"The Supermassive Black Hole in Arp102B"

Harlan Devore (Lead), Cape Fear High School, Fayetteville, NC
HDev48@aol.com

Lauren Chapple, Traverse City East Junior High School, Traverse City, MI
chapplela@hotmail.com

Howard Chun, Cranston High School, East Cranston, RI
howiec1@earthlink.net

Dr. Ranga-Ram Chary, Spitzer Science Center, California Institute of Technology, Pasadena, CA
rchary@caltech.edu

ABSTRACT: Arp102B is a radio-loud, Seyfert 1 galaxy located in the constellation Hercules with a B-band magnitude of 15.2 mag. It has a redshift z = 0.024, giving it a recessional velocity of 7250 km/s and a distance of about 99.1Mpc. At its core is a low luminosity AGN with a black hole estimated to be ~10^8 solar masses. Although there have been many radio, X-ray, UV, optical, and ground-based IR studies of the Arp102B nucleus, they have not converged to produce a single, unified model for the nucleus. For example, Chen and Halpern (1989) used a geometrically thin, optically thick accretion disk model to fit double-peaked Balmer lines in the spectrum of Arp102B. Sulentic (1998) suggested that a bicone model would better fit the Fe K alpha lines in the x-ray spectrum. Korista summarizes the current state of our understanding as follows: "Despite significant progress, some fundamental issues relating to the geometry of the broad line emitting gas remain unsolved. We do not know whether in general the broad line region is composed of discrete clouds, winds, disks, or bloated stellar atmospheres or a combination of these." (Strateva et al., 2003)

We believe that quality spectral data covering the IR spectrum may be the key to resolving these differences and could lead to a unified model for this type of AGN. Therefore, we propose to use Spitzer's IRS instrument to obtain LH, SH, SL1 and SL2 spectral data of Arp102's supermassive blackhole. With this data, we can measure the mass of the black hole, analyze the geometry, composition, and physical properties of the dust structure surrounding the black hole and reach conclusions about the energy production mechanism(s) in the nucleus.

Science Goals and Data analysis: One of the most important problems in the study of active galaxies is to understand the detailed geometry, physics, and evolution of the central engines and their environments. We hope to contribute to this understanding as follows:

Goal 1: Calculate the dust column density for the torus structure by measuring extinction in silicate lines at 9.7 microns. ASCA X-ray observations have been used to determine the intrinsic neutral gas column density responsible for absorption at both soft X-ray and UV wavelengths.[1] The value obtained was N_H=2.8x10^{21} cm^{-2}. The same study concluded that the absorbing material must be mostly free of dust in order for the density to be consistent with the inferred optical extinction. They further speculated that the absorber might be a "failed" accretion disk. Calculating dust column density directly would resolve this apparent discrepancy. In addition, it would allow us to estimate the thickness of the dust torus and to compare gas/dust ratios for Arp102B with ratios from our own galaxy. It would also allow us to estimate true (extinction-corrected) brightness of energy producing structures behind the dust.

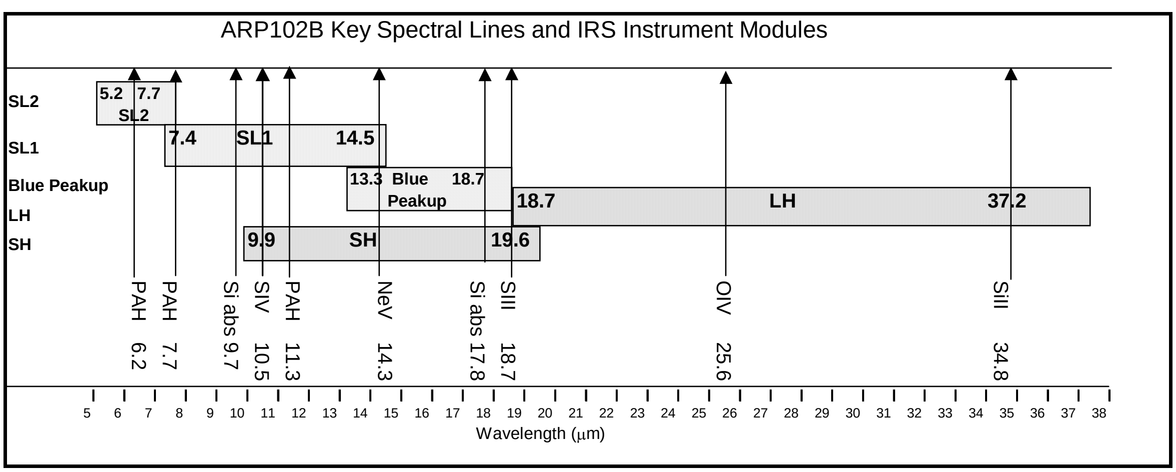
Goal 2: Determine the IR spectral energy distribution for the dust structure, analyze blackbody temperature(s) from the continuum, and identify sources of thermal and non-thermal energy heating the structure. The leading models involve a warm (and perhaps warped) accretion disk, a dusty torus structure, and perhaps a neutral and ionized "cocoon" around a supermassive black hole. Energy sources for these structures may include 1) thermal dust emission from an accretion disk (black body T~ 200-300K), 2) starburst activity heating dust in the torus, 3) nonthermal accretion flow/ shock at base of jet. SEDs are available for radio, UV, X-ray, and optical. These can be combined with our IR SED to produce a more complete picture of the energy production and transfer processes in the nucleus of Arp102B. In addition, we have selected high-resolution coverage of key emission lines such as OIV and SIII. Intensity ratios of these emission lines will help us to distinguish the nature of these energy sources.

Goal 3: Determine whether any of the IR line spectra have double peaks. Arp102B may be the prototype of a set of broad-line radio galaxies whose hydrogen Balmer line profiles are double-peaked. These unusual line profiles have been used to support an accretion disk model with emission from a photoionized atmosphere in the disk. (Eracleous, Halpern, & Livio 1994). The gravitational redshifting of these peaks leads to the conclusion that they originated in disk gas orbiting at a distance of 100 to 1000 SR from the black hole. We calculate that IR emitters at similar distances would have a resolution ($\lambda / \Delta\lambda$) between 14 and 45 and will produce spectrally resolved peaks in our data. Observations of IR emission lines with double peaks would add support to the accretion disk model for Arp102B and would provide an independent measure of the black hole mass.

Goal 4: Produce a model of the torus/disk structure for Arp102B. We intend to use the CLOUDY algorithm to produce a model of the dusty structure surrounding the supermassive black hole that will best fit our spectral data. CLOUDY [2] is program that accepts as its input the shape, density, temperature, and composition of a gas, as well as the radiation field of the central continuum source. It then incorporates all the needed physics into a large-scale numerical simulation that predicts the observed spectrum. If possible, we also want to integrate spectral data from other observations into the model and to consider the constraints suggested by radio, UV, and X-ray models.

Topic development: Dr. Chary suggested "The Supermassive Black Hole in NGC4258" as a possible topic. After a literature search showed that NGC4258 had been extensively studied by radio, x-ray, HST, and ground based IR telescopes, we asked Dr Chary about some alternative targets that might have been less studied, but that might potentially contribute significantly to scientific knowledge. He offered four candidates, and suggested we review journal articles to see which might be the most interesting. We selected Arp102B because many of the studies done on it reached contradictory conclusions. It seems likely that Spitzer data can resolve some of this controversy. We then reviewed dozens of journal articles on NGC4258, NGC1068, and Arp102B to learn what types of studies had already been done, what methods and models were being used, and what questions remained. Finally, we again talked to Dr. Chary about how Spitzer could be used answer these questions. Dr. Chary has been especially helpful as we developed the AOR by asking pointed questions that forced us to analyze the numbers and instruments used.

Observations: We propose to target the nucleus of ARP102B using IRS in the stare mode after peaking up the bright nuclear source in the 16 micron band. We propose to use the Short-Low module (SL 1 and 2) (6s ramp x 2 cycles) for the low end of the spectrum, then use the Short-High (6s ramp x 3 cycles) and Long-High (60s ramp x 6 cycles) modules to cover the middle and upper wavelength range and to provide greater resolution for the longer wavelengths. The table below shows the continuum ranges covered by each IRS spectral module, as well as key spectral strong lines to be used in our analysis.



Keck measurements (Ho et al, 2000) indicate that the target is bright at 12 microns (~90 mJy), but drops below the threshold value of 50 mJy at 18 microns. To estimate the flux at other wavelengths, we used Excel to model the Planck curve.

This suggested that the target temperature was at least 283K, and perhaps higher. To test sensitivities for flux estimates, we input a target temperature of 320K, the blackbody temperature of NGC1068's torus.

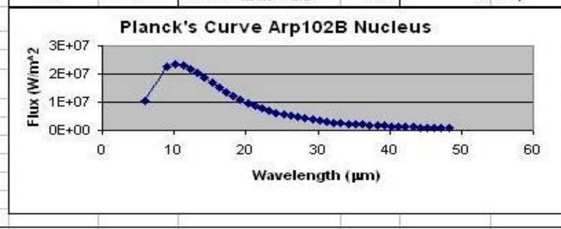
Estimated Line Intensity of Selected Lines

T_{peak} =	283	K
Speed light: c =	3.00E+08	m/s
Planck's Const: h =	6.63E-34	J*s
Boltzman's Const: k	1.38E-23	J/K
Known intensity:	90	mJy @ 12.0 microns
Known intensity:	> 50	mJy @ 18.0 microns

$P = 2\pi hc^2/(\lambda^5(e\wedge(hc/(\lambda kT))-1)$

	µm	m	P (W / m²)
	6	6.0E-06	1E+07
	9	9.0E-06	2E+07
λ_{max} =	10.2	1.0E-05	2E+07
	11	1.1E-05	2E+07
	12	1.2E-05	2E+07
	13	1.3E-05	2E+07
	14	1.4E-05	2E+07
	15	1.5E-05	2E+07
	16	1.6E-05	2E+07
	17	1.7E-05	1E+07
	47	4.7E-05	8E+05
	48	4.8E-05	8E+05

Spectral Line		Flux ratio		Expected Flux at Specific Wavelengths
PAH	6.2 µm	ratio: $P_{\lambda 6.2}/P_{\lambda 12}$ =	0.44	40 mJy
SIV	10.5 µm	ratio: $P_{\lambda 10.5}/P_{\lambda 12}$ =	1.02	92 mJy
SIII	18.7 µm	ratio: $P_{\lambda 18.7}/P_{\lambda 12}$ =	0.53	48 mJy
OIV	25.6 µm	ratio: $P_{\lambda 25.6}/P_{\lambda 12}$ =	0.24	22 mJy
SiII	34.8 µm	ratio: $P_{\lambda 34.8}/P_{\lambda 12}$ =	0.10	9 mJy



We then used these flux values to select ramp and cycle times for each of the four IRS spectral modes we are requesting. Signal to noise ratios for each Planck temperature are shown in the table below:

Estimated Signal/Noise Ratios at Key Wavelenths							
Module Settings				Estimated Planck Temperature 283 K		Estimated Planck Temperature 320 K	
Module	Ramp Time (s)	Cycles	Wavelength (µm)	Flux (mJy)	S/N	Flux (mJy)	S/N
Short Low 2	6	2	6.2	62	64	40	46
Short Low 1	6	2	10.5	96	110	92	110
High Short	6	3	18.7	40	3.1	48	3.7
High Long	60	6	25.6	17	9.7	22	12
High Long	60	6	34.8	7	0.63	9	0.81

This analysis indicates that, depending upon the blackbody temperature, the continuum spectrum near the upper end of the HL mode may have a S/N ratio that will make it unusable. However, it is likely that line spectra will still be available in this range because they are radiatively excited rather than thermally excited. SPOT calculations indicate that the total Spitzer time required will be 1683.9 seconds.

Scientific Merit: Arp102B has been suggested as the prototype for a subclass of radio loud AGNs with intermediate inclination that have double peaked Balmer lines. A survey of 5000 AGNs taken from the SDSS database indicates that several hundred fit this profile. (Eracleous & Halpern 1992, 1993). Our project will increase understanding of the structure, composition, and energy processes that take place in the dusty environment surrounding Arp102's supermassive black hole. It may also help scientists determine whether Arp102 is indeed prototypical for this subclass of AGNs. Finally, it may provide evidence needed to support the AGN unification theory.

Outreach and Educational Merit of Project: This project will support at least three National Science Education Standards, including Standards A (develop abilities necessary to do scientific inquiry), B (structure and properties of matter/interactions of energy and matter), D (evolution of the universe), and E (abilities of technological design.) Implementation plans are as follows:

Lead Teacher (Harlan Devore): I teach AP Physics, Research in Science, and Astronomy. In my physics classes, I will integrate analysis of our IR spectra into the curriculum as lab activities to support topics such as blackbody radiation, Doppler shifts, Keplerian mechanics, and line spectra. Each year in my Astronomy course we select a class project, then work in teams to perform the analysis and publish our results on the Internet. Last year, for example, we imaged 13 open star clusters with B and V filters, analyzed the images, then created H-R diagrams to calculate their ages and distances. Next year we will create a class project based upon our Arp102B data. My Research in Science students are required to select their own research topics, conduct authentic research, then present their projects at competitions such as the regional science fair, the NC Student Academy of Sciences, or the NC Junior Science and Humanities Symposium. They must also publish their research in a national student science journal. I will encourage them to base their projects on some aspect of our Arp102 data. As lead teacher for the project, I will coordinate with my team to write an article for a refereed science journal. I also plan to present papers at the NC Association of Physics Teachers and at the Fayetteville Astronomical Society. In addition, I will present Spitzer workshops at the NC Science Teachers Association convention and at the Hands-On Universe conference. These workshops will probably focus on how to download Spitzer images, tools available for analysis, and their application in the science classroom. I will also be presenting "IR in the Classroom" professional development training for the 12 high schools in my school district.

Co-Investigator (Howard Chun): I use Research Based Science Education as the foundation for my honors physics class (12-15 students). I start off with modern physics (relativity, quantum physics-spectroscopy, nuclear physics-fission, fusion) and related astronomy topics and incorporate five areas of research: Sunspot monitoring, Active Longitude monitoring, stellar spectroscopy, M31 novae search, and AGN spectroscopy. Each of my students work in small groups on each research project for a few weeks. Near the end of the second quarter, each student team selects one of the research topics and develops a science fair project. Finally the science fair project is turned into a paper for submission to the RBSE Journal. Spectra from Arp102B should fit very well into the AGN portion of my class. My students could create a science fair project around Arp102B and a library search of similar objects. As for professional development, I plan to hold school and district wide workshops on using research in the science classroom. I will demonstrate what I do in the classroom and then show teachers what could be done in the chemistry and physics classroom (spectroscopy in particular). Obviously, I will emphasize IR, but I will include the rest of the EM spectra. What I do at the school and district level can also be adapted for the state and national level One of us will attend the NSTA convention as a RBSE delegate to talk about how we use research in the classroom. Of course, we will also want to present our findings at the AAS conventions.

Co-Investigator (Lauren Chapple): I have 130 students that will self-select their topic of research after my presentation of areas of study. Currently, I have several students working with spectroscopy relating to classification of stars and active galactic nuclei. I expect them to take advantage of the Spitzer data next year. When possible, students will compare infrared and optical data from the same or similar objects. I will be presenting the Spitzer Space Telescope Teachers program to the Travesre City Area Public Schools science department at our fall inservice session. I am currently developing a proposal to the Intermediate School District (ISD) for delivery to surrounding schools. This will include use of the materials kit being put together by NOAO for our use. I will also send a proposal to present at our Michigan Science Teachers Association meeting in 2006. The details are in the development stage.

References:

1. Eracleous, Michael: *Mass Outflow in Active Galactic Nuclei: New Perspectives* eds. D. M. Crenshaw, S. B. Kraemer, and I. M. George (San Francisco: ASP), p. 131.
2. See http://www.nublado.org for the CLOUDY manual.