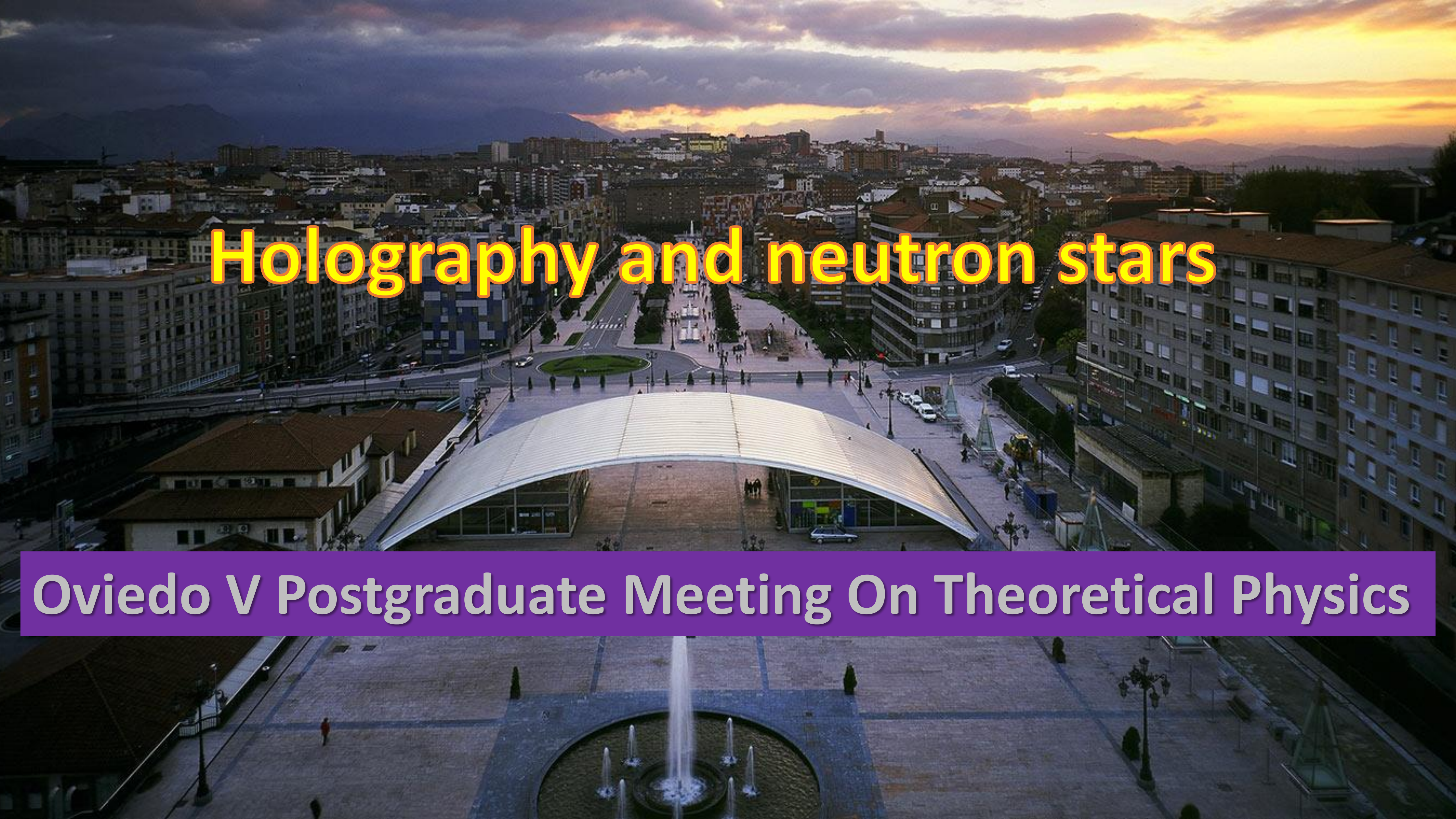

Holography and neutron stars

Oviedo V Postgraduate Meeting On Theoretical Physics

List of star extremes

From Wikipedia, the free encyclopedia

normal star							massive stars

Most massive stars by type

Title	Object	Date	Data	Comments	Notes	Refs	See more
Most massive brown dwarf	PPI 15	1996	80 $M_{Jupiter}$	This is at the limit between brown dwarfs and red dwarfs.[23][24]		[23][25][26][27]	
Most massive degenerate star	The most massive type of degenerate star is the neutron star. See *Most massive neutron star* for this recordholder. [NB 4]						
Most massive neutron star	PSR J1614−2230	2010	1.97 M_{Sun}	This millisecond pulsar greatly exceeds the predicted limit of neutron star size of roughly 1.5 solar masses. The previous titleholder only massed of 1.67 solar masses.		[28][29][30]	Black Widow Pulsar
Most massive white dwarf	RE J0317-853	1998	1.35 M_{Sun}			[31][32]	

Least massive stars by type

Title	Object	Date	Data	Comments	Notes	Refs	See more
Least massive brown							List of least

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RESEARCH ARTICLE

A Massive Pulsar in a Compact Relativistic Binary

John Antoniadis[1,*], Paulo C. C. Freire[1], Norbert Wex[1], Thomas M. Tauris[2,1], Ryan S. Lynch[3], Marten H. van Kerkwijk[4], Michael Kramer[1,5], Cees Bassa[5], Vik S. Dhillon[6], Thomas Driebe[7], Jason W. T. Hessels[8,9], Victoria M. Kaspi[3], Vladislav I. Kondratiev[8,10], Norbert Langer[2], Thomas R. Marsh[11], Maura A. McLaughlin[12], Timothy T. Pennucci[13], Scott M. Ransom[14], Ingrid H. Stairs[15], Joeri van Leeuwen[8,9], Joris P. W. Verbiest[1], David G. Whelan[13]

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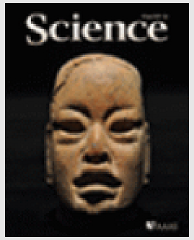
Vol. 340, Issue 6131,
DOI: 10.1126/science.1233232

2.01 ± 0.04 solar mass

Article | Figures & Data | Info & Metrics | eLetters | PDF



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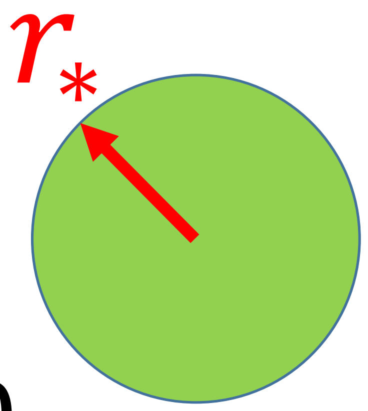
Neutron star structure



$$ds^2 = -e^{\nu(r)}dt^2 + e^{\lambda(r)}dr^2 + r^2 d\Omega_2$$

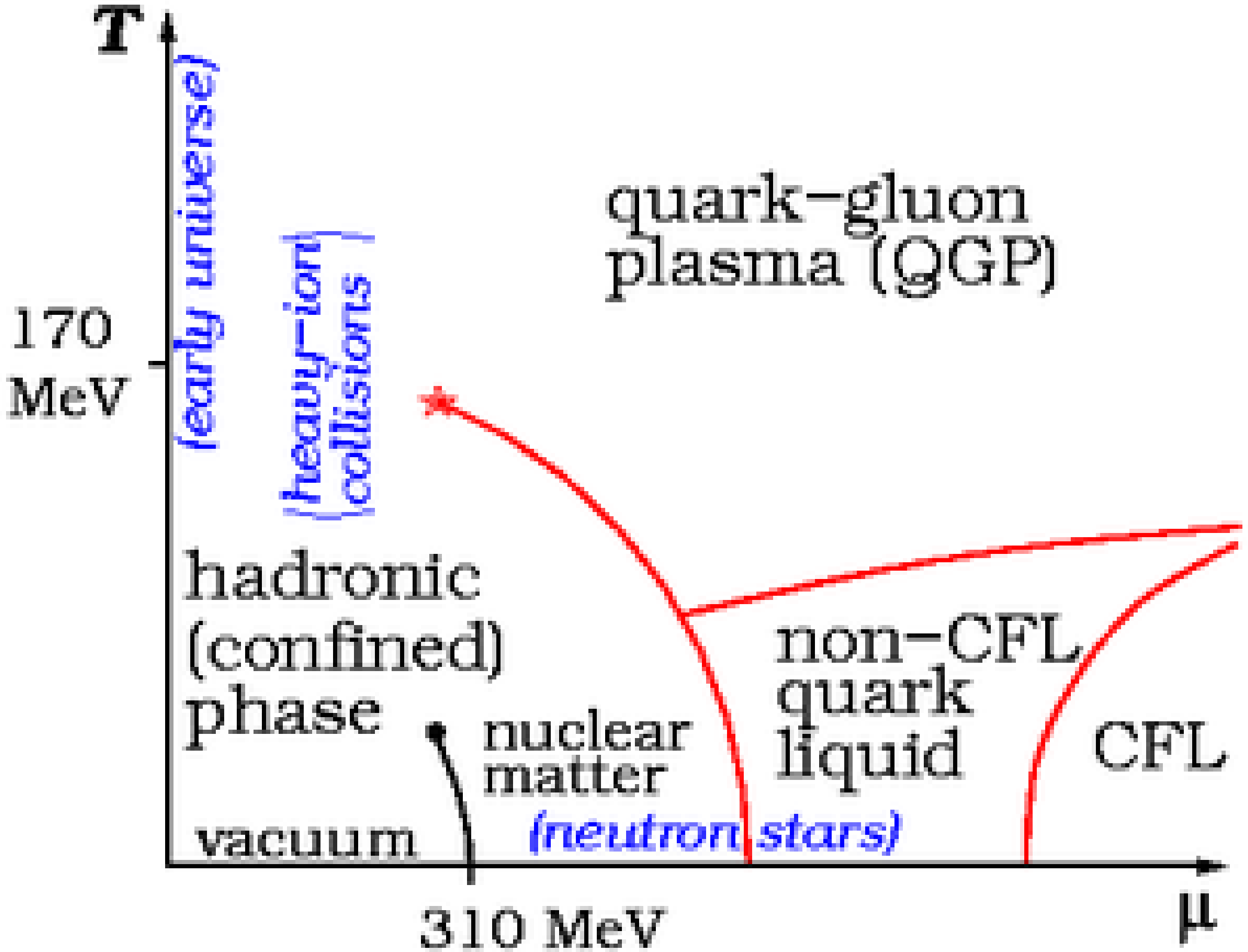
$$T_0{}^0 = \varepsilon(r) \qquad T_i{}^j = P(r)\delta_i^j \qquad P(r_*) = 0$$

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\,\pi\, G\, T_{\mu\nu} \qquad \partial_\mu T^\mu_\nu = 0$$

Tolman–Oppenheimer–Volkoff equations

Only unknown: Equation of State $\quad \mathrm{F}(\varepsilon, P) = 0$

QCD phase diagram



QCD phase diagram

Perturbation Theory $\mu > 1\ GeV$ $\mu < 500\ MeV$

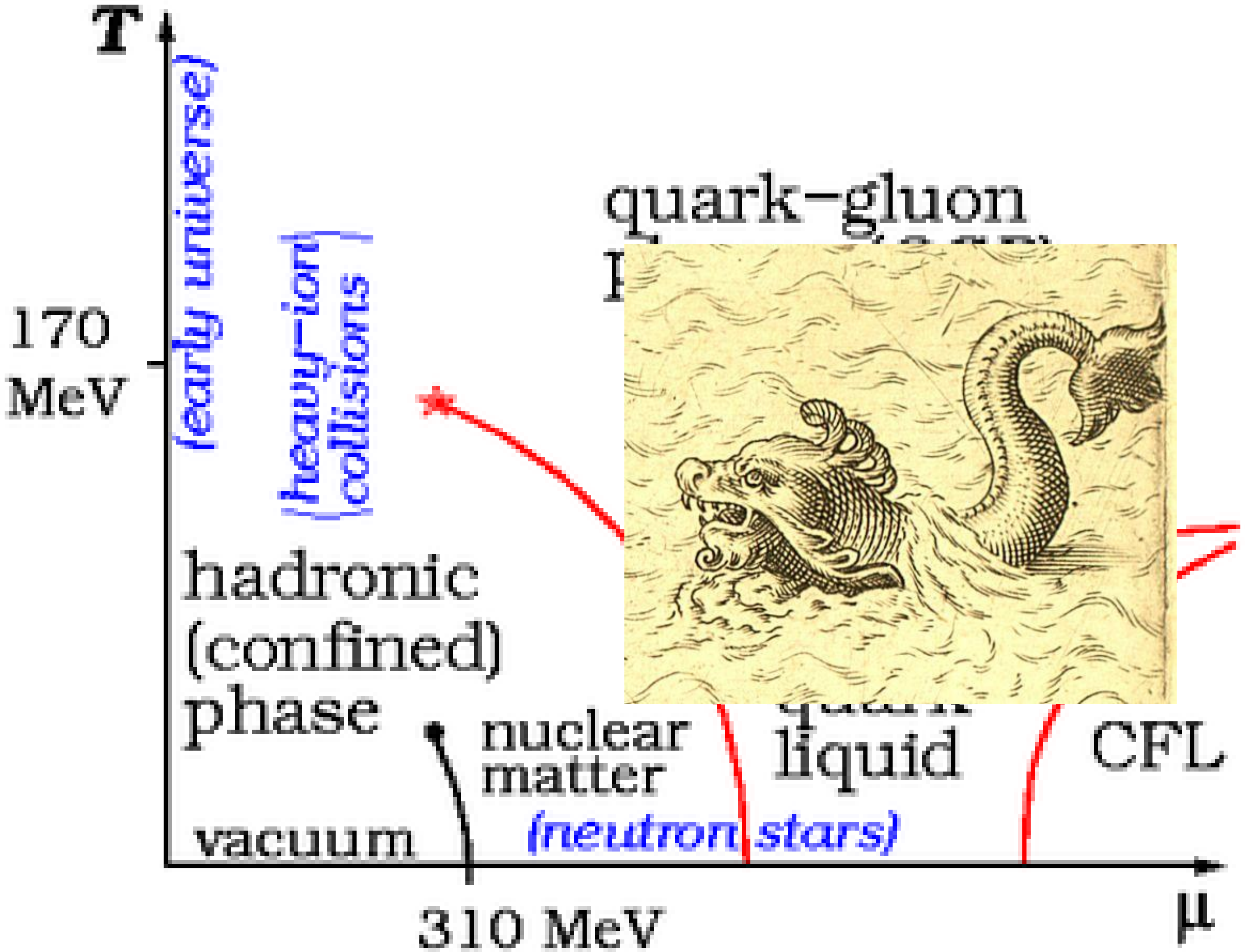
Lattice QCD $\mu \ll T$ $T \sim 0.1 - 1\ keV$

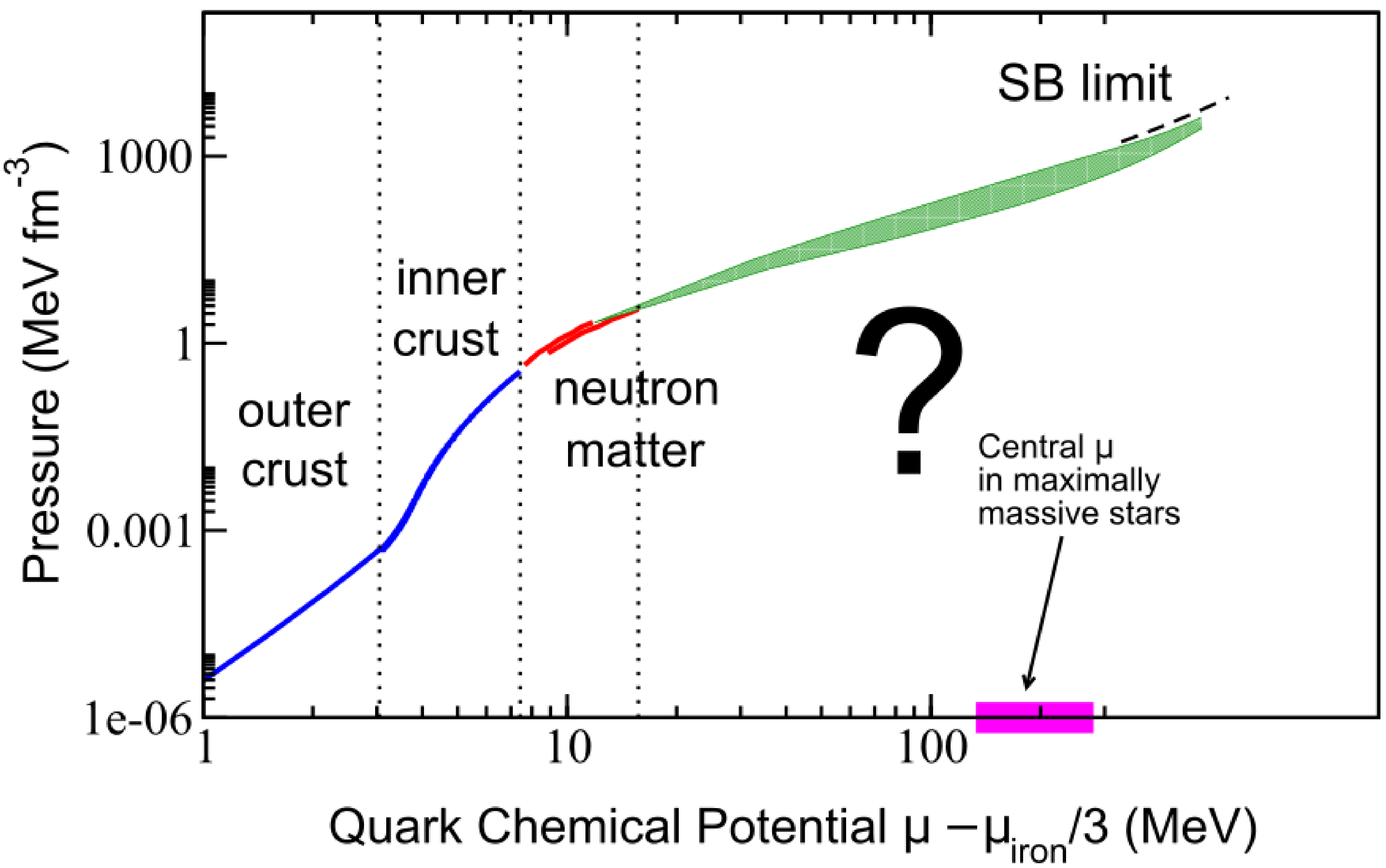
Chiral Perturbation Theory $n \leq n_s \simeq 0.16\ fm^{-3}$ $n \sim 5\, n_s$

Phenomenological models: Nambu-Jona-Lasinio, Walecka

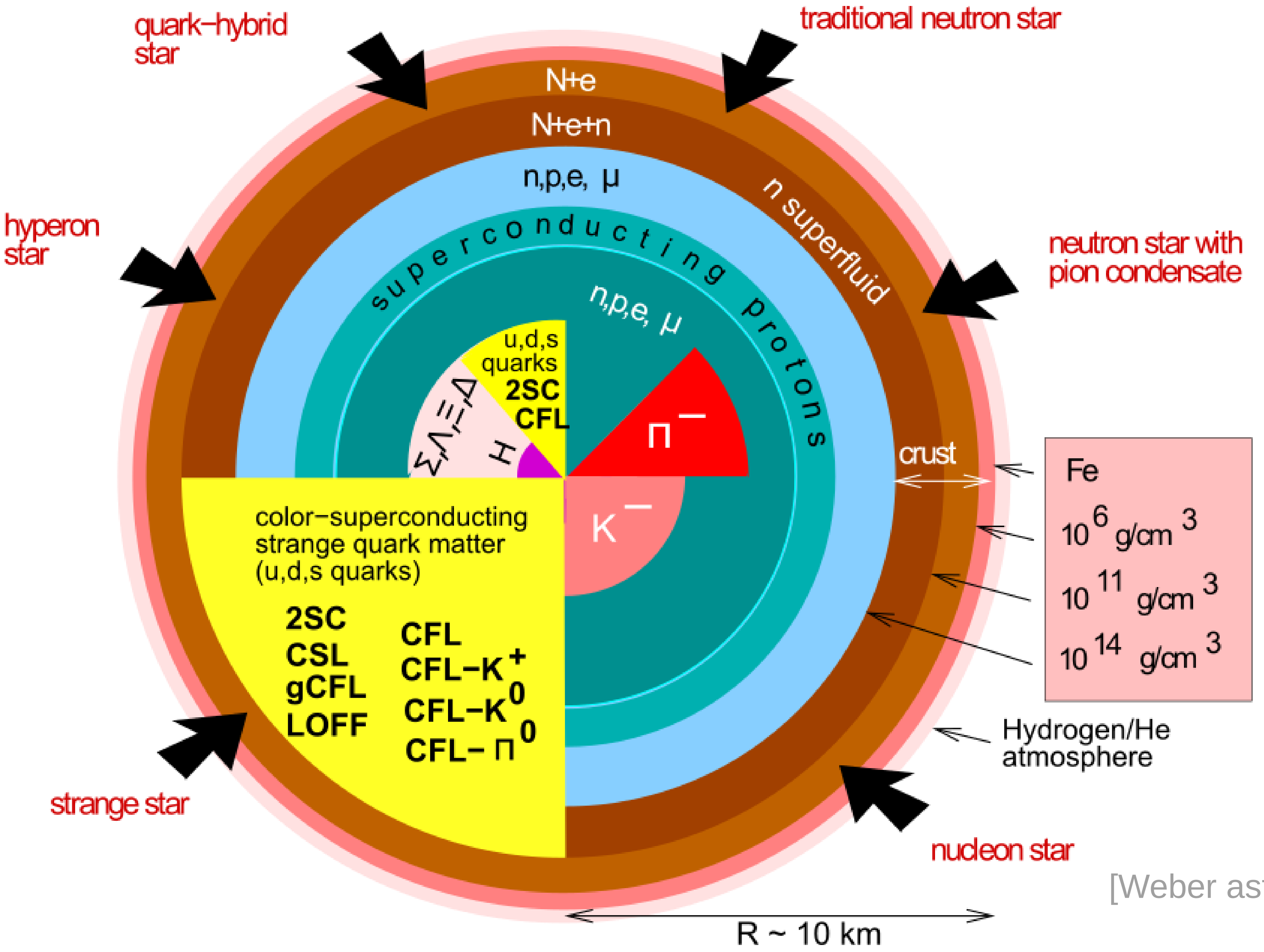
Extrapolated from low density

QCD phase diagram





[Kurkela, Fraga, Schaner-Bielich, Vuorinen 1402.6618]



[Weber astro-ph/0407155]

What about holographic models?

Strong coupling 

No problems with large density 

Large-N: baryons are difficult 

Not QCD: systematic uncertainty 

What about holographic models?

Strong coupling 

No problems with large density 

Alternative large-N limits

Not QCD: systematic uncertainty 

What about holographic models?

Strong coupling

No problems with large density

Restrict to deconfined phase

Not QCD: systematic uncertainty

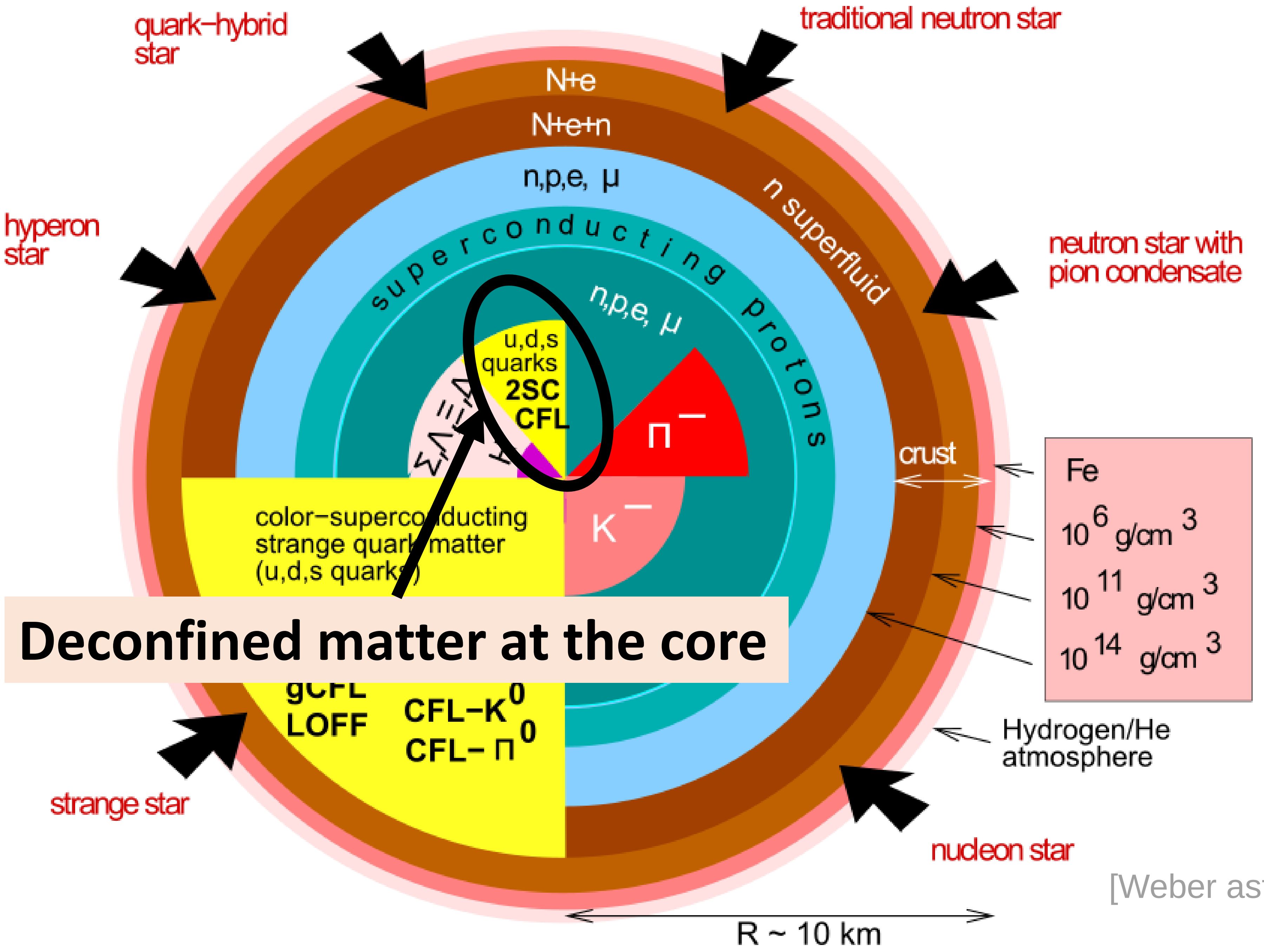
What about holographic models?

Strong coupling

No problems with large density

Restrict to deconfined phase

universality in quark-gluon plasma (?)



Deconfined matter at the core

[Weber astro-ph/0407155]

Quick introduction to AdS/CFT

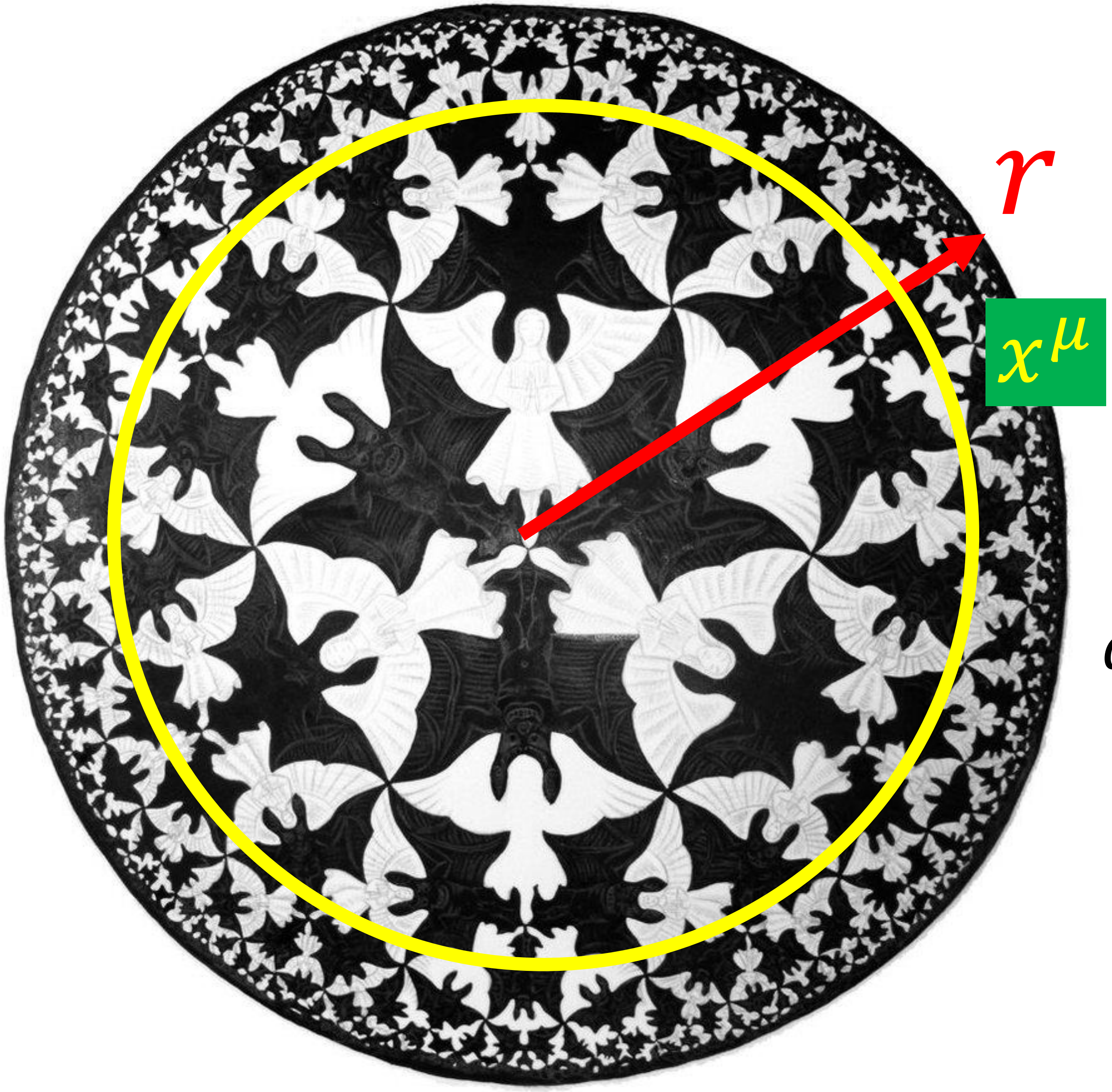
Basics

AdS

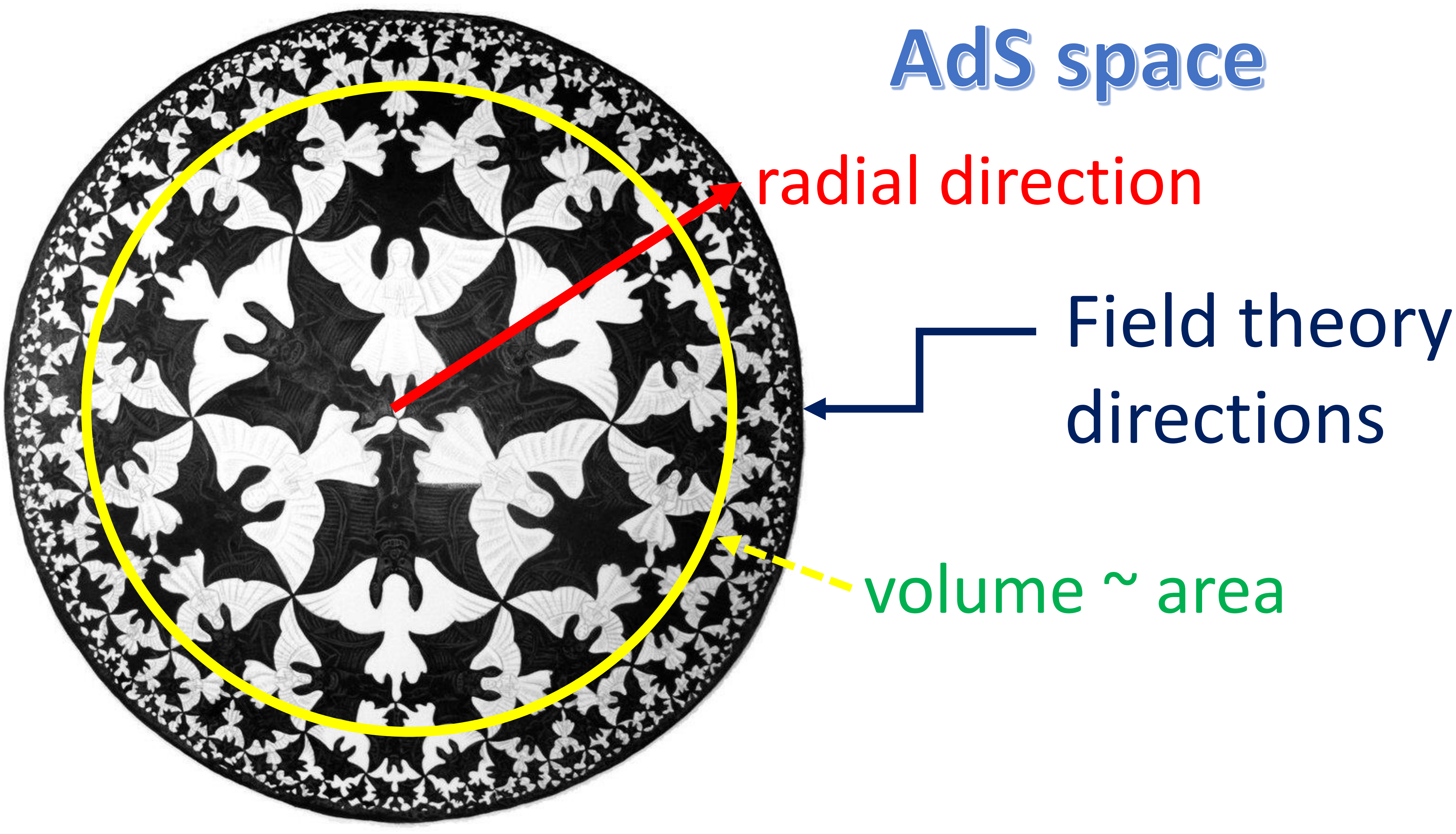
UV/IR

Black holes

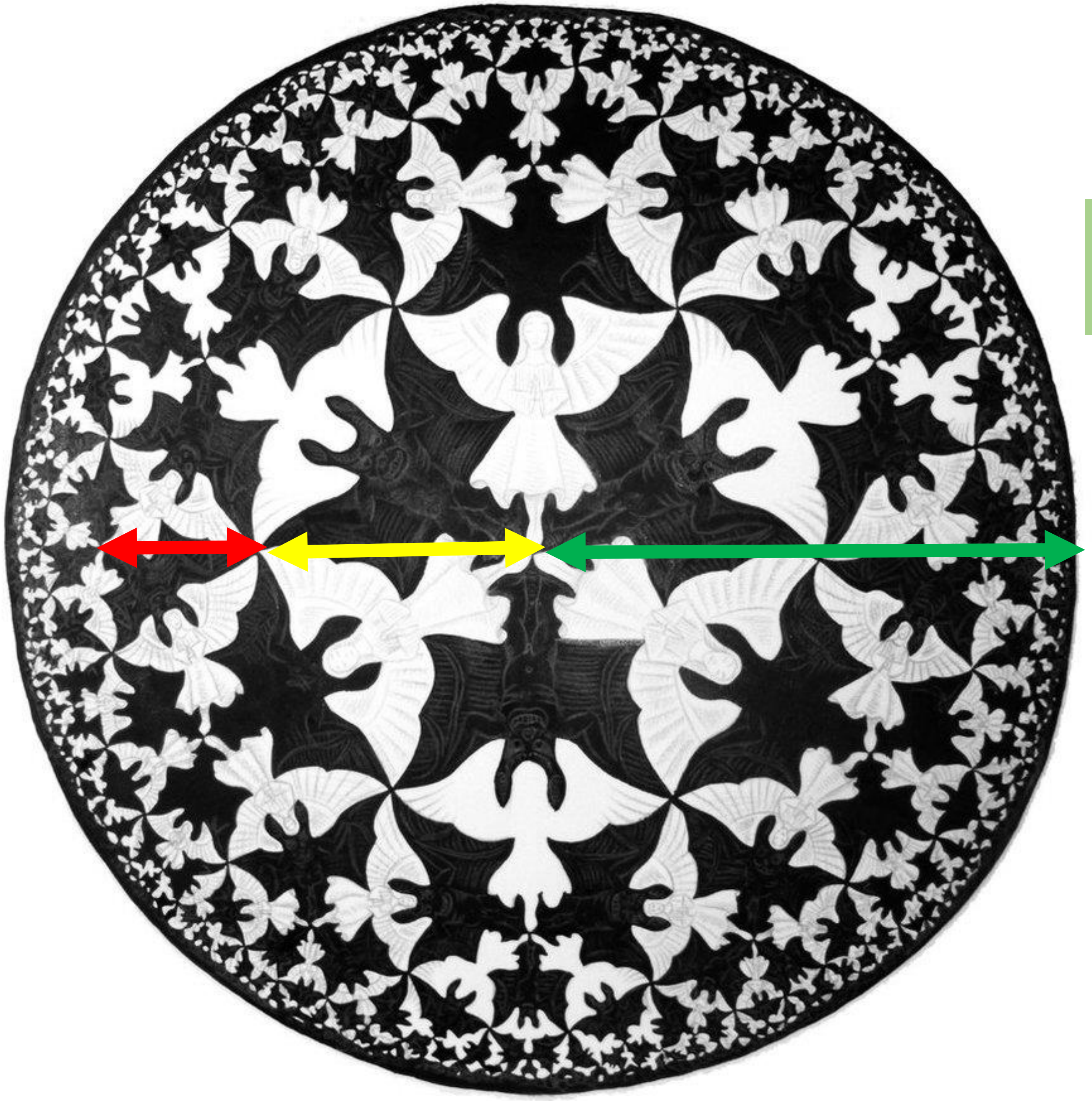
AdS space



$$ds^2 = \frac{dr^2}{r^2} + r^2 \underbrace{\eta_{\mu\nu} dx^\mu dx^\nu}_{d \text{ dimensions}}$$


AdS space
radial direction
Field theory
directions
volume ~ area

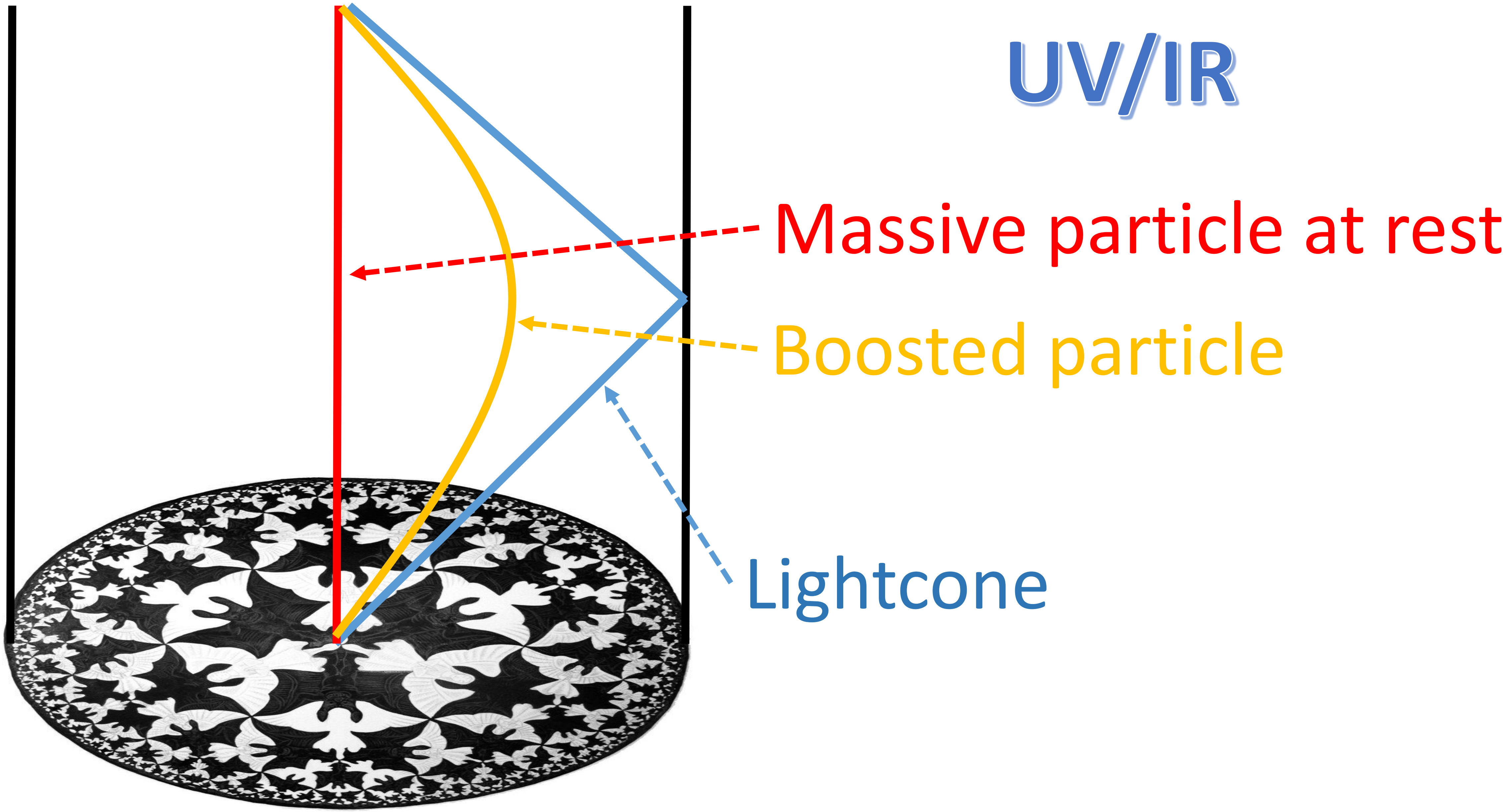
AdS space



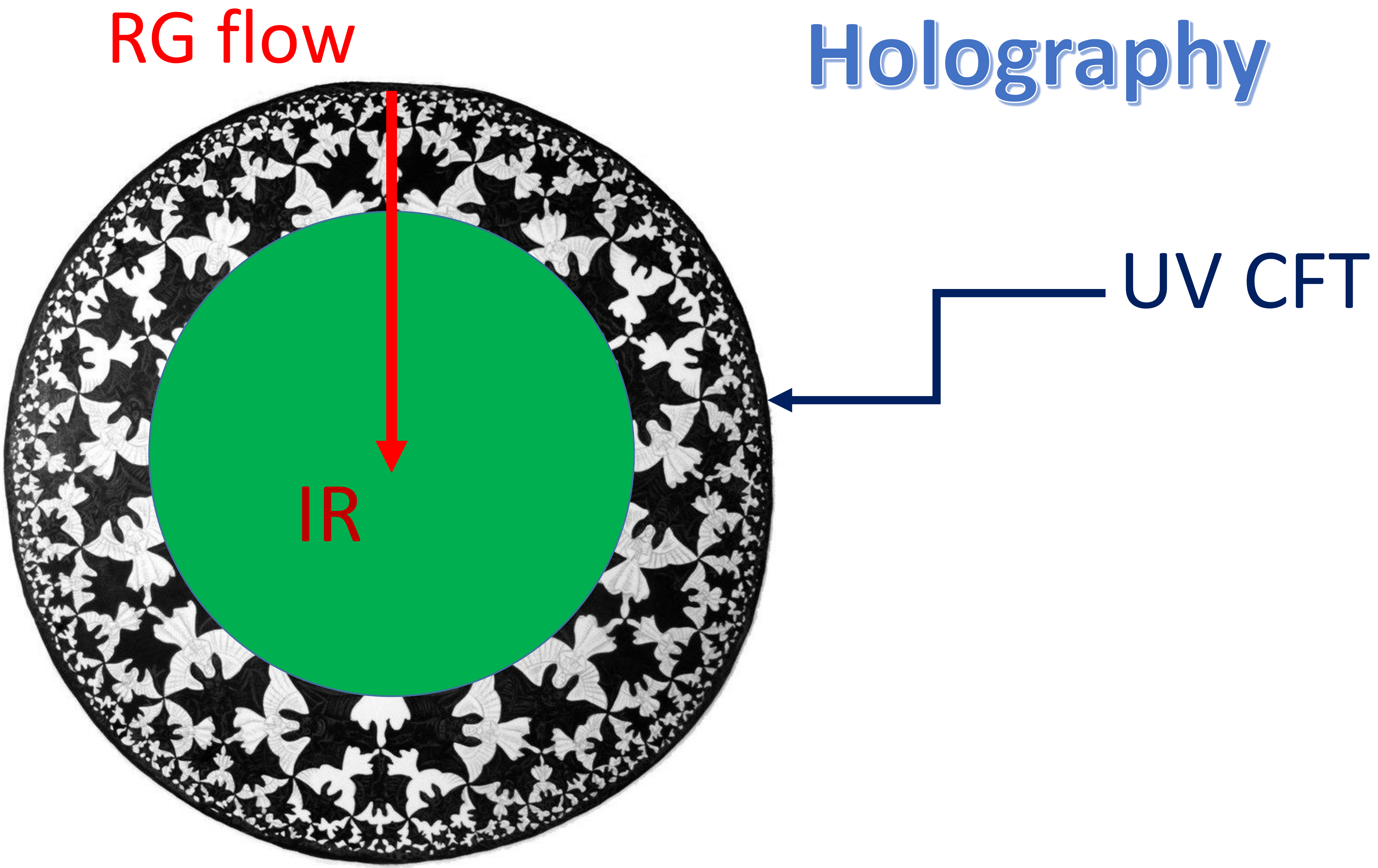
length = length

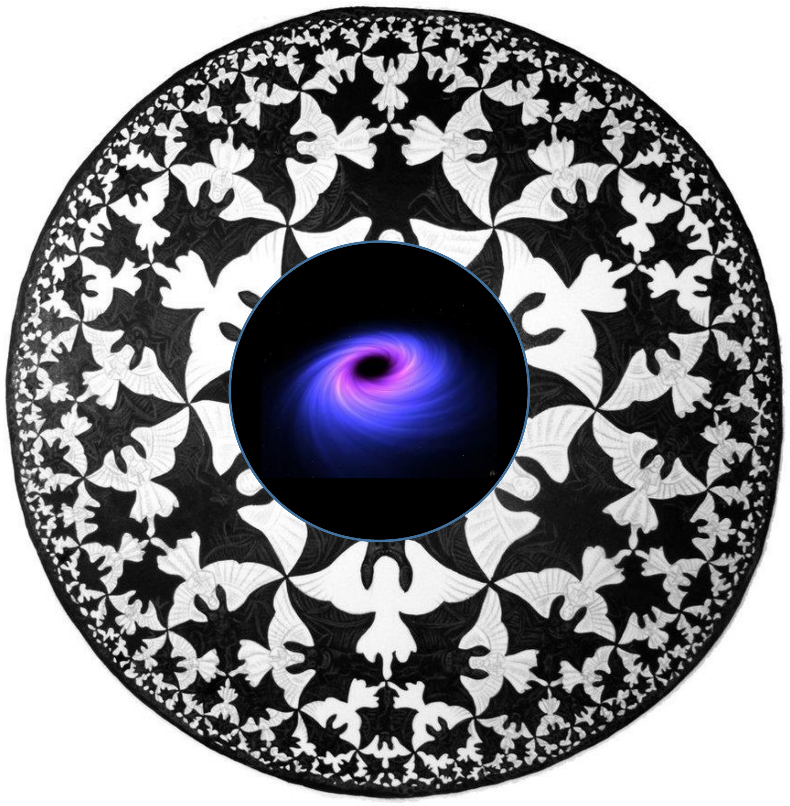
infinite distance

UV/IR



Holography





Black hole

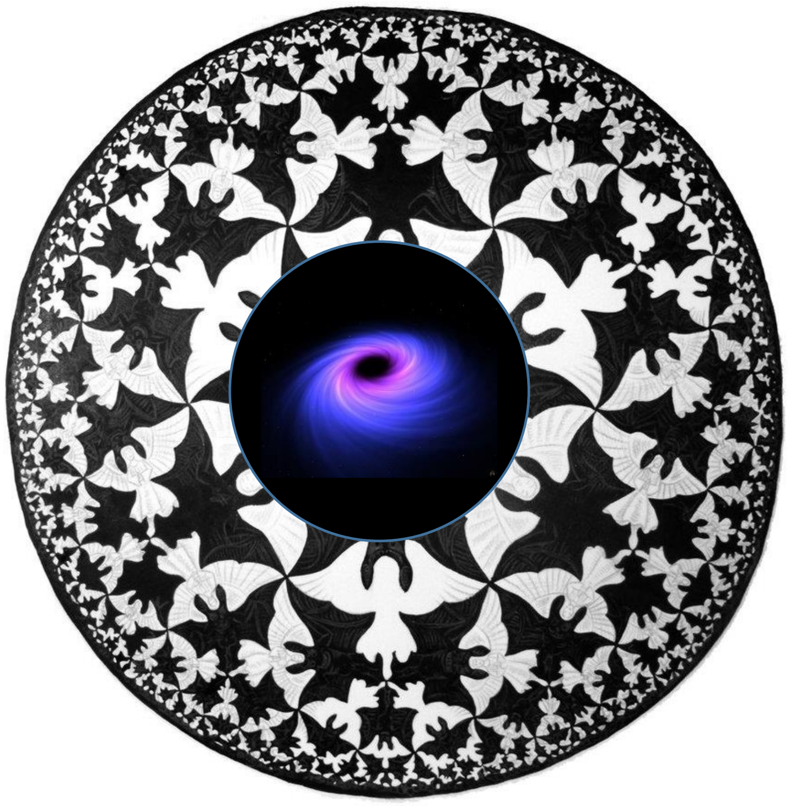
Thermal state

Temperature = Hawking temperature

Thermal Entropy = Black hole area

$$ds^2 = \frac{dr^2}{f(r)r^2} + r^2\left(-f(r)dt^2 + \delta_{ij}dx^i dx^j\right)$$

$$f(r) = 1 - \frac{{r_H}^d}{r^d}$$



Black hole

Thermal state

Temperature ~ r_H

Thermal Entropy ~ $r_H{}^{d-1}$

$$ds^2 = \frac{dr^2}{f(r)r^2} + r^2(-f(r)dt^2 + g_{ij}dx^i dx^j)$$

$$f(r) = 1 - \frac{r_H{}^d}{r^d}$$

The correspondence

Symmetries
Fields/Operators
Action

Symmetries

<u>Field theory</u> <u>Gravity</u>

Local symmetries are not ``physical''

Global symmetries $\longleftrightarrow$ **Asymptotic symmetries**

Conformal symmetries $\longleftrightarrow$ AdS isometries

$$r \to \lambda r \qquad x^\mu \to x^\mu/\lambda$$

$$ds^2 = \frac{dr^2}{r^2} + r^2 \eta_{\mu\nu} dx^\mu dx^\nu$$

Operators/Fields

Field theory Operators $\longleftrightarrow$ Gravity fields

Local gauge-invariant

$\mathcal{O}(x)$

Local fields

$\Phi(x, r)$

Conformal dimension Δ

Mass ${M_s}^2 = \Delta(\Delta - d)$

Equal charges and spin

$$\Phi(x, r) \sim \frac{g}{r^{d-\Delta}} + \frac{\langle \mathcal{O} \rangle}{r^{\Delta}}$$

Action

Field theory | **Gravity**

Generating functional ⟷ On-Shell action

$$W[g] = \left\langle e^{\int g\,\mathcal{O}} \right\rangle \qquad S[g] = \frac{1}{16\,\pi G}\int (R + \mathcal{L}_{matter})$$

$$\langle \mathcal{O}\mathcal{O} \rangle = \frac{\delta^2\, W}{\delta\, g^2}$$

A model of deconfined matter

Field theory

$N_c \to \infty$

$\mathcal{N} = 4\ \mathrm{SU}(N_c)$ Super Yang-Mills $\lambda_{YM} = {g_{YM}}^2 N_c \gg 1$

$\mathcal{N} = 2 \quad N_f \ll N_c$ Flavor hypermultiplets

Fields in adjoint of color: $A_\mu \,, \phi^{i=1,\cdots,6} \,, \lambda^{a=1,\cdots,4}$

Fields in (anti)fundamental of color: $q, \tilde{q}, \psi, \tilde{\psi}$

Gravity dual

$AdS_5 \times S^5 + \; N_f$ D7 flavor branes

$$ds^2 = \underbrace{\frac{dr^2}{f(r)r^2} + r^2(-f(r)dt^2 + \delta_{ij}dx^i dx^j)}_{\text{D7 flavor branes}} + d\Omega_5$$

$$\left\{ \; d\Omega_3 \right.$$

probe approximation

Gravity dual

$AdS_5 \times S^5 + \; N_f$ D7 flavor branes

$$S_{D7} = -T_7 \int e^{-\varphi} \sqrt{\det(g_{ab} + F_{ab})} + T_7 \int C_4 \wedge F \wedge F$$

$$A_0 \approx \mu + \frac{\langle J^0 \rangle}{r^2}$$

baryon chemical potential

baryon charge density

(beta-equilibrium: no electrons)

Free energy

free energy = -on-shell action (gravity+D7)

gravity action does not depend on chemical potential

$$\mathcal{F}_G \sim -{N_c}^2\, T^4$$

D7 brane action at small temperatures

$$\mathcal{F}_{D7} = -\frac{N_c N_f}{4\gamma^3 \lambda_{YM}} \left(\mu^2 - {\mu_0}^2\right)^2 + O(\mu^3 T)$$

[Karch, O'Bannon 0709.0570]

Extrapolation to QCD

Number of color and flavors the same as QCD $N_c = N_f = 3$

Stefan-Boltzmann result at large chemical potentials

$$\mathcal{F}_{D7} \simeq -\frac{N_c N_f}{4\gamma^3 \lambda_{YM}} \mu^4 = -\frac{N_c N_f}{12\,\pi^2} \mu^4$$

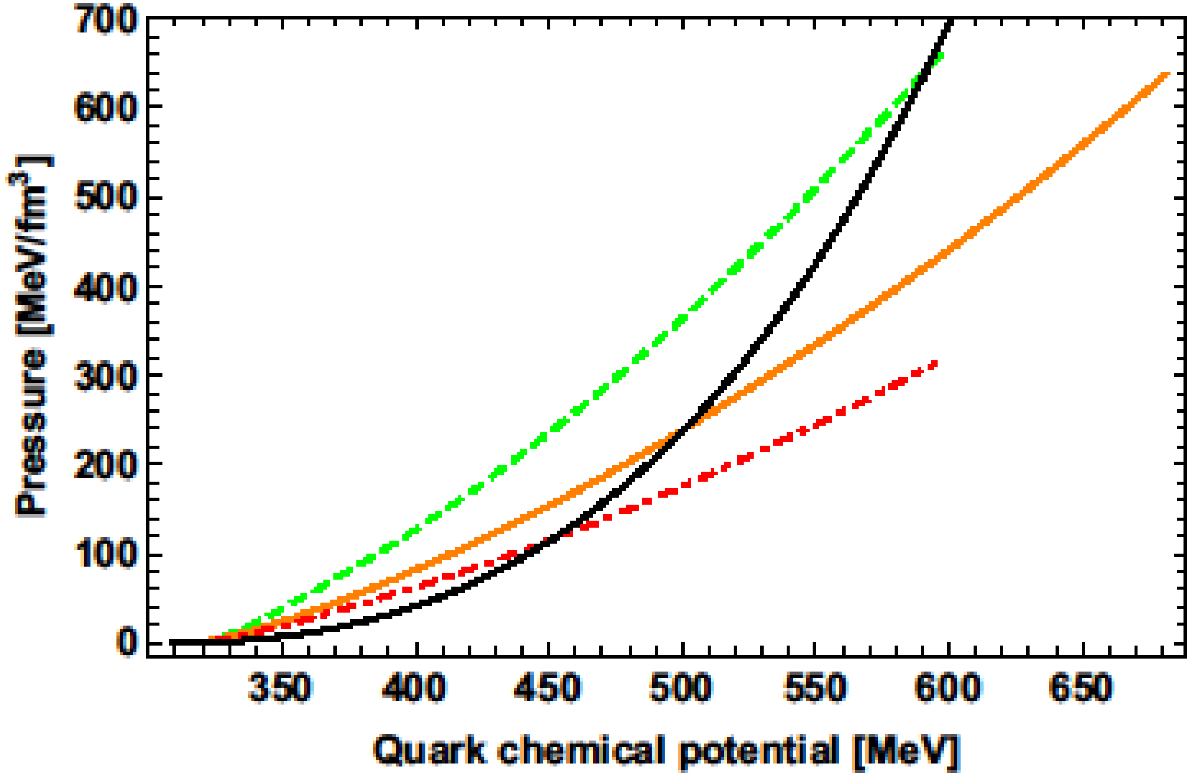
$$\lambda_{YM} = \frac{3\,\pi^2}{\gamma^3} \simeq 10.74$$

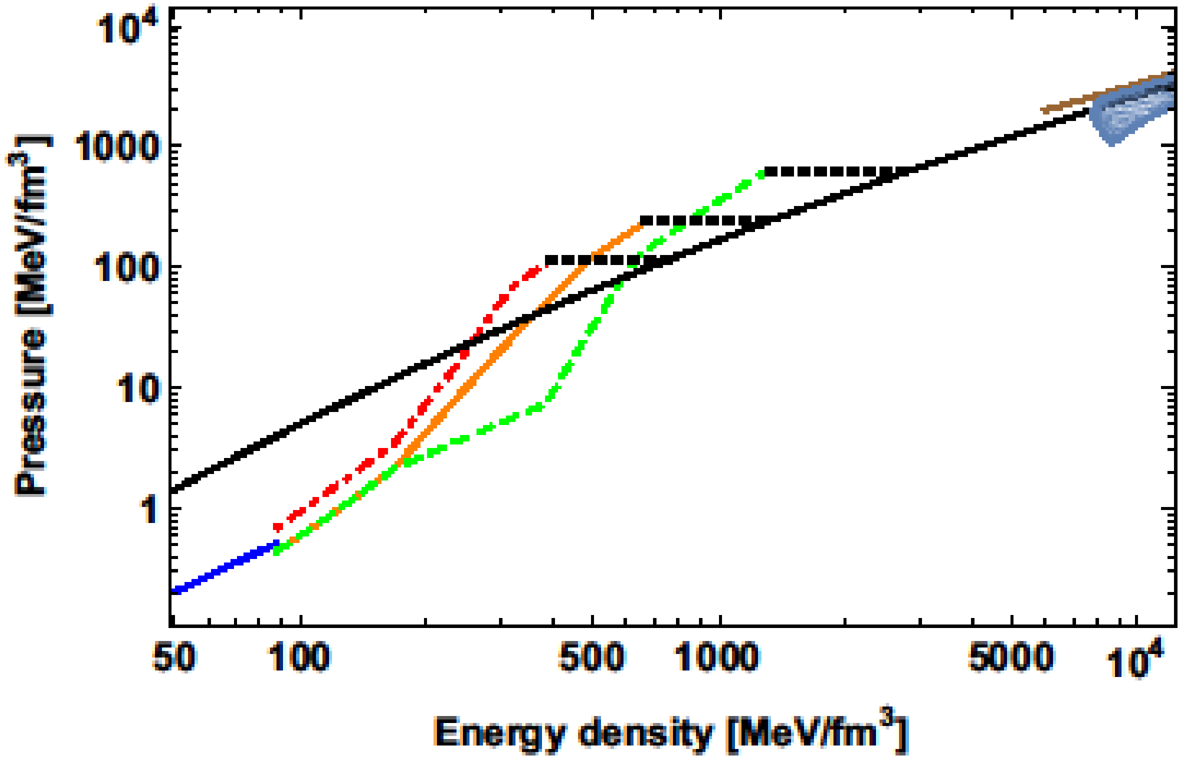
Pressure (=- free energy) vanishes ~ 1/3 nucleon mass

$$\mu_0 \simeq 308.55\, MeV$$

Application to neutron stars

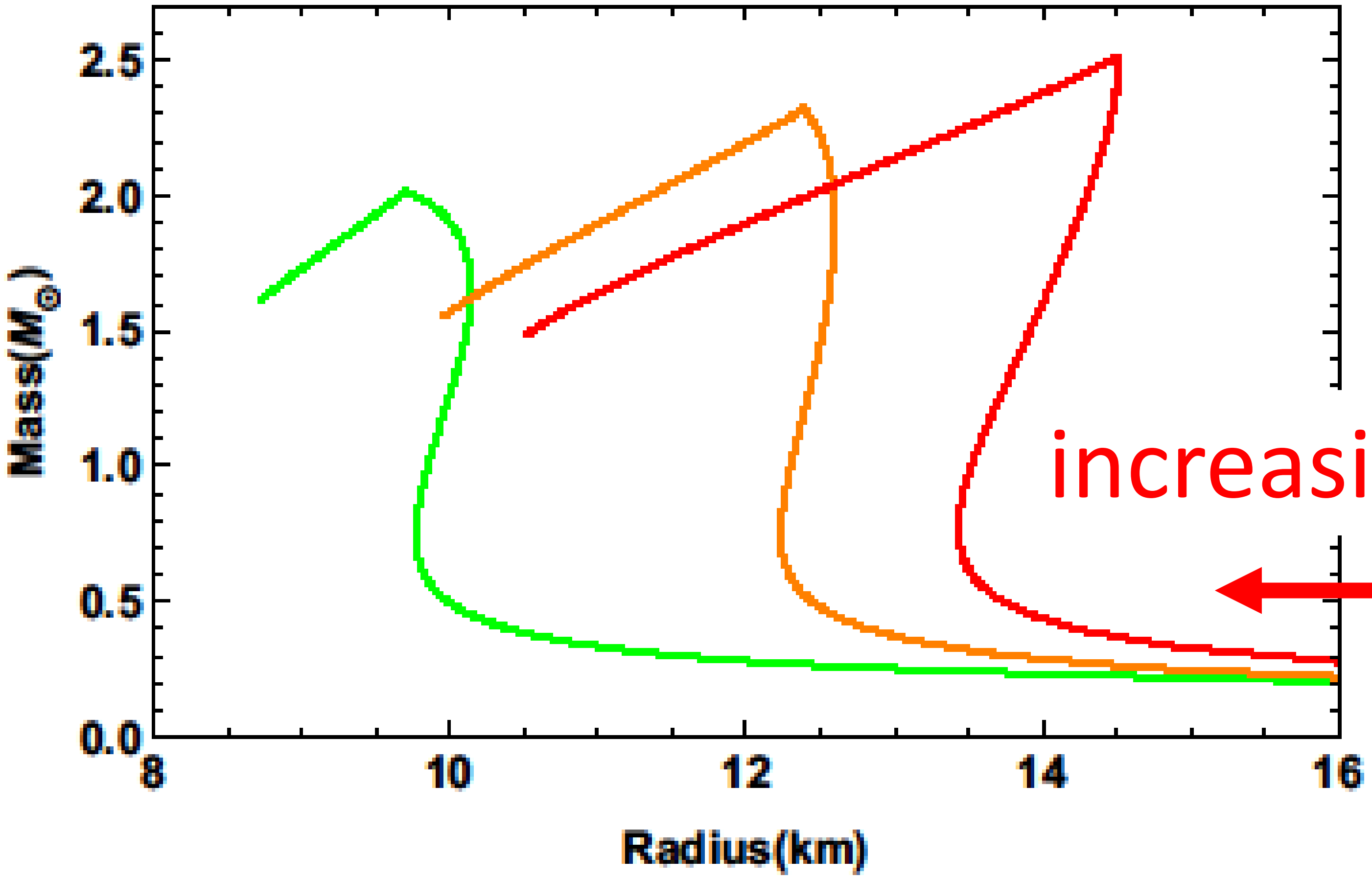
Comparison to nuclear matter





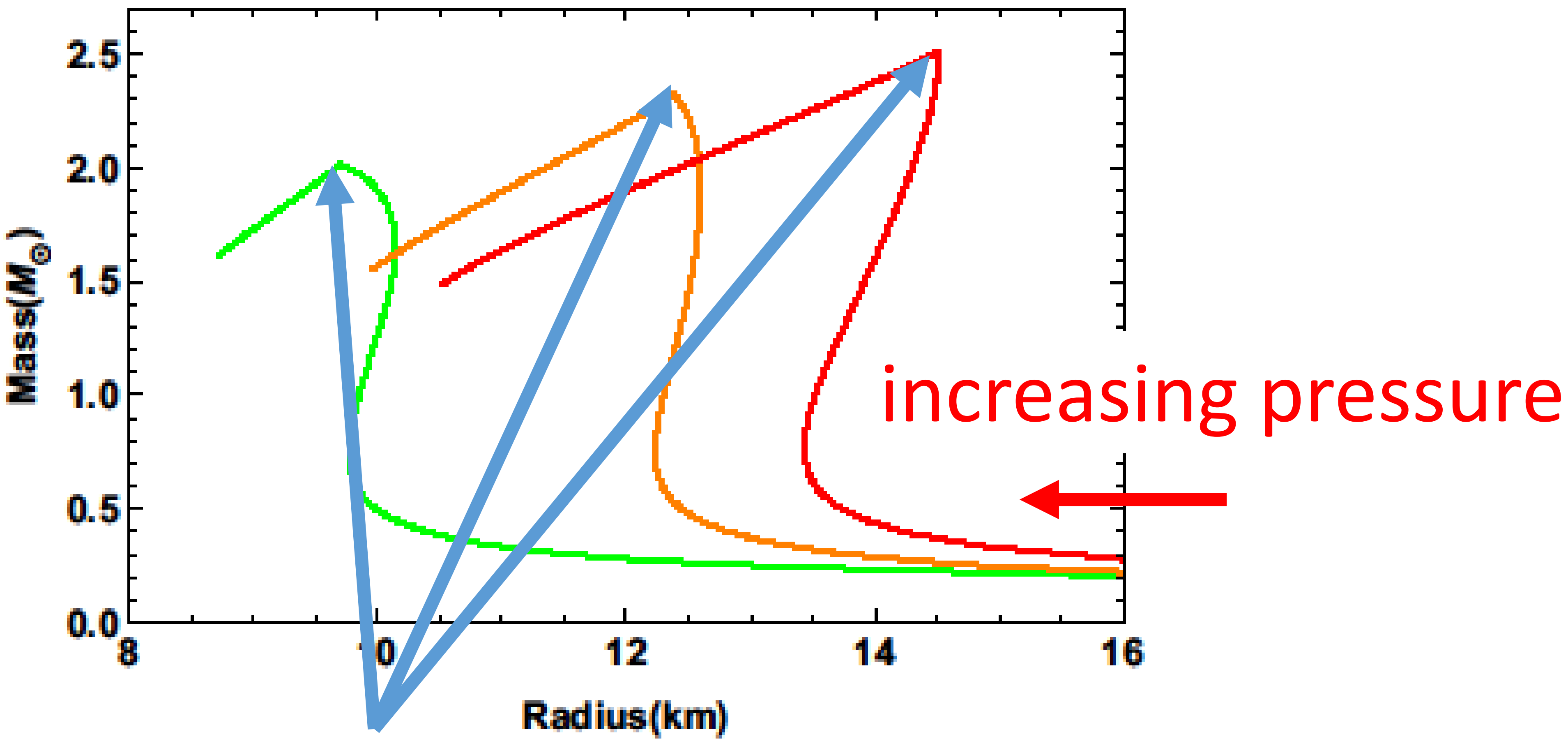
first order phase transition

Structure from TOV equations



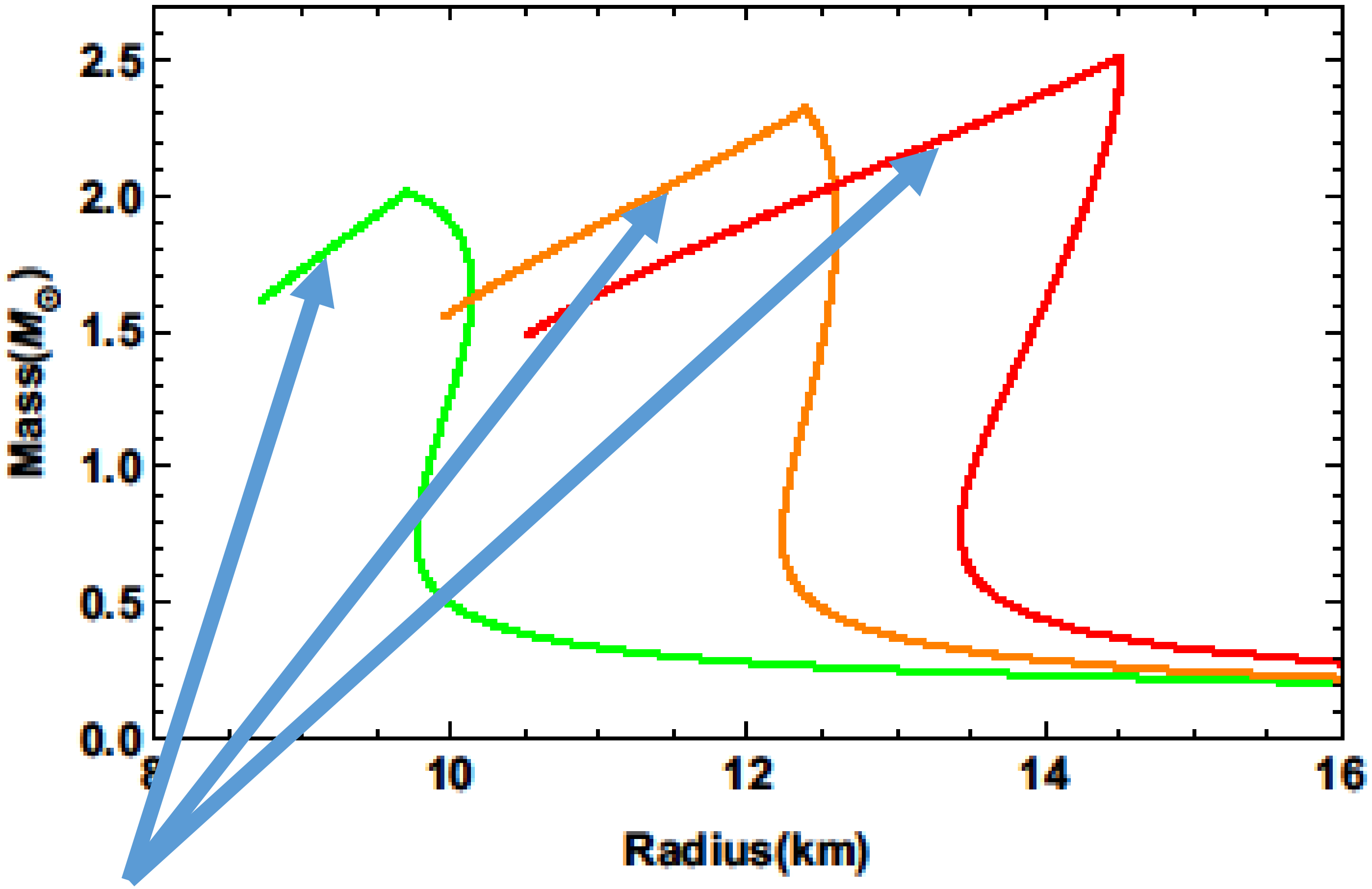
increasing pressure

Structure from TOV equations



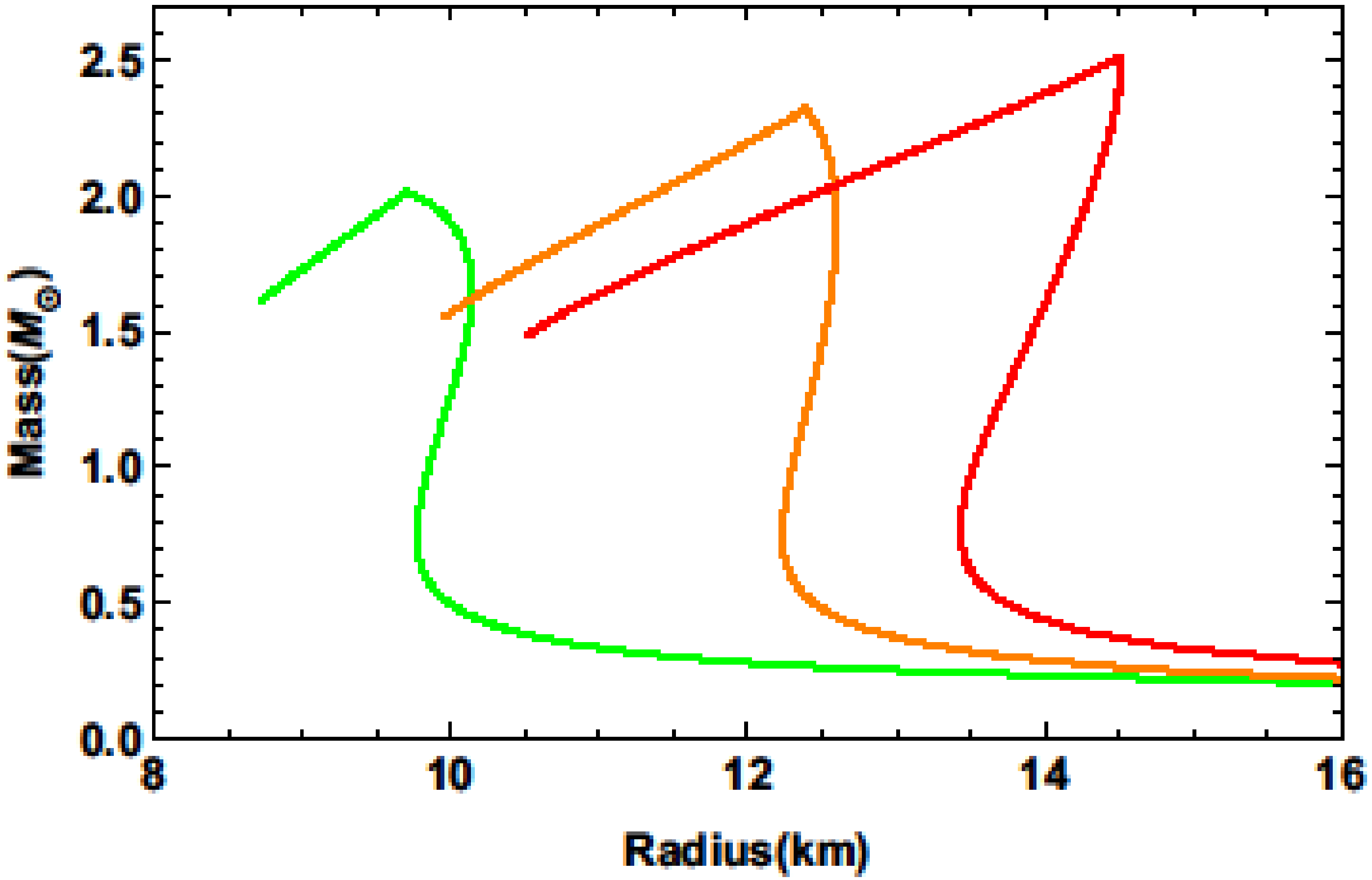
deconfined matter at the core starts

Structure from TOV equations



unstable branches

Structure from TOV equations

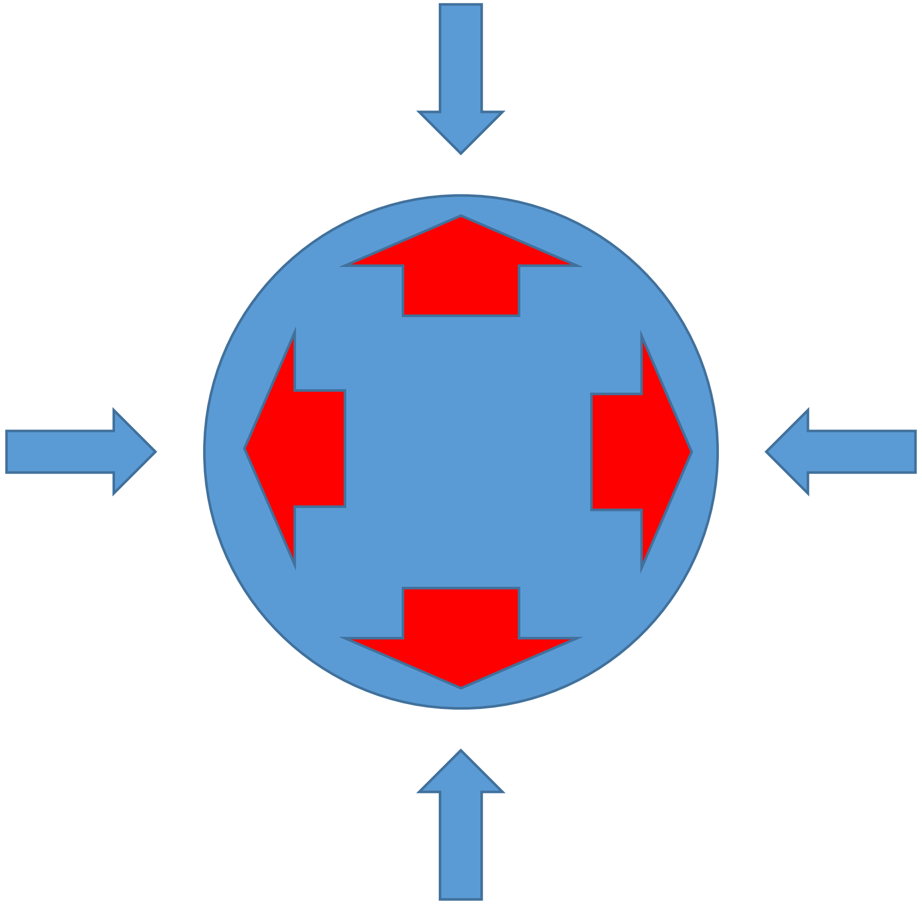


no deconfined matter in stable stars

The importance of being stiff

A non-Trivial Condition for Serious EoS

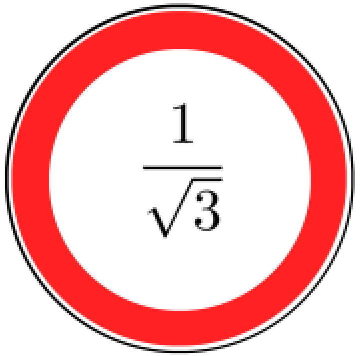
Neutron star mass larger for stiffer EoS



stiffness ~ speed of sound

$$v_s{}^2 = \frac{\partial\, P}{\partial \varepsilon}$$

Conjecture: speed of sound is bounded in holographic models



[Cherman, Cohen, Nellore '09; Hohler, Stephanov '09]

[Cherman, Nellore '09]

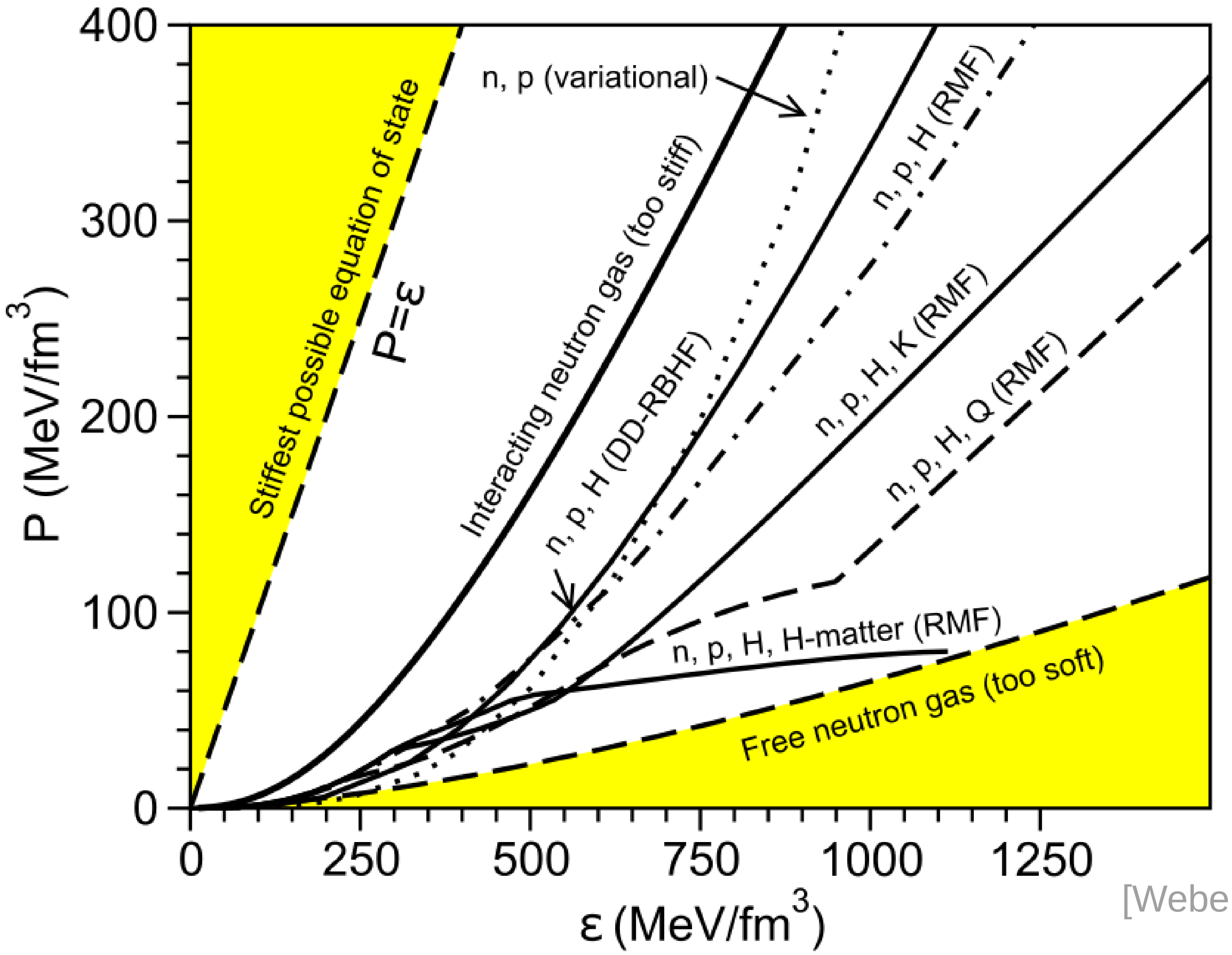
Assumptions: UV fixed point (asymptotically AdS)

Shown true for: scalars at finite temperature

Holds in SUGRA models: Klebanov-Strassler, N=2*

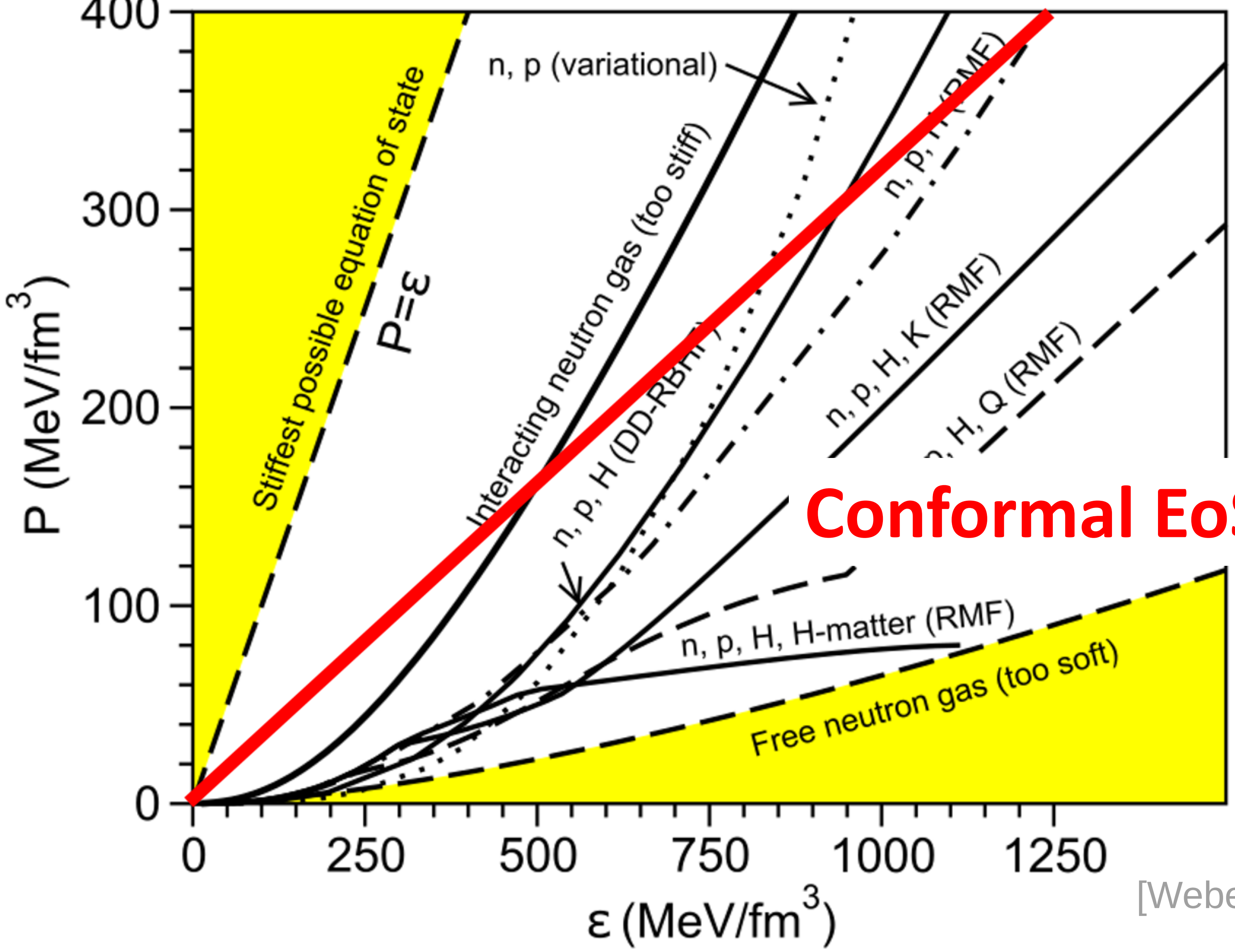
Holds in D-brane models even at finite density (D7 model)

EoS of nuclear matter models



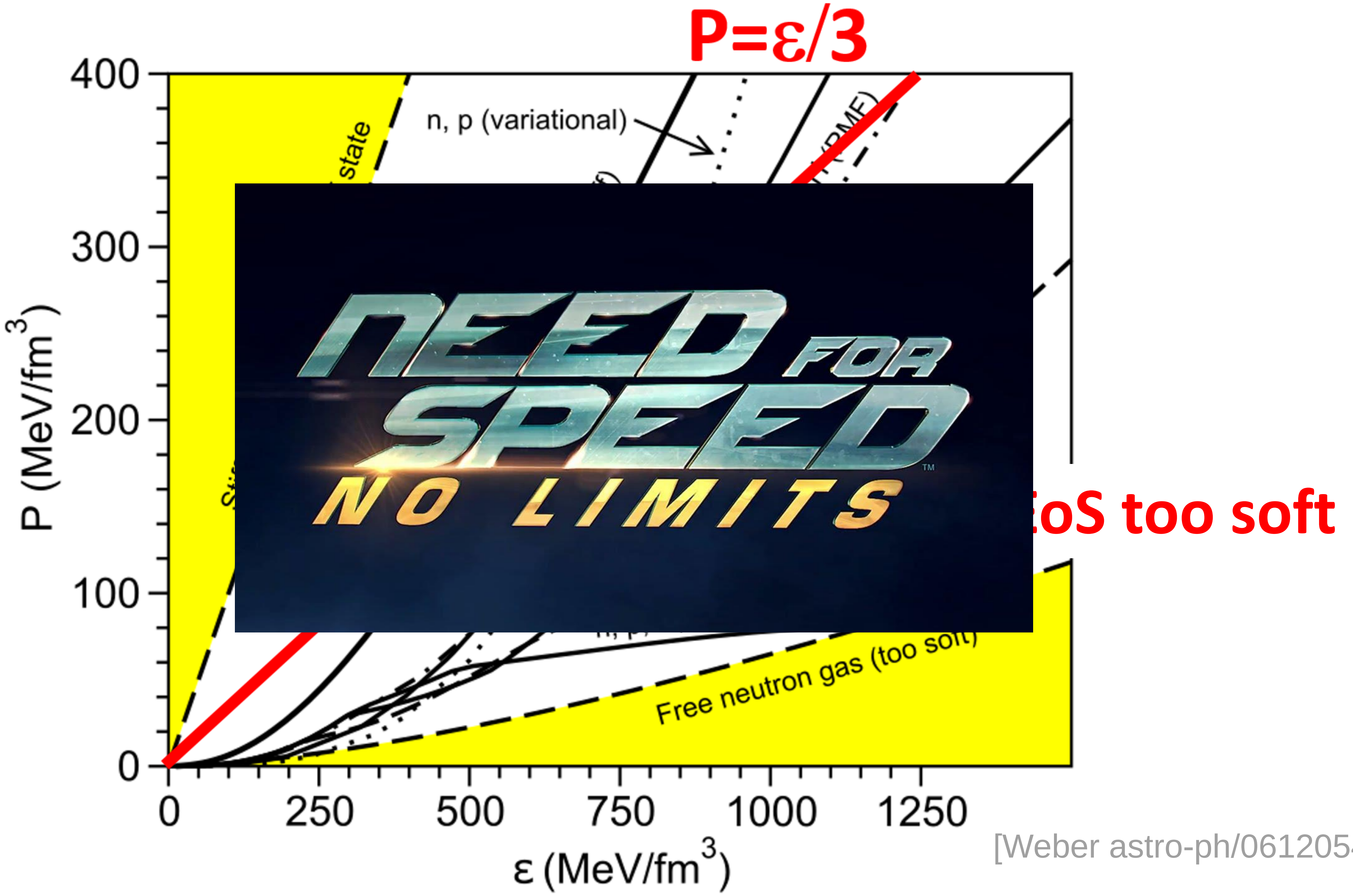
[Weber astro-ph/0612054]

$P=\varepsilon/3$



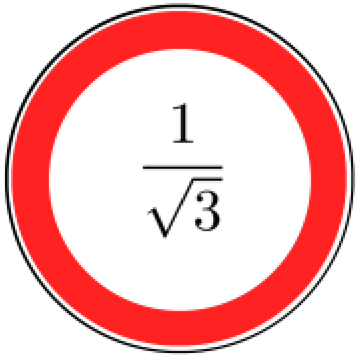
Conformal EoS too soft

[Weber astro-ph/0612054]



[Weber astro-ph/0612054]

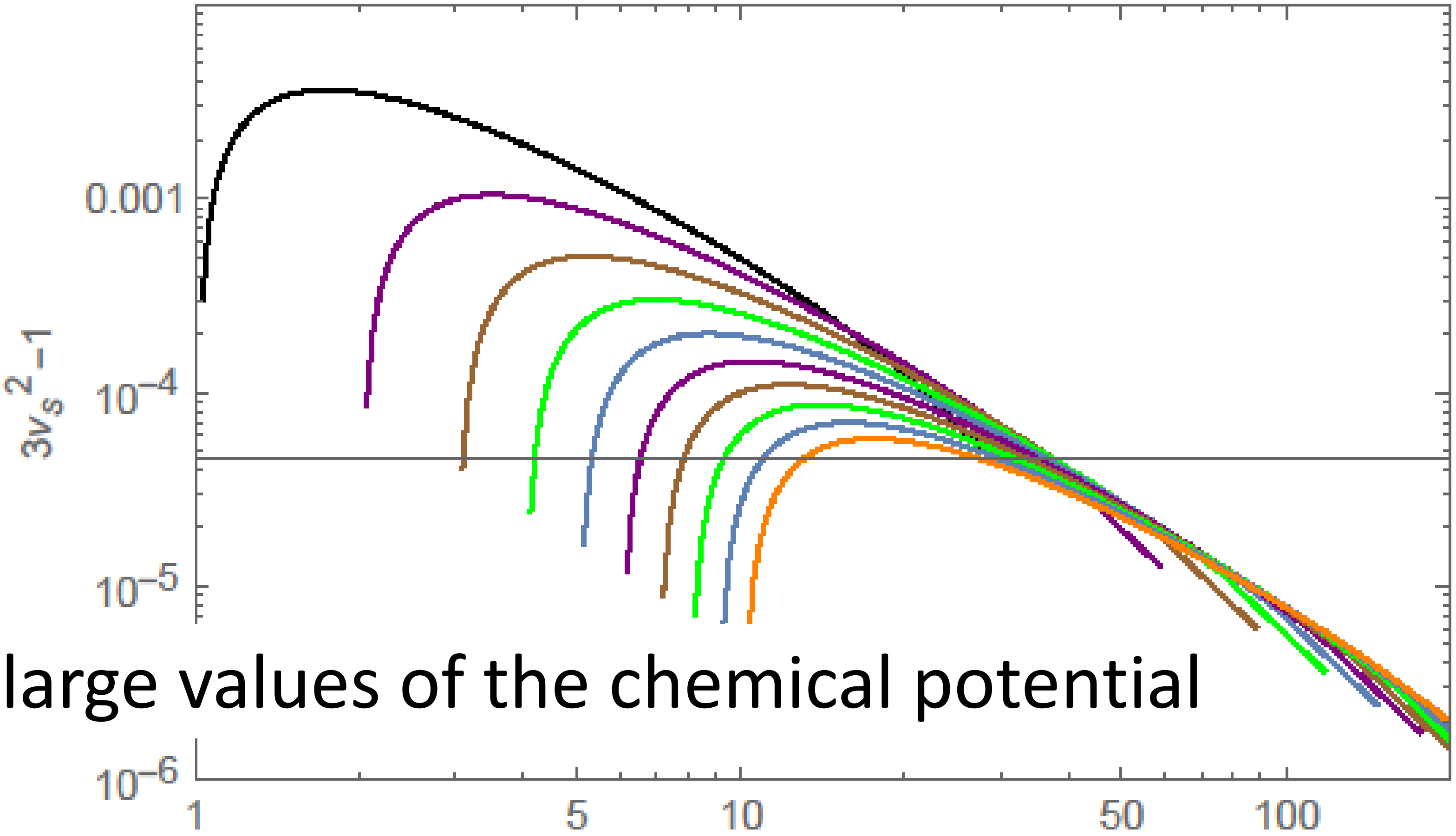
Conjecture: speed of sound is bounded in holographic models



Assumptions: UV fixed point (asymptotically AdS)

scalar at low temperature and finite density
small breaking of conformal invariance
SUGRA model: R-charged black hole

~~Conjecture: speed of sound is bounded in holographic models~~



also analytic results at large values of the chemical potential

Stability OK (no homogeneous condensates)

Outlook

Speed of sound with large breaking of conformal invariance

Mixed phases in neutron stars

Nuclear matter in holographic models (light baryons?)

Surface tension of bubbles in mixed phases

Transport properties, emissivities, etc

¡ Gracias !