Galaxy Collisions & the Origin of Starburst Galaxies & Quasars

February 24, 2003
Hayden Planetarium
“Normal” massive galaxy types – elliptical & spiral galaxies

**Elliptical**
- Bulge of old stars
- Large black hole
- Very little gas & dust

**Spiral**
- Bulge of old stars + large black hole
- Disk of young stars & gas
Infrared emission

- Stars are very hot & emit the most energy in the visible
- People are warm & emit the most energy at 10 microns
- Dust in galaxies is cool-to-warm & emit the most energy at 2 – 100 microns

Visible (0.55 micron) light

10 micron light

- Observed the sky at 12, 25, 60, 100 microns
- Emission from dust
- Revealed imbedded star formation
- And…

Orion Star Formation Regions

Andromeda Galaxy (M 31)
... Some other, unknown sources.

IRAS – 60 micron images
Optical follow-up revealed a population of infrared bright, interacting galaxies
How do we know that they are interacting/merging?
Why were these galaxies easy for IRAS to detect?

Visible (Starlight)

Infrared (Dust)

Energy

Wavelength $\lambda(\mu m)$

Bright IRAS Galaxy

Normal Spiral Galaxy

IRAS

$E Watts/Hz$
Center of Galaxy Merger

- Dust is Efficient at Absorbing Ultraviolet & **Optical Light**
- **Optical Light** from Embedded Stars is Absorbed by Dust and Reradiated as **Infrared Light**.
- But **Infrared Light** from this Warm Dust has a much Higher Chance of Escaping.
Molecular gas in a nearby spiral galaxy – star formation rate: few solar masses/year
... Compared with molecular gas in infrared galaxies. SFR = 100 Solar masses/year
Compression of gas in merger = star formation

2. Gas Only
Star formation signatures also seen in optical spectroscopy

Produced by gas heated by young stars

Energy

Wavelength
Late 1980s: … But often, Quasar-like signatures are seen in spectra…

- … And bright, compact Quasar-like nuclei
- … And a few Quasars have distorted host galaxies
- … And many nearby Quasars were detected by IRAS
- … And Quasars are about as common as the intrinsically brightest IRAS galaxies

- Maybe the intrinsically brightest IRAS galaxy mergers evolve into quasars
The Model

**Progenitors**

**Merger phase**
- Gas compression
- Star formation
- Black hole fueling/building

**Quasar phase**

**Elliptical**

100 million years

1 billion years

Time
## Infrared Galaxies vs. Quasars

<table>
<thead>
<tr>
<th></th>
<th>Infrared galaxies</th>
<th>Quasars</th>
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<tbody>
<tr>
<td>Signs of galaxy collision</td>
<td>X</td>
<td></td>
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<td>Star-forming gas</td>
<td>X</td>
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<tr>
<td>Young, bright star clusters</td>
<td>X</td>
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<tr>
<td>Quasar-like gas heating</td>
<td></td>
<td>X</td>
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<tr>
<td>Bright, compact nucleus</td>
<td></td>
<td>X</td>
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Do stars or Quasars energize bright infrared galaxies? Problem 1: Dust.

- **Optical light** from the center of the galaxy does not escape the galaxy, but optical light from stars in the outer galaxy can.

- Young stars
- Dust
- Feeding black hole
Thus, Quasars can hide beneath the dust.

The effects of dust.

Ultraviolet
(0.1-0.2 μm)

Near-Infrared
(1 – 2 μm)

(Note: Optical = 0.55 μm)

Thus, Quasars can hide beneath the dust.
Problem 2 - Imaging Quasar host galaxies:

- Problem – The brightness of the Quasar makes it difficult to see the underlying galaxy.
Addressing the IRAS Galaxy – Quasar Connection

- Approach 1 – Image IRAS galaxies in the near-infrared and look for bright, compact nuclei

- Approach 2 – Image a large sample of Quasars and look for evidence of galaxy merger-like signatures

- Approach 3 – Look for molecular gas in Quasar host galaxy that must be left over from earlier, IRAS-bright phase
A 1 – Hubble Space Telescope Near-Infrared Camera

Quasar-Like nucleus

Extended distribution of star clusters
HST Data

Lots of star clusters

Inner spirals

Embedded compact nuclei
But only about 35% have bright, Quasar-like nuclei
To get clear images, we go to space, or we go to a high mountaintop. Why? To lessen the blurring effects of the dense atmosphere.
Some Quasars have star clusters
Diverse host galaxy types – half are spiral galaxies
...A Quarter are mergers
... And some have too little detail to classify
A 3 – Looking for molecular gas in nearby Quasars

- Thus far, most (60%) of the 20 Quasars observed have molecular gas.
- The gas content are similar to those of bright infrared galaxies.
## Infrared galaxies vs. Quasars

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<th>Infrared galaxies</th>
<th>Quasars</th>
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<tbody>
<tr>
<td></td>
<td>(25)</td>
<td>(20)</td>
</tr>
<tr>
<td>Signs of galaxy collision</td>
<td>100%</td>
<td>25-50%</td>
</tr>
<tr>
<td>Star-forming gas</td>
<td>100%</td>
<td>~60%</td>
</tr>
<tr>
<td>Young, bright star clusters</td>
<td>&gt;90%</td>
<td>~20%</td>
</tr>
<tr>
<td>Quasar-like gas heating</td>
<td>30%</td>
<td>100%</td>
</tr>
<tr>
<td>Bright, compact nucleus</td>
<td>35%</td>
<td>100%</td>
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The Future – Space Infrared Telescope Facility (SIRTF)

Launch date: April 2003

SIRTF will probe deep into the dusty regions of galaxies

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Visible

Infrared

Normal Spirals

Infrared Galaxies

Energy

Wavelength $\lambda (\mu m)$

$L_v$ (Watts/Hz)

$10^1$ to $10^7$
Half of the energy emitted since the Big Bang is observed at infrared wavelengths.
SIRTF will routinely detect early universe galaxies

The Hubble Deep Field

Optical – Hubble Space Telescope (HST)

850 microns – Submillimeter Common User Bolometer Array (SCUBA)
Molecular gas in a galaxy at 80% look-back times

... About 20 galaxies at these distances detected to date
The Future (Part 2) – Atacama Large Millimeter Array will routinely detect star-forming gas in early universe galaxies at high resolution.

The Present – Owens Valley Millimeter Array: Six 10m dishes.

ALMA: 64 12m dishes.
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