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New digital beacon receiver for the study of ionosphere with satellites TBEx, FORMOSAT-7/COSMIC, and PROPCUBE

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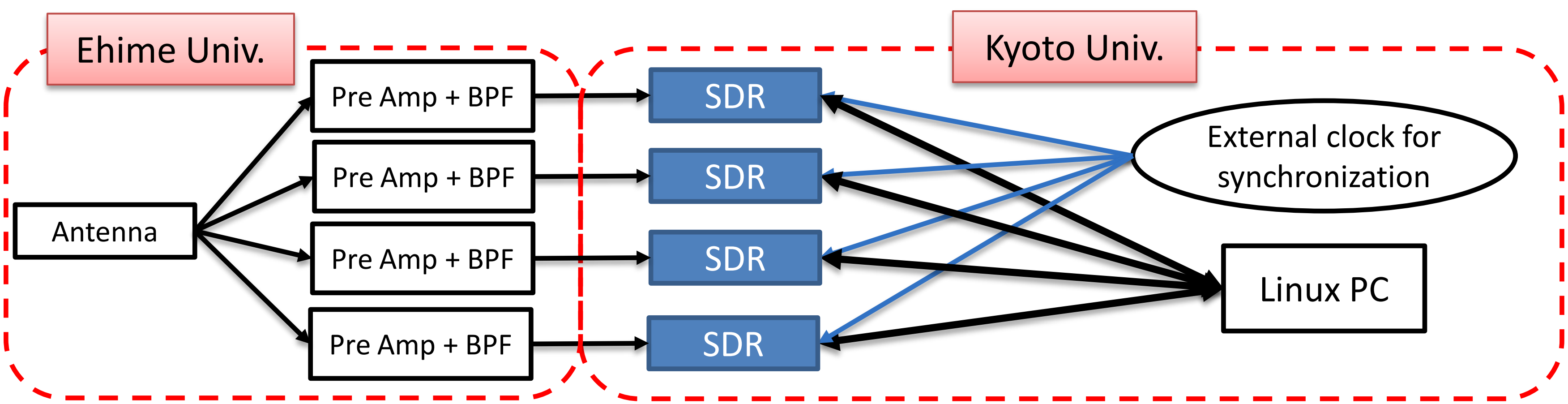
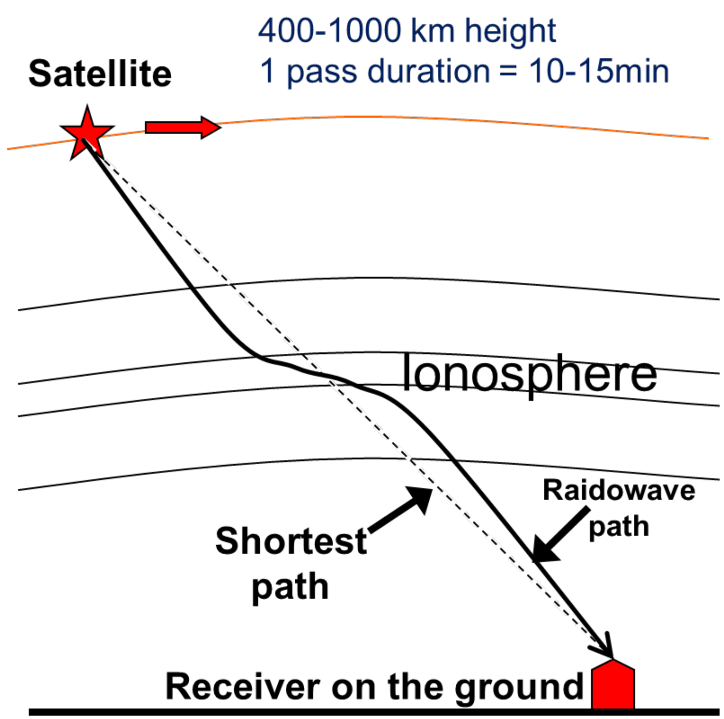
Summary

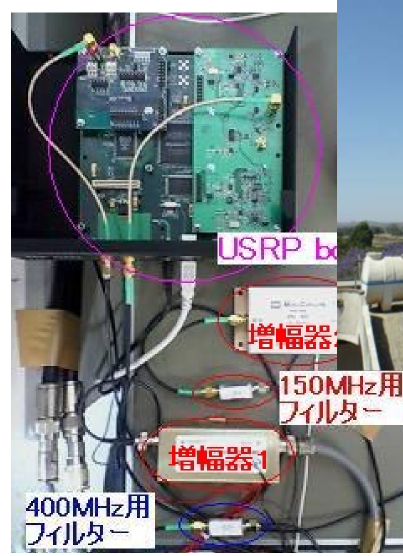
- What we did …
  - GRBR (digital 150/400MHz beacon receiver).
- What we want to do …
  - Plasma bubble study
    - How LSWS affects/works for onset of bubbles.
  - TBEx (2 units of 3U-cubesat) launch by F7/C2 piggyback.
- FROMOSAT-7/COSMIC-2 (F7/C2) beacon is important.
  - New GRBR development for TBEx + F7/C2 beacon.
  - Patch antenna + digital RX under development/test.



LEO satellite beacon and GRBR

- VHF(150MHz)/UHF(400MHz) beacon signals from LEO satellite are used for ionospheric TEC measurement for long time.
- GRBR (GNU Radio Beacon Receiver) was developed with GNU Radio and USRP-1 board at cost of 2000-3000 USD/system.
- Network of about 30 GRBRs already exist over Japan, southeast Asia, Pacific, etc., and used for studies.

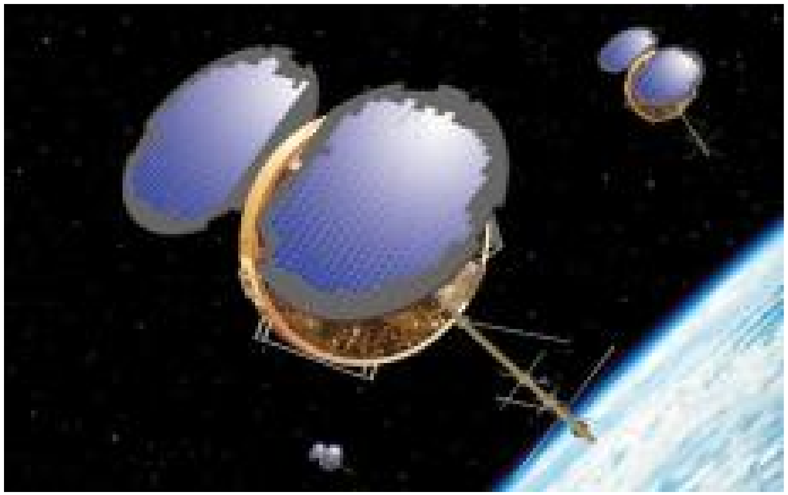


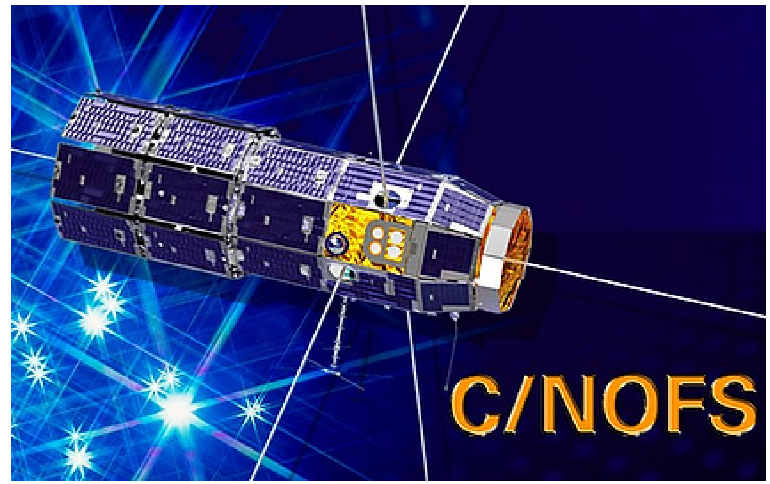


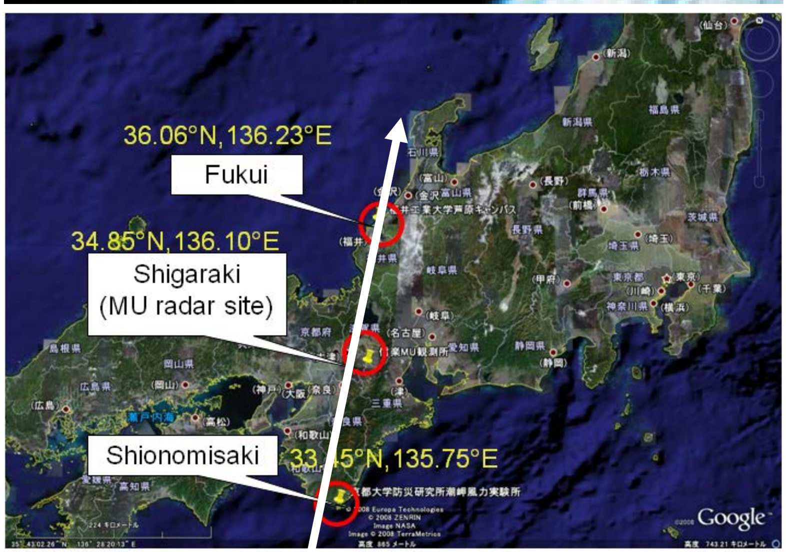
F3/C and C/NOFS used for beacon experiment

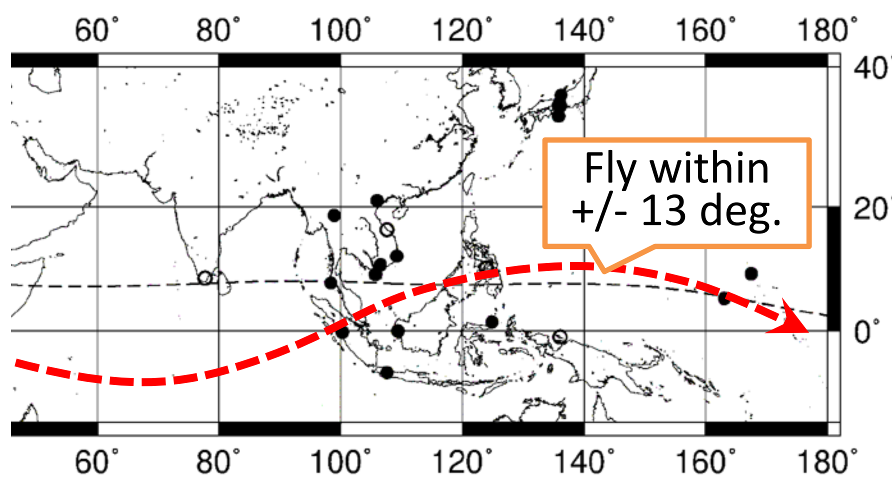
FORMOSAT-3/COSMIC
2D tomography over Japan

C/NOFS
GRBR network in SE-Asia & Pacific

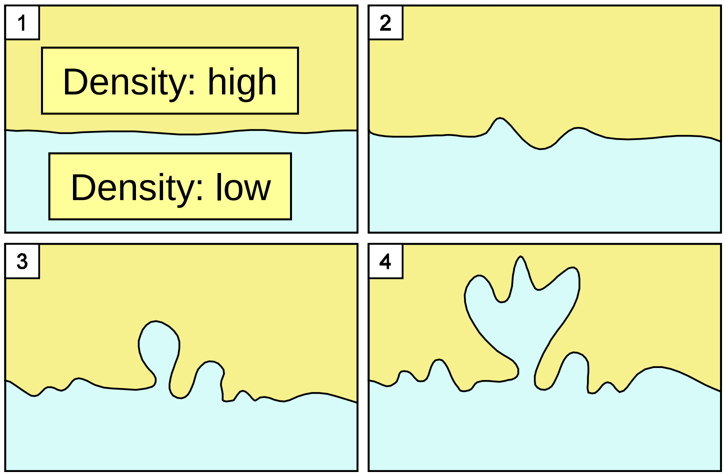




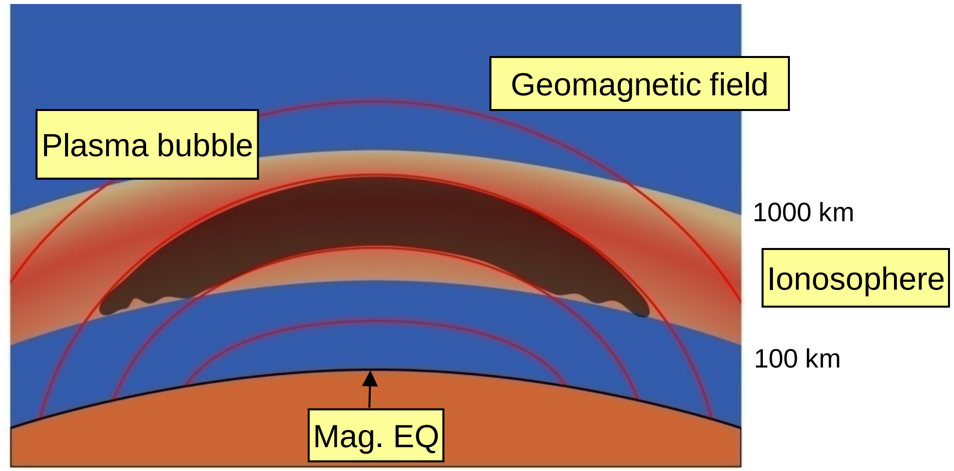




Low-latitude ionosphere
Bubble or Equatorial Spread-F (ESF)



Development of plasma bubbles



Meridional structure of plasma bubbles

- Rayleigh-Taylor instability is the mechanism.
- ESF occurs mainly near F-region sunset over the magnetic equator.
- VHF radar is very useful of observing bubble (ESF).

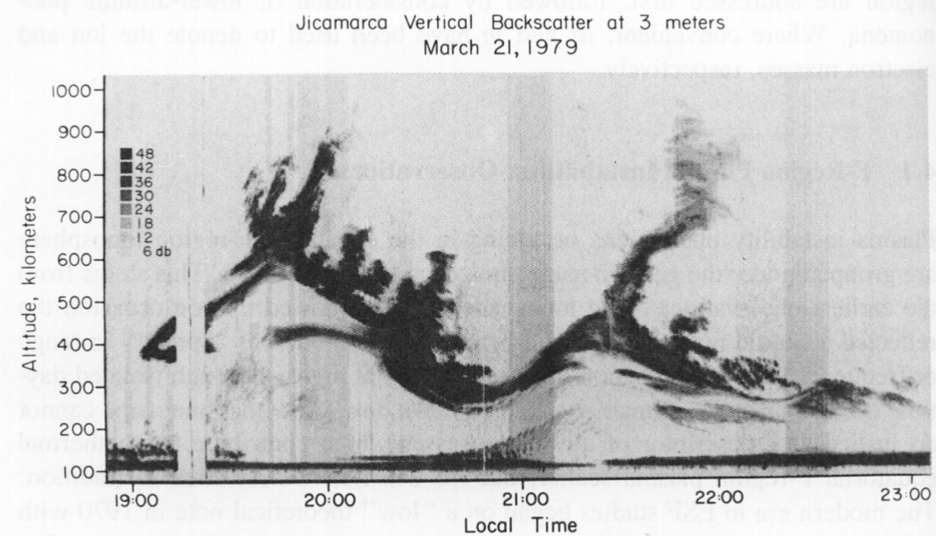
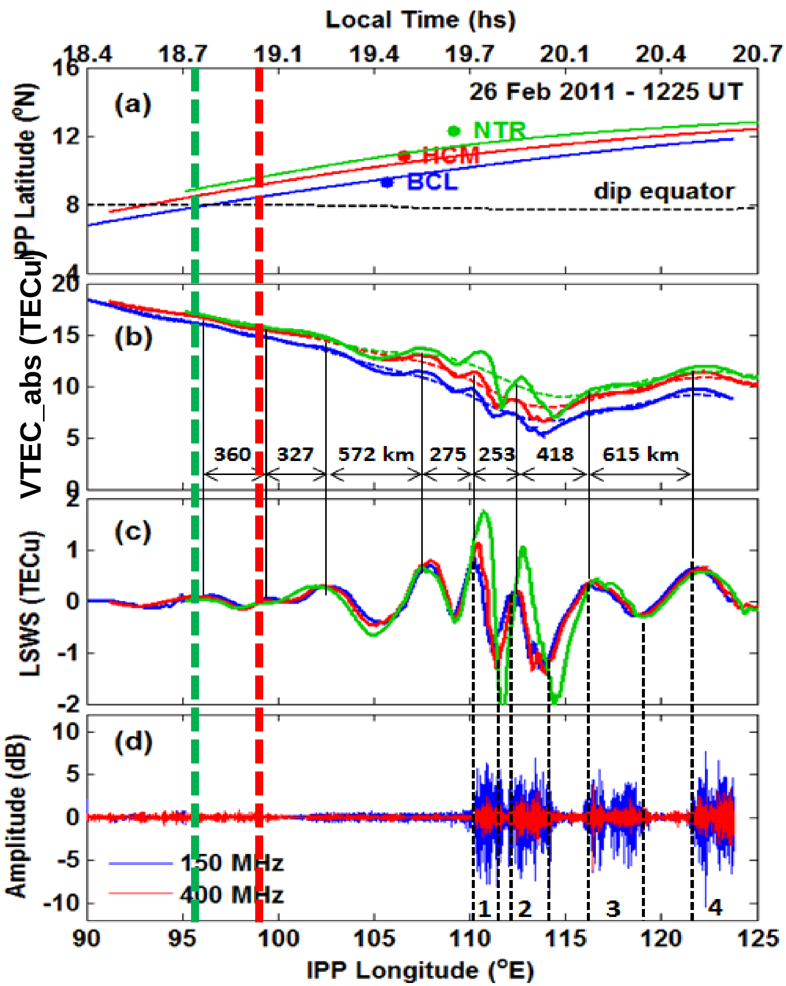


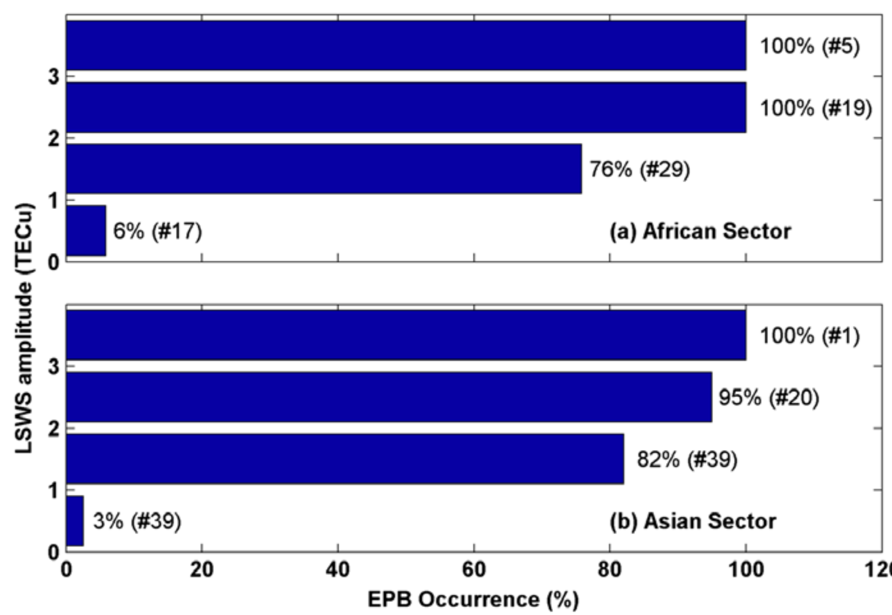
Fig. 4.1. Range–time–intensity map displaying the backscatter power at 3-m wavelengths measured at Jicamarca, Peru. The gray scale is decibels above the thermal noise level. [After Kelley *et al.* (1981). Reproduced with permission of the American Geophysical Union.]

C/NOFS study: LSWS (Large-Scale Wave Structure) and bubble occurrence



Tulasi Ram,et al, Radio Sci. 2012, JGR 2014

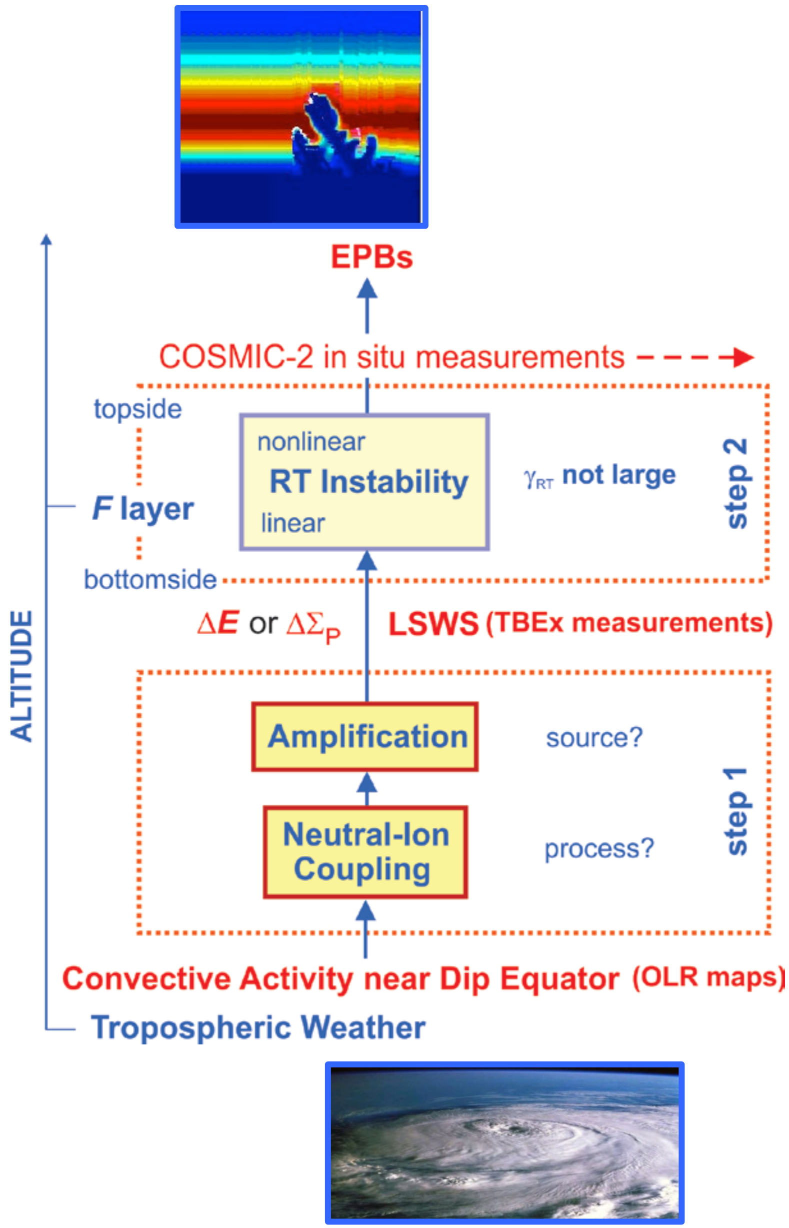
- LSWS: zonal wave-like structures from C/NOFS pass over Vietnam which follow onset of bubbles. (left)
- Statistics show occurrence of ESF is more at intense LSWS events. (bottom)



TBEx: Tandem Beacon Experiment by SRI International

- Funded by NASA: Low-Cost Access to Space (LCAS) Program
- Two CubeSats: Identical tri-frequency (150, 400, 1067 MHz) radio beacons
- To be launched in tandem into near-identical (~28 deg inclination) orbits (Piggyback with F7/C2!!)
- TBEx objective: Capture space-time description of equatorial plasma bubbles (EPBs)
- Overall science question: Does causal relationship exist between tropospheric weather, large-scale wave structure (LSWS), and EPBs?

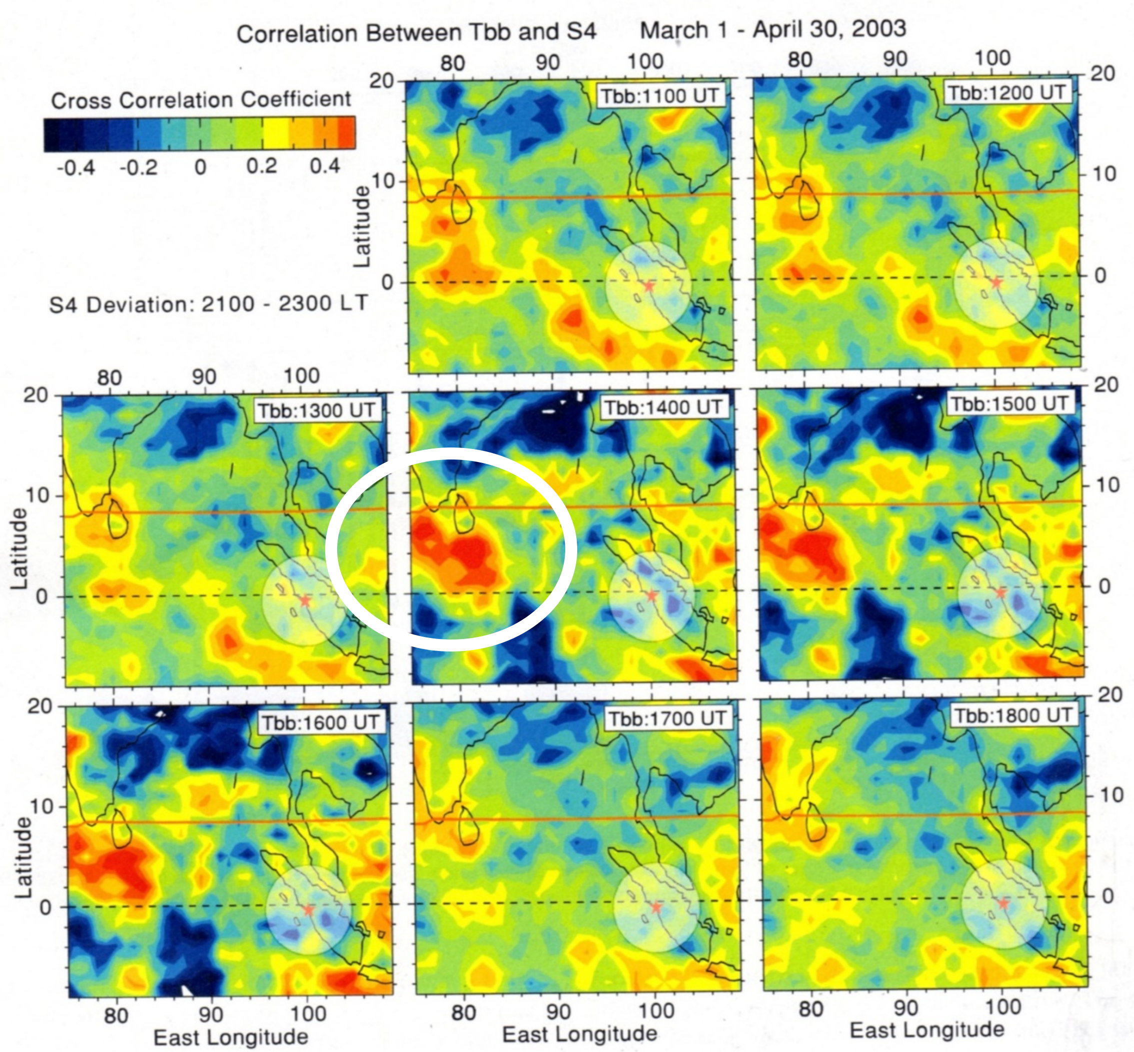
Causal Link: Convective Activity to EPBs?



- Input, Stage 1: Outgoing longwave radiation (OLR) can be used to map distribution of convectively active regions
- Output, Stage 1 (or Input, Stage 2): Large-scale wave structure (LSWS) can be measured as TEC variations using TBEx & cluster of ground receivers
- Output, Stage 2: Equatorial plasma bubbles (EPBs) can be measured with ground-based radar & F7/C2 in situ sensors
- Partitioning link into two stages allows clear evaluation of roles played by contributing sources and processes

Relationship between plasma bubble and weather

Ogawa et al, Earth Planets Space, Vol. 61, pp. 397-10, 2009



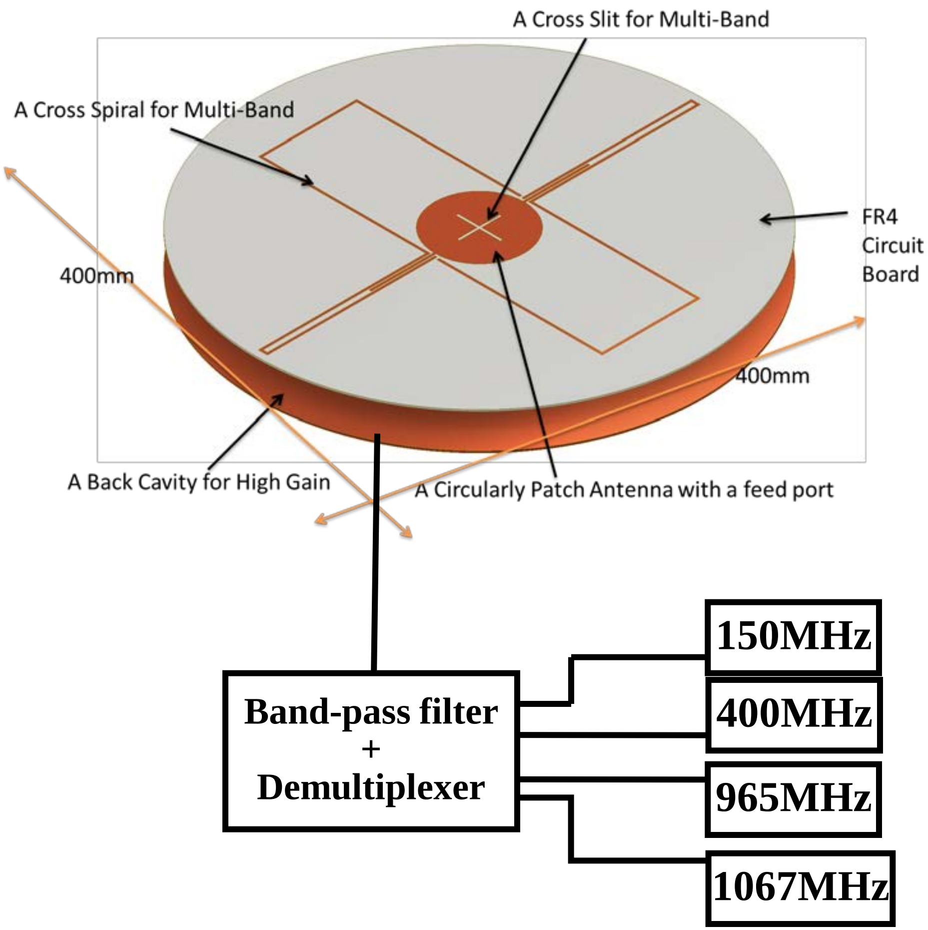
- Correlation between
  - Daily variation of nighttime GPS S4 index at the EAR site (Indonesia)
  - Daily variation of Tbb as cloud-top temperature
- Maximum correlation was ~0.4. Enhanced region is shifted west of S4 measurement location.

TBEx and COSMIC-2 beacon signals

Project Name	Units	Inclination	Beacon frequency	Note
FORMOSAT-7/ COSMIC-2 (USA,Taiwan)	6	24°	383 MHz 400 MHz 965 MHz 2200 MHz	383 MHz modulated Others are CW.
TBEx (USA)	2	28.5°	150 MHz 400 MHz 1067 MHz	Decided launch with COSMIC-2.

- Satellites for 150/400MHz beacon are getting old. C/NOFS stopped.
- COSMIC-2 and TBEx will be launched in 2017 1Q. They fly in the low-latitude region with triple-band beacon TXs.
- We develop a new GRBR system that covers 150/400/965/1067MHz signals for these satellites.

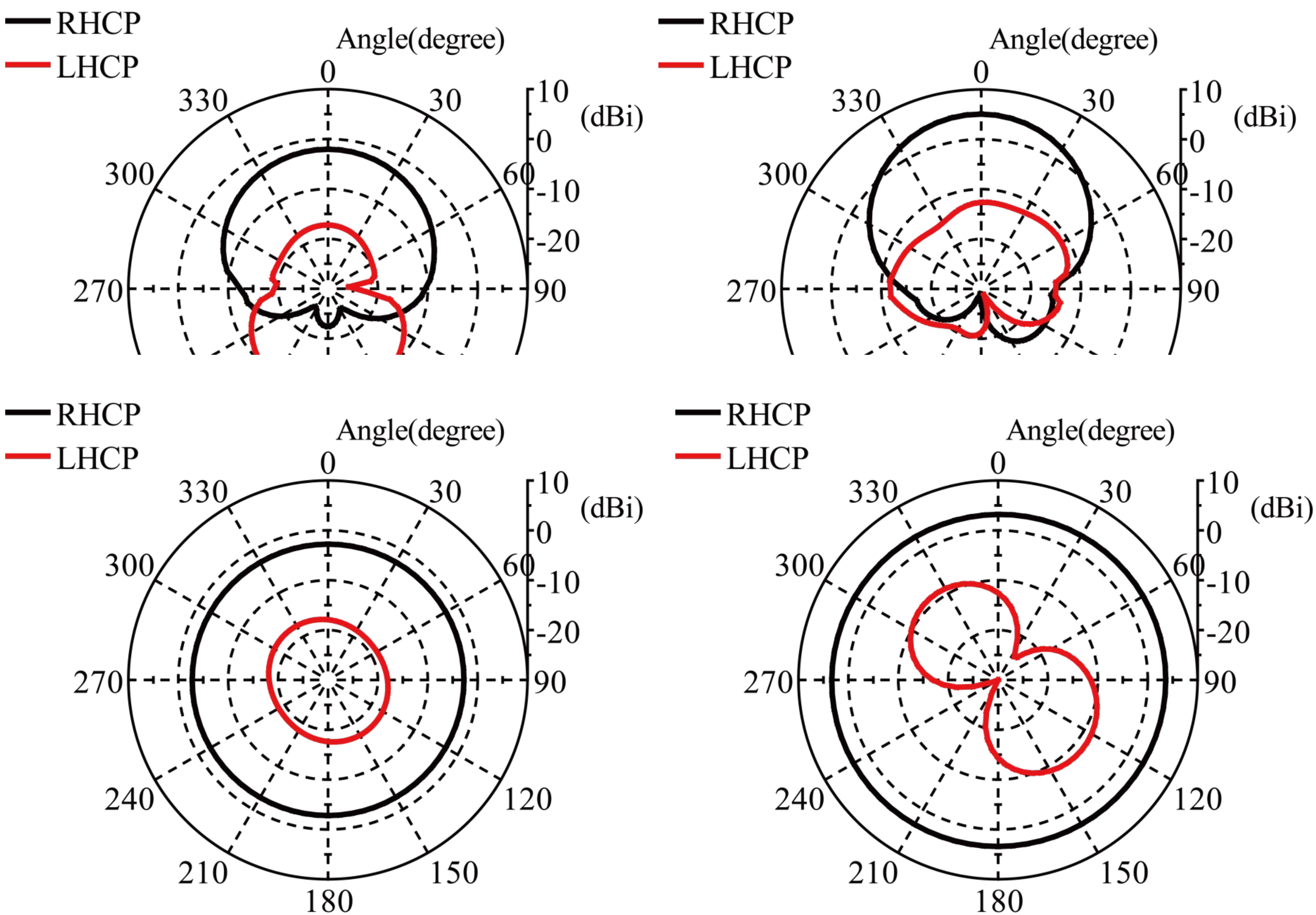
Development of new GRBR
Antenna part by Prof. Matsunaga at Ehime Univ.



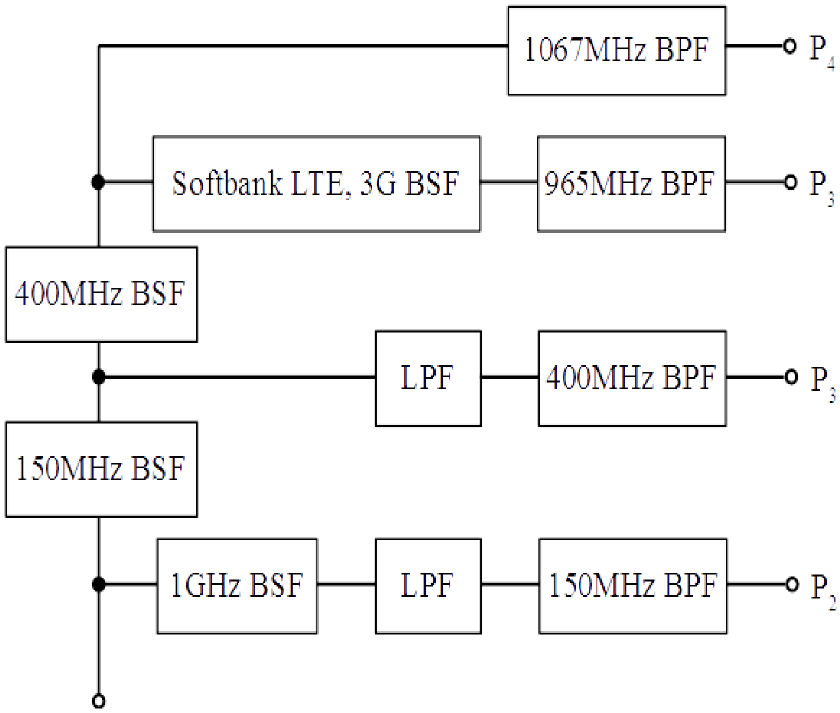
CONCEPT

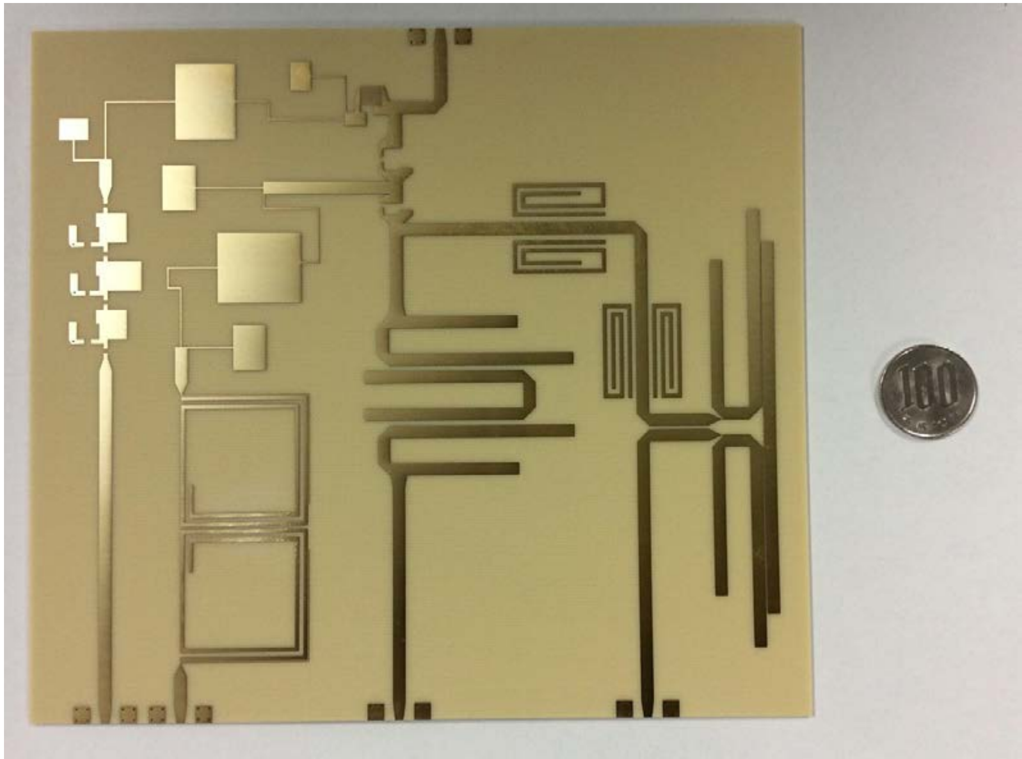
- 150MHz, 400MHz, 965MHz and 1067MHz Right-Hand Circular polarization
- Single feed (One port)
- Maximum size: 400mm x 400mm
- Getting high antenna gain with cavity back

Calculated antenna radiation pattern



Design of Demultiplexer





Development of new GRBR

SDR part by Kyoto Univ. + Hsing Wu Univ.

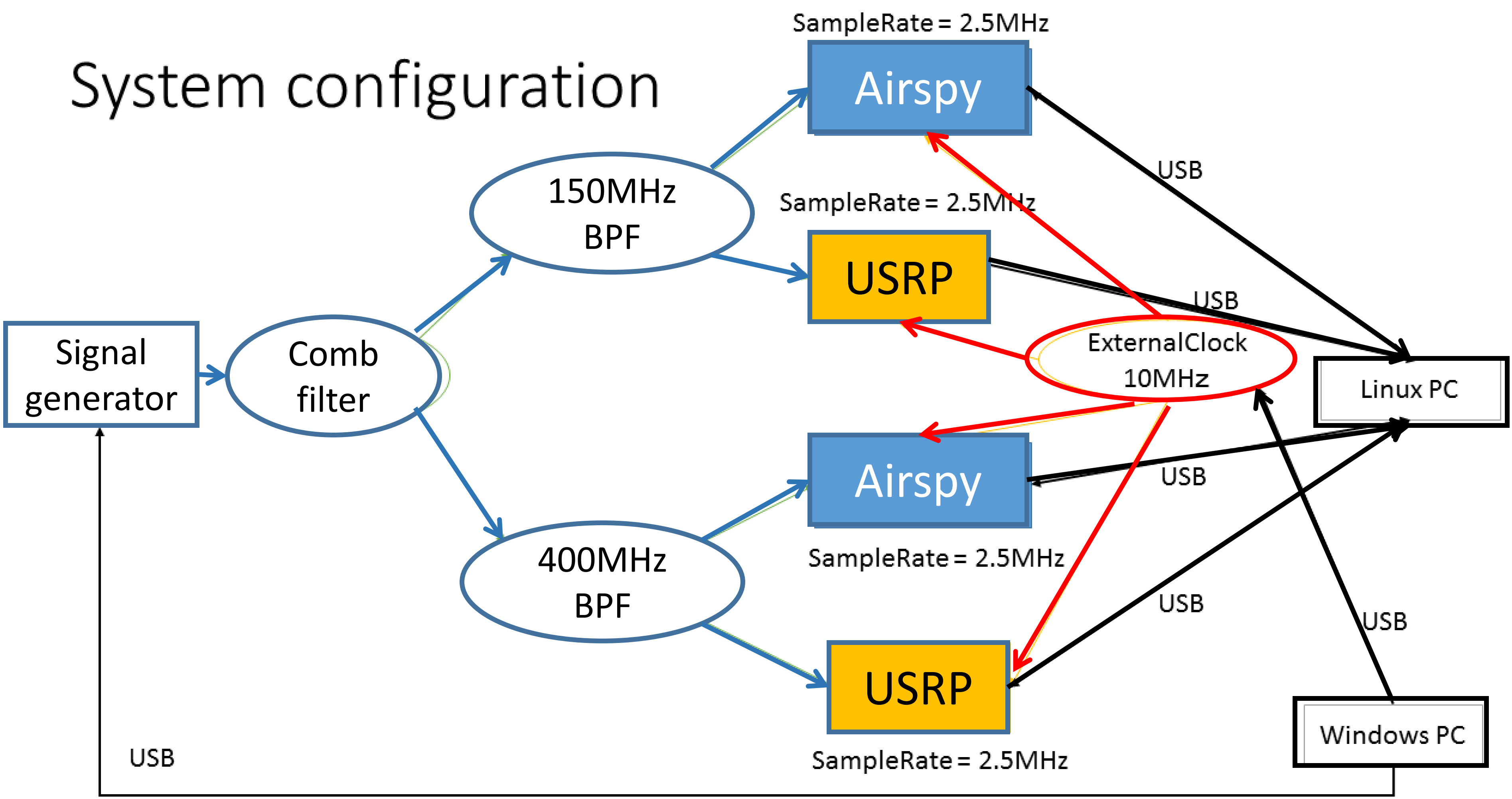
Software: Keep using GNU Radio (Open SDR toolkit, very popular)
Hardware: Now evaluating three different SDR boards shown below.


USRP B200 (left) and B210 (right) from Ettus.
Cost: highest, F-tune: wide-band, most accurate
RX + TX, USB3.0, Sync: 10MHz
https://www.ettus.com/


Blade RF x40 (left) and up/down converter XB-200 (right) from Nuand.
Cost: middle, F-tune: wide-band, coarse tuning
RX + TX, USB3.0, Sync:38.4MHz
https://www.nuand.com/

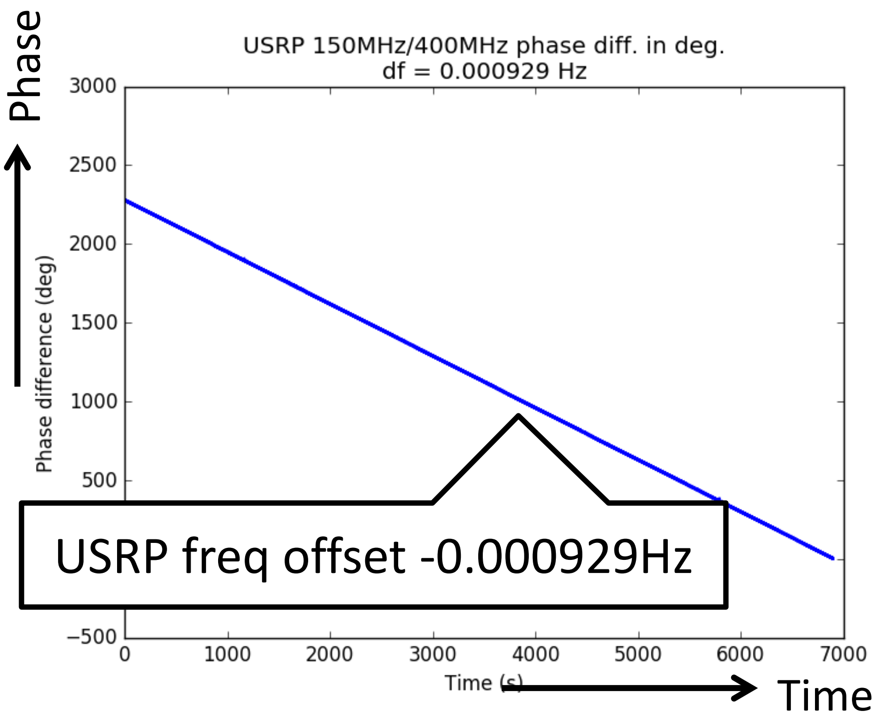
Airspy
COST: lowest, F-tune: narrower, coarse tuning
RX only, USB2.0, Sync: 10MHz
http://airspy.com/

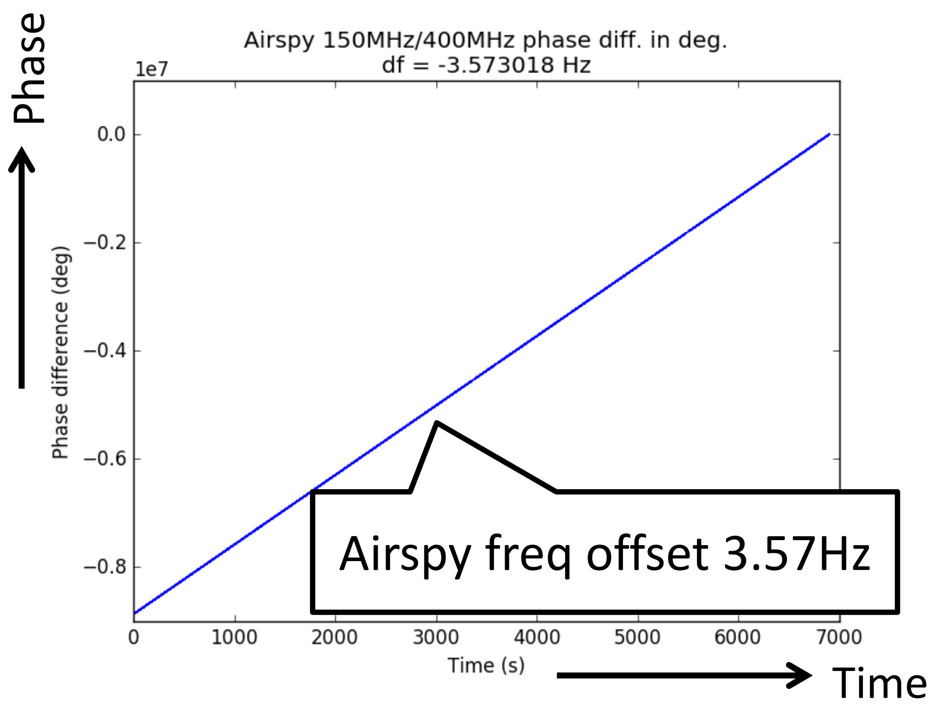
USRP/Airspy mixed synchronization
Test of 150/400MHz signal on desk



Results of USRP and Airspy

SDR: USRP / Airspy, Signal pair: 150MHz / 400MHz





Delta f is found as 400MHz – 150MHz x 8/3.

When 2 boxes are in perfect synchronization Delta f should be 0.

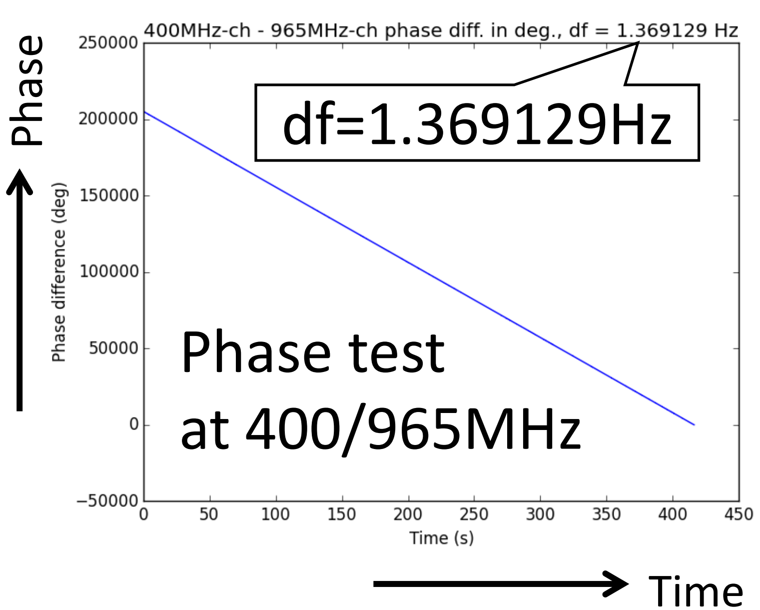
USRP: Very good. 2 boxes are synchronized < 1mHz

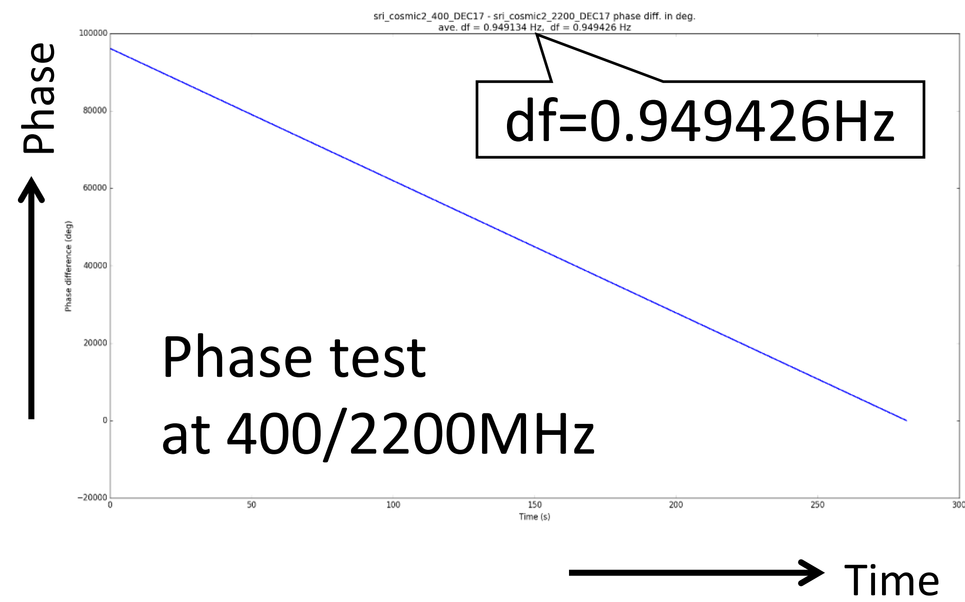
Airspy: Not very good. Frequecby bias of 3.57Hz exists.

(Airspy should useful as far as the offset is stable enough. Now checking)

Test of COSMIC-2 beacon TX (Dec. 2015 at SRI)

400MHz/965MHz/2200MHz by USRP B210

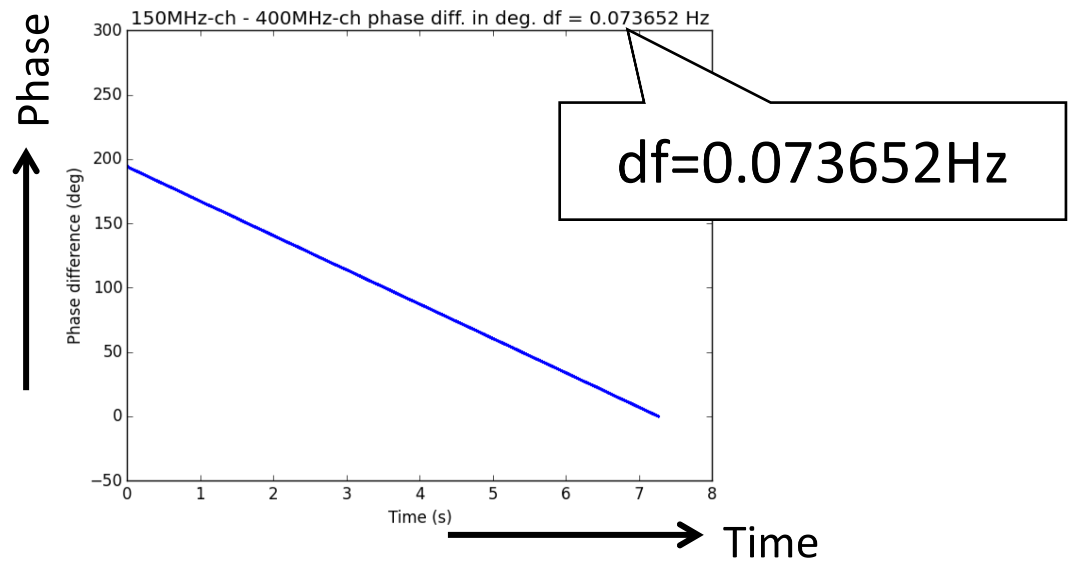




- We found phase slope between channels!!
- Understood by PLL off-tune from nominal (=aiming) frequency.

Band	Aimed (MHz)	PLL tune freq. (MHz)	df at 400MHz (Hz)
UHF	400.9000	400.8999986715266236563173	-------
L-band	965.5918	965.5918000941235646496352	1.36755…
S-band	2200.2702	2200.270197931199789047241	0.95152…

Test of TBEx beacon transmitter (150MHz/400MHz)

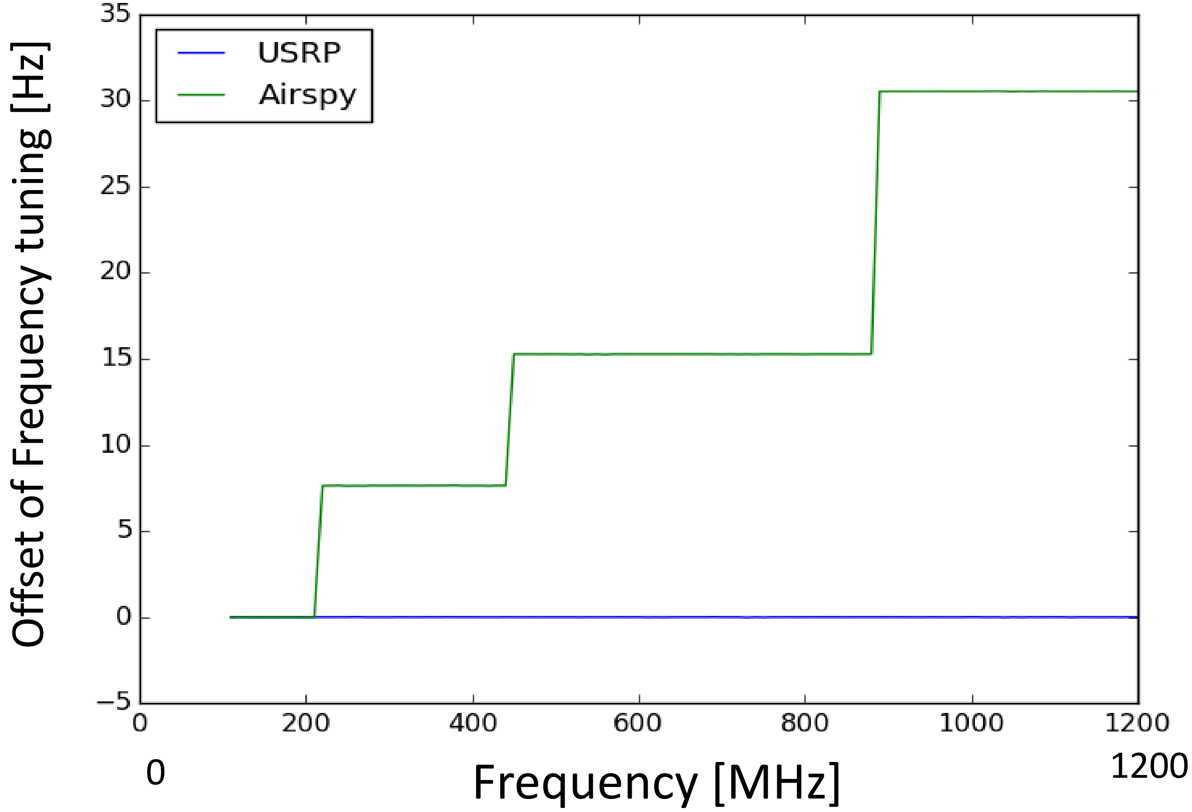


Same behavior as COSMIC-2 beacon TX!!

Band	Aimed (MHz)	PLL tune freq. (MHz)	df in reference to 150MHz band (Hz)
VHF	150.012	150.011999905109405517578	-------
UHF	400.032	400.031999945640563964843	0.074505805…

Reason of Airspy phase shift

Precise check of Airspy tuning frequency

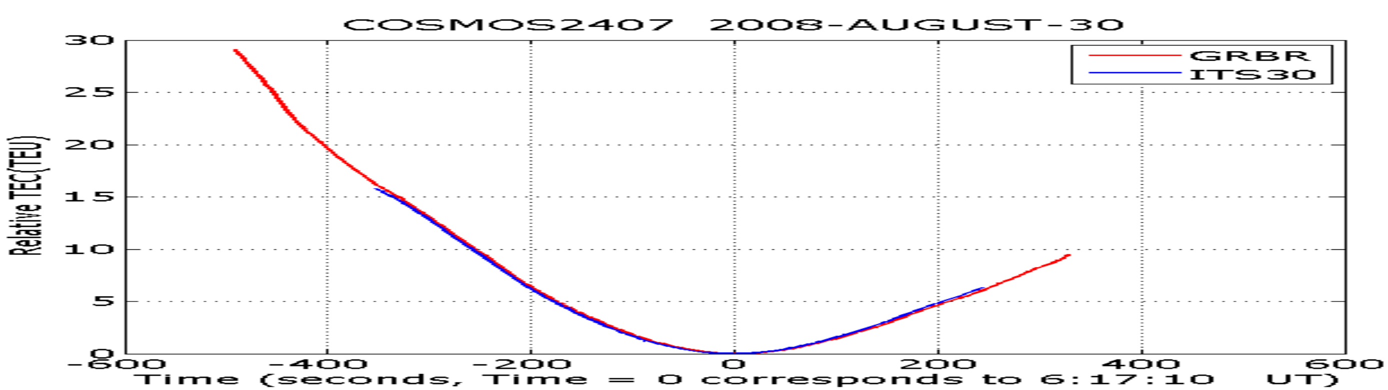


USRP: Very precise tuning through 100-1200 MHz range.
Airspy: Offset of seeral Ha exists above 200MHz. → Generating phase slope. Mechanism is unknown, maybe attributed to PLL LSI.

How effective theses phase offsets?

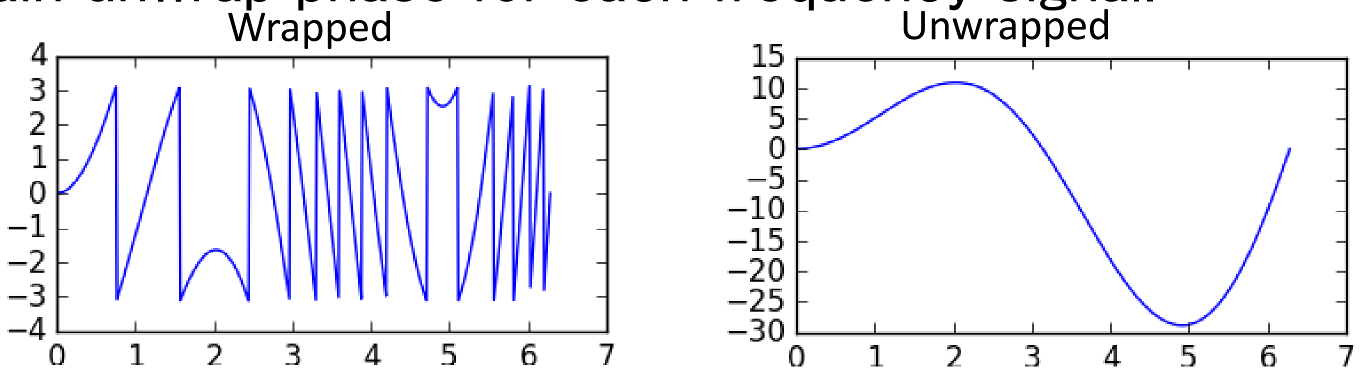
- Expeted TEC offset at 20minutes (1200s) satellite pass

Cases	Frequency pair	Delta TEC after 20minutes (TEU)
USRP (RX)	150MH/400MHz	0.0351
USRP (RX)	400MHz/1067MHz	0.374
Airspy (RX)	150MH/400MHz	135
TBEx (TX)	150MHz/400MHz	11.6
COSMIC-2 (TX)	400MHz/965MHz	590
COSMIC-2 (TX)	400MHz/2200MHz	351



TIPS: Unwrap-phase problem

- We obtain unwrap phase for each frequency signal.



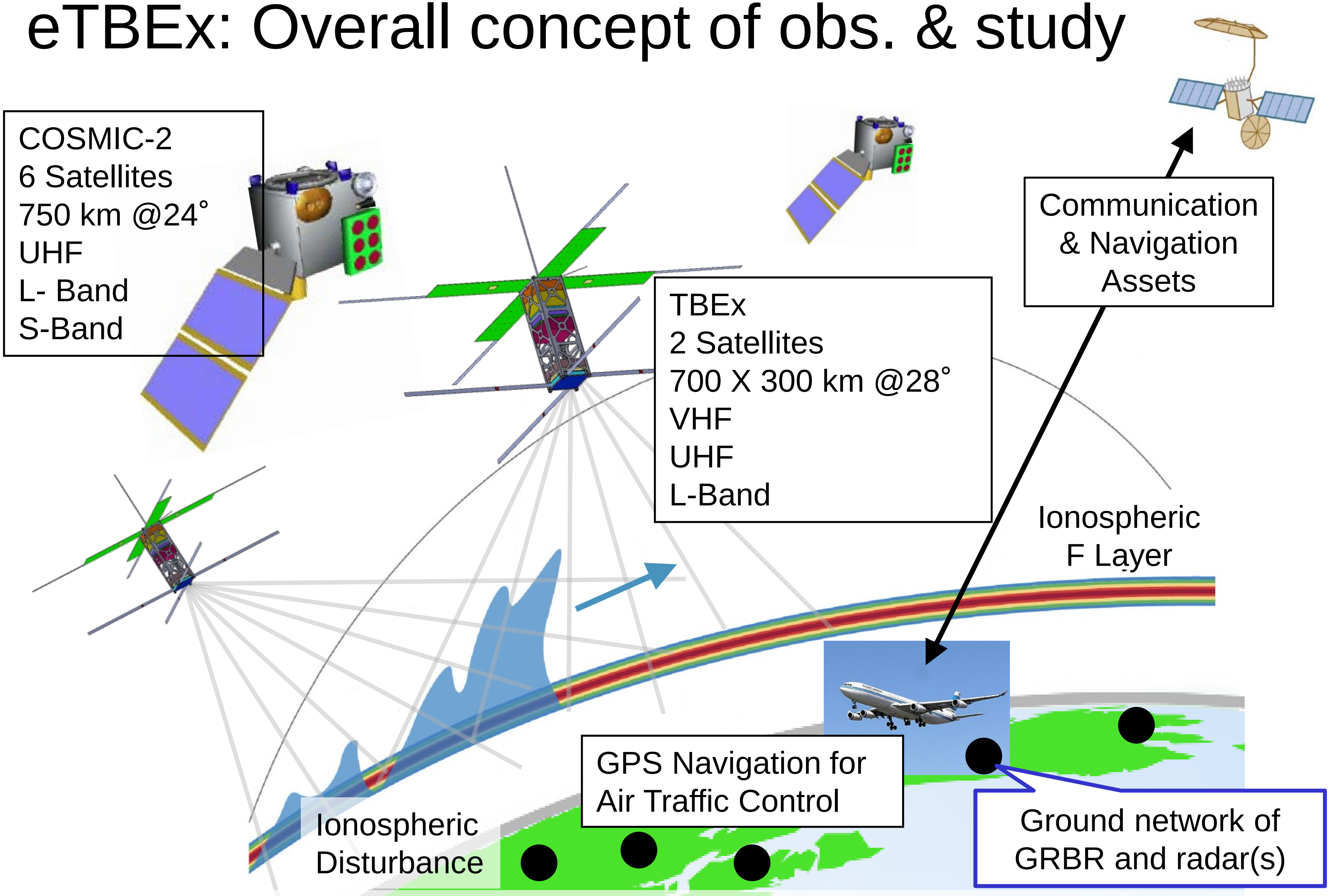
- TEC calculateion may include this type calculation.

  Delta phase = unwrap (phase @ 400MHz) −

  unwrap (phase @ 150MHz) x 8/3

- This is dangerous when number of phase wrap is very large because of "large number +/− small number" calculation.
- It is recommended to evaluate the phase difference by counting number of unwraps in a single function.ap

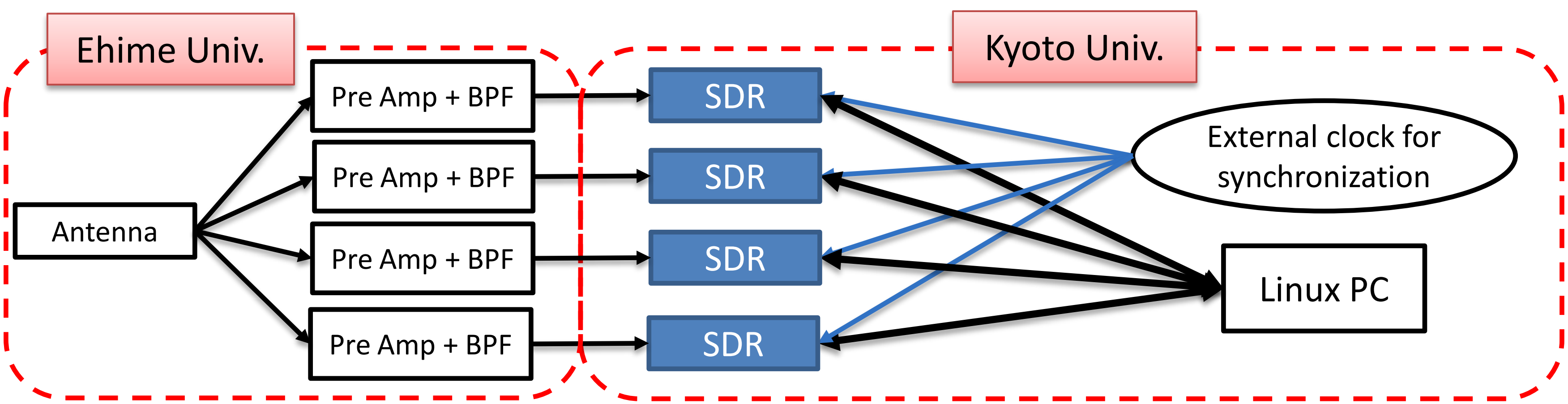
eTBEx: Overall concept of obs. & study



eTBEx orbit & frequency diversity enhances awareness of impending RF disturbances

Summary

- What we did …
  - GRBR (digital 150/400MHz beacon receiver).
- What we want to do …
  - Plasma bubble study
    - How LSWS affects/works for onset of bubbles.
  - TBEx (2 units of 3U-cubesat) launch by F7/C2 piggyback.
- FROMOSAT-7/COSMIC-2 (F7/C2) beacon is important.
  - New GRBR development for TBEx + F7/C2 beacon.
  - Patch antenna + digital RX under development/test.



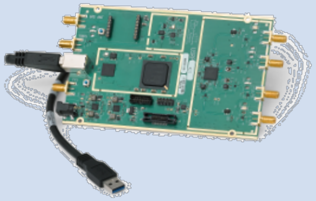
Backup

Summary

- What we did …
  - GRBR (digital 150/400MHz beacon receiver).
  - Success with beacon from F3/C and C/NOFS satellites.
- What we want to do …
  - Plasma bubble study
    - How LSWS affects/works for onset of bubbles.
    - Find source of LSWS (comparison with low-atmosphere signals).
  - TBEx (2 units of 3U-cubesat) launch by F7/C2 piggyback.
- FROMOSAT-7/COSMIC-2 (F7/C2) beacon is important.
  - New GRBR development for TBEx + F7/C2 beacon.
  - Patch antenna + digital RX under development/test.
  - 1 set cost will be 5000 USD (hope 4000 USD range).

まとめ

- SDRの比較
  - SDRで期待する動作はほとんど行えた。
  - 各SDRの利点と欠点は以下の表のようになっている。

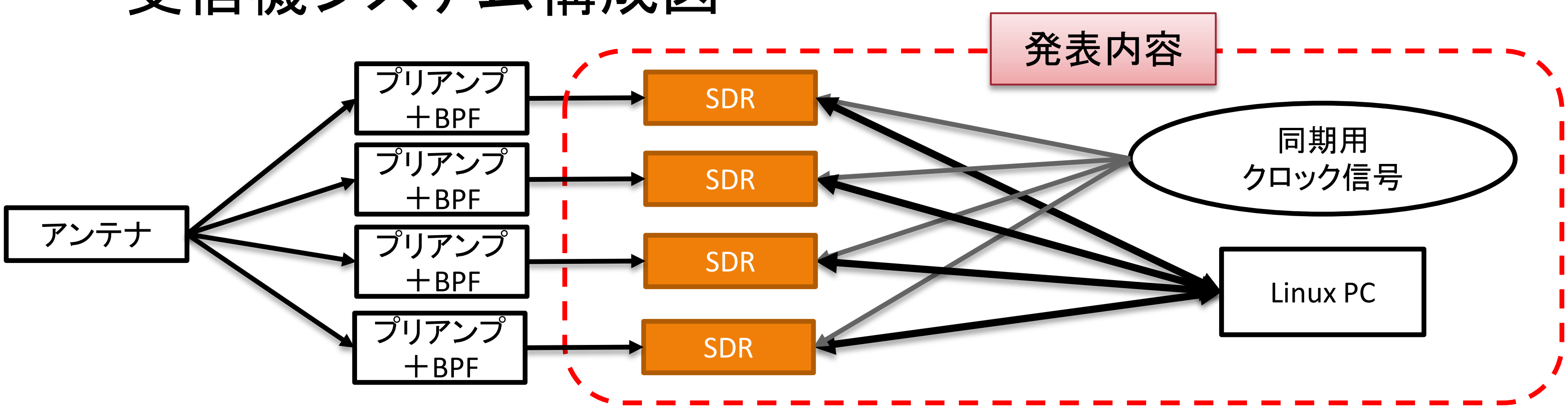
SDR機器の名称	利点	欠点
USRP B200/B210 	**周波数チューニングが良い。** 対応する周波数範囲が広い。 信頼性が高い。 購入が簡単。	コストが高い。
Airspy 	コストが低い。 小型である。	**周波数チューニングが荒い。** 対応する周波数帯が低い。 同時動作が3台まで。

- 実際のビーコン送信機でのテスト
  - 送信機側の設定周波数とPLLの同調のズレも、TEC推定時に考慮する必要がある。
  - アンラップ位相差を求める際に桁落ちが発生したため、専用ルーチンを開発した。

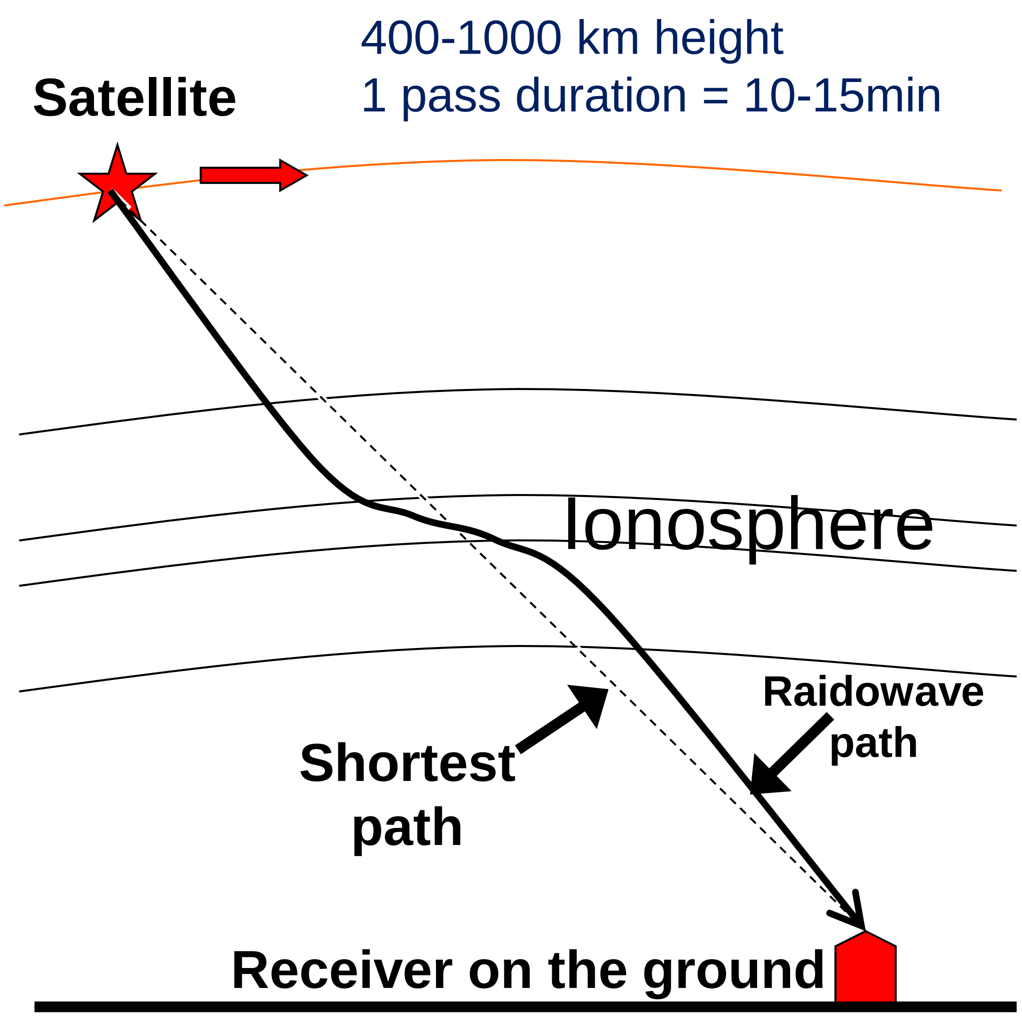
手法:ビーコン受信機

- ビーコン受信機はソフトウェア無線機（SDR: Software-Defined Radio）技術を用いる。
  - ソフトウェアの変更で機能を変化（python、GNU Radioで制御）。
  - アナログ信号をディジタル信号として解析に便利な形で保存。
  - USRP B210、bladeRF x40、Airspy R2の3種類のSDRを検討。
    - ただし今回、bladeRFに関しては省略。

- 受信機システム構成図

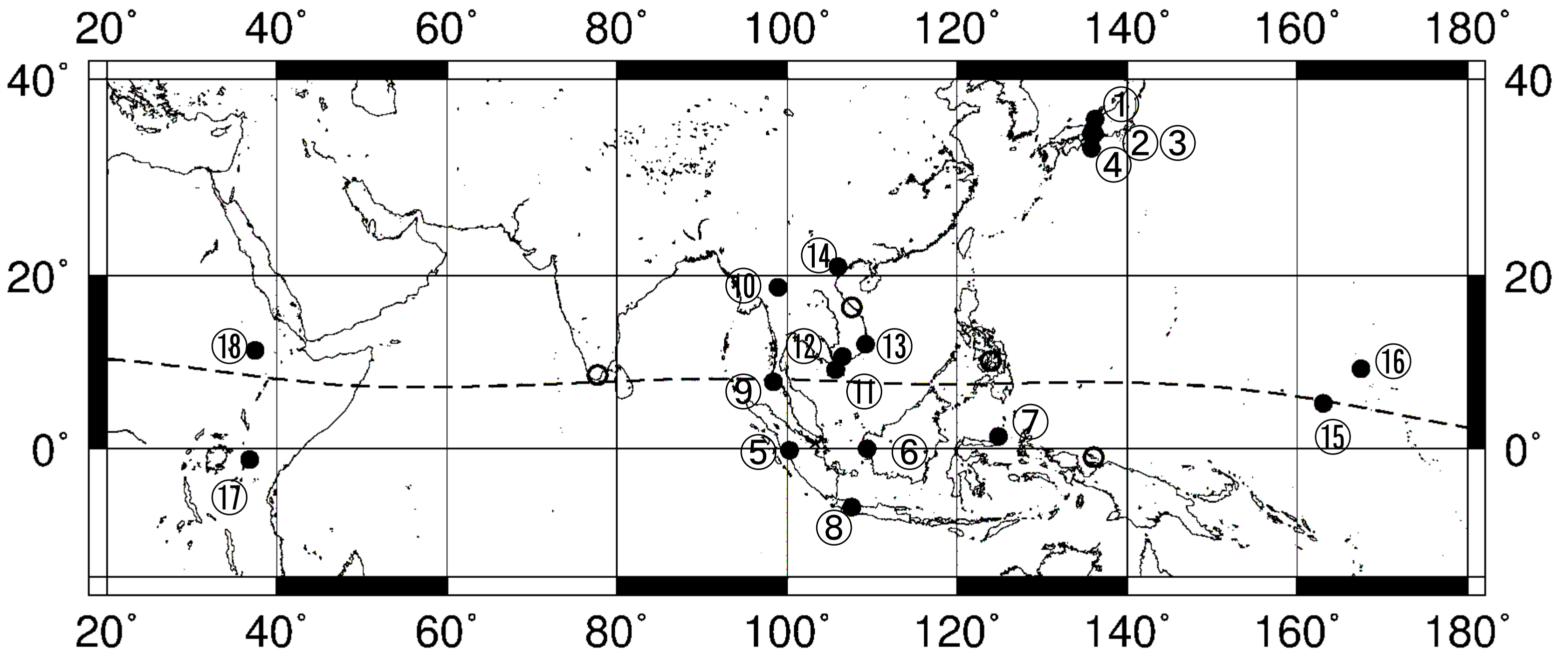


Radio beacon experiment and GRBR



- VHF(150MHz)/UHF(400MHz) beacon signals are transmitted from satellite, and received on the ground.
- Radiowaves propagate through the Ionosphere that is dissipative media where refractive index is modulated owing to the local plasma density.
- Radiowave ray paths are then bended from the shortest path. The ray paths vary at different wave frequency.
- From close analysis of phase difference between two signals, we can estimate total electron content (TEC) between the satellite and the receiver.

Current GRBR Network (May 2011)



Japan (FUT)
①Fukui, ②Shigaraki, ③Uji,
④Shionomisaki

Indonesia (LAPAN)
⑤Kototabang, ⑥Pontianak,
⑦Manado, ⑧Bandung

Thailand (KMITL/NICT)
⑨Phuket, ⑩Ciang Mai

Vietnam (HGI/SRI)
⑪Bac Lieu, ⑫Ho Chi Minh,
⑬Nhatrang, ⑭Phu Thuy

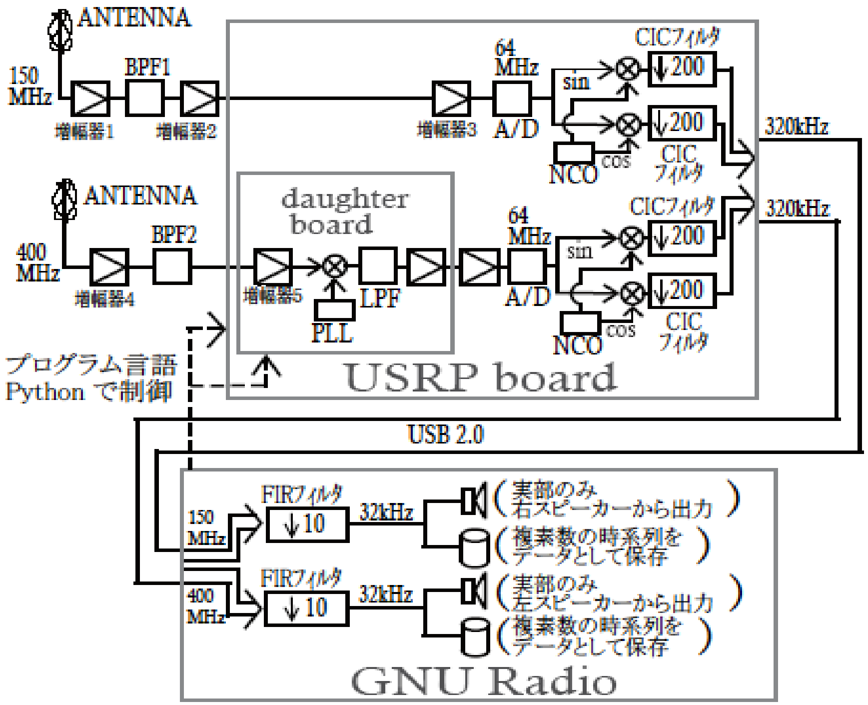
Pacific (SRI)
⑮Kosrae, ⑯Kwajalein

Africa (local univ./AFRL)
⑰Nairobi, ⑱Bahir Dar

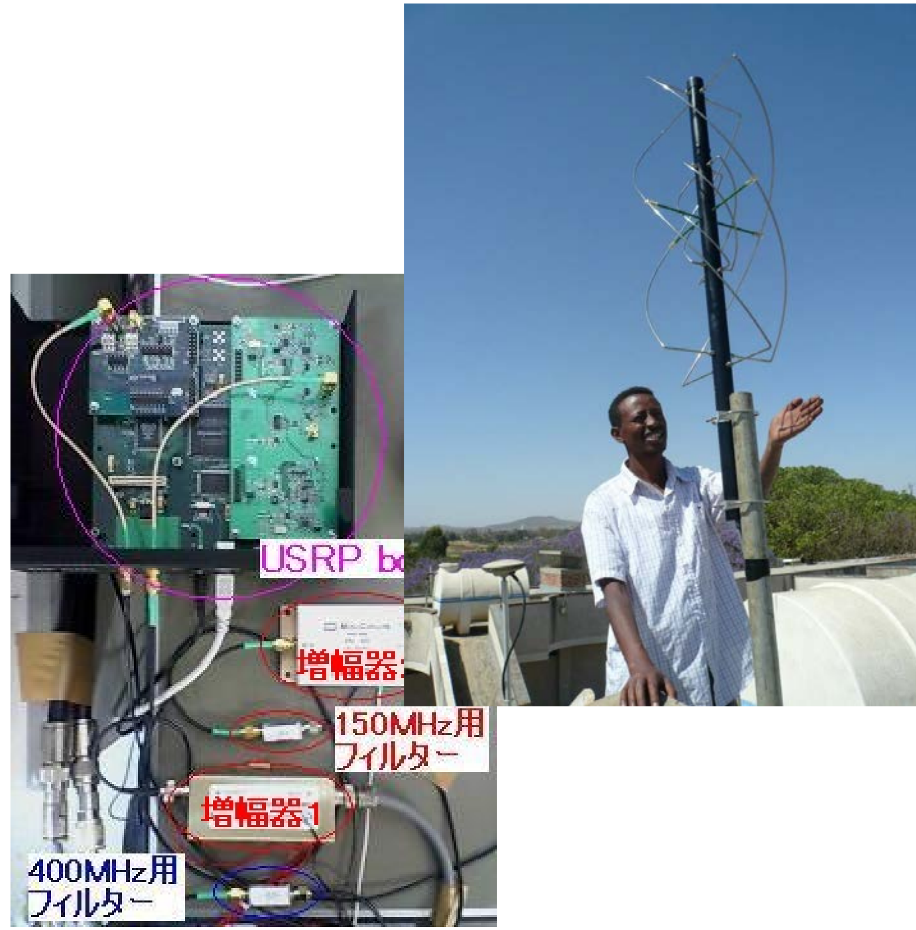
On schedule / Planned
Biak, Hue, Tirunelveli / Cebu

GNU Radio Beacon Receiver (GRBR)

-- Digital radio for 150/400MHz beacon experiment --



PLL (Phase Locked Loop)
NCO(Numerically Controlled Oscillator)
CIC (Cascaded Integrate Comb)
FIR (Finite Impulse Response)



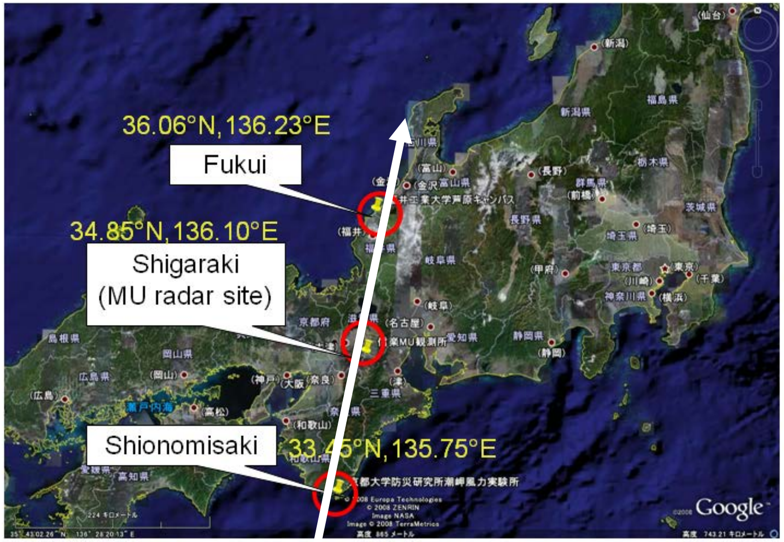
GNU Radio: Open software package for digital radio

USRP: A/D + demodulator/modulator peripheral

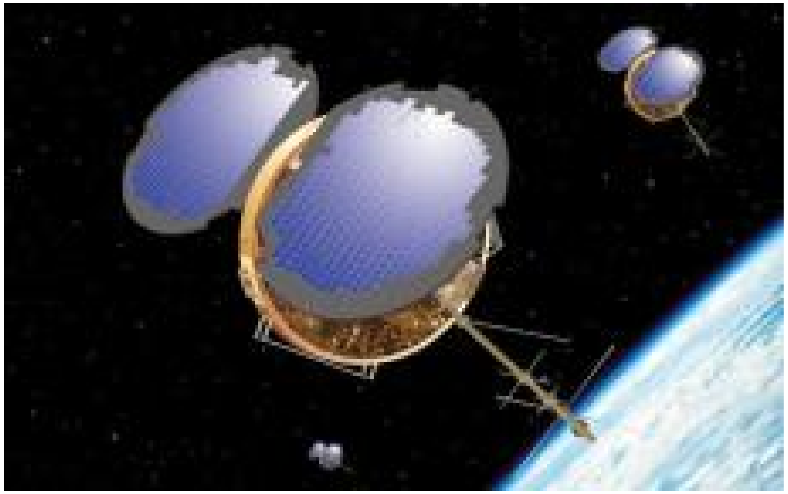
Japan: 2D tomography Experiment

with Smitha Thampi, Charles Lin

GRBR network over Japan (135-136 deg. Longitude)



FORMOSAT-3/COSMIC GPS radio occultation



Study purpose: Meridional structures of ionosphere over japan
MSNA (Mid-latitude Summer Nighttime Anomaly)

Tomographic Reconstruction *

Algorithm – Algebraic Reconstruction Technique (ART)

Initialization – IRI 2007 model

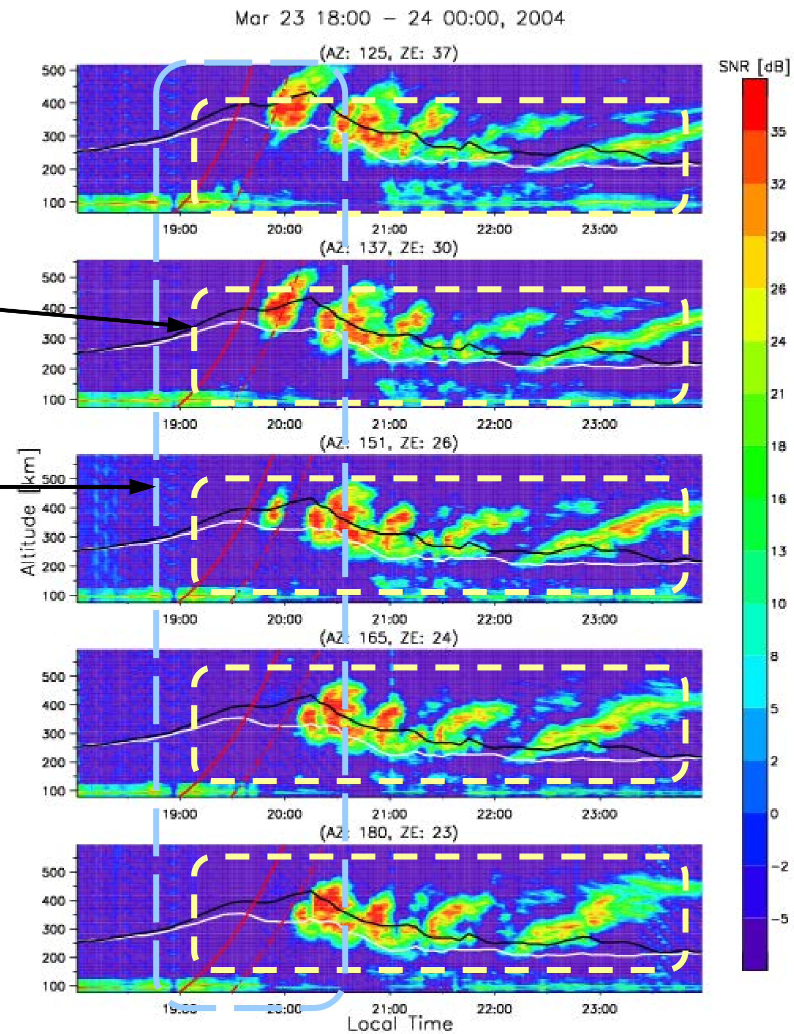
Observation Period
July- August 2008

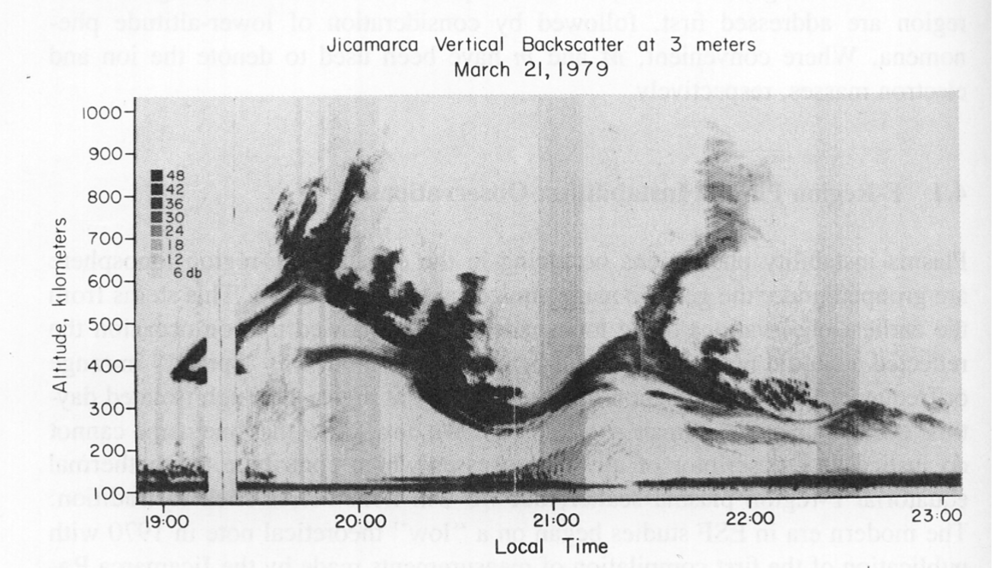
EAR + SEALION experiment

ESF echoes (EAR) and ionosphere height (SEALION)

Lower boundary of PB echoes corresponds to bottom height of F-region.

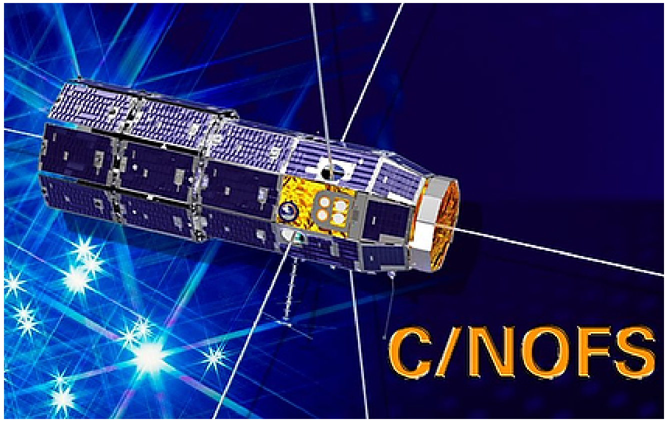
F-region ascends around sunset because of pre-reversal enhancement. PBs appear when F-region starts to descend.





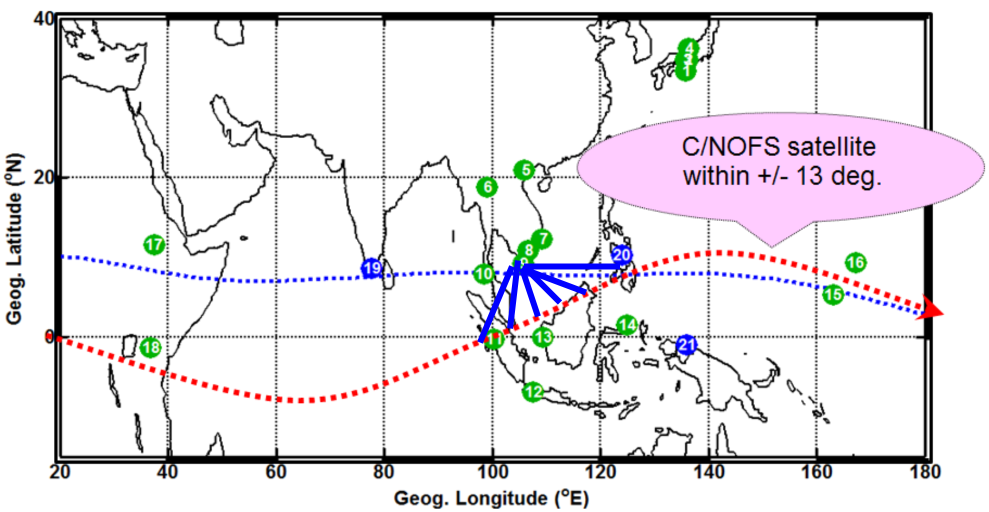
SW Asia: Study of large-scale wave activity (LSWS)

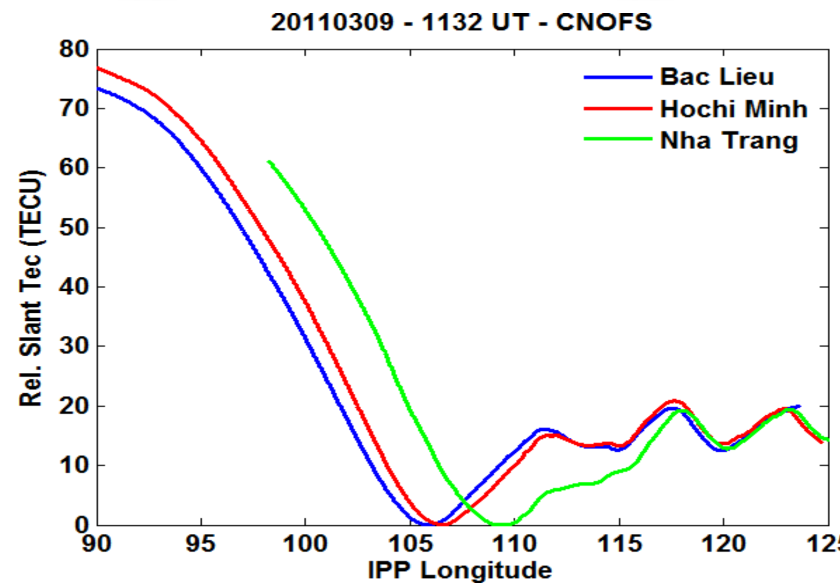
with Smitha Thampi & Tulasi Ram



- 13^{o} inclination angle
- Provides a wide zonal (longitudinal) coverage
- GRBR offers a fine spatial resolution

Snap-shot of TEC and ESF variation over wide longitudes





LSWS intensity occurrence
(Amplitude in TEC unit)