Cosmic Microwave Background

Measuring the temperature of the Universe with a radio telescope

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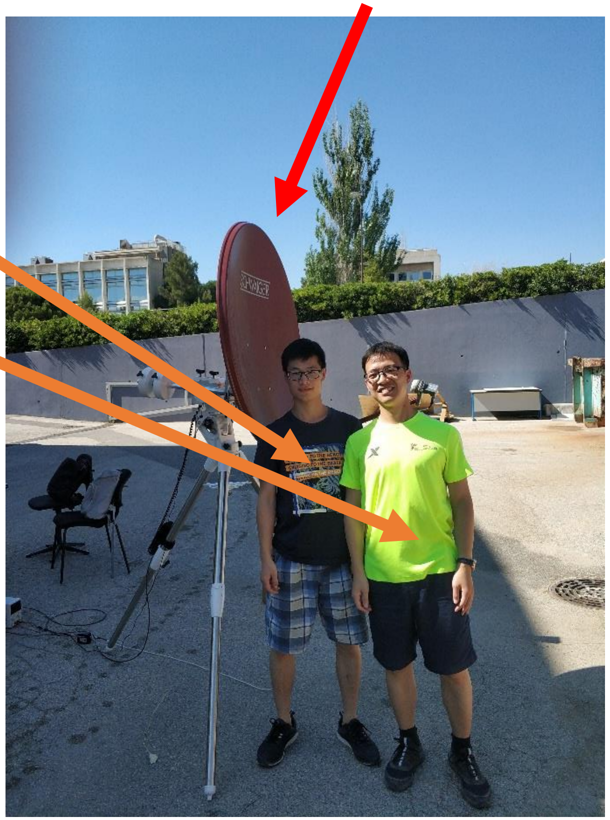
7/10/2018



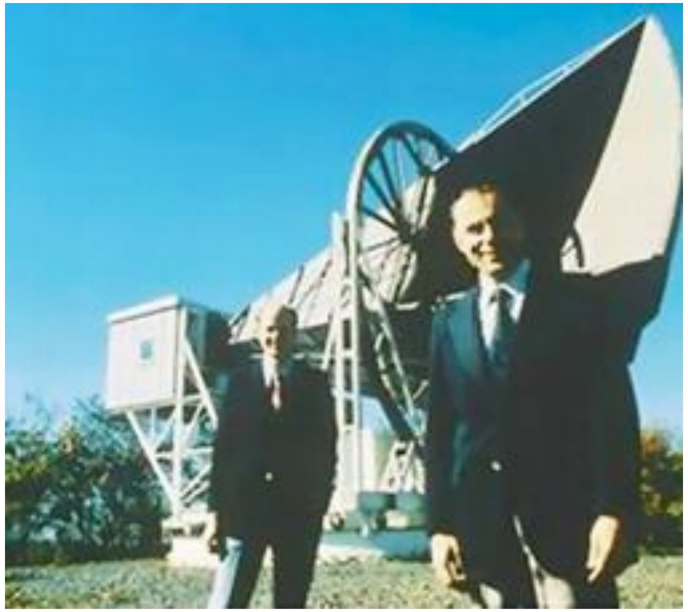
Introduction to Cosmic Microwave Background (CMB)

The Significance of CMB

- It is an image of the universe at the time of recombination (baryon-photon decoupling), when the universe was just a few hundred thousands years old (z~1100)
- The CMB frequency spectrum is a perfect blackbody at T=2.725 K: confirmation of the hot big bang model

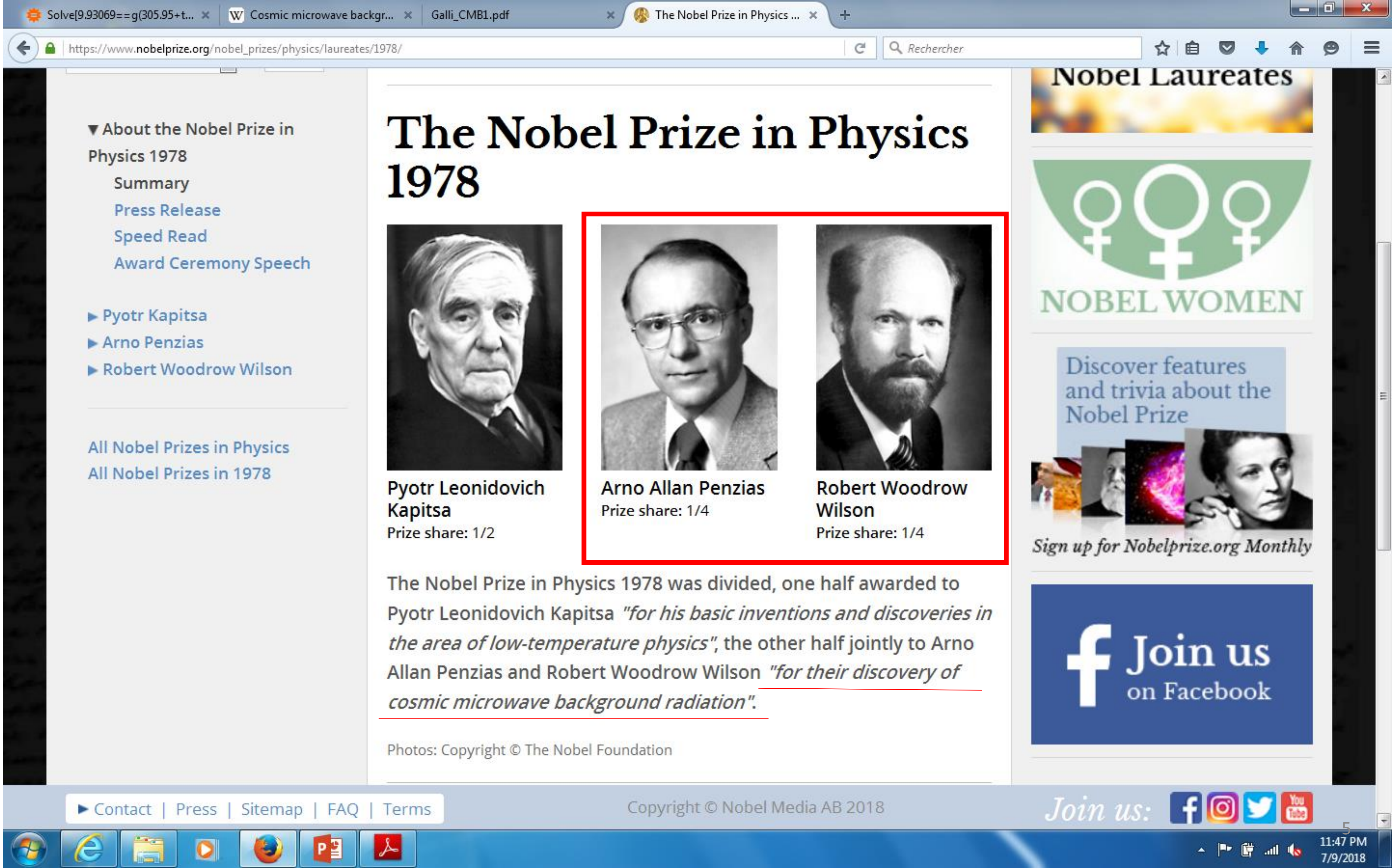
Discovery

1965. Arno Penzias and Robert Wilson, radio astronomers at Bell Labs in Crawford, New Jersey. Microwave horn radiometer first used for telecommunication, then for astronomy.



A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Astrophysical Journal, vol. 142, p.419---421



Solve[9.93069==g(305.95+t...
Cosmic microwave backgr...
Galli_CMB1.pdf
The Nobel Prize in Physics ...
https://www.nobelprize.org/nobel_prizes/physics/laureates/1978/
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▼ About the Nobel Prize in Physics 1978
Summary
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▶ Pyotr Kapitsa
▶ Arno Penzias
▶ Robert Woodrow Wilson
All Nobel Prizes in Physics
All Nobel Prizes in 1978
The Nobel Prize in Physics 1978
Pyotr Leonidovich Kapitsa
Prize share: 1/2
Arno Allan Penzias
Prize share: 1/4
Robert Woodrow Wilson
Prize share: 1/4
The Nobel Prize in Physics 1978 was divided, one half awarded to Pyotr Leonidovich Kapitsa "for his basic inventions and discoveries in the area of low-temperature physics", the other half jointly to Arno Allan Penzias and Robert Woodrow Wilson "for their discovery of cosmic microwave background radiation".
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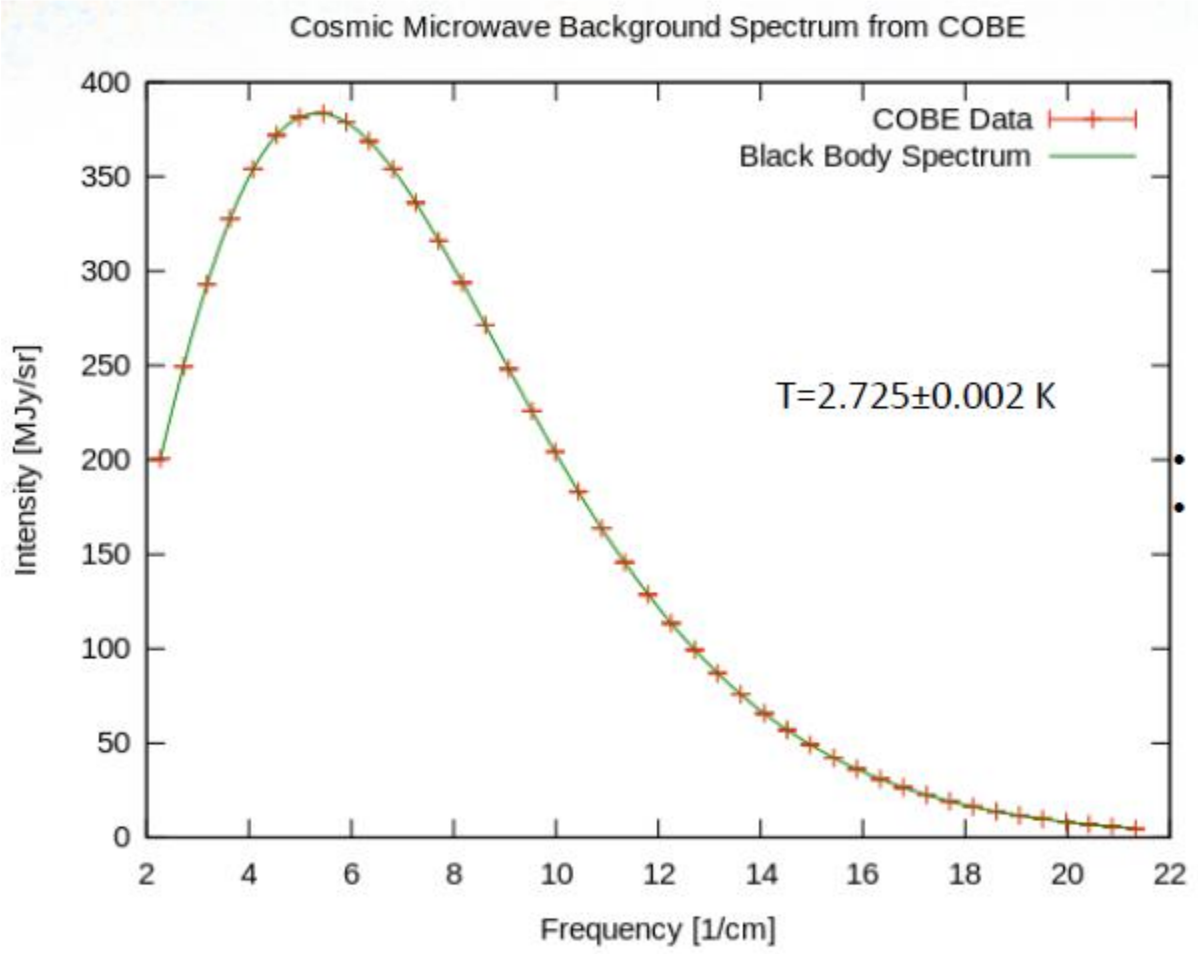
Accurate measurement: COBE

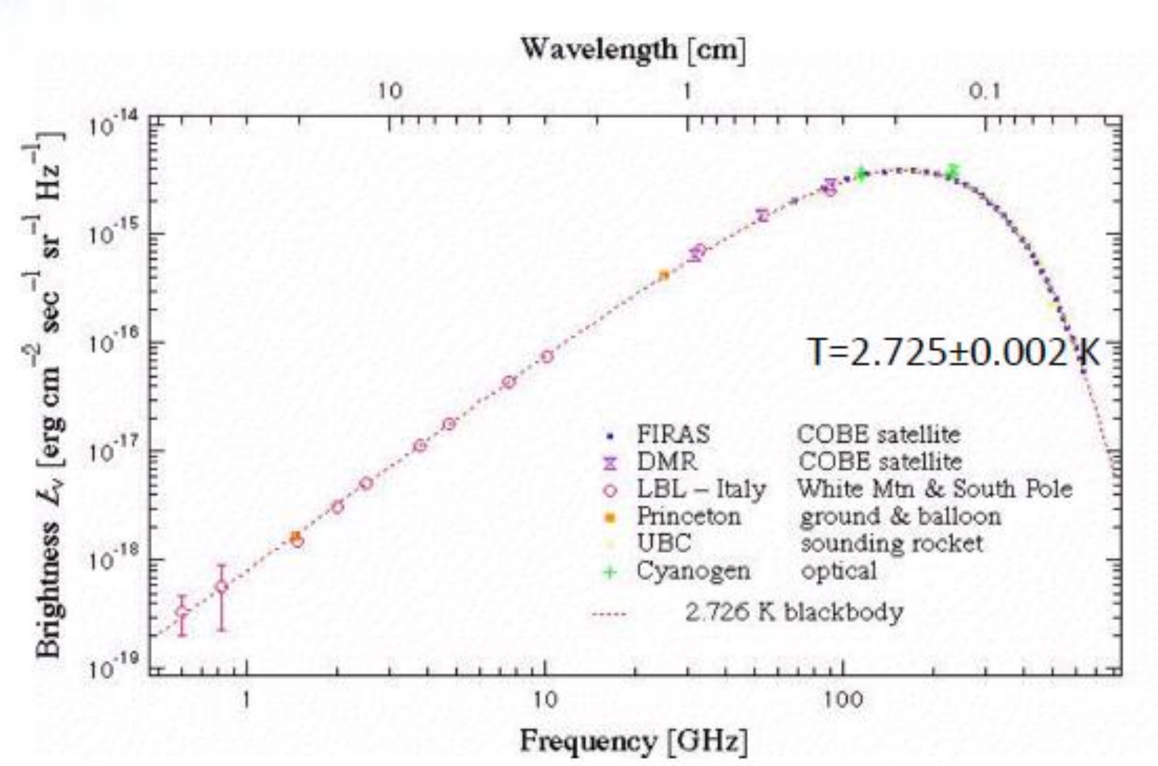


- Launched in 1989.
- Three instruments:

---FIRAS (BB spectrum)
[60---2880GHz],1yr
---DMR (anisotropies)
[31.5,53,90GHz],4yr
---DIRBE (CIB)
[infrared]

FIRAS measurements. Mather et al. (1994, 1996), Fixten1996
Peak BB(ν) at ~160GHz.

Accurate measurement: COBE



FIRAS measurements. Mather et al. (1994, 1996), Fixten 1996
Peak BB(ν) at ~160GHz.

The Nobel Prize in Physics 2006

Photo: P. Izzo
John C. Mather
Prize share: 1/2

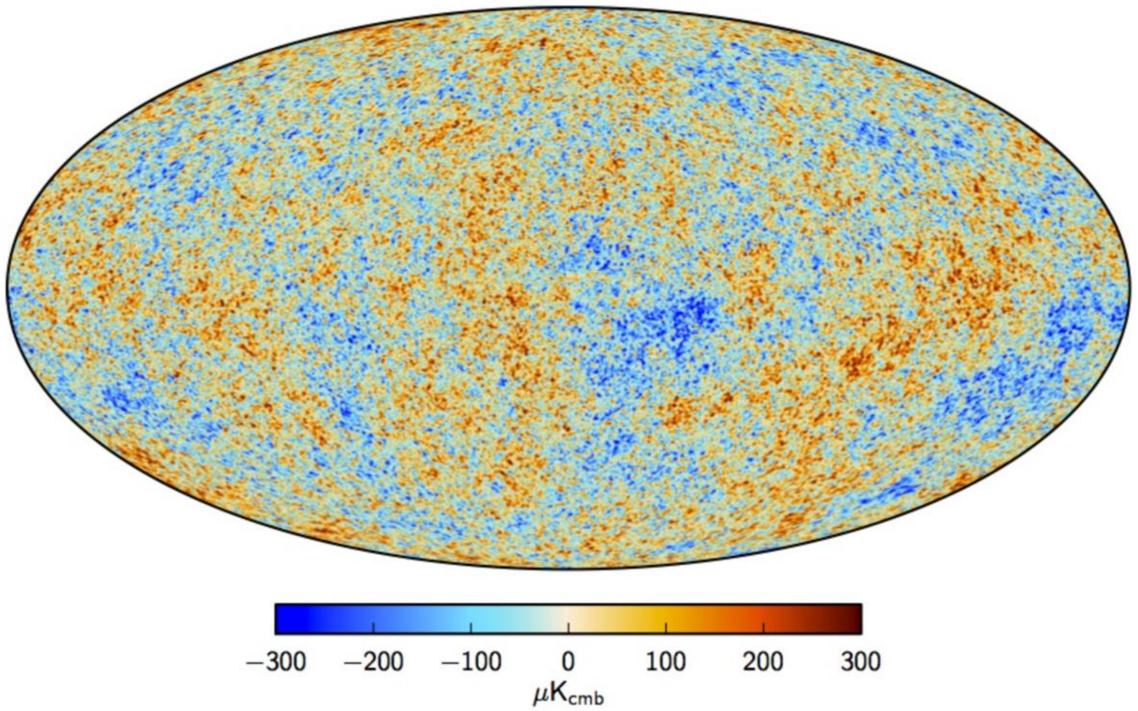
Photo: J. Bauer
George F. Smoot
Prize share: 1/2

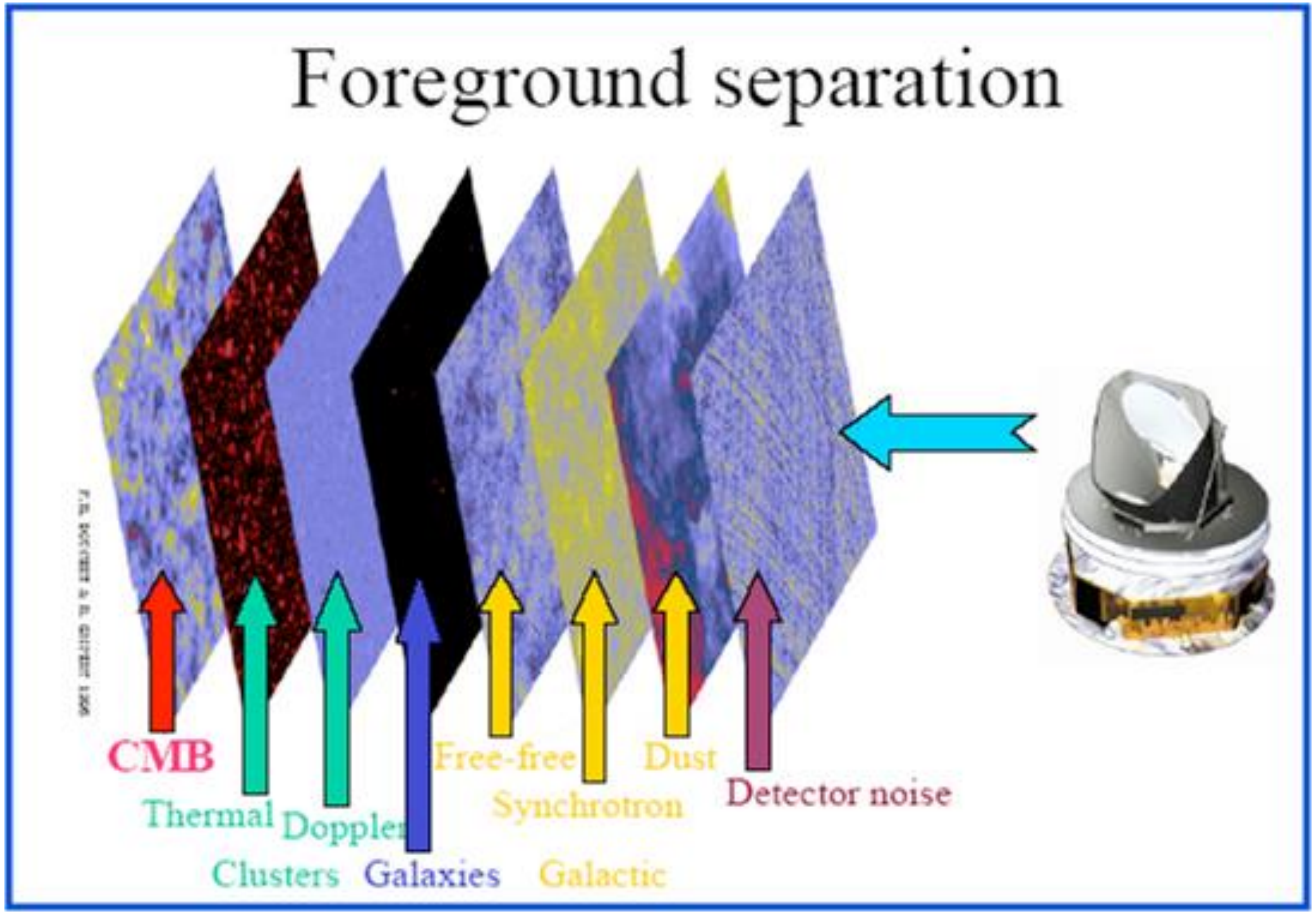
The Nobel Prize in Physics 2006 was awarded jointly to John C. Mather and George F. Smoot *"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"*

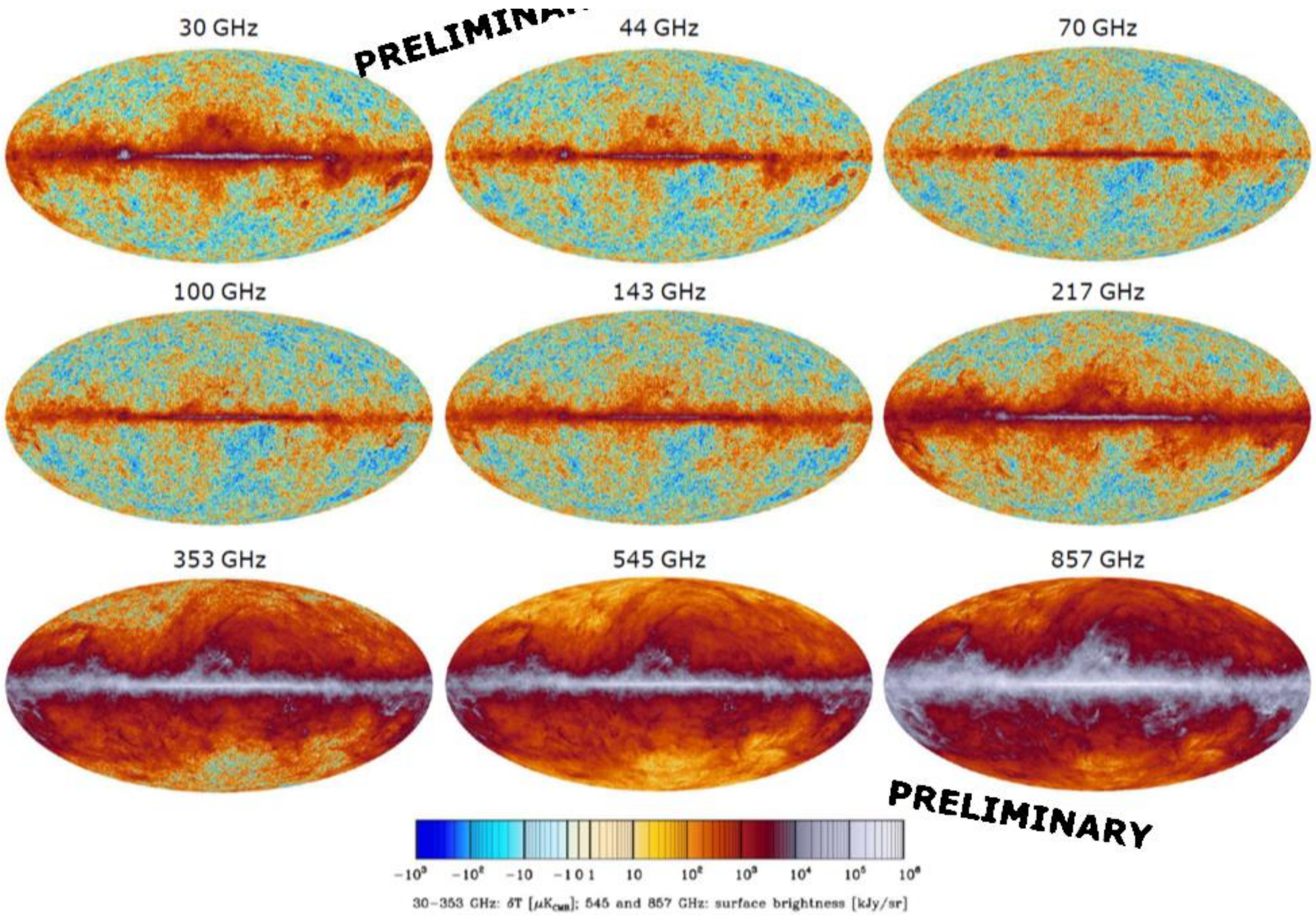
Anisotropies

- At the μK level, CMB anisotropies (and foregrounds)

The Planck Map




Foreground separation
CMB
Thermal
Doppler
Clusters
Galaxies
Free-free
Synchrotron
Dust
Galactic
Detector noise



Planck 2015

Microwave sky

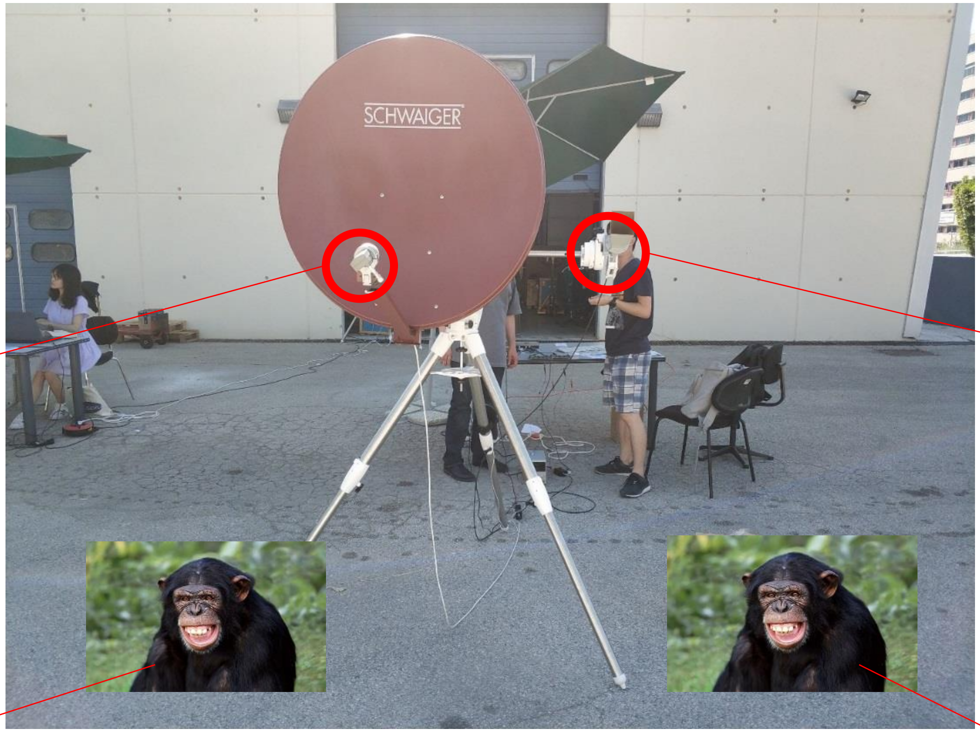
Our Experimental Work

The objective of this experimental work is to use a radiometer system to evaluate the average black body temperature of the Cosmic Microwave Background (no need to consider the anisotropies)

- Radiometer system
- Two Black bodies (different temperature)

Low Noise Background (LNB) converter

12 GHz



24 GHz

Black Body - 1 (room temperature, 32.8 ℃)

Black Body - 2 (liquid nitrogen, 77 K)

OUTPUT POWER FROM LNB

$$P_a = G(\nu)k(T_a + T_{rec})\Delta\upsilon$$

↓

$$P_a = G_{eff}\,(T_a + T_{rec})$$

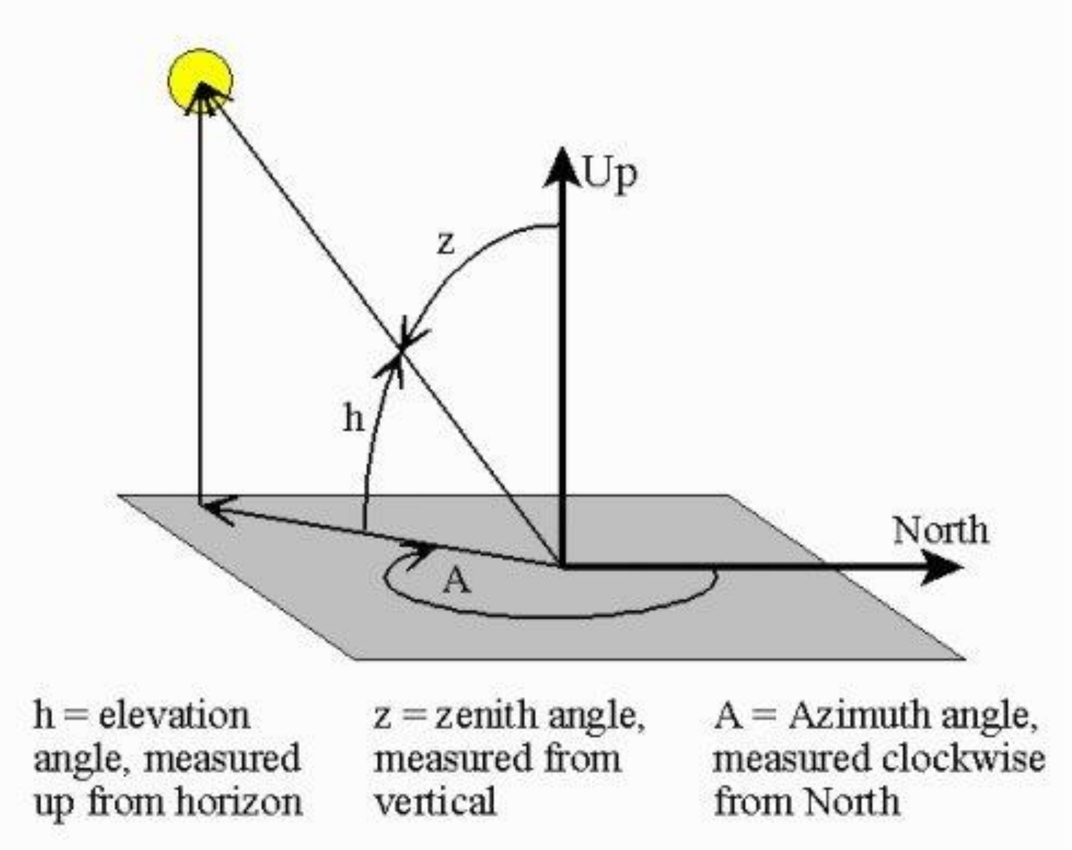
- $G(\nu)$ is the antenna gain
- k is the Boltzmann constant
- $\Delta\upsilon$ is the LNB bandwidth

→ G_{eff}

- T_a: antenna temperature, $T_{cmb} + T_{atmosphere}$
- T_{rec}: receiver temperature(power generated internally)
- $T_{atmosphere}$: depend on the air mass along the line of sight

DATA TAKING

- Record output power of room temperature and liquid nitrogen temperature
- Record output power at different Zenith angle and Azimuth angle
- Some tips:
  - Avoid sunshine by choosing suitable Azimuth angle
  - Avoid the influence of buildings and mountains by choosing suitable zenith angle
  - Use suitable angle interval



DATA ANALYSIS

- Calculate average value of power with same Azimuth angle to reduce error
- Relation between power and temperature:

$$\left(\frac{P_a}{G_{eff}} - T_{rec}\right) = T_a = T_{cmb} + T_{atmosphere}$$

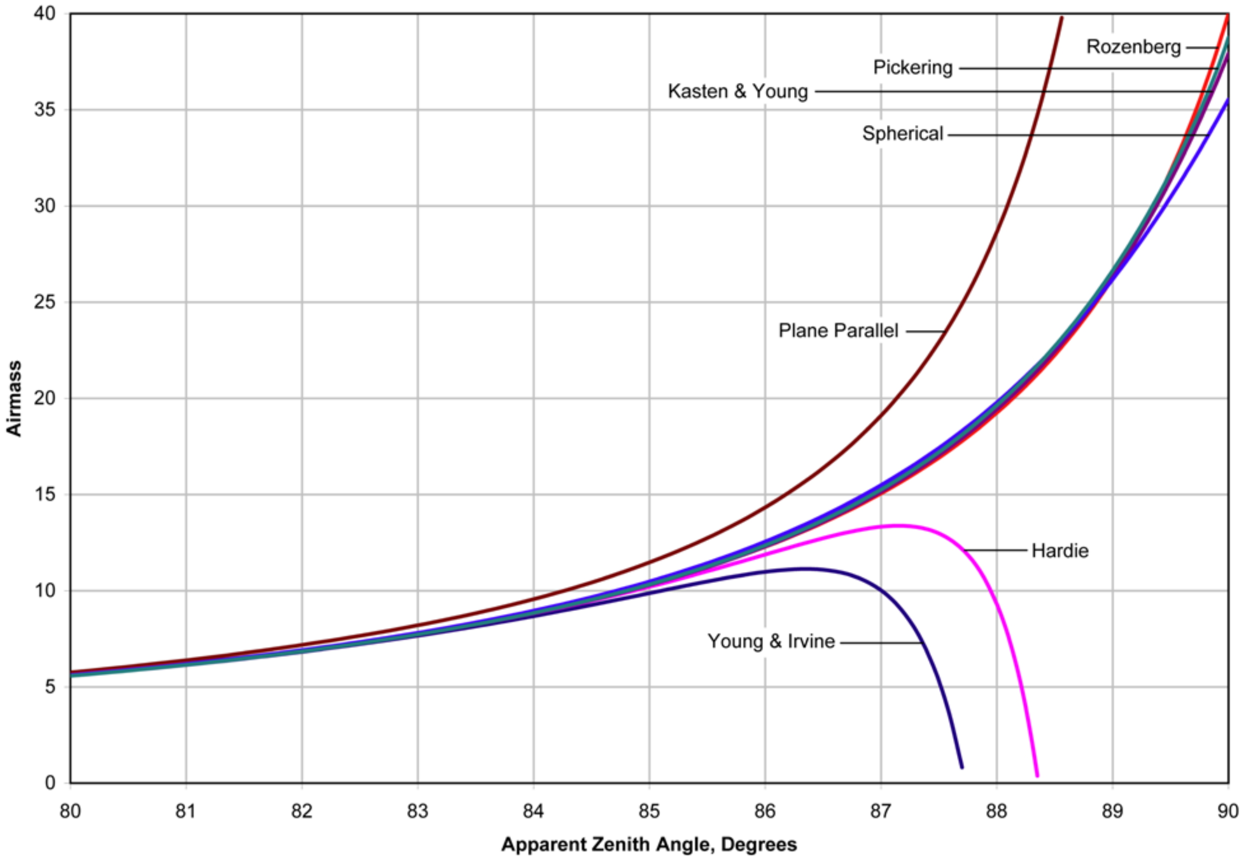
$T_{atmosphere}$ depend on air mass

$$\left(\frac{P_a}{G_{eff}} - T_{rec} - T_{cmb}\right) \sim air\ mass$$

- Atmospheric air mass can be estimated with Zenith angle (https://en.wikipedia.org/wiki/Air_mass_(astronomy))

DATA ANALYSIS

- Calculate ave
- Relation betw



to reduce error

- Atmospheric air mass can be estimated with Zenith angle (https://en.wikipedia.org/wiki/Air_mass_(astronomy))

CALIBRATION

- Room temperature and Liquid nitrogen temperature are used:

  - 24 GHz:

$$9.93069 = G_{eff}\,(305.95 + T_{rec})$$
$$1.76238 = G_{eff}\,(77 + T_{rec})$$

$$G_{eff} = 0.0357$$
$$T_{rec} = -27.6022$$

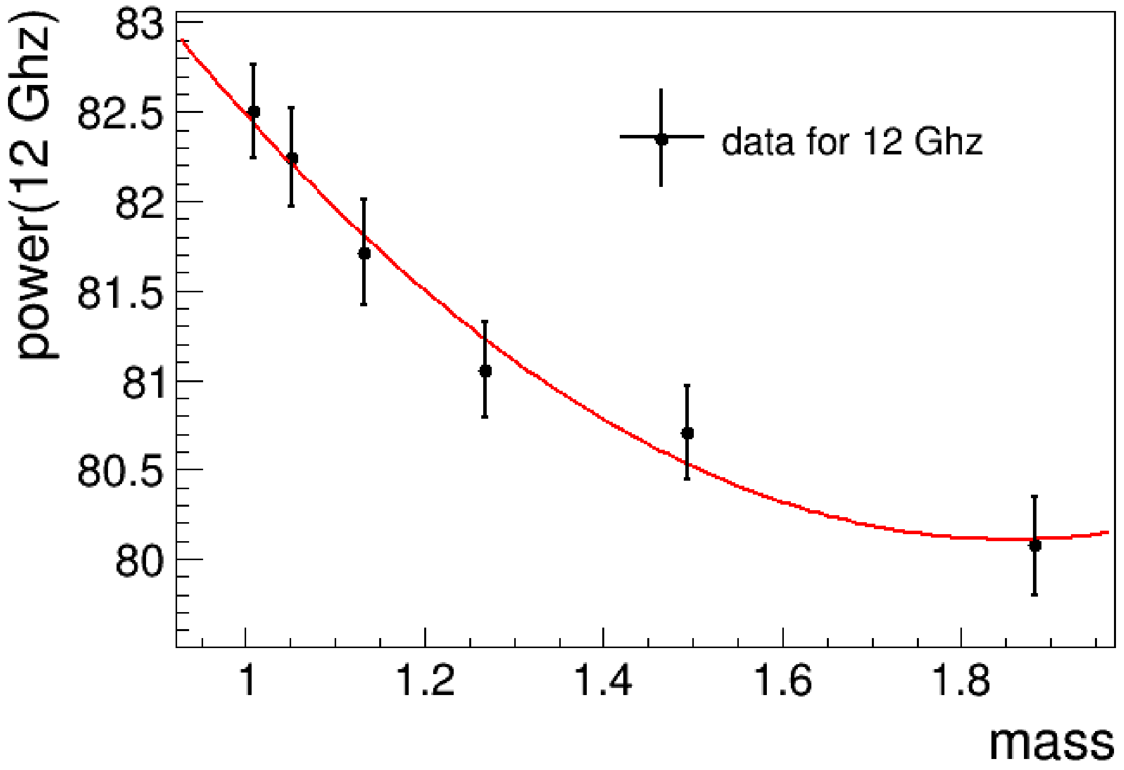
  - 12 GHz:

$$90.9406 = G_{eff}\,(305.95 + T_{rec})$$
$$91.0099 = G_{eff}\,(77 + T_{rec})$$

$$G_{eff} = -3.03 \times 10^{-4}$$
$$T_{rec} = -3.01 \times 10^{5}$$

DATA ANALYSIS

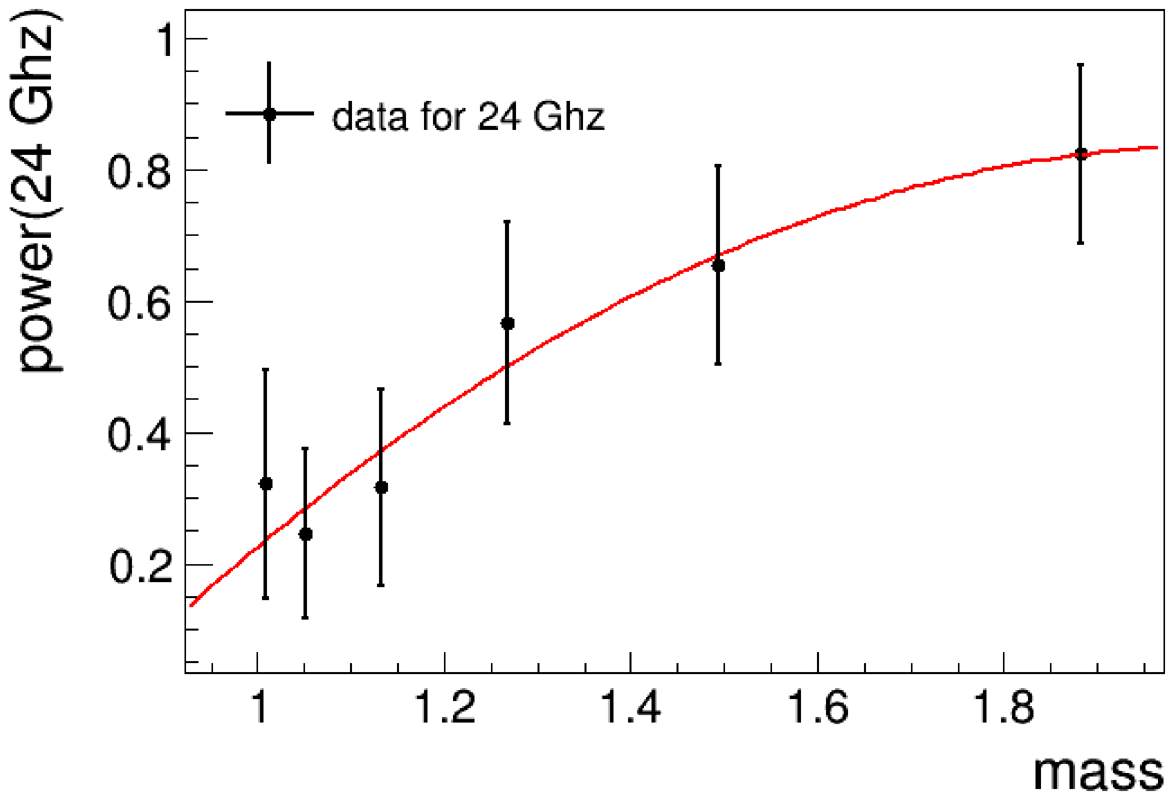
Fit method: Second polynomial



- $P = t_0 + t_1 m + t_2 m^2$
  $t_0 = 91.28 \pm 2.90$
  $t_1 = -12.05 \pm 4.21$
  $t_2 = 3.25 \pm 1.46$
  $\chi^2 = 1.04$

DATA ANALYSIS

Fit method: Second polynomial



- $P = t_0 + t_1 m + t_2 m^2$
  $t_0 = -1.53 \pm 1.67$
  $t_1 = 2.33 \pm 2.41$
  $t_2 = -0.57 \pm 0.83$
  $\chi^2 = 0.66$

RESULTS

$$\left(\frac{P_a}{G_{eff}} - T_{rec}\right) = T_{cmb}$$

- Result of 12 GHz: $(-0.000816 \pm 0.291) \times 10^6$ K
- Result of 24 GHz: $(-0.15 \pm 0.74) \times 10^2$ K

RESULTS

$$\left(\frac{P_a}{G_{eff}} - T_{rec}\right) = T_{cmb}$$

- Result of 12 GHz: $(-0.000816 \pm 0.291) \times 10^6$ K
- Result of 24 GHz: $(-0.15 \pm 0.74) \times 10^2$ K

Unbelievable !!!

SOME ASSUMPTION

- Wrong operation to equipment
- Record wrong output power when do calibration
  - wrong value of effective antenna gain G_{eff} and temperature T_{rec}
- Unsuitable angle interval and too less data point
  - influence the trend of power
- Unsuitable fit method
  - power while 0 air mass is not precise
- Some reasons out of control

……

CONCLUSION

- Introduction to Cosmic Microwave Background
- Introduction to experiment about measurement of T_{cmb}
- Bad results and some assumptions
- Better results will be presented if we have the chance to do this experiment again

Merci