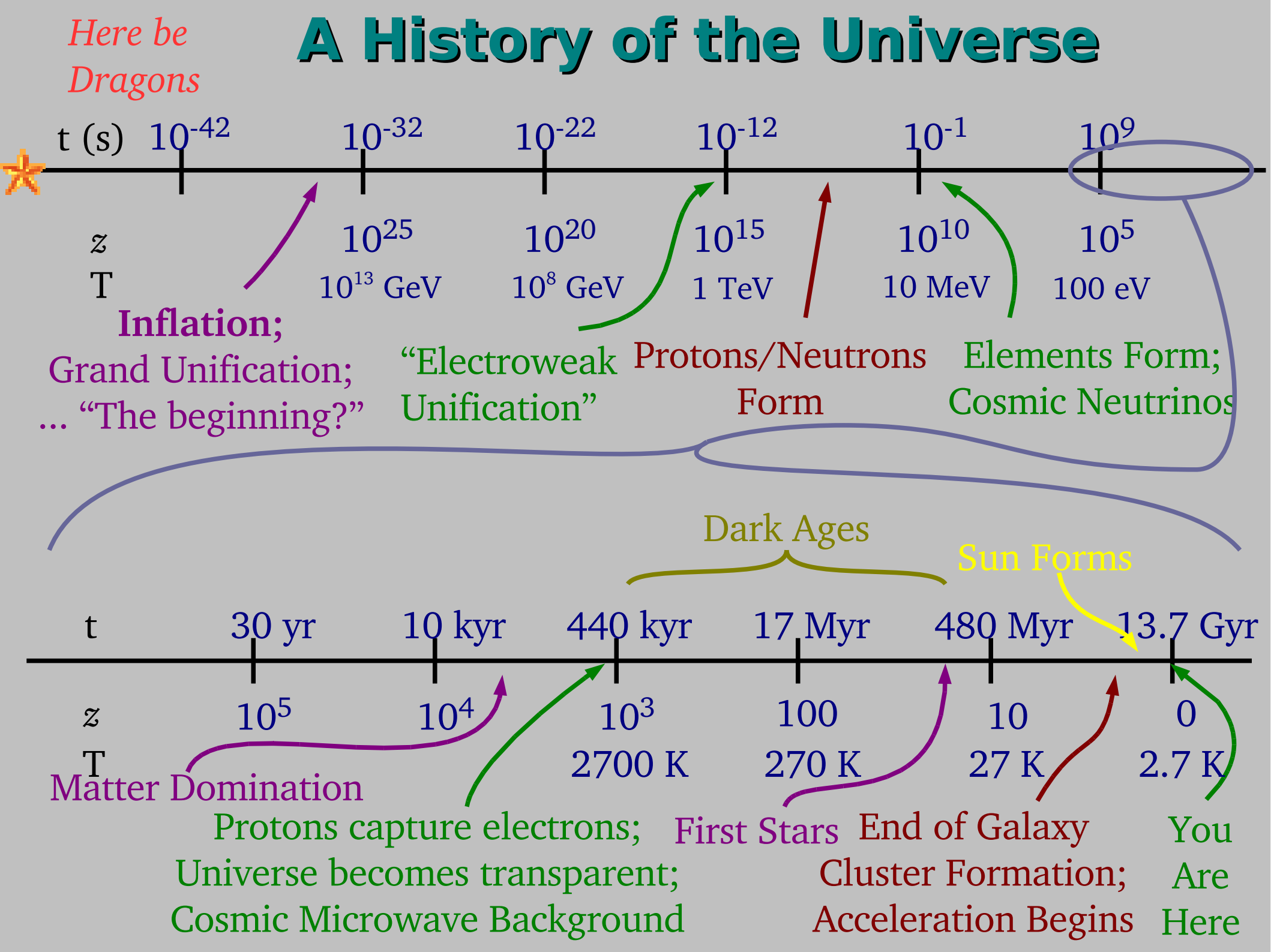
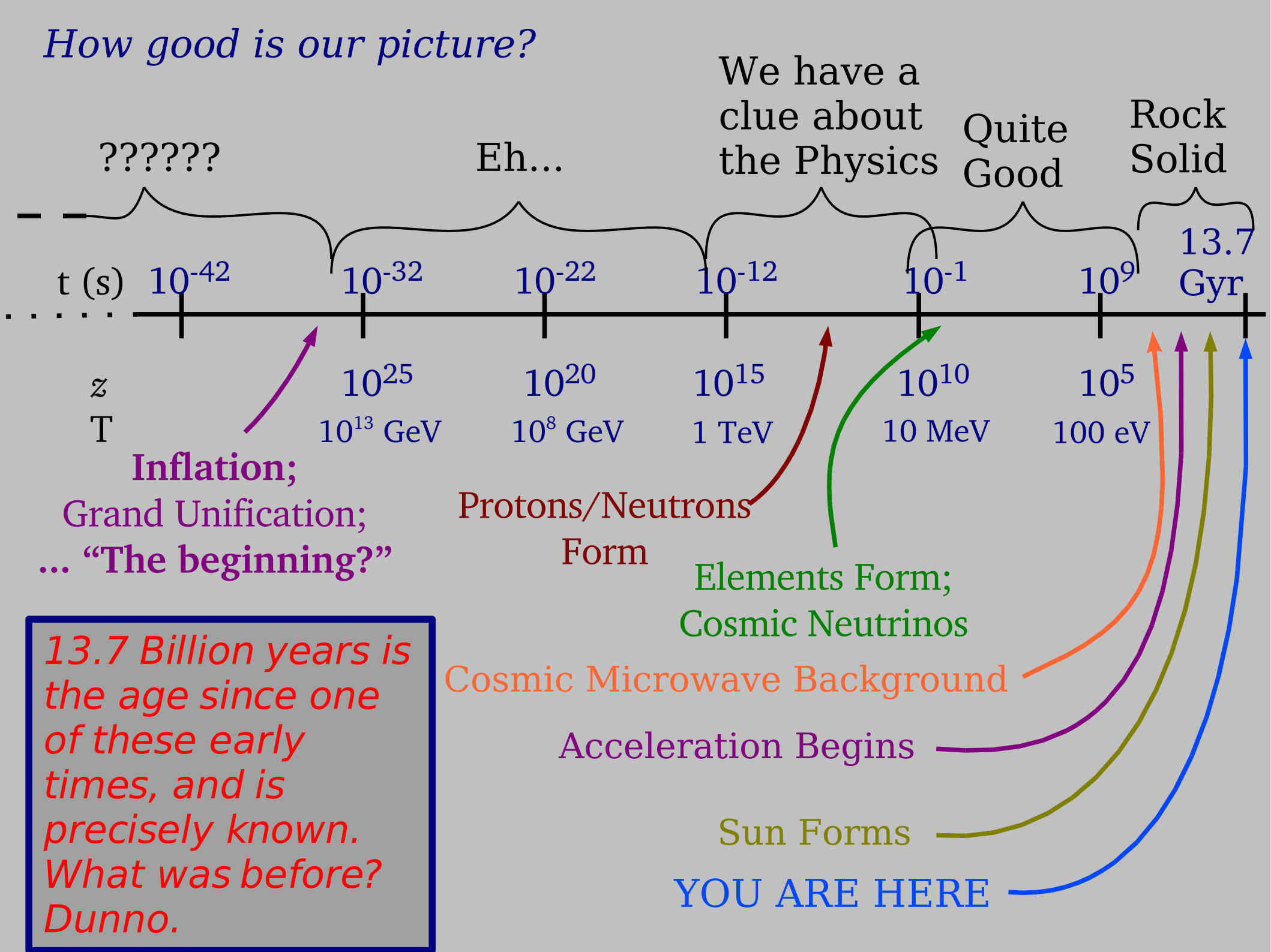

Here be Dragons
A History of the Universe
t (s)
10-42
10-32
10-22
10-12
10-1
109
z
T
1025
1013 GeV
1020
108 GeV
1015
1 TeV
1010
10 MeV
105
100 eV
Inflation;
Grand Unification;
... "The beginning?"
"Electroweak Unification"
Protons/Neutrons Form
Elements Form;
Cosmic Neutrinos
Dark Ages
Sun Forms
t
30 yr
10 kyr
440 kyr
17 Myr
480 Myr
13.7 Gyr
z
T
105
10
4
103
2700 K
100
270 K
10
27 K
0
2.7 K
Matter Domination
Protons capture electrons;
Universe becomes transparent;
Cosmic Microwave Background
First Stars
End of Galaxy
Cluster Formation;
Acceleration Begins
You
Are
Here

How good is our picture?



13.7 Billion years is the age since one of these early times, and is precisely known. What was before? Dunno.

How old is the Universe? How do we know?

I. Solar system age : 4.6 billion years

- Radiometric dating
  - Half-life
  - K-40/Ar-40 ratios
  - Starting ratios : Ar-40 doesn't chemically combine, only there if trapped
- Geological, evolutionary timescales
- Powering the Sun
  - Contraction : only lasts millions of years
  - **Fusion** : can last long enough
  - $E=mc^2$
  - Efficiency *eff* for various processes (chemical : 10^{-9} ; fusion, 10^{-2}); not the same as rate fuel is "used," but rate mass goes to energy.

II. All about light

- Electromagnetic spectrum
  - Wavelength and frequency, $\lambda f = c$
  - E-M spectrum :
    radio–IR–visible–UV–X-rays–Gamma rays
  - Bluer = shorter wavelength
- Photons
  - $E = hf$
- Continuum, absorption, & emission spectra
  - transitions in atoms: one photon at a time
  - abs. & emis. spectra require *low-density* gas
- Blackbody radiation
  - Bluer = hotter (higher temperature)
  - Bluer = brighter *for sources of the same size*
  - $L = A\ \sigma\ T^4 = (4\pi\ R^2)\ \sigma\ T^4$

II. All about light (continued)

- Brightness & distance
  - $B = \frac{L}{4\pi\ d^2}$
  - $B \propto \frac{1}{d^2}$
- Doppler Effect
  - Redshift z : $z = \frac{\lambda_{obs} - \lambda_{emit}}{\lambda_{emit}}$
  - Doppler effect for $v \ll c$: $z = \frac{v}{c}$
  - v>0 = receding = redshift
  - v<0 = approaching = blueshift

III. Ages of the oldest stars : 12-13 billion years

- Spectral classification : OBAFGKM
  - *All stars*: Sequence of temperature & color
  - *Main sequence stars only* : sequence of decreasing temperature, luminosity, mass
- The H-R Diagram
  - Luminosity vs. Color (or temperature)
  - Regions : main sequence, giants, supergiants, white dwarfs
  - Motion on diagram during evolution
- Stellar Evolution
  - Stages : protostar, main sequence, giant, stellar remnant
  - Endpoints for low-mass and high-mass stars (white dwarf, neutron star, black hole)
  - Lifetime: longer for lower-mass stars

III. Ages of the oldest stars (continued)

- Star clusters
  - Stars all formed at once
  - Stars all about the same distance from Earth
  - Open & Globular clusters
- The H-R Diagram of Clusters
  - Main sequence turn-off
  - Match to stellar evolution models
  - Ability to date the cluster
- Oldest globular clusters:
  - 12—13 billion years old