OASES IN THE DARK:
galaxies as probes of the Cosmos

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What are we talking about?

Simple facts, some history

Galaxy clusters, galaxy collisions

Some galaxies you can see
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Galaxies Everywhere

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The largest easily observed structures in the Universe

There are more than 100 billion galaxies

There are about 100,000 per square degree on the sky

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Simple Facts

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In 1755, Immanuel Kant speculated (on philosophical grounds) that there should exist distant “island universes” of stars (much like the Milky Way)
THE MILKY WAY
In 1785, William Herschel decides to map the Milky Way by counting all the stars he can see in every direction.

He finds we are near the center of a flattened distribution of stars (a disk).
In the olden days...

- We used to think that galaxies were nebulae
- Through a scope, you might see how this could be

Centaurus A (NGC 5128)  Trifid Nebula (M20)
In 1845, William Parsons (the 3rd Earl of Rosse) was observing with his 72-inch Leviathan of Parsonstown.

He detected spiral structure in nebulae, and promptly adopted the name “island universes.”
Spiral Nebulæ
Shapley-Curtis Debate

Harlow Shapley

Heber Curtis
Harlow Shapley (Mt. Wilson Observatory) & Heber Curtis (Allegheny Observatory) debated the nature of the spiral nebulae and the size of the Universe.

26 April 1920: Smithsonian Museum of Natural History

Technical papers about the nature of galaxies were presented all day.

Live debate between Shapley and Curtis that evening.

Open scientific debate; did little to change anyone’s mind.

Needed more and better observational data!
Resolving the galaxy debate would depend on getting distances.

Henrietta Swan Leavitt discovered Cepheid variables in 1912 at HCO.

Period of variability and the brightness can be used to determine distance! (Period-luminosity relation)
Enter Hubble...
On 30 Dec 1924, Hubble announced observations of Cepheid variables in other galaxies, firmly establishing that the spiral nebulae were distant star systems.
Over 10 days in 1995, the Hubble Space Telescope looked at the same spot in Ursa Major (an “empty spot”).

The result was the Hubble Deep Field (North).

~3000 galaxies in this single image!
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HOW MANY & HOW FAR?

- Anglo-Australian Observatory galaxy redshift survey
- Can map 2 degrees on the sky at once; covered over 1500 square degrees
- The 2dF Redshift Survey mapped the location of 245,000 galaxies
How many & how far?
Galaxy Clusters

- It seems galaxies cluster on large scales in the Cosmos
- Supercomputer simulations are attempting to explain this
- Depends on our understanding of cosmology, and the matter content of the Universe
Galaxy Clusters

$z = 1.10$
NGC 4631
NGC 4656
M87
M51
NGC 891
NGC 4414
NGC 4622
Hoag's Object
NGC 4038
M104
NGC 1300
M81 & M82
M87
Galaxies You Can See

Milky Way (Home)

RA = 17h 45.5m
DEC = -28d 55m

Visible from dark sites, spans the entire sky!

To the South tonight
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M31 (Andromeda)
RA = 00h 42.7m
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Visible to the naked eye, easily seen in binoculars
M32 & M110 nearby!
Rising late, in the East tonight
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In 3 billion years, the Milky Way will collide with the Andromeda Galaxy. NOTE: The Sun will not be dead yet!

Simulation by John Dubinski (CITA): www.galaxydynamics.org
Galaxy Collisions

- Modern computers allow us to simulate galaxies & collisions.
- We see evidence of collisions all the time!
- Important unresolved questions: what happens to the two black holes after a collision?
- **Gravitational wave astronomy** should be able to tell us...
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Galaxy Mysteries

- The fate of galaxies after mergers is only one mystery.

- There is still a tremendous amount we don’t know:
  - What is the dark matter in galaxies?
  - How do different kinds of galaxies form?
  - Which came first, the star or the galaxy?
  - Where do the central black holes come from?
  - What happens in the cores of galaxies?
  - What is the shape and density of the galaxy?
Galaxies are among the largest objects we can see.

Galaxies are diverse in their structure and appearance, and still of great scientific interest [black holes, formation, dark matter, ...]

Galaxies cluster and group together, forming the structure of the skeleton of the Cosmos.

Many can be seen by average folks like us!