Research Activities of Astrophysics at CCS

Division of Astrophysics and Nuclear Physics :
Astrophysics Group

Masao Mori

April 10, 2014 CCS - LBNL Collaborative Workshop @ CCS

Member

Prof. Masayuki Umemura, Director of CCS

Cosmology, First Stars, Galaxy Formation, Astrobiology

Associate Prof. Masao Mori

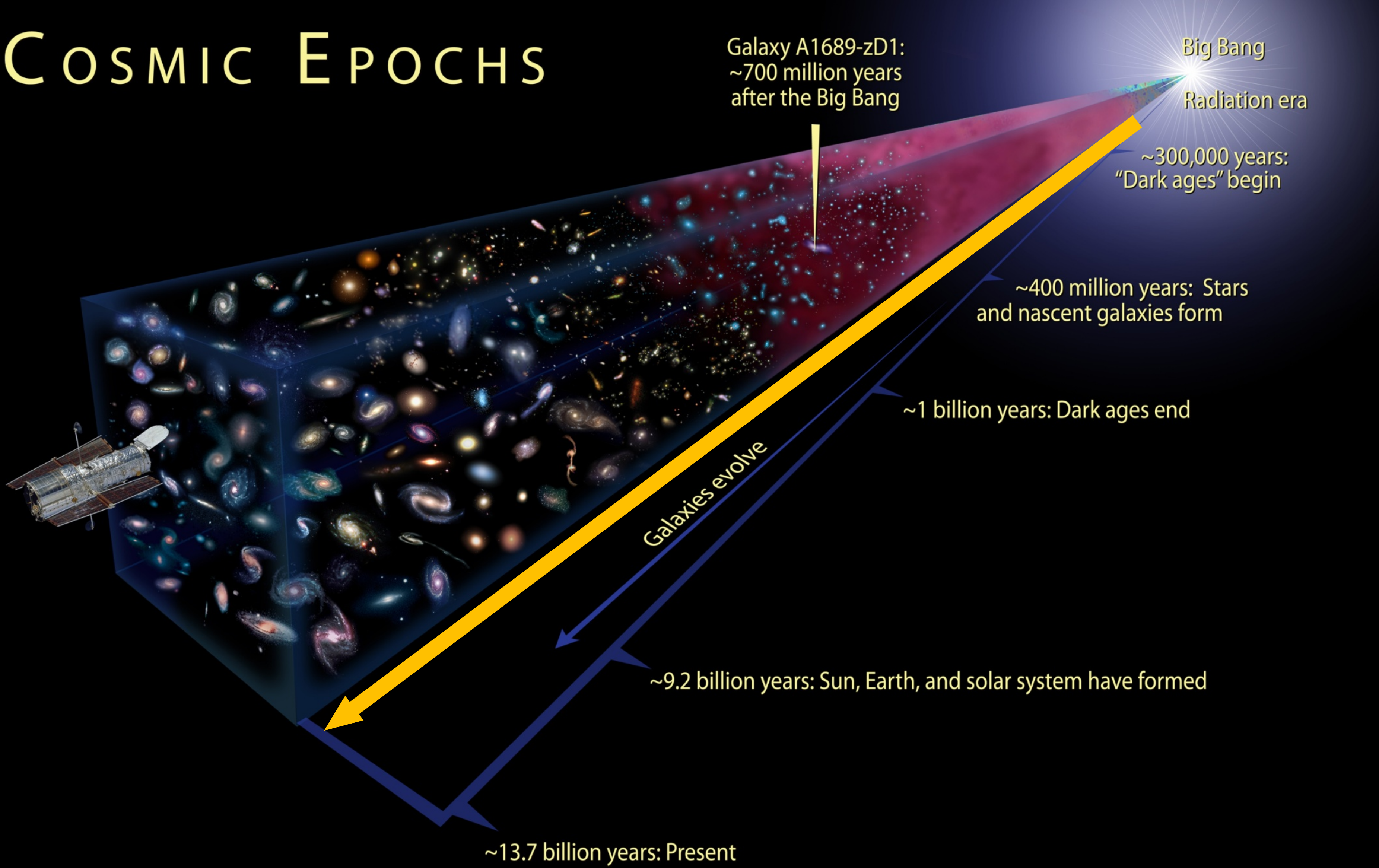
Galaxy Formation and Evolution, Galaxy Collision, Hydrodynamics

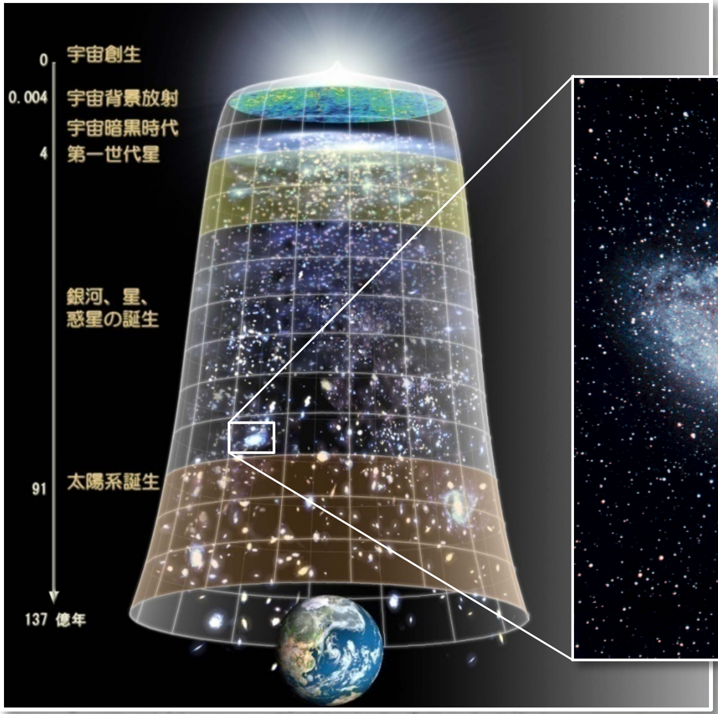
Lecturer Kohji Yoshikawa

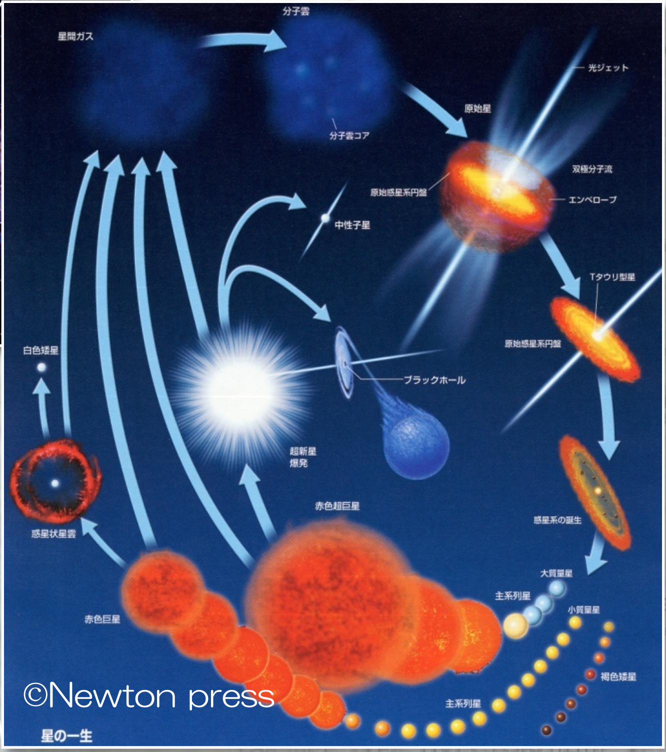
Observational Cosmology, Cluster of Galaxies, Intergalactic Medium

- 7 Posdocs
  - Alexander Wagner : Galaxy formation, AGN feedback
  - Yohei Miki : Galaxy collision, Galaxy evolution
  - Kenji Hasegawa (Kobe branch) : First stars, Radiation hydrodynamics
  - Tomoaki Ishiyama (Kobe branch) : Dark matter simulation
  - Daisuke Namekata (Kobe branch) : Gas accretion, Radiation hydrodynamics
  - Go Ogiya (University Munich) : Structure of dark matter halos, Galaxy formation
  - Takatoshi Shibuya (U. Tokyo) : Observation of the high-z galaxies
- 16 Grad. Students and 8 Students

Cosmic Epochs







- **Gravity**
  dark matter, stars, gas
- **Hydrodynamics**
  gas motion, energy transfer, …
- **Radiation transfer**
  cooling, heating, ionize, atomic process, …

→ ***Radiation Hydrodynamics***

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(2008-2013)

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First objects in the universe
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Super massive black hole
- Hunting a wandering supermassive black hole in M31 halo
- Successive merger of multiple massive black holes in a primordial galaxy

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Astrobiology
- Light harvesting and energy transfer in photosystem: Implication for bio-signatures

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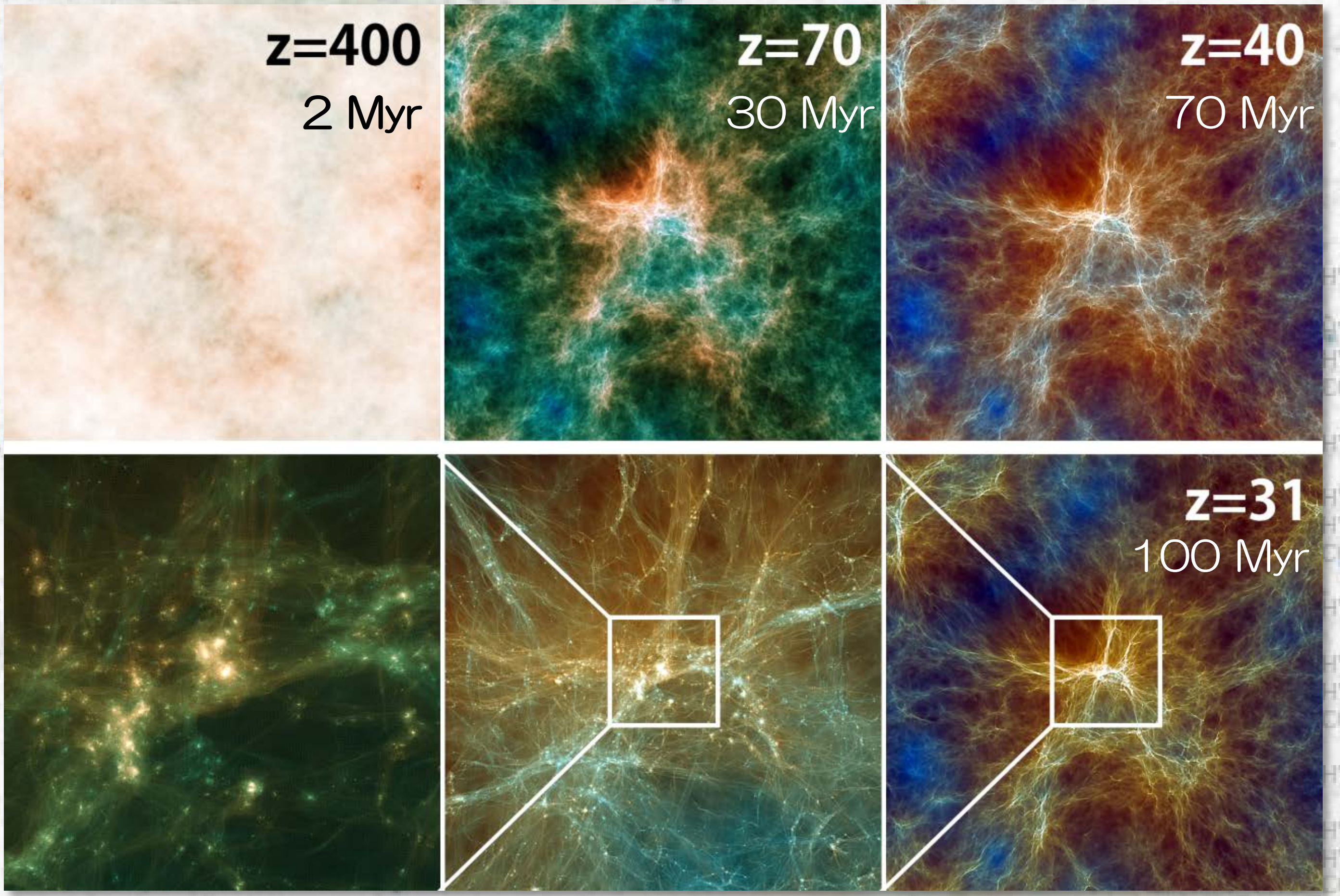
Structure formation in the universe



The distribution of dark matter in a 16.8G particles simulation at redshift z=400 (initial), 70, 40, and 31. The distribution is almost uniform at the beginning (z=400, about two million years after the Big Bang, the width of the image corresponds to about five light years). Gradually, dark matter concentrates via the gravity and forms large structures. Bottom-left and bottom-middle images are enlargement of the image of z=31 (about 100 million years after the Big Bang, the width corresponds to about 65 light years). Ishiyama , et al. (2012)

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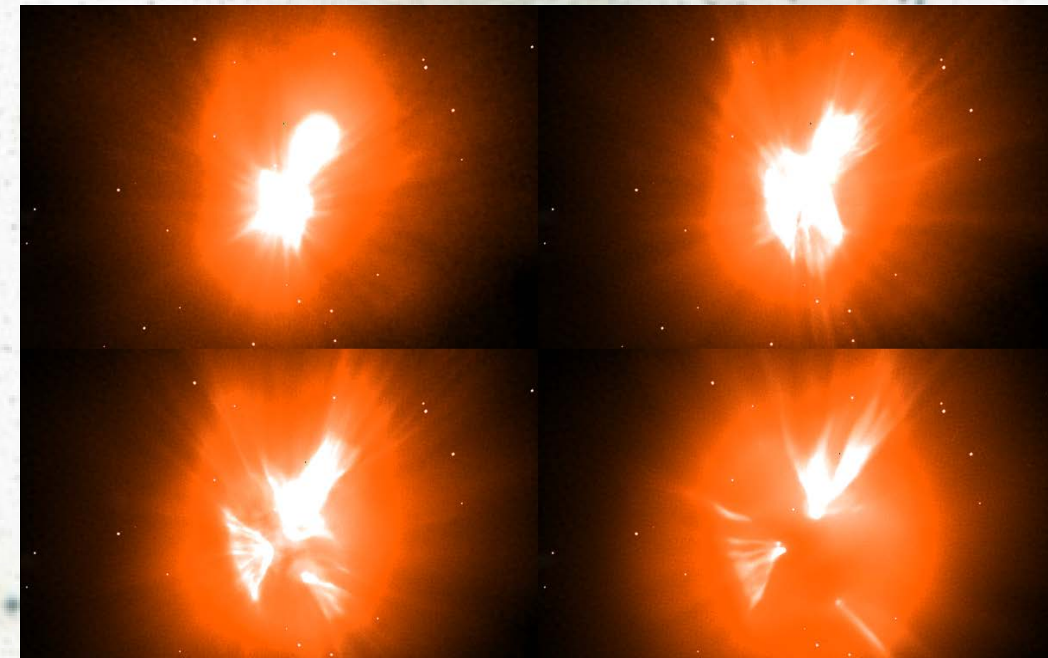
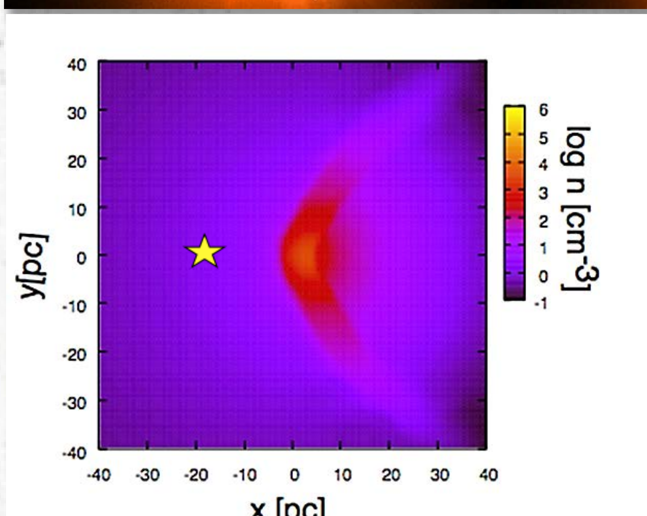
Star formation in the early universe



Three-dimensional radiation hydrodynamic simulations of the secondary star formation in the early universe.

Using three-dimensional radiation hydrodynamic simulations, we explore the formation of secondary Population III stars under radiation hydrodynamic feedback by a preformed massive star in the early universe.

Each panel shows the evolution of a collapsing cloud nearby a first luminous star as a function of time.



$$D_{\mathrm{cr,sh}} = 147\mathrm{pc}\left(\frac{L_{\mathrm{LW}} f_{\mathrm{s,sh}}}{5\times10^{23}\,\mathrm{erg\ s^{-1}}}\right)^{1/2}\left(\frac{n_{\mathrm{c}}}{10^{3}\,\mathrm{cm^{-3}}}\right)^{-7/16}\left(\frac{T_{c}}{300\mathrm{K}}\right)^{-3/4}$$

Hasegawa, Umemura & Susa (2009)

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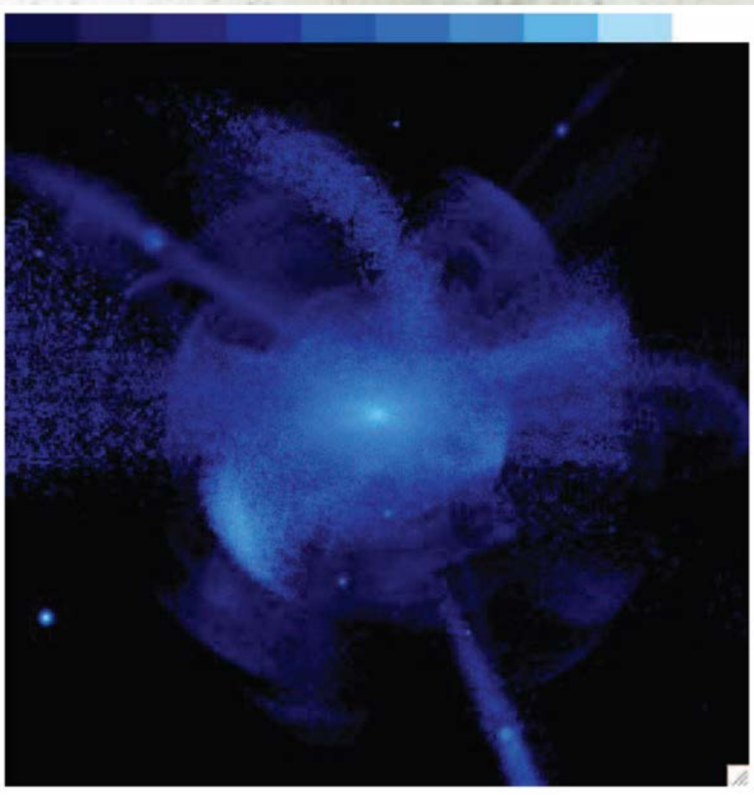
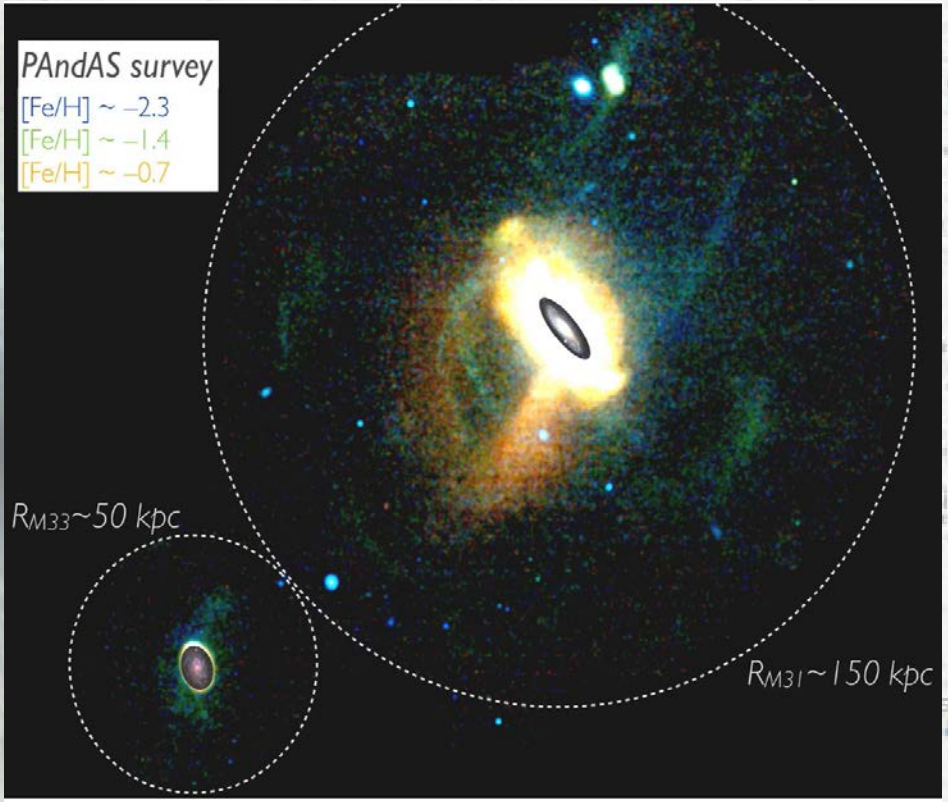
Pan-Andromeda Archaeological Survey



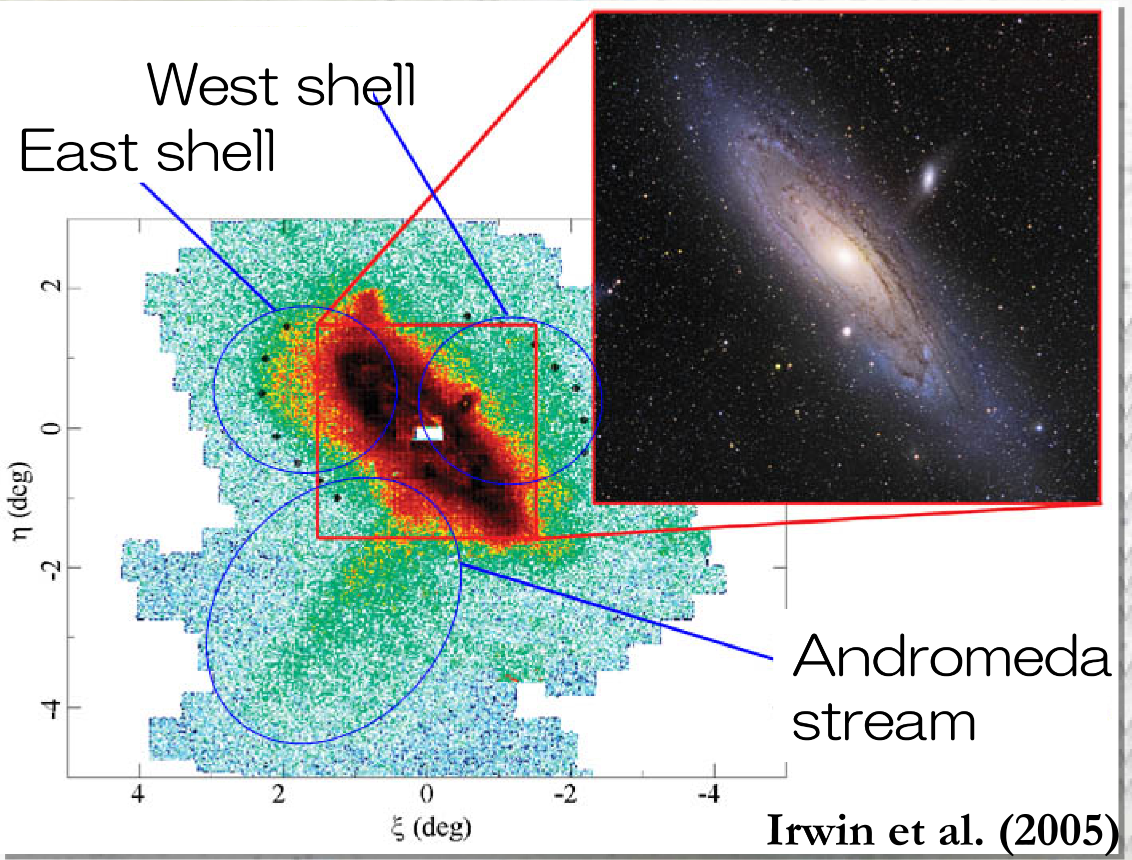
Bullock & Johnston (2005)



Martin et al. (2013)

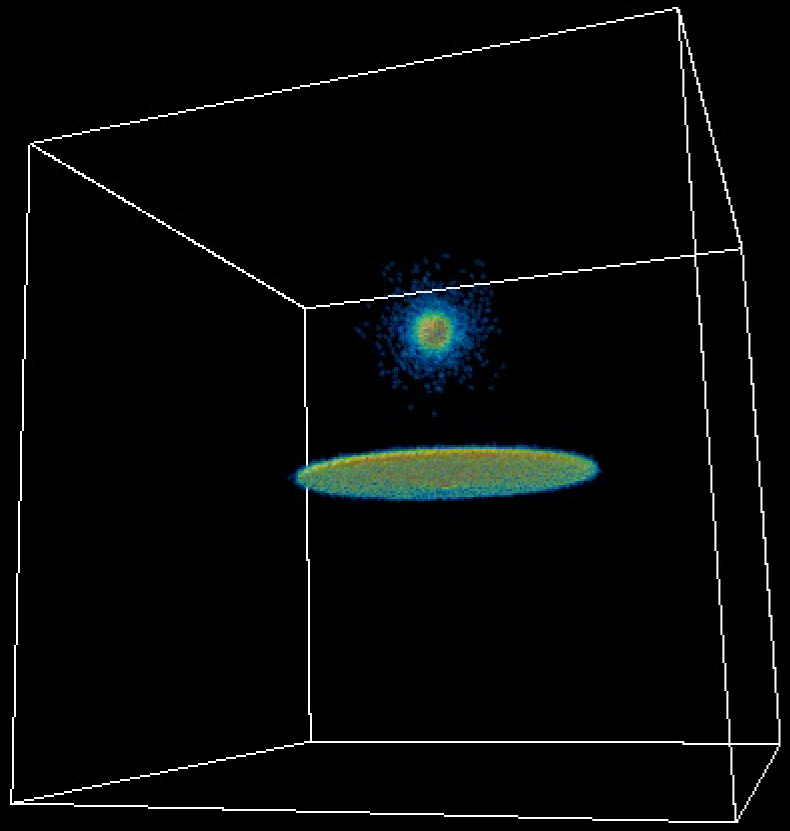
The giant southern stream has a projected length of ~180 kly and a physical length of ~360 kly from its tip south and behind M31 into M31's center. There is further a shell-like overdensity at the east (west). (McConnachie et al. 2009)

Giant stream and shells around M31

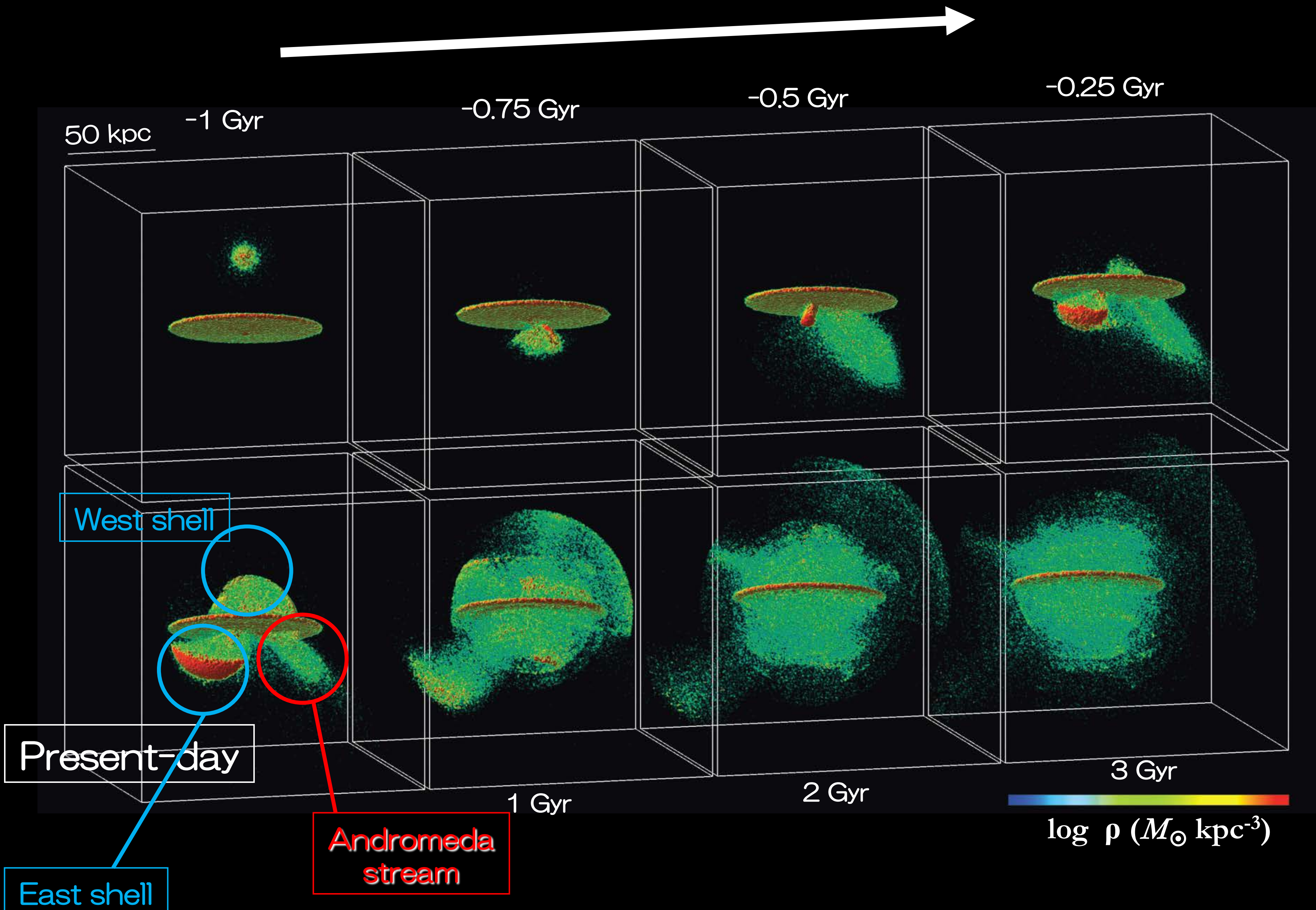


Starcount maps and radial velocities of red giant stars near M31 exhibit a giant stellar stream to the south of this galaxy, as well as giant stellar shells to the east and the west of M31's center. (Ibata et al 2001; Ferguson et al 2002)

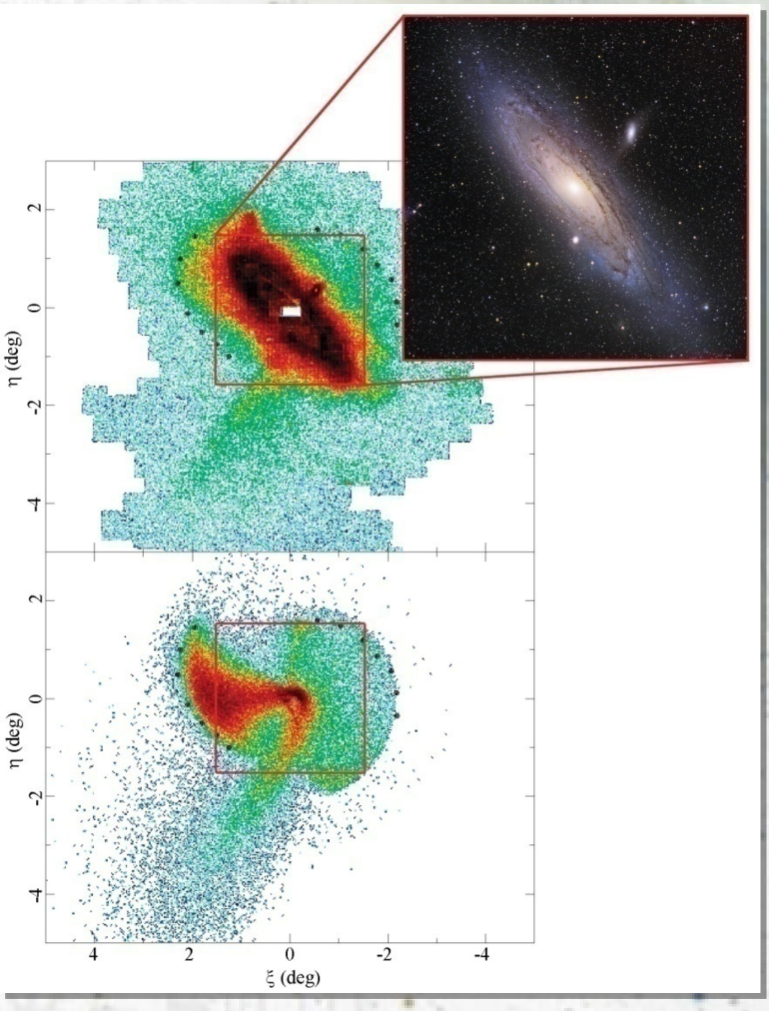
N-body simulations of the interaction between the progenitor of the giant stream and M31 suggest that these structures are the tidal debris formed in the last pericentric passage of a satellite on a radial orbit. (Fardal et al. 2007; Mori & Rich 2008; Miki et al. 2014)



Mori & Rich 2008


50 kpc
-1 Gyr
-0.75 Gyr
-0.5 Gyr
-0.25 Gyr
West shell
Present-day
East shell
Andromeda stream
1 Gyr
2 Gyr
3 Gyr
log ρ ($M_\odot$ kpc^{-3})

Simulation and observation



The map of stellar density around M31 observed by Irwin et al. (2005) and the projected stellar density at the present-day in our simulation.

The satellite is entirely disrupted, and the giant stream of debris arising from the tidal destruction of the accreting satellite at the southern part of M31 is observed.

The simulation reproduces the butterfly-shaped shells in the northeast and the west part of M31.

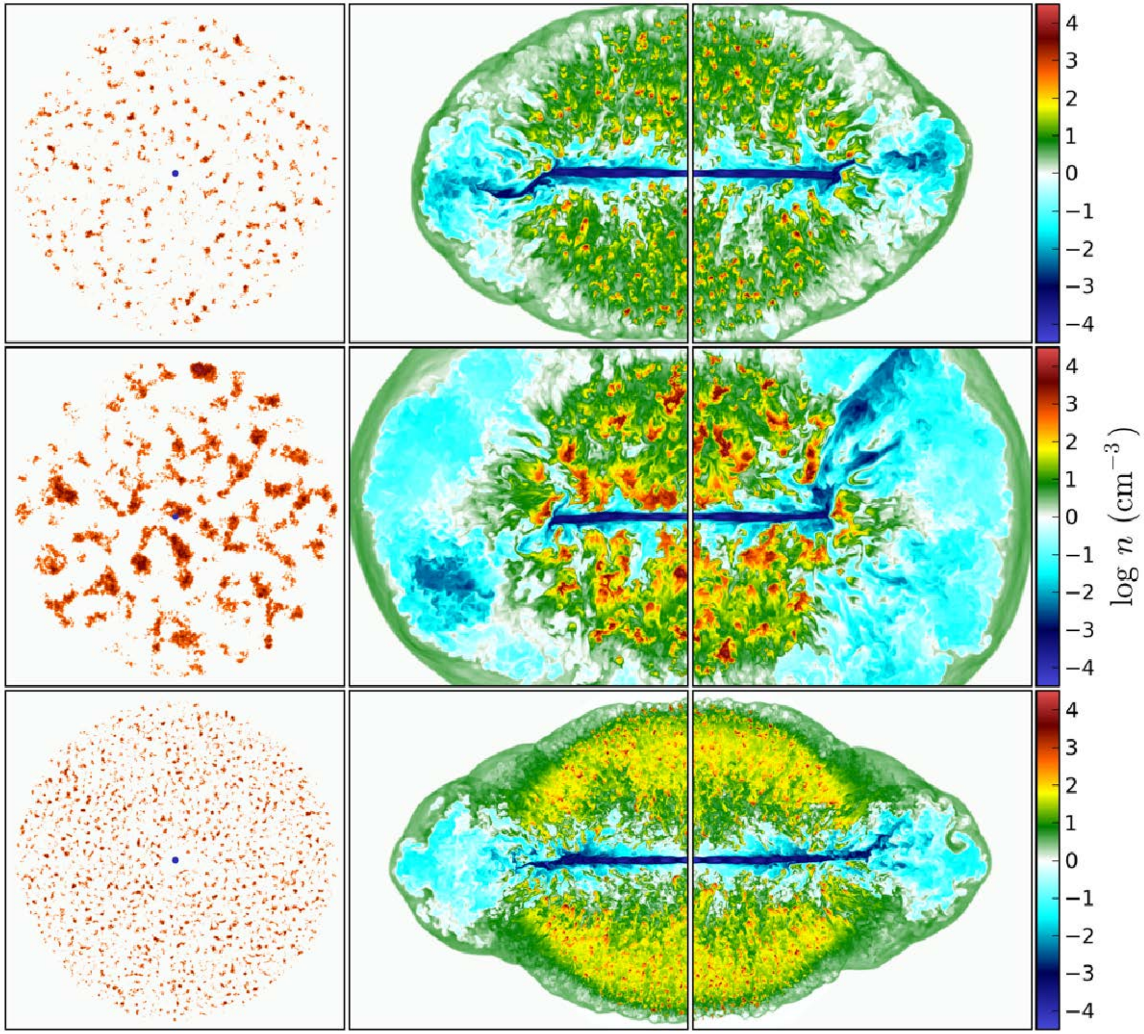
Mori & Rich 2008; Miki et al 2014

Galaxy Scale Feedback by Active Galactic Nuclei (AGN) Jets and Winds

(Wagner, Bicknell, & Umemura 2012; Wagner, Umemura, & Bicknell 2013)

- Parsec resolution, relativistic hydrodynamic simulations of AGN Feedback by jets and ultrafast outflows (UFOs) in gas-rich forming galaxies using a realistic (fractal, lognormal) two-phase interstellar medium.

- The evolution of jets and UFOs is different in a clumpy ISM, compared to a homogeneous one. Light jets can process the entire bulge and disc of galaxies because they are confined and deflected by clouds that are 8 orders of magnitude denser. We measure the efficiency of feedback on the cold dense phase.



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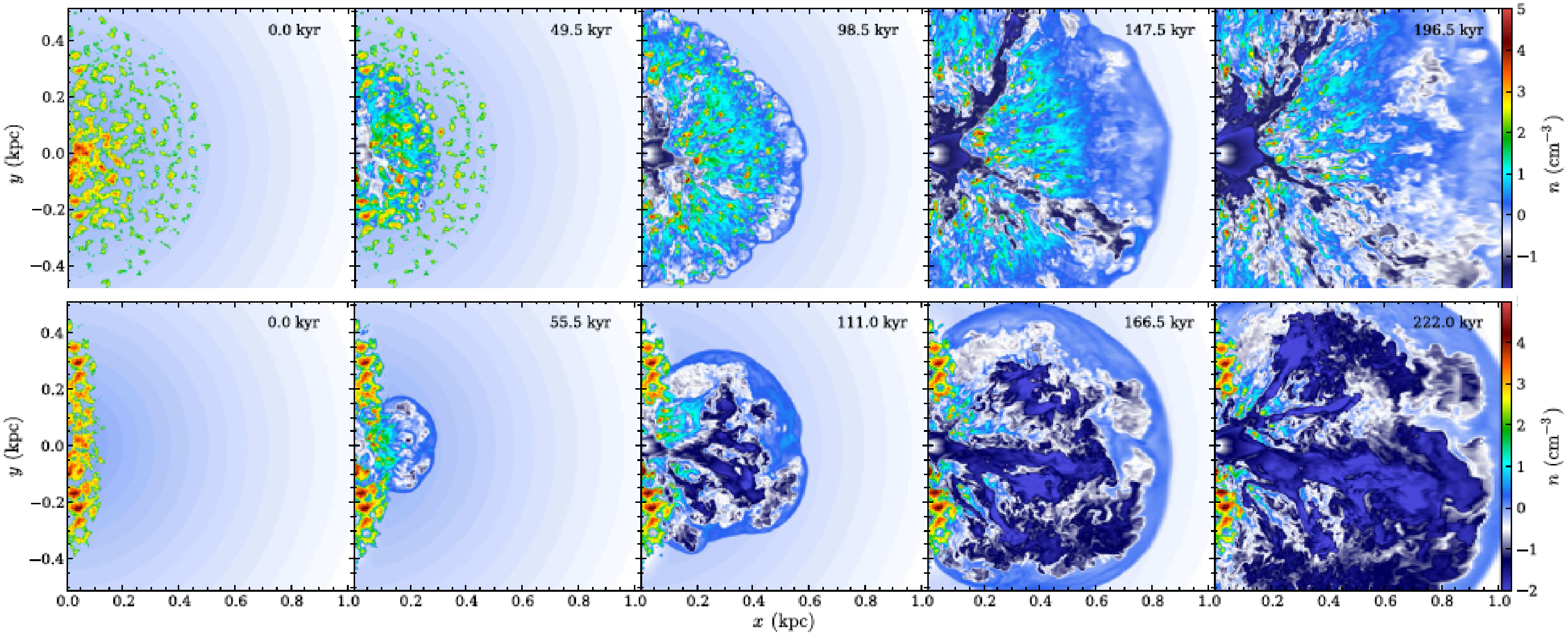


- **Negative Feedback**: The amount of cloud dispersal depends strongly on mean density, mean cloud size, but only weakly on volume filling factor. Clouds in the bulge of galaxies can be dispersed to values implied by the M–σ relation, if the jet power is greater than 10^{43} erg s^{-1}, the Eddington ratio of the jet is greater than 10^{-4}, and cloud sizes are smaller than 50 pc.
- **Positive Feedback**: The star–formation rate increases in large cloud complexes (>50 pc) due to the over–pressurization by factors of 100–1000. Especially in gaseous discs, the star–formation rate increases by at least a factor of a few.

Evolution of gas clouds exposed to AGN radiation

Daisuke NAMEKATA, Masayuki UMEMURA, and Kenji HASEGAWA

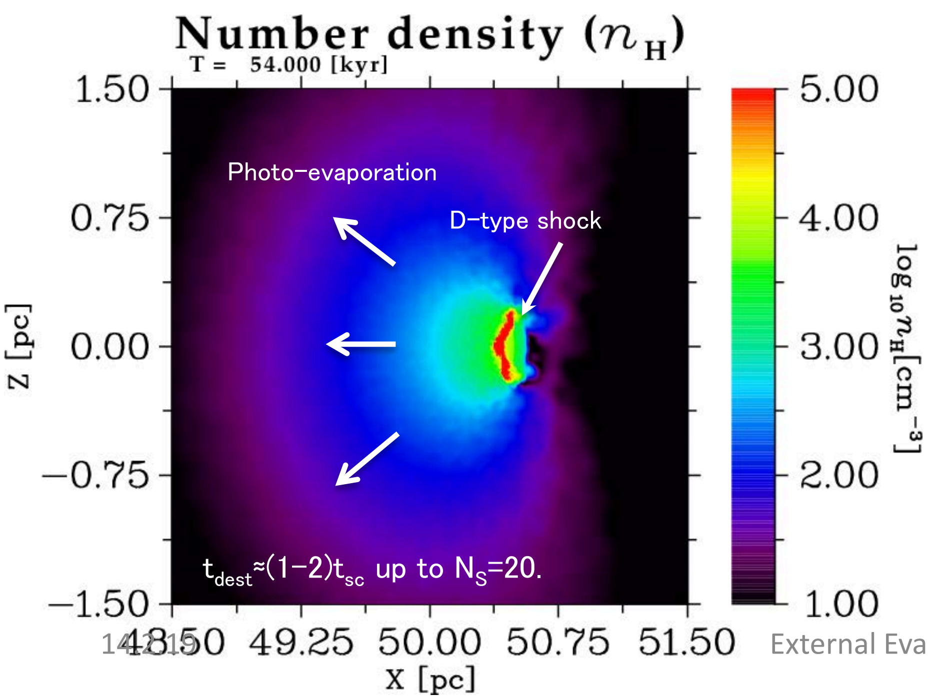
Evolution of a dusty cloud can be classified into two cases:

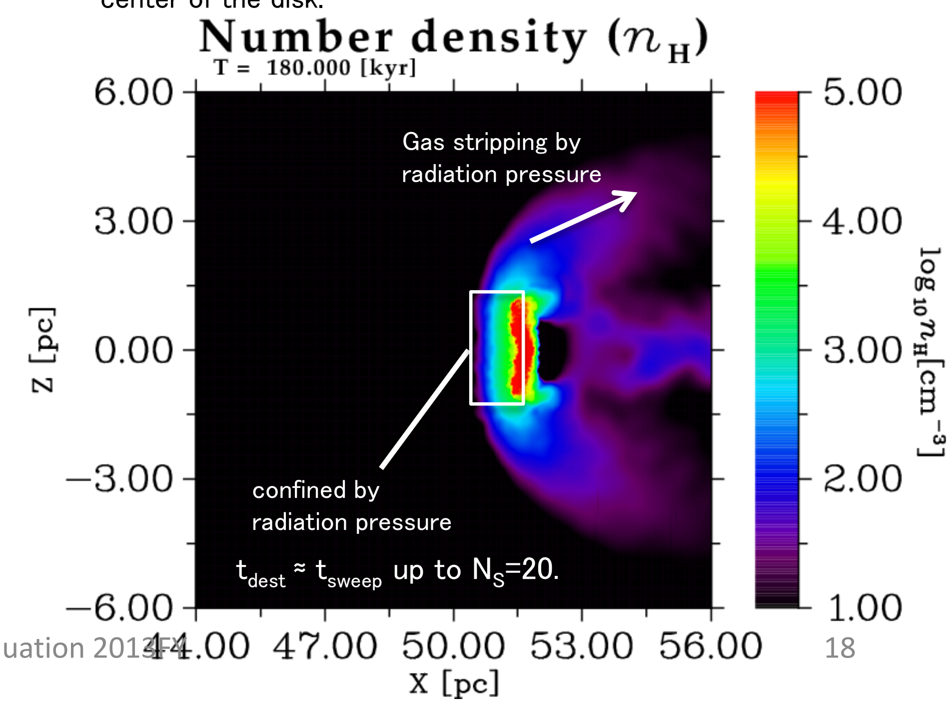
Photo–evaporation–driven (U=0.01)

- Photo–evaporation flow is launched at the irradiated face of a cloud with a velocity of 100[km/s]. Its counter–action generates a D–type shock.
- The shock compresses the cloud as if it makes a fist and a very high dense region is formed.
- Mass–loss by photo–evaporation is 40%–60%。

Radiation pressure–driven (U=0.05)

- Majority of photo–evaporation flow is confined near the cloud surface by strong radiation pressure. As a result, the cloud evolves without losing its mass largely (Mass–loss fraction is 20%–40%).
- A shock is initially generated by photo–evaporation, but, driven by radiation pressure.
- In later phase of the evolution, (self–)gravitationally unstable disk is formed at the post–shock and gas in the disk collapses into the center of the disk.





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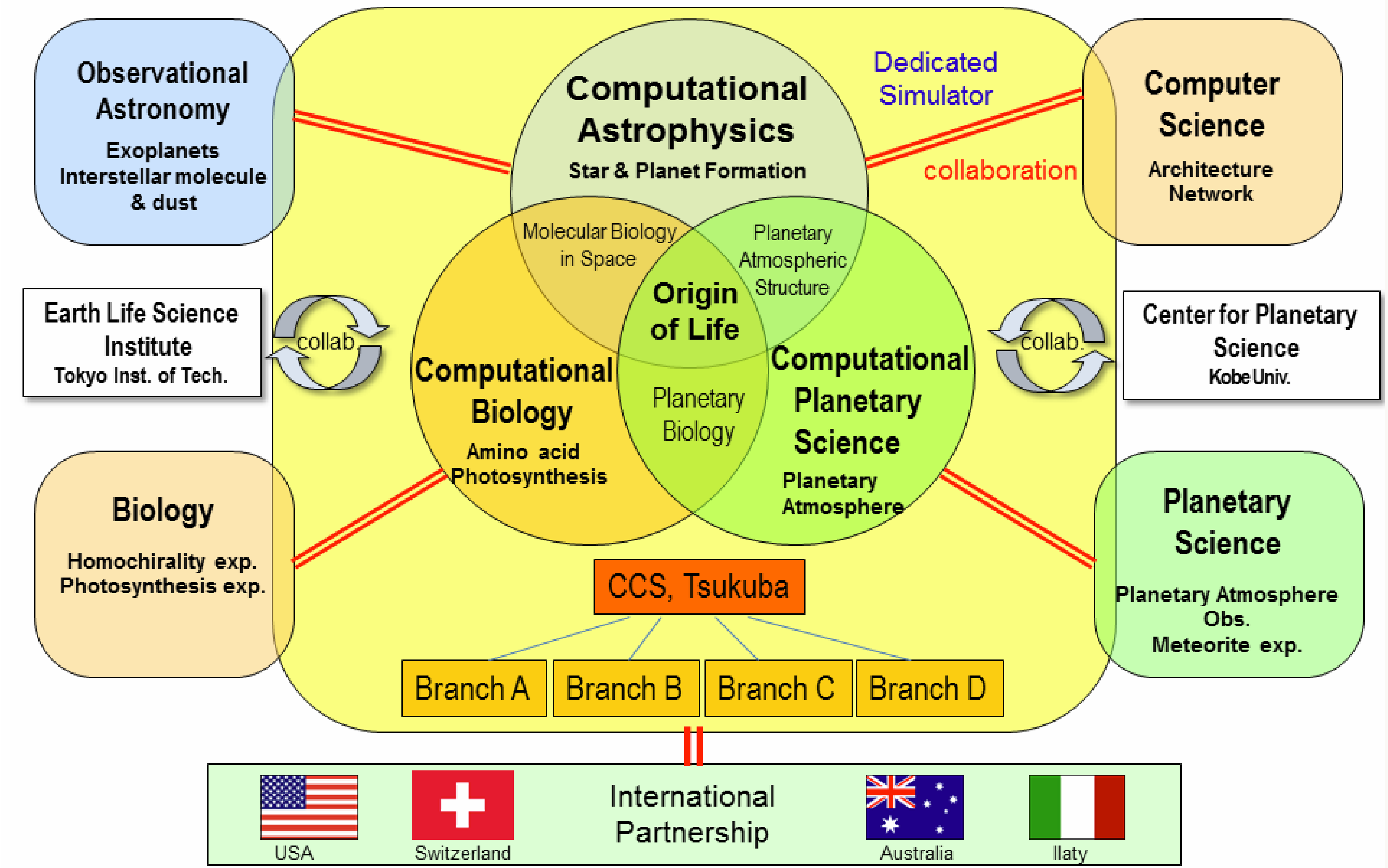
Organization for Collaborative Research on Computational Astrobiology



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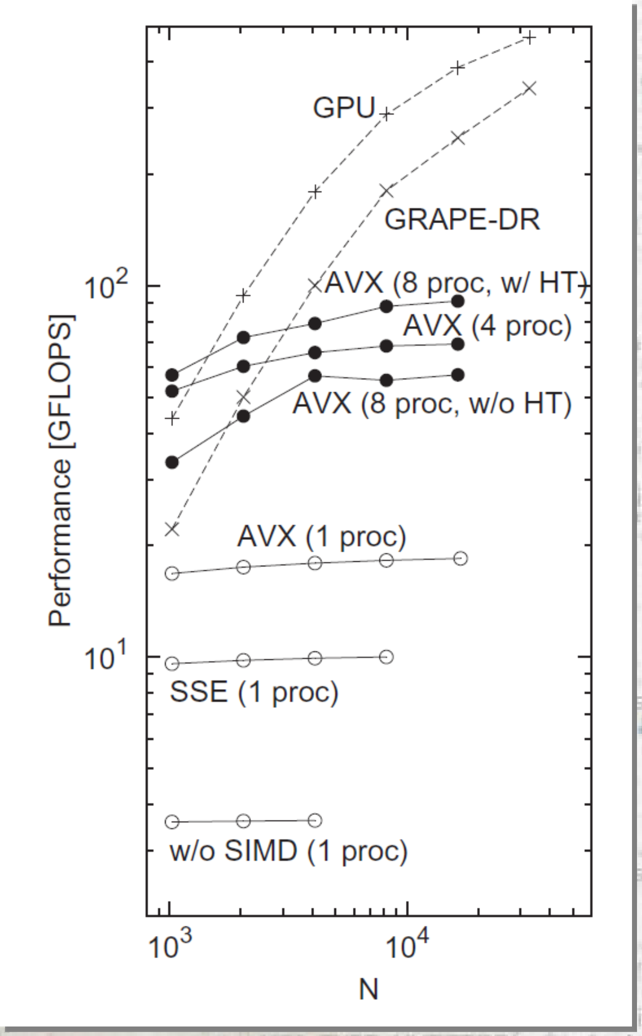
High-Performance N-body Library "Phantom-GRAPE"

- Highly optimized software library for N-body calculation
- Fully utilize the SIMD instruction set equipped with recent processors
- Capable to compute both the Newtonian force and arbitrary-shaped forces.
- Performance is almost independent of number of particles and comparable to that with GPUs
- Publicly available at
https://code.google.com/p/phantom-grape/



Tanikawa, W., Yoshikawa, K., Okamoto, T., Nitadori, K. 2012, New A., 17, 82
Tanikawa, W., Yoshikawa, K., Nitadori, K., Okamoto, T. 2013, New A., 19, 74

Novel Schemes for Radiation Transfer

- Two ray-tracing schemes of radiation transfer suitable for highly parallel architectures (multi- / many-core CPUs and GPUs)

- **ARGOT (Accelerated Ray tracing on Grids using Oct-Tree) scheme**
  - accelerates the computation of radiation transfer from large number of point sources
  - Oct-tree structure is adopted to reduce the effective number of point sources.
  - 2-3 times faster calculation on GPUs

    Okamoto, T. Yoshikawa, K. Umemura, M. 2011, MNRAS, 419, 2855

- **ART (Accelerated Ray Tracing) scheme**
  - accelerates the calculation of diffuse radiation transfer
  - 10 times speed-up with the aid of GPU accelerators

Collaborations

- We have pursued an active role in the Strategic Programs for Innovative Research Field 5 "The origin of matter and the universe", the Ministry of Education, Culture, Sports, Science and Technology of Japan.
- In addition, we have collaborated with High Performance Computing Systems division at CCS, for development and tuning of simulation codes on FIRST, T2K-Tsukuba and HA-PACS.
- For the study of the galaxy formation and the reionization of the universe, joint researches have been promoted with the Institute for Cosmic Ray Research at the University of Tokyo and Astronomical Institute at Tohoku University. Those projects are funded by JSPS Grant-in-Aid for Scientific Research.
- In the international collaborations, we have partnered with groups at Department of Physics and Astronomy, University of California at Los Angeles, Institute of Astronomy, University of Vienna, Mt Stromlo Observatory, Department of Physics and Astronomy, John Hopkins University, the Institut Astrophysique de Paris, at the Observatoire de Paris, and University Observatory Munich.

Future plan

- In a cold dark matter universe, the hierarchical structure formation scenario posits that large galaxies have enlarged through multiple mergers with smaller galaxies. To test the theory, we will promote strongly research in the Numerical Galactic Archaeology using the hydrodynamic/N-body simulations of the dynamical, chemical, and spectrophotometric evolution of nearby galaxies.

- Furthermore, the mass of the spheroidal component of galaxies is correlated with the mass of their central SMBHs. This relation implies that galaxies coevolve with their central SMBHs. However, the coevolution process of galaxies and SMBHs is largely unknown.

- To solve these problems, we aim to develop a next-generation hybrid computer system that can extract the potentiality of special purpose processor and new-generation acceleration-board to the maximum. Using such a next-generation hybrid computer, we would like to perform the general relativistic radiation hydrodynamics further.