

GUIDELINES FOR FUTURE UV OBSERVATORIES

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Abstract Ultra-violet image sensor and UV optics have been developed for a variety of space borne UV astronomy missions. Technology progress has to be made to improve the performance of future UV space missions. Throughput is the most important technology driver for the future. Required developments for different UV detector types – detectors are one of the most problematic and critical parts of a space born mission- and for optical components of the instruments are given in these guidelines. For near future missions, we need high throughput optics with UV sensors of large formats, which show simultaneously high quantum efficiency and low noise performance.

Keywords UV astronomy

1. INTRODUCTION

Within the last years a lot of workshops have taken place in which the need for new instruments for future space-borne UV astronomy missions was discussed (e.g. “Report of UV/O Working Group to NASA”, 1999, “Hubble’s Science Legacy: Future Optical-Ultraviolet Astronomy for Space”, 2002, “Innovative Design for the next large aperture optical/UV Telescope”, STSI, 2003). In a large number of publications the characteristic parameters for new developments and associated technologies for future UV instrumentations are described (eg. Proc SPIE, Volume 2999, 1997 “Photodetectors: Materials and Devices II”). Therefore this paper is not a comprehensive review of future UV technology developments, but focuses on the requirements for new UV instruments which will give the astronomical UV community the possibility to meet the science goals, described in the papers of this book.

2. GENERAL REMARKS

An improvement on current UV capabilities of the HST in the order of magnitudes could be made by high quantum efficiency UV detectors, high efficiency optics and the use of 3-4 m telescopes. The technology needed for advanced UV-astronomy can benefit from advances being made in other wavelength regimes, in particular from developments in the visible, infrared and x-ray wavelength bands. In general throughput is the most technology driver for future UV space astronomy missions, especially for UV spectroscopy. UV technology development has to be made in the areas of detectors, optical components and their coatings and large light weighted mirrors.

2.1. UV sensors

Many astronomical objects produce orders of magnitudes more photon fluxes at optical wavelengths than they do in the vacuum UV. In order to eliminate this huge background contribution and substantial source of noise solar-blind detector and imaging systems are required. A comprehensive overview about UV imaging detectors is given by Joseph (2000). Furthermore the reader is referred to Welsh and Kaplan (1992), Ulmer (2002) and references therein.

Several specific detector types can be used for vacuum UV astronomy in the future, multidimensional detectors, semi-conductive array (e.g. CCDs) and microchannel plate detector (MCP). The further development of technologies for these detector is the basis to enhance the performance for UV applications. The current technology can be classified in two categories: Solid-state devices based on silicon or wide bandgap semiconductors and photoemissive devices, coupled with a gain component and an electron detector. The detective quantum

efficiencies (DQE) for various UV detectors as MCPs, CCDs, Electron-Bombarded CCDs and for the expected DQEs for future AlGaN solid-state sensors are shown in Fig.1.

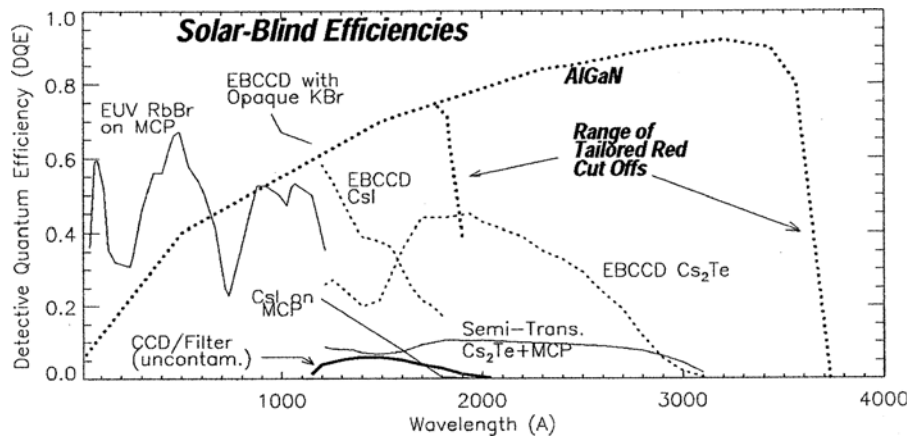


Fig. 1 Solar-blind detective quantum efficiencies obtained by various UV detectors adopted from Joseph (2000)

“3D” energy resolving detectors such as photon counting superconducting tunnel junction (STJ) or transition-edge detectors (TES) have the potential to replace the detectors which are now in use for UV missions in the far future. The development of these energy resolving detectors will improve efficiency and reduce the number of optical elements.

MCPs have a good potential to stay for the new years the default detectors in the UV regime especially below 200 nm, due to the fact that they have a very good flight history, they are solar blind, have a very low readout-noise and are radiation hard. A review about the actual image detector technology, including different readout anode types, like image readout anodes, delay line image readout anode, intensified CCD/CIDs (CCD devices couples to an MCP image intensifier), cross strip anodes and pixel array anodes, is given by Siegmund (2000). A review about the performance of larger format CCDs suitable for wide field UV imaging is given by Clampin (2000). The primary technical problems of CCDs are the high QE in the visible, low QE in the UV and the radiation tolerance of these imaging sensors. Improvement of solar-blind UV imaging CCDs with excellent radiation tolerances have made by the production of CCDs made out of SiC (Sheppard, 1996) and GaN.

Dynamic range and linearity technology investments should be made to ensure that potential flight detector have large dynamic range. It is very important that detectors are stable and provide a linear response to the signals. It is essential to reduce substantially the background rates: the detector background noise should not become the limiting factor and should not determine the sensitivity of the measurements.

2.2 Photocathodes

The development of new photocathodes is the approach to lead devices for UV space mission for the next decade. Significant impact on future capabilities can be made by advances in new material for the photocathodes as GaN, diamond or GaAs (e.g. Ulmer, 2003). For example diamond photocathodes show efficiencies of 50% in the 200-1200 Å band. For MCP detectors based on silicon substrates diamond can be used as a direct opaque cathode (e.g. Beetz, 2000). A comparison of GaN photocathodes with other photocathodes is shown in Fig.2.

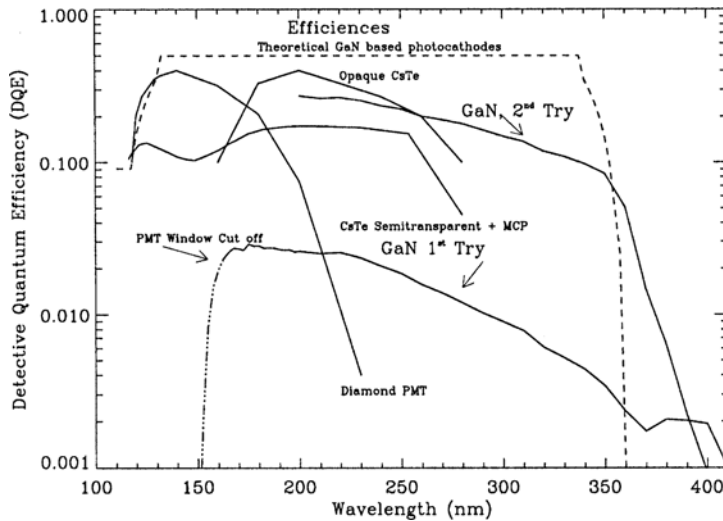


Fig. 2 GaN photocathodes compared with other photocathodes adopted from Ulmer (2002)

Walker (2000) has reported the fabrication and characterization of solar-blind $\text{Al}_x\text{Ga}_{1-x}\text{N}$ photodiodes ($x \sim 0.70$) grown on sapphire with an internal quantum efficiency which is greater than 90%. The device response drops four orders of magnitude at 275 nm and remains at low response for the entire near-ultraviolet and visible spectrum. Promising future technology is based on the production of high quality films made of wide bandgap semiconductors. For UV detectors it is absolutely necessary to suppress the sensitivity in the red, and wide-band gap semi-conductors fulfill this requirement very well. Coupling the resulting photocathode to a device such as a micro-channel plate (MCP) is necessary to produce imaging (Ulmer, 2002). Because UV coatings are extremely sensitive to highly absorbing molecular contaminations careful attention must be paid to possible contamination sources and investments have to be made in the long term stability of the coatings.

2.3 Optical components: Gratings

Throughput can be maximized with intelligent optical system designs and by judicious use of optical materials and coatings. Effective coatings for the optical elements are needed to maximize throughput: high reflectivity particular below 200 nm is required. One part of the optical elements are gratings and therefore it is essential to develop grating which have high efficiency, efficient groove shapes and produce very low scatter. Holographic gratings are today's standard gratings for most UV spectroscopic instruments. This is largely due to their scattering (typically around 10^{-5} \AA^{-1}) and to their large sizes. Interesting developments are made by direct-writing technologies. Today they are still in an early stage of development, but this technology is able to produce gratings with very low scatter, efficient groove shapes, and excellent aberration correction. Due to low ruling intensities direct-write technologies cannot be used in the current stage of development in high-resolution UV spectroscopy but within the next years large, corrective gratings with high groove densities will be available (e.g. Wilkinson, 1999).

2.4 Optical components: Filters

Several designs of filters for use in vacuum UV imaging systems are discussed, These designs incorporate all reflective optics, and are characterized by comparatively high in-band throughput and very low out-of-band transmission. Filters which can be tuned over ranges useful for vacuum UV astronomical observations will be a very good tool for imaging.

Adjustable broad band and small band imaging will give access to a bunch of diagnostic lines over the whole UV wavelength regime.

Acousto-optical-tunable-filters (AOTFs) have the potential of providing a bandwidth selectable across 1 octave. A tunable RF signal is applied across the birefringent crystal, resulting in a selectable output wavelength. AOTFs have been built and are in use at IR wavelengths on ground-based instruments. To use these filters at vacuum UV wavelengths in the future, considerable work must be done to characterize birefringent UV-transmitting crystals, followed by extensive prototype development (e.g. Voloshinov, 2004).

Preliminary research by Jelinsky (2000) indicates that alkali halides, as CaF_2 , BaF_2 , LiF , MgF_2 , may be excellent candidates for FUV tunable transmission crystal filters. The transmission curves of these halides shift to longer wavelengths as the temperature is increased and to shorter wavelengths if the halides are cooled down (Davis, 1966). This temperature dependents optical behavior can be utilized in the design of tunable filters in two different ways, with tunable bandwidth or tunable center wavelength.

2.5 Optical components: Micro-mirrors , fibers

Very efficient spectroscopic observation can be done by observing multiple objects or positions simultaneously in the focal plane. In ground based instruments more than 1000 objects can be observed. Micro-mirror arrays can be used as programmable masks. In this arrangements, micro-mirrors are reflecting/blocking unwanted light and open a path for the desired rays. This concept shows great promise for UV applications although it is in an early phase of development. In another arrangement the incoming light is partly reflected into a spectrograph (from the desired objects) and the other part is reflected into a light baffle. To use micro-mirror arrays in the UV wavelength regime, UV coatings should be applicable to these arrays but it needs to be verified that the mirrors can be manufactured with the required surface quality.

In ground-based multiple objects instruments light-transmitting fibers feed light from selected targets into a spectrograph. However, development of new fibers with excellent transmission throughout the UV would greatly simplify this concept since the entire focal plane would be accessible to a single spectrograph with fibers reformatting. Unfortunately optical fibers are opaque in the UV. Progress is made for example with silica-core fibers (e.g. Wang, 2005) and one type of fused silica fibers will transmit light to wavelengths as short as 180 nm. Developments have to be made to create transmissive fibers for use at shorter wavelengths down to 91nm. Considerable development work also needs to be done to couple this fibers into a powered optical system, to bundle them, and to understand their flexibility properties and their behavior under extreme thermal conditions.

3. REQUIREMENTS FOR UV MISSION IN THE NEAR FUTURE

The detailed needs for future UV space-born instruments and the justification for the required parameters are given for every science case described in the papers of this book. High throughput is a request from all science cases (e.g. $S/N = 10$ within 10 minutes for a target with a flux of 10^{-16} ergs cm^{-2} sec^{-1}). The specific requirements to the wavelength range and the spectral resolution for spectroscopic ($R = \lambda/\delta\lambda$) and imaging observations are summarized as follows:

1. Medium spectral resolution:
 $R \leq 5000$ with a simultaneous wavelength coverage from 91 nm to 450 nm.
Additionally a spatial resolution in the order of ~ 0.01 arcsec is required.
2. High spectral resolution:
 $R \leq 30.000$ with a simultaneous wavelength coverage from 91 nm to 350 nm.

High spectral resolution of $R \sim 50,000$ or even $R \sim 100,000$ is required for example for a galactic white dwarf spectroscopic survey (Barstow and Werner, this book), for resolving plasma velocities in a number of environments such as cometary comae (Brosch et al., this book), for measurements of thermal broadening of absorption lines in exospheres (Gómez et al. this book), for studies of cool winds and astrospheres (Pagano et al., this book) and for detailed ISM studies (Wamsteker et al. this book).

3. Efficient spectroscopic observation should be performed by integral-field spectroscopy, for example multiple object spectroscopy of white dwarfs in the 90-130 nm range with $R \sim 1,000$ and a limiting flux of around 10^{-20} ergs cm^{-2} sec^{-1} (Barstow and Werner, this book).

4. For imaging at least a spatial resolution of 0.01 arcsec and field of views with up to 2 arcmin is required (Brosch et al., this book). For a white dwarf survey of the LMC/SMC and of globular clusters a field of view of 10 arcmin is required (Barstow and Werner, this book). Additionally tunable filters will be a very good tool to select spectral lines of interest.

5.- Furthermore some science cases need time-tagged observations with a time accuracy down to fractions of a second (e.g. Gänsicke et al., this book).

Similar science questions given in this book can be addressed with a planned 2m – class UV mission, the WSO/UV project. The spectroscopic capabilities of this mission are a spectral resolution of $R \sim 50,000$ and a coverage of the whole wavelength regime (102-310 nm) with two observations (102-178 nm and 275-310 nm). A detailed overview of this project is given by Barstow et al. (2003).

4. SUMMARY

In summary it is shown, that with modest developments the scientific objectives outlined in this book can be achieved with 3-4 m class telescopes. Most of the described science in this book can be achieved basically by two spectrographs, which should have a simultaneous wavelength coverage from 90 nm to 450 nm and a high throughput.

1. A high spectral resolution spectrograph with $R \sim 50,000-100,000$
2. A medium spectral resolution spectrograph with $R \sim 1,000-5,000$ allowing integral field spectroscopy with a spatial resolution of ~ 0.01 arcsec.

To fulfill these requirements for near future UV missions especially developments of microchannel-plate detectors and semiconductor arrays with high quantum efficiency, large dynamic range, low background noise and with large formats are necessary. This should be accompanied by improving the technology of optical components to provide high throughput and low scatter and by the development of large, precision, lightweight mirror surfaces with good micro-roughness properties.

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