



# Analysis of Comet Tails for Turbulence in the Solar Wind

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- Hometown: Grimes, Iowa
- Northwestern University – Evanston, IL
  - Rising Junior
  - Majors: Integrated Science

Physics and Astronomy

Earth and Planetary Sciences

- Research Experience
  - Assistant to Jason H. Steffen – CIERA
    - Simulating planetary ejecta and studying mass transfer of orbital bodies with various initial orbital conditions



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- Turbulence Theory

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- Why Comets??

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- PDL

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- HI-1 Image Processing

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- Tracking Tool

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- Verifying Machholz

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- Lovejoy

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- ISON

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- Encke

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- Velocity Analysis

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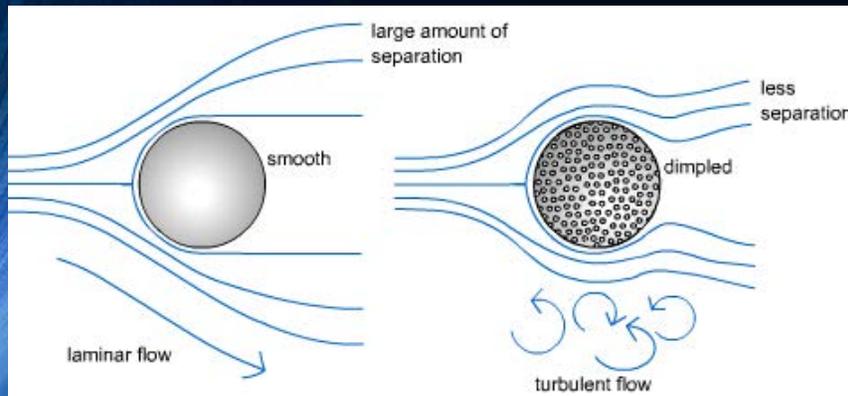
- $R^2$  Analysis

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- Conclusions

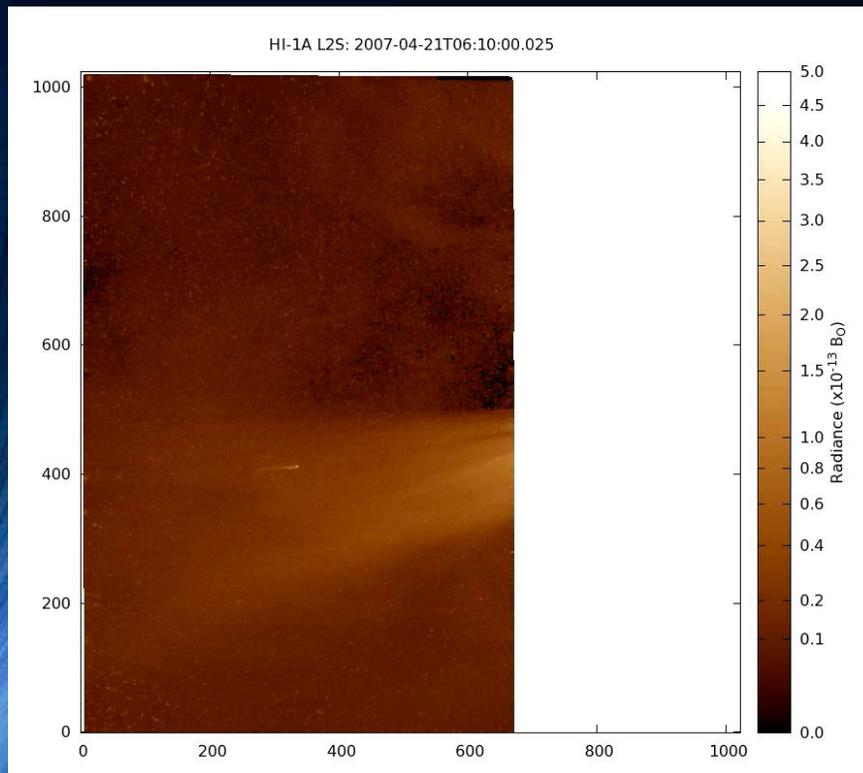
# Turbulence

- Type of fluid flow containing chaotic property changes
- Features: Irregularity, Diffusivity, Rotationality, Dissipation
- Eddies contain most of the kinetic energy of the turbulent motion
- Eddies have defined length scales



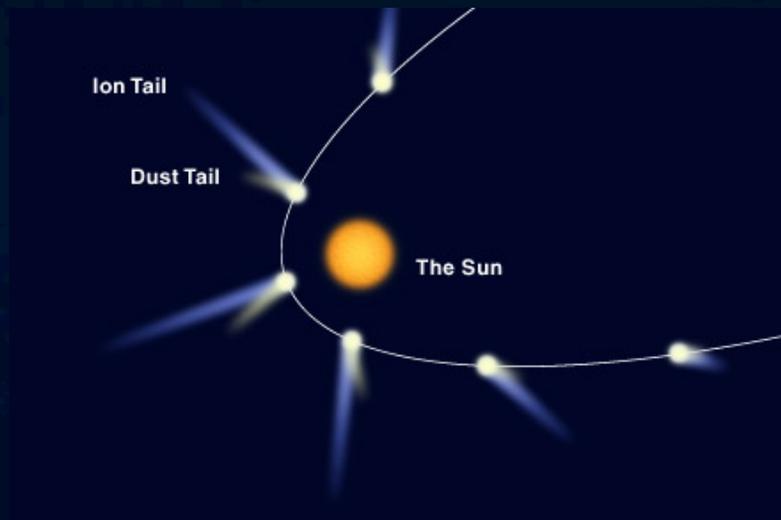
- “Chaos isn’t a pit. Chaos is a ladder.”  
– Littlefinger
- The Kolmogorov length scale is the scale where there is viscous dissipation of energy
- Ex. Atmospheric circulation, cigarette smoke, flow over a golf ball

# Solar Wind Gusts

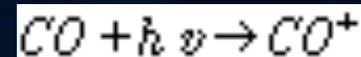


- Solar wind has speeds between 200 and 800 km/s
- Wind is not constant on even short periods much like Earth's winds
- Causation of gusts?
  - From the source
  - Processing of the wind (turbulence)
- “I’m an agent of chaos, and you know the thing about chaos? It’s fair.” – The Joker
- Need for CME Breakup predictions

# Sungrazing Comets



- 1488 known comets come within ~12 solar radii <sup>1</sup>
- Close to the sun comets develop long ion tails that can extend over 3.8 AU <sup>2</sup>
- Neutral gas species in coma are ionized by solar UV photons

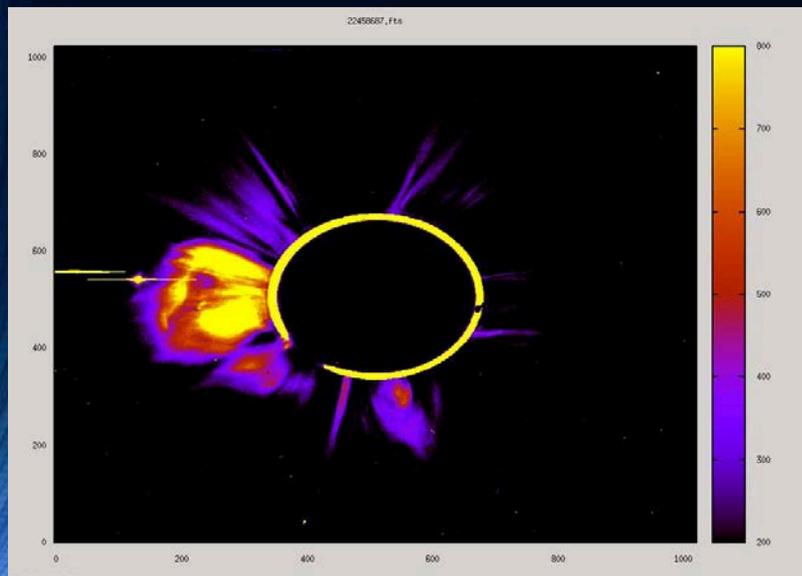


- Ions are carried by the magnetic field of the solar wind
- Wind causes ropes, knots, disconnections, and streamers
- “In-Situ Probes are like studying the human body with an electron microscope” -Craig

1. JPL Small-Body Database [http://ssd.jpl.nasa.gov/sbdb\\_query.cgi#x](http://ssd.jpl.nasa.gov/sbdb_query.cgi#x)

2. Yeomans, Donald K. (2005). "Comet". World Book Online Reference Center. World Book

# Perl Data Language



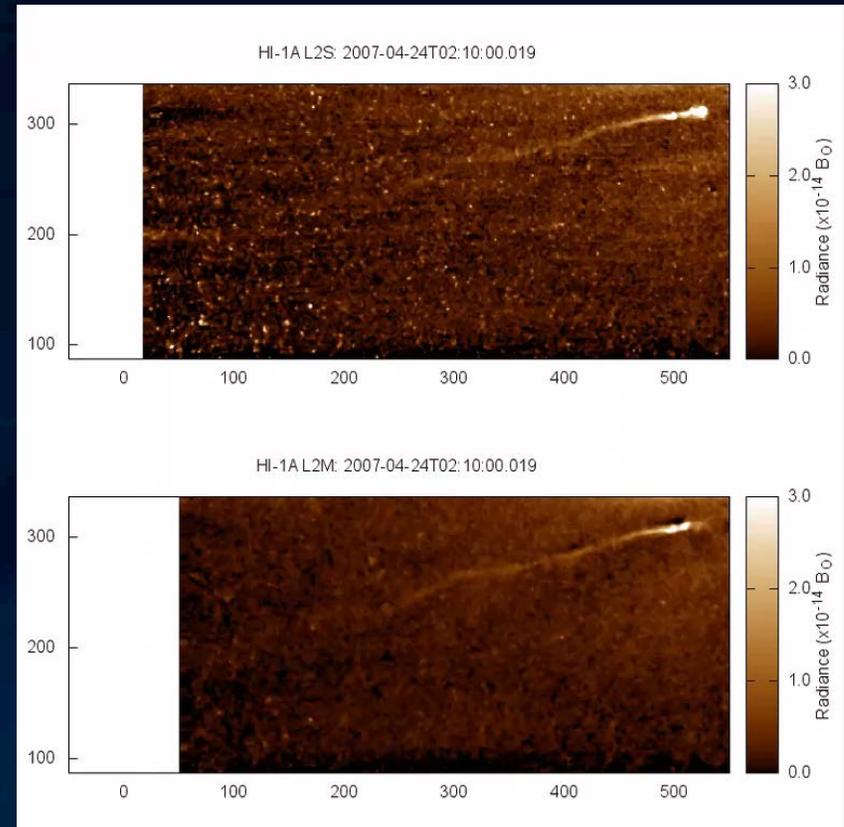
- Gives Perl ability to efficiently manipulate large N-dimensional arrays
- Allows greater indexing and vectorization than MATLAB or IDL

$$\text{Ex. } 3 * (1,2,3,4) = (3,6,9,12)$$

- Supports FITS
- Includes interactive shell
- FREE!!!

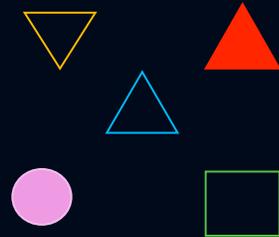
# Image Processing

- Using STEREO HI-SECCHI 1 images large field of view with good resolution
- Batches of images help remove background
  1. Remove fixed patterns
  2. Co-align starfield
  3. Background subtract
  4. Remove 2<sup>nd</sup> order zodiacal light
  5. Moving object filter



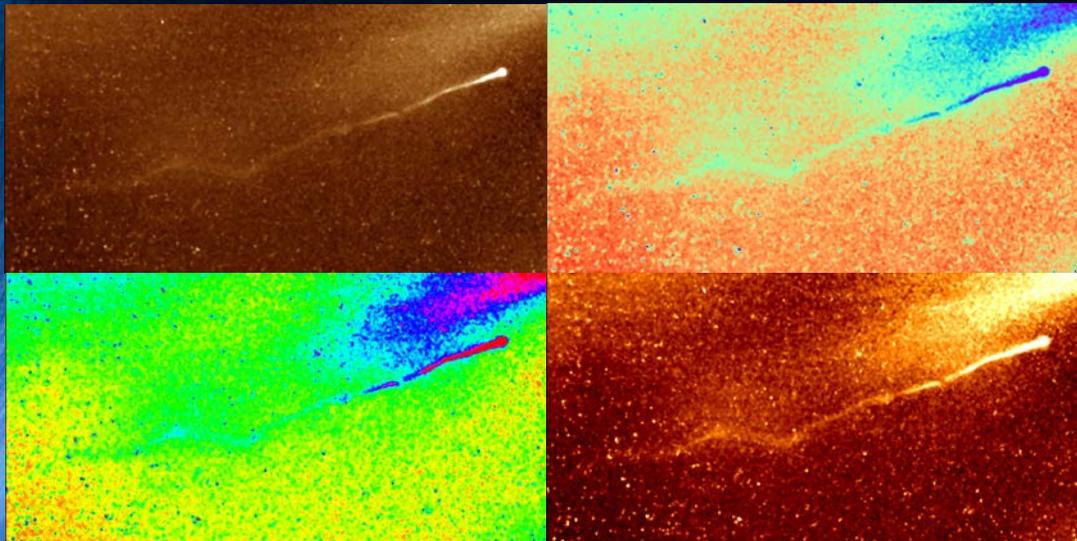
# Tracking Tool

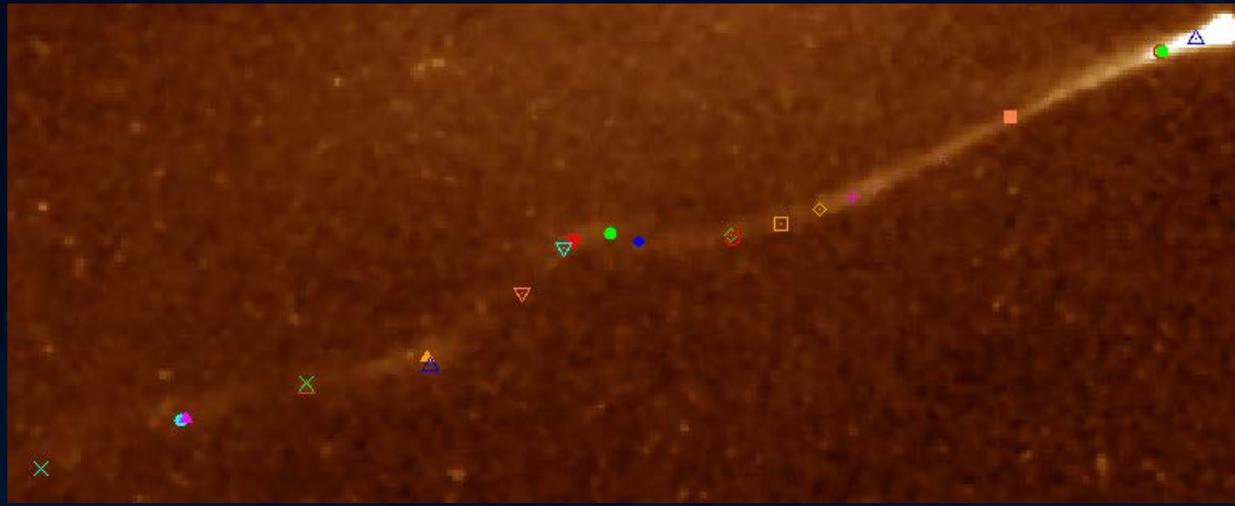
- Gnuplot tool to place test particles on tail perturbations
- Track comet head and keep justified in frame of view
- Turn motion filter on and off
- Adjust the brightness



## My Additions

- Change color pallet.  
Sepia, Rainbow, Heat, Wheel
- Sort-Track function
  - Removes undefined
  - Orders tracks
- Small Bug Fixes





## Human Data Collection

- All test particles are being tracked with the eye
- Craig tracked 170 test particles on Comet 96P/Machholz
- 9 out of 13 comparable in first test
- Second test
  - 20 out of 31 good/perfect
  - 7 out of 31 'ok' may skip between 2 tracks mostly near the head

# Comet Lovejoy (C2/2011 W3)

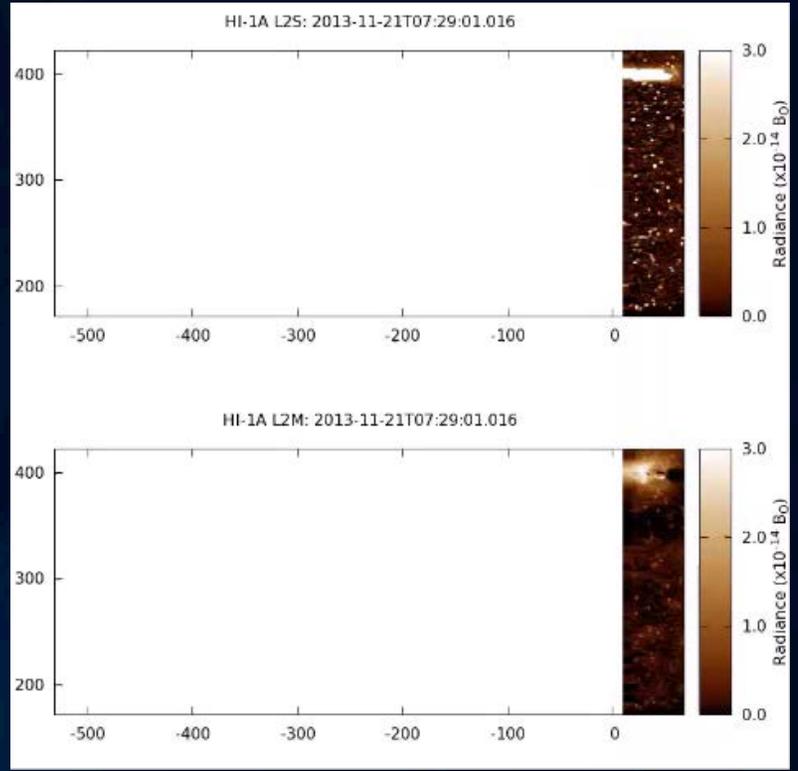


- The Great Birthday Comet (SOHO's 16<sup>th</sup>)
  - Dec 2011 12<sup>th</sup>-22<sup>nd</sup>
- As bright as Venus<sup>1</sup>
- Exit 3 orders of magnitude brighter than everything else
  - Pixel Overload
- Entry only 2 days
- 40 traces but short

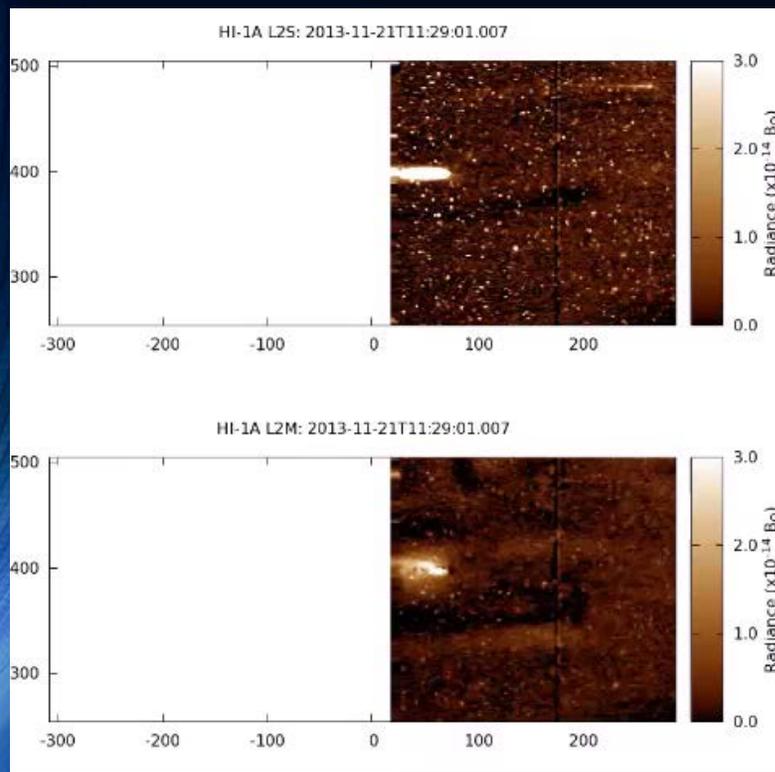
1. Phillips, Tony (15 December 2011). "What's Up in Space". *Spaceweather.com*

# Comet ISON (C/2012 S1)

- Nov 2013 20<sup>th</sup>-29<sup>th</sup>
- Media reported that it may become brighter than the Moon
- Never became bright enough for the naked eye
- 50 traces
- Difficulties
  - Exhibits few fluctuations
  - Projection Angle
  - Tracking near head

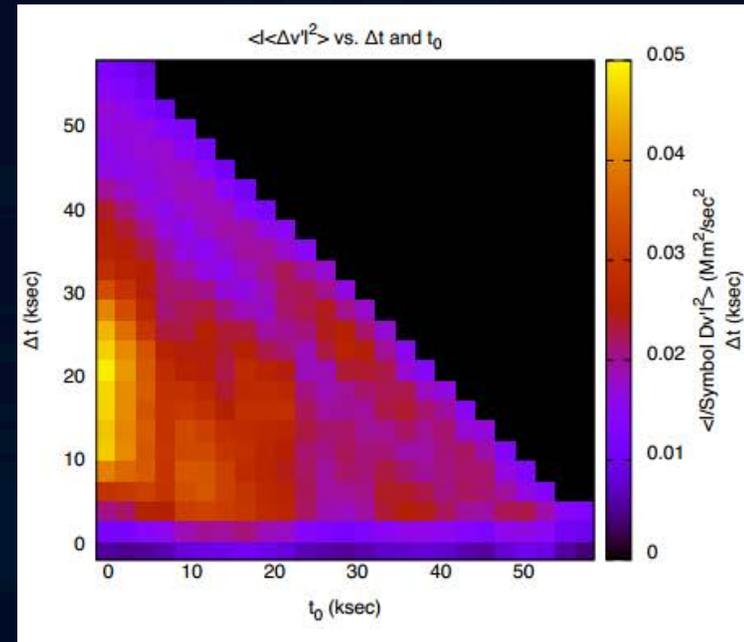
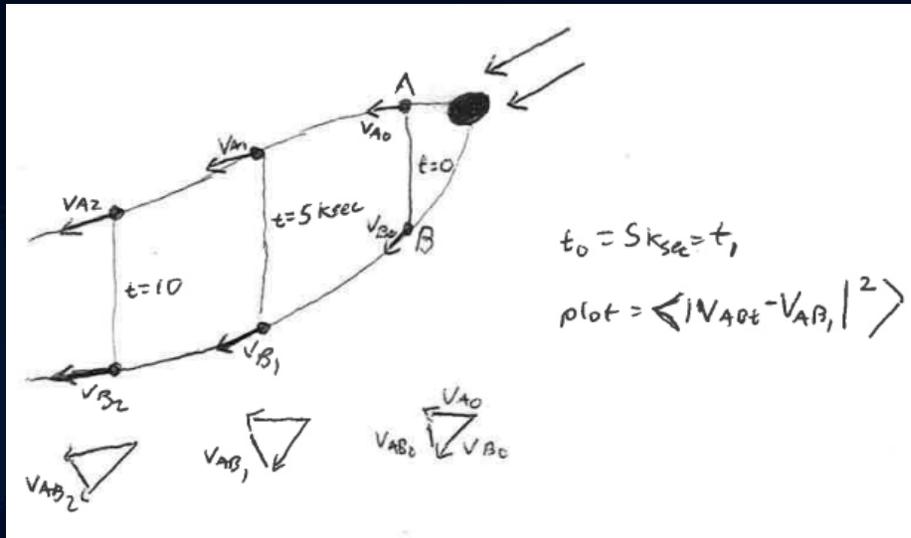


# Comet Encke (2P/Encke)

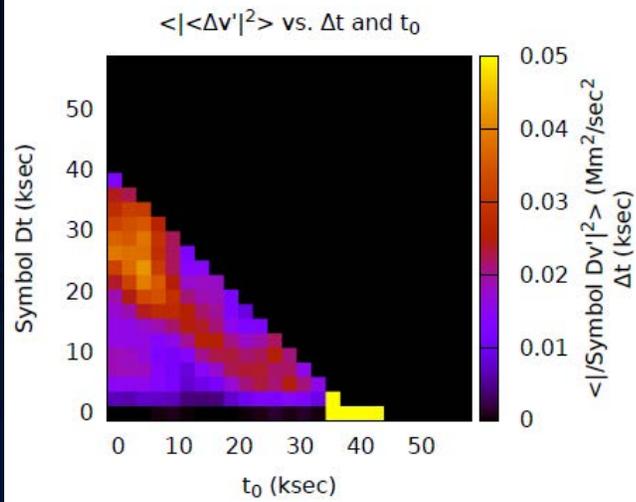


- Nov 2013 18<sup>th</sup>-29<sup>th</sup> with ISON
- Periodic every 3 years
- Close approaches to Earth happen every 33 years
- 44 traces
- Difficulties
  - Farther away than ISON
  - Crosses ISON
  - Solar Maximum

# Velocity Analysis

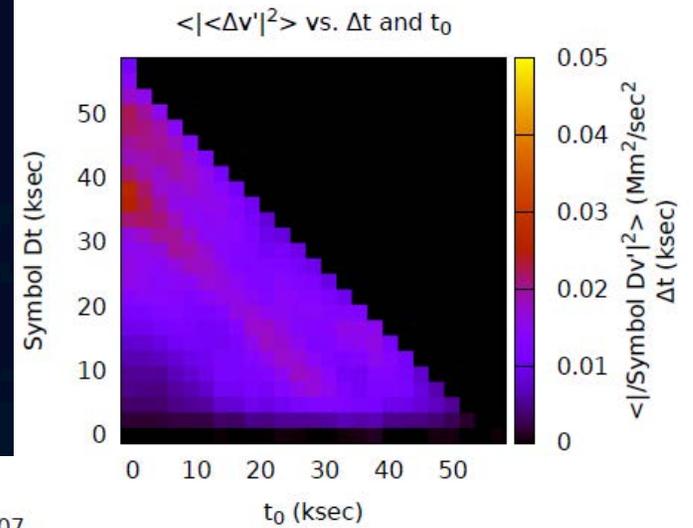


- Analyzed the velocity of test particles over time many different tests
- Above is map of the evolution of difference in relative velocity of two points
- By examining  $t_0=0$  we find when the particles have been accelerated to wind speeds
- We see further increase in the difference in velocity after initial acceleration

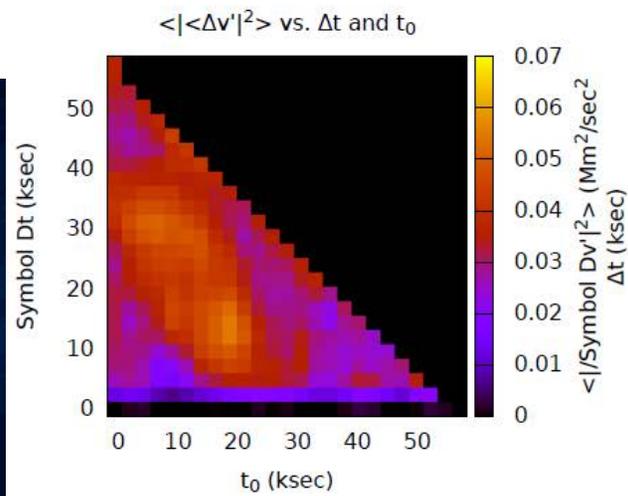


Lovejoy

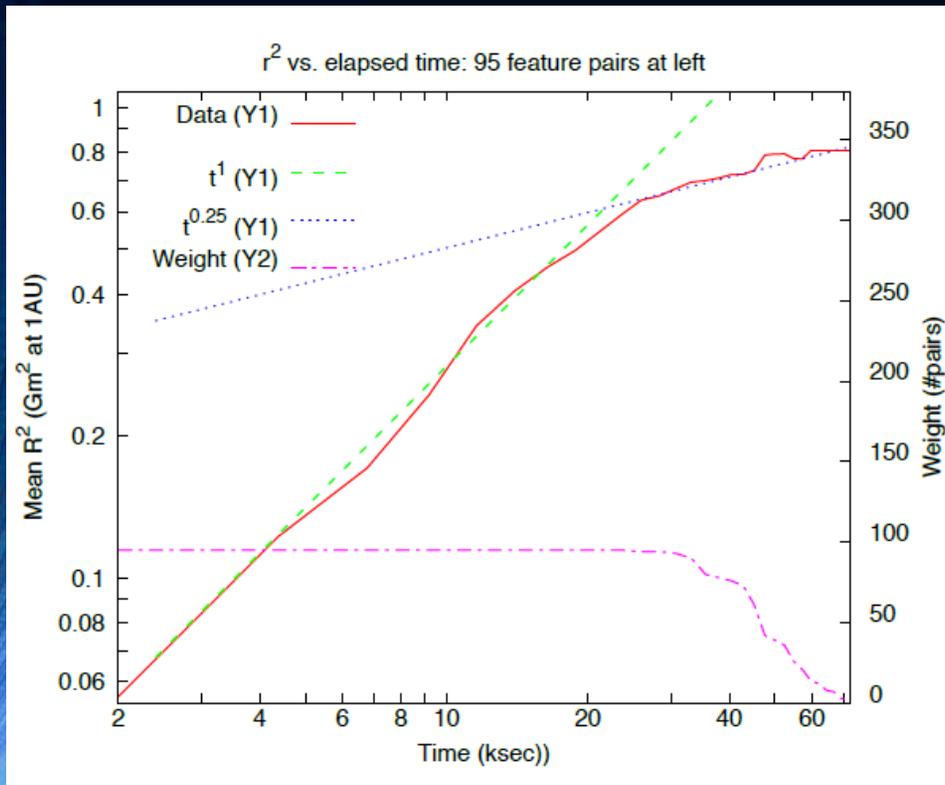
ISON



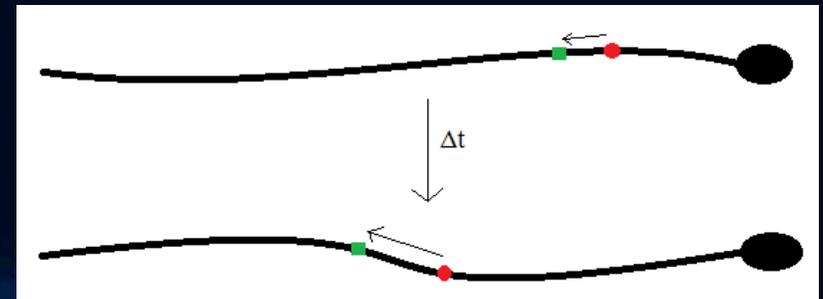
Encke

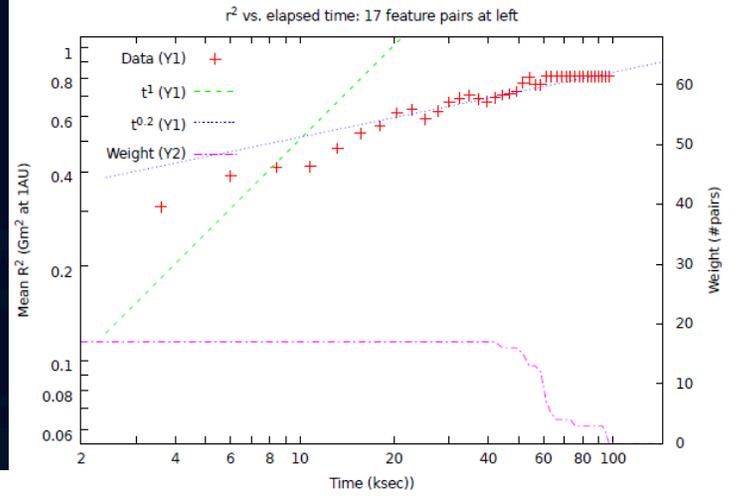
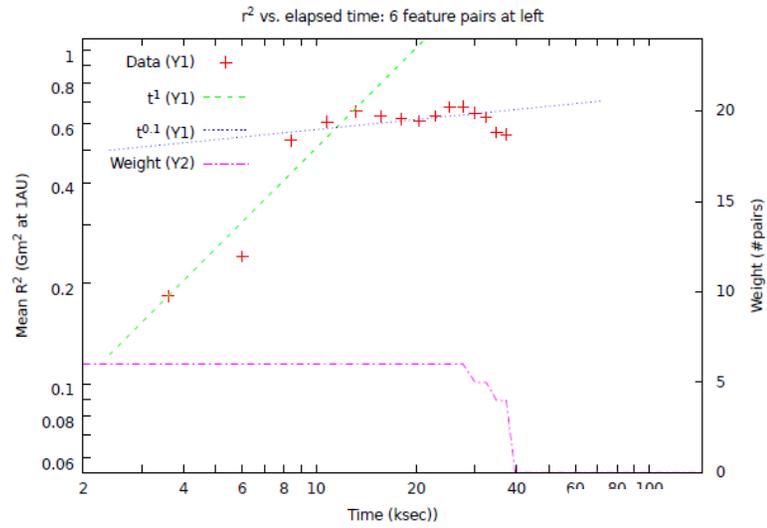
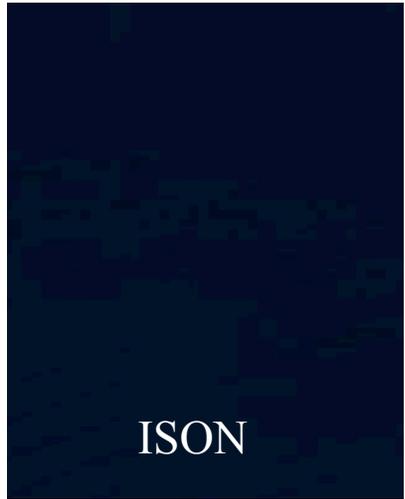


# Structure Function

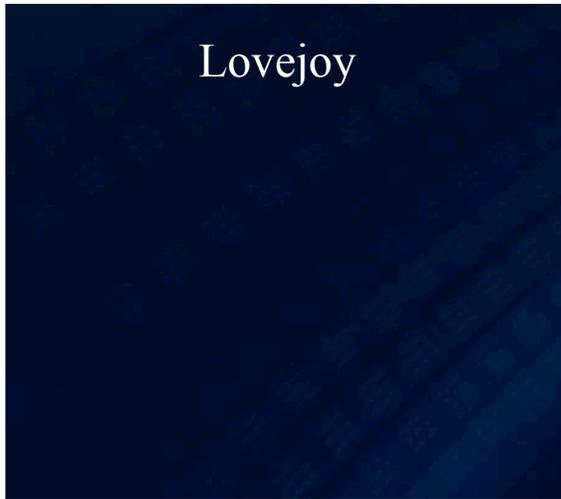
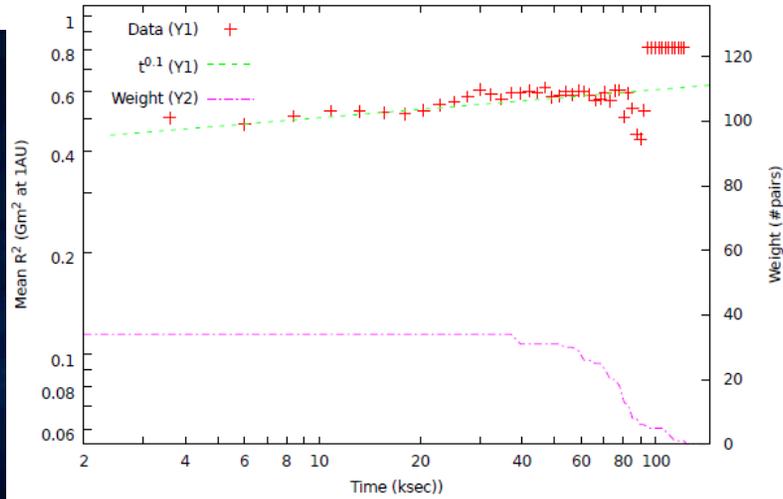


- SF is a statistical test of particle motion and memory
- $R^2 = \|\vec{dp}_1 - \vec{dp}_2\|^2$
- Difference in the displacement vectors for a given  $\Delta t$
- Log-Log Plot exponent corresponds to slope
- Quadratic – Free Propagation  
Linear – Random Walk  
Sub Linear – Confined (Eddies)



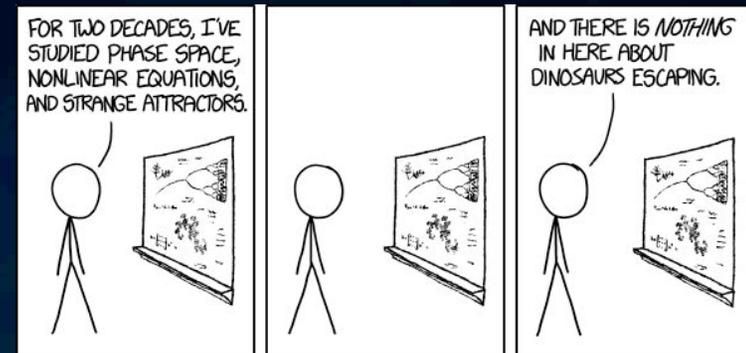


r<sup>2</sup> vs. elapsed time: 34 feature pairs at left



# Conclusion

- With better background subtraction and our tracking tool we are able to track perturbations in the comet tail and hence test particles in the solar wind for over 20 hours (Some up to 30+)
- The structure function qualifies the existence of turbulence in the solar wind exhibited in comet Machholz
- Although inconclusive on their own comets Lovejoy, ISON, and Encke support that the Machholz conclusions are repeatable with stricter comet selection.
- Ideal comets:
  - Large Tail fluctuations throughout HI-1
  - Not during solar maximum
  - No fantail or breakup
  - Comet head brightness comparable to max f-corona
  - Projection Angle: points need visible movement



Xkcd.com

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