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小行星族群热物理参数及分布特征研究

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小行星热物理是近年来小行星研究领域的一个重要环节, 随着红外观测技术的进步, 该领域的研究取得了长足发展. 小行星发出的热辐射取决于小行星的尺寸、形状、反照率、热惯量(Γ)、粗糙度等热物理参数. 研究小行星热物理特性的科学意义是多方面的, 比如能够帮助我们计算小行星的Yarkovsky效应和YORP (Yarkovsky-O'Keefe-Radzievskii-Paddackor)效应, 还能对小行星表面的表壤颗粒尺寸进行估算, 从而能更好地对小行星表面的物质成分特征进行研究. 另一方面, 研究小行星族群的热物理特性, 可进一步为研究小行星、小行星带乃至太阳系的形成和演化机制提供重要科学依据. 本文借助先进热物理模型(Advanced Thermophysical Model, ATPM), 结合相应的中红外观测资料计算了Vesta族群、Nysa-Polana族群、Pallas族群、Themis族群、近地小行星(341843) 2008 EV5、近地小行星(3200) Phaethon的热物理参数, 揭示了不同种类、不同族群的小行星之间热物理参数的差异和造成这些差异的原因, 以及相同族群中的小行星热物理参数的相似性, 并且基于这些差异和相似性对近地小行星和族群之间的联系及其轨道演化过程进行了讨论.

Vesta族群是由小行星(4) Vesta经历碰撞后产生的碎片形成的. 本文研究了该族群中的10颗小行星, 得到这10颗Vesta族群小行星的平均热惯量为42 $\mathrm{Jm^{-2}\cdot s^{-1/2}\cdot K^{-1}}$, 平均几何反照率大小0.328, 并发现与之对应的表面粗糙度普遍较低. 此外, 对已有的主带区域小行星几何反照率进行统计后, 发现Vesta族群小行星的几何反照率普遍偏大, 基于这些热物理参数, 我们进一步估算了这10颗小行星的表壤粒径尺寸范围在0.006–1.673 mm之间. Themis族群也是小行星带中重要的族群之一, 该族群小行星物质成分比较原始, 且成员中大部分可能都有水冰的存在, 对其成员小行星的热物理特性研究可为我们提供该族群母体小行星的内部信息. 我们借助WISE (Wide-field Infrared Survey Explorer)红外观测和ATPM对该族群中3颗体积较大的小行星(62) Erato、(171) Ophelia和(222) Lucia的热物理参数进行了计算, 发现3者之间的热参数大小非常接近, 从热物理的角度证明了这3颗小行星有可能是来自于同一个母体.

小行星(341843) 2008 EV5是一颗Aten型近地小行星(NEA), 光谱类型为C型, 具有潜在撞击地球的危险, 该小行星曾是欧洲空间局(ESA)的小行星探测任务Marco-Polo-R的基准探测目标, 我们借助ATPM和WISE红外观测得到2008 EV5的热惯量$\Gamma = 110^{+30}_{-10}$ $\mathrm{Jm^{-2}\cdot s^{-1/2}\cdot K^{-1}}$, 几何反照率$p_{\mathrm{v}} = 0.095^{+0.016}_{-0.003}$, 有效直径$D_{\mathrm{eff}} = 431^{+6}_{-33}$ m. 由于其热惯量相对大多数近地小行星较小, 我们推测其可能来自主带区域, 并对其1000条克隆轨道进行了逆向积分1 Myr, 发现其来自主带区域的概率为6.1%, 同时估算了表壤粒径尺寸为0.58–1.3 mm. 研究表明, 2008 EV5有可能来自于Nysa-Polana族群, 我们对这个族群中的小行星(135) Hertha的热参数进行了计算, 得到该小行星的$\Gamma = 30^{+35}_{-21}$ $\mathrm{Jm^{-2}\cdot s^{-1/2}\cdot K^{-1}}$, $p_{\mathrm{v}} = 0.135^{+0.018}_{-0.034}$, $D_{\mathrm{eff}} = 82.863^{+12.937}_{-5.027}$ km.

小行星(3200) Phaethon是日本航空航天局探测器(Japan Aerospace Exploration Agency, JAXA) DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage

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Phaethon fLyby dUSt science)的探测目标, 其特殊的轨道形状(大偏心率、小近日点距离)导致在一个轨道周期内温度的变化幅度较大, 使之具有特殊的物理特性. 此外, 该小行星也是双子座流星雨的起源. 研究表明Phaethon起源于主带区域中的Pallas族群, 该族群是小行星带中B-type小行星的重要来源, 其成员数目不多, 但目前大部分的具有活动性的小行星均与Pallas族群相关. 本文中, 我们借助ATPM和WISE的红外观测得到Phaethon和Pallas族群小行星Zerlina的热惯量分别为: $\Gamma_{\rm Phaethon} = 550^{+920}_{-290}$ $\rm Jm^{-2}\cdot s^{-1/2}\cdot K^{-1}$, $\Gamma_{\rm Zerlina} = 0^{+34}_{-0}$ $\rm Jm^{-2}\cdot s^{-1/2}\cdot K^{-1}$, 几何反照率分别为: $p_{\rm v,Zerlina} = 0.1435^{+0.0420}_{-0.0325}$, $p_{\rm v,Phaethon} = 0.1253^{+0.0034}_{-0.0020}$, 热参数上的差异可能是由于Phaethon较强的活动性, 当Phaethon的轨道演化至当前位置时, 其较高的近日点温度会使表面的物质发生变化, 同时观测也表明Phaethon有质量流失现象, 使得Phaethon与Pallas族群其他小行星相比, 其表面特性发生改变, 从而热物理参数也随之改变.

Studies of Thermophysical Parameters and Distribution Characteristics of Asteroid Families Based on Infrared Observations

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The field of asteroid themophysical modeling is an important part in the study of asteroid. In recent years, with the development of infrared observation technology, this research field has experienced extraordinary growth. Thermal radiation emitted by an asteroid depends on thermophysical parameters such as the size, shape, albedo, thermal inertia, roughness, etc, of the asteroid. The scientific significance of studying the thermophysical properties of asteroids is multifaceted. For example, it can help us investigate asteroids' Yarkovsky effect and YORP (Yarkovsky-O' Keefe-Radzievskii-Paddackor) effect. Besides, thermal parameters are necessary to evaluate asteroid's regolith grain size which can help us better study the asteroid's surface compositional properties and provide important clues for investigating the evolution mechanisms of asteroid belt and even the solar system. In this work, by combining the Advanced Thermophysical Model (ATPM) and mid-infrared observations, we studied thermal properties of Vesta family asteroids, Nysa-Polana complex asteroid (135) Hertha , Pallas family asteroid (531) Zerlina, 3 Themis family members, near-Earth asteroid (3200) Phaethon and (341843) 2008 EV5. This work reveals the differences in thermal parameters between different asteroid families, as well as the similarities of the thermal parameters in the same asteroid family. The connections between NEAs (Near-Earth Asteroids) and asteroid families are also discussed.

Vesta family is the fragments of asteroid (4) Vesta after a catastrophic cratering event. In this work, we studied thermal parameters of 10 Vesta family members and obtained their mean thermal inertia of 42 $\rm Jm^{-2}\cdot s^{-1/2}\cdot K^{-1}$, mean geometric albedo of 0.328, and relatively low roughness. Comparing with the geometric albedos of other asteroids, the albedos of Vesta family members are relatively high. Furthermore, we evaluated the regolith grain sizes of these asteroids ranges from 0.006 to 1.673 mm. Themis family is also one of the most important asteroid families in which the material compositions of the family members are relatively primitive, and most members may have water ice. We derived thermal parameters

of 3 Themis family asteroids (62) Erato, (171) Ophelia and (222) Lucia by using WISE (Wide-field Infrared Survey Explorer) observations and ATPM. The values of the three asteroids' thermal parameters are very close, which may indicate that they come from the same parent body.

Asteroid (341843) 2008 EV5 is a C-type Aten asteroid , and is also a potentially hazardous asteroid (PHA). It is used to be the base-line target of ESA's Maro-Polo-R spacecraft. In this work, we obtained its thermal inertia of $\Gamma = 110^{+30}_{-10}$ Jm^{-2}·s$^{-1/2}$·K^{-1}, geometric albedo of $p_{\rm v} = 0.095^{+0.016}_{-0.003}$ and effective diameter $D_{\rm eff} = 431^{+6}_{-33}$ m by using ATPM and WISE observations. Since its thermal inertia is relatively small compared to other near-Earth asteroids, we thus inferred that it originates from the main belt region. We integrated 1000 clone orbits of 2008 EV5 for 1 Myr backwards, and we obtained a probability of 6.1% that this asteroid comes from the main belt. Previous studies showed that 2008 EV5 could come from the Nysa-Polana family, thus we also studied physical properties of this asteroid family (135) Hertha, and obtained its thermal parameters as follows, $\Gamma = 30^{+35}_{-21}$ Jm$^{-2}\cdot$s$^{-1/2}\cdot$K^{-1}, $p_{\rm v} = 0.135^{+0.018}_{-0.034}$, and $D_{\rm eff} = 82.863^{+12.937}_{-5.027}$ km.

Asteroid (3200) is the target of spacecraft DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage Phaethon fLyby dUSt science) of JAXA (Japan Aerospace Exploration Agency). Its special orbital shape (large eccentricity, small perihelion distance) leads to a large range of temperature difference, giving it special physical characteristics. Besides, Phaethon is also the origin of the Gemini meteor shower. Previous investigations showed that Phaethon may originate from the Pallas family. Although there are not many members of Pallas family, it is an important source of B-type asteroids in the main belt. In this work, we investigate the thermal properties of Pallas family asteroid (531) Zerlina and (3200) Phaethon together. We obtained the thermal inertia of these two asteroids are $\Gamma_{\rm Phaethon} = 550^{+920}_{-290}$ Jm$^{-2}\cdot$s$^{-1/2}\cdot$K^{-1} and $\Gamma_{\rm Zerlina} = 0^{+34}_{-0}$ Jm$^{-2}\cdot$s$^{-1/2}\cdot$K^{-1}, the geometric albedos are $p_{\rm v,Zerlina} = 0.1435^{+0.0420}_{-0.0325}$, $p_{\rm v,Phaethon} = 0.1253^{+0.0034}_{-0.0020}$, respectively. The differences in thermal parameters may be due to Phaethon's outburst activities. When Phaethon is near the perihelion, its high surface temperature will change the physical properties of the materials on the surface. Observations also showed that Phaethon has mass loss events, making it have different thermal properties from other Pallas family asteroids.