

CFA OBSERVING TIME REQUEST

Program No.: _____

P. I.: Peter Challis Semester: 2006 January-June

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Col.: Robert kirshner

Program Title: Investigations of SNR 1987A

Telescope: Magellan 6.5m

Instrument: LDSS3 Spectrograph

Other (multislit, ap plates, etc): Red grism

(Remember: it is YOUR responsibility to make sure the instrument setup is correct for your project)

Nights Requested: D 0 G 0.25 0

Queued Observing: Yes ___ No X Home Phone _____

Term: long/initial ___ long/cont ___ short X engineering ___ Additional nights _____

Student Project: research exam ___ thesis ___ other ___

Optimum Dates: Jan 7, 2005 or any

Acceptable Dates: any

Dates You Cannot Use: none

Targets: Number 1 Magnitude Range 18

Targets: RA Range 05 35 00 Dec Range -69 18 00

Abstract Include a short summary of your project. The summary should outline the main goals of the project and should not exceed 100 words.

SN1987A is the brightest supernova in 384 years and it is turning into the youngest supernova remnant at age 19. We are proposing observations with all three Magellan spectrographs in 2006A. The LDSS3 spectrograph to continue measuring the flux of a reverse shock in SN1987A. The IMACS+IFU to map the spatial variations of the reverse shock. Finally, MIKE to measure the emission lines that are produced by the supernova shockwave crushing into the hotspots. These ground-based observations will allow us to follow SN1987A as it evolves on the time scale of 6-12 months and provide complimentary observations to HST and CHANDRA. Even in average seeing at Magellan, ground-based observations can spatially separate SN1987A from the nearby stars.

■ Scientific Justification

Supernova 1987A, the brightest supernova since Kepler's in 1604, provides a unique opportunity to study the mechanics of a supernova explosion and the birth of a supernova remnant. Today, a blast wave driven by the expanding debris of SN1987A is striking the inner circumstellar ring, exciting a rapidly increasing number of hot spots that emit infrared, optical, and ultraviolet emission lines. Bright spots in X-ray images from CHANDRA correlate with the optical hot spots from HST and this emission changes noticeably in 6 months. Astronomers have never before had the tools to observe an event as we are observing SN 1987A, and we are unlikely to see another in our lifetimes. SN 1987A offers a unique object to study the physics of radiative shocks, how supernovae energize the interstellar gas, and how supernovae create the chemical history of the Universe. Our team has been observing SN 1987A with HST since its discovery and has worked to understand the data. Ground-based telescopes are once again providing valuable observations to the continuing saga of SN 1987A and SNR 1987A.

The Reverse Shock

The Reverse Shock (see Figures 1,2,3) is the surface where the freely expanding supernova debris is first decelerated by pressure from the surrounding medium. As neutral hydrogen atoms in the debris cross the shock and enter the shocked plasma downstream, they emit at 15,000 km/s. Our first mapping observations, with HST+STIS, took place in 2001, and we reconstructed the shape of the reverse shock surface at Ly and H alpha with a 3-dimensional map: 2 dimensions come from the angular resolution of the image and the depth from the Doppler shifts (see figure 3). In July 2004, new observations at H alpha with HST+STIS created a better map of the reverse shock surface and a comparison of the 2 epochs is now underway. The mass flux across the reverse shock is increasing and the emission is continuing to get brighter. By comparing maps of the 15,000 km/s shock with those of the radio and X-ray emission, we can investigate the cause of the asymmetry of the shock, study the way relativistic particles are accelerated by the shock, and examine the physics of particle isotropization in a collisionless shock. Since the radio and X-ray fluxes of SNR 1987A, as well as the brightness of the hotspots, are doubling on timescales of 1 year, and all these phenomena are driven by the evolving flow of gas across the reverse shock, we are proposing Magellan observations to continue the investigation of these shocks.

Proposed Observations: We propose one epoch of observations of SN 1987A with both IMACS+IFU and LDSS3 in 2006A to observe the reverse shock region. The IFU will yield a 30 spectra of the reverse shock from across the entire SN 1987A field of view. This new set of IMACS+IFU observations will enable us to track changes in the morphology of the reverse shock to see whether this asymmetry increases or decreases as the shock digs deeper into the supernova debris. In this way, we will begin to map the structure of the explosion itself, which set the gas in motion in the first hours after the core collapse. It is not surprising that the shock surface is brightest in the equatorial plane of the inner ring, but also it is much brighter on the East side of the major axis than it is on the West. The observed asymmetry of the remnant represents a real asymmetry in the mass flux through the reverse shock of about 30 percent. Continued ground-based observations of emission from the reverse shock will allow us to monitor the rapid changes in its geometry and asymmetry, expansion rate and luminosity. By comparing observations of the

development of the reverse shock with those of the X-ray emission from the blast wave and the brightening spots on the equatorial ring, we have a unique opportunity to develop a full picture of the global hydrodynamics of the birth of this remarkable supernova remnant. In the next decade, we expect to see this spectrum change suddenly as clumps of heavy elements from deep within the chemically inhomogeneous envelope of SN 1987A across the shock and reveal the distribution of nucleosynthetic products in the supernova debris.

Recent Developments: Magellan has observed SN 1987A with LDSS3 twice in 2005 (See Figure 2). First in Feb 2005 (see astro-ph/0510835 Smith et al) and second Oct 2005. The flux of the reverse shock has increased by 30 percent over the 6 months. These proposed observations will allow us to build a light curve of the broad H alpha emission with a consistent set of observations started at Magellan in Feb 2005. While the IMACS+IFU data will be used to map and measure flux increases spatially, the LDSS3 will provide complimentary flux calibration of the entire shock and provide direct comparison to previous observations.

Hotspots

The optical hot spots appear where the supernova blast wave encounters fingers of relatively dense gas protruding inward from the ring (See Figure 4). The optical emission from the spots comes from relatively slow $V < 200 \text{ km s}^{-1}$ shocks that have had time to undergo radiative cooling. The X-ray emission must come from a gas heater by faster $V > 1000 \text{ km s}^{-1}$ shocks, either transmitted shocks entering the protrusions or shocks reflected from the protrusions. Observations with MIKE can provide the profiles of several emission lines at high resolution. In poor seeing we can still spectrally resolve the broader shocked hotspot emission from the narrower photoionized preshock gas in the ring. If the seeing is good, then MIKE can spatially resolve the N and S parts of the ring. We are particularly interested in obtaining the [Fe X] and [Fe XIV] fluxes to compare with recent CHANDRA spectra. We propose one epoch of observations of SN 1987A with MIKE in 2006A to observe the entire optical to near-IR spectrum of the hotspots.

Observing details:

We are proposing for 1 full night of time, but 0.25 nights with CLAY+LDSS3, 0.25 nights with BADDE+IMACS+IFU, and 0.50 nights with CLAY+MIKE to get both Blue and Red sides of the spectrum. For LDSS3, 2 hours is all that's needed. An observation of a standard star, then 3x1200 seconds with 2.0" centered on SN1987A, and, if the seeing is excellent, 3x1200 seconds with the narrowest slit at various positions to help investigate the asymmetry. For IMACS+IFU, with a similar dispersion as LDSS3, a similar exposure time as LDSS3 should yield similar S/N. With 2 hours, we can get both a standard star and science exposures. For MIKE, ideally, we would like to match up the parallactic angle with a position angle of -30 degrees to place the slit between nearby bright stars, so the best plan would be 1 hour per night for 4 nights.

Scheduling:

Any time in 2006A is fine. Pete Challis will already be at Magellan Jan 6, 2006. If there is a chance to trade half a night from a Harvard block to Jan 7th or so, that would save a trip. If there are other MIKE proposals, perhaps we can ask someone to observe SN 1987A an hour per night for 4 nights.

Michael, E., et al. 1998, ApJ, 509, L117. “New HST Observations of High Velocity Ly α and H α in SNR 1987A.” (Draws inferences about shock heating of the inner ring of SN 1987A as the SN ejecta collide with the gas.)

McCray, R. 2000, in *A Decade of HST Science* (Cambridge: Cambridge Univ. Press). “SN 1987A: the Birth of a Supernova Remnant.” (Discusses the transition of SN 1987A from a supernova to a supernova remnant: collision of the ejecta with the inner ring, etc.)

Michael, E., et al. 2003, ApJ, 593, 809. “*Hubble Space Telescope* Observations of High-Velocity Ly α and H α Emission from Supernova Remnant 1987A — The Structure and Development of the Reverse Shock.” (Analysis of the reverse shock in the SN ejecta as the debris collides with the inner ring.)

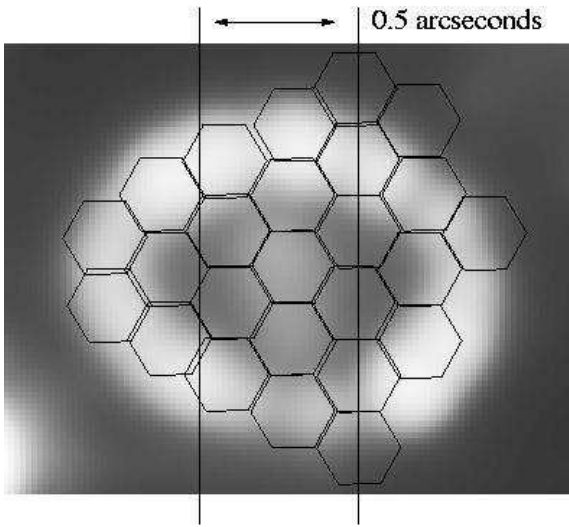
McCray, R. 2004, “Supernova 1987A: the Birth of a Supernova Remnant” in *Cosmic Explosions*, ed. J. M. Marcaide and K. W. Weiler (Heidelberg: Springer-Verlag), 77. (Reviews impact of debris with circumstellar rings, especially in light of HST and *Chandra* observations.)

Park, S., et al., *Astrophys. J.*, 610, 275-84, “A Chandra View of the Morphological and Spectral Evolution of Supernova Remnant 1987A.”

Zhekov, S. A., et al., *Astrophys. J. Letters*, 628, L127-30, “Chandra Observations of Shock Kinematics in Supernova Remnant 1987A.”

Smith, N., et al. 2005, astro-ph/0510835, *Astrophys. J. Letters*, in press, “The Reverse Shock of SNR1987A at 18 Years after Outburst” - Shows Magellan data from Feb 2005, measures flux of reverse shock and predicts a shut off in about 7 years.

Figure 1: SN 1987A in 0.4" seeing with some of the IMACS+IFU 0.2" lenslets



An observation with the IMACS+IFU will yield a measure of the entire flux of the reverse shock with any seeing. In good seeing, a spatial mapping of the shock can be obtained.

Figure 2: Magellan with LDSS3+0.8" slit 02/2005

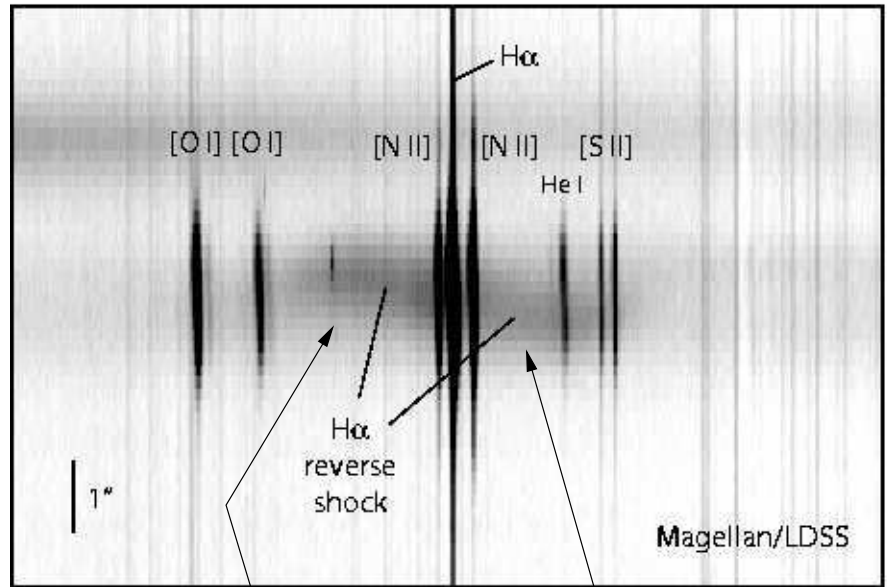
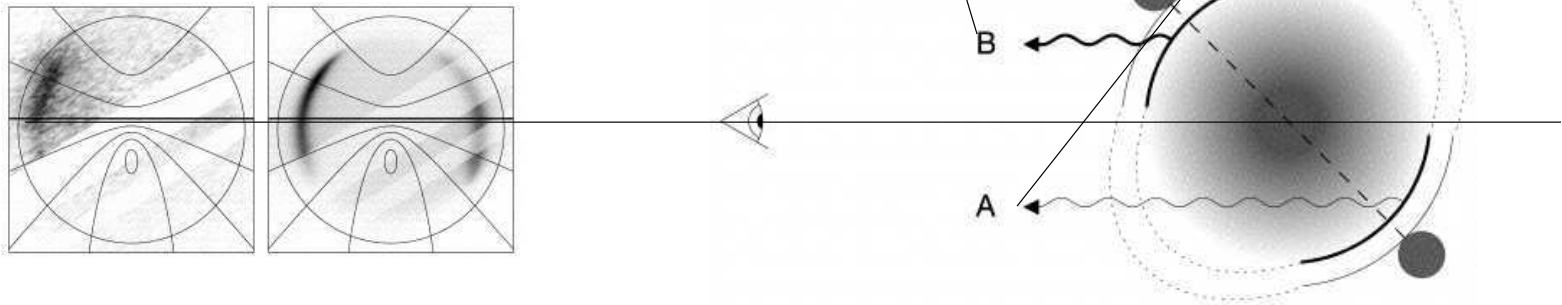


Figure 3: Remapped obs. and model
The locations of the Reverse shock A and B



The ground-based IMACS+IFU observations of the reverse shock can be mapped from spectral to physical space and will allow us to continue measuring the changes in the geometry, asymmetry, expansion rate, and luminosity.



Figure 4: LDSS3 spectrum Oct. 2005, showing narrow hotspot emission from ~5500A – 9500A