Study of NRO Telescopes for WFIRST

AFTA (WFIRST-NRO) SDT Telecon #3

Jeffrey Kruk
GSFC

October 25, 2012

Outline

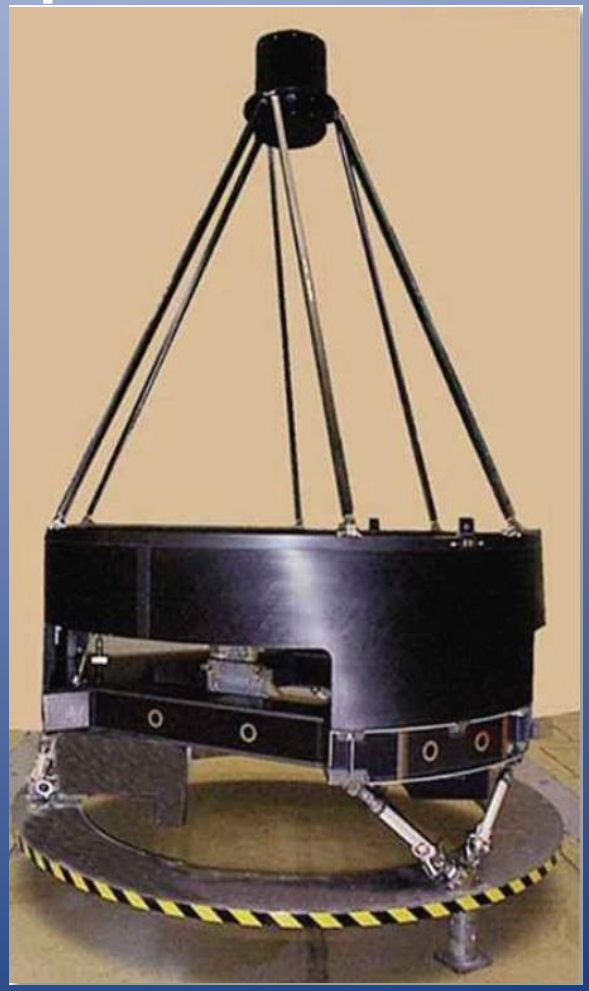
- Intro: Open questions – 1
- Present payload concept(s)
- Science programs
  - Implications of NRO telescope capabilities, comparison against prior DRM1,2
- Open Questions – 2

Open Questions - 1

- Topics to be addressed by new SDT and by upcoming telescope studies
  - What is optimal pixel scale?
  - Image Quality requirements
    - Imaging: 2X margin against diffraction limit @ 1um
    - Spectroscopy: diffraction limit at 2um
  - Reassess depth vs. area trade for each survey
    - Implications for data volume, slew speed
  - What is the red wavelength cutoff?
  - Orbit trades
    - L2, equatorial Geo-synch, other high Earth orbits…
    - Implications for PSF stability, radiation, downlink, etc

NWNH Enabling Widefield (NEW) telescope

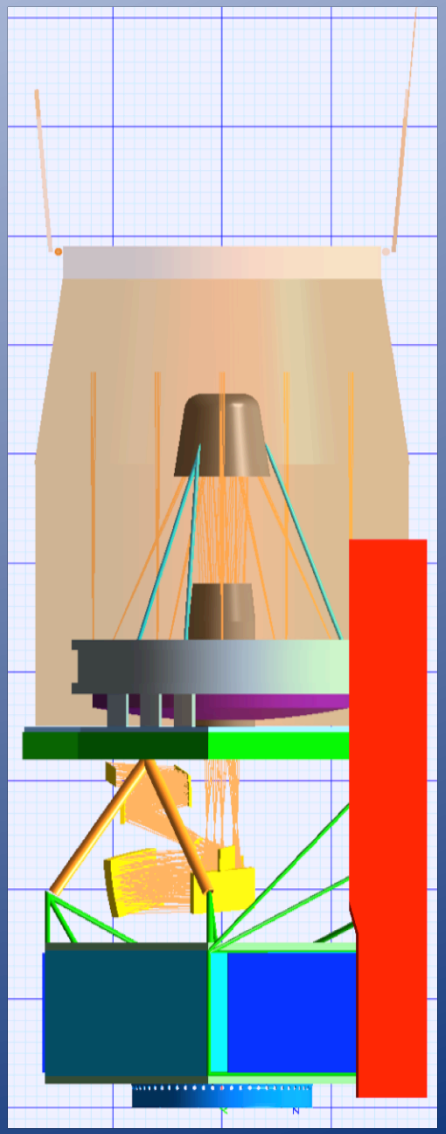
- 2.4m f/8 optical system
- 2 out of 3 mirrors from original TMA telescope
- Includes metering structure, aperture door, most of the 6-dof SM actuator system, outer baffle assembly, etc.



Dynamic test unit

2.4m Observatory Concept

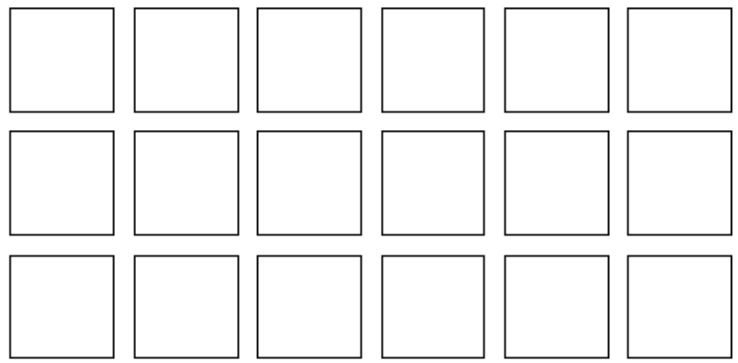
- Assumed requirements:
  - Multiple instruments
  - On-orbit servicing
  - NO CHANGES!
  - Three instrument bays are natural fit to existing structure.
    - Present wide-field instrument design fits in one such bay (barely).
  - Meet all prior observing requirements, only more so
    - Diffraction-limited imaging @ 1um
    - Diffraction-limited spectroscopy @ 2um
    - Accessible cold pupil
    - Image stability scales with PSF
    - etc



2.4m FOV diagram

(investigating additional detectors)

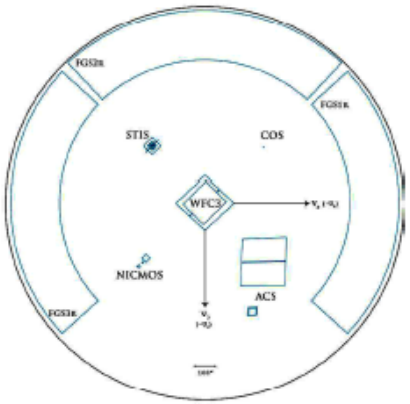
6x3 H4RG @ 0.11"/p, 0.28 sq.deg



0.425 wide°

288 Mpix

0.874°



HST [all instruments]

JWST [all instruments]

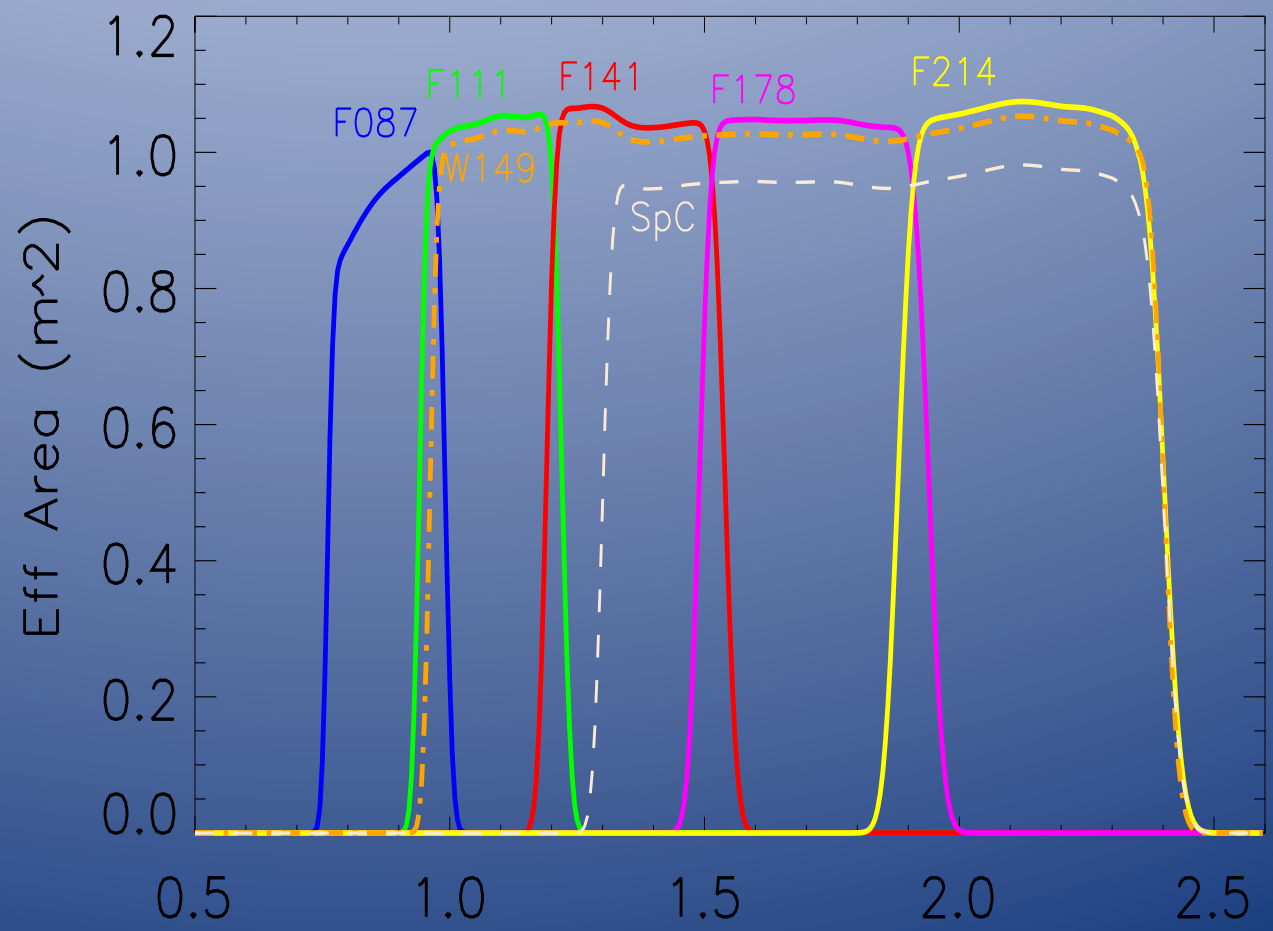
Moon (average size seen from Earth)

FILTERS

Filter	Bandpass
z	0.732 – 0.962
Y	0.920 - 1.209
J	1.156 – 1.520
H	1.453 – 1.910
K	1.826 – 2.400
W	0.962 – 2.400

DRM-1 Effective Area

(scale by 2.5 for NRO)



DISPERSERS

Supernova Prism

	Bandpass (microns)	Resolving power per pixel	Spectral length (pixels)
DRM1	0.6 – 2.0	100-200	160
DRM2	“	“	“
2.4m	“	“	“

Galaxy Redshift Prism

	Bandpass (microns)	Ext’d source Resolution (km/s/ arcsec)	Point Source Resolution (per pixel)	Spectral length (pixels)
DRM1	1.3-2.4	950-1760	950-1800	680
DRM2	1.7-2.4	1050-1860	900-1600	380
2.4m	1.3-2.0(TBD)	1150-1760	1540-2350	723

Pointing Performance
preliminary design requirements

- Pointing jitter: < 24 mas rms (0.22 pix)
- Revisit accuracy: ~15 mas (0.14 pix)
  - Limited by settle time
- Short slews (survey steps): <60s, 30s goal
- Long slews: 180° in < 10 minutes
- The antenna is on a gimbal, so no observing time is lost to downlink

Dynamic Range

- Baseline: 32-channel output @ 100kHz: 5.3s frame time
- What is impact of persistence on your data?
  - Good (new process, still developing): rate = $5*10^{-7}$ of prior integrated signal100 sec after reset
  - Typical (prior baseline process): 10X higher, likely worse

Magnitude at which signal=60000e- in peak pixel						
T(sec)	Z	Y	J	H	K	W
15*	15.9	15.9	15.7	15.5	15.3	16.8
40	17.1	17.1	16.9	16.7	16.5	18.0
250	19.0	19.0	18.8	18.6	18.3	N/A

* Assume minimum of 3 readouts before saturation

Science Program

- Microlensing campaigns for exoplanet census
- High-latitude survey
  - Imaging for weak lensing & other programs
  - Spectroscopy for galaxy redshift survey
- Galactic plane survey
- SNIa synoptic survey
- Guest Observer program
- Option for exoplanet coronagraphy

Microlensing

- Observe >2 sq deg of Galactic bulge
  - Revisit each field every 15 minutes over 72 days
  - Depth: S/N >100 in W149 filter for J(AB)=20.5
- For DRM1,2 area was 3.38, 3.51 sq

J(AB) at which S/N=100 in W149 vs. Exposure Time				
	40s	60s	80s	100s
2.4m NRO	21.3	21.7	22.0	22.2
1.3m DRM1	20.5	20.9	21.2	21.4
1.1m DRM2	20.2	20.6	20.8	21.0

Microlensing-2

Mean # stars per 0.01°^{2}

	Baade	OGLE 29	Stanek	SWEEPS
Jmax / l, b	1.06, -3.81	-6.75, -4.72	0.25, -2.15	1.26, -2.65
20.25	690	260	1265	1060
20.5	815	310	1515	1265
20.75	955	365	1795	1480
21.0	1105	425	2085	1710
21.25	1265	490	2385	1950
21.5	1435	560	2700	2200
21.75	1620	640	3025	2460
22.0	1815	720	3360	2745
22.25	2025	810	3700	3040

GB MCT preliminary catalog courtesy of Tom Brown

Microlensing-3
Impact of 2.4m telescope

- Smaller FoV than DRM1,2
- Goes ~1 mag deeper for given exposure time
- Doubles density of stars exceeding S/N reqm't
- Better isolation of stars at high densities:
  - 3000 stars / 0.01° bin
    - = 1 star per 3.6x3.6 pixels for DRM1,2
    - = 1 star per 6x6 pixels for NRO.
- Relative proper motions of source-lens stars measured for many more microlensing events

High Latitude Survey

- Survey area: 3,400 deg^2
- Imaging
  - YJHK to AB=26 (5σ point source)
  - Sampling suitable for weak lensing in J,H,K
  - >30 galaxies/$arcmin^2$ per band, 40 in combined dataset for DRM1, (25 and 31 for DRM2).
- Spectroscopy
  - Emission line 7σ flux limit: 1.0 10^{-16} ergs/cm^2/sec
    - 4858 galaxies/deg^2 over 1.3<z<2.65
  - Continuum S/N=1 per pix at AB= 22.65

High Latitude Survey-2
Impact of 2.4m telescope

- Imaging:
  - Keep AB=26 limiting magnitude, reduce exposure time from 150 -> 90s, and make up for small FoV
    - Don't gain by PM area because of greater readnoise
  - Keep exposure time ~constant and go to AB=27
    - Triples number of usable galaxies to ~90/arcmin^2
  - K band: one mag shallower, lose entirely, …?
- Spectroscopy:
  - Likely choose to go deeper rather than faster
  - BUT depends greatly on telescope temperature

S/N Budget example

H-band imaging

	PM Dia	Pixel scale	Source AB=26	Pix per point src	Pt Src Bkgd	Pix per galaxy *	Galaxy Bkgd
DRM1	1.3m	0.18”	0.6 c/s	8	6.5 c/s	24	19.5 c/s
DRM2	1.1m	0.18”	0.4 c/s	11	6.6 c/s	27	16.1 c/s
2.4m	2.4m	0.11”	1.5 c/s	16	24.3 c/s	63	97.0 c/

* 0.2” half-light radius

All quantities for H-band filter

Dark current: 0.05 c/p/s

Readnoise: 20e- CDS, SUTR floor=5e-

$$N_{pix} = 1 / \sum_{i,j} PSF_{i,j}^2$$

H-band background per pixel

	Thermal	Zodi medium	RN eq rate AB=26 survey
DRM 1	0 c/p/s	0.398 c/p/s	0.365 c/p/s
DRM 2	0	0.277	0.271
2.4m	0.003	0.363	1.124*

*For AB=27 survey, this drops to 0.24 c/p/s

SNIa Survey

- Two-tier deep synoptic survey(s) in JHK, R=75 prism:
  - 1.8 deg^2 for z<1.7, 6.5 deg^2 for z<0.8 (2.0,5.9 for DRM2)
  - Imaging: 15σ at peak of light curve
  - Spectroscopy: 5σ across Si 6100Å line
  - 5-day revisit cadence over 1.8 years
    - *Ranga Ram Chary WFIR 2012 talk: 1-10 FIGN/deg^2/yr*

5σ point-source limiting sensitivity:

	Low-z area	High-z area
Single visit	26.0	26.8
Cumulative	28.6	29.6

SNIa Survey
Impact of 2.4m telescope

- Go ~1 mag deeper for fixed exposure time
  - Re-optimize 2-tier layout to increase SNe yield
  - Tiers change from low & high z to *high & higher z*
    - ~triple number of mid-z SNe
- Improved angular resolution provides better host galaxy subtraction
- If K band is lost, will need some adjustment to observing strategy

Galactic Plane Survey

- Survey 1240 – 1600 deg^2 in YJHK to AB=26
  - Same tiling strategy as the high latitude survey

Impact of 2.4m telescope:

- Likely similar to the high latitude survey
  - Exposures are already short, so may leave as-is and go deeper
  - Devote extra time to recovering K-band depth, if possible

Coronagraphy

- Not part of prior studies, so I didn't address at the P.U. workshop
- Questions not already addressed elsewhere:
  - What are timescales for ultimate S/C stability?
    - Scheduling antenna gimbal motions, momentum unloading,…
  - Present fixed sunshield concepts only give access to a wide range of S/C roll angles at high ecliptic latitude. Is this acceptable?
  - In a Geo orbit, upper baffle design is complicated by fact that Earth revolves around S/C. What are the stray light rejection requirements?
  - Detector lifetime requirements?

Telescope Temperature

- NRO Telescope is designed for “room temperature” operation.
- Designed for survival @T= 250K. Preliminary assessment at JPL/ Exelis: PM in isolation has low additional WFE @ 230K.
- **Nominal WFIRST band pass of 0.7 – 2.0 microns is viable at 280K.**
- Extension to 2.4 microns is possible with 2x higher background at T=250K.

Obs time (sec) to reach AB=26 5σ (Imaging), or Hα flux $1*10^{-16}$ at z=1.8, 6.5σ(SPC)

Temp	z085	Y106	J134	H168	K211	SpC	SpC
	0.732-0.962	0.92-1.209	1.156-1.52	1.453-1.91	1.826-2.40	1.1-2.0	1.1-2.4
200K	800	755	755	800	830	1200	1342
220K	800	755	755	800	855	1200	1373
240K	800	755	755	800	1220	1200	1934
250K	800	755	755	800	2260	1210	3151
280K	800	755	755	885	28050	1620	31000
300K	800	755	755	1480	125600	3640	136000

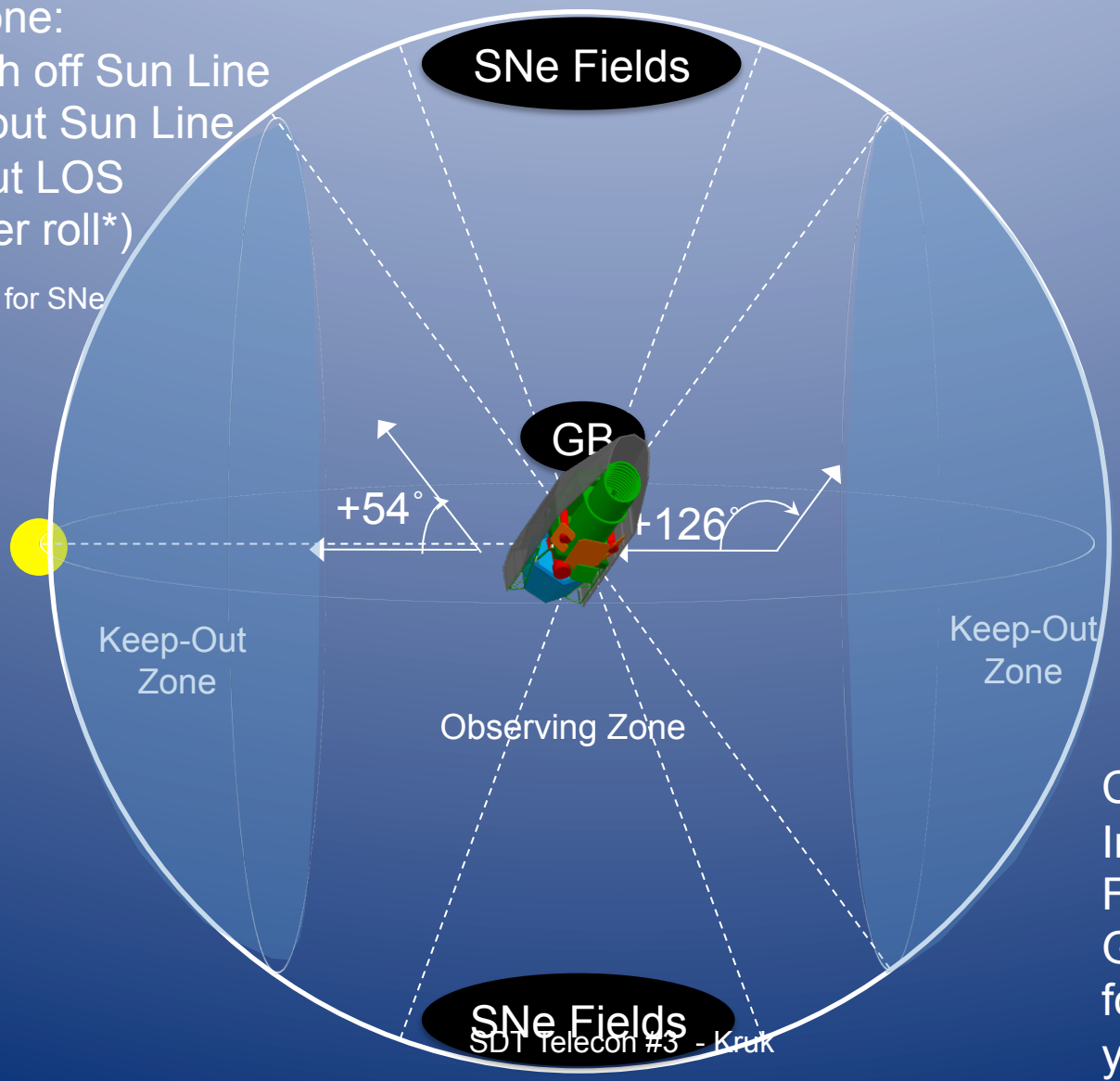
Orbit trades

- Sun-Earth L2 was prior baseline, driven by thermal stability, survey scheduling
  - Can manage data volume with high-TRL systems but not much room for growth
- Geosynchronous and higher Earth orbits under consideration for servicing
  - Thermal impact of Earth revolving around S/C?
  - Moving Earth avoidance zone in scheduling
  - Go higher than geo-synch to avoid radiation?
  - Robot availability uncertain beyond geo-synch

Field of Regard

Observing Zone:
54°-126° Pitch off Sun Line
360° Yaw about Sun Line
±10° roll about LOS
(off max power roll*)

* Larger roll allowed for SNe



SNe Inertially Fixed Fields must be within 20° of one of the Ecliptic Poles, will be rotated every ~45 days

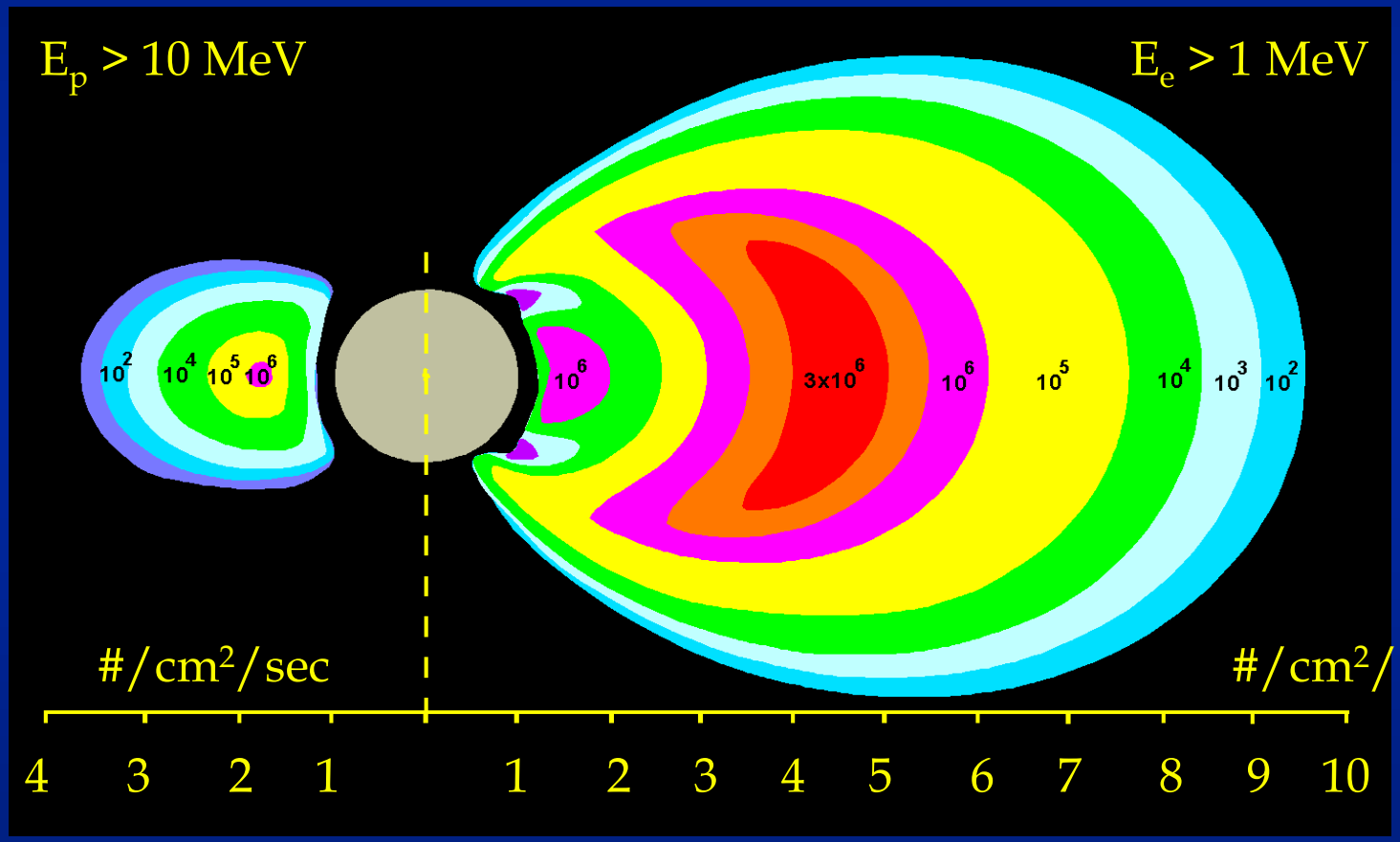
Can observe Inertially Fixed Fields in the Galactic Bulge (GB) for 72 days twice a year

Radiation Environment

- L2: 5 high-energy particles/cm^2/sec
  - A lot more during solar flares, but duty cycle is low
- GEO: same, plus 3x10^5 e-/cm^2/sec

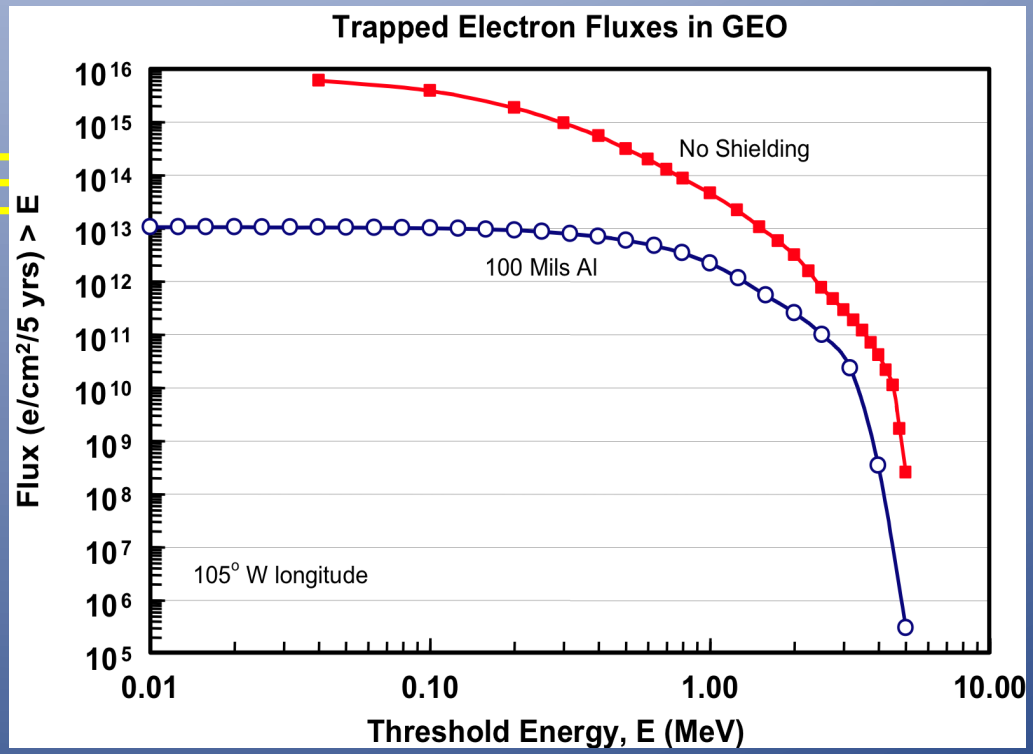
Proton & Electron Intensities

AP-8 Model AE-8 Model



Shielding

- ~$5*10^5$ e-/cm^2/s @ 1MeV and above*
- Easy to shield low E
- ~1cm Al for 4MeV
  - More helps slowly
  - dE/dX 90% ionization below 4MeV
  - 10% bremsstrahlung
    - Hard to shield



*based on 5-yr avg – 'typical' day will be lower

Open Questions - 2

- Things needed *ASAP* to meet deadline for costing exercise:
  - What is optimal pixel scale?
    - Baseline is 0.11”/pix – if we want a different value used in the engineering study, we need to know now
  - Image Quality requirements
    - Imaging: 2X margin against diffraction limit @ 1um
    - Spectroscopy: diffraction limit at 2um
    - Do we need to maintain margin at all wavelengths and all field angles?
      - *If no, especially for GRS, then larger field may be feasible*

Open Questions - 2

- Answers needed ASAP, continued:
  - Is it necessary to have 3 ~equal-size instrument bays, or can we shift to one large and one that is somewhat smaller?

Open Questions - 2

- Items for which we have a bit more time:
  - Reassess depth vs. area trade for each survey
    - Implications for data volume, slew speed
  - What is the red wavelength cutoff?
    - Implications for GRS prism as well as thermal design
  - Are grisms acceptable for galaxy redshift survey?
    - May enable larger FoV
  - How does choice of orbit affect each program?
    - Implications for PSF stability, scheduling, radiation, downlink, etc
  - What are the detector persistence requirements?
    - Other detector performance questions to follow!