NOAO Observing Proposal *MDTAC proposal* **Panel:** *For office use.*
Date: March 31, 2008 **Category:** Resolved Galaxies

Deep Emission-Line Imaging of Local Galactic Winds with NEWFIRM

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
Galactic winds or "superwinds" are the primary mechanism by which energy and metals are recycled in galaxies and are deposited into the intergalactic medium. New observations are revealing the ubiquity of this process, particularly at high redshift. Here we propose to use the narrowband filters on NEWFIRM to study the NIR "dust-free" emission-line properties of a small but representative set of local wind galaxies. Deep images of these objects will be obtained at H_2 2.12 μm, [Fe II] 1.64 μm, and Brγ 2.17 μm and then combined with existing optical emission-line maps to constrain better than ever (1) the importance of molecular gas in the energetics of these winds (from H_2) and (2) the nature of the interaction between the central energy injection zone (starburst, SNe, AGN) and the wind (from [Fe II] and Brγ). These data will nicely complement an approved Spitzer program and a request for follow-up spectroscopic observations on Keck.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	KP-4m	NEWFIRM	4	dark	Nov - Jan	Nov - Jan
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

M82 is the prime target in the sample and is observable for more than 3 hours only in Nov-Jan.

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

1. Background. Galaxy-scale outflows of gas ("superwinds") are a ubiquitous phenomenon in both starburst galaxies and those containing an active galactic nucleus (e.g., Veilleux, Cecil, & Bland 2005). Winds are active contributors to the evolution of galaxies and the surrounding intergalactic or intracluster medium (IGM/ICM) in which they are embedded, and are especially important at high redshift, where strong starbusts dominate the star formation budget and the number density of AGN is greater. Winds have been invoked to resolve a number of issues in cosmology and galaxy evolution: the mass-metallicity relation of star-forming galaxies, discrepancies between observed and predicted galaxy luminosity functions, bimodal color distribution of galaxies, and the presence of metals in IGM/ICM (see Veilleux et al. 2005 for more detail).

2. Proposal. The observational data set on outflows is steadily increasing, but difficult issues remain. One vexing problem is how much different phase of the ISM contribute to the mass and energy of superwinds. Measurements have shown that winds contain cool (molecular and emitting, neutral and absorbing), warm (ionized and emitting), and hot gases. However, the relative contribution of these phases to the total mass and energy of the wind is uncertain by an order of magnitude. The contribution from dust and molecular gas to the mass and energy in the wind is almost completely unknown. The impact of superwinds on their environments depends strongly on these quantities. Superwinds are invoked as enrichers of galactic halos and the IGM, but it is not yet clear if the winds extend far enough to carry dust/molecular gas/metals out of the galaxy.

To our knowledge, M82 is the only object with unambiguously detected large-scale CO outflow (Walter, Weiss, & Scoville 2002). The lack of sensitivity and spatial resolution of mm-wave arrays have prevented the detection of CO winds in fainter, more distant wind galaxies (although CARMA may change this state of affairs in the very near future). Here we propose to obtain deep H_2 2.12 μm images of a small set of local wind galaxies, with a particular emphasis on M82. There are two basic ways to excite molecular hydrogen: collisional excitation, i.e. inelastic collisions between molecules in a warm gas (> 1000 K), or fluorescent excitation through absorption of soft-UV radiation (912 – 1108 Å) in the Lyman and Werner bands. The detection of H_2 emission far from the central source would therefore be an excellent indicator of shocked molecular gas associated with nuclear outflows (see, e.g., Veilleux et al. 1997a for a more detailed discussion).

Nearly all of these objects are edge-on disk galaxies. So the second observational goal of this program is to image these objects in Brγ and [Fe II] 1.644 μm to probe the energy source at a wavelength that is less prone to dust extinction. Published HST/NICMOS emission-line images of M82 show that [Fe II] originates in shocks from supernova explosions and is therefore indeed an excellent indicator of star formation in starburst-driven wind galaxies (Alonso-Herrero et al. 2003; see also Veilleux et al. 1997a and references therein). To first order, Brγ emission will follow the Hα emission and therefore also probe the energy injection zone in star-forming and active galaxies.

Alonso-Herrero, A., et al. 2003, AJ, 125, 1210
Lehnert, M. D., Heckman, T. M., & Weaver, K. A. 1999, ApJ, 523, 575-584
Veilleux, S., Cecil, G., & Bland-Hawthorn, J. 2005, ARA&A, 43, 769
Veilleux, S., Goodrich, R. W., & Hill, G. J. 1997a, ApJ, 477, 631
Veilleux, S., et al. 2003, AJ, 126, 2185
Walter, F., Weiss, A., & Scoville, N. 2002, ApJ, 580, L21

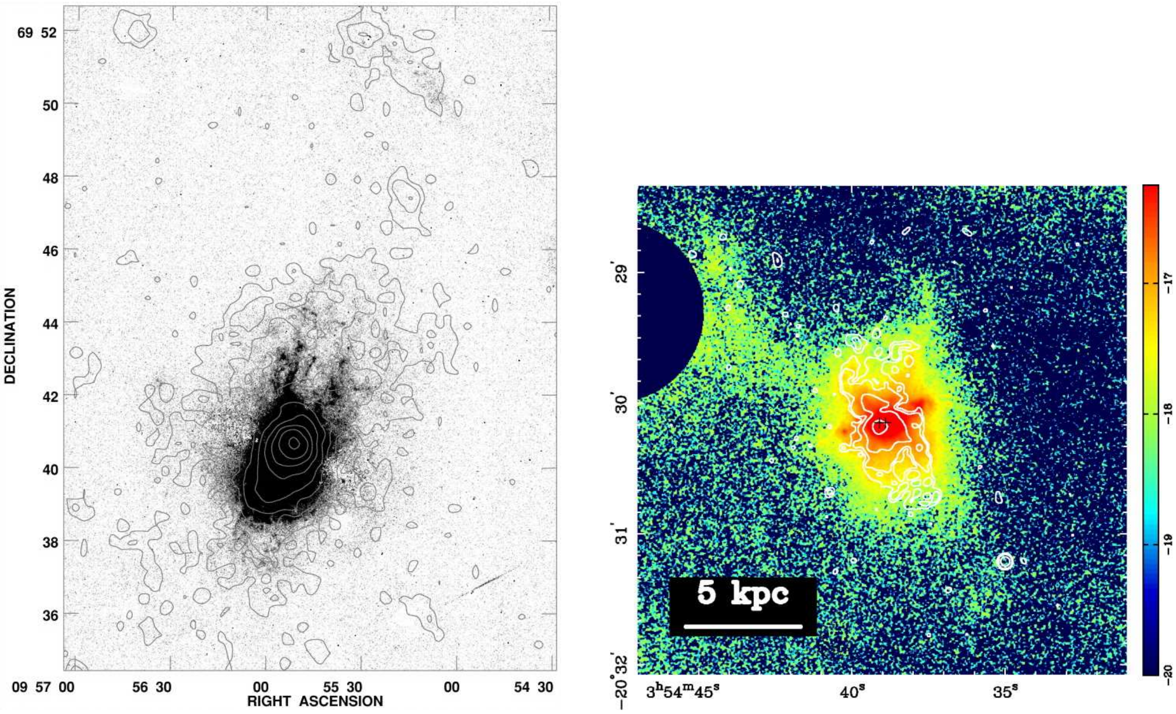

Figure 1: (*Left*) Gray scale showing the Hα image and contours showing the ROSAT PSPC image of M82. North is up and east to the left. The lowest surface brightness emission visible in the Hα corresponds to a flux of 3.5×10^{-17} ergs s^{-1} cm^{-1} arcsec^{-2}. The spatial coincidence of the Hα and X-ray emission is quite good. Note the Hα/X-ray "cap" about 11′ (11.6 kpc) from the disk of M82. (from Lehnert, Heckman, & Weaver 1999). (*right*) Chandra X-ray contour map superposed on a deep Hα+[N II] λ6583 image of NGC 1482. North is up, and east to the left. The crosses indicate the locations of the two peaks in the red continuum. The flux scale is logarithmic. Filamentary line emission is detected out to $\sim$7 kpc northwest of the nucleus and perhaps out to $\sim$12 kpc to the northeast. Diffuse emission may also be present $\sim$10 kpc southwest of the nucleus. A bright star on the eastern edge of the image was masked for display purposes; it may be responsible for reflective ghosts that can be confused with faint emission-line features. (from Veilleux et al. 2003)

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

The experimental design of this program is very straightforward. A standard random dither pattern will be used to obtain very deep images of each target in each of the ∼1.3% narrowband filters of NEWFIRM: Brγ 1.17 μm, [Fe II] 1.644 μm, and H_2 2.12 μm. The required exposure times are justified in the Technical Description below. The objects in the sample were selected from the approved Spitzer program of Veilleux & Rupke (see section below on Other Facilities or Resources) with the additional condition of being visible from Kitt Peak in November - January, when M82 is visible.

Proprietary Period: 18 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

Co-I Rupke has submitted a request for 2 nights on Keck to carry out follow-up NIR long-slit spectroscopy of the more interesting objects in the sample. Veilleux and Rupke also have an approved Spitzer archival program to study these objects in the IRAC bands. These Spitzer data will provide new constraints on the hot dust content in galactic winds and therefore nicely complement the NEWFIRM data.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

In the past 4 years, PI Veilleux has obtained ∼ 10 nights / year on the Mayall 4m and WIYN telescopes through the Maryland TAC. 15 nights were allocated for the Dark Ages Survey in 07B and 08A (combined into a single run at the end of Feb/beginning of March). The data from this run have not yet been reduced.

Select refereed publications resulting from these data:

1. Veilleux, Cecil, & Bland-Hawthorn 2005, Galactic Winds, ARAA, 43,
2. Rupke, Veilleux, & Sanders 2005a, Outflows in Infrared-Luminous Starbursts at z < 0.5. I. Sample, Na I D Spectra, and Profile Fitting, ApJS, 160, 87
3. Rupke, Veilleux, & Sanders 2005a, Outflows in Infrared-Luminous Starbursts at z < 0.5. II. Analysis and Discussion, ApJS, 160, 115
4. Rupke, Veilleux, & Sanders 2005a, Outflows in Active Galactic Nucleus/Starburst-Composite Ultraluminous Infrared Galaxies, ApJ, 632, 751
5. Rupke, Veilleux, & Baker 2008, The Oxygen Abundances of Luminous and Ultraluminous Infrared Galaxies, ApJ, 674, 172

Observing Run Details for Run 1: KP-4m/NEWFIRM

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

Based on our experience with near-infrared spectrographs on 4-m class telescopes (e.g., CGS4 on UKIRT: Veilleux et al. 1997ab, 1999), we estimate that point sources ($\sim 1''$ seeing) with a H_2 flux of 1×10^{-15} will be detected ($\sim$ 3 sigmas) within about an hour. The numbers in Table 2 of the Updated Technical and Performance Information for Proposal Preparation website suggest that the sensitivity through the [Fe II] (Brγ) filter(s) is slightly better (worse) than at H_2 2.12 μm, but this difference is within the uncertainties of our estimates so we don't take it into account in the following calculations. The priority is to go deeper in the H_2 filter to try to detect H_2 emission as far as possible in the entrained outflowing material, while shallower images at Brγ and [Fe II] will be sufficient to probe the brighter, central source. Exposures of order $\sim$ 1 hour will typically be sufficient for Brγ and [Fe II], but $\sim$ 4-6 hours will be needed for H_2. M82 is the best target for this program (due to proximity, angular size, and brightness) so we wish to at least double these exposure times for this object. We also plan to take shorter ($\sim$ 30 min) exposures in H and K to match our NB data. The plan for the request 4 nights is to observe $\sim$4 objects, with M82 as the top priority.

References

Veilleux, S., Goodrich, R. W., & Hill, G. J. 1997a, ApJ, 477, 631
Veilleux, S., Sanders, D. B., & Kim, D.-C. 1997b, ApJ, 484, 92
Veilleux, S., Sanders, D. B., & Kim, D.-C. 1999, ApJ, 522, 113

Instrument Configuration

Filters: NB: Brγ, H_2, [Fe II], H, K	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 0 to 12

Dec. range of principal targets (degrees): -20 to +70

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 1: KP-4m/NEWFIRM

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	M82	09:56	+69:40	2000	9:30 V	NB, H, K	15 hrs	tot	7	phot	1.0	Top Priority
2	NGC 1068	02:43	-00:01	2000	9.61, V	NB, H, K	8 hrs	tot	7	phot	1.0	
3	NGC 1482	03:54	-20:30	2000	13.10 V	NB, H, K	8 hrs	tot	7	phot	1.0	
4	NGC 2992	09:46	-14:19	2000	13.14 V	NB, H, K	8 hrs	tot	7	phot	1.0	
5	NGC 3077	10:03	+68:44	2000	10.2, B	NB, H, K	8 hrs	tot	7	phot	1.0	
6	NGC 3628	11:20	+13:35	2000	10.2, B	NB, H, K	8 hrs	tot	7	phot	1.0	
7	NGC 4388	12:26	+12:40	2000	12.1, g	NB, H, K	8 hrs	tot	7	phot	1.0	

NOAO observing proposal LaTeX macros v2.14.