ASTRONOMICAL IMPLICATIONS OF STABLE, QUANTUM BLACK HOLES

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Based on http://arxiv.org/abs/0806.3381 (Phys Rev D)
in collaboration with Steven B. Giddings, UCSB

Part of the LSAG study,
J.Ellis, G.Giudice, MLM, I.Tkachev, U.Wiedemann,
http://arxiv.org/abs/0806.3414 (J. of Physics G)

http://www.google.com/search?client=safari&rls=en&q=lhc+%22black+hole%22+risk&ie=UTF-8&oe=UTF-8 | lhc "black hole" risk

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Risk Evaluation Forum
In the worst case, a mini **black hole** could swallow Earth. ... Even a small **risk** has a large negative expected value (probability times cost) when the lose ...
www.**risk**-evaluation-forum.org/ - 4k - Cached - Similar pages

BBC NEWS | Science/Nature | Earth 'not at **risk**' from collider
23 Jun 2008 ... Most physicists believe the **risk** of a cataclysm lies in the realms of ... If a **black hole** is produced, it might look like this in **LHC** data ...
news.bbc.co.uk/2/hi/science/nature/7468966.stm - 49k - Cached - Similar pages

The Reference Frame: Nostradamus: the **LHC black hole** will eat us
Here is our proof that the accelerator will create a **black hole** that will .... Conclusion about MBHs : We estimate that for **LHC** the **risk** in the range of 7% ...
motls.blogspot.com/2008/05/ nostradamus-**lhc**-black-hole-will-eat-us.html - 168k - Cached - Similar pages

CERN **LHC BLACK HOLE** EATING US! PROF ROESSLER HAS SOLUTION: MOON **LHC**
7 May 2008 ... Large Hadron Collider buys **Black Hole** Insurance Policy .... What is the price to reduce **risk** here? Additionally, if the **LHC** has to be redone ...
www.notepad.ch/blogs/index.php/2008/ 05/07/cern-**lhc**-black-hole-eating-us-prof-roess-1 - 35k - Cached - Similar pages

Large Hadron Collider - **Risk** of a **Black Hole** - Dennis Overbye ...
15 Apr 2008 ... Whom can we trust to do hard-headed calculations to prove that a scientific experiment will not lead to the end of the world?

Richard A. Posner, Catastrophe: Risk and Response (Oxford and New York: Oxford University Press, 2004).

> “Congress should consider enacting a law that would require all scientific research projects in specified areas, such as **nanotechnology and experimental high-energy physics**, to be reviewed by a federal catastrophic-risks assessment board and forbidden if the board found that the project would create an undue risk to human survival”

Posner’s principal recommendation of how to deal with possible catastrophes is to **establish national or international science courts** composed of lawyers and other public-policy makers. Members of these courts would conduct thorough analyses of the risks involved and the costs of attempting to avert those risks, and would then recommend to government agencies suitable courses of action to take. **Rather than leaving these analyses to the scientific and technical community, Posner argues for the establishment of a scientifically literate legal profession, largely on the grounds of presumed greater impartiality.**

Science 25 February 2005: Vol. 307. no. 5713, p. 1205

RISK AND PUBLIC POLICY:
Courting Disaster
A review by Kenneth R. Foster*

“The [BNL] lab director took the **ethically dubious step** of appointing an evaluation panel of physicists, all of whom had professional interests in seeing the experiments go forward.”

LARGE HADRON COLLIDER - THE LEGAL DEFENSE FUND SITE

The Legal Intervention Donation Site

- Home Page
- WHAT SCIENTISTS SAY
- LHC FACTS
- LHC Legal Defense Fund
- LHC THEORETICAL PARTICLE

Home Page

This is the interim web-site for the Large Hadron Collider [LHC] legal defense fund. This fund has been established by Walter L. Wagner, a nuclear physicist, to initiate legal action to require that CERN and the Large Hadron Collider engage in a full safety analysis for all potential theoretical hazards inadequately addressed to-date. Such hazards include theoretical miniature black holes, theoretical strangelets, deSitter Space transitions, etc. The existing "cosmic ray argument" has been proven falacious for a variety of reasons [see risk-evaluation forum], and no existing proof of safety is currently available. The LHC propaganda machine that 'everything is safe' is well funded by your tax dollars, paying large salaries to thousands of people who have much to lose financially should the LHC be unable to prove its safety. As most of them perceive the risk to be small, they are willing to take that 'small risk' at our expense. The actual risk cannot presently be calculated.

http://www.lhcdefense.org/

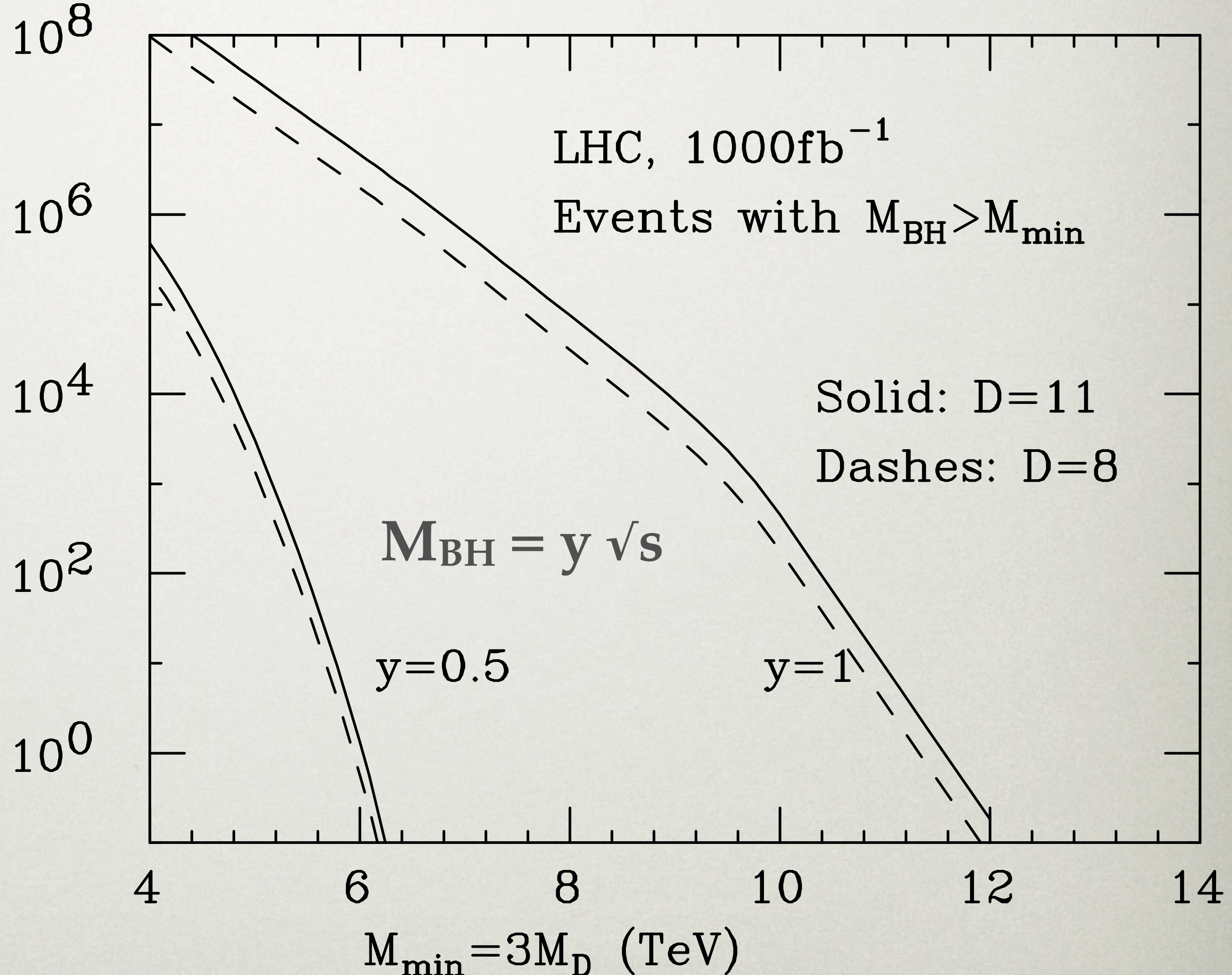
http://www.lhcconcerns.com/

Production of extra-dim BHs at LHC

For $r < R_D$ gravitational forces become as large as EM ones

High-energy, small impact parameter collisions lead to trapping: angular momentum barrier insufficient to keep two particles outside of the event horizon generated by the large concentration of energy

formation of a black hole



Basic relations for D-dim gravity

$$ds^2 = -\left[1 - \left(\frac{R(M)}{r}\right)^{D-3}\right] dt^2 + \frac{1}{1 - \left(\frac{R(M)}{r}\right)^{D-3}} dr^2 + r^2 d\Omega^2$$

	D-dim	4-dim
Event horizon	$R(M) = \frac{1}{M_D}\left(\frac{k_D M}{M_D}\right)^{1/(D-3)}$	$R(M) = \frac{M}{4\pi M_{Plank}^2} \equiv 2GM$
Gravitational potential	$\Phi(r) = \frac{1}{2}\left(\frac{R(M)}{r}\right)^{D-3}$	$\Phi(r) = \frac{GM}{r} = \frac{1}{8\pi M_{Plank^2}} \frac{M}{r}$

If $M_D \sim M_{EW} \sim 1$ TeV, then

$$R_D = 4.8 \times 10^{-2}\text{cm}\ , \quad \text{for } D = 6$$
$$R_D = 3.6 \times 10^{-7}\text{cm}\ , \quad \text{for } D = 7$$
$$R_D = 9.8 \times 10^{-10}\text{cm}\ , \quad \text{for } D = 8$$
$$R_D = 2.8 \times 10^{-11}\text{cm}\ , \quad \text{for } D = 9$$
$$R_D = 2.7 \times 10^{-12}\text{cm}\ , \quad \text{for } D = 10$$
$$R_D = 4.9 \times 10^{-13}\text{cm}\ , \quad \text{for } D = 11$$

D- and 4-dim behaviours match at $r \sim R_D$, with

$$R_D \sim \frac{1}{M_D}\left(\frac{M_{Planck}}{M_D}\right)^{2/(D-4)}$$

Fate of extra-dim BHs at LHC

– No conseved quantum number

– CPT: If **q q′** → **BH** then **BH** → **q q′**

➩**decay with τ~1/M~1/TeV**

Hawking thermal radiation ➩

- similar probabilities for all different fundamental particles in the final state
- spectacular signatures

On the other hand

- CPT: what do we know that it's valid in quantum gravity?
- Could Hawking radiation depend on details of Plank-scale degrees of freedom? (see e.g. Unruh and Schutzhold, arXiv:gr-qc/0408009)
- After all, the paradox of information-loss in BH evaporation is still not understood ....

Bottom line: it is interesting to address the possible visible/macroscopic consequences of BH's stability

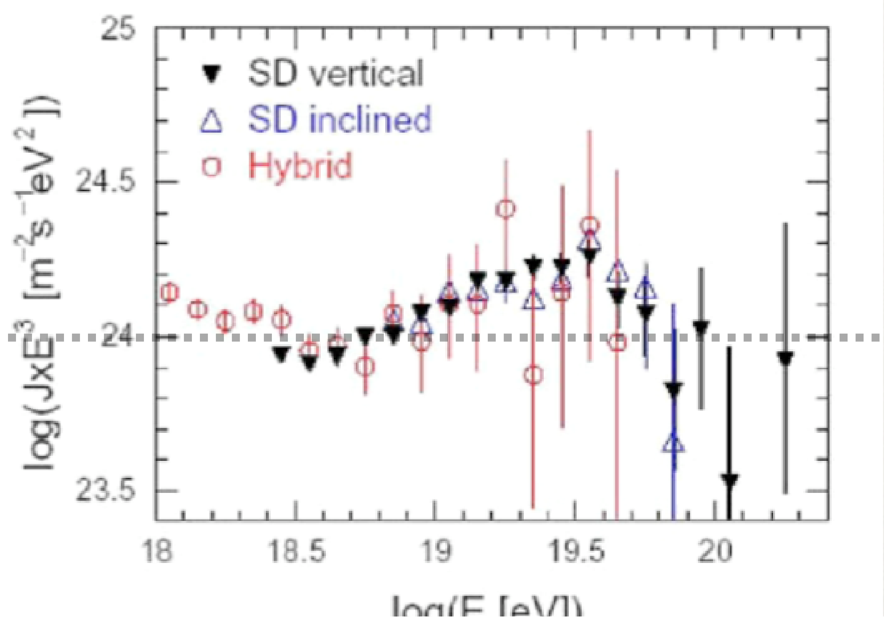
…. besides: we are being explicitly asked to do it by the public, by judges, and by MoPs ….

From the verdict of the US judge who dismissed the case in Hawaii:

"It is clear that Plaintiffs' action reflects **disagreement among scientists** about the possible ramifications of the operation of the Large Hadron Collider. This extremely complex debate **is of concern to more than just the physicists."**

CR Collisions on Earth's atmosphere

N.B.: $S=2Em_p \Rightarrow E=[14\ \text{TeV}]^2/2m_p \sim 10^{17}$ eV



Auger spectra

$$\frac{d\Phi}{dE} \gtrsim 10^6 (E/\text{GeV})^{-3}\ \text{m}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}\,\text{GeV}^{-1}$$

$$N(\sqrt{S} > E_{LHC}) = A \int_{E>E_{min}(A)} \frac{d\Phi}{dE}\, dE \sim \frac{1.6\times 10^3}{A}\ \text{yr}^{-1}\,\text{km}^{-2}\,\text{sr}^{-1}$$

A=CR atomic number (p=1, Fe=56)

$\Rightarrow 10^{22}$ / A collisions above $\sqrt{S}$=14 TeV since 5 Byrs

cfr LHC: 100mb x 10^{34} cm^{-2}s^{-1} x 10 yrs ~ 10^{17}

Problems with using "cosmic rays hitting the Earth" to rule out macroscopic effects of Black Holes

- CR-produced BHs have large velocity

$$\gamma \sim M/m_p \gtrsim 1000$$

- At production, neutral BHs have small interaction rates:

$$\sigma \sim R^2 \sim 1/\mathrm{TeV}^2$$

➡ Unless they are charged, they fly through the Earth (or the Sun) like a neutrino

➡ no limit can be set on effects of growth

- At the LHC, some of them will have v<10 km/s, will be gravitationally trapped, and could start growing

- BHs at production **are** charged: **q q′ → BH**
  - ➡ classical physics (Bethe-Bloch) establishes their stopping inside the Earth (or the Sun, etc)
  - ➡ issue solved!

- Devil's advocate:
  - ➡ the BH could discharge via a Schwinger mechanism (e^+e^- pair creation) in the intense gravitational field at the BH surface
  - ➡ as the BH accretes in Earth, each proton will be accompanied by an electron, keeping it neutral

Need to consider possibility that LHC-produced BHs are stable and neutral, and start accreting.

Is there a chance that this process can have macroscopic consequences for the Earth?

Modeling BH accretion

$$\frac{dM}{dt} = \pi r_c^2 F$$

r_c is the accretion radius, a priori only constrained by $r_c > R$ (event horizon)

If BH moving at velocity **v** larger than other velocity-scales (e.g. immediately after production) in a medium of density **ϱ** ➡ $F = \rho v$

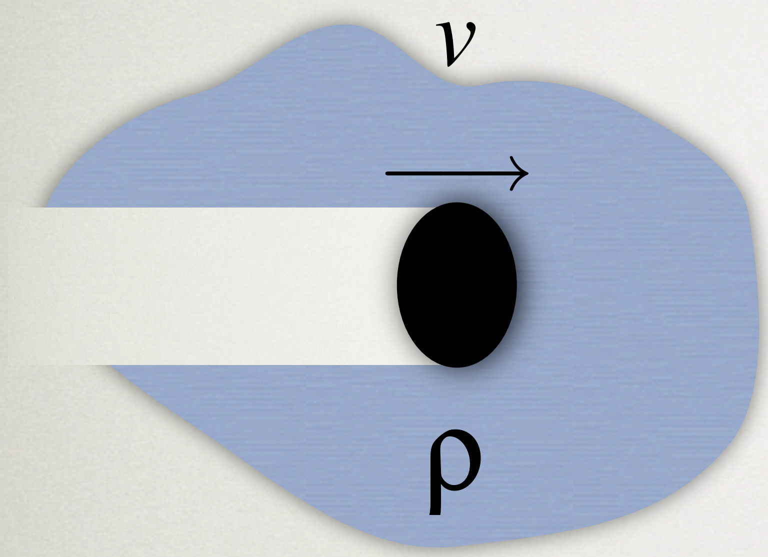
➡
$$\frac{dM}{dt} = \pi \rho v r_c^2(M)$$

Need to establish what $\mathbf{r_c(M)}$ and **v** are. Conservatively,

➡ select largest dM/dt for the Earth (fast growth)

➡ select smallest dM/dt for the NS (slow growth)

Example



$$r_c = R \qquad R = \frac{1}{M_D}\left(\frac{k_D M}{M_D}\right)^{\frac{1}{D-3}}$$

$$\frac{dM}{dt} = \pi R^2 v \rho$$

$$d = d_0 \frac{1}{k_D}\frac{D-3}{D-5}\left[(M_D R_f)^{D-5} - (M_D R_i)^{D-5}\right], \quad D>5$$

Time scale depends only on final radius $\mathbf{R_f}$:
- indep. of initial mass
- insensitive to pile-up of many BHs

$$d = d_0 \frac{2}{k_5}\log\frac{R_f}{R_i}, \quad D=5$$

Time scale ~ indep. of initial/final mass

$$d = d_0 \frac{1}{k_4}\frac{M_4^2}{M_D^2}\left(\frac{1}{M_D R_i} - \frac{1}{M_D R_f}\right), \quad D=4$$

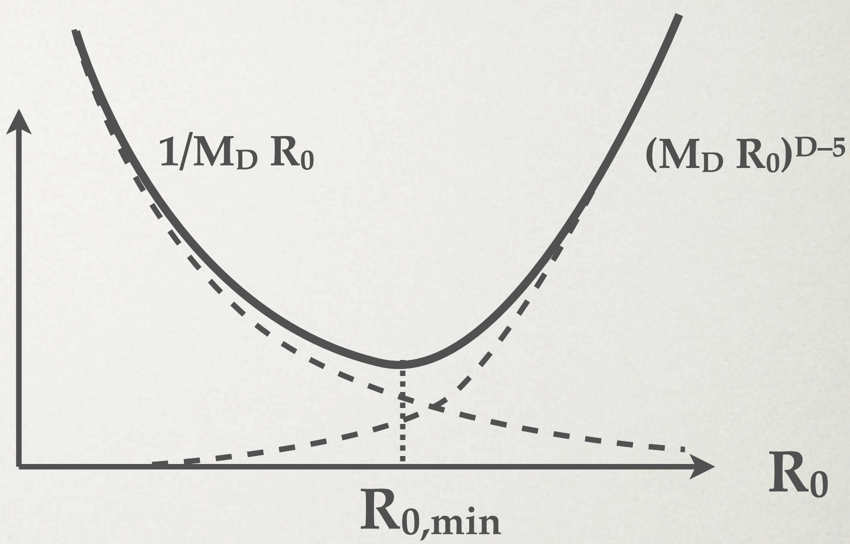
Time scale determined by starting point, $\mathbf{R_i}$

$$d = d[R : R_i \to R_f] \qquad d_0 = \frac{M_D^3}{\pi\rho} \sim 2\times 10^{11}\ \mathrm{cm} \Rightarrow \sim 10^{-2}\mathrm{yr} \quad @ \quad v = 10\,\mathrm{km\,s^{-1}}$$

Time scales for r_c=R (D≠5)

$$d_{tot} = d_D[R < R_0] + d_4[R > R_0]$$

$$\frac{d_{tot}}{d_0}(R_0) \sim \frac{M_4^2}{M_D^2}\frac{1}{M_D R_0} + (M_D R_0)^{D-5}$$



Minimizing w.r.t. R_0 :

$$\left(\frac{d_{tot}}{d_0}\right)_{min} \sim \left(\frac{M_4}{M_D}\right)^{2(D-5)/(D-4)} \sim 10^{15-30}$$

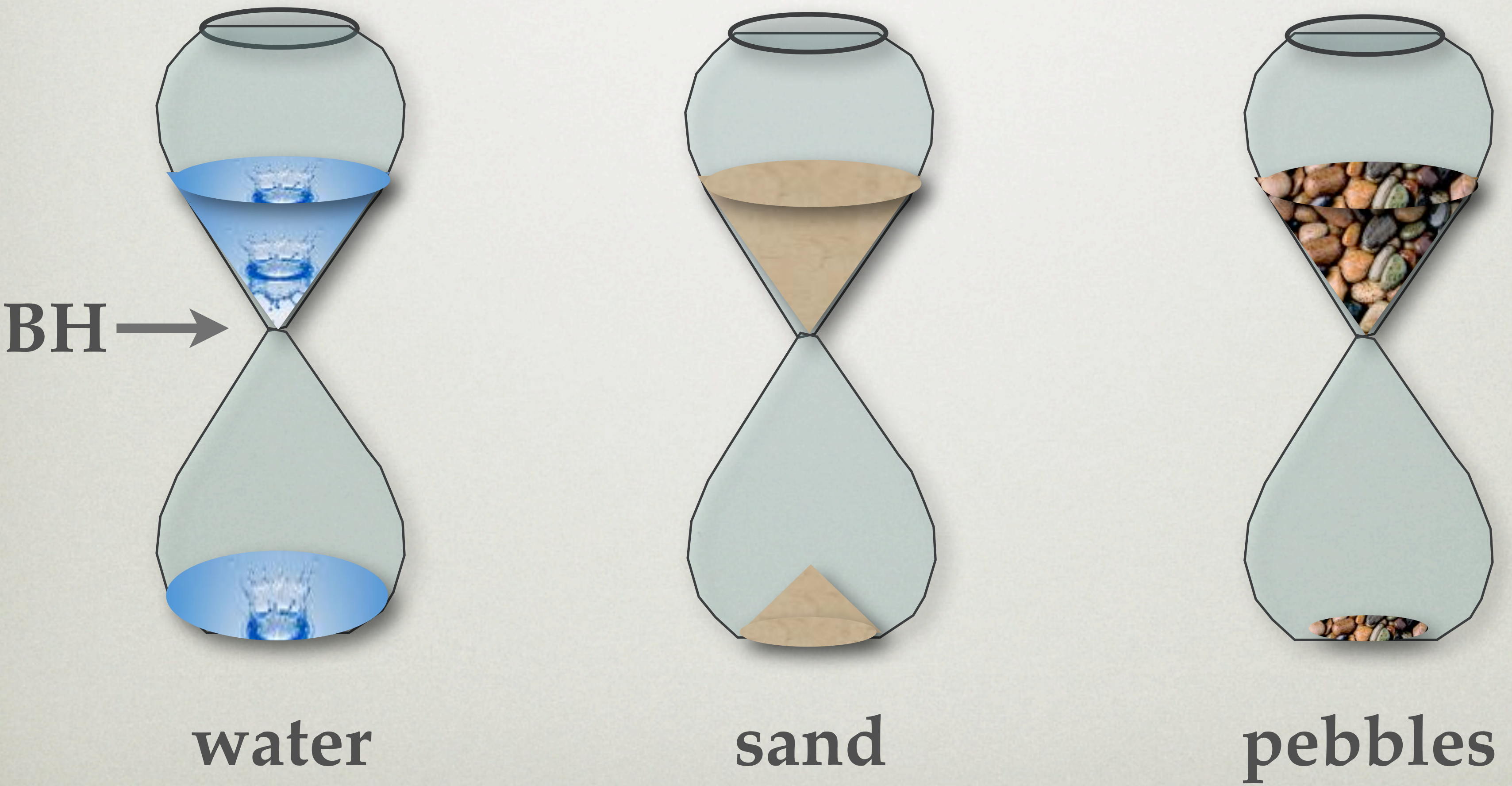
for $R_{0,min} \sim \frac{1}{M_D}\left(\frac{M_4^2}{M_D^2}\right)^{1/(D-4)} \sim R_D$

Timescale for macroscopic accretion on Earth ~ 10^{13-28} yrs

Accretion needs to be macroscopic (r_c>>R) to pose any danger

The relevant physics then takes place far away from the event horizon, so we only need to deal with well understood phenomena

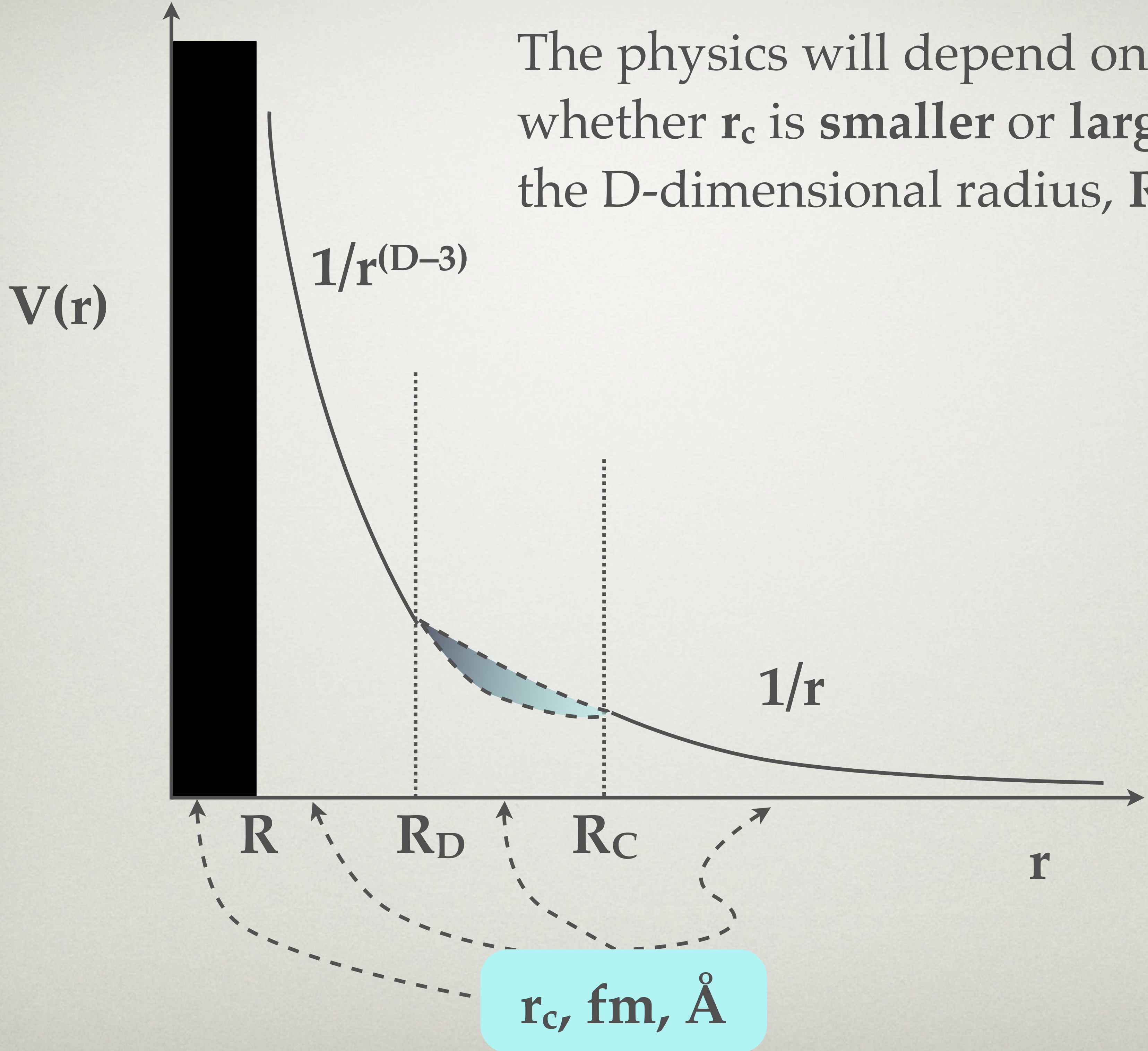
Once the "size" of the "hole" is specified, time evolution for accretion depends on the macroscopic properties of the accreted medium



Accretion regimes

1) r_c < fm	Nuclear regime
2) fm < r_c < Å	Sub-atomic regime
3) r_c > Å	Atomic regime

The physics will depend on whether $\mathbf{r_c}$ is **smaller** or **larger** than the D-dimensional radius, $\mathbf{R_D}$



Nuclear regime, R_c < fm

Fast evolution (Earth):

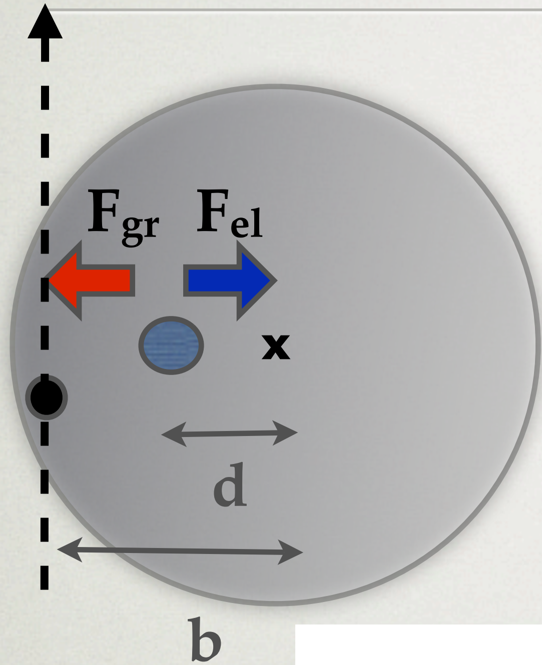
- **r_c (M) ~ 1fm** even if BH mass is such that its radius is << 1fm.
- Equivalent to assuming that the BH spends inside a nucleon enough time for quarks and gluons to be captured as they bounce back and forth the nucleon bag.

Slow evolution (WD/NS):

- **r_c (M) = R**

Subatomic regime, fm < R_c < Å

(Only relevant for Earth)



r_c = impact parameter such that gravitational force strong enough to pull nucleous out of the atomic center

$$F_G(d) = -\frac{\tilde{k}_D M m}{M_D^{D-2}(b-d)^{D-2}}$$

vs

$$F_E(d) = -Kd$$

$F_G(d) > F_{el}(d)$ for all d<b defines

$$\mathbf{r_c} = R_{\rm EM} = \frac{1}{M_D}\left(\frac{\beta_D M}{M_D}\right)^{1/(D-1)}$$

with

$$\beta_D = \frac{(D-1)^{D-1}}{(D-2)^{D-2}}\frac{\tilde{k}_D M_D^2 m}{K}$$

This continues while R_{EM}<Å; beyond that, macroscopic accretion

$$F_E(d) = -Kd$$

K defines the growth rate

$$K \sim \frac{\alpha}{a^3} \sim \frac{14\,\mathrm{eV}}{\mathrm{\AA}^2}$$

or

$$\frac{K}{m} = \frac{\omega_D^2}{\gamma} \quad \Rightarrow \quad K = \frac{12\,\mathrm{eV}}{\gamma\mathrm{\AA}^2}\left(\frac{m}{40\mathrm{GeV}}\right)\left(\frac{T_D}{400\mathrm{K}}\right)^2$$

$\gamma \sim O(1)$

T_D=Debye temperature

$$(T_D^{\mathrm{Fe}} = 460\mathrm{K},\ T_D^{\mathrm{Si}} = 625\mathrm{K},\ T_D^{\mathrm{Mg}} = 320\mathrm{K})$$

Integrating the accretion equation,

$$\frac{dM}{dt} = \pi\rho R_{EM}^2 v$$

leads to the distance required to accrete enough mass to reach a given value R_{EM} of the capture radius:

$$d = d_0 \left(\frac{M_D}{\mathrm{TeV}}\right)^3 \frac{D-1}{(D-3)\beta_D} (M_D R_{\mathrm{EM}})^{D-3}$$

with $d_0 = \dfrac{\mathrm{TeV}^3}{\pi\rho} \sim 2 \times 10^{11}$ cm

$$t = \frac{1}{V} \times \quad d = d_0 \left(\frac{M_D}{\mathrm{TeV}}\right)^3 \frac{D-1}{(D-3)\beta_D} (M_D R_{\mathrm{EM}})^{D-3}$$

t is minimized by using $V = v_{escape} \sim 10$ km/sec

If $R_D <$ Å, once R_{EM} gets larger than R_D we move from D-dim to 4-dim evolution

4-dim evolution is governed by D=4 gravity force, which is very weak, so accretion becomes extremely slow

$$R_D = 4.8 \times 10^{-2}\mathrm{cm} \,, \quad \text{for } D = 6$$
$$R_D = 3.6 \times 10^{-7}\mathrm{cm} \,, \quad \text{for } D = 7$$
$$R_D = 9.8 \times 10^{-10}\mathrm{cm} \,, \quad \text{for } D = 8$$
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$$R_D = 2.7 \times 10^{-12}\mathrm{cm} \,, \quad \text{for } D = 10$$
$$R_D = 4.9 \times 10^{-13}\mathrm{cm} \,, \quad \text{for } D = 11$$

For D>7 we get $T>10^{11}$ years to grow up to R_{EM}=Å

ATOMIC REGIME, R_c > Å

- Macroscopic growth: start swallowing entire atoms at once.
- Maximize growth rate by assuming a fluid

$$\frac{dM}{dt} = 4\pi\,\rho(r)\,r^2\,v(r) = \text{constant}$$

➡ Continuity equation

$$v\frac{dv}{dr} + \frac{1}{\rho}\frac{dP}{dr} = -\frac{GM}{r^2}$$

➡ Euler equation

$$P = k\,\rho^{\Gamma} \qquad c_s^2 = \frac{dP}{d\rho} = \frac{\Gamma P}{\rho}$$

➡ Equation of state

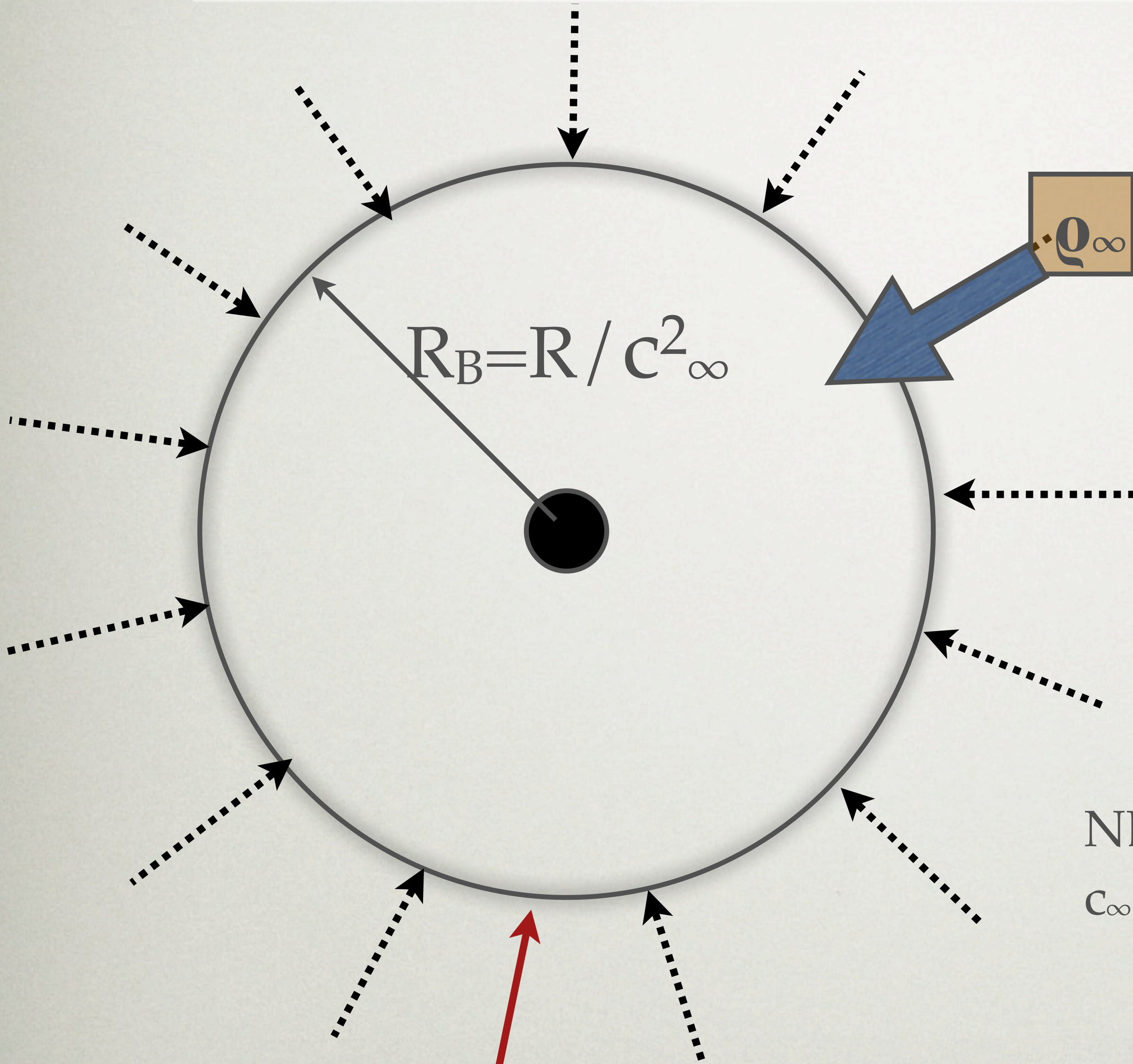
➡ **Bondi accretion evolution:**

$$\frac{dM}{dt} = 4\pi\rho_\infty c_\infty \lambda \left(\frac{GM}{c_\infty^2}\right)^2 = \pi\rho_\infty c_\infty \lambda \left(\frac{R}{c_\infty^2}\right)^2$$

Bondi, Hoyle, Lyttleton (1939-1952)

c_∞ and ρ_∞ = sound speed and density away from the BH

Picture of Bondi accretion



Falling in from radius $R_B = R/c^2_\infty$ with velocity $= c_\infty$

Gravitational free-fall for $r < R_B$

NB: for Earth

$c_\infty \sim$ Å $\omega_D \sim 6$ km/s $\sim V_{escape}$

$R_B \sim$ sonic radius, where $v_{free\ fall} \sim c_{sound}$

Issues requiring care

- Generalize Bondi accretion to D dimensions
- Establish continuity of evolution at $r_c \sim$ Å scale, and across the D→4 transition
- etc

Accretion inside Earth

$$t = \frac{4\, d_0\, c_s}{(D-5)\lambda_D\, k_D} \left(\frac{M_D}{\mathrm{TeV}}\right)^{D-2} (M_D R_B)^{D-5} \;, \quad D > 5$$

$$t = \frac{4\, d_0\, c_s}{\lambda_5\, k_5} \left(\frac{M_5}{\mathrm{TeV}}\right)^{3} \log \frac{R_B}{R_{B,i}} \;, \quad D = 5$$

$$t = \frac{4\, d_0\, c_s}{\lambda_4\, k_4} \left(\frac{M_4}{\mathrm{TeV}}\right)^{2} \frac{1}{\mathrm{TeV} \times R_{B,i}} \;, \quad D = 4$$

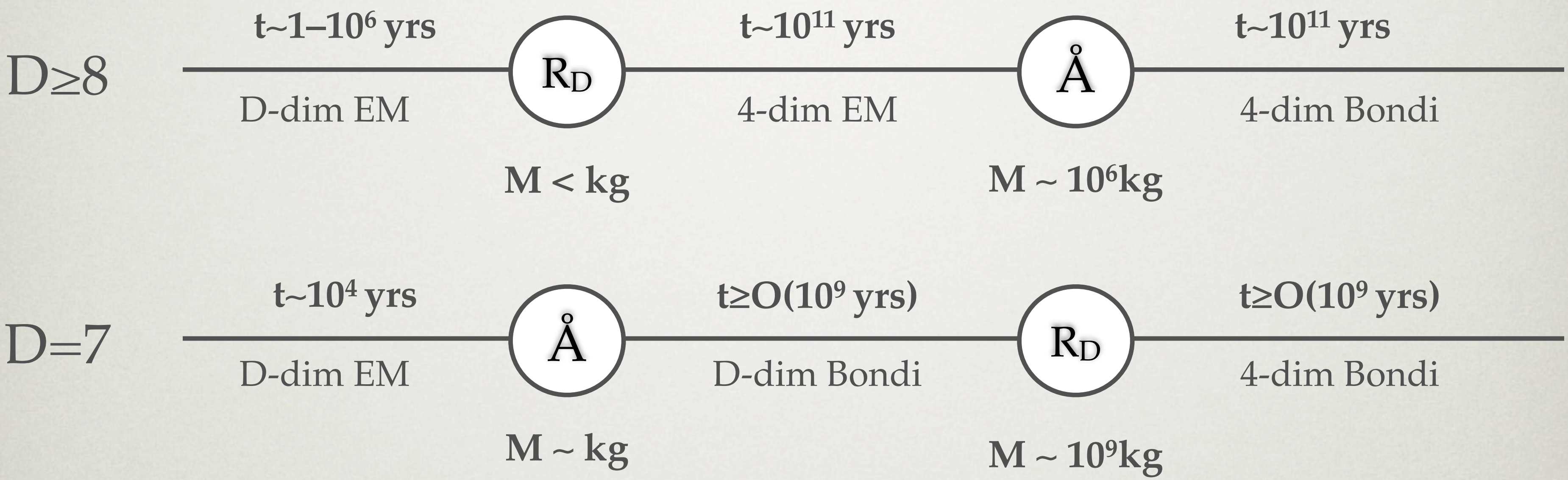
$$d_0\, c_s = \frac{\mathrm{TeV}^3}{\pi} \frac{c_s}{\rho} \sim 1.33 \times 10^{-4}\ \mathrm{s}$$

using Birch’s law, $\frac{c_s}{\rho} = \mathrm{const}$

experimentally tested for Fe up to p=400 GPa (pressure at Earth’s centre)

Notice that, for D=4, t>10^{10} yr if R_D<200 Å

Accretion inside Earth, bottom line



Accretion faster for D=5,6, O(yr)

Study dense stars, where such timescales should lead to very fast annihilation by CR-induced BHs

Example

For D=4,

$$t = \frac{4\, d_0\, c_s}{\lambda_4\, k_4} \left(\frac{M_4}{\mathrm{TeV}}\right)^2 \frac{1}{\mathrm{TeV} \times R_{B,i}}, \quad D = 4$$

$$(d_0\, c_s)_{WD} \sim 1.5 \times 10^{-4} (d_0\, c_s)_{Earth}$$

Complete study of accretion confirms that

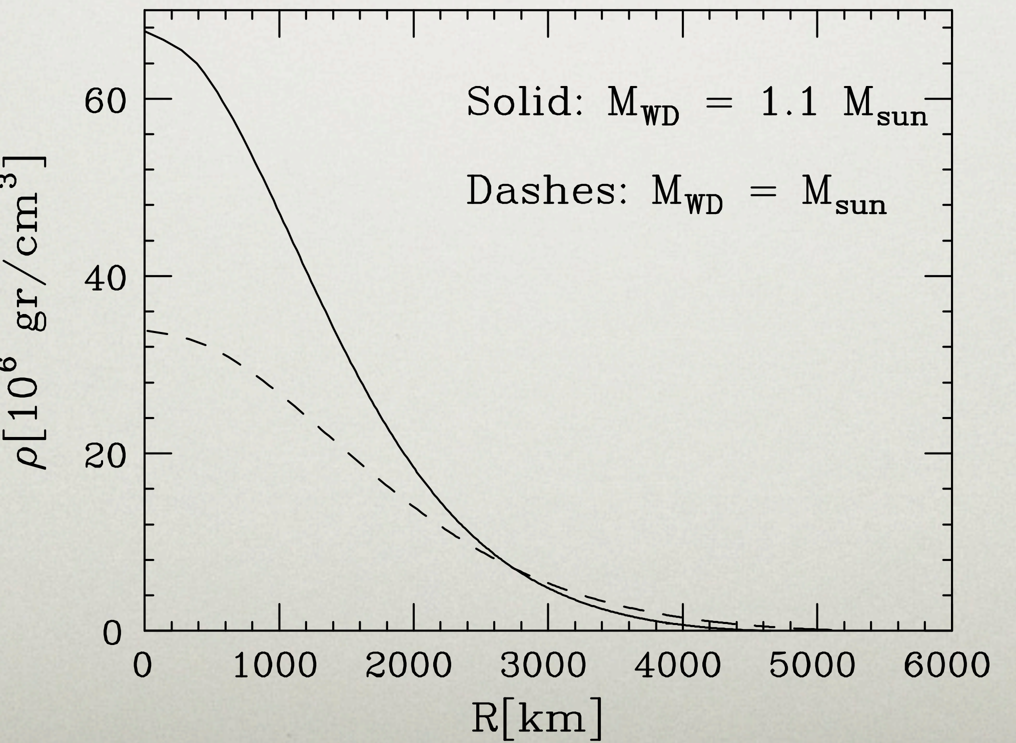
NS are accreted for **all D** within times between few yrs and Myr
WD are accreted for **D<8** within times no more than few 10 Myr

Issues to be assessed for NS & WD

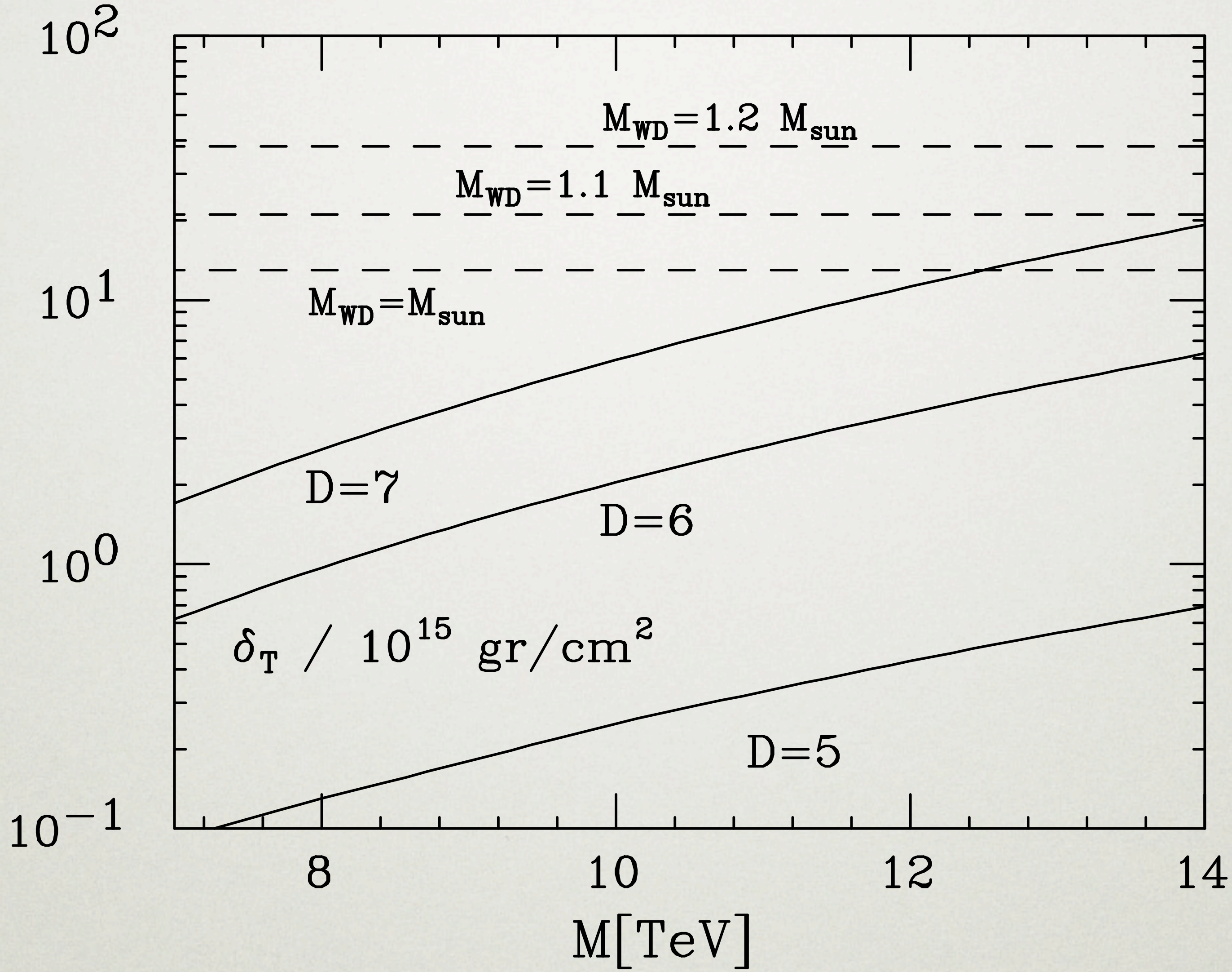
- Stopping power of WDs (trivial for NSs)
- Eddington-limited accretion
- Effective cosmic ray rates on WDs and NSs
- Cosmic ray composition

Stopping inside WDs

- Conservatively neglect elastic gravitational scattering (most effective slow-down mechanism)
- Slow-down by accretion only (mass grows, BH slows)
    - scrupulous study of gravitational capture in D-dimensions, both in classical and quantum regimes
- Realistic description of WD density profile (WD structure codes)



Stopping inside WDs



Column densities required for BH stoppping, vs BH mass, and column densities available in a WD

Stopping guaranted up to 14 TeV

Eddington limit

$$L = \eta \frac{dM}{dt}$$

η = fraction of absorbed mass radiated away during accretion

$$S = \frac{\eta}{4\pi r^2}\frac{dM}{dt}$$

flux of energy at distance **r** from BH

$$F_L = \frac{\eta}{4\pi r^2}\frac{dM}{dt}\sigma_T$$

radiative force acting on an e-p pair

$$F_L < \frac{GMm}{r^2} \quad \Rightarrow \quad \frac{dM}{dt} < \frac{4\pi m G}{\eta \sigma_T} M$$

Eddington-limited accretion

$$t_{Edd} = \eta \frac{\sigma_T}{4\pi m G} \sim 2.3\eta \times 10^8 \text{ yr}$$

Eddington e-fold time scale

If η = O(1), BH growth in WD or NS could be dramatically slowed down, spoiling our argument. Careful study of radiative transport inside WD and NS proves that this does not happen

Some of the radiative transport issues we studied and discussed in the paper

- Thermal brem, free-free scattering dominate, emissivity $\Lambda_{ff} \sim \varrho^2 T$
- Radiative transport properties depend on shape of grav potential, thus on D:
  - Luminosity $\int \Lambda_{ff} \, 4\pi \, r^2 \, dr$ dominated by medium properties at horizon in D=4, but at the sonic radius in D≥5
  - Medium more opaque at small r for D=4, at large r for D>5
  - in general, need to study different regimes depending on relative sizes of mean free paths, R_B, R_D, etc.
- Impact of magnetic fields, Pauli blocking in free-free scattering, etc.
- ….

Bottom line

- Medium too opaque to allow radiation out to sonic radius (a sort of event horizon for radiation) ⇨ **no Eddington limit for WD and NSs**

See also Begelman, 1978

- Also, BHs radiating at the Eddington limit would greatly affect WD coling rates

CR fluxes on WD/NS

- Large B-field outside white dwarfs and neutron stars
  - Larmor radius:

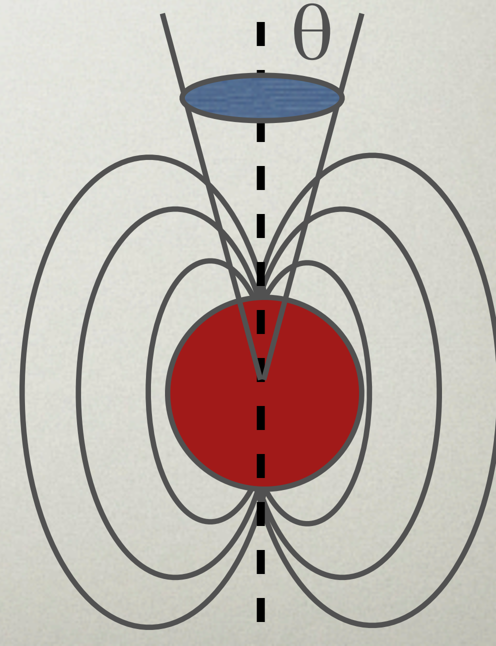
$$p \gtrsim 0.75 \times 10^{17}\ \mathrm{eV}\, \frac{R_0}{5000\ \mathrm{km}}\, \frac{ZB_p}{10^6\ \mathrm{G}} = 1.5 \times 10^{17}\ \mathrm{eV}\, \frac{R_0}{10\ \mathrm{km}}\, \frac{ZB_p}{10^9\ \mathrm{G}}.$$

OK for several WD and some NS

  - Synchrotron energy loss softens CR spectrum, reducing the incoming energy to no more than

$$E_{\mathrm{max}} \approx 1.8 \times 10^{17}\ \mathrm{eV}\, \frac{A^4}{Z^4}\, \frac{10\ \mathrm{km}}{R_0} \left(\frac{10^8 G}{B_p \sin\theta}\right)^2.$$

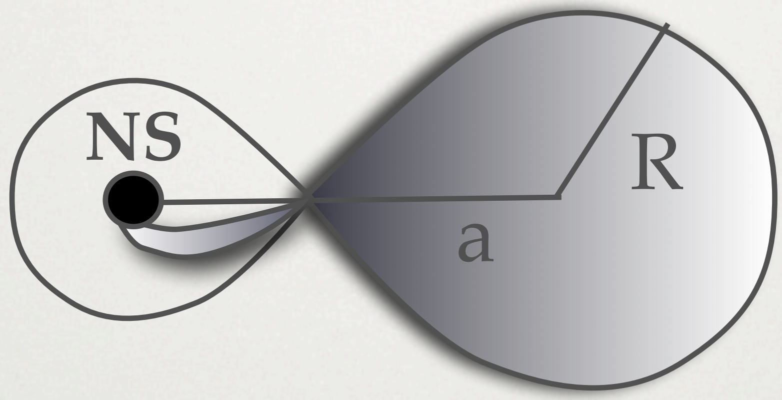
Bad for NS



reduced acceptance for CRs

Alternative for NSs

- Use NS companion as "beam dump" for the CR (the BH will then penetrate B and hit the NS)



Companion star filling its Roche lobe

Shadow acceptance:

$$f = \frac{1 - \cos\theta}{2}$$

with: $$\tan\theta = \frac{R}{a} = 0.49\,[0.6 + q^{-2/3}\,\ln(1 + q^{1/3})]^{-1}$$

$$q = \frac{M_{comp}}{M_{NS}}$$

Eggleton, 1983

For M_{comp}=0.01 – 10 M_{sun} ➡ f = 0.002 – 0.06

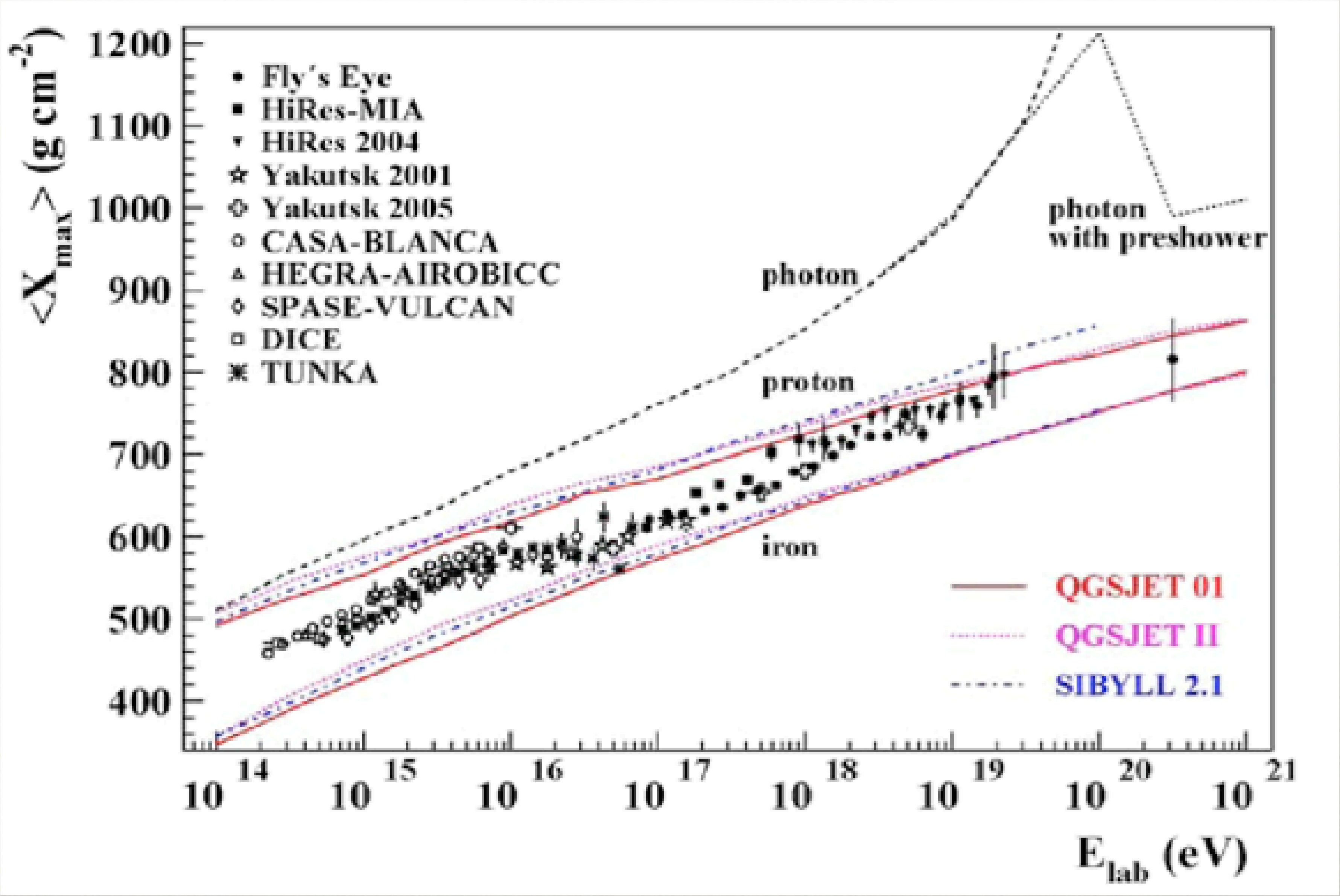
Need to estimate the effective exposure (in years/ 4π equivalent) for existing, known systems:

$$T_{eff} = \int dt\, f(t)$$

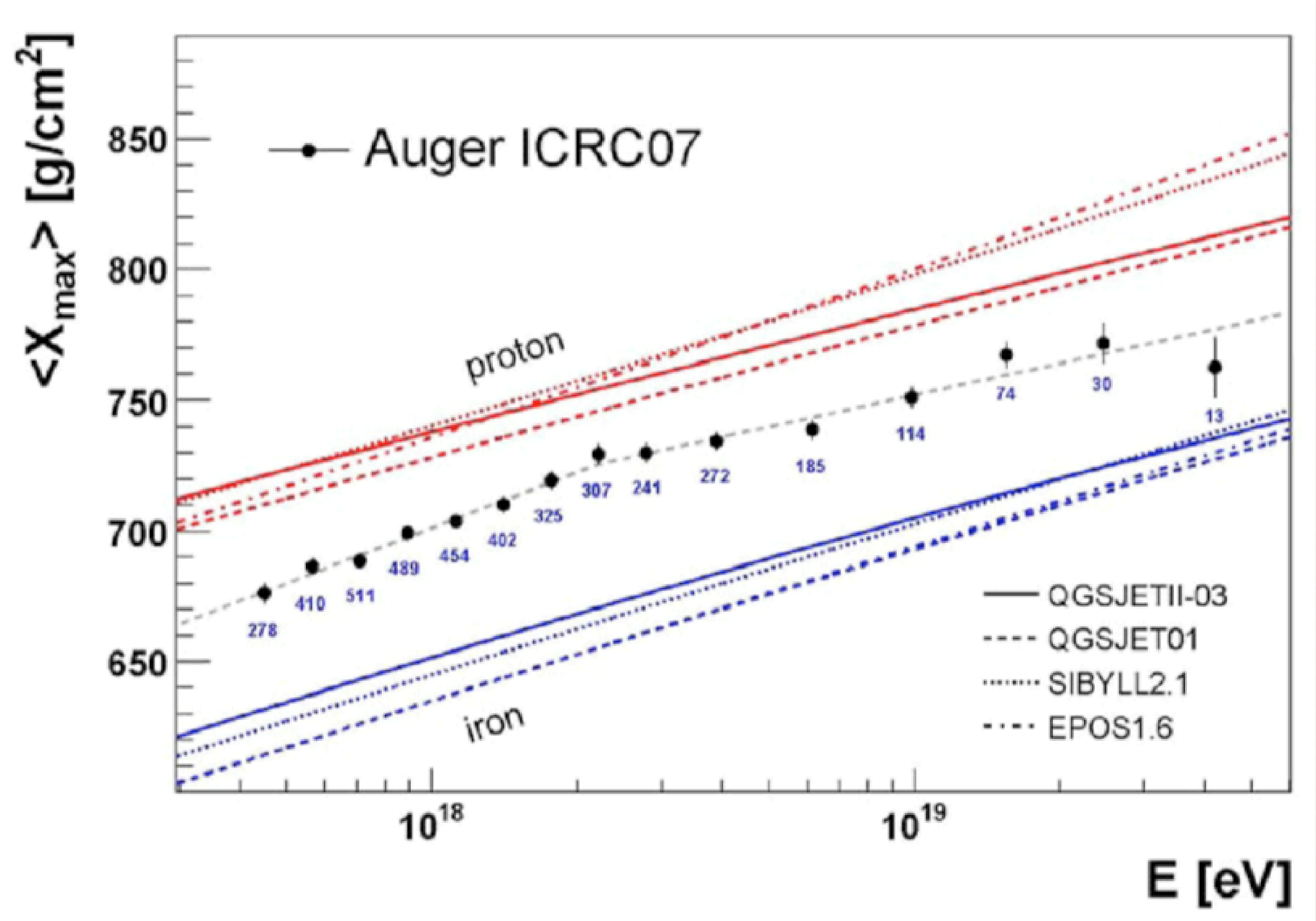
Lifetimes of the order of several 100M years, with f of the order of %, lead* to values of T_{eff} in excess of 2 Myrs for many X-ray binary systems

** Simulations by Lars Bildsten, UCSB, private comm.*

CR composition, pre-Auger



CR composition, Auger



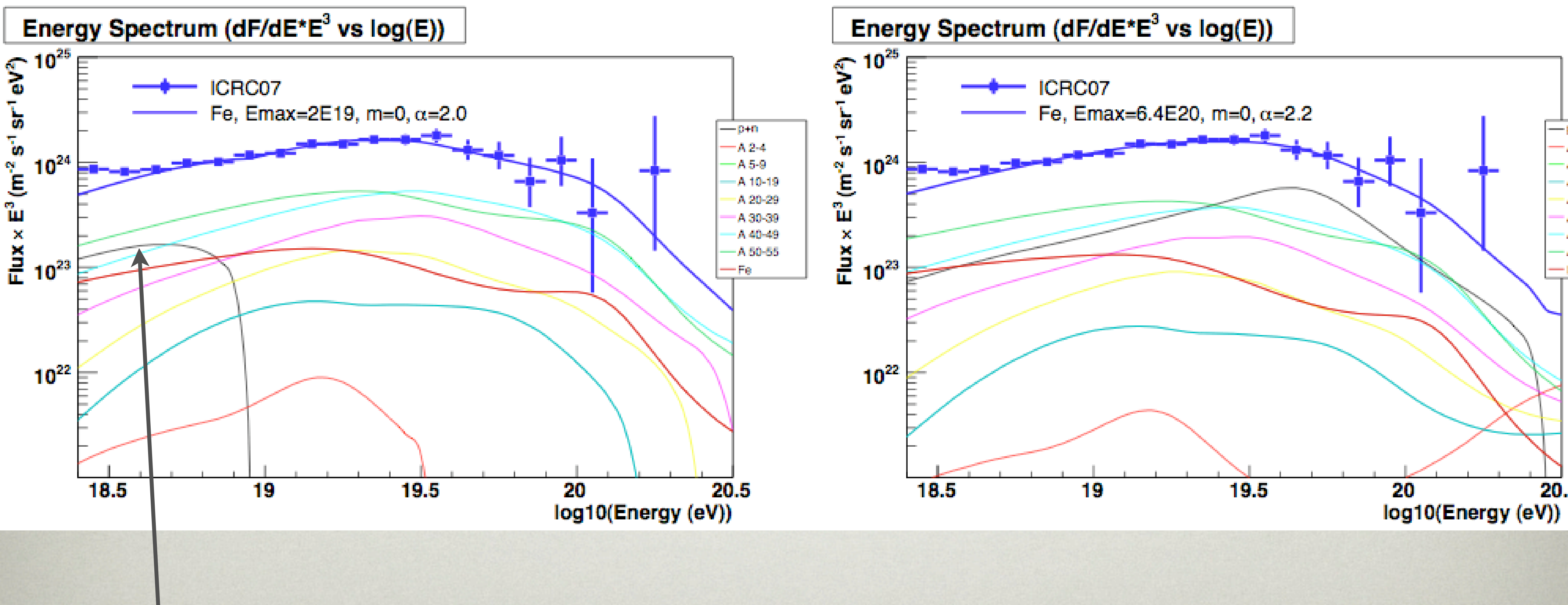
Extreme composition scenarios

Katsushi Arisaka[a], Graciela B. Gelmini[a,b], Matthew Healy[a],
Oleg Kalashev[c] and Joong Lee[a]
arXiv:0709.3390v2

Assume 100% Fe at the source, $F(E) \sim E^{-n}\,\Theta(ZE_{max}-E)$

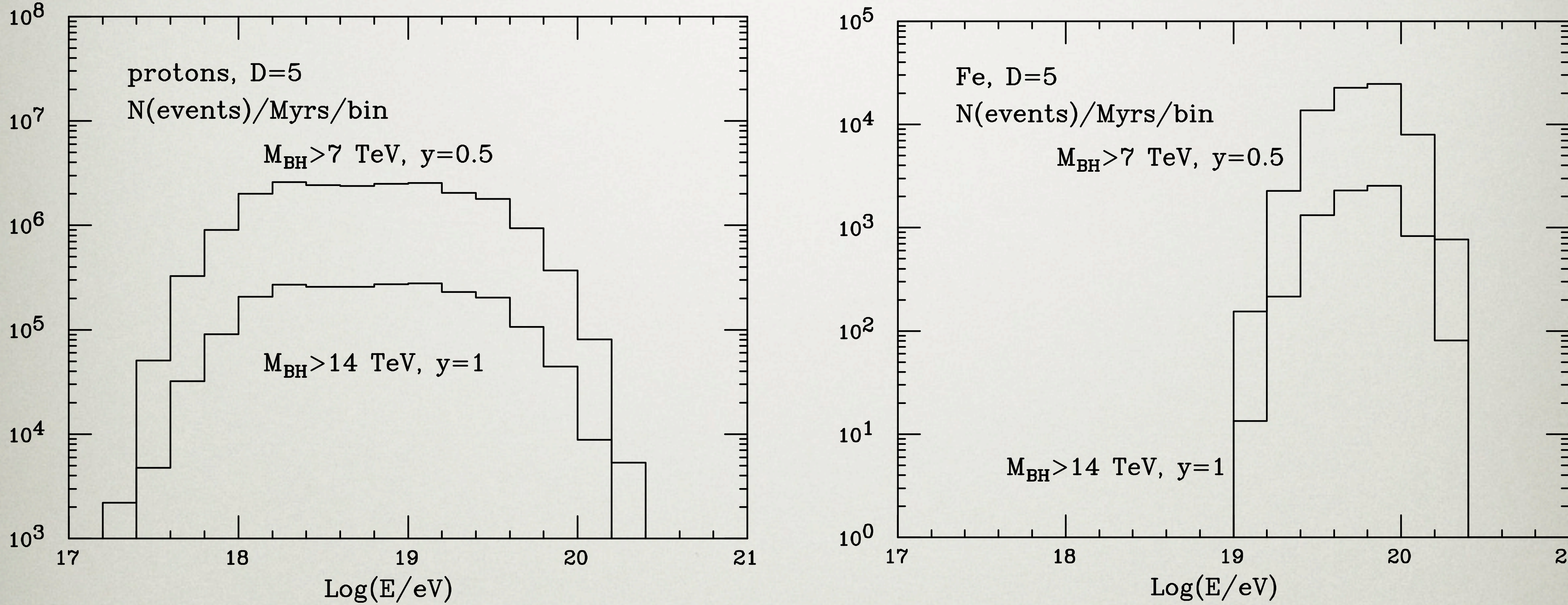
Left: $E_{max} = 2 \times 10^{19}$ eV, n=2

Right: $E_{max} = 6.4 \times 10^{20}$ eV, n=2.2



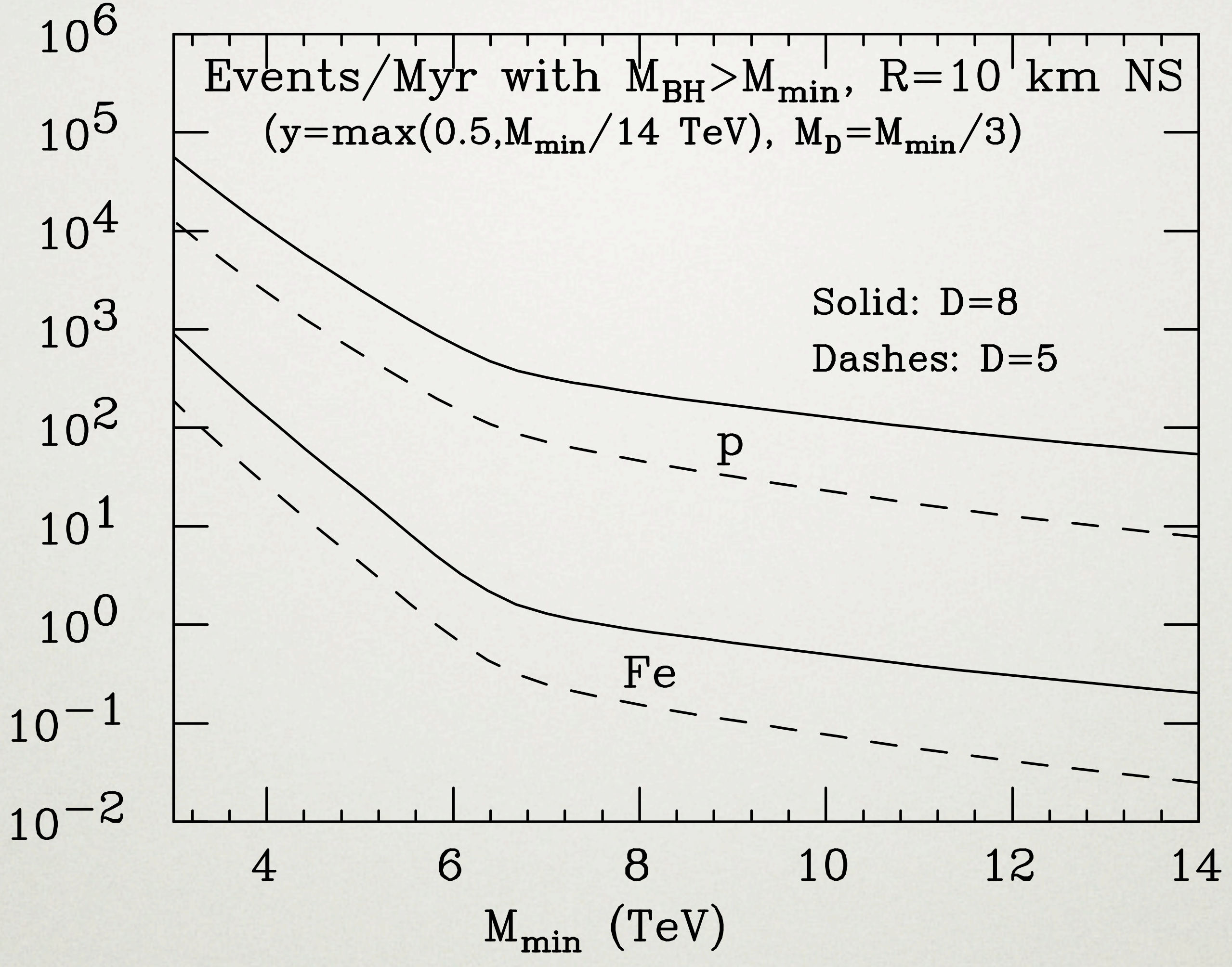
Even in this worse case, $\#p \geq 10\%$ in the relevant energy range

Impact of CR composition on the BH-production rate on a WD



Rates are large enough even under the most conservative assumptions on CR flux

BH rates on neutron stars



Rates are large enough assuming at least 10% protons, and for D>5

Rate summaries

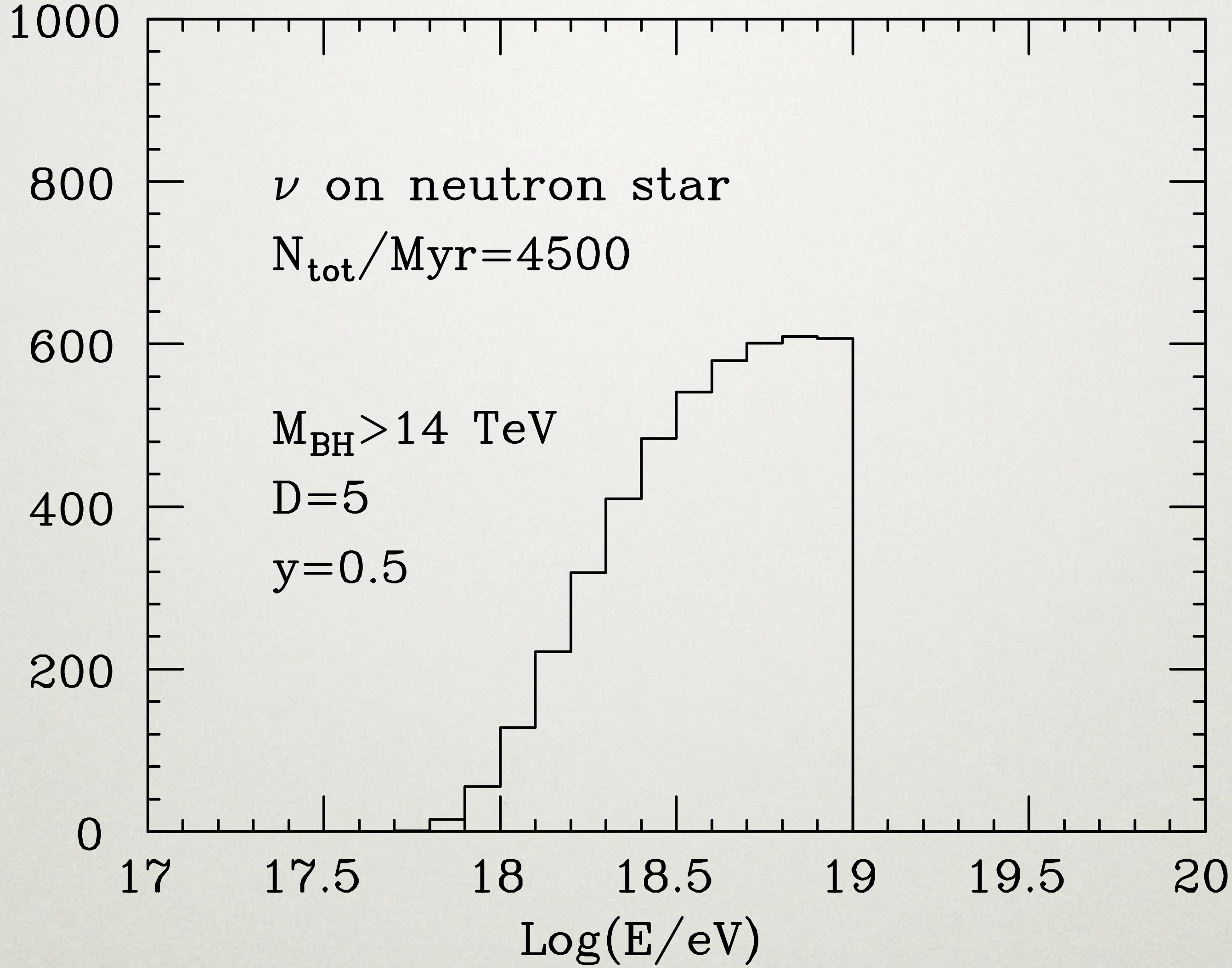
TABLE VII. Black hole production rates, per million years, induced by cosmic rays impinging on a $R = 5400$ km white dwarf. N_p refers to the case of 100% proton composition, N_{Fe} refers to 100% Fe. $M_D = M_{min}/3$ and inelasticity $y = 0.5$.

$D =$	5	6	7
N_p/Myr, $M_{min} = 7$ TeV	2.1×10^7	4.3×10^7	6.7×10^7
N_{Fe}/Myr, $M_{min} = 7$ TeV	7.2×10^4	1.6×10^5	2.6×10^5
N_p/Myr, $M_{min} = 14$ TeV	2.8×10^5	5.7×10^5	9.1×10^5
N_{Fe}/Myr, $M_{min} = 14$ TeV	35	80	135

TABLE IX. Black hole production rates, per million years, induced by proton cosmic rays impinging on a $R = 10$ km neutron star. $M_D = M_{min}/3$ and $y = \max(0.5, M_{min}/14\text{ TeV})$.

M_{min}	$D = 5$	$D = 6$	$D = 7$	$D = 8$	$D = 9$	$D = 10$	$D = 11$
3 TeV	1.3×10^4	2.5×10^4	4.0×10^4	5.6×10^4	7.4×10^4	9.2×10^4	1.1×10^5
4 TeV	2.2×10^3	4.5×10^3	7.0×10^3	9.9×10^3	1.3×10^4	1.6×10^4	1.9×10^4
5 TeV	570	1100	1800	2500	3300	4100	5000
6 TeV	190	380	590	830	1100	140	1600
7 TeV	72	146	231	323	422	526	633
8 TeV	47	99	161	229	301	378	457
10 TeV	23	52	88	129	172	218	265
12 TeV	13	31	54	80	109	139	171
14 TeV	8	20	36	54	74	95	118

CR Neutrinos' production of BH on NS



Chosen here the lowest predicted neutrino flux, assuming Fe-only flux.
10^{-3} smaller than Bachall-Waxman bound

Additional possibilities, to be studied in more detail

- BH production by CR on the interstellar medium
    - by-passes the B-field constraint of NSs
- BH production by CR on DM WIMPS
    - much higher mass reach ($m_{DM} >> m_{proton}$)
    - much smaller γ factor of the resulting BH (easier to trap it in WDs at much higher masses)

Conclusions

Conservative arguments, based on detailed calculations and the best-available scientific knowledge, including solid astronomical data, conclude, from multiple perspectives, that there is no risk of any significance whatsoever from such black holes

In order for this study to be of any relevance, several independently-unlikely things must happen

- Large extra-dimensions
- BHs within the reach of the LHC
- Hawking radiation not at work, and BH absolutely stable for all masses
- Black hole cannot maintain an electric charge (Schwinger discharge)

It is good to know that even if all of this goes wrong, we can assess the absence of macroscopic consequences of BH’s stability.

Some lessons

- Data speak: there is no telling a priori what data can be used for.
  - Auger data are crucial to understand the origin of cosmic rays, but input on rates and composition turned out to be crucial for our exercise
  - Measurements of kG magnetic fields in WDs
  - Understanding of the evolution of compact binary systems with NSs
  - Properties of Fe at ultrahigh pressures
  - …

Food for thought

- Black holes at the LHC:
  - from battle-horse for public relations, press, ...
  - ... to Trojan horse

All fed by another "CERN" product, the WEB

Comments

- Need to convey the message that research at the HEP frontier is unlike genetics etc.: the control over the fundamentally elementary is greater than the one over the intrinsically complex and non-linear nature of biological phenomena
  - is it really true?
  - anyway a message that other fellow scientists will not endorse ....
- Perhaps not an issue for astrophysics/cosmology, where exploration is limited to observation, not to the (re-)creation of the experimental conditions

Things that trigger public concerns
(I know it, since I get mail about it!)

Worrying titles

1) **Dangerous implications of a minimum length in quantum gravity.**
Cosimo Bambi (Wayne State U. & Michigan U., MCTP) , Katherine Freese (Michigan U., M
e-Print: **arXiv:0803.0749** [hep-th]

3) **Dangerous Angular KK/Glueball Relics in String Theory Cosmology.**
J.F. Dufaux (Madrid, IFT & Canadian Inst. Theor. Astrophys.) , L. Kofman (Canadian Inst.
07-66, UMN-TH-2637-08, Feb 2008. 58pp.
e-Print: **arXiv:0802.2958** [hep-th]

Misleading associations

The RHIC fireball as a dual black hole.
Horatiu Nastase (Brown U.) . BROWN-HET-1439, Jan 2005. 10pp.
e-Print: **hep-th/0501068**

from the Abstract:

deconfining quarks and gluons. Thus RHIC is in a certain sense a string theory testing machine, analyzing the formation and decay of dual black holes, and giving information about the black hole interior.