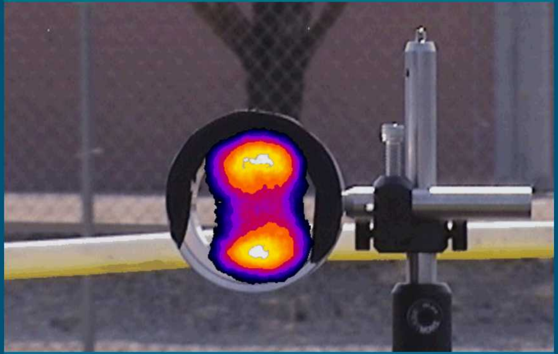
SAND2020-8226PE

Solar-blind Radioluminescence Imaging of Alpha Radiation in Air



PRESENTED BY

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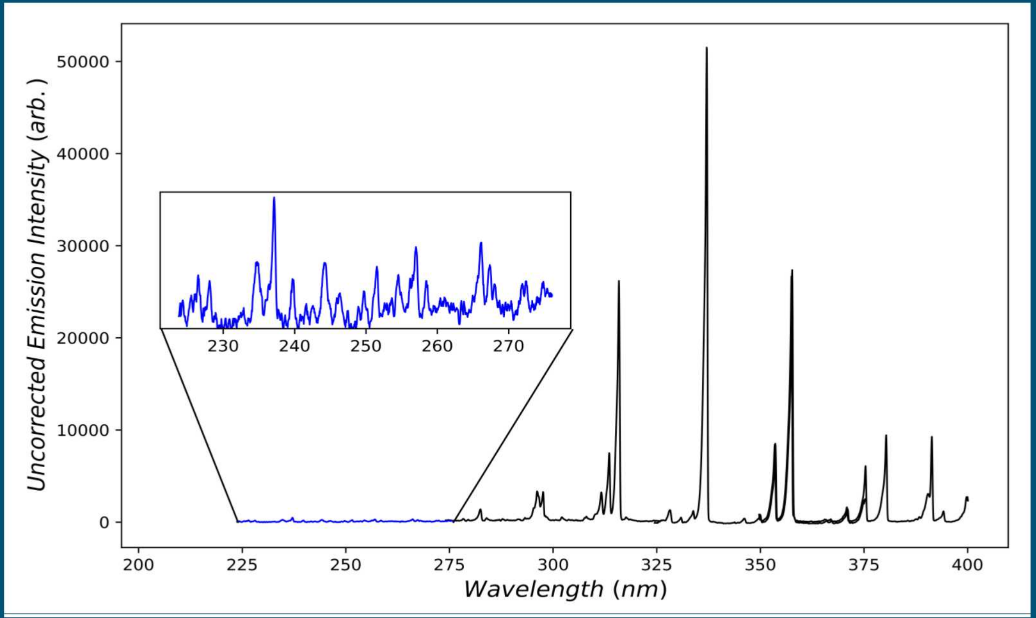
Background

Radioluminescence:

- Fluorescence produced by species excited and ionized in the presence ionizing radiation
- In air, N_2 dominates radioluminescent spectrum but other *radiolytic* species may contribute (N_2^+ NO, OH)
- N_2 and N_2^+ fluorescence is most intense in the 300-400 nm region: optical imaging of this spectral region produces high resolution quasi-dose maps



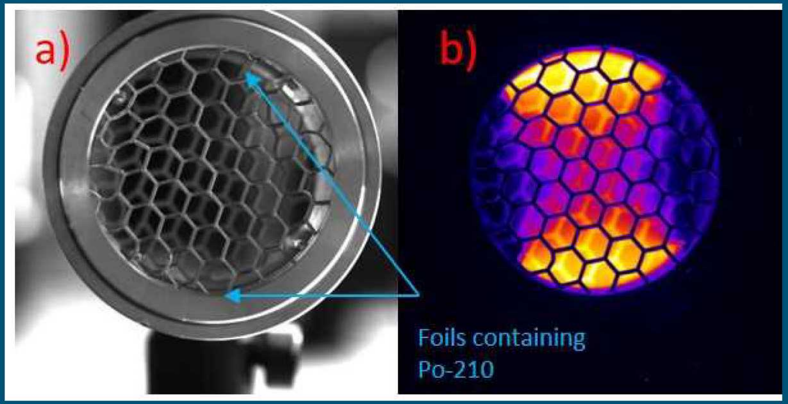
Above: Radioluminescence spectrum of air irradiated by Po-210
Below: CoroCam 7

Solar-blind imaging

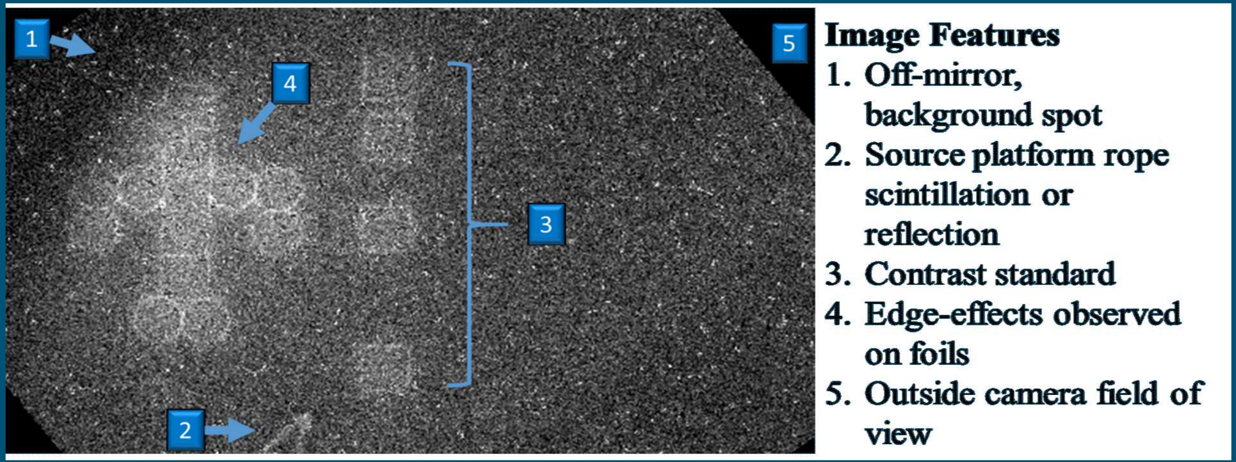
- UV background from the sun and artificial lighting obscures the weak radioluminescent signal in the field
- Radioluminescence in the solar-blind (sub-300 nm) region is much less intense but is not obscured by typical backgrounds
- The UViRCO CoroCam 7 is a COTS Solar-blind ICCD video camera typically used by electricians to detect HV coronal discharge, which can also be used to image radioluminescence.

Prior work at SNL

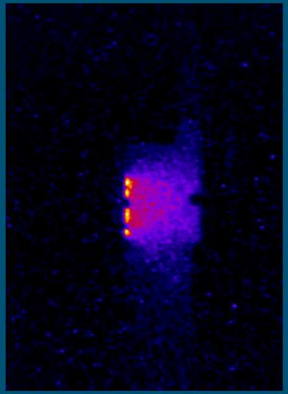
- SNL has conducted a multitude of broad-band UV radioluminescence imaging experiments, primarily with Andor iKon CCD and iStar ICCD sensors, specialized for sensitivity in the UV.
  - Alpha, Beta, and Gamma radioisotope sources (iKon)
  - Pulsed accelerator electron + x-ray sources (iStar)
- These laboratory-grade sensors provide high spatial resolution, high quantum efficiency, and low thermal and readout noise (sensors are deep cooled)
- Sensors are paired with UV-transmissive lenses and UV band-pass filters in low-light conditions for imaging experiments



10 mCi Po-210 from 1 m



Y-90 foils irradiated at SNL ACRR

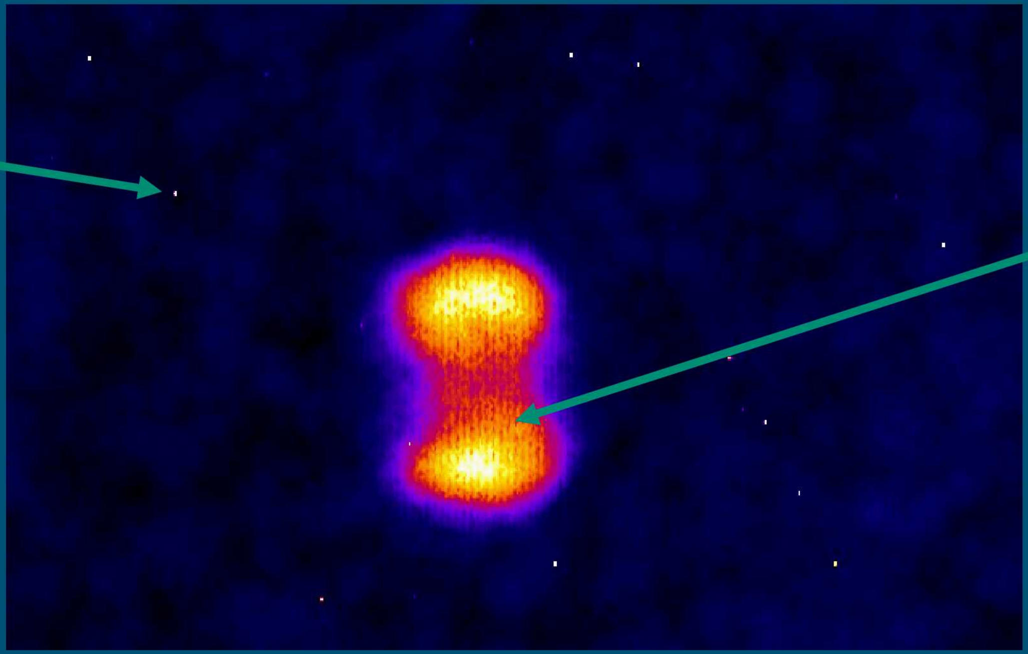


~2 MeV electrons from SPHINX accelerator

UViRCO CoroCam characteristics

- ICCD video camera with static frame rate of 25 fps
- Single, long acquisition impossible, video frames must be added for long exposures
  - Introduces significant read-out cyclical noise: must be mitigated
- Optical system splits light input, passes one to visible camera and other to SB system and detector
- ICCD is sensitive to gamma rays and cosmic rays, these hot pixels must be mitigated in post processing
- Sensor does not require external cooling, and can be battery-powered internally.

Hot pixel induced by gamma ray or cosmic ray



Linear read-out noise from addition of many frames

Image shown is a ~10 mCi Po-210 “can” at 2 m distance, acquired over 8 minutes

CoroCam experiments

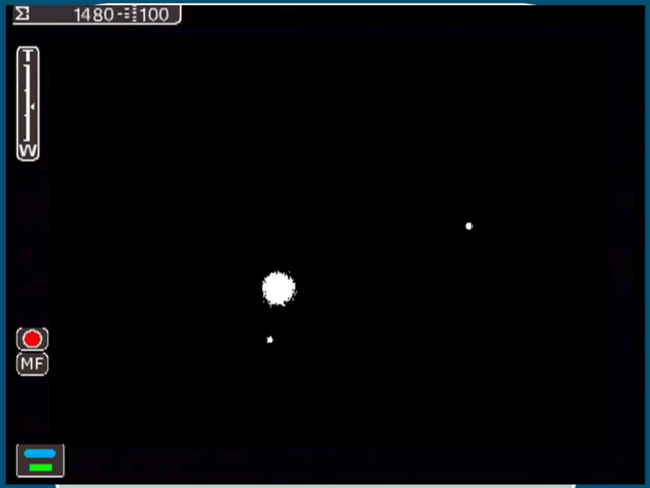
Characterize sensitivity with respect to acquisition time:

- Po-210 source was imaged outdoors in sunlit conditions for 8 minutes at 1 meter distance
- Final images are produced by integrating different numbers of frames, and the images are processed to determine image parameters for analysis

Characterize sensitivity with respect to distance:

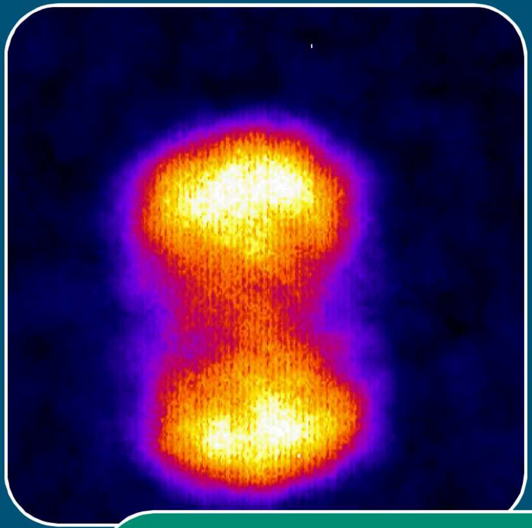
- Po-210 source was imaged outdoors in sunlit conditions for 8 minutes each at distances from 1-50 m
- The same number of frames was used for each final image (8 min worth), and images are processed same as previously

Image Processing



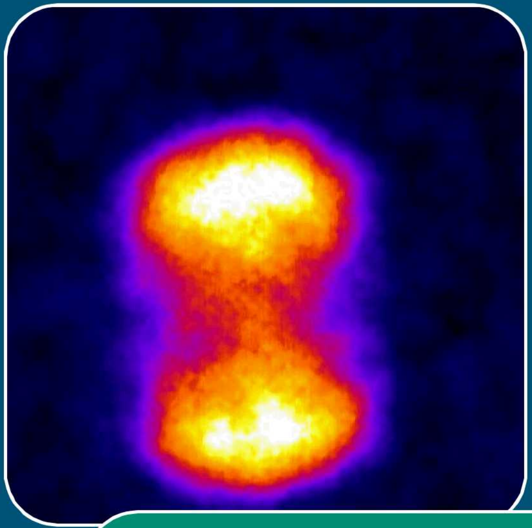
Raw Video

- 25fps binary images w/UV-C hits in white
- Contains image settings which must be cropped



Raw integrated image

- Desired number of frames added together into single image



Median-filtered image

- 5 pixel radius median filter
- Removes linear readout noise and hot pixel noise

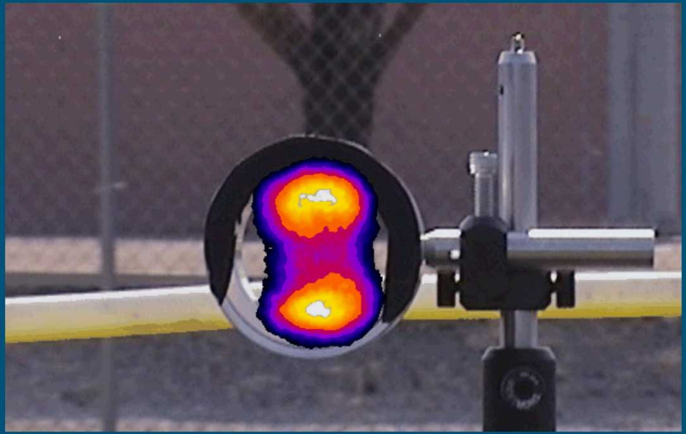
Image data analysis

Images are evaluated for the following parameters:

- Average background signal value and variance:
  - a large known background region of the image is evaluated
- Total integrated signal intensity and signal “size”:
  - the average background value is subtracted from every image pixel. Pixels with a value larger than $3\sigma_{bkg}$ after subtraction are binned and integrated.
- “SNR” figure of merit
  - The quality of the image is determined by calculating a FOM:
    - $SNR = \frac{\sum I}{N * \sigma_{bkg}}$
  - where I is the subtracted signal pixel value and N is the number of signal pixels as determined previously.

Image results

Images below were acquired in Albuquerque on June 19 2020, from 10am to 3pm MDT in bright sunlight conditions. The UV-C radioluminescence image is overlaid above a visible still image of the same field of view.



2 m, 8 min, t = 10:31

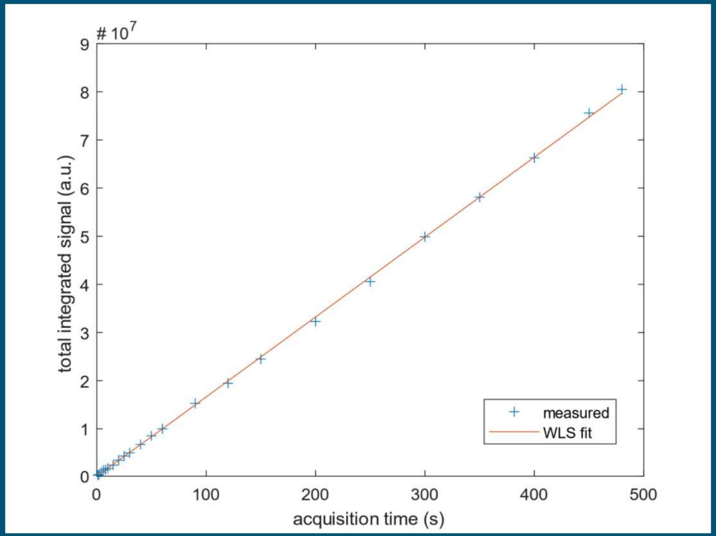
10 m, 8 min, t = 12:02

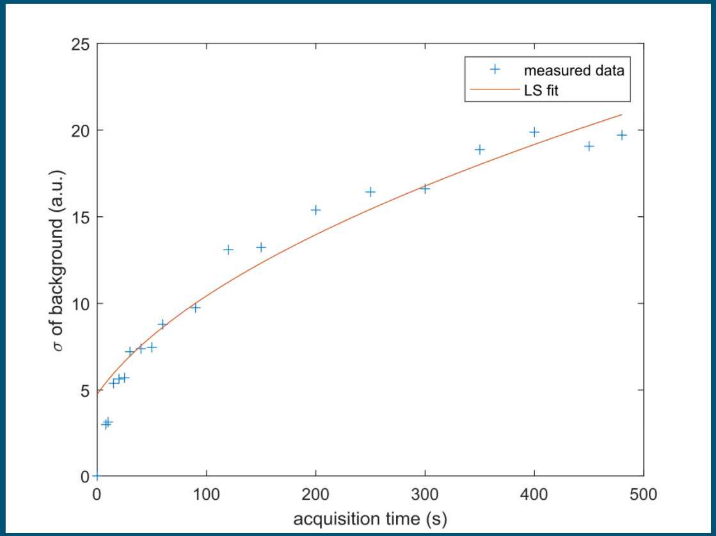
30 m, 8 min, t = 14:03

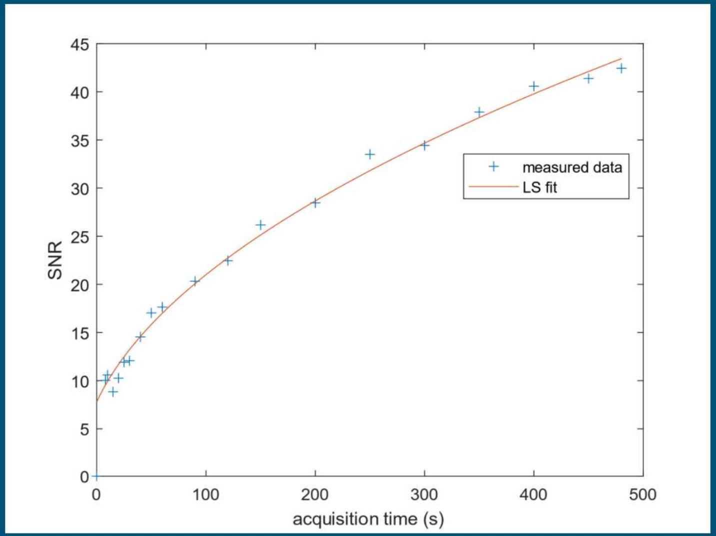
Range of these alphas in ABQ air: ~5 cm

Detection of alphas at 30 m increases the detection range by *600x*

Image results: t-dependent data





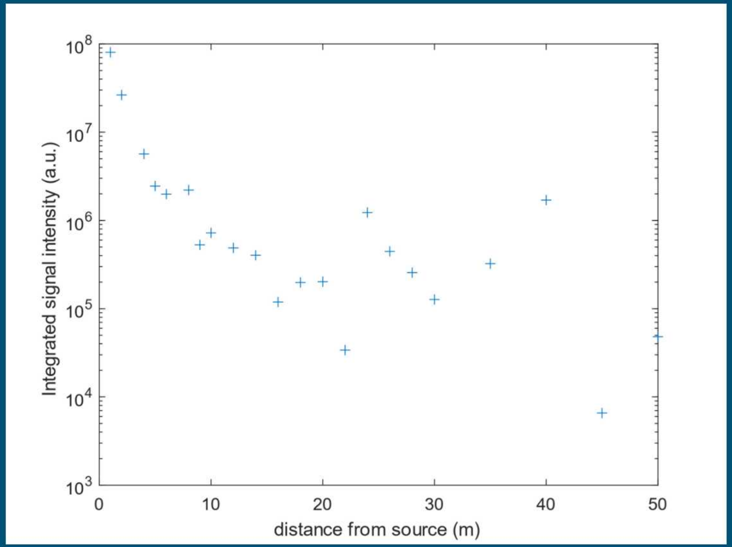


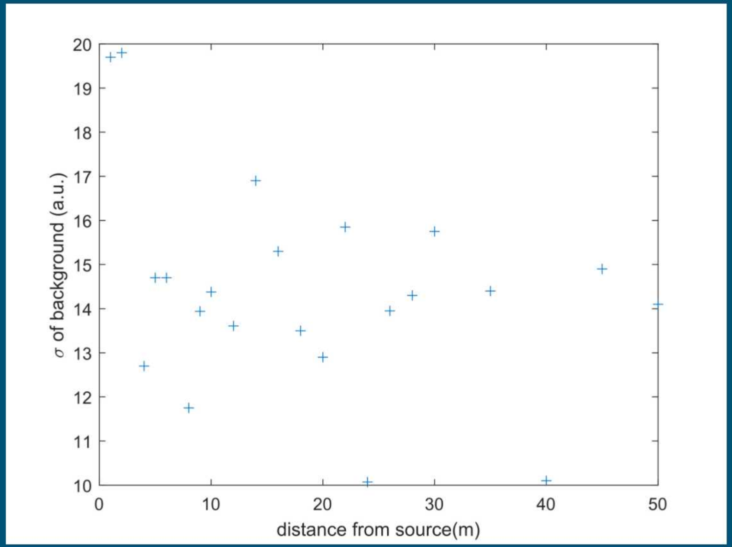
Time-dependent results match basic theory well: the integrated signal is linear with respect to time and the background standard deviation is well fit by a function of sqrt(t).

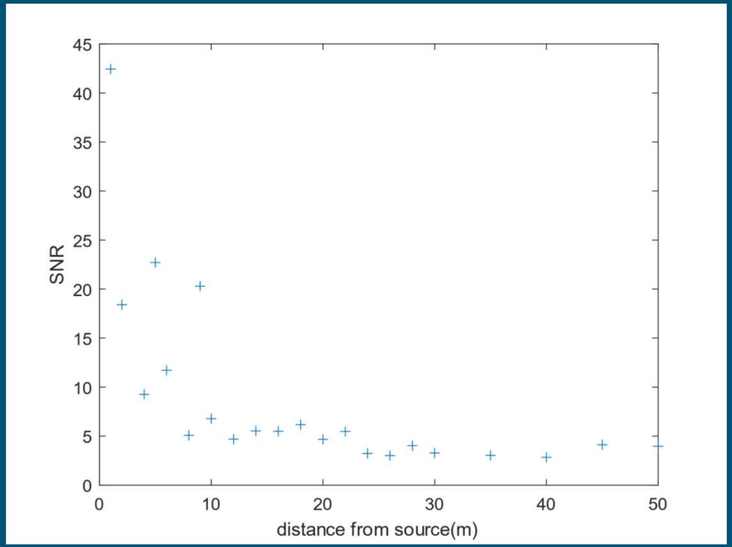
Since SNR is proportional to intensity divided by background standard deviation, SNR should be well fit by a function of sqrt(t), which it is.

$$\sum I = I_o t \qquad \sigma_{bkg} = \sqrt{I_{0,bkg} * t} \quad \longrightarrow \quad SNR \propto \frac{t}{\sqrt{t}} = \sqrt{t}$$

Image results: distance-dependent data







X-dependent data is much messier.

Signal intensity should decrease as x^{-2}, and if attenuation/scatter is important, may depend on e^{-kx}. Consequently, quantitative data quality diminishes rapidly as distance increases.

With poorly-sampled images (total intensity < 1e7), image data analysis results are less reliable. Possible issues:

- population of signal pixels on order of population of background pixels with greater than 3 sigma over mean background
- Bulk of real signal pixels could be just below 3 sigma threshold, but consistently so
- -> need to refine image analysis program to allow for quantitative analysis of low-intensity images

Conclusions

- Work is first demonstration of daylight-background radioluminescence imaging
- Alpha sources can be qualitatively confirmed to at least 30 m: extends detection range of alpha particles at least 600x with COTS equipment
- UViRCO CoroCam well characterized for sensitivity to ~10 mCi Po-210 source with respect to acquisition time

Planned future work

- Measure quantitative UV-C radioluminescence spectrum in:
  - Air
  - N_2
  - O_2
  - This may allow for identification of species responsible for UV-C radioluminescence spectral bands
- Refine image analysis code for use in low-intensity images and allow for automated confirmation of presence of radiation