

On new-generation instruments for solar radio imaging spectroscopy

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National Major Scientific Research Facility R&D Program (ZDYZ2009-3)

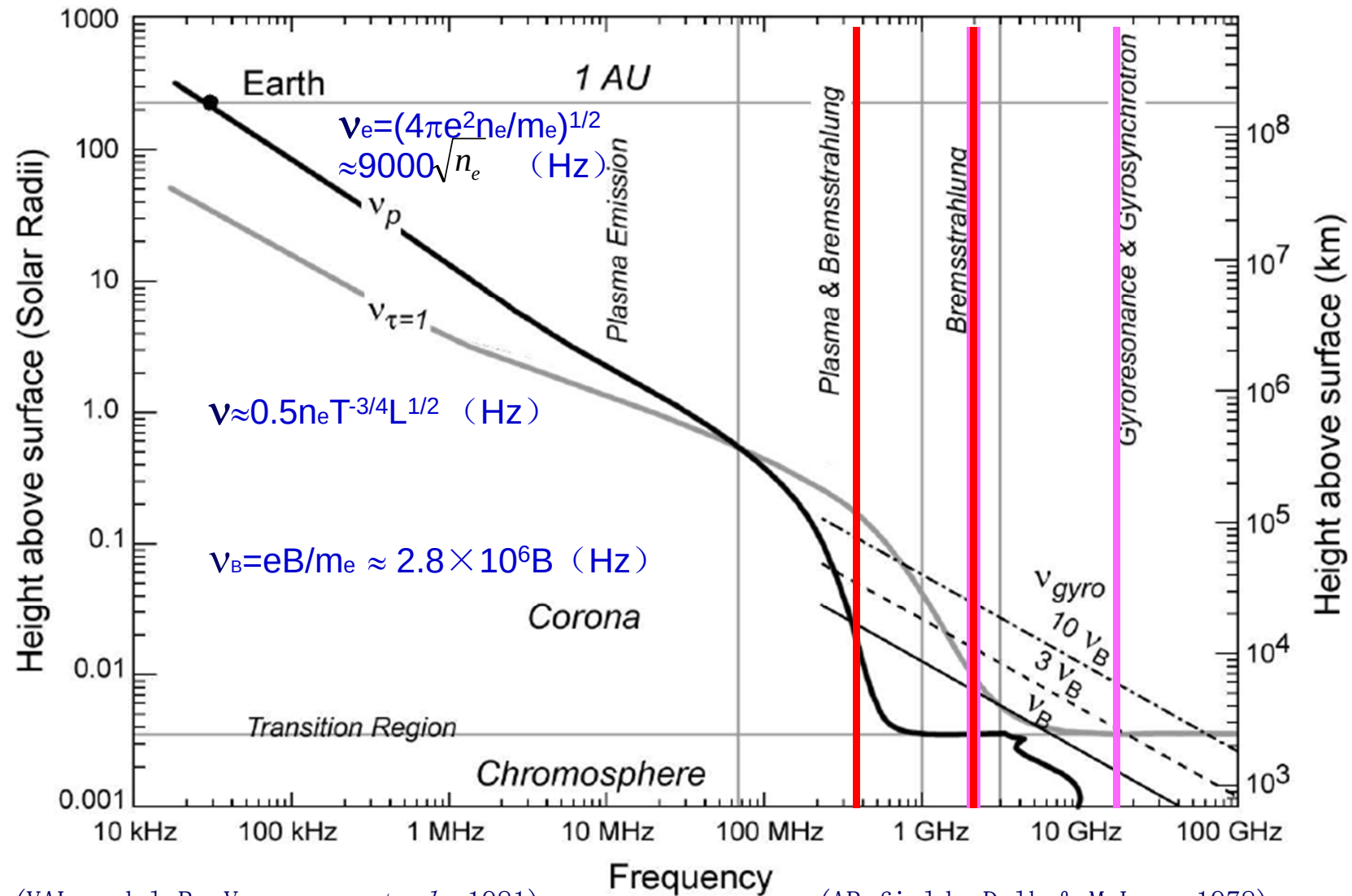
Outline

- **Motivation for radio imaging-spectroscopy**
- **Technical challenges:**
 - Issues due to **high cadence imaging at wide-band & >2 order higher multiple frequencies**
- **Introduction of CSRH progress**
- **Summary**

Scientific Motivations:

- **Radio bursts are prompt indicators of the various solar activities including flares and CMEs, etc.**
- **The available radio facilities are either with high time and spectral resolution but without spatial resolution, or with high time and spatial resolution but at only one or a few frequencies.**
- **Imaging spectroscopy over cm- λ & dm- λ is important for addressing the problems of primary energy release, particle acceleration, and transportation processes, and the coronal magnetic fields (Bastian, et al., ARAA, 1998; Gary & Keller 2004; Aschwanden 2004; Pick & Vilmer 2008).**

CSRH-I CSRH-II

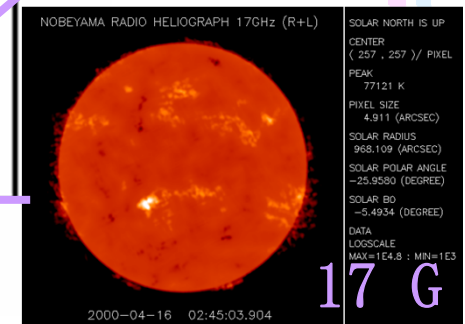
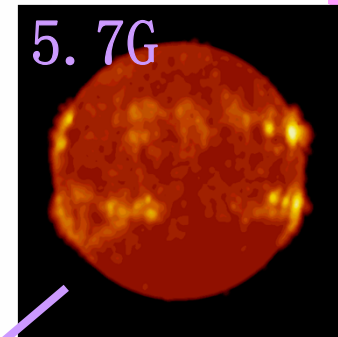
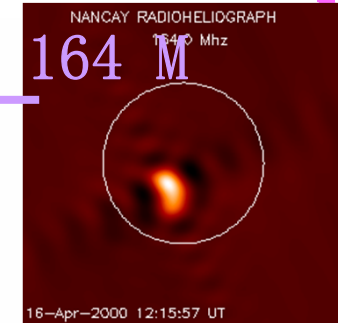
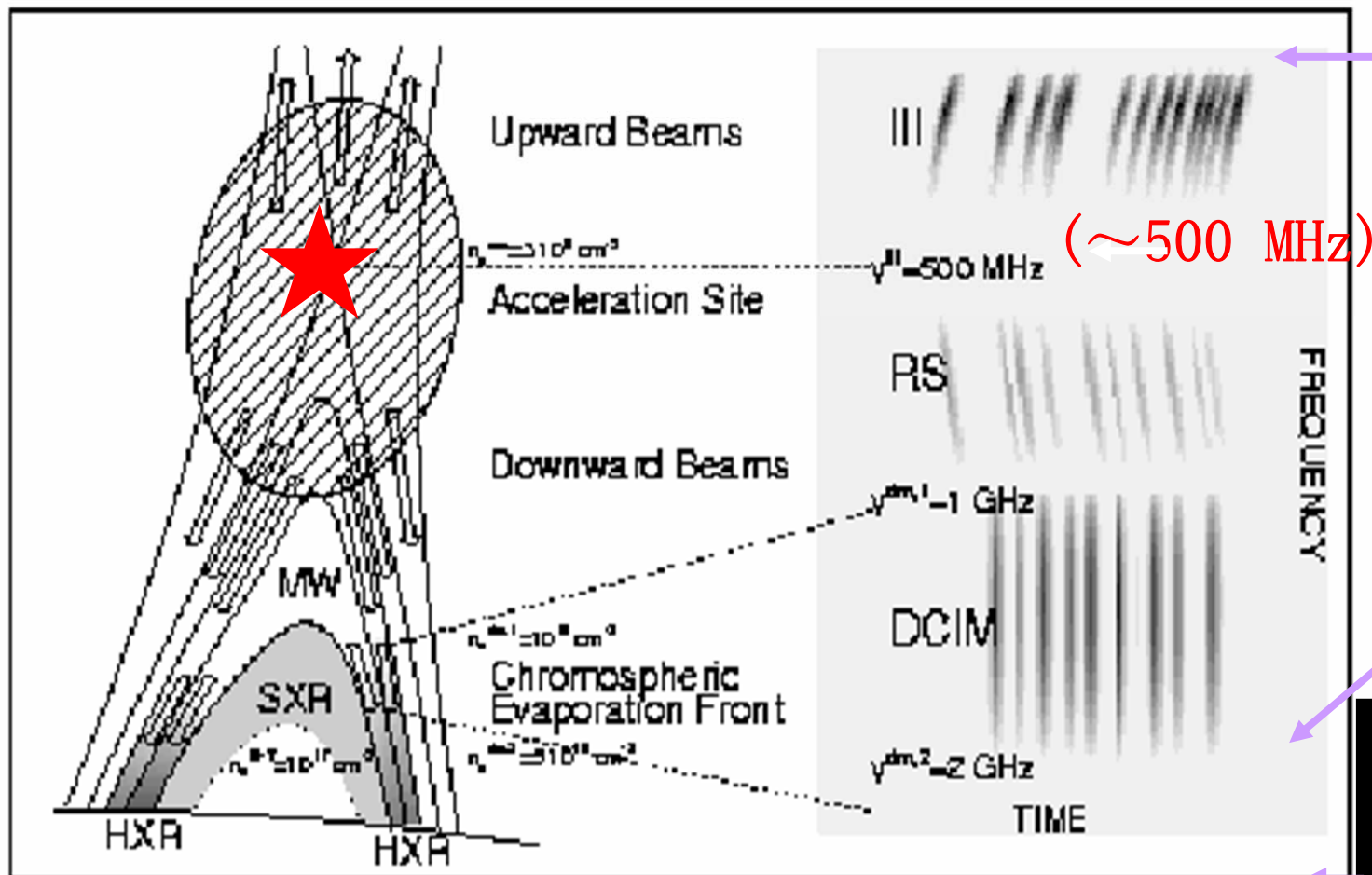


(VAL model B, Vernazza *et al.* 1981)
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(AR field, Dulk & McLean 1978)
Solar Physics with Radio Observations, Nagoya, 2012

(Gary *et al.* 2004)

40 - 150 MHz Gauribidanur, India



Solar bursts

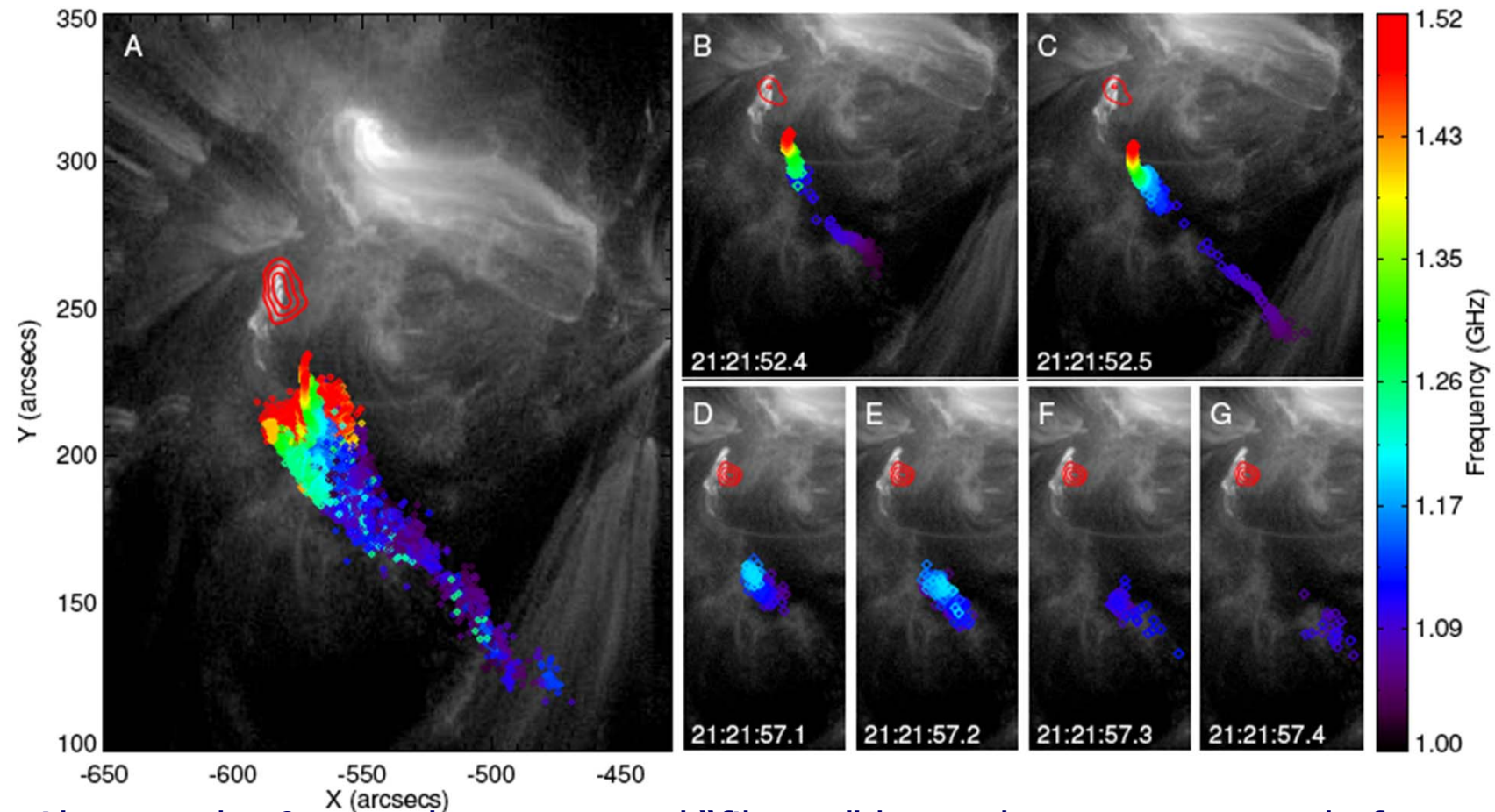
Aschwanden et al.

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Type IIIdm Bursts (Bastian's talk)

Chen et al.

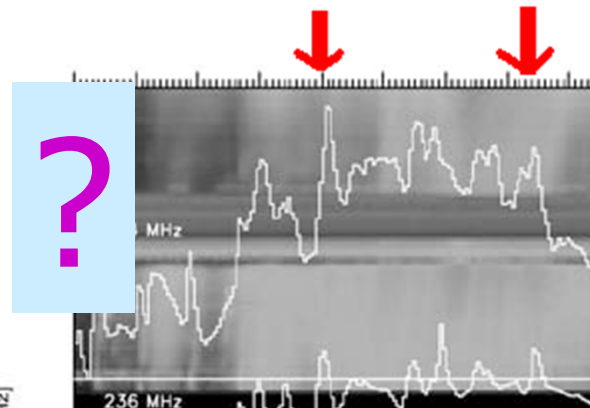
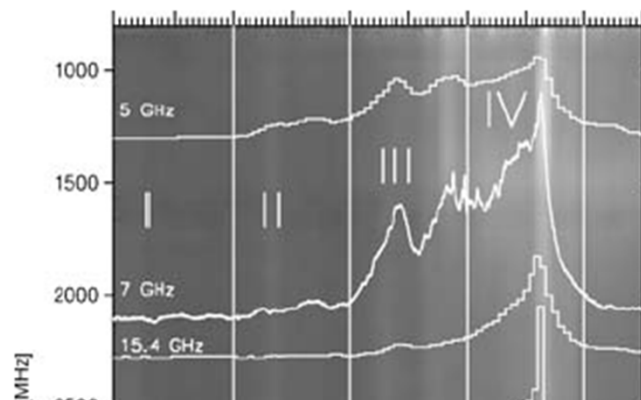


- Along cooler & over-denser coronal "fibrous" loops that are composed of unresolved "strands" and invisible in other band, e.g., EUV images.
- ⑩ → The need of radio imaging spectroscopy!

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Event study: 5-Nov-1998 flare



Radio
bursts
at 410,
327,
236, &
164 M

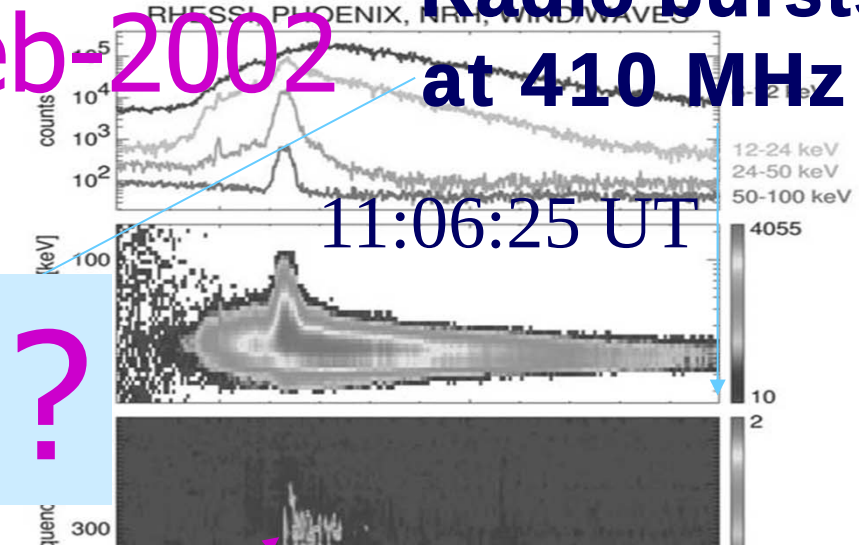
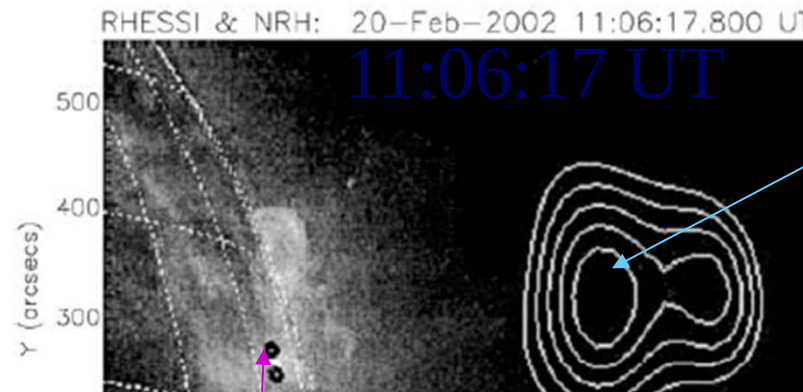
Why the radio and HXR sources are not aligned but, instead, in perpendicular?

⇒ Need multi-wave imaging observations in dm-cm ($\geq 400\text{MHz}$) ranges!

Trottet G., et al. (2006, Sol. Phys.)

Event study: 20-Feb-2002

Radio bursts at 410 MHz

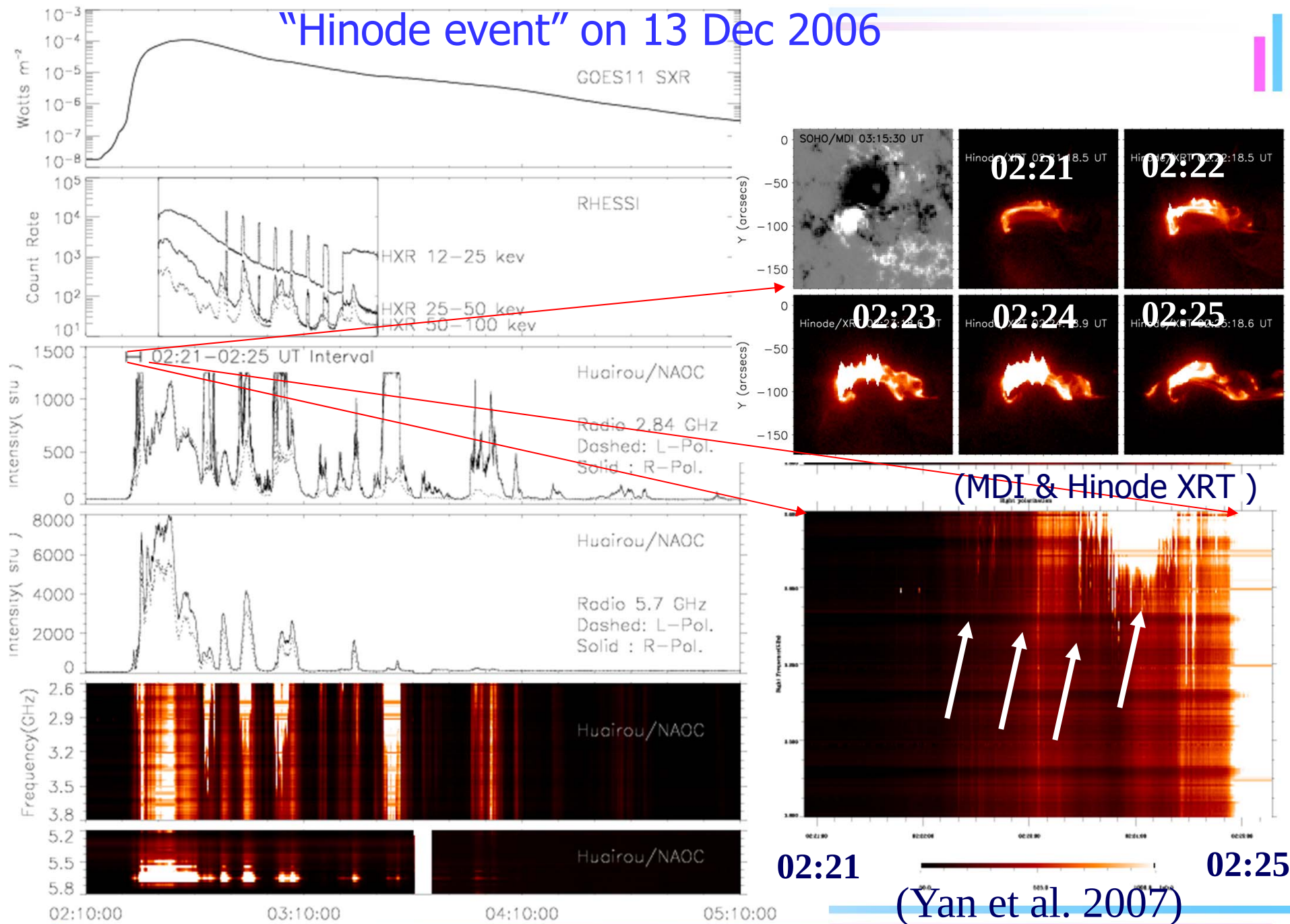


What is the magnetic structure connecting radio and HXR sources?

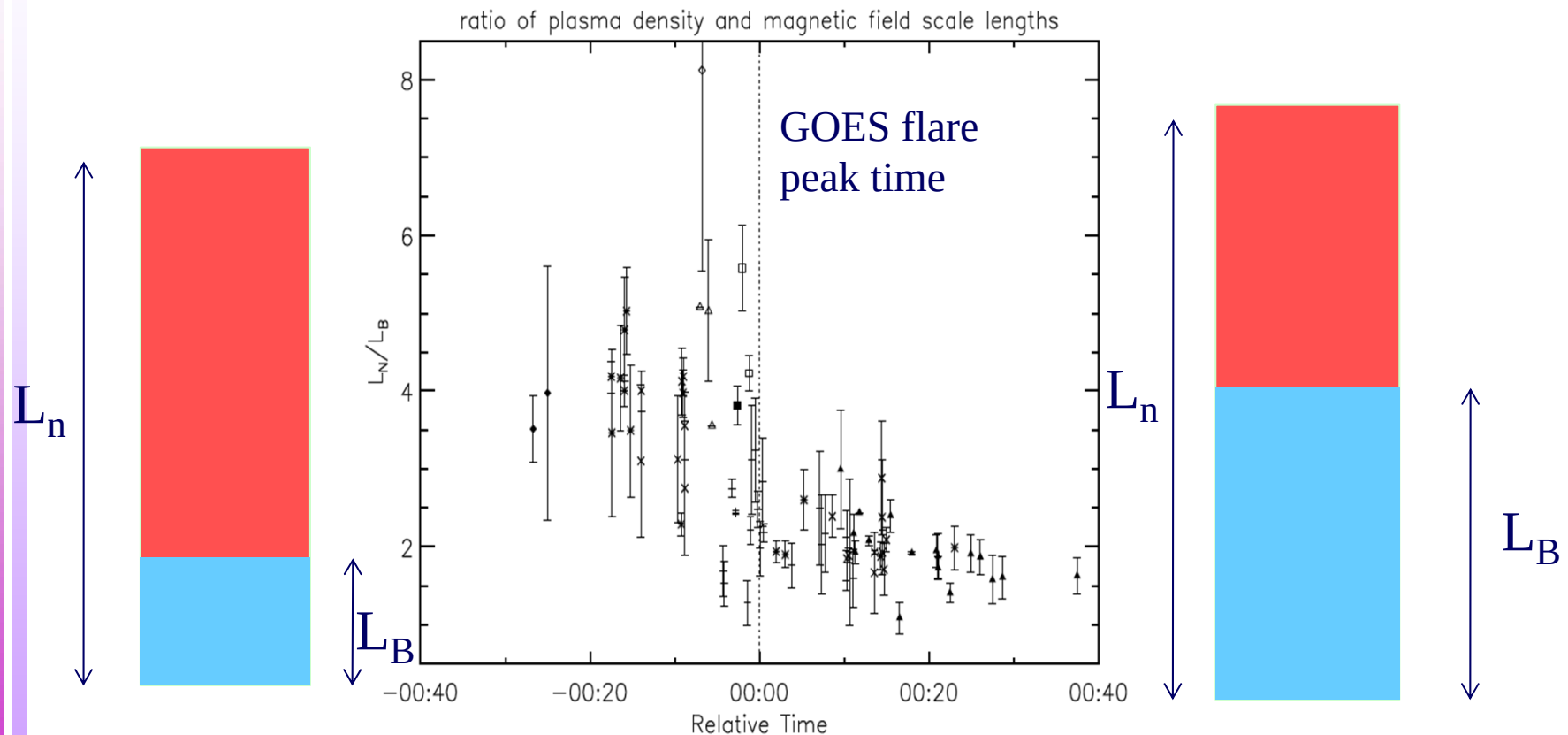
⇒ Need multi-wave imaging observations in dm-cm (≥ 400 MHz) ranges!

Vilmer N., et al. (2002, Sol. Phys.)

"Hinode event" on 13 Dec 2006



Statistic study of 74 ZPs show n & B scale height ratio L_n/L_B decreasing during flares (Yu et al. 2012, ApJ, in press)



What's the exact magnetic structure?

→ **require a new instrument:
capable of true imaging
spectroscopy, with high
temporal, spatial, and spectral
resolution ---- CSRH or
FASR**(Hudson & Vilmer 2007, Pick &
Vilmer 2008, Klein et al 2008).

How to reach this goal?

Main issues should be considered:

- high spatial resolution ----- λ/D
- High temporal resolution ----- computer throughput
- High spectral resolution ----- computer throughput
- Wide band coverage -----super-wideband feed
- Dual polarizations ----- isolation in wide band
- Dynamic range ----- optical transmission
- Sensitivity
- Data processing ----- huge data output

The challenges

- **To implement high cadence imaging at wide-band & >2 order higher multiple frequencies**
- **Data process for such a system**

Radio Imaging Techniques

1. Scan Aperture

Simple, but slow and low space resolution
synthesis

2. Multi-beam

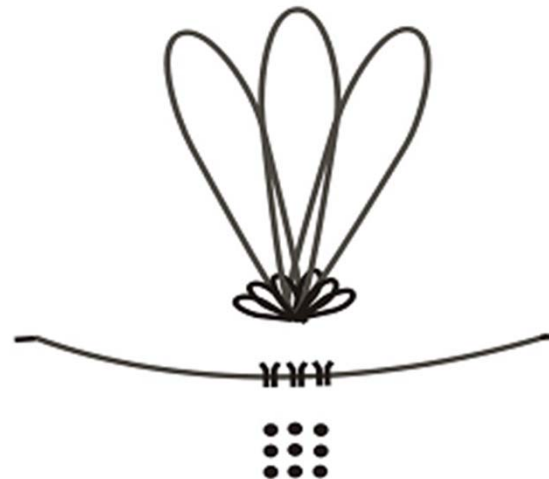
Single system, fast but low space resolution

3.

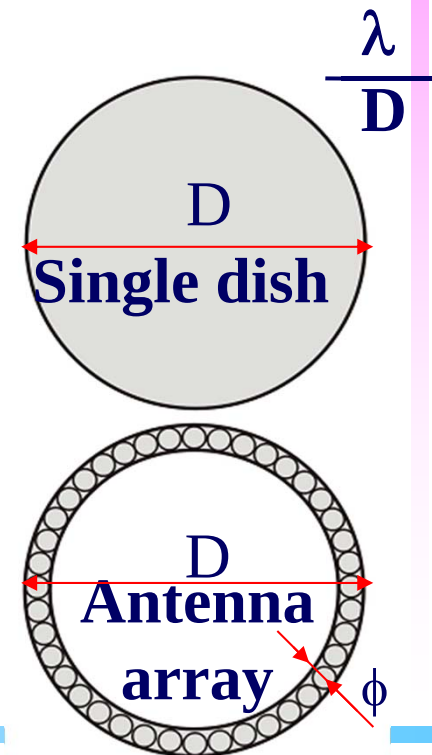
Fast and high space resolution but with complicated system,



单天线扫描观测成图的方栅格，
栅格间隔为 $\lambda / 2D$ 。



天线的焦点放置3 x 3的馈源阵，
形成多波束天线。



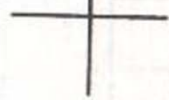
Aperture Synthesis Technique well-established:

Antenna

Array:

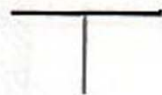
+

Circular



T

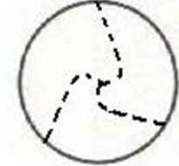
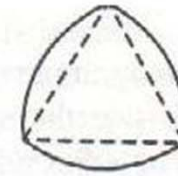
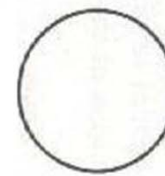
Tri-angle



Spiral



Y



Max

Baseline: D



D



D



D

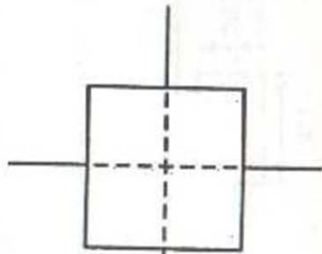


D



D

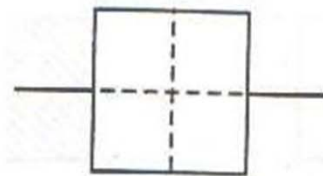
UV-plan distribution:



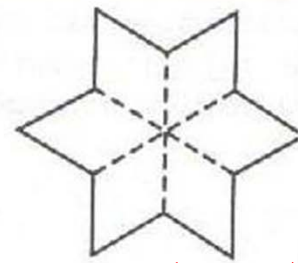
Max space
frequency:



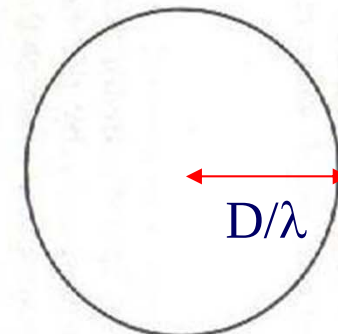
D/λ



D/λ



D/λ



D/λ

Issues to be solved due to wideband coverage & high cadence

Super broadband high performance feeds:

- wide impedance bandwidth, low profile, symmetrical radiation patterns and fixed phase center **over whole band**
- solar radio bursts and their polarizations normally vary quickly. Therefore the **polarization isolation is very important.**

Wideband digital correlation:

- Correlations at wide bandwidth

High performance data processing capacity:

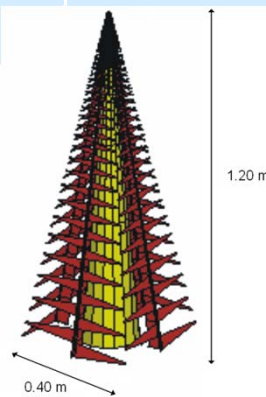
- CSRH-I with ~ 1.2 TB/day data at 25 ms cadence
- CSRH-II with ~ 3.2 TB/day data at 200 ms cadence

Some typical feeds for dual polarization wideband coverage:

	Super-wide band	Feed size	Symmetrical radiation patterns	fixed phase center
Log-periodic dipoles	yes	large	no	no
Sinus antenna	yes	OK	yes	Depend on types
Horn feed	no	large	no	no
Eleven feed	yes	OK	yes	yes
etc				

ATA feed:

Too large
&
Problem with phase center variations

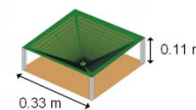


Eleven feed:

Eleven times smaller

&

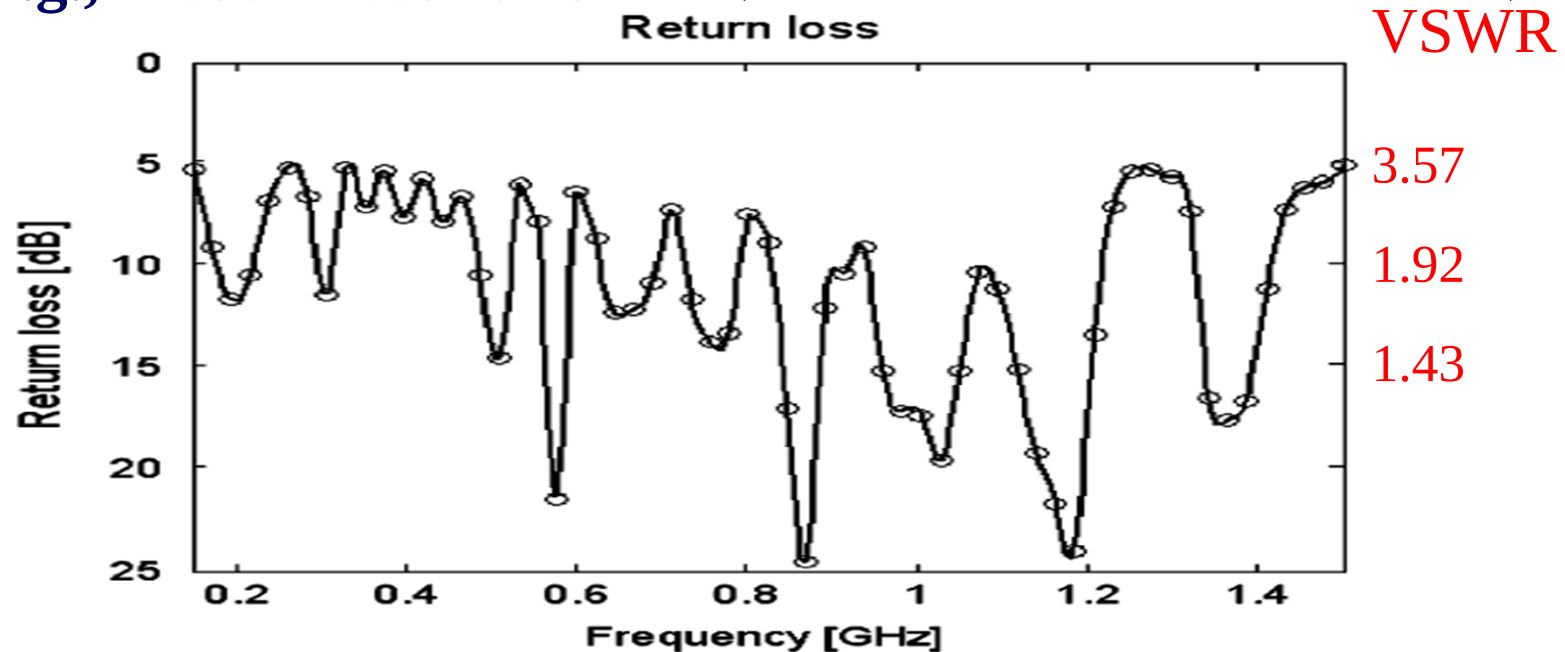
No problem with phase center variations



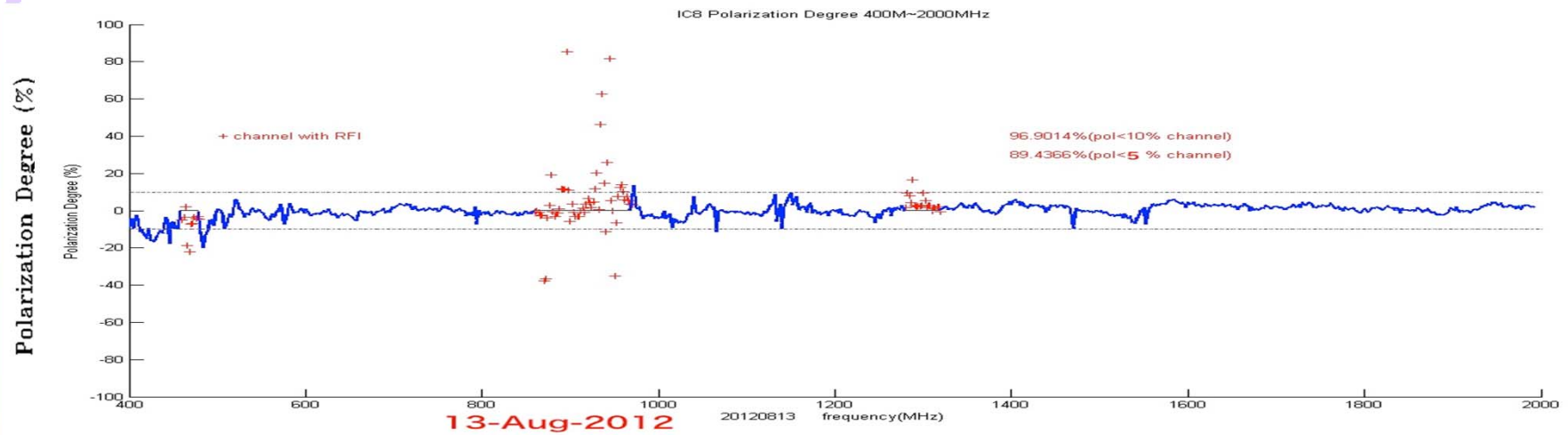
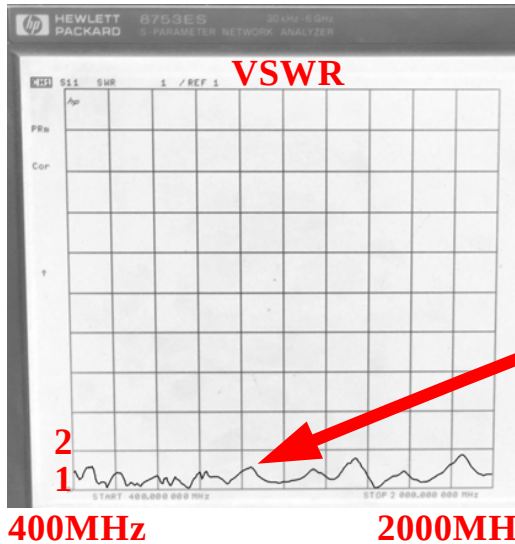
High Performance Feed Development

The available Eleven feed cannot meet the needs of solar observations as some parameters including VSWR, cross circular polarization degree are not with high performance.

E.g., Eleven Feed for SKA (Olsson, Kildal, Weinreb 2006, IEEE)



Test for high performance feed



(2011 March 4) Frequency (MHz)

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History for Constructing Chinese Radioheliograph

- The Chinese solar physics community had planned to build a radioheliograph since 1960s. Some pre-studies were carried out on proposals for radioheliograph in either centimeter-band (Hu et al. 1984) or millimeter-band (Fu et al. 1997), but none of these had been implemented.
- Following these lines, it was suggested to build a Chinese Spectral Radioheliograph (CSRH) in the dm- to cm-wave range with a limited budget, and later recommended as one of 2 major ground facilities by Chinese solar physics community in 2006.
- A 2-element prototype interferometer had been built and tested for CSRH overall design in 2004-2005 with 3M RMB from MOST.
- MOST grant 1M RMB, NSFC grant 1.6M RMB & CAS grant 3 M RMB since 2006 for tackling key technology.
- MoF fund 65M RMB for CSRH construction during 2009-2013.

CSRH Specifications

(Yan et al. 2009, Earth, Moon Planet)

Range	~0.4–15 GHz (λ : ~75 –2 cm)	
Frequency Res.	64	chan (I: 0.4-2 GHz)
	>32(~500)	chan (II: 2-15 GHz)
Spatial Res.	1.3"– 50"	
Temporal Res.	I: ~ 25 ms	
	II: ~200 ms	
Dynamic Range	25 db (snapshot)	
Polarizations	Dual circular L, R	
Array	I: 40×4.5m	
	II: 60×2m	parabolic antennas
Lmax	3 km	
Field of view	0.6°– 7°	

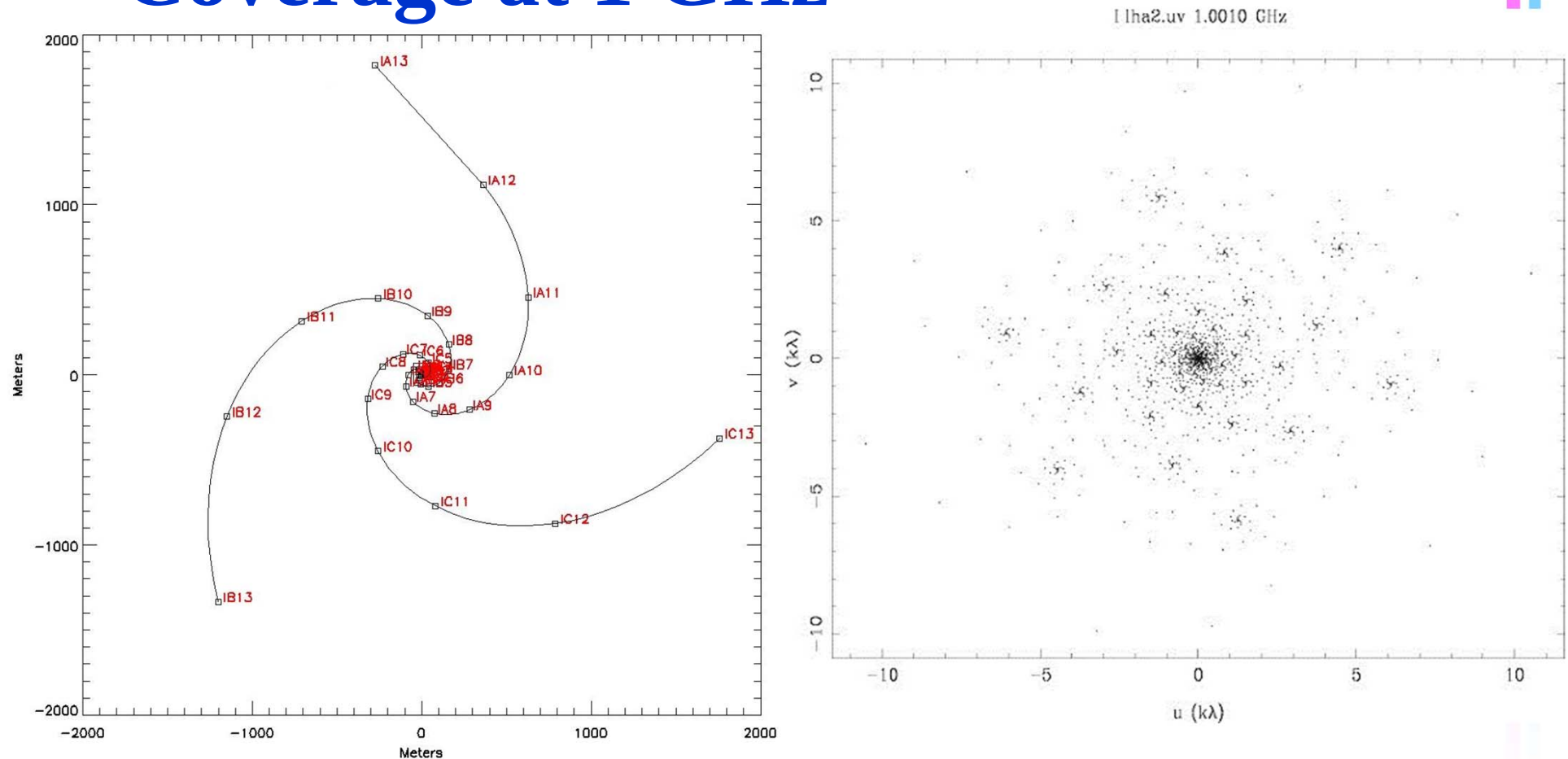
Present Solar Radioheliograph

Array	NRH	CSRH	NoRH	EOVSA
Freq. range	150 - 500 MHz	I : 0.4-2GHz II : 2-15GHz	17 GHz 34 GHz	1 – 18 GHz
Freq. chan	5	I:64 + II:>500 @1.6 - 25MHz	2	~500@122 kHz ~50 MHz
Antennas	43	I:40 + II:60	84	15
Baselines	903 (redundant)	I:780 II: 1770	3486 (redundant)	105
correlator	Time domain	polyphase filter bank+correlation	Time domain	FX

Correlation capacity	$903 \times 5 = 4515$	$780 \times 16 = 12480$ + $1770 \times 16 = 28320$	$3486 \times 2 = 6972$	$105 \times 12(?) + \text{RFI rejections}$
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Note: SSRT at 5.7GHz is not a aperture synthesis system

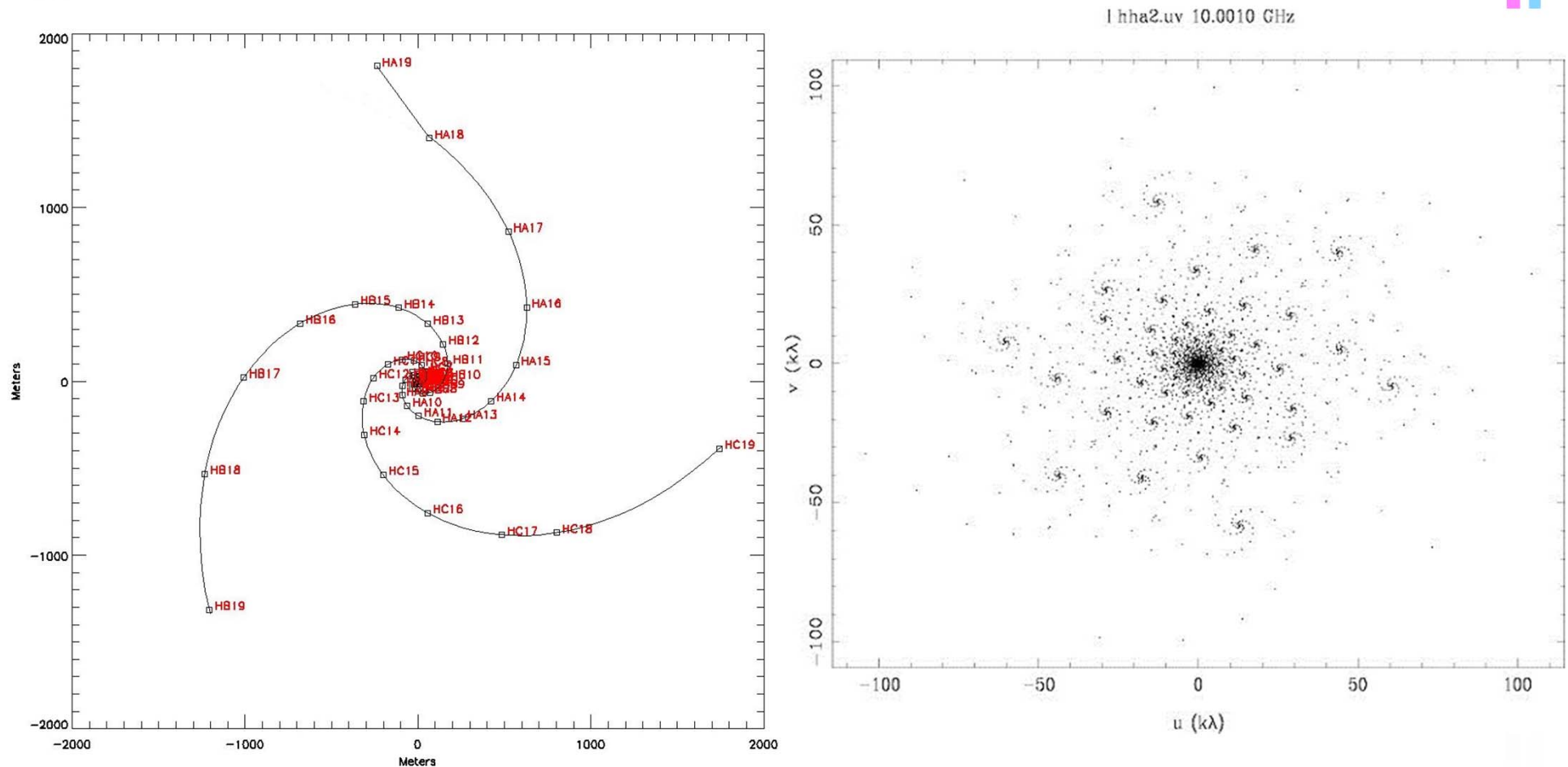
CSRH-I 40-antenna Array & UV Coverage at 1 GHz



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CSRH-II 60-antenna Array & UV Coverage at 10 GHz



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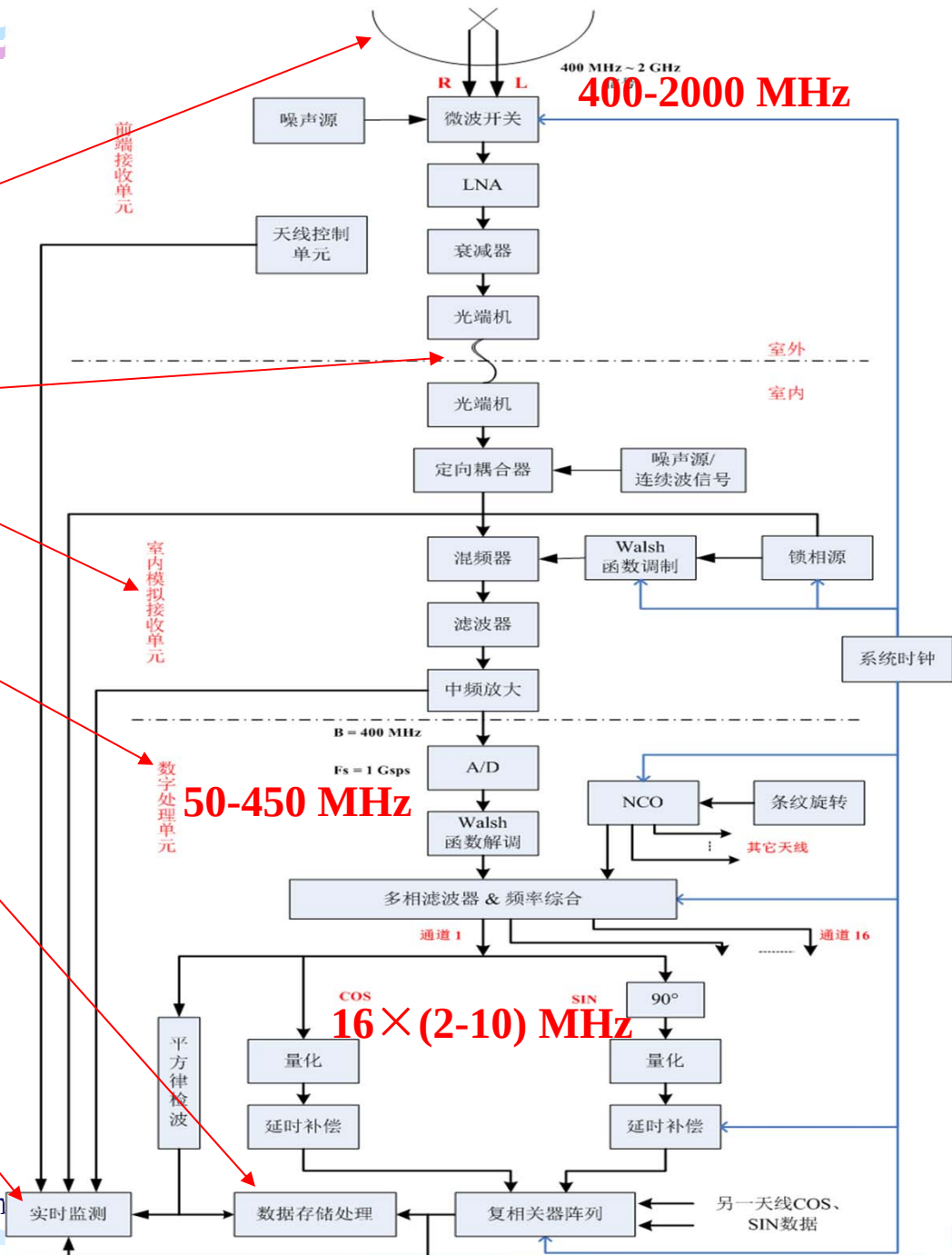
CSRH-I Block Diagram in 400MHz-2 GHz

- Antennas & feeds
- Op T/R & Analog
- Digital Correlation
- Monitoring
- Data Storage & Pre-processing
- Image Processing

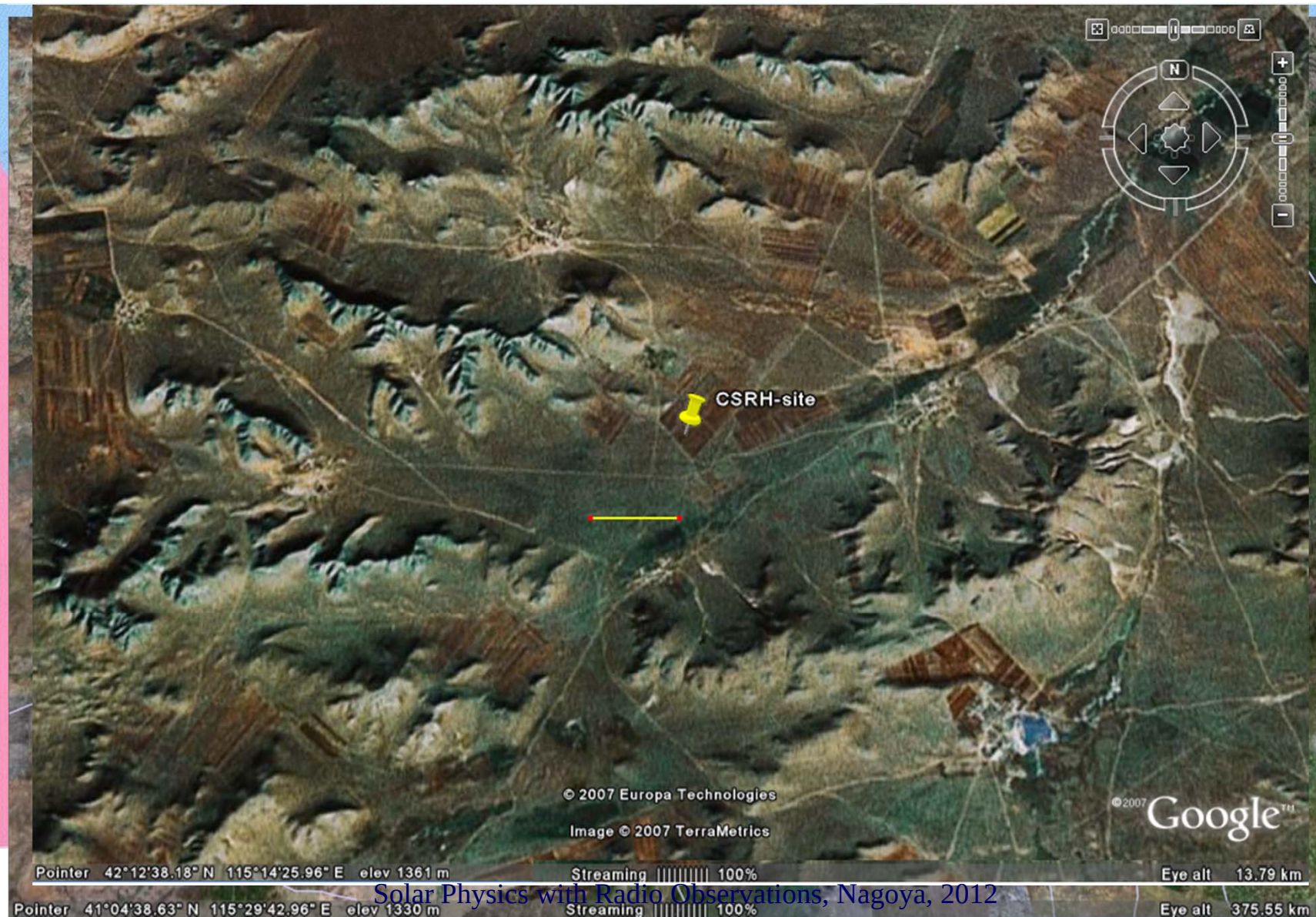
Similar for CSRH-II
in 2-15 GHz

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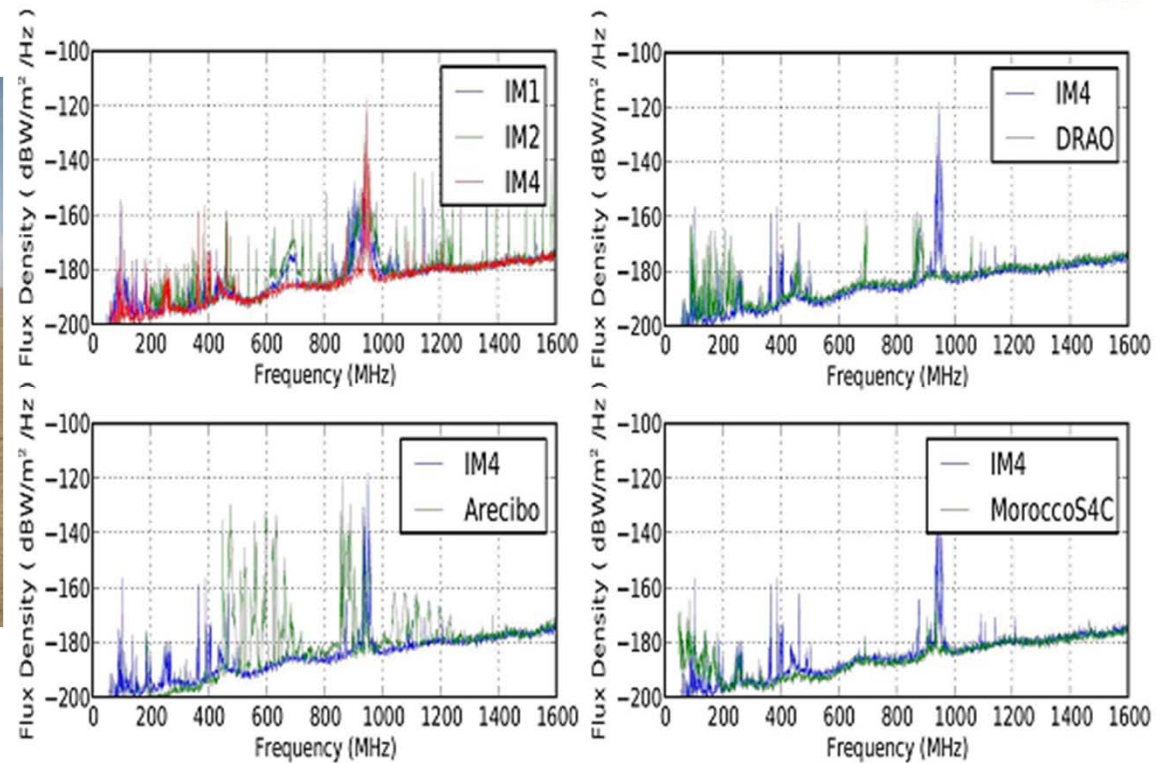
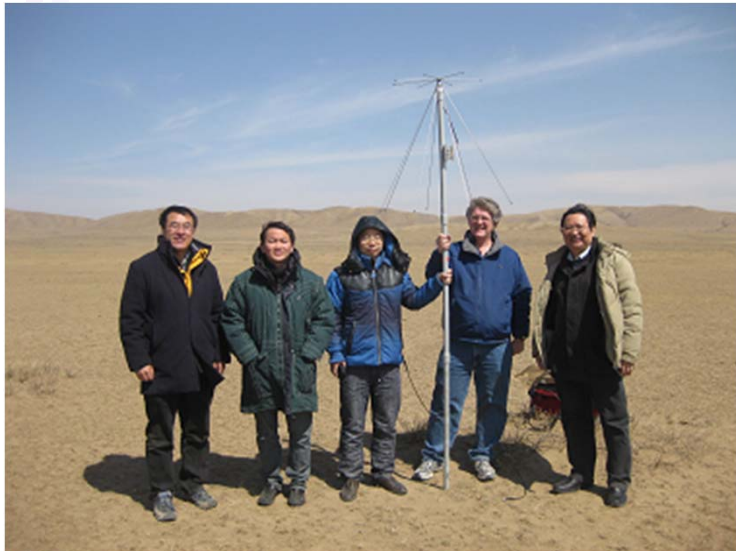
Solar Physics with



Site and Construction of CSRH



50MHz–1600MHz RFI Measurement (24–25 April 2010)

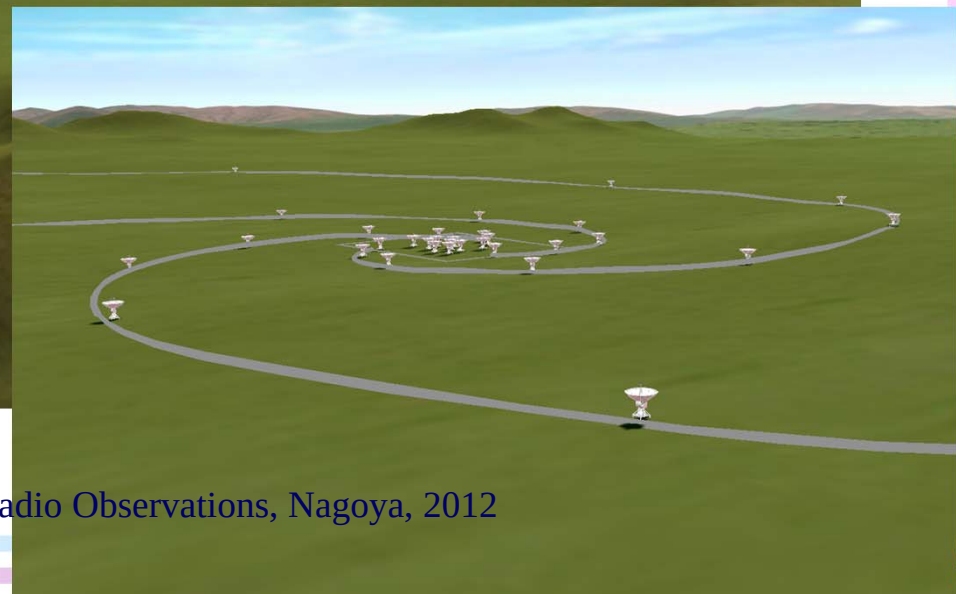
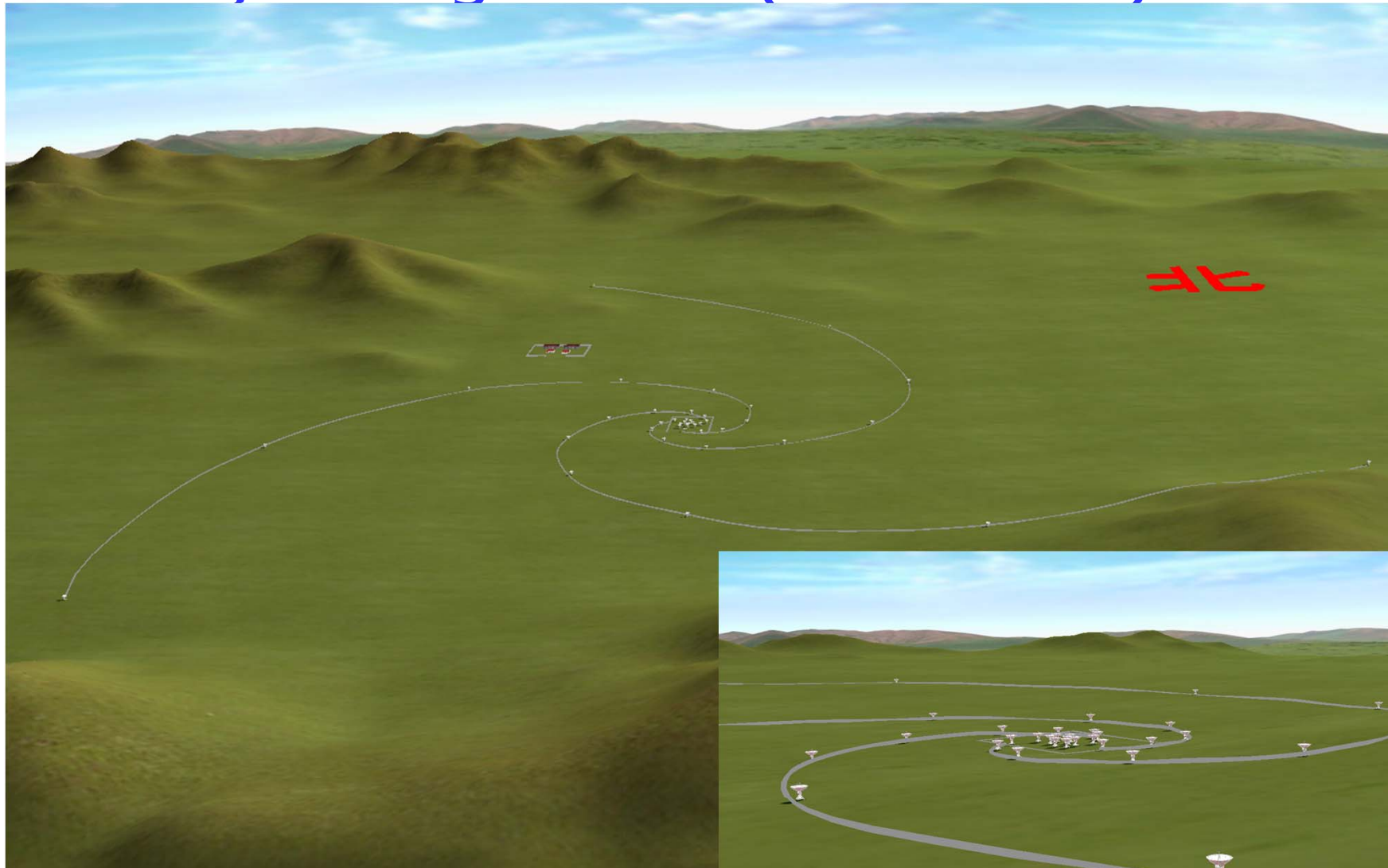


Comparison with Arecibo, DRAO & Morocco.

Ceremony for Construction of CSRH at Ming'antu Observatory on 9/9/2008



Array configuration (simulation):



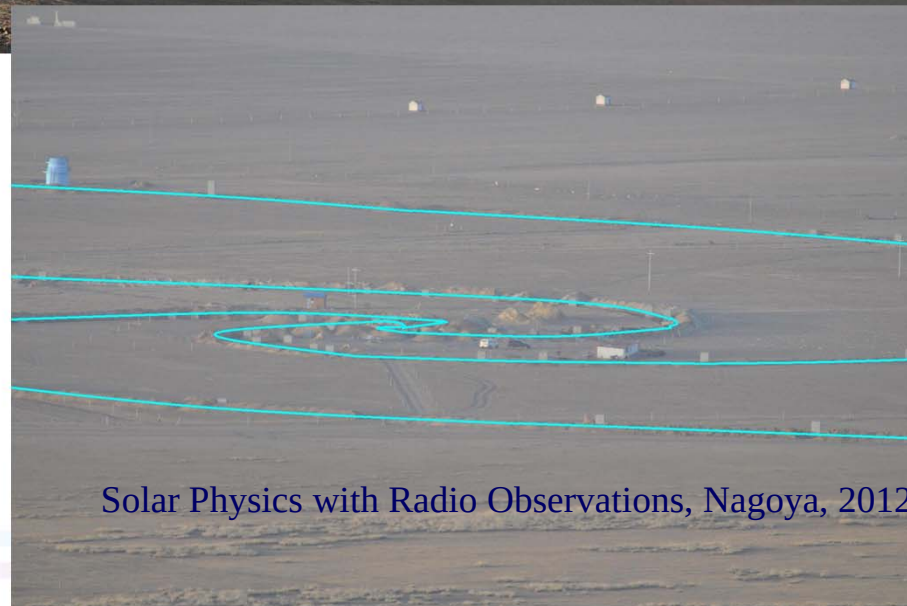
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Array construction:



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Optical fibers deployed

2009.9.8



2009.11.8

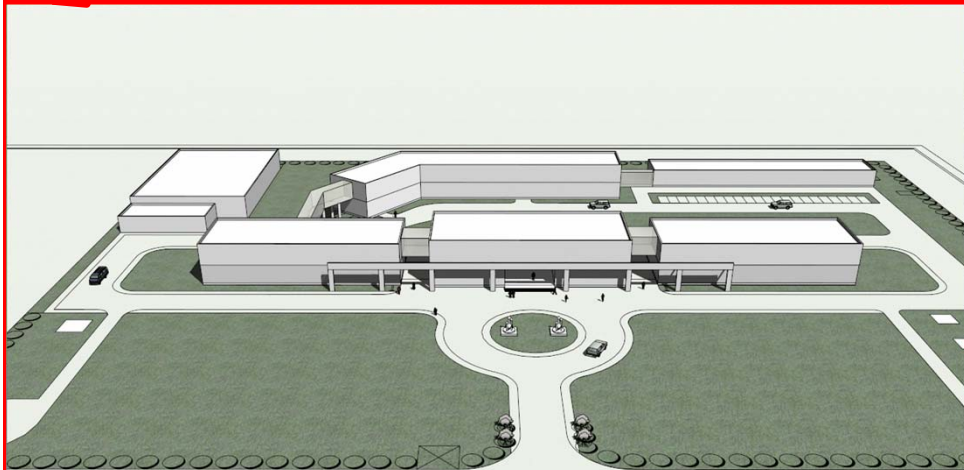
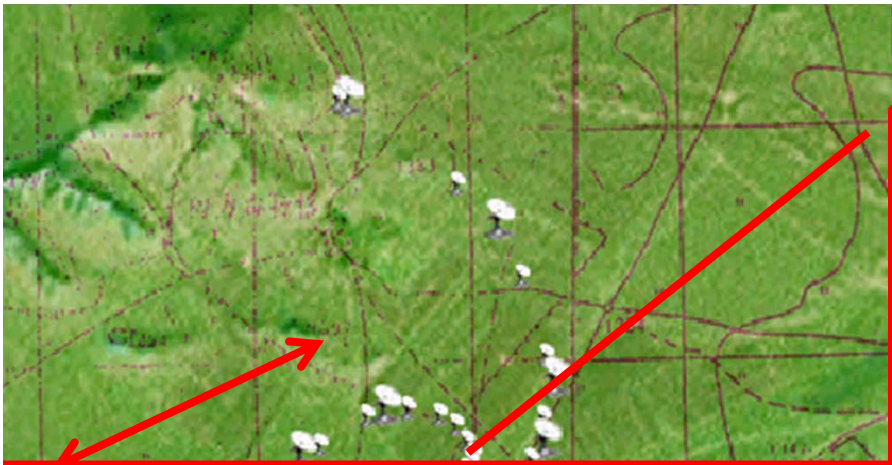


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12

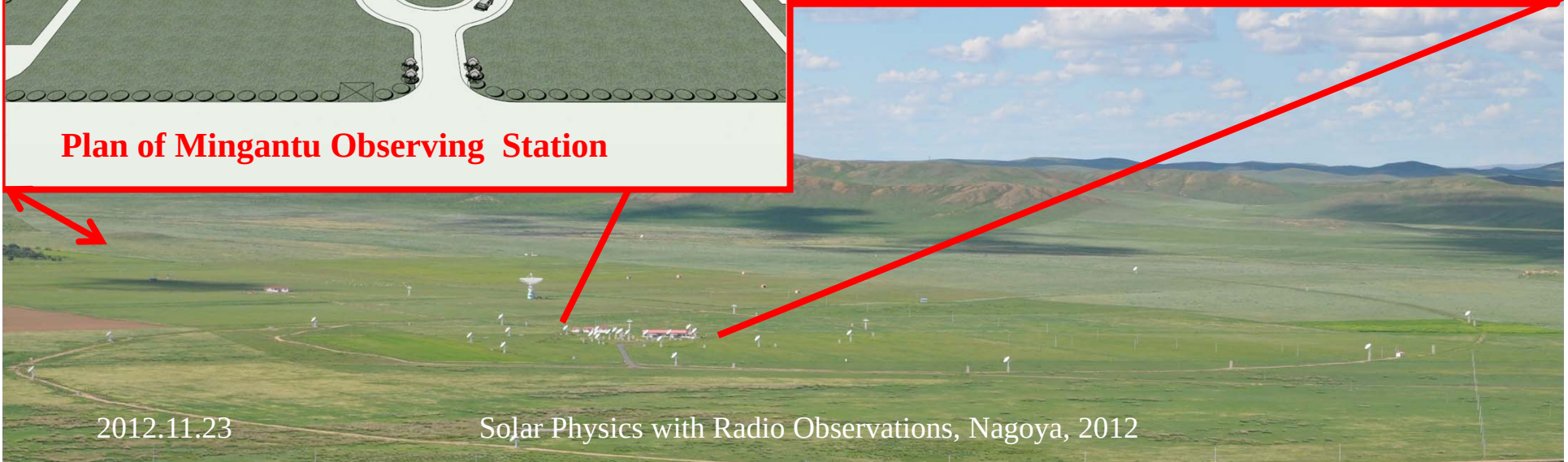
Array Construction



Plan of Mingantu Observing Station



Aug 2012

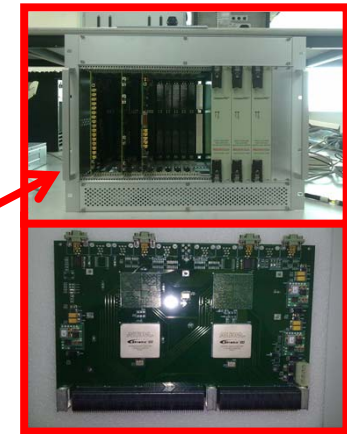
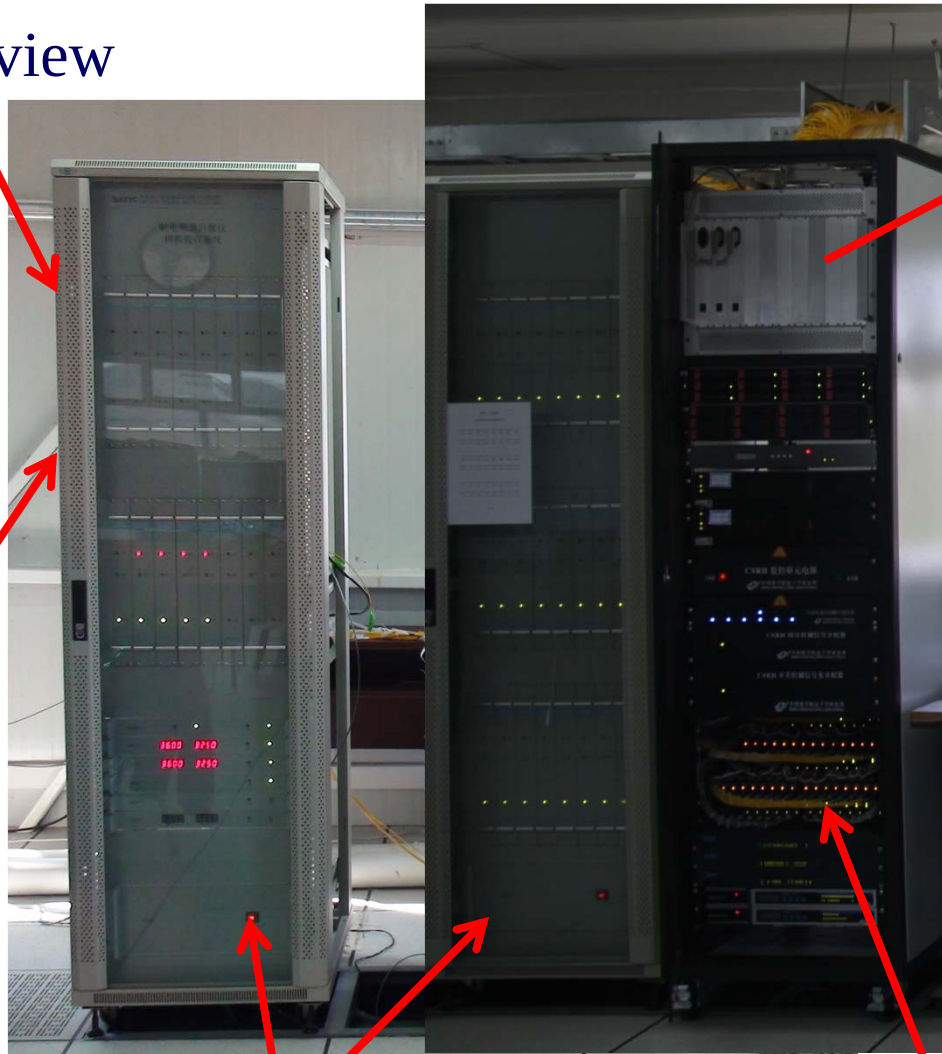
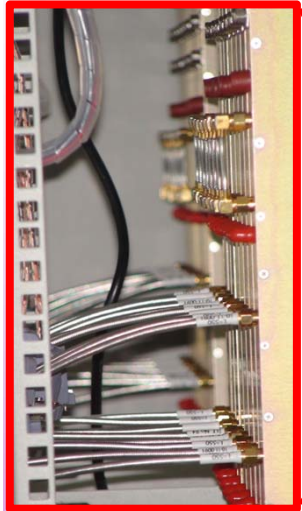


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Indoor devices

Back side view



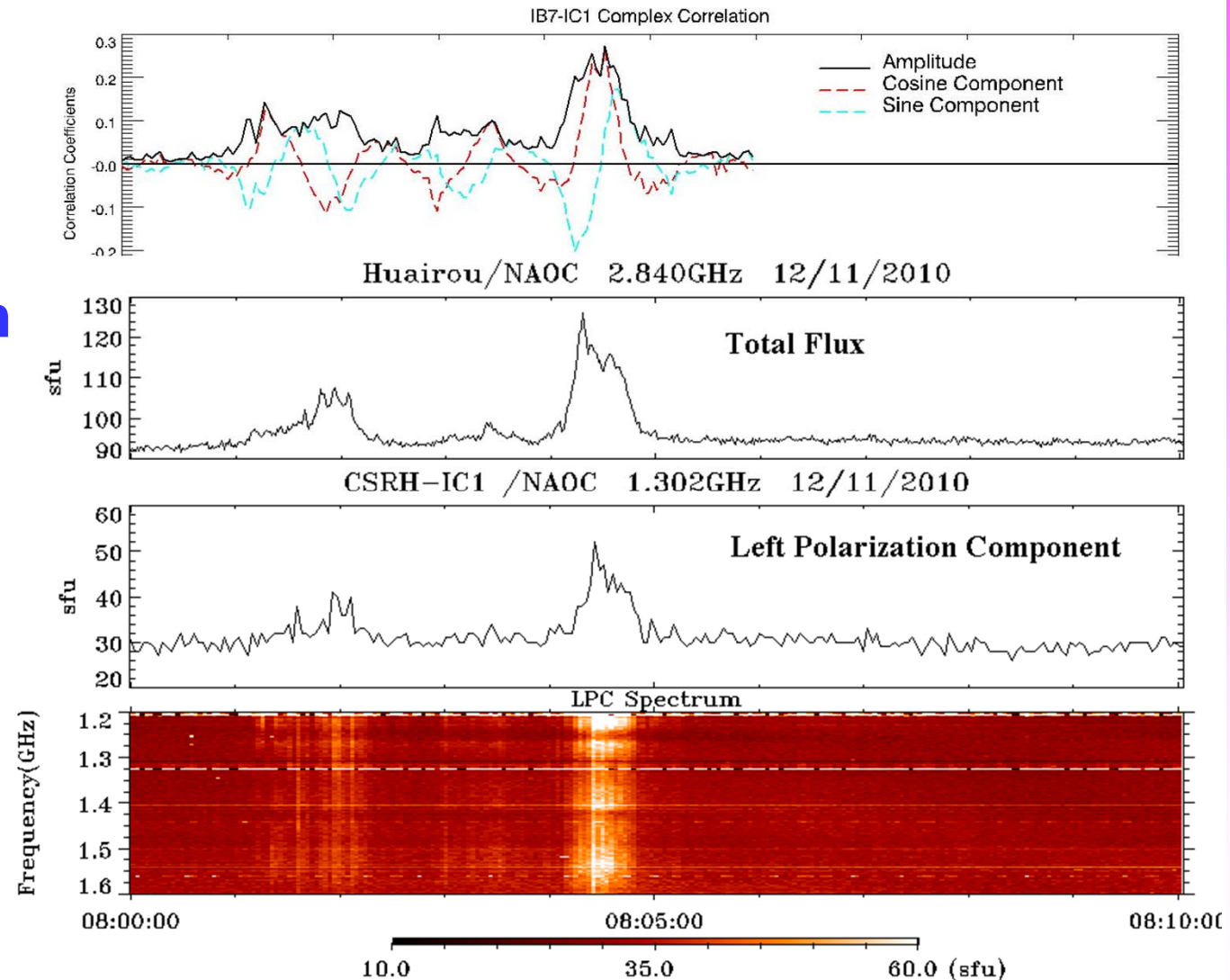
Digital
receivers
&
correlation
board

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CSRH-I analog receivers and monitoring sub-system
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Test Observations and Current Status:

**First
observation
of a solar
flare on 12
Nov 2010
during 5-
element
test of
CSRH-I**

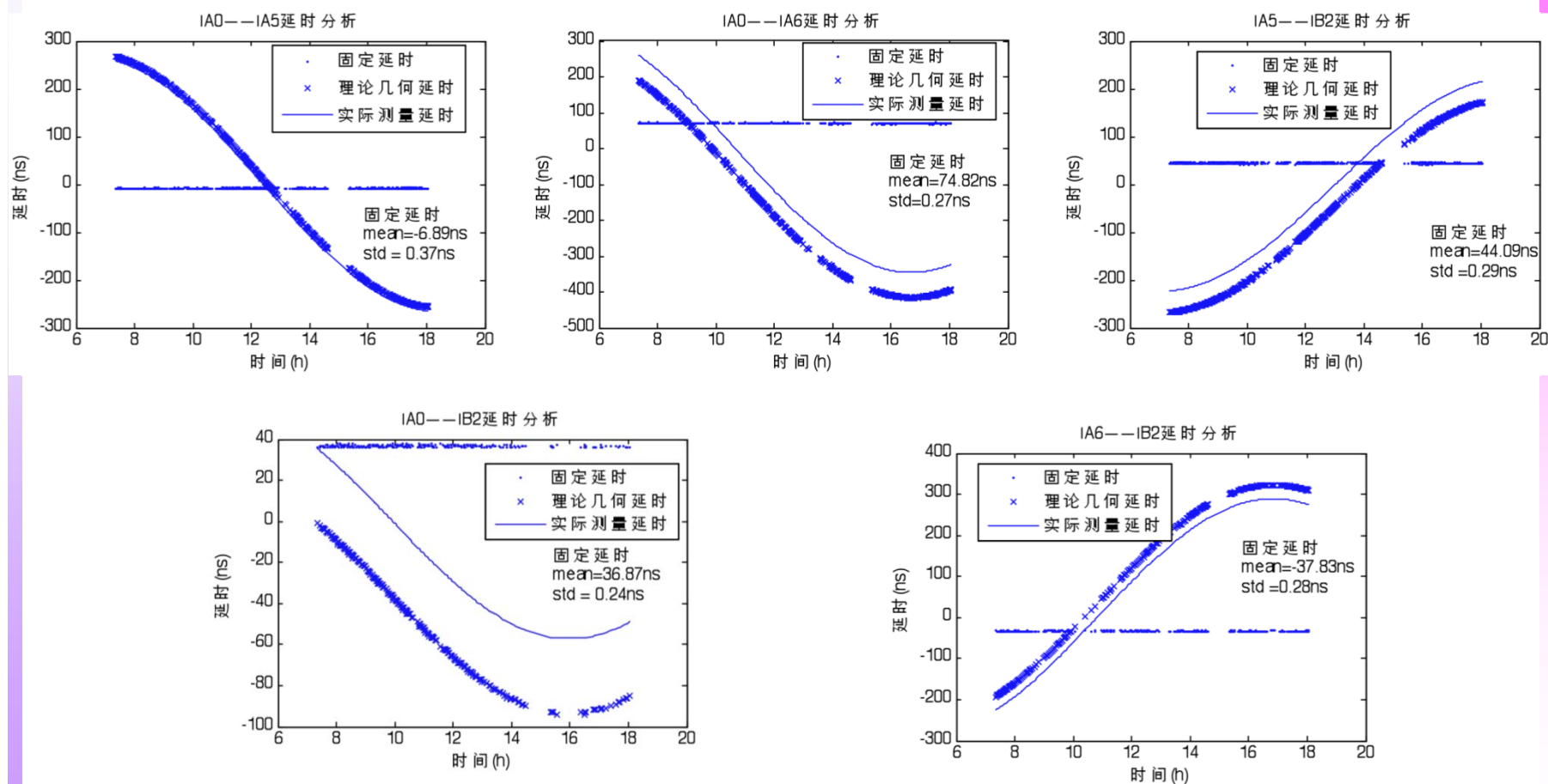


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Calibration of fixed time delays for CSRH-I

Some measurements among IA0, IA5, IA6 and IB2 antennas, $\text{RMS} < 1\text{ns}$, similar results obtained after 1 year's interval (Liu et al 2012).



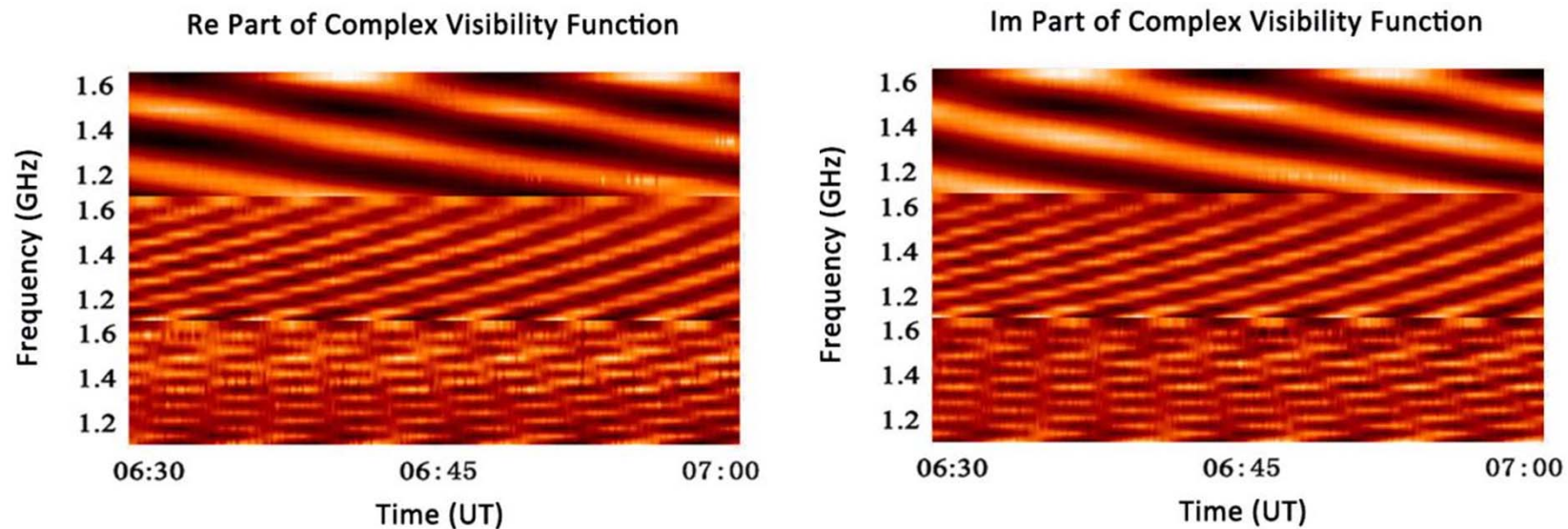
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CSRH-I test observation on 27 Dec 2011

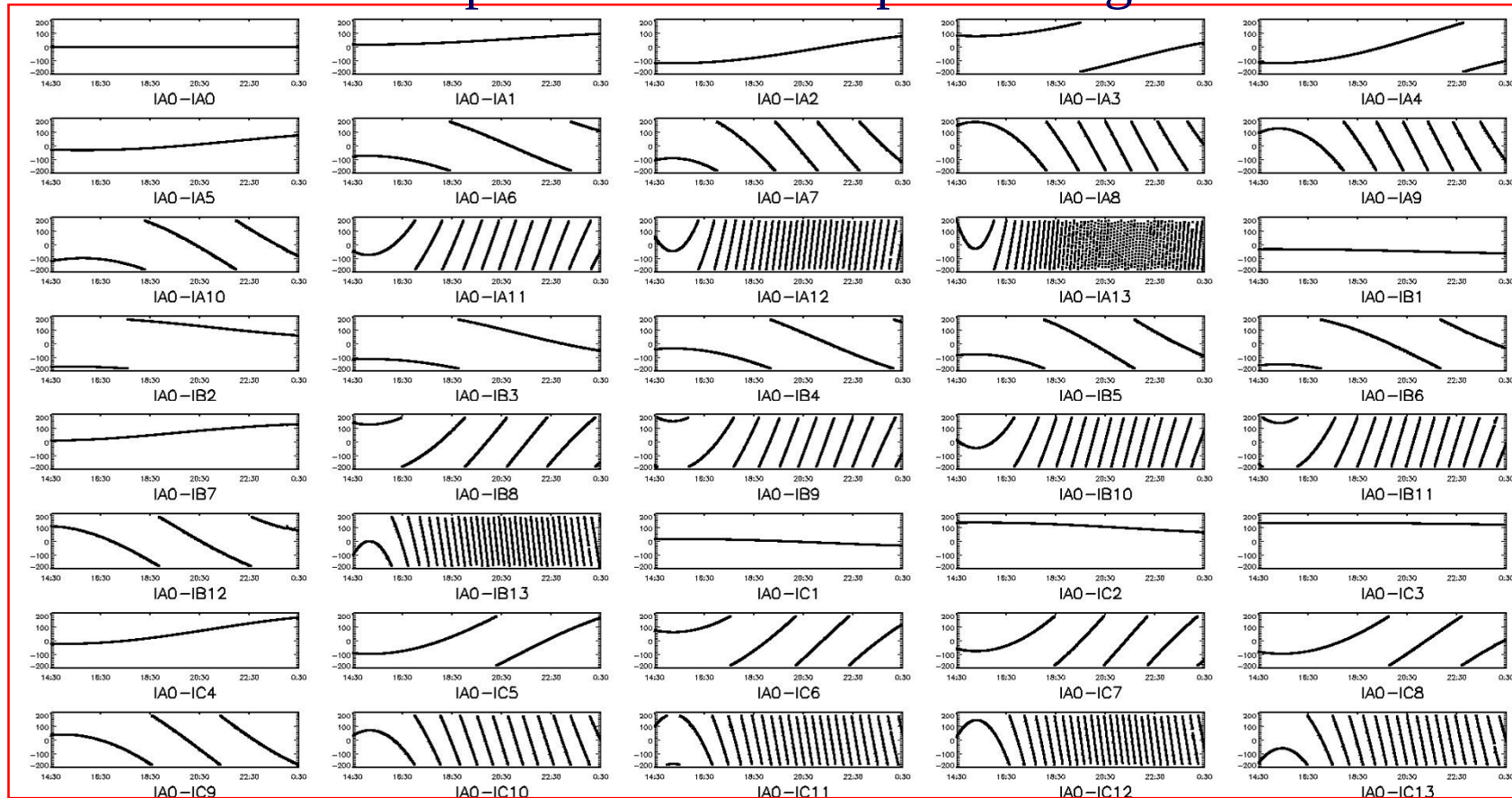
First recording of the correlation fringes of the Sun from 3 different short baselines.

Preliminary results



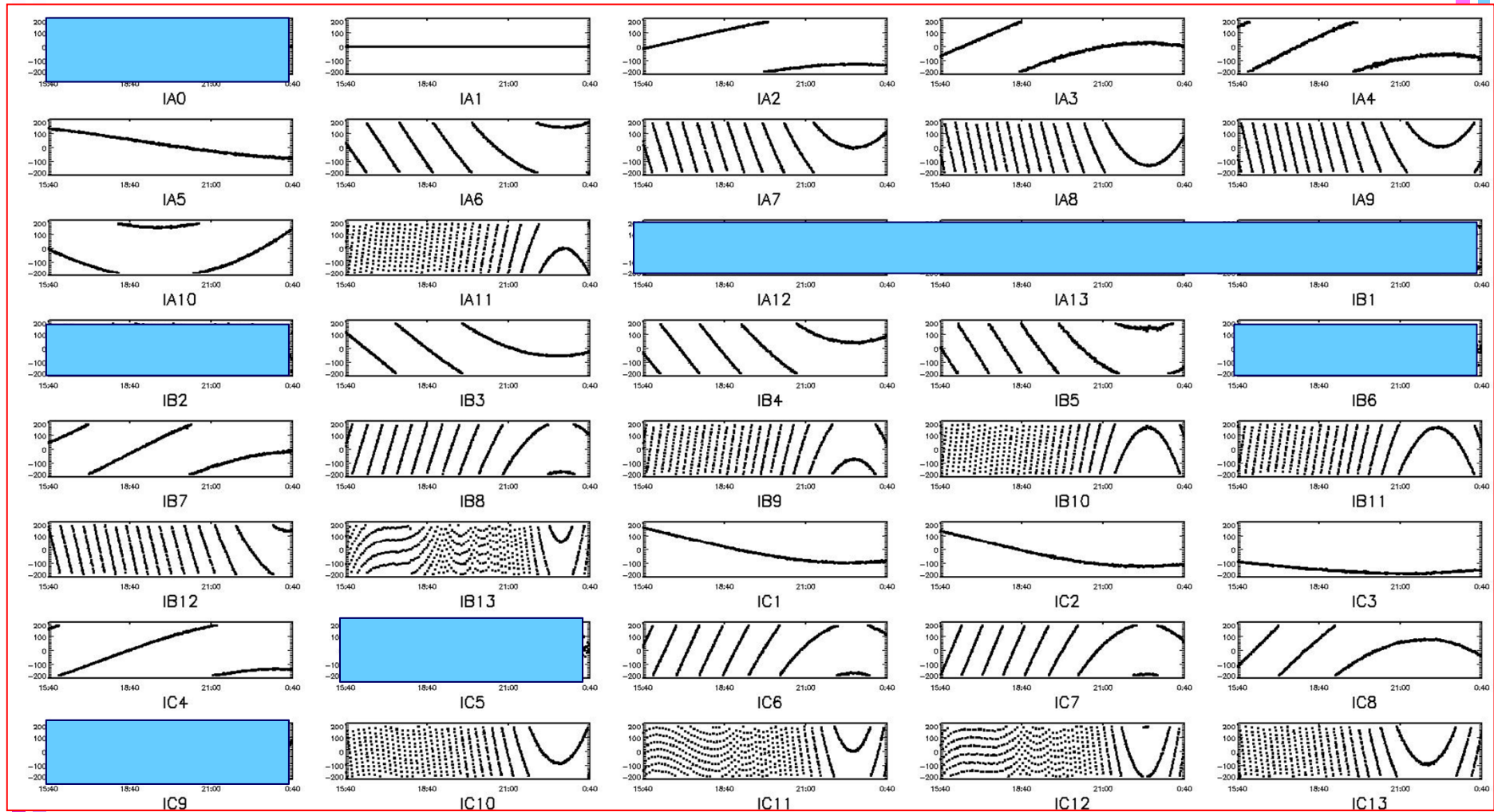
Preliminary results of CSRH-I test observation of FY-2E satellite during Jan 5–9, 2012

Expected calculated phase fringes



First measured phase fringes basically agree.

Preliminary results of CSRH-I test observation of FY-2E satellite on 2012-March-27

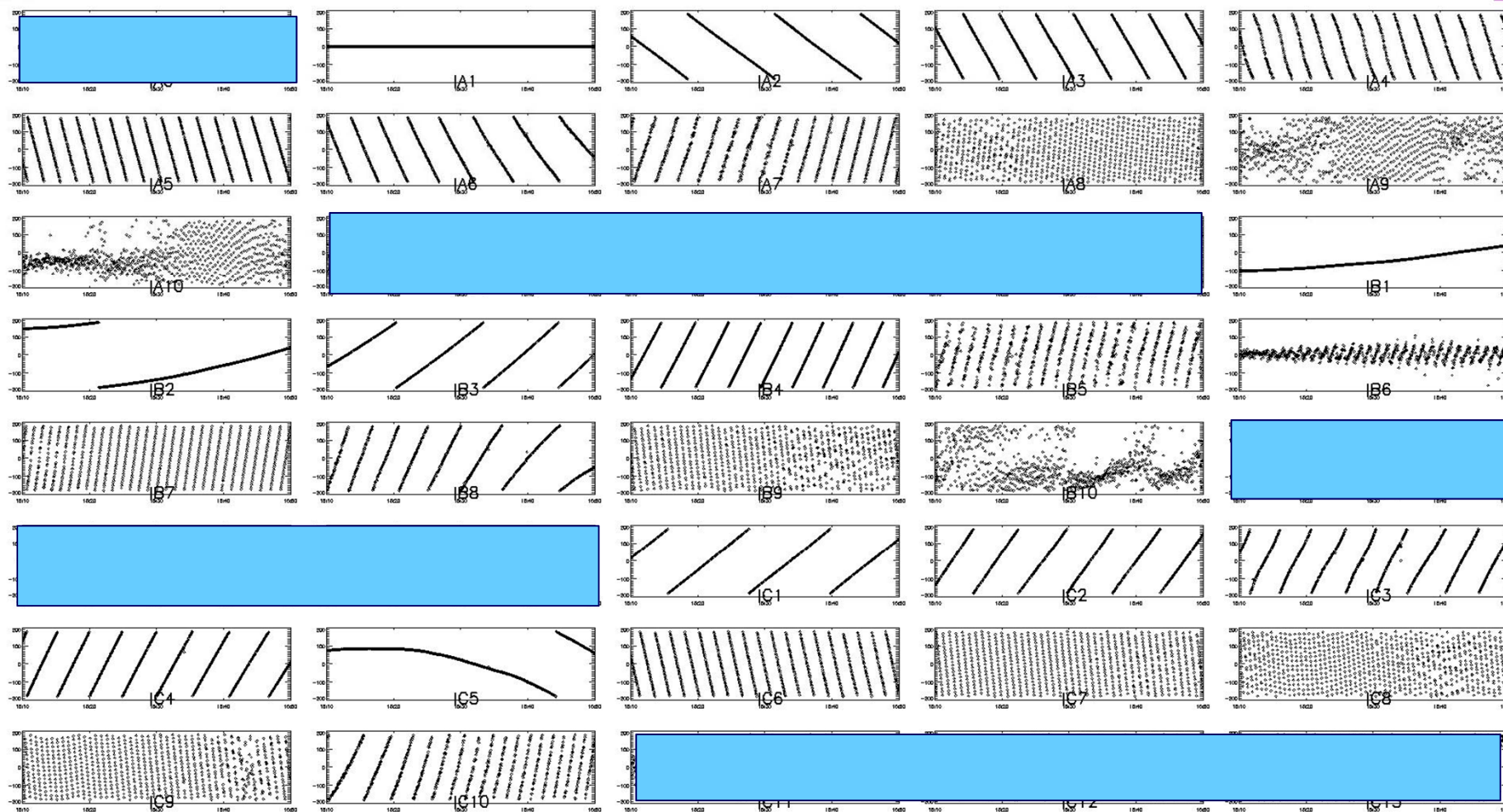


Fringes have been obtained for all baselines.

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Solar Physics with Radio Observations, Nagoya, 2012

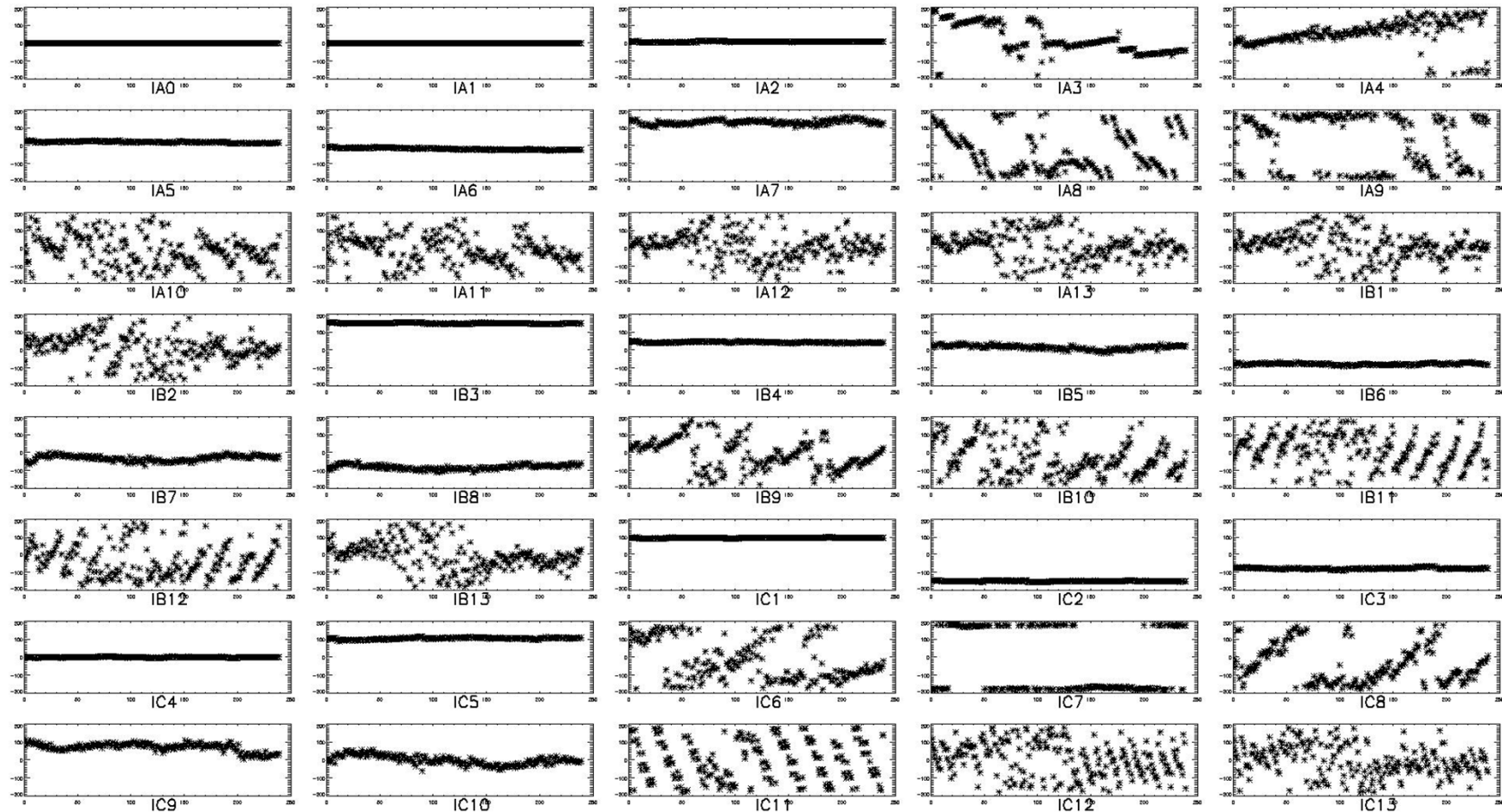
Preliminary results of CSRH-I test observation of the Sun on 2012-March-31



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Solar Physics with Radio Observations, Nagoya, 2012

Preliminary results of fringe stopping on 17 Aug 2012 of the Sun by CSRH-I

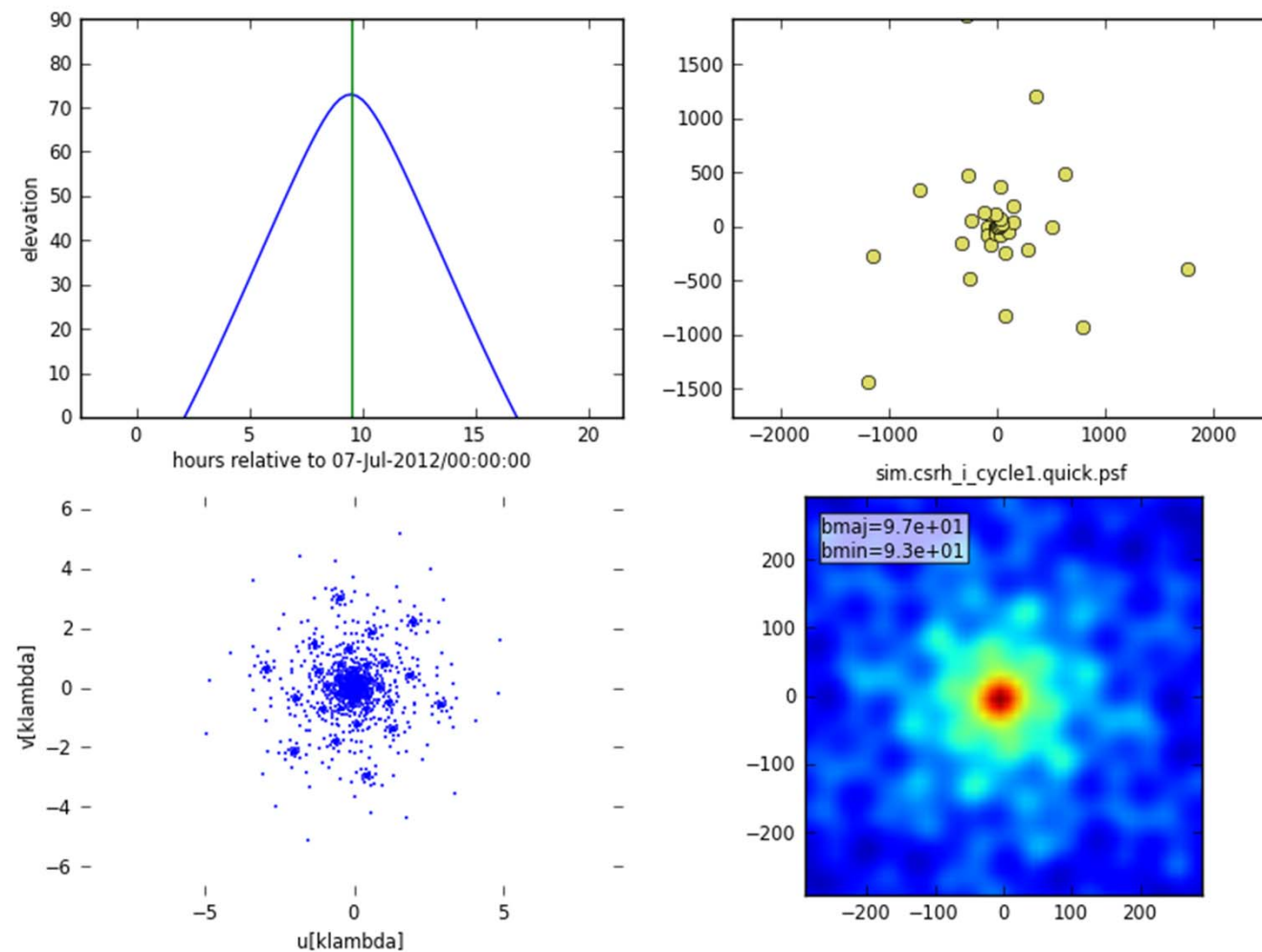


Fringe stopping has been obtained for short and mid baselines whereas further parameter verifications are needed for long base lines.

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CSRH-I in CASA



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CSRH-II in Manufacturing and Assembling

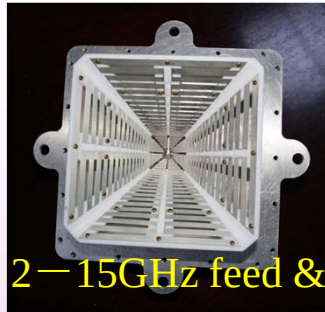


For 60 2m-antennas

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Test & field mounting of 2m antennas



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Test observation yesterday at CSRH site



2012.11.23

Solar Physics with Radio Observations, Nagoya, 2012

Summary

- I. Radio imaging spectroscopy is in its infancy and will open new observational windows on flares and CMEs. It will also provide coronal magnetograms.
- II. For CSRH, radio quiet zone protection is established:
 - I. CSRH-I during 2008-2011:
Obtained fringes for all baselines, fringe stopping obtained for short and mid baselines. Go on calibration and verification. Expect first solar maps
 - II. CSRH-II will be finished in 2013.

Thanks