## 29-Jan-18 Ground-based Observations of the Io Plasma Torus & Neutral Clouds

1982 – green colored date means also included under UV emissions bibliography
1982 – blue colored date means also included under physical chemistry model bibliography
1982 – red colored date means also included in torus variability bibliography
Highlighted papers are useful overview/review/summary

| Date | Authors, title, reference | Summary |
|---|---|---|
| 1974 | Brown, R.A., F.H. Chaffee, High-resolution spectra of sodium emission from Io, *Ap. J., 187*, L125 | Na D1,2 lines – D2/21 shows optically thick |
| 1974 | Mekler, Eviatar, Spectroscopic observations of Io, Ap. J., 193, L151 | Detection of Na, also claims Ca |
| 1974 | McElroy, Yung, Brown, Sodium emission from Io: Implications, *Ap. J., 187,* L127 | Explains Na D1,2 lines as surface covered in ammonia ice! |
| 1974 | Trafton et al., The spatial extent of sodium emission around Io, *Ap. J., 190*, L85 | Sodium emission extends around Jupiter at Io's orbit, but not all way around. |
| 1974 | Matson, Johnson, Fanale, Sodium D-line emission from Io: Sputtering and resonant scattering hypothesis | Model of sputtering of surface, cloud ejection and resonant scattering of sunlight. |
| 1975 | Parkinson, Excitation of sodium D-line emission observed in the vicinity of Io, J. Atm. Sci., 32, 630 | Observation of D-lines at Kitt Peak. Observations constrain neutral cloud. |
| 1975 | Bergstralh, Matson, Johnson, Sodium D-lin emission from Io: synoptic observations from Table Mountain Observatory, *Ap. J. Lett., 196*, L131 | 7-week observing of sodium emission shows strong correlation with Io's position, distributed in a partial toroid, more leading than trailing. D-line does not depend on solar phase angle. |
| 1975 | Macy, Trafton, Io's sodium emission cloud, Icarus, 25, 432 | Argues for resonant scattering excitation mechanism.<br>Interprets spatial distribution of at least 1/5 of orbital circumference |
| 1975 | Macy, Trafton, A model for Io's atmosphere and sodium cloud, *Ap. J., 200*, 510 | Sputtering source of atmosphere and escaping sodium.<br>Resonant scattering of sunlight causes sodium emission. |
| 1975 | Trafton, L., High-resolution spectra of Io's sodium emission, Ap. J., 202, L107 | Shape of emission profile varies with orbital phase of Io.<br>Width suggests v~18 km/s. |

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| 1975 | Trafton, Macy, An oscillating asymmetry of Io's sodium emission cloud, *Ap. J., 202,* L155 | Reports variation in sodium emission with Io's magnetic longitude.<br>Argues cause is variations in sputtering by trapped charged particles. |
| 1975 | Carlson, Matson, Johnson, Electron impact ionization of Io's sodium emission cloud, *Gephys. Res. Lett., 2,* 469 | Model of sodium cloud assuming uniform source and electron impact ionization as loss process.<br>Assume plasma densities of 30-200 cm^-3 |
| 1975 | Brown, Goody, Murcray, Chaffee, Further studies of line emission from Io, *Ap. J., 200*, L49 | Defines region A = disk, region B = 10s arcsec from Io, region C = extended neutral cloud<br>Reports column abundance for region B |
| 1975 | Ershkovich, Mekler, Jovian sodium cloud geometry, Astrophs. Space Sci, 38, L1 | Models sodium cloud (4-10 RJ). Assumes v~2.3 km/s escaping from Io. Estimates lifetime of 10^5 s |
| 1975 | Trafton, Detection of potassium cloud near Io, Nature, 258, 690 | First detection of potassium.<br>Assumed sputtering source. |
| 1976 | Fang, Smyth, McElroy, The spatial distribution of long lived gas clouds emitted by satellites in the outer solar system, *Planet. Space Sci., 24,* 577 | Generalized description of neutral clouds coming from satellites in orbit around giant planets. |
| 1976 | Mekler, Eviatar, Coroniti, Sodium in the jovian magnetosphere, Astrophys. Space Sci., 40, 63 | Map of sodium cloud from 4 to 10 RJ<br>Argues for sputtering source |
| 1976 | Eviatar, Mekler, Coroniti, Jovian sodium plasma, Ap. J., 205, 622 | Model of production, transport, loss.<br>Discussion of sodium atoms reaching out into the solar wind. |
| 1976 | Wehinger, Wyckoff, Fohlich, Mapping of the sodium emission associated with Io and Jupiter, *Icarus, 27,* 425 | Mapping sodium out to 23 RJ |
| 1976 | Kupo, Mekler, Eviatar, Detection of ionized sulfur in the jovian magnetosphere, *Ap. J., 205,* L51 | Ionized sulfur – SII – disk around Io's orbit.<br>Electron impact excited, n<<10^4 cm^-3<br>c.f. Pioneer 10 estimate from Frank's plasma data of ~100 |
| 1976 | Brown, R.A., A model of Jupiter's sulfur nebula, Ap. J., 206, L179 | Spectral analysis puts limits on electron density and temperature.<br>Argues for higher density, lower temperature than claimed by Frank from Pioneer 10 plasma data |

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| 1977 | Mekler, Eviatar, Kupo, Jovian sulfur nebula, *JGR, 82,* 2809 | Observations modeled with Te~10eV, Ne~500 cm^-3, of which 24% is sulfur.<br>Argues against Frank's Pioneer 10 in situ data (Ne~100 cm^-3)<br>Long recombination times.<br>Suggests radial diffusion timescale ~90 days. |
| 1977 | Bergstralh, et al., Sodium D-line emission from Io: A second year of synoptic observations from Table Mountain Observatory, *Ap. J., 211,* L51 | 1974 and 1975 apparitions similar<br>Some dawn-dusk asymmetry |
| 1977 | Trafton, Periodic variations in Io's sodium and potassium clouds, *Ap. J., 215,* 960 | 17 nights of observing in 1975.<br>Shows magnetic latitudinal and longitudinal variations.<br>Potassium similar structure to sodium, but weaker. |
| 1977 | Trafton, Macy, Io's sodium emission profiles: variations due to Io's phase and magnetic latitude, *Ap. J., 215,* 971 | Strong, persistent variations in emission wavelength with orbital phase of Io. |
| 1977 | Smyth, McElroy, The sodium and hydrogen gas cloud of Io, *Planet. Space Sci., 25,* 415 | Numerical modeling of atoms ejected from Io, following their path through the system under Jupiter's gravity. |
| 1977 | Goody, Apt, Observations of the sodium emission from Jupiter, Region C, *Planet. Space Sci., 25,* 603 | Claims the Na emission beyond about 9 RJ is terrestrial noise. |
| 1977 | Münch, Bergstralh, Io: Morphology of its sodium emission region, Astronomical society of the Pacific, 89:232-237 | Compares GB observations of Na and SII with electron properties from Pioneer – and has hard time reconciling with low densities and protons. |
| 1978 | Trafton, Macy, On the distribution of sodium in the vicinity of Io, *Icarus, 33*, 322 | Further study of Io phase and East-West effects |
| 1978 | Matson, Goldberg, Johnson, Carlson, Images of Io's sodium cloud, *Science, 199,* 531 | Images of the sodium cloud showing "banana" shape of cloud.<br>More atoms on leading than trailing side of Io.<br>Models with non-uniform source direction |
| 1978 | Murcray, Goody, Astronomical monochromatic imaging as applied to the Io sodium cloud, *Applied Optics, 17,* 3117 | Describes method of imaging the sodium D-lines to get images of the neutral cloud. |
| 1978 | Murcray, Goody, Pictures of the Io sodium cloud, *Ap. J., 226*, 327 | Images of the sodium cloud showing steady-state shape of cloud which changes with viewing as well as magnetic field geometry. |

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| 1978 | Carlson, Matson, Johnson, Bergstralh, Sodium D-line emission from Io: Comparison of observed and theoretical line profiles, *Ap. J., 223*, 1082 | Line profiles of emission consistent with escape velocity and from leading hemisphere |
| 1978 | Mekler, Eviatar, Thermal Electron density in the jovian magnetosphere, JGR, 83, 5679 | Distant sodium cloud observed and shows variability.<br>Argues this variability due to changes in the thermal electron population. |
| 1978 | Smyth, McElroy, Io's sodium cloud: comparison of models and 2-dimentional images, *Ap. J., 226,* 336 | Further particle tracing modeling of the sodium cloud that are then compared with images.<br>Concluded the effective life time is 15-20 hours before ionization. |
| 1979 | Smyth, Io's sodium cloud: Explanation of the East-West asymmetries, Ap. J., 234, 1148 | Explains the East-West asymmetry of the sodium cloud via radiation pressure on the atoms. |
| 1979 | Pilcher, Schempp, Jovian sodium emission from region C, *Icarus, 38,* 1 | Sodium D-lines observed out to 35 RJ from Jupiter. |
| 1979 | Eviatar, Siscoe, Mekler, Temperature anisotropy of the Jovian sulfur nebula, *Icarus, 39,* 450 | GB observations of SII suggest Tpar>>Tperp~3eV. Propose model of plasma (dominated by protons & e-) that allows parallel heating. |
| 1979 | Mekler, Eviatar, Siscoe, Discontinuities in jovian Sulphur plasma, *MNRAS, 189,* 15-17 | Discusses difficulties in reconciling radial distribution of SII from ground-based observations with in situ measurements of plasma from Pioneer. |
| 1980 | Cummings, Dessler, Hill, Latitudinal Oscillations of Plasma within the Io Torus, JGR, 85, A5, 2108 | Calculates equilibrium latitude location of peak density for range of Tperp. High Tperp -> Mag Eq., low Tperp to Cent. Eq. |
| 1980 | Pilcher, Images of Jupiter's sulfur ring, *Science, 207,* 188 | SII torus observed April 1979. Thin inner torus one night, thick ribbon another. |
| 1980 | Pilcher, Morgan, Distribution of SII emission around Jupiter, *Ap. J.,* 238, 375 | Ring of SII emission 4-7 RJ with thickness +-0.7 RJ<br>Variable with longitude.<br>No variation with Io phase |
| 1980 | Trauger, Munch, Roesler, A study of the jovian [S II] nebula at high spectral resolution, *Ap. J., 236*, 1035-1080 | Plots of SII vs. R, lat, long.<br>Scaleheight~0.13 RJ giving T~1.7 eV<br>Ne~2000 cm^-3 |

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| 1980 | Macy, Trafton, The distribution of sodium in Io's cloud: Implications, *Icarus, 41,* 131 | Particle-tracing model of sodium atoms ejected from Io (inside hemisphere), followed to ~30 RJ.<br>Distant cloud losses by ionization. |
| 1980 | Trafton, The jovian SII torus: Its longitudinal asymmetry, *Icarus, 42,* 111 | Plots of SII vs. R, lat, long, in weird plotting technique<br>Te=10^4.4<br>Ne~20,000 cm^-3<br>(no wonder m'sphere people ignored such papers) |
| 1980 | Goldberg, Mekler, Carlson, Johnson, Matson, Io's sodium emission cloud and the Voyager 1 encounter, *Icarus, 44,* 305 | Review of Na observations from GB telescopes. |
| 1980 | Trafton, An explanation for the alternating North-South asymmetry of Io's sodium cloud, *Icarus, 44,* 318 | Explains longitudinal asymmetry of the Na cloud by ionization by plasma torus tilted by magnetic field wrt neutral cloud in Io's orbital plane.<br>Post-Voyager |
| 1980 | Mekler, Eviatar, Time analysis of Volcanic activity on Io by means of plasma observations, *JGR, 85,* A3, 1307 | Model of Io volcanic activity based on 15 volcanoes and binomial distribution. Assumes low activity during Pioneer (compared with Voyager). |
| 1981 | Brown, R.A. and N.M. Schneider, "Sodium Remote from Io", *Icarus 48,* 519-535 | Distant (10-20 RJ) sodium - fast, up to 100 km/s.<br>Suggest charge exchange source. |
| 1981 | Trafton, A survey of Io's potassium cloud, *Ap. J., 247,* 1125 | Similar spatial variations as sodium – but noisier. |
| 1981 | Brown, R.A., The Jupiter hot plasma torus: Observed electron temperature and energy flows, *Ap. J., 244* 1072 | Detection of OI 6300 and SIII 6312<br>Te~4 eV plus few % hot electrons<br>T(SIII)~90 eV |
| 1981 | Brown, R.A., W-H. Ip, Atomic clouds as distributed sources for the Io plasma torus, *Science, 213,* 1493 | High resolution spectrum of SII shows both cold (16 eV) and hot (360eV – but not well determined). |
| 1981 | Brown, R.A., Heavy ions in Jupiter's environment, *Adv. Space Res., 1*, 75 | Review of optical (cold) and warm (UV) torus and flow of mass and energy through the system. |
| 1981 | Haff, Watson, Yung, Sputter ejection of matter from Io, *JGR, 86*, A8, 6933 | Claims source of plasma is sputtering of surface by pick-up S+ and O+ ions. |
| 1982 | Brown, R.A. The probability distribution of S+ gyrospeeds in the Io torus, *JGR, 87*, 230 | Tperp from high resolution optical observations of S+ emission with average Tperp of 60 eV – though spatially smeared and likely the distribution is not Maxwellian. |

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| 1982 | Brown, Shemansky, On the nature of SII emission from Jupiter's hot plasma torus, *Ap. J., 263,* 433 | Compares GB optical and Voyager UV emission from S+ ions. Shows compatible Te~7eV at ~5.9 RJ.<br>Variable SII/SIII suggested to be due to charge exchange reactions. |
| 1982 | Morgan, J.S., C.B. Pilcher, Plasma characteristics of the Io torus, *Ap. J., 253*, 406 | Observation of both SII and OII emissions – 2 lines each.<br>Allows determination of electron density and temperature – roughly consistent with Voyager<br>Longitude variations in SII, less clear for OII<br>3 spectra suggest v. cold, dense plasma |
| 1982 | Goertz, Ip, On the structure of the Io torus, *Planet. Space. Sci, 30*, 9, 855 | Claims importance of charge exchange reactions as source of fresh ions from exosphere of Io. Modeling of neutral banana cloud. |
| 1982 | Roesler, Oliversen, Scherb, Lattis, Williams, York, Jenkins, Lowrance, Zucchino, Long, Farby-Perot/CCD observations of [S III] and [S II] emissions from the Jupiter Plasma Torus, *Ap. J, 259*, 900 | Both SII and SIII from GB optical emissions.<br>Vertical scaleheight gives T(S+)~ 5 eV and T(S++) ~ 19 to 55 eV<br>Emission line profiles gives Tperp(S++)~ 27-120 eV |
| 1983 | Brown, Pilcher, Strobel, Spectrophotometric studies of the Io torus, in *Physics of the Jovian Magnetosphere,* Dessler (ed), Cambridge University Press | Review of physical processes of production, loss and emission of neutral and ionized species – both UV and optical |
| 1983 | Smyth, Io's sodium cloud: Explanation of the East-West Asymmetries II, *Ap. J., 264*, 708-725 | Ballistic trajectories of escaping sodium atoms, shaped by ionization, radiation of scattered sunlight depending on motion relative to Sun, discusses motion of Io in the plasma torus. |
| 1983 | Brown, Shemansky, Johnson, A deficiency of OIII in the Io plasma torus, *Ap. J., 264*, 309 | Lack of OIII optical emission suggests low density – but lower than suggested by Voyager UV<br>CHEX decreases OIII but not enough. Otherwise need to decrease fraction of hot electrons or transport time.<br>Low limit on Cl III |
| 1983 | Brown, Observed departure of the Io plasma torus from rigid co-rotation with Jupiter, *Ap. J., 268,* L47 | Line shift suggests 4-6% co-rotation lag at 5.9 RJ |
| 1983 | Smyth, Shemansky, Escape and ionization of atomic oxygen from Io, Ap. J, 271, 865 | Modeling of production from Io, constrained by UV emissions close to Io. Just OI~17 kg/s. Add sulfur and CHEX increases mass-loading. Diffusive timescale~200 days. Total mass loss from Io ~270 kg/s. Total plasma production ~ 150 kg/s |

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| 1984 | Goertz, Ip, A dawn-to-dusk electric field in the jovian magnetosphere, Planet. Space Sci., 32, 179-185 | Detailed explanation of basic idea set out in Ip & Goertz (1983) and in Barbosa & Kivelson (1983) of global E-W electric field produced by ejection of material down the tail. |
| 1984 | Pilcher, Smyth, Combi, Fertel, Io's sodium directional features: evidence for a magnetospheric-wind-driven gas escape mechanism, *Ap. J., 287*, 427 | Detection of sodium jets coming from Io<br>Suggests due to CHEX during interaction |
| 1984 | Trauger, The jovian nebula: A post-Voyager perspective, *Science, 226*, 337-341 | With insight of Voyager, SII and SIII images converted into radial profiles of S+ and S++ densities – cold and hot components |
| 1984 | Roesler, Scherb, Oliversen, Periodic intensity variation in SIII 9531A emission from the Jupiter plasma torus, *GRL, 11,* 128-130 | 43 Jupiter rotations of SIII emission shows periodicity at 2.8% slower than corotation.<br>First report of what later was called System IV. |
| 1984 | Goldberg, Garneau, LaVoie, Io's Sodium Cloud, *Science, 226,* 4674 | 2-D images from 1981 of Na cloud (claims first 2-D images – but previously reported by Murcray in 1978.<br>Variations with Io phase, longitude, look direction. |
| 1984 | Sieveka, Johnson, Ejection of atoms and molecules from Io by plasma-ion impact, *Ap. J, 287,* 418 | Ranges of escape speed of neutral material via different processes. |
| 1985 | Pilcher, Morgan, Magnetic longitude variations in the Io torus, *Adv. Space Res. 5*, 337 | Variations in optical properties of SII and SIII emission with longitude<br>Argues for local production causing longitudinal variations |
| 1985 | Pilcher, Fertel, Morgan, SII images of the Io torus, *Ap. J., 291*, 377 | System III longitude effect<br>East-West effect |
| 1985 | Morgan, Temporal and spatial variations in the Io torus, *Icarus, 62,* 389 | 1981 observations of 2 lines of SII and OII and 1 line of SIII<br>East-West effect<br>Longitude effect<br>Line ratios of SII suggest increase in Ne over 4 months |

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| 1985 | Morgan, Models of the Io torus, *Icarus, 63,* 243 | Models constructed from optical observations – both spectroscopic and images (from Oliversen) and compared with Voyager.<br>Indicates differences: 1981 1.5-2 times denser >5.7 RJ, SII temperatures half that measured by Voyager, OII mixing ratio lower – dropping inside 6 RJ.<br>Factor 2 variations in intensity with longitude<br>East-West asymmetry consistent with B&K and G&I theory.<br>Notes difficulty in measuring OII line ratios. |
| 1986 | Moreno, Barbosa, Mass and energy balance of the cold Io torus, JGR, 91, 8993-8997 | Physical chemistry model of the cold inner torus starting with SO2+ ions. Points out issue with NL2 profile, DLL, radiation vs. diffusion times. Notes important CHEX reactions. |
| 1986 | Summers, Siscoe, A model of the Io plasma ribbon, Icarus, 67, 520-524 | Models the Ribbon as a localized source region. |
| 1987 | Schneider, Hunten, Wells, Trafton, "Eclipse Observations of Io's Sodium Atmosphere", *Science 238,* 55-58 | 1985 Gal sats eclipse – 2 give depth of sodium cloud<br>Column abundance ~3 x 10^12 cm-2, dropping off as 1/R^2 |
| 1987 | Smyth, Combi, Correlating east-west symmetries in the jovian magnetosphere and the Io sodium cloud, *GRL, 14,* 973-976 | Modeling effects of E-W offset and longitudinal variations in torus on the Na cloud models. |
| 1987 | Eviatar, Volcanic control of the Io Atmosphere and neutral and plasma Torus, *JGR, 92*, A8, 8800 | Early model of plasma interaction producing torus production at Io.<br>Depends on model assumptions about the atmosphere, the incoming plasma and the reactions. |
| 1987 | Ballester, Moos, Feldman, Strobel, Summers, Bertaux, Skinner, Festou, Lieske, Detection of neutral oxygen and sulfur emissions near Io using IUE, *Ap. J., 319,* L33 | Comparison of UV emissions when Io in/out of IUE FOV.<br>Multiple overlapping lines make separation of species difficult.<br>Suggests extended emissions coming from interaction of electrons associated with ionosphere and/or plasma interaction impacting the SO2 atmosphere. |
| 1988 | Smyth, Combi, A general model for Io's neutral gas clouds: I Mathematical description, *Ap. J. Supp., 66,* 397 | Description of method for doing neutral atom ballistic trajectories. |
| 1988 | Smyth, Combi, A general model for Io's neutral gas clouds: II. Applications to the sodium cloud, *Ap. J, 328,* 888 | Model of the Na cloud that includes E-W variations, Io phase effect, System III longitude |

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| 1989 | Summers, Strobel, Yung, Trauger, Mills, The structure of Io's thermal corona and implications for atmospheric escape, *Ap. J., 343,* 468 | Modeling of thermal and non-thermal escape from Io's atmosphere.<br>Concludes that atmospheric sputtering is high – requires deflection of plasma flow around Io<br>O-dominated corona, T~1000K. Exobase/plasma interaction 1.5 RIo<br>Na mixing ratio ~ $10^{-3}$ |
| 1990 | Mendillo, Baumgardner, Flynn, Hughes, The extended sodium nebula of Jupiter, *Nature, 348,* 312 | Sodium cloud detected out to nearly 300 RJ<br>The Mendillosphere! |
| 1991 | Schneider., Hunten, Wells, Schultz, Fink, The Structure of Io's Corona, Ap. J. 368, 298-315 | Details of mutual events and derivation of column abundances |
| 1991 | Schneider., Trauger, Wilson, Brown, Evans, Shemansky, Molecular Origin of Io's Fast Sodium, *Science, 253,* 1394-1397 | Explains the fast jets with dissociative recombination of sodium molecular ion |
| 1991 | Smyth, Combi, The sodium zenocorona, *J. Geophys. Res., 96,* 22,711 | Particle tracing modeling of both banana cloud and the extended Mendillosphere (>200 RJ). |
| 1991 | Oliversen, Scherb, Roesler, The Io sulfur torus in 1981, *Icarus, 93,* 53-62 | SII and SIII. Inner, cold torus vs. warm outer torus. |
| 1991 | Yang, Dessler, Sandel, Is System IV Independent of System III? *JGR, 96,* A3, 3819 | Tests idea that System IV and III are beat frequencies – concludes that they are separate periodicities. |
| 1992 | Thomas, N., Optical observations of Io's neutral clouds and plasma torus, *Surveys Geophys., 13,* 91-164 | Review of optical observations – both neutrals and ions<br>Pre-Voyager, Voyager (in situ and UV), emission model, mass & energy flow,<br>Good diagrams. |
| 1992 | Mendillo, Flynn, Baumgardner, Imaging observations of Jupiter's sodium magnetonebula duing the Ulysses encounter, *Science, 257,* 1510 | Mendillosphere Nov-Dec 1989, Jan 1990, Feb 1992.<br>Brightness at 100 RJ ranges from 75 to 25 to 10 R.<br>Sodium source drops correspondingly. |
| 1992 | Cremonese, Thomas, Barbieri, Pernechele, High resolution spectra of Io's neutral sodium cloud, *Astron. Astrophys. 256,* 286 | Both fast and slow sodium observed.3<br>Mapped to show both Io-phase and longitudinal effects.<br>Fast neutral production of 2-5 x 10^25 atoms/s derived. |
| 1992 | Jockers, Thomas, Bonev, Ifanova, Shkodrov, Observations of Io's sodium cloud and torus, *Adv. Space Res. 12,* 347 | New observing system.<br>Similar results to previous. |

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| 1992 | Smyth, Neutral cloud distribution in the Jovian System, *Adv. Space Res., 12,* 337-346 | Nice diagram of reactions between Io and the torus. Shows reactions and emissions.<br>Summary of features and explanations |
| 1992 | Yang, Wolf, Spiro, Dessler, Numerical simulation of plasma transport driven by the Io torus, *GRL, 19,* 10957 | Rice convection model produces fingers of outward-moving plasma.<br>System III variation imposed due to variation in B with longitude. |
| 1993 | Thomas, Detection of [OIII] 5007 emission from the Io plasma torus, *Ap. J., 414*, L41-L44 | First detection of OIII (5007) emission 5.5 – 5.8 RJ.<br>Higher intensity than reported.<br>Ne (from SII line ratio) 2-3000. Te 2-3 eV<br>O2+/Ne~3.4% |
| 1993 | Rauer, Bonev, Jockers, Thomas, Low-resolution spectra of the Io plasma torus 2 doys after the Ulysses*, Planet. Space Sci., 41,* 1021 | SII and SIII observed during Ulysses (10-11 Feb 1992).<br>Higher density than Voyager.<br>Local time & System III variations. |
| 1993 | Thomas, The variability of the Io plasma torus, *JGR, 98,* 18,737-18,750 | Review of variability of the IPT.<br>System III, IV<br>East-West – local time, Io-phase<br>Problem is comparison of UV and optical with v. different knowledge of excitation physics as well as dependence on fraction of hot electrons |
| 1994 | Flynn, Mendillo, Baumgardner, The jovian sodium nebula: Two years of ground-based observations, *JGR*, *99*, 8403 | +-500 RJ sodium nebula monitored late 1989 to early 1992.<br>R^-1 intensity variation<br>Sharp decrease over time, followed by lower-level variations<br>Multiple explanations for variation in morphology. |
| 1994 | Brown, M.E., Observations of mass loading in the Io plasma torus, *Geophys. Res. Lett*, *21*, 837 | High resolution Doppler shift of SII emission indications (over 7 months) deviation from corotation – up to 4 km/s<br>Uniform with longitude – systematic dawn-dusk effect.<br>Io phase effect |
| 1994 | Wilson, J.K., N.M. Schneider, Io's Fast Sodium: Implications for Molecular and Atomic Escape, *Icarus 111*, 31-44 | High resolution imaging of fast sodium jets.<br>Modelled as dissociation, ionization or chex of molecular species. |
| 1995 | Thomas, Ion temperatures in the Io plasma torus, *JGR*, *100*, 7925 | S+, S++, O+, O++ observed with sufficient resolution to determine perpendicular temperatures.<br>Tpar from images<br>60-120 eV in warm torus, ~30 eV in cold torus.<br>Should be compared with physical chemistry model of Delamere & Bagenal 2003 and re-analysis of Voyager data by Bagenal 2017 |

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| 1995 | Schneider, Trauger, The Structure of the Io Torus, *Astrophys. J. 450*, 450-462 | High resolution imagery provides structure of S+ emission.<br>Radial, latitude, longitude, local time variations.<br>Significant deviation from O6+ magnetic field model<br>Reference ribbon positions – System III & local time |
| 1996 | Spencer, Schneider, Io on the eve of the Galileo mission, *Ann. Rev. Earth Planet. Sci., 24*, 125-190 | First half about Io out to atmosphere.<br>Summary of atmospheric loss rates, plasma-atmosphere interactions, 7 neutral Na populations, O and S clouds,<br>Io plasma torus, average composition, density, spatial distribution,<br>Mass and energy flows<br>List of outstanding Qs |
| 1996 | Thomas, High resolution spectra of Io's neutral potassium and oxygen clouds, *Astron. Astrophys., 313,* 306-314 | Neutral K and O |
| 1997 | Brown, Bouchez, The response of Jupiter's magnetosphere to an outburst on Io, *Science, 278*, 268-271 | Io outburst March 1992. Both Na and SII emissions increased. Timing indicates sodium increase preceded SII by about 10-20 days.<br>Modeling time profiles suggests that the increased production produced a faster loss from radial transport. |
| 1997 | Schneider, Taylor, Crary, Trauger, On the nature of the System III brightness asymmetry in the Io torus, *J. Geophys. Res., 102,* 19823-19833 | Compares optical and UV brightness asymmetries with longitude which are found to be out of phase.<br>Explains with small amount of additional energy being put into system, e.g. via hot electron component.<br>Strong ion temperature variation in the ribbon.<br>Model with cubic-centimeter models |
| 1997 | Smyth, Combi, Io's Sodium Corona and Spatially Extended Cloud: A Consistent Flux Speed Distribution, *Icarus, 126,* 58-77 | Comparison of model with data – from ~2 RIo to ~40 RIo<br>Best fit to Na emissions data with collisional cascade function of power-law alpha~3 to 7/3 |
| 1997 | Küppers, Jockers, A Multi-emission imaging study of the Io Plasma Torus, *Icarus, 129*, 48 | 2D images of torus from GB optical observations SII, SIII, OII.<br>Consistent dawn-dusk nor longitude variations not so clear.<br>Claims Te~11eV in ribbon from line ratios. Uses CITEP. |
| 1998 | Smyth, Marconi, An explanation for the east-west asymmetry of the Io plasma torus, *J. Geophys. Res., 103*, 9091 | Took Schneider et al. 1997 variations in brightness and applied offset, tilted dipole OTD to displace the ribbon. 2-D diffusion equation, allowing for E-W variations in L-shells. Produces offsets of S+ vs S++ ribbons. Comments needs molecular chemistry for S+ loss |

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| 1998 | Kuppers, M. and N.M. Schneider, The density of the Io plasma torus ribbon, *Geophys. Res. Lett., 25*, 2757-2760 | Used CITEP to compare emission models for GB, Voyager and UV views of the ribbon. Not able to explain high densities of Volwerk et al. 1997. Model of cooling via radiation. Points to stochastic heating by variable E-W electric fields. |
| 1998 | Smyth, Marconi, An initial look at the iogenic SO2+ source during the Galileo flyby, *J. Geophys. Res., 103*, 9089 | Models Huddleston et al. 1997 profile of EMIC waves from production of SO2+ and SO+<br>Uses OTD plus E-W electric field to get offset torus which produces asymmetric ionization of SO2 and short lifetimes |
| 1998 | Smyth, Energy escape rate of neutrals from Io and the implications for local magnetospheric interactions, *JGR, 103,* A6, 11941 | Plasma-Io interaction to produce neutrals. Diagram to show energy flow through the system. |
| 1999 | Burger, M.H. and N.M Schneider, Galileo's Close-up View of Io's Sodium Jet, *Geophys. Res. Lett., 26*, 3333-3336, | Optical observations of the sodium jet close to Io |
| 1999 | Wilson, J.K. and N.M. Schneider, Io's Sodium Directional Feature: Evidence for Ionospheric Escape, *J. Geophys. Res., 104*, 16567-16583 | Model of jet close to Io using multiple CHEX reactions. |
| 2000 | Kuppers, M.H and N.M. Schneider, The Discovery of Chlorine in the Io Plasma Torus, *Geophys. Res. Lett., 27,* 513-516 | Optical detection of Cl+ at 2+-0.5%<br>Proposed coming from NaCl |
| 2000 | Bouchez, Brown, Schneider, Eclipse spectroscopy of Io's atmosphere, *Icarus 148,* 316-319 | Galileo SSI images when Io moves in front of Jupiter.<br>Auroral emission 5 lines of Na and O |
| 2000 | Smyth, Marconi, Io's oxygen source: Determination from ground-based observations and implications for the torus plasma, *JGR, 105,* 7783-7792 | Limited GB observations of 6300 OI emission (Brown 1981, Thomas 1996)<br>Modeled with atmospheric production via atmospheric sputtering (similar to sodium)<br>Main losses CHEX (68%) and electron impact ionization (22%)<br>Uses COREQ. Consistent with SO2. |
| 2001 | Burger, et al., Mutual event observations of Io's sodium corona, *Ap. J. 563,* 1063-1074 | Extensive observations of Na emission extending out to 10 RIo<br>Fit to radial profiles suggest ~50% densier on sub-jovian hemisphere.<br>$n(r)=6700\ r^{-3.34}\ cm^{-3}$ |

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| 2001 | Lichtenberg, Thomas, Fouchet, Detection of S(IV) 10.51-micron emission from the Io plasma torus, *JGR, 106,* 29,899-29,910 | Detection of long-wavelength emission from S+++ ions<br>1.5-3.5 times brighter than predicted by Voyager<br>Chemistry model based on COREQ<br>Would be good to compare with Steffl/Delamere analysis of Cassini data using CHIANTI |
| 2001 | Oliversen, et al., Sunlit Io atmospheric [OI] 6300 A emission and the plasma torus, *JGR, 106,* 26,183-26,193 | Optical 6300A OI mission from Io 1990-1990<br>Longitude, E-W and temporal variations<br>Disk-average column density ~1 x $10^{15}$ $cm^{-2}$<br>2-10 Rayleigh emission – mostly varying with System III plus ~25% scatter<br>Uses Voyager-based Smyth & Combi (1988) and Smyth & Marconi (1998) models |
| 2001 | Thomas, Lichtenberg, Scotto, High-resolution spectroscopy of the Io plasma torus during the Galileo mission, *JGR, 106,* 26,277-26,291 | High-resolution observations taken Sept 1997 and Oct 1999<br>Radial profiles of SII, SIII, OII emissions produce radial profiles of Ti, Ni from 4 to 7.5 RJ<br>System III variations variable<br>High resolution Doppler shift shows deviation from corotation at ~2-4 km/s<br>Compare with Steffl/Delamere observations/model of Cassini UVIS |
| 2001 | Wolven et al., Emission profiles of neutral oxygen and sulfur in Io's exospheric corona, *JGR, 106*, 26155-26182 | 30 HST/STIS observations of atmosphere/corona emission out to 10 RIo.<br>Brighter downstream than upstream by ~2<br>Dusk brighter than dawn<br>Suggestion of System III variations but coverage is poor. |
| 2002 | Wilson, Mendillo, Baumgardner, Schneider, Trauger, Flynn, The Dual Sources of Io's Sodium Clouds, *Icarus, 157,* 476-489 | Models close and far Na clouds with exospheric production plus CHEX production of Na ENAs to make Mendillosphere<br>Warns that extending to S, O clouds involves complications of SO2 and SO |
| 2003 | Lellouch, Paubert, Moses, Schneider, Strobel, Volcanically emitted sodium chloride as a source for Io's neutral clouds and plasma torus, *Nature, 421, 45-*47 | Detection of millimeter emission from NaCl in Io's atmosphere<br>Abundance ~0.3%<br>Compared with brighter SO2 emissions |
| 2003 | Smyth, Marconi, Nature of the iogenic plasma source in Jupiter's magnetosphere I. Circumplanetary distribution, *Icarus, 166,* 85-106 | Model predictions of O and S neutral clouds around Jupiter.<br>O ~2-3 times S and more spread out<br>Compares with other estimates of local and extended sources |

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| 2004 | Nozawa et al., Long-term SII emissions from the Io plasma torus between 1997 and 2000, *JGR, 109,* A07209 | 4 observing periods during S+ emission during Galileo epoch<br>1 - C9 – 1997 doy 240-252 (Aug26-Sep9)<br>2 - E16-1998 doy 235-270 (Aug23-Sep27)<br>3 - C23-1999 doy 250-265 (Sep7-Sep22)<br>4 - G28-2000-1 doy 350-372 (Dec16-Jan7)<br>Steady decrease in intensity by a factor of ~2 |
| 2004 | Mendillo, Wilson, Spencer, Stansberry, Io's volcanic control of Jupiter's extended neutral clouds, *Icarus, 170,* 430 | Extended Na cloud varies shape with volcanic eruption rate.<br>Active is brighter and square in shape.<br>Quiet is dimmer and oval/pointed in shape<br>Correlation with IR eruptions on Io over 1990 to 1998 |
| 2005 | Nozawa et al., Relationship between the jovian magnetic plasma density and the Io torus emission, *GRL, 32,* L11101 | Relates 1997-2000 observations to factor of ~8 decrease in electron density 30-60 RJ observed by the GLL-PWS instrument.<br>Note that the Cassini flyby dust increase (~Aug 2000) followed by decrease in UV torus emissions was Oct 1-Dec1 2000 (see Delamere 2005) between observation periods 3 and 4. |
| 2005 | Smyth, Marconi, Nature of the iogenic plasma source in Jupiter's magnetosphere II. Near-Io observations, *Icarus, 176,* 138-154 | Local interaction of plasma (as described in paper I) with Io's atmosphere to produce neutral clouds of S and O around Io (10s RIo) from electron impact ionization and CHEX.<br>3 regions: Inner (below exobase), corona (below Lagrange sphere), and neutral clouds. Mass and energy sources comparable to GLL estimates from Bagenal 1997 and Saur 2003 |
| 2006 | Nozawa et al., Implications for the solar wind effect on the Io plasma torus, *GRL, 33,* L16103 | S+ emission observed Sept 1998.<br>2 points of enhanced emission in late Sept (DOY 267-9).<br>Argued related to QP radio bursts (Morioka 2006) and auroral flares (Waite 2001). |
| 2007 | Mendillo, Laurent, Wilson, Baumgardner, Konrad, Karl, The sources of sodium escaping from Io revealed by spectral high definition imaging, *Nature, 448,* 330-332 | Jet from wake side of Io – not upstream.<br>Extends 3-5 RIo downstream from Io |
| 2007 | Schneider, Bagenal, Io's neutral clouds, plasma torus, and magnetospheric interaction, in *Io After Galileo*, (ed. R. Lopes), Praxis | Survey of observations, models and status of understanding of sources and losses of mass and energy from Io to the magnetosphere. |

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| 2008 | Herbert, Schneider, Dessler, New description of Io's cold plasma torus, *J. Geophys. Res., 113,* A01208 | Re-analysis of Schneider's 1991 observations of S+ emission.<br>Quantitative description of the "washer" of cold inner torus.<br>Dawn-dusk and System III variations,<br>Tpar temperatures in the ribbon – variable – shows how varies over time (observer) between 20 eV and 100 eV.<br>Vertical offset (probably high-order structure of magnetic field).<br>Points out difficulty in modeling the physical chemistry of the inner torus and need for additional heat source. |
| 2010 | Yoneda, Nozowa, Misawa, Kagitani, Okano, Jupiter's magnetospheric change by Io's volcanoes, *GRL, 37,* L11202 | Na and S+ emissions for 20 days in 2003.<br>Enhancement late Feb – early Mar for few days.<br>Factor 2 increase in Na emission for 2 days.<br>Total fluxtube content of S+ increased by ~25% |
| 2010 | Moore, et al. Monte Carlo modeling of Io's OI 6300A and SII 6716 A auroral emission in eclipse, *Icarus, 207,* 810-833 | Electron impact excitation of the atmosphere.<br>Atmosphere modeled with geographically-varying density (including volcanic plumes) of SO2<br>Input is inflowing-electrons at 5eV from torus, bounces from edge of torus – longitude-dependent.<br>Predicts OI 6300 emissions observed from different angles.<br>SII emission much weaker. |
| 2011 | Smyth, Peterson, Marconi, A consistent understanding of the ribbon structure for the Io plasma torus at the Voyager 1, 1991 ground-based and Galileo J0 epochs, *JGR, 116,* A07205 | Focus mostly on SII emission and electron density.<br>Ratio of outer/inner torus densities varies with time by upto ~4<br>Quantifies location of ribbon: Dawn 5.8-5.9, Dusk 5.5-5.6<br>Farthest at System III 120, closest at System III 300.<br>Empirical model with electron density, longitude, LT. |
| 2013 | Yoneda, Tsuchiya, Misawa, Bonfond, Tao, Kagitani, Okano, Io's volcanism controls Jupiter's radio emissions, *GRL, 40,* 671-675 | Enhanced Na observations May – June 2007.<br>Hectrometric radio emission observed by WIND at 1 AU.<br>Over same period the enhanced Na correlated with weaker HOM. |
| 2014 | Grava, Schneider, Leblanc, Morgenthaler, Mangano, Barbieri, Solar control of sodium escape from Io, *JGR, 119,* 404-415 | Observations of Na neutral cloud near Io when it comes out of eclipse (behind Jupiter) suggests interruption of photodissociation of NaCl. |
| 2015 | Yoneda, Kagitani, Tsuchiya, Sakanoi, Okano, Brightening event seen in observations of Jupiter's extended sodium nebula, *Icarus, 261,* 31-33 | Na observations 2013-2015.<br>Faint emissions except Feb-Mar 2015 when enhanced by a factor of 3 |