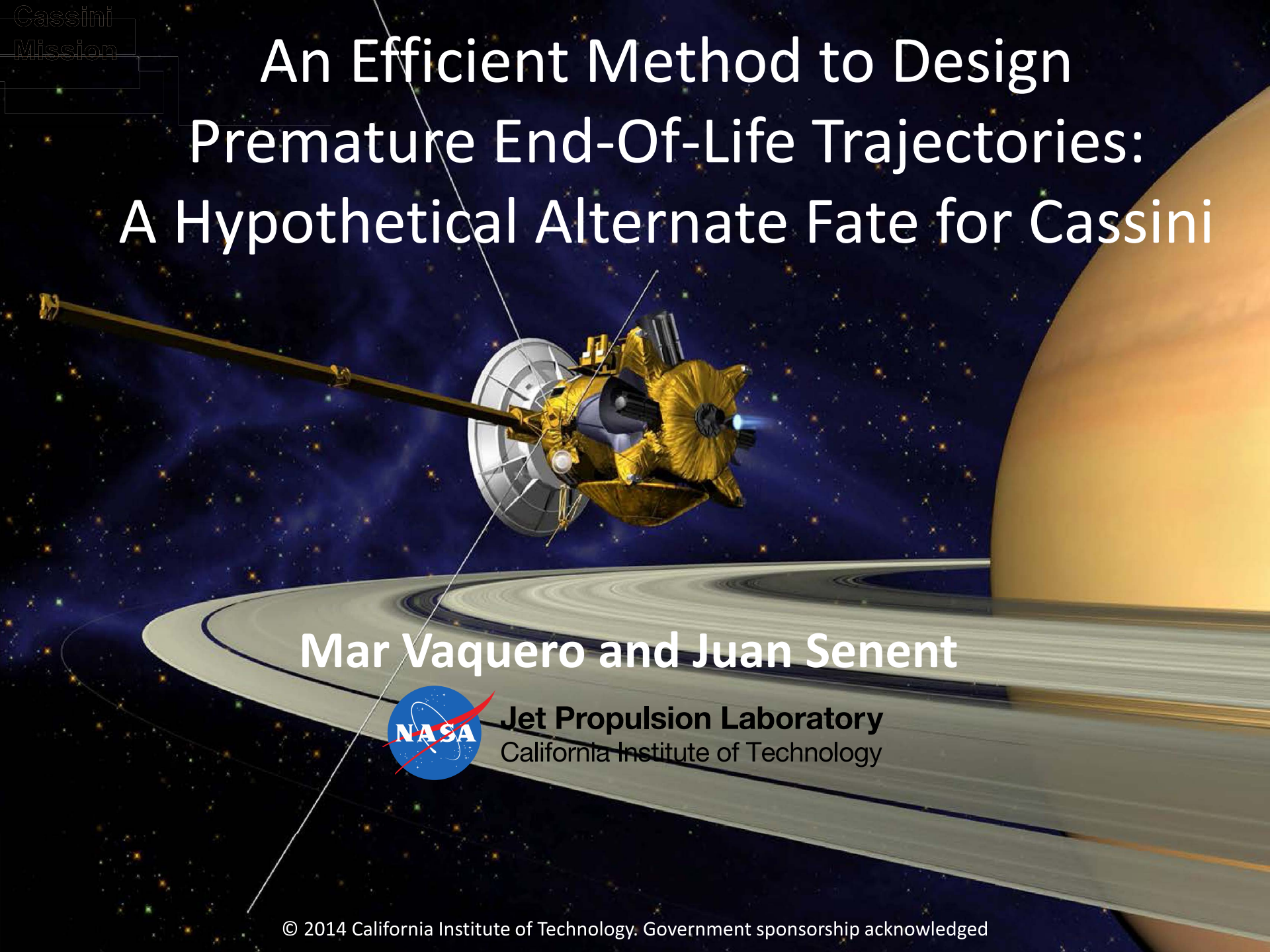
Cassini Mission

An Efficient Method to Design Premature End-Of-Life Trajectories: A Hypothetical Alternate Fate for Cassini



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Jet Propulsion Laboratory
California Institute of Technology

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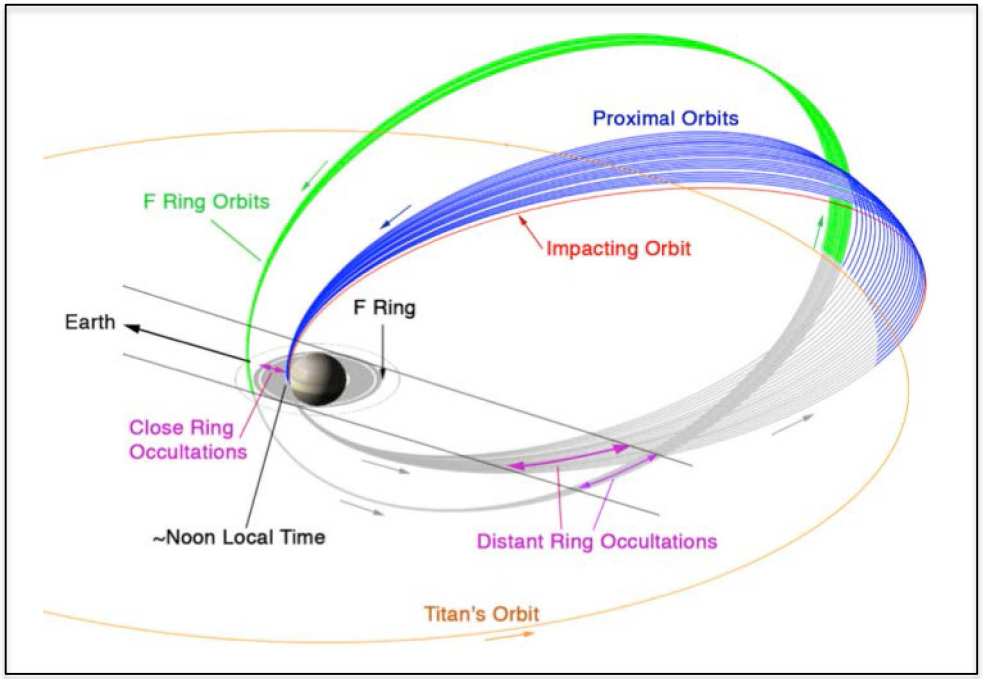
Motivation

Cassini's Grand Finale



F-ring Orbits Grand Finale Orbits Final Impact Orbit

culminating with Saturn atmospheric entry on September 15, 2017

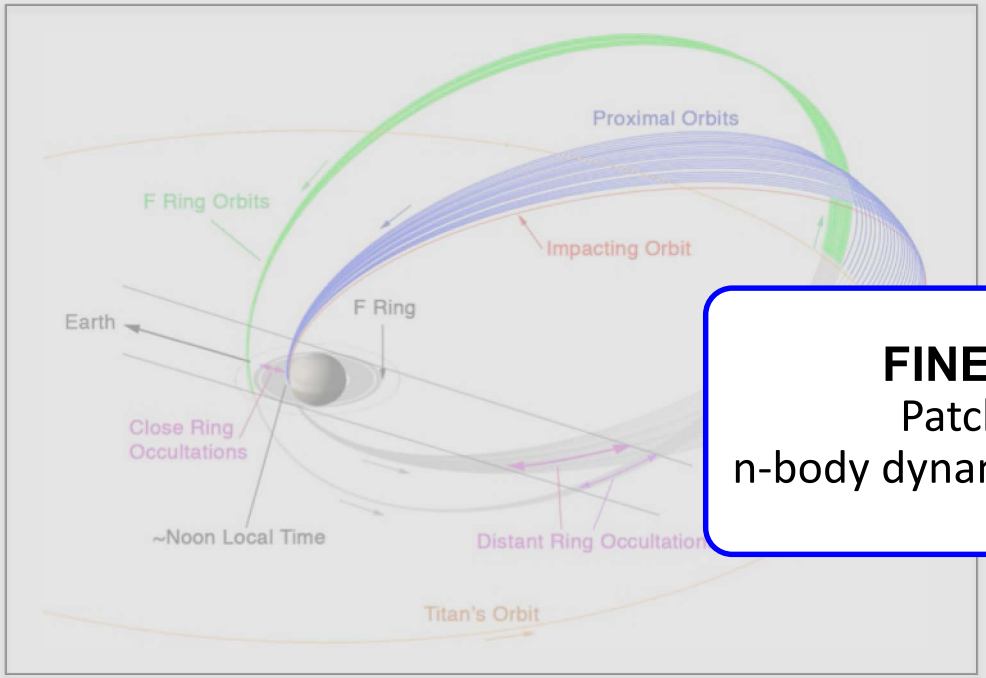
Nominal EOM traj tied to specific epoch and flyby geometry

What if propellant shortage or sudden subsystem failure occur?

Need to quickly produce terminal trajectories that meet requirements

Motivation

Cassini's Grand Finale



F-ring Orbits Grand Finale Orbits Final Impact Orbit

culminating with Saturn atmospheric entry on September 15 2017

FINE SEARCH
Patched conics
n-body dynamics + optimization

Nominal EOM
tied to specif
epoch and fly
geometry

GLOBAL SEARCH
Mapping techniques
Three-body dynamics

Need to quickly produce terminal trajectories that meet requirements

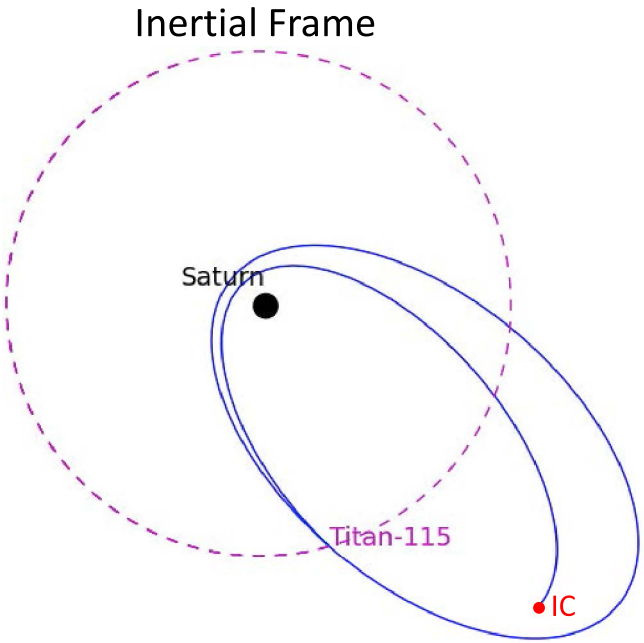
The Problem

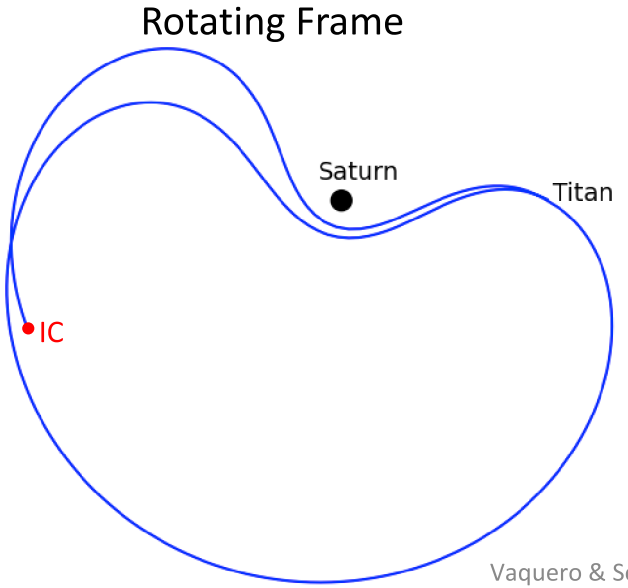
Problem Statement and Constraints

- One ΔV modifies nominal Titan flyby aimpoint
- SC placed on a ballistic impact trajectory
- Minimum Titan flyby altitude = 1,300 km
- Total TOF under 6 months
- No ring crossings (< 140,000 km)
- No impact with selected icy moons
- Limited ΔV budget → optimized maneuver

Test Scenario: Assumptions

- Starting point: few days prior 16-JAN-2016 (T-115)
- Orbital inclination ~1.3°
- Non-resonant orbit before T-115
- 1:1 resonant orbit after T-115
- Ring crossings determined by distance to F-ring
- Saturn and Mimas considered for impact





Trajectory Design Approach

GLOBAL SEARCH

Impact Map	Initial guess for ballistic impact trajectory
↓	
Corrections Algorithm	Computation of continuous trajectory with corrective ΔV

Used for:

Feasibility studies
Rapid assessment of solution space

Advantages:

Applicable to any point on reference path
Fast & efficient method to compute solutions

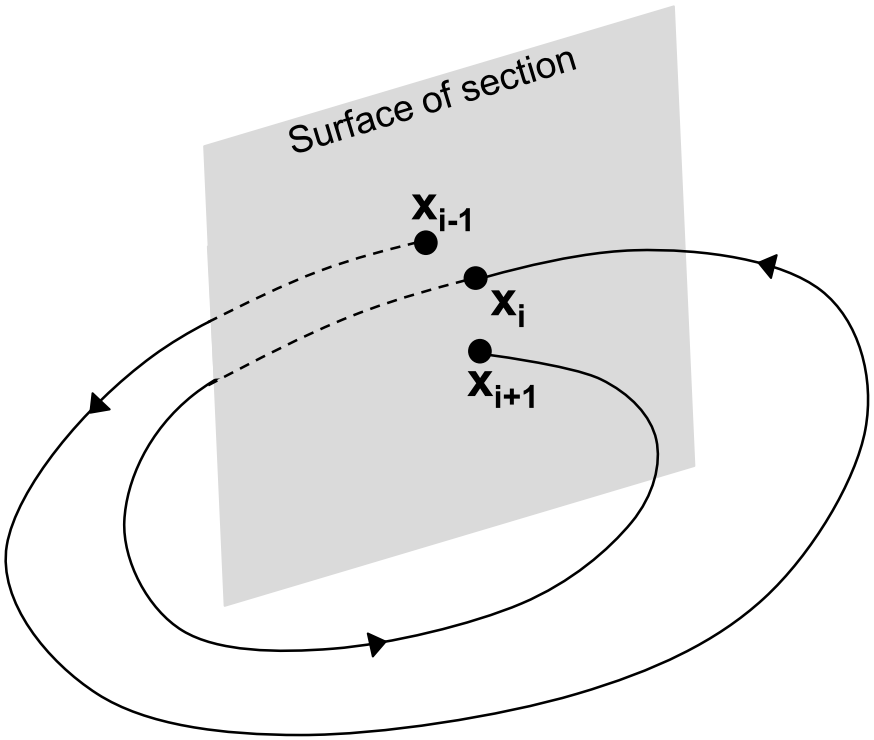
Limitations:

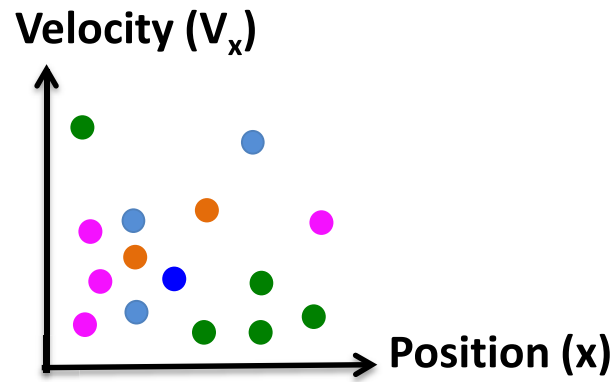
Smaller set of constraints are met
Lower-fidelity solutions (CR3B model analysis)

Trajectory Maps

Why use maps?

- Discretize the continuous time system to form a map
- Reduction of dimension
- Global dynamics and conceptual clarity: orbits and flow nearby

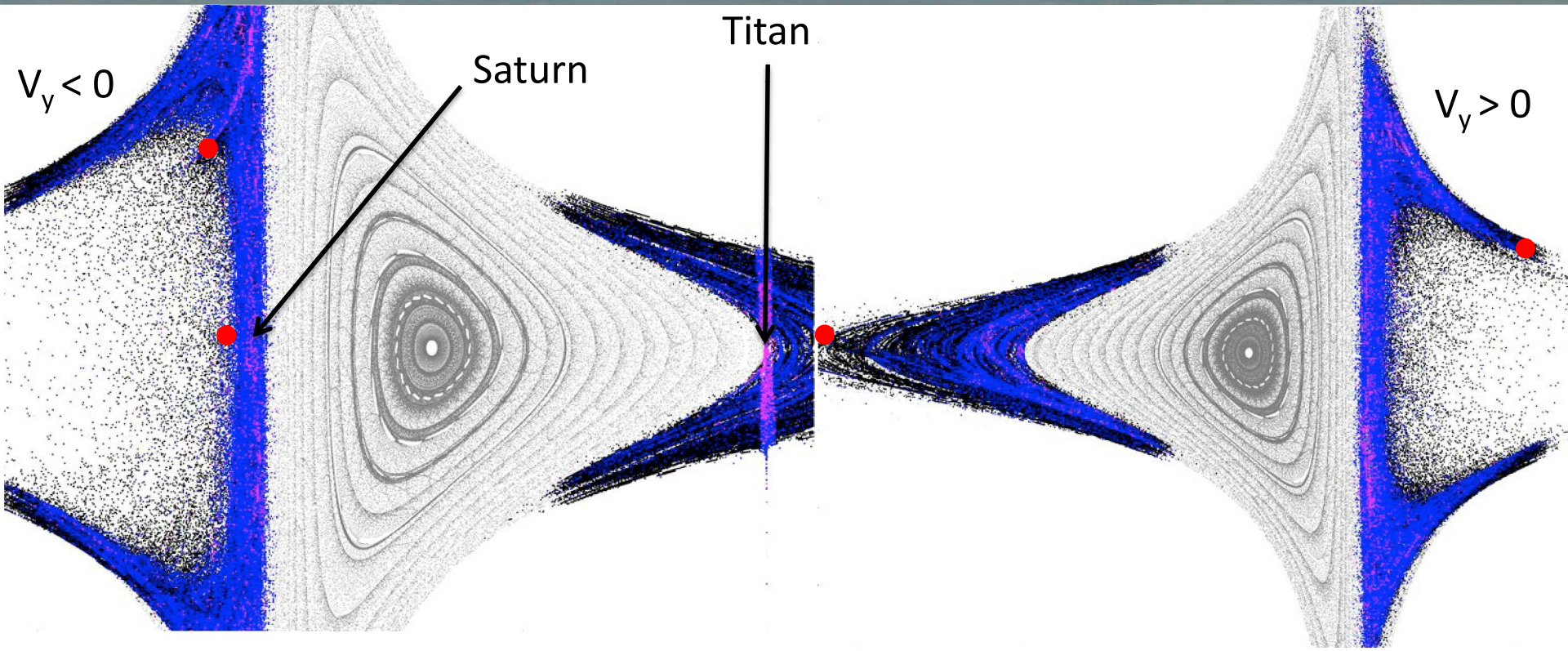




color for third parameter
inclination, r_p, # of flybys

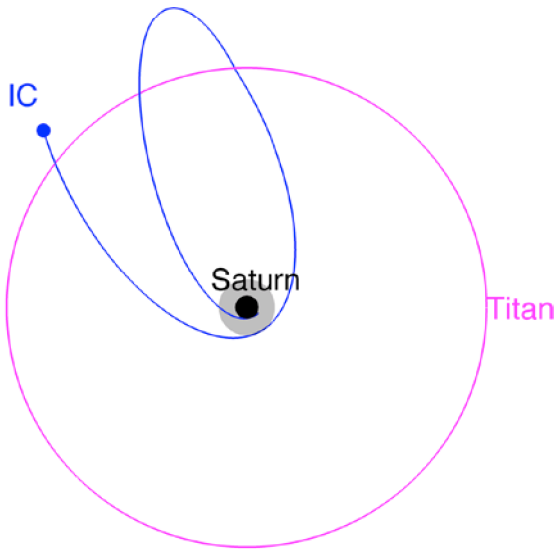
$\mathbf{x}_i$ = initial state [x y z V_x V_y V_z]
$\mathbf{x}_{i+1}$ = return of $\mathbf{x}_i$ to the map after forward propagation
$\mathbf{x}_{i-1}$ = return of $\mathbf{x}_i$ to the map after backward propagation

Saturn Impact Maps

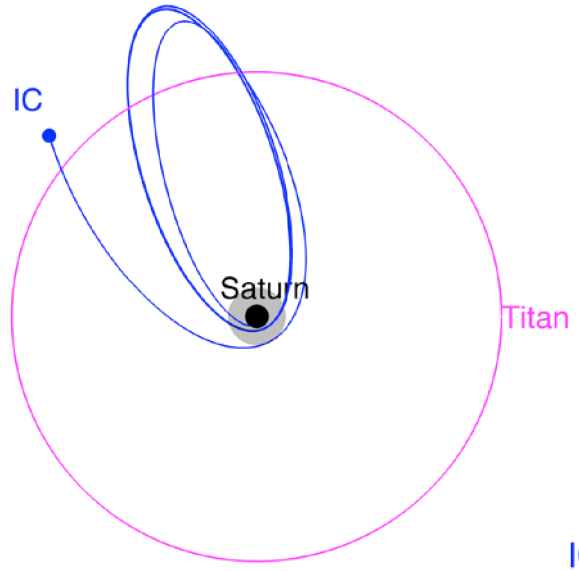


- Impact trajectories with large out-of-plane component (not useful)
- Near-equatorial trajectories with one Titan flyby
- Near-equatorial trajectories with two Titan flybys
- Near-equatorial trajectories with three Titan flybys
- Reference Trajectory
- Stability regions – periodic & quasi-periodic orbits (no impact, not useful)

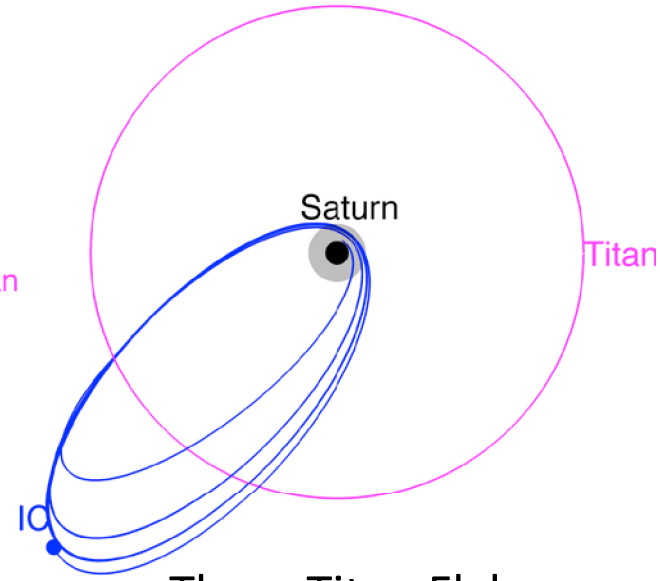
Sample Saturn Impact Trajectories



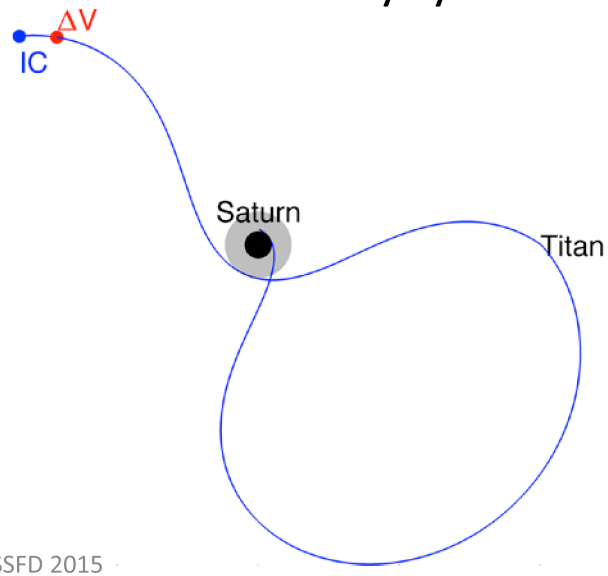
One Titan Flyby

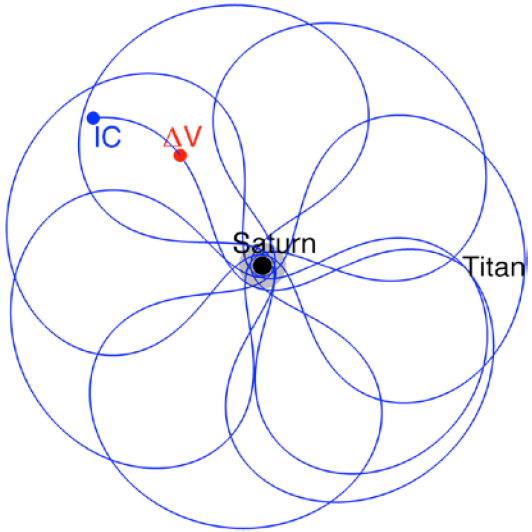


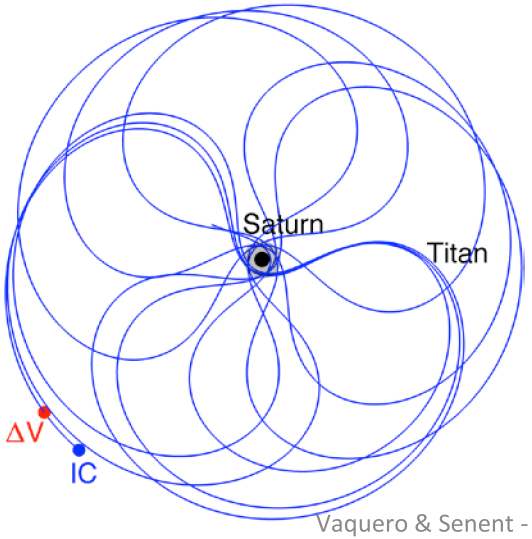
Two Titan Flybys



Three Titan Flybys







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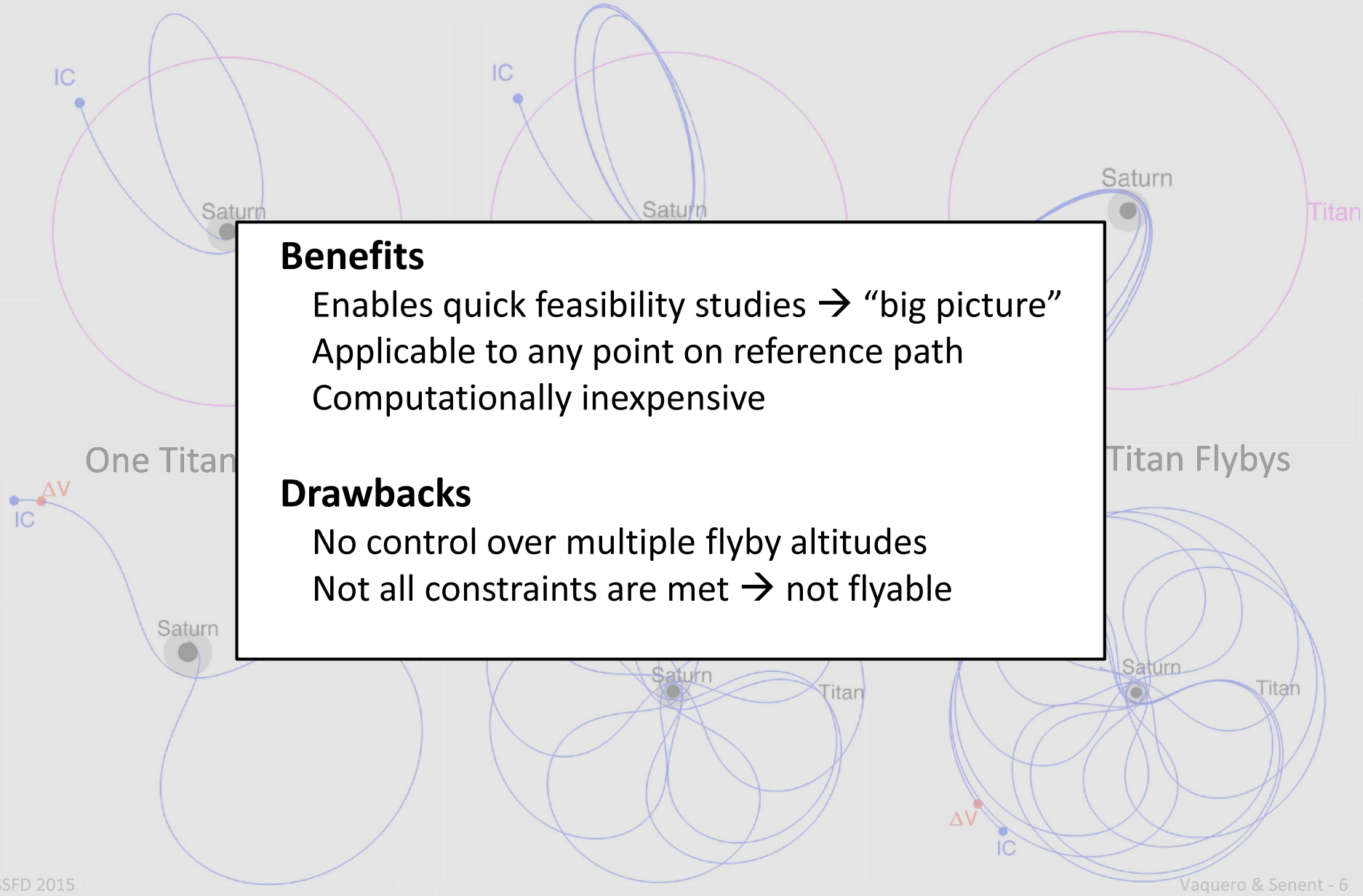

Benefits

- Enables quick feasibility studies → "big picture"
- Applicable to any point on reference path
- Computationally inexpensive

Drawbacks

- No control over multiple flyby altitudes
- Not all constraints are met → not flyable

Trajectory Design Approach

GLOBAL SEARCH

Impact Map

↓

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FINE SEARCH

Patched-Conics for Impact Arc Guess

↓

High-Fidelity Optimal Solution

↓

Flyable Solution w Current SC & System Models

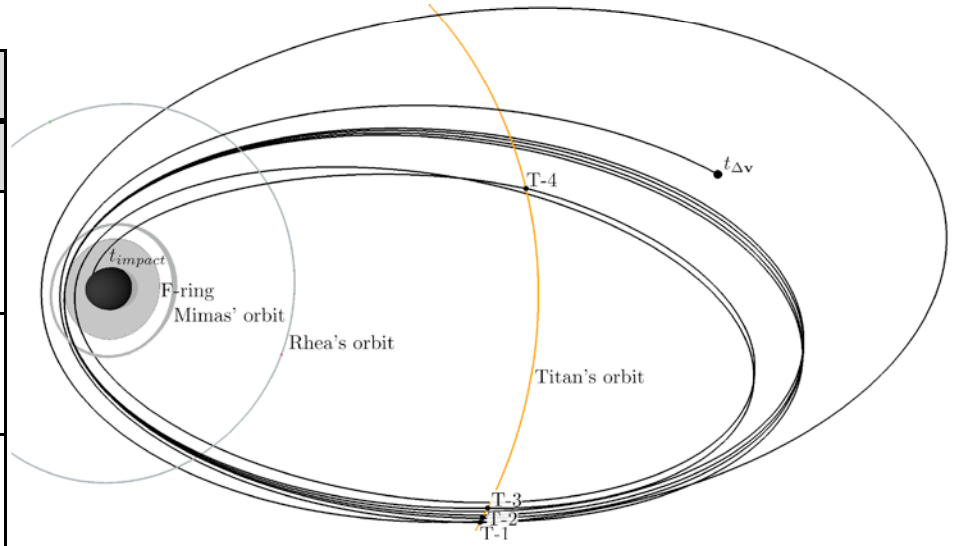
Used for:
- Detailed assessment of point solutions

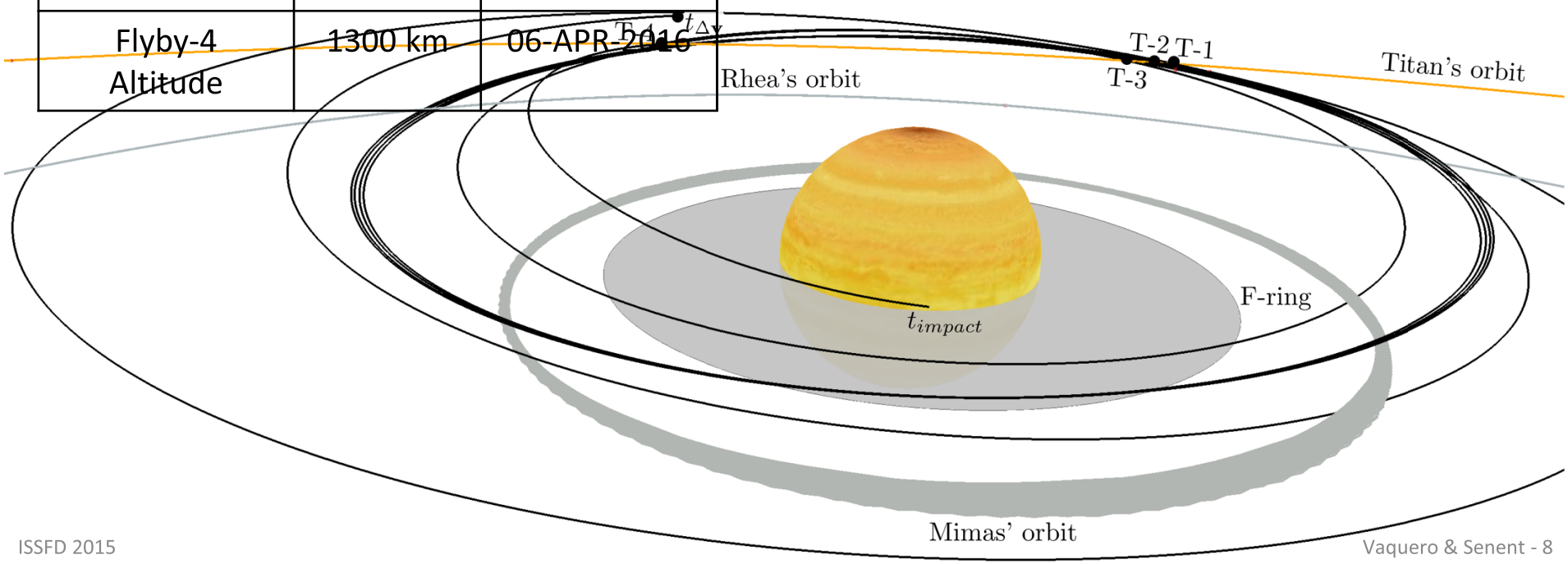
Advantages:
- Generates optimal, flyable solutions
- All constraints are met

Limitations:
- Only applicable to specific ICs on nominal path
- Computationally expensive process

Sample Saturn Impact Trajectory

ΔV	3.99 m/s	10-JAN-2016
TOF to impact	**88.66 days**	08-APR-2016
Flyby-1 Altitude	3874 km	16-JAN-2016
Flyby-2 Altitude	1890 km	01-FEB-2016
Flyby-3 Altitude	6304 km	19-MAR-2016
Flyby-4 Altitude	1300 km	06-APR-2016





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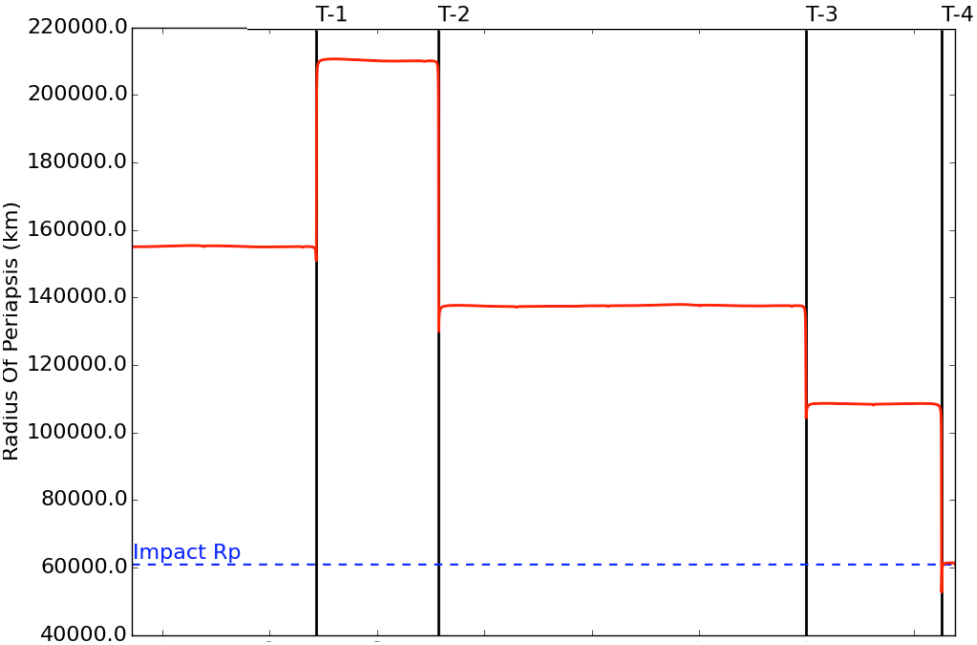
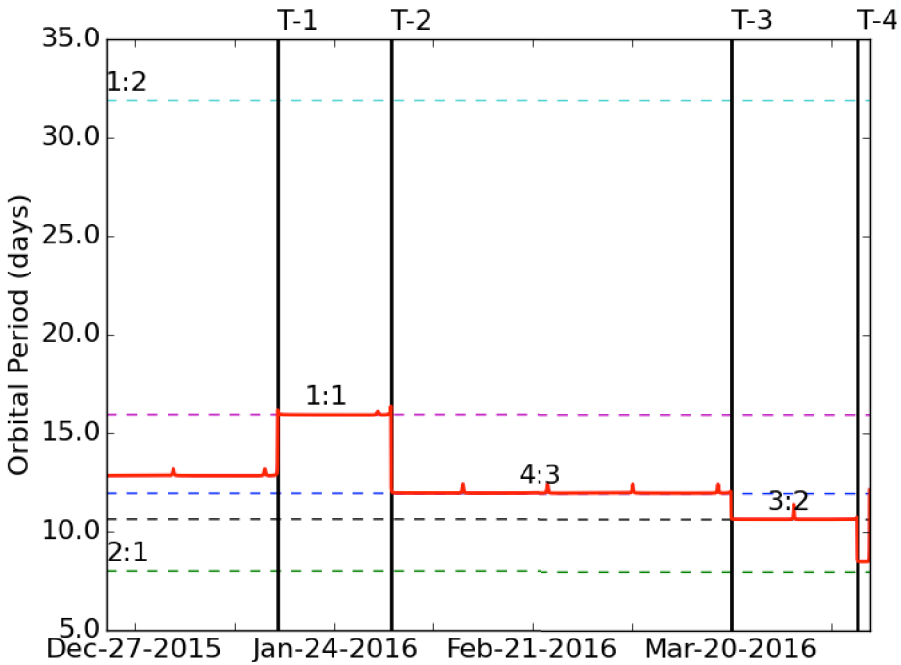
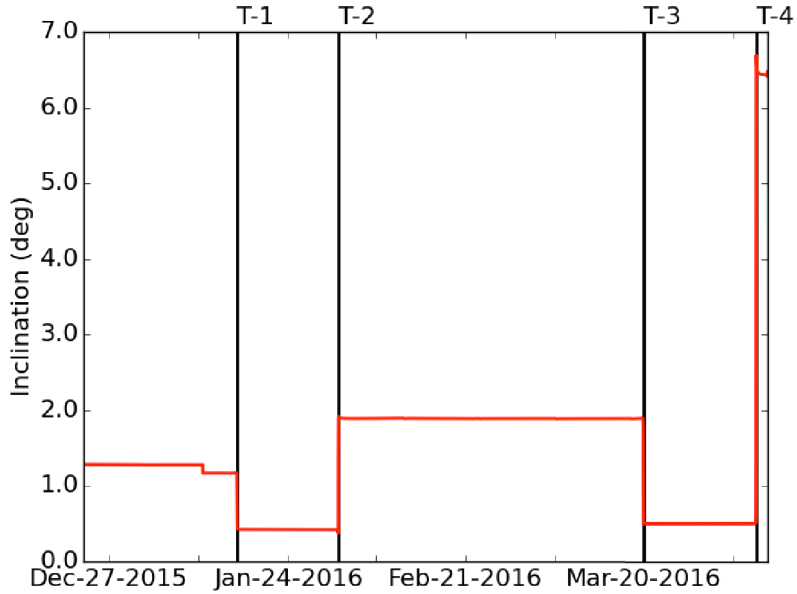
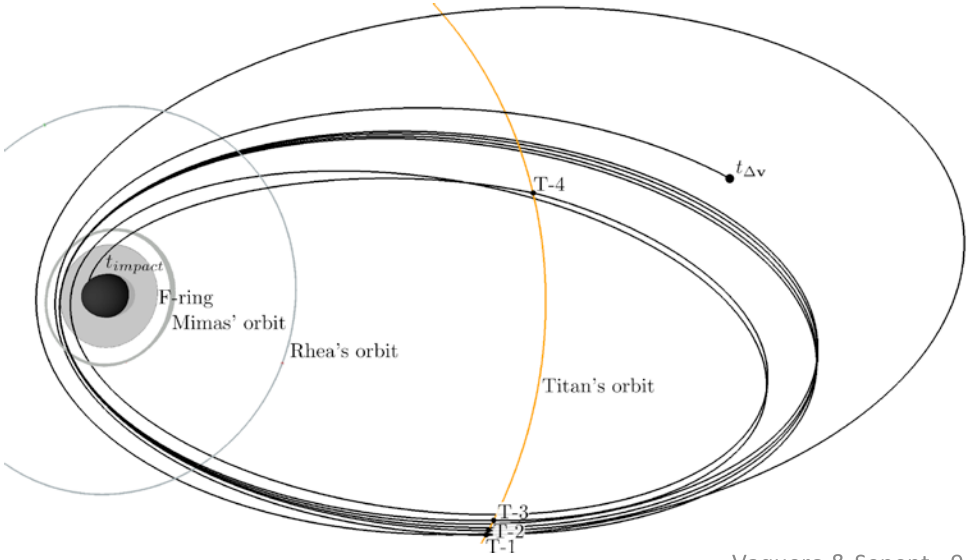




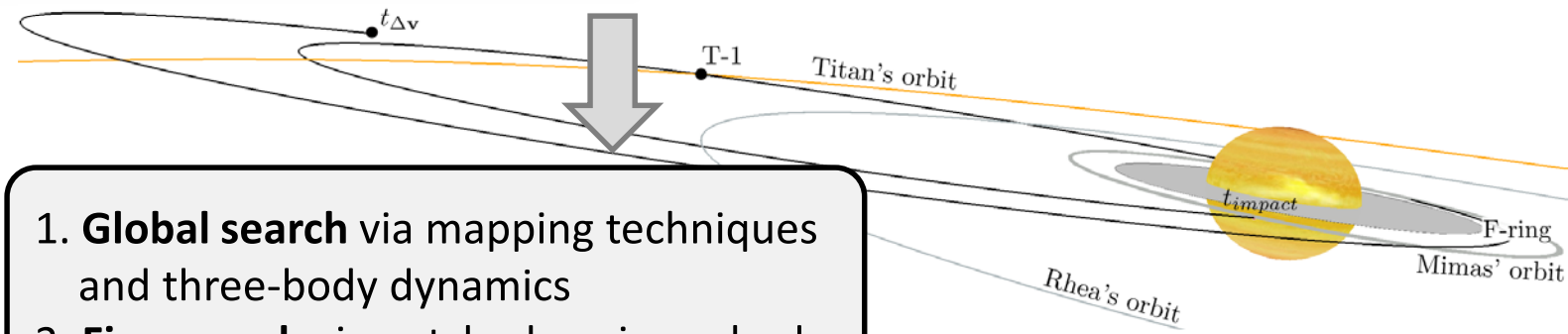




Summary of Findings

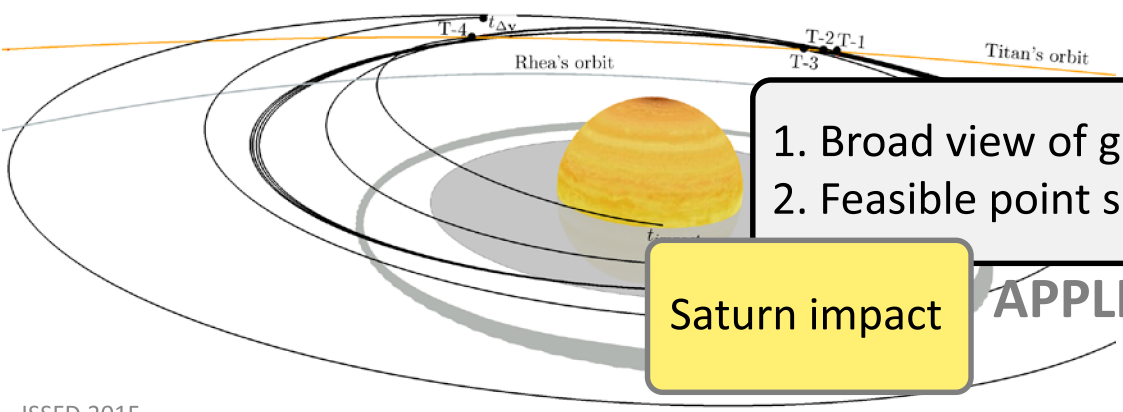
Development of a robust method to quickly produce flyable end-of-mission trajectories in an emergency situation

OBJECTIVE



1. **Global search** via mapping techniques and three-body dynamics
2. **Fine search** via patched conics, n-body dynamics and optimization techniques

DESIGN PROCESS



Mimas impact

1. Broad view of global solution space
2. Feasible point solutions that satisfy all constraints

Saturn impact

APPLICATION TO CASSINI MISSION

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