Early dust

Cosmic neutrinos

Erik Elfgren

Part I

Part II
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Part I
Early dust

Eagle nebula
Outline part I: Early dust

Cosmic microwave background

First generation of stars

Dust evolution

Spatial distribution

Results
Cosmic microwave background

WMAP temperature map
Cosmic microwave background

Nobel prize 2006 – CMB

John C. Mather
– Project coordinator

George F. Smoot
– Anisotropies

My research

Dust

Evolution

Distribution

Results

Theory

CMB

Stars

Dust

Neutrinos

Dust
Cosmic microwave background

Why is the CMB interesting?

Stephen Hawking: “the greatest discovery of the century, if not of all times.”

- Expansion rate
  \[ \Rightarrow \text{Age of the universe} \]

- Amount of dark matter, dark energy
  \[ \Rightarrow \text{Shape of the universe} \]

- Matter distribution at \( t = 400,000 \) years
  \[ \Rightarrow \text{Closing in on the big bang} \]

- Structure formation
  \[ \Rightarrow \text{How galaxies and stars form} \]
Cosmic microwave background

CMB

• 400,000 years after BB: 
  \( T \sim 3000 \text{ K} \)

• 13.7 billion years after BB: 
  \( T = 2.725 \text{ K} = \text{microwaves} \)

• Everywhere
  Isotropic to within \(10^{-5}\)

• Blackbody radiation
  better than the sun
Cosmic microwave background

How?

- Temperature map (whole sky)

⇒ Power spectrum = angular correlations
First generation of stars

The Sun
First generation of stars

- $z \sim 5-20$
  - $\sim 12.3-13.3$ Gyr
- Heavy
  - $\sim 100 \, M_{\odot}$
- Short-lived
  - $\sim 1$ Million years
- Metal-poor
  - $Z \sim 10^{-6}$
- Hot
  - $\sim 100,000 \, K$
- End as supernovæ
Dust

Eagle nebula

Gaseous Pillars • M16

PRC95-44a • ST ScI OPO • November 2, 1995

J. Hester and P. Scowen (AZ State Univ.), NASA

Eagle nebula
Why is cosmic dust interesting?

- Absorbs CMB light
- Emits radiation similar to the CMB
- Absorbs star light
- Comes from the first stars
Dust evolution

Orion nebula
Dust density evolution:

\[ \frac{d\Omega_d}{dt} = f_d J_* \frac{\Omega_d}{\Delta t} \]

Analytical solution, for different dust lifetimes, \( \Delta t \):
Spatial distribution

Dark matter simulation
Spatial distribution

- Dust in filaments (100 Mpc/h) $\rho_d \propto \rho_{DM}$
- Dark matter $N^3$ body simulations
- GalICS – simulation program
- $\Rightarrow$ Fairly realistic galaxies
Results

The Planck satellite
Results

Dust spectrum

\[ \Delta i_v \equiv i_v - B_v \left( T_{\text{CMB}} \right) = T_{\text{CMB}} \frac{dB_v}{dT} \bigg|_{T=T_{\text{CMB}}} \int_0^i T_d \left( \frac{T_{\text{CMB}}}{T_{\text{CMB}}} \right) d\tau \]

\[ \frac{\Delta \lambda}{\lambda} \left[ \text{Wm}^{-2} \text{sr}^{-1} \right] \text{Intensity} \]

CMB

- FIRAS
- \( \Delta t = 10 \, \text{Gyr} \)
- \( \Delta t = 1 \, \text{Gyr} \)
- \( \Delta t = 0.1 \, \text{Gyr} \)

\[ \lambda \left[ \text{mm} \right] \text{Observed wavelength} \]

Dust
Results

Detection with Planck satellite?

- Might be possible

![Angular correlation graph]

- CMB
- Local dust
- Planck total noise
- Dust $\Delta t = 10$ Gyr
- Dust $\Delta t = 1$ Gyr
- Dust $\Delta t = 0.1$ Gyr

Results

Early dust

Planck noise

Might be possible
Part II

Cosmic neutrinos

Heavy neutrino
Outline part II: Cosmic neutrinos

Standard model of particle physics

Extensions of the SM

Preons

Preons in LEP data?

Heavy neutrinos

Summary and outlook
Standard model of particle physics

Feynman diagram
Standard model of particle physics

The SM describes

- The fundamental particles
  (like electrons, quarks and neutrinos)
- The forces that govern their interactions

The SM is used to calculate

- Probability of interaction between particles
  (= cross section, $\sigma$)
- Lifetimes of unstable particles
### Standard model of particle physics

#### Fermions

<table>
<thead>
<tr>
<th>Family</th>
<th>Flavor</th>
<th>Charge</th>
<th>Flavor</th>
<th>Charge</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>$d$</td>
<td>-1/3</td>
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<td></td>
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<td>-1</td>
<td>$u$</td>
<td>2/3</td>
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<td>$s$</td>
<td>-1/3</td>
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<tr>
<td></td>
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<td>$c$</td>
<td>2/3</td>
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<tr>
<td>3</td>
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<td>$b$</td>
<td>-1/3</td>
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<tr>
<td></td>
<td>tau neutrino</td>
<td>-1</td>
<td>$t$</td>
<td>2/3</td>
</tr>
</tbody>
</table>

My research

Theory

Preons

Extensions

Dust

Neutrinos

Conclusions
Standard model of particle physics

Forces

- Electromagnetic photons – $\gamma$
- Weak $W^-$, $W^+$, $Z^0$
- Strong gluons
- (Gravitational – not included in SM gravitons)
Standard model of particle physics

Shortcomings

- > 20 arbitrary parameters
  (masses, coupling constants, mixings, CP-violation, neutrino oscillations)

- Higgs boson is not yet discovered
  (gives mass to other particles)

- Why three generations? Why same charges?

No known connections between ingredients
Extensions of the SM

Feynman diagram
Extensions of the SM

Superstring theory

• The fundamental particle is a vibrating string
• Includes gravity and all other forces
• No testable prediction

Grand unified theories

• Unifies all forces except gravity
• Predicts many new particles

Supersymmetry

• All fermions have a partner with spin = 0
• Neutralino could be dark matter
Extensions of the SM

A fourth generation?

\[ M \sim 100 \text{ GeV} \]

\[
\begin{array}{c|cc}
\text{ch} & \text{down} & \text{up} \\
\text{d} & -1/3 & 2/3 \\
\text{s} & -1/3 & 2/3 \\
\text{b} & -1/3 & 2/3 \\
\text{Q}_1, \text{Q}_2 & -1/3, 2/3 \\
\text{ν}_{e} & 0 & -1 \\
\text{ν}_{\mu} & 0 & -1 \\
\text{ν}_{\tau} & 0 & -1 \\
\text{N/L?} & 0, -1 \\
\end{array}
\]
Preons Basics

- Preons (spin = 1/2)
- Dipreons (spin = 0)
- Fermions: preon + dipreon

<table>
<thead>
<tr>
<th>Charge</th>
<th>+1/3</th>
<th>-2/3</th>
<th>+1/3</th>
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<tbody>
<tr>
<td>preon</td>
<td>α</td>
<td>β</td>
<td>δ</td>
</tr>
<tr>
<td>antidipreon</td>
<td>(αδ)</td>
<td>(αδ)</td>
<td>(αβ)</td>
</tr>
</tbody>
</table>

Leptons:
- α → ν_e, μ⁺, τ⁻
- β → e⁻, ν_µ, τ⁺
- δ → ν_κ, κ⁺, ν_κ⁻

Quarks:
- u, d, s, c
- X, b
- h, k, t

Force carriers:
- Z⁰/Z', W⁺, Z⁺
- W⁻, Z⁺/Z⁰, W⁻
- Z⁺, W⁺⁺, Z''
Preons

Features

• No Higgs boson needed

• Only three fundamental particles

• Fundamental particles are stable

• Symmetry between quarks and leptons

• Mixings explained (of neutrinos, quarks and gauge bosons)

• Lepton number conservation
  = Dipreon and energy conservation
Preons in LEP data?

OPAL event
Preons in LEP data?

Why LEP?

- Right energy scale $E_{\text{max}} \sim 210$ GeV
- Clean signal from $e^+e^-$
- (I have worked in the OPAL group)

Predictions

\[ e^+e^- \rightarrow \nu_{\kappa 2} + \nu_e / \nu_\mu \]
\[ \nu_{\kappa 2} \rightarrow e^- / \mu^+ + W^{+/–} \]
\[ W^{+/–} \rightarrow q_1 \bar{q}_2 / \ell^{+/–} \bar{\nu} \]

\[ e^+e^- \rightarrow k + \bar{b} / h + c \]
Heavy neutrinos

My research

Conclusions
Heavy neutrinos

Contribution to dark matter

• Heavy neutrinos annihilate slowly
  ➔ Most of them remain even today
  ➔ Annihilation $N\bar{N}$ still going on and gives gamma rays

\[
\frac{dn}{dT} = - \frac{dt}{dT} \left[ H(T)n(T) + \langle \sigma v \rangle_{\text{all}} (T)^2 - n_{eq}^2(T) \right]
\]

Relative neutrino density

$\Omega_{N0}$
Heavy neutrinos

Clumping enhancement

- Annihilation of $N\bar{N}$ proportional to $\rho_N^2$

- $\rho_N^2$ enhancement due to galaxies etc (Calculated with GalICS)

$$\frac{dI}{dz} = C(z) \frac{dI_0}{dz}, \quad C(z) = \sum_{\text{halos}} \frac{m_{\text{halo}} \rho_{\text{halo}}}{\rho_{\text{DM}}} + \left( \frac{m_{\text{DM}} - m_{\text{halo}}}{m_{\text{DM}}} \right)^2$$

![Graph showing clumping enhancement with and without clumping](image)

With clumping

No clumping

With clumping

No clumping
Heavy neutrinos

Gamma ray signal

- Peak at $E_\gamma \sim 1$ GeV
- $M_N \sim 100$ or 200 GeV could fit with data

$$I = \int C(T) \frac{n^2 \langle \sigma v \rangle_{\text{tot}}}{4\pi} N_\gamma \left. \frac{dn_\gamma}{dE} \right|_{E_0} \frac{dt}{dT} dT$$
Heavy neutrinos

Gamma ray signal

- $M_N \sim 100$-200 GeV excluded by EGRET
Heavy neutrinos

Finding new particles

• Weak signal

• Significant background

• Multiple variables
  (like energies, momenta, angles etc)

Monte Carlo cuts

• Change variable cuts randomly

• If better signal over background ⇒ keep

• Iterate
Summary and outlook
Summary and outlook

Summary

- Dust
- Preons
- Heavy neutrinos

Dust

1st stars ➔ Supernova ➔ Dust ➔ Star light ➔ Dust emission ➔ Planck detector

Preons

Atom ➔ Nucleus ➔ Proton ➔ Quark

Heavy neutrinos

N ➔ N
Summary and outlook

Outlook

Dust
- Collaboration with Lyon
- Dust in the first galaxies

Preons
- Neutrino oscillations
- Top decays

Heavy neutrinos
- Contribution to reionization
- Spatial correlations