Results and recent advances with the CHIMERA and FARCOS detectors

Physics cases: Working with Chimera + Farcos array (examples with stable and exotic beams)

A the new front-end electronic and hybrid-DAQ
GET: generic electronics for TPC: a compact system going from front-end electronic to data readout. FARCOS status

Recent results: PYGMY and Gamma-Hoyle experiments

Recent results: Isospin influence on dynamical production of IMFs in $^{124}$Xe+$^{64}$Ni, $^{64}$Zn, $^{124}$Sn+$^{64}$Ni isobaric systems

Asy-Eos II: Plans for high density symmetry energy studies at GSI
Physical cases:

Upgrades: pulse shape, digital electronics, Coupling of $4\pi$ detectors with ancillary arrays (correlators), Neutron detection signal (see E.V. Pagano talk).
Physical cases:

Upgrades: pulse shape, digital electronics, Coupling of $4\pi$ detectors with ancillary arrays (correlators), Neutron detection signal (see E.V. Pagano talk).
Physical cases:

Upgrades: pulse shape, digital electronics, Coupling of 4π detectors with ancillary arrays (correlators), Neutron detection signal (see E.V. Pagano talk).

Nuclear Equation of State and Symmetry energy of asymmetric nuclear matter: Symmetry energy parametrization at low and high densities.

Dynamics and thermodynamics in heavy ion-reactions: time scale of particles and cluster emission, neck emission: fragment-fragment and particle correlations. Dynamical fission.


Correlations of light particles from break-up reactions in neutron rich nuclei. Isoscalar excitations of PDR (FRIBs beams, CLIR, PYGMY). (see N. Martorana poster).

Isospin dependence of compound nucleus formation and decay: study of the isospin influence on the reaction dynamics and competition between different decay modes (ISODEC) at 10 MeV/A. (see B. Gnoffo talk)
An example: three body analysis of fragments

$^{124}\text{Xe} + ^{64}\text{Ni}$ 35 A.MeV
An example: three body analysis of fragments

$^{124}_{\text{Xe}} + ^{64}_{\text{Ni}}$ 35 A.MeV

$\Delta E - E \rightarrow Z$
An example: three body analysis of fragments

$^{124}\text{Xe} + ^{64}\text{Ni}$ 35 A.MeV

TARGET

Beam

CsI(Tl)

Si

$\Delta E-E$ ToF

$Z,M$

$V_{par}$ (cm/ns)
An example: three body analysis of fragments
An example: three body analysis of fragments

What is FARCOS and why we need it?
What is FARCOS and why we need it?

- High energy and angular resolution \((\Delta \vartheta < 1^\circ)\)
- Low thresholds \(<1 \text{ MeV/A}\):
- Pulse-shape on first Si layer for low energy experiments
- High counting rate \((1 \text{KHz})\)
- Large Dynamic range \((1 \text{ MeV to 2GeV})\)
- Flexibility, Modularity, Transportability
- Easy coupling to \(4\pi\) detectors or spectrometers
- Integrated Electronics \((\text{GET})\)

132 channels by each cluster

- DSSSD 1500 \(\mu\)m (2nd stage)
- 4 CsI(Tl) 6 cm (3rd stage)
- DSSSD 300 \(\mu\)m (1st stage)

Farcos: a 3 stage telescope
FARCOS: Femtoscope Array for Correlations and Spectroscopy

Technical Design Report (TDR): [https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWFE/view](https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWFE/view)

64 mm, 32 strips, Double-Sided Silicon Strip Detectors produced by Micron Semiconductor. 
(300 and 1500 µm / C= 25pF and 5pF )
Capton cable 2x32pin connectors 
Minimum PCB frame-area thick, 4 mm, frame-thick 6.5 mm 
\[ \Delta \text{E} = 20\text{KeV} \ (\alpha \ 5.48 \text{MeV}) \ \Delta \text{E}/\text{E} \ (\text{elastic})=0.2-0.3\% \]
Rise time<20ns

Highly homogeneous CsI(Tl) crystals produced by SCIONIX. 
Wrapped with 0.12 mm thick white reflector +50 µm aluminized mylar. 
Aluminized mylar window 2 µm thick (0.29 gr/cm²). Read by Photodiode Hamamatsu 300 µm 
\[ \Delta \text{E}/\text{E}=2-3\% \ (\alpha \ 5.48 \text{MeV}) \]
Assembling of the «real» FARCOS: high modularity


<table>
<thead>
<tr>
<th>Year</th>
<th>Tel.</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>6</td>
<td>test acq. GET for FARCOS construction of 2 telescopes purchase of final GET electronics</td>
</tr>
<tr>
<td>2016</td>
<td>10</td>
<td>test dual gain module test GET electronic +DAQ Study of alignment system</td>
</tr>
<tr>
<td>2017</td>
<td>10(14)</td>
<td>test newasic pre-amplifiers final design modular support implementationasic pre-amplifier newDAQ VME+ GET running</td>
</tr>
<tr>
<td>2018</td>
<td>14</td>
<td>First experiments with new Chimera+Farcos front-end</td>
</tr>
<tr>
<td>2019</td>
<td>20+2</td>
<td>20 telescopes ready</td>
</tr>
</tbody>
</table>

Final cost prediction: ≈ 1 M€

Design simulation: Luis Acosta
Selectable-Gain CMOS Charge Preamplifier for Pulse Shape Analysis in Double Sided Silicon Microstrip Detectors for FARCOS

✓ single design for both thicknesses and of both polarities
✓ strip capacitance about 65 pF (300 µm) and 35 pF (1500 µm)
✓ strip leakage current ~5 nA (300 µm) and ~25 nA (1500 µm)
✓ target dynamic ranges: 90 MeV, 200 MeV, 350 MeV and 500 MeV.
✓ static power consumption ~10 mW/channel
✓ Selectable gain

16-ch ASIC layout
0.35 µm C35B4C3 AMS tech

✓ 16-ch CPA for DSSSD
✓ 2-ch CPA for CsI(Tl) + PD readout
✓ on-chip pulser
✓ channel-by-channel test signal injection
✓ temperature monitor

A Kapton cable connects each face of each DSSSC to a custom PCB motherboard housing the front-end ASIC (2x(16+1) channels.)

See Chiara Guazzoni talk
Selectable-Gain CMOS Charge Preamplifier for Pulse Shape Analysis in Double Sided Silicon Microstrip Detectors for FARCOS

- Single design for both thicknesses and of both polarities
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- On-chip pulser
- Channel-by-channel test signal injection
- Temperature monitor

Alpha source with FARCOS DSSSD, 300 mm thick
**HBT interferometry:**
- Particle correlations at small relative momentum;
- Nuclear dynamics;
- Space-time characterization of the emitting source;
- Emission time: from pre-equilibrium emission to secondary decay;
- Information on reaction mechanism and time-scales.

**Multi particle correlations:**
- Spectroscopy of unbound states;
- Cluster structures, IMF-IMF correlations (example for $^{124}$Sn+$^{64}$Ni@35 A.MeV reaction, E.V. Pagano, PoS, Bormio 2017).

**Correlators:**
- Physics case

More correlation if source is smaller in **space**

More correlation if source is smaller in **time**
Dynamical processes in projectile break-up and Intermediate Mass Fragments production at 20 A.MeV beam incident energy studied with the CHIMERA and FARCOS devices. CHIFAR: CHImera-FARcos (approved LNS-PAC proposal) spokes: E.V. Pagano, E.d.F., P. Russotto

CHIMERA + 10 FARCOS telescopes in a “quasi”-ring configuration

\[ ^{124}\text{Xe}, \, ^{124}\text{Sn} + ^{64}\text{Ni}, \, ^{64}\text{Zn} \]
\[ ^{112}\text{Sn} + ^{58}\text{Ni} \, @ \, 20\text{A}.\text{MeV} \]

Configuration CAD study for 10 FARCOS telescopes between the sphere and ring 9; Luis Acosta group, Mexico
The CLIR experiment (clustering phenomena in exotic nuclei)

Study of the structure of $^{10}$Be* ($^4$He + $^6$He) and $^{16}$C* ($^{10}$Be + $^6$He or $^4$He + $^6$He + $^6$He) by means of sequential break-up at intermediate energy.

**FRIBs cocktail beams from $^{18}$O + 1.5 mm Be target, 55 A.MeV primary beam, as seen by the Chimera tagging system**

$^{16}$C (49.5 MeV/u) 10$^5$ pps;
$^{13}$B (49.5 MeV/u) 5 · 10$^4$ pps;
$^{10}$Be (56.0 MeV/u) 4 · 10$^4$ pps;

$^4$He+$^6$He correlations: a new state at about 13.5 MeV (J$^\pi$=6+ spin parity assignment)

The CLIR experiment (clustering phenomena in exotic nuclei)

Study of the structure of $^{10}\text{Be}^*$ ($^4\text{He} + ^6\text{He}$ ) and $^{16}\text{C}^*$ ($^{10}\text{Be} + ^6\text{He}$ or $^4\text{He} + ^6\text{He} + ^6\text{He}$) by means of sequential break-up at intermediate energy

**FRIBs cocktail beams from $^{18}\text{O} + 1.5 \text{ mm Be target}$, 55 A.MeV primary beam, as seen by the Chimera tagging system**

$^{16}\text{C}$ (49,5 MeV/u) $10^5$ pps;
$^{13}\text{B}$ (49,5 MeV/u) $5 \cdot 10^4$ pps;
$^{10}\text{Be}$ (56,0 MeV/u) $4 \cdot 10^4$ pps;

$^4\text{He} + ^6\text{He}$ correlations: a new state at about 13.5 MeV ($J^\pi=6+$ spin parity assignment)

$^{10}\text{Be}$: Signals of molecular structure

M. Freer et al. PRL 96, 042501 (2006)

The CLIR-II experiment (clustering phenomena in exotic nuclei)

exp CLIR-II: CHIMERA + FARCOS prototype
Analysis in progress ...

4 FARCOS telescopes placed symmetrically around the beam axis)
The CLIR-II experiment (clustering phenomena in exotic nuclei)

Monte Carlo simulations for the $^{10}\text{Be}^*$ decay ($\alpha + ^6\text{He}$ channel)

Farcos

$^{10}\text{Be}$

4 FARCOS telescopes placed symmetrically around the beam axis)

exp CLIR-II: CHIMERA + FARCOS prototype

Analysis in progress ...
Search of the isoscalar excitation of the PYGMY resonance in $^{68}\text{Ni}$ using the LNS FRIB facility from a 40 A.MeV $^{70}\text{Zn}$ primary beam.
Search of the isoscalar excitation of the PYGMY resonance in $^{68}\text{Ni}$ using the LNS FRIB facility from a 40 A.MeV $^{70}\text{Zn}$ primary beam.

$^{68}\text{Ni} + ^{12}\text{C}$ reactions mostly produce:

- quasi-elastic reactions $\rightarrow ^{68}\text{Ni}$
- Emission of neutrons $\rightarrow ^{66,67}\text{Ni}$

The CsI(Tl) in the Sphere provide $\gamma$ detection.
The Pygmy experiment

First measurement of the isoscalar excitation above the neutron emission threshold of the Pygmy Dipole Resonance in $^{68}\text{Ni}$

N.S. Martorana$^{a,b}$, G. Cardella$^a$, E.G. Lanza$^a$, L. Acosta$^{a,c}$, M.V. Andrés$^a$, L. Auditiore$^{a,d}$, F. Catarò$^a$, E. De Filippo$^a$, S. De Luca$^{a,e}$, D. Dell’Aquila$^b$, B. Gnoatto$^{a,e}$, G. Lanzalone$^{a,b}$, I. Lombardo$^a$, C. Maiolino$^a$, S. Norella$^{a,b}$, A. Pagano$^a$, E.V. Pagano$^a$, M. Papa$^a$, S. Pirrone$^a$, G. Politi$^{a,h}$, L. Quattrocchi$^{a}$, F. Rizzo$^{a,b}$, P. Russotto$^a$, D. Santonocito$^a$, A. Trifirò$^{a,e}$, M. Trimarchi$^{a,f}$, M. Vigilante$^a$, A. Vitturi$^a$

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$^d$Istituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico
$^e$Departamento de FAMN, Universidad de Sevilla, Sevilla, Spain
$^f$Dipartimento MHT, Messina, Italy
$^g$INFN- Sezione di Napoli and Dipartimento di Fisica, Università di Napoli Federico II, Napoli, Italy
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$^i$Dipartimento di Fisica e Astronomia, Università G. Galilei and INFN- Sezione di Padova, Padova, Italy

Abstract

The excitation of the Pygmy Dipole Resonance (PDR) in the $^{68}\text{Ni}$ nucleus, above the neutron emission threshold, via an isoscalar probe has been observed for the first time. The excitation has been produced in reactions where a $^{68}\text{Ni}$ beam, obtained by the fragmentation of a $^{68}\text{Zn}$ primary beam at INFN- Lyons, impinged on a $^{12}\text{C}$ target. The $\gamma$-ray decay was detected using the CsI(Tl) detectors of the CHIMERA multidetector sphere. The $^{68}\text{Ni}$ isotope as well as other heavy ion fragments were detected using the FARCOS array. The population of the PDR was evidenced by comparing the detected $\gamma$-ray energy spectra with statistical code calculations. The isotopic resolution of the detection system allows also to directly compare neutron decay channels with the $^{68}\text{Ni}$ channel, better evidencing the PDR decay response function. This comparison allows also the extraction of the PDR cross section and the relative $\gamma$-ray angular distribution. The measured $\gamma$-ray angular distribution confirms the E1 character of the transition. The $\gamma$ decay cross section for the excitation of the PDR was measured to be 0.32 mb with a 18 % of statistical error.


doi.org/10.1016/j.physletb.2018.05.019

Evidences of the PDR:

- $\gamma$-rays energy spectrum in coincidence with $^{66,67}\text{Ni}$ channels

- $\gamma$-rays energy spectrum in coincidence with $^{68}\text{Ni}$ channel
The Pygmy experiment


doi.org/10.1016/j.physletb.2018.05.019

Evidences of the PDR:

- $\gamma$-rays energy spectrum in coincidence with $^{66,67}$Ni channels
- $\gamma$-rays energy spectrum in coincidence with $^{68}$Ni channel

Cross section for the PDR $\gamma$-decay, $\sigma_\gamma = 0.32$ mb ($\pm 18\%$)
Why a new front-end electronic?

CHIMERA CsI(Tl) front-end (1192 detectors) is now obsolete, in particular the amplifiers and the VME QDCs for CsI fast-slow component integration (more than 15 years old technology). The final FARCOS array constituted by 5 modules (20 telescopes, in the final project) needs the readout of about **4k** channels.

Our choice was to develop a first stage front-end circuit for FARCOS (including new ASIC pre-amplifiers) and new dual-gain modules coupled to a compact hardware architecture covering digitalization and signal readout, synchronization and trigger functions. All these last aspects are covered by the GET project.

Consequences → digital DAQ for Farcos and CHIMERA (CsI) + Analog DAQ (Silicons)
Upgrade of the CHIMERA front-end for CsI(Tl) (in progress...)

R&D Financed 75% (France)  
25% (USA)
Project supervisor: E. Pollacco

GET Project

256 + (16 FPN) input channels
Hybrid DAQ based on «NARVAL» supervisor for both CHIMERA and GET data acquisitions

- Narval developed at IPN-Orsay by X. Grave
- based on the concept of generic Actors
- written in OO language ADA with C++ interface
- Data flow: TCP/IP
- Run Control Core and GUI interface based on Java (GANIL)

VME DAQ, VME-GET Coupling, Data Analysis software for CoBo(s) and VME and general off-line MERGER, Dual Gain Modules developed at INFN Catania
GET tests: fragmentation beams (primary 55 A.MeV \(^{18}\text{O}\)) on plastic target

- Standard CHIMERA preamplifier used in the silicon stage (2 mV/MeV) [Chimera, ring 2E]
- The signals are digitized at a frequency of 50MHz
- Both signals Si/CsI are shaped with a 1µs shaping time in the SKF filter stage of AGET chips.
- Better isotopic resolution obtained with GET respect to analog DAQ.
- Note the CHIMERA CsI fast component signal saturation $\rightarrow$ dual gain (DG) module needed (as well for FARCOS silicon strips)

See: E.C. Pollacco et al., NIM A 887, 81-93 (2018)

Neutron signals: tests with the **EJ299-33** and GET electronics

A 3x3x3 cm **EJ299-33** plastic scintillator was tested with radioactives sources and Tandem beams for its capability to detect neutrons along with light charged particles.

Output signal is digitized by GET electronics after and sampled at 100 MS/s after filter shaping. Fast and Slow gates are obtained by software integration of the digital pulse.

Decay time of the digitized signals as a function of the total component, *accepted in NIM A (2018)*
The Hoyle-GAMMA experiment: search of the $\gamma$-decay branching ratio of the Hoyle state and first excited 3- level of $^{12}$C by $\alpha$ (60 MeV) + $^{12}$C reaction (2017)

The proposed method: CHIMERA is able to see the 4-fold coincidence (scattered alpha + recoiling carbon + $\gamma$-$\gamma$ coincidence with good efficiency)
The Hoyle-GAMMA experiment: first results, alpha-Carbon-γ correlations

Chimera sphere
Isospin influence on dynamical production of IMFs in the InKilsSy (Inverse Kinematics Isobaric Systems) experiment: $^{124}\text{Xe} + ^{64}\text{Zn, Ni}@35\text{ A.MeV}$

Physical case: competition between dynamical and statistical IMF emission. Influence of the N/Z ratio of the entrance channel in the dynamical fission of the quasi-projectile.

### Table

<table>
<thead>
<tr>
<th>System</th>
<th>N/Z Projectile</th>
<th>N/Z Target</th>
<th>N/Z Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{124}\text{Sn}+^{64}\text{Ni}$</td>
<td>1.48</td>
<td>1.29</td>
<td>1.41</td>
</tr>
<tr>
<td>$^{124}\text{Xe}+^{64}\text{Ni}$</td>
<td>1.30</td>
<td>1.29</td>
<td>1.29</td>
</tr>
<tr>
<td>$^{124}\text{Xe}+^{64}\text{Zn}$</td>
<td>1.30</td>
<td>1.13</td>
<td>1.24</td>
</tr>
<tr>
<td>$^{112}\text{Sn}+^{58}\text{Ni}$</td>
<td>1.24</td>
<td>1.07</td>
<td>1.18</td>
</tr>
</tbody>
</table>
Our approach to dynamical IMF emission is to use angular distribution of fragments in order to estimate the probabilities or cross-sections of dynamical vs. statistical emission as a function of IMFs charge.
Our approach to dynamical IMF emission is to use angular distribution of fragments in order to estimate the probabilities or cross-sections of dynamical vs. statistical emission as a function of IMFs charge.

This is a different and complementary study respect the case where the relation between the N/Z of fragments is observed as a function of the break-up angular distributions, finally related to the time-scale of the process.

A. RODRIGUEZ MANSO et al.

PHYSICAL REVIEW C 95, 044604 (2017)
Main experimental Result: dynamical emission is favored by an increase of projectile and target Isospin and is independent by the system size.

Evaluation method based on $\cos(\theta_{\text{prox}})$

Linear Scaling with a weighted N/Z content of projectile and target

Dynamical emission is mainly ruled by the N/Z content of both projectile and target.
Constrained Molecular Dynamics simulation (CoMD-3)

PRELIMINARY

650 fm/c and stiffness parameter on $E_{\text{sym}}(\rho)$, $\gamma=1$ (stiff). Data analysis as for the experimental data.

(work in progress...)

Model $\rightarrow$ see M. Papa, Phys. Rev. C87, 014001 (2013) and refs therein
DENSITY AND ISOSPIN DEPENDENCE OF EOS: ASYEOS and ASYEOS-II

**Sources:**

- Finite nuclei \( \rho/\rho_0 \leq 1 \)
- Heavy ions \( \rho/\rho_0 \leq 3 \)
- Neutron stars \( \rho/\rho_0 \leq 10 \)

**ASYEOS Method Used:** Collective Elliptic Flow


**see: J. Lukasik talk on Thursday**

**Elliptic Flow:**

\[
\frac{dN}{d(\phi - \phi_R)}(y, p_t) = \frac{N_0}{2\pi} \left( 1 + 2 \sum_{n \geq 1} v_n \cos n(\phi - \phi_R) \right)
\]

**Transverse Flow**

\[
V_1(y, p_t) = \left( \frac{p_x}{p_t} \right)
\]

**Elliptic Flow**

\[
V_2(y, p_t) = \left( \frac{p_x^2 - p_y^2}{p_t^2} \right)
\]

**Elliptic Flow:** competition between in plane \((V_2 > 0)\) and out-of-plane ejection \((V_2 < 0)\)
FLOW ratios of neutrons/Charged particles in comparison with UrQMD predictions

\[ \gamma = 0.7 \pm 0.2 \]
\[ L = 72 \pm 13 \text{ MeV} \]

HIC: (mainly Sn+Sn . . . )

M.B. Tsang et al., PRC 86, 015803 (2012)


FOPI DATA: P. Russotto et al., Phys. Lett. B 697 (2011): \( \gamma = 0.9 \pm 0.4 \); \( L = 83 \pm 26 \)

ASYEOS DATA
\[ \gamma = 0.72 \pm 0.19 \]; \( L = 72 \pm 13 \)
ASYEOS-II@GSI: towards higher incident energies and higher explored densities

UrQMD predictions (AsyEos meeting, LNS 2017)

J. Xu et al. PRC 87, 067601 (2013)

Constrain the symmetry term of EOS: New data occur at suprasaturation densities

New possible setup: G-PAC Lol S464
ASYEOS-II@GSI: towards higher incident energies and higher explored densities

Constrain the symmetry term of EOS: New data occur at suprasaturation densities

J. Xu et al. PRC 87, 067601 (2013)

UrQMD predictions (AsyEos meeting, LNS 2017)

New possible setup: G-PAC LoI S464

Krakow Barrel (rings of scintillating fibers): hit distributions at backward angles for triggering, reaction plane and centrality determination
A suggestion for the future presented by M.D. Cozma at AsyEos 2017 meeting at LNS:

Look simultaneously at slope (L) and curvature (K_{sym}) of the symmetry energy by using the experimental elliptic flow data.
Summary

Advances and news in «Chimera» Instrumentation

Due to the construction of 20 Farcos telescopes we have adopted a compact electronic front end based on the design of new ASIC preamplifiers for silicon strips and the GET electronics for digitalization and data readout in FARCOS and CHIMERA CsI.

FARCOS, with its high and angular resolution, enhances the physics that can be studied with the CHIMERA array (including two and multi-particles correlations) It can be coupled with other devices in laboratories (LNS, SPES,GANIL,GSI...) following the physics cases

A research to develop a multi-detector plastic prototype based on EJ299-33 devoted to neutron detection has been started

Results and news in «Physics»

I have shown a summary of activities performed by CHIMERA collaboration spanning from nuclear dynamics to nuclear structure by using both stable and radioactive beams to the ASYEOS collaboration plannings for new experiments at GSI related to the symmetry energy parametrization at high density.

The project of LNS Cyclotron upgrade and new Fragment Separator «Fralse» match perfectly with our planning and perspectives for the next future.
Collaboration for Farcos project and Chimera upgrade

L. Acosta¹,², L. Auditore⁴, C. Boiano⁵, G. Cardella¹, A. Castoldi⁵, M. D’Andrea¹, E. De Filippo¹, D. Dell’Aquila⁶, S. De Luca⁴, F. Favela¹, F. Fichera¹, N. Giudice¹, B. Gnoffo¹, A. Grimaldi¹, C. Guazzoni⁵, G. Lanzalone²,⁷, F. Librizzi¹, P. Litrico², I. Lombardo⁶, C. Maiolino², S. Maffesanti⁵, N. Martorana², A. Pagano¹, E. V. Pagano²,³, M. Papa¹, T. Parsani⁵, G. Passaro², S. Pirrone¹, G. Politi¹,³, F. Previdi⁵, L. Quattrocchi⁴, F. Rizzo²,³, P. Russotto¹, G. Saccà¹, G. Salemi¹, D. Sciliberto¹, A. Trifirò⁴, M. Trimarchi⁴, M. Vigilante⁶

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