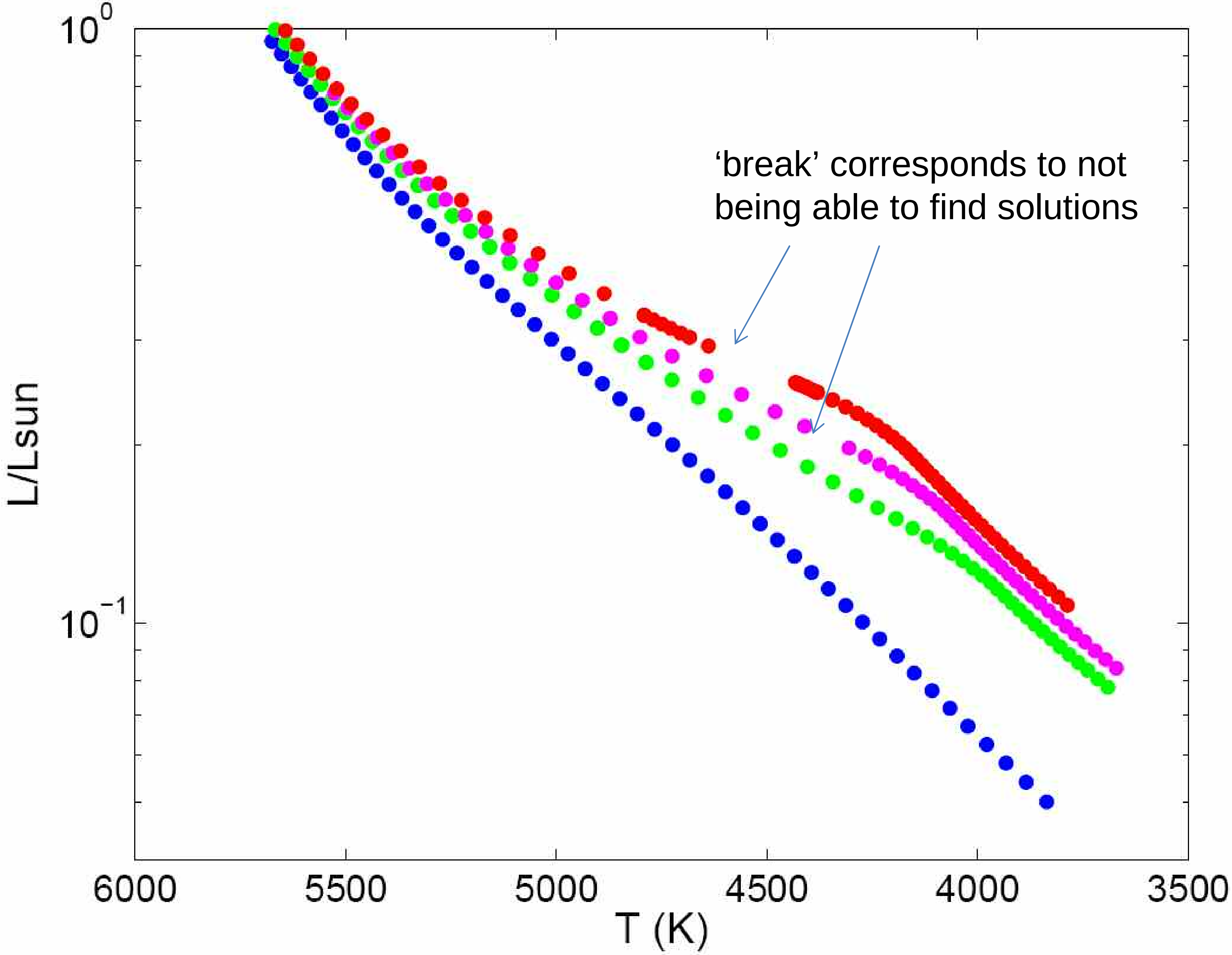
Looks like Hayashi track of protostars?

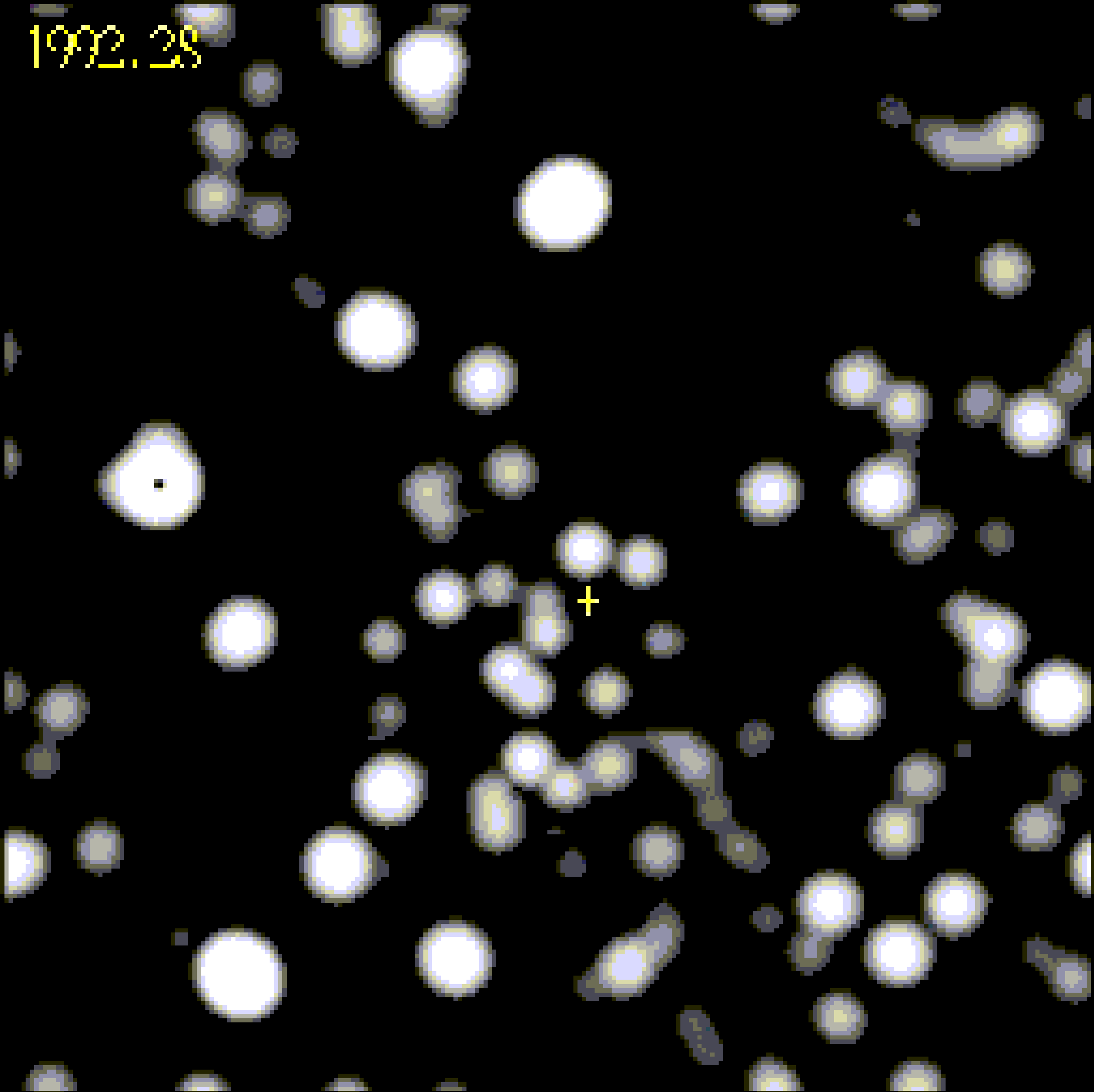


Break in Main Sequence Solutions Physical?



Effect of WIMP accretion on HR diagram

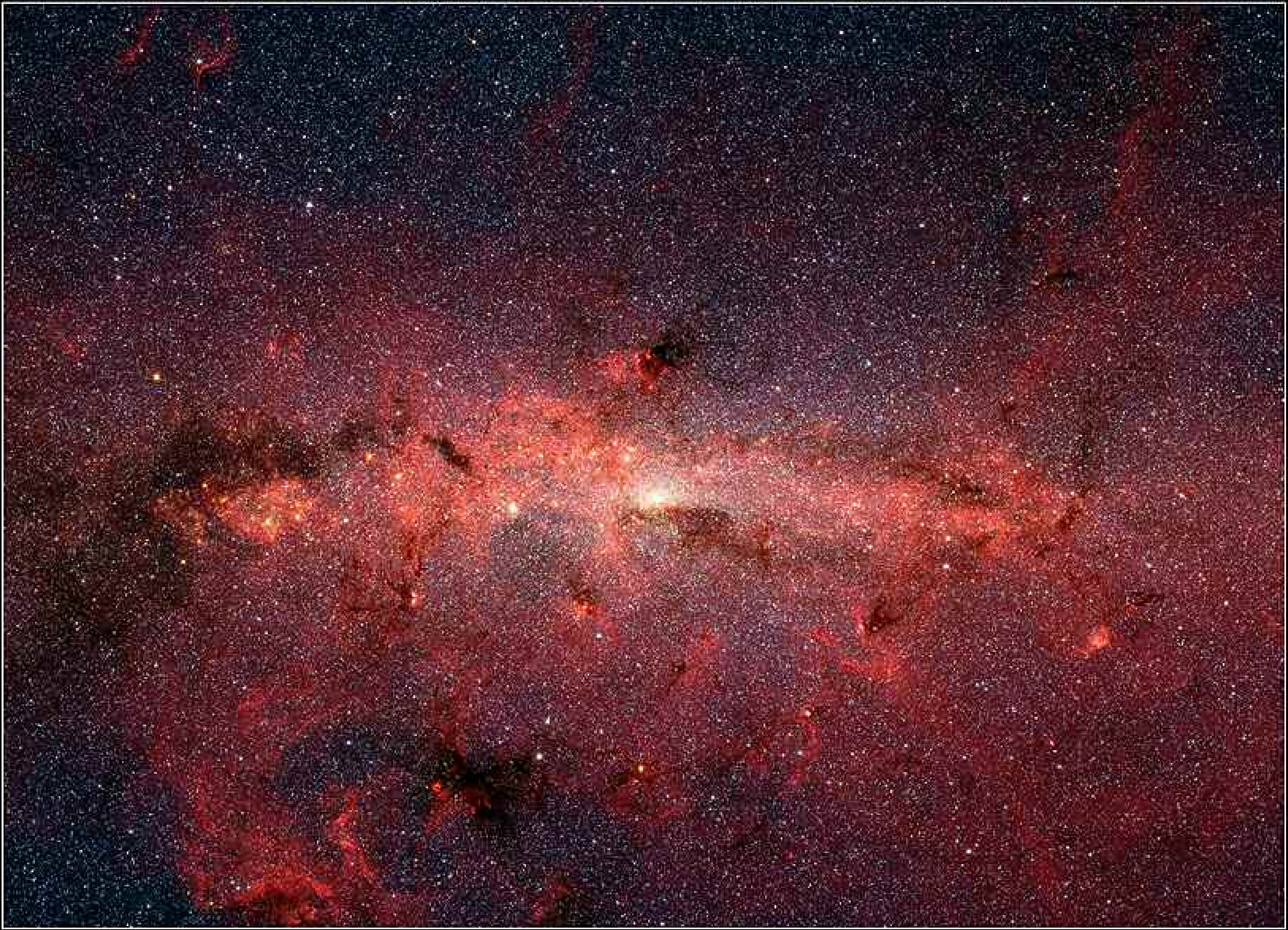




Eckart and Genzel

200 x 275 pc

distance 8500 pc



The Center of the Milky Way Galaxy

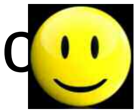
NASA / JPL-Caltech / S. Stolovy (Spitzer Science Center/Caltech)

Spitzer Space Telescope • IRAC

ssc2006-02a

$$\Gamma_c = \left(\frac{8\pi}{3\pi}\right)^{1/2} \frac{\rho_\chi \bar{v}}{m_\chi} \left[\zeta + \frac{3v_{esc}^2}{2\bar{v}^2}\right] \sigma_{eff}$$

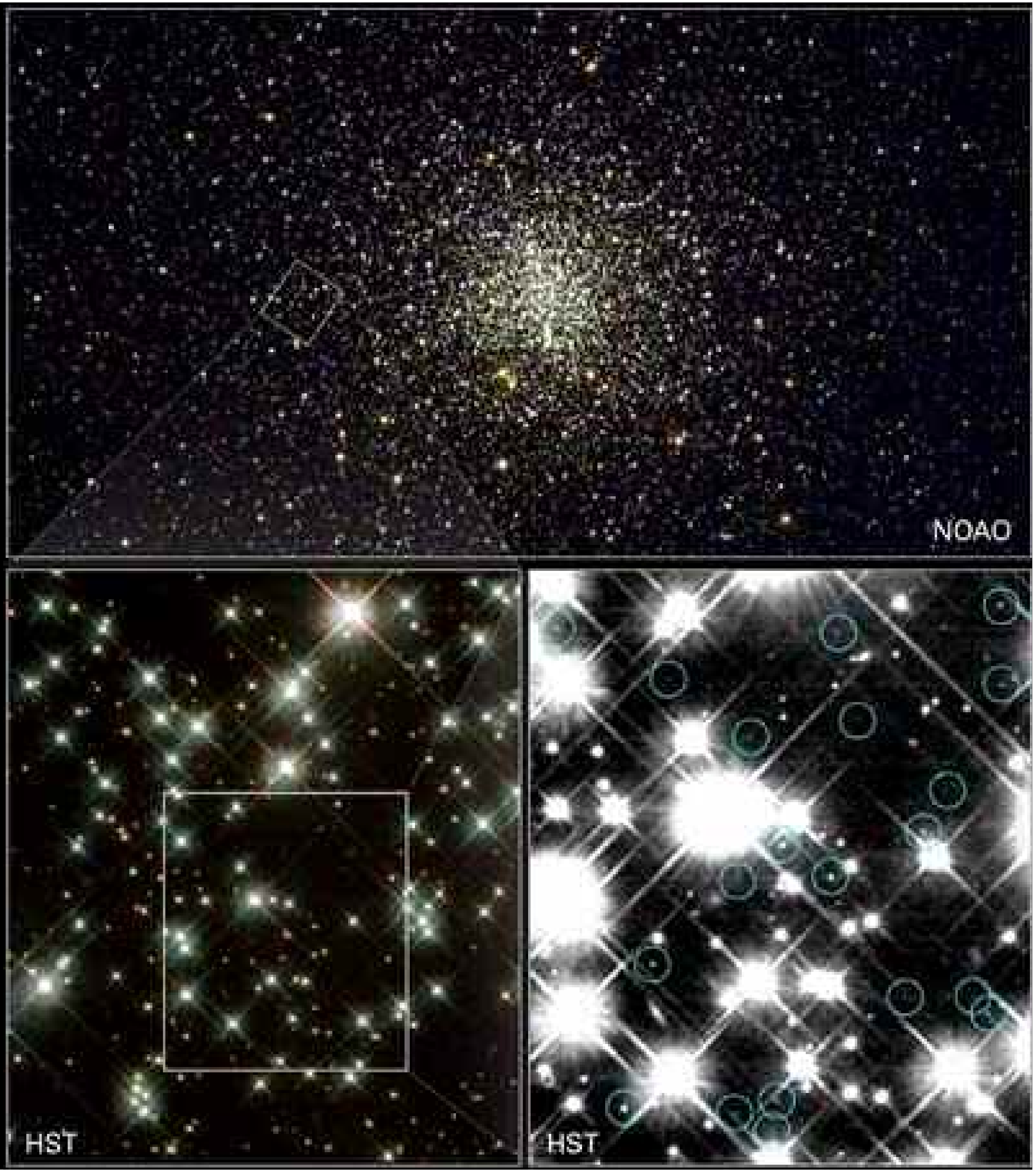
What about increasing escape velocity?

White dwarves - high escape veloc 

- born 

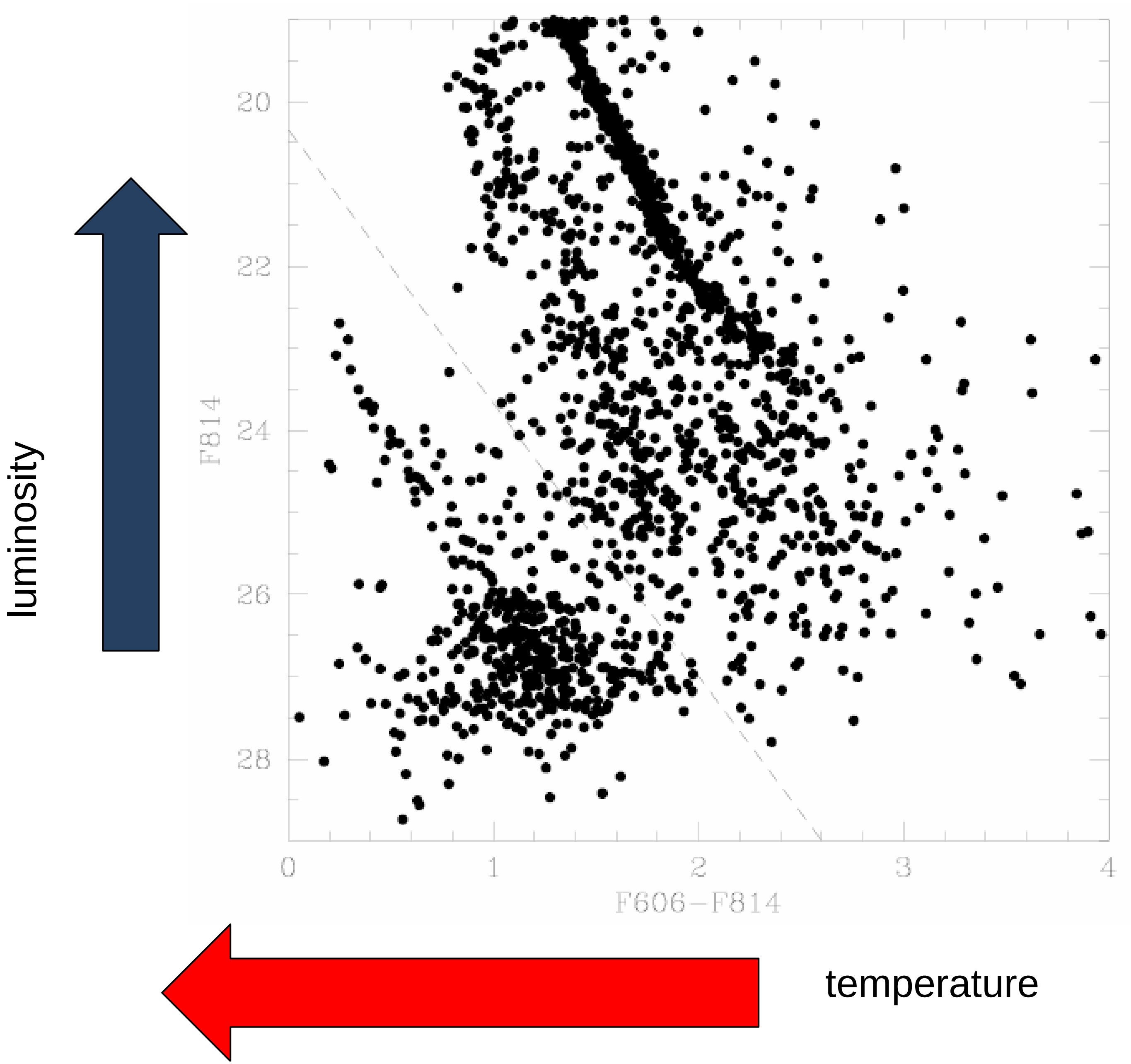
NEED TO FIND SOME OLD ONES

White Dwarves in Globular Cluster M4

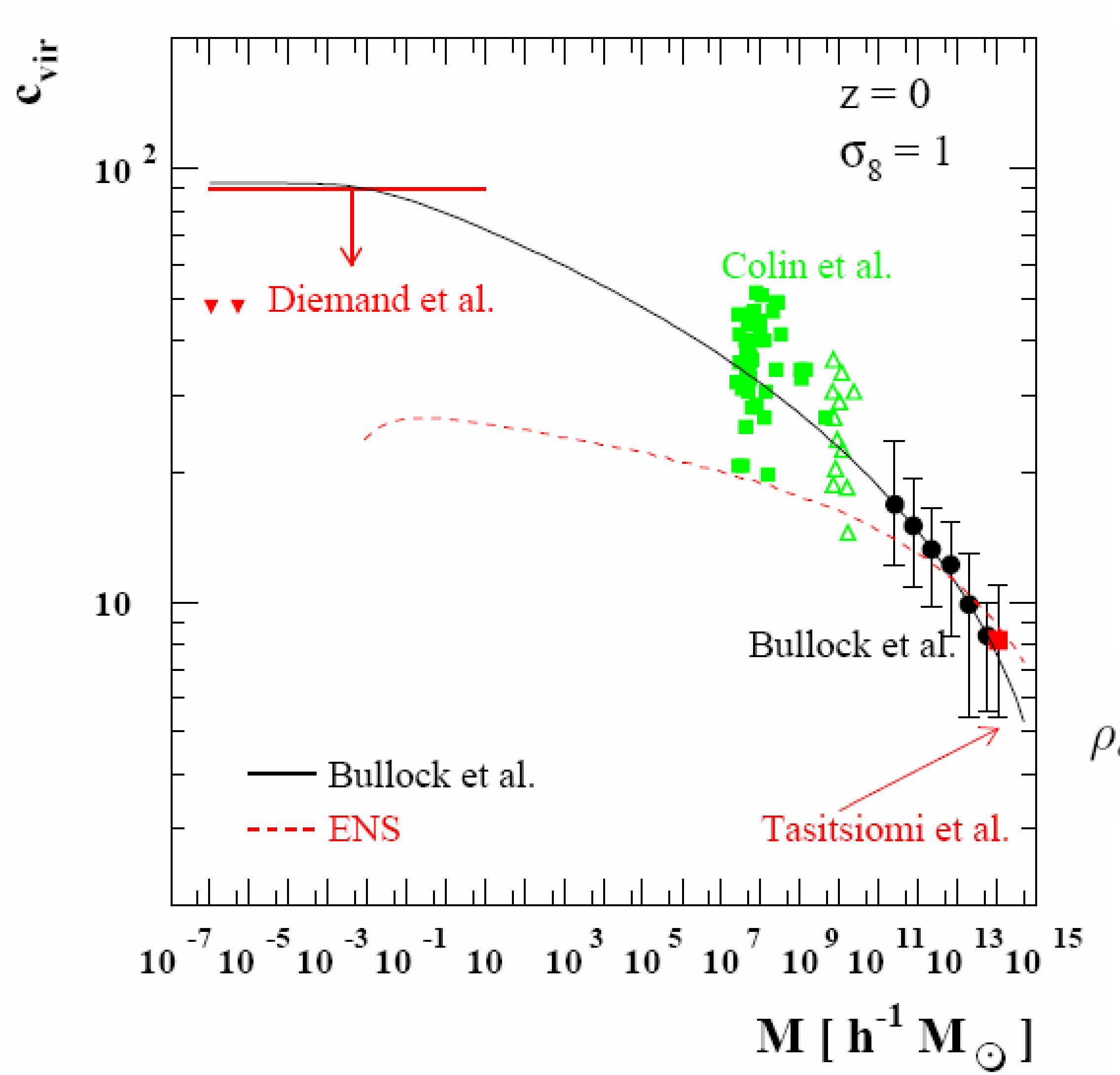


Richer et al. 2004

Bottom of HR diagram in Globular Cluster M4



Need to work out density of dark matter in globular cluster



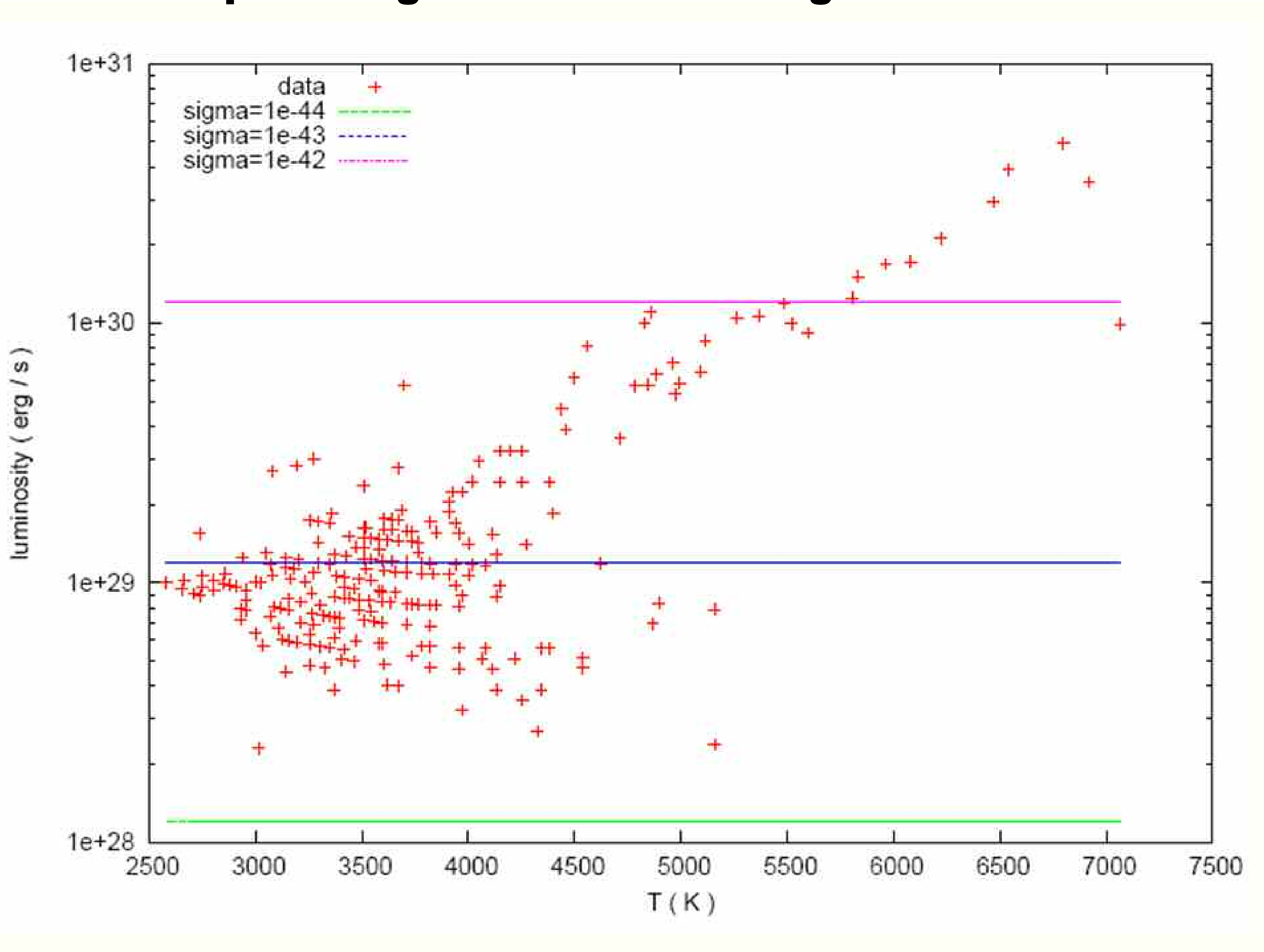
Colafrancesco et al. Astro-ph/0507575

$$\rho(r) = \frac{\rho_c}{\frac{r}{a}\left(1+\frac{r}{a}\right)^2}$$

$$c_{vir} = \frac{R_{vir}}{a}$$

$$\rho_c = \frac{M_{DM}}{4\pi a^3}\left[\ln(1+c) - \frac{c}{1+c}\right]^{-1}$$

Wimp burning white dwarves in globular clusters



MF and G.Bertone, in preparation

Conclusions

- accretion of dark matter onto stars can in principle seriously affect their nature
- white dwarfs already place interesting constraints on dark matter scenarios