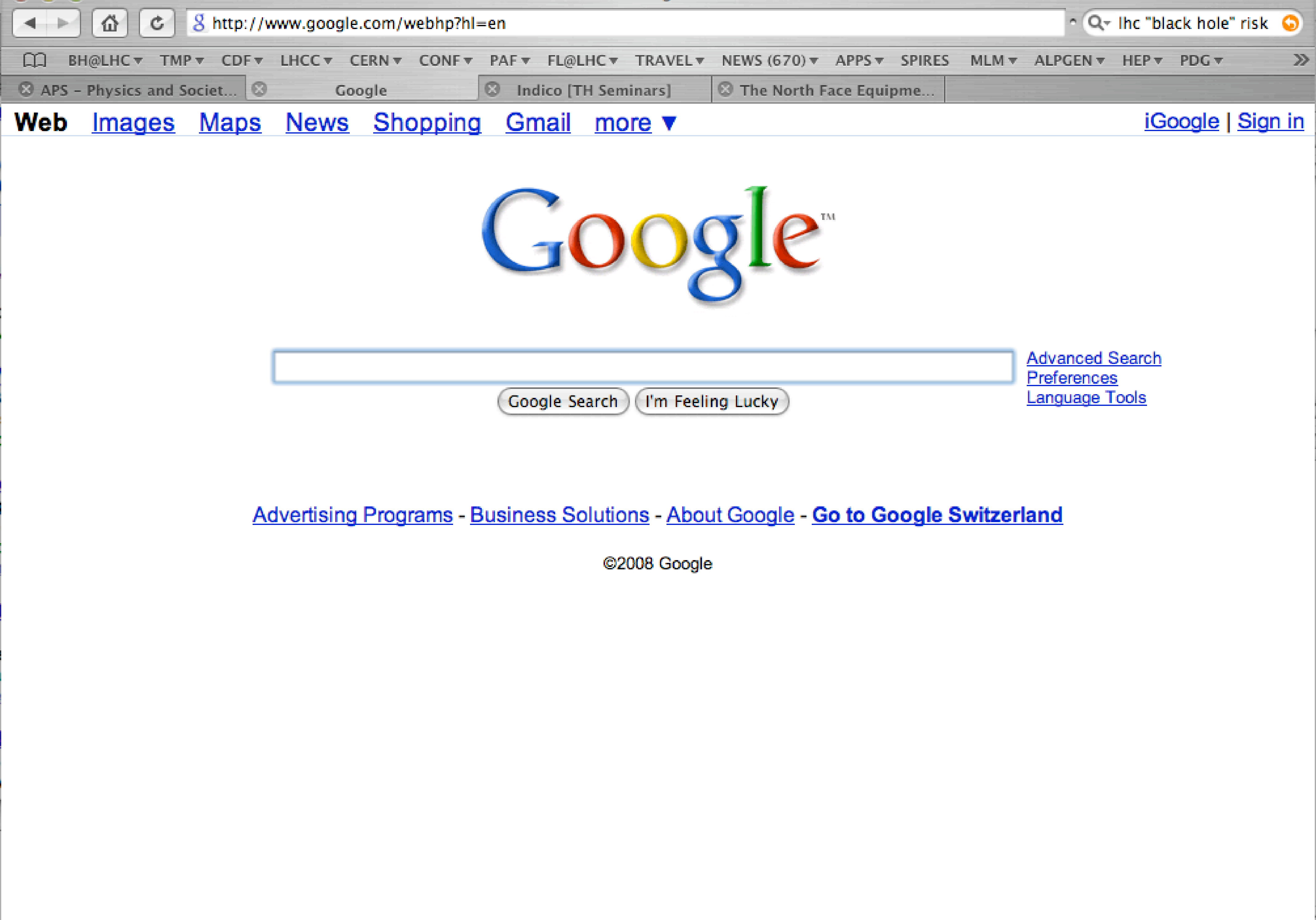
Black Holes at the LHC: safety and society

Michelangelo Mangano
CERN, TH-PH

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

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



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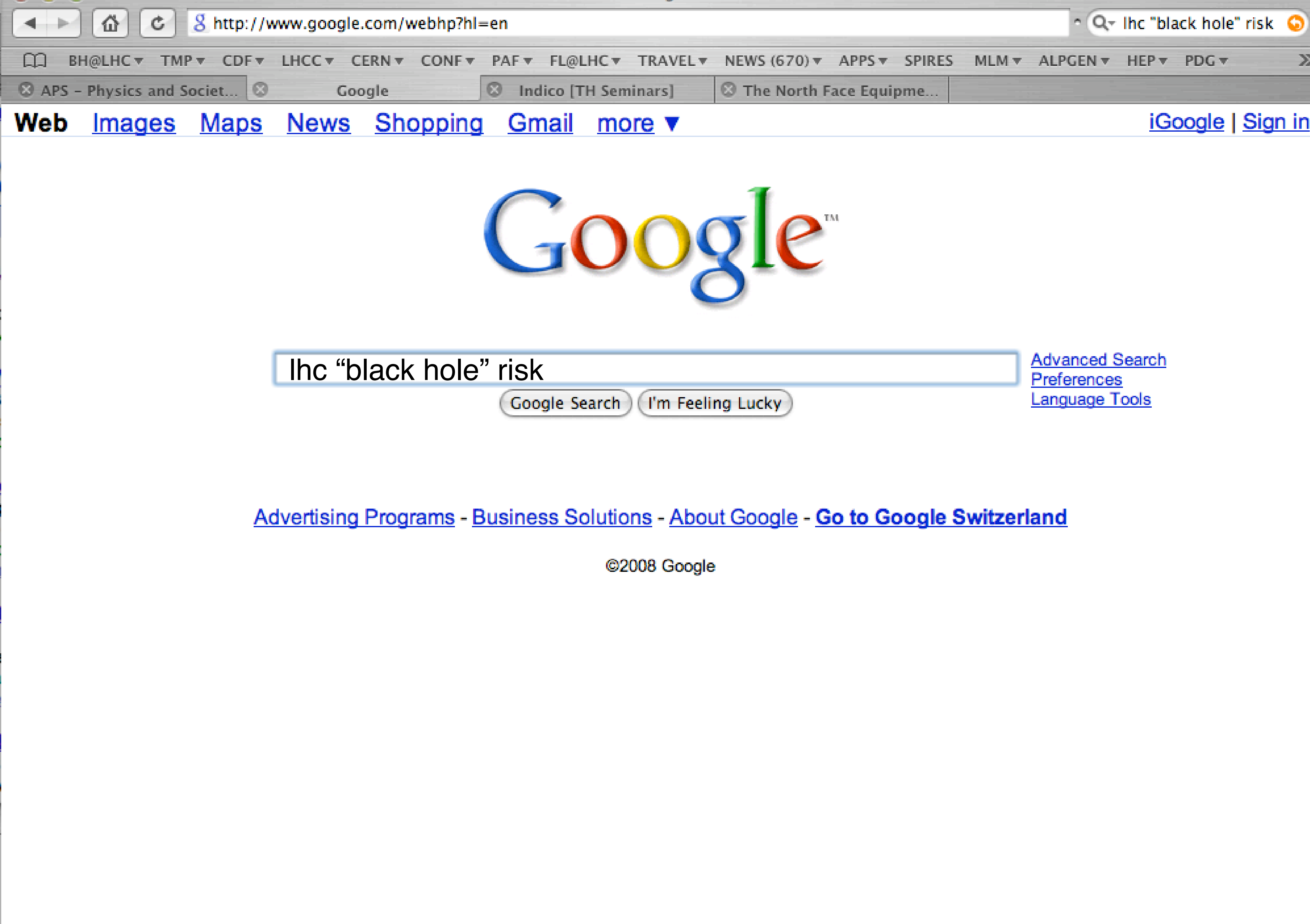
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The Reference Frame: Nostradamus: the **LHC black hole** will eat us
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Large Hadron Collider - **Risk** of a **Black Hole** - Dennis Overbye **...**
15 Apr 2008 **...** Whom can we trust to do hard-headed 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”

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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.**

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

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

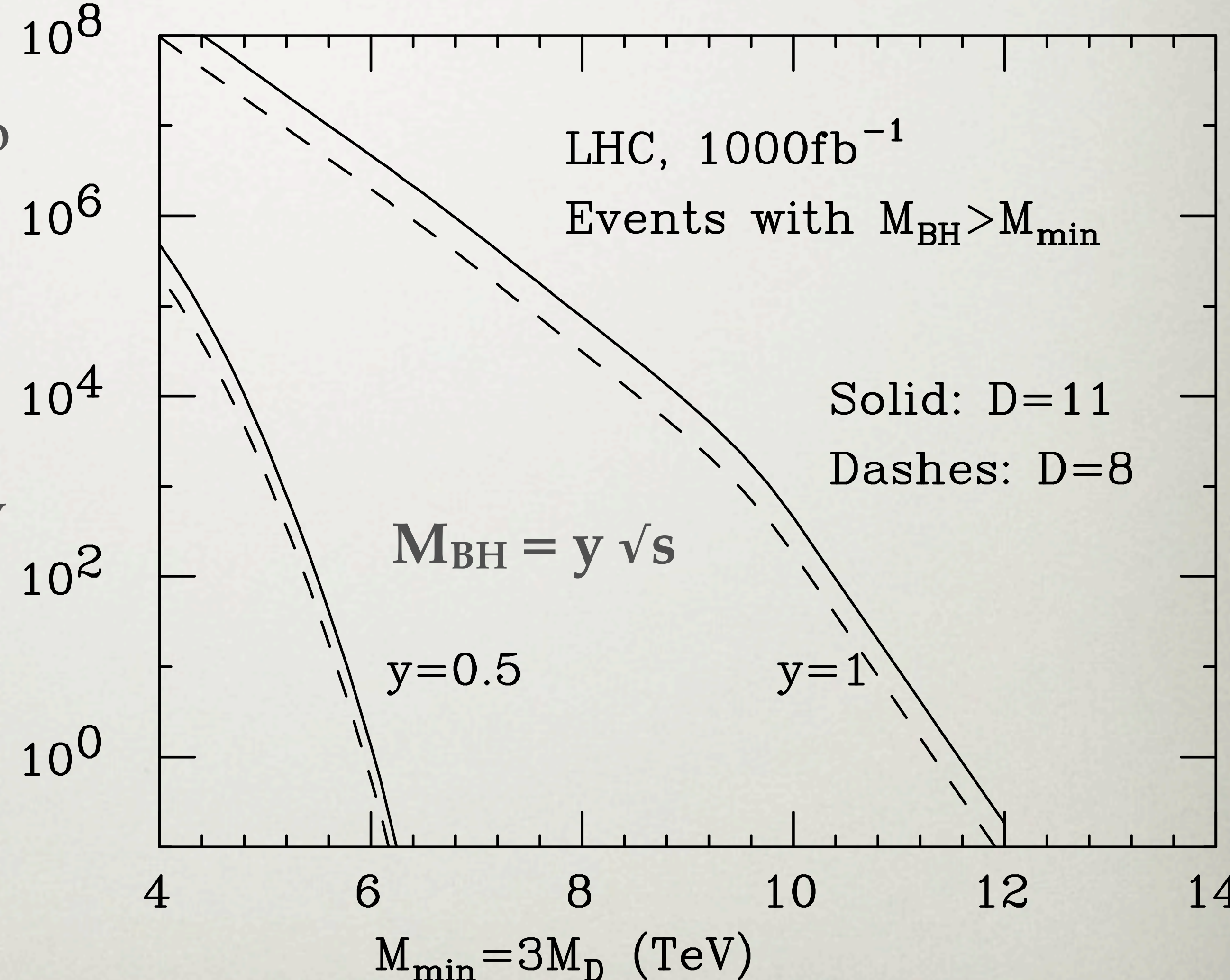
"The [BNL] lab director took the **ethically dubious step** of appointing an evaluation panel of physicists, all of whom had professional interests in seeing the experiments go forward."

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 ~ 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 conserved 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: how 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

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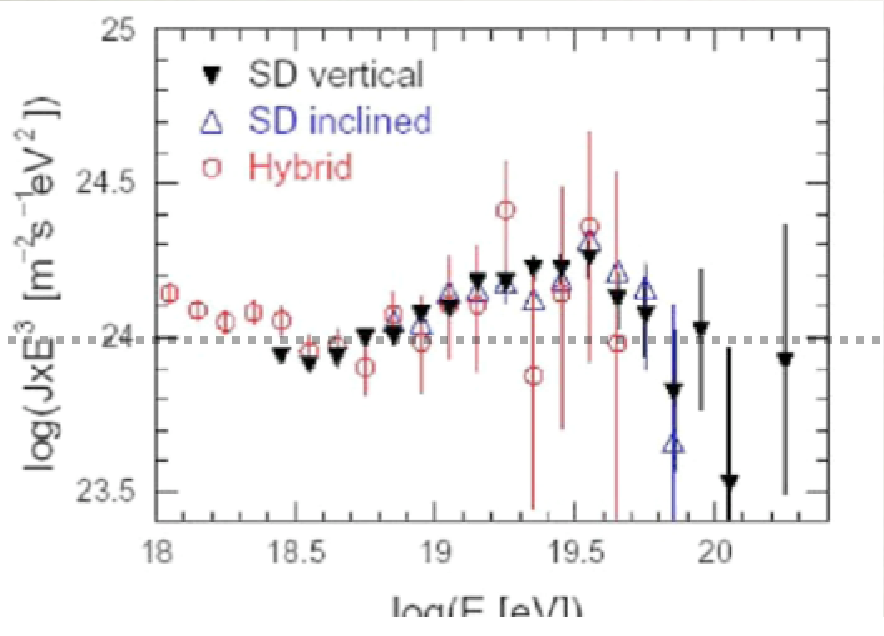
Bottom line: it is interesting to address the possible visible/macroscopic consequences of BH’s stability

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

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}

Notice

- 10^{22} / 10^{17} is not a large number, but consider that the argument can be applied also to the Sun, to all other stars in the galaxy, etc.
- Since R_{sun}~$100R_{earth}$, with 10^{10} sun-like stars in the galaxy, we get an additional factor of 10^{14}
- ..... Then count galaxies causually connected with our slice of the universe ...

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:

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

➡ 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** ➡

$$F = \rho v$$

➡

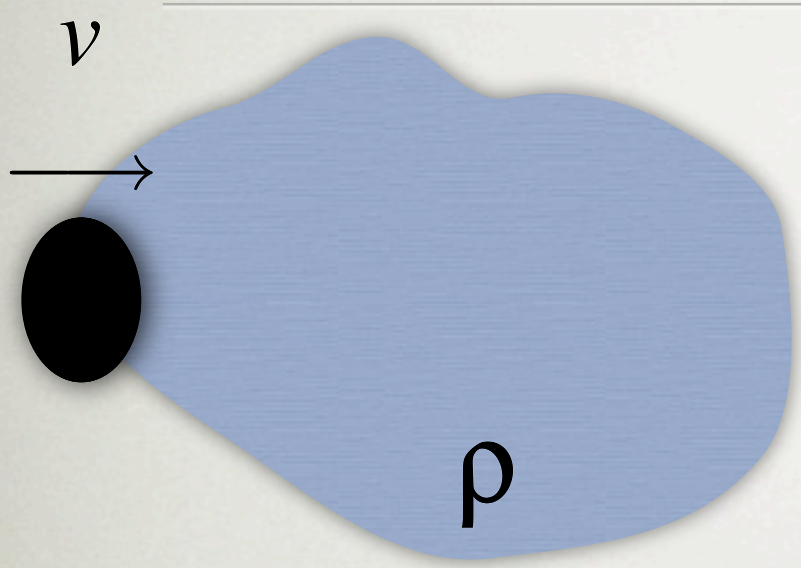
$$\frac{dM}{dt} = \pi \rho v r_c^2(M)$$

Need to establish what **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



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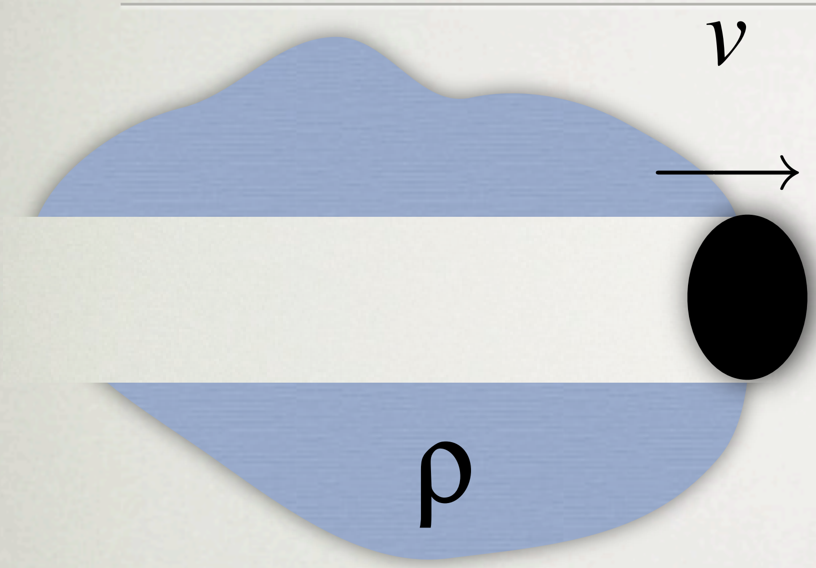

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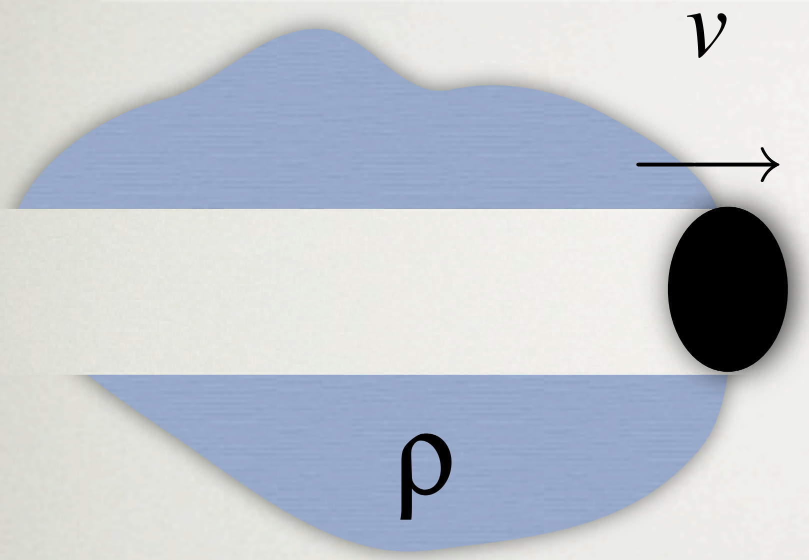

$$r_c = R \qquad R = \frac{1}{M_D}\left(\frac{k_D M}{M_D}\right)^{\frac{1}{D-3}}$$

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

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

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

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

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

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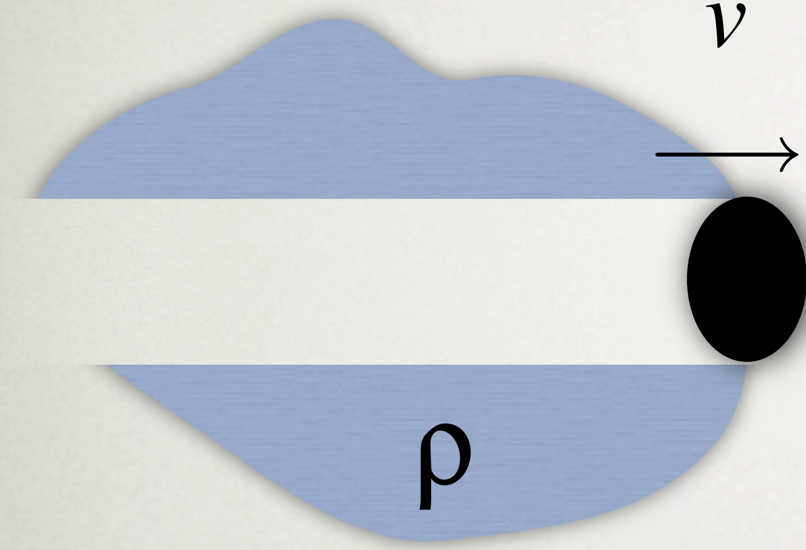

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Time scale depends only on final radius $\mathbf{R_f}$:
- indep. of initial mass
- insensitive to pile-up of many BHs

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

Time scale ~ indep. of initial/final mass

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

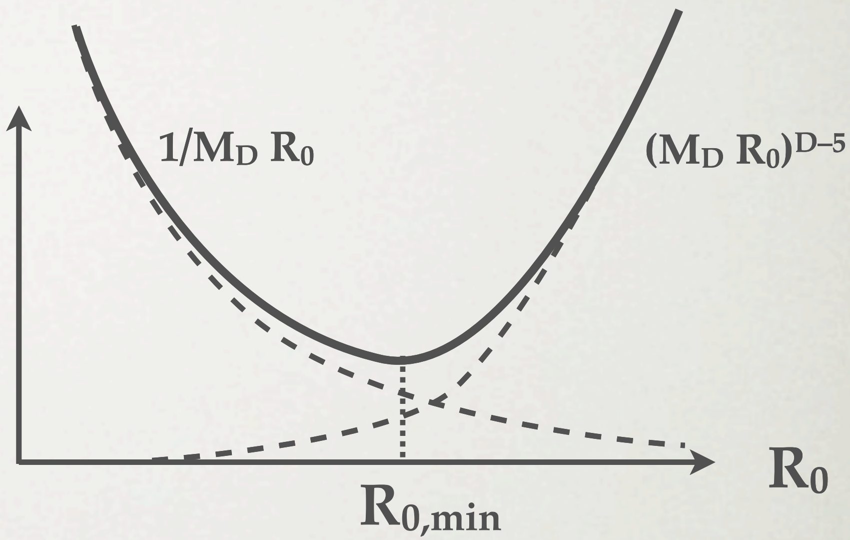
Time scale determined by starting point, $\mathbf{R_i}$

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

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

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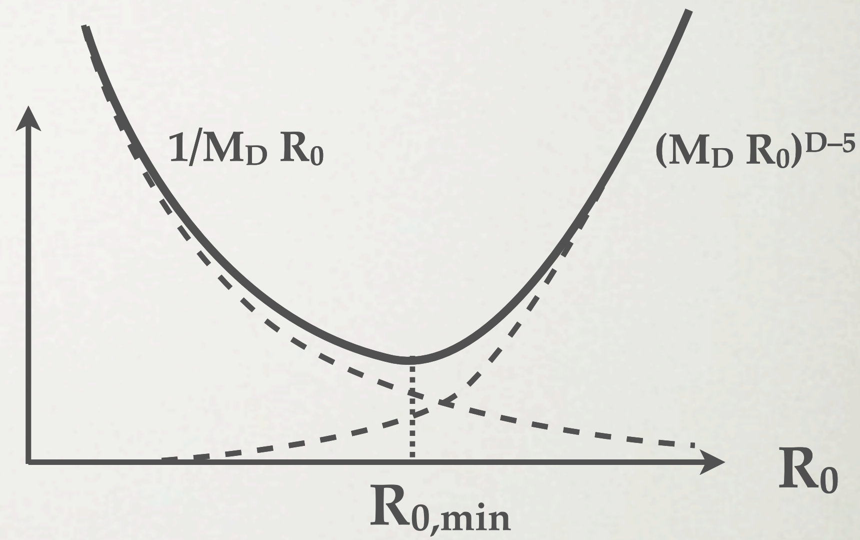

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Timescale for macroscopic accretion on Earth ~ 10^{13-28} yrs

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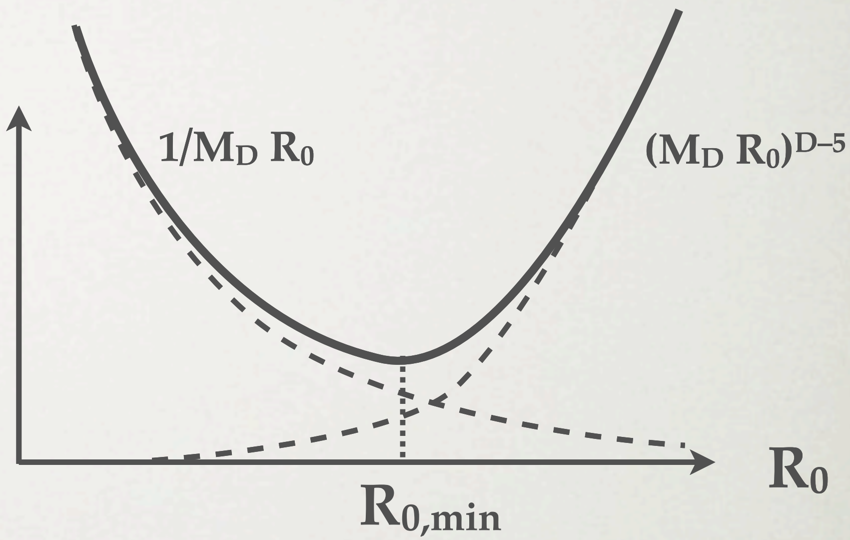

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Accretion needs to be macroscopic (r_c>>R) to pose any danger

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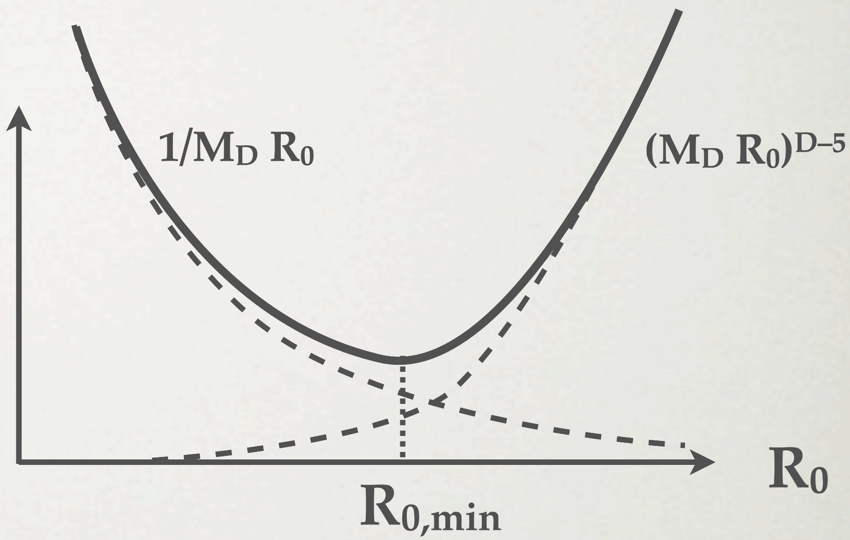

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Timescale for macroscopic accretion on Earth ~ 10^{13-28} yrs

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

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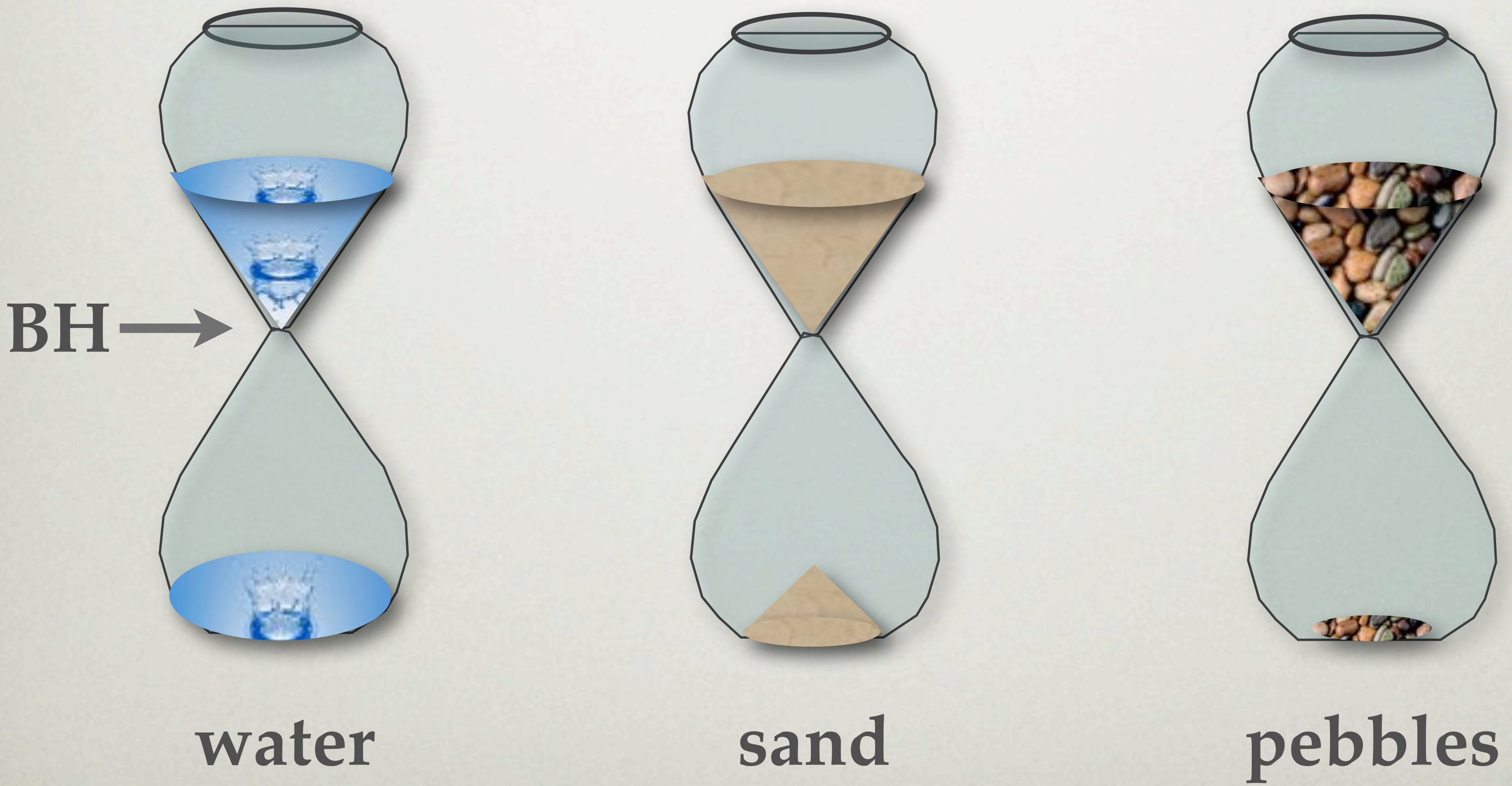


Accretion regimes

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

Nuclear regime, R_c < fm

Fast evolution (Earth):

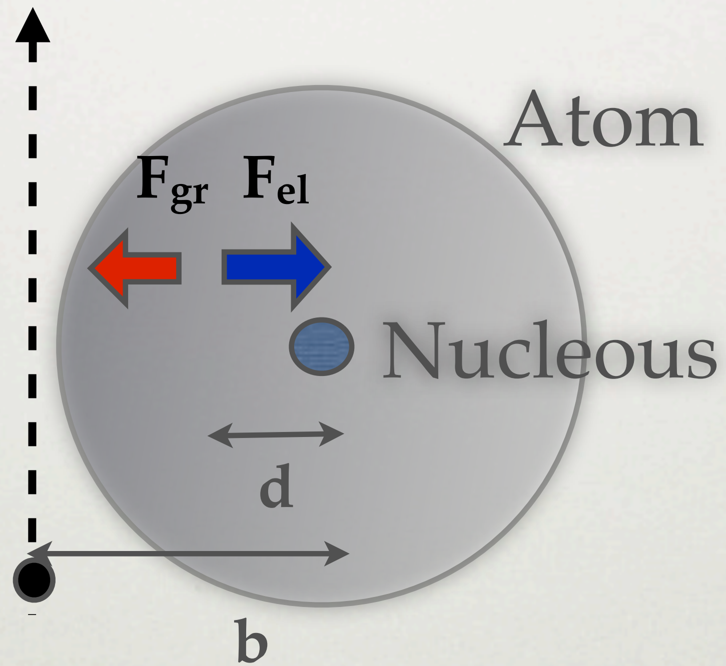
- **r_c (M) ~ 1fm** even if BH mass is such that its radius is << 1fm.
- Equivalent to assuming that the BH spends inside a nucleon enough time for quarks and gluons to be captured as they bounce back and forth the nucleon bag.

Slow evolution (WD/NS):

- **r_c (M) = R**

Subatomic regime, fm < R_c < Å

(Only relevant for Earth)



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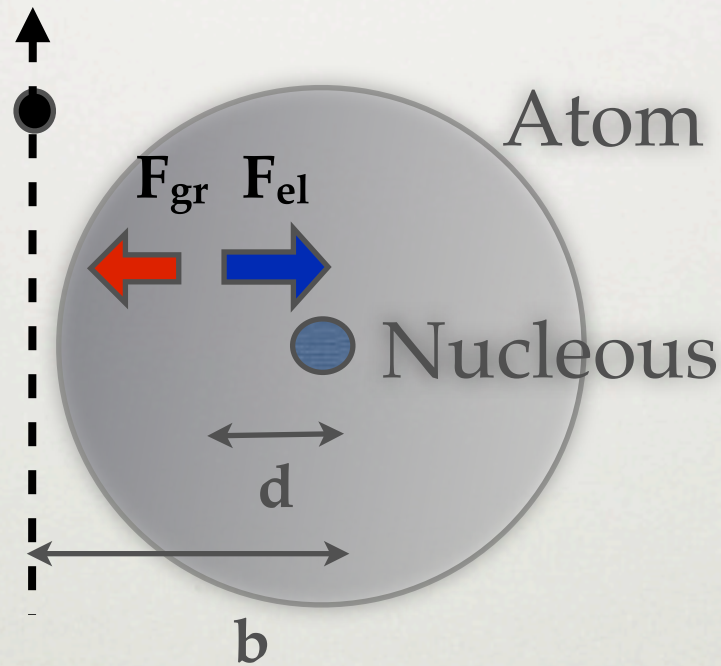

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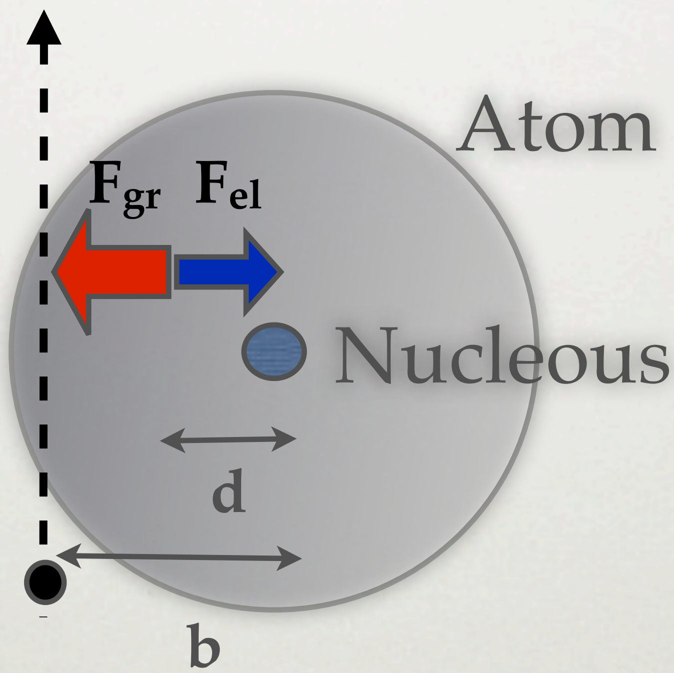

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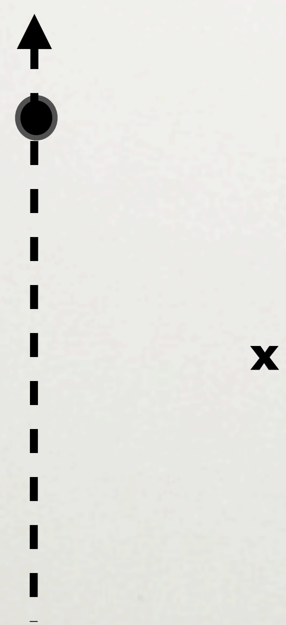

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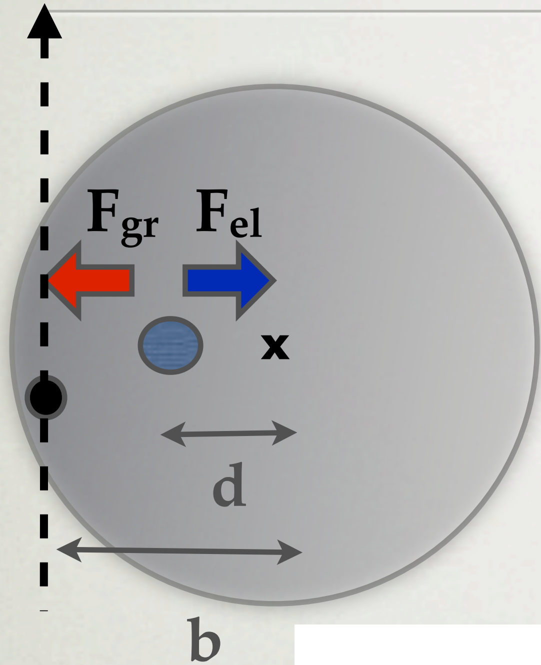

r_c = impact parameter such that gravitational force strong enough to pull nucleous out of the atomic center

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

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

$$F_E(d) = -K d$$

K defines the growth rate

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

or

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

γ~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:

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

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

$$
\begin{aligned}
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R_D &= 3.6 \times 10^{-7}\mathrm{cm}\ , \quad \text{for } D = 7 \\
R_D &= 9.8 \times 10^{-10}\mathrm{cm}\ , \quad \text{for } D = 8 \\
R_D &= 2.8 \times 10^{-11}\mathrm{cm}\ , \quad \text{for } D = 9 \\
R_D &= 2.7 \times 10^{-12}\mathrm{cm}\ , \quad \text{for } D = 10 \\
R_D &= 4.9 \times 10^{-13}\mathrm{cm}\ , \quad \text{for } D = 11
\end{aligned}
$$

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

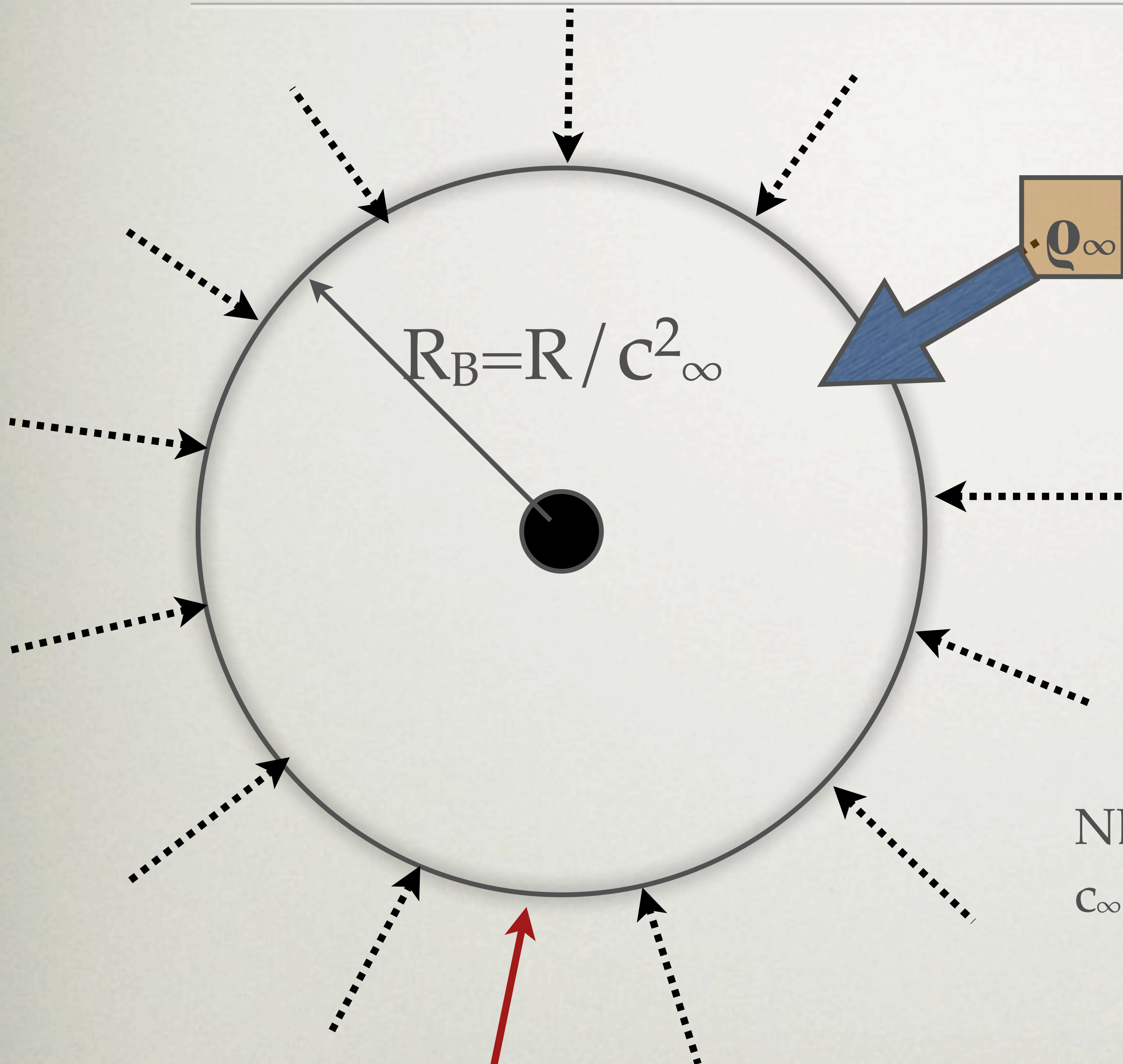
➡ **Bondi accretion evolution:**

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

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 $r<R_B$

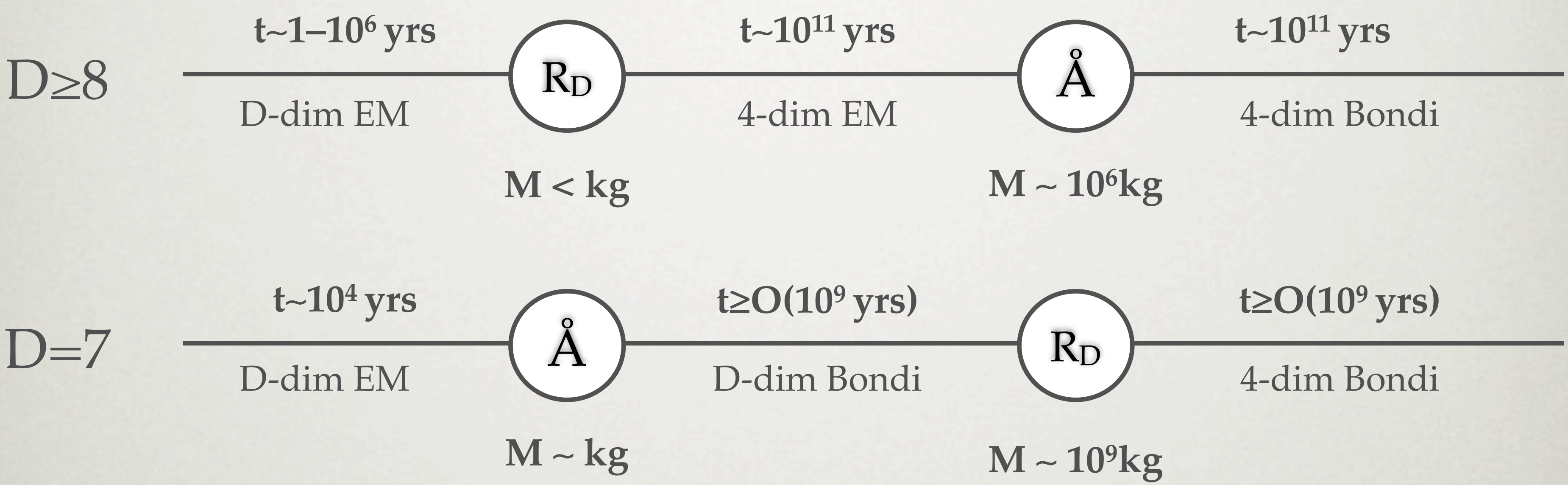
NB: for Earth
$c_\infty \sim$ Å $\omega_D \sim 6$ km/s $\sim V_{escape}$

$R_B \sim$ 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, 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,

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

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

$t > 10^{10}$ yr on Earth **$R_D < 200$ Å** **R_D**

$R_D > 15$ Å **$t < 10^7$ yr on a WD**

Complete study of accretion confirms that

NS are accreted for **all D** within times between few yrs and Myr

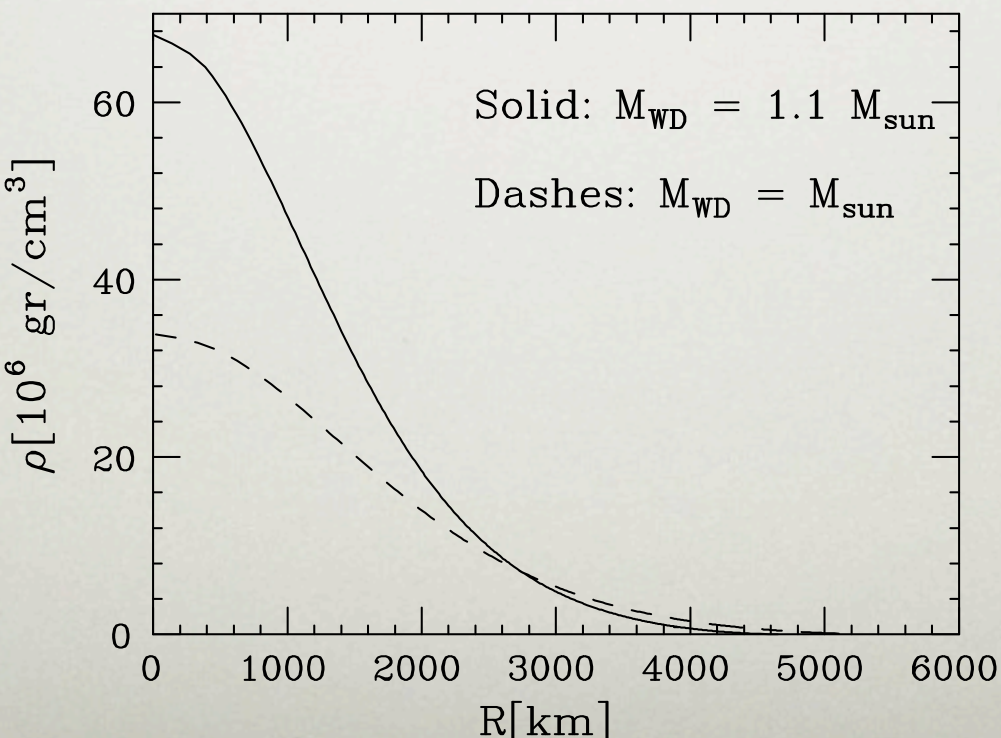
WD are accreted for **D<8** within times no more than few 10 Myr

Issues to be assessed for NS & WD

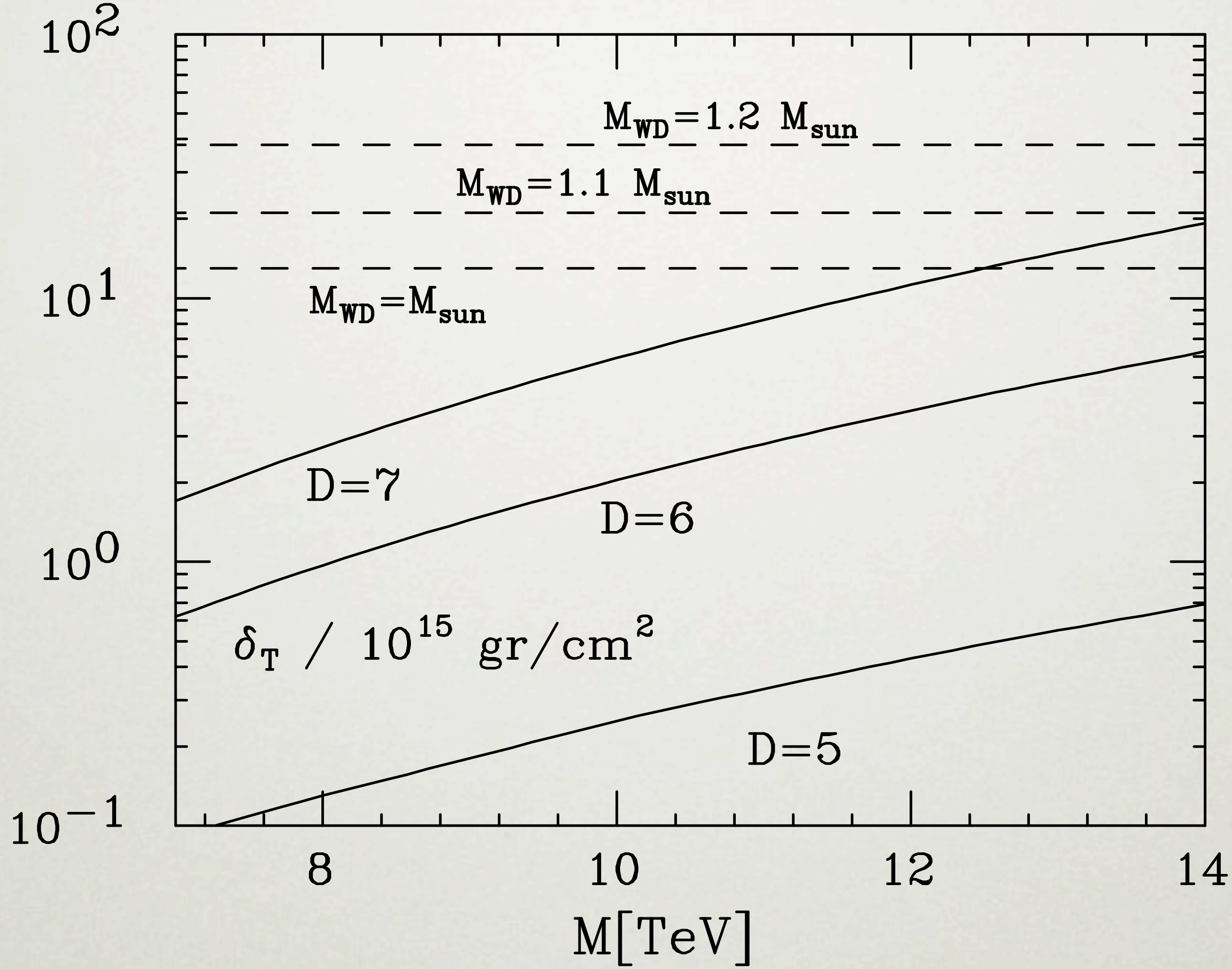
- Stopping power of WDs (trivial for NSs)
- Eddington-limited accretion
- Effective cosmic ray rates on WDs and NSs
- Cosmic ray composition

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 guaranteed up to 14 TeV

Eddington limit

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

η = fraction of absorbed mass radiated away during accretion

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

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

radiative force acting on an e-p pair

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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

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

Eddington e-fold time scale

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

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:

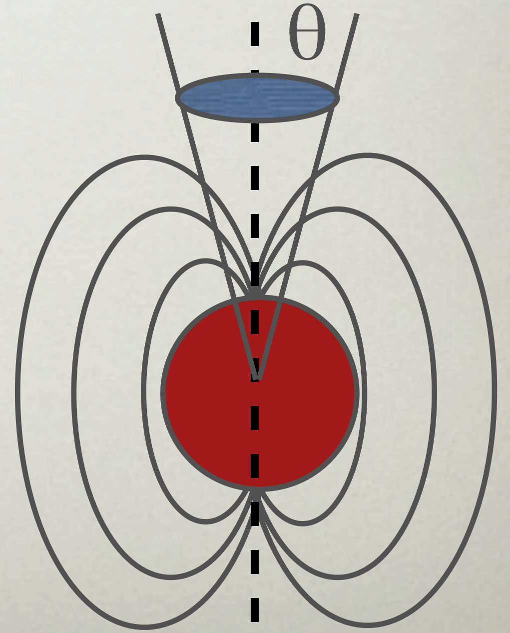
$$p \gtrsim 0.75 \times 10^{17}\ \mathrm{eV} \frac{R_0}{5000\ \mathrm{km}} \frac{ZB_p}{10^6\ \mathrm{G}} = 1.5 \times 10^{17}\ \mathrm{eV} \frac{R_0}{10\ \mathrm{km}} \frac{ZB_p}{10^9\ \mathrm{G}}.$$

OK for several WD and some NS

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

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

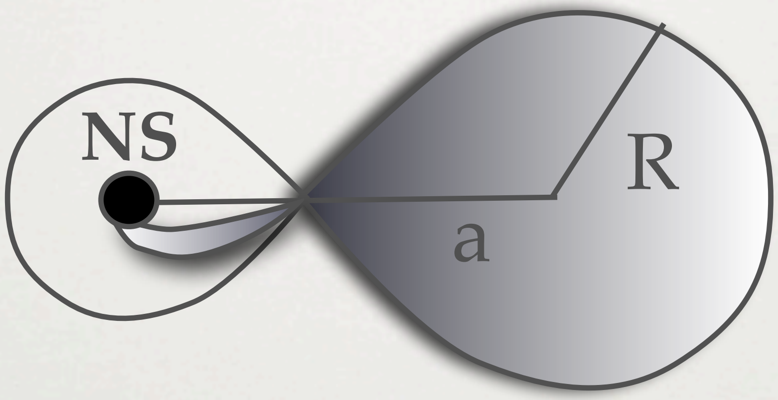
Bad for NS



→ 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:

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

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

Eggleton, 1983

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

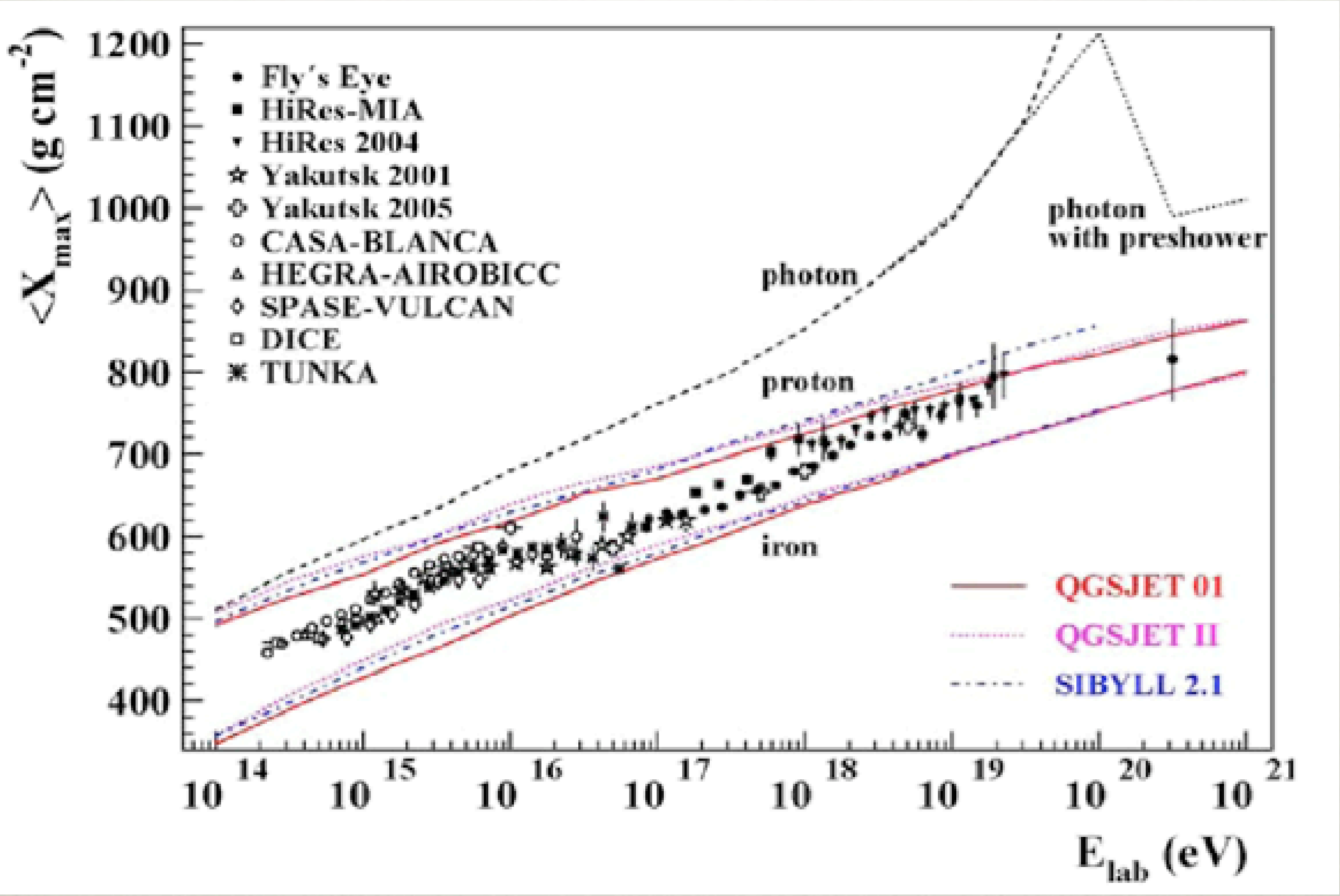
Need to estimate the effective exposure (in years/ 4π equivalent) for existing, known systems:

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

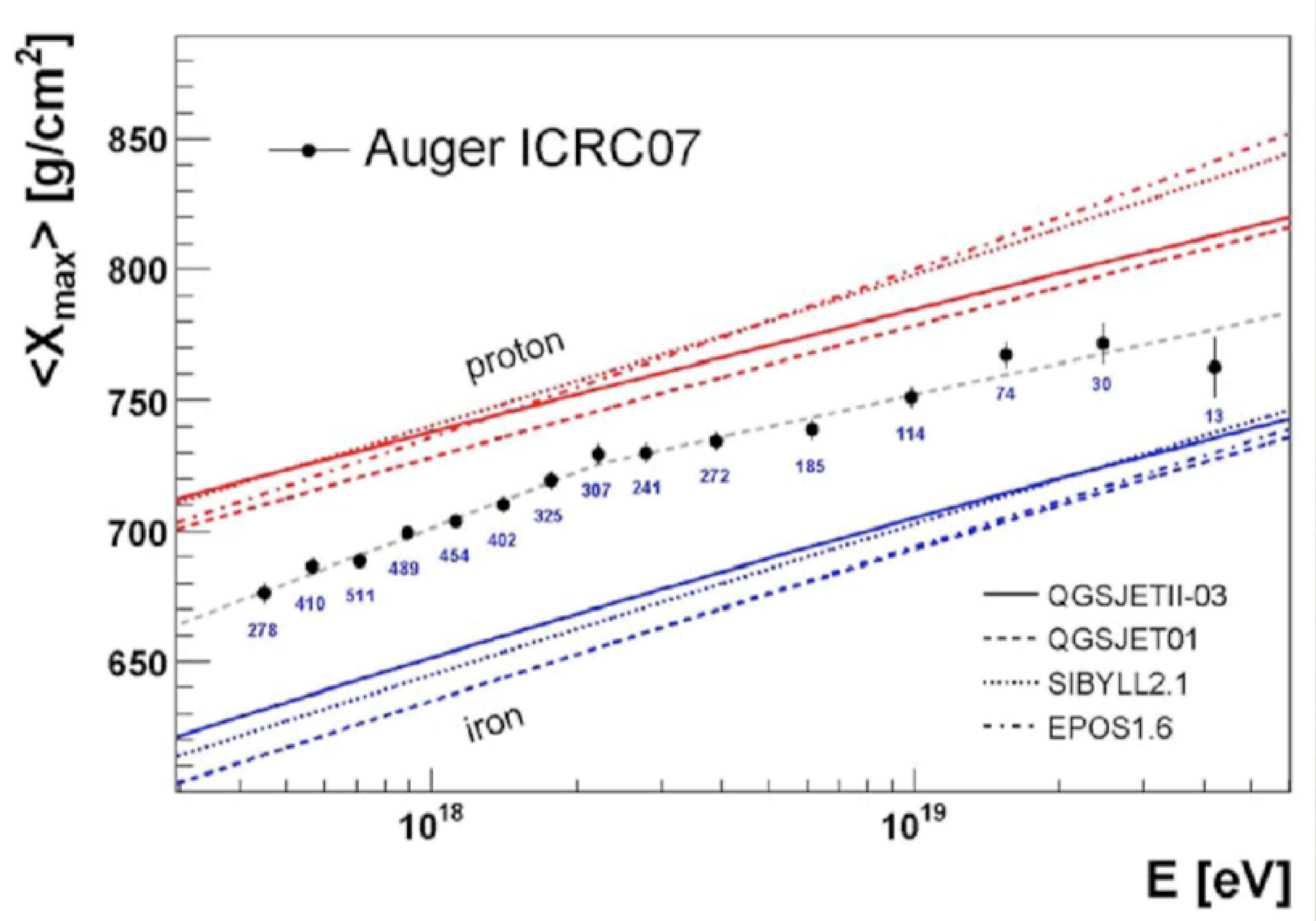
Lifetimes of the order of several 100M years, with f of the order of %, lead* to values of T_{eff} in excess of 2 Myrs for many X-ray binary systems

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

CR composition, pre-Auger



CR composition, Auger



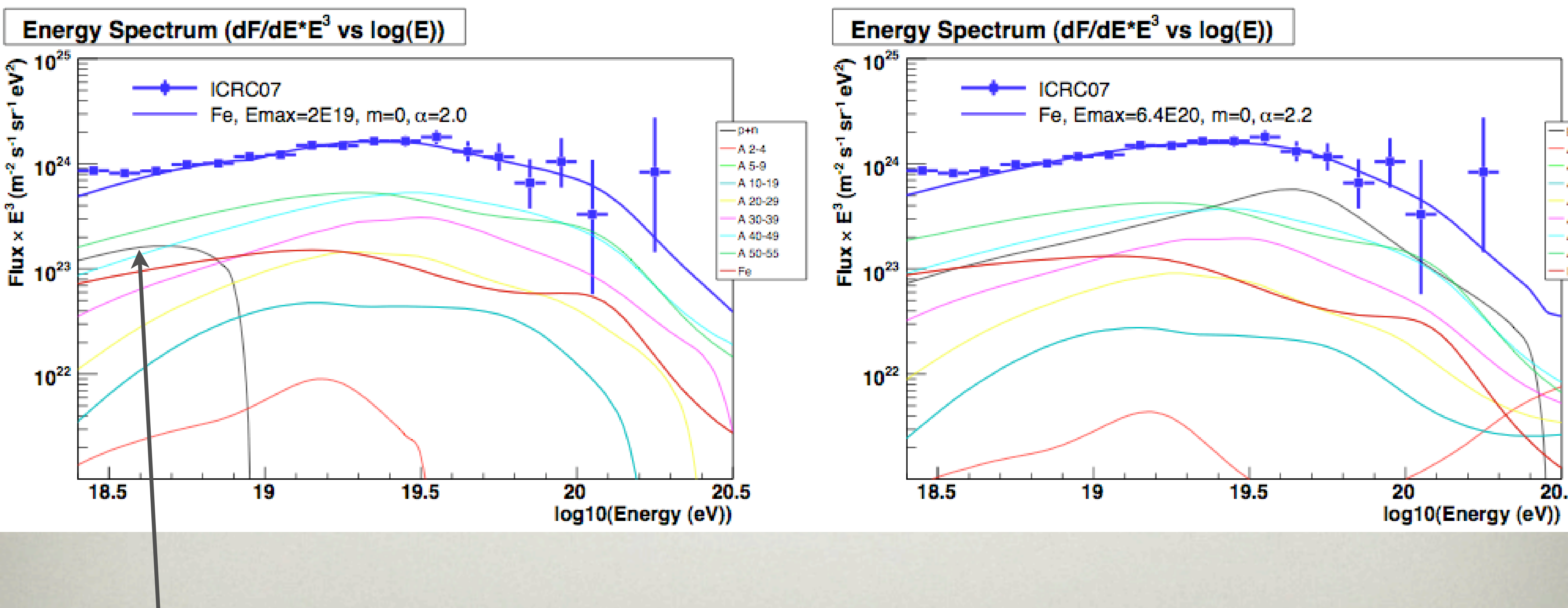
Extreme composition scenarios

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, $F(E) \sim E^{-n}\,\Theta(ZE_{max} - E)$

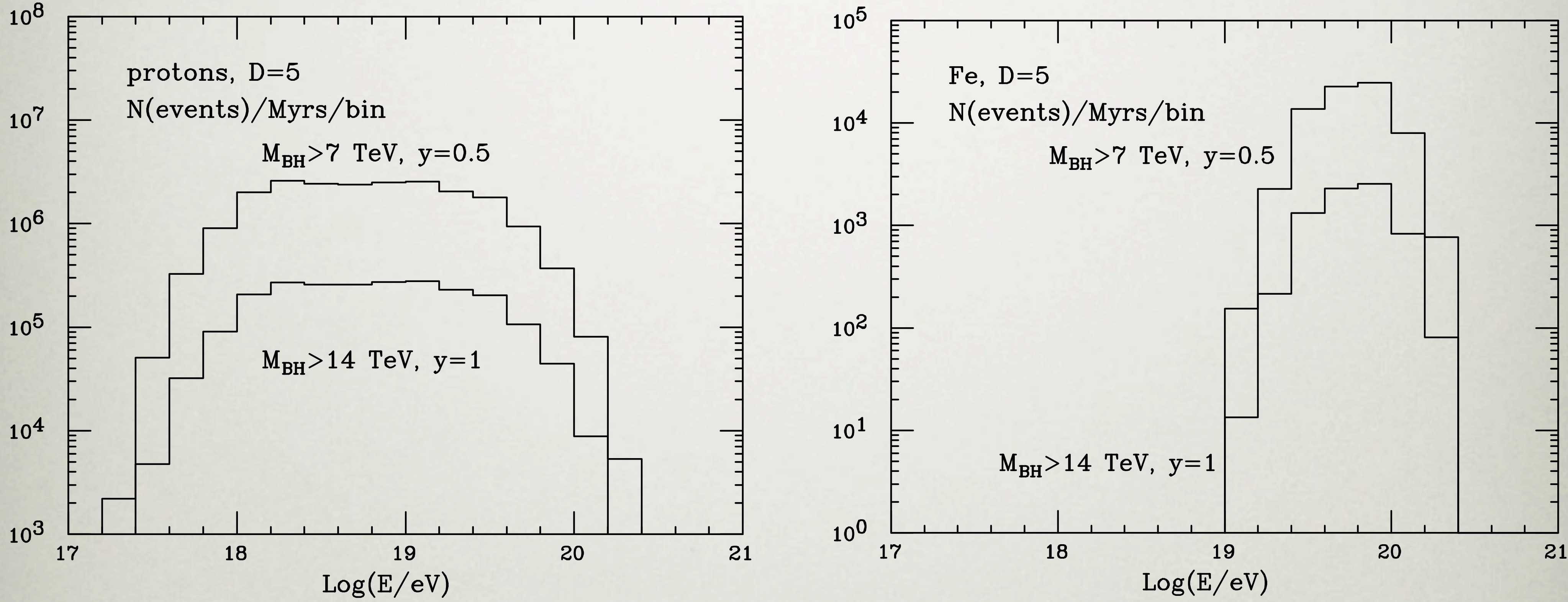
Left: $E_{max} = 2\text{x}10^{19}$ eV, n=2

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



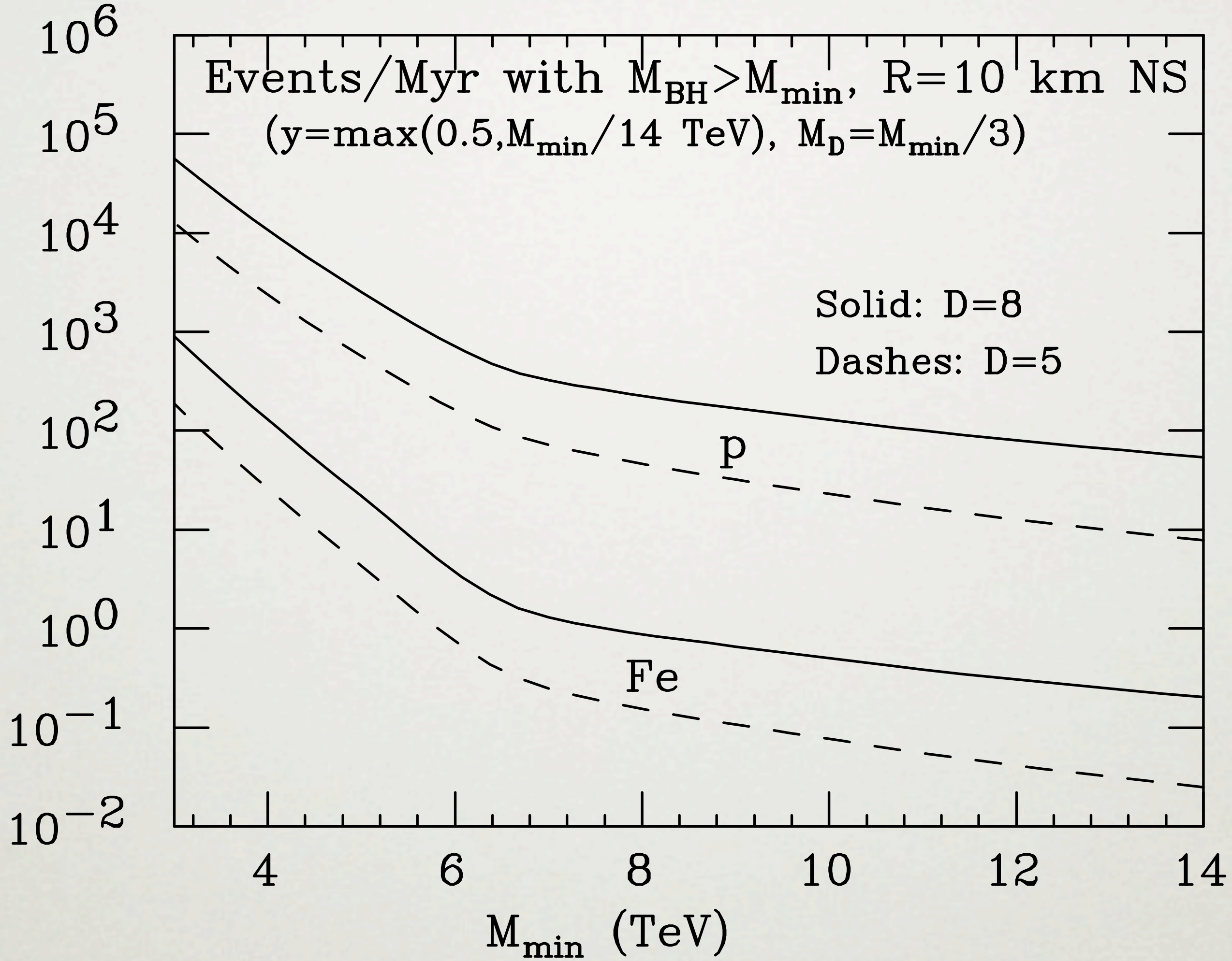
Even in this worse case, #p ≥ 10% in the relevant energy range

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. $M_D = M_{\mathrm{min}}/3$ and inelasticity $y = 0.5$.

$D =$	5	6	7
N_p/Myr, $M_{\mathrm{min}} = 7$ TeV	2.1×10^7	4.3×10^7	6.7×10^7
N_{Fe}/Myr, $M_{\mathrm{min}} = 7$ TeV	7.2×10^4	1.6×10^5	2.6×10^5
N_p/Myr, $M_{\mathrm{min}} = 14$ TeV	2.8×10^5	5.7×10^5	9.1×10^5
N_{Fe}/Myr, $M_{\mathrm{min}} = 14$ 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. $M_D = M_{\mathrm{min}}/3$ and $y = \max(0.5, \mathrm{M_{min}}/14\ \mathrm{TeV})$.

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

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.

Our work was reviewed and published, CERN's SPC and Council endorsed these conclusions on june 20th 2008, and some (naive) people thought that this was going to set the black-hole case to rest .....

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."**

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Fear review

By Luis Sancho

From an affidavit submitted March 21 by Luis Sancho to the U.S. District Court of Honolulu in support of a lawsuit against the Department of Energy, Fermi National Accelerator Laboratory, the National Science Foundation, and the European Organization for Nuclear Research (CERN). Sancho, a cosmologist who specializes in time theory, is among plaintiffs seeking an injunction to halt further work on the Large Hadron Collider, located on the border of Switzerland and France.

[...] Since the production of dark matter is neither necessary for the advancement of science nor safe for mankind, the LHC should be forbidden to operate. As we close Chernobyl-like plants for security reasons and forbid the reproduction of the Ebola virus in an open environment (though some specialized virologists would like to study it for research purposes), so should we forbid the reproduction of free, uncontrolled dark matter, even if its theorists would like to study it at CERN. [...]

From a psychological point of view, physicists are a curious group. We are responsible for creating scientific explanations for the nature of God and the universe, and we sometimes act with an arrogant fundamentalism. It is not strange that fundamentalist scientists behave like fundamentalist religious people. Both groups believe in their dogmas with such force that they can justify acts of collective murder all over the world. [...]

It should not be surprising, then, that CERN would commit a terrorist act by switching on the LHC. [...] This they propose to do in order to foster the career goals of a few thousand specialists. [...].

CERN's efforts must be judged as acts of criminal negligence and irresponsibility that could harm billions of human beings, or worse, as a potential terrorist act. [...]

Follow-up phenomena: the BH case became for many people, in academia and beyond, an exciting playground to exercise theories on risk assessment, ethics, legal procedures for science matters, etc.etc.

Few examples follow .....

Risk mitigation

- Proposals for risk mitigation that appeared in connection with the safety of particle physics experiments are, if not just useless, irresponsible, and expose the basic misunderstanding and, occasionally, the lack of integrity of those who put them fwd.

Probing the Improbable: Methodological Challenges for Risks with Low Probabilities and High Stakes

Toby Ord, Rafaela Hillerbrand, Anders Sandberg[*]
[*] Future of Humanity Institute, University of Oxford.

http://arxiv.org/abs/0810.5515v1

"When an expert provides a calculation of the probability of an outcome, they are really providing the probability of the outcome occurring, given that their argument is watertight."

$$P(X) = P(X|A)\,P(A) + P(\neg A)\,P(X|\neg A)$$

- Errors of modeling, e.g.
  - Lord Kelvin: age of the Earth (20-40 M yrs)
  - Castle Bravo fusion-bomb test (5 Mton vs 15 -- neglect of Li7)
  - ..
  - estimate probability at % level, based on number of published papers retracted
- Errors of calculation:
  - estimate at 0.001/equation
- Errors of numerical computation
  - e.g. Ariadne 5 explosion due to software bug
  - estimate at 0.001, based on records of medical radiation dosimetry

THE BLACK HOLE CASE: THE INJUNCTION AGAINST THE END OF THE WORLD

ERIC E. JOHNSON*

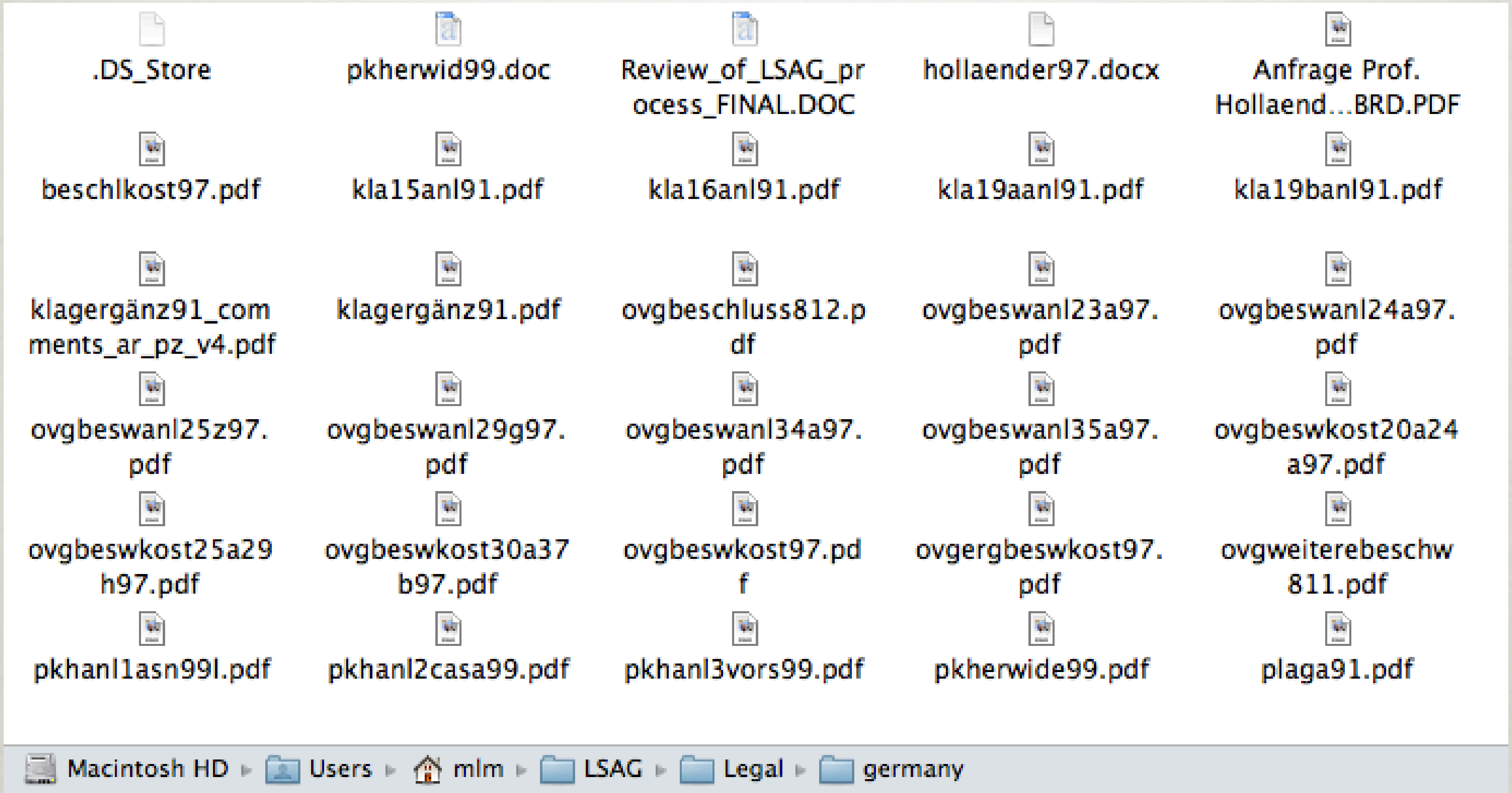
TENNESSEE LAW REVIEW [Vol. 76:819

Courts may, with some probing, determine that there is some unsettling inconsistency in the persistent duality whereby particle physicists espouse general skepticism of their craft yet maintain perfect, or nearly perfect, confidence on safety issues. Whether this apparent contradiction should be troubling appears to be answered by a consideration of scientific precedent. The history of particle-collider safety assurances contains a quick succession of flip- flops on theory that necessitated rethinking prior conclusions.

SAFETY ARGUMENT AGAINST BLACK-HOLE SCENARIO			UNDERMINED BY EVOLVING THEORY			ULTIMATE DISPOSITION OF SAFETY ARGUMENT
1999	Accelerators for the foreseeable future will not be powerful enough to create black holes.[555]	→	2001	Theorists demonstrate that with extra dimensions, the LHC has the energy required to synthesize black holes.[556]	→	***Abandoned:*** CERN acknowledged the need for a new examination of potential hazards, since, under new theory, black holes "will be produced."[557]
2003	Hawking radiation will cause accelerator-produced black holes to evaporate.[558]	→	2004	Unruh, a respected pioneer of black-hole evaporation theory, calls the theory into question.[559]	→	***Abandoned:*** CERN declined to continue resting its safety argument on black-hole evaporation.[560]
2008	Under some scenarios, synthetic black holes will grow too slowly to be a threat. Under the remaining scenarios, dangerous black holes are excluded on the basis of empirical observation of specified white dwarf stars.[561]	→		*???*	→	*???*

Table 1: Chart of arguments advanced against black-hole disaster scenarios to demonstrate particle-accelerator safety.

Legal cases based on arguments such as those above continue appearing .....



Should we ever end up with a judge who wants to decide the scientific issue based on input from experts, who decides who are the experts? What is "legitimate" scientific literature?

Read Johnson's article too learn about what lawyers think, based on precedents ...

A XXI Century witch-hunt

- Ignorance and prejudice about science can compromise the future of civilization
- The attack on fundamental research brought at all levels has reached witch-hunt tones, and global proportions
- Web technology empowers everyone to appoint themselves as experts and generate, from seeds of scary misinformation, waves of popular rebellion against science. Complete lack of fact-checking, verification of credentials, allow the spread of ignorance, prejudice and, ultimately, panic, more than the TV or the press could have ever achieved!

Food for thought

- Scientists still unable to properly educate the public (causes?? our lazyness? the public's lazyness? too much TV? lack of resources?)
    - ignorance about basic philosophical/scientific tools, such as use and applications of syllogisms, probability, empirical evidence, etc.
    - ignorance about basic facts of nature, such as centuries-old established laws (electromagnetism, thermodynamics, quantum mechanics)
    - confusion between "technology" and "science" deeply rooted
    - often education left in the hands of the PR experts: emphasis on "spectacularization" of science, rather than on real contents → wrong, misleading messages
    - given that technical information is now accessible to everyone on the web, even "technical" language should be carefully considered

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    - given that technical information is now accessible to everyone on the web, even "technical" language should be carefully considered

Example:

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]