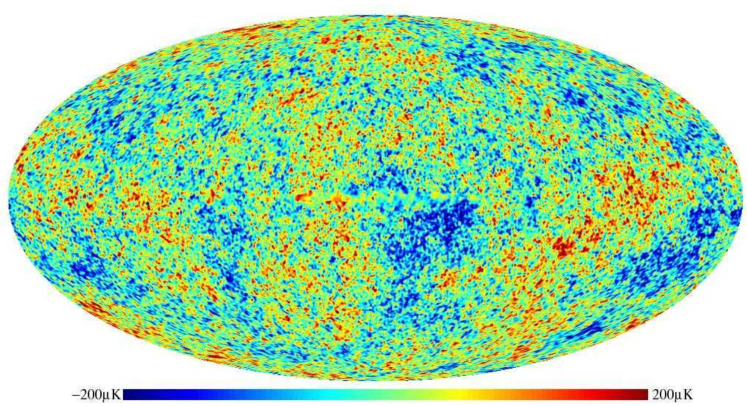
Brightly Shines the Quark-Gluon Plasma

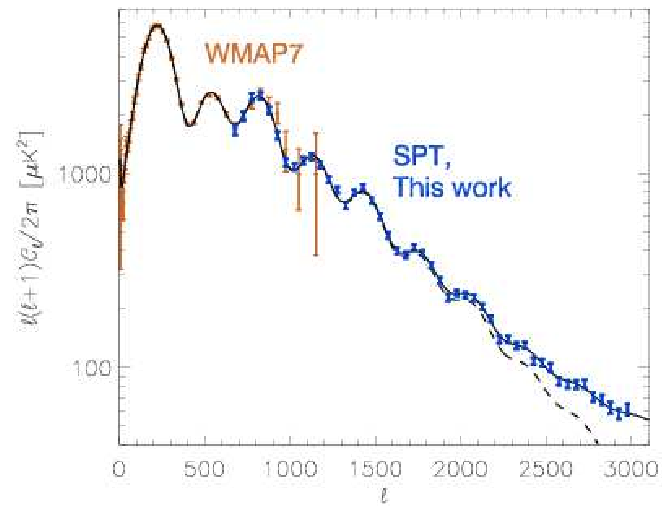
- Review of the Big Bang picture
- How hot was the early Universe?
- Can we reproduce similar conditions in the lab?
- How do you study what you make in the lab?

Hubble 1929: Stellar physics + observations of distant galaxies $\Rightarrow$ Universe is expanding.

Expanding objects cool. Early Universe was hot vs. 2.7K today

Atomic physics: when $T > 3000$K, atoms shredded into ions. Specific prediction for "Glow" of distant universe.

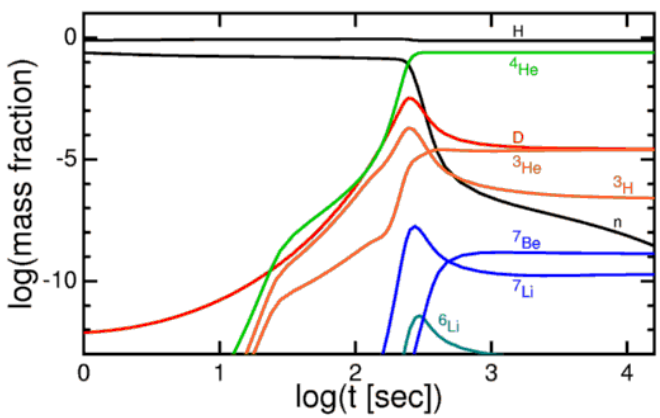


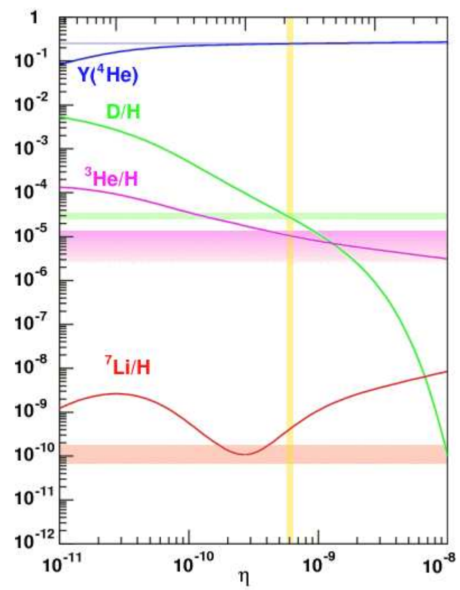


Fits perfectly. Universe was 3000K at 380,000 yr age.

Can we go back earlier? At $T =$6,000,000,000K, atomic nuclei also shredded into neutrons+protons.

3 minutes age: cooling Universe $\Rightarrow$ nuclei formed. Known nuclear physics. Predicts 76% H, 24% He,...





Again, works perfectly.

Earlier? At 2,400,000,000,000K (10 microsec), protons and neutrons shredded into quarks and gluons. What then?

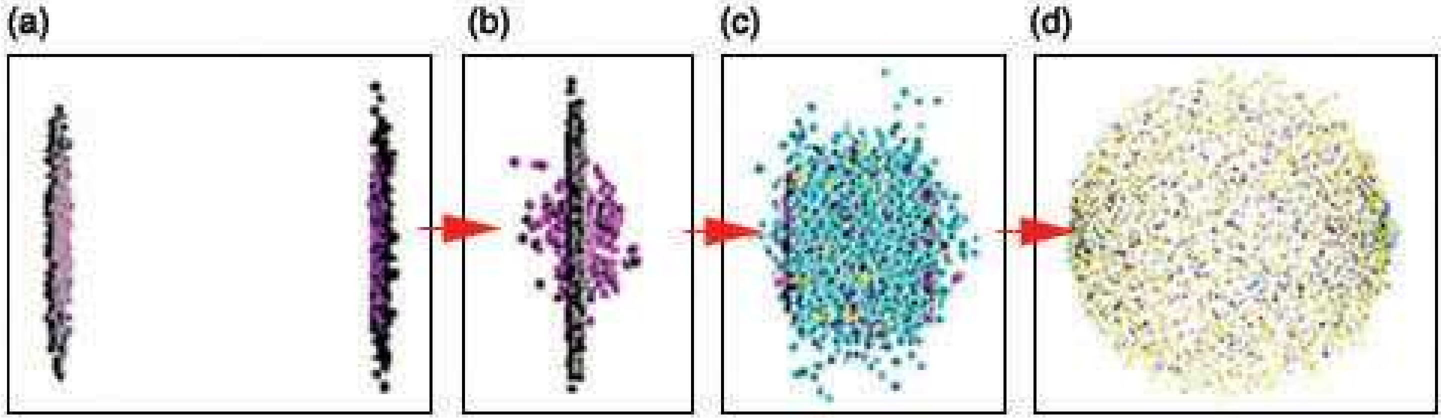
To understand consequences in Universe, need to understand physics holding together protons,neutrons: Theory known: Quantum Chromodynamics.

$$\mathcal{L} = \frac{1}{4g^2} \sum_{A=1...8} G^A_{\mu\nu} G^{\mu\nu}_A + \sum_{f=1...3} \bar{\Psi}_{fa} (i\gamma^\mu \partial_\mu \delta_{ab} + \gamma^\mu A_{A\mu} T^A_{ab} + m_f \delta_{ab}) \Psi_{fb}$$

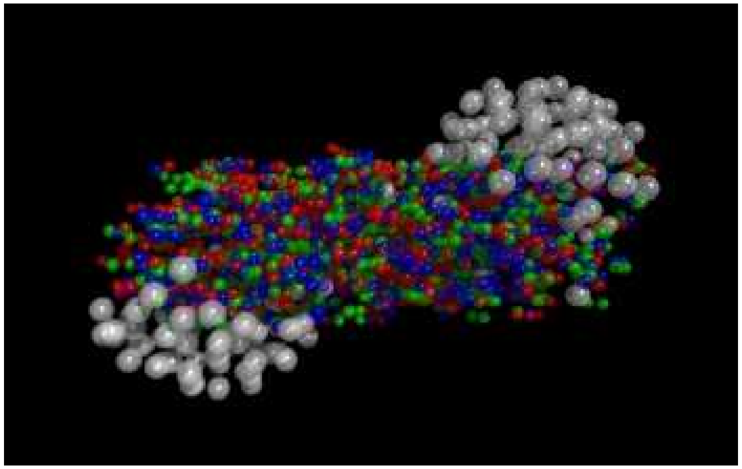
Theory says early Universe should have been in phase called Quark-Gluon Plasma. Theory less advanced than atomic physics: experiments less advanced than atomic or nuclear.

Study Quark-Gluon Plasma directly: let's make some!

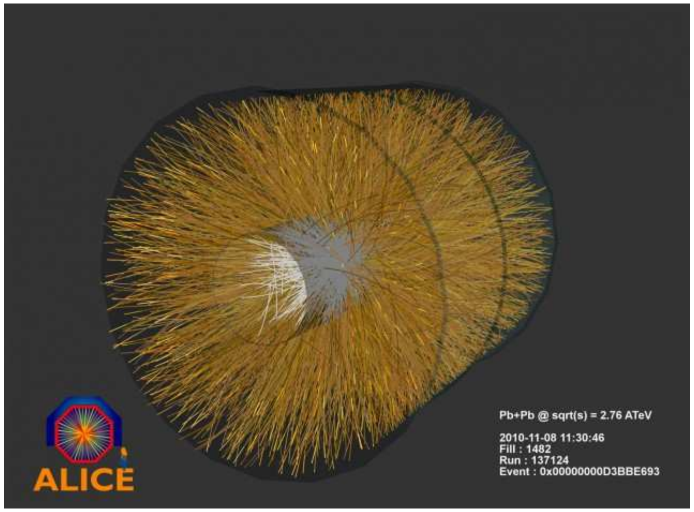
Collide nuclei at high energy:



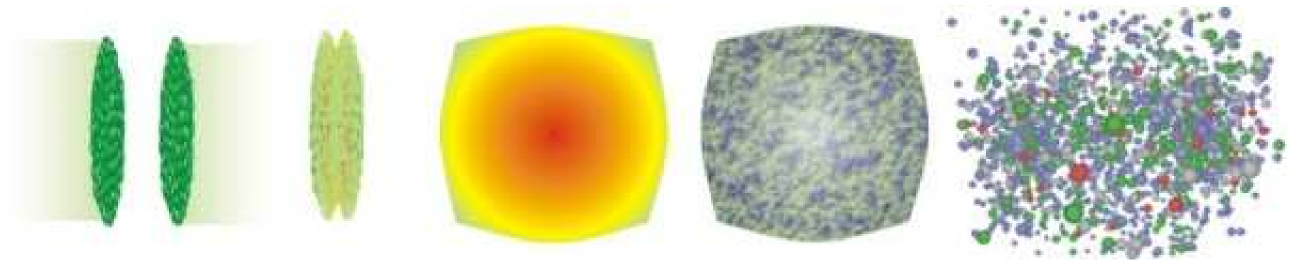
Another artist's impression



Detector sees: .

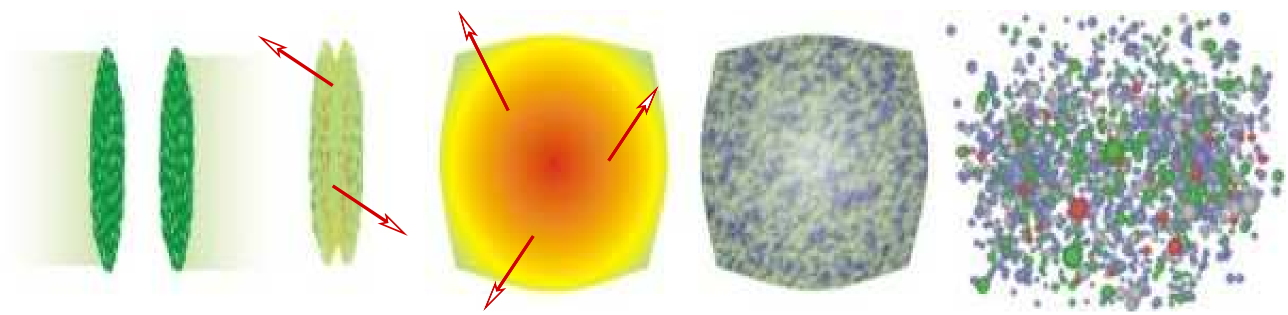


Collision goes through stages



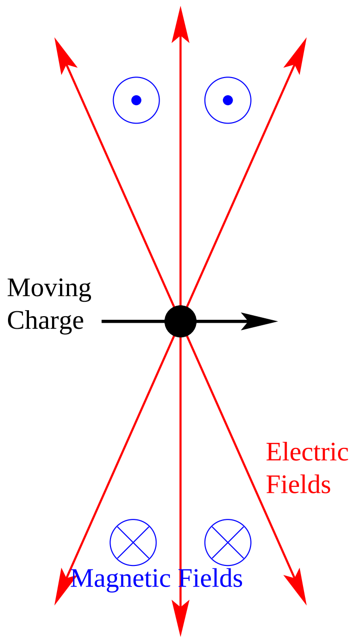
most info about early stages is destroyed by later ones.

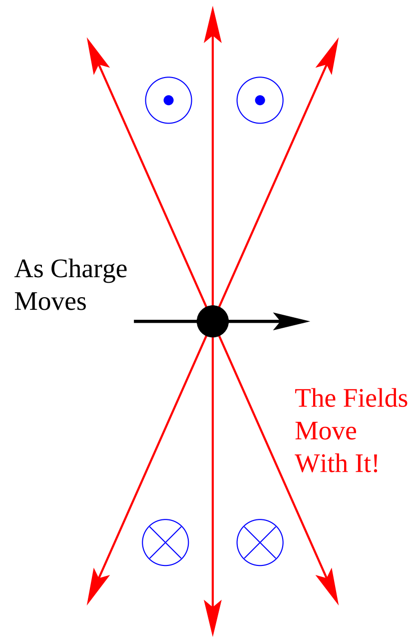
Something which escapes from the earliest times: photons



Computing photon production, comparing with experiment is excellent probe of what goes on at the highest temperatures.

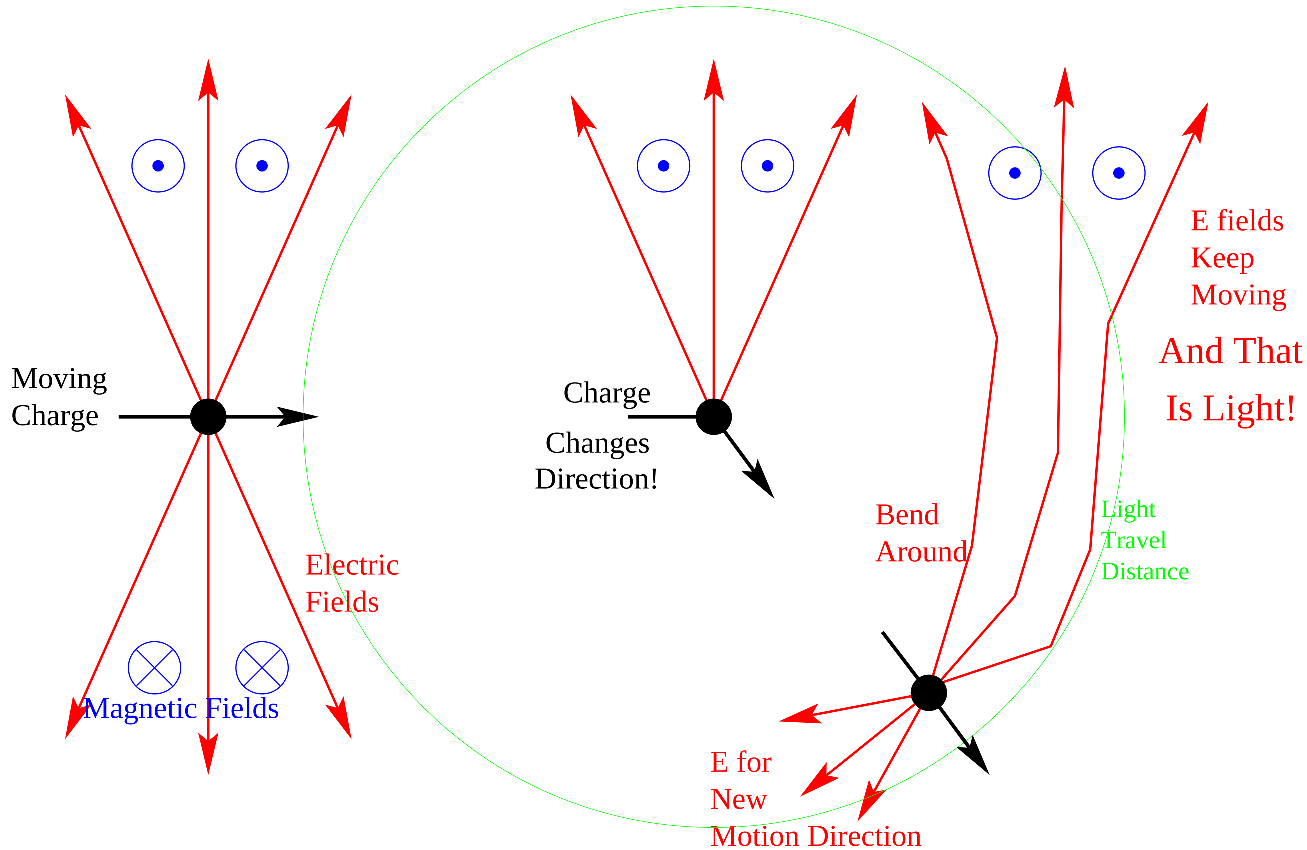
Where light comes from





Charges have $\mathbf{E}$, $\mathbf{B}$ fields, which move with charge. $\mathbf{B}$ "helps" $\mathbf{E}$ field move.

If charge changes direction



Relativity: $\mathbf{E}, \mathbf{B}$ don't "know" until light-travel-time. They keep moving with "ghost" charge. Become radiation.

Theorist's job

- How many charges are produced in the collision? Do they get made or destroyed over time?
- How often, how violently do they change direction?
- Interference effects between different direction changes? Between different charges?
- Other sources of gamma rays?