An Interstellar Mission to the Closest Black Hole?

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Summary

An Interstellar Mission to the Closest Black Hole?

- There are 10^8-10^9 black holes in the Galaxy
  - The closest black hole maybe within 20-25 light years of Earth

- Can we send a probe to the closest black hole to test the nature of the compact object?
  - Are astrophysical black holes the Kerr black holes of GR?
  - Do astrophysical black holes have an event horizon?

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- Certainly extremely challenging, but it may not be unrealistic
- It is not obvious that a probe can do better than astrophysical observations

Some Premises...

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- Laser propulsion:
  - G. Marx, Interstellar Vehicle Propelled by Terrestrial Laser Beam, Nature 211, 22-23 (1966)
  - J.L. Redding, Interstellar Vehicle Propelled by Terrestrial Laser Beam, Nature 213, 588-589 (1967)

- Interstellar missions to nearby exoplanets:
  - Breakthrough Initiative
  - Project Starlight (UC Santa Barbara)
  - Interstellar Probe (JHU & NASA)
  - Project Dragonfly (I4IS)
  - Gossamer Roadmap (ESA)

1. The Closest Black Hole

The Known Stellar-Mass Black Holes in the Milky Way

- ~70 black hole "candidates" in X-ray binary systems
  - ~25 black holes in X-ray binary systems with a dynamical measurement of their mass
- 3 GAIA black holes in binary systems
  - GAIA-BH1 at ~480 pc (~1,560 light years) from Earth (El-Badry+ 23)
- 1 isolated black hole
  - OGLE-2011-BLG-0462 at 1.6 kpc (Sahu+ 22)

Milky Way

- White dwarfs: ~1 10^{10}

- Black holes: ~1 10^{8} to ~1 10^{9}
  - Timmes+ 96: ~1 10^{9} black holes
  - Olejak+ 20: 1.0 10^{8} isolated black holes in the Galactic disk

    8 10^{6} black holes in binary systems in the Galactic disk

1 black hole : 10-100 white dwarfs

Nearby Objects

- 10 white dwarfs within ~25 light years of the Solar System
  - Sirius B (at 8.6 light years)

- 30 white dwarfs within ~30 light years of the Solar System

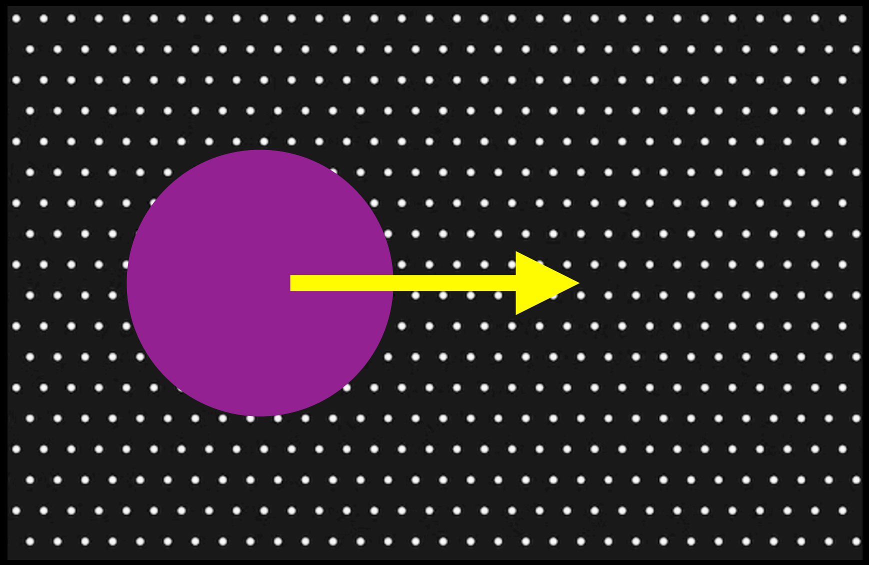
- A black hole within ~15 light years of the Solar System
- A black hole within ~50 light years of the Solar System

Detecting Nearby Black Holes

- Shvartsman 71
- Meszaros 75
- McDowell 85
- etc.

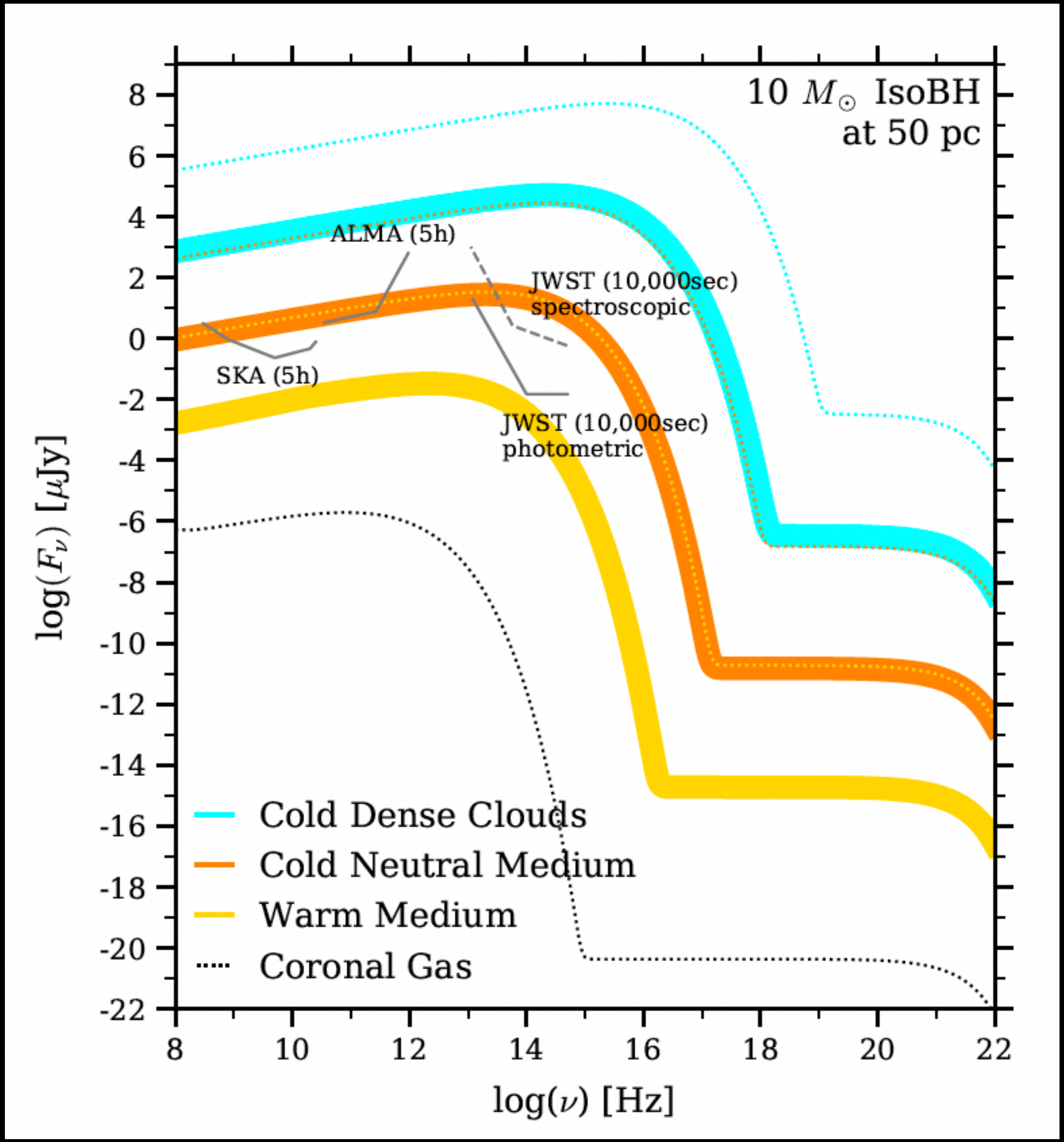
- Mass accretion rate from the interstellar medium

$$\dot{M}_{\rm B} = 4\pi \frac{(GM_\bullet)^2}{(v_\bullet^2 + C_{\rm ISM}^2)^{3/2}} \mu_{\rm ISM} n_{\rm ISM} m_p$$



Detecting Nearby Black Holes

- Murchikova & Sahu 25
- Multi-telescope observations
- Current observational facilities may detect isolated black hole in a warm interstellar medium within 150 light years of Earth



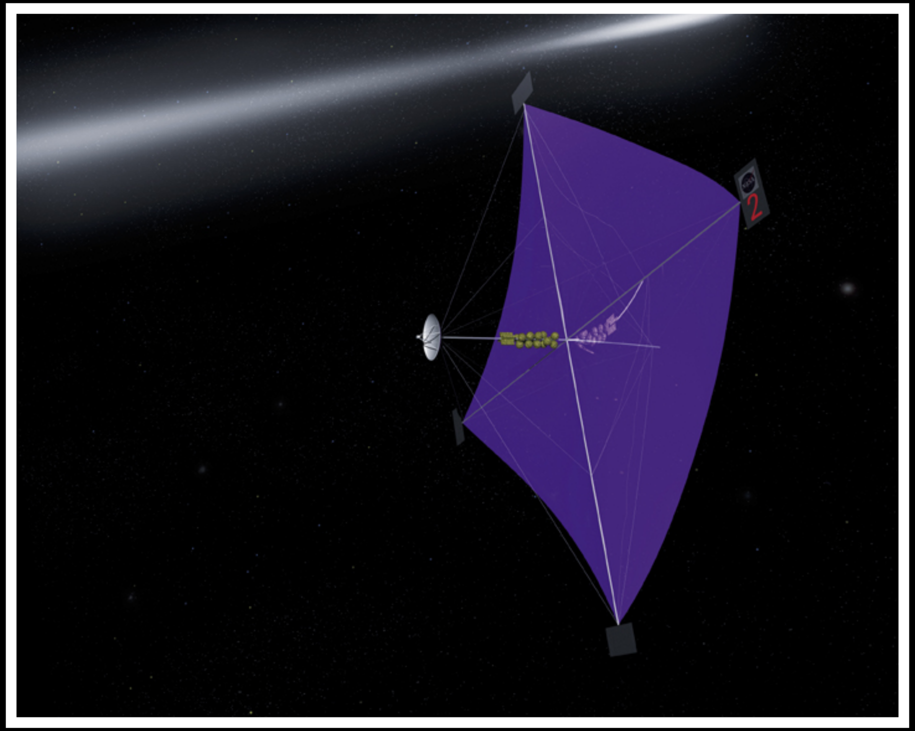
2. Interstellar Mission

Chemically Propelled Spacecrafts

- Tsiolkovsky rocket equation:
  - $m_i / m_f = \exp(\Delta v/v_e)$
  - Liquid hydrogen/liquid oxygen:
    - $v_e \sim$ 4.5 km/s
    - $\Delta v = 0.1$ c and $m_f = m_p$
      - $m_i \gg m_{Universe}$

Nanocraft

- Gram-scale spacecraft:
  - Gram-scale wafer: fully functional space probe (computer processor, thrusters, solar panels, navigation and communication equipment, etc.)
  - Light sail: thin, meter-scale, dielectric metamaterial (to accelerate the probe)



Nanocraft

- Ground-based high-power lasers should accelerate the nanocraft
- Breakthrough Starshot Initiative:
  - Nanocraft to reach Alpha Centauri in ~20 years (Parkin 18), $v/c = 0.2$
- Higher velocities can be reached at higher costs for the mission
- No specific technical problems to reach $v/c = 0.9$

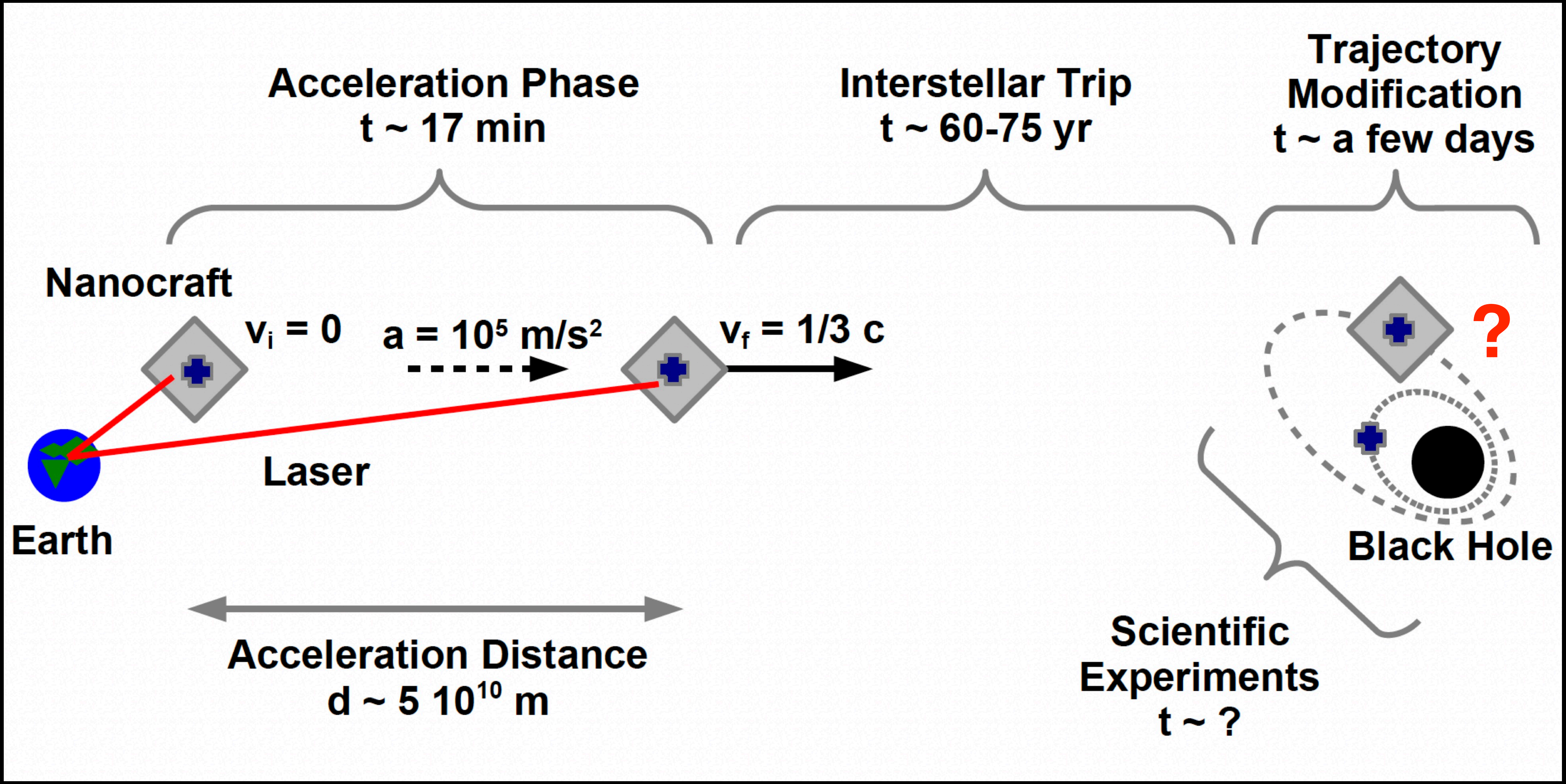
Mission

- Black hole at 20-25 light years

- Nanocraft with $v/c = 1/3$

- 60-75 years for the nanocrafts to reach the black hole
- 20-25 years for the signal to reach the Earth
- 80-100 years the total mission

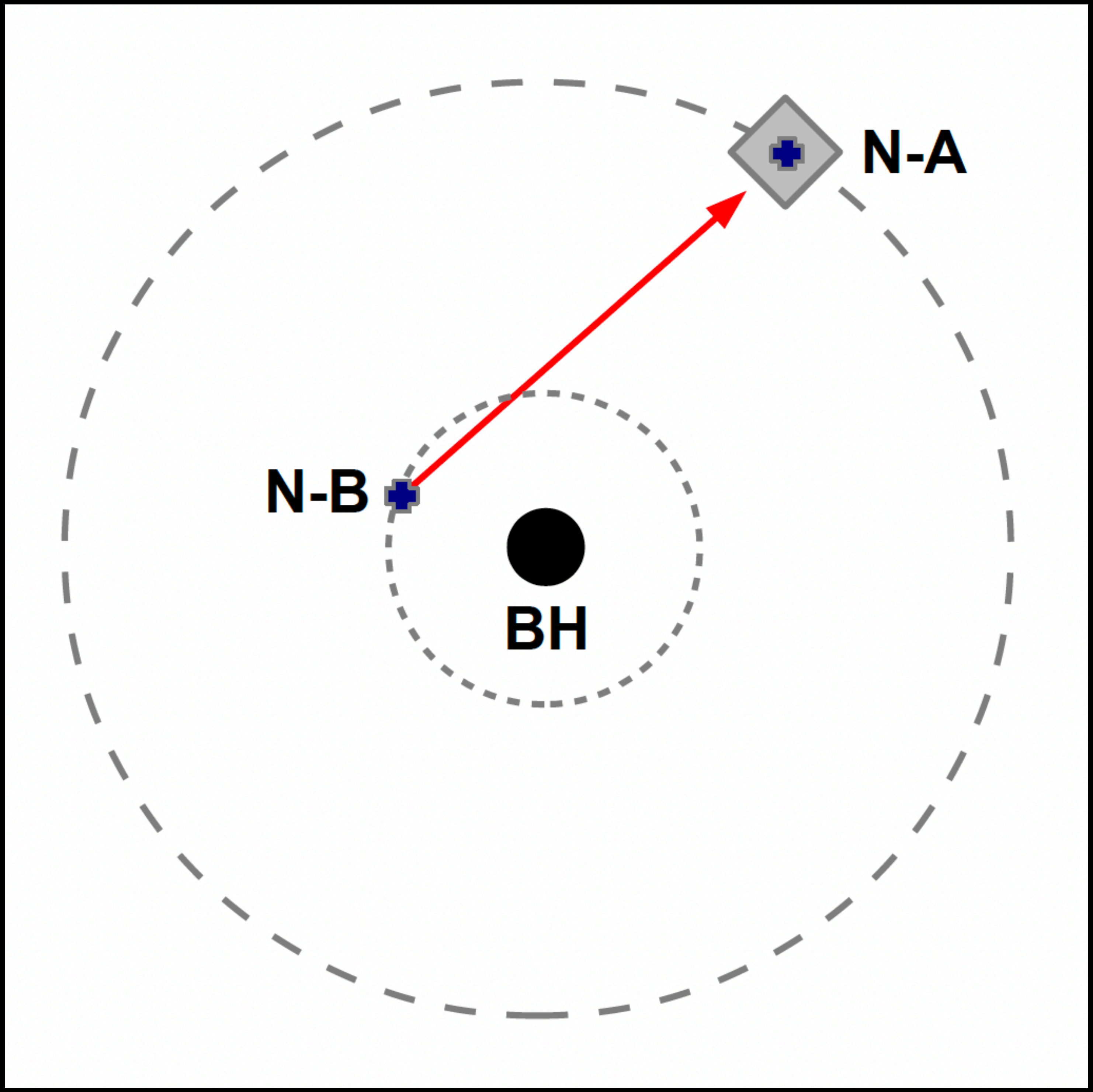
Mission



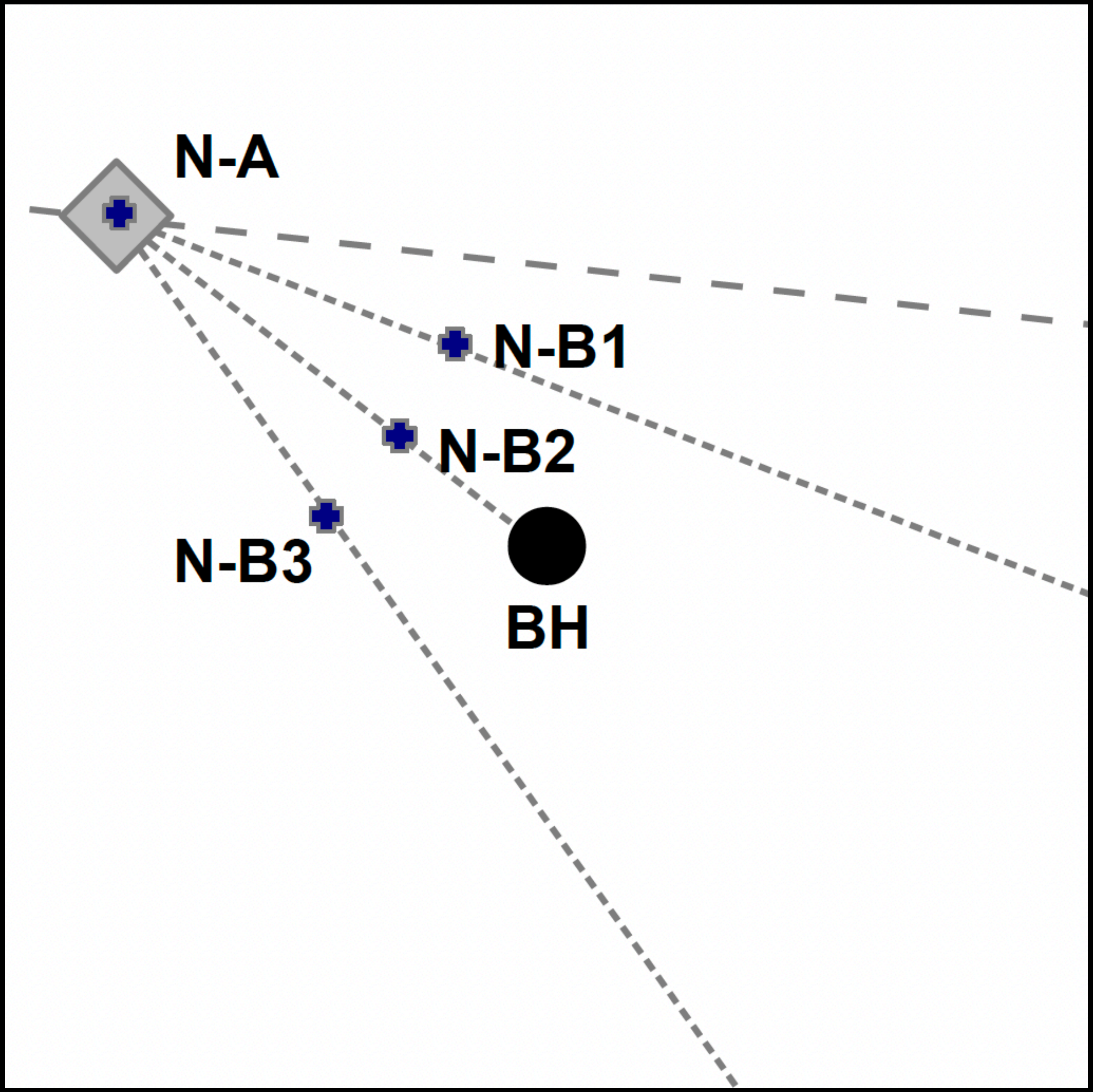
Acceleration Phase
t ~ 17 min
Interstellar Trip
t ~ 60-75 yr
Trajectory
Modification
t ~ a few days
Nanocraft
$v_i = 0$
$a = 10^5$ m/s^2
$v_f = 1/3$ c
?
Laser
Earth
Black Hole
Acceleration Distance
d ~ 5 10^{10} m
Scientific
Experiments
t ~ ?

3. Near the Black Hole...

Orbiting Configuration (?)



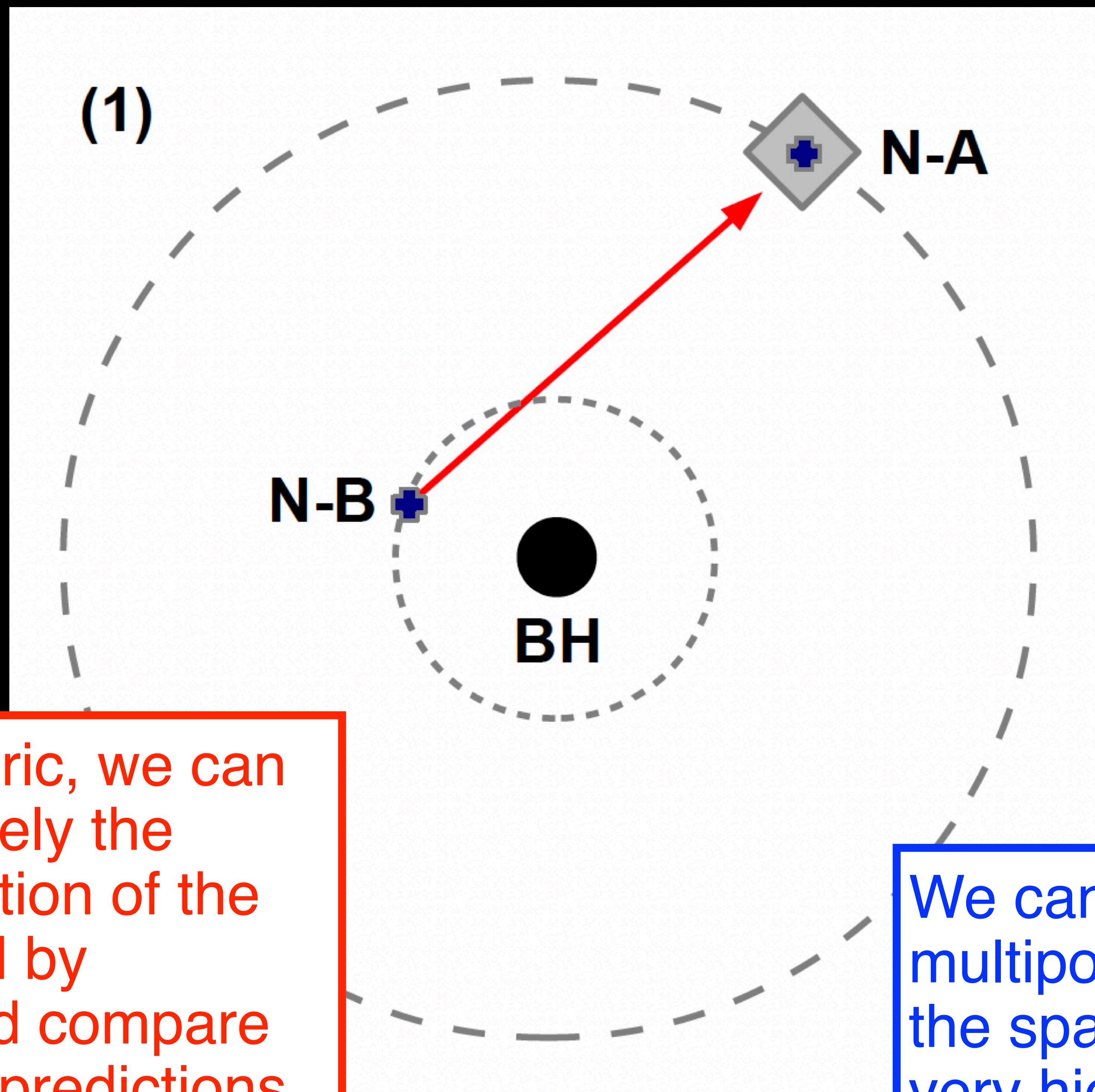
Flyby Configuration



Tests of Fundamental Physics

- Kerr metric
- Event horizon
- Variation of fundamental constants

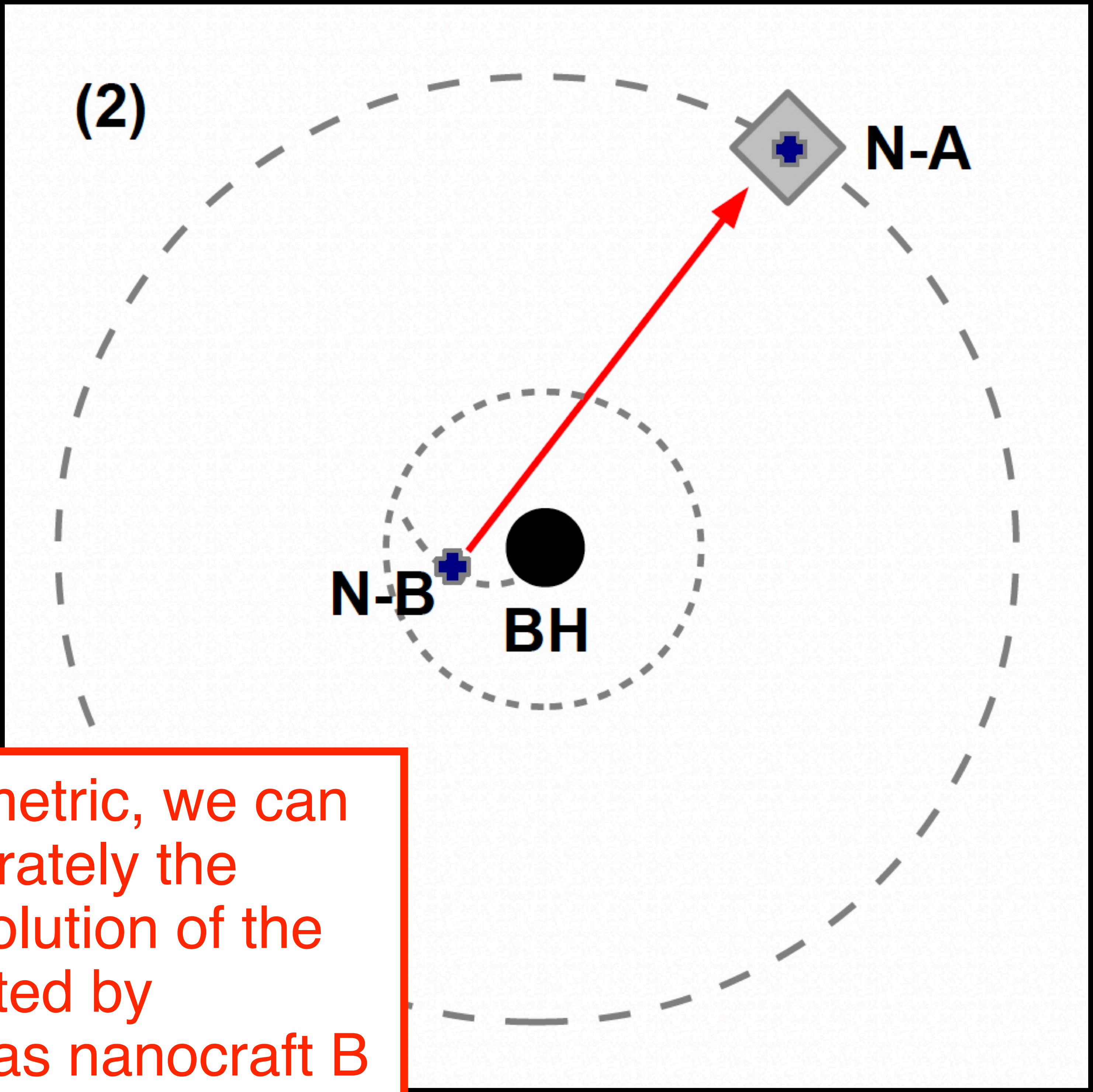
Tests of the Kerr Metric



In the Kerr metric, we can predict accurately the temporal evolution of the signal detected by nanocraft A and compare the theoretical predictions with the detected signal

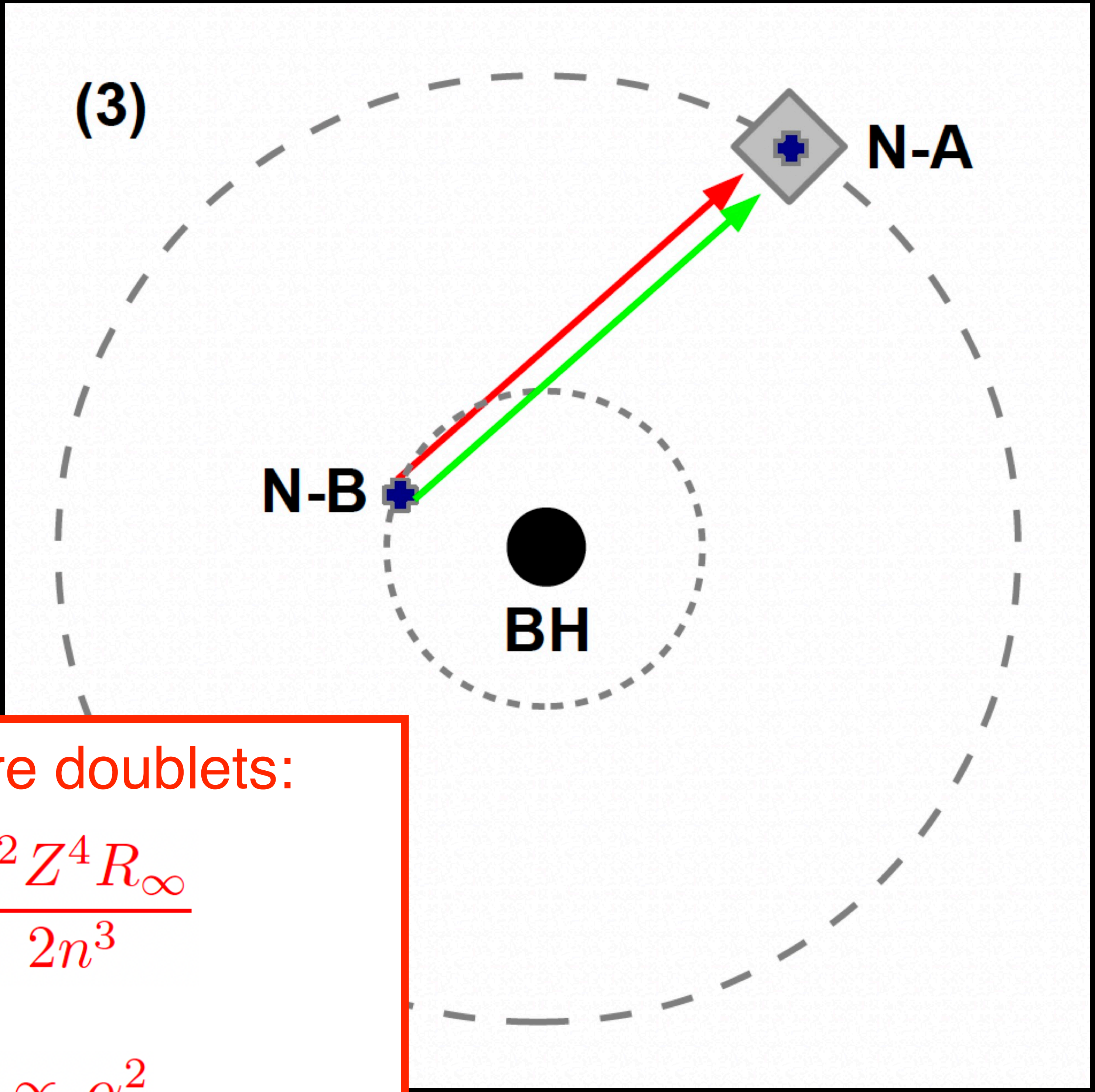
We can measure the multipole moments of the spacetime with very high accuracy

Event Horizon



In the Kerr metric, we can predict accurately the temporal evolution of the signal detected by nanocraft A as nanocraft B approaches the black hole

Variation of Fundamental Constants



Fine structure doublets:

$$\Delta\nu = \frac{\alpha^2 Z^4 R_\infty}{2n^3}$$

$$\Delta\nu/\nu \propto \alpha^2$$

Conclusions

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  - The technology may be developed within 20-30 years
- If the black hole is not within 20-25 light years, but still within 40-50 light years
  - The technological requirements are more challenging

Conclusions

- First step: we need to find a black hole at a reasonable distance from Earth
- If the black hole is within 20-25 light years
  - The technology may be developed within 20-30 years
- If the black hole is not within 20-25 light years, but still within 40-50 light years
  - The technological requirements are more challenging
- If the distance of the black hole is more than 40-50 light years
  - It is not a problem of technology: the black hole is too far...

Issues...

- How can we find the closest black hole?
- How can we send the spacecrafts to the right place?
- Technology for the spacecrafts... nanocrafts?
- How can the nanocraft start orbiting around the black hole?
- Designing the scientific tests
- Tidal effects near the black hole?
- How can the nanocraft send the data to Earth?

Thank You!