



**GW170817**: a gravitational wave signal observed by the LIGO and Virgo detectors on 17 August 2017. **GRB 170817A**: a short gamma-ray burst detected by the Fermi and INTEGRAL spacecraft 1.7 seconds after the GW signal ended



The neutron star merger event is thought to result in a kilonova, characterized by a short gamma ray burst followed by a longer optical "afterglow" powered by the radioactive decay of heavy r-process nuclei.

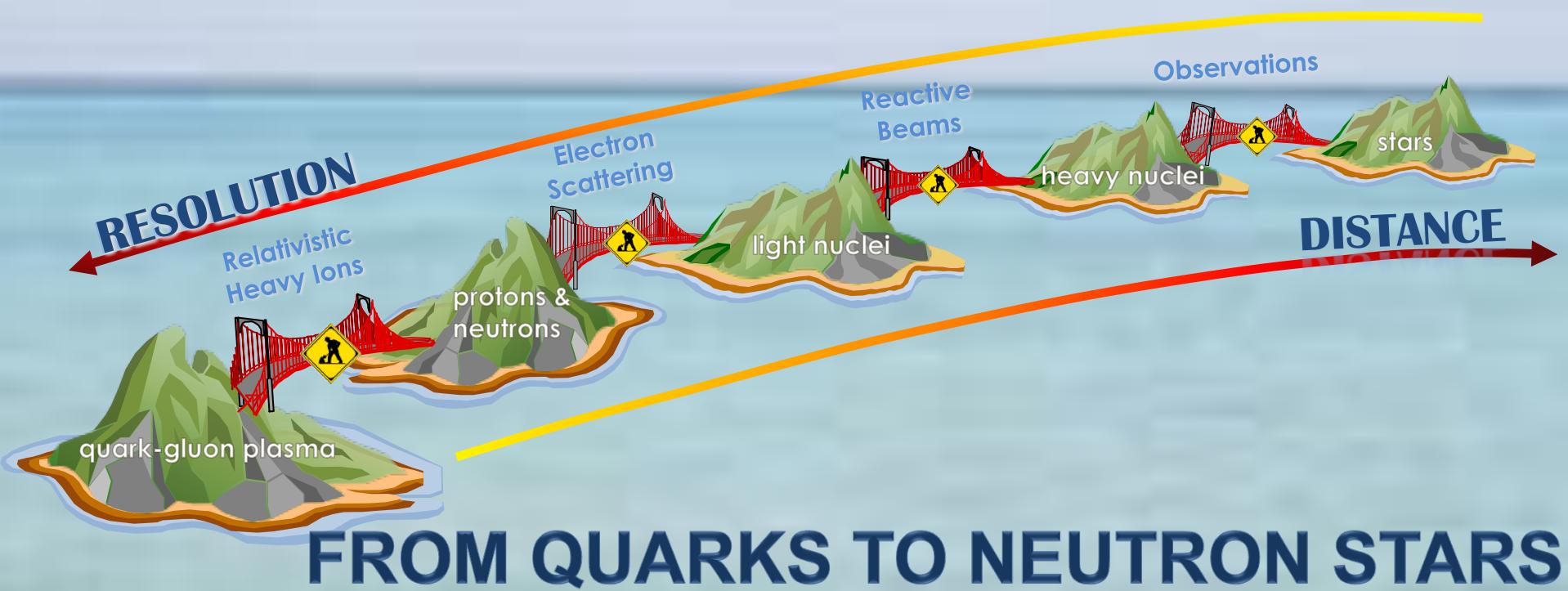


A total of 16,000 times the mass of the Earth in heavy elements is believed to have formed, including approximately ten Earth masses just of the two elements gold and platinum.

The paper describing the multi-messenger observations is coauthored by almost 4,000 astronomers (about one-third of the worldwide astronomical community) from more than 900 institutions, using 70 observatories on all seven continents and in space.

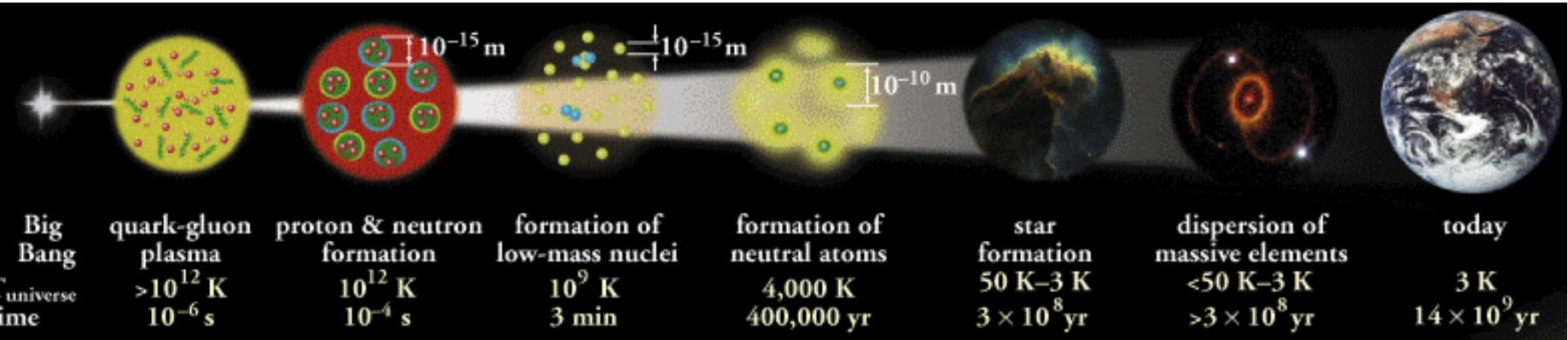
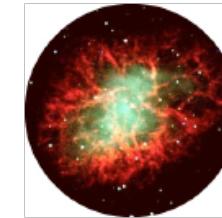
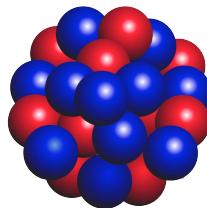
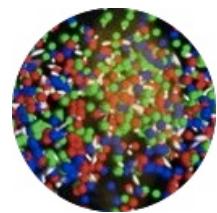
# Subfields of nuclear physics

- Nuclear structure, whose goal is to build a coherent framework for explaining all properties of nuclei and nuclear matter and how they interact;
- Nuclear astrophysics, which explores those events and objects in the universe shaped by nuclei and nuclear reactions;
- Hot QCD, or relativistic heavy ions, which examines the state of melted nuclei and with that knowledge seeks to shed light on the nature of those quarks and gluons that are the constituent particles of nuclei;
- Cold QCD, or hadron structure, which explores the characteristics of the strong force and the various mechanisms by which the quarks and gluons interact and result in the properties of the protons and neutrons that make up nuclei;
- Fundamental symmetries, those areas on the edge of nuclear physics where the understandings and tools of nuclear physicists are being used to unravel limitations of the Standard Model and to provide some of the understandings upon which a new, more comprehensive Standard Model will be built.



# Nuclear Physics in the Universe:

The Big Bang timeline, from inflation to quark soup to the birth of the light nuclei to the formation of atoms and gravitationally bound structures.

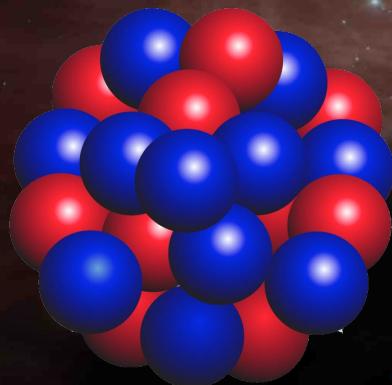
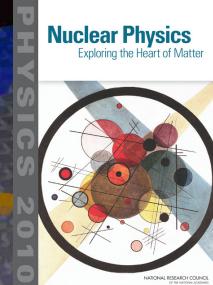


<http://www.lbl.gov/abc/wallchart/>

Image: Particle Data Group/Lawrence Berkeley National Laboratory

# The Nuclear Landscape and the Big Questions

- Where do nuclei and elements come from?
- How are nuclei made and organized?
- What are practical and scientific uses of nuclei?



## TIMESCALE

→ from QCD transition (color singlets formed; 10 ms after Big Bang) till today (13.8 billion years later)

## DISTANCE SCALE

→ from  $10^{-15}$  m (proton's radius) to  $\sim 12$  km (neutron star radius)

# The scientific agenda (questions that drive the field)

## PERSPECTIVES ON THE STRUCTURE OF ATOMIC NUCLEI

- What are the limits of nuclear existence and how do nuclei at those limits live and die?
- What do regular patterns in the behavior of nuclei divulge about the nature of nuclear forces and the mechanism of nuclear binding?
- What is the nature of extended nucleonic matter? What are its phases?
- How can nuclear structure and reactions be described in a unified way?
- How can the symbiosis of nuclear physics and other subfields be exploited to advance understanding of all many-body systems?

## NUCLEAR ASTROPHYSICS

- How old is the universe?
- How did the elements come into existence?
- What makes stars explode as supernovae, novae, or X-ray bursts?
- What is the nature of neutron stars?
- What can neutrinos tell us about stars?

## EXPLORING QUARK-GLUON PLASMA

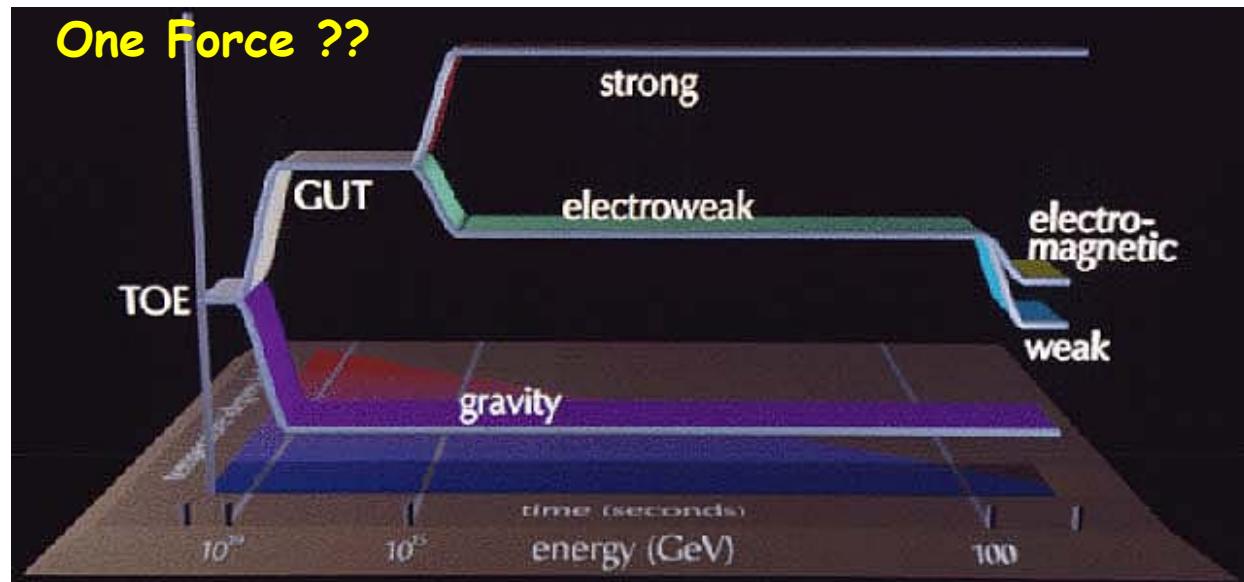
- What are properties of near-perfect liquid QGP
- What is the origin of confinement?
- What are the properties of the QCD vacuum? What is the origin of chiral symmetry breaking?
- What are the experimental signatures for a transition to new phases in relativistic heavy-ion collisions?
- What are the implications for the analogous epoch in the Big Bang?

## THE STRONG FORCE AND THE INTERNAL STRUCTURE OF NEUTRONS AND PROTONS

- What are the internal structural properties of protons and neutrons and how do those properties arise from the motions and properties of their constituents?
- How do those properties change when protons and neutrons are combined into complex nuclei?
- Can QCD describe the full spectrum of hadrons in both their ground and excited states?
- How do the nucleonic models emerge from QCD?

## FUNDAMENTAL SYMMETRIES

- What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the cosmos?
- Why is there now more visible matter than antimatter in the universe?
- What are the unseen forces that were present in the dawn of the universe but disappeared from view as it evolved? Once very hot and very homogeneous, the universe now displays a preferred “handedness” and so the existence of lost forces.
- What are the low-energy manifestations of physics beyond the Standard Model? How can precision experiments in nuclear physics reveal them?

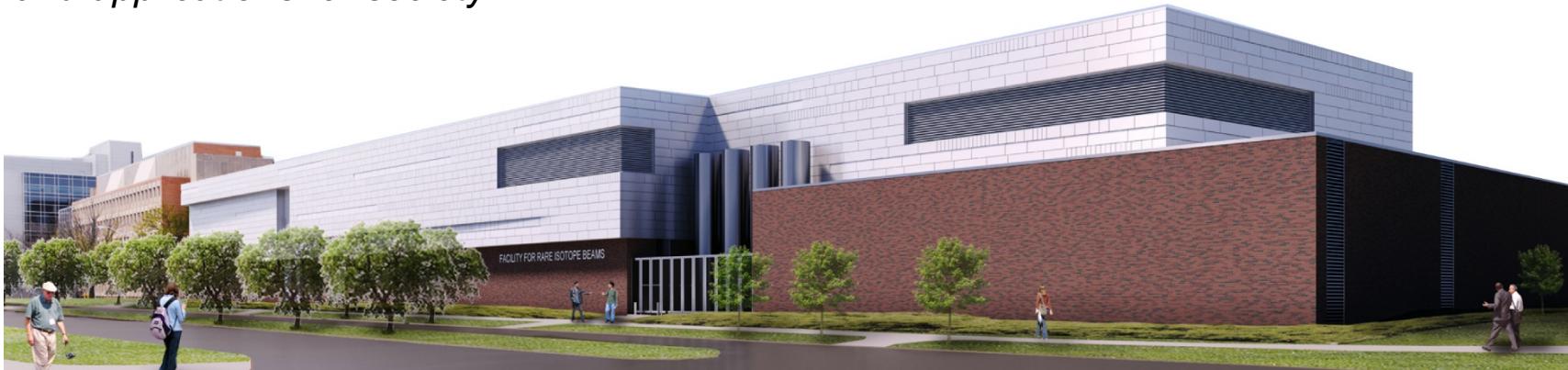


# Facility for Rare Isotope Beams at MSU



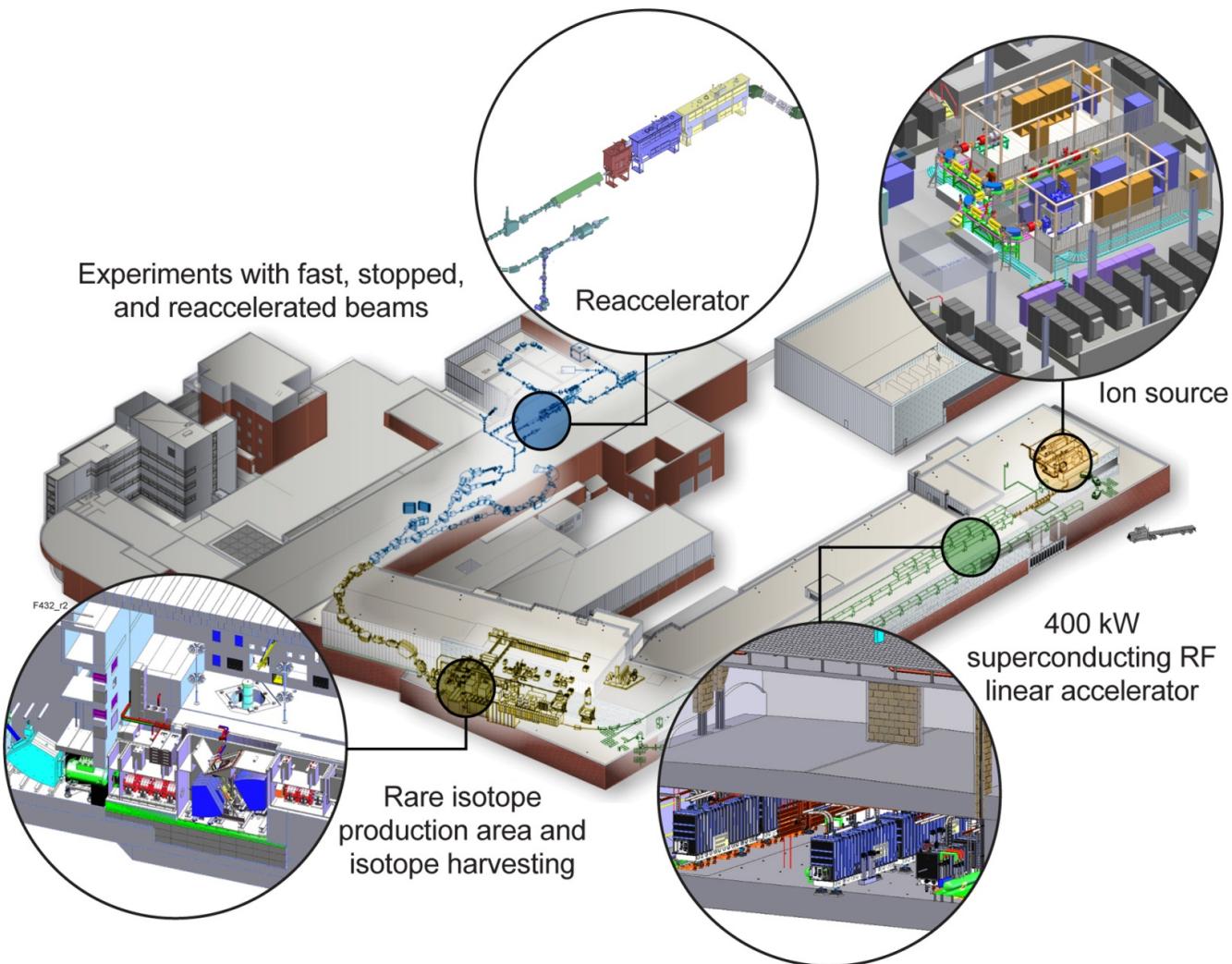
- FRIB will be a \$730 million national user facility funded by the Department of Energy Office of Science (DOE-SC), Michigan State University, and the State of Michigan
- FRIB Project completion date is June 2022, managing to an early completion in fiscal year 2021
- FRIB will serve as a national user facility for world-class rare isotope research, and builds on more than 50 years of nuclear science expertise developed at MSU

*FRIB will enable scientists to make discoveries about the properties of these rare isotopes in order to better understand the physics of nuclei, nuclear astrophysics, fundamental interactions, and applications for society*



<http://www.frib.msu.edu/news/photo-gallery/four-camera.html>

# World's Most Powerful Rare Isotope Research Facility



# The Science is in the FRIB Logo

## Properties of atomic nuclei

- Develop a predictive model of the atomic nucleus

## Nuclear processes in the cosmos

- Origin of the elements
- Stellar explosions
- Neutron stars

Middle circle:  
FRIB capabilities (fast, stopped, reaccelerated, and harvested beams) that match the science program



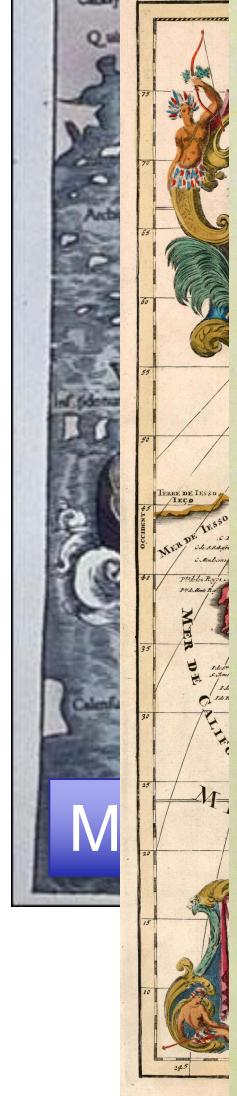
## Societal applications and benefits

- Medicine, energy, materials, national security

## Tests of laws of nature

- Tiny effects amplified in certain nuclei; complementary information to collider data, e.g., at LHC

Die Neuen Anseln als hinterer Grenzland gegen Orient bei dem Lande Nubia liegen.



AMERI

MICHIGAN TERRITORY.

SITUATION, BOUNDARIES, AND EXTENT.

*Michigan occupies a strip between 41° 31' and 46° 29' N. lat. and 87° 10' and 100° 37' W. long. It is bounded by lake Superior; east by lakes Huron, St. Clair, and Detroit, these two latter streams being also by Ohio and Indiana; and west by the Northwest Territory. The area is about 50,000 square miles, with that of the United States. It is 250 miles long from north to south, and about 200 broad, containing about 3000 square miles of water surface.*

FACE OF THE COUNTRY, SOIL, &c.

The country along the eastern shore of lake Michigan, and extending into the interior as far as the Grand Traverse, is generally flat, covered with dense forest of tall timber trees, and a scanty vegetation, but generally bare, and blown by the wind into a thin, tangled, broken shape. The soil of this tract originally formed part of this lake, and the soil is therefore very thin and poor, though there is a greater depth in some parts than in others. The eastern part of the territory, consisting of lands ceded by the Indians, has never been cultivated, and is covered with a scrubby vegetation, with scattered trees, and almost bare, except for what and fruit of all kinds. It is generally level, and watered by five rivers, which have their sources in the hills on the west, and run down to the lake. The lands on Saginaw river and bay, which were ceded by the Indians in 1813, are represented as being well cultivated, and beautifully situated. The lands on the banks of the river St. Mary are also in good order.

LAKES, BAYS, AND RIVERS.

*Michigan lake is 260 miles long, 88 broad, and 5000 in circumference, containing, according to Hennepin, 10,000,000 acres of water surface, and 5000 square miles of land. On the northeast it connects with lake Huron, through the strait of Mackinac, and on the northwest with lake Superior, through the strait of Michilimackinac. The water of the lake is navigable for ships of any burden. It has but of various kinds, particularly trout and salmon. Salmon are found in its bays and rivers. Green bay extends from the south side of the lake about 100 miles, and contains 1000 square miles, and slopes of this can be navigated to the head of the bay. The chief port of entry is Marquette, which is on the lake about 120 miles from east to west, and from north to south 180. On the north-west side it receives the outlet of the Grand River, and on the south-west the outlet of the Muskegon. The Muskegon flows east to west along the northern side of the lake for 150 miles. Many of them are in great numbers, and form a barrier to navigation. There are many others of inferior dimensions, which render the navigation difficult, and sometimes dangerous.*

*Superior lies up from lake Huron between Point six Barques on the south, and the Cape of the North on the north. It is 300 miles long, and 50 miles wide, and 100 miles from north to south. It is 60 miles long, and 20 wide at its mouth, and is navigable for vessels of 1000 tons. Its capital port is Marquette.*

St. Clair lake is about 90 miles in circumference.

*It receives the waters of lake Huron through the St. Clair river, and then largely into lake Erie through Detroit river. The latter is the outlet of the lake. The distance from Detroit to the lake is about 12 miles. The lake is about 100 miles long, connects lake Superior with lake Huron. The fall or grade of St. Mary is near the head of the strait, in 40° 37' N. lat., 12° miles from Detroit. It is 40 miles long, and 1000 feet deep. It is navigable for small steamers, and can be crossed at any season with large vessels; but canoes and barges are towed up along the shore.*

*The St. Mary falls are the greatest falls in the world, and are considered by many as dangerous as Niagara. The Indians have drawn holes in great numbers by theadvantages of their knowledge of the current, to facilitate their passage through the rapids, which skilled sailors often take 800 in two hours. They are the southern extremity of Green bay. There are many small streams which fall into lake Michigan from the east.*

St. Mary river, a large slow stream, with bold shores, falls into the southern extremity of Green bay.

*The river Huron flows into lake Erie, near the mouth of Detroit river.*

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ANIMALS. &c.

*No native or the wild is generally supplied with wild game, fish, and aquatic fowls. The species of birds are those common in the northern states. Bunting, sparrow, quail, plover, and teals are found in the forests. The trout of Michigan have a superior quality to those of the Atlantic coast.*

*The territory is divided into nine counties, which are much smaller than in the case of the Atlantic states, in the same latitude. In the eastern part of the territory, that of the western confederacy of New York and Pennsylvania, there are nine counties. In the western part of the territory, that of Michigan, there are eight counties. The western boundary of the territory is a tract in the southwest along the banks of lake Erie, lake St. Clair, and lake Huron. It is a tract of 200 miles in length, and about 50 miles in breadth; some small tracts at the head of Green bay, at the straits of St. Mary, and along the lakes. The territory is divided into seven counties, as follows:*

Counties.	Population.
Wayne.	3374
Monroe.	909
Oakland.	1293
Macomb.	1200
Michilimackinac.	819
Detroit.	652
Gratiot.	652
Muskegon.	1012
<b>Total,</b>	<b>8896</b>

*Population 8896.*

TOWNS AND VILLAGES.

*Battle, the capital of the territory, is on Detroit river, 9 miles from lake St. Clair. It is a small town of about 100 houses, and has a population of 1500, and is a port of entry.*

*At present no trade is shipped with Ohio and New York, and with the military stores to be sent to the frontier posts. Last year the amount of shipping was 600 tons. The fort is a regular work, with parapets 12 feet high, and 6000 feet long. It is situated on a rock, 100 feet high, on the top of which stands the fort. Behind the fort, at the distance of 1000 feet, is a village of 200 houses, and a garrison of 1000 men.*

*Algoma, a village situated on Mackinac, is on an island of the same name, in the straits of Michilimackinac. The island is about 9 miles in circumference, and the village is situated on the south side of the island. It is a small village, but has a good harbor, and is a port of entry for ships of 1000 tons.*

*Mackinac is a village situated on Mackinac. It is the chief post of the frontier of the Indian tribes. The Indians are numerous, and are numerous, and are situated on the bank of the lake Michigan. During the summer, Mackinac is the resort of many Indians and fur traders.*

*The present fort is on a low sandy spot, half a mile from the mouth of the river; but a new fort is now under construction on a higher elevation, and a bridge will be built across the river, 12 miles above the old fort.*

*The position of the fort de St. Marie is of the first importance as a military station. It is situated on a high rocky point, and is surrounded by a wall of stone 100 feet high, on the top of which stands the fort. Behind the fort, at the distance of 1000 feet, is a village of 200 houses, and a garrison of 1000 men.*

*The grand thoroughfare of the northwest was compelled to pass through St. Louis, all the time that the Indians were in possession. The fort is a small village, and is situated on the bank of the lake Michigan. During the summer, Mackinac is the resort of many Indians and fur traders.*

Finlayson 1822

GEOGRAPHICAL, STATISTICAL, AND HISTORICAL MAP OF MICHIGAN TERRITORY.



MICHIGAN TERRITORY. No. 36.

GOVERNMENT.

The legislative power is vested in a governor and a supreme court, composed of three judges, all appointed by the president and senate of the United States. The executive power is vested in a governor and the judges, in the three judges, and in such civil magistrates as the laws may direct. The power of the judiciary is given to the three judges, and of probate in each district, and justices of the peace, who hold jurisdiction of petty causes. The legislature has original jurisdiction in all cases of treason. The supreme court has original jurisdiction in all other cases. The ministerial officers are a marshal for the territory, and a deputy marshal for each district.

