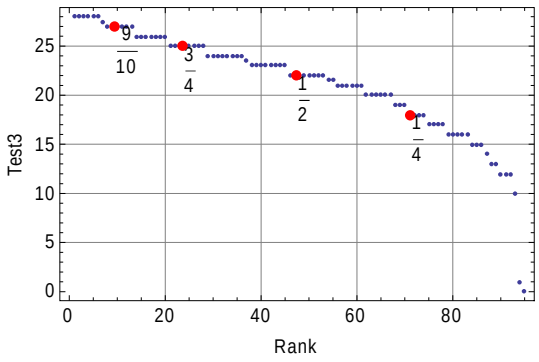
Universe at 400,000yr
Weighing the universe—3 Dec

- Homework 11 will be due on the last day of classes (Fri, 10th). Answers will be posted after class. No late papers.
- Final exam
  - Covers the entire term with more emphasis on 20th century cosmology
  - Wed, 15th, 3:00-5:00 in 1415
  - Missouri Club: BPS-1420 on Mon, 12/13, 11:30am - 12:30pm
- Cosmic background radiation is not completely isotropic.
  - Hotter by 0.004K in one direction and cooler in opposite direction. ⇒ We move.
  - Largest fluctuations (0.0002K) are at an angular scale of 1º.
- Use fluctuations to weigh the universe (determine the mass density).

Test 3: Average: 21.4/28 (76%) Good job!

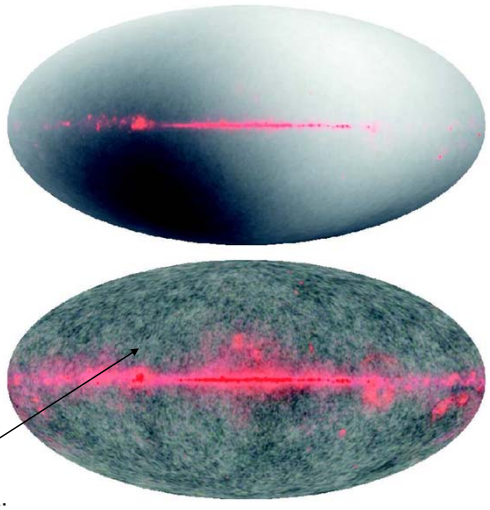
Test 2: Average: 14.2 (50%)
Test 1: Average: 75%



- Answers: Link T3 on syllabus on angel
- Grade is on angel
  - Report>Report Setting
  - Choose "Grades"
  - Overall % (Course grade)
    - Eg., 90% (4.0)
- Course grade
  - Test 1-3 are weighted 10%, 27%, and 27% to make tests count same as all tests at end of course.
  - Average is 3.0
- Final counts for 30% of grade.

Remove motion

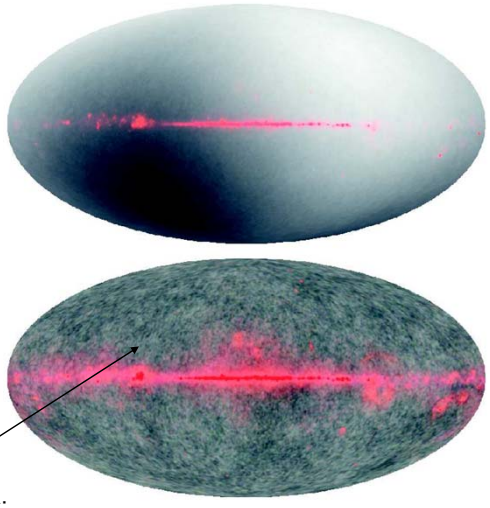
- Remove motion and show with increased contrast
- Largest fluctuations are at an angular scale of 1º.



Temperature fluctuations:
Light & dark mottling

Fluctuations at an angular scale of 1º

- Largest fluctuations are at an angular scale of 1º.
- Fluctuations are dense & sparse regions
  - Dense regions are hotter by 0.0002K whereas the average is 2.7K.
  - Sparse regions are cooler.



Temperature fluctuations:
Light & dark mottling

How fluctuations work

- Fluctuations are growing dense & sparse regions.
- Conditions:
  - The universe is 400,000 years old.
  - Energy is carried predominantly by light.
- What happened to fluctuations at smaller scales?

1. By chance, a part of the universe is born hotter and denser than the surroundings. Its radiation warms up the surroundings and smooths out the hot spot. The smoothing is limited in size because ___.
2. By chance, a part of the universe is born hotter and denser that the surroundings. Its gravity pulls and makes the region larger. The size of the region cannot grow to infinite size because ___.

- At small scales, temperature is more uniform.
  - Radiation dominates. Radiation from hotter regions warms up cooler regions.
- Universe was not old enough for dense regions to grow larger.

How fluctuations work

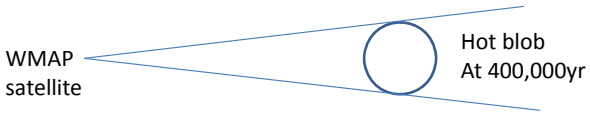
1. The universe is smooth at scales smaller than ___ and larger than ___.
   A. About 100,000light years
   B. About 1,000 light years
   C. About 10 light years
   D. About 3 light minutes

- Effect of gravity can only go as fast as speed of light. Universe was not old enough to grow at large scales.
- Warming effect of light can only go as fast as speed of light.
- Precisely, size of largest fluctuations is

  1/3 (Age of universe)×(speed of light)

Key measurement

- The size of the largest fluctuation is about 100,000 light years.
- The angle of the largest fluctuation is 1°.
- Can measure the distance from us to hot blob.
  - Can measure time because distance=time×(speed of light)

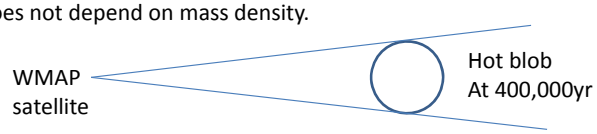


Key idea for weighing the universe

- Principle for astronomical weighing:
  - Define a motion
  - Time the motion
  - If the motion takes longer, the mass is less.
- To find mass of sun, measure period & size of a planet's orbit. Under influence of the gravity of the sun, a planet moves a given distance. If the time is short, the mass of the sun is greater.
- To find the mass density of the universe, measure the time for the universe to expand by a factor of about 1000 (Temperature changes from 3000K to 2.7K.) If the time is short, the mass density of the universe is greater.

- The size of the largest fluctuation is about 100,000 light years.
- The angle of the largest fluctuation is 1°.
- The motion is expansion of the U by a factor of 1000.
- Can measure the time for the motion.
  - Measure distance from us to hot blob.
  - Time = distance/(speed of light)

1. The universe has a higher mass density if the angle of the largest fluctuations is ___.
   A. Bigger
   B. Smaller
   C. Angle does not depend on mass density.



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