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State of the Universe

February 5, 2015

(Slide 1) Mr. Chairman, Ms. Ranking Member, Legislative and Executive staff: the State of the Universe – I hope you can read the title, it's written in galaxies – the State of the Universe is … *amazing*. 13.7 billion years after its big bang origin, we still have much to learn about it. Our Universe is:

(Slide 2) *Curious*…
NASA's *Curiosity* rover has been exploring Mars since August 2012, exciting a lot of public interest.

(Slide 3) Nearly a thousand people watched in Times Square as the rover survived its "7 minutes of terror" landing.

(Slide 4) The Universe is: *beautiful*.
New stars forming in the Eagle Nebula.

(Slide 5) And deeply *inspiring*.
The *Hubble Space Telescope* showed there are 100s of billions of galaxies throughout the universe, each full of 10s of billions of stars like our own Sun.

(Slide 6) And the Universe is *critical* to understanding the world we live in.
Its primary constituents, Dark Matter and Dark Energy, remain mysterious, but without them, our own Milky Way galaxy as we know it – the galaxy we live in – would not exist.

It's staggering – the knowledge we humans have acquired – just one species on one planet around one star.

And recent years have seen an accelerated pace of discovery – the result of an effective partnership among researchers, industry and government.

(Slide 7) **SDSS movie.**

The American Astronomical Society and Association for Women in Science thank Chairman Lamar Smith and Ranking Member Eddie Bernice Johnson for hosting this event and for their steadfast support for the astronomical sciences.

With powerful new spacecraft and telescopes, we are today exploring a new frontier – the cosmos – much as earlier humans explored terrestrial frontiers. I remember learning in my high school history class that, according to Frederick Jackson Turner, the expanding western frontier may well have formed our national character. Exploring is a human thing, maybe an especially American thing, and federal investments in the astronomical sciences allow this journey through our era's frontier.

(Slide 8) Some exploration happens right in our cosmic neighborhood: like the Sun, our nearest star, whose light takes only a few minutes to reach us. It supplies the energy that allows life on Earth to flourish – though it also has the potential to threaten our *way* of life. For example, the kind of super-strong solar storm recorded in 1859 by *astronomer* Richard Carrington…

(Slide 9) …would wipe out today's communications satellites and cause global power outages. So understanding extreme "space weather" is pretty important.

(Slide 10) Our Milky Way galaxy is a large spiral, with about 100 billion stars like our Sun, most of which probably host planetary systems. The discovery of "exoplanets" – which is what we astronomers call planets around stars other than our Sun – is one of the most exciting discoveries ever in astronomy.

Since our first *State of the Universe* briefing one year ago, NASA's Kepler telescope –

(Slide 11) …built by Ball Aerospace, where panelist Makenzie Lystrup works today –

(Slide 12) …has doubled the number…

(Slide 13) …of known exoplanets.

(Slide 14) Several are of similar size and composition to the Earth, …

(Slide 15) …including one of the most exciting, reported last April, Kepler 186-f (Slide 15), which is in the habitable zone – that means: an orbit around the star where liquid water could exist on the planet's surface.

Let me quote an enthusiast on this topic, your own Chairman Smith, who said at a recent astrobiology symposium, "[that] curiosity about life on other planets is something that unifies us all. The discovery of life elsewhere would alter […] how we view our place in the universe, [and] the discovery of sentient life […] outside this solar system would be the biggest news in the history of the world."

Kepler 186-f is just one of a growing cadre of planets that could very well be home to life outside our solar system.

(Slide 16) Using a fantastic new radio telescope – the Atacama Large Millimeter Array, or ALMA, funded by the National Science Foundation (or NSF) …

(Slide 17) … astronomers found signs of planets forming around a *very* young nearby star, challenging the best current theories, which say planets should not form so early. *Every gap in these rings represents a potential planet in formation.*

(Slide 18) A little closer to home, astronomers using NASA's *Cassini* spacecraft in orbit around Saturn for the past decade, looked at…

(Slide 19) … Saturn's moon Enceladus, an icy body covered with geysers spewing icy water particles into space at some 800 miles per hour.

(Slide 20) With these new observations, the scientists were able to link the water spewing out of these geysers to warmer salt-water seas beneath the moon's icy crust, …

(Slide 21) … perhaps like Europa, a moon of the planet Jupiter.

(Slide 22) Let's talk about black holes, my research specialty. **This movie** shows stars orbiting the very center of our Milky Way galaxy. Their motion – particularly the fastest ones – requires a very strong gravitational force, implying there must be a super-massive black hole, weighing some *4 million times* the mass of our Sun, sitting right at the center of the galaxy.

(Slide 23) This past year, using NASA's *Chandra X-Ray Telescope*, astronomers saw the brightest-ever outburst of X-rays from that supermassive black hole. They think the flare may have erupted when the black hole gobbled up a giant asteroid that passed by.

(Slide 24) And one final highlight: astronomers are using *Hubble* to see more distant galaxies than ever before, taking advantage of "nature's telescope" – a phenomenon, known as "gravitational lensing," whereby massive clusters of galaxies (those fuzzy yellow things) bend light from distant background galaxies (those blue streaks) stretching and magnifying them so they are bigger and bright enough to see. Keep an eye on these *Hubble* "Frontier Fields" – until the *James Webb Space Telescope* is launched, this is our best chance to witness the earliest formation of galaxies.

(Slide 25) These are all *amazing* discoveries. And…

(Slide 26) … they were all made by teams led by women astronomers.

(Slide 27) We are really delighted to partner with AWIS on today's briefing, not only to highlight the exciting news in astronomy but also to highlight the importance of diversity in strengthening the STEM enterprise.

(Slide 28) Over past few decades, we have seen an increasing fraction of women graduating with STEM degrees – women now represent about 1/3 of the PhDs in Physical

Sciences, which includes astronomy, but only around 20% in engineering, physics and computer science. Physics and astronomy – same skill set, vastly different numbers – that tells you it's not math or computing ability.

(Slide 29) Although astronomy used to be below 20% female, women now earn ~40% of Bachelor's degrees and PhDs awarded in the US.

(Slide 30) Unfortunately we are still training far too few people of color, first-generation college students, veterans, and graduates of community colleges… And where these backgrounds intersect – e.g., for women of color – the situation is worse still.

In short, we are failing to engage the full population of talent. As NSF- and AWIS-supported studies have shown, the playing field is not yet level. Minorities of all kinds fail to resemble our dominant image of a scientist…

(Slide 31) …and this leads to biases –

(Slide 32) some conscious, but many unconscious – against their success, in hiring, promotion, awards, and other rungs of the career ladder. Research has shown it's these biases that close off opportunity, not native ability, or math skills, or family obligations.

(Slide 33) AWIS has been leading a project called Advancing Ways of Awarding Recognition in Disciplinary Societies, or AWARDS, which looks beyond representation, to recognition of achievement. Specifically, looking at prizes awarded by professional societies, including the AAS, they found women's research contributions are under-recognized and under-rewarded, while their service – the stereotypical "help-mate" role – is over-emphasized.

(Slide 34) So AWIS developed a set of "best practices" for objective review. After the American Astronomical Society instituted one of those recommendations – self-nomination – suddenly women started to win AAS prizes, and the fraction of awards to women is where it should be given the pool of eligible astronomers.

Of course it's only fair for everyone to have the same opportunity to be a scientist – it's a fascinating life – but diversity is also essential if our STEM enterprise is to be as good as it could possibly be. That's because diversity leads to innovation. Scientists talking to other scientists who think the same way don't learn anything new. It's the clash of ideas that leads to discovery.

(Slide 35) That's why great civilizations were borne at the intersection of trade routes – where diverse peoples mingled and exchanged ideas.

Diversity in STEM is essential to the excellence of the enterprise.

(Slide 36) … and astronomy plays a special role. First, we led the way for women in science. These are the Harvard "Computers" – a group of very well-educated women hired

to do astronomy because, as the observatory director – Edward Pickering – said, he could hire twice as many women because he could pay them half as much as men.

The Harvard Computers – and later women in astronomy – made amazing discoveries about the Universe.

(Slide 37) Henrietta Leavitt figured out how to measure the distance to other galaxies, a critical step in understanding the size and expansion history of the Universe – it enabled modern cosmology.

(Slide 38) Cecilia Payne established that stars are mostly made of hydrogen – notwithstanding the objections of her thesis advisor – an absolutely huge theoretical leap.

(Slide 39) Katherine Johnson did essential orbital calculations for Alan Shepherd's pioneering flight around the earth and for the historic moon landing in 1969.

(Slide 40) Margaret Hamilton wrote code for the Apollo program – Without her, we simply wouldn't have landed on the moon. *She is standing next to the printout of her computer code.*

(Slide 41) And Vera Rubin found the first conclusive evidence that galaxies are made largely of dark matter, which we can't see directly but which weighs far more than the stars and galaxies we *can* see.

(Slide 42) And there are many, many more amazing women in astronomy, past, present and future.

(Slide 43) So as we make steady progress toward the next great discoveries…

(Slide 44) …let's make sure the excitement and rewards of a scientific career are open to everyone, because that is what will propel basic research forward and lead to greater innovation, a stronger economy and a faster pace of discovery.

(Slide 45) Astronomy is thriving because of a combination of key federal investments in facilities and training, plus continuing technical advances by industry, all fueling competitive peer-reviewed research by scientists.

We will do even better if we increase diversity.

It is *such* a thrill to be here with such highly accomplished colleagues – all women – something that was rare when I was starting out in astronomy and physics.

We have very similar training and skills but as you will hear, we play different roles in the astronomy ecosystem: I teach and do research at a university, Dr. Lystrup is a leader in industry, Dr. Kirkpatrick works to broaden educational opportunities, and Dr. Norman does research in a federally-funded research lab, and this year, is on

sabbatical at Howard University, a flagship among Historically Black Colleges and Universities