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REVIEW on
"RECEIVERS for RADIO ASTRONOMY" REPORT

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Download at <http://rx2017.inaf.it/RX2017/review.html>

OVERVIEW of the TALK

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REPORT FRAMEWORK

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Part 1
REPORT FRAMEWORK
Terms of Reference,
Working Group,
Executive Summary

PART 1: MOTIVATIONS

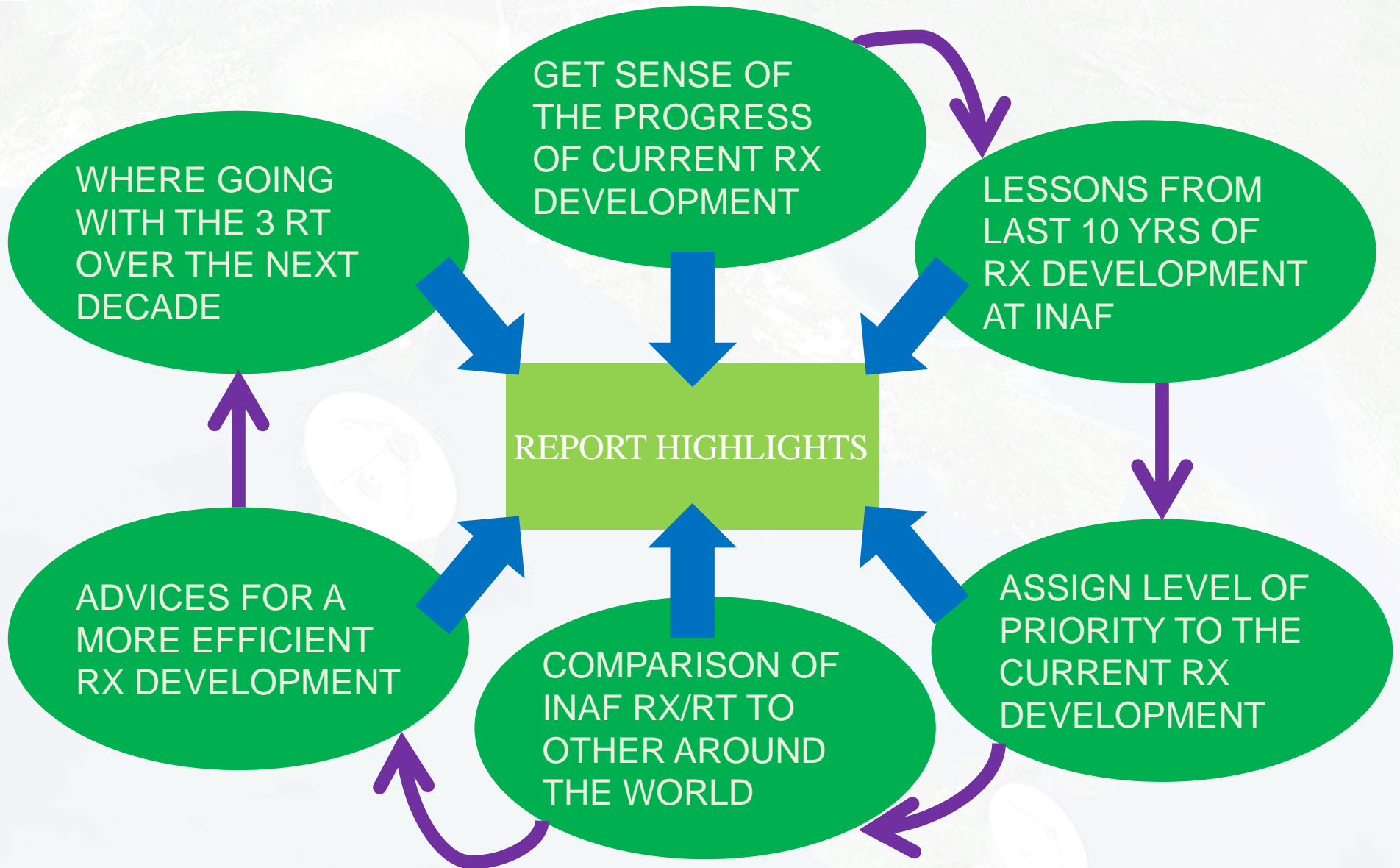
INPUT COMING FROM STEVEN TINGAY, HEAD OF SECTION II OF THE INAF SCIENTIFIC DIRECTORATE, ON SPRING 2016

<<...to review the existing and future radio astronomical receivers for the INAF radio telescope facilities. This initiative is the first step of a more general process aimed at harmonizing and coordinating efforts and resources in radio astronomy. The receiver review included the front-end developments underway within INAF, the existing instrumentation requiring major maintenance/repair, and a roadmap for future receiver developments at INAF. >>

FUTURE (Tingay talk at the Workshop)

- ❖ Development of a “five+ year plan” for receiver development at INAF, agreed by the major stakeholders (scientists, technologists, and observatories/institutes)
- ❖ Science-driven and serves the broad community
- ❖ Project managed: Project Scientist, Project Engineer, Project Manager for each development
- ❖ A Project Plan for each project (science case, reviewed design process, accurate costs and schedule, staff dedicated to task, milestones etc)

PART 1: DESIRED OUTCOME



PART 1: TASK FLOW

APPOINTED WORKING GROUP

P. Bolli, M. Beltrán

INAF – Osservatorio Astrofisico di Arcetri

M. Burgay, P. Marongiu, T. Pisanu

INAF – Osservatorio Astronomico di Cagliari

C. Contavalle, A. Orfei, C. Stanghellini, G. Zacchiroli, A. Zanichelli

INAF – Istituto di Radioastronomia

Period: June 6th, 2016 to April 13th, 2017

69 PEOPLE INVOLVED

20 IRA 20 OAC 8 OAA 2 OAct 2 INAF-HQ 1 IASF-BO 2 ASI 2 UNIVERSITIES 12 FOREIGN PEOPLE

Workshop on March 21, 2017 at INAF Headquarter, Roma

- ✓ 49 PARTICIPANTS
- ✓ Streaming at <https://www.youtube.com/watch?v=wpcV8YdV6HQ>
- ✓ Report: 260 pages A4 size, 12 Chapters + 4 Appendices

- *Report final version 7.1 – June 1st, 2017* (communication to INAF DS and President)
- *Report version 8.0 – October 17th, 2017* (under publication, about 60 copies)
- Paper in progress on the results of the international survey, to be submitted on a referred review.



Part 2
REPORT CONTENTS
Chapters 1 to 10 + Appendices



PART 2: INFRASTRUCTURE

ITALIAN TELESCOPES

| MAIN CHARACTERISTICS | | | |
|---|---------------------------------|---------------------------------|-----------------------------------|
| | MEDICINA | NOTO | SRT |
| <i>Inauguration Date</i> | October 18 th , 1983 | October 28 th , 1988 | September 30 th , 2013 |
| <i>Location</i> | Medicina (Bologna) | Noto (Siracusa) | S. Basilio (Cagliari) |
| <i>Diameter (m)</i> | 32 | 32 | 64 |
| <i>Optics</i> | Parabola/Cassegrain | Parabola/Cassegrain | Shaped Parab./Greg. |
| <i>Foci</i> | Primary/Secondary | Primary/Secondary | Prim./Second./BWG |
| <i>Total Surface Accuracy</i> | 700 to 900 micron | 350 to 400 micron | 305 to 500 micron |
| <i>Active Surface</i> | No | Yes | Yes |
| <i>max/min Antenna Gain (K/Jy)</i> | 0.16/0.11 C/K-band | 0.16/0.11 C/Q-band | 0.66/0.52 K/L-band |
| <i>Pointing Accuracy</i> | 0.002° Az/EI | 0.002° Az/EI | 0.002° Az/EI |
| <i>Frequency Agility</i> | Yes | Partially Yes | Yes |
| <i>Major maintenances status</i> | Completion in 2018 | To do | Completed in 2017 |

PART 2: INFRASTRUCTURE

BACK-ENDS AT THE ITALIAN TELESCOPES

| Technical Specs | TotalPower | XARCOS | SARDARA | DFB3 | DBBC2 | DiFX Correlator |
|--------------------------|-------------------------|---------------------------------------|--------------------------|-------------------------|---|---|
| Features | Continuum | Full Stokes spectroscopy Zoom mode | Full Stokes spectroscopy | Pulsar; spectroscopy | VLBI | - 3 servers - 50TB storage |
| Nr. of Input | 2; 4; 14 | 8 or 16 | 2 | 4 | 16 | - 10G connection + 40G Infiniband |
| Input BW (MHz) | 300; 730; 1250; 2000 | 125; 250 | 300; 500; 1250; 2300 | 256; 512; 1024 | 512; 1024; 0.512 to 32 in Baseband mode | - VDIF standard - 720GB/h correlation rate with 3 antennas @ 1Gb/s |
| Integ. time | 1 - 1000 ms | 10 s | Up to 0.5 ms | 0.1 ms | 1 – 60 s | |
| Channels | Not applicable | 2048 | 1024 or 16348 | 2048 to 8192 | firmware not available | |
| Freq. or Time Resolution | Not applicable | Up to 250 Hz | 90 KHz | 0.008 – 8 ms | 1 Hz | |
| Interface | Ether./TCP | Ether./TCP | Ether./TCP | Ether./TCP | FILA10G | |



PART 2: INFRASTRUCTURE

OPACITY EFFECTS AT THE ITALIAN SITES: A COMPARISON

| GLOBAL mm VLBI ARRAY (GMVA) at 86 GHz | | | | | |
|---------------------------------------|--------------|-------|--------------------|-------------|-----------|
| Station | Altitude (m) | D (m) | Tsys at zenith (K) | Gain (K/Jy) | SEFD (Jy) |
| GBT | 807 | 100 | 100 | 0.73 | 137 |
| Effelsberg | 319 | 80 | 140 | 0.14 | 1000 |
| Plateau de Bure | 2552 | 33 | 180 | 0.22 | 818 |
| Pico Veleta | 2850 | 30 | 100 | 0.15 | 654 |
| Yebes | 931 | 40 | 150 | 0.09 | 1667 |
| VLBA (8x25m) | 300/././3763 | 25 | 100 | 0.040 | 2500 |
| KVN (3x21m) | 120;260;320 | 21 | 200 | 0.062 | 3226 |
| Onsala | 20 | 20 | 250 | 0.049 | 5102 |
| Metsähovi | 33 | 14 | 300 | 0.017 | 17647 |
| LMT (prelim) | 4640 | 32 | 240 | 0.14 | 1714 |
| ALMA | 5059 | 80 | 90 | 1.32 | 68 |

BEWARE! Assumed Opacity = 0.1

| SRT today (estimate at 86 GHz) | | | |
|-----------------------------------|--------------------|-----------------------|---------------------|
| Opacity | Tsys (K) EL=45° | Gain (K/Jy) EL=45° | SEFD (Jy) EL=45° |
| 0.25 | 124 | 0.14 | 865 |
| 0.35 | 148 | 0.12 | 1182 |

Assumed receiver noise = 50K at 86GHz

FOR LARGE TELESCOPES POINTING IS AN ISSUE!

| MEDICINA refurbished (estimate at 86 GHz) | | | |
|--|--------------------|-----------------------|---------------------|
| Opacity | Tsys (K) EL=45° | Gain (K/Jy) EL=45° | SEFD (Jy) EL=45° |
| 0.25 | 124 | 0.09 | 1383 |
| 0.35 | 148 | 0.07 | 2089 |

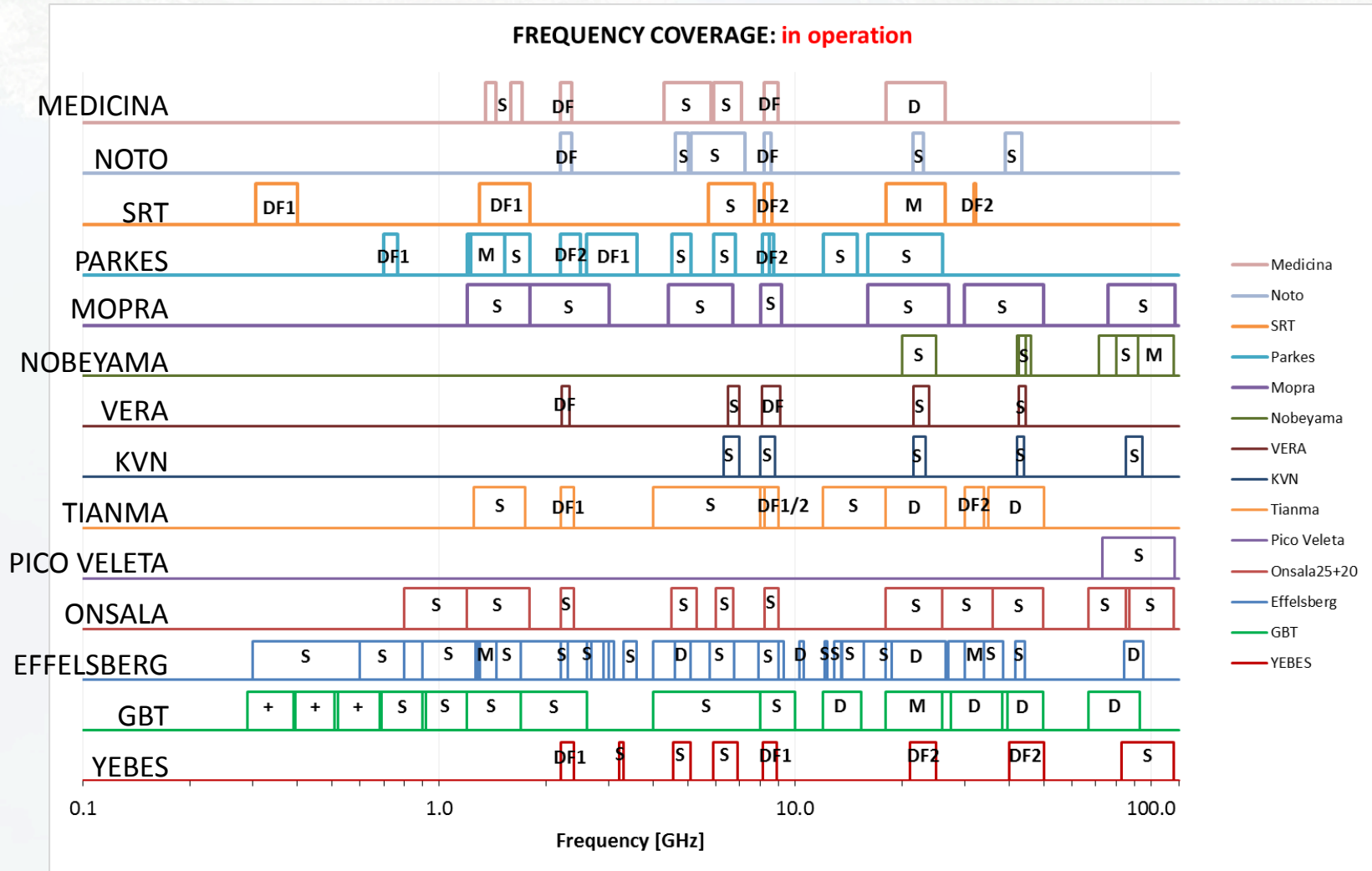
Assumed receiver noise = 50K at 86GHz



PART 2: RECEIVERS IN OPERATION

OFFER OF FREQUENCY BANDS

S = mono-feed; D = dual-feed; M = multi-feed; DF = dual frequency; + = crossed dipoles





PART 2: RECEIVERS

AGILITY IN CHANGING THE BANDS

| FREQUENCY AGILITY | | | |
|-------------------|----------------------|-------------------------------|---------------------------------|
| TELESCOPES | Primary to Secondary | Among Primary focus receivers | Among Secondary focus receivers |
| MEDICINA | 4 min | ≤ 45 sec | ≤ 14 sec |
| NOTO | 4 min | 10 sec | 4 hour |
| SRT | 4 min | 2 min | 2 min |
| Parkes | | 2 min + manual change | |
| Mopra | | | some min |
| Nobeyama | | | 1 min |
| VERA | | | No agility |
| KVN | | | Simultaneity |
| Tianma | | | seconds |
| Pico Veleta | | | 2-bands simultaneous |
| Onsala25 | | | sec to 1 hour |
| Onsala20 | | | sec to 30 min |
| Effelsberg | 30 min | 1 min + manual change | 30 sec |
| GBT | 10 min | 2 hour | 1 min |
| Yebes | | | No data |

DYNAMIC SCHEDULING POSSIBLE.
 VERY IMPORTANT TO OBSERVE AS MUCH AS POSSIBLE AT HIGH FREQUENCIES!

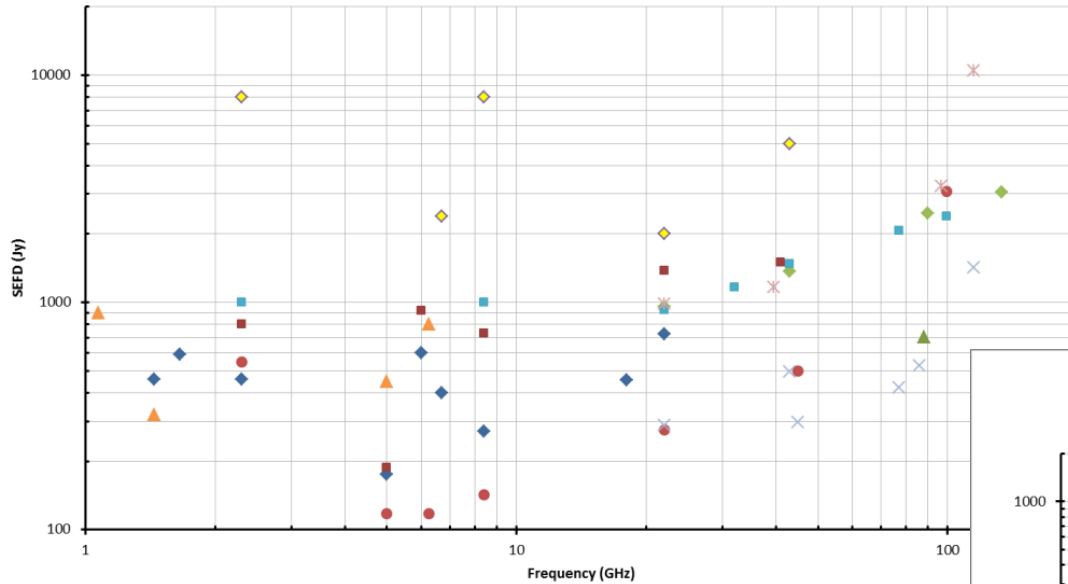
PART 2: RECEIVERS IN OPERATION

PERFORMANCE



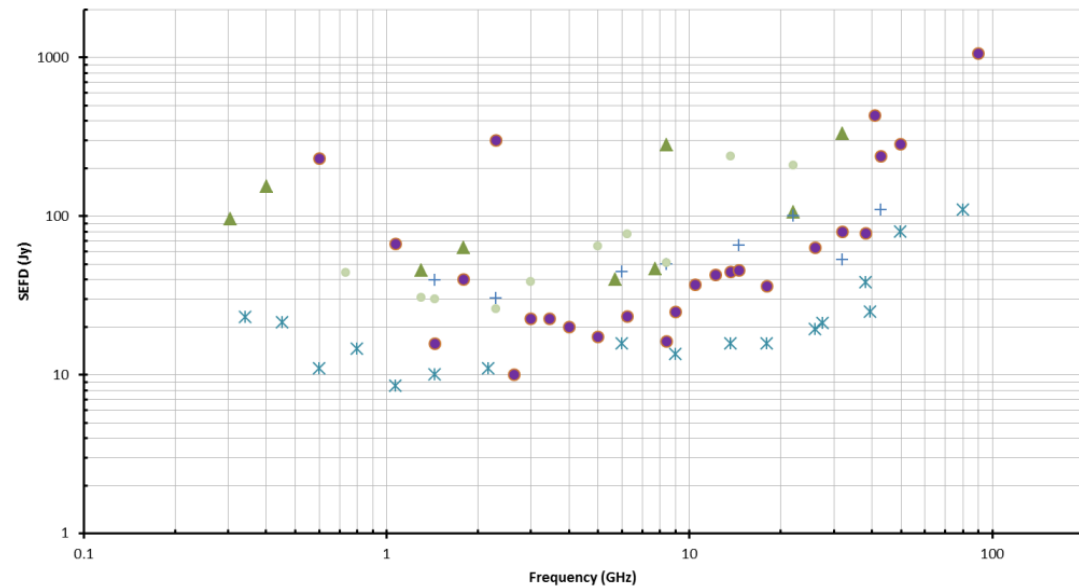
SEFD of receivers in operation: **medium class antennas**

◆ Medicina32 ■ Noto32 ● Yebes40 ◆ KVN21 ◆ VERA20 ■ Onsala20 ▲ Onsala25 × Nobeyama45 ▲ PicoVeleta30 × Mopra22



SEFD of receivers in operation: **large class antennas**

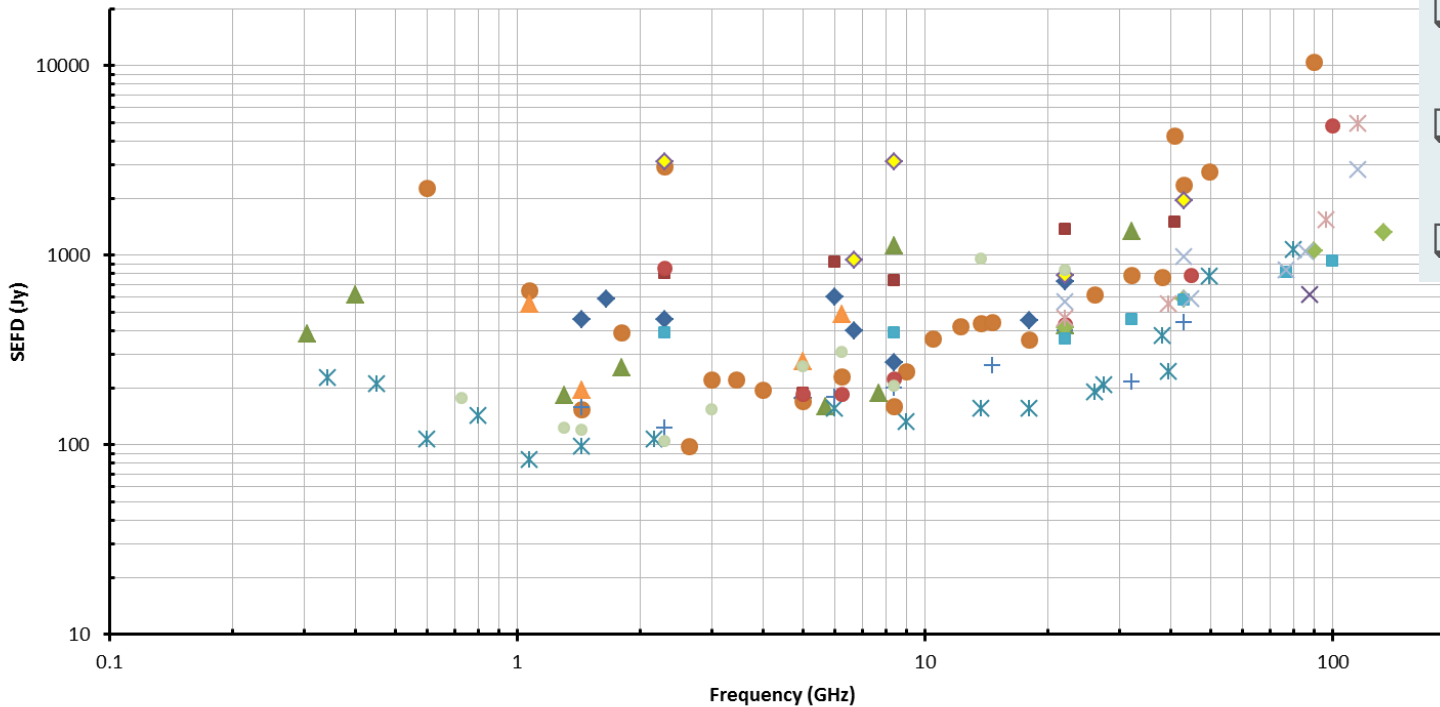
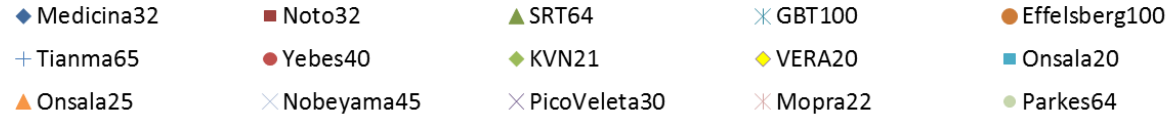
▲ SRT64 × GBT100 ● Effelsberg100 + Tianma65 ● Parkes64



PART 2: RECEIVERS IN OPERATION

NORMALIZED PERFORMANCE

Normalized SEFD of receivers in operation

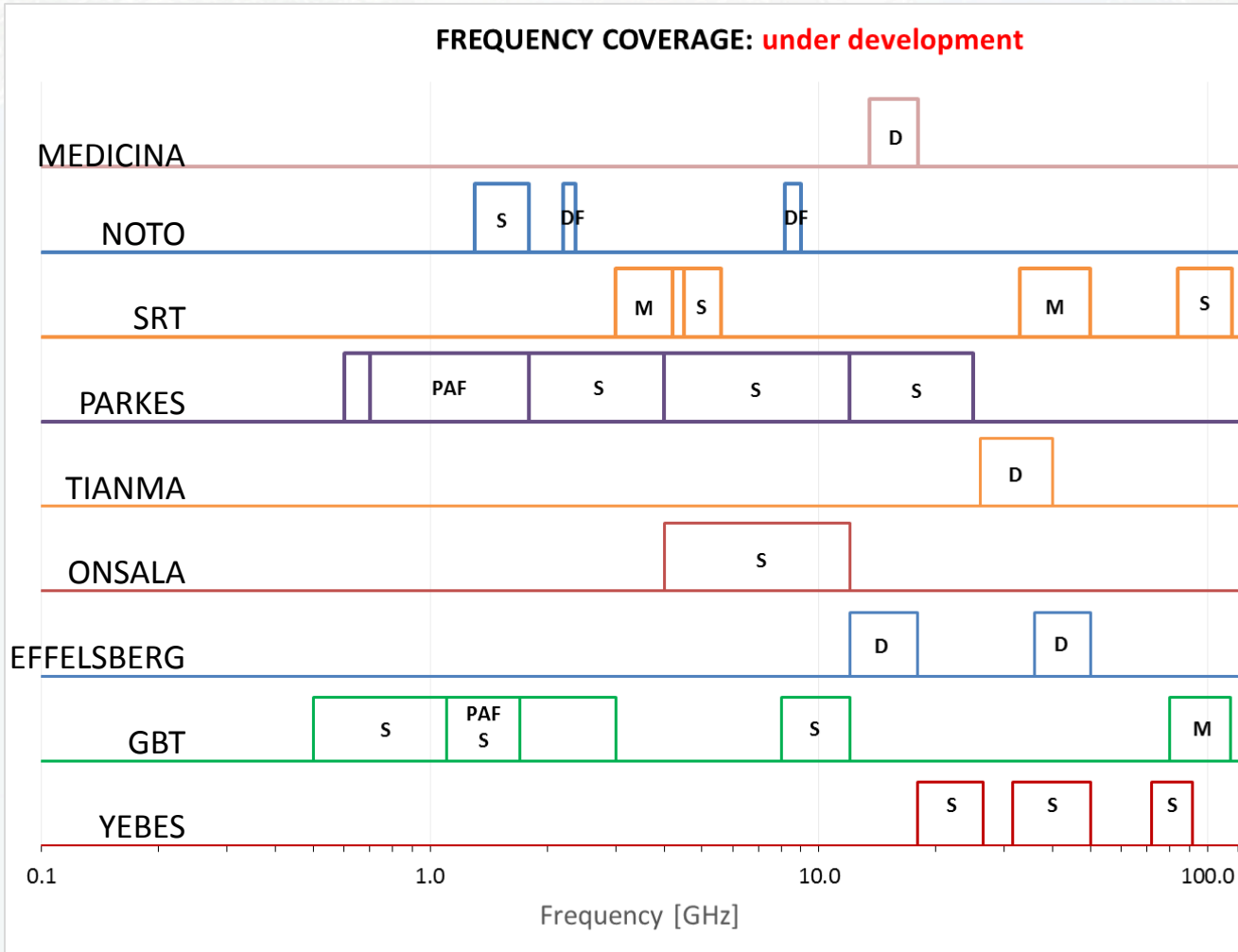


RESIDUAL EFFECTS

- SURFACE ACCURACY
- OFFSET ANTENNA
- RX NOISE
- ATMOSPHERE

PART 2: RECEIVERS UNDER DEVELOPMENT

S = mono-feed; D = dual-feed; M = multi-feed; PAF = phased array feed



TREND

- ENLARGE the BANDWIDTH
- BOTH POLARIZATIONS
- FILL FREQUENCY COVERAGE GAPS
- SPECIFIC MULTI-PIXEL RECEIVERS

PART 2: RECEIVERS

INTERNATIONAL PROJECTS & IDEAS for FUTURE

INTERNATIONAL PROJECTS OF ITALIAN TELESCOPES INTEREST

iALMA 2+3
1 feed, 67-116 GHz

PHAROS/PHAROS2
PAF 4-8 GHz

BRAND
1 feed 1.5-15 GHz, VLBI

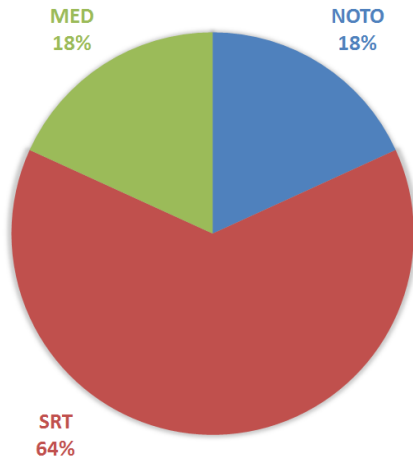
CALL FOR IDEAS

15 IDEAS FOR NEW RXs
BANDS 1-100GHz

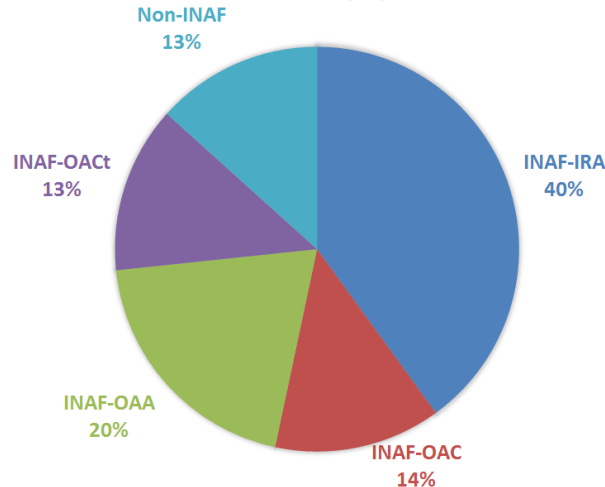
FROM A LARGE COMMUNITY
PAF/M/D/S/DF/Simultaneous Triband/Bolometer

INTERACTION & SYNERGIES

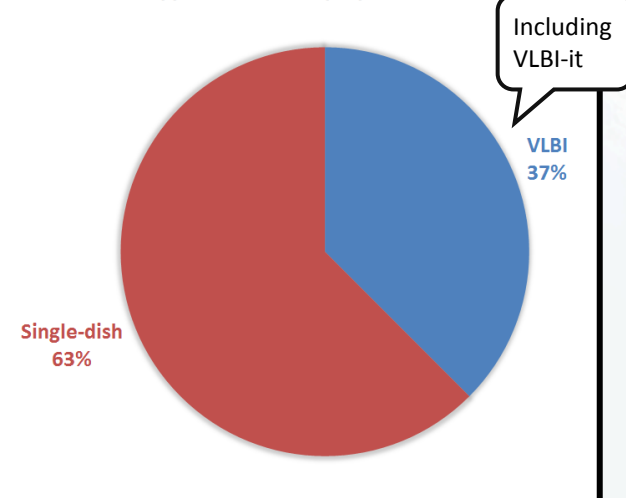
Radio telescopes for the proposed receivers

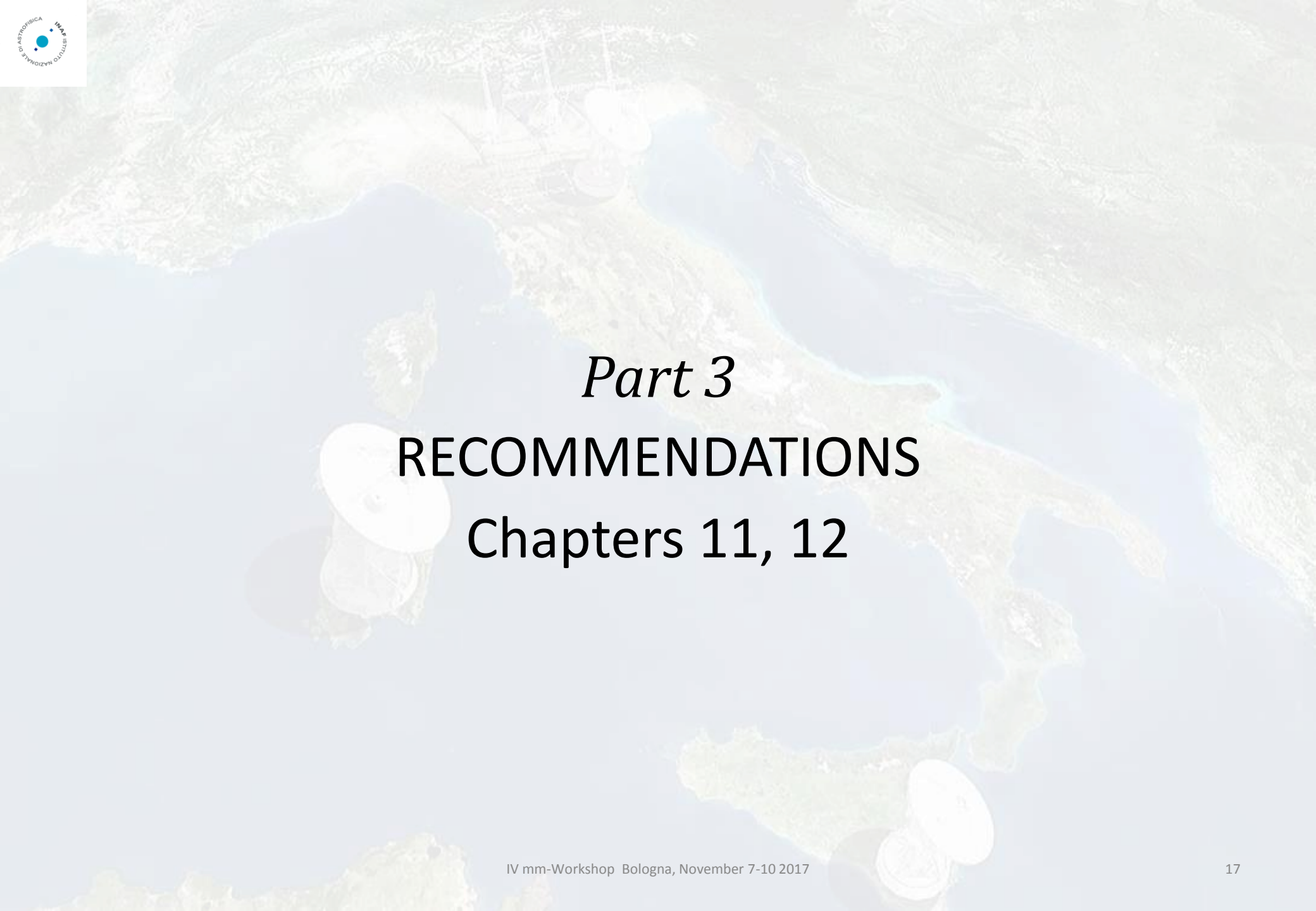


Affiliation of the PI of the proposed receivers



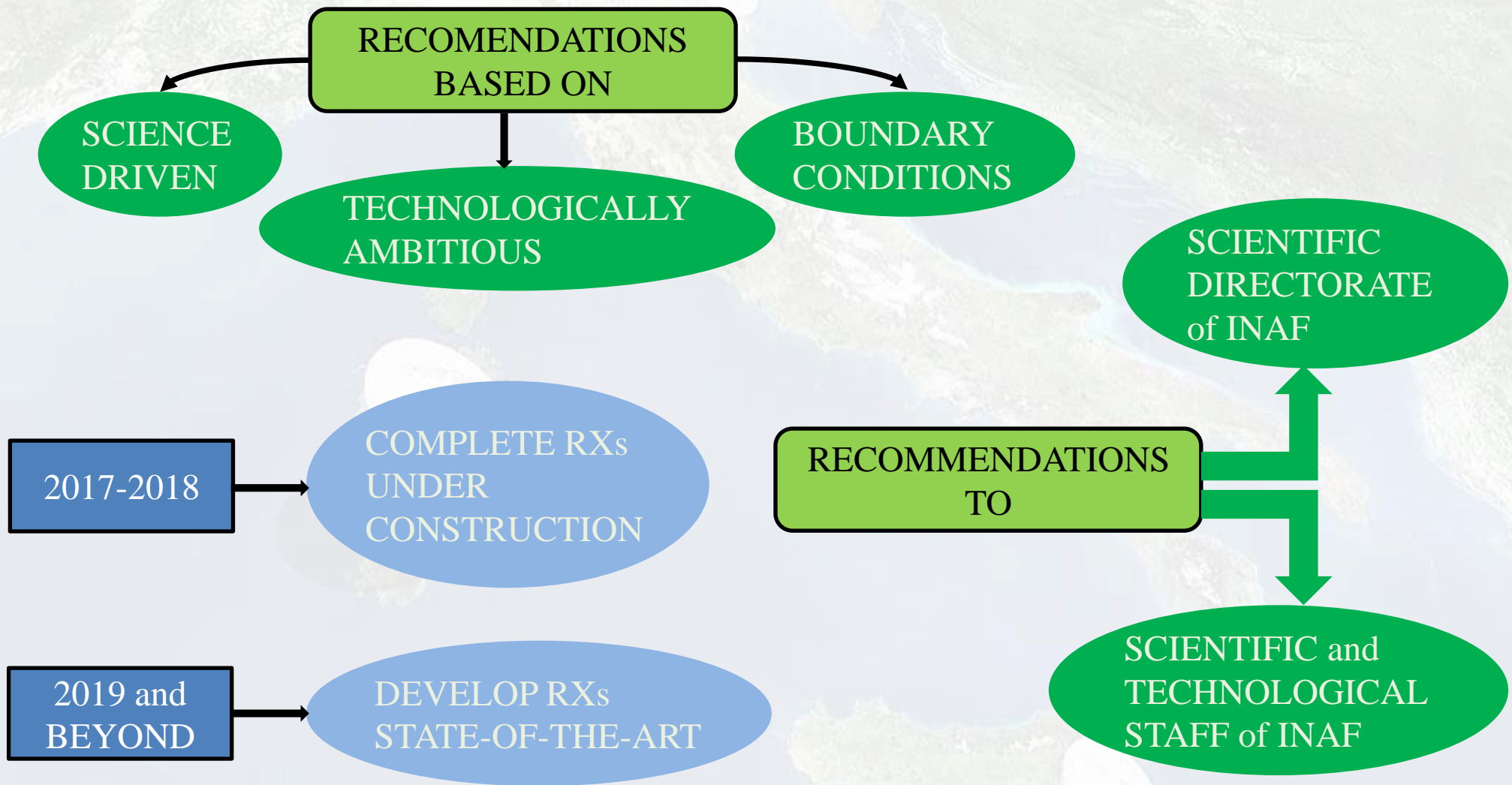
Application for the proposed receivers





Part 3
RECOMMENDATIONS
Chapters 11, 12

PART 3: AIMS, RECIPIENTS and TIME SCALE





PART 3: 2017-2018

| RXs FINALIZATION at SRT | | |
|-------------------------|-----------|---|
| | BAND(GHz) | REMARKS |
| S-band | 3-4.5 | Unique in International scenario. SD continuum observations |
| C _{low} -band | 4.2-5.6 | Most used in VLBI. Hottest topics in today radio astronomy |
| Q-band | 33-50 | Unique in Intl scenario. SD spectroscopy; join more VLBI networks |
| iALMA 2+3-band | 67-116 | SD spectroscopy; join more VLBI networks |

| RX FINALIZATION at MEDICINA | | |
|-----------------------------|-----------|--|
| | BAND(GHz) | REMARKS |
| Ku-band | 13.5-18 | Continuous coverage 13-26GHz for continuum and redshifted spectral lines |

| RX FINALIZATION at NOTO | | |
|-------------------------|-------------------------|--|
| | BAND(GHz) | REMARKS |
| TELESCOPE | | Recover a full and reliable operation of the antenna |
| S/X/L-band | 2.2-2.4/8.2-9.0/1.3-1.8 | Mandatory to serve our commitment in EVN and Geo-IVS |
| W-band | 85.9-86.5 | Join more VLBI networks. Very low priority. |

PART 3: 2019 and BEYOND

RECOMMENDED RX at SRT

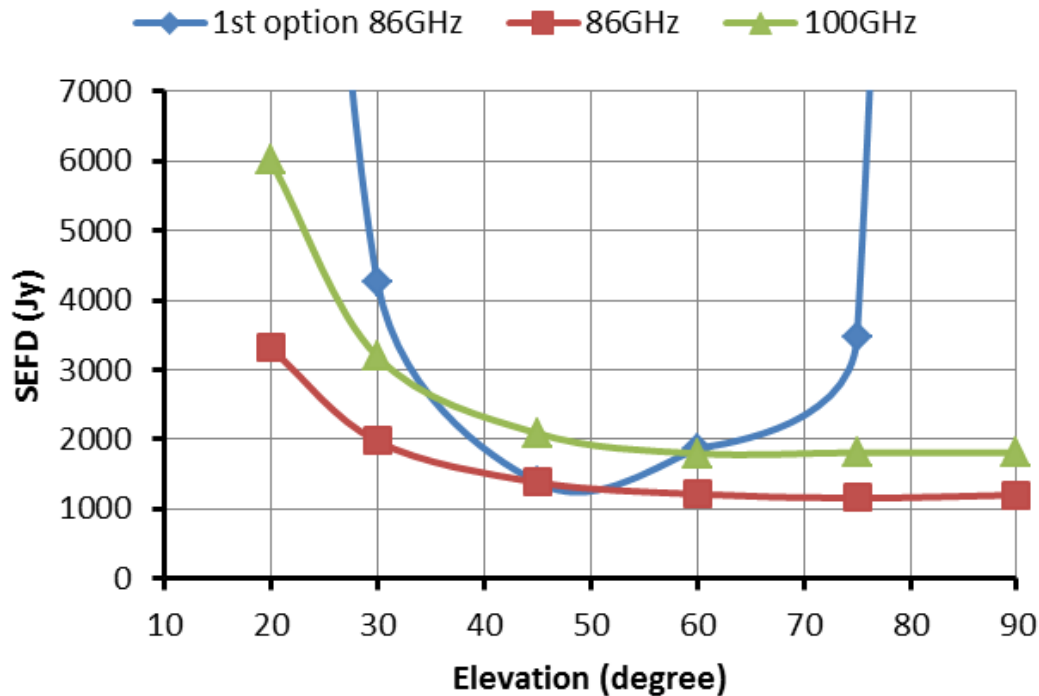
| | |
|-------------------------|--|
| MFEED W-band (19 pixel) | Considerable interest in such front-ends emerged from the Call for Ideas (2 proposals). |
| PAF C-band | Relevant interest both as a technological demonstrator and as a new receiver to perform cutting-edge science (3 proposals from the Call for Ideas). A PAF receiver matches with the involvement of INAF in the SKA AIP project (PHAROS2). |

VALUABLE PROJECTS FOR FUTURE EVALUATION

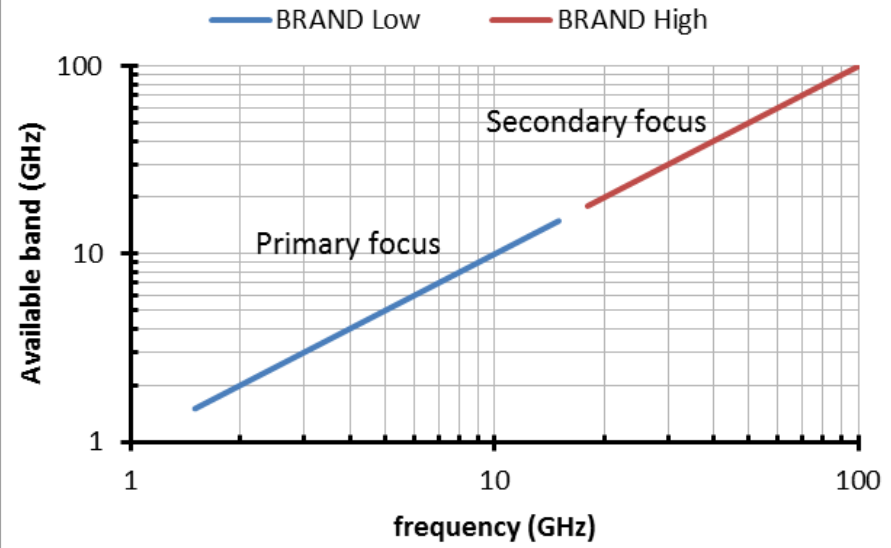
| | |
|----------------------------|--|
| BRAND | 6 astro VLBI current frequencies by one RX only. New bands up to 15.5 GHz. Includes the new standard for Geodetic observations (1 proposal). |
| W-band 400 pixel BOLOMETER | Coming from De Bernardis (Roma-La Sapienza). New scientific application for SRT (similar activities at IRAM and GBT). |

PART 3: 2019 and BEYOND

MED32 PARTIALLY OR TOTALLY REFURBISHED



FUTURE Simultaneous frequency?



RECOMMENDED RX at MEDICINA

SIMULTANEOUS K/Q/W-band

A niche in which also the smaller Italian radio telescopes can give a substantial contribution. Strong collaborations are already in place with the KVN and VERA arrays (1 proposal from the Call for Ideas).
 Calibrating tropospheric delay at 3mm, via K-band, increase coherence time.
IT NEEDS AN UPGRADE OF THE ANTENNA SURFACE ACCURACY.

PART 3: TIME LINE and WORKLOAD

| STATUS | RT | RX | 2017 | 2018 | 2019 and BEYOND |
|--------------------|------|-------------------------|-------------|---------|--|
| UNDER CONSTRUCTION | SRT | S-band | OAC | OAC | <p>THE CONSTRUCTION OF 4 OVER 6 RX IS IN A QUITE ADVANCED STAGE, BUT <i>i</i>ALMA FOR SRT NEEDS VERY FAST DECISIONS.</p> |
| | SRT | C _{low} -band | IRA,OAC,OAA | OAC | |
| | SRT | Q-band | IRA,OAC | IRA | |
| | SRT | <i>i</i> ALMA 2+3 | IASF-BO | IASF-BO | |
| | MED | Ku-band | IRA,OAA | IRA | |
| | NOTO | S/X/L-band | IRA | IRA | |
| | NOTO | W-band | | IRA | |
| NEW PROJECTS | SRT | PAF C-band | | | OAC |
| | SRT | MFEED W-band | | | OAC |
| | MED | SIMULTANEOUS K/Q/W-band | | | IRA |

PART 3: DEVELOPMENT at 3mm

| STATUS | RT | RX NAME | FREQUENCY RANGE (GHz) | Inst.aneous BW (MHz) | OUTPUT and POL. |
|---------------------------------------|------|-------------------------|-----------------------|----------------------|-----------------|
| WORK IN PROGRESS | SRT | ex-IRAM | 84-116 | 500 | 1 C |
| WORK IN PROGRESS | SRT | iALMA 2+3 | 67-116 | 8000 | 2 L |
| STAND BY | NOTO | MPIfR | 85.9-86.5 | 100 | 1 C |
| AVAILABLE | NOTO | ex-IRAM (x2) | 84-116 | 500 | 1 C |
| | | | | | |
| NEW PROJECTS (from Call for Ideas) | SRT | MFEED 19 | 70-116 | > 8000 | 2 L x 19 |
| | SRT | BOLOMETER 400 | 80-100 | 20000 | 400 |
| | MED | SIMULTANEOUS K/Q/W-band | 18-26/33-50/80-110 | TBD | 2C/2C/2C |

PART 3: FINANCIAL CONSIDERATIONS

| STATUS | RT | RX | 2017-2018 (K€) | 2019 and BEYOND (K€) |
|-----------------------|------|----------------------------|---|--------------------------------------|
| UNDER CONSTRUCTION | SRT | S-band | Fully funded | |
| | SRT | C _{low} -band | Fully funded | |
| | SRT | Q-band | 600 (19 feeds) 180 (7 feeds) | |
| | SRT | iALMA 2+3 | 80 | |
| | MED | Ku-band | Fully funded | |
| | NOTO | S/X/L-band | 80 (Now Funded) | |
| | NOTO | W-band | Negligible | |
| NEW PROJECTS | SRT | PAF C-band | | 2700 |
| | SRT | MFEED W-band | | 1700 |
| | MED | SIMULTANEOUS K/Q/W-band | | 2400 (w AS) 1600 (w/o AS) |
| TOTAL | | | 760 (19 feeds) 340 (7 feeds) | 6800 (w AS) 6000 (w/o AS) |

PART 3: A PROPOSAL

PROJECT MANAGEMENT

Project Scientist & System engineering methodologies

Each new receiver should be assigned to a well-designed management scheme to limit delays & financial issues and to maintain high the scientific interest of the receiver.

Local responsibility

Each project should be in charge of a specific group and locally managed. Interactions and scientific collaborations among classical groups and also extended to other INAF groups (IASF, SKA group) are encouraged.

Coordination

The development of radio astronomical instrumentation coordinated under the supervision of Section II of the INAF Scientific Directorate.

Call for Projects

A survey of the interest of the astronomical community in new instrumentation should be conducted by INAF periodically.

Permanent commission

Composed by astronomers and technologists who will regularly meet to review the status of the ongoing projects and issue recommendations.

A satellite map of Europe with several satellite ground stations marked by white and grey parabolic antennas. The text 'Decisions needed!' is overlaid in a large, orange, handwritten-style font across the center of the map.

Decisions
needed!