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Extra Dimensions and Stellar Evolution

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SUMMARY

-- Main problem for extra dimensional theories:
How to confine the SM fields on the brane!
[Rubakov,Shaposhnikov (1983);Dvali, Shifman(1997); B.Bajc, G.Gabadadze (2000) ....]
In effective field theory it is difficult to localize gauge fields.

-- It was shown that the photon field can be confined on the brane only through gravity, in an extended RS model
S. Dubovsky, V. Rubakov and P.Tinyakov, JHEP **0008** 041 (2000);
[*see also K.Goroku, A Nakamura(2002), B. Bathell, T. Gherghetta(2006)*]

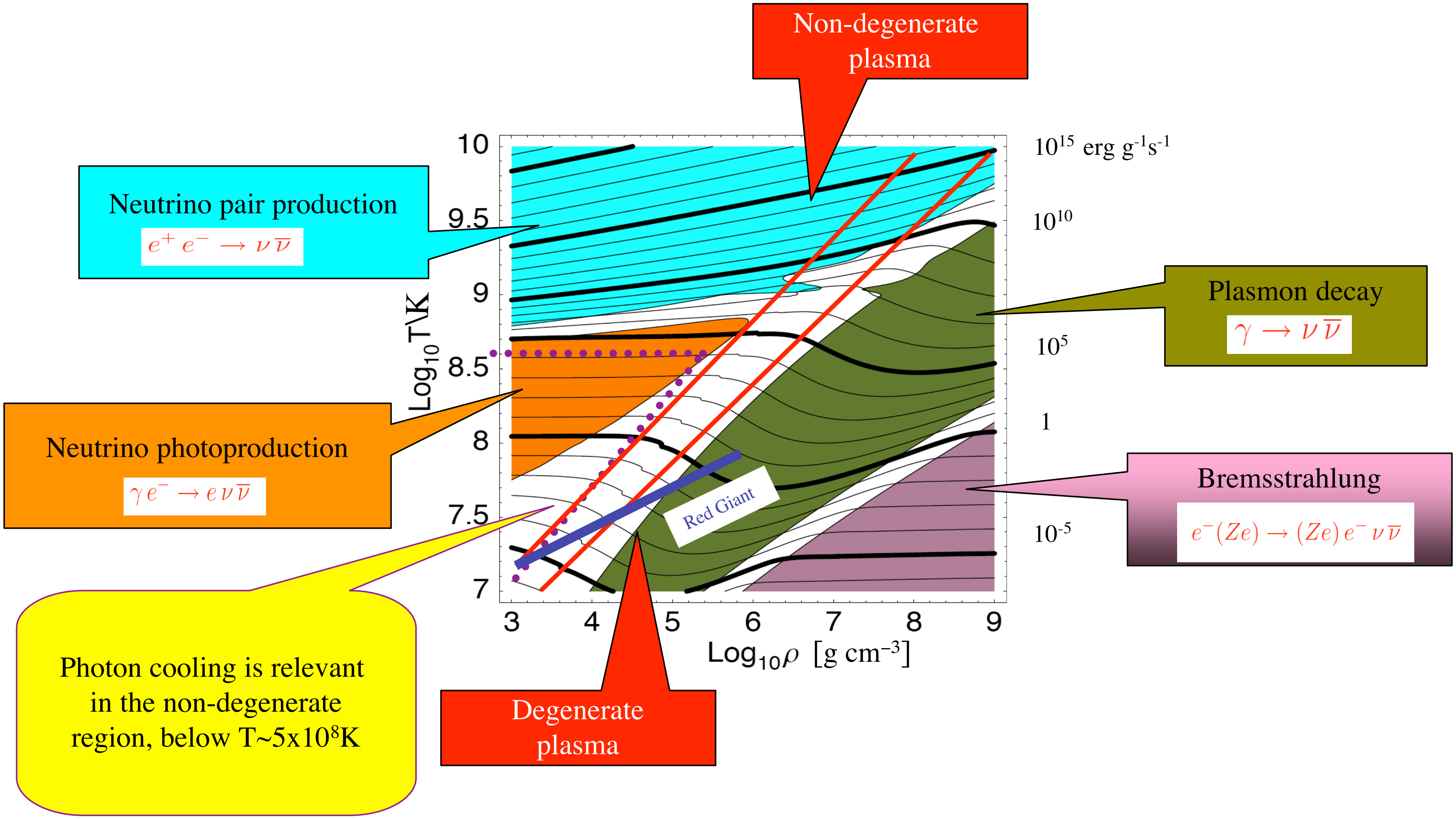
-- A prediction of this model is that virtual photons can tunnel in the extra-dimensions, and therefore disappear.

-- Several groups, in the US (VLAnd extra Dimensions Detector), Europe and Japan, are testing or proposing to test this appealing hypothesis, searching for an invisible decay mode of the ortho-positronium.

-- We showed that bounds from stellar cooling are many orders of magnitude more stringent than what can be achieved in the ortho-positronium experiments in the near future
A. Friedland, M. Giannotti **Phys.Rev.Lett.100 (2008).**

Neutrino Cooling in Stars

Standard Cooling: photons and neutrinos



Particles leaking in the extra dimensions

RS Metric (RS II, 1 brane)

L. Randall and R.~Sundrum
Phys. Rev. Lett. 83, 4690(1999)

$$ds^2 = a(z)^2 \eta_{\mu\nu} dx^\mu dx^\nu - dz^2$$

$$a(z) = \exp\left(-k|z|\right)$$

-- Massless scalar fields can be confined on the brane only through gravity

B.Bajc, G.Gabadadze
Phys.Lett. B474 (2000).

-- Massive scalar fields can decay into the extra dimensions

There is a mode peaked on the brane, but it is instable.

S. Dubovsky, V. Rubakov and P.Tinyakov **Phys.Rev.D62 (2000)**

$$\Gamma \propto m \left(\frac{m}{k}\right)^2$$

Particles leaking in the extra dimensions

Extended RS Metric

$$ds^2 = a(z)^2 \left(\eta_{\mu\nu} dx^\mu dx^\nu - \sum^n \delta_{ij} d\theta_i d\theta_j \right) - dz^2$$

$$a(z) = \exp(-k|z|)$$

If n>0
Photon confinement on the brane

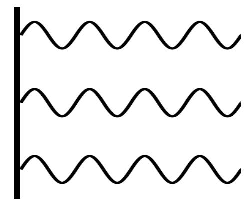
S. Dubovsky, V. Rubakov and P.Tinyakov,
JHEP **0008** 041 (2000);

Virtual photons can decay into the extra dimensions

$$\Gamma \propto \sqrt{p^2} \left(\frac{\sqrt{p^2}}{k} \right)^n$$

Orthopositronium decay and new physics

Orthopositronium:
-- electron-positron bound state of spin=1
It cannot decay in 2 photons => main decay rate is in 3 photons =>
lifetime (~150 ns) longer than the corresponding spin 0 state (parapositronium)



Standard decay:
oPs --> 3 γ

-- It is a "clean" bound state of pure leptons => non strong interaction,
only electromagnetic

-- In fact, there is also a little of weak interactions

$$\Gamma(o\text{Ps} \to \nu\,\overline{\nu}) < 10^{-17}\Gamma_{3\gamma}$$

This is so small than any measurable invisible decay mode would be an indication of new physics such as

-- Invisible decay into (infinite) extradimension

-- Other possibilities are:
Mirror World: Invisible decay through photon mirror-photon mixing,
Invisible decay into millicharged particles
......

The goal is

$$\Gamma_{\text{invisible}} = 10^{-8}\Gamma_{3\gamma}$$

See, e.g.,
A. Badertscheret al.,
Phys. Rev. D75 (2007).

Orthopositronium decay in the extra dimensions

Orthopositronium decay into the extra dimensions (n=2)

$$\frac{\Gamma(o\mathrm{Ps} \to \text{extra dim})}{\Gamma(o\mathrm{Ps} \to 3\gamma)} \simeq 1.2 \times 10^5 \left(\frac{m_{o\mathrm{Ps}}}{k}\right)^2 < 10^{-8}$$

This implies the bound
n=2 => k ~ 1 TeV
comparable to the bounds from Lep and Z decay width

For n>2 the bound is very weak (n=3 => k>20GeV).
From Z decay width: k> 100 GeV for any n

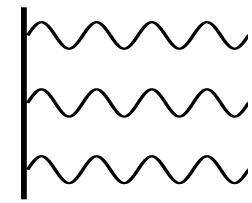
REFERENCES

Gninenko, Krasnikov, Rubbia, **Phys.Rev.D67 (2003);**

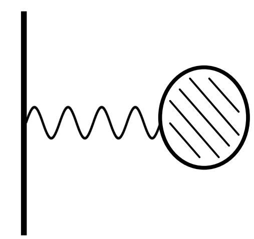
A. Badertscheret al., **Phys. Rev. D75 (2007);**

Proceedings of the 2005 APS April Meeting,
http://meetings.aps.org/link/BAPS.2005.APR.T12.7;

Proceedings of the2006Joint APS/JPSMeeting,
http://tabletop.icepp.s.u-tokyo.ac.jp/invisi/jps2006Hawaii.pdf;



Standard decay:
oPs --> 3 γ



Non-standard decay:
oPs --> γ* –> extra dim

Plasmon decay into the extra dimensions

The different photon polarizations in a plasma behave like massive particles with mass ~ ω_{pl}

They can decay into the extra dimensions.

We found

$$\Gamma_{\rm ED} \simeq \omega_{\rm pl} \left(\frac{\omega_{\rm pl}}{k}\right)^n$$

n = number of extra compact dimensions

A. Friedland, M. Giannotti
Phys.Rev.Lett.100 (2008).

We can now compute the energy loss and consider what that would imply for different stars.

The strongest impact would be for Red Giant stars:
The energy loss through photon decay into the extra-dimensions would delay the ignition of helium in the core of a RG. The new energy-loss rate must not exceed the standard loss through plasmon decay by more then a factor of 2-3.

Plasmon decay into the extra dimensions and stars

From RG stars
Delay of the He-flash

$$k \gtrsim 108\, M_W \left(\frac{M_W}{\omega_{\rm pl}}\right)^3 \simeq 10^{21}\,{\rm TeV} \qquad n=1$$

$$k \gtrsim 10\, M_W \left(\frac{M_W}{\omega_{\rm pl}}\right) \simeq 10^{6}\,{\rm TeV} \qquad n=2$$

$$k \gtrsim 5\, M_W \left(\frac{M_W}{\omega_{\rm pl}}\right)^{1/3} \simeq 10^{2}\,{\rm TeV} \qquad n=3$$

The goodness of our result depends on the huge ratio between the weak scale and the plasma frequency

Our bounds imply that to keep the scales in the model close to the electroweak scale one either needs a large (n=4 or more) number of extra dimensions, or to arrange for an additional binding mechanism for the photon

Plasmon decay into the extra dimensions and stars

From RG stars
Delay of the He-flash

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The goodness of our result depends on the huge ratio between the weak scale and the plasma frequency

From HB stars
(observed number ratio of HB/RG stars) we find comparable results

From SN87A
Neutrino signal from SN87A

$$k \gtrsim 10^{14}\,\mathrm{TeV} \qquad \text{n=1}$$

$$k \gtrsim 10^{4}\,\mathrm{TeV} \qquad \text{n=2}$$

$$k \gtrsim 30\,\mathrm{TeV} \qquad \text{n=3}$$

Comments on the experiment of oPs decay and Conclusions

A terrestrial experiments sensitive to the invisible decay modes of the orthopositronium should have the following sensitivities in order to provide an analogous bound on k

$\mathrm{BR} < 2 \times 10^{-24+1.75\,n}$	for RG stars
$\mathrm{BR} < 2 \times 10^{-26+2.5\,n}$	for HB stars
$\mathrm{BR} < 2 \times 10^{-15-1.5\,n}$	for SN87A

-- The models which try to confine the photon on the brane through gravity only are severely constrained by stellar evolution considerations.

-- Our analysis shows that, for n=2, the sensitivity for the BR in the o-Ps experiment should improve by about 13 orders of magnitude to be competitive with the astrophysical bounds. The SN bound requires at least 8 orders of magnitude better sensitivity for the BR than the present sensitivity of the oPs experiment, for any n

-- The experiment can sill be interesting to test other physics beyond the standard model such as mirror world, millicharged particles etc.