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SPECIAL REPORT INDIA

Building on a Mars success story

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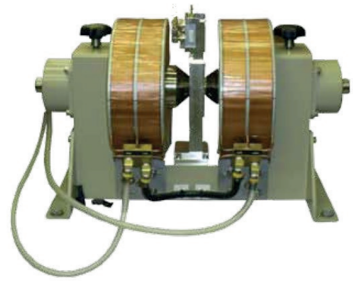

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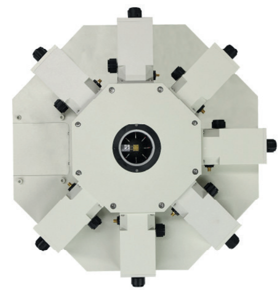

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Printed in the UK by Cambrian Printers Ltd,
Llanbadarn Road, Aberystwyth,
Ceredigion SY23 3TN

IOP Publishing

Physics World
Temple Circus, Temple Way, Bristol BS1 6HG, UK
Tel: +44 (0)117 929 7481
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Special report: India

In September 2014 India finally emerged as a major player in space exploration when it put a craft into orbit around Mars on its first attempt. It led to joyous scenes in the control room at the Indian Space Research Organisation (ISRO) as the scientists celebrated having just carefully manoeuvred the Mars Orbiter Mission into position around the red planet. Even India's newly elected Prime Minister, Narendra Modi, was personally on hand to witness the event, which will not only please ISRO chairman K Radhakrishnan (p9), but could also be taken as a sign that the new administration is serious about boosting science in the country (p5). Yet for all the out-of-this-world success this year, challenges still remain. India's education system continues to support its top research institutes while leaving lower-tier universities well behind (p11). More also needs to be done to boost science communication (p13) and international collaboration (p15). We hope you enjoy this *Physics World* special report and please do e-mail us your comments to pwld@iop.org.

Michael Banks, Contributing Editor, *Physics World*

On the cover
Building on a Mars success story (*Manjunath Kiran/AFP/Getty Images*)

News

New home for international centre

A major new international centre to boost interdisciplinary research is set to open in Hesarahatta, Bangalore, by mid-2015. Set up by the Mumbai-based Tata Institute of Fundamental Research (TIFR), the new International Centre for Theoretical Sciences (ICTS) aims to be a leading centre for higher education, training and research in India.

The proposal for an interdisciplinary institution in India first emerged in 2004, with the idea receiving a strong recommendation two years later from an international visiting committee that had reviewed the TIFR's theoretical-physics department in September 2006. A month later, the concept of a national centre for theoretical sciences was put forward to the TIFR's council, which quickly endorsed the idea.

In 2007 the International Centre for Theoretical Sciences of TIFR was established; but given that the TIFR's campus in Mumbai would struggle to accommodate the new centre, a decision was taken to move the ICTS to Bangalore. Housed to date on the campus of the Indian Institute of Science (IIS), the ICTS will move into a new dedicated building in northern Bangalore when construction is complete next year. One advantage for locating the ICTS is that it will be close to other top institutions such as the IIS, the Jawaharlal Nehru Centre for Advanced Scientific Research and the Indian Space Research Organization.

ICTS

Building foundations CNR Rao (left), Nobel laureate David Gross (centre) and Srikumar Bannerjee, former chairman of the Atomic Energy Commission, inaugurate the International Centre for Theoretical Sciences in 2009.

While the TIFR has mainly focused on research in traditional fields such as physics, mathematics, computer science and biology, the ICTS will target activities in areas such as astrophysics, gravitational-wave astronomy, statistical physics, complex systems, earth science and string theory. The ICTS is also a member of the LIGO Collaboration, which is aiming to build a gravitational-wave detector in India. A PhD programme, with degrees awarded by the TIFR, will be set up as well.

According to ICTS director and string theorist Spenta Wadia, the ICTS will in addition branch out into physical biology and condensed-matter physics next year, as well as set up a group in interdisciplinary mathematics. "The ICTS is unlike a standard research-based institute as it integrates multi- and interdisciplinary visitor-driven programmes with outstanding in-house research," says Wadia.

Indeed, the ICTS models itself on world-leading theory centres such as the Kavli Institute of Theoretical Physics at Santa Barbara, US, the Isaac Newton Institute for Mathematical Sciences in Cambridge, UK, and the Abdus Salam International Centre for Theoretical Physics in Trieste, Italy. However, Wadia maintains that the ICTS will have a "distinct identity" as it aims is to play "a catalytic role for research and education" in India.

Michael Banks

Energy

World's biggest solar power plant set to open

India has unveiled ambitious plans to build the world's largest solar-energy park. Dubbed the Ultra Mega Solar Power Project and located about 550 km south-west of New Delhi in the state of Rajasthan, the plant is projected to generate 4000 MW. When complete, it will be 16 times bigger than the 250 MW Agua Caliente Solar Project located in Arizona, US, which is currently the world's biggest such facility.

The country is proposing to construct the plant on an empty salt pan in the Thar Desert in western India. Having an area of about 10 km^2, it will be set on the banks of a highly saline natural inland lake. The first phase of the project will involve the installation of 1000 MW of capacity and is likely to be finished by 2016. When fully commissioned a decade from now, the Indian government estimates that the plant will supply enough energy to light more than 40 000 typical Indian homes.

Power from the Sun The next step in India's National Solar Energy Plan is the 4000 MW Ultra Mega Solar Power Project.

Pallava Bagla

According to the Indian Ministry of New and Renewable Energy, the plant is estimated to cost around Rs61bn ($1bn) but the government is hoping that it can source Rs30bn of subsidized green funding from the World Bank. The project is being spearheaded by the Solar Energy Corporation of India and is being supported by six public-sector companies that specialize in power, electronics and construction.

The idea for the plant stems from 2009, when India released its ambitious National Solar Energy Plan that set a target of generating 20 000 MW of solar power by 2022 at a cost of Rs1228bn. In 2013 India's installed capacity for solar stood at 2100 MW (with the highest being Germany at 32 000 MW).

Speaking at the Delhi Sustainable Development Summit in New Delhi earlier this year, Rajendra K Pachauri, chairman of the Intergovernmental Panel on Climate Change and director-general of the Energy and Resources Institute in New Delhi, emphasized the need to embrace clean energy, adding that "a large proportion of human society remains totally outside modern energy systems".

Pallava Bagla
New Delhi

News

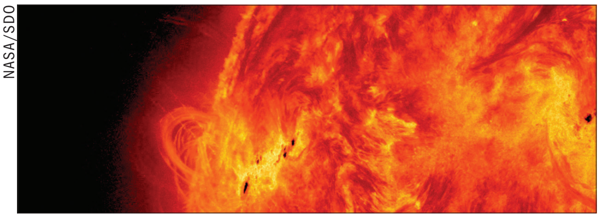
Solar physics

Scientists aim for the Sun with Aditya

The Indian Space Research Organisation (ISRO) has announced it will launch the country's first dedicated mission to study the Sun. Called Aditya-1 – meaning "Sun God" in Hindi – the Rs3.7bn ($61m) mission is expected to take off in 2017 or 2018 and will study the Sun for five years. The 400 kg satellite will be placed about 800 km above the Earth's surface to continuously track the Sun for a period of five years.

Aditya-1 will carry a solar coronagraph that will work at visible and near-infrared wavelengths together with polarimeters, a spectrograph and a charge-coupled device (CCD) camera. One of its main aims will be to improve our understanding of coronal mass ejections. These events – in which bursts of magnetic fields from the interior of the Sun emerge at its surface – are important as they can lead to a large increase in charged particles that hit Earth.

Being India's first dedicated mission to study the Sun's corona, the ISRO will have several technological challenges, including developing a highly polished mirror for the satellite, as well as implementing a way of quickly reading out data from its CCD camera. "This mission will be particularly looking at the Sun and


NASA/SDO

Solar surveyor India's Aditya-1 mission will study the Sun to see what effect it has on the Earth.

corona, which has the advantage that you avoid the interference of the Earth's atmosphere so you avoid all the scattered-light contributions," says K Sankarasubramanian, a solar scientist at ISRO. "We can expect very crisp images of the solar corona from space."

Aditya-1 could also help astronomers to gain more insights into the Sun's influence on the Earth. "We have seen over the years that the pattern of the climate has changed, so is there an effect of the Sun?" asks Dipankar Banerjee, a solar scientist at the Indian Institute of Astrophysics in Bangalore, which is a lead institution in building the craft together with the ISRO's Udaipur Solar Observatory in Rajasthan. "We also want to study space weather as we have many satellites in space and telecommunication gets affected because of changes within the Sun."

Pallava Bagla
New Delhi

Events

India embarks on a year of light

The historic city of Goa will be the host for India's first festival exploring the connection between science and art and design. To be held from 14–18 January 2015, the Story of Light Festival, featuring exhibitions, workshops and screenings, will be a collaboration between scientists and artists who will take topics in modern physics and make them accessible to the public through different art forms. The festival will be free and it is expected that around 50 000 visitors – including school and college students as well as the public – will attend.

The festival is a key part of India's plans to celebrate the International Year of Light (IYL). A resolution endorsing the IYL was first adopted by the UN Educational, Scientific and


IYL2015

Let there be light India will host a number of events in 2015 to celebrate the International Year of Light.

Cultural Organization (UNESCO) in October 2012 and submitted to the UN in November 2013. The UN's general assembly in Paris then officially declared 2015 the International Year of Light and Light Based Technologies in December 2013. Involving more than 100 partners from 85 countries, the goal of the IYL is to highlight the importance to society of light and optical technologies.

Other events in India to celebrate the IYL include talks to school children about light-based technologies. To be held on 20–21 June in the southern Indian city of Tumkur, the lectures aim to "make students appreciate, develop and promote efficient eco-friendly light-based technologies in their lives". The event will also include an evening seminar about light in art, culture and everyday life.

Michael Banks

Sidebands

Astrosat set for launch

India's first dedicated astronomy satellite is due to be launched in May 2015 by the Indian Space Research Organisation (ISRO). Dubbed AstroSAT, the Rs4bn ($70m) mission will study black holes, neutron stars and active galactic nuclei over a wide range of wavelengths from visible light to hard X-rays. The mission will take off on a polar satellite launch vehicle from the ISRO's Satish Dhawan Space Centre located in Sriharikota, Andhra Pradesh. Weighing around 1600 kg, AstroSAT will operate for five years in a near-equatorial orbit 650 km above the Earth's surface. The satellite is capable of gathering 420 gigabits of data every day and the craft will be controlled by a ground station at the ISRO's Satellite Centre in Bangalore, with data download possible during every visible pass over the city. AstroSAT will contain a 750 kg payload featuring five instruments, including imagers and detectors. It will use these instruments for studies such as surveying the skies in the hard X-ray and ultraviolet bands, as well as monitoring the sky for new transients and studying X-ray binaries, active galactic nuclei and clusters of galaxies. While many astronomers have warned that space-based X-ray astronomy could be hit hard over the coming years as key satellites go offline and are not replaced, AstroSAT could help to replace some of that missing capacity in X-ray observations.

New tsunami system begins

A new tsunami early-warning system based in Hyderabad is set to come online in early 2015. Built by the UK health-services firm RegPoint, the warning service will send SMS messages to all mobile phones in a designated location to give users guidance and information – such as the size, scale and expected time of the disaster -- before a tsunami strikes. RegPoint has teamed up with the Indian National Center for Ocean Information Services in Hyderabad, which operates a network of seismic stations and tide gauges around the Indian Ocean. No suitable warning systems were in place when a tsunami struck in the Indian Ocean on 26 December 2004, killing 230 000 people in 14 countries and displacing around two million people. It is hoped that the new early-warning system will help stop similar tragedies from happening again. "We are making the final improvements to a system that will undoubtedly save hundreds of lives," says Siddharatha Das, director of RegPoint's India operations.

To Mars and beyond

Following India's Mars success, **Pallava Bagla** looks at how science is faring under new Prime Minister Narendra Modi

ISRO

All change at the top India's new Prime Minister, Narendra Modi, has taken a keen interest in science, visiting the Indian Space Research Organisation twice since coming to office in May.

India's general election in May was truly the world's largest example of democracy. More than 814 million eligible voters from around the country went to the polls over a six-week period to cast their vote. The election was finally won by the Bhartiya Janata Party (BJP), which, led by Narendra Modi, then went on to form a government by building a broad coalition called the National Democratic Alliance.

In a boost to researchers in India, science seems to be a source of energy for the new government – indeed, the alliance's 42-page manifesto features more than two pages devoted to issues relating to science and technology. In the document, the BJP promises an "innovative and technologically driven society", claiming that India has "a knowledge economy and has been a leader in science and technology from ancient times". The manifesto also calls for an "ecosystem for fundamental research and innovation…scientific education and technology, promoted, practised and leveraged with renewed vision and vigour".

Since becoming Prime Minister, Modi has made all of the right noises regarding science and has already visited a number of institutions, including the Indian Space Research Organisation (ISRO) on two occasions as well as the Bhabha Atomic Research Centre in Mumbai, the Indian Council of Agriculture Research and the Defence Research and Development Organisation. "Our scientists are our strength and will help shape our future in the knowledge era," Modi noted on 11 May, which was dubbed "national technology day".

That month also saw Modi appoint physician Jitendra Singh, a respected diabetes researcher who has authored a dozen books on the subject, as the minister of state for the Department of Atomic Energy and the Department of Space. In November, Modi then chose surgeon Harsh Vardhan as cabinet minister for science and technology and earth sciences, as well as engineer Y S Chowdary as minister of state for science and technology and earth sciences. One key position that remains vacant, however, is the Prime Minister's science advisor – a post previously occupied since 2005 by the chemist C N R Rao.

Singh was quick to make his mark. To tackle the problem that many university posts cannot be filled, Singh has made it mandatory for every scientist working for the Ministry of Science and Technology to teach at least 12 hours of lecture classes per academic year (see p12). This move comes without any extra pay, however, and scientists will have to fit in the extra work on top of their other commitments. Meanwhile, new finance minister Arun Jaitley has also announced the creation of five new Indian Institutes of Technology (IIT), most of which are focused on engineering, as well as five new Indian Institutes of Management and four new All India Institutes of Medical Science.

Budget means business

While positive moves have been made in science, the Indian economy has recently been in the doldrums, growing at about 5% per year with inflation at about 6.5%. Many thought that this economic position would hit science, but in July, Jaitley presented the government's maiden budget, which saw cash for the Ministry of Science and Technology for 2014/15 rise by 11% to Rs35bn ($700m). Some of the winners from the budget include the Indira Gandhi Centre for Atomic Research in Kalpakkam, located about 80 km south of Chennai, which runs India's fast-breeder atomic reactor programme. It will get a Rs2150m increase – to Rs8270m. The Prototype Fast Breeder Reactor – a 500 MW atomic reactor fuelled using plutonium currently being built at Kalpakkam – was given a Rs7750m increase, boosting its chances of becoming operational next year.

In very difficult times, an extraordinarily favourable budget has been delivered

"In very difficult times, an extraordinarily favourable budget has been delivered to the Indian scientific community," says K VijayRaghavan, officiating secretary at the Department of Science and Technology. Promises that the BJP have already made include building world-class regional centres of excellence in nanotechnology, materials science and brain research, as well as seeking to establish "institutes of technology for rural development". Yet the budget was not all good news as the leading centre for basic research in the physical sciences – the Tata Institute of Fundamental Research (TIFR) in Mumbai – saw a drop in its budget by almost a third, down from Rs4220m. It was also announced in October that some 71 000 government researchers had their grants cut by as much as 60%.

"I see several indications in the budget that confirm the government's intention to support and encourage science and technology – the actual financial allocations are not as large as they need to be but we

Introduction

all expected this to be a cautious budget," says Raghavendra Gadagkar, president of the Indian National Science Academy in New Delhi. Gadagkar, who is also an evolutionary biologist at the Indian Institute of Science in Bangalore, warns that a more important factor for science in India is to remove bureaucratic hurdles, particularly when applying for funding. "While one cannot expect the budget speech to give any indication of how this problem will be dealt with, it is my hope that this government will make radical reforms in the bureaucratic control over research," he says.

A red-letter day

As has been the tradition since India's independence in 1947, the Prime Minister has also retained the role of being in charge of space and nuclear issues. Indeed, space is one area of science where India is slowly becoming a major player (see p9). On 24 September, India's 1350 kg Mars Orbiter Mission (MOM) was successfully put in orbit around Mars with Modi himself at the ISRO's Mission Control Complex in Bangalore as it happened.

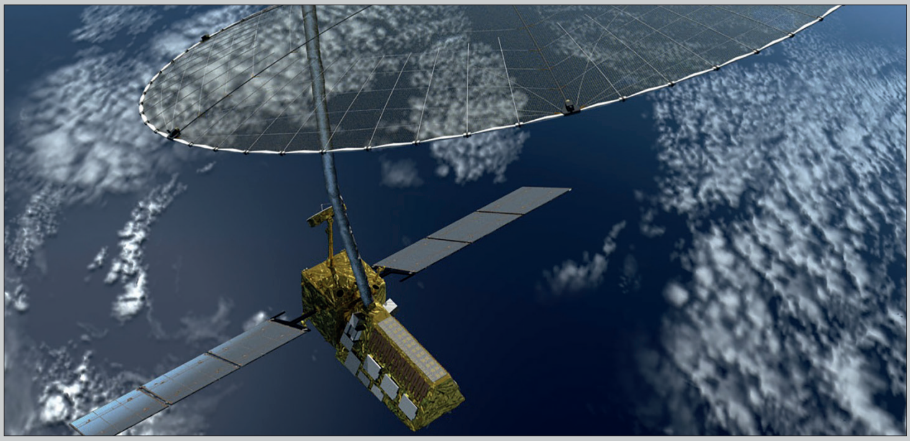
The usually sombre engineers and scientists at the Mission Control Centre erupted into a thunderous applause when the first data arrived on their screens. In a stirring speech after the success, Modi asked Indians to join in the celebration, suggesting that when India wins a cricket tournament the country erupts in joy. "The silent saints of science who work behind closed doors away from media and public also need to be applauded," he noted. MOM will now study Mars for six months looking for signatures of methane gas, which, if present, could indicate the presence of carbon-based life. Lauding India's achievement, NASA boss Charles Bolden called it "an impressive engineering feat". India's Rs4500m Mangalyaan craft had been launched on 5 November 2013, making it the lowest cost interplanetary mission ever – cheaper than the Rs6120m Hollywood blockbuster *Gravity*.

Within hours of India's historic rendezvous with Mars, the Indian government also gave its final stamp of approval for the country's participation in the Rs90bn Thirty Meter Telescope (TMT), which will be based at Mauna Kea, Hawaii. The TMT will be one of the largest optical-infrared telescopes with a 30 m diameter primary mirror that consists of 492 segments each with a diameter of 1.44 m. The telescope's performance will be further improved by employing "adaptive optics" to allow it to achieve a similar performance as if the telescope was located above the Earth's atmosphere. India's involvement in the TMT will be a national project run by the Indian Institute of Astrophysics in Bangalore, where planetary scientist Sujan Sengupta described 24 September as "India's red-letter day" where "physics had won big gains".

The TMT is an international consortium consisting of institutions from the US, Canada, Japan, India and China. India will provide about Rs13bn to the project, funded by the Department of Science and Technology and the Department of Atomic Energy, making the country a 10% partner in the project. This will translate into 25–30 observing nights on the telescope for Indian scientists per year, enabling them to study faint objects in the universe – giving information about the early universe – as well as to hunt for undiscovered planets. It will also allow Indian industry to acquire or gain access to sophisticated technologies.

K Kasturirangan, an ISRO astrophysicist and a former member of India's Planning Commission – a think tank that formulates government policies – called the country's involvement in the TMT a "marvellous development that will serve the aspirations of a large body of astronomers in India". Yet he goes further still, highlighting the general positive feeling in India about the new government and its initial policies towards science, saying that it gives researchers a "sense of positive energy". But with the new projects and funding comes a pressure to now deliver results that would warrant further investment in the future. "Now we will also be made more accountable," adds Kasturirangan.

India forges ahead with international space collaboration



NASA

Flying high A collaboration between NASA and the Indian Space Research Organisation will involve building the NASA–ISRO Synthetic Aperture Radar that will measure the causes and consequences of a variety of land surface changes on Earth.

India's Mars Orbiter Mission (MOM) is currently in orbit around Mars alongside NASA's MAVEN mission, which will explore the planet's upper atmosphere and reached Mars two days ahead of MOM. While India and the US will work together to co-ordinate observations between the missions, other areas of collaboration are also coming to fruition. On 30 September NASA boss Charles Bolden and K Radhakrishnan, chairman of the Indian Space Research Organisation (ISRO), signed an agreement to launch a NASA–ISRO satellite to observe Earth and establish a pathway for future joint missions to explore Mars. They also agreed how to work together on the NASA–ISRO Synthetic Aperture Radar (NISAR) mission. "These two documents reflect the strong commitment that NASA and the ISRO have to advancing science and improving life on Earth," says Bolden. "This partnership will yield tangible benefits to both our countries and the world."

Set to launch in 2021, NISAR will make measurements of the causes and consequences of a variety of land-surface changes on Earth. Potential areas of research include ecosystem disturbances, ice-sheet collapse and natural hazards. Indeed, NISAR will be the first satellite to use two different radar frequencies – L-band and S-band – to measure changes in the Earth's surface that are less than a centimetre across. This allows the mission to observe a wide range of changes, from the flow rates of glaciers, ice sheets and the Earth's crust to the dynamics of earthquakes and volcanoes.

Under the terms of the new agreement, NASA will provide the mission's L-band synthetic aperture radar (SAR), a high-rate communication subsystem for science data, GPS receivers, a solid-state recorder and a payload data subsystem. The ISRO will provide the spacecraft bus, an S-band SAR, and the launch vehicle and associated launch services.

"NASA and India have a long history of collaboration in space science," says John Grunsfeld, NASA associate administrator for science. "These new agreements in earth science and Mars exploration will significantly strengthen our ties and the science that we will be able to produce as a result."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Interview: K Radhakrishnan

At the cosmic helm

India is now a major player in space science after putting a craft in orbit around Mars at the first attempt earlier this year. Pallava Bagla talks to **K Radhakrishnan**, chairman of the Indian Space Research Organisation (ISRO), about what comes next

How does it feel now that India has reached the red planet?
I am happy and contented that we have done our job. It was a historic moment for everyone in the country. It was a technological mission primarily, and we have successfully achieved that.

How challenging was it to develop the Mars Orbiter Mission?
It was a race against time to build the craft as we had to make sure that it was launched no later than November 2013, since the specific celestial positions of the Earth, Mars and the Sun gave India the opportunity to use a relatively low-power launcher – the Polar Satellite Launch Vehicle (PSLV) – to head to Mars.

ISRO

Space leader K Radhakrishnan is currently head of the Indian Space Research Organisation.

How long did it take to build?
The mission was realized in less than two years. We also had to build autonomy into the spacecraft and then go through all simulations to ensure that the satellite does not make wrong decisions by itself.

What are you studying on Mars?
The primary objective is establishing the capability of keeping a spacecraft around Mars. We also have five scientific instruments on board to see if methane is present, and whether its origin is biological or geological.

So, we are asking if we're alone in the universe?
Yes. The second aim is to study the atmosphere of Mars in terms of the deuterium and hydrogen, and the other particles that are there.

To find out why Mars has lost water?
Yes, that is one of the questions.

What are the big things from this mission that the world needs to wake up to?
What we have established is that our PSLV is capable of delivering a mission to Mars. We are also showing that there is a novel way of doing low-cost planetary exploration and that we can do such complex missions in a short time. There are also several technological spin-offs from this mission in communication, navigation and observation.

What does it mean for India?
There have been 51 missions to Mars, and the success rate has not been high because of the sheer complexity of the missions.
So, we are the fourth group in the world to succeed after Europe, Russia and the US – and also the first to do so at the first attempt.

After Mars, what other big missions is India planning?
Two things are happening. One is that our Geosynchronous Satellite Launch Vehicle Mark III – the vehicle needed to put a four-tonne class of communication satellite into orbit – is going through experimental mission preparation. The vehicle is being integrated and we should be able to have the launch in 2014. This mission is essentially to understand the atmospheric phase of the flight. The second thing is that we are also building a crew module that could be used for a possible human spaceflight.

So you are the testing technology for putting Indian astronauts into space?
This crew module, without any human beings, is being tested to see how it withstands re-entry into the Earth's atmosphere.

What is the state of India's second mission to the Moon?
Chandrayaan II is a mission with a lander and a rover. At the moment, we are designing the Indian lander for Chandrayaan II. It should take at least three years for us to have that lander ready.

And what about the Sun?
The Aditya satellite will study the Sun and scientists would like to put it in the Langrangian point, which is 1.5 million kilometres away from Earth. Preparations and studies are under way and we should be able to synchronize that with the solar activity, so it would come somewhere in 2017–2018. Another exciting mission is AstroSAT, which is going to be a multiwavelength astronomy satellite. We are in the final phase of integration and testing, so it should launch by 2015.

And how are spirits inside the ISRO?
It is exciting, it is challenging, it is rewarding, and at the end of the day we feel there is a purpose in life in working in this organization.

Is India in a 21st-century space race?
Yes, we are in race, but with ourselves. We need to excel. We need to do much more and get into the next level of excellence. This is our objective.

Educating India

While India boasts some world-leading research institutes, more needs to be done to bolster universities to attract the next generation, as **T V Padma** finds out

In the euphoria of India's independence in 1947, the country's first Prime Minister Jawaharlal Nehru described its national laboratories as "temples of modern India". These national institutes have for decades played a key role in India's progress in science and technology by carrying out basic science research often of world-leading quality. The Tata Institute of Fundamental Research in Mumbai, for example, was built to kick-start Indian research in the aftermath of the Second World War.

Yet what Nehru and other Indian leaders since him have neglected, however, is to support the nurseries that train budding young scientists to go and work at such "temples". Except for a few pockets of excellence, university science education in India is in the doldrums. The result is that Indian universities are now the poor cousins of elite, national research institutes when it comes to receiving government funds and in infrastructure.

The Indian university system comprises a mix of public- and private-funded universities plus single institutions that are autonomous but not allowed to have off-campus colleges. The latter are dubbed "deemed" universities and the Indian Institute of Science (IIS) in Bangalore, for example, is one. According to India's University Grants Commission, there are now an estimated 45 national universities, 320 state universities, 130 deemed universities together with 189 private universities.

It is the publicly funded universities that form the backbone of India's higher education, but they have endemic problems ranging from poor funding and neglected buildings to a lack of staff and equipment, too much red tape and political influences in some university appointments. But what holds such universities back the most is that funding and research focus is so skewed in favour of the national institutes. This leaves most public-funded universities, except a few such as those in Delhi, Jammu, Kolkata and Punjab, unable to engage in quality research. "Isolated cases of academic excellence are not enough," says Sunil Mukhi, chair of the physics programme at the Indian Institute of Science Education and Research (IISER), Pune. "You need them across the country."

NCSM

Inspiring the next generation While interest in physics is high among school children, more needs to be done so that they carry their interest further to university level.

Divides and divorces

State universities in India mostly offer students three-year undergraduate degrees that are done in "colleges" and two-year postgraduate degrees that they carry out in university departments. What this means is that most undergraduate lecturers at public-funded universities do not carry out any research as they are forced to spend all of their time teaching – only those who teach postgraduate students can engage in research, as at Delhi University. Elite institutions such as the IIS in Bangalore, on the other hand, run degrees that do offer a year of hands-on research experience. "It is a very big gap and an artificial divide," says physicist Vikram Vyas of St Stephens College, which is Delhi University's top-ranked undergraduate college.

There is a feeling, however, that if those who teach undergraduates also did research, it could benefit their teaching. "These lecturers could then point out the messy areas at the frontiers, where knowledge is still evolving, and where there are unsolved problems and unanswered questions with no clear answers," says Vyas. "I believe that the absence of this perspective in undergraduate teaching is one of the main reasons for the paucity of original ideas in science" Vyas adds that India needs to rethink its university system so that every teacher in an undergraduate college is associated with the corresponding research department in the university. Similarly, every faculty member in the main department should be associated with an undergraduate college. "This is possible only if we have many more smaller and compact universities," he says.

However, Sri Krishna Joshi of the National Physical Laboratory (NPL) in Delhi, and a former head of the Council of Scientific and Industrial Research, says that many state and central universities do not in fact distinguish between those who teach undergraduate and postgraduate courses. Institutions like Delhi University are an exception, not the rule, according to Joshi, a former member of India's University Grants Commission that funds public universities. The main issue, he says, is rather the quality of physics teachers in state universities. Such staff are responsible for teaching more than four-fifths of India's postgraduate physics students and even higher numbers of undergraduate students (see box on p12). "On both counts, nearly all state universities, barring a few, and even some central universities are not doing well," Joshi says.

Whatever the causes, the bottom line is that physics students in India are by and large disconnected from top-class research and researchers. Indeed, Joshi goes as far as saying that there is a "total divorce" between teaching and research outside

Education

the country's elite institutions such as the Indian Institutes of Technology, the IISERs or some central universities where teachers are appointed after taking their research contributions into account.

Another problem at non-elite institutions is the often outdated nature of the syllabus itself. Joshi says that universities often follow a syllabus that may not have changed much over the years or even have been decided by India's leading physicists. "The syllabus does not offer students the scope to know the latest trends in the field or be exposed to emerging interdisciplinary areas of research," he says.

The physics syllabi for undergraduate courses are often based on broad guidelines and updating them is time-consuming, complicated and often involves bitter wrangles. They also do not give undergraduate physics students problem-solving skills but rather only encourage derivations to be memorized. Grants to buy laboratory equipment are based on a decades-old syllabus, which leaves little or no scope for colleges to devise new teaching and experimental projects in tune with recent advances in a field.

Infrastructure woes

The poor condition of laboratories in most state universities is a big problem in the declining quality of university physics education in India. Unlike national research institutes, where funds for costly, hi-tech equipment are more readily available, most state universities have to go with a begging bowl for funds. "Even to buy a simple thing like a laptop, not to speak of equipment, we face delays and difficulties," complains Amitava Raychaudhuri, a physicist at Calcutta University. "Departments in state universities are so cash-strapped that they cannot get modern laboratories or equipment. Students make do with aging equipment."

Even if money is forthcoming, delays and red tape can be an issue. Unlike research institutes that receive research project funds direct from the government, universities depend on funds from national funding agencies. Unfortunately, India's funding agencies are slow moving and the money can arrive months after a university department has had a project sanctioned, according to Raychaudhuri, who insists that despite the problems his university still gets "extremely sharp, intelligent and motivated students".

What is more, as grant money is handed out towards the end of a financial year, undergraduate colleges end up buying equipment or software towards the end of the teaching year. So even if a university gets approval to buy something, any students whose semesters have already ended (or are about to end) lose out on learning how to work with the equipment. "Apart from administration and salary funding, there is not much available for development of infrastructure," says Shobhit Mahajan, a physicist at Delhi University who teaches postgraduates and researchers. "Poor infrastructure and lack of opportunities is a major determinant."

Back at the IISER in Pune, Mukhi suggests that the government should also periodically review universities through external committees, as is already done with the IISERs. "Reviews are an important tool to assess if universities are performing according to expectations," adds Mukhi. He thinks that universities should not merely follow a textbook-bound approach, but encourage creative ideas and a research spirit in the classroom. "If we could do it in the five years since the IISERs were set up, the universities should be able to do it too."

Filling the vacancies

One major problem for physics in India is that most universities, especially those that are state funded, have many job vacancies that they cannot fill. In the case of physics, around 30–40% of the faculty positions are lying vacant. "Universities are not able to hire people," says Atul Gurtu, a former researcher at the Tata Institute of Fundamental Research in Mumbai. "It is very frustrating."

What this means is that physics and other sciences are therefore mostly taught by *ad hoc* teachers who are not well paid and who face an uncertain future, including candidates with just a Master's degree and no research track record. Despite their lack of experience, if such appointees continue for several years, they are eventually appointed as regular teachers. "This is doing a lot of damage to science education in general, including physics education," says Sri Krishna Joshi of the National Physical Laboratory in Delhi.

To make matters worse, advertisements for faculty positions are often not well publicized to attract the best talent. Even if top people are interested in the positions, they have to battle through university red tape before they can start work. At the University of Calcutta, for example, it may take up to two years between the advertisement of a position and final recruitment. "By then, the best candidates would have a found a good job elsewhere," says theoretical particle physicist Amitava Raychaudhuri of the University of Calcutta.

Another deterrent is the comparatively low salaries for state universities compared with central universities and national research institutes. Many say that political interference and corruption in university appointments, including even the vice-chancellor, is a common and serious problem across India. Unlike central universities, which usually boast a top-class academic as vice-chancellor, the bosses at state universities are often political appointees. "In India, state governments are like parasites, using state universities to wield clout but not rewarding academic performance," says Raychaudhuri. "This is demoralizing to the state universities and political appointments are destroying universities."

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Lying vacant In physics, some 30% of faculty positions still need to be appointed.

Reason for hope

One brief opportunity for students to learn directly from top researchers are summer camps and training programmes run by science academies, the Department of Science & Technology and the Council of Scientific and Industrial Research. Active researchers do most of the teaching, giving students first-hand experience about research. "Teaching should not be reduced to a blackboard exercise," says physicist Anand Bharadvaja of the Bhaskaracharya College of Applied Sciences, one of the newer colleges run by the Delhi state government.

Another welcome step, says Bharadvaja, is Delhi University's new initiative to encourage undergraduate teachers to carry out interdisciplinary and innovation-driven research. Bharadvaja's team, for example, has collaborated with other scientists in a study on the potential of agricultural waste as an alternative source of energy. Some also see benefits to undergraduate students of universities that are engaged in international collaborations. "When they see hardware activities centred on the cutting-edge technology being done at their home institutions, they get enthused to take up challenging tasks in science and technology as a career option," says Archana Sharma, an Indian physicist at CERN.

Things, however, might about to be turning out for the better, given that science minister Jitendra Singh announced in September that scientists from national institutes would be required to spend a few months teaching in universities. However, not everyone is convinced. "I don't think that a handful of scientists from research institutes jet-setting to a university to deliver some lectures will make too much of a difference," says Mahajan. "Unless they have a stake in the teaching *per se*, it will soon evolve into a chore that is performed for the sake of regulation."

Interview: Kanchan Chowdhury

Enthusing the public

Michael Banks talks to **Kanchan Chowdhury**, physics curator of the National Council of Science Museums, about how India is boosting science communication to get more people interested in physics

What is the role of the National Council of Science Museums (NCSM)?
With a network of 23 science museums and science centres, we are involved in enhancing the public understanding of science. Set up in 1978, the NCSM is an autonomous organization under the Indian government's Ministry of Culture. It also operates 23 mobile science-exhibition buses with theme-based science and technology exhibitions for rural India. So far, we have set up 48 science centres and handed 25 over to different states and union territories of India.


NCSM

Communicating science Kanchan Chowdhury.

How do you go about designing the exhibits?
The exhibits, exhibitions and educational programmes are on contemporary and relevant science and technology topics, and are developed with interactivity and engagement in mind. The exhibitions are sent to various centres around the country, where they are usually installed for a couple of months at a time.

Can you give a couple of examples?
I was inspired by G S Rautela, the NCSM's director-general, to set up NANOLAB in Kolkata with the aim of educating the public about nanotechnology. It includes hands-on activities in nanoscience, popular lectures by eminent scientists and film shows. Another exhibition, "Understanding the Universe", examines the fascinating history and future of our universe and the impact of particle physics on society using a range of exhibits including a model of the Hubble Space Telescope. We are also working on having a cloud-chamber model so that people can see particle tracks for themselves and understand how certain particles were discovered.

Are such exhibitions well attended?
Yes, especially by school children. People seem to enjoy them and it is hoped that as a result they will be more interested in the science.

Why do you think science communication is so important?
In order to win new students, science needs to be made attractive, accessible and comprehensive in a way that doesn't dilute the substance. We are living through the age of interdisciplinary science, where communication of research findings is as important as ever. Everyone who has a background in science should be involved in outreach in some way.

What about the wider benefits?
Good science communication is not only good for students, but also the public. People should understand the impact of science and technology, and without science communication you cannot achieve this.

How would you rate the state of science communication in India?
We are in the process of setting up more centres as the demand for them is very high. On average, 9 million visitors, including 2.5 million students, visit these science museums and centres every year and the number is growing annually. About 2.5 million rural children have also benefitted from the mobile science exhibitions. So, in general, I would say we are in a good position.

How does your background in physics help you in the role?
I have a PhD in physics from Jadavpur University in Kolkata, and my training in physics has helped me greatly in conceptualizing interactive exhibits, exhibitions and the educational programmes. I have now been working at the NCSM for 17 years.

Do you think researchers in India do enough outreach?
In India, scientific research is funded by public money, so scientists should use the outcome of their research to benefit society; but I would say that the lack of outreach done by researchers is a global problem and not just for India.

What is the NCSM doing to improve science communication in schools?
This is a major area for us and the NCSM aims to improve the science-communication skills among teachers in schools, colleges and universities. Basic science training in India is still very formal, so teachers sometimes find it hard to generate interest in students. If teachers have other tools at their disposal that can help to tell a story, then, combined with formal teaching, those tools can have a much better impact on students. Having said that, we still need to attract talented teachers who have good science-communication skills.

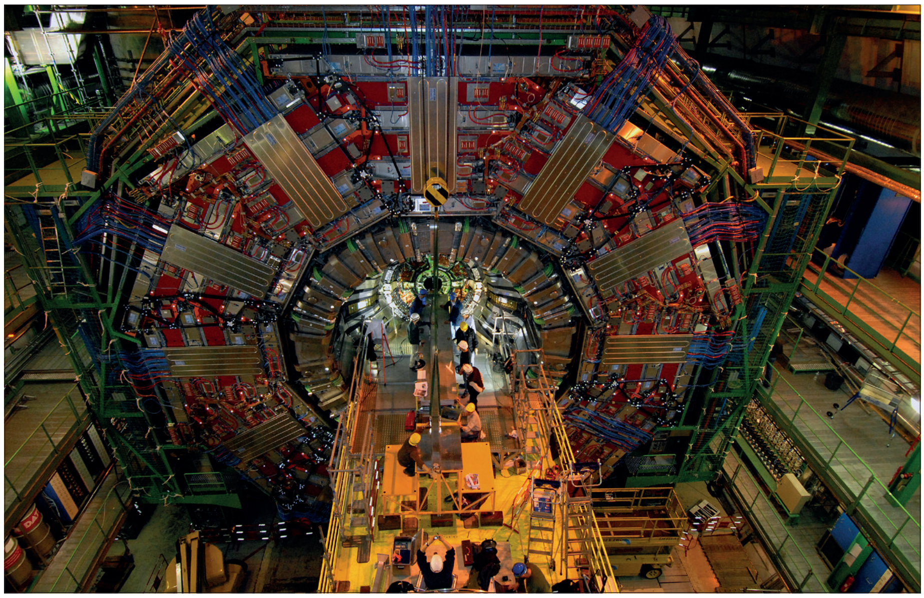
What about helping students at university level?
We offer a two-year Master's degree in science communication in collaboration with Birla Institute of Technology and Science in Pilani. This course aims to train science graduates to be skilled science communicators.

Are you planning to expand the centres abroad?
The NCSM is recognized as a world-class institution in the science-museum profession. We have set up the Rajiv Gandhi Science Centre in Mauritius. We have also supplied exhibits to Singapore, Australia and Turkey, and organized international exhibitions on science and technology in the US, France, Germany, Russia, Bhutan, Trinidad and Tobago, Guyana and South Africa.

Particle physics

Going global

While India has been participating in international particle-physics collaborations for many years, challenges remain before it can become a major player, as **T V Padma** reports



CERN

Getting involved As an "observer" country, India contributes towards many aspects of CERN, including the design of the detectors for the Large Hadron Collider such as the Compact Muon Solenoid.

Particle physicists in India have had much to cheer about since 2012. Not only could they take some of the credit for having helped to discover the Higgs boson at the CERN particle-physics lab near Geneva, but also the discovery spilled over from the confines of department coffee rooms to newsrooms around the country. The resulting TV and press bulletins clearly pointed to the enormous contributions that Indian physicists from both national research institutes and universities had played in one of the biggest discoveries in particle physics in recent memory – a finding that led to François Englert and Peter Higgs being awarded the 2013 Nobel Prize for Physics.

India's Department of Atomic Energy entered into an agreement with CERN in 1991 to participate in the lab. Since 2002, India has had "observer" status at CERN and contributes towards many aspects of the lab, including the design of the detectors at the Large Hadron Collider (LHC) – including CMS and ATLAS – as well as the software that is used to monitor and analyse data. Indeed, those efforts will be all the more important given that CERN will begin to hunt for particles beyond the Standard Model of particle physics when the LHC starts up again in mid-2015. It is expected that the LHC will then be accelerating and colliding protons with an energy of about 6.5 TeV – near the LHC's 7 TeV design energy. "For the past 40 years, international collaboration in particle physics has always been our strength," says particle physicist Atul Gurtu of the Tata Institute of Fundamental Research (TIFR) in Mumbai, who is a former spokesperson for the LHC's CMS experiment.

Still miles to go

With an economy that was expanding by around 10% a year, the Indian government recognized that more scientists and engineers were needed to sustain the continued development of science. So in 2008 the then Prime Minister Manmohan Singh announced that the government would set up eight new Indian Institutes of Technology (IIT) to build on the country's five existing IITs. Singh also announced the new Indian Institute of Science Education and Research, as well as plans to fund 30 new central universities.

While these initiatives will take time to have an effect, most scientists in India agree that the country has done exceedingly well in theoretical particle physics, but needs to improve its performance in experimental particle physics before the country can emerge as a top player in the field. India's weaknesses include a lack of financial clout as well as a lack of technological expertise to do the necessary hardware and instrumentation R&D. "We do not have that many financial resources as well as the necessary number of trained scientists to participate in diverse international projects," says Gurtu. "That is now biting us."

Sunanda Banerjee from the Saha Institute of Nuclear Physics in Kolkata heads a 22-member group that works at the LHC. The team is involved with CMS, monitoring the performance of its hadron calorimeter, which measures the energies of elementary particles that are produced during the collisions. Banerjee's team is also involved in constructing the electronics for a planned upgrade to the hadron calorimeter and tracking system.

Although particle physicists in India have gained recognition for their work in software, Banerjee says that the credit for that mostly goes to the efforts of individual physicists rather than "concerted institutional efforts in the sector". Another area of struggle is specifically in acquiring the know-how to build particle detectors. "We are good in following well-established techniques in making a detector, but we are far away from making a detector of novel design," adds Banerjee, who is also a member of the Geant4 team – an international collaboration with scientists from CERN, Fermilab and other key international labs – that is developing a software toolkit to track particles.

One reason why India is struggling in these areas could be because the country does not have an indigenous high-energy particle accelerator of its own. "In India, we don't have an accelerator that can provide even 1 GeV centre-of-mass energy," says CERN-based physicist Archana Sharma. "We need to learn from CERN how to design high-current, high-energy accelerators." Sharma adds that even if India did build a new particle collider, it would also need to develop much more expertise in electronics design and microchip development.

That view is backed by physicist Jasbir Singh from Panjab University. "In experimental particle physics, most faculty members and students are involved in data analysis and software development, but participation in detector development, especially making detectors for big projects is lacking," says Singh. "Most Indian universities do not create facilities to strengthen the experimental base."

Particle physics

Chasing China

While India has not yet been able to reach a level competitive with that of Europe, the US or Japan, some physicists in India think that the country has slipped behind China – its long-time rival since the mid-1970s. China has been developing the necessary technology for accelerators such as high-vacuum systems, fast electronics and precision-guided waveguides as well as sending hundreds of young physicists to labs abroad to learn.

"China is doing better than India when it comes to taking on big projects domestically," says Rohini Godbole of the Indian Institute of Science's Centre for High Energy Physics in Bangalore. Singh agrees that China is doing well in detector development adding that some aspects of Chinese development such as accelerator technology is "on par with the West".

While many say that India needs to provide much greater investment to train scientists and develop the necessary technology so that it can compete globally, it is not all doom and gloom for India's particle physicists. Fermilab director Nigel Lockyer says that in some areas, such as the design of cyclotron accelerators, India is "neck and neck with other countries". Lockyer predicts that India will be a leading nation in particle physics in the coming decade, even with competition from China, thanks to India's national commitment to science, from training in schools and universities to advanced research institutes.

"This gives India a significant advantage compared with its peers, as evidenced by its early and significant participation in the software and computing industries," says Lockyer. "With these successes, India has the chance to continue to lead through focused commitment to national science facilities such as observatories, accelerators and new laboratories."

Towards the forefront of neutrino physics

It is not just CERN where India has a focus on particle physics but also at Fermilab near Chicago in the US. A number of Indian institutes, including the Bhabha Atomic Research Centre in Mumbai, Raja Ramanna Centre for Advanced Technology in Indore and the Variable Energy Cyclotron Centre in Kolkata, are involved in developing the technology for accelerators based on superconducting magnets. The country's universities are also making their presence felt too. Physicists at Panjab University in Chandigarh, for example, contributed towards the construction of the Tevatron's now-defunct DZero detector as well as the Bubble Chamber Detector Neutrino Experiment.

Physicists at Panjab are now involved in the planned Long Baseline Neutrino Experiment (LBNE), which will study neutrino mass and interactions when it is switched on in the coming decade. They are involved in the integration and construction of one of the LBNE's two main detectors – the "near" neutrino detector that will be placed right at the neutrino beam at Fermilab. (The second detector – the far neutrino detector – lies 800 km away from the Chicago lab.)

Reidar Hahn/Fermilab

Guided tour Researchers from the Bhabha Atomic Research Center see the construction of the Main Injector Neutrino Oscillation Search – a long baseline experiment at Fermilab.

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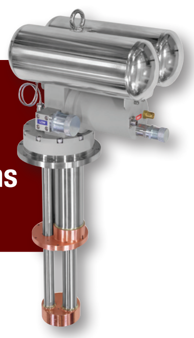

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