# Consideration of the On-board Calibration of Interferometric Synthetic Aperture Microwave Radiometer:

## *Using Geostationary Interferometric Microwave Sounder (GIMS) for Example*

***Hao LIU, Lijie NIU, Cheng ZHANG, Xi GUO, Ji WU***

**CAS/NSSC**

**2018.03.22**

National Space Science Center
Chinese Academy of Sciences
(NSSC, CAS)

Key Laboratory of Microwave Remote Sensing
Chinese Academy of Sciences
(MiRS, CAS)

# Outline

- **Synthetic aperture radiometer overview**
  - Real Aperture Vs. Synthetic Aperture
- **GIMS overview**
  - System concept
  - Demonstrator development
- **GIMS calibration consideration**
  - Overview of calibration for real aperture and synthetic aperture radiometer
  - Ground-based Calibration & Imaging Results
- **Conclusion**

# Outline

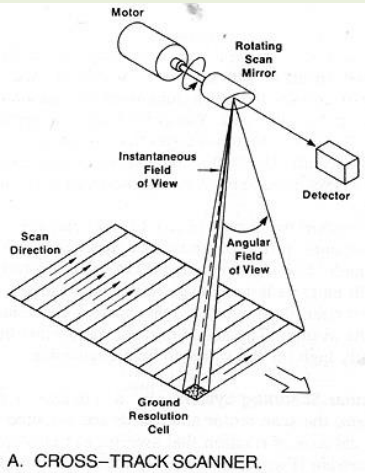
- **Synthetic aperture radiometer overview**
  - **Real Aperture Vs. Synthetic Aperture**
- **GIMS overview**
  - **System concept**
  - **Demonstrator development**
- **GIMS calibration consideration**
  - **Overview of calibration for real aperture and synthetic aperture radiometer**
  - **Ground-based Calibration & Imaging Results**
- **Conclusion**

# Microwave radiometry: sounder & imager

## Sounders:

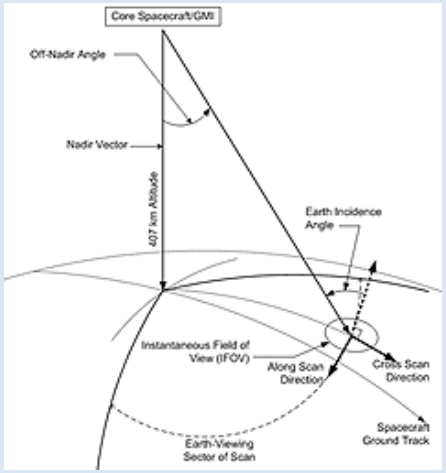
- AMSU-A/B,MHS, etc
- Cross-track scan
- 53GHz, 183GHz

FY-3C/MWTHS



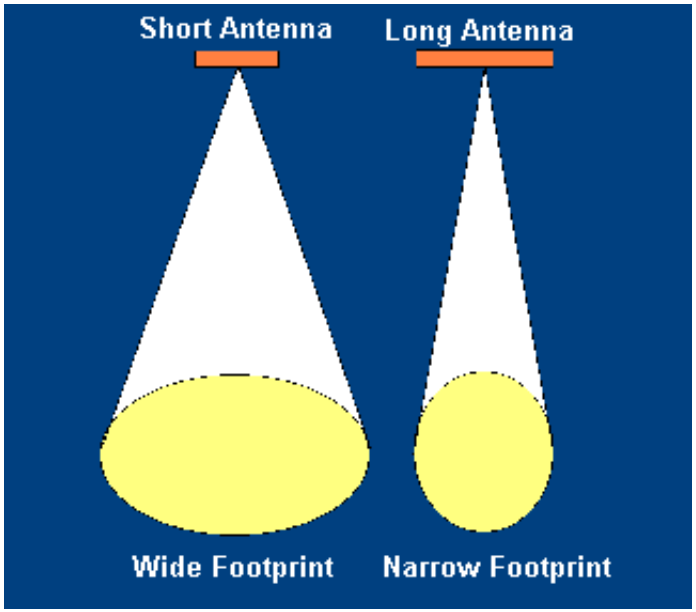

## Imagers:

- SSMI/S, TMI, GMI, AMSR2, etc
- Conical scan
- C/X band - 183GHz

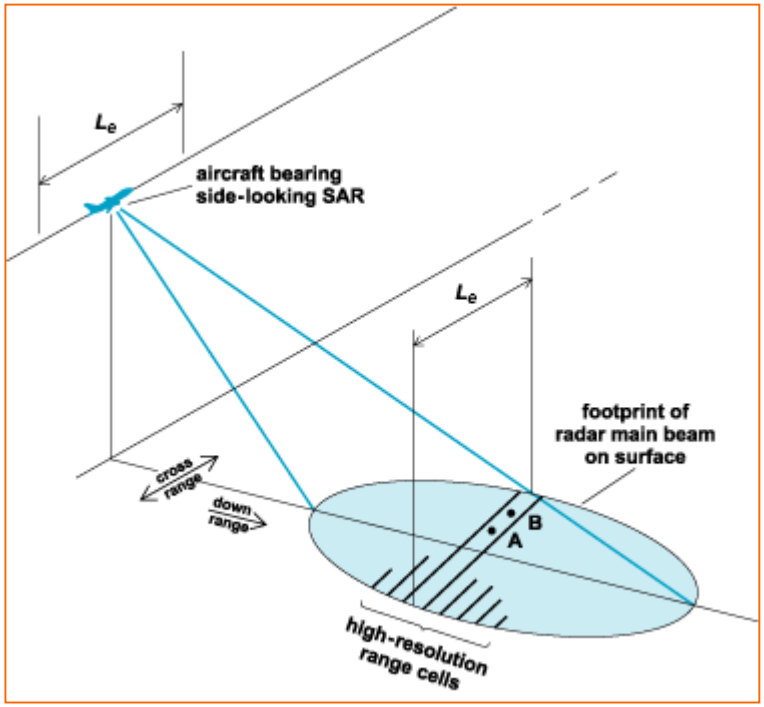



GMI

# The spatial resolution of passive microwave sensors



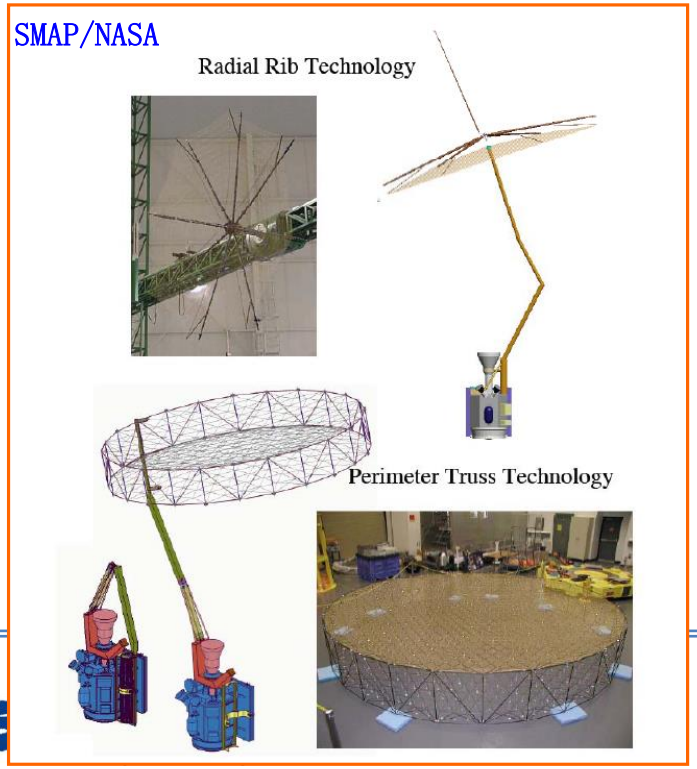

spatial resolution of passive sensors: totally determined by the antenna aperture size




**Spatial resolution of active sensors: can be improved by range compression, and aperture synthesis.**

# How to improve the spatial resolution of the passive microwave sensors?

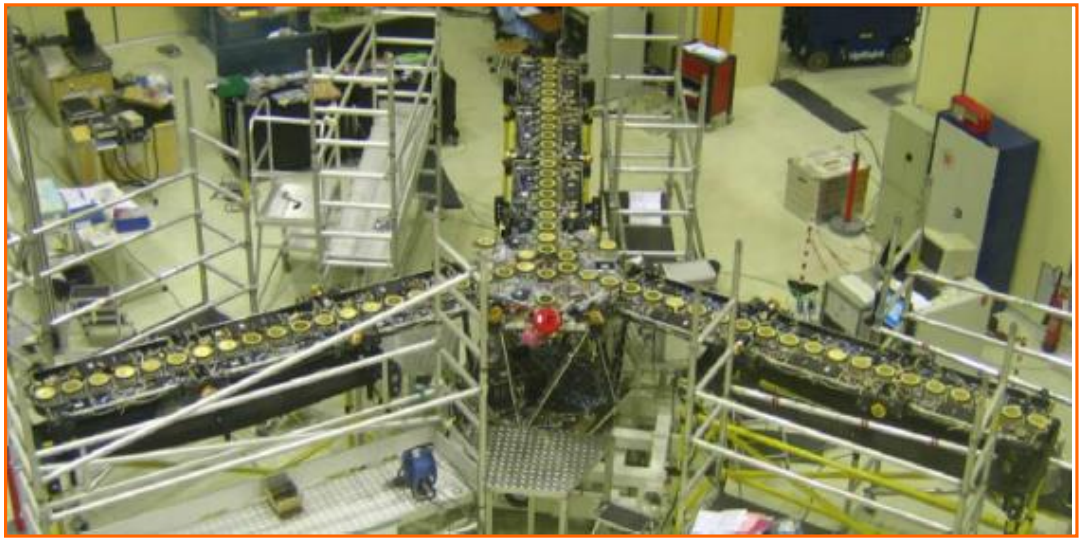
- **Real aperture technologies:**
  - large deployable antennas (low frequency)
  - Large reflector antennas (high frequency)



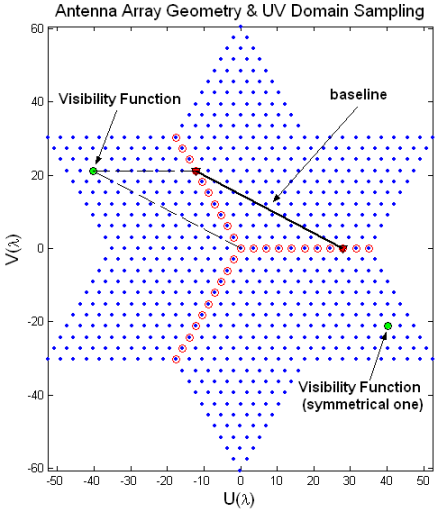

# Synthetic Aperture Radiometry

- **Synthetic Aperture Radiometer (interferometric radiometer, synthetic thinned array radiometer):**
  - **Using thinned array to replace the real aperture**
  - **Measuring the Fourier transform of the brightness temperature distribution**

**MIRAS/SMOS/ESA,Y-shape thinned array**

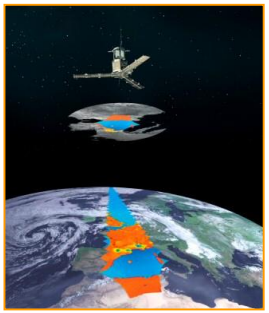


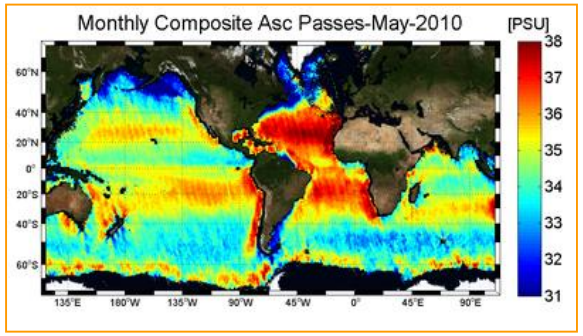
**Equivalent Observation Aperture**



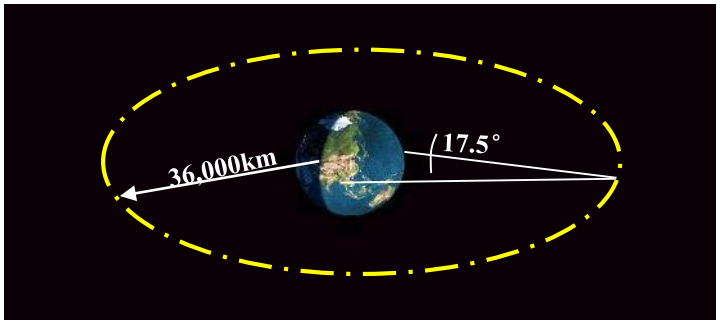
# Applications of Interferometric Synthetic Aperture Radiometer

- **Soil Moisture & Ocean Salinity: L band**
  - **SMOS**
  - **Chinese Salinity Mission**
  - **WCOM**

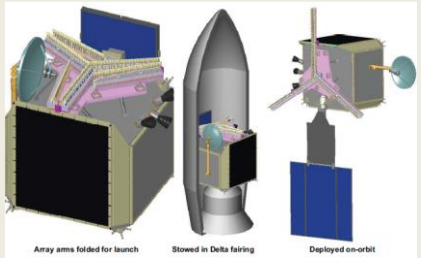


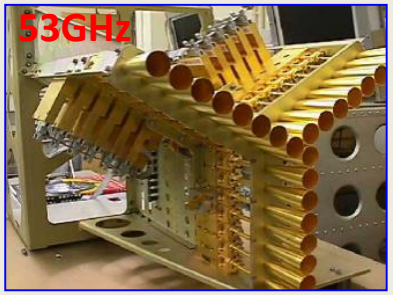


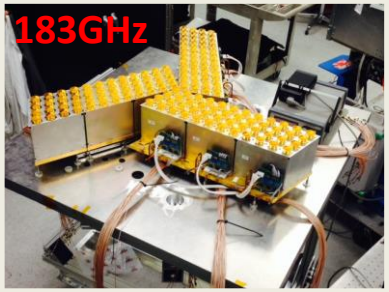

- **Geostationary Microwave Atmospheric Sounding: millimeter and sub-millimeter wave band**
  - **GeoSTAR, NASA/JPL**
  - **GAS, ESA**
  - **GIMS, CAS/NSSC**

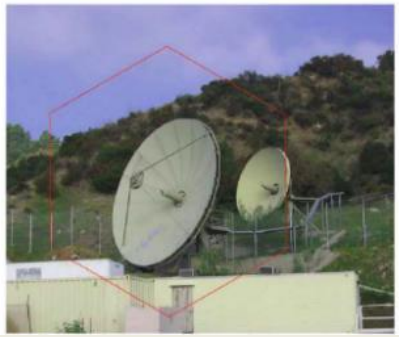


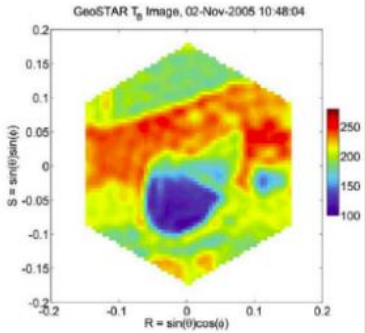
| Synthetic Aperture: Y-shape stationary array | Synthetic Aperture: Rotating Y-shape array |
|---|---|
| **GeoSTAR (JPL/NASA) From 2000~** | **GAS (ESA) From 2002~** |



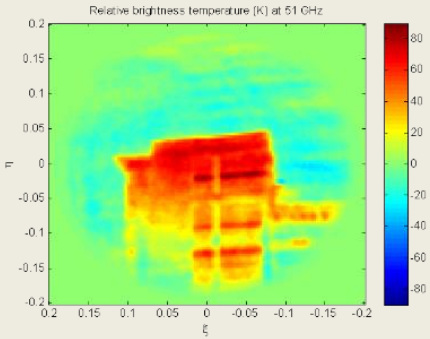



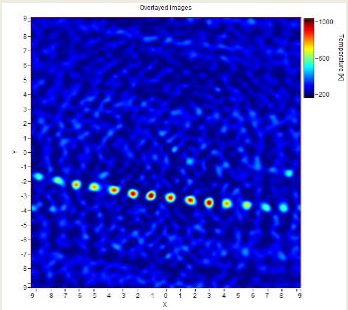







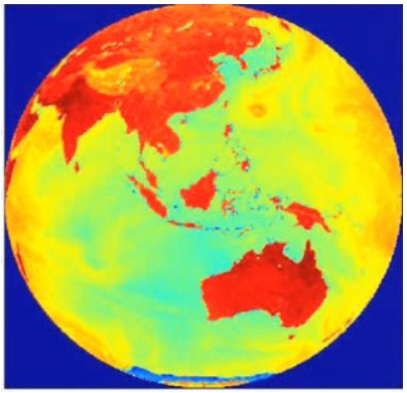



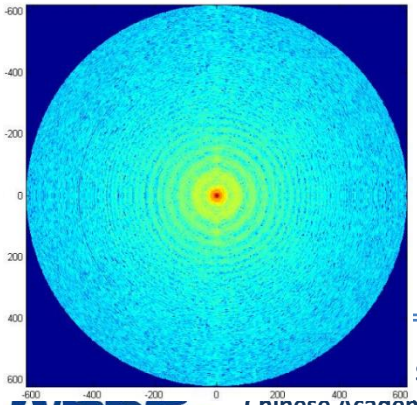
# Outline

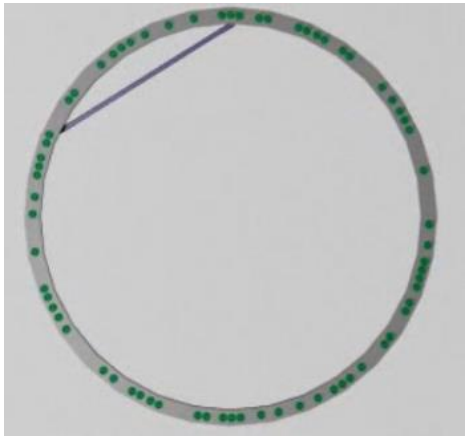
- Synthetic aperture radiometer overview
  - Real Aperture Vs. Synthetic Aperture
- GIMS overview
  - System concept
  - Demonstrator development
- GIMS calibration consideration
  - Overview of calibration for real aperture and synthetic aperture radiometer
  - Ground-based Calibration & Imaging Results
- Conclusion

# GIMS Concept

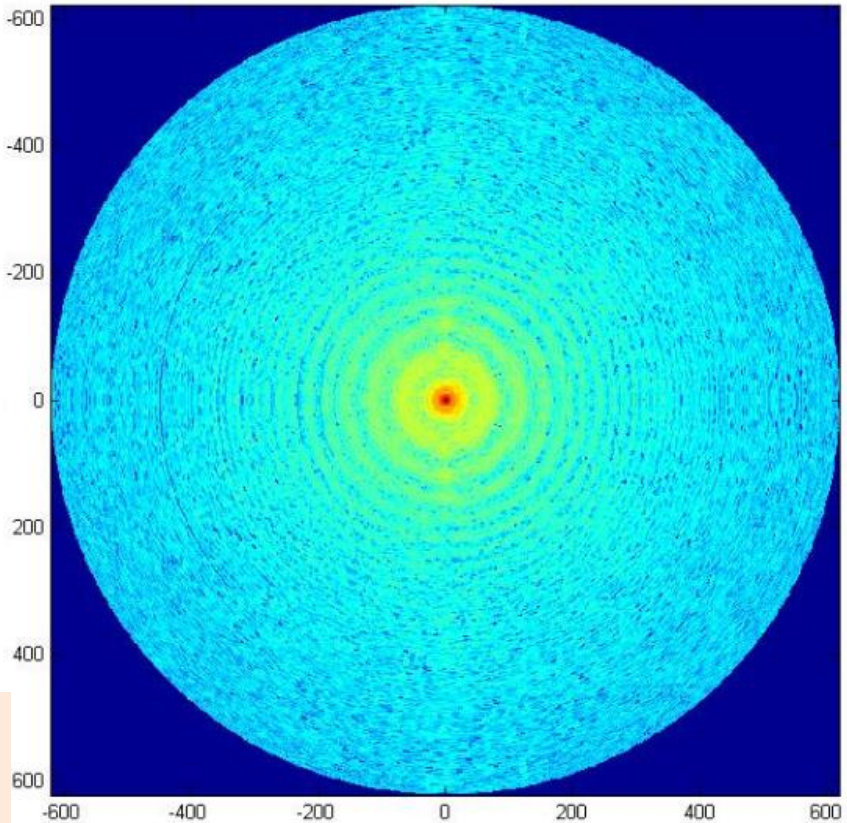
- GIMS （ Geostationary Interferometric Microwave Sounder ）
  - Fourier Relationship: TB (Spatial Domain) ←→ VF (Spatial Frequency Domain)
  - Timeshared Sampling in SF Domain with Rotating Thinned Circular Array





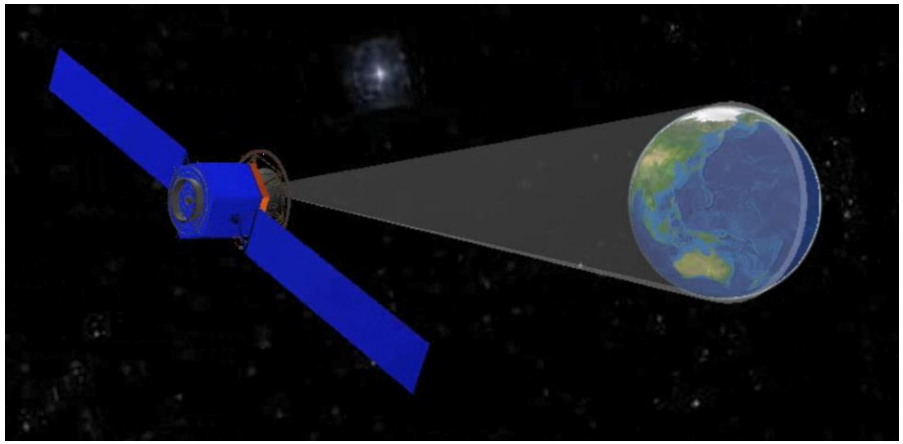



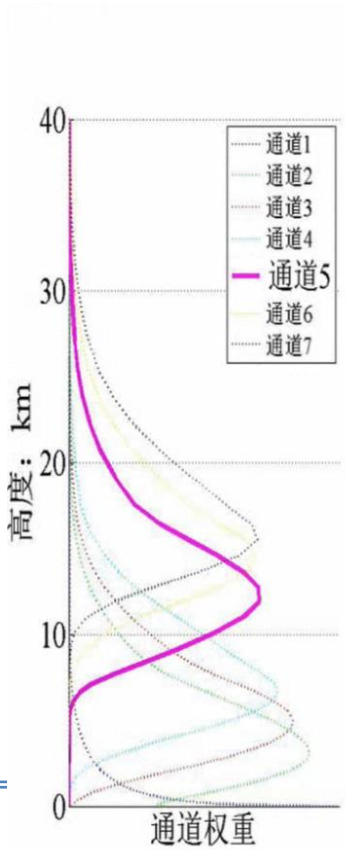
**Rotating circular thinned array**

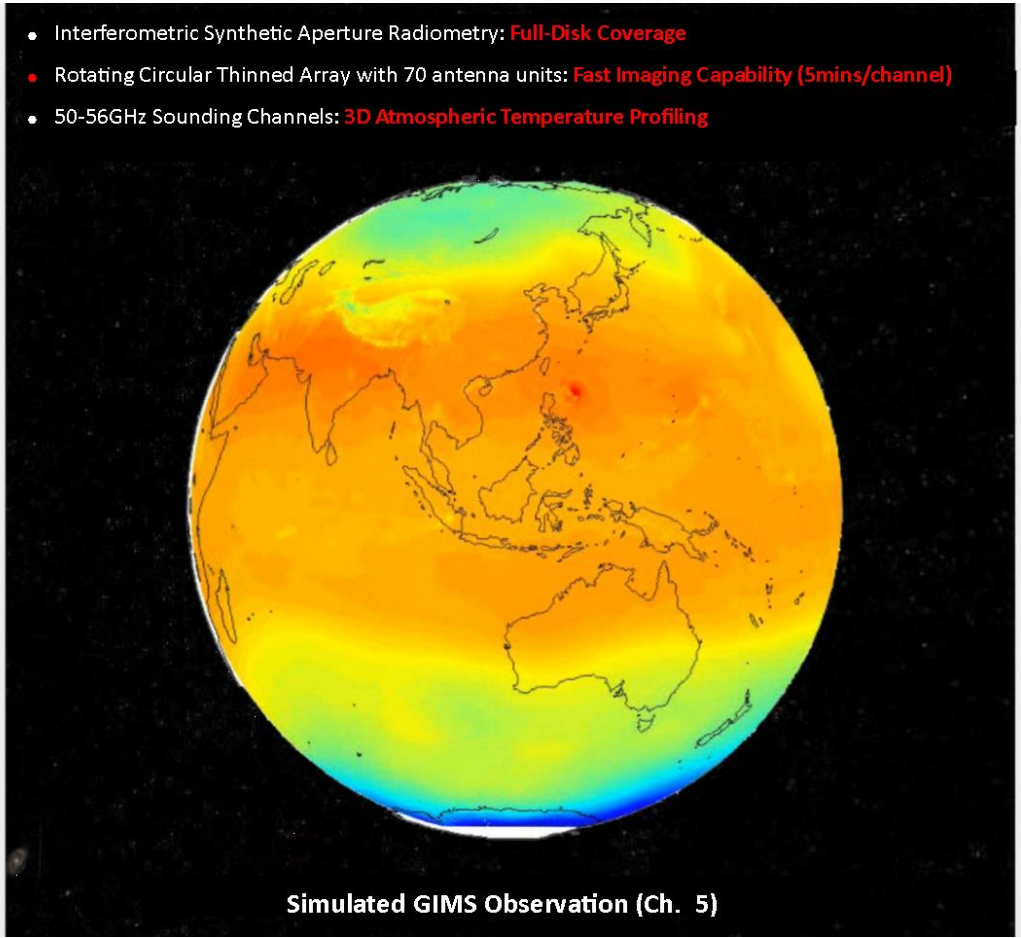


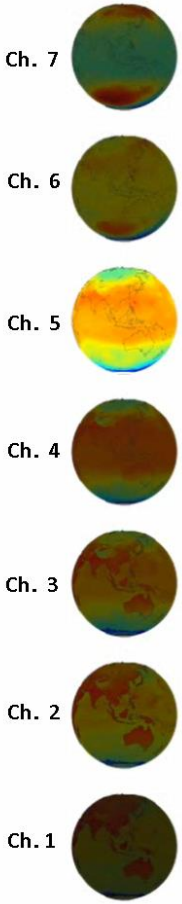

- *Number of antenna units: N*
- *Number of instantaneous VF samplers:* $C_N^2 = \frac{N(N-1)}{2}$

# Full-disk Coverage & 3D Sounding



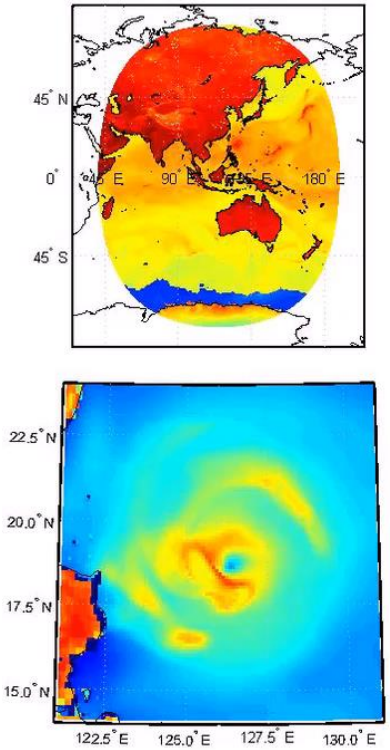


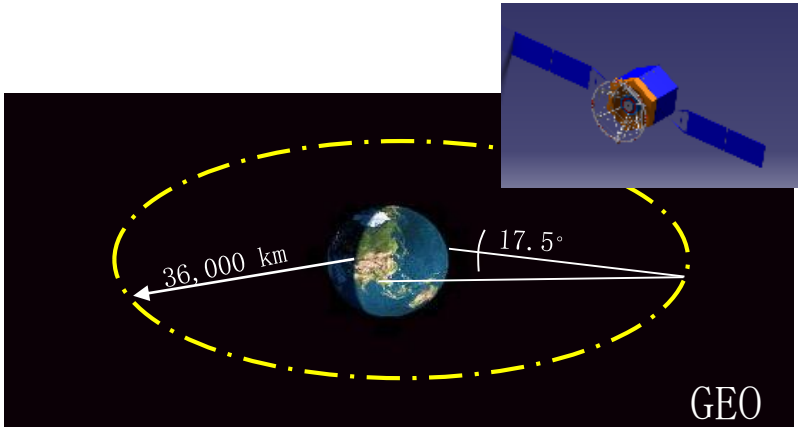



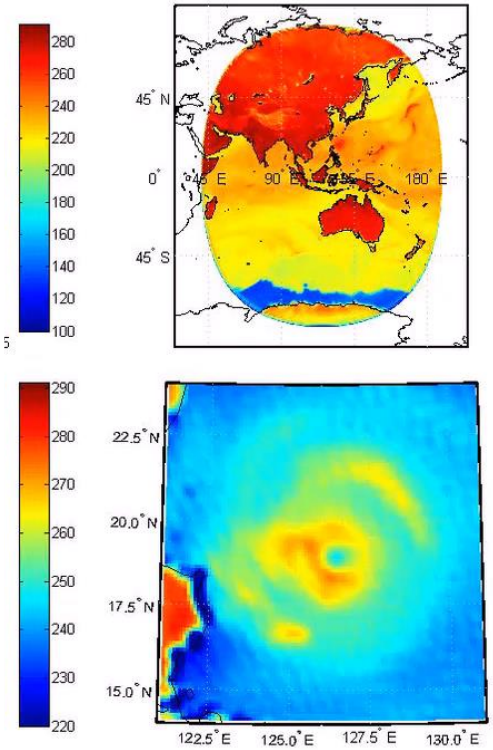
# Fast Imaging → Tracking the evolution of TCs

**Dynamic Target (FNL+WRF+RTTOV)**




**Simulated GIMS Observation (Full-disk， 30km res, 5mins)**



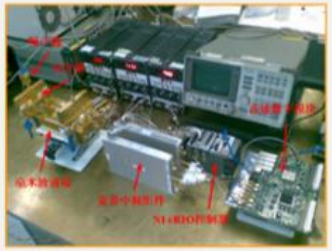

- **30-mins duration**
- **5-min imaging period，**
- **10s image refresh based on kalman-filtering & interpolation processing**

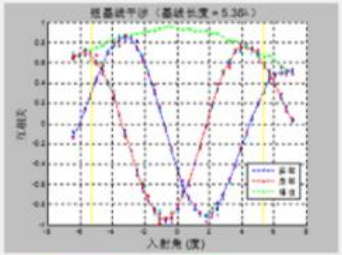
*Ying ZHANG, Hao LIU, Ji WU, etc, Method to Reduce Imaging Errors in Dynamic Target Observation of the Geostationary Interferometric Microwave Sounder [J]. IEEE Geoscience and Remote Sensing Letters, 2017, 14(2): 267-271*

# GIMS development roadmap

**2006~2008：**

**Two-element Interferometer**

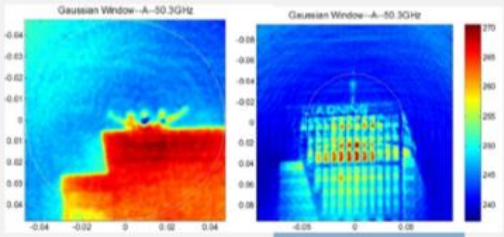




Point Source Fringe test

**2008~2012：**

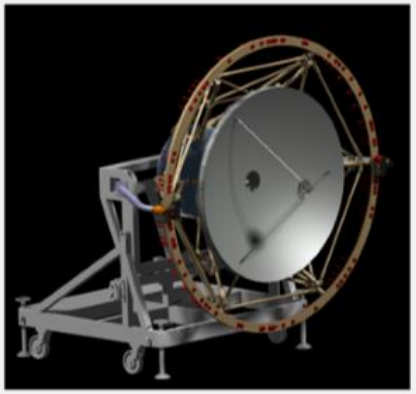
**28-element GIMS-I Demonstrator**



GIMS-I Field Imaging Results

**2014~2017：**

**Dual-mode microwave humidity/temperature sounder concept**



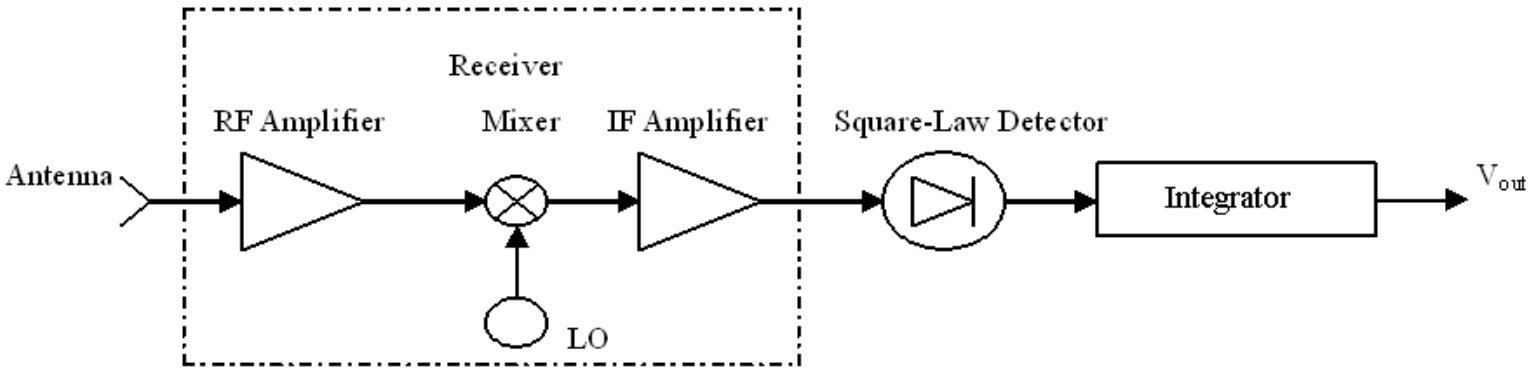
Where we are now!

*Cheng Zhang, Hao Liu, Ji Wu, etc, Imaging Analysis and First Results of the Geostationary Interferometric Microwave Sounder Demonstrator, IEEE Transactions on Geoscience and Remote Sensing 01/2015; DOI:10.1109/TGRS.2014.2320983*

# Outline

- Synthetic aperture radiometer overview
  - Real Aperture Vs. Synthetic Aperture
- GIMS overview
  - System concept
  - Demonstrator development
- **GIMS calibration consideration**
  - **Overview of calibration for real aperture and synthetic aperture radiometer**
  - **Ground-based Calibration & Imaging Results**
- Conclusion

# Calibration of traditional total power radiometers




- Two-point calibration

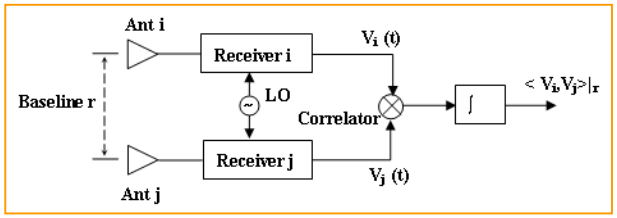
$$v = aT + b$$

- **Receiver gain**

- **Receiver noise temperature**
- **Loss before the first LNA, including antenna, isolator, switch, etc..**
- **Detector bias**

# Calibration Considerations for Synthetic Aperture Radiometers (1)

- **(1). Calibration is done on Visibility Functions, not on TB**




$$T = a_0 V_0 + a_1 V_1 + a_2 V_2 \cdots\cdots + a_n V_n + b$$

$$V_{ij}(u,v) = \frac{\sqrt{D_i D_j}}{4\pi} \iint_{\xi^2+\eta^2 \le 1} \frac{T_B(\xi,\eta) - T_r}{\sqrt{1-\xi^2-\eta^2}} \cdot F_{n,i}(\xi,\eta) F_{n,j}^*(\xi,\eta) \cdot \tilde{r}\left(-\frac{u\xi + v\eta}{f_0}\right) \cdot e^{-j2\pi(u\xi+v\eta)} d\xi d\eta$$

Receiver Backward noise coupling

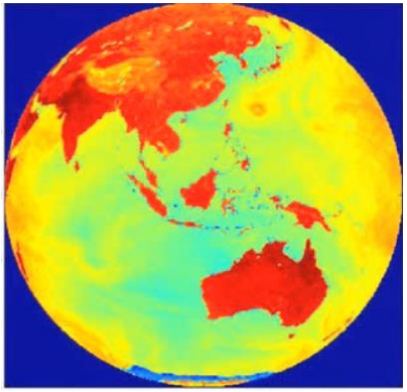
Element Antenna Pattern

Fringe-washing (Spatial de-correlation)

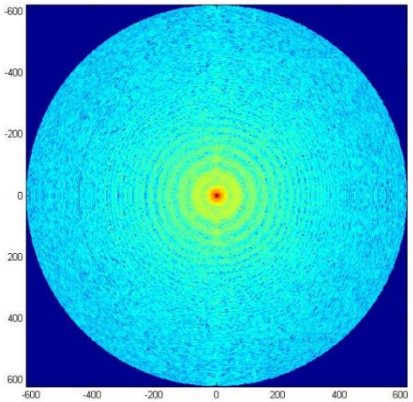
# Calibration Considerations for Synthetic Aperture Radiometers (2)

- **(2). Short baselines is much more important that the long baselines**
  - **The value of the VF decrease very quickly from several tens K to $10^{-3}$K with the baselines length**

TB distribution in spatial domain



VF samples in spatial frequency domain

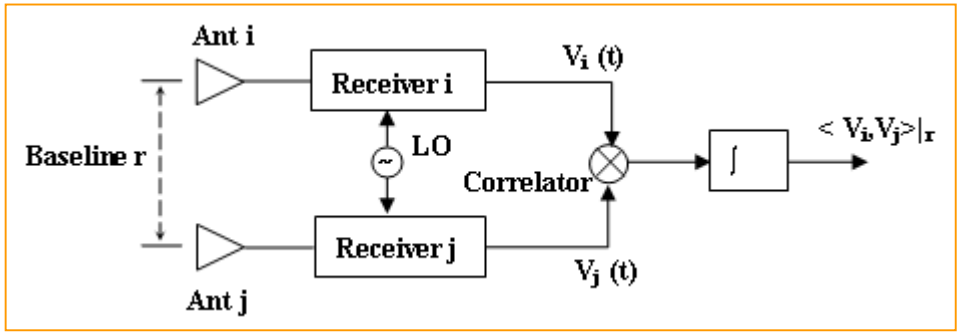



$$T = a_0 V_0 + a_1 V_1 + a_2 V_2 \cdots\cdots + a_n V_n + b$$

# Calibration Considerations for Synthetic Aperture Radiometers (3)

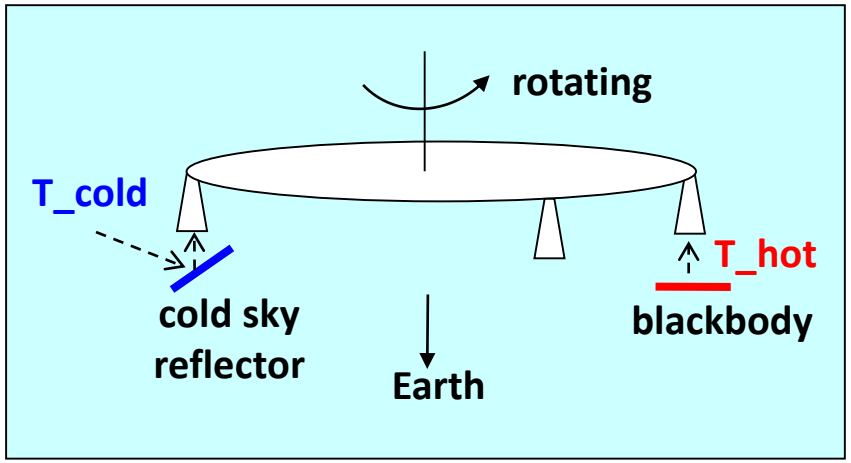
- **(3). In-orbit Calibration approach**
  - **Inter-channel Amplitude Calibration**
    - Noise injection
    - Two-point calibration
  - **Inter-channel phase alignment:**
    - Correlated Noise Injection
    - Redundant calibration
  - **Antenna pattern calibration:**
    - flat target response
  - **Other issues:**
    - Backward Noise coupling
    - IQ imbalance
    - Fringe-washing effects
    - Imaging algorithm error

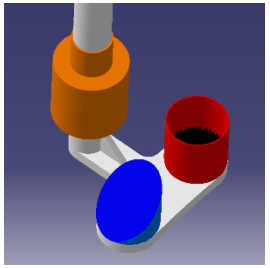
$$T = a_0 V_0 + a_1 V_1 + a_2 V_2 \cdots\cdots + a_n V_n + b$$

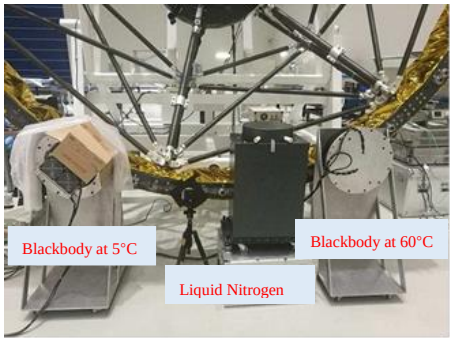


# GIMS Calibration Approach

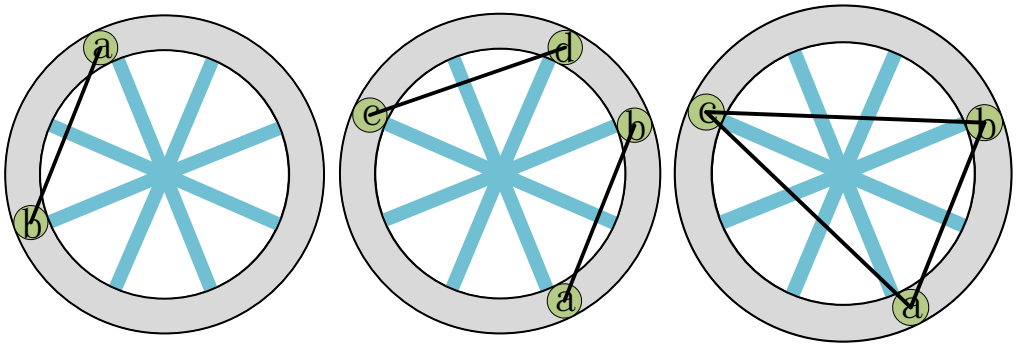
- Amplitude:
  - two-point calibration






- Phase:
  - Self-calibration



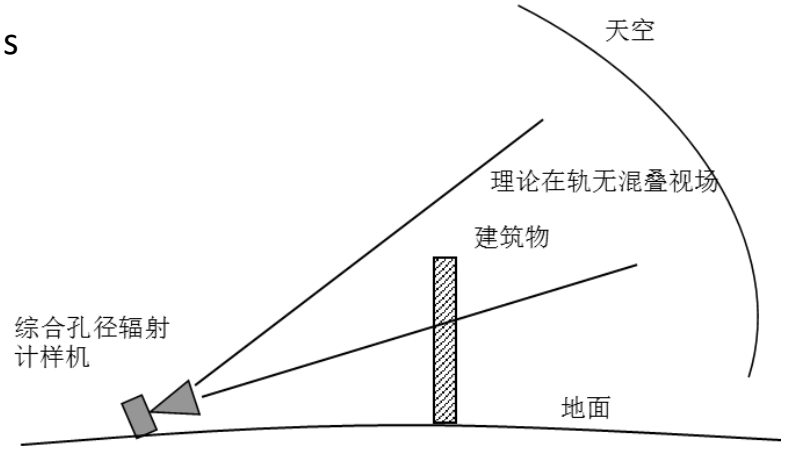

$$\phi_{ab\_0}^{raw} + \phi_{ab\_180}^{raw} = 2(\alpha_a - \alpha_b)$$

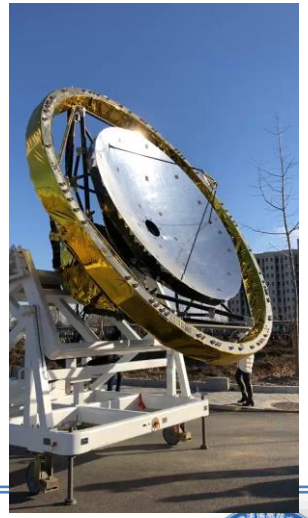
$$\begin{aligned}
&\phi_{ab}^{raw} + \phi_{bc}^{raw} + \phi_{ca}^{raw} \\
&= \phi_{ab}^{id} + \alpha_a - \alpha_b + \phi_{bc}^{id} + \alpha_b - \alpha_c + \phi_{ca}^{id} + \alpha_c - \alpha_a \\
&= \phi_{ab}^{id} + \phi_{bc}^{id} + \phi_{ca}^{id}
\end{aligned}$$

*HAN D, LIU H, WU J, etc, "Inter-element Phase Calibration for Geostationary Interferometric Microwave Sounder (GIMS)", IEEE GRS Letter, 2016, 13(9)*

# GIMS-II Demonstrator Calibration & Imaging Test

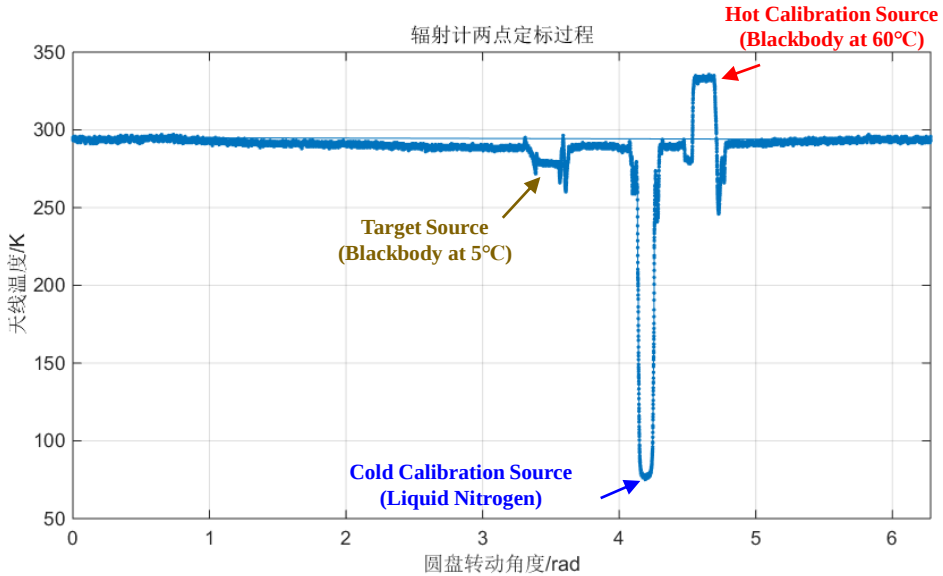
- **Calibration**
  - ① Two-point Calibration of 70-element Receiving Channels
  - ② Redundant phase calibration: point source imaging
- **Imaging Tests**
  - ① Point Source: evaluation on spatial resolution
  - ② Building
  - ③ Solar transit
  - ④ Imaging on Targets with changing temperature
  - ⑤ Cold sky imaging: NEDT evaluation
- **Restriction of On-ground Tests**
  - Aliasing: no cold sky background > 18 degree
  - Near Field: D>600 wavelength → Farfield > 5km。
  - Calibration: No Cold Sky reference, Redundant Phase calibration in Near field
  - Environment effects: temperature variation, wind, solar illumination, etc



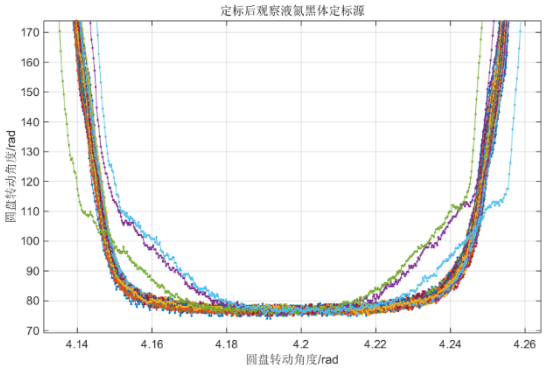



# End-to-end Two-point Calibration（70-elements）

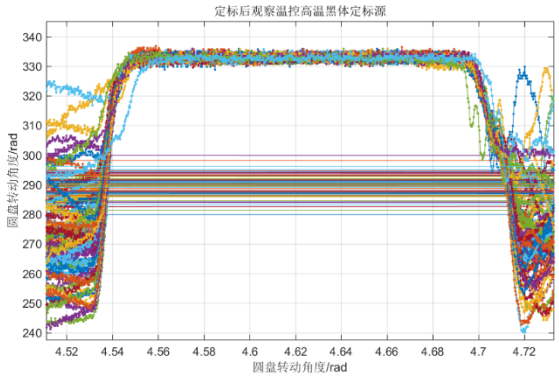
- Two calibration source + one target source



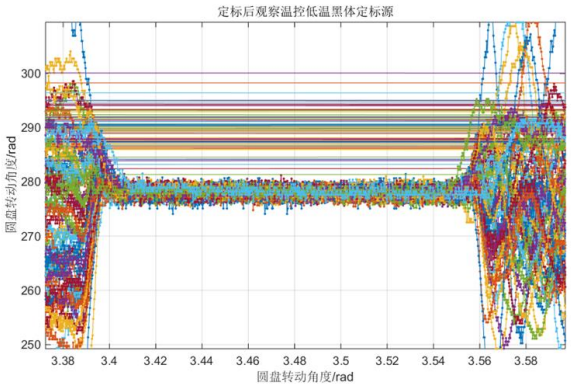
## Liquid Nitrogen

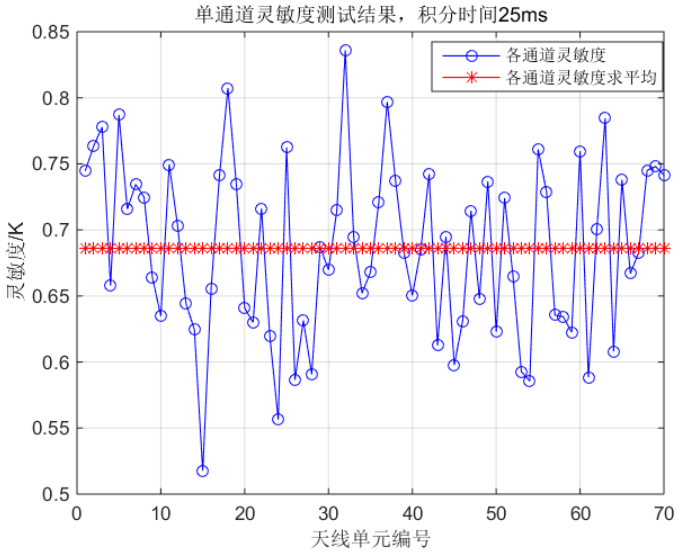



## Blackbody at 60 ℃

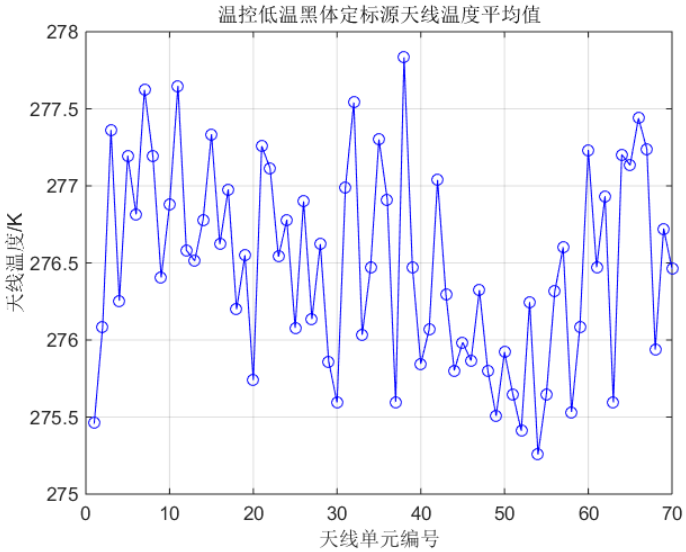



## Blackbody at 5 ℃



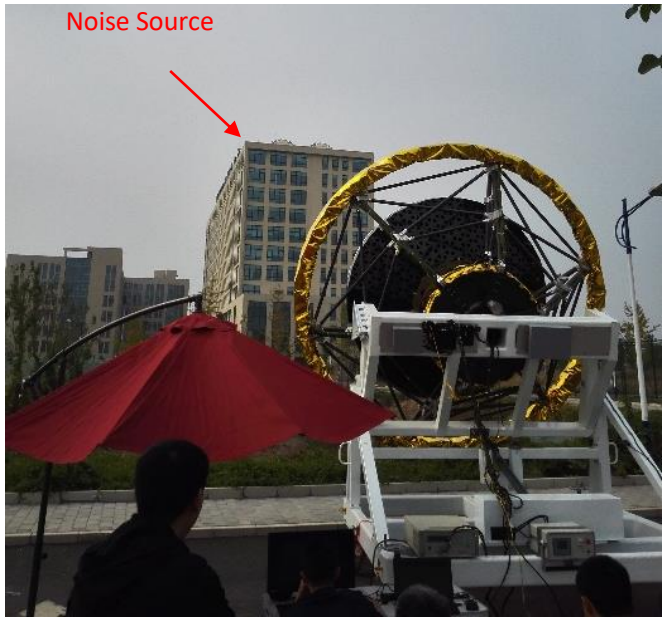



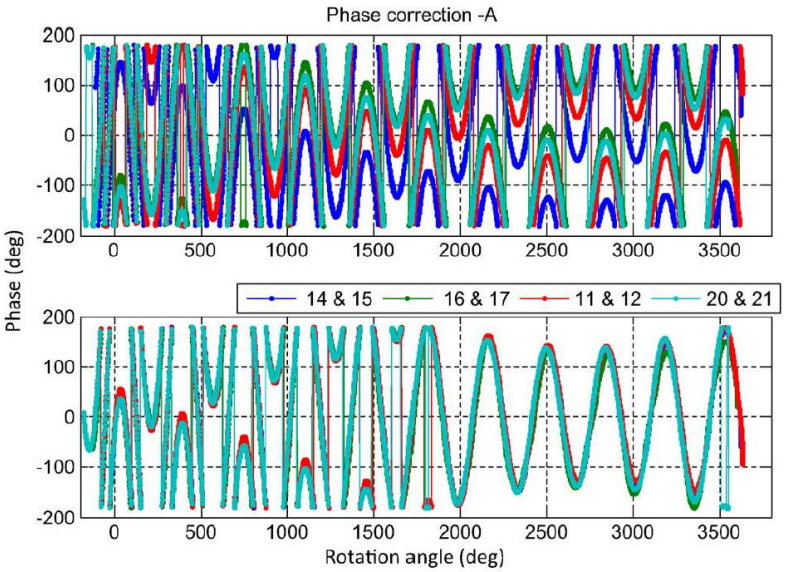

Mean NEDT of 70 receivers: 0.686K

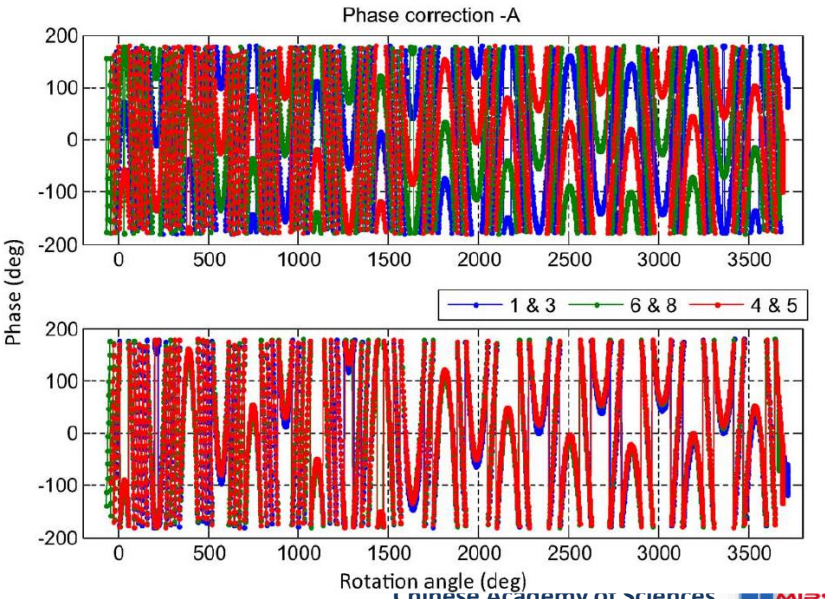



Mean TB of 70 receivers measurements: 276.48 K
STD: 0.65K

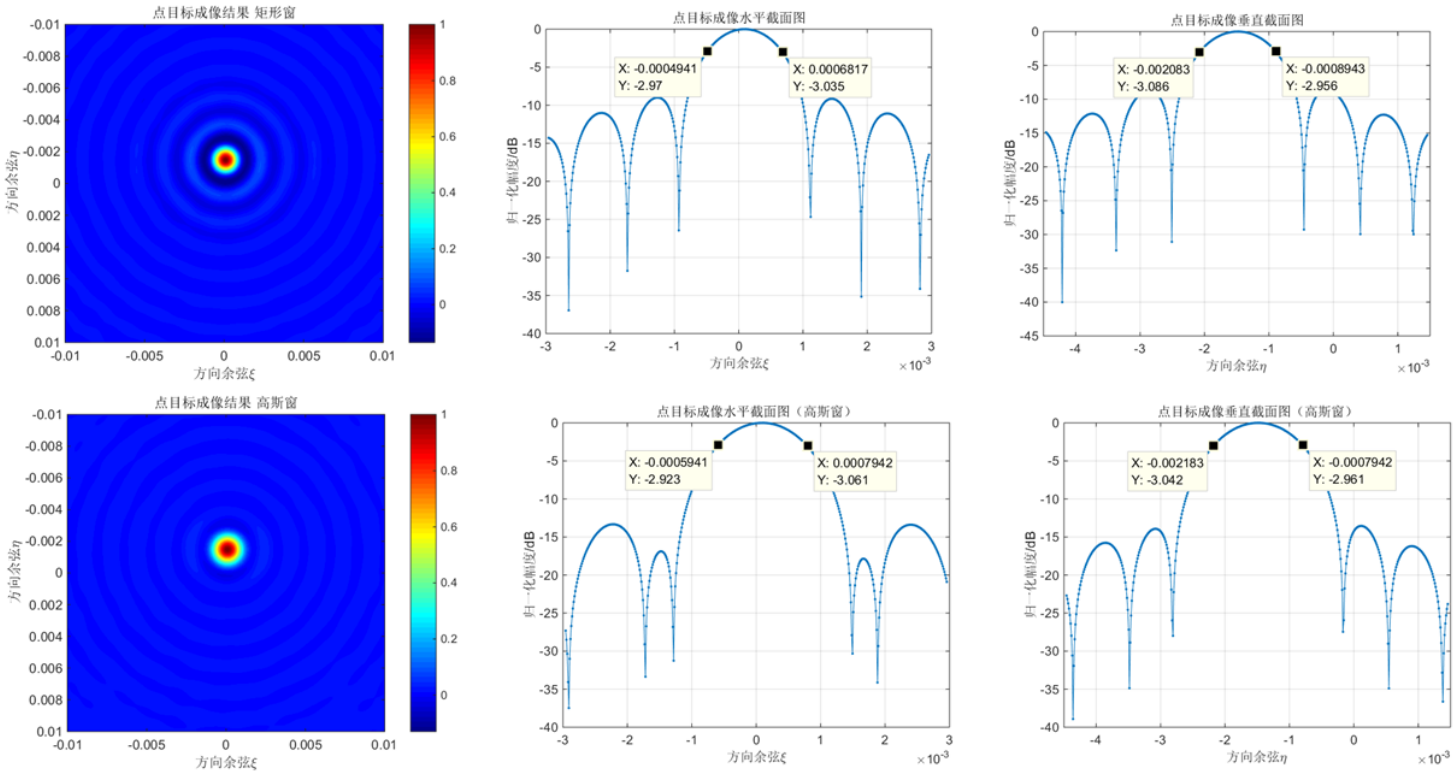
# Redundant Phase Self-Calibration

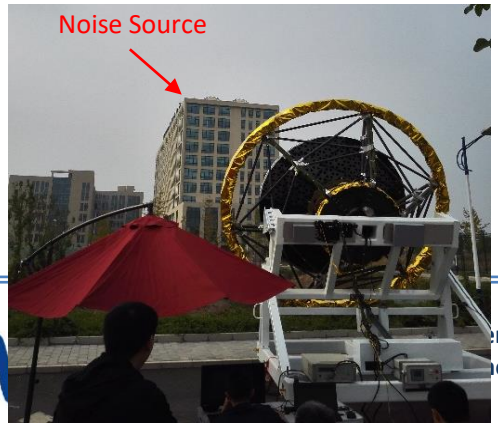


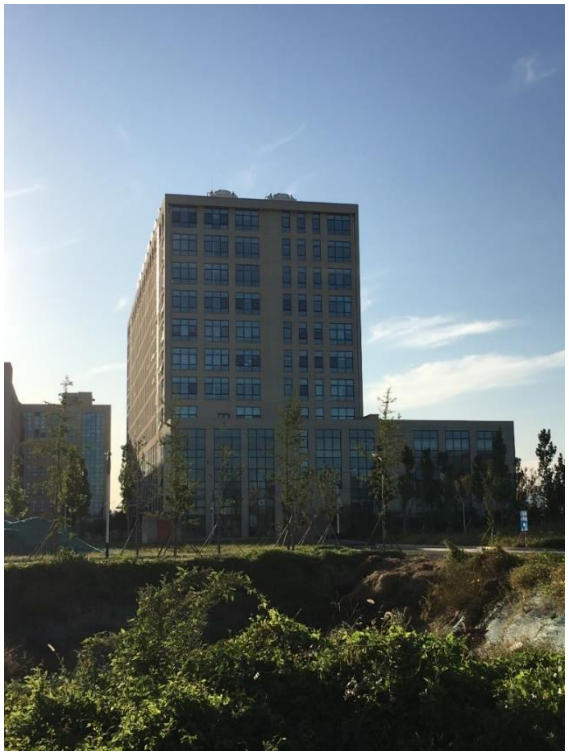
# Point Source Imaging（spatial resolution）

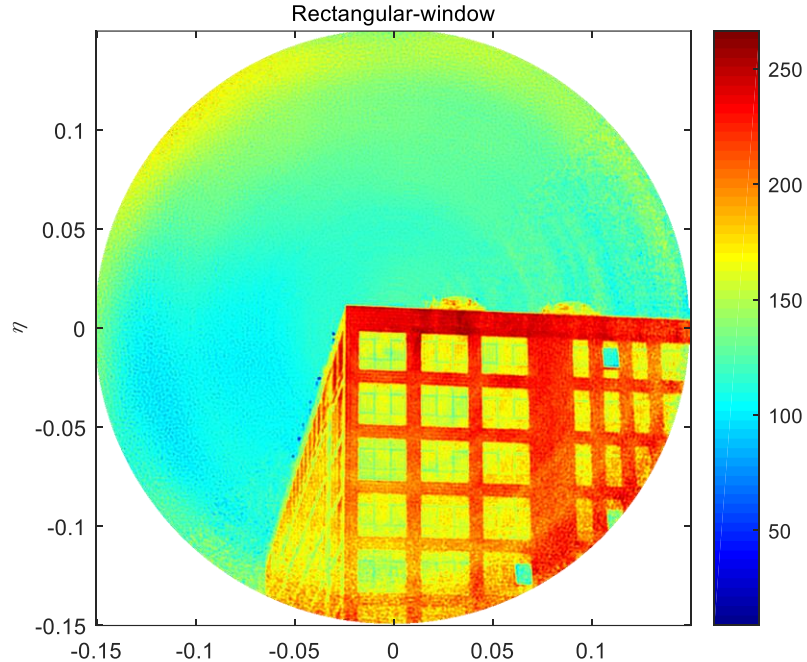


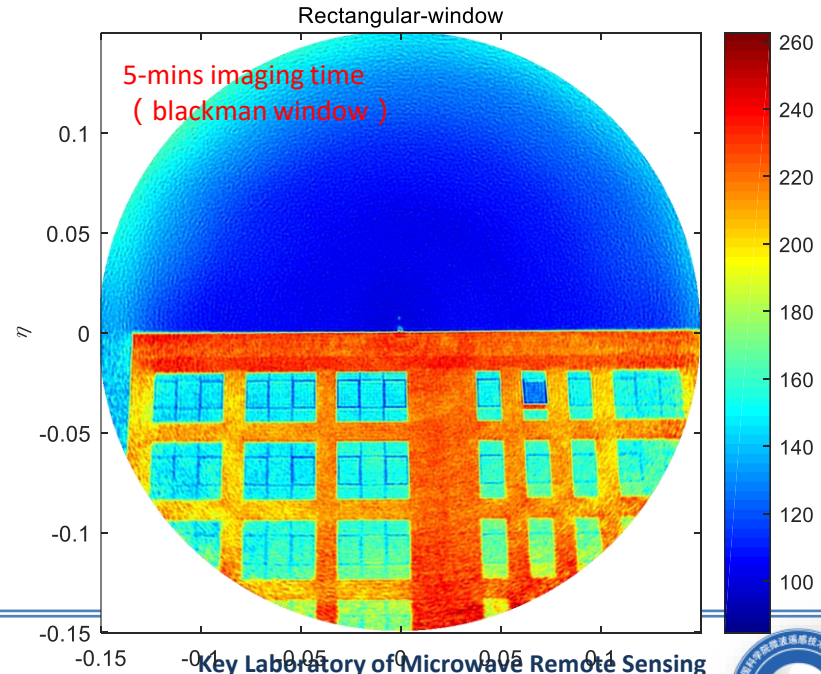



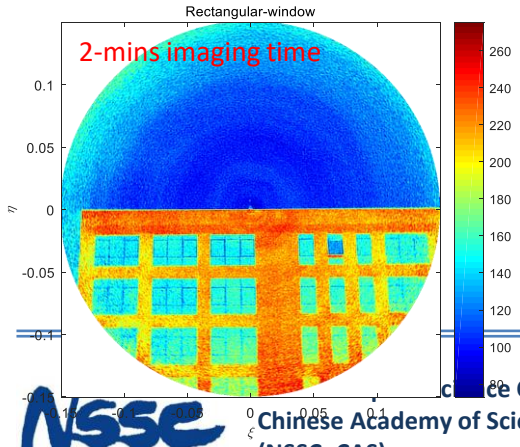

| | 测试结果 | 等效在轨分辨率 |
|---|---|---|
| Rectangular Window | (6.817+4.941)*1e-4*180/pi=0.067° | 42.1 公里 |
| | (20.83-8.943)*1e-4*180/pi=0.068° | 42.7 公里 |
| Guassian Window | (5.941+7.942)*1e-4*180/pi =0.080° | 50.0 公里 |
| | (21.83-7.942)*1e-4*180/pi = 0.080° | 50.0 公里 |

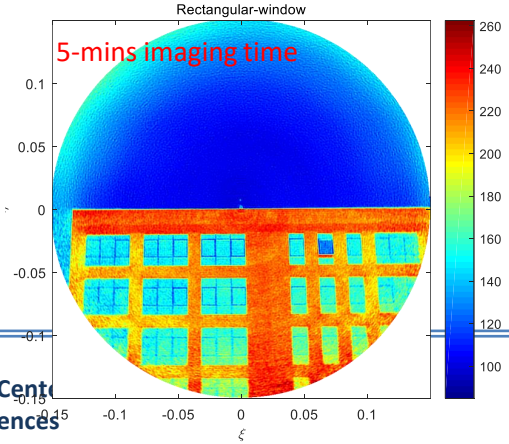
# Building imaging



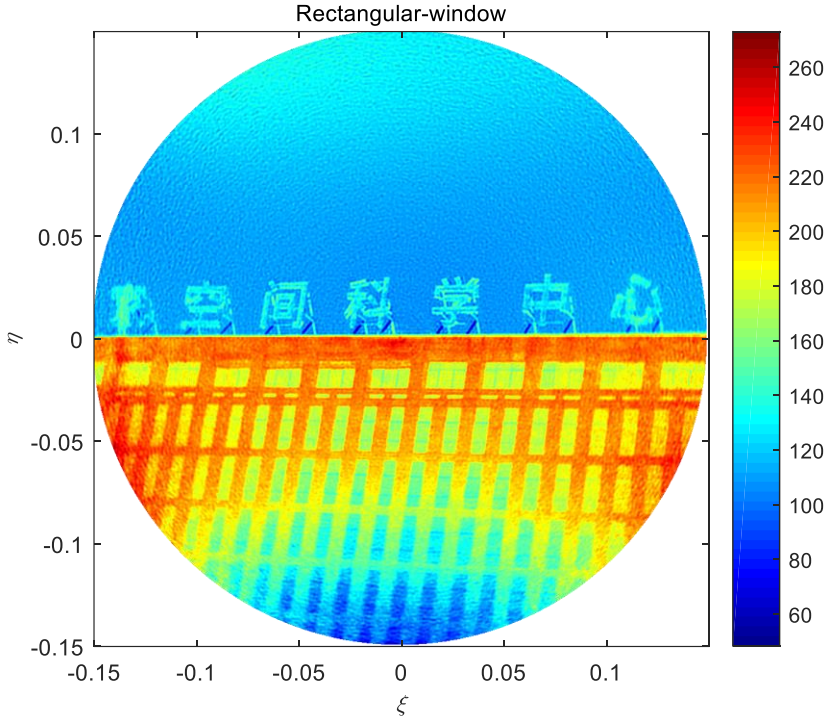


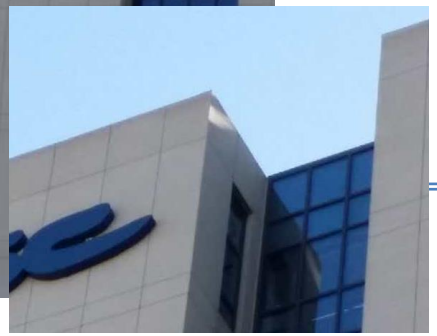



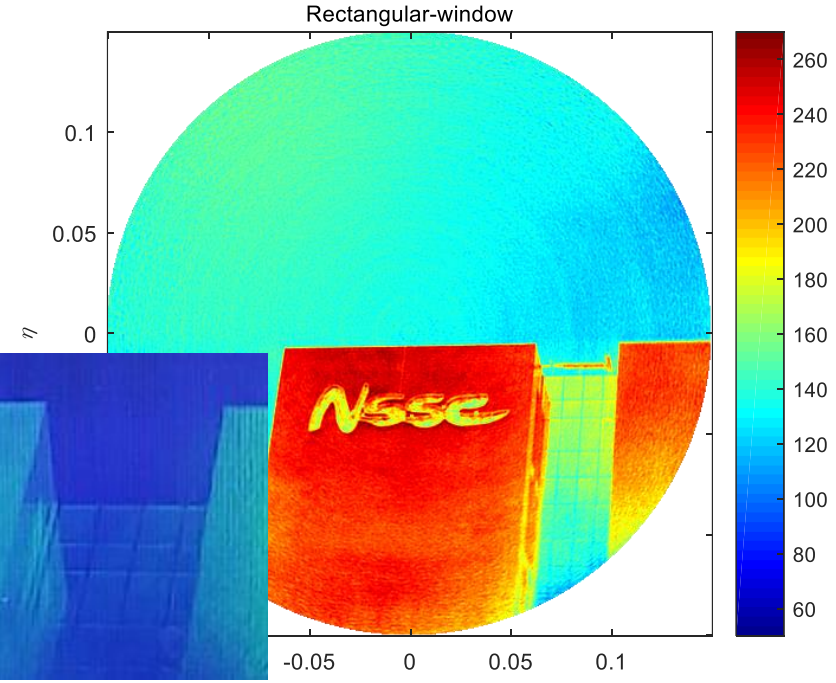




國家空间科学中心

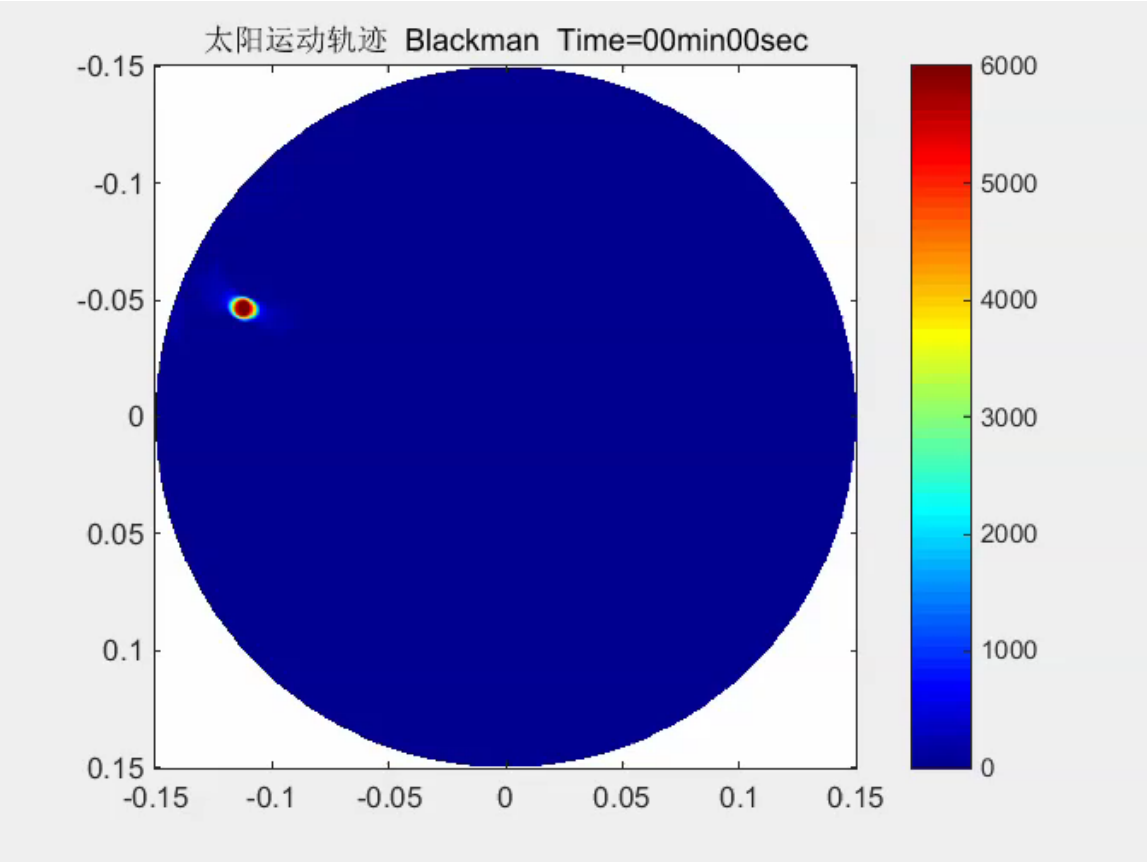

Rectangular-window
0.1
0.05
0
-0.05
-0.1
-0.15
η
-0.15
-0.1
-0.05
0
0.05
0.1
ξ
260
240
220
200
180
160
140
120
100
80
60

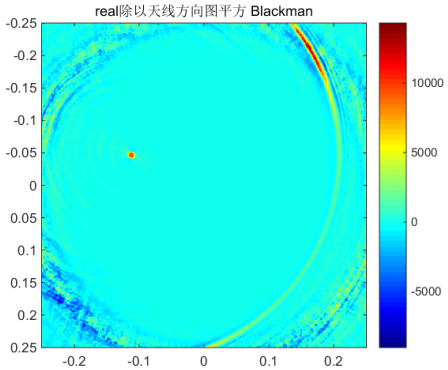

Nssc

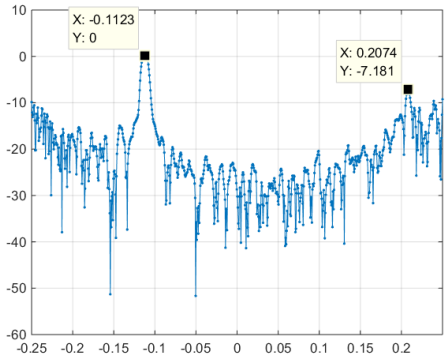



Rectangular-window
0.1
0.05
0
η
-0.05
0
0.05
0.1
260
240
220
200
180
160
140
120
100
80
60

# Solar transit



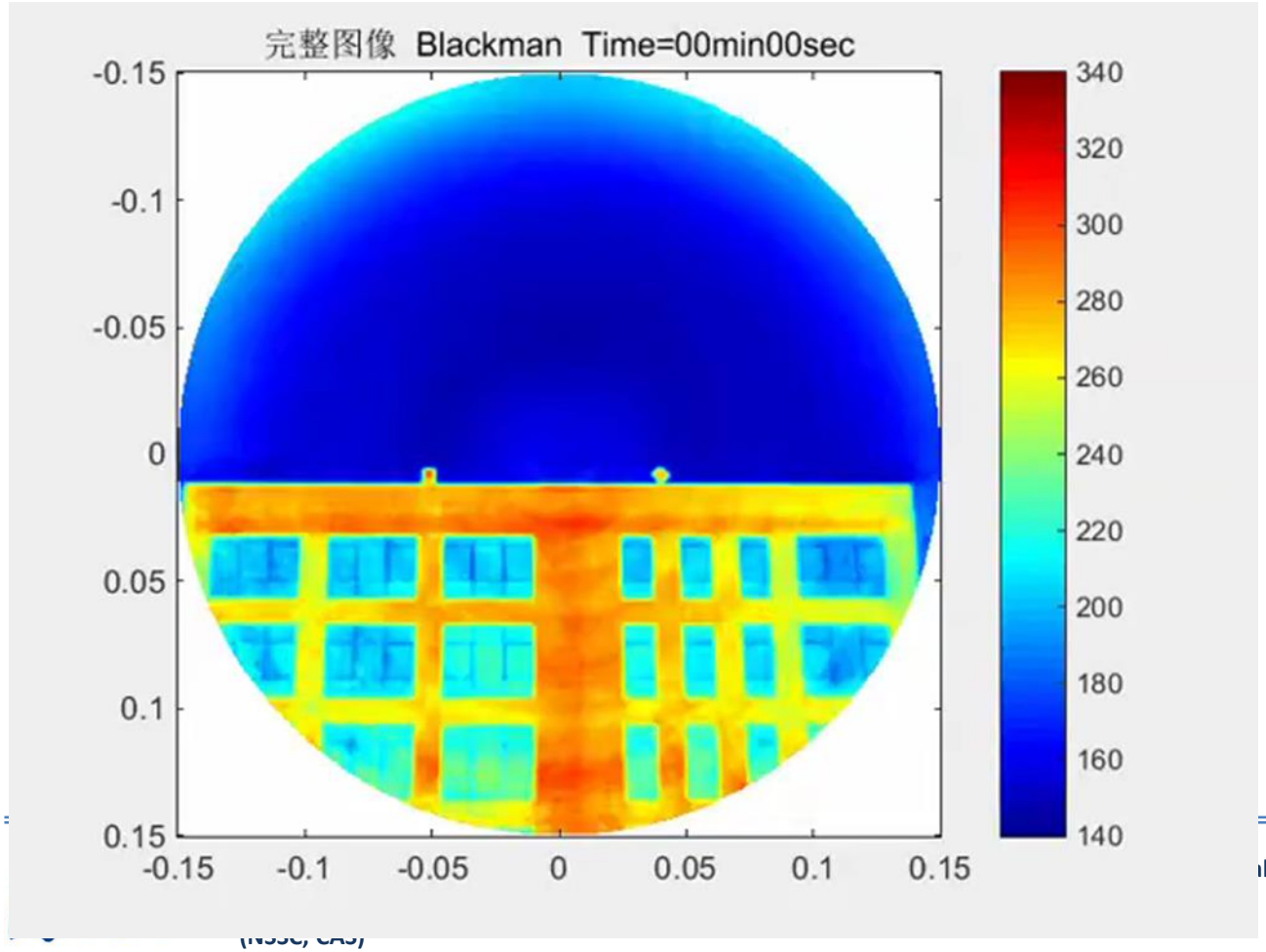

## Aliasing free field of view evaluation

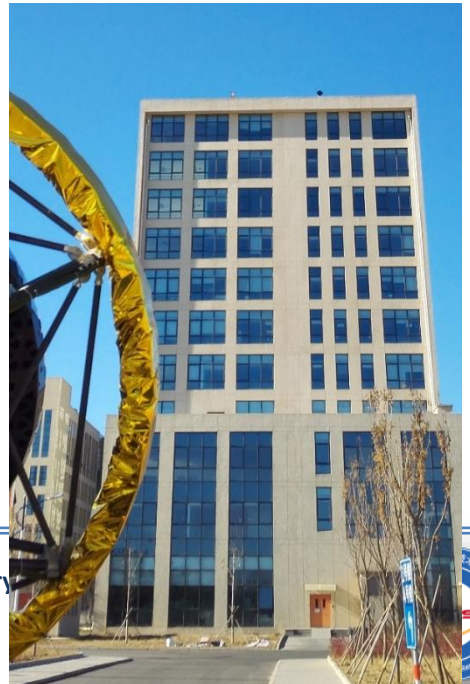
| | Results |
|---|---|
| Left-side grating-lobe | ±asin[(0.2074+0.1123)/2] = ±9.198° |
| Right-side grating-lobe | ±asin[(0.1336+0.1849)/2] = ±9.163° |

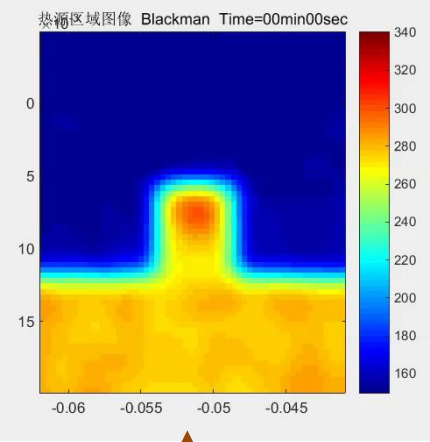

Key Laboratory of Microwave Remote Sensing
Chinese Academy of Sciences
(MiRS, CAS)

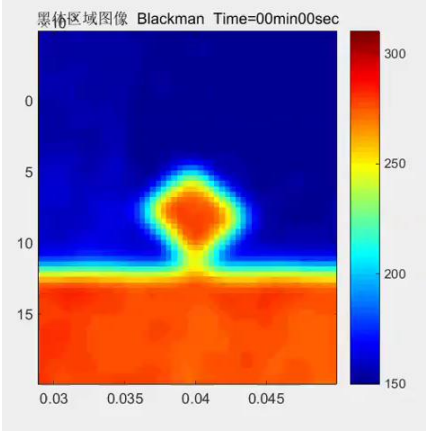
# Continuous Imaging Tests on Thermal Sources with Changing Temperature

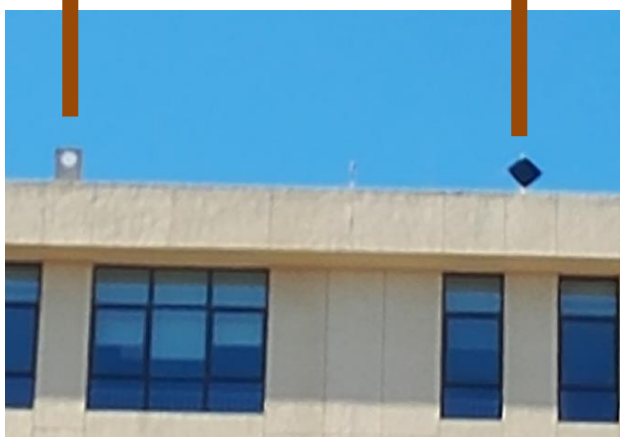
- Continuous Observation 110-mins
  - Hot Source（~20℃→60℃，switch-off）
  - Blackbody（illuminated by an heater，switch-off）

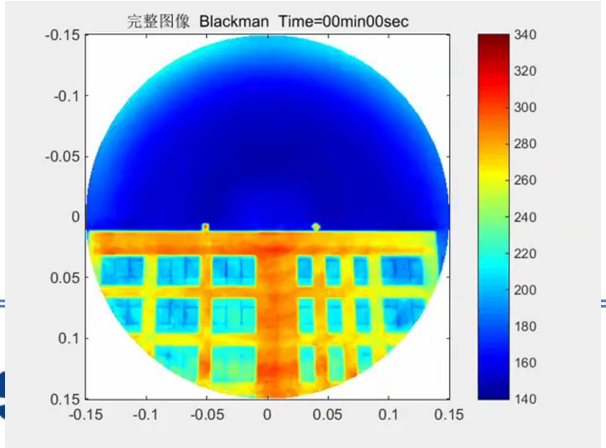


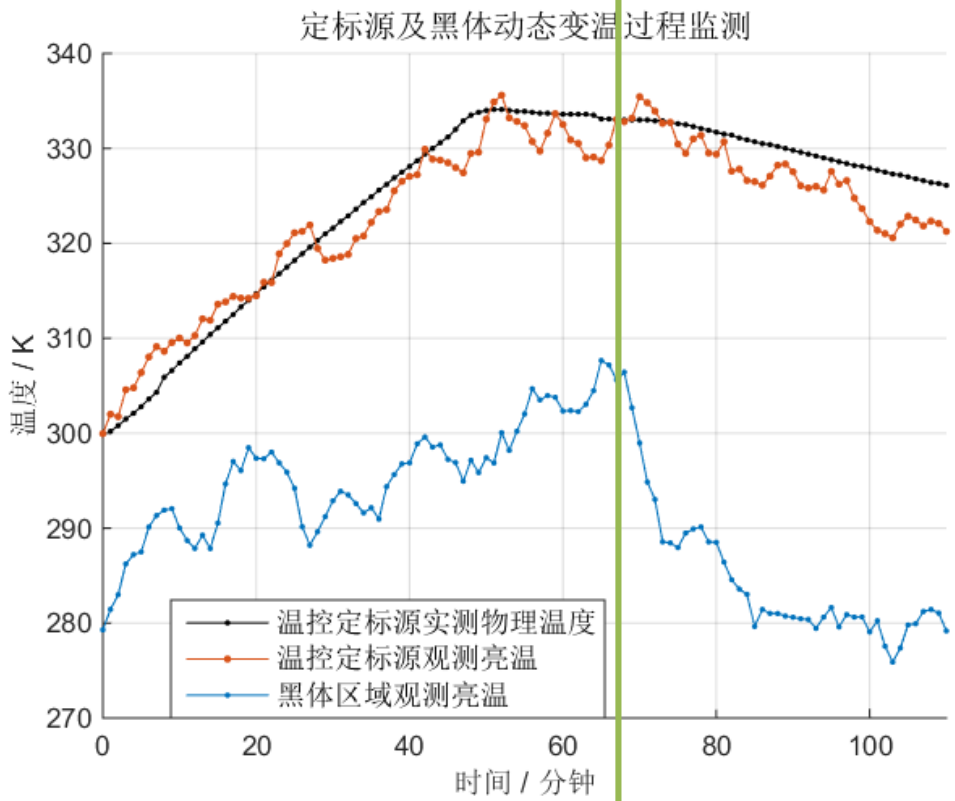








Key Laboratory of Microwave Remote Sensing
f Sciences
IiRS, CAS)

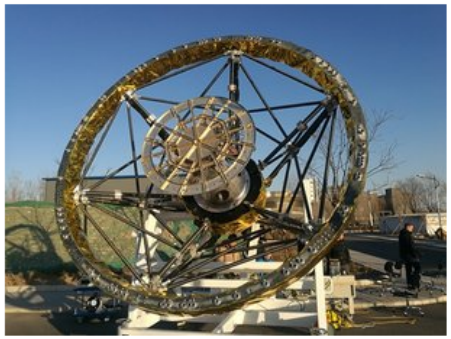
Switch-off

# Perspectives (1)

- 53/183GHz Joint-demonstration with ESA
  - 2015.01.30： PDR, ESTEC, Noordwijk, the Netherland
  - 2015.12.08： DDR, NSSC, Beijing, China
  - 2017.11.09： TRR, Omnisys, Gothenburg, Sweden

ESA > Our Activities > Space Engineering & Technology

## ESA AND CHINA TEAM UP ON TYPHOON-TARGETING IMAGER

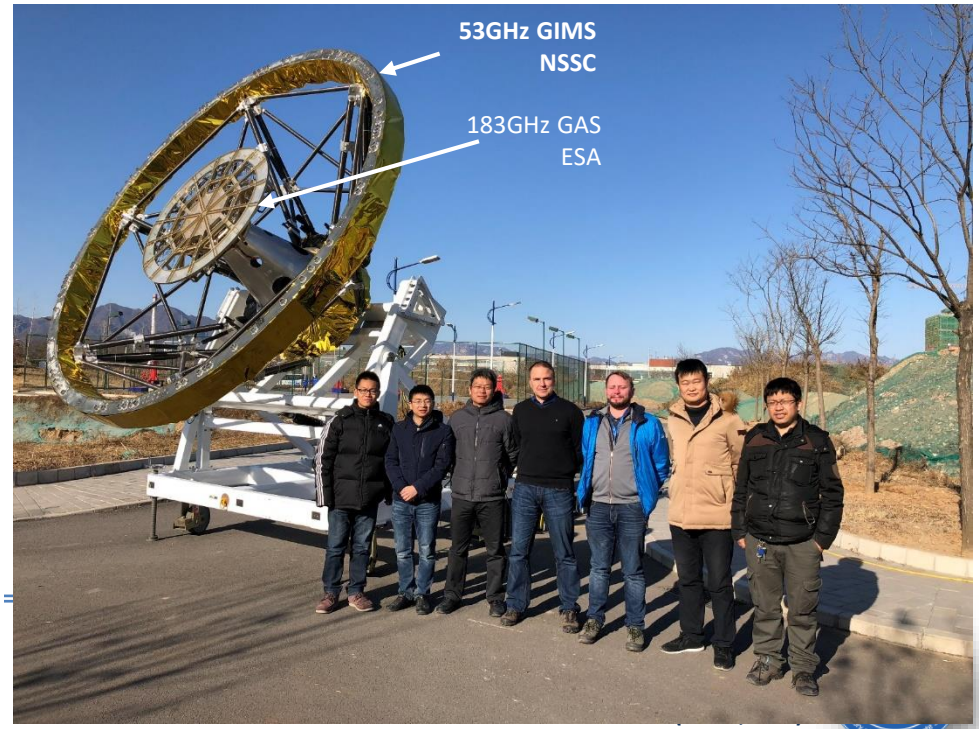


Prototype for ground testing

17 January 2018 ESA has teamed up with the Chinese Academy of Sciences to test an instrument capable of peering down from orbit through dense clouds and rain to sound the depths of typhoons and storms.

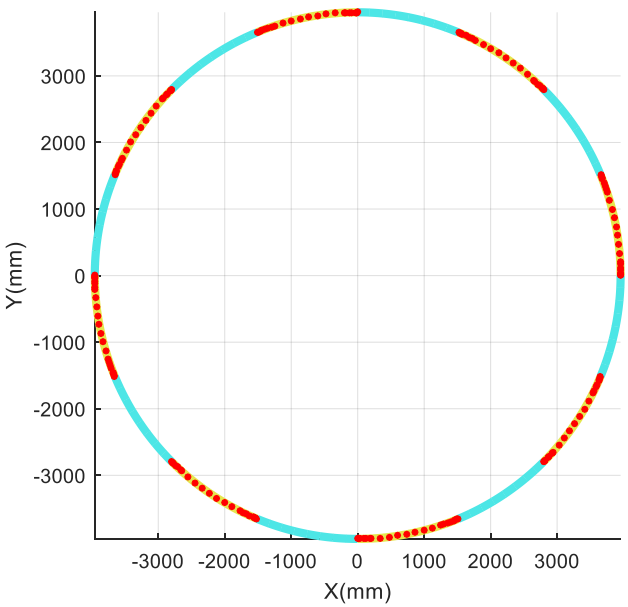
China's National Space Science Center – an entity under the Academy – in Beijing has built a 3 m-diameter prototype millimetre-wave instrument for ground testing. A smaller ESA-led instrument that works on a separate, complementary frequency band was slotted into it, then the combined instrument underwent ground testing.

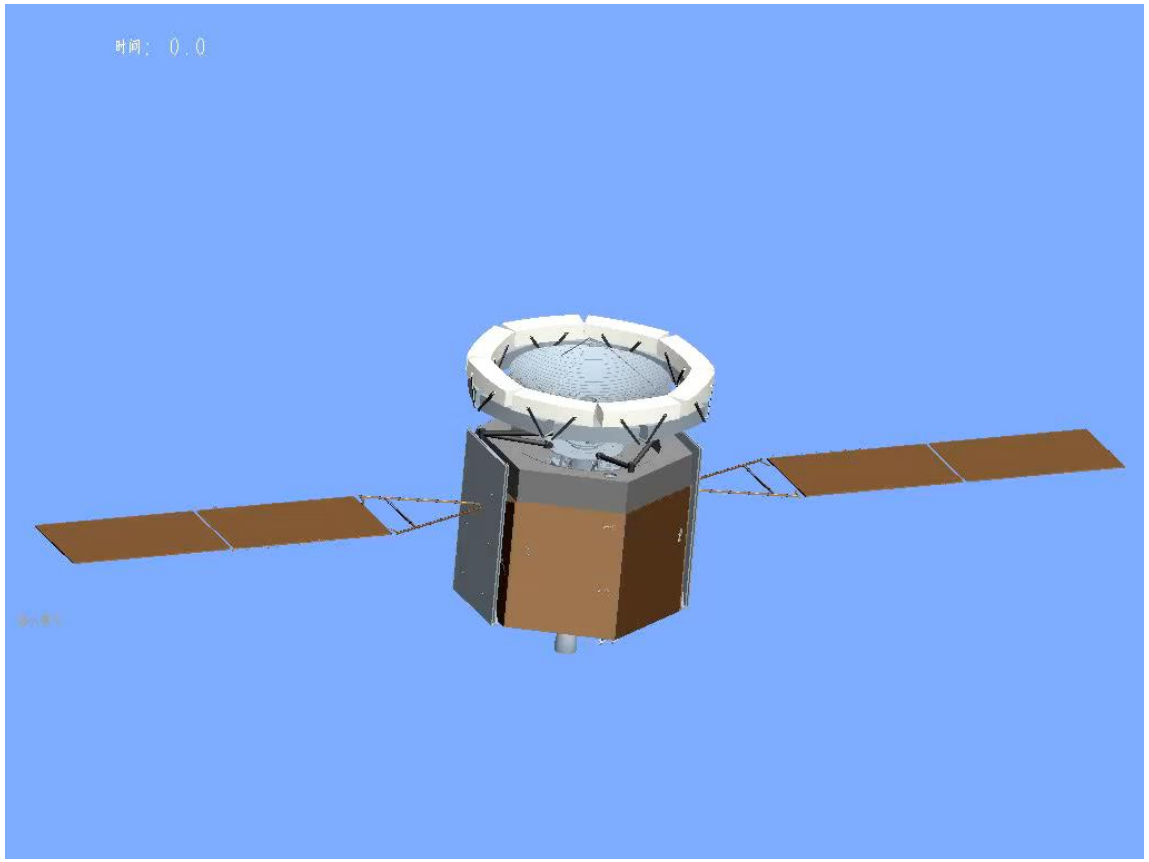
"China has an obvious interest in typhoons, and enhanced weather and climate forecasting is important to everyone," explains Peter de Maagt, heading ESA's Antennas and Sub-Millimetre Wave section.



# Perspectives (2)

- Improved GIMS Design with deployable sub-array structure




- 50GHz
- Physical dimension Da=7.91m
- Equivalent dimension: Db=14.82m
- Ground resolution: 24km
- Antenna elements：8*15=120


Thanks!