METEORITE FALLEN IN '600 NEAR VAGO (VERONA)

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Abstract

The history of meteorites passes through the ancient document about spectacular events. This research is an historical and scientifical investigation about a meteorite fallen in 1668 at Vago di Lavagno, near Verona. I consider the witness of Count Lodovico Moscardo who find meteorite remnants and wrote about meteor event and ceraunie stones. I calculated main physical parameters to reconstruct the meteorite characteristics also for understand the coherence of description and the reliability of the paper about astronomical phenomena written in seventeenth century.

1 Introduction

The passage of a meteor and the consequent falling of a meteorite crashed with a portion to Verona countryside and with another one to the hills, was registered in 1668. After several centuries the event was reported in Catalogues of Meteorites(1) with the name of Vago, a village in the municipal territory of Lavagno, because an international convention decided that the name of meteorites descends from the postal office or the geographic structure nearest to the impact point. The rereading of documents about this event was the basic for this historical investigation and for some reflections from which I try to characterise some physical parameters about meteoric phenomena and about distinctiveness of this meteorite.

2 Meteorites origin and provenience.

The well-known phenomenon about meteorites falling on Earth and the following study about their composition and origin have a significant role in the astronomical research longer than a century, exciting an amazement mythical at first in the past, and than several attempts to explain their origin. Today we know they are frequent events(2), in fact one meteorite over 500 g falls on each km^2 of terrestrial surface every million of years, on average; besides hundred tons of extraterrestrial matter fall on Earth each day as dust or small fragments.
Meteorites sources are probably multiple and the elaborated models make reasonable the cometary origin(3)(4)(5) (some authors observed fireballs apparently similar to those once associated with known comets(6)(7)), or extinct cometary residuals (with a contribute about 15-20%), and mainly asteroids(8) to obtain the falling flux on Earth. The most actual scenario foresees that the meteorites derive from Earth-Crossing asteroids whose orbits intersect or approach the Earth orbit under 10^6 km; many asteroids, as Aten-Apollo-Amor class(9), have a perihelion distance like that of the Earth. Rocky fragments move in the solar system tracing very complex orbits with characteristic parameters in evolution, however when some of them undergo the Earth gravity field a fall on Earth. Some authors, from orbital evolution studies, think the

origin of the Apollo Amor objects(10) is in the Main Belt(11)(12) and that the Jupiter resonance 2:1 removes asteroids from this zone.
Several statistical studies show there is surely a collision probability between the Main Belt and Apollo Amor asteroids, 10^4 times more frequent than that one between the Main Belt asteroids themselves. This mechanism contributes to the progressive distruction of such objects after one or multiple collisions. Gravitational perturbations deriving from planets produce an argumentum perihelion precession of fragments and then a shift of their orbits till they intersect Earth orbit, on a time scale about 10^4 years, a short period in comparison with 10^6 or 10^8 years for collisional life of these bodies. A research of Olsson-Steel(13)(14) about 3759 meteoritic orbits, determined with a survey radar using Adelaide radar observatory, compared with all orbits of known Apollo Amor asteroids, gave strong respondences with the fluxes associated to Icarus, Hermes, Adonis, Oljato, Hephaistos, 5025 P-L, 1982 TA e 1984 KB(15)(16). There are different mechanisms able to remove the asteroidal fragments from collisional regions and the most reliable is due to asteroids nearness to a resonant orbit with Jupiter.
Wetherill and Williams(17)(18) and Wetherill(19)(20) elaborated a method to calculate the fragments quantity from collisions, and the resulting mass from total fragmentation is:

$$\frac{dM}{dt} = \int_{\frac{r}{k^{1/3}}}^{R_{max}} \frac{4p}{3} r^3 \rho C R^{-p} P_i (R + r)^2 \, dR \qquad (1)$$

with dM/dt is the yearly mass falling on Earth in grams, R is the asteroid belt ray, R_{max} the ray of greatest asteroid on crossing orbit, r Apollo object ray, 1/k minimum mass target fraction of projectile sufficient to fragment totally the Apollo target, ρ the projectile density (in Main Belt), P_i the intrinsic collisional probability (yearly probability of collision between an Apollo asteroid with nominal ray 0,5 km and a Main Belt asteroid with same ray, assuming that the asteroids with every dimension have an orbital distribution like that of asteroid in observing belt). If we have the average diameter of asteroids about 17.3 km, the total average production of debris from whole fragmentation results dM/dt = 5.42×10^{10} g/year.
The terrestrial meteorites(21), with bodies in the range 100 - 10^{-6} g, were revalued(22)(23) also with the new data about asteroids albedo and from the experimental studies about ipervelocity impact by Bianchi et al(24)(25)(26). The terrestrial rate of these fragments impacts with a low velocity (to penetrate the Earth atmosphere) is estimated about 2×10^8 g/year, that is the half of present rate of known extraterrestrial impacts observed with a photographical survey. Further test is devised comparing some asteroids spectra with particular meteoritic spectra (chondrites, eucrits, mesosiderites): the found similarities support the hypotesis, also if they are not conclusive and they maintain open several questions also about their origin(27).

3 The meteorites in history

In the studies for the meteorites analysis the historic archives research reveal itself very interesting(28), to locate ancient description about these events, which allow to renovate the statistical falling and about the recovery (finding) of meteoritical material, to augment the quantity of specimens to investigate with chemical-physics analysis, and also because going back in time it is possible to compare the interpretations of such phenomena in the past and to refine also the evolution of the epistemological points of view.

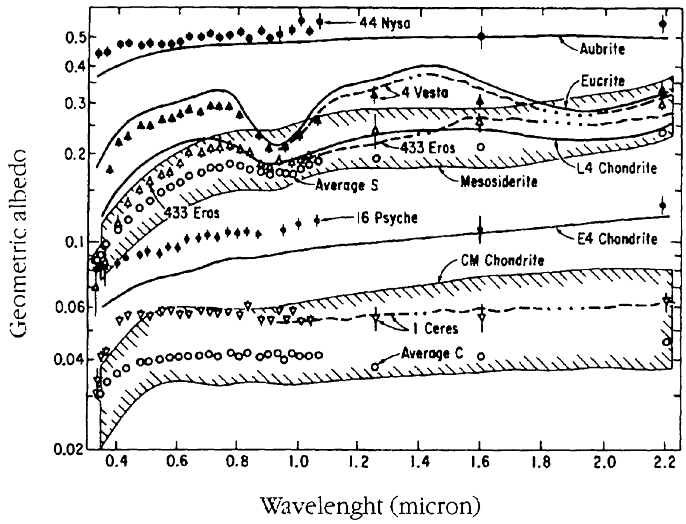


Fig. 1 Reflectance spectra (visible through infrared) of representative asteroids and meteorites. The two shaded bands indicate the ranges of spectral albedo curves for typical mesosiderites and typical CM chondrites. It is evident that the L4 chondrite spectrum bears some similarities to S type, but most ordinary chondrites resemble S types even less. In general detailed analysis of reflectance spectra show that the range of diverse mineral assemblages found in meteorite collections are also represented in the asteroid belt (modified from Wetherill e Chapman, 1988).

One of this event involved the district of Verona three century ago and remains a clear testimony about it as well as some fragments coming from the original rock, unfortunately lost. The meteoritical falling remains fixed in the writings of the Count Lodovico Moscardo (Verona, 1611-1681) enthusiast and eclectic collector, and his collections constitute the principal and the most ancient core of present museum Miniscalchi-Erizzo Foundation[29] in Verona, with many objects which form the "Wunderkammern" and united with cores coming from the families which became related historically with Miniscalchi, as Erizzo and Pullè.
In the museum is still kept an autograph copy of the "Historia di Verona" published by Count Moscardo[30] in 1668 in which there is the exactly description of the entry in the atmosphere of the flaming fireball and its crossing over the city, in addition to the effects yield on people and the appearance of the finding remnants.
Another interesting volume published by the Count[31] few years later, in 1672, is the "Note, ovvero Memorie del Museo del Conte Lodovico Moscardo Nobile Veronese: uno dei padri nell'Accademia filarmonica: Dal medesimo descritte in Tre libri..." in which the objects constituting the collections and a comment about their origin are described; besides the theories on that time about the mechanisms originating the stones falling from sky are reported: these stones in that period were not yet compared with the meteorites as we draw up today.

Fig. 2 A painting of Lodovico Moscardo in an oil on canvas portrait ascribed at Andrea Voltolini (1681 ca.)

To understand what persuaded Moscardo to get in his museum a big stone plumped down near his property it is necessary to open a short parenthesis about his figure and the '600 cultural world(32). Count Moscardo was a member of a noble family but he had not many wealths at his disposal.

When he was about twenty, he began to collect the objects that then formed his domestic museum. One hundred and fifty paintings, two thousands drawings and engravings, two hundred and fifty bronze idols, about fifty renaissance bronzes, ancient marble sculptures, a coins and epigraphs collection. There were some arms and also a naturalistic section. This collection gave an eclectic aspect that was conceptually connected to the models of the «Kunst-und Wunderkammern» called also «cabinets des merveilles». This one inaugurated a new seventeenth-century concept of the museum seen as microcosm where every curiosity had its place, near art, as a documentation of the world(33). We must not be amazed if inside this ambient there was also the meteorite, sought and rapidly picked up by Moscardo, because it was a phenomenon that had attracted his curiosity, a natural event which had to be witnessed, with a description and with a find.

More recently the methodical collection of meteorites was pursued by Adrien Charles marquis de Maruoy that had about 400 samples(34).

554 *HISTORIA DI VERONA*
LIBRO DUODECIMO

In queſt'anno à hore 5 della notte del Martedì venendo il Mercordì 20 Giugno, mentre ſi ritrouaua il Cielo ſereno, compareuero dalla parte d'Occidente diuerſi fuochi nell'aria, & vno particolarmente maggiore dell'altri nella forma d'vn traue, con raggi che all'occhio ſi diſteſero per molta miglia, rendendo maggior luce del sole nel mezo giorno. Queſto doppo hauer fatto vn horrido, & ſpauentoſo rumore vomitò tre Pietre, la maggior grande quant'è vn ſtaro, & l'altre minori. Cadè la prima nella Villa del Vago Territorio Veroneſe, ſei miglia diſcoſto dalla Città, non molto lungi d'alcuni miei beni, in certi campi detti le Macchie lunghe, di ragione delli Monachi Caſſinenſi di S. Nazaro di Verona, & l'altre due ſoprà li Monti di Lauagno poco diſcoſto dalla prima, e per la vehemenza del fuoco, & della caduta quella nel piano ſi profondò nel terreno vn piede, e mezzo, & quelle nel Monte fecero altretanta impreſſione nel ſcoglio. Il rumore, che conquaſsò, & fece crolare le Caſe, fu ſentito dalla maggior parte della Città, & del Contado, & molti, che in quell'hora viaggiauano verſo la Città, vidde to li fuochi reſtādo atterriti, & alcuni, ch'erano à cauallo, cadettero a terra ſpauentati, inſieme con caualli. Le Pietre ſono molto peſanti: nel eſterno ſono coperte da vna cortecia nera, dura che col focile rende aſſai fuoco: nel interno ſono di color cinericio, fragili, ripiene di minera di ferro, hauendone fatta l'eſperienza con la Pietra Calamita, che poſta ſopra piccioli fragmenti leuati da groſſi pezzi, che nel Muſeo conſeruo, l'attrahe. Vedeſi in eſſe anco altra minera, che ſembra al colore argento.

Fig. 3 A page of the "Historia di Verona" published by Moscardo in which there is described the meteoritical phenomenon.

4 The Vago meteorite

We report now what count Lodovico Moscardo witnessed at page 554 in the twelfth book of his *Historia di Verona*,:

> *In quest'anno a hore 5 della notte del Martedì venendo il Mercordì 20 Giugno, mentre si ritrovava il Cielo sereno, comparvero dalla parte d'Occidente diversi fuochi nell'aria, e uno particolarmente maggiore dell'altri nella forma d'un trave, con raggi che all'occhio si distesero per molte miglia, rendendo maggior luce del sole nel mezo giorno. Questo dopo aver fatto un horrido, e spaventoso rumore vomitò tre Pietre, la maggiore grande quant'è un staro, e l'altre minori. Cade la prima nella Villa del Vago Territorio Veronese, sei miglia discosto dalla Città, non molto lungi d'alcuni miei beni, in certi campi detti le Macchie lunghe, di raggione delli Monaci Cassinensi di S. Nazaro di Verona, e l'altre due sopra li Monti di Lavagno poco discosto dalla prima, e per la vehemenza del fuoco, e*

della caduta, quella nel piano si profondò nel terreno un piede e mezzo, e quelle nel Monte fecero altre tanta impressione nel scoglio. Il rumore, che conquassò, e fece crollare le Case, fu sentito dalla maggior parte della Città, e del Contado, e molti, che in quell'hora viaggiavano verso la Città, videro li fuochi restando atterriti, e alcuni, ch'erano a cavallo cadettero a Terra spaventati, insieme con (i) cavalli. Le pietre sono molto pesanti: nel(l') esterno sono coperta da una corteccia nera, dura che col focile rende assai fuoco: nel(l') interno sono di color cinericio, fragili, ripiene di minera di ferro, havendone fatta l'esperienza con la Pietra Calamita, che posta sopra piccioli fragmenti levati da grossi pezzi, che nel Museo conservo, l'atrahe. Vedesi in esse anco altra minera, che sembra al colore argento.


NOTE
OVERO MEMORIE
DEL MVSEO
DEL
CONTE LODOVICO MOSCARDO
NOBILE VERONESE:
VNO DE PADRI NELL'ACCADEMIA FILARMONICA:
Dal medeſimo deſcritte in Trè Libri.

Nel primo ſi diſcorre delle coſe antiche, che in detto Muſeo ſi ritrouano.
Nel ſecondo delle Pietre, Minerali, e Terre.
Nel terzo de Corali, Conchiglie, Animali, Frutti, & altre coſe in quello contenute.

Furono conſacrate, nella prima editione alla Glorioſiſſima memoria
DELL'ALTEZZA SERENISSIMA
DI FRANCESCO FV DVCA
DI MODENA E REGGIO.

Con l'aggiunta in queſta Seconda Impreſſione della Seconda Parte dello Steſſo Autore, accreſciuta di coſe ſpettanti particolarmente all'antichità. Con l'Indice d'vna gran parte delle ſue Medaglie, & Pitture, come anco delli ritratti de Prencipi, & altri Illuſtri huomini, così in arme, come in lettere.

IN VERONA. M DC LXXII.
Per Andrea Roſſi. Con Licenza de'Superiori.

Fig. 4 The title-page of the "Memorie" written by Moscardo, a sort of catalogue of his museum, in which he writes about rocks called "ceraunie".

The description brings us again the most typical features of the entrance in the atmosphere of a meteorite, revealed with the classic fireball composed by many fires, of which one principal, with a length that covered a heavenly arch by many miles with bright trail. It could mean that at the entrance in the atmosphere probably the meteorite broke in several pieces because of a thermal shock, which had enough effect in a relatively deep in the body. The brightness was valued superior to that one of the Sun at midday therefore it was a body of notable angular dimension and mass to produce such visual effect, evaluation to take with prudence an to put under comparisons. In its run probably flew over Lombardia and perhaps there are some documents dated 1668 or later reporting the sighting in other districts, and if we will be able to find them it will be very interesting because we could reconstruct the meteor source direction with more precision, so the sky quadrant from which it started away, and compare a different description about the same phenomenon. Another characteristic, that can be more evident in the brightest fireballs, is the deceleration and this page seems to confirm a prolonged vision. Sometimes it is possible to have the sensation that the meteor is stopping in the sky: generally this event happens few moments before a final explosion and it protracts the effect of motion. This event happens at an altitude in the range of 10 - 30 km, that is in the atmospheric region called stop zone, because the meteoroid loses its kinetic energy and then it falls because of gravity.

The motion across the sky was accompanied by a strong noise heard at a remarkable distance too, frightening people and arousing also some damages. The sounding phenomena are not an exception, in fact sometimes the gradient of temperature between surface and internal part can arouse an explosion that destroys the object completely or simply fractures it, producing some trails, as reported by Moscardo. The fireball, in the final phase, can transform itself in a swarm of small meteorites. On October 19 1863 J. Julius Schmidt was in Aten and he observed a similar phenomenon with a very bright fireball which was unusually visible for more then 20 seconds. The meteor fragmentation was described at first time by Millman in 1935, using the tracks in a photograph recorded at Harvard in 1910, in which he noted many small bursts along the trajectory.

Moscardo could detail his vision very well because of the strong brightness. This one is caused by the meteorite incandescence produced by atmospherical friction only for a small percentage. From spectra observations, we can see it is composed almost completely by neutral and ionised gas emission. It is the product of vaporisation of incandescent surface and it forms a halo, or coma, around the meteoroid; the atoms of this gas collide with the molecules of atmospheric gas and a part of kinetic energy is lost under form of electromagnetic visible radiation[35]. In any case, so that a rocky meteorite survives at the terrestrial atmosphere crossing (range of geocentric velocity is 12 - 72 km/s) it is necessary the velocity of fragments may be not over 22 km/s. Then a mass about several quintals can produce an energy nearly $2 \div 3 x 10^{10}$ J. Naturally the impact with atmosphere brakes the falling in superior layers and when it arrives on ground the velocity is about some hundreds km/h. During atmospheric trajectory the meteor brightness is a velocity, mass and entrance angle function. These parameters can be determined with good precision if we have an appropriate photographical equipment. So, beyond obtaining data enough exact to evaluate the meteoroid initial mass, it is possible to obtain signs also about density of constitution matter and we can know what can be the eventual surviving mass scattered on land with a certain error margin.

We prevent a possible objection about the stones collected by Moscardo, because they could be local geological rests. The ipothesis is not real because the plain at south-east of Verona is geologically incompatible with those found stones. In fact the region is a great alluvial depot from glacial and fluvial-glacial origin[36] in which there are sedimentary and incoherent materials as stratum pebbles, gravels, sands and debris (rhyolites, porphyries, lavas, granites), deposited by rivers, principally Adige, in Quaternary, as we can see from the near large gravel quarry. In a word incoherent depots with aspect clearly different by collected fragments[37].

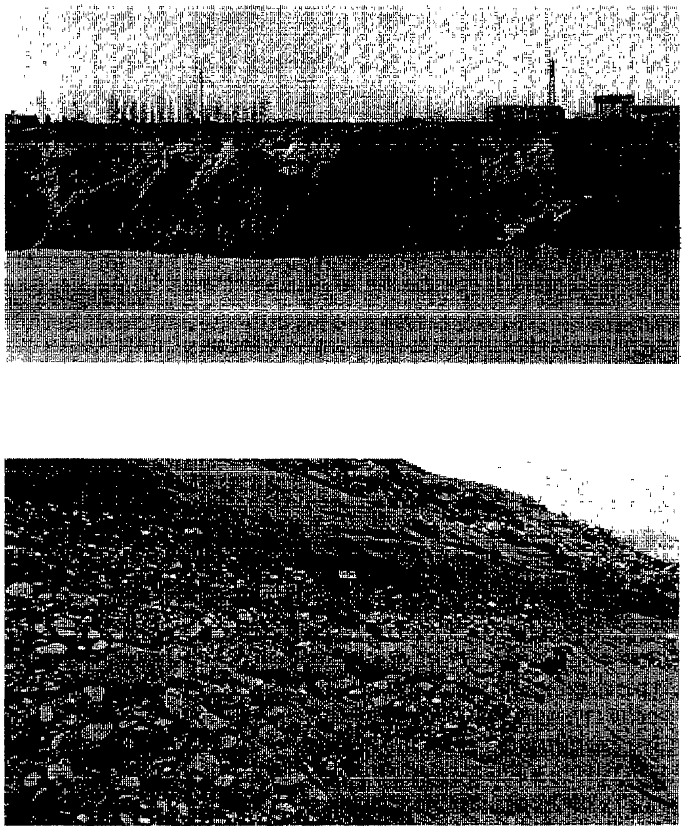


Fig. 5 Up: a little lake formed by a gravel quarry near Vago. Down: pebbles, gravels and sands, deposited by ancient Adige, constitute the Veronese plain: detail of debris of Veronese underground.

Generally how can we be sure the collected fragments were awardable to a meteorite? If weather terrestrial conditions have not the time to act on stone surface for modifying it there are clear features that allow to identify the object. Meteorites have variable shape, often irregular, and they are covered by a thin melting crust developed during atmospheric trajectory for high temperature (~3000° C). Normally it is black, or in meteoritical irons the melting crust can be dark and bright, and only for achondrites eucrites can be vitreous and transparent. Often the thickness is about 0.1 mm only. For old fallings the identification of meteorites can be very difficult because the surface of specimens changes easily for the effects of atmospheric agents[38].
Further confirmation arrives from Vago specimens composition analysed by Brian Mason (1963): there is a closed coincidence with iron content not negligible in stones, as we can infer from two tests carry out by Moscardo who noted the possibility to obtain sparks as flint and that the stones experienced the attraction exercised by a magnet.
Then on meteorite surface it is also possible recognise some small cavities, called piezoglithic dimples. The origin of these structures is correlated with fragmentations phenomena and/or a inhomogeneous fusion caused on small meteorite areas during

atmospheric flight in which the fragments and melting material were removed. The finding of principal meteoritical component could confirm this description.

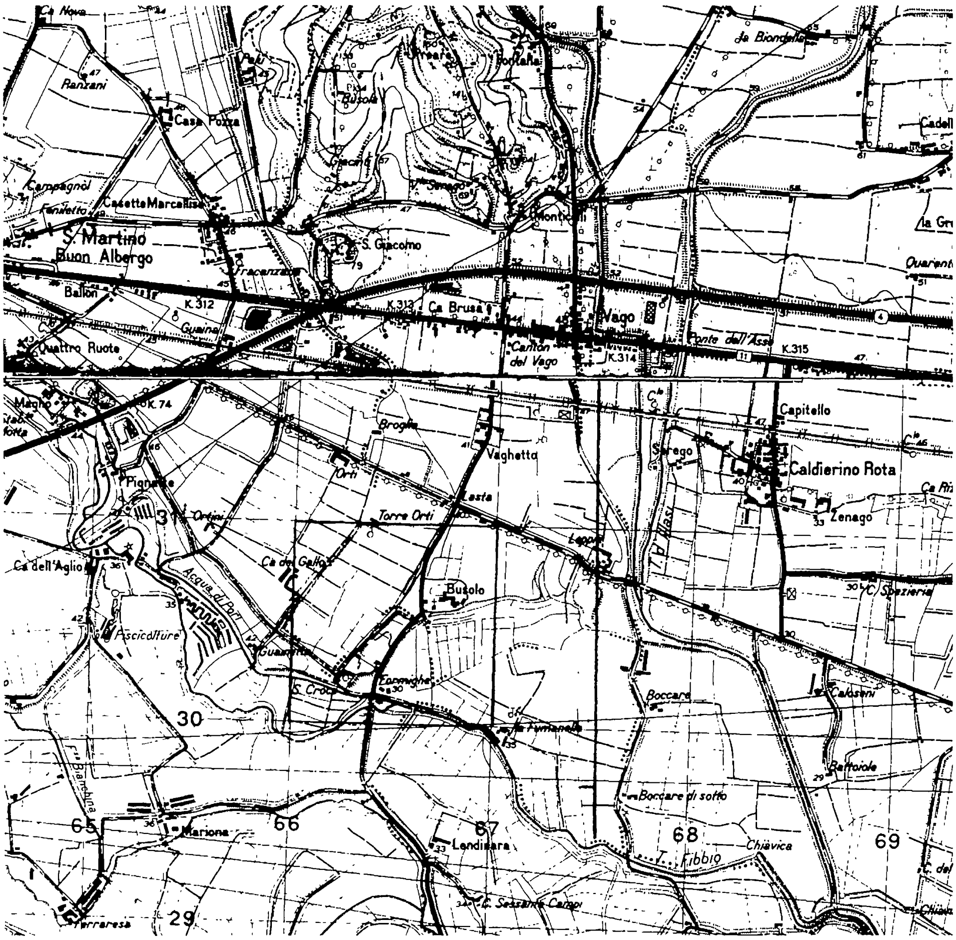


Fig. 6 Meteorite falling zone can be located among Formighé, Santa Croce, Ca' del Gallo, Torre Orti and Busolo, near Vago of Lavagno and Caldiero, underlined in the box on IGM topographical map.

Since the text contains informations precise enough about the falling locality, I faced a research on '600-'700 maps at Verona State Archiv; these ones permitted to interpret the geographical description about territory in which there was the impact and to locate the concerned area by the event with an approximation of nearly one km^2.

Count Moscardo cites "Villa del Vago" in a territory near Verona, and in seventeenth century a borough in the country was called *villa*, therefore the zone was situated nearby a built up area. It is at a about six miles distance(39) from the city, near the locality called Vago, still existent and corresponding to a place at an equivalent distance, 10 km far from Verona. Here monks of Monte Cassino abbey, that guided San Nazaro church in Verona, had some properties near the fields belonging to Moscardo family.

The locality called "Macchie lunghe", probably due to the type of vegetation, today it is not traceable with precision, since the historic memory is lost, as we deduced from an

investigation among local inhabitants; probably it was a toponym used locally only and for a small territory that it was not on any map. Anyhow, from comparison among ancient maps with a modern IGM topographical map (tav. *Zevio* f. 49III SE) it is possible to circumscribe the zone and to locate it among Formighè, Santa Croce, Ca' del Gallo, Torre Orti and Busolo, near Vago of Lavagno and Caldiero.
The localisation of stones fallen on Lavagno mounts is vary vague, because they could be small hills or the offshoots of piedmont zone of Lessinia mountains; this fact does not permit a precise geographical location. However also the plain surface involved is deeply changed in its territorial configuration, in comparison to three centuries ago: near this territory there is Milan-Venice Highway and there are some gravel caves which modifies the country.

5 Mass assumption

We can derive some physical indications and marks also from hole caused by the meteorite in the impact with soil. Often meteorites do not sink in the soil, they sometimes concerning the pedological layer only, and they remain on surface. Instead samples of remarkable weight can form small craters or holes deep enough. The problem of earth surface craterization was developed by Grieve et al.(40)(41), in researching of impact craters remnants(42) either on continents or oceanic soundings. Their dimensions, the shape and internal structure permit to trace back with sufficient safety to size order of projectile(43). Studies about impact craterization(44) today permit interesting consideration about phenomenon dynamic and they are useful to explain the fragmentation mechanics, dispersion of meteorite remnants and to know some its physical characteristics.
Residual craters can help us to solve the most difficult problem, that is mass determination, because in many cases the matter seems disappeared, without remnants(45), (as Tunguska event), or we can find few fragments scattered on large ray. The principal difficulty to determine Vago meteorite mass is due to its breakage during atmospherical travel, besides a part fallen on hills far from Vago.
Moscardo affirms to have weighed the two collected stones for 227 kg. We obtain further informations for verification from his description where he says that the luminous object vomited three stones, and the largest of them had the dimension of a "staro"(46). Unfortunately it is possible to interpret terminology staro either "stero" or "staio", measure that was not constant even within Verona province(47)(48). If we consider the first hypotesis, probably the largest part of meteor had a mass about $3x10^2$ kg (perhaps one ton the entire mass) while in the second case it was in the range 25 - 38 kg, not consistent with 227 kg collected. Therefore stero seems to be more coherent with physical data.
Another indication comes from the description of effects caused by impact with soil of meteorite which sink for 1,5 feet(49), that is about 50 cm(50)(51). These informations can help us to understand if the mass valuation is coherent with the depth of this crater; and we must correlate the two quintals collected, making allowance for collision and the decompression wave, for impact velocity, for meteoritical and local earth composition, even less for temperature induced in the collision. Here I can only hazard some very simplified hypotesis: we could estimate the energy, in first approximation, considering a mass about $3 \div 5x10^2$ kg and a maximum impact velocity about 80 m/s (terrestrial atmosphere brakes remarkably the bodies of fewer dimension) from which the kinetic energy would be about $16x10^5$ J. Unfortunately the author does not retain noteworthy to record also the crater diameter, an important measure to elaborate further considerations about whole meteoritical mass. However let us see if the order of size is still coherent

with the recorded data, making some suppositions. It is possible to correlate the diameter of a planetary crater with other measures with a formula proposed by Schmidt-Holsapple(52) on a non porous target:

$$D = 1.248\ d^{0.781} \sin(i^{1/3}) (g/V_I^2)^{-0.216} (\rho/\delta)^{-1/3}\ S \qquad (2)$$

where D is the crater diameter, d is the projectile diameter, i incidence angle (taken equal to 45°), g is the surface earth gravity, V_I the impact velocity, ρ and δ are the target and of projectile densities, and S the crater enlargement factor caused by post impact slumping (considered to be 1.30). Now two hypoteis are possible. Considering the ratio $\rho/\delta = 2/3$, $g = 9{,}82\ m/s^2$ and impact angle i = 45° we obtain an equation with three variables D, d and V_I:

$$D = 1.0743\ d^{0.781}\ V^{0.432} \qquad (3)$$

with the course represented in fig. 7 (left). If instead we consider the crater with a diameter fivefold depth, that is of 2,5 m, we can look for trend of a function that ties the diameter d with impact angle and impact velocity, namely:

$$d = 2.7522\ \sin(i)^{-2.434}\ V^{-1/0.432} \qquad (4)$$

whose trend it is in fig. 7 (right) (naturally there are two simmetrical trends around the value of 45°, but the most interesting is for 45° < i < 90°).

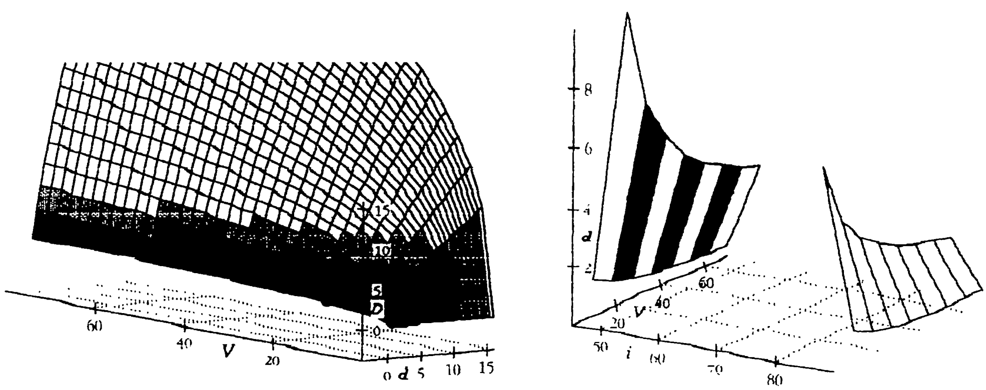


Fig. 7 (left) Dimensional trend of crater diameter vs meteoritical diameter and its impact velocity. (right) Dimensional trend of meteoritical diameter vs impact angle and velocity.

At this time we can value for example: with an atmospherical velocity at fall about v = 55 m/s, impact angle i = 70° the resulting diameter is d ≈ 0.80 m (surely it was an object irregular enough with at least two principal axis, perhaps resembling an triaxial ellipsoid) which corresponds to a spherical volume about $V \leq 0.26\ m^3$ which multiplied for density d ≈ 3 g/cm^3 (obtainable in first approximation from Mason analysis), furnishes a mass m ≈ 780 kg that is coherent with the probable size order of the whole meteorite. We could also add that there is a relation between falling and atmospherical impact velocities, and the second is related to the provenience direction, namely with radiant elongation from which the meteoritical object moved. Wetherill emphasised that the impact velocity is particularly high for an elongation near 90°, unfortunately the ancient text is not useful with specific details to obtain this parameter.

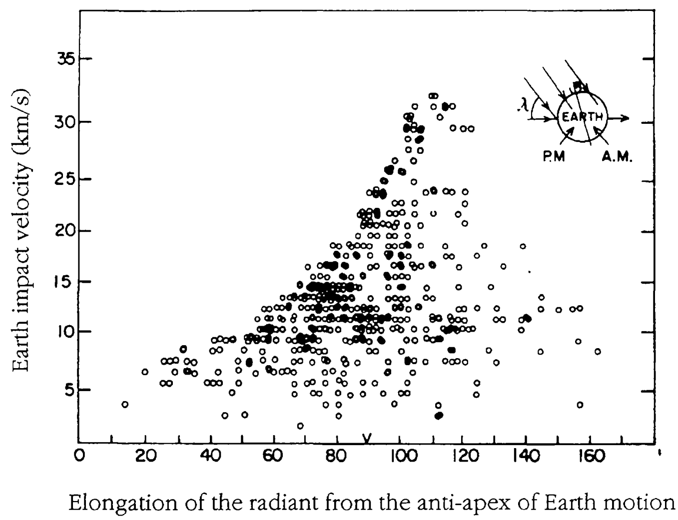


Fig. 8 Distribution of geocentric velocities vs. elongation of the radiant from the anti-apex of earth's motion (modified from Wetherill, 1979)

If we admit that the collected fragments were the prevalent part and supposing that they were comparable to the size order of those ones not found, for a total mass between 300 and 1000 kg(53), we can try to go up, with some approximation, to the apparent magnitude through Opik(54) equation, that links the mass with the apparent magnitude, and it is expressed by:

$$M_m = K \times 10^{-0,4\,m} \qquad (5)$$

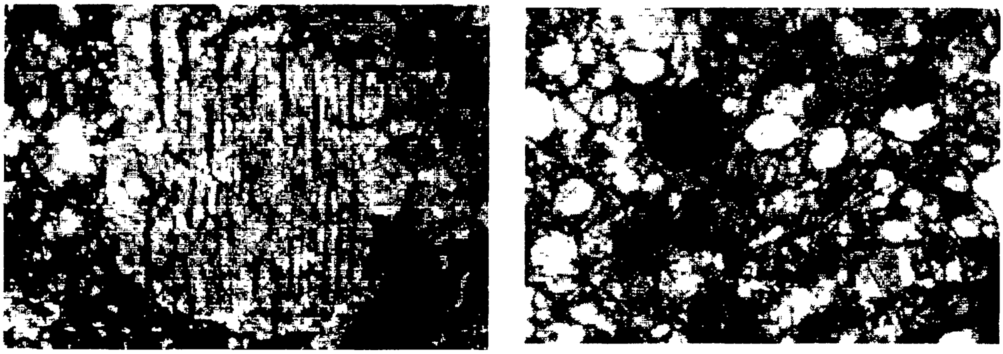
where M_m is the meteorite mass in grams, K=0,268 g a constant and m the visual apparent magnitude of meteor. From (5) we derive the magnitude, that can be estimated about m = -15 ÷ -16. But if we make a reference to Moscardo's words, in which the splendour of meteor is similar at least to Sun, and if we use its visual apparent magnitude m = -26,74(55) we obtain a mass M = 1.330,8674 t, that it is not realistic: this carries us to underline the difficulty of a correct interpretation about the brightness evaluation, that it is not considered a good reference as a documentary source. However it is possible consider also another relationship among projectile diameter d, albedo P_v and absolute visual magnitude V(1,0) when sufficient data are available: if the average albedos is known or calculable we can use:

$$d(km) = [10^{\,3.12-0.2\,V(1,0)}]/P_v^{1/2} \qquad (6)$$

This carry us to a hint about the value of descriptive elements in a cultural context of three hundred years ago, or rather which weight and scientific valence can have the past description about physical phenomena from which we try to extrapolate some informations helpful to reconstruct these events. But a question remains: to which point can we use the past witnesses and through which filters must we interpret them? It is also an epistemological problem I leave open to more competent authors, remembering only that the meteoritical interplanetary origin was recognised only 150 years ago, while before the phenomenon was believed atmospheric merely.

6 Vago meteorite composition

I searched into the collection of Museum Miniscalchi Erizzo Foundation but I did not find any meteoritical remnant. Few grams are preserved in two foreign museums. In a 1890 Paris Natural History Museum publication three fragments are cited related to Vago, one of these was a 9 g intermediate chondrite(56), another a 7 g spherical chondrite(57) and the third an eucrite. Two pieces, 26 and 7 g respectively, catalogued E3759 and E3760, were presented to A. Brezina by count Miniscalchi in 1921, for the collection Wien Natural History Museum, then handled in thin sections obtained in Göttingen in 1922, one of these kept in London, only a fragment of 6,75 g: they are spherical chondrites, probably coming from the original that was in Moscardo museum, passed to Miniscalchi family, as we can infer from a letter of 1922.
Brian Mason(58), of the American Museum of Natural History, in 1963 analized their composition and they result to be chondrites containing olivine-bronzite (Fe_2SiO_4) Fa = 19 moles %. The olivine composition was obtained with method of X ray diffraction and it is included in the superior limit (20.4) of olivines composition found in H group chondrite. Pyroxenes appear normally as fibrous crystals with orthorhombic prismatic structure. From an inspection of material we can see a variety of chondrules (spheroidal inclusions that don't exist in terrestrial rocks and produced by meteoritical heating when they come in contact with terrestrial atmosphere): some of these are fibrous, consisting mainly of pyroxene accompanied by turbid glass, others are barred, others are porphyritic. An analysis at high magnification showed cracking and microdeformation but shock induced metamorphic products as Maskelynite(59) are absent; this fact leads us to suppose the meteorite suffered low level of efforts induced by temperature increase (this last has usually as consequence some mechanical deformations). Afterwards these considerations Vago meteorite was classified as H5-H6 chondrite(60)(61) with medium degree of metamorphism.
Today which importance hold the study about a find so ancient and then the eventuality to find the principal pieces of a body similar to Vago? If we examine a fragment not contaminated by earth atmosphere we can analyze ancient material composition, probably near in the time to the solar system primordial composition, therefore we can obtain information of its genesis. For this aim the studies of the testimonies of meteoritical falling have still significance: they spangle the history in any time and they grow under the push of exceptional events, for instruments observation perfectioning and for the good organisation of observative campaigns, particularly from amateur astronomers. Every year 5 or 6 meteoritical rains are identified and they constitute only a part extremely small of fallings on dry lands.
To understand the Moscardo's writings we must remember that at the end of XVIII century there were no great progresses to explain the origin of meteorites, often attributed to big natural strengths: violent and stormy air motions could lift stones from a place to another, or sudden unknown vulcan eruptions which cease their activity after a powerful explosion, leaving only some incandescent projectiles. In the same year the German physic Ernst Chladni (1756-1827) in "Die Feuer-Meteore" supposed for the first time that all the objects, different from terrestrial rocks, came from cosmic space.



a b

Fig. 9 Sections of the preserved fragments of Vago meteorite: a) barred condrules with clean contours, showing evidence of fractures and faultings; b) porphyritic condrules.

Meteor origin was indirectly demonstrated by H.W. Brandes and J.F. Benzenberg in 1798, with contemporary observations from two different places near Göttingen. In fact if the trajectories of the same object are drawn on a stellar map seen from different places, it is possible to note a displacement (parallax) compared to stars on background[(62)].

7 The ceraunie stones

From Moscardo's witness, it would have been interesting to investigate about more consisting fragments. However on the basis of his writings I looked for other descriptions about these phenomena and eventual signs about their cataloguing. In 1672 he published by Andrea Rossi publisher a second catalogue about his collection entitled *Note, ovvero Memorie del Museo del Conte Lodovico Moscardo Nobile Veronese...Dal medesimo descritte in Tre Libri. Nel primo si discorre delle cose antiche, che in detto Museo si ritrovano. Nel secondo delle Pietre, Minerali, e Terre... Con l'aggiunta in questa seconda impressione della Seconda Parte ....*At chapter 47 in the second book the author reports a description about thunderbolts type and formation, interesting for our research because it illuminates some historical aspects about hypotesis that circulated in '600 joining thunderbolts and meteorites.

> *... veniamo hormai a quello, che sopra di ciò hanno scritto gl'Historici delle cose naturali, parte de quali credettero il Fulmine essere pietra, ò altro corpo solido, & altri asserirono essere un solo spirito acceso. Fra quelli annoverati principalmente Aristotile, il quale lo diffinisce, per una semplice esalatione secca, accesa, ma sottile, e d'assai quantità, la quale scacciata dal freddo, che ritrovasi nelle nubi con gran vehemenza penetra, e sovente abbrucia:il medesimo ne forma di due spetie, dicendo, che quando l'esalatione, è più sottile, che calda, si genera il fulmine chiamato Ages, il qual'è più penetrante, ch'ardente; ma quando l'esalatione è meno sottile, e assai calida, allora nominansi Psolenta, e questo più tardamente penera, ma maggiormente abbrucia.*
>
> ...
>
> *Nulladimeno, ciò non ostante, vedasi diversa l'opinione di Pietro Tolosano nel suo Sintasse, ove dice, che nel folgore si genera la pietra d'una essalazione molto*

terrestre, e densa, la quale attratta dalla nube humida, si converte in massa, e mistura non altrimente come la creta in quadrello o mattone. Molti altri asseriscono, come attesta Ortensio Vescovo, generarsi la pietra nei fulmini prodotta dalle medesime cause, cioè da una viscosa esalazione, ch'alle volte si contiene nelle nubi, la quale si concuoce, e diviene durissima pietra. Conferma ciò ch'ho detto, Vital Zuccolo, che questa esalazione ascesa, s'infiamma, e mescolata con una certa umidità viscosa, e tenace, onde fra le agitazioni, che sono in quelle nubi, le parti più viscose s'uniscono: sì che poi, consumata l'humidita, resta generato un corpicello a guisa d'una pietra, che alfine uscendo fuori di quella nuvola, accompagnata dalle reliquie dell'esalazione infiammata, che prossimamente la circondano, la qual poi con tanto empito, e rumore straccia la nuvola, e discende al basso: il medesimo pare ch'accenni San Tommaso nel commento sopra Aristotile dicendo alle volte da fulmini, e da tuoni esser portata seco una pietra, o altra cosa simile, la quale, overo portata in alto da un vento circolare ... ma solamente dico, che volgarmente sono tenute per Saette alcune pietre, che si trovano nella Terra, formate nella guisa, che , qui disegnate, le quali sono della forma di un cunio, lunghe, liscie, di color verde oscuro, che nel nero verdeggia, e la parte più larga è acuta, e quasi tagliente, e durissima, e fa gran copia di fuoco, se col ferro vien percossa.

In chapter 50 the author continues again:

Alberto Magno(63) *dice che le pietre Ceraunie*(64) *cadono dalle nubi insieme co i tuoni, onde avviene, che da alcuni sono chiamate Saette. Cleandro Arnobio nella sua miniera delle Gioie, dice di aver veduto molte di queste Saette, ritrovate, da' contadini ne' campi come pietra focaia: le quali alcune tranno al gialletto, altre al cinerino, o grigio, e altre al rosso; non sono trasparenti, ne men polite, ma durissime, e diversamente formate, alcune biforcate, altre acute, altre strette, e lunghe, come ferro di partigiana. E altre più corte, e più quadre, e quelle, ch'io tengo, sono formate nella maniera, che dal disegno qui si vede. Narra il Bonardo nella sua miniera del Mondo, che queste cadono dalle nubi, e chi le portano, non si può sommergere, ne meno essere percosso dal fulmine, e producono sogni piacevoli.*

In these rows the meteorite found four years before is not cited, but the theories about ceraunie stones history are exposed making reference instead to the findings by other authors, in addition to report the theories of Pietro Tolosano, Vital Zuccolo, Alberto Magno, Cleandro Arnobio. In such circumstance it is not possible to distinguish to which phenomena these authors refer effectively: probably they refer to some fallings of meteorites, or, more often, to the terrestrial effects produced by thunderbolts. This hypotesis about genesis of stones fallen from sky continues a traditional way of thinking previous 1600; meteorological phenomena are mixed with clouds, steams, flames, wet exhalations that flare up and then condense, a whole sample-case used in various occasions in the different sciences for many centuries. So people thought the stones rains were concomitant with storm, probably because some stones were found crushed and singed by effects of a thunderbolt fallen in that place. The prehistorical points of arrows and utensils made of flintstones (Neolithic age and Eneolithic age) were often related to ceraunie stones, as we can see in the following figures taken from Moscardo's Note.

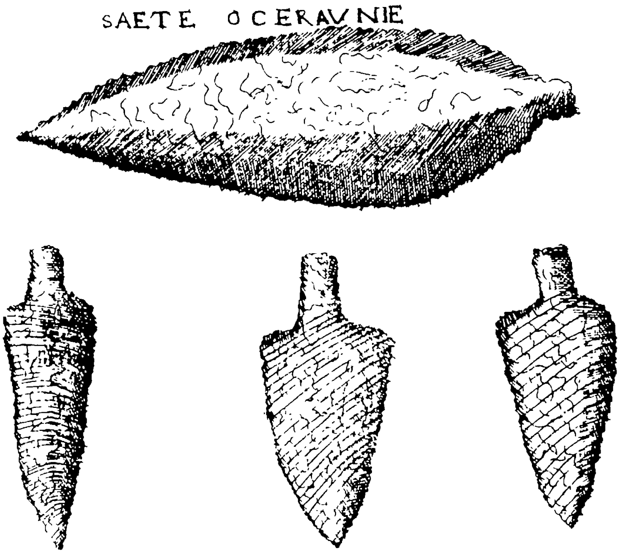


Fig. 10 The ceraunie stones or saete drawing in an incision of "Memorie del Museo" written by count Lodovico Moscardo.

Moscardo was very eclectic because he found out his lectures from everywhere, even if he didn't worry himself of a scientific elaboration, and he didn't refer to experimental methodology, but he recalled instead S. Thomas and Aristotile; at the same time it is clear above all the concentrating cumulative of his museum, without a logic privileging an order or an attempt to understand the world through it with the instruments of private research. So it seems that Galilei and his revolution had not left a great trace in this count and we can say that in his collections he didn't elevate beyond an amateur stage.
We can make a consideration about his period: the models about solar system formation and dynamics elaborated with hypotesis which can be said "scientific" begin from Kepler, Copernicus, Galilei: but the thesis from ancient thinkers seem to resist dogmatically notwithstanding Galileian revolution.
The followed model of way of thinking reveals itself still mechanic, in which the association between known natural manifestations and effects similar only in exterior appearance are not supported by chemical-physical-mathematical equipment.
But Moscardo's voice is not isolated and of low credibility, and we can compare it directly with parallel lectures by Pietro Martire di Anghiera(65) and by Pietro da Terno in '500 with his document of second half of '600, and a mutilated article entitled "Della Cometa la quale apparve l'anno 1680", kept in parochial archive of Palazzone, church of S. Maria Assunta, in Siena province (66).

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(46) In nine teenth-century manuals *stero* (from Latin sterròs, solid) is equivalent to 1 m^3, used to measure timber or used for burning, faggots, straw, etc; this word must not to be mixed up with *staio*, from Latin sextarius. However Moscardo wrote staro and we can consider the metrical denomination as *bag at three stari*: the bag, a cylindrical vessel in canvas or leather, had a capacity of 115,95 l, or 114,6535 l for Martini (1883), so a staro had a volume of 38,65 l or 38,2178 l; the bag could measure also three or four staia namely 70-75 or 90-100 kg. Our staio was used in country till few decades but it maintained only the Roman name.
The measures formalization of Venice and Veneto are very exact (Beggio, 1968) while the Veronese word is relative, because the measures varied among different localities in the province, varying mostly in frontier lands.

(47) AA.VV., 1981, Le vecchie misure veronesi, *Notiziario della Banca popolare di Verona*, **2**, 37

(48) Manuale dei ragguagli fra le misure e pesi veronesi ed il sistema metrico-decimale e viceversa nonché fra la valuta italiana e l'austriaca (Verona: Stabil. Tip. Vicentini e Franchini), 1867.

(49) Also length measures were not univocal. We can find the "foot by factory" (*piede*

da fabbrica) (perhaps for building)) or "piede censuario veronese" (to measure land) which was worth 0,340333 m and "simple foot" which was worth 0,342915 m. Another author gives the foot by factory or Venetian of 0,347735 m for some zones, as Villa d'Adige, while the surveying foot was fixed in 0,384230 m. However there was much confusion because in a part of Rovigo province the same measure of 0,347735 m was called "foot by factory "and in others (Adria) it was the "piede agrimensorio."

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(63) Alberto Magno (1193÷1206 - 1280) was a Dominican who had fulfilled his studies in Padua, character with great talent, author of an encyclopedic work and bishop of Ratisbona.

(64) *Ceraunio* o *ceraunite* was the name of different stones that the ancients believed fallen on Earth during thunderbolt burst. In the Tommaseo dictionary (1879) it was described "similar to a yellow crystal", and such term was used also by Plinio, in popularization of Rasis book and in aggregation of medicine doctrines of ser Zucchero Bencivenni.

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