VLBI – A PERSONAL VIEW

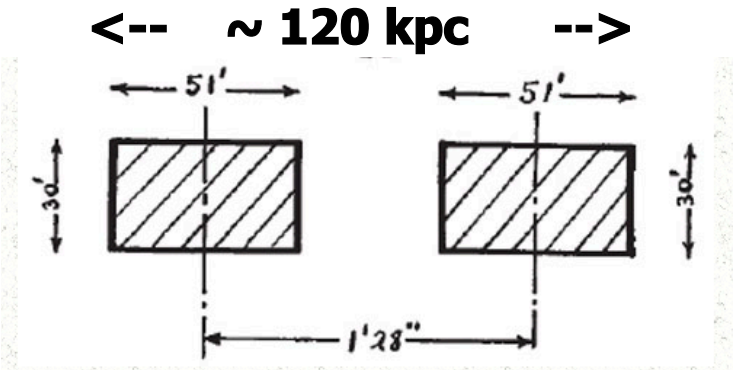
FROM "FIELD 80" TO INTERNATIONAL DEVELOPMENT

- IMPORTANT ERA IN DEVELOPMENT OF VLBI
  - JODRELL BANK IN THE SIXTIES
- POLITICAL DIMENSIONS OF VLBI
- VLBI AND ASTRONOMY FOR DEVELOPMENT

DEVELOPMENT OF RADIO LINK INTERFEROMETRY
DOUBLENESS OF RADIO SOURCES

- 1948 - TRAUMATIC SHOCK FOR ASTRONOMERS
  IDENTIFICATION OF CYGNUS A
  - 2nd brightest radio source in sky
    identified with
    - faint galaxy at z = 0.06
      - Baade & Minkowski (1954)
- In principle observable to z > 10

- 1953 Jodrell Bank
  - Radio link Intensity interferometer to 4km
    - Jennison and Das Gupta



DOUBLE!!

JODRELL BANK - CRADLE OF VLBI

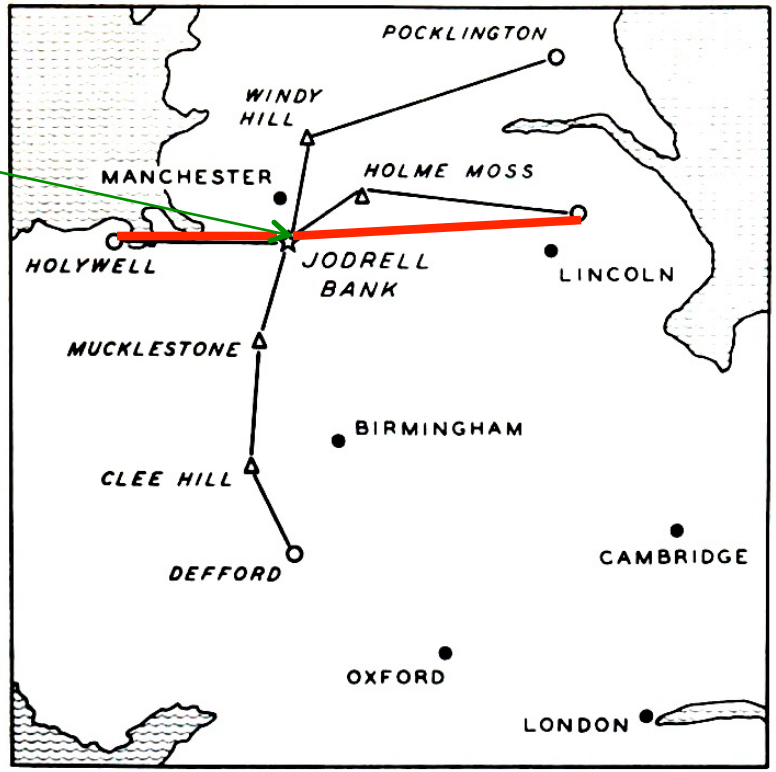
Mark I Control Room

Long baseline interferometer control room

- 1957 Completion of Mark I Telescope – later Lovell Telescope
  - Largest telescope - 250 ft diameter- x3 larger than Dwingeloo radio telescope
- 1959 - 1968 Development of phase coherent radio link interferometry
  - Only show in town

DEVELOPMENT OF RADIO LINK INTERFEROMETRY
1959 – 1962 158 MHz with Yagi Remote Antennas

Holywell
60 km 32000λ



Lincoln
115 km 61000λ

- 133 sources to 100 km at 158 MHz
  - Allen, Anderson, Conway, Palmer, Reddish, & Rowson, 1962, MNRAS, 124,477
  - Allen, Hanbury Brown and Palmer 1962, MNRAS., 125, 57. (combined with Moffet & Maltby Caltech)

- AT LEAST 40% DOUBLE
- BUT ~10% UNRESOLVED ~ 1” !! > QUASARS

DISCOVERY OF QUASARS Alan Sandage

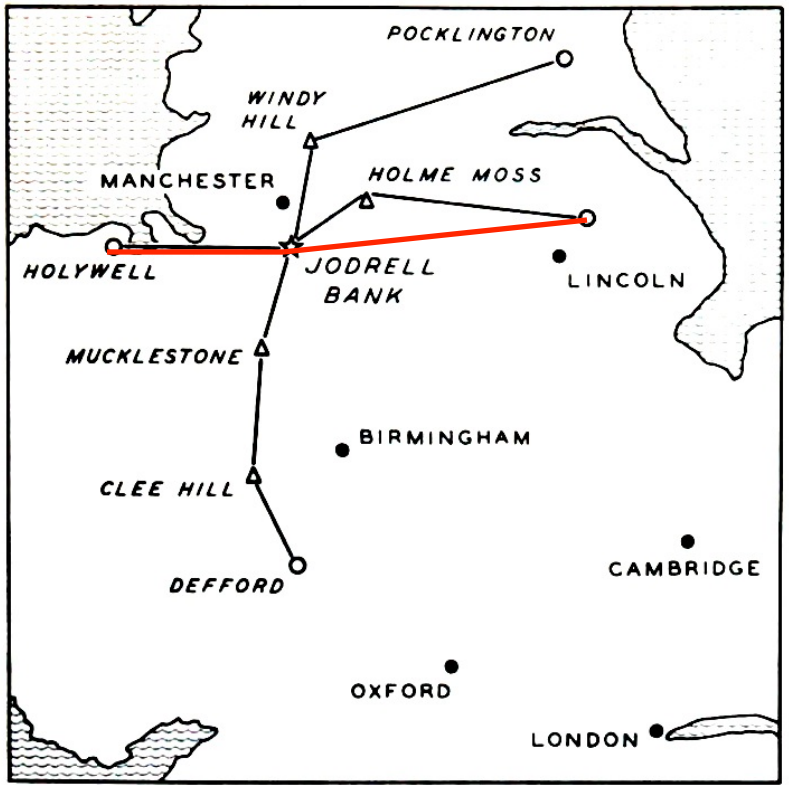
Ann. Rev. Astron. Astrophys. 1999. 37: 445-486

- **"Particularly important for the quasar history was the long base-line interferometry made by the Jodrell Bank radio astronomers.**

- **They performed interferometry with the Jodrell Bank 250-foot antenna, measuring the fringe visibilities of more than 350 3CR sources. With baselines ranging from 2200 to 61,100 wavelengths (Allen et al 1962, Rowson 1962), they compiled a list of unresolved 3C sources whose angular diameters were smaller than one arcsec, and therefore had "brightness temperatures" larger than 107 K, a telling indication of nonthermal radiation (Palmer 1961). Also from these data, Allen, Hanbury Brown, & Palmer (1962) surmised that many resolved 3CR sources were double, following the previous demonstration by Hanbury Brown & Das Gupta that Cygnus A is double.**

- **The heroes of the quasar discoveries were clearly Palmer for his brilliant measurements with his Jodrell Bank colleagues of the radio angular diameters, ……."**

THE "HENRY PALMER" LONG BASELINE GROUP
ONLY LONG BASELINE INTERFEROMETRY 1959 - 68



JODRELL GROUP 1963 WHEN I JOINED

- **Forgotten heroes of VLBI**

HENRY PALMER

BARRIE ROWSON

BRYAN ANDERSON

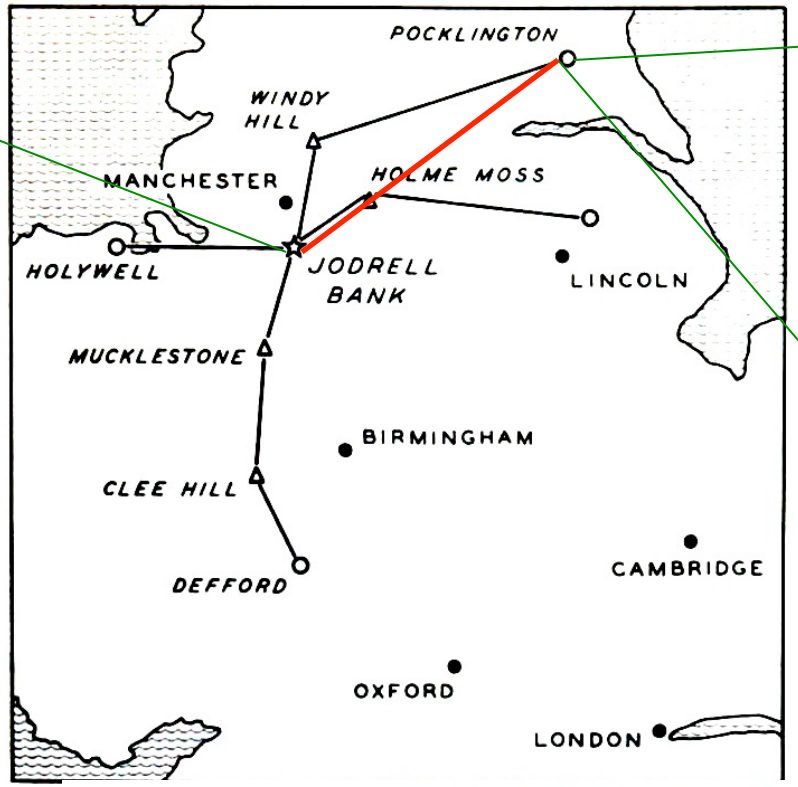
WILF DONALDSON

MOST RECENT LONG-BASE-LINE EXPERIMENTS

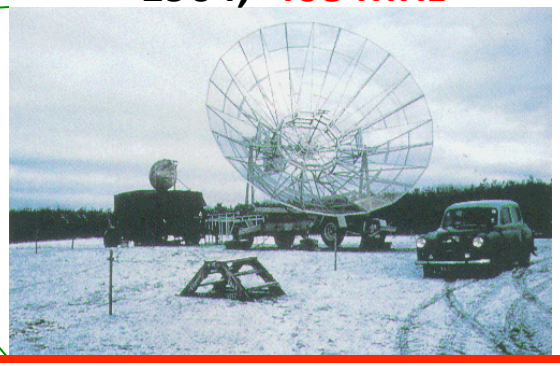
Date	*Name*	*Frequency (mHz.)*	*Base Line (km.)*	*Base Line (wavelengths)*	*Collecting Area*
1961	Holywell	158.0	60.3	32,000	710
1963	Lincoln	158.0	115	61,000	710

1963

LONG BASELINE INTERFEROMETRY IN THE SIXTIES
QUEST FOR HIGHER AND HIGHER RESOLUTION



1964, 408 MHz



Wilf's 8m diam. dish at Pocklington
Controlled remotely
Built by a PhD student

MOST RECENT LONG-BASE-LINE EXPERIMENTS

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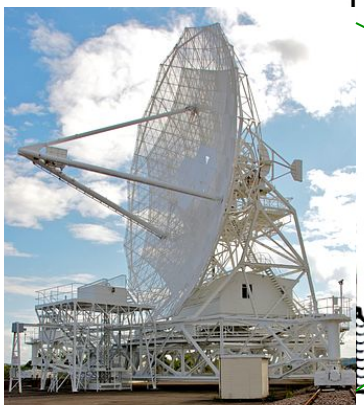
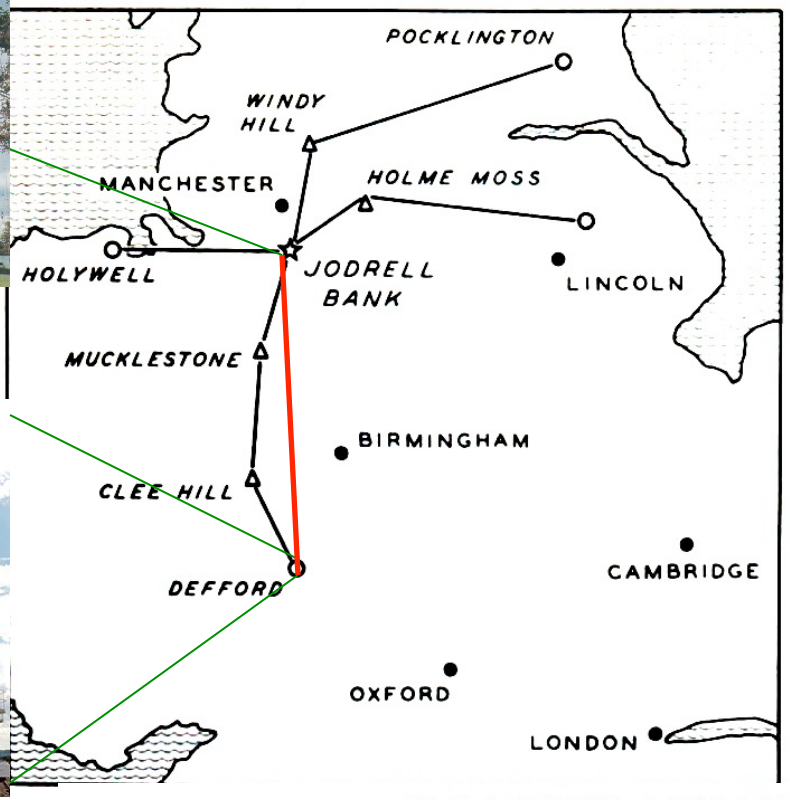
1961	Holywell	158.0	60.3	32,000	710
1963	Lincoln	158.0	115	61,000	710
1964	Pocklington	408.0	131	180,000	390
1965	Malvern (Defford)	1420.0	127	600,000	1,600
1966	Malvern (Defford)	5000.0	127	2,100,000	940 (Mark II)

1963

LONG BASELINE INTERFEROMETRY IN THE SIXTIES
QUEST FOR HIGHER AND HIGHER RESOLUTION





Defford 1965 – 67

1.4GHz, 5 GHz

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Date	*Name*	*Frequency (mHz.)*	*Base Line (km.)*	*Base Line (wavelengths)*	*Collecting Area*
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ELGAROY, MORRIS, ROWSON MNRAS, 124, 395 (1962)
A radio interferometer for use with very long baselines

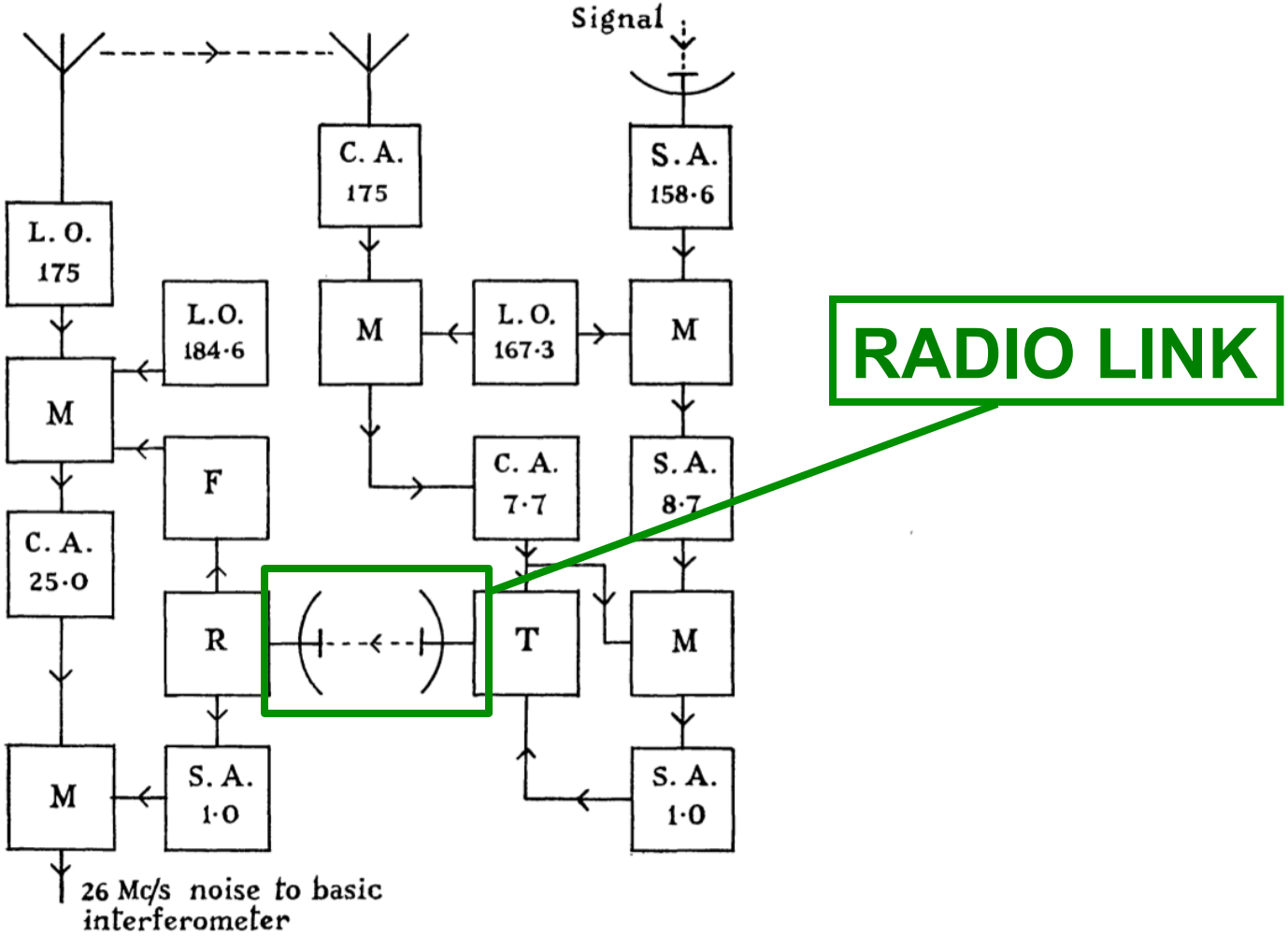


FIG. 3.—*Block diagram of radio link system.* M, *mixer;* T, *microwave transmitter;* R, *microwave receiver;* S.A., *signal amplifier;* C.A., *continuous wave amplifier;* F, *frequency multiplier to convert* 7·7 *Mc/s to* 15·4 *Mc/s;* L.O., *local oscillator. The numbers are frequencies in Mc/s.*

ELGAROY, MORRIS, ROWSON MNRAS, 124, 395 (1962)
A radio interferometer for use with very long baselines

"FIELD 80"

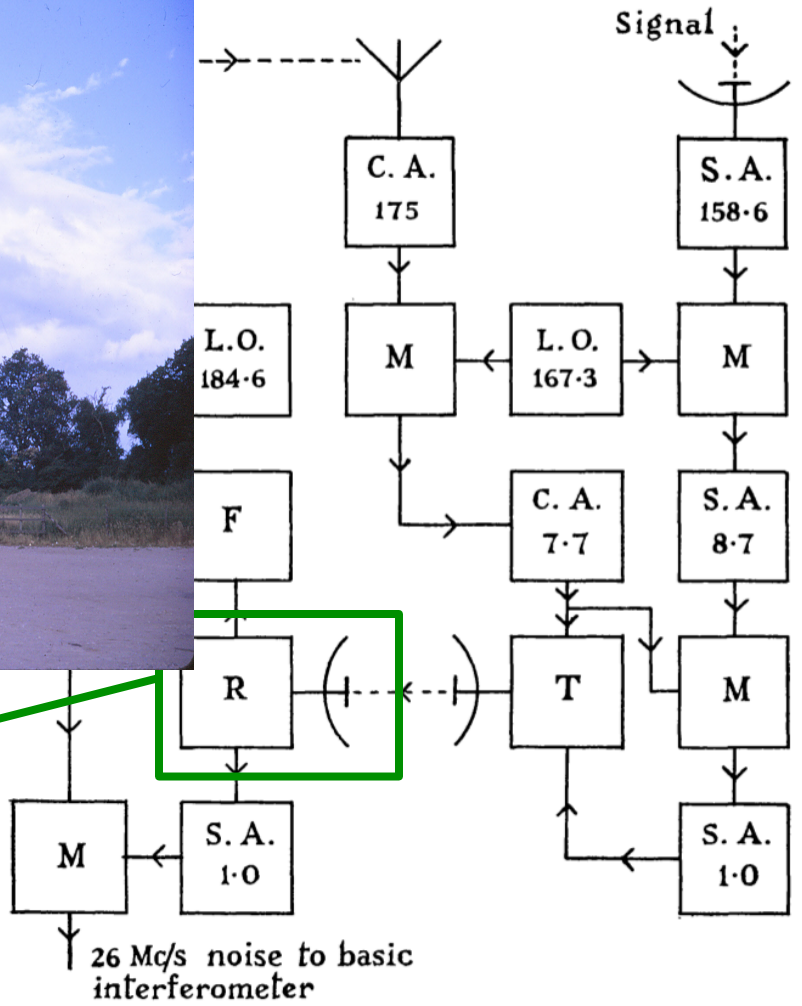


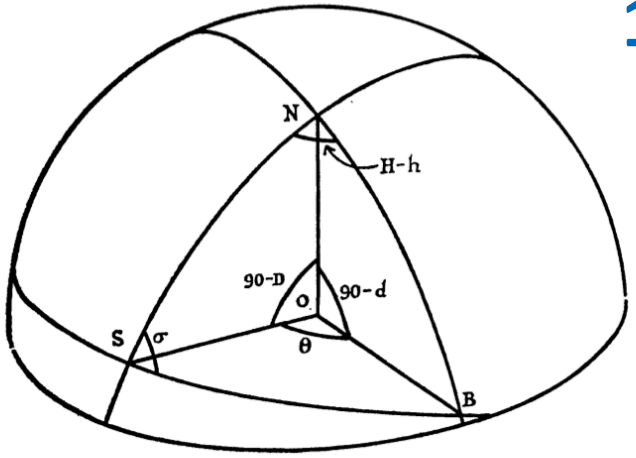
FIG. 3.—*Block diagram of radio link system.* M, *mixer;* T, *microwave transmitter;* R, *microwave receiver;* S.A., *signal amplifier;* C.A., *continuous wave amplifier;* F, *frequency multiplier to convert 7·7 Mc/s to 15·4 Mc/s;* L.O., *local oscillator. The numbers are frequencies in Mc/s.*

CLASSIC PAPER BY BARRIE ROWSON

MNRAS 125, 177 (1963)

"High resolution observations with a tracking interferometer"

1 THEORY OF THE "U-V" ELLIPSE



-The spherical triangle used for calculating differential delays and reso

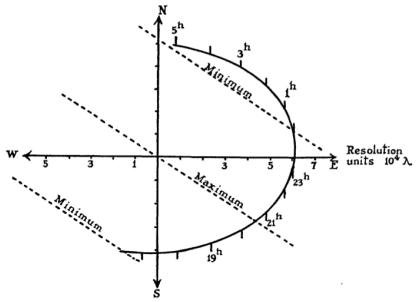


FIG. 7(*b*).—*The locus of observations on the fringe amplitude plane showing the positions of maxima and minima for the source model consisting of two points.*

Two deductions can be made from these equations. First, equation (8) shows that, for a given actual baseline, the east-west component of the resolution depends only on the hour angle of the source and not on its declination. Secondly, it can be shown that the locus of the point of observation on the fringe amplitude plane is an ellipse, for if we have an ellipse with semi-major axis a and semi-minor axis b its equation can be given in terms of the parameter ϕ as

$$x = a \sin \phi$$

$$y = b \cos \phi$$

CLASSIC PAPER BY BARRIE ROWSON MNRAS 125, 177 (1963)

"High resolution observations with a tracking interferometer"

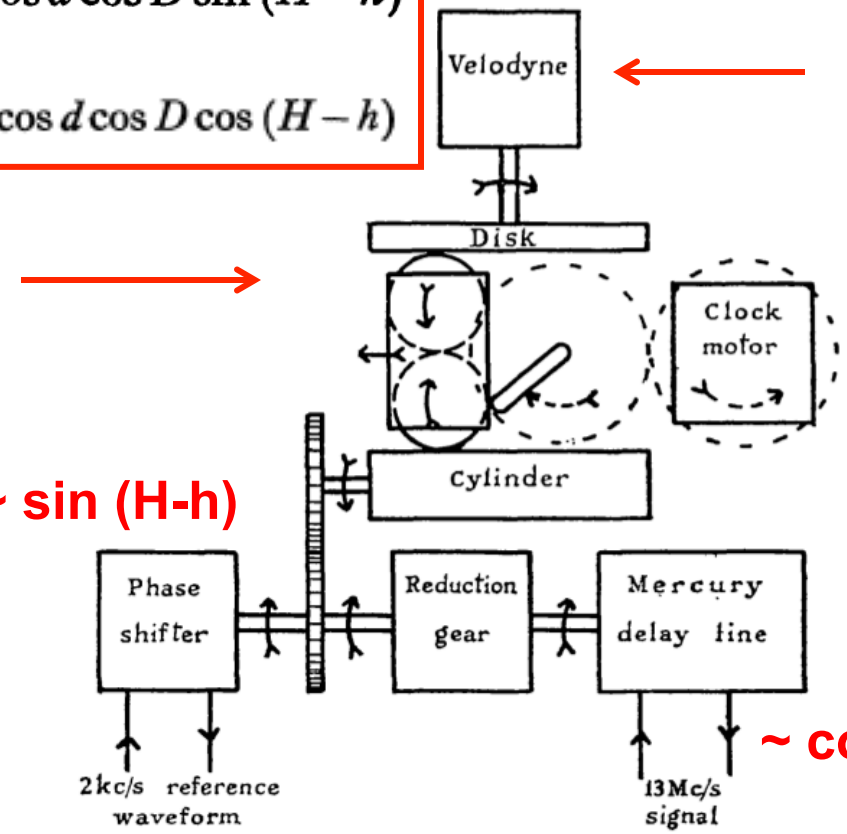
2. PRACTISE - FRINGE FREQUENCY/ DELAY MACHINE

Ingeneous analogue computer

Tracks fringe frequency and delay out to B >100 km

Fringe freq. $F = -\frac{dH}{dt}\frac{Lf}{C}\cos d \cos D \sin(H-h)$

Delay $= k + K\int F\,dt = k + \frac{KLf}{C}\cos d \cos D \cos(H-h)$



Speed ~ cos δ

Meccano gears

1 revolution in 24h

~ sin (H-h)

~ cos (H-h)

ROWSON FRINGE FREQUENCY/ DELAY MACHINE ON TEST BENCH

Tracked fringe frequency and delay out to B >100 km

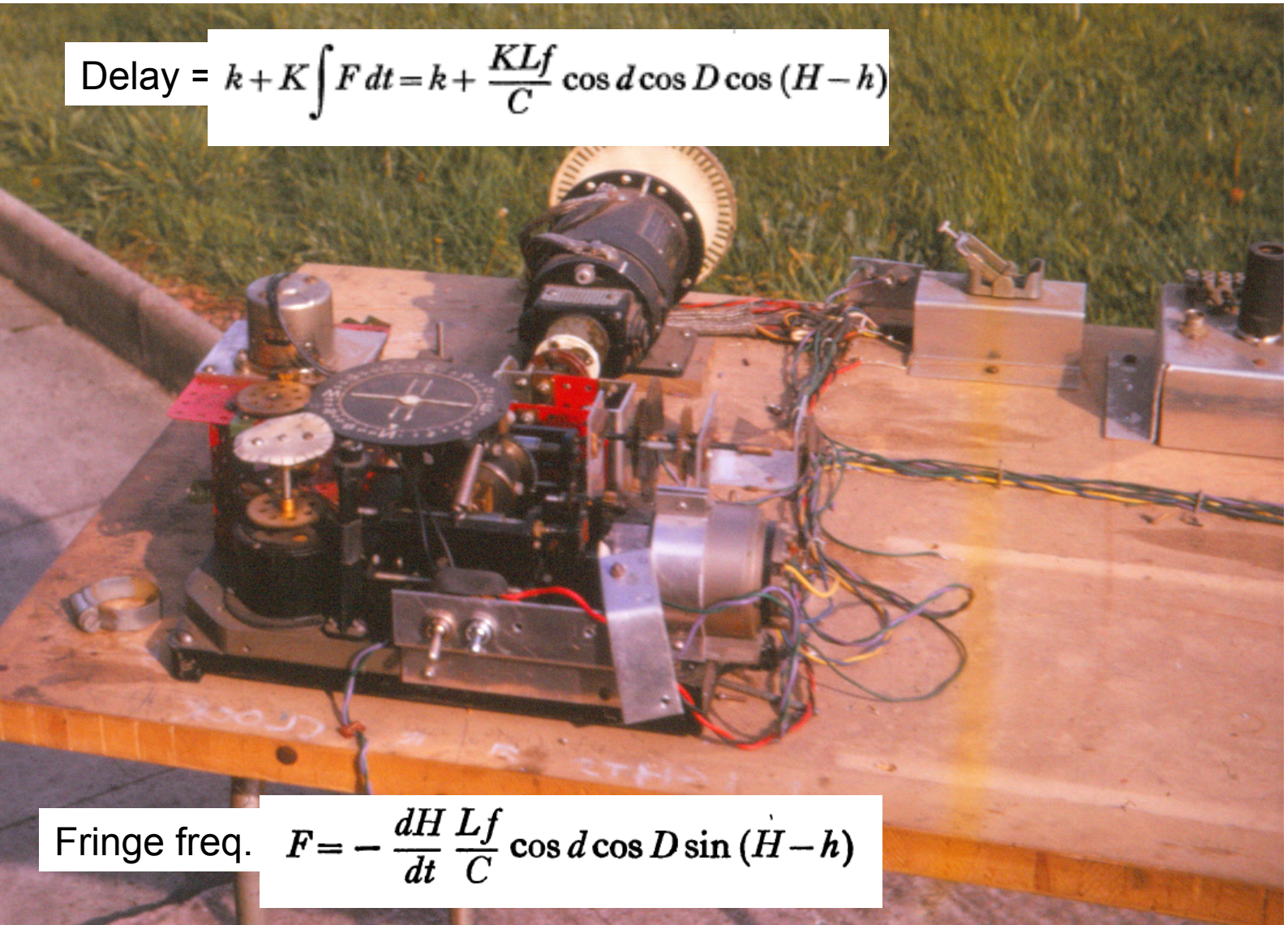


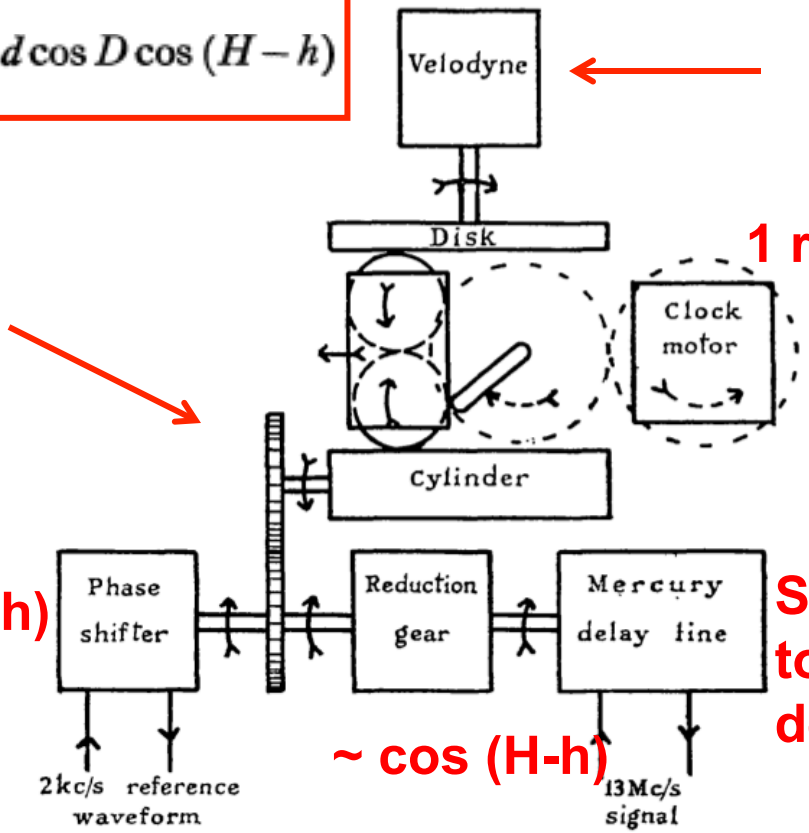
Photo courtesy Barrie Rowson

ROWSON FRINGE FREQUENCY/ DELAY MACHINE

Tracked fringe frequency and delay out to B >100 km

Fringe freq. $$F = -\frac{dH}{dt}\frac{Lf}{C}\cos d \cos D \sin (H-h)$$

Delay = $$k + K\int F\,dt = k + \frac{\text{[illegible]}}{C}\cos d \cos D \cos (H-h)$$



Speed ~ cos δ

1 revolution in 24h

Meccano

~ sin (H-h)

~ cos (H-h)

Set initial delay to calculated delay for start HA

TURN ON MOTOR AT CORRECT TIME

QUEST FOR HIGHER RESOLUTION - ARE THERE FRINGES?

Jodrell – Defford Baseline - 5 GHz 2 Mλ

3C273 YES!!!
UNRESOVED

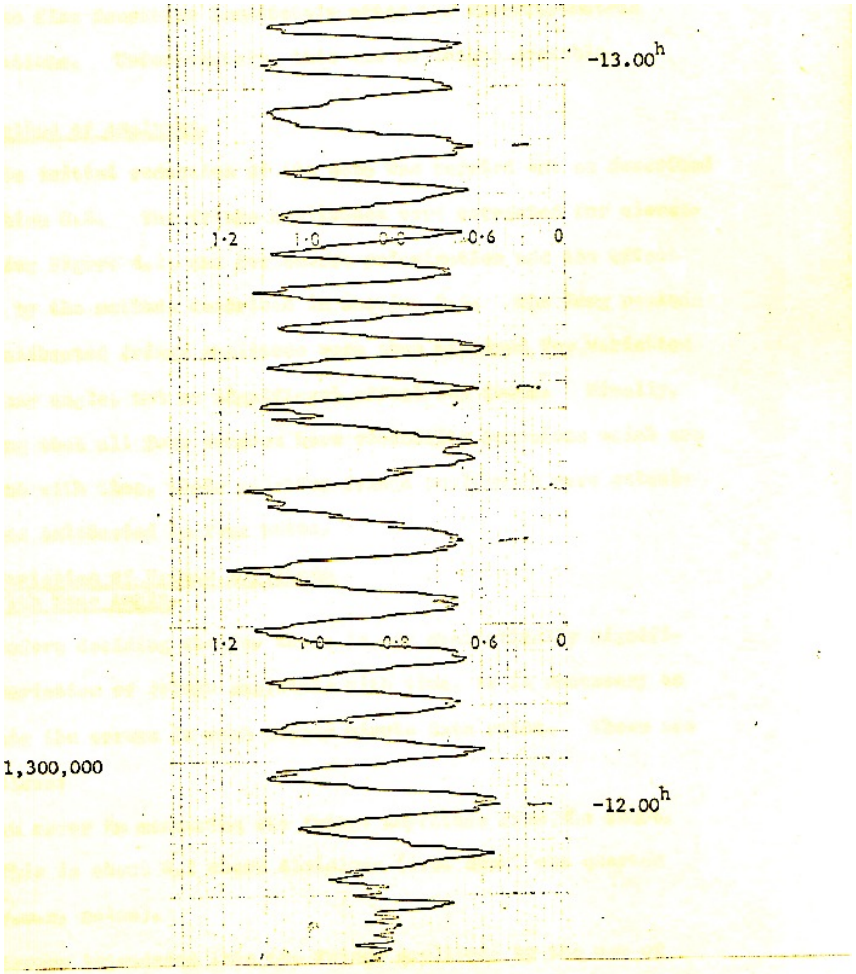
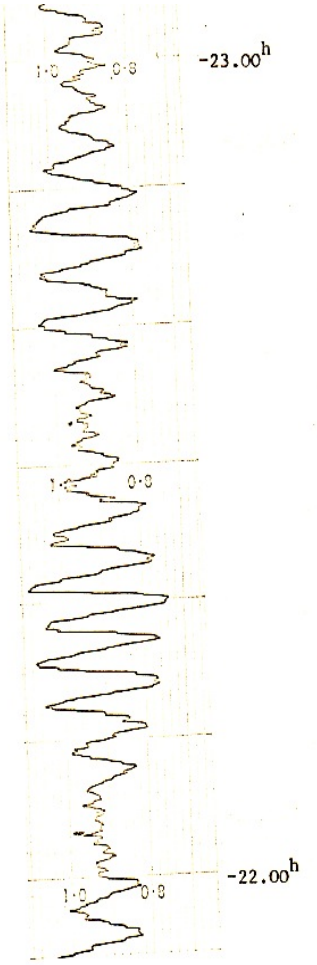


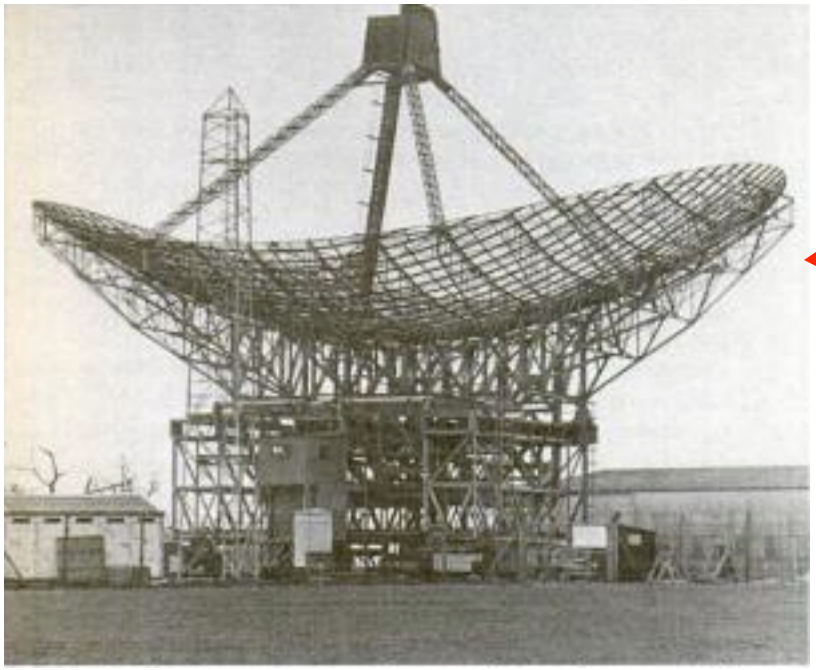
Figure 4.2 Fringes observed from 3C 273 on 19th December 1966 (4998 MHz)

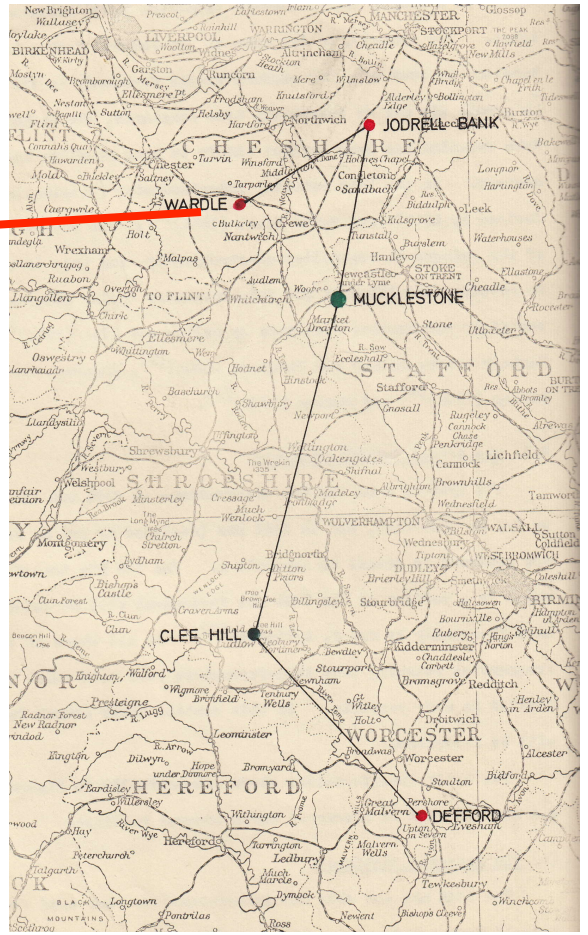
1938-15 YES!!!
RESOLVED



ges from PKS 1938-15 (1422 MHz)

QUEST FOR MORE SENSITIVITY
THE MARK III TELESCOPE 1967

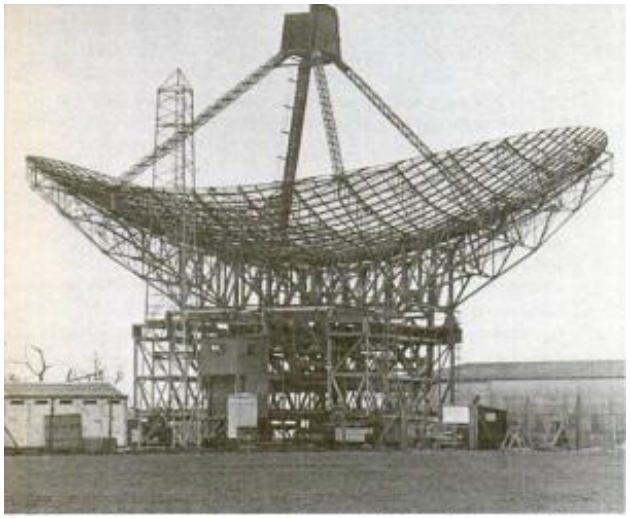




- 35m x 28m Increased sensitivity
  - "Transportable", but never transported

QUASAR ANGULAR SIZES DECREASE WITH REDSHIFT

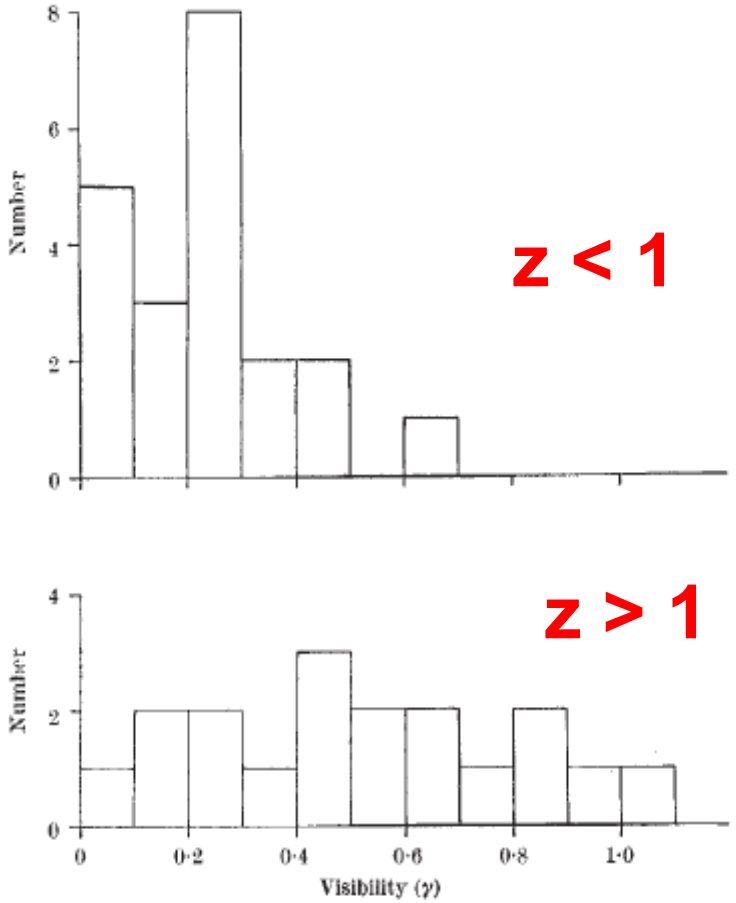
GM Nature 218, 933 (1968)



STEEP-SPECTRUM QUASARS

SPECTRAL INDEX < -0.7

No.



Fringe Visibility

< Large **Small >**

DEVELOPMENT OF INDEPENDENT LOCAL OSCILLATOR INTERFEROMETRY

- 1963 Visit by Lovell to Crimea
  - Discussions with Shlovsky and Matveyenko
    - Crimea – Jodrell 42 cm 2200 km
  - Memo by Palmer, Anderson, Rowson
    - Impossible/ too expensive with linked interferometer
    - Possibility of phase coherent tape recording interferometer

- 1965- 67 Development of tape recording interferometers
    - Video tape recorders
    - Atomic clocks
- 1967
  - Canada. Broten et al (Algonquin-Penticton)
  - US. NRAO – Cornell Kellermann, Cohen, Clark ; MIT Moran et al
- 1969
  - Jodrell – Arecibo (too late – Jodrell lost the race)

VLBI = SCIENCE + SCIENCE DIPLOMACY IN COLD WAR

VLBI = SCIENCE + POLITICS

- Science
  - Unique spatial resolution
    - Wide range of astrophysics

- Politics
  - Attractiveness of VLBI to policy makers for building international scientific bridge between countries
    - Europe, EVN, Radionet, JIVE
    - Africa, AVN, SKA
    - ERC Synergy Project “Event Horizon Telescope”

  - Attractiveness of VLBI in using science for capacity building
    - Africa, AVN, SKA-Africa
    - Technology development
    - Human capacity development

HIGH-LEVEL SUPPORT FOR ASTRONOMY FOR DEVELOPMENT

- **Written Declaration 45/2011 of European Parliament 15 March 2012 (signed by 394 MEPs)**
  - RECOGNISING THAT ***further European involvement in African radio astronomy can become a powerful driver of socioeconomic growth in Africa***
  - SUPPORTS *the development of science capacity in Africa through* ***greater investment in research infrastructures, with particular focus on radio astronomy***

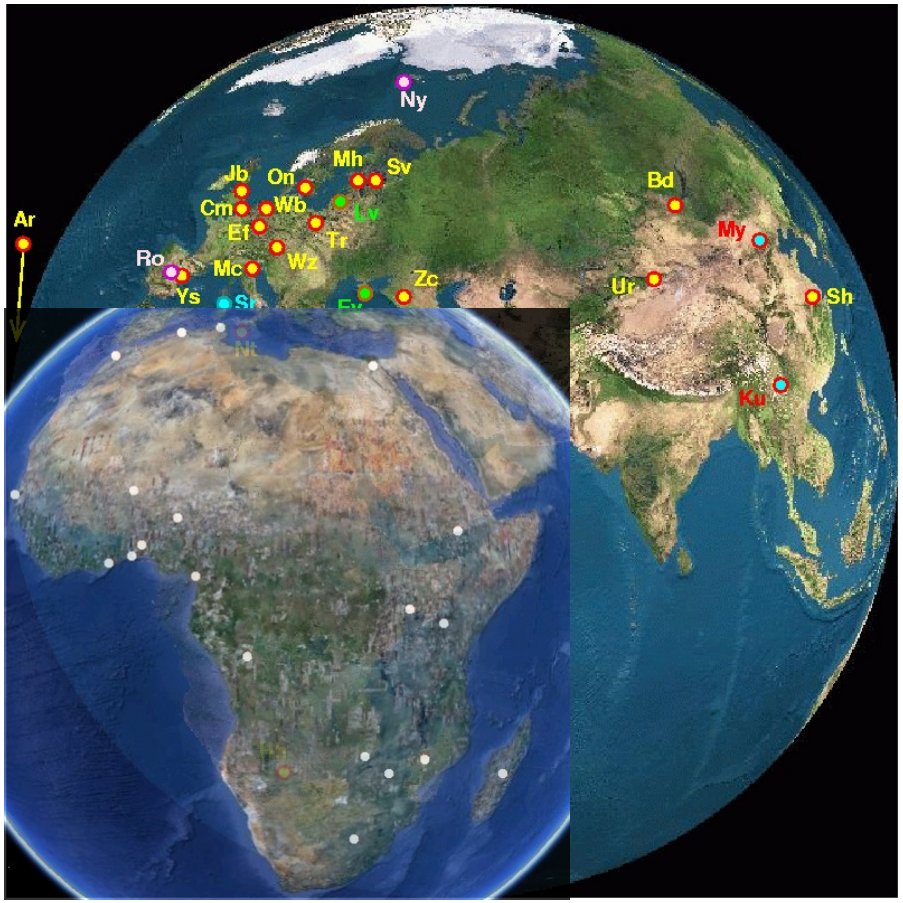
- **African Union Declaration (AU Assembly 18th ordinary session 29 -30 Jan 2012)**
  - STRESSES *the significant potential of* ***investment in African Radio Astronomy initiatives, such as the planned African Very Long Baseline Interferometry (VLBI) Network, to rapidly enhance Africa's science and technology capacities****, and therefore;*
  - PROPOSES the inclusion of ***Radio Astronomy as a priority focus area for Africa's international science and technology partnerships***

BECAUSE OF VLBI !!!

VLBI FOR INTERNATIONAL DEVELOPMENT

RADIO ASTRONOMY CAN FACILITATE GEODESY

AFRICAN VLBI ARRAY (AVN) WITH EVN



- Can also do geodesy
  - Tides of the solid Earth and oceans
  - Weather and climate
  - Regional deformation: uplift/ subsidence
  - Variations in the Earth's orientation and length of day.
  - Terrestrial reference frame
  - Ocean and atmospheric circulation
  - Changes in sea level
  - Crustal motion, plate tectonics
    - Earthquakes, and volcanos
  - Postglacial rebound.

See talk by Anita Loots

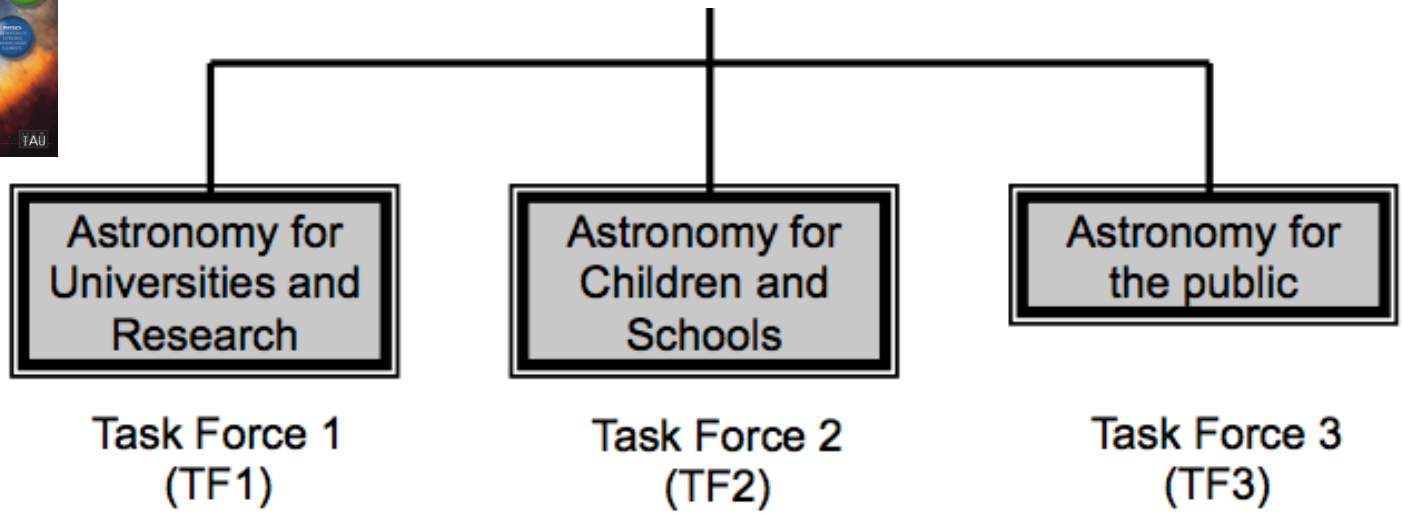
IAU STRATEGIC PLAN
"ASTRONOMY FOR DEVELOPMENT"

http://iau.org/static/education/strategicplan_091001.pdf

Some Elements

- Long-term Vision
- Goals for 2010 – 2020
- Strategy includes
  - Integrated strategic phased approach
  - Driven by regional demand
  - Emphasis Sub-Saharan Africa
  - Build on International Year of Astronomy
  - Mobilize volunteers
    - Professional + amateur astronomers
    - Teachers
    - Science outreach experts
  - Exploit new possibilities
- Implementation
  - IAU Office for Astronomy for Development
  - Joint venture between South Africa and IAU
  - Office in Cape Town

OAD Task Force membership



Jean-Pierre de Grève (Belgium, C46)
Richard de Grijs (China)
Michèle Gerbaldi (France)
Edward Guinan (USA – Chair)
Roger Hajjar (Lebanon)
Edward Jurua (Uganda)
Katrien Kolenberg (USA - VC)
Hakim Malasan (Indonesia, Div C)
Shengbang Qian (China)
Nicole van der Bliek (Chile)

Rosa Doran (Portugal)
Edward Gomez (LCOGT,Cardiff - VC)
Mary Kay Hemmenway (USA, **observer**)
Robert Hollow (Australia)
Ofodum Chukwujekwu Nworah (Nigeria)
Rosa Maria Ros (Spain)
Pedro Russo (Leiden/UNAWE/C55, Chair)
Cecilia Scorza (Venezuela/Germany)
Linda Strubbe (Canada)
Akihiko Tomita (Japan)
Jinhua He (China, Observer)

Thilina Heenatigala (Sri Lanka)
Sarah Kendrew (UK - New Media)
Lars Lindberg Christensen (Germany, IAU C55)
Carolina Ödman (South Africa – VC)
German Puerta (Colombia)
Sze-leung Cheung (Japan, OAO)
Ian Robson (UK - Chair)
Komiko Usida (Japan)
Ziping Zhang (China)

1st Element: Foundations

OAD Regional Nodes

Middle-East/Eastern Europe
Armenia

Lusophone
Portugal

Middle East
North Africa

East Asia,
China

South East Asia
Thailand

Andean Countries
Colombia

West Africa
Nigeria

East-Africa
Ethiopia

Southern Africa
Zambia

OAD

Global Office,
South Africa

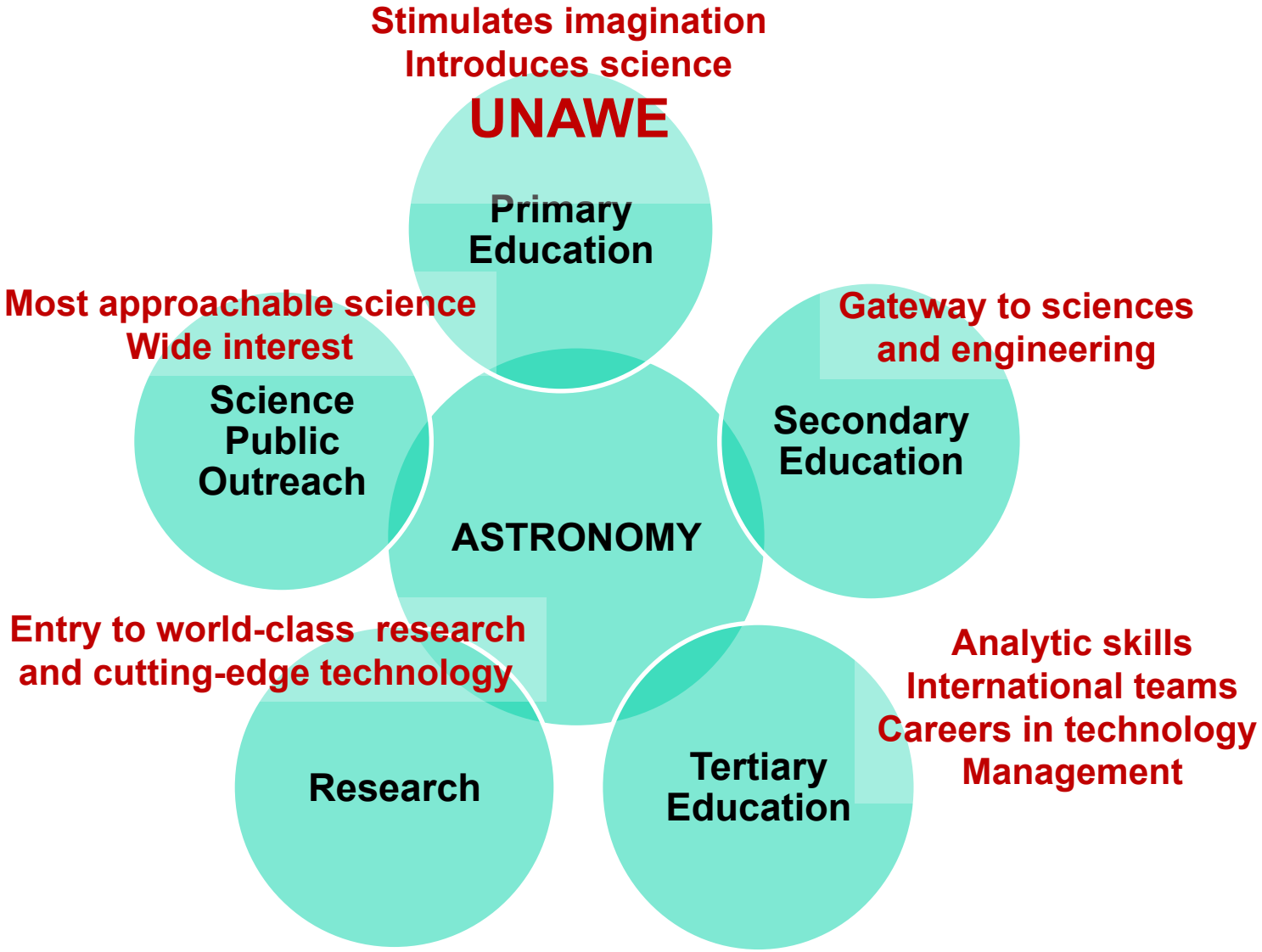
Operational
Proposal submitted
Proposal approved

1st Element:
Foundations

2nd Element:
Impact

PILLARS OF ASTRONOMY FOR HUMAN CAPACITY BUILDING

"from the cradle to the grave"



UNIVERSE AWARENESS (UNAWE)
Astronomy-based program with social goals

Exposes DISADVANTAGED young children (4 – 10) to INSPIRATIONAL aspects of astronomy

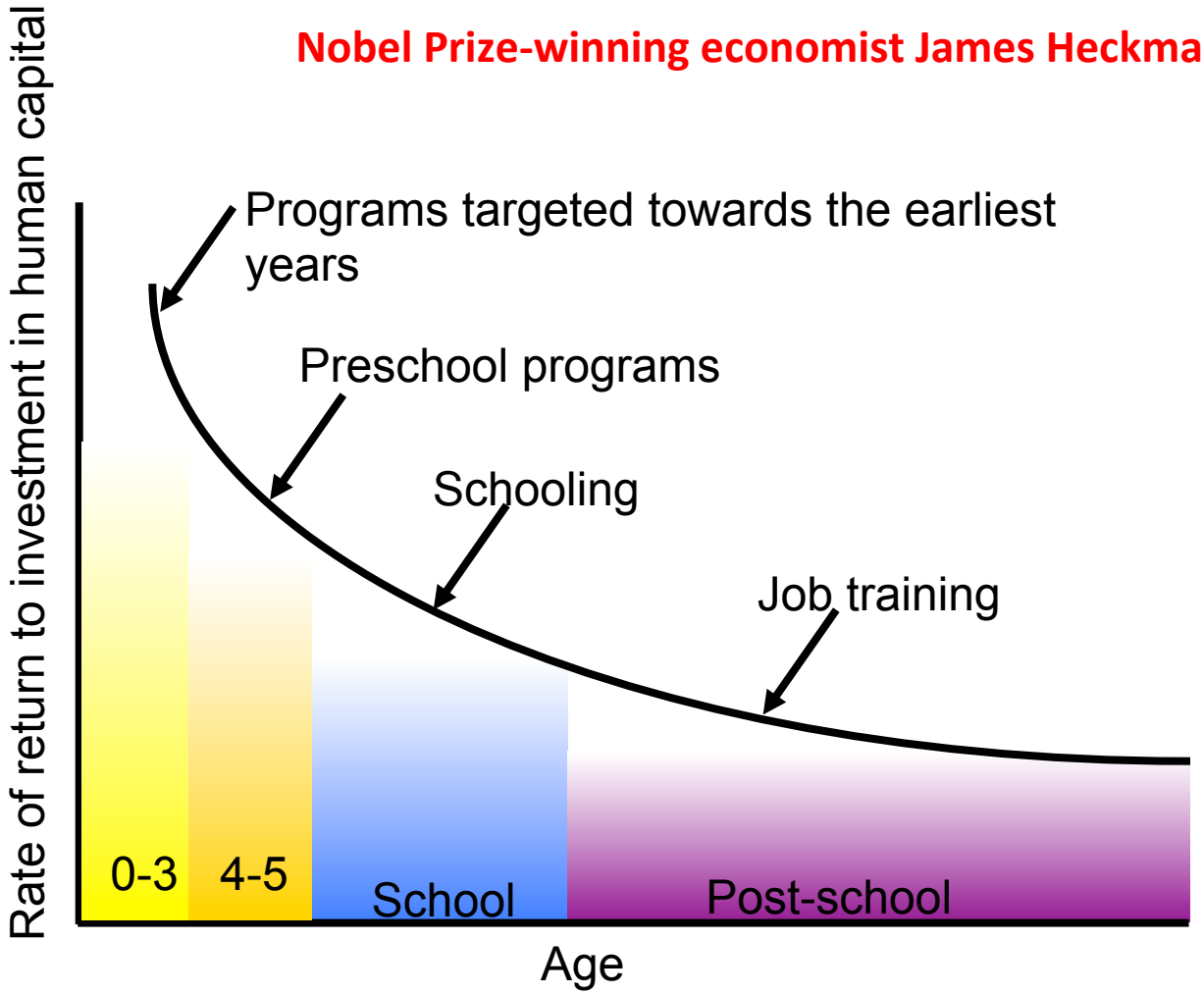
- Use INSPIRATION and FUN of astronomy to
  - Introduce excitement of science
    - Demonstrate power of rational thought
    - Motivate development of language and numeric skills

- Use PERSPECTIVE of astronomy to
  - Broaden children's minds
    - Stimulate sense of internationalism, tolerance, respect at formative age
    - Combat extremism

WHY YOUNG DISADVANTAGED CHILDREN?
ECONOMIC RATIONALE

Rates of Return for Human Capital Investment at Different Ages
$1 Investment in pre-school education yields $7 on long term

Nobel Prize-winning economist James Heckman (2007)



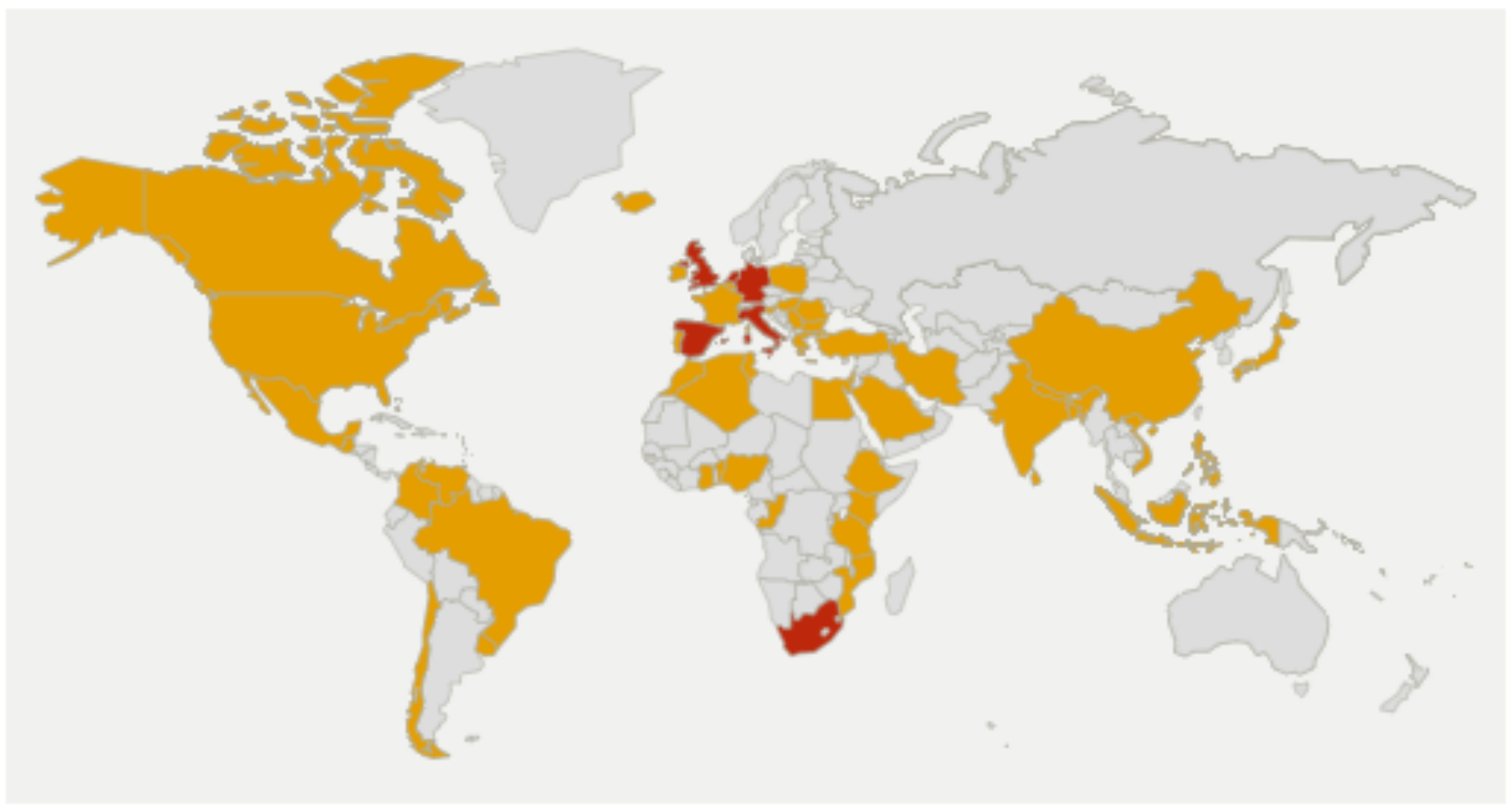
MOTIVATION BEGETS MOTIVATION BEGETS MOTIVATION

MUCH MORE THAN JUST ECONOMIC EFFECTIVENESS
AWARENESS OF UNIVERSE GIVES PERSPECTIVE
CAN HELP COMBAT FANATICISM

"*Fanatic ethnic, religious or national identifications* are difficult to support when we see our planet as a fragile, blue crescent fading to become an inconspicuous point of light against the bastion and citadel of the stars. "
CARL SAGAN

EARTH FROM SATURN (CASSINI)

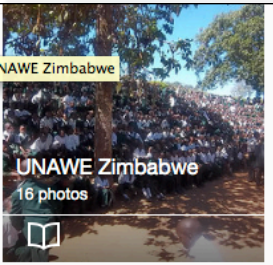
UNAWE NOW IN ~ 60 COUNTRIES

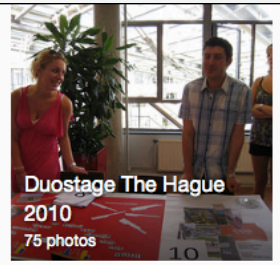


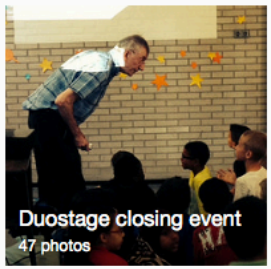
56 UNAWE Countries
(6 of them EU-UNAWE)

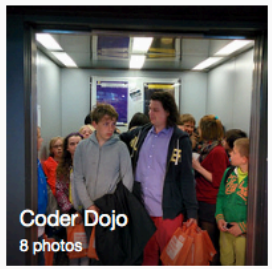
500+ Educators/Teachers/
Astronomers

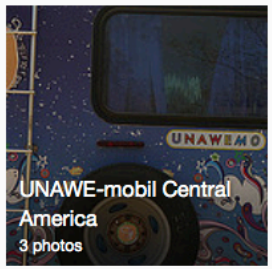
UNAWE NOW IN ~ 60 COUNTRIES

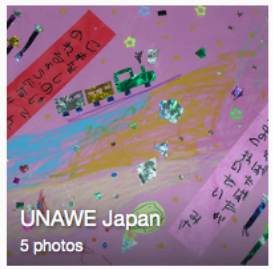


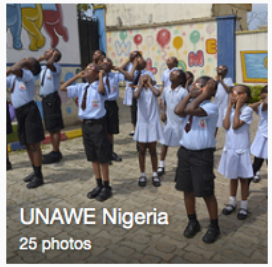


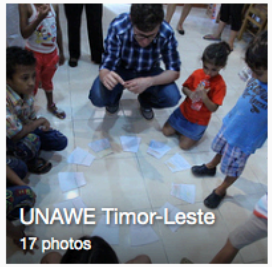


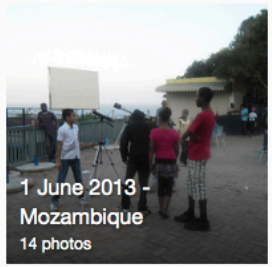


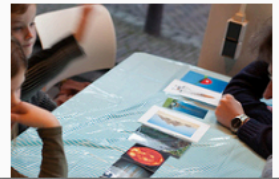










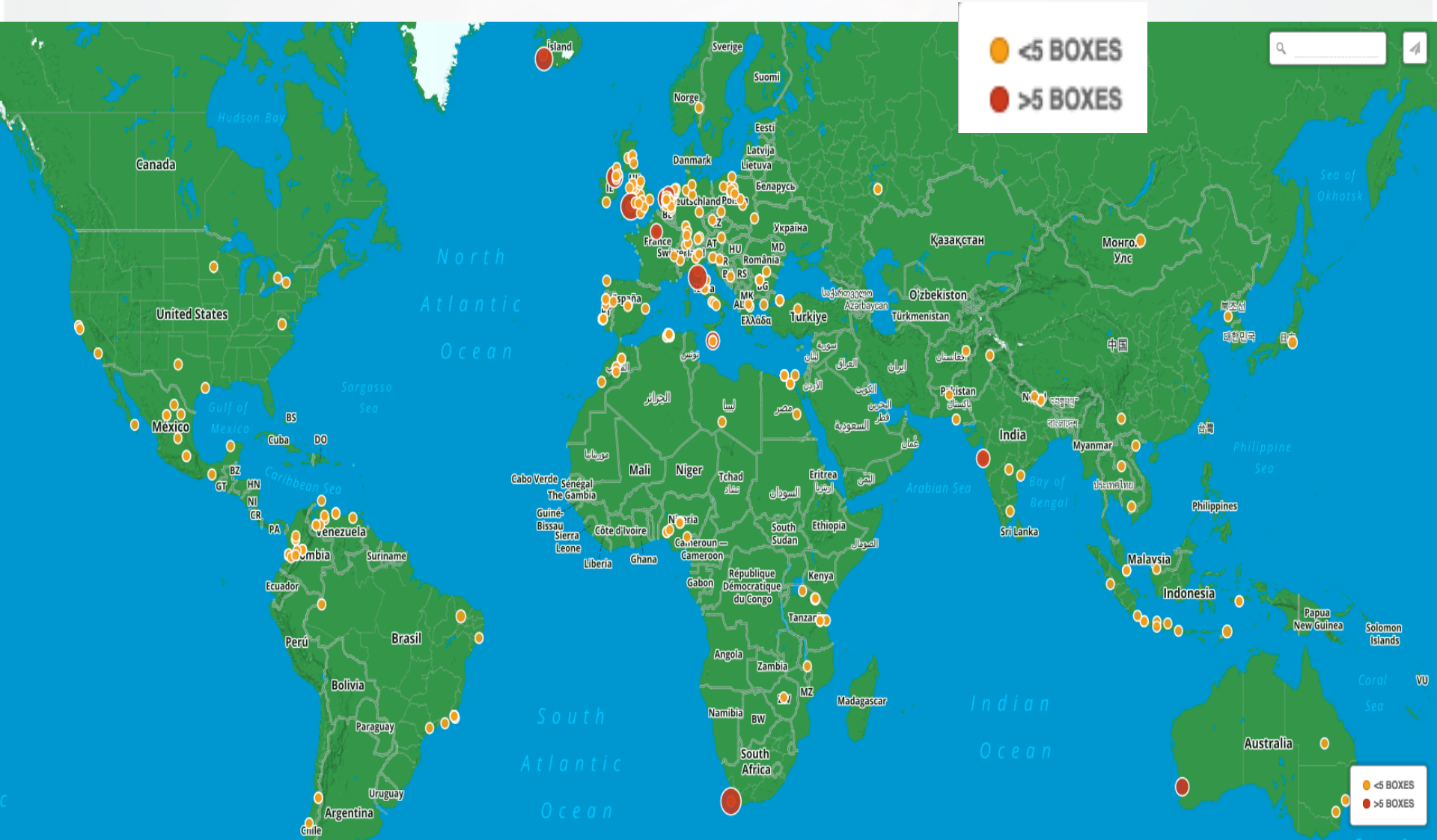


EU-UNAWE RESOURCES - e.g. UNIVERSE IN A BOX

- Developed by HdA Heidelberg
- 10 000 distributed to schools and teachers
- 57 Different countries

UNIVERSE IN A BOX GLOBAL DISTRIBUTION VIA CROWD FUNDING

Ashton, Russo and Heenatigala, 2014



LOFAR WOULD NEVER HAVE BEEN FUNDED AS PURE SCIENTIFIC PROJECT

FUNDS FOR SKA PHASE2
NEEDS STRONG POLITICAL RATIONALE
IN ADDITION TO PURE SCIENCE

VLBI > TECHNOLOGICAL AND HUMAN CAPACITY BUILDING ACROSS COUNTRIES
INTERNATIONAL DEVELOPMENT

SHOULD BE INTEGRATED PART OF SKA PROJECT

CONGRATULATIONS JIVE

European Research Infrastructure Consortium

CONGRATULATIONS HUIB JAN

CONGRATULATIONS MIKE

CONGRATULATIONS RICHARD