Meteor shower identification and characterization with Python

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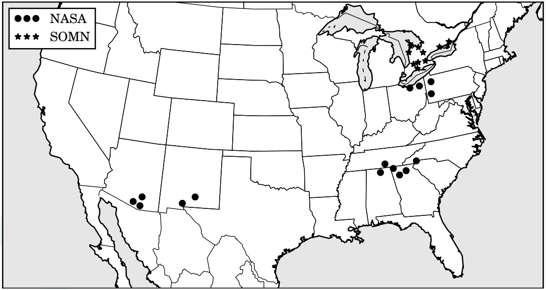
Outline

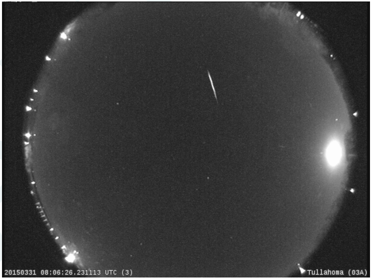
NASA's Meteoroid Environment Office (MEO) is the NASA organization responsible for meteoroid environments pertaining to spacecraft engineering and operations.

Fireball Networks



- NASA All Sky Fireball Network
- Southern Ontario Meteor Network (SOMN – UWO)

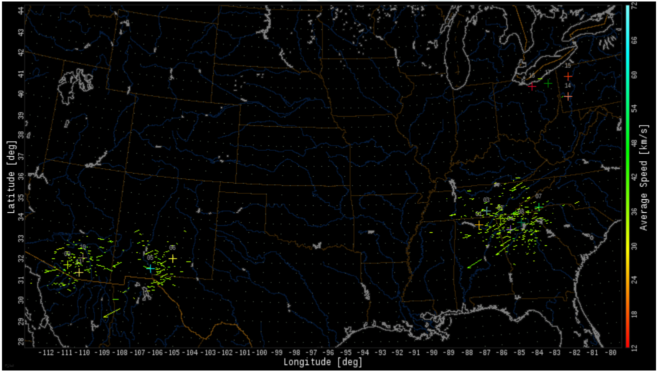
Events



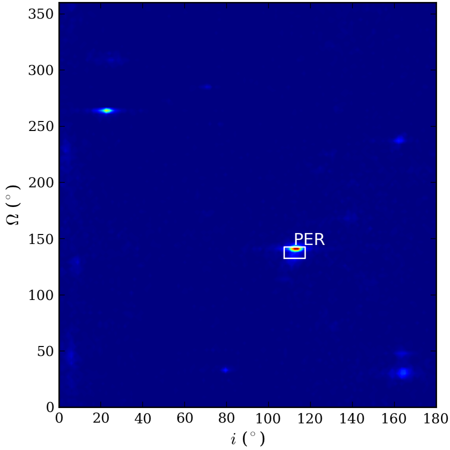
- Overlapping fields of view for trajectory triangulation
- Automatic meteor detection using ASGARD (Weryk et al. 2008)

Daily reports

- Radiant, speed, and atmospheric height
- Geocentric trajectory and heliocentric orbit
- Categorized using shower surveys (IAU MDC, Brown et al. 2008)



Shower identification using orbital angles



- Need agnostic approach for new/outbursting showers
- Need thorough shower removal
- Showers show up clearly in orbit angles, sometimes more obviously than in radiant space (KCGs, ZCSs)

Shower membership using orbital similarity

- Drummond (1981) D parameter:

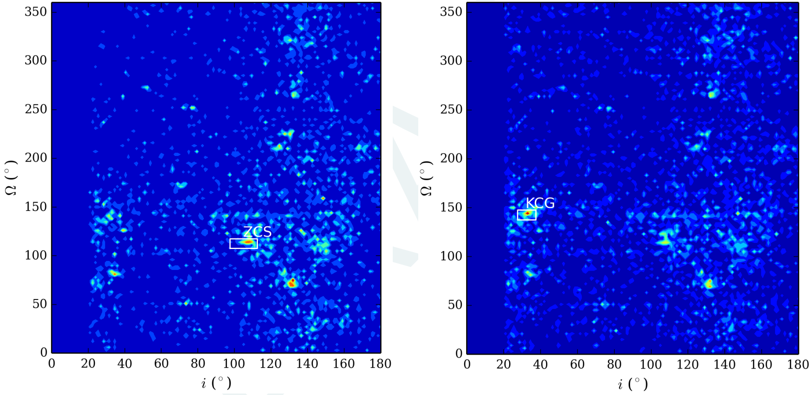
$$D^2 = \left(\frac{\Delta q}{\Sigma q}\right)^2 + \left(\frac{\Delta e}{\Sigma e}\right)^2 + \left(\frac{I_{a,b}}{180^\circ}\right)^2 + \bar{e}^2 \left(\frac{\theta_{a,b}}{180^\circ}\right)^2$$

- Is often used for both parent body identification and meteor classification
- We Monte-Carlo meteor orbits using uncertainties and look for overlap with showers

Algorithm

1. Python code:
   a. Bin meteors by date, i, and Ω
   b. Take most populated bin and compute average orbit.
      - Weight meteors by $1/D$ and iterate.
   c. Compare to list of showers. If there is no match, output bin meteors and exit.
   d. Assess shower membership using D for each meteor, taking uncertainties into account (5% overlap counts as membership)
   e. Remove shower meteors, go to a.
2. Inspect for similarity to known shower
3. Add shower to list of showers. Go to 1.

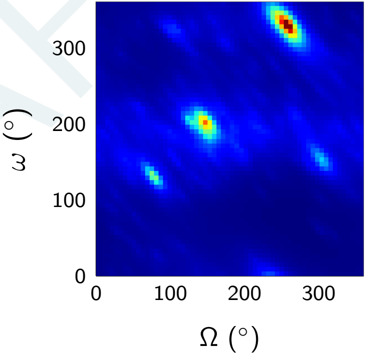
2014 κ Cygnid outburst



Work in progress: D weighting

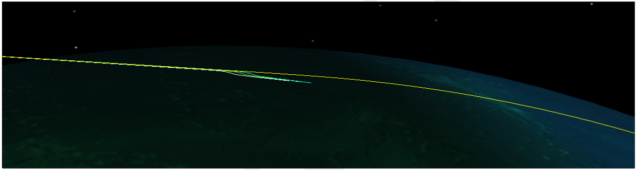
- Detects major showers (and outbursts!)
- Identified minor showers that made significant contributions (e.g., ZCS)
- Ongoing:
  - Use D to detect orbit clusters
  - Quantify shower membership probability

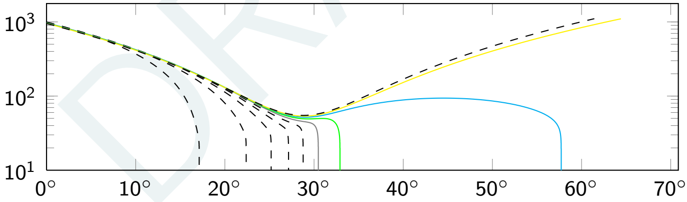
$i = 39°$



Atmospheric trajectories of meteors

STK



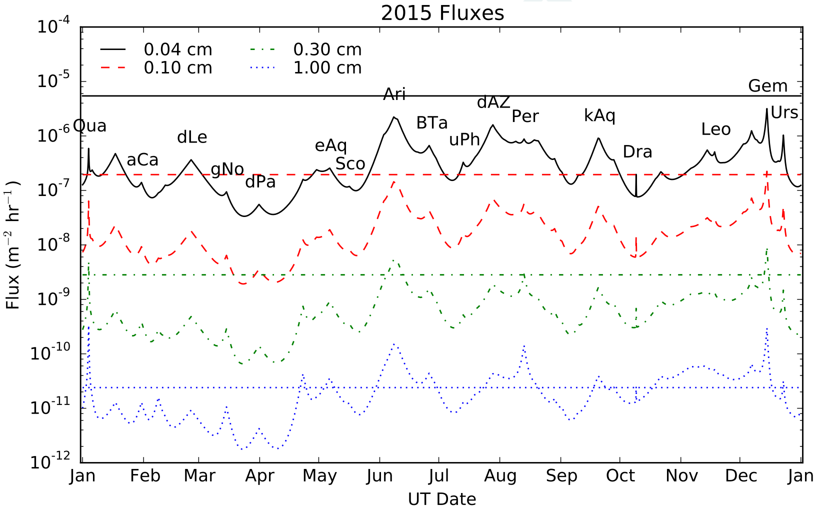


Atmospheric trajectories of meteors

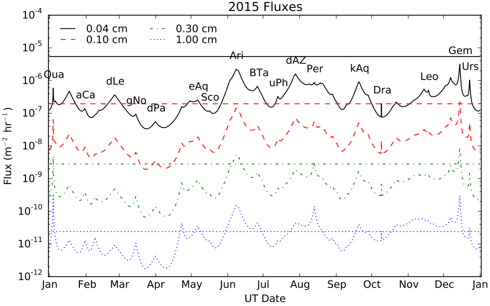
Uses Scipy's ODE modules:

```
# ---------------------------------------------------------------
# Calculate trajectory through atmosphere from orbit

def get_traj(xv0, pm, cd, dt=0.1, ablate=False, frag=False) :

    # Do the integration, stop with landfall or escape
    r = ode(derivs).set_integrator('vode', method='bdf',
            with_jacobian=False)
    r.set_initial_value(xv0, 0.0)
    r.set_f_params(pm, cd, ablate)

    # Integrate while in atmosphere and at least a cm in diameter
    ts, ls, ps, hs, xvs, dt = [], [], [], [], [], 0.1
    sz = r.y[0]
    while r.successful() and (0 < h_r(r.y) < 1.1*h_atmo) and (r.y[0] > minsz) :

        if r.y[0] - sz > 1.0e-10 :
            print sz, r.y[0]
            raise Exception('meteoroid has grown!')
```

Annual shower forecasts



Annual shower forecasts



- Translated from IDL to Python, using array broadcasting to eliminate FOR loops
- New version is significantly faster
- Python version of VSOP87 solar longitude calculation

Comet/meteoroid ejection model

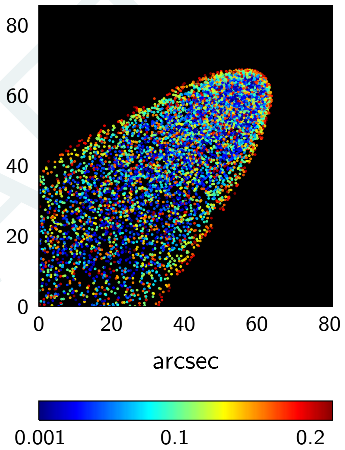
1. Comet state vector + meteoroid ejection
2. Gravity + radiation pressure:

$$\vec{F} = -\frac{GMm}{r^2}(1-\beta)\,\hat{r}$$

3. Solve Kepler's equation (Gooding & Odell, 1988)

→ 10^6 particles in seconds.

4. JPLEphem, pyfits, astropy.wcs to compare with images



$\beta \propto 1/\rho s$