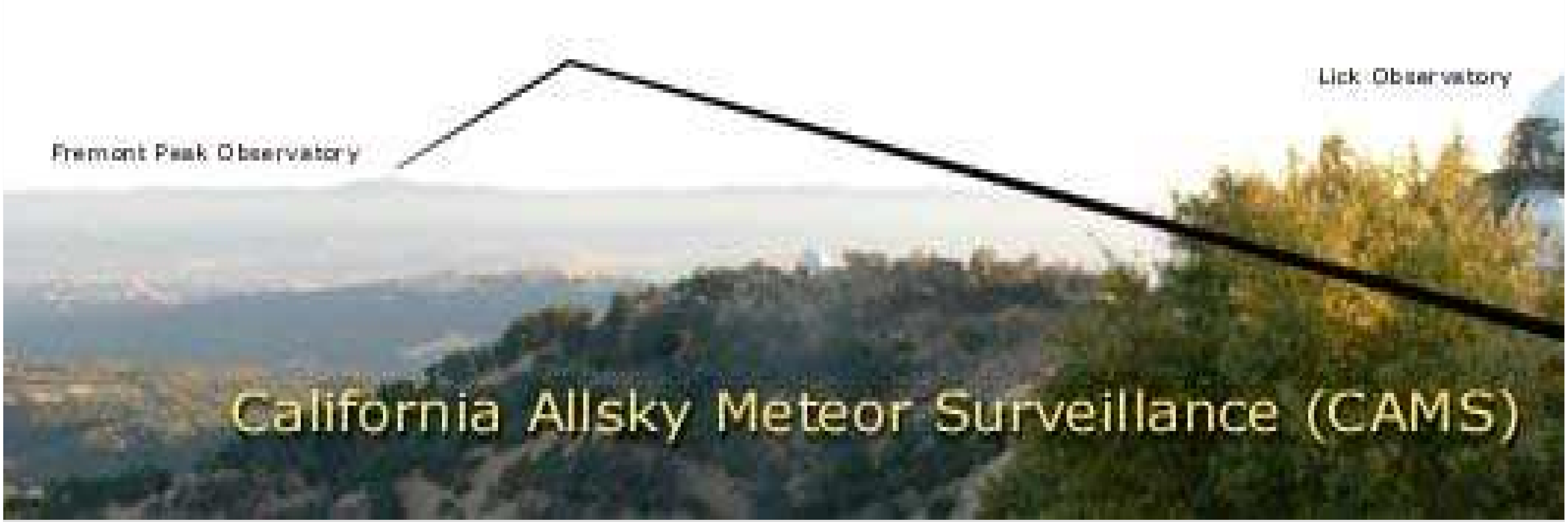


http://cams.seti.org/

Principle Investigator: Dr. Peter Jenniskens

CAMS System and Software Development Progress
and
Meteor Camera Trade Study

Pete Gural

<u>Mission Statement</u>: *Validate minor streams in the IAU Working List of Meteor Showers through automated video meteor surveillance of the night sky.*

IMC Armagh, N. Ireland – Sept 16-18, 2010

CAMS Participants

Funding Agency

Prime Contract

DVR Development

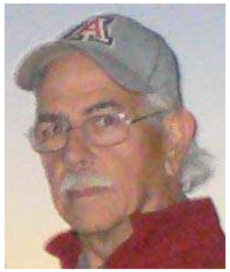
Software Development

Dr. Peter Jenniskens
Principle Investigator
SETI Institute

Kevin Newman
Steffi Valkov
Erin Leidy
Summer interns
SETI Institute

Pete Gural
Meteor analysis software
Consultant

Matt Day
DVR development team lead
Border Collie Solutions Inc



Rick Morales
Head ranger
Fremont Peak Observatory

Bryant Grigsby
Support astronomer
Lick Observatory

David Nesvorny
Zodiacal dust cloud modeling
SWRI, Boulder CO

Dr. Jeremie Vaubaillon
Meteor stream dynamics
Observatoire de Paris

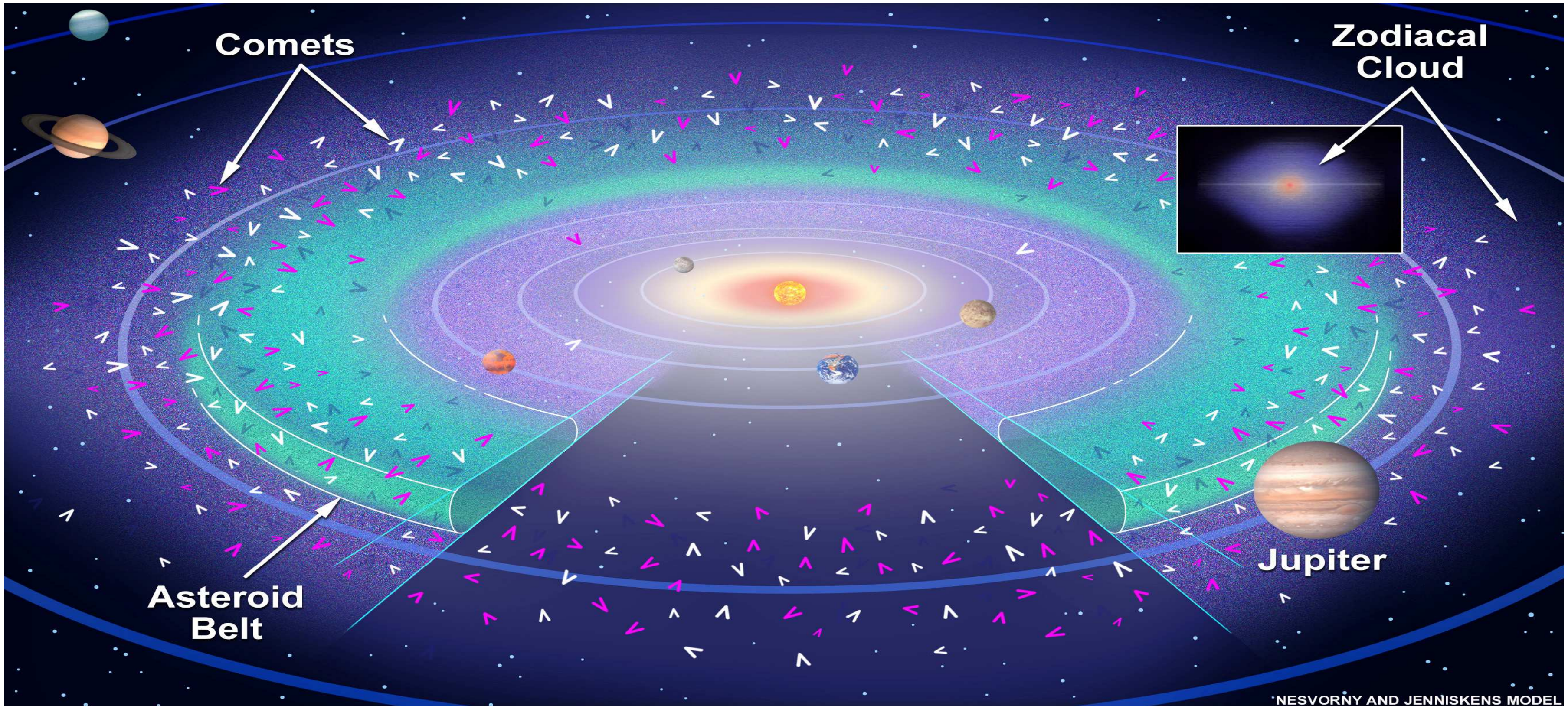
CAMS Mission Goal

The IAU working list includes 365 meteor showers, only 64 established

CAMS will try to establish the remaining ~300 minor meteor showers

Hope is to make links with dormant comets and show they broke apart in the past.

Prove cometary breakup events generated the dust of minor streams seen today.



>85% of Zodiacal Cloud dust is from (now dormant) Jupiter Family comets.

Nesvorny, et.al, 2010, "Cometary Origin of the Zodiacal Cloud and Carbonaceous Micrometeorites: Implications for Hot Debris Dust", AJ 713, pp 816-836

Example: Alpha Capricornids

IAU Data Base | **Multi-Camera Survey** | **Parent Comet Association**

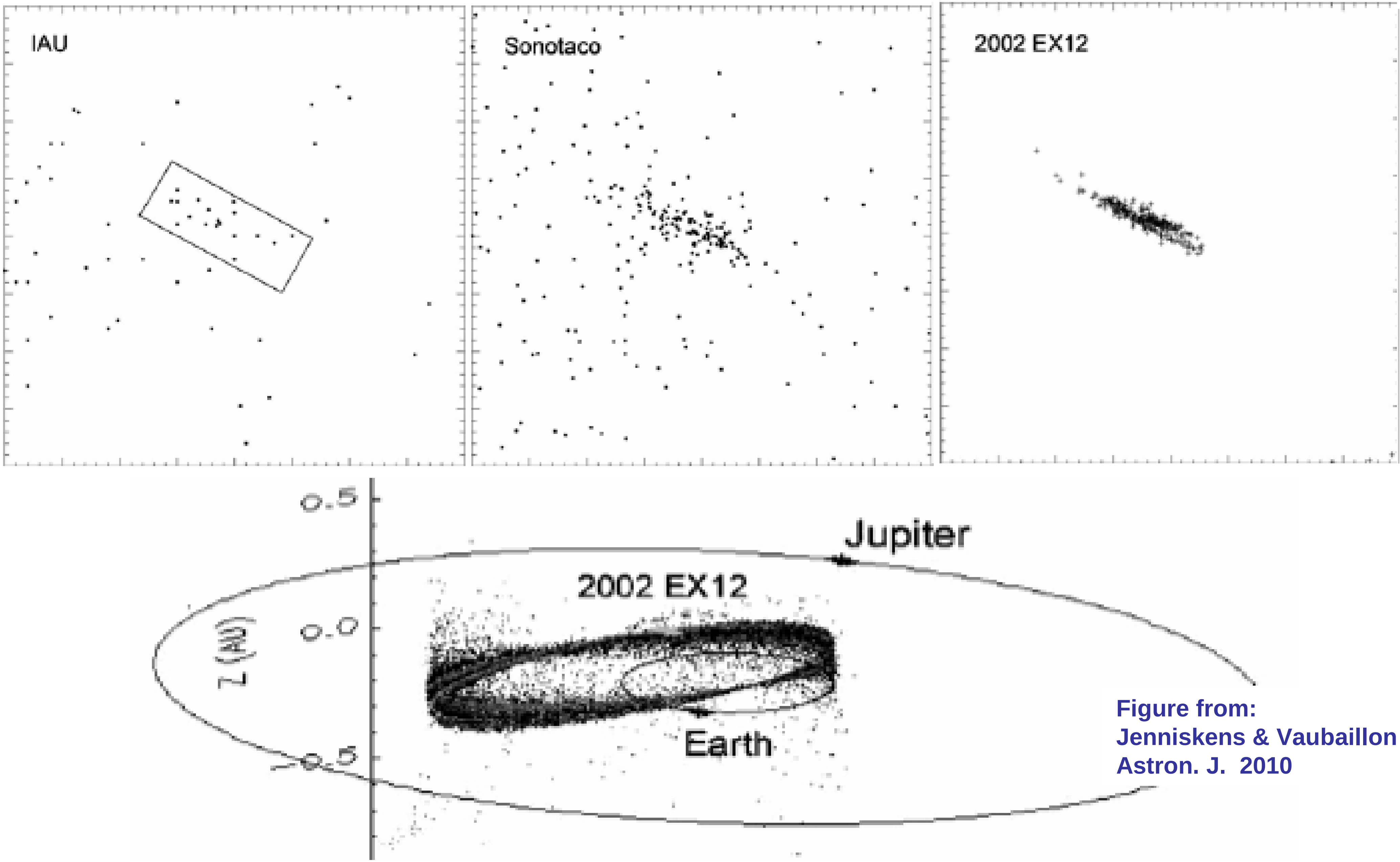
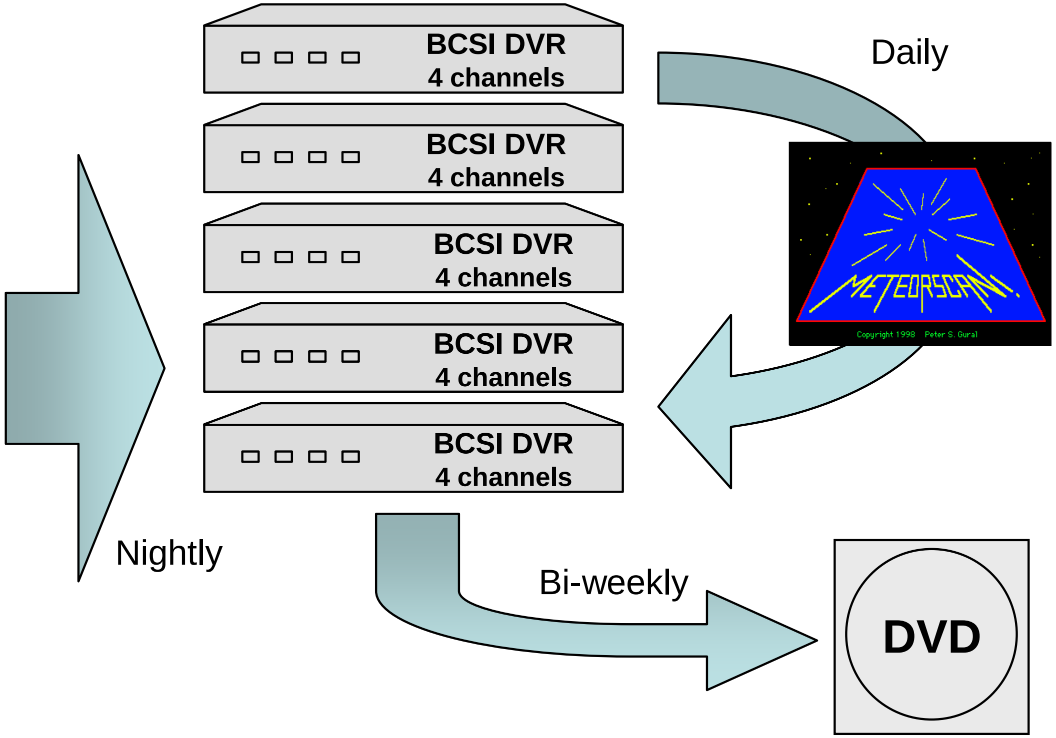


Figure from:
Jenniskens & Vaubaillon
Astron. J. 2010

CAMS Concept of Operations

Two triangulation sites providing automated all-sky coverage with higher angular resolution and sensitivity than a pair of fisheye cameras → orbits.



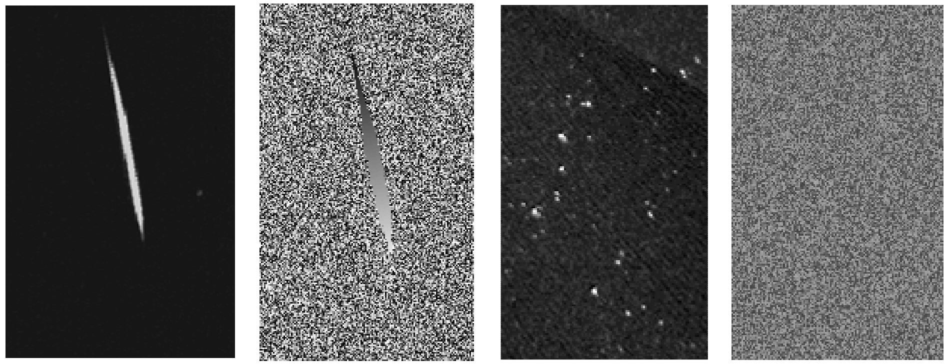
5 DVRs compress 20 frame-rate CCDs.
Store entire night's video on hard drive.
Daytime detection processing → cull files.
Archive detection-only files to DVD.

20 Watec 902H2 Ultimates per Site

11 at elevation = 41°	12mm (21.0° x 27.4°)	f/1.2
8 at elevation = 62°	12mm (21.0° x 27.4°)	f/1.2
1 at elevation = 90°	6mm (28.6° x 36.9°)	f/1.4

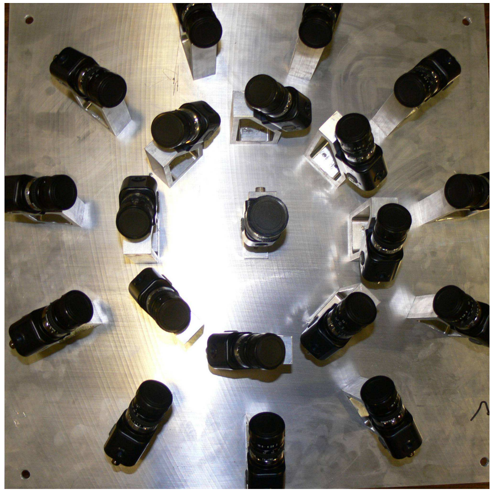
FTP: Flat-field Temporal Pixel Contents

256 Frames compressed to:

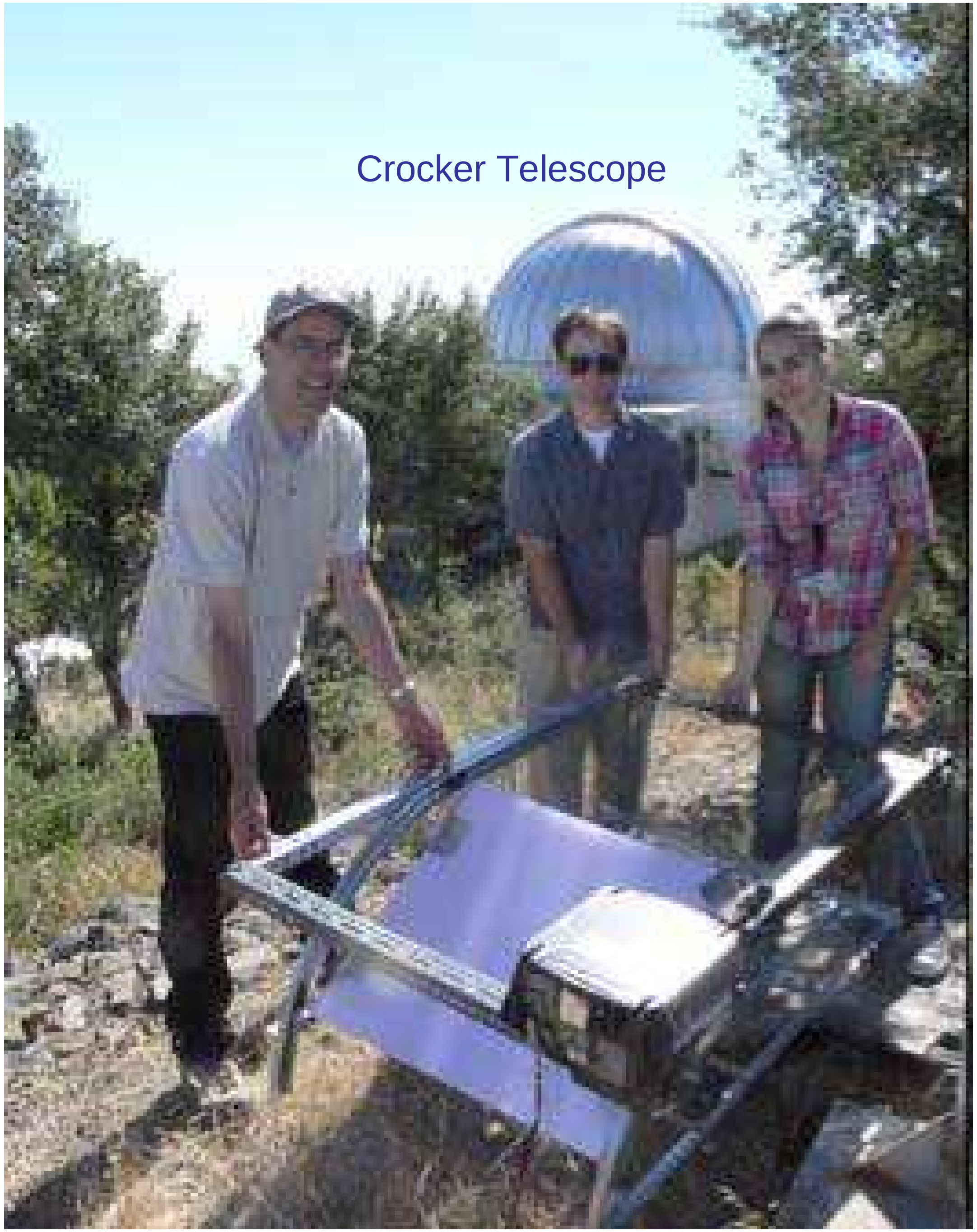


Max Value | **Max Frame#** | **Mean** w/o Max | **Std Dev** w/o Max

CAMS Installation at Fremont Peak

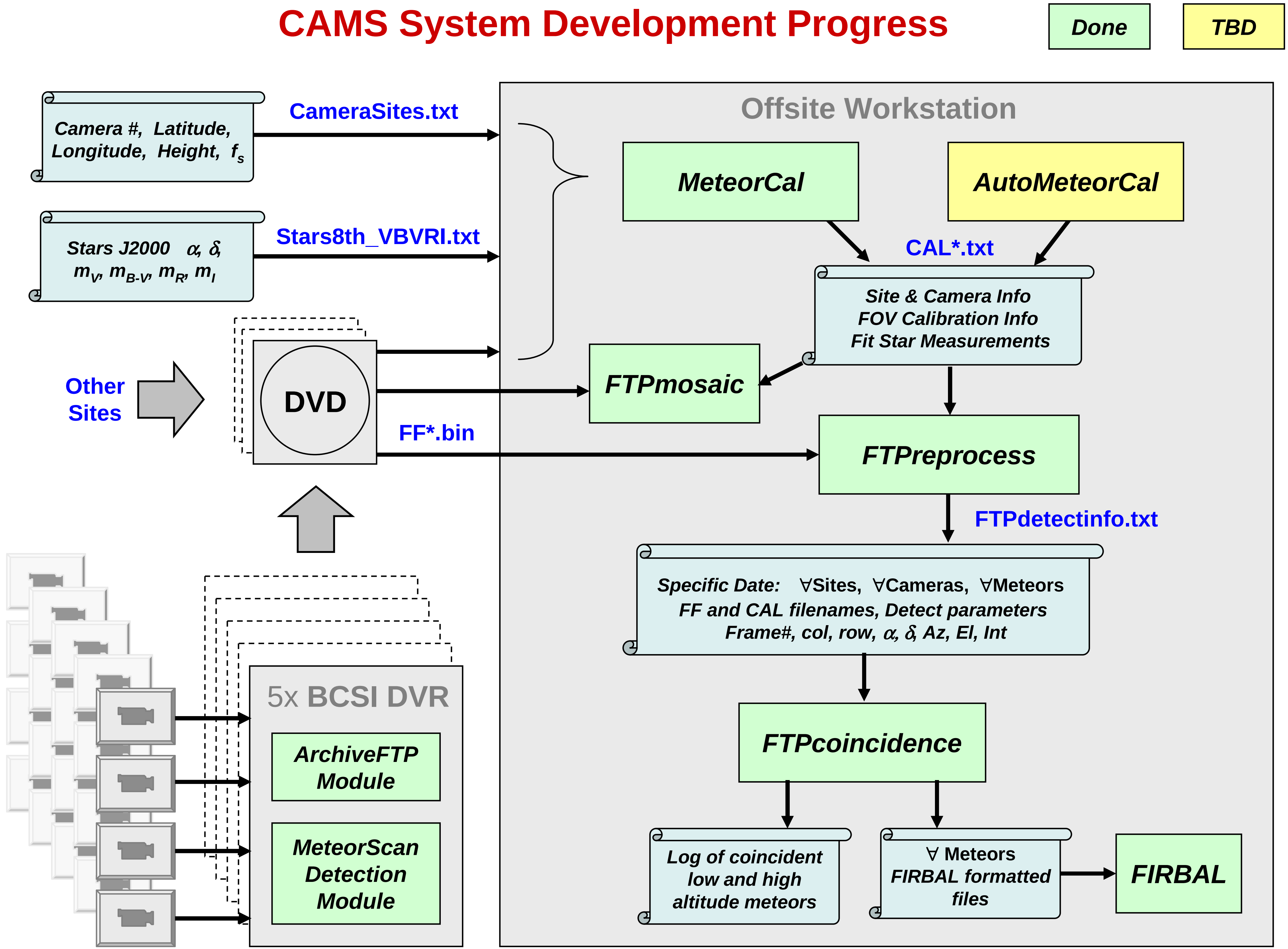


CAMS Site Survey at Mt. Hamilton, Lick Observatory

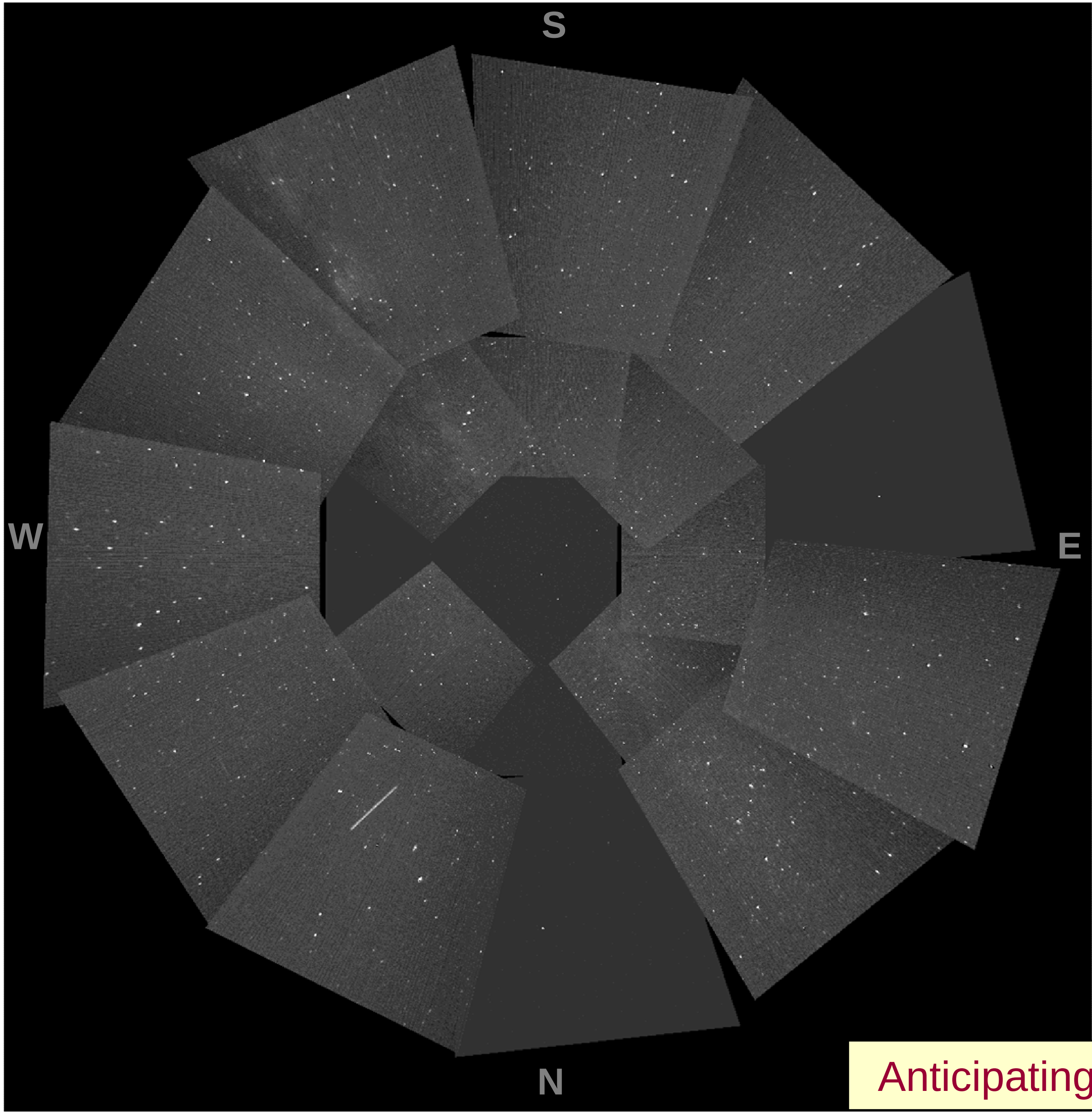


Dave Holman: Enclosure with wind deflectors

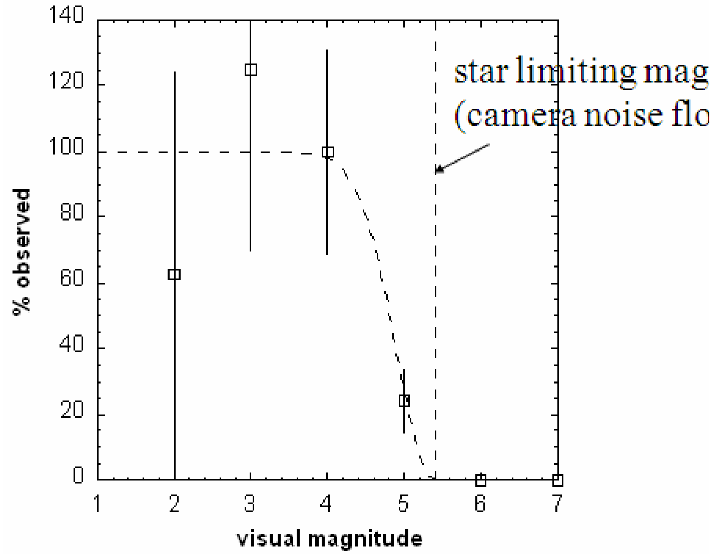
CAMS System Development Progress

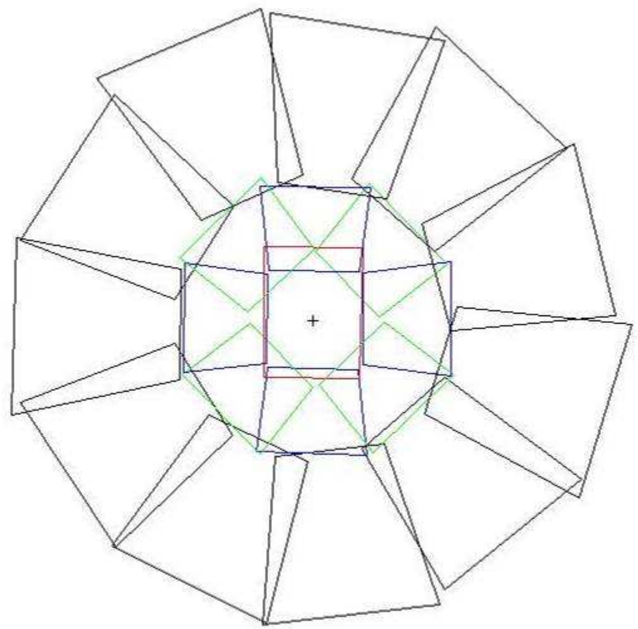


CAMS First Light at Fremont Peak – August 2010 Perseids



Gnomic Projection of all 20 Cameras

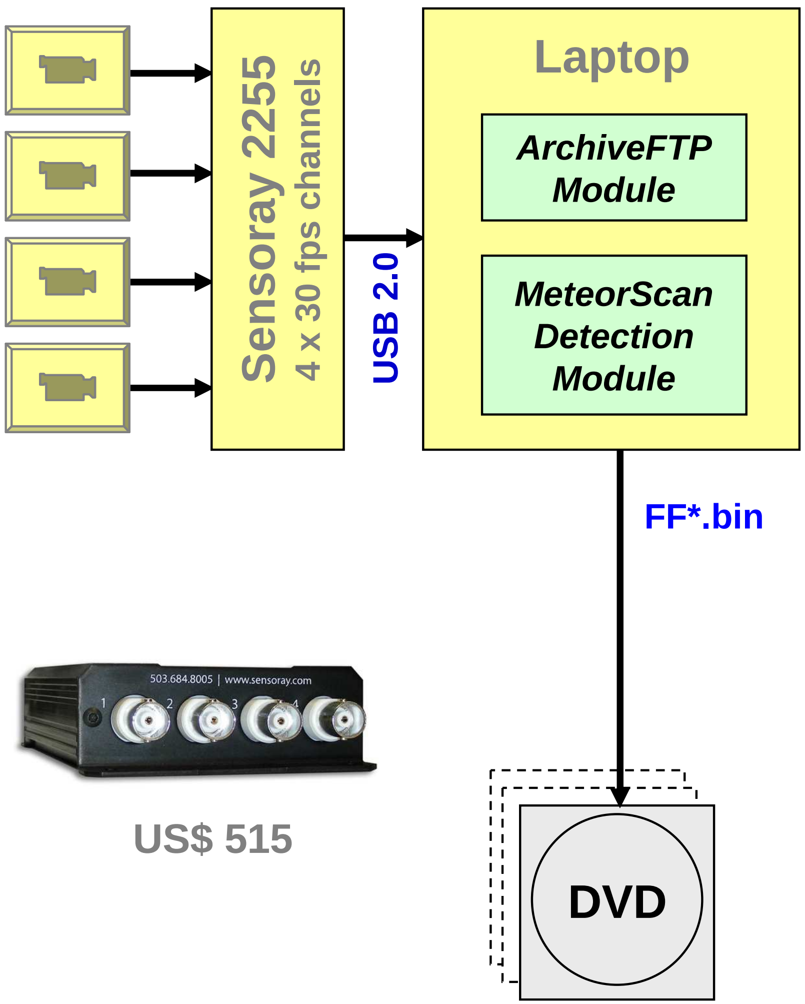




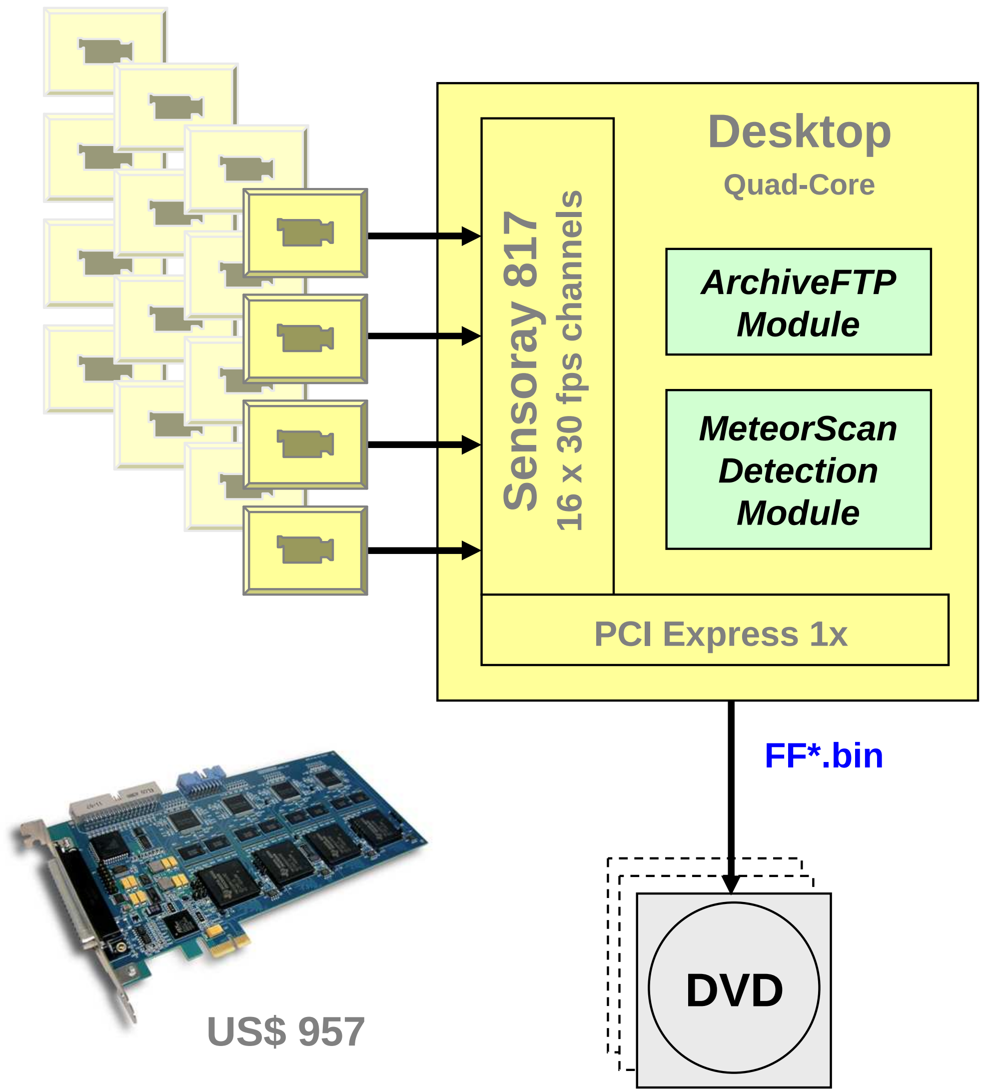
Anticipating #meteor pairs / night > 100

New Technologies for Multi-Camera Meteor Collection

4-Camera Highly Portable



16-Camera Large Coverage Area



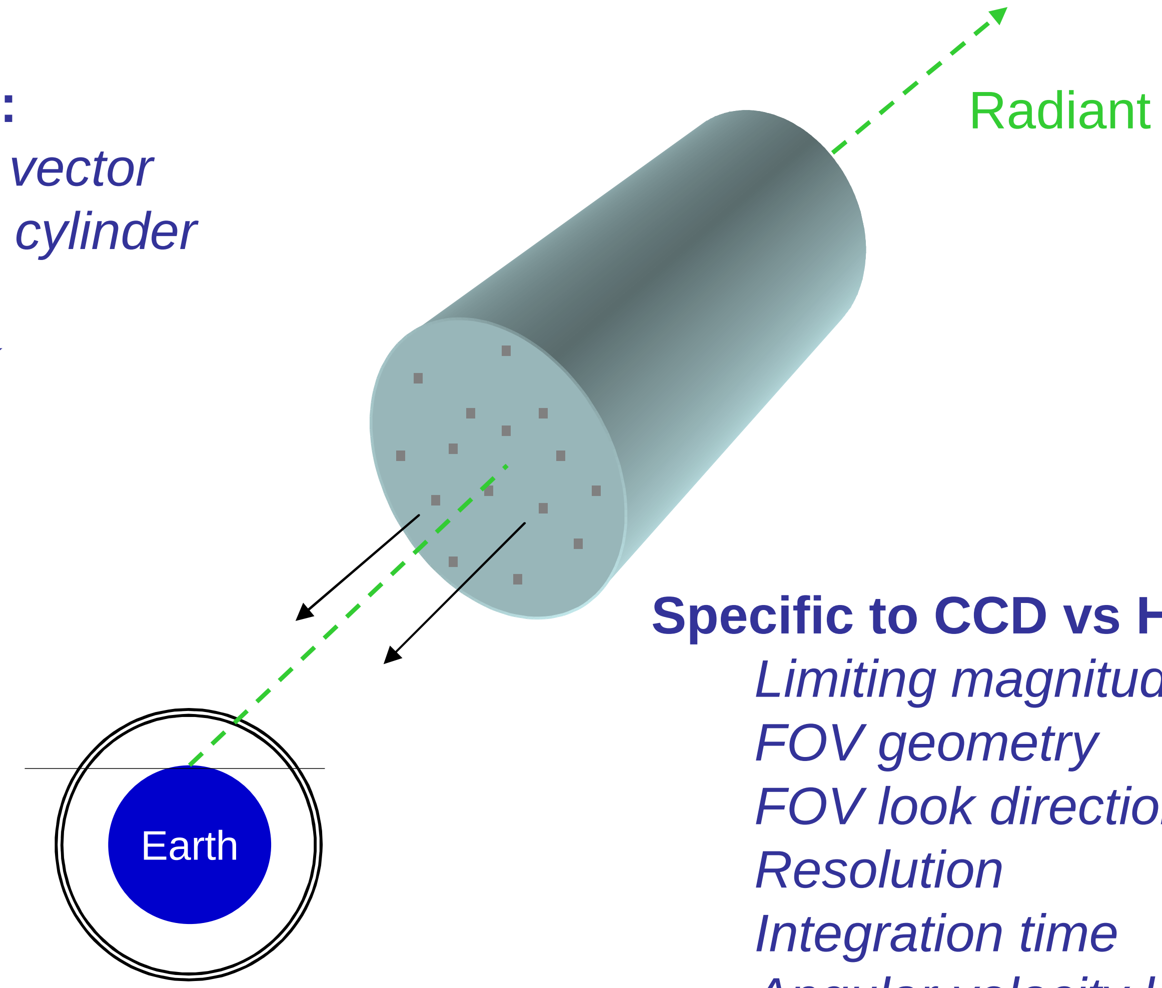
Meteor Camera Trade Study

- **Examined a variety of meteor imaging configurations**
  - *Detection sensitivity, resolution, cost, and count statistics*
- **Performed under the SAME observing environment**
  - *Compiled system configurations and specs*
  - *Employed a meteor simulation tool → MeteorSim*
    - V_∞=42 km/sec, h_b=98km, h_e=86km, r=3.0, radiant @zenith,
    - H_{sensor}=0km, θ_{sensor}=50º except all-sky
    - Losses for angular velocity, extinction, and distance fading
    - 1 Billion meteoroids
  - *Developed trade-off plots*
- **Note that scientific rationale governs "best" system**
  - *Fireballs, Stream Flux, Orbits, Fragmentation, …*

MeteorSim – Meteor Simulation for CCD Cameras and Human Observers

Meteorids assumed to have:

Initial direction along radiant vector
Random start position within cylinder
Fixed begin and end heights
Fixed magnitude along track
Initial speed V_∞
Fixed population index r
Mag distribution = [-8,+8]
Undergone zenith attraction
Not decelerated
Distance fading loss
Atmospheric extinction loss
Lens loss



Specific to CCD vs Human:

Limiting magnitude
FOV geometry
FOV look direction
Resolution
Integration time
Angular velocity loss
Off-axis perception

Monte Carlo meteor influx simulation for video and visual observations/calibration

Converts video counts → Spatial flux → Human ZHR

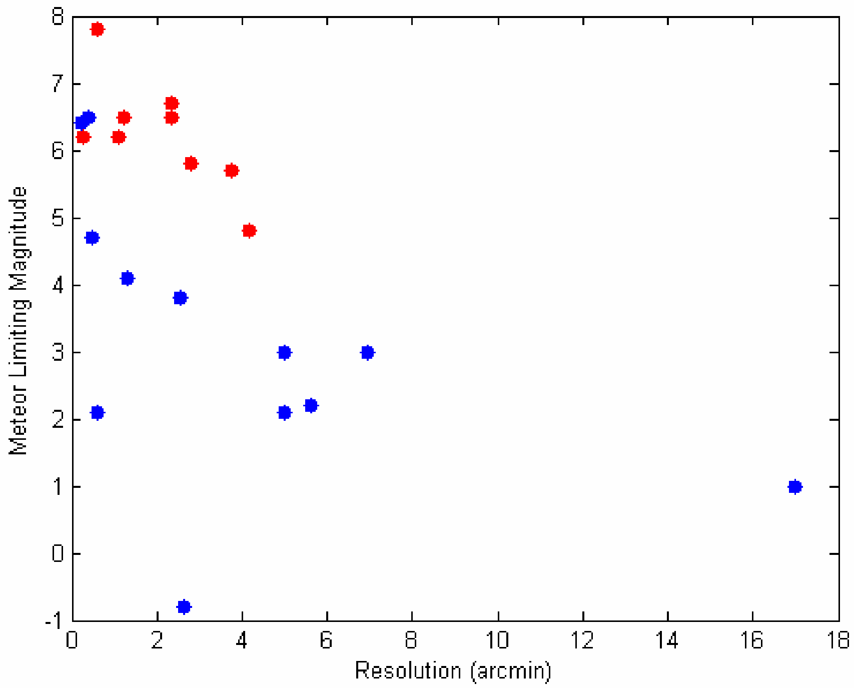
Representative Meteor Camera Systems in use Around the World

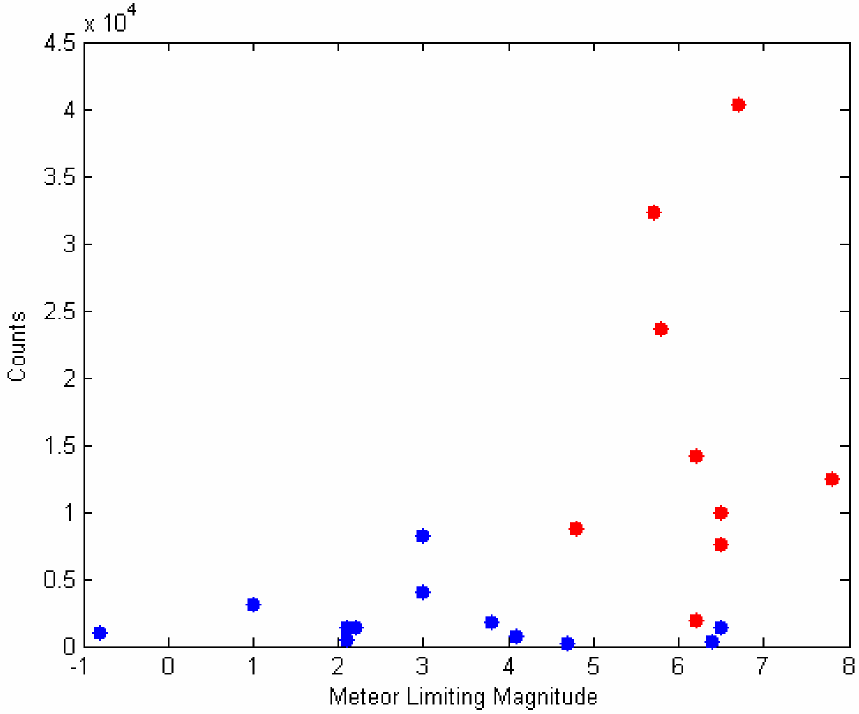
	Camera	Rate fps	Δt sec	Lens Focal length in mm	Focal ratio	FOV H x W	Resol per pix	Stellar *lm*	Meteor *lm* *	Counts MeteorSim
A	Sony HB-710E	30 i	0.017	Rainbow 1.6mm	f/1.4	180°	17’	+1.0	+1.0	3050
B	SPFN 4Kx4K	.033 i	30			180°	2.63’	+9.0	-0.8	970
C	MTV12V6EX	25 i	0.02	Computar 3.8mm	f/0.8	69° x 89°	6.95’	+3.8	+3.0	8280
D	1004X	25 i	0.02	AVC 4mm	f/1.2	48° x 64°	5.0’	+3.2	+2.1	1410
E	Watec 902H2U MTV12V6EX	30 i 25 i	0.017 0.02	Computar 6mm	f/0.8	44° x 60° 48° x 64°	5.62’ 5.0’	+3.0 +3.5 to +4.5	+2.2 +2.4 to +3.4	1340 1940 – 6030
F	Watec 902H2U	30 i	0.0167	Pentax 12 mm	f/1.2	21° x 27.4°	2.57’	+5.4	+3.8	1750
G	Watec 902H2U	30 i	0.0167	Fujinon 25 mm	f/0.85	11° x 14°	1.31’	+6.5	+4.1	780
H	LH1 11000 Kodak	1 p	0.5	Canon 50mm	f/1.2	27° x 40°	36”	+9.0	+2.1	460
J	PC164C 1/3”	30 i	0.0167	Computar 50mm	f/1.3	3.75° x 5°	28”	+8.2	+4.7	260
K	Watec 902H2U PC164C 1/3”	30 i	0.0167	Orion w/ f-reducer Orion 9x50 150mm	f/1.6 f/3.0	3° x 4° 1.1° x 1.5°	23” 14”	+10.2 +10.7	+6.5 +6.4	1340 350
L	X1332 + Generic	25 i	0.02	50mm	f/1.4	33° x 43° c	4.17’	+6.0	+4.8	8770
M	X1332 + PC164C	30 i	0.0167	Nikon 50mm	f/1.4	30° x 40°	3.75’	+7.0	+5.7	32300
N	Gen II + COHU	30 i	0.0167	Fuji 25mm	f/0.85	23° x 30°	2.81’	+7.5	+5.8	23500
P	Gen III + COHU	30 i	0.0167	Fuji 25mm	f/0.85	19° x 25°	2.34’	+8.5	+6.7	40300
Q	Gen III + Imperix	80 p	0.0125	Fuji 25mm	f/0.85	19° x 25°	2.34’	+7.0	+6.5	7540
R	Gen III + Imperix	80 p	0.0125	ZenithStar80 545mm	f/6.5	1.1° x 1.5°	8.44”	TBD	Limit by ↑	N/A
S	Gen II + ?	30 i	0.0167	Pentax 85mm	f/1.2	10° x 13°	1.22’	+9.0	+6.5	9940
T	NiteCam Gen III	20 p	0.05	Fuji 25mm	f/0.85	19° circ	1.11’	+10.0	+6.2	14100
U	Gen II + COHU	30 i	0.0167	155mm	f/1.2	5.0° x 6.6°	37”	+11.0	+7.8	12400
V	Gated	200 p	0.005	50mm	f/0.95	4.6° x 6.0°	16”	+9.0	+6.2	1860

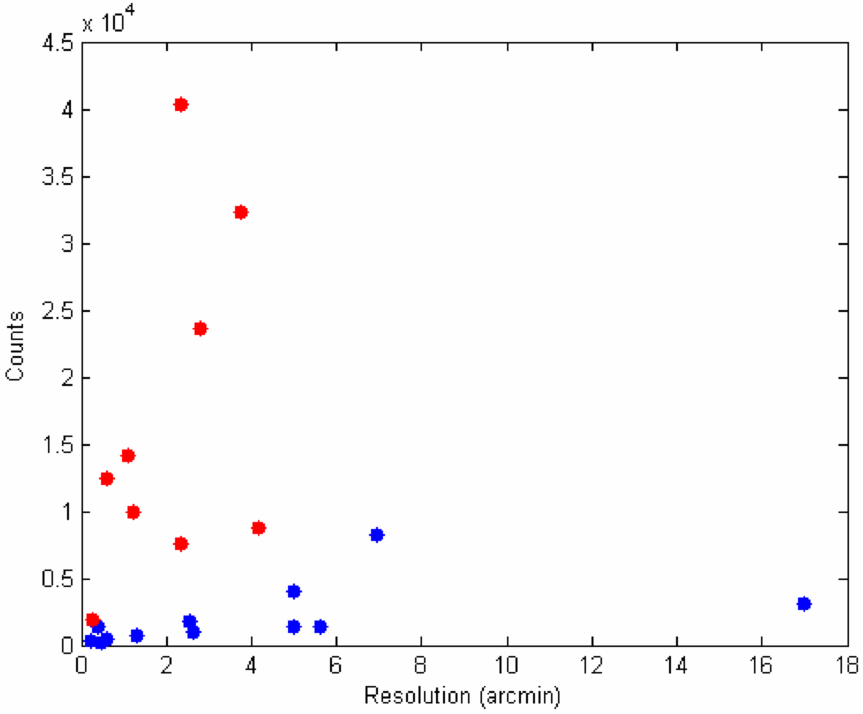
Processing parameters (V_∞=42 km/sec, h_b=98km, h_e=86km, r=3.0, Radiant @zenith, θ_{sensor}=50°, Loss for ω, extinct & dist)

*** *lm* is for a typical meteor with angular velocity losses** (V_∞=42 km/sec, q=130km, D=40°)

Camera Trade Study Results

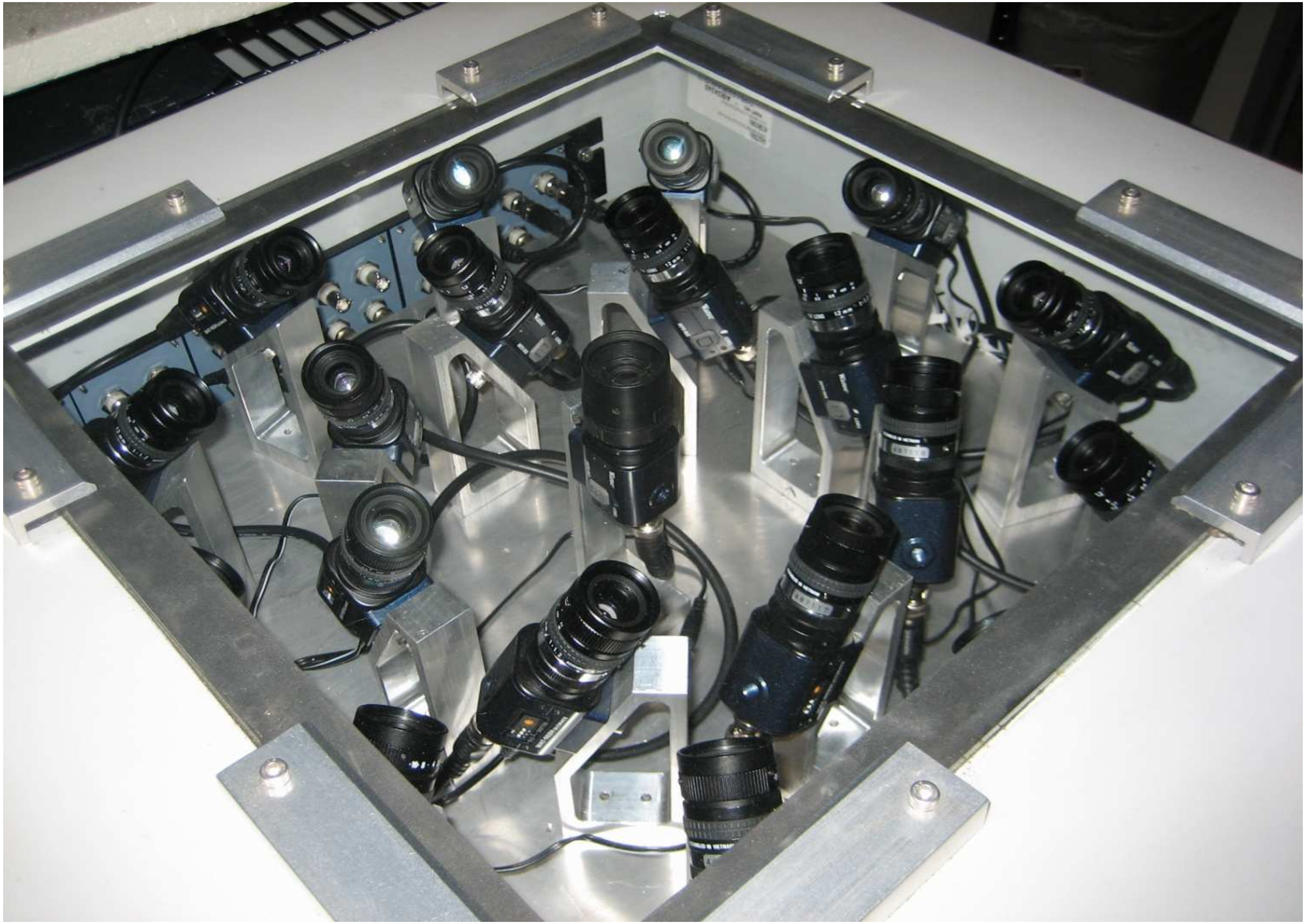






- Intensifiers generally outperform non-intensified systems
- Intensifiers 1.5 mag fainter where r helps increase counts
- Increased sky coverage usually an advantage for stats except at the extreme end of all-sky

Questions ?



Backup Charts

Camera system component costs

FTPcoincidence Logic Flow Chart

- ***Overview***
- ***Coincidence between sites***
- ***Other pairs at different sites***
- ***Pairs at same site and co-linear***

File Formats

- ***CamerasSites.txt***
- ***Stars8th_VBVRI.txt***
- ***CAL###_YYYYMMDD_HHMMSS.txt***
- ***FTPdetectinfo.txt***
- ***FIRBAL Input***
- ***FF###_YYYYMMDD_HHMMSS_MSC_FRAMENO.bin***

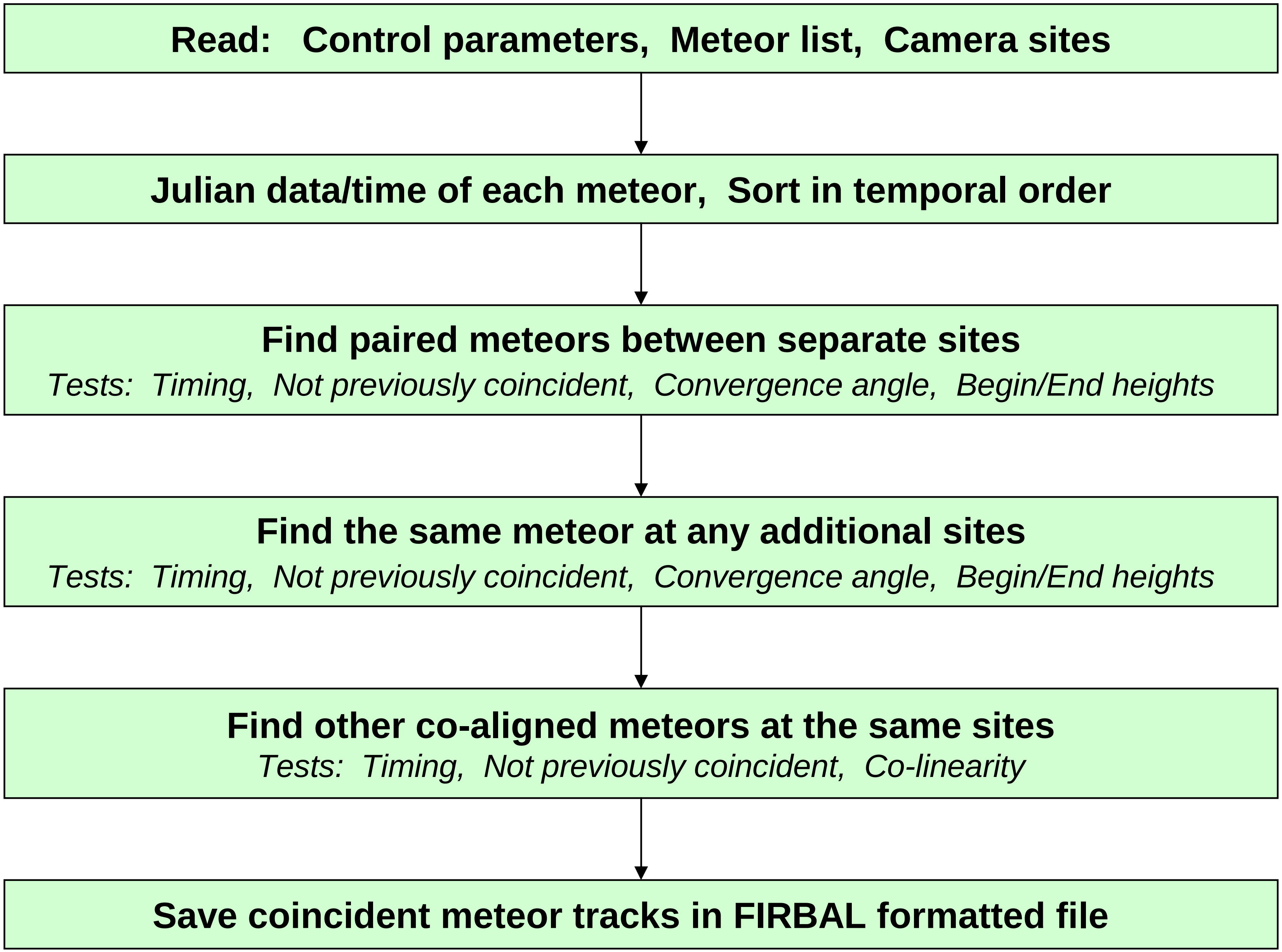
Meteor Camera Component Costs

Camera	LUX	Cost $US
Watec 902H2U 1/2”	0.0001	$317
PC164C-EX2 1/3”	0.0001	$140
Mintron MTV12V6EX	0.0002	$490
LH 11000		$19000

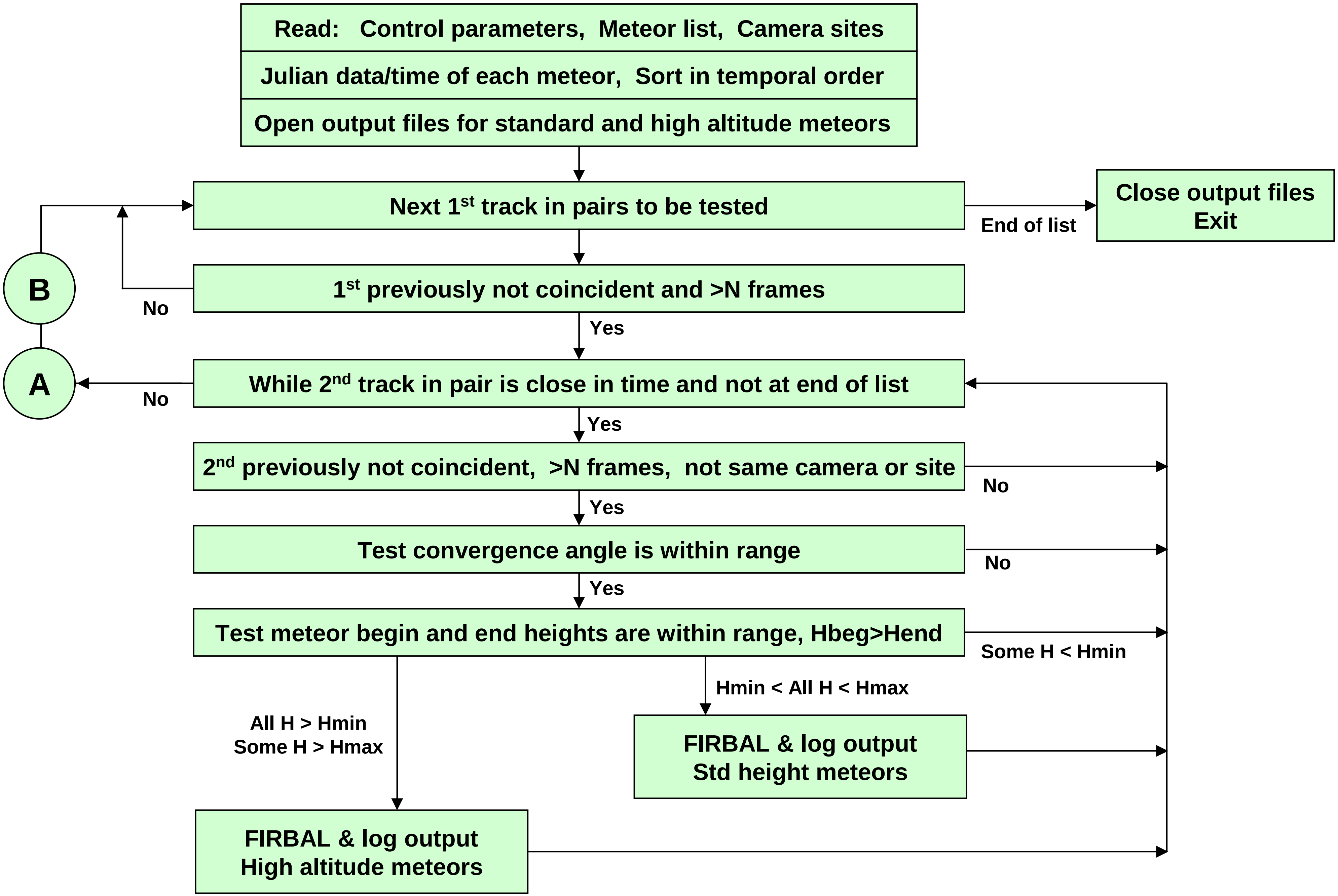
Intensifier	Cost $US
Gen II	$400
Gen III	$7000
Imperix	$2000
PCO (gated)	$25000

Lens	Cost $US
Computar 6mm f/0.8	$ 300
Computar 8mm f/0.8	$ 116
Computar 12mm f/0.8	$ 112
Navitar 12mm f/1.3	$ 135
Navitar 17mm f/0.95	$ 390
Navitar 25mm f/1.4	$ 95
Fujinon 25mm f/0.85	$ 400
Computar 50mm f/1.3	$ 130
Nikon 50mm f/1.4	$ 280
Canon 50mm f/1.2	$ 2100
Orion 9x50 150mm f/3	$ 80
Pentax 85mm f/1.2	$1750
Meade 400mm f/4.5	$

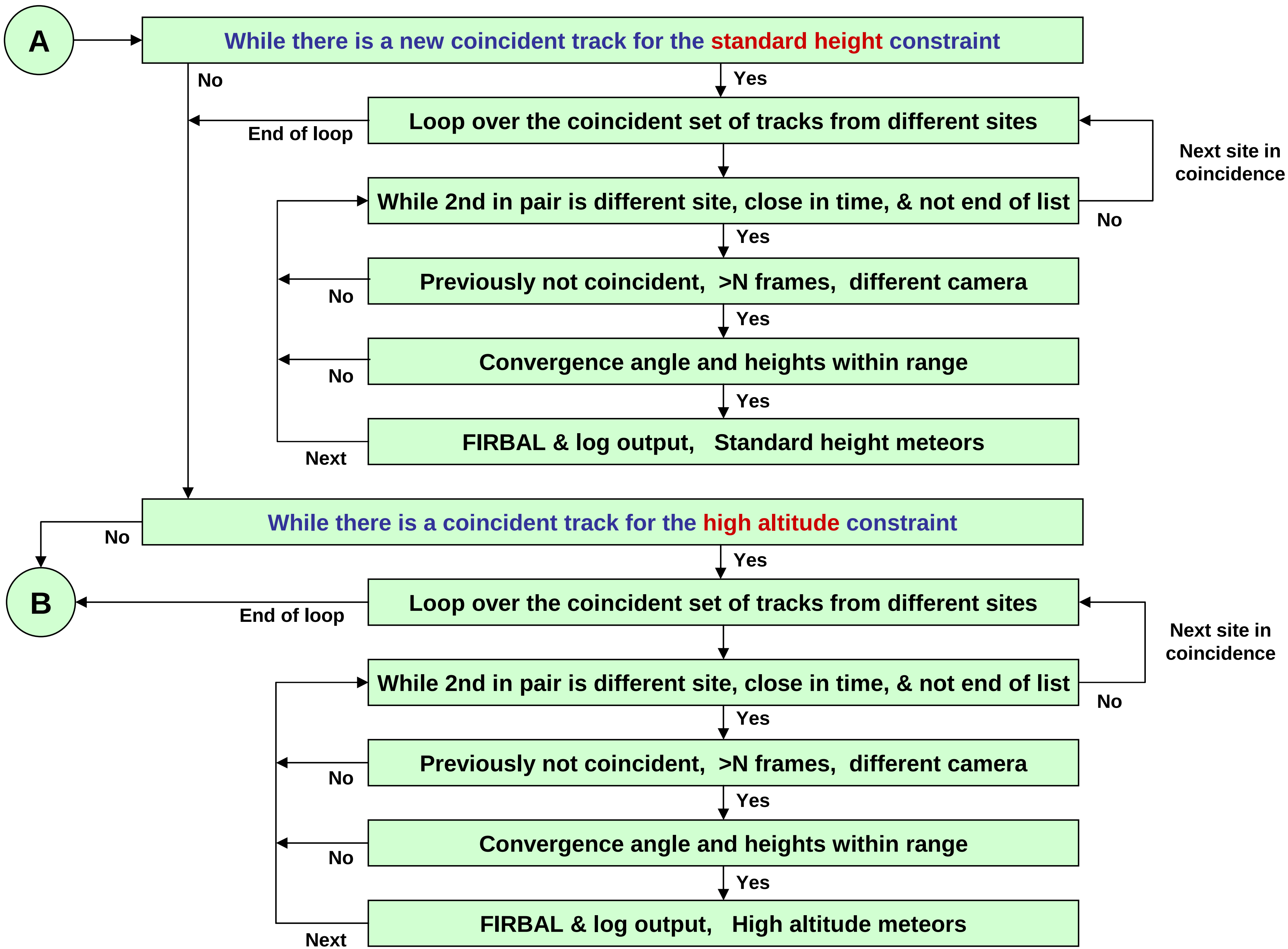
FTPcoincidence - Flow Chart Overview



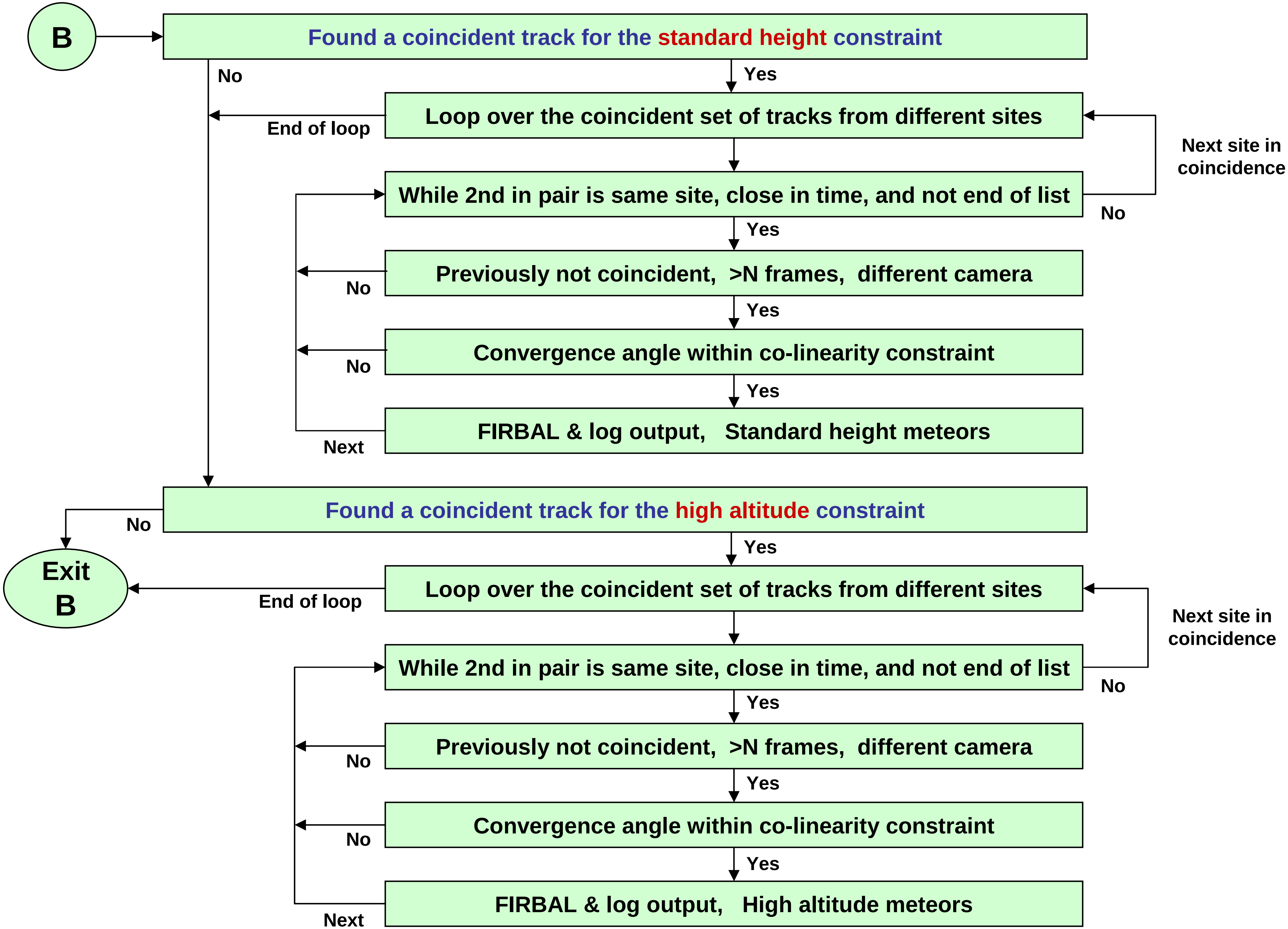
FTPcoincidence Flow Chart *(Coincidence between sites)*



FTPcoincidence Flow Chart *(Other pairs at different sites)*



FTPcoincidence Flow Chart *(Pairs at same site and co-linear)*



CameraSites.txt

Cam#	Lat(+N)	Long(+W)	Height(km)	Rate(Hz)	Code	Station Name
----	--------	---------	----------	--------	----	----------------
1	+39.0010	+73.0120	0.01	29.97	ST	SterlingVirginia
2	+39.0020	+73.0220	0.02	29.97	ST	SterlingVirginia
3	+39.0030	+73.0320	0.03	29.97	ST	SterlingVirginia
4	+39.0040	+73.0420	0.04	29.97	ST	SterlingVirginia
5	+39.0050	+73.0520	0.05	29.97	ST	SterlingVirginia
6	+39.0060	+73.0620	0.06	29.97	ST	SterlingVirginia
7	+39.0070	+73.0720	0.07	29.97	ST	SterlingVirginia
8	+36.7602	+121.5030	0.966	29.97	FP	FremontPeakObs
9	+36.7602	+121.5030	0.966	29.97	FP	FremontPeakObs
10	+36.7602	+121.5030	0.966	29.97	FP	FremontPeakObs
11	+36.7602	+121.5030	0.966	29.97	FP	FremontPeakObs
12	+36.7602	+121.5030	0.966	29.97	FP	FremontPeakObs
13	+36.7602	+121.5030	0.966	29.97	FP	FremontPeakObs
...						

Stars8th_VBVRI.txt

Stars J2000

α, δ, m_V, m_{B-V}, m_R, m_I

0.00502	38.85928	6.63	-0.04	6.63	6.63
0.00863	-51.89355	8.05	0.35	7.83	7.62
0.03734	46.93999	7.36	0.07	7.30	7.24
0.04090	-35.96022	8.41	1.48	7.56	6.75
0.04302	-19.41465	8.38	1.48	7.53	6.72
0.04842	-0.36045	7.26	1.23	6.55	5.87
0.05099	-40.19239	8.13	0.43	7.87	7.61
0.05331	38.30405	6.53	0.95	5.98	5.45
0.06639	8.00723	7.52	1.44	6.69	5.91
0.07456	13.31223	7.56	0.41	7.31	7.07
0.07558	60.35044	8.46	1.65	7.51	6.61
0.07820	65.94470	8.49	0.43	8.23	7.98
0.07956	-44.29056	6.29	0.76	5.85	5.42
0.09611	42.14148	8.25	0.13	8.16	8.06
0.09808	2.67548	7.62	1.45	6.78	5.99
0.09917	-10.46239	8.11	0.44	7.85	7.59
0.09958	26.91811	6.44	0.51	6.13	5.84
0.10340	12.26713	7.67	1.15	7.01	6.37
0.10366	67.85191	8.11	0.22	7.97	7.83

…

CAL###_YYYYMMDD_HHMMSS.txt, ### = Camera Number

```
Camera number              = 12
Calibration date           = 07/02/2010
Calibration time (UT)      = 05:09:04
Longitude +west (deg)      =  121.50300
Latitude +north (deg)      =   36.76020
Height above 6378 km       =    0.96600
FOV dimension hxw (deg)    =   22.7 x   30.2
Plate scale (arcmin/pix)   =    2.835
Plate roll wrt Std (deg)   =  -28.201
Cam tilt wrt Horiz (deg)   =   -0.943
Frame rate (Hz)            =   29.970
Cal center RA (deg)        =  208.345
Cal center Dec (deg)       =   -5.347
Cal center Azim (deg)      =  217.378
Cal center Elev (deg)      =   40.648

Magnitude = A + B log Intensity
        A = 13.09
        B = -3.41

Spectral Class used in fit = V
```

Star	RA (deg)	DEC (deg)	row	col	V	B-V	R	IR	logInt	Int
----	---------	---------	------	------	------	------	------	------	------	-------
1	201.29825	-11.16132	421.8	389.9	1.06	-0.14	1.12	1.16	3.517	3287
2	197.48746	-5.53901	355.0	518.1	4.39	0.00	4.37	4.35	2.489	308
3	210.41164	1.54453	86.0	350.0	4.24	0.10	4.17	4.09	2.641	438
4	213.22394	-10.27370	284.1	180.1	4.18	1.33	3.42	2.69	2.672	470
5	212.71036	-16.30203	405.0	131.0	4.94	1.67	3.98	3.07	2.360	229

FTPdetectinfo.txt

Filename of processed flat field temporal pixel data
Filename used for calibration
Camera #, Meteor #, #Frames, Frame rate, HNR, MLE, BIN, Δd, Hough ρ, ϕ
Frame #, Column, Row, α, δ, Azim, Elev, Integrated counts

```
Processed with FTP on Sat Jul 17 15:51:16 2010
-------------------------------------------------
FF012_20100702_050904_376_0034048.bin
CAL012_20100702_050904.txt
0012 0001 0020 0029.97 079.5 034.6 -05.4 007.0 0010.1 0084.2
0139 0153.4 0210.4 215.95 -07.77 206.94 041.69 000090
0140 0162.6 0208.4 215.61 -07.50 207.50 041.82 000190
0141 0171.8 0211.6 215.16 -07.43 208.09 041.72 000508
0142 0177.2 0214.1 214.88 -07.42 208.44 041.62 000760
0143 0183.5 0214.6 214.61 -07.30 208.84 041.62 000884
0144 0190.6 0215.1 214.30 -07.17 209.28 041.63 000769
0145 0197.6 0216.7 213.98 -07.09 209.72 041.58 000892
0146 0203.7 0217.2 213.71 -06.97 210.10 041.57 001008
0147 0210.0 0218.2 213.42 -06.88 210.50 041.54 001327
0148 0217.3 0218.7 213.10 -06.74 210.96 041.54 000965
0149 0224.1 0219.8 212.80 -06.64 211.39 041.50 001151
0150 0230.6 0220.9 212.50 -06.54 211.80 041.47 001000
0151 0237.0 0221.4 212.22 -06.42 212.20 041.46 000537
0152 0243.4 0222.3 211.93 -06.32 212.61 041.43 000598
0153 0250.1 0223.2 211.63 -06.21 213.03 041.40 000491
0154 0256.6 0224.0 211.34 -06.10 213.44 041.37 000751
0155 0263.2 0223.6 211.08 -05.94 213.85 041.39 000604
0156 0270.0 0226.1 210.74 -05.89 214.28 041.28 000287
0157 0280.5 0225.1 210.32 -05.62 214.94 041.34 000249
0158 0283.4 0226.1 210.18 -05.59 215.12 041.29 000192
```

FIRBAL Input File Format

Station name, Station code, Meteor #, Year, Month, Day, Hour, Minute, Second
Latitude (deg min sec), Longitude (deg min sec) positive east, Altitude (m)
Frame rate (Hz), ?
?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?
0 Azimuth positive west of south (deg), Zenith angle (deg)
1 Azimuth positive west of south (deg), Zenith angle (deg)
2 Azimuth positive west of south (deg), Zenith angle (deg)
3 ...
0 Azimuth positive west of south (deg), Zenith angle (deg)

```
Lick ObservatoryBM    10290 2007    9    1       11.  59.  19.
    0  37.  20. 27.6 238.  21. 28.81284.0
    29.970     1.000
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
     0.       212.001    60.028
     1.       211.658    60.245
     2.       211.315    60.462
     3.       210.972    60.679
     4.       210.629    60.896
     5.       210.286    61.113
     6.       209.943    61.330
     7.       209.600    61.547
     8.       209.257    61.764
     9.       208.914    61.981
    10.       208.571    62.198
    11.       208.228    62.415
    12.       207.885    62.632
    13.       207.542    62.849
     0.       207.199    63.066
```

FF###_YYYYMMDD_HHMMSS_MSC_FRAMENO.bin