Remarks as Prepared for Presentation to the
100^{th} Anniversary Meeting of
the American Astronomical Society
by NASA Administrator Daniel S. Goldin
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Thank you for that kind introduction. Thank you again for having me back to address the American Astronomical Society.

I would also like to thank a number of people I consulted with and tested my ideas against in preparation for this speech: my friend Alan Dressler, Bob Brown and Harvey Moseley, Pierre Bely, Lowell Wood, and Tim Harden, one of our new NASA astrobiologists, Ken Nealson, and its new director, Dr. Baruch Blumberg, and the new head of Space Science, Ed Weiler.

I particularly want to thank Roger Angel for reigning in my enthusiasm and sanding my rough edges and Sam Venneri for pushing beyond where I expected to go. I also want to thank Harley Thronson for his patience through many discussions.

My speech today is part of a series of speeches I have been giving over the last few months and will continue over the months ahead. I have spoken about the need for safer, more reliable and more cost effective access to space. I have outlined NASA's vision to integrate biology in our future missions and how the NASA Astrobiology Institute will seek to answer fundamental questions like: is life unique to planet Earth? And just last week at Fermilab I talked about the NASA vision for high energy and particle physics in space. Today, is the second half – the vision for optical astronomy. In the coming months, I intend to delve more deeply into the role of robots and humans in space exploration.

In the next couple of weeks, all of these speeches will be on the NASA web site, www.nasa.gov. The reason I point these speeches out is because all these issues – propulsion, biology, astrobiology, x-ray astronomy, optical astronomy, astronauts and robots – are becoming increasingly inter-related.

I am honored to be here today, because I understand the importance of what you do. The new millennium will bring profound understanding of our place in the universe, and many of you will play a key role in leading us there.

As we stand at the threshold of great change, I am reminded of something I heard Bruce Lehman of the Fetzer Institute say in a little different context. “In times of great change,” Lehman said, “there are two kinds of people. There are those who usher out the old, and they are the pallbearers. And there are those who usher in the new, and they are the torchbearers.” Well I am proud to be in a room full of torchbearers today!

I call you all “torchbearers,” because you have always responded to challenges by putting your full intellectual weight behind a problem until it is solved. Every time I come to the AAS, I give you a new challenge, and you always respond.

Three years ago, when I spoke to you in San Antonio, the discovery of the first new planets outside our Solar System was revolutionizing our thinking about planetary formation. I challenged astronomers that day to make the Next Generation Space Telescope a truly ‘great observatory’ of at least twice the diameter my good friend Alan Dressler had advocated . . . and go for 8 m.

Remember, Alan? Your ‘most memorable AAS meeting’?

But that challenge . . . and your creative response . . .will produce a superb scientific tool that will penetrate the ‘dark ages’ of cosmology and reveal the secrets of the birth of galaxies.

And when we met last year in Washington, I challenged you again, that time to turn the powerful analytical tools of your profession toward solving fundamental problems of biology on a cosmic scale: astrobiology, the search for life beyond our Earth.

The Space Interferometry Mission (SIM) and Terrestrial Planet Finder (TPF) will be astronomy's first responses to this challenge, using astronomy’s most powerful tools to explore the most basic properties of biology . . . and begin to answer the question, “Are we alone?”

Well, I am here to challenge you to open the new millennium with visionary goals that will resonate, that will excite, that will carry humanity far, far into the future . . .a future to which there will be many paths. I can see it no better than you, but I want us to look beyond our dreams and explore the exciting possibilities.

As you know, lofty ambitions and challenging dreams are nothing new to this Society.

A century ago, at the birth of the AAS, George Ellery Hale envisioned a series of ever-greater telescopes, and Albert Michelson, America’s first Nobel laureate in science, dreamed of applying spatial interferometry to the unbelievable task of measuring stellar diameters. These were men who looked to the future but were not limited by their dreams.

Likewise, there are scientists in this room who will answer the challenge I will lay before you . . .

Not much more than a decade from now -- thanks to SIM and TPF--we will have searched for Earth-like planets around thousands of nearby stars. We will use low-resolution spectroscopy to search the most promising planets. Perhaps we will find water, ozone, and carbon dioxide in the thick atmosphere of a warm planet. These results will guide a possible subsequent mission, called Life Finder. This will be a larger interferometer and will obtain higher-resolution spectra that could identify gases, such as methane, that are out of equilibrium with their environment. If successful, the Life Finder should be able to detect seasonal variations in these gases, changes in atmospheric chemistry, phase transitions of liquids on the surface, and spectral variations in the dominant biomass.

As we search for living planets around neighboring stars, we will intensify our investigations within our own Solar System. Increasingly intelligent robotic probes may plunge deeply beneath the icy surface of Europa and sample material along dry riverbeds and in seas on Mars, and bore beneath the dry Martian surface, bringing samples back to Earth for sophisticated analysis.

We will also explore Earth in greater detail than ever. A few years ago, NSF initiated the "Life in Extreme Environments" program, which NASA recently joined. This program explores all the nooks and crannies on Earth where life may have settled and flourished.

We will also use analytic tools such as complexity theory to mimic the pre-biotic and biotic pathways to complex life. Along with new laboratory techniques that will attempt to duplicate the origin and evolution of life, we will rapidly compile the basic knowledge about the grandest of all astronomical events in the Universe . . . the emergence of life.

And we will be prepared to be surprised, just as you were with the discovery of the first extra-solar planets a few years ago. During the first few decades of this great adventure, we must control our pre-conceived expectations of what it means to be living. Of course, our missions will concentrate on worlds with accessible sources of energy. But our philosophy will be to search primarily for systematic disequilibrium: life follows a different thermal and chemical path from that of geology, life radically alters a planet's chemistry, the thermal equilibrium of a planet's surface, and may also produce time-varying phenomena that inorganic chemistry simply cannot duplicate.

Our first astronomy missions -- SIM, TPF, and Life Finder -- must, therefore, be powerful, general purpose observatories. One thing that studying life has already taught us, is that specialization leads to extinction.

In a decade or two, if we find warm, potentially habitable planets with our first spectroscopic missions, all of humanity will want to know much more about them.

Are there continents? Oceans? Mountain ranges? Forests and fields? Lakes and seas? Are there seasons? What is the climate like?

Are these worlds living? What kinds of life might exist there and how complex is it? If the life is complex, what are the signs of its complexity?

To answer these questions, we must examine these worlds closely and survey their surfaces. Therefore, the next step after spectroscopy will be imaging. We do not know now what those future imaging missions will be, and we face substantial technological problems. But we must vigorously pursue the breakthrough technologies to give you the most possible options.

As a schoolchild, I was fascinated by the maps of our planet that I saw hanging on the classroom walls. I was always amazed that our world had such a rich variety of features—oceans, mountains, continents, and rivers.

Now imagine the classrooms of the mid-21st century, if we have been able to find those warm wet worlds that have conditions suitable for life. When you look on the walls, you see a dozen maps detailing the features of Earth-like planets orbiting neighboring stars. Schoolchildren could study the geography, oceans, and continents of other planets and imagine their exotic environments, just as we studied the Earth and wondered about exotic sounding places like Bangkok and Istanbul . . . or, in my case growing up in the Bronx, exotic far-away places like Brooklyn.

What kinds of tools will the 'torchbearers' among you create to produce those fascinating maps for those schoolroom walls? The answer depends on the choices you make for how best to study the new worlds that will be revealed to you.

Perhaps we will choose to image those new worlds with telescopes in space starting at diameters of 50 or 100 m—and growing far larger—to detect faint light from target worlds.

The telescopes might be strung out in interferometers, with elements separated not by tens of meters but by hundreds or thousands of kilometers, to separate the faint light of the planets from the blinding glare of the stars and to achieve the angular resolution that our science goals require.

Or we may choose to use the sun’s gravity to precisely image the surface details of another world, by placing our future spacecraft at about 550 AU in the opposite direction. This will require new generations of propulsion, which might also give us the ability one day to send our robots directly to another world.

Some of you may think I’ve been in Washington so long that I don’t understand the magnitude of the challenge I’m setting before you. Yes, it is ambitious, but it really isn’t much different than the challenges faced by George Ellery Hale a century ago.

At that time, the largest telescope in the country was barely over a meter in diameter, at Yerkes Observatory. A half-century later, thanks to Hale, the largest telescope on Earth was just about 5 times larger in diameter.

Hale worked on new telescopes while the old ones were still under construction. He was always ahead of his time, and ahead of the pack, as torchbearers always are . Boy he drove people crazy sometimes!

Don't laugh too long, because I may soon drive you crazy. Too many of you are hugging the Hubble Space Telescope (HST). HST is not your most important optical telescope today. And neither is the Keck, or Gemini, or NGST! No, for the 'torchbearers' among you, <u>your</u> most important telescope must always be the one <u>after</u> the one you are dreaming about now: the telescope beyond your dreams.

Hale constantly pushed the boundaries of technology. He refused to be limited by what already existed. He was too busy looking at where he wanted to go next . . . and where to go after that. That is where I expect NASA to operate, and that is where I am challenging you to operate.

Just a few weeks ago, I visited JPL, where one of our more forward-thinking technologists, Art Chmielewski, walked me through a sequence of ever-larger, more ambitious apertures. Each major step produced a multi-use design: light and rf collectors, laser concentrators, solar sailing among the planets, and future generations of optical telescopes.

But Art's dream for huge apertures in space does not merely challenge us to find new materials. We will want to embed intelligent controls directly within the structures, with sensors and flexible electronics integrated throughout. Those multi-functional structures will need to adapt, react and evolve in changing environments. Perhaps this giant intelligent system could morph itself from a solar sail into a high-precision infrared telescope once it moves into position. Think of the vast amounts of mass . . . and money . . . we would save if our giant optical systems were also our propulsion systems.

You are probably wondering how to fund these dreams. I can tell you that NASA cannot rely on an expanding budget to pay for brute-force technological solutions to these scientific challenges. NASA is a tiny fraction of the federal budget but a large portion of the discretionary funds that Congress will look to (once again) to balance the budget.

To respect budgetary constraints and to fund our dreams, NASA has developed some very simple principles.

Principle One: NASA will sustain a continuing line of cutting-edge technology for developing imaging and spectrographic systems in space. These may be large apertures and interferometers, giant Fresnel lenses, interconnected light-collecting flats, precision inflatables that could be positioned within our solar system, or giant apertures precisely positioned about 550 AU from the sun. Perhaps these apertures will be biomimetically generated on our morphed Coke can-sized probe . . . I talk more about that later. We do not have to choose until those first wonderful spectra come back from neighboring planets. But we must be ready to make the best choices for our missions and must not be limited to merely doubling yesterday's telescope technology!

We must also adopt "Just-in-time" technology, with major missions launched as soon as the technology is ready and no later. We cannot suffer from the “ready-aim-aim” syndrome. We must constantly move forward.

Principle Two: we will only undertake smart design and operations, leaving people to do what we do best: imagine and create. NASA will lead in developing new life cycle design tools, like totally immersive geographically-distributed interactive virtual presence, with sight, sound, and haptic feel. They will use physics- and biology-based analytic tools, with a common data base among all systems. This will enable the engineer and scientist to collaborate as one integrated team in developing the future space science system architecture. Neural nets and genetic algorithms will allow our robotic voyagers to rely <u>less</u> on commands from Earth and <u>more</u> on their own learned experience, eliminating the need for rescue instructions from Earth, which may be light days—or further—away.

Future advancements in computational systems can only be achieved by developing hybrid systems that mimic biological processes and combine new concepts based not only in silicon but biochemical, quantum and optoelectronics. A hybrid system could be faster, and it could be a billion times more energy efficient. This will be critical, as we dispatch our telescopes far beyond the asteroid belt.

Just imagine our first interstellar probe that may give us new clues to new life forms on planets in other solar systems. The Coke can-sized spacecraft will reach and land on a passing asteroid two years after it is launched from Earth.

Aboard the asteroid, the spacecraft will use its DNA-based biomimetic system as a blueprint to evolve, adapt and grow into a more complex exploring and thinking system. It will ride the asteroid like a parasite until it transforms itself into its next evolvable state – an intelligent interstellar probe. It will use the asteroid's native resources to accomplish the first phase of its mission. This may mean using the asteroid's iron, carbon and other materials to build its structure, nervous system, and communications. This reconfigurable hybrid system can adapt form and function to deal with changes and unanticipated problems. Eventually it will leave its host carrier and travel at a good fraction of the speed of light out to the stars and other solar systems.

Such a spacecraft sounds like an ambitious dream, but it could be possible if we effectively utilize hybridized technologies.

And to be successful, we will not be passive observers of this grand exploration*:* we must use our most versatile space voyagers -- humans -- as intimate partners with our robots, traveling with them in space, assembling the most complex systems, servicing the sophisticated components that cannot yet service themselves and performing the deep intellectual and creative tasks of in situ science and technology development. The human experience is also something we can all share.

This group is no stranger to the adaptable success of astronauts. Most of you must remember how you felt about space astronomy in 1991, versus how you felt just three years later, after the thrilling flight of the astronauts to rescue not only the Hubble Space Telescope . . . but possibly Space Science itself.

Principle Three: we must constantly experiment in space. We will 'build a little, test a little, fly a little, fail a little . . .but learn a lot.' We have an invigorated program to carry new technologies into space and validate them-- the New Millennium Program -- which is open to all advanced ideas. It centers on technology validation with fast turn-around times of only a couple years and costs of just a few million dollars, not hundreds of millions.

Our Fourth Principle: scientists must have maximum flexibility in placing satellites to assure optimal science return. Future observatories may perform best at the second Lagrangian point, where the Sun and Earth are constantly on one side, making thermal design, power generation and communications far more effective and simple. Or they may need to fly beyond the asteroid belt, where the sky is a few hundred times darker than it is at one AU. Today, there is new excitement in Earth and Space Science to look at positioning spacecraft at L1 and L2. Future scientific discoveries may require imaging from the Sun's gravitational lensing point, where nature provides a lens larger than the sun and a focal surface distributed across a sphere at a radius approximately 550 AU around our sun.

From this location, we may map the surface features and monitor characteristics of target planetary systems with giant telescopes that alternatively observe throughout the electromagnetic spectrum, looking for planetary emission from the visual and the infrared, and out to the radio wavelengths.

Wherever your science program takes us, NASA must be prepared to supply the ride. For years NASA launched massive spacecraft, but recently, we have reduced spacecraft size and cost by almost a factor of 10. However, things like aperture size cannot be shrunk, and as long as it costs $10,000 to put one pound of payload in Earth orbit, we will be forced to make our biggest space-based telescopes “lightweights.”

However, with operating costs 10 to 100 times lower than today, with the reliability of a commercial airliner and the payload capacity of the Shuttle, an advanced reusable launch vehicle could eliminate this burden. With advanced launch technology, weight becomes a variable to be dealt with as any other, not the absolute constraint it is today.

To leave Earth orbit today, we rely on heavy chemical rockets, and we are launching mostly fuel. The Deep Space 1 probe NASA launched last fall is the first to use electric propulsion. It will fly close to an asteroid -- and then maybe on to a second asteroid or a comet. It carries only 80 kg of fuel.

In the future, solar electric propulsion will be the “system of choice” for rapidly moving about the inner solar system – out to about Jupiter. With advanced systems we can move larger payloads to libration points or to Jupiter’s orbit to avoid the infrared glare of dust.

If the payload is very small, light sails pushed by the pressure of sunlight or laser energy may be an option. At Earth, the available thrust is about a milli-gram per square meter at best, but the pressure is unrelenting. Sails could be accelerated for months and then coast to their destination. Light solar sails also offer unique opportunities to help keep a spacecraft on station, or in position.

Reaching beyond the planets may require propulsion systems with much higher energy density processes than the combustion we currently use. Such systems might allow us to get out to the sun's gravitational lensing point and stop in 10 years or less. All that is necessary is to dream and think creatively once again in America.

Our Fifth Principle: I am challenging the country's technologists to produce advances in optical systems that are an analog of 'Moore's Law,' where computing power doubles every 18 months. At the same time, price is reduced as much as 50%.

In honor of one of the early visionaries, this doubling of telescope collecting power could be called 'Hale's Law.' George Hale got the century off to a terrific start, but for the past several decades, telescope collecting area has doubled only every 25 years! What should the time frame be? Ten years? Five years? Three? You tell me.

In a decade or so, the NGST's 8 meter technology will be obsolete, so the country's most creative technologists should already be at work today on optical systems 3 to 10 times larger in diameter, and 10--or even 100--times less dense than NGST. And we will want baselines for the interferometers of not just tens of meters, but thousands of kilometers!

To aid this growth, we at NASA have made the development and testing of innovative optical systems and precision free-flying spacecraft one of NASA's highest technological priorities. We will make it a priority of NASA to fund those technologists who will not be limited by their dreams.

My friend, Roger Angel, has been a 'torchbearer', with the wonderful lightweight mirrors that he has designed and his work with arrays of flat collectors--designs for future precision optical systems, with surface densities more than two orders of magnitude lighter than we built for HST. But, Roger, please, no more creative ideas on what to do with HST: after two decades of forefront scientific research, it will be time for that spacecraft to go into well-deserved retirement.

Which brings me to the sixth and final principle: let it go. Given the budget constraints science and technology projects face, we need to be willing to let go of old observatories when new technologies are ready for launch. We tend to hold tight to older technologies because we are comfortable with them. But those older systems consume a great deal of money for maintenance and updating, preventing us from developing and launching new and improved systems. We cannot continue on this path.

These principles should help us launch into a brave new future in space, but as I have said before, it will require dreaming big dreams and looking far into the future.

Perhaps a decade after SIM, TPF, and Life Finder have discovered several dozen warm and wet worlds in our stellar neighborhood, even lighter-weight optical structures will be ready, and we may choose as our next step apertures of 100 m and a baseline of 1000 km. Even while we are building such a system, our technologists will already be at work on 1 km apertures and baselines of 10,000 km and propulsion systems for rapid travel to the solar lensing sphere.

With these giant observatories, future observational astrobiologists might produce the first crude images of newly discovered planets. Scientists will debate the structure of continents and oceans, weather patterns, climates, storms, and the nature of seasons on dozens of new worlds, just as many of you today are debating the nature of the planets newly discovered around Upsilon Andromedae. The new century's students will be able to study the accretion of planetesimals and the impacts between young planets in newly-forming star systems. Larger systems could reveal lakes and rivers, the growth and destruction of forests, and the melting of ice caps could be revealed in planets around the nearest thousand stars. We might even be able to see global mats of algae or signs of bacteria reminiscent of the early Earth or vast forest fires on other planets . . . or the emissions from cities!

Let us not forget that while we are searching for life, we are also producing incredible tools for all of astronomy. As we perfect the control of these giant apertures, astronomers might use them to first gather radio and sub-mm light, perhaps from generations of young evolving stars halfway across the Universe. As our precision control improves, we will operate at infrared and visual wavelengths. We could investigate the collisions of gigantic dust clouds in the early Universe and the ejection of carbon-rich material, as the first stars end their lives.

And the scientists of the mid-century will use the same powerful optical systems to investigate the outer portions of the accretion disks surrounding supermassive black holes in the Virgo Cluster of galaxies. Imagine the spectacle of being able to watch the torrential effects of matter spiraling downward into this gravitational abyss.

Their colleagues will be equally vigorously investigating the processes of formation of the very first stars--and the generation of the first elements necessary for life—studied in detail from across the Universe.

Well, this has been quite a trip into the future, hasn't it? But I know that the torchbearers of the American Astronomical Society are equal to grand challenges. That's why I presented these possibilities to you today.

T.S. Eliot could have been speaking about the journey we embark on today when he said: "Only those who will risk going too far can possibly find out how far one can go."

Thank you for rising to yet another challenge. And thank you for daring not to be limited by your dreams!