Hottest ever since the Big Bang!

Sangyong Jeon

Department of Physics
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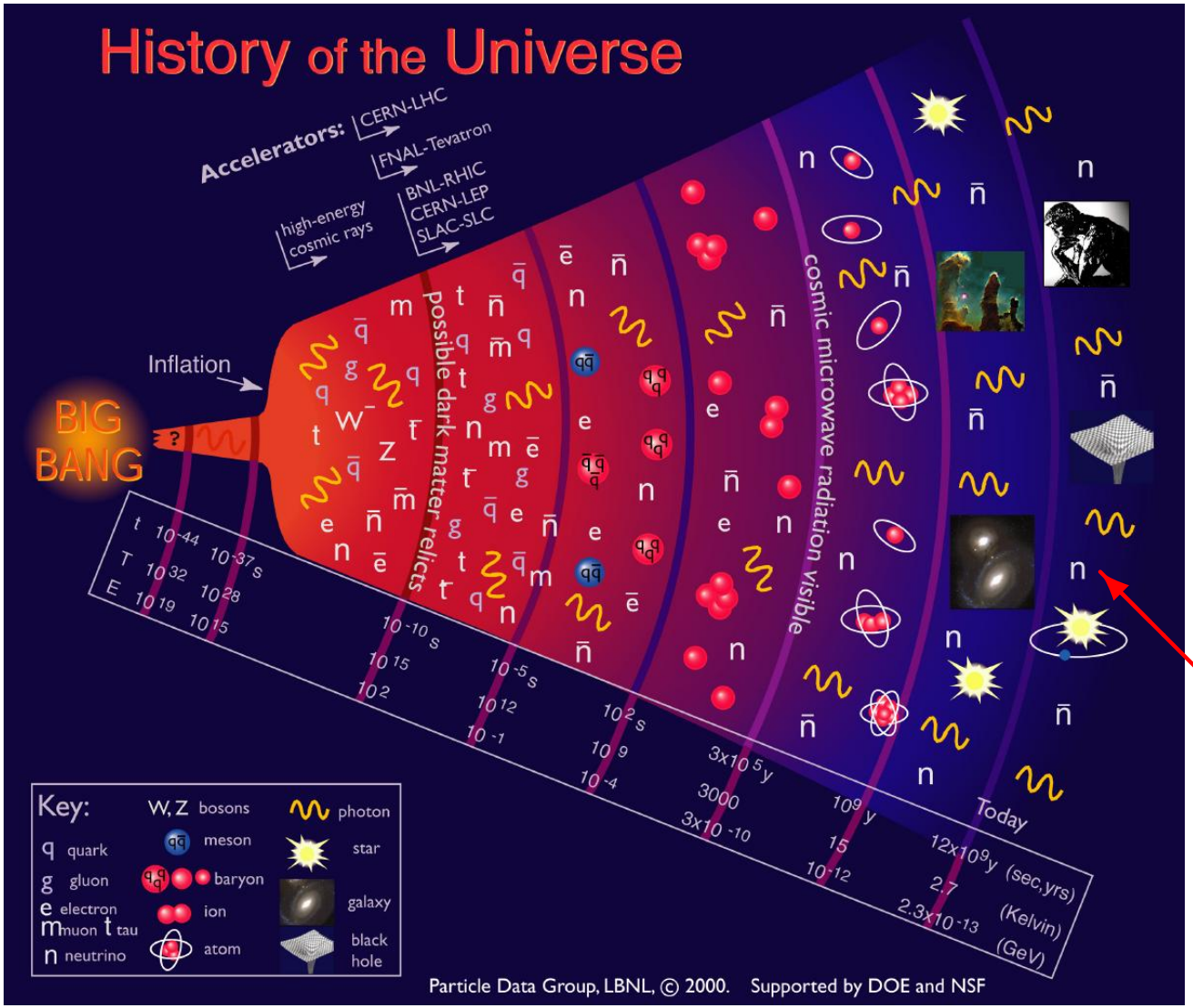
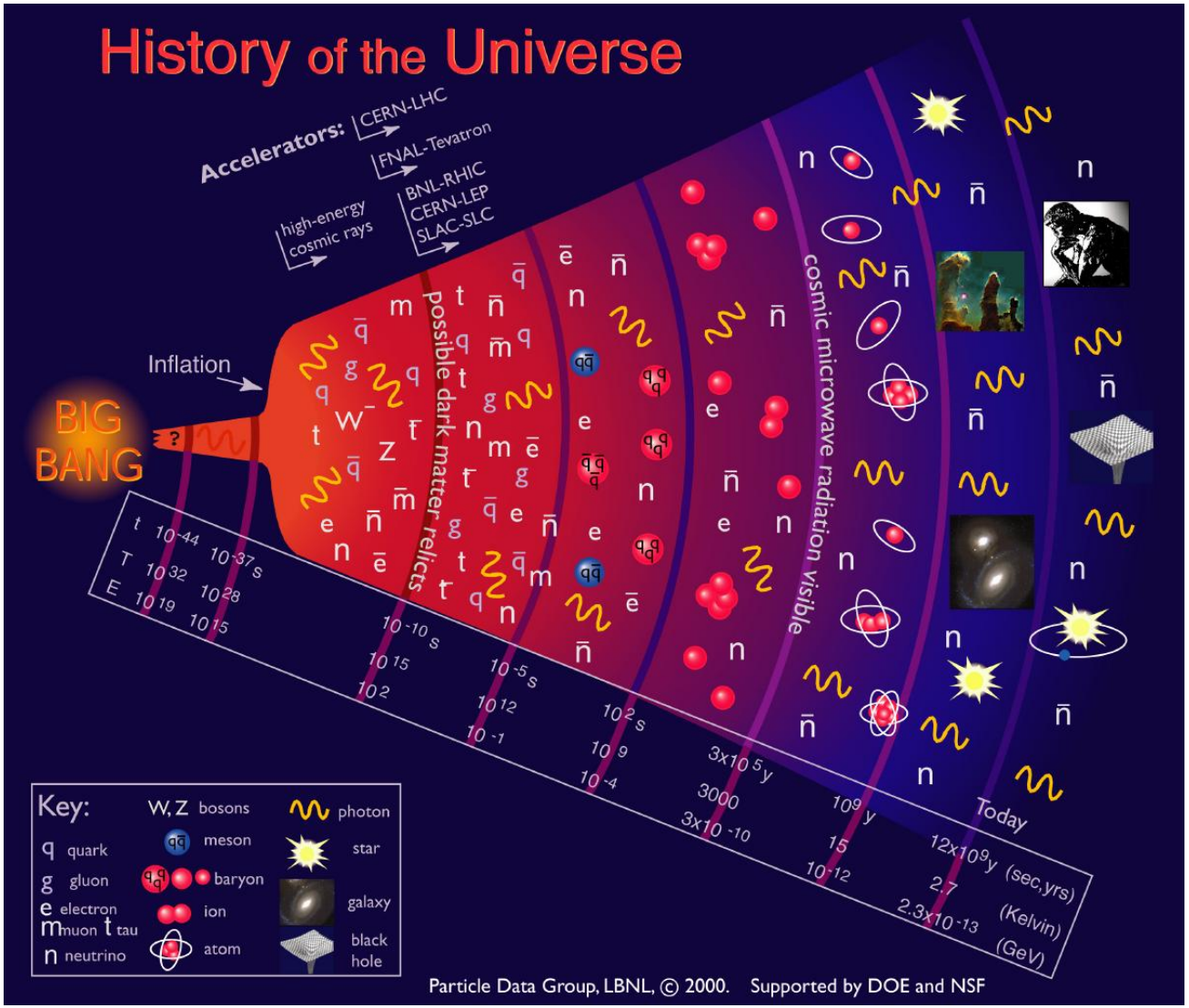
March 14, 2008

Story so far ...



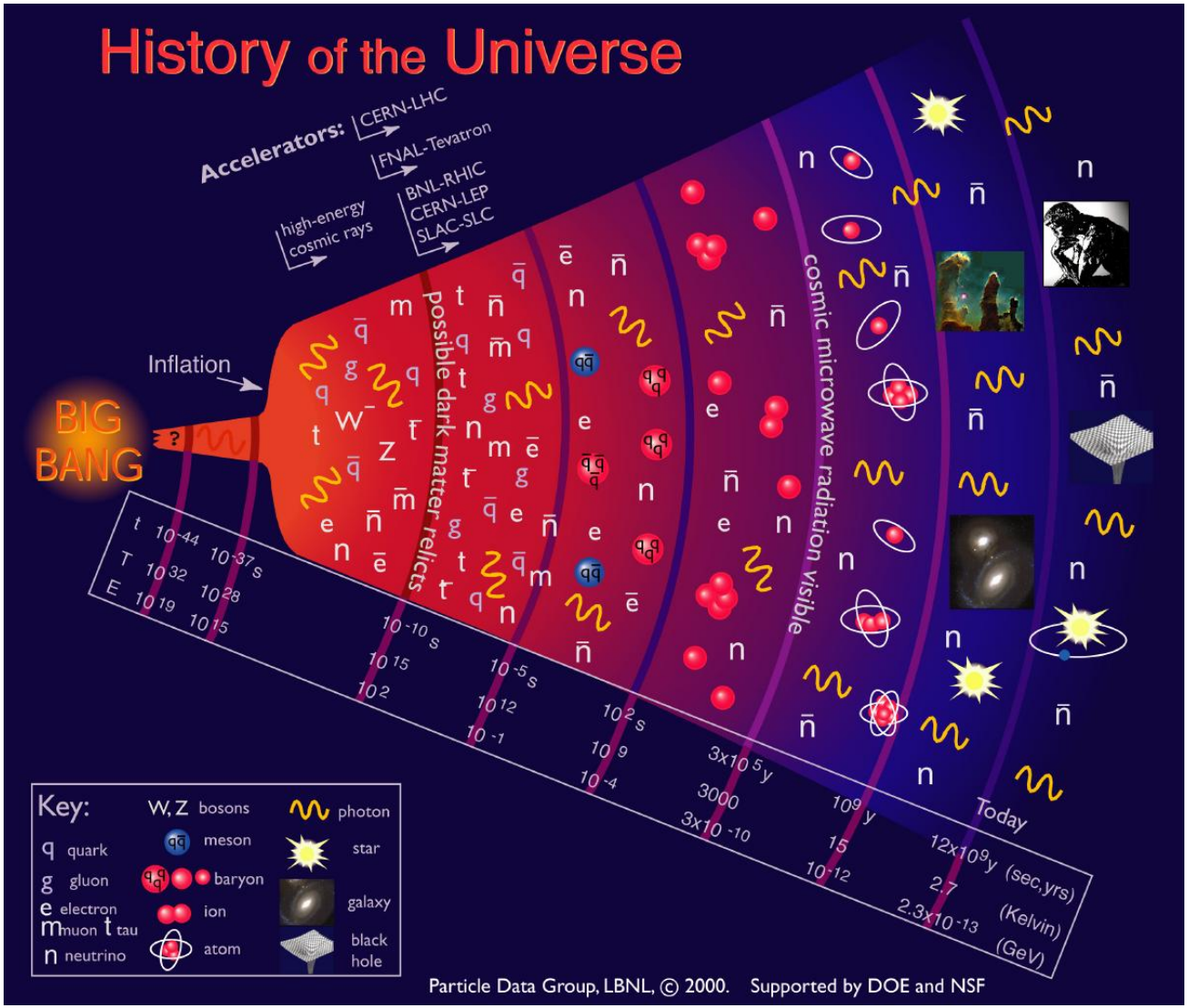
We are here!

Story so far ...



Going back in time ...

Story so far ...



Things get hotter and hotter...

What do we mean by “hot”?

- What do we mean by hot?
- In other words, what do we mean by “temperature”?

What do we mean by “hot”?

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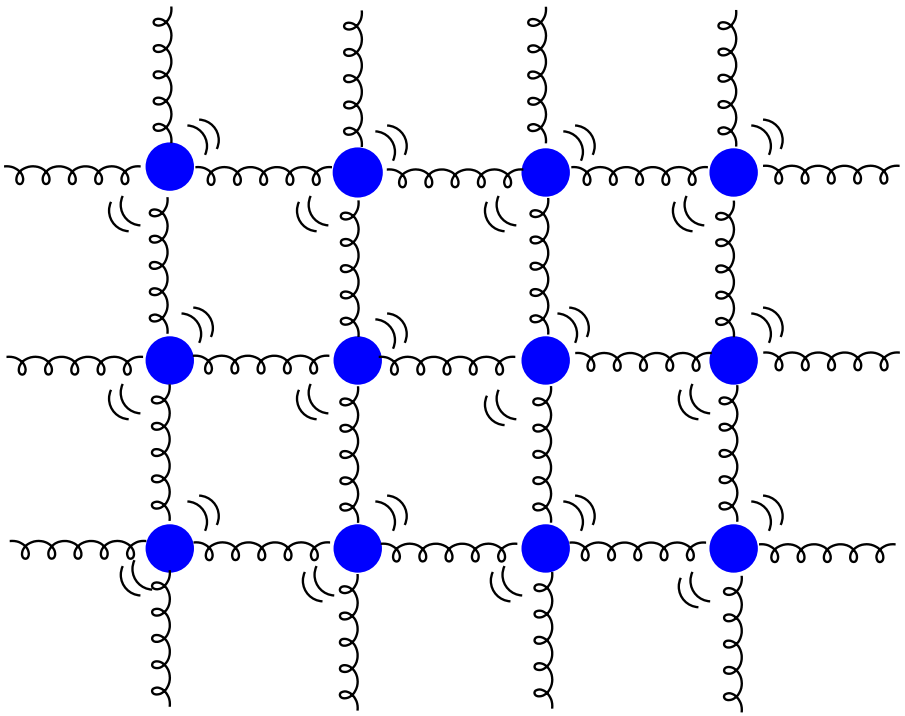
- In other words, what do we mean by “temperature”?
- Temperature = Energy

What do we mean by "hot"?

- For solids, T = "How hard are the molecules shaking?"



What do we mean by "hot"?

- For gases, T = "How hard are the molecules bumping into each other?"

Hot

Cold

What does temperature do?

- A good story always needs battle between Good and Evil, Order and Chaos.
  Physics of Many Particles $\Longrightarrow$ Battle between

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  Physics of Many Particles $\Longrightarrow$ Battle between

  Order ...

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Low T organizes things (solidifies, condensates, ...)

What does temperature do?

- A good story always needs battle between Good and Evil, Order and Chaos.
  Physics of Many Particles $\Longrightarrow$ Battle between
  Order ... and Chaos

Low T organizes things (solidifies, condensates, ...)
High T breaks things (melts, boils, ...)

What happens when things get hotter and hotter?

What happens when things get hotter and hotter?

What happens when things get hotter and hotter?

Things “melt”.

Why do things melt?

Because they are shaken!

Why do things melt?

Animation by Ing. Mario Valle (CSCS), Data from Davide Donadio, Computational Science, Department of Chemistry and Applied Biosciences, ETH Zürich.

Because they are shaken!

Hotter yet!

Double, double toil and trouble
Fire burn, and caldron bubble.

Things boil!

Movie by Viorel Mihalef, Rutgers

Hotter yet!

Double, double toil and trouble
Fire burn, and caldron bubble.

Things boil! Movie by Chamot Labs, inc.

How hot is a flame?

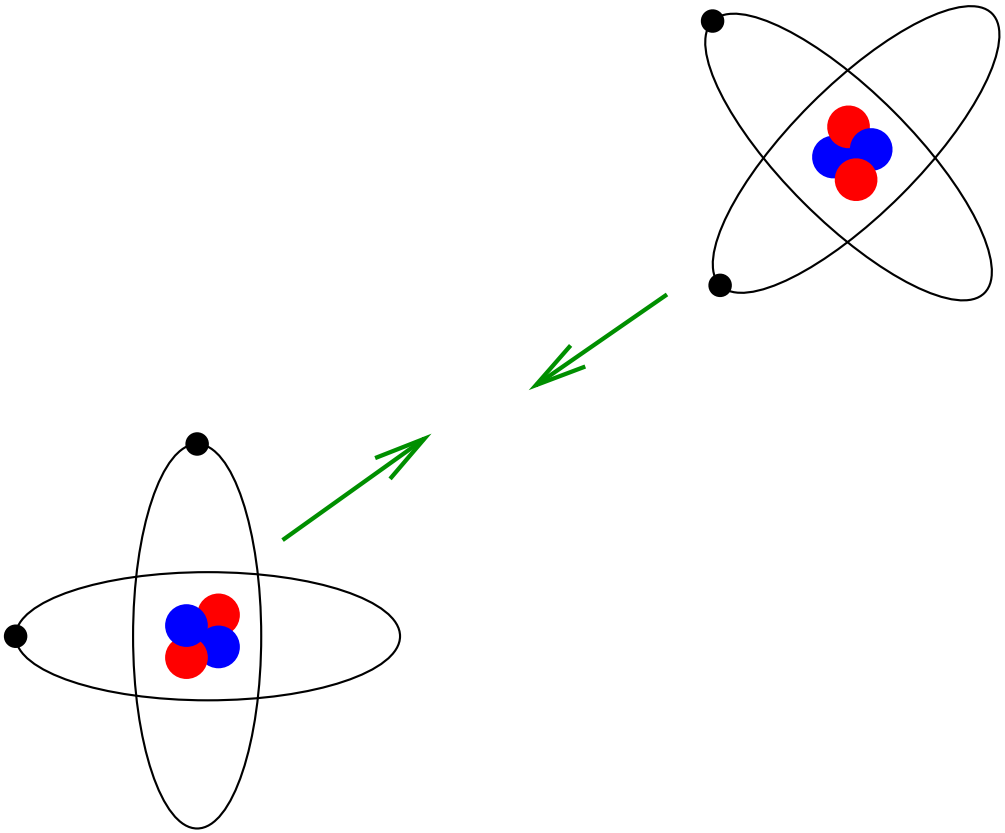
- Temperature obtainable by “burning fuel” (chemical reactions): Up to $10,000\,^{\circ}\mathrm{C}$.[1]

$\sim 2000\,^{\circ}\mathrm{C}$

$5,000 - 10,000\,^{\circ}\mathrm{C}$

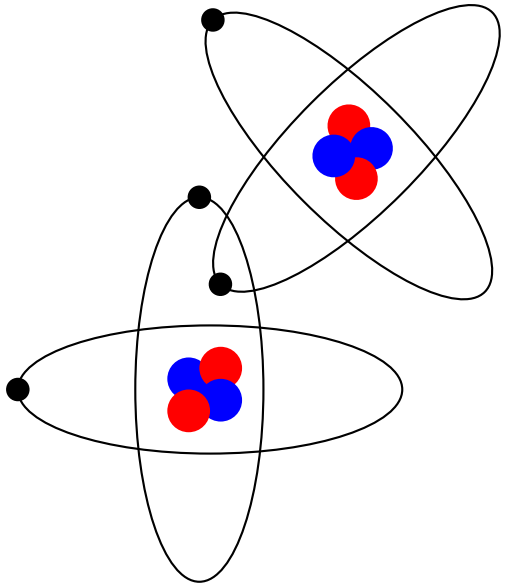
[1] Tungsten melts at $3400\,^{\circ}\mathrm{C}$ and boils at $5560\,^{\circ}\mathrm{C}$.

Way too hot!



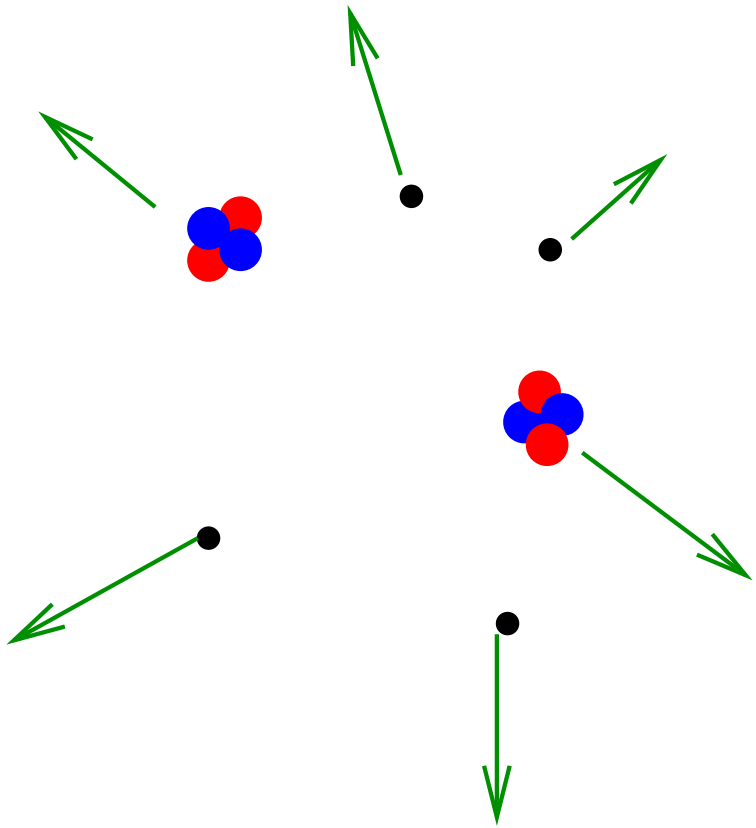
At few thousand °C, atoms have enough energy to ...

Way too hot!



collide...

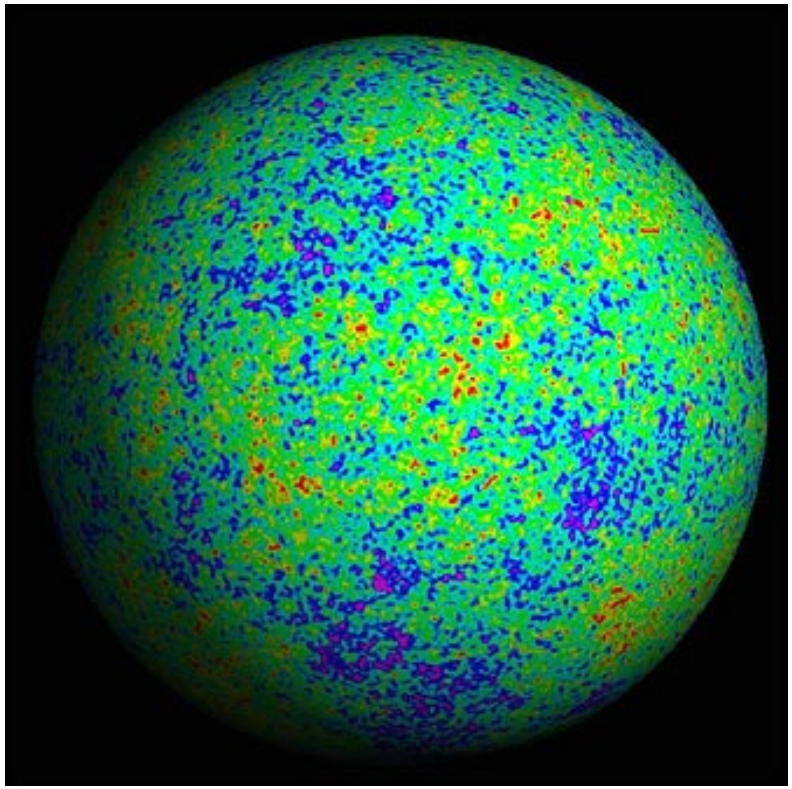
Way too hot!



and break up into nuclei and electrons

Way too hot!

- Few thousand °C was the temperature when the universe was only a few hundred thousand years old.



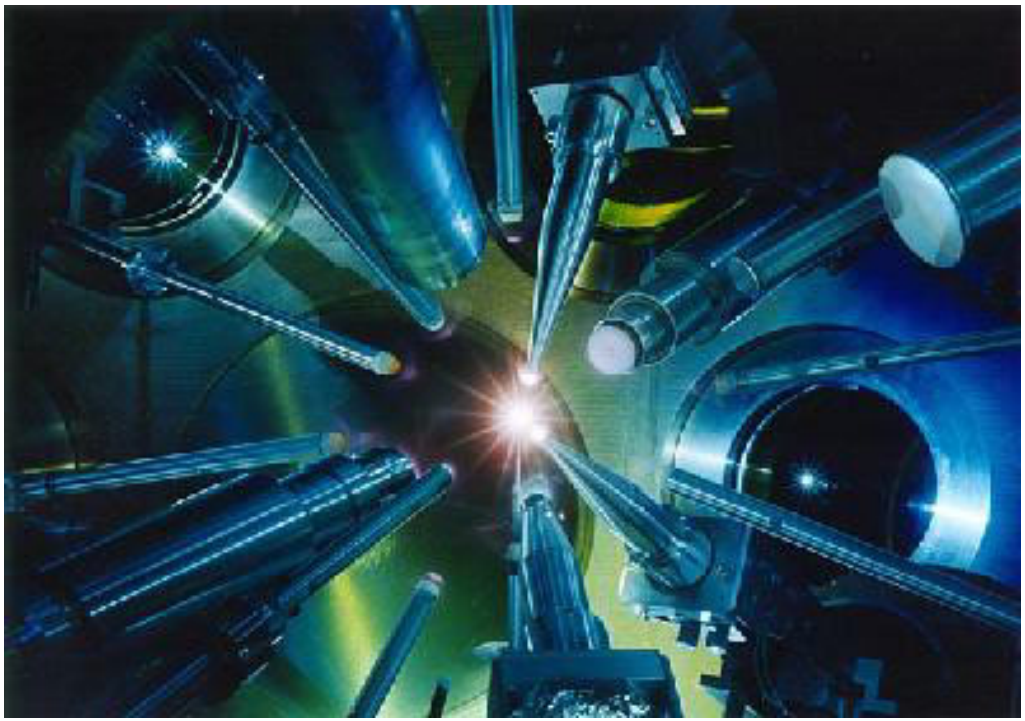
- Here is the snap shot at that age. Can't see beyond that.
- Current estimate of the age of universe: 14 billion years.

How can you make hotter temperature than any flame?

- Temperature = Energy. So dump enough energy into a system and let it cook.

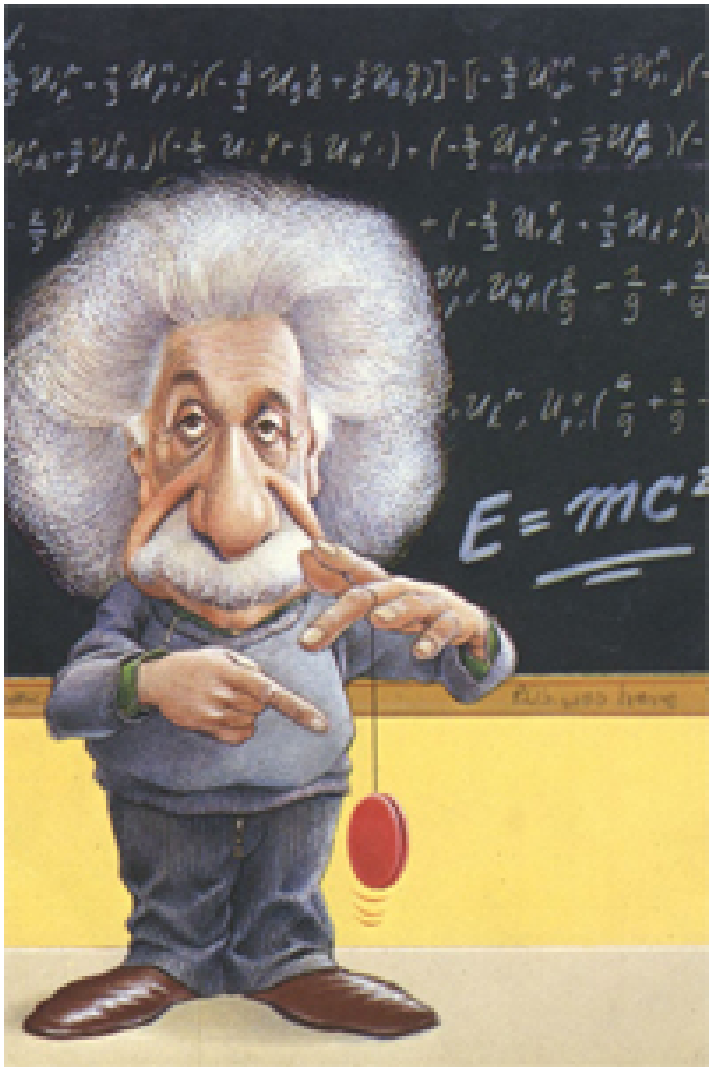
How can you make hotter temperature than any flame?

- Temperature = Energy. So dump enough energy into a system and let it cook.
- Can use electricity, laser, etc. to provide “enough” energy.



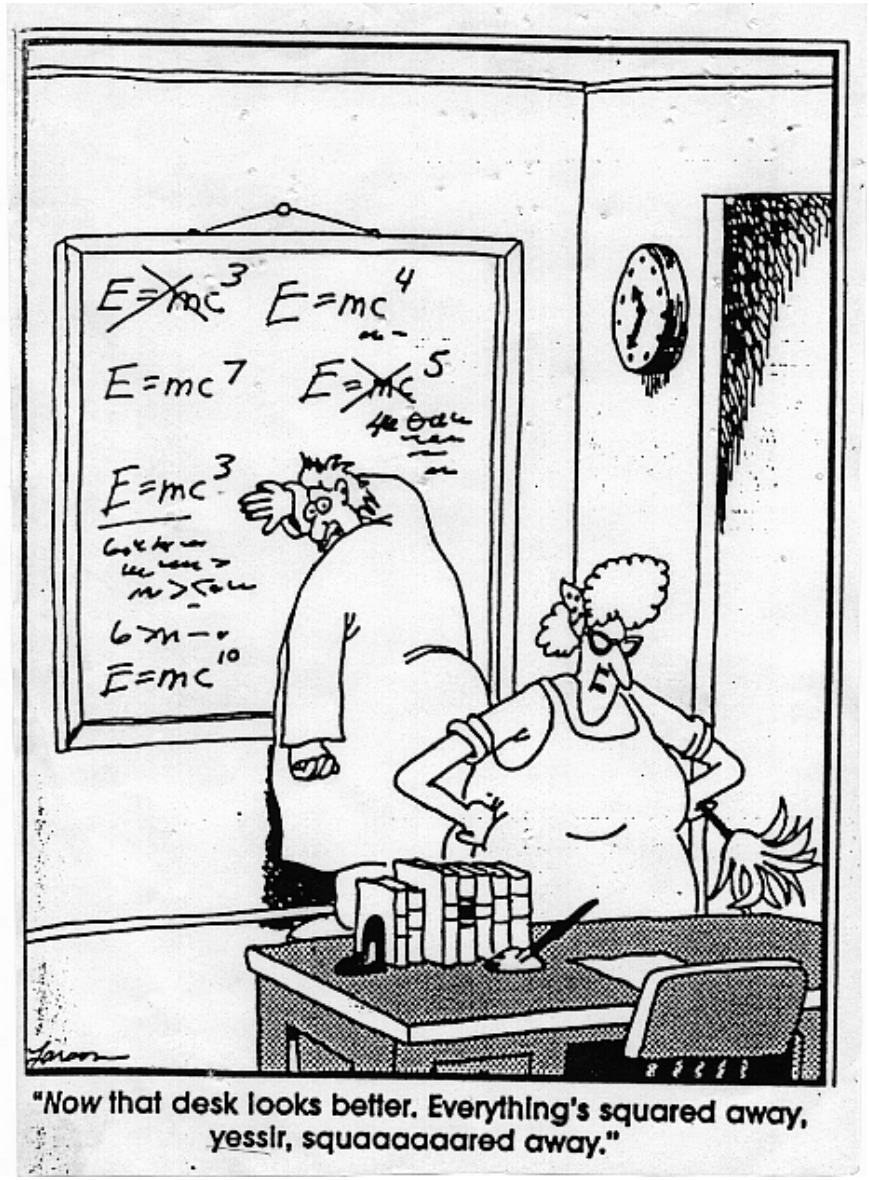
Lasers at the Omega Exp (Nuc. Fusion), U of Rochester

Hot! I mean *really* hot!



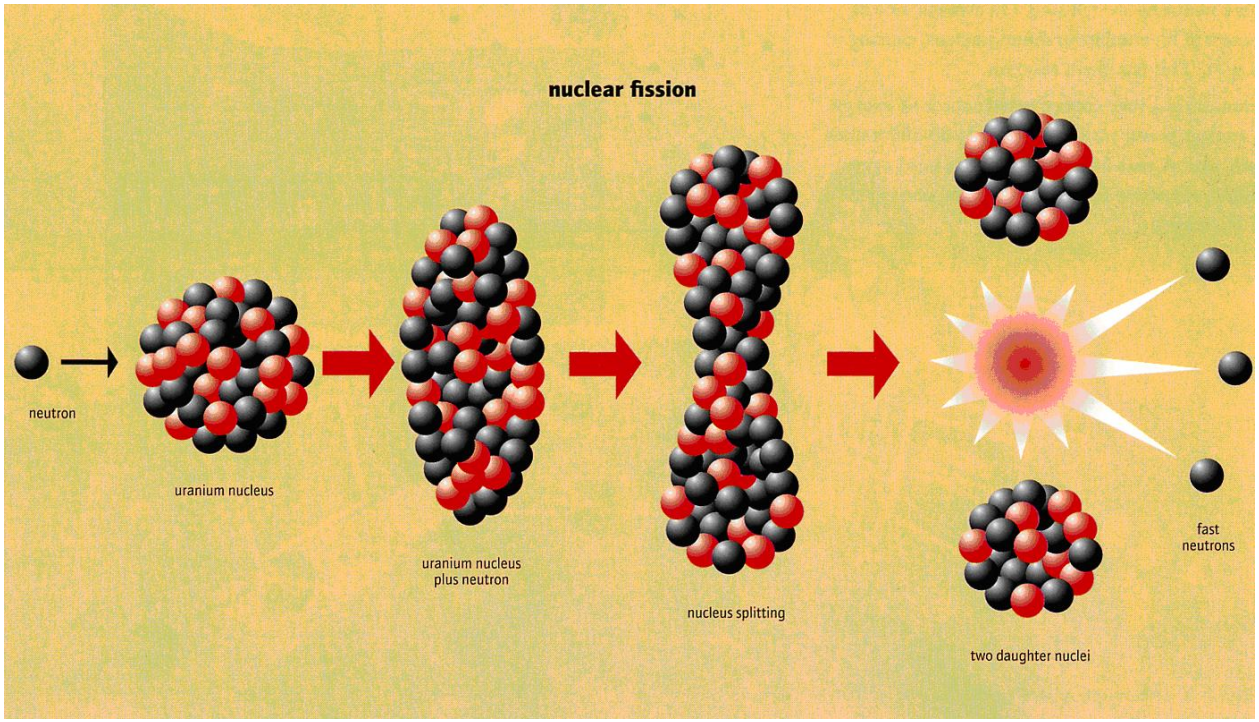
Happy Birthday, Big Al!

Hot! I mean *really* hot!



Hot! I mean *really* hot!

- $E = mc^2$
- Atomic reaction can convert mass into energy.



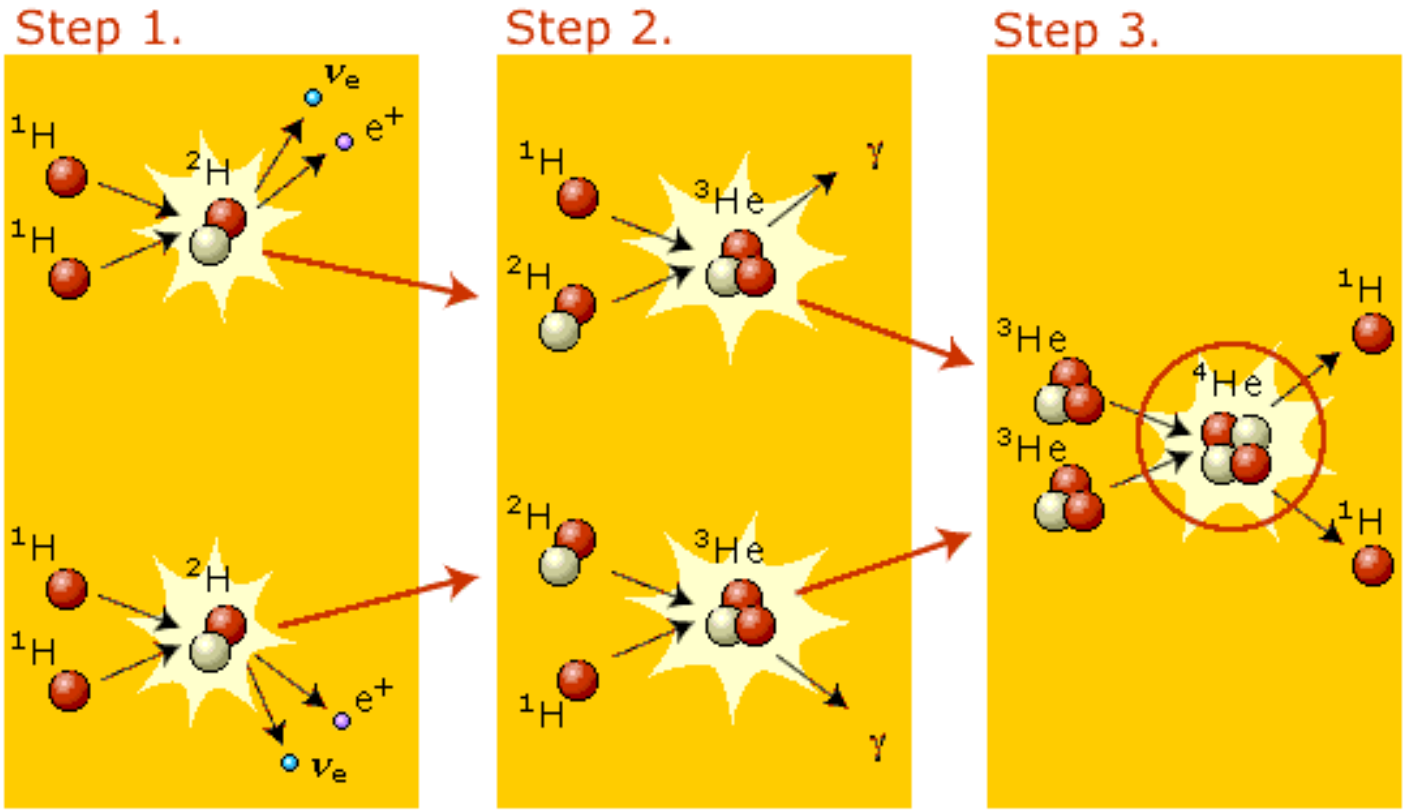
- This is a lot of energy since the speed of light c is so big.

Hot! I mean *really* hot!

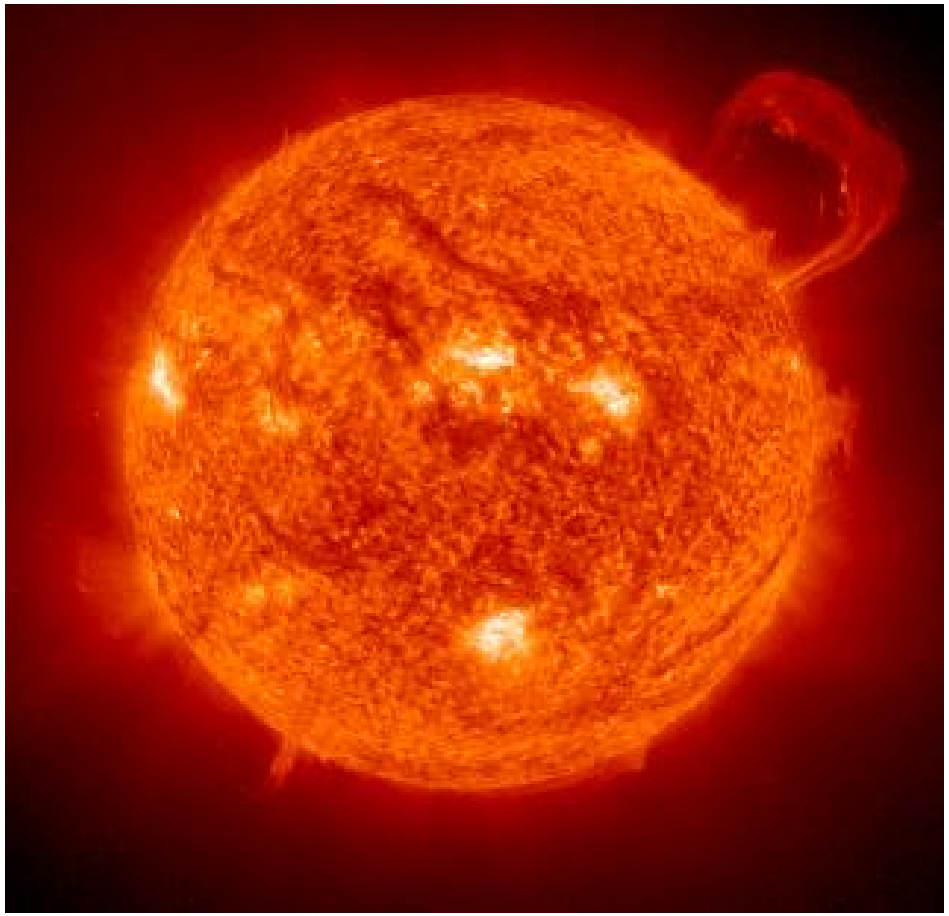
Millions of °C

Hot! I mean *really* hot!

Nuclear Fusion releases more energy



Hot! I mean *really* hot!



Tens of millions °C at the core
About 6000 °C at the surface

Hot! I mean *really* hot!

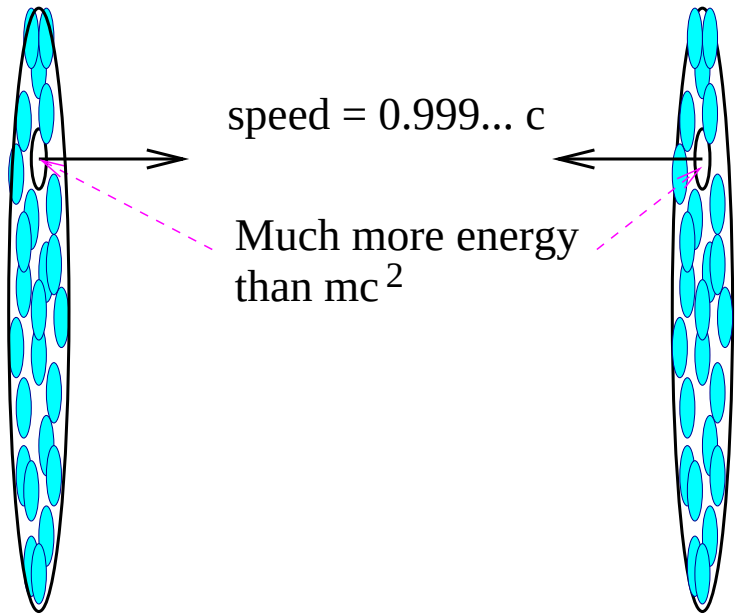
- Millions of °C $\Longrightarrow$ The universe was only about few years old.
- Tens of Millions of °C $\Longrightarrow$ The universe was only about few months old.
- To go back more, you need hotter temperature.

Hot enough for you?

Hot enough for you?

- How do you make thing hotter still? $\Longrightarrow$ How do you cram a lot more energy into a small system?

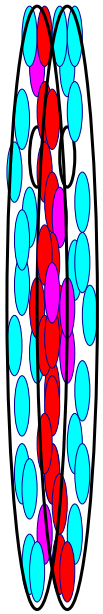
Accelerate ...



Hot enough for you?

- How do you make thing hotter still? $\Longrightarrow$ How do you cram a lot more energy into a small system?

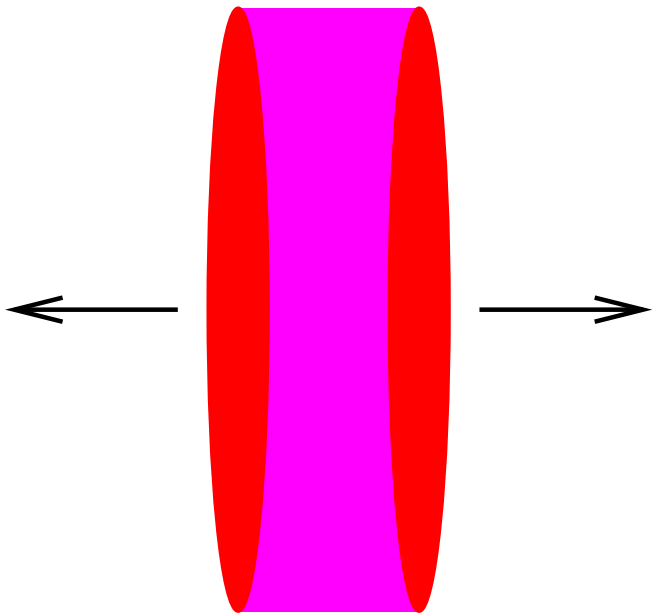
and smash!



Hot enough for you?

- How do you make thing hotter still? $\Longrightarrow$ How do you cram a lot more energy into a small system?

... and cook.



Hot enough for you?

- Nuclear collision in action

Hundreds of Million °C

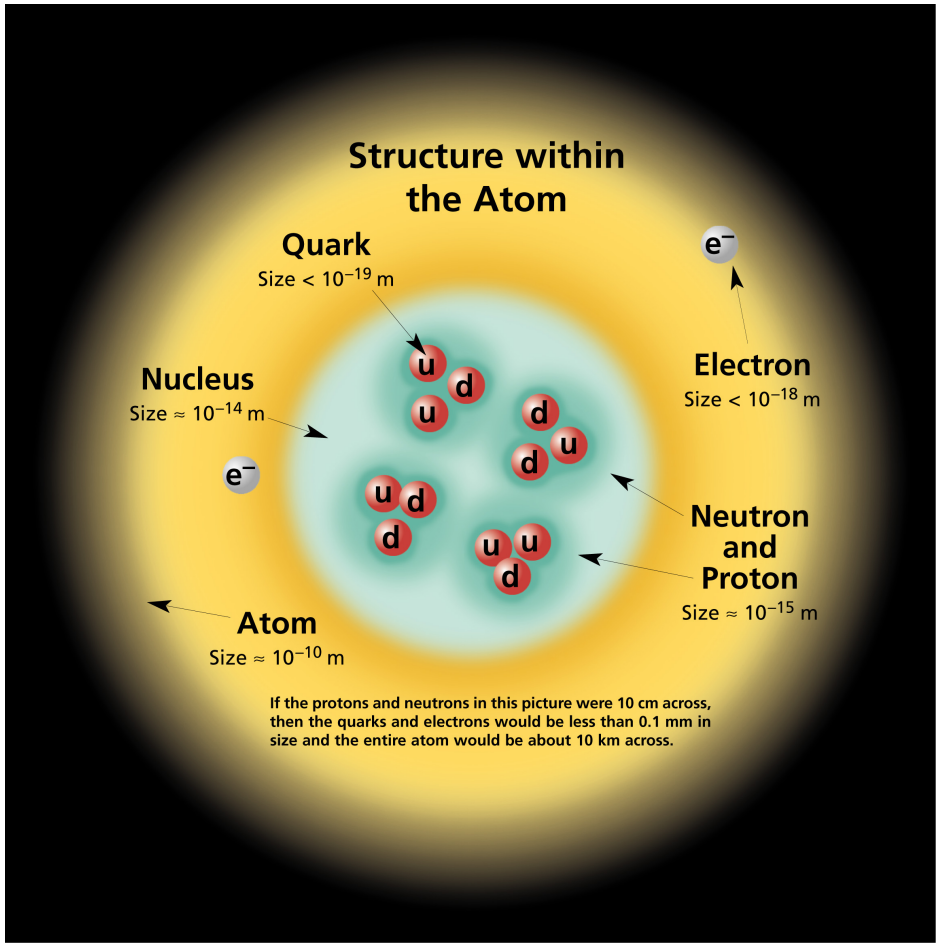
Hot enough for you?

- Going up in energy...

Few Trillion °C

Hot enough for me! – Hottest ever since the Big Bang!

Nucleus is made of quarks and gluons



Hot enough for me! – Hottest ever since the Big Bang!

Ordinary matter has paired up quarks

Hot enough for me! – Hottest ever since the Big Bang!

Pump up the volume (I mean, energy)!

Hot enough for me! – Hottest ever since the Big Bang!

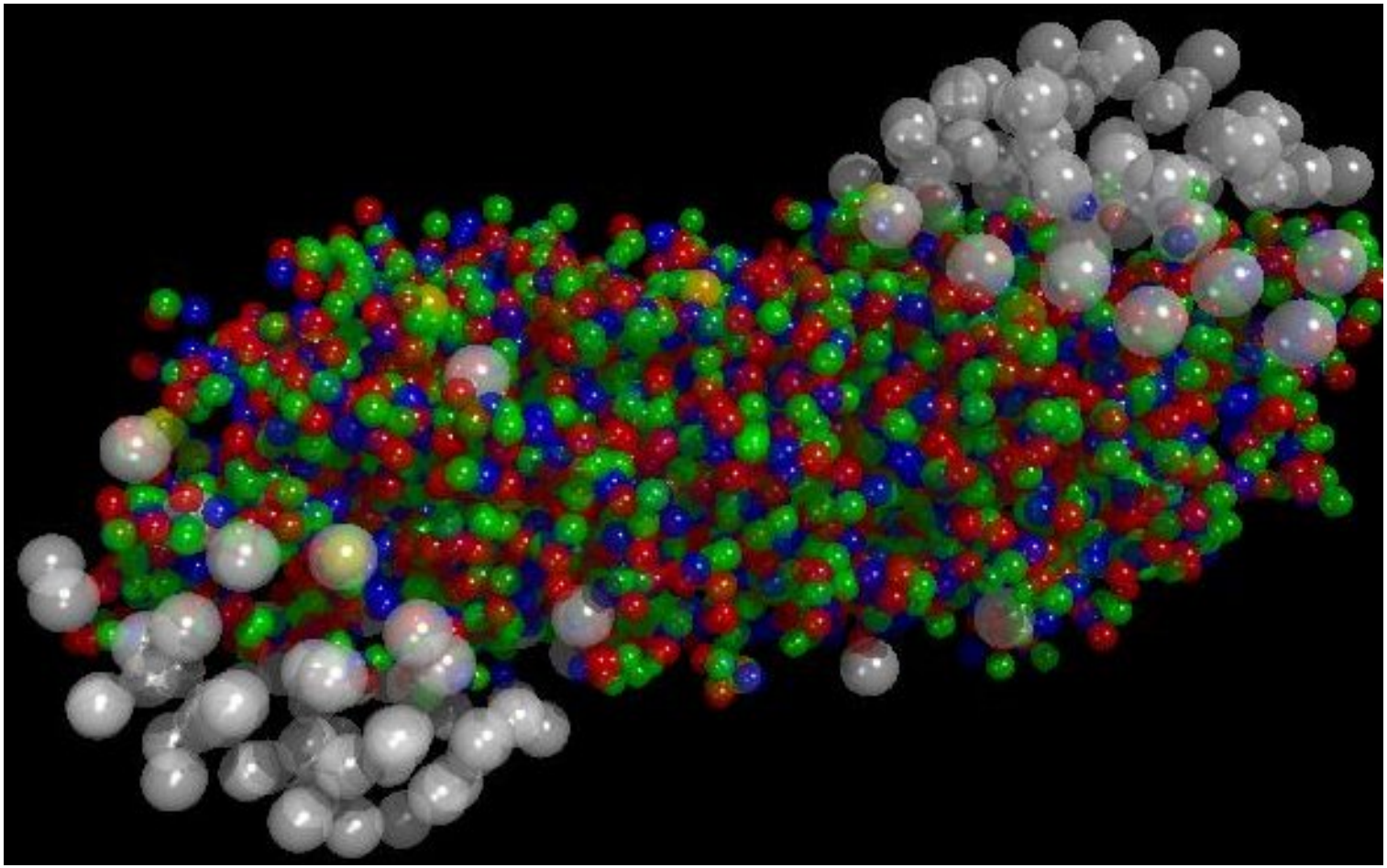
Some times, unexpected things (collective behaviors) do happen...

Hot enough for me! – Hottest ever since the Big Bang!

Some times, unexpected things (collective behaviors) do happen...

Hot enough for me! – Hottest ever since the Big Bang!

When $T \sim$ Trillion °C, nucleus melts into Quark-Gluon Plasma!



April 19, 2005

At One Trillion Degrees, Even Gold Turns Into the Sloshiest Liquid

By KENNETH CHANG

It is about a trillion degrees hot and flows like water.

Actually, it flows much better than water.

Scientists at the Brookhaven National Laboratory on Long Island announced yesterday that experiments at its Relativistic Heavy Ion Collider - RHIC, for short, and pronounced "rick" - had produced a state of matter that is unexpectedly sloshy.

"Every substance known to mankind before would evaporate and become a gas at two million, three million degrees," said Dr. Dmitri Kharzeev, a theoretical physicist at Brookhaven. "So the big surprise here is the matter created at RHIC is a liquid."

It even approaches the best of all possible liquids, with almost no viscosity. "It's more fluid than the water in this glass," Dr. Kharzeev said, referring to a glass of water in front of him at a news conference at a meeting of the American Physical Society in Tampa, Fla.

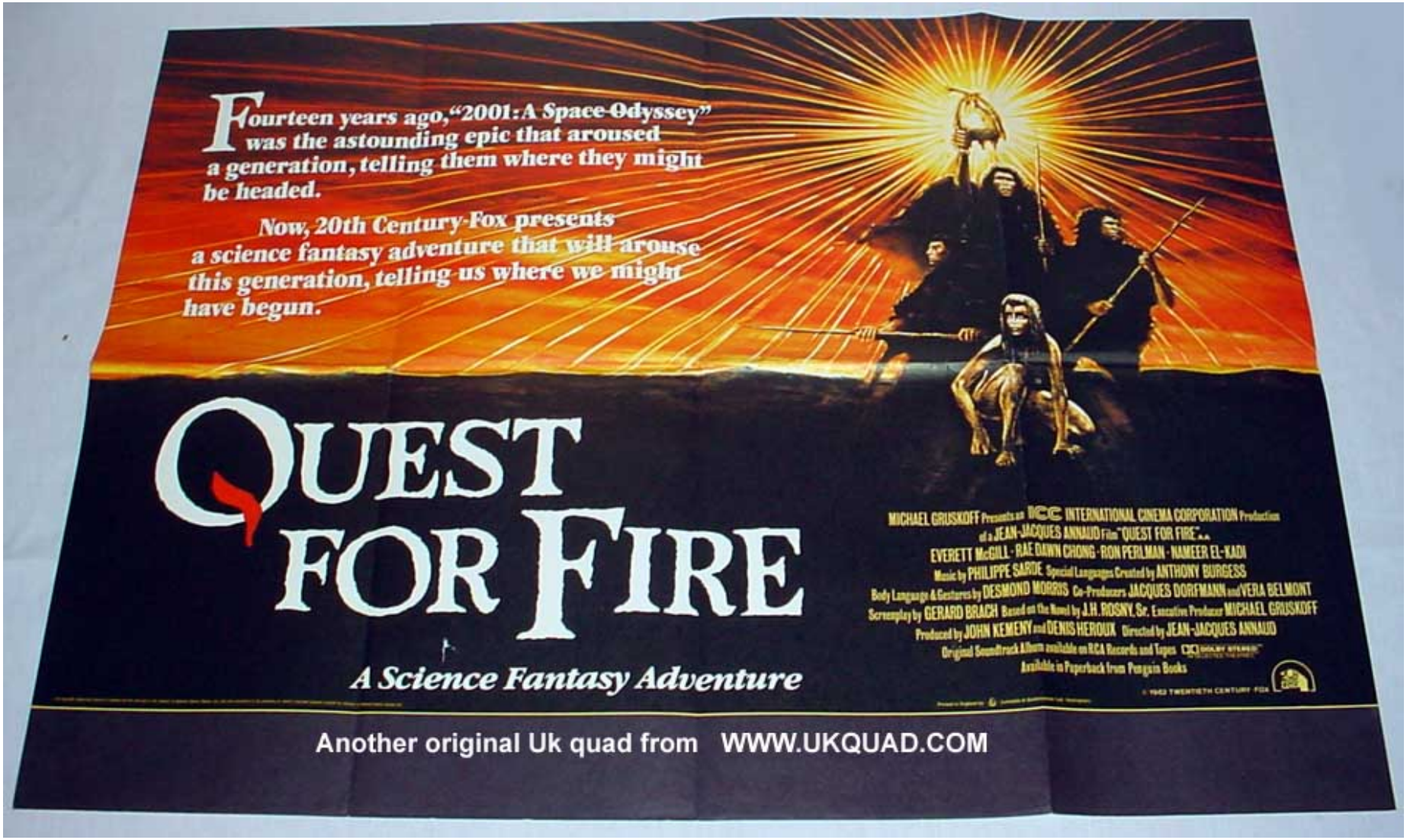
Four scientific papers totaling hundreds of pages and analyzing three years of data from the RHIC have been accepted for publication in the journal Nuclear Physics A.

But as they have for the last couple of years, the scientists stopped short of announcing that they had created a subatomic soup known as quark-gluon plasma, the impetus for building the $600 million collider.

Hot enough for me! – Hottest ever since the Big Bang!

- Few trillion °C $\Longrightarrow$ The universe was only about few micro-seconds old. (Few hundreds million °C $\Longrightarrow$ The universe was only about few hours old.)
- Hottest ever since the Big Bang! (It's a Little Bang.) To go back more, you need yet hotter temperature.

Quest for fire



Quest for fire

Few hundred degrees

Quest for fire

Few thousand degrees

Quest for fire

GSI: 10 - 100 Million degrees

Quest for fire

SPS: Trillion degrees

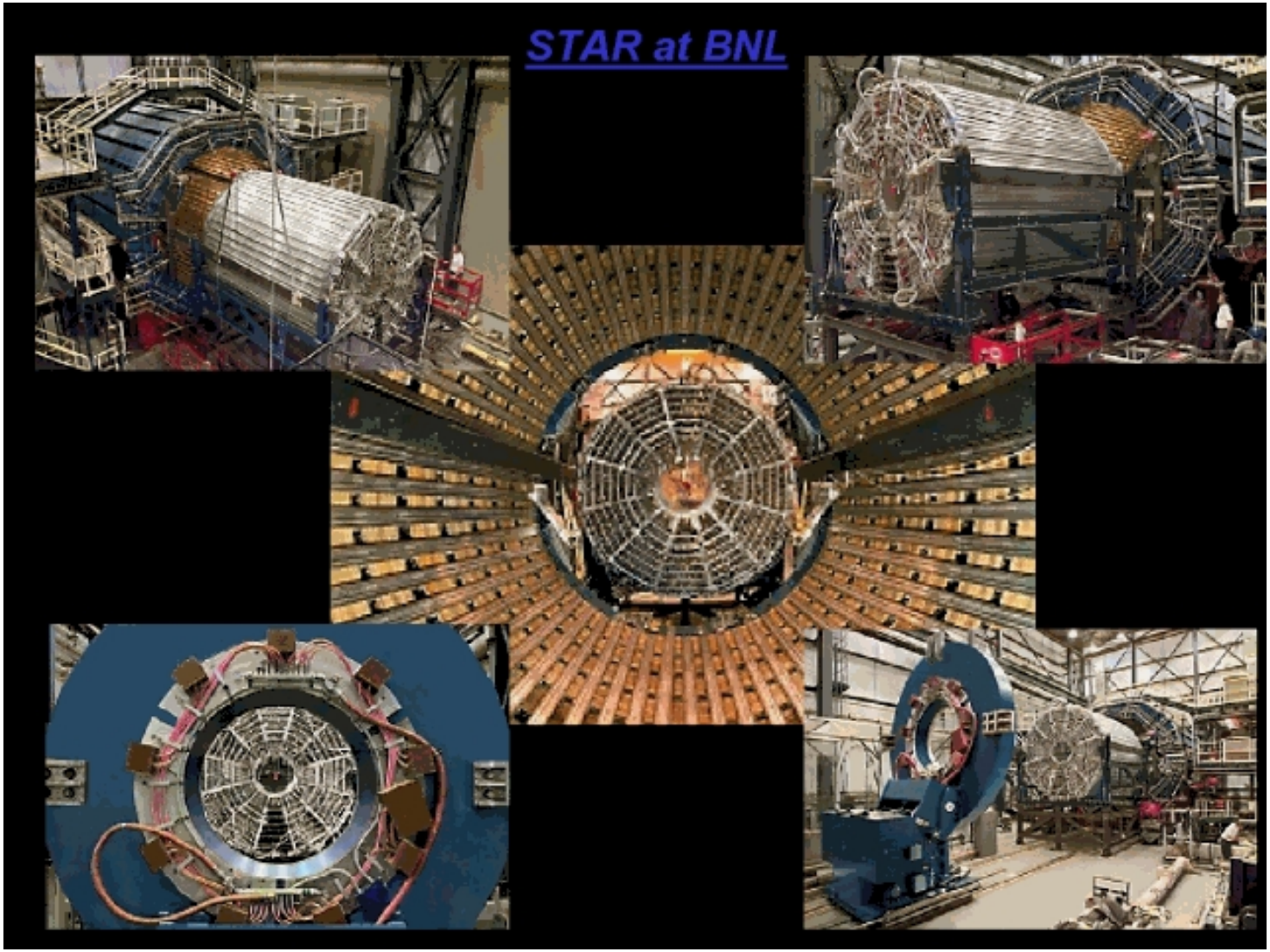
Quest for fire

RHIC:

Quest for fire

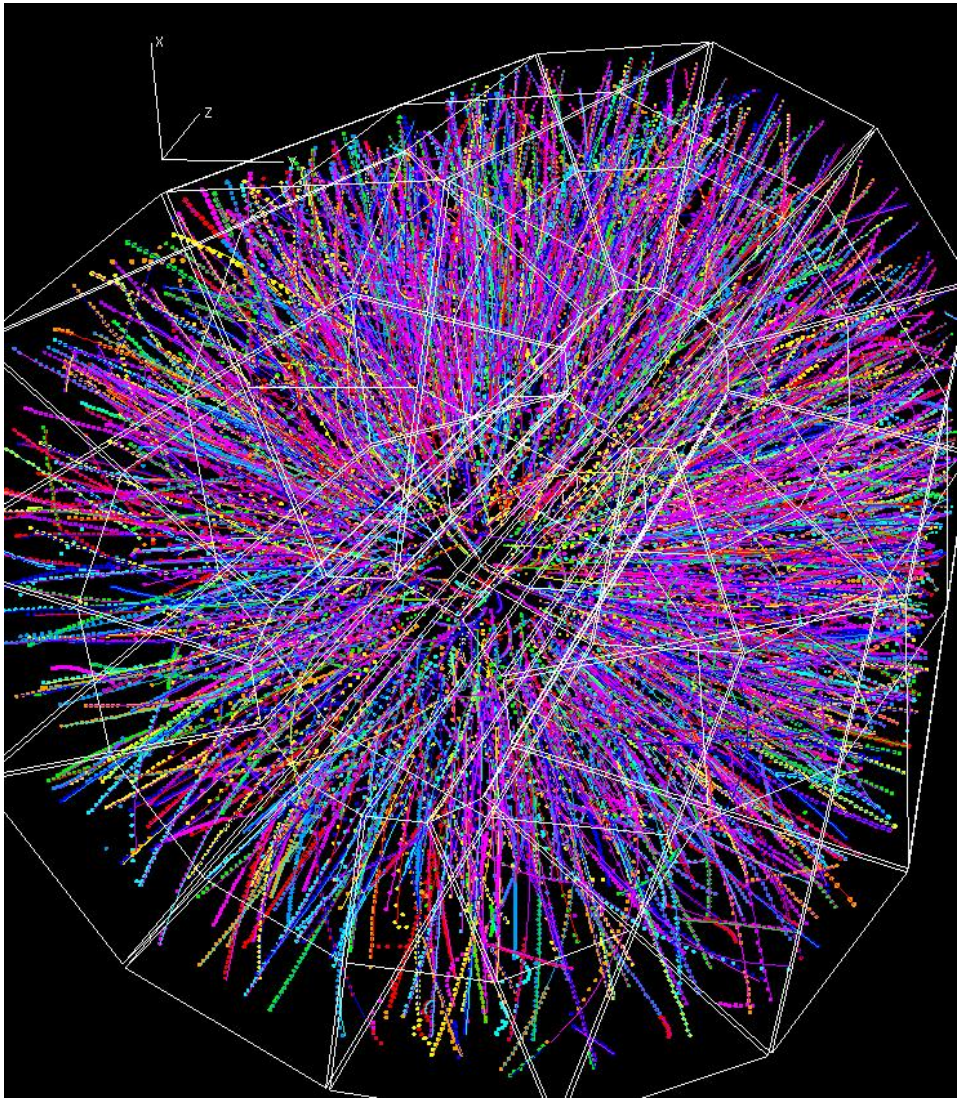
RHIC:

To see the fire



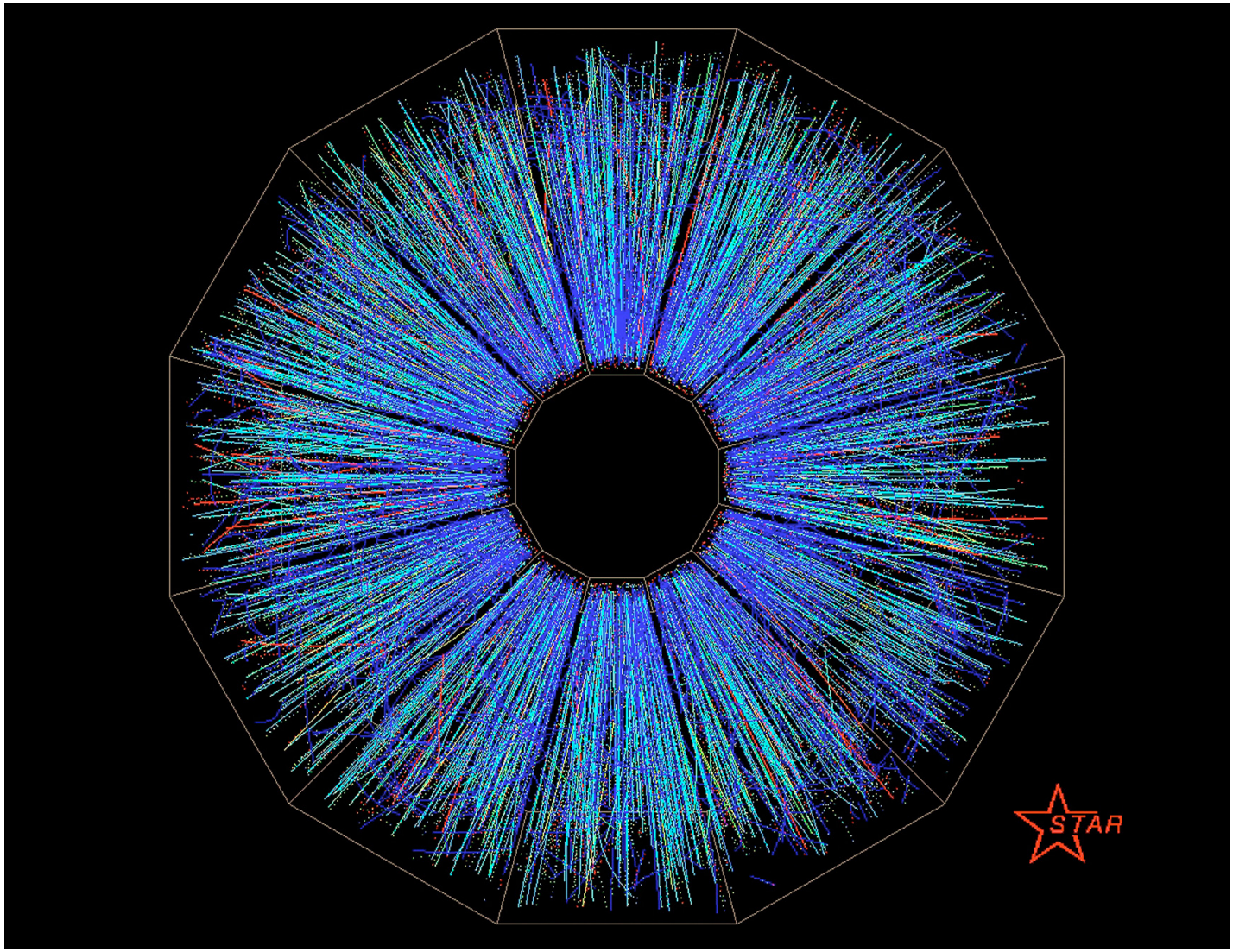
RHIC:

Hottest flame ever!



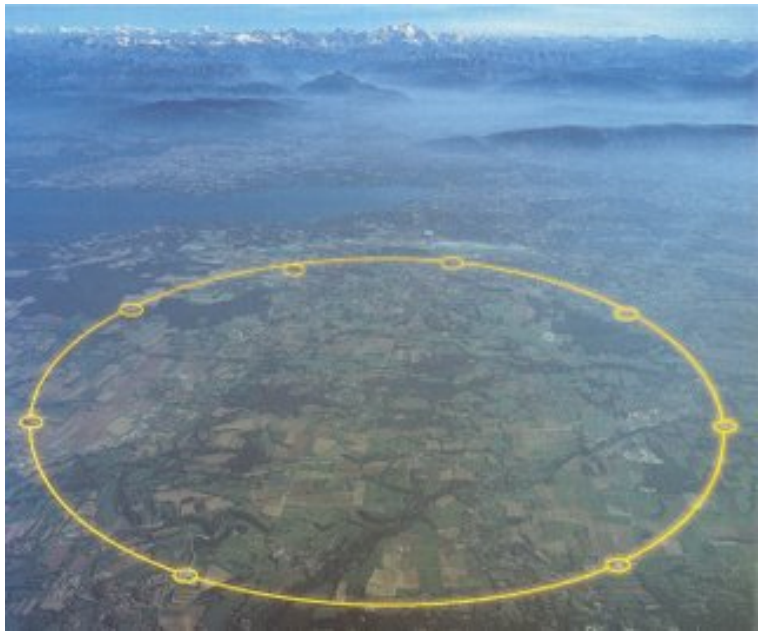
RHIC:

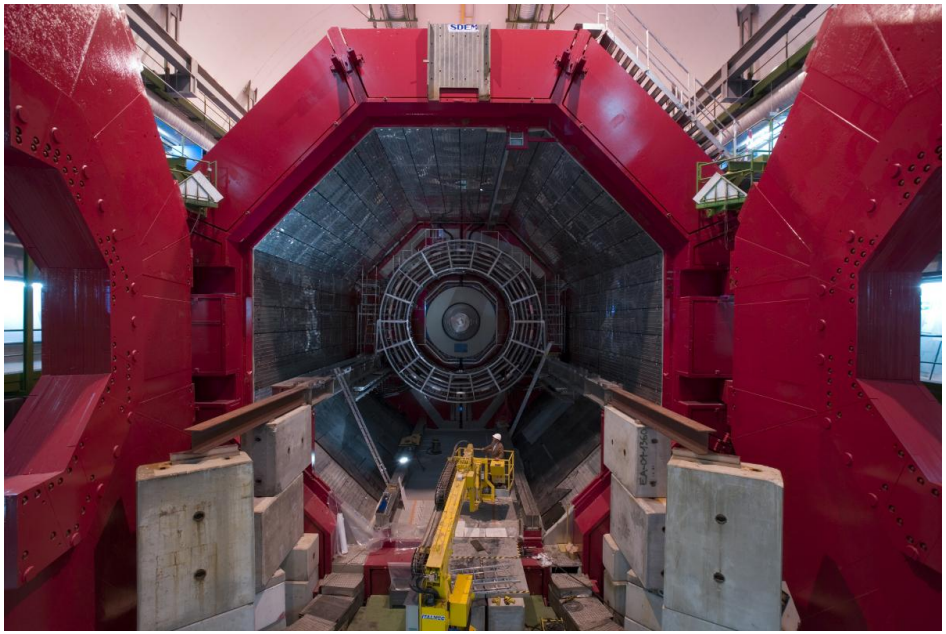
Hottest flame ever!



RHIC:

Hotter, hotter!





LHC ALICE

Up to tens of trillion K!

Quest for disaster?

THE SUNDAY TIMES: NEWS

July 18 1999 BRITAIN

Ready for blastoff: a Brookhaven engineer puts finishing touches to the ion collider

Next: Aitken fights auction of his private letters

Big Bang machine could destroy Earth

by Jonathan Leake
Science Editor

RHIC

Quest for disaster?

Nobelprize.org

The Nobel Prize in Physics 2004

"for the discovery of asymptotic freedom in the theory of the strong interaction"

David J. Gross

1/3 of the prize

USA

University of California, Kavli Institute for Theoretical Physics
Santa Barbara, CA, USA

b. 1941

H. David Politzer

1/3 of the prize

USA

California Institute of Technology (Caltech)
Pasadena, CA, USA

b. 1949

Frank Wilczek

1/3 of the prize

USA

Massachusetts Institute of Technology (MIT)
Cambridge, MA, USA

b. 1951

Titles, data and places given above refer to the time of the award.
Photos: Copyright © The Nobel Foundation

He started it!

Quest for disaster?

Quest for disaster?

Science

Department of Inadvertent Astrophysics

The fallacy of the black hole in Switzerland that would swallow Earth.

By Gregory Mone | January 2004

Nathan Fox

A reader asks: "I heard that a new particle accelerator might create black holes. Won't these end up destroying Earth and everything on it?"

The planet is safe. (From particle accelerators, anyway.) While there is a slight chance that the Large Hadron Collider (LHC), a next-generation particle accelerator scheduled for completion in 2007, could produce black holes, they will certainly not be of the planet-swallowing variety. No, these would be about a million times smaller than the nucleus of an atom, and they'd "evaporate" -- essentially disappear -- in roughly 10-27 seconds. Apologies to the doomsday crowd, but the LHC won't be powerful enough to produce anything more threatening.

A quasi-controversy of this type first made the rounds

But ...

This is the way the world ends

This is the way the world ends

This is the way the world ends

Not with a bang but a whimper.

– T.S. Elliot, Hollow Men