VLBI with the SKA

Zsolt Paragi
JIVE

Dutch interest in EVN and in SKA-VLBI

- **NL provides the second largest user community to the EVN (2017 stats)**
- **JIVE is the hart of the EVN, hosted by ASTRON in Dwingeloo**

SKA High Priority Science Objectives

Science Goal	SWG	Objective	SWG Rank
1	CD/EoR	Physics of the early universe IGM - I. Imaging	1/3
2	CD/EoR	Physics of the early universe IGM - II. Power spectrum	2/3
3	CD/EoR	Physics of the early universe IGM - III. HI absorption line spectra (21cm forest)	3/3
4	Pulsars	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	Pulsars	High precision timing for testing gravity and GW detection	1/3
6	Pulsars	Characterising the pulsar population	2/3
7	Pulsars	Finding and using (Millisecond) Pulsars in Globular Clusters and External Galaxies	2/3
8	Pulsars	Finding pulsars in the Galactic Centre	2/3
9	Pulsars	Astrometric measurements of pulsars to enable improved tests of GR	2/3
10	Pulsars	Mapping the pulsar beam	3/3
11	Pulsars	Understanding pulsars and their environments through their interactions	3/3
12	Pulsars	Mapping the Galactic Structure	3/3
13	HI	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	HI	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	HI	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
16	HI	HI absorption studies out to the highest redshifts.	4/5
17	HI	The gaseous interface and accretion physics between galaxies and the IGM	5/5
18	Transients	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
19	Transients	Accessing New Physics using Ultra-Luminous Cosmic Explosions	=1/4
20	Transients	Galaxy growth through measurements of Black Hole accretion, growth and feedback	3/4
21	Transients	Detect the Electromagnetic Counterparts to Gravitational Wave Events	4/4
22	Cradle of Life	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
23	Cradle of Life	Characterise exo-planet magnetic fields and rotational periods	2/5
24	Cradle of Life	Survey all nearby (~100 pc) stars for radio emission from technological civilizations.	3/5
25	Cradle of Life	The detection of pre-biotic molecules in pre-stellar cores at distance of 100 pc.	4/5
26	Cradle of Life	Mapping of the sub-structure and dynamics of nearby clusters using maser emission.	5/5
27	Magnetism	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
28	Magnetism	Determine origin, maintenance and amplification of magnetic fields at high redshifts - I.	2/5
29	Magnetism	Detection of polarised emission in Cosmic Web filaments	3/5
30	Magnetism	Determine origin, maintenance and amplification of magnetic fields at high redshifts - II.	4/5
31	Magnetism	Intrinsic properties of polarised sources	5/5
32	Cosmology	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	Cosmology	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
34	Cosmology	Map the dark Universe with a completely new kind of weak lensing survey - in the radio.	3/5
35	Cosmology	Dark energy & GR via power spectrum, BAO, redshift-space distortions and topology.	4/5
36	Cosmology	Test dark energy & general relativity with fore-runner of the 'billion galaxy' survey.	5/5
37	Continuum	Measure the Star formation history of the Universe (SFHU) - I. Non-thermal processes	1/8
38	Continuum	Measure the Star formation history of the Universe (SFHU) - II. Thermal processes	2/8
39	Continuum	Probe the role of black holes in galaxy evolution - I.	3/8
40	Continuum	Probe the role of black holes in galaxy evolution - II.	4/8
41	Continuum	Probe cosmic rays and magnetic fields in ICM and cosmic filaments.	5/8
42	Continuum	Study the detailed astrophysics of star-formation and accretion processes - I.	6/8
43	Continuum	Probing dark matter and the high redshift Universe with strong gravitational lensing.	7/8
44	Continuum	Legacy/Serendipity/Rare.	8/8

- **No VLBI?**
- **Look closer…**

Highest-ranked HPSOs and VLBI

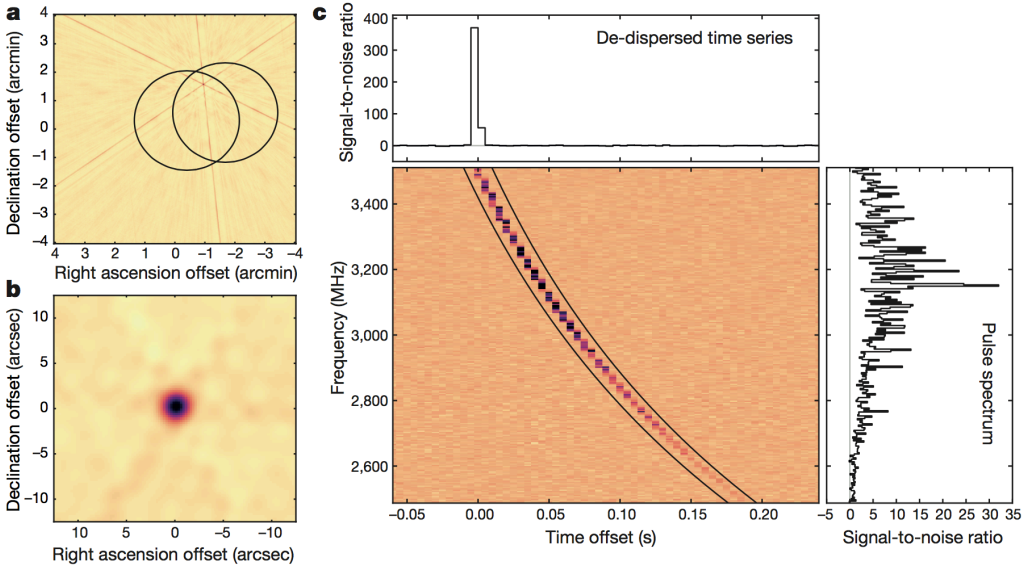
	Science Goal	SWG	Objective	SWG Rank	VLBI with:
	1	CD/EoR	Physics of the early universe IGM - I. Imaging	1/3	
	2	CD/EoR	Physics of the early universe IGM - II. Power spectrum	2/3	
	4	Pulsars	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3	
→	5	Pulsars	High precision timing for testing gravity and GW detection	1/3	LOW/MID
(→)	13	HI	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5	LOW/MID
	14	HI	High spatial resolution studies of the ISM in the nearby Universe.	2/5	
	15	HI	Multi-resolution mapping studies of the ISM in our Galaxy	3/5	
→	18	Transients	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4	MID
(→)	22	Cradle of Life	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5	MID
	27	Magnetism	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5	
	32	Cosmology	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5	
	33	Cosmology	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5	
→	37 + 38	Continuum	Star formation history of the Universe (SFHU) – I+II. Non-thermal & Thermal processes	1+2/8	MID

Also note: VLBI science = SKA2 science!

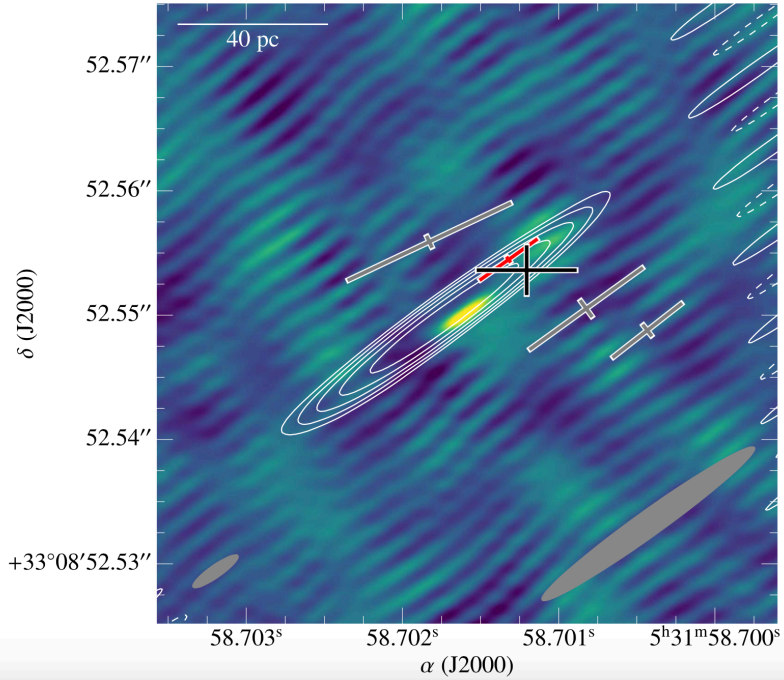
Science highlights: FRB 121102 localized

Very Large Array (VLA) signal detection
27 telescopes, few tens of km area

European VLBI Network (EVN) images
11+ telescopes, baselines up to 7000+ km

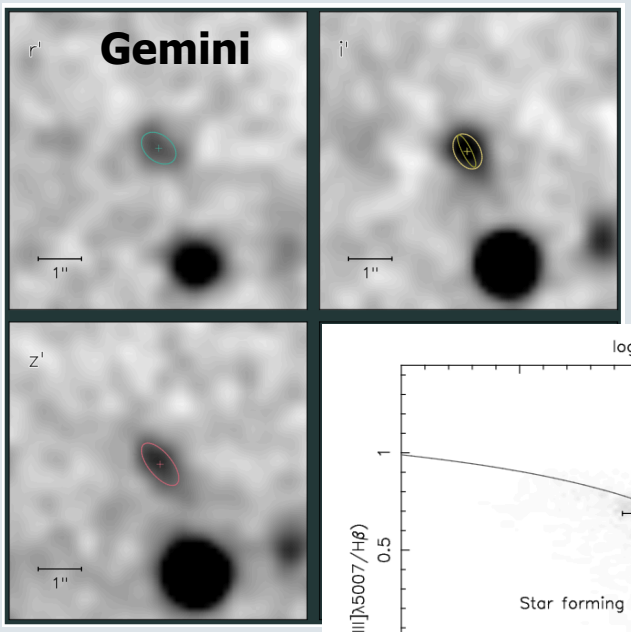


5-ms image (dispersion corrected) of one burst.

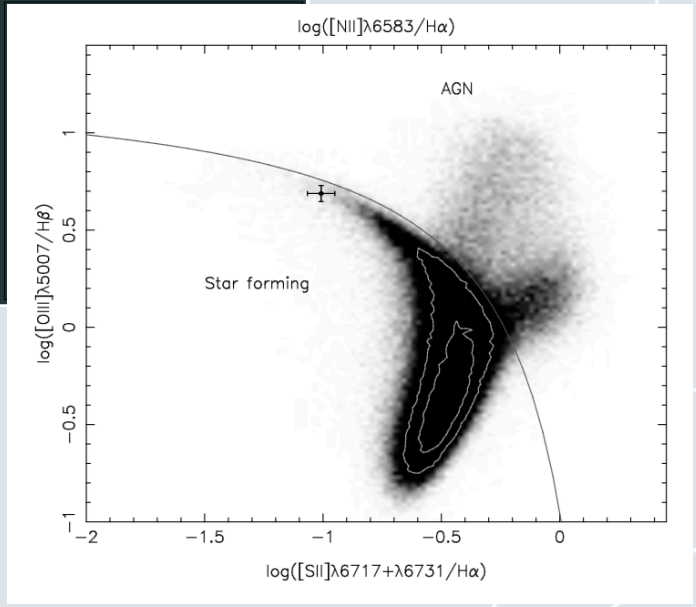


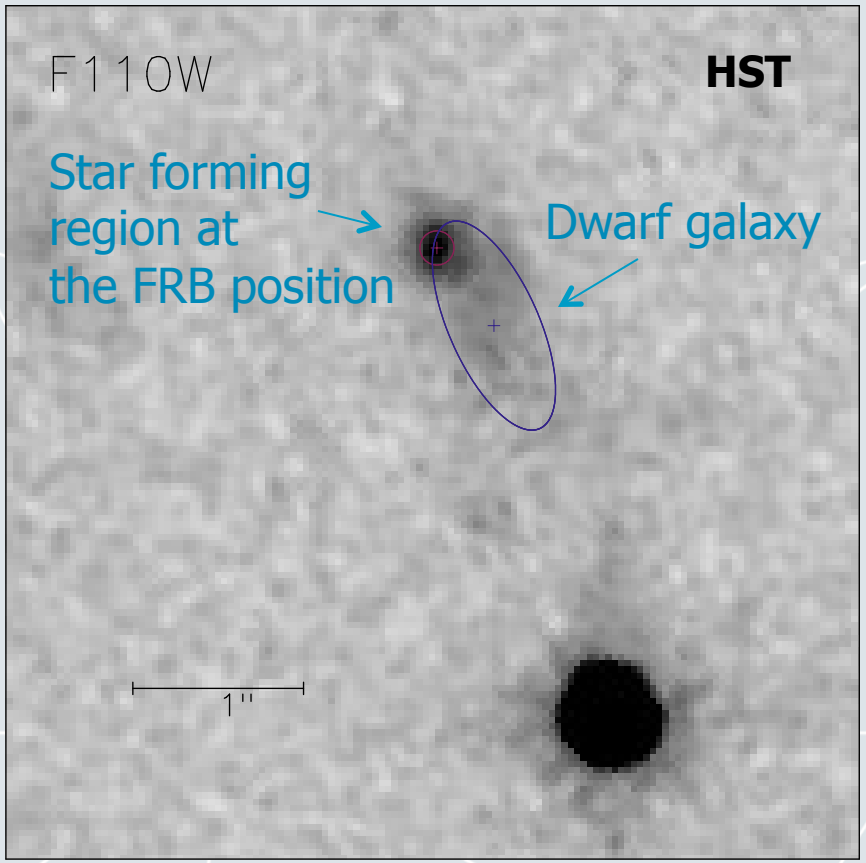
- **VLA precision (~0.1 arcsec) sufficient to prove extragalactic origin**
- **EVN refined position (~0.01 arcsec): pulses appear in the near vicinity of a permanent radio source of unknown nature**

Peculiar object in a dwarf galaxy



Tendulkar et al. 2017

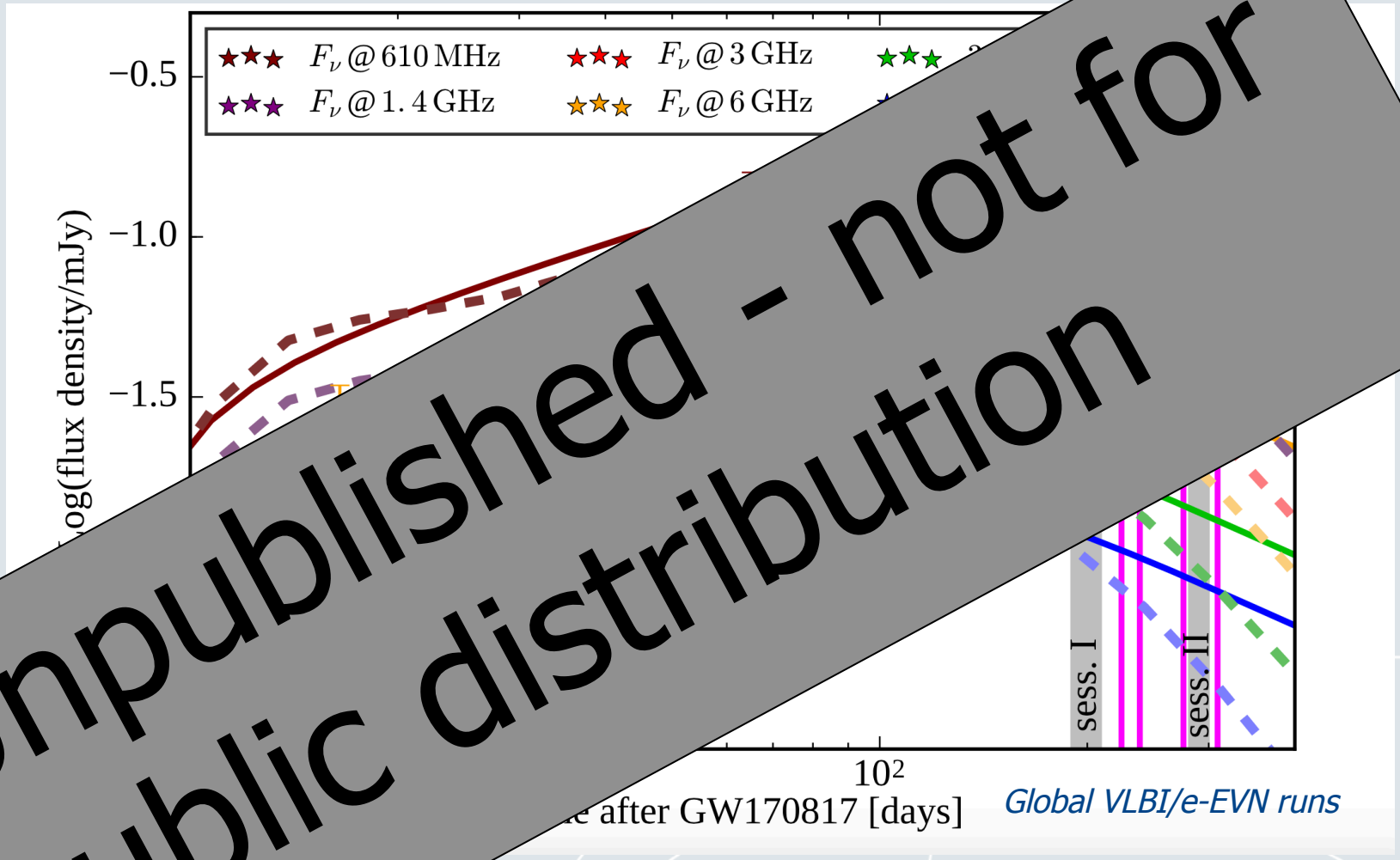




Bassa et al. submitted

- **A young (superluminous) supernova remnant powered by a magnetar?**
  Host properties are consistent with SLSNe hosts, low-metallicity dwarfs.

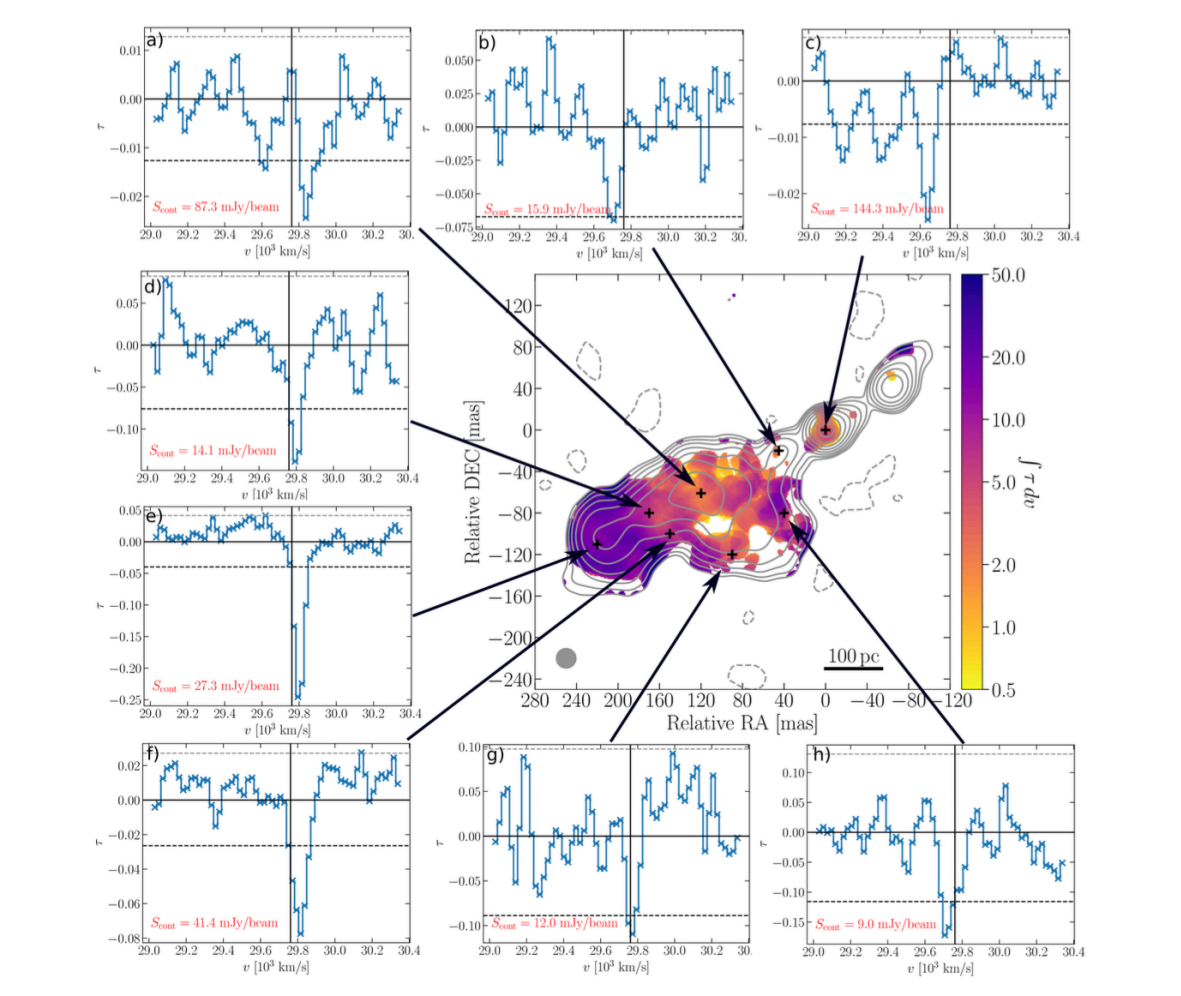
BNS merger EM170817



Global VLBI/e-EVN runs

- **eball models by Salafia+17; Mooley+17**
- **tured jet model by D'Avanzo+18**

HI outflow on tens of pc scales in 3C236



Schulz et al. (2018)

- **Feedback processes => High velocity HI outflows; appear to consist of discrete clouds**
- **Outflow driven by jets (low excitation galaxy, unlikely to produce strong winds)**

VLBI "Focus Group"

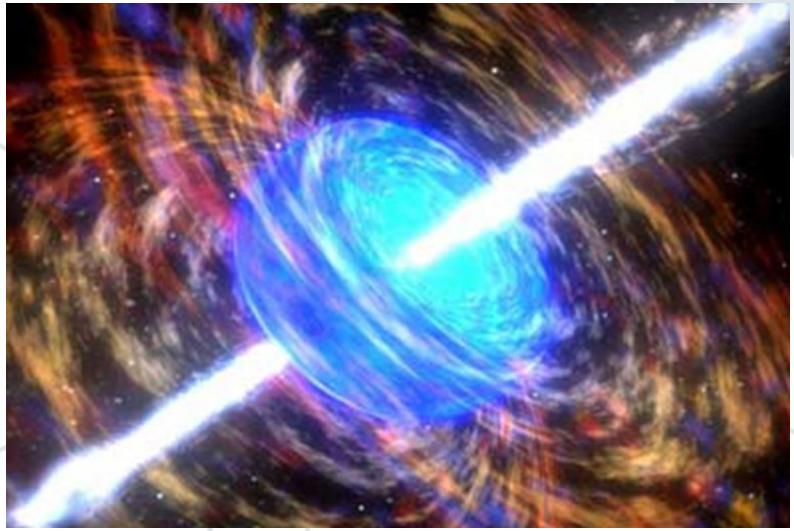
- **Fully science driven working group**
- **Co-chairs: Cormac Reynolds (CASS), Zsolt Paragi (JIVE, till end 2017), Tao An (ShAO, since end 2017); office contact: Evan Keane**

Jumping JIVE support

- **WP10: Promoting VLBI with the SKA (lead Antonio Chrysostomou-SKAO, Zsolt Paragi-JIVE)**
- **Supporting SKA-VLBI group activities; science portfolio (Key Science Projects)**
- **SKA-VLBI Scientist position at the SKA HQ: Cristina Garcia-Miro**

Evolution to KSP

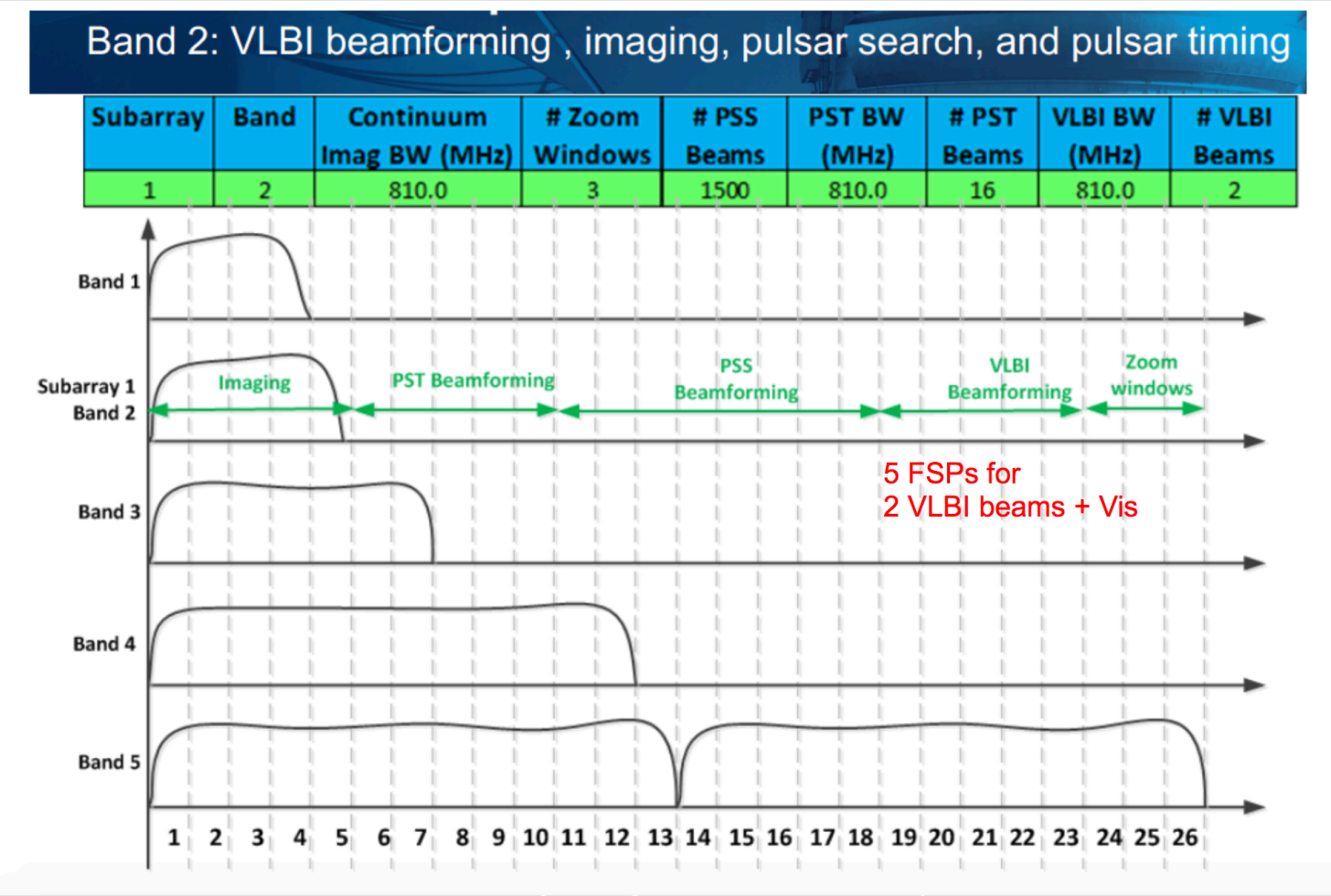
- **Organize/support KSP meetings**
  - Bring together different communities
- **Initiate EVN/global VLBI surveys overlapping with future SKA surveys**
  - involve MeerKAT & AVN
- **Promote SKA science with Early Production Array**
  - **SKA-VLBI is probably the only case where immediate success is guaranteed**



VLBI KSP strategies

- **Umbrella proposal for VLBI**
  - Unlikely; this did not work out with MeerKAT for example
- **Identify a few "killer" science cases eligible for SKA-VLBI KSPs**
  - There is good science but chances for major projects are not great
- **Support other SWGs to include a VLBI component in their KSPs**
  - Will definitely pursue this way
- **To proceed must understand:**
  - **The fraction of time that may be available for VLBI**
  - **Whether commensial VLBI will be possible**

Is commensal VLBI possible?

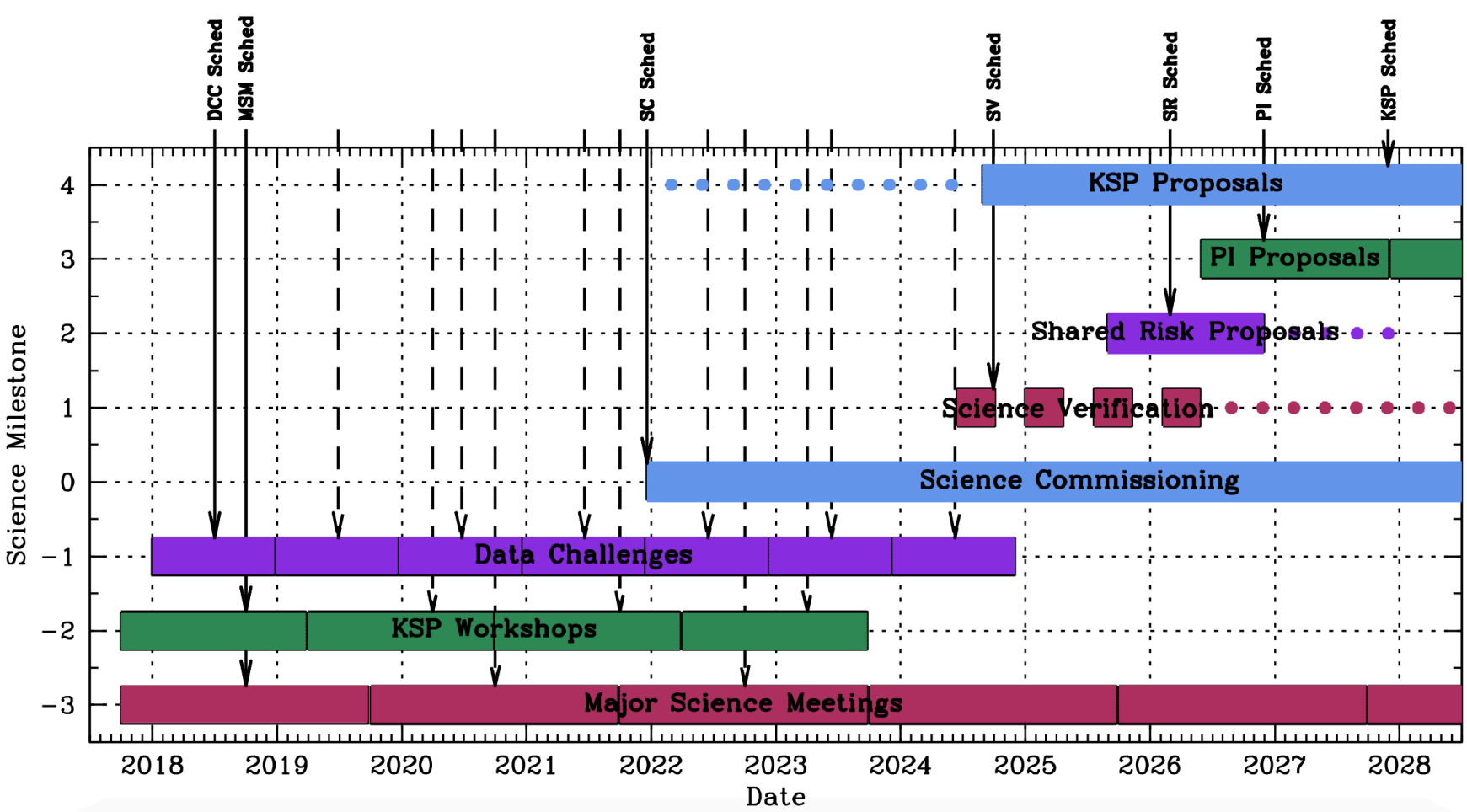


- **Frequency Slice Processor architecture: 1 FSP can handle two VLBI beams**
- **Band 2: no problem; Band 5: commensal VLBI and imaging not possible!**

Key issues

- **Are VLBI requirements fulfilled?**
  - Paul Boven (JIVE), Cristina Garcia-Miro (SKAO) involved in CDRs
  - Critical component is TM (telescope manager), to support special obs. modes
- **Are VLBI developments around the world aligned with SKA**
  - Receiver coverage, large bandwidths
  - NG Correlator to handle large N data streams (telescopes, beams)
  - Software development for wide-bw, larg-FoV VLBI processing
- **Operational model for SKA includes VLBI**
  - Need to form a global VLBI consortium?
  - Data rights VLBI vs. SKA interferometer (esp. for commensal case)

SKA milestones



- **WP10 support LC workshop on multiple AGN; EVN Symposium 2018 SKA-VLBI session**
- **Major SKA-VLBI science/operational meeting end 2019 (location TBD)**

Conclusions

- **Work on SKA-VLBI KSPs definiton has started**
- **Similar process under JJ WP7: "EVN Future"**

- **Must also make sure SKA-VLBI is technically/ operationally possible**
- **JIVE may serve as SKA-VLBI hub for a regional SKA Data Science Center in Dwingeloo**