Galactic environment — The possibility of Galactic Paleoclimatology

Jun Makino

with

Takayuki Saito, Junichi Baba

ELSI

In short...

Q: Has the Milky Way Galaxy anything to do with Earth's environment?

A: Yes, but not in the way people has been discussing.

Structure of my talk

- Who am I?
- Introduction: The Svensmark Hypothesis and interaction between galactic environment and heliosphere
- The dynamics of the spiral structure of the galaxy
- Tracing back the orbit of Sun for 450Myrs
- Summary

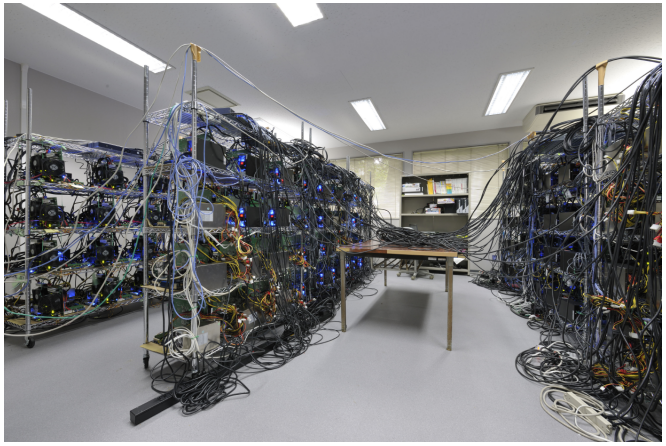
Who am I?

Current position (as of Apr 1st):

- PI, ELSI
- Team leader, Particle Simulator Research Team, Advanced Institute of Computational Science, RIKEN

What I have been doing for the last 20 years:
Develop GRAPE and similar hardware for astrophysical N-body simulations, Use them for research.

Planetary formation, star cluster dynamics, galactic dynamics, cosmology



GRAPE-DR

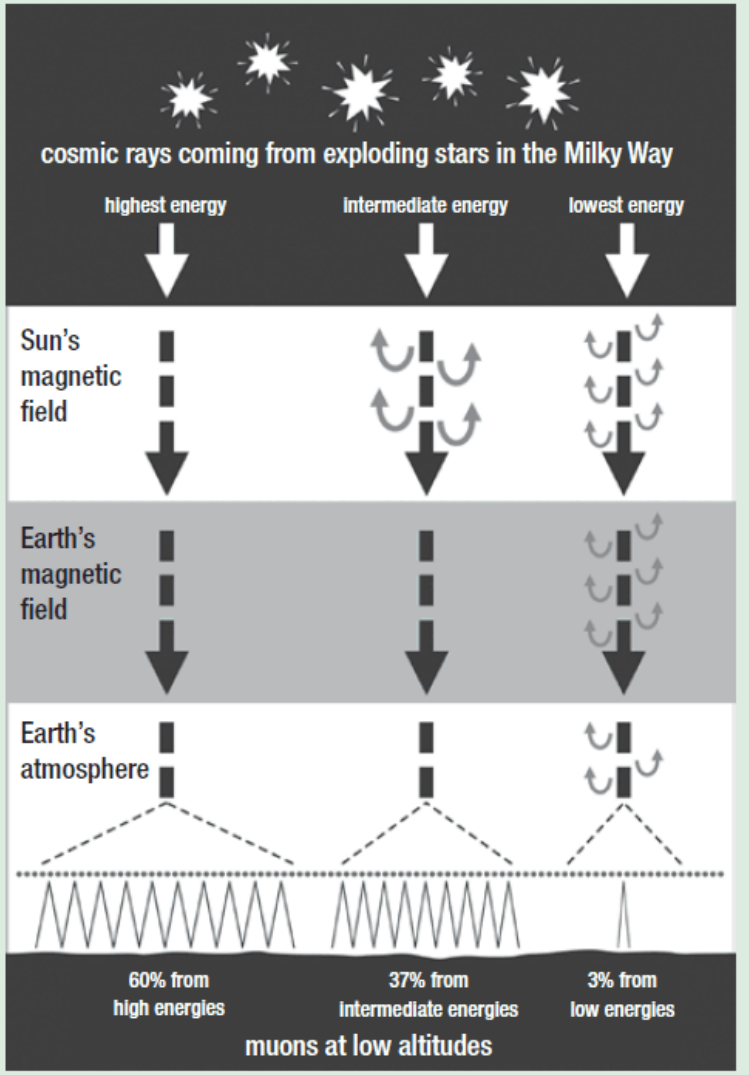
K Computer

The Svensmark Hypothesis and interaction between galactic environment and heliosphere

- **The Svensmark Hypothesis**
- **Spiral arms and Sun**

The Svensmark Hypothesis

Svensmark 2007

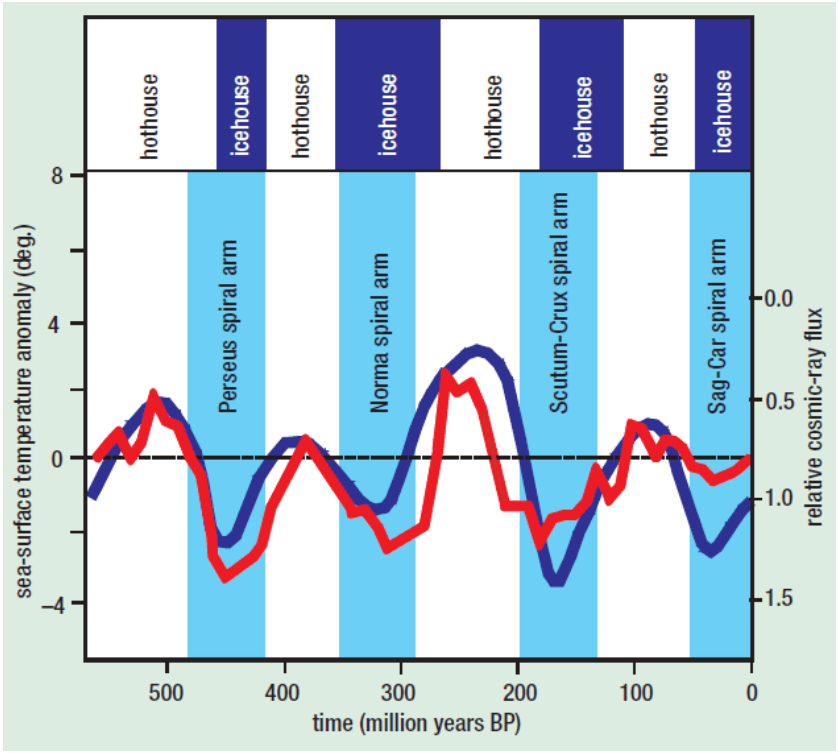


Basic idea: the increase of galactic cosmic ray at Earth causes the increase of cloud coverage and global cooling

Cosmic ray increase due to:

- Change in Earth's magnetic field
- Change in the solar activity
- Change in the galactic cosmic ray density itself

Very long-term climate change

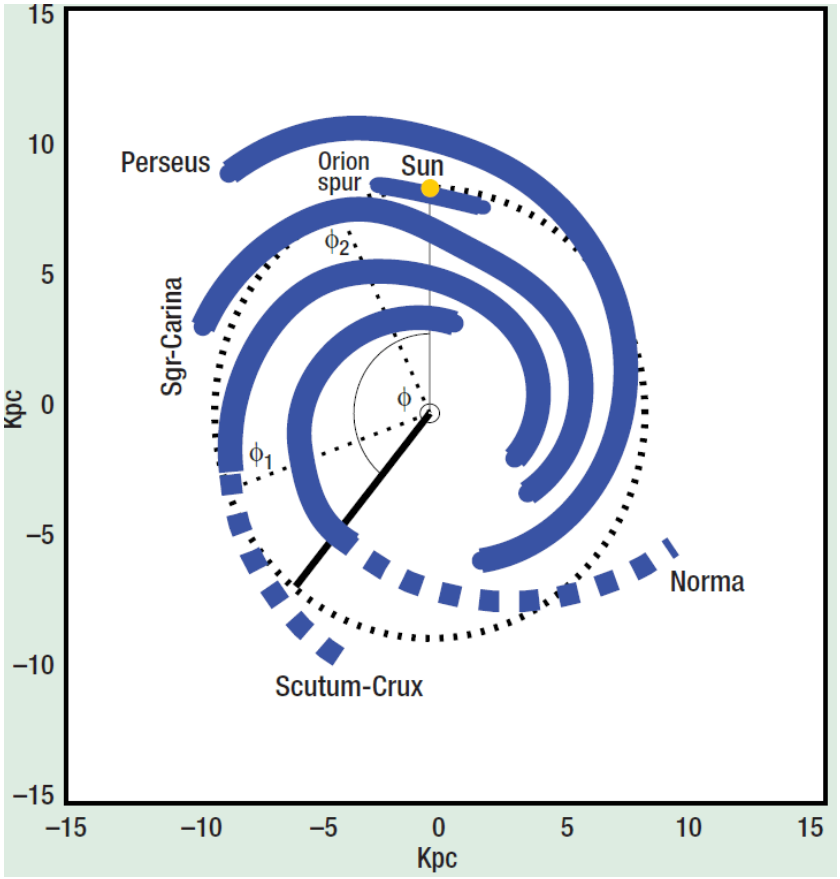


- Climate change with ~ 140 Myrs period.
  (Don't ask me details. There are many experts in this room)

- Origin of this long period: unlikely to be orbital motion/internal dynamics of the Earth(???)

- Cosmic ray might increase when the Earth goes through the spiral arms of the Galaxy.

The Galaxy and our Sun



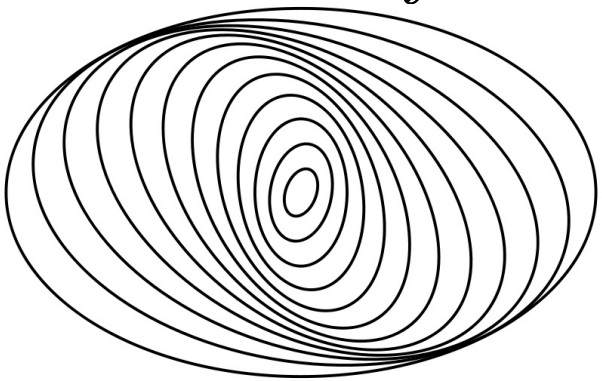
- Spiral arms are stationary density waves with angular velocity different from that of our Sun.
- Therefore, our Sun encounters the arms periodically.
- Star formation activity is high in the arms.
- Thus, in arms, high cosmic ray density causes global cooling.

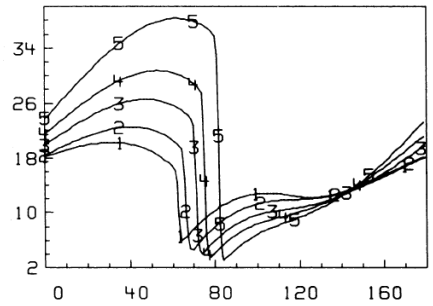
A few questions

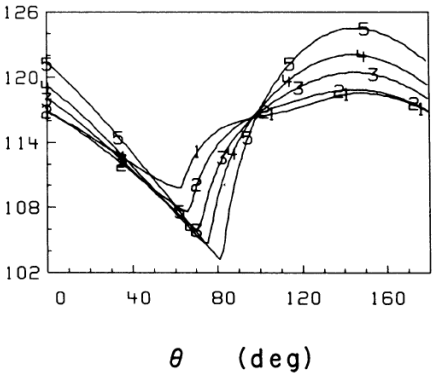
- Does high star formation rate cause global cooling? (I'll skip this issue today. Those who interested in, talk to Toshi.)
- Are spiral arms really stationary?
- What is the real orbit of our Sun?

Textbook theory of spiral arms

— Stationary density wave





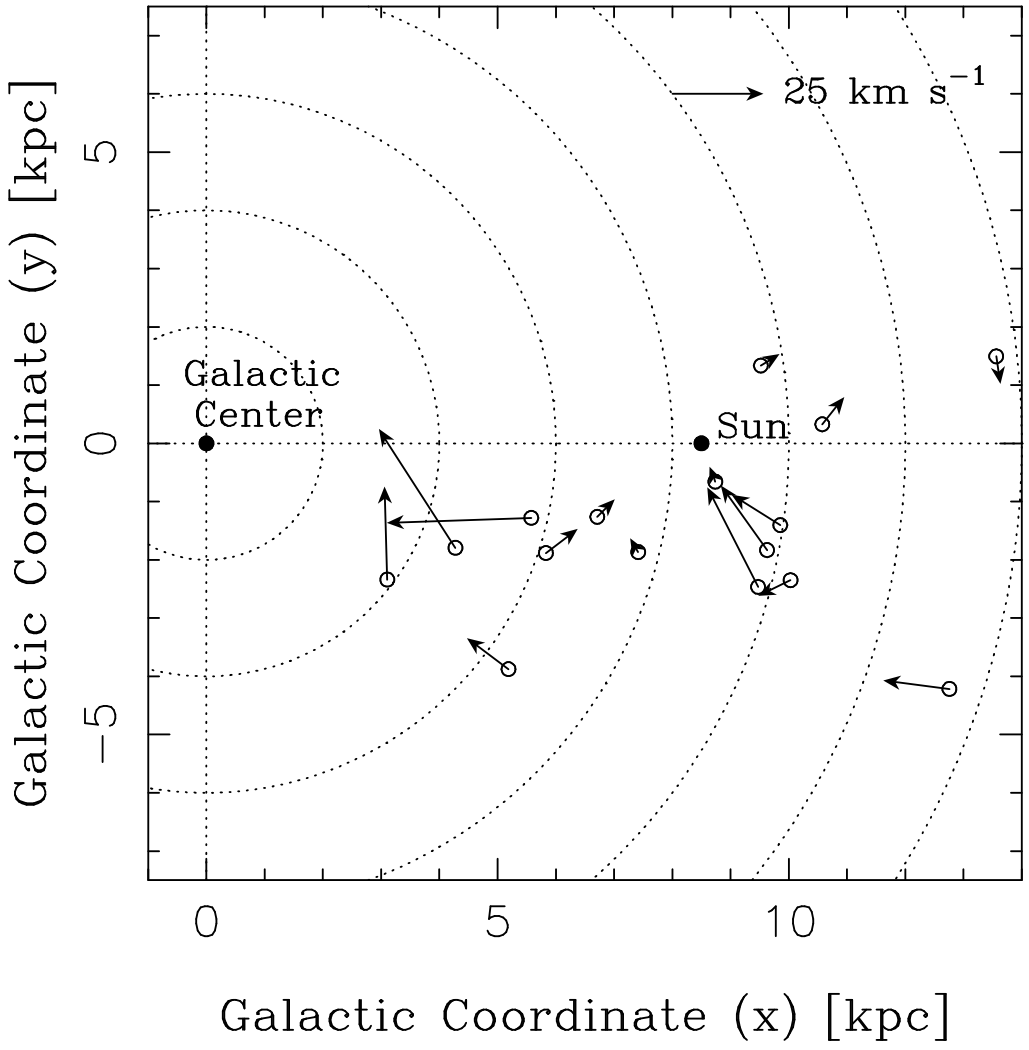


- Let's assume that stars are in ellipsoidal (in the case of two arms) orbits, and the axis depends on the radius
- Then there exists stationary spiral arms
- There were competing theories, but none definitive.
- We can make many predictions with density wave theory. Motion of gas, star formation, etc etc...

Recent observation

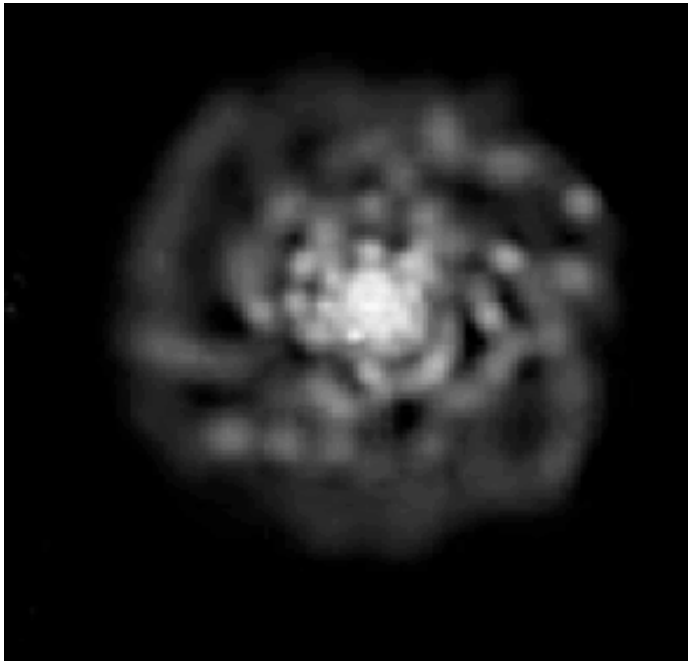
- **Trigonometric observation with VLBI (VLBA and VERA)**
- **Large and apparently random deviation from the circular motion**
- **Not consistent with the density wave theory**

???



Numerical Simulation of galaxy formation

Five years ago ...



Governato et al. 2007

SPH particle mass $> 10^5 M_\odot$
Gravitational softening 325pc
Star formation at 3×10^4K

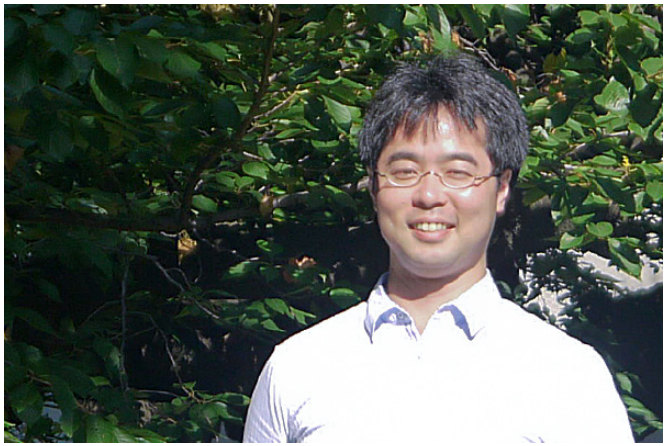
One should follow low-temperature, high density gas, but couldn't

No star forming region
No molecular cloud
Spiral arms???

Our (Baba and Saito's) calculation

- Follow low-temperature, high density gas
- Need large number of particles and small timesteps
- Efficient parallel code (ASURA)+Fast parallel computer (GRAPE, Cray XT4)
- 10pc softening ($\leftarrow$ 500pc)
- Gas cooling down to 10k ($\leftarrow 10^4$K)
- Particle mass $3000 M_\odot$ ($\leftarrow 10^5 M_\odot$)

Junichi Baba

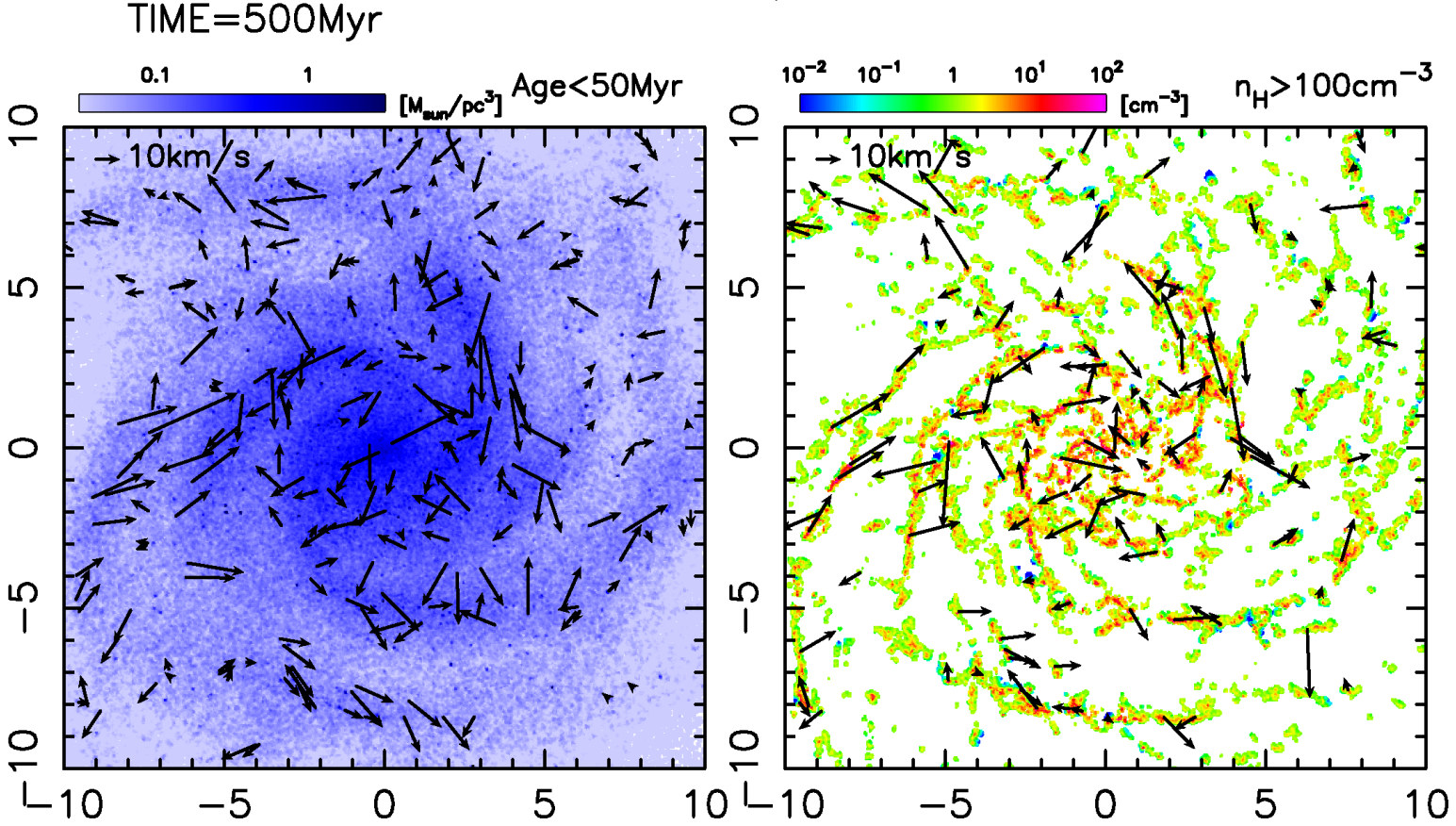


Takayuki Saito

Self-consistent simulation of our Galaxy

(Baba et al. 2009, Calculation done by Saito's ASURA code)

animation 1 2 3 4)

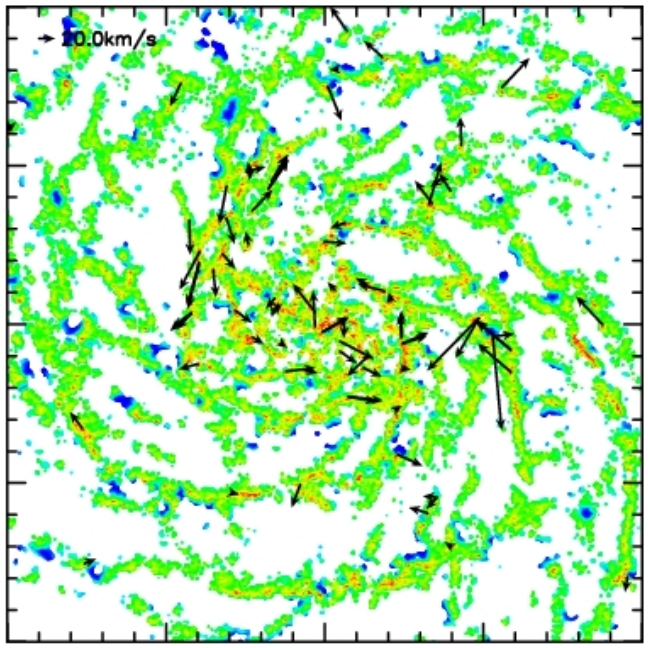


Stars

cold interstellar gas

(Arrows: young stars)

Comparison with observation

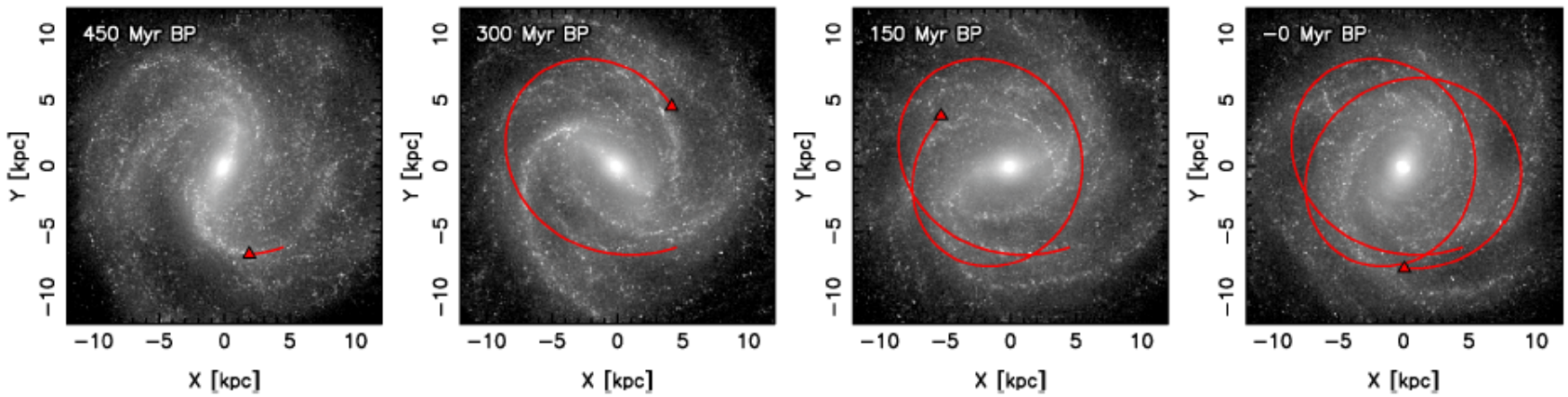


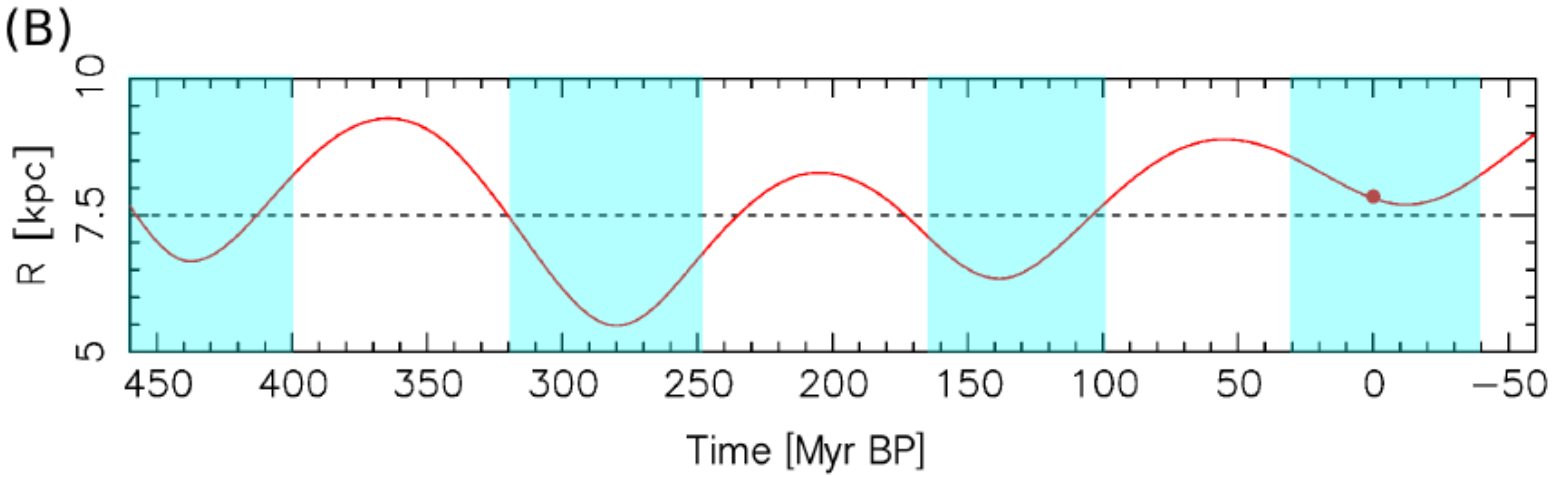
Not too bad.

So, what about the Svensmark Hypothesis?

- No stationary spiral arms. Pattern speed not different from the local circular velocity.
- There cannot be "periodic encounter with spiral arms."
- To see what really happened, we traced back the orbit of a star with the present position and velocity close to that of our Sun, in a model galaxy with global structure similar to our Galaxy now.

Result: our Sun in the past 450 Myrs



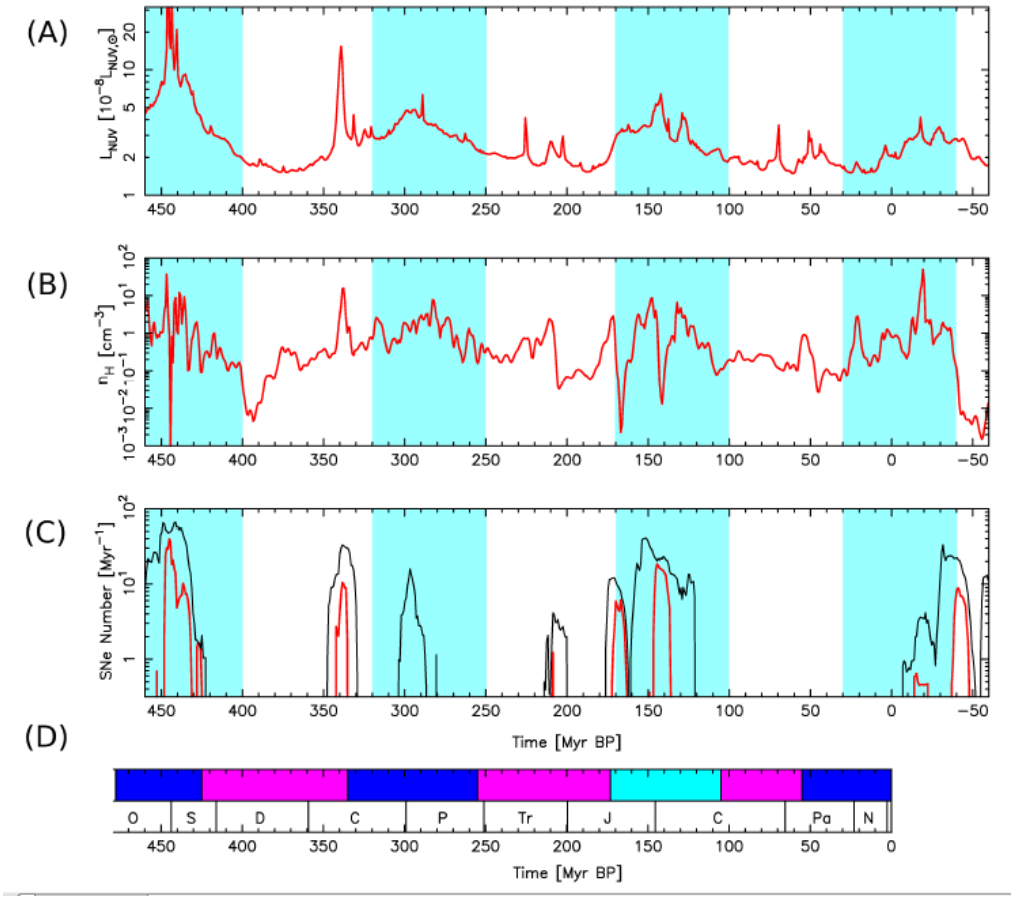


Blue: cold periods

Cold period = Sun close to the galactic center.

Phase and period both agree, without any adjustable parameter.

Environmental Change around our Sun



- Top: Ultraviolet luminosity (star formation rate)
- Middle: interstellar gas density
- Bottom: Supernovae rates
- Global cooling caused by these activities?

Summary

- The Svensmark Hypothesis: Periodic encounter with spiral arms causes global cooling.
- In modern simulation of galactic disk, such periodic encounter does not take place.
- However, the epicycle motion of our Sun causes periodic change in the galactic environment
- The period and phase of this change agree well with those of observed long-term climate change
- The interaction with bar would cause changes with 600-1000Myrs timescale
- "Galactic Paleoclimatology" may be important to understand the history of Earth and evolution of life.

What's next

- Include more physics — cosmic ray propagation etc.
- Higher resolution — better treatment of star formation and supernovae
- Investigate the range of possible "Suns"
- Investigate the interaction with the bar.
- Investigate the environment where the Sun and Earth were born — may be quite different from the present solar neighborhood.

- 3D simulation Planetary formation process
- Giant Impact simulation with new numerical schemes
- Convection in stars, planets, ...
- Molecular-level simulations of origins of life...