UVSTIG/Technology White Paper

COPAG/Cosmic Origins Program Analysis Group

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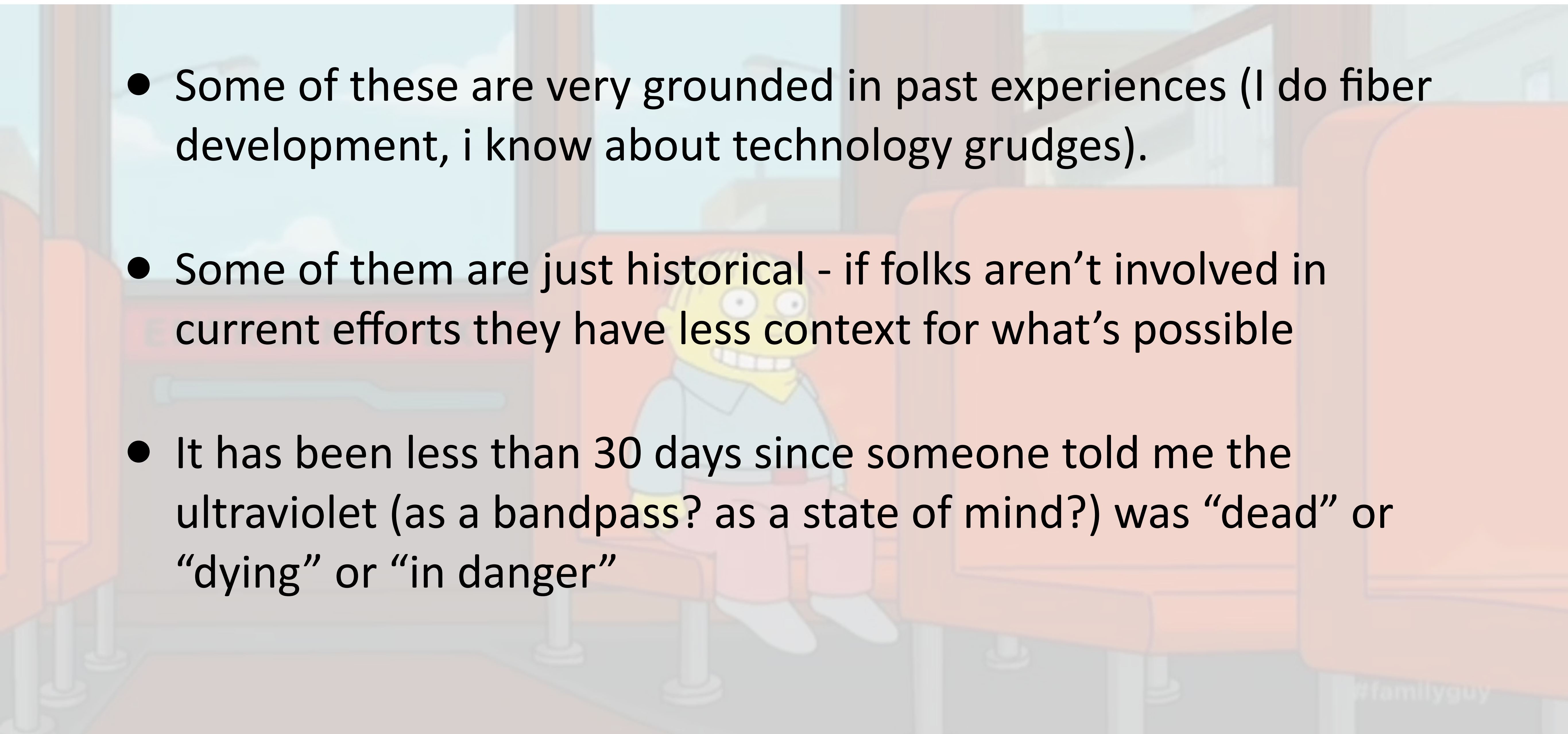
Who are we?

- A combination of UV technologists and astronomers who are excited about the potential of HWO
- A cross-section of career stages - from graduate students to retired experts
- A broad multi-institution collection - contributors from Universities, NASA centers, and industry

Why this working group?

- The road to HWO is both really long (work wise) and surprisingly short (time wise)
- Crucial to capture the current state of UV technology
- Want to document and address some past concerns & experiences
- Demonstrate current state of the art
- Instrumentalists are surprisingly (not that surprisingly) mediocre at publishing things. Building things? Great. Documenting that? A… little less great.

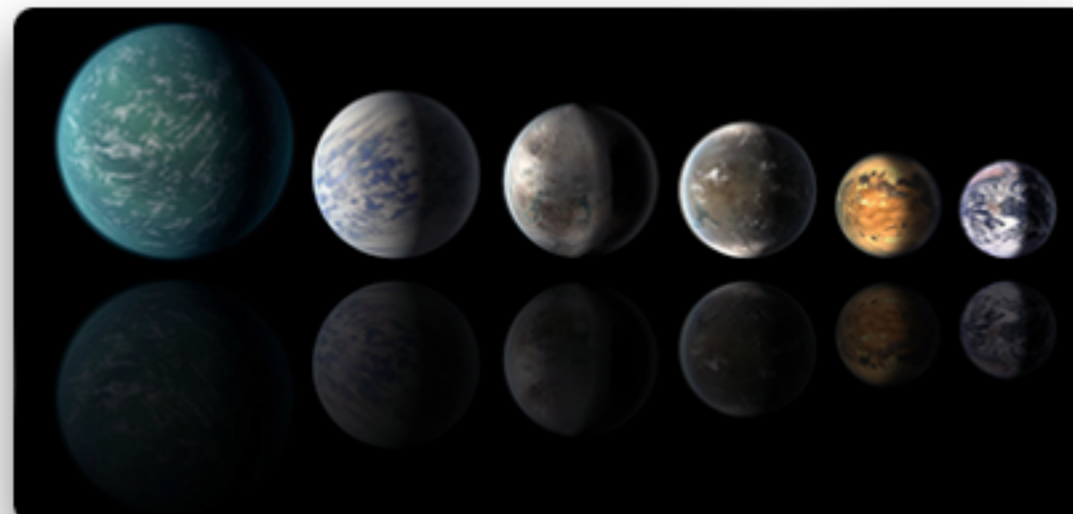
…People have big UV-related feelings



- Some of these are very grounded in past experiences (I do fiber development, i know about technology grudges).
- Some of them are just historical - if folks aren't involved in current efforts they have less context for what's possible
- It has been less than 30 days since someone told me the ultraviolet (as a bandpass? as a state of mind?) was "dead" or "dying" or "in danger"

Main HWO takeaways

Habitable Worlds Observatory (HWO)



PIA19830: Pantheon of Planets Similar to Earth (Artist's Concept). Image Credit: NASA/Ames/JPL-Caltech

"Inspired by the vision of searching for signatures of life on planets outside of our solar system, and by the transformative capability such a telescope would have for a wide range of astrophysics, the priority recommendation in the frontier category for space is a large (~6 m diameter) IR/O/UV telescope with high-contrast (10^{-10}) imaging and spectroscopy. This is an ambitious mission, of a scale comparable to the HST and JWST space telescopes. It is also one that will be revolutionary, and that worldwide only NASA is positioned to lead." (Text source: Decadal Survey on Astronomy and Astrophysics 2020 [Astro2020])

Ultraviolet Astrophysics

Ultraviolet wavelengths are important to answer many questions in astrophysics. In addition to being sensitive to optical and near-infrared, Habitable Worlds Observatory will be sensitive to ultraviolet light.

Main HWO takeaways

Habitable Worlds Observatory (HWO)

PLANETS!!!!!!!

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Ultraviolet Astrophysics

UV-ish

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What did we do?

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UV Science Driven Technology White Paper

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Take aways

- Both planetary characterization and the circumgalactic medium (key science drivers) require pushing down to the 100nm cutoff.
- Current coatings reach nominal desired (reflectance) values in the UV.
- Electron-beam lithography is our most promising UV grating technology and has been tested sub-orbitally.
- Several mature UV detector technologies are available and flight qualified (with several more in the wings). There is room for performance improvement - this will especially benefit the transformational astrophysics goal of HWO.
- Contamination must be controlled at the systems level and the component level. We capture the wealth of knowledge on this topic to provide a strong start for HWO.
- Several multiplexing technologies have been space qualified. When combined with UV coating development, there is a very exciting path to a multiplexed UV instrument.

Key Science: Atmospheric Characterization

Drives a short wavelength cutoff of 250nm for direct imaging and low resolution spectroscopy targeting O_3

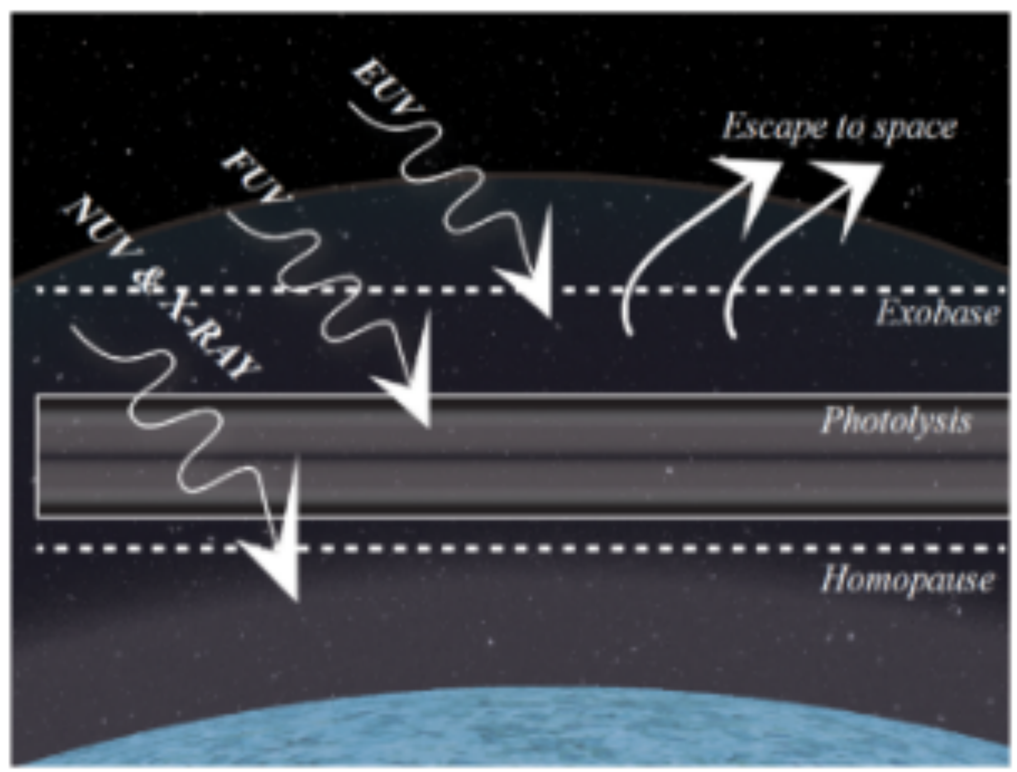


Figure 1: The ultraviolet stellar spectrum drives photochemistry (FUV and NUV photons, 100 – 320 nm) and atmospheric escape (EUV photons, 10 – 90 nm) on orbiting planets. The EUV spectrum is calculated from chromospheric and coronal lines in the FUV spectrum, with the 100 – 115 nm band providing unique diagnostics for temperature and abundances. The host star spectra are used to predict the most promising habitable planet candidates and to interpret atmospheric spectra (Tsai et al. 2023).

Key Science: Atmospheric Characterization

The 102-115 nm range includes unique spectral tracers of portions of the host star chromosphere and coronae.

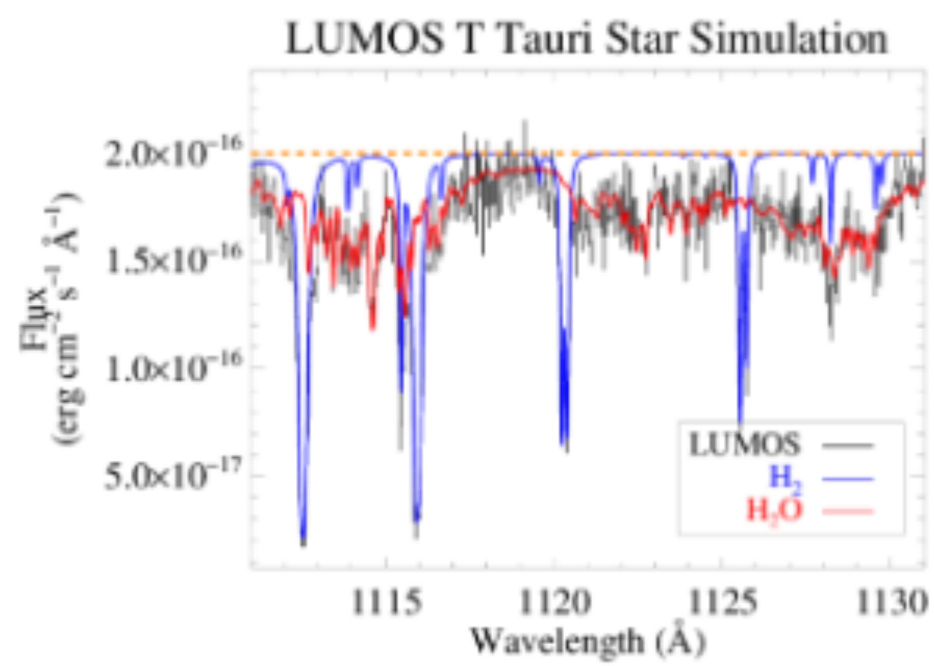


Figure 2: Spectral simulation the 111.1 – 113.2 nm spectrum of an edge-on protoplanetary disk, a spectral region containing strong lines of H_2 and H_2O (France et al. 2014; Cauley et al. 2021). Multi-object spectroscopy from 100 – 170 nm enables simultaneous detection of up to 30 young stars in a region like the Orion Nebula Cluster (ONC). A multiplexed instrument on a ≈6-m space observatory would eclipse the total UV disk archive of HST in 2 -0 4 pointings in the ONC.

Elements traced by 100-115 nm are also critical for characterizing protoplanetary disks

Key Science: Circumgalactic Medium

100 - 120 nm captures OVI (103.2nm) at z > 0.1 and Ne VIII and Mg X at z > 0.5

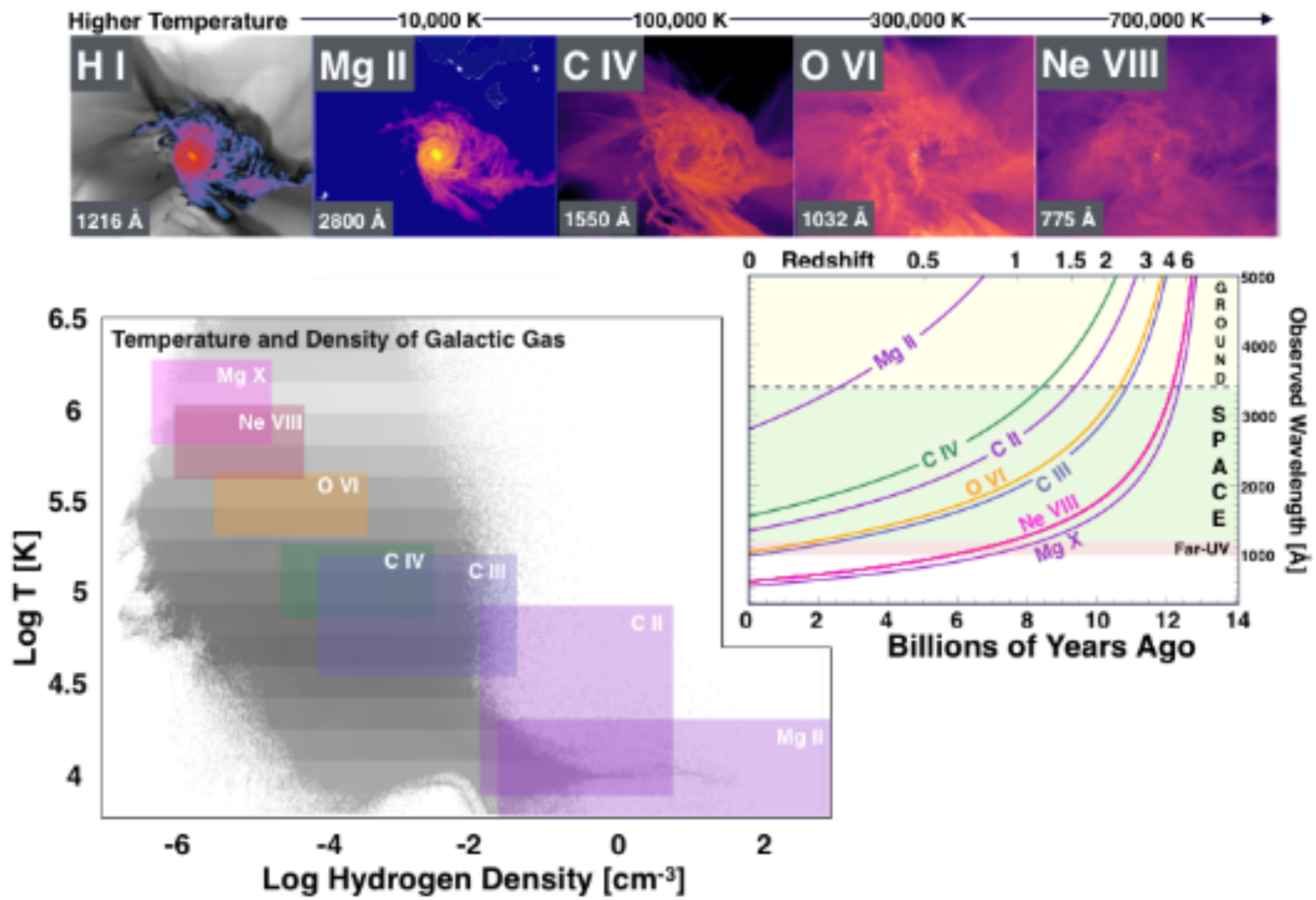


Figure 4: Diffuse gas in and around galaxies requires UV capability for most of cosmic time. The top row shows a simulated galaxy at z = 0.7 from the FOGGIE suite (Peeples et al. 2019), rendered in some key diagnostic ions. The temperature and density regimes probed by these ions are marked in the "phase diagram" of this galaxy's gas. In upper right, we show how these lines, ranging from Mg X at 68nm to Mg II at 280 nm, vary in observed wavelength with redshift. Even with redshift, most of this diffuse gas is visible only in the UV for the last 10 Gyr of cosmic time. X-ray lines such

Key Science: Circumgalactic Medium

100-200 nm

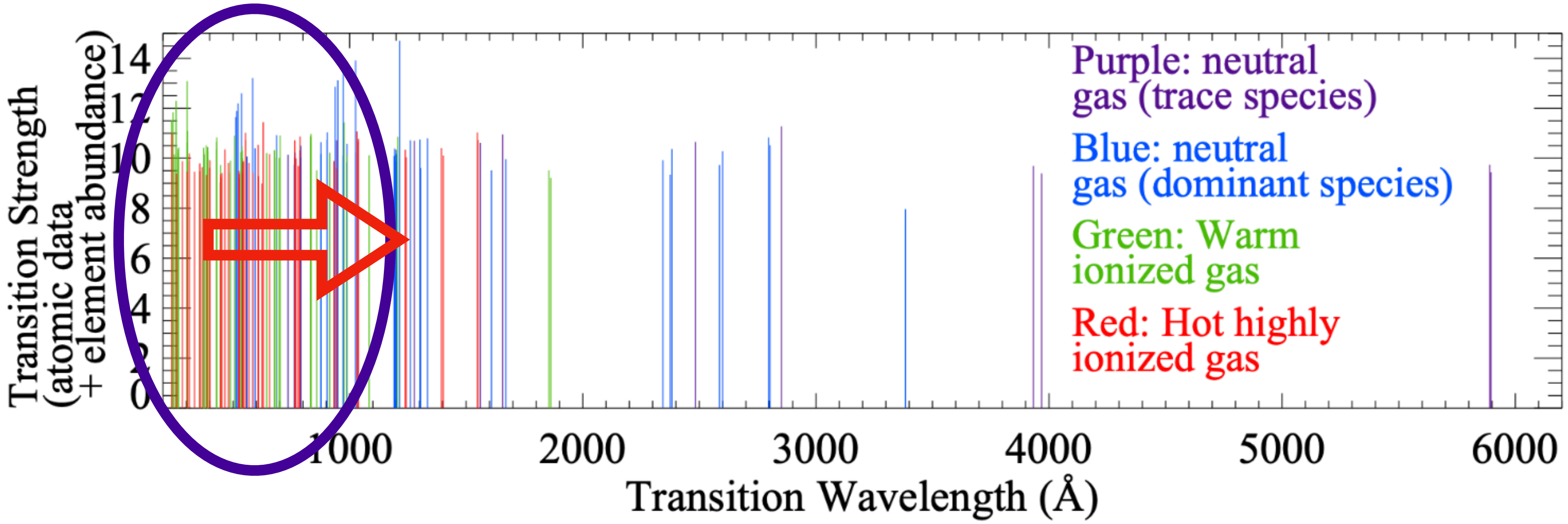
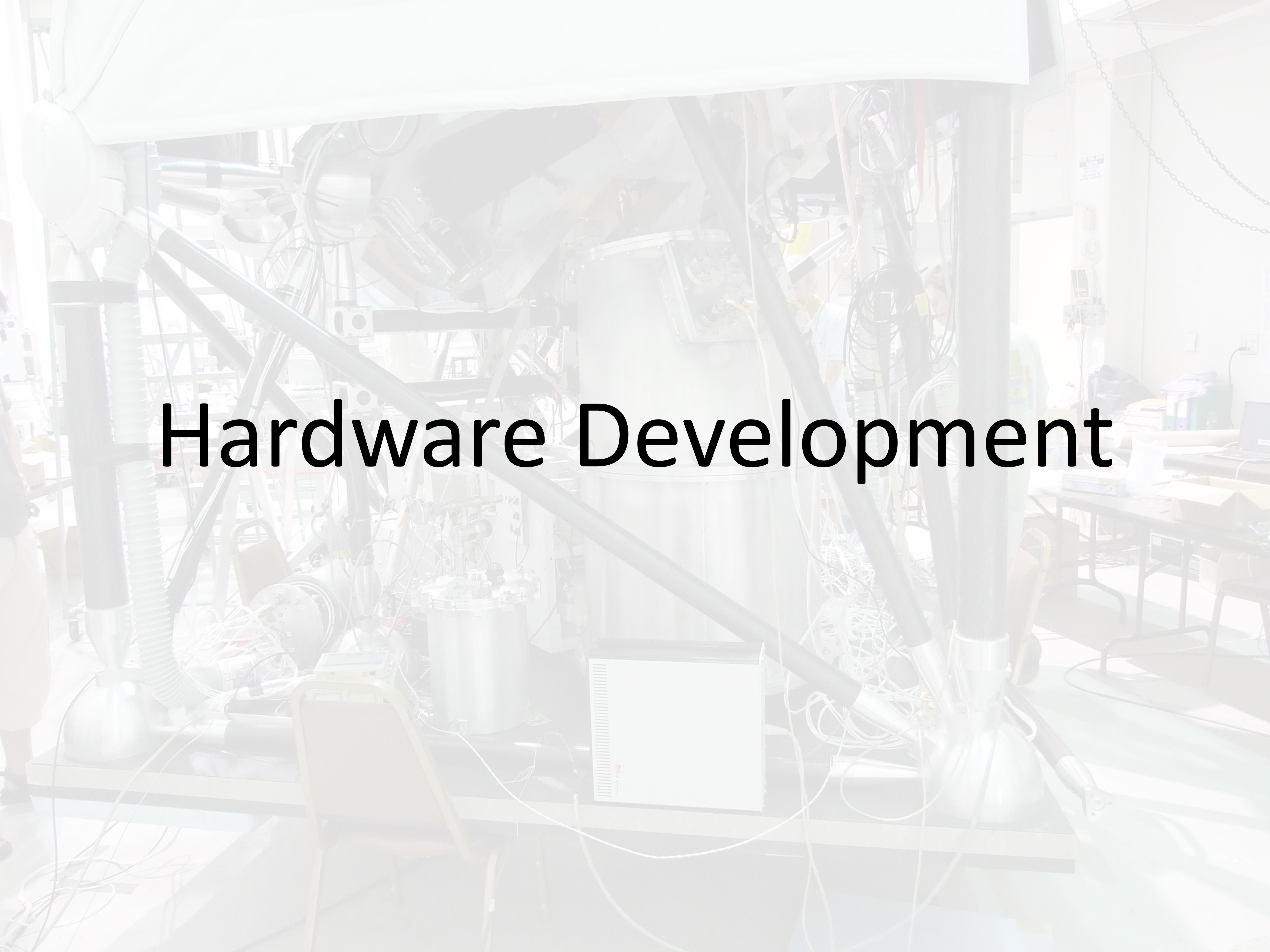


Figure 3: The distribution of resonance lines as a function of the rest-frame wavelength in the ultraviolet regime (adapted from Tripp 2013). The strength of the line represents the elemental abundance and strength of the transitions. The colors indicate the ionization state of the gas the lines are expected to trace.

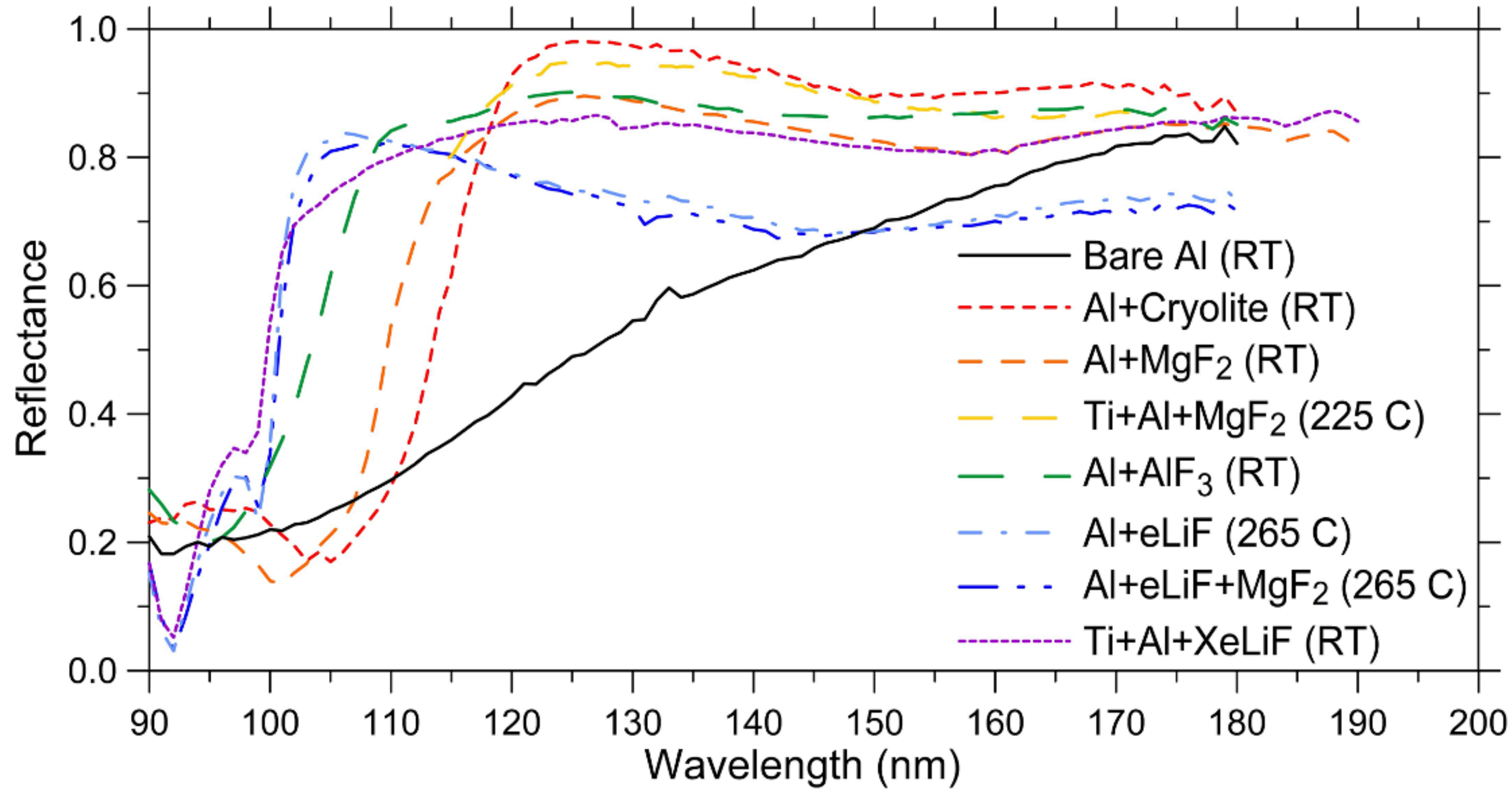
- Enables Baryon Census
- Multiphase metals census (including OII, OIII, OIV)
- Mapping nearby - lower redshift, deeper UV, better spatial resolution
- Includes high ionization lines usually considered X-ray only like Ne VIII (77.5 nm), Mg X (61 nm), Si VII (50nm)

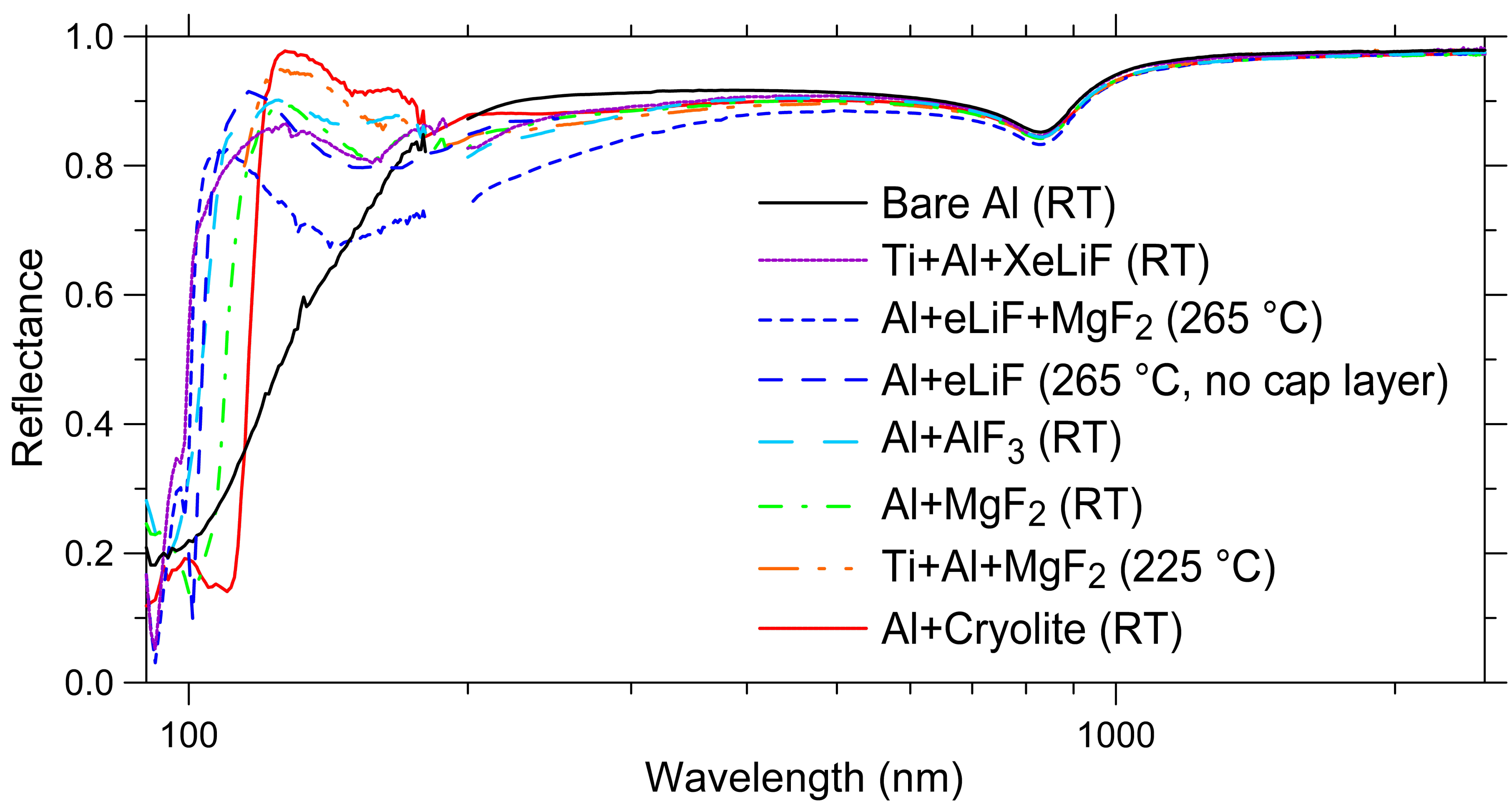
Hardware Development



Coatings

UV





UVOIR

Coatings

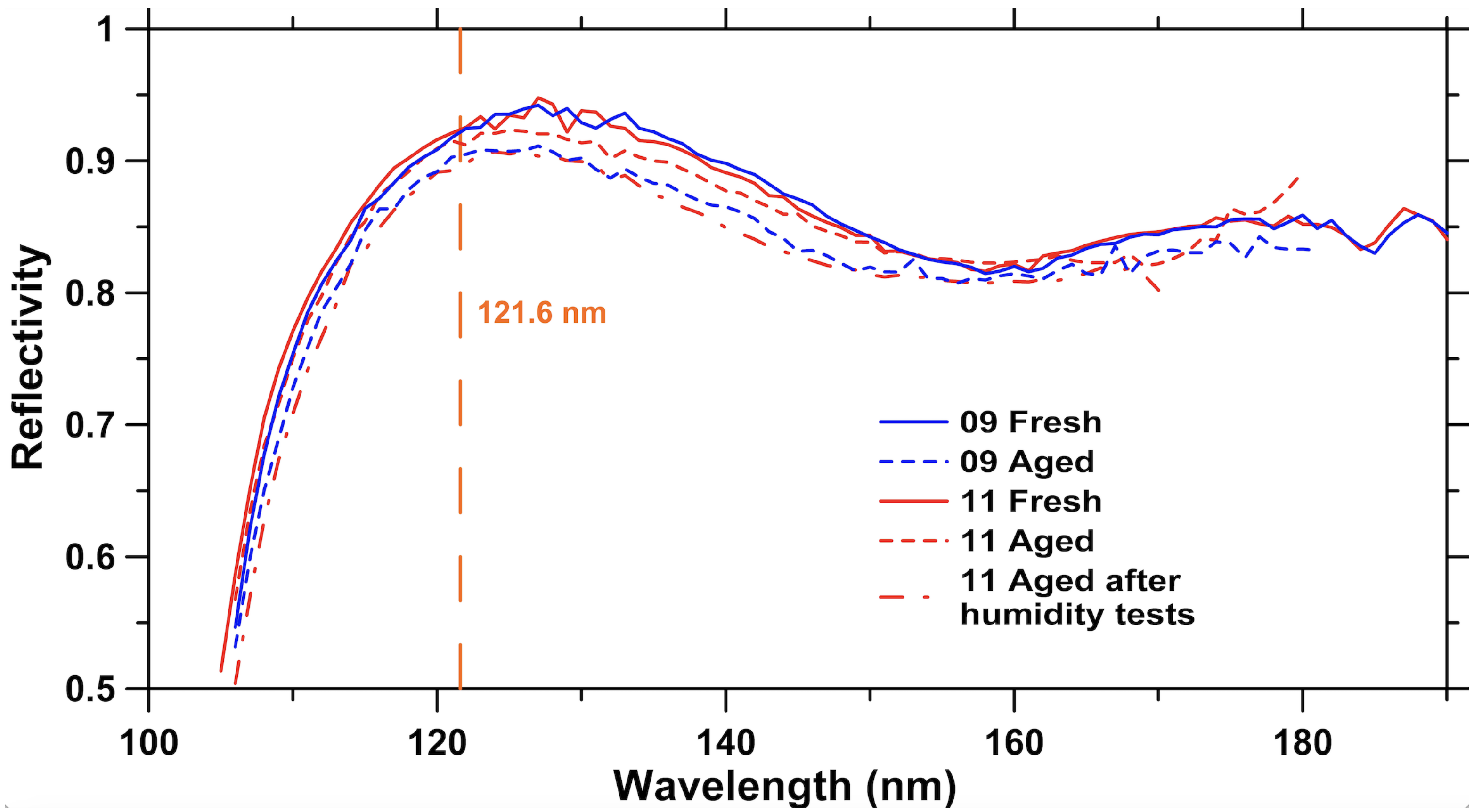


Figure 35: Reflectivity of two XeLiF samples (ID 09 and 11) both fresh and aged (18 and 12 weeks, respectively).

Technology development with XeLiF capping procedure provides robust humidity protection

Coatings

Coating Technology	Coating Properties						
	λ Value @ R>60%	TRL	Largest Optics Coated	Elevated Substrate Temperatures Required?	Max. Relative Humidity for Coating Stability	Dielectric Layer Deposition Process	μ-roughness
Bare Al	>150 nm	6	> 1 meter	No	~70-100%	-	~0.78 nm
Al+MgF_2	>111 nm	6	> 1 meter	No	~70%	PVD	~1.84 nm
Al+LiF	>101 nm	6	~0.5 meter	No	< 30%	PVD	Fresh 1.5-2.5 nm Aged >3 nm
Al+eLiF+MgF_2	>102 nm	~5-6	~ 0.3 meter	Yes	~60 %	eLiF (PVD) MgF_2 (ALD)	1.5-2.5 nm
Al+XeLiF	>103 nm	~3	5x5 cm^2	No	~60%	Reactive PVD	~1-1.5 nm
Al+AlF_3 (e-beam)	>105 nm	~4	5x5 cm^2	No	~60%	E-beam Plasma	~0.81 nm

The absence of TRL 9, even for coatings that have flown, emphasizes that any coating used will require scaling up, polarization characterization, and adequate uniformity - a new set of requirements for HWO

Detectors - MCPs

Heritage performance + flight qualification

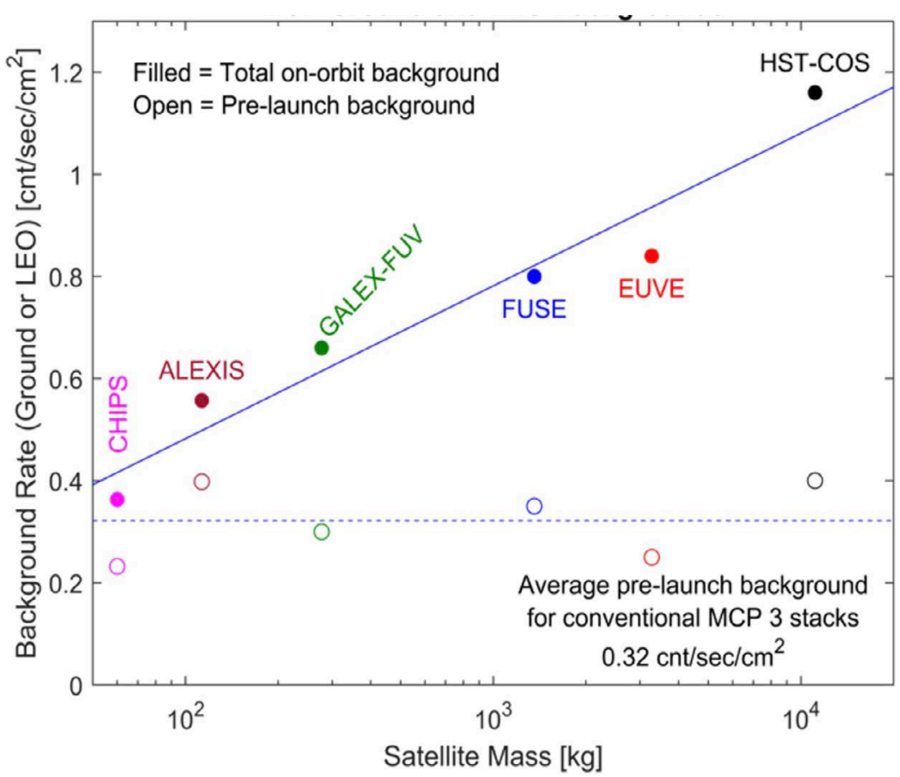


Figure 19: Background for LEO MCP detectors (Siegmund et al. 2020)

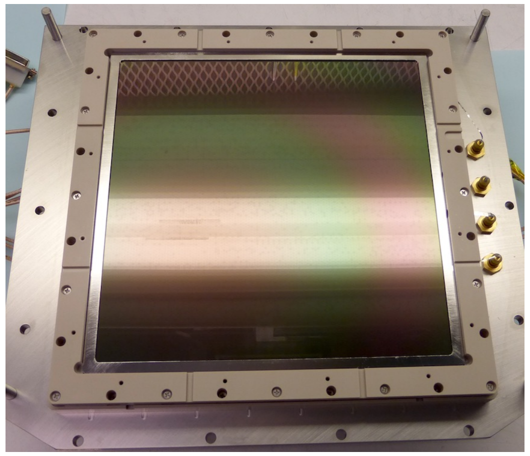


Figure 20: 20 x 20 cm Microchannel Plate with XDL readout for the DUCE rocket program.

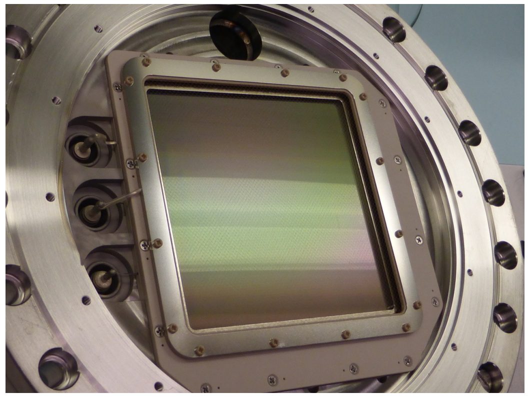


Figure 21: INFUSE (2023) 100 mm XS Detector with 25 µm resels.

This mass related impact (satellite converts galactic cosmic rays into local background radiation) is improved with recent ALD borosilicate MCP updates

Detectors - CCDs

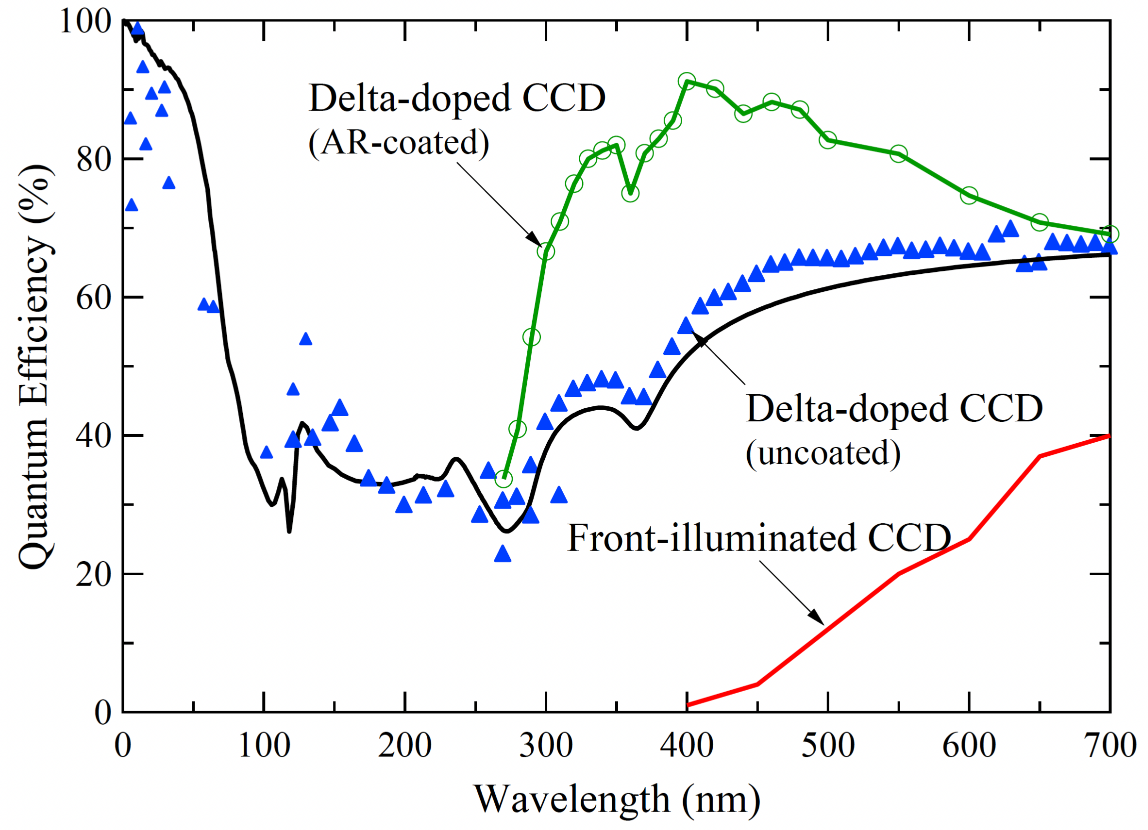


Figure 23: Delta-doping involves a doping layer to a back-illuminated silicon detector, which eliminates an electron well in the detector surface. The result is silicon detectors sensitive in the UV. The QE can be further increased by the addition of anti-reflection coatings. In the figures, solid lines are models, markers are measurements (Hoenk et al. 2022).

QEs as large as 50-60% are possible with 3-4 orders of magnitude out of band rejection

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What comes next?

We suggest….

- Process level (material physics) development (polarimetry performance of coatings, for example)
- Technologies need to scale up in aperture. We need to support facility to begin testing these larger scale components.
- Shifting modes from proving components to developing production lines and systems development and testing.
- Development of laboratory prototype testbed instruments
- Investment beyond APRA (sub-orbital) missions
- Technology Demonstration Missions (smallsats/pathfinders) to do systems level testing and provide early-career mission training

What comes next?

That's up to you.

- GOMAP START and TAG efforts are underway
- UV rockets, cubesats, and smallsats are at every stage of development
- Coordination with the Coronograph/Exoplanet group is on going, including potential shared testbed facility development

Check out the UVSTIG/Mine/Mind the Gap Sessions on Tuesday!

9:30-11:30am, 1:30-3:30pm (Room R07)