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# *Spitzer* Observations of Stephan's Quintet – IGM Dust and Gas in a Multi-galaxy Collision

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**Abstract.**
Stephan's Quintet (SQ) is the most famous and well studied compact group of galaxies. Spectacular activity is triggered by interactions between member galaxies and various constituents of the intragroup medium (IGM), including a  40 kpc large scale-shock and IGM starbursts more than 20 kpc away from any neighboring galaxy centers. Our new *Spitzer* IRS (SH, LH, and SL) and MIPS ($70\mu m$ and 160 $\mu m$) observations of SQ with unprecedented resolution and sensitivity give new constraints on the physical conditions of the IGM gas and dust. In particular, our IRS observations discovered very strong pure MIR emission lines of molecular hydrogen in the SQ shock, the first time such a spectrum is detected in an extragalactic source. And the MIPS $160\mu m$ map of SQ shows clear evidence for the diffuse IGM dust emission.

## 1. Introduction

Stephan's Quintet (hereafter SQ) is a compact group of galaxies (Hickson 1982) involved in violent multi-galaxy collisions. It has been observed in almost all wavebands with the most advanced instruments. The rich multiband data reveal one of the most fascinating pictures in the universe, depicting a very complex web of interactions between member galaxies and various constituents of the IGM (see Xu 2006 for a review). With our new *Spitzer* observations, we try to address the following questions:
**(1) Physical conditions of gas and dust in the large scale shock.** Discovered by Allen & Hartsuiker Allen  (1972), this IGM shock is truly unique to SQ. Its size is second only to that of the radio relics caused by cluster mergers (Enßlin & Brüggen 2002). The shock is triggered by a high velocity collision ($\delta V \gtrsim 900$ km sec$^{-1}$) between an intruder galaxy NGC 7318b and the cold IGM. The ISO

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observations found $L_{\rm dust} = 1.9\ 10^{42}$erg s$^{-1}$ in the shock (Xu et al 2003, hereafter X03), about an order of magnitude more than the X-ray luminosity (Trinchieri et al. 2005). Apparently, the dust grains can survive the shock and dominate the cooling. With the IRS observations, we probe the physical conditions (e.g. temperature, density and composition) of the shocked gas, and the abundance and grain size distribution of shock heated dust.

**(2) The Diffuse IGM dust emission and its mechanism**. Dust emission in the IGM and intracluster medium (ICM) is particularly interesting because it provides important constraints on the interaction between the intergalactic medium and galaxies, a crucial input for the hierarchical galaxy formation models. There is marginal evidence for diffuse IGM dust emission in the ISO observations of SQ (X03). With the new MIPS observations at $70\mu m$ and $160\mu m$, we aim to constrain the origin of the dust (i.e. where it is produced) and the heating mechanism (collisional heating by hot IGM gas versus radiative heating by the diffuse IGM radiation field).

## 2. Observations and Results

### 2.1. IRS Observations — Very Bright $H_2$ Emission in the Shock

The IRS observations were made on Nov. 17 and Dec. 8, 2004 using the Short-low (SL), Short-Hi (SH) and Long-Hi (LH) modules of the spectrograph covering the wavelength range 5.3-14.0 $\mu m$ (SL), 10.0-19.5 $\mu m$ (SH) and 18.8-37.2 $\mu m$ (LH). The positions of the slits are given in Fig.1 (left). Details of the observations and data reduction can be found in Appleton et al. (2006). The IRS spectra are presented in Fig.1 (right). Unlike most mid-IR spectra of galaxies, our observations reveal very bright emission lines of the pure-rotational molecular hydrogen and little else. Along with the absence of PAH-dust features and very low excitation ionized gas tracers, the spectra resemble the shocked gas seen in Galactic supernova remnants (Reach et al. 2002), but on a vast scale. The $H_2$ emission extends over 24 kpc along the X-ray emitting shock-front. It has ten times the surface luminosity as the soft X-rays, and about one-third the surface luminosity of the IR continuum. We suggest that the powerful $H_2$ emission is generated by the shock wave caused by the high-velocity collision between the intruder galaxy and filaments of cold gas in the IGM. Our observations suggest a close connection between galaxy-scale shock-waves and strong broad $H_2$ emission lines, like those seen in the spectra of ULIRGs where high-speed collisions between galaxy disks are common.

### 2.2. MIPS Observations — Diffuse IGM Dust Emission

The MIPS observations in the $70\mu m$ and $160\mu m$ bands were made on Dec. 12, 2004. The BCD data were taken from the *Spitzer* Science Center (SSC) pipeline. Corrections for the long term detector drift were carried out on the post-BCD data for both the $70\mu m$ and $160\mu m$ maps. Details of data reduction will be presented else where. Angular resolution (FWHM) of the $70\mu m$ map is $17''$, and the R.M.S. noise (1-$\sigma$) is 0.19 MJy/sr = 1.44 mJy/beam. For the $160\mu m$ map, the angular resolution (FWHM) is $37''$ and R.M.S, noise (1-$\sigma$) is 0.28 MJy/sr = 10.2 mJy/beam. The two MIPS maps are presented in Fig.2.

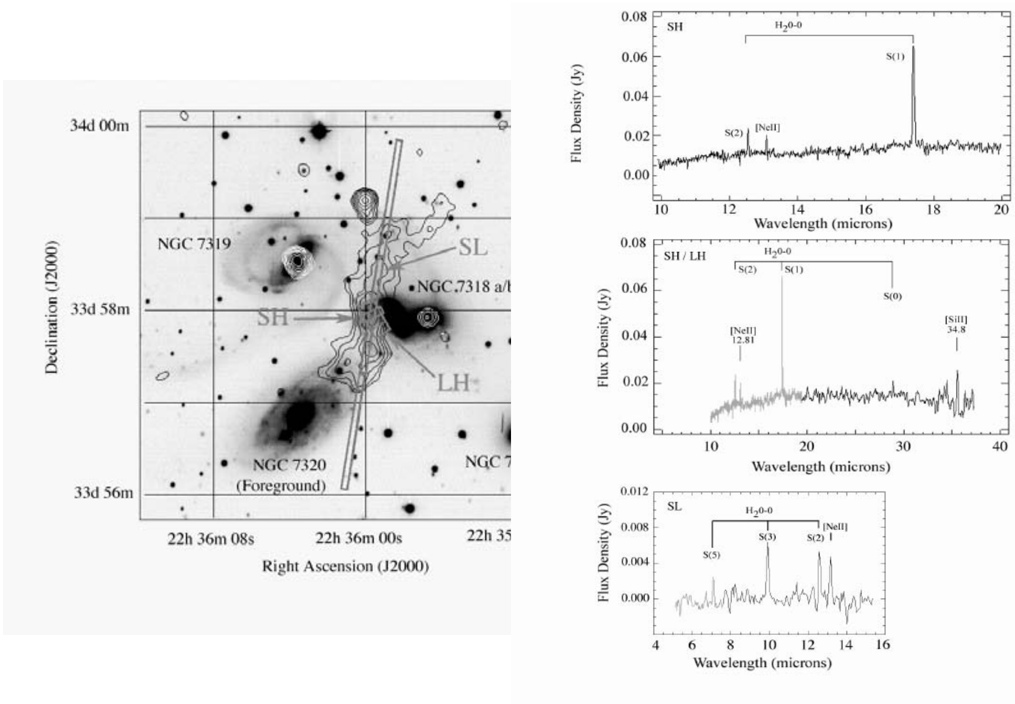


Figure 1. **Left:** IRS slits (Short-Low=SL, Short-High=SH and Long-High = LH) overlaid on an R-band image of Stephans Quintet. The radio continuum (1.40 GHz) contours show a ridge corresponding to a large scale shock. All IRS slits are centered at a position (22h 35m 59.57s +33d 58m 1.8s) where the shock emission in the radio and X-ray peaks. **Right:** *Top*: The IRS SH spectrum of the brightest radio/X-ray point in the shock-front. Note the high signal-to-noise ratio detection of molecular hydrogen 0-0 S(1). *Middle*: The combined SH and LH spectrum. Note the rather weak metal lines ([SII] and [NeII]) compared to 0-0 S(1). *Bottom*: The SL spectrum of the same position. There is no evidence for PAH emission.

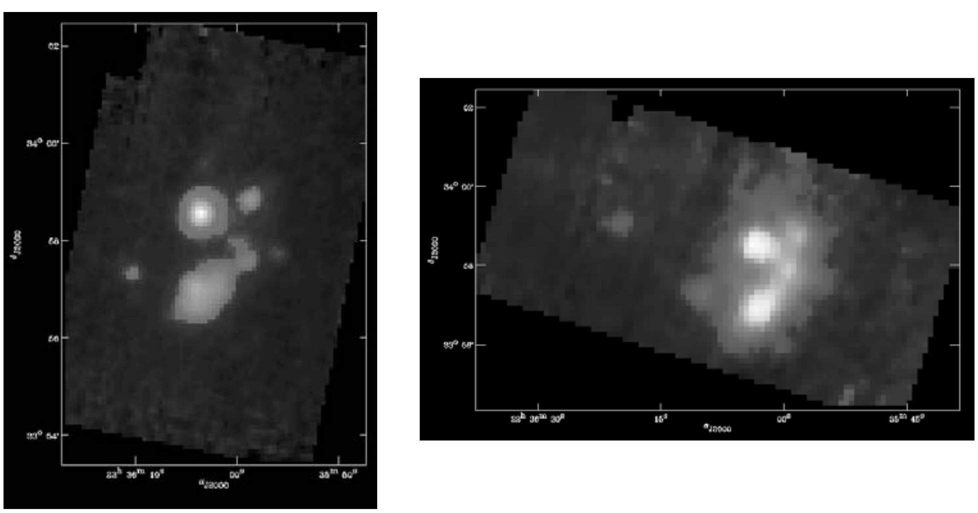

Figure 2. **Left**: *Spitzer* MIPS 70$\mu m$ map. **Right**: *Spitzer* MIPS 160$\mu m$ map.

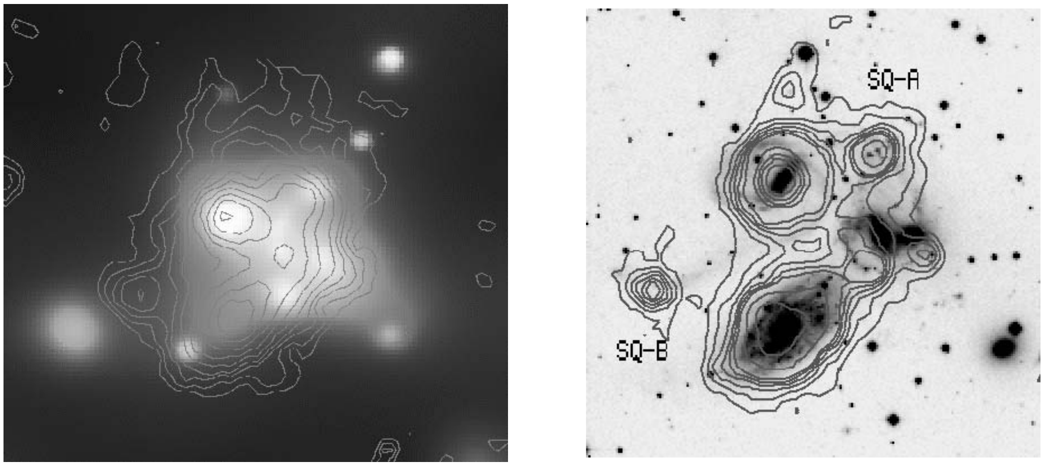


Figure 3. **Left**:160$\mu m$ contours overlaid on an XMM image (Trinchieri et al. 2005) of the X-ray emission. **Right**: 70$\mu m$ contours overlaid on an optical image. The collision induced starburst SQ-A and the tidal starburst SQ-B are marked.

There is a clear detection of the diffuse dust emission in the 160$\mu m$ map. Detailed photometry shows that at least half of the 160$\mu m$ emission in SQ is in a diffuse component outside member galaxies. The origin of this emission is still unclear. There are two competing possibilities: (1) emission of collisionally heated grains in the hot IGM; and (2) emission of radiative heated grains in the cold neutral IGM. The better correspondence between the morphology of the 160$\mu m$ map and that of the X-ray map (compared to that between 160$\mu m$ and HI) favors the possibility (1). However, the luminosity of the diffuse 160$\mu m$ is more than 10 times that of the diffuse X-ray. More quantitative analysis is needed. In contrast, most of the detected 70$\mu m$ emission is in galaxies and in IGM starbursts SQ-A and SQ-B (Fig.3).

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