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Speech for International Year of Astronomy
Public Lectures

Contributions of astronomy to all of
science (and vice versa)

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- Thank you for that kind introduction.
- We are here today as part of the International Year of Astronomy, a global celebration of astronomy.
- This is a good time to reflect on the contributions that astronomy has made to all of science, and indeed to society at large.
- But also to reflect on the interconnectedness of science: the gifts that one science gives to another and to society.
- And to see science as one of the many threads that reinforce and strengthen one another to form the tapestry of modern society.
- Four hundred years ago this year Galileo made his first wonderful observations with a small handmade telescope, the best of his day.
- With that telescope, he discovered:
 - That the sun was not a perfect celestial sphere, but a changeable, spotted globe;
 - That neither was the moon perfect, but rather its flat smooth regions were interspersed with higher peaks and giant craters;

- That Jupiter had four moons of its own, each orbiting it, not the Earth, showing that not all heavenly bodies orbited the Earth;
 - That Venus underwent phases, as the moon did, that could only be understood if it revolved around the Sun, not the Earth.
- However inconvenient that truth might have been for some at the time, Galileo's discoveries clearly showed that Earth was not the centre of the physical heavens.
 - This was a fundamental contribution not only to science, but to all of humanity, altering our understanding of our place in the cosmos.
 - Much later, forty years ago this year, a small landing module called Apollo 11 avoided the highest rough points on the moon --- whose vertical height Galileo had estimated centuries earlier with the aid of mathematics --- and safely landed the first humans on the dry Sea of Tranquility on the moon's surface.
 - The best science today is characterised by the three elements that Galileo employed:
 - careful observations using the best instruments of the day,

- mathematics to describe and quantify what is observed; and
 - a model to explain how the system (in his case the solar system) fits together, in a way that makes sense of current observations and predicts new ones.
- Since the time of Galileo, astronomers have learned that the planets and moons that he observed are part of our own back garden: the universe is much, much vaster.
- We now know that the nearest star (other than the Sun) is more than one-quarter of a million times further from us than our own Sun.
- The centre of our own cosmic metropolis, the Milky Way Galaxy, is another 6,000 times further still.
- But even this is only our hometown.
- If you can imagine a distance 6,000 larger still, you will have the scale on which galaxies group together in clusters of clusters. These are the largest structures of the Universe, which are scattered like so many continents across the emptiness of the cosmos.

- How do astronomers measure these vast distances?
- Through years of painstaking work, they have built a “distance ladder” that begins by measuring distances on the earth, then the size of the Earth’s orbit, and from there to the distance to the nearest star.
- The distance ladder has been tested for over one hundred years, and is still being refined in detail today.
- One of the first steps was to determine the size of the Earth’s orbit by use of Kepler’s laws and observations of the transits of Venus, which were once also important for determining the precise longitudinal position of any place on Earth.
- In fact, one of the missions of James Cook’s voyage on the Endeavour, which brought him to Australia, was to measure the transit of Venus across the face of the Sun from a location in Tahiti.
- Another step on the distance ladder uses the parallax effect to measure the distances to the nearest stars.

- The Yale telescope on Mount Stromlo was quite famous for such measurements and is immortalized by this statue created by physicist-artist Tim Wetherill after the tragic Canberra bush fires of 2003.
- For the largest distances, the relationship between the periods with which certain types of stars (called Cepheids) pulsate and their brightness is used.
- If two Cepheids pulsing at the same rate appear to be of different brightnesses, it is because the fainter one is further away by an amount that can be calculated.
- This effect was discovered and first used by astronomer Henrietta Leavitt at the turn of the last century at Harvard to estimate the distance to the nearest galaxy to us, the Large Magellanic Cloud.
- A century later, Melbourne Professor Jeremy Mould, and his colleagues Professors Wendy Freedman of the Carnegie Institute and Robert Kennicutt of Cambridge, firmly attached another rung to the distance ladder by using Cepheids in much more distant galaxies.
- For that work, which accurately determined the Hubble constant, the team of three were awarded

the prestigious, international Gruber Cosmology Prize just a month ago.

- The Hubble constant, named after that famous astronomer Edwin Hubble for whom the space telescope is also named, enables astronomers to determine the distance to an extremely remote cosmic object, if its redshift can be measured.
- To understand this, it is first important to know that objects in the universe emit a continuous spectrum of colours, from the high frequency blues to low frequency reds.
- Some objects emit radiation in the high bluer-than-blue ultraviolet, or even the truly squeaky notes X-ray and gamma radiation.
- Other objects boom away at lower notes in the redder-than-red infrared, or the bass notes of radio waves.
- If you have ever wondered why astronomers need so many different kinds of telescopes --- optical telescopes, radio telescopes and X-ray telescopes, eg, --- it is so that they can detect and understand all the melodies and harmonies of the cosmic symphony.

- But back to the rainbow spectra from which redshifts are measured.
- Imprinted on these beautiful spectra are dark and bright chemical fingerprints that tell astronomers what cosmic objects are made of.
- Physicists and chemists in Earth-bound laboratories measure the precise colour (or frequency) at which certain chemical elements and compounds emit or absorb radiation, leaving behind a set of fingerprints.
- Redshift is the amount by which the chemical fingerprint of distant objects are colour shifted toward the red (or low frequency) end of the spectrum compared to objects composed of the same chemical signature measured in a laboratory on Earth.
- The effect is due to the expansion of the universe during the time that the light has been travelling.
- Redshift is used to measure the most distant objects in the universe.
- But more than just the distance can be learned.

- The frequencies at which the chemical fingerprints are seen in the laboratory and the shape of those fingerprints depend on the temperature, pressure and even the magnetisation of the material.
- So physicists and chemists on earth have provided many of the tools that astronomers use in the heavens to determine the temperatures of the stars, the chemical composition of planetary atmospheres, and the distances to the most distant galaxies.
- What has astronomy given to chemistry and physics?
- Remarkably, the second simplest atom on the periodic table, helium, was discovered first by astronomers, not on earth, but in the spectrum of the Sun.
- Later, it was discovered on Earth, and now the inert gas is used in manufacturing processes and to fill party balloons.
- What has astronomy given physics?
- Mathematical descriptions developed by astronomers for the way planets move across the

sky helped Isaac Newton formulate the Law of Gravity, one of only four fundamental forces of nature.

- Observations of how Mercury's orbit deviated slightly from Newton's predictions helped to convince scientists that Einstein was on to something with his modifications that led to his General Theory of Relativity.
- Space scientists are continually testing Einstein's description of gravity by watching how spacecraft travel in the distant reaches of space, looking for any deviations from Einstein's predictions in the so-called weak field limit, that is, when the gravitation force is weak.
- Astronomers test Einstein's theory in the strong field limit too, by collecting careful observations of matter and radiation in the vicinity of black holes and pulsars, old stars not quite dense enough to make it to black hole status.
- So far, the theory is holding up very well indeed, and may even give rise to a new form of astronomy.
- In several places in the world, including just outside Perth in a place called Gingin, astrophysicists are building instruments to detect

the gravitational waves that Einstein's theory predicts should be emitted by enormously massive cosmic objects undergoing violent change --- like colliding black holes.

- Perhaps, within a few years time, they will be able to tell us the answer.
- What about geology? What has geology given astronomy and astronomy given back to geology?
- Geology tells us that for hundreds of millions of years the continents of earth have been drifting on giant plates, surfing on and sometimes diving into the underlying upper mantle.
- Over very long time scales, this movement refreshes the surface of the earth and its atmosphere, and is responsible for volcanic activity, earthquakes, and the formation of mountains.
- The rate at which the plates move across the surface of the earth is now being measured accurately by radio astronomers, including some in Tasmania, using a technique called Very Long Baseline Interferometry.

- The speeds they measure are quite slow, a few centimetres a year.
- In our own solar system, only Earth is thought to undergo continental drift, but what about some of the more than 350 planets now known to be orbiting other stars? Could some of these be undergoing continental drift?
- The debate is raging, but generally it is thought that planets need to meet a minimum mass requirement of at least 1 to 10 Earth masses in order to have massive plates that move on top of a softer mantle.
- About 15 known exoplanets fall within that category, so perhaps some have active surfaces that replenish their atmospheres with chemical nutrients over time.
- What else has astronomy given back to chemistry?
- Well, for one, a start on the discovery of buckyballs and nanotechnology.
- In the 1980s Harold Kroto was analysing the chemical spectra emitted by the atmosphere of giant red stars, rich in carbon.

- He deduced the presence of very long chains of carbon, and wondered if he could study why they formed by trying to reproduce them in a laboratory on earth.
- Working with two other scientists, Smalley and Curl, he produced a beautiful new stable form of carbon composed of 60 atoms arranged in a chicken-wire like hollow sphere.
- They nicknamed this new structure “buckyballs” after Buckminster Fuller, the architect that designed the geodesic dome.
- The three later won the Nobel Prize for their discovery.
- Elongated forms of buckyballs, called carbon nanotubes are one of the basic building blocks of nanotechnology, which is now creating lightweight, incredibly strong new materials.
- What has astronomy given the field of biology?
- Remarkably, all of the carbon and all of the oxygen in the Universe, including that that makes up our bodies, was formed in the nuclear furnaces in the interior of stars.

- In fact, just about all atoms more complex than hydrogen and helium were formed in stars.
- As the US astronomer, Carl Sagan, put it simply, “We are all made of star stuff.”
- I could give other examples, from medical imaging and radio astronomy, to the use of adaptive optics to study the retina of living human eyes and to obtain Hubble Space Telescope crisp images from telescopes built on the ground instead of in space.
- But the overall message would be the same.
- Nature does not distinguish between the disciplines of science --- the arbitrary human boundaries we place around our knowledge and our class curricula.
- Nature does not distinguish between continents that over time separate or crash into one another to create new land forms.
- Certainly she does not recognise the boundaries of our nation states.
- Nor does nature see the invisible fence we place around ourselves as humans, life forms giving

and taking from this Earth, from the rest of the world that we call “The Environment.”

- We live in a complex and interconnected world.
- At times this can be overwhelming and occasionally, we are tempted to, and perhaps even need to, retreat into a view of the world that is simpler, isolated and compartmentalised.
- But if compartmentalization and simplification separates us from a true understanding of the physical, biological and sociological environment in which we live, and the influence we have on that environment, we run the risk that our decisions and actions will not lead to the results we desire.
- Historically, there was no distinction between scientific disciplines. Indeed there was no clear distinction between scientists and philosophers.
- Philosophy is the study of general and fundamental problems concerning matters such as existence, knowledge, truth, beauty, law, justice, validity, mind, and language through critical, generally systematic approach and reasoned argument.
- When Galileo, then in his mid forties, wrote the *Starry Messenger* describing his first

observations with his telescope, he wrote especially for philosophers and astronomers, though he described himself as a mathematician.

- It was Galileo, who melding of observation using the best instruments of the day, with logical and mathematical descriptions and models, who is often called the "father of modern physics."
- Indeed, more than that, Stephen Hawking has said, "Galileo, perhaps more than any other single person, was responsible for the birth of modern science."
- Standing on the shoulders of Galileo and scientists since then, we now use the same methods, discipline, and imagination to understand:
 - how quarks behave inside the protons and neutrons in the nuclei of atoms;
 - the life cycle of the platypus;
 - the breathing cycles of the earth as it exchanges carbon dioxide between its oceans, vegetation and atmosphere; and
 - the workings of our own brains, and the biological and social systems that influence how we think and what we feel.
- I see some young people in the audience.

- Some of you will be certain already that you would like to study more science, because you are interested in a career in science, technology or engineering.
- Others of you may be considering studying science, but uncertain about where that might lead you.
- Still others of you will be certain that a career in science, technology or engineering is not what you imagine you would like to pursue, but still have a curiosity about certain aspects of science.
- Australia --- and indeed the world --- needs and depends on all of you.
- If there is one thing I want to say to you today, it is this: You are our future.
- We need young scientists who question the world around them, and take the time to learn how to use mathematics, experimentation, observation, and logic to interpret the answers that the universe whispers back them.
- We need engineers and architects that are interested not in building more, but in building better, smarter and more responsibly.

- We need citizens who, whatever their walk of life, understand that sound evidence is how we as individuals and as societies can honestly assess where we are and what may lie ahead.
- Only with farmers and lawyers, physicians and physicists, teachers and tradespeople, writers and businesspeople, voters and politicians who are informed with solid evidence and willing to act upon it, will we make good choices for Australia and for humanity.
- Thank you