Progress on Multi-object Exoplanet Search Spectral Interferometer

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ABSTRACT

It's a very important point that fully open up power of Gou Shoujing telescope (LAMOST) in exoplanet detection field by developing a multi-exoplanet survey system. But it's an indisputable truth in the present astronomy that a traditional type of multi-object high resolution spectrograph is almost impossible to be developed. External Dispersed Interferometry is an effective way to improve the radial velocity measuring accuracy of medium resolution spectrograph. With the using of this technique, Multi-object Exoplanet Search Spectral Interferometer (MESSI) is an exploratory system with medium measuring accuracy based on LAMOST low resolution spectrograph works in medium-resolution mode (R=5,000 - 10,000). And it's believed that will bring some feasible way in the future development of multi-object medium/high resolution spectrograph. After prototype experiment in 2010, a complete configuration is under the development, including a multi-object fixed-delay Michelson interferometer, an iodine cell with multi-fiber optical coupling system and a multi-terminal switching system in an efficient fiber physical coupling way. By some effective improvement, the interferometer has smaller cross section and more stable interference component. Moreover, based on physical and optical fiber coupling technique, it's possible for the iodine cell and the switching system to simultaneously and identically coupling 25 pairs of fibers. In paper, all of the progress is given in detail.

Keywords: Exoplanet detection, External dispersed interferometry, Fixed-delay Michelson interferometer, Multi-fiber plugs, Iodine cell

1. INTRODUCTION

It's a very important point that fully open up power of Gou Shoujing telescope (original name is LAMOST) in exoplanet detection field by developing a multi-exoplanet survey system, especially which is based on the present instruments. LAMOST is an unparalleled survey telescope that feeds 16 multi-object low-resolution fiber spectrographs. When the spectrograph works in medium-resolution model, its resolution is about 5,000 – 10,000 [1]. Under these favorable conditions, it's hardly to stop the ideal pace that images a multi-object stellar radial velocity measuring function. But it's an indisputable truth in the present astronomy that a traditional type of multi-object high-resolution spectrograph is almost impossible to be developed. All of CCD detecting surface is usually covered by 2-D high-resolution spectrum of single object so that is hardly to accommodate more objects' spectrum. How does it balance between high-resolution and multi-object?

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Fortunately, it's worthwhile news that an exoplanet HD 102195b was confirmed and named as 'ET-1' in 2005 [2]. A related new technique, which is External Dispersed Interferometry (EDI) created by David Erskine [3], and its instrument Exoplanet Tracker (ET) attracted our attention very much. Its most advantage is that preciously measures stellar radial velocity by combining a fixed-delay Michelson interferometer with a medium-resolution spectrograph. A new interference spectrum introduces a big fixed optical delay to enhance measuring sensitivity of Doppler shift to some extent. Consequently, it's quite possible that CCD accommodates several objects' interference spectrums due to 1-D medium-resolution spectrum. For instance, W. M. Keck Exoplanet Tracker developed by Prof. Ge and his team at the University of Florida has been included as a part of the Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS) action in SDSS III program since 2008 [4].

A Multi-object Exoplanet Spectral Search interferometer (MESSI) (original name is Multi-object Exoplanet Survey System, MESS) is under development by collaboration between Nanjing Institute of Astronomical Optics and Technology (NIAOT) and National Astronomical Observatories of China (NAOC) [5]. In 2010, a prototype of three-object fixed-delay Michelson interferometer was tested with one of LAMOST Low-resolution spectrographs (in medium-resolution model) in Xinglong station. Problem of central obscuration and instrumental stability was exposed in this feasible experiment. And then some improved subsystems are developed in accordance with technical demand of an integrated system, including a new multi-object fixed-delay Michelson interferometer, a pair of multi-fiber coupling plugs and a multi-fiber iodine system based on optical coupling.

2. MESSI

It's well known that LAMOST is a complicated modern telescope with 4000 optical fibers, which directly links 16 spectrographs. When the new technique EDI is applied into the present instruments, some practical problem has to be faced. First of all, typical Schmidt system of spectrograph necessarily leads to serious central obscuration caused by CCD and fiber components. Even if external interferometer was incredibly small, optical loss should be hardly avoided. Second, pursuit of a feasible multi-terminal switching measure is necessary to alter between integrated system and original spectrograph quickly and efficiently. Meanwhile, it's also paid increasing attention with the expansion of optical fiber application. Finally, wavelength calibration in radial velocity measure demands corresponding assistant system, for example, iodine cell and ThAr calibration.

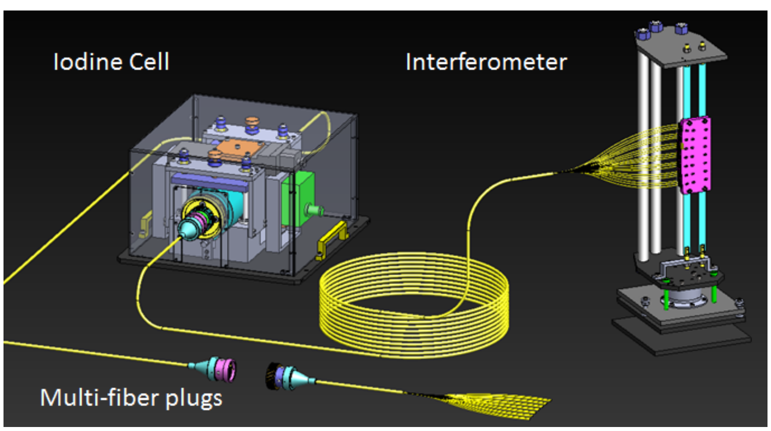

Fig. 1 3-D models of three subsystems

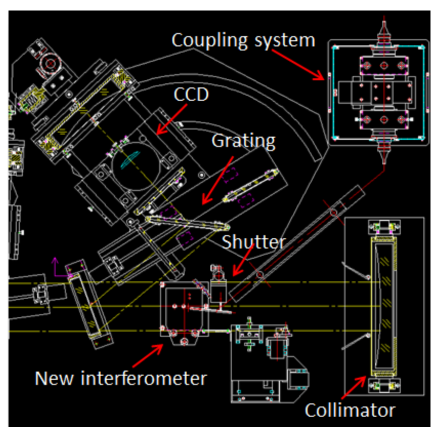

Fig. 2 Schematic diagram of MESSI

In MESSI designing process, the external interferometer is directly linked to spectrograph, and the other assistant subsystems are located at the outside of spectrograph. Moreover, three improving schemes are possibly worth of sharing here, as the following in general, Fig. (1):

- A new multi-object fixed-delay Michelson interferometer with a novel fold structure accommodates 21 stellar objects. The using of fold structure significantly results in a symmetric small cross section.
- With comparison between pros and cons, convenience is obviously more important even at a cost of efficiency loss. Multi-terminal switching system adopts scheme of a pair of multi-fiber coupling plugs, which is theoretically based on a physical coupling way.
- An iodine cell with multi-fiber optical coupling system is used to realize simultaneously multi-fiber optical coupling through iodine cell. It's undoubtedly difficult and costly in efficiency.

From the perspective of structural sequence, stellar light gathered by telescope firstly transmits to iodine cell by multi-fiber coupling plug, and then the infected stellar light finally transmits to spectrograph via interferometer, Fig. (2).

3. INTERFEROMETER

It's necessarily admitted that multi-object fixed-delay Michelson interferometer is key point and highlight in the whole designing process. A typical Michelson interferometer usually causes an asymmetric and big cross section, because input optical axis and output optical axis are perpendicular to each other in meridian plane. As described above, optical path of interferometer is easily folded by adding a reflective surface with 45 arcdeg in order to make cross section symmetric and as small as possible, as the following Fig. (3). As a result, area of its cross section reduces up to 45% in practice.

Moreover, a fixed interference component takes the place of an adjustable interference structure in order to keep Optical Path Difference (OPD) stable. Random vibration is possibly restrained to some extent by gluing two relevant interference arms. And thermal stability is also enhanced, when materials of two relevant interference arms are altered in accordant with certain demand of thermal compensation [6]. So it's generally composed of three prisms, including a rhombic prism, a wedge and a rectangular prism, Fig. (4).

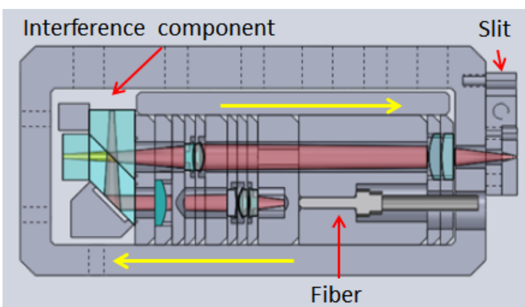

Fig. 3 Single module of interferometer

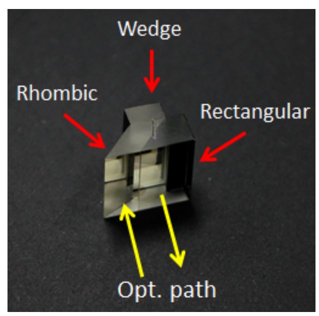

Fig. 4 Interference component

Besides of these, it's a feasible module scheme that each module with a removable slit accommodates 3 sub-interferometers and then integrates 7 modules together on an integrated plane. Likewise, an external suspended structure with five adjusting degree of freedom is used to fix the integrated interferometer into the spectrograph with negligible extra obscuration, as the following Fig. (5). For the sake of stability, an electronic shutter is independent from interferometer.

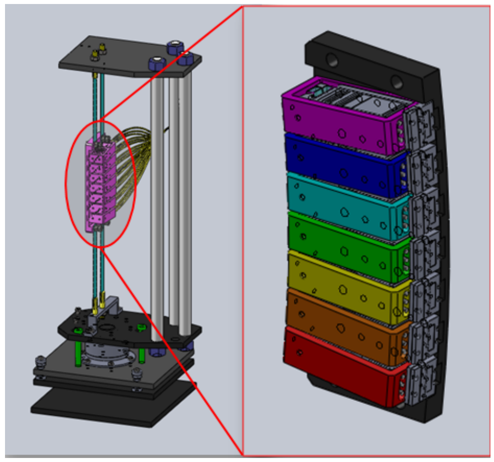

Fig. 5 Interferometer

4. MULTI-TERMINAL SWITCHING SYSTEM

With the expansion of fiber telescopes, it's a practical problem to solve that quickly and efficiently switches among several terminals. Independent instrument is usually in need of special fiber-link with telescope. Obviously, multi-fiber coupling means gradually becomes an inevitable trend in multi-terminal switching field. Although some kind of adapter with a small number of fibers has been prevalent in the field of optical communication, efficient multi-fiber adapter is still in the developing phase.

In MESSI project, a multi-terminal switching scheme, which contains a pair of multi-fiber plugs designed on the basic of physical coupling means, is adopted to realize alteration between original spectrograph and MESSI. Thereof, the pair of multi-fiber plugs are respectively an inserter and a receptor, so called are a male plug and a female plug, Fig. (6). Each plug accommodates 25 fibers. And fiber bunch from telescope is defined as 'Bus', which equips some identical receptors at its end; fiber bunch from different terminals is defined as 'Extension' in general, which equips identical inserters at their ends, as the following Fig. (7). According to the using demand, the inserter belongs to the needed terminal can quickly connect to the receptor belongs to telescope.

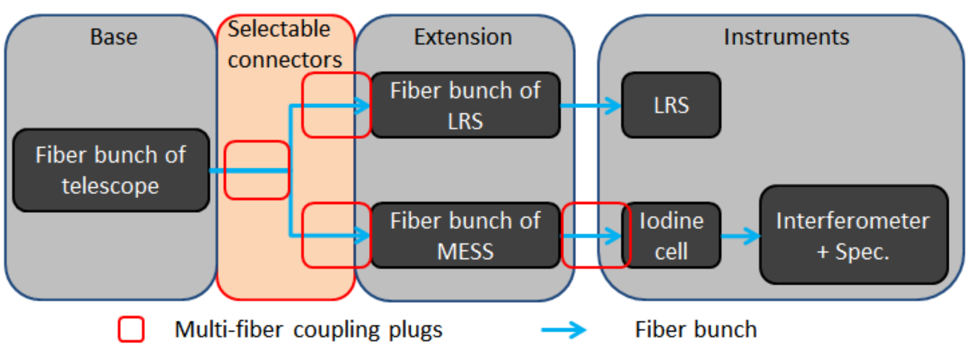

Fig. 6 Multi-terminal switching scheme

Fig.7 (left) Multi-fiber inserter; (Middle) Multi-fiber receptor; (Right) Socket

5. IODINE CELL

In MESSI, iodine cell is used as a wavelength calibrator, however, fiber-link and multi-object feature rise another question that how stellar light of different object simultaneously infected by iodine vapor. The answer to this question is a multi-fiber optical coupling system with 25 pairs of coupling fibers and a removable iodine cell. From the perspective of structure, it's a double-telecentric optical system, which is composed of two identical telecentric lenses, an iodine cell, an air cell and two inserters in general, as the following Fig. (8). At each end of lens, it equips a socket for the inserter in order to realize optical coupling. And according to observing steps, an electric translation stage is controlled in remote for alteration between iodine cell and air cell. From the perspective of structural sequence, it's an important hub between telescope and interferometer in MESSI.

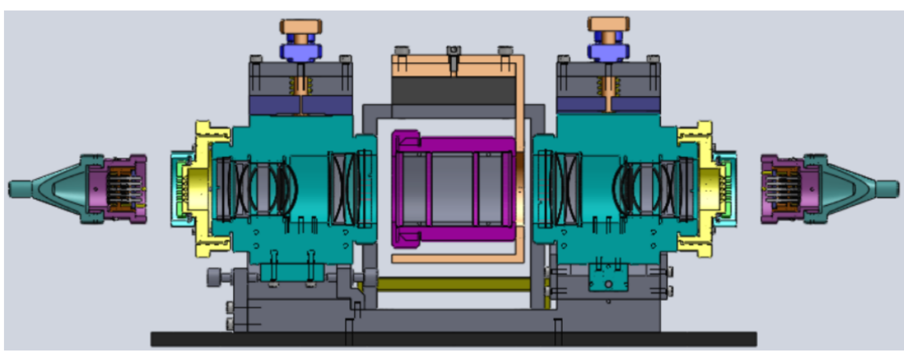

Fig.8 Model of iodine cell with a multi-fiber optical coupling system

6. CONCLUSIONS

It's undoubtedly an exciting try that applies EDI technique into the present LAMOST spectrograph. In the developing process, some practical instrumental condition brings extra technical difficulty and limit of performance besides of EDI own difficulty, for example, central obscuration and stability. Yet the difficult situation is possible changed because some subsystems are being developed for the integrated system, including a new multi-object fixed-delay Michelson interferometer, a pair of multi-fiber coupling plugs and a multi-fiber iodine system based on optical coupling. Even if the integrated system possibly gives an acceptable performance in test, it's always believed that there's still additional improvement in detail for further enhancement.

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