# Rocket astronomy

The discipline that makes use of sounding rockets (**Fig. 1**) that fly near-vertical paths carrying scientific instruments to altitudes ranging from 25 to more than 900 mi (40 to 1500 km). Altitudes up to 30 mi (48 km) can be reached by balloons, so sounding rockets are typically used for higher altitudes in order to measure sources with telescopes or particles and fields in space with in situ observations that do not penetrate the Earth's atmosphere. Sounding rockets do not achieve escape velocity; after completion of the launch phase, the payload follows a ballistic trajectory that permits 5–15 min of data taking before reentry. *See* ROCKET.

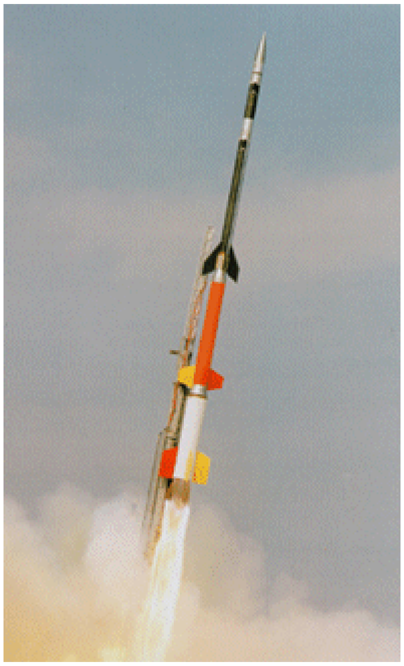

**Fig. 1** Launch of a NASA Black Brant XII sounding rocket. (*NASA Goddard Space Flight Center*)

## Mission profile.

Suborbital rocket astronomy began in the United States in 1946, using captured German V-2 rockets with no pointing capability and very simple instrumentation. A typical modern launch is comparatively sophisticated, involving multiple stages of engine ignition, vehicle spinup to inhibit tumbling, payload separation and thruster firing to control or eliminate the experiment from spinning, target acquisition if the experiment is remote sensing, attitude control system (ACS) operation, telemetry and data command via the ground station. For payloads that are to be recovered, the mission also completes door closure or boom retraction, reentry and chute deployment, impact and recovery, and reuse of the scientific payload.

In comparison with experiments launched on satellites, rockets offer the advantages of simplicity of mission design, low mission cost, and rapid response to unique observing opportunities. Several science disciplines now routinely utilize the suborbital rocket, including Astronomy, Heliophysics, Geospace, and Planetary, and these diverse science disciplines have extended the types of experiments performed using rockets to remote sensing instruments (telescopes) and in-situ measurements. Benefiting from relatively frequent access to launch opportunities, an experimental payload can be launched once per year, if retrieved, in Heliophysics or Astrophysics or multiple launches per year in Geospace and Planetary experiments. The suborbital missions have a shorter time scale from conception to launch, 3–5 years for a suborbital rocket versus 5–20 years for satellites or experiments on the International Space Station. The suborbital payloads are lower cost than satellite-based instruments, and a suborbital flight allows recoverability of the payload and the possibility of postflight instrument calibration, refurbishment, and reflight. NASA currently launches roughly 20 suborbital missions per year. The major disadvantages are short observing time, minutes versus months or years for satellites; localized coverage, with observations restricted to a celestial hemisphere or region of space over the launch site; and size and weight restrictions on payloads.

The United States, Canada, Japan, and many European countries, including Germany, France, Sweden, Norway, Switzerland, and the United Kingdom, maintain scientific rocket programs.

Nearly a dozen different launch vehicles are in common use (**Fig. 2**), ranging in length from 10 to 65 ft (3 to 20 m) and in diameter from 4.5 to 22 in. (11 to 56 cm). Payloads up to 2200 lb (1000 kg) can be carried to altitudes that are typical of those at which the space shuttle operates, 150–200 mi (250–320 km). For each launch vehicle the maximum altitude is strongly dependent upon payload weight (**Fig. 3**). For instance, the Black Brant X can carry a 200-lb (91-kg) payload to an altitude of 620 mi (1000 km) and can boost an 800-lb (364-kg) payload to 250 mi (400 km).

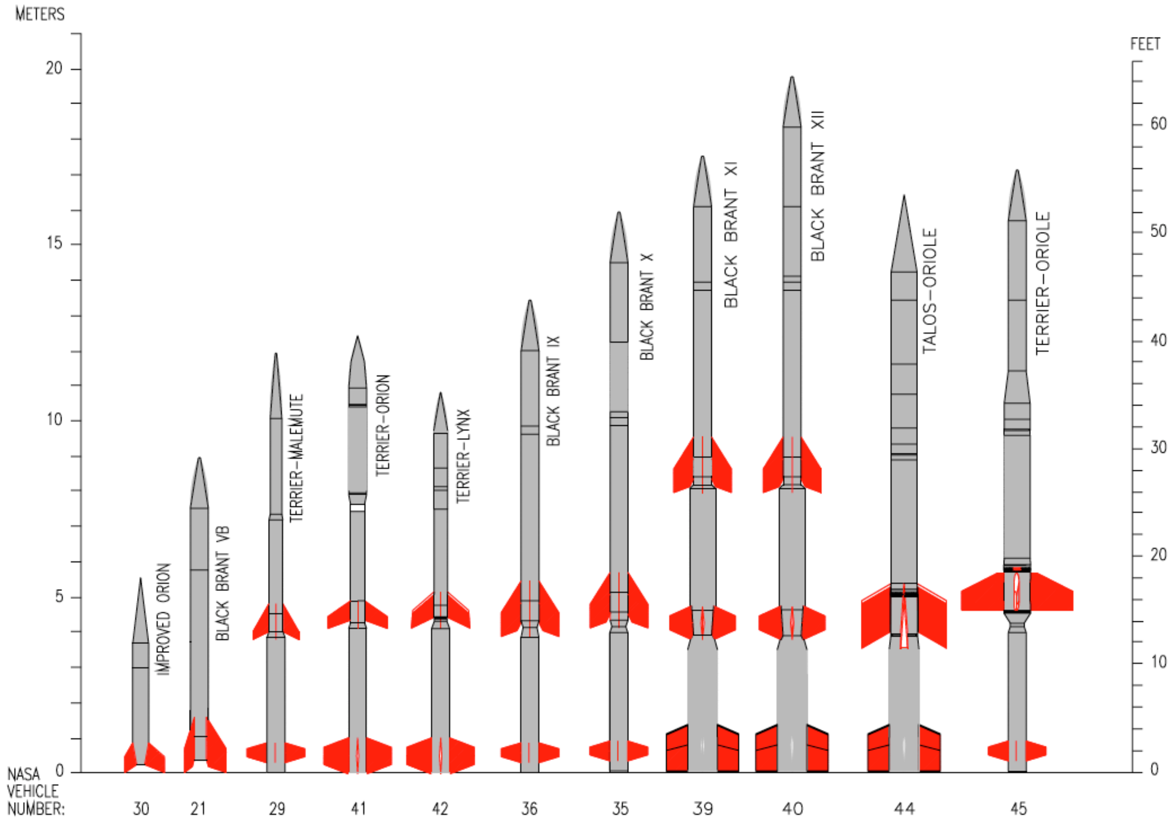


**Fig. 2** Current NASA sounding rockets. (*NASA Sounding Rockets Projects Office, Wallops Flight Facility*)

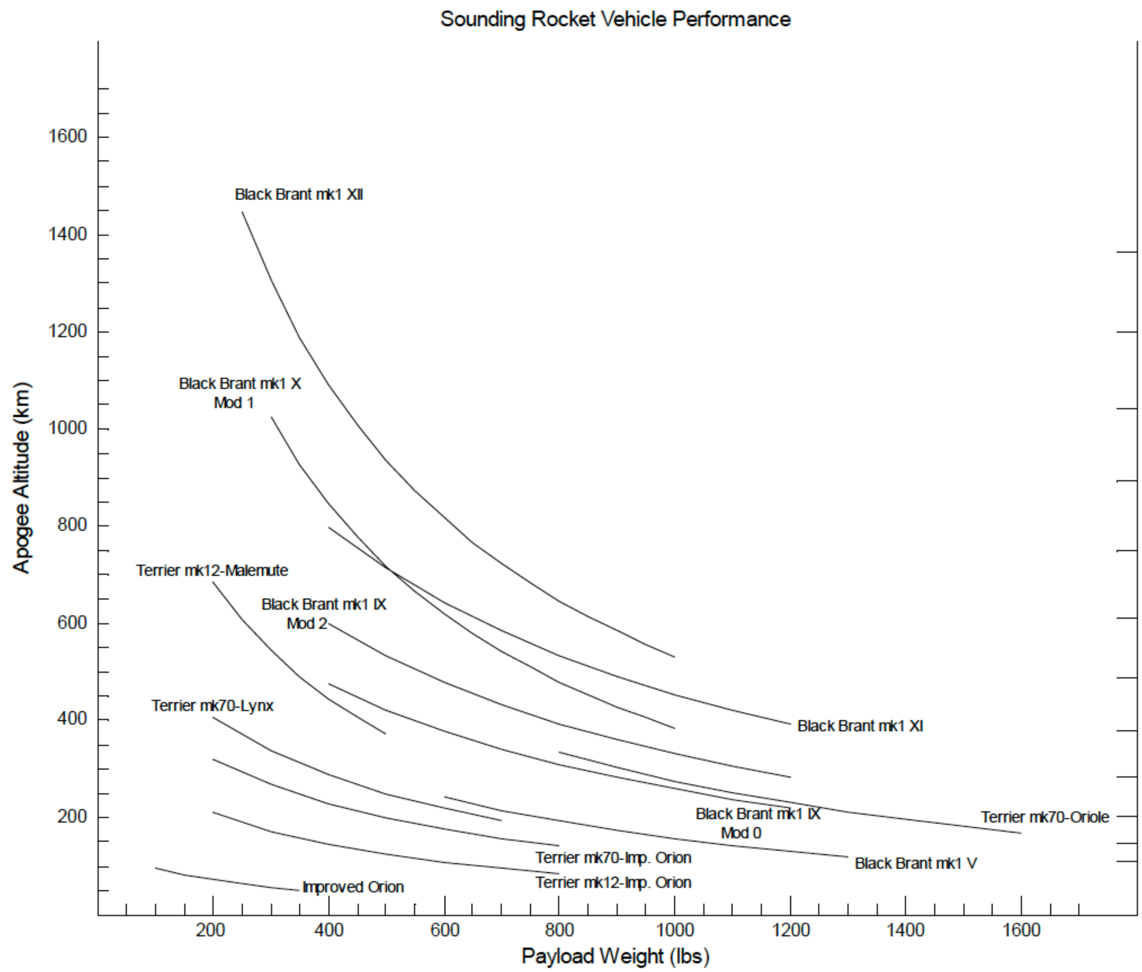


**Fig. 3** Lift capability of NASA sounding rockets. Apogee is shown as function of payload weight.

Sounding rockets are routinely launched in the United States from Wallops Island, Virginia; Poker Flats Research Range, Alaska; and White Sands Missile Range, New Mexico. Sites in Australia, Norway, Sweden, Canada, Peru and Brazil are also used. Temporary launch ranges are arranged when needed, and scientific requirements may dictate heavy usage of a particular facility. This was the case in 1988 and 1989 when numerous observations of Supernova 1987*a* were carried out from Woomera, in Australia. The United States sounding rocket program makes extensive use of surplus military rockets as an economical source of engines. NASA's Orion was formerly a Hawk ground-to-air missile, while Nike, Taurus, and Terrier engines are used as boosters in two- and three-stage flights. These components are usually supplied without guidance control systems.

## Heliophysics rocket astronomy.

### Solar Astronomy

The Earth's atmosphere is opaque to wavelengths shorter than ~300 nanometers. Observations in the ultraviolet and x-ray regions of the spectrum therefore require that instruments be placed at altitudes exceeding 25–87 mi (40–140 km), depending upon wavelength. The outer portion of the Sun's atmosphere, the corona, is at a substantially higher temperature than is the photosphere, several million kelvins versus 6000 K. The emission from this region is dominated by ultraviolet and x-ray photons, whose total luminosity is very weak in comparison to the Sun's visible light output because of the extremely low density of the corona. During the late 1950s and early 1960s, techniques were developed for focusing x-rays and thereby providing direct imaging of the corona. These early studies revealed the highly structured nature of the atmosphere, with approximately semicircular loops of hot plasma outlining the shape of the magnetic field threading the hot gas. Areas of the solar surface at which strong magnetic fields emerge are known as active regions; in addition to producing strong x-ray and ultraviolet emission, they are the sites of explosive solar flare events. In such events the plasma is temporarily heated to temperatures exceeding $10^7$ K by the rapid release of stored magnetic energy; in addition, material is often ejected into interplanetary space. These solar energetic events also produce bursts of high-energy particles, microwave emission, and gamma rays. The radiation, ejected plasma and magnetic field that intercepts the Earth disrupts the Earth’s magnetosphere and ionosphere – a so called “magnetic storm”. *See* X-RAY TELESCOPE.

Among the notable advances in coronal studies from rockets has been the development of a new technique for x-ray imaging, with concomitant improvements in imaging spectroscope methods. The fabrication of multilayer coatings for enhanced x-ray reflectivity may be viewed as depositing an artificial Bragg crystal onto a figured substrate. This technique offers the advantage of substantially higher image sharpness, and provides simultaneous spectroscopy because of the narrow x-ray bandwidth of the coatings. The major technological limitation of this technique is the inability to produce adequate normal-incidence reflectivity at short wavelengths (less than 1 nm); in this spectral region, grazing-incidence methods continue to be the most appropriate.  Heliophysics suborbital missions are also now used to calibrate satellite-borne instruments such as the Extreme ultraviolet Variability Experiment (EVE) on NASA’s Solar Dynamics Observatory. Similar calibration missions are expected for the Radiation Belt Storm Probes that will study the radiation belts of the Earth.  *See* SUN; X-RAY DIFFRACTION.

### GEOSPACE

The transition between the terrestrial atmosphere and near-Earth space occurs in the lower portion of ionosphere/thermosphere/mesosphere (ITM) region or Geospace, between 60 and 180 km. This region, which is largely unexplored, is an important link in the chain that connects the Sun to the Earth. The region is characterized by complex coupling between the ionized plasma in the ionosphere, the neutral atmosphere of the thermosphere and mesosphere, and electric fields, currents, and charged particles imposed from above by the magnetosphere. Little is known about the physical processes that operate in this region because of its relative inaccessibility: the region between maximum balloon altitudes (~40 km) and minimum satellite altitudes (~150 km) is accessible only to sounding rockets. The region is a complex one, which encompasses the mesosphere, its upper boundary, the mesopause, and the transition into the lower thermosphere. The relative inaccessibility of these regions has resulted in serious gaps in our knowledge of this portion of the upper atmosphere, which is particularly frustrating because this is just where the heating rate due to absorption of solar EUV and UV radiation peaks.

Carefully conceived sounding rocket experiments carrying particles and fields instruments to very high altitudes (> 1000 km) at high latitudes have unveiled new classes of natural acceleration phenomena, while shedding light on several critical aspects of the general question of how electrons and ions are accelerated in space. NASA sounding rocket experiments have, for instance discovered and/or explored in unprecedented detail several new plasma physics phenomena, including intense Langmuir waves associated with field-aligned electron bursts, the relationship of perpendicular ion beams to lower hybrid wave bursts, flickering aurora and extremely low frequency waves, and bursty field-aligned electron fluxes. Future rockets involving a number of sub-payloads that are spaced only a few hundred meters apart will address important questions concerning the spatial and temporal variations of these phenomena, as well as collect the data necessary to understanding the relationship between auroral microphysics and larger scale dynamics. *See* IONOSPHERE; MAGNETOSPHERE

## Other celestial sources.

Observations of nonsolar sources from sounding rockets encounter two major difficulties: the low intensity of the emission and the technological problem of pointing the payload at the source during the flight. The two problems are related in that the low flux levels generally lead to a requirement for long exposure or integration times, and the faintness of the source leads to difficulty in constructing a sensor that can provide the appropriate detection signal to an attitude control system. The development of a gas-jet attitude control system for Aerobee rockets in 1964 and the addition of gyroscopic stabilization in 1965 permitted ultraviolet spectroscopy of stars with high enough dispersion to record interstellar absorption features in the 130–160-nm range. Such data permit measurement of interstellar hydrogen, carbon, nitrogen, oxygen, silicon, and sulfur. Spectra in the 100–250-nm region permit studies of stars with surface temperatures of 10,000–30,000 K; in addition to total-luminosity determination, a major discovery from line-profile measurements of hot-star absorption features was the finding that such stars have large mass loss due to high-velocity (greater than 600 mi/s or $10^3$ km/s) stellar winds. In 1970, a sounding rocket detected the absorption line of interstellar molecular hydrogen; this detection was the forerunner of later extensive studies from the *Copernicus* satellite, which have had a major impact on the field of interstellar chemistry. *See* ASTRONOMICAL SPECTROSCOPY; COSMOCHEMISTRY; INTERSTELLAR MATTER; SPACECRAFT PROPULSION; ULTRAVIOLET ASTRONOMY.

In 1962, a rocket experiment detected nonsolar x-rays for the first time from within the constellation Scorpius, at a level many orders of magnitude higher than would be produced by an equivalently placed solar-strength source. The observer, Riccardo Giacconi, won the Nobel prize in 2002, in part, for this suborbital rocket observation. Subsequent flights confirmed the initial result and discovered other x-ray sources, as well as a diffuse x-ray background and an emission source in the Crab Nebula. The field of x-ray astronomy is now dominated by observations from satellites such as Chandra, XMM-Newton, and Fermi, which have the ability to carry out all-sky surveys and to integrate for many hours in order to study low-intensity sources. *See* X-RAY ASTRONOMY.

**Microgravity**

The use of sounding rockets by the US microgravity community is just beginning: the first NASA microgravity sounding rocket experiment flew in October 1994. Rocket contributions to studies of the effects of microgravity on fluid dynamics and combustion are expected to be quite important. Studies of the process of combustion under conditions of microgravity, for instance, are important both for understanding the fundamental physics of the process and in preparing for habitation of the Space Station. Fundamental advances in understanding can arise from such studies because buoyancy is one of the dominant effects in flame spreading; the microgravity environment eliminates this force from the equation thus enabling details of flame spreading to be studied in a simpler situation.

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