

Looking deep into galaxies

Part two of Astrowatch's coverage of the meeting of the International Astronomical Union in Manchester: *Emma Sanders* reports on new studies of active galaxies and the latest innovative instrumentation.



A Hubble Space Telescope image of the region surrounding the black hole in Centaurus A, our nearest active galaxy. (NASA/ESA.)



Bar structures facilitate gas flow, feeding activity at the centre of galaxies. (ESO.)

Today's telescopes allow astronomers to probe deep into the active inner regions of galaxies and see far back in time to the periods of momentous upheaval in the early universe. At this year's International Astronomical Union (IAU) conference in Manchester, attention focused on new high-resolution studies of some of the most energetic objects known to exist.

Around a billion years ago, at a redshift of about 5, the first galaxies started to agglomerate. They were very different from the galaxies we see around us today.

During this period of intense activity, quasars released extraordinary amounts of

energy into the interstellar medium, outshining galaxies of hundreds of billions of stars. These quasi-stellar objects are thought to be associated with the growth of big black holes in the inner parts of the first galaxies. Quasar activity is seen to peak at a redshift of around 3 – the same time at which bulges start to form in the centres of spiral galaxies.

Extra-galactic black holes

"The most convincing information about black holes comes from water maser emission in the surrounding accretion disks," said Martin Rees of Cambridge. Maser microwave emission also comes from OH and CH₂O

(formaldehyde) present in the disk, which is pumped by the far infrared emission. The maser allows astronomers to detect the transverse motion of material orbiting the black hole and to calculate the mass and density of the central region. We now know of 21 such megamasers.

Last May's meeting of the International Telecommunications Union provided good news for astronomers, as proposals were adopted to protect maser wave bands from radio pollution from mobile phone networks (March p11).

Dayton Jones of Caltech presented a radio image of the centre of galaxy NGC6241, ▷

showing two jets projecting outwards from the centre, as is common in such active galaxies. However, Jones has observed a gap in the jets that he believes is caused by absorption from the accretion disk of gas and dust orbiting the central black hole. The gap matches up with an optical image of the accretion disk taken using the Hubble Space Telescope (HST). The fact that different wavelength observations can be matched up in this way is a step forward in the understanding of black holes.

Radio observations of gas movement in the centres of galaxies and spectral line data from the HST suggest that super-massive black holes exist in the centre of every galaxy. "So why aren't more galaxies active?" asked John Conway of the Onsala Space Observatory.

With advances in interferometry instrumentation and techniques, studies of active galactic nuclei (AGN) have dramatically improved over recent years. Roeland Van der Marel of the Space Telescope Science Institute stressed the importance of bar structures in spiral galaxies that encourage gas to flow into the centre, feeding star formation. He believes that many AGN are hidden by dust

and will only be revealed as observations at other wavelengths improve. "With X-ray imaging now advancing, it will be interesting to see how much obscure AGN activity is actually going on," he said.

Sagittarius A*

The nearest black hole is in the centre of our galaxy, the Milky Way. It lies in a region of high activity known as Sagittarius A*. Recording

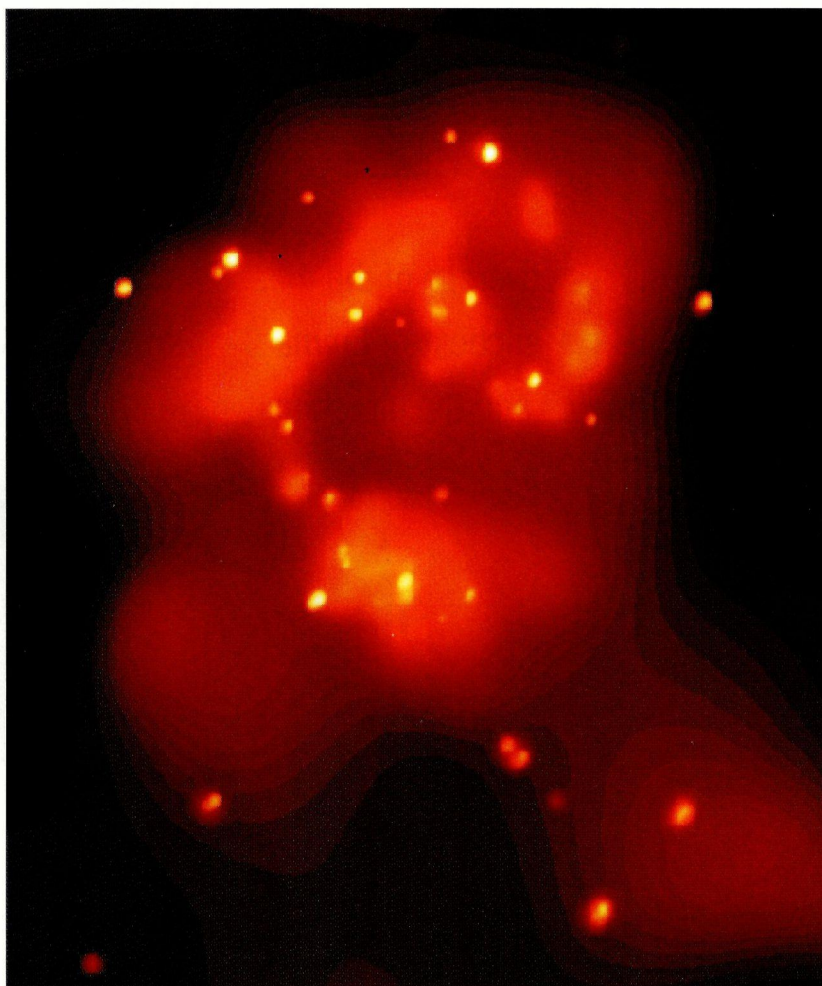
the movements of the stars in orbit around Sagittarius A* shows that the central black hole is 3 million times heavier than the Sun.

In the summary of the session on galaxies and their components at high-angular resolution, Peter Wilkinson of Jodrell Bank looked at what future telescopes will reveal. The Large Binocular Telescope being built by Italy, the US and Canada should record the orbits of individual stars close enough to measure whether general relativistic effects come into play. Does the black hole act as a point source mass (relativistic) or as a distributed mass (non-relativistic)? Using today's Very Long Baseline Interferometry (VLBI) radio observations, we can see Sagittarius A* down to 15 times the effective size of the black hole (Schwartzchild

radius). "By the end of the decade, sub-millimetre VLBI will be able to image the event horizon of the black hole," said Wilkinson.

New X-ray observations

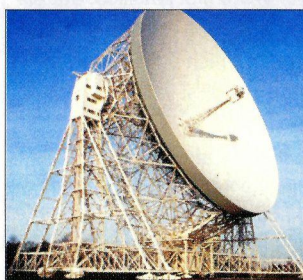
"What is new at this conference is that for the first time we have comparable resolution between radio and X-ray," said Rees. Indeed, with the launch of two new X-ray satellites, astronomers are spoilt for choice (April p11).



The interacting antennae galaxies X-ray imaged by the Chandra satellite. (NASA.)

Astronomy in Manchester

Manchester University, founded in 1851, was a fitting venue for this year's IAU conference. For nearly 50 years, the university's Jodrell Bank Observatory has been at the forefront of radio astronomy. The site is now headquarters for the MERLIN radio telescope network which pioneered high-resolution studies of galaxies. The network has a resolution of at least 50 milli-



The Lovell radio telescope at Jodrell Bank.

arcseconds, better than the HST.

The linchpin of MERLIN, the 76 m steerable Lovell radio telescope, named after Jodrell Bank's founder Sir Bernard Lovell, is undergoing a £2 million upgrade which is due to be completed by the end of 2002. This will allow the telescope to operate in a higher frequency range and will more than double its sensitivity.

In Manchester, X-ray images from NASA's Chandra satellite stole the show. The new results were presented by Guiseppina Fabbiano of the Smithsonian Astrophysical Observatory. "For the first time, we have sub-arcsecond resolution in conjunction with spectral resolution," she said.

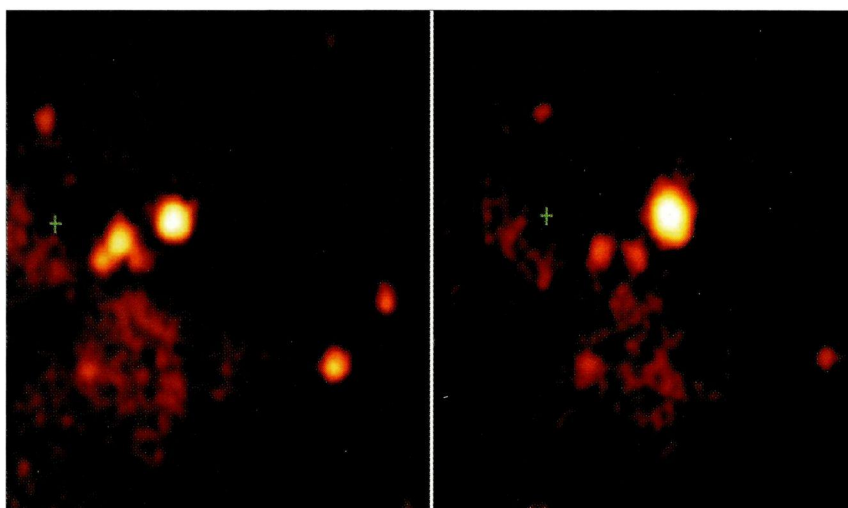
X-rays are emitted by the hottest, most energetic regions of the universe. Fabbiano

gave a run-down of the impressive range of observations now possible, including new estimates of the baryonic content of the universe, measures of the elemental composition of stars from supernova remnants, and a new perspective on the evolution of galaxies.

Observations of the antennae galaxies, colliding galaxies with streams of material emanating from their core, reveal huge bubbles of hot gas at X-ray wavelengths, and provide an example of conditions when our universe was young and galaxies were forming. "This is just the beginning," said Fabbiano.

Starburst galaxies

Andrea Prestwich of Chandra showed new X-ray images of starburst galaxies. M82 is particularly bright in the X-ray region, emitting a total of 10^{42} ergs/s. What was previously detected as X-ray background emission can now be resolved into point sources. Alan Pedlar of Jodrell Bank told the conference how radio images of the supernovae in M82 can be used for studies of the star formation rate and as a probe of the interstellar medium



Two Chandra images of the centre of M82, taken 3 months apart. (NASA.)

(February 1999 p9).

Much interest was generated by attempts to match up the X-ray sources with radio counterparts. The strongest X-ray source has no radio counterpart. The flickering of the source and its high luminosity are strong evidence that the X-rays are produced by matter accreting onto a black hole with a mass more than 500 times that of the Sun (see above).

Future instrumentation

Richard Schilizzi, director of the European VLBI network and chair of the symposium on galaxies and their components at high-angular resolution, told *CERN Courier* that his aim had been to bring together people from different wavelength ranges who work on the same things but who are perhaps not fully aware of what the others are doing. "It's been a real showcase of the latest experiments," he said. He was particularly enthusiastic about the many presentations on new instrumentation: "There are plans right across the spectrum, it really is fantastic."

During the meeting, astronomers from

Europe, the US, Asia and Australia signed an agreement to plan a huge new radio telescope, the Square Kilometre Array. Construction is scheduled to begin in 2010 and the finished telescope should give milli-arcsecond resolution, with a collecting area 50-100 times larger than existing radio interferometers.

In infrared, ALMA (Atacama Large Millimeter Array) will

bring equivalent resolution, with 64 12 m diameter antennae to be built over a 10 km area in Chile.

"What was completely new to me was the presentation on X-ray interferometry," said Schilizzi. "Gamma ray was a real eye-opener too - that Bragg diffraction crystals could give milli-arcsecond resolution at gamma-ray wavelengths."

At the start of a new millennium, astronomy is poised for a big leap forward in instrumentation across the whole electromagnetic spectrum. The future lies in combined multi-wavelength observations, which are set to provide new perspectives on the many fundamental questions waiting to be answered: How much mass is there in the universe? What is dark matter? How did large-scale structure form? How did galaxies form? Are there any pockets of antimatter left in the universe? What physical processes are behind the prodigious amounts of energy released in gamma-ray bursts? Does this have anything to do with high-energy cosmic rays? It's an exciting time to be working in the field. □

Astroparticle physics

"Astronomers are looking to establish new collaborations with research labs such as CERN and Fermilab," the new president of the IAU Franco Pacini told *CERN Courier*. Pacini is a great believer in the importance of increasing the ties between particle physics and astronomy. He points to many key areas of research that will benefit from combined efforts. "Neutrino experiments are

getting bigger and bigger," he said. "Many physicists are already involved in gamma-ray astronomy." The two communities should share knowledge of new advances in detector technology, and the organization of large experiments.

Research into fundamental cosmological values and the formation and evolution of stars will also benefit from new

collaborations. "Dark matter was discovered by astronomers," Pacini added. "Now, to find out what it is, is up to the physicists." The IAU is setting up a working group on particle astrophysics within its division on high-energy astrophysics. He promised that by the next IAU meeting, in Sydney in 2003, the working group will be in place and more joint projects will be underway.

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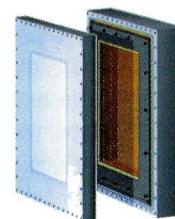
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