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Limit on reflected sunlight from satellites.	Reflected sunlight shall be slowly varying with orbital phase as recorded by high etendue, large-aperture ground-based telescopes to be fainter than 7.0 V_mag +2.5 × log(r_orbit / 550 km), equivalent to 44 × (550 km / r_orbit) watts/steradian, for r > 550 km; V=7.0 mag for lower orbits.	1) Make satellites in operational orbit invisible to the unaided eye, 2) Guarantee that satellite reflections do not make the cross-talk parallel streaks in Rubin Observatory images uncalibratable, which would increase lost area by ~10x. Satisfying the condition for this telescope, with the highest etendue (field of view x primary mirror (effective) area), is assumed to satisfy most other telescopes' constraints.	Etendue is effective area × field of view; r_orbit is the mean altitude of the satellite orbit in km and V is the Johnson V bandpass at 550 nm.	0.25 mag / 10%	D&QS1 Report p153. [Ref: M2 and M3 from Mitigations WG report; S5 from SATCON1; see also Tyson et al. 2020, Fig 5 & 6 for context to the formula.]	Brightness limits in multiple color bands (Tyson et al. 2020): Band Wave Lim mag Refl Sun wrt g u 367 nm 5.5 0.047 g 467 7.0 1.00 r 622 6.9 1.14 i 755 6.8 1.06 z 870 6.7 0.73 y 1004 6.2 0.35	Operators to provide public radiometric visibility model based on materials reflectivity, bidirectional reflectance distribution function as function of wavelength of reflected sunlight. The physical basis of the model should be provided to the degree possible. Validation through ground-based measurement of in-orbit apparent brightness as function of orbital phase.	Operators to demonstrate best efforts technical approach to meeting the brightness requirements.	1) General derivation of tolerances for quantitative limits. 2) Validated modeling approach for predicting reflectivity as function of solar phase angle and viewing angle. 3) Reference libraries and measuring capabilities for materials reflectivities.
Flares & Glints	Minimize the occurrence of high-amplitude flares projected onto the ground; design for as little fluctuation in detected visible brightness as possible for small changes in sun/viewing angle; share modeling predictions as part of coordination process.	Enabling time and position prediction for avoidance of brightest, rarest events; characterizing lower-amplitude variability to minimize during design phase and predict during streak passage.	Function defining upper limit of amplitude vs. temporal frequency. A high-amplitude flare is any instance where a satellite's streak brightness is observed to increase by at least 2x (approx 0.75 mag) over its quiescent/baseline level for the amount of time for the satellite to traverse at least 0.5" in a telescope field of view.	Defined by "structure function", the limits on the distribution of variability amplitude as a function of timescale.	Requests from industry for clear limits on variability.		Operators to design mitigation measures to minimize the projection of high-amplitude flares onto the ground in normal operaitons. Operators to provide radiometric variability model based on materials reflectivity, bidirectional reflectance distribution function as function of wavelength of reflected sunlight, along with routine in-orbit predictions of flare events. The physical basis of the model should be provided to the degree possible. Validation through ground-based measurement of in-orbit flare incidence and brightness compared to modeling predictions.	Operators encouraged to choose materials with reflection slowly varying with illumination and viewing angles; include as part of best efforts in coordination agreements.	1) Metric for acceptable limit on flares/glints in terms of delta V mag as a function of frequency of occurrence. 2) Statistical properties of reflectance variations based on BRDF materials measurements. 3) Validated modeling approach for predicting changes in reflectivity for small changes in solar phase angle and viewing angle.
Short and long-term optical/IR monitoring	Support an immediate coordinated effort for multiple spectral bands in optical and infrared observations of LEOsat constellation members. In the longer term, support a comprehensive satellite constellation multispectral observing network with uniform observing and data reduction protocols.	The purpose is to characterize both slowly and rapidly varying reflectivity and the effectiveness of experimental mitigations. Such observations require facilities spread over latitude and longitude to capture Sun-angle-dependent effects. The comprehensive network is for feedback to operators and astronomical programs.			D&QS1 Report p155 [Ref: Satellite Observations WG report]		National Agencies to fund their component of the coordinated observing network for a publicly accessible dataset..	IAU CPS SatHub to coordinate volunteer efforts and communicate with Industry Hub participants. Commercial monitoring services available for validation.	Standardization of measurement and data reporting protocols. [Currently under development by SatHub and to be disseminated via Satellite Constellation Observation Repository (SCOR).]
BRDF	In an an effort to minimize the brightness of satellite surfaces during the satellite design and development phase, LEOsat operators possibly in collaboration with astronomers should do one of the following: 1) Perform adequate laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements; 2) Base their reported model (for reflectance simulation analysis) on the best available such measurements for the materials that they used; 3) Convince governments to share their libraries of such materials with the operators for that purpose. In each of the three cases, the BRDF values used for the various surface materials should be made available to other stakeholders like astronomers. If public disclosure of BRDF values for specific materials is not possible, LEOsat operators could provide a global BRDF model for the satellite as a whole.	BRDF testing of various materials (used or considered for use on LEO satellites) provides measurements that will indicate best choices for reduced brightness toward observatories.	Satellite bi-directional reflectance distribution function (BRDF) measurements to characterise how incident light is reflected, diffused, or absorbed by exposed surface elements during the design process	For optical wavelengths, the threshold target is fainter than V=7th magnitude.	Recommendation 4. SATCON1 Report p.6 & p.21		Operators to provide radiometric visibility model based on materials reflectivity, bidirectional reflectance distribution function as function of wavelength of reflected sunlight. Validation through ground-based measurement of in-orbit apparent brightness as function of orbital phase.	Operators to demonstrate best efforts technical approach to meeting the brightness requirements. Operators encouraged to use and contribute to open-source tools and collaborate with astronomers to publish techniques to more effectively model satellite brightness.	1) Metric for acceptable limit on flares/glints in terms of delta V mag as a function of frequency of occurrence. 2) Acceptable quality of BRDF materials measurements for this purpose.

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Agreement to protect radio observatories	In collaboration with the radio astronomy community and industry, governments should develop an internationally agreed mechanism to protect radio-quiet zones and observatories from unnecessary and unintentional electromagnetic radiation.	Radio-quiet zones are now protected typically by national regulation from ground-based radio transmissions and EMI. No such protection exists from radiation from satellites.	A radio quiet zone (RQZ) is an area in which radio transmissions are restricted by law to facilitate scientific research and/or military activities. Most broadcast transmitters in the central area of an RQZ are required to operate at reduced power and use directional antennas.	The threshold levels for radio astronomy bands are defined in the Recommendation ITU-R RA.769. Governments can can define wider frequency protections in RQZs with thresholds tailored to the specifics of the instruments and the geographic site. (See Report ITU-R RA.2259 "Characteristics of Radio Quiet Zones")	D&QS2 Report p87		National governments to require as a condition of licensing that large satellite constellations in operation mitigate the impact of their intentional and unintentional radiation at Radio Quiet Zones. International regulatory process be extended to include limits on aggregate interference from all constellations in radio astronomy bands due to intentional or unintentional radiation.	Inform and solicit cooperation of new operators to execute voluntary coordination agreements with radio observatories to mitigate impacts. Industry should be encouraged to utilize technology that allows satellites to avoid direct illumination of radio telescopes and radio-quiet zones, especially high-power applications. Industry should be encouraged to minimize antenna sidelobe levels so that their indirect illuminations of radio telescopes and radio-quiet zones do not generate interference, individually or in aggregate.	1) methods to consider aggregate effect of satellite constellations. 2) Effect of Unintended Electromagnetic Radiation in radio astronomy bands. 3) Authoritative list of worldwide radio-quiet zones for protection - ITU-R item adopted 2023.
Sharing technical information	Operators should provide relevant metadata, including, e.g., effective isotropic radiated power (EIRP), transmission band passes, nominal flux density at different frequencies, measured spectral masks, etc.	Such information may assist observers in assessing and avoiding threats to radio observations through observation planning including choice of frequency and through more detailed modeling.			SATCON1 Rec 9 & 10; SATCON2 Report p21; D&QS1 Report p153 [Ref: S4 in SATCON1] Ref: Radio WG report; also discussed as part of general radio recommendations in M12 Mitigations WG report]; D&QS2 Report p85.		ITU and national governments require, as a condition of licensing, the sharing of as much relevant metadata as practicable, consistent with protection of competition-sensitive information.	Satellite operators should be encouraged to share the details of their radio systems to a much greater extent than contained currently in public filings with the International Telecommunications Union or radio spectrum regulators that support their authorization or licensing.	Detail description of the parameters required to be shared, comparison with the currently available parameters in ITU-R filings.
Funding radio technical development	Support the development of reliable and accurate simulations that enable calculation of equivalent power flux density at radio observatory locations. (Industry role – provision of data); Support developments to increase the robustness of receiver electronics and prevent saturation: Increase robustness of radiofrequency system's low noise amplifiers to tolerate higher input radiation power over a wide band. Increase dynamic range of receivers within data processing trade-off limits. Design radiofrequency and digital transport system to the highest possible dynamic range. (Industry role – provision of data);	Assess and mitigate the impact of the increasing activity in the electromagnetic environment due to large satellite constellations.			D&QS1 Report p152;		National funding agencies provide support for radio technology development through universities, national centers and industry.	Existing research programs prioritize these issues; IAU CPS Industry and Technology Hub catalyze research partnerships between industry and academic institutions.	
Developing techniques and standards for spacecraft	Government and industry should develop techniques and operational standards aimed to mitigate impacts on radio astronomical science. Areas include: spurious and out-of-band emissions and unintentional electromagnetic radiation (i.e., electronic noise), coordination methods.	Codifying industry best practices.			D&QS2 Report p89		Licensing requirements to include technical best practices for mitigating impact on radio astronomy.	Encourage the development, implementation and sharing of technical best practices, including through the IAU CPS I&T Hub.	1) technical best practices 2) Development of standards
Creating radio dynamic zones	Develop inquiries and recommendations that encourage flexible technology that can better share spectral resources while ensuring protection of sensitive radio astronomy operations. Consider study of and incentives for new transmitter requirements toward a dynamic approach where coordination could be automated and based on the frequency of the scientific observation being taken and the direction in the sky where the radio telescope is pointed.	Coupled with dynamic spectrum hopping and other techniques, these types of dynamic models could enhance spectrum efficiency and replace the current static model of quiet zones that assume fixed transmitter requirements based on a given set of parameters.			D&QS1 Report p156		Expand ITU rules and national implementations of protection of radio observatories and radio quiet zones to enable radio dynamic zones with appropriate technical coordination.	Begin the technical development of the required technical coordination mechanisms and execute pilot experiments.	

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Orbital altitude	Operate in orbits with altitudes below about 600 km, if practicable, when consistent with operational and safety objectives and constraints. If the constellation cannot be planned for altitudes below ~600 km, choose the lowest practicable operational altitude.	Satellites in constellations with higher orbital shells are illuminated by the Sun for longer during the night and appear more 'in focus' to telescopes; in general, the impact on astronomy increases with constellation altitude. Scientific analysis shows that orbits approximately 600 kilometers or below offer a compromise between brightness and the length of time satellites are illuminated during the night. This choice minimizes the rate of sunlight streaks in the dark hours between evening and morning twilight for the largest-aperture telescopes, which are located in the range of |latitude| < 35 deg.		Tolerance of at least 100 km for significant increase of frequency of streaks after twilight.	D&QS1 Report p152. [Ref: M4 from Mitigations WG report] D&QS1 Report p153. [Ref: M1 from Mitigations WG report; Simulations WG report] D&QS2 Report p88 D&QS2 Report p238		Create regulatory incentive for LEO constellation operators to choose lower orbits, consistent with their mission specifications and space traffic management requirements. Fund research on carrying capacity of orbital shells at lower elevations.	Inform and solicit cooperation of new operators to choose lower orbits.	
Number of constellation satellites	Minimize the number of satellites required to fulfill their missions.	The astronomy figure of merit is minimizing the number of streaks per exposure. Programs that are particularly impacted are those observing closer to the horizon in twilight. It is recognized that astronomy's need for lower orbits and smaller numbers is in direct conflict with operator need for more satellites at lower altitudes to maintain constant latency/bandwidth. In general, minimizing altitude has the most positive impact on minimizing the incidence of streaks in dark time. Any steps that reduce the risk of debris-producing collisions thereby reduce the risk of increased diffuse scattered sunlight.			D&QS1 Report p153. [Ref: M1 from Mitigations WG report; Simulations WG report]		Regulatory filings should contain the latency/bandwidth requirements for the specific areas that drive the design choice for number of satellites, to demonstrate that the minimum number (with margin) are being deployed.	Encourage transparency in regulatory filings in defining the scope of planned constellations.	Astronomical definition of the threshold for harm in number of streaks per exposure.
Minimizing visibility throughout mission lifetime	Minimize the time satellites spend in orbit when not in service. Conducting orbit raising and deorbiting as soon and as quickly as practicable, taking due account of relevant protocols for such operations and space sustainability practices, while also taking into account brightness mitigations, where practicable.	During the orbit raising period, satelites are in a lower altitude and therefore are brighter and/or in a closely packed configuration, which more severly impacts naked eye visibility of the night sky and astronomical observations. Assuming a steady state constellation in its final configuration, the number of satellites in orbit raising / deorbiting phases is equal to the 2 x (Final constellation number / average satellite lifetime). For a constellation of 42,000 satellites with a lifetime of 5 yrs, 2 x (42000/5) = 16,800 satellites per year.	IADC guidelines call for a 25y deorbit phase. FCC requires 5 year deorbit phase for satellites below 2000km. Space Safety Coalition (SSC) Best Practices for the Sustainability of Space Operations, April 2023, calls for 'no more than' 5 yrs		"D&QS1 Report p153. [[Ref: Simulations WG report]" D&QS2 Report p89 D&QS2 Report p239		Operators to provide a plan of how orbit raising will be conducted and what steps will be taken to minimise sunlight reflectance towards Earth. Operators to provide a deorbiting plan in the event of malfunction, and post-mission disposal, and what steps will be taken to minimise sunlight reflectance towards Earth. (combine 2 above) Operators to provide a model prediction of the apparent brightness during representative times in these transitional phases, with a plan for validating the models by observation. This information should be made public in a timely way provided to the astronomy community.	Operators implement voluntary plan for minimizing visibility during orbit raising and de-orbiting.	1) Simulations of the total satellites in orbit raising and deorbiting phases for a given set of constellations (e.g. Starlink, Kuiper, OneWeb...). What are they doing in practice. 2) A review of the use of solar drag sails on visibility of satellites. 3) Review and simulate impacts of the April 2023 Space Safety Coalition document (para h (i)), which states: "As part of the passivation process, operators should place spacecraft into a final configuration that maximizes the average (uncontrolled) drag-facing cross-sectional area (in LEO) and minimizes solar array input after the spacecraft reaches it natural spin rate and attitude."
TLE / Ephemerides accuracy	Satellite ephemeris data with covariances shall be provided in a standardized format (e.g. CCSDS OEM) and make planned maneuvers known in advance with every ephemeris update. Ephemeris data shall be sufficiently detailed and accurate so that they can be used for astronomy observation planning up to 8 hours in advance.	1) Provide the astronomy community with the information necessary to enable active avoidance of satellites. 2) Move away from TLEs to a more comprehensive ephemerides exchange format such as CCSDS Orbit Ephemeris Messages that include information on uncertainties. 3) 1 second cross track uncertainty will allow for pass predictions for fibre spectrographs. 4) 1 second timing uncertainty will ensure data loss during shuttering is not unnecessarily large and on the same order as the average shutter speed.	The Consultative Committee for Space Data Systems (CCSDS) is a multi-national forum for the development of communications & data systems standards for spaceflight.	1-sigma tolerance: 1 arcsecond cross track uncertainty / 1 second timing uncertainty 8 hours in advance	D&QS1 Report p151. [Ref: SATCON1 rec.2], D&QS1 Report p153 [Ref: M10 in SATCON1; M5 in Mitigations WG report], D&QS2 Report p239, Recommendation 10. SATCON Report p7., Implementation of SATCON1 Rec 9 & 10. SATCON2 Report p20-21., Implementation of SATCON1 Rec 9 & 10.		Satellite operators to provide ephemeris data to the appropriate national or international agencies with sufficient accuracy and cadence to meet astronomical observation planning requirements as well as Space Traffic Management requirements.	Switch to CCSDS OEM format or any format acceptable to 18th or 19th SDS for exchanging ephemeris and covariances in a standardized fashion. Use DoD VCMs as basis for ephemerides if possible. Construct a freely available dynamical model that is compatible with VCMs.	1) Ephemeris update cycle of 8 hours or less.

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Cadence sufficient for ephemeris prediction	Operators shall provide data on satellite attitude and ephemerides with covariances every 8 hours or at intervals that are commensurate with staying below the ephemeris prediction accuracy requirments, particularly when maneuvers are executed.	1) After 8 hours, typically maneuver plans have changed and the uncertainties in the ephemerides have grown beyond the required limits. 2) The attitude uncertainties stem from 1 second timing accuracy requirement, as 360deg/7200s=0.05deg/s is the number of degrees traveled in one second if the orbital period is two hours.	Satellitte attitude is the orientation of the satellite and/or its gimbled parts with respect to an external reference frame (e.g. GCRF). Satellite ephemerides refer to the position of satellites with respect to the gravitational center of attraction and a frame of reference (e.g. ITRF or GCRF). GCRF is the geocentric celestial reference frame. ITRF is the international terrestrial reference frame that is corotating with the Earth.	Tolerances for 8 hour updates depend on the frequency of unscheduled maneuvers. Attitude uncertainties shall be less than 0.05 deg (1-sigma)	D&QS2 Report p85, D&QS2 Report p88, (Implementation of SATCON1 Rec 9 & 10.) SATCON2 Report p20.		Satellite operators to provide ephemeris data to the appropriate national or international agencies with sufficient accuracy and cadence to meet astronomical observation planning requirements as well as Space Traffic Management requirements.	Operators shall provide attitude data and update attitude, ephemerides and maneuver plans at least every 8 hours.	1) TLE/Ephemeris accuracy