# Research contributions of Aurelio Piazzi

The main research results focus on the following topics:

- Geometric approach to linear multivariable control theory
- Analysis and control of linear uncertain systems
- Semi-infinite optimization and applications
- Trajectory planning for robot manipulators
- Inversion-based control
- Path generation and motion control for autonomous wheeled vehicles
- Time-optimal constrained feedforward control
- Feedforward-feedback control
- Mechatronics applications
- Vision-based automation
- Velocity planning

## Geometric approach to linear multivariable control theory

The main problem considered in this context has been a **general regulator problem** whose aim is the synthesis of a multivariable feedback controller to achieve asymptotic tracking of exogenous signals and a complete (vector) disturbance decoupling. The chosen approach to deal with this problem was the geometric approach introduced by Giuseppe Basile and Giovanni Marro in 1969 with the pioneering work "Controlled and conditioned invariants in linear system theory", Journal of Optimization Theory and Applications 3 (1969) 305-315. The systematic use of **controlled and conditioned invariance** and of **geometric duality** between controllability and observabilty has led to results presented in [3J], [5J], [6P], [2C].

Synthesis methods that avoid eigenspaces computations, which are notoriously difficult and ill-conditioned, were reported in [1C], [1J], [4J], [1P]. These methods are based on the lattice properties of **self-bounded controlled invariants** and on the dual notion of **self-hidden conditioned invariants**. New low-order controller synthesis for disturbance rejection were proposed in [2P], [6J]. An investigation to robust regulation with standard geometric approach techniques was reported in [3P] and [7P]. The role of **invariant zeros** in regulation problems has been highlighted in [4P] and [3C]. A problem of **perfect output tracking** was solved in [11P].

The majority of research results in this topic was coauthored with the guidance and collaboration of Professor Giovanni Marro during the PhD course in System Engineering and subsequent years at the Department of Electronics, Computer Science and Systems, University of Bologna.

In [75P] for linear multivariable systems, a new closed-form expression of the free (or zero-input) output response is presented. The relevant new concept of **output mode subspace** is also introduced.

## Analysis and control of linear uncertain systems

Uncertainty in linear systems has been mainly focused on systems affected by uncertain parameters belonging to known real intervals. An approach using **decision algebra methods** was devised to analyze the robust stability in a case where the system characteristic polynomial depends nonlinearly on the uncertain parameters [7J]. A study on interval analysis – which is the extension of the "standard" mathematical analysis over the arithmetic of real interval - was also pursued to devise tools for the analysis of linear systems affected by uncertain parameters. The results were exposed in [9J] and [5C]; the latter paper describes an **interval algorithm** to determine the **stability margin of an uncertain system**.

The synthesis of an **optimal fixed-structure controller** for scalar system was established by minimazing an H2-index subject to an H-infinity constraint that accounts for a robust closed-loop requirement [15J]. The focus of [25J] was the **worst-case design of a static output feedback** for a multivariable system: robust stability is guaranteed for the whole set of uncertain paramenters while minimizing a worst-case quadratic index. A robust synthesis for set-point scalar regulation using inversion-based control was presented in [17J].

**Semi-infinite optimization and applications**

A significant variety of design problems for control systems and also for engineering are amenable to be recasted as semi-infinite optimization problems. Recognizing this potential, a research was performed to develop an algorithm for solving a standard semi-infinite problem. The result was proposed in [16J] where an **hybrid genetic/interval algorithm** is described. The underlying idea is to conjugate a stochastic global optimization technique (a genetic algorithm) with a deterministic global one (an interval procedure) by means of a penalty method. The penalty functions are computed via an interval procedure and the resulting unconstrained problem is solved using a partially elitistic genetic algorithm [8J].

This hybrid approach has been successfully applied to the trajectory planning of mechanical manipulators [4C], [23P] and for the steering of car-like vehicles [6C]. An advantage of this technique with respect to conventional alternatives is that the estimated global solution of the semi-infinite problem is feasible with certainty. This feature is particularly significant in dealing with control systems design problems for uncertain systems [15J], [19P], [25J].

**Trajectory planning for robot manipulators**

**Optimal trajectory planning of rigid-links manipulators** can be applied to industrial robots to achieve high-performance in manufacturing production. With this aim, using interpolation schemes with cubic splines in the joint space, **minimum-time problems** with velocity, acceleration, and jerk constraints has been addressed in [10J], [15P], [16P] or when travelling time is fixed, **minimum-jerk problems** have been posed [12J], [17P]. The proposed algorithms use interval routines that find global solutions [12J].

The minimum-time problem has also been addressed considering **dynamic constraints** [23J], [4C], [23P]. In this case, the algorithmic solutions are based on the mixed genetic/interval approach presented in [16J].

**Inversion-based control**

Inversion-based control is a feedforward methodology. Its development started in the 90's as a new technique to achieve high-performance in the control or regulation of systems. The basic idea is to define the desired output signal according to the addressed application with the aim to determine the input that, when applied to the nominal system, causes the desired output. The procedure to determine this **inverse input** is usually called **input-output (stable) dynamic inversion**.

Inversion-based control has been applied to the regulation of minimum-phase linear scalar systems in [18J]. To this aim, **"transition" polynomials** are introduced as desired outputs. They are a family of polynomials parametrized by a transition time that allows a smooth transition between two constant output values. Extension to the nonminimum-phase case was addressed in [29J] where the input-output inversion is stable, i.e. the sought inverse input is bounded despite the presence of an unstable zero dynamics. In both works [18J] and [29J], the inverse input has been determined by closed-form expressions depending on the the transiotion time. This has allowed a straightforward solution to a time-optimal regulation problem with constraints on the input and its derivatives. The inverse input exhibits the so-called **pre-action** and **post-action** when the regulated system has unstable and stable zero dynamics respectively. A MATLAB-based implementation of transition polynomials and stable input-output inversion has been presented in [33J], [46P], [50P]. A more general closed-form expression of the inverse input is presented in [47P] where the desired output can be an arbitrary bounded function satisfying a relative degree condition.

A **smooth feedforward regulation problem** for linear multivariable plants is addressed in [48P]. Using transition polynomials as desired outputs, **Pareto optimal inverse inputs** are found by minimizing the output transition times with amplitude constraints on the inputs and their derivatives.

A possible cause of output errors in the implementation of inversion-based control is the unreliability of the nominal system (over which the inversion procedure is applied) due to system's parameter variations. To overcome this difficulty, a recursive estimation of the system's parameters is presented in [56P]. It uses a gradient descend algorithm to minimize the integrated square error of the regulated output.

The inverse input can be applied as the command input of a closed-loop PID control system in order to improve the regulation performances. In [61P], the three parts of the inverse input, i.e., the preaction, the central action, and the postaction are proposed to be implemented as causal step-responses of second-order filters. This significantly facilitates the implementation in an industrial context such as, e.g., when Distributed Control System (DCS) is on the use.

A **dynamic path inversion** problem, a variant ot the standard input-output inversion problem, has been proposed for a class of nonlinear systems in [39P]. Given a path on the system output space, the problem is to find a feedforward input that causes the system to follow the given path. Solution conditions and constructive procedures are given by paper [39P] to solve this inversion problem both locally and globally.

A **new simplified behavior theory** has been proposed in [40J] to address inversion-based control for linear, nonminimumphase SISO systems. In particular, it is introduced the output–input (or inverse) representation of the system behaviour. This representation leads to **the solution of a general stable**

**inversion problem** where polynomially unbounded, noncausal desired outputs are allowed. It is shown that this problem has a solution if and only if the **smoothness degree** of the desired output is greater than or equal to the system relative degree minus one. When this straightforward condition is satisfied, a closed-form expression provides the inverse input.

**A new inversion formula** to solve the stable input-output inversion problem is presented **for multivariable nonminimum-phase linear systems** in [72P]. It is based on the computation of the system transfer function inverse and the splitting of the zero dynamics transfer function into stable and unstable parts. Differently from the known alternative statespace methods, the presented approach is applicable to systems that cannot be input-output decoupled by state feedback.

A **polynomial interpolation technique** is presented in [41J] for the inversion-based control of scalar (SISO) nonminimum-phase systems. The design of an inverse input to smoothly switch from a current, arbitrary, steady-state regime to a new, future, desired steady-state output is achieved by means of new closed-form expressions. The (interpolation) transition time can be also minimized in order to optimally reduce the delay with which the future desired output occurs.

### Path generation and motion control for autonomous wheeled vehicles

Considering a kinematics model of a car-like vehicle, a **dynamic path inversion** procedure is presented in [32P]. It is shown how to determine the vehicle's steering input in such a way a front point of the vehicle exactly follows a pre-specified Cartesian path. Motivation for this special motion planning problem arises from the need of vision-based autonomous vehicle driving. In [37P], [27J], an extension of this technique has led to a path following control scheme where the feedforward action is given by the dynamic path inversion of [32P] and the feedback is proportional to the trajectory tangential and normal errors. A quantitative convergence analysis has been also carried out by considering an uncertain model of the car-like vehicle.

The **vision-based automatic driving** of the **ARGO car**, a vehicle prototype of the University of Parma, has been described in [11J]. In particular, its motion control system which is based on a look-ahed gain-scheduled controller is presented. The more advanced iterative trajectory control that uses the **path generation with quintic G2-splines** [21J] is also outlined. A method for sensing obstacles and vehicles based on artificial vision has been presented with the implementation for the platooning of the ARGO vehicle [14J]. The adopted gain-scheduled controller for automatic steering is also decribed.

**Trajectory tracking of wheeled mobile robots** is the topic of [63P]. **Feedforward inverse control** and **recursive convex replanning** of the reference trajectory are proposed to form a hybrid control scheme when only discrete-time low-frequency measurements of the robot state are available. This scheme applied to the standard unicycle model is shown to maintain its efficacy also in presence of noise or unmodeled robot dynamics. Explicit, sufficient conditions are also provided to ensure global boundedness of the tracking error. Experimental resuts are included to highlight the new approach.

A new motion planning primitive, the **quintic G2-spline**, has been introduced in [27P], [21J] for the iterative steering of vision-based autonomous vehicles. It is a parameterized fifth-order polynomial curve that makes possible to exactly interpolate any sequence of Cartesian points with associated arbitrary unit tangent vector and curvature. In such a way, the resulting composite path has an overall **second-order geometric continuity** (G2-continuity). A supervisory strategy for iterative steering that integrates vision data processing feedback with inversion-based feedforward is described in [21J]. The quintic G2-spline depends on four (eta) parameters that can be selected to achieve an optimal path planning. An example of this optimization is described in [28P] where the maximum of the curvature derivative with respect to the arc length is minimized. The dynamic path inversion control of a **wheeled omnidirectional robot** is presented in [44P] with the use of quintic G2-splines to achieve a robot's **smooth motion**.

Using smooth continuous-acceleration inputs for a **unicycle mobile robots (UMRs)**, it is shown in [28J], [35P] that a robot's path is feasible, apart kinematics singularities, if and only if it is a path with **third-order geometric continuity** (G3-path). This continuity accounts for a path whose unit tangent vector, curvature, and curvature derivative with respect to the arc length are continuous along the path. This path property justifies the use of **eta3-splines** in the **dynamic path inversion** procedure for the UMR. Eta3-splines were originaly presented in [41P] and subsequently in [32J], [8C] with more details. The eta3-spline, which is a generalization of the eta2-spline (or quintic G2 spline), is a seventh-order polynomial curve that interpolates arbitrary Cartesian points with associated arbitrary unit tangent vectors, curvatures, and curvature derivatives. It depends on six (eta) parameters that can be freely chosen to shape the spline without changing the interpolation conditions at the curve endpoints. Papers [32J], [8C] also give a glimpse on the more general eta-k-splines.

In [67P] an application of eta3-splines to the **autonomous parking of car-like vehicles** is presented. It proposes a multi-optimization approach to build up intrinsically feasible path maneuvers over which to minimize the total length of parking paths and the maximum absolute values of curvature and curvature derivative. This approach takes into account the mandatory constraint of obstacle avoidance and maximal steering angle and the constraint of maximal curvature derivative which is a selectable limit to ensure the desired smoothness of the parking paths.

Generation of high-quality drive paths for a **truck and trailer vehicle** is the topic of [38J]. First, it is shown the need of generating **G4-paths**, i.e. paths with **fourth-order geometric continuity**. Secondly, **eta4-splines** are developed and presented to be used in the generation of the trailer G4-paths. The method gives the explicit closed-form expressions of the smooth feedforward control to drive the articulated vehicle between arbitrary dynamic configurations along a path that can be shaped with the free parameters of the eta4-spline.

### Time-optimal constrained feedforward control

A line of research has considered the time-optimal (i.e. minimum-time) feedforward control of linear plants with input and output constraints. Preliminarily results were presented in [54P], [34J] where the minimum-time rest-to-rest control of a flexible joint is addressed and comparisons with the inversion-based control solution are discussed.

For linear scalar systems, a more general approach was presented in [52P], [53P] and with full details in [35J]. In addressing the minimum-time feedforward control problem with input constraints only, the well-known solution is the so-called bang-bang control. When output constraints are also considered as in [35J], the emerging solution is the **generalized bang-bang control**, i.e. the time-optimal input is characterized by a sequence of **bang-bang functions** and linear combinations of the **system zero modes**. By time–discretization, an approximate determination of the generalized bang-bang control can be found by solving a sequence of linear programming feasibility problems. **Generalized bang-bang control** has the potential to improve the regulation performances of a large class of engineering control problems, also comprising mechatronics and process control problems.

The paper [69P] considers a **minimum-time feedforward motion control** problem for an **open container carrying a liquid**. The proposed solution, a form of generalized bang-bang control in a multivariable context, is a time-continuous acceleration planning that avoids liquid spilling and satisfies **amplitude constraints on jerk, acceleration, and velocity of the container** moving on a linear guide of an **automation line**. The devised solution can provide **rest-to-rest liquid motion** planning or, alternatively, a **rest-to-disequilibrium** planning with **bounded post-motion liquid oscillations**. Experimental results on a test bench have shown the practicability and the effectiveness of the approach.

The time-optimal trajectory planning of an **automatic guided vehicle (AGV)** on a given feasible path while respecting velocity, acceleration and jerk constraints is addressed in [65P]. A theoretical result showing the connection between the geometric continuity of AGV paths and the smoothness of its control inputs (linear velocity and steering angle of the AGV motor wheel) is established. The solution hence proposed for the optimal planning is based on a **dynamic path inversion algorithm** for which first the optimal velocity profile is determined and then the optimal steering signal is derived from a geometrical construction. **Eta3-splines** [32J] can be effectively used to plan the desired paths in this AGV application.

**Feedforward-feedback control**

A possible classification of contributions on this topic is as follows:

1. Inverse feedforward and feedback control for uncertain systems
2. Inverse feedforward and PID feedback control
3. Inverse feedforward and feedback control for multivariable systems
4. Iterative output replanning
5. Generalized bang-bang control for closed-loop systems

**1. Inverse feedforward and feedback control for uncertain systems**

This line of research has been mainly devoted to devise **new high-performance feedforward-feedback schemes** for the fundamental problem of set-point regulation. The main idea is to use feedforward and feedback in a combined way. Feedback has to reduce the sensitivity of the (system) plant to disturbances, unmodelled dynamics, and parameter variations whereas feedforward improves the transient responses on the plant output. Specifically, the feedforward action, which is applied to the command input of the (feedback) closed-loop, is proposed to be determined by **inversion-based control** (i.e., by input-output stable dynamic inversion) or alternatively by **time-optimal constrained control**.

The majority of contributions addresses the former case. A first scheme addressing minimum-phase plants appeared in 1998 [20P] and with full details in [17J]. The case of scalar regulation of linear, stable, **nonminimum-phase plants** that are affecteted by uncertain parameters is preliminarily addressed in [26P], [29P]. A complete exposition of the design method, which comprises **transition polynomials** [18J] as desired outputs, is presented in 2001 in [19J]. The feedback controller and the feedforward inverse input are designed together to minimize the worst-case settling-time of the set-point transition. Constraints on the amplitude of the control variable and on maximum overshoot and undershoot are taken into account. Extensions to possibly unstable plants are presented in [33P] and [31J]. In these works, the feedback parts of the overall design use the linear quadratic regulator theory and the H-infinity control theory respectively. It is worth emphasizing that all the proposed inversion-based feedforward-feedback schemes adhere to the **internal model principle** so that robust steady-state regulation is ensured. This feature appears an improvement over the first inversion-based feedforward-feedback scheme proposed in 1996 by Devasia and co-researchers (cf. doi 10.1109/9.508898).

The main inversion-based control schemes are the **plant and closed-loop inversion architectures**. For scalar continuous-time linear systems, these feedforward-feedback control architectures are shown to be fully equivalent for both the minimum and nonminimumphase cases when exact stable inverses are used. This equivalence, deduced by using a behavioral approach in [74P,42J], dictates that the two architectures deliver the same performances for any disturbance and mis-modeling affecting the controlled plant.

## 2. Inverse feedforward and PID feedback control

An application to a DC motor-position servo is presented in [22J]. Two feedforward-feedback schemes are designed and experimented. One scheme adopts a standard PD feedback controller and the inverse feedforward improves the servo performances. The second scheme that couples an high-gain feedback controller with the inverse feedforward significantly improves over the first one also exhibiting better robustness against the possible variation of the motor inertia. In [26J], a PID feedback controller is considered to be already designed. Then, the numerical identification of the closed-loop system permits to determine the command input from the desired output signal. The works in [38P], [45P], [49P], [30J] propose **to enhance PID control** for set-point regulation by setting coordinated designs. The PID feedback controller is tuned to achieve the best load rejection while **inversion-based feedforward** establishes high-performances in the regulation transients. The methodology gives as a tuning parameter the **transition time** that can effectively handle the **trade-off between performance and control activity**. Detailed closed-form expressions of the inverse command input, which are expecially useful in industrial implementations, are reported in [30J].

A **cascade control system** with two nested PID feedback loops is considered in [51P]. The command signal applied to the outer loop is determined by stable inversion having previously approximated the process dead time dynamics with Padé approximants. The design of an industrial control system is addressed with a new methodology in [58P], [59P]. This integrates identification, PID feedback tuning based on frequency loop shaping and (noncausal) inversion-based feedforward.

**3. Inverse feedforward and feedback control for multivariable systems**
**Multivariable regulation** is addressed for two-inputs two-outputs (TITO) plants in [31P] and in [36P] more generally for **multi-inputs multi-outputs (MIMO) nonminimum-phase plants** affected by uncertain parameters. The proposed control architecture consists of a high-gain decoupling feedback controller and a vector command input determined by stable inversion. This architecture, which enforces the **internal model principle**, is finally tuned to minimize the worst-case settling-time subject to amplitude limits on the control variables and constraints on the overshoots and undershoots of the outputs.

**4. Iterative output replanning**
**Output tracking of nonlinear flat systems** is the topic of [64P] and [36J]. When the system's state can be acquired with low-frequency measurements, a **hybrid feedforward-feedback control scheme** is proposed. It is based on an inverse feedforward command input that is periodically updated by means of an **iterative output replanning** that uses interpolating Hermite polynomials. Theoretical convergence results, simulations and comparisons for the unicycle and the one-trailer system are presented.

**5. Generalized bang-bang control for closed-loop systems**
In [55P], PID feedback control is improved by applying to the closed-loop system a **minimum-time feedforward input** for which amplitude constraints on the plant's input and output are satisfied. The proposed scheme considers a rest-to-rest transition for the overall closed-loop system. The time-optimal input is computed by solving a sequence of linear programming feasibility tests. An extension of this technique to **MIMO plants** is presented in [68P]. Two feedfoward/feedback schemes are devised. Both use decentralized PID feedback controllers. The first scheme is the direct extension of that in [55P]. For the second one, first the plant input is determined as the **generalized bang-bang control** relative to the plant (cf. [35J]), then the actual feedforward command input is determined by means of a dynamic inversion procedure.

**Mechatronics applications**

Inversion-based control has been successfully applied to various mechatronics devices. A series of works has focused on **positioning control with elastic linkages**. The aim is to achieve a fast rest-to-rest motion with suppression of final parasitic vibrations. Paper [13J] shows how to achieve it. **Transition polynomials** are used to plan the desired **vibration-free motion**. Then, the input motion that is implemented by a servo-actuator is deduced by input-output dynamic inversion. Minimum-time motion is also achieved by solving a bisection-type procedure with pertinent actuator constraints. Preliminarily results and variations of this approach have been presented in [18P], [21P], [24P]. In [20J] with the use of experiments for parameter estimation, an improvement that minimizes the maximal residual vibrations is proposed. An iterative approach for the determination of the input-output inversion feedforward control law for residual vibration reduction is proposed in [57P]. It is based on a gradient-based minimization of the integrated square error on the system output. Simulation results show the effectiveness of this approach.

**Control of the transient sway** and residual oscillations of a payload carried by an **overhead crane** is the topic of [24J], [25P]. These papers propose a feedforward-feedback scheme that comprises a robust observer-based feedback controller and an inversion-based feedforward command control. The control design based on this scheme uses transition polynomials and takes into account parameter uncertainties. Simulation results, based on a nonlinear crane model, show that the proposed method is also effective when the payload is hoisted or lowered during the motion, and when friction effects are considered.

The **end-point control of a flexible link** is addressed with inversion-based control in [30P]. The nonminimum-phase dynamics of the link end-point (output) commanded by the hub angle (input) has required applying a stable dynamic inversion procedure. The desired vibration-free motion modelled by transition polynomials has been optimized to obtain a minimum-time movement while given constraints on velocity and accelerations are satisfied. Experimental results, reported in [34P], show that the proposed method is effective and inherently robust to modelling errors.

Set-point regulation of a **magnetic levitation apparatus** is addressed with a combined feedforward-feedback approach in [62P]. An integral action and a state feedback set the structure of the closed-loop system. Its command input is determined by dynamic inversion with the use of transition polynomials. The design method exploits the nonlinear flatness of the levitation system and achieves a minimum-time in performing the required set-point regulation. Simulations highlight the robustness and good performances of the proposed approach.

The **flux observer for induction servo motors** is designed by a **genetic algorithm** in [8P]. This new approach makes the flux observer robust against variations of operational conditions and very large perturbations of the machine model parameters. **Harmonic disturbance attenuation** in the motion control of **wood countouring machines** is addressed in [10P]. Frequency- and time-domain specifications are dealt within a unified framework with the use of integral quadratic indexes. The controller design is then reduced to a mini-max optimization problem.

## Vision-based automation

Paper [40P] shows how **artificial vision** can be successfully used for the automatic control of an **industrial tunnel baking oven**. The baking status of food products (biscuits in the experimental application) is estimated by data from a color line-scan camera placed at the outlet of the tunnel oven. Then, a feedback fuzzy strategy is designed to control the oven burners with the aim to achieve optimal baking. This research has been carried out in collaboration with Colussi s.p.a. (Perugia, Italy) in the 5$^{th}$ Framework Programme, EUropean Take-up of essential Information Society Technologies - Integrated Machine Vision (EUTIST-IMV).

A computer vision system for the **inspection of locomotive pantographs**, named **PAVISYS**, is described in [66P]. This automatic inspection algorithm consists of three main steps: a pantograph classifier, a modular quality assessment system, and a report generator. The paper provides details about this architecture, reporting the most significant experimental results obtained in the extensive set of lab tests that were run to assess its performances. The research that has led to PAVISYS was originally developed in collaboration with the Italian Train Network (RFI, Rete Ferroviaria Italiana). Presently, PAVISYS is the heart of the PANTOBOT system (Henesis srl, Parma, Italy), a full-fledged monitoring system for train pantographs, which also adds remote analysis and management of images coming from the Inspection Points located along the railway.

## Velocity planning

Velocity planning for autonomous vehicles is the topic of [43P]. A **minimum-jerk continuous-acceleration planning** for a given travel distance is sought with arbitrary interpolation conditions on velocity and acceleration at the endpoints of an assigned time-interval. Interpolating cubic splines are used to obtain an approximate solution scheme which is suitable for real-time implementation by using a new heuristic optimization algorithm.

The paper in [37J] addresses the problem of **minimum-time velocity planning** subject to a **jerk amplitude constraint** and to arbitrary velocity and acceleration interpolation conditions. This problem which is relevant in the field of autonomous robotic navigation and also for linear one-dimensional mechatronics systems is dealt with an **algebraic approach based on Pontryagin's Maximum Principle**. Specifically, it is shown that solution to this velocity planning can be found by solving a **quartic algebraic equation**. Hence, to compute the velocity profile a **finite-step algorithm** that is suitable for real-time applications is then presented. In [60P], this **minimum-time velocity planning** problem is considered by adding arbitrarily given **constraints on velocity and acceleration**. These constraints make the problem significantly more difficult. First, it is presented a sufficient condition for the feasibility of the constrained velocity planning. Then, an approximate solution is determined by time-discretization and by solving a sequence of linear programming feasibility tests. Further results on velocity planning have been presented in [71P] e [39J].

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