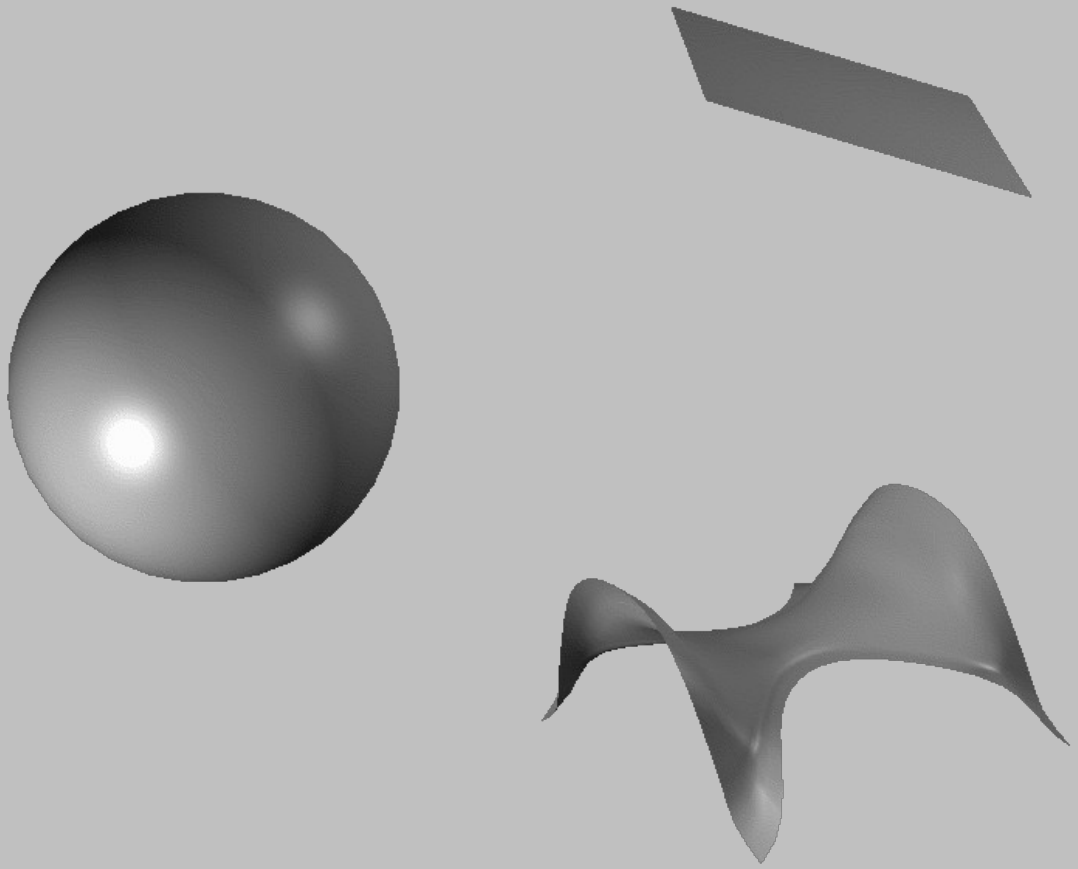
The Shape of the Universe

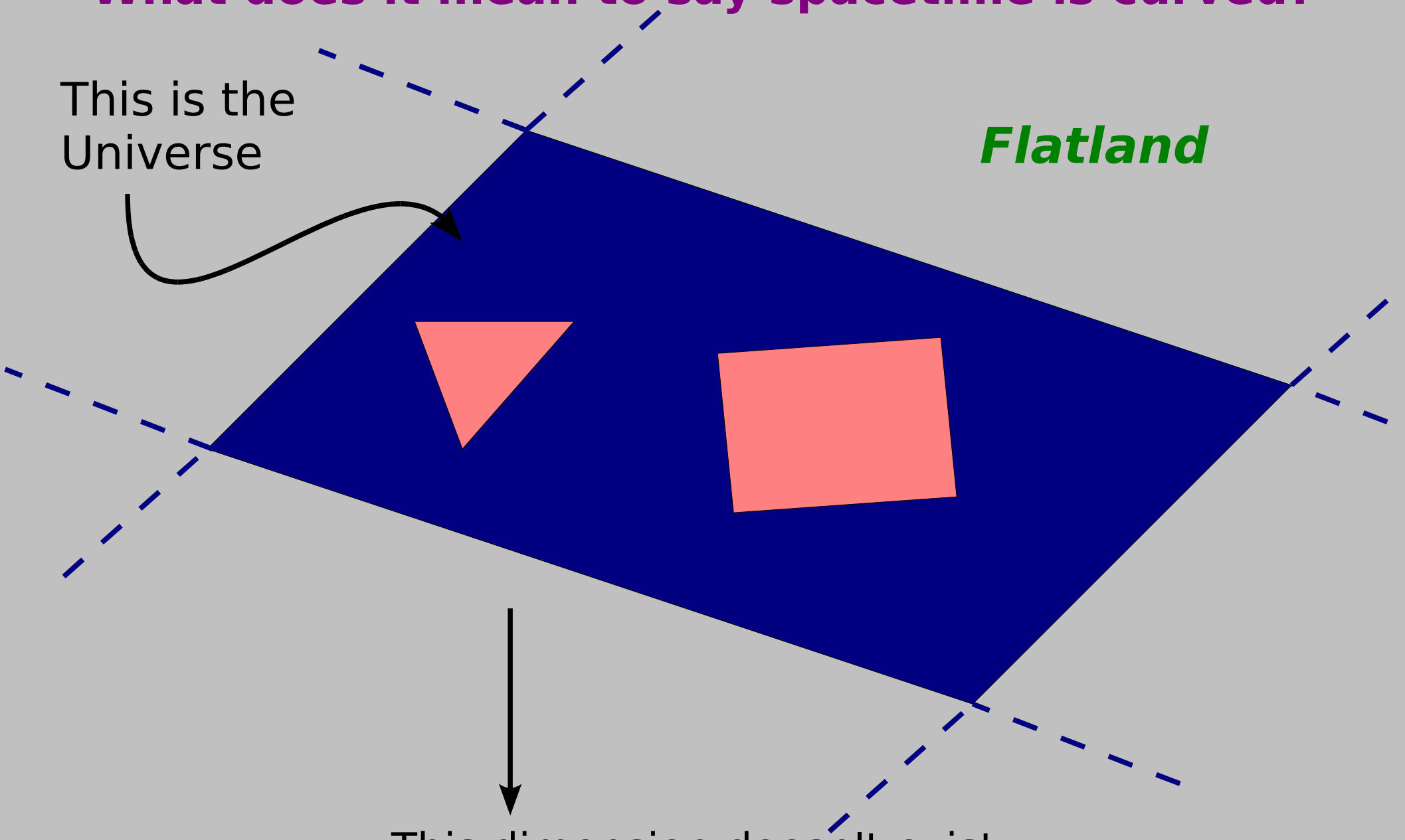


Dr. Rob Knop

MICA (www.mica-vw.org)

Second Life, 2009-02-27

What does it mean to say spacetime is curved?



(or is something we can't measure, and thus is meaningless)

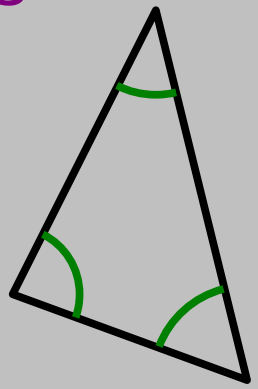
“Flat” space is Euclidean space

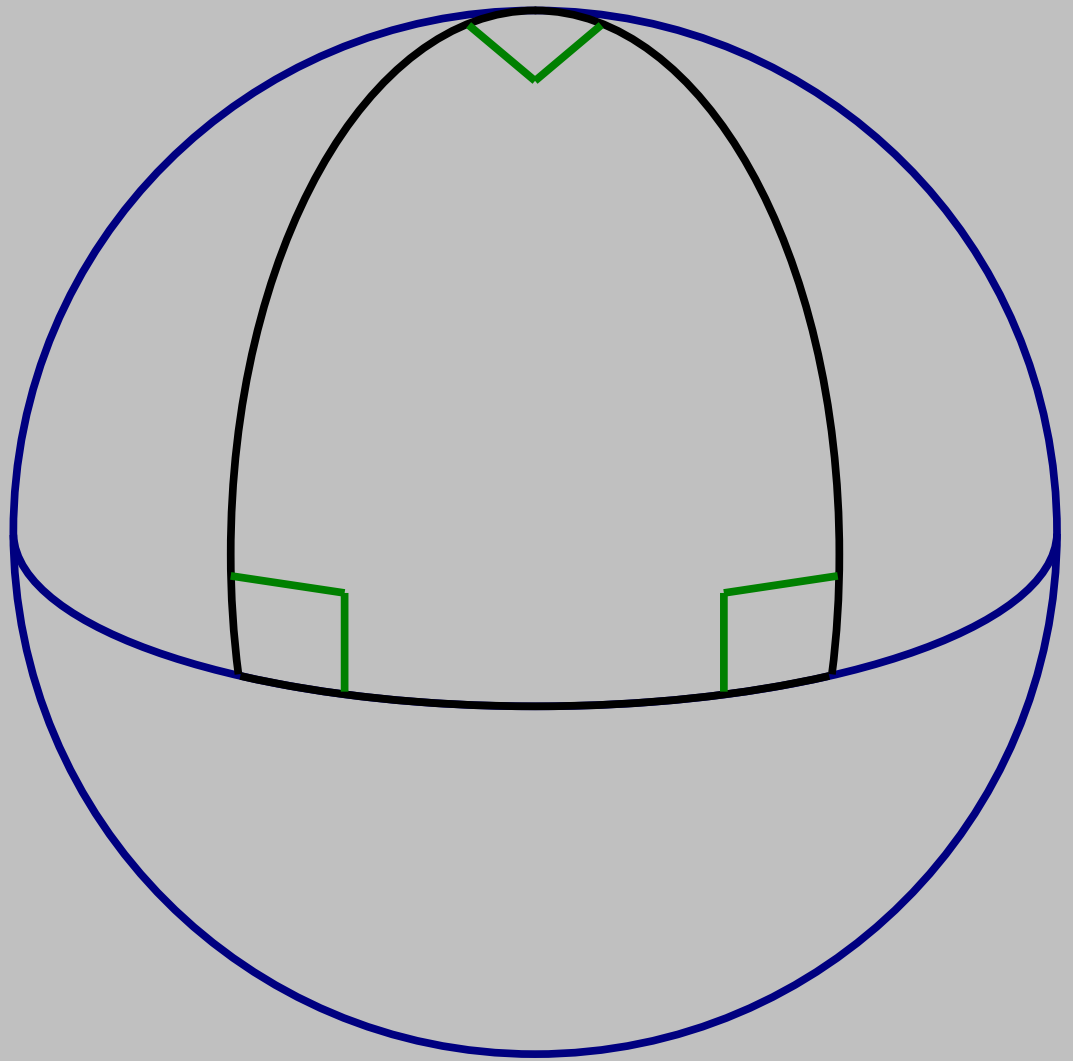
- Triangle angles sum to 180°
- Circumference/Diameter = π
- Parallel lines don't converge or diverge

“Curved” space has different geometry

Flat (Euclidean) Space:

Any triangle, three interior angles add to 180°





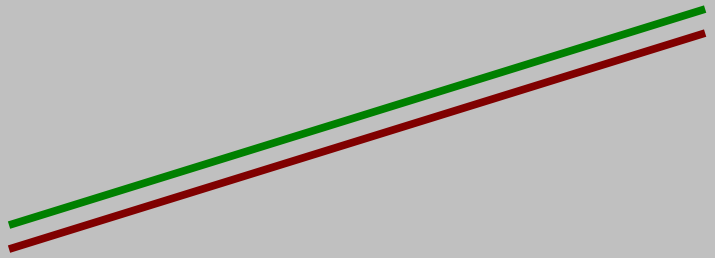
Curved Space: *This* triangle, three interior angles add to 270°

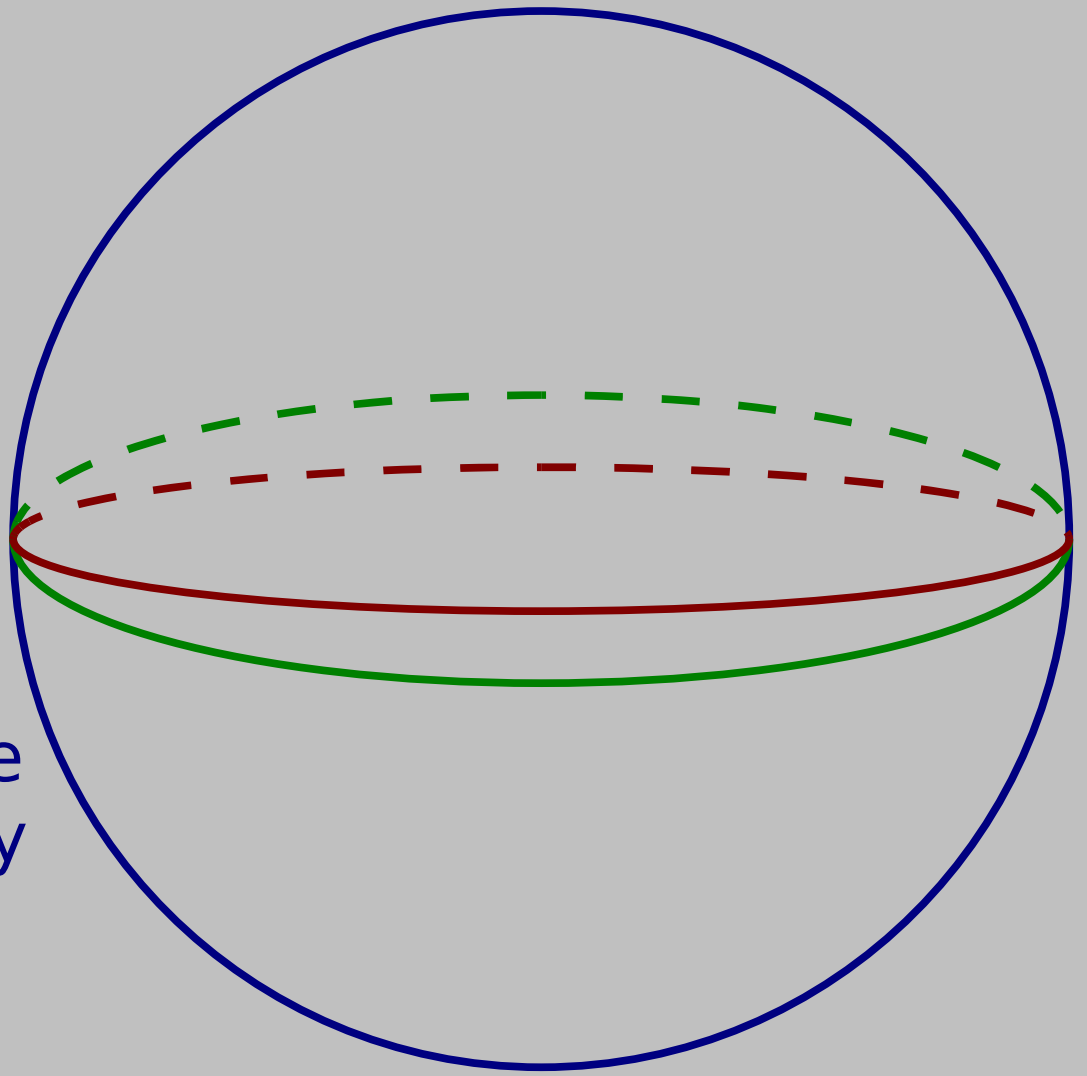
(In general: >180° : positive curvature

<180° : negative curvature)

Flat (Euclidean) Space:

Parallel lines neither converge nor diverge

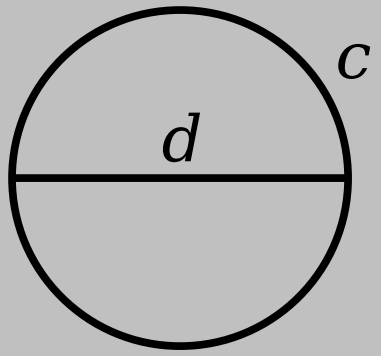


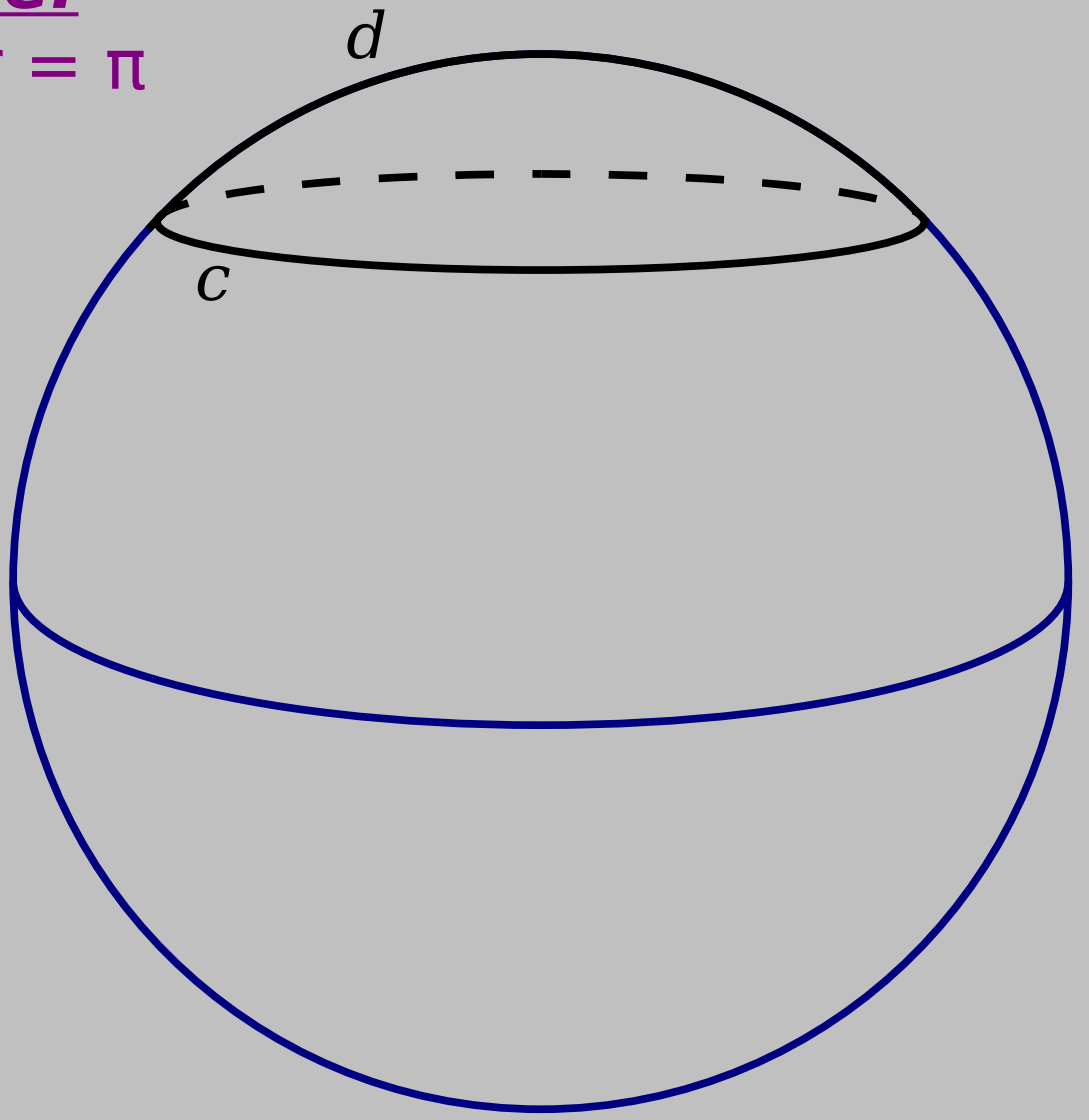


2-Sphere: “lines” are great circles, and they do cross

Flat (Euclidean) Space:

Circumference / Diameter = π





2-Sphere:

Circumference / Diameter < π

These properties are *intrinsic* curvature

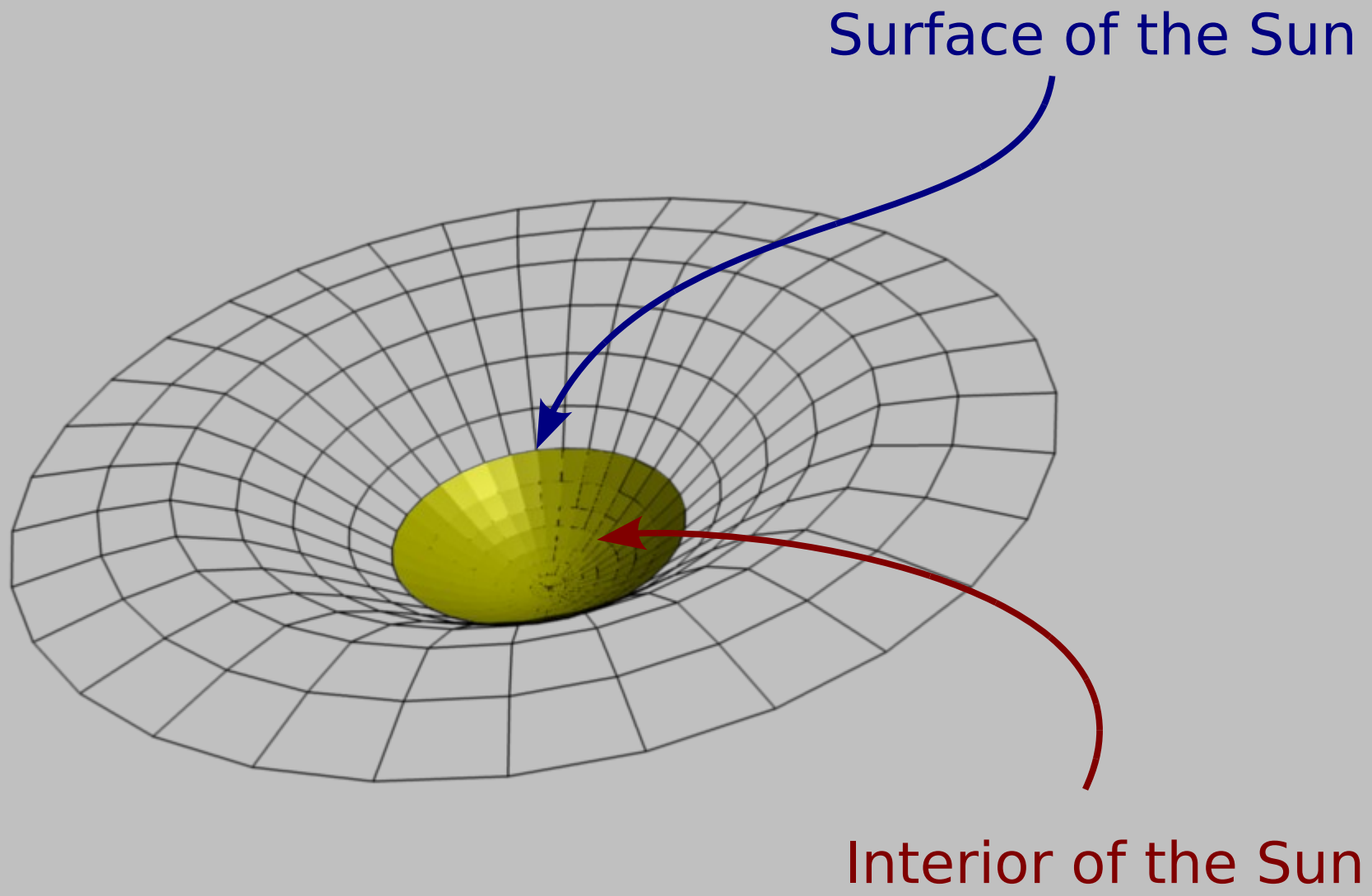
They can be measured entirely *within* the space

I have “embedded” the 2-sphere into our 3d space for purposes of visualization... but there is no *need* to do that to measure the curvature.

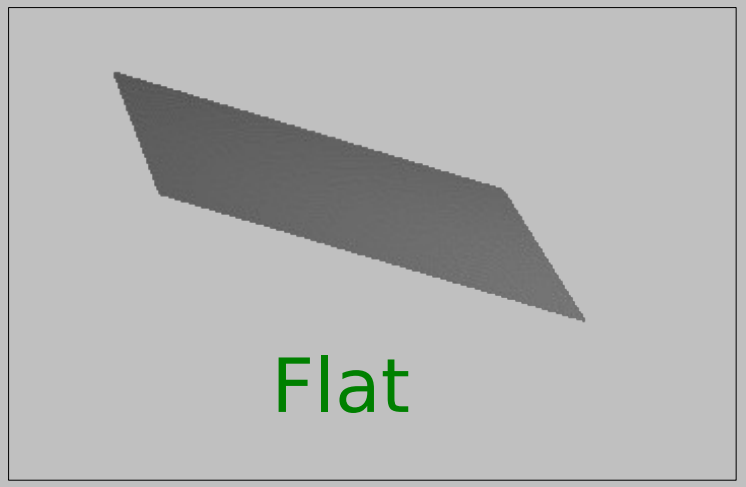
The surface of a cylinder has no intrinsic curvature!

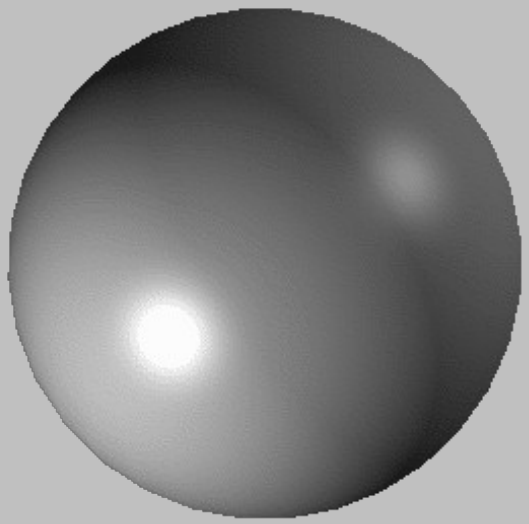
- Draw triangles, parallel lines, circles, on a piece of paper.
- Pick it up and curve it into a cylinder... no crunching or tearing needed. Euclid's rules still work on the cylinder.
- The cylinder's curvature is *extrinsic*.

Spacetime is curved by the presence of mass

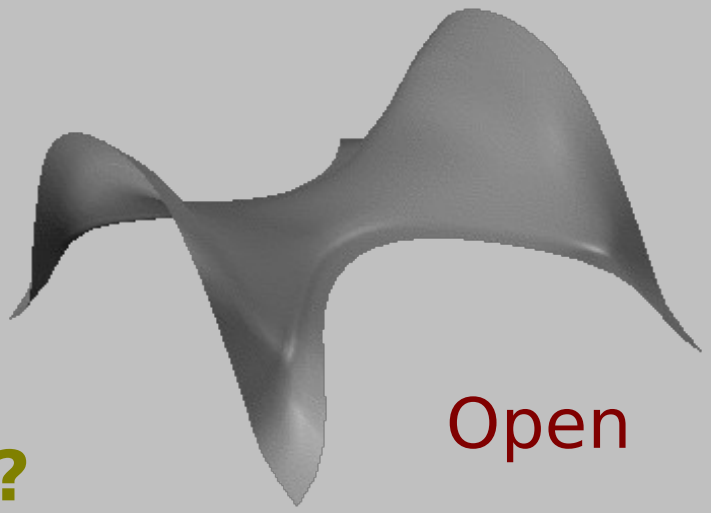


Possible shapes for the whole Universe





Closed



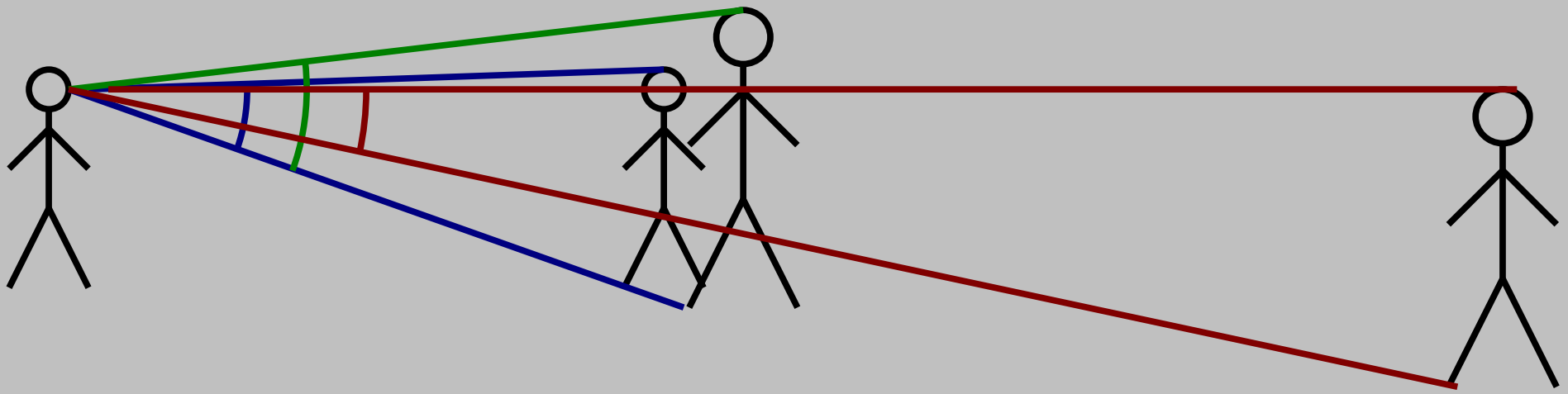
Open

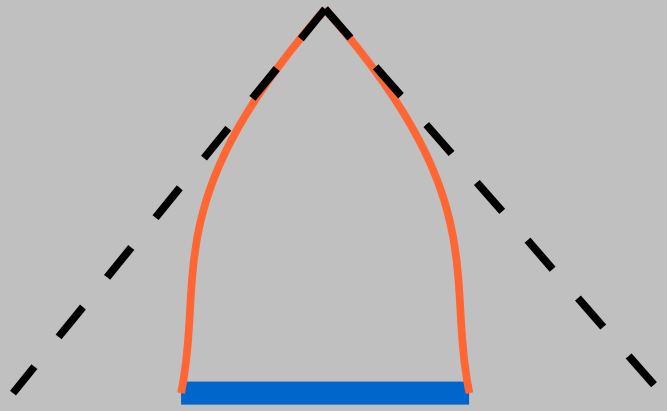
How to figure out which?

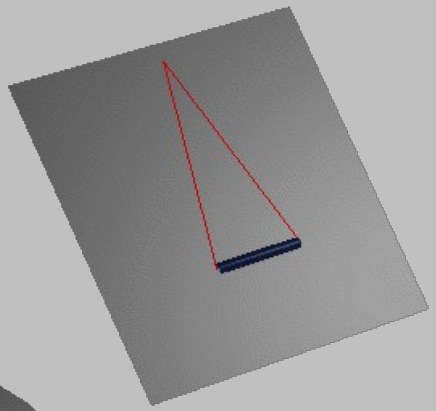
Draw triangles! Big ones...

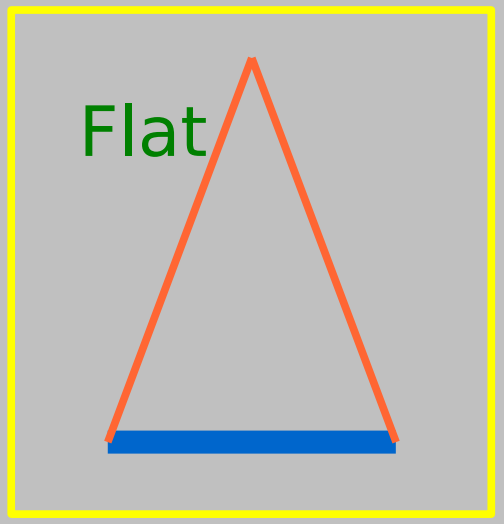
What do we mean when we say how big something looks?

The angle that it *subtends*.



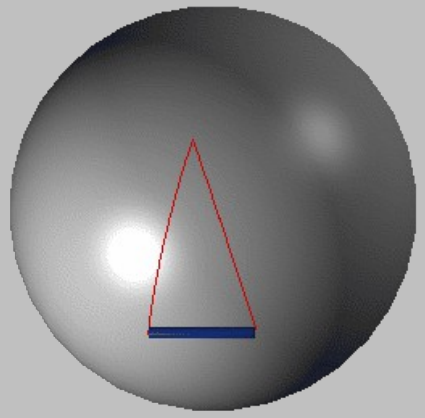


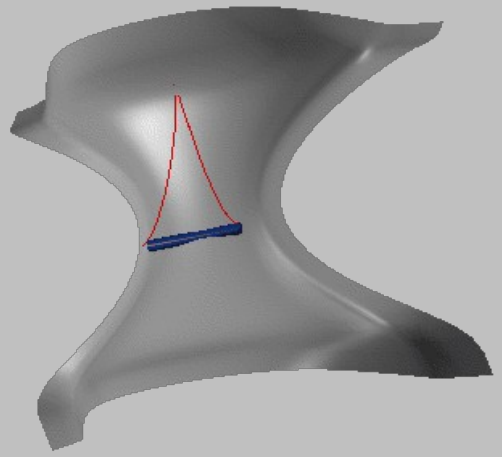




Closed:

Looks Bigger

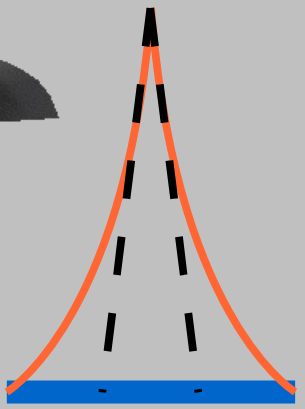




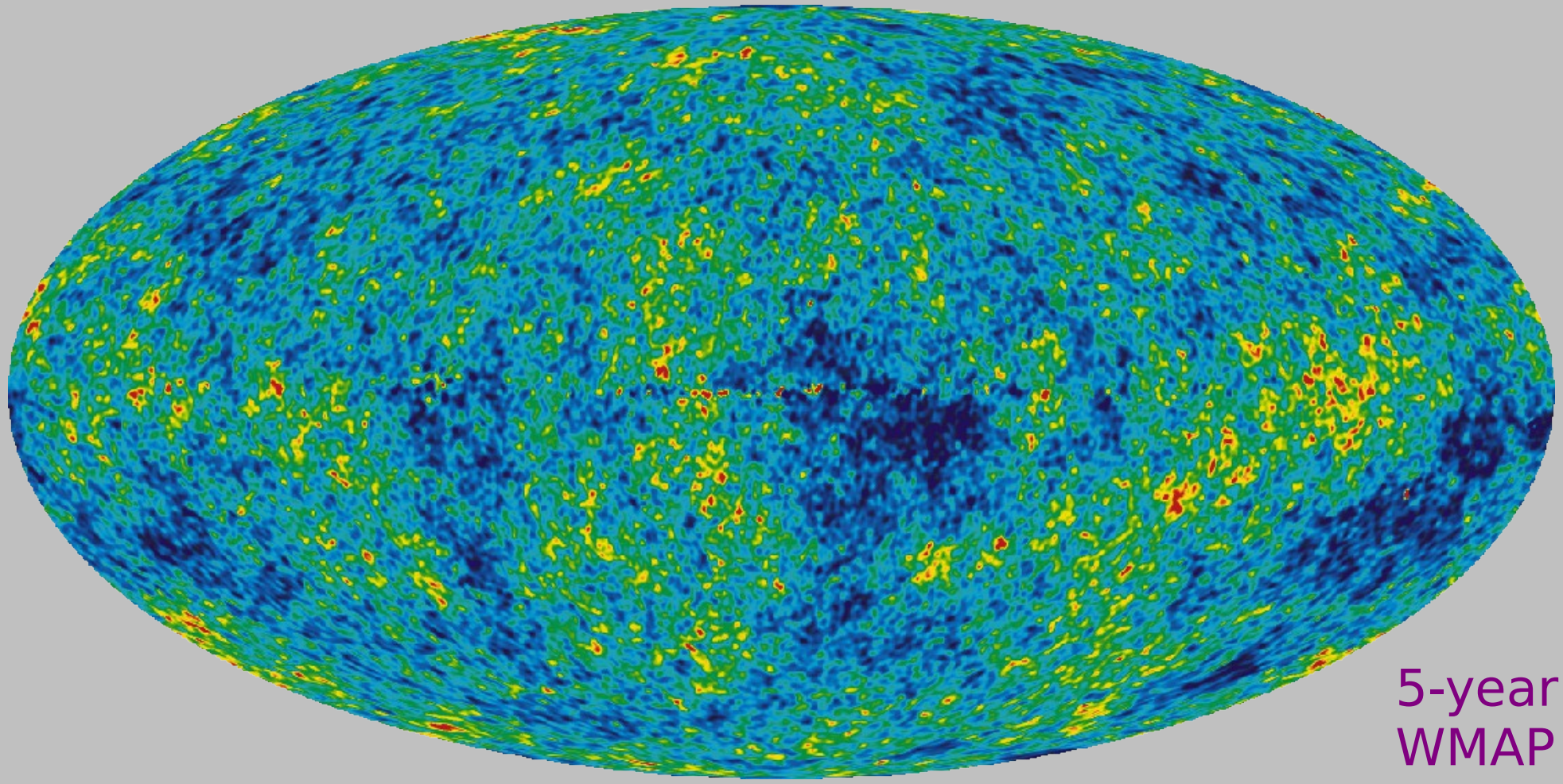
We need something in the very distant Universe whose intrinsic size we know. We can figure out the Universe's curvature by measuring how big an angle it subtends.

Open:

Looks Smaller



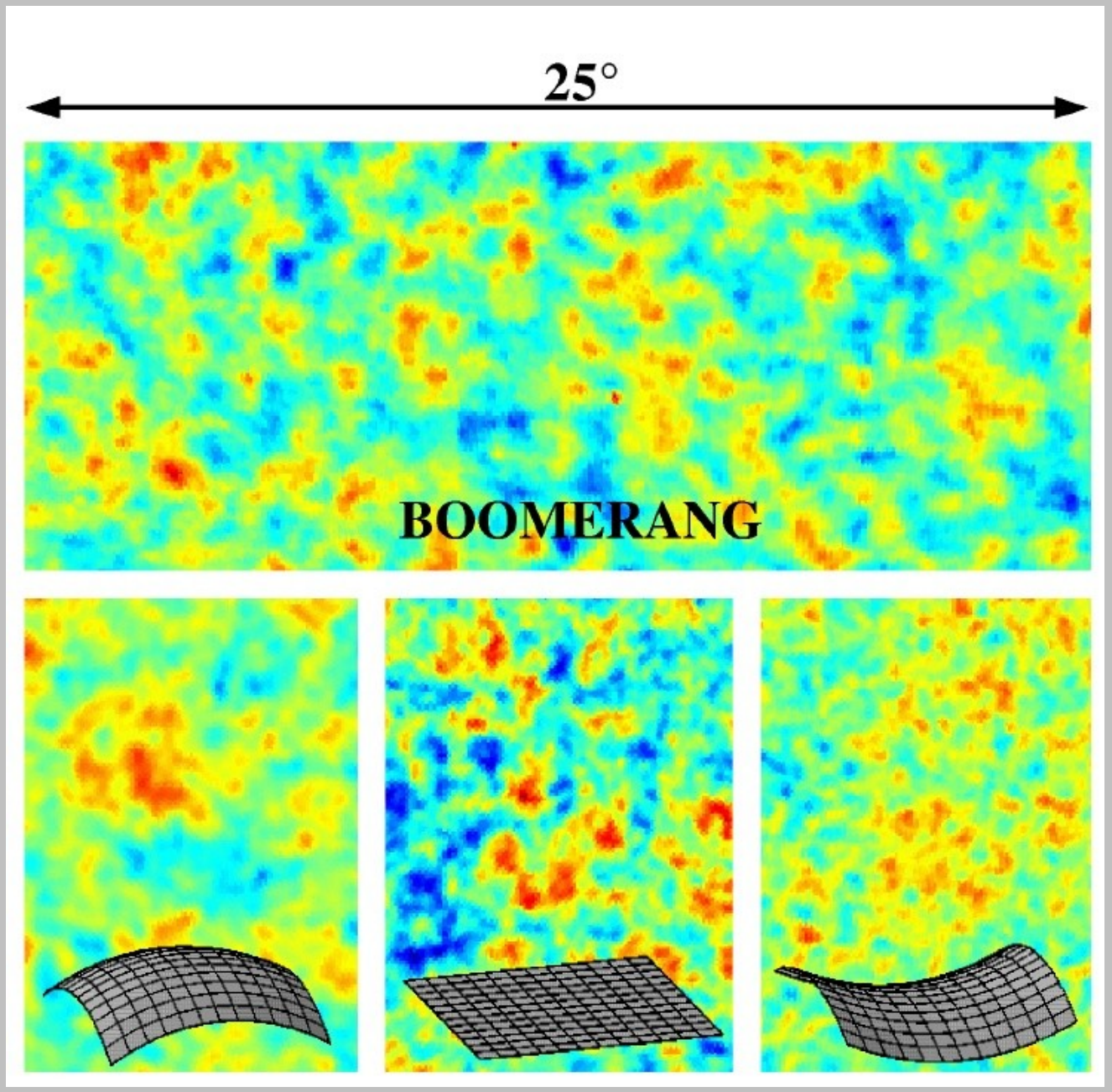
The Cosmic Microwave Background



5-year
WMAP
Data

Maximum fluctuation amplitude : 75 μK

(The CMB is smooth to one part in 40,000)



BOOMERANG *and* MAXIMA

Two balloon-borne telescopes measured the CMB in 1998, indicating the Universe was close to flat.

de Bernardis, *et al.*, 2000, *Nature*, 404, 955

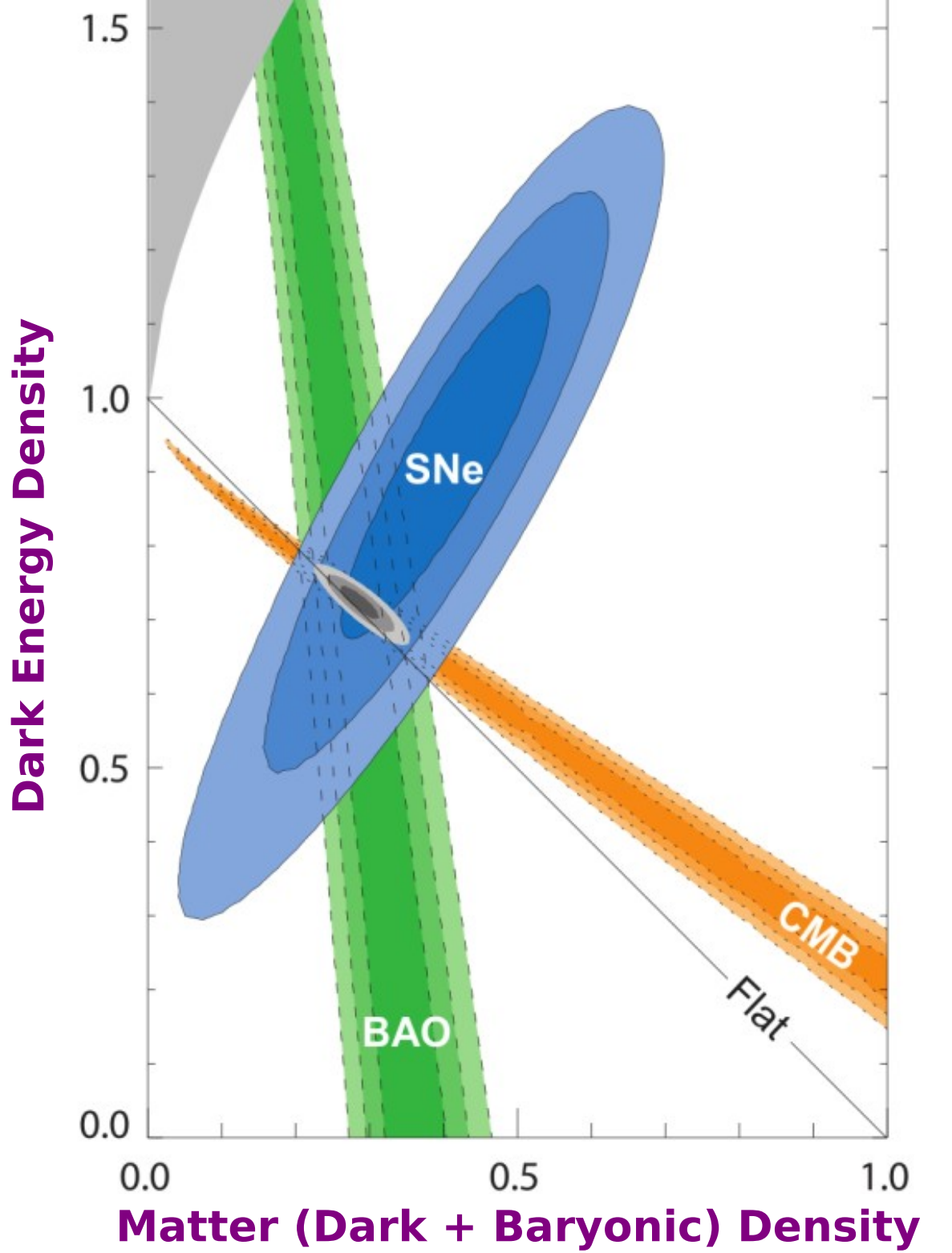
http://cmb.phys.cwru.edu/boomerang/press_images/index.html

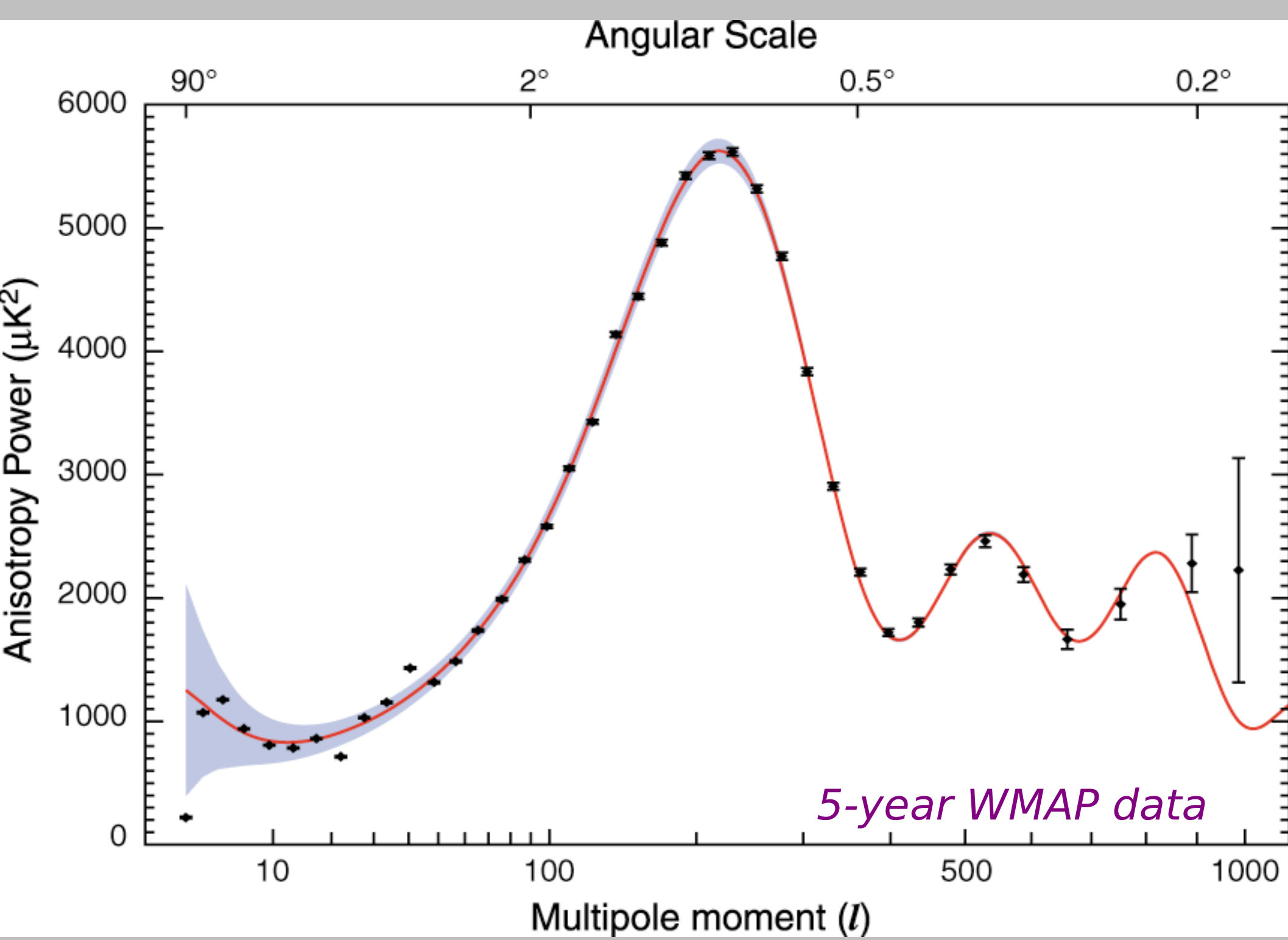
Observations of **Supernovae**, the **Cosmic Microwave Background**, and **Galaxy Clustering** together provide a consistent cosmology.

$\Omega_{tot} = 1.009 \pm 0.009$

$\Omega_{M} = 0.29 \pm 0.02$

$\Omega_{\Lambda} = 0.72 \pm 0.02$



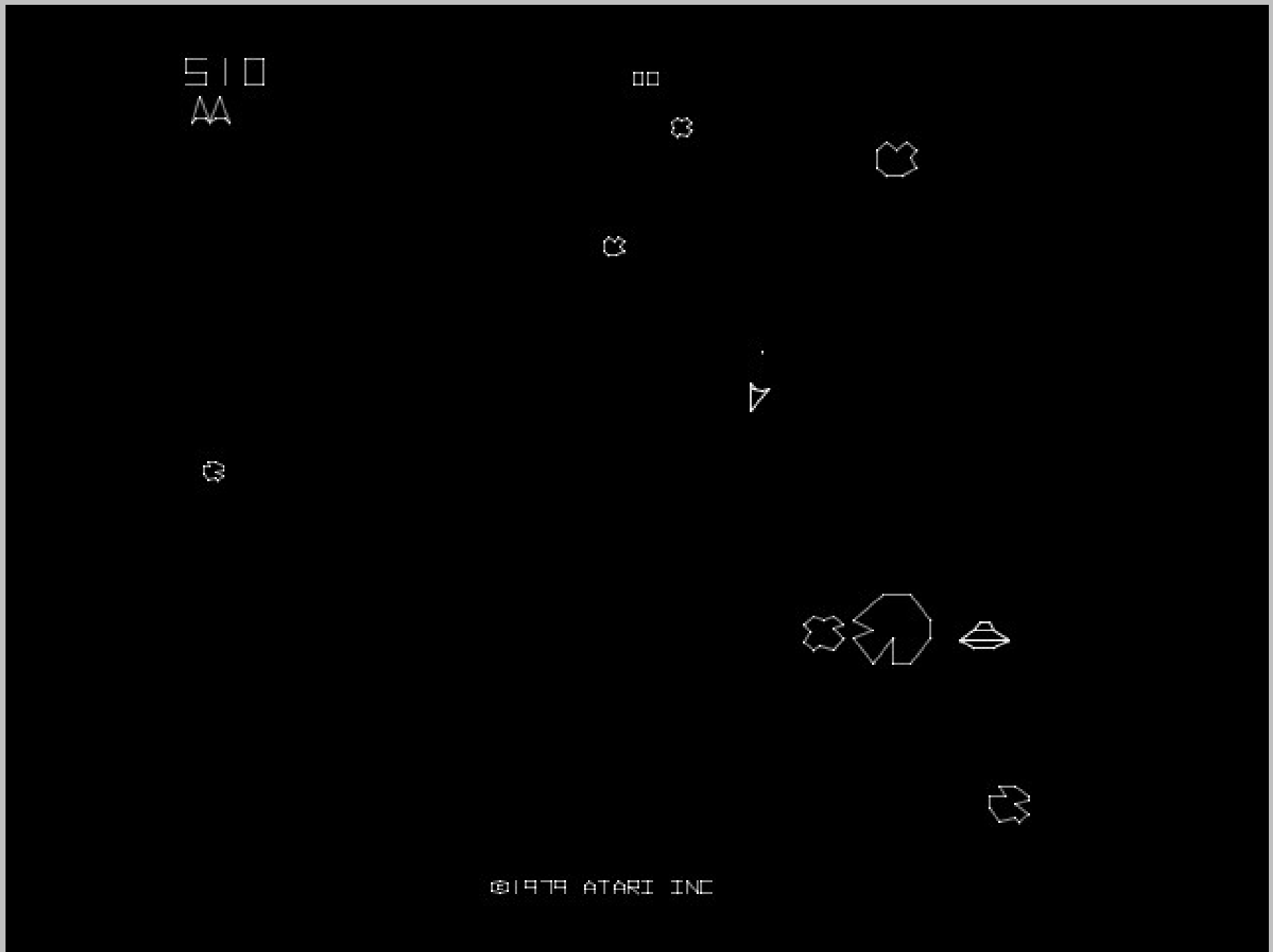

Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
Anisotropy Power (μK²)
10
100
500
1000
Multipole moment (l)
5-year WMAP data

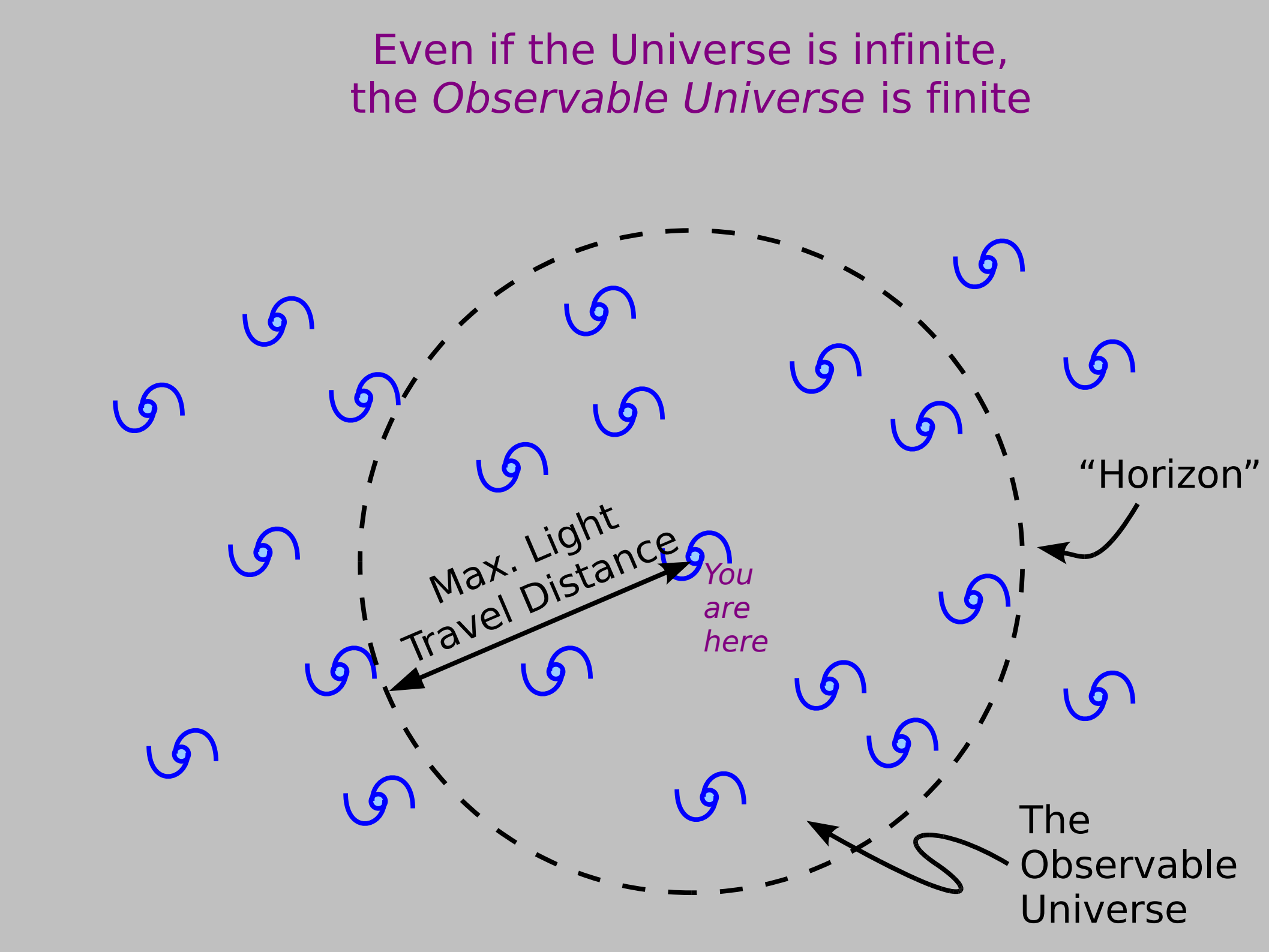
Geometry vs. Topology

Curvature is a local property of space, and can in principle be measured locally (although in practice you may need to draw big triangles to be able to detect it).

Topology does not tie to geometry, but deals with the global connectedness of parts of space. Consider, for example, the cylinder mentioned previously.

A 2-d flat Universe with toroidal topology




Even if the Universe is infinite,
the *Observable Universe* is finite
Max. Light
Travel Distance
You
are
here
“Horizon”
The
Observable
Universe

IF our Universe has an interesting topology, it's almost certainly on scales larger than our observable Universe.

Otherwise, we would have detected signals of it in the CMB. (Yes, people have looked.)

Fin

- Intrinsic vs. Extrinsic Curvature
- Topology vs. Curvature
- Spacetime is curved by mass!
- The Universe is flat on the largest scales

For related considerations, listen to my *365 Days of Astronomy* podcast from this last Tuesday, “Where is the Center of the Universe?”

http://365daysofastronomy.org/2010/02/23/february-23rd-where-is-the-center-of-the-universe/