Comet and NEO hunting (and follow-up) with the *SkySift* pipeline

Paulo Holvorcem Holvorcem Consultoria e Comércio de Software Ltda. [Holvorcem Consulting & Software Ltd.] Porto Seguro, Bahia, Brazil

> 2015 Winter Star Party Camp Wesumkee, Big Pine Key, Florida Feb. 19, 2015

Motivation: Why I came to need a moving object detection pipeline

Comet searches with Charles Juels (1944-2009)



- 200-mm lens + CCD systems on Paramounts (up to 6)
- Image acquisition automated with *Tools for Automated Observing* (TAO)

Motivation: Why I came to need a moving object detection pipeline

Comet searches with Charles Juels (1944-2009)



Sky coverage for 2005 May 25

- 2000+ images per night, each 6 megapixels
- Visual blinking of full frames impractical
- I had a very limited number of Spousal Permission Units (SPUs) to stay up late at night
- Major NEO surveys at the time had their own pipelines but they were not available to others

Initial implementation: late 2004 to early 2005

- As I worked on the first pipeline version, we lost C/2005 A1 to LINEAR (imaged it first, but LINEAR reported it much faster)
- Around March 2005, started searching with the first version of the pipeline:
 - Detecting objects in near real time (no more reporting delays!)
 - Fast blinking of small subframes around detections (no more long hours of blinking full images!)
 - Checking only unidentified objects (no more distraction with known asteroids and comets!)

First discovery, after 3 months of searching

C/2005 N1 (Juels-Holvorcem)

- Magnitude 14.5
- Solar elongation 47 degrees
- 19 degrees from Milky Way (crowded field)
- Comet eluded detection until we discovered it



Increasing detection efficiency with image subtraction

- Involvement between moving objects and stars may prevent their automated detection
- Problem is more acute in crowded fields near the Milky Way plane, a prime area for comet/NEO discovery (less/no competition)

Increasing detection efficiency with image subtraction



- These are the discovery images of 2012 WX32 (mag. 18.2, 55 deg from 100% illuminated moon, 18 deg from the Milky Way plane),...
- soon recognized as comet P/2012 WX32 (Tenagra),...
- later linked to 2003 WZ141 (a LINEAR discovery) and...
- to 1931 AN (Clyde Tombaugh's long-lost comet),
- now known as 274P/Tombaugh-Tenagra

Next major application of the pipeline (now named "SkySift")

- Comet/NEO/asteroid searches with Tenagra Observatory's 0.41-m f/3.75 astrograph (observers: myself and Michael Schwartz)
- 4096 x 4096 pixel CCD
- 1.39 x 1.39 deg field of view
- Mag. 20.3 in 150 s



- First searches: May-June 2010
 - Discovered NEOs 2010 KA8 and 2010 LN14
- Next campaign: May-June 2011
 - Discovered NEOs 2011 KP17, 2011 KF4
 - Discovered comet C/2011 K1 (Schwartz-Holvorcem): mag. 19.2, 14 deg from Milky Way plane



- Dark blue = Tenagra search fields
- Red circle shows discovery position of C/2011 K1

• Discovery images of C/2011 K1: image subtraction was crucial:



• Discovery images of C/2011 K1: image subtraction was crucial:



- 2012-2013 observing season (October to June):
 - Seven NEO discoveries
 - 2012 TV came within 255,000 km from earth two days after discovery (moving at 300 deg/day at closest approach)
 - Two unusual asteroid discoveries
 - Six comet discoveries, including:
 - P/2012 TK8 (Tenagra): mag. 19.6, reported among many asteroid discoveries, coma recognized by Pan-STARRS, quasi-Hilda orbit
 - P/2012 WX32 (Tenagra), later renamed 274P/Tombaugh-Tenagra
 - And...

• C/2013 C2 (Tenagra): mag. 19.1 – Centaur with cometary activity (like Chiron), perihelion at 9.1 AU (near Saturn's orbit)



- 2013-2014 observing season (October to June):
 - Four comet discoveries, including:
 - C/2014 B1 (Schwartz): mag. 19.9, perihelion at 9.6 AU (near Saturn's orbit)
 - Fifth highest known comet perihelion distance (as of Feb. 2014)
 - One Centaur object without cometary activity (so far):
 - 2013 XZ8: mag. 20.0, discovered at 12.1 AU from the Sun (beyond Saturn's orbit)



New SkySift users: SONEAR and ISON-NM

- Southern Observatory for Near Earth Research (SONEAR)
 - First NEO/comet survey using telescopes located in Brazil
 - Team of three amateur astronomers (Jacques, Pimentel, Barros)
 - Two telescopes equipped with 4096 x 4096 CCDs:
 - S1: 0.45-m f/2.9 reflector
 - S2: 0.28-m f/2.2 astrograph
 - Image acquisition automated with TAO
 - Moving object detection automated with SkySift
 - Fully operational since January 2014



SONEAR

- 2014 campaign:
 - Two comet discoveries (first made with telescopes in Brazil since at least the 19th century):
 - C/2014 A4 (SONEAR)
 - C/2014 E2 (Jacques) reached binocular visibility



SONEAR

- 2014 campaign:
 - 11 NEOs (including two PHAs):



2014 KP4 (PHA) on 2014 May 20 Mag. 16.2 2.87 deg/day

- 2015 campaign (so far):
 - 2015 BL311: PHA, may come within 0.05 AU from Mars, Earth, Venus, and Mercury!

ISON-NM (Leonid Elenin, Moscow)

- 0.4-m f/3 telescope at New Mexico Skies
- Observing remotely from Moscow
- Moving object detection with *SkySift*
- Comet discovery less than two months after starting to use *SkySift*:
 - P/2014 X1 (Elenin): mag. 18.2, 2 deg from Milky Way plane
- NEO discovery shortly thereafter:
 - 2014 YU43: mag. 19.2, 2 deg from Milky Way plane

Yuri Petrunin (Telescope Engineering Company – TEC)

- New TEC300VT 0.3-m f/1.44 catadioptric telescope
- 4096 x 4096 pixel CCD
- 5 x 5 deg field of view
- Scale: 4.36"/pixel
- Test searches at WSP 2015:
 - Image acquisition with TAO
 - Moving object detection with *SkySift*
- Mag. 18.2 in 60 s, 370 sq. deg/h (3 revisits/field)
- Mag. 17.0 in 8 s, 1010 sq. deg/h (3 revisits/field)





C/2014 W6 Mag. 17.5 0.4 deg/day

Discovery statistics

- *SkySift* was used in about half of recent amateur comet discoveries:
 - Amateur comet discoveries, 12/jun/2012 to present (orange = using SkySift):

C/2012 S1 ISON		C/2013 V2	Borisov
P/2012 TK8 Tenagra		C/2013 V3	Nevski
P/2012 T7 Vorobjo	I	C/2013 V5	Oukaimeden
P/2012 WX32 Tomba	augh-Tenagra	C/2014 A4	SONEAR
C/2013 C2 Tenagra		C/2014 B1	Schwartz
P/2013 CE31M MOS	5	C/2014 E2	Jacques
C/2013 D1 Holvorc	em	C/2014 F2	Tenagra
P/2013 EW90 Tenag	ra	C/2014 Q2	Lovejoy
C/2013 E2 Iwamoto)	C/2014 Q3	Borisov
C/2013 G9 Tenagra		C/2014 R1	Borisov
C/2013 N4 Borisov		P/2014 X1	Elenin
C/2013 R1 Lovejoy			
P/2013 T2 Schwart	Z	Total: 25	

C/2013 U2 Holvorcem

Using SkySift: 13 (52%)

Astrometric follow-up work with SkySift

- *SkySift* can also be used in NEO/comet/asteroid follow-up observations
- Images tracked on a moving target can be processed by *SkySift*:



2014 GA on 2014 Apr. 6: Mag. 20.9 5.9 deg/day Tenagra 0.81-m Ritchey-Chrétien

Astrometric follow-up work with SkySift

- Tenagra II 0.81-m telescope (Sept. 2013 to Apr. 2014):
 - Using 50% of telescope time
 - 3,153 astrometric measurements of NEOs down to mag. 21.7
 - Recovered 26 single-opposition NEOs (often requires searching for the object along a calculated "uncertainty line")

SkySift is available for licensing

- If you would like to try *SkySift* on your NEO/comet/minor planet search or follow-up images, and/or to purchase a license, please contact me (holvorcem@mpc.com.br)
- List of most interesting discoveries using SkySift is kept at: http://sites.mpc.com.br/holvorcem/obs/SkySift_disc.html

Thanks for your time!