Observation of New Baryons in the $\Xi_b^\pm \pi^+\pi^-$ and $\Xi_b^0\pi^+\pi^-$ Systems

R. Aaij et al. (LHCb Collaboration)

(Received 30 July 2023; accepted 14 September 2023; published 23 October 2023)

The first observation and study of two new baryonic structures in the final state $\Xi_b^0\pi^+\pi^-$ and the confirmation of the $\Xi_b(6100)^-$ state in the $\Xi_b^0\pi^+\pi^-$ decay mode are reported using proton-proton collision data collected by the LHCb experiment, corresponding to an integrated luminosity of 9 fb$^{-1}$. In addition, the properties of the known $\Xi_b^0$, $\Xi_b^-$ and $\Xi_b^+$ resonances are measured with improved precision. The new decay mode of the $\Xi_b^0$ baryon to the $\Xi_b^\pm \pi^- \pi^+ \pi^-$ final state is observed and exploited for the first time in these measurements.

DOI: 10.1103/PhysRevLett.131.171901

The $\Xi_b^{(-0)}$ baryons form an isospin doublet and are made of a $b$ quark, an $s$ quark and a lighter $q$ ($u$ or $d$) quark. Their ground states have no angular momentum between the $b$ quark and the light diquark. Three isospin doublets of such nonexcited states are expected in the quark model [1–3] with different spin-parity $J^P$ and angular momentum of the $sq$ diquark $J_{sq}$. The $\Xi_b^{(-0)}$, $\Xi_b^{(0)-}$, and $\Xi_b^{(1)-}$ states are characterized by $(J_{sq}, J^P)$ values of $(0, \frac{1}{2}^+)$, $(1, \frac{1}{2}^+)$, and $(1, \frac{3}{2}^+)$, respectively. Although five of these states have been observed experimentally [4–7], the $\Xi_b^0$ baryon remains unobserved. This is presumably because its mass lies below the threshold for the $\Xi_b^0 \rightarrow \Xi_b^+ \pi^-$ decay [8,9], meaning that it only decays to either the $\Xi_b^0\pi^0$ or $\Xi_b^0\gamma$ final states making it experimentally challenging to observe. Several excited states of higher mass are expected, with predictions for their properties available, e.g., in Refs. [9–17]. The CMS Collaboration has reported the observation of the $\Xi_b(6100)^-$ resonance in the $\Xi_b^0\pi^+\pi^-$ final state, using $\Xi_b^0$ decays to final states containing $J/\psi$ mesons [18], which is a candidate for one of these excited states.

In this Letter, both the $\Xi_b^{(0)} \pi^+ \pi^-$ and $\Xi_b^{(1)} \pi^+ \pi^-$ final states and their intermediate $\Xi_b^+ \pi^-$ and $\Xi_b^- \pi^-$ states are investigated experimentally (the inclusion of charge conjugate processes and the use of natural units are implicit throughout this Letter), using $pp$ collision data collected by the LHCb experiment at center-of-mass energies of 7.8, 13 TeV, corresponding to an integrated luminosity of 9 fb$^{-1}$. The observation of three narrow states is reported and their properties are measured.

The LHCb detector [19,20] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector surrounding the $pp$ interaction region [21], a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes [22,23] placed downstream of the magnet. Different types of charged hadrons are distinguished using information from two ring-imaging Cherenkov detectors [24]. Simulated data samples are produced with the software packages described in Refs. [25–29] and are used to model the detector resolution and optimize the selection criteria.

Samples of $\Xi_b^{(-0)}$ candidates are formed from $\Xi_b^{0\pi^-}$ ($\Xi_b^-\pi^-$) and $\Xi_b^{0\pi^-\pi^-}$ ($\Xi_b^-\pi^+\pi^-$) combinations, where the $\Xi_b^{0\pi^-}$ ($\Xi_b^-\pi^-$) baryon is reconstructed in the $pK^-\bar{K}^+\pi^-$ ($pK^-\bar{K}^+\pi^-$) final state. To suppress background coming from promptly produced particles, all $\Xi_b^{(-0)}$ decay products are required to be displaced significantly from all primary $pp$ collision vertices (PVs) in the event. The reconstructed $\Xi_b^{0\pi^-}$ ($\Xi_b^-\pi^-$) candidates are required to have a mass within 20 MeV (25 MeV) of the respective world-average mass values [30]. Displaced pion tracks are combined with $\Xi_c$ candidates to form $\Xi_b^{(-0)}$ candidates, requiring good vertex-fit quality and significant displacement of the $\Xi_b^{(-0)}$ decay point from any PV in the event. All charged particles are required to have particle-identification (PID) information consistent with their respective mass hypotheses. PID variables are based on neural network algorithms [31] and their distributions in simulation are calibrated using data [32]. If multiple candidates per collision event pass the selection requirements, all of them are preserved in the data sample. The topological, kinematic and PID variables are used as inputs to a boosted decision tree (BDT) classifier [33] that discriminates $\Xi_b^{(-0)}$ signal candidates from random track.

Published by the American Physical Society under the terms of the Creative Commons Attribution 4.0 International license. Further distribution of this work must maintain attribution to the author(s) and the published article’s title, journal citation, and DOI. Funded by SCOAP3.
The classifier is trained using simulated $\Xi_b^{(-)}$ decays as a signal proxy and $\Xi_b^{(-)}$ data candidates in the sideband $5900 < m(\Xi_b^{(-,0)}\pi^-)$, $\Xi_{cc}^{(0,+)}\pi^-\pi^+\pi^-$) < 6000 MeV as a background proxy. The mass distributions of the selected $\Xi_b^{(-)} \rightarrow \Xi_b^{(-,0)}\pi^-$ and $\Xi_b^{(-)} \rightarrow \Xi_{cc}^{(0,+)}\pi^-\pi^+\pi^-$ candidates are shown in the Supplemental Material [34]. The decay mode $\Xi_b^{0} \rightarrow \Xi_b^+\pi^-\pi^+$ is observed for the first time experimentally. The selection requirement on the BDT classifier output is optimized for the observation of new states and retains 96% of the $\Xi_b^-$ and 92% of the $\Xi_b^0$ signal candidates. Additional vetoes are imposed, as described in Ref. [35], to suppress other abundant processes with displaced vertices, e.g., those coming from $D^0$, $D^+$, $D_s^+$, and $\Lambda_b^0$ decays with a misidentified particle.

The $\Xi_b^{(-)}$ candidates within a ±75 MeV window around the peak position are combined with one charged pion (two pions) to investigate the $\Xi_b^+\pi^+$ and $\Xi_b^0\pi^-\Xi_b^{(-)}\pi^-\pi^-$ and $\Xi_b^0\pi^-\pi^+$ mass spectra. In order to improve the mass resolution, the obtained candidates are refitted with the masses of the $\Xi_b^{(-)}$ and $\Xi_b^{(0,+)}$ baryon candidates constrained to their known values [30] and the $\Xi_b^{(-)}$ flight direction to originate from the PV [36]. Additional requirements are applied to the $\Xi_b\pi^-\pi^+$ candidates, where the $\Xi_b$, $\Xi_b^-$, and $\Xi_b^{(-)}$ intermediate states are selected according to their observed widths and known mass values [30]. Signal mass windows for the $\Xi_b\pi$ intermediate resonances are defined as $|m(\Xi_b\pi) - m_{\Xi_b}| < 3$ MeV, $|m(\Xi_b\pi) - m_{\Xi_b^0}| < 1.25$ MeV, and $|m(\Xi_b\pi) - m_{\Xi_b^-}| < 5$ MeV, each corresponding to $2.5\sigma$ of the observed experimental peak.

The signal yields and lineshape parameters of the signal resonances are determined with an extended unbinned maximum-likelihood fit to the $Q$-value distributions defined as $m_{\Xi_b^0} - m_{\Xi_b^0} - m_\pi$ and $m_{\Xi_b^-} - m_{\Xi_b} - 2m_\pi$ for $\Xi_b\pi$ and $\Xi_b\pi\pi$ decays, respectively. The mass distributions of the $\Xi_b^{(-)}\pi^+$ and $\Xi_b^{(0,+)}\pi^-$ ($\Xi_b^{(-)}\pi^-\pi^+$ and $\Xi_b^{(0,+)}\pi^-\pi^+$) samples are shown in Fig. 1 (Fig. 2), together with the results of the fit. All signal components are modeled using relativistic Breit-Wigner distributions [37] including Blatt-Weisskopf form factors [38] with a radius of 3 GeV$^{-1}$. The orbital angular momentum between the $\Xi_b^{(-)}$ baryons and the pions is assumed according to the expected spin assignment. The relativistic Breit-Wigner distributions are convolved with functions parametrizing the detector resolution. These resolution models are determined from simulation samples and are consistent with a resolution that scales as $\sqrt{Q}$. Simulation shows that for each resonance, the resolution is comparable to or smaller than the measured natural widths of the peaks, with the exception of the $\Xi_b^-$ baryon. The background contribution is parametrized as $(Q - d)^n$, where $d$ and $n$ parameters vary freely in the fit. This function, which is validated using wrong-charge $\Xi_b\pi^-\pi^+$ and $\Xi_b\pi^0\pi^+$ candidates, is sufficient to describe the smooth background coming from random track combinations. Additional components are included in the fit to the $\Xi_b^{(+)}\pi^-$ spectrum to describe partially reconstructed candidates coming from higher mass resonances. These components are referred to as reflections in the rest of this Letter. The reflections of the newly observed states in the $\Xi_b\pi\pi$ mode to the $\Xi_b\pi$ spectrum are studied with simulation and dedicated components are included in the fit, modeled as Gaussian functions with power-law tails [39]. The means of the reflection components vary freely in the fits to data and their fitted values are consistent with expectations from simulated backgrounds, generated with different mass and width hypotheses according to the observed mass splitting measured in the known states, and cross-checks in data. The fit confirms the presence of partially reconstructed $\Xi_b^{(0, +)}\pi^- \rightarrow \Xi_b^{(0, +)}\pi^0\pi^-\pi^+$ decays and shows hints of a contribution from the decay chain $\Xi_b^{(+)}(1P, 1/2)^- \rightarrow \Xi_b^{(0, +)}(\Xi_b^{(+)}\pi^0)\pi^-$, where neither the $\Xi_b^{(0, +)}(1P, 1/2)^-$ state, the expected lighter resonance equivalent to that found in the neutral system, nor the $\Xi_b^{0}$ state has been observed experimentally to date (Fig. 2). This component has been validated simulating different mass and width hypotheses for the two particles involved, taking into account expected isospin splittings given the masses of their charged

![FIG. 1. Distributions of the mass difference $Q = m_{\Xi_b^0} - m_{\Xi_b} - m_\pi$ for selected (a) $\Xi_b^+\pi^+$ and (b) $\Xi_b^0\pi^-$ candidates. The fit results are superimposed.](image)
partners. However, a precise estimation of the \( \Xi_b(1^+P, 1/2^-) \) and \( \Xi_b^0 \) state properties is not possible due to the limited yield and the presence of two unknown mass values. The resolutions of the signal components are fixed to the values obtained from simulation. The fit models are validated with pseudoexperiments and no significant bias is found on any of the parameters of interest.

The fitted yields in the \( \Xi_b \pi \) mass spectra are \( 2019 \pm 58 \) for the \( \Xi_b^0 \) baryon, \( 1750 \pm 50 \) for the \( \Xi_b^- \) baryon, and \( 3380 \pm 110 \) for the \( \Xi_b^- \) baryon. The \( \Xi_b(6100)^- \) state [18] is confirmed in the \( \Xi_b^- \pi^- \) mass distribution [Fig. 2(a)], while two new peaks are observed in the \( \Xi_b^- \pi^+ \) [Fig. 2(b)] and \( \Xi_b^- \pi^- \) [Fig. 2(c)] mass distributions, referred to as \( \Xi_b(6087)^0 \) and \( \Xi_b(6095)^0 \) in this Letter. For the newly observed states, the signal yields are \( 136 \pm 17 \) for the \( \Xi_b(6100)^- \) resonance, \( 147 \pm 19 \) for the \( \Xi_b(6087)^0 \) resonance, and \( 69 \pm 14 \) for the \( \Xi_b(6095)^0 \) resonance. The three peaks are observed with local significances of \( 18\sigma \), \( 15\sigma \), and \( 9\sigma \), based on the differences in log-likelihood between a fit with the signal yield fixed to zero and the default fit. These significances are reduced to \( 12\sigma \), \( 10\sigma \), and \( 6\sigma \), once systematic uncertainties on the yields are taken into account.

Different sources of systematic uncertainties are considered in the determination of the resonance parameters. All these systematic uncertainties are summarized in Table I. One of the most important contributions to the mass measurements comes from the knowledge of the momentum scale at LHCb. The associated systematic uncertainty is assigned as the larger of the changes in the measured parameters when the momentum scale is changed by its uncertainty, which is estimated to be \( 3 \times 10^{-5} \) [40]. An additional uncertainty arises from the empirical description of the background shapes and is estimated by modeling them with alternative functions. A third uncertainty is assigned by varying the description of the reflection components and their properties, obtained either from simulation or from data, where relevant. Further sources of uncertainty on the measurement of the natural widths are included to describe the known differences in resolution between data and simulated events. Differences are expected to be within 5\%, based on previous studies [41–44], therefore

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\textbf{Source} & \textbf{\( \Xi_b^- \) \( Q_0 \)} & \textbf{\( \Xi_b^- \) \( \Gamma_0 \)} & \textbf{\( \Xi_b(6087)^0 \) \( Q_0 \)} & \textbf{\( \Xi_b(6087)^0 \) \( \Gamma_0 \)} & \textbf{\( \Xi_b(6095)^0 \) \( Q_0 \)} & \textbf{\( \Xi_b(6095)^0 \) \( \Gamma_0 \)} \\
\hline
Momentum scale & 0.006 & 0.001 & 0.001 & 0.008 & 0.001 \\
Background & 0.003 & 0.029 & 0.000 & 0.004 & 0.073 \\
Reflections & 0.000 & 0.000 & 0.002 & 0.002 & 0.007 \\
Resolution & 0.001 & 0.038 & 0.002 & 0.027 & 0.000 & 0.033 \\
BW parameter & 0.001 & 0.001 & 0.000 & 0.000 & 0.001 & 0.002 \\
Total & 0.007 & 0.048 & 0.002 & 0.028 & 0.010 & 0.081 \\
\hline
\end{tabular}
\caption{Systematic uncertainties (MeV) on the measured physical properties. The parameters \( Q_0 \) and \( \Gamma_0 \) are the mean and the width of the Breit-Wigner distribution, respectively.}
\end{table}
uncertainties are estimated by varying the resolution function width and the parametrization of the mass resolution function by that amount. Possible uncertainties can arise from the assumed relativistic Breit-Wigner distributions and their parameters. Lower mass states are assumed to decay to final angular momentum $l = 0$, while higher mass states with $l = 1$. For the newly observed states, the hypotheses assuming $l = 0, 2, 3$ are tested and the largest shifts of the fitted parameters with respect to the default fit are assigned as systematic uncertainties. A further uncertainty on the baryon mass $m_{b}$ is assigned due to the limited knowledge of the $\Xi_{b}^{−}$ and $\Xi_{b}^{0}$ baryon masses [30].

The numerical results are summarized in Table II. The properties of the $\Xi_{b}^{0}, \Xi_{b}^{−}$, and $\Xi_{b}^{+}$ baryons are measured with world-leading precision. For the narrow $\Xi_{b}^{−}$ state, its natural width is compatible with zero once the systematic uncertainties are considered, and an upper limit less than 0.05 MeV is estimated at 90% confidence level.

In summary, the first observation of two new baryons $\Xi_{b}(6087)^{0}$ and $\Xi_{b}(6095)^{0}$, with quark content $b s u$, is reported in the $\Xi_{b}^{0} \pi^{+} \pi^{-}$ final state. Additionally, this Letter confirms the observation of the $\Xi_{b}(6100)^{−}$ charged state by the CMS Collaboration [18], with improved significance and sensitivity on its physical parameters. This measurement uses final states with up to nine tracks, most of which are pions, showing excellent performance of the LHCb tracking, reconstruction, and PID systems. Finally, the decay mode $\Xi_{b}^{0} \rightarrow \Xi_{b}^{+} \pi^{-} \pi^{+} \pi^{-}$ is observed for the first time. The properties of the $\Xi_{b}^{0}, \Xi_{b}^{−}$, and $\Xi_{b}^{+}$ baryons are measured with high precision. Determination of the spin and parity for the new baryons is not possible given the low signal yields. However, data indicate that the $\Xi_{b}(6100)^{−}$ baryon decays mainly through the $\Xi_{b}^{0} \pi^{−}$ state, the $\Xi_{b}(6087)^{0}$ baryon mainly through the $\Xi_{b}^{−} \pi^{+}$ state, and the $\Xi_{b}(6095)^{0}$ baryon mainly through the $\Xi_{b}^{+} \pi^{-}$ state, with no significant contributions to the signals from events outside their respective $m_{q\pi}$ mass windows [34]. These patterns closely resemble those observed in the $\Xi_{b}^{0}$ and $\Xi_{b}^{+}$ baryon systems [30]. An interpretation would be that the new states are P-wave states ($l = 1$ between the $b$ quark and the $q s$ diquark) coupling to the $b$ quark to give a pair of states with $J^{P} = \frac{1}{2}−$ and $\frac{3}{2}−$. One might expect the dominant decay mode of the lighter one to be $\Xi_{b}^{0} \pi^{−}$ and for the heavier one $\Xi_{b}^{+} \pi^{-}$. The lighter $\Xi_{b}(1P, 1/2)^{−}$ state could not be observed as it would likely decay primarily through the intermediate $\Xi_{b}^{0}$ resonance which is below threshold to decay to $\Xi_{b}^{+} \pi^{-}$. However, hints of such $\Xi_{b}(1P, 1/2)^{−} \rightarrow \Xi_{b}^{0} \pi^{−}(\Xi_{b}^{0} \pi^{0})\pi^{-}$ decay are observed in the $\Xi_{b}^{0} \pi^{−}$ spectrum as a partially reconstructed feed-down component.

We express our gratitude to our colleagues in the CERN accelerator departments for the excellent performance of the LHC. We thank the technical and administrative staff at the LHCb institutes. We acknowledge support from CERN and from the national agencies: CAPES, CNPq, FAPERJ, and FINEP (Brazil); MOST and NSFC (China); CNRS/IN2P3 (France); BMBF, DFG, and MPG (Germany); INFN (Italy); NWO (Netherlands); MNiSW and NCN (Poland); MCID/IFAJI (Romania); BNL, CERN, and DESY (Germany), INFN (Italy), SURF (Netherlands), PIC (Spain), GridPP (United Kingdom), CSCS (Switzerland), IFIN-HH (Romania), CBPF (Brazil), Polish WLCG (Poland), and NERSC (USA). We acknowledge the computing resources that are provided by CERN, IN2P3 (France), KIT and DESY (Germany), INFN (Italy), SURF (Netherlands), PIC (Spain), GridPP (United Kingdom), CSCS (Switzerland), IFIN-HH (Romania), CBPF (Brazil), Polish WLCG (Poland), and NERSC (USA). We are indebted to the communities behind the multiple open-source software packages on which we depend. Individual groups or members have received support from ARC and ARDC (Australia); Minciencias (Colombia); AvH Foundation (Germany); EPLANET, Marie Skłodowska-Curie Actions, ERC and NextGenerationEU (European Union); A*MIDEX, ANR, IPanU and Labex P2I20, and Région Auvergne-Rhône-Alpes (France); Key Research Program of Frontier Sciences of CAS, CAS PIFI, CAS CCEPP, Fundamental Research Funds for the Central Universities, and Sci. & Tech. Program of Guangzhou (China); GVA, XuntaGAL, GENCAT, Inditex, InTalent and Prog. Atracción Talento, CM (Spain); SRC (Sweden); the Leverhulme Trust, the Royal Society and UKRI (United Kingdom).
[8] R. Aaij et al. (LHCb Collaboration), First branching fraction measurement of the suppressed decay $\Xi^+_c \to \pi^- \Lambda^+_c$, Phys. Rev. D 102, 071101(R) (2020).
[44] R. Aaij et al. (LHCb Collaboration), Observation of two resonances in the $\Lambda^0_b \pi^\pm$ systems and precise measurement of $\Sigma_b^\pm$ and $\Sigma_b^{*\pm}$ properties, Phys. Rev. Lett. 122, 012001 (2019).
48 University of Birmingham, Birmingham, United Kingdom
49 H.H. Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom
50 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
51 Department of Physics, University of Warwick, Coventry, United Kingdom
52 STFC Rutherford Appleton Laboratory, Didcot, United Kingdom
53 School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
54 School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
55 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
56 Imperial College London, London, United Kingdom
57 Department of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
58 Department of Physics, University of Oxford, Oxford, United Kingdom
59 Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
60 University of Cincinnati, Cincinnati, Ohio, USA
61 University of Maryland, College Park, Maryland, USA
62 Los Alamos National Laboratory (LANL), Los Alamos, New Mexico, USA
63 Syracuse University, Syracuse, New York, USA
64 School of Physics and Astronomy, Monash University, Melbourne, Australia
(associated with Department of Physics, University of Warwick, Coventry, United Kingdom)
65 Pontificia Universidade Católica do Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil
(associated with Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil)
66 School of Physics and Electronics, Hunan University, Changsha City, China
(associated with Institute of Particle Physics, Central China Normal University, Wuhan, Hubei, China)
67 Guangdong Provincial Key Laboratory of Nuclear Science, Guangdong-Hong Kong Joint Laboratory of Quantum Matter,
Institute of Quantum Matter, South China Normal University, Guangzhou, China
(associated with Center for High Energy Physics, Tsinghua University, Beijing, China)
68 Lanzhou University, Lanzhou, China
(associated with Institute Of High Energy Physics (IHEP), Beijing, China)
69 School of Physics and Technology, Wuhan University, Wuhan, China
(associated with Center for High Energy Physics, Tsinghua University, Beijing, China)
70 Departamento de Física, Universidad Nacional de Colombia, Bogota, Colombia
(associated with LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS-IN2P3, Paris, France)
71 Universität Bonn - Helmholtz-Institut für Strahlen und Kernphysik, Bonn, Germany
(associated with Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany)
72 Eotvos Lorand University, Budapest, Hungary
(associated with European Organization for Nuclear Research (CERN), Geneva, Switzerland)
73 INFN Sezione di Perugia, Perugia, Italy
(associated with INFN Sezione di Ferrara, Ferrara, Italy)
74 Van Swinderen Institute, University of Groningen, Groningen, Netherlands
(associated with Nikhef National Institute for Subatomic Physics, Amsterdam, Netherlands)
75 Universiteit Maastricht, Maastricht, Netherlands
(associated with Nikhef National Institute for Subatomic Physics, Amsterdam, Netherlands)
76 Tadeusz Kosciuszko University of Technology, Cracow, Poland
(associated with Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland)
77 Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
(associated with School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom)
78 University of Michigan, Ann Arbor, Michigan, USA
(associated with Syracuse University, Syracuse, New York, USA)

a Deceased.
b Also at Università di Roma Tor Vergata, Roma, Italy.
c Also at Università di Firenze, Firenze, Italy.
d Also at Scuola Normale Superiore, Pisa, Italy.
e Also at Università di Ferrara, Ferrara, Italy.
f Also at Università di Milano Bicocca, Milano, Italy.
g Also at Università di Bologna, Bologna, Italy.
h Also at Università di Genova, Genova, Italy.
i Also at Universidade da Coruña, Coruña, Spain.
j Also at Universidad Nacional Autónoma de Honduras, Tegucigalpa, Honduras.
k Also at Università di Bari, Bari, Italy.
l Also at Università di Cagliari, Cagliari, Italy.
Also at Università di Perugia, Perugia, Italy.
Also at Università degli Studi di Milano, Milano, Italy.
Also at Universidade Federal do Triângulo Mineiro (UFTM), Uberaba-MG, Brazil.
Also at Universidade de Brasília, Brasília, Brazil.
Also at Hangzhou Institute for Advanced Study, UCAS, Hangzhou, China.
Also at Università di Pisa, Pisa, Italy.
Also at Central South U., Changsha, China.
Also at Università di Padova, Padova, Italy.
Also at Excellence Cluster ORIGINS, Munich, Germany.
Also at Università della Basilicata, Potenza, Italy.
Also at Universidad de Alcalá, Alcalá de Henares, Spain.
Also at Università di Urbino, Urbino, Italy.