Total Comet Magnitudes from CCD- and DSLR-Photometry

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1. Introduction

- Motivation and Background
  - Comets are exciting objects!
  - Photometry is fundamental to describe cometary activity, but CCD and DSLR photometry of extended objects poses a challenge
  - Goal: closer match of visual brightness estimates
  - Some experience in image reduction (IRAF, MIDAS, …) and stellar photometry

- Why not stick to visual observations?
  - CCD and DSLR imaging is 'easy'
  - Reaching fainter magnitude limits
  - Larger number of comparison stars
  - Allow for later verification or check of results
  - Create nice images to show to your friends
2. Observation

- Definition of the goal
  - Allow for brightness estimates of brighter comets to complement and possibly extend visual observations using DSLR or CCD camera (with green filter)
  - Do photometric calibration using unsaturated field stars from single reference catalog

- Instrumentation
  - Fast telescope or telelens (f/3 to f/5)
  - Suitable CCD (large size, linear response) or DSLR camera
  - Focussing aid (Bahtinov mask)
  - Motorized mount
• Site considerations

• Currently used setups
  - Local: Newton f=800mm f/4 with DSLR Pentax K5IIs on Celestron ADM
  - Mobile: Telelens f=200mm f/2.8 with DSLR Pentax K5IIs on Astrotrac
  - Remote: Refractor FSQ 106mm f/5.0 with CCD SBIG STL11000M (iTelescope.net from New Mexico or Australia)

• Observation planning
  - Avoid bright stars close to comet
  - Check comets motion (ideally cover 5-10 x FWHM of stars)
  - Choose appropriate f-stop, gain (ISO), exposure time
  - Image series to increase dynamic range, apply dithering, exclude satellite trails
Telelens 200mm f/2.8 with DSLR Pentax K5IIs on Astrotrac
3. Image Reduction

- Basic image reduction is the same for CCD and DSLR observations

- Calibrations
  - Bias and dark: $f(T, t_{\text{exp}}, \text{gain})$
  - High quality flat-field (white screen, twilight sky, super-sky-flat)
  - Verification of sensor linearity

![Sensor Linearity (Pentax K5IIs, ISO 200)](image)
● Peculiarities of DSLR cameras
  - RAW-development using modded dcraw
  - Bayer matrix requires RGB-Interpolation
  - Sampling depends on color (possible undersampling of stars)
  - internal bias- and dark-subtraction
  - internal noise reduction on RAW data (e.g. Nikon "star eater")
- Registration and stacking of images
  - stack on stars (excluding bad image regions like satellite trails)
  - WCS calibration (e.g. telelens 2.8/200mm: pixel scale 5", rms=0.3")
  - stack on comet using comets motion according to ephemerides
- Software
  - Imagemagick, Netpbm and other standard tools available for Linux
  - sextractor, scamp, swarp (E. Bertin, IAP Paris)
  - wcstools (J. Mink, SAO Harvard)
  - cdsclient (CDS Strasbourg)
  - DS9, ImageJ for image display and interactive analysis
  - Shell scripts to combine all the tools
4. Comet Extraction

- Outline
  - identify bright, isolated stars to extract star-PSF and startrail-PSF
  - identify field stars in a region around the comet
  - aperture photometry of field stars (arbitrary zero point, aperture depending on FWHM)
  - remove star trails from comet stack using scaled startrail-PSF
  - problematic cases: double stars, saturated stars

- Example:
  Comet C/2014 Q2 (Lovejoy), 2015-02-13, telelens 200mm, Pentax K5IIs, 45x 1min
Comet Stack
... after subtraction of ~3000 star trails
... after contrast stretch
5. Large Aperture Photometry

- Comet image:
  - heavy smoothing and contrast stretching to determine coma extent and background area(s)
  - measure counts for comet and background
  - determine background error (e.g. for DSLR imaging: +-0.2% of background signal)

- Star stack:
  - query photometric reference catalog (Tycho-2, GSPC2)
  - automatic cross-matching with stars in the image within given distance to comet (for wide field images)
  - aperture photometry of stars
  - photometric calibration of the arbitrary magnitude scale (removal of outliers, if necessary correct for differential extinction)
  - determine magnitude correction for very large apertures
- Example: Comet C/2014 E2 (Jacques), 2014-05-03, altitude 11°, telelens 200mm, Pentax K5IIs
6. Light Curves of Bright Comets

- C/2012 K1 (PANSTARRS)
  - 42 DSLR observations
  - 22 CCD observations
  - June 2013 - May 2015

- C/2014 Q2 (Lovejoy)
  - 17 DSLR observations
  - 42 CCD observations
  - September 2014 - May 2015
C/2012 K1 (PANSTARRS) - Light Curve 2013 - 2015

- DSLR/G (T. Lehmann)
- CCD/G (T. Lehmann)
- visual (ICQ, FGK)

Date:
- Jun '13
- Oct '13
- Feb '14
- Jun '14
- Oct '14
- Feb '15
- Jun '15
C/2012 K1 (PANSTARRS) - Bright Section (2014)

- DSLR/G (T. Lehmann)
- CCD/G (T. Lehmann)
- visual (ICQ, FGK)
- $m = 6 + 5\log(D) + 3.2 \times 2.5\log(r)$
- Model (MPEC 2015-K84)
C/2012 K1 (PANSTARRS) - Model Fit (2013 - 2015)

- DSLR/G (T. Lehmann)
- CCD/G (T. Lehmann)
- $m = 6 + 5\log(D) + 3.2 \times 2.5\log(r)$
- Model (MPEC 2015-K84)
- Heliocentric Distance

Date:
- Jun '13
- Oct '13
- Feb '14
- Jun '14
- Oct '14
- Feb '15
- Jun '15

Mag:
- 16
- 14
- 12
- 10
- 8
- 6
- 4
- 2
- 1

$r_{\text{sun}}$ / AU:
- 3
- 2
- 1
- 0.5
- 0.1

Distance:
- P
C/2014 Q2 (Lovejoy) - Coma Diameter 2014 - 2015

- DSLR/G (T. Lehmann)
- CCD/G (T. Lehmann)
- visual (ICQ, FGK)

Date

Oct Dec Feb Apr Jun

arcmin

0  10  20  30  40  50  60  70
7. Faint or Diffuse Comets

- C/2010 S1 (LINEAR)
  - bright, distant ($r_{\text{min}}=5.9$ AU) object, with coma $\sim1'$ and tail
  - scatter of data points (DSLR): $\text{rms}=0.1\text{mag}$
7. Faint or Diffuse Comets

- 32P/Comas Sola
  - Newton f=800mm f/4, Pentax K5IIs, 40-70min exposure time:
    - geometric projection affects definition of coma size
    - comet tail may contribute to large aperture photometry
- 22P/Kopff
  - comet with large diffuse coma

- scatter of mag estimates: large aperture: 0.25mag vs. fixed aperture of 60": 0.09mag

- correlation between 'coma diameter' and brightness
7. Summary

- Large aperture photometry has been demonstrated to match visual observations for comets as bright as 4mag.
- Internal scatter of rms<=0.1mag for most comets brighter 10mag using small telescopes.
- No evidence of systematic instrumental differences (<0.1mag).
- Limiting factor for photometric accuracy of:
  - bright comets: photometric calibration (accuracy of reference stars).
  - faint diffuse comets: local background variation (flat field, galactic cirrus, halos around bright field stars, reflections, …).
• Large Aperture Photometry does NOT replace other techniques
  - monitoring of faint comets for outburst activity (timescale of days) is best achieved by small, fixed aperture photometry (→ FOCAS)
  - physical dust parameters should be derived from red images, preferably using narrow band filters (→ CARA, Afp)

• Future work
  - follow bright comets over large time span
  - analyze color information from DSLR data
  - wish to work on fainter comets using larger telescopes
  - wish to develop more user-friendly reduction procedure
Thanks!