



Institute of Remote Sensing and Digital Earth
Chinese Academy of Sciences

Recent Advances in Chinese Spaceborne Hyperspectral Missions

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28-July-2015



OUTLINE



- **Introduction**
- **Review of current sensors in China**
- **Ongoing and future missions in China**
- **Pre-measure for upcoming missions**
- **Conclusions**

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Introduction

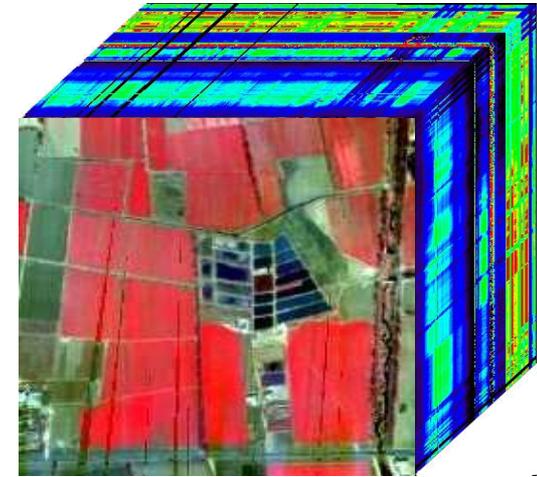


Conception of HRS

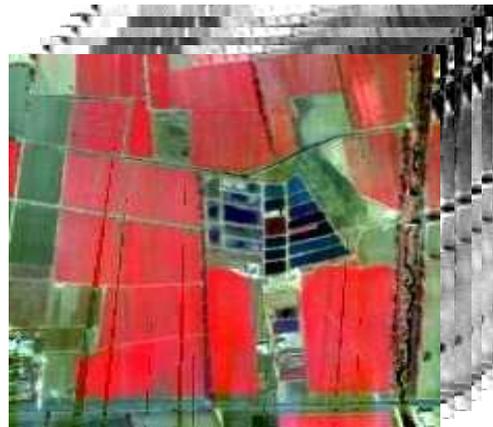


From Panchromatic to
Hyperspectral—Increasing
the Spectral Resolution

Hyperspectral



Multispectral



Color photography



When the spectral Resolution reached higher than $\lambda/100$ the Optical Remote Sensing can be Considered as **Hyperspectral Remote Sensing**

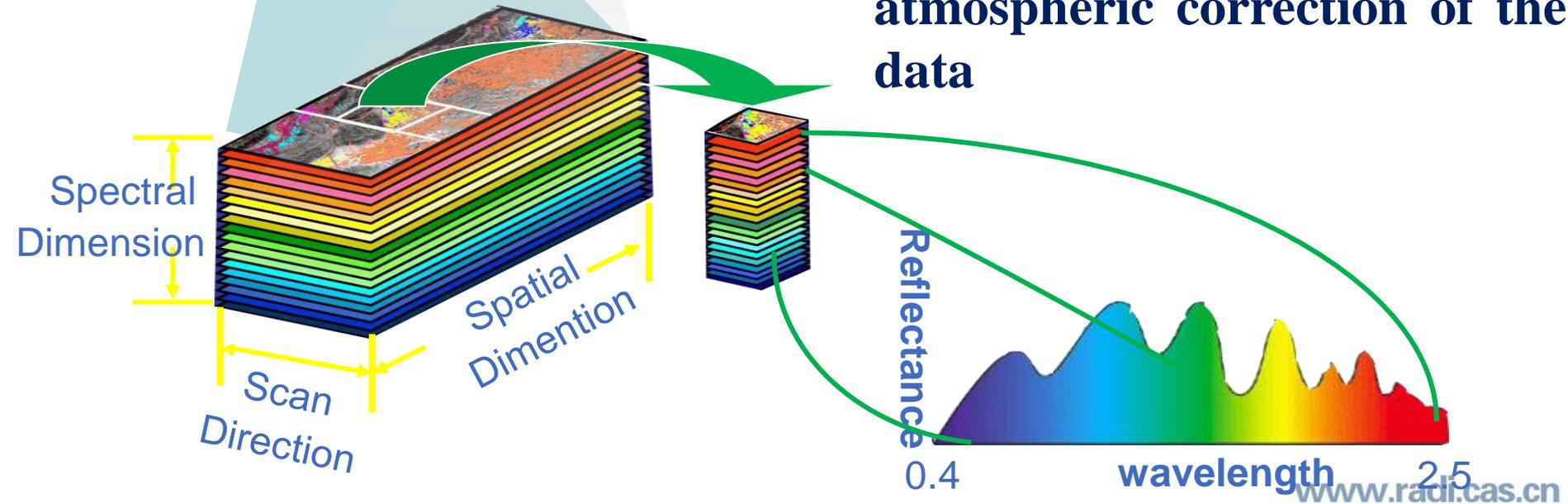
Introduction



Conception of HRS



- Each pixel or a group of pixels contains a unique continuous spectrum of the earth objects, which can be served as a signature for the identification of terrestrial materials after atmospheric correction of the data



Introduction



Progress of HRS

SCIENCE

7 JUNE 1985, Volume 228, Number 4704

Imaging Spectrometry for Earth Remote Sensing

Alexander F. H. Goetz, Gregg Vane
Jerry E. Solomon, Barrett N. Rock

Remote sensing of the earth's surface from aircraft and from spacecraft provides information not easily acquired by surface observations. Until recently, the main limitations of remote sensing were that no subsurface information could be acquired and that surface information lacked specificity (1). Orbital imaging radar can now provide subsurface data in

portions of the spectrum. In addition, we discuss several approaches to the analysis of the resulting hyperspectral image data sets. Hyperspectral refers to the multidimensional character of the spectral data set. In the past, data were acquired in four to seven spectral bands. Imaging spectrometry now makes possible the acquisition of data in hundreds of

Summary. Imaging spectrometry, a new technique for the remote sensing of the earth, is now technically feasible from aircraft and spacecraft. The initial results show that remote, direct identification of surface materials on a picture-element basis can be accomplished by proper sampling of absorption features in the reflectance spectrum. The airborne and spaceborne sensors are capable of acquiring images simultaneously in 100 to 200 contiguous spectral bands. The ability to acquire laboratory-like spectra remotely is a major advance in remote sensing capability. Concomitant advances in computer technology for the reduction and storage of such potentially massive data sets are at hand, and new analytic techniques are being developed to extract the full information content of the data. The emphasis on the deterministic approach to multispectral data analysis as opposed to the statistical approaches used in the past should stimulate the development of new digital image-processing methodologies.

arid regions (2), and recent work in high-spectral-resolution radiometry shows that mineral components in the surface, as well as vegetation stressed by metals in the substrate, can be identified (3). In this article we discuss early results of a

spectral bands simultaneously. Because of the specificity of the data acquired by imaging spectrometry, many more problems can now be addressed by this remote sensing technique. The value of the technique lies in its

thematic mapper (TM) is able to acquire only one data point in this wavelength region. Many surface materials, although not all, have diagnostic absorption features that are 20 to 40 nm wide at half the band depth (5). Therefore, spectral imaging systems, which acquire data in contiguous 10-nm-wide bands, can produce data with sufficient resolution for the direct identification of those materials with diagnostic spectral features. The Landsat scanners, which have bandwidths between 100 and 200 nm, cannot resolve these spectral features. Some important rock-forming minerals, such as quartz and feldspar, do not have any fundamental or overtone absorption features in the region from 0.4 to 2.5 μm and therefore cannot be detected directly. On the other hand, neither do these minerals mask the absorption features of the important minor minerals in rocks and soils. Similarly, mineral mixtures, and mixtures with vegetation in an individual pixel, can be separated if the components have unique spectral features.

Data Collection

Simultaneous imaging in many contiguous spectral bands requires a new approach to sensor design. Sensors such as the Landsat multispectral scanner (MSS) or TM are optomechanical systems in which discrete detector elements are scanned across the surface of the earth perpendicular to the flight path, and these detectors convert the reflected solar photons from each pixel in the scene into a sensible electronic signal (Fig. 2a). The detector elements are placed behind filters that pass broad portions of the spectrum. The MSS has four such sets of filters and detectors, whereas TM has seven. The primary limitation of this

Alexander F. H. Goetz, et.al. **SCIENCE**, 1985

7 JUNE 1985 2147

Remote Sensing of Environment 113 (2009) 55–516

Contents lists available at ScienceDirect

Remote Sensing of Environment

Journal homepage: www.elsevier.com/locate/rse

Three decades of hyperspectral remote sensing of the Earth: A personal view

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ARTICLE INFO

Article history:
Received 8 October 2006
Received in revised form 23 November 2007
Accepted 9 December 2007

Keywords:
Imaging spectrometry
Hyperspectral imaging
Spectroscopy
Earth observations
Remote sensing applications
Sensor development
Historical perspective

ABSTRACT

Imaging spectrometry, or hyperspectral imaging as it is now called, has had a long history of development and measured acceptance by the scientific community. The impetus for the development of imaging spectrometry came in the 1970's from field spectral measurements in support of Landsat-1 data analysis. Progress required developments in electronics, computing and software throughout the 1980's and into the 1990's before a larger segment of the Earth observation community would embrace the technique. The hardware development took place at NASA/JPL beginning with the Airborne Imaging Spectrometer (AIS) in 1983. The airborne visible/infrared imaging spectrometer (AVIRIS) followed in 1987 and has proved to this day to be the prime provider of high-quality hyperspectral data for the scientific community. Other critical elements for the exploitation of this data source have been software, primarily ENVI, and field spectrometers such as those produced by Analytical Spectral Devices Inc. In addition, atmospheric correction algorithms have made it possible to reduce sensor radiance to spectral reflectance, the quantity required in all remote sensing applications. The applications cover the gamut of disciplines in Earth observations of the land and water. The further exploitation of hyperspectral imaging on a global basis awaits the launch of a high performance imaging spectrometer and more researchers with sufficient resources to take advantage of the vast information content inherent in the data.

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1. Introduction

The term "hyperspectral imaging" was first coined in a paper discussing the early results of the technique of imaging spectrometry (Goetz et al., 1985). The term, it appears, made its way into the scientific vernacular in the late 1980's by way of the Department of Defense and intelligence communities as they became interested in this civilian sector-developed technique and required a catch phrase. The modifier "hyper" has a negative connotation, meaning too much, such as in hyperinflation or hyper-kinetic. However, it is, in fact, an apt description of the size of the spectral data set collected by the sensors, which makes solutions possible to problems over-determined in the mathematical sense. In other words, no single material requires hundreds of spectral bands spread over several octaves of the electromagnetic spectrum to be identified uniquely. However, when

Alexander F. H. Goetz. **RSE**, 2009

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doi:10.1016/j.rse.2007.12.014

70 IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 7, NO. 1, JANUARY 2014

Progress in Hyperspectral Remote Sensing Science and Technology in China Over the Past Three Decades

Qingxi Tong, Yongqi Xue, and Lifu Zhang, Member, IEEE

Abstract—This paper reviews progress in hyperspectral remote sensing (HRS) in China, focusing on the past three decades. China has made great achievements since starting in this promising field in the early 1980s. A series of advanced hyperspectral imaging systems ranging from ground to airborne and satellite platforms have been designed, built, and operated. These include the field imaging spectrometer system (FISS), the Modular Airborne Imaging Spectrometer (MAIS), and the Chang'E-1 Interferometer Spectrometer (IM). In addition to developing sensors, Chinese scientists have proposed various novel image processing techniques. Applications of hyperspectral imaging in China have been also performed including mineral exploration in the Qilian Mountains and oil exploration in Xinjiang province. To promote the development of HRS, many generic and professional software tools have been developed. These tools such as the Hyperspectral Image Processing and Analysis System (HIPAS) incorporate a number of special algorithms and features designed to take advantage of the wealth of information contained in HRS data, allowing them to meet the demands of both common users and researchers in the scientific community.

Index Terms—Hyperspectral remote sensing, imaging spectrometry, remote sensing technology, remote sensing application.

I. INTRODUCTION

HYPERSPECTRAL imaging, also known as imaging spectrometry or imaging spectroscopy, has become established as a critical technique for Earth observation since it was first proposed by A. F. H. Goetz in the 1980s [1]. Imaging spectroscopy began a revolution in remote sensing by combining traditional two-dimensional imaging remote sensing technology and spectroscopy [1]–[3], allowing for the synchronous acquisition of both images and spectra of objects. Hyperspectral images contain a wealth of geo- and radiometric information as well as abundance spectral information

for narrow spectral bands (typically about 10^{-2} \AA) from the ultraviolet and visible to shortwave infrared for each pixel. Hyperspectral remote sensing (HRS) has greatly improved our ability to qualitatively and quantitatively sense the Earth and outer space and has therefore attracted growing interest from researchers worldwide. HRS has been used successfully in various applications including agriculture, forestry monitoring, food security, natural resources surveying, vegetation observation, and geological mapping.

Hyperspectral data are obtained from ground, airborne, or spaceborne measurements, such as by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the EO-1 Hyperion (both launched by NASA). They generally consist of tens to hundreds of contiguous spectral bands with narrow bandwidths of typically about 10^{-2} \AA . The special characteristics of hyperspectral datasets make HRS of the Earth and outer space an appealing but challenging prospect. Much pioneering work in the HRS community has focused on developing new algorithms, models, and tools for data processing. These techniques greatly facilitate the understanding and quantitative analysis of HRS and have been employed in various applications, such as target detection [4], precise classification [5], and quantitative retrieval [6].

China, as one of the pioneers in HRS technology development, has made great achievements since the 1980s. To meet the increasing demand for fast and precise surveying and mapping of natural resources on a large scale, many outstanding hyperspectral sensors have been designed and launched in China (particularly on aircraft) with the support of various national major projects. Some of them, such as the Modular Airborne Imaging Spectrometer (MAIS), the Pushbroom Hyperspectral Imager (PHI), and the Operational Modular Imaging Spectrometer (OMIS-I and OMIS-II), played important roles in cooperative projects between China and the USA, France, Australia, Japan, and Malaysia during the 1990s. As a result, these sensors are well known worldwide and opened opportunities for

Q. Tong, Y. Xue and L. Zhang, **JSTARS**, 2014

Manuscript received August 29, 2012; revised November 20, 2012 and May 05, 2013; accepted June 02, 2013. Date of publication July 22, 2013; date of current version December 18, 2013. This work was supported by the National

1939-1404 © 2013 IEEE

First paper of HRS

Three decades of HRS Three decades of HRS in China

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Review of current sensors in China



Overview

Spaceborne Hyperspectral Imaging Sensor

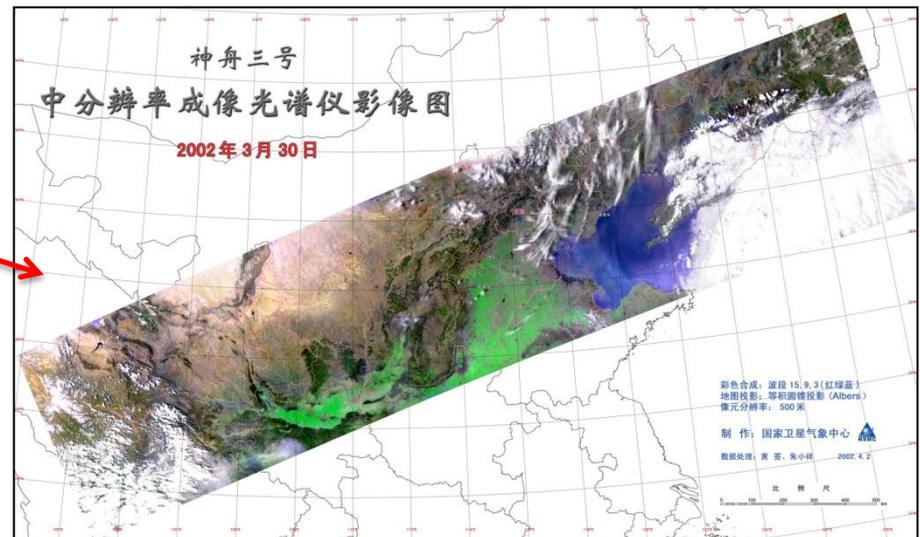
Sensor	Spectral Coverage / μm	Spectral Res. /nm	No. of Bands	Available Date
CMODIS	0.4-12.5	20	34	2002
HJ-1A HSI	0.45-0.95	5	115	2008
FY-3 MERSI	0.44-0.89	50	5	2008
	0.39-1.04	20	12	
	1.62-2.15	50	2	
	10-12.5	2500	1	
Chang'E-1 IIM	0.48-0.96	15	32	2009
TG-1 HSI	0.40-1.0	10	128	2011
	1.0-2.5	23		

Review of current sensors in China



CMODIS: first satellite hyperspectral imager

- No. bands: 34, Include:
- Visible: 20 (20nm, from 412 nm)
- NIR: 10 (20nm, from 822 nm)
- SWIR: 1 (2.150-2.250 μm)
- TIR: 3
(8.40-8.90, 10.30-11.30 μm , 11.50-12.50 μm)



A typical CMODIS image

Review of current sensors in China



MERSI/ FY-3A

Launched in 2008



A global image mosaic from MERSI with natural color and resolution of 3 km

(Courtesy: Chaohua Dong *et al.*)

Spec.Range: 0.4-12.5um
Spatial Resolution: 0.25-1km
Quantization: 12 bit
Assembling two onboard calibration systems

Number of Bands: 20
Scanning range: $\pm 55.4^\circ$
Radiometric calibration Accu. <7%

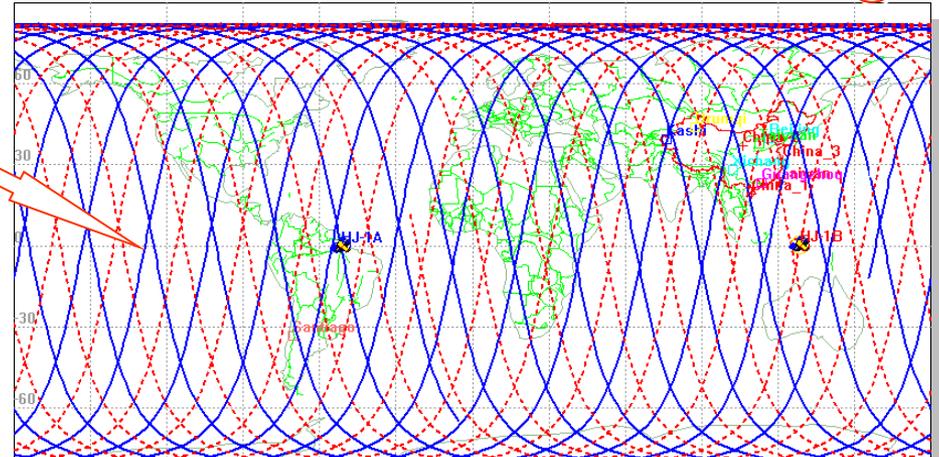
Review of current sensors in China



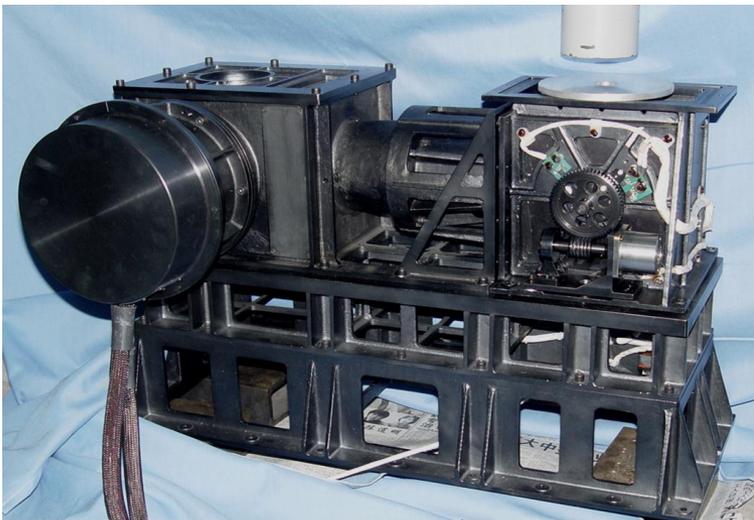
HJ-1A HSI



A Constellation of 2 Small Satellites (HJ-1) was launched in Sept. 6, 2008 for Environment and Disasters Monitoring



One of the Main Payloads on Board of the Satellite is a VIS-NIR Imaging Spectrometer (HSI)



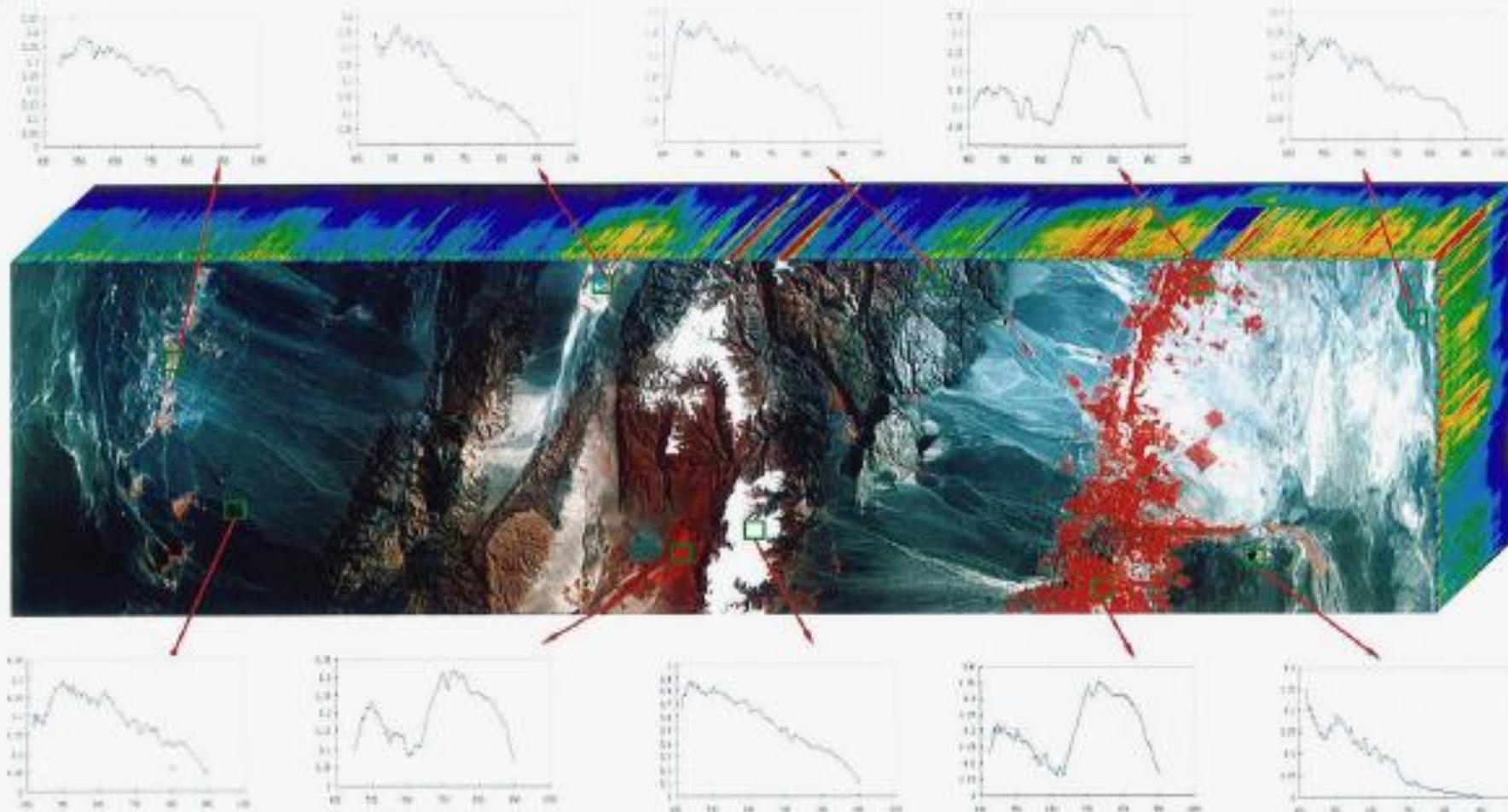
Spec.Range: 450nm-900nm
Number of Bands: 115
Spatial Resolution: 100m
Ground Coverage: 50km
Side Looking: $\pm 30^\circ$
Revisit: 4-31days

Review of current sensors in China



HJ-1A HSI

A typical Image Cube from HJ-1 Satellite



Review of current sensors in China



TG-1 HSI: China's first target vehicle



Hyperspectral sensor

Spectral Coverage /nm	400-2500
Spectral Res. /nm	10/23
No. of Bands	128
MTF	0.34
Swath/km	10
SNR	180@1600nm

Review of current sensors in China



TG-1 Image, South Australia

Review of current sensors in China

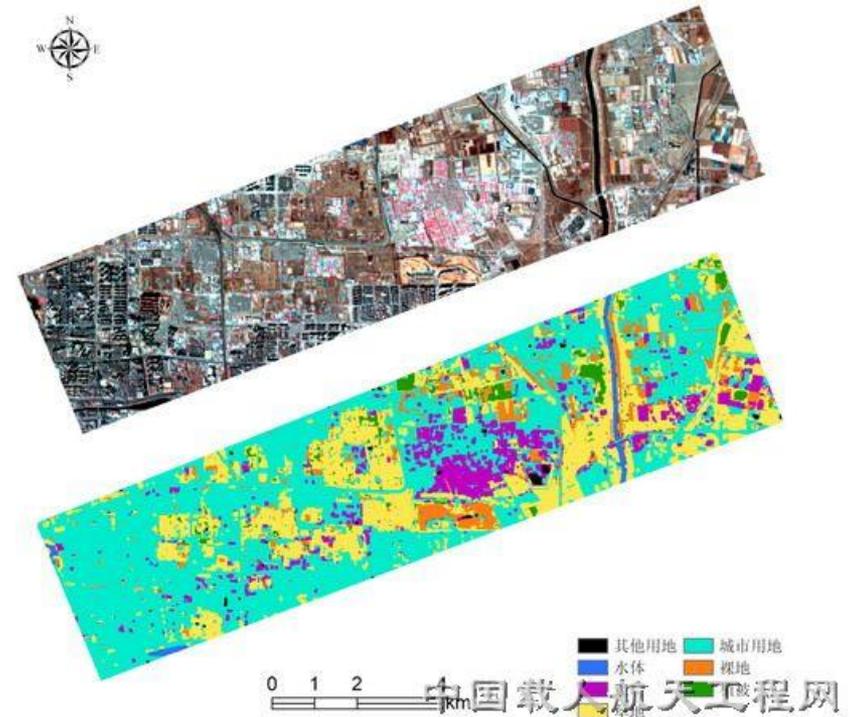


❏ TG-1 HSI: China's first target vehicle



Qinghai, China

- ❑ Numerous applications have indicated that the TG-1 HSI has achieved high performance levels in spatial, spectral, and SNR (Signal to Noise Ratio).



Land use monitoring, Beijing, China

(China Manned Space Engineering)

Review of current sensors in China

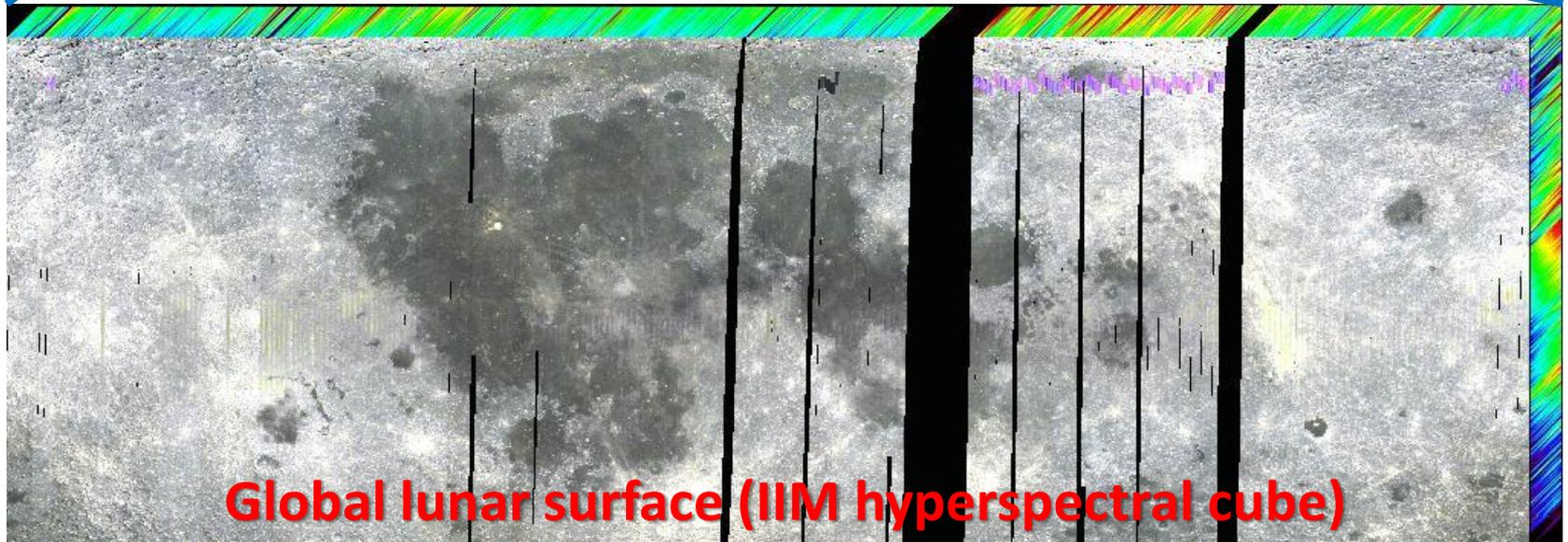


Chang'E-1 IIM: for Lunar exploration



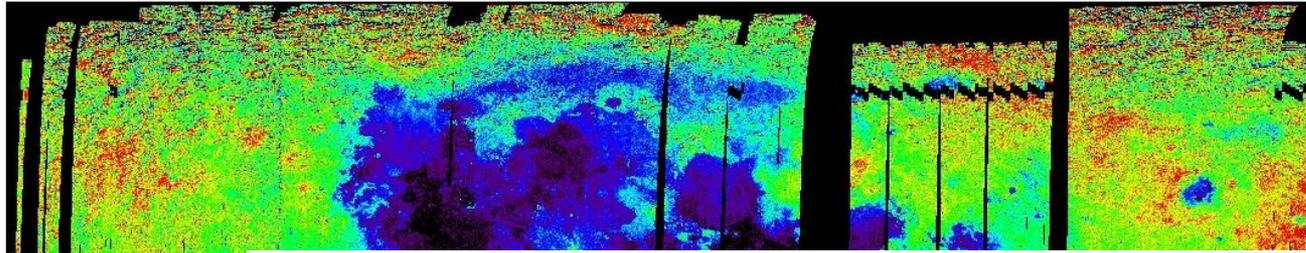
24-Oct-2007

Width of Swath	25.6km
Spatial Resolution	200m
Imaging Region	75° N~75° S
Spectral Range	480~960nm
Spectral Bands	32
Digitization	12bit
MTF	≥0.2

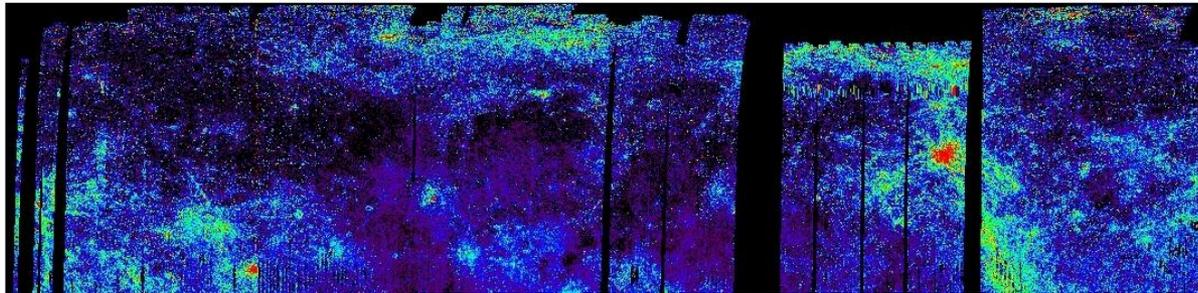


Global lunar surface (IIM hyperspectral cube)

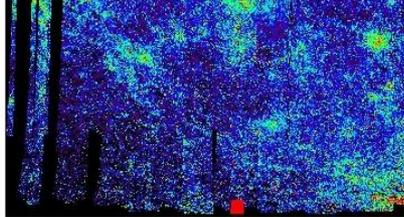
Abundance Analyses Map of Some Lunar Minerals



Plagioclase



Olivine

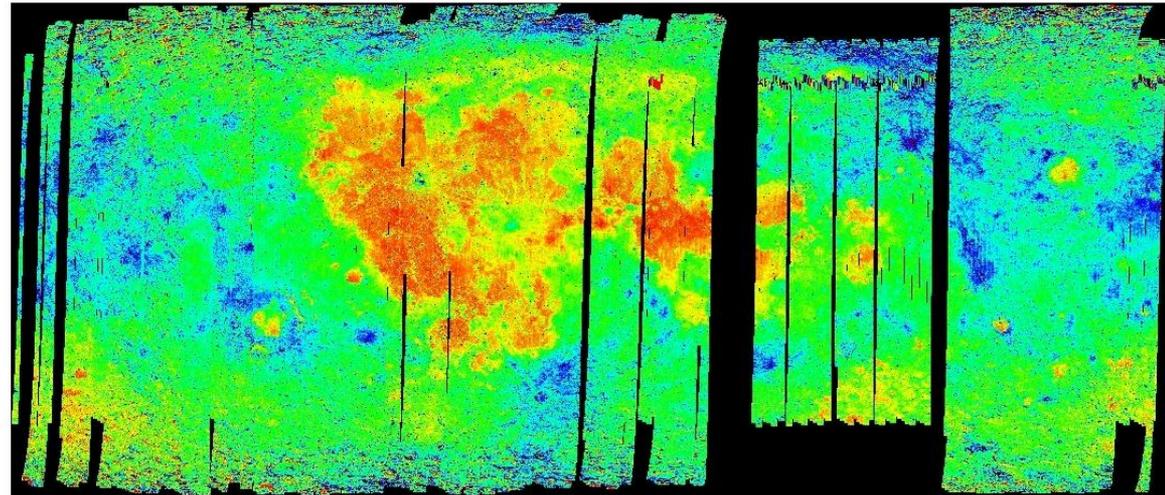


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Km



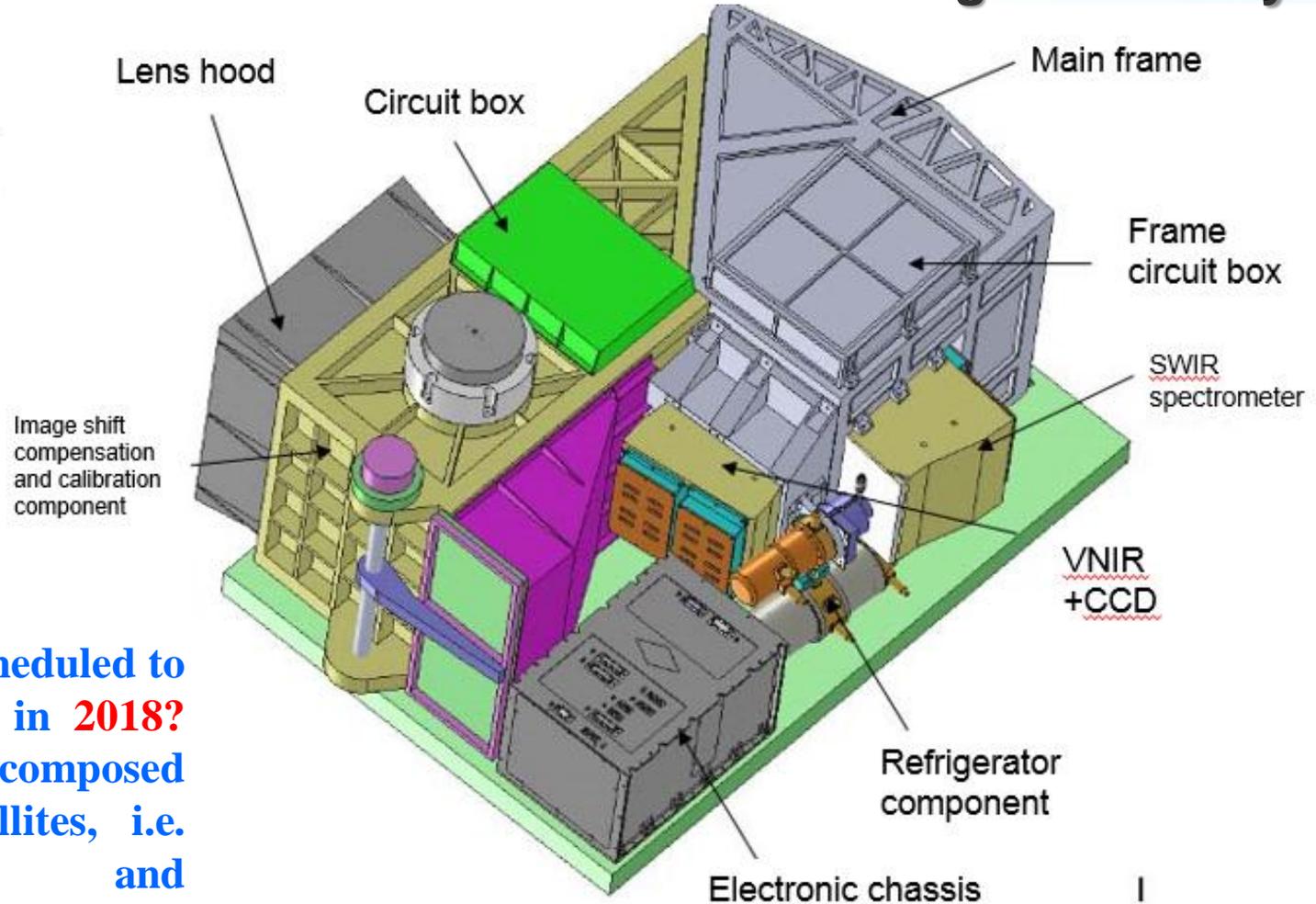
OUTLINE

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Ongoing & future missions in China



CCRSS: China Commercial Remote-sensing Satellite System



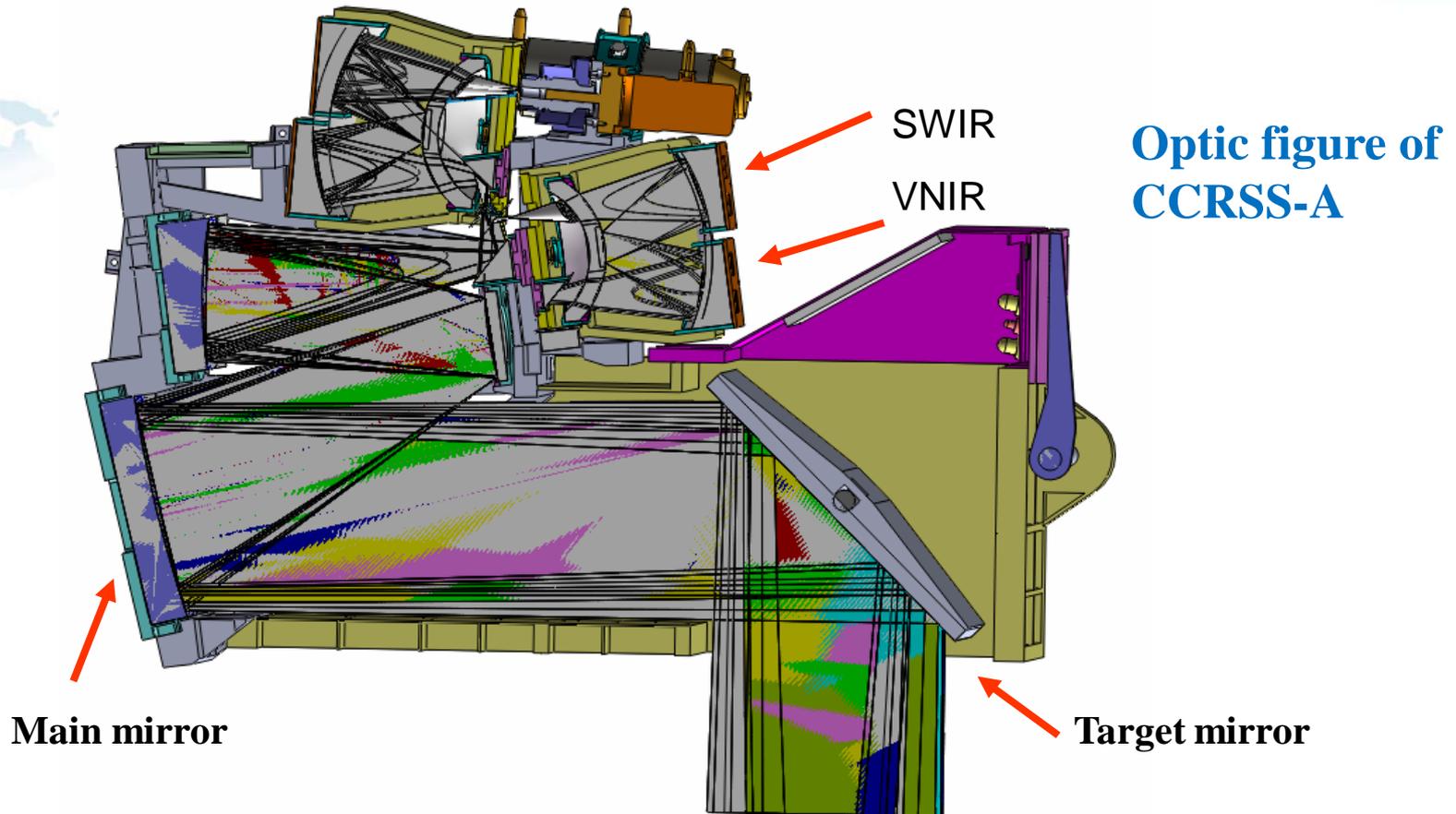
- CCRSS is scheduled to be launched in **2018?** (TBD). It is composed of two satellites, i.e. **CCRSS-A** and **CCRSS-B**.

Framework of CCRSS-A

Ongoing & future missions in China



■ CCRSS: China Commercial Remote-sensing Satellite System



■ CCRSS-A will provide commercially panchromatic/ multispectral imagery and hyperspectral imagery from visual to shortwave infrared.

Ongoing & future missions in China

CCRSS: China Commercial Remote-sensing Satellite System

Scheme & Para.	Scheme I	Scheme II	Scheme III	Scheme IV
	HRS	HRS+ Thermal infrared	HRS	HRS+ Thermal infrared
Spec. range	0.4-2.5 μ m	0.4-2.5 μ m 8.0-12.5 μ m	0.4-2.5 μ m	0.4-2.5 μ m 8.0-12.5 μ m
No. bands	328	328+2~5	328	328+2~5
Swath	40km	30 km	30 km	30 km
Spatial Res.	30m	30/60m	15m	15/30
Aperture	180mm	135mm	300mm	300mm
Volume	1020*980*550mm	1150*1000*500mm	1600*1100*800mm	1600*1200*700mm
Weight	147kg	187 kg	260 kg	300 kg
Power	260W	360 W	300 W	400 W
Budget	170 million	220 million	180 million	230 million
Period	2.5 years	3.5 years	2.5 years	3.5 years

Ongoing & future missions in China

GF-series: high-resolution satellite program

GF-3 (2016)
■ CSAR

GF-4 (2015)
■ 50m-geostationary

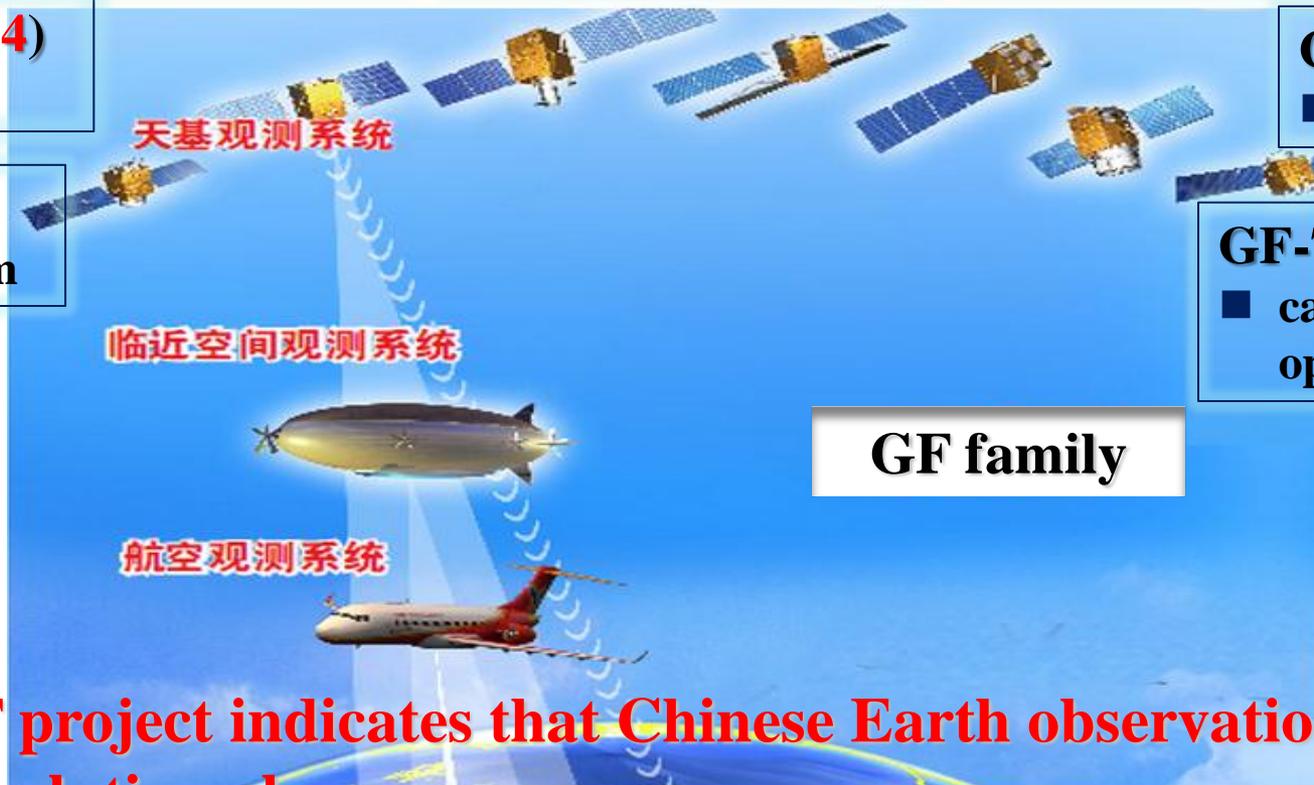
GF-5 (2016)
■ HRS

GF-2 (2014)
■ 1m/4m

GF-6 (2017)
■ Like GF-1

GF-1 (2013)
■ 2m/8m/16m

GF-7 (2018)
■ cartographic optical satellite

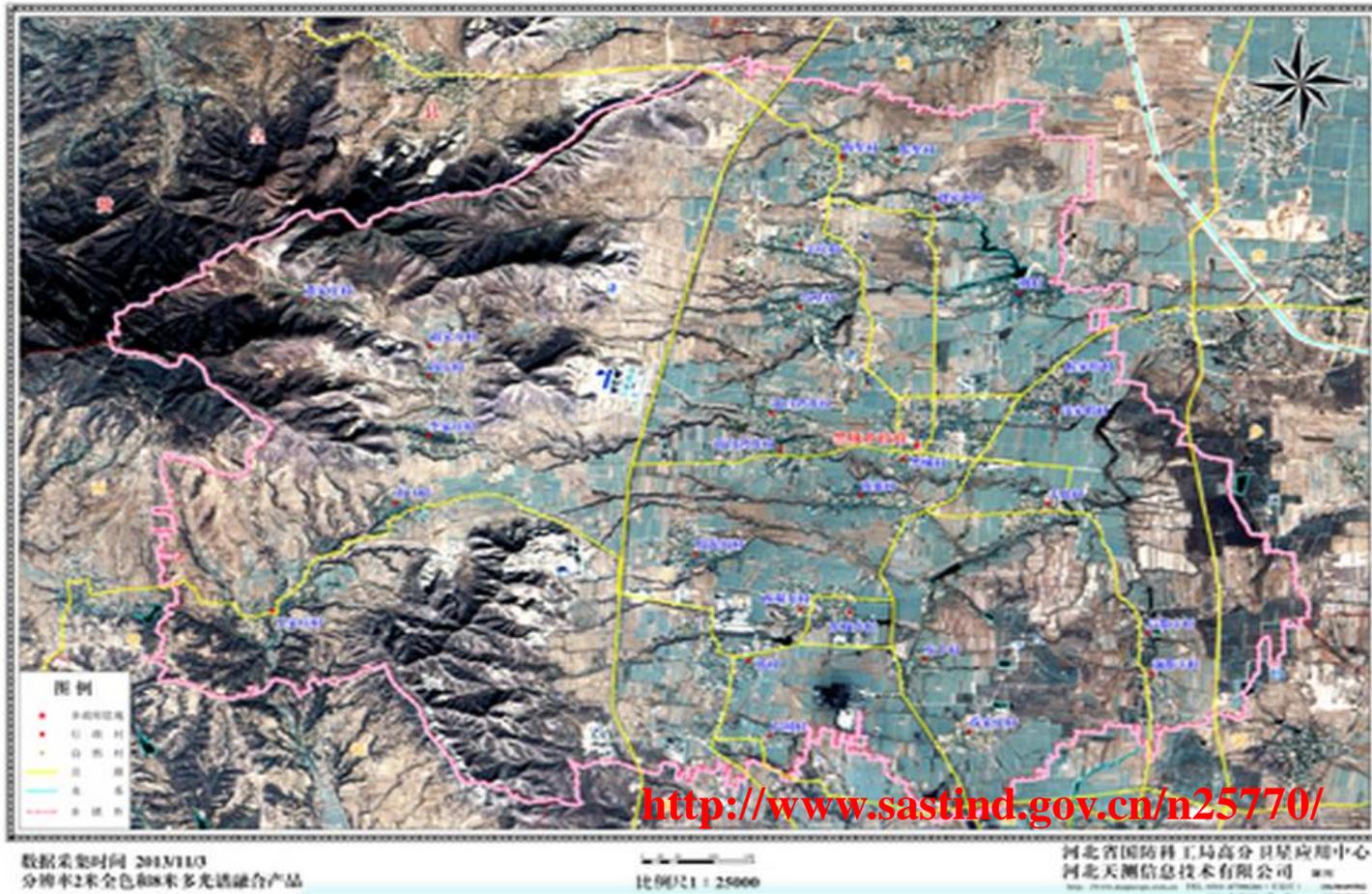


The GF project indicates that Chinese Earth observation enters high-resolution phase

Ongoing & future missions in China

 GF-series: high-resolution satellite program

黑城乡高分一号遥感影像图



Heicheng, Hebei by GF-1, 2013

www.radi.cas.cn

Ongoing & future missions in China

GF-series: high-resolution satellite program

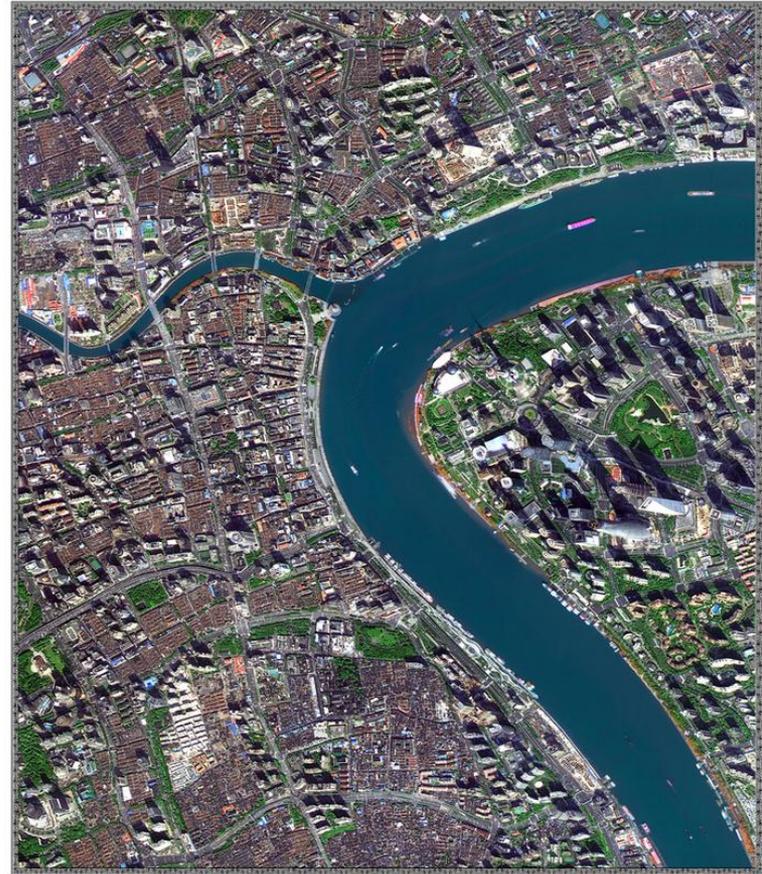
高分二号卫星北京影像



融合方式: 全色影像(0.8米)和多光谱影像(3.2米)融合
比例尺 1:4 000
国防科工局重大专项工程中心
中国资源卫星应用中心 制作
接收日期: 2014年09月27日

Beijing by GF-2, 2014

高分二号卫星上海融合影像



融合方式: 全色影像(0.8米)和多光谱影像(3.2米)融合
比例尺 1:4 000
国防科工局重大专项工程中心
中国资源卫星应用中心 制作
接收日期: 2014年09月25日

Shanghai by GF-2, 2014

Ongoing & future missions in China

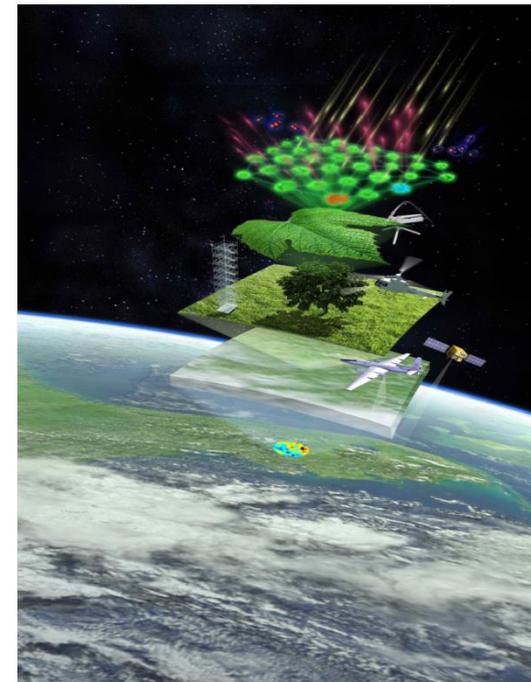
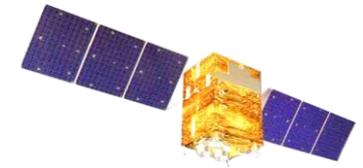


CarbonSat: Super-spectral spectrometer

Objective: Global carbon cycle monitoring by integrating vegetation reflectance and **sun-induced fluorescence** emission flux.

- Launch date: 2018 (TBD)
- Spectral range: 670-780 nm
- FWHM: less than 0.3 nm
- SNR: 200-600

Similar to ESA FLEX-FLORIS



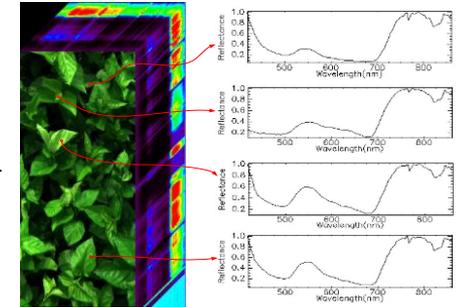
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Pre-measure for upcoming missions



New instrument: Field Imaging Spectrometer System (FISS)

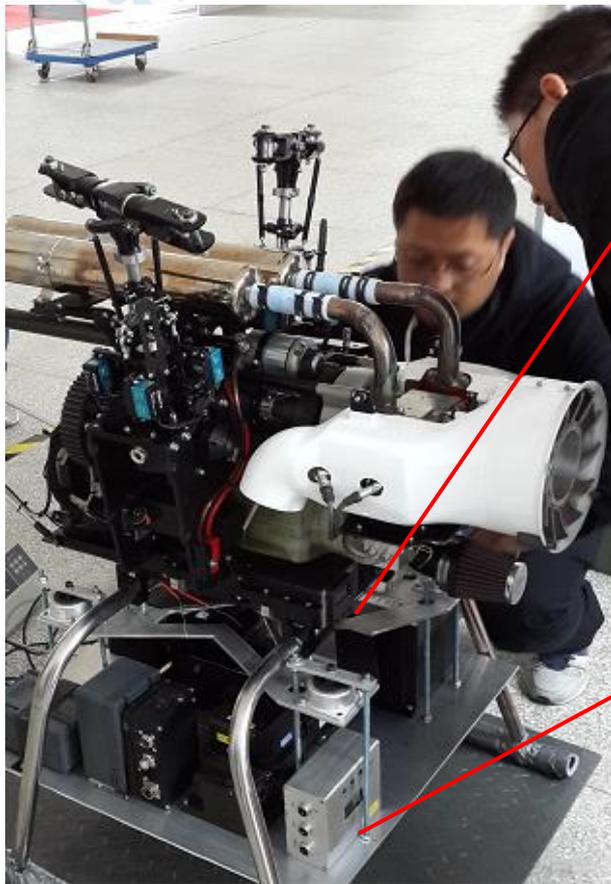


Number of bands	344	Imaging rate	Maximum 20 frames/s
Spectral range	437–902 nm	Scan field	–20° to +20°
Spectral resolution	Better than 5 nm	Quantitative value	12 bit
Spatial resolution	Maximum < 2 mm	Signal to noise ratio	>500 (60% bands)
Radiance calibration precision in laboratory	Better than 5%	Spectral sampling interval	About 1.4 nm

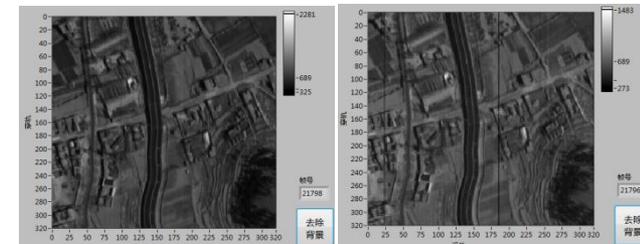
- Field Imaging Spectrometer System was developed by **IRSA (CAS)** which is considered **the first** field imaging spectrometer in China.

Pre-measure for upcoming missions

New instrument: Light Weight airborne Imaging spectrometer remote sensing system

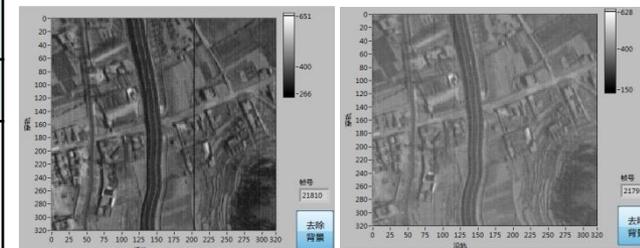


Spectral curve



$\lambda=2100\text{nm}$

$\lambda=2200\text{nm}$



$\lambda=2300\text{nm}$

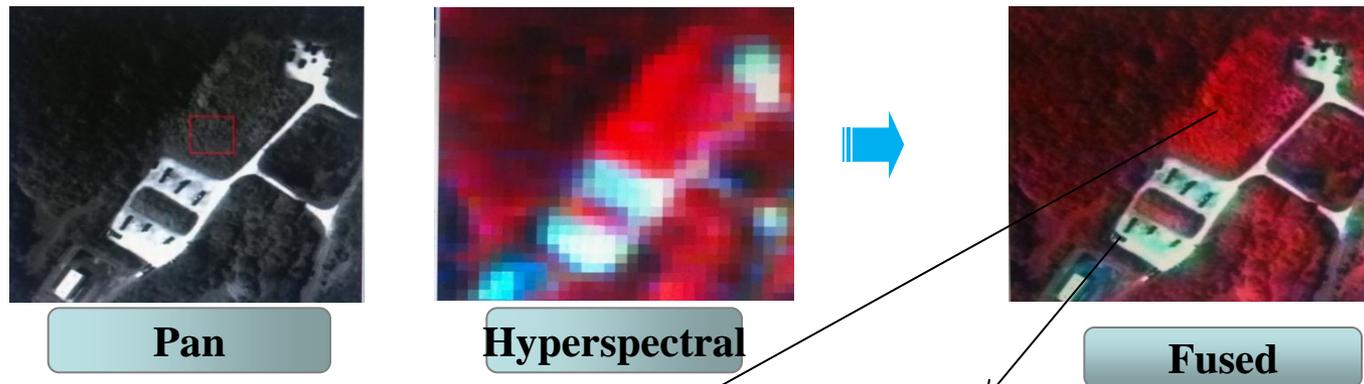
$\lambda=2400\text{nm}$

Spectral Interval	400–2500nm
weight	25kg
Visible - Near Infrared Imaging Spectrometer	
Shortwave Infrared Imaging Spectrometer	
PHASE ONE high resolution camera	
High accuracy IMU	

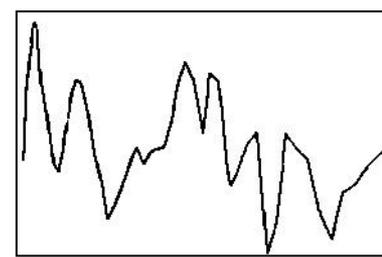
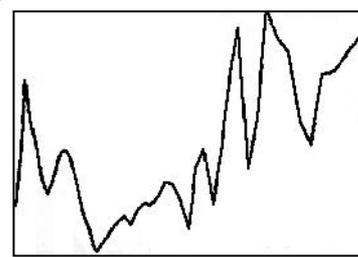
Pre-measure for upcoming missions

New techniques: Spatial and spectral information fusion

- Application of hyperspectral data fusion technology on TG-1 data for target detection and classification.
- Separability between target and background is enhanced.



Background (trees)

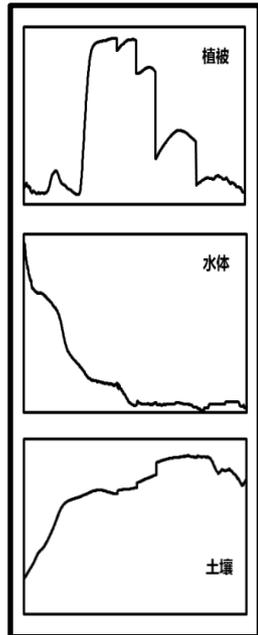


Target (vehicles)

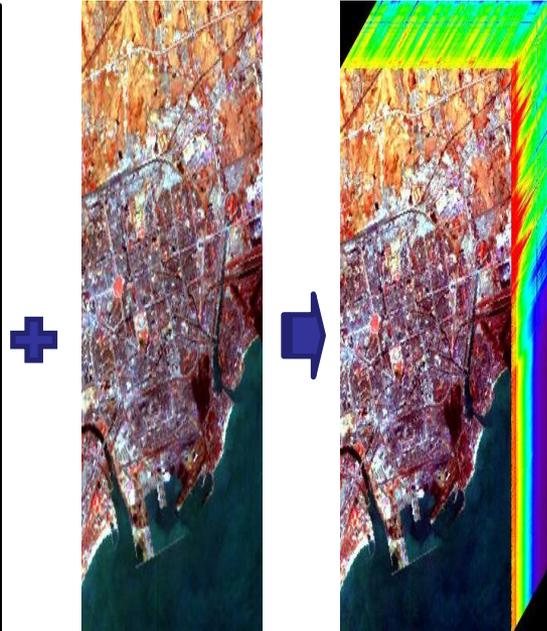
Pre-measure for upcoming missions

New techniques: Coverage area extending

- Research on hyperspectral image simulation based on standard spectrum
- Research on hyperspectral information extending on spatial dimension

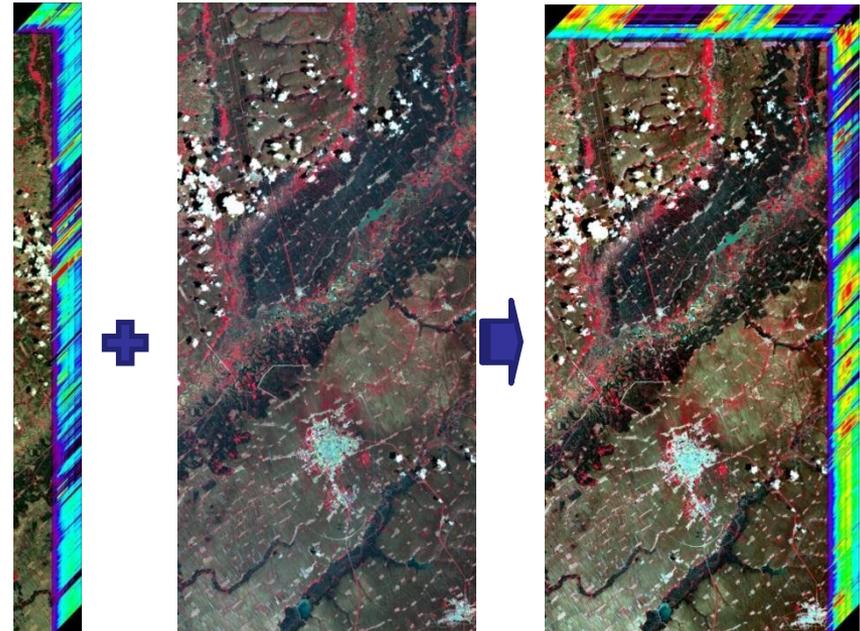


Standard spectrum



Multispectral image

Simulated image



Hyperspectral image

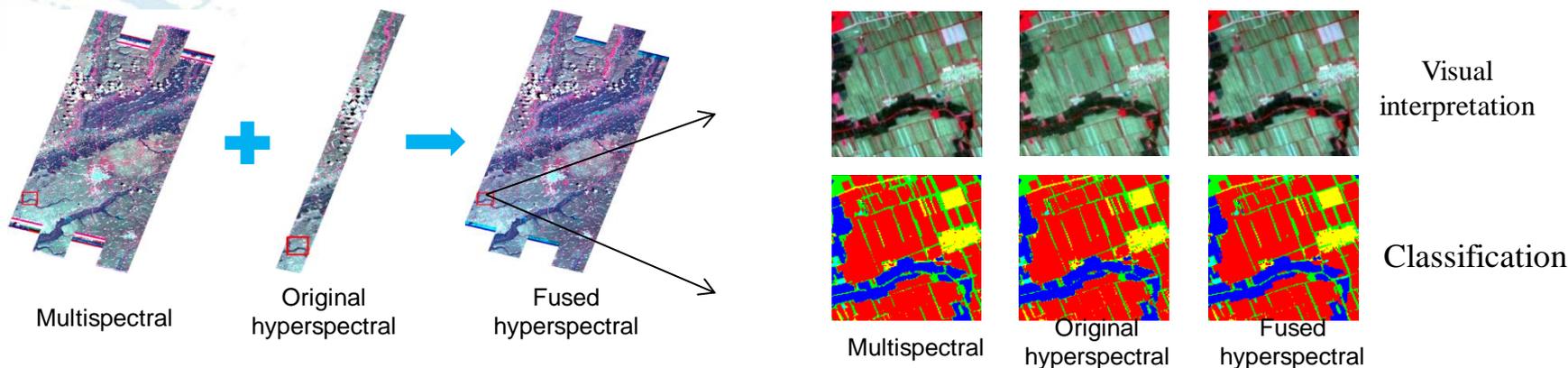
Multispectral image

Fused image

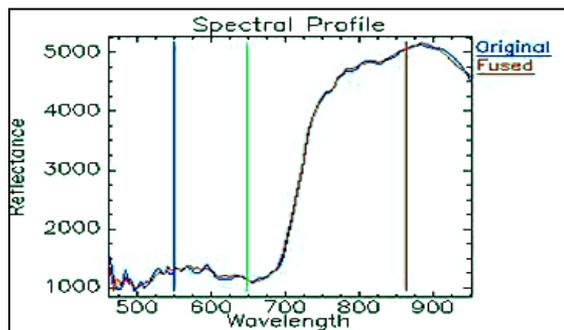
Pre-measure for upcoming missions

New techniques: Coverage area extending--results

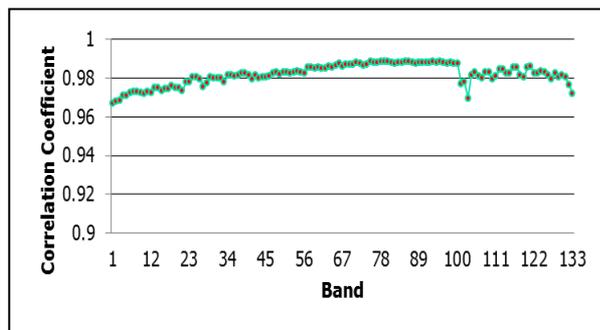
Fusion results for visual interpretation and classification



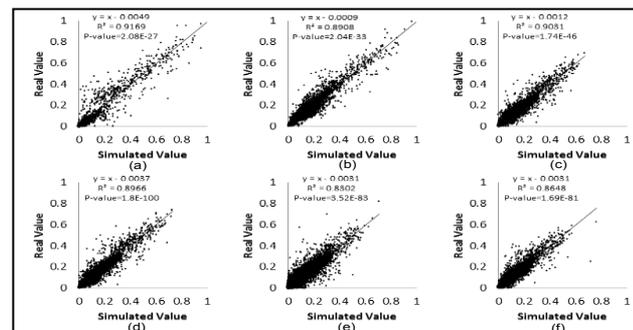
Quantitative assessment



Comparison of spectral curve



Correlation coefficients of each band

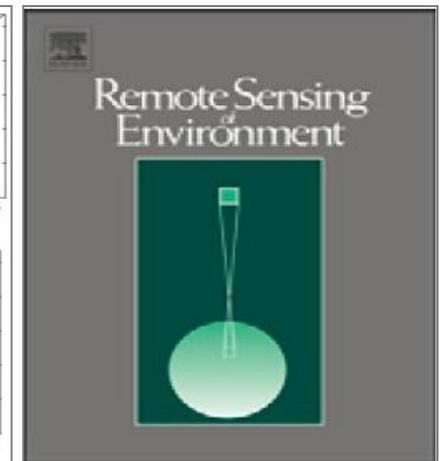
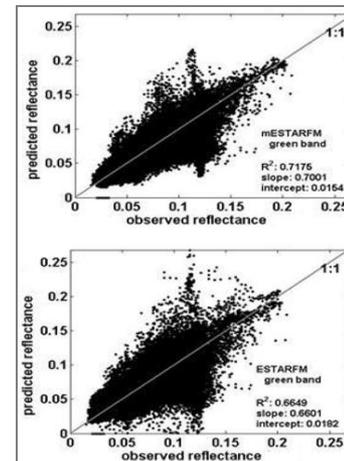
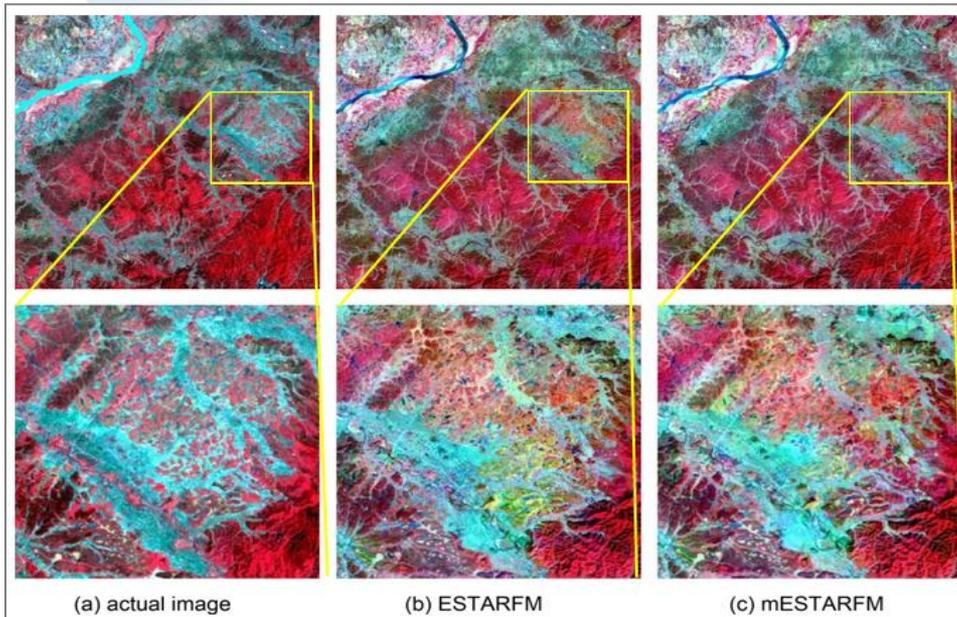


regression analysis

Pre-measure for upcoming missions

New techniques: Spatial and temporal fusion

mESTARFM



Blending algorithms have been developed to enhance the temporal frequency of high spatial resolution data using high temporal medium resolution data (Emelyanova, McVicar, Van Niel, Li, & van Dijk, 2013; Fu, Chen, Wang, Zhu, & Hilker, 2013; Gao, Masek, Schwaller, & Hall, 2006; Gumma, Thenkabail, Hideto, et al., 2011; Zhu, Chen, Gao, Chen, & Masek, 2010). Emelyanova et al. (2013) tested these approaches in areas corresponding to IA1 (during a flooding episode) and IA 10 (during the peak irrigation-season) with good results (see Emelyanova et al.,

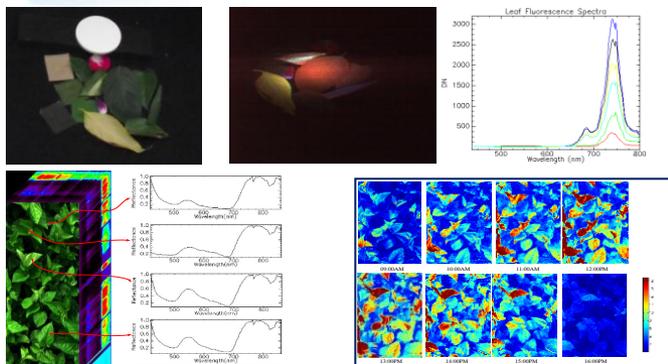
Fu, D., Chen, B., Wang, J., Zhu, X., & Hilker, T. (2013). An Improved Image Fusion Approach Based on Enhanced Spatial and Temporal the Adaptive Reflectance Fusion Model. *Remote Sensing*, 5, 6346-6360

Pre-measure for upcoming missions

New techniques: Solar induced vegetation fluorescence remote sensing

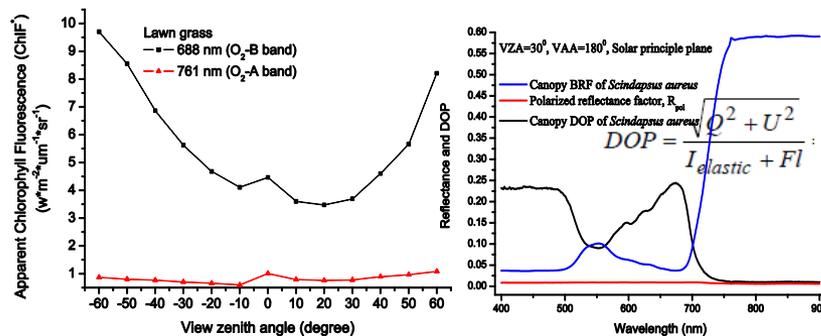
(1) Fluorescence emission mechanism by FISS

UV excited
Sun induced



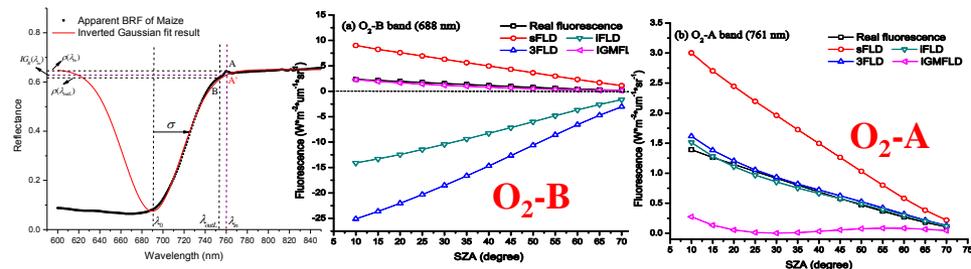
Huang C., Zhang L., et al., 2014

(2) Fluorescence characteristics investigation



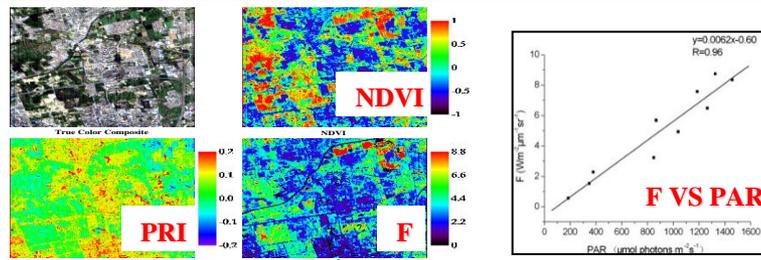
Huang C., Zhang L., et al. IGARSS, 2013

(3) SIF retrieval methods development



Huang C., Zhang L., et al. WHISPERS, 2015

(4) SIF retrieval from Hyperion satellite



Hu S. PhD thesis, 2013

OUTLINE

- Introduction
- Review of current sensors in China
- Ongoing and future missions in China
- Pre-measure for upcoming missions
- **Conclusions**

Conclusions



- We update recent advances and future plans in Chinese satellite hyperspectral missions, including
 - ✓ **CCRSS: China Commercial Remote-sensing Satellite System**
 - ✓ **GF-serie satellites: high-resolution satellites (GF-1 to GF7)**
 - ✓ **CarbonSat: to detect sun induced vegetation fluorescence**

- We introduce pre-measure for upcoming advanced missions, as
 - ✓ **New instrument development: from field to UAV platforms**
 - ✓ **New techniques development: novel methods & algorithms**
 - ✓ **New software development: HyLab1.0 for HRS data**

These pre-measure may improve data use efficiency of Chinese hyperspectral satellites, once they are launched and available.

Thanks!



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