



# INTERNATIONAL SPACE OLYMPIAD 2026

## SYLLABUS – SENIOR & SUPER SENIOR CATEGORY

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### Preliminary Level

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#### 1.1 Celestial Mechanics and Coordinate Systems

- The celestial coordinate system: right ascension, declination, altitude, and azimuth
- Sidereal time vs solar time; the equation of time and its annual variation
- Kepler's three laws of planetary motion with their mathematical expressions
- Orbital parameters: semi-major axis, eccentricity, inclination, argument of perihelion, longitude of ascending node
- Synodic vs sidereal periods; deriving planetary periods from observation
- Precession of the equinoxes: cause, rate (~26,000-year cycle), and effect on coordinate systems

#### 1.2 The Sun: Physics and Solar Activity

- The proton-proton chain in detail: pp-I, pp-II, pp-III branches and their energy yields
- The CNO cycle: conditions for dominance and the stellar mass threshold
- Solar luminosity, effective temperature, and application of the Stefan-Boltzmann law
- The solar neutrino problem: the deficit, flavour oscillations, and resolution via neutrino mass
- The solar activity cycle: sunspot number, polarity reversals, and the Maunder Minimum
- Helioseismology: p-modes, g-modes, and what they reveal about the solar interior

#### 1.3 The Solar System: Dynamics and Comparative Planetology

- Bode's Law (Titius-Bode rule): the empirical pattern, its successes, and failure at Neptune
- Orbital resonances: Kirkwood gaps in the asteroid belt and Jupiter's Trojan asteroids
- Classification of small solar system bodies: asteroids, comets, TNOs, KBOs, and scattered disk objects
- Planetary atmospheres compared: Venus greenhouse effect, Mars atmospheric loss, Jupiter's banded structure
- The Nice Model: late heavy bombardment, Grand Tack hypothesis, and solar system reshaping
- Tidal locking, tidal heating, and their role in the geology of Io and Europa

## 1.4 Stars: Quantitative Properties and Classification

- Stellar parallax as a distance technique; definition of the parsec and its relation to the AU
- The magnitude system: apparent vs absolute magnitude; the distance modulus  $m - M = 5 \log(d/10)$
- Spectral classification OBAFGKM and LTY extensions: temperature ranges and characteristic absorption lines
- Luminosity classes Ia, Ib, II, III, IV, V: from dwarf to supergiant on the HR diagram
- Binary star systems: visual, spectroscopic, and eclipsing binaries and what each reveals
- Proper motion, radial velocity, and space velocity of nearby stars

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# Intermediate Level

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## 2.1 Stellar Structure and Physics

- Hydrostatic equilibrium: the pressure gradient force balancing self-gravity in stellar interiors
- The mass-luminosity relation ( $L$  proportional to  $M^4$ ): physical basis and observational verification
- Energy transport in stars: radiative diffusion vs convection; the Schwarzschild stability criterion
- Stellar opacity sources: electron scattering, free-free, and bound-free absorption
- Nucleosynthesis beyond hydrogen burning: helium, carbon, oxygen, and silicon burning chains
- The iron peak: why nuclear burning halts at iron-56 and its consequence for core collapse

## 2.2 Stellar Evolution in Detail

- Stellar evolution tracks on the HR diagram: Zero-Age Main Sequence (ZAMS) to final states
- The subgiant and red giant branch: hydrogen shell burning, core contraction, and envelope expansion
- Horizontal branch stars and helium main sequence: core helium burning and the instability strip
- Asymptotic Giant Branch (AGB) stars: thermal pulses, third dredge-up, and s-process element synthesis
- Type Ia vs Type II supernovae: progenitor systems, explosion mechanisms, and light curve distinctions
- Neutron star properties: degenerate matter, the Tolman-Oppenheimer-Volkoff limit, pulsars, and magnetars
- Black hole formation thresholds: core collapse, fallback accretion, and the mass gap (2-5 solar masses)

## 2.3 Galactic Astronomy

- The 21-cm hydrogen line: physics of the hyperfine spin-flip transition and its use in mapping the Milky Way
- Galactic rotation curves: observed flat profiles vs Keplerian prediction and the dark matter inference
- Stellar populations: Pop I (young, metal-rich, disk) vs Pop II (old, metal-poor, halo and bulge)
- The galactic centre: Sgr A\*, stellar orbit monitoring, and evidence for a 4-million solar mass black hole
- Star formation: giant molecular clouds, the Jeans mass criterion, proto-stellar collapse, and HII regions
- Galactic chemical evolution: successive stellar generations and interstellar medium enrichment

## 2.4 Foundations of Cosmology

- Hubble's Law:  $v = H_0 \times d$ ; the Hubble constant and the  $H_0$  tension between Planck and the distance ladder
- Olbers' Paradox: why the finite age and expansion of the universe explains a dark night sky
- The cosmic distance ladder: parallax, Cepheid period-luminosity relation, and Type Ia supernovae
- Lookback time: relating observed redshift to the age of the emitting object
- The Cosmic Microwave Background (CMB): blackbody spectrum at 2.725 K, temperature anisotropies, and acoustic peaks
- Big Bang nucleosynthesis: predicted primordial abundances of H, He, D, and Li and their observational tests

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# Final Level

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## 3.1 Black Holes, Neutron Stars, and Extreme Objects

- Types of black holes: stellar, intermediate, and supermassive -- formation routes and mass ranges
- The event horizon: why nothing escapes, and the concept of the last stable orbit
- Supermassive black holes in galactic centres: evidence from stellar orbits (S2 star around Sgr A\*)
- The Event Horizon Telescope: how a global radio array imaged M87\* and Sgr A\*
- Neutron stars: pulsars as natural clocks, millisecond pulsars, and magnetar outbursts
- Gravitational waves: what they are physically, how LIGO detects them, and what binary mergers reveal
- Hawking radiation: qualitative concept of black hole evaporation and its timescale

## 3.2 Cosmology: Evidence, Structure, and Fate

- The three pillars of Big Bang evidence: cosmic expansion, CMB, and primordial nucleosynthesis abundances
- The CMB in depth: what the hot and cold spots (anisotropies) tell us about early universe density fluctuations
- Dark matter: the full case from rotation curves, gravitational lensing, and galaxy cluster dynamics
- Dark energy: the supernova evidence for accelerating expansion and what it implies for the universe's fate
- Possible fates of the universe: heat death, Big Rip, Big Crunch -- conditions that lead to each
- The cosmic timeline: inflation, quark epoch, nucleosynthesis, recombination, reionisation, and structure formation
- Large-scale structure: filaments, voids, and galaxy clusters as the cosmic web

## 3.3 Active Galaxies and Extreme Phenomena

- Active Galactic Nuclei (AGN): what makes a galaxy 'active' and the role of the central black hole
- The AGN zoo: Seyfert galaxies, quasars, radio galaxies, and blazars -- properties and differences
- Accretion as an energy source: why infalling matter onto a black hole outshines entire galaxies
- Jets in active galaxies: directionality, synchrotron radiation, and effects on the host galaxy
- Gamma-ray bursts: the most energetic explosions since the Big Bang; long vs short burst origins
- Galaxy mergers and interactions: tidal forces, starburst triggering, and eventual coalescence

### **3.4 Exoplanets and the Search for Life**

- Detection methods compared: transit, radial velocity, direct imaging, and microlensing -- strengths and limits
- Atmospheric characterisation: transmission spectroscopy and what molecular signatures reveal
- Biosignature gases: why O<sub>2</sub>, O<sub>3</sub>, CH<sub>4</sub>, and N<sub>2</sub>O together suggest biological activity
- The habitable zone in depth: inner edge (runaway greenhouse), outer edge (CO<sub>2</sub> condensation), and exceptions
- The TRAPPIST-1 system: properties of its seven planets and assessment of habitability
- The Drake Equation: each term, current estimates, and why the answer is so uncertain
- The Fermi Paradox: the Great Silence, proposed explanations, and the Great Filter argument

### **3.5 Modern Observatories and Future Space Science**

- The James Webb Space Telescope: mirror design, L2 orbit, wavelength coverage, and first science results
- Multi-messenger astronomy: combining gravitational waves, neutrinos, and light from the same event (GW170817)
- The Vera Rubin Observatory (LSST): all-sky time-domain surveys and transient discovery at scale
- The Tsiolkovsky rocket equation concept: why carrying more fuel has diminishing returns for spaceflight
- Future flagship missions: Artemis lunar programme, Mars sample return, Europa Clipper science goals
- Interstellar travel: energy requirements, proposed concepts (Breakthrough Starshot), and fundamental challenges

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