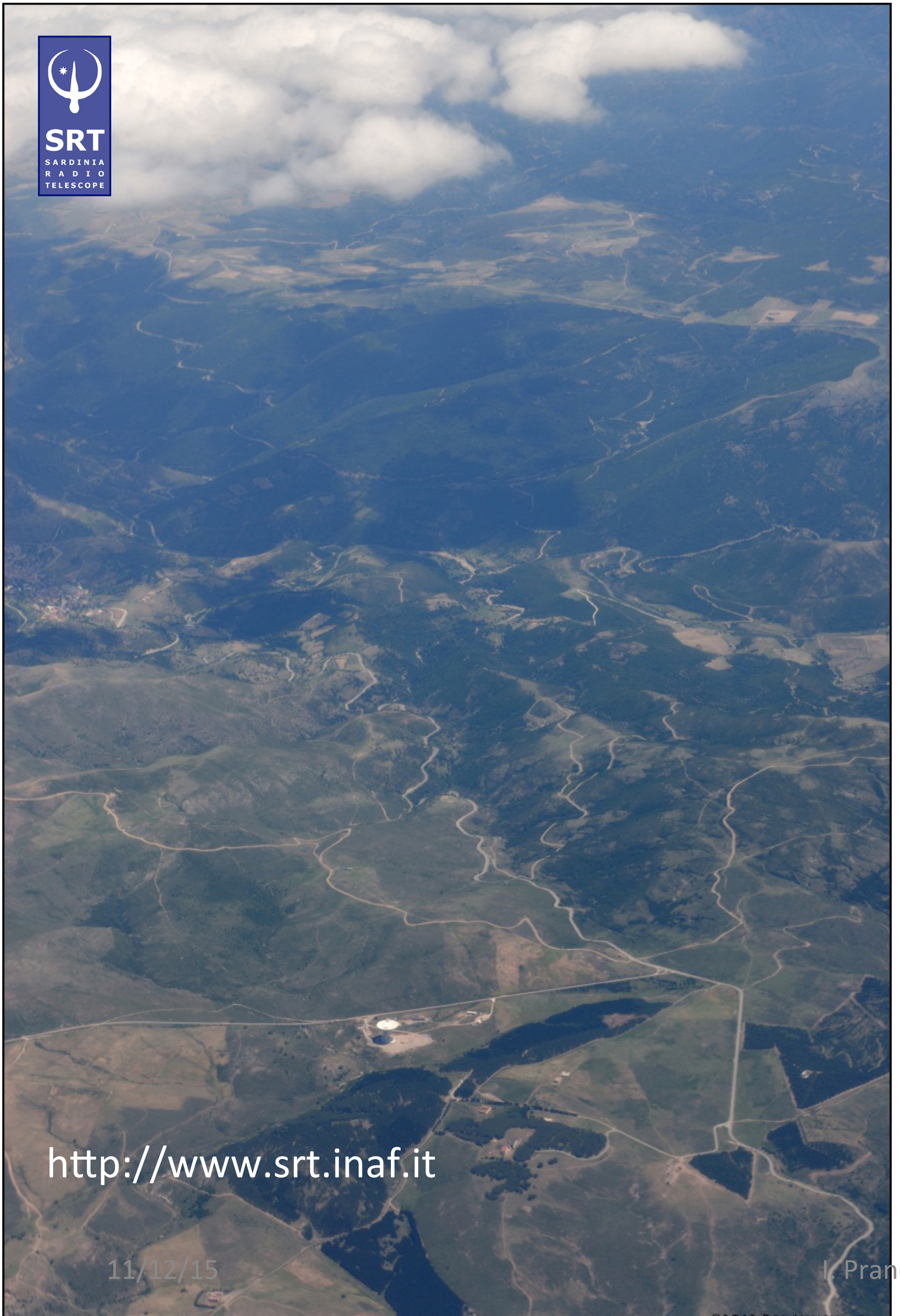


The SRT as a Science Facility

Astronomical Validation & Future Perspectives

Isabella Prandoni
Project Scientist

SRT
Main Characteristics

Fully steerable, 64m diameter, paraboloidal radio telescope.

3,000 t, 70m height

Alt- Azimuth mounting
Quasi-Gregorian Optical design with shaped surfaces

Multiple focal positions
(P, G, 4 BWG)

Can host up to 20 receivers with frequency agility

Wide frequency range: from 300MHz to 100GHz ($\lambda \sim 3$ mm)
Surface Accuracy: rms << $\lambda/10 << 300\ \mu m$

Active surface: efficiency ranges from ~63% at ~10GHz to ~67% at ~100GHz

1008 panels, 1116 electro-mechanical actuators with remote control

MULTIPLE FOCAL POSITIONS

Primary, Gregorian, 2 Beam Wave Guide:

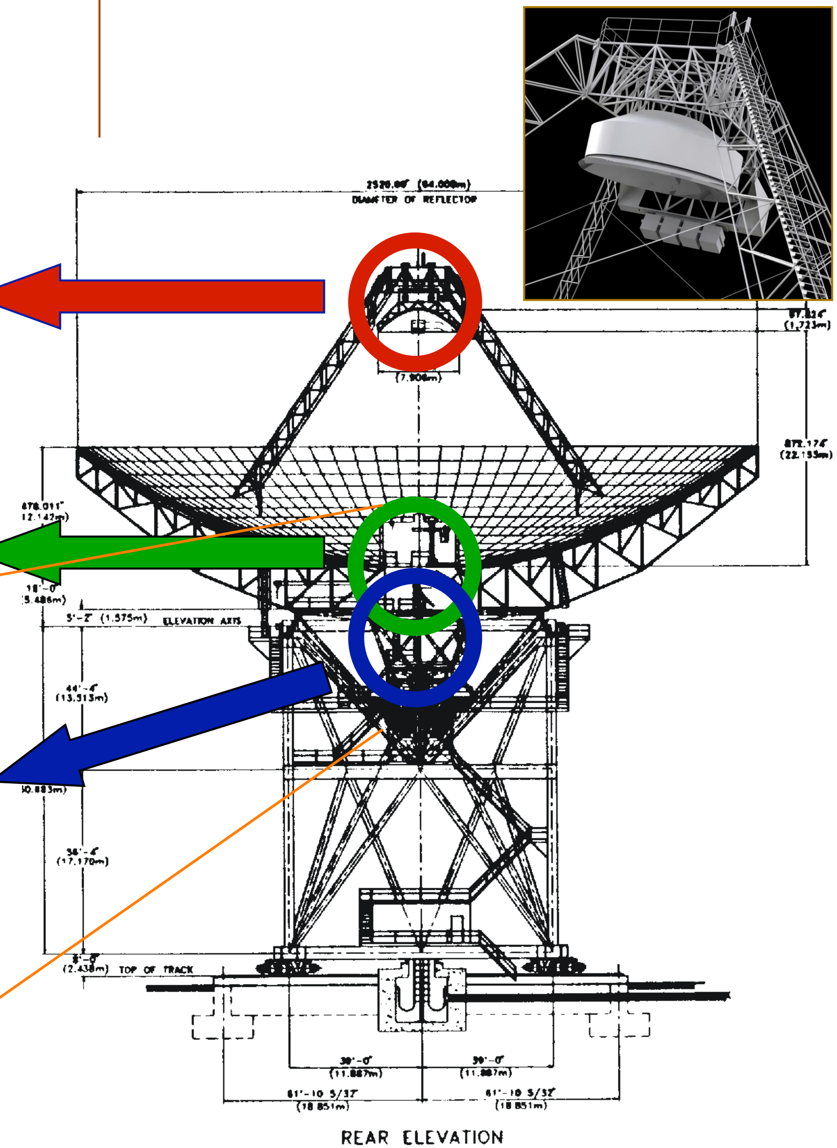
→ **20 Receivers**

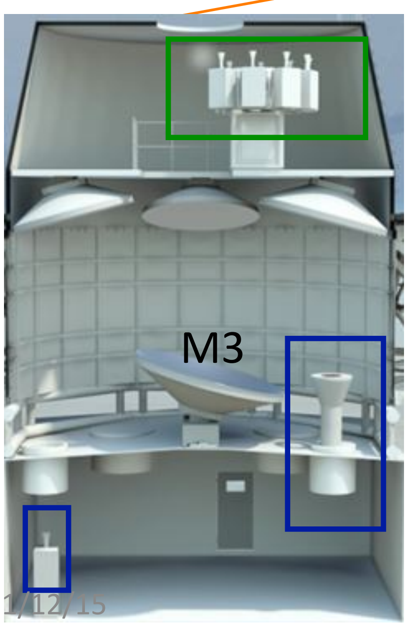
[Frequency agility]

Primary Focus
F/D ratio=0.33
300MHz < f < 20GHz
8 receivers

Gregorian Focus
F/D ratio=2.35
7.5GHz < f < 100GHz
8 receivers

4 BWG Foci
F/D ratio=1.37 & 2.81
1.4GHz < f < 35GHz
2+2 receivers

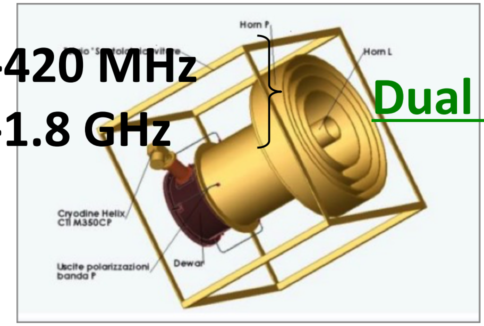




FIRST GENERATION INSTRUMENTATION

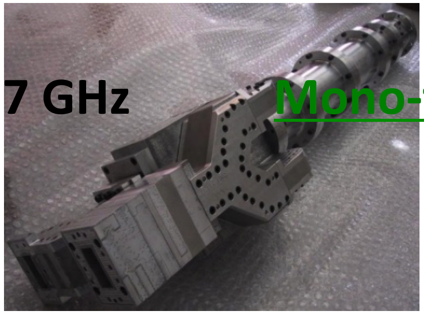
RECEIVERS

310-420 MHz
1.3-1.8 GHz



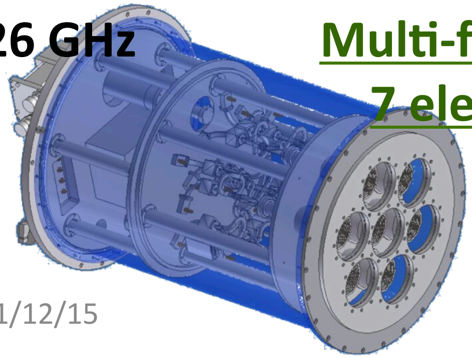
Dual Band

5.7-7.7 GHz



Mono-feed

18-26 GHz



Multi-feed
7 elements

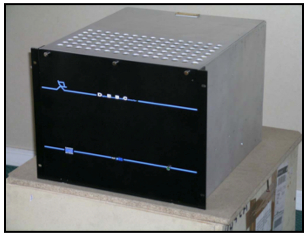
BACK-ENDs

DFB: Digital Spectrometer (pulsar)

(ATNF Pulsar Digital Filterbank)

1 GHz BW, up to 16384 channels

ROACH: 2x512 MHz/1x1024 MHz



DBBC2 (1 GHz, 4 IFs) + MARK 5C (VLBI) + SW Correlator

TP: analog back-end Total Power

7x2 outputs, 2 GHz BW

XARCOS: Digital Spectrometer

8 outputs, 60 MHz BW, 4096 channels

SRT – Future Development
2° Generation Instrumentation

Banda (Sigla)	ν_0 (GHz)	λ (cm)	N° Ricevitore	ν_{Lsky} (GHz)	ν_{Hsky} (GHz)	$\Delta\nu/\nu_c$ (%)	Banda ricevitore (MHz)	Temperatura di rumore (K)	Configurazione
P	0.3	90	1P	0.31	0.42	12	2X110	30	Coassiale a 1.5 GHz
L	0.6	50	1P	0.58	0.62	7	2X40	25	
L	1	30	1P	0.70	1.30	60	2X600		
L	1.5	18-21	2P	1.30	1.80	32	2X500	5	Coassiale a 0.3 GHz
S	2	13	2P	2.20	2.36	7	2X160		Coassiale a 8 GHz
S	3	10	3P	2.36	3.22	27	2X860		
S	4	7.5	3P	3.22	4.30	32	2X1080		
C	5	6	1B	4.30	5.80	32	2X1500	15	
C	7	5	2B	5.70	7.70	30	2X2000	15	[illegible]
X	8	3.6	2P	8.18	8.98	9	2X800		
X	9	3.3	1G	7.50	10.40	32	2X2000	[illegible]	
Ku	13	2.3	2G	10.30	14.40	33	2X2000	14	
Ku	17	1.8	3G	14.40	19.80	32	2X2000	18	
K	23	1.3	4G	19.00*	26.50	33	2X2000	21	Multifeed (7 elementi)
Ka	32	0.9	5G	26.00	36.00	32	2X2000	25	
Q	43	0.7	6G	35.00	50.00	31	2X2000	40	
E	86	0.4	7G	70.00	90.00	25	2X2000	90	
W	100	0.3	8G	90.00	115.00	25	2X2000	100	

Pulsar

RAS

Geo/ASI

MIUR

→VLBI

Coaxial S/X/Ka →Geo/ASI

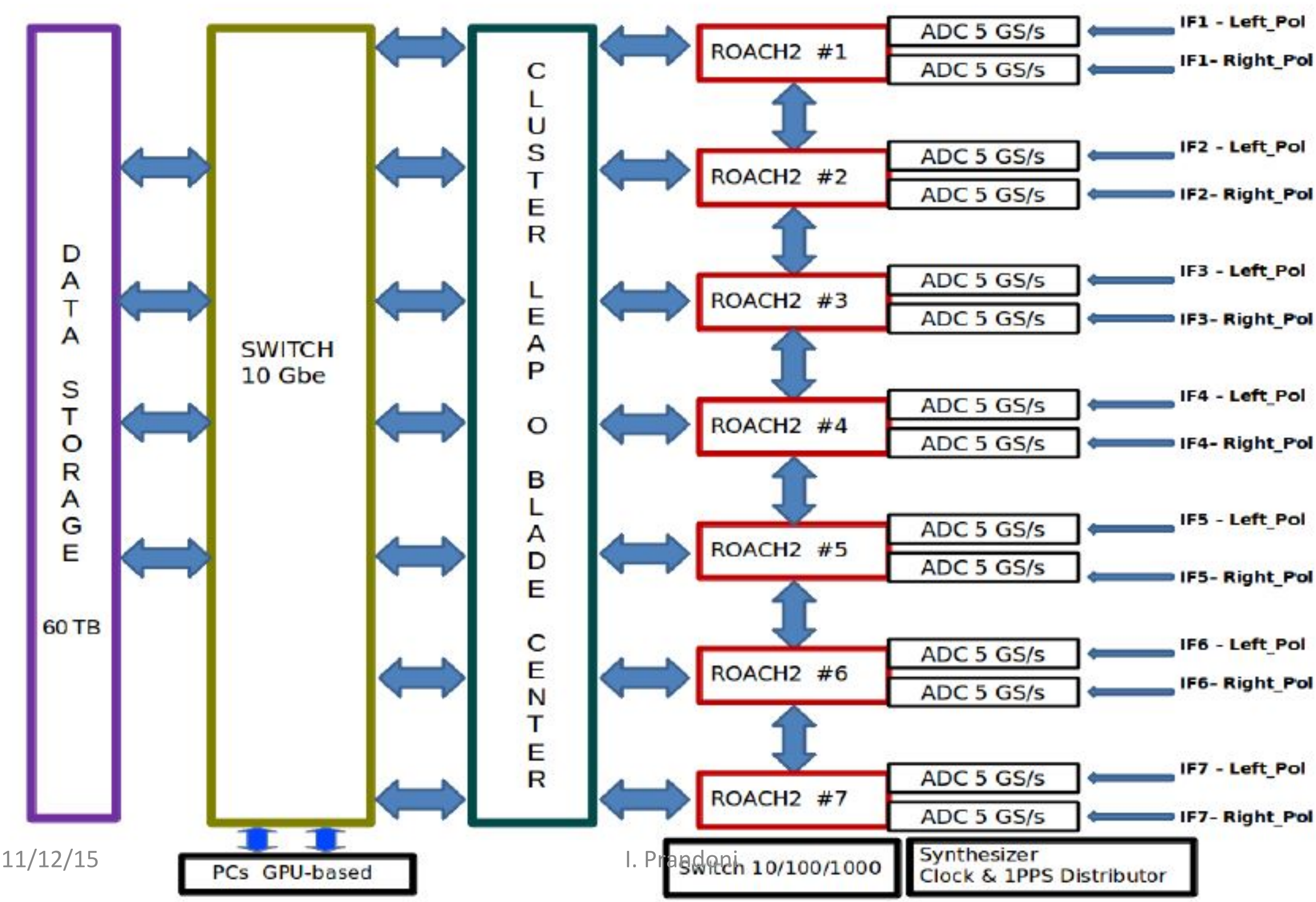
Surveys

MIUR/RAS
RADIONET

19-feeds

19 feeds

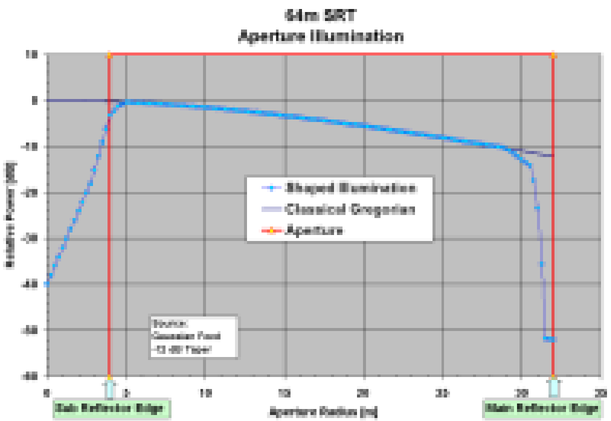
Multi-feed general purpose ROACH2-based backend

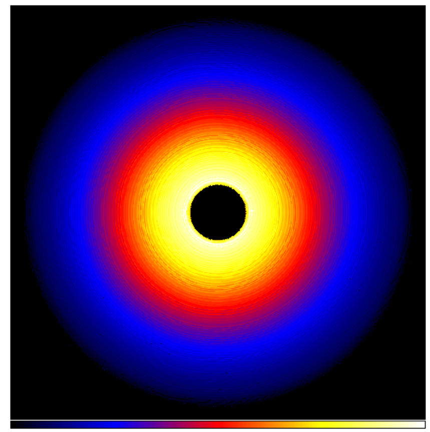


ACTIVE SURFACE – I

Shaping: better illumination of secondary foci

- Null field in region blocked by sub-reflector
- Redistribution of the field over unblocked region
- Under-illumination of the external edge

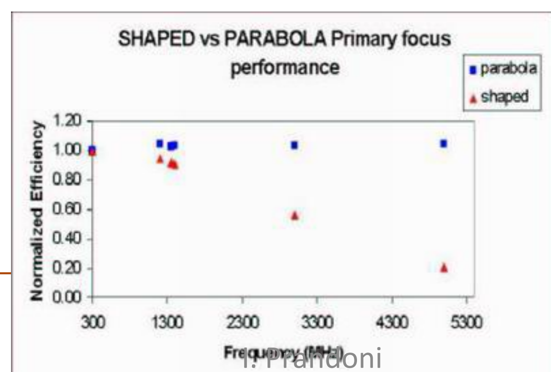




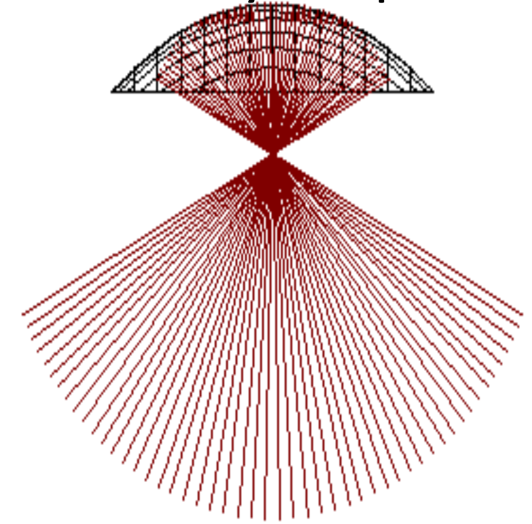
➔ Better efficiency over reduced FoV, No spillover, No multiple reflections [high efficiency spectroscopy]

Parabolic/Elliptical:

➔max eff. & FOV @ primary focus (low freq.)

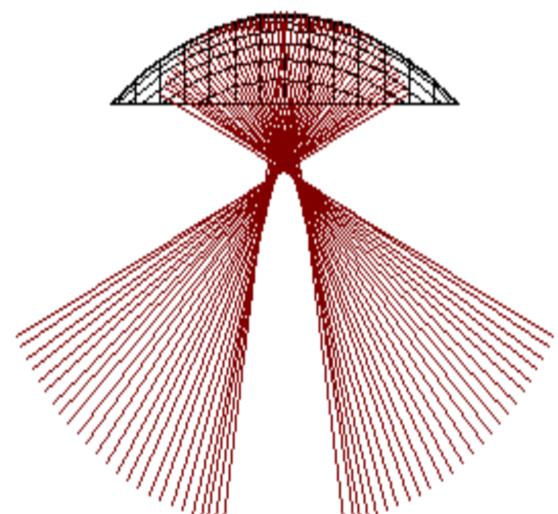


Secondary → Elliptical



Primary → parabolic

Secondary → shaped



Primary → shaped

ACTIVE SURFACE – II

Passive Surface: Surface Accuracy: RMS = 306 μm @ 45° Elevation

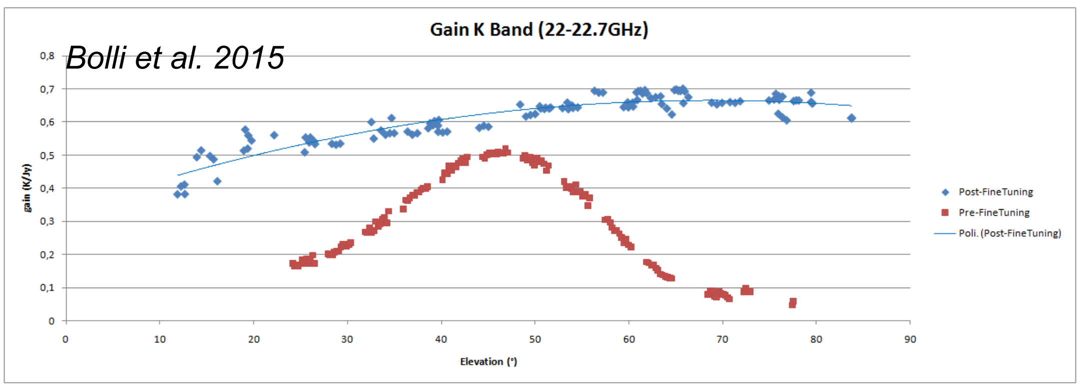
Active Surface: Correct deformations of backup structure to increase efficiency

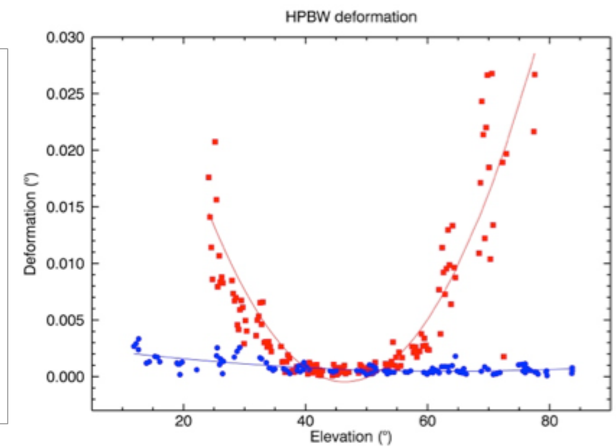
- **phase 1:** gravity deformations only (repeatable effect) ➔ **Optimize Performance @ 20 ÷ 50 GHz**

Photogrammetry: Finite Element Analysis (FEA) for correction of antenna geometry at any elevation:

Gain vs El K band

Beam Deformations





- **phase 2:** wind pressure, temperature gradients corrections (non repeatable effects)
  ➔ **Optimize Performance up to 100 GHz** → RMS ~150 μm → Efficiency @ 100 GHz ~67%

Metrology: pressure/temperature sensors to measure and correct deformations in real time (Microwave Holography)

TELESCOPE SITE

Pranu Sanguni, San Basilio,
35 km North of Cagliari

Altitude	585 m
Longitude	$-09^{0}\ 14^{m}\ 40^{s}$
Latitude	$+39^{0}\ 29^{m}\ 50^{s}$

Optimize UV coverage

Natural wind screen
Low RFI
Rain < 600 mm/yr

Fig. 1 – Precipitazioni medie in Italia (Elaborazione SIAN – UCEA).

PROJECT STATUS

2014 - 2015+:

- **Fine Tuning:** Integration & optimization of all sub-systems
- **Precursors:** backends (DFB, XARCOS, ROACH), derotator, etc.
- **Astronomical Validation**

2013, Sept. 30: Opening

2016:

- Move to final buildings
- Optical fibre link

Astronomical Validation (AV) *from a project to a science facility*

- Last phase before first astronomical observations (*shared risk, early science*) [**2014 -2015+**]

- **Goal 1:** *Tests on predefined sources to* ***characterize the SRT astronomical performance in all standard observing modes****; identification of technical problems and/or limitations*

- ***Goal 2: maximization of science exploitation since first light*** *(science-driven HW modifications; prioritization of AV activities)*

- **Goal 3:** ***Transforming the SRT into a real Observatory*** *(HW/SW development, observing/analysis tools, cook-book, etc.);*

Team AV

- **PS:** Isabella Prandoni
- **Co-PS:**
  Matteo Murgia,
  Andrea Tarchi,
  Sandro Orfei,
  Gianni Comoretto

- **~40 members** covering various technical/astronomical expertises (Bo/Med; Cagliari; Arcetri)

→ Pulsar; Galactic & Extra-galactic, etc.
→ Continuum, Line, Mapping, VLBI, etc.
→ SW, Receivers, Backends, etc.
[interface with commisioning team]

ASTROPHYSICAL VALIDATION TEAM

The SRT astrophysical validation team

1. **Isabella Prandoni**, i.prandoni@ira.inaf.it (Project Scientist)
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6. **Roberto Ricci**, r.ricci@ira.inaf.it
7. **Gianni Comoretto**, comore@arcetri.inaf.it
8. **Matteo Murgia**, matteo@oa-cagliari.inaf.it
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36. **Raimondo Concu**, rconcu@oa-cagliari.inaf.it
37. **Marco bartolini**, bartolini@ira.inaf.it
38. **Marco Buttu**, mbuttu@oa-cagliari.inaf.it
39. **Daria Guidetti**, d.guidetti@ira.inaf.it

AV - SW DEVELOPMENT

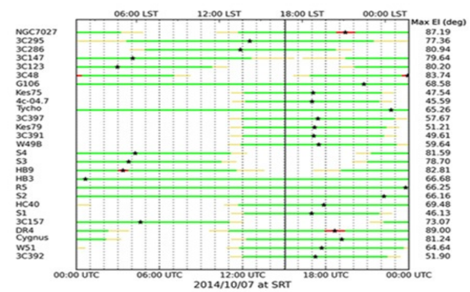
Observing with SRT:

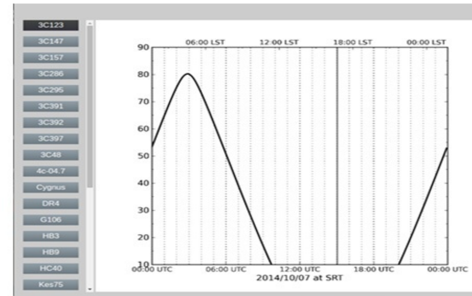
- **ETC:** SRT/Medicina Exp. Time Calc. on line — ***Zanichelli et al.***
- **CASTIA:** Source Visibility — ***Vacca et al.***
  >30 telescopes (incl. EVN), on line
- **ScheduleCreator** — ***Righini et al.***
  Nuraghe SD Operations (TP/XARCOS)
- **SEADAS** — ***Corongiu et al.***
  Interface for Pulsar Obs. (DFB/ROACH)
- **Meteo Forecasting** — ***Buffa et al.***
  Weather predictions on 24/48h timescale

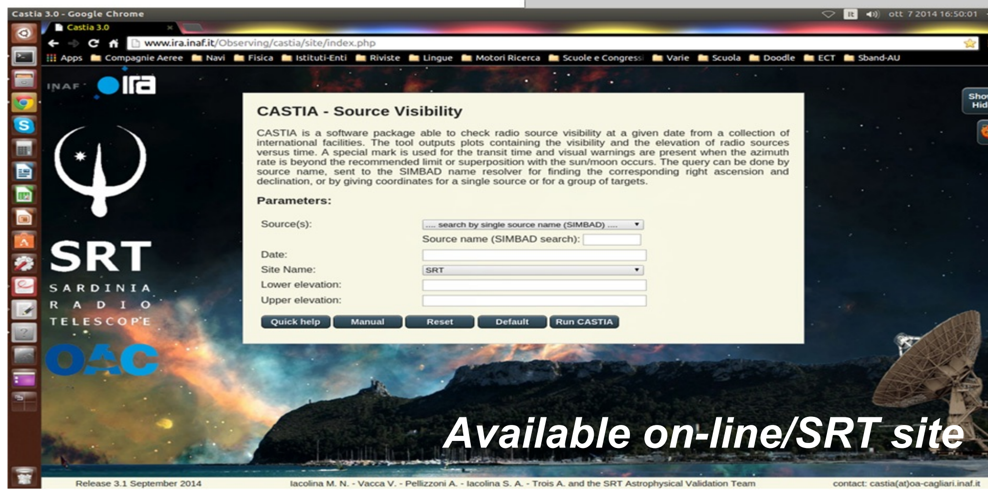
Data Monitoring/Handling:

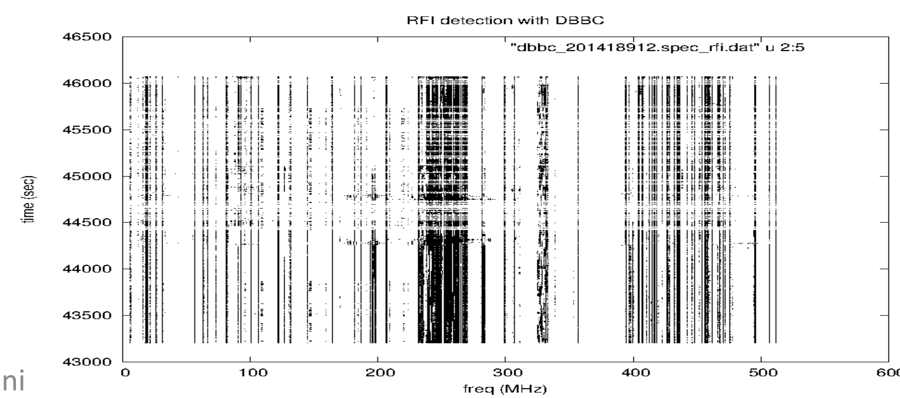
RFI monitoring (DBBC) — ***Melis et al.***

- **RFI detection/excision** — ***Ricci et al.***
- **Format Converter** — ***Trois et al.***
  FITS to CLASS
- **Cross Scan Quick Look/Reduction** — ***Righini et al.***
- **Single Dish Imager** — ***Pellizzoni et al.***
  SD multi-feed Imager (OTF)







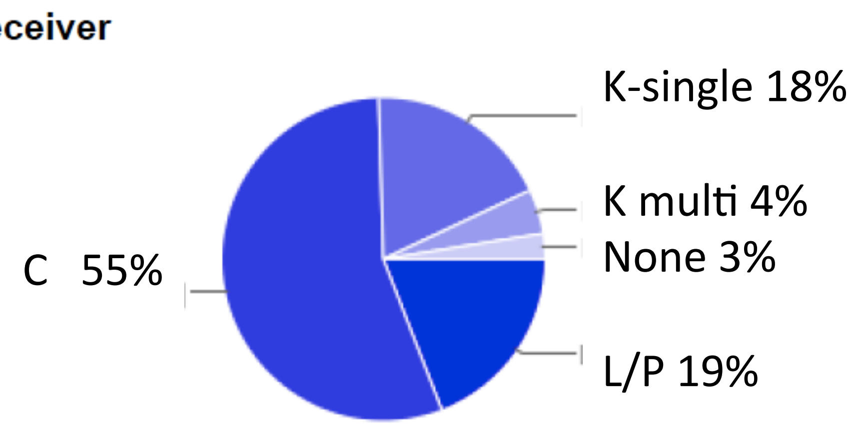


I. Prandoni

Single Dish – AV Basic Tests

2014-2015 → mainly C-band
+K-band single

TP + XARCOS



A) Pointing Accuracy

Calibrator Campaigns

2014-2015: C & K bands

→ 200/260 calibrators validated for C-band

→ El./Az. Average Offsets: -7.6±0.9/8.1±0.4 arcsec

≅**5% HPBW (**≈156 arcsec)

Credits: Ricci

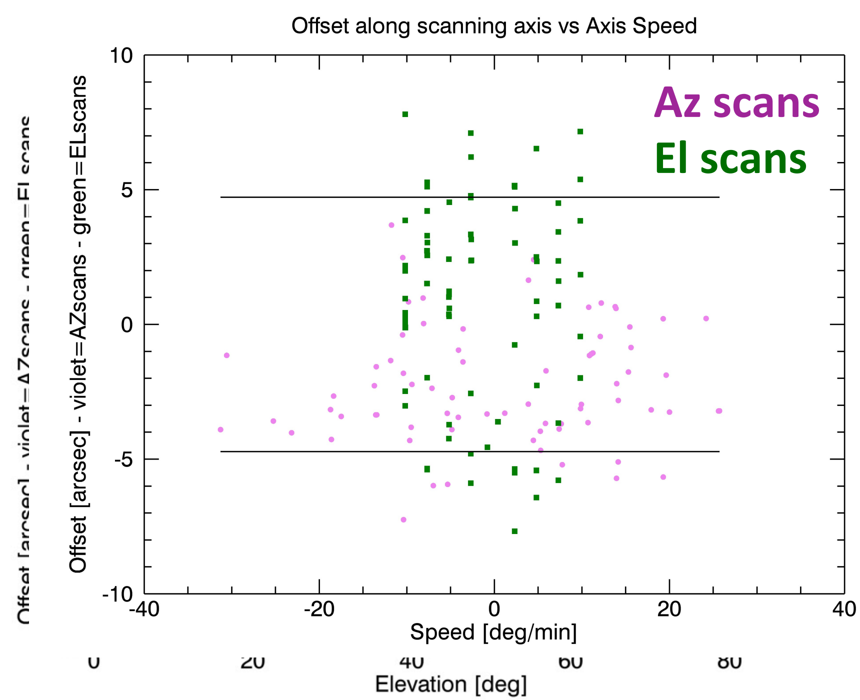
Pointing Offsets vs. Scanning speed @ K Band

24-24.68 GHz – vel_{scan} up to 30 deg/min

HPBW ≈ 50 arcsec

Tolerance ≈ 5 arcsec

Credits: Righini



Single Dish – AV Basic Tests

B) Band Limited Noise for TP:

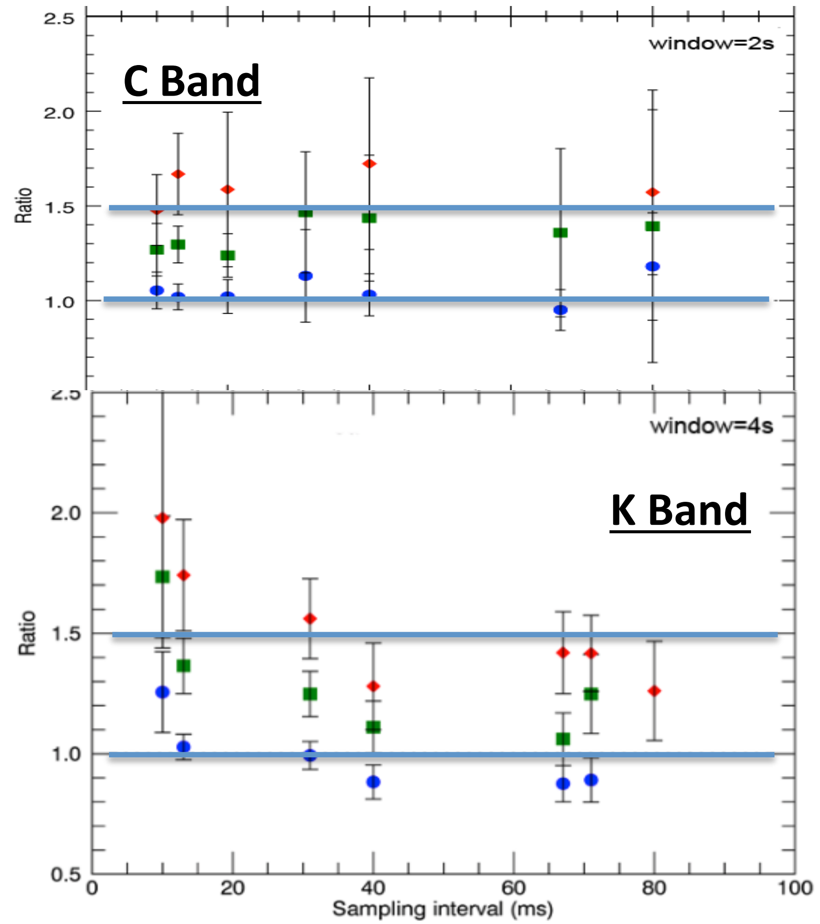
Measured/Expected noise
vs sampling interval

2 different time window: 2sec; 4 sec

[Expected noise ~ radiometer formula]

250 MHz Band
680 MHz Band
1200 MHz Bandwidth

➔ Ratio up to ≥1.5 for largest bandwidth due to increasing RFI

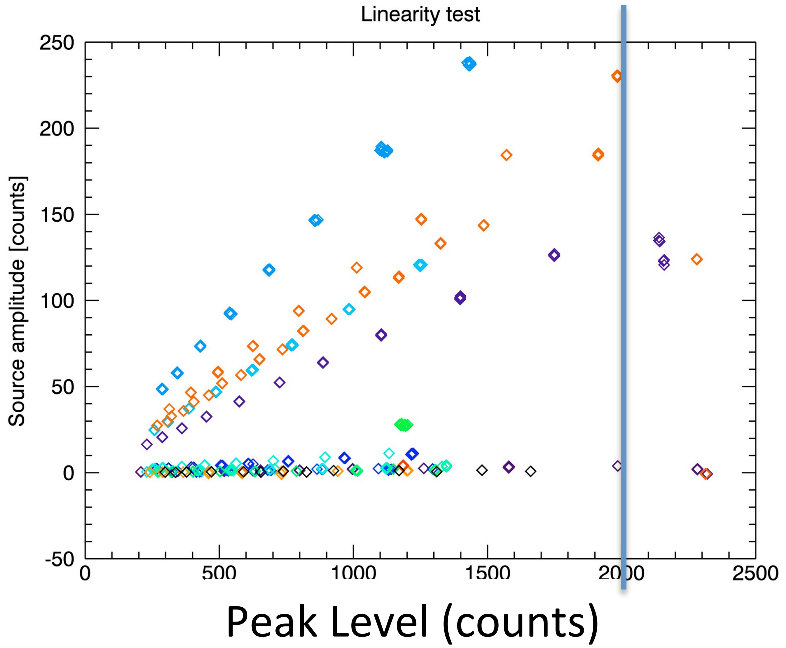


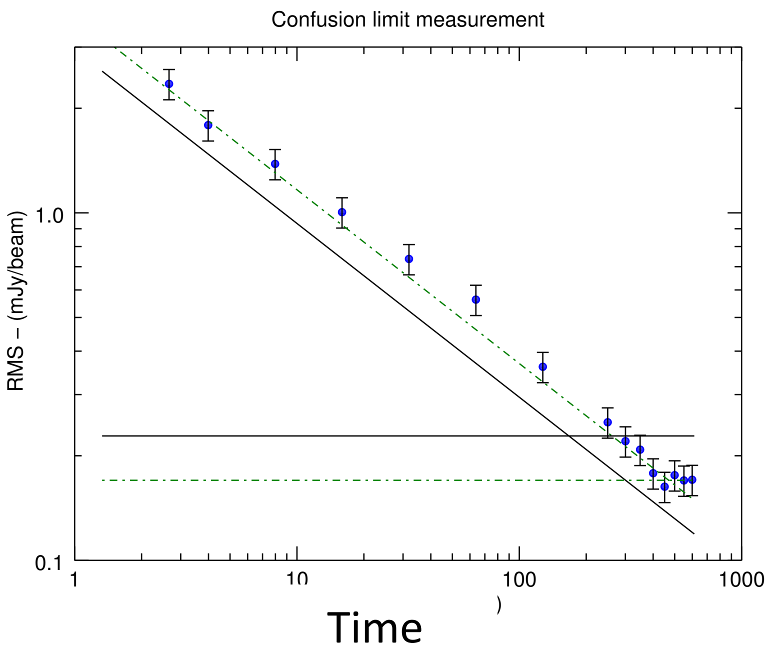
Credits: Righini

Single Dish – AV Basic Tests

C) Linearity Response Range:

→ 400-2000 counts





D) Confusion Noise - C Band:

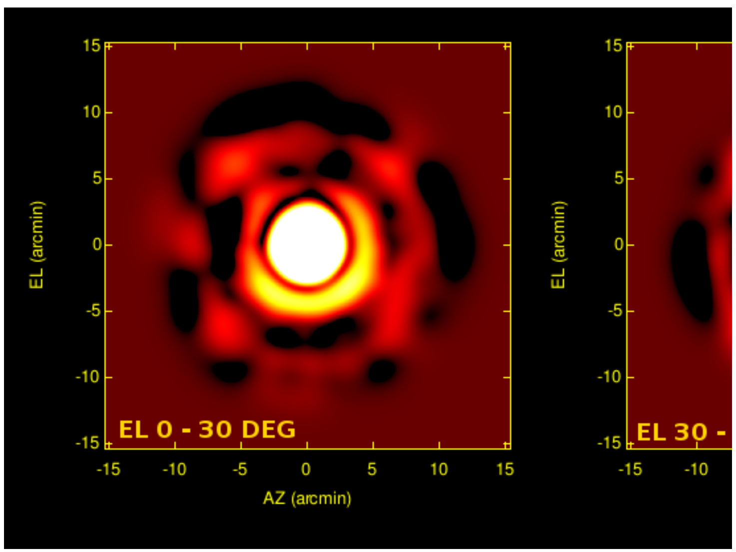
→ reached in ~400s
~0.17±0.02 mJy/b at 7.4-7.65 GHz

Credits: Righini

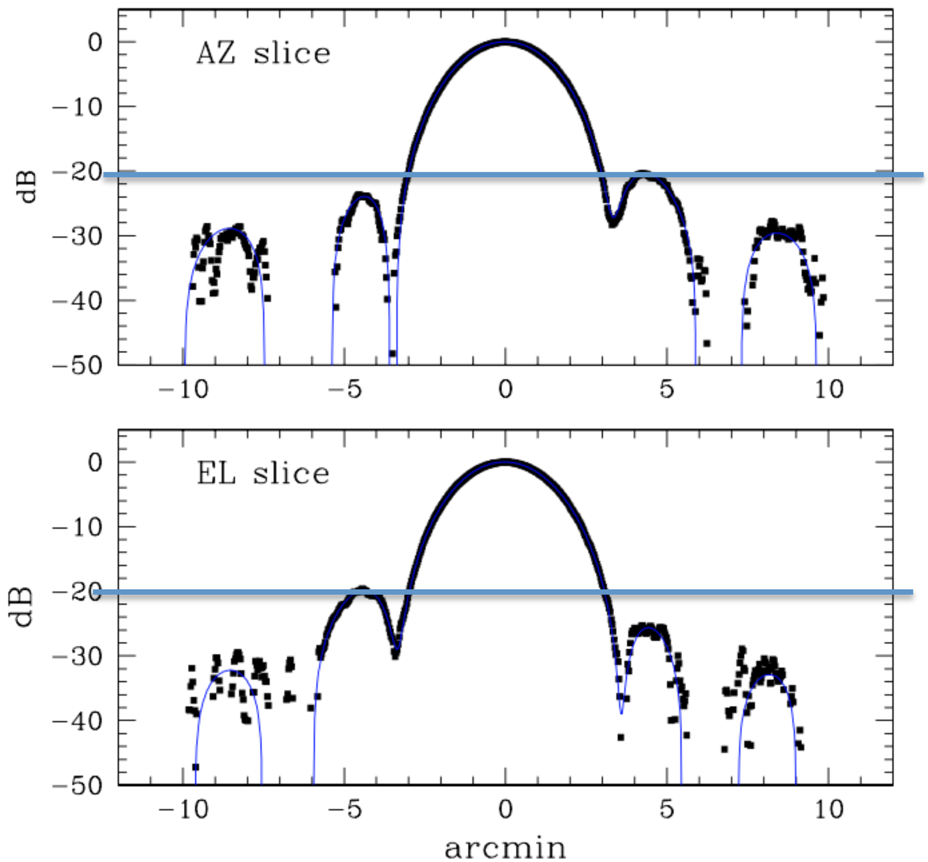
Single Dish – AV Advanced Tests

C-Band BEAM PATTERN vs Elevation

Observations with TP (C Band). 300 1x1
Reduction with SW SCUBE (Govoni et al.



Restoring beam FWHM=2.6’



Credits:

M. Murgia, F. Govoni, S.Poppi, V.Vacca, P.Castangia, A.Tarchi

The SRT: INTERNATIONAL CONTEXT

•Single-Dish Operations: Competitors

-60/100m class radio telescopes: SRT, JB (70m), Eff (100m), GBT(100m), Parkes (64m)

- Dishes with active surface: SRT, Effelsberg, GBT

+ Yebes (40m), Noto (32m), IRAM (30m), Onsala (25m), Metshaovi (14m)

W, etc)

eds, etc.)

•Net

- E

- P

etc.)

→SW Correlation for Italian VLBI, AVN (DIFX)

Highest Priority:

•Include SRT in International Networks: **EVN, LEAP**

•SD Operations: K-band Surveys (multi-feed+active surface)
Pulsars (dual-band RX + DFB)

•National Expertise/Scientific Interests

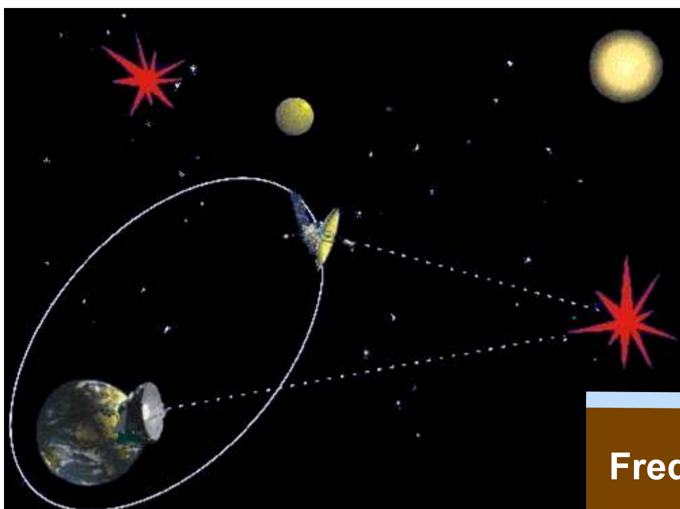
DBBC2 + Mark5C

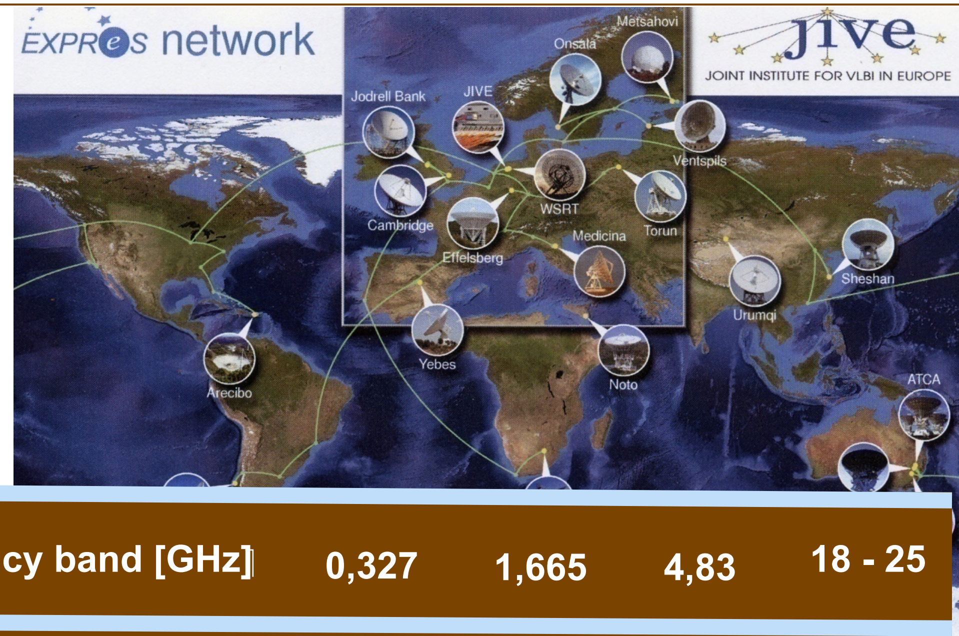
SRT as part of VLBI Networks

EVN (14 Institutes):

- **Large collecting area → *Sensitivity Increment (especially for Space VLBI)***
- **Geographical position → improve UV coverage → *improve image fidelity***
- **Active surface → high efficiency at high frequency → *mm-VLBI***
- **SRT, Noto, Medicina → *Italian VLBI***
- ***optical fiber link → eVLBI***

RadioAstron





Frequency band [GHz]	0,327	1,665	4,83	18 - 25
Ang. Res. At 350.000 km baseline [microas]	540	106	37	7 - 10

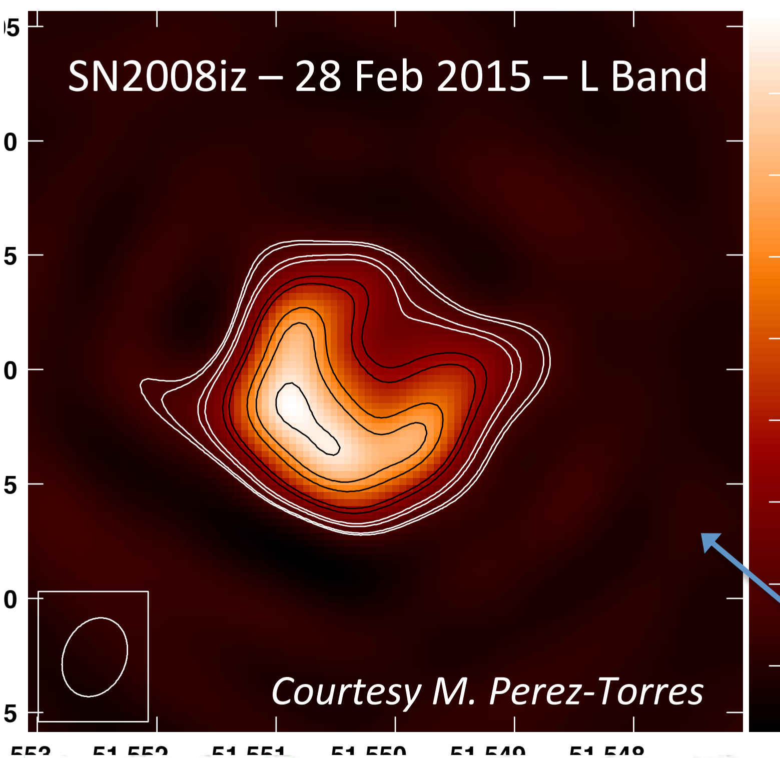
Orbital Period: 7-10 gg
Apogee : 310.000-390.00 km
Perigee : 300-7.000 km

DBBC2 + Mark5C

SRT &VLBI – Milestones

- **2013, Oct. 10 → First Italian VLBI test**:
  Medicina-Noto-SRT + SW correlator

fringes Med-SRT K-band 27-01-2014!



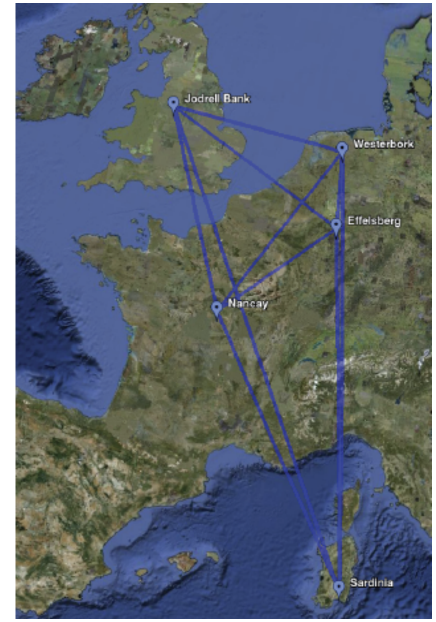
/Mar 2014 → First EVN tests
performed, 3 successful (2 L-band + 1 K-band)

- **29 May 2014 → 1st EVN experiment**
  L-band - PI Perez-Torres 6h
- **4/5 June 14: 1st RadioAstron Experiment**
  L-band 13.5h - PI Sovolainen
- **Feb/Mar 2015: 1st full participation to EVN**
  Shared-risk mode;
  11/17 successful experiments

L/P Dual Band

+ ROACH1

PULSAR STUDIES WITH SRT



•Dual band 20+90 cm receiver ➔ unique capability to remove interstellar medium effects

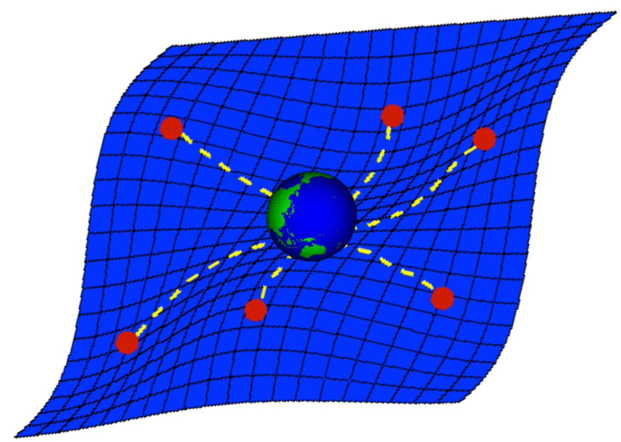
•LEAP: Large European Array for Pulsars

(Westerbork, JB, Effelsberg, Nancay, SRT)

Phased Array: 'Coherent' combination of the 5 major European telescopes ➔ **most sensitive telescope at L-band for timing (~200m, ie ~ Arecibo-illuminated dish, but able to track sources, and observe larger region of sky)**

➡ **Ultra-precision Pulsar Timing:** Searching for signature of space-time perturbations in pulsar timing residuals

Leader experiment for detecting GW from cosmological background or from local SMBH in merging systems



Courtesy A. Possenti

L/P Band

+ ROACH1

SRT & LEAP – AV Milestones

2013, July 27th → First LEAP session including SRT
5 telescopes - ROACH installed – only 1 band (16 MHz)
→ Only brightest pulsars
Goal: 128 MHz → LEAP; 500 MHz → EPTA

Feb. 2014: 8-node cluster available

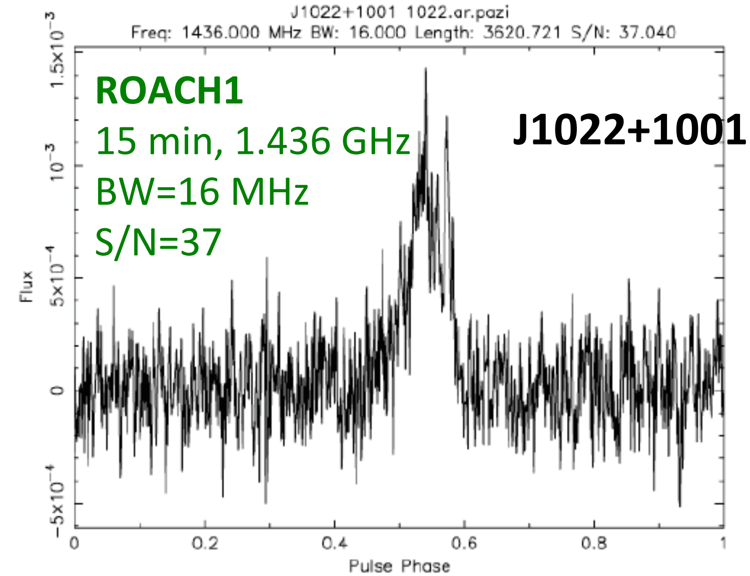
31/03/14: First LEAP session with 8 bands (128 MHz)!

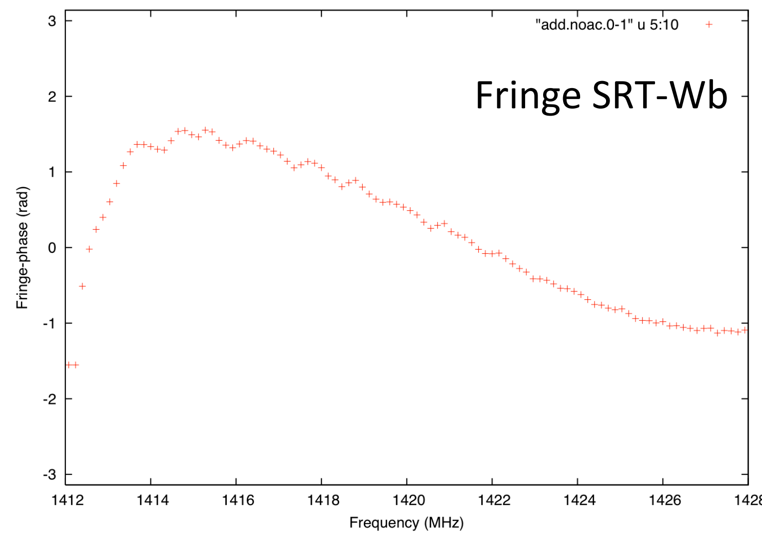
→ **SRT participate to all monthly 25h LEAP sessions** (nearly all msec pulsars detected)

- **May 9, 2014: Correlation between SRT and Westerbork**
- **Sept. 2014:** data acquisition completely automatized (SEADAS+NURAGHE)

- **In progress: 5 Telescope LEAP coherent addition**
  P-band validation

Main Issue: Strong RFIs in L-band → Site + nearby radar (RFI up to 1460 in 1 pol)





Perrodin, Concu, Melis, & Pulsar Group @ OAC

L/P-Band DFB

AV – PULSARS: SD (DFB)

Credits: M. Burgay + Pulsar Grou

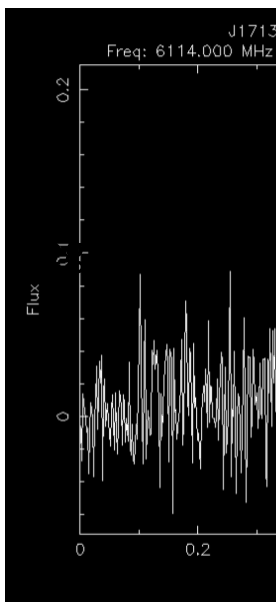
PSR J1713+0747 Effelsberg (

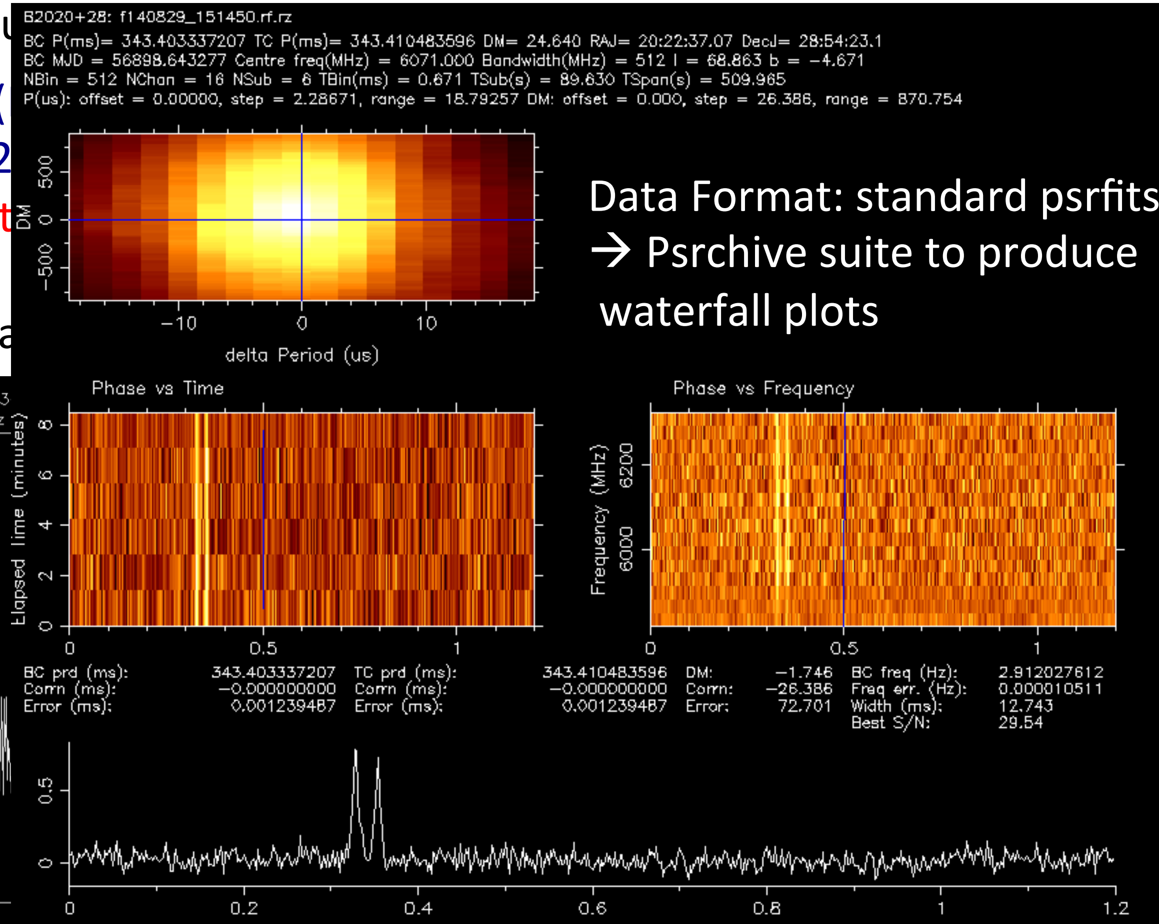
SRT: **6.1 GHz** (400 MHz BW, 512

→ one of highest frequency det

Intrinsic profile asymmetry disa
frequency

J1713+0747:
one of the best
for timing arrays





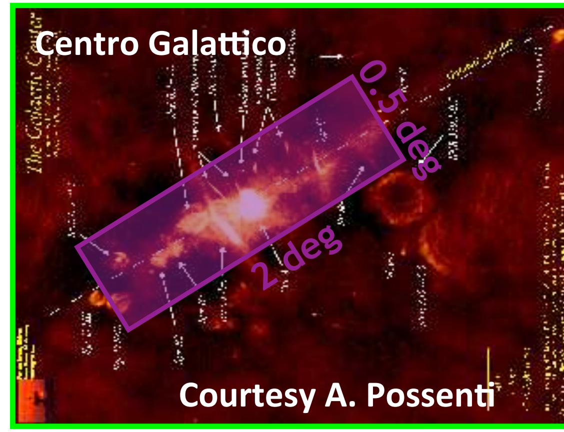
Data Format: standard psrfits
→ Psrchive suite to produce
waterfall plots

Nov. 2015: Implementation of **Winking Calibration Mark** at DFB
→ accurate flux calibration

18-26 GHz

Multi-feed

K BAND SURVEYS



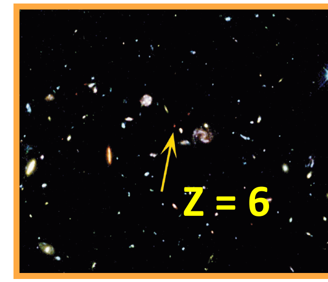
Courtesy A. Possenti

- Pulsars:

- Searching Recycled/msec pulsars in Galactic Center
  - → chance to reveal binary systems
  - msec pulsar/BH → gravitational tests

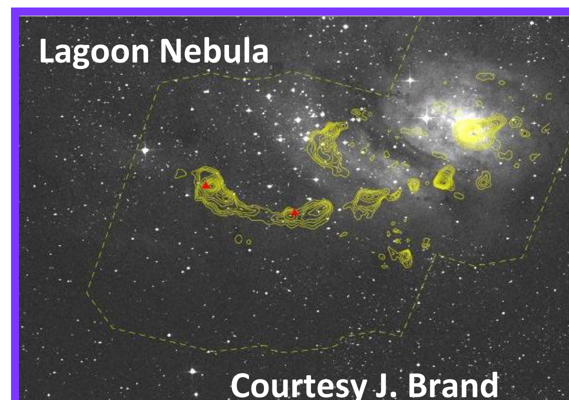
- Continuum Surveys:

- free-free emission in Galactic Plane
  - → Ultra-Compact HII Regions
- Deep Fields [SRT confusion limit: 50-70 μJy (rms)]
  - → adding information @ ≥ 10 GHz → AGN/ SF thermal emission



- Line Surveys:

- Searching maser H_2O in Local Group
  - → Distance & 3D motions → Dark Matter & Cosmology
- Unbiased Mapping NH_{3in} galactic Plane
  - → Astrochemistry in SF Regions



Courtesy J. Brand

18-26 GHz

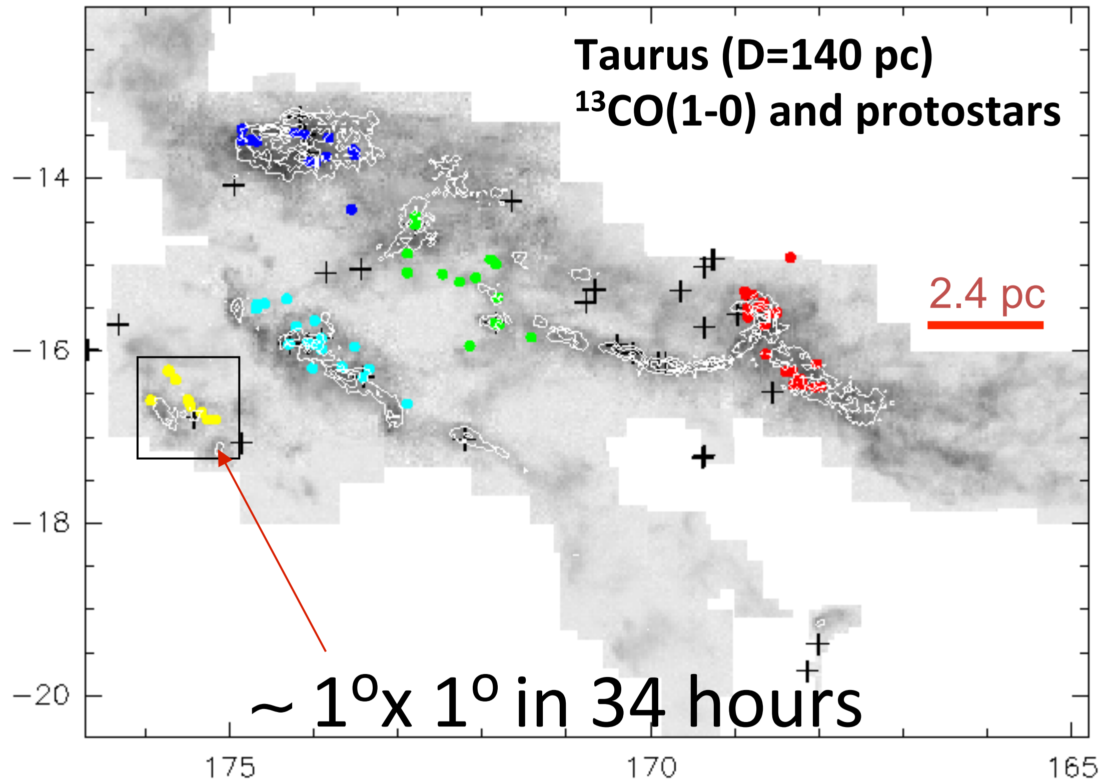
Multi-feed

SPECTROSCOPY @ SRT & Line Surveys @ K-band

Example: NH_3 Unbiased Mapping in star forming regions

NH_3(1,1) and (2,2) at ~23.7 GHz
+ hyperfine transitions [τ]
➔ Temp. of molecular clouds

In sinergy with JCMT, Herschel/ Spitzer, APEX, ALMA
➔ Localization pre-stellar cores
➔ Study physical and chemical properties of various components: gas, dust, stars

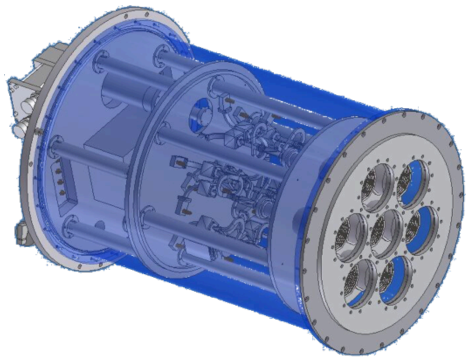


Courtesy P. Caselli & J. Brand

18-26 GHz

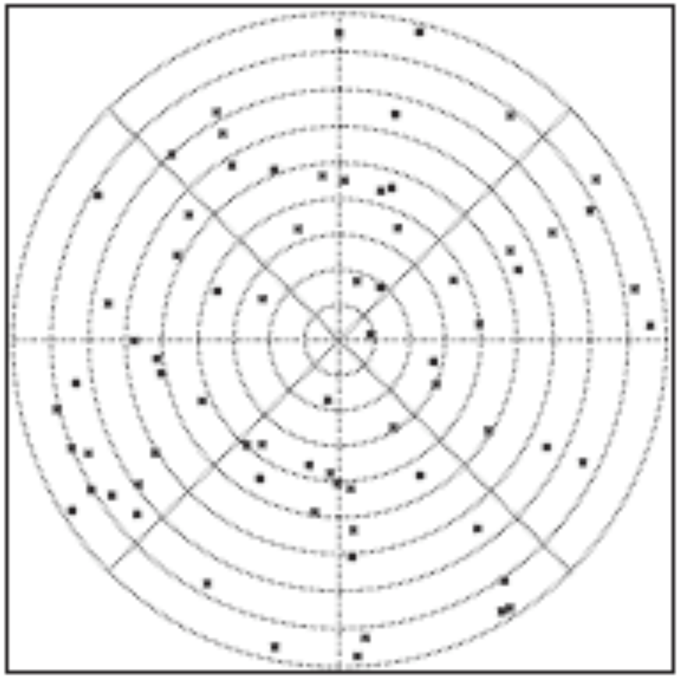
Multi-feed

Pilot Survey with K-band Multi-feed @ Medicina



•Pre-commissioning + AV @ Medicina in 2010-11
(Multi-feed + TP + ESCS OTF mode)
•Pilot survey North Polar Cap (~900 deg^2 @ Decl. +72.3°)
• ~70 RS with S>100 mJy

•**Precursor:** Implementation of derotator



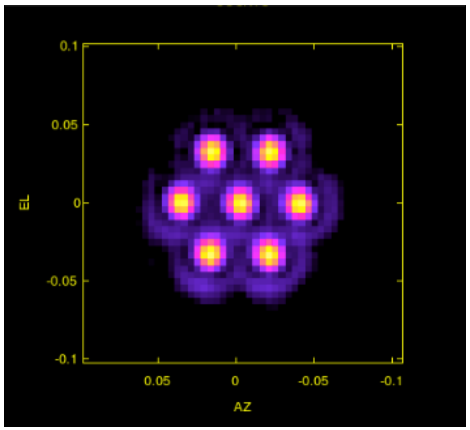
Righini et al. 2012
Ricci et al. 2013

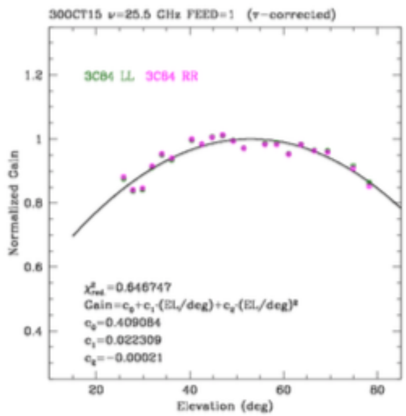
18-26 GHz

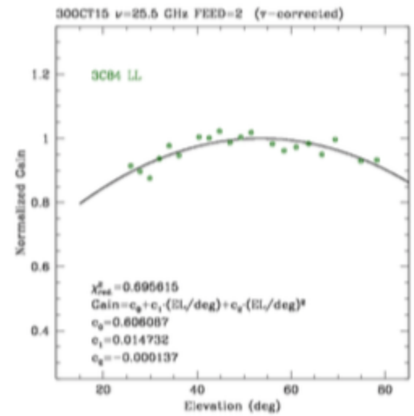
Multi-feed

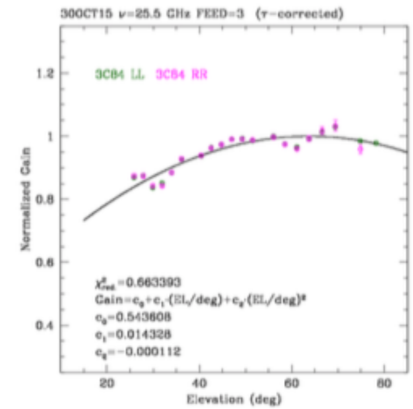
TP – Gain Curves

4 sub-bands centered @ 18.3 – 22.0 - 23.7 – 25.5 GHz





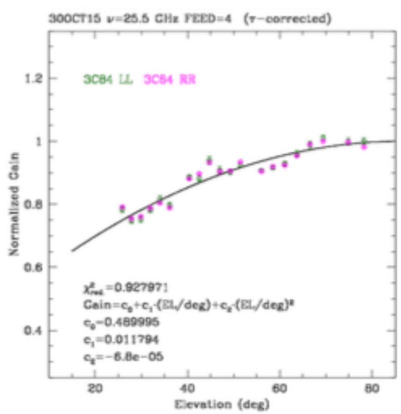


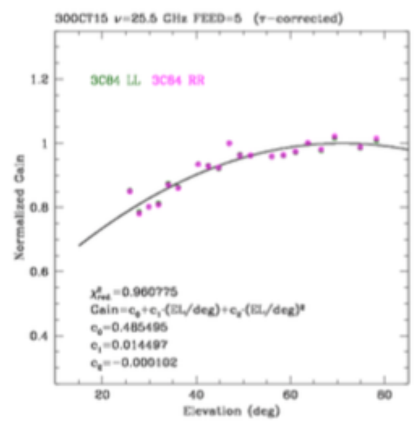


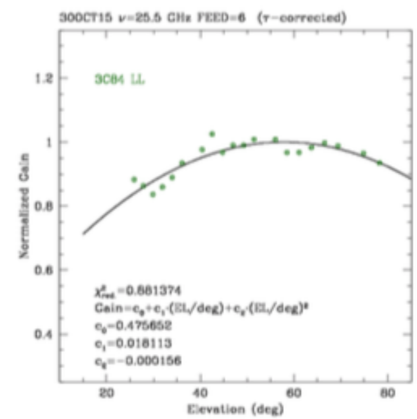
OTF Imaging:

7 feeds simultaneously

22 GHz, BW=680 MHz



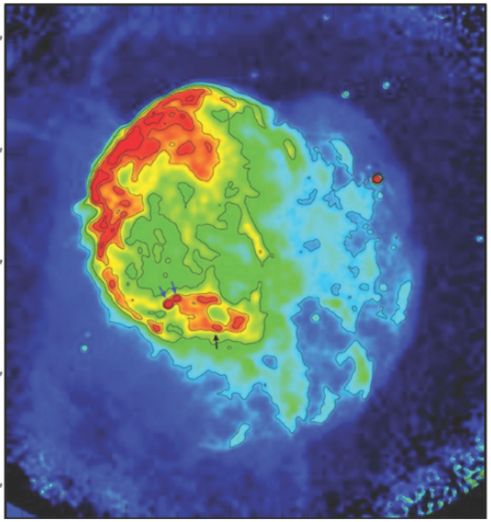




SRT – Imaging Performance

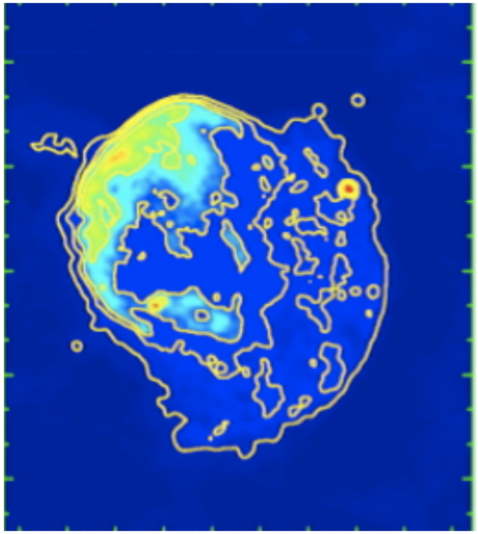
C-band - SNR 3C157/IC 443: TP + SDI SW → DR~ few 100s, Good Image Fidelity

VLA+Arecibo 1.4 GHz
40” res. + 3.9’ res.
~6.3 hours



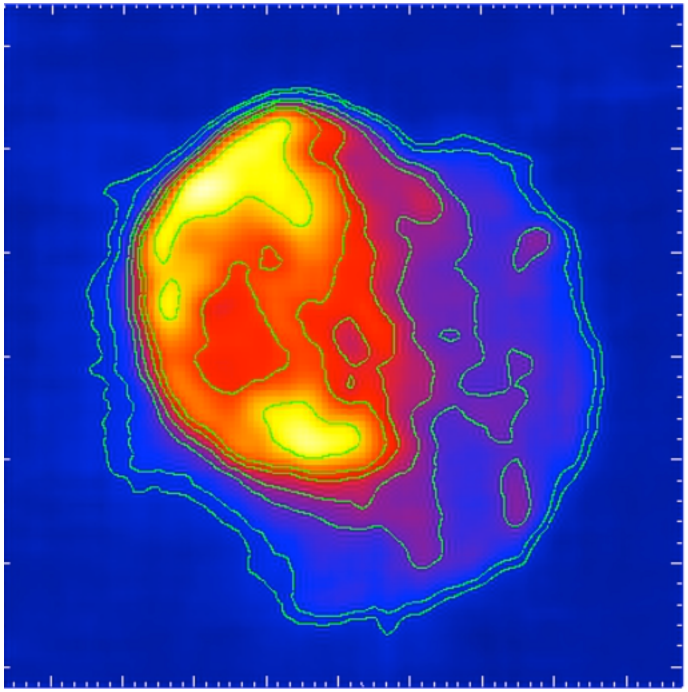
Lee et al. 2008

VLA 330 MHz
64”x74” res. ~1 hour



Hewitt et al. 2006

SRT 6.9 GHz - TP
2.7’ res. ~13 hours



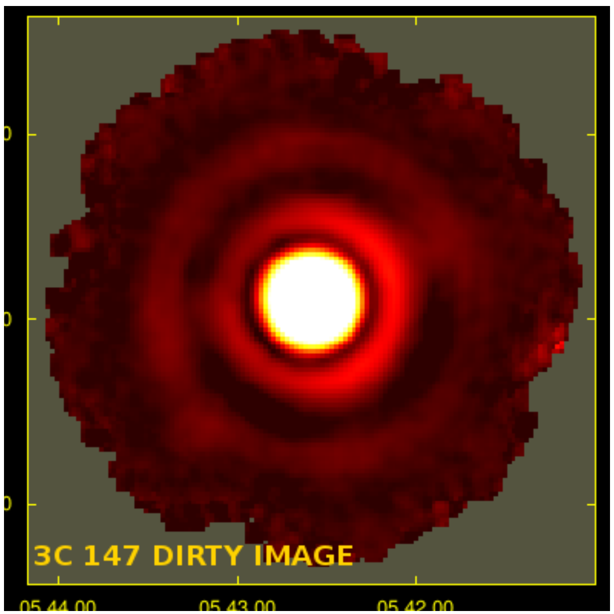
AV: June 2014

SDI SW: Baseline subtraction + RFI flagging + Calibration
Credits SDI Team: A.Pellizzoni, E.Egron, N.Iacolina, S.Righini, A.Trois, V.Vacca

SRT – High Dynamic Range Imaging

Observations with TP (C Band) to test/debug beam deconvolution procedures (based on Imaging SW SCUBE (Govoni et al.). 300 1x1 deg^2 maps of 3C147

•**PRECURSOR:** deep beam pattern measurements at fine El. steps



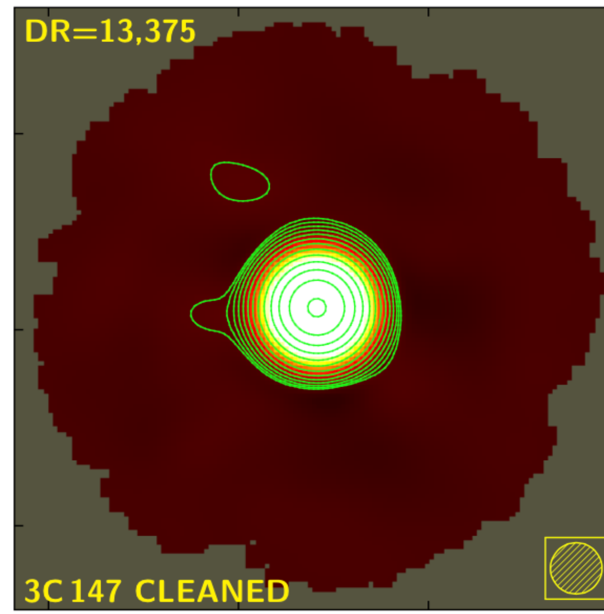
rms noise ~ 1.2 mJy/b

•Beam reconstruction & shapelet modeling

🡐 DR<500

➔ DR=13375

3C147 Image:
Dirty/Cleaned

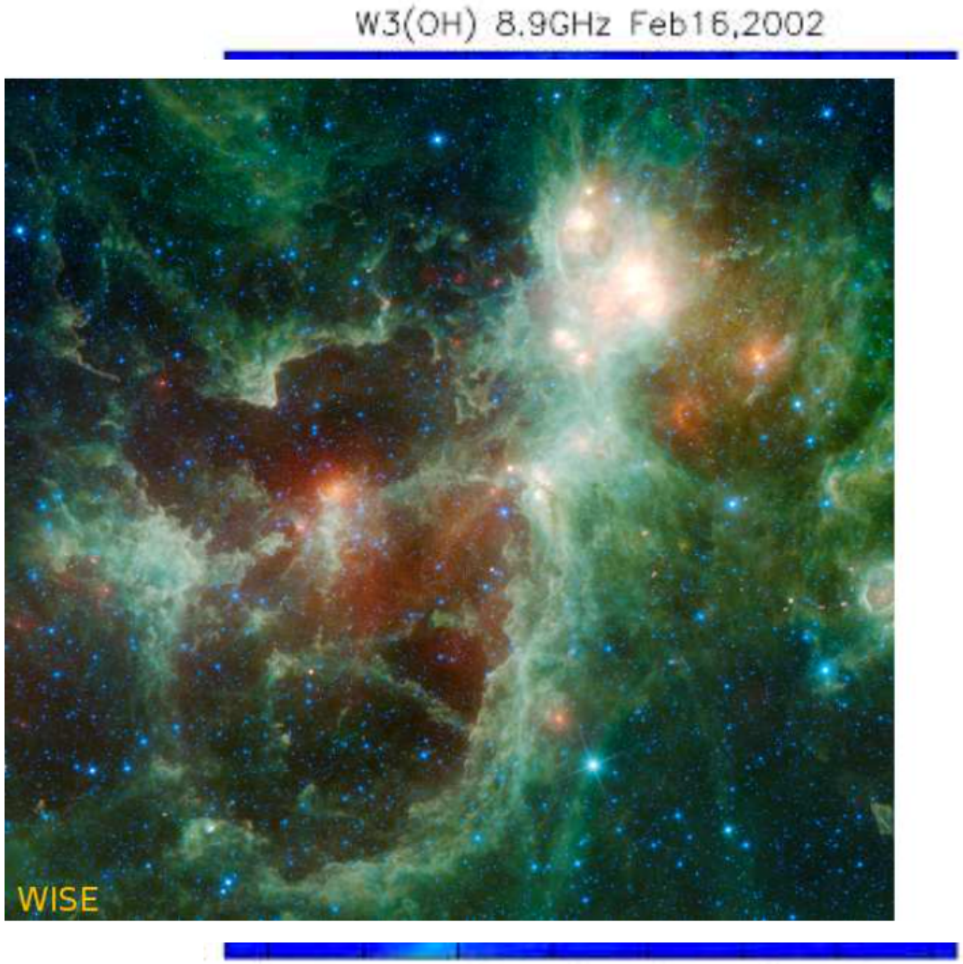


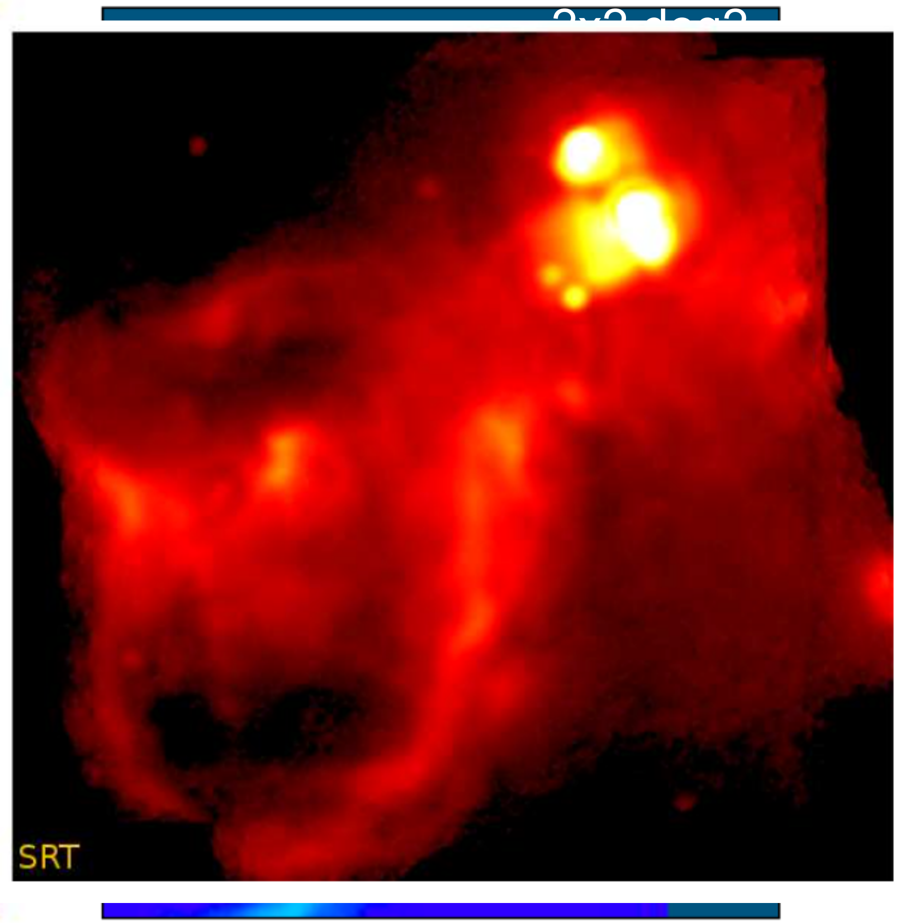
rms noise ~ 0.4 mJy/b

Credits:
M. Murgia, F. Govoni, S.Poppi, V.Vacca, P.Castangia, A.Tarchi

SRT – HDR Imaging

W3(OH) – TP C-band – SCUBE Imaging SW → High DR & Image Fidelity: DR~9000

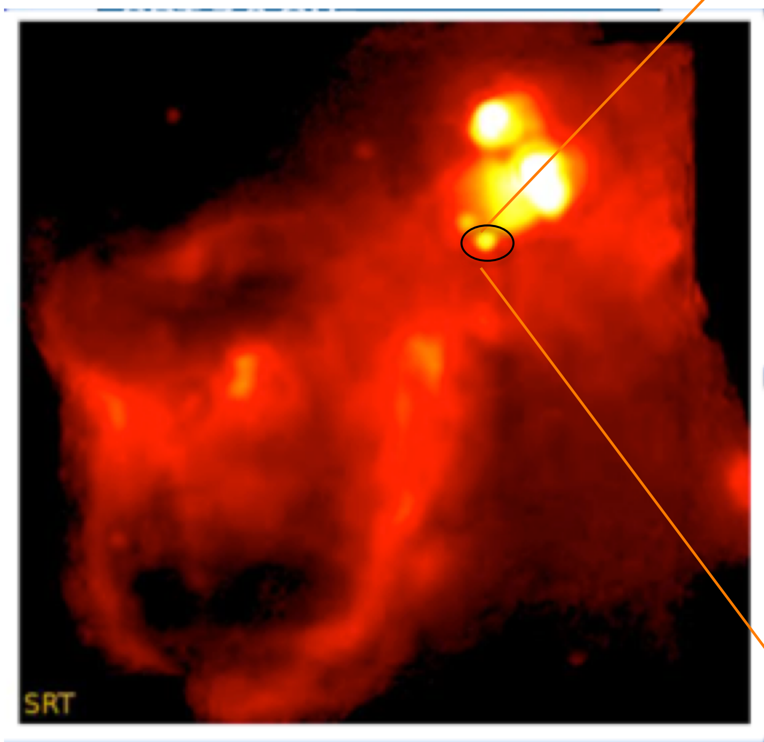


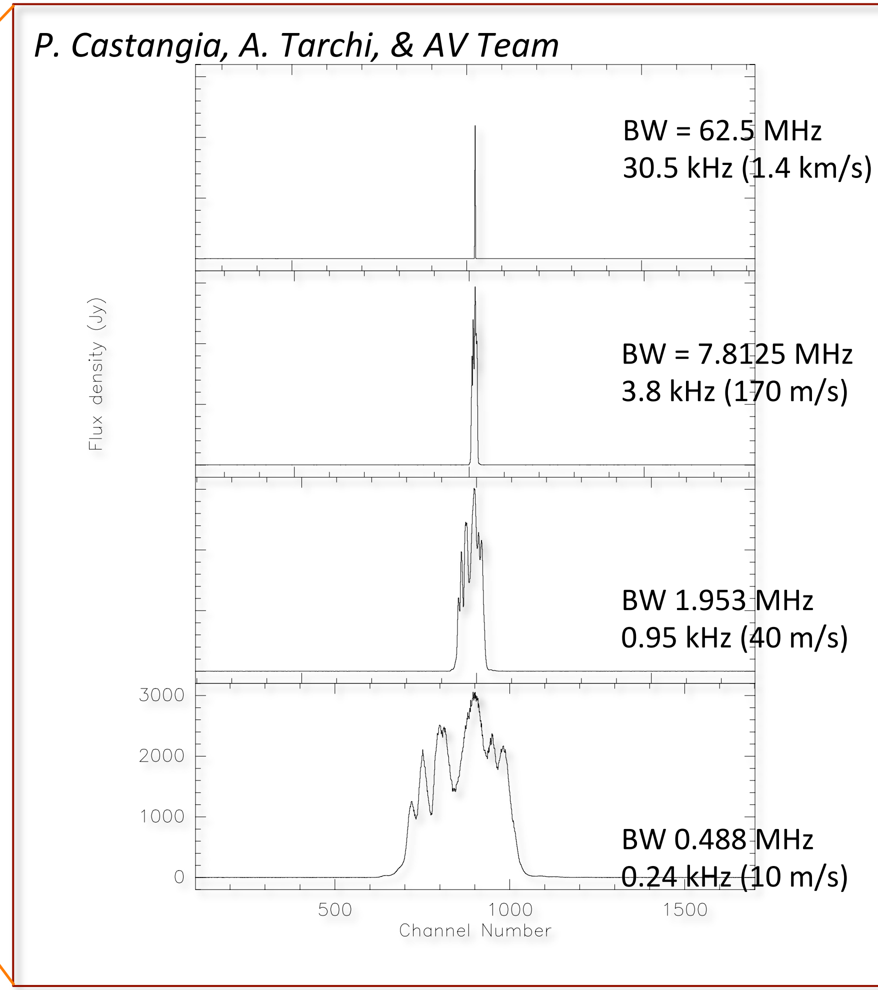


Credits: M. Murgia, F. Govoni, S.Poppi, V.Vacca, P.Castangia, A.Tarchi, F. Loi

SRT – Spectroscopy with XARCOS

W3(OH)
6.7 GHz Methanol maser emission
with XARCOS [2048 channels]



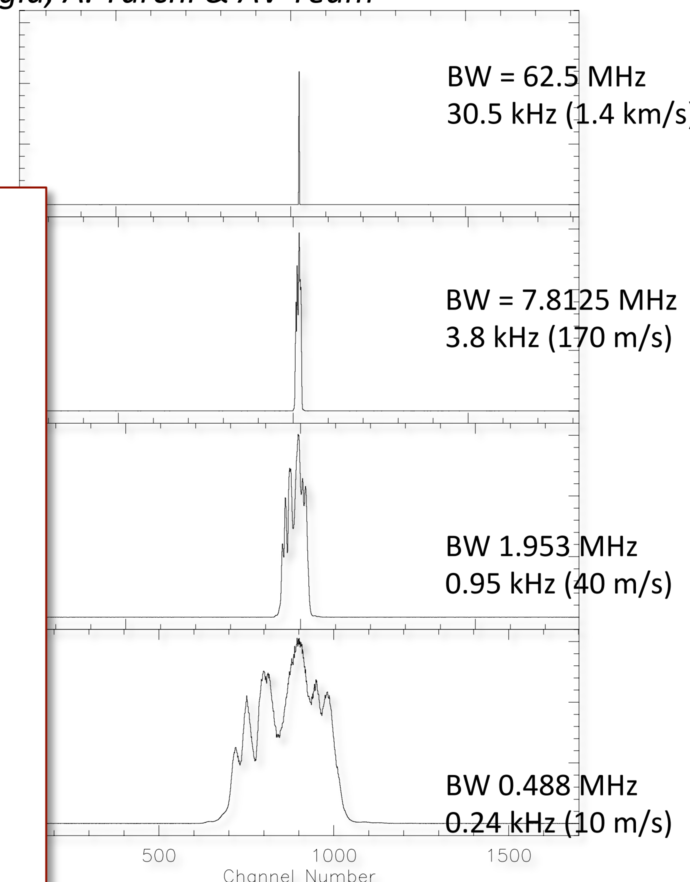


Four simultaneous sub-bands with increasing spectral resolution

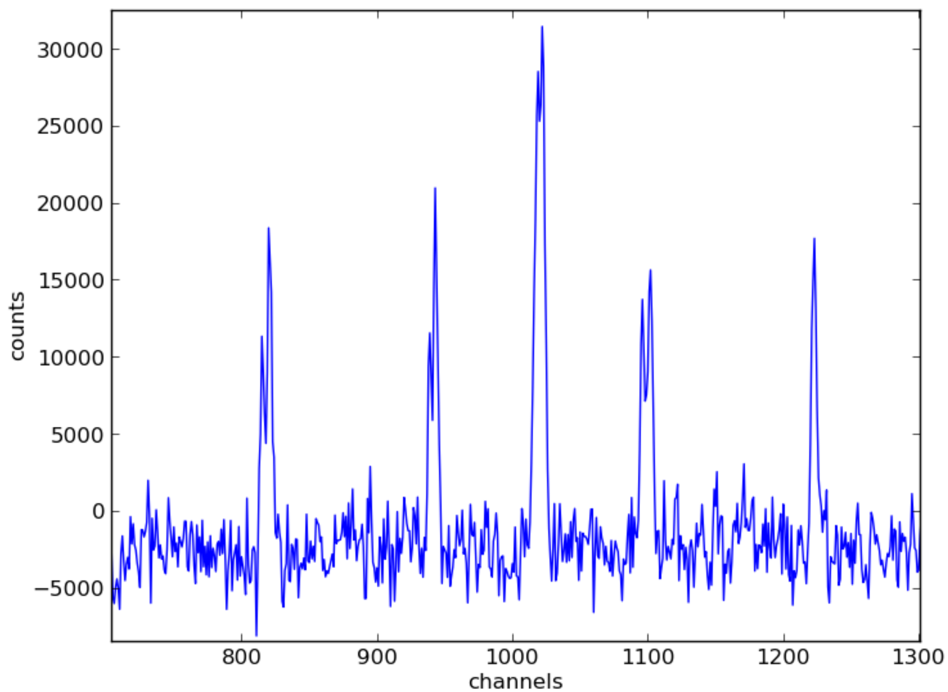
SRT – Spectroscopy with XARCOS

L483 Molecular Cloud
NH3(1-1) line spectrum

P. Castangia, A. Tarchi & AV Team



S. Poppi, A. Tarchi & the AV Team



SUMMARY

SRT station not fully staffed yet.. **BUT** we are gradually moving into regular operations:

- **VLBI/LEAP Operational** (early 2015) (see *Prandoni et al. 2015*)
- **ToO → limited time available as DDT since May 2013** (see *Buttu et al. 2013*)
- Single-Dish Operations & 1st generation backends largely validated:

  TP, XARCOS and DFB/ROACH for pulsars

  → **A Call for proposals (shared risk/ES) is expected later this year**

NB: Period of stop planned for the second half of next year:

→ refurbishment of the active surface actuator boxes
→ implementation of optical fibre [eVLBI]
→ moving instrumentation and control room to final destination buildings
[full validation of L/P bands, incl spectro-polarimetry with ROACH]

Grazie!