NASA's Next Astrophysics Flagship: The Nancy Grace Roman Space Telescope (Roman)

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Why Nancy Grace Roman?

- PhD U Chicago 1949
- NASA’s First Chief Astronomer in 1959
- Championed space telescopes
- Mother of the Large Space Telescope (now Hubble)
Guidance from NWNH

Dark Energy and the Fate of the Universe

Wide-Field Infrared Surveys of the Universe (General Observer & Archival Research)

The full distribution of planets around stars

Technology Development for Exploration of New Worlds
A Bigger Roman

- Uses repurposed 2.4 m telescope from another government agency
- Three science pillars: dark energy, exoplanets, infrared surveys
- Science done with Wide Field Instrument (WFI), with 18 H4RG detectors

- Coronagraph Instrument (CGI) is a tech demo that will be ~1000x better than previous coronagraphs
- Designed to be ~Starshade ready
- Designed to be ~serviceable
- 5 year primary mission at L2
- 10+ year extended mission possible
The Universe as a Pie Chart

- Normal matter: ~5%
- Dark matter: ~27%
- Dark energy: ~68%
- Gas, Stars, Neutrinos
Consequences of DE

Dark Energy affects the:

• **Expansion history** of the Universe
  • How fast did the Universe expand?
  • Also called the **geometry** of the Universe

• **Growth of structures**
  • How do structures (which are mostly dark matter) evolve and grow over time
  • Attractive gravity competes with repulsive dark energy

If Einstein’s General Relativity is wrong, **modified gravity theories** could explain the accelerating expansion.

This would change the above effects differently, **so we must measure them both!**
If there is any intervening dark matter, light follows the **distorted path** (exaggerated).

Background images are magnified and sheared by ~2%, mapping a circle into an ellipse. Like glass lenses, gravitational lenses are most effective when placed roughly half way between the source and the observer.
Roman will measure galaxy shapes to map dark matter and measure the growth of galaxies over the Universe’s life.

From Massey, Rhodes, et al. 2007
Roman will map the positions of galaxies to establish a cosmic standard ruler to measure the Universe’s expansion history.
Roman will discover exploding stars (supernovae) across cosmic time to establish precise distances to galaxies
<table>
<thead>
<tr>
<th>Band</th>
<th>Element name</th>
<th>Min (μm)</th>
<th>Max (μm)</th>
<th>Center (μm)</th>
<th>Width (μm)</th>
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<td>F062</td>
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<td>0.977</td>
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<td>F</td>
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<td>1.464</td>
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<td>GRS</td>
<td>G150</td>
<td>1.0</td>
<td>1.93</td>
<td>1.465</td>
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<td>461(\lambda)(2pix)</td>
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<td>1.80</td>
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<td>Proposed lifetime</td>
<td>2022 - 2032</td>
<td>2022 - 2029</td>
<td>2025 - 2031</td>
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<tr>
<td>Mirror size (m)</td>
<td>6.5 (effective diameter)</td>
<td>1.2</td>
<td>2.4</td>
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<tr>
<td>Survey size (sq deg)</td>
<td>~20,000</td>
<td>15,000</td>
<td>2,227</td>
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<td>Median z (WL)</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
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<tr>
<td>Depth (5σ AB mag point source)</td>
<td>~27</td>
<td>~24 (NIR)</td>
<td>~27</td>
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<tr>
<td>FoV (sq deg)</td>
<td>9.6</td>
<td>0.5 (Vis) 0.5 (NIR)</td>
<td>0.28</td>
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<tr>
<td>Filters</td>
<td>u-g-r-i-z-y</td>
<td>Y-J-H-Vis</td>
<td>Y-J-H-F184</td>
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<tr>
<td>PSF Size</td>
<td>~0.7”</td>
<td>~0.2” (Vis)</td>
<td>~0.2” (NIR)</td>
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<tr>
<td>Mode</td>
<td>Photometry</td>
<td>Photometry/Grism</td>
<td>Photometry/Grism</td>
<td></td>
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</tr>
</tbody>
</table>

Roman*

*cool logos and graphics are coming
Exoplanets:
Detections by Discovery Year

1989-2018

Plots generated Sept. 27, 2018
WFIRST Complements Kepler

Kepler’s Search Area

WFIRST’s Search Area
From Penny et al 2018

- 2600 planet detections
- 370 with Earth mass and below
Also known as: Rogue Planets!
First (?) paper to suggest using a space telescope to directly image exoplanets.
A Firefly and a Spotlight

Seeing an exoplanet around a star is like trying to see a firefly near a spotlight in Los Angeles... when you are at CERN.

Seeing an Earth-like exoplanet in the habitable zone around a Sun-like star is like trying to see a firefly near ONE THOUSAND spotlights in Los Angeles... when you are at CERN!

Credit: S Gaudi
Contrast Ratio (planet light to star light)

$10^{-5} - 10^{-6}$ 1 part in 100,000 to 1,000,000
What we can get from coronagraphs now and in the near future

$10^{-9}$ 1 part in 1,000,000,000
What WFIRST’s coronagraph is being designed to achieve (already demonstrated in lab- idealized conditions)

$10^{-10}$ 1 part in 10,000,000,000
What we need to see another Earth (with a future mission like HabEx or LUVOIR)
CGI is a Pathfinder for Direct Imaging and Spectroscopy of Earth-like Exoplanets

- CGI projected capabilities represent a 1000 fold compared to current capabilities
  - Enabled by active control of optical wavefront errors and pointing
- Dozens of planets within reach of characterization
- exoEarths in Habitable zone further x10-100 improvement in contrast and x2 in spatial resolution
- CGI is a major stepping stone that will obtain optical spectra of mature exoJupiters
CGI will premiere in space many key technologies required for the characterization of rocky planets in the Habitable Zone, significantly reducing the risk and cost of future possible missions such as HabEx and LUVOIR.

CGI is a direct & necessary predecessor to these missions, and is a crucial step in the exploration of Sun-like planetary systems.
Actuators and Mechanisms

- FSM: Fast Steering Mirror
- FCM: Focus Control Mirror
- DM (2x): Deformable Mirror
- DPAM: Prisms & Lenses
- CFAM: Color Filters
- FSAM: Field Stops & Slits
- LSAM: Lyot Stops
- FPAM: Focal Plane Masks
- SPAM: Shaped Pupil Masks

Used in control loops
Used in setting up modes
Self-luminous, Young Super Jupiters: Atmospheric Properties

Mature Jupiter Analogue in Reflected Light: Atmospheric Properties

Circumstellar disks: Protoplanetary (young) Debris (mature) Exozodi (mature, HZ)

Blind Searches for Exoplanets

Orbital Solution and Mass Measurement

Neil Zimmermann (GSFC)
Potential Starshade with WFIRST
Starshade
Starshade at JPL
## Observing Program Overview

<table>
<thead>
<tr>
<th>Observing Program</th>
<th>Program Attributes</th>
<th>Notional Time Allocation</th>
<th>Current Time Estimate</th>
</tr>
</thead>
</table>
| **HLIS**          | Survey Speed: 0.20 sq-deg/hour  
Reference Survey: 2000 sq-deg, 2 passes, 4 filters  
Baseline Survey: 1700 sq-deg, 2 passes, 4 filters | Survey Time: 352 days  
Deep-field observations: 39 days  
Total: 391 days | 291-342 days*  
(1700-2000 sq-deg) |
| **HLSS**          | Survey Speed: 0.34 sq-deg/hour  
Reference Survey: 2000 sq-deg, 4 passes, Grism  
Baseline Survey: 1700 sq-deg, 4 passes, Grism | Survey Time: 211 days  
Deep-field observations: 23 days  
Total: 234 days | 169-199 days*  
(1700-2000 sq-deg) |
| **SNS**           | Survey Area: 5 sq-deg, up to 6 filters + Prism  
Survey Cadence: 30 hours every 5 days over 2 year period | Survey Time: 183 days | |
| **EMS**           | Reference Survey Coverage: 731.7 sq-deg-days  
Baseline Survey Coverage: 585.4 sq-deg-days  
Survey Area: 2 sq-deg  
Survey Cadence: 15 minutes | Survey Time: 372 days | |
| **GO**            | Full sky availability throughout the mission | Program Time: 456 days | |
| **EC**            | 90 days of observing to support technology demonstration | Program Time: 90 days | |
| **TOTAL**         | | TOTAL: 1726 days (4.73 years) | |
| **Schedule Reserve (Used for Mission Overheads)** | | 99 days (0.27 years) * Using MEV slew durations |
## Partnerships

| **JAXA** | Coordinated, contemporaneous ground-based observations on Subaru Ground station for data downlink  
Polarization optics for the CGI  
Microlensing data from the MOA project & new PRIME observatory |
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>MPIA</strong></td>
<td>Precision mechanisms for the CGI</td>
</tr>
</tbody>
</table>
| **ESA*** | Star trackers, possibly other S/C components  
EMCCD detectors for the CGI (e2v in UK)  
Ground station for telemetry and tracking |
| **CNES** | Superpolished optics for the CGI  
Grism data processing  
Cosmology simulations |

*Interested? Contact rlaureij@cosmos.esa.int or Andrea.Santovincenzo@esa.int

**Interested? Contact Pascale.Danto@cnes.fr
Roman Status (Notwithstanding COVID Delays)

- Roman remains on the plan approved at the beginning of Phase B in 2018
- Development cost of $3.2B, excluding coronagraph technology development instrument
- Advanced to Phase C in 2020
- FY2020 and FY2021 are the peak budget years
  - Approaching 1000 people working on WFIRST!
- 12 of 18 H4RG detectors in hand
- Launch in late 2025

- Roman Science Interest Group (RSIG) recently formed
- CGI Community Participation Program (CPP) solicited in 2021
- New science teams solicited in late 2021

Roman primary mirror at L3/Harris in Sept 2020, refuged and recoated
Additional Slides
Observing Program Overview

**NOTIONAL OBSERVING PROGRAM LAYOUT**

Assuming 09/11/2025 launch, 90-day commissioning and orbit insertion by 12/31/2025

<table>
<thead>
<tr>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
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<tr>
<td><strong>MISSION YEAR 1 (2026)</strong></td>
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<tr>
<td>HLS</td>
<td>EMS</td>
<td>EMS</td>
<td>HLS</td>
<td>EC</td>
<td>GO</td>
<td>HLS</td>
<td>EMS</td>
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<td>HLS</td>
<td>EC</td>
<td>EC</td>
<td>GO</td>
<td>GO</td>
<td>PA/C</td>
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</table>

| **MISSION YEAR 2 (2027)** | | | | | | | | | | | |
| EC | EMS | EMS | HLS | HLS | HLS | SNS | SNS | SNS | SNS | SNS | SNS |
| GO | EC | GO | HLS | GO | HLS | GO | HLS | HLS | HLS | HLS | PA/C |

| **MISSION YEAR 3 (2028)** | | | | | | | | | | | |
| SNS | SNS | SNS | SNS | SNS | SNS | SNS | SNS | SNS | SNS | SNS | SNS |
| HLS | GO | HLS | HLS | HLS | GO | HLS | GO | HLS | GO | GO | PA/C |

| **MISSION YEAR 4 (2029)** | | | | | | | | | | | |
| SNS | SNS | SNS | SNS | SNS | SNS | HLS | GO | EMS | EMS | HLS | GO |
| HLS | HLS | GO | HLS | GO | PA/C | HLS | PA/C | |

| **MISSION YEAR 5 (2030)** | | | | | | | | | | | |
| HLS | EMS | EMS | HLS | HLS | GO | EMS | EMS | GO | HLS | GO | PA/C |
| GO | GO | GO | GO | HLS | HLS | PA/C | |

**LEGEND**

- HLS: High Latitude Survey (Imaging & Spectroscopy)
- SNS: Supernova Survey (Imaging & Spectroscopy)
- EMS: Exoplanet Microlensing Survey
- GO: General Observer Program
- EC: Exoplanet Coronagraphy Program
- PA/C: Payload Alignment/Calibration

- Notional Observing Program activities are represented in each month as a **percentage of time dedicated to that activity**
- Durations range from 1 week (25%) to 4 weeks (100%)
- Routine mission overheads (e.g. large slews between observing programs, momentum unloads, station-keeping) are interleaved with the observing program activities
### DE Survey Complementarity at a Glance

<table>
<thead>
<tr>
<th>STAGE IV</th>
<th>LSST</th>
<th>WFIRST</th>
<th>Euclid</th>
<th>DESI</th>
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<tbody>
<tr>
<td><strong>Start, duration</strong></td>
<td>2022, 10 yr</td>
<td>\sim 2025, 5 (-10) yr</td>
<td>2021, 6 yr</td>
<td>2019, 5 yr</td>
</tr>
<tr>
<td><strong>Area (sq. deg.)</strong></td>
<td>20,000 (S)</td>
<td>2,000 (S)</td>
<td>15,000 (N+S)</td>
<td>14,000 (N)</td>
</tr>
<tr>
<td><strong>FOV (sq. deg.)</strong></td>
<td>10</td>
<td>0.281</td>
<td>0.53</td>
<td>7.9</td>
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<tr>
<td><strong>Diameter (m.)</strong></td>
<td>6.7</td>
<td>2.4</td>
<td>1.3</td>
<td>4</td>
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<tr>
<td><strong>Photometric Survey</strong></td>
<td>6 bands (u,g,r,i,z,y)</td>
<td>6 bands (Z,Y,J,H,F,184,W149)</td>
<td>4 bands (VIS,Y,J,H)</td>
<td></td>
</tr>
<tr>
<td><strong>Photometric Galaxies (w/ shapes) (#/arcmin²)</strong></td>
<td>\sim 30 in 6 bands (ugrizy)</td>
<td>\sim 68 in 4 bands (YJHF184)</td>
<td>\sim 30-35, in 1 band (VIS)</td>
<td></td>
</tr>
<tr>
<td><strong>SN1a</strong></td>
<td>(10^4-10^5/\text{yr} ) (z=0-0.7) photometric</td>
<td>2700 (z=0.1-1.5) IFC spectroscopy</td>
<td></td>
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<tr>
<td><strong>Spectroscopic Survey</strong></td>
<td>Grism R=550-800 1-2 μm</td>
<td>Grism R=250 1.1-2 μm</td>
<td>Fibers R=4000 0.36-0.98 μm</td>
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<tr>
<td><strong>Spectroscopic Galaxies</strong></td>
<td>ELGs (z=0.5-1.8) (Ha/\sim 20M) (z=0.9-2.8) (OIII/\sim 2M)</td>
<td>ELGs, z\sim 0.7-2.1 (20M)</td>
<td>LRGs+ELGs z\sim 0.6-1.7 (20-30M) QSOs/Lya 1.9&lt;z&lt;4 (1M)</td>
<td></td>
</tr>
</tbody>
</table>
WFIRST Surveys

- Multiple surveys:
  - High-Latitude Survey
    - Imaging, spectroscopy, supernova monitoring
  - Repeated Observations of Bulge Fields for microlensing
  - 25% Guest Observer Program
  - Coronagraph Observations
- Flexibility to choose optimal approach

![Near Infrared Surveys Diagram]
Field of Regard (FOR)

Observing Zone:
- 54°-126° off Sun Line
- 360° about Sun Line
- ±15° about line of sight (LOS) off max power roll angle

HLS/GO/Coronagraph observations can be optimized within the full Observing Zone.

SNe fixed fields ±20° off of the ecliptic poles, located in continuous viewing zone.

Earth/Moon LOS avoidance angles are a minor sporadic constraint.

Microlensing can observe inertially fixed fields in the Galactic Bulge (GB) for 72 days twice a year.