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Hubble and the GOALS Survey

The Great Observatory All-sky LIRG Survey (GOALS) combines imaging and spectroscopic data from the NASA/ESA Hubble Space Telescope and NASA's Spitzer, Chandra and GALEX space observatories in a comprehensive study of over 200 of the most luminous infrared-selected galaxies in the local Universe. The sample consists of approximately 180 Luminous Infrared Galaxies (LIRGs), as well as over 20 Ultra-Luminous Infrared Galaxies (ULIRGs). The LIRGs and ULIRGs targeted in GOALS span the full range of nuclear spectral types and interaction stages. They provide an unbiased picture of the processes responsible for enhanced infrared emission in the local Universe.

Hubble's role in the project is to use its high optical resolution to study star formation and active galactic nuclei (AGN) processes and the possible connection between these two phenomena. In addition, the detailed structural properties of the underlying galaxy, which may provide clues to the observed dynamics, are also part of the Hubble Space Telescope portion of GOALS.

Star formation in the centres of luminous infrared galaxies seen in visible light
One of the primary science drivers for the Hubble part of the Great Observatory All-sky LIRG Survey (GOALS) is to make use of the high resolution possible with Hubble and the wide field-of-view of Hubble's Advanced Camera for Surveys (ACS) to study star formation at visual wavelengths in a large and statistically complete sample of luminous and ultraluminous infrared galaxies.

These galaxies are primarily mergers and interactions of gas-rich spiral galaxies like the Milky Way and the Andromeda Galaxy, and as the galaxies interact, the large reservoir of gas in their discs is compressed into stars. Some fraction of the gas also feeds giant black holes (i.e., with masses a million to a billion times the mass of our Sun) in the centres of the merging galaxies, sometimes making their nuclei outshine all of the stars in the merging galaxies. The colour and location of the star formation within each galaxy, and the small-scale structures associated with the regions of star formation, provide clues as to when and how the star formation began. Further, because the GOALS sample covers the full evolutionary range of merging galaxies, from the first encounter of the progenitor galaxies to the final coalescence, star formation in the visible can be studied as a function of evolutionary stage.

There was a worry that a study of star formation in visible light in these luminous infrared galaxies would not be very fruitful — why use a visible-light telescope to study an infrared-selected sample of galaxies? Indeed, these galaxies become "infrared" luminous by producing new stars and feeding their giant black holes in dust-enshrouded regions of the galaxy, i.e., regions opaque to visible light. This dust is then heated by the stars and black holes to temperatures of roughly -240 to -210°C - at such temperatures, the dust radiates strongly in the infrared. As it turns out, this portion of the survey has been a major success — the Hubble data have revealed evidence of star formation in most of the infrared galaxies, and

not only in the extended discs and tails, but also in the central regions of the galaxies where one would expect the star formation to be completely enshrouded by dust (based on the Spitzer Space Telescope imaging survey). These star clusters in the central regions that are bright in visible light are essentially tracers of the more embedded star formation that accounts for the bulk of the energy generated in these galaxies. The detection of visible-light signatures of star formation means that standard visible-light techniques used to study star formation in nearby normal galaxies can be applied to the study of these galaxies. Ultraviolet data is currently being collected to establish the age of the clusters properly.

Hubble and the wide-field of view of the ACS are indispensable tools for this kind of project as they have the high resolution necessary to establish the existence of super star clusters in very active star-forming regions. These compact clusters are rich in young stars and resemble theoretical models for early precursors of globular clusters. Although these clusters can be resolved in the infrared, it is the visible-light studies with Hubble that allow scientists to make inferences about the stellar populations. This is an important result with implications for theories of galaxy evolution that aim to explain how the galaxies we know today formed.

Bright infrared radiation from "minor mergers"
The Hubble images can also be used to examine other paths to the generation of bright infrared radiation. The standard picture is that interactions and mergers of gas-rich spiral galaxies (we can call these "major mergers") are the trigger for the emergence of high infrared brightness. However, in about ten percent of the sample there is no clear evidence that a major merger is the cause of the observed activity. The galaxies in this ten percent are observed to be face-on or edge-on spiral galaxies — in about half of these infrared galaxies, the high-resolution Hubble images reveal no structural features that would distinguish them from normal spiral galaxies observed locally. Half of them are accompanied by small companion galaxies, suggesting that an interaction between disc galaxies and much less massive galaxies ("minor mergers") may also be sufficient to push a galaxy to produce copious amounts of infrared radiation, possibly by channelling gas into the central supermassive black hole of the larger galaxy and fuelling the burst of high activity revealed in the infrared.

Summary
As a visible-light telescope Hubble has filled the gap between Spitzer imaging in the infrared and GALEX ultraviolet images. But Hubble has been much more than a stopgap: the superb sensitivity, resolution and field of view of the ACS Wide Field Camera have revealed the detailed structure of galaxies captured at all stages of the interaction process and have been an essential part of the success of the GOALS project in the study of the link between star formation, ultraluminous infrared galaxies and the evolution of the galaxies we know today.

Links
http://goals.ipac.caltech.edu/
http://goals.ipac.caltech.edu/hst/HST.html