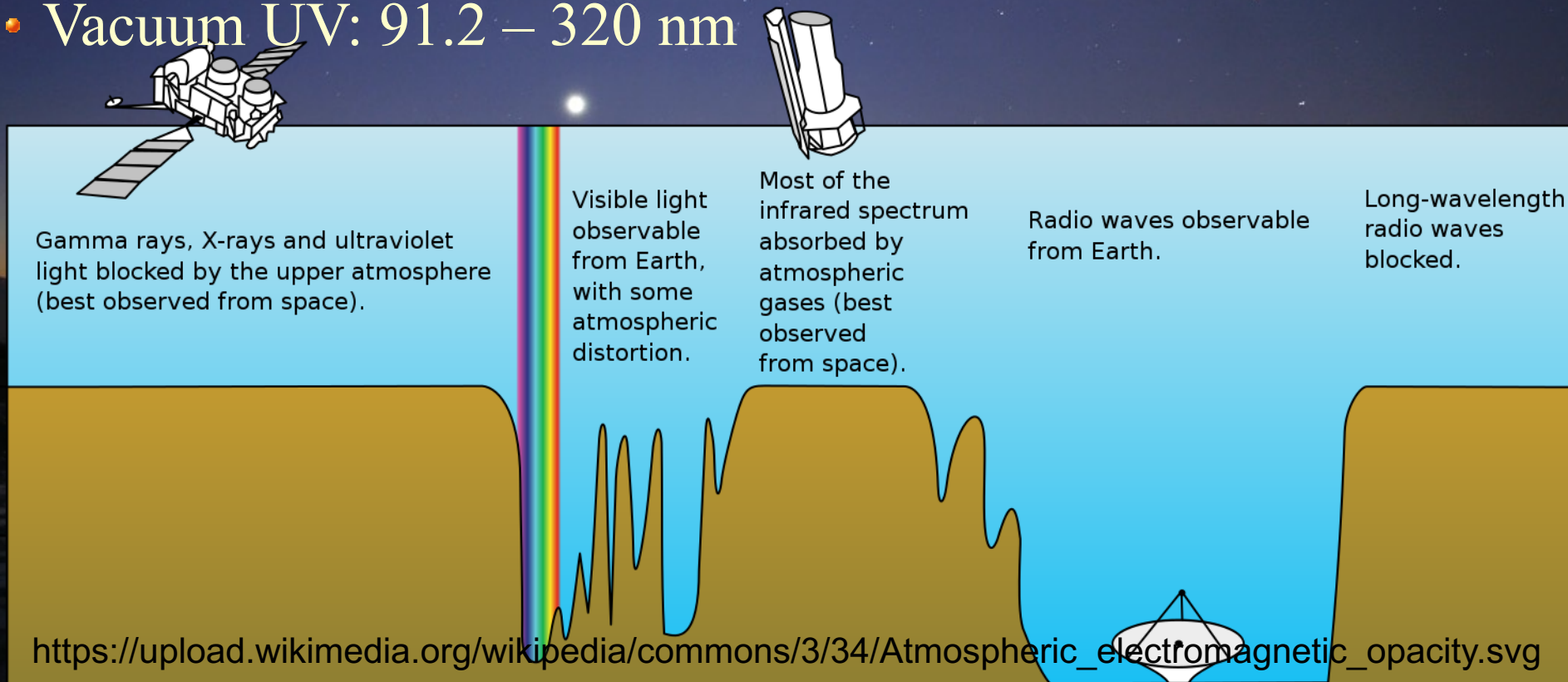


UV Astronomy and UVIT

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UV Definitions

- Wavelength regions defined by technology
 - EUV: 7 – 91 nm.
 - FUV: 91 – 120 nm (FUSE)
 - NUV: 120 – 300 nm (GALEX)
 - Vacuum UV: 91.2 – 320 nm

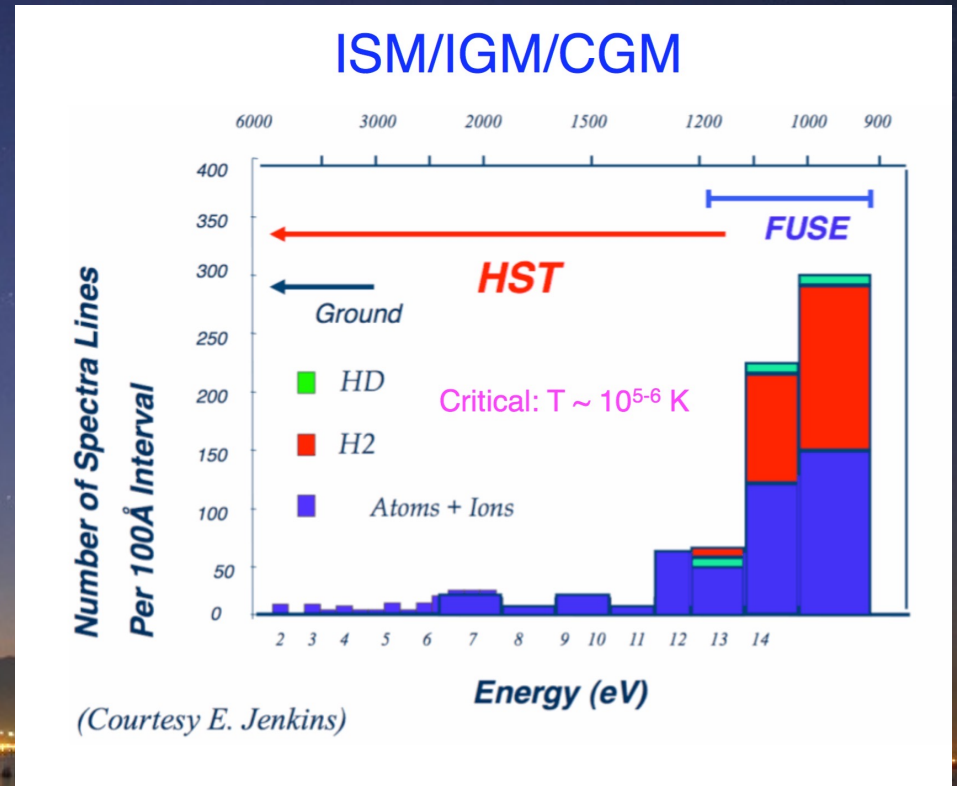


History

- First UV observations made from V-2 rockets.
 - Operation Paperclip brought German rocket scientists to Huntsville, Alabama.
 - *The solar ultraviolet spectrum from a V-2 rocket.*
 - Tousey et al. 1947 AJ, 52, 158.
- Sounding rockets (many from NRL) made the first observations in UV, X-ray and gamma ray astronomy.
- Major push into UV astronomy because it was close to optical astronomy.

Why UV

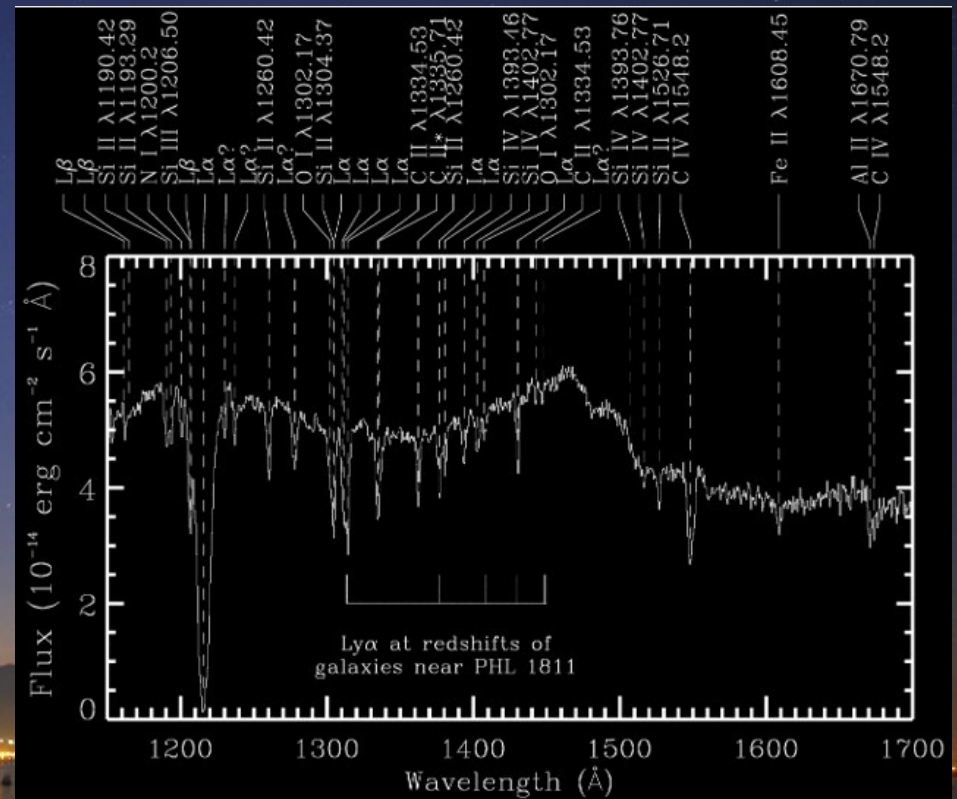
- Many electronic transitions of atoms/molecules.



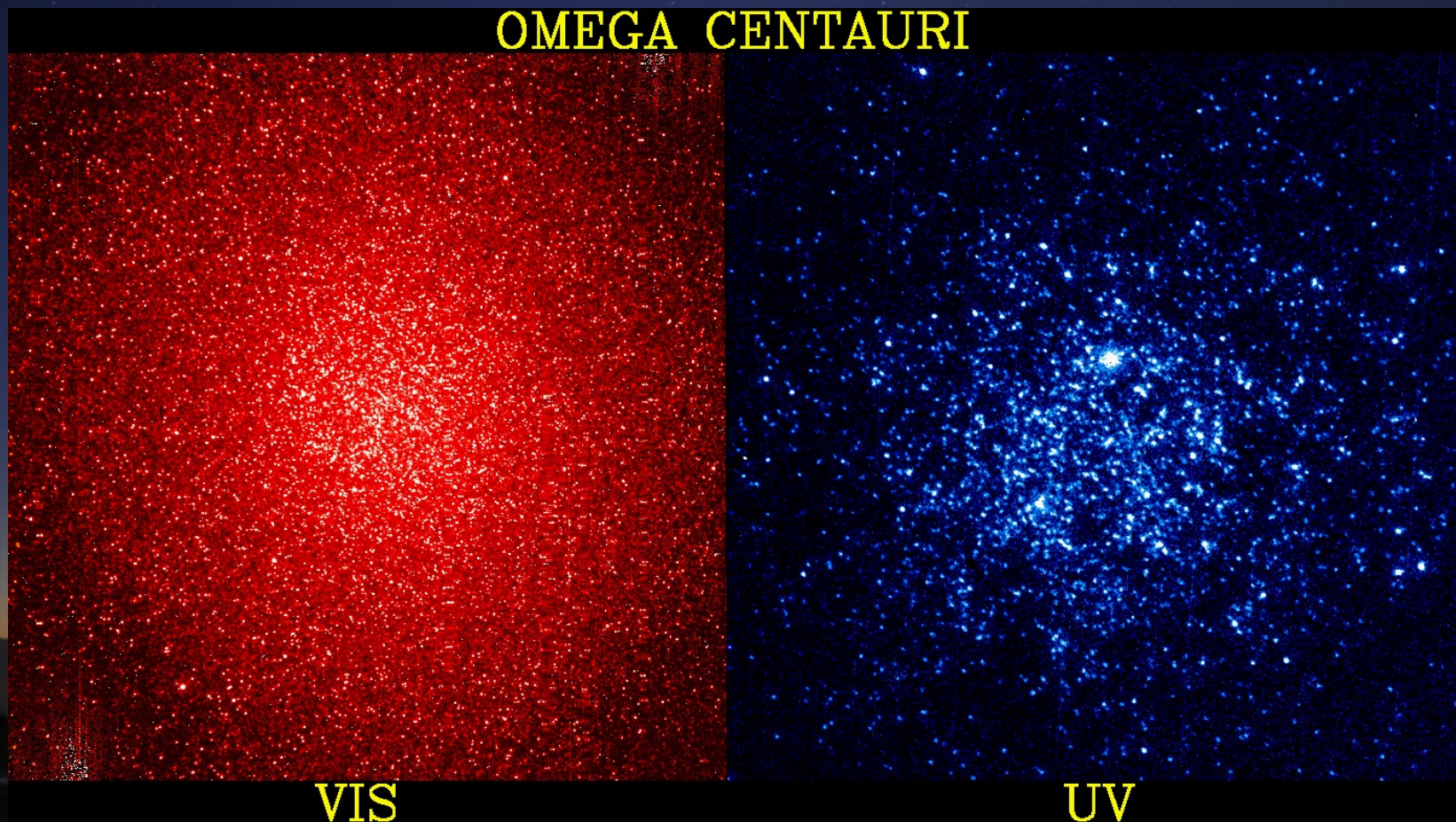
<https://rwoconne.github.io/rwoclass/ast511/im/line-count-vs-wavelength-Jenkins-label.jpg>

Why UV

- Many electronic transitions of atoms/molecules.
- Physics is in the UV.
 - Temperature, density, pressure, velocity.



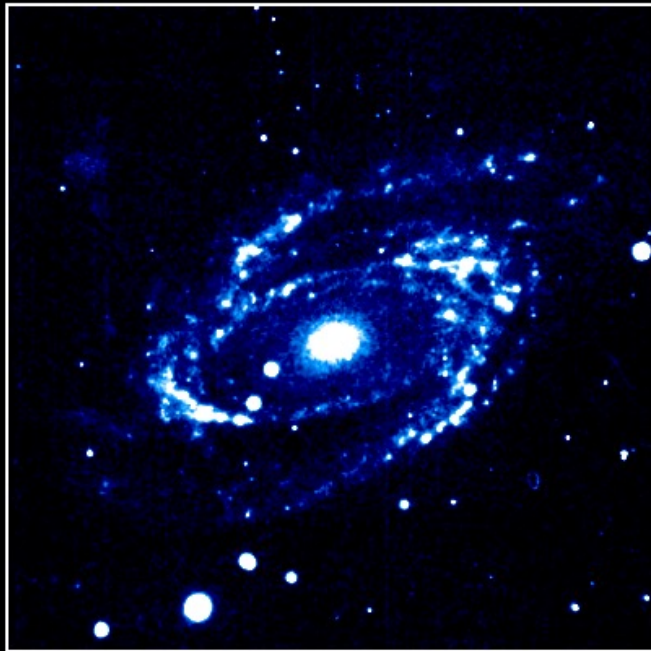
Why UV



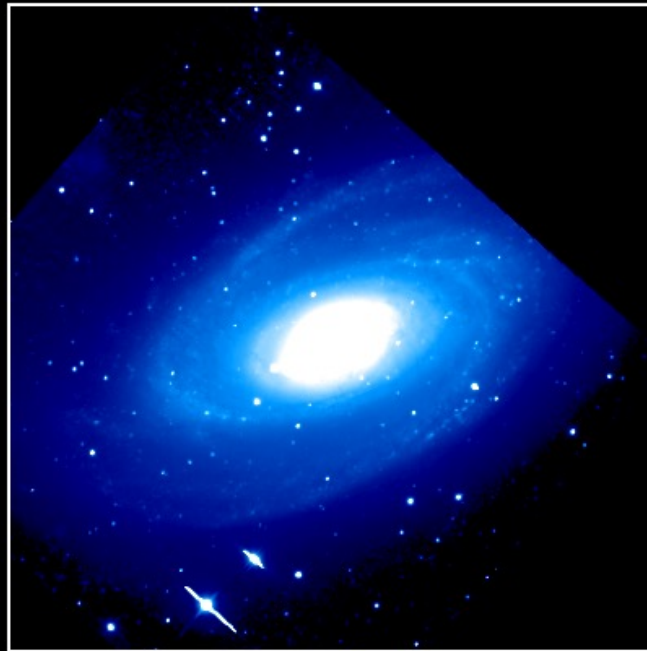
https://apod.nasa.gov/apod/image/omgcn_uit_big.gif

Why UV

M81 (Sb)



Mid-UV



R

<https://rwoconne.github.io/rwoclass/astr511/im/M81uvr.gif>

UV Definitions

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 - NUV: 120 – 300 nm (GALEX)
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EUV

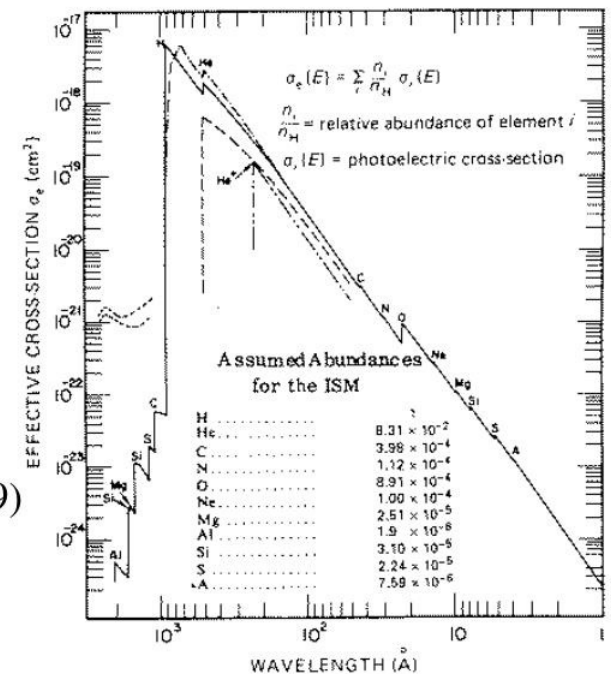
- EUV: 70 Å to 912 Å
- Lower limit is decided by grazing angle optics.
- Upper limit is HI ionization

<https://image.slideserve.com/404263/interstellar-medium-absorption-cross-section-1.jpg>

<https://www.slideserve.com/meg/radiation-processes>

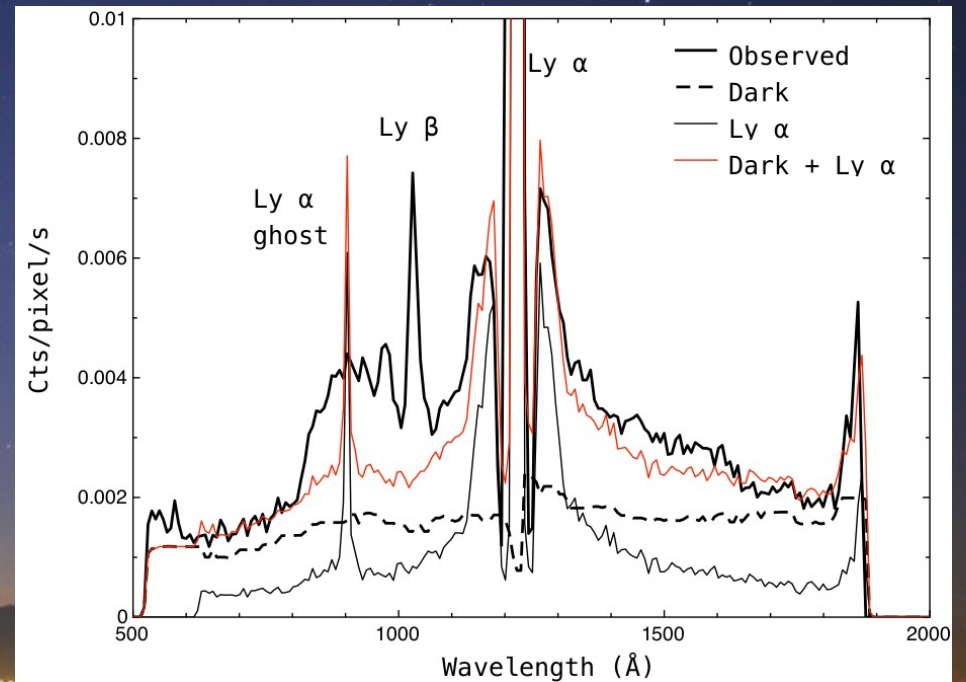
Interstellar Medium Absorption Cross-section

The effective photoelectric absorption cross-section, σ_{eff} , is plotted against wavelength in Å for the interstellar medium for an assumed set of interstellar element abundances (Morison and McCammon, 1983, Ap.J., 270, 119)



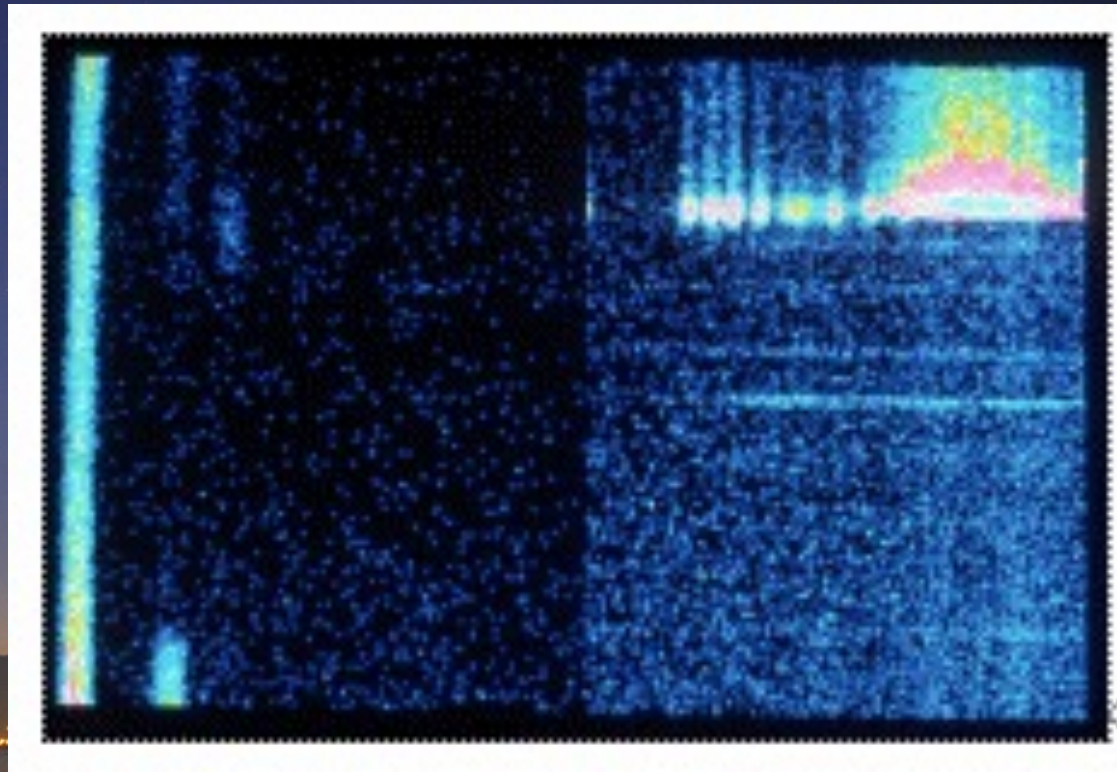
FUV

- FUV: 91 – 120 nm
 - 912 Å: HI ionization.
 - 1216 Å: HI Lyman alpha.
- Windowless detectors.



NUV

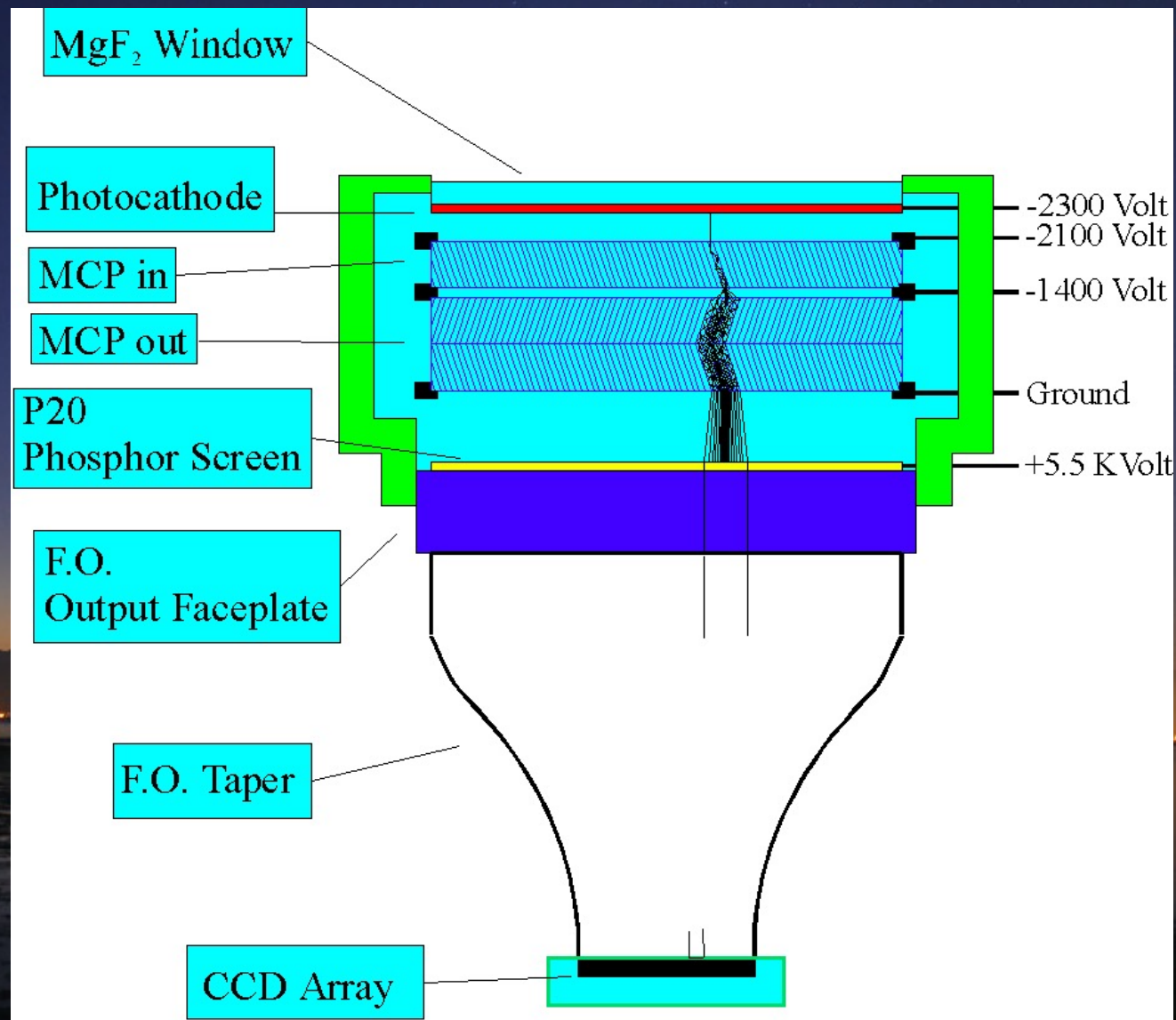
- NUV: 120 – 320 nm
 - 1216 Å: Ly α
 - 3200 Å: Solar flux.



Optics

- Normal incidence.
- Minimize number of elements.
- Long-pass crystalline filters.
 - MgF₂
 - CaF₂
- Mirror reflectivity
 - Al+MgF₂
 - 80% (> 1200 Å)
 - SiC
 - 40% (< 1200 Å)
- Filters ~ 80%
- Contamination control mandatory.

Detectors





Microchannel Plate Detectors (current)

Our current workhorse is the cross delay line readout MCP detector

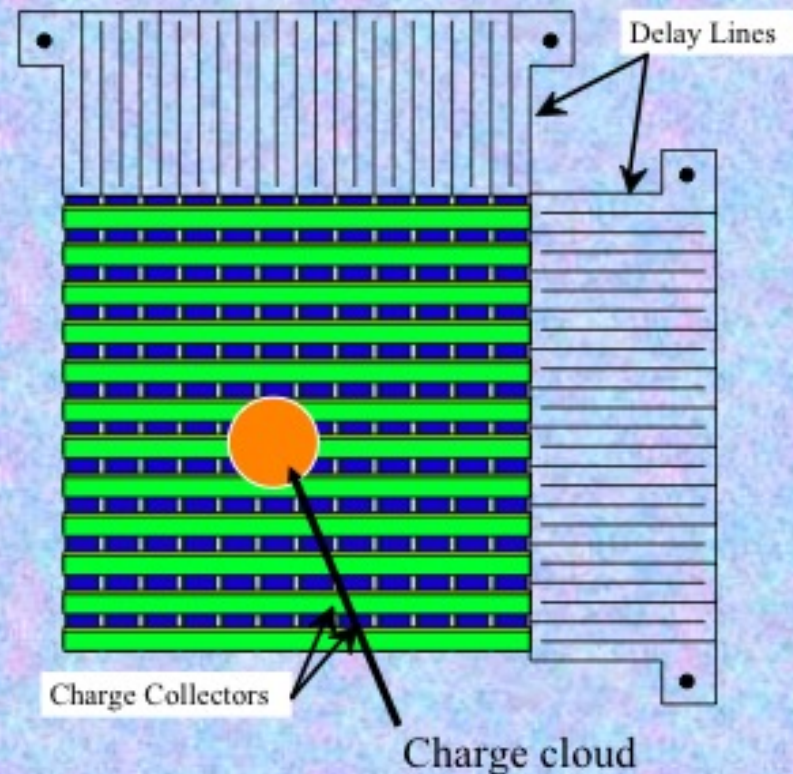
Typical characteristics

Use alkali halides for XUV QE (~50%),
Glass MCPs. Gain $\sim 10^7$
Photon, ion, electron, neutron sensing
Size formats to 100mm, Resolution $\sim 30 \mu\text{m}$
Event rates to $>1 \text{ MHz}$, (kHz/pixel rates)
Timing $<100\text{ps}$ ($\sim 20\text{ps}$ limit)

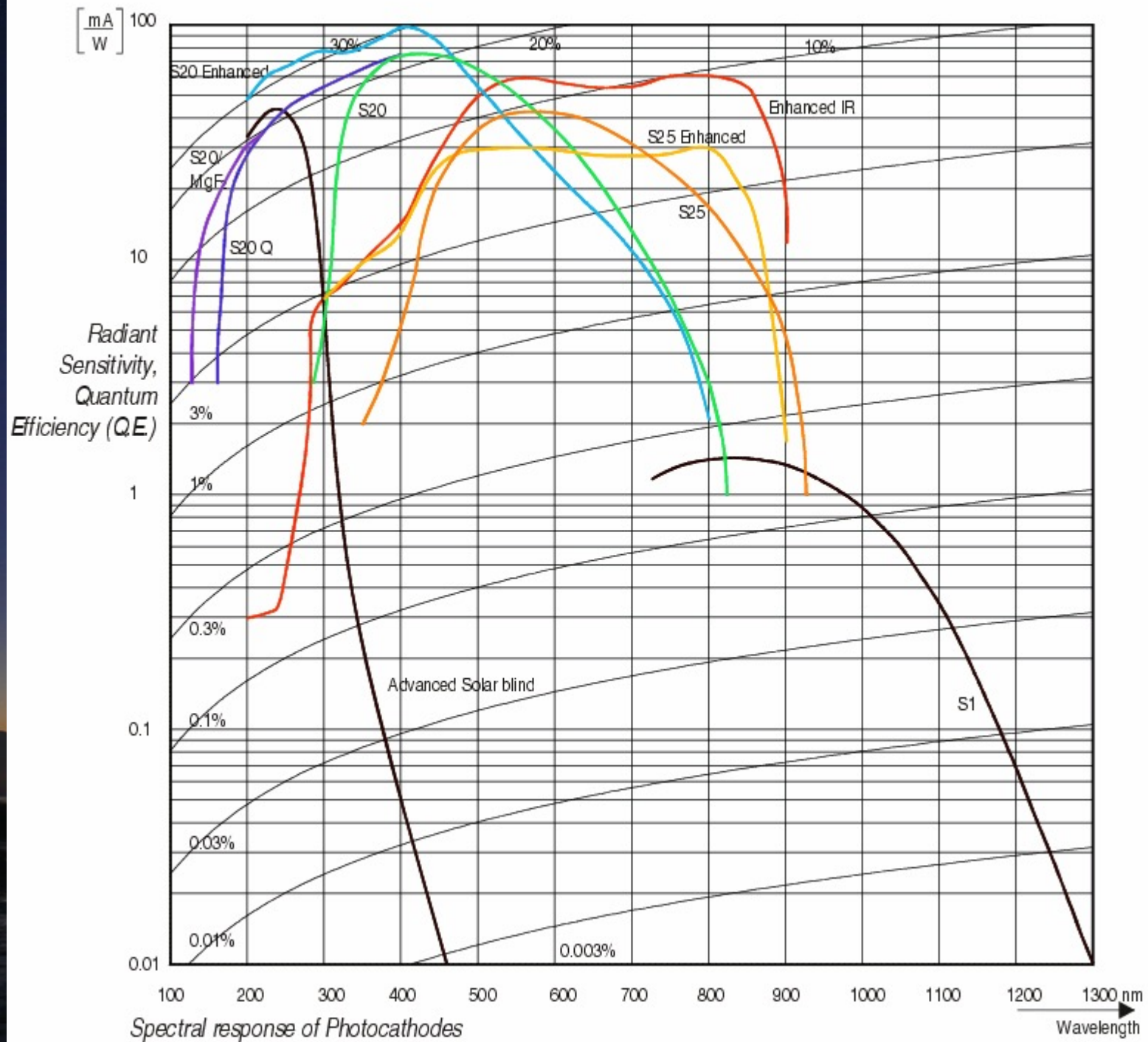
Issues,

High gain/lifetime/local-global rate limits
Single event sequential processing

Cross delay line anode is a multi-layer
crossed conductor layout. Period is
 $\sim 0.5\text{mm}$ on ceramic. MCP charge divides
between upper and lower charge collectors,
Event centroids are linearly proportional to
signal arrival time difference at ends of
delay lines. Fast event propagation (50 ns).
Compact and robust (900°C).

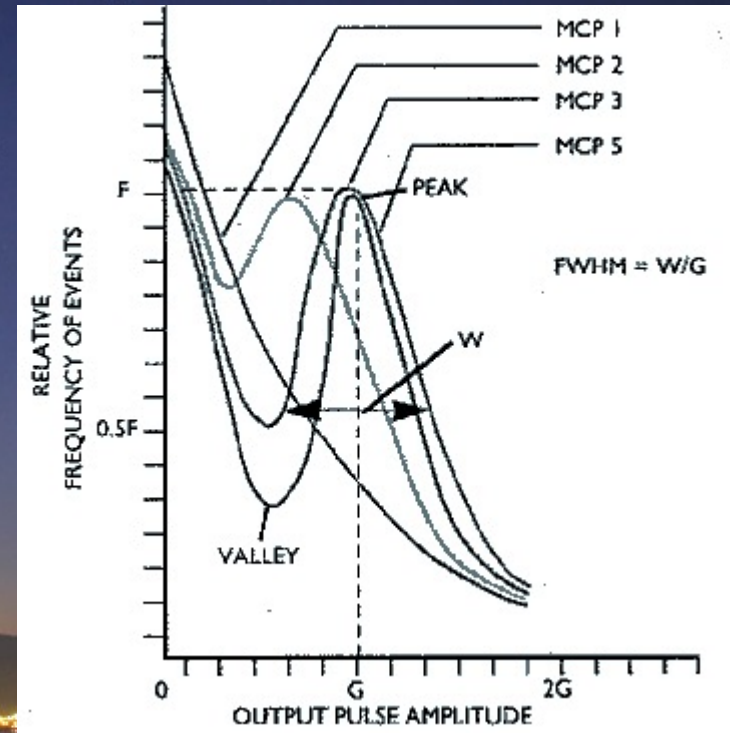


Cross delay line readout scheme



Counting Events

- Measure X, Y, PH, time.
- Exclude background events.
- Not possible to distinguish multiple events.



Quantum Throughput

- $q.t.(\lambda) = 0.8 \times 0.8 \times 0.8 \times 0.1 = 0.05 = 5\%$
- $\text{Counts} = F \times A \times \Delta\lambda \times q.t.$

Filter	Slot	Slope	Slope error	R	Conversion factor ^a
FUV CaF2_1	F1	0.3619	0.0013	0.9845	3.8689e-15
FUV BaF2	F2	0.3330	0.0018	0.9978	4.2036e-15
FUV Sapphire	F3	0.2574	0.0008	0.9986	5.4399e-15
FUV Silica	F5	0.0980	0.0011	0.9848	1.4273e-14
NUV Silica	F1	1.0586	0.0027	0.9873	1.9459e-16
NUV B15	F2	0.0353	0.0001	0.9956	5.8360e-15
NUV B13	F3	0.1995	0.0005	0.9941	1.0327e-15
NUV B4	F5	0.2959	0.0014	0.9825	6.9611e-16
NUV N2	F6	0.0736	0.0002	0.9723	2.7988e-15

^a $\text{erg cm}^{-2} \text{ \AA}^{-1} \text{ cnt}^{-1}$

Units

- We measure counts per pixel per second.
- Magnitudes are difficult because A0 stars have no flux in UV.
 - **FUV:** $m_{AB} = -2.5 \times \log_{10}(\text{Flux}_{FUV} / 1.40 \times 10^{-15} \text{ erg sec}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}) + 18.82$
 - **NUV:** $m_{AB} = -2.5 \times \log_{10}(\text{Flux}_{NUV} / 2.06 \times 10^{-16} \text{ erg sec}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}) + 20.08$
- Limiting magnitudes ~ 20 magnitude in 100 second observation.

Counting details

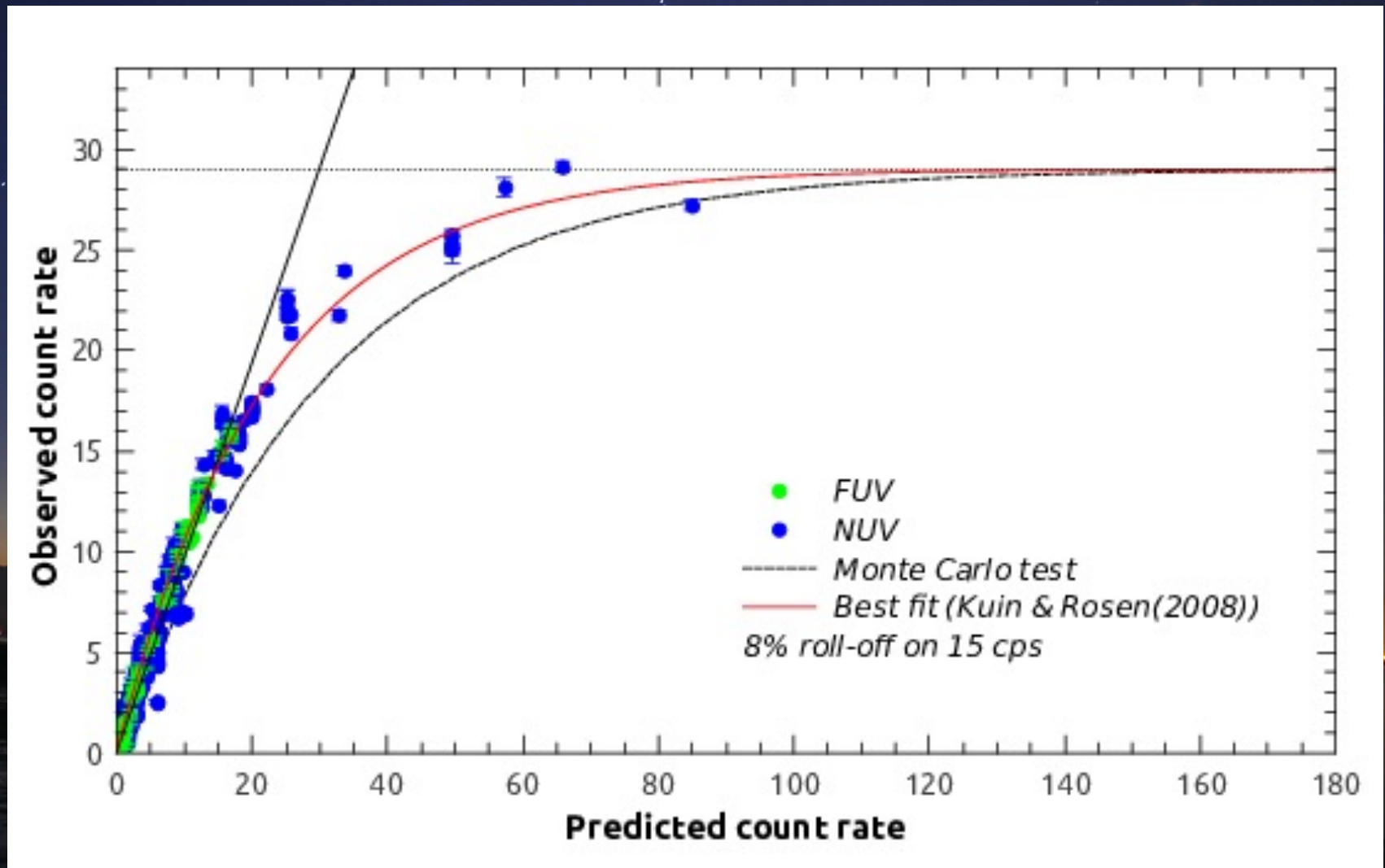
- Zero noise detectors.
- Counts are Poissonian so S/N increases by square root of observation time.
 - 20th magnitude in 100 seconds (GALEX AIS) => 23rd magnitude (GALEX DIS) in 30,000 seconds.
 - 10 counts for 3 sigma detection.
- Similar scaling with mirror area.

Detector Issues

- Lifetime of MCP ~ 1 Coulomb of charge.
 - Avoid bright regions, particularly in the beginning of a mission. For large FOV missions, diffuse background may be important.
 - There are only a countable number of hot stars which can be avoided.
- Avoid Galactic Plane, Magellanic Clouds.

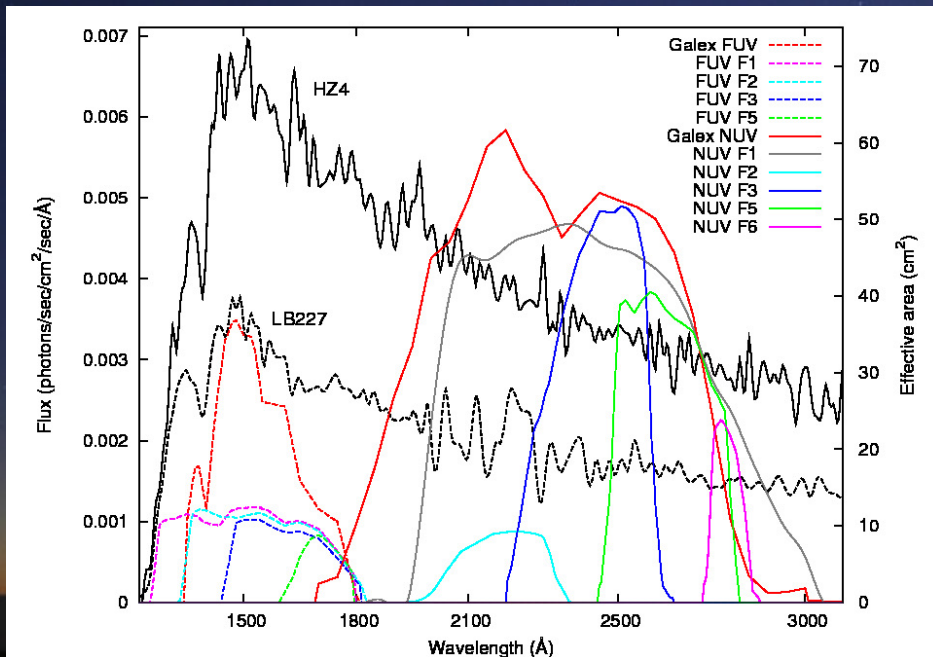


Nonlinearity



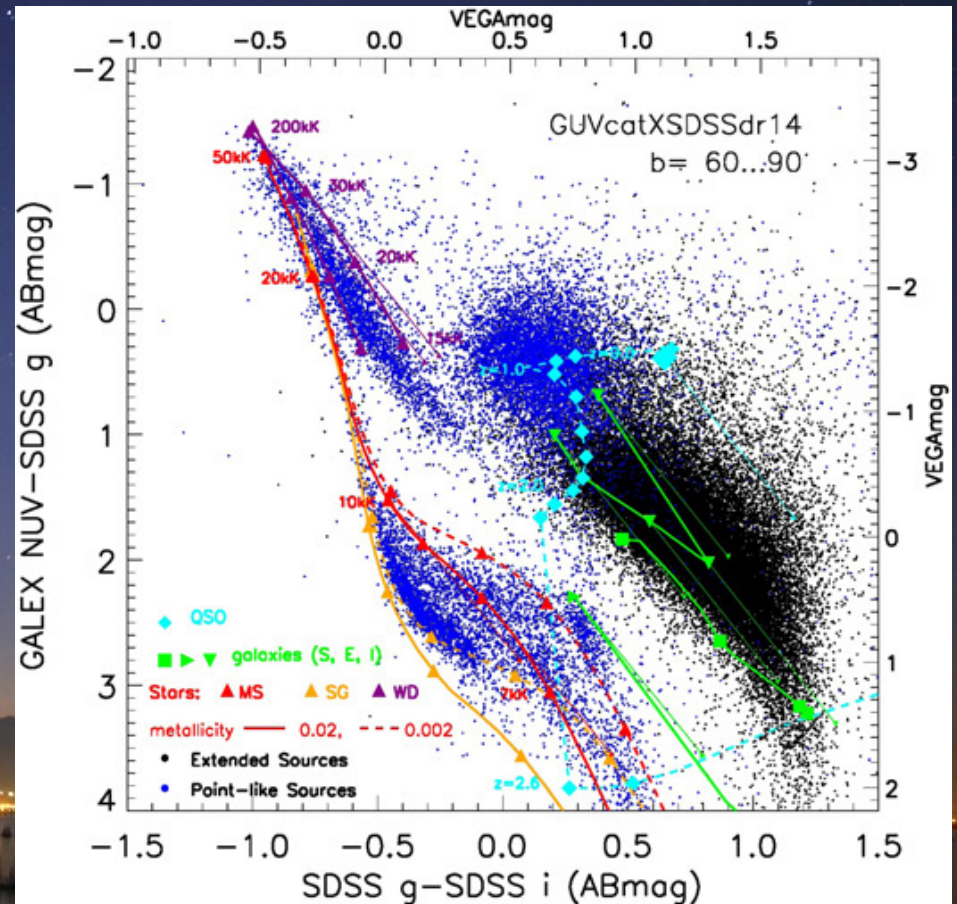
GALEX/UVIT

- UVIT multiple filters.
- ~1.5 arcsec resolution
- GALEX: 2 filters
- ~5 arcsec resolution

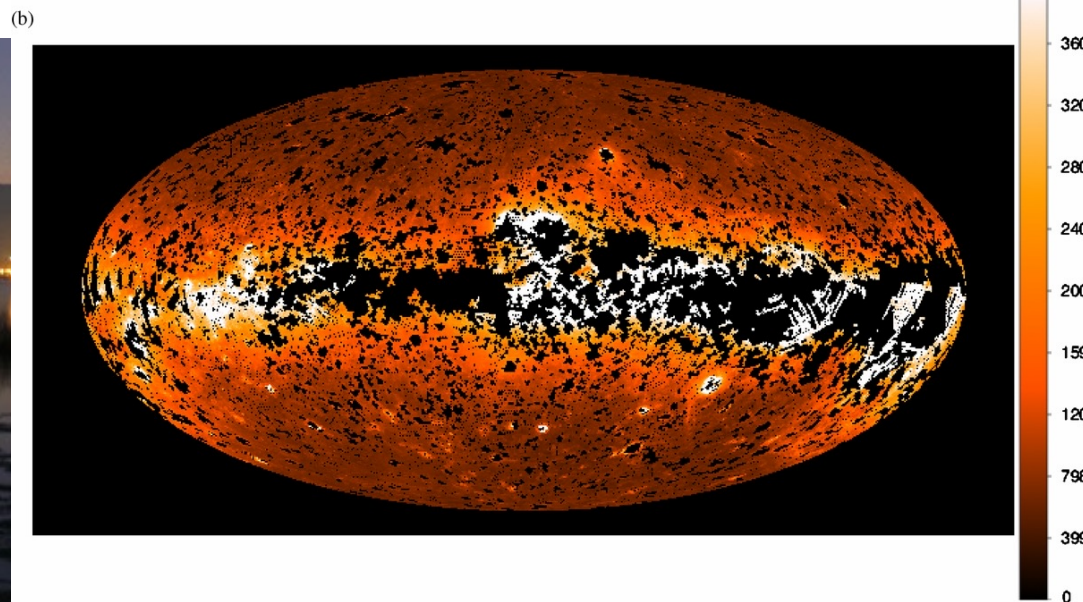
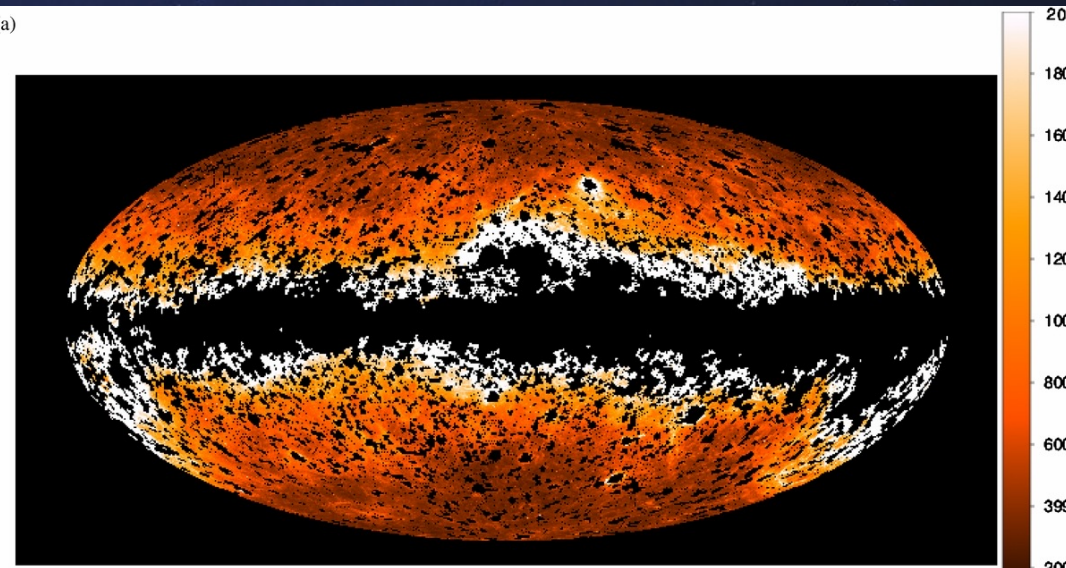
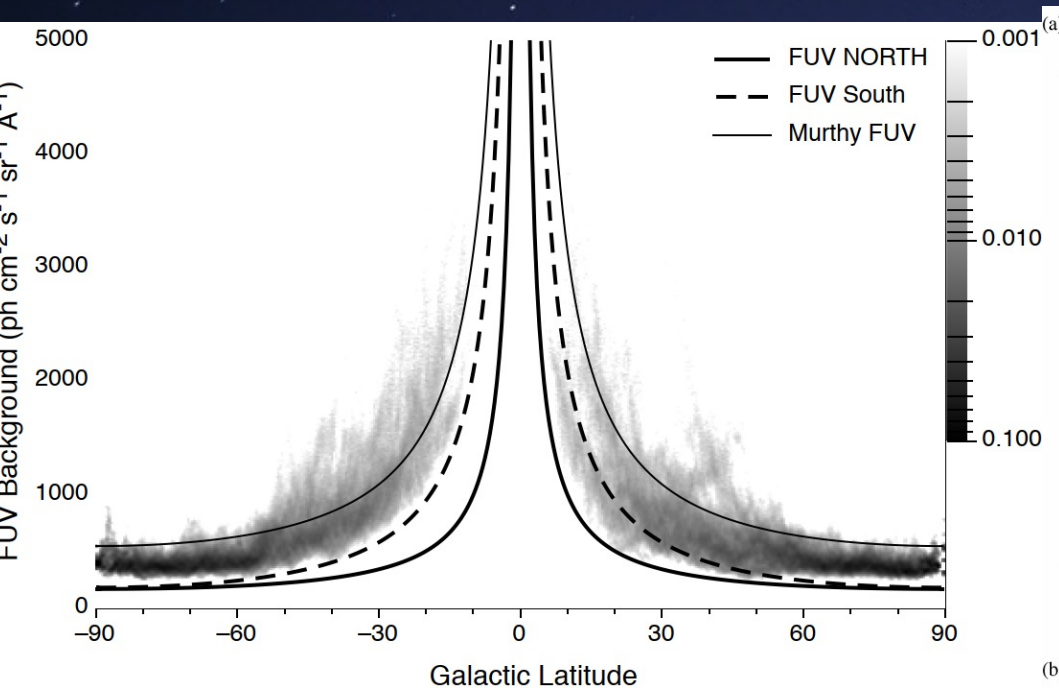


GALEX Data

- Available from MAST.
- Point source list.
- <https://ui.adsabs.harvard.edu/abs/2002ApJS..250...36B/abstract>

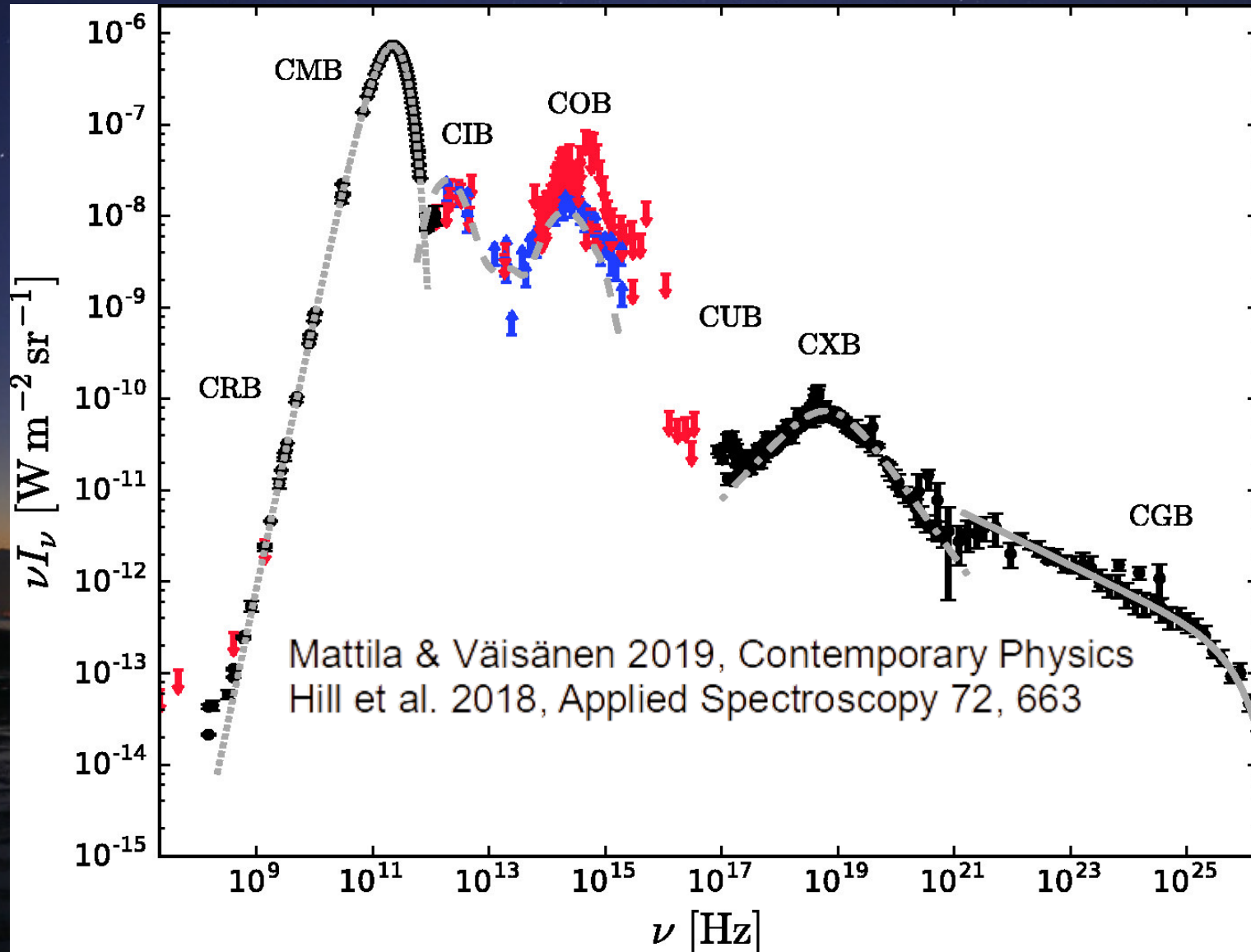


GALEX Diffuse Observations



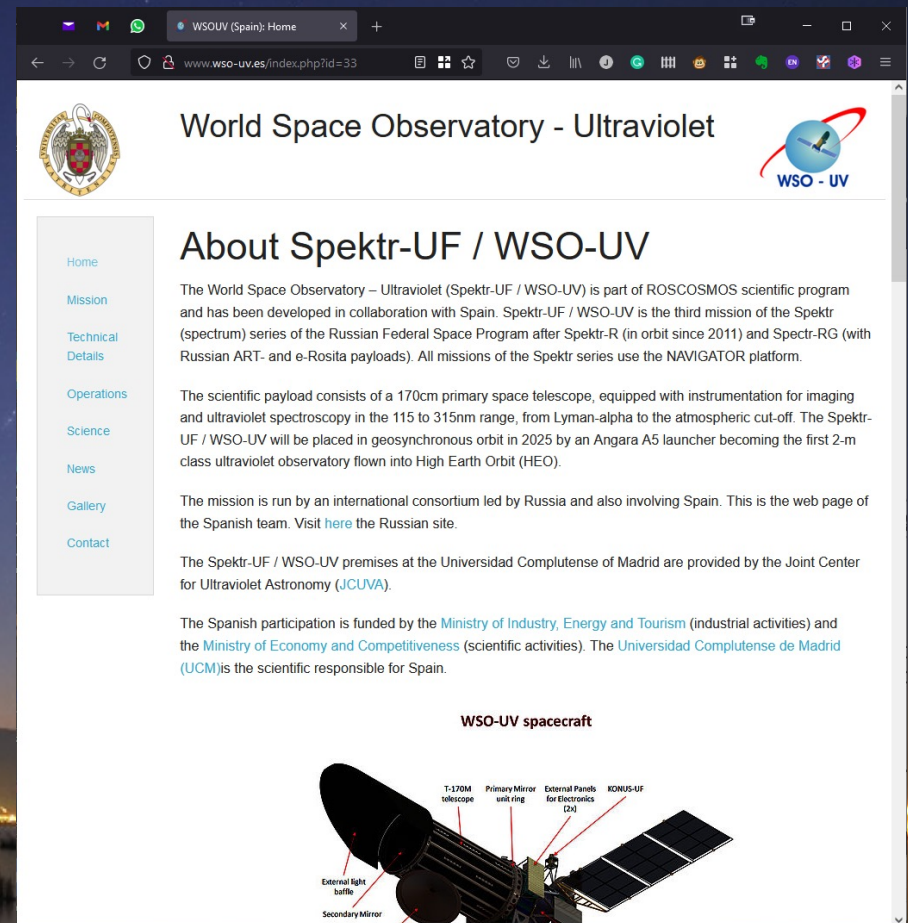
- Murthy 2014
- Cosecant falloff from plane to poles.
- Baseline of about 200 photon units.
 $100 \text{ ph cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ \AA}^{-1} = 2 \text{ nW m}^{-2} \text{ sr}^{-1}$.

EBL



Future Directions

- No UV capability once HST/UVIT die.
- World Space Observatory
- 1.7 m telescope.
- ~2025 launch



The screenshot shows the website for the World Space Observatory - Ultraviolet (WSO-UV). The page title is "World Space Observatory - Ultraviolet" and the URL is "www.wso-uv.es/index.php?id=33". The page content includes a navigation menu on the left with links for Home, Mission, Technical Details, Operations, Science, News, Gallery, and Contact. The main content area is titled "About Spektr-UF / WSO-UV" and contains the following text:

The World Space Observatory – Ultraviolet (Spektr-UF / WSO-UV) is part of ROSCOSMOS scientific program and has been developed in collaboration with Spain. Spektr-UF / WSO-UV is the third mission of the Spektr (spectrum) series of the Russian Federal Space Program after Spektr-R (in orbit since 2011) and Spectr-RG (with Russian ART- and e-Rosita payloads). All missions of the Spektr series use the NAVIGATOR platform.

The scientific payload consists of a 170cm primary space telescope, equipped with instrumentation for imaging and ultraviolet spectroscopy in the 115 to 315nm range, from Lyman-alpha to the atmospheric cut-off. The Spektr-UF / WSO-UV will be placed in geosynchronous orbit in 2025 by an Angara A5 launcher becoming the first 2-m class ultraviolet observatory flown into High Earth Orbit (HEO).

The mission is run by an international consortium led by Russia and also involving Spain. This is the web page of the Spanish team. Visit [here](#) the Russian site.

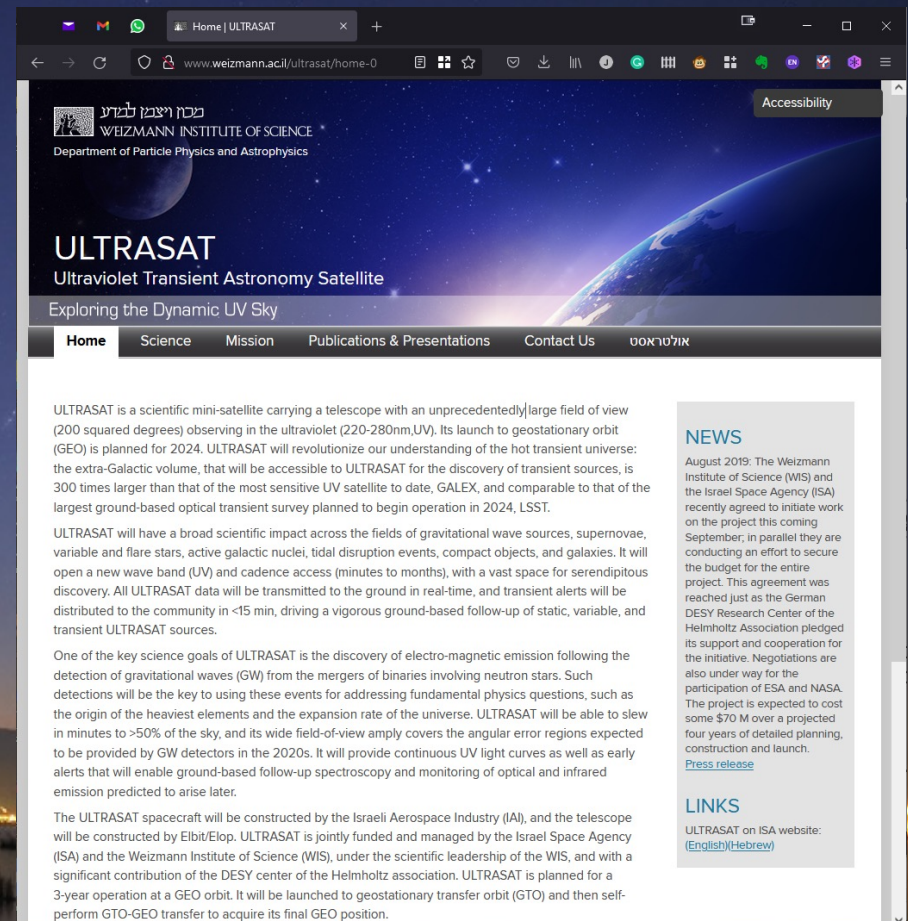
The Spektr-UF / WSO-UV premises at the Universidad Complutense of Madrid are provided by the Joint Center for Ultraviolet Astronomy (JCUVA).

The Spanish participation is funded by the [Ministry of Industry, Energy and Tourism](#) (industrial activities) and the [Ministry of Economy and Competitiveness](#) (scientific activities). The [Universidad Complutense de Madrid \(UCM\)](#) is the scientific responsible for Spain.

Below the text is a diagram of the WSO-UV spacecraft with the following labels: External light baffle, Secondary Mirror, T-170M telescope, Primary Mirror unit ring, External Panels for Electronics (2x), and KOMUS-UF.

Future Directions

- No UV capability once HST/UVIT die.
- ULTRASAT
 - Large FOV.
 - Continuous UV alerts.



The screenshot shows the homepage of the ULTRASAT website. The header includes the Weizmann Institute of Science logo and the text "Department of Particle Physics and Astrophysics". The main title is "ULTRASAT" with the subtitle "Ultraviolet Transient Astronomy Satellite" and the tagline "Exploring the Dynamic UV Sky". A navigation menu at the top includes "Home", "Science", "Mission", "Publications & Presentations", "Contact Us", and "אולטראסט". The main content area features a large image of the Earth from space. Below the image, there is a detailed text block about the satellite's capabilities and mission goals. To the right, there is a "NEWS" section with a date "August 2019" and a "LINKS" section with a link to the "ULTRASAT on ISA website: (English/Hebrew)".

ULTRASAT is a scientific mini-satellite carrying a telescope with an unprecedentedly large field of view (200 squared degrees) observing in the ultraviolet (220-280nm,UV). Its launch to geostationary orbit (GEO) is planned for 2024. ULTRASAT will revolutionize our understanding of the hot transient universe: the extra-Galactic volume, that will be accessible to ULTRASAT for the discovery of transient sources, is 300 times larger than that of the most sensitive UV satellite to date, GALEX, and comparable to that of the largest ground-based optical transient survey planned to begin operation in 2024, LSST.

ULTRASAT will have a broad scientific impact across the fields of gravitational wave sources, supernovae, variable and flare stars, active galactic nuclei, tidal disruption events, compact objects, and galaxies. It will open a new wave band (UV) and cadence access (minutes to months), with a vast space for serendipitous discovery. All ULTRASAT data will be transmitted to the ground in real-time, and transient alerts will be distributed to the community in <15 min, driving a vigorous ground-based follow-up of static, variable, and transient ULTRASAT sources.

One of the key science goals of ULTRASAT is the discovery of electro-magnetic emission following the detection of gravitational waves (GW) from the mergers of binaries involving neutron stars. Such detections will be the key to using these events for addressing fundamental physics questions, such as the origin of the heaviest elements and the expansion rate of the universe. ULTRASAT will be able to slew in minutes to >50% of the sky, and its wide field-of-view amply covers the angular error regions expected to be provided by GW detectors in the 2020s. It will provide continuous UV light curves as well as early alerts that will enable ground-based follow-up spectroscopy and monitoring of optical and infrared emission predicted to arise later.

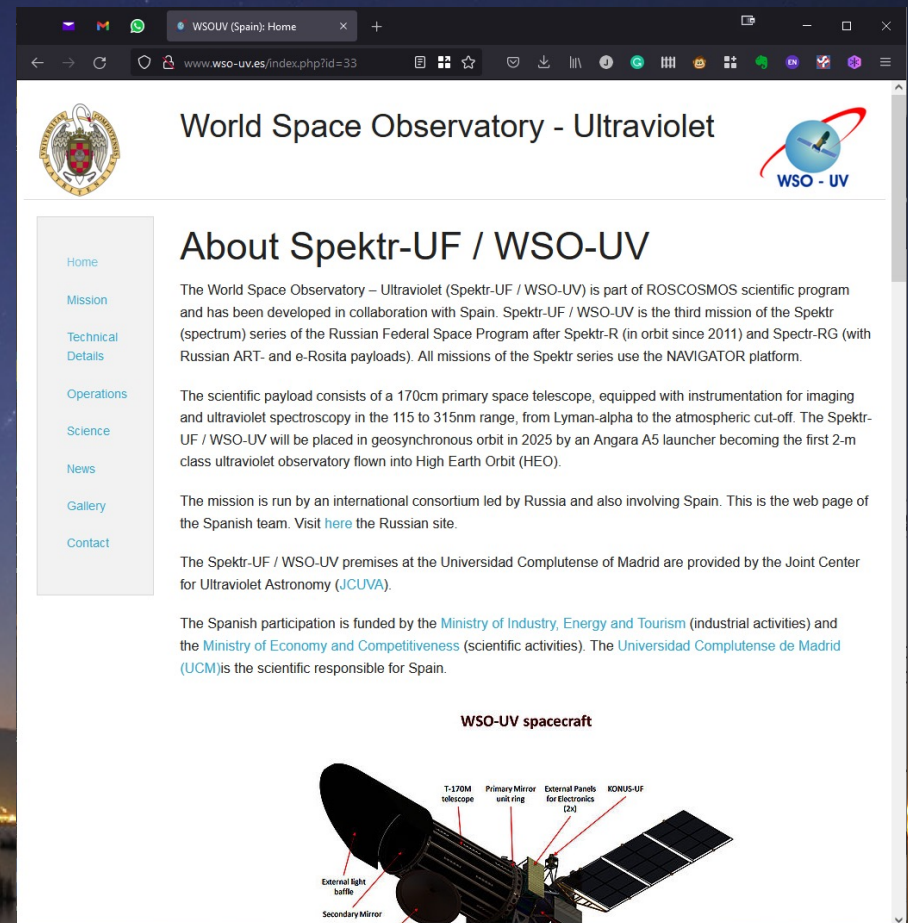
The ULTRASAT spacecraft will be constructed by the Israeli Aerospace Industry (IAI), and the telescope will be constructed by Elbit/Elop. ULTRASAT is jointly funded and managed by the Israel Space Agency (ISA) and the Weizmann Institute of Science (WIS), under the scientific leadership of the WIS, and with a significant contribution of the DESY center of the Helmholtz association. ULTRASAT is planned for a 3-year operation at a GEO orbit. It will be launched to geostationary transfer orbit (GTO) and then self-perform GTO-GEO transfer to acquire its final GEO position.

NEWS
August 2019: The Weizmann Institute of Science (WIS) and the Israel Space Agency (ISA) recently agreed to initiate work on the project this coming September; in parallel they are conducting an effort to secure the budget for the entire project. This agreement was reached just as the German DESY Research Center of the Helmholtz Association pledged its support and cooperation for the initiative. Negotiations are also under way for the participation of ESA and NASA. The project is expected to cost some \$70 M over a projected four years of detailed planning, construction and launch.
[Press release](#)

LINKS
ULTRASAT on ISA website:
[\(English/Hebrew\)](#)

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Future Directions

- No UV capability once HST/UVIT die.
- CUTE
 - Atmospheres of exoplanets.
 - To launch ~2021

The Colorado Ultraviolet Transit Experiment (CUTE) is a 4-year, NASA-funded project to design, build, integrate, test, and operate a 6-unit CubeSat (30 cm x 20 cm x 10 cm). CUTE will have a 1-year mission life time and will launch in 2020 and use near-ultraviolet (NUV) transmission spectroscopy from 295 to 330 nanometers (nm) to characterize the composition and mass-loss rates of exoplanet atmospheres. CUTE measures how the NUV light from the host star is changed as the exoplanet transits in front of the star and passes through the planet's atmospheres. CUTE's spectrally resolved lightcurve will provide constraints on the composition and escape rates of these atmospheres, and may provide the first concrete evidence for magnetic fields on extrasolar planets.

The keys to unlocking the diagnostic potential of these systems are spectral coverage in the appropriate bandpass and the ability to follow the systems for several orbital periods. CUTE is designed to provide exactly that – low resolution spectroscopy of critical atmospheric tracers (Fe II, Mg II, Mg I, OH) that are inaccessible from the ground, and a dedicated mission architecture that enables the survey required to characterize atmospheric structure and variability on these worlds.

CUTE is being constructed at the University of Colorado, Boulder and the Laboratory for Atmospheric and Space Physics (LASP). Dr. Kevin France is the Principle Investigator of the CUTE mission at LASP.

We're just getting started with CUTE, so stay tuned for more details and updates!

Cut-away rendering of CUTE, with transparent top and sides to display the telescope and spectrograph. CUTE has three coarse sun sensors, a star tracker, an S-band transmitter

Labels in the cut-away diagram: Heat Strap, Radiation Panel, NUV Telescope, Star Tracker, Sun Sensor, Spectrograph + CCD, Inst. Electronics, Sun Sensors, S-Band Transmitter, GPS.

Future Directions

- SING

- To fly on CSS in 2023
- Low resolution spectroscopy of nebulae.

- NUTS

- Planned for PS4 launch.
- ~3 degree FOV to search for transients.
- Total cost: ~USD 30,000 + 1 graduate student.

Small Satellites

- UV is where to go for niche science at low cost!

