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From Pinholes to Black Holes

Ed Fenimore
National Security Education Center
Los Alamos National Laboratory

October 12, 2014
New Mexico Museum of History

LA-UR 14-xxxxx

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Abstract

Pinhole photography has made major contributions to astrophysics through the use of “coded apertures”. Coded apertures were instrumental in locating gamma-ray bursts and proving that they originate in far away galaxies, some from the birth of black holes from the first stars that formed just after the big bang.

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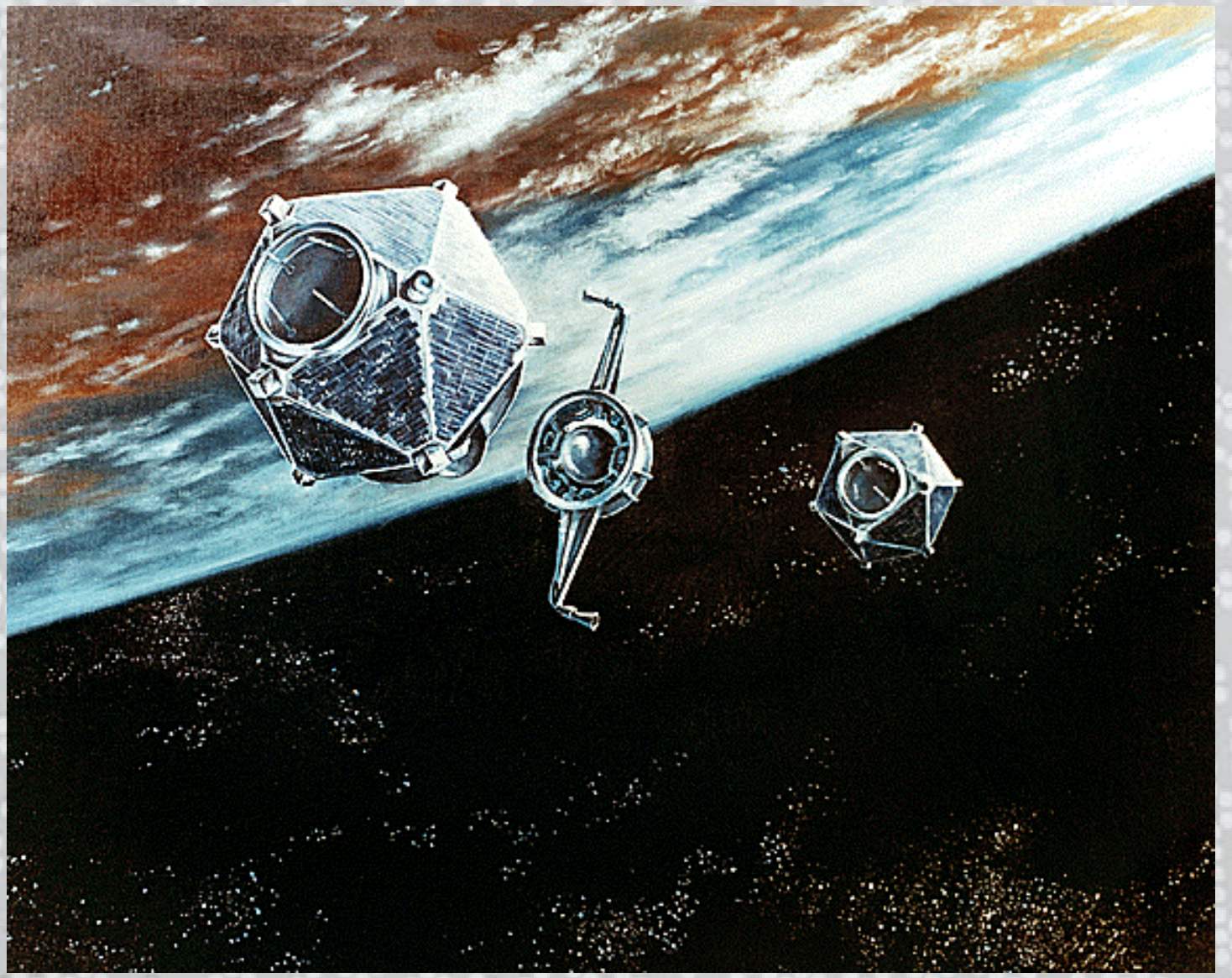
It started with the 1963 treaty to stop nuclear weapon testing



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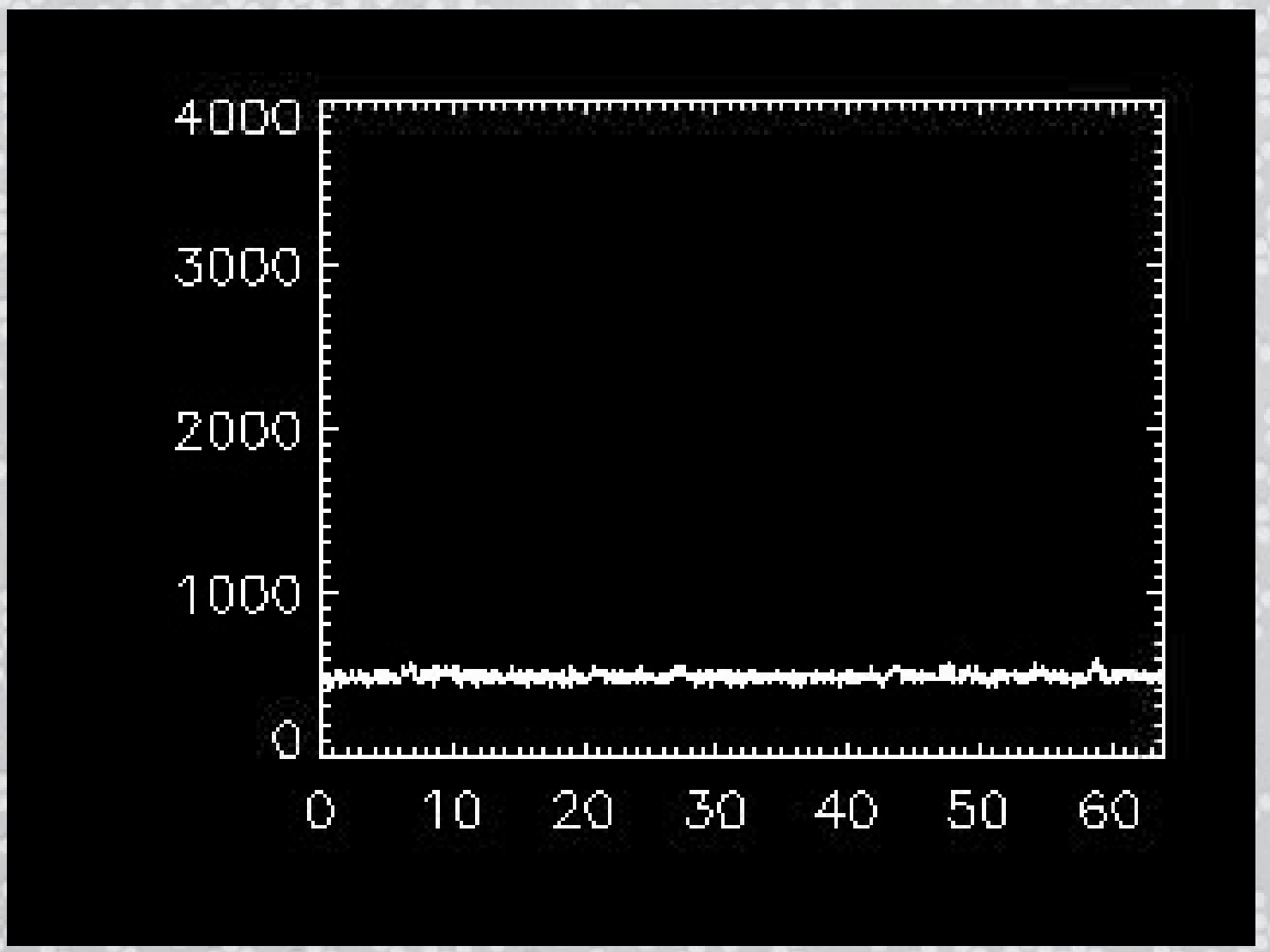
The Vela satellites were launched to look for x-rays and gamma-rays from a hidden nuclear test.

Should be easy: stars were thought to be steady and certainly not emit x-rays or gamma-rays.

What does a gamma-ray detector see: mostly static



The Times GRBs hit the satellites gives direction

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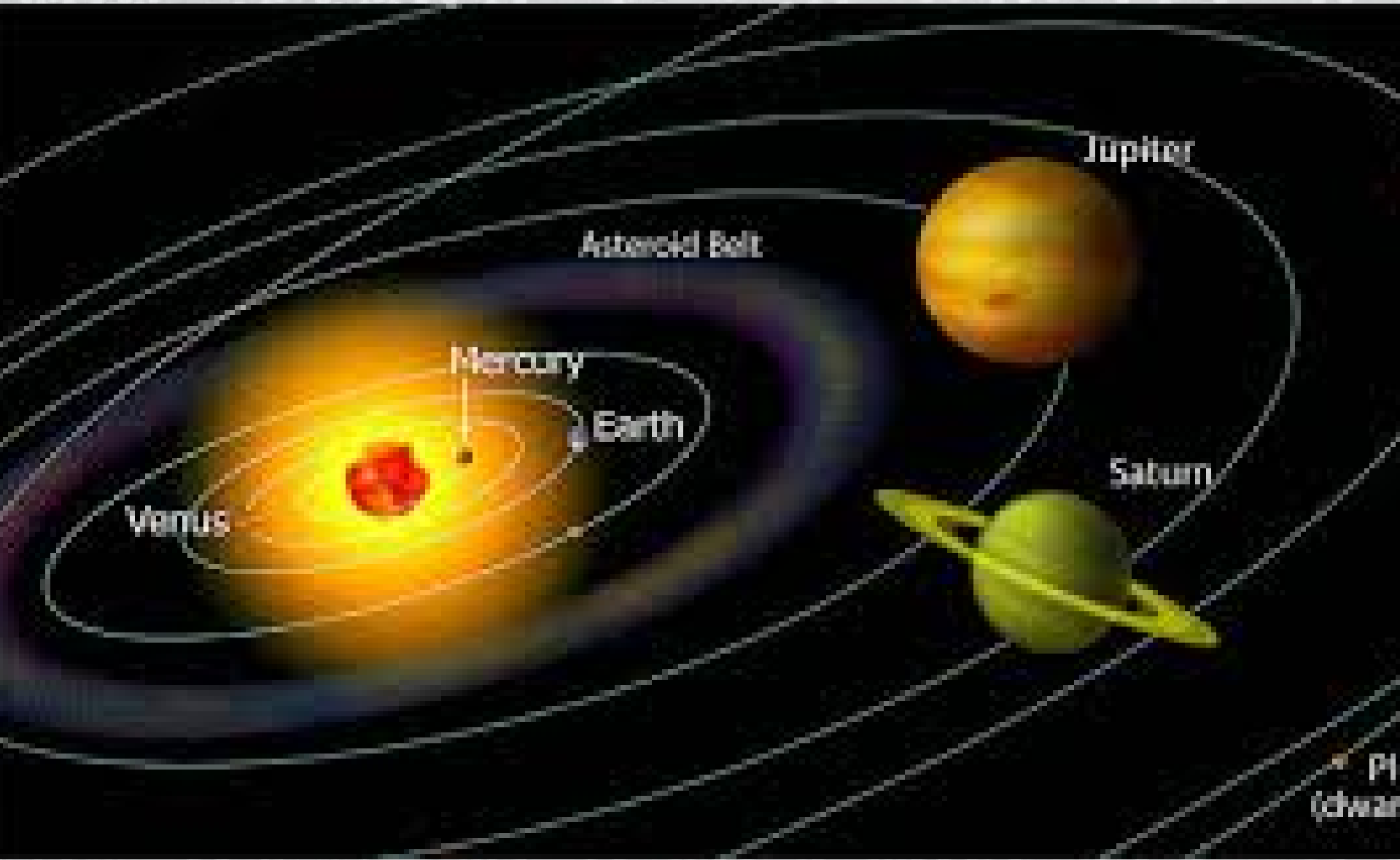
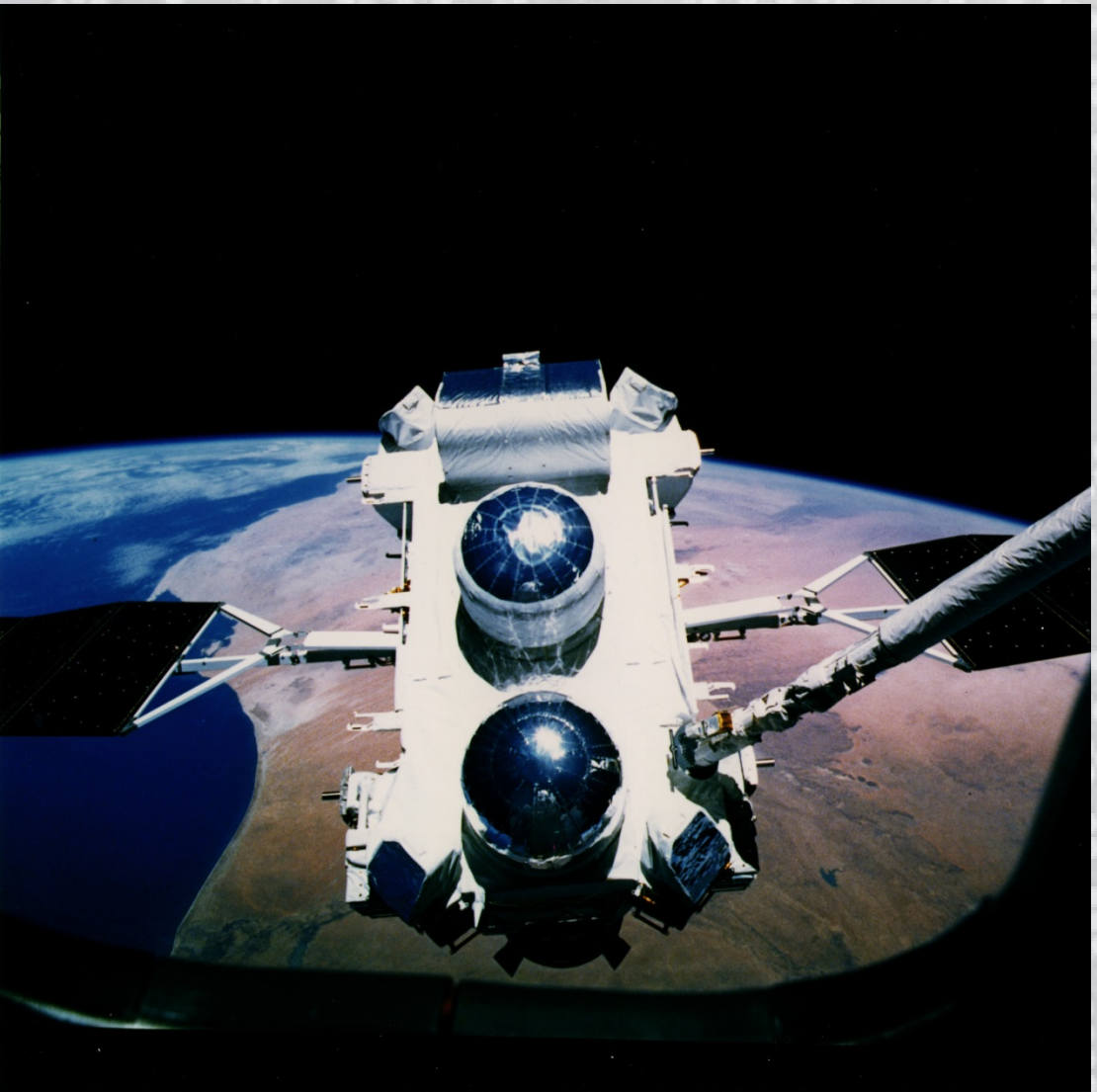
The Times GRBs hit the satellites at other planets gives direction



1991: Launch of “Burst and Transient Source Experiment” BATSE



Eight huge detectors

Location by different angles into the detectors

Found about one GRB per day

Many locations will give us an idea of how far away GRBs are

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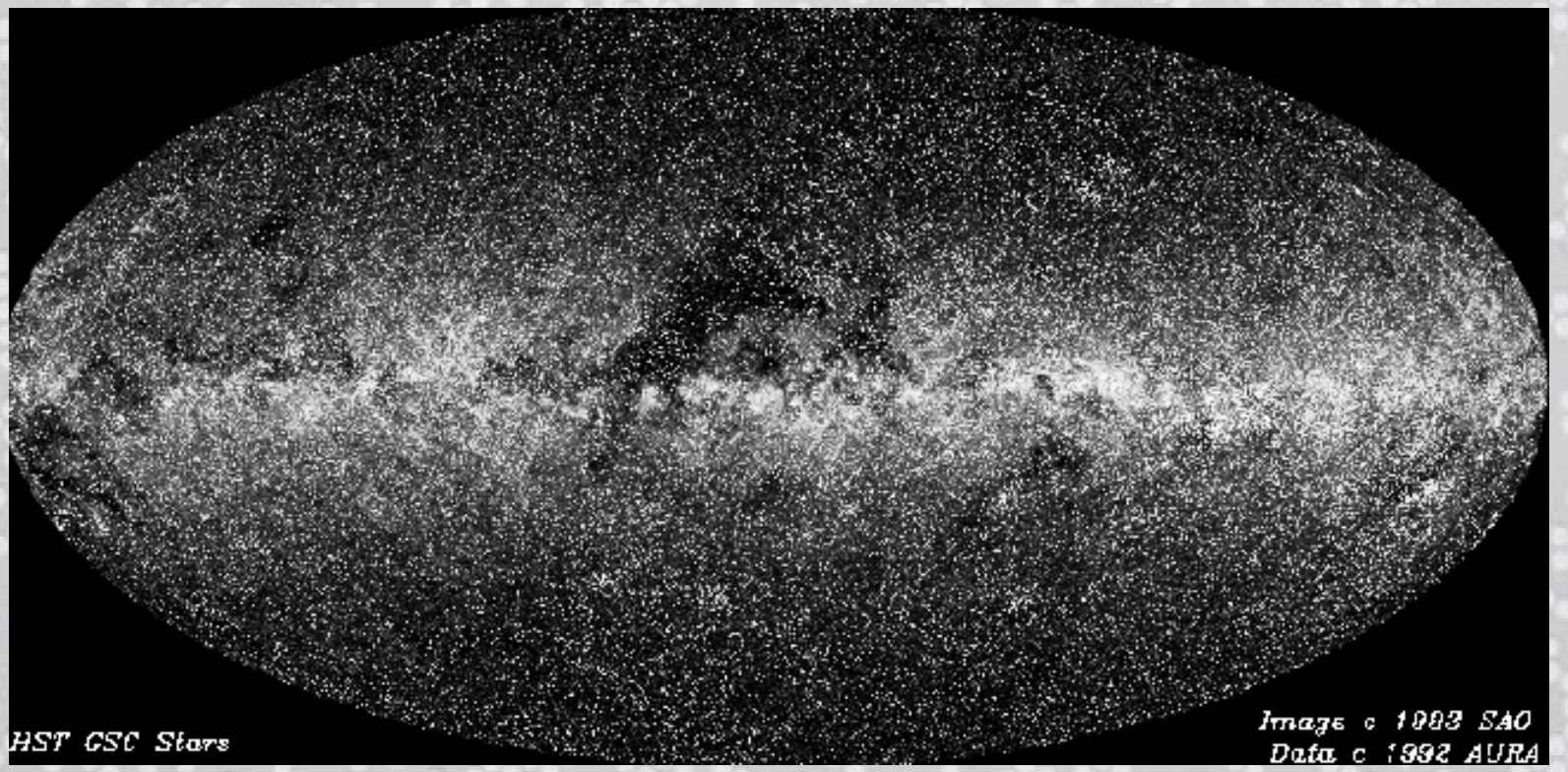
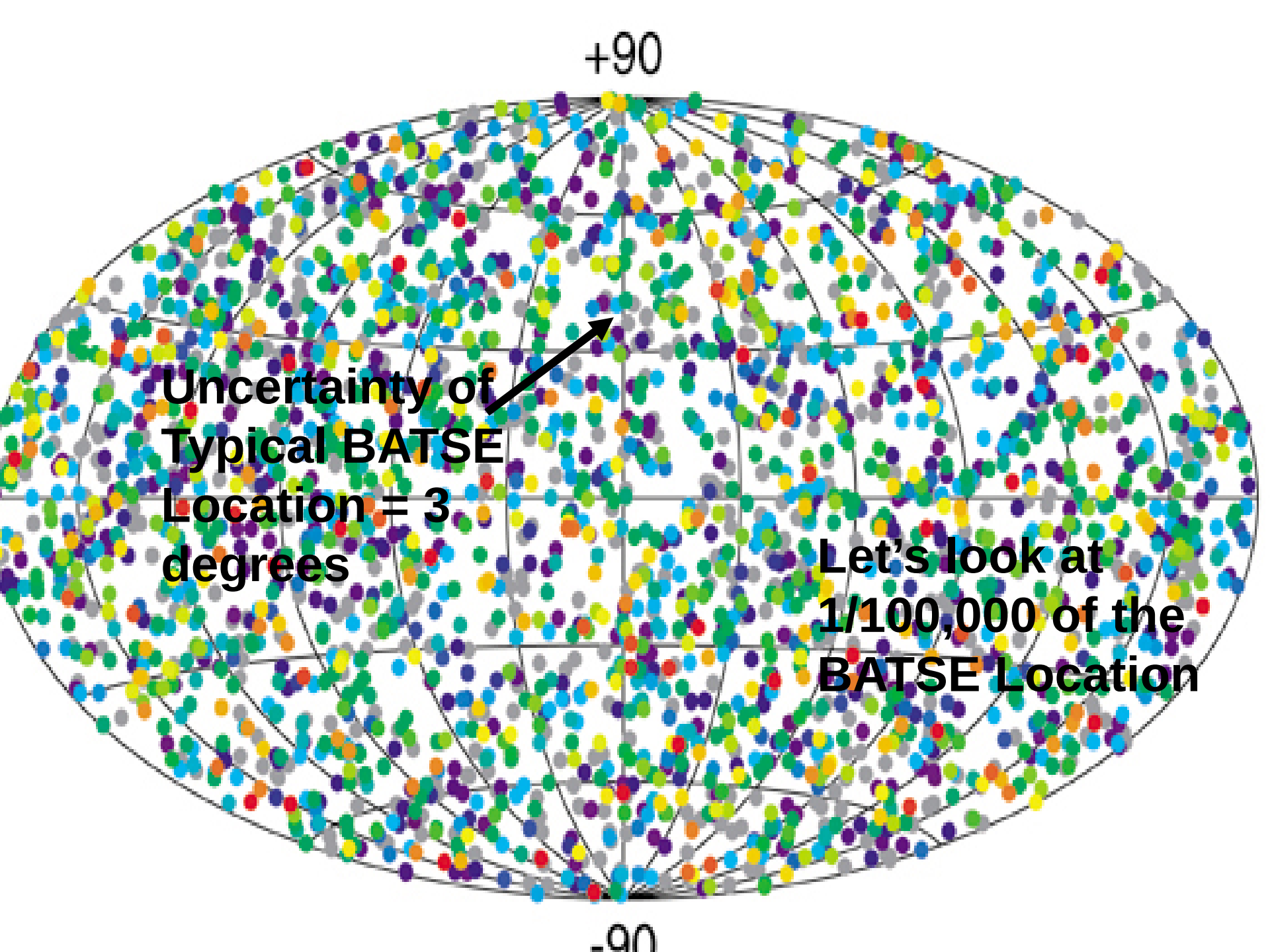
Map the stars like a flat map of Earth



Map of the stars in our galaxy, the Milky way


+90
Uncertainty of Typical BATSE Location = 3 degrees
Let's look at 1/100,000 of the BATSE Location
-90

The Hubble Deep Field North
HUBBLESITE.org

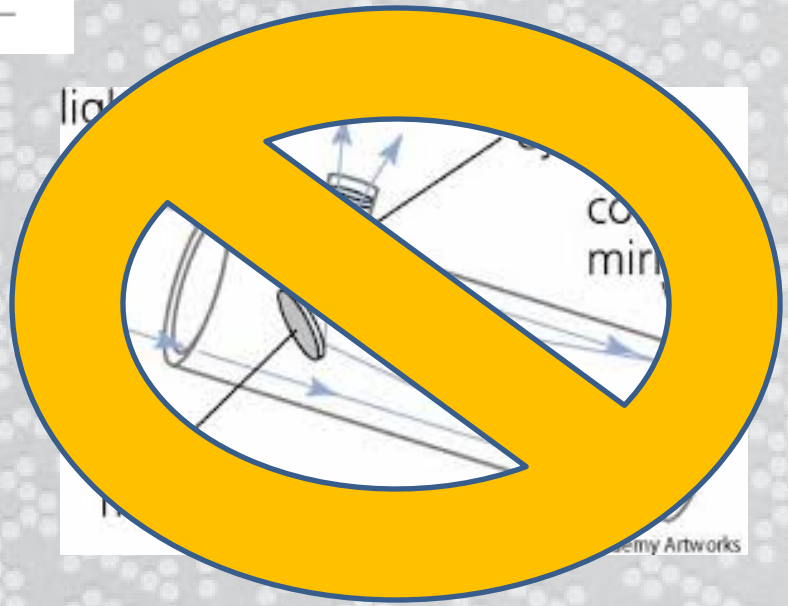


Image gamma-rays with mirrors?

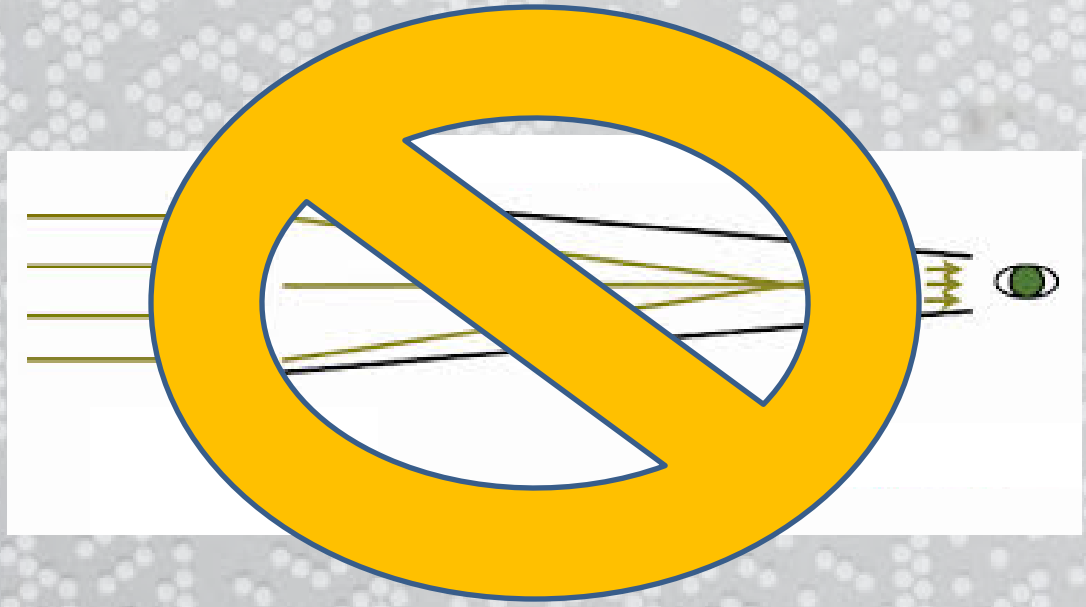
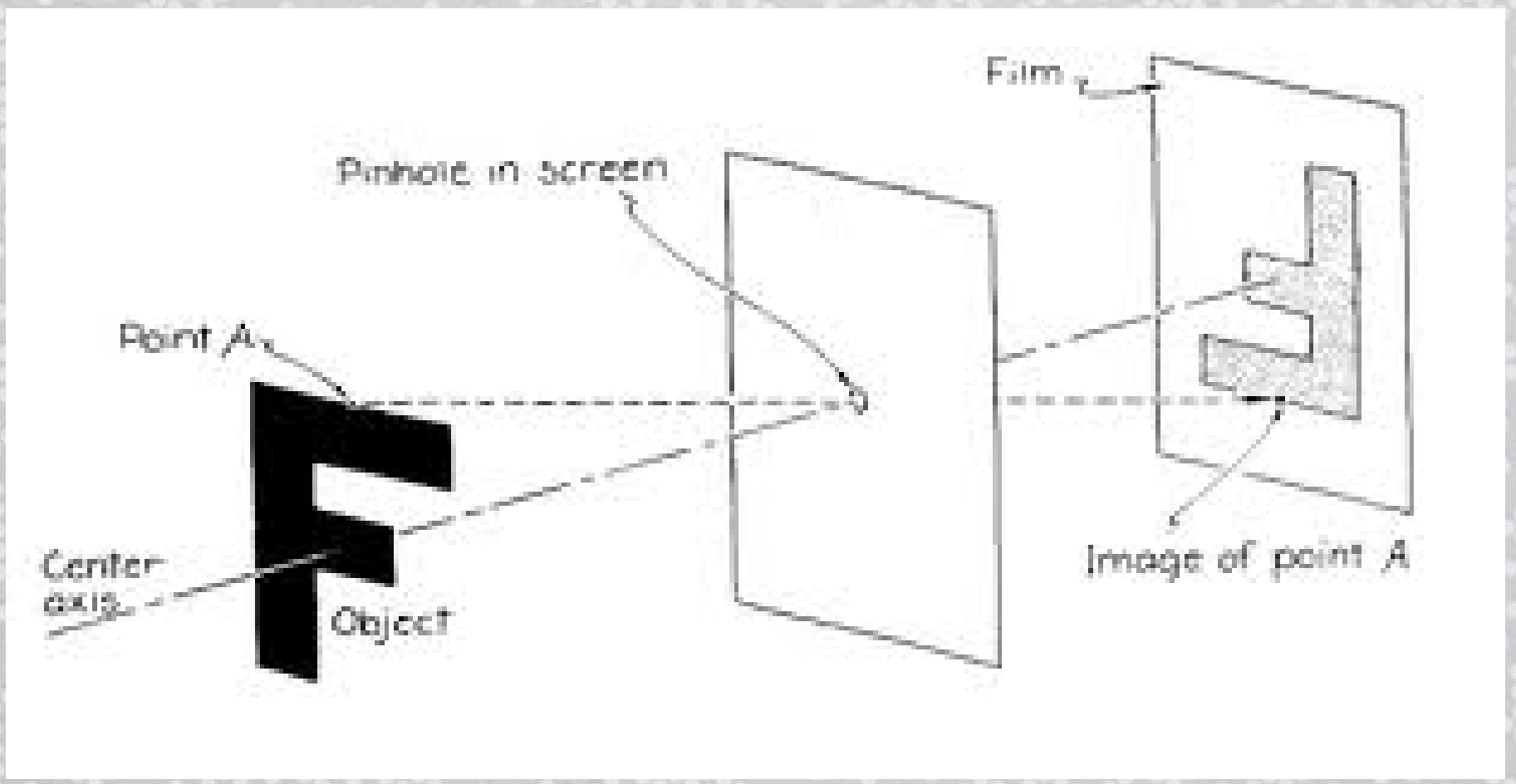


Image gamma-rays with lenses?


Film
Pinhole in screen
Point A
Center axis
Object
Image of point A

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Design #1: pinhole camera with small pinhole. Does not see enough x-rays.

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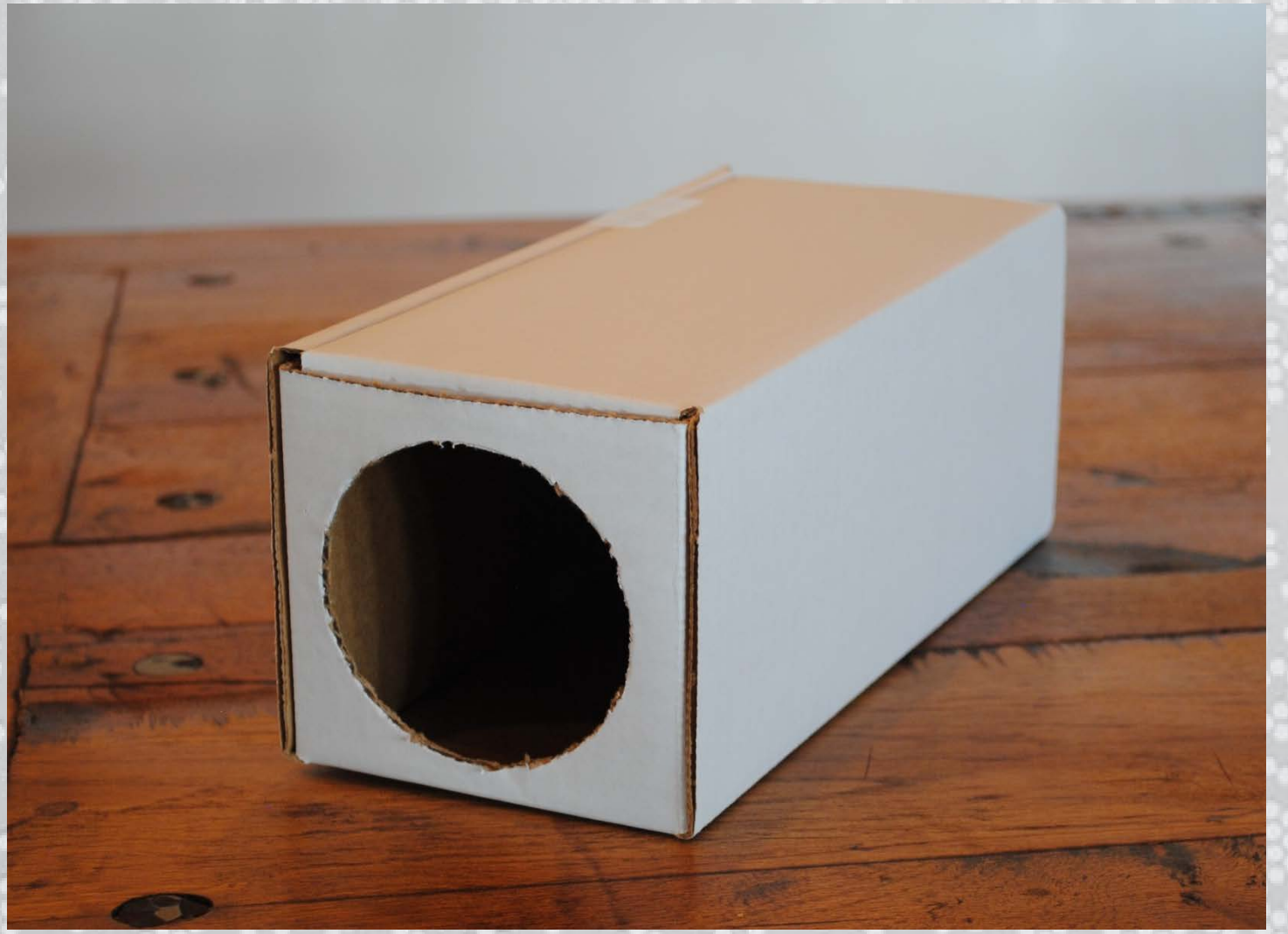
Design #2: pinhole camera with big pinhole. No resolution.



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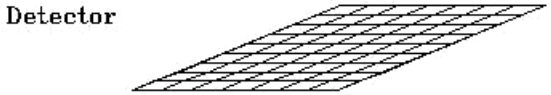
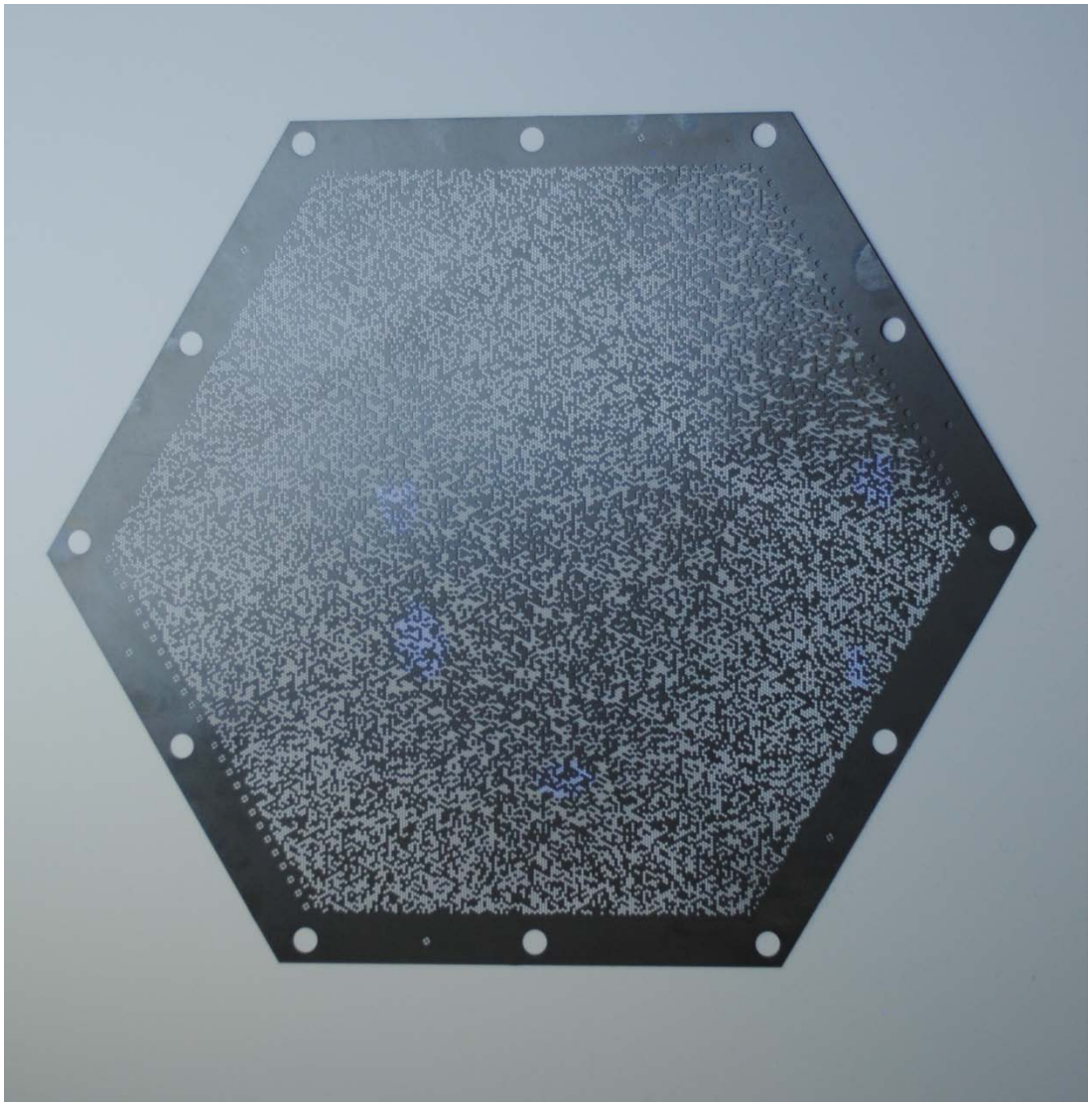
Design #3: pinhole camera with many small pinholes. But, many overlapping images.

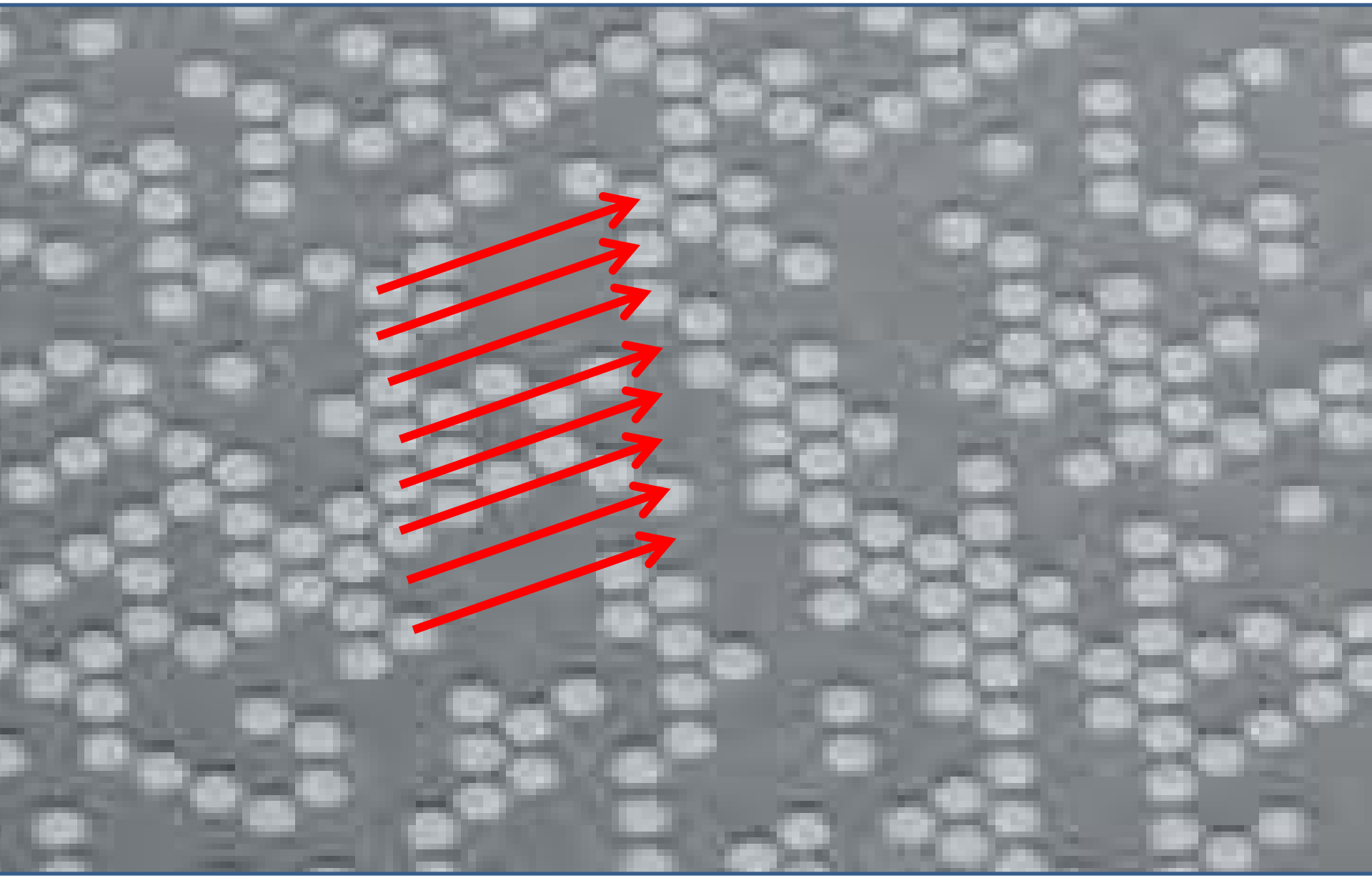
Aperture


Detector

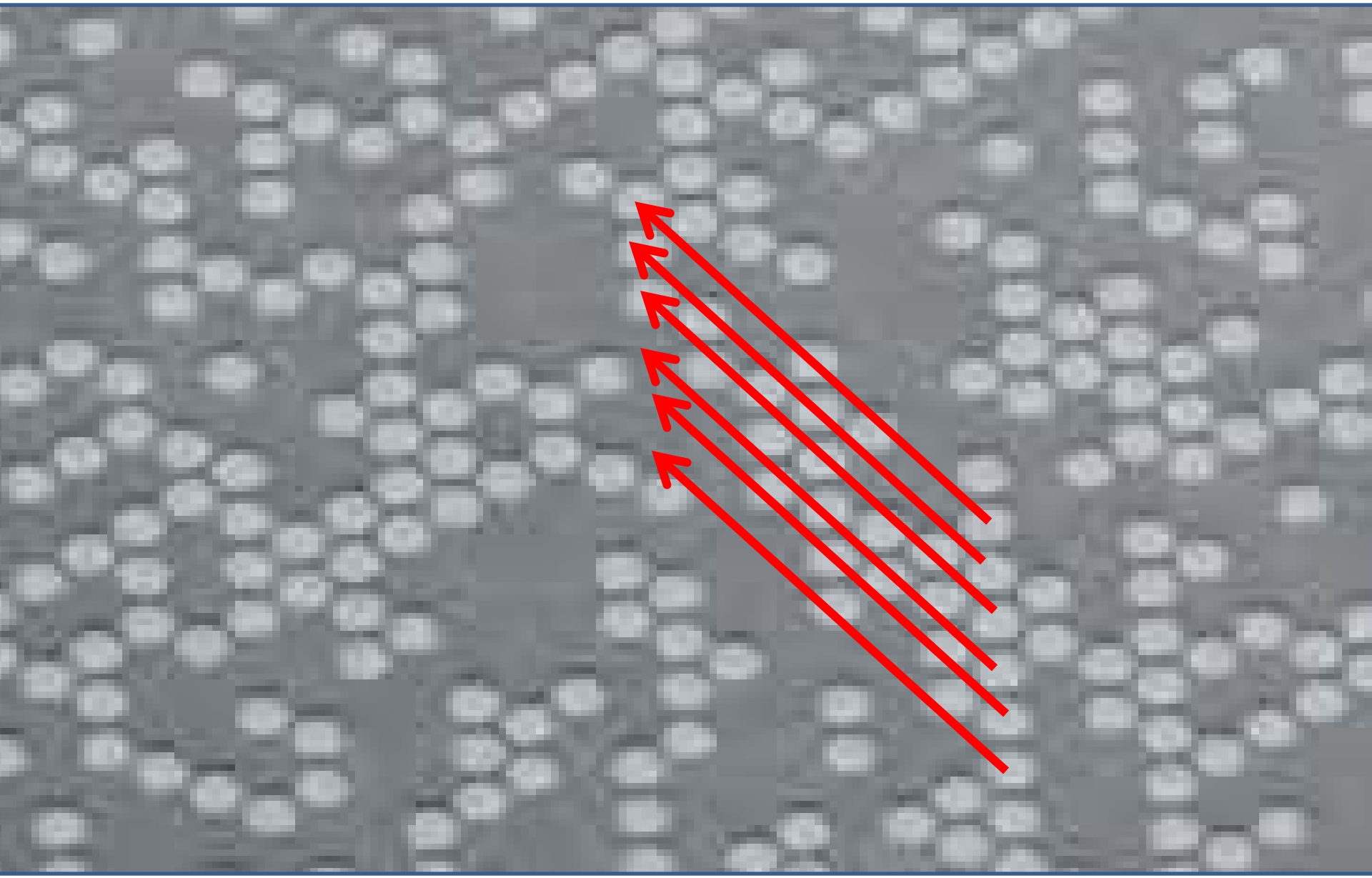
Pattern used in URA-shuttle experiment
Special mathematical function gives pinhole locations



Pick a vector. Move it's tail to each hole.
How many times is there a hole at the head?



Pick another vector. Move it's tail to each hole. How many times is there a hole at the head?



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Special mathematical properties

No matter what vector you choose, the number of times there is a hole at both ends is always exactly the same (e.g., 5201)

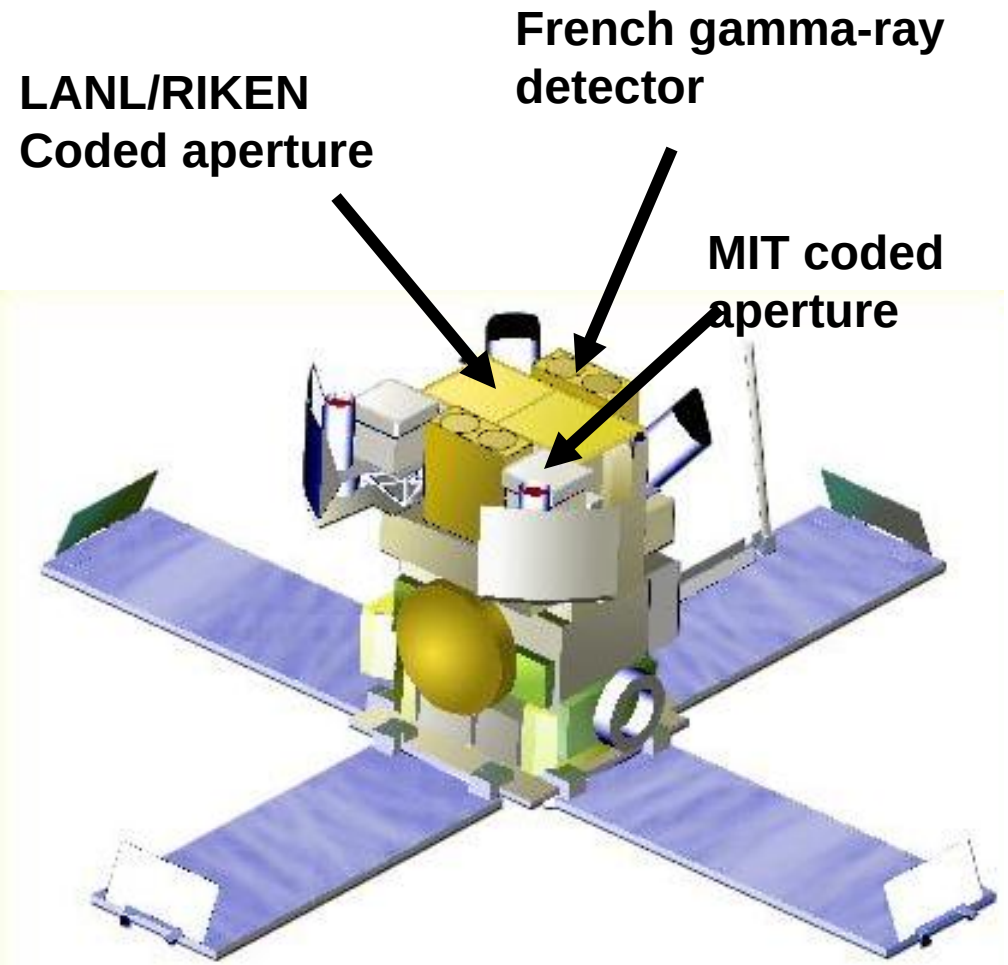
The autocorrelation is perfectly flat.

$$\mathcal{F}(A(x,y)) = 1/\mathcal{F}(A(x,y))$$

High Energy Transient Experiment

First satellite to autonomously locate Gamma-ray bursts

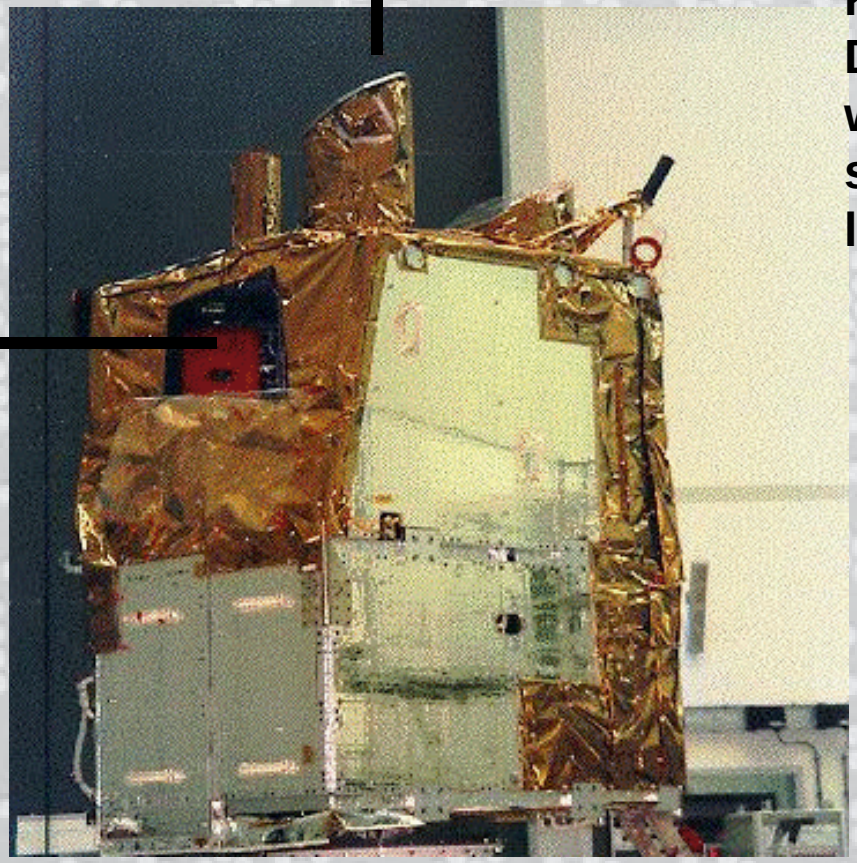
HETE-II 2000



Key: on-board software processes the coded aperture images and immediately sends to telescopes on the ground where the GRB is located

Italian-Dutch “BeppoSax” Satellite 1997

X-ray telescopes look this direction



Coded aperture looks this direction

Key:Coded aperture
Data sent to ground and, within ~8 hours, the satellite is repointed to look toward the GRB

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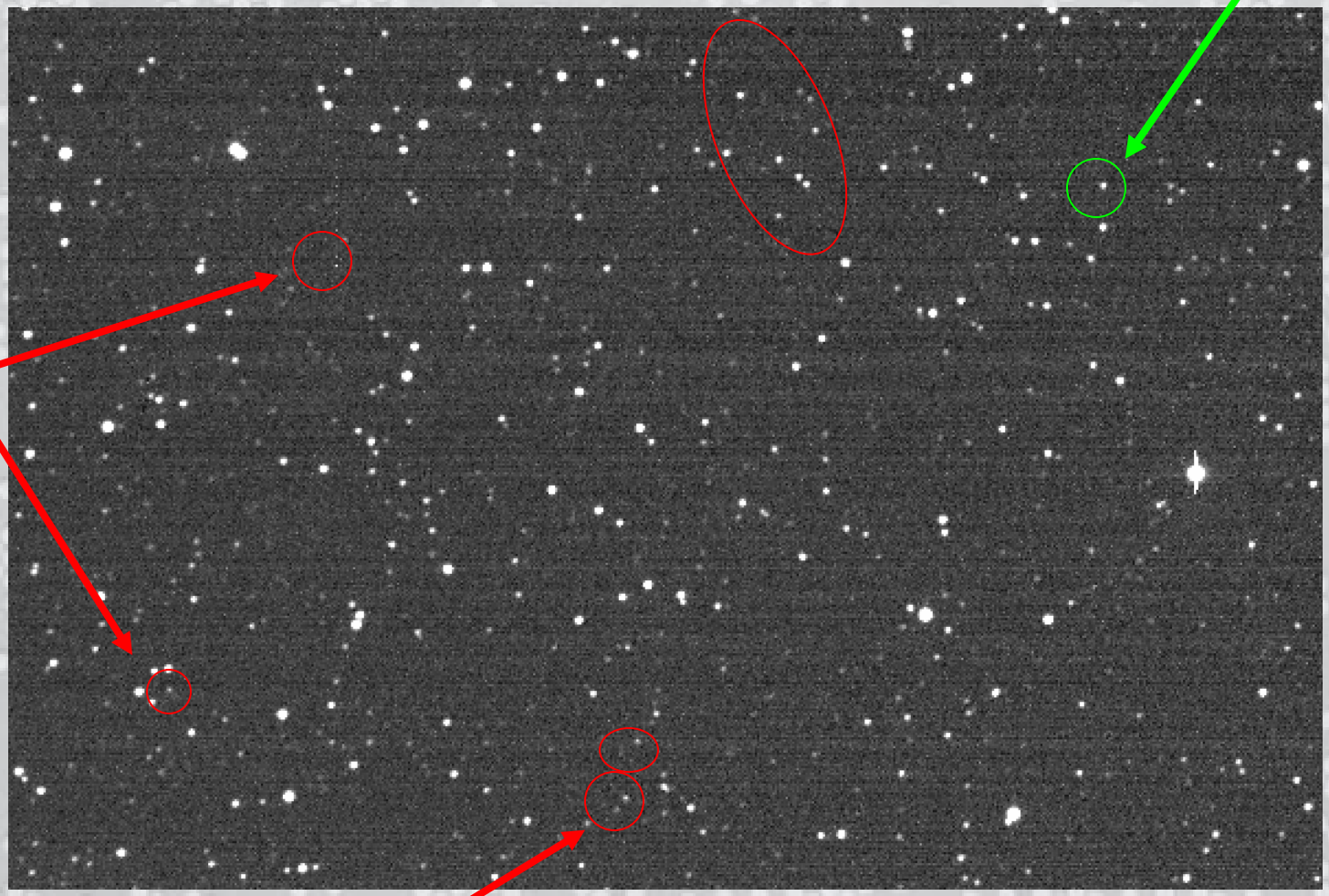
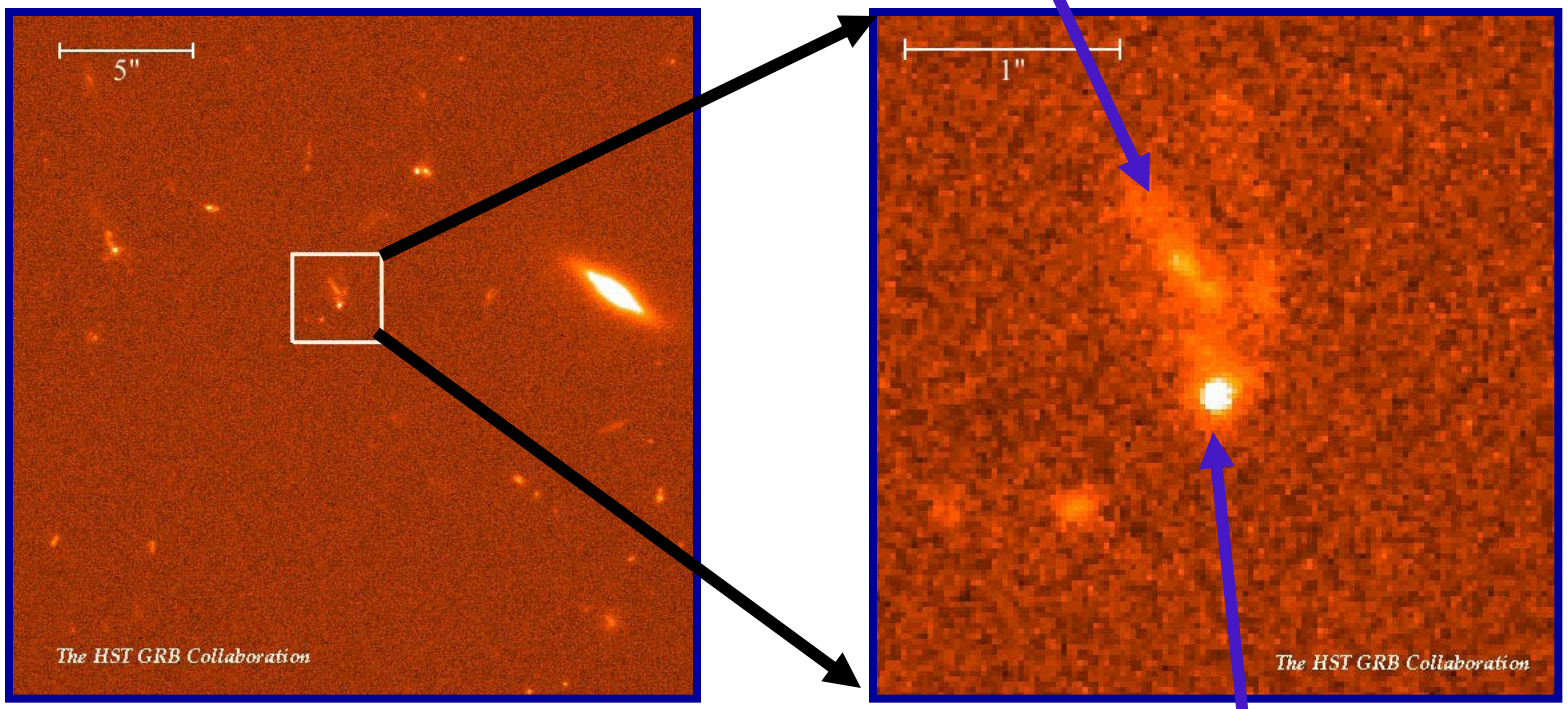
Six pictures over 10 minutes of a small piece of sky



Changes in a galaxy shows which galaxy hosted the GRB

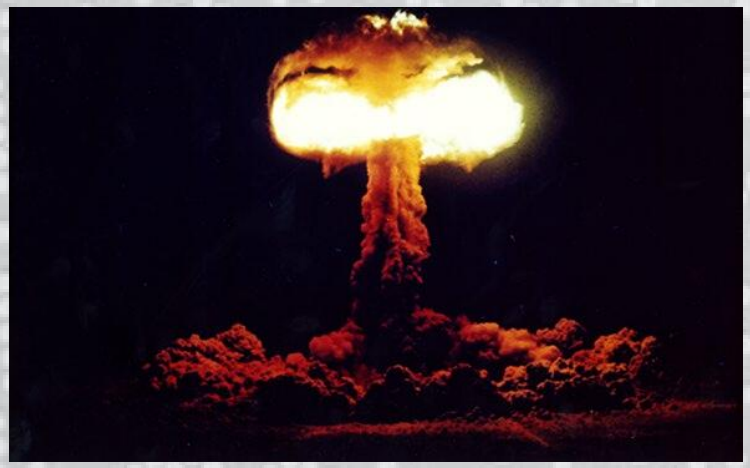
Host galaxy at 12 billion light years !



GRB

Need a huge reservoir of energy when 6-12 billion light years away!

E=M C^2 means matter can be turned into (a lot) of energy



1 raisin * c^2 = nuclear bomb energy

400,000 Earths * c^2 = GRB Energy

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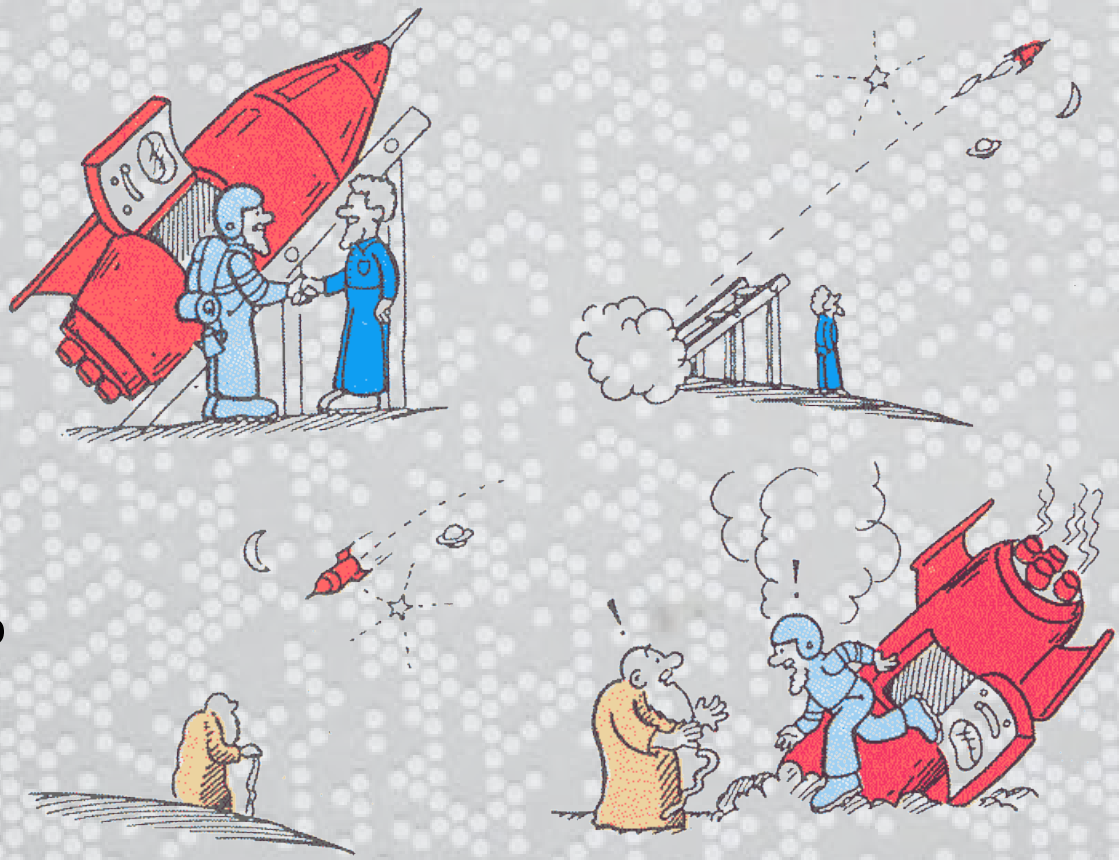
Black Holes are at the center of the brightest objects in the universe

The Twin paradox

One twin goes to another star, one twin stays on Earth

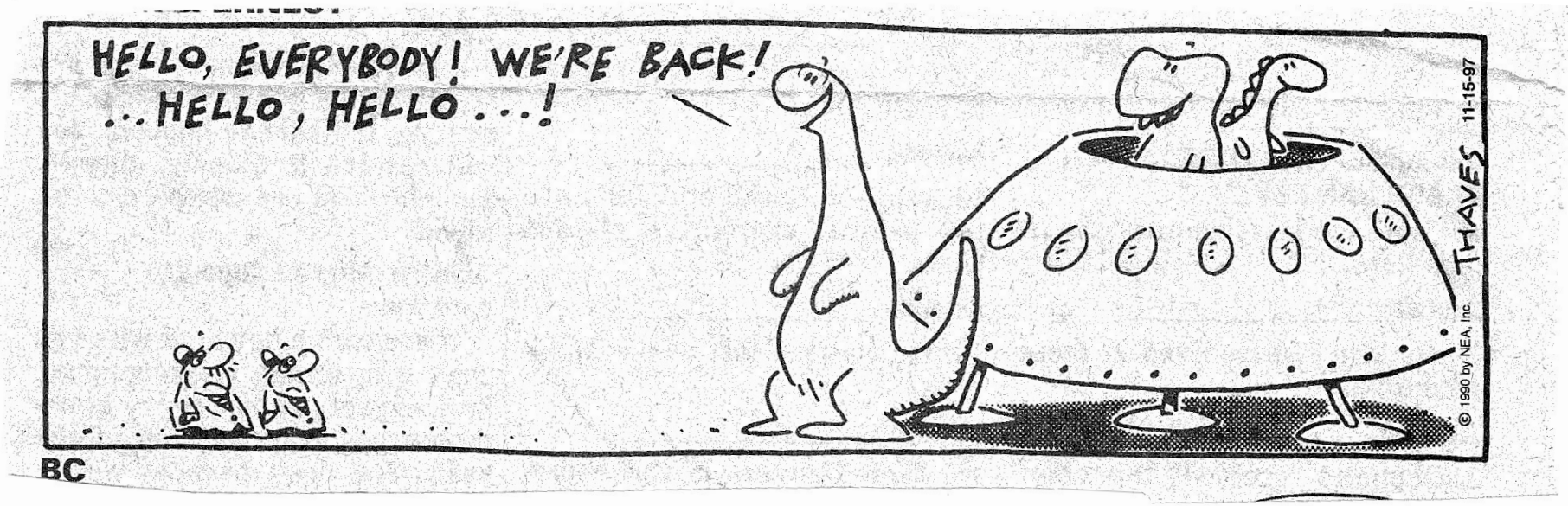
Rocket goes at 0.9999 c to a star that is 10 light-yr away: 10 yrs



Takes 10 yrs to return

The twin that stayed on the Earth is 20 years older. The rocket twin is only 3.4 months older!

Even if aliens could travel near the speed of light, they could not visit someplace and return home. Their home would be 1000's of years in their future.



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How much space is inside a empty sphere? Two ways to find out

1) Use the radius: vol= $4\pi R^3/3$

2) Take the sphere apart and count how much space is inside

Why are Black Holes “black”

Black holes have an infinite amount of space inside them.

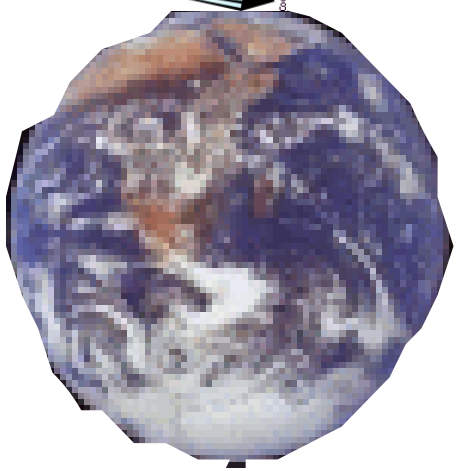
At the “event horizon” it takes an infinite amount of time for light to get out of them. Thus they are black.

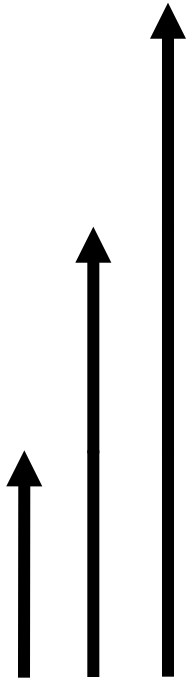
Force of gravity depends on distance as 1/distance^2

150 /3^2 = 16.6 pounds

150/2^2 = 37 pounds

150 pounds





1 2 3

$$F = \frac{M_{Earth}\, M_{Man}}{D^2}$$

$1/D^2$ becomes very important near a black hole

The black hole pulls with a force of 6 Million tons on a 4 pound head

1 Billion Tons

The black hole pulls with a force of 13 Million tons on a 2 pound foot

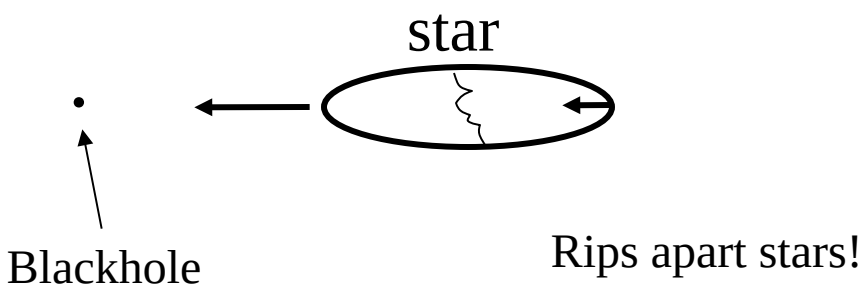
6ft 12ft

Earth as Black hole (2 inches)

Why are black holes the brightest objects in the universe?

Gravity decreases with distance (1/distance^2)

The ***difference*** in gravity at one side of objects compared to the other side tears everything apart, making huge explosions.



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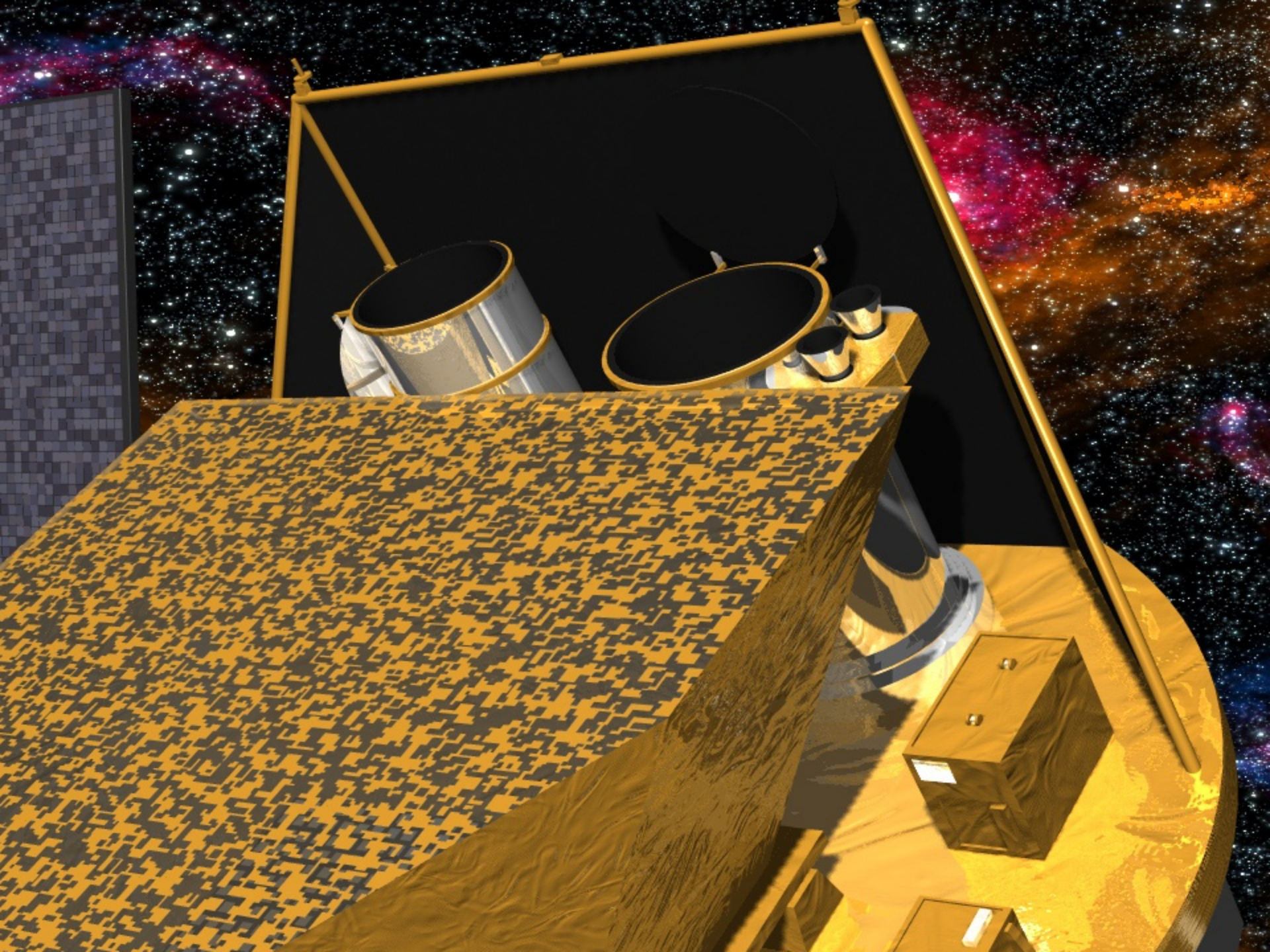
Swift satellite ready for launch at Kennedy Space Center



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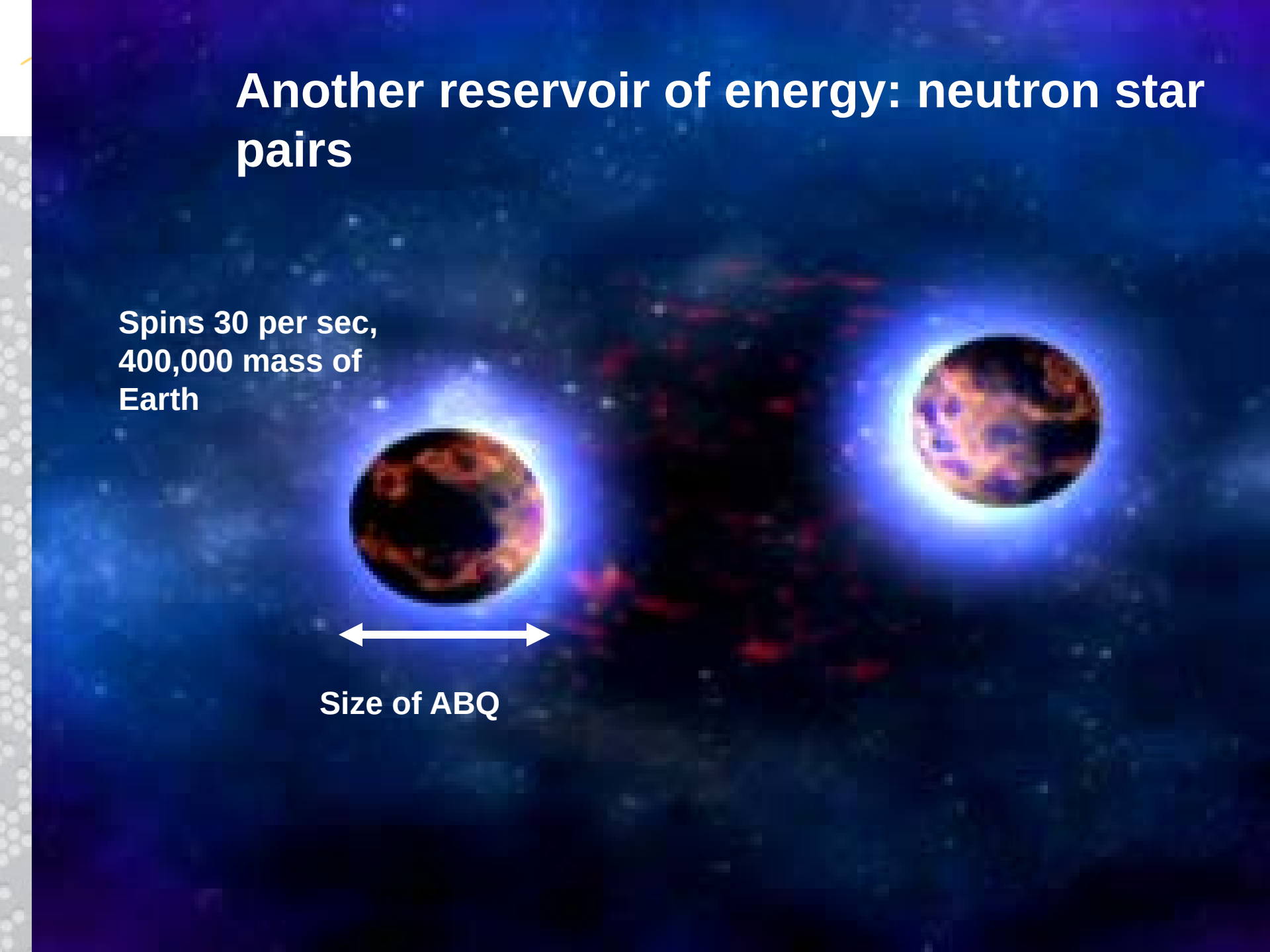
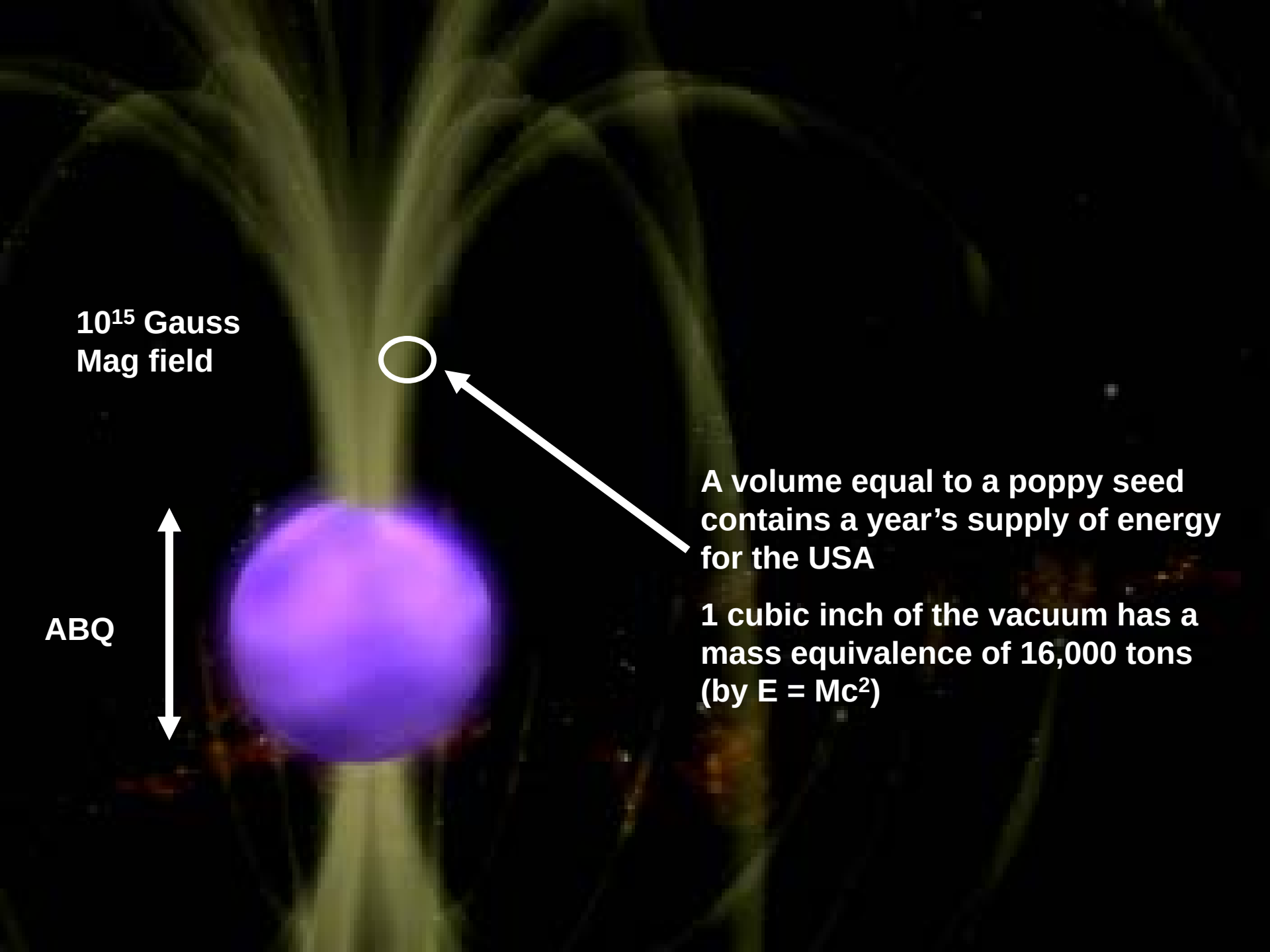
Swift and Vela

Another reservoir of energy: neutron star pairs



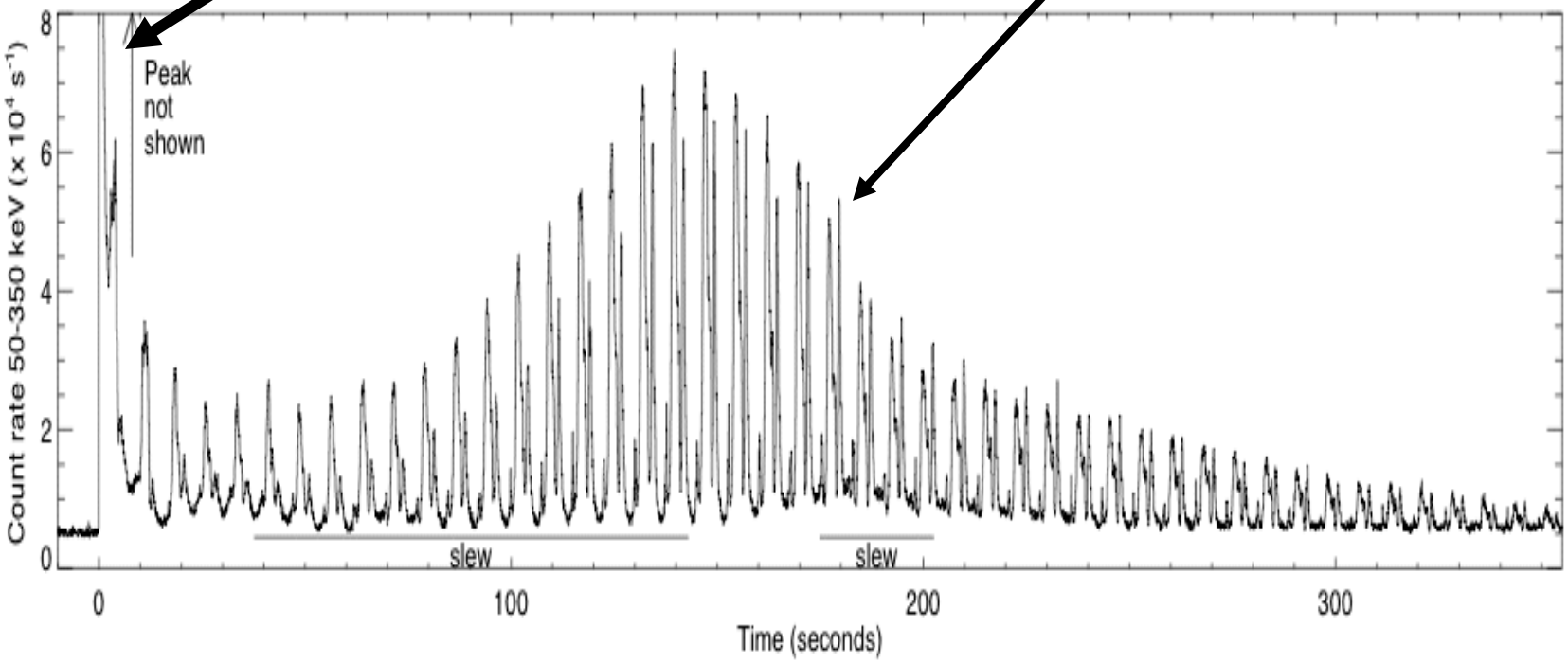

10^{15} Gauss
Mag field
ABQ
A volume equal to a poppy seed contains a year's supply of energy for the USA
1 cubic inch of the vacuum has a mass equivalence of 16,000 tons (by $E = Mc^2$)

Dec 27, 2004: a super burst from a "soft gamma-repeater"

Hit the earth with 5 erg/sec/cm^2 = dime hitting every square inch at 2 inches per sec

Huge peak, 0.16 sec long

Emission over 100's seconds



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Summary

Gamma-ray bursts were the first indication that the universe contains violent explosions

Multiple pinhole “coded apertures” are well suited to locating bursts of gamma-rays.

The location revealed that the bursts were coming from the other side of the universe.

Only black holes are powerful enough to be seen so far away

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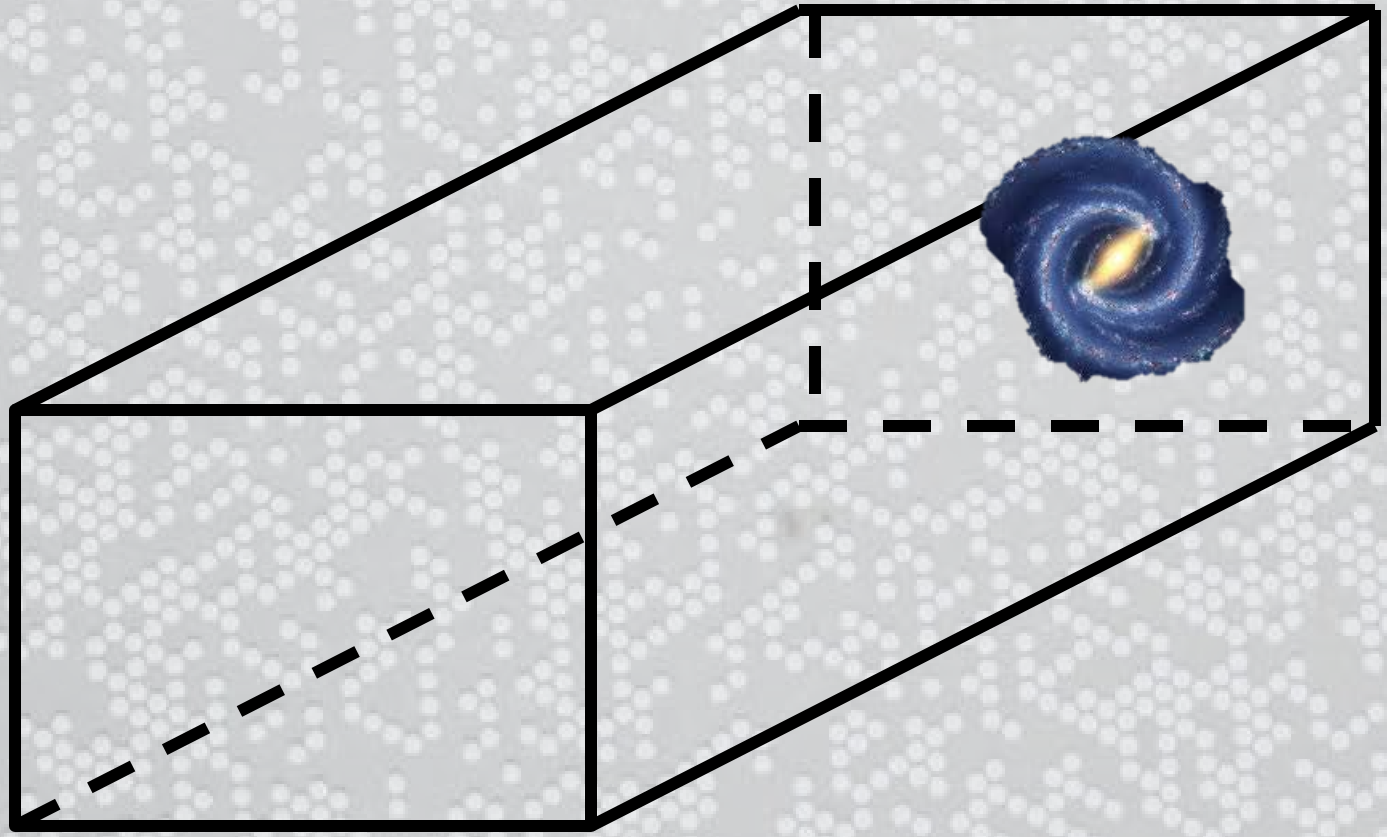
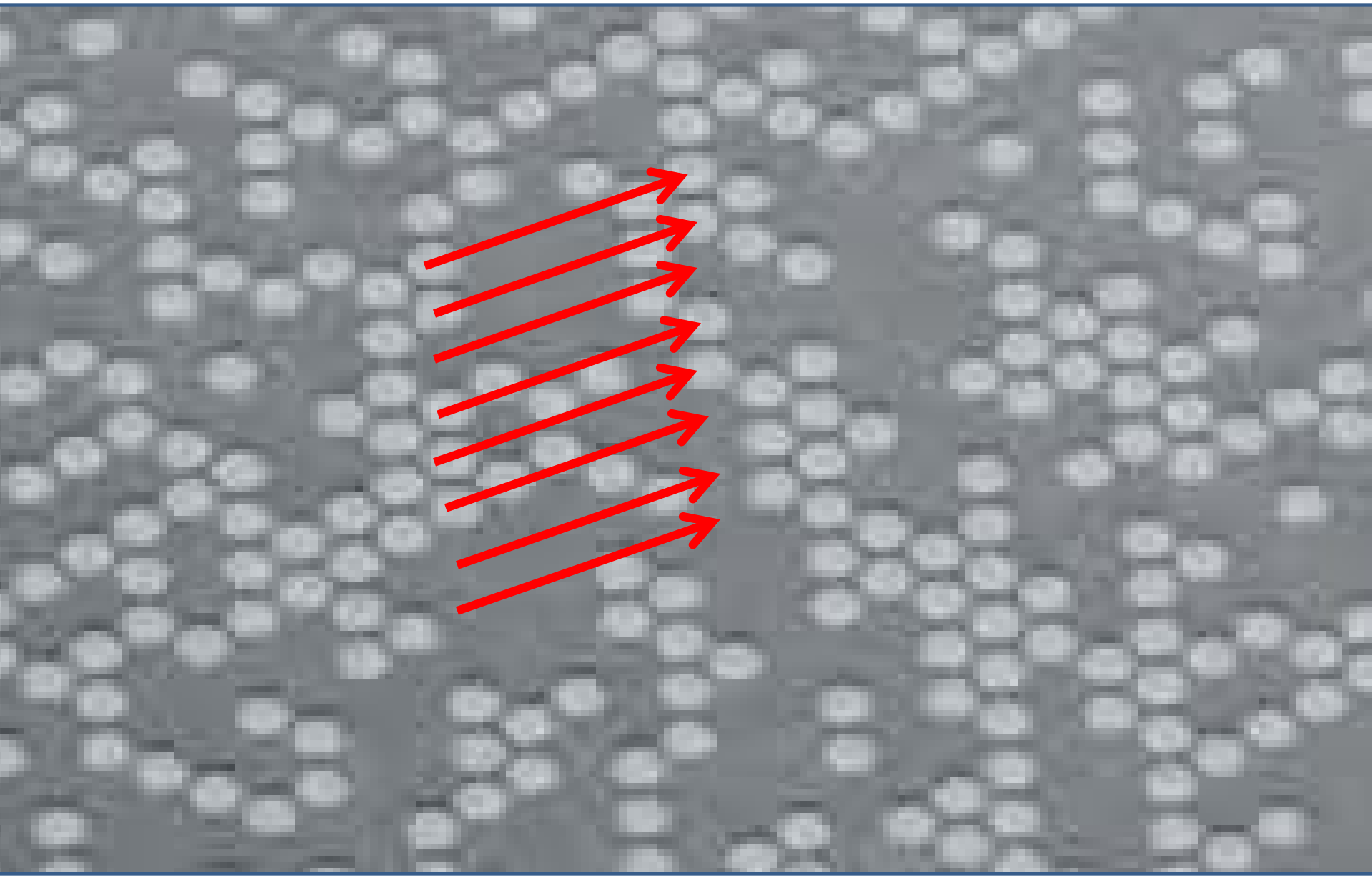
Backup

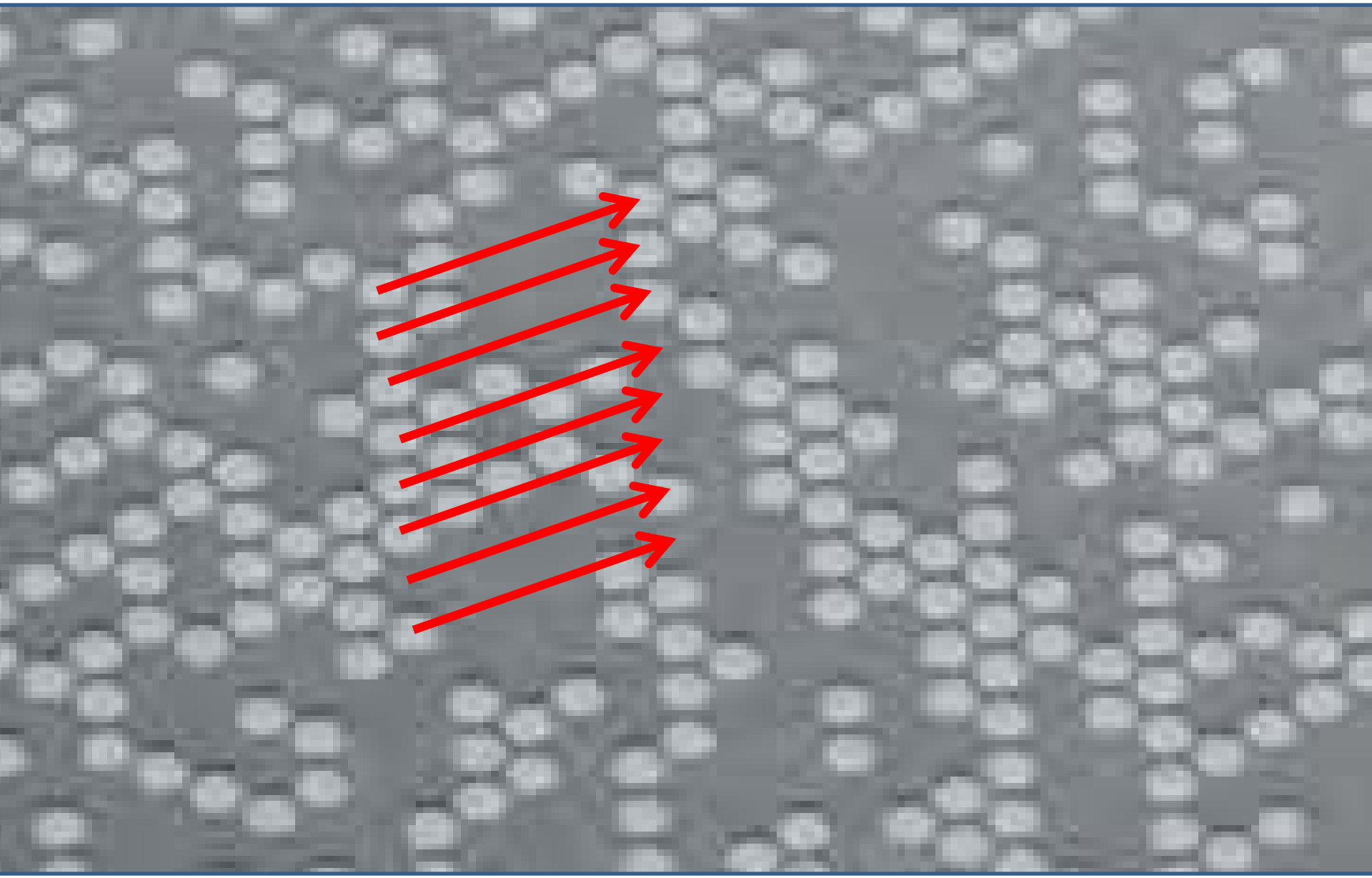
SUN
EARTH
URANUS

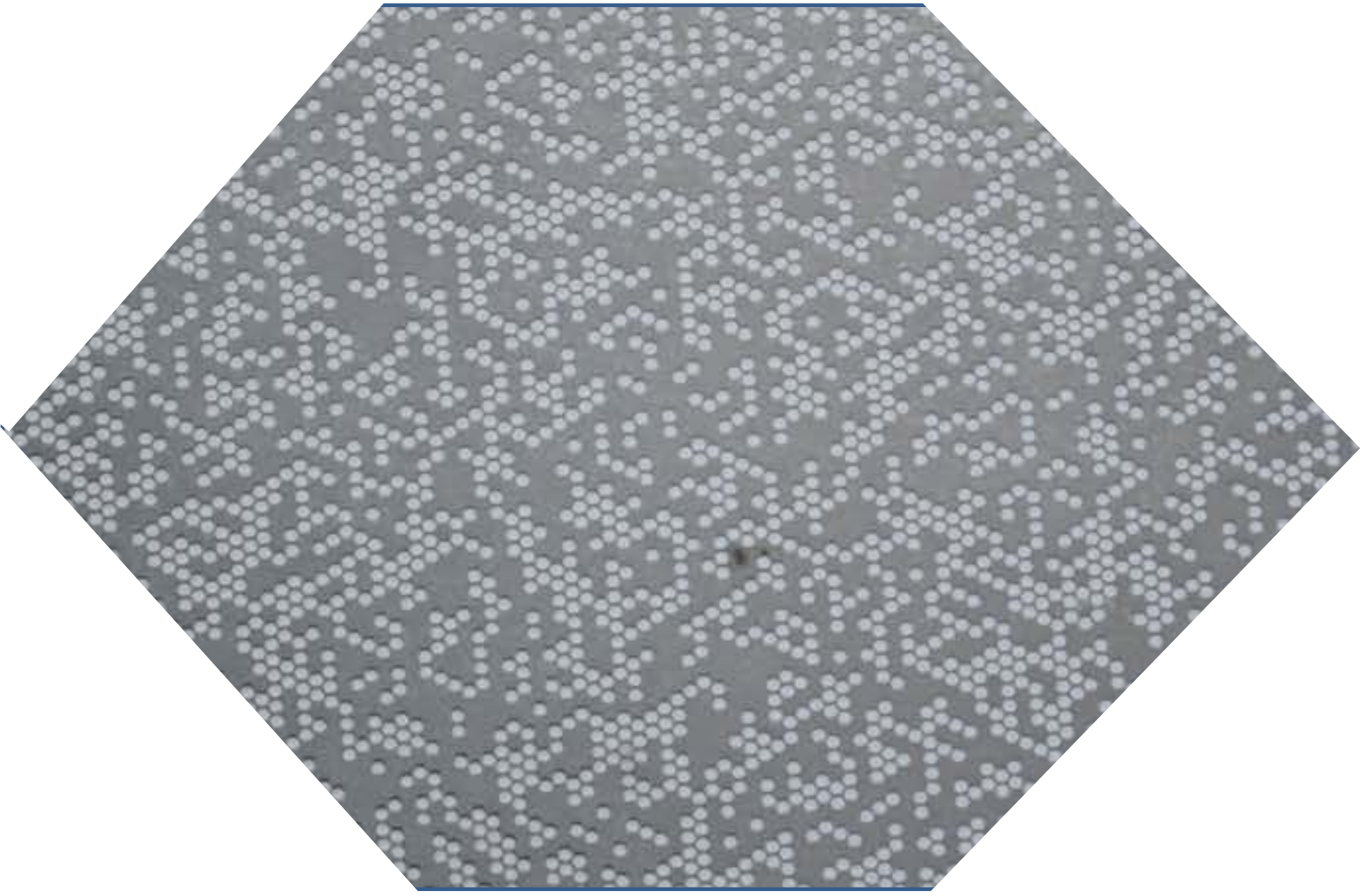


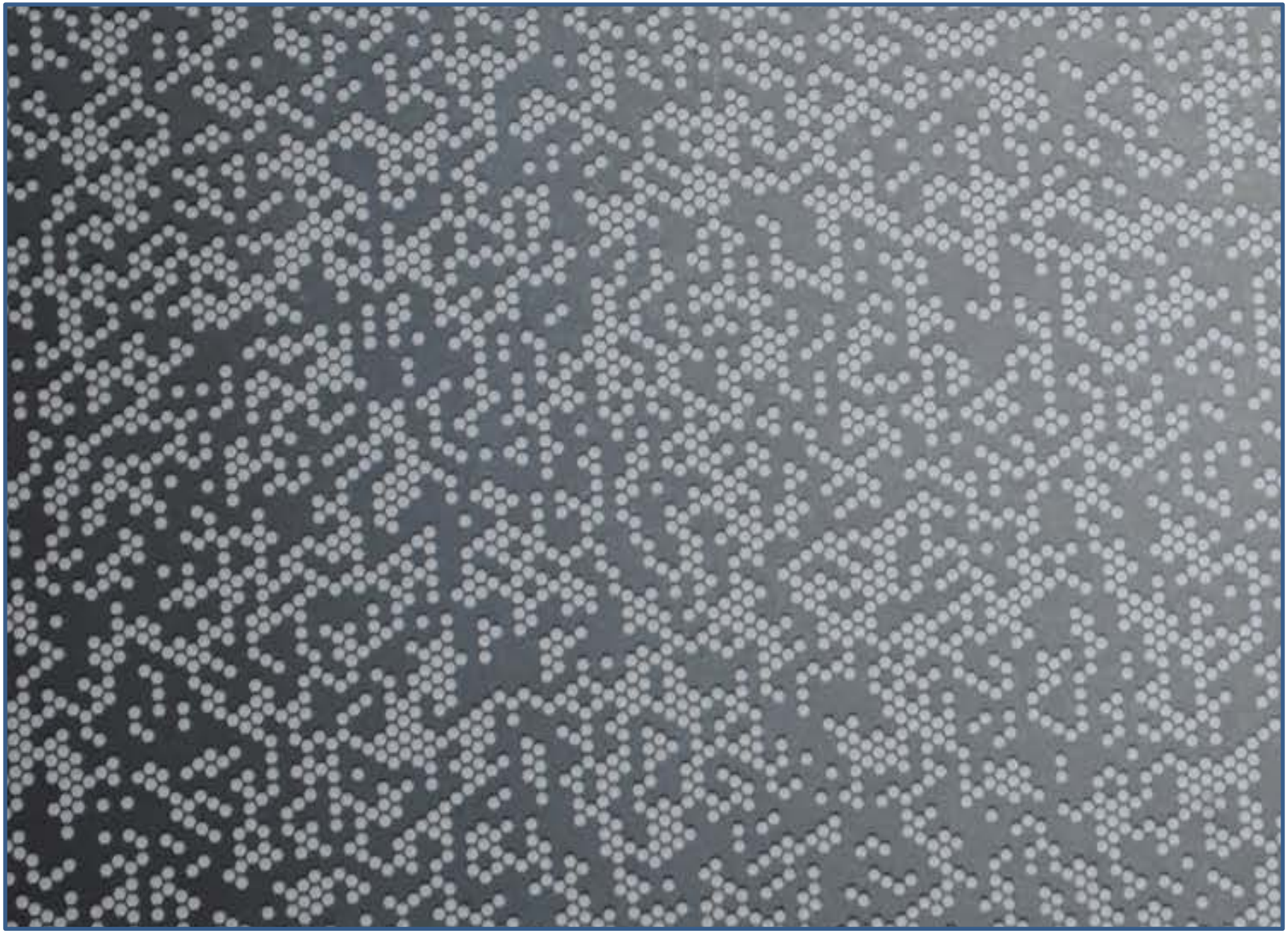
GRBs only last milliseconds to tens of seconds.

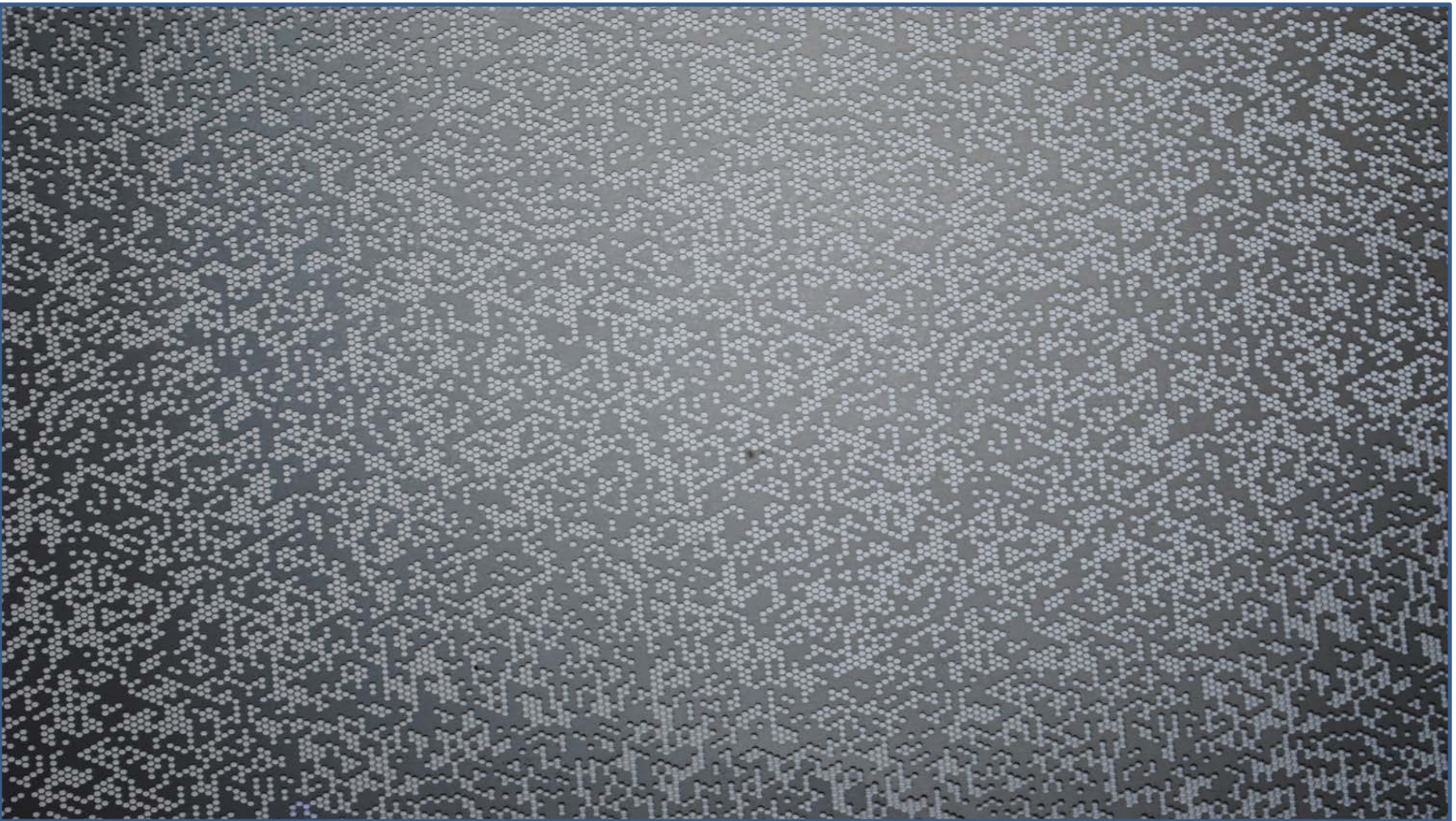
We had to build completely robotic instruments that could detect the gamma-rays and find which galaxy the GRB came from.





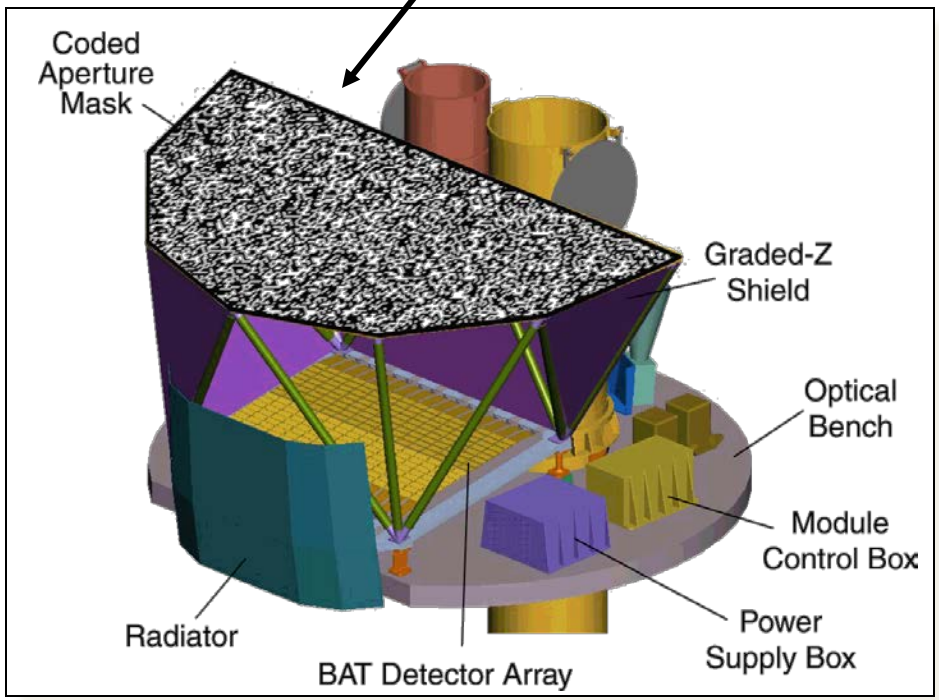






Burst Alert Telescope (BAT)

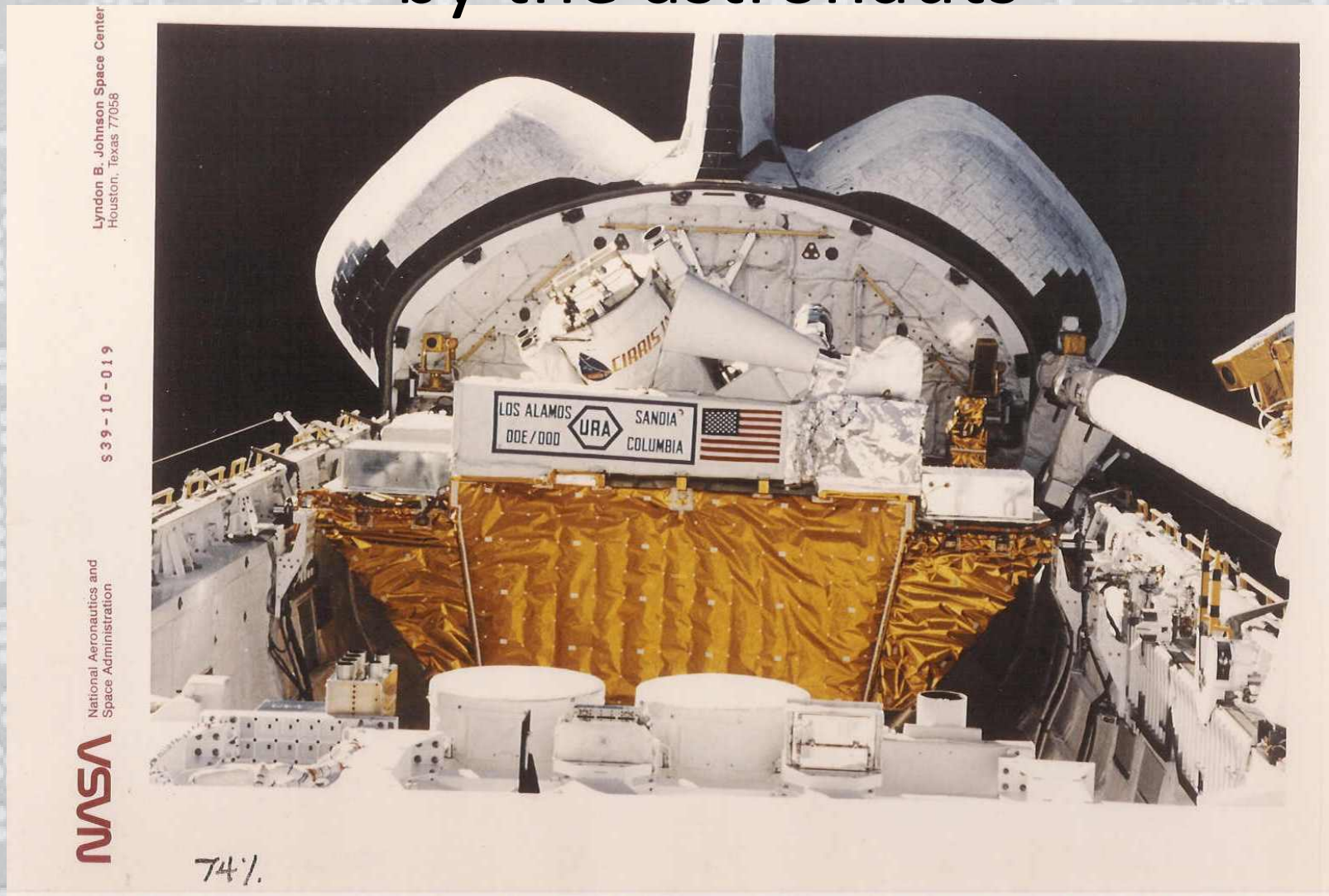
LANL designed
Coded Aperture Mask

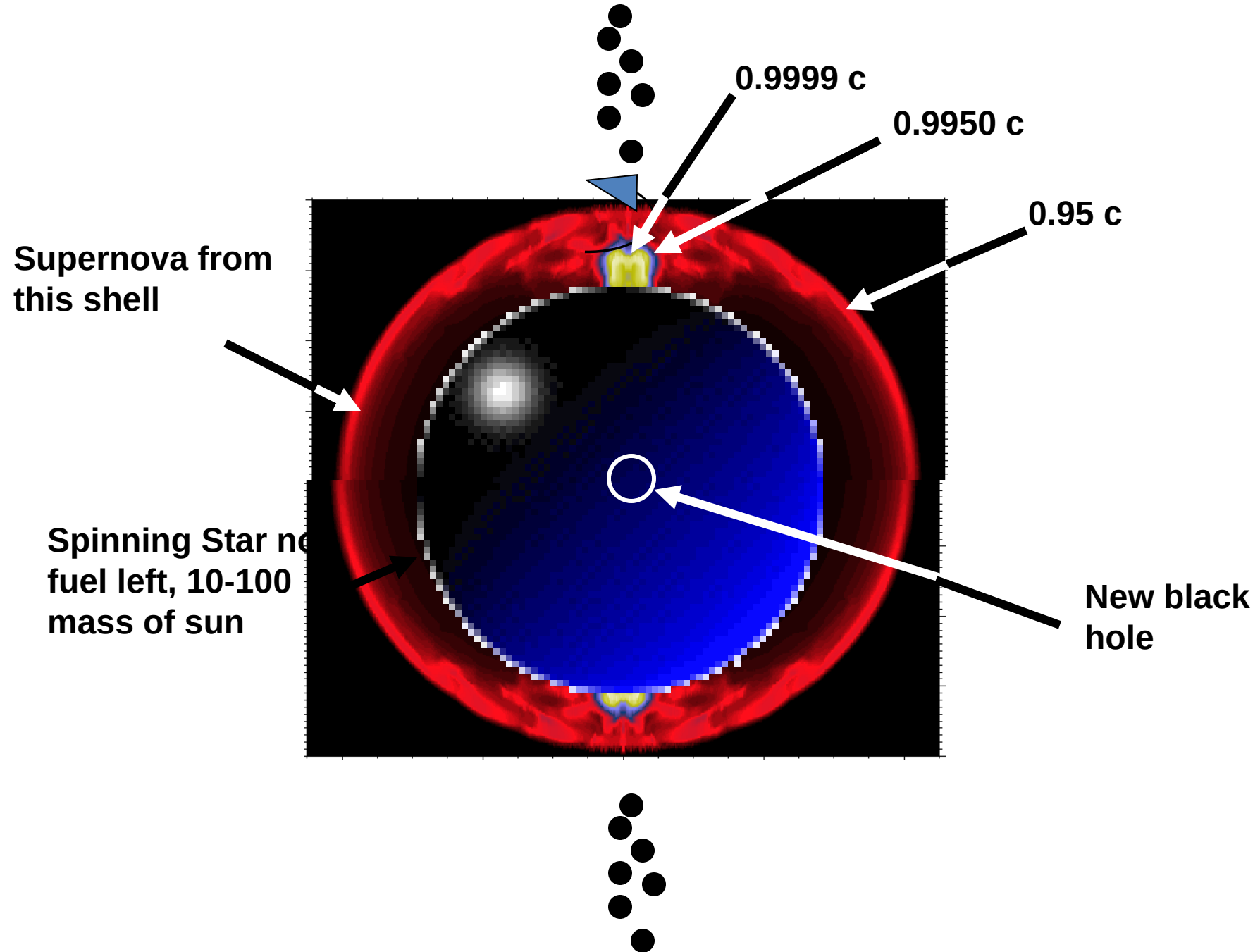


BAT Characteristics

- E Range: 15 - 350 keV
- E Resoln: 7 kev
- Loc Resoln: 1-4 arcmin
- 2 steradian field of view
- 32K CZT dets, 5200 cm2
- First satellite to autonomously detect new event and slew satilite to observe

Picture of experiment in space taken by the astronauts




0.9999 c
0.9950 c
0.95 c
Supernova from this shell
Spinning Star ne
fuel left, 10-100
mass of sun
New black hole