ASTE 535: Space Environment and Spacecraft Interactions
Course Syllabus and other information (August 4, 2016)

Dr. W. Kent Tobiska[i]

Course Description

Space Environment and Spacecraft Interactions is a survey course that provides a broad scientific and engineering background in the natural and artificial space environment as it affects spacecraft and ground systems. The course includes sufficient technical detail to allow a student to pursue independent research in areas of interest.

Topics Covered through lecture material

1) *Introduction to the space environment and spacecraft interactions* (definitions; space physics; space weather; spacecraft interactions at GEO, LEO, atmosphere, ground; organizations; space weather drivers; space standards activities);
2) *Introductory space physics and solar-planetary relationships – I* (atomic physics; photon radiation; solar interior, atmosphere; solar irradiances);
3) *Introductory space physics and solar-planetary relationships – II* (solar gravitational field; solar magnetic field, dynamo, MHD; local magnetic/bipolar fields, CMEs, flares; solar wind magnetic field, current sheet, electrons, protons; GCRs; comets, asteroids, dust, and gas in heliosphere)
4) *Planetary space environment* – I (gas kinetic theory; molecular and atomic collisions; atmospheric physics; Earth's neutral atmosphere: surface and lower atmosphere, upper atmosphere with solar, auroral, conduction, mixing heating, cooling by conduction and mixing, and dynamics)
5) *Environmental effects - I (neutral atmosphere)* (kinetic energy: drag, perturbations, sputtering; chemical energy: atomic oxygen erosion, UV degradation, s/c glow; thermal: temperature control; particulate: contamination; standards/guidelines and models)
6) *Planetary space environment – II (Earth's ionosphere)* (ionospheric physics; thermospheric coupling; electron-ion production and loss processes: solar EUV photoionization, charged particle precipitation, Joule heating, waves, winds; ionospheric structure and dynamics; ionospheric features)
7) *Environmental effects – II (ionosphere)* (systems of models characterizing the ionosphere; physical environment; example models and data streams; GPS signal uncertainties: TEC variability and scintillation; radio propagation: reflecting layers and propagation; radar system: scatter and clutter; standards and guidelines; models)
8) *Planetary space environment - III (Earth's magnetosphere)* (Plasma physics basics: Maxwell's Equations, Ohm's Law, Equation of continuity, hydrodynamic equation; particle motion and drifts; magnetic mirroring; geomagnetism; IGRF, dipole field; geomagnetic coordinates; magnetospheric structure: bow shock, magnetosheath, magnetotail, plasma sheet, neutral sheet, polar cusps; magnetospheric variability: currents, convection, storms and substorms, magnetic variations, magnetic storms, magnetic indices)
9) *Environmental effects - III (plasma)* (Plasma effects: electron and ion surface interactions, current collection; spacecraft charging: sources, photoelectric effect,

plasma bombardment, discharge; LEO charging: unbiased, biased (solar arrays), grounding, within auroras, field aligned currents; high altitude charging: GEO, SCATHA; electrostatic discharge (ESD): Paschen discharge and arcing, design considerations, materials selection and plasma contactors)

10) *Planetary space environment - IV (Plasmasphere and radiation belts)* (magnetosphere: BL coordinate system, L-shells, magnetic rigidity; plasmasphere: ionosphere topside, composition, formation, variability; radiation physics: radiation-surface interactions (photons: photoelectric effect, Compton scattering, pair production), linear attenuation, radiation damage effects; radiation environment - the Van Allen Belts: inner, outer, new belts and their sources; standards and guidelines)

11) *Environmental effects - IV (radiation effects)* (radiation physics: radiation-surface interactions (photons, electrons, ions, neutrons); radiation environment characteristics: radiation units (gray, Rad, dose), Van Allen belts, solar energetic photons, solar energetic particles, galactic cosmic rays; radiation (charged particle) effects: surface impacting effects (conducting material, solar arrays, optical surfaces), penetration effects (single event upsets, latchup, deep dielectric charging), example events (Mar1991, Jan 1994 (Anik), May 1998 (Galaxy-4), Oct 28-31 2003), linear energy transfer, doses, radiation shielding, radiation hazards; standards, guidelines, models (AE8, AP8, JPL, CRÈME, L2-CPE))

12) *Micrometeoroid and orbital debris environment* (Micrometeoroid (MM) environment: sources, terrestrial effects, fluences, directionality; Orbital Debris (OD) environment: population/sources, types, detectability, fluences, perturbations/lifetime; effects: hypervelocity impacts (cratering, spallation, penetration, perforations, cracks), thickness of materials; mitigation paths for debris: ISO TC20/SC14 ODCWG; standards, guidelines, models)

Expectations

Attendance: students are expected to attend all classes either in person or remotely. Midterm and Final exams must be taken on-campus or at a monitored site as determined by DEN. The locations will be provided prior to the exam. **MAKEUP EXAMS ARE NOT OFFERED.** Students are strongly encouraged to actively participate in the class with questions (verbal and email) and discussion.

Grades: grades will be determined by a student's performance in three ***approximately*** equally weighted areas (final exam, mid-term exam, and homework) ***plus** extra credit*. **The student's final course grade will be based on a class-weighted curve determined from a combination of these 4 areas FOLLOWING THE FINAL EXAM.** Exams and homework will include quantitative and qualitative problem-solving questions. Active class participation can improve a student's grade and can affect the overall class curve (see NOTE below). For borderline grades, this participation almost always makes a difference in a final course grade. *Your grade can be incrementally lowered or raised, depending upon what your peers do in the class for their participation*. Course passing grades are standardized to the class-weighted curve and the grade allocations are A+: 97-100; A: 93-96; A–: 90-92; B+: 87-89; B: 83-86; B–: 80-82; C+: 77-79; C: 73-76; C–: 70-72). A total cumulative grade ≥ 70 passes the course. However, it is expected that a student achieve a B or higher for graduate level work.

Please note that USC provides official class grades at semester end, not the professor. The professor is NOT ABLE to provide an official final course grade for those students who need tuition reimbursement from their institution.

NOTE: Class participation includes in-class questions and discussion as well as email contributions, questions, and discussion (email to ktobiska@spacenvironment.net; **subject line should include "ASTE 535" and the topic or else the question may be lost via a spam filter**). Not all contributions are necessarily answered personally by the professor nor provided to the class. Because full-time students spend focused time on campus while off-campus students have extended professional expertise, each student has unique strengths and contributions of new or updated material that may not included in lectures, texts, or bibliographical material, the professor encourages contributions of materials. Relevant material includes *a*) recognized design guidelines, *b*) broad technical requirements, *c*) interesting testing results, *d*) original (open literature and non-proprietary) source material, *e*) major references and errors in texts, and *f*) new topical areas of broad interest (see *Course Description* and *Topics Covered* above).

Web site: USC provides a Distance Education Network (DEN) web site for the class and instructions for access will be given in the first class. All homework assignments will be posted on the DEN site as well as described in the lectures. All class announcements will be located on the DEN web site. Solutions to the previous week's homework problems will be posted on the site. Qualitative answers of exceptional merit may be provided for the benefit of the class as a whole. Supplementary class material will also be available at the web site.

Recommended (Optional) Textbooks

The texts for ASTE 535 are **optional** and can be used as a supplement for practical applications to the theory and concepts presented in the lectures. The texts available from Microcosm Astronautics Books, 4940 W. 147th Street, Hawthorne, CA 90250; Phone: 310-219-2700; FAX: 310-219-2710 866-ASTROBK; www.astrobooks.com; email: bookstore@smad.com are (prices may change):

1) *Space Mission Engineering: The New SMAD*, ed. James R. Wertz, David F. Everett, Jeffery J. Puschell, Microcosm Press, ISBN 978-1-881-883-15-9, 2011. $67 (PB)
2) *Understanding Space Weather and the Physics Behind It*, Delores J. Knipp, McGraw Hill, ISBN-13: 978-0-07-340890-3, 2011. $87.50 (PB)

Bibliography

In addition, there are other supplemental books that may be of particular interest to individuals and that may be used as reference material:

3) *The Space Environment*, Alan C. Tribble, Princeton University Press, ISBN 0-691-102996, 2003. $45 (SB; estimated)
4) *The Space Environment*, Alan C. Tribble, Princeton University Press, ISBN 0-691-03454-0, 1995. $85 (HB, estimated) – out of date.
5) *Space Weather & Telecommunications,* John M. Goodman, Springer,

ISBN 0-387-23670-8 (hc), 2005 $159 (estimated); ISBN 0-387-23671-6 (eBook), 2005, $??? (unknown)
6) *Spacecraft-Environment Interactions*, Daniel Hastings and Henry Garrett, Cambridge University Press, ISBN 0-521-47128-1 (hc), 1996; ISBN 0-521-60756-6 (pb), 2004, $65 (estimated)
7) *Introduction to the Space Environment*, 2nd Edition, Thomas F. Tascione, Krieger Publishing Company, ISBN 0-89464-044-5, 1994. $37 (estimated)
8) *Space Weather*, Paul Song, Howard J. Singer, and George L. Siscoe (eds), American Geophysical Union, Geophysical Monograph 125, ISBN 0-87590-984-1, 2001. $85 (estimated)
9) *Theory of Planetary Atmospheres*, J.W. Chamberlin and D.M. Hunten, Academic Press, Inc., NY, 1987. ISBN 0-12-167252-2
10) *Aeronomy*, (Parts A and B), P.M. Banks and G. Kockarts, Academic Press, NY, 1973.
11) *Solar Interior and Atmosphere*, Ed. A.N. Cox, W.C. Livingston, M.S. Matthews, Univ. of Arizona Press, Tucson, 1991. ISBN 0-8165-1229-9
12) *The Sun in Time*, Ed. C.P. Sonett, M.S. Giampapa, M.S. Matthews, Univ. of Arizona Press, Tucson, 1991. ISBN 0-8165-1297-3
13) *The National Space Weather Program*, The Implementation Plan 2nd Edition, National Space Weather Program Council, Office of the Federal Coordinator for Meteorology, FCM-P31-2000, 2000. (no cost)
14) *Report of the Assessment Committee for the National Space Weather Program,* Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), FCM-R24-2006, 2006. (no cost)
15) *Radiation Hazard in Space*, Leonty I. Miroshnichenko, Kluwer, Astrophysics and Space Science Library, Vol. 297, ISBN 1-4020-1538-0, 2003. $85 (estimated)
16) *Solar Cosmic Rays*, Leonty I. Miroshnichenko, Kluwer, Astrophysics and Space Science Library, Vol. 260, ISBN 0-7923-6928-9, 2001. $165 (estimated)
17) *Handbook of Geophysics and the Space Environment*, Adolph S. Jursa (ed), Air Force Geophysics Laboratory, AF Systems Command, USAF, 1985. (no cost - can obtain a copy from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; document accession number ADA 167000).
18) *Allen's Astrophysical Quantities,* Arthur N. Cox, Springer/Verlag, ISBN 0-387-98746-0, 2000. $99 (estimated)
19) *Guide to Global Aerosol Models (GAM)*, G-065-1999, ANSI/AIAA, ISBN 978-1-56347-348-7, 1999. $55 (estimated; free to AIAA members)
20) *Guide to Modeling Earth's Trapped Radiation Environment*, AIAA G-083-1999, ISBN 978-1-56347-349-4, 1999. $45 (estimated; free to AIAA members)
21) *Guide to Reference and Standard Atmosphere Models*, G-003C-2010,

AIAA, ISBN 978-1-60086-784-2, 2010. $110 (estimated; free to AIAA members)
22) *Guide to Reference and Standard Ionosphere Models*, G-034-2014, ANS/AIAA, AIAA, ISBN 978-1-62410-270-7, 2014. $110 (estimated; free to AIAA members)
23) *Low Earth Orbit Spacecraft Charging Design Standard Requirement and Associated Handbook*, S-115-2013, ANS/AIAA, ISBN 978-1-62410-246-2, 2013. $65 (estimated; free to AIAA members)
24) *The Extra-Terrestrial Space Environment* reference chart, AIAA SP-078, 2007 (free to class members at midterm and final exams; email request to spacenvironment@spacenvironment.net).
25) *Space Weather*, Daglis Bothmer, Springer-Praxis, 2006. (HC) $190.
26) *The Space Environment and Its Effects on Space Systems (AIAA Education Series)*, Pisacane, AIAA, 2008. (HC) $95.

Aerospace book sources on the web:
http://www.astrobooks.com (Microcosm bookstore, phone is 310-219-2700)
http://www.amazon.com

Space Weather apps
Recommended Apple iPhone, iPod touch app

1. *SpaceWeather* or *SpaceWx* (education and weather, free, developed by USU Space Weather Center and Space Environment Technologies; 150+ real-time solar, heliosphere, magnetosphere, ionosphere, and atmosphere space weather data streams from 19 institutions)

Other Apple iPhone, iPod touch apps

2. *Solar Monitor* (weather, $9.99)
3. *Solar Telescope* (weather, $1.99)
4. *NASA SWx* (weather, free)
5. *NASA Space Weather Media Viewer* (weather, free)
6. *Solar Alert* (weather, $0.99)
7. *3-D Sun* (education, free)
8. *SWx Monitor* (weather, free)
9. *CliMate*
10. *Sun Viewer*

Recommended Apple iPad app

1. *SpaceWeather* or *SpaceWx* (education and weather, free, developed by USU Space Weather Center and Space Environment Technologies; 150+ real-time solar, heliosphere, magnetosphere, ionosphere, and atmosphere space weather data streams from 19 institutions)

Recommended Android app

1. *SpaceWx* (weather, free, developed by USU Space Weather Center and Space Environment Technologies; 150+ real-time solar, heliosphere, magnetosphere, ionosphere, and atmosphere space weather data streams from 19 institutions)

Other Android apps

2. *SpaceWeather* (education, free, developed by ASTRA)

Recommended Space Environment and Space Weather websites

1. **Space Weather Now**: Current and forecast space weather including solar irradiances, flare alerts, ionosphere and HF conditions, GEO charging conditions, radiation environment conditions, JB2008 model: http://spacewx.com/Space_Weather_Now.html
2. **Space environment standards**: Draft space environment standards from ISO and AIAA (in preprint/review form): http://www.SpaceWx.com/ (Standards link)
3. **Atmosphere**: Code and indices for JB2008 thermosphere: http://sol.spacenvironment.net/~JB2008/
4. **Ionosphere**: Real-time global and CONUS ionosphere GAIM TEC: http://spaceweather.usu.edu
5. **Radio**: Real-time global HF ray-trace maps: http://q-upnow.com
6. **Radiation**: Real-time commercial aviation altitude radiation environment: http://sol.spacenvironment.net/~nairas/index.html
7. **NASA space weather** (CCMC): http://iswa.gsfc.nasa.gov/iswa/iswa.html
8. **NOAA space weather** (SWPC): Solar protons, electrons, wind, fields: http://www.swpc.noaa.gov/

Other Space Environment and Space Weather websites

9. Earth ionosphere and TEC: http://iono.jpl.nasa.gov/
10. LASP/CU space environment information: http://lasp.colorado.edu/
11. Earth magnetosphere: http://www.magnetosphere.ru/
12. Space Weather at Earth: http://www.windows.ucar.edu/spaceweather/
13. NOAA data archive: http://www.ngdc.noaa.gov/ngdc.html
14. GSFC data archive: http://umbra.gsfc.nasa.gov/sdac.html
15. NASA ISTP space environment information: http://www-istp.gsfc.nasa.gov/istp/
16. Satellite failure listing: http://www.sat-index.co.uk/failures/
17. SPENVIS (Space Environment Information System)
    With SPENVIS, one can generate a spacecraft trajectory or a coordinate grid for:
    * geomagnetic coordinates
    * trapped proton and electron fluxes and solar proton fluences
    * radiation doses (ionising and non-ionising)
    * damage equivalent fluences for Si and GaAs solar panels
    * LET spectra and single event upset rates
    * trapped proton flux anisotropy
    * atmospheric and ionospheric densities and temperatures
    * atomic oxygen erosion depths

    Register for SPENVIS at http://www.spenvis.oma.be/spenvis/

Recommended Google Earth space weather displays

Download free KMZ files at http://spacewx.com/Innovation_KML.html

Recommended Twitter feeds

@spacenvironment
@spacenv
#spacewx
#spacenvironment
#solarflares

Course Calendar

Class #	Date	Start-End time	Broad Topical Areas and Lecture #	HW # due
1	Aug 23, 2016	18:40-21:20	1. Introduction to the space environment and spacecraft interactions (definitions; space physics; space weather; spacecraft interactions at GEO, LEO, atmosphere, ground; organizations; space weather drivers; standards activities)	–
2	Aug 30, 2016	18:40-21:20	2. Introductory space physics and solar-planetary relationships – I (atomic physics; photon radiation; solar interior, atmosphere; solar irradiances)	1
3	Sep 06, 2016	18:40-21:20	3. Introductory space physics and solar-planetary relationships – II (solar gravitational field; solar magnetic field, dynamo, MHD; local magnetic/bipolar fields, CMEs, flares; solar wind magnetic field, current sheet, electrons, protons; GCRs; comets, asteroids, dust, and gas in heliosphere)	2
4	Sep 13, 2016	18:40-21:20	4. Planetary space environment – I (gas kinetic theory; molecular and atomic collisions; atmospheric physics; Earth's neutral atmosphere: surface and lower atmosphere, upper atmosphere with solar, auroral, conduction, mixing heating, cooling by conduction and mixing, and dynamics)	3
5	Sep 20, 2016	18:40-21:20	5. Environmental effects - I (neutral atmosphere) (kinetic energy: drag, perturbations, sputtering; chemical energy: atomic oxygen erosion, UV degradation, s/c glow; thermal: temperature control; particulate: contamination; standards/guidelines and models)	4
6	Sep 27, 2016	18:40-21:20	6. Planetary space environment – II (Earth's ionosphere) (ionospheric physics; thermospheric coupling; electron-ion production and loss processes: solar EUV photoionization, charged particle precipitation, Joule heating, waves, winds; ionospheric structure and dynamics; ionospheric features)	5
7	Oct 04, 2016	18:40-21:20	7. Environmental effects – II (ionosphere) (systems of models characterizing the ionosphere; physical environment; example models and data streams; GPS signal uncertainties: TEC variability and scintillation; radio propagation: reflecting layers and propagation; radar system: scatter and clutter, SuperDARN; standards and guidelines; models)	6
8	Oct 11, 2016	18:40-21:20	Exam #1	7
9	Oct 18, 2016	18:40-21:20	8. Planetary space environment - III (Earth's magnetosphere) (Plasma physics basics: Maxwell's Equations, Ohm's Law, Equation of continuity, hydrodynamic equation; particle motion and drifts; magnetic mirroring; geomagnetism; IGRF, dipole field; geomagnetic coordinates; magnetospheric structure: bow shock, magnetosheath, magnetotail, plasma sheet, neutral sheet, polar cusps; magnetospheric variability: currents, convection, storms and substorms, magnetic variations, magnetic storms, magnetic indices)	–
10	Oct 25, 2016 (lecture	18:40-21:20	9. Environmental effects - III (plasma) (Plasma effects: electron and ion surface interactions, current collection; spacecraft charging: sources, photoelectric effect, plasma bombardment, discharge; LEO charging: unbiased, biased (solar arrays),	8

	to be pre-taped)		grounding, within auroras, field aligned currents; high altitude charging: GEO, SCATHA; electrostatic discharge (ESD): Paschen discharge and arcing, design considerations, materials selection and plasma contactors)	
11	Nov 01, 2016	18:40-21:20	10. Planetary space environment - IV (plasmasphere and radiation belts) (magnetosphere: BL coordinate system, L-shells, magnetic rigidity; plasmasphere: ionosphere topside, composition, formation, variability; radiation physics: radiation-surface interactions (photons: photoelectric effect, Compton scattering, pair production), linear attenuation, radiation damage effects; radiation environment - the Van Allen Belts: inner, outer, new belts and their sources; standards and guidelines)	9
12	Nov 08, 2016	18:40-21:20	No class – Election Day	–
13	Nov 15, 2016	18:40-21:20	11. *Environmental effects - IV (radiation effects)* (radiation physics: radiation-surface interactions (photons, electrons, ions, neutrons); radiation environment characteristics: radiation units (gray, Rad, dose), Van Allen belts, solar energetic photons, solar energetic particles, galactic cosmic rays; radiation (charged particle) effects: surface impacting effects (conducting material, solar arrays, optical surfaces), penetration effects (single event upsets, latchup, deep dielectric charging), example events (Mar1991, Jan 1994 (Anik), May 1998 (Galaxy-4), Oct 28-31 2003), linear energy transfer, doses, radiation shielding, radiation hazards; standards, guidelines, models (AE8, AP8, JPL, CRÈME, L2-CPE))	10
14	Nov 22, 2016	18:40-21:20	12. *Micrometeoroid and orbital debris environment* (Micrometeoroid (MM) environment: sources, terrestrial effects, fluences, directionality; Orbital Debris (OD) environment: population/sources, types, detectability, fluences, perturbations/lifetime; effects: hypervelocity impacts (cratering, spallation, penetration, perforations, cracks), thickness of materials; mitigation paths for debris: ISO TC20/SC14 ODCWG; standards, guidelines, models)	11
15	Nov 29, 2016	18:40-21:20	Exam #2	12
16	Dec 06, 2016	18:40-21:20	No class – finals preparation week (study days period)	–
17	Dec 13, 2016	19:00-21:00	No Class (Happy Holidays)	–

[i]Dr. Tobiska is the President and Chief Scientist of Space Environment Technologies (SET), Director of the Utah State University Space Weather Center (SWC), and President of Q-up, LLC. His early research of solar XUV to FUV irradiances led to the creation of the internationally distributed Solar Irradiance Platform (SIP) modeling system. He invented the world's first operational computer code for solar irradiance forecasting while serving as a senior scientist at Northrop Grumman/Logicon. At SET, he extended this expertise into the development of operational space weather systems that now produce solar irradiances, geomagnetic indices, and ground-to-space radiation environment dose rates. At SWC, he has led the effort to produce and disseminate information layers in operational HF communications and GPS accuracies for use by broader technological systems. At Q-up, he organized the activity to commercialize ionospheric communications and navigation products. His career spans work at the NOAA Space Environment Laboratory, UC Berkeley Space Sciences Laboratory, Jet Propulsion Laboratory, Northrop Grumman, SET, SWC, and Q-up. He has been a USAF and a NASA Principal Investigator (PI) in the LWS, SOHO, JSDAP, and UARS programs, a Co-Investigator (Co-I) on the NASA SDO, TIMED, Galileo, and ESA component of the International Space Station (ISS) SOL-ACES instruments. He has been the COSPAR C1 Sub-Commission (Thermosphere & Ionosphere) Chair, the COSPAR International Reference Atmosphere (CIRA) Task Force Chair, and was a Session Organizer for 2002, 2004, 2006, 2008, 2010, 2012, and 2014 COSPAR scientific sessions. He serves as lead U.S. delegate to the International Standards Organization (ISO for the space environment and developed the ISO solar irradiance as well as Earth atmosphere density standards. He is the AIAA Atmospheric and Space Environment Technical Committee (ASETC) Committee on Standards (CoS) chair. He has been an actively participant on the American Meteorological Society (AMS) annual Space Weather Symposium organizing committee, the Research-to-Operations Working Group for the National Research Council Decadal Survey, the NASA Heliophysics Division Science Advisory Committee, and the NASA Living With a Star Steering Committee. Dr. Tobiska is an Associate Fellow of the American Institute of Aeronautics and Astronautics and a member of American Geophysical Union, Committee On Space Research, AMS, and ISO TC20/SC14 U.S. Technical Advisory Group. He is a founding member, and Executive Committee member, of the American Commercial Space Weather Association (ACSWA). He has authored/co-authored over 165 peer-review scientific papers as well as 10 books and major technical publications.