Galactic environment —
The possibility of
Galactic Paleoclimatology

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with
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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
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 $\sim 140$ 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 \( 3 \times 10^4 K \)

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 (← 500pc)
- Gas cooling down to 10k (← 10^4 K)
- Particle mass $3000M_\odot$ (← $10^5 M_\odot$)

Junichi Baba  Takayuki Saito
Self-consistent simulation of our Galaxy

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

Stars
(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.

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• 3D simulation Planetary formation process

• Giant Impact simulation with new numerical schemes

• Convection in stars, planets, ...

• Molecular-level simulations of origins of life...