When Worlds Collide: Thermal Emission Spectra of Post-Giant-Impact Earths

Mark Marley
Kerri Cahoy
Kevin Zahnle
Bruce Fegley
Katharina Lodders
Laura Schaeffer

Tuesday, October 18, 2011
Collisions Rampant

- Final assembly of terrestrial planets: a series of giant impacts between planets
- Occurs over ~30–50 million years
- Earth’s Moon–forming impact is archetype
- Takes ~10 collisions between planets to make an Earth
- Surviving planet hot for a long time
Zahnle (2006)
THE DETECTABILITY OF EXTRASOLAR TERRESTRIAL AND GIANT PLANETS DURING THEIR LUMINOUS FINAL ACCRETION

S. ALAN STERN
Space Science Department, Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78238
Electronic mail: alana@swri.space.swri.edu
Received 1994 June 3; revised 1994 July 12

ON THE EMERGENT SPECTRA OF HOT PROTOPLANET COLLISION AFTERGLOWS

ELIZA MILLER-RICCI¹, MICHAEL R. MEYER², SARA SEAGER³, AND LINDA ELKINS-TANTON⁴
Self-luminous jovians

Terrestrial planets

Reflected-light jovians

H band contrast

TMT + coronagraph

GPI

H band contrast

0.01                              0.1                                       1.00

Radius (arcsec)

Nearby post-collision worlds

Self-luminous jovians

Reflected-light jovians

Terrestrial planets

“Nearby” means < 50 pc, e.g., Tucana-Horologium Assoc. (10-30 Myr)

original figure: GPI project
Chemistry of Molten Worlds
Assumed Elemental Composition

BSE = mantle + crust + ocean + atmosphere

<table>
<thead>
<tr>
<th>Element</th>
<th>Continental Crust (wt%)</th>
<th>Bulk Silicate Earth (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>47.20</td>
<td>44.42</td>
</tr>
<tr>
<td>Si</td>
<td>28.80</td>
<td>21.61</td>
</tr>
<tr>
<td>Al</td>
<td>7.96</td>
<td>2.12</td>
</tr>
<tr>
<td>Fe</td>
<td>4.32</td>
<td>6.27</td>
</tr>
<tr>
<td>Ca</td>
<td>3.85</td>
<td>2.46</td>
</tr>
<tr>
<td>Na</td>
<td>2.36</td>
<td>0.29</td>
</tr>
<tr>
<td>Mg</td>
<td>2.20</td>
<td>22.01</td>
</tr>
<tr>
<td>K</td>
<td>2.14</td>
<td>0.02</td>
</tr>
<tr>
<td>Ti</td>
<td>0.401</td>
<td>0.12</td>
</tr>
<tr>
<td>P</td>
<td>0.076</td>
<td>0.008</td>
</tr>
<tr>
<td>Cr</td>
<td>0.013</td>
<td>0.29</td>
</tr>
<tr>
<td>Mn</td>
<td>0.072</td>
<td>0.11</td>
</tr>
<tr>
<td>H</td>
<td>0.045</td>
<td>0.006</td>
</tr>
<tr>
<td>C</td>
<td>0.199</td>
<td>0.006</td>
</tr>
<tr>
<td>N</td>
<td>0.006</td>
<td>0.88x10^-4</td>
</tr>
<tr>
<td>S</td>
<td>0.070</td>
<td>0.027</td>
</tr>
<tr>
<td>F</td>
<td>0.053</td>
<td>0.002</td>
</tr>
<tr>
<td>Cl</td>
<td>0.047</td>
<td>0.004</td>
</tr>
</tbody>
</table>

TOTAL: 99.822 (Continental Crust) 99.776 (Bulk Silicate Earth)

1 Wedepohl (1995). 2 Kargel & Lewis (1993). 3 Totals are less than 100% because Ni is not considered.

Lodders & Fegley (1997)
Atmospheric Composition

- Compute chemical equilibrium for each case at various pressures up to 100 bars
- Gibbs energy minimization by Fegley, Lodders, & Schaeffer
- 810 compounds
Continental Crust

Graph showing log mole fraction vs. Temperature (K) for various compounds such as H₂O, CO₂, N₂, HCl, SO₂, H₂, O₂, NaCl, KCl, NaF, KF, NaOH, KOH, Fe(OH)₂, CH₄, H₂O, and K.
absorption coef. (cm$^{-2}$)

1000 K, 1 bar

H$_2$O

Wavelength (µm)

Tuesday, October 18, 2011
Surface Pressure = 10 bar

Brightness Temperature

$T_{\text{brt}}$ (K)

$\lambda$ ($\mu$m)

90% H$_2$O case
Miller-Ricci et al.
Surface Pressure = 10 bar

Brightness Temperature

$T_{brt} (K)$

$\lambda (\mu m)$
Thermal Emission

- $\text{H}_2\text{O}$
- $\text{HCl}$
- $\text{CO}_2 + \text{H}_2\text{O}$
- $\text{CO}_2$
- $\text{HF} + \text{H}_2\text{O}$

Flux

$\lambda$ (\text{\mu m})

- 10 bar
- 100 bar

Tuesday, October 18, 2011
Cautionary Tale
Deep H$_2$O atmosphere 1 $M_{Earth}$
Center of habitable zone
Deep H$_2$O atmosphere
1 M$_{\text{Earth}}$
Center of habitable zone

$T_{\text{surf}} \sim 2000$ K
$10^4 \times$ fatal HF conc.
Conclusions

- Post-impact worlds are highly detectable
- Realistic cases somewhat less favorable than exploratory models by Miller–Ricci et al.
- HF & HCl are markers of $T_{\text{surf}} > 1000$ K.
- CH$_4$ is signature of BSE (Fe$^{2+}$ vs. Fe$^{3+}$)
- Remember....