



The HR diagram of WIMP burning stars

Malcolm Fairbairn



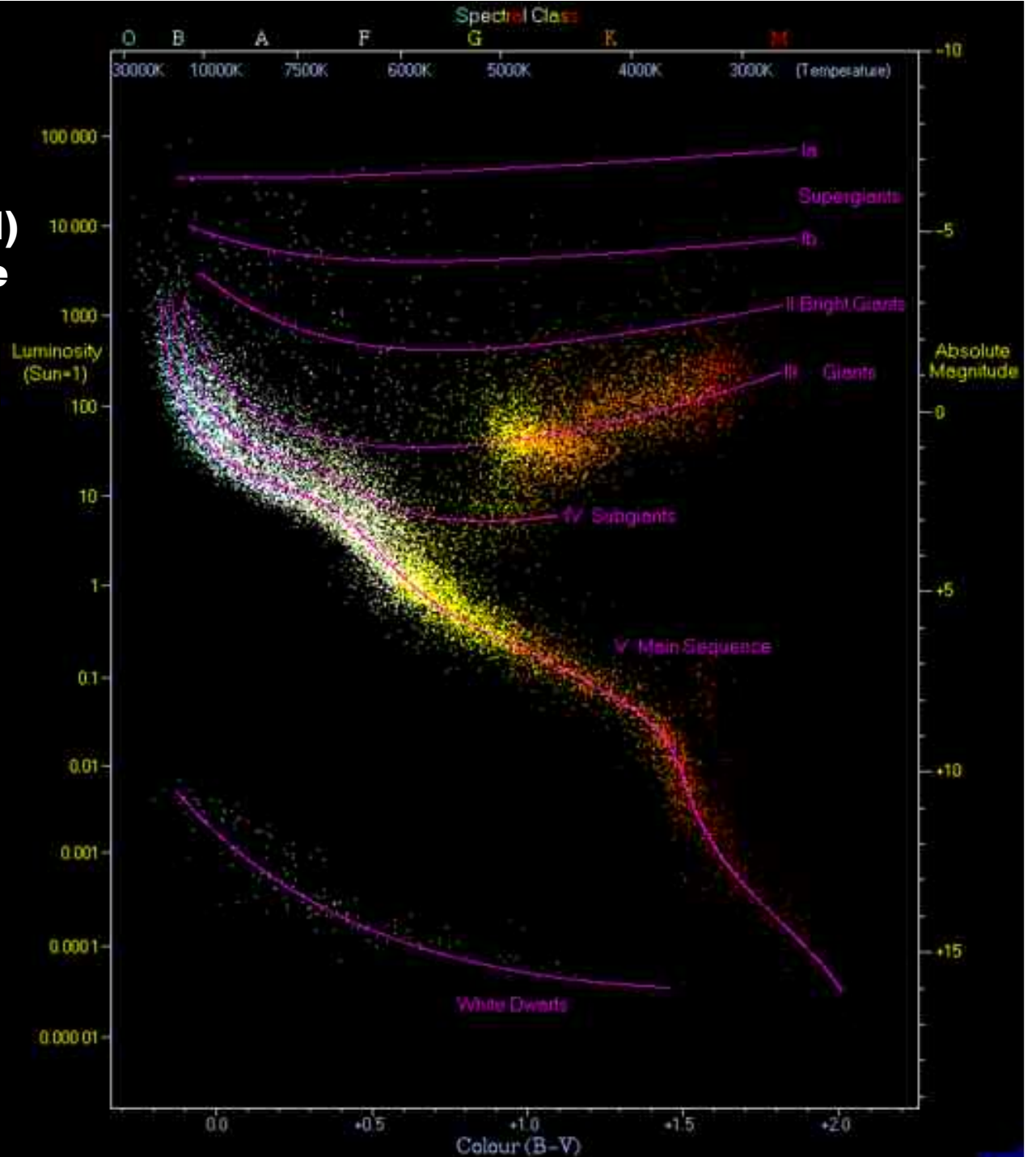
See also related work:-

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

Moskalenko and Wai

2006

HR (Hertzsprung-Russell) luminosity-temperature diagram



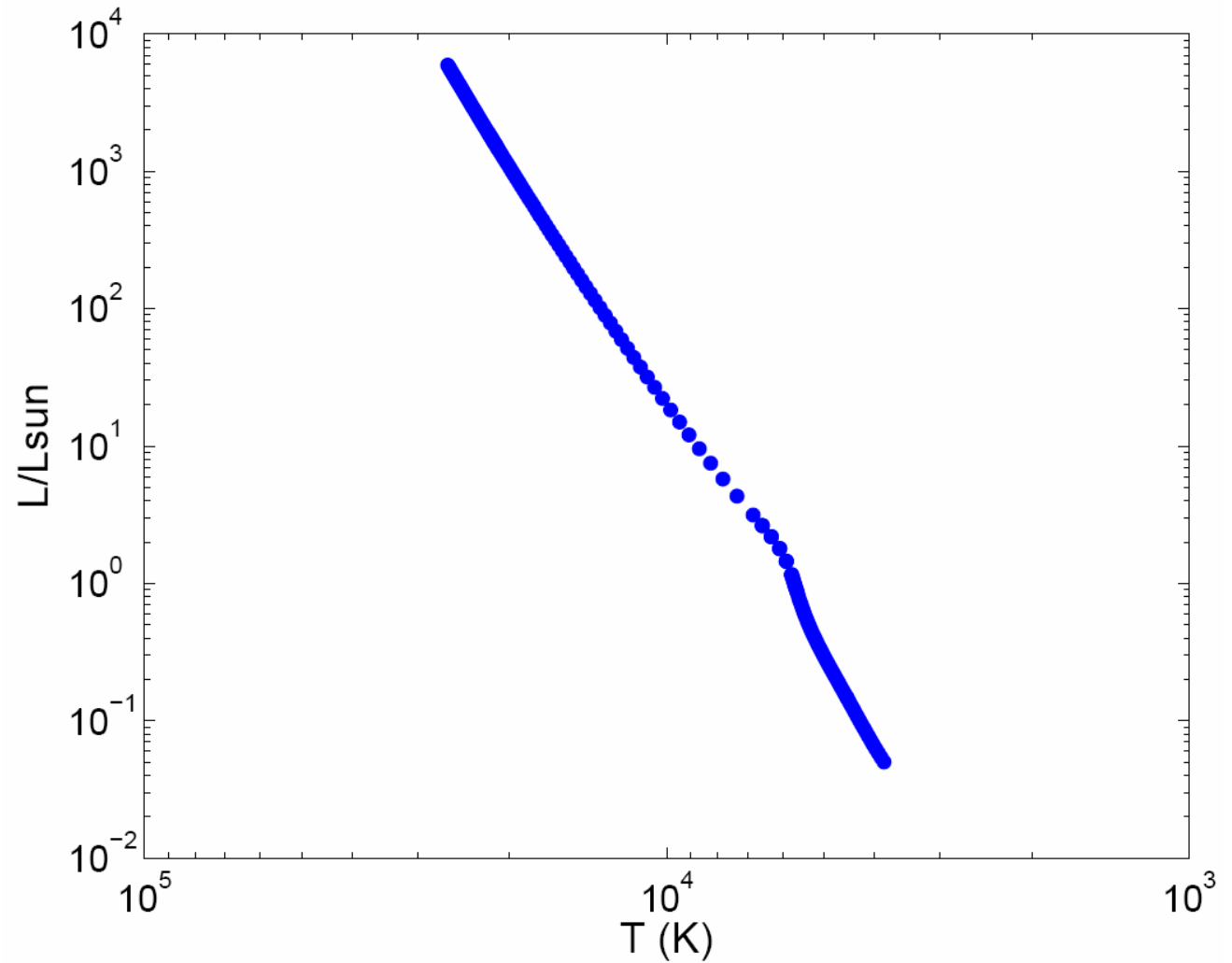
Hertzsprung-Russell diagram from computer

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

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

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

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



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

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

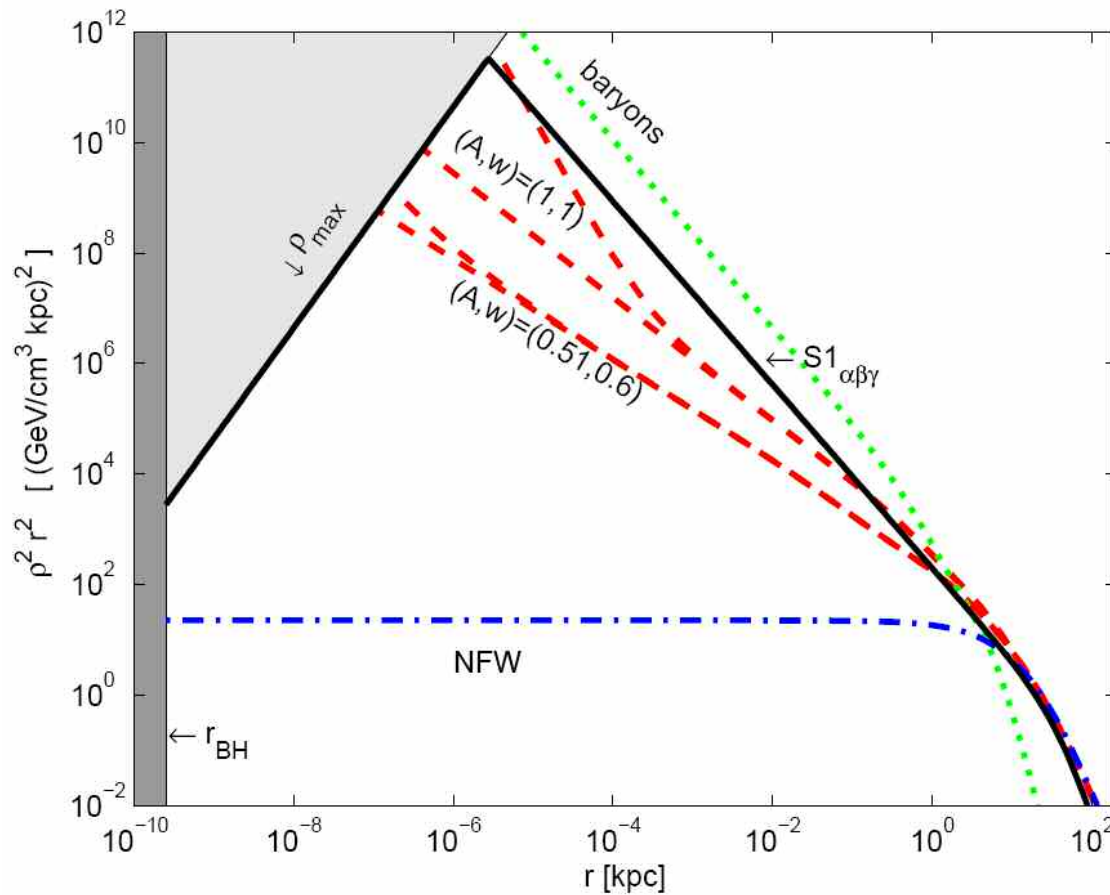
annihilation rate inside the core given by $\Gamma_a = \frac{1}{2} \frac{N^2 \langle \sigma v \rangle}{\frac{4}{3} \pi r_{th}^3}$

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

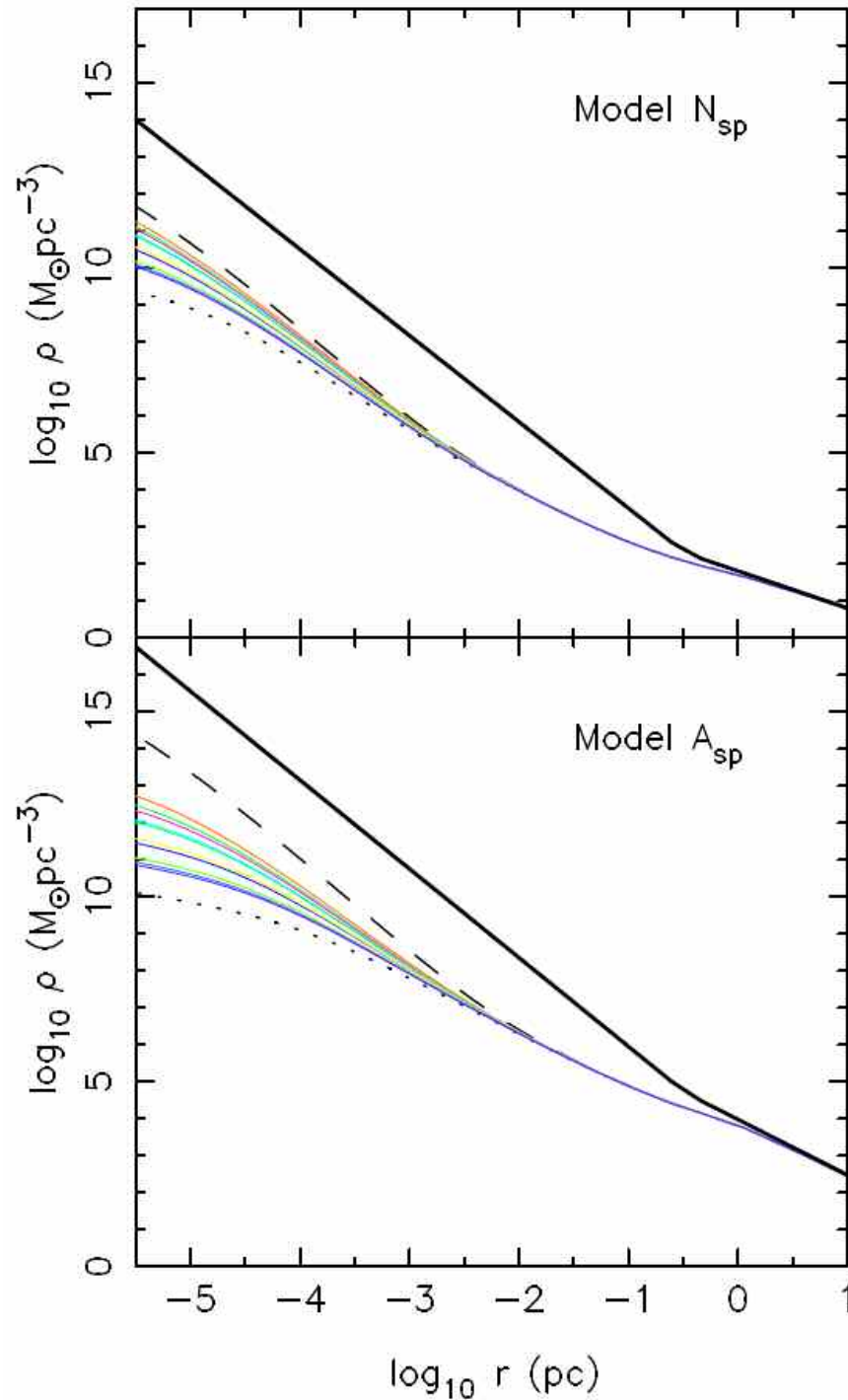
$f(\mathbf{r}, \mathbf{v}, t)$ = mass density of dark matter particles in phase space

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

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

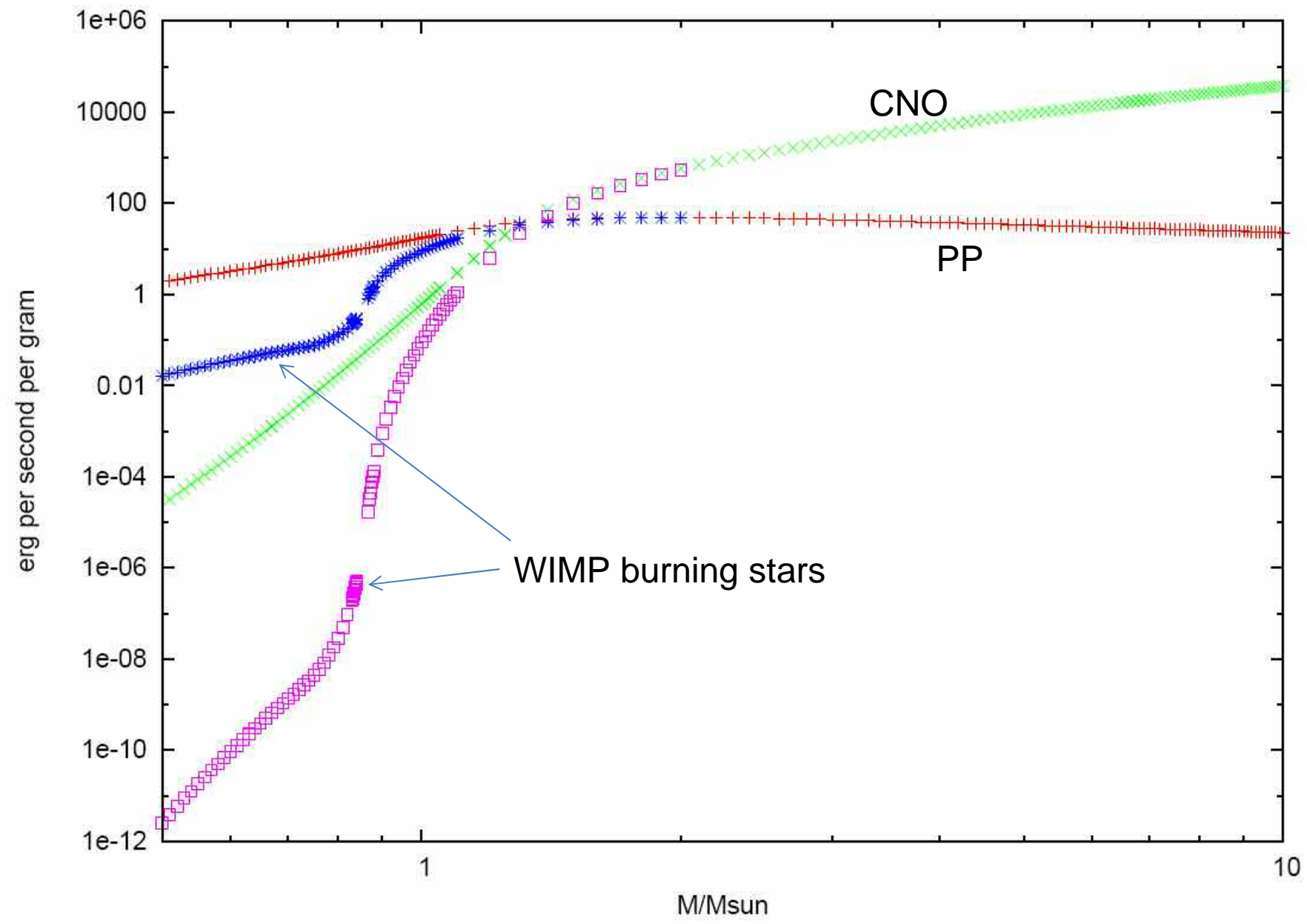
$$\sigma_{si} \sum_i \frac{M_*}{m_p} \frac{x_i}{A_i} A_i^4$$

For the solar composition,
this yields extra factor 216

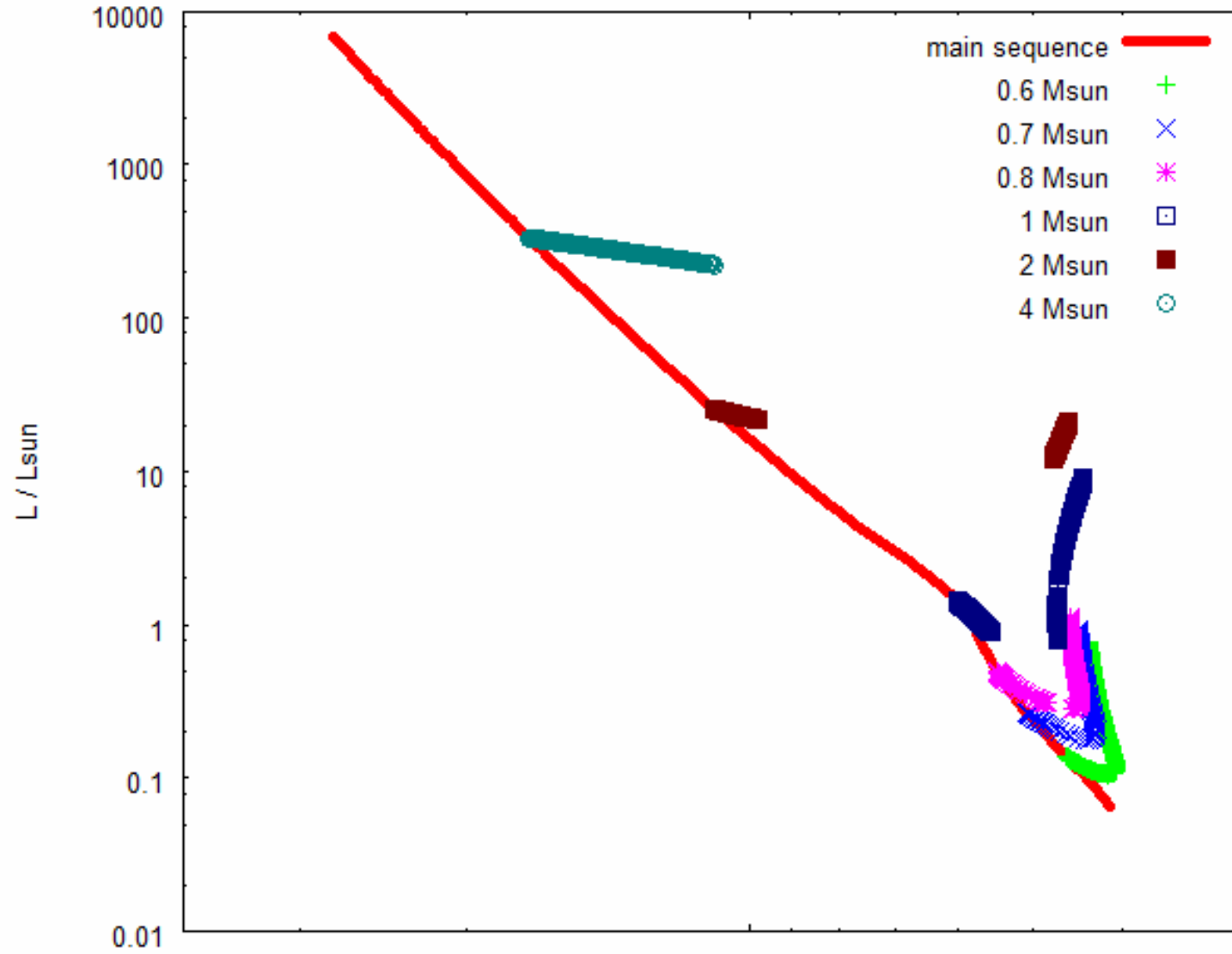
Table 1. Element abundances in the present-day solar photosphere and in meteorites (C1 chondrites). Indirect solar estimates are marked with [..]

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

Central nuclear energy generation rates



The HR diagram of WIMP burning stars



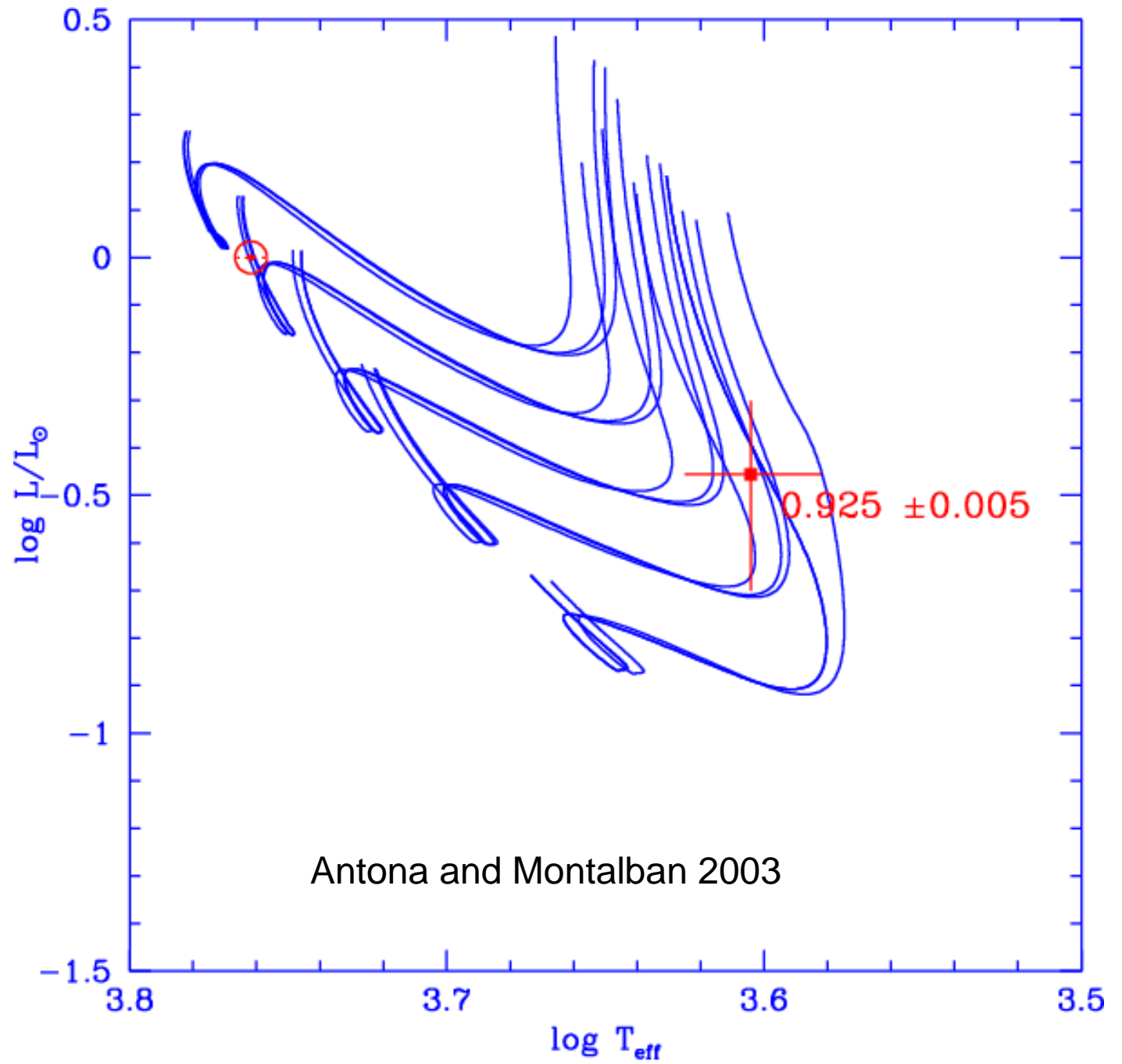
Plots here up to 10^{11} GeV/cc

10000

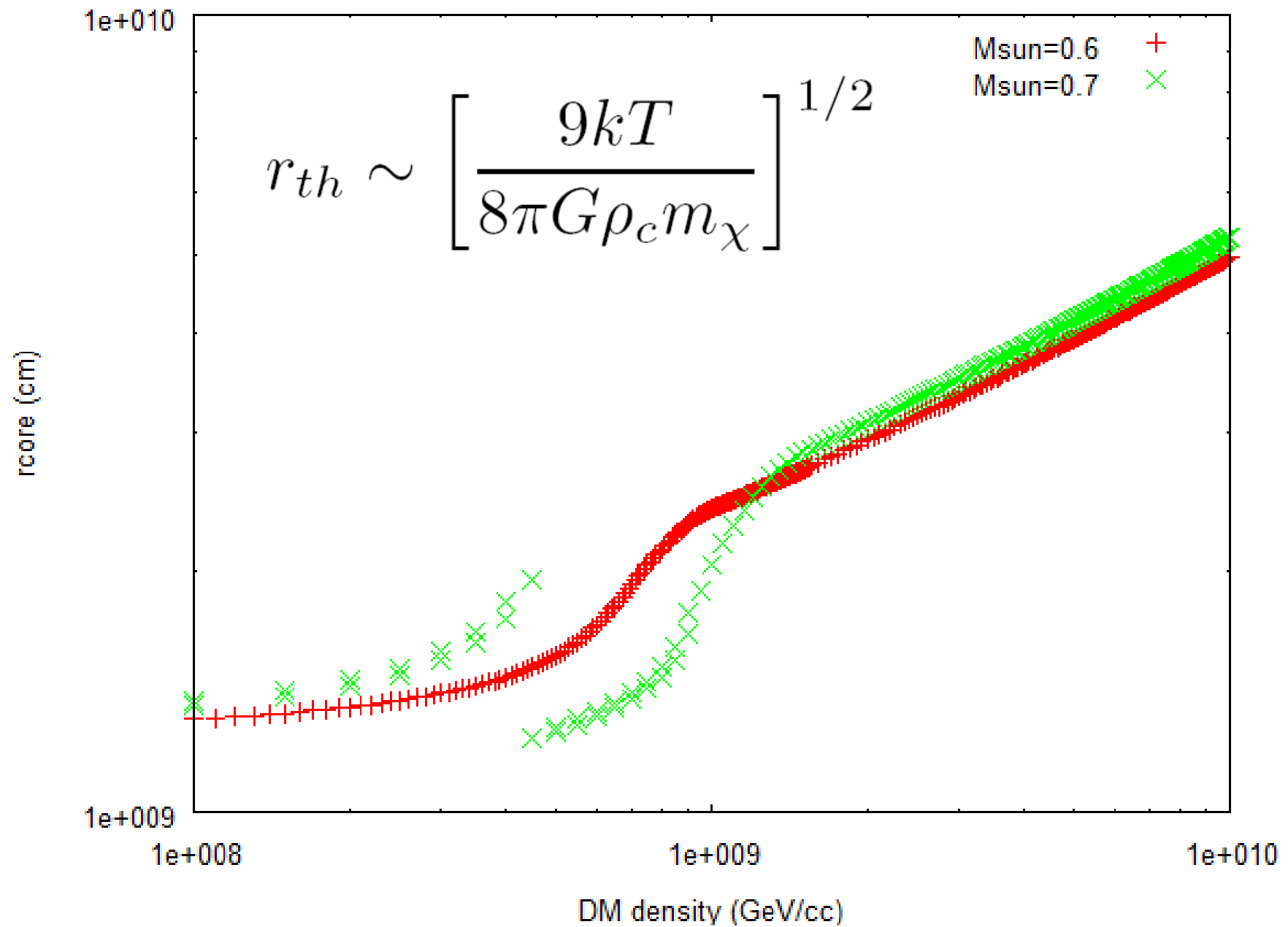
Breaks around 10^9 GeV/cc

T (K)

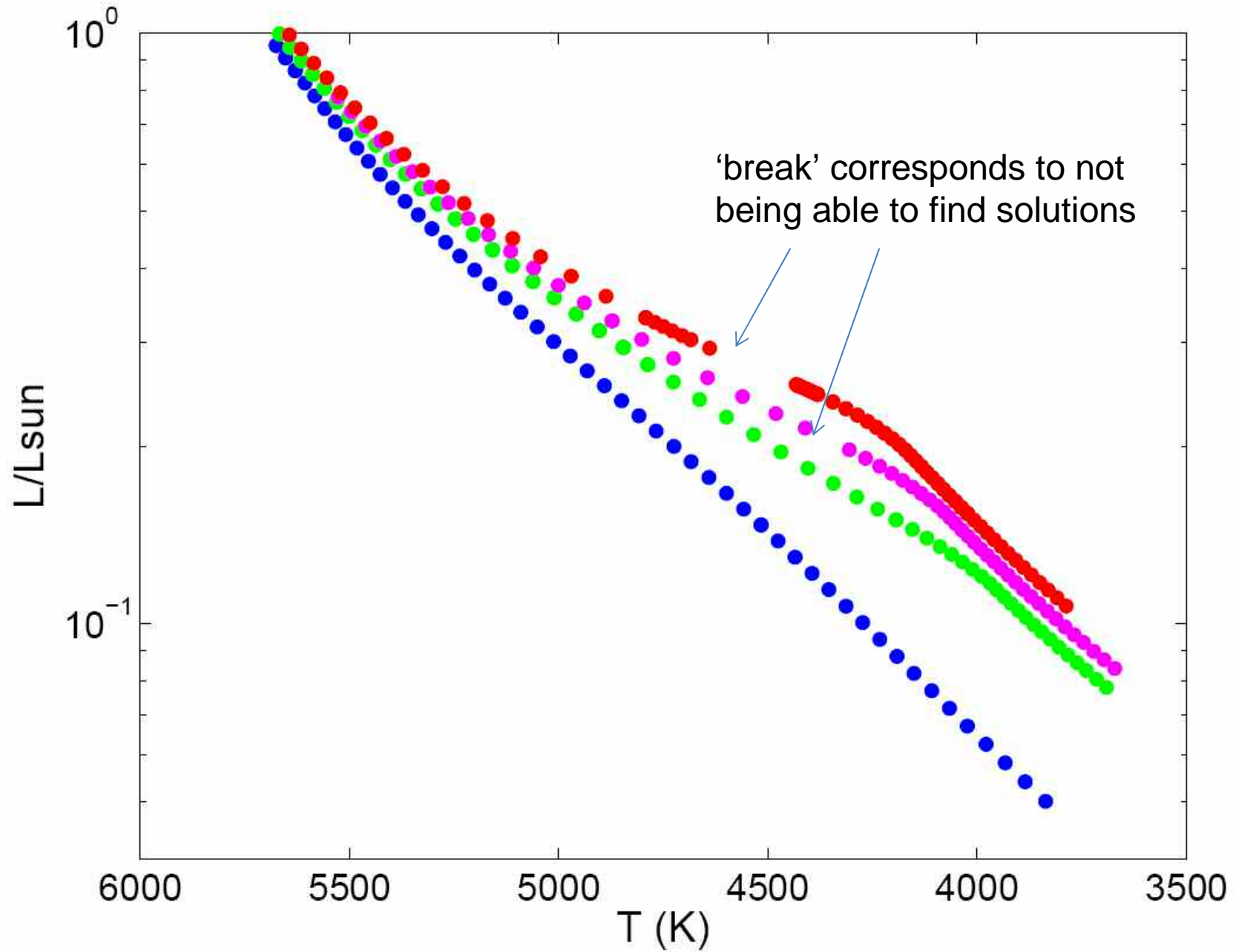
Looks like
Hayashi track
of protostars?



Break in Main Sequence Solutions Physical?

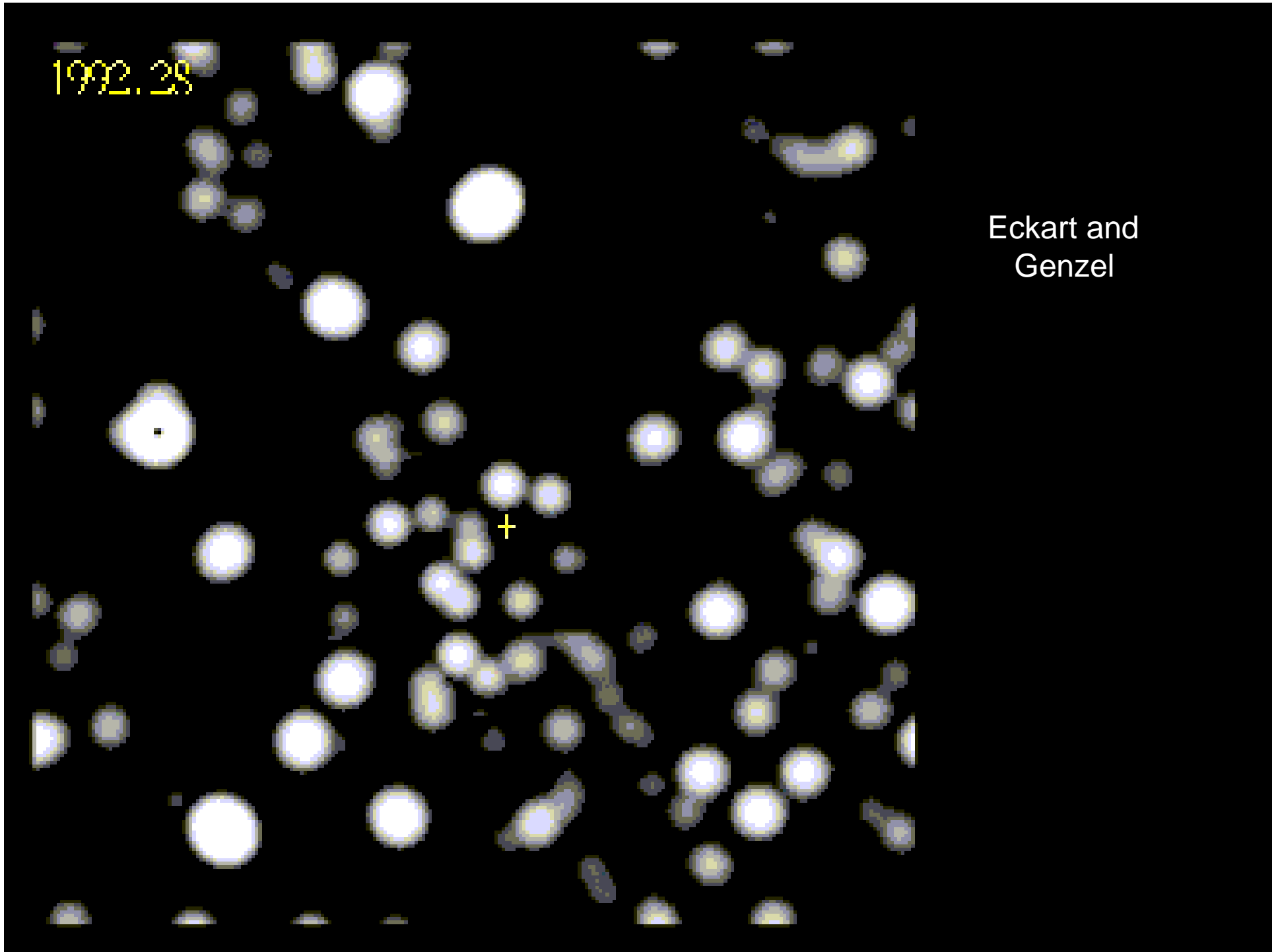


Effect of WIMP accretion on HR diagram



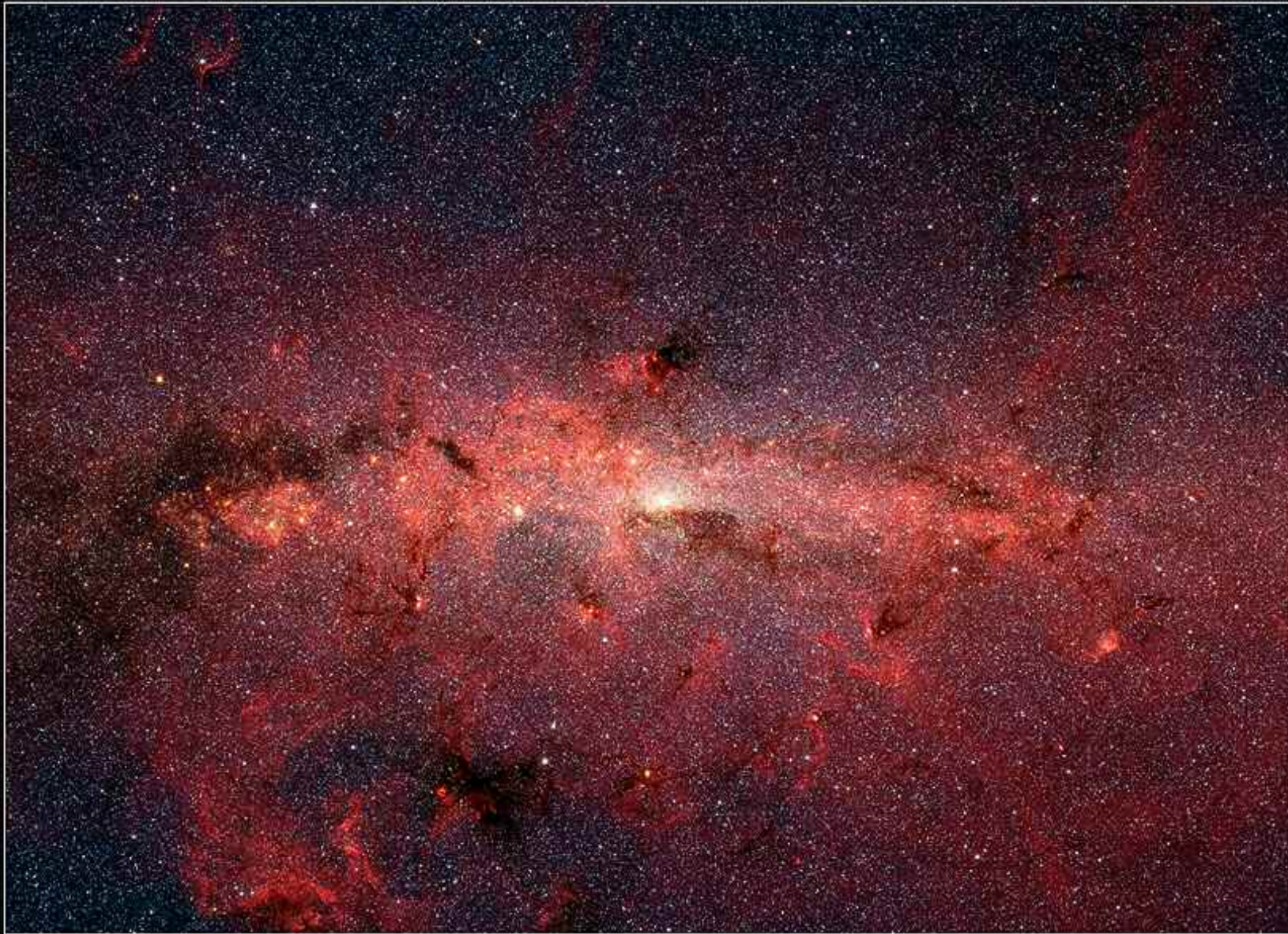
1992.28

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?

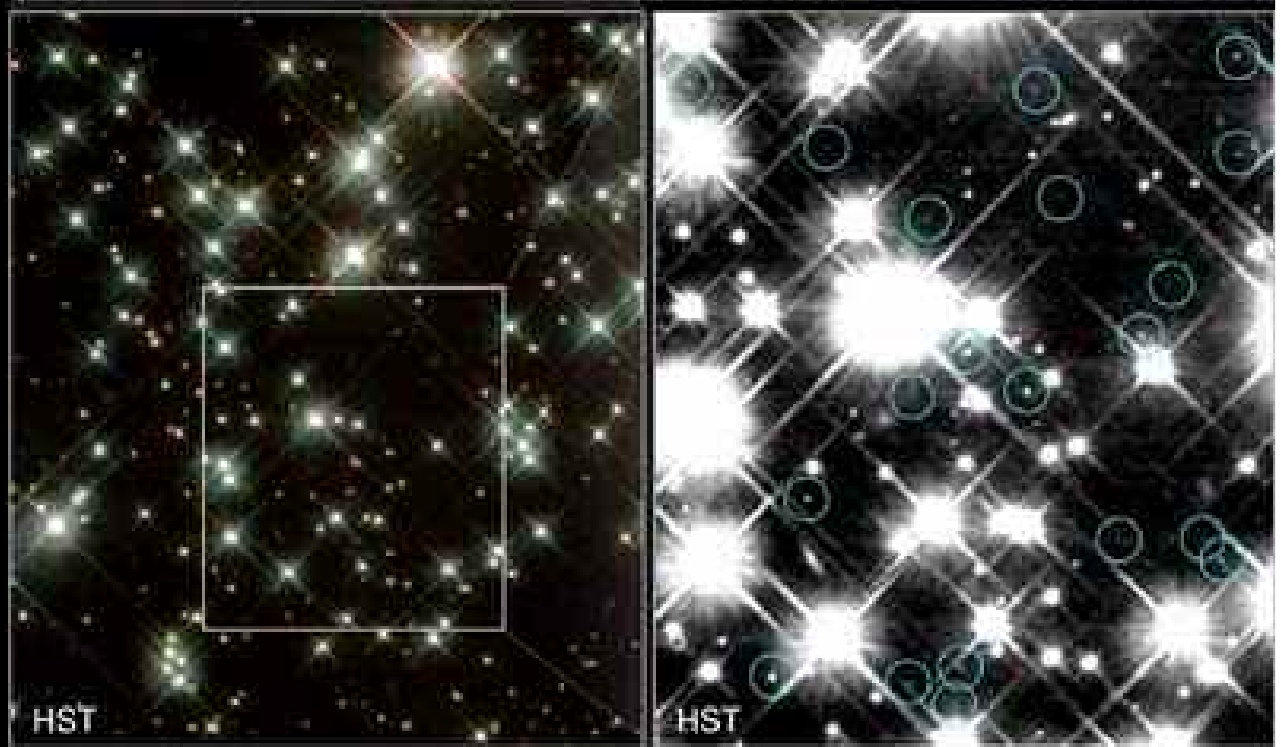
White dwarves - high escape velocity 😊
- born 😞

NEED TO FIND SOME OLD ONES

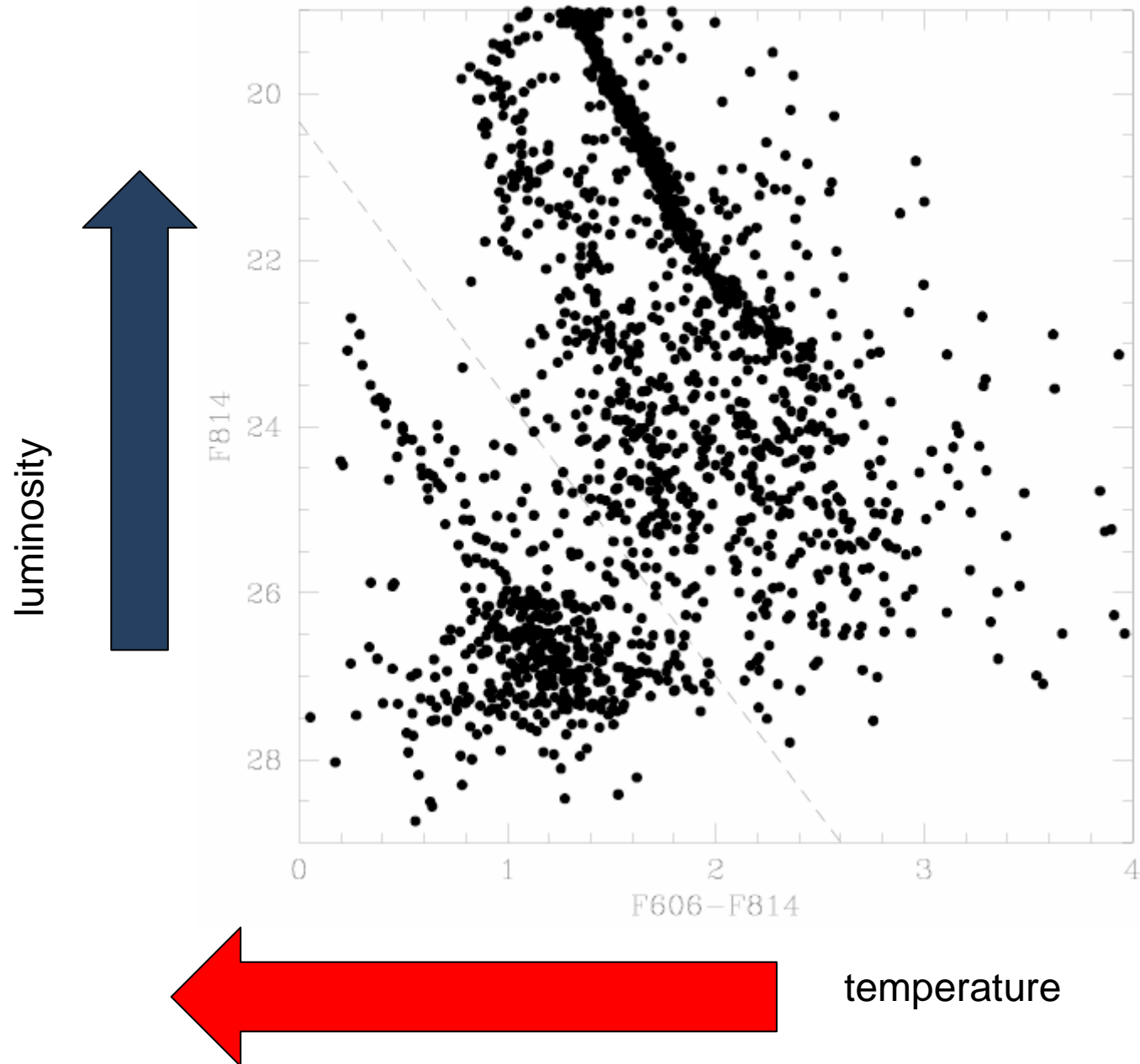
White Dwarves in Globular Cluster M4



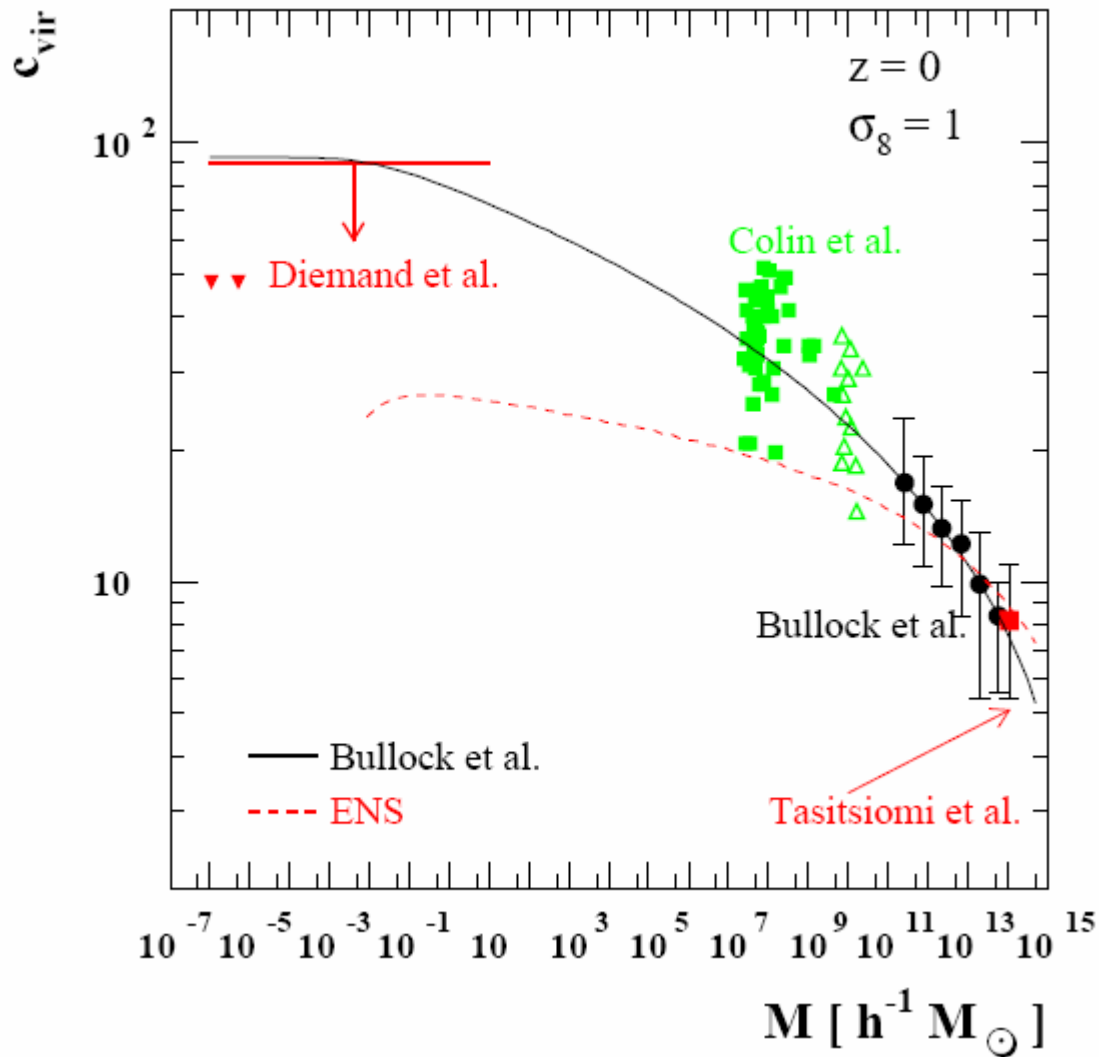
Richer et al. 2004



Bottom of HR diagram in Globular Cluster M4



Need to work out density of dark matter in globular cluster



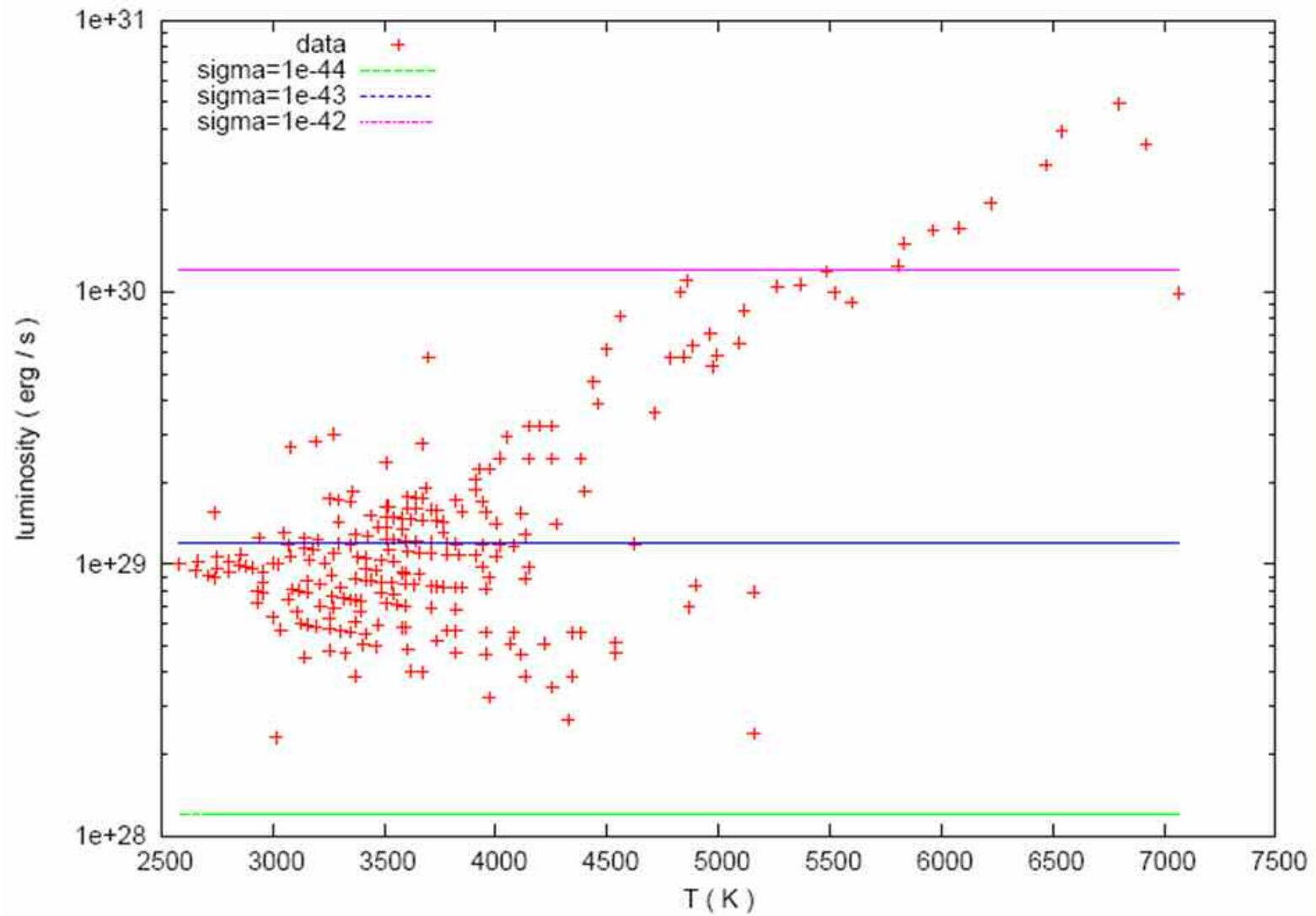
$$\rho(r) = \frac{\rho_c}{\frac{r}{a} \left(1 + \frac{r}{a}\right)^2}$$

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

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

Colafrancesco et al. Astro-ph/0507575

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

