VILA DO CONDE,
PORTUGAL,
29-31 MARCH, 2016

11th Iberian Cosmology Meeting

IBERICOS 2016

SOC **ANA ACHÚCARRO** (LEIDEN/BILBAO), **FERNANDO ATRIO-BARANDELA** (SALAMANCA), **MAR BASTERO-GIL** (GRANADA), **JUAN GARCIA--BELLIDO** (MADRID), **RUTH LAZKOZ** (BILBAO), **CARLOS MARTINS** (PORTO), **JOSÉ PEDRO MIMOSO** (LISBON), **DAVID MOTA** (OSLO)

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SERIES OF MEETINGS WHICH AIM TO ENCOURAGE INTERACTIONS AND COLLABORATIONS BETWEEN RESEARCHERS WORKING IN COSMOLOGY AND RELATED AREAS IN PORTUGAL AND SPAIN.

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Inflation, CMB anomalies, particle physics fine-tuning and all that jazz...

Juan C. Bueno Sánchez

Universidad Antonio Nariño (Bogotá), Universidad del Valle (Cali), Universidad Industrial de Santander (Bucaramanga)

Based on JCBS: Phys. Lett. B 739,2014 (arXiv:1405.4913), arXiv:1602.06809, arXiv:1603.01603

Inflation & CMB anomalies

CMB anomalies as an indirect probe of the inflaton dynamics + interactions

What is the prediction from motivated inflationary models?

Come to IberiCOS 2016 to find out!

Let me address a more interesting, related question arising after envisaging:

A framework providing a common origin for anomalies

CMB anomalies as the result of statistical inhomogeneity & anisotropy developed by isocurvature fields of mass m~H present during inflation

(arXiv:1602.06809)

⇓

Can account for Cold Spot, power deficit and statistical anisotropy

Phys. Lett. B 739,2014 (arXiv:1405.4913)   arXiv:1602.06809   arXiv:1603.01603

The particle physics side

The framework requires the following:

1- Abundance of isocurvature fields (σ): SUGRA can do that if m~H

2- **Sustained, previous** stage of fast-roll inflation: SUGRA -> inflaton mass m~H

3- Interactions for σ with other degrees of freedom χ:

$$\mathcal{L} = \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma + \frac{1}{2}\partial_\mu\chi\partial^\mu\chi - \frac{1}{2}\bar{m}_\sigma^2\sigma^2 - \frac{1}{2}\bar{m}_\chi^2\chi^2 - \frac{1}{2}g^2\sigma^2\chi^2$$

The problem is the length of the fast-roll $\Rightarrow$
- Long enough -> Give rise to appropriate ICs
- Short enough -> Statistical inhomogeneity likely

How likely is that one such field σ with m~H gives rise to statistical inhomogeneity on CMB scales?

Anomalies again: Statistical inhomogeneity on CMB scales

1- Evolve σ-field distribution with correlations on CMB scales

$$\frac{\partial P}{\partial t} = \frac{\partial}{\partial \sigma}\left(\frac{V'(\sigma)}{3H} P\right) + \frac{1}{2}\mathcal{D}\,\theta(t_k - t)\,\frac{\partial^2 P}{\partial \sigma^2}$$

2- Field interactions to influence the σ-field distribution

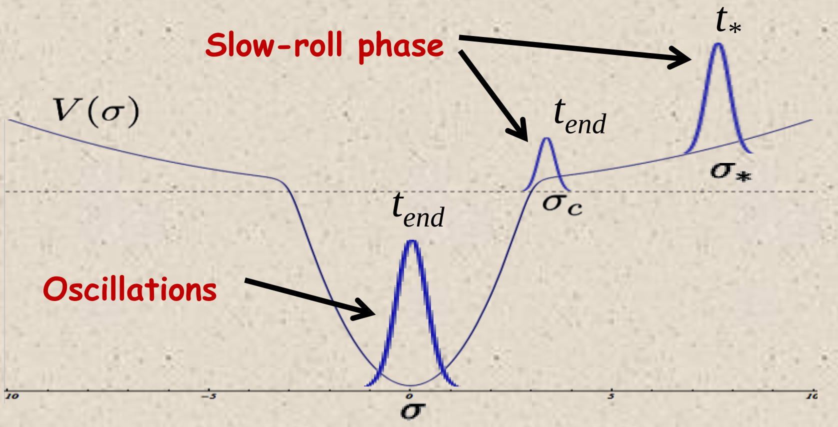
$$P_k(\sigma_c, t) = 0$$

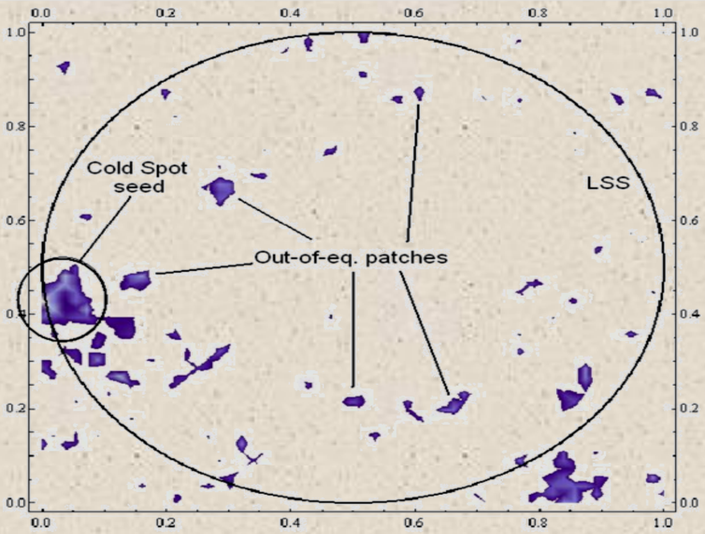
AB: instantaneous transition

$$P_k^{(\mathrm{ext})}(\sigma, t) = \theta(\sigma - \sigma_c) P_k(\sigma, t) + P_k^{(\mathrm{ph})}(\sigma, t)$$

Beyond AB: transition time ~ H^{-1}

3- Find parameters to get to this





The fine-tuning

The computation is quite simple:

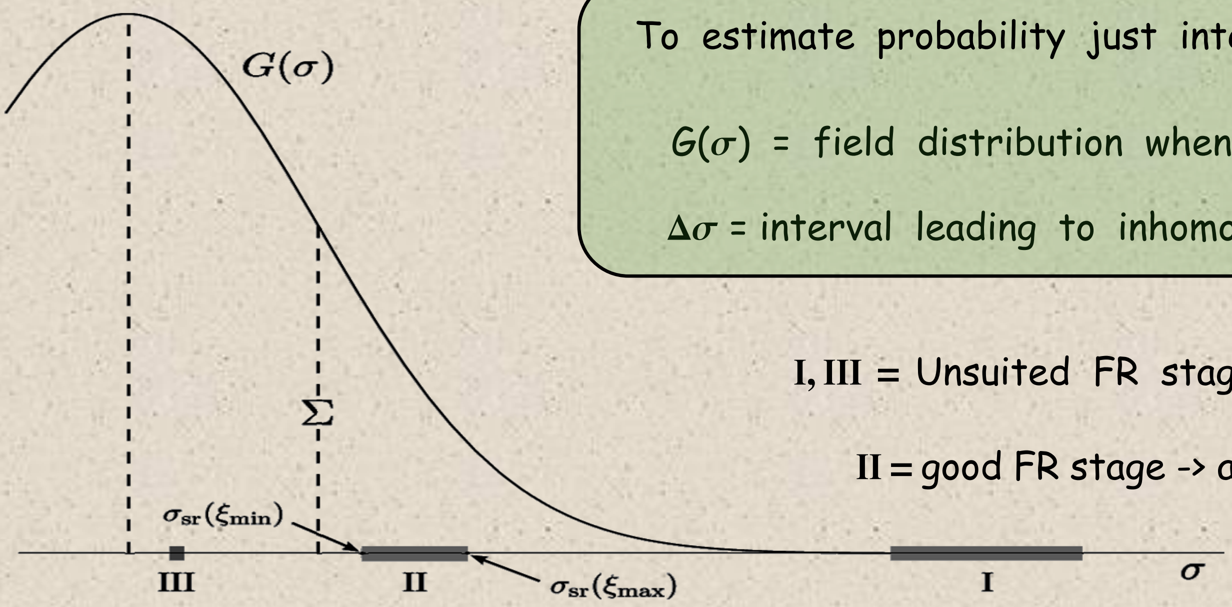
Begin inflation with $\sigma = 0$ -> Classical σ generated during FR

$$\begin{cases} N_{\rm tot} = N_{\rm fr} + N_{\rm sr} \\ N_{\rm sr} = N_{\rm sr}^{p} + N_{*} \end{cases}$$

To estimate probability just integrate $I \equiv \int_{\Delta\sigma} G\, d\sigma$

$G(\sigma)$ = field distribution when slow-roll begins

$\Delta\sigma$ = interval leading to inhomogeneous distribution of σ



I, III = Unsuited FR stage -> Catastrophically unlikely

II = good FR stage -> appropriate for CMB anomalies

The fine-tuning

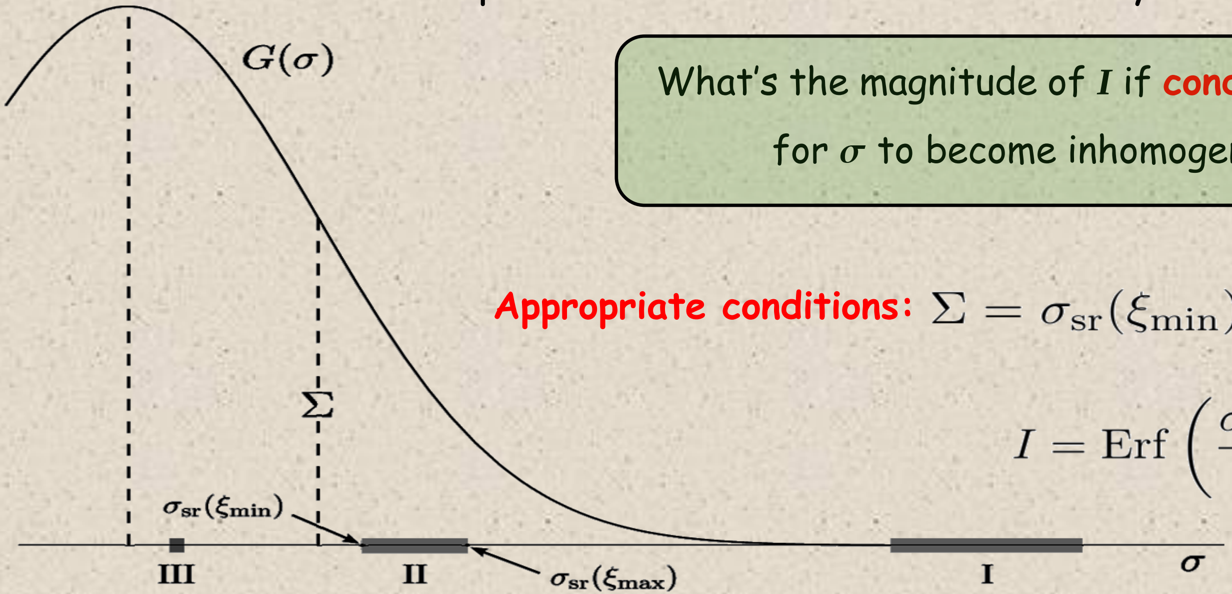
To estimate probability just integrate $I \equiv \int_{\Delta\sigma} G\, d\sigma$

$G(\sigma)$ = **depends on the inflationary model**

$\Delta\sigma$ = interval leading to inhomogeneous distribution of σ

No particular model considered -> try a different, meaningful question

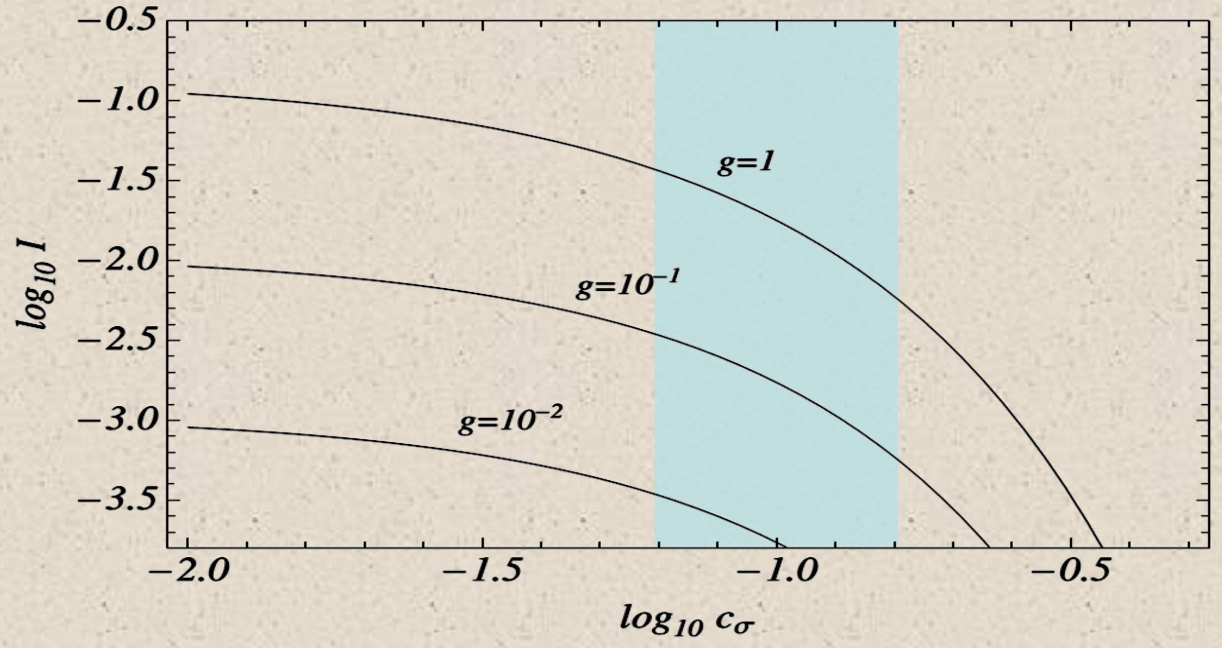
What's the magnitude of I if **conditions are appropriate** for σ to become inhomogeneousy distributed?



Appropriate conditions: $\Sigma = \sigma_{sr}(\xi_{min})$

$$I = \mathrm{Erf}\left(\frac{\sigma_{sr}(\xi_{max})}{\sqrt{2}\,\Sigma}\right) - \mathrm{Erf}\left(\frac{1}{\sqrt{2}}\right)$$

The jazz: all of them playing together



Absorbing barrier:

Instantaneous transition

⇩

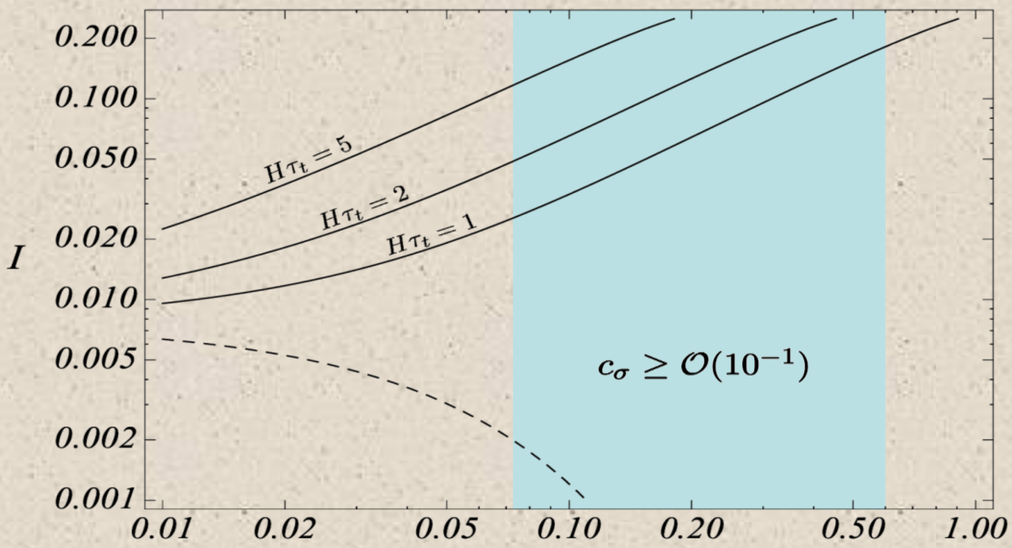
Very many χ fields involved in the coupling $g^2\sigma^2\chi^2$

+

Tuning grows for smaller g

Very unlikely for small g

The jazz: all of them playing together



Phenomenological model: transition ~ H^{-1}

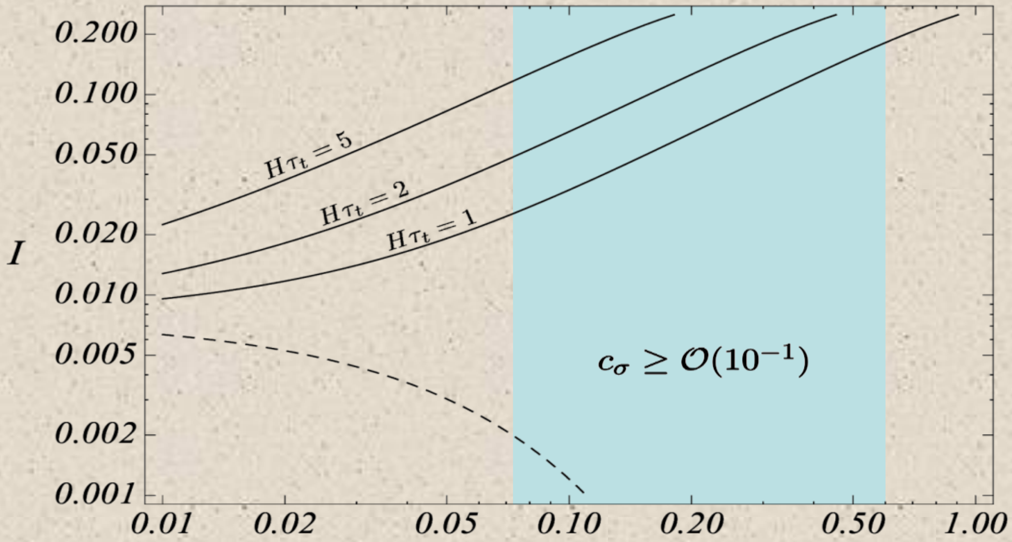
Moderate no. χ fields involved in the coupling $g^2\sigma^2\chi^2$

+

Independence from g

$$c_\sigma > \left(\frac{N_{\rm CMB}}{4\pi^2}\right)^{1/2} \exp(-c_\sigma N_*/3)$$

The jazz: all of them playing together



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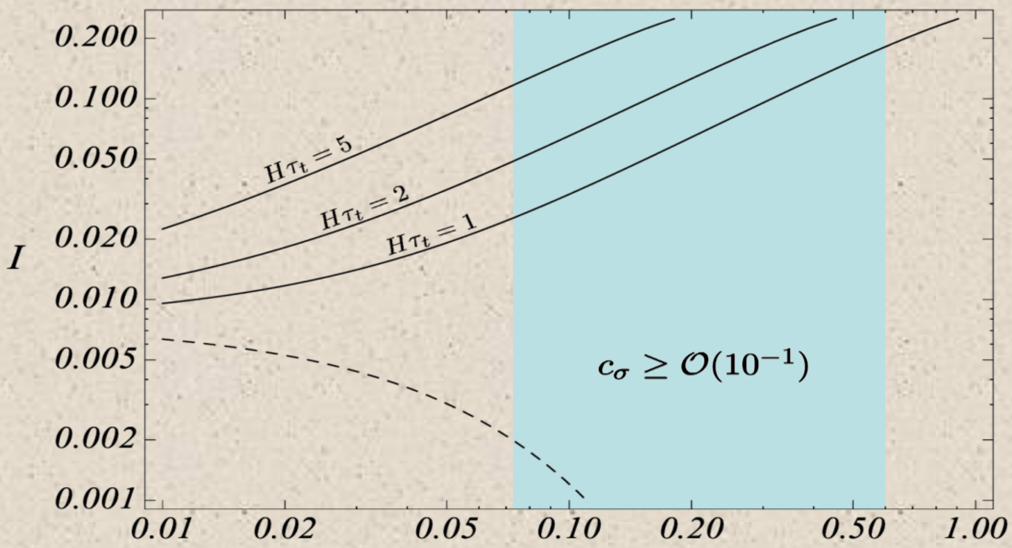
For scalar masses generally predicted by SUGRA and independently of the strength coupling g $\Longrightarrow$ $I \geq \mathcal{O}(10^{-2})$

The jazz: all of them playing together



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What's the inflationary model providing the **appropriate conditions**?

(CMB anomalies to seriously discriminate inflationary models)


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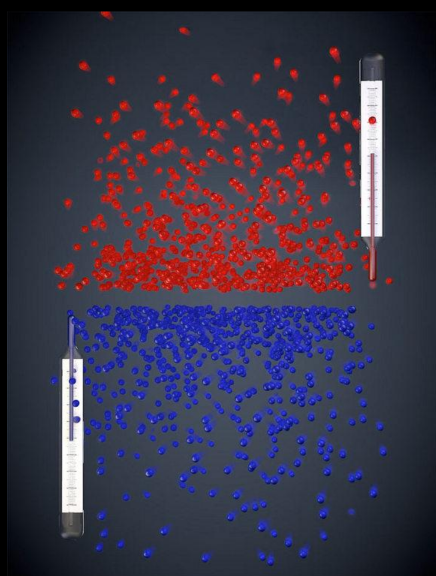
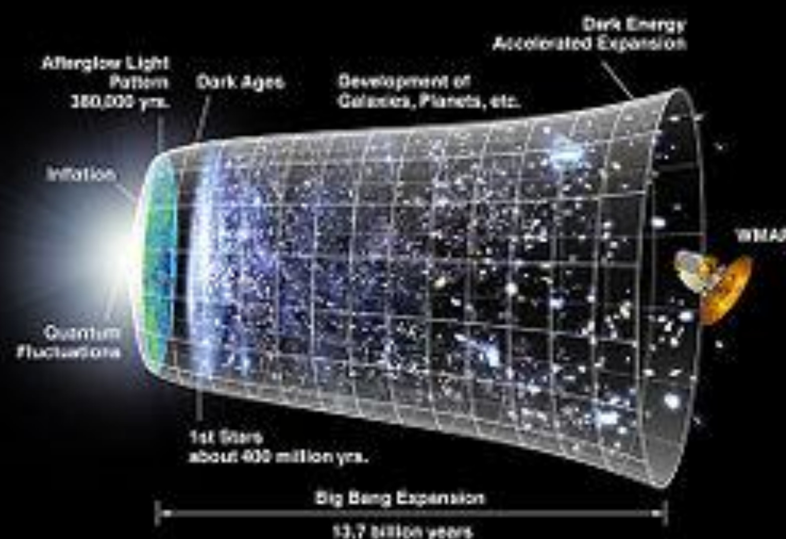
Cosmology With Negative Absolute Temperatures

José P. P. Vieira
Christian Byrnes
Antony Lewis

IberiCos 2016

31st March 2016





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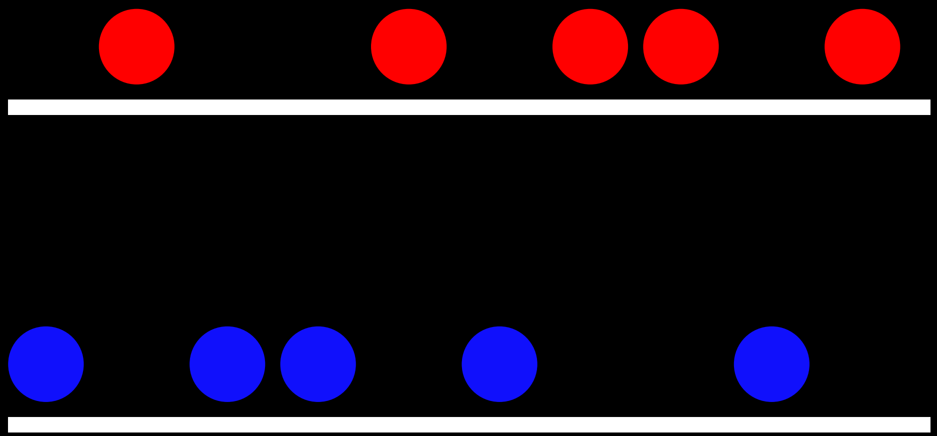
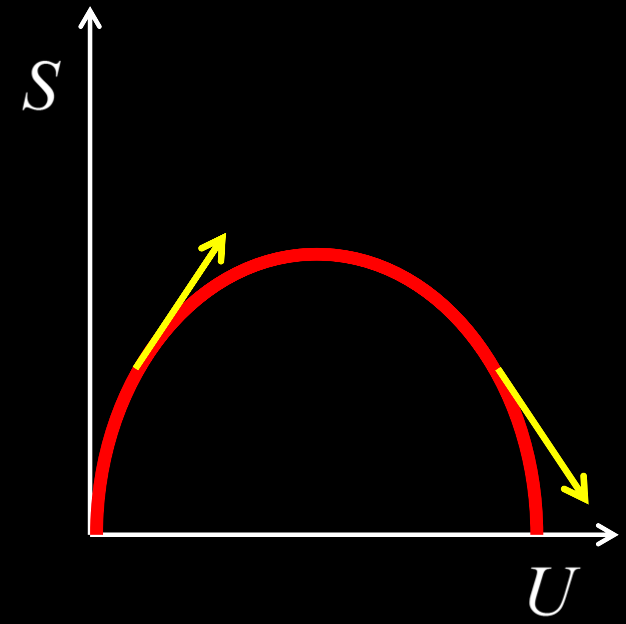
Science & Technology Facilities Council

What do you mean T<0?

$$\frac{1}{T} = \left(\frac{\partial S}{\partial U}\right)_V$$

$$S = k_B \ln W$$





Some landmarks in NAT

- 1949 – NAT(?) solution to turbulent vortices

  Onsager, *supp. to Nuovo Cimento, 6:279-287*

- 1951 – LiF at -1K

  Purcell & Pound, *Phys. Rev., 81:279-280*

- 1956 – Theoretical framework

  Ramsay, *Phys. Rev., 103:20-28*

- 2012 – T<0 with motional degrees of freedom

  Braun et al, *Science 339(6115)*

Why do we care?

$$dU = TdS - PdV$$

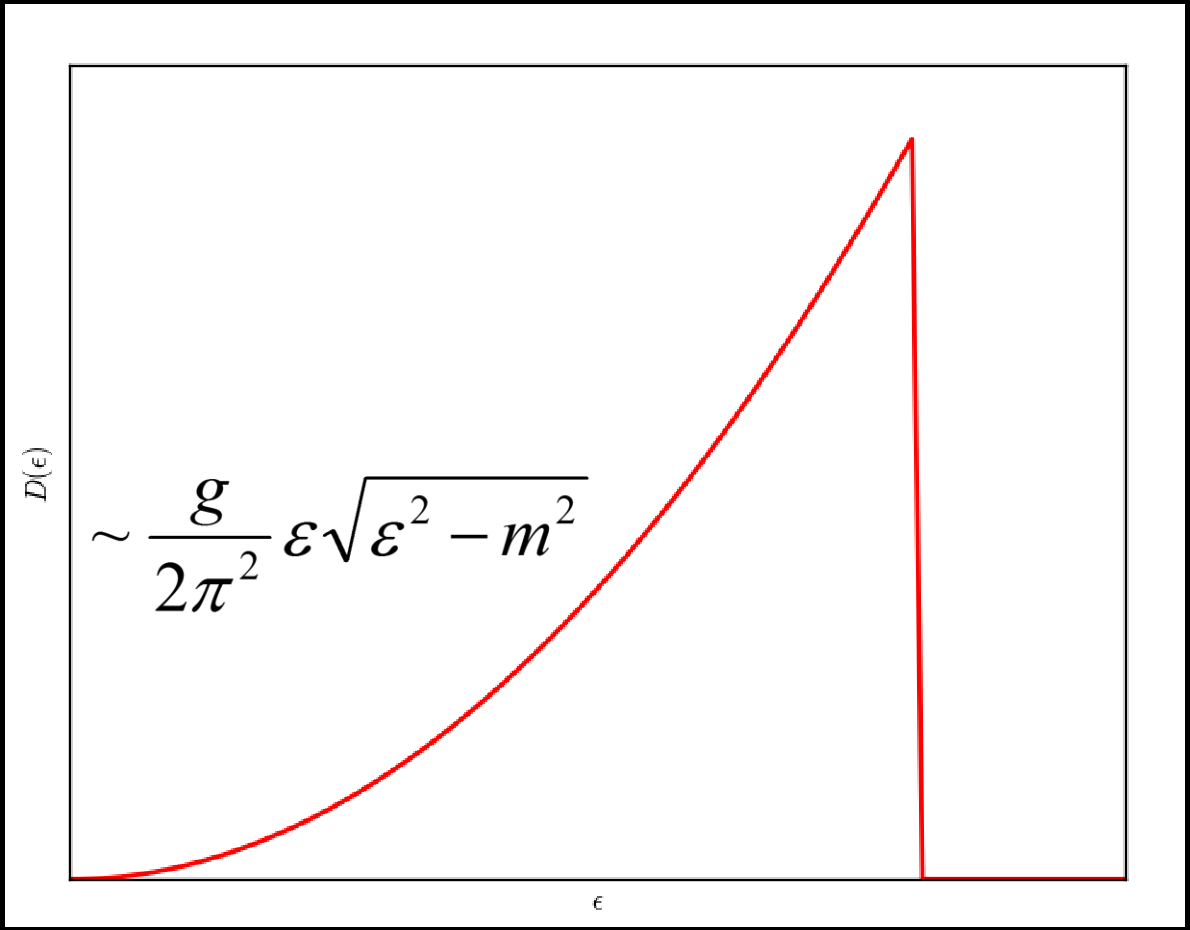
$$\Downarrow$$

$$P = sT - \rho$$

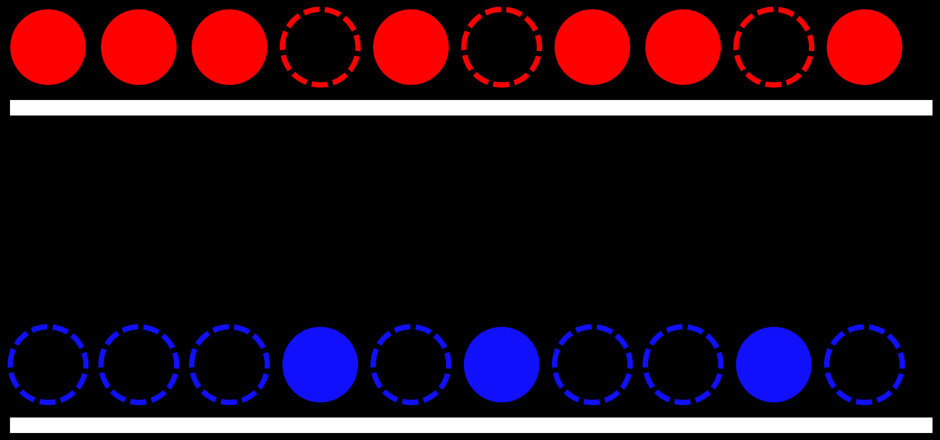
$$\Downarrow$$

$$T < 0 \Rightarrow P < 0$$

Cosmology with an energy cut-off?

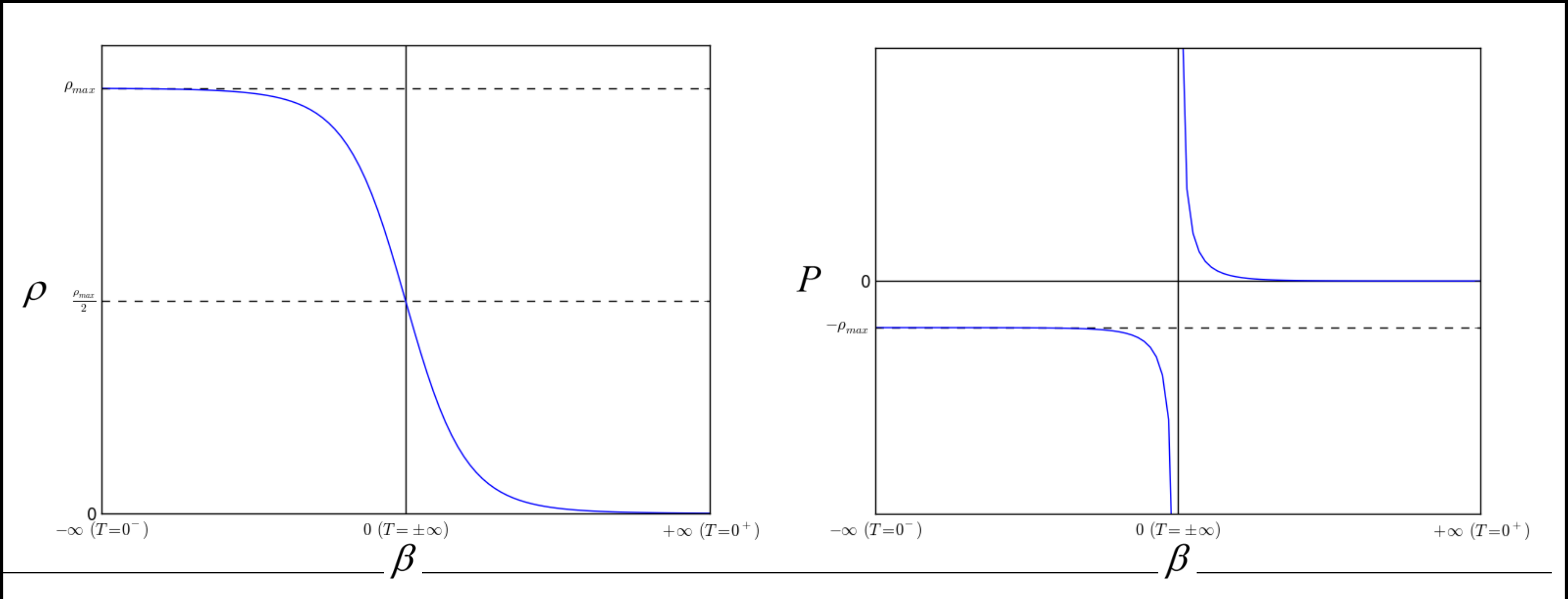


Making use of holes



Making use of holes

$$f(\varepsilon;T)=1-f(\varepsilon;-T)$$
$$\rho(T)=\rho_{\max}-\rho(-T)$$
$$P(T)=-\rho_{\max}-P(-T)$$



Expanding Universe

Low-temperature holes may behave like

radiation

$$w = -\frac{1}{3}\left(4\frac{\rho_{\max}}{\rho} - 1\right)$$

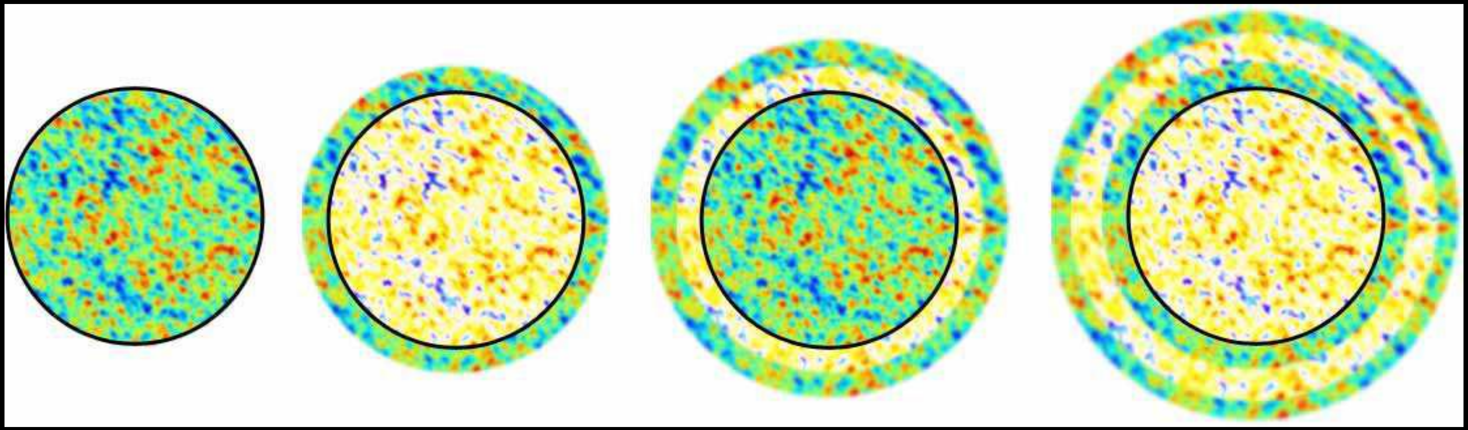
matter

$$w = -\frac{\rho_{\max}}{\rho}$$

$$\boxed{\frac{d\ln\rho}{dt} = -3H(1+w) \geq 0}$$

Perturbations (and a little extra)

Chen et al (2007)
arXiv:0712.2345v3

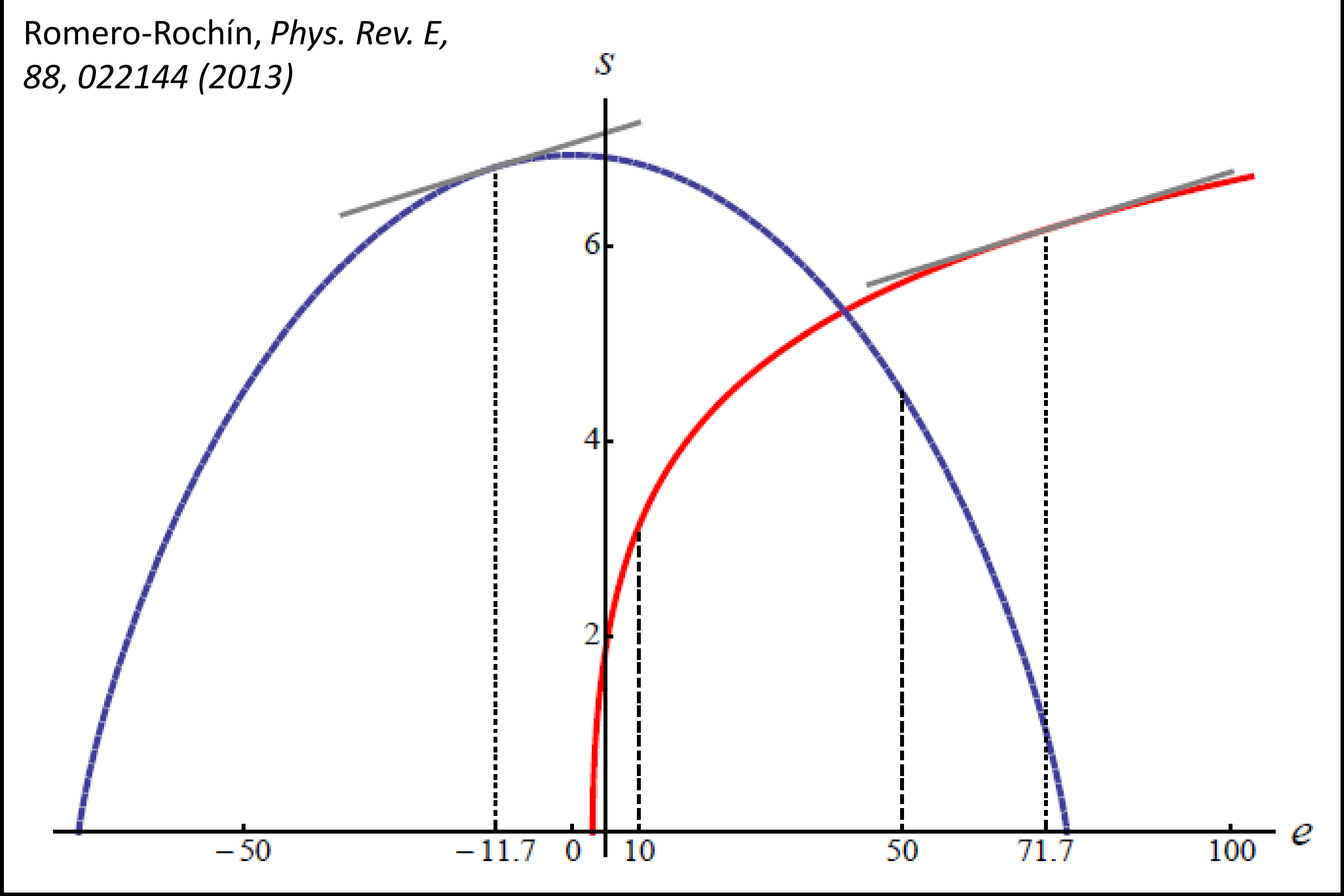


$$\left\langle \delta\rho_T{}^2 \right\rangle = \propto \rho_h{}^{5/4} \to 0$$

$$\left\langle \zeta^2 \right\rangle = H^2 \frac{\left\langle \delta\rho_T^2 + \delta\rho_\sigma^2 \right\rangle}{\left(\dot{\rho}_T + \dot{\rho}_\sigma\right)^2} \xrightarrow[T\to 0^-]{} H^2 \frac{\left\langle \delta\rho_\sigma^2 \right\rangle}{\dot{\rho}_\sigma^2}$$

Depends only on H!

Ending inflation




THE
END

T=∞ crunch

$$\boxed{\frac{d\ln\rho}{dt} = -3H\left(1+w\right)} \Rightarrow \begin{array}{l} \rho \xrightarrow[H<0]{} \frac{1}{2}\rho_{\max} \\ \beta \xrightarrow[H<0]{} 0 \end{array}$$

$$\rho = \frac{1}{2}\rho_{\max} - \frac{\left\langle \varepsilon^2 \right\rangle_0}{4}\beta + \ldots \qquad P = \frac{\ln 2}{\beta} n_{\max} - \frac{1}{2}\rho_{\max} + \frac{\left\langle \varepsilon^2 \right\rangle_0}{8}\beta + \ldots$$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White dwarfs in an ungravity-inspired model

Hodjat Mariji

in collaboration with

Orfeu Bertolami

at the Departament of Physics and Astronomy, University of Porto

- ❑ **Ungravity (UG) Model**
- ❑ **UG Equilibrium Equations**
- ❑ **WD's Equilibrium Equations**
- ❑ **Results & Discussion**

❑ Ungravity (UG) Model

UG arises from the coupling between spin-2 “*unparticle*” to the stress tensor!

$$T^{\mu\nu} \longrightarrow T^{\mu\nu} + T^{\mu\nu}_{\mathcal{U}} \quad , \quad T^{\mu\nu}_{\mathcal{U}} \sim \sqrt{|g|}\,T^{\alpha\beta}\mathcal{O}^{\mathcal{U}}_{\alpha\beta}\, g_{\mu\nu}$$

[H. Goldberg and P. Nath, PRL **100**, 031803 (2008)]

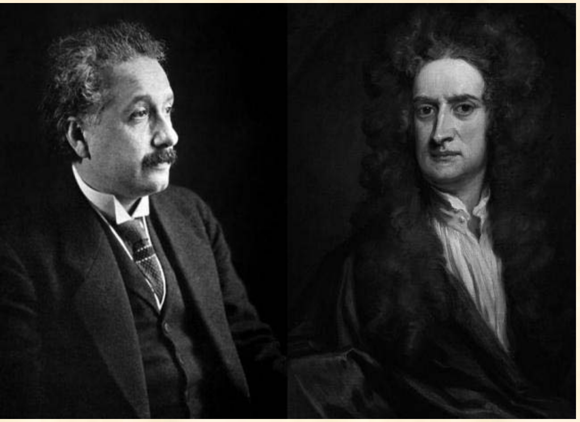
Unparticle?

In order to compensate the *lack of scale invariance* at the low energy sector of the Standard Model, **Howard Georgi** presented an appealing idea by introducing a type of Stuff, dubbed “**Unparticle**”.

Howard Georgi:

[H. Georgi, PRL **98**, 221601 (2007); PLB **650**, 275 (2007)]

“ I found a scheme in which this may be possible by keeping the unparticle world and the world of standard model particles separate from one another except at very high energies. ”



Universal Gravitation Law $F_N = G_N \dfrac{MM'}{r^2}$

General Relativity

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G_N}{c^4} T_{\mu\nu}$$

Need to be modified for **Unparticle Physics**

Ungravitational potential

Lowest order correction of ungravity alters the classical laws of gravitation

Newtonian ungravitational potential

$$\phi_*(r) = -\frac{G_* M}{r}\left[1 + \left(\frac{R_*}{r}\right)^{\alpha-1}\right]$$

$$G_* = \frac{G}{1+\left(\frac{R_*}{R_0}\right)^{\alpha-1}}, \quad G_* \simeq G/2$$

$$\alpha = 2d_u - 1$$

[O. Bertolami, *et. al*, PRD **80**, 022001 (2009)]

Ungravitational Constant

Characteristic Length Scale of UG

Scaling Dimension of UG operator

❑ WD's Equilibrium Equations

The most general hydrostatic equilibrium equation (TOV)

$$4\pi r^2 dP(r) = -\frac{GM(r)dM(r)}{r^2}\left[1 + \frac{P(r)}{\rho(r)c^2}\right]\left[1 + \frac{4\pi r^3 P(r)}{M(r)c^2}\right]\left[1 - \frac{2GM(r)}{c^2 r}\right]^{-1}$$

$$dM(r) = 4\pi\rho(r)r^2 dr$$

For a WD $\Longrightarrow$ $\dfrac{dP(r)}{dr} = -\dfrac{GM(r)\rho(r)}{r^2}$ $\Longrightarrow$ $\dfrac{1}{r^2}\dfrac{d}{dr}\left(\dfrac{r^2}{\rho}\dfrac{dP(r)}{dr}\right) = -4\pi G\rho(r)$

(I will show later)

NHE equation

o EoS for WD

$T_{int} \sim 10^7\,K \Rightarrow$ WDs are too cold to ignite nuclear reactions **(***a mixture gas of ions & electrons***)**

Bounded nucleons contribute to all the WD energy density ($\mu_e n_e m_H c^2$, $\mu_e = A/Z$)

Pressure of degenerate electrons (rather than temperature) supports a WD against gravitational collapse!

- ***Polytropic gas***

$$P = K\rho^{(n+1)/n}$$

$$\left\{\begin{array}{l} \rho = \rho_c\theta^n, \\ r = \beta_p \xi, \\ \beta_p = \left[\frac{(n+1)K}{4\pi G}\rho_c^{(1-n)/n}\right]^{1/2} \end{array}\right. \xrightarrow{\text{NHE equation}} \frac{1}{\xi^2}\frac{d}{d\xi}\left(\xi^2\frac{d\theta}{d\xi}\right) = -\theta^n \quad \left\{\begin{array}{l} \theta(\xi=0) = 1 \\ \theta'(\xi=0) = 0 \end{array}\right.$$

(Lane-Emden (**LE**))

$$\left\{\begin{array}{l} R = \beta_p \xi_{10} \\ M(\xi_{10}) = 4\pi\rho_c\beta_p^3\left(-\xi^2\frac{d\theta}{d\xi}\right)\Big|_{\xi=\xi_{10}} \end{array}\right.$$

ξ_{10}: *first zero of the LE equation solution*

- ***Degenerate gas***

$$\rho_{c,WD} \approx 10^4 - 10^8\,g/cm^3$$

$$E_{0,e} \approx 10^{-5}\,erg\,\left(T_{0,e} \approx 10^9\,K \cong 10^2\,T_{int}\right);\ E_{F,e} = \sqrt{(p_{F,e}c)^2 + E_{0,e}^2} \gg E_{0,e} \Rightarrow T_{int} \ll T_{F,e}$$

$\Longrightarrow$ WDs satisfy degeneracy condition

$$P = \frac{1}{3\pi^2\hbar^3}\int_0^{p_F}\frac{p^2}{\sqrt{m^2+\frac{p^2}{c^2}}}p^2dp = Af(x)$$

$$\begin{cases} A = E_{0e}^4/24\pi^2(\hbar c)^3 \simeq 6.002\times 10^{22} erg/cm^3 \\ f(x) = x(2x^2-3)(x^2+1)^{1/2} + 3sinh^{-1}(x) \end{cases}$$

$\rho = Bx^3$, $B = E_{0e}^3\mu_e m_H/3\pi^2(\hbar c)^3 \simeq 9.74\times 10^5\mu_e\ g/cm^3$ $x = p_F/m_e c$

NHE equation $\longrightarrow$ $$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dX}{dr}\right) = -\frac{\pi G B^2}{2A}x^3$$ $X = \sqrt{x^2+1}$

$$\begin{cases} X = X_c\Phi, \\ X_c = (x_c^2+1)^{1/2},\ \ x_c = (\rho_c/B)^{1/3} \\ \xi = r/\beta_d \quad \beta_d = \sqrt{\frac{2A}{\pi G B^2 X_c^2}} \end{cases}$$

$\Rightarrow$ $$\frac{1}{\xi^2}\frac{d}{d\xi}\left(\xi^2\frac{d\Phi}{d\xi}\right) = -(\Phi^2 - X_c^2)^{\frac{3}{2}}$$

(**LE** equation)

$X(\xi_{10}) = 1$, $\Phi(\xi = 0) = 1$, $\Phi'(\xi = 0) = 0$

$$\begin{cases} R = \beta_d\xi_{10} \\ M(\xi_{10}) = 4\pi B X_c^3\beta_d^3(-\xi^2\frac{d\Phi}{d\xi})\ |_{\xi_{10}} \end{cases}$$

Point:

For WDs

$x \ll 1 \longrightarrow \frac{P}{\rho c^2} \sim \frac{8A}{5Bc^2}x^2 \simeq 5\times 10^{-5}x^2 \ll 1$

$x \gg 1 \longrightarrow \frac{P}{\rho c^2} \sim \frac{2A}{Bc^2}x \simeq 7\times 10^{-6}\left(\frac{p_F c}{E_{0e}}\right) \ll 1$ $\begin{cases} \rho = 10^9 g/cm^3 \\ p_F c/E_{0e} \sim 17 \end{cases}$

$\Rightarrow$ TOV ~ NHE

❑ UG Equilibrium Equations

$$\frac{dP(r)}{dr} = -\frac{G_* M(r)\rho(r)}{r^2}\left[1+\left(\frac{R_*}{r}\right)^{\alpha-1}\right]$$

$$\frac{1}{r^2}\frac{d}{dr}\left(\frac{r^2}{\rho}\frac{dP(r)}{dr}\right) = -4\pi G_*\rho(r)\left[1+\alpha\left(\frac{R_*}{r}\right)^{\alpha-1}\right] + \frac{G_* M(r)}{R_*^3}\left[\alpha(\alpha-1)\left(\frac{R_*}{r}\right)^{\alpha+2}\right]$$

Modified LE Equation for WD (polytropic gas model)

$$\frac{1}{\xi^2}\frac{d}{d\xi}\left(\xi^2\frac{d\theta}{d\xi}\right) = -\frac{G_*}{G}\left\{\left[1+\alpha\left(\frac{\xi_*}{\xi}\right)^{\alpha-1}\right]\theta^n + \left[\alpha(\alpha-1)\left(\frac{\xi_*}{\xi}\right)^{\alpha-1}\left(\frac{1}{\xi}\frac{d\theta}{d\xi}\right)\right]\right\}$$

Modified LE Equation for WD (degenerate gas model)

$$\frac{1}{\xi^2}\frac{d}{d\xi}\left(\xi^2\frac{d\Phi}{d\xi}\right) = -\frac{G_*}{G}\left\{\left[1+\alpha\left(\frac{\xi_*}{\xi}\right)^{\alpha-1}\right](\Phi^2 - X_c^2)^{\frac{3}{2}} + \left[\alpha(\alpha-1)\left(\frac{\xi_*}{\xi}\right)^{\alpha-1}\left(\frac{1}{\xi}\frac{d\Phi}{d\xi}\right)\right]\right\}$$

$$\xi_* = \frac{R_*}{\beta_{p(d)}}$$

M & R are calculated at the first zero of these modeified LE equation solution (ξ_{10}^*)

❑ Results & Discussion

WD	$(M_0 \pm \triangle M_0)/M_S$	$(R_0 \pm \triangle R_0)/R_S$	$T_{eff} \pm \triangle T_{eff}(K)$	$(L_0 \pm \triangle L_0)/L_S$
SIB	1.02±0.02	0.0081±0.0002	25193±37	0.0237±0.0013
HDB	0.616±0.022	0.0129±0.0003	15310±350	0.0082±0.0011

ϵ Reticulum

M. A. Barstow, *et. al*, Mon. Not. R. Astron. Soc. **362**, 1134 (2005)

J. Farihi, *et. al*, Mon. Not. R. Astron. Soc. **417**, 1735 (2011)

(calculated) $L = 4\pi R^2 \sigma T_{eff}^4$

Inputs:

$\rho_c = 3.20 \times 10^7 (3.22 \times 10^6) g/cm^3$

$n = 2.03(1.73)$

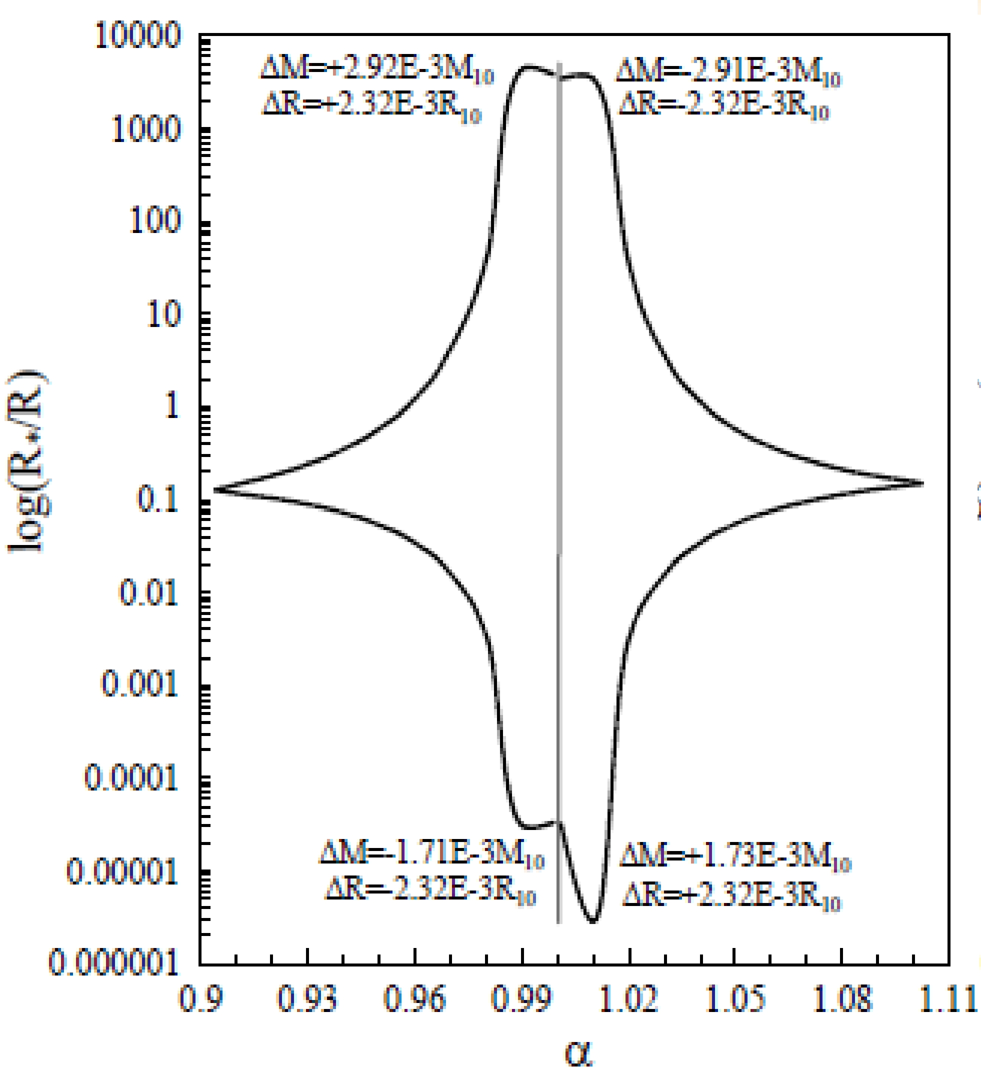
Model	WD	M_{10}/M_S	R_{10}/R_S	L_{10}/L_S
Degenerate	SIB	1.0988	0.0080	0.0231
	HDB	0.6012	0.0127	0.0079
Polytropic	SIB	1.0201	0.0081	0.0237
	HDB	0.6162	0.0129	0.0082

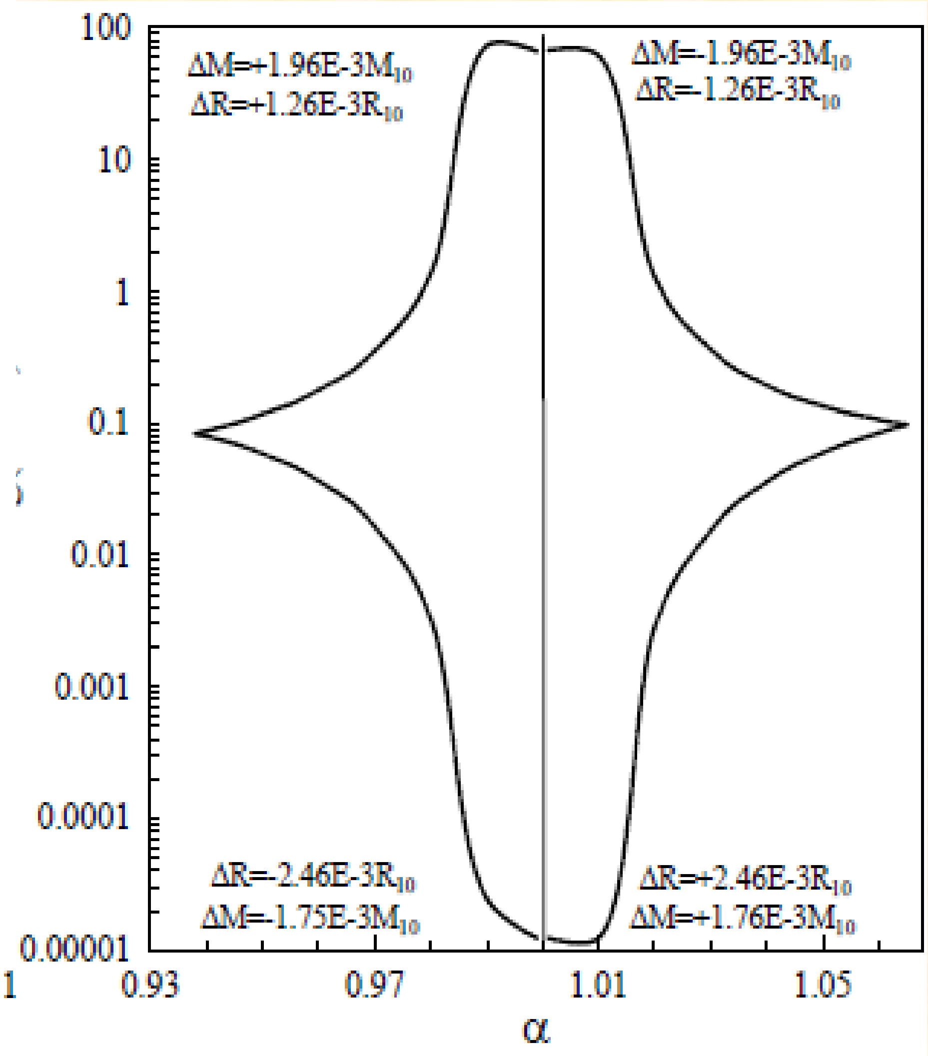
For the UG-LE equations, by keeping the same inputs:

- We select those solutions for which M, R, and L, calculated at ξ_{10}^*, stay within the observational range $[M_0 - \Delta M_0, M_0 + \Delta M_0]$, etc.
- In order to find the allowed region for α and R_*, we compute R_*^+ and R_*^-, the upper and lower bound on R_*, respectively, by setting the upper and lower values of M (calculated at ξ_{10}^*) so that the values of R and L remain within the observational range.
- In each portion of the allowed regions we set a fixed value for the uncertainty in M, R, and L:

$$\Delta M = \left[\left(\frac{\xi_{10}^*}{\xi_{10}}\right)^2 \left(\frac{\eta_{11}'}{\eta_{10}'}\right) - 1\right] M_{10}, \quad \Delta R = \left[\left(\frac{\xi_{10}^*}{\xi_{10}}\right) - 1\right] R_{10}, \quad \Delta L = \left[\left(\frac{\xi_{10}^*}{\xi_{10}}\right)^2 - 1\right] L_{10},$$

η' indicates $\theta'(\Phi')$



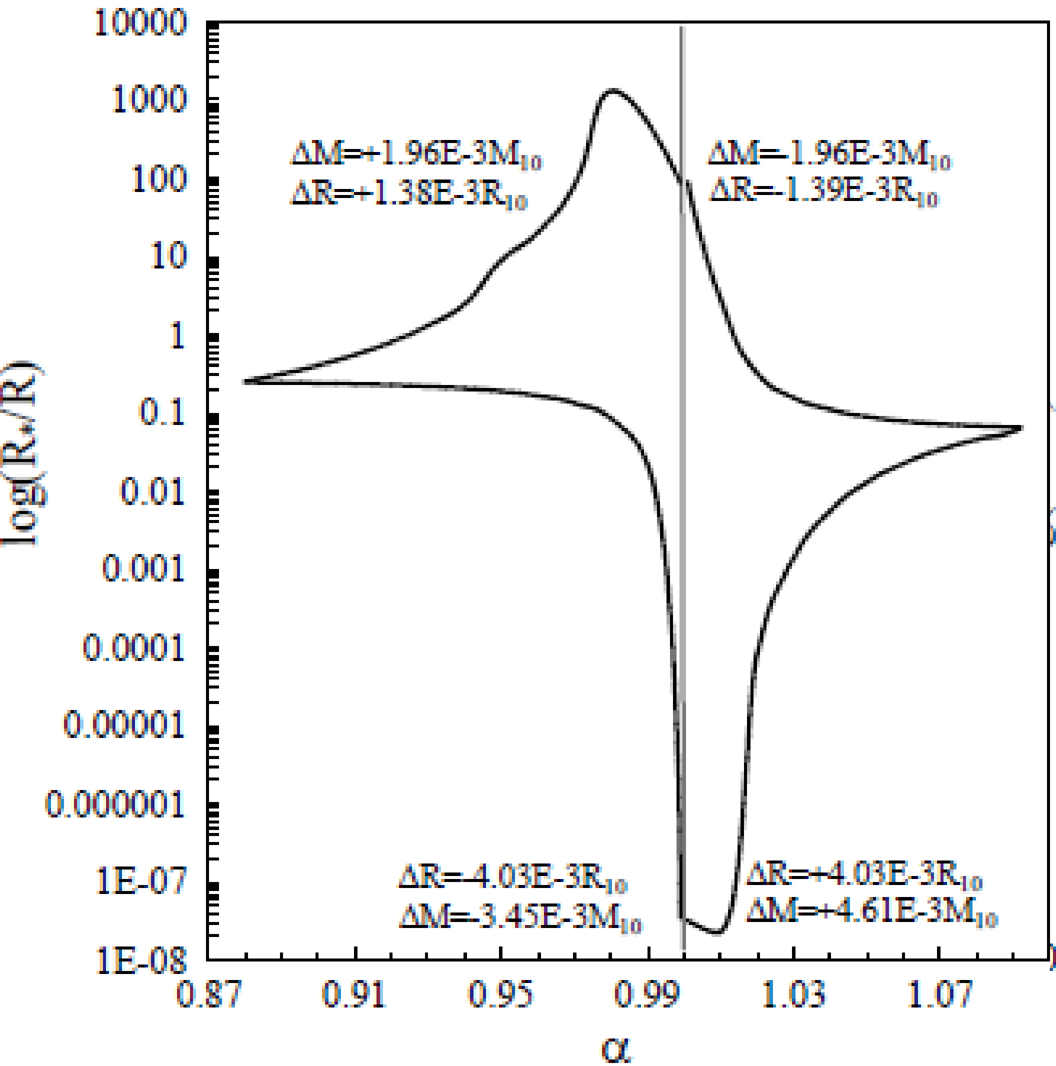


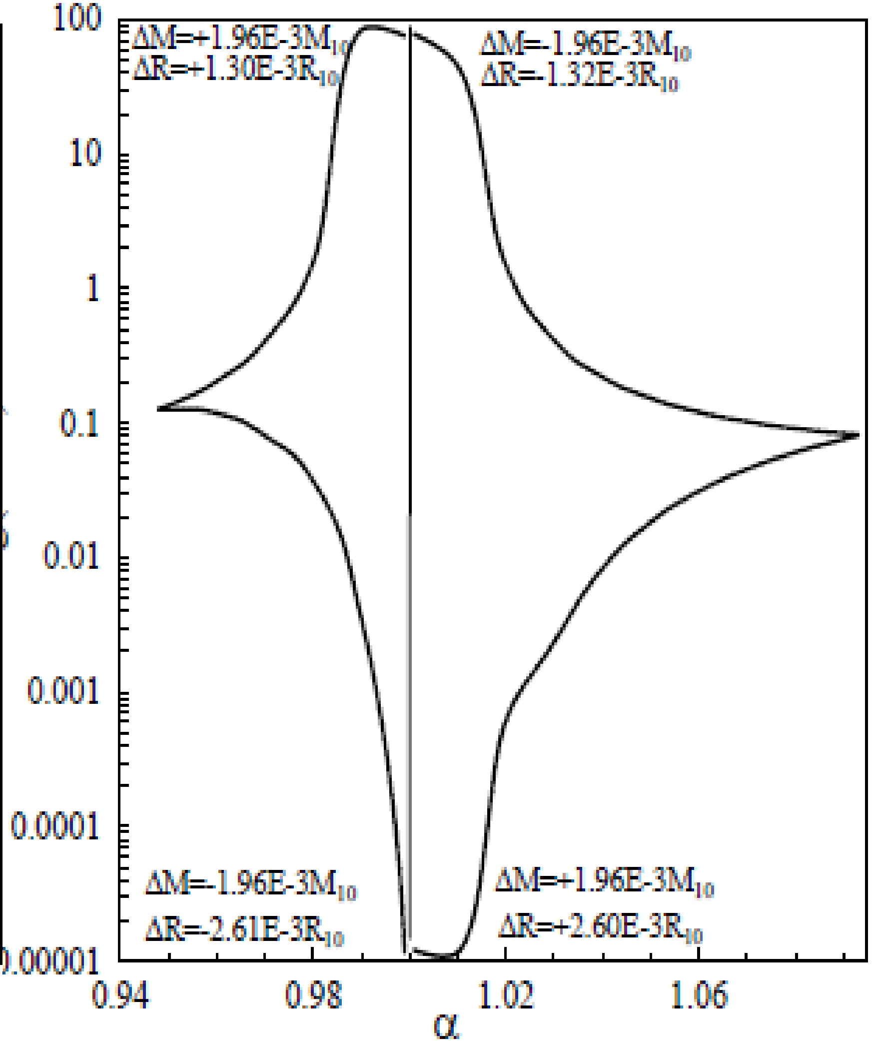
HDB **SIB**

(Polytropic)

The allowed region for the UG parameters

The characteristic length has been normalized by R, the radius of the relevant WD





HDB **SIB**

(Degenerate)

The allowed region for the UG parameters

The characteristic length has been normalized by R, the radius of the relevant WD

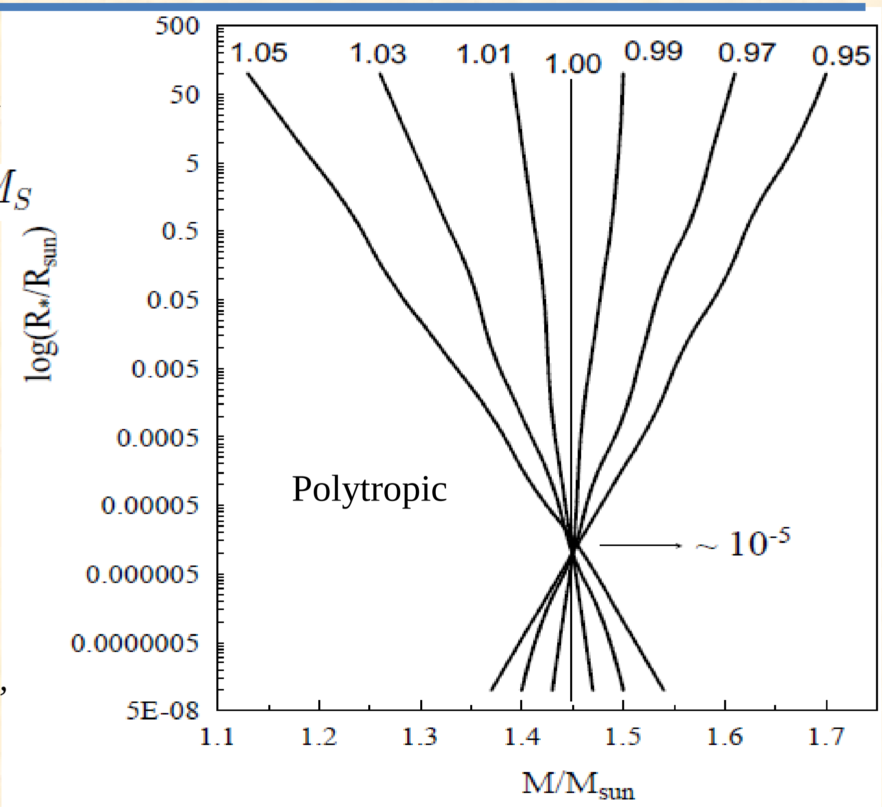
Model	WD	α	$R_*(m)$	M/M_S	R/R_S	L/L_S
Degenerate	SIB	0.948	713.707	1.040	0.0079	0.0226
		1.093	460.951	1.000	0.0083	0.0248
	HDB	0.880	2261.582	0.638	0.0126	0.0078
		1.092	581.410	0.594	0.0132	0.0858
Polytropic	SIB	0.942	445.632	1.038	0.0079	0.0226
		1.065	550.077	1.000	0.0083	0.0248
	HDB	0.904	1141.932	0.638	0.0126	0.0078
		1.102	1345.948	0.594	0.0132	0.0858

By increasing the ratio M/R, the allowed region for the UG parameter becomes smaller.

For example, when the ratio M/R increases about 2.5 times, α gets closer to unity by about 4% and R_* gets reduced by 60% based on the limit values of α for the polytropic model.

UG effect on the Chandrasekhar mass limit M_{Ch}

$$\begin{cases} M_{Ch} = 0.721\left(-\xi^2\theta'\right)\big|_{\xi_{10}} M_S \\ \xi_{10} = 6.89679 \text{ and } \theta'_{10} = -0.04243, \end{cases} \Rightarrow M_{Ch} = 1.45 M_S$$



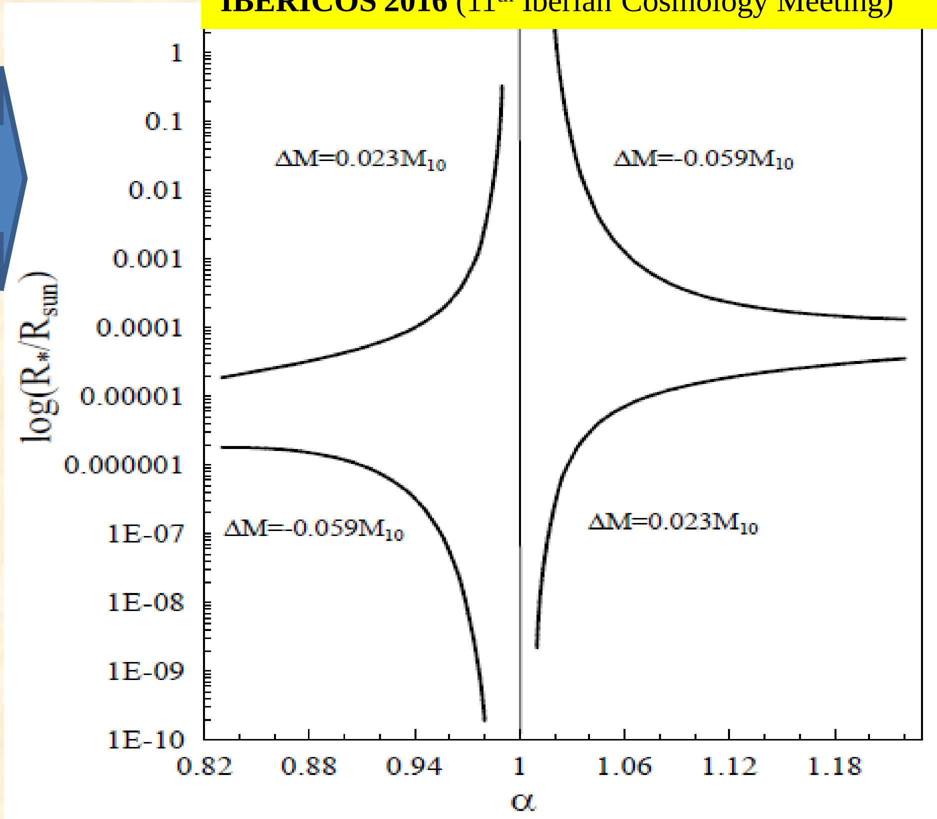
It is possible to have WDs with masses greater than M_{Ch} The existence of WD 1143+321 (M=1.52 M_S) can be accommodated within the UG model.

[N. K. Glendenning, *Compact Stars: Nuclear Physics, Particle Physics, and General Relativity* (Springer-Verlag, New York, 2000) 2nd edition]

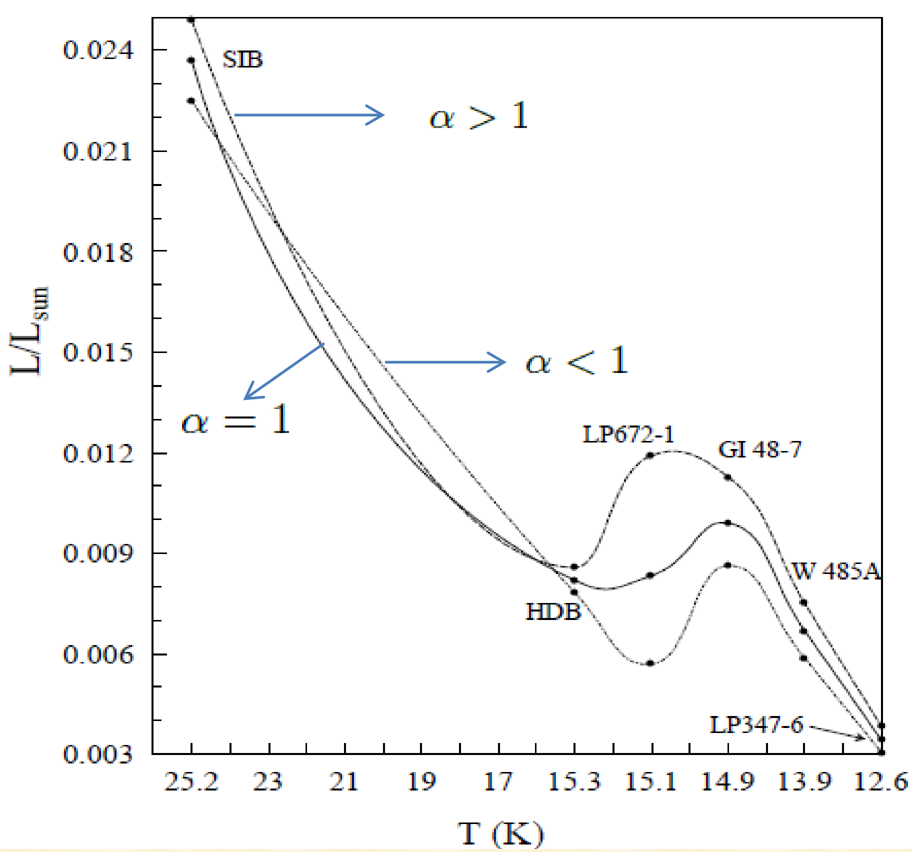
Ultra-massive WDs ($M > 1.1\ M_S$)

EUVE J1746-706, $M = 1.43 M_S$ $\Delta M = 0.06 M_S$

UG polytropic gas model ($n = 3$)



It seems that one should include general relativity corrections in UG-LE equation

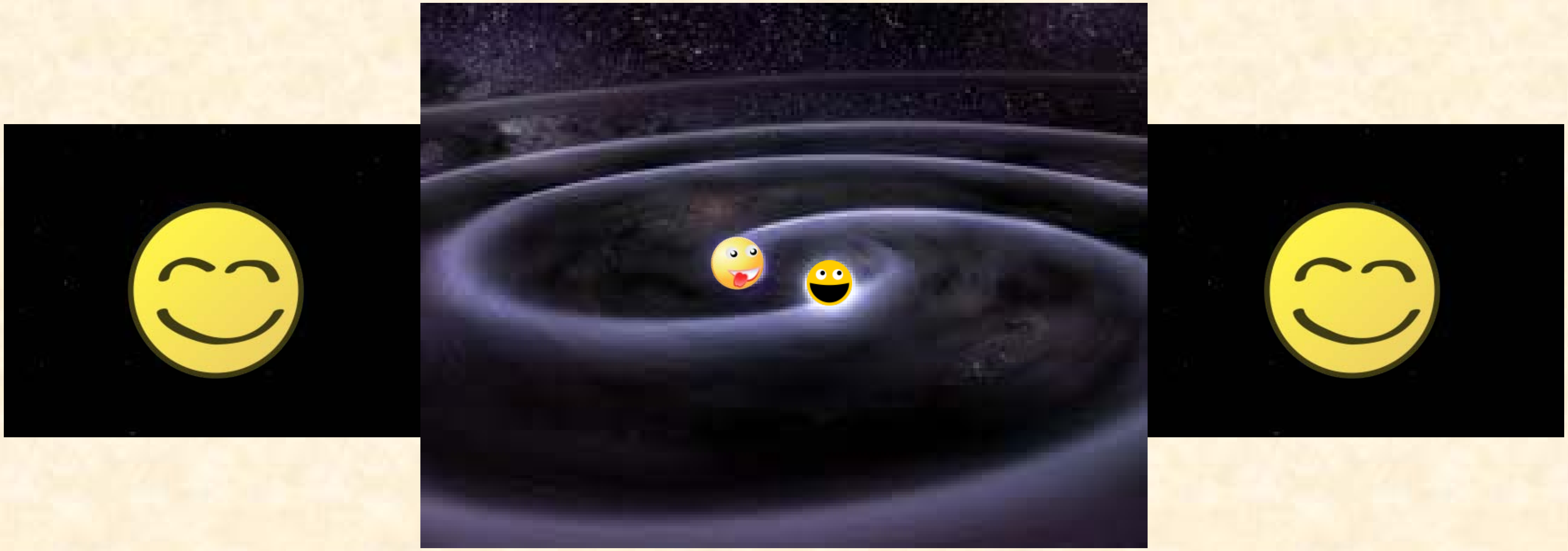


UG effect on the location of WDs in H-R diagram

Ongoing …

UG Effects on Neutron Stars

Thanks for your attention

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