Far-IR luminous SNR Kes 17

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Introduction: FIR luminous SNR & interaction with MC

- Luminous ($>10^4 \, L_\odot$) FIR SNRs (IRAS; Saken et al 1992)
  - Many of them are SNRs interacting with MC
  - Kes73, 3C391, W49B, HC30, W51, OA189 (H II region), Monoceros Loop (220'), Kes17, G349.7+0.2
- Well identified at NIR & MIR images

RGB [8/5.8/4.5um] (Lee 2005)

MIPS 24um

3C391, W49B, Kes17, G349.7+0.2
Previous/other observations of Kes17

- **Bright IR SNR**
  - Spitzer IRAC (Lee 2005, Reach et al. 2006); Spitzer IRS MIR spectra (Hewitt et al. 2009)

- **Mixed morphology**
  - MMX X-ray (Combi et al. 2010); OH detection (Frail et al. 1996)

- **Distance**
  - HI absorption: >8 kpc (Caswell et al. 1975)
Observations

- Imaging
  - AKARI IRC L & FIS pointed observations
  - Spitzer inner Galactic plane survey (GLIMPSE, MIPSGAL)

<table>
<thead>
<tr>
<th>Band</th>
<th>Spitzer 4.5 μm</th>
<th>Spitzer 8 μm</th>
<th>AKARI 15 μm</th>
<th>Spitzer 24 μm</th>
<th>AKARI 24 μm</th>
<th>AKARI 65 μm</th>
<th>AKARI 90 μm</th>
<th>AKARI 140 μm</th>
<th>AKARI 160 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>IRAC 4.5</td>
<td>IRAC 8</td>
<td>IRC L15</td>
<td>MIPS 24</td>
<td>IRC L24</td>
<td>FIS N60</td>
<td>FIS Wide-S</td>
<td>FIS Wide-L</td>
<td>FIS N160</td>
</tr>
<tr>
<td>Reference wavelength (μm)</td>
<td>4.49</td>
<td>7.87</td>
<td>15.0</td>
<td>23.68</td>
<td>24.0</td>
<td>65</td>
<td>90</td>
<td>140</td>
<td>160</td>
</tr>
<tr>
<td>Effective bandwidth (μm)</td>
<td>1.01</td>
<td>2.93</td>
<td>5.98</td>
<td>5.3</td>
<td>5.34</td>
<td>21.7</td>
<td>37.9</td>
<td>52.4</td>
<td>34.1</td>
</tr>
<tr>
<td>FWHM (&quot;)</td>
<td>1.72</td>
<td>1.98</td>
<td>5.7</td>
<td>6</td>
<td>6.8</td>
<td>37</td>
<td>39</td>
<td>58</td>
<td>61</td>
</tr>
</tbody>
</table>

- Spectroscopy
  - AKARI NIR grism (2.5-5μm; warm phase)
  - Selected from NIR imaging (Western shell)

<table>
<thead>
<tr>
<th>Slit</th>
<th>Position</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$(13^h05^m48.s, -62^d38'39&quot;)$</td>
<td>$1 \times 308$ s</td>
</tr>
<tr>
<td>B1</td>
<td>$(13^h05^m33.s, -62^d40'00&quot;)$</td>
<td>$2 \times 308$ s</td>
</tr>
<tr>
<td>B2</td>
<td>$(13^h05^m33.s, -62^d40'19&quot;)$</td>
<td>$1 \times 308$ s</td>
</tr>
<tr>
<td>C1</td>
<td>$(13^h05^m32.s, -62^d42'34&quot;)$</td>
<td>$1 \times 308$ s</td>
</tr>
<tr>
<td>C2</td>
<td>$(13^h05^m33.s, -62^d42'16&quot;)$</td>
<td>$1 \times 308$ s</td>
</tr>
<tr>
<td>Background</td>
<td>$(13^h05^m20.s, -62^d39'11&quot;)$</td>
<td>$1 \times 308$ s</td>
</tr>
</tbody>
</table>

- 20cm continuum for comparison
  - ATCA archive uv-data
Results (imaging)

- IR images of Kes 17: Bright western shell

![IR images of Kes 17 with ATCA 20 cm image](image_url)
Results (MIR images)

- Background subtracted 15 & 24um images:
  - western + southern shell along the radio boundary
  - Swept-up hot dust
- Background: using 4 & 8um images

![AKARI 15um](image1.png)  ![Spitzer 24um](image2.png)
Results (NIR spectroscopy)

- NIR spectra of positions of western shell

Bright H2 lines ⇒ Molecular shock
Results (H2 lines)

- H2 line population diagram

![H2 line population diagram](image)

Surface Brightness of the Observed H$_2$ lines

<table>
<thead>
<tr>
<th>Line</th>
<th>Wavelength (µm)</th>
<th>A</th>
<th>B1</th>
<th>B2</th>
<th>C1</th>
<th>C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$ 1–0 O(3)</td>
<td>2.80</td>
<td></td>
<td>11.6 (4.8)</td>
<td>9.7 (4.3)</td>
<td>12.4 (4.7)</td>
<td>2.8 (2.0)</td>
</tr>
<tr>
<td>H$_2$ 1–0 O(5)</td>
<td>3.24</td>
<td>4.3 (3.1)</td>
<td>10.6 (6.6)</td>
<td>16.4 (4.5)</td>
<td>10.3 (3.1)</td>
<td>5.7 (2.9)</td>
</tr>
<tr>
<td>H$_2$ 1–0 O(6)</td>
<td>3.50</td>
<td></td>
<td>4.2 (2.0)</td>
<td>7.8 (4.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$ 0–0 S(14)</td>
<td>3.72</td>
<td></td>
<td>2.5 (1.9)</td>
<td>2.9 (1.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$ 1–0 O(7)</td>
<td>3.81</td>
<td></td>
<td>2.6 (1.4)</td>
<td>5.8 (2.2)</td>
<td>6.1 (3.3)</td>
<td>2.2 (2.3)</td>
</tr>
<tr>
<td>H$_2$ 0–0 S(13)</td>
<td>3.85</td>
<td></td>
<td>6.9 (2.3)</td>
<td>8.4 (2.2)</td>
<td>7.7 (2.4)</td>
<td>3.5 (1.4)</td>
</tr>
<tr>
<td>H$_2$ 0–0 S(12)</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$ 0–0 S(11)</td>
<td>4.19</td>
<td>7.1 (2.5)</td>
<td>16.0 (2.7)</td>
<td>18.6 (2.3)</td>
<td>17.1 (2.1)</td>
<td>10.7 (2.2)</td>
</tr>
<tr>
<td>H$_2$ 0–0 S(10)</td>
<td>4.41</td>
<td>8.5 (2.6)</td>
<td>14.0 (2.4)</td>
<td>14.5 (2.5)</td>
<td>15.3 (2.5)</td>
<td>7.8 (2.1)</td>
</tr>
<tr>
<td>H$_2$ 0–0 S(9)</td>
<td>4.69</td>
<td>13.1 (3.7)</td>
<td>35.1 (1.9)</td>
<td>39.5 (2.9)</td>
<td>37.5 (1.9)</td>
<td>18.5 (1.7)</td>
</tr>
</tbody>
</table>

$\text{Tex} = 2200 \pm 400 \text{ K}$
Results (IR SED)

- Two Temperature modified BB fit
  - Flux measurement after subtraction of
    - Background: images
    - Line contribution: Spitzer IRS, MIPS SED spectra
  - Cold component:
    - 27±3 K, 6.7± 4.0 M⊙, (8.1±5.0)×10³ L⊙
  - Hot component:
    - 79±6 K, (6.2±4.6)×10⁻⁴ M⊙
  - Si+C IS grains (Draine 2003)

### Flux of the Western and Southern Shells

<table>
<thead>
<tr>
<th>Band</th>
<th>Western Shell</th>
<th>Southern Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fluxa</td>
<td>Line Contributionb</td>
</tr>
<tr>
<td>AKARI 15 μm</td>
<td>2.6 ± 0.5 Jy</td>
<td>75% ± 21%</td>
</tr>
<tr>
<td>Spitzer 24 μm</td>
<td>2.2 ± 0.4 Jy</td>
<td>38% ± 10%</td>
</tr>
<tr>
<td>AKARI 24 μm</td>
<td>3.1 ± 0.7 Jy</td>
<td>39% ± 11%</td>
</tr>
<tr>
<td>AKARI 65 μm</td>
<td>75 ± 15 Jy</td>
<td>16% ± 8%</td>
</tr>
<tr>
<td>AKARI 90 μm</td>
<td>90 ± 27 Jy</td>
<td>3% ± 2%</td>
</tr>
<tr>
<td>AKARI 140 μm</td>
<td>104 ± 44 Jy</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>AKARI 160 μm</td>
<td>75 ± 31 Jy</td>
<td>&lt;5%</td>
</tr>
</tbody>
</table>
Discussions (NIR & FIR)

- Good correlation between NIR and FIR images
  - Bright western shell (only)
  - Note. MIR: Western + southern shell

- NIR emission
  - H2 lines (+ some ionic lines): AKARI & Spitzer spectra
    - Kes 17 is interacting with MC
  - Shock velocity < 50 km/s (molecular shock)
    - Otherwise H2 may be dissociated

- FIR emission
  - Dust continuum (~27 K)
    - Line is not dominant contributor: Spitzer MIPS SED spectra
  - No H2 line in FIR
  - Needs hot gas

- So... why there is such a good correlation?
Discussions (H2 excitation)

- H2 line population diagram from AKARI & Spitzer H2 pure rotational line fluxes

- Thermal admixture model (various T gas with $dN \sim T^{-b}dT$)
  - $b \sim 3.0$, NH2 $\sim 1.5 \times 10^{21} \text{ cm}^{-2}$, n $\sim 3.2 \times 10^5 \text{ cm}^{-3}$
  - Obtained $b(\sim 3.0)$ can be explained by shocks in clumpy MC
  - Inter-clump medium: lower than MC but high enough to explain IR emission?
Discussions (FIR: scenario I)

- Shock-heated dust in swept-up inter-clump medium
  - Shock sweeps not dense clumps (>10^4 cm^-3) but inter-clump medium (10~100 cm^-3)
  - Sedov solution for radius ~ 7 pc
    - V_{ic} = 200 (n_{ic} / 40 cm^-3) km/s
  - IR surface brightness (Draine 1981)
    \[ I_v \approx 90 \left( \frac{n_{ic}}{40 \text{cm}^{-3}} \right) \left( \frac{v_{ic}}{200 \text{km s}^{-1}} \right)^3 \left( \frac{\lambda}{90 \mu\text{m}} \right) \text{MJy sr}^{-1} \]
    - Peak: at MIR (~30um) ⇒ having more large dust?

- Ejected dust in evaporating cloud
  - Evaporating cloud in hot X-ray gas (Dwek 1981)
  - n_{hot} ~ 10^7 K, n_{hot} ~ 1 cm^-3 (XMM; Combi et al. 2010)
    \[ L_{IR} \approx 200n_{h}^2 \left( \frac{R_c}{1 \text{pc}} \right)^3 \left( \frac{T_h}{10^7 \text{K}} \right)^{1.5} L_\odot, \]
    - Insufficient as long as XMM values work
Discussions (FIR: scenario II)

- Illuminated dust by radiative shock
  - Radiative shell forming (Cox et al. 1999)
  - SNR evolve fast, if cooling is effective.
  - For \( n_o = 20 \text{ cm}^{-3} \) and \( t_{sh} = 10000 \text{ yr} \)
    - \( R_{sh} = 7 \text{ pc} \), \( V_{sh} = 200 \text{ km/s} \)
    - Kes17 can be radiative when \( n_o > 20 \text{ cm}^{-3} \)
  - IR luminosity from radiative shock (Hollenback & McKee 1989)
    \[
    L \simeq 2.6 \times 10^4 \left( \frac{R_c}{3 \text{ pc}} \right)^2 \left( \frac{n_o}{20 \text{ cm}^{-3}} \right) \left( \frac{v_s}{200 \text{ km s}^{-1}} \right)^3 L_\odot,
    \]
- This scenario (radiative) is consistent with X-ray morphology
  - Lack of high temperature X-ray emitting shell
- Expectation (can be resolved from FIS image of nearby SNR?)
  - FIR dust is in front of shocked H2 emission!!!
  - Note: H2 is in front of [Fe II]/radio shell (not downstream)
  - G11.2-0.3 (Koo et al. 2007), 3C396 (Lee et al. 2009)
Kes 17 is one of the IR bright SNRs

IR morphology
- NIR & FIR: Bright western shell
- MIR: western + southern shell

NIR spectroscopy of the peak of western shell
- H2 lines (Tex ~ 2000 K) by molecular shock
- H2 excitation: combined with Spitzer MIR spectroscopy
  - Consistent with clump molecular cloud

SED fit of IR emission
- Hot: 79±6 K, (6.2±4.6)×10^{-4} M_⊙
- Cold dust: 27±3 K, 6.7± 4.0 M_⊙, (8.1±5.0)×10^{3} L_⊙

FIR luminosity
- Shock-heated dust in Swept-up inter-clump
- Ejected dust in evaporating cloud
- Illuminated dust by radiative shock

Reference
Then…

- Can IR data prove SNR interacting with MC?
  - BB curve \((T_d < 100 \text{ K})\): steep decrease at MIR
  - Emission at < 10um: due to line
  - An easy idea: they are distinguishable in color !!!
    - \(F(<10\text{um}) / F(>10\text{um}) > 1(?)\)

- Difficulties
  - There exists several attempts, however
    - Flux measure
      - Sensitivity, Confusion, resolution
    - Waveband

- AKRI IRC/FIS survey?
  - 9um & 18um (+ FIR)
  - All sky sample
AKARI IRC 9 & 18um

- G11.2-0.3: Young SNR
- HB21: SNR interacting with MC