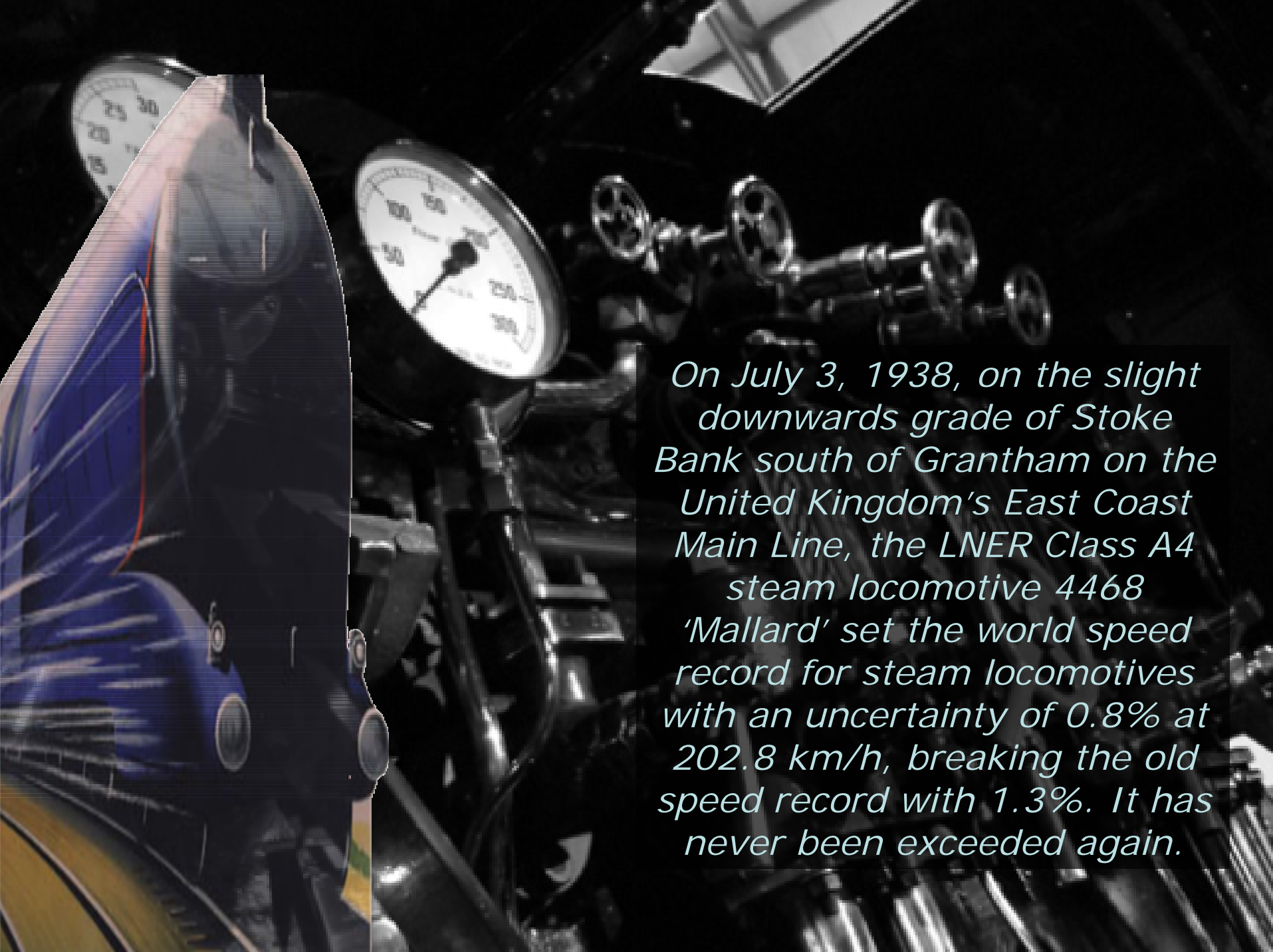


Velocity determination based on sinodial modulation and frequency analysis

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On July 3, 1938, on the slight downwards grade of Stoke Bank south of Grantham on the United Kingdom's East Coast Main Line, the LNER Class A4 steam locomotive 4468 'Mallard' set the world speed record for steam locomotives with an uncertainty of 0.8% at 202.8 km/h, breaking the old speed record with 1.3%. It has never been exceeded again.

Introduction

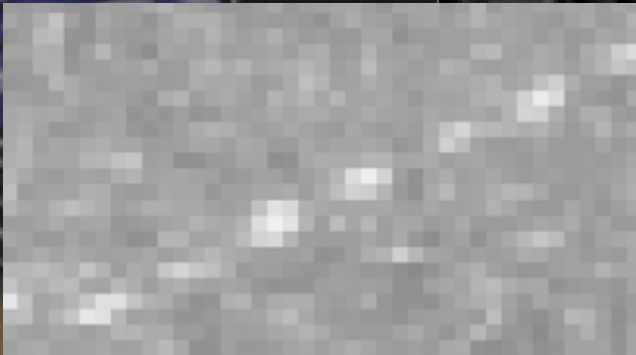
Conventional shutters

- n blades rotating in front of lens with a constant speed
- edge of each break forms measurement point



Digital all-sky cameras

- 4 Mpxl fisheye cam; $1800 \text{ pxl} = 180^\circ$
- Typical angular velocity: $10^\circ/\text{sec}$
- Typical shutter speed: 10 brks/sec
- 1 break measures only 10 pxl



Sinodial modulation



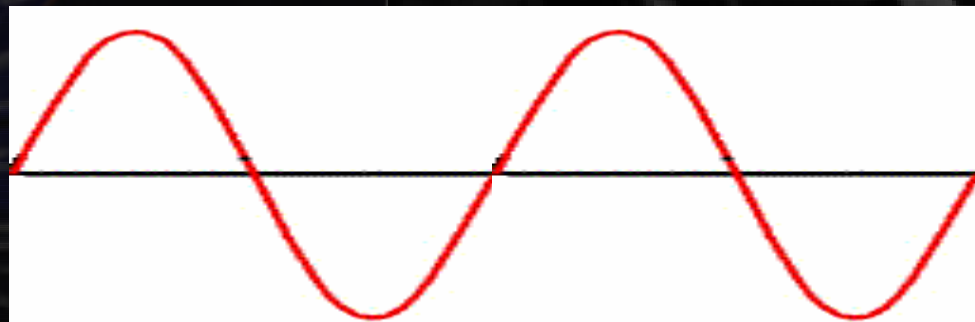
'ideal' trail



Conventional shutter



Idem, not ideal



Sinodial modulation

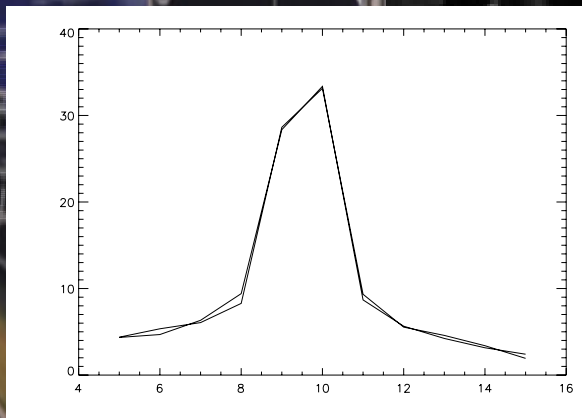
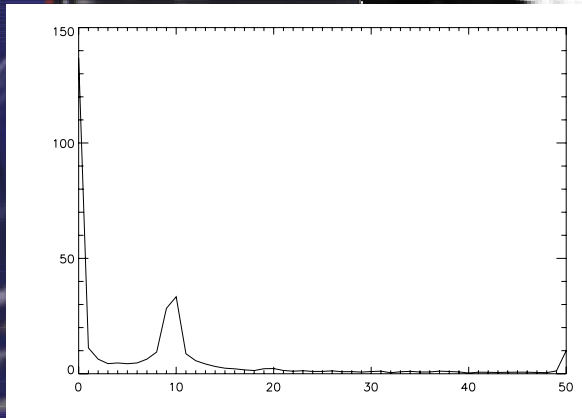
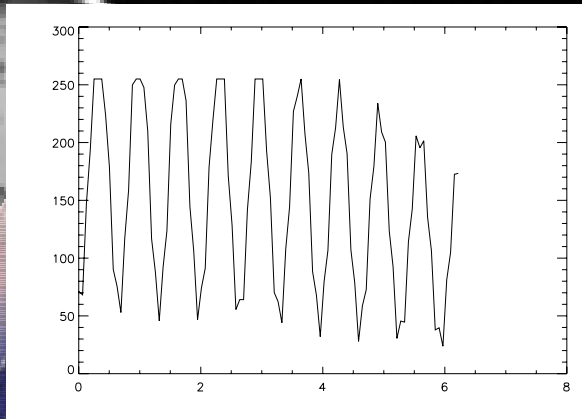


Characteristics-Pros-Cons

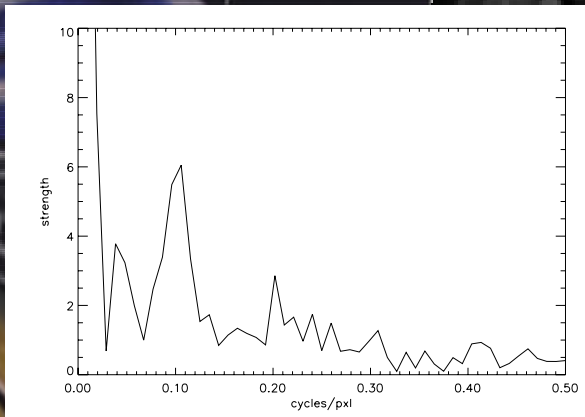
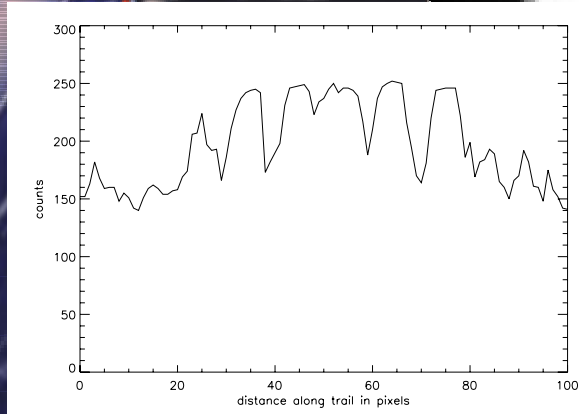
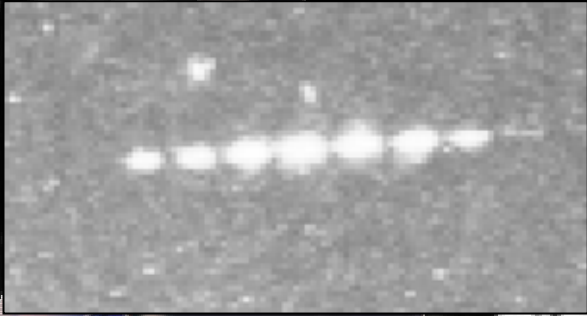
- all pixels contribute in velocity measurement
 - FFT/ wavelets analysis applicable
- less trouble with merged breaks, brightness increases, flares, persistent trains
 - more accurate?
- sinodial or triangular modulation is however more difficult to realize

Simulations

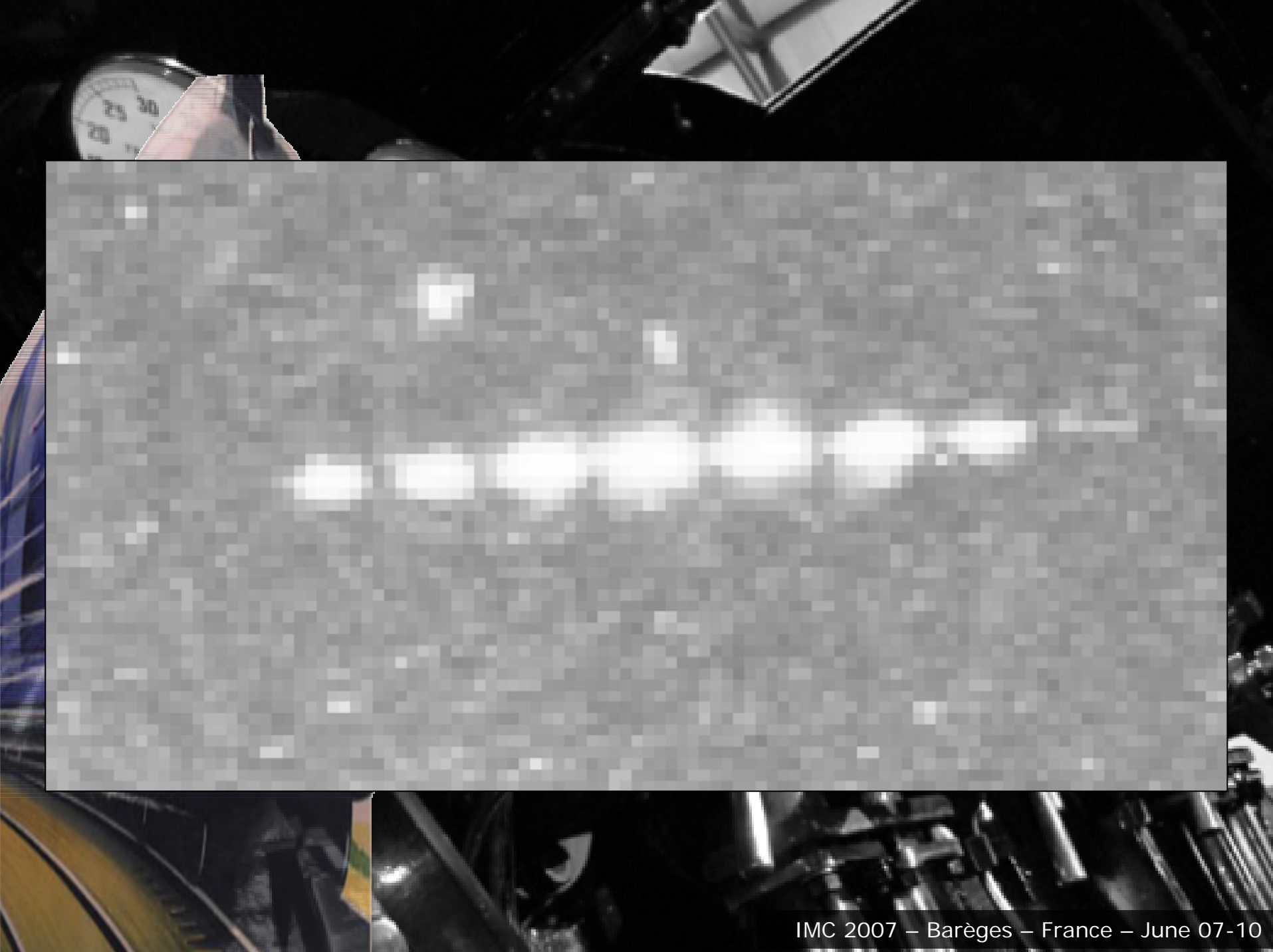
- trails of 100 pixels long, including
 - variable intensity
 - sinodial modulation
 - background
 - saturation
 - noise/interference
 - 8 bit-digitization
- frequency spectrum with Fast Fourier Transform
 - strongest peak represents modulation
 - Gaussian fit around peak
 - errors 0.1-0.5%
 - error estimations 0.2-0.7%
- fast modulations give best results



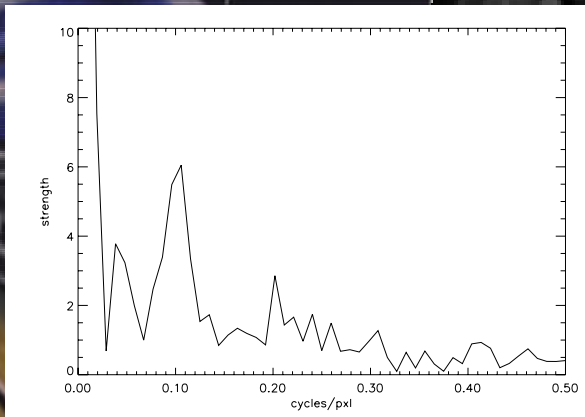
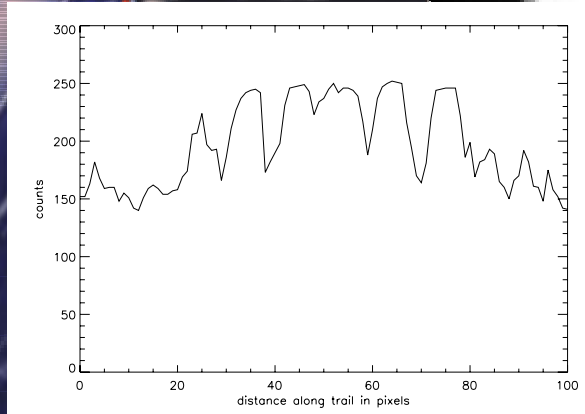
Simulations II



- test of method on video meteor with sinodial appearance
 - error estimation 0.5%
 - conventional measurement (weighted, no interpolation) gives an error estimation of 1.7%
- the error between the two methods is 2%



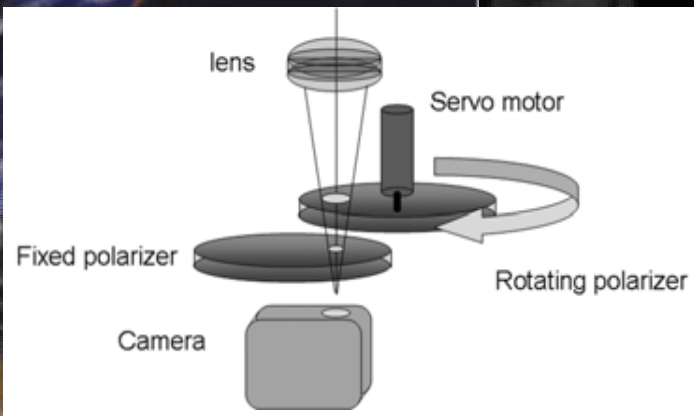
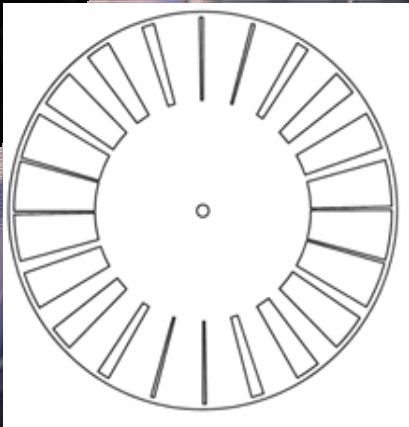
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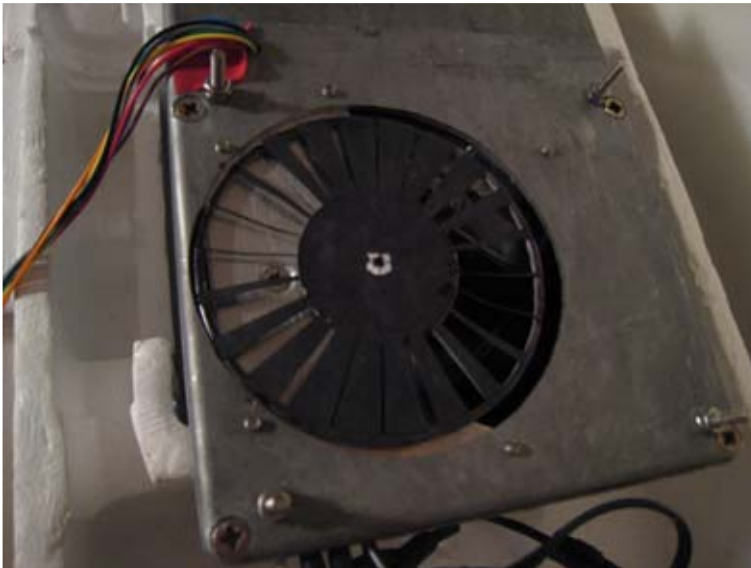
Experimental setup

- modified rotating shutter
 - variable ratio open/closed
 - difficult to manufacture



- modulation with polarizers
 - continuous modulation
 - transmission $< 50\%$
 - meteor should not show (variable) polarization

Experimental setup



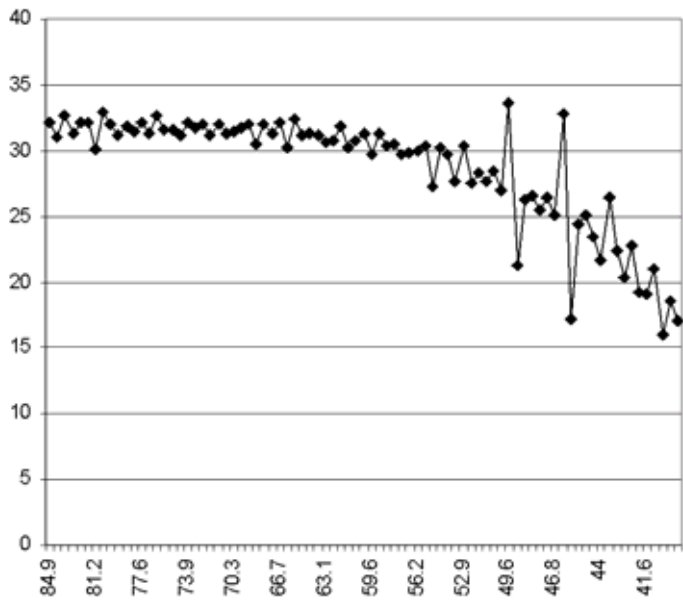
Experimental setup II

- A higher accuracy implies that care should be taken to ensure a stable and precise modulation frequency
- For rotating shutters it asks for a stable and accurate motor
 - We recommend only servo motor systems
 - motor with sensor(s)
 - power amplifier
 - control electronics (μC)
 - accuracy/stability $<0.1\%$
- Motor + shutter should be tested & calibrated

Deceleration

A higher accuracy implies too: more sensitive to deceleration

- Deceleration causes broadening of peak in frequency spectrum
- It results in \sim average velocity, but not exact
 - Remedy: take only first half of trajectory, assuming the first part is deceleration free.
- For deceleration pure FFT analysis not enough:
 - WFT, Windowed Fourier Transforms
 - Wavelet analysis



Conclusions

- Prototypes ready, field tests underway
 - Polarizers give strong reduction of number of reference stars
- Simulations show that sinodial modulation and frequency analysis work and are a good alternative for the common method of velocity determination
 - They can lead to a higher precision
 - The simulations show that the highest precision is obtained for fast modulation frequencies
 - The method is not confined to all-sky work only but should work with longer focal lengths too, which should give accurate velocity determinations
- No deceleration taken into account. Study to be done with use of WFTs, wavelets