RS OPHIUCHI SPITZER IRS CAMPAIGNS

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AND THE SPITZER PID 270 AND PID 30007 TEAMS

**SPITZER IRS RS Oph DDT Rationale**

1. There will be a strong thermal continuum in the far-IR. This, combined with the ongoing radio and x-ray observations, will provide strong constraints on models of the interaction of the ejecta with the red giant wind;

2. There are several strong coronal and fine structure lines in the IR which we anticipate will be bright and which Spitzer can observe (e.g. [Ne II], [Ne III], [Ne V], [O IV], [Mg V], [Ar III]); these will provide unique insight into the environment of the recurrent nova and its aftermath.

3. There is a need to understand and to determine the effect of the eruption on the red giant, whose far IR continuum will become visible after the eruption has subsided. In particular, Spitzer observations of the giant will likely tell us (for example) whether the giant becomes bloated, or is irradiated by the hot white dwarf.

**DDT Proposal Submitted 23 Feb 2006, 4.9 hrs awarded time (PID 270)**
Jeff Van Cleve and the IRS at Ball Aerospace.

(modules counter clockwise) Short-High, Short-Low and Peakup, Long-High, Long-Low
### SPITZER IRS INSTRUMENT CHARACTERISTICS

<table>
<thead>
<tr>
<th>Module</th>
<th>Detector</th>
<th>Wavelength Range (μm)</th>
<th>Resolv Pwr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-Low (SL)</td>
<td>Si:As</td>
<td>5.2-8.7 (SL 2nd)</td>
<td>60-127*</td>
</tr>
<tr>
<td>Blue Peak-Up (SL)</td>
<td>Si:As</td>
<td>7.4-14.5 (SL 1st)</td>
<td>61-120*</td>
</tr>
<tr>
<td>Red Peak-Up (SL)</td>
<td>Si:As</td>
<td>(13.5-18.7)</td>
<td>(~3)</td>
</tr>
<tr>
<td>Long-Low (LL)</td>
<td>Si:Sb</td>
<td>14.0-21.3 (LL 2nd)</td>
<td>57-126*</td>
</tr>
<tr>
<td>Short-High (SH)</td>
<td>Si:As</td>
<td>9.9-19.6</td>
<td>~600</td>
</tr>
<tr>
<td>Long-High (LH)</td>
<td>Si:Sb</td>
<td>18.7-37.2</td>
<td>~600</td>
</tr>
</tbody>
</table>

**Figure 1:** Summary of IRS module properties. The slits are not parallel as depicted in this figure. Actual slit position angles relative to a Spitzer roll angle of 0° are SL = +84.7°, LL = +181.2°, SH = +221.5°, LH = +136.7°, and IRS Peak-up = +177.0°.
RS Oph — Keele U. 2007

AOR On-Target Sequence 2006 Apr 26

IRS HIRes Bkgr Field 2006 Apr 26
RS Oph — Keele U. 2007

SPITZER IRS 2006 APR 16.33 UT

t (day) = 62.5
RS Oph — Keele U. 2007

UKIRT/IRTF 2006 APR / MAY

$t (\text{day}) = 62.5$
The Spitzer IRS data show a rich emission line spectrum superimposed on a free-free continuum (continuum declines as $f \sim l^{-2}$).

The presence of fine structure (Ne, Mg) and coronal IR lines ([Si VI]/[Si X]) suggests there are at least two temperatures ($1.5 \times 10^5$ K and $9 \times 10^5$ K) in the ejecta/wind environment.

Estimate that the electron density in the ‘cooler’ region is $2.2 \times 10^5$ cm$^{-3}$.

Determination of elemental abundances is not straightforward but on the assumption that the Ne and O fine structure lines arise in the same volume of the ejecta, the O/Ne ratio is $> 0.6$ by number (n.b., solar value $\sim 6.6$).
### Table 1: Estimated temperatures from IR coronal lines

<table>
<thead>
<tr>
<th>Line ratio</th>
<th>Flux ratio</th>
<th>at 1 e5 K</th>
<th>logT (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Si VI]1.96μm/[Si X]1.43μm</td>
<td>0.26</td>
<td>0.43, 0.13</td>
<td>5.96</td>
</tr>
<tr>
<td>[Mg VII]5.50μm/[Mg V]5.61μm</td>
<td>3.25</td>
<td>1.36, 1.06</td>
<td>5.85</td>
</tr>
<tr>
<td>[Ne III]15.55μm/[Ne V]14.32μm</td>
<td>1.18</td>
<td>0.79, 2.16</td>
<td>5.18</td>
</tr>
<tr>
<td>[Ne III]15.55μm/[Ne V]24.32μm</td>
<td>4.53</td>
<td>0.79, 0.75</td>
<td>5.15</td>
</tr>
<tr>
<td>[Ne VI]7.65μm/[Ne III]15.55μm</td>
<td>7.29</td>
<td>1.70, 0.79</td>
<td>5.34</td>
</tr>
<tr>
<td>[Ne II]12.81μm/[Ne V]14.32μm</td>
<td>0.99</td>
<td>0.40, 2.16</td>
<td>5.08</td>
</tr>
</tbody>
</table>
Inflection interpreted as shock “break out”

Iijima (this conference): approximate date that shock clears boundary of circumstellar envelope
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SPITZER IRS 2006 APR 26.33 UT — EPOCH 1
AAVSO DATA FOR RS OPH - WWW.AAVSO.ORG

Mag

2453900  2454000  2454100  2454200
Julian Date

Visual Unvalidated
Visual Validated

Fainter-Than
V

E2
RS Oph — Keele U. 2007

SPITZER IRS 2006 SEP 09.83 UT — EPOCH 2
The Spitzer IRS data still shows a rich emission line spectrum superimposed on a free-free continuum (continuum declines as $f \sim r^{-2}$).

Strong signature of dust emission now present in the spectra, possible due to presence of silicate grains (broad emission at both 10 and 18.5 micron).

The mid-IR fine structure ($N_e, Mg$) still present, while the [O VI] 25.2 micron line flux increasing in intensity (strong plasma coolant).

J. Van Loon (this conference): models emission with $T_{dust} \sim 600$ K, optical depth $\sim 0.1$, with $dM/dt = 2.3 \times 10^{-8} M_{sun}$/yr with Dusty, reproduces mid-IR broadband SED characteristics from 1970, 1982, 2006.
RS Oph — Keele U. 2007

SPITZER IRS 2006 OCT 10.40 UT — EPOCH 3
Strong signature of dust emission still present in the spectra, possible due to presence of silicate grains (broad emission at both 10 and 18.5 micron), although 18 micron feature fading somewhat.
Now over one-year post-outburst, and over 220.9 days since detection of dust features in the mid-IR spectra.

Spitzer data “hot-off the press,” just recently (23 May 2007) released into archive of PID 30007.

Long term IR evolution of RS Oph unknown, especially the persistence of both the fine structure emission lines (Ne, Mg, etc), and dust emission signature.

Visual light curve returned to near pre-outburst brightness.
RS Oph — Keele U. 2007

\[ t \text{ (day)} = 62.5 \]

*Spitzer E1*

\[ t \text{ (day)} = 367.5 \]

*Spitzer E4*
Detailed Temporal Evolution Spitzer IRS E2 though E4
Detailed Temporal Evolution Spitzer IRS E2 though E4
Detailed Temporal Evolution Spitzer IRS E2 though E4
Detailed Temporal Evolution Spitzer IRS E2 though E4
Next target visit tentatively constrained to occur between 2007 Sep 15 to 2007 Oct 26 under PID 3007.

Possibility that the system, in particular the red giant envelope, return to quiescent state by this epoch.

Origin of dust (highly likely material entrained in the shock, “lighting-up”) need to be discerned.

Mid-IR observations provide a baseline for further study in the era of JWST.

Coordinated Swift, Chandra, RXTE, XMM, VLA, VLBA, Spitzer, and ground-based observations revealing unprecedented insight into the physics of how the ejected material runs into, and shocks, a dense red giant wind and of the RS Oph eruption itself.
RS Oph — Keele U. 2007
AAVSO DATA FOR RS OPH - WWW.AAVSO.ORG

Mag

2453792 2453922 2454052 2454183

Julian Date


RS Oph — Keele U. 2007

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