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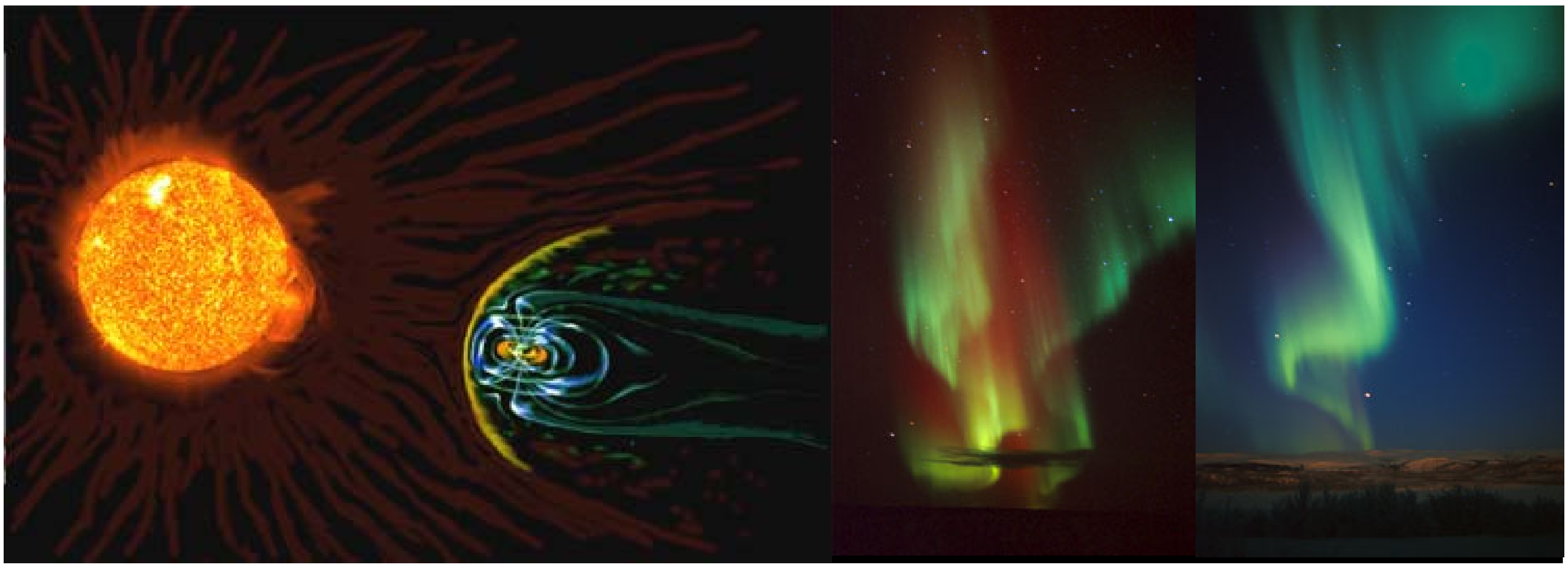
Ground-based optical auroral measurements

FYS 3610



Background

Ground-based optical measurements provides a unique way to monitor spatial and temporal variation of auroral activity at high resolution – up to 10 meters near zenith.

- All-sky camera
- Photometer

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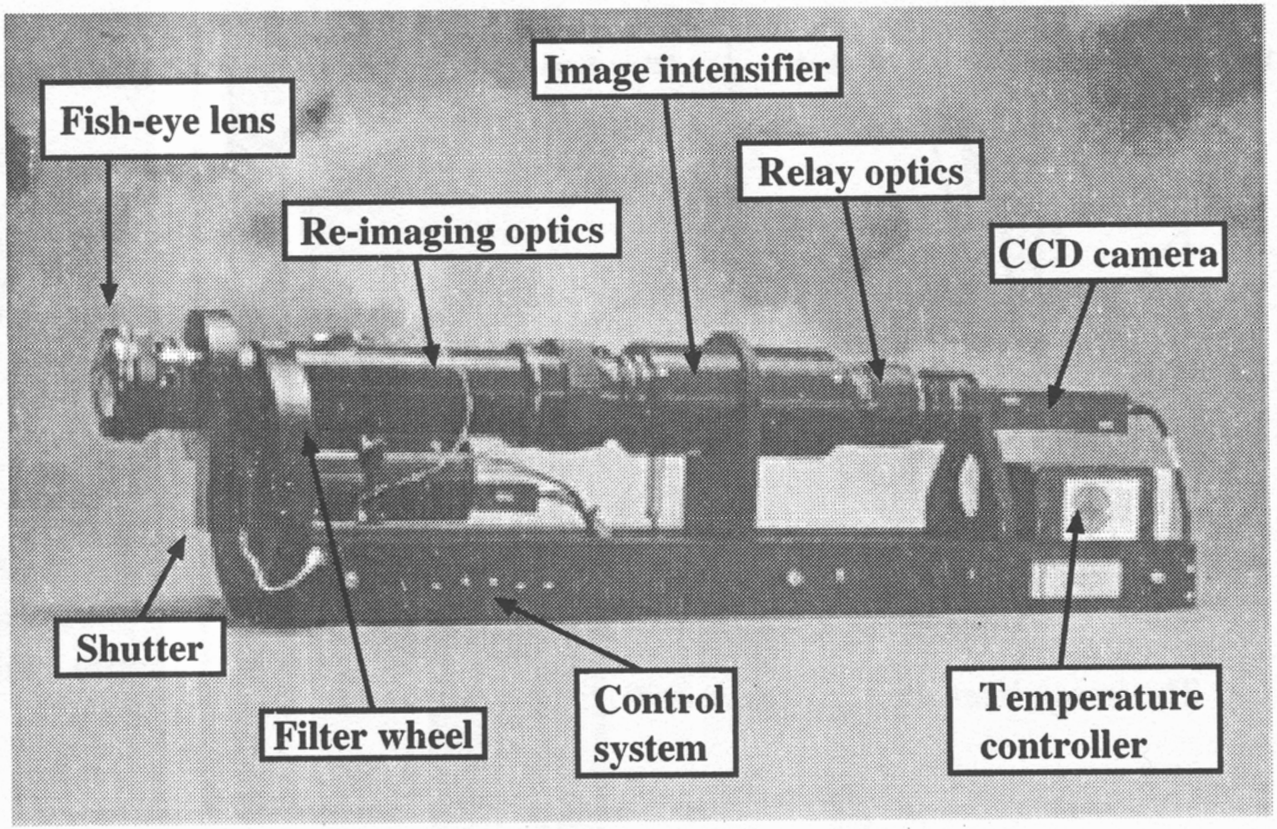
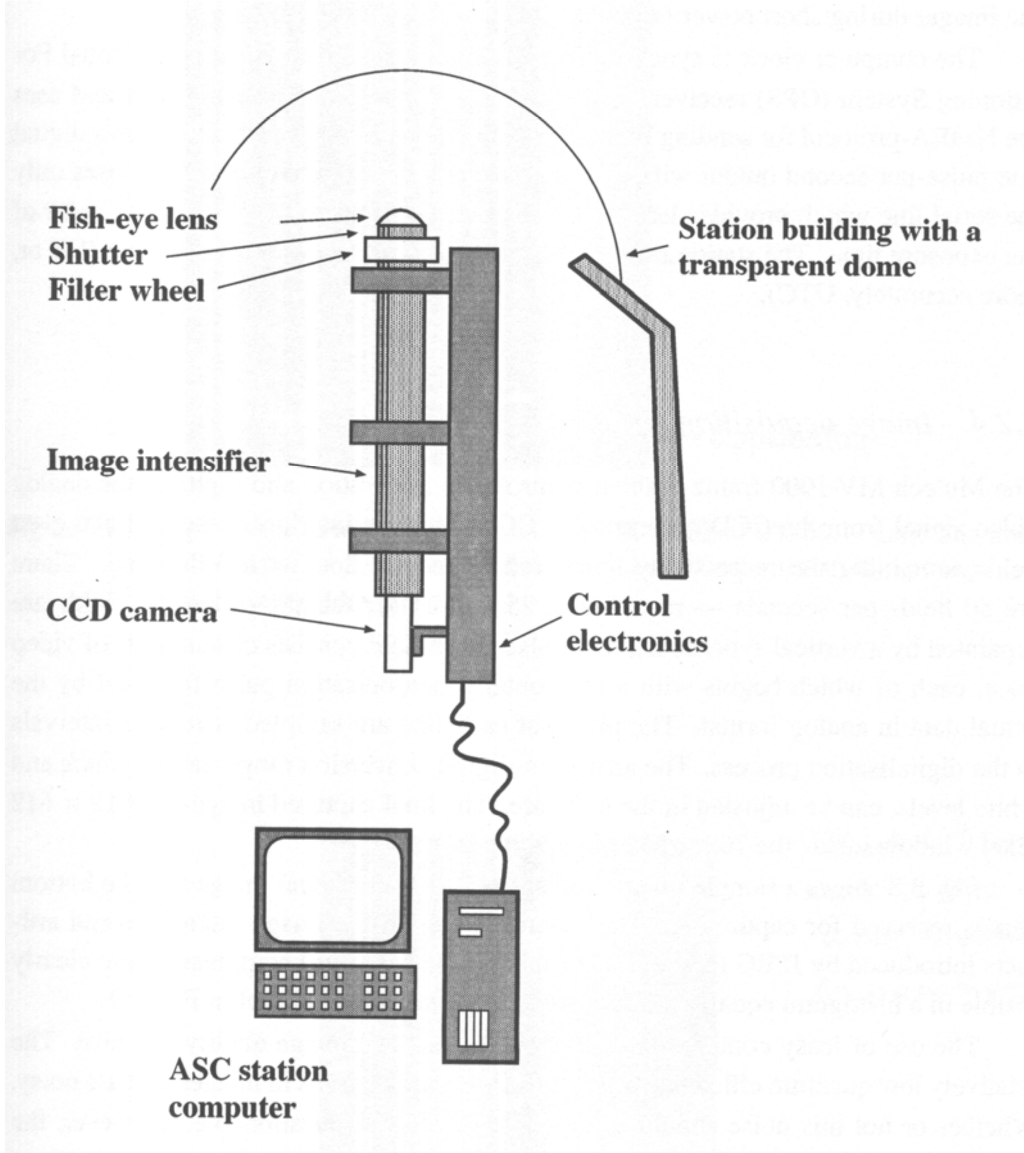
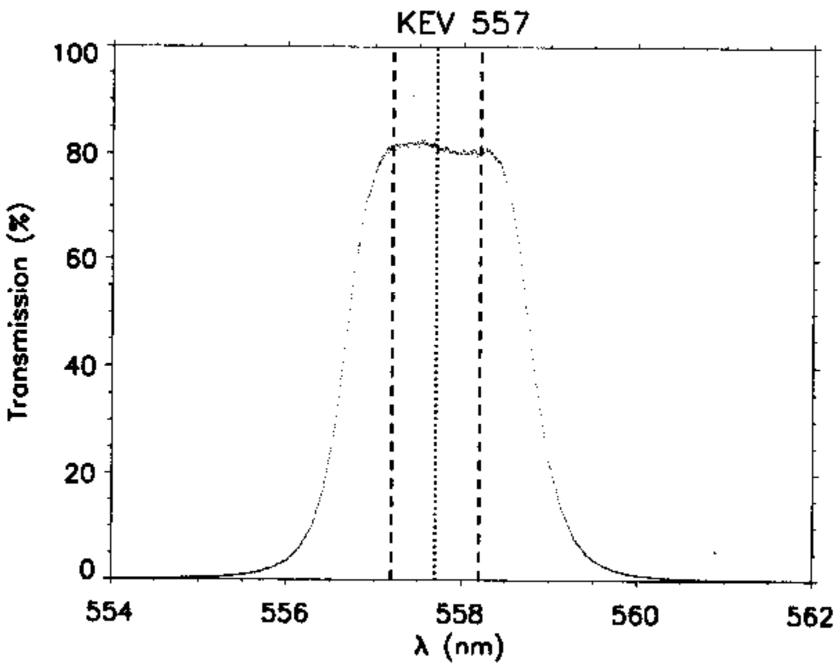
CCD All-sky Camera with filterwheel



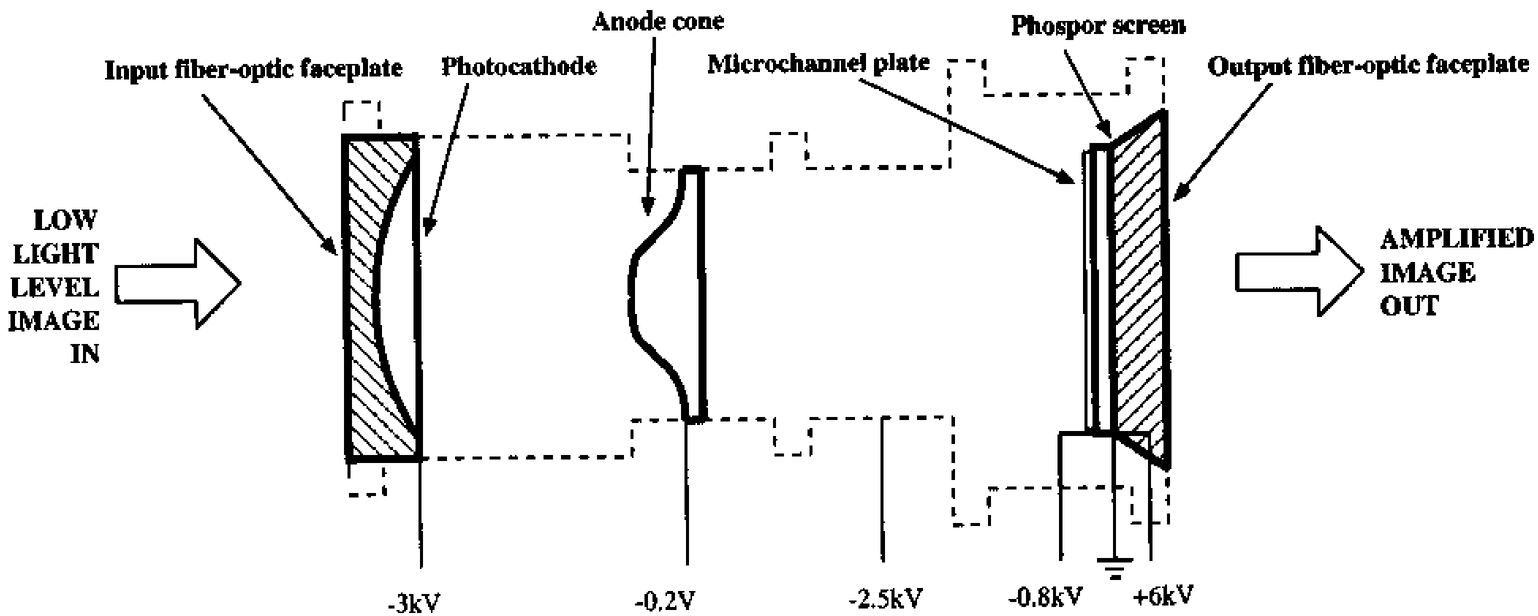

Fish-eye lens
Shutter
Filter wheel
Station building with a transparent dome
Image intensifier
CCD camera
Control electronics
ASC station computer

Monochromatic filtering/ Narrow band interference filter



- **The half-width is about 2-3 nm**

Image intensifier



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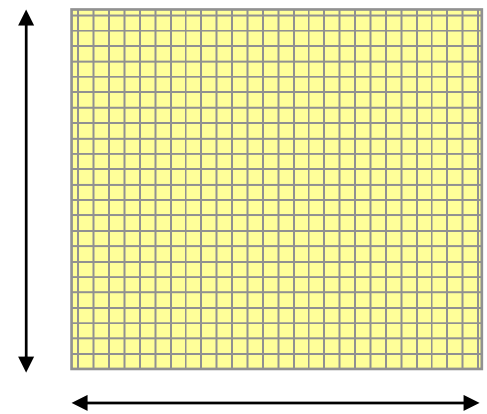
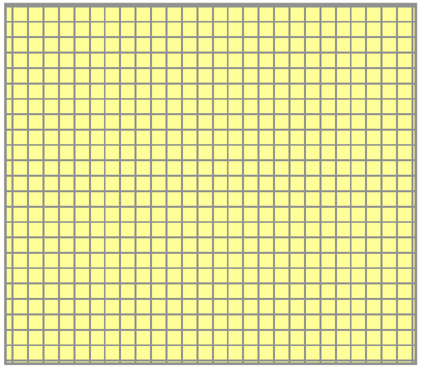
CCD light detector

- Each detector element (pixel) measures the intensity of incoming light, and sends out a signal which is proportional with the light intensity.
- The pixels are arranged in an array; typically 512 x 512 and up to 2000 x 2000 pixels.
- More pixels = higher spatial resolution and more data
- Modern pixel sizes are between 4 and 10 µm in height and width



Charge-coupled device (CCD)

- Consist of thousands of light sensitive elements arranged in an array.
- **Each element is an** oxide semiconductor (MOS) **capacitor**.
- The photoelectric effect produce charges on this capacitors.



Charge-coupled device (CCD)

- The charges in each capacitor row is shifted to the output, and each charge is converted to a voltage.
- The advantage of the CCD is that no high voltage is required (compared to the photomultiplier).
- The disadvantage is low time resolution (because it is an integrating type of detector) and it is therefore not suitable to look at very weak photon sources (without use of a light amplifier)

Charge-coupled device (CCD)

- The quantum efficiency (QE) is typically 40 to 80 % for a CCD.
- **But**, even if a photon produce one electron in the detector, this electron is not necessary detected at the detector output. Because this photon can get lost during signal transportation or be burried in noise. So QE is not a good measure on how good the detector system is.

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Colours in the aurora

630.0 nm – red upper boundary

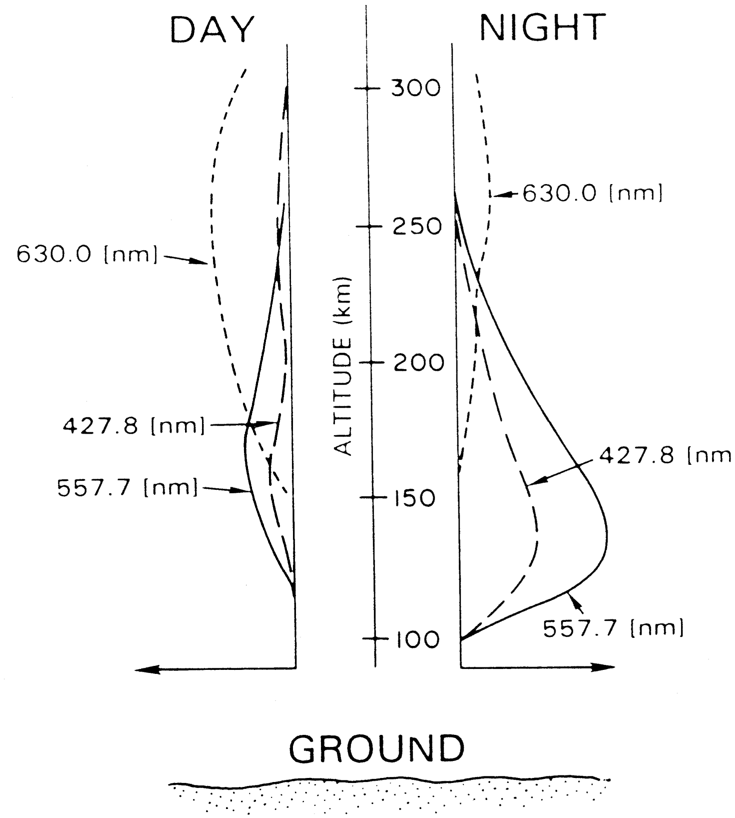
Atomic Oxygen: ^1D-^1S transition

557.7 nm – green

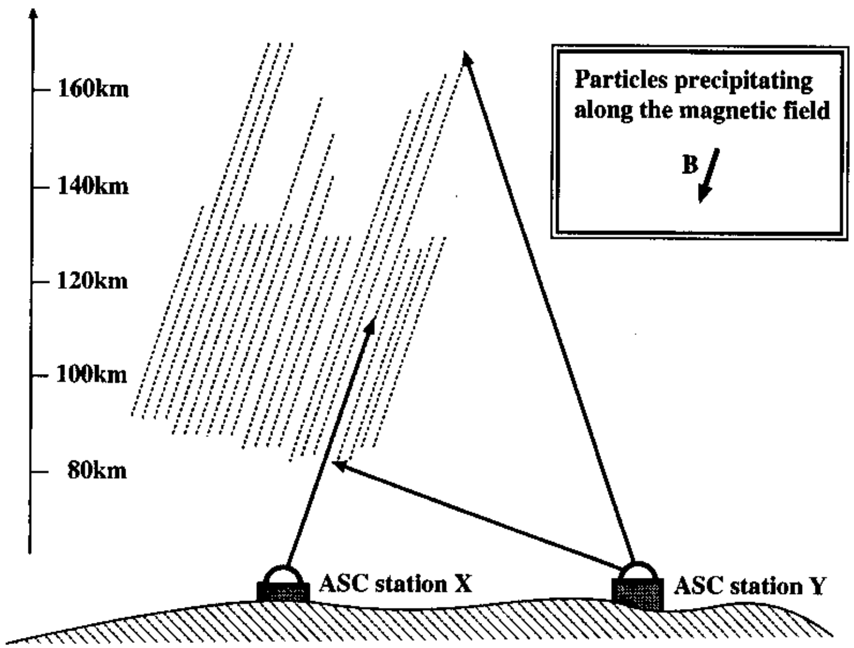
Atomic Oxygen : ^1D - ^3P transition

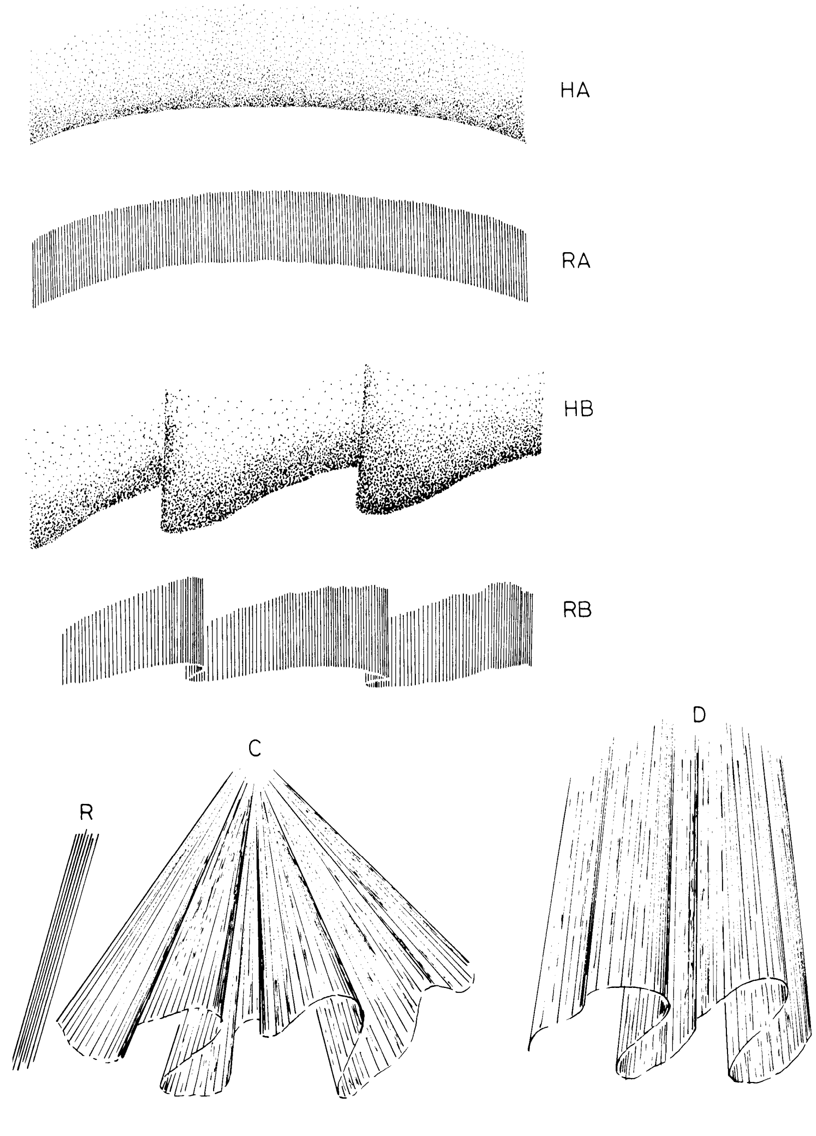
427.8 nm – magenta lower boundary

N_2^+ - First negative band



Geometry of auroral observations





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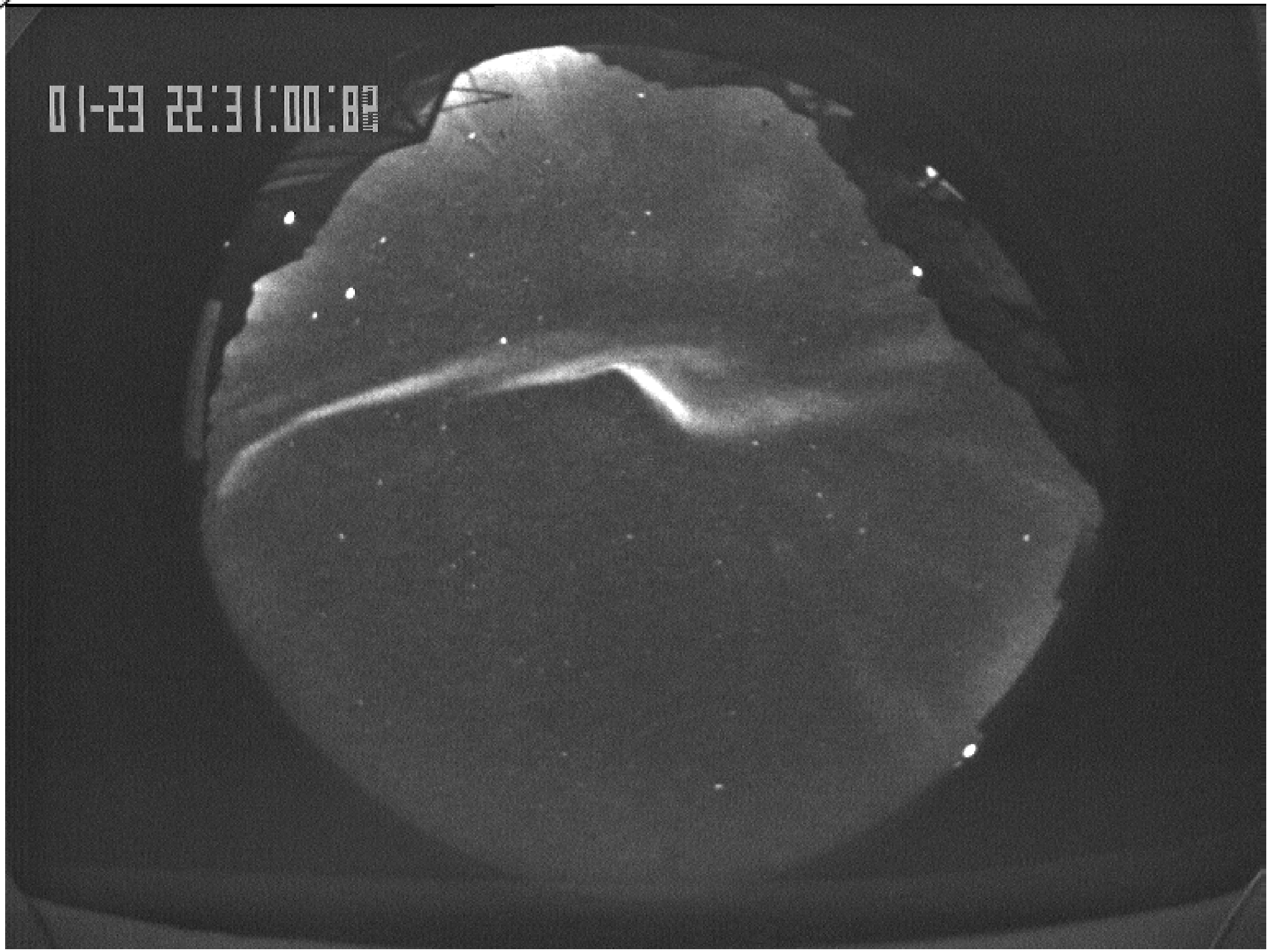
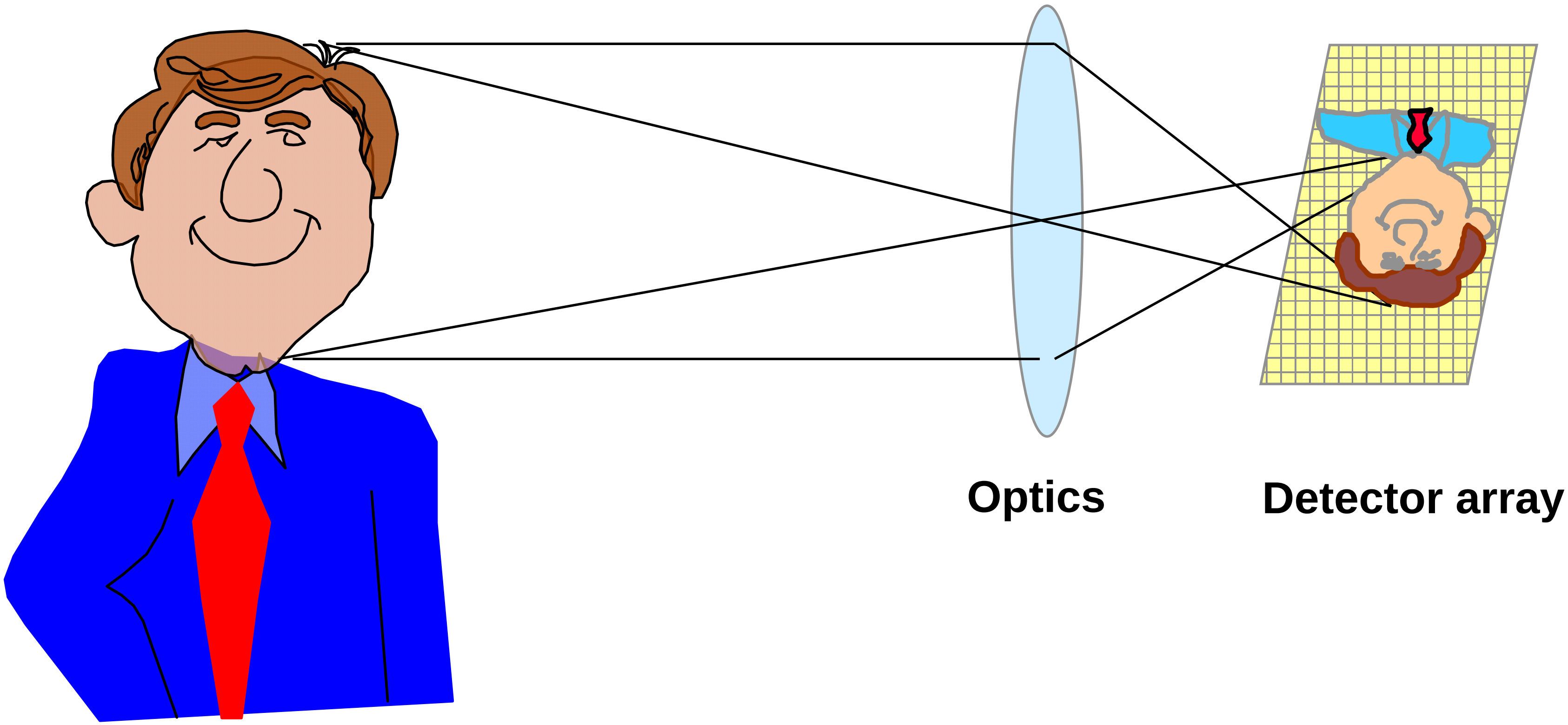
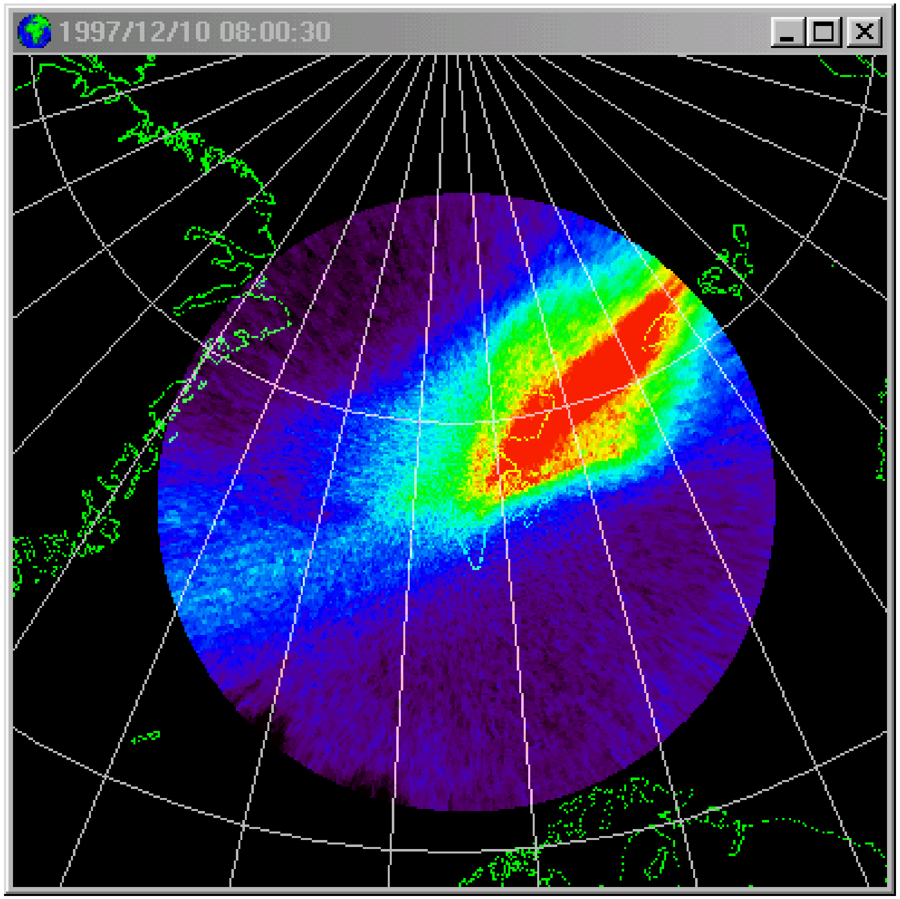


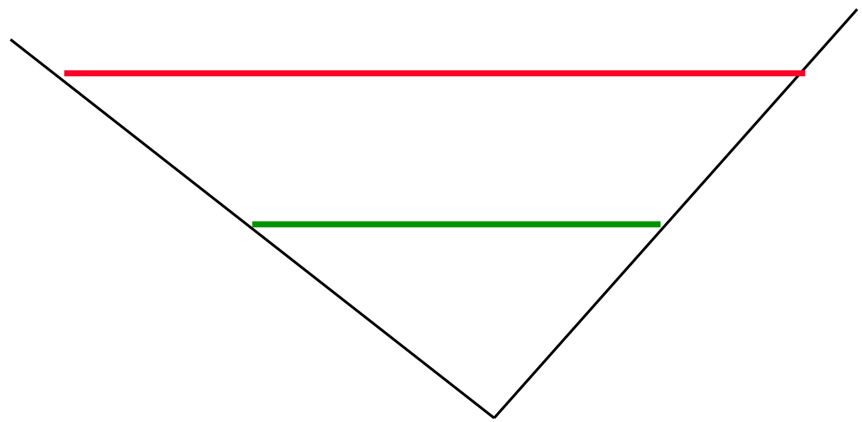
White light image from ARR unmapped

Be also aware of flipping!!



Gegraphical coverage depends on emission altitude





630.0 nm image mapped to 250 km altitude

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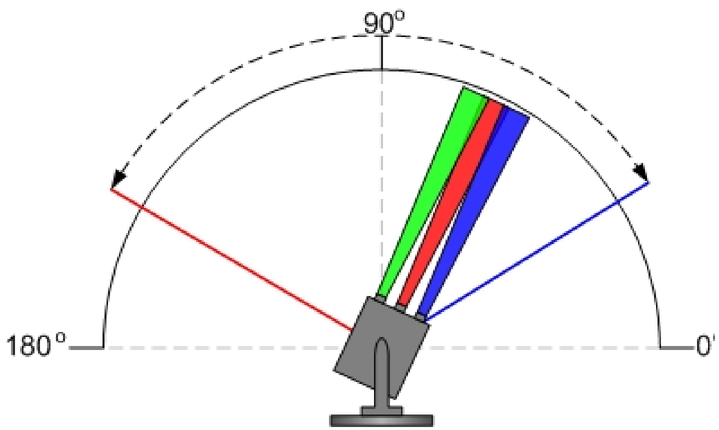
PHOTOMETERS



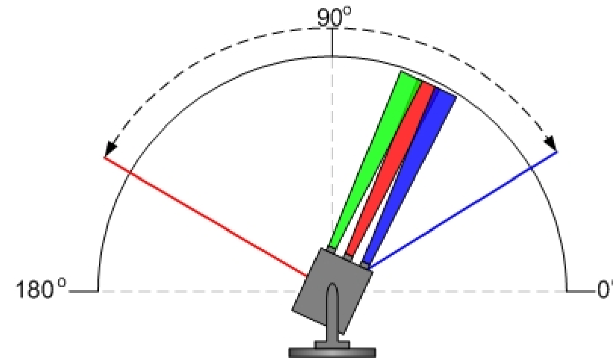
Photometer

- **Measures the light intensity (for a given wavelength).**
- Very sensitive.
- Good spatial resolution and time resolution.
- A photometer cannot image the auroral morphology, so it is used as a supplement to all-sky cameras.

Photometers – Operational mode

- It can be pointed at a fixed point (a given elevation). But this doesn't give any information about auroral morphology/structures
- Therefore it is most often used in a scanning mode, where the instrument sweeps out a larger area. F.ex. meridian scanning

  from north to south



Meridian scan

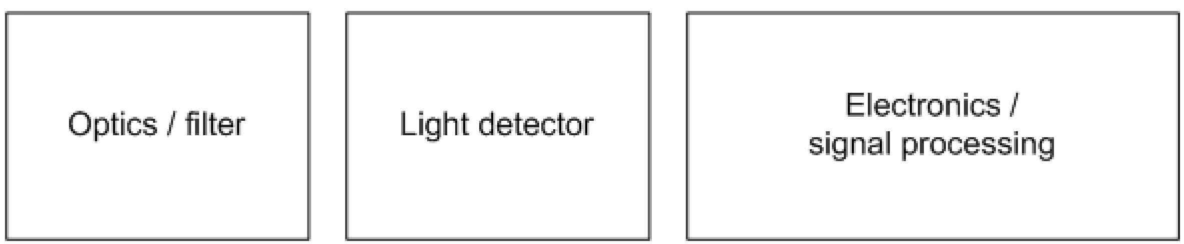
Azimuth scan

Photometers

- A photometer (with mobility around horizontal and vertical axes) can be programmed to follow a rocket trajectory, to compare the measurements of the particle precipitation and the aurora.

Photometer

- Optics
- Light detector
- Electronics/signal processing



Optics and filters

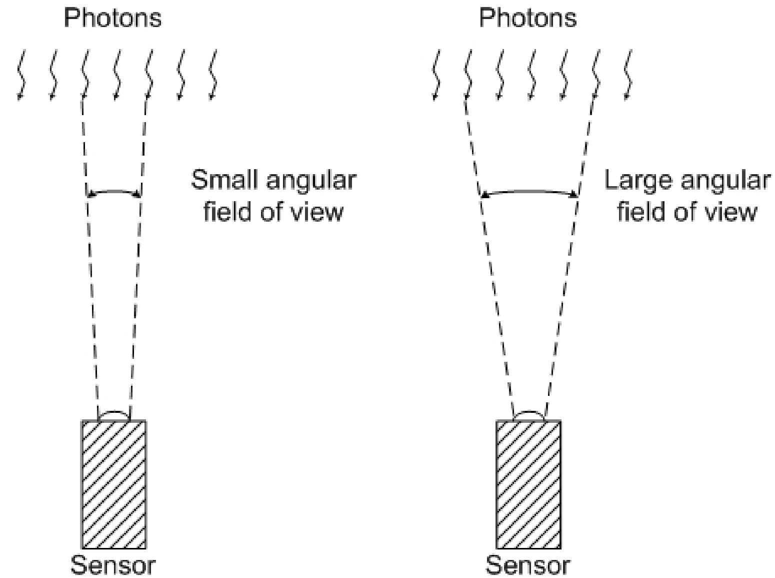
- The optical part can be a lense or a lense system, used to focus the light on the detector(s).
- A filter is used to transmit only particular wavelengths to the detector.
- Two common type of filters:

  Interference filter

  Absorbtion filter
- The bandwidth of an absorption filter is much larger than for an interference filter.

Optics – angular field of view

- The angular field of view decides how much of the sky the detector sees, and with that the photometers spatial resolution.
- We want as large resolution as possible (small angular field of view), but at the same time as much light as possible into the detector. This is incompatible.
- A common compromise is to have an angular field of view of ~ 2° (the angular field of view of the moon seen from the earth is ~ 0.5°)



Optics – angular field of view

- A lense system can be used to define the angular field of view.
- A single lense and an aperture opening in front can be used to define the angular field of view.

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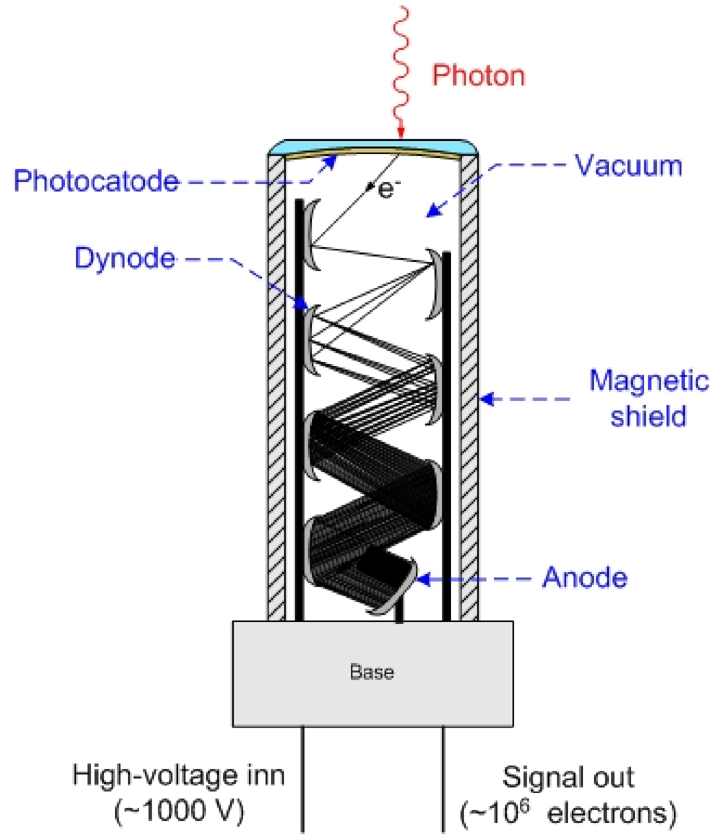
Photon Detector

- The detector is usually a photomultiplier
- A Charge-Coupled Device (CCD) can also be used, and CCD based photometers are used in many satellites.
- In satellites and rockets the photomultiplier tubes and the high voltage source are usually sealed in a silicone die, to prevent corona discharge and to attenuate (damp down) the vibrations.

Photomultiplier (PM)

- When a photon of sufficient energy is incident on the photocatode, a single electron may be ejected (refered as a photoelectron).
- **The probability that a single photon produce a photoelectron that is detected in the phototube is called the quantum efficiency (QE).**



Photomultiplier

- QE is a function of the wavelength of the incident photon.
- A typical value for quantum efficiency in a phototube is 20 - 30% (at wavelength of 400 nm).
- The photoelectron is accelerated through a potential difference, and hits a secondary electrode called a **dynode.**
- At the this first dynode the photoelectron frees other electrons, and this secondary electrons are accelerated and focused on a second dynode and so on.

Photomultiplier

- The multiplication effect take place at the dynodes, and the process results in an increasing number of available electrons (avalanche effect).
- The electrons are guided by the electrostatic field between the dynodes.
- An external magnetic field can distort the focusing, as the electrons travel from dynode to dynode. Therefore the photomultiplier tubes are shielded.

Photomultiplier

- A photomultiplier typically have 10 – 12 stages (dynodes) and a multiplication of ~ 10^6

  → This signal is easily detected in an external circuit.

- The total voltage (the potetial difference between the photocatode and the anode) is typically 1000 – 2000 volt.
- Photomultipliers are sensitive detectors of single photons, and as such are designed to operate in the dark.

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Electronics /signal processing

- The output signal from the photomultiplier is current pulses, where each pulse correspond to a detected photon.
- This current pulses are converted to voltage pulses by a current to voltage converter.
- Some of the voltage pulses generated are caused by noise, and thereby not desired. To eliminate them, a **voltage discriminator** is inserted. The discriminator is adjusted to remove all pulses with an amplitude smaller than a predefined limit.

Noise

- There are several noise sources, but the dominating noise source fore the photomultiplier tube is thermal electron emission from the photocatode (can be reduced by cooling).
- This noise result in what is known as dark current or dark counts; dark counts is the number of counts made by the photmultiplier when it is in complete darkness.
- The dark current must be as low as possible, since it sets the lower limit on how low intenisty the instrument can detect.

Meridian Scanning Photometer data from Longyearbyen