The Interstellar Extinction Law in the Near- and Mid-Infrared Based on the APOGEE Spectroscopic Survey

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Collaborators: Mengyao Xue, Jian Gao, Shu Wang, Aigen Li
1. A Precise Determination of the Mid-Infrared Interstellar Extinction Law Based on the APOGEE Spectroscopic Survey
   • Mengyao Xue, B. W. Jiang, Jian Gao, Jiaming Liu, Shu Wang, and Aigen Li
   • 2016, ApJS, in proof

2. Universality of the Near-infrared Extinction Law Based on the Apogee Survey
   • Shu Wang and B. W. Jiang
Preface
\[ A_\lambda = -2.5 \log \frac{F_\lambda}{F_\lambda^0} = 1.086 N_d \Omega_e(\lambda, a, \text{shape}) \sigma_d \]

\[ N_d = \int n_d ds \]

\[ E(B-V) \equiv (B-V)_{\text{observed}} - (B-V)_{\text{intrinsic}} \]

\[ R_V \equiv \frac{A_V}{E(B-V)} \]
Li et al. 2015, Lessons from the Local Group
\[
A_\lambda = -2.5 \log \frac{F_v}{F_v^0} = 1.086 N_d Q_e (\lambda, a, \text{shape}) \sigma_d
\]

\[
N_d = \int n_d ds
\]

\[
E(B - V) \equiv (B - V)_{\text{observed}} - (B - V)_{\text{intrinsic}}
\]

\[
R_V \equiv \frac{A_V}{E(B - V)}
\]
Outline

• Interstellar extinction law in the infrared
• Method based on the APOGEE spectroscopic survey
• Result: mean
  • Near-infrared
  • Mid-infrared
• Result: variation
  • Near-infrared
  • Mid-infrared
• Dust models for the infrared extinction curve
Interstellar Extinction Law

• Variation of interstellar extinction with wavelength
• Continuum extinction
  • Decreasing with wavelength
  • Steep rise to the UV range
• Spectral features
  • 2175A bump
  • 9.7um and 18um silicate features
  • Some DIBs
• In the infrared
  • Much weaker than V/UV
Galactic Center
Gao, Li, Jiang, 2013
EPS, 65,1127
Infrared Extinction Law

- Power law, 1-7 μm, $A_\lambda \propto \lambda^{-\alpha}$
  - Index, $\alpha \sim 1.7$
- Silicate spectral features around 10μm and 20μm
- Much flatter than the model derived from the UV/V extinction law in the 3-8um range
- Lack the dip around 7um predicted by the classical dust model
- Dispersion between works
Wang, Li & Jiang 2014 PSS

\[ \frac{A_{\lambda}}{A_{Ks}} \]

vs \( \lambda \) (\( \mu \)m)

- WD01 \( R_{\nu} = 3.1 \)
- MRN \( R_{\nu} = 3.1 \)

- Wang et al. (2013)
- Nishiyama et al. (2009)
- Gao et al. (2009)
- Flaherty et al. (2007)
- Jiang et al. (2006)
- Indebetouw et al. (2005)
- Lutz (1999)
Uncertainty from photometric method

- Impurity of the sample
  - Selection of red giants and red clump stars
  - Contamination by AGB stars and YSOs
- Dispersion of the intrinsic colors
  - Red clump stars, $\Delta C_{J/K/S}^0 \sim 0.1$ mag
  - Red giants, $\Delta C_{J/K/S}^0 \sim 0.2$ mag
2MASS + Spitzer/GIMPLSE

Source selection
• Color indexes based on photometry
• Red clump
• Red giant

Gao, Jiang & Li 2009
Method
- Linear fitting of observed color respective to J-Ks
- Convert to relative extinction
- Color ratio instead of color-excess ratio

\[
k_{\lambda} = \frac{E(K_S - \lambda)}{E(J - K_S)} = \frac{(K_S - \lambda) - (K_S - \lambda)_0}{(J - K_S) - (J - K_S)_0} = \frac{A_{K_S} - A_{\lambda}}{A_J - A_{K_S}}
\]

\[
\frac{A_{\lambda}}{A_{K_S}} = 1 + k_{\lambda} \left(1 - \frac{A_J}{A_{K_S}}\right)
\]
New method: color-excess method with intrinsic color correction

• Selection of G-type and K-type giants by $T_{\text{eff}}$, log $g$ and $Z$
• Relation of intrinsic color with stellar effective temperature $T_{\text{eff}}$
  • Choosing nearly zero extinction stars
  • Taking the observed color as the intrinsic color
• Determination of intrinsic color from $T_{\text{eff}}$
• Statistical linear fitting between color excesses

$J - K_S$ vs $T_{\text{eff}}$ diagram

The bluest envelope

Selection of zero-reddening stars

APOGEE stellar parameters

$C_{\lambda_1\lambda_2}^0 - T_{\text{eff}}$

Photometry $C_{\lambda_1\lambda_2}$

$E_{K_S\lambda}, E_{K_S\lambda}/E_{JKS}$
The APOGEE Spectroscopic Survey

- SDSS/DR12
- >100,000 red giant stars to magnitude H=12.2
- Resolution R=λ/Δλ ~22,500
- Typical S/N > 100
- Stellar parameters: log g<3.0, $T_{\text{eff}}$, Z >-1.0
- Spectral type: A, F, G, K
- J_err <0.05 mag, Ks_err <0.05 mag
- VSCATTER < 0.3 km/s
- 63,330 stars
## Mid-infrared bands

<table>
<thead>
<tr>
<th>Survey</th>
<th>AKARI</th>
<th>WISE</th>
<th>Spitzer/GLIMPSE</th>
<th>Spitzer/MIPSGAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bands</td>
<td>S9W</td>
<td>L18W</td>
<td>W1 W2 W3 W4</td>
<td>[3.6] 4.5 5.8 8.0 [24]</td>
</tr>
<tr>
<td>( \lambda_{\text{eff}} ) (( \mu \text{m} ))</td>
<td>8.23</td>
<td>17.61</td>
<td>3.35 4.60 11.56 22.09</td>
<td>3.55 4.49 5.73 7.87 23.68</td>
</tr>
<tr>
<td>area</td>
<td>All sky</td>
<td>All sky</td>
<td>[ ] [ ] [ ] [ ] [ ]</td>
<td>[ ] [ ] [ ] [ ] [ ]</td>
</tr>
<tr>
<td>5( \sigma ) limit (mag)</td>
<td>7.6</td>
<td>5.0</td>
<td>16.9 16.0 11.5 8.0</td>
<td>15.0 14.5 12.5 12.5 7.9</td>
</tr>
<tr>
<td>Cross radius</td>
<td>3&quot;</td>
<td>1&quot;</td>
<td>*</td>
<td>3&quot;</td>
</tr>
<tr>
<td>No. of sources ( \otimes ) APOGEE</td>
<td>4,296</td>
<td>901</td>
<td>154,842 154,845 154,735 154,793</td>
<td>15,058 15,307 15,251 15,071 3,045</td>
</tr>
<tr>
<td>( \sigma_\lambda ) (mag)</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1 0.2</td>
</tr>
<tr>
<td>No. of sources qualified</td>
<td>1,024</td>
<td>108</td>
<td>61,734 61,935 41,510 2,008</td>
<td>5,411 5,540 5,474 5,502 806</td>
</tr>
</tbody>
</table>
The $C_{\lambda_1\lambda_2}^0 - T_{\text{eff}}$ relation

• (Nearly) zero-reddening sources
  • Blue envelop in the $C_{\lambda_1\lambda_2} - T_{\text{eff}}$ diagram (Ducati 2001)
    • The least extinction
  • Practice
    • In the $C_{\text{JKS}} - T_{\text{eff}}$ diagram
• The photometric error is taken into account
  • Deviation less than 1 sigma from the blue envelop
• Fitting function
  • Exponential or quadratic
$C_{JKs}^{0} = 20.285 \times \exp\left(\frac{-T_{\text{eff}}}{1214K}\right) + 0.209$
## Comparison of $C^0_{JKs}$

<table>
<thead>
<tr>
<th>$T_{\text{eff}}$</th>
<th>3630K</th>
<th>3710K</th>
<th>3780K</th>
<th>3820K</th>
<th>3980K</th>
<th>4080K</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work</td>
<td>1.21</td>
<td>1.15</td>
<td>1.10</td>
<td>1.07</td>
<td>0.97</td>
<td>0.91</td>
</tr>
<tr>
<td>Bessell &amp; Brett (1988)</td>
<td>1.13</td>
<td>1.08</td>
<td>1.05</td>
<td>1.01</td>
<td>0.95</td>
<td>0.88</td>
</tr>
<tr>
<td>Wang &amp; Jiang (2014)</td>
<td>1.43</td>
<td>1.35</td>
<td>1.28</td>
<td>1.25</td>
<td>1.11</td>
<td>1.03</td>
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</table>

<table>
<thead>
<tr>
<th>$T_{\text{eff}}$</th>
<th>4320K</th>
<th>4500K</th>
<th>4610K</th>
<th>4810K</th>
<th>4960K</th>
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</thead>
<tbody>
<tr>
<td>This work</td>
<td>0.78</td>
<td>0.70</td>
<td>0.65</td>
<td>0.57</td>
<td>0.52</td>
</tr>
<tr>
<td>Bessell &amp; Brett (1988)</td>
<td>0.82</td>
<td>0.74</td>
<td>0.68</td>
<td>0.63</td>
<td>0.58</td>
</tr>
<tr>
<td>Wang &amp; Jiang (2014)</td>
<td>0.87</td>
<td>0.78</td>
<td>0.73</td>
<td>0.66</td>
<td>0.62</td>
</tr>
</tbody>
</table>
\[ C(K_S - [9])_{\text{intrinsic}} = 0.145 \left( \frac{T_{\text{eff}}}{1000 \text{K}} \right)^2 - 1.372 \left( \frac{T_{\text{eff}}}{1000 \text{K}} \right) + 3.419 \]

AKARI/S9W

[9]_err < 0.2 mag

1024 sources

188 (red)
\[ C_{KsW1}^0 = 0.041 \times \left( \frac{T_{\text{eff}}}{1000K} \right)^2 - 0.388 \times \left( \frac{T_{\text{eff}}}{1000K} \right) + 1.006 \]

\[ C_{KsW2}^0 = 0.029 \times \left( \frac{T_{\text{eff}}}{1000K} \right)^2 - 0.208 \times \left( \frac{T_{\text{eff}}}{1000K} \right) + 0.327 \]
\[ C_{KsW3}^0 = 9.634 \times 10^{10} \times \exp\left(\frac{-T_{\text{eff}}}{1340 \text{K}}\right) + 0.103 \]

\[ C_{KsW4}^0 = 6.824 \times 10^3 \times \exp\left(\frac{-T_{\text{eff}}}{3580 \text{K}}\right) + 0.135 \]
Linear fitting of color excesses

• Subtraction of the intrinsic color indexes
• Linear fitting of the color excesses $E(Ks - \lambda)$ and $E(J - Ks)$
• Exclusion of outliers by 3 sigma criterion
  – Important for sources with silicate features
• Intercept
  – Nearly zero
• Conversion to $A_\lambda/A_{Ks}$ given $\frac{A_J}{A_{Ks}} = 2.72$ from $\frac{E(Ks-\lambda)}{E(J-Ks)}$
\[ E(\text{Ks-W1}) = 0.238 \times E(\text{J-Ks}) - 0.013 \]
\[ A_{W1}/A_{Ks} = 0.591 \]

\[ E(\text{Ks-W2}) = 0.312 \times E(\text{J-Ks}) - 0.017 \]
\[ A_{W2}/A_{Ks} = 0.463 \]

\[ E(\text{Ks-W3}) = 0.269 \times E(\text{J-Ks}) - 0.016 \]
\[ A_{W3}/A_{Ks} = 0.537 \]

\[ E(\text{Ks-W4}) = 0.370 \times E(\text{J-Ks}) - 0.036 \]
\[ A_{W4}/A_{Ks} = 0.364 \]
$E(K_s-[3.6]) = 0.260 \cdot E(J-K_s) - 0.012$
$A_{3.6}/A_{K_s} = 0.553$

$E(K_s-[4.5]) = 0.313 \cdot E(J-K_s) - 0.009$
$A_{4.5}/A_{K_s} = 0.461$

$E(K_s-[5.8]) = 0.355 \cdot E(J-K_s) - 0.014$
$A_{5.8}/A_{K_s} = 0.389$

$E(K_s-[8.0]) = 0.334 \cdot E(J-K_s) - 0.001$
$A_{8.0}/A_{K_s} = 0.426$
\[ E(\text{Ks-S9W}) = 0.273 \cdot E(\text{J-Ks}) - 0.013 \]
\[ A_{\text{S9W}} / A_{\text{Ks}} = 0.530 \]

\[ E(\text{Ks-[24]}) = 0.428 \cdot E(\text{J-Ks}) - 0.016 \]
\[ A_{\text{[24]}} / A_{\text{Ks}} = 0.264 \]
Result-1: Near-IR

\[ \frac{E_{JH}}{E_{JKs}} = 0.652, \quad \frac{A_J}{A_{KS}} = 2.72, \quad \alpha = 1.79 \]
## Result-2: Mid-IR

Table 4: The relative extinction in the mid-infrared bands and comparison with other work

<table>
<thead>
<tr>
<th></th>
<th>$E_{Ks\lambda}/E_{JKs}$</th>
<th>$A_\lambda/A_{Ks}$ (1)</th>
<th>$A_\lambda/A_{Ks}$ (2)</th>
<th>$A_\lambda/A_{Ks}$ (3)</th>
<th>$A_\lambda/A_{Ks}$ (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WISE/W1</strong></td>
<td>0.238</td>
<td>0.591</td>
<td>0.638</td>
<td>0.621</td>
<td>0.600</td>
</tr>
<tr>
<td><strong>WISE/W2</strong></td>
<td>0.312</td>
<td>0.463</td>
<td>0.526</td>
<td>0.500</td>
<td>0.333</td>
</tr>
<tr>
<td><strong>WISE/W3</strong></td>
<td>0.269</td>
<td>0.537</td>
<td>0.591</td>
<td></td>
<td>0.867</td>
</tr>
<tr>
<td><strong>WISE/W4</strong></td>
<td>0.370</td>
<td>0.364</td>
<td>0.438</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AKARI/S9W</strong></td>
<td>0.273</td>
<td>0.530</td>
<td>0.585</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spitzer/3.6</strong></td>
<td>0.260</td>
<td>0.553</td>
<td>0.605</td>
<td>0.63</td>
<td>0.56</td>
</tr>
<tr>
<td><strong>Spitzer/4.5</strong></td>
<td>0.313</td>
<td>0.461</td>
<td>0.524</td>
<td>0.57</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>Spitzer/5.8</strong></td>
<td>0.355</td>
<td>0.389</td>
<td>0.460</td>
<td>0.49</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>Spitzer/8.0</strong></td>
<td>0.334</td>
<td>0.426</td>
<td>0.492</td>
<td>0.55</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>Spitzer/24</strong></td>
<td>0.428</td>
<td>0.264</td>
<td>0.349</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*References: (1) GJL2009; (2)Indebetouw et al. (2005); (3)Yuan et al. (2013); (4)Davenport et al. (2014).*
## Error analysis: Bootstrap and Monte Carlo: 20000

### Table 5: Results of linear fitting (LF), Bootstrap Re-sampling (BR) and Monte Carlo (MC) simulation

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{Ks\lambda}/E_{JKS}$</td>
<td>0.238</td>
<td>0.260</td>
<td>0.313</td>
<td>0.312</td>
<td>0.355</td>
<td>0.334</td>
<td>0.273</td>
<td>0.269</td>
<td>0.370</td>
<td>0.428</td>
</tr>
<tr>
<td>$\sigma$ (LF)</td>
<td>2.260E-04</td>
<td>0.001</td>
<td>0.002</td>
<td>2.560E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>0.009</td>
<td>0.001</td>
<td>0.004</td>
<td>0.016</td>
</tr>
<tr>
<td>Mean (BR)</td>
<td>0.238</td>
<td>0.260</td>
<td>0.313</td>
<td>0.312</td>
<td>0.355</td>
<td>0.334</td>
<td>0.274</td>
<td>0.269</td>
<td>0.371</td>
<td>0.428</td>
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<tr>
<td>$\sigma$ (BR)</td>
<td>5.015E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>5.956E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>0.020</td>
<td>0.002</td>
<td>0.012</td>
<td>0.020</td>
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<tr>
<td>Mean (MC)</td>
<td>0.236</td>
<td>0.259</td>
<td>0.312</td>
<td>0.310</td>
<td>0.354</td>
<td>0.332</td>
<td>0.268</td>
<td>0.265</td>
<td>0.360</td>
<td>0.426</td>
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<tr>
<td>$\sigma$ (MC)</td>
<td>4.592E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>4.518E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>0.015</td>
<td>0.001</td>
<td>0.010</td>
<td>0.007</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.013</td>
<td>-0.012</td>
<td>-0.009</td>
<td>-0.017</td>
<td>-0.014</td>
<td>-0.001</td>
<td>-0.013</td>
<td>-0.016</td>
<td>-0.036</td>
<td>-0.017</td>
</tr>
<tr>
<td>$\sigma$ (LF)</td>
<td>3.660E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>4.170E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>0.021</td>
<td>0.001</td>
<td>0.010</td>
<td>0.014</td>
</tr>
<tr>
<td>Mean (BR)</td>
<td>-0.013</td>
<td>-0.012</td>
<td>-0.009</td>
<td>-0.017</td>
<td>-0.014</td>
<td>-0.001</td>
<td>-0.013</td>
<td>-0.016</td>
<td>-0.036</td>
<td>-0.017</td>
</tr>
<tr>
<td>$\sigma$ (BR)</td>
<td>1.596E-04</td>
<td>0.001</td>
<td>0.002</td>
<td>1.808E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>0.006</td>
<td>3.873E-04</td>
<td>0.002</td>
<td>0.018</td>
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<tr>
<td>Mean (MC)</td>
<td>-0.012</td>
<td>-0.011</td>
<td>-0.007</td>
<td>-0.031</td>
<td>-0.012</td>
<td>0.001</td>
<td>-0.012</td>
<td>-0.015</td>
<td>-0.034</td>
<td>-0.015</td>
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<tr>
<td>$\sigma$ (MC)</td>
<td>1.889E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>1.897E-04</td>
<td>0.001</td>
<td>0.001</td>
<td>0.004</td>
<td>3.619E-04</td>
<td>0.003</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Comparison with other results

1. Consistent in 3-8um, flat
2. Smaller than others
3. Agree with $R_V=5.5$ (WD01)
Variation or not?
Universality of the Near-IR Extinction Law

- \( E(J - H)/E(J - K_S) = 0.652 \)
- If a star have \( E(J - K_S) = 0.3 \)
  - \( [E(J - H)/E(J - K_S)]_{err} = 0.38 \)
- If a star have \( E(J - K_S) = 3 \)
  - \( [E(J - H)/E(J - K_S)]_{err} = 0.038 \)
- At \( E(J - K_S) = 0.1 \)
  - the error reaches 1.14
- The dispersion can be fully explained by the error
- Pearson correlation coefficient of 0.03
No apparent variation in the mid-IR with the extinction depth $A_{K_S}$. 
Error Analysis

• Bootstrap resampling test
  – Introduced by Efron (1979)
  – Generates a large number of datasets, each with N data points randomly drawn from the original data.
  – 20000 times Bootstrap for each pair of color excess

• Monte-Carlo simulation
  – To investigate the influence of photometric error
  – A sample is selected within the photometric error of each source
  – 20000 times for each band.
The slope distribution of 20000 times Bootstrap resample test of $E(K_s-9)/E(J-K_s)$. The red line indicates the linear fitting result.
The slope $E(K_S-\lambda)/E(J-K_S)$

<table>
<thead>
<tr>
<th></th>
<th>W1</th>
<th>W2</th>
<th>[8.0]</th>
<th>[9]</th>
<th>W3</th>
<th>W4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.4μm</td>
<td>4.6μm</td>
<td>8.0μm</td>
<td>9μm</td>
<td>12μm</td>
<td>22μm</td>
</tr>
<tr>
<td>$E(K_S-\lambda)/E(J-K_S)$</td>
<td>0.240</td>
<td>0.313</td>
<td>0.335</td>
<td>0.271</td>
<td>0.277</td>
<td>0.388</td>
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<tr>
<td>Bootstrap Mean</td>
<td>0.240</td>
<td>0.313</td>
<td>0.335</td>
<td>0.272</td>
<td>0.270</td>
<td>0.371</td>
</tr>
<tr>
<td>Bootstrap σ</td>
<td>5.253E-04</td>
<td>5.929E-04</td>
<td>0.001</td>
<td>0.021</td>
<td>0.002</td>
<td>0.012</td>
</tr>
<tr>
<td>Monte-Carlo Mean</td>
<td>0.238</td>
<td>0.310</td>
<td>0.333</td>
<td>0.266</td>
<td>0.265</td>
<td>0.359</td>
</tr>
<tr>
<td>Monte-Carlo σ</td>
<td>4.580E-04</td>
<td>4.518E-04</td>
<td>0.001</td>
<td>0.013</td>
<td>0.001</td>
<td>0.010</td>
</tr>
<tr>
<td>Linear fitting σ</td>
<td>0.030</td>
<td>0.033</td>
<td>0.051</td>
<td>0.159</td>
<td>0.060</td>
<td>0.075</td>
</tr>
</tbody>
</table>
# The intercept

<table>
<thead>
<tr>
<th></th>
<th>W1</th>
<th>W2</th>
<th>[8.0]</th>
<th>[9]</th>
<th>W3</th>
<th>W4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.4μm</td>
<td>4.6μm</td>
<td>8.0μm</td>
<td>9μm</td>
<td>12μm</td>
<td>22μm</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.028</td>
<td>-0.031</td>
<td>-0.003</td>
<td>-0.019</td>
<td>-0.021</td>
<td>-0.040</td>
</tr>
<tr>
<td>Bootstrap Mean</td>
<td>-0.028</td>
<td>-0.031</td>
<td>-0.003</td>
<td>-0.019</td>
<td>-0.021</td>
<td>-0.038</td>
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<tr>
<td>Bootstrap σ</td>
<td>1.739E-04</td>
<td>1.897E-04</td>
<td>0.001</td>
<td>0.006</td>
<td>4.031E-04</td>
<td>0.002</td>
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<tr>
<td>Monte-Carlo Mean</td>
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<td>-0.031</td>
<td>-0.002</td>
<td>-0.017</td>
<td>-0.019</td>
<td>-0.036</td>
</tr>
<tr>
<td>Monte-Carlo σ</td>
<td>1.936E-04</td>
<td>1.897E-04</td>
<td>0.001</td>
<td>0.004</td>
<td>3.720E-04</td>
<td>0.003</td>
</tr>
<tr>
<td>Linear fitting σ</td>
<td>0.030</td>
<td>0.033</td>
<td>0.051</td>
<td>0.159</td>
<td>0.060</td>
<td>0.075</td>
</tr>
</tbody>
</table>
With error from MC simulation
Summary

• With the stellar parameters of G- and K-type giants from the APOGEE spectroscopic survey, we precisely determined the relative extinction in the 2MASS, AKARI, WISE and Spitzer/IRAC photometric bands, consistent with the $R_v=5.5$ curve except in the W4 band.

• A quite complete mid-Infrared extinction Law of the MW is derived, with the extinction at 9μm, 12μm, and 22μm for the first time to characterize the silicate extinction profile.

• No apparent variation is found of the infrared extinction law.

• The relations between infrared intrinsic colors and $T_{\text{eff}}$ are derived for G- and K-type giants.
Dust modelling: very large grains

  Very large interstellar grains as evidenced by the mid-infrared extinction

• Wang, Li & Jiang 2015, MNRAS 454, 569
  The interstellar oxygen crisis, or where have all the oxygen atoms gone?

• Wang, Li & Jiang 2014, PSS 100, 32
  Modeling the infrared interstellar extinction
Post-Doctoral Position

• [https://jobregister.aas.org/node/53477](https://jobregister.aas.org/node/53477)
• Interstellar/Circumstellar Dust
• Deadline to Apply for Job: June 1, 2016
Merci Beaucoup