PERSPECTIVES: ASTROPHYSICS

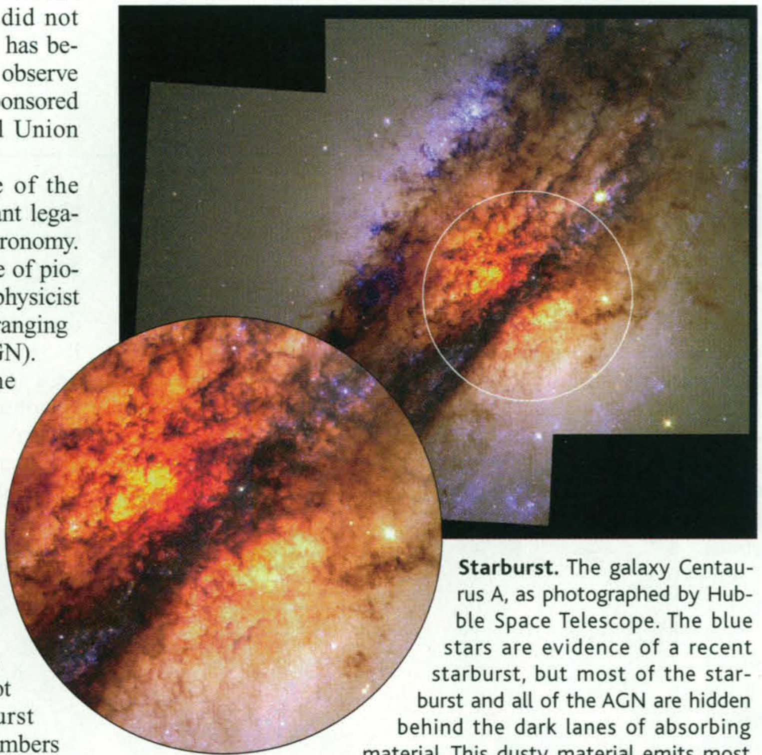
Making Sense of Active Galaxies

Daniel W. Weedman

Because of its strategic location and intellectual resources, the small Republic of Armenia prospered when it was the extreme southern frontier of the Soviet Union. Among its important scientific institutions was the Byurakan Astrophysical Observatory, founded a half-century ago. After the dissolution of the Soviet Union in 1991, maintenance of the observatory became very limited, and the telescopes did not function for several years. Renewal has begun. The 2.6-m telescope began to observe again this year, and a symposium sponsored by the International Astronomical Union was recently held at Byurakan (*1*).

The "Active Galaxies" theme of the meeting reflected the most important legacy of Byurakan Observatory to astronomy. Observations initiated there because of pioneering interest by Armenian astrophysicist Victor Ambartsumian led to wide-ranging studies of active galactic nuclei (AGN). Beniamin Markarian surveyed the extragalactic sky beginning in 1965 using Byurakan's 1-m telescope to find the many unusual galaxies now labeled with his name. Among the Markarian galaxies are examples of virtually all specimens of active galaxies, such as starburst galaxies, Seyfert galaxies, blazars, and ultraluminous infrared galaxies. The luminosities of these galaxies do not arise from ordinary stars. Starburst galaxies shine because of large numbers of very young stars. Extremely hot interstellar material produces the light from AGN in Seyfert galaxies and blazars. The glow of infrared galaxies arises from heated dust. Unifying such diverse manifestations of galaxy activity was an objective of the symposium. What would have been Ambartsumian's 90th birthday was acknowledged by the dedication of a museum and memorial in his former home on the observatory grounds, probably the only museum in the world celebrating the life of a modern astrophysicist.

Although Ambartsumian had often challenged mainstream thinking, few unconventional ideas were presented at the meeting. Halton Arp (Max Planck Institute, Garching) reviewed his long-standing hypothesis that quasars are born in ejections from galaxies, but he gained no new supporters. Sufficient observational evidence has accumulated for the existence of massive black holes in the centers of galaxies (*2*) that explanations for quasars as anything other than the most luminous extremes of AGN—fundamentally powered by black holes—have decreasing appeal. Rather than seek "new physics," participants focused on the problems that remain in explaining how the presence of a central black hole can lead to the various characteristics of active galaxies.



Starburst. The galaxy Centaurus A, as photographed by Hubble Space Telescope. The blue stars are evidence of a recent starburst, but most of the starburst and all of the AGN are hidden behind the dark lanes of absorbing material. This dusty material emits most of its luminosity at infrared wavelengths and is characteristic of the shroud that obscures activity in much more luminous galaxies found in the early universe (*5*).

Dominant among these problems is finding an explanation of how material that initially falls into the accretion disk around a black hole can then spurt away from the nucleus at relativistic speeds. Observational evidence of such ejection is unambiguous and is in the form of particle jets, or beams, that dominate the energetics of active galaxies in radio and gamma ray observations. Rita Sambruna (Pennsylvania State University) reviewed the comprehensive evidence that the most extreme cases, the blazars, have jets beamed toward us such that the resulting relativistic enhancement produces the highest energy electromagnetic radiation observed from galaxies. (Appropriately for this meeting, the energy record is held by Markarian 501.) Richard Lovelace (Cornell University) clearly summarized the daunting complexity facing theorists who are attempting to explain these astrophysical accelerators using magnetohydrodynamic effects that start with an accretion disk rotating at nearly the speed of light. He made clear, however, that it is the complexity of three-dimensional magnetohydrodynamics that is the obstacle rather than any fundamental misunderstanding of the physical principles involved.

Hydrogen and molecular material accumulating in the center of a galaxy can give rise to exceptional luminosity from intense star formation within this gas (a "starburst"), requiring star birthrates up to 100 solar masses per year (see figure). The most dramatic examples are ultraluminous infrared galaxies, described by David Sanders (University of Hawaii) and Felix Mirabel (Service d'Astrophysique, Saclay). Disentangling the luminosity of an accretion disk around the black hole from the luminosity generated by the starburst in a larger surrounding disk is a major observational challenge. Although starburst regions are thousands of light years in diameter, whereas accretion disks are only light weeks in diameter, these regions are unresolved at typical distances. As comprehensively modeled by Suzy Collin-Zahn (Paris Observatory) and others, many of the phenomena associated with AGN, such as the high-velocity gas clouds, can be explained as originating from the starburst in the disk surrounding the nucleus. A consistent theme for the meeting was the observational evidence and theoretical desirability of having both starbursts and AGN, with comparable luminosities from each, to explain the details of an entire active galaxy.

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The relation between the central black hole and the surrounding starburst is a crucial puzzle. Did the black hole arise from the condensation of small, stellar-mass black holes produced in earlier starbursts within the galaxy? Determining the answer requires observations of primordial starburst galaxies and primordial quasars. Several speakers pointed out that galaxies are now winning the redshift race because the most distant objects currently known in the universe are starburst galaxies rather than quasars.

Malcolm Longair (University of Cambridge) summarized the new and intriguing evidence that we may not yet have seen the real contestants in this race because they are obscured by dust. New observations from the SCUBA (Submillimeter Common-User Bolometer Array) submillimeter camera imply a large population of very dusty objects at high redshifts (*3*). They supplement similar hints from deep infrared images with the European Space Agency's Infrared Space Observatory (*4*). These mysterious sources are evidence that the bulk of luminosity in the distant universe, whether from young stars or AGN, is so obscured by dust as to be invisible in the optical and ultraviolet light observable by Hubble Space Telescope or large ground-based optical telescopes. Such evidence reinforces the motivation for NASA's Space Infrared Telescope Facility (SIRTF), scheduled for 2001, and makes more compelling the plan by the U.S. National Radio Astronomy Observatory to lead development of a millimeter array interferometer project.

Astronomers in attendance at the Byurakan symposium were gratified that 30 years' accumulation of observational data on active galaxies, at wavelengths from gamma ray to radio, has yielded unified explanations for a once-bewildering assortment of galaxies. Fundamentally similar phenomena can now be described and traced over three-fourths of the history of the universe.

References and Notes

1. "Activity in Galaxies and Related Phenomena," International Astronomical Union Symposium 194, 17 to 21 August 1998, Byurakan Astrophysical Observatory, Republic of Armenia (proceedings to be published in Astronomical Society of the Pacific Conference Series).
2. Reviews of evidence for massive black holes are summarized by G. S. Bisnovatyi-Kogan [*Science* **279**, 1321 (1998)].
3. D. H. Hughes *et al.*, *Nature* **394**, 241 (1998).
4. M. Rowan-Robinson *et al.*, *Mon. Not. R. Astron. Soc.* **289**, 490 (1997).
5. Material created with support to AURA/ST ScI from NASA contract NAS5-26555 is reproduced here with permission.

PERSPECTIVES: IMMUNOLOGY

Developmental Options

Ken Shortman and Eugene Maraskovsky

Dendritic cells (DCs)—sparsely distributed migratory immune cells that can ingest and display antigens on their surfaces—link the innate and the adaptive immune systems. "Immature" DCs in peripheral tissues prone to invasion by infectious agents form a network of sentinels that sample the antigenic environment. Infection or tissue damage initiates migration of antigen-bearing DCs out of the tissue, through the endothelium into lymphatic ducts and thence to lymph nodes. In the lymph nodes, the now "mature" DCs initiate immune responses by efficiently presenting the processed antigen to T lymphocytes (*1*). On page 480 in this issue, Randolph *et al.* (*2*) investigate the migration of DCs and their precursors through a layer of vascular endothelial cells in vitro. The results revealed much more than the mechanics of transendothelial movement; in fact this migration process turns out to be central to the developmental choice between macrophages and DCs.

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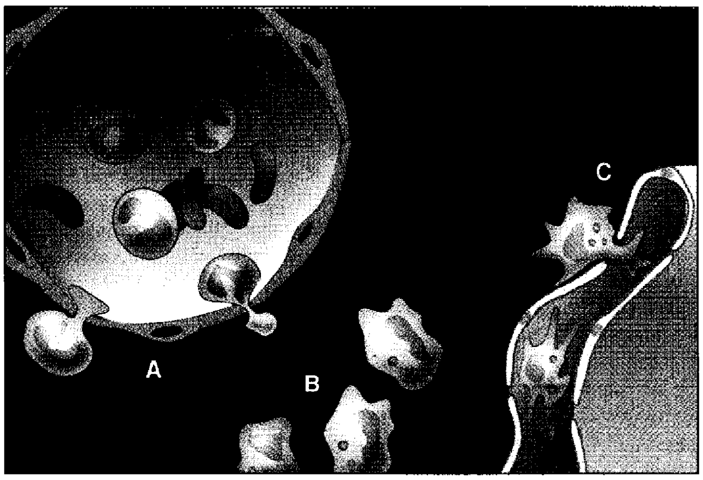

Dendritic cell origins. Migration and differentiation of dendritic cells and their precursors in intact tissues.

The capacity for antigen uptake and general morphology of the DCs suggest that they are related to blood monocytes and tissue macrophages. Whether DCs are a distinct cell lineage or merely a form of macrophage was vigorously debated 5 to 10 years ago. The conclusion: They are related but clearly distinct, not just in morphology and surface marker expression, but in antigen processing and T cell activation functions (*1, 3, 4*). This notion is now complicated by evidence that DCs are heterogeneous in lineage origin (*5*). The Langerhans cells of the skin epidermis are the immature form of one DC lineage that, despite a common myeloid precursor origin, seems separate from most macrophage-related DCs in intermediate precursors, in tissue localization, and in several antigenic markers (*6, 7*); these DC lineages are nevertheless closely related, because certain cytokines induce markers for Langerhans cells in monocyte-derived DCs (*8*). More distinct is a subgroup of lymphoid-related DCs found in mouse spleen and thymus; these DCs express several markers characteristic of lymphoid cells, and they derive from a precursor closer to the lymphoid than to the myeloid lineage (*9–11*). The DC type with the closest relation to macrophages appears to be the interstitial DCs of tissues such as heart or skin dermis. The study of Randolph *et al.* applies particularly to this DC type, although similar issues probably arise with all migratory DCs.

Cell cultures treated with cytokines clearly demonstrate that blood monocytes have a capacity to differentiate, with little or no cell division, either into macrophages or into these macrophage-related DCs (*3–5, 12*). Exposure to macrophage colony-stimulating factor (M-CSF) induces only macrophage formation, whereas granulocyte-macrophage colony-stimulating factor (GM-CSF) also induces DC formation. Although the initial transformation into a DC form is reversible, exposure to proinflammatory cytokines such as tumor necrosis factor–α (TNFα) induces an apparently irreversible maturation to DCs. GM-CSF, TNFα, and interleukin-4 are widely used to induce DC development from blood mono-

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