Lab Notes - for Teachers

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Telescope Dreaming

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Article

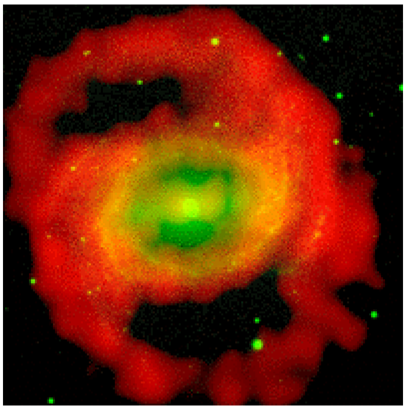
Telescope dreaming

- by Helen Sim (from http://www.abc.net.au/science/slab/sim/)

It's 10 pm on 5 March, 2013, and you've just checked the Net for the latest results on a newly discovered parallel universe.

You, and thousands of other people in your city, are taking part in a giant new experiment in astronomy. On the roof of your large communal building is a set of flat 'tiles', each about 2 square metres. Each tile is a piece of a radio telescope. All up, there are more than half a million of them - that's a million square metres in all, so the whole outfit is called the one-square-kilometre telescope.

Most of the time the tiles catch satellite TV broadcasts for you - in fact the instrument was funded by selling them for this purpose - but for an hour each day, at a specified time, all the tiles turn their attention to deep space. Today you are studying a riotous party the Universe had in its teenage years, when it went into a frenzy of galaxy-making. The data stream in from space. Each tile takes its share and, with built-in intelligence, does processing on the spot. From there, the data are piped through the central processor for your building, then squeezed down the optical fibres that connect your home to the world.

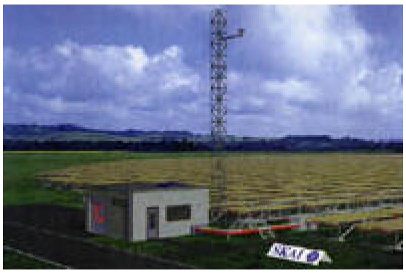


Thumbnail Image: S. Ryder et al. Data: ATNF and CTIO
(Click on image for full size and explanation)

From across the city the data converge to one building, where they are threshed and winnowed and turned into a picture - a radio picture, red yellow and green maybe, or whatever colours you like, but an otherwise true picture of objects 8 billion light-years away. Tomorrow you will be looking for signals from extraterrestrial intelligence; the day after that, Earth-sized planets around nearby stars.

Your part of the telescope is new. The first bits were built in 2010, on flat barren land far from the city - much of it land ruined by salination. Patches of the tiles, 100 m across, dotted the landscape: they were like flattened white cows corralled in the paddocks, continuously milked for the signals trickling from space. But the final oil crisis has struck, and the new bits of the telescope have been built in more accessible spots - somewhere cheaper to get to. The telescope tiles themselves, however, are solar-powered.

In any case, they have no moving parts. There is nothing mechanical to go wrong. But if a panel dies - zapped by lightning - the monitoring system in your building alerts you to the fact. You, like many other people around the city, are paid to maintain the system, which just means pulling out dead panels and replacing them with spares.



Thumbnail Image: Netherlands Foundation for Research in Astronomy
(Click on image for full size and explanation)

You can also take part in some of the telescope's many projects. Most people doing this are attracted to the SETI program, the search for extraterrestrial intelligence, although some like to get updates on the cosmology-related programs, such as that new universe found budding off our own. Results and discussion are updated continuously on the Net.

The Dark Ages

But why was this thing built in the first place? Back in the '90s of the last century the Hubble Space Telescope gave humanity its first good look at galaxies in the distant, early Universe. Not the super-bright quasars but ordinary galaxies, like the ones in today's Universe.

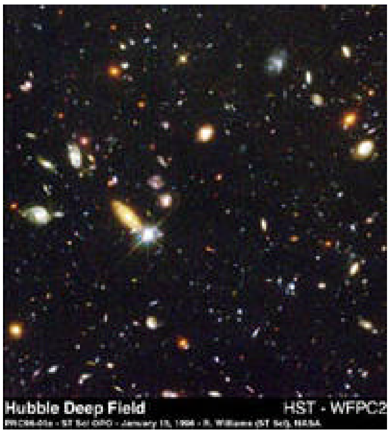


Image: Robert Williams and the Hubble Deep Field team (STScI) and NASA
(Click on image for full size and explanation)

A few years earlier, before Hubble was really into the swing of things, another miracle machine called the COBE satellite had measured the ripples in the Cosmic Microwave Background - the after-glow of the Big Bang. This was going as far back as you can see - as far back as we will ever be able to see using light or other wavelengths of the electromagnetic spectrum. Beyond that, the Universe is not dark, but opaque. That realm we'll learn about only - if we ever do learn about it - from exotic stuff such as neutrinos and gravity waves.

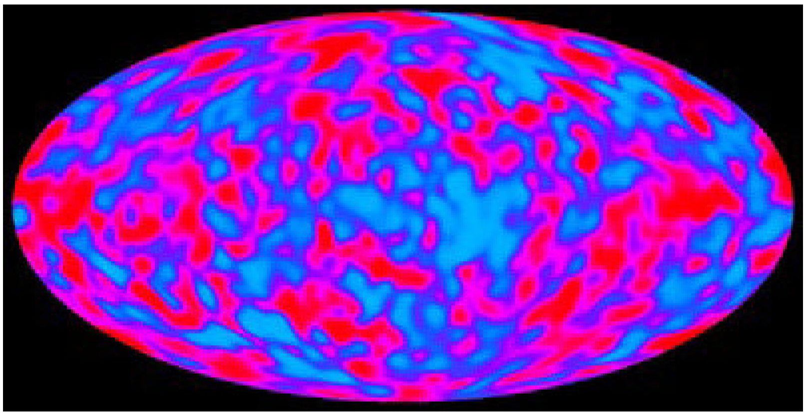


Image created from COBE DMR data sets developed by the NASA Goddard Space Flight Center under the guidance of the COBE Science Working Group and provided by the National Space Science Data Center (NSSDC).
(Click on image for full explanation)

But between the distant galaxies and the even more distant Cosmic Microwave Background lay a lightless region that astronomers had nicknamed the Dark Ages. This was the time before the stars. Here the earliest galaxies were born. Here the primordial stuff of the Universe, hydrogen gas, was gathered by gravity into the large clouds, clouds that one day would condense and shine forth as stars, lighting the Universe and creating the elements from which we are made.

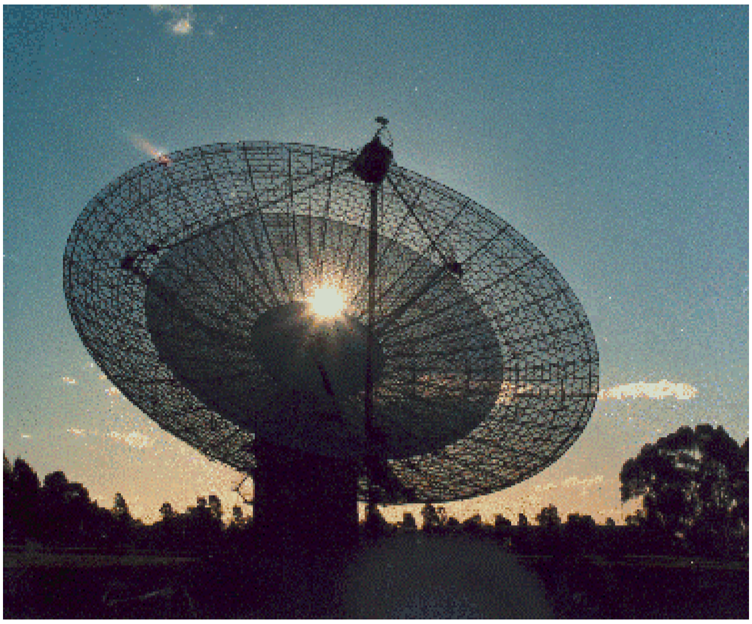
Astronomers hungered to map and weigh the primordial hydrogen. Yes, they could do it - in principle. Hydrogen gas puts out a characteristic radio signal with a wavelength of 21 cm. And so to see back to the Dark Ages, the astronomers built a mega-telescope, the one-square-kilometre telescope.

OK, enough fantasy. Rewind to December 1997. Radio astronomers from ten countries are meeting at CSIRO's Australia Telescope National Facility in Sydney to discuss their visions of the mega-telescope of the future. Visions, plural. As well as the magic tiles, there's a telescope with bits held 3 km up in the air by balloon. A landscape of dishes nestled into the Earth. A small army of satellite TV receivers. But the astronomers are not just discussing a single telescope, however ambitious. They are contemplating the whole future of their science, which has reached a cross-roads. A point where decisions must be made.

What is this thing called radio astronomy?

Radio astronomy was born 60 years ago, fathered by a couple of engineers, blokes more familiar with vacuum tubes that with the vacuum of space. It was an accident, really. In the early 1930s Bell Labs engineer Karl Jansky was trouble-shooting problems with transatlantic telephone calls when he found radio signals coming from space.

After the World War II groups of Brits, Aussies and Dutch worked up this finding into a new branch of astronomy. By the end of the '50s it was a science symbolised by the Big Dish - a giant radio-receiving instrument such CSIRO's at Parkes, New South Wales. Big Dishes now dot the globe. The grandest, 305 m across, lives in Arecibo, Puerto Rico. Too big to push around, it crouches in a hole in the ground, and acts in James Bond movies in its spare time.



CSIRO's Parkes telescope, 64 m edge to edge. Here's part of the control desk inside.
Photos: J. Masterson, B. Gaensler

These telescopes are essentially machines for making pictures. The pictures are like photographs, but made from radio waves instead of light. (Being made from radio waves, you can have them whatever colours you like.) They give an alternative view of reality. Traditional, light-based astronomy left us blind to a large part of what goes on in the Universe. It's been likened to trying to understand 'the symphony of the Universe' with ears that can hear only middle C and the two notes either side of it.[1] Radio astronomy was the first kind of astronomy to open a window on the Universe that is not limited by what we can see.

And what has it found? Violence: galaxies colliding, ripping each other to bits, blowing themselves apart. Monster black holes spouting like whales. Smog clouds of chemicals in space, some of them key chemicals for life. The tiny ticking critters called pulsars (hear some here.) Natural equivalents of lasers. Radio astronomers also found the key to quasars, determined the structure of the Galaxy and found the Cosmic Microwave Background - the 'smoking gun' of the Big Bang.

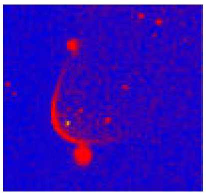


Image: Andrew Fruchter, STScI

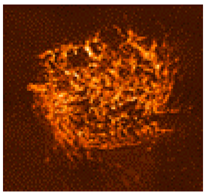
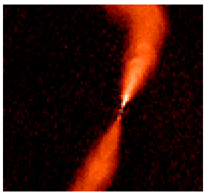


Image: S. Kim et al. Data from the Australia Telescope



A galaxy spouting like a whale. Image: R. Laing et al.

Compact Array

(Click on images for full size and explanations)

These are all still current areas of research, and things astronomers would be happy to turn a mega-telescope on. If you want the details, wander through the piece by Richard Strom. (And to see a telescope in action, look here.)

Another big use for a mega-telescope is SETI - the search for extraterrestrial intelligence. Most of these searches are done with radio telescopes: the listeners hope to pick up either purpose-built radio 'beacons' ("Hey guys, we're here!") or stray signals leaking off another planet. In 1995 CSIRO's telescopes were used for part of the large Project Phoenix search (check it out at the Ingenious page, or sing about it here). Starting in 1998 the Southern SERENDIP project, run by SETI Australia, will be 'piggybacking' on another project running on the Parkes telescope.

For these searches, the bigger the telescope the better. A one-square-kilometre telescope would have 400 times the collecting power of the Parkes telescope for a Project Phoenix-type search.

Back in 1971 the SETI community dreamed of their own version of a mega-telescope: Project Cyclops, a multi-eyed monster of 900 dishes, each 100 m across. The technology wasn't affordable then, but it may be soon.

Why bigger is better

Everything radio astronomers have learned about space is from tiny weeny whispers. The energy from all the cosmic signals collected by all the radio telescopes for the past sixty years adds up to less than that of a falling raindrop.

Which is why bigger is better. A bigger bucket collects more rain, and a bigger telescope collects more of the very weak signals, which is essential if you want to hear the proto-galaxies muttering.[2]

Collateral damage

However, there's a snag. It's no good turning up your hearing aid to hear someone whisper if there's a party raging on around you. Swirling around today's telescopes is a cloud of electromagnetic smog - radio interference. All radio telescopes are under attack, especially from communications satellites. Trying to record the cosmic whispers under these conditions is like trying to record birdsong on the runway of an international airport.

How serious is the interference problem? Very. Extreme pessimists fear their science will be wiped out, and soon. Less extreme pessimists are still frustrated to think that their telescopes are doomed to grow increasingly deaf. Only 2% of the radio spectrum is set aside for exploring the Universe, and even that sliver is polluted by signals spilling over from bands allocated for other purposes.

"Do not go gentle into that good night," advised poet Dylan Thomas. "Rage, rage against the dying of the light". But raging isn't enough. There are only four ways to fight this electromagnetic pollution:

- the national park strategy - regulate to keep pieces of 'untouched wilderness' in the spectrum
- the shark-net strategy - suppress interference before it gets into your telescope (by teaching the telescope to recognise these signals and reject them)
- the oil-spill strategy - clean the signals out of the recorded data
- the Bart Simpson ("I'm out of here man") strategy - go to the far side of the Moon, which is sheltered from Earth's radio signals. (OK, there are a few problems putting a telescope there, including serious risk of being hit by chunks of rock from space, but it looks good to some people.)

Regulation is essential, but the astronomers have to find a technological solution too, if they are not to be wiped out. Without this, it wouldn't be worth building a one-square-kilometre telescope.

Change or die

But even if interference weren't beating down the door, the astronomers would still be pushing for radical change. They reckon Nature demands it.

Growth in many areas - internet use, the human population - starts off exponential. Then it hits a crisis point. "The outcome of the battle at the point of no return is complete reorganization or violent fluctuation or death …", said Derek de Solla Price, who wrote about this behaviour 25 years ago.[3] The best outcome is reorganisation, which leads to a new period of exponential growth. The message is clear: "change or die".

Radio astronomy has been in the exponential growth phase. Radio telescopes' sensitivity - that is, their power to detect weak signals - has increased exponentially since 1940, increasing by a factor of 100 000. Astronomers such as Ron Ekers, Director of CSIRO's Australia Telescope National Facility, reckon it's crunch time now:

If the improvement in sensitivity has reached a ceiling the rates of new discoveries will decline and the field of radio astronomy … will become uninteresting and die out. On the other hand if we can shift to new technology or find new ways to organize our resources the exponential increase in sensitivity can continue …[4]

To follow the trend line you need an instrument with the sensitivity you'd get from a collecting area of one square kilometre - a hundred times more than today's leading radio telescope, the Very Large Array in New Mexico.

"Field of Dreams"

That may seem like a very abstract, even arbitrary, way to decide on the future of your science. But the lesson from de Solla Price ties in with what you might call the 'Field of Dreams' factor, after the 1989 baseball movie of that name.

"If you build it," said the mysterious Voice in the movie, "he will come." The Voice was talking of a dead baseball hero. Astronomers would prefer to be visited by new discoveries, but the principle is the same. Build a new instrument, one with new capabilities - far more sensitivity, or wavelength range, or whatever - and you will discover new phenomena that have been lurking there out, undetected. The Hubble Space Telescope pictures showed us how this works. Many are of things that literally couldn't be seen before.

The argument and evidence for this process were set down in 1981 by Martin Harwit in his book, "Cosmic Discovery."[5] The astronomers have read Harwit, and factor his arguments into their planning. Of all the parameters that they can work for, sensitivity promises the most. And the minimum collecting area needed to put them in a new regime of discovery is … you guessed it, one square kilometre.

Going for broke

Perhaps the mega-telescope could be more than a sensitive new-age detector. Perhaps it could 'multi-task' as well.

A conventional radio telescope can't see all of the sky at once. Because of the way its dish catches and focuses radiation, it is blind to all but a tiny spot of sky. This spot is called the telescope's 'beam'. Traditionally, telescopes such as Parkes have had only one beam. But you can have more. The Parkes telescope, for instance, recently had fitted to it a 13-beam receiving system, which allows it to see 13 times more sky at once than it normally would (and thus to rip through a sky survey about a dozen times faster than usual).

In the 'magic tile' concept for the mega-telescope, the direction in which the flat plates 'look' is orchestrated by electronics. In theory, the magic of quantum mechanics allows such an instrument to have many, many simultaneous beams - a hundred? more? - which means that it can be doing many things at once. Instead of observers queuing up to take their turn, they could all crowd onto the telescope at once, in a kind of cosmic jam session.

In practice, however, the technology to do all this does not yet exist. It would take a hundred thousand times more computing power than exists today. The astronomers hope to lean heavily on Moore's law, which says that processing capability doubles every 18 months. The crucial strategy for the 'magic tile' approach is not to work with technology that exists now, and nail it down, but to anticipate where the technology will be when it comes time to build the telescope. The Moore's Law solution, however, will not be enough. In 10 years Moore's Law will 'automatically' deliver astronomers only a 100-fold improvement in processing power. Any more than that would require extra effort - and money.

Magic tiles are not the only game in town. But the other proposed designs are less startlingly different from today's telescopes. All have their strengths and weaknesses. Canada backs a very large dish with an 'adaptive' surface and with the business end of the telescope held 3 km up in the air by balloon. China wants to clone the Arecibo telescope and settle the many offspring in the 'karst' limestone country in the country's south-west. India and the SETI Institute are talking about a battalion of conventional dishes.

Whatever the design, it will be viable only if costs can be kept down, to around a few hundred dollars a square metre of collecting area. This is a tenth of the lowest-cost telescope built recently, India's Giant Metre-wave Radio Telescope. Another huge problem is how to connect all the various elements - the individual tiles or small dishes - without getting too complex for the available computing power.

Born international

The technical problems, though great, are not the only ones to overcome. This is the first project in the field of radio astronomy that has been 'born international'. Large astronomy projects - such as the Hubble Space Telescope, Gemini or the alcoholic-sounding VSOP - tend to be led by one country, with others joining later. But the one-square-kilometre telescope grew out of discussions held in two 'umbrella' bodies, the International Union of Radio Science and the International Astronomical Union. It does not have a single nation championing it, and it exists outside the major existing frameworks for this kind of project.

The fight to be the telescope's host country has not yet begun but the preliminary issues - how to decide how to decide - are being thrashed out at present. Australia is one of many countries in the running.

Choosing a future

Despite these difficulties the radio astronomers will chase their dream. There will be discussions, yea, and arguments, and wheeling and dealing. Because the alternative is a slow lingering death for radio astronomy, perhaps over a couple of decades.

But why should we - even a worldwide "we" - fund such an instrument? At the beginning I painted a picture of a future which includes a slick new telescope but also an energy crisis and land ruined by salination. Would we not be better putting our money into trying to solve those problems? In her recent book, *Pythagoras' Trousers*, science writer Margaret Wertheim levels a charge at the high-energy physicists seeking a Theory of Everything, namely that they

"have become like a decadent priesthood, expecting the population to build them ever more lavish and costly cathedrals, with spires reaching every higher,"[6] *for exploring "territory that is not only irrelevant to most people's lives [but also] beyond their comprehension".*[7]

These are serious charges. Do the radio astronomers stand accused as well?

First, a one-square-kilometre telescope is likely to cost on the order of US$500 million. Unless you work in the financial markets, this seems like a lot of money. One could think of many alternative uses for it. In relative terms, however, it is less than 1% of the International Space Station that will start construction this year, at an estimated cost of US$58 billion. It is less than a thousandth of the world's expenditure on arms, which is running at about US$860 billion a year. It is even only 5% of the $9.6 billion Australians spend on gambling each year. And the burden would be borne by several countries and spread over at least five years. These numbers don't make some absolute argument in favour of building a large telescope but they do highlight that making choices about social expenditure involves weighing up many areas.

Second, building such a telescope is not something we can put off for fifty years or so, while we fix up other aspects of our existence. Without continued development, the whole science of radio astronomy - in other words, the people with the desire and the skills to do it - will disappear.

Would findings of a mega-telescope be "beyond [the] comprehension" of most people? They would certainly be more accessible than a Theory of Everything. Astronomers deal with a historical account of the Universe rather than with an abstract blueprint. They are genealogists, on a grand scale, and what they discover about the Universe is much more amenable than a Theory of Everything to being formulated as a good old-fashioned narrative. Astronomers have a social responsibility to communicate what they do. In Australia, at least, they are strongly committed to doing so.

Still, what people would receive is an account of the Universe handed out by an elite. The way the science is organised today, amateurs contribute in only a limited way to professional astronomy (mainly in the fields of supernovae and comets) and the general public not at all. This is quite different to a field such as palaeontology, for instance, as Thomas Rich has described.

However, the line between professionals and amateurs was much more blurred in Australia (and elsewhere) before the 20th century, and conceivably could be again. There are some experiments in public involvement taking place - for instance, the SETI@home project of the University of California, Berkeley. The idea is to distribute the processing of the large amounts of data gathered in UC Berkeley's SERENDIP project, a SETI search. Ordinary people could download data and the software to process it with, run it on their home computers, and return the results to UC Berkeley via the Net. The project is not yet running but already 70 000 people have offered to take part. It's at least possible that a SETI project running on a one-square-kilometre telescope could offer this kind of involvement.

Could a one-square-kilometre telescope be too powerful? CSIRO's Dr Ray Norris has been musing recently about whether a SETI detection would kill science. He argues that if we got hold of an 'Encyclopedia Galactica', scientists (in some fields at least) would give up doing science for themselves and concentrate on interpreting The Book. Would a mega-telescope also give us too many answers, too fast? What if you had so much power you could answer all questions in astronomy by Friday lunchtime?

A telescope is not a book. The questions we ask with it, and the information it provides, depend on the view of the world we have constructed for ourselves. A mega-telescope working in only one part of the spectrum is unlikely to answer all the questions. Indeed it should generate more.

While we tend to pay more attention to the process of getting answers, astronomy can also be viewed as a process of creating new questions to ask about the Universe, whether by extending existing problems or by shifting paradigms. If this is so, it implies that astronomers can never attain a final, completed picture of the Universe (nor, perhaps, do they want one). An evolving picture of the world seems intrinsic to astronomy as it is currently practiced.

Fields die when they become uninteresting: when their problems cannot be solved, or when all their problems can be solved, and there are no new interesting ones to work on. This will happen to astronomy when it reaches an end to the problems amenable to observation: if astronomers run out of ways to wring information out of radiation, or they lose the interest, talent or just money to do so. It's unclear what some of the consequences of building a mega-telescope would be - for instance, how the existence of such an international instrument would affect the nation-based institutions that have fostered radio astronomy so far. But the consequences of not building it seem clear.

A mega-telescope will not 'take us to God' - as proponents of the Theory of Everything have claimed for their science.[8] It will simply answer some questions about the Universe, questions which will probably be followed by other questions. We, as a community, have to decide if that is worth doing.

Notes

1. Nigel Henbest and Michael Marten, **The New Astronomy**, CUP, 1996, p. 6

2. Actually, this is only one reason for building bigger telescopes. The other is to get more resolving power - to be able to see more detail. This is what astronomers have concentrated on in the past. But you can sneak around that problem in a different way, by building a giant 'virtual' telescope. The problem of collecting enough signal - 'sensitivity' - needs lots of collecting area - a big real telescope.

3. Derek de Solla Price, **Little Science, Big Science**, Columbia University Press, 1963, p. 30

4. R.D. Ekers, "SETI and the One Square Kilometre radio telescope" (Pesek Lecture, 46th International Astronautical Congress) International Astronautical Federation, 1995, p.3

5. Martin Harwit, **Cosmic Discovery**, The Harvester Press, 1981

6. Margaret Wertheim, **Pythagoras' Trousers**, Fourth Estate, 1997, p. 239

7. Ibid.

8. Ibid.

Activities

Read the article carefully and complete the following activities.

Meanings

This article uses many expressions which are "analogies". For example, it talks about the universe having a party during "its teenage years". What does the author mean by that here?

Here are some more analogies used in the article. Write their usual meaning and what the author meant by them in this article. (A dictionary and thesaurus will help!)

Expression	**Usual meaning**	**The meaning within this article**
threshed and winnowed		
milked		
The Dark Ages		
hungered		

Questions

1. At the start of the article, you are asked to imagine you are taking part in a "giant new experiment in astronomy". Describe that experiment. What do you have to do in the experiment?

2. How could the tiles have "built-in intelligence"?

3. In the section called "The Dark Ages", the article describes some of the most important discoveries in today's radio astronomy. What are those discoveries? Why are they important?

4. Why are astronomers particularly interested in studying a patch in space called "The Dark Ages"?

5. How did radio astronomy start?

6. The article says: "Radio astronomy was the first kind of astronomy to open a window on the Universe that is not limited by what we can see." What does this sentence mean?

7. Radio astronomy has discovered great violence in the sky. Describe some of these violent happenings.

8. How are radio telescopes being used in the search for extra-terrestrial life?

9. Why is "bigger better" in radio astronomy?

10. Some radio astronomers "fear their science will be wiped out, and soon". Why do they think this will happen?

11. Here is a passage from the article: "'If you build it,' said the mysterious Voice in the movie [The Field of Dreams], 'he will come.' The Voice was talking of a dead baseball hero. Astronomers would prefer to be visited by new discoveries, but the principle is the same." How is "the principle the same"?

14. The article argues that "decisions must be made". What are these decisions, and why must they be made?

15. The article describes a few different types of huge radio telescopes that might be built. Describe them. (Include a diagram in your answer.)

16. The article gives a few reasons why such huge telescopes should be built. What are those reasons?

Cloze Activity

Here are some extracts from the article. Complete the sentences by filling in the spaces.

It's 10 p.m. on 5 March, 2013, and you've just __________ the Net for the latest results on a newly discovered parallel universe...

The Hubble Space __________ gave humanity its first good look at __________ in the distant, early Universe...

Radio __________ was born 60 years ago, fathered by a __________ of engineers, blokes more familiar __________ vacuum tubes that with the vacuum of space...

Everything radio astronomers ___________ learned about space is from ___________ weeny whispers...

Swirling around today's telescopes is a ___________ of electronic smog - radio interference...

If ___________ improvement in sensitivity has reached a ___________ the rates of new discoveries will decline and the field of ___________ astronomy will become uninteresting and ___________ out...

Build a new instrument, one with ___________ capabilities - far more sensitivity, or wavelength range, or time discrimination, or whatever - and you will ___________ new phenomena that have been ___________ there out, undetected...

Perhaps the mega-telescope ___________ be more than a sensitive new-age detector...

The ___________ to be the telescope's host country has not yet begun...

Despite these ___________ the radio astronomers will chase their dream...

Debate

Think of all the arguments for and against these statements. (To help you, use this article and others that you can find.)

"Why should we - even a world-wide 'we' - fund such an instrument? There are far more important problems to solve, including an energy crisis and land ruined by salination. We would be better putting our money into trying to solve those problems."

"One day we will make contact with intelligent life somewhere else in the universe."

"There is no role for ordinary people in radio astronomy."

Summary

This article has a number of sections. Each section has a main point. Write down the main point of the sections named here.

Telescope dreaming

The Dark Ages

What is this thing called radio astronomy?

Going for broke

Why bigger is better

"Field of Dreams"

Research

Use this article, the Internet and libraries to find information on one of these topics:

a) The Hubble Telescope gave humanity its first good look at galaxies in the distant early universe.

b) Another miracle machine called the COBE satellite had measured the ripples in the Cosmic Microwave background - the after-glow of the Big Bang.

c) Galaxies are born where the primordial stuff of the Universe, hydrogen gas, is gathered by gravity into the large clouds, clouds that one day condense and shine forth as stars, lighting the Universe and creating the elements from which we are made.

d) Galaxies collide, ripping each other to bits, blowing themselves apart.

e) Monster black holes spout like whales.

f) Smog clouds of chemicals float in space, some of them key chemicals for life.

Instructions to Students
Use the library or the Internet to collect information about the topic. Find at least four different articles or chapters.

Write down about three ideas from each article you find.

You now have about a dozen ideas on this topic. Choose which idea is the most important, which is second-most important, and so on.

Write them in order, from most important to least important.

Write a paragraph to explain each idea.

Write down where you found the information you used. This is your "bibliography".

Be prepared to deliver your report on the date it is due!

Teachers Guide for the Research Section

Oral Reports
Have students work in groups of two or three to prepare a short talk on one of the research topics.

Write down which topic each group chooses to research. Make sure there is at least one group for each topic.

Tell the class:
- how long the talks are to be (two to four minutes is effective),
- when they will give the talks, and
- how marks will be allocated.

Go through with the students the instructions on how to research (or use your own version!)

Written Reports
Have students write a report on one of the research topics.

Tell the class:
- how long the written reports are to be,
- when the reports are due, and
- how marks will be allocated.

Go through with the students the instructions on how to research (or use your own version!)

Suggested Marking Scheme

5 marks - Quantity of information

5 marks - Accuracy of information

5 marks - Relevance of information

5 marks - Clarity of presentation / use of diagrams

20 marks TOTAL