天 文 学 报
ACTA ASTRONOMICA SINICA

博士学位论文摘要选登

多目标太阳系外行星搜寻技术的研究

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搜寻太阳系外行星不仅具有十分重要的天文意义，而且与地外生命的探索紧密相连，关系到人类未来的发展. 高分辨率阶梯光栅光谱仪是视向速度法最常用的探测仪器之一，随着探测精度的提高，这种仪器要求更加苛刻的工作环境和更加高昂的研制费用. 1997 年, David J. Erskine 发明了一种视向速度法的改进技术 — 外部色散干涉技术 (EDI). 通过将固定延迟迈克尔逊干涉仪与中分辨率光谱仪组合使用，能够有效地提高视向速度的探测精度. 大口径大视场 LAMOST 望远镜配备有 16 台可切换到中分辨率模式 ($R = 5\mathrm{K} \sim 10\mathrm{K}$) 的低分辨率光纤光谱仪. 引入 EDI 技术，有望使 LAMOST 成为世界上最具有威力的多目标太阳系外行星搜寻系统之一.

对于国内的天文仪器研制领域, EDI 是一项全新技术, 2009 年完成的一项可行性实验验证了 EDI 技术的工作原理，并设计一个基于 LAMOST 的多目标太阳系外行星搜寻系统方案. 根据方案主要完成 3 项工作:

第一, EDI 工作原理的仿真，主要包括恒星光谱模型、干涉仪透过率模型、光谱仪调制模型和视向速度解算模型. 为了符合实际，模拟了时域和空域移相法的两种探测方式. 在干涉光谱的分析中，利用傅里叶变换算法分解干涉光谱，还原出更高分辨率的寻常光谱.

第二，基于 LAMOST 光谱仪的 EDI 样机研制和实验. 样机主要由 LAMOST 光谱仪和多目标干涉仪样机所组成. 采用诸如模块化、内 / 外部调节架等设计，减少仪器的中心遮拦和弧形狭缝造成的严重影响. 2010 年，样机在兴隆观测站与 LAMOST 进行了对接实验，获得多目标干涉光谱，并初步测试数据处理程序和仪器的稳定性.

第三，固定延迟迈克尔逊干涉仪的参数优化. 通过这项研究能够有效地提高干涉仪本身的热稳定性，有助于缓解仪器对外部环境的苛刻要求. 借鉴大视场迈克尔逊干涉仪在上层大气风场研究领域的应用，设计一个玻璃配对筛选方案来达到优化参数的目的. 现有方案通过选择合适的干涉臂参数能够将温度变化引起的视向速度误差控制在数百 $\mathrm{m\cdot s^{-1}\cdot {}^{\circ}C^{-1}}$.

开展 EDI 技术的仿真、样机的研制和干涉仪的参数优化等工作，为研制多目标太阳系外行星搜寻系统奠定理论基础并积累经验，能够使 LAMOST 为国际天文学做出更大的贡献.

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A Multi-object Exoplanet Detecting Technique

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Exoplanet exploration is not only a meaningful astronomical action, but also has a close relation with the extra-terrestrial life. High resolution echelle spectrograph is the key instrument for measuring stellar radial velocity (RV). But with higher precision, better environmental stability and higher cost are required. An improved technique of RV means invented by David J. Erskine in 1997, External Dispersed Interferometry (EDI), can increase the RV measuring precision by combining the moderate resolution spectrograph with a fixed-delay Michelson interferometer. LAMOST with large aperture and large field of view is equipped with 16 multi-object low resolution fiber spectrographs. And these spectrographs are capable to work in medium resolution mode ($R = 5\mathrm{K} \sim 10\mathrm{K}$). LAMOST will be one of the most powerful exoplanet detecting systems over the world by introducing EDI technique.

The EDI technique is a new technique for developing astronomical instrumentation in China. The operating theory of EDI was generally verified by a feasibility experiment done in 2009. And then a multi-object exoplanet survey system based on LAMOST spectrograph was proposed. According to this project, three important tasks have been done as follows:

Firstly, a simulation of EDI operating theory contains the stellar spectrum model, interferometer transmission model, spectrograph mediation model and RV solution model. In order to meet the practical situation, two detecting modes, temporal and spatial phase-stepping methods, are separately simulated. The interference spectrum is analyzed with Fourier transform algorithm and a higher resolution conventional spectrum is resolved.

Secondly, an EDI prototype is composed of a multi-object interferometer prototype and the LAMOST spectrograph. Some ideas are used in the design to reduce the effect of central obscuration, for example, modular structure and external/internal adjusting frames. Another feasibility experiment was done at Xinglong Station in 2010. A related spectrum reduction program and the instrumental stability were tested by obtaining some multi-object interference spectrum.

Thirdly, studying the parameter optimization of fixed-delay Michelson interferometer is helpful to increase its inner thermal stability and reduce the external environmental requirement. Referring to Wide-angle Michelson Interferometer successfully used in Upper Atmospheric Wind field, a glass pair selecting scheme is given. By choosing a suitable glass pair of interference arms, the RV error can be stable as several hundred $\mathrm{m{\cdot}s^{-1}{\cdot}{}^{\circ}C^{-1}}$.

Therefore, this work is helpful to deeply study EDI technique and speed up the development of multi-object exoplanet survey system. LAMOST will make a greater contribution to astronomy when the combination between its spectrographs and EDI technique comes true.