From Black-belt Specialism to Main-stream Astrophysics

Inaugural Symposium of Joint Institute for VLBI – European Research Infrastructure Consortium (JIVE-ERIC)

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From Black-belt Specialism to Main-stream Astrophysics

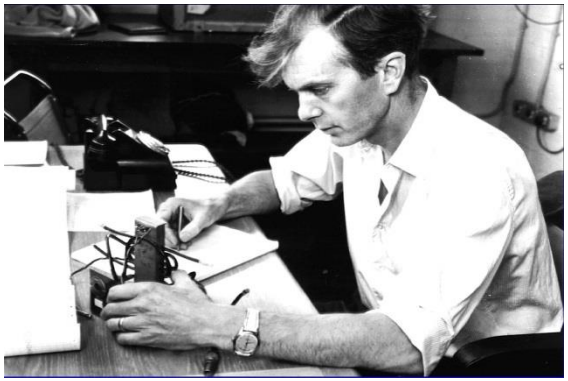
- Reflections on the opportunities offered by JIVE-ERIC and how it can have the maximum impact upon main-stream astrophysics.
- JIVE-ERIC should be part of the toolkit of all astronomers and not just the black-belt specialist in the art of VLBI.

Dedication

- I dedicate this lecture to the memory of Derek D. Vonberg who died recently at the age of 93.
- His story has remarkable parallels with the case I want to make in this lecture about bringing JIVE-ERIC into the mainstream of astrophysics and cosmology.

Ryle and Vonberg

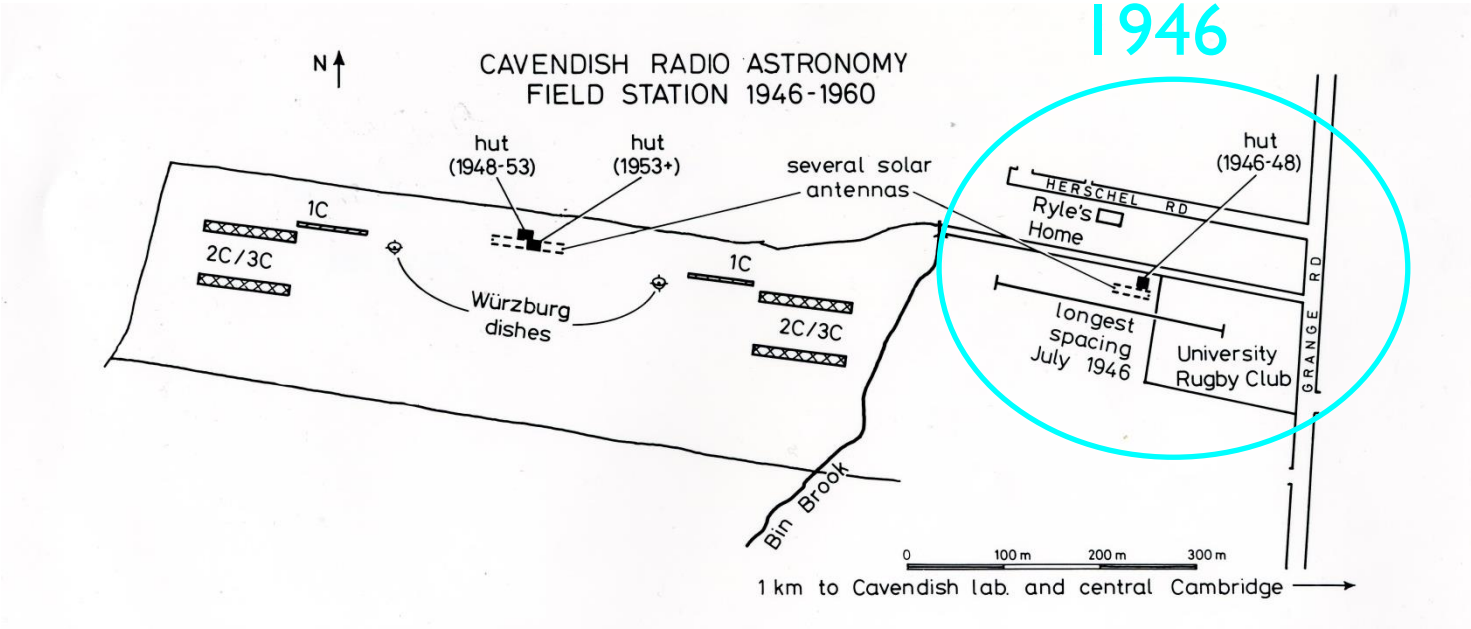
In 1945, immediately after the War, Martin Ryle and Derek Vonberg joined the Cavendish Laboratory Radio Group under Jack Ratcliffe.



- Ryle came from five years of development of radar at TRE.
- Vonberg was an electrical engineer from Imperial College.

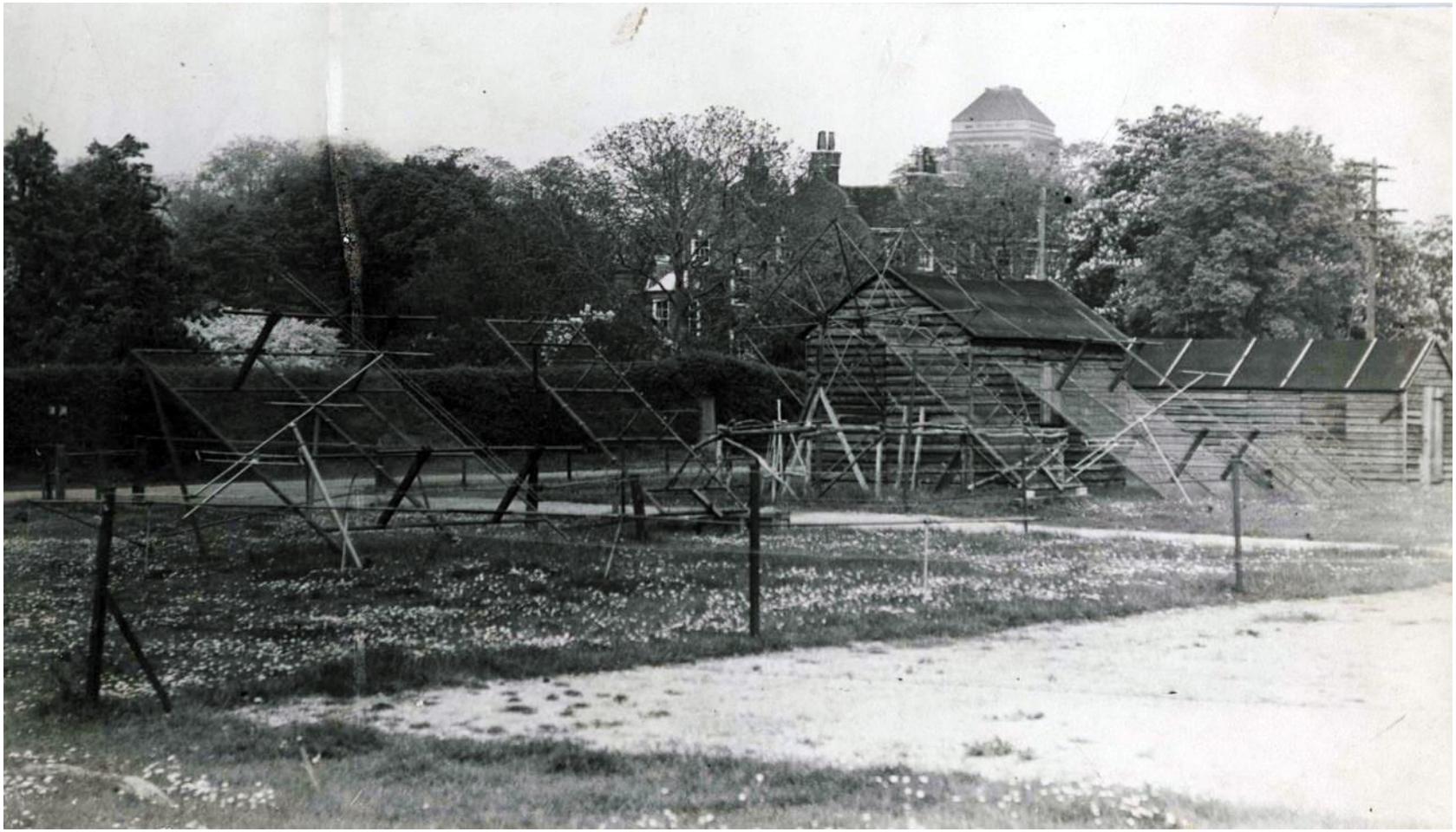
Their pioneering radio astronomical observations of the Sun were made from Cambridge in1946.

Ryle and Vonberg (1946)

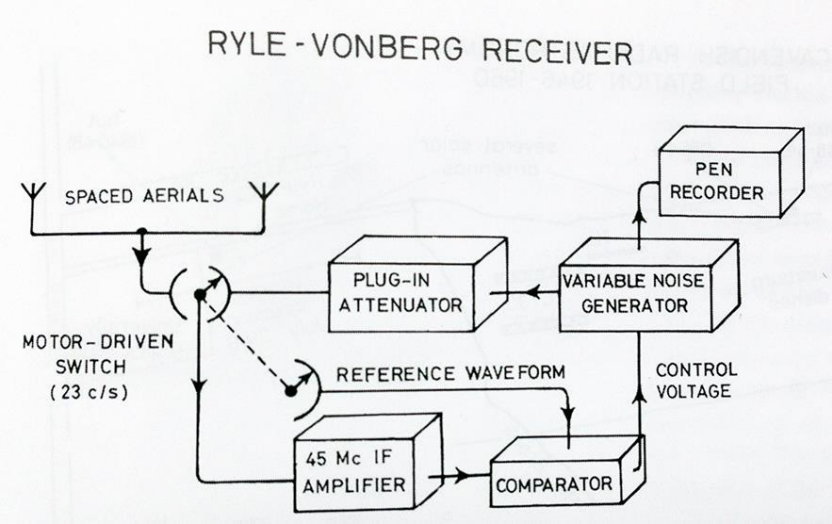


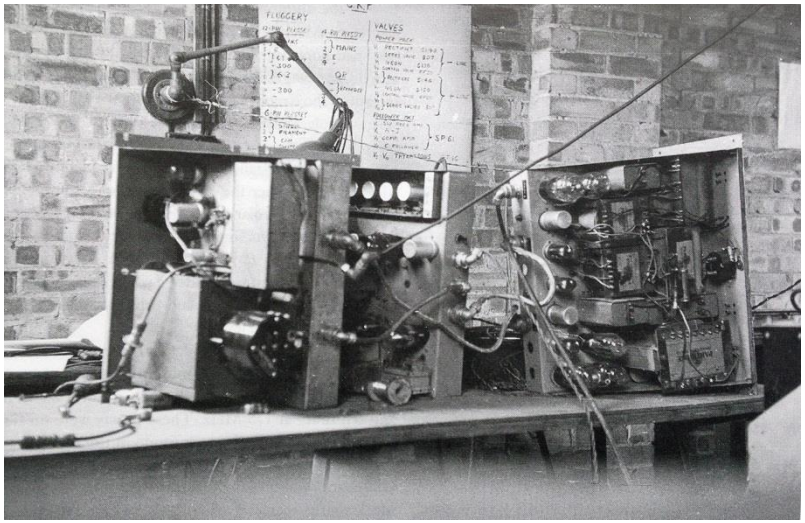
- Ryle and Vonberg lived as graduate students in a large house at 5b Herschel Road.

Ryle and Vonberg (1946 - 48)



Ryle and Vonberg (1946, 1948)





- Ryle and Vonberg's 1946 receiver design
- Machin's 1948 improved Ryle-Vonberg CRP receiver (CRP = Cosmic Radio Pyrometer).

Ryle and Vonberg (1946)

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LETTERS TO THE EDITORS

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Solar Radiation on 175 Mc./s.

Appleton[1] and Hey[2] have directed attention to the fact that radio-frequency energy, with some of the characteristics of random 'noise', is emitted with greatly increased intensity from the sun under the conditions of violent disturbance associated with a large sunspot. These observations were confined mainly to the region of frequencies near 60 Mc./s.

Pawsey, Payne-Scott and McCready[3], who have made observations on 200 Mc./s., suggested that radiation of this type is also observable under less disturbed conditions.

In order to investigate other aspects of this phenomenon, we have constructed a device which automatically records and measures the 'noise' received on 175 Mc./s., and which has a sensitivity such that a power of 3×10^{-13} watts (approximately 1 per cent of the receiver noise power) can be detected. This sensitivity corresponds to a thermal energy temperature of 30° K., and it has been possible to record the 'noise' received from the galaxy on a small broadside aerial consisting of eight half-wave dipoles.

For the purpose of investigating solar radiation under conditions of low solar activity, it is necessary to discriminate against the background of galactic radiation. While this could be achieved by building an aerial to give a sufficiently narrow beam, a very large structure would be required, and observation would be restricted to a short time every day unless arrangements were made for moving the polar diagram of the aerial. An alternative method was therefore used, analogous to Michelson's method for determining stellar diameters. Two aerial systems were used with a horizontal separation of several wave-lengths, and their combined output was fed to the receiving equipment. Such an arrangement produces a polar diagram of the form shown in Fig. 1 where the angle between zeros is governed by the spacing of the two aerials and the envelope is determined by the polar diagram of each individual aerial system. If the angle between minima is sufficiently large compared with the solar angular diameter, then, as the aerial polar diagram is swept past the sun by the earth's rotation, any radiation from the sun should be recorded as an oscillatory trace.

Fig. 2 shows a typical record obtained with an aerial separation of 10 λ, and with only slight solar activity (July 17). The oscillatory contribution due to radiation from the sun can be seen superimposed on the slowly varying background of the galactic radiation. Records of this type enable an estimate to be made of the level of solar radiation even when it is only about one quarter the galactic contribution, and at the present time we have found that the sun is usually sufficiently disturbed to give such records. The power is indicated on the diagram in terms of an 'equivalent aerial temperature', and is the power which has to be fed to an aerial in a black-body enclosure of this temperature, to maintain equilibrium. The temperature of a distant source whose radiation obeys a black-body distribution may be estimated from the observed equivalent aerial temperature by correcting for the ratio of solid angles of source and aerial polar diagram.

During the appearance of a large sunspot between July 20 and August 1, the solar radiation was much increased, and the opportunity was taken to use the apparatus to determine the angular diameter of the source, by observing the ratio of maximum to minimum intensity as the polar diagram of the two aerials with a separation of many wave-lengths was swept past the sun. This experiment was carried out with a series of different aerial spacings, the final value being 140 λ, and a sample of the records obtained with this spacing is shown in Fig. 3. The maximum/minimum ratio obtained under these conditions corresponds to a source diameter of 10 minutes of arc. Any inequalities in the two aerial systems would result in an over-estimate of diameter, and this is therefore a maximum value.

Since the value obtained does not greatly exceed the diameter of the visual spot, it is reasonable to relate the source of this radiation with the visual spot itself, or a region closely associated with it.

During the afternoon of July 25 the observed intensity attained a value which would correspond, in the case of black-body radiation from a source of this diameter, to a temperature greater than $2 \cdot 10^9$° K.

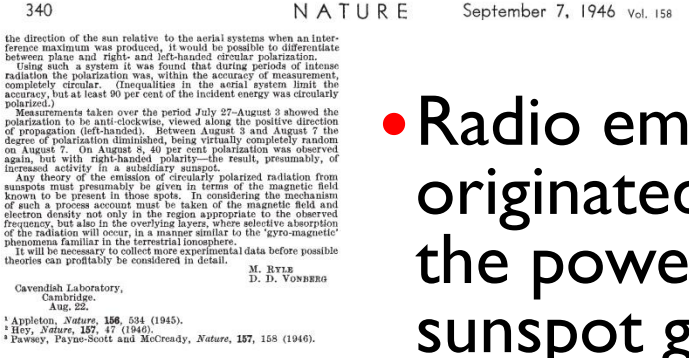
Since the existence of such temperatures in a region from which radiation of this wave-length would escape seems improbable, we considered that the radiation was non-thermal in origin, and the possibility of ordered electron motion was therefore investigated by an examination of the polarization of the radiation. This was carried out by arranging the two aerial systems of the 'Michelson' device to be polarized in planes at right angles to each other. If the radiation were emitted by a completely random 'thermal' source, the two perpendicularly polarized components would not be phase-coherent and no interference effects would be observed. The existence of interference effects would show the presence of phase coherence, and hence prove that the radiation was not of 'thermal' origin. Further, by noting

Fig. 2. RECORD OBTAINED WITH 10 λ SEPARATION (JULY 17, 1946)

Fig. 1 POLAR DIAGRAM OF TWO 8-ELEMENT AERIAL SYSTEMS WITH SEPARATION OF 10 λ

Fig. 3. RECORD OBTAINED WITH 140 λ SEPARATION (JULY 26, 1946)

- Large sunspot group 20 July-1 August, 1946



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the direction of the sun relative to the aerial systems when an interference maximum was produced, it would be possible to differentiate between plane and right- and left-handed circular polarization.

Using such a system it was found that during periods of intense radiation the polarization was, within the accuracy of measurement, completely circular. (Inequalities in the aerial system limit the accuracy, but at least 90 per cent of the incident energy was circularly polarized.)

Measurements taken over the period July 27–August 3 showed the polarization to be anti-clockwise, viewed along the positive direction of propagation (left-handed). Between August 3 and August 7 the degree of polarization diminished, being virtually completely random on August 7. On August 8, 40 per cent polarization was observed again, but with right-handed polarity—the result, presumably, of increased activity in a subsidiary sunspot.

Any theory of the emission of circularly polarized radiation from sunspots must presumably be given in terms of the magnetic field known to be present in those spots. In considering the mechanism of such a process account must be taken of the magnetic field and electron density not only in the region appropriate to the observed frequency, but also in the overlying layers, where selective absorption of the radiation will occur, in a manner similar to the 'gyro-magnetic' phenomena familiar in the terrestrial ionosphere.

It will be necessary to collect more experimental data before possible theories can profitably be considered in detail.

M. RYLE
D. D. VONBERG

Cavendish Laboratory,
Cambridge.
Aug. 22.

[1] Appleton, *Nature*, **156**, 534 (1945).
[2] Hey, *Nature*, **157**, 47 (1946).
[3] Pawsey, Payne-Scott and McCready, *Nature*, **157**, 158 (1946).

- Radio emission originated from the powerful sunspot group

- First radio Michelson interferometer with variable antenna spacing.
- Brightness temperature of radio emission of sunpots greater than 2×10^9 K.
- Radio emission circularly polarised – non thermal emission.

Derek Vonberg

- Vonberg left the group after 2 years and became the leader of the efforts at the Hammersmith Hospital to develop the cyclotron, producing neutrons and short-lived radioactive isotopes for medical purposes.
- He became Director of the Unit and in 2005 he was recognised by

  'the unveiling of the Vonberg Suite in the Cyclotron Building, named after Derek Vonberg who guided the MRC Cyclotron Unit through the early years of its pioneering work.'

Review Committee for JIVE March 2012

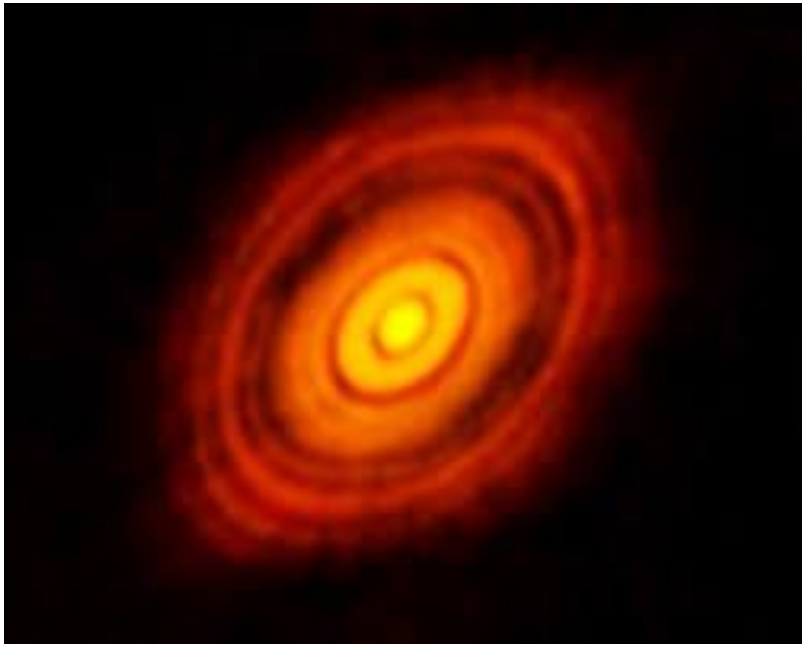
- JIVE provides essential infrastructure for the EVN/VLBI network.
- The EVN and JIVE teams should grasp the opportunities expanding the scope of VLBI observations to much wider areas of astrophysics.
- The profile of the EVN is lower in Europe than it should be. Increased awareness throughout the European community should be strongly fostered
- The capabilities for precise solar system astrometry are of considerable interest for the European Space Agency (ESA).

Review Committee for JIVE March 2012

- In the early days of VLBI, the observations and data analysis were confined to a relatively small community of radio astronomers. That perspective has changed dramatically over the last 20 years. The techniques and data analysis are much more accessible to the user community.
- The development of real-time VLBI changes the astronomical perspective and capabilities.
- Compare with the ALMA story.

HL Tau as observed by ALMA

- Spectacular image of the disc of protoplanetary disc about the newly-forming star.
- ALMA part of the main-stream of astrophysics with capabilities for use by non-expert interfer-ometrists.

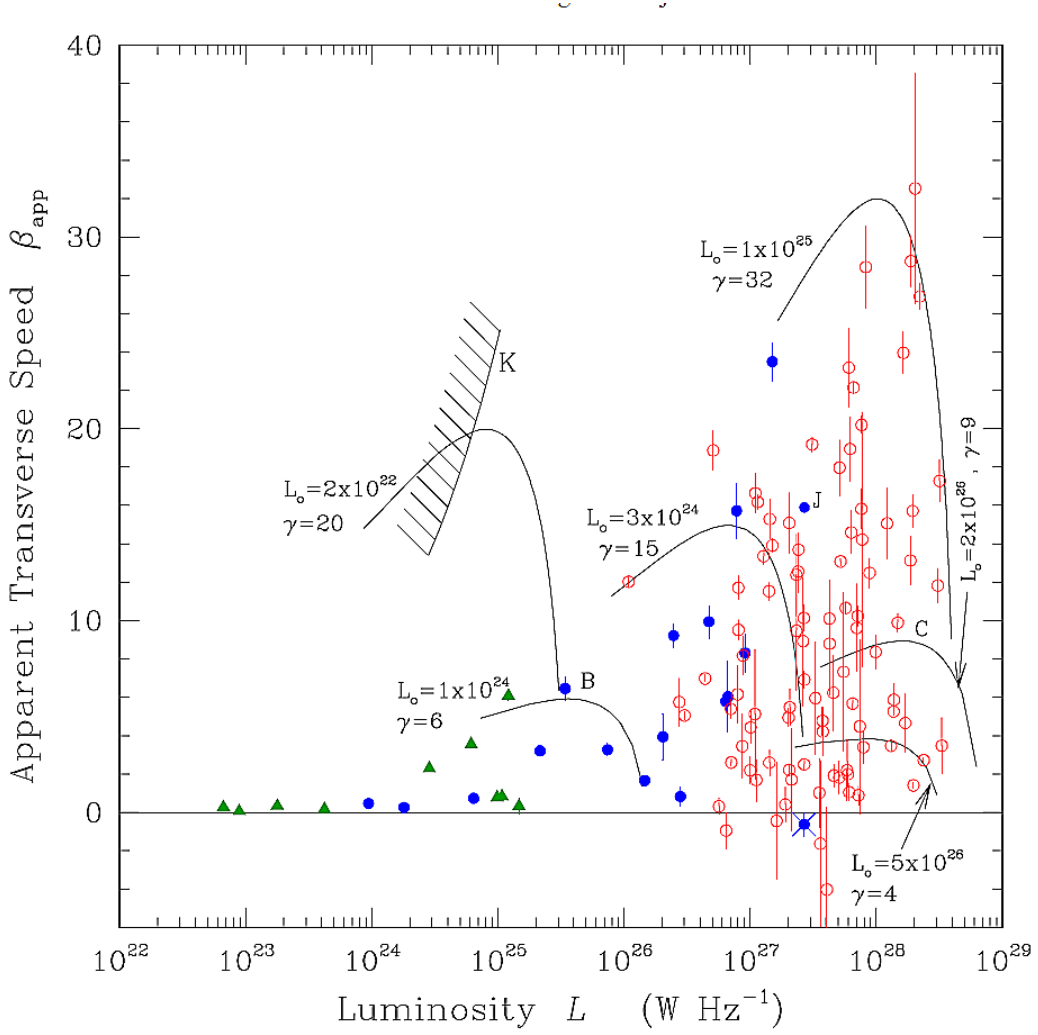


Science Highlight of VLBA

- **Superluminal motions**

One of the great contributions of VLBI concerns the large samples of superluminal sources (Cohen et al 2007).

NB: 20 years of observation

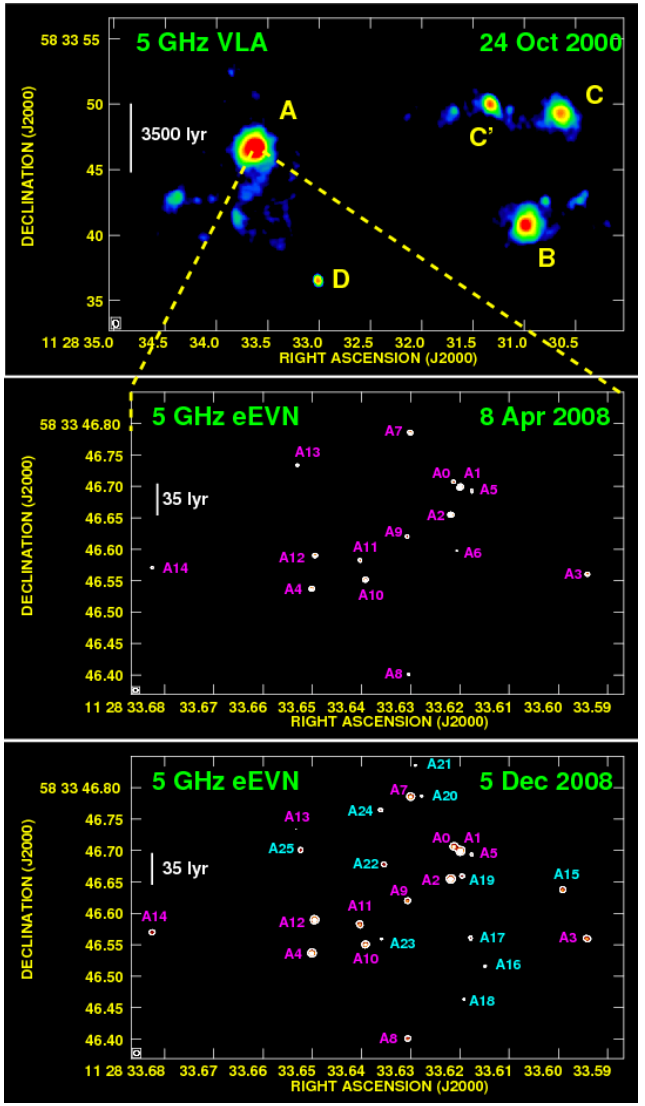


Science Highlights March 2012

Supernovae

The milliarcsec resolution available by the VLBI technique enables young supernovae and supernova remnants to be detected in nearby galaxies. The radio supernovae can be monitored, both for their discovery and their evolution.

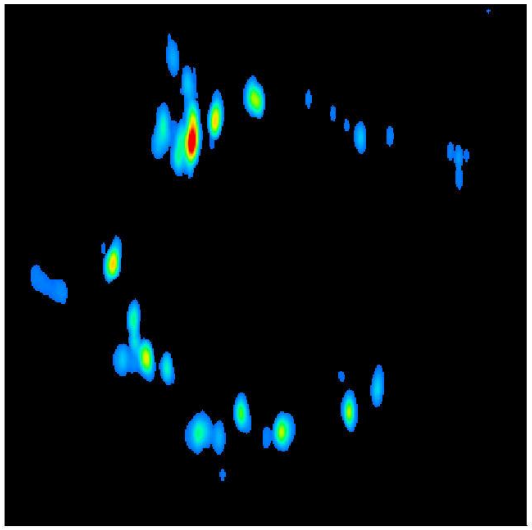
(2015: See talk by Miguel Perez-Torres)

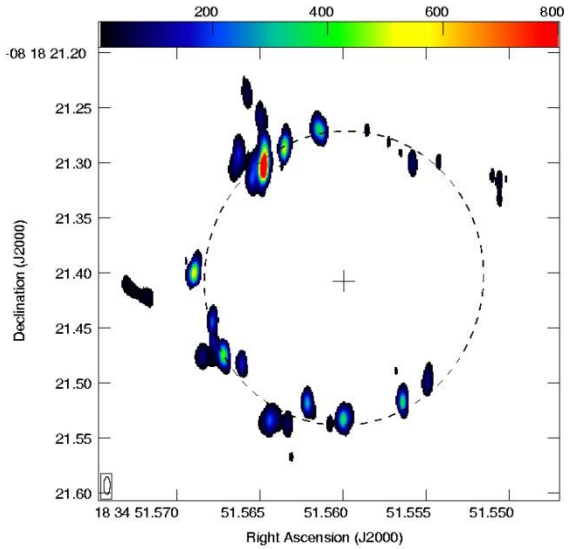


Science Highlights March 2012

Circumstellar rings and high mass star formation

The observation of intense methanol and water vapour maser sources in star forming regions has enabled unique information to be obtained about the kinematics of the rings which form about newly-formed stars.

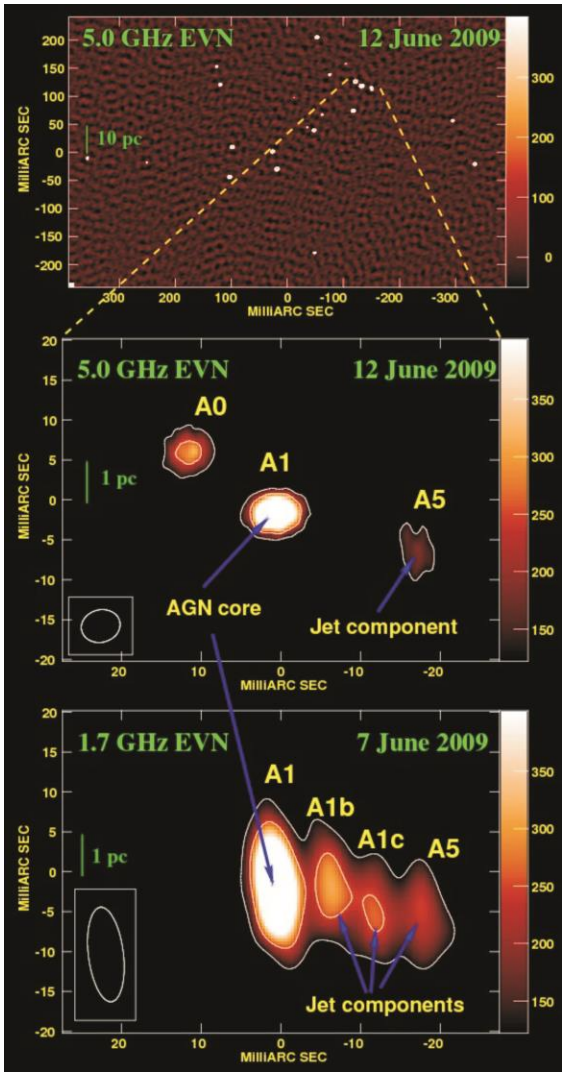




Science Highlights March 2012

Distant star-forming galaxies

Impressive images have been taken of the central regions of nearby and very distant star-forming systems. The VLBI observations allow the nature of distant ultra-luminous galaxies to be revealed, namely whether they are powered by star formation or by active galactic nuclei.



Science Highlights March 2012

Astrometry

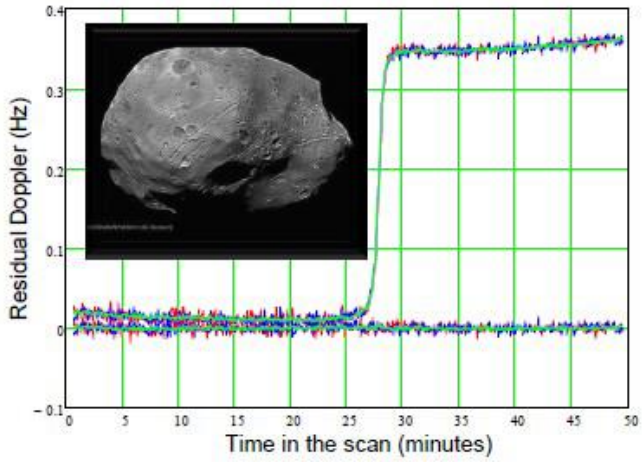
VLBI has provided the most precise astrometry yet achieved in any waveband. The use of methanol masers in star-forming regions has enabled remarkably precise distance measurements to be made. (2015: See talk by Andreas Brunthaler)

These types of observation will be crucial in relating the astronomical fundamental reference frame determined by GAIA to the radio frame established with even higher precision from the VLBI extragalactic reference frame established by observations of quasars.

Science Highlights March 2012

Spacecraft tracking

VLBI has been used to determine extremely precise determination of the state vectors of planetary probes. Positions have been measured to a few tens to hundreds of metres precision at a distance of several AU. Examples include Titan atmospheric dynamics and the mass distribution of Phobos (2015: See talk by Walter Brisken, ± 10 μarcsec).



Science Highlights: April 2015

- Pulsar distances and positions by VLBI trigonometric parallaxes (See talk by Adam Deller): towards a few μarcsec – SKA-VLBI.
- Gravitational lensing at the highest resolution (John McKean) – tests of CDM/WDM models.
- Black Hole Event Horizons – (Heino Falcke). Imaging the shadow of black hole event horizon.
- Deep, wide-field VLBI imaging (Mike Garrett). L band data can now image wide fields anywhere on the sky. Next generation HDF survey will have 5 mas resolution over a 15 arcmin field of view with microJy sensitivity.

The Science Case for the Future

- The Committee's view is that the continuation of the present programme with all the planned enhancements of the facilities and development initiatives is to be strongly supported. In addition, we strongly recommend that the EVN and JIVE teams grasp the opportunities for innovative science which will be of strong interest outside the traditional VLBI community.

The Science Case for the Future

- The full EVN collecting area already amounts of about 10% of that of the SKA.
- Using the real-time facility increases the synergies with other telescopes across the electromagnetic spectrum. We would expect strong interest in the study of, for example, LOFAR and for all classes variable or burst phenomena and can lead to significant discoveries.

The Science Case for the Future

- The success of the near-field VLBI observations of space vehicles involved in planetary missions such as Huygens, Mars Express and others planetary missions indicate the possibilities for significant contributions to planetary science.
- The science includes the study of planetary atmosphere, the surface and sub-surface properties of planets and their satellites and their mass profiles.
- Note important/essential synergies with geodetic VLBI.

The Science Case for the Future

- Capabilities for fundamental physics include precise satellite tracking. The comparative accuracy of VLBI and clock timings for accurate positioning of, say, GPS or Galileo satellites, should be investigated, ideally in collaboration with ESA.
- The importance of relating the GAIA reference system with the quasar-defined absolute fundamental reference system is an important area for fundamental astrometry.
- The development of high frequency VLBI which should include ALMA as a phased array will open a new window in high resolution observations.

The Challenges

- To continue to exploit to the full the unique opportunities for innovative physics and astrophysics provided by the JIVE-ERIC initiative.
- To broaden the community of users to include non-traditional VLBI scientists.
- JIVE staff and EVN users should give talks at international topical meetings which are not specialised VLBI meetings.
- The identification of champions in each of the partner countries who promote the importance of the science for astronomy as well as enhancing outreach activities in all member states of the JIVE-ERIC initiative.