Total Comet Magnitudes from CCD- and DSLR-Photometry

Thomas Lehmann, Weimar (Germany)

Overview

1. Introduction
2. Observation
3. Image Reduction
4. Comet Extraction
5. Large Aperture Photometry
6. Light Curves of Bright Comets
7. Faint or Diffuse Comets
8. Summary

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

Comet C/2014 Q2 (Lovejoy) - 2015-02-13, 18:53 UT, field size 5.7°x4.0°

2. Observation

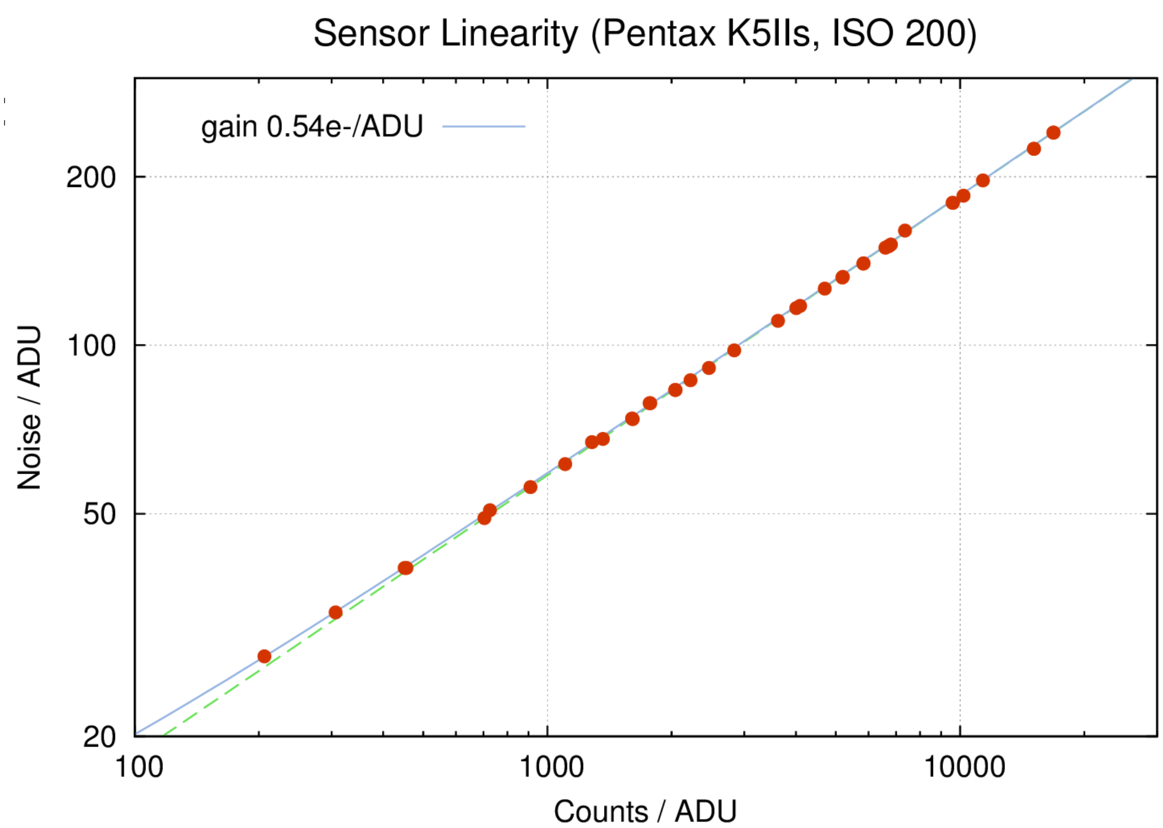
- Definition of the goal
  - Allow for brightness estimates of brighter comets to complement and possibly extend visual observations using DSLR or CCD camera (with green filter)
  - Do photometric calibration using unsaturated field stars from single reference catalog
- Instrumentation
  - Fast telescope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

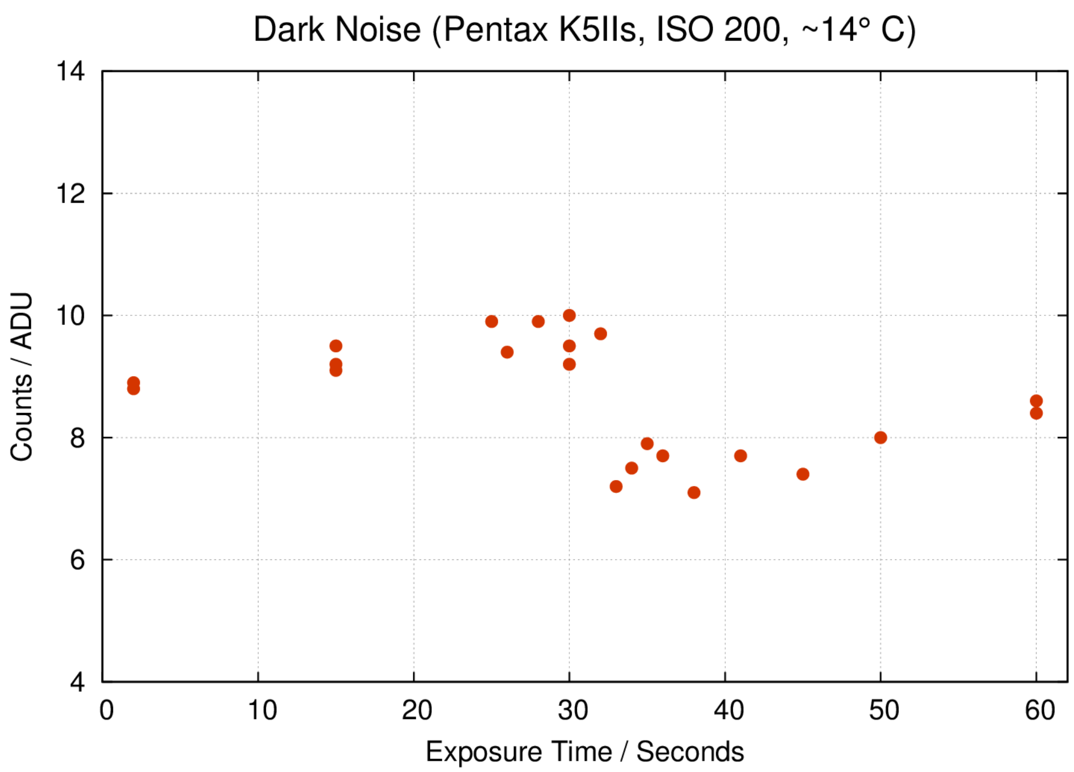
Telelens 200mm f/2.8 with DSLR Pentax K5IIs on Astrotrac

3. Image Reduction

- Basic image reduction is the same for CCD and DSLR observations
- Calibrations
  - Bias and dark: $f(T, t_{exp}, gain)$
  - High quality flat-field (white screen, twilight sky, super-sky-flat)
  - Verification of sensor linearity:



- 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:

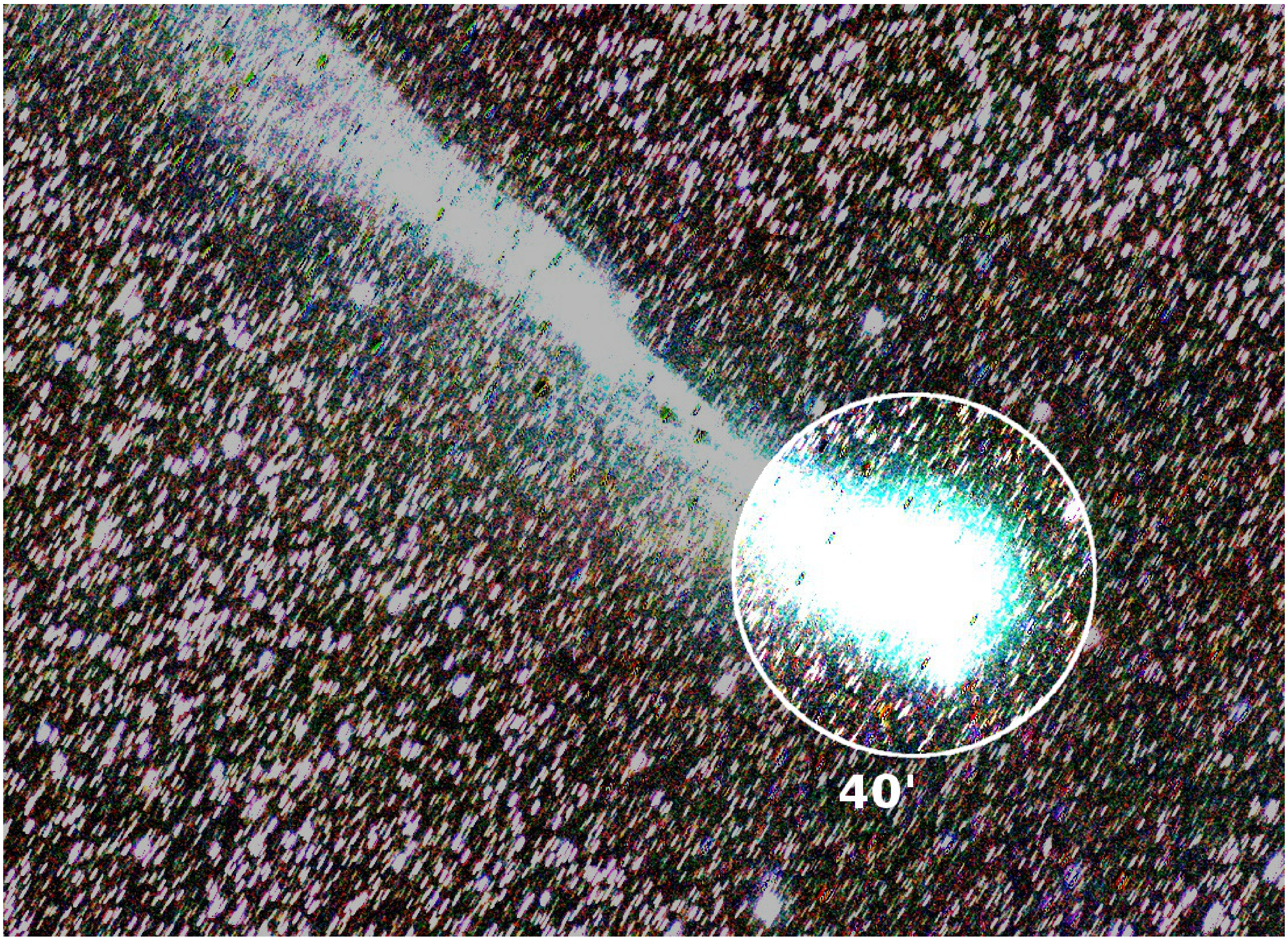
  Comet C/2014 Q2 (Lovejoy), 2015-02-13,

  telelens 200mm, Pentax K5IIs, 45x 1min

Comet Stack

… after subtraction of ~3000 star trails

… after contrast stretch

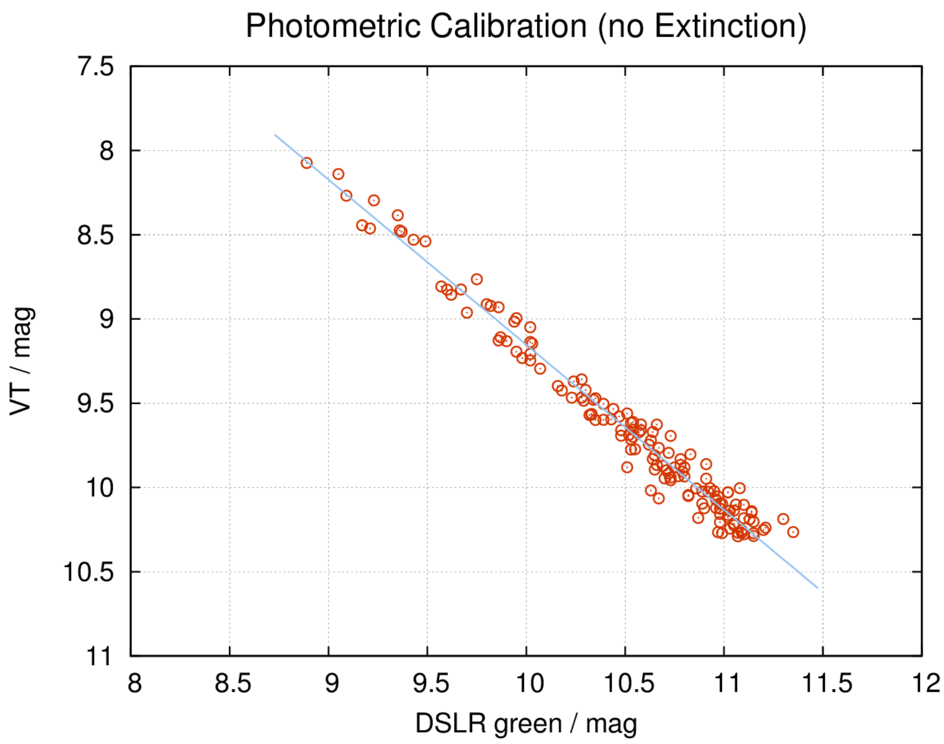


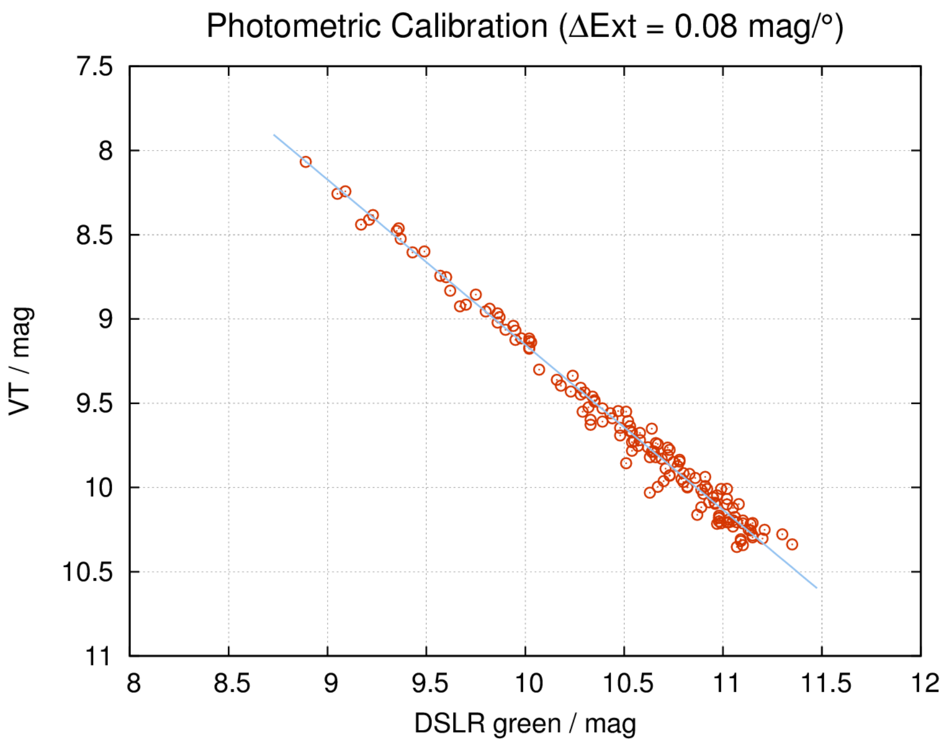
5. Large Aperture Photometry

- Comet image:
  - heavy smoothing and contrast streching 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

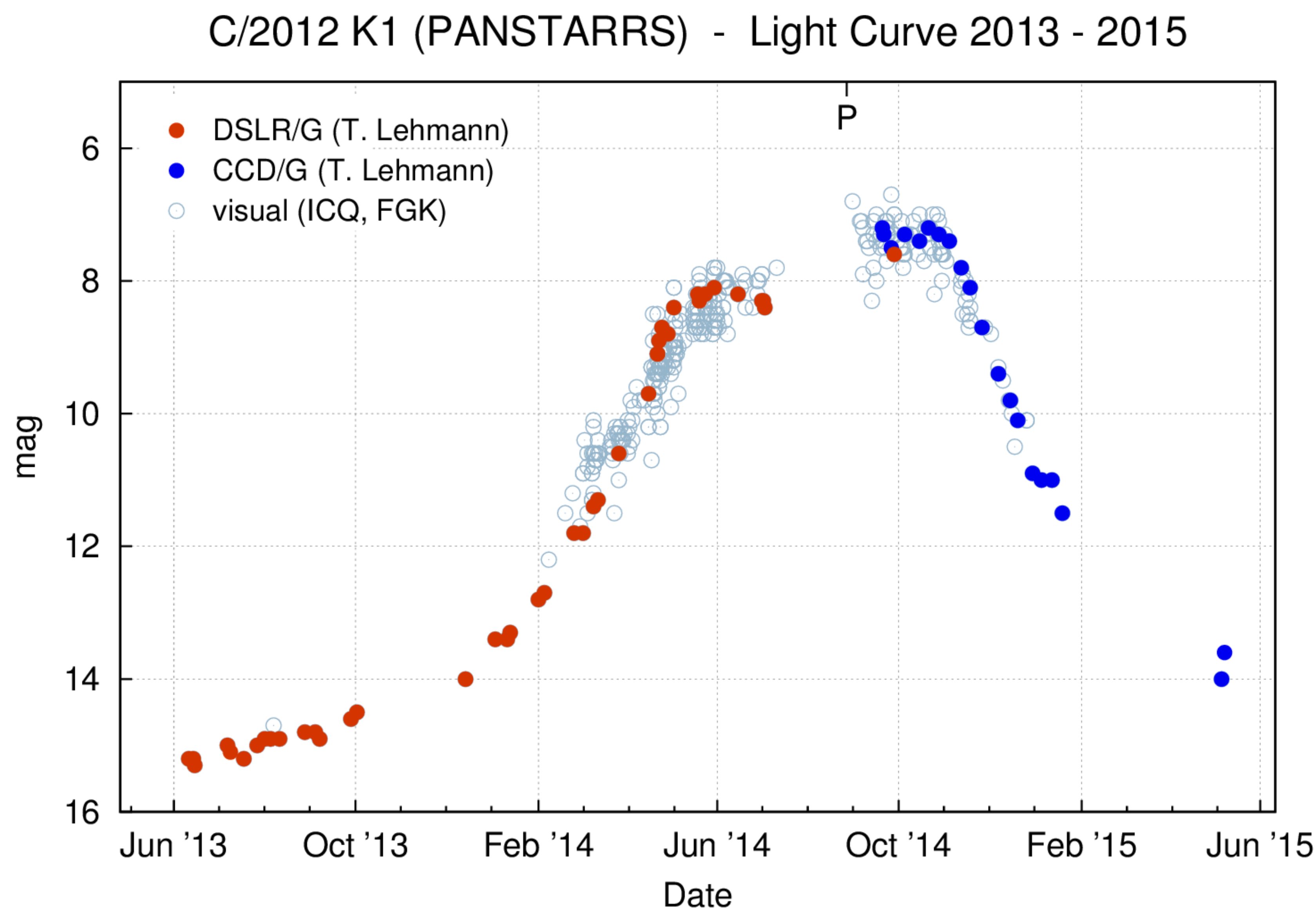
- Example: Comet C/2014 E2 (Jacques), 2014-05-03, altitude 11°, telelens 200mm, Pentax K5IIs

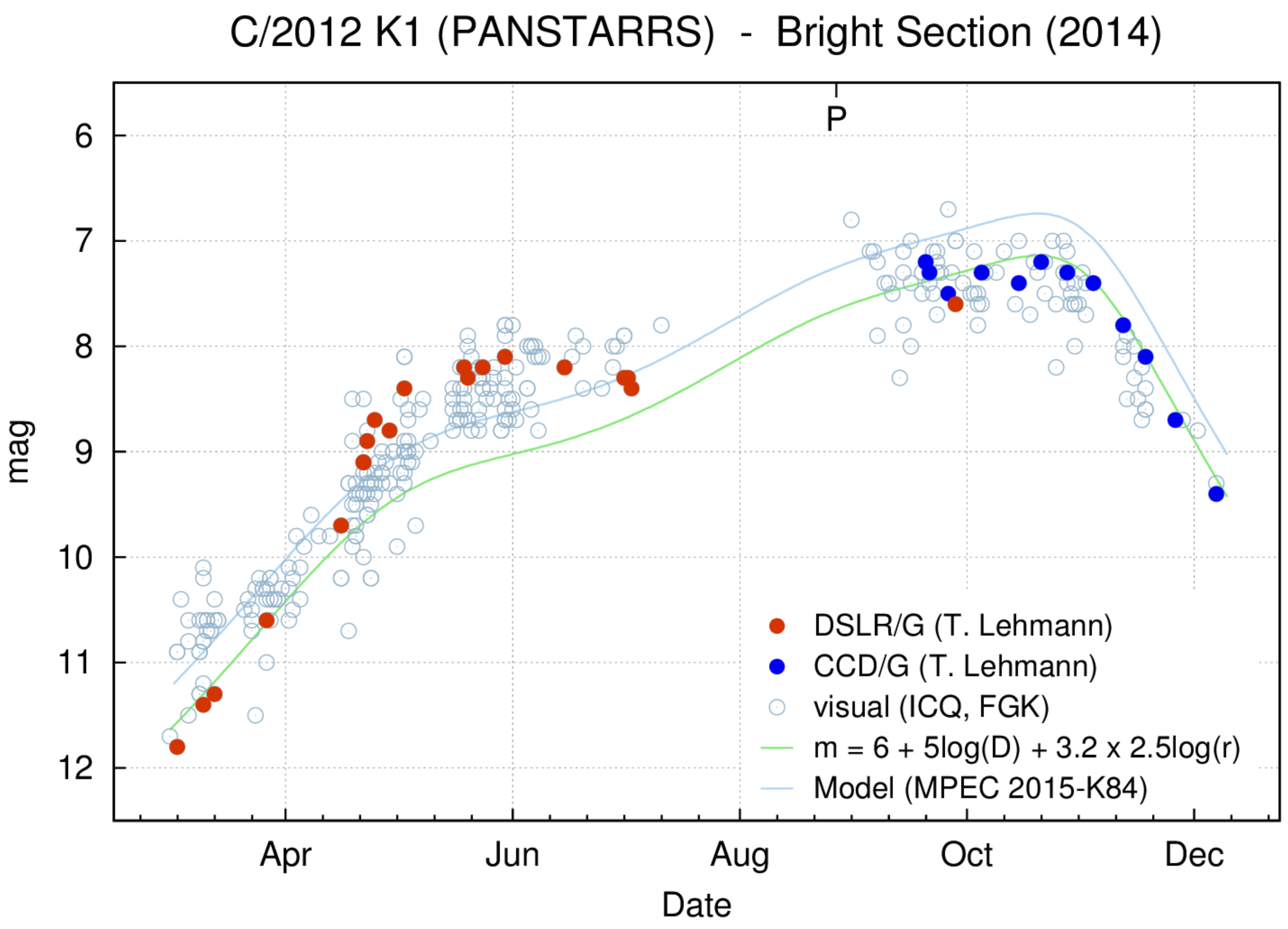




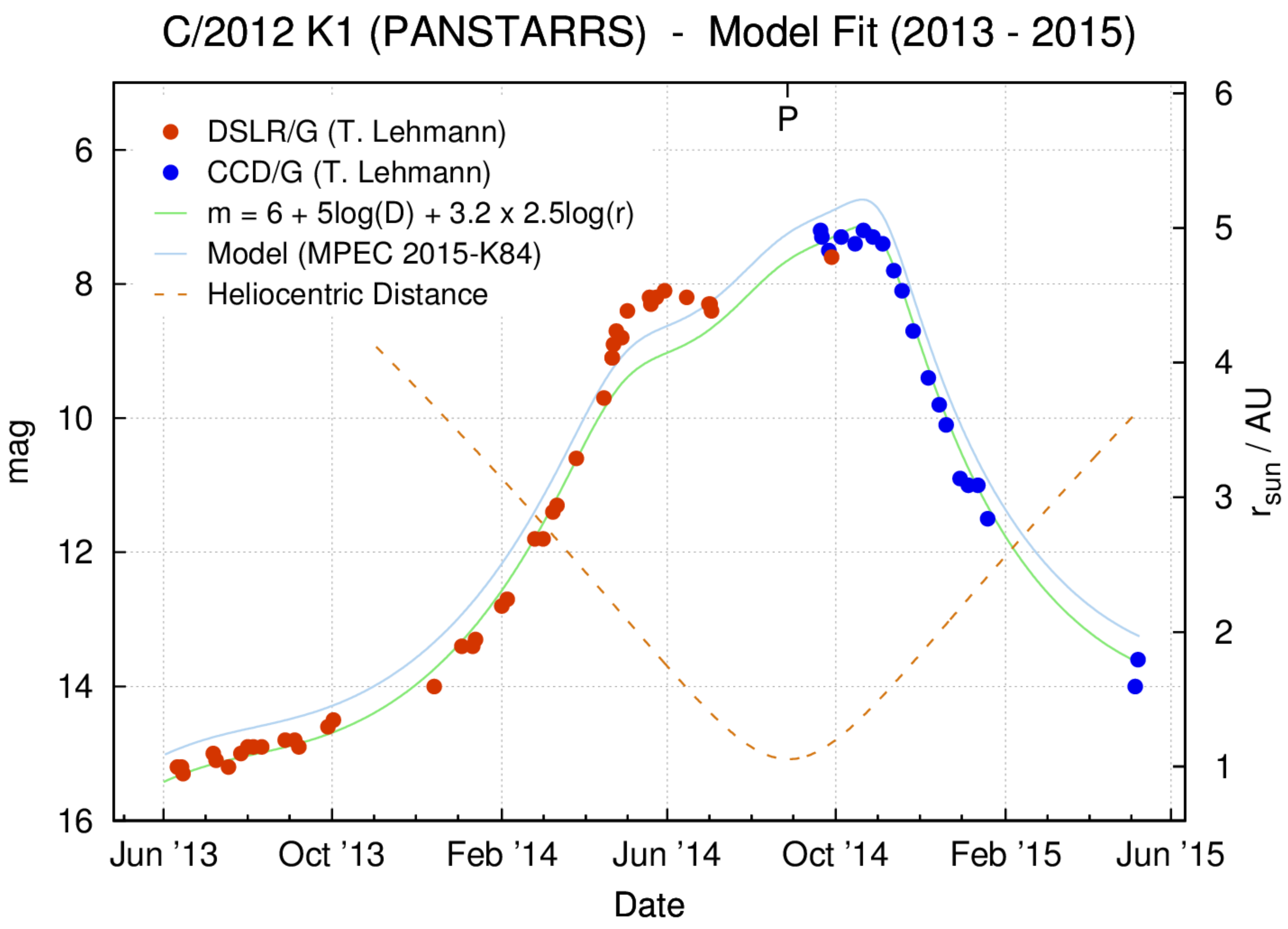
6. Light Curves of Bright Comets

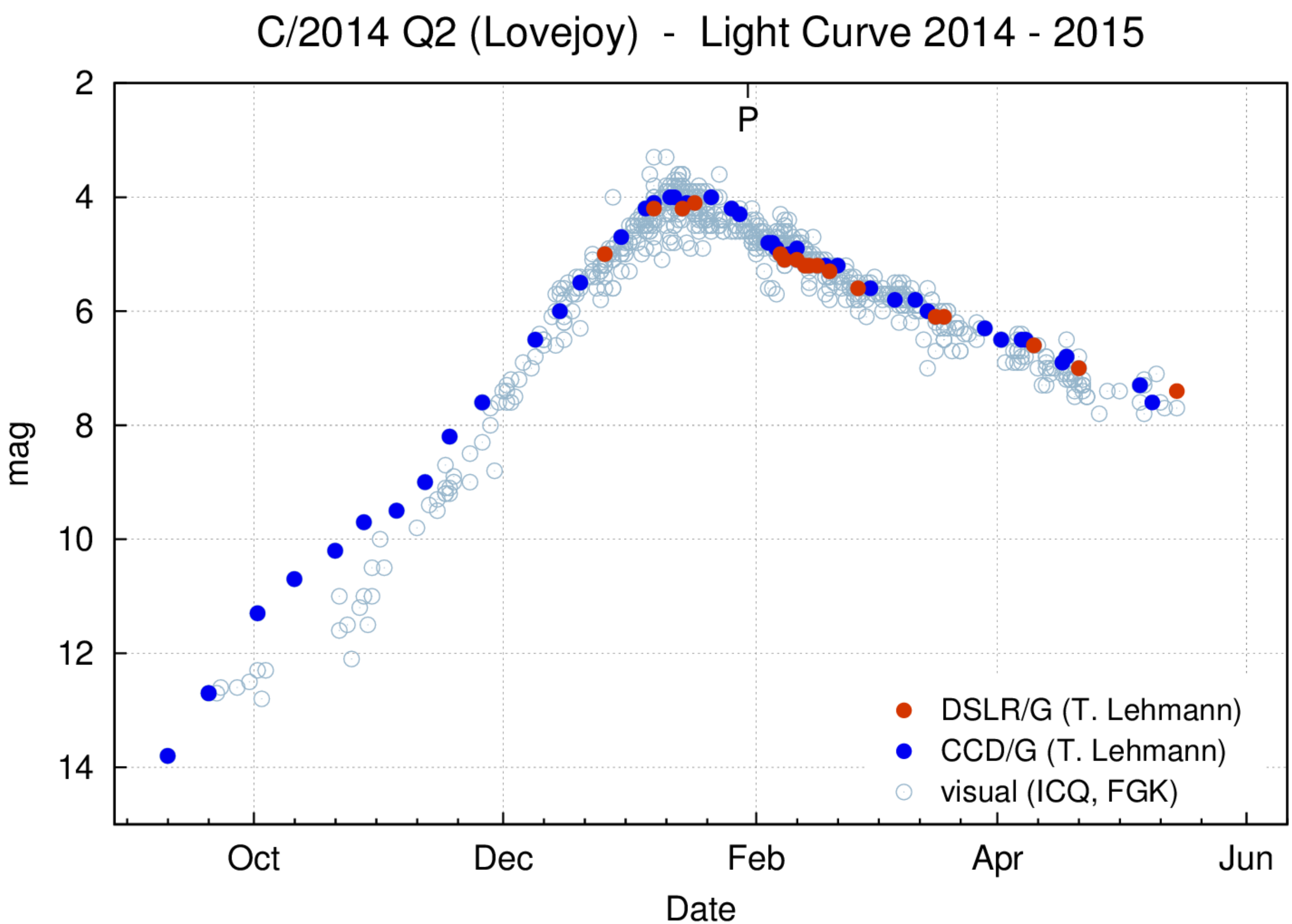
- C/2012 K1 (PANSTARRS)
  - 42 DSLR observations
  - 22 CCD observations
  - June 2013 - May 2015
- C/2014 Q2 (Lovejoy)
  - 17 DSLR observations
  - 42 CCD observations
  - September 2014 - May 2015


C/2012 K1 (PANSTARRS) - Light Curve 2013 - 2015
P
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
visual (ICQ, FGK)
mag
6
8
10
12
14
16
Jun '13
Oct '13
Feb '14
Jun '14
Oct '14
Feb '15
Jun '15
Date

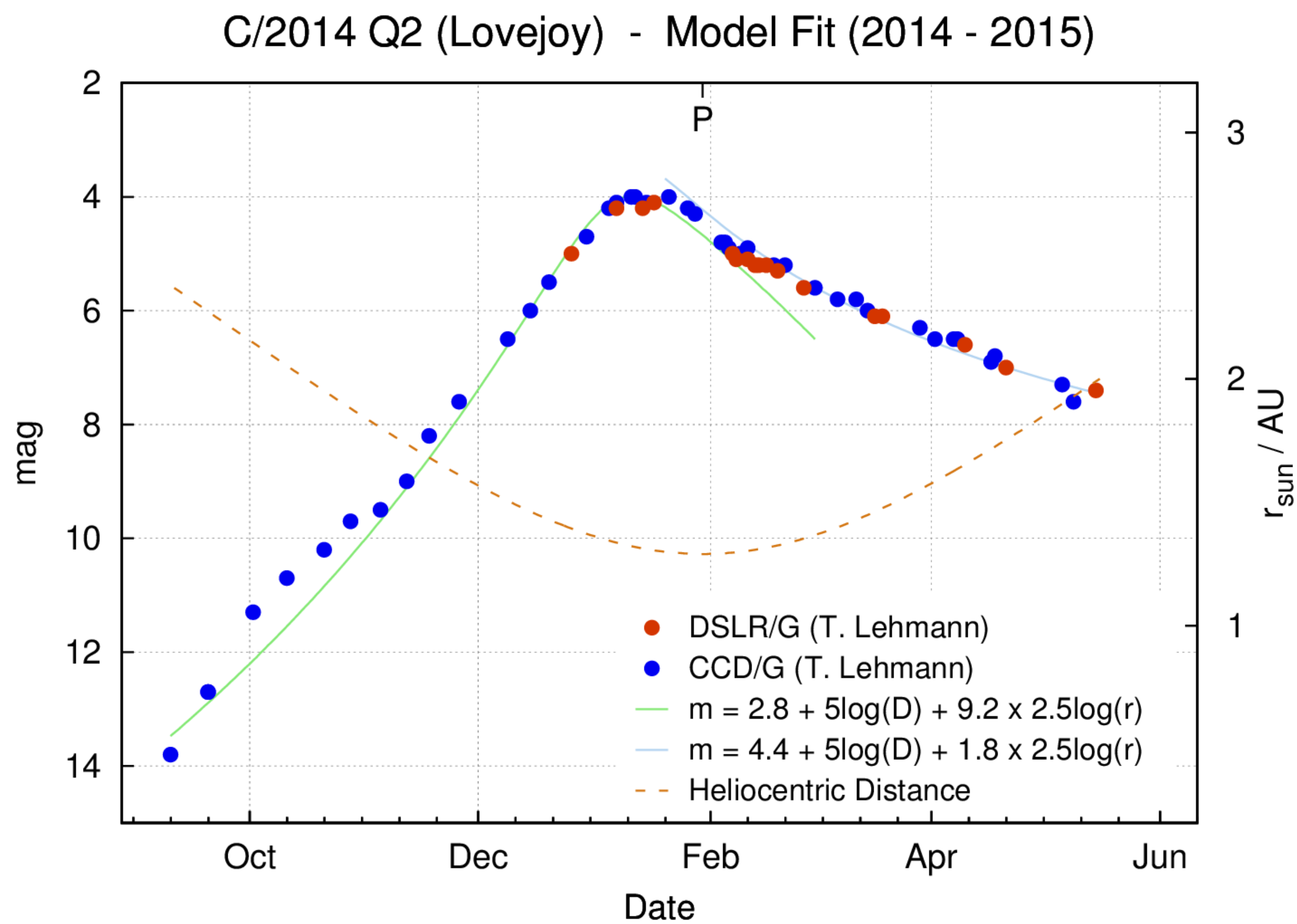


C/2012 K1 (PANSTARRS) - Bright Section (2014)
P
6
7
8
9
10
11
12
mag
Apr
Jun
Aug
Oct
Dec
Date
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
visual (ICQ, FGK)
m = 6 + 5log(D) + 3.2 x 2.5log(r)
Model (MPEC 2015-K84)

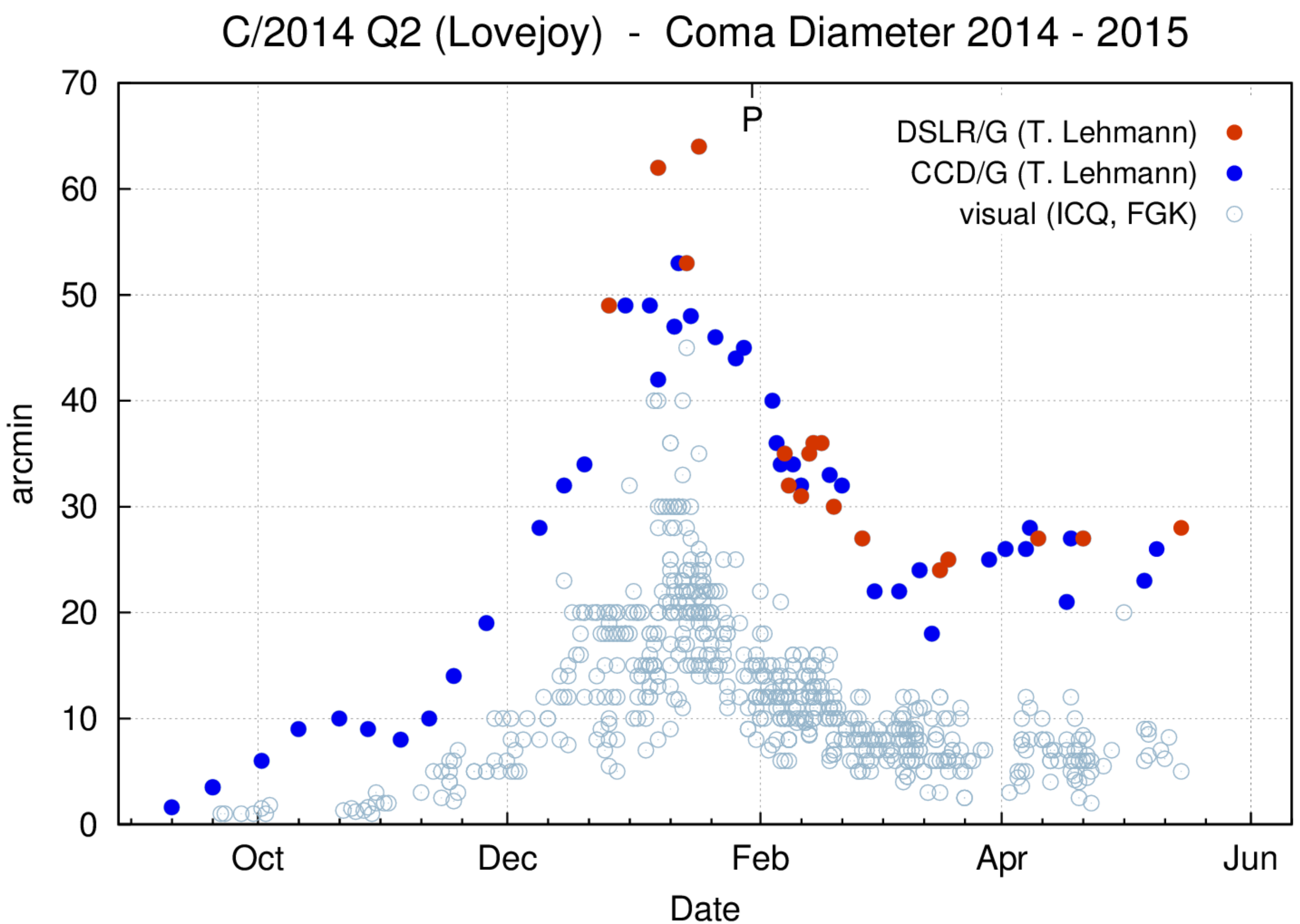

C/2012 K1 (PANSTARRS) - Model Fit (2013 - 2015)
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
m = 6 + 5log(D) + 3.2 x 2.5log(r)
Model (MPEC 2015-K84)
Heliocentric Distance
P
mag
6
8
10
12
14
16
6
5
4
3
2
1
r_{sun} / AU
Jun '13
Oct '13
Feb '14
Jun '14
Oct '14
Feb '15
Jun '15
Date



C/2014 Q2 (Lovejoy) - Light Curve 2014 - 2015
mag
2
4
6
8
10
12
14
P
Oct
Dec
Feb
Apr
Jun
Date
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
visual (ICQ, FGK)



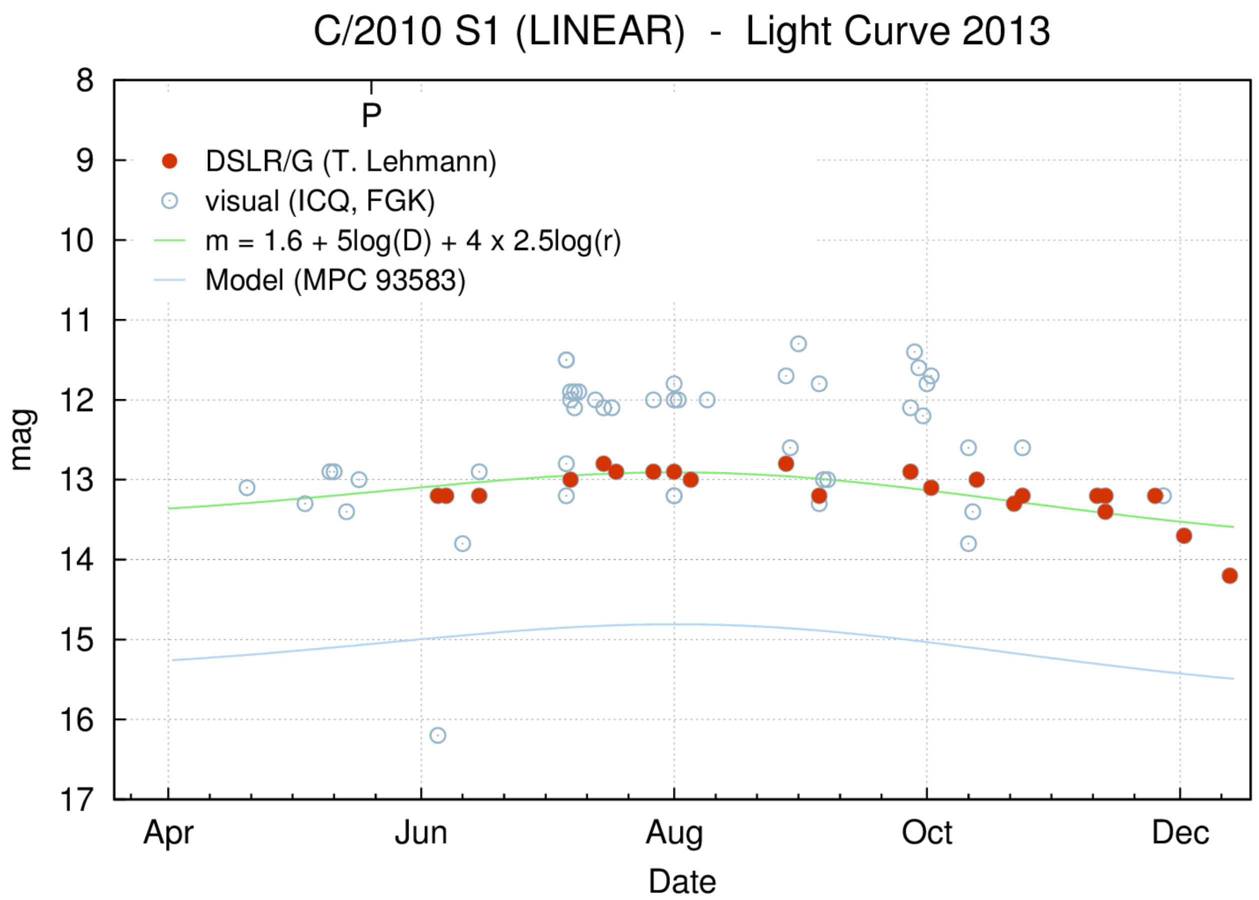
C/2014 Q2 (Lovejoy) - Model Fit (2014 - 2015)
mag
2
4
6
8
10
12
14
P
3
2
1
r_{sun} / AU
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
m = 2.8 + 5log(D) + 9.2 x 2.5log(r)
m = 4.4 + 5log(D) + 1.8 x 2.5log(r)
Heliocentric Distance
Oct
Dec
Feb
Apr
Jun
Date



C/2014 Q2 (Lovejoy) - Coma Diameter 2014 - 2015
70
60
50
40
30
20
10
0
arcmin
P
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
visual (ICQ, FGK)
Oct
Dec
Feb
Apr
Jun
Date

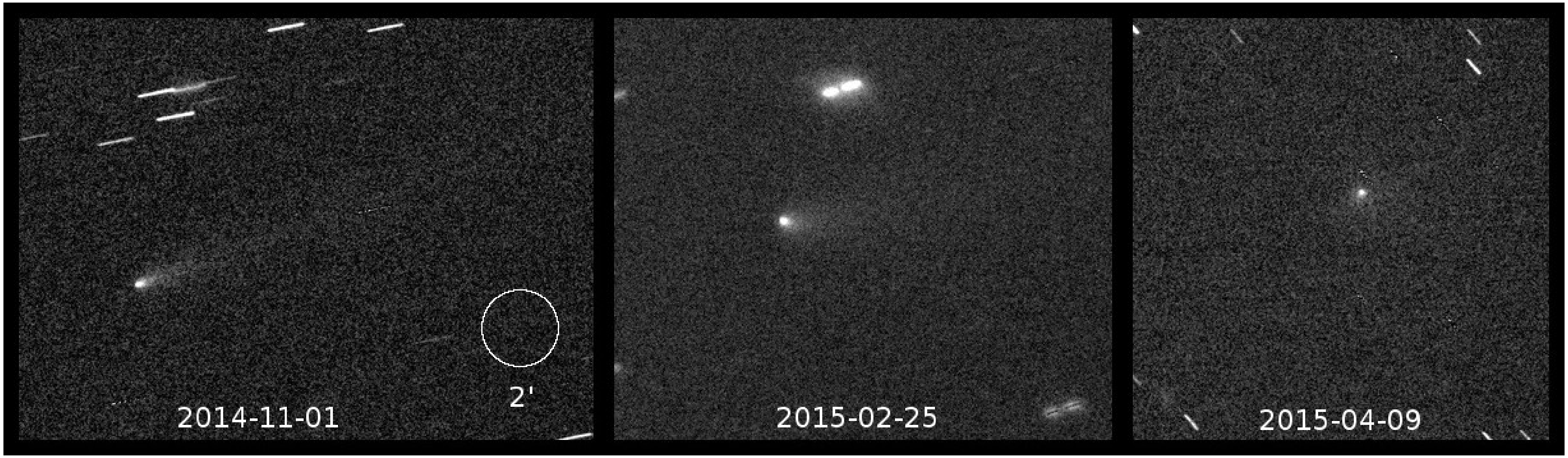
7. Faint or Diffuse Comets

- C/2010 S1 (LINEAR)
  - bright, distant (r_{min}=5.9 AU) object, with coma ~1' and tail
  - scatter of data points (DSLR): rms=0.1mag

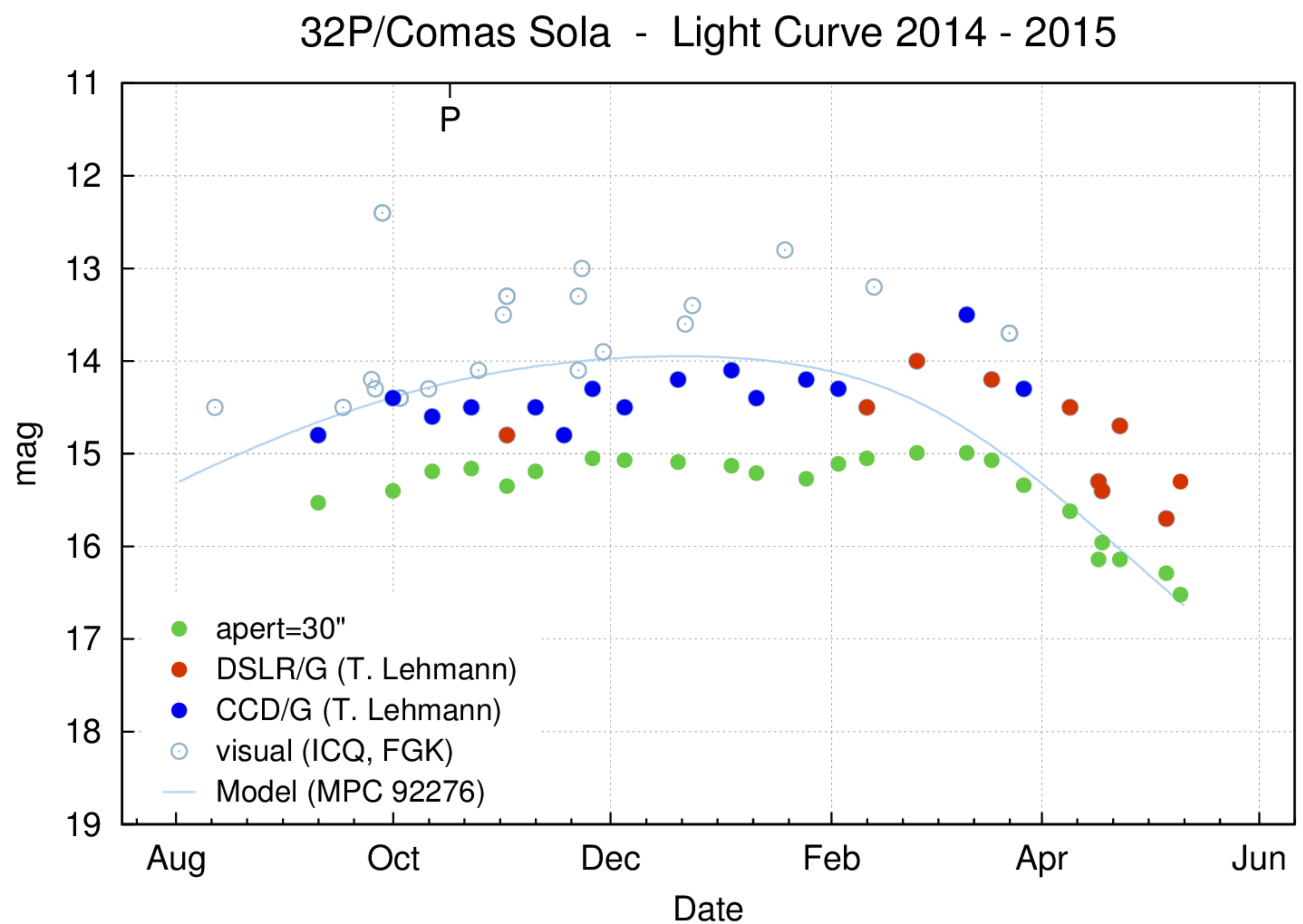


7. Faint or Diffuse Comets

- 32P/Comas Sola
  - Newton f=800mm f/4, Pentax K5IIs, 40-70min exposure time:

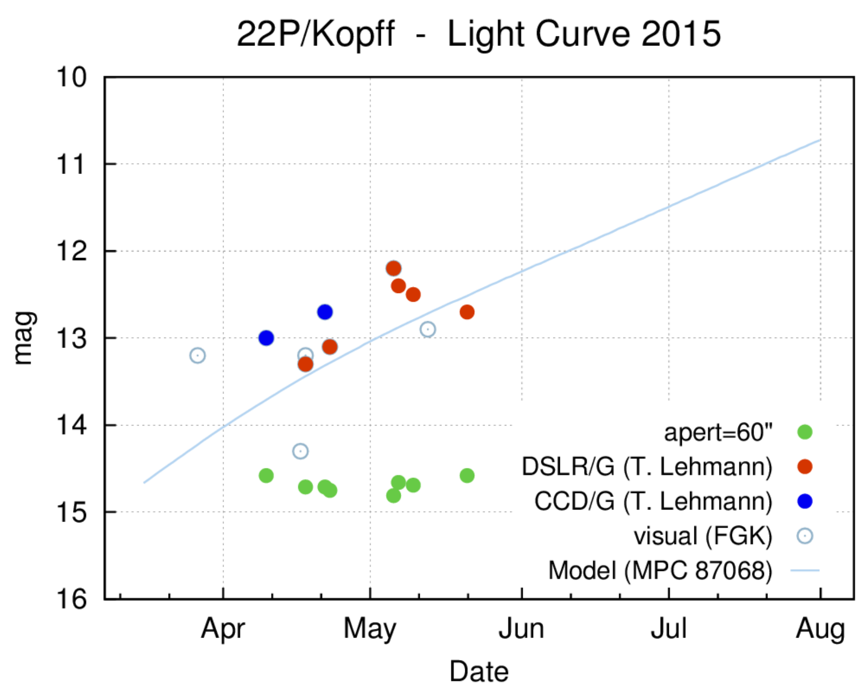


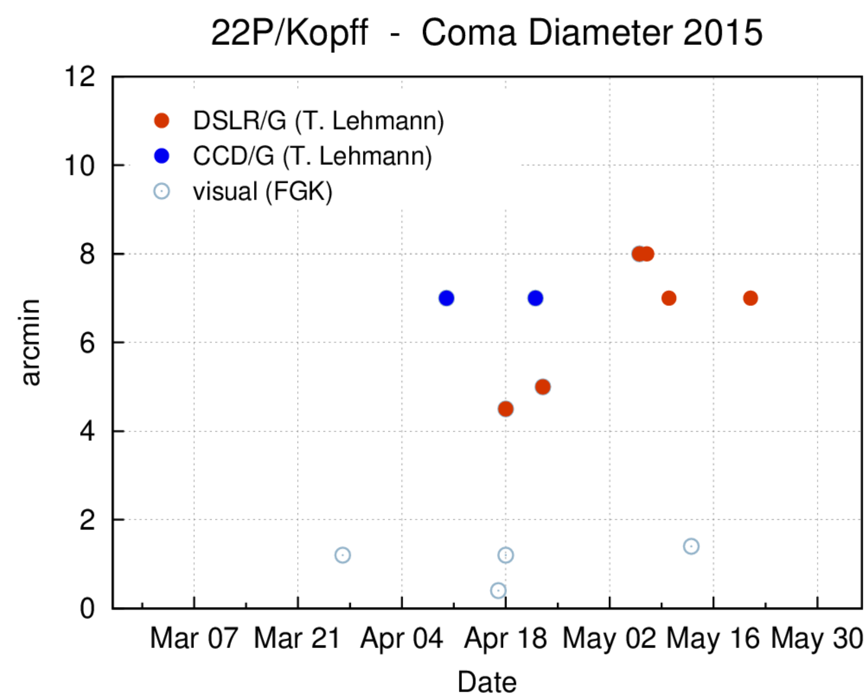
  - geometric projection affects definition of coma size
  - comet tail may contribute to large aperture photometry



32P/Comas Sola - Light Curve 2014 - 2015
P
mag
11
12
13
14
15
16
17
18
19
Aug
Oct
Dec
Feb
Apr
Jun
Date
apert=30"
DSLR/G (T. Lehmann)
CCD/G (T. Lehmann)
visual (ICQ, FGK)
Model (MPC 92276)

- 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, $Af\rho$)
- 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!


Comet C/2014 Q2 (Lovejoy) - 2015-02-19, 20:56 UT, field size 5.3°x2.7°
© 2015, Thomas Lehmann