

Caso04

November 10, 2025

1 Evaluación del caso “Trío no colineal con planeta errante”

Exploramos un sistema de tres cuerpos inicialmente no colineales: dos estrellas masivas y un planeta errante que parte con desplazamiento lateral. Buscamos combinaciones de masa que reduzcan la sensibilidad caótica y mantengan la órbita del planeta dentro de un lazo estable durante integraciones largas.

Interpretación - Un reducido indica que el planeta soporta mejor las perturbaciones y permanece ligado al sistema. - La penalización de periodicidad ayuda a mantener la topología orbital tras miles de unidades de tiempo, evitando salidas balísticas.

1.1 Preparación del entorno

Localizamos la carpeta raíz `two_body`, la añadimos a `sys.path` y exponemos `PARENT` para reutilizar módulos comunes del repositorio. Garantizamos que los imports funcionen sin importar la ruta desde la que se ejecute el notebook.

```
[1]: 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 principales

Importamos los componentes clave del pipeline: - `Config` y utilidades de seeding. - El controlador híbrido (GA + refinamiento). - Herramientas de visualización y simulación `REBOUND`. - `numpy`

para cualquier análisis adicional.

```
[ ]: 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 las variables de entorno de la suite de timings y cargamos `time_block`, `latest_timing_csv`, etc. Esto nos permitirá auditar qué tan costosa es cada fase (integración short/long, refinamiento continuo, métricas).

```
[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 Logging amigable para notebooks

Definimos un `NotebookHandler` que acumula los mensajes del optimizador y los muestra en vivo dentro de la celda. Mantiene la salida legible mientras corren las generaciones y el refinamiento continuo.

```
[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)

      handler = NotebookHandler()
      handler.setFormatter(logging.Formatter("%(asctime)s %(levelname)s -□
          %(message)s"))
```

```

logger = setup_logger(level="INFO")
logger.handlers.clear()
logger.addHandler(handler)
logger.setLevel(logging.INFO)

```

1.5 Configuración del escenario “Trío no colineal” físico

Trabajamos con unidades astronómicas (UA, años, masas solares): - Binaria compacta $\sim 1.05/0.75$ Msun separada 0.7 UA. - Intruso tipo planeta/enano marrón que cruza el plano con fuerte componente tangencial. - Presupuestos moderados del GA para barridos rápidos.

```

[ ]: # Tres cuerpos caótico (unidades físicas)
case = {
    # Integración (UA, años, masas solares)
    "t_end_short": 0.6,
    "t_end_long": 3.5,
    "dt": 2.0e-4,
    "integrator": "ias15",

    # Condiciones iniciales: binaria compacta + intruso
    "r0": (
        (-0.2916667, 0.0, 0.0),      # estrella primaria
        (0.4083333, 0.0, 0.0),      # estrella secundaria
        (0.0, 1.8, 0.0),            # intruso (planeta/brown dwarf)
    ),
    "v0": (
        (0.0, -4.19812977, 0.0),    # velocidad orbital de la primaria
        (0.0, 5.87738168, 0.0),    # velocidad orbital de la secundaria
        (-3.2, 0.0, 0.0),          # intruso con trayectoria rasante
    ),

    # Rangos de masa físicos pero amplios (fomenta caos)
    "mass_bounds": (
        (1.00, 1.50),
        (0.5, 1.0),
        (5e-5, 5e-1),
    ),
    "G": 39.47841760435743,
    "periodicity_weight": 0.02,

    # GA / búsqueda continua
    "pop_size": 180,
    "n_gen_step": 5,
    "crossover": 0.85,
    "mutation": 0.20,
    "elitism": 2,
    "seed": 98765,
}

```

```

# Control de ejecución (rápido pero con margen)
"max_epochs": 50,
"top_k_long": 12,
"stagnation_window": 5,
"stagnation_tol": 1.25e-4,
"local_radius": 0.04,
"radius_decay": 0.85,
"time_budget_s": 1800.0,
"eval_budget": 16000,

# Artefactos / salida
"artifacts_dir": "artifacts/caso04_caotico",
"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)
set_global_seeds(cfg.seed)
logger = setup_logger()
```

1.6 Validación rápida del estimador de Lyapunov

Antes de lanzar el controlador, construimos una simulación con las masas promedio y ejecutamos `LyapunovEstimator.mLCE`. Esto sirve como smoke test para confirmar que el integrador produce trayectorias razonables y que el cálculo de `responde` al nuevo escenario.

```
[7]: from two_body.simulation.rebound_adapter import ReboundSim
from two_body.simulation.lyapunov import LyapunovEstimator

masses = tuple(np.mean(bounds) for bounds in cfg.mass_bounds)
sim = ReboundSim(G=cfg.G, integrator=cfg.integrator).setup_simulation(
    masses, cfg.r0[:len(masses)], cfg.v0[:len(masses)])
estimator = LyapunovEstimator()
ret = estimator.mLCE({"sim": sim, "dt": cfg.dt, "t_end": cfg.t_end_short,
    "masses": masses})
print(ret)
```

```
{'lambda': -2.805939681704063, 'series': None, 'meta': {'steps': 3000, 'dt': 0.0002, 'n_bodies': 3, 'masses': (1.25, 0.75, 0.250025), 'impl': 'rebound_megno'}}
```

```
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
```

1.7 Recarga del evaluador de fitness

Si se modificó `two_body.logic.fitness`, recargamos el módulo con `importlib.reload` y reiniciamos `setup_logger`. Así garantizamos que el notebook utilice la versión fresca del evaluador antes de iniciar la optimización.

```
[ ]: import logging
      import importlib

      from two_body.core.telemetry import setup_logger
      import two_body.logic.fitness as fitness_mod

      logger = setup_logger(level="INFO")           # asegura nivel INFO
      logger.setLevel(logging.INFO)
      for handler in logger.handlers:
          handler.setLevel(logging.INFO)
```

1.8 Ejecución del controlador híbrido

Instanciamos `Config`, el `logger` y `ContinuousOptimizationController`, y envolvemos `controller.run()` dentro de `time_block("notebook_run")` para medir la ejecución total (GA + refinamiento continuo) sobre el sistema no colineal.

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

```
((1.0, 1.5), (0.5, 1.0), (5e-05, 0.5)) 50 16000
```

```
[10]: with time_block("notebook_run", extra={"source": "Caso04.ipynb"}):
        controller = ContinuousOptimizationController(cfg, logger=logger)
        results = controller.run()
```

```
[2025-11-02 18:03:26,843] INFO - Starting optimization | pop=180 | dims=3 |
time_budget=1800.0s | eval_budget=16000
[2025-11-02 18:03:42,588] INFO - Epoch 0 | new global best (short)
lambda=-5.242842 | fitness=4.406297 | penalty=41.827273 | masses=(1.319555,
0.57681, 0.269317)
[2025-11-02 18:03:49,934] INFO - Epoch 0 complete | lambda_short=-5.242842 |
fitness_short=4.406297 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=192 | radius=0.0400
[2025-11-02 18:04:13,818] INFO - Epoch 1 complete | lambda_short=0.718596 |
fitness_short=-1.309171 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=384 | radius=0.0400
[2025-11-02 18:04:37,285] INFO - Epoch 2 complete | lambda_short=0.379757 |
```

```
fitness_short=-0.893305 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=576 | radius=0.0400
[2025-11-02 18:05:00,950] INFO - Epoch 3 complete | lambda_short=-1.257952 |
fitness_short=0.883234 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=768 | radius=0.0400
[2025-11-02 18:05:24,821] INFO - Epoch 4 complete | lambda_short=3.470348 |
fitness_short=-3.884954 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=960 | radius=0.0400
[2025-11-02 18:05:48,141] INFO - Stagnation detected; reseeding around best
candidate.
[2025-11-02 18:05:48,142] INFO - Epoch 5 complete | lambda_short=3.636562 |
fitness_short=-4.176819 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=1152 | radius=0.0340
[2025-11-02 18:06:11,086] INFO - Epoch 6 complete | lambda_short=-1.094959 |
fitness_short=0.139358 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=1344 | radius=0.0340
[2025-11-02 18:06:34,228] INFO - Epoch 7 complete | lambda_short=-2.147810 |
fitness_short=1.545542 | lambda_best=-5.242842 | fitness_best=4.406297 | evals
short/long=180/12 | total evals=1536 | radius=0.0340
[2025-11-02 18:06:49,767] INFO - Epoch 8 | new global best (short)
lambda=-5.605208 | fitness=4.511233 | penalty=54.698750 | masses=(1.318306,
0.58385, 0.230678)
[2025-11-02 18:06:57,497] INFO - Epoch 8 complete | lambda_short=-5.605208 |
fitness_short=4.511233 | lambda_best=-5.605208 | fitness_best=4.511233 | evals
short/long=180/12 | total evals=1728 | radius=0.0340
[2025-11-02 18:07:13,003] INFO - Epoch 9 | new global best (short)
lambda=-5.884791 | fitness=5.344857 | penalty=26.996707 | masses=(1.350137,
0.612541, 0.247566)
[2025-11-02 18:07:20,684] INFO - Epoch 9 complete | lambda_short=-5.884791 |
fitness_short=5.344857 | lambda_best=-5.884791 | fitness_best=5.344857 | evals
short/long=180/12 | total evals=1920 | radius=0.0340
[2025-11-02 18:07:44,224] INFO - Epoch 10 complete | lambda_short=-1.684532 |
fitness_short=1.115705 | lambda_best=-5.884791 | fitness_best=5.344857 | evals
short/long=180/12 | total evals=2112 | radius=0.0340
[2025-11-02 18:08:09,323] INFO - Epoch 11 complete | lambda_short=-2.898377 |
fitness_short=2.086180 | lambda_best=-5.884791 | fitness_best=5.344857 | evals
short/long=180/12 | total evals=2304 | radius=0.0340
[2025-11-02 18:08:33,740] INFO - Epoch 12 complete | lambda_short=-3.275199 |
fitness_short=2.684519 | lambda_best=-5.884791 | fitness_best=5.344857 | evals
short/long=180/12 | total evals=2496 | radius=0.0340
[2025-11-02 18:08:58,377] INFO - Epoch 13 complete | lambda_short=-4.280937 |
fitness_short=3.722199 | lambda_best=-5.884791 | fitness_best=5.344857 | evals
short/long=180/12 | total evals=2688 | radius=0.0340
[2025-11-02 18:09:22,893] INFO - Stagnation detected; reseeding around best
candidate.
[2025-11-02 18:09:22,893] INFO - Epoch 14 complete | lambda_short=-2.907988 |
fitness_short=2.103063 | lambda_best=-5.884791 | fitness_best=5.344857 | evals
short/long=180/12 | total evals=2880 | radius=0.0289
```

```
[2025-11-02 18:09:48,200] INFO - Epoch 15 complete | lambda_short=-3.805980 | fitness_short=3.286464 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=3072 | radius=0.0289
[2025-11-02 18:10:13,385] INFO - Epoch 16 complete | lambda_short=-5.765463 | fitness_short=5.133278 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=3264 | radius=0.0289
[2025-11-02 18:10:38,884] INFO - Epoch 17 complete | lambda_short=-5.797970 | fitness_short=5.245888 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=3456 | radius=0.0289
[2025-11-02 18:11:04,016] INFO - Epoch 18 complete | lambda_short=-1.430910 | fitness_short=0.827178 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=3648 | radius=0.0289
[2025-11-02 18:11:29,563] INFO - Stagnation detected; reseeding around best candidate.
[2025-11-02 18:11:29,564] INFO - Epoch 19 complete | lambda_short=-3.868243 | fitness_short=3.343240 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=3840 | radius=0.0246
[2025-11-02 18:11:54,979] INFO - Epoch 20 complete | lambda_short=-3.797886 | fitness_short=3.235140 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=4032 | radius=0.0246
[2025-11-02 18:12:20,569] INFO - Epoch 21 complete | lambda_short=-0.088115 | fitness_short=-0.555465 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=4224 | radius=0.0246
[2025-11-02 18:12:45,883] INFO - Epoch 22 complete | lambda_short=-3.836831 | fitness_short=3.313787 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=4416 | radius=0.0246
[2025-11-02 18:13:11,312] INFO - Epoch 23 complete | lambda_short=-2.303366 | fitness_short=1.761710 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=4608 | radius=0.0246
[2025-11-02 18:13:36,525] INFO - Stagnation detected; reseeding around best candidate.
[2025-11-02 18:13:36,525] INFO - Epoch 24 complete | lambda_short=-2.520787 | fitness_short=1.951041 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=4800 | radius=0.0209
[2025-11-02 18:14:02,002] INFO - Epoch 25 complete | lambda_short=-3.272019 | fitness_short=2.720868 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=4992 | radius=0.0209
[2025-11-02 18:14:28,191] INFO - Epoch 26 complete | lambda_short=-2.570379 | fitness_short=2.007345 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=5184 | radius=0.0209
[2025-11-02 18:14:52,972] INFO - Epoch 27 complete | lambda_short=-3.846711 | fitness_short=3.283028 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=5376 | radius=0.0209
[2025-11-02 18:15:18,666] INFO - Epoch 28 complete | lambda_short=-2.747833 | fitness_short=2.191760 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=5568 | radius=0.0209
[2025-11-02 18:15:44,239] INFO - Stagnation detected; reseeding around best candidate.
```

```
[2025-11-02 18:15:44,239] INFO - Epoch 29 complete | lambda_short=-5.847755 | fitness_short=5.285585 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=5760 | radius=0.0177
[2025-11-02 18:16:10,287] INFO - Epoch 30 complete | lambda_short=-1.938500 | fitness_short=1.389567 | lambda_best=-5.884791 | fitness_best=5.344857 | evals short/long=180/12 | total evals=5952 | radius=0.0177
[2025-11-02 18:16:27,644] INFO - Epoch 31 | new global best (short) lambda=-6.006424 | fitness=5.459386 | penalty=27.351882 | masses=(1.360786, 0.597936, 0.263548)
[2025-11-02 18:16:36,276] INFO - Epoch 31 complete | lambda_short=-6.006424 | fitness_short=5.459386 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=6144 | radius=0.0177
[2025-11-02 18:17:01,589] INFO - Epoch 32 complete | lambda_short=-3.745032 | fitness_short=3.210636 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=6336 | radius=0.0177
[2025-11-02 18:17:28,026] INFO - Epoch 33 complete | lambda_short=-2.157464 | fitness_short=1.626995 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=6528 | radius=0.0177
[2025-11-02 18:17:54,050] INFO - Epoch 34 complete | lambda_short=-1.051655 | fitness_short=0.516843 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=6720 | radius=0.0177
[2025-11-02 18:18:20,519] INFO - Epoch 35 complete | lambda_short=-1.126079 | fitness_short=0.572053 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=6912 | radius=0.0177
[2025-11-02 18:18:46,372] INFO - Stagnation detected; reseeding around best candidate.
[2025-11-02 18:18:46,373] INFO - Epoch 36 complete | lambda_short=-5.837279 | fitness_short=5.295536 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=7104 | radius=0.0151
[2025-11-02 18:19:11,654] INFO - Epoch 37 complete | lambda_short=-2.375983 | fitness_short=1.810755 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=7296 | radius=0.0151
[2025-11-02 18:19:36,793] INFO - Epoch 38 complete | lambda_short=-3.428939 | fitness_short=2.875037 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=7488 | radius=0.0151
[2025-11-02 18:20:01,998] INFO - Epoch 39 complete | lambda_short=-3.496655 | fitness_short=2.943177 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=7680 | radius=0.0151
[2025-11-02 18:20:27,415] INFO - Epoch 40 complete | lambda_short=-1.277911 | fitness_short=0.700409 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=7872 | radius=0.0151
[2025-11-02 18:20:52,274] INFO - Stagnation detected; reseeding around best candidate.
[2025-11-02 18:20:52,274] INFO - Epoch 41 complete | lambda_short=-3.983617 | fitness_short=3.455740 | lambda_best=-6.006424 | fitness_best=5.459386 | evals short/long=180/12 | total evals=8064 | radius=0.0128
[2025-11-02 18:21:16,912] INFO - Epoch 42 complete | lambda_short=-3.941209 | fitness_short=3.381490 | lambda_best=-6.006424 | fitness_best=5.459386 | evals
```

```

short/long=180/12 | total evals=8256 | radius=0.0128
[2025-11-02 18:21:57,053] INFO - Epoch 43 complete | lambda_short=-0.485512 |
fitness_short=-0.057889 | lambda_best=-6.006424 | fitness_best=5.459386 | evals
short/long=180/12 | total evals=8448 | radius=0.0128
[2025-11-02 18:23:45,295] INFO - Epoch 44 | new global best (short)
lambda=-6.012074 | fitness=5.463014 | penalty=27.452985 | masses=(1.373724,
0.607631, 0.262543)
[2025-11-02 18:23:53,282] INFO - Epoch 44 complete | lambda_short=-6.012074 |
fitness_short=5.463014 | lambda_best=-6.012074 | fitness_best=5.463014 | evals
short/long=180/12 | total evals=8640 | radius=0.0128
[2025-11-02 18:24:18,135] INFO - Epoch 45 complete | lambda_short=-3.986036 |
fitness_short=3.413644 | lambda_best=-6.012074 | fitness_best=5.463014 | evals
short/long=180/12 | total evals=8832 | radius=0.0128
[2025-11-02 18:24:43,569] INFO - Epoch 46 complete | lambda_short=-2.795152 |
fitness_short=2.235435 | lambda_best=-6.012074 | fitness_best=5.463014 | evals
short/long=180/12 | total evals=9024 | radius=0.0128
[2025-11-02 18:25:09,448] INFO - Epoch 47 complete | lambda_short=1.116597 |
fitness_short=-1.666811 | lambda_best=-6.012074 | fitness_best=5.463014 | evals
short/long=180/12 | total evals=9216 | radius=0.0128
[2025-11-02 18:25:35,165] INFO - Epoch 48 complete | lambda_short=-4.016143 |
fitness_short=3.470410 | lambda_best=-6.012074 | fitness_best=5.463014 | evals
short/long=180/12 | total evals=9408 | radius=0.0128
[2025-11-02 18:26:00,880] INFO - Stagnation detected; reseeding around best
candidate.
[2025-11-02 18:26:00,880] INFO - Epoch 49 complete | lambda_short=-3.426243 |
fitness_short=2.884421 | lambda_best=-6.012074 | fitness_best=5.463014 | evals
short/long=180/12 | total evals=9600 | radius=0.0109
[2025-11-02 18:26:00,880] INFO - Optimization completed | epochs=50 | evals=9600
| best lambda=-6.012074 | wall=1354.0s

```

1.9 Métricas base y comparación con la solución óptima

Calculamos el fitness del punto central (`center`) y lo comparamos con `results["best"]`. Guardamos `baseline_details` para estudiar la dinámica inicial y recuperamos `metrics` para posteriores visualizaciones de , fitness y estadísticas del experimento.

```
[11]: metrics = controller.metrics
```

```
[12]: results
```

```
[12]: {'status': 'completed',
       'best': {'masses': [1.3737238714189304,
                         0.6076306072941796,
                         0.2625428800333757],
                'lambda': -6.012073605236613,
                'fitness': 5.4630139063358545,
                'm1': 1.3737238714189304,
                'm2': 0.6076306072941796,
```

```
'm3': 0.2625428800333757},
'evals': 9600,
'epochs': 50}
```

1.10 Visualización de convergencia y órbitas

Generamos: - `plot_lambda_evolution` y `plot_fitness_evolution` para revisar la trayectoria del GA. - Integraciones 2D (`quick_view`) y 3D (`animate_3d`) con las masas óptimas, verificando si el planeta errante permanece confinado pese a la geometría no colineal.

```
[13]: from two_body.core.cache import HierarchicalCache
from two_body.logic.fitness import FitnessEvaluator

#original_masses = tuple((lo + hi) / 2.0 for lo, hi in cfg.mass_bounds)
original_masses = (1.25, 0.7, 0.05)
center = original_masses

baseline_entry = ret
baseline_lambda_short = baseline_entry.get("lambda")
if baseline_lambda_short is None or not np.isfinite(baseline_lambda_short):
    baseline_lambda_short = -float(baseline_entry.get("fitness", 0.0))

best_payload = results.get("best") or {}
best_lambda_short = best_payload.get("lambda")
if best_lambda_short is None and best_payload.get("fitness") is not None:
    best_lambda_short = -float(best_payload["fitness"])

print(
    f" original (short) = {baseline_lambda_short:.6f}, "
    f" optimizado (short) = {best_lambda_short:.6f}"
    if best_lambda_short is not None
    else f" original (short) = {baseline_lambda_short:.6f}, optimizado = N/A"
)

RUN_LONG_CHECK = False
if RUN_LONG_CHECK and best_payload.get("masses"):
    evaluator = FitnessEvaluator(HierarchicalCache(), cfg)
    orig_fits, orig_details = evaluator.evaluate_batch(
        [original_masses],
        horizon="long",
        return_details=True,
    )
    opt_fits, opt_details = evaluator.evaluate_batch(
        [tuple(best_payload["masses"])],
        horizon="long",
        return_details=True,
    )
```

```

lambda_orig_long = orig_details[0].get("lambda")
if lambda_orig_long is None or not np.isfinite(lambda_orig_long):
    lambda_orig_long = -orig_fits[0]
lambda_opt_long = opt_details[0].get("lambda")
if lambda_opt_long is None or not np.isfinite(lambda_opt_long):
    lambda_opt_long = -opt_fits[0]
print(
    f" original (long) = {lambda_orig_long:.6f}, "
    f" optimizado (long) = {lambda_opt_long:.6f}"
)

```

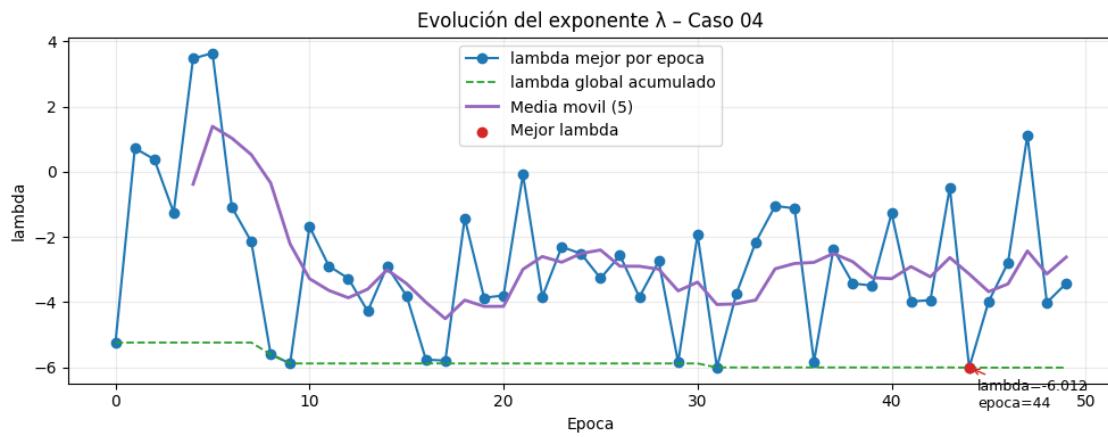
original (short) = -2.805940, optimizado (short) = -6.012074

[14]: viz_3d = Visualizer3D(headless=cfg.headless)

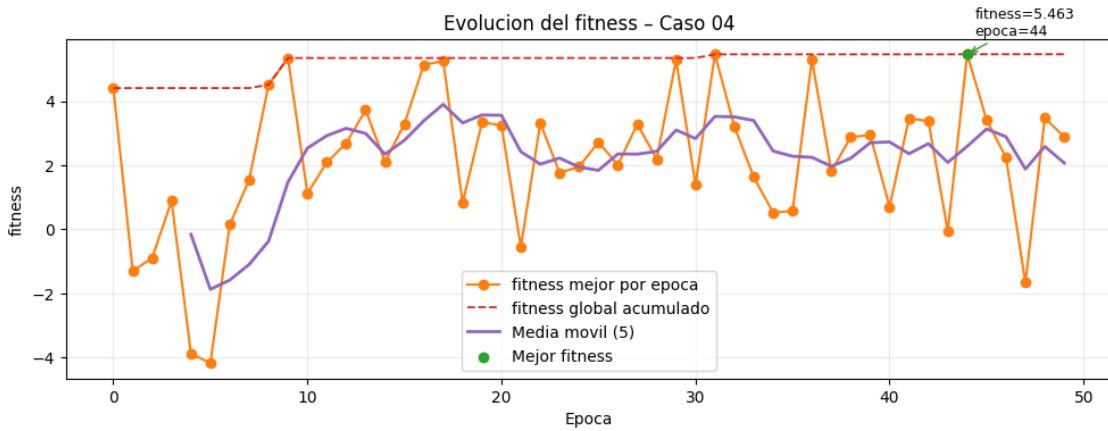
```

_ = viz_3d.plot_lambda_evolution(
    lambda_history=metrics.best_lambda_per_epoch,
    epoch_history=metrics.epoch_history,
    title="Evolución del exponente - Caso 04",
    moving_average_window=5, # opcional
)

```



[15]: _ = viz_3d.plot_fitness_evolution(
 fitness_history=metrics.best_fitness_per_epoch,
 epoch_history=metrics.epoch_history,
 title="Evolucion del fitness - Caso 04",
 moving_average_window=5,
)



```
[16]: 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)
print("Trayectoria calculada con masas óptimas.")
print(traj.shape)
print(traj[-1])
xyz_tracks = [traj[:, i, :3] for i in range(traj.shape[1])]
```

Trayectoria calculada con masas óptimas.

```
(17500, 3, 6)
[[ 0.37714083 -0.10369043  0.           0.91793287 -1.15881464  0.          ],
 [-1.01846405  0.16785092  0.           -0.56286727 -4.67812295  0.          ],
 [ 0.38379472  0.15407259  0.           -3.50026983 16.89042955  0.          ]]
```

```
[17]: from two_body.scripts.demo_tierra import (
    summarize_trajectory,
    compute_total_energy,
    estimate_orbital_period,
)

summarize_trajectory(
```

```

        logger=logger,
        traj=traj,
        masses=best_masses,
        cfg=cfg,
    )

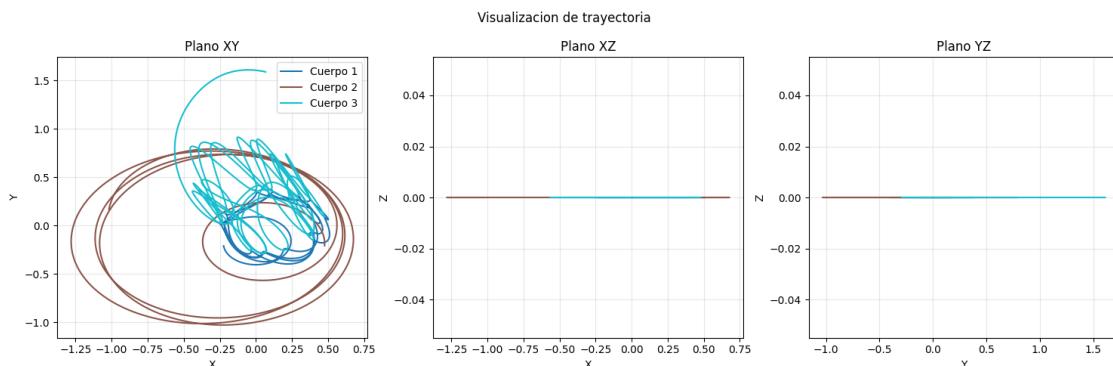
```

```

[2025-11-02 18:26:01,866] INFO - Resumen de simulacion
[2025-11-02 18:26:01,866] INFO -    pasos=17500 | dt=0.000200 anos | duracion
total=3.500 anos
[2025-11-02 18:26:01,866] INFO -    masas=(1.3737238714189304,
0.6076306072941796, 0.2625428800333757) (M_sun) | G=39.478418
[2025-11-02 18:26:01,867] INFO -    centro de masa: desplazamiento maximo =
5.559e-14 UA
[2025-11-02 18:26:01,868] INFO -    cuerpo 0 -> radio[min, max]=[0.0903, 0.5236]
UA | radio sigma=1.0422e-01 | velocidad media=2.8624 UA/ano
[2025-11-02 18:26:01,869] INFO -    cuerpo 1 -> radio[min, max]=[0.2301, 1.3093]
UA | radio sigma=2.5661e-01 | velocidad media=6.2407 UA/ano
[2025-11-02 18:26:01,870] INFO -    cuerpo 2 -> radio[min, max]=[0.0315, 1.6115]
UA | radio sigma=3.3721e-01 | velocidad media=7.4889 UA/ano
[2025-11-02 18:26:01,873] INFO -    energia total (media)=-3.558373e+01 |
variacion relativa=6.651e-09
[2025-11-02 18:26:01,874] INFO -    periodo orbital estimado para la Tierra ==
0.345634 anos
[2025-11-02 18:26:01,874] INFO -    error relativo vs 1 ano =~ 6.544e-01

```

[18]: viz_planar = PlanarVisualizer(headless=cfg.headless)
 $_$ = viz_planar.quick_view(xyz_tracks) # usa una asignación para que Jupyter no_u
 \hookrightarrow duplique la figura

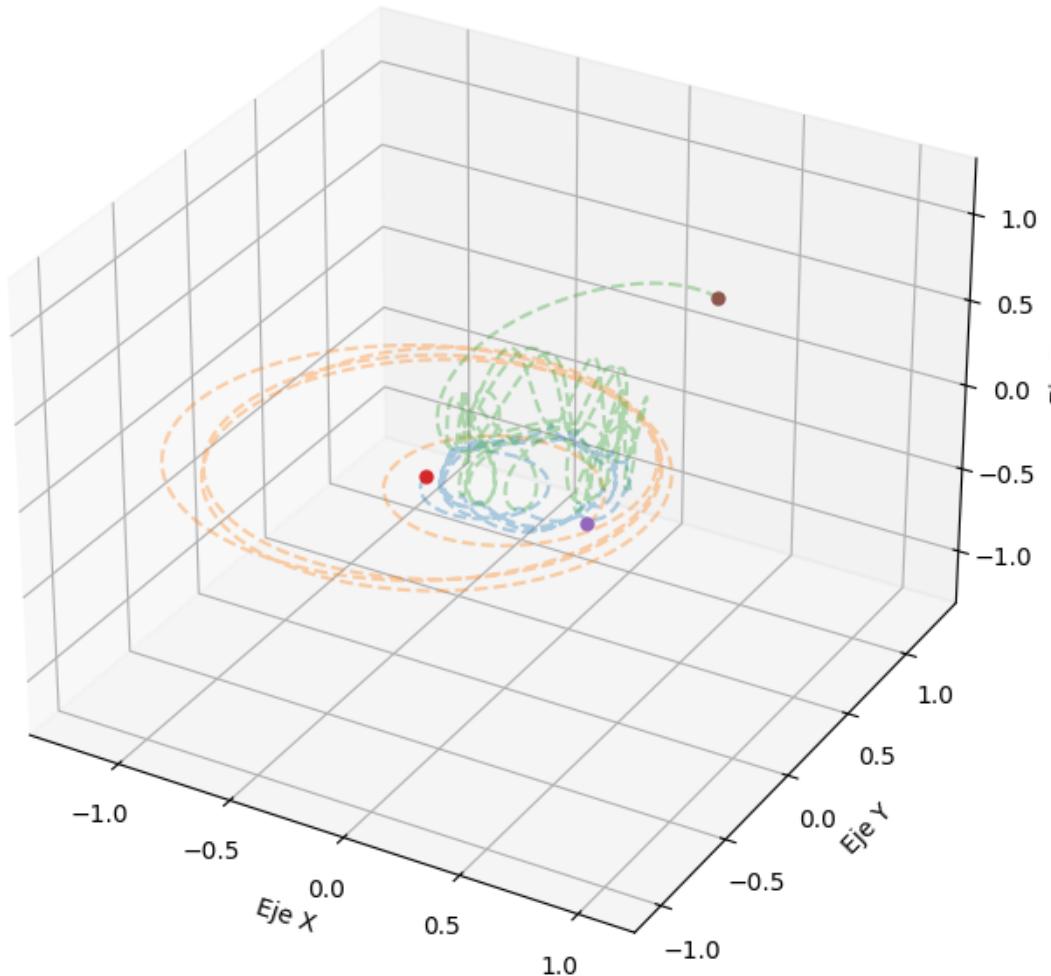


[19]: `from IPython.display import HTML`
`import matplotlib as mpl`
`mpl.rcParams['animation.embed_limit'] = 50 # MB`

```
[20]: 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())
```

Trayectorias 3D m1=1.374, m2=0.608



1.11 Exportación de animaciones

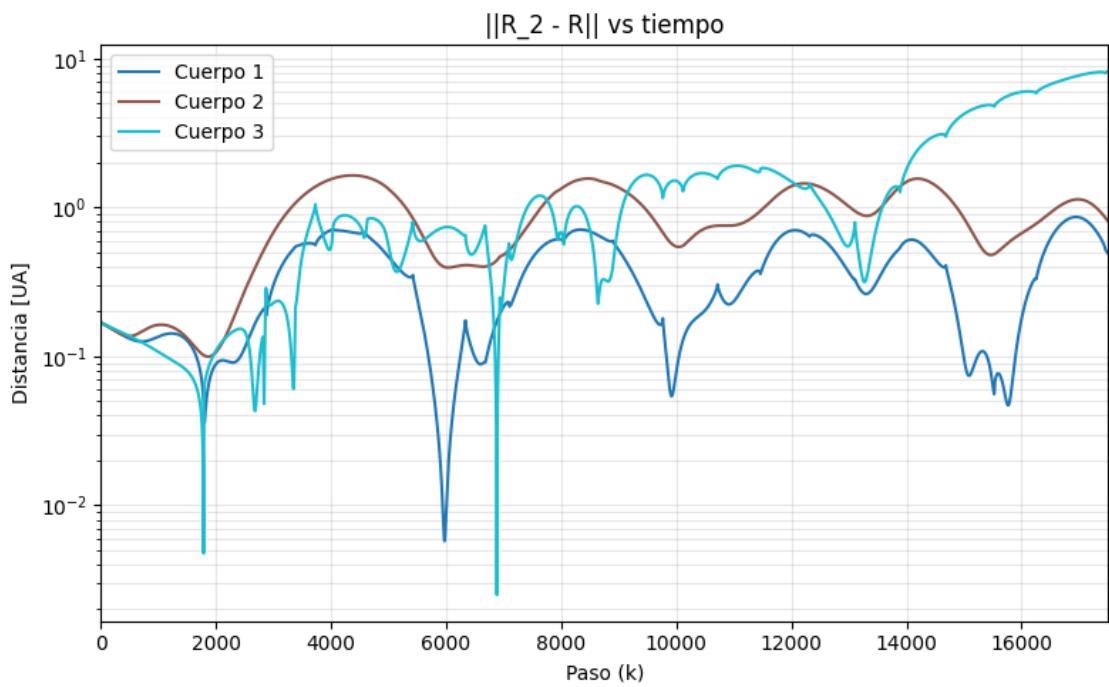
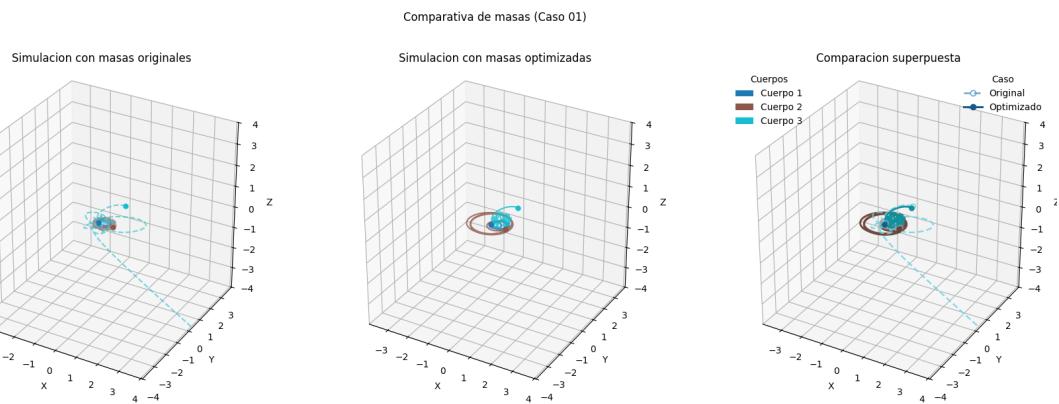
Preparamos un FFMpegWriter, creamos `artifacts/caso04` y guardamos los MP4 tanto de la órbita como de la comparación de masas. Ajusta fps, bitrate o dpi si necesitas equilibrar rapidez y calidad de render.

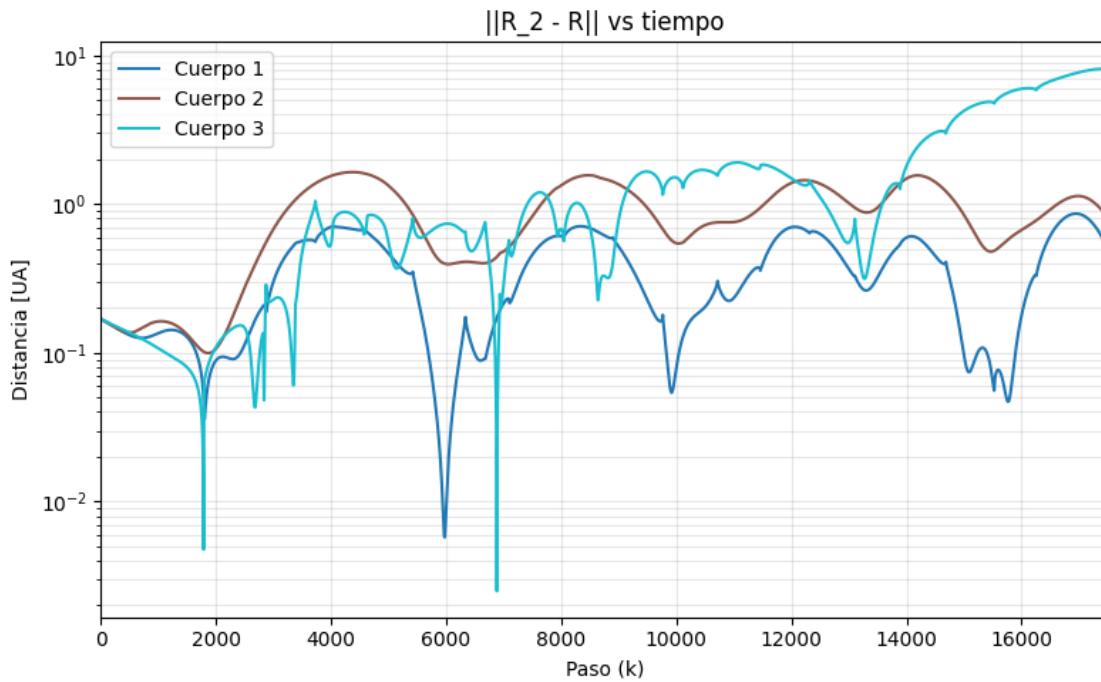
```
[21]: from matplotlib.animation import FFMpegWriter # o PillowWriter para GIF
```

```
writer = FFMpegWriter(  
    fps=20,  
    bitrate=1800,  
    extra_args=["-vcodec", "libx264", "-preset", "ultrafast", "-crf", "28"],  
)  
output_path = Path("artifacts/caso04") # ajusta a tu gusto  
output_path.mkdir(parents=True, exist_ok=True)  
  
anim.save(output_path / "trayectoria_optima.mp4", writer=writer)
```

```
[ ]: sim_orig = sim_builder.setup_simulation(center, r0, v0)  
traj_original = sim_builder.integrate(sim_orig, t_end=cfg.t_end_long, dt=cfg.dt)  
  
traj_opt = traj
```

```
[ ]: orig_tracks = [traj_original[:, i, :3] for i in range(traj_original.shape[1])]  
opt_tracks = [traj_opt[:, i, :3] for i in range(traj_opt.shape[1])]  
  
anim_mass = viz_3d.plot_mass_comparison(  
    original_tracks=orig_tracks,  
    optimized_tracks=opt_tracks,  
    original_masses=center,  
    optimized_masses=best_masses,  
    body_labels=[f"Cuerpo {i+1}" for i in range(len(opt_tracks))],  
    dt=cfg.dt,  
    title="Comparativa de masas (Caso 01)",  
)  
  
if anim_mass is not None:  
    dist_fig = viz_3d.plot_mass_distance_evolution(  
        comparison_data=anim_mass.mass_comparison_data,  
        title="||R_2 - R|| vs tiempo",  
    )  
    if dist_fig is not None:  
        display(dist_fig)  
        # display(HTML(anim_mass.to_jshtml())) # descomenta para ver la animación  
        ↵embebida
```





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

1.12 Reporte de tiempos

Leemos el CSV más reciente de la instrumentación, mostramos una muestra y agrupamos por sección para identificar los cuellos de botella (por ejemplo, integración larga con tres cuerpos no colineales).

```
[25]: 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_b
 ↵_csv'

          run_id  epoch  batch_id  individual_id  \
0  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
1  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
2  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
3  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
4  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
5  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
6  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
7  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
8  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0
9  ddf0b833-a5c4-4572-b8c0-19a388d2f328      0        0        0

          section      start_ns      end_ns duration_us  \
0  simulation_step  19529689749600  19529689791500       41
1  simulation_step  19529689823000  19529689841300       18
2  simulation_step  19529689854900  19529689868200       13
3  simulation_step  19529689878500  19529689890900       12
4  simulation_step  19529689898600  19529689910900       12
5  simulation_step  19529689918600  19529689931400       12
6  simulation_step  19529689938900  19529689951000       12
7  simulation_step  19529689958000  19529689971200       13
8  simulation_step  19529689977700  19529689989400       11
9  simulation_step  19529689996600  19529690008400       11

           extra
0  {'step': 0, 'dt': 0.0002, 't_target': 0.0002}
1  {'step': 1, 'dt': 0.0002, 't_target': 0.0004}
2  {'step': 2, 'dt': 0.0002, 't_target': 0.000600...}
3  {'step': 3, 'dt': 0.0002, 't_target': 0.0008}
4  {'step': 4, 'dt': 0.0002, 't_target': 0.001}
5  {'step': 5, 'dt': 0.0002, 't_target': 0.001200...}
6  {'step': 6, 'dt': 0.0002, 't_target': 0.0014}
7  {'step': 7, 'dt': 0.0002, 't_target': 0.0016}
8  {'step': 8, 'dt': 0.0002, 't_target': 0.001800...}
9  {'step': 9, 'dt': 0.0002, 't_target': 0.002}
```

| | count | mean | sum |
|------------------|----------|--------------|------------|
| section | | | |
| notebook_run | 1 | 1.096908e+09 | 1096907618 |
| batch_eval | 101 | 1.083186e+07 | 1094018184 |
| fitness_eval | 9601 | 1.139131e+05 | 1093680126 |
| lyapunov_compute | 9593 | 1.137711e+05 | 1091406360 |
| simulation_step | 34559992 | 1.975024e+01 | 682568261 |
| ga_main | 50 | 5.628382e+04 | 2814191 |

| | | | |
|----------------------|------|--------------|--------|
| crossover | 1170 | 6.534650e+02 | 764554 |
| selection_tournament | 1170 | 2.775957e+02 | 324787 |
| mutation | 1170 | 1.874342e+02 | 219298 |

```
[ ]: 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"

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")),
)

```

Ejecutando: c:\Users\emicr\anaconda3\envs\grav2body\python.exe
scripts/plot_timings.py --run-id ddf0b833-a5c4-4572-b8c0-19a388d2f328 --top-n 5

```
[ ]: # from pathlib import Path
#
#
```

```
# output_path = Path("artifacts/animations/caso01_orbit.gif")
# output_path2 = Path("artifacts/animations/caso01_comparasion.gif")
# output_path.parent.mkdir(parents=True, exist_ok=True)
#
# anim.save(
#     output_path,
#     writer="pillow",
#     fps=20,
#     dpi=100,           # opcional
# )
#
# print(f"Animación 3D guardada en {output_path}")
#
```