Chinese Spectral Radioheliograph - CSRH

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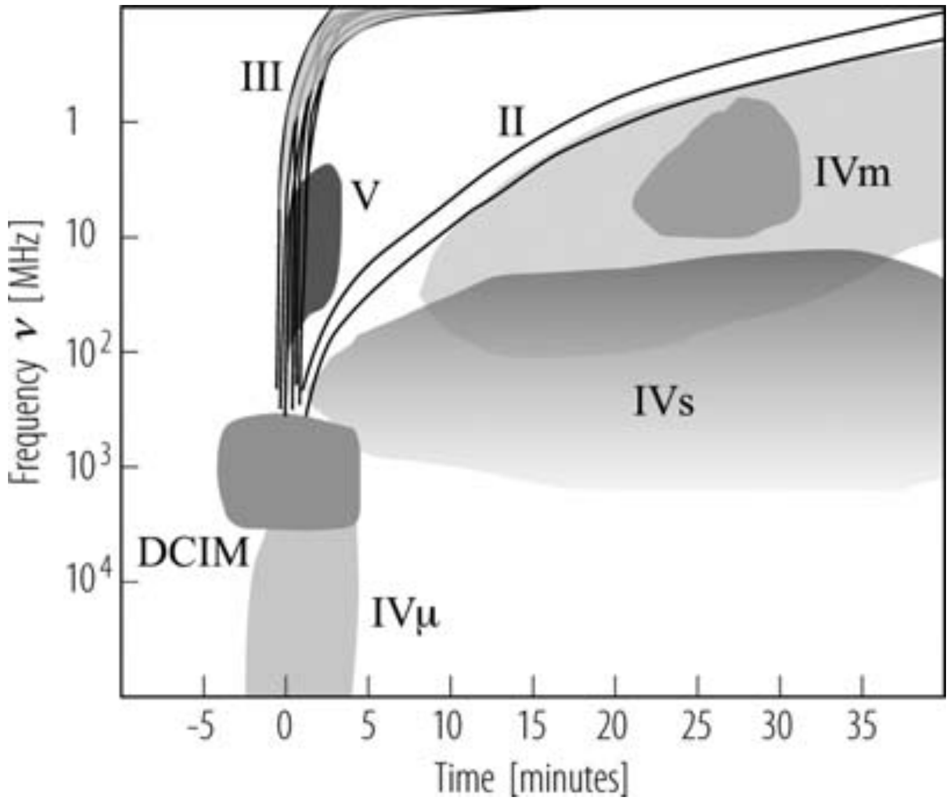
National Major Scientific Research Facility R&D Program （ZDYZ2009-3）

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.**



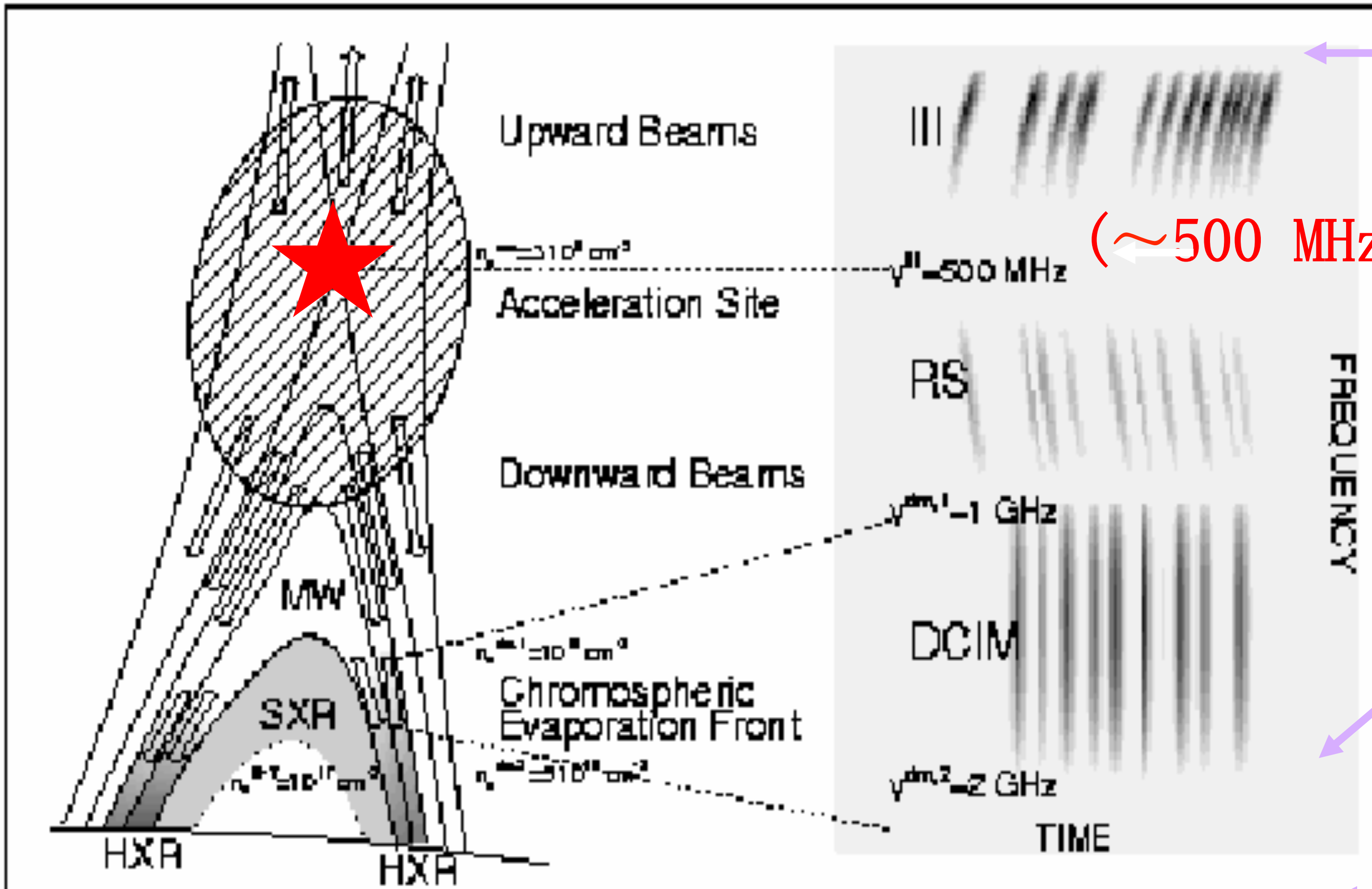
（Benz 2009）

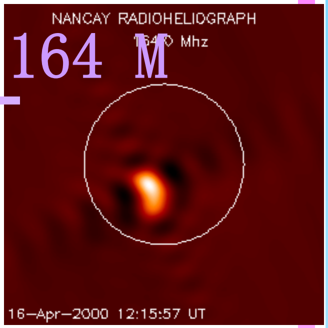
Scientific Motivations:

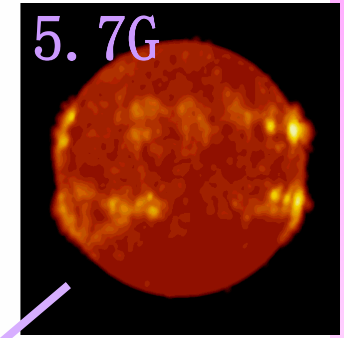
- **The available radio facilities are either with high time and spectral resolution but without spatial resolution, or with high time and spatial resolution but at only one or a few frequencies.**

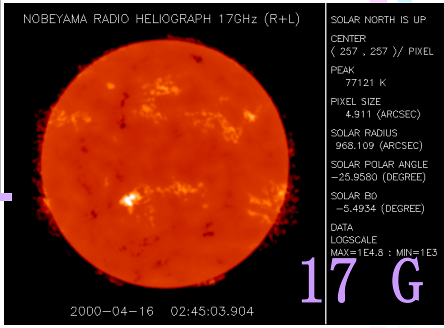
- **Imaging spectroscopy over cm-λ & dm-λ is important for addressing the problems of primary energy release, particle acceleration, and transportation processes, and the coronal magnetic fields** (Bastian, et al., ARAA, 1998; Gary & Keller 2004; Aschwanden 2004; Pick & Vilmer 2008).

40 - 150 MHz Gauribidanur, India





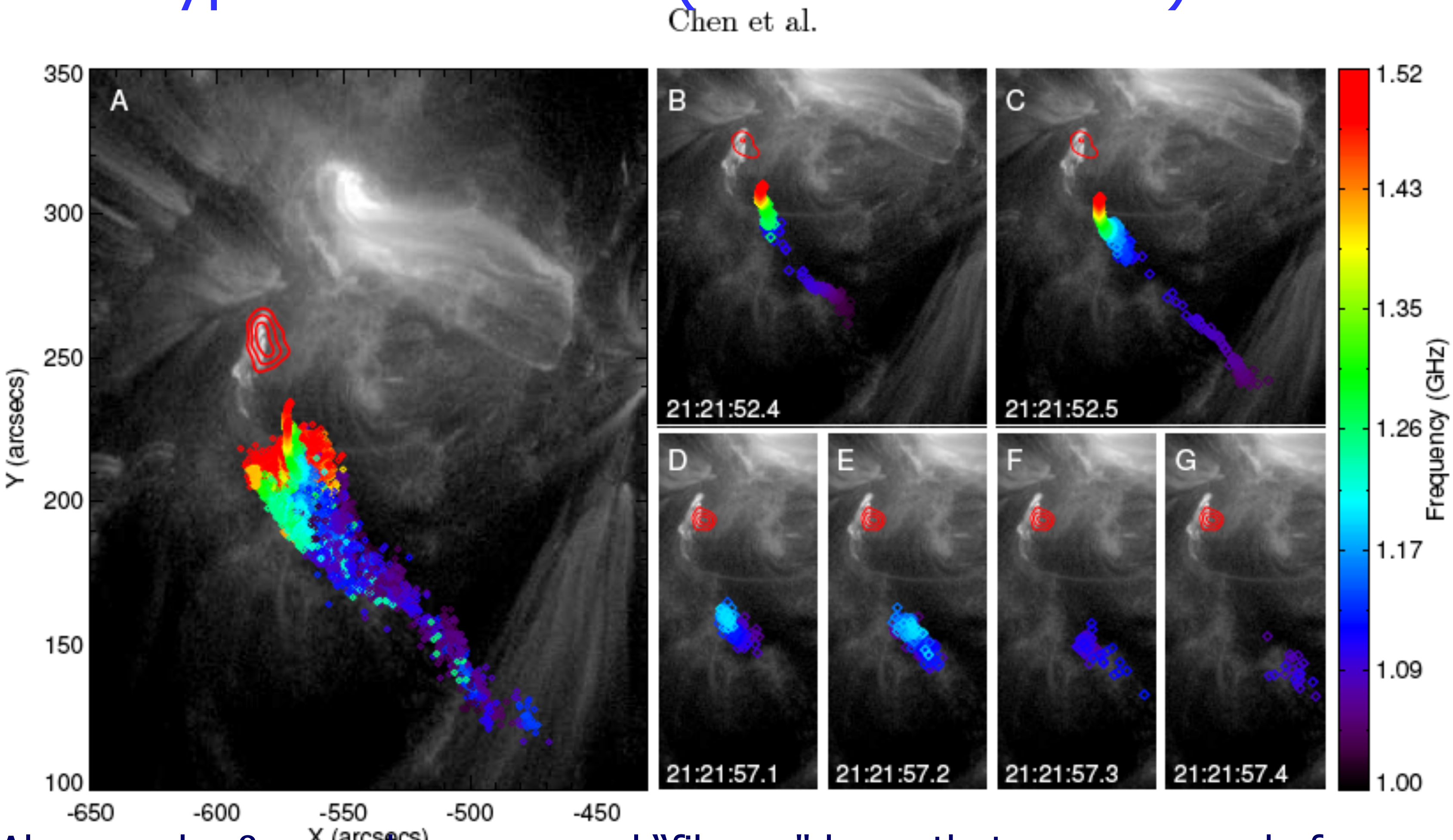




Solar bursts

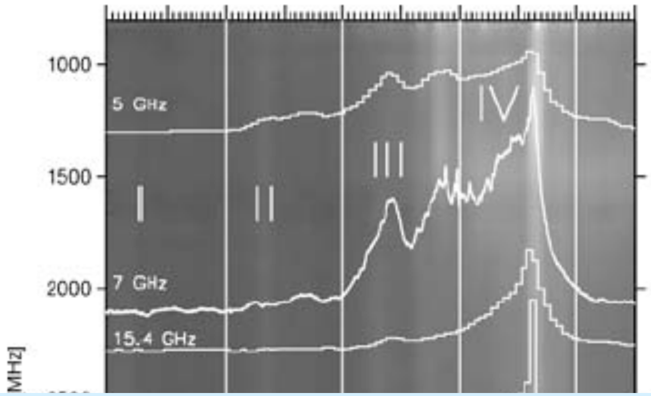
Aschwanden et al.

EVLA Type IIIdm Bursts (Chen et al. 2013)

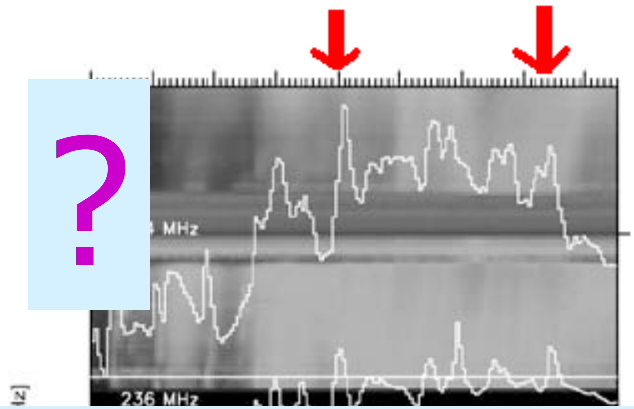


- Along cooler & over-denser coronal "fibrous" loops that are composed of unresolved "strands" and invisible in other band, e.g., EUV images.
- ➔The need of radio imaging spectroscopy!

Event study: 5-Nov-1998 flare



?



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

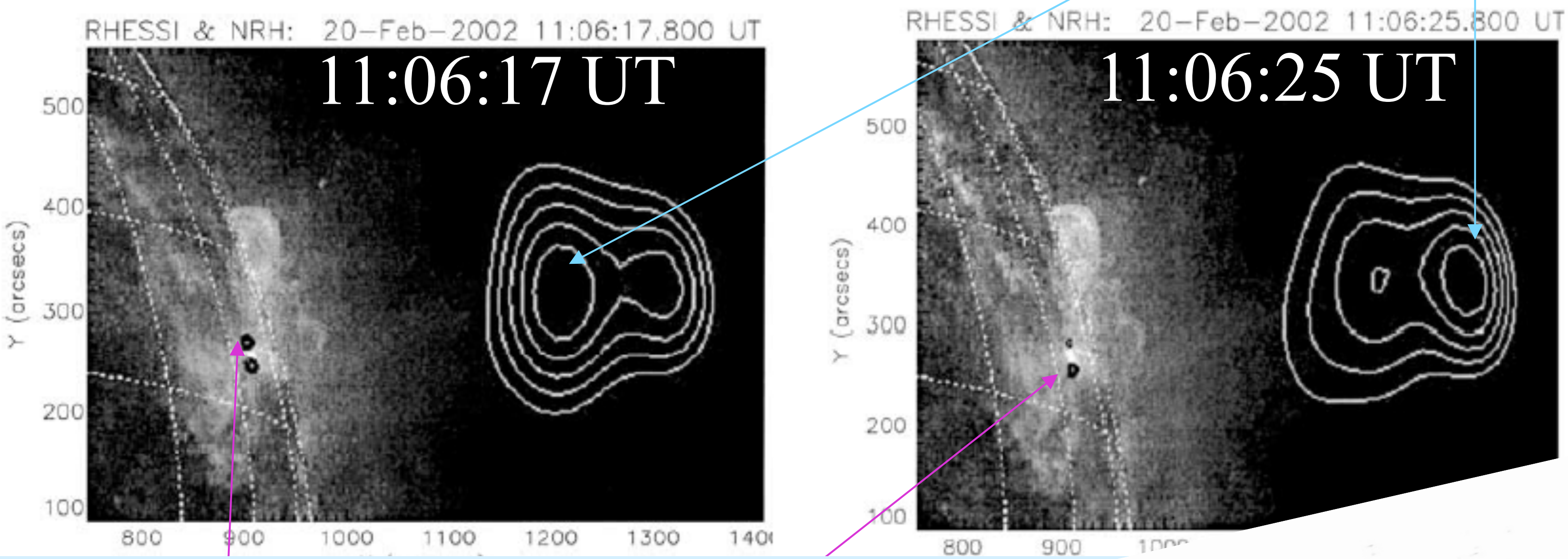
Why the radio and HXR sources are not aligned but, instead, in perpendicular?

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

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

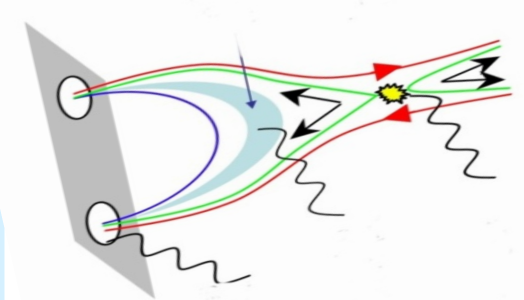
20-Feb-2002 flare event:

Radio bursts at 410 MHz



The magnetic structure connecting radio and HXR sources may be due to standard flare model ?

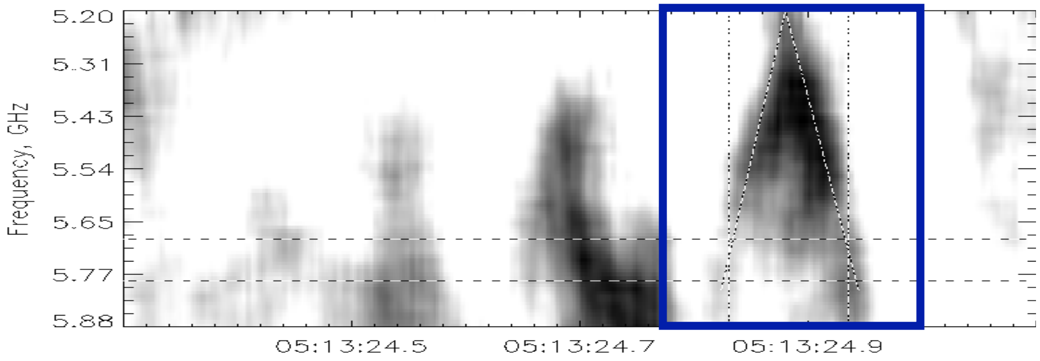
⇒Need multi-wave imaging observations in dm-cm (≥ 400MHz) ranges!



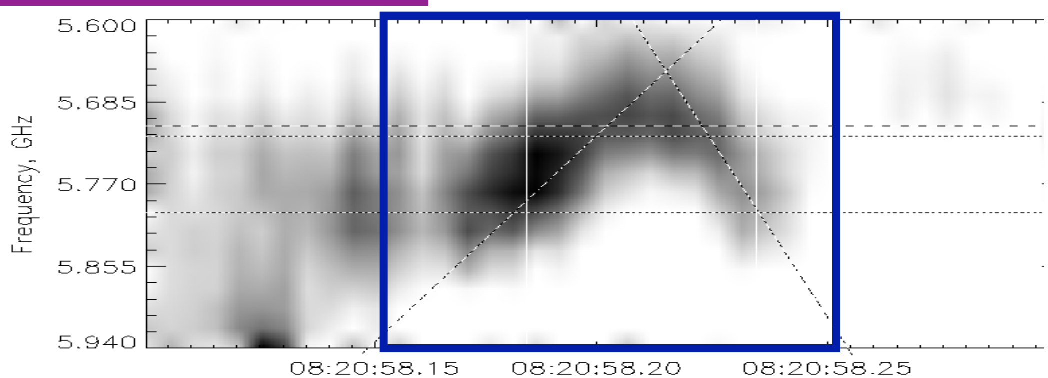
Vilmer, et al. (2002, Sol. Phys.)

Coherent emission: U-burst

30 March 2001



17 September 2001



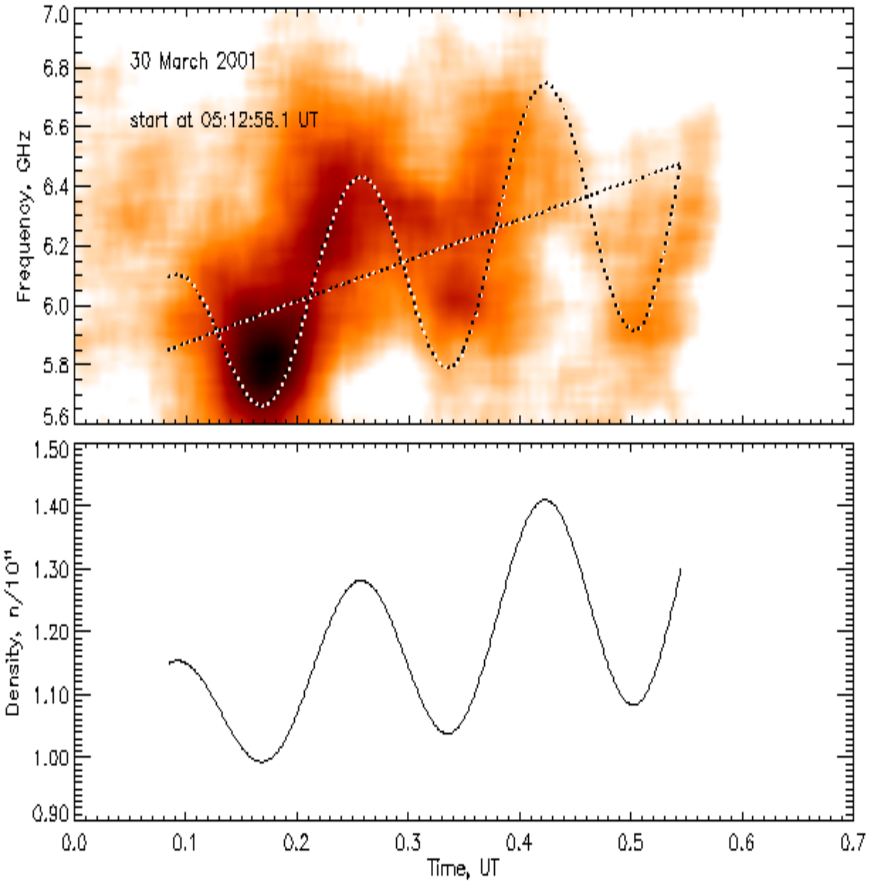
(Altyntsev A.T. et al. 2003, A&A)

Exciter at meter-decimetric wavelengths: electron beam moving along a magnetic loop with density minimum at the loop top (beam instability, kinematics). Plasma parameters are stationary.

But the SSRT observations does not show a large distance (>30 Mm) between sources at different branches.

In cm-wavelengths U-structures are produced by density variations due to a plasma response to a heating pulse. The source size along the loop is order of a few Mm. (Loss-cone instability, MHD time-dependent process)

Bounce period or transverse MHD oscillations of loop?



Two variants to explain:

- Bounce period of the short electron beam in the long magnetic loop.

From lifetime duration follows beam velocity of 0.45c and the loop length about 20 Mm

- Transverse MHD oscillations of the loop (for B=100 G, diameter of the loop must be about 100 km)

Trend of the frequency drifting rate corresponds to density rising

$$\partial f / \partial t \approx 1.25 \ GHz/s \Rightarrow \partial n / \partial t \approx 5 \times 10^{10} cm^{-3}/s$$

Altyntsev A.T, et al. (2003, A&A)

→ **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, Tomczyk, et al 2013).

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 by MOST grant.
- MOST grant, NSFC grant & CAS grant since 2006 for tackling key technology.
- MoF fund for CSRH construction during 2009-2013.

CSRH Specifications

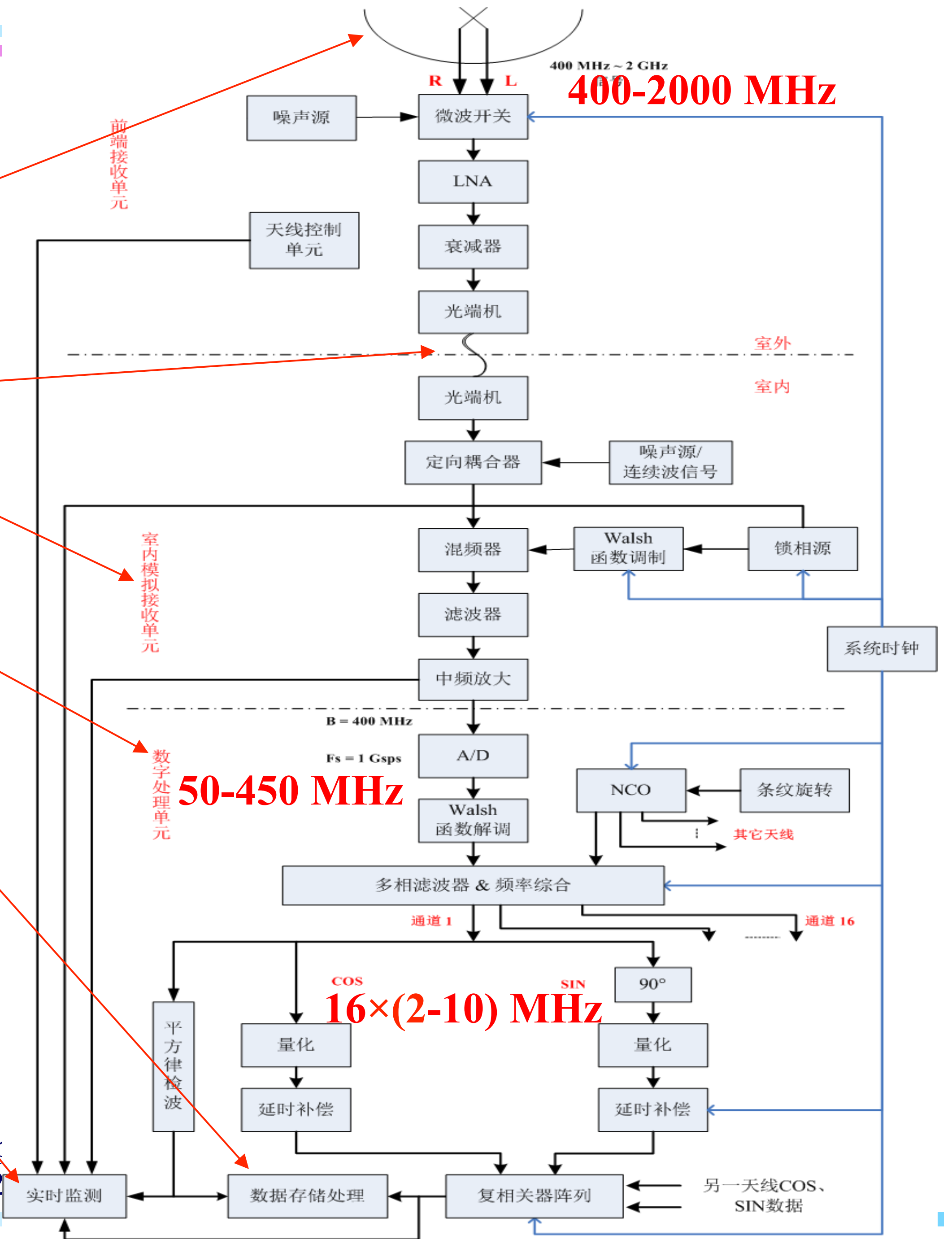
(Yan et al. 2009, Earth, Moon Planet)

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°	

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



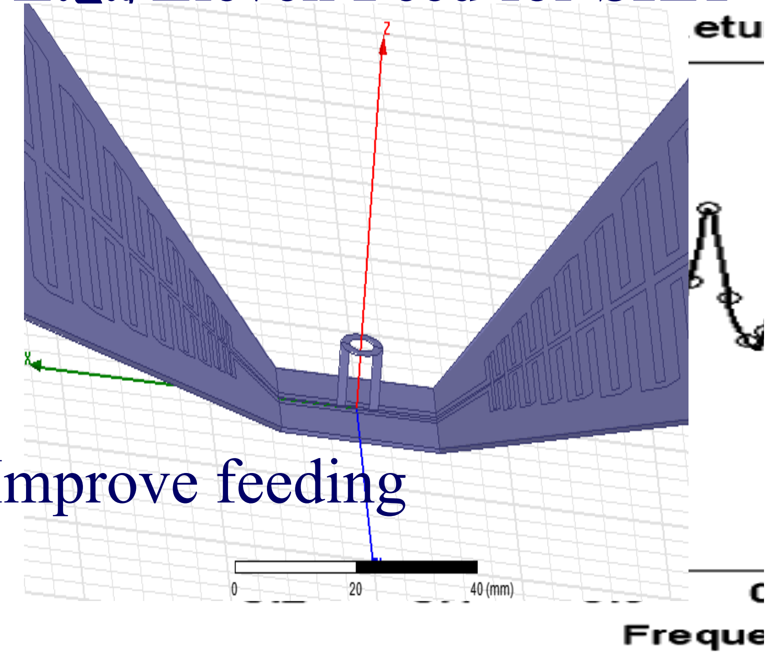
Technical challenges

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

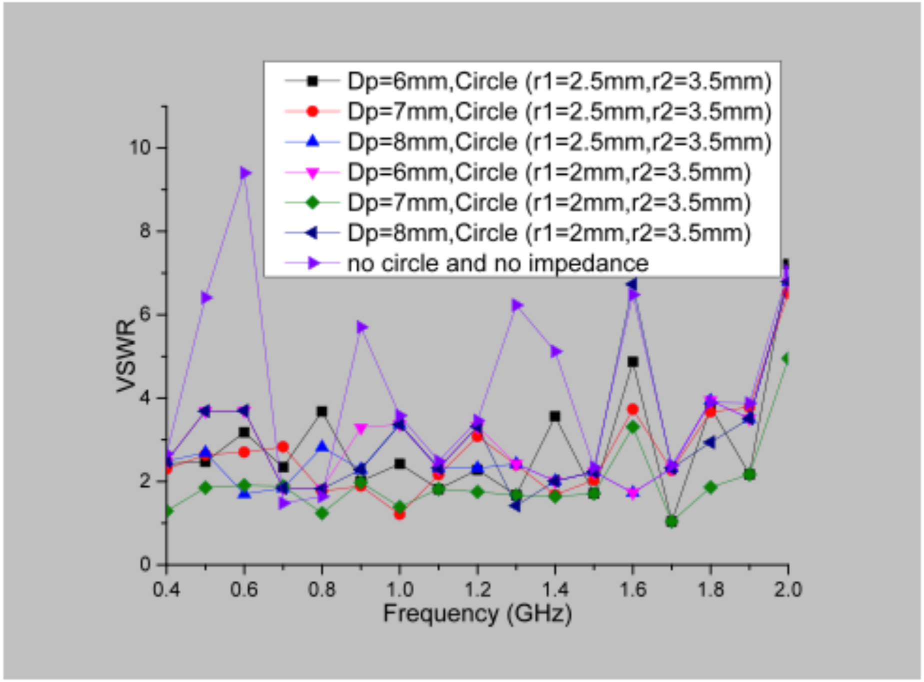
High Performance Feed Development

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.

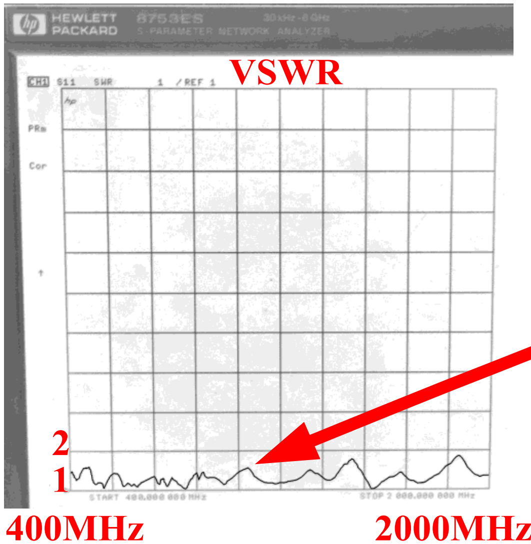
E.g., Eleven Feed for SKA (Olsson,Kildal, Weinreb 2006, IEEE)

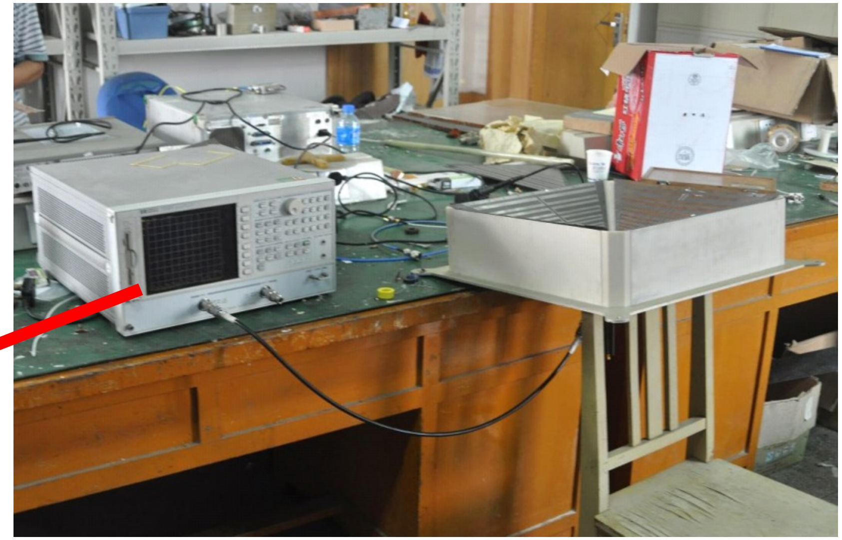


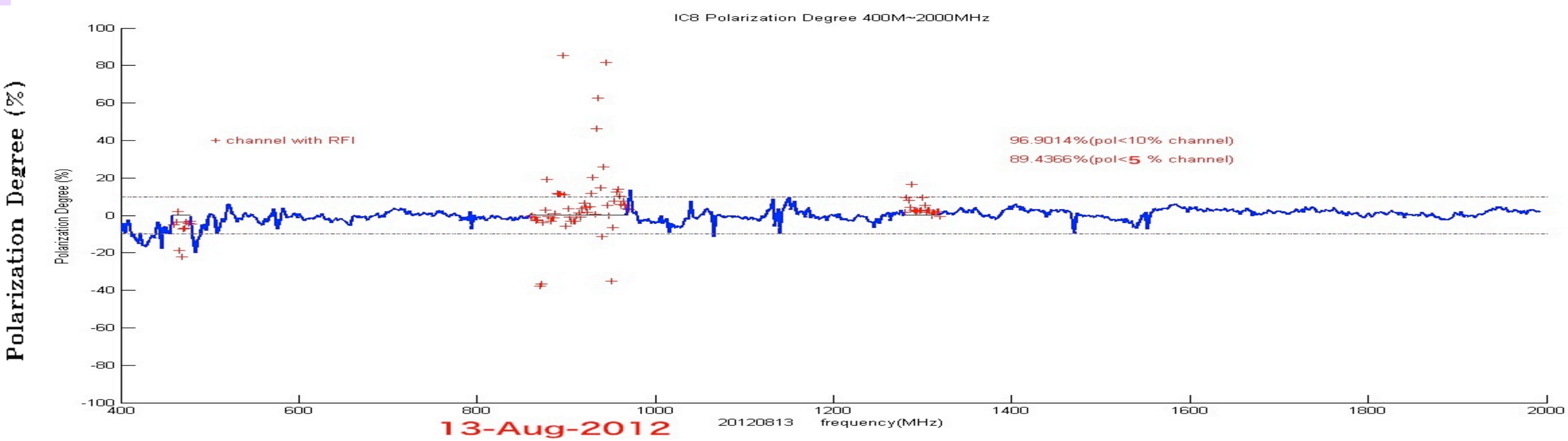
Improve feeding

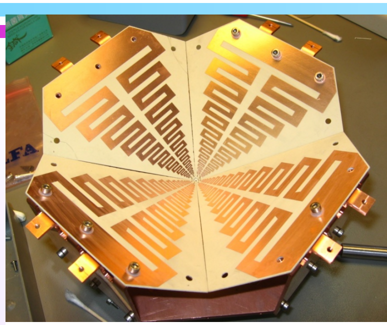


Test for CSRH-I high performance feed







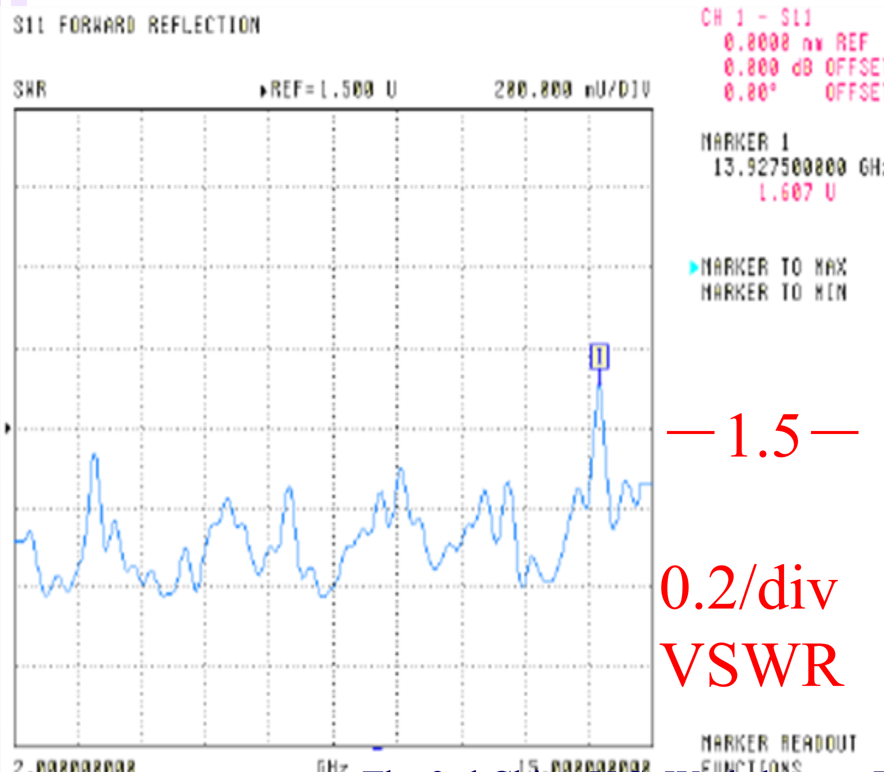


Swedish E up to 14 G[illegible] （Yang 20[illegible]

2-13 GHz

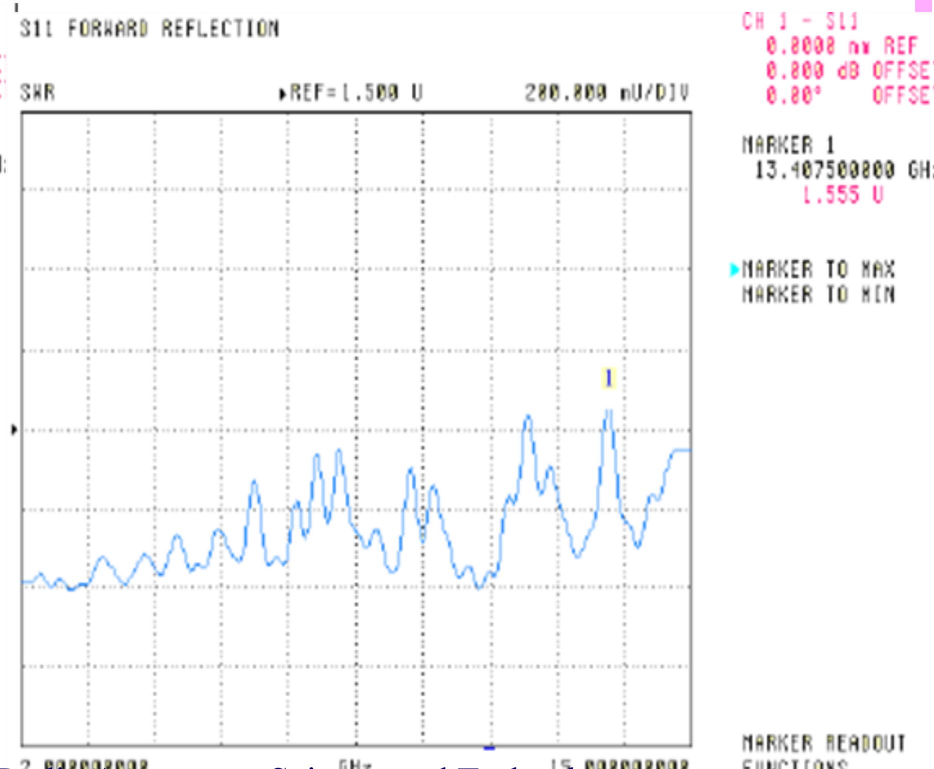
CSRH-II 2-15GHz

Reflection coefficient



—1.5—

0.2/div
VSWR



Present Solar Radioheliograph

Array	NRH	CSRH	NoRH
Freq. range	150 – 500 MHz	I: 0.4-2GHz II: 2-15GHz	17 GHz 34 GHz
Freq. chan	5 10	I:64 + II:>500 @1.6 – 25MHz	2
Antennas	43	I:40 + II:60	84
Baselines	903 (redundant)	I:780 II: 1770	3486 (redundant)
correlator	Time domain	polyphase filter bank +correlation	Time domain

Correlation capacity	903×5= 4515	780 ×16=12480 + 1770×16=28320	3486×2= 6972

Note: SSRT at 5.7GHz is not a aperture synthesis system

CSRH Digital Correlation Receiver (CDCR)

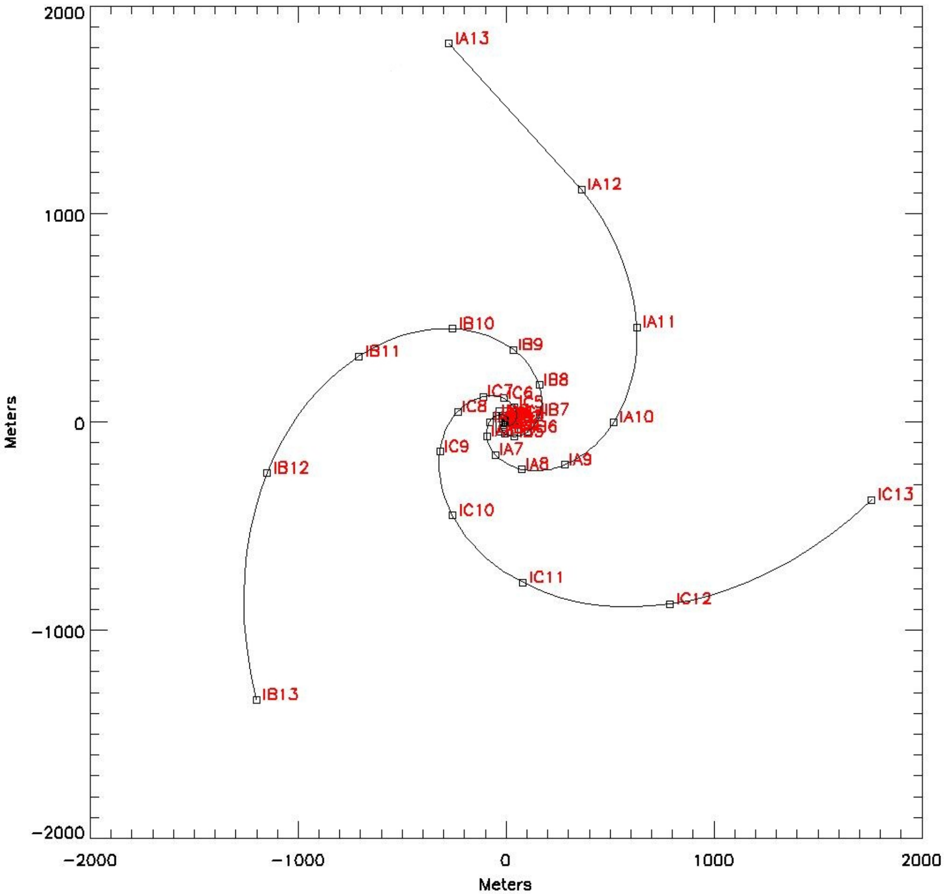
Specifications

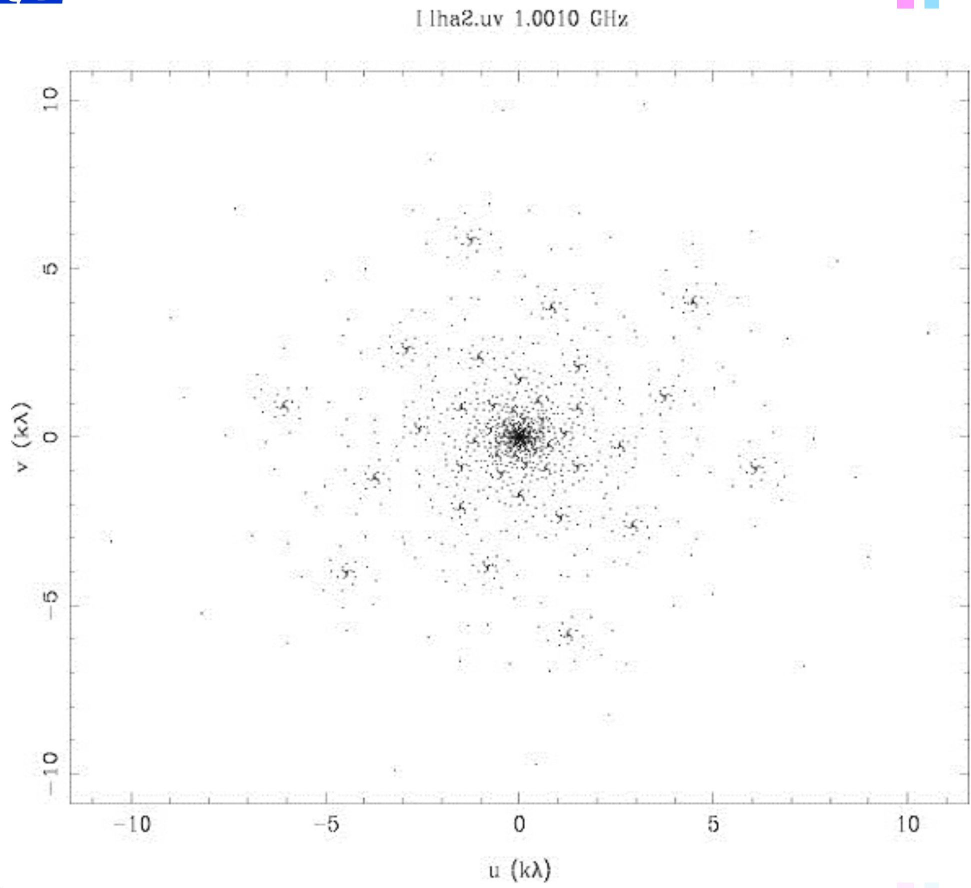
Specifications	CDCR-I	CDCR-II
Sampling	1GSPS, 8 bits	
Antenna IF input Bandwidth	400 MHz (50 MHz ~ 450 MHz)	
Max Antenna IF inputs	44	64
Correlation Bandwidth	25 MHz 12.5 MHz 6.25 MHz 3.125 MHz 1.5625 MHz	
Integration Time	~ 3ms	

CDCR Specifications (continue)

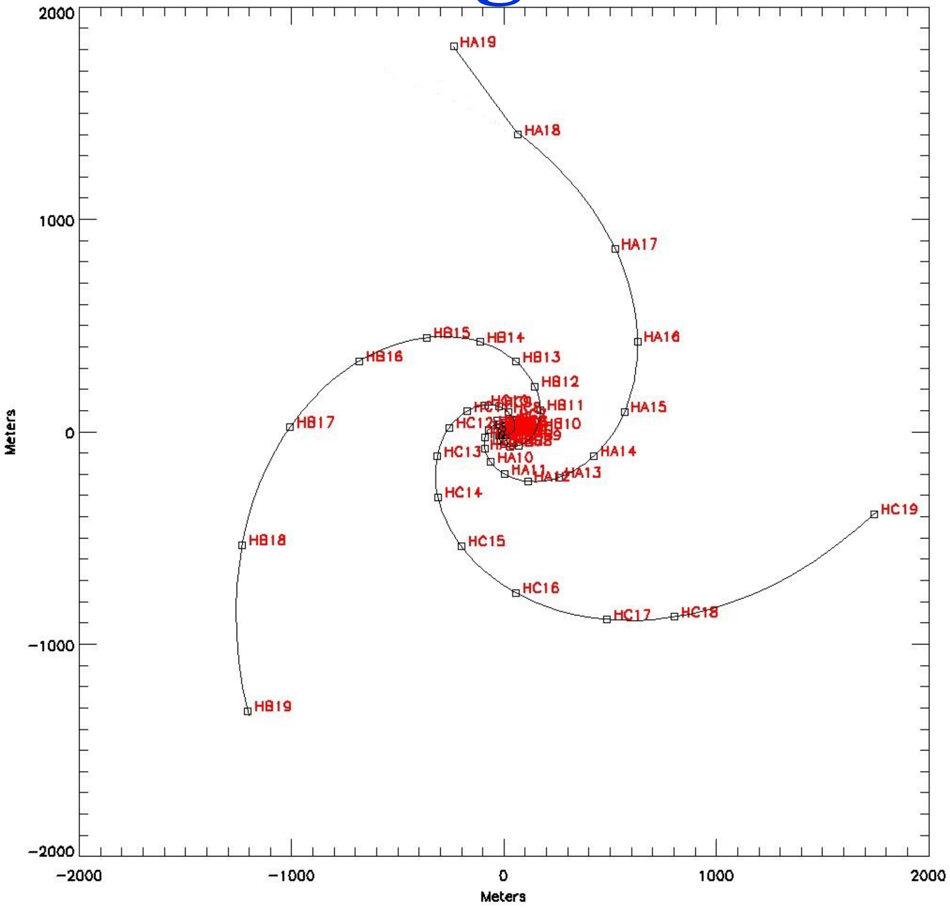
Specifications	CDCR-I	CDCR-II
Max cross correlation Outputs in integration time	15,136	32,256
Delay Compensation Accuracy	±0.5 ns (1 ns step)	
Delay Compensation Range	0 ~ 11 us	
Fringe Rotation Accuracy	±1°	
Quantification	Four-level (2-bit)	
Storage Capacity	40 TB (~ 1 Month)	100 TB (~ 1 Month)

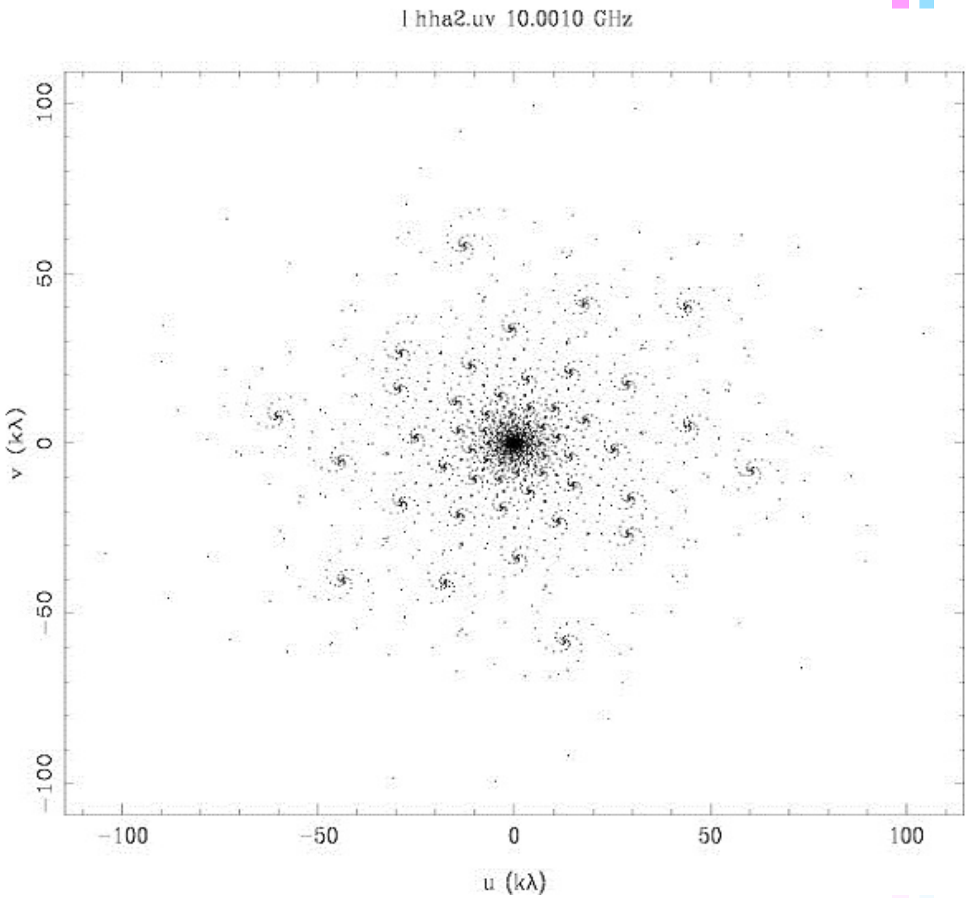
CSRH-I 40-antenna Array & UV Coverage at 1 GHz



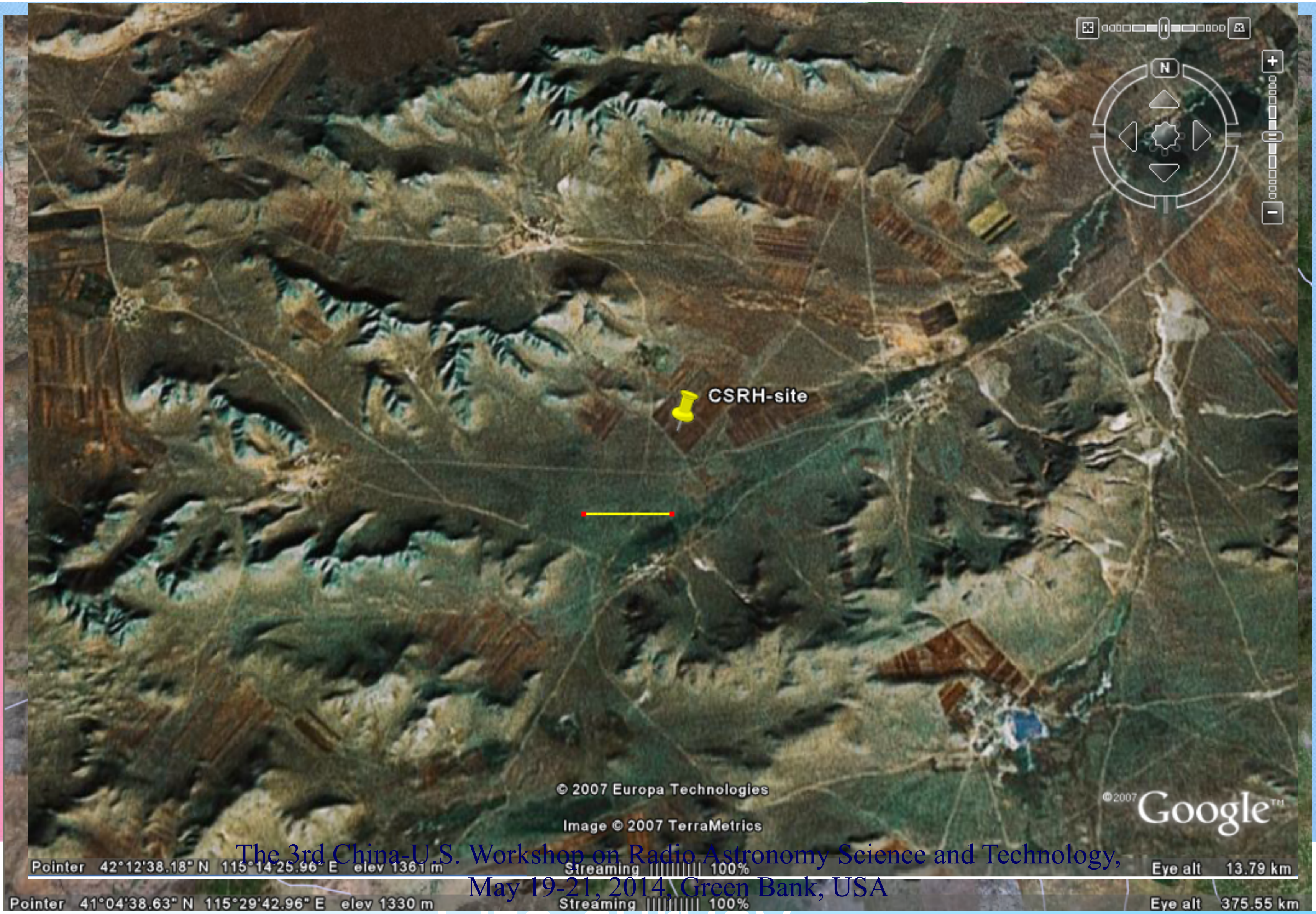


CSRH-II 60-antenna Array & UV Coverage at 10 GHz



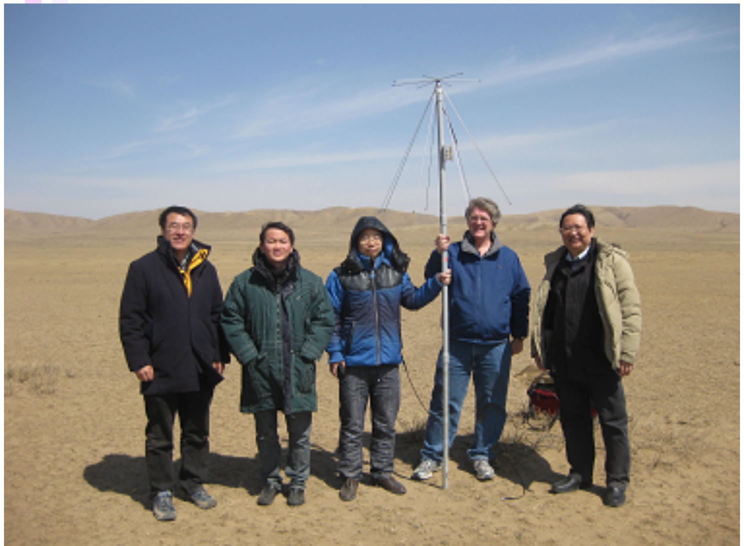


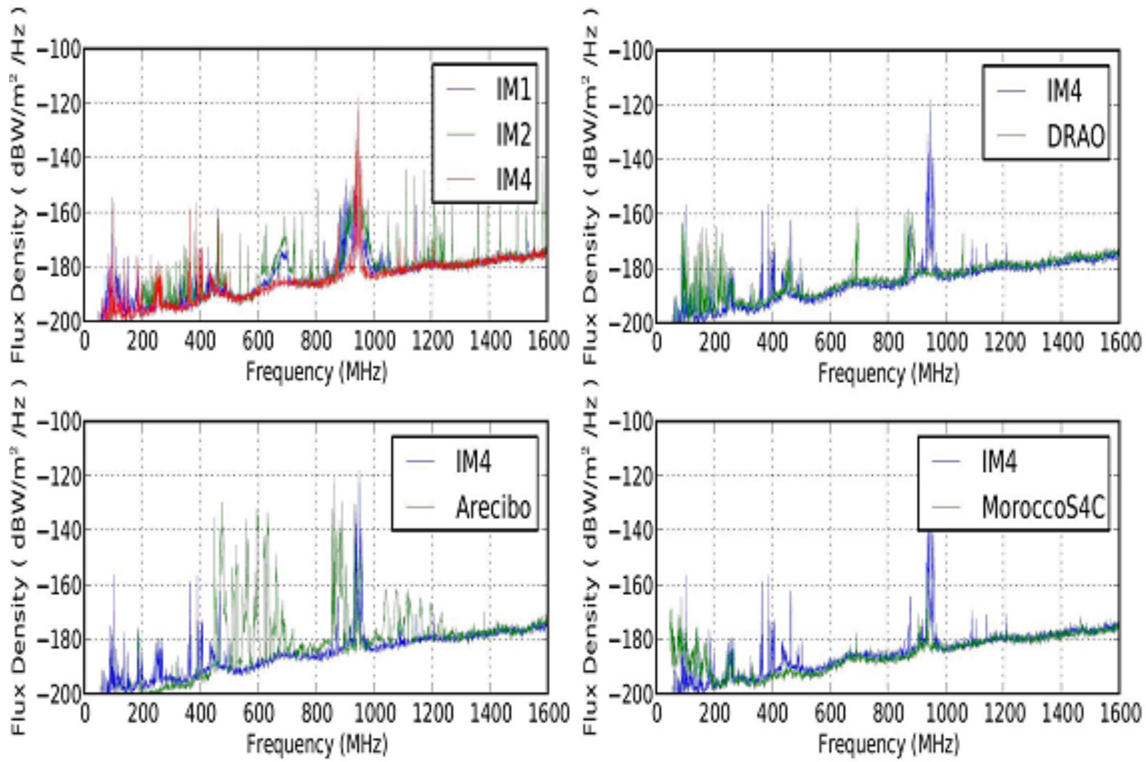
Site and Construction of CSRH



Site survey

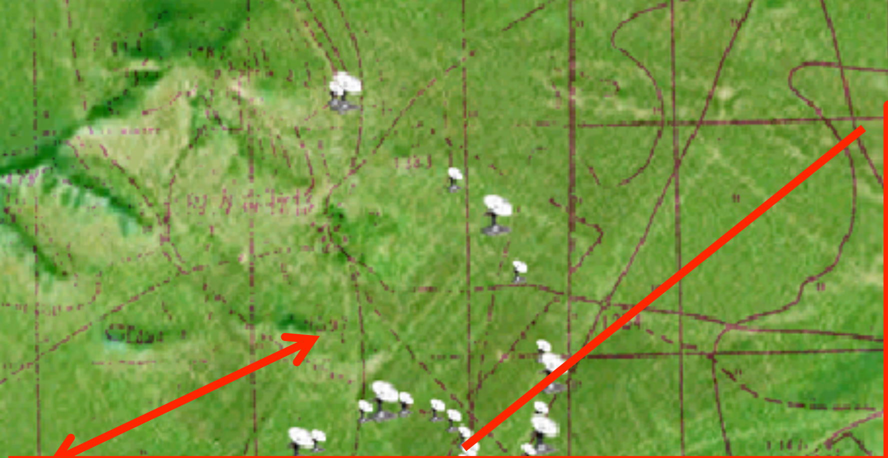
50MHz-1600MHz RFI Measurement (24-25 April 2010)



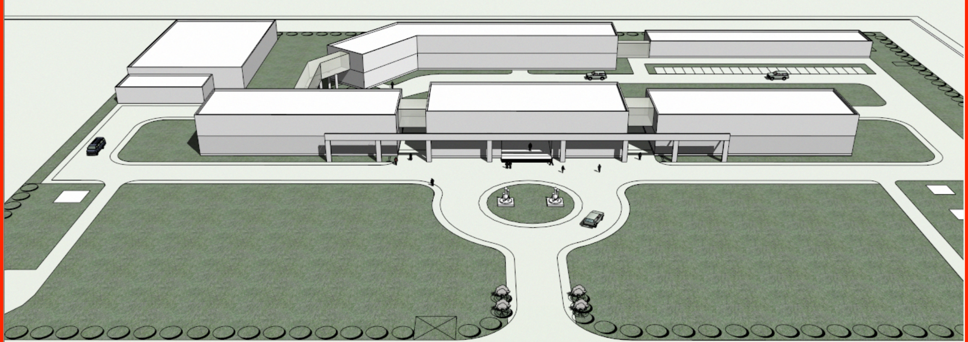


Comparison with Arecibo, DRAO & Morocco.

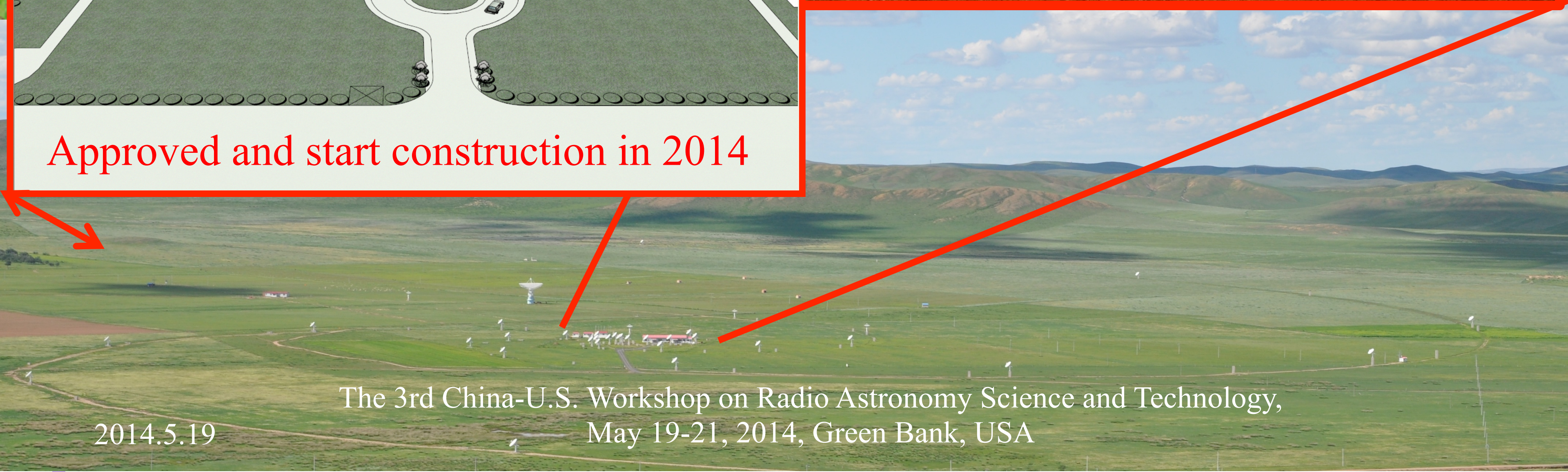
Array Construction



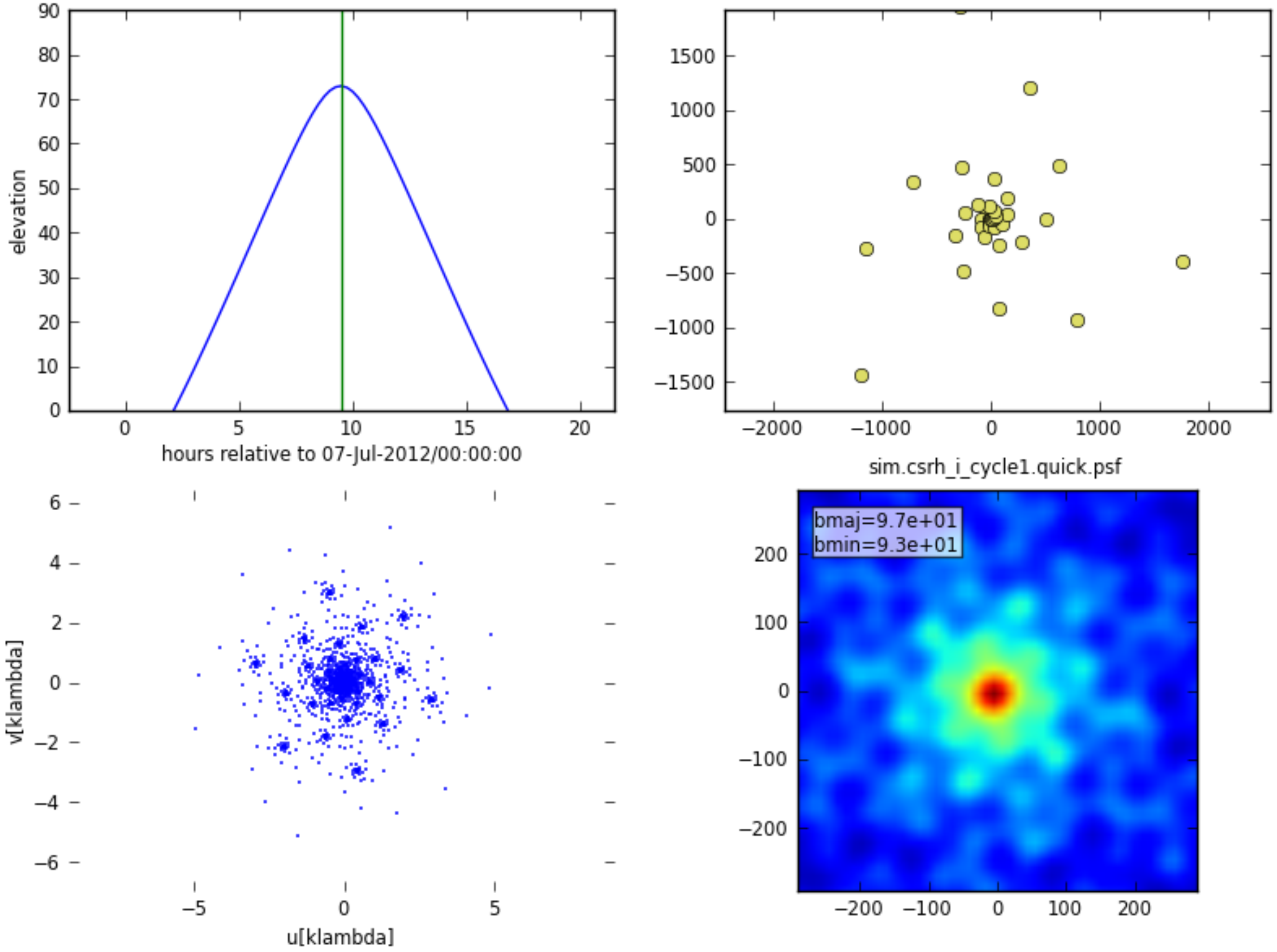
Ming'antu Observing Station Plan



Approved and start construction in 2014

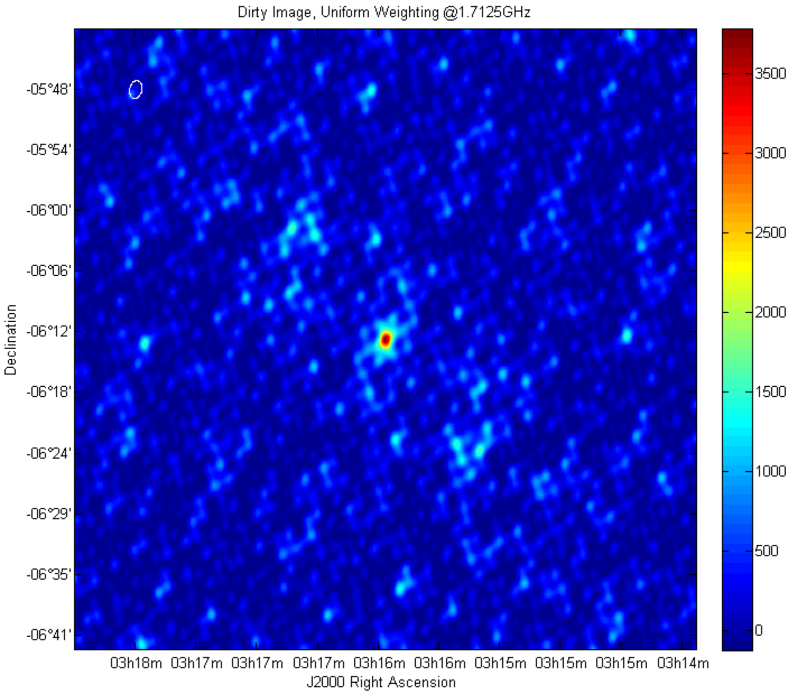


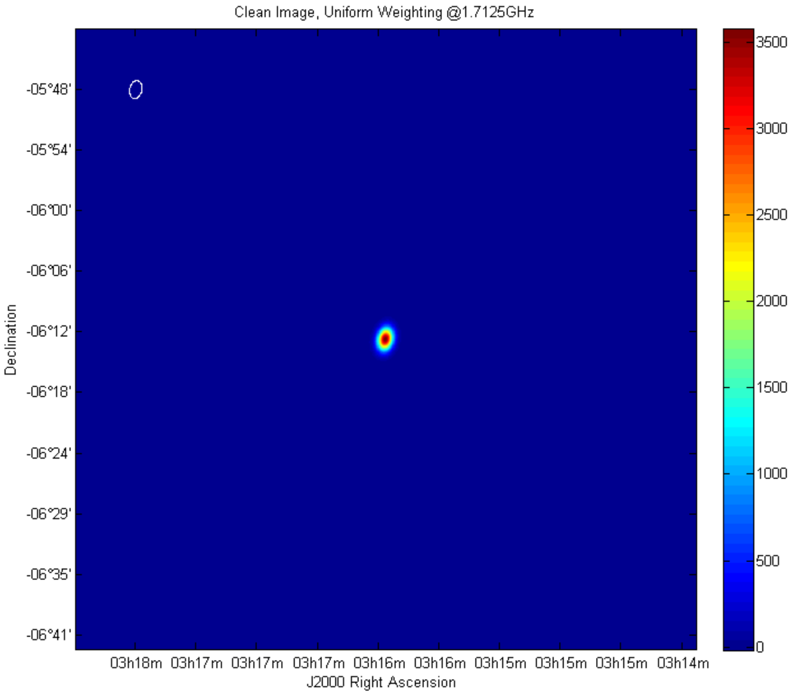
CSRH-I in CASA



FY-2 satellite 1.7 GHz (CSRH Beam at 1.7GHz)

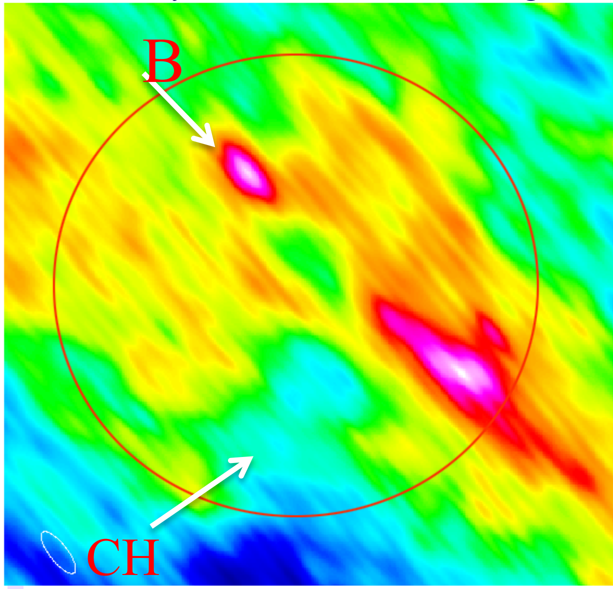
Dynamic Range in cleaned map:　about 30dB



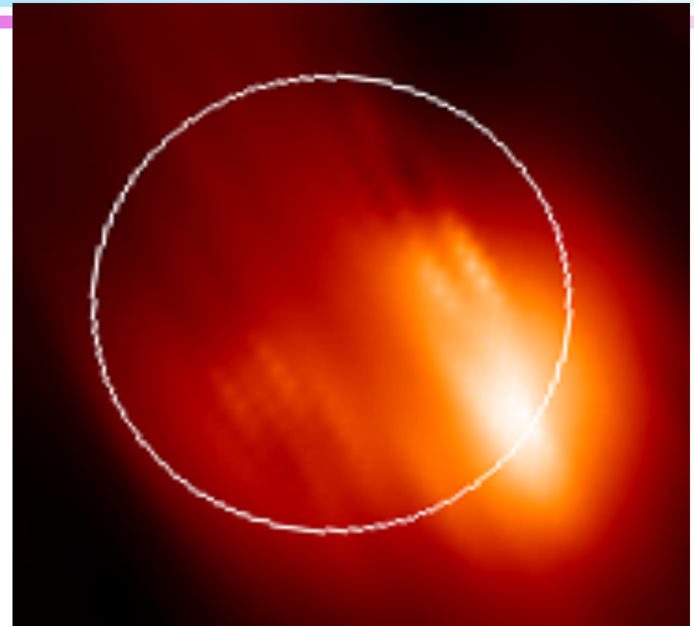


Dirty Beam　　　　Cleaned Beam

Preliminary result with 30 ms integral time



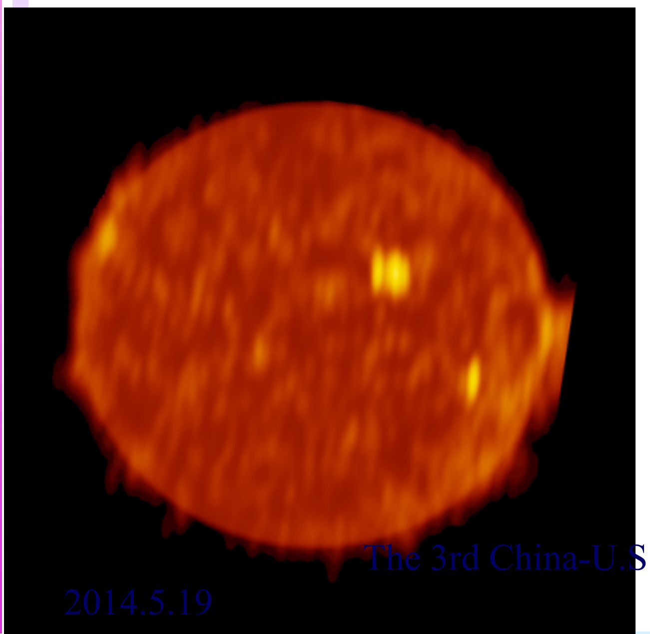
(a) CSRH-I 1.7 GHz 06:30UT



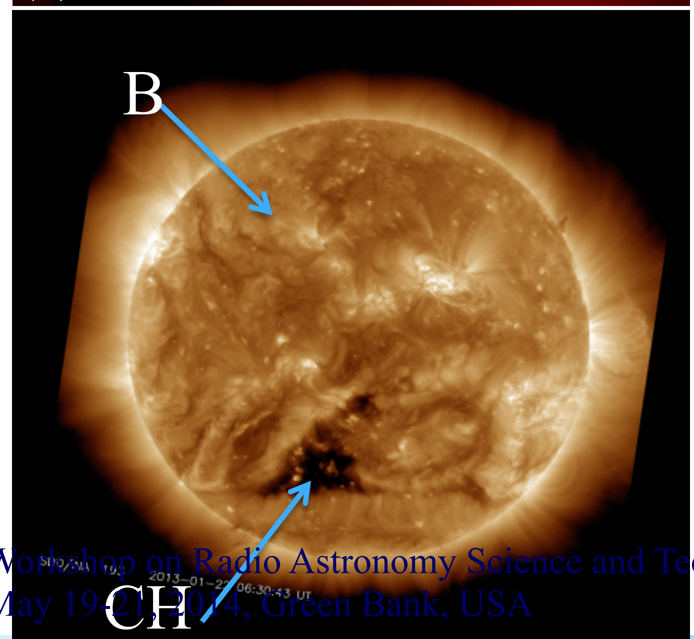
(b) NRH 432 MHz 15:13:53UT

CSRH-I first image of the quiet Sun on 22 Jan 2013

The bright source B in 1.7 GHz co-spatial with bright loops in EUV image, not in 432 MHz and 5.7GHz images. The dark area was also co-spatial with coronal holes as seen in EUV image.

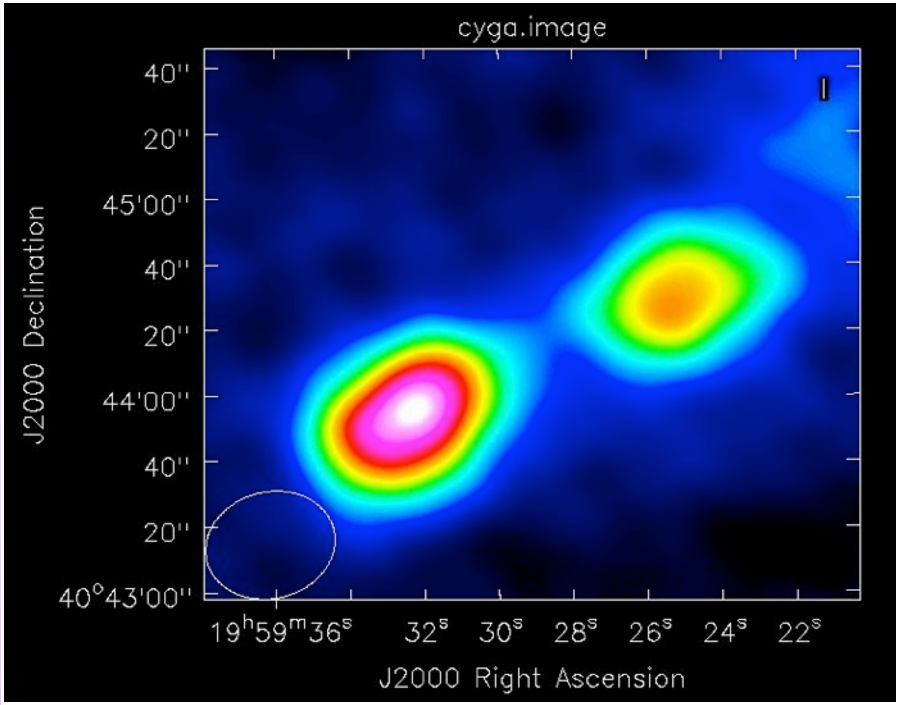


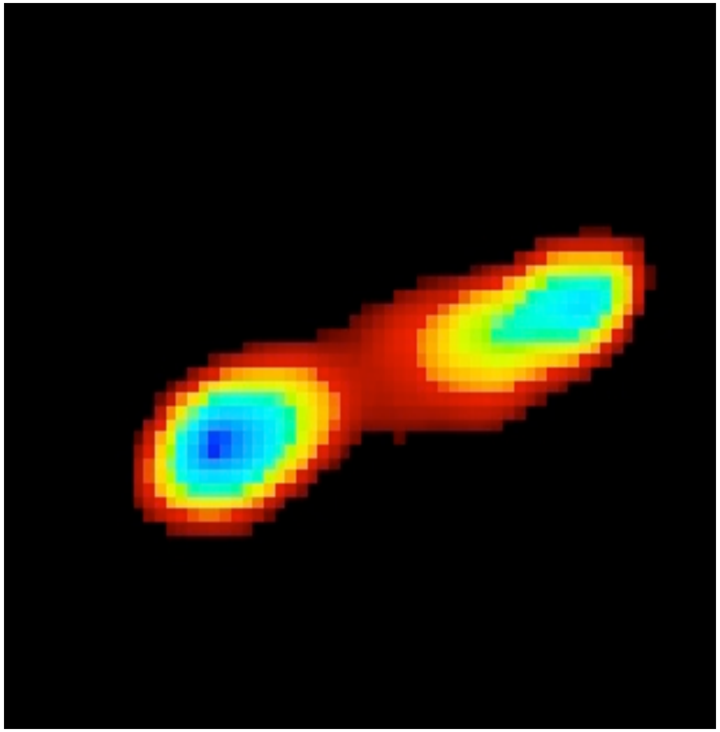
(c) SSRT 5.7 GHz 05:50 UT



(d) AIA/SDO 193Å 06:30:43UT

Test observations with CSRH-I



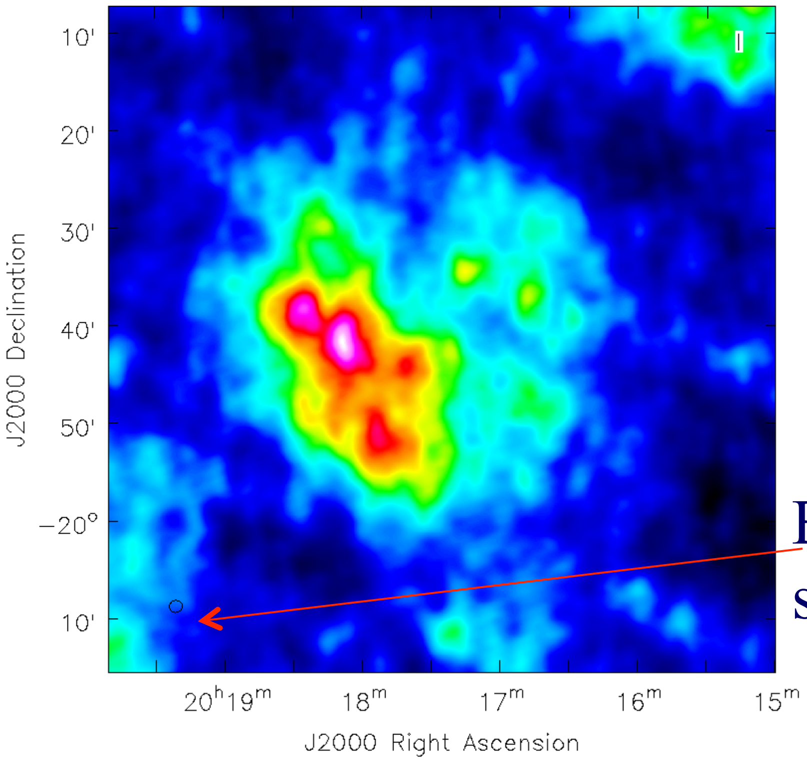


Test of Cyg A observed at 1.7 GHz on 5 Jun 2013 at 5:30 UT with 1s integral time.

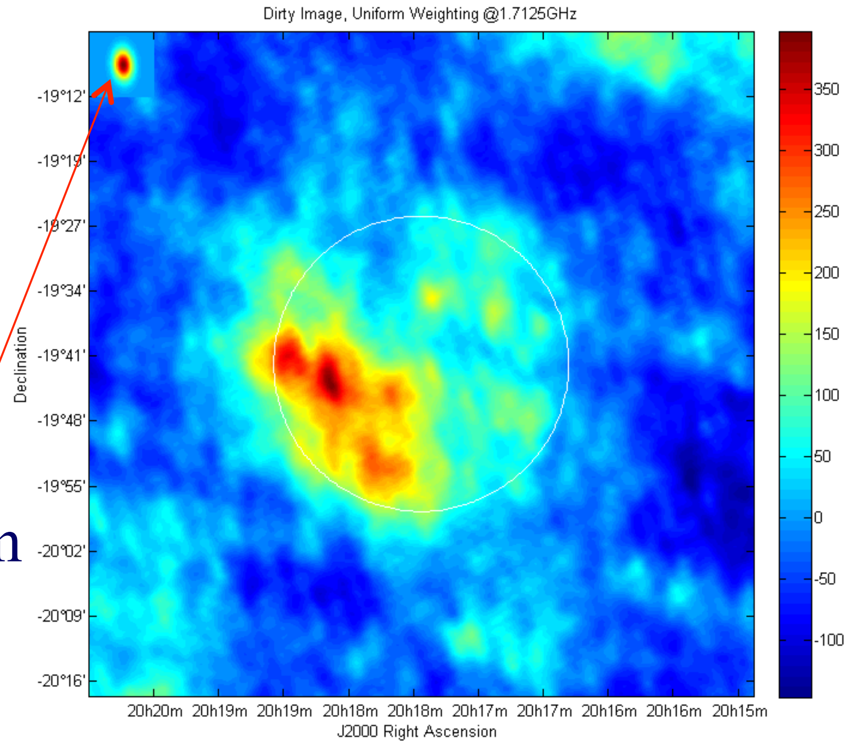
GMRT 610 MHz Image （not scaled, GMRT web）

CSRH-I image of the quiet Sun on 22 Jan 2014

Preliminary result with 30 ms integral time

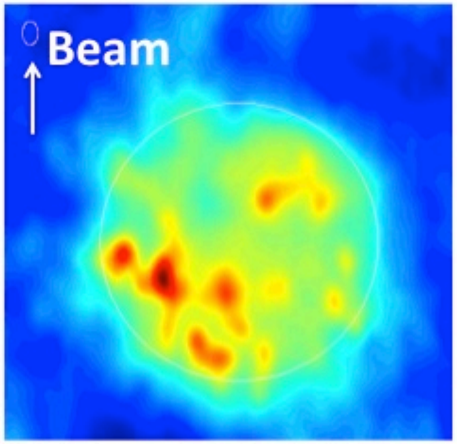


Beam size

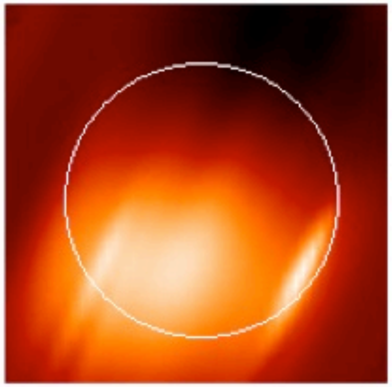


Dirty map (by CASA) **Dirty map with direct FT**

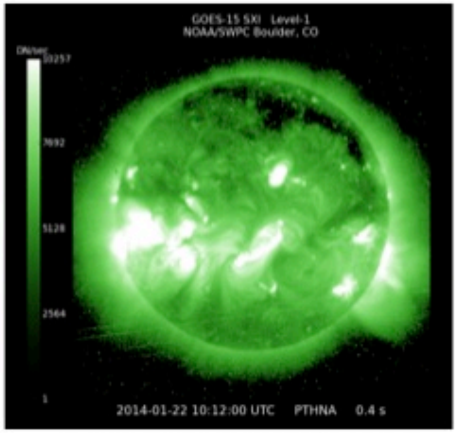
Preliminary result with 30 ms integral time



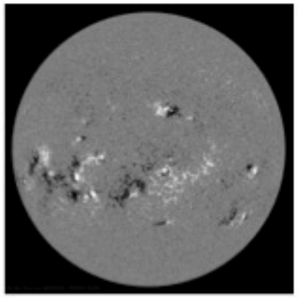
(a) CSRH-I 1.7 GHz 05:15:00UT

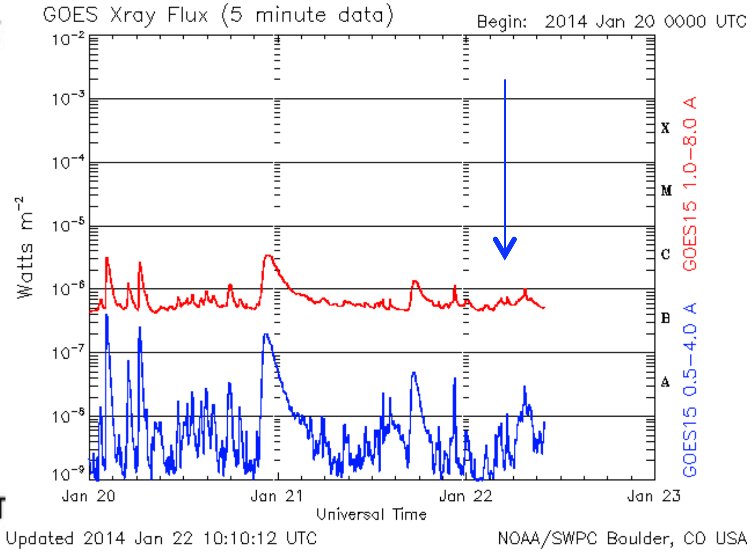

(b) NRH 432 MHz 08:46:02UT

CSRH-I image of the quiet Sun at 1.7GHz and comparisonswith other observations on 22 Jan 2014

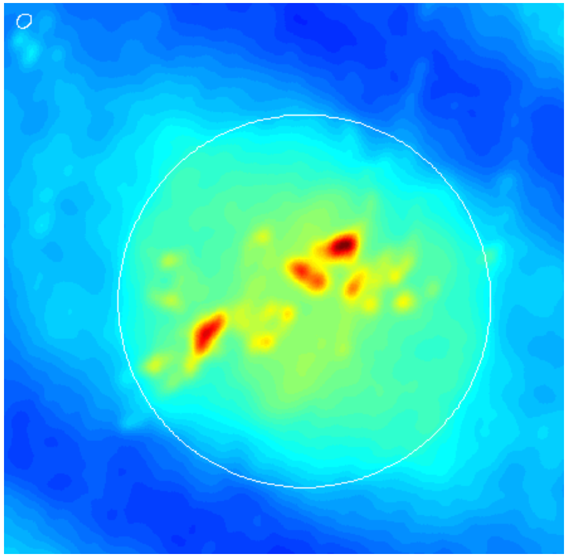


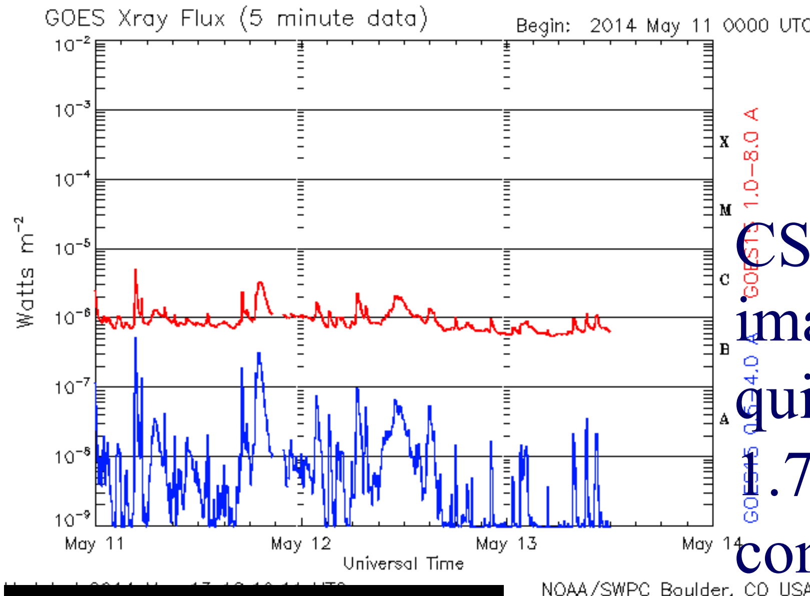
(c) GOES SXR 10:12:00UT

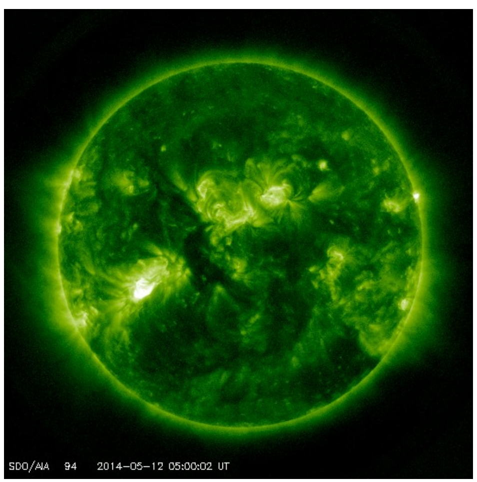

(d) HMI/SDO Bz 05:15:00UT

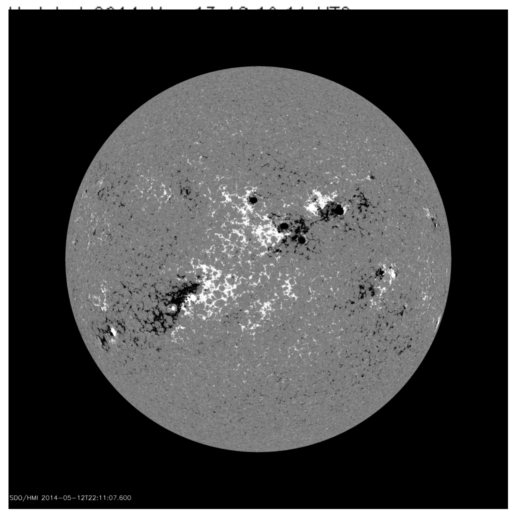


Preliminary result with 30 ms integral time





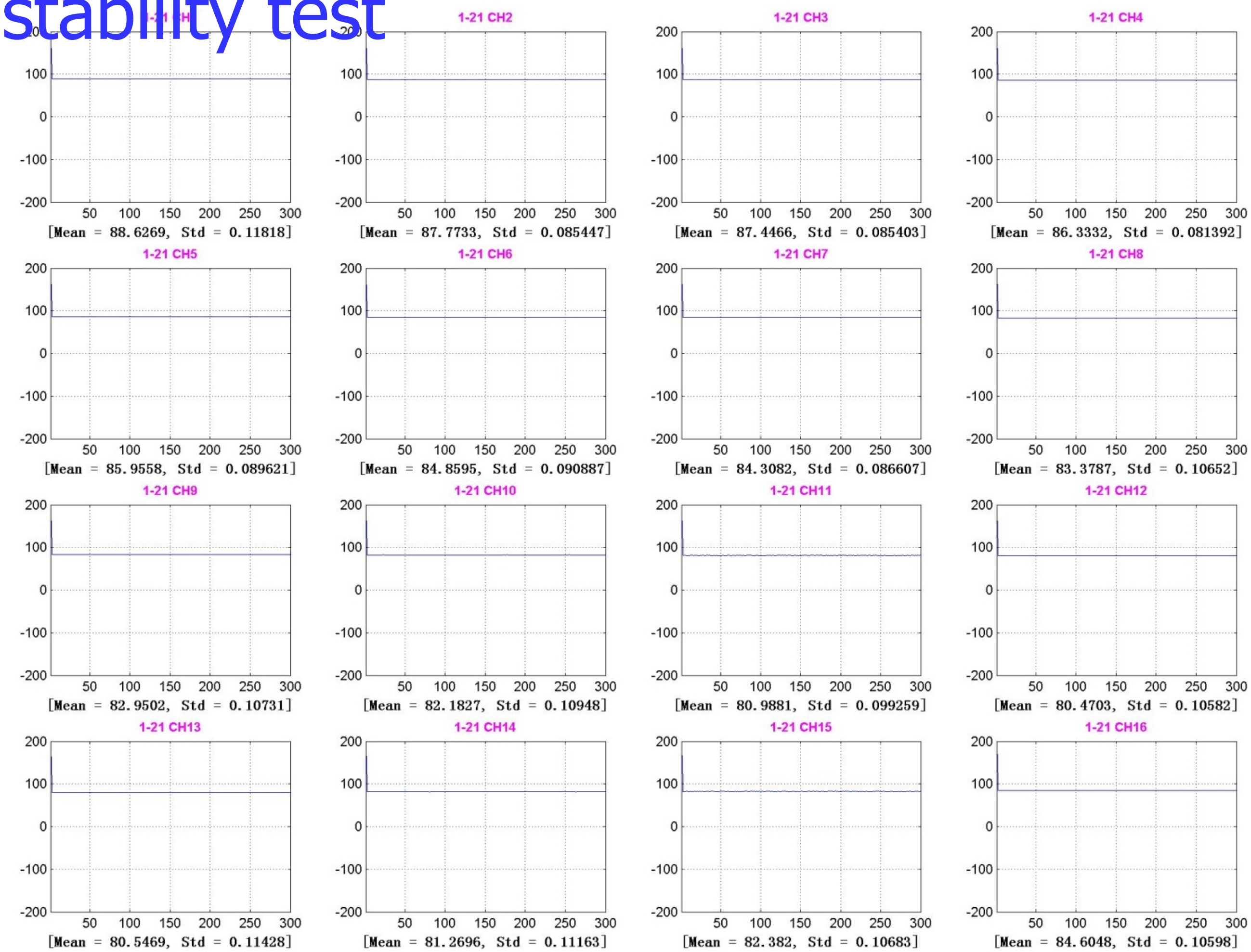




CSRH-I image of the quiet Sun at 1.7GHz and comparisons with SDO EUV 171A image and magnetogram on 12 May 2014

CSRH－II：16 channels cross-correlation phase stability test

ADC 1 - ADC21 cross-correlation phase stability test

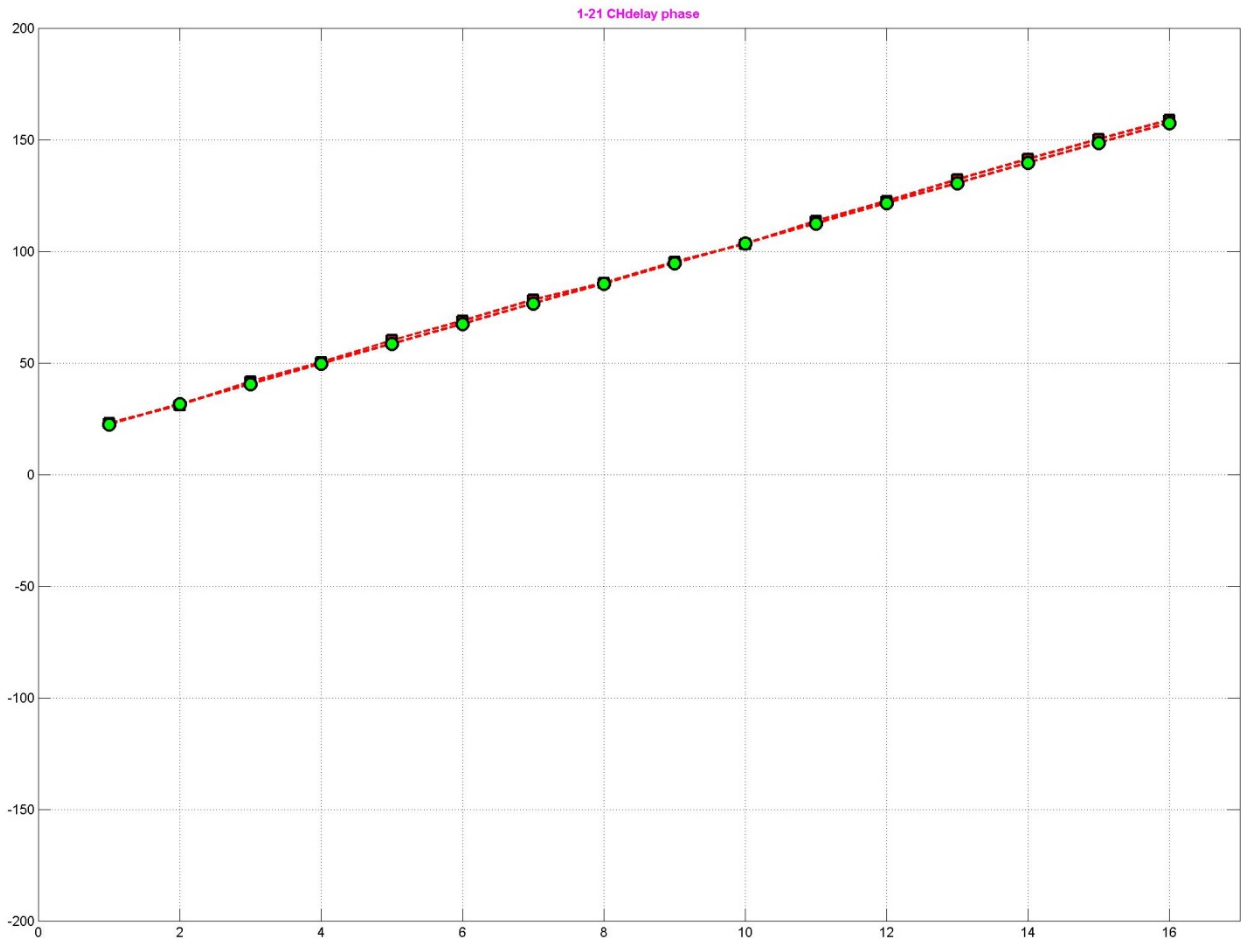


Test case:
~1 second data length
(one data every 3.125 ms)

Test output:
RMS of phase in the central frequency of the 25MHz band-limited signal.
All RMS of phase are less than 1 degree.

CSRH－II：16 channels cross-correlation delay function test

ADC 1 - ADC21 cross-correlation delay function test



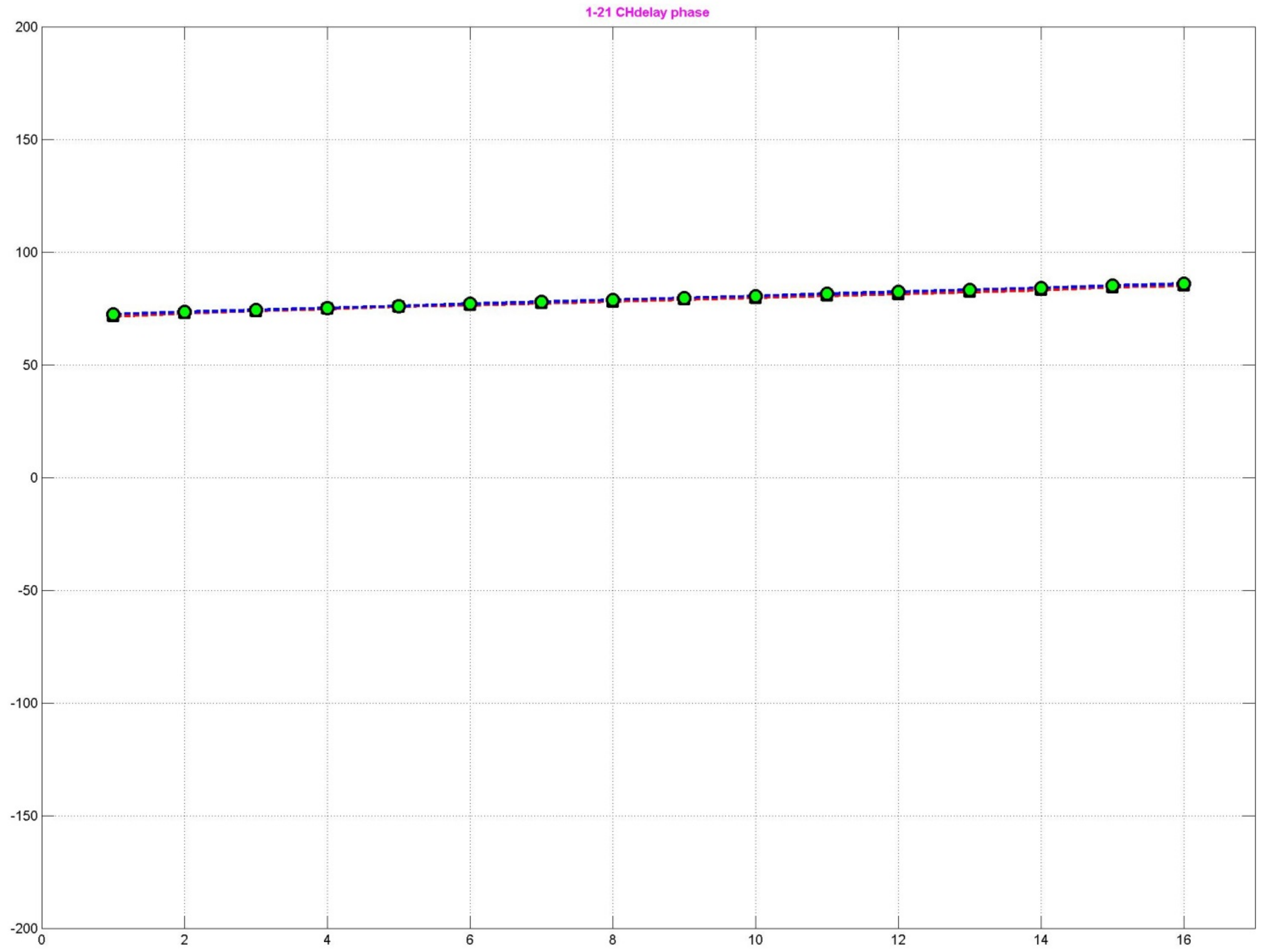
Test case:
1 ns delay is applied to ADC-1 and ADC-21.

Green circle: phase difference by theoretical calculation due to 1 ns delay.

Red square: phase difference by practical measurement due to 1 ns delay.

CSRH－II：16 channels cross-correlation fringe function test

ADC 1 - ADC21 cross-correlation delay function test



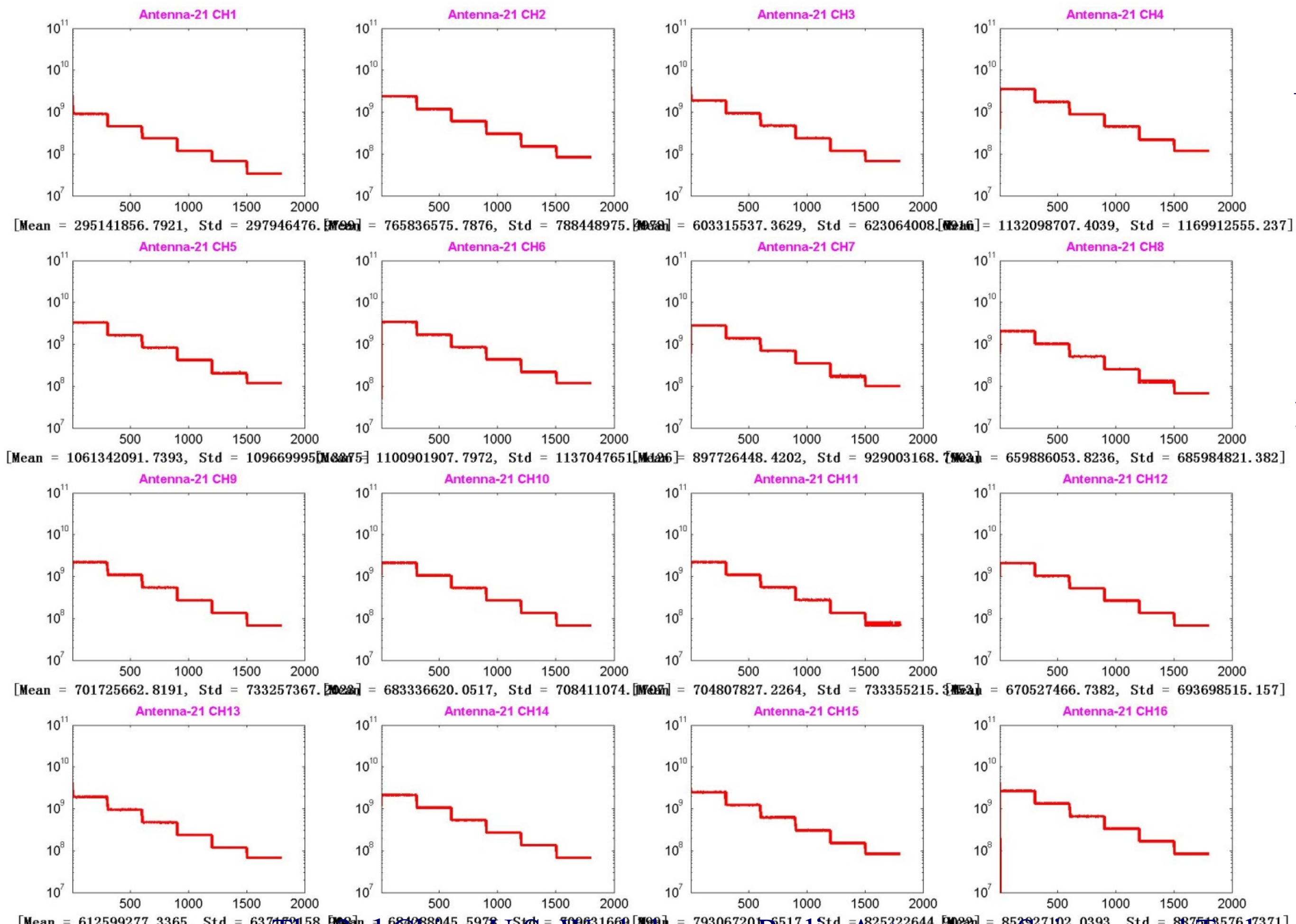
Test case:
The fringe difference(100 ps delay) is applied to ADC-1 and ADC-21.

Green circle:
phase difference by theoretical calculation due to the fringe function.

Red square:
phase difference by practical measurement due to the stripe function.

CSRH－II：16 channels auto-correlation function test

ADC-21 auto-correlation function test



Test Case:
Noise source input range: 15dB (-18~-33dBm)
Step size: -3dB

Summary

I. Solar 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 of 10km radius is established:

   I. CSRH-I during 2008-2011:

      Calibration and verification. Test observations

   II. CSRH-II finished in 2013:

      Technical testing now. Starting Test observation soon

III. Develop data pipe-line now

IV. Observing Station construction in 2014

(Photo by S.J. Yu)