Title: A new method to construct waveforms for Extreme-Mass-Ratio Inspirals

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Abstract: TBA

A New Method to Construct Waveforms for Extreme-Mass-Ratio Inspirals

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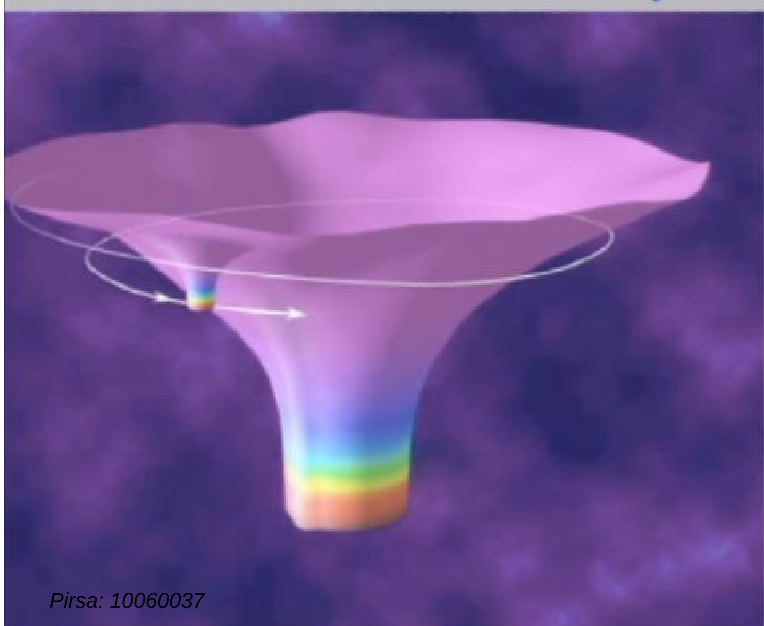
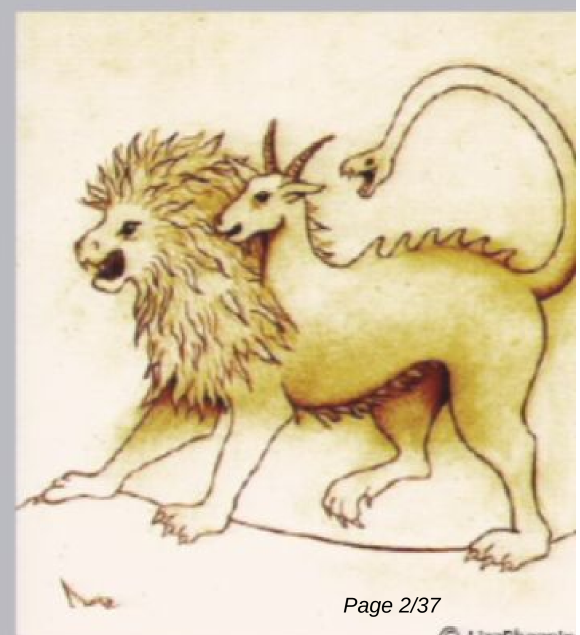


Work in collaboration with Nico Yunes (Princeton)



Outline

- Motivation for a scheme to construct approximate EMRI waveforms.
- A brief review of previous approximate methods
- A new Method: The Chimera Scheme
- Present Status and Future Prospects

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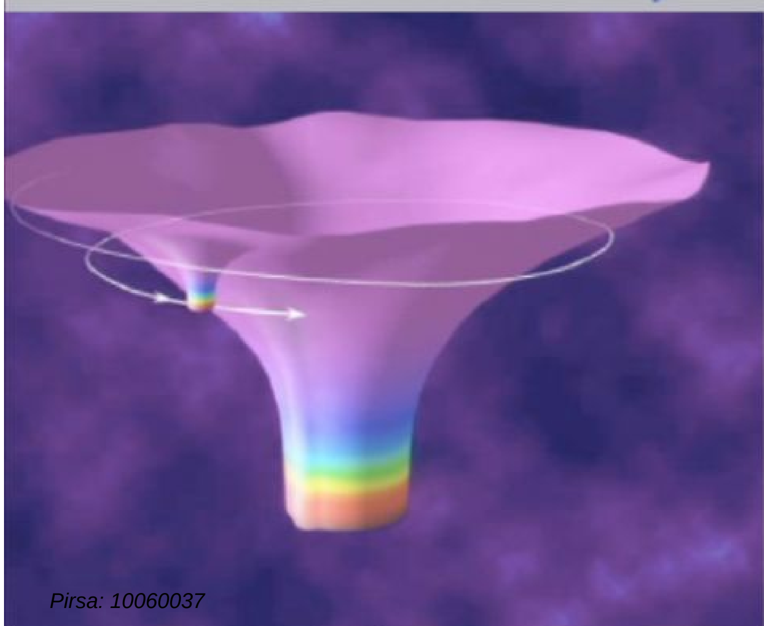

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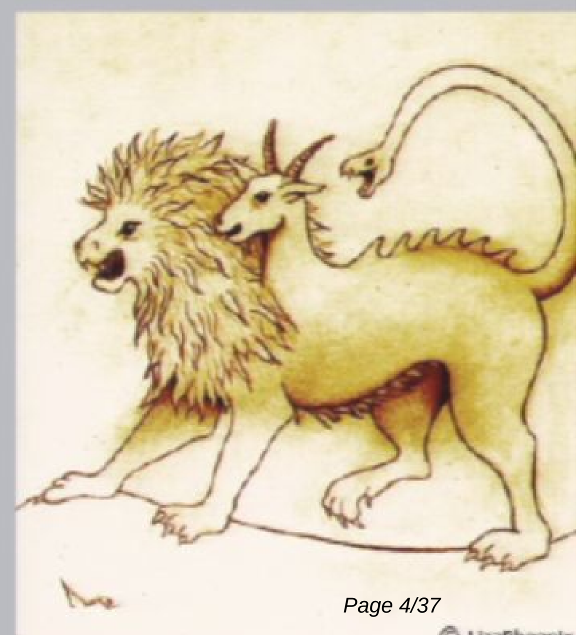

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Motivation

EMRIs are one of the main sources of GWs for LISA. The parameters of interest are:

$$\left.\begin{array}{lcl} m & \sim & 1-30\,M_\odot \\ M_\bullet & \sim & 10^5-10^7\,M_\odot \end{array}\right\} \Longrightarrow \mu = \frac{m}{M_\bullet} \sim 10^{-7}-10^{-3}$$

The number of orbital cycles of an EMRI during the last year before plunge (inside the LISA band) is:

$$N_{\rm cycles} \sim 10^5 - 10^6$$

Then, it is clear that we cannot produce EMRI waveform template banks from the best methods presently available (self-force, Teukolsky + radiative approximation).

Motivation

Therefore, we need an approximate scheme that captures the essential characteristics of the EMRI dynamics (in particular coming from self-force calculations) in such a way that it can produce accurate waveforms in an efficient way.

Apart from their use for Data Analysis purposes, these approximate waveforms can also be used for parameter-estimation purposes.

Review of Approximate Methods

Newtonian [Peters & Mathews (1963)]: Newtonian trajectories + Quadrupolar waveforms.

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<u>Teukolsky</u> [Drasco & Hughes (2004)]: Kerr geodesics + Teukolsky fluxes + Teukolsky waveforms.

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Numerical Kludge [Babak et al (2007); Gair & Glampedakis (2006)]: Kerr geodesics + pN fluxes + Multipolar waveforms

A new Method: The Chimera Scheme

- In Greek mythology, the Chimera was a monstrous fire-breathing creature of Lycia (in Asia Minor), composed of the parts of multiple animals: upon the body of a lioness with a tail that terminated in a snake's head, the head of a goat arose on her back at the center of her spine.

A new Method: The Chimera Scheme

- The term chimera has also come to mean, more generally, an impossible or foolish fantasy, hard to believe… [Wikipedia]

A new Method: The Chimera Scheme

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Kerr geodesics +
Harmonic Coordinates

Radiative Self-Force
from post-Minkowskian
approximation +
Asymptotic matched
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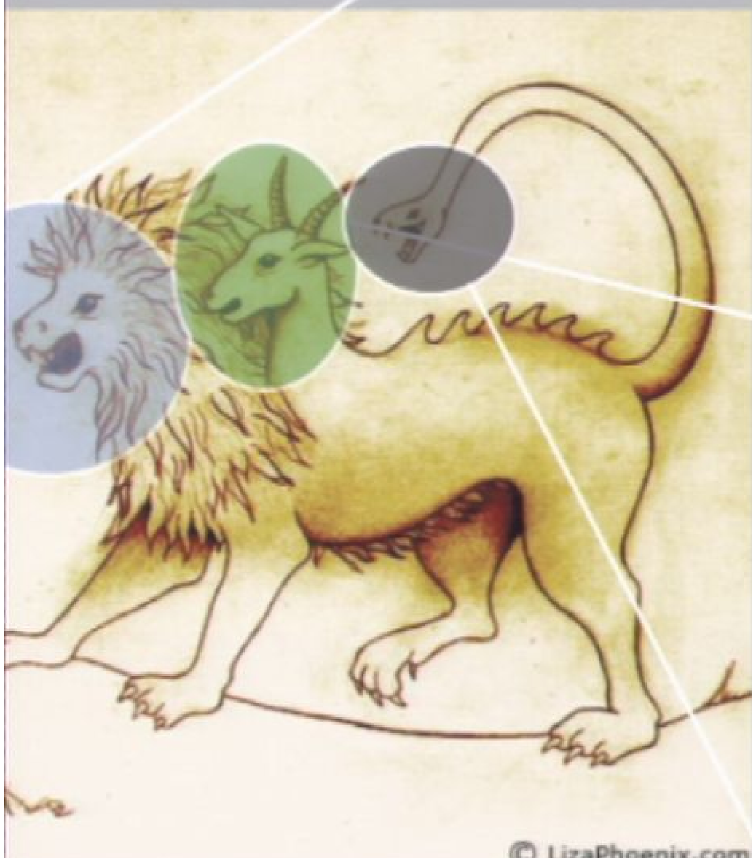
A new Method: The Chimera Scheme



Kerr geodesics +
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Multipolar Expansion
of the Gravitational

A new Method: The Chimera Scheme

* Radiative Self-From from post-Minkowskian pproximation + Asymptotic matched expansions Blanchet & Damour (1984); Iyer & Will (1995); lanchet (1997)]

* Basic Idea: To determine the gravitational field oth at the "near zone" and the "exterior zone" and to natch the two solutions at the overlapping region. hese solutions for the gravitational fields are xpanded in G (post-Minkowskian expansion) and n harmonics (multipoles).

A new Method: The Chimera Scheme

* Radiative Self-From from post-Minkowskian
pproximation + Asymptotic matched expansions
Blanchet & Damour (1984); Iyer & Will (1995);
lanchet (1997)]

* Using the half retarded minus half advanced
olution, the matching of the solutions provides an
xpression for a dissipative (radiative) self-force.

A new Method: The Chimera Scheme

* At 1PN order, the radiative self-force is determined from a scalar and a vector radiation-reaction potentials:

$$
\begin{aligned}
V_{\mathrm{RR}}(t,\mathbf{x}) &= -\frac{1}{5}x^{ij}M^{(5)}_{ij}(t) + \frac{1}{189}x^{ijk}M^{(7)}_{ijk}(t) \\
&- \frac{1}{70}\mathbf{x}^2 x^{ij}M^{(7)}_{ij}(t)\,, \\
V^i_{\mathrm{RR}}(t,\mathbf{x}) &= \frac{1}{21}\hat{x}^{ijk}M^{(6)}_{jk}(t) - \frac{4}{45}\epsilon_{ijk}x^{jl}S^{(5)}_{kl}(t)\,,
\end{aligned}
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* Comment: All this assumes a harmonic gauge
harmonic coordinates for the multipolar expansion).

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* The radiative self-force has two pieces:
i) Gradients of the potentials [this implies we need
up to eight-order time derivatives of the trajectory].
ii) Interaction terms of the radiative potentials with
he near-zone potentials (Kerr gravitational field).

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A new Method: The Chimera Scheme

* Kerr geodesics + Harmonic Coordinates [Ding 1983); Abe, Ichinose & Nakanishi (1987)] [See also Ruiz (1986)]:

$$
\begin{aligned}
t_{\mathrm{H}} &= t\,,\\
x_{\mathrm{H}} &= \sqrt{(r-M_{\bullet})^2+a^2}\ \sin\theta\ \cos[\phi-\Phi(r)]\,,\\
y_{\mathrm{H}} &= \sqrt{(r-M_{\bullet})^2+a^2}\ \sin\theta\ \sin[\phi-\Phi(r)]\,,\\
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A new Method: The Chimera Scheme

* Kerr geodesics + Harmonic Coordinates: An lternative to this is to use Asymptotically Cartesian nd Mass Centered coordinates (ACMC) [Thorne 1980)]

* This may be a convenient path to deal with the case n which the massive object is not described by the Kerr metric.

A new Method: The Chimera Scheme

- Multipolar Expansion of the Gravitational waveforms [Thorne (1980)]

$$h_{ij}^{\rm TT} = \frac{4}{r}\sum_{\ell=2}^{\infty}\Bigg[\frac{1}{\ell!}\mathfrak{M}^{(\ell)}_{ijI_{\ell-2}}(t-r)N_{I_{\ell-2}}$$

$$+ \frac{2\ell}{(\ell+1)!}\varepsilon_{kl(i}\mathfrak{I}^{(\ell)}_{j)kI_{\ell-1}}(t-r)n_l N_{I_{\ell-2}}\Bigg]^{\rm TT}$$

- Here, we also use harmonic coordinates (improving over the procedure of the Numerical Kludge waveforms).

A new Method: The Chimera Scheme

* General Procedure, Step by Step: For initial data xo,yo,zo) & (p,e,i)/(E,Lz,C)

I) Evolution of the Geodesic Equation from a time tep Dt (in harmonic coordinates).

II) Evaluation of the dissipative self-force.

III) Estimation of the change in the constants of notion (E,Lz,C)

$$
\begin{aligned}
\dot{E} &= -\Gamma^{-1} u^{\mu} \nabla_{\mu} \left(\xi^{(t)}_{\mu} u^{\mu} \right) = -\Gamma^{-1} \, \xi^{(t)}_{\mu} \, a^{\mu}_{\mathrm{RR}} \,, \\
\dot{L}_z &\equiv \Gamma^{-1} u^{\mu} \nabla_{\mu} \left(\xi^{(\phi)}_{\mu} u^{\mu} \right) = \Gamma^{-1} \, \xi^{(\phi)}_{\mu} \, a^{\mu}_{\mathrm{RR}} \,,
\end{aligned}
$$

A new Method: The Chimera Scheme

* General Procedure, Step by Step: For initial data
xo,yo,zo) & (p,e,i)/(E,Lz,C)

IV) Evaluation of the waveforms (can be done at ay
ime).
V) Go back to (I).

* Note: Since our self-force is not averaged over a
umber of orbital cycles, this procedure can be
pplied, in principle, for an arbitrary time step.

Present Status and Future Prospects

* We have constructed numerical codes that mplement of the steps described in this talk.

Present Status and Future Prospects

- We have constructed numerical codes that mplement of the steps described in this talk.

- The only difficulty is to evaluate the numerical ime derivatives that enter in the self-force: up to ight-order derivatives (six-order if we use analytical xpressions for the second-order derivatives of the ultipole moments). This requires high-order ifferentiation rules and the use of Richardson xtrapolation (in part to check the accuracy).

Present Status and Future Prospects

* We are currently generating waveforms with the goal of comparing with other approximate approaches (Numerical Kludge, Teukolsky, EOB).

* We want to study the evolution of the "constants of motion" and compare with several approximations in the literature.

Present Status and Future Prospects

- For the future, we would like to investigate the ossibility of using the Chimera waveforms for arameter-estimation analysis.

- It can clearly be improved in several ways: ntroducing conservative pieces of the self-force, etc.

- It would be interesting to see how this Scheme can e extended to other geometries (non-Kerr) and even other gravitational theories.

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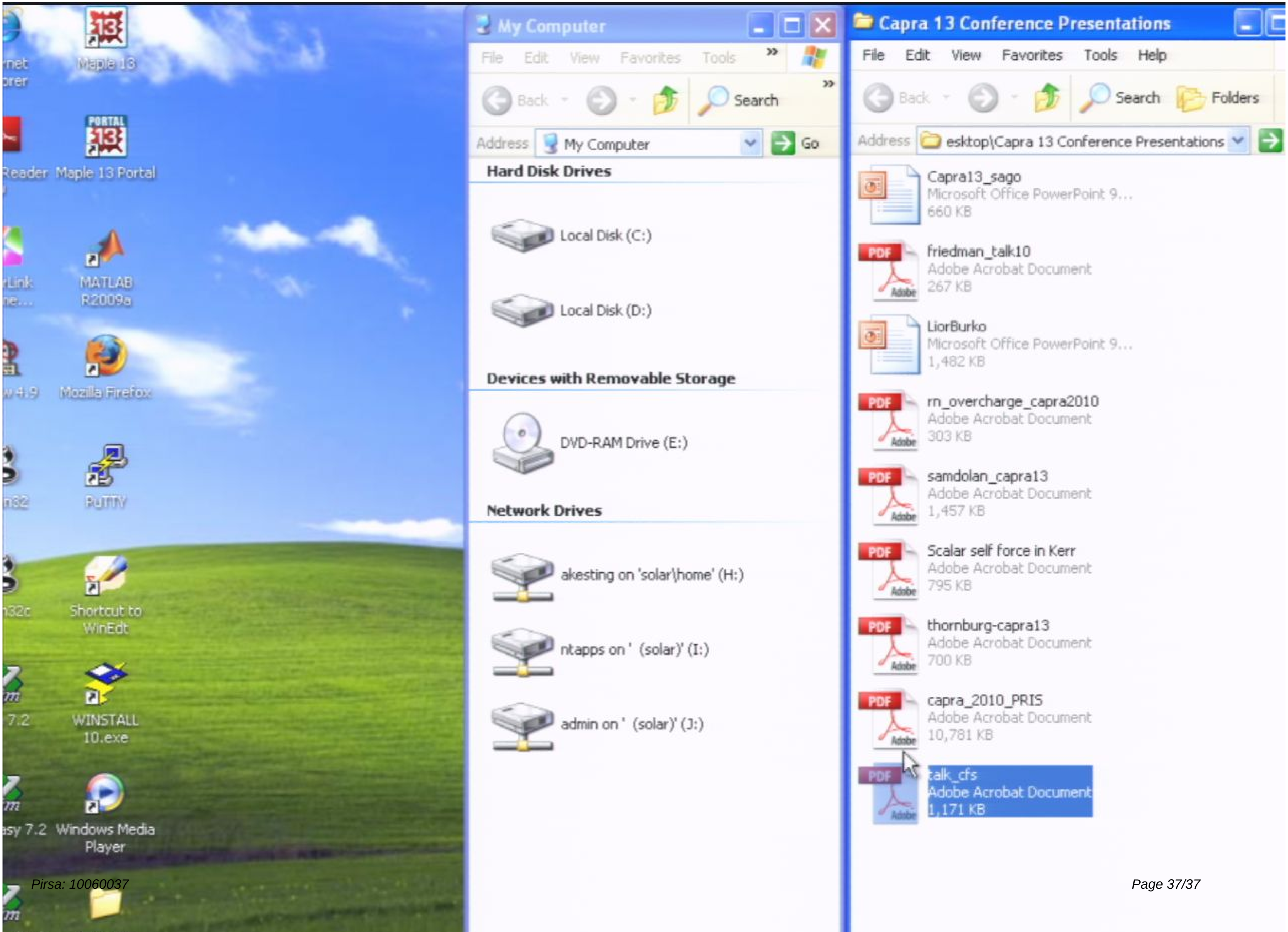
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Shortcut to WinEdt
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Windows Media Player
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