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(Review)

Physical Science Items of China's Human Space Project in Near Future

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Abstract

Human Space Project of China is going to the stage of space station construction. This stage involves a space laboratory which will be launched in near future, and the space station which will be constructed since 2018 and completed around 2022 or so, then operated on orbit for more than 10 years. This paper reviews the physical science items on board of china's space laboratory and cargo ship which will be docked with space laboratory. It is related with fundamental physics such as cold atom clock and quantum key distribution from space to the grand, microgravity fluid physics experiment, material science experiment in microgravity condition, astronomy, and earth observation for geophysical research. This paper also gives a brief introduction of the research fields and main research direction of physical science plan, as well as main research facility and experiment platform on board of China's space station.

Keyword(s): China's space station, Space laboratory, Item of physical science, Research field, Research facility, Experiment platform.

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1. Introduction

China's Human Space Project (CHSP) started in 1992. For utility mission of CHSP an organization named General Establishment of Space Science and Application (GESSA), Chinese academy of Sciences (CAS) was funded in 1993. Later GESSA extended his duty and change the name became the Technology and Engineering Center for Space Utilization (CSU) in 2011, CAS. Nowadays, CSU is responsible for space science activities of CHSP, such as strategy study and research planning, opportunity announcement, organizing of peer evaluation, item & project definition, mission management, system design and integration, ground segment development and operation, engineering reliability and assurance, science outlet and achievement distribution, popularization of science and engineering, etc.

Along with the roadmap of China's human space project, a space laboratory Tian Gong-2 (TG-2) will be launched in 2016 then docked with Shen Zhou-11 (SZ-11) manned spaceship and Tian Zhou-1 (TZ-1) cargo-ship in 2016-2017. China's Space Station (CSS) will be built up starting in 2018, and completed in 2022 or later.

TG-2 is first space laboratory of CHSP which is weights 8 tons class with 2-4 years of life time. The TZ-1 is weights 13 tons with cargo transportation capacity of 6 tons. They are run on a circle orbit with altitude of 350-450 km, declination of 42°. According to preliminary design the main part of CSS is a combination of 3 modules including one core module and two experimental modules. In addition there is an independent flight module for optical astronomy with same obit. It could be easy to perform rendezvous and docking for maintenance & service if necessary. The weight of combination of CSS is more than 66 tons. The orbit parameters of CSS are as same as space laboratory, attitude with accuracy of 0.1° and attitude stabilization of 10^{-3}°/s, predicted microgravity level of 10^{-3}g, effective payload weight of 15 tone with 12KW power supply, crew number of 3, communication of down link though relay satellite of 1.1Gbps with 90% global coverage. The life time of CSS will be more than 10 years.

A series of physical science mission will be carried out on TG-2, TZ-1 and CSS.

2. Physical Science mission on TG-2 and TZ-1

The research items on board of TG-2 and TZ-1 cargo ship are related with physical science in microgravity as well as astrophysics and geophysics. These experiments are focused on forefront fundamental questions in science nowadays. There are 3 experiments on the field of fundamental physics, 1 for astrophysics, 3 for fluid physics. Besides, there are 3 new generation remote sensors will be sent to orbit with TG-2 for global climate change and geophysics research, as well as wide application. The item's name and flight arrangement are listed on **Table 1**.

2.1 Cold Atom Clock Experiment in Space

The space-borne cold atom clock experiment could get benefit because of microgravity environment in which the temperature of cold atoms could be down to μK class by using

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Table 1 List of Physical Science Items on TG-2/TZ-1.

	Scientific Item
TG-2	Cold Atom Clock Experiment in Space
TG-2	Quantum Key Distribution experiment
TZ-1	Electrostatic Suspension Accelerometer Experiment
TG-2	Gamma-Ray Burst Polarimeter (POLAR)
TG-2	Thermo-capillary Convection in Liquid Bridge
TG-2	Multiple Sample Materials Processing
TZ-1	Two Phase Flow Experiment
TG-2	Multi-angle Polarization and Wide-band Spectral Imager
TG-2	Interferometry Imaging Radar Altimeter
TG-2	Multi-band Ultraviolet Limb Imager

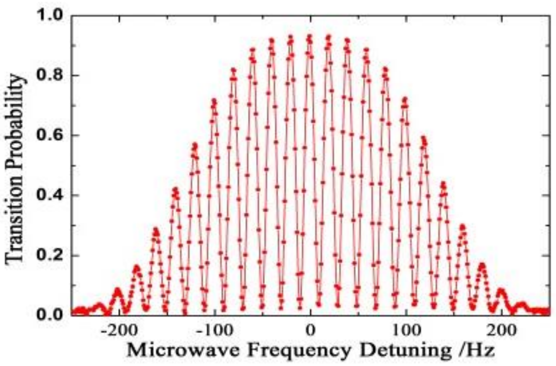

Fig. 1 Transition probability as a function of the microwave frequency around 87Rb on the ground.

laser cooling[1] and the cooled atoms interrogate with microwave in ultra-slow speed. In this experiment the Rubidium atoms are used on ultra-high vacuum condition[2]. The number of cold atom is more than 106, predicted line-width of Ramsey fringe in microgravity will be 0.1-0.2Hz. It leads to the frequency stability of clock say 10-16 order. The Ramsey curve of cold atom clock taken on the ground is show in **Fig. 1**.

2.2 Quantum Key Distribution Experiment

In this experiment the photons as quantum key will be sent from LRO to ground by using so called "Decoy State Method" in which the photons are modulated in polarization angular. The key technologies on the generation, distribution and distillation of quantum keys and the stabilization of optical channels[3, 4] will be demonstrated. The dynamic accuracy of on board ATP is better than 10 μrad. Raw quantum key rate will be 3 Kbps. Space to ground laser communication will also be implemented with bit rate of 1.6 Gbps.

2.3 Electrostatic Suspension Accelerometer Exp.

The final purpose of the electrostatic suspension

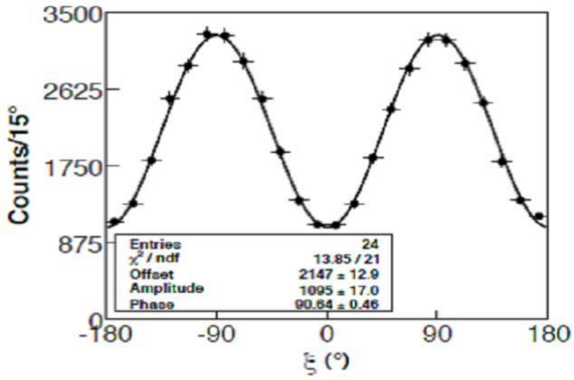

Fig. 2 Modulation curve measured with 100 % polarized hard X-ray beam at 200 KeV.

accelerometer experiment in TZ-1 is to explore potential "non-Newtonian force in 5-10 μm range" in microgravity[5]. The resolution of an electrostatic suspension accelerometer is better than $3\times10^{-10}m/s^2/Hz^{1/2}$ [6]. An active magneto-electric vibration attenuation device is developed and used for reducing mechanical disturbances for this experiment.

2.4 Gamma-Ray Burst Polarimeter (POLAR)

The Gamma-Ray Burst Polarimeter (POLAR), based on the Compton scattering principle, is a novel compact space-borne polarimeter conceived for a precise measurement of hard X-ray/Gamma-ray polarization and optimized for the detection of the prompt emission of Gamma-Ray Bursts (GRB) in the energy range of 50-500 keV [7]. The detailed measurement of the polarization of GRB will lead to a better understanding of the geometry of radiation region and emission mechanisms. Thanks to its large modulation factor, wide field of view (±70°×±70°) and large effective area, POLAR will be able to reach a minimum detectable polarization of less than 10 % for GRBs with a flux larger than 3×10^{-5} erg cm^{-2} and open a new window for high energy astronomy. This instrument was developed under an international collaboration of China, Switzerland and Poland. The calibration result of modulation factor of POLAR is shown in **Fig. 2**[8].

2.5 Thermo-capillary Convection in Liquid Bridge

The experiment is focused on thermo-capillary convection instability, turning and second turning, temperature oscillation, and there mechanism in liquid bridge with large Prandtl number [9,10]. The experimental facility consists of liquid bridge and pulling mechanism, liquid storage and injection unit, liquid bridge clearance unit, temperature controllers an acquisition unit, etc. The aspect ratio and volume ratio could be adjusted on a liquid bridge with 20 mm in diameter for space borne experiment.

2.6 Multiple Sample Materials Processing

A multiple sample materials processing furnace (MMPF) with double zone resistance heater provides opportunity for varied materials processing and formation mechanism study[11,12]. The

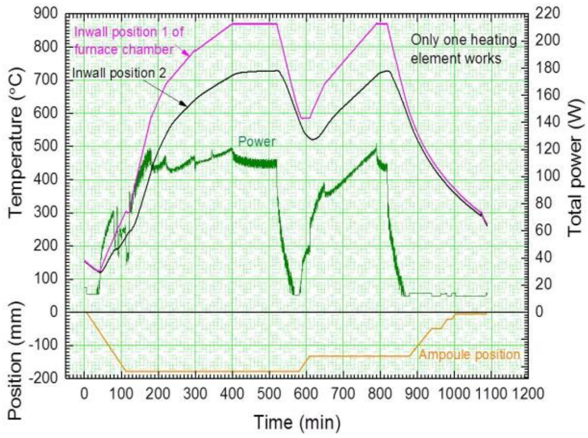

Fig. 3 A typical sample temperature and position plot.

sample candidates are involving semiconductor, optoelectronics materials, alloys and metastable materials, functional single-crystal, nano-materials and composites. The furnace is with ampoule number of 6 each batch, ampoule size of ∅16 mm × 260 mm, temperature range of 500-950 °C. Temperature profiles can be realized to meet various science requirements in stability of ±0.5 °C. The astronaut could operate loading and down loading material samples. A temperature control test example on the ground is shown in **Fig. 3.**

2.7 Two Phase Flow Experiment

A two phase flow experiment will investigate the phase change process of evaporation and condensate in two-phase fluid system, the phase-change interfacial hydrodynamic theory and thermal flow transport theory in microgravity. Some key technology related two-phase system rack on space station such as two-phase thermal control loop will be tested on-obit. It will deliver useful data for fluid management, two phase flow heat transfer with high efficiency on spacecraft, and industrial application on the ground[13]. The evolution of liquid film evaporation thermal patterns and heat flux measured at heating solid substrate on the ground[14] is shown in **Fig.4.**

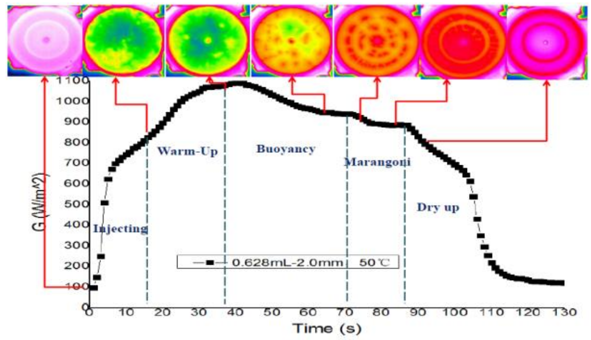

Fig.4 vaporation thermal patterns and heat flux during the liquid film evaporation on the ground.

Fig. 5 Outdoor image in TIR band of spectral imager.

2.8 Multi-angle Polarization and Wide-band Spectral Imager

There are two major imagers composited. A wide band Imager with spectrum range of 0.4-10 μm (including VNIR, SWIR and LWIR), spectrum resolution of 5-10 nm (VNIR) , imaging resolution of 100 m (VNIR) -400 m (SWIR and LWIR), FOV of 42° and swath of 300 km. A multi-angle imager using super wide-angle optics and filter wheel technique achieves wide coverage of 87.6° (770 km), imaging resolution of 3 km, Number of multi-angle of 12 polarization observation capability. The tungsten halogen lamp, neophane glass, and black body are used for on-orbit spectrum and radiometric calibration in VNIR, SWIR and LWIR channel of wide-band imager respectively to issue application with quantitative determination. **Fig. 5** shows a image of TIR band on the ground.

2.9 Interferometry Imaging Radar Altimeter (InIRA) [15,16]

A new generation radar altimeter is developed to measure, in a wide swath, the sea surface height (SSH), the significant wave height (SWH) as well as the sea surface wind speed (SSWS). The principle of InIRA is to use high-accuracy capability of interferometric phase measurement owning to a small off-nadir observation geometry with short baseline and high coherent two-channel receiving, to accurately retrieve the three dimensional information of the target with the help of waveform tracking. To improve the azimuthal resolution, synthetic aperture processing is adopted. The main Parameters of InIRA is Swath of 30 km, Image resolution of 100×100 m, measurement accuracy of SSH of 10 cm, SWH of 10 cm or 10 %, SSWS of ±2 m/s. **Fig. 6** shows the interferometric phase of water surface measured by InIRA.

2.10 Multi-band Ultraviolet Limb Imager

This instrument will obtain ultraviolet and wider bandwidth spectrum emitted from earth atmosphere by Limb observation. There are two Limb spectrum Imagers. An ring form imager (RI) is with field of view of 360° (138.0° ~147.2°), and 3

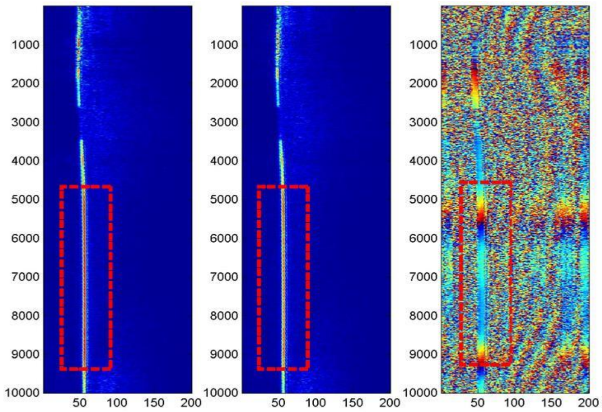

Fig. 6 Phase interferometry data of InIRA.

spectrum channel of 265 nm (±10 nm), 295 nm (±10 nm), 360 nm (±20 nm). The geometric resolution is 4 km. Another front view limb imager (FI) is to observe along with flight direction of spacecraft. It is with field of view of 0.05×3.3°, geometric resolution of 4 km, bandwidth from 280 nm to 1000 nm, spectrum resolution of 1.8 nm @ 290 nm. The ultraviolet limb imager could take data acquisition of 3D dynamic distribution of air density, ozone, aerosol, etc. in earth atmosphere. And it will promote understanding the relation of solar activity and atmosphere process [17,18)].

All flight models of instrument on TG-2 are ready for launch. The engineering models on TZ-1 are already completed.

3. Physical Science Plan of China's Space Station

3.1 Research Fields and Major Directions

Based on "science and requirement driven" and "bottom-up" approach, and procedure of AO, proposal and peer evaluation, the approved science and application plan on China's space station has been defined as 8 research fields, and several major research directions in each field respectively. There are 5 physical science related fields involving microgravity fluid physics and combustion, material science, fundamental physics in microgravity and astrophysics. Besides, we have another research fields that is space life sciences and biotechnology, earth science on space, space physics and environment, and new technology testing for space application.

The field of microgravity fluid physics and combustion focuses on the special laws of hydrodynamics in microgravity, physical and chemical process of combustion in microgravity to promote the understanding of mechanism and its application in industry, to improve the ground combustion efficiency and fire safety of space mission even on the ground. The emphases are the complex fluids, evaporation/condensation and two-phase transfer system, fluid dynamics, combustion dynamics of solid and liquid droplets and combustion prevention.

The purpose of material science research in space is to get new knowledge of materials processing in microgravity and improve materials synthesis and processing on the ground, and to create new materials with high performance. The main research direction is formation dynamics of materials in microgravity, thermo-physical properties measurement, new and high performance materials processing, service behavior research of materials in space.

Fundamental physics in microgravity is a developing aria in space science. We have arranged a series of high precise experiment to examine the existing physical theories, and try to discover new phenomena and new laws in fundamental physics. The major experiments are extra-cold atom and new physical state of matter, high-precision time-frequency system and related physics, quantum physics in space, relativity and equivalence principle demonstration. There are two equivalence principle experiment proposals in which one is to use two concentric spinning masses with different momenta, another is by using cold atom interferometer.

For astronomy and astrophysics research on China's space station, we are taking great effort to promote the observing capability to understand the nature of universe expansion acceleration and dark energy, to check the cosmological model and gravitational theory, and to investigate the formation and structure of galaxy & galaxy cluster, black hole, quasi-stellar, etc. The main mission we will carry out involving multi-band photometry and all sky spectrum survey, dark matter and high energy cosmic ray detecting, all sky X-ray survey, solar high energy emission observation, and extreme physics exploration to neutron star.

3.2 Research Facilities

For promoting science outputs by CSS, some backbone research facility is planned and implementing.

An optical astronomical facility to all sky multi-band photometry and spectrum survey with 3 mirror optical system is under developing. The optical astronomy spacecraft as an independent module of CSS is designing. The main mirror of this facility is 2 m to arrive angular resolution of 0.15″ in visual band and effective field of view of 1.5°. Systematic pointing accuracy will be 0.05″ (300S pointing period). It also could carry out observation on sub-millimeter band. The optical facility could dock with combination of CSS for maintenance and may promotion.

A cosmic radiation and dark matter facility is under argumentation. The concept design is focus on higher sensitivity, wider energy range and higher energy resolution. It is expected to detect high energy cosmic rays with energy range of GeV-PeV (for nucleon), and MeV-10 TeV (for γ-ray and electron), energy resolution of 1.0 % @ 100 GeV, and geometric factor of more than 5 m^2.sr, distinguish capacity of γ/p better than 1E-7, to understand origin, propagation of cosmic rays, and the innate character of dark matter.

3.3 Scientific Experiment Platforms

Total 11 experimental platforms with standard rack style are for physical scientific experiments. Another 3 are for life science and human medical science. They are installed in pressurized capsules respectively.

The Fluid Physics Rack is suitable for any transparence fluid system and complex fluid experiment. The Two-Phase System Rack is used for two-phase loop, phase change and heat transit experiment. Combustion Science Rack could operate with solid, liquid (droplet) and gas combustion. The complete diagnosis devices such as numerical holographic meter, high-speed CCD, thermal imager, skiametry, dynamic light scatter-meter, optical spectrum, rheometry, mass-spectrum, etc. are equipped.

There are two racks for material processing in space. The High Temperature Furnace Rack is used for melt formation, solidification experiment in ampoule packaged style. The maximum temperature of the finance will be 1600 °C with temperature field of gradient, isothermal, zone-melting. The X-ray and optical diagnosis devices are equipped. The core device of Container-Less Rack is a electrostatic levitator. The size of material sample will be 2 mm-5 mm, maximum temperature to sample heating will be 3000 °C or higher. It is to use for material under-cooling and thermo-physical properties measurement. Besides, there is an exposed equipment for functional material experiment in real outer space.

Total 4 racks are prepared for fundamental physics experiments. The Cold Atomic Physics Rack try to achieve quantum degenerate gas with temperature of 10^{-12} K order which is impossible implemented on the ground for potential novel phenomena investigation. A High-precision Time-Frequency Rack composed by hydrogen clock, cold atom clock, the new generation optical clock and microwave/laser link chain, with stability of 10^{-18} class, is to realize the fundamental physics measurement such as fine structure constant and gravitational redshift. A Quantum and Optical Transmission Rack is used for quantum operation, storage, relay and destitution experiment as well as laser communication experiment. Finally, a special rack, High Micro-gravity Level Rack by using quasi drag-free technology is developing for equivalence principle experiment and other precise requirement. The rack carries a capsule which could be moved out from rack and float in pressurized module to provide microgravity environment better than 10^{-6}g level.

The general-purpose racks also have been designed. The Gloves Box Rack serves closed/clean space for astronaut operation with hand and fine robotics, and provides low temperature store condition with 4 °C, -20 °C, and -80 °C. A Variable Gravity Rack could provide simulating gravity with 0.01 g-2 g by a centrifuge of 90 cm in diameter. A Working Bench Rack provides capacity of on-board assembly, maintenance, adjustment, operation for experiment devices with supporting robotic mechanism.

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References

1) Qiuzhi Qu, Bin Wang, Desheng Lu, Jianbo Zhao, Meifeng Ye, Wei Ren, Jingfeng Xiang and Liang Liu: Chin. Opt. Lett, **13**(6), (2015), 061405. doi:10.3788/COL201513.061405.
2) Wei Ren, Jingfeng Xiang, Yuantao Zhang, Bin Wang, Qiuzhi Qu, Jianbo Zhao, Meifeng Ye, Desheng Lü and Liang Liu: Vacuum **116** (6) (2015) 54. doi:10.1016/j.vacuum.2015.03.001.

3) J.-Y. Wang, B. Yang, S.-K. Liao, L. Zhang, Q. Shen, X.-F. Hu, J.-C. Wu, S.-J. Yang, H. Jiang, Y.-L. Tang, B. Zhong, H. Liang, W.-Y. Liu, Y.-H. Hu, Y.-M. Huang, B. Qi, J.-G. Ren, G.-S. Pan, J. Yin, J.-J. Jia, Y.-A. Chen, K. Chen, C.-Z. Peng and J.-W. Pan: Nature Photonics, **387** (2013) 7.

4) S. Nauerth, F. Moll, M. Rau, C. Fuchs, J. Horwath, S. Frick and H. Weinfurter: Nature Photonics, **382** (2013) 7.

5) Sheng-guo Guan, Liang-cheng Tu, Ze-Bing Zhou and Jun Luo: J. Jpn. Soc. Microgravity Appl. Special Issue: Sixth Japan/China Workshop on Microgravity Sciences, **24** (2007) 86.

6) H.B. Tu, Y.Z. Bai, Z.B. Zhou, L. Liu, L. Cai and J. Luo: Class Quantum. Grav, **27** (2010) 205016.

7) S. Orsi, D.Haas, W.Hajdas, V.Honkimaki, G.Lamanna, C.Lechanoine-Leluc, R.Marcinkowski, M. Pohl, N.Produit, D.Rapin, E.Suarez-Garcia, D.Rybka and J.-P.Vialle: Nuclear Instruments and Methods in Physics Research, A **648** (2011) 139.

8) H.L. Xiao, W. Hajdas, T.W. Bao, T. Batsch, T. Bernasconi, I. Cernuda, J.Y. Chai, Y.W. Dong, N. Gauvin, M. Kole, M.N. Kong, S.W. Kong, L. Li, J.T. Liu, X. Liu, R. Marcinkowski, S. Orsi, M. Pohl, N. Produit, D. Rapin, A. Rutczynska, D. Rybka, H.L. Shi, L.M. Song, J.C. Sun, J. Szabelski, B.B. Wu, R.J. Wang, X. Wen, H.H. Xu, L. Zhang, L.Y. Zhang, S.N. Zhang, X.F. Zhang, Y.J. Zhang and A. Zwolinska : Calibration of Gamma-ray Burst Polarimeter POLAR, arXiv:1512.02784.

9) W.R. Hu and Z.M. Tang: Crystal Research and Technology, **38** (2003) 627.

10) P. Zhu, L. Duan and Q. Kang: Int. J. of Heat and Mass Transfer, **457** (2013) 57.

11) Y. Liu, F. Ai, C. Feng, Q. Yu and X. Tan: Space Technology, **124** (2006) 26.

12) Y. Liu, F. Ai, Y. Zhou, X. Pan and W. Jin: J. Jpn. Soc. Microgravity Appl., **23** (2007) 24.

13) Liu Qiusheng, Nie Yuxing, Feng Meifu and Hu Wenrui: Chin. J. Space Sci., **150** (Supp) (2006) 26.

14) X. Chen, Z-Q. Zhu, Q-S. Liu and X-W Wang: Microgravity Science and Technology, **27** (2015) 353.
DOI 10.1007/s12217-015 -9426-0).

15) Yunhua Zhang, Xiangkun Zhang, Xin Meng, Wei Luo, Zhixin Zhou and Jingshan Jiang: An Interferometric Imaging Altimeter Applied for both Ocean and Land Observation, IGARSS 2007, Barcelona, (2007) 3821.

16) Yunhua Zhang, Wenshuai Zhai, Xiang Gu, Xiaojin Shi and Xueyan Kang: 15th International Radar Symposium, Gdansk, Poland, (2014) 422.

17) Yu Xiangyang, Wang Shurong and Huang Yu: Lin Guangyu: Acta Optica Sinica., **32**(12) (2012) 1211004.

18) Xue Qingsheng, Lin Guanyu and Chen Wei: J. of Scientific Instrument, **33**(5) (2012) 1167. (in Chinese)