Theme	Objective	Investigation	Required measurements	Instrumentation
Uranus as an ice giant: How do ice giant planets work?	What is the internal structure and composition of Uranus?	Determine the bulk composition and elemental enrichment of Uranus to constrain deep thermochemistry and planetary formation theories in the unique environments of ice giants	Measure the spatial distribution of microwave opacity sources in the deep troposphere (e.g., H2O, H2S, NH3)	MWR
			Remote sensing determination of isotopic composition of methane/ethane isotopologues (12C/13C, D/H)	NIR/MSIC
			Refine He abundance determination	RSE, UTIRM
			Upper limits on disequilibrium species (PH3, AsH3, GeH4, CO) from near-IR spectroscopy (4-5 μm)	NIR/MSIC
		Infer the vertical structure and mass/density distribution profile (ice/rock and ice/gas ratios) within the Uranian interior and determine the existence/size of a core	Determine higher order gravitational moments of inertia (J6 and beyond) to understand vertical distribution or rock, ice and gas from the core to the outer atmosphere, place limits on the possible inhibition of convection within the interior and identify the equation of state of the Uranian interior.	RSE
			Radio occulations to determine vertical temperature structure to high precision, estimate atmospheric stability and identify condensation levels	RSE
			Measure precession of the rings to determine high order gravitational moments of inertial (J2 and J4)	NAC
	Why does Uranus emit very little heat?	Investigate Uranus' energy balance and the relationship between the spatial variation of internal heat emission (i.e., self-luminosity) and seasonal insolation	Visible-near-IR albedo measurements at multiple solar phase and incidence angles to constrain Uranian reflectivity and bond albedo.	NIR/MSIC
			Measure global thermal emission and its latitudinal variability to determine effective temperature, self-luminosity and regions of maximal heat transport, and determine whether there is a detectable internal heat source.	UTIRM
			Study the spatial variation of small-scale dynamical activity (e.g., convective processes) to determine the amount of energy injected into the weather-layer from below.	NIR/MSIC, NAC, UTIRM
	What is the configuration and origin of Uranus' highly asymmetric magnetic field?	Model the magnetic field of Uranus to at least 4th order and compare with predictions of dynamo models; search for evidence of secular variation of the magnetic field.	Magnetic field observations over a wide range of latitudes and longitudes and as close to the planet as possible.	MAG
			Particle measurements to assess the configuration of the magnetosphere and determine magnetospheric regions suitable for modelling the internal field.	PPS
			Auroral images to constrain high-latitude magnetic field configurations.	UVIS
	What is the rotation rate of Uranus' interior?	Estimate the rotation rate of Uranus' atmosphere and interior and constrain models of Uranus' magnetic field generation and internal	Measurements of Uranian Kilometric Radiation to determine radio rotation rate.	RPW
			Magnetic field observations over a wide range of latitudes and longitudes and as close to the planet as possible to infer the rotation rate from magnetic field modelling.	MAG
			Track the motion of clouds to determine the rotation rate of the atmosphere.	NAC, NIR/MSIC
	How is Uranus' weather structure and composition influenced by its unique seasons?	Determine the 3D distributions of chemical species as a function of altitude, latitude and time as tracers of atmospheric motion	Spatial variability of fluorescent CO 4.7-μm emission to map tropospheric and stratospheric CO	NIR/MSIC
			Search for previously unidentified species using high-resolution spectroscopy	UVIS, NIR/MSIC
			Study the meridional variation of CH4 in the troposphere	NIR/MSIC
			Distribution of microwave opacity sources (e.g. key volatiles, NH3, H2S, clouds, H2O) to constrain deep circulation,	MWR
			Spatial variation of photochemical products (ethane, acetylene, ethylene) with latitude as tracers of middle atmosphere circulation	NIR/MSIC, UVIS
			Determine the meridional temperature field to relate to the distribution of volatiles and disequilibrium species	NIR/MSIC, UTIRM
			Distribution of disquilibrium species (PH3, AsH3, GeH4, if detected) in the near-IR.	NIR/MSIC
		Investigate the zonal organisation (e.g.., winds and their variation with altitude) of Uranus through material tracers	Tracking of discrete cloud features at visible wavelengths to measure zonal windspeeds at the cloud-tops and below. Dayside imaging with a resolution of 200 km, timescales of hours.	NAC, NIR/MSIC
			5-μm nightside imaging to search for thermal emission and opacity variations (e.g., VIMS Saturn observations) to measure wind velocities at depth	NIR/MSIC
			Global mapping of the thermal field to infer vertical windshears and the meridional temperature distribution.	UTIRM
			Determine the 3D structure of the retrograde equatorial jet via multi-spectral sounding	NIR/MSIC, UTIRM, NAC, MWR
			Long-term tracking of discrete cloud-features to trace meridional motions at the cloud tops	NIR/MSIC, NAC
			Determine the depth of zonal organisation into the troposphere (e.g., jets) by searching for perturbations to gravity and magnetic field measurements.	RSE, MAG
			Determine the distribution of microwave opacity sources to understand zonal organisation at depth.	MWR

			Polar atmospheric studies to establish the presence/absence of a discrete polar vortex (e.g, Saturn, Neptune)	UVIS, NIR/MSIC, UTIRM
		Understand the implications of extreme seasonal forcings on Uranus due to unique obliquity	Study hemispheric asymmetries in cloud and haze properties (caused by extreme variations in UV flux and hence photochemistry, radiative heating) via UV, visible and near-IR imaging/spectroscopy	UVIS, NIR/MSIC
			Contrast meridional temperature structure with Voyager/IRIS results in a different season to constrain the thermal response to seasonal variability.	UTIRM
			Study the variations in discrete cloud activity and thermal structures over long temporal baselines (more likely from Earth-based supporting observations) to understand dynamic response to extreme insolation contrasts.	Ground-based imaging campaigns
			Determine hemispheric asymmetries in composition in the radiative atmosphere (e.g. photochemical species such as hydrocarbons, photochemical destruction of volatiles like NH3) and in the convective atmosphere.	NIR/MSIC, UVIS, MWR, UTIRM
		Assess the vertical atmospheric structure and the influence of wave propagation in atmospheric coupling and upper atmospheric heating	Radio occultations at multiple latitudes and times to determine the vertical variability and influence of wave activity.	RSE
			UV and near-IR stellar/solar occulations to determine the vertical density structure and search for the spatial variation of wave activity.	UVIS, NIR/MSIC
			Limb-sounding (thermal or stellar occultation) to measure T(p) in the stratosphere and upper troposphere, and to search for evidence of equatorial wave activity (e.g. Jupiter's QQO).	NIR/MSIC, UTIRM
			Nadir thermal mapping to measure the global temperature field and identify slowly-moving zonal wave activity in the middle atmosphere and upper troposphere	UTIRM
		Search for evidence of lightning activity and the importance of moist convection	Nightside broad-band imaging to search for lightning flashes associated with discrete cloud structures	NIR/MSIC, NAC
			Identify electrostatic discharges in radio data	RPW
			Distribution of potential lightning clouds in microwave data	MWR
	What processes shape atmospheric chemistry and cloud formation on an Ice Giant?	Constrain the inventory, vertical extent and optical properties of clouds and hazes in the troposphere and stratosphere	Reflection spectroscopy in the UV, visible and near-IR at a range of solar phase and incidence angles to determine vertical distribution of clouds and hazes, optical thickness, size distribution, shape and scattering properties	UVIS, NIR/MSIC
			Determine the origin, nature and seasonal variabilty of the two bright zones observed in each hemisphere	NIR/MSIC, MWR, NAC
			Continuum microwave imaging (1-100 cm) to determine vertical distribution of opacity sources and their contributions to the cloud-decks (e.g. NH3, H2S and potentially H2O).	MWR
			Thermal mapping to constrain the thermodynamics of the cloud-forming regions	NIR/MSIC, UTIRM
			Stellar and solar occultation through stratospheric haze layers to determine vertical distributions	UVIS, NIR/MSIC
		Determine cloud composition and the effects of condensation on the thermal profile	Meridional distribution of microwave opacity sources as a proxy for cloud composition and locations	MWR
			Identify cloud composition from spectral modelling in the near-IR	NIR/MSIC
			Stellar and solar occultation through stratospheric haze layers to determine composition	UVIS, NIR/MSIC
			High spatial-resolution thermal sounding to identify latent heat release from condensing volatiles and assess their influence on the vertical temperature structure.	RSE
		Identify the chemical processes governing the distribution of species in the middle atmosphere	Mapping of hydrocarbon distributions (ethane, acetylene and higher-order hydrocarbons) to identify chemical and transport processes in the stratosphere	NIR/MSIC
			Hydrocarbon distributions determined at microbar pressures from UV spectroscopy	UVIS
			UV and IR imaging of polar emissions to map the spatial variability of solar energy deposition (modulated by the magnetic field) and its interaction with the neutral atmosphere.	UVIS, NIR/MSIC
			Determine the meridional distribution of stratospheric hazes and their relation to photochemistry/auroral energy deposition.	UVIS, NIR/MSIC
		Understand the nature of convective processes and the frequency, distribution, morphology and lifetime of discrete cloud activity (storms, vortices)	Visible and near-IR tracking of the spatial distribution and lifetimes of discrete cloud activity (e.g., use storm clouds to assess convective energy and stability of the troposphere)	NIR/MSIC, NAC
			3D structure of discrete cloud features via multi-wavelength imaging and microwave sounding, tying thermodynamic properties and aerosol structure together.	NIR/MSIC, MWR
			Compare optical properties of aerosols in bright cloud features with those of the surrounding atmosphere to constrain the underlying mechanisms. Track these features over multiple phase and incidence angles.	NIR/MSIC, NAC
			Determine the atmospheric stability of discrete cloud features and the processes responsible for maintenance/dissipation	NIR/MSIC, UTIRM
stem	What is the composition of the uranian rings?	Map the size distribution of the uranian ring particles	Stellar and radio occultations across the ring system	NIR/MSIC, RSE, UVIS
			Photometry of the ring system across a range of viewing geometries	NAC, NIR/MSIC

Uranus' ice giant planetary sy		Map the composition of the rings	Measure IR and UV spectra across the ring system across a range of viewing geometries and conduct microwave soundings.	NIR/MSIC, UVIS, MWR
	How do dense rings behave dynamically?	Study resonant interactions, shepherding and self-maintenance of the dense rings	High resolution images of the rings	NAC, NIR/MSIC
			Stellar and radio occultations across the ring system	NIR/MSIC, RSE, UVIS
			Determine the thermal properties of particles in the dense rings by mapping temperatures across the ring system with a range of viewing geometries	UTIRM
	How do Uranus' dusty rings work?	Estimate the spatial distribution of dust grains with sizes <1 micron	Infer dust densities using dust impact plasma cloud signatures	RPW
			Measure positively and negatively charged dust grains entering ion and electron plasma sensors during periods of ram pointing	PPS
			High-resolution and wide-field images of dusty rings across a range of viewing geometries	NAC, NIR/MSIC
		Map the size distribution of particles in the dusty rings	Wide-field images of dusty rings across a range of viewing geometries	NAC, NIR/MSIC
	How do the rings and inner satellites interact?	Determine how Mab interacts with the mu ring	High resolution and wide-field images at a range of orbital phases	NAC, NIR/MSIC
		Track the orbits of the inner satellites	Frequent high-resolution astrometry	NAC
	What is the origin of Uranus' moons and how have they evolved?	Determine the time-dependent radiation environment of the moons	Measure the structure of the interaction region	MAG, PPS
			Measure the time-dependence of energetic particle fluxes to establish space weathering processes	PPS
		Search for evidence of active or dormant dynamos and for the existence of internal oceans	Measure the magnetic field as close as possible to the moon	MAG
		Search for evidence of tenuous atmospheres	Radio occultations to determine atmospheric/ionospheric densities	RSE
			Ultraviolet occultations to determine atmospheric/ionospheric densities	UVIS
			Measure any ionospheric plasma that the spacecraft might encounter	PPS
		Determine the orbits and orbital evolution of the inner satellites and main moons	Astrometric imaging of the moons over many orbits of Uranus	NAC, NIR/MSIC
anus' aeronomy, aurorae, and highly asymmetric magnetosphere	What is the overall configuration of the uranian magnetosphere?	Determine the 3D magnetic and plasma properties of the main magnetospheric regions and their boundaries.	Magnetic field measurements over wide range of magnetic local times, magnetic latitudes and radial distances to determine the location of boundaries and current sheets.	MAG
			Plasma electron and ion measurements to determine the source populations for the plasma in different plasma regions.	PPS
			Plasma electron and ion measurements to determine particle trapping regions.	PPS
			Energetic particle measurements to determine the location, stability and properties of Uranus' radiation belts.	PPS
			Determine the location of field-aligned currents by surveying plasma waves.	RPW
		Determine the important plasma processes involved in loss and transport of plasma.	Use electron spectra to infer important ionisation processes.	PPS
			Measure plasma waves to determine neutral-plasma processes.	RPW
			Search for ion cyclotron waves to identify ion pickup.	MAG
			Monitor absorption of energetic particles as markers of neutral clouds.	PPS
			Search for enhancements/reductions in magnetic flux as signatures of flux tube interchange.	MAG
			Search for step-wise changes in plasma distributions as signatures of flux tube interchange.	PPS
		Determine the stresses involved in the reconfiguration of the magnetosphere during a uranian day.	Estimate magnetic stresses in magnetospheric current sheets.	MAG
			Use magnetic field measurements to build empirical magnetic field models to infer time-dependent magnetospheric processes.	MAG
	How does magnetosphere-ionosphere-Solar Wind coupling work at ice giants?	Determine the spatial distribution of auroral emissions in UV, IR and radio.	Take images of UV and IR auroral emission at multiple times, rotational phases and solar wind conditions.	UVIS, NIR/MSIC
			Use goniopolarimetry (direction-finding) to map and classify auroral radio emissions and associated field li	RPW
			Determine the state of the solar wind or magnetosphere at the times of auroral images or radio emission maps.	MAG, PPS
		Determine the precipitated power, the types and energy spectra of charged particles responsible for auroral	Determine the precipitated power and the mean energy of precipitating particles responsible for auroral emissions.	UVIS, NIR/MSIC, RPW
			Survey particle populations at high magnetic latitudes on auroral field lines.	PPS

Ura		emissions and where do they originate in the magnetosphere to constrain the nature of auroral accelerations processes.	Survey equatorial particle populations over as wide a range as possible in magnetic local time and radial distance.	PPS
		Determine the effects of energy deposition in the energy balance and dynamics of Uranus's ionosphere and atmosphere.	Estimate energy input into the upper atmosphere as a function of rotational phase and solar wind conditions.	PPS, MAG, UVIS, NIR/MSIC, RPW
		Determine how the variable solar wind-magnetosphere interaction is interrupted and modulated by the diurnally changing magnetospheric geometry.	Take sequences of auroral images and monitor auroral radio emissions covering many rotations of Uranus whilst monitoring solar wind conditions.	UVIS, NIR/MSIC, MAG, PPS, RPW
		Determine the vertical, latitudinal and longitudinal structure of the ionosphere	Monitor uranian electrostatic discharges (UEDs) and their frequency envelope to infer the sub-spacecraft peak electron density.	RPW
			Use occultations to map the vertical structure of the ionosphere.	RSE, UVIS
		Search for evidence of magnetic reconnection at the magnetopause	Search for evidence of magnetic fields threading the magnetopause with accelerated plasma	MAG, PPS
		Search for evidence of wave activity at the magnetopause	Measure repeated magnetopause crossings on the flanks of the magnetopause	MAG, PPS
	How are auroral radio emissions generated at ice giants?	In situ characterization of the UKR source regions and search for their mechanism of generation and source of free energy	Measure the UKR electric and magnetic fields, the pitch angle distributions and energy of electrons and the local planetary magnetic field vector with high temporal cadence	RPW, MAG, PPS
		Search for UKR fine structures	Take high cadence UKR measurements	RPW
			Determine the locus of radio sources from goniopolarimetric (direction-finding) measurements and monitor	RPW
		Characterization of the wave polarization state and polarization transfer through propagation	Determine the full set of Stokes parameters from goniopolarimetric (polarization) measurements	RPW
Cruise phase science	How does the outer heliosphere work?	Determine the amount of open solar flux from single spacecraft observations.	Measure magnetic fields from <1AU to 19 AU	MAG
		Characterise field fluctuations at a variety of heliocentric distances.	Measure magnetic fields at high resolution from <1 AU to 19 AU	MAG
		Determine the structure of Interplanetary Coronal Mass	Measure magnetic fields at a cadence less than 1 minute.	MAG
			Measure solar wind ion and electron populations at a cadence less than 1 minute	PPS
		Monitor the evolution of corotating interaction regions into global merged interaction regions.	Survey the solar wind at low resolution from <1 AU to 19 AU	MAG, PPS
		Survey interplanetary field enhancements and establish their occurrence rates with heliocentric distance	Survey interplanetary field enhancements from <1AU to 19 AU	MAG
		Determine the flow of mass and energy through the heliosphere	Measure magnetic fields from <1 to 19 AU	MAG
			Measure plasma velocities and temperatures from <1 to 19 AU	PPS
			Measure solar wind electron core, halo and strahl components from <1 to 19 AU	PPS
		Understand the behaviour of solar wind pickup ions	Measure pickup ions from <1 to 19 AU	PPS, MAG
	What can we learn from observations of Centaurs?	Determine the mass distribution to infer the structure of a Centaur	Measure gravity field	RSE
		Determine the surface composition	Measure infrared and ultraviolet spectra	NIR/MSIC, UVIS
		Determine crater statistics	Take high resolution surface images	NAC, NIR/MSIC
		Examine surface geology	Take high resolution surface images at a range of phase angles	NAC, NIR/MSIC

		Measure spin rate and shape	Take sequences of images covering a whole rotation to determine the 3D shape and rotational state of the object	NAC, NIR/MSIC
		Determine how the solar wind interacts with the Centaur	Measure the flow of the solar wind and interplanetary magnetic field around the object	MAG, PPS
		Search for evidence of pickup ions from the surface	Measure ion distributions perpendicular to the motional electric field and IMF	MAG, PPS
		Search for evidence of remnant magnetisation	Measure the magnetic field as close to the object as possible	MAG
		Determine surface and near-surface thermal inertia	Measure surface and near-surface temperature as a function of local time-of-day	MWR