From Spitzer to Herschel and Beyond

Conference Summary

Martin Harwit
Cornell Univserity

From Spitzer to Herschel and Beyond

(An Extragalactic Perspective
on some messages this workshop has conveyed)

I. Some Purely Technical Matters

II. Recent Successes and Lessons for the Future

III. Astronomy and Society

I. Some Purely Technical Matters

Primordial Inflationary Fluctuations

We learned from Lloyd Knox that the microwave background has not yet released all of its secrets. By digging still deeper than Wilkinson and Planck, the scalar and tensor primordial fluctuations may yet be discovered and tell us more about our origins.

This will be challenging: Current anisotropy measurements are already laboring at levels as low as 10 parts per million.

Each further order of magnitude will become progressively more demanding on instrumental capabilities and stability, and will require increasing care in recognizing and compensating for distracting foreground radiation.

The First Stars

How the very first stars formed has puzzled us for decades:

The work of Mizusawa et al., on which Ryoichi Nishi reported, clarified that this is not a process that any of the observatories we discussed for the decades ahead will be able to detect.

The expected telltale, highly redshifted H_2 lines will only yield a disappointing 10^{-29} W/m^2 per star. We do not expect an abundance of these stars, and this phase of their existence is short-lived.

Even if the sky were swept clear of the many distracting foreground sources, we would have a hard time achieving the necessary sensitivities. This may be disappointing for now, but perhaps we'll return to the problem later with a new tack and solve it then.

Galaxy Evolution

As George Rieke showed, the great sensitivity of Spitzer will give us galaxy statistics that, though still confusion-limited, will provide many new insights into galactic evolution.

With a progression of larger telescope apertures and baselines, SPICA, SAFIR, SPIRIT, SPECS, ALMA, …, confusion will eventually be overcome and the history of galaxy evolution will yield its secrets.

The rates at which massive mergers have taken place in recent times will also be better documented, and the nature of the puzzling submillimeter sources should become much clearer.

We think we know what to do, but do not yet know how to get there. We will need to work closely with talented engineers to solve these problems together.

If We Needed any Reminder…

of our debt to truly breathtaking engineering, all doubts were dispelled right from the start on the first day, when Lionel Duband, Toshio Matsumoto, Keith Parrish, and Peter Shirron, spoke of the great advances in passive cooling and cryomotor construction in Europe, Japan and the USA, just in the last decade. Ron Ross, in particular recalled the struggle over four decades that has finally yielded the breakthroughs that will replace massive helium tanks with reliable cryomotors, making for far more cost-effective, longer-lived cryogenic missions.

Then, yesterday, Dave van Buren portrayed the equally impressive advances in optical alignment techniques, now a necessity with ever larger optics.

Detectors

We also heard about great strides in detector development, this morning, from Dominic Benford, Kent Irwin, John Pearson, Erick Young and Jonas Zmuidzinas.

In the past, we could depend on superb, hand-me-down infrared detectors originally developed by the military. But with astronomy venturing to longer wavelengths and into the submillimeter domain, we now are in territory where neither the military nor industry have an interest.

We will have to persuade our respective space agencies to fund the next generation of detector development. Without increasingly sensitive detectors we will not be able to press forward.

Distant Galaxies

But to return to science . . .

IRAS, IRTS, ISO and Spitzer have all been reaching to ever greater distances to study the nature of individual galaxies and how they differ from each other.

George Helou emphasized how low-resolution spectroscopy with Spitzer will detect the fine-structure lines and provide red shifts for individual galaxies superposed along a line of sight. The PAH features may also help to serve this purpose.

Spitzer data for NGC 300 show that the PAH features are remarkably good tracers of photodissociation regions, and may turn out to be some of the most reliable tracers of star formation.

The Nearby Universe

These ratios of the C[II], O[III] and O[I] fine-structure lines also serve as signposts to physical conditions, both in distant and nearby galaxies.

Ranga Ram Chary gave us hope that we will be able to use these spectral tools to help identify the rise of dust and increasing metallicities at red shifts $2<z<3$ or 4 and beyond.

But there are many puzzles. The blue dwarf galaxy SBS0335-052 at 60 Mpc appears strikingly anomalous, seemingly as though a primordial galaxy. How many other surprises await us?

Many of these questions will only be solved with more powerful observatories.

The Tight Coupling of Chemistry and Dynamics

Ted Bergin led us through the complex interplay of chemistry and dynamics. The release of kinetic energy inevitably leads to dissociation, ionization, and and chemical changes. New atomic, ionic or molecular species, in turn, can rapidly cool their environment, inducing new dynamics, or form grains that increase opacities and lead to alternative evolutionary paths. Unraveling this chemodynamic interplay will require high spectral and spatial resolution, not only in Galactic, but also for nearby extragalactic observations. At FIR wavelengths inaccessible to ALMA, we will most likely require heterodyne spatial interferometry from space.

The Need for Global Models

Joel Primack convincingly demonstrated that we cannot hope to understand extragalactic processes with piecemeal explanations. We need a global vision that will emerge only from comprehensive models, self-consistently applied, end-to-end, from the first moments of the Universe right up to the present day.

These models will have to account not only for the formation of structure, but consistently depict the rise in heavy elements, the progressive merging of galaxies, the increasing sizes of galaxy clusters, the changing initial mass functions of stars and corresponding supernova rates, and the metallicity of intracluster gas as a function of red shift.

We will require not only powerful new observatories but also powerful modeling techniques to gain insight.

II. Recent Successes and Lessons for the Future

The Small Missions We have Flown to Date Have Served us Extraordinarily Well

IRAS, ISO, IRTS, Spitzer, and ASTRO-F to be launched soon, all have had modest apertures, less than 1 meter. Herschel will have a 3.5 meter aperture with a passively cooled primary that will undoubtedly continue to provide new insights.

But we already know that we will continue to be limited by a lack of sensitivity and light-gathering power. We also know that the images we now can obtain lack sufficient clarity to lead to comprehensive understanding.

What, then, is the best way to go forward?

Far-Infrared/Submillimeter Priorities 1.

The presentations we heard repeatedly called for higher spatial resolution to provide clearer images of complex scenes, particularly at the longest wavelengths. They also emphasized a need for greater light-gathering power to extend our search back to the earliest cosmic epochs. Both priorities can be met with progressively larger telescopes:

- In a first step, we should seek to increase light-gathering power by an order of magnitude and image clarity by a factor of order 5, with a cryogenically cooled 3-4 meter class telescope in space.
- With the experience gained in this step, a further gain in sensitivity and light collecting power should be sought with a 10-meter cryogenic telescope in space.

Far-Infrared/Submillimeter Priorities 2.

Light-gathering power alone, however, will not suffice to resolve the major questions on the origins of stars and the rise in the Cosmos of the heavy chemical elements needed for the formation of planets and the origins of life. To delve into these questions, greater spatial and spectral resolution will be needed:

- Increased spatial resolving power at all wavelengths in the far-infrared will require long-baseline interferometers in space, again in progressive steps, with baselines of order 30 meters and 1 kilometer.
- Engineering economies suggest two different approaches: Direct interferometry for low and intermediate spectral resolution; heterodyne interferometry where cosmic dynamics cannot be disentangled from underlying chemical processes.

Specifics

With a look to the future, our community has been defining these alternatives for some years. While we have often assigned them provisory names, their design still awaits detailed specifications:

SPICA: A cryogenic 3-4 meter telescope in space.

SPIRIT: A 30 meter-baseline space interferometer.

SAFIR: A 10 meter cryogenic space telescope.

SPECS: A kilometer-baseline interferometer in space.

All four will operate at wavelengths from 30 to ~ 800 microns to which JWST and ALMA have no access, and will complement Spitzer and Herschel, whose capabilities they will greatly surpass.

The Key Importance of Great Engineering

The technical challenges of these ventures will be considerable:

- Large telescopes entail new deployment strategies.
- Future missions will be cryomotor-cooled and longer lived, requiring meticulous thermal engineering.
- Detector arrays are becoming increasingly complex.
- Data gathering rates are expanding by orders of magnitude, demanding commensurate downlink capacities.
- Tethers for interferometers need development.

To succeed in combining all these demands we will need to work even more closely than in the past with the most talented engineers we can attract.

III. The Place of Astronomy in Society

How should we plan our Future?

John Hong reminded us, in his thoughtful introduction to this workshop, that we are the sole customers for the facilities we are proposing. Society has many priorities -- food, shelter, security -- that are understandably more pressing than astronomy.

Only limited funds can be assigned, in any century, for delving into our heritage and the origins of the Cosmos. The search through the Universe has continued for thousands of years, and can continue at an appropriate pace. It is up to us to persuade our fellow citizens that our proposals are worth pursuing.

With this in mind:

How should we recommend that funds be spent to advance far-infrared/submillimeter investigations?

Some Simple Rules

As Gordon Stacey and Grant Wilson pointed out, a set of immensely powerful, large-aperture ground-based submillimeter telescopes are coming on line. We need to make sure that missions we propose for space avoid duplicating whatever can be done more cost effectively from the ground.

We also need to recognize that high-spectral-resolution heterodyne work requires less cryogenic cooling and may more effectively be carried out in specially dedicated, rather than all-purpose missions.

It is our responsibility to minimize cost in whatever way we can.

Community and Public Support

Because we are the sole customers for the missions we advocate, we also need to make sure that fellow scientists as well as the public appreciate what we do:

Astronomy has become far more integrated across wavelength bands than ever before. We will have to reach out to colleagues normally focused on other spectral ranges and make our powerful new tools available to help them gain new insights on sources that have interested them in their own fields.

Equally important:

We will have to convey to our fellow citizens an appreciation for the excitement and breathtaking advances that our searches have provided -- thanks largely to the new facilities the public chose to fund.

We will have to work hard, and work in unison so the advances of recent years may continue