Ultra Luminous Infrared Galaxies

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The Biggest and the brightest

- “Biggest and the best” & “best and the brightest”
- Definition:
  - LIRG: $L_{8-1000\mu m} < 10^{11}L_\odot$
  - ULIRG: $10^{12}L_\odot < L_{8-1000\mu m} < 10^{13}L_\odot$
  - HILRG: $L_{8-1000\mu m} > 10^{13}L_\odot$
Overview

- First discovered in large numbers by IRAS ("first" discovery of optically invisible or exceptionally faint sources by Houck et al. 1985 ApJ )
- Comparatively rare locally (space density several orders of magnitude lower than normal galaxies and a factor of a few higher than QSOs)
- Orders of magnitude more numerous at z>1 than locally
- A lot of them are found in major disk mergers, and the central few hundred pc of nuclear regions harbor large masses of gas and dust
- Power source behind IR emission: some combination of "starburst" and "AGN"
IRAS: Infrared Astronomical Satellite

- Surveyed over 96% of the sky at 12, 25, 60 and 100um.
- Provided first view of the extragalactic sky in the infrared
- Sensitivity limits:
  - 0.5 Jy at 12, 25 and 60um
  - 1.5 Jy at 100um
- Negligible galactic extinction
- Typical position uncertainty: $4'' \pm 15'' (1\sigma)$
What did IRAS find?

- IRAS detected $\sim 25,000$ galaxies
  - $\sim 100$ previously detected in the IR
- Mostly late-type spirals
  - Ellipticals and S0 galaxies rarely detected
- FIR luminosity span a range from $10^6 < L_{\text{FIR}} < 10^{13} L_\odot$
- Hundreds of galaxies detected which emit over 95% of their luminosity in the IR
- Galaxies detected to $z > 0.4$
Sample Energy Distributions for Galaxies

- ULIRG
- Starburst
- Typical Spiral Galaxy
- Old Stellar Population
SED of ULIRG

[Graph showing SED of ULIRG with log(v_rest) vs. lambda_rest (mu m)]
Luminosity Effects & Galaxy Properties

- $L_{\text{bol}} < 10^{11} L_\odot$
  - IR selected galaxies $\sim 20\text{-}25\%$ of the number of optically selected galaxies
  - FIR luminosity $\sim 25\%$ of total galaxy luminosity

- $L_{\text{bol}} > 2 \times 10^{11} L_\odot$
  - IR bright galaxies become the dominant population
  - Space density greater than normal and optically selected starburst galaxies
  - Space density equals that of optically selected Seyferts

- $L_{\text{bol}} > 10^{12} L_\odot$
  - Exceed space density of quasars
  - [QSO] are the only other known objects with such high luminosities
Luminosity Functions

Solid curve is luminosity function for normal galaxies (Schechter)

Straight lines represent best fit of two power laws to bright-galaxy luminosity function without Virgo
The physics of ULIRGs

- Strong interactions and mergers
  \[ L_{\text{ir}} < 10^{11} L_\odot \]: single, gas rich spirals whose infrared luminosity can be accounted for largely by star formation

  \[ L_{\text{ir}} = 10^{11} - 10^{12} L_\odot \]: a dramatic increase in the frequency of strongly interacting systems that are extremely rich in molecular gas

  \[ L_{\text{ir}} > 10^{12} L_\odot \]: contain exceptionally large central concentrations of molecular gas (heavy dust obscuration made it hard to distinguish starburst and AGN activity)
First imaging surveys (Armus, Heckman & Miley, 1987) showed at least 70% of systems with ULIRG or near-ULIRG luminosities are interacting.

Optical and near-IR studies (Melnick & Mirabel, 1990; Hutchings & Neff, 1991; Clements et al., 1996) found a higher faction of ULIRGs involved in interactions (90%).

HST studies (Surace et al., 1998; Farrah et al., 2001): nearly all of the sample are interacting, with a wide range of merger stages.
Early optical spectroscopic survey show that ULIRGs are mostly starburst-like in the optical, while samples with “warmer” infrared colors appear more biased towards Seyferts or LINERS, or even optical QSOs.

Large-scale surveys as followup to IRAS observations showed the majority of ULIRGs have optical spectra reminiscent of starbursts, but with a systematic increase in the fraction of ULIRGs with Seyfert spectra with increasing IR luminosity.

Followup spectroscopy in the near-IR show ~25% of ULIRGs have evidence for an AGN and this fraction increases with increasing IR luminosity.
The background level at $\lambda > 200\mu m$ implied a population of "colder" sources, probably $z > 1$ systems with IR emission shifted to longer wavelengths.

The advent of sub-mm array instruments prompted surveys to find distant "cold" sources, which indeed find a huge population of sub-mm bright, optically faint sources, and can account for 50% of the CIB detected by FIRAS on board COBE.

- SCUBA, SHARC-II, Caltech Sub-mm Obs. etc.
Radio continuum

- Radio-FIR correlation: allows us to use high-resolution radio interferometric techniques to study the compact nuclei of luminous IR galaxies.
- Nearly all galaxies with $L_{ir} \leq 10^{11} L_\odot$ are dominated by extended, diffuse radio emission, whereas most ULIRGs are dominated by compact, sub-arcsec radio sources.