Caso02

October 29, 2025

1 Evaluación del caso "Sitnikov modificado con control de periodicidad"

Este notebook estudia una variante del problema de Sitnikov: dos estrellas de masas similares orbitan en el plano XY y un tercer cuerpo ligero se mueve a lo largo del eje Z. Ajustamos las masas mediante el pipeline híbrido (GA + refinamiento continuo) para buscar órbitas casi periódicas y con menor sensibilidad caótica medida mediante el exponente de Lyapunov.

> **Interpretación** - La penalización `periodicity_weight` fuerza que el estado final se acerque al inicial; un valor pequeño del fitness implica trayectoria casi repetitiva. - Comparar   del centro del rango de masas contra el   optimizado permite medir cuánto se estabiliza la dinámica vertical del tercer cuerpo.

1.1 Preparación del entorno

Normalizamos la ruta raíz del proyecto y la insertamos en `sys.path` para que los imports funcionen sin importar desde qué carpeta se lance el notebook.

[1]:
```python
import sys
from pathlib import Path

PROJECT_ROOT = Path.cwd().resolve()
while PROJECT_ROOT.name != "two_body" and PROJECT_ROOT.parent != PROJECT_ROOT:
    PROJECT_ROOT = PROJECT_ROOT.parent

if PROJECT_ROOT.name != "two_body":
    raise RuntimeError("No se encontró la carpeta two_body")

PARENT = PROJECT_ROOT.parent  # directorio que contiene a two_body
if str(PARENT) not in sys.path:
    sys.path.insert(0, str(PARENT))

print("PYTHONPATH += ", PARENT)
```

```
PYTHONPATH +=
C:\Users\emicr\Documents\CODIGOS_FUENTES\TrabajoTerminal\collision_of_two_bodies
```

1.2 Dependencias y utilidades clave

Cargamos los componentes fundamentales del flujo: - `Config` y utilidades de seeding para reproducibilidad. - El `ContinuousOptimizationController`, visualizadores 2D/3D y el adaptador REBOUND base. - `numpy` y `pathlib` para manejar resultados y artefactos en disco.

[ ]:
```
from two_body import Config, set_global_seeds
from two_body.core.telemetry import setup_logger
from two_body.logic.controller import ContinuousOptimizationController
from two_body.presentation.visualization import Visualizer as PlanarVisualizer
from two_body.presentation.triDTry import Visualizer as Visualizer3D
from two_body.simulation.rebound_adapter import ReboundSim
import numpy as np
from pathlib import Path
```

1.3 Instrumentación de rendimiento

Activamos trazas de tiempo a nivel de bloque (`time_block`) y preparamos utilidades para recuperar los CSV agregados. Esto permite auditar el costo de cada fase del pipeline directamente desde el notebook.

[3]:
```
import os
os.environ["PERF_TIMINGS_ENABLED"] = "1"
os.environ.setdefault("PERF_TIMINGS_JSONL", "0")

from two_body.perf_timings.timers import time_block
from two_body.perf_timings import latest_timing_csv, read_timings_csv,␣
 ↪parse_sections_arg, filter_rows
```

1.4 Formato de logging para el notebook

Registramos un `logging.Handler` personalizado que acumula los mensajes y los muestra con `display(Markdown(...))`, manteniendo limpio el flujo de salida mientras corren las generaciones del GA.

[4]:
```
import logging
from IPython.display import display, Markdown

class NotebookHandler(logging.Handler):
    def __init__(self):
        super().__init__()
        self.lines = []

    def emit(self, record):
        msg = self.format(record)
        self.lines.append(msg)
        print(msg)  # aparece en la celda conforme avanza

handler = NotebookHandler()
```

```
handler.setFormatter(logging.Formatter("[%(asctime)s] %(levelname)s -␣
↪%(message)s"))

logger = setup_logger(level="DEBUG")
logger.handlers.clear()          # quita otros handlers previos
logger.addHandler(handler)
logger.setLevel(logging.DEBUG)
```

1.5 Configuración del escenario "Sitnikov modificado"

Definimos el diccionario `case` con: - Integración a largo plazo (`t_end_long = 6000`, `dt = 0.08`) usando `whfast`. - Condiciones iniciales simétricas para el binario y un tercer cuerpo con desplazamiento ligero en Y/Z. - Límites estrechos para las masas estelares y un rango reducido para el tercer cuerpo. - Penalización de periodicidad (`periodicity_weight = 0.08`) y presupuesto de evaluación amplio para que el GA explore soluciones estables.

[5]:
```
case = {
    # Integración
    "t_end_short": 600.0,
    "t_end_long": 6000.0,
    "dt": 0.08,
    "integrator": "whfast",

    # Condiciones iniciales (Sitnikov modificado)
    "r0": (
        (-1.2, 0.0, 0.0),
        (1.2, 0.0, 0.0),
        (0.0, 0.1, 0.0),
    ),
    "v0": (
        (0.0, -0.32, 0.0),
        (0.0, 0.32, 0.0),
        (0.0, 0.55, 0.0),
    ),

    # Parámetros físicos
    "mass_bounds": (
        (0.48, 0.55),    # estrella 1
        (0.48, 0.55),    # estrella 2
        (5e-3, 1.5e-2),  # tercer cuerpo, rango acotado
    ),
    "G": 1.0,
    "periodicity_weight": 0.08,   # penaliza la deriva entre estado inicial y␣
↪final

    # GA / búsqueda continua
    "pop_size": 150,
```

```
    "n_gen_step": 1,
    "crossover": 0.85,
    "mutation": 0.06,
    "elitism": 1,
    "seed": 1234,

    # Control de ejecución
    "max_epochs": 12,
    "top_k_long": 10,
    "stagnation_window": 6,
    "stagnation_tol": 5e-4,
    "local_radius": 0.05,
    "radius_decay": 0.85,
    "time_budget_s": 1800.0,
    "eval_budget": 60000,

    # Artefactos / salida
    "artifacts_dir": "artifacts/sitnikov_opt",
    "save_plots": True,
    "headless": False,
}
```

[6]:
```
from two_body.logic.controller import ContinuousOptimizationController
from two_body.core.config import Config
from two_body.core.telemetry import setup_logger
from two_body.core.cache import HierarchicalCache

cfg = Config(**case)
logger = setup_logger()
```

1.6 Adaptador especializado de REBOUND

Subclasamos `ReboundSim` para imponer la restricción de Sitnikov: tras cada paso, fijamos `x = vx = 0` del tercer cuerpo de modo que la partícula se mantenga sobre el eje Z. Mediante un monkeypatch temporal logramos que el `FitnessEvaluator` utilice este integrador personalizado durante todo el experimento.

[7]:
```
import rebound

class SitnikovReboundSim(ReboundSim):
    def setup_simulation(self, *args, **kwargs):
        sim = super().setup_simulation(*args, **kwargs)

        def clamp(_sim_ptr=None):
            if len(sim.particles) > 2:
                particle = sim.particles[2]
                particle.x = 0.0
```

```python
                particle.vx = 0.0

        sim.post_timestep_modifications = clamp
        return sim

# Monkeypatch para que FitnessEvaluator use el adaptador sitnikov
from two_body.simulation import rebound_adapter
rebound_adapter.ReboundSim = SitnikovReboundSim
```

```
c:\Users\emicr\anaconda3\envs\grav2body\Lib\site-
packages\rebound\__init__.py:58: UserWarning: pkg_resources is deprecated as an
API. See https://setuptools.pypa.io/en/latest/pkg_resources.html. The
pkg_resources package is slated for removal as early as 2025-11-30. Refrain from
using this package or pin to Setuptools<81.
  import pkg_resources
```

[8]:
```python
print(cfg.mass_bounds, cfg.max_epochs, cfg.eval_budget)
```

```
((0.48, 0.55), (0.48, 0.55), (0.005, 0.015)) 12 60000
```

1.7 Ejecución del controlador híbrido

Creamos la configuración, el `logger` y el `ContinuousOptimizationController`. Usamos `time_block("notebook_run")` para medir la ejecución completa (GA + refinamiento), registramos los eventos relevantes y recopilamos el mejor individuo encontrado.

[9]:
```python
with time_block("notebook_run", extra={"source": "Caso01.ipynb"}):
    controller = ContinuousOptimizationController(cfg, logger=logger)
    results = controller.run()
```

```
[2025-10-29 00:08:17,249] INFO - Starting optimization | pop=150 | dims=3 |
time_budget=1800.0s | eval_budget=60000
[2025-10-29 00:08:35,320] INFO - Epoch 0 | new global best (short)
lambda=0.000552 | fitness=-299.518313 | penalty=3743.972014 | masses=(0.547512,
0.481192, 0.011766)
```

```
c:\Users\emicr\anaconda3\envs\grav2body\Lib\site-
packages\pymoo\termination\ftol.py:27: RuntimeWarning: invalid value encountered
in scalar subtract
  return max(0, prev - current)
```

```
[2025-10-29 00:08:47,604] INFO - Epoch 0 complete | lambda_short=0.000552 |
fitness_short=-299.518313 | lambda_best=0.000552 | fitness_best=-299.518313 |
evals short/long=150/10 | total evals=160 | radius=0.0500
[2025-10-29 00:09:06,916] INFO - Epoch 1 | new global best (short)
lambda=0.000553 | fitness=-298.433754 | penalty=3730.415018 | masses=(0.548833,
0.482667, 0.005301)
[2025-10-29 00:09:19,012] INFO - Epoch 1 complete | lambda_short=0.000553 |
fitness_short=-298.433754 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=320 | radius=0.0500
```

```
[2025-10-29 00:09:48,400] INFO - Epoch 2 complete | lambda_short=0.000557 |
fitness_short=-399.688160 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=480 | radius=0.0500
[2025-10-29 00:10:16,413] INFO - Epoch 3 complete | lambda_short=0.000560 |
fitness_short=-531.284020 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=640 | radius=0.0500
[2025-10-29 00:10:46,061] INFO - Epoch 4 complete | lambda_short=0.000562 |
fitness_short=-1125.426150 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=800 | radius=0.0500
[2025-10-29 00:11:14,091] INFO - Epoch 5 complete | lambda_short=0.000562 |
fitness_short=-2931.357039 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=960 | radius=0.0500
[2025-10-29 00:11:41,766] INFO - Epoch 6 complete | lambda_short=0.000562 |
fitness_short=-2935.231342 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=1120 | radius=0.0500
[2025-10-29 00:12:08,367] INFO - Stagnation detected; reseeding around best
candidate.
[2025-10-29 00:12:08,367] INFO - Epoch 7 complete | lambda_short=0.000562 |
fitness_short=-5172.724446 | lambda_best=0.000553 | fitness_best=-298.433754 |
evals short/long=150/10 | total evals=1280 | radius=0.0425
[2025-10-29 00:12:22,279] INFO - Epoch 8 | new global best (short)
lambda=0.000548 | fitness=-249.857500 | penalty=3123.211891 | masses=(0.55,
0.48, 0.005)
[2025-10-29 00:12:23,403] INFO - Epoch 8 complete | lambda_short=0.000548 |
fitness_short=-249.857500 | lambda_best=0.000548 | fitness_best=-249.857500 |
evals short/long=150/10 | total evals=1440 | radius=0.0425
[2025-10-29 00:12:37,265] INFO - Epoch 9 complete | lambda_short=0.000548 |
fitness_short=-249.857500 | lambda_best=0.000548 | fitness_best=-249.857500 |
evals short/long=150/10 | total evals=1600 | radius=0.0425
[2025-10-29 00:12:51,577] INFO - Epoch 10 complete | lambda_short=0.000548 |
fitness_short=-249.857500 | lambda_best=0.000548 | fitness_best=-249.857500 |
evals short/long=150/10 | total evals=1760 | radius=0.0425
[2025-10-29 00:13:05,059] INFO - Epoch 11 complete | lambda_short=0.000548 |
fitness_short=-249.857500 | lambda_best=0.000548 | fitness_best=-249.857500 |
evals short/long=150/10 | total evals=1920 | radius=0.0425
[2025-10-29 00:13:05,059] INFO - Optimization completed | epochs=12 | evals=1920
| best lambda=0.000548 | wall=287.8s
```

1.8 Métricas de referencia y resultado óptimo

Calculamos el fitness del centro de los intervalos (`center`) como línea base y lo comparamos con la solución óptima (`results["best"]`). También recuperamos `metrics` para inspeccionar la evolución de por época y cualquier otra estadística almacenada por el controlador.

[10]:
```
metrics = controller.metrics
results
```

[10]:
```
{'status': 'completed',
 'best': {'masses': [0.55, 0.48, 0.005],
  'lambda': 0.000548244429386521,
  'fitness': -249.85749952249697,
  'm1': 0.55,
  'm2': 0.48,
  'm3': 0.005},
 'evals': 1920,
 'epochs': 12}
```

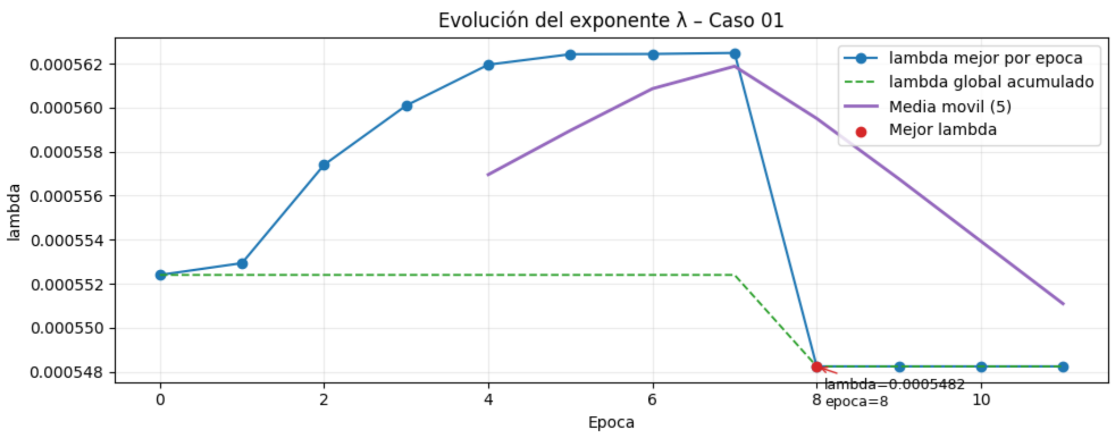
1.9 Seguimiento de y reconstrucción de trayectorias

Visualizamos: - La secuencia `metrics.best_lambda_per_epoch` y, opcionalmente, un suavizado para detectar tendencias. - Las trayectorias 3D integradas con las masas óptimas (`viz_3d.animate_3d`) y cualquier proyección 2D rápida (`viz_planar.quick_view`) para confirmar la estabilidad obtenida.

[11]:
```python
from two_body.logic.fitness import FitnessEvaluator
from two_body.core.cache import HierarchicalCache
from two_body.simulation.rebound_adapter import ReboundSim

cache = HierarchicalCache()
evaluator = FitnessEvaluator(cache, cfg)

center = tuple((lo + hi) / 2.0 for lo, hi in cfg.mass_bounds)
baseline = evaluator.evaluate_batch([center], horizon="long")[0]
best_fit = results["best"]["fitness"]

print(f" inicial = {-baseline:.6f},  óptimo = {-best_fit:.6f}")
```

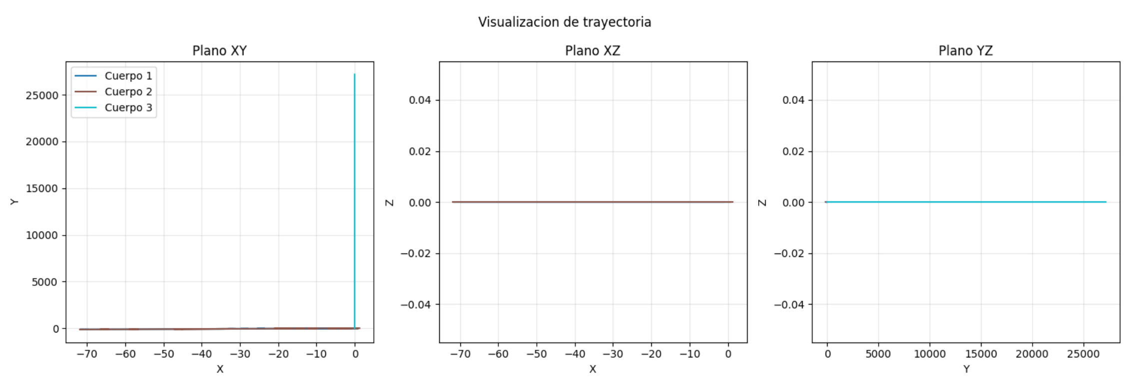
```
 inicial = inf,  óptimo = 249.857500
```

[12]:
```python
viz_3d = Visualizer3D(headless=cfg.headless)

_ = viz_3d.plot_lambda_evolution(
    lambda_history=metrics.best_lambda_per_epoch,
    epoch_history=metrics.epoch_history,
    title="Evolución del exponente  - Caso 01",
    moving_average_window=5,   # opcional
)
```



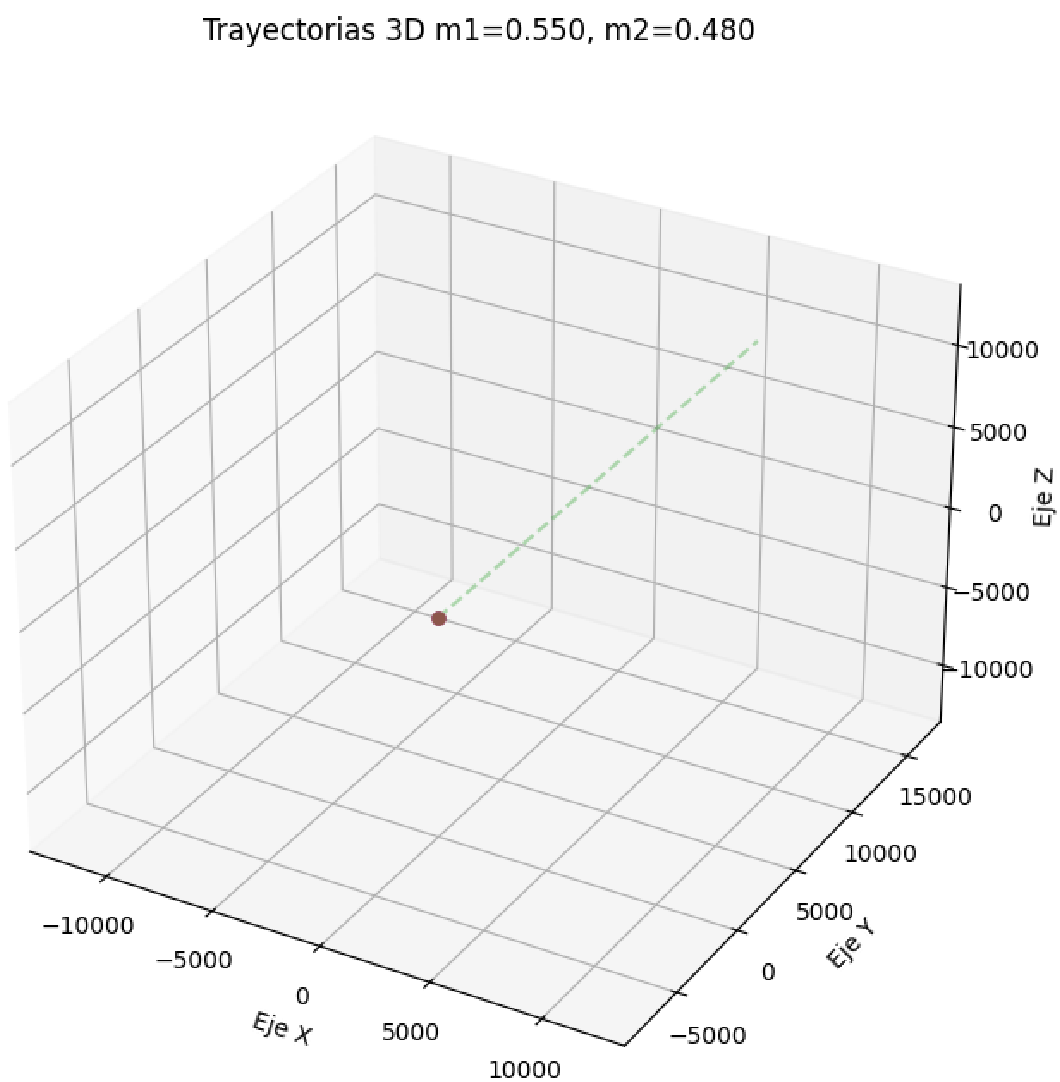
[13]:
```
sim_builder = ReboundSim(G=cfg.G, integrator=cfg.integrator)
best_masses = tuple(results["best"]["masses"])

def _slice_vectors(vectors, count):
    if len(vectors) < count:
        raise ValueError("Config no tiene suficientes vectores iniciales")
    return tuple(tuple(float(coord) for coord in vectors[i]) for i in␣
 ↪range(count))

r0 = _slice_vectors(cfg.r0, len(best_masses))
v0 = _slice_vectors(cfg.v0, len(best_masses))

sim = sim_builder.setup_simulation(best_masses, r0, v0)
traj = sim_builder.integrate(sim, t_end=cfg.t_end_long, dt=cfg.dt)
xyz_tracks = [traj[:, i, :3] for i in range(traj.shape[1])]
```

[14]:
```
viz_planar = PlanarVisualizer(headless=cfg.headless)
_ = viz_planar.quick_view(xyz_tracks)
```



[15]:
```
from IPython.display import HTML

import matplotlib as mpl
mpl.rcParams['animation.embed_limit'] = 1024  # MB
```

[17]:
```
viz_3d = Visualizer3D(headless=False)

anim = viz_3d.animate_3d(
    trajectories=xyz_tracks,
    interval_ms=50,
    title=f"Trayectorias 3D m1={best_masses[0]:.3f}, m2={best_masses[1]:.3f}",
    total_frames=len(xyz_tracks[0]),
)
#HTML(anim.to_jshtml())
```



1.10 Exportación de animaciones

Configuramos un `FFMpegWriter`, nos aseguramos de que el directorio `artifacts/caso02` exista y persistimos los MP4 de la trayectoria final y de la comparación de masas. Ajusta `fps`, `bitrate` o el preset de ffmpeg si necesitas reducir el tiempo de render.

[18]:
```python
from matplotlib.animation import FFMpegWriter  # o PillowWriter para GIF

writer = FFMpegWriter(fps=1000 // 50, bitrate=2400)   # fps = 1000/interval_ms
output_path = Path("artifacts/caso02")                # ajusta a tu gusto
output_path.mkdir(parents=True, exist_ok=True)

anim.save(output_path / "trayectoria_optima.mp4", writer=writer)
```

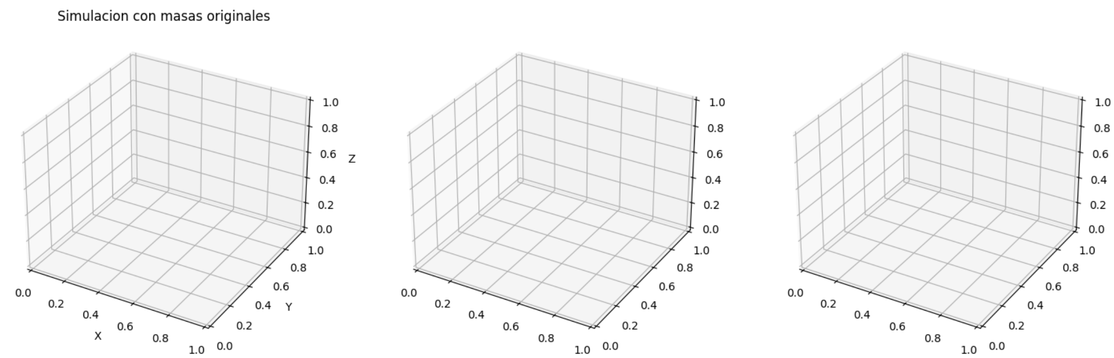
[19]:
```python
anim_mass = viz_3d.plot_mass_comparison(
    original_masses=center,
    optimized_masses=best_masses,
    body_labels=[f"Cuerpo {i+1}" for i in range(len(best_masses))],
    title="Comparativa de masas (Caso 01)",
)
#HTML(anim_mass.to_jshtml())
```

```
c:\Users\emicr\anaconda3\envs\grav2body\Lib\site-
packages\rebound\simulation.py:259: RuntimeWarning: WHFast convergence issue.
Timestep is larger than at least one orbital period.
  warnings.warn(msg[1:], RuntimeWarning)
```

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
Cell In[19], line 1
----> 1 anim_mass = viz_3d.plot_mass_comparison(
      2     original_masses=center,
      3     optimized_masses=best_masses,
      4     body_labels=[f"Cuerpo {i+1}" for i in range(len(best_masses))],
      5     title="Comparativa de masas (Caso 01)",
      6 )
      7 #HTML(anim_mass.to_jshtml())

File ␣
  ↪~\Documents\CODIGOS_FUENTES\TrabajoTerminal\collision_of_two_bodies\two_body\presentation\
  ↪py:642, in Visualizer.plot_mass_comparison(self, original_masses,␣
  ↪optimized_masses, body_labels, title, t_end, dt, interval_ms, trail_length,␣
  ↪total_frames, r0, v0)
    639         ax.set_box_aspect([1, 1, 1])
    641 for ax, subtitle in zip(axes, subtitles):
--> 642     _configure_axis(ax, subtitle)
    644 trail = max(1, int(trail_length))
```

```
    646 def _setup_artists(ax: Any, alpha_line: float, alpha_point: float,␣
↪linestyle: str = "-"):

File␣
↪~\Documents\CODIGOS_FUENTES\TrabajoTerminal\collision_of_two_bodies\two_body\presentation\t
↪py:635, in Visualizer.plot_mass_comparison.<locals>._configure_axis(ax,␣
↪subtitle)
    633 ax.set_zlabel("Z")
    634 ax.grid(True, alpha=0.2)
--> 635 ax.set_xlim(centers[0] - max_range, centers[0] + max_range)
    636 ax.set_ylim(centers[1] - max_range, centers[1] + max_range)
    637 ax.set_zlim(centers[2] - max_range, centers[2] + max_range)

File c:
↪\Users\emicr\anaconda3\envs\grav2body\Lib\site-packages\mpl_toolkits\mplot3d\axes3d.
↪py:869, in Axes3D.set_xlim(self, left, right, emit, auto, view_margin, xmin,␣
↪xmax)
    800 def set_xlim(self, left=None, right=None, *, emit=True, auto=False,
    801              view_margin=None, xmin=None, xmax=None):
    802     """
    803     Set the 3D x-axis view limits.
    804 
   (…)
    867     >>> set_xlim(5000, 0)
    868     """
--> 869     return self._set_lim3d(self.xaxis, left, right, emit=emit, auto=auto,
    870␣
↪                           view_margin=view_margin, axmin=xmin, axmax=xmax)

File c:
↪\Users\emicr\anaconda3\envs\grav2body\Lib\site-packages\mpl_toolkits\mplot3d\axes3d.
↪py:798, in Axes3D._set_lim3d(self, axis, lower, upper, emit, auto,␣
↪view_margin, axmin, axmax)
    796 lower -= delta
    797 upper += delta
--> 798 return axis._set_lim(lower, upper, emit=emit, auto=auto)

File c:\Users\emicr\anaconda3\envs\grav2body\Lib\site-packages\matplotlib\axis.
↪py:1216, in Axis._set_lim(self, v0, v1, emit, auto)
   1213 name = self._get_axis_name()
   1215 self.axes._process_unit_info([(name, (v0, v1))], convert=False)
-> 1216 v0 = self.axes._validate_converted_limits(v0, self.convert_units)
   1217 v1 = self.axes._validate_converted_limits(v1, self.convert_units)
   1219 if v0 is None or v1 is None:
   1220     # Axes init calls set_xlim(0, 1) before get_xlim() can be called,
   1221     # so only grab the limits if we really need them.
```

```
File c:
↪\Users\emicr\anaconda3\envs\grav2body\Lib\site-packages\matplotlib\axes\_base
↪py:3739, in _AxesBase._validate_converted_limits(self, limit, convert)
   3736     converted_limit = converted_limit.squeeze()
   3737 if (isinstance(converted_limit, Real)
   3738         and not np.isfinite(converted_limit)):
-> 3739     raise ValueError("Axis limits cannot be NaN or Inf")
   3740 return converted_limit

ValueError: Axis limits cannot be NaN or Inf
```




```
[ ]: anim_mass.save(output_path / "comparativa_masas.mp4", writer=writer)
```

1.11 Reporte de tiempos

Leemos el CSV más reciente generado por la instrumentación, mostramos las primeras filas y podemos agregar estadísticas por sección para identificar cuellos de botella del pipeline en este escenario.

```
[22]: import pandas as pd

csv_path = latest_timing_csv()
display(f"Usando CSV: {csv_path}")

rows = read_timings_csv(csv_path)
df = pd.DataFrame(rows)
display(df.head(10))

# Estadísticas rápidas por sección
section_stats = (
    df.groupby("section")["duration_us"]
    .agg(["count", "mean", "sum"])
    .sort_values("sum", ascending=False)
)
```

```
section_stats
```

```
'Usando CSV: C:
↪\\Users\\emicr\\Documents\\CODIGOS_FUENTES\\TrabajoTerminal\\collision_of_two_bodies\\two_bo
↪csv'

                                 run_id  epoch  batch_id  individual_id  \
0  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
1  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
2  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
3  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
4  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
5  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
6  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
7  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
8  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1
9  410c61c6-2269-43f3-b56e-21b33937096b     -1        -1             -1

           section        start_ns          end_ns  duration_us  \
0  simulation_step  23344070622800  23344070691700           68
1  simulation_step  23344070727400  23344070752600           25
2  simulation_step  23344070767900  23344070800400           32
3  simulation_step  23344070812700  23344070835600           22
4  simulation_step  23344070843800  23344070868000           24
5  simulation_step  23344070876300  23344070907100           30
6  simulation_step  23344070914800  23344071017100          102
7  simulation_step  23344071024300  23344072015300          991
8  simulation_step  23344072024300  23344072438300          414
9  simulation_step  23344072446700  23344072541000           94

                                             extra
0           {'step': 0, 'dt': 0.1, 't_target': 0.1}
1           {'step': 1, 'dt': 0.1, 't_target': 0.2}
2  {'step': 2, 'dt': 0.1, 't_target': 0.300000000…
3           {'step': 3, 'dt': 0.1, 't_target': 0.4}
4           {'step': 4, 'dt': 0.1, 't_target': 0.5}
5  {'step': 5, 'dt': 0.1, 't_target': 0.600000000…
6  {'step': 6, 'dt': 0.1, 't_target': 0.700000000…
7           {'step': 7, 'dt': 0.1, 't_target': 0.8}
8           {'step': 8, 'dt': 0.1, 't_target': 0.9}
9           {'step': 9, 'dt': 0.1, 't_target': 1.0}
```

[22]:

section	count	mean	sum
batch_eval	81	2.563310e+07	2076281003
fitness_eval	4481	4.633180e+05	2076127746
lyapunov_compute	3833	5.414733e+05	2075466980
notebook_run	1	2.074689e+09	2074688739

```
simulation_step       10396975  1.846217e+02  1919506905
ga_main                     40  2.688555e+04     1075422
crossover                  607  4.878023e+02      296096
selection_tournament       607  1.949127e+02      118312
mutation                   607  1.720148e+02      104413
```

[ ]:
```
import os
import subprocess
from pathlib import Path
from IPython.display import Image, display

PROJECT_ROOT = Path.cwd()
while PROJECT_ROOT.name != "two_body" and PROJECT_ROOT.parent != PROJECT_ROOT:
    PROJECT_ROOT = PROJECT_ROOT.parent

env = os.environ.copy()
env["PYTHONPATH"] = str(PROJECT_ROOT)

run_id = df["run_id"].iloc[0]
cmd = [
    sys.executable,
    "scripts/plot_timings.py",
    "--run-id", str(run_id),
    "--top-n", "5",
]


print("Ejecutando:", " ".join(cmd))
result = subprocess.run(cmd, cwd=PROJECT_ROOT, env=env, text=True,
  capture_output=True)
print(result.stdout)
print(result.stderr)
result.check_returncode()

reports_dir = PROJECT_ROOT / "reports"
```

```
Ejecutando: c:\Users\emicr\anaconda3\envs\grav2body\python.exe
scripts/plot_timings.py --run-id 410c61c6-2269-43f3-b56e-21b33937096b --top-n 5
```

[ ]:
```
display(
    Image(filename=str(reports_dir / f"timeline_by_individual_{run_id}.png")),
    Image(filename=str(reports_dir / f"timeline_by_batch_{run_id}.png")),
    Image(filename=str(reports_dir / f"timeline_simulation_{run_id}.png")),
    Image(filename=str(reports_dir / f"pie_sections_{run_id}.png")),
)
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
```

```
Cell In[20], line 2
      1 display(
----> 2     Image(filename=str(reports_dir / f"timeline_by_individual_{run_id}.
 ↪png")),
      3     Image(filename=str(reports_dir / f"timeline_by_batch_{run_id}.png")),
      4     Image(filename=str(reports_dir / f"timeline_simulation_{run_id}.
 ↪png")),
      5     Image(filename=str(reports_dir / f"pie_sections_{run_id}.png")),
      6 )

NameError: name 'Image' is not defined
```