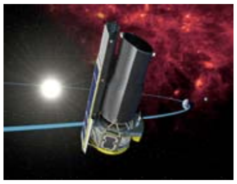
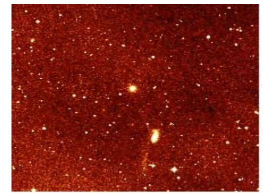


Mid-Infrared Properties of ARP 102B



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ABSTRACT

ARP 102B is a subluminous, radio-loud LINER1.8 galaxy at z=0.024. It is thought to harbor a nuclear black hole, estimated to be $10^8 M_\odot$. We present sub-arcsec imaging of the nucleus between 10-20 μm from Keck and R~60-600 spectroscopy between 5-40 μm with the Spitzer/IRS. We use the data to place constraints on the bolometric luminosity, dust temperature, nature of dust and physical conditions of the line emitting gas in the vicinity of the supermassive black hole.

INTRODUCTION

ARP 102B is a radio-loud elliptical (E0) galaxy at a redshift of 0.02436 (Eracleous & Halpern 2004). ARP 102B is prototypical of a small class of AGNs that produce double peaked Balmer lines. Although it has been extensively studied in radio, Near IR, optical, and x-ray, a complete consensus has not yet existed as to its geometry and energy producing mechanisms. Unlike many AGNs, ARP 102B is devoid of an obscuring dusty torus. Without this dust to reprocess radiation, ARP 102B provides an excellent laboratory to study the innermost geometry of an AGN.

As part of the Spitzer Research Program for Teachers, we were granted 30 minutes of Director's Designated Time on the Spitzer Space Telescope. Our goals were:

- To determine dust column density of ARP 102B using silicate absorption at 9.7 _m.
- To measure mid-IR spectral energy distribution and integrate with SEDs from other bands to determine the bolometric luminosity.
- Find and analyze double peaked molecular hydrogen lines if they exist.
- To assess energy sources and geometry of the AGN.

OBSERVATIONS

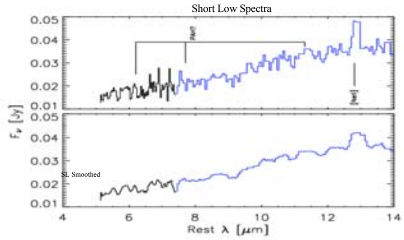
High and low resolution spectra of the nucleus of ARP 102B were obtained on 2005 March 18 using the Spitzer Space Telescope's Infrared Spectrograph (IRS) in its staring mode. The target was centered on the slits using the 16mm blue peak-up camera. Spectral coverage was as follows:

IRS Module	Spectral Coverage μm	Resolution λ / Δλ	Integration Time s
Short Low	5.2 - 14.5	R~64-128	24
Short High	9.6 - 19.6	R~600	36
Long High	18.7-37.2	R~600	720

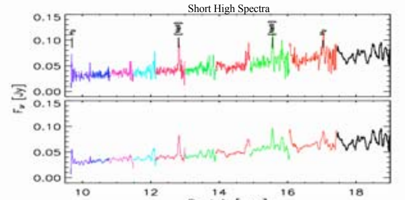
RESULTS

After pipeline processing, post process cleaning, and sky subtraction, we obtained the following spectra:

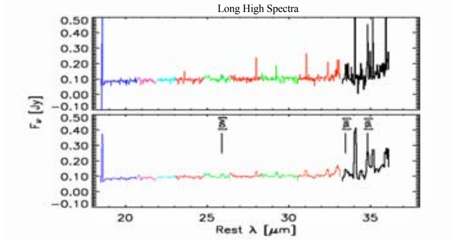
Short Low Spectra



Short High Spectra



Long High Spectra



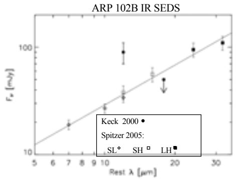
ANALYSIS

o Peak up image:
- Nuclear radius <250 pc
- Flux @ 16μm: 55 +/- 10 mJy

o Broad band properties:
- The flux density is best represented by the power equation:
$F\nu(mJy) = 1.7 \times \lambda^{1.23+/-0.15}$ with evidence of turnover at $\lambda > 20\mu m$.
- MIR spectral energy distribution from Spitzer data is shown by the line on log-log graph.

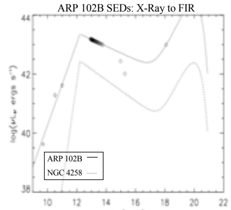
- Data points from Keck observations (Chary, 2000) made in Apr 2002 are shown as solid circles. Comparison shows that the MIR source brightness has decreased by a factor of ~2.5 at 12μm, with a corresponding change in the SED.

ARP 102B IR SEDS



o Bolometric Luminosity
- Our MIR SEDs were combines with nonconcurrent radio/millimeter measurements by Puschell etal (1986) to produce an IR SEDs.
- The combined IR SEDs gave a spectral index for the of $\alpha < -0.25$, consistent with self-absorbed synchrotron emission from a thermal distribution of electrons arising from an ADAF.
- A total SED for ARP 102B is shown on the right (solid line) with SEDs for NGC 4258 (dotted line) shown for comparison. The spectral index for NGC 4258 is $\alpha \sim -1.25$, consistent with self-absorbed synchrotron emission from a nonthermal distribution of electrons arising from shock.
- Bolometric luminosity derived from integrating the spectrum from 6 cm to 10 keV is about 8×10^{43} ergs s^{-1}.
- Implied Eddington ratio then is $\sim 6 \times 10^{-3}$ and marginally within the ADAF limit.

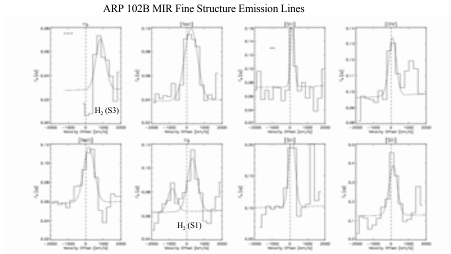
ARP 102B SEDs: X-Ray to FIR



NOTE: NGC 4258 SEDs is scaled up for comparison to ARP 102B using the mass ratio of their black holes.

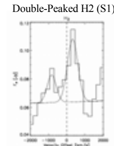
o Fine Structure Lines: Emission lines clearly detected in the spectrum of ARP 102B are shown below, with best-fit Gaussian curves superimposed.

ARP 102B MIR Fine Structure Emission Lines



o Double-peaked molecular hydrogen lines:
- Asymmetrically double peaked molecular H_2 (S1) lines suggest a rotating molecular gas ring, possibly warped.
- We interpret the line at 9.6μm to be the redshifted peak from a double-peaked H_2 (S3) line. The blueshifted peak was not detected because it is below the wavelength limit for the SH module.
- Flux ratio of S(3)/S(2) = 1.6 suggests warm gas with an average temperature ~ 400K
- If Keplerian, the gas ring size is ~ 1 pc for a black hole mass of $10^8 \odot$.

Double-Peaked H2 (S1)



o Analysis of key lines is shown in the table to the right. Note that high ionization potential lines were absent. [OIV] at 55eV was the highest found.

ARP 102 Key Emission Lines

Feature	λ_o μm	λ_{obs} μm	Flux 10^{-21} W cm^{-2}	FWHM km s^{-1}
H_2 S(3)	9.6649	96922	2.9+/- 0.54	609+/-60
[NeII]	12.8135	12.8236	4.13+/-0.50	846+/-60
[NeIII]	15.5551	15.5626	2.46+/-0.77	626+/-75
H_2 S(1)	17.0348	17.0530	1.86+/-0.78	675+/-100
[OIV]	25.8903	25.9874	0.85+/-0.17	545+/-60
[FeII]	25.9883	25.9889	0.73+/-0.16	694+/-60
[SIII]	33.4810	33.4921	1.82+/-0.35	468+/-60
[SiII]	34.8152	34.8269	5.74+/-0.86	550+/-60

o Line ratio analysis: Starburst, shock, or photon ionization dominated source?

[OIV]/[NeII] = 0.21 ± 0.05
[FeII]/[OIV] = 0.86 ± 0.25
} Suggests possible starburst dominated source (Sturm et al, 2002)

[NeII]/[SIII] = 2.3 ± 0.5
[NeIII]/[ArII] >3.1
([ArII] was undetected, with upper limit of 0.8×10^{-21} W cm^{-2})
} Places ARP 102B out of starburst regime and intermediate between shock-excited and photo ionization-excited regime. See Spinoglio & Malkan (1992)

o Starburst dominated source is also inconsistent with other observations:
1. Absence of strong polycyclic aromatic hydrocarbon dust emission features.
2. Broadband IR SED
3. Hard x-ray source.

o Absorption features: There was a complete absence of silicate absorption features in the spectrum of ARP 102B. This places a limit of $N_H < 10^{21}$ cm^{-2} on the column density.

CONCLUSIONS

o We find strong evidence that ARP 102B contains an H_2 molecular gas structure that appears to be distributed in a ring of radius ~1 pc.

o We find that ARP 102B varied in mid-infrared brightness by a factor of ~2.5 between 2000 and 2005 based on comparison of Keck and Spitzer observations

o We interpret this and the implied change in SED distribution as evidence for a transition to an advection dominated accretion flow.

o Finally, we find that the lack of high ionization lines and the low ionization fine structure line ratios are consistent with excitation from both slow shocks from nuclear star-formation and the central photo ionizing source with the latter process dominating.

ACKNOWLEDGEMENTS

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