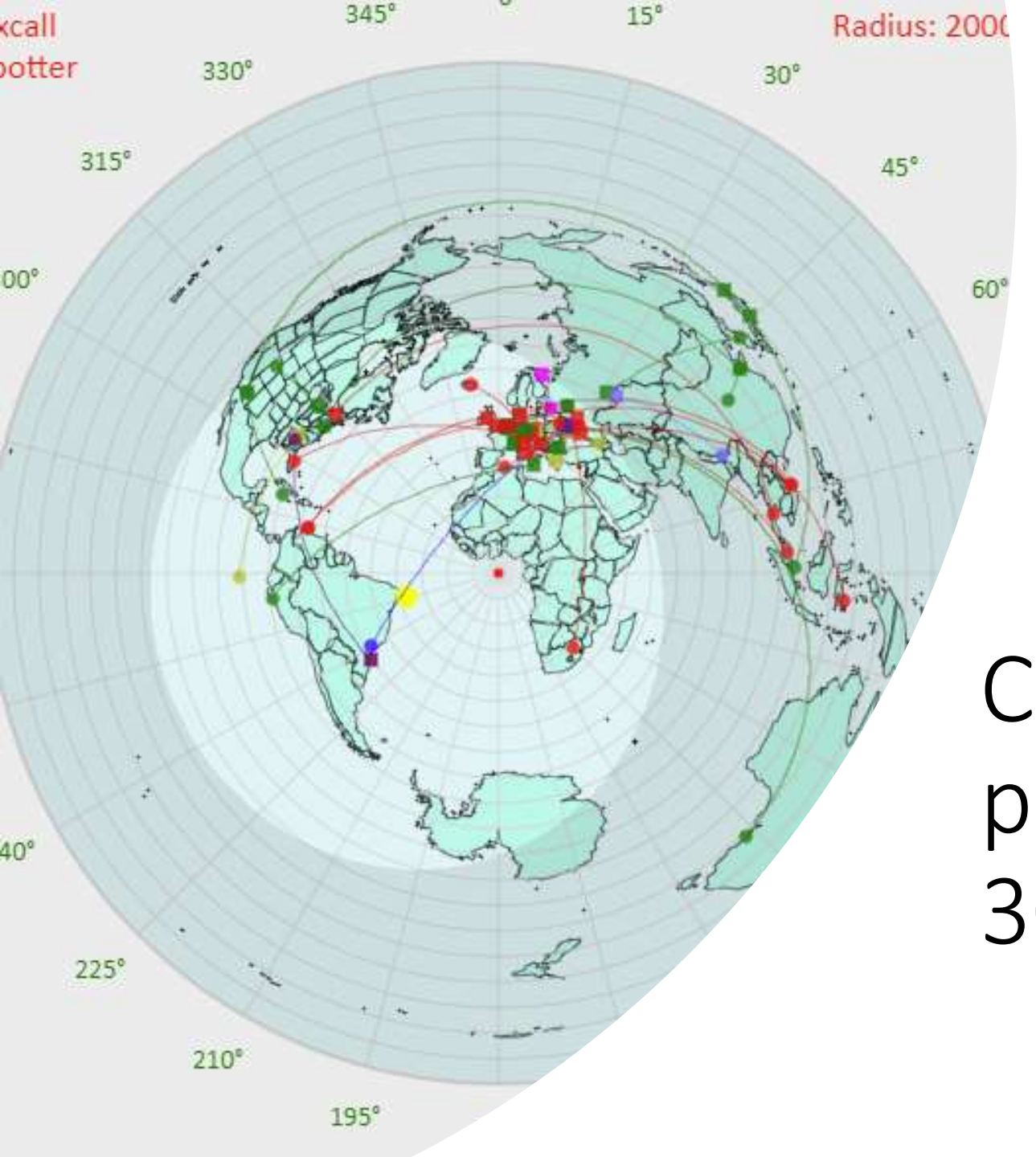


Communications and propagation below 30MHz – as a hobby?

Björn Ekelund - Ericsson Research

Amateur ham radio

- A internationally recognized, social, and scientific hobby
- Is regulated by ITU and national authorities (e.g. FCC, PTS)
- Requires a license from a accredited authority (CEPT HAREC)
- ITU removed the Morse code skill requirement in 2003
- Over 2.6 million licenses globally
- Approximately 10,000 licenses in Sweden

Some well-known Swedish hams

Prof. Jens Zander
Head of School, EE & CS,
Royal Institute of Technology
Director of Wireless@KTH

Peter Hultqvist
Swedish secretary of defense

Christer Fuglesang
Astronaut
Professor, Royal Institute of Technology

Peter Löthberg
Swedish Internet legend

And many more: Erik Bergsten, Egon Kjerrman, Bengt Feldreich, Johan Ekelund, …

Famous international hams

Prof. Ted Rappaport
Founder and Director, NYU Wireless Center

Prof. Joe Taylor
Physics Department, Princeton University
Nobel Laureate

Sir Cliff Richard
Artist and musician

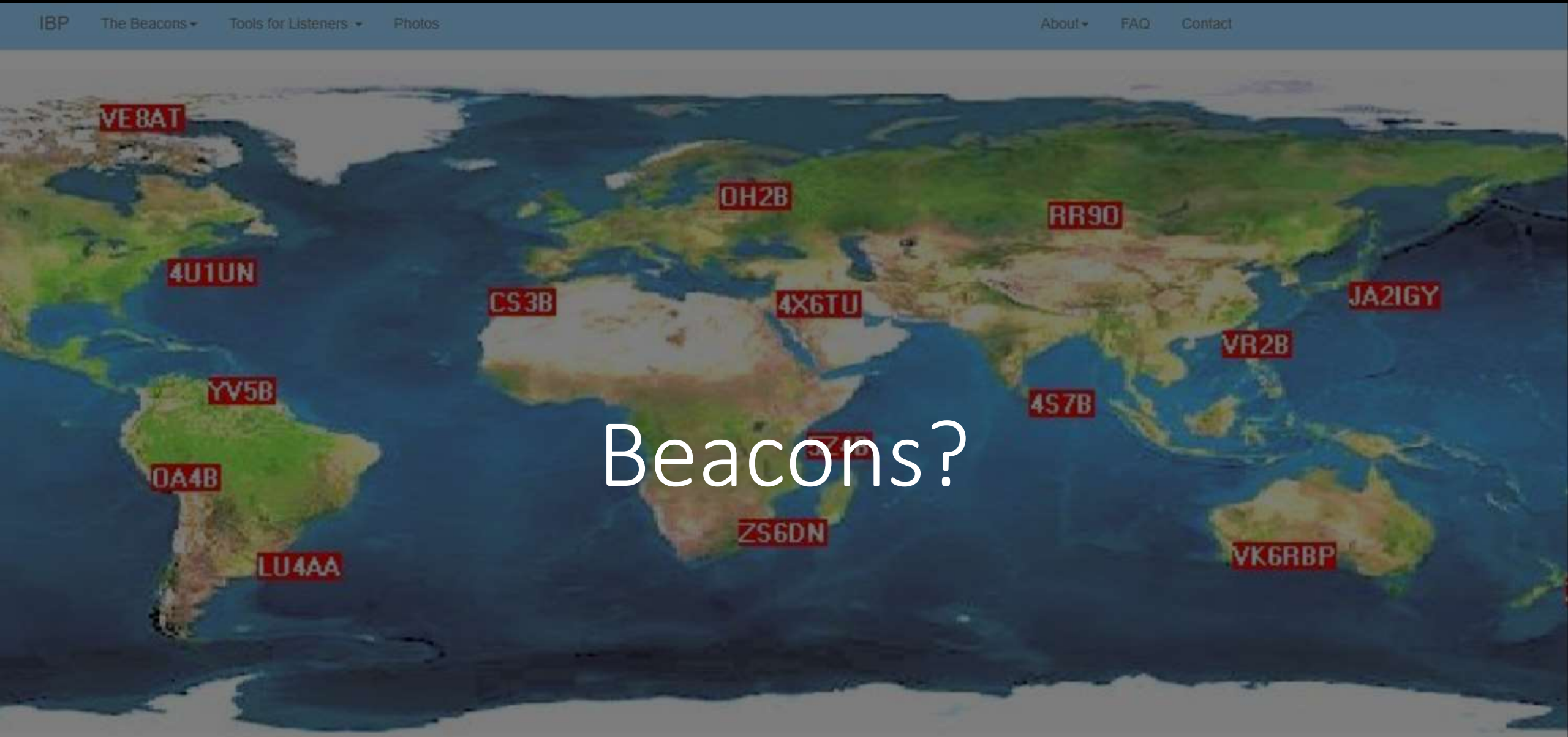
And so many more: Yuri Gagarin, Jack Kilby, John Sculley, Marlon Brando, Walter Cronkite, Patty Loveless, Tony Bonjovi, Bob Heil, Sergey Rebrov, Joe Walsh, Feargal Sharkey, Cliff Richard, Chet Atkins, King Juan Carlos, King Hussein, Priscilla Presley, Tony Dolby, Francesco Cossiga, Barry Goldwater, Rajiv Gandhi, Augusto Pinochet, …

The Reverse Beacon Network

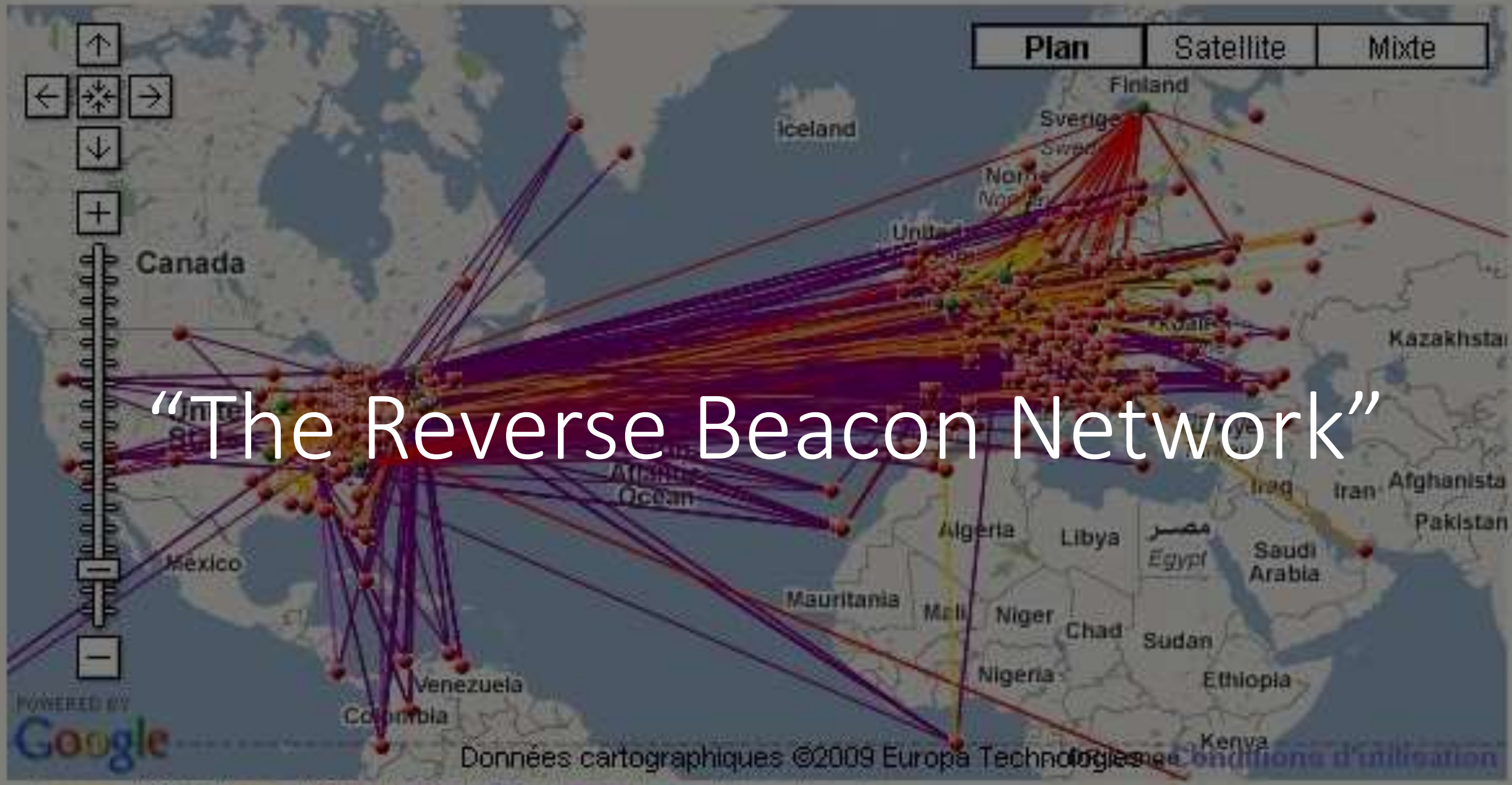
A free cloud service supported by a global network of robot receivers

Franke-Taylor 8-PSK a.k.a. FT8

A modern digital communications protocol for shortwave communications


IBP
The Beacons
Tools for Listeners
Photos
About
FAQ
Contact
VE8AT
OH2B
RR9O
4U1UN
CS3B
4X6TU
JA2IGY
VR2B
YV5B
4S7B
OA4B
ZS6DN
VK6RBP
LU4AA
NCDXF/IARU International Beacon Project
Transmission Schedule

Beacons?



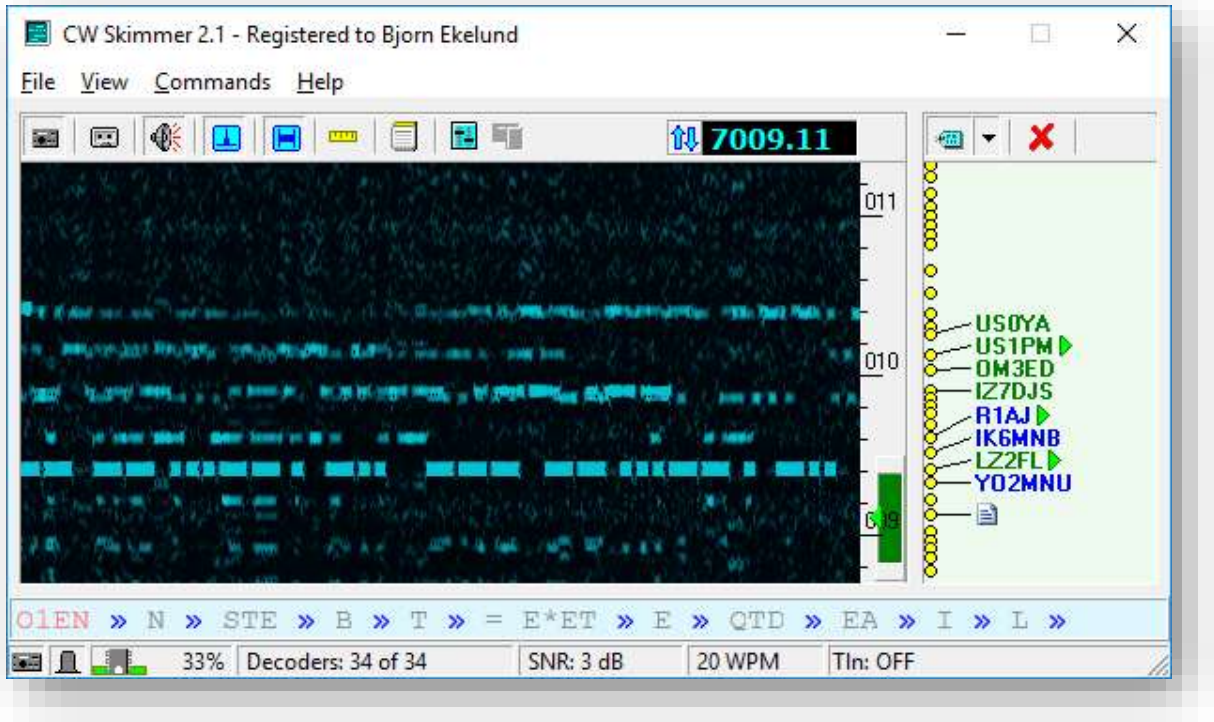
"The Reverse Beacon Network"

It started with one brilliant engineer…

Alex Shovkoplyas, VE3NEA (b. 1965, ex-UR5EMI, Canadian resident since 1998)

”Canadian ham of the year” 2014

Morse code decoder ”CW Skimmer”

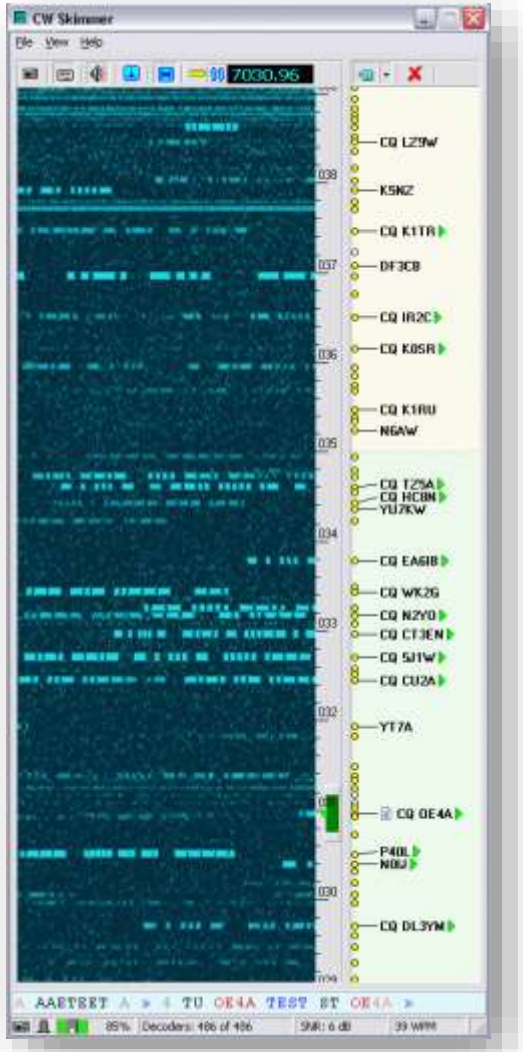


Published by Alex in 2008 after “seven years of thinking”.

Based on Bayesian statistics, a “kind of” AI.

Originally intended as a tool to manage DX pile-ups.

“CW Skimmer”



- Works with a range of SDR front-ends
- Parallel decoding of Morse code signals across an entire passband
  - Standard 3.5kHz audio
  - Wideband I-Q up to 192kHz bandwidth
- Graphical “waterfall” illustration of signals
- Uses a recognized call sign data base for sanity checking

2008: The planets lined up…

Alex VE3NEA

Felipe PY1NB

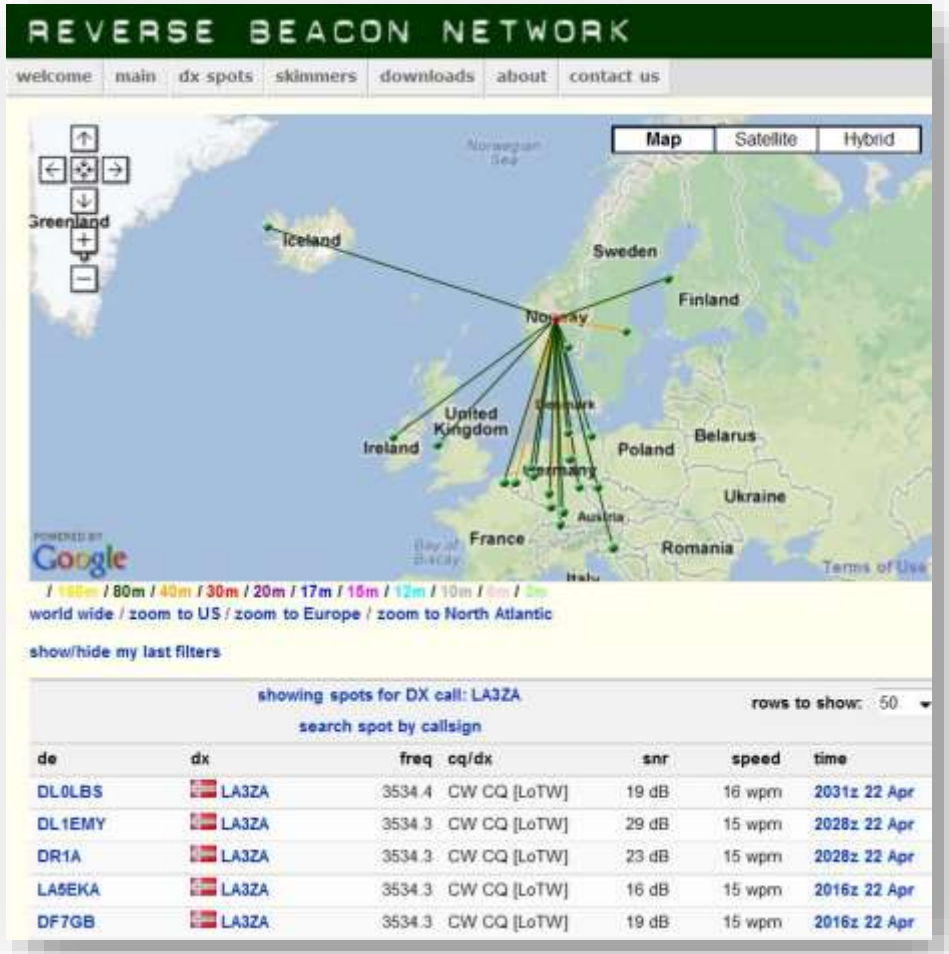
DX WATCH

Dick W3OA

Nick F5VIH

Pete N4ZR

Phil N8VB

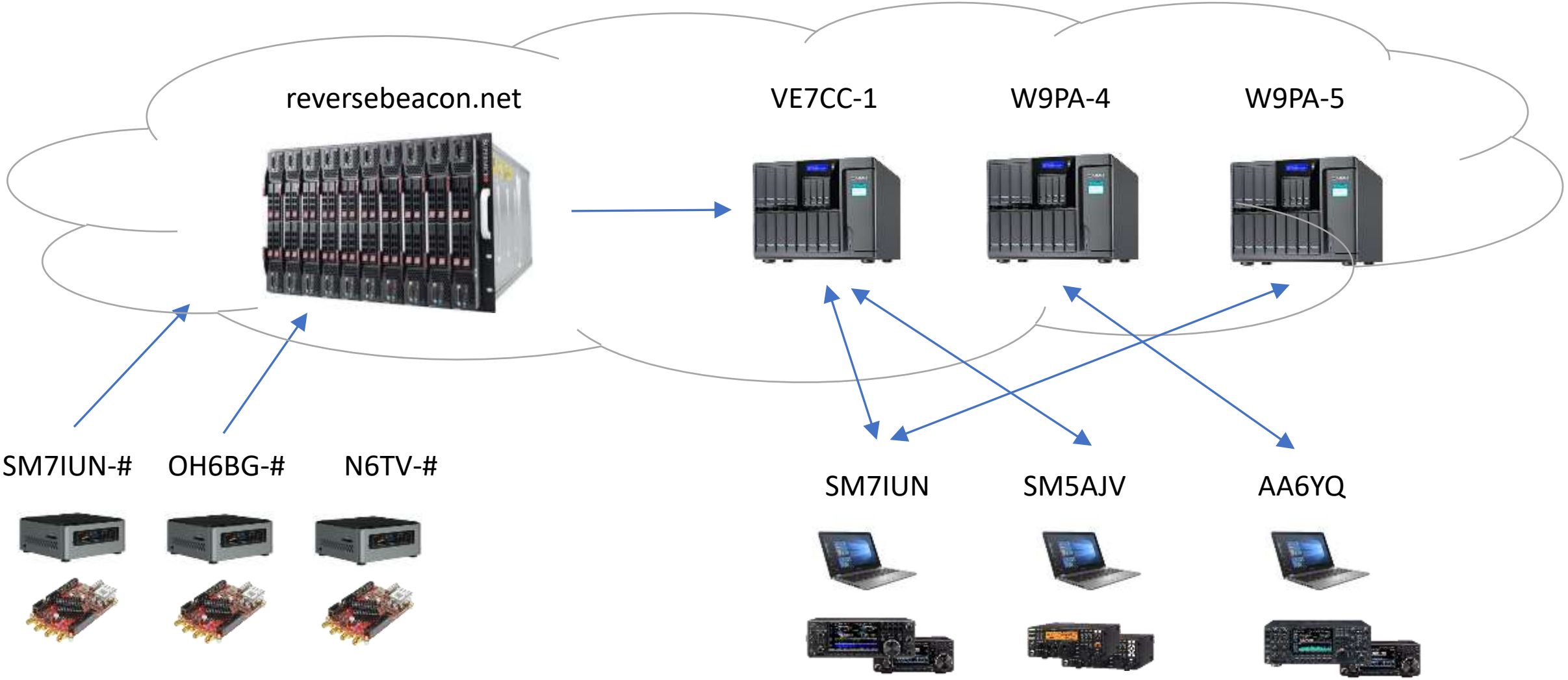


The Reverse Beacon network

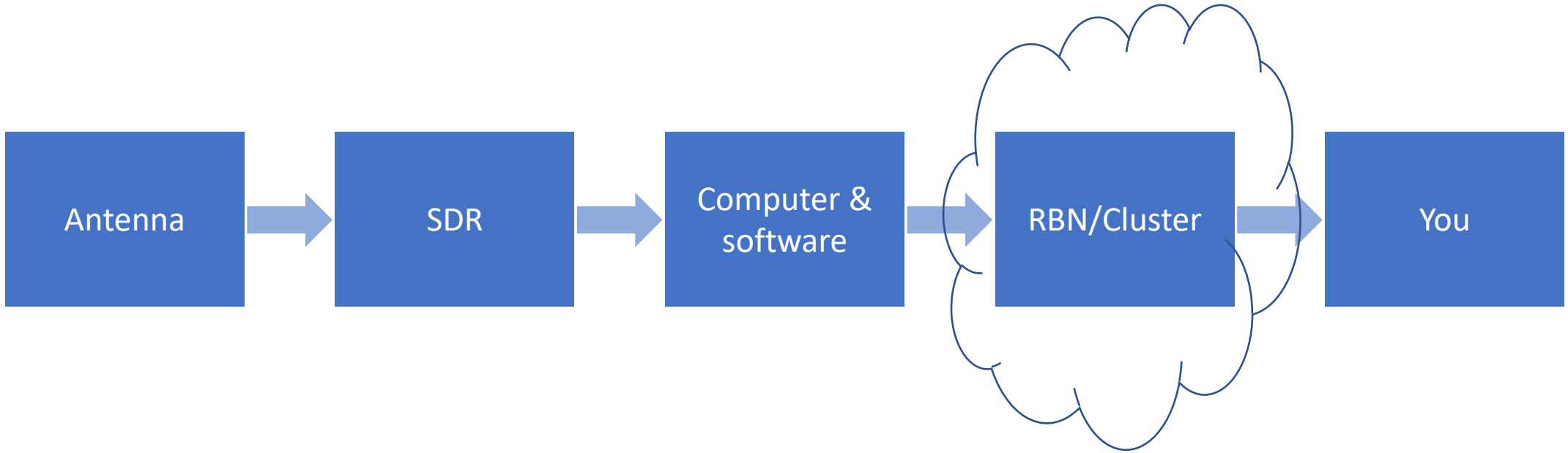
- A global network of skimmer receivers for both Morse code and digital protocols
- ~200 24/7 “skimmers”
- Global coverage
- Highest density in EU & NA

http://www.reversebeacon.net

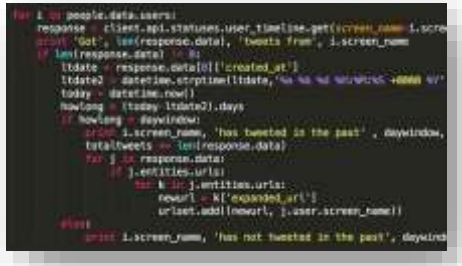
Reverse beacon network & The DX cluster

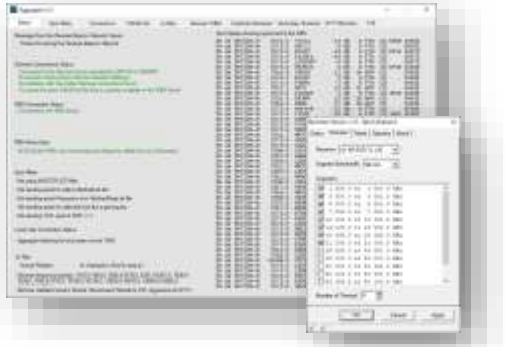


The whole chain

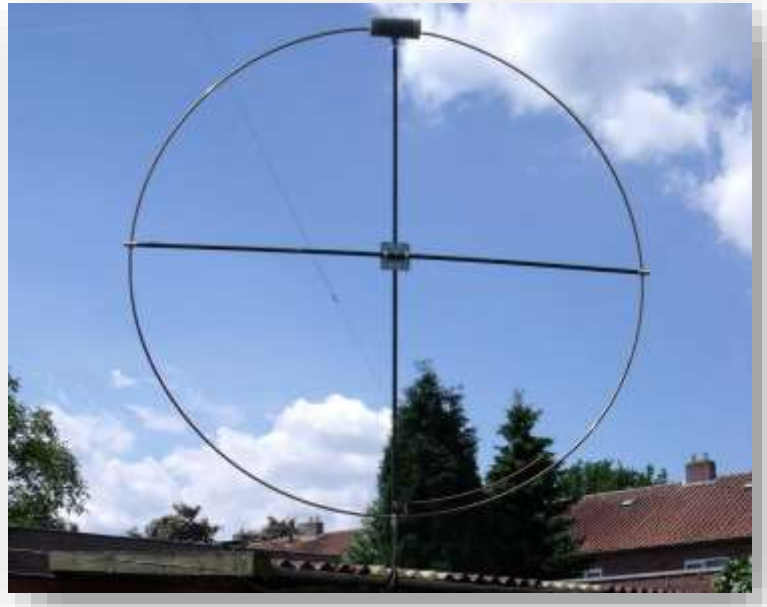


What are the parts in a skimmer?





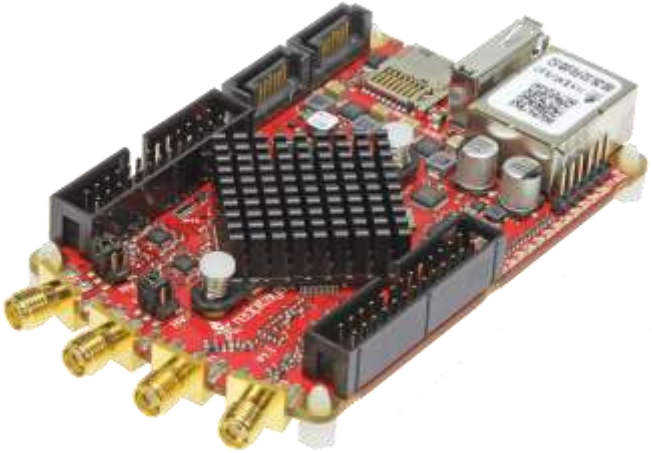
#1 Antenna



- Should be
  - broadband, preferably 1.8-50MHz
  - always connected
  - be immune to local noise or in a low noise environment
- Does not need
  - to work for transmission
  - to be very efficient, SNR is more important than RSSI
  - to be large

#2 Receiver

- Should
  - have a digital quadrature output sampled at 48, 96 or 192kHz
  - be wideband, preferably 1.8-50MHz
  - be support multiple receiver instances
  - preferably be networked (Ethernet)



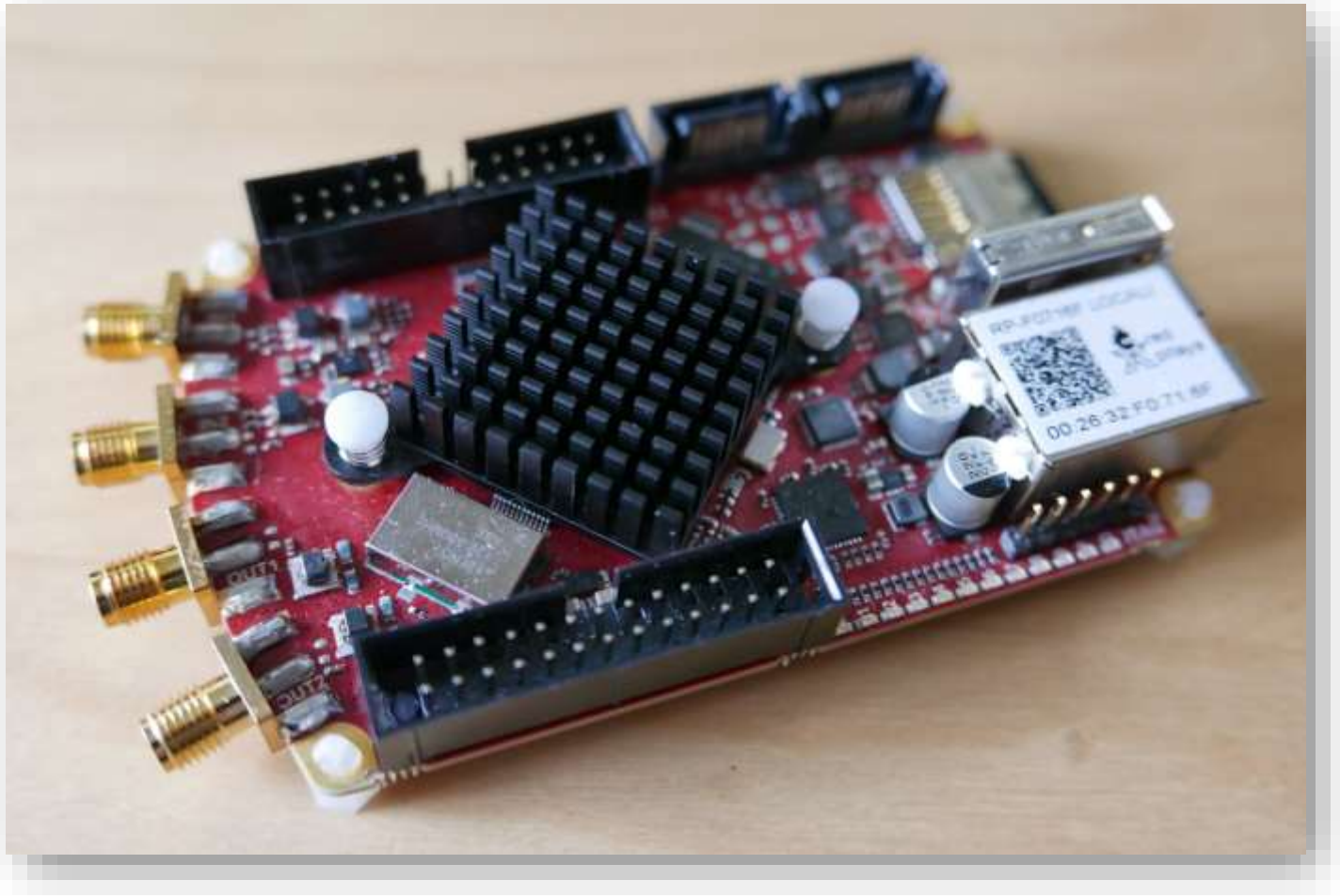
- Does not need
  - knobs and buttons
  - an audio chain

SDR receivers

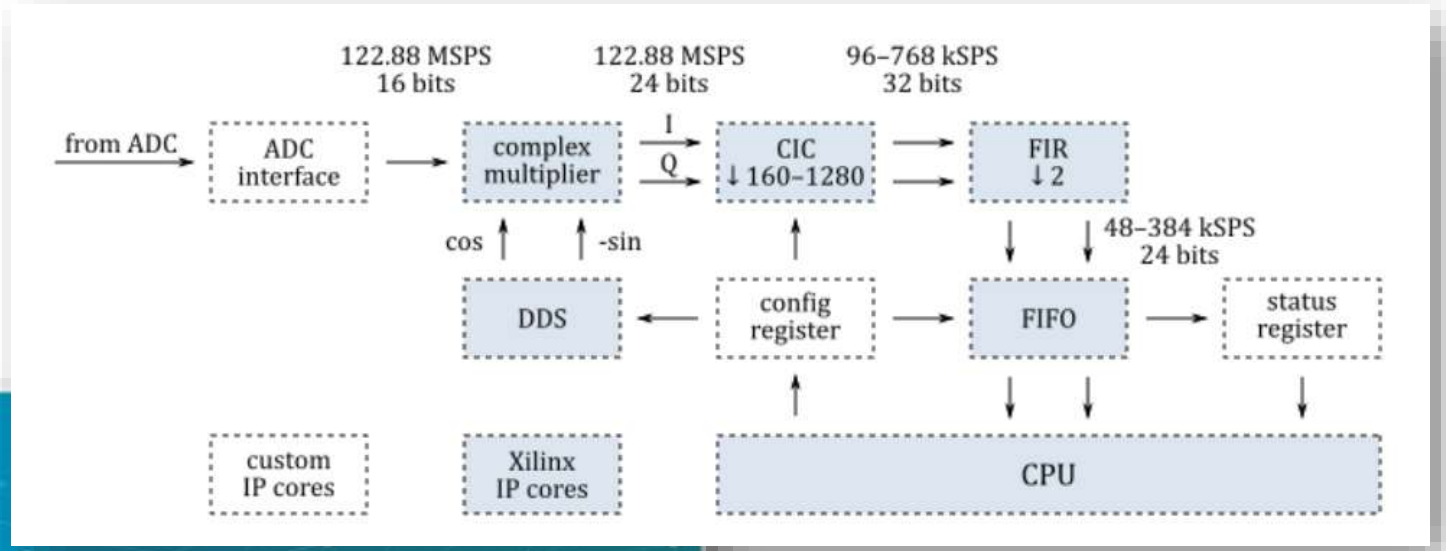
“The Raspberry Pi of DSP”
Red Pitaya 122.88-16

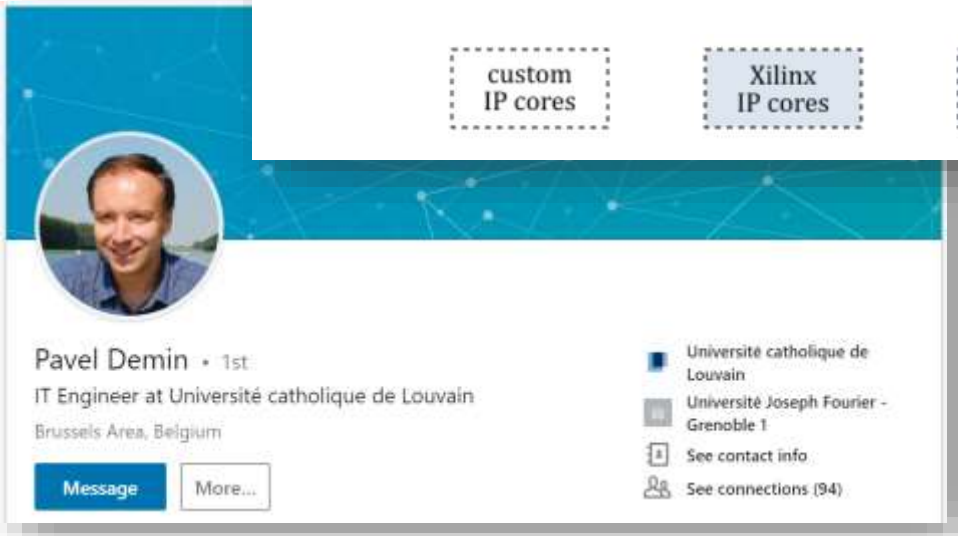
- Based on Xilinx Zynq 7020
- ~1.3M gates FPGA
- 220 programmable DSP slices
- >200 GMAC/s performance
- 667MHz Cortex A9 MPcore with Neon and CoreSight
- Two 122.88MHz 16 bit ADC/DAC
- Four 100kHz ADC/DAC
- 16 GPIO
- ABLNO XO <50fs jitter

- Red Pitaya started as a Kickstarter project with Red Pitaya 125-10 and 125-14 based on Zynq 7010.
- Over 30,000 sold
- Base ports for Ubuntu and Alpine Linux
- Free Xilinx Vivado tool suite



Pavel Demin @ KU Leuven





1. List of components
2. Links
3. Development machine
4. LED blinker
5. SDR receiver
6. SDR transceiver
7. SDR transceiver compatible with HPSDR
8. SDR receiver compatible with HPSDR
9. Embedded SDR transceiver
10. Wideband SDR transceiver
11. Multiband WSPR transceiver
12. Multiband FT8 transceiver
13. Pulsed Nuclear Magnetic Resonance
14. Multichannel Pulse Height Analyzer
15. Scanning system
16. Vector Network Analyzer
17. Alpine with pre-built applications

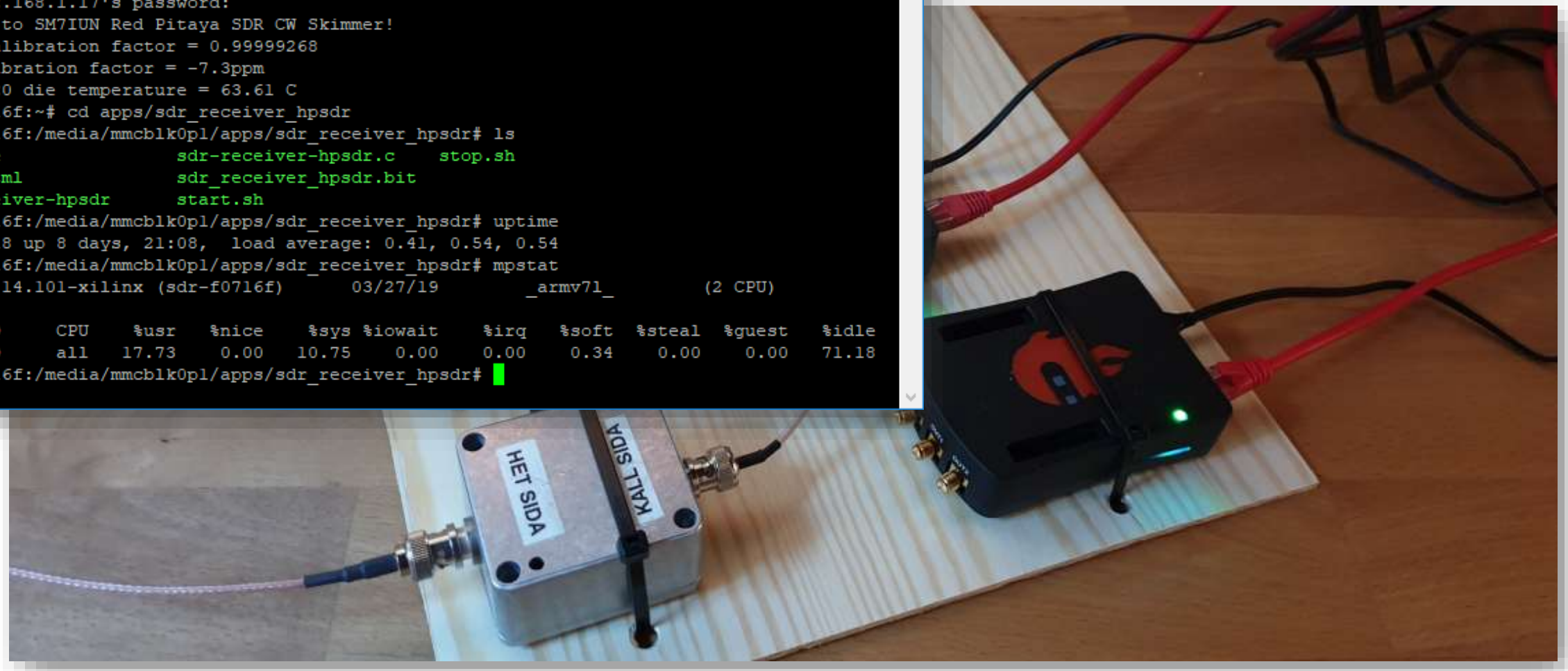
http://pavel-demin.github.io/red-pitaya-notes/

CW and FT8 skimmers @ SM7IUN

192.168.1.17 - PuTTY

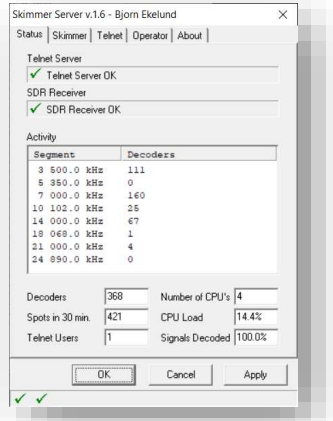
```
login as: root
root@192.168.1.17's password:
Welcome to SM7IUN Red Pitaya SDR CW Skimmer!
HPSDR calibration factor = 0.99999268
FT8 calibration factor = -7.3ppm
Zynq 7020 die temperature = 63.61 C
sdr-f0716f:~# cd apps/sdr_receiver_hpsdr
sdr-f0716f:/media/mmcblk0p1/apps/sdr_receiver_hpsdr# ls
Makefile                sdr-receiver-hpsdr.c    stop.sh
index.html              sdr_receiver_hpsdr.bit
sdr-receiver-hpsdr      start.sh
sdr-f0716f:/media/mmcblk0p1/apps/sdr_receiver_hpsdr# uptime
 12:20:18 up 8 days, 21:08,  load average: 0.41, 0.54, 0.54
sdr-f0716f:/media/mmcblk0p1/apps/sdr_receiver_hpsdr# mpstat
Linux 4.14.101-xilinx (sdr-f0716f)      03/27/19        _armv7l_        (2 CPU)

12:20:19     CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest   %idle
12:20:19     all   17.73    0.00   10.75    0.00    0.00    0.34    0.00    0.00   71.18
sdr-f0716f:/media/mmcblk0p1/apps/sdr_receiver_hpsdr#
```

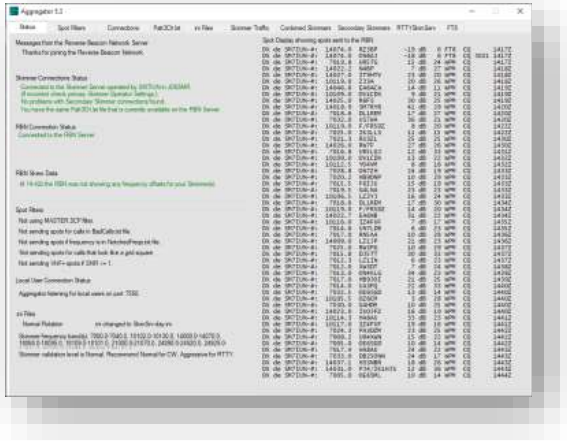


#3 Host computer and software

- **“CW Skimmer Server” or “RTTY Skimmer Server”**
  - Decodes the Morse code transmissions in the passband of the radio front end
  - Computationally intense. RTTY more than CW.
  - CW is 5-25% on 2GHz Core i5 depending on bandwidth

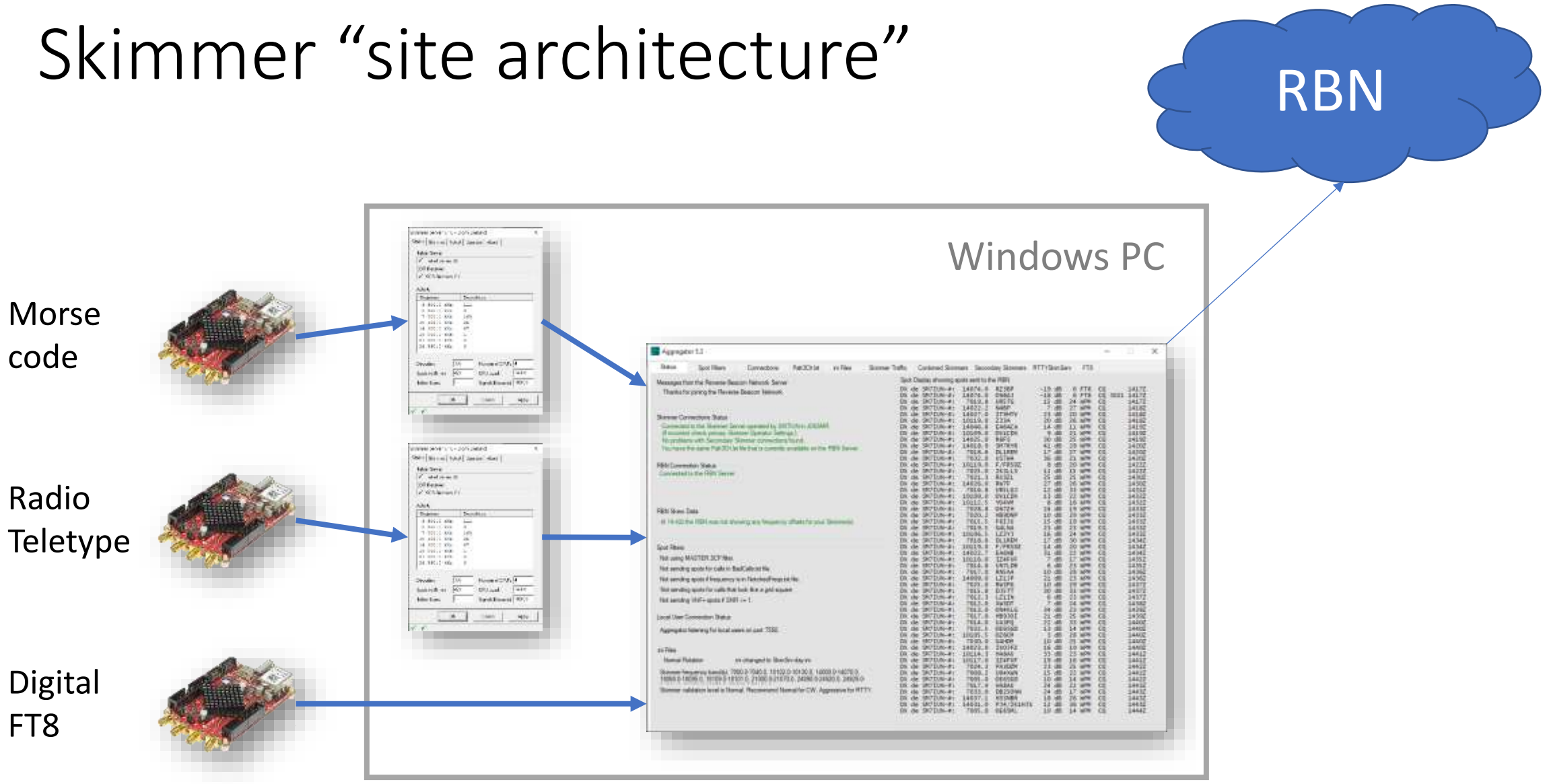


- **“RBN Aggregator”**
  - Consolidates and curates streams of decoded call signs from several radio front ends
  - Adds origin information
  - Controls daylight/twilight/night cycle
  - Etc. housekeeping



- Decoding of the FT8 digital transmission protocol is much less computationally intense and can be done in the radio front end.

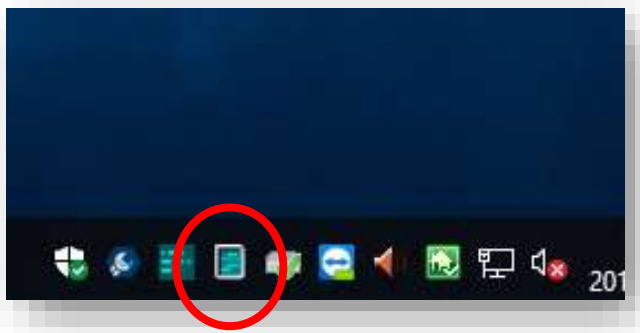
Skimmer “site architecture”



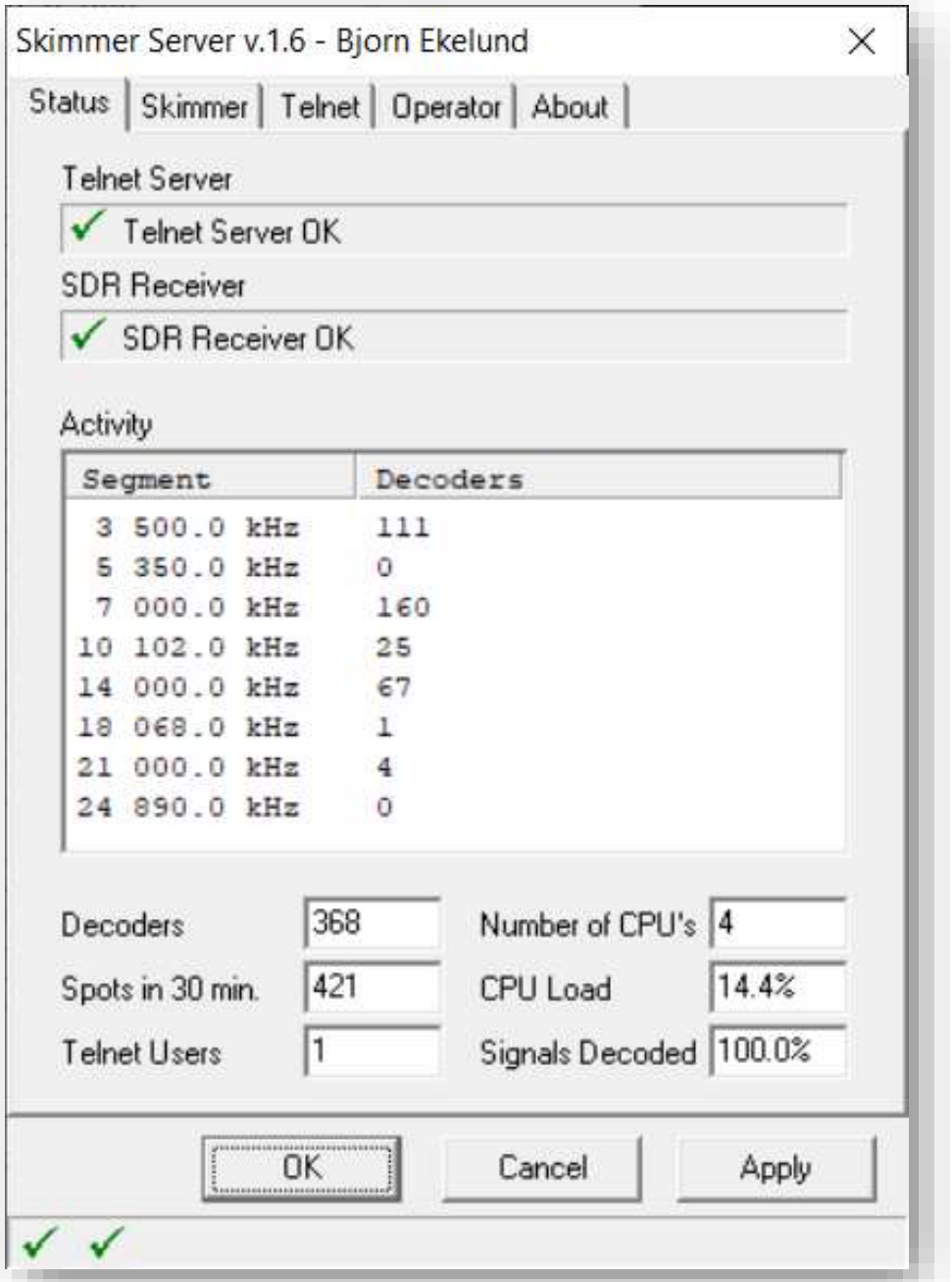
CW Skimmer Server

An “embedded” CW Skimmer with Telnet interface for RBN Aggregator or a DX cluster node

8 × 91kHz segments shortwave
bands = 10-15% CPU load on 2GHz Core i5

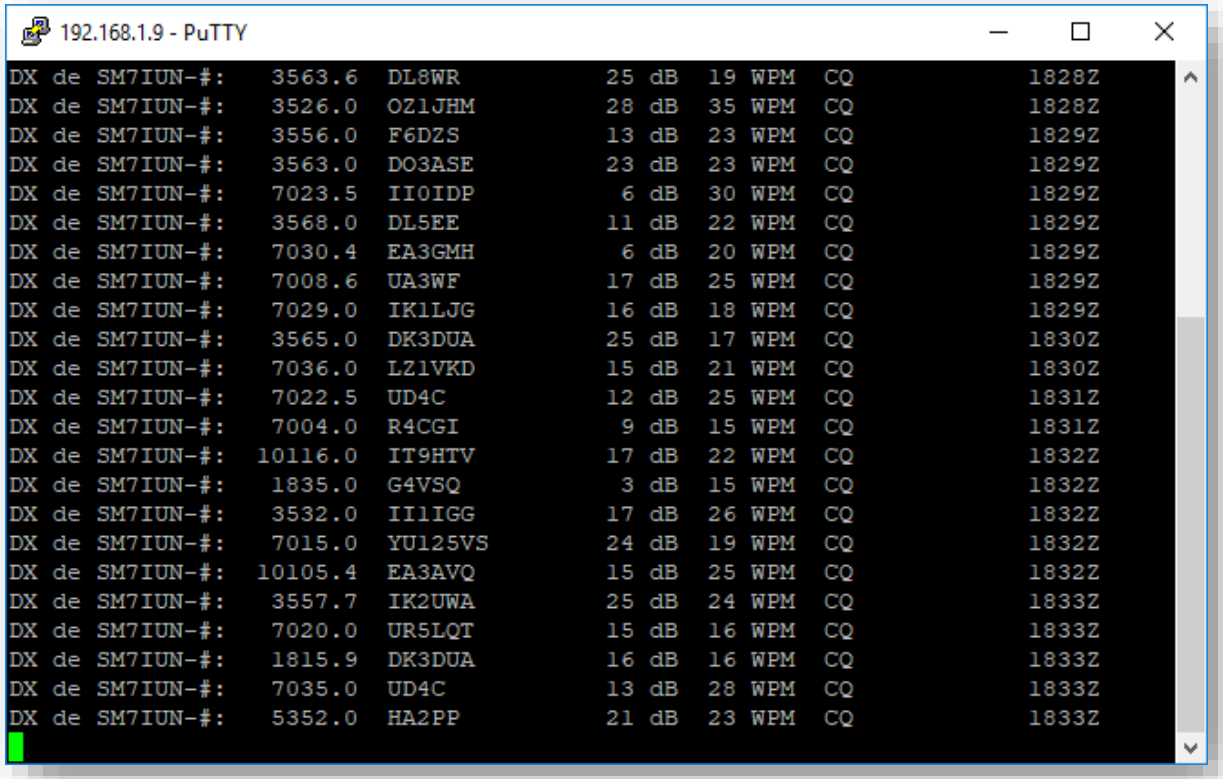


http://www.dxatlas.com/SkimServer



CW Skimmer Server

Simple Telnet feed with frequency, call sign, SNR, transmission speed and time

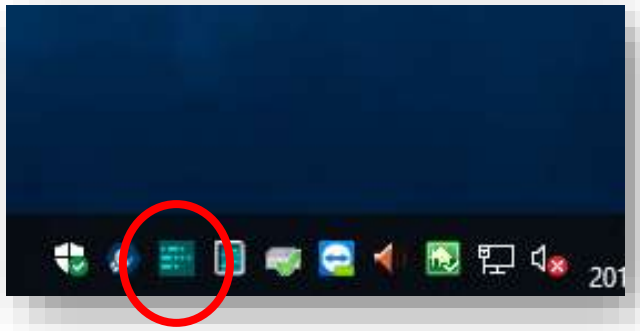


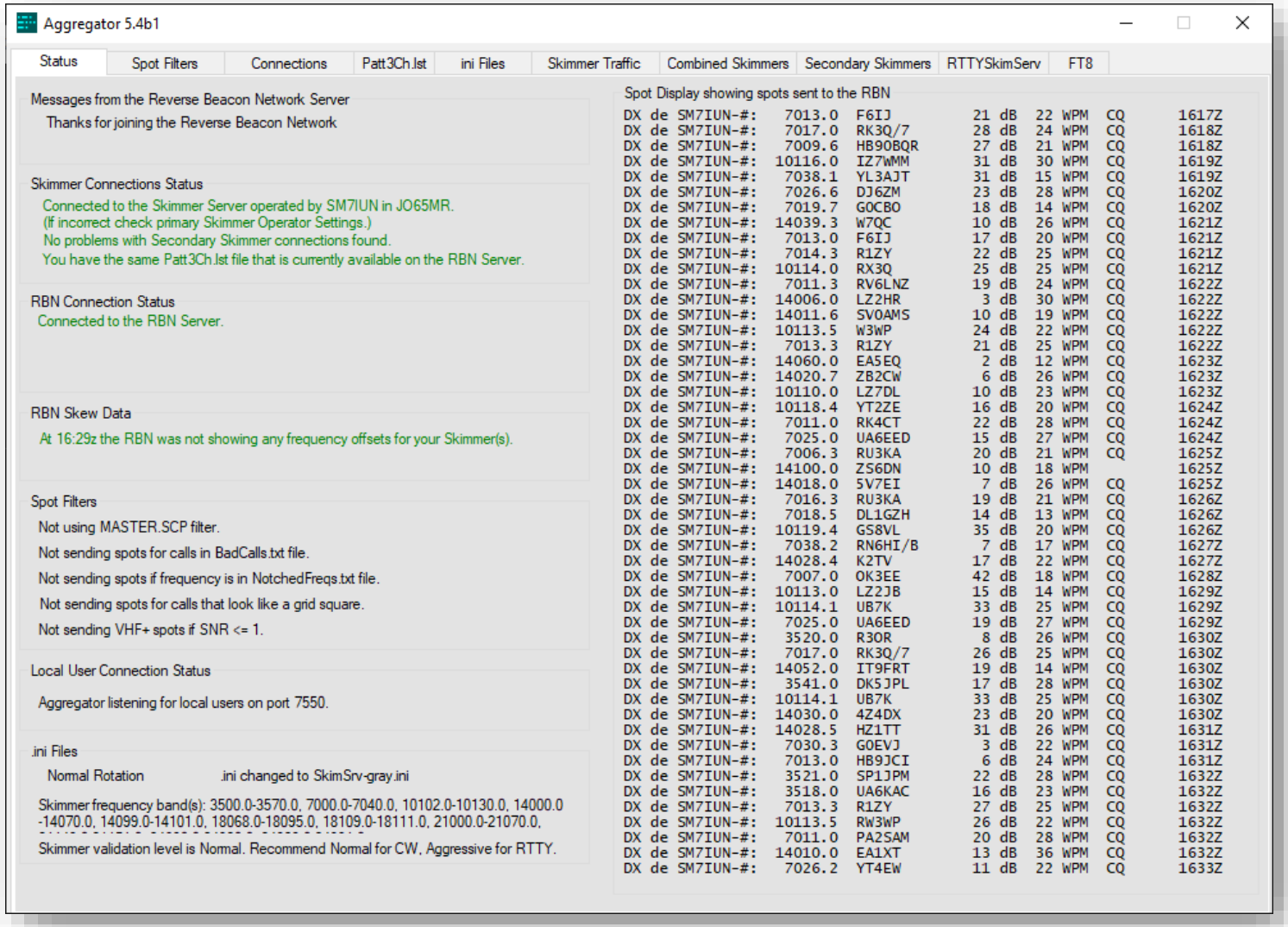
- Typically CW Skimmer Server does not report party stations, only “CQ-ers”
- Spotting keywords:
  CQ QRZ TEST NA SS FD UP
- Short call signs (e.g. SE5E) should be repeated for secure spotting
- Remember that spotting is not guaranteed even if propagation is sufficient, e.g. due to interference

RBN Aggregator

Curates and aggregates spots before uploading to RBN cloud. Negligible CPU load on host.

Telnet client for CW and RTTY skimmers. UDP broadcast listener for FT8 skimmers.

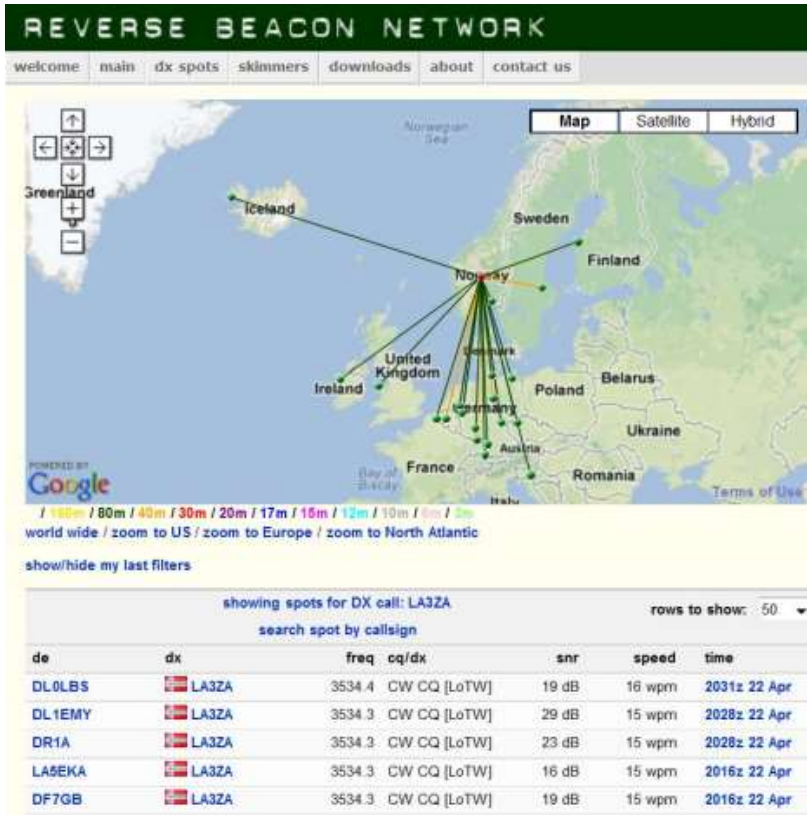


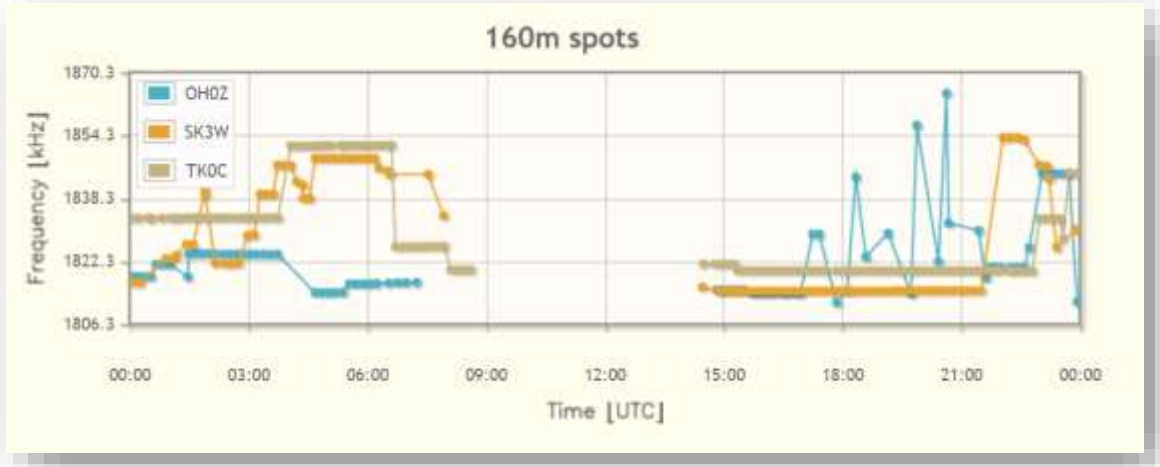


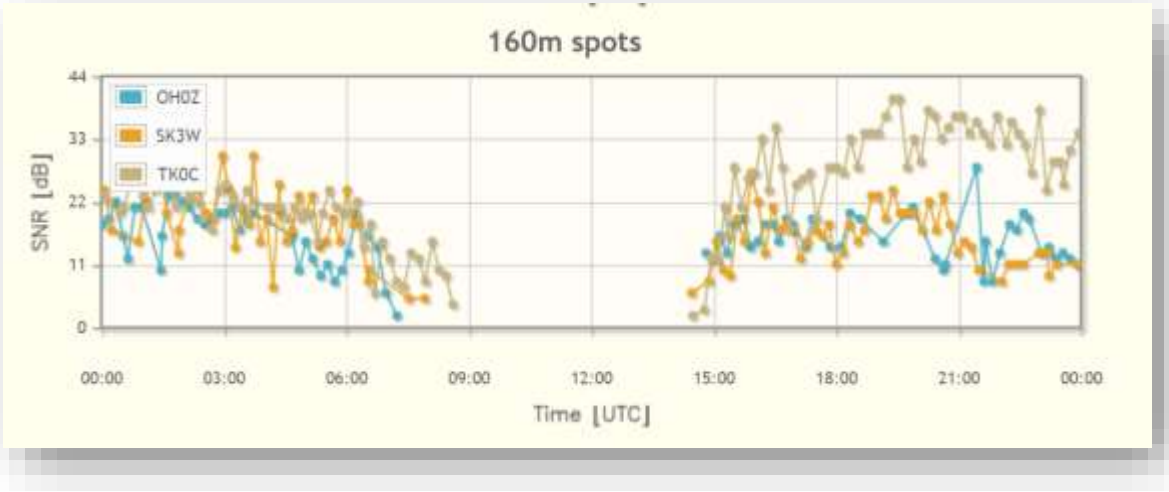
http://www.reversebeacon.net/pages/Aggregator+34

The Reverse Beacon network

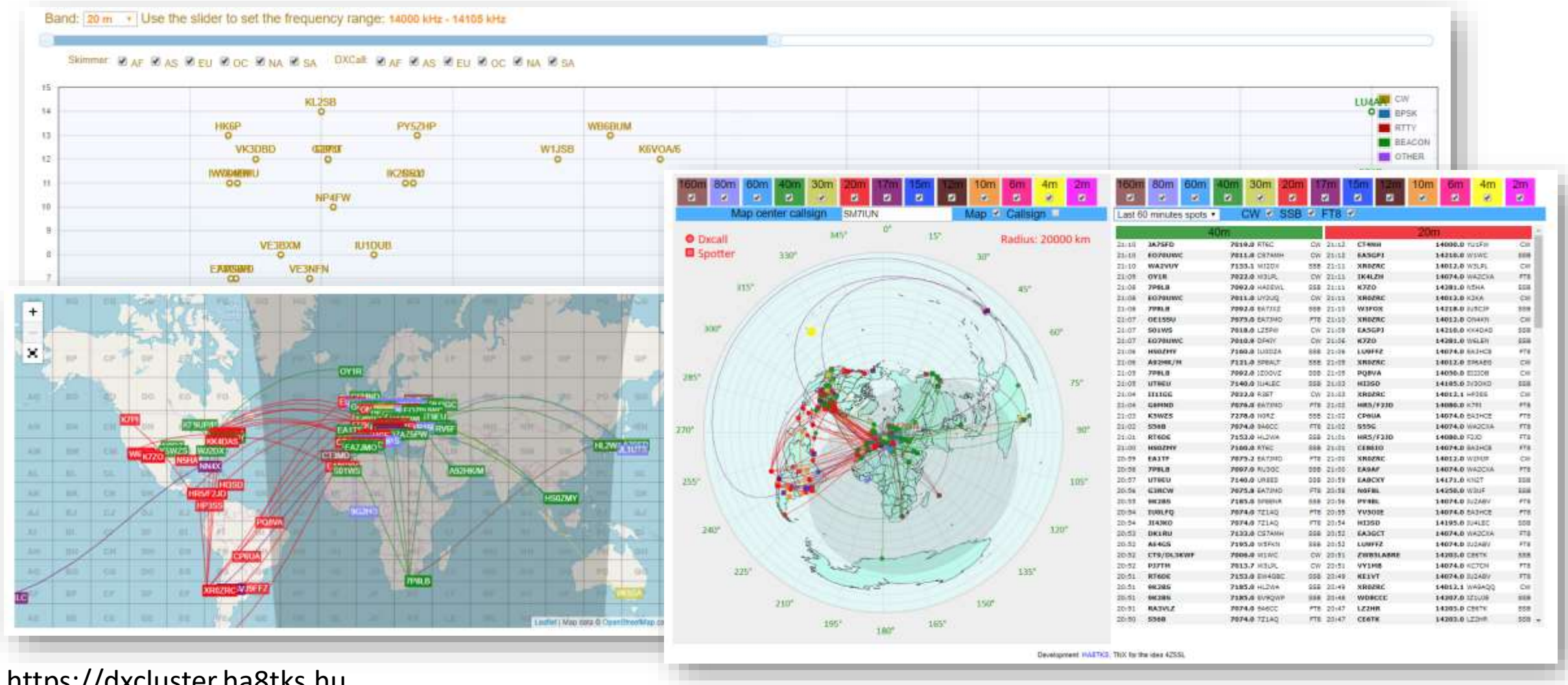
- A cloud service
- “A shortwave communications data lake”
  - All data available for download
- 300,000,000+ data points collected since 2009
- Extensive suite of online analysis tools





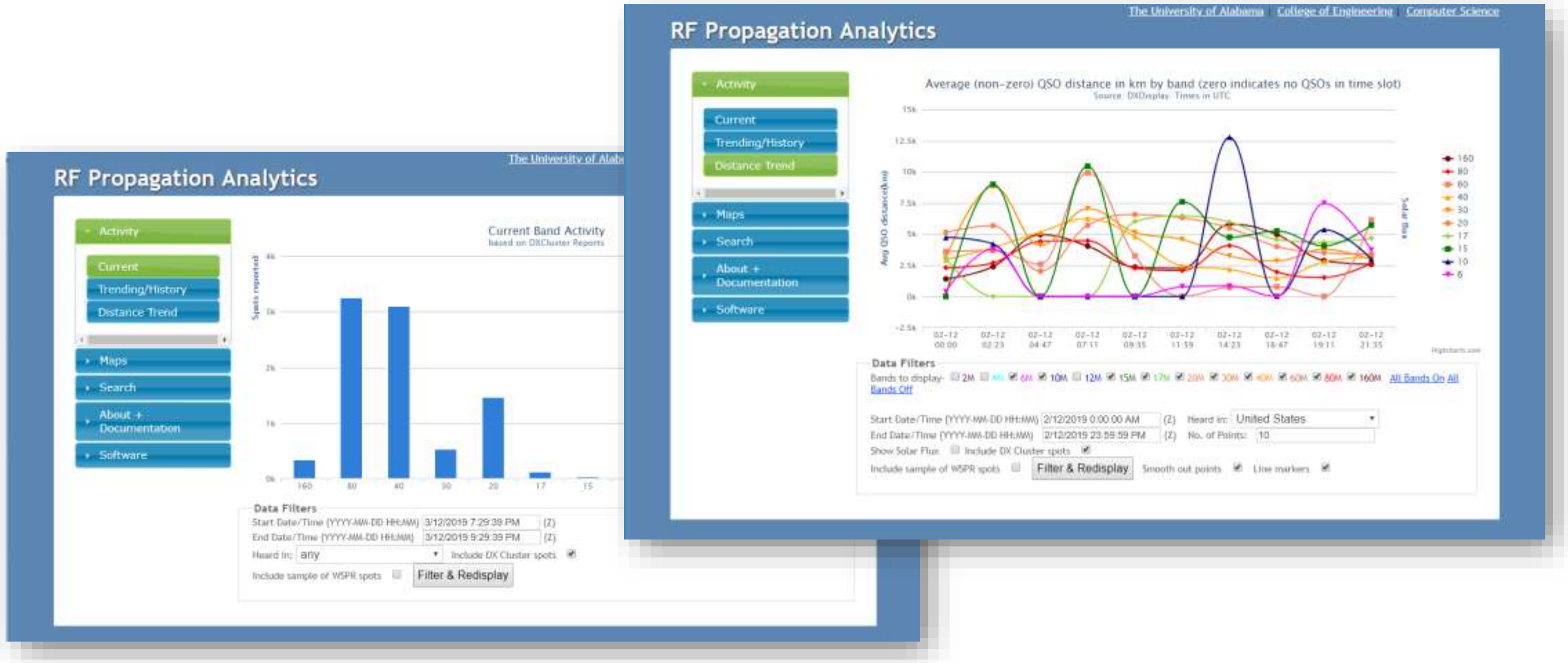


Cloud-to-cloud: HA8TKS



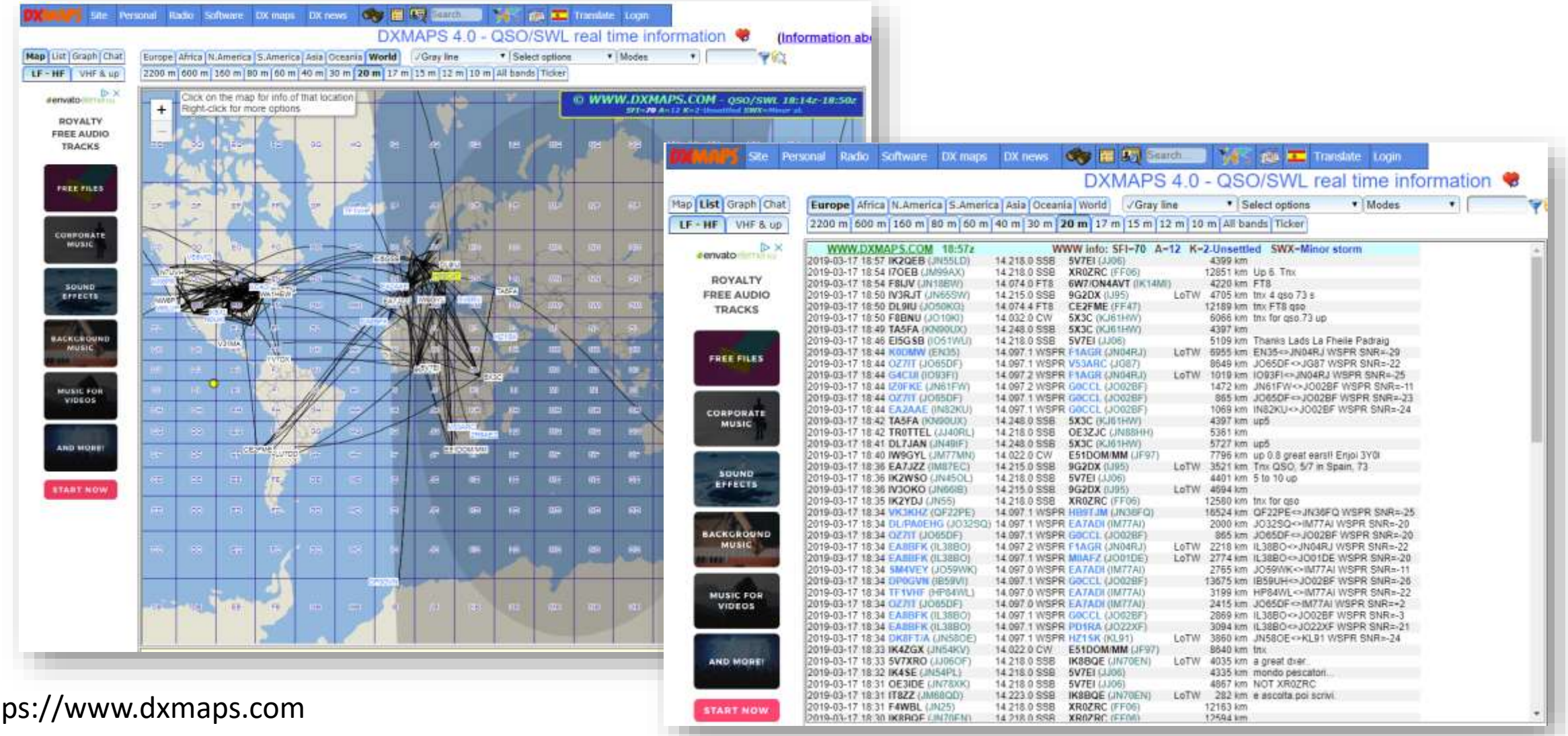
https://dxcluster.ha8tks.hu

Cloud-to-cloud: University of Alabama



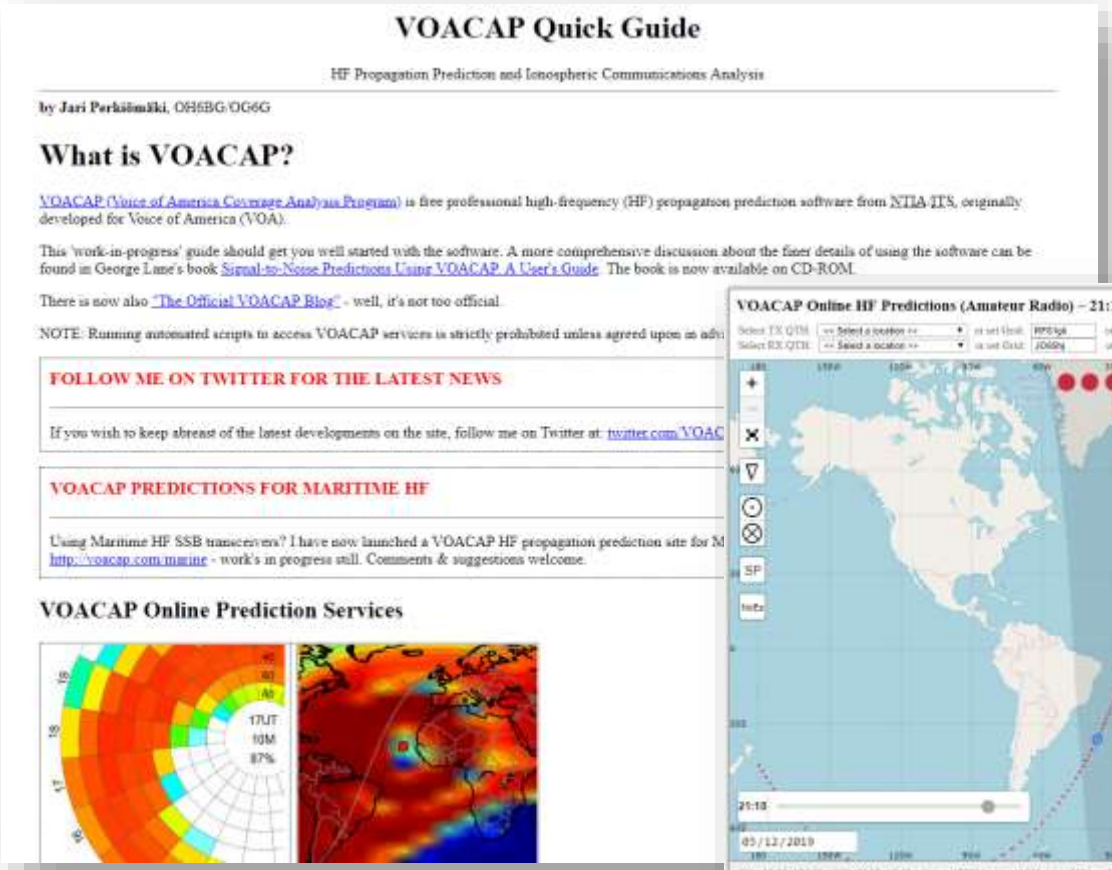
https://dxdisplay.caps.ua.edu

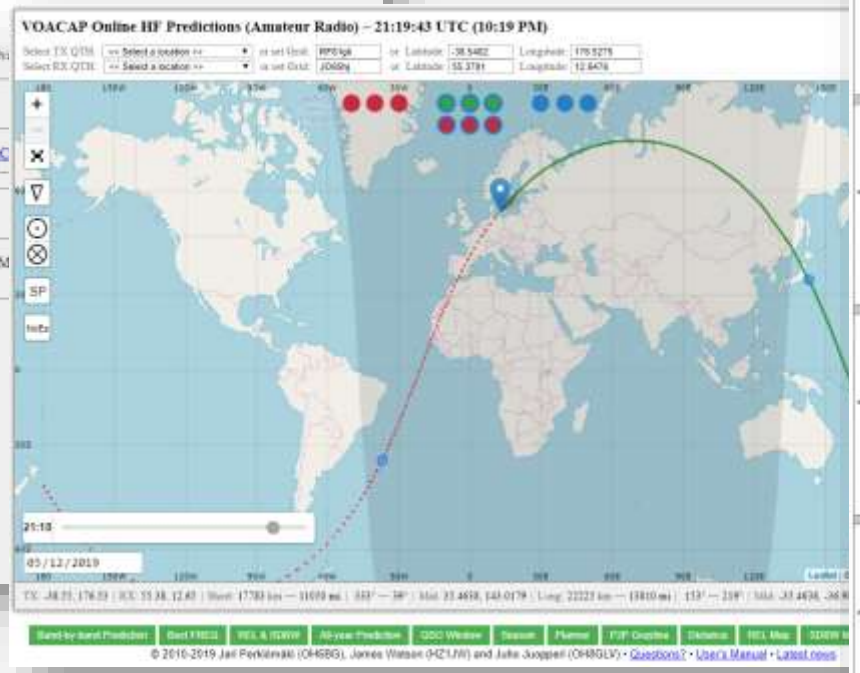
Cloud-to-cloud: DX maps

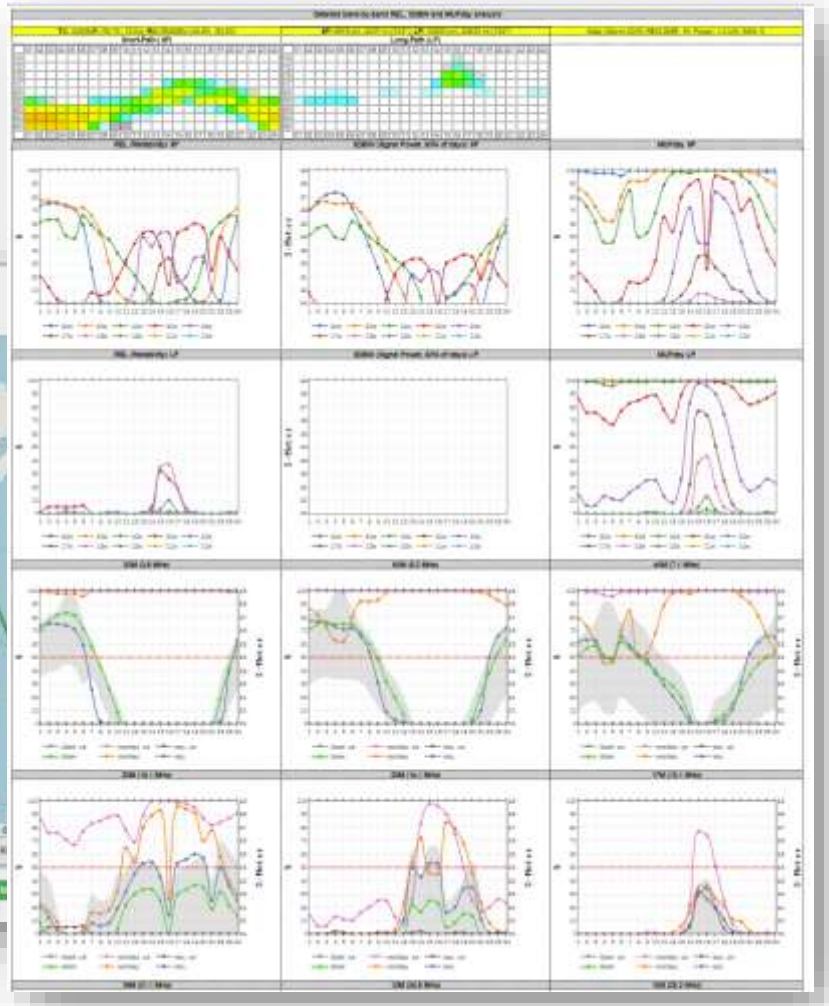


https://www.dxmaps.com

Cloud-to-cloud: VOACAP



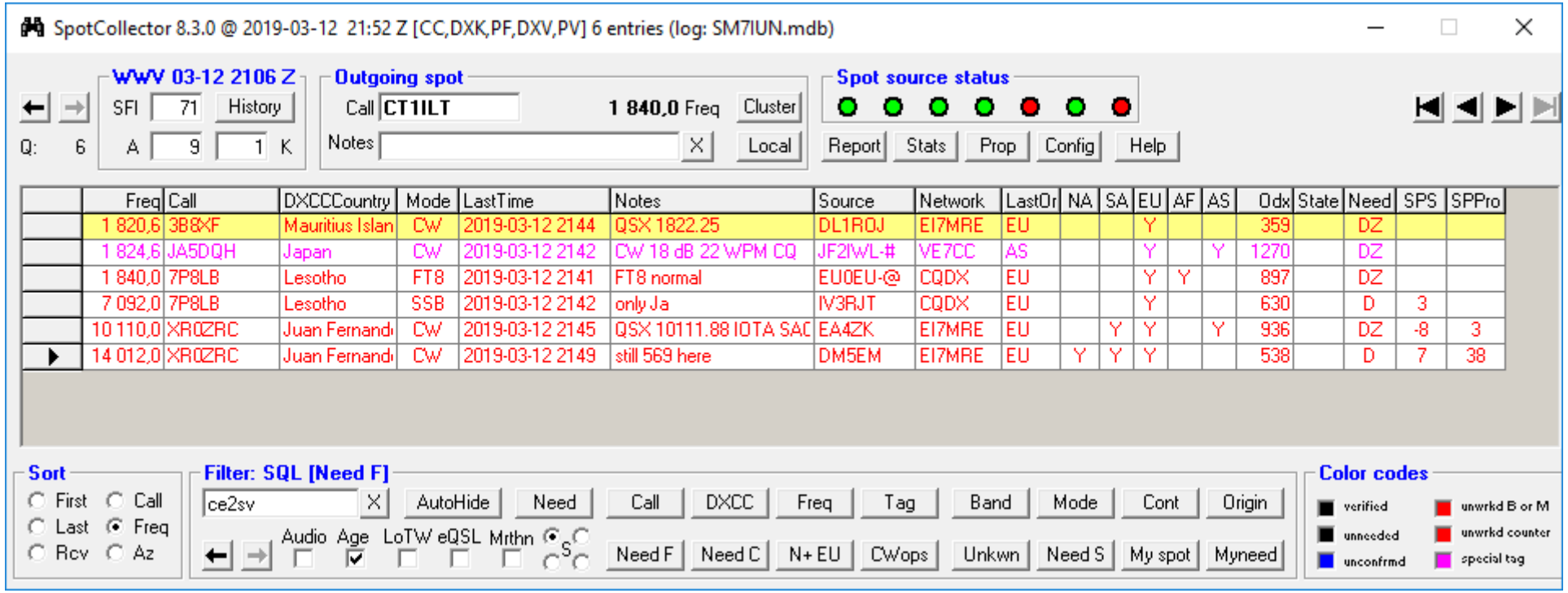




http://www.voacap.com

Client software: SpotCollector

Part of the larger DXLab radio station management suite.
Integration with propagation prediction tools, call sign data base, station logbook, awards rule base, etc.



http://www.dxlabsuite.com

What use is the RBN for me?

Contesting

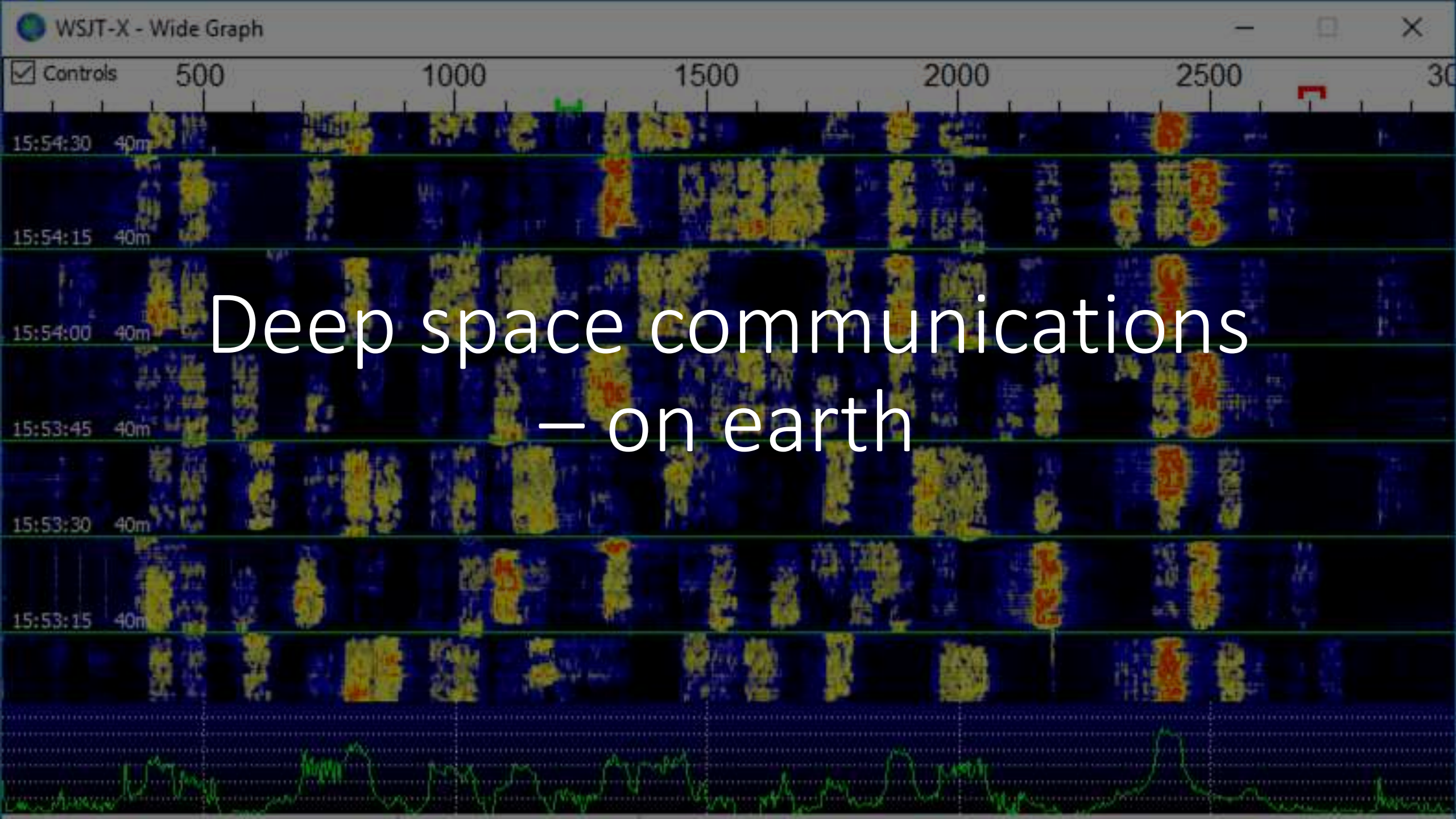
- Band openings
- Band-map filler
- Spots you
- Find clear spots
- Strategizing
- Benchmarking competition

DX-ing

- Band openings
- Alerts for rare stations
- Propagation reports

Antenna experiments

- Antenna directivity
- Radiation angle
- A-B testing

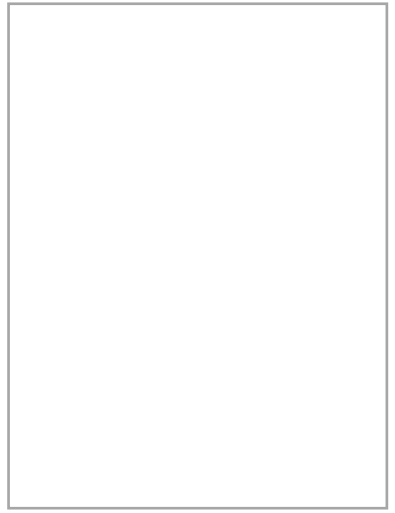


Deep space communications — on earth

Two professors and a software guru

Prof. Joe Taylor
Former Dean of the Physics Department, Princeton.
Nobel Laureate

Prof. Steven J. Franke
Electrical and Computer Engineering
University of Illinois at Urbana

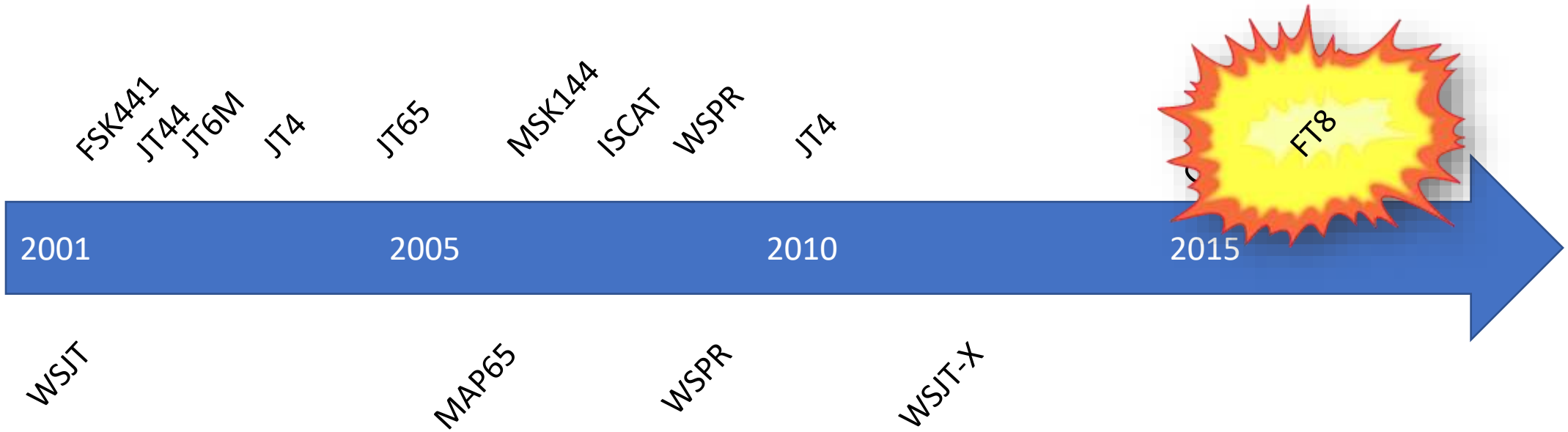


Bill Somerville
Brilliant software guy
Stokenchurch, UK

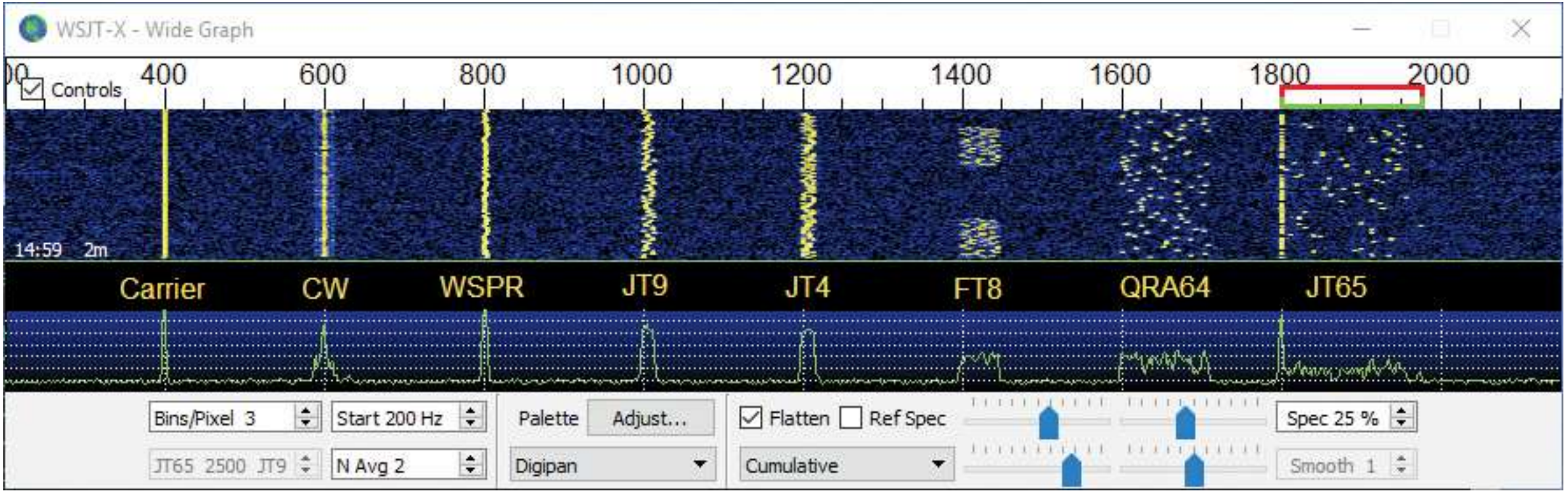
The back story

- When Joe Taylor was approaching 60 in the late 90's, he got an urge to return to the hobby of his teens: ham radio.
- A childhood dream was to communicate using moon-bounce but he was also fascinated by intermittent propagations, such as meteor scatter.
- Having extensive experience from weak signal detection (radio astronomy) and deep space communications he wanted to try this also for himself.
- In 2001 the DOS-based software WSJT was released.
- He later joined forces with remote sensing Professor Steve Franke and brilliant British software designer Bill Somerville.

Evolution


FSK441
JT44
JT6M
JT4
JT65
MSK144
ISCAT
WSPR
JT4
FT8
2001
2005
2010
2015
WSJT
MAP65
WSPR
WSJT-X

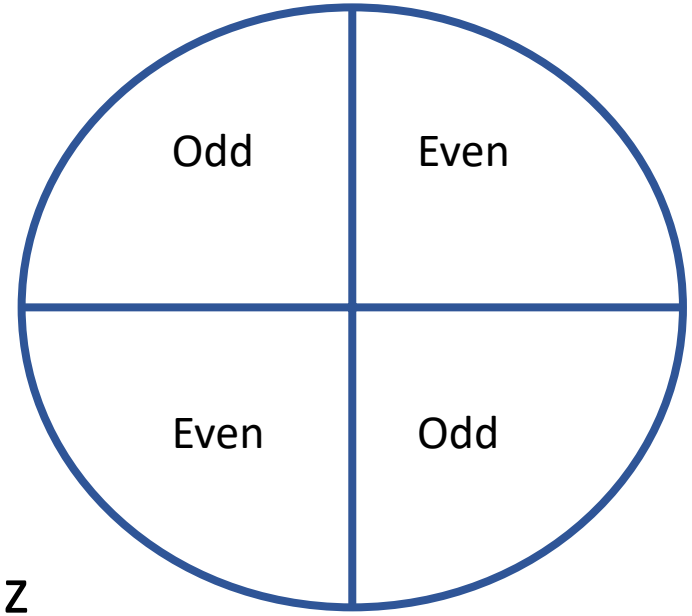
Modulation characteristics



Required SNR

Modulation + protocol	SNR @ 2.5kHz
SSB (telephony)	~10dB
MSK441	-8dB
Human Morse code	-15--18dB
FT8	-21dB
JT4	-23dB
JT65	-25dB
JT9	-27dB
QRA65	-27dB
WSPR	-31dB

FT8 – Franke-Taylor-8FSK

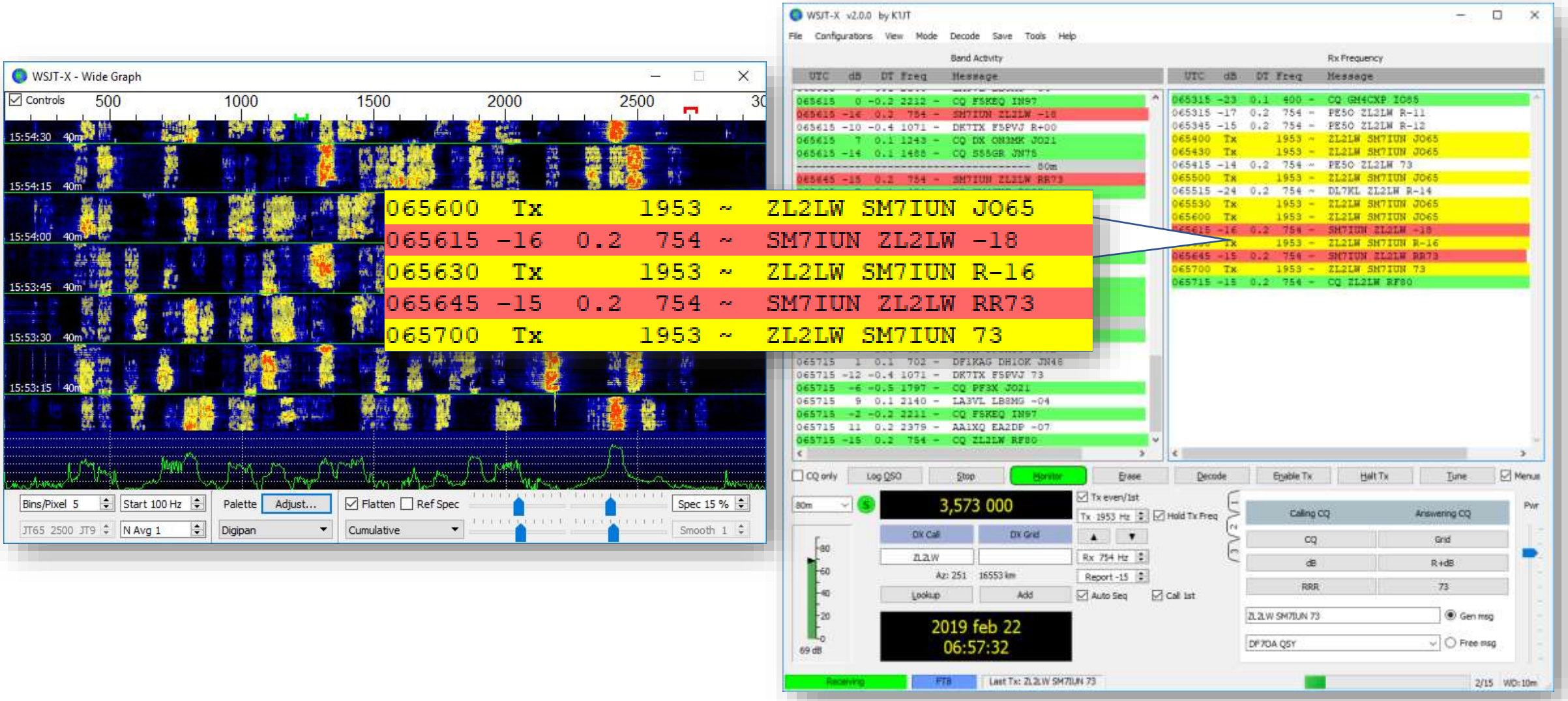


- T/R sequence length: 15s
- Message length: 75 bits + 12-bit CRC
- FEC code: (174,87) LDPC
- Modulation: 8-FSK, keying rate = tone spacing = 6.25Hz
- Waveform: Continuous phase, constant envelope
- Occupied bandwidth: 50Hz
- Synchronization: Three 7 x 7 Costas arrays (start, middle, end of transmission)
- Transmission duration: 79 x 1920/12000 = 12.64s
- Decoding threshold: -20dB SNR (down to -24dB with a priori decoding)
- Multi-decoder: finds and decodes all FT8 signals in passband

Typical contact – message exchange

Party station	You
CQ ZL2LW RF80	
	ZL2LW SM7IUN JO65
SM7IUN ZL2LW -18	
	ZL2LW SM7IUN R-16
SM7IUN ZL2LW RR73	
	ZL2LW SM7IUN 73

Using the software



PSK Reporter

On all bands ▾, show signals ▾ rcvd by ▾ the callsign ▾ sm7iun using all modes ▾ over the last 24 hours ▾ Go! Display options Permalink

Automatic refresh in 3 minutes. Small markers are the 1621 transmitters (show logbook) heard (distance chart) at SM7IUN (22426 reports, 135 countries last 24 hours; 158269 reports, 150 countries last week).

There are 3357 active monitors: 1031 on 40m, 918 on 20m, 474 on 30m, 284 on 80m, 131 on 17m, 128 on 160m, 109 on 60m, 87 on 15m, 60 on 2m, 56 on 6m, 33 on unknown, 4 on 10m, 4 on 600m, 3 on 23cm, 3 on 4m, 2 on 2200m, 1 on uhf. Legend

istance chart) at SM7IUN (24775 reports, 143 countries last 24 hours; 160391 reports, 149 countries last we

Statistics — Comments to Philip Gladstone — Online discussions — Reception records: 6,529,442,773 (150/sec) — Hosting by Fast Serv Networks, LLC

PSKREPORTER.INFO

Table 1: Parameters of the Slow *WSJT-X* Protocols

Bandwidths (BW) are for the narrowest submodes. S/N threshold is referenced to a 2,500 Hz bandwidth at a 50% probability for decoding of an unfading signal.

Mode	FEC type (n,k)	q m	Modulation	Keying rate, baud	BW, Hz	Sync energy	TX duration, s	S/N threshold, dB
FT8	LDPC(174,87)	1 3	8-FSK	6.250	50.0	0.27	12.6	–20
JT4	C(206,72)	1 2	4-FSK	4.375	17.5	0.50	47.1	–23
JT9	C(206,72)	1 3#	9-FSK	1.736	15.6	0.19	49.0	–27
JT65	RS(63,12)	6 6#	65-FSK	2.692	177.6	0.50	46.8	–25
QRA64	QRA(63,12)	6 6	64-FSK	1.736	111.1	0.25	48.4	–26
WSPR	C(162,50)	1 2	4-FSK	1.465	5.9	0.50	110.6	–28

#Modulation includes one additional tone used for synchronization.

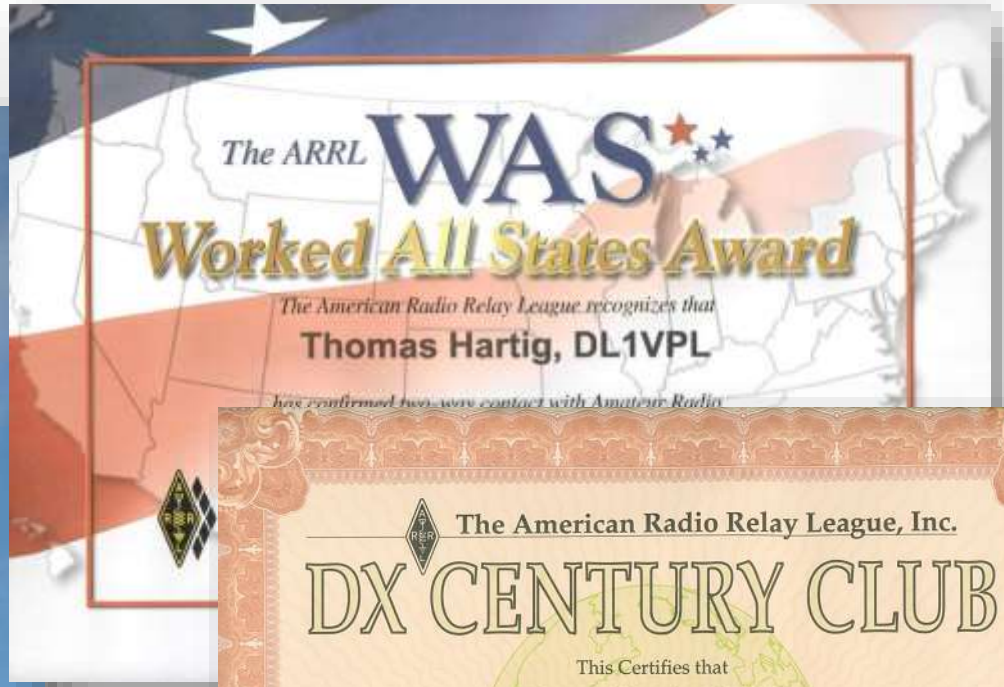
Table 2: Parameters of the Fast WSJT-X Protocols

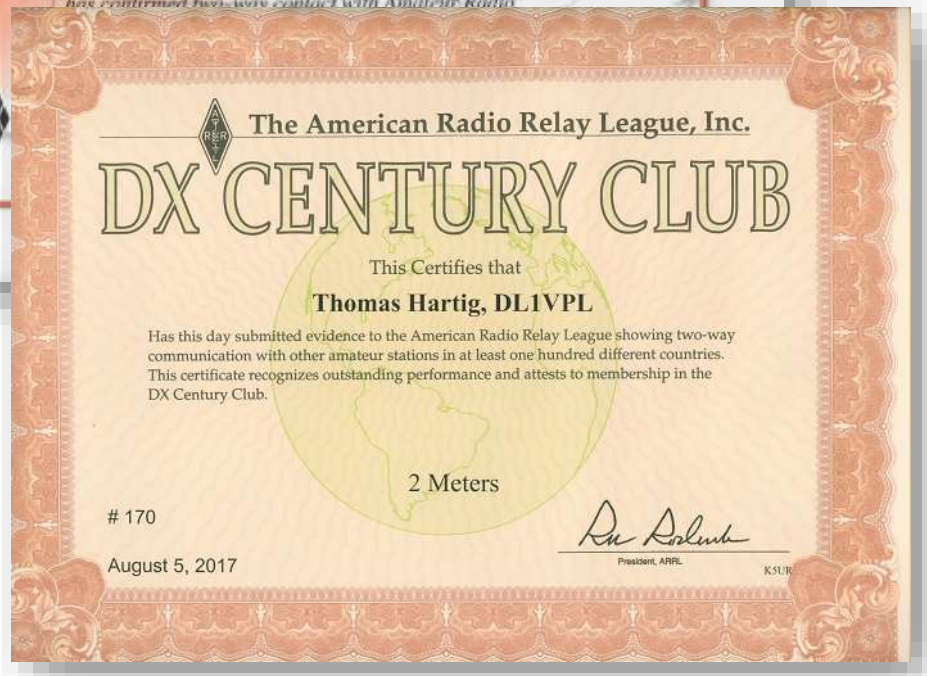
MSK144-Sh is the optional short-message format in the MSK144 protocol.

Mode	FEC type (n,k)	q m	Mod	Keying rate, baud	BW, Hz	Sync energy	Message duration, s
ISCAT-A	—	—	42-FSK	21.5	905	0.17	1.176
ISCAT-B	—	—	42-FSK	43.1	1809	0.17	0.588
JT9E	C(206,72)	1 3#	9-FSK	25	225	0.19	3.400
JT9F	C(206,72)	1 3#	9-FSK	50	450	0.19	1.700
JT9G	C(206,72)	1 3#	9-FSK	100	900	0.19	0.850
JT9H	C(206,72)	1 3#	9-FSK	200	1800	0.19	0.425
MSK144	LDPC(128,80)	1 1	OQPSK	2,000	2400	0.11	0.072
MSK144-Sh	LDPC(32,16)	1 1	OQPSK	2,000	2400	0.20	0.020

#Modulation includes one additional tone used for synchronization.

Example: DL1VPL Thomas Hartig in Dresden





Resources

- The Swedish association for radio amateurs
  https://www.ssa.se/
- Online Morse code training
  https://morsecode.scphillips.com/trainer.html
  https://lcwo.net/
- Lecture on weak signal communications by Joe Taylor
  https://youtu.be/233HQs_8JGQ
- Joe Taylor's web page at Princeton University
  https://physics.princeton.edu/pulsar/k1jt
- Ham radio science organization
  http://www.hamsci.org/