Fluid-Aerosol Modelling for Astrophysics and Computer Games

PHD YEAR 2 PROGRESSION PANEL

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Summary

YEAR 1

- 2D fluid solver for Internal Gravity Waves
- Python post-processing tool

YEAR 2

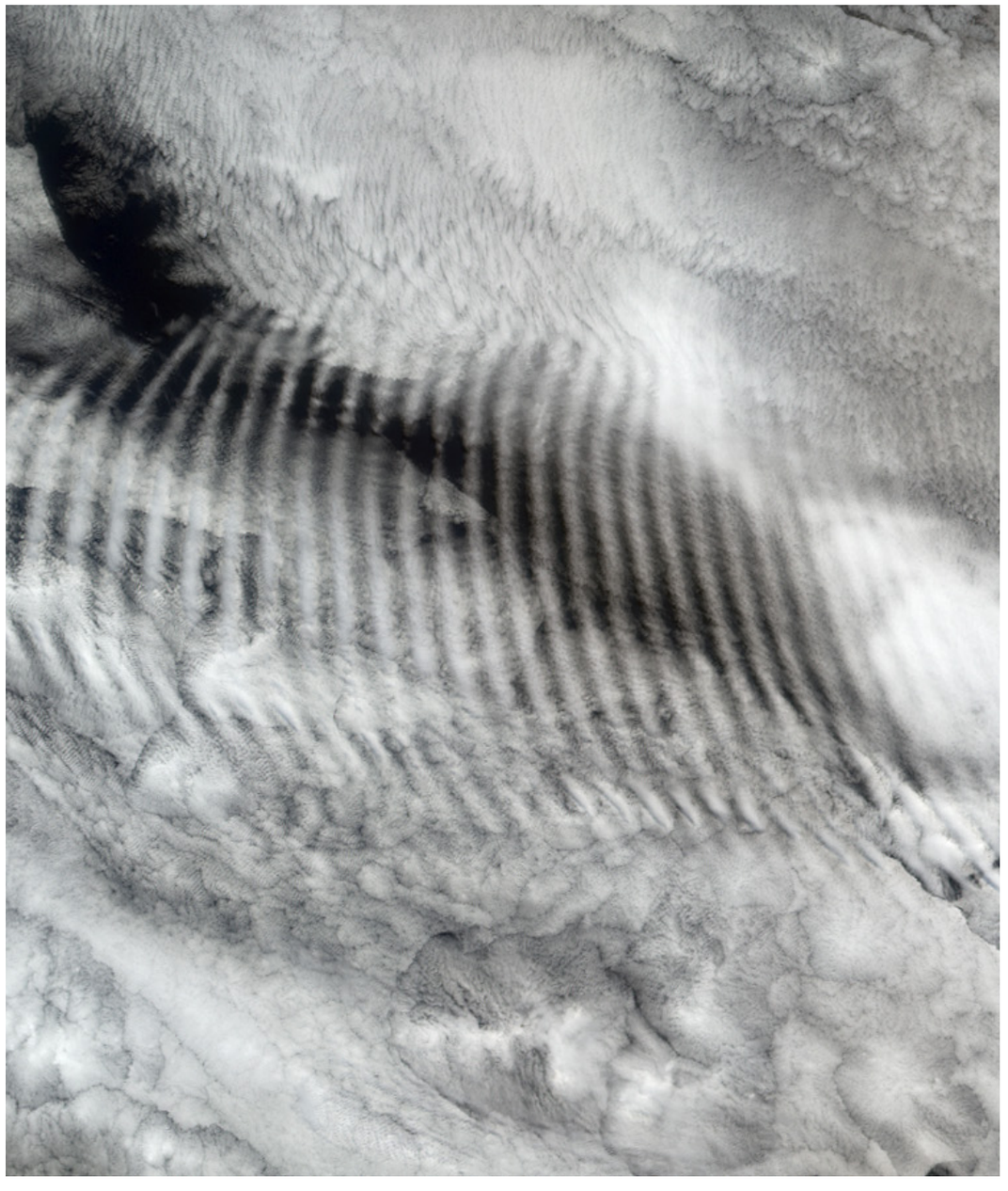
- Impact of gravity waves on dust clouds
- Numerical methods comparison
- Bézier curves/particle dynamics prep. Work

Internal Gravity Waves in Brown Dwarfs

YEAR 1 UPDATE & PROGRESS

Internal Gravity Waves

- Density or velocity perturbations create atmospheric oscillations;
- IGW lead to banded structures in clouds on Earth & Solar System Planets
- *Can similar structures teach us about brown dwarf atmospheres?*

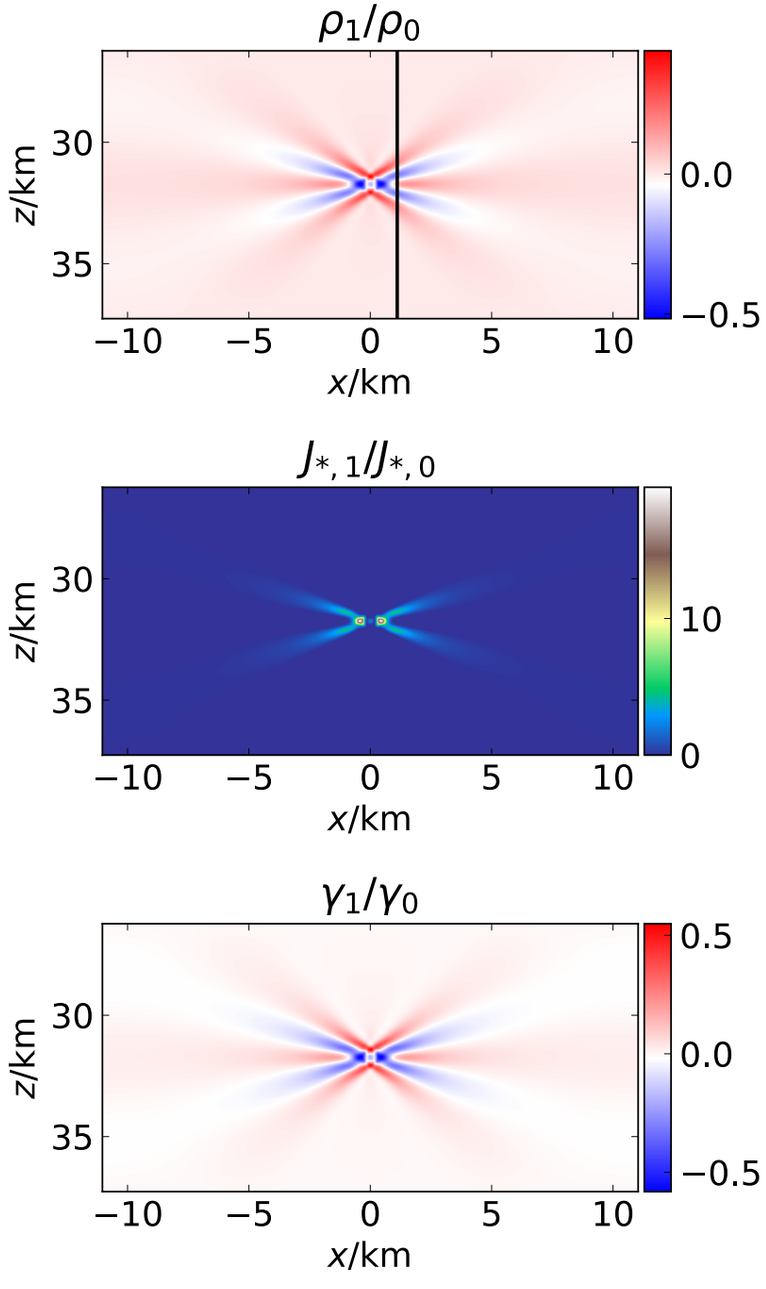


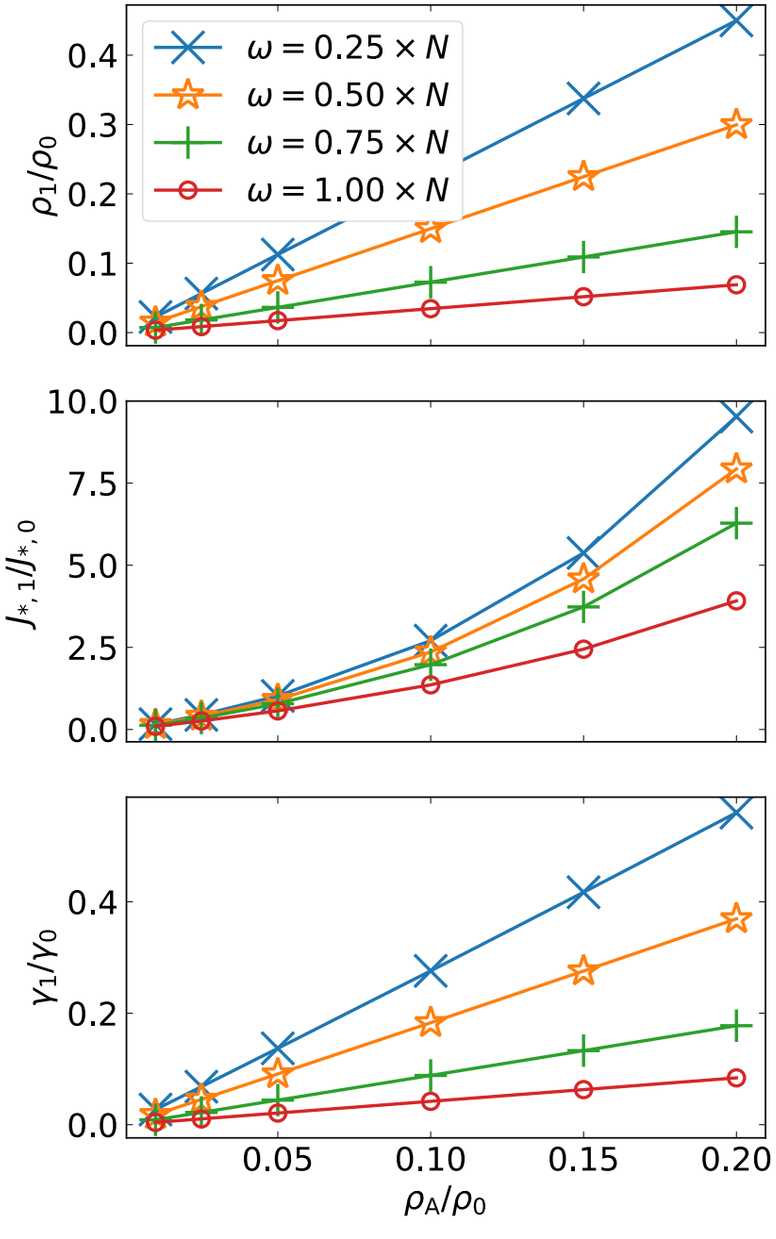
Gravity Waves Ripple over Marine Stratocumulus Clouds
NASA/GSFC/LaRC/JPL, MISR Team

IGW: Year 2 Progress

- Year 1 fluid solver finished
- Dust solver coupled to fluid solver
  - Dust formation (nucleation) equations
  - Dust growth equations
  - Relationship established between observable characteristics and atmospheric profile

IGW: Results


ρ_1/ρ_0
z/km
30
35
−10
−5
0
5
10
x/km
0.0
−0.5
$J_{*,1}/J_{*,0}$
10
0
γ_1/γ_0
0.5
0.0
−0.5


$\omega = 0.25 \times N$
$\omega = 0.50 \times N$
$\omega = 0.75 \times N$
$\omega = 1.00 \times N$
ρ_1/ρ_0
0.0
0.1
0.2
0.3
0.4
$J_{*,1}/J_{*,0}$
0.0
2.5
5.0
7.5
10.0
γ_1/γ_0
0.0
0.2
0.4
0.05
0.10
0.15
0.20
ρ_A/ρ_0

IGW: Research Output

- Poster presentation at Extreme Solar Systems IV conference (Reykjavík, Aug. 2019)
- A&A article in prep., submission Sept. 2019
- Open-source codes (public access ~2020)

Particle Dynamics & Numerical Methods

PRELIMINARY WORK & GAMES APPLICATIONS

Particle Dynamics

- IGW projects focuses on dust formation and growth
- Next focus: dust particle motion
  - Dust particles impacted by wind, magnetic fields
  - Particle motion is a common problem in computer games

Numerical Methods

Explicit Euler
Semi-Implicit Euler
Velocity Verlet

Runge-Kutta 4
Leapfrog
Midpoint

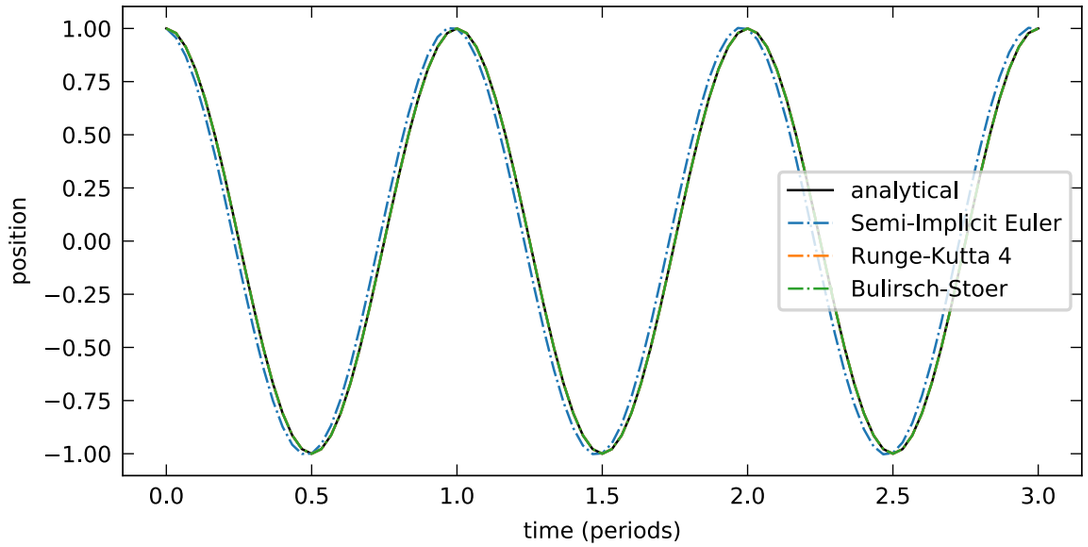
Predictor-Corrector
Bulirsch-Stoer

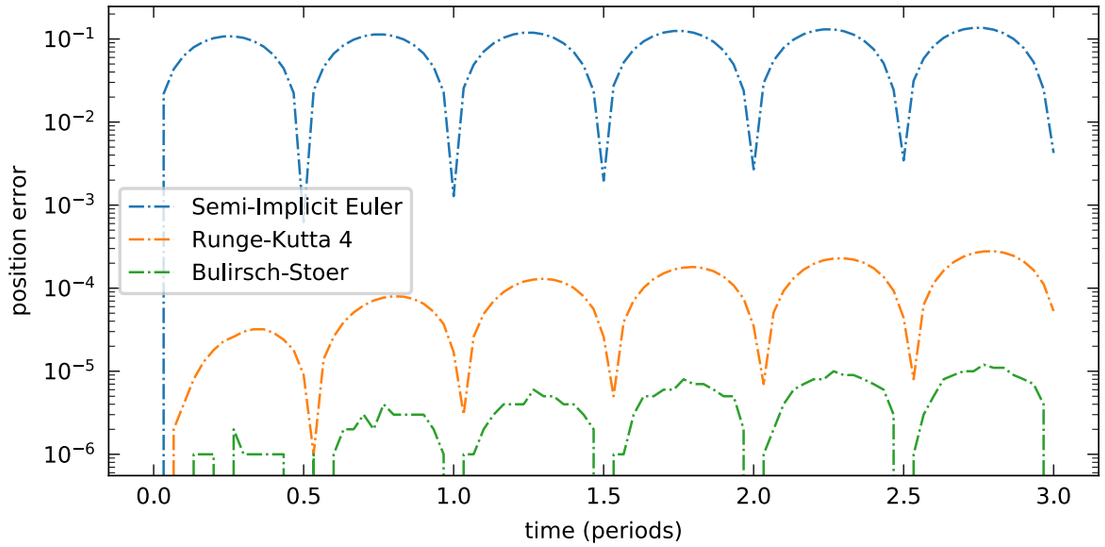
Games Methods

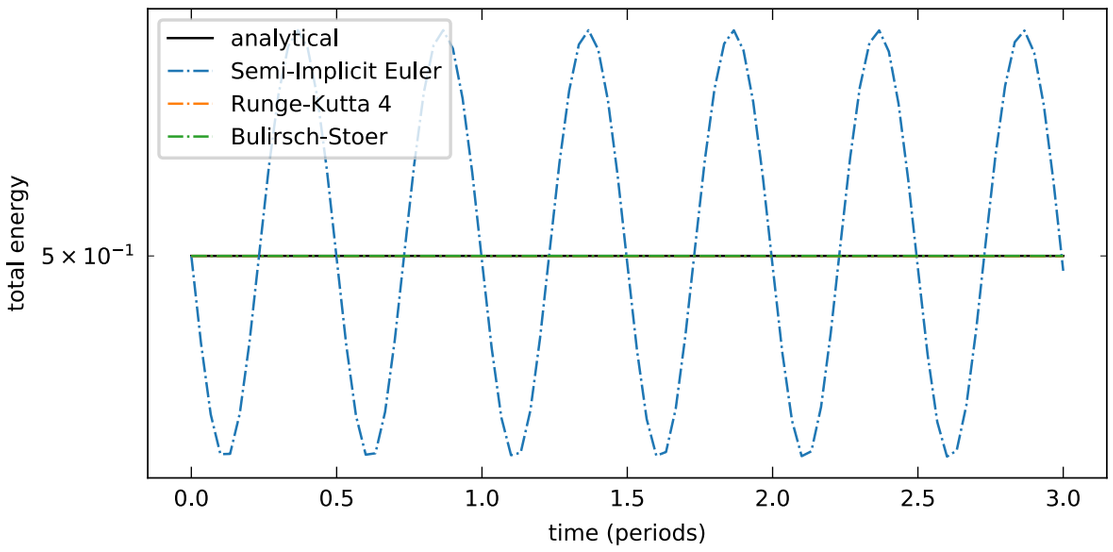
Scientific Methods

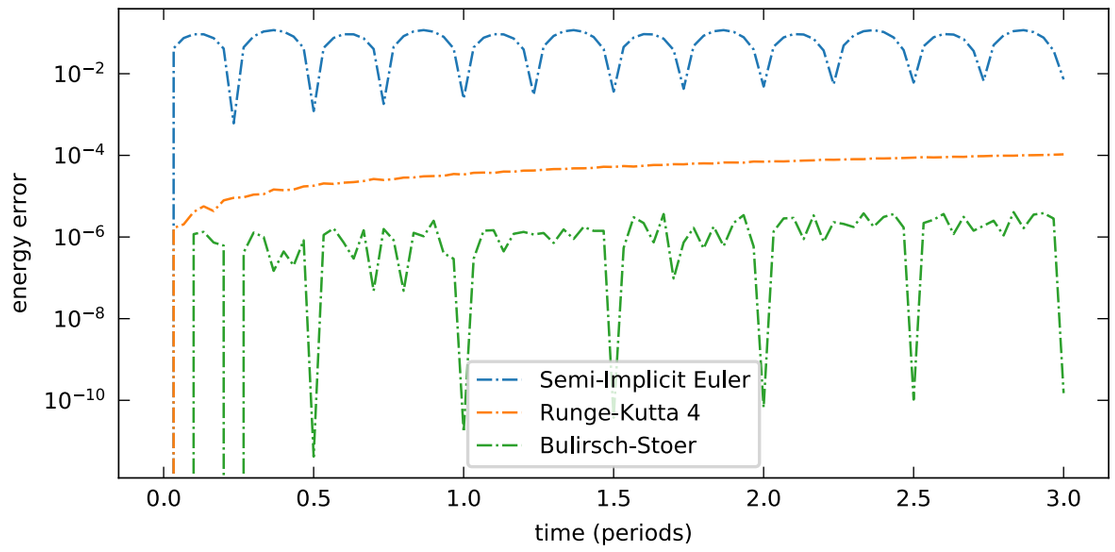
Simple Harmonic Motion

$$\ddot{x} = -\frac{k}{m}x$$



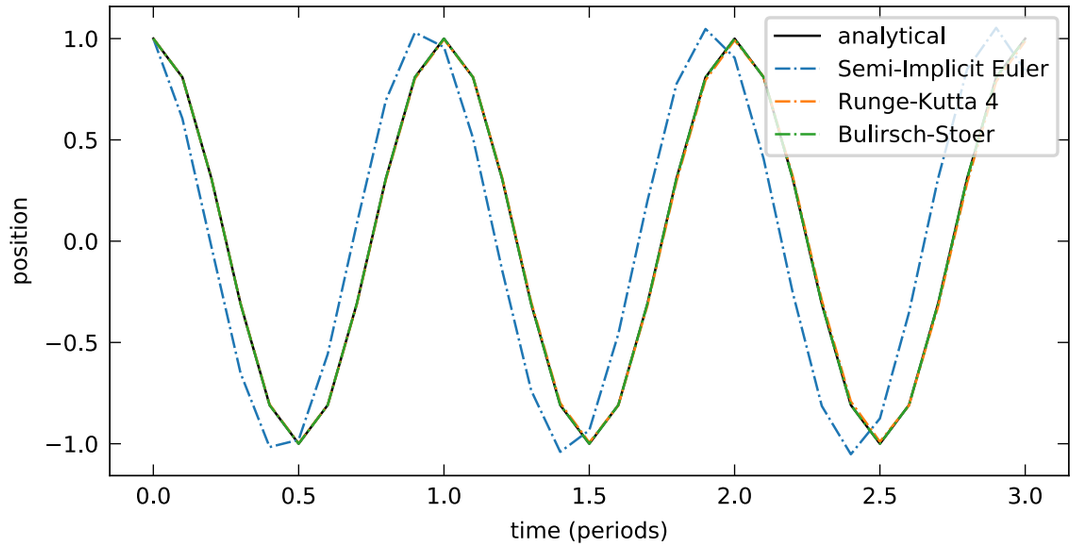


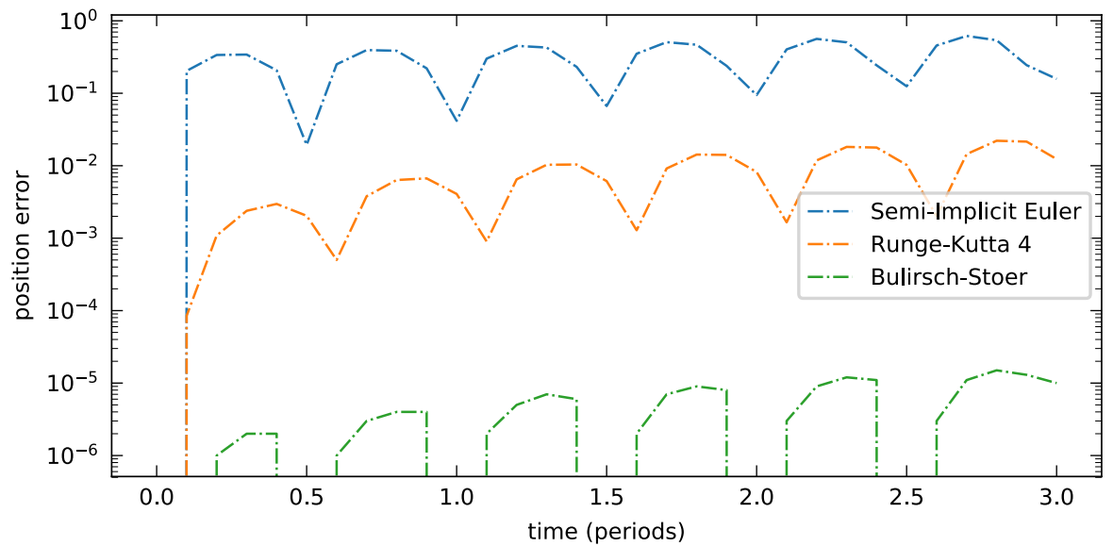


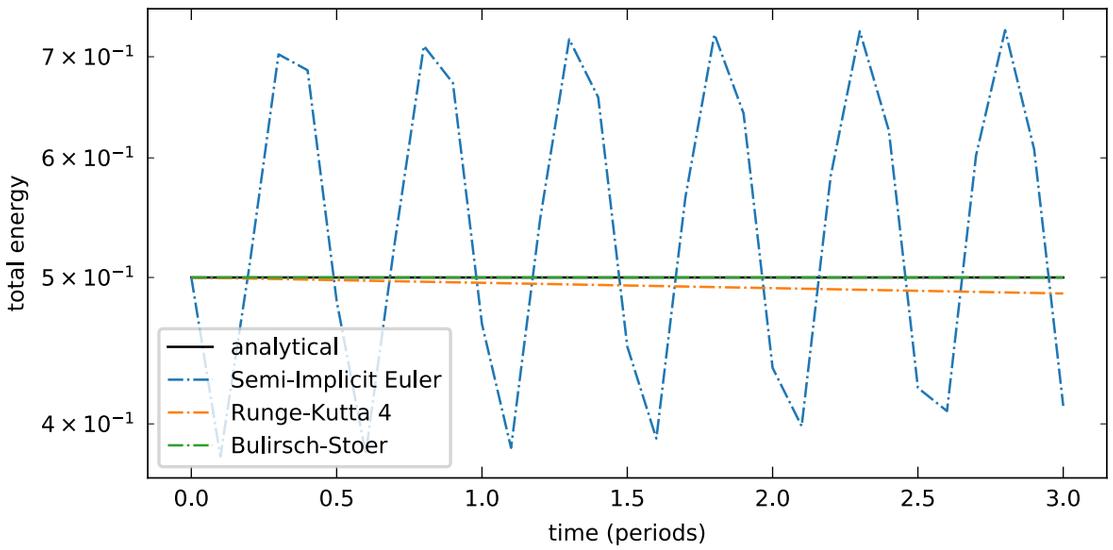


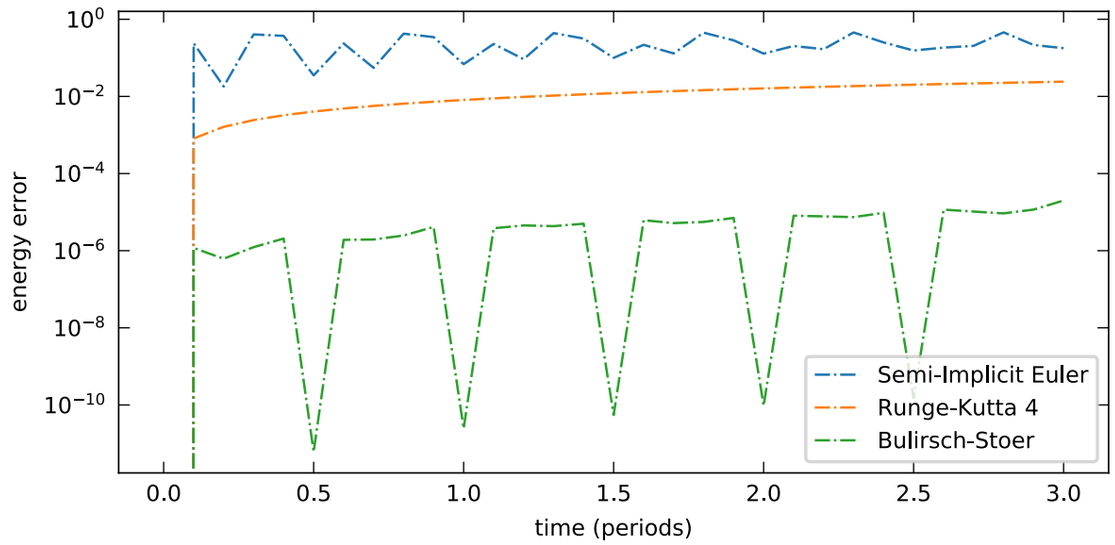
Simple Harmonic Motion

30 STEPS/PERIOD









Simple Harmonic Motion

10 STEPS/PERIOD

Numerical Methods: Results

- Bulirsch-Stoer method is interesting:
  - Allows larger time steps without loss of accuracy
  - Large time steps are a problem (sync with graphics)

New idea: use Bézier curves

- Cast numerical scheme in terms of Bezier curves
- Larger time-steps, using interpolation
- Established algorithms for collision detection, etc.
- benefits for physics engines and scientific programming

Numerical Methods: Bézier

- Semi implicit Euler:
  piece-wise polynomial

$$\boldsymbol{r}_{n+1} = \boldsymbol{r}_n + \boldsymbol{v}_n \Delta t + \boldsymbol{a}_n \Delta t^2$$

- Bézier curve:
  start, end and control points $\boldsymbol{b}_i$
  can be written as polynomial

$$\boldsymbol{B}(t_0) = (1 - t_0)^2 \boldsymbol{b}_0 + t_0(1 - t_0)\boldsymbol{b}_1 + t_0^2 \boldsymbol{b}_2$$

- Goal: store physics steps as Bézier curves to interpolate position, velocity, acceleration for visual frames

Year 3: Further Work

BÉZIER & PARTICLES
+ LATTICE-BOLTZMANN

Further Work

- Implement & test Euler/ Bézier hybrid method
- Couple particle dynamics solver with Lattice-Boltzmann fluid solver
- Publish results
- Write thesis!