Fireballs and meteor showers as seen by the NASA All Sky Fireball Network

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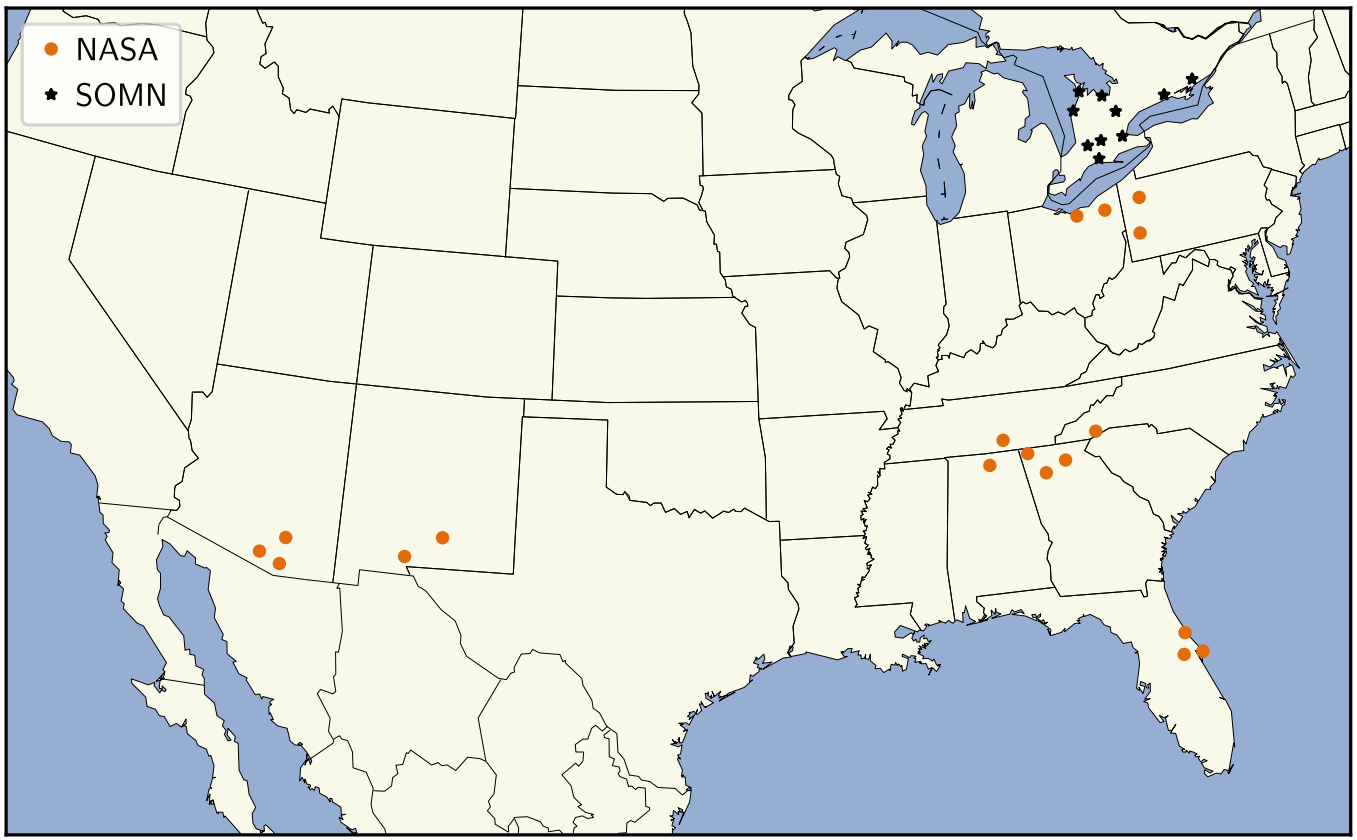
Outline

- Overview of all-sky network and data
- Discussion of shower and sporadic meteors
- Past and current projects that use all-sky data
- Potential student projects

All-sky meteor camera and sample image

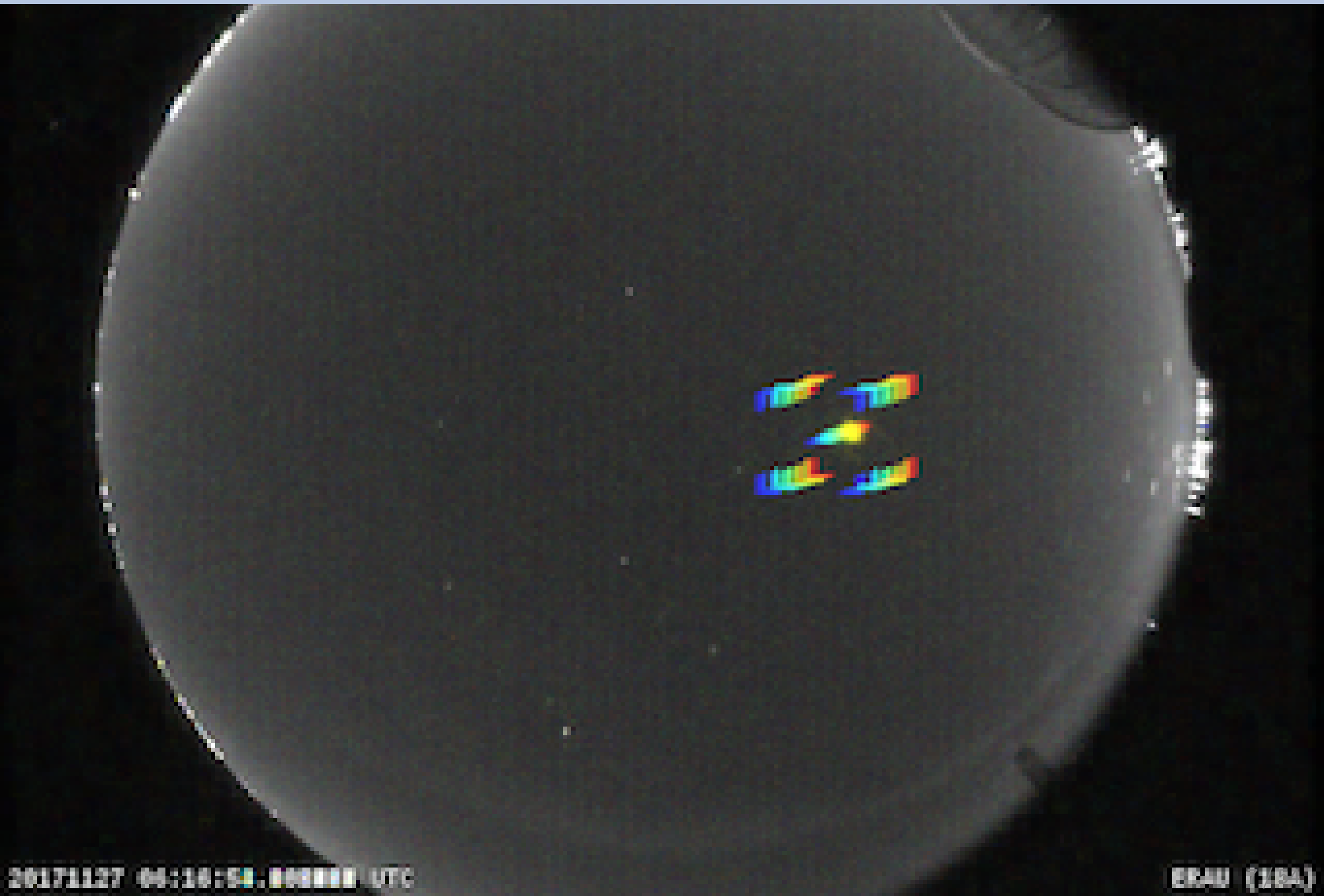
Map



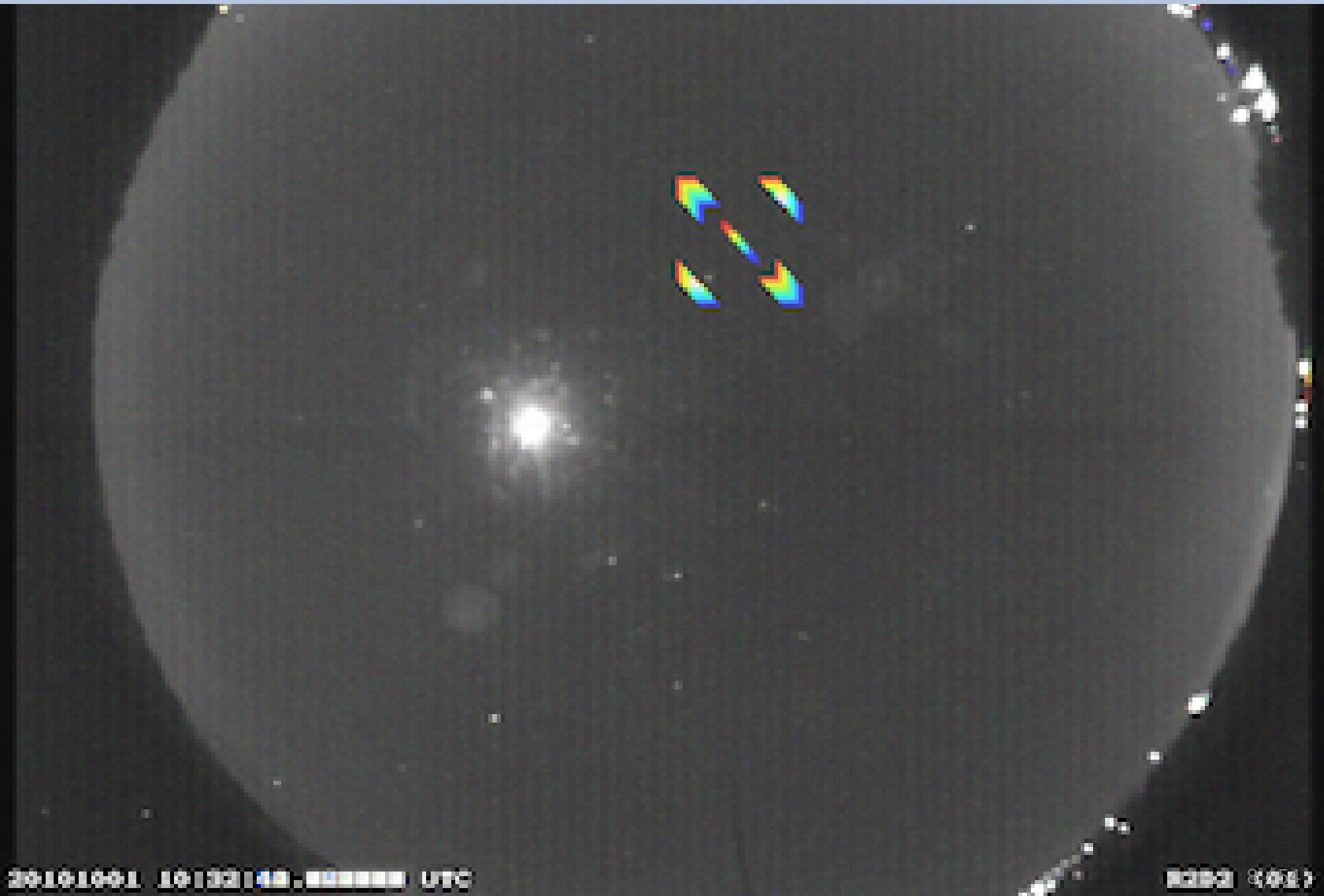
Meteor detection

Meteor detection

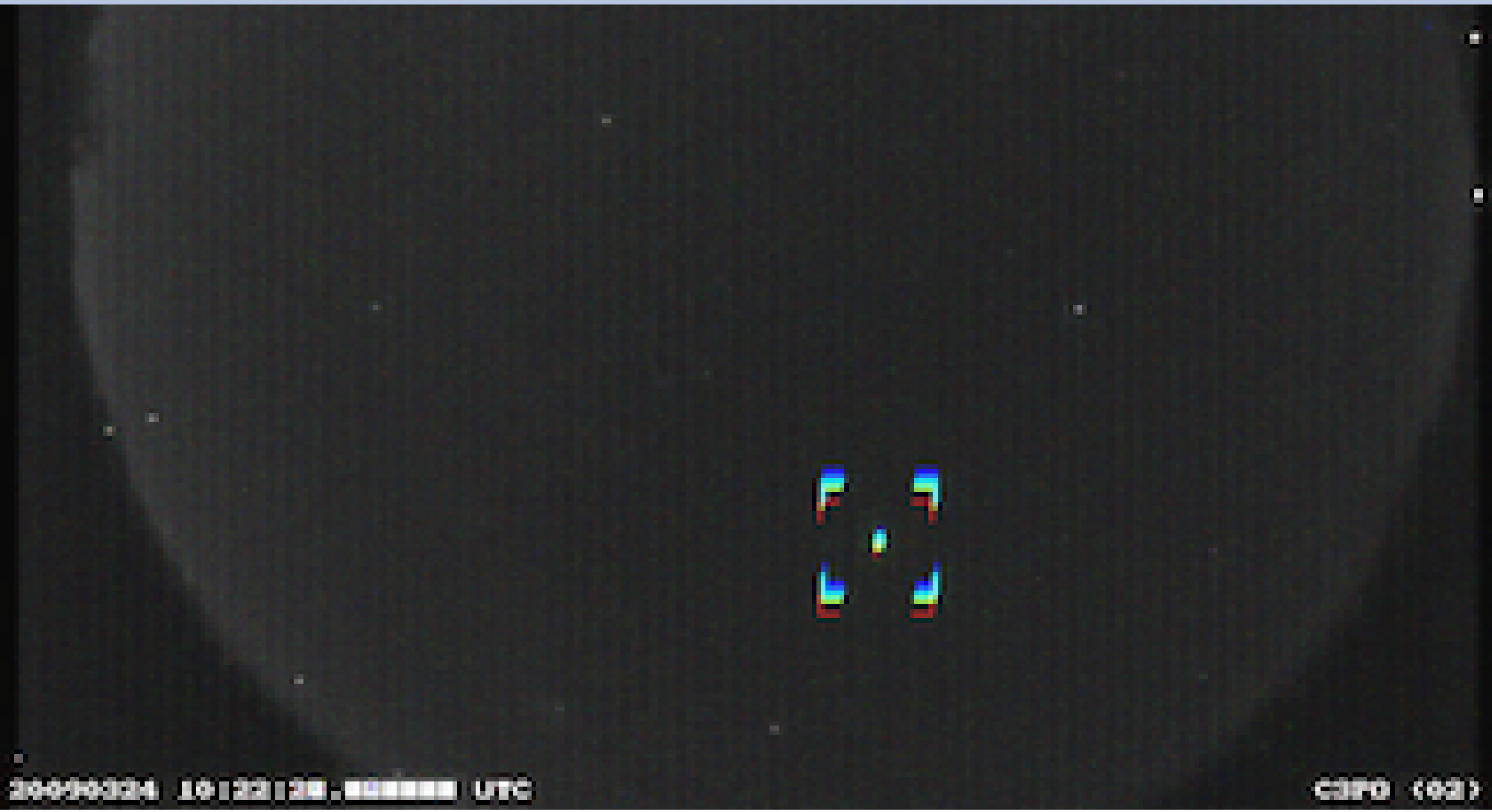
Meteor detection



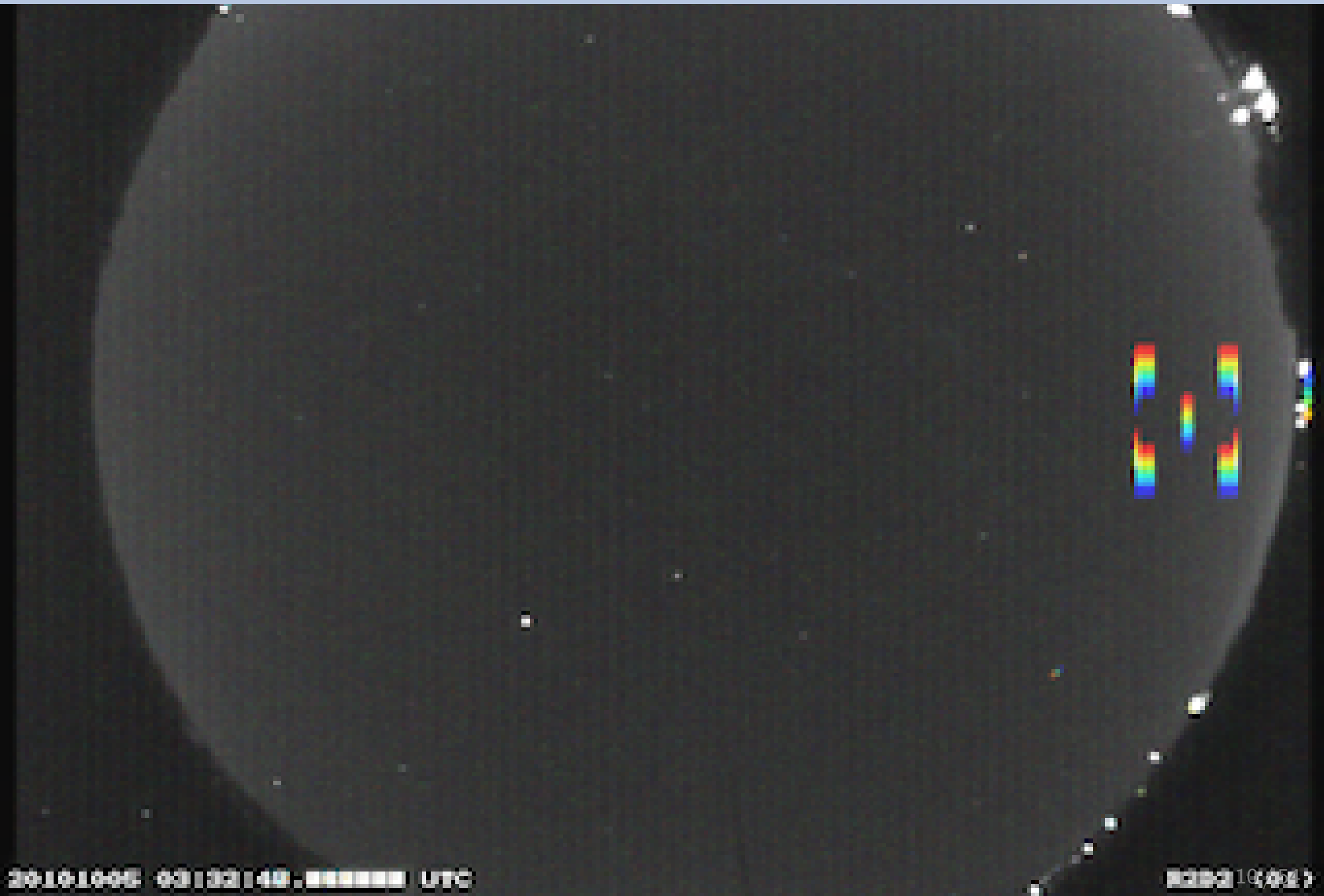
False positives: satellites (ISS)



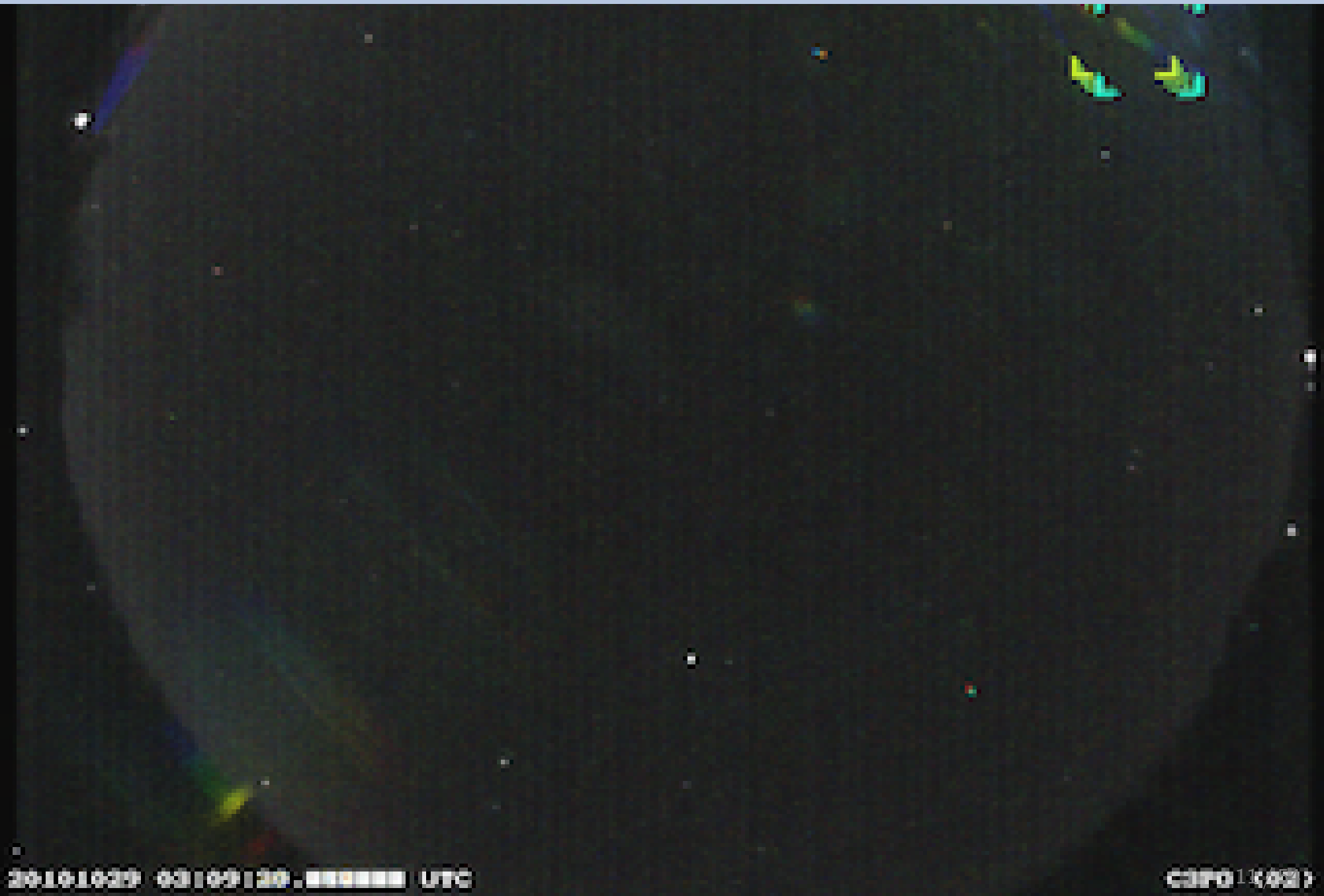
False positives: satellites (Iridium Flare)



False positives: airplanes

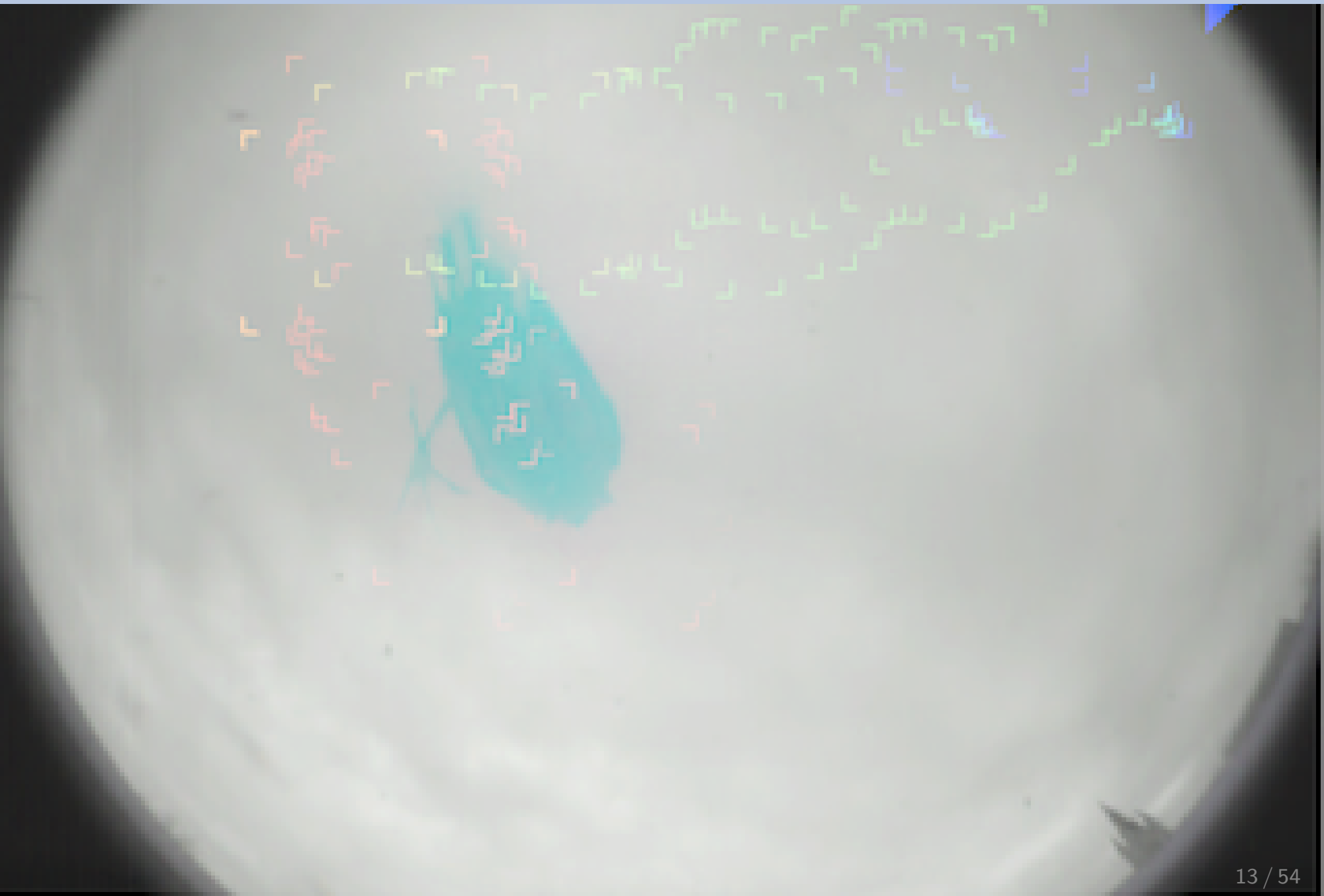


False positives: vehicle headlights

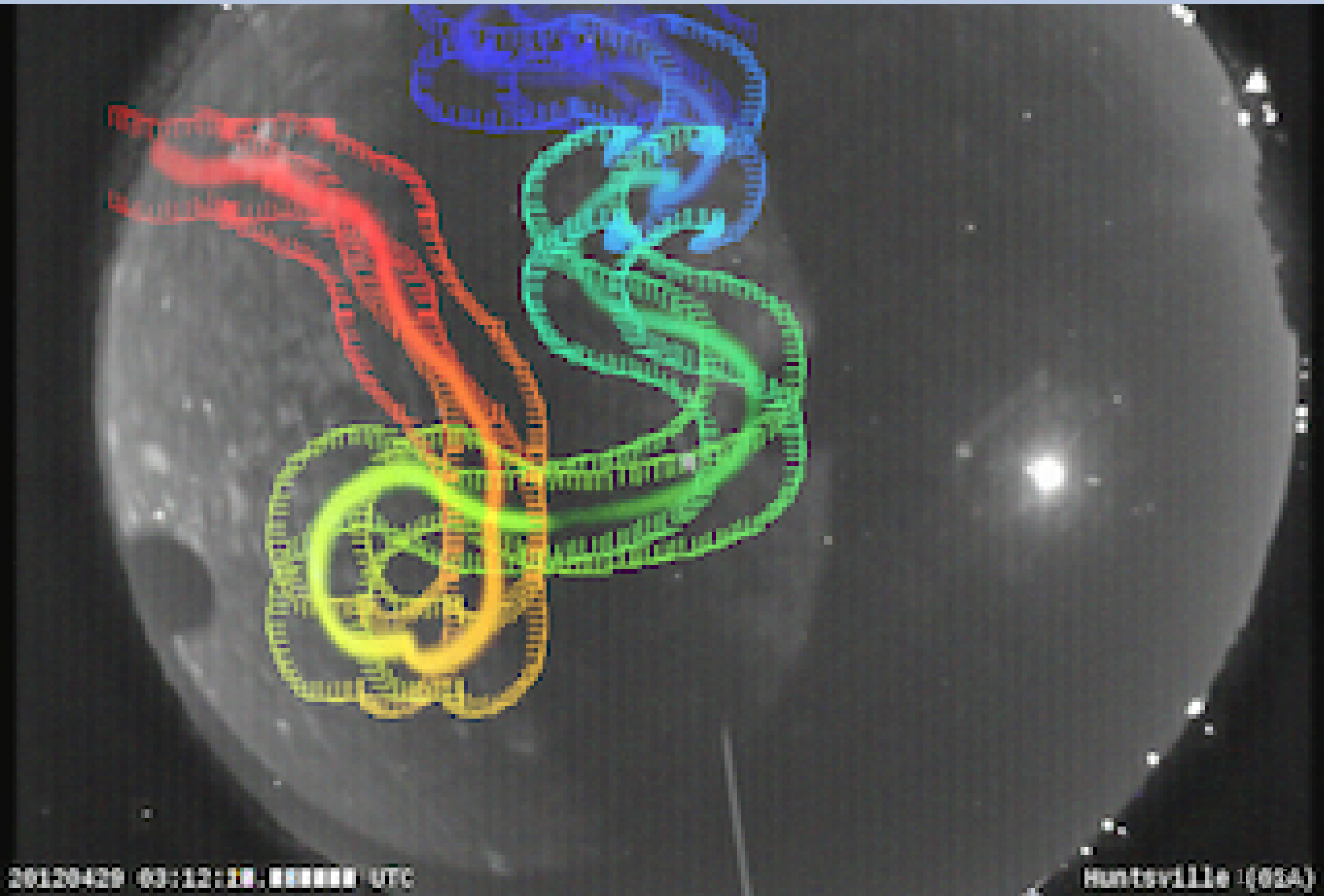


False positives: lightning

False positives: birds



False positives: insects and spiders



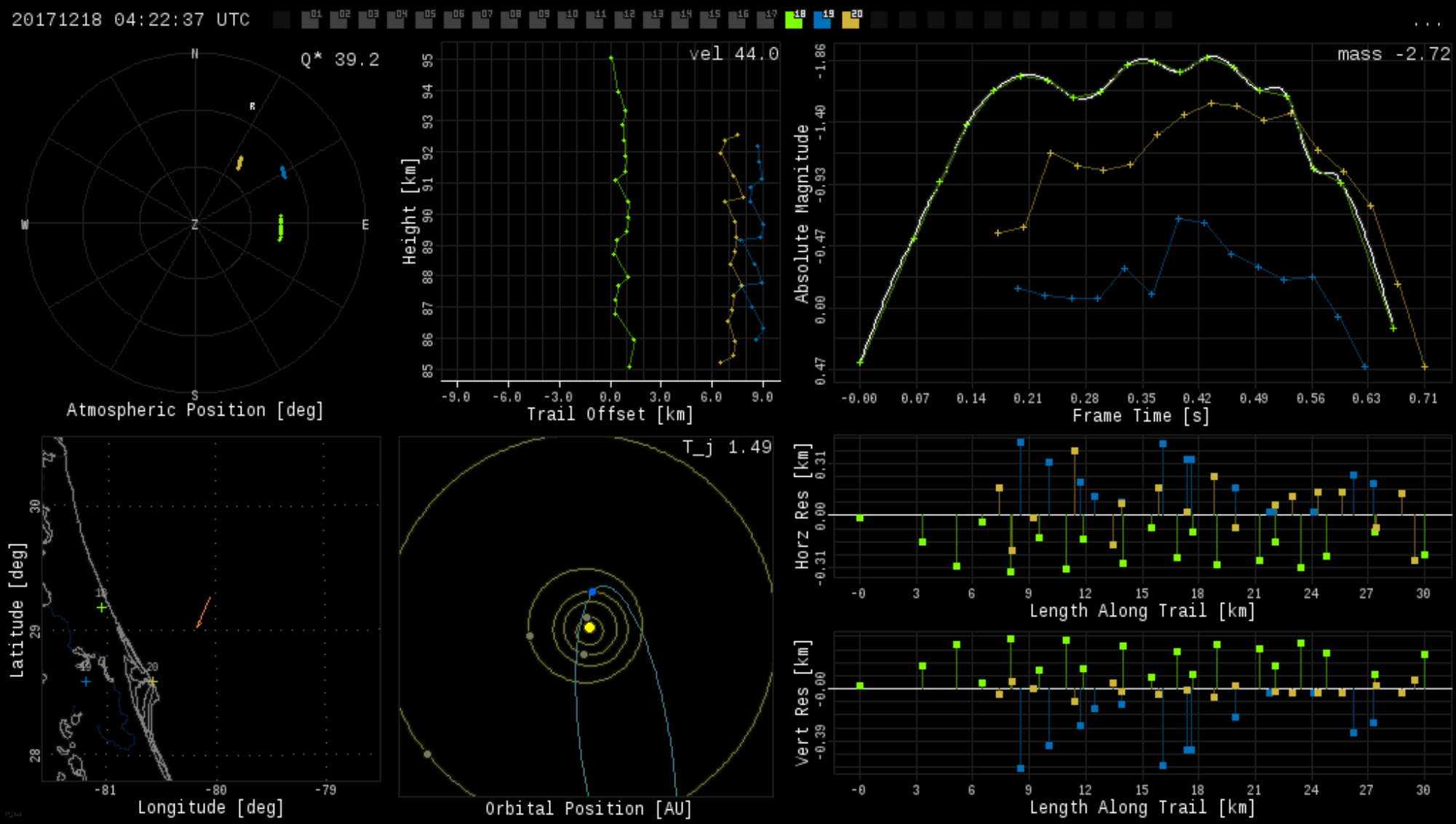
False positives

- Satellites: too high
- Airplanes: too low
- Headlights: only one camera
- Lightning: too low, track is erratic
- Birds and bugs: only one camera, track is erratic

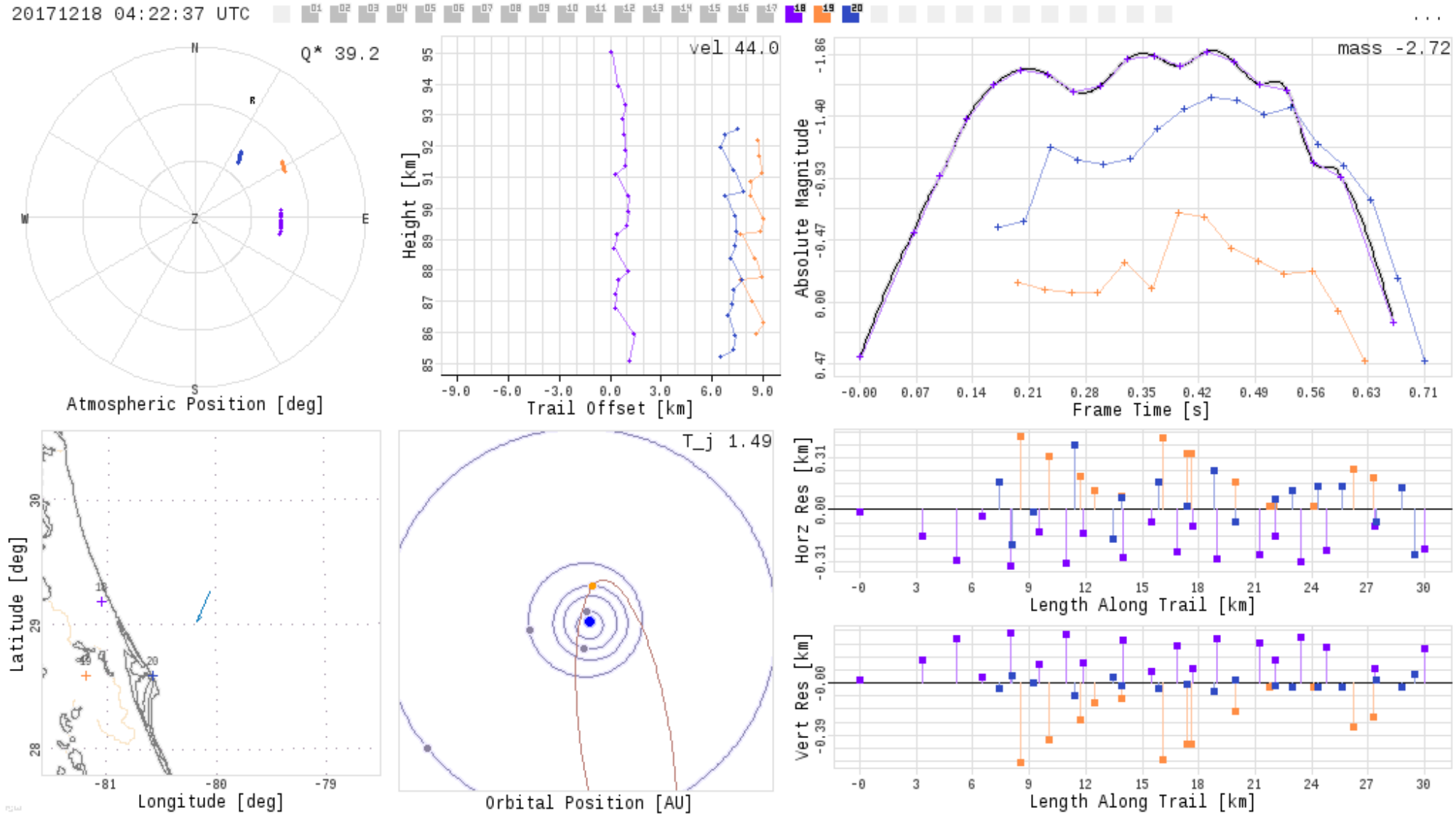
Meteor detection: false negatives

- We get false negatives as well (meteors that are rejected)
- We review these rejects near-daily and override as needed
- These show up in the log more than a day later

Event data


20171218 04:22:37 UTC
Q* 39.2
N
E
S
W
R
Z
Atmospheric Position [deg]
vel 44.0
Height [km]
Trail Offset [km]
mass -2.72
Absolute Magnitude
Frame Time [s]
Latitude [deg]
Longitude [deg]
T_j 1.49
Orbital Position [AU]
Horz Res [km]
Length Along Trail [km]
Vert Res [km]
Length Along Trail [km]

Event data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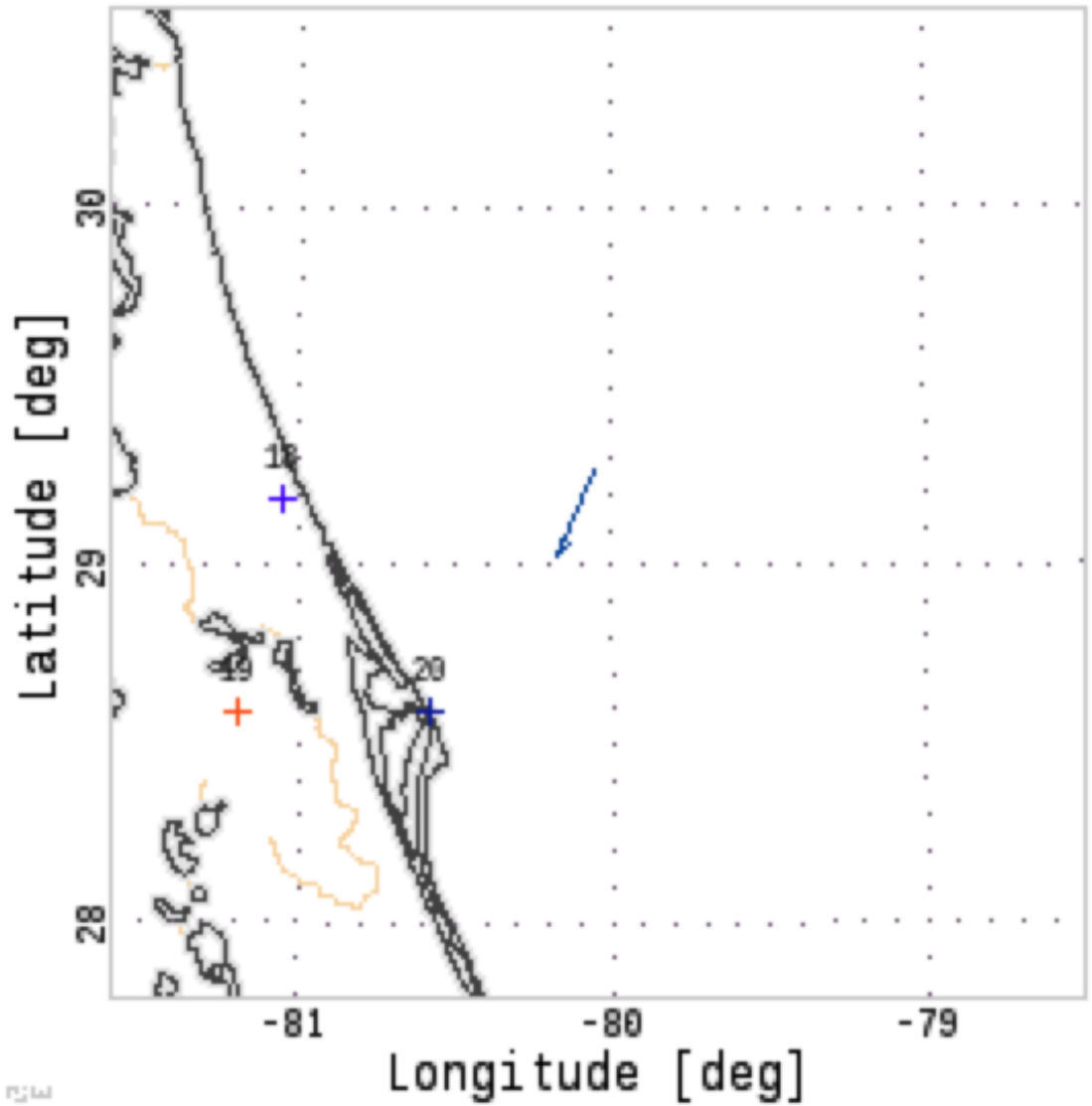
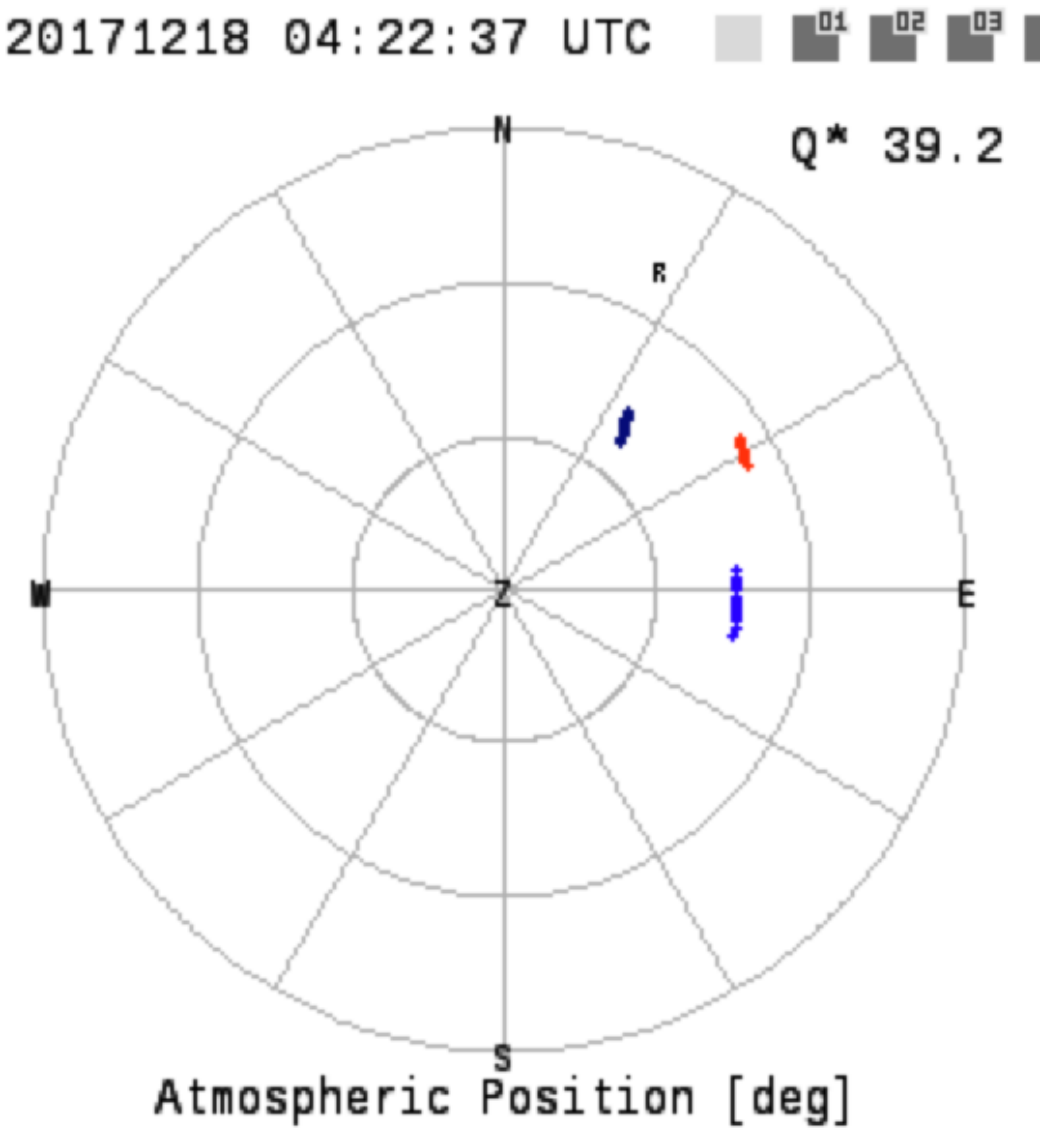
Length Along Trail [km]

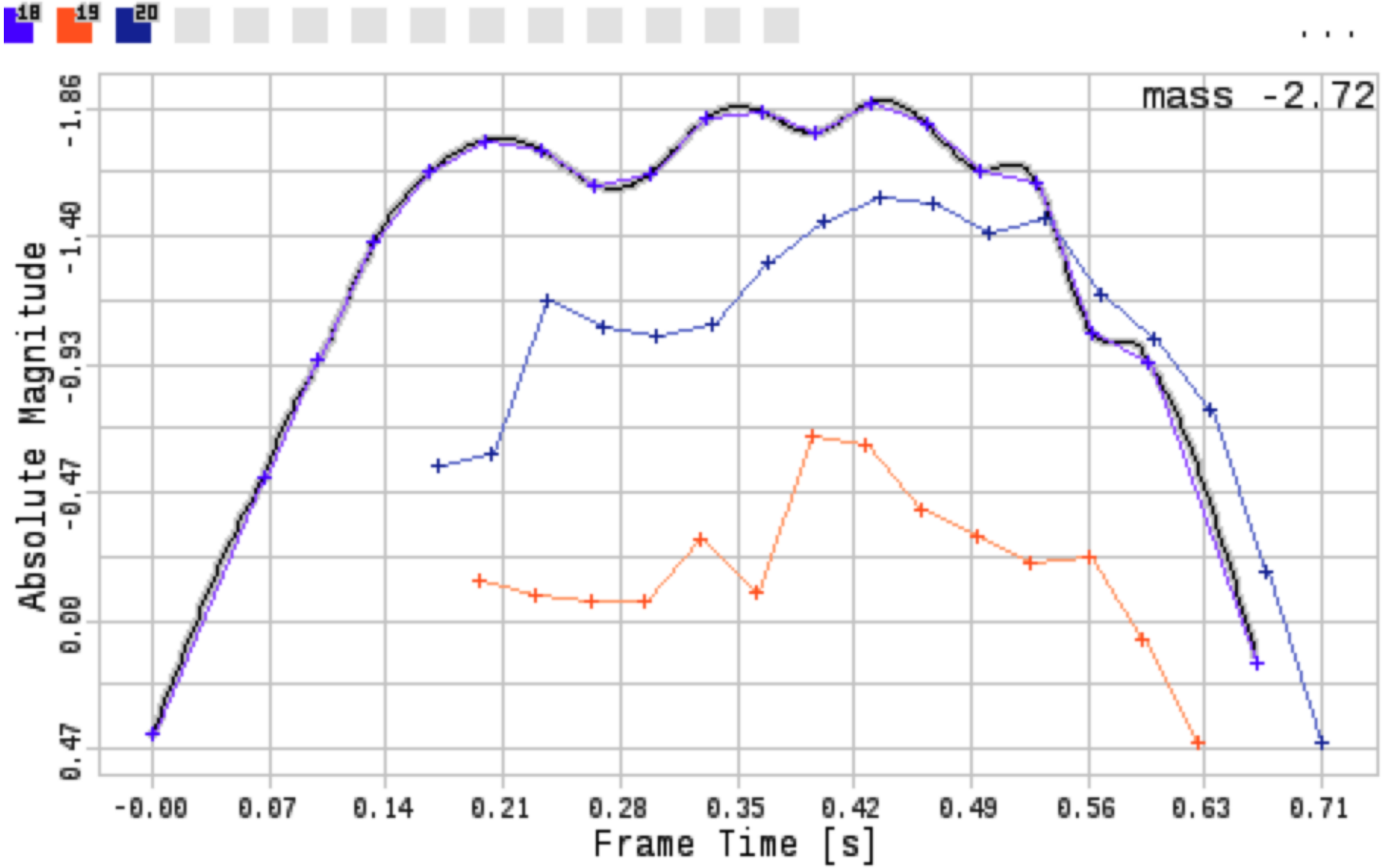
Camera stations



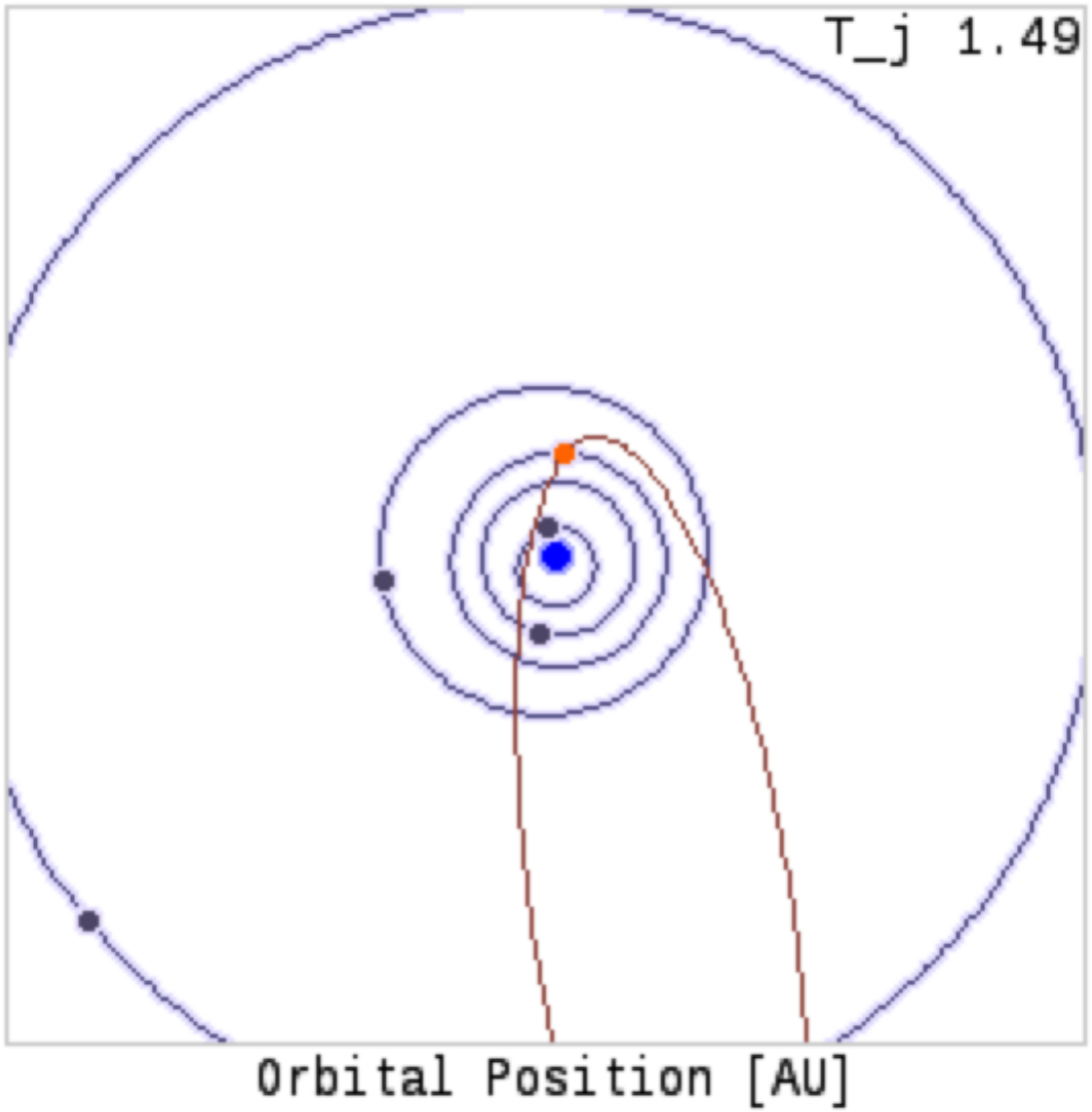
Position relative to cameras



Brightness


18
19
20
mass -2.72
Absolute Magnitude
-1.86
-1.40
-0.93
-0.47
0.00
0.47
-0.00
0.07
0.14
0.21
0.28
0.35
0.42
0.49
0.56
0.63
0.71
Frame Time [s]

Orbit



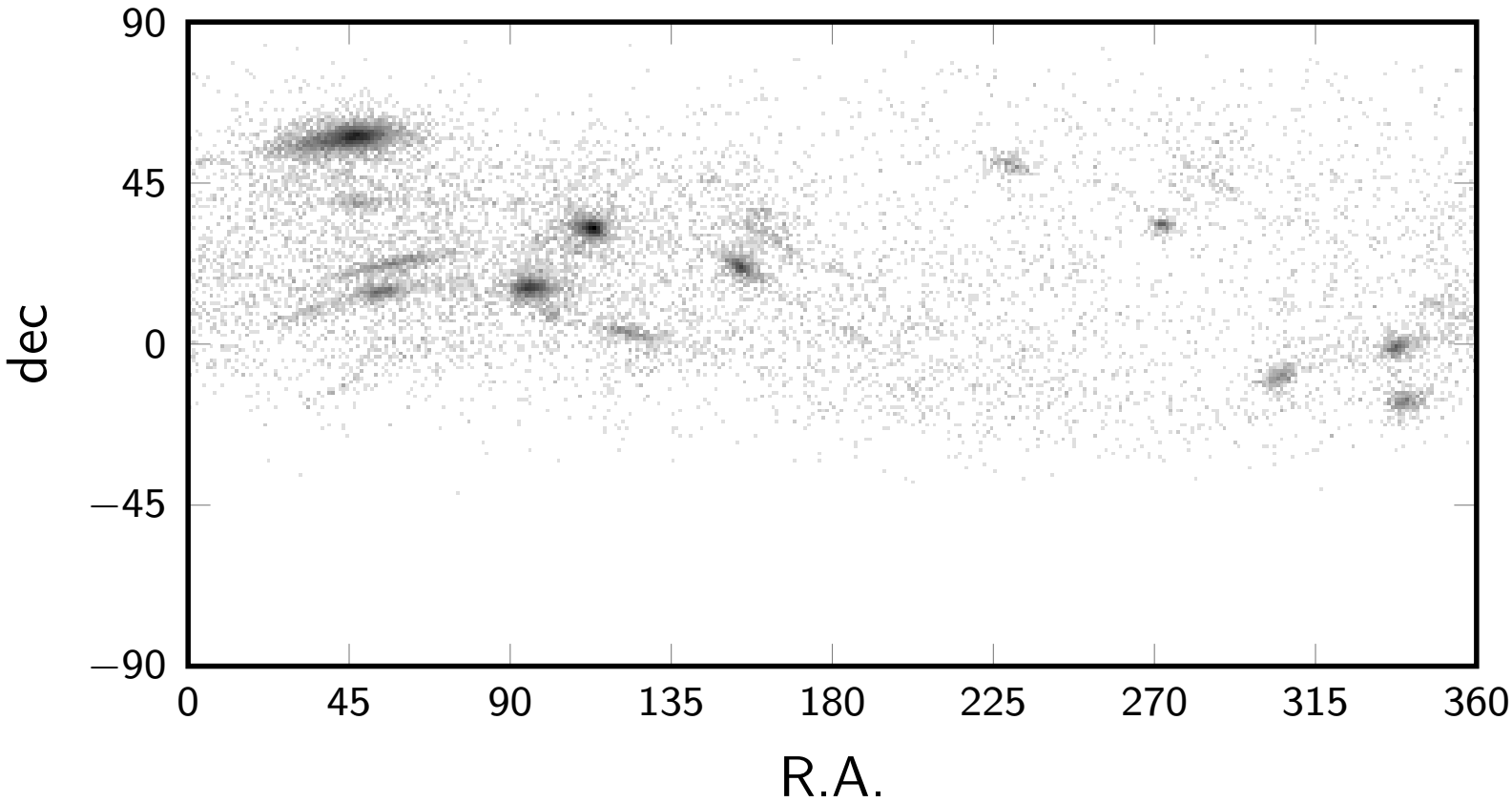
Orbit

```
time 20180108 4.7600 hours
 lat  33 22 29.208 =  33.3748 deg
 lon 250 53 24.216 = 250.8901 deg
  ht 54.610 b -14.07390 7.06982 -5.75963 19.87105
      alp  84.870 +/- 19.112 deg
      del  22.386 +/- 10.702 deg
    v_inf  21.555 +/-  2.256 km/s
    v_avg  21.555 +/-  2.256 km/s

        a   7.214 +/- 22.675 AU
        e   0.888 +/-  0.338
     incl   0.863 +/-  5.700 deg
    omega  51.721 +/- 23.497 deg
 asc_node 107.747 +/-  0.979 deg
      v_g  18.350 +/-  2.643 km/s
      v_h  41.004 +/-  4.713 km/s
  alp_geo  84.476 +/- 20.584 deg
  del_geo  21.582 +/- 11.588 deg
    q_per   0.806 +/-  0.118 AU
    q_aph  13.622 +/- 45.252 AU
   lambda  85.120 +/- 19.140 deg
     beta  -1.757 +/- 11.604 deg
true anom 308.131 +/- 11.604 deg

      T_j   1.8
```

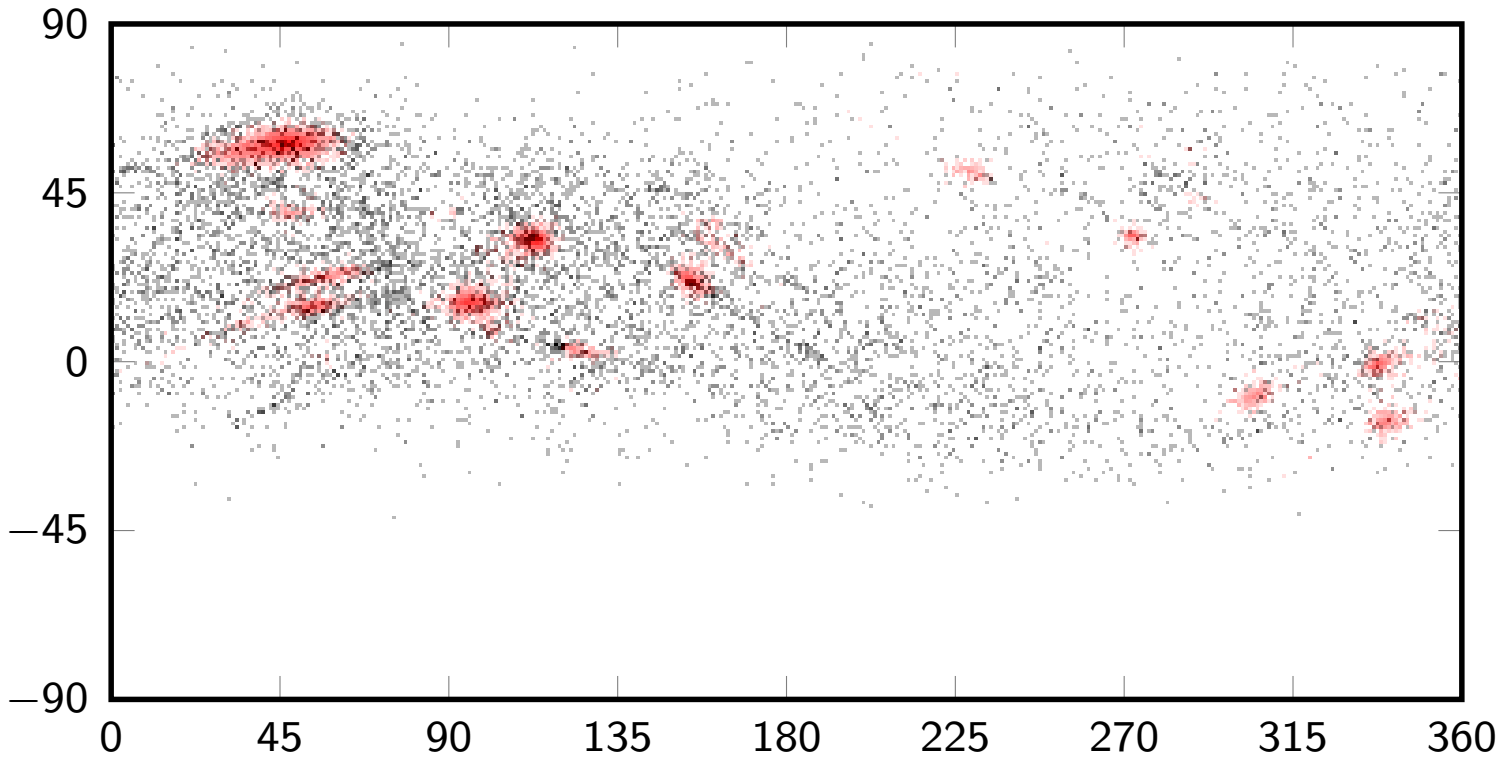
Shower vs. sporadic meteors

- It is a common misconception that all or most meteors belong to meteor showers.
- Showers have steeper mass indices and are more important at large sizes.
- But sporadic meteors are the majority even at fireball sizes: 2/3 of all-sky detections are classed as sporadic

Shower vs. sporadic

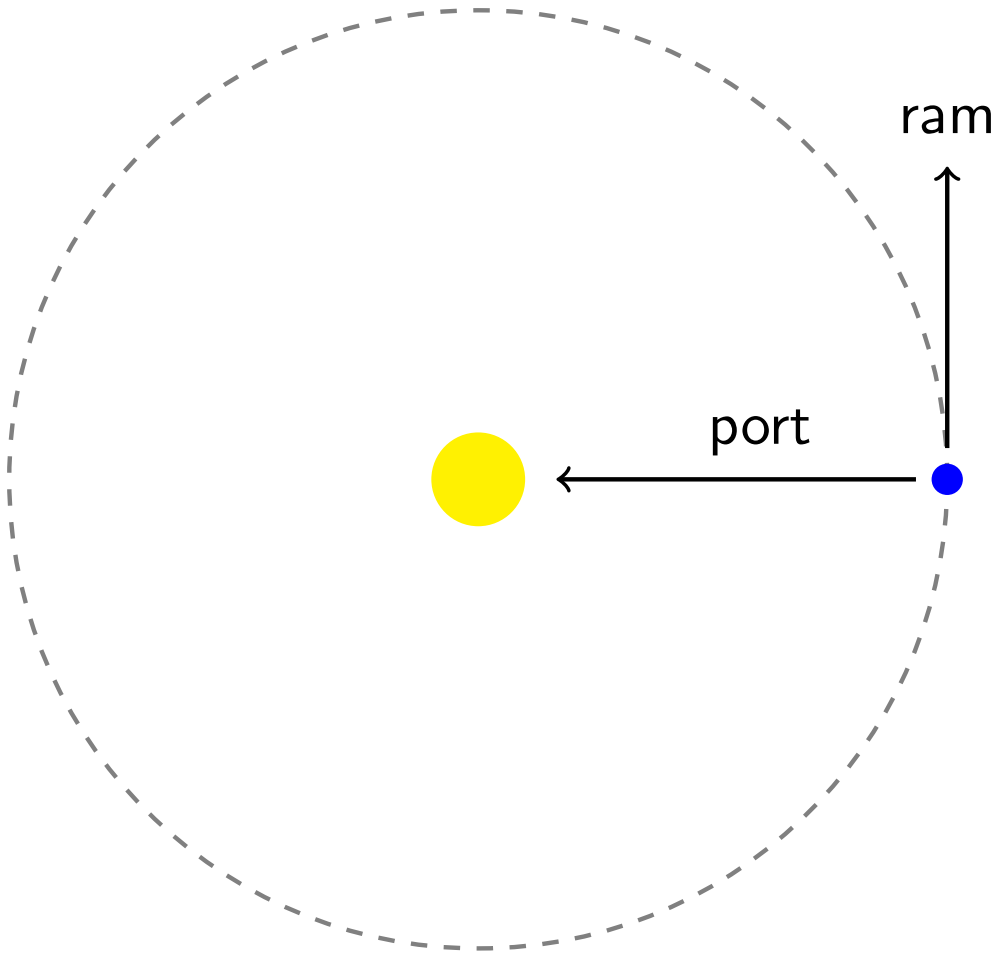


Shower vs. sporadic

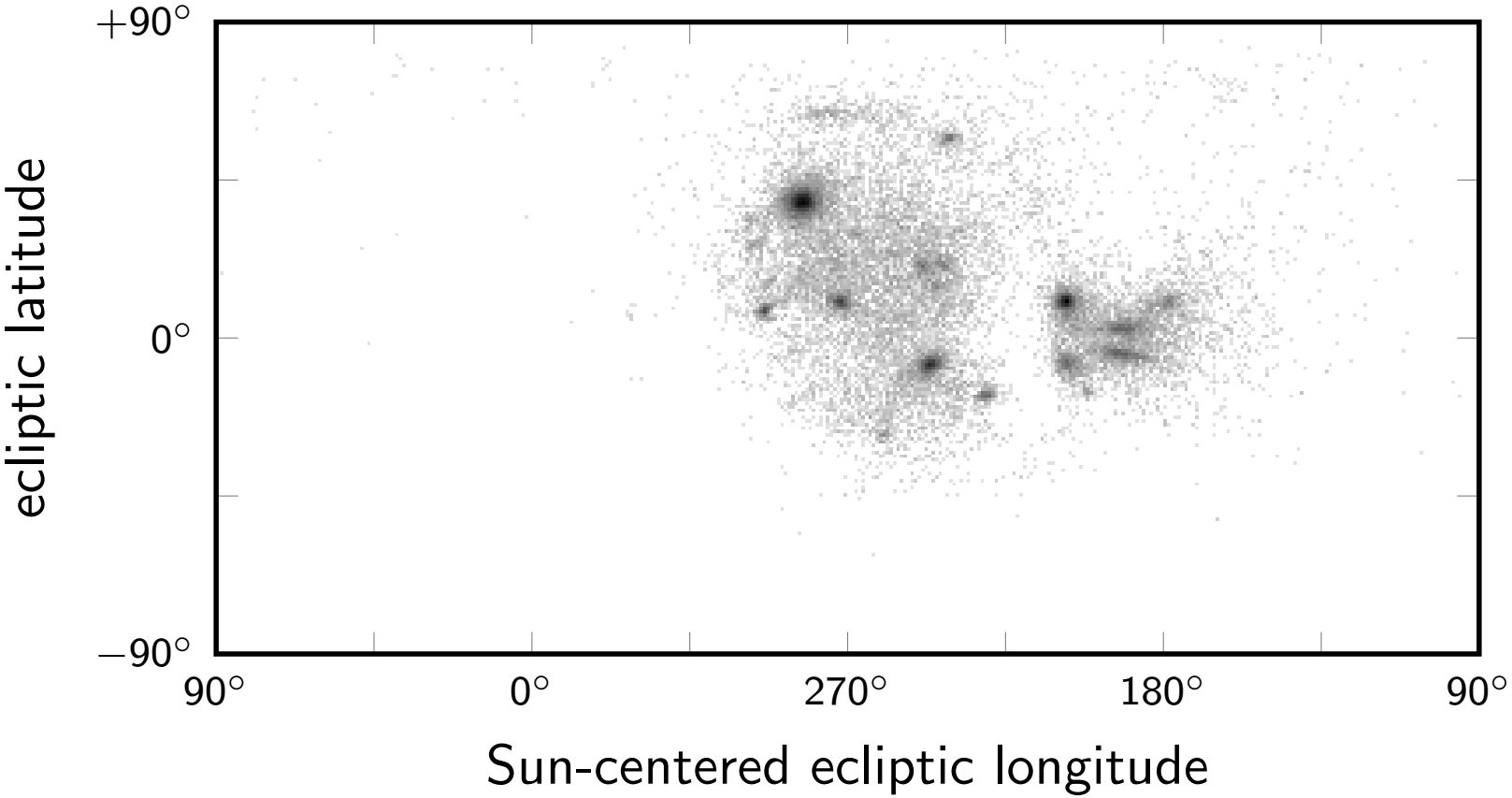


Sun-centered ecliptic coordinates

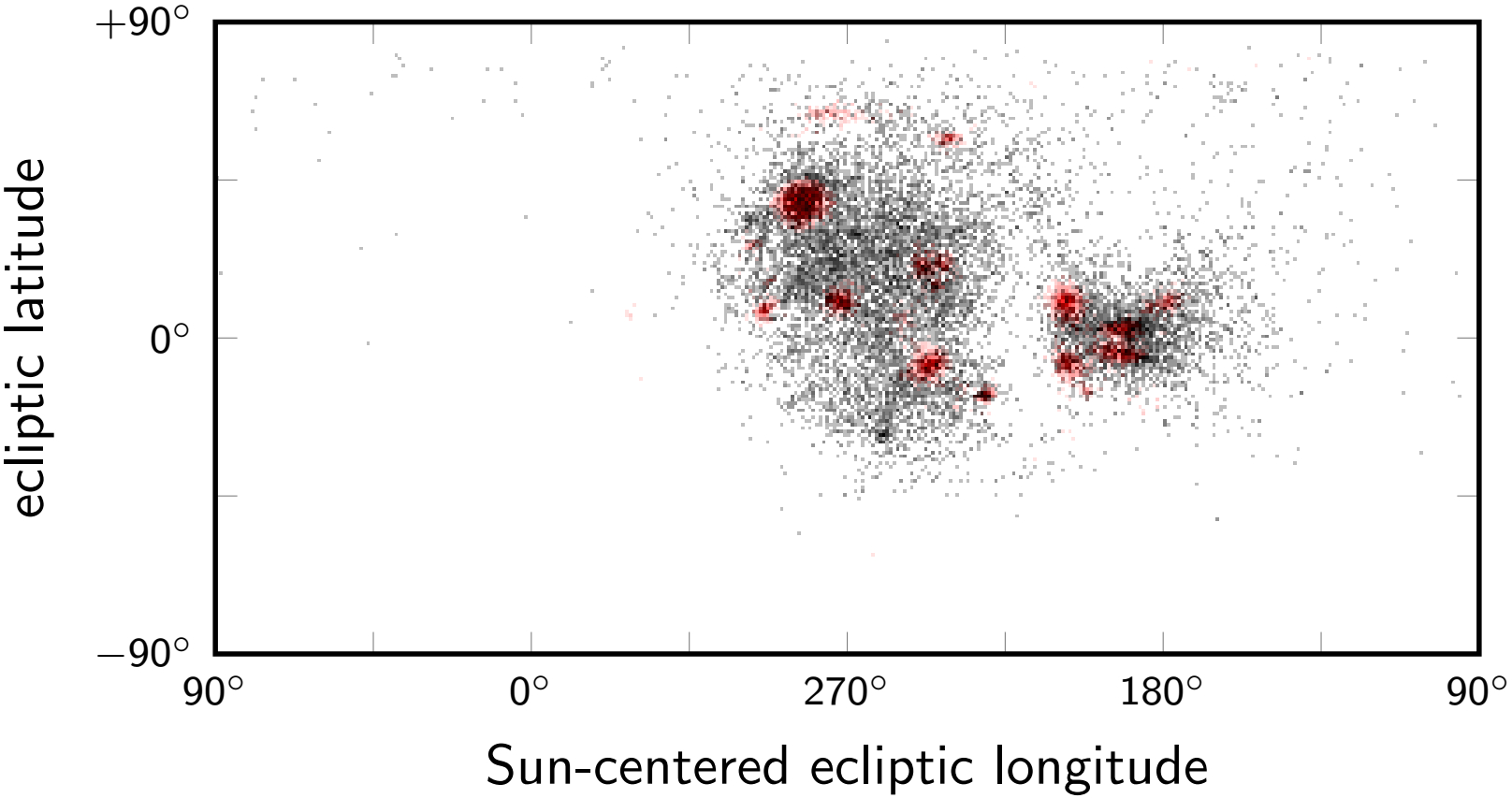
$\lambda - \lambda_\odot$, β



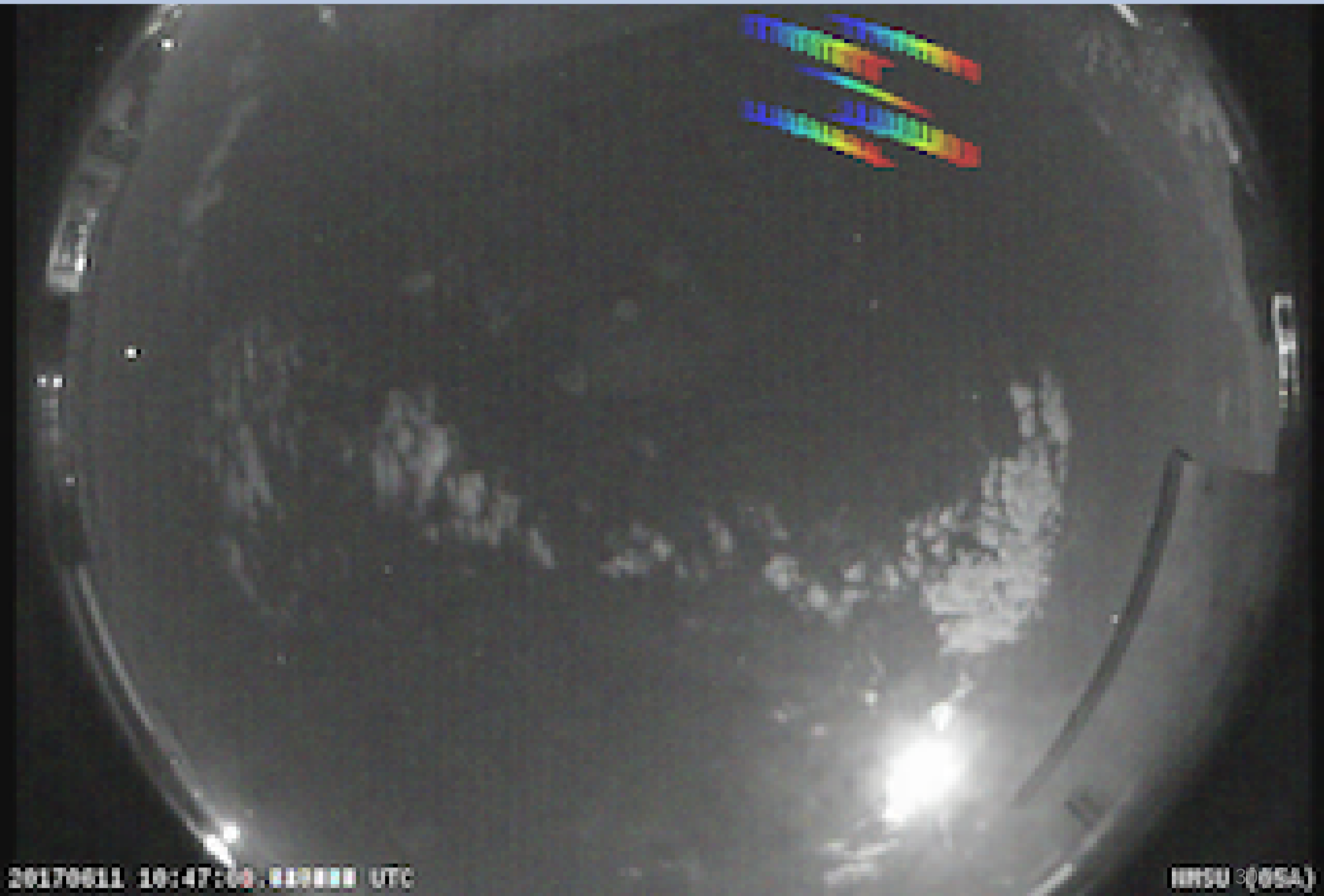
Shower vs. sporadic



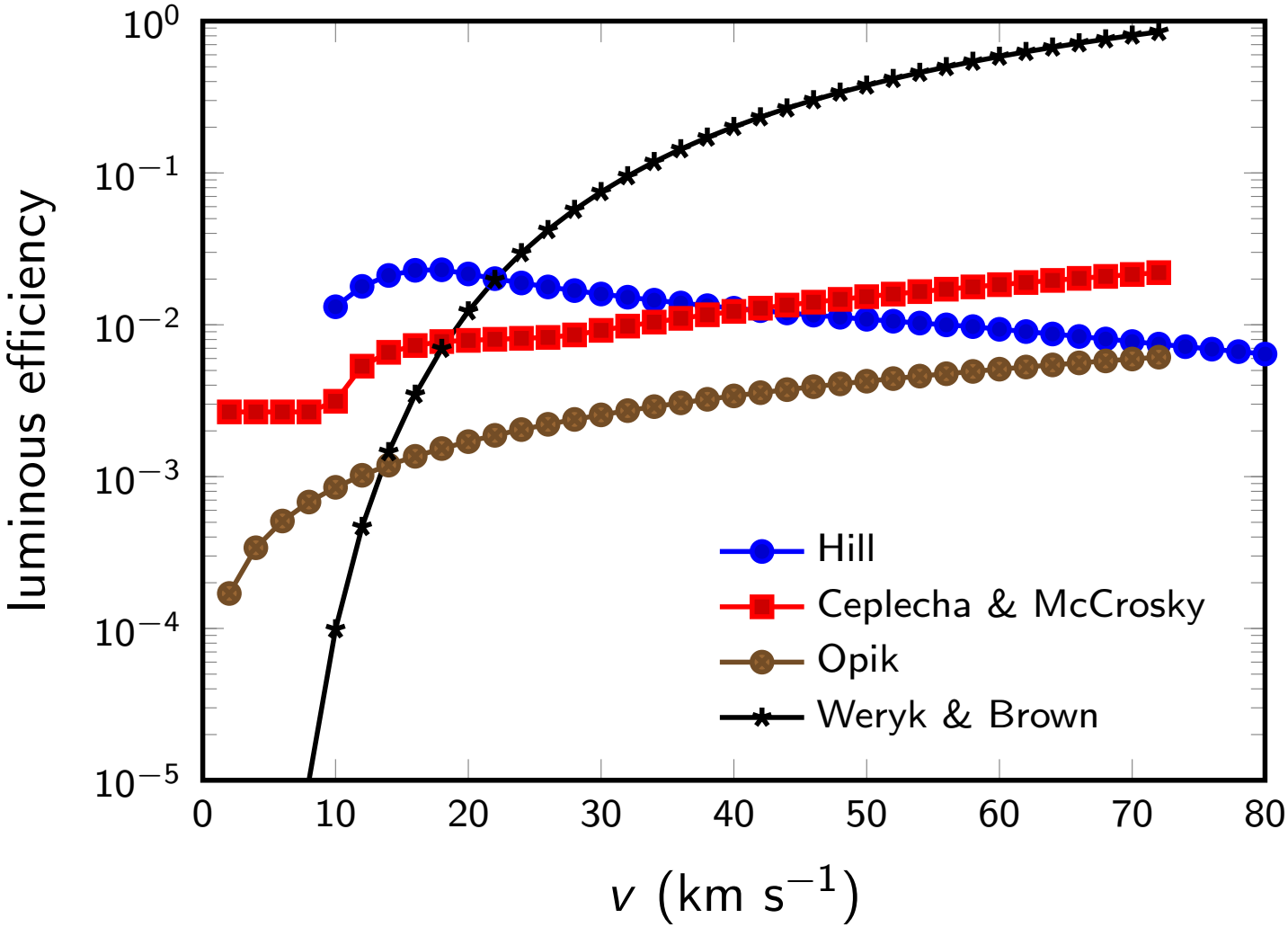
Shower vs. sporadic



Daytime showers



What you see is *not* an unbiased sample



Meteor Data Center: 821 showers as of 7 Dec 2017

00006	LYR	April Lyrids
00007	PER	Perseids
00008	ORI	Orionids
00009	DRA	October Draconids
00010	QUA	Quadrantids
00011	EVI	eta Virginids
00012	KCG	kappa Cygnids
00013	LEO	Leonids
00014	XOR	chi Orionid Complex
00015	URS	Ursids
00016	HYD	sigma Hydrids
00017	NTA	Northern Taurids
00018	AND	Andromedids
00019	MON	December Monocerotids
00020	COM	Comae Berenicids
00021	AVB	alpha Virginids
00022	LMI	Leonis Minorids
00023	EGE	epsilon Geminids
00025	NOA	Northern October delta Arietids
00026	NDA	Northern delta Aquariids
00027	KSE	kappa Serpentids
00028	SOA	Southern October delta Arietids
00029	DLE	delta Leonid Complex
00030	PSC	Piscid Complex
00031	ETA	eta Aquariids
00033	NIA	Northern iota Aquariids
00034	DSE	delta Serpentids
00038	CUR	xi Ursae Majorids
00039	NAL	Northern alpha Leonids
00040	ZCY	zeta Cygnids
00043	ZSE	zeta Serpentids
00045	PDF	phi Draconids
00046	BCR	beta Craterids
00047	DLI	mu Virginids
00049	LVI	lambda Virginids
00050	VIR	March Virginid Complex
00052	OUM	omega Ursae Majorids
00061	TAH	tau Herculids
00063	COR	Corvids
00065	GDE	gamma Delphinids
00066	NSC	Northern omega Scorpiids
00067	NSA	Northern mu Sagittariids
00223	GVI	Daytime gamma Virginids
00224	DAU	October delta Aurigids
00225	SOR	sigma Orionids
00226	ZTA	zeta Taurids
00227	OMO	October Monocerotids
00228	OLY	October Lyncids
00229	NAU	nu Aurigids
00230	ICS	October iota Cassiopeiids
00231	ACM	Daytime alpha Canis Majorids
00232	BCN	Daytime beta Cancrids
00233	OCC	October Capricornids
00234	EPC	October epsilon Piscids
00235	LCY	lambda Cygnids
00236	GPS	gamma Piscids
00237	SSA	sigma Arietids
00238	DOR	alpha Doradids
00239	GPU	October gamma Puppids
00240	DFV	Daytime psi Virginids
00241	OUI	October Ursae Minorids
00242	XDR	xi Draconids
00243	ZCN	zeta Cancrids
00244	PAR	psi1 Aurigids
00245	NHD	November Hydrids
00246	AMO	alpha Monocerotids
00247	TAU	Taurid Complex
00249	NAR	November nu Arietids
00250	NOO	November Orionids
00251	IVI	Daytime iota Virginids
00252	ALY	alpha Lyncids
00253	CMI	December Canis Minorids
00254	PHO	Phoenicids
00255	PUV	Puppid-Velid I Complex
00256	ORN	Northern chi Orionids
00257	ORS	Southern chi Orionids
00258	DAR	December alpha Aurigids
00259	CAR	Carinid Complex
00260	GTI	gamma Triangulids
00261	DDC	Daytime delta Scorpiids
00262	KLI	Daytime kappa Librids
00263	NAN	nu Andromedids
00264	XCE	xi Cetids
00265	JGD	January gamma Delphinids
00409	NCY	nu Cygnids
00410	DPI	delta Piscids
00411	CAN	c Andromedids
00412	FOP	f Ophiuchids
00413	MUL	mu Lyrids
00414	ATR	alpha Triangulids
00415	AUP	August Piscids
00416	SIC	September iota Cassiopeiids
00417	ETT	eta Taurids
00418	BHE	beta Herculids
00419	DAC	Daytime April Cetids
00420	CCA	chi Capricornids
00421	MMI	May Microscopiids
00422	NLL	Northern Librids-Lupids
00423	SLL	Southern Librids-Lupids
00424	SOL	September-October Lyncids
00425	PSA	psi Aurigids
00426	DCR	Daytime Craterids
00427	FED	February eta Draconids
00428	DSV	December sigma Virginids
00429	ACB	alpha Coronae Borealids
00430	POR	September pi Orionids
00431	JIP	June iota Pegasids
00432	NBO	nu Bootids
00433	ETP	eta Pegasids
00434	BAR	beta Arietids
00435	MPR	mu Perseids
00436	GCP	gamma Cepheids
00437	NLY	November Lyncids
00438	MLE	mu Leonids
00439	ASX	alpha Sextantids
00440	NLM	November Leonis Minorids
00441	NLD	November lambda Draconids
00442	RLE	rho Leonids
00443	DCL	December Leonids
00444	ZCS	zeta Cassiopeiids
00445	KUM	kappa Ursae Majorids
00446	DPC	December phi Cassiopeiids
00448	AAL	April alpha Librids
00449	ABS	April beta Sextantids
00450	AED	April epsilon Delphinids
00451	CAM	Camelopardalids
00599	POS	72 Ophiuchids
00600	FAU	43 Aurigids
00601	ICT	iota Craterids
00602	KCR	kappa Craterids
00603	FCR	15 Cancrids
00604	ACZ	zeta1 Cancrids
00605	FHR	52 Herculids
00606	JAU	January alpha Ursae Majorids
00607	TBO	12 Bootids
00608	FAR	14 Aurigids
00609	BOT	37 Comae Berenicids
00610	SGM	68 Geminids
00611	VCF	4 Canum Venaticids
00612	NCA	19 Canum Venaticids
00613	TLY	31 Lyncids
00614	JOS	January omega Serpentids
00615	TOR	35 Comae Berenicids
00616	TOB	26 Comae Berenicids
00617	IUM	iota Ursae Majorids
00618	THD	12 Hydrids
00619	SLM	7 Leonis Minorids
00620	SBO	sigma Bootids
00621	SUA	73 Ursae Majorids
00622	PUA	phi Ursae Majorids
00623	XTC	xi2 Capricornids
00624	XAR	xi Arietids
00625	LTA	lambda Taurids
00626	LCT	lambda Cetids
00627	MPI	mu Piscids
00628	STS	s Taurids
00629	ATS	A2 Taurids
00630	TAR	tau Arietids
00631	DAT	delta Arietids
00632	NET	November eta Taurids
00633	PTS	p Taurids
00634	TAT	tau Taurids
00635	ATU	A1 Taurids
00636	MTA	m Taurids
00637	FTR	f Taurids
00638	DZT	December zeta Taurids
00640	AOA	August omicron Aquariids
00641	DRG	December rho Geminids

International Meteor Organization (IMO): 37 showers in 2018 calendar

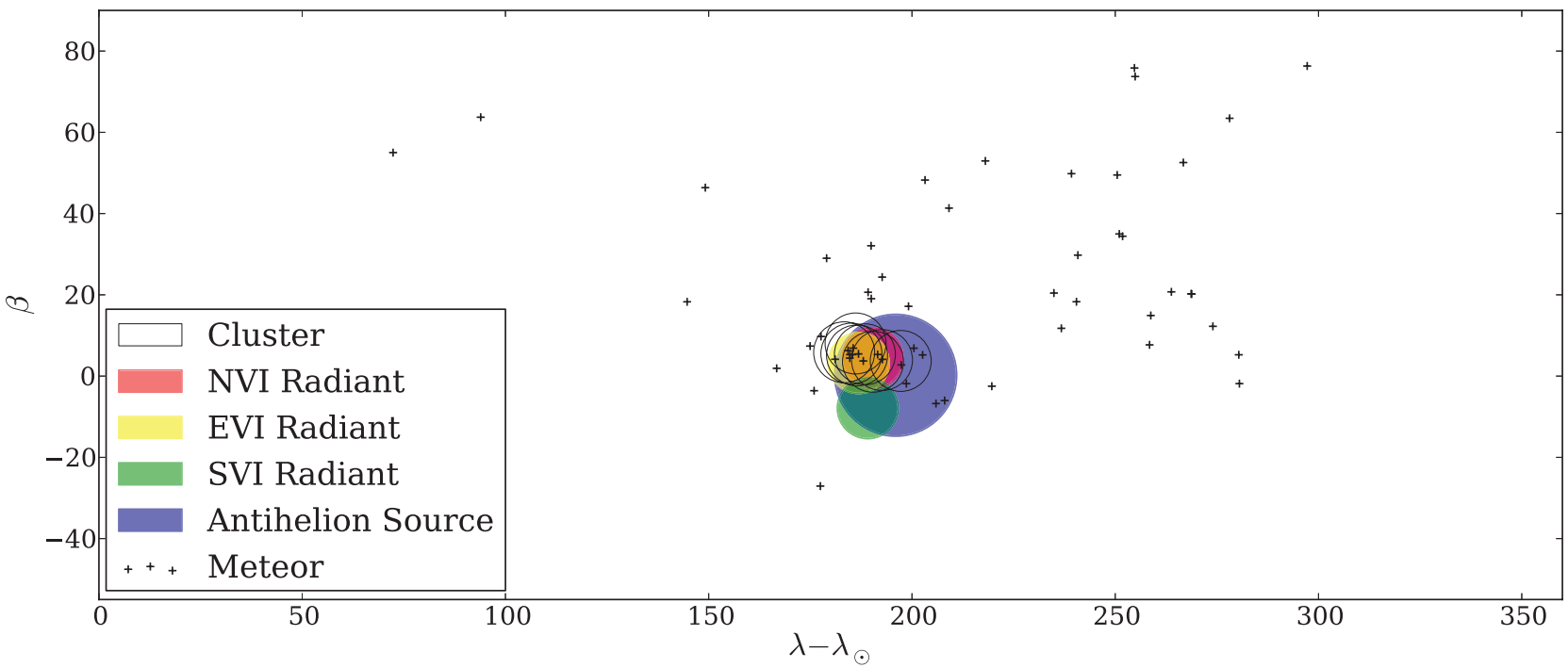
Shower	Activity	Maximum Date	$\lambda_\odot$	Radiant α	δ	V_∞ km/s	r	ZHR
Antihelion Source (ANT)	Dec 10–Sep 10 –	March–April, late May, late June		see Table 6		30	3.0	4
Quadrantids (010 QUA)	Dec 28–Jan 12	Jan 03	283.°15	230°	+49°	41	2.1	110
γ-Ursae Minorids (404 GUM)	Jan 10–Jan 22	Jan 18	298°	228°	+67°	31	3.0	3
α-Centaurids (102 ACE)	Jan 31–Feb 20	Feb 08	319.°2	210°	−59°	58	2.0	6
γ-Normids (118 GNO)	Feb 25–Mar 28	Mar 14	354°	239°	−50°	56	2.4	6
Lyrids (006 LYR)	Apr 14–Apr 30	Apr 22	32.°32	271°	+34°	49	2.1	18
π-Puppids (137 PPU)	Apr 15–Apr 28	Apr 23	33.°5	110°	−45°	18	2.0	Var
η-Aquariids (031 ETA)	Apr 19–May 28	May 06	45.°5	338°	−01°	66	2.4	50
η-Lyrids (145 ELY)	May 03–May 14	May 09	48.°0	287°	+44°	43	3.0	3
Dayt. Arietids (171 ARI)	May 14–Jun 24	Jun 07	76.°6	44°	+24°	38	2.8	30
June Bootids (170 JBO)	Jun 22–Jul 02	Jun 27	95.°7	224°	+48°	18	2.2	Var
Piscis Austr. (183 PAU)	Jul 15–Aug 10	Jul 28	125°	341°	−30°	35	3.2	5
S. δ-Aquariids (005 SDA)	Jul 12–Aug 23	Jul 30	127°	340°	−16°	41	2.5	25
α-Capricornids (001 CAP)	Jul 03–Aug 15	Jul 30	127°	307°	−10°	23	2.5	5
Perseids (007 PER)	Jul 17–Aug 24	Aug 12	140.°0	48°	+58°	59	2.2	110
κ-Cygnids (012 KCG)	Aug 03–Aug 25	Aug 18	145°	286°	+59°	25	3.0	3
Aurigids (206 AUR)	Aug 28–Sep 05	Sep 01	158.°6	91°	+39°	66	2.5	6
Sep. ε-Perseids (208 SPE)	Sep 05–Sep 21	Sep 09	166.°7	48°	+40°	64	3.0	5
Dayt. Sextantids (221 DSX)	Sep 09–Oct 09	Sep 27	184.°3	152°	+00°	32	2.5	5
Oct. Camelopard. (281 OCT)	Oct 05–Oct 06	Oct 06	192.°58	164°	+79°	47	2.5	5
Draconids (009 DRA)	Oct 06–Oct 10	Oct 09	195.°4	262°	+54°	20	2.6	10
S. Taurids (002 STA)	Sep 10–Nov 20	Oct 10	197°	32°	+09°	27	2.3	5

... plus 11 daytime showers

Shower	Activity	Max Date	$\lambda_\odot$ 2000	Radiant α	Radiant δ	Rate
Capricornids/Sagittariids (115 DCS)	Jan 13–Feb 04	Feb 01*	312.°5	299°	−15°	M*
χ-Capricornids (114 DXC)	Jan 29–Feb 28	Feb 13*	324.°7	315°	−24°	L*
April Piscids (144 APS)	Apr 20–Apr 26	Apr 22	32.°5	9°	+11°	L
ε-Arietids (154 DEA)	Apr 24–May 27	May 09	48.°7	44°	+21°	L
May Arietids (294 DMA)	May 04–Jun 06	May 16	55.°5	37°	+18°	L
o-Cetids (293 DCE)	May 05–Jun 02	May 20	59.°3	28°	−04°	M*
Arietids (171 ARI)	May 14–Jun 24	Jun 07	76.°6	42°	+25°	H
ζ-Perseids (172 ZPE)	May 20–Jul 05	Jun 09*	78.°6	62°	+23°	H
β-Taurids (173 BTA)	Jun 05–Jul 17	Jun 28	96.°7	86°	+19°	M
γ-Leonids (203 GLE)	Aug 14–Sep 12	Aug 25	152.°2	155°	+20°	L*
Daytime Sextantids (221 DSX)	Sep 09–Oct 09	Sep 27*	184.°3	152°	0°	M*

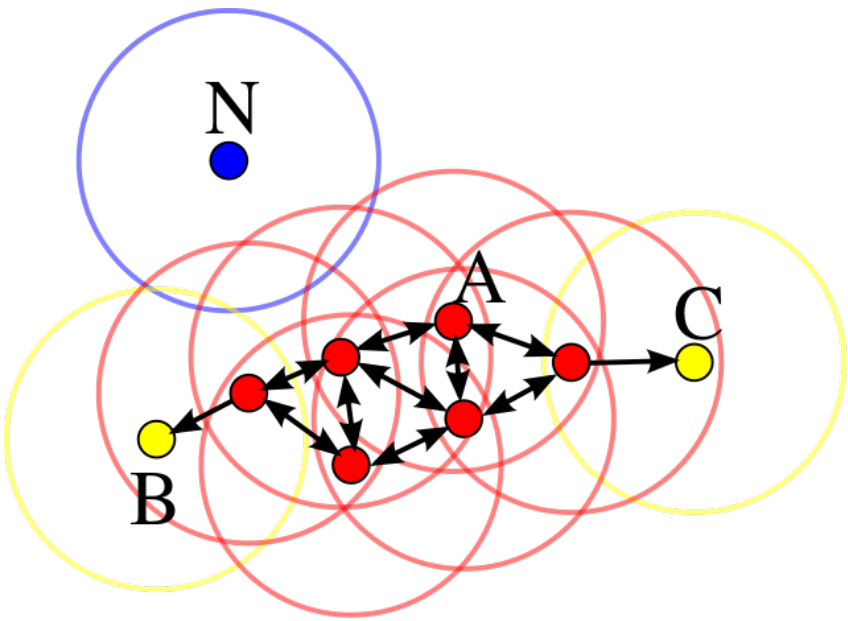
Cluster algorithm

- We see new showers and outbursts from time to time:
  - 2014 May Camelopardalids
  - 2014 Phoenicids
  - 2016 γ Draconids
- Former intern Josh Burt wrote a script to automatically detect clusters of 5 or more meteors in 3 day intervals (Burt et al. 2014):

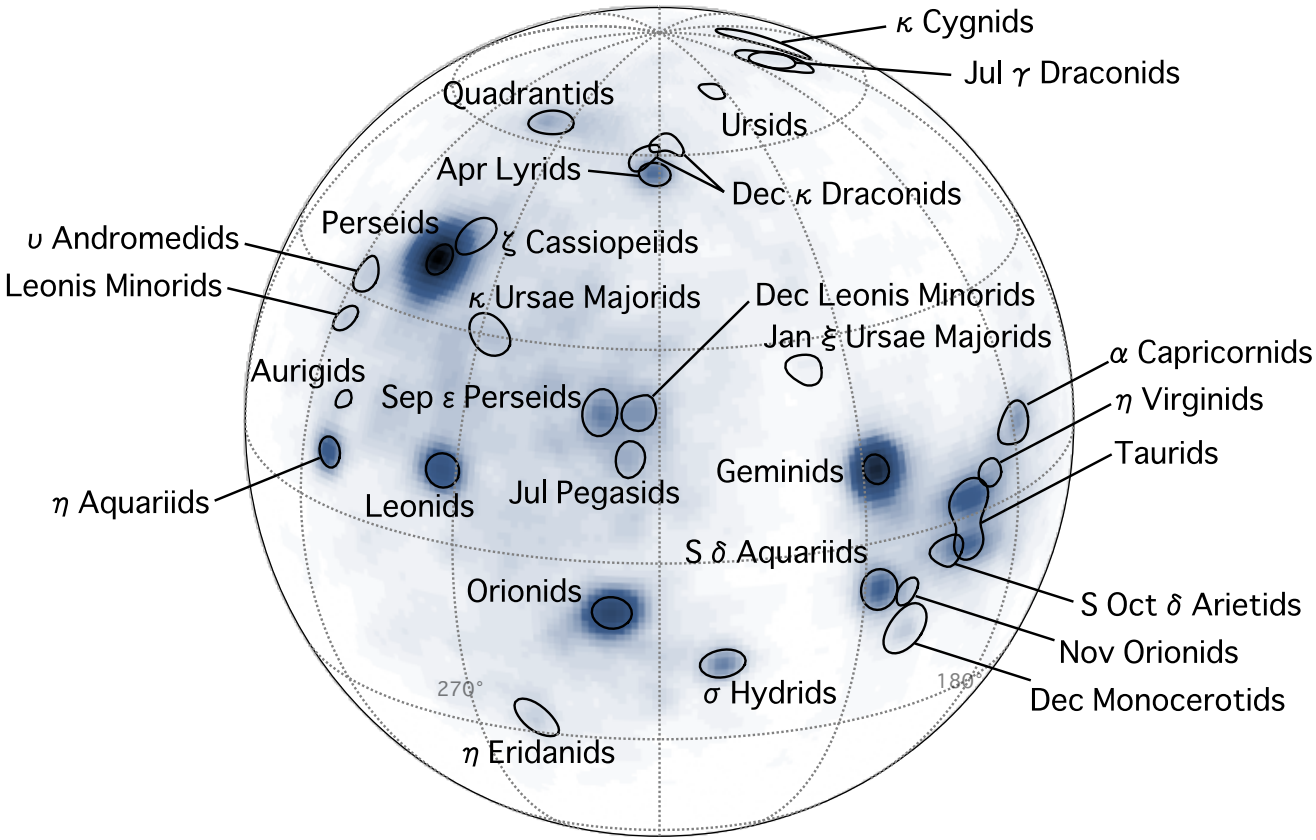


Shower surveys

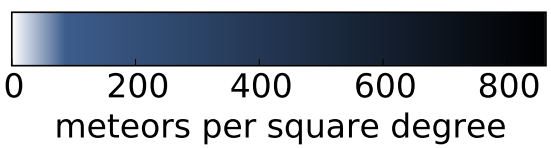
- Shower surveys are a fun way to begin working with meteor data
- Former MEO intern Glenn Sugar used density-based cluster algorithm DBSCAN to automatically detect showers in the all-sky data (Sugar et al. 2017)



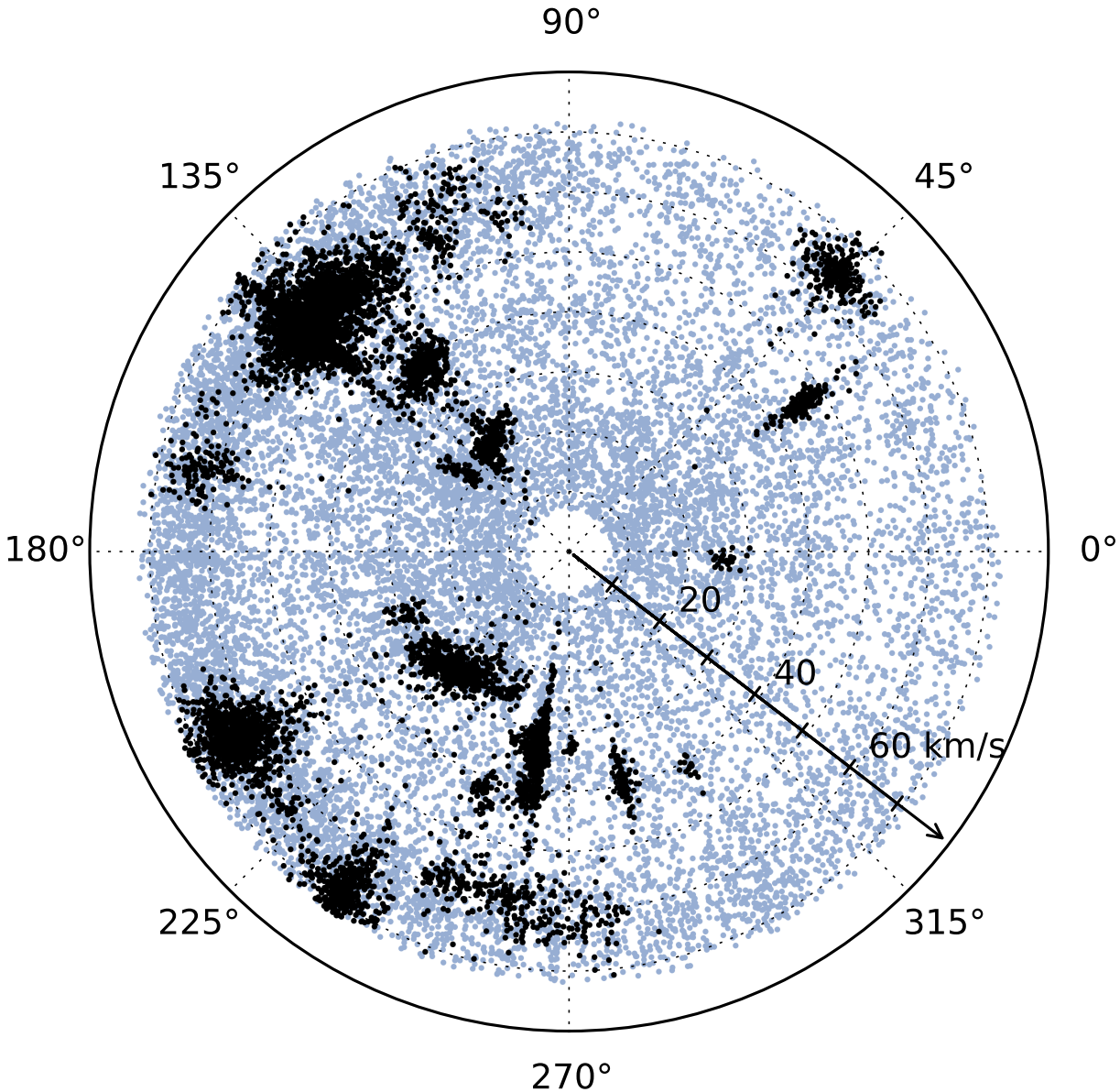
Shower surveys



Meteor radiant density in Sun-centered ecliptic coordinates. Detected showers are labeled.

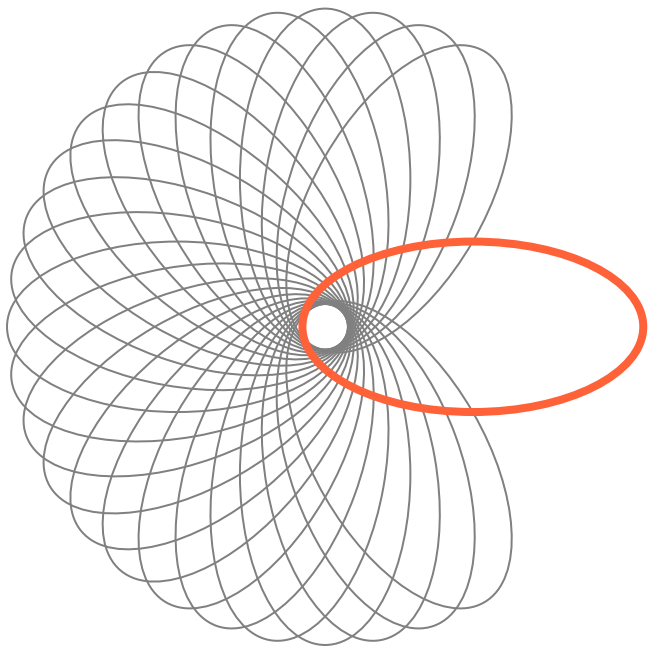


Shower surveys

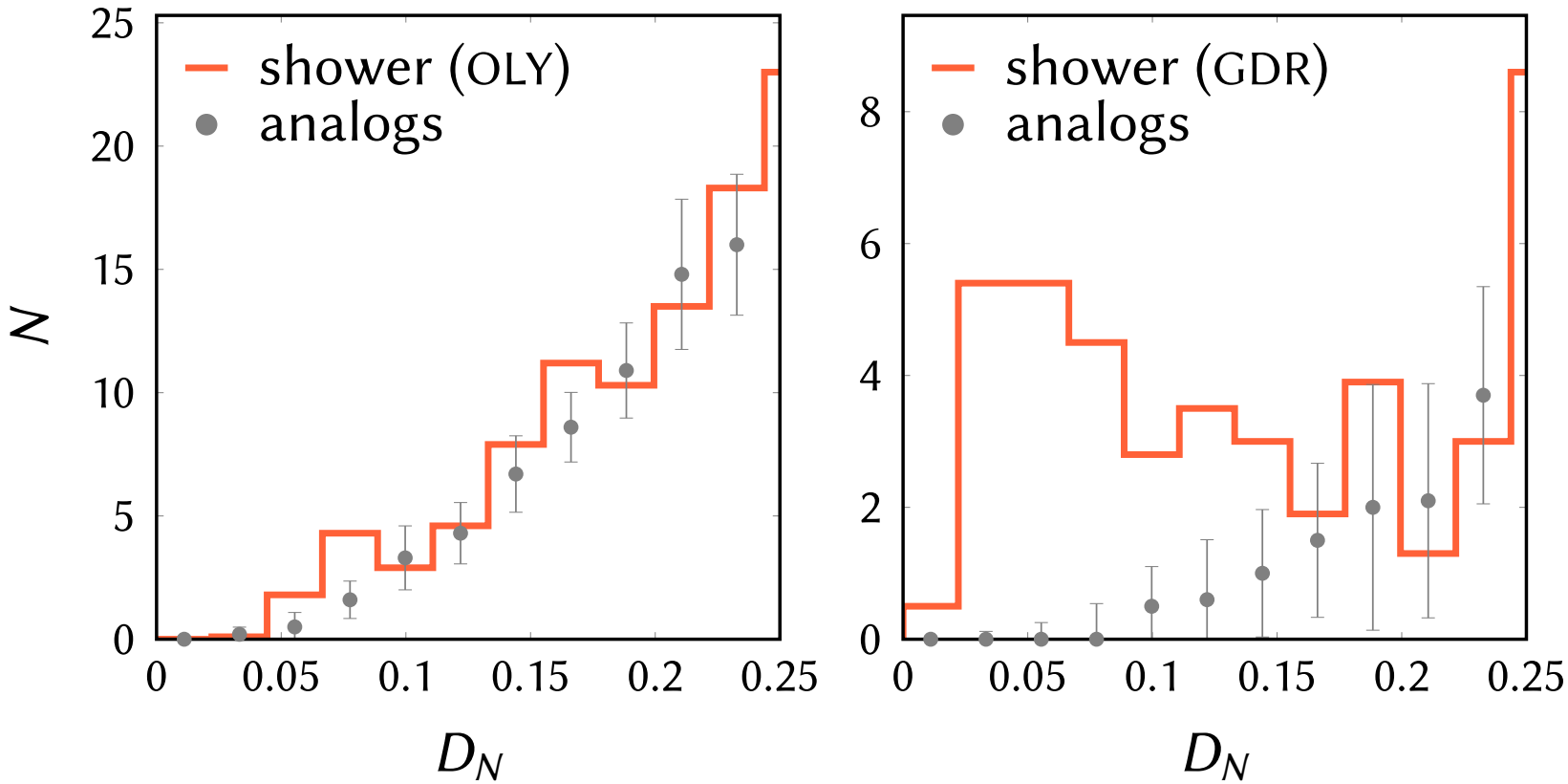


Shower significance

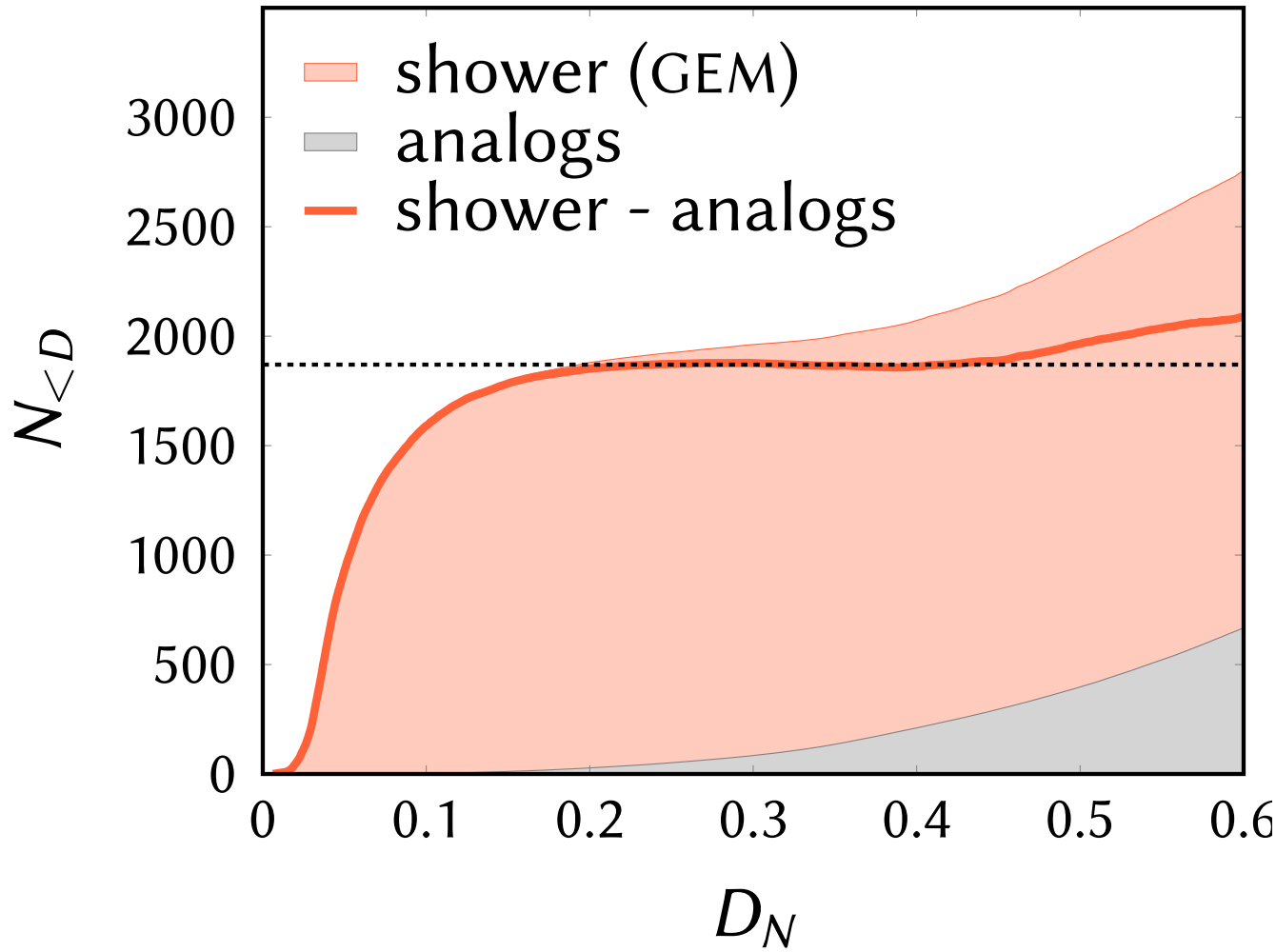
- The sporadic background is not isotropic
- False positives for shower association depend on nearby sporadics
- But showers are shorter-lived than sporadics
- So how does clustering around a given orbit (measured by D_N) vary by time of year?



Shower significance



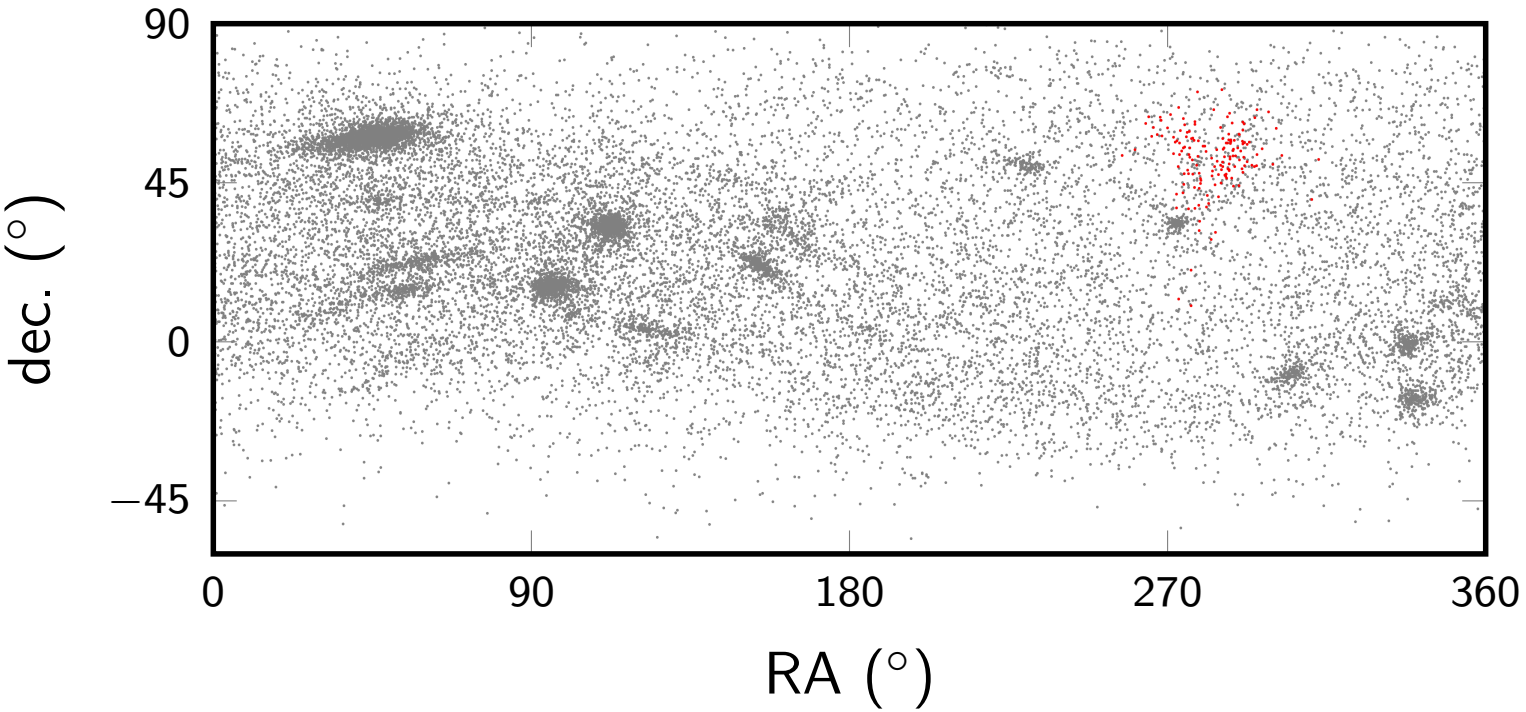
Shower significance



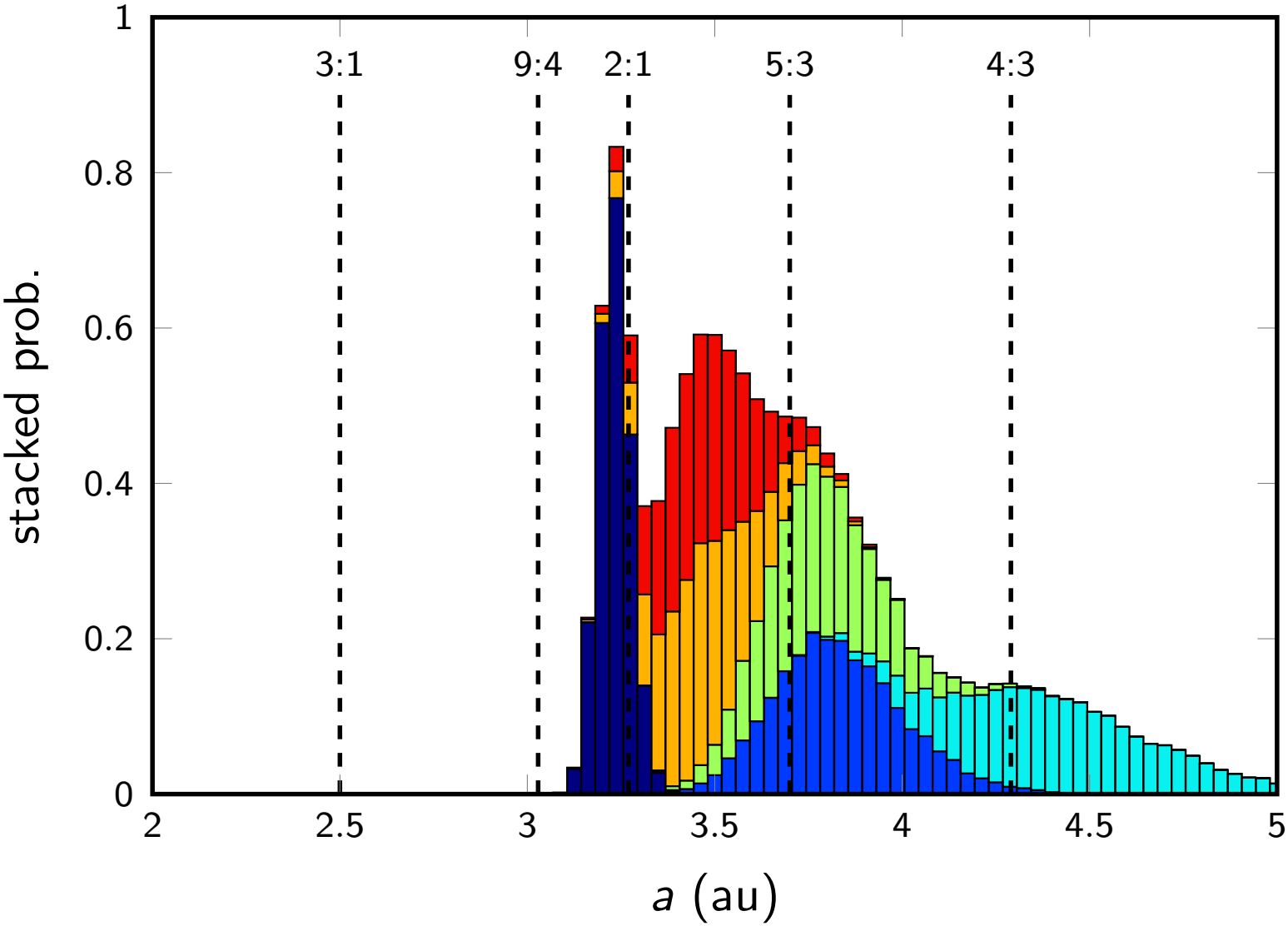
Individual showers

κ Cygnid outburst in 2014

- Diffuse radiant makes membership determination tricky

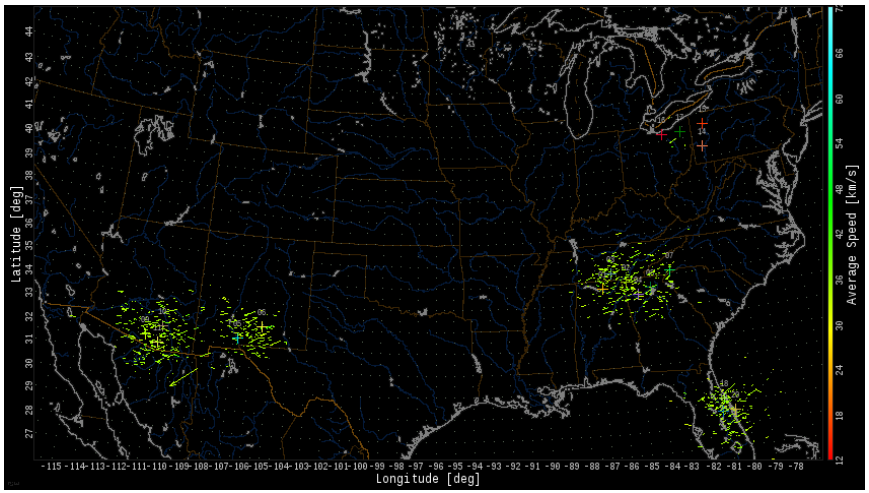


Individual showers

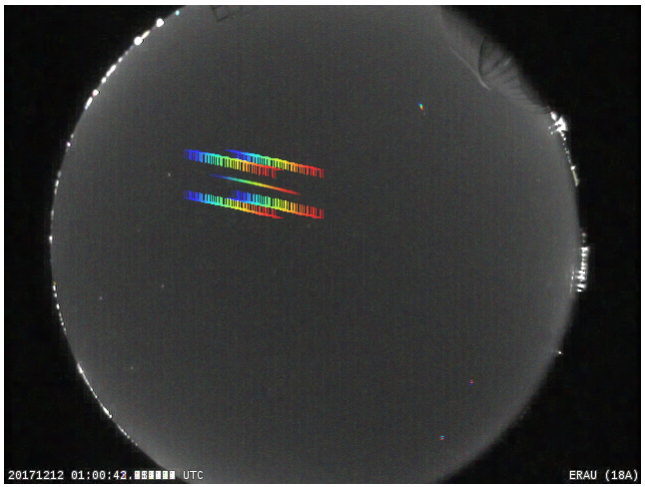


Shower reports

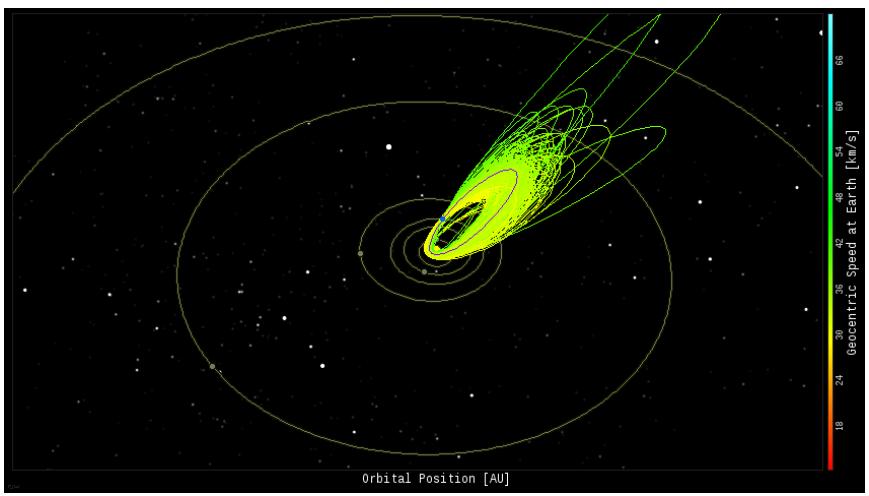
ground tracks for all-sky Geminids



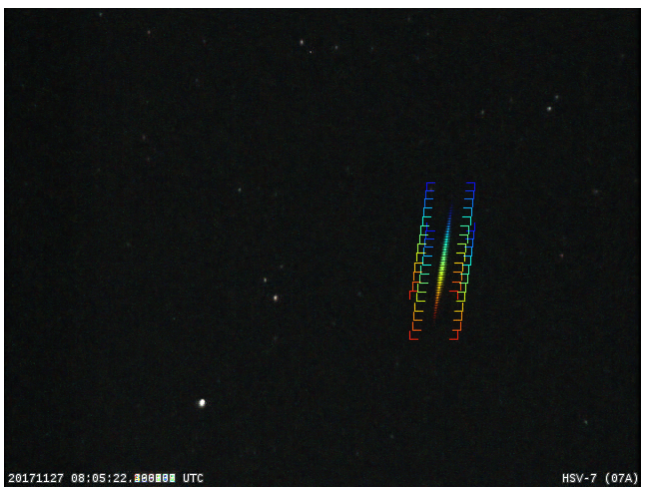
sample all-sky Geminid



orbits of all-sky Geminids

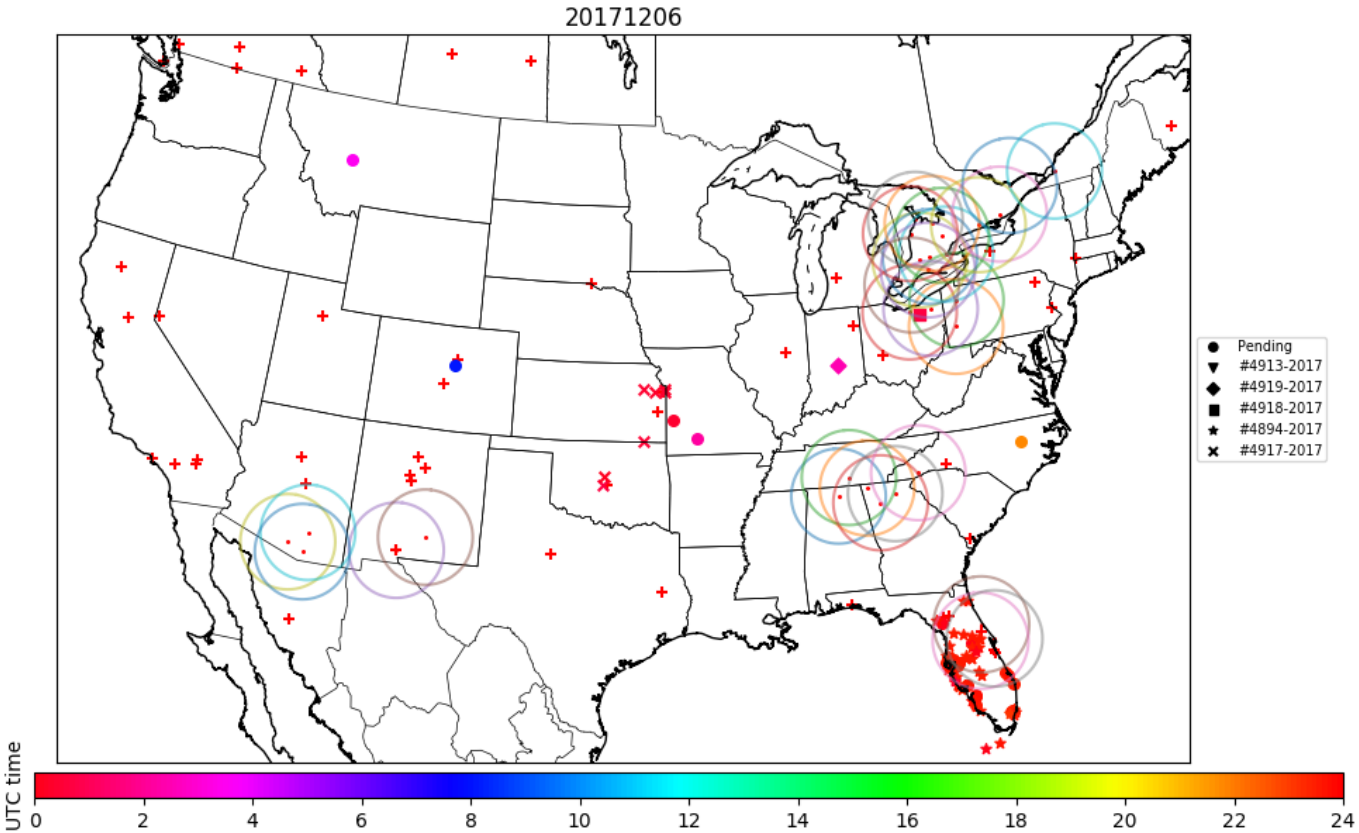


sample wide-field Geminid

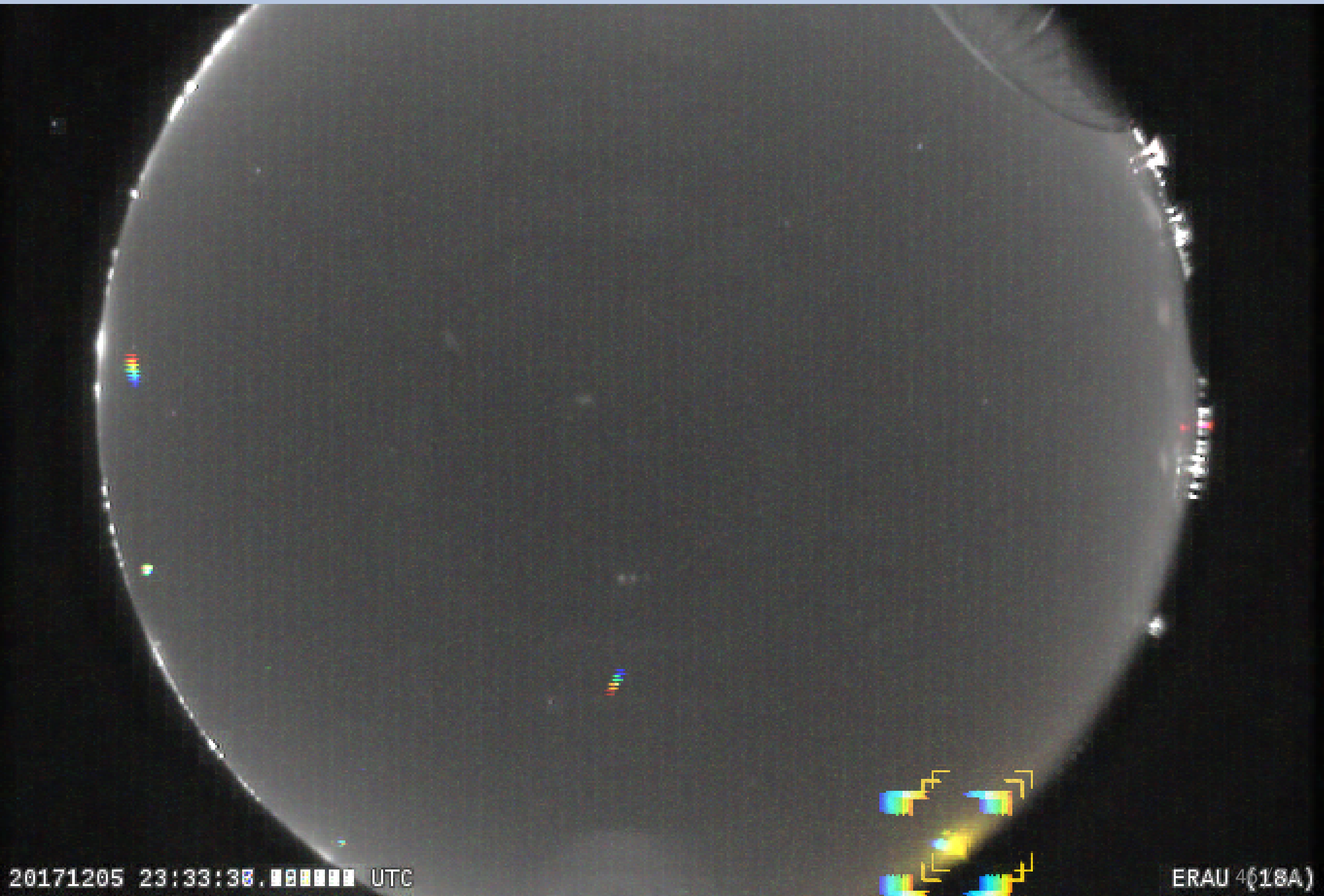


“Skyfalls”

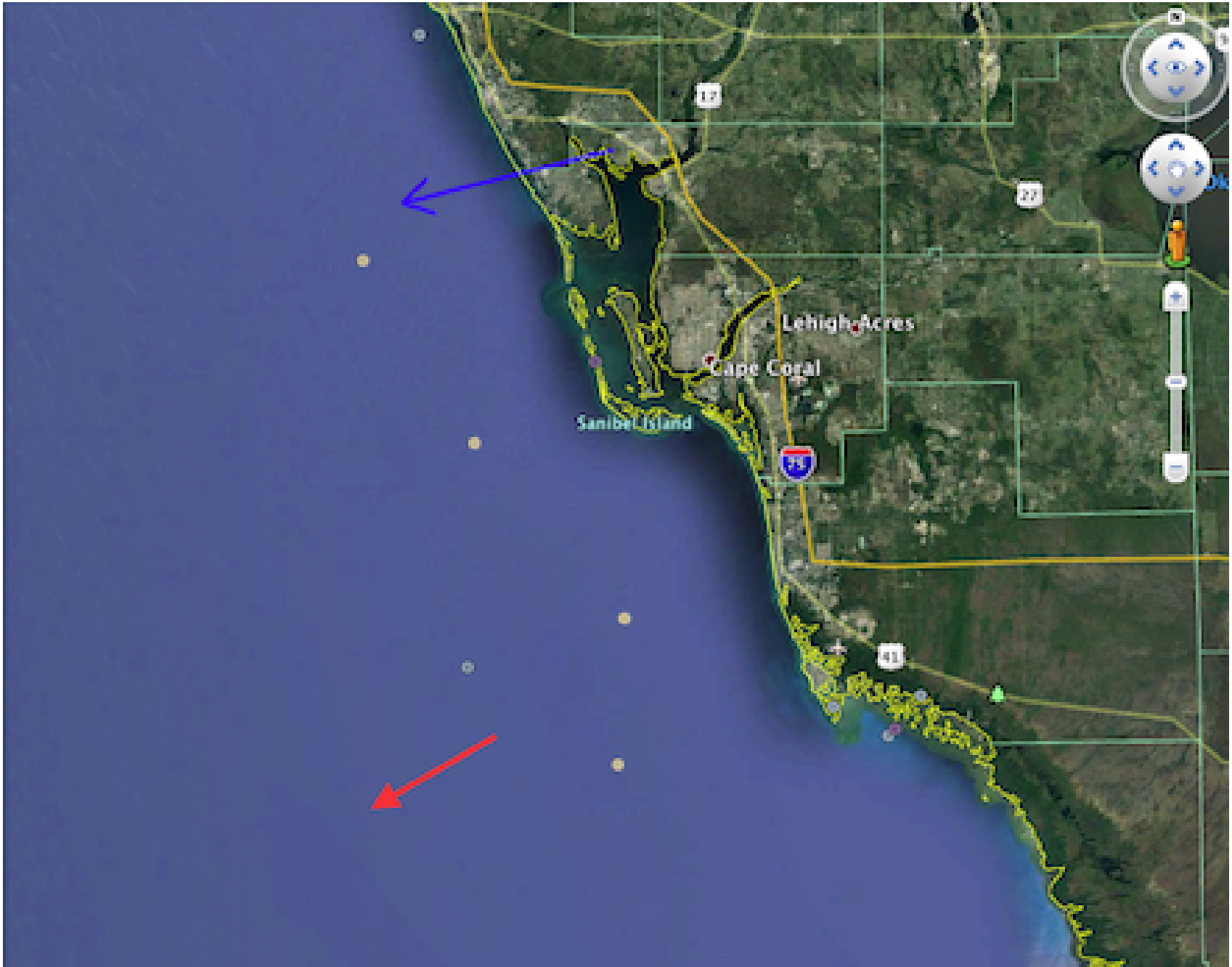
Map of observer reports from amsmeteors.org



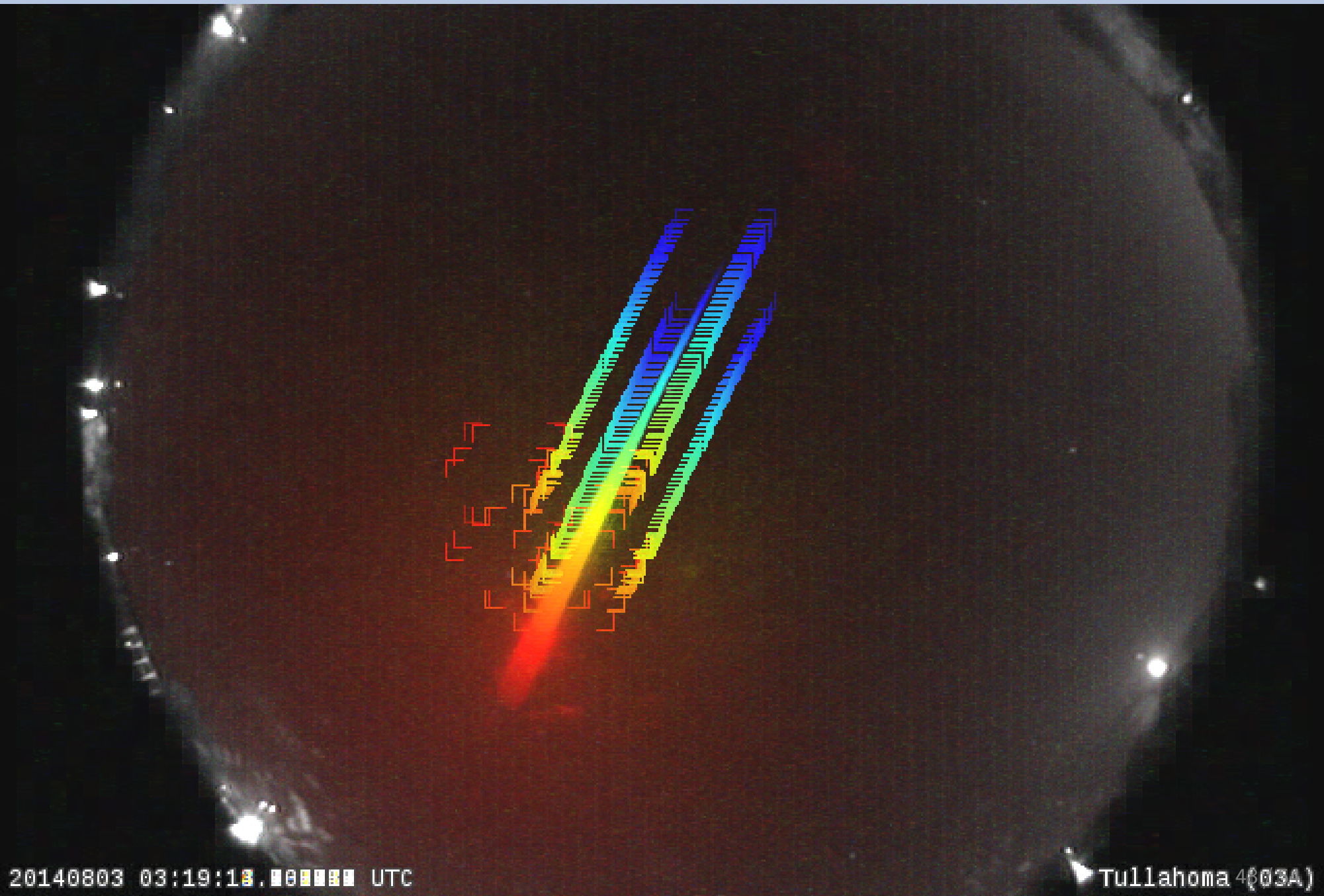
“Skyfalls”



“Skyfalls”



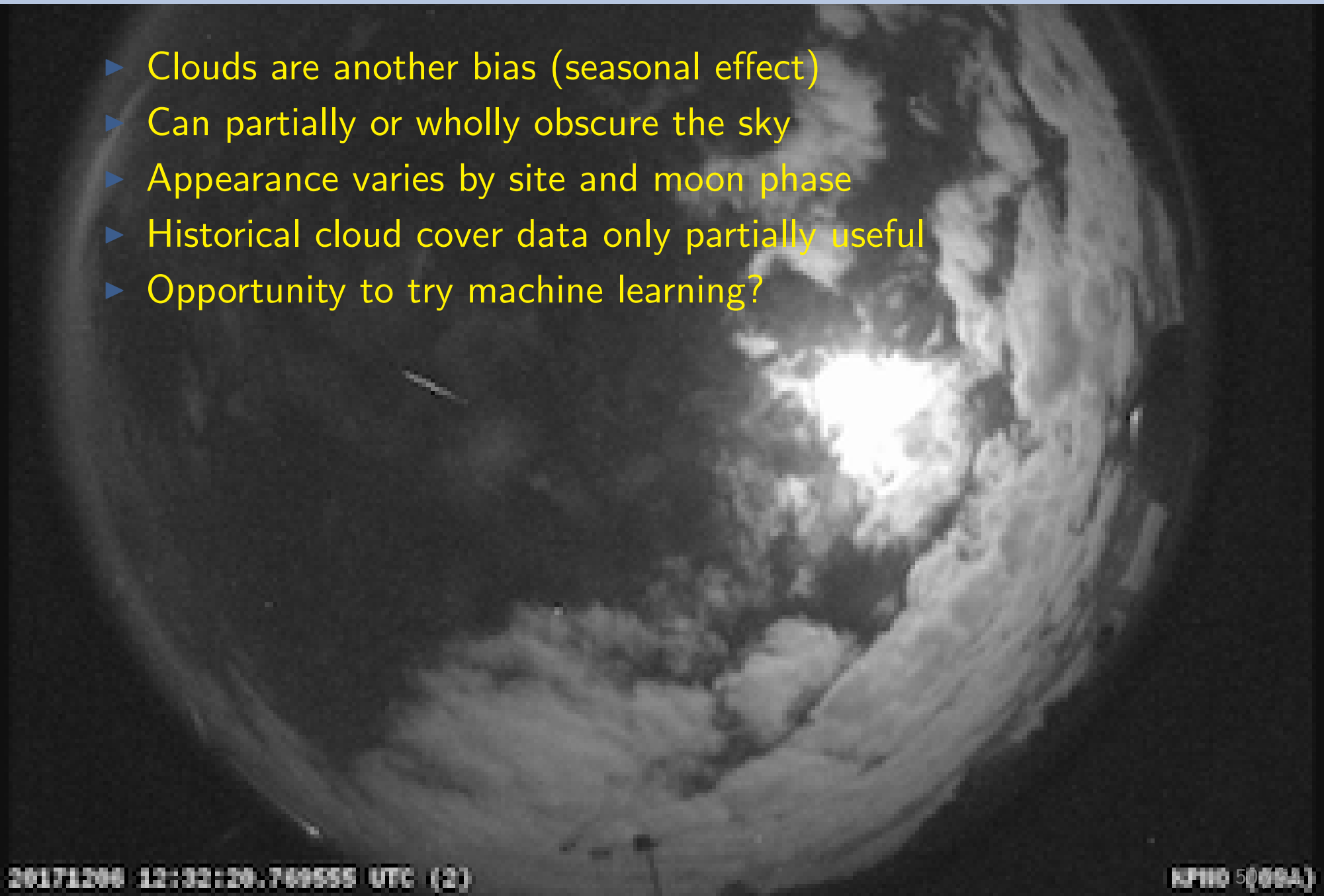
Meteorite falls



Meteorite falls

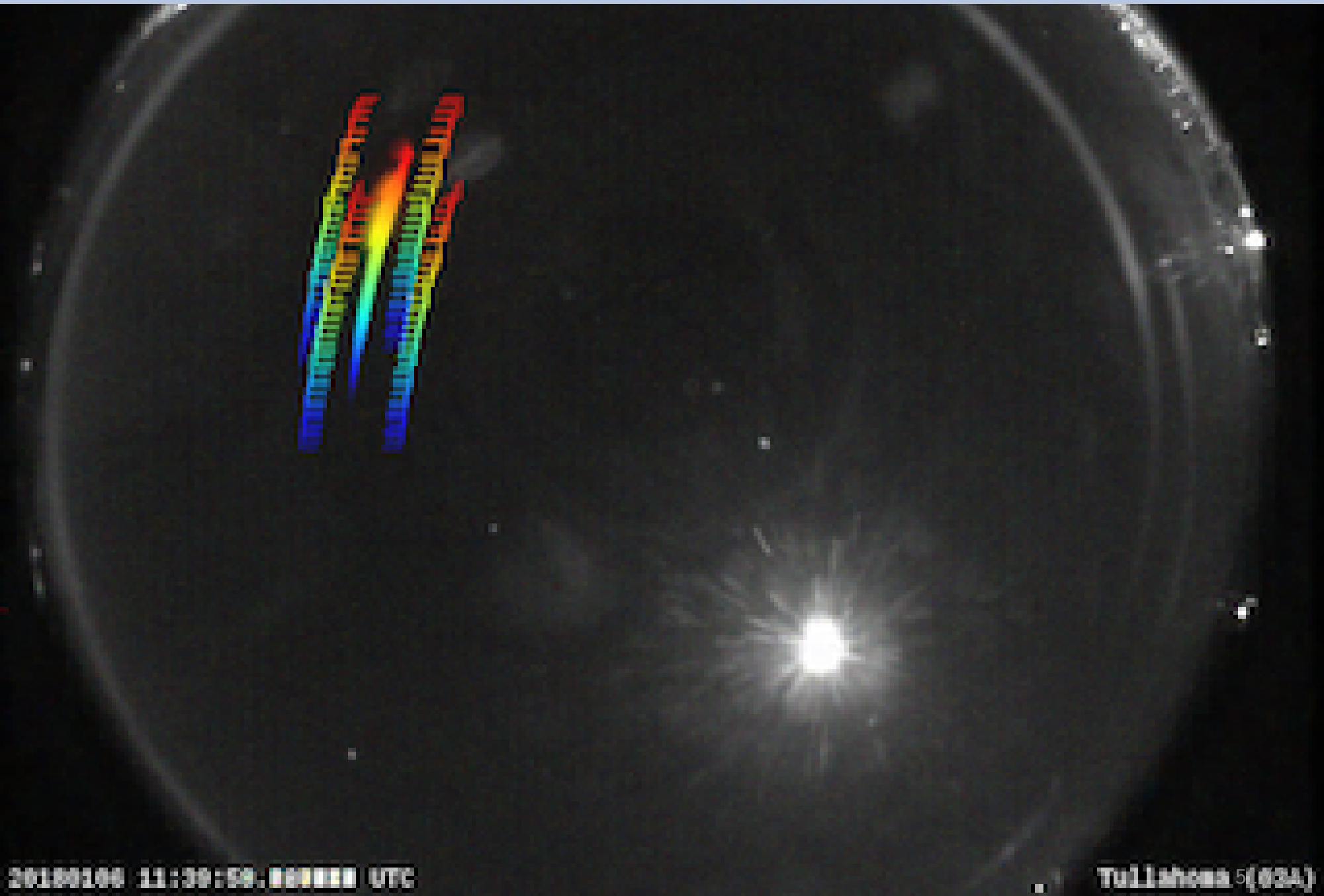
Meteorite pieces found near Addison, AL by Stephen Beck, Tommy Brown, Jerry Hinkle, and Robert Woolard. Credit: Tommy Brown

Potential projects: Cloud detection

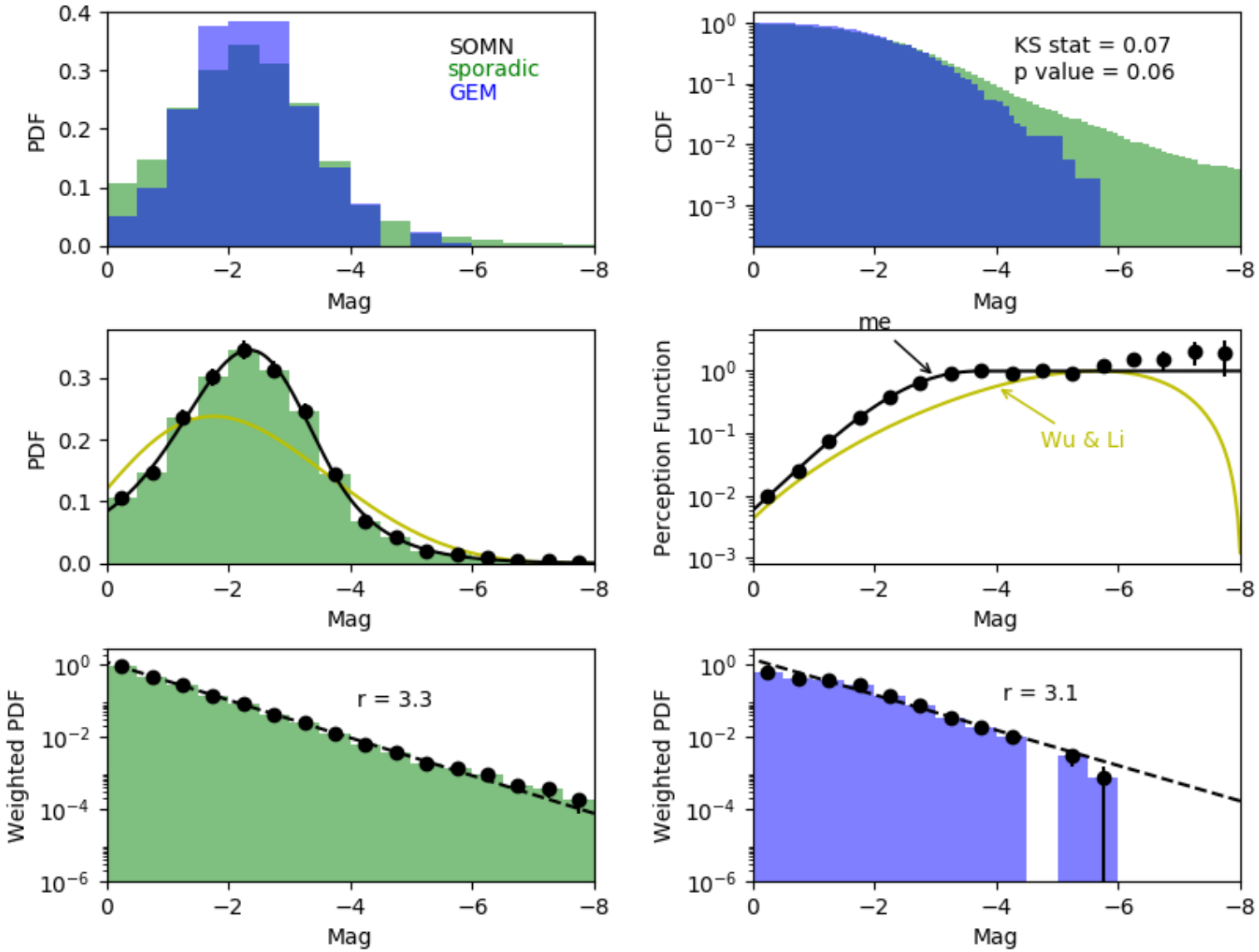


- Clouds are another bias (seasonal effect)
- Can partially or wholly obscure the sky
- Appearance varies by site and moon phase
- Historical cloud cover data only partially useful
- Opportunity to try machine learning?

Potential projects: Saturation correction

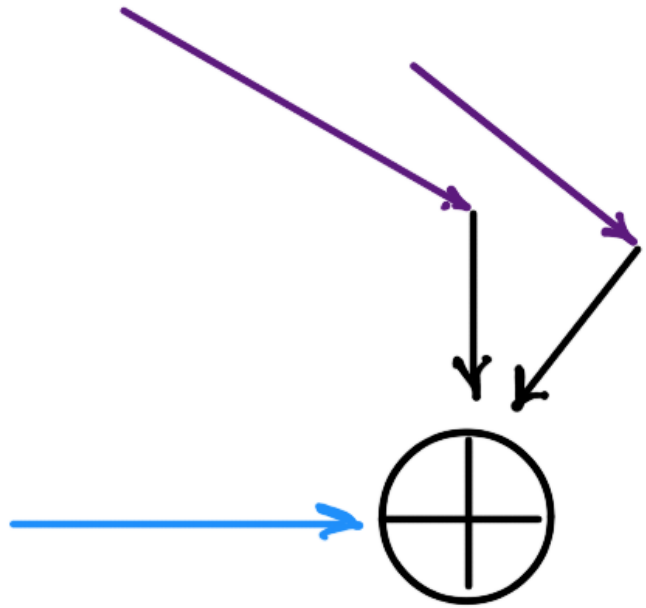


Potential projects: Mass indices



Potential projects: Slow shower survey

- We generally use *geocentric* radiant to identify meteor showers
- This can increase the apparent dispersion for slower showers
- Could survey using heliocentric radiant instead



Summary

- Embry-Riddle and UCF host two of the newest cameras in the NASA All Sky Fireball Network (welcome!)
- The data from this network are used in a variety of tasks and projects
  - shower detection
  - shower surveys
  - shower reports
  - bright bolide analyses ("skyfalls")
  - meteorite hunts
- The data can be used for student research projects. Potential projects include:
  - cloud detection
  - saturation correction
  - mass indices
  - a survey of slow showers