An incomplete introduction to Computational Astrophysics community in China

Liang Gao

Key laboratory for Computational Astrophysics

National Astronomical Observatories

Outline

- The Computational Astrophysics community in China
  - Galaxy formation and Cosmology
  - Dynamics （galaxy, binary black holes)
  - High energy Astrophysics, MHD (Black hole accretion disk, Solar Physics)
- Computational Facilities (hardware and software development)
- A brief introduction to an international Astronomical Journal--RAA (if time is allowed)

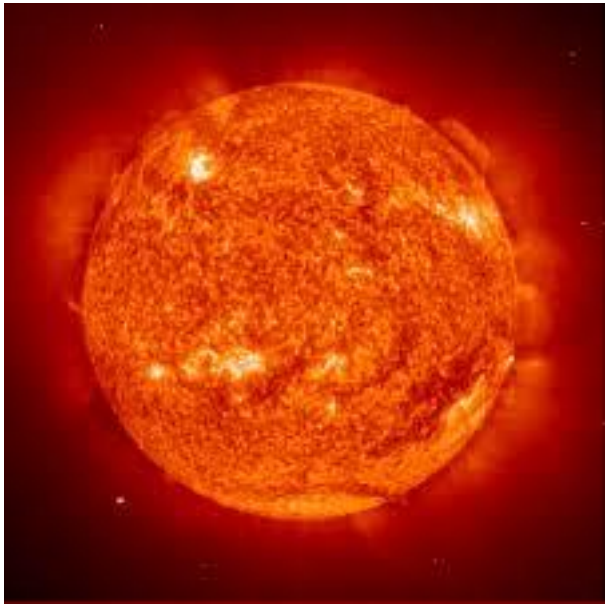
The community—Research subjects

Galaxy formation and Cosmology

Black hole accretion physics

Dynamics of BBH

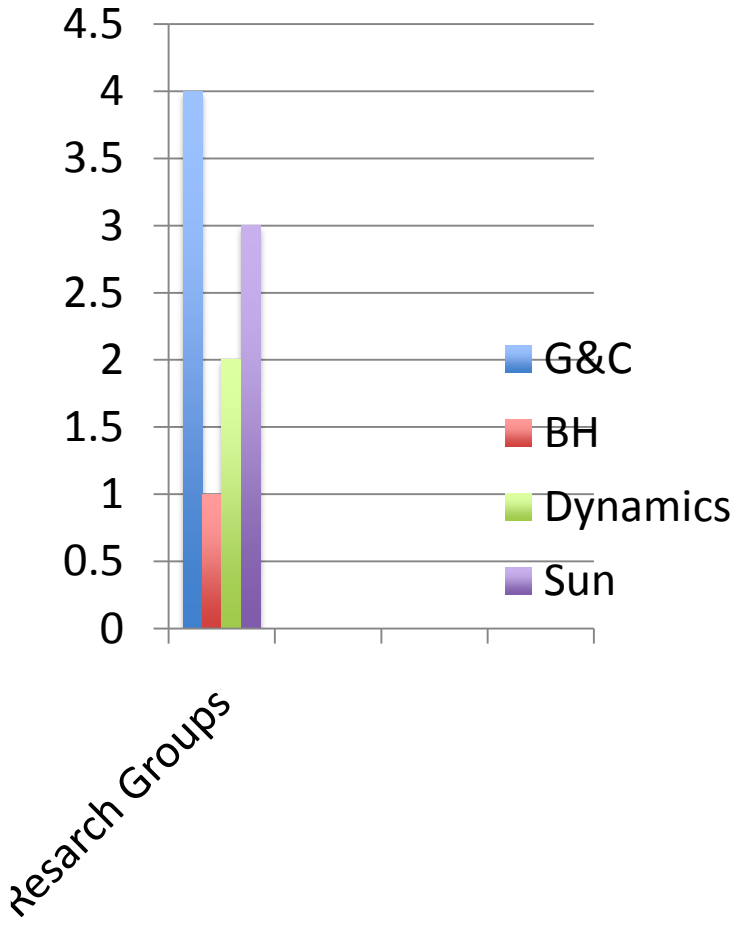
Galactic dynamics



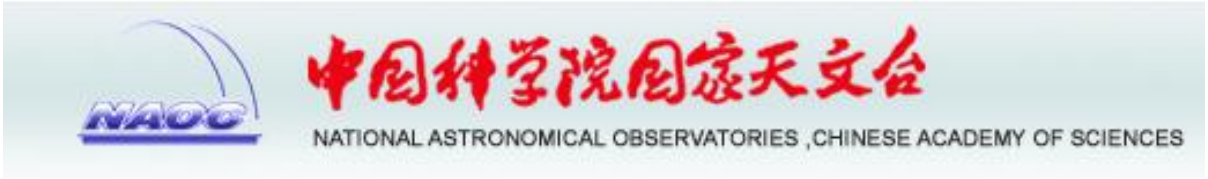
Solar physics

The community-geographical distribution

Research groups Distribution among the subjects



Galaxy formation and Cosmology



3 senior research staffs

1 senior research staff

2 senior research staffs

1 senior research staff

Four major programmes have been carried out by the groups at NAOC

1. The dark matter universe
2. First stars and the formation of galaxies
3. The universe on Gigaparsec scales
4. Dynamics of binary BH in Galactic nuclei

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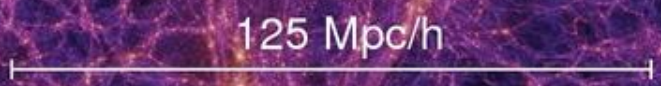
1: the dark matter universe



Goals:

- Characterize the large-scale distribution of dark matter
- Establish the formation paths and structure of dark matter halos

Often require extremely large N-body simulations!

The Phoenix Project

- A suit of N-body simulations of 9 indiviadul rich clusters with ultra-high resolution (10^8 DM particles)
- One simulation has evolved 1 billion particles.

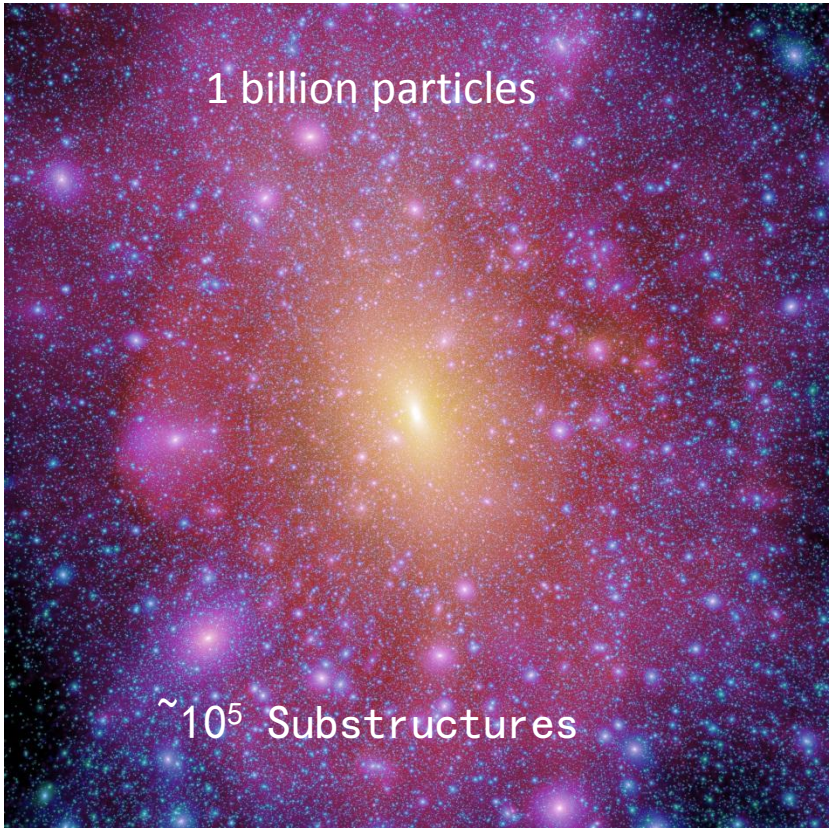
Scientific projects:

- The dark side of rich cluster (Gao et al 2012a)
- Dark matter annihilation (Gao et al. 2012b)
- Intra-cluster light (Cooper et al. 2014)

…….

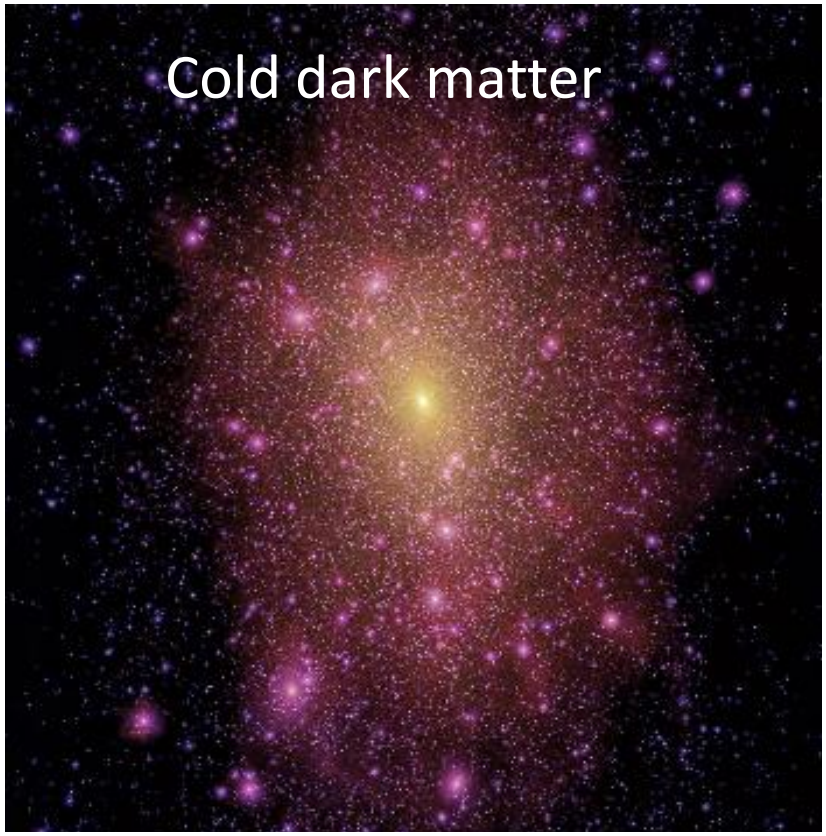
2 Million CPU hours at
Super computer center @CAS

Pha-1 run



China, UK, Germany collaboration
Gao et al. 2012, a,b

Structure formation and the nature of dark matter



A WDM simulation of MW halo with 10^8 particles

Lovewell et al. 2009
Wang et al. 2013
Li et al. 2016a, b

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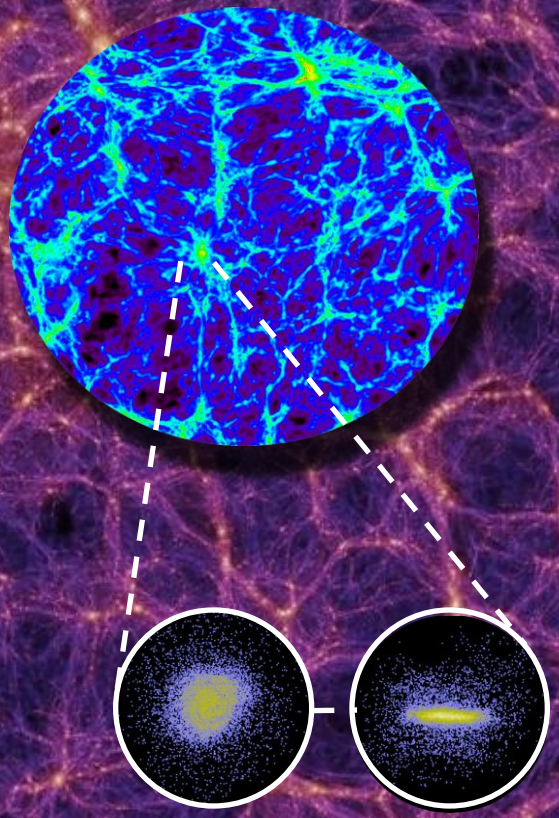
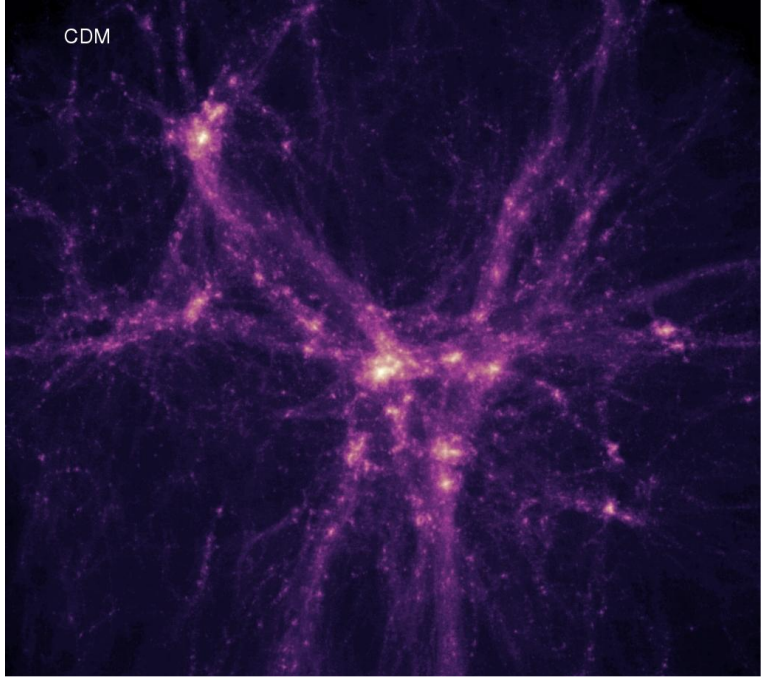
2: first stars and galaxy formation

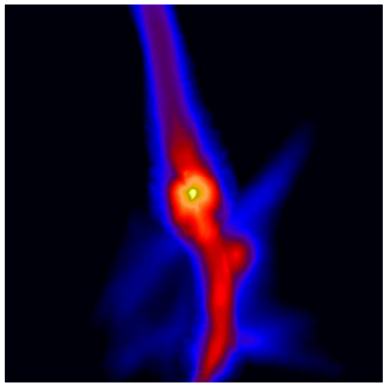
125 Mpc/h



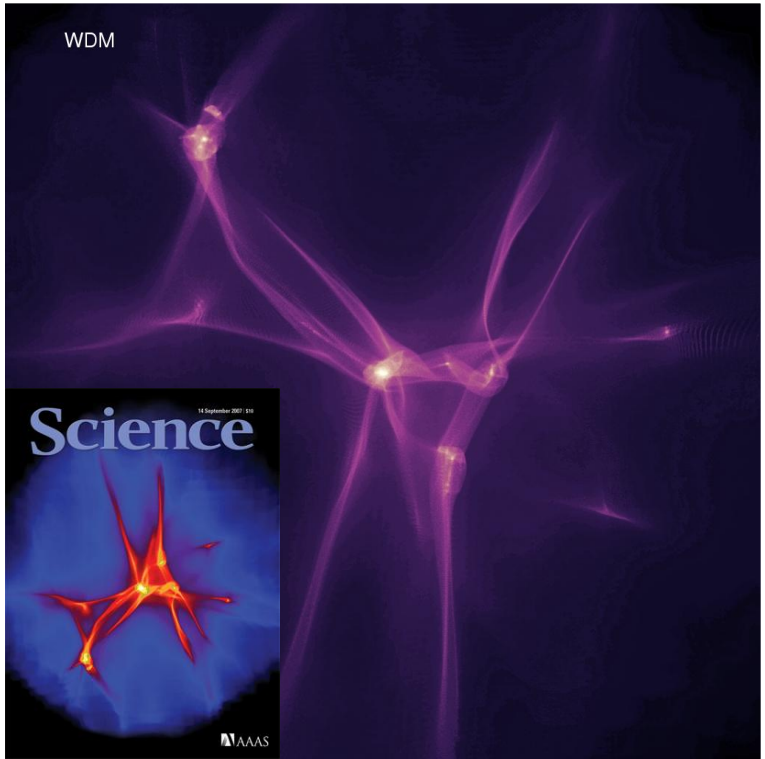
Formation of the first stars

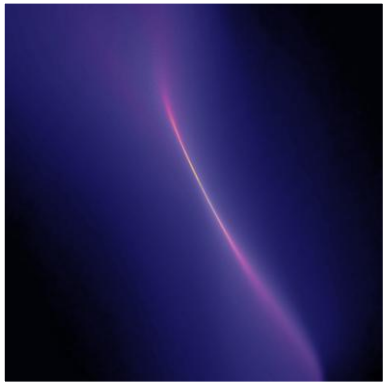
Galaxy formation: disk formation, morphology, chemistry, dynamics, satellites, effect of SMBHs, etc





First star formation in different dark matter models





Non-equilibrium chemical hydro dynamical Simulation of first stars

Gao &Theuns, 2007a,b

Whether star/galaxy formation can occur in WDM filaments at lower redshifts

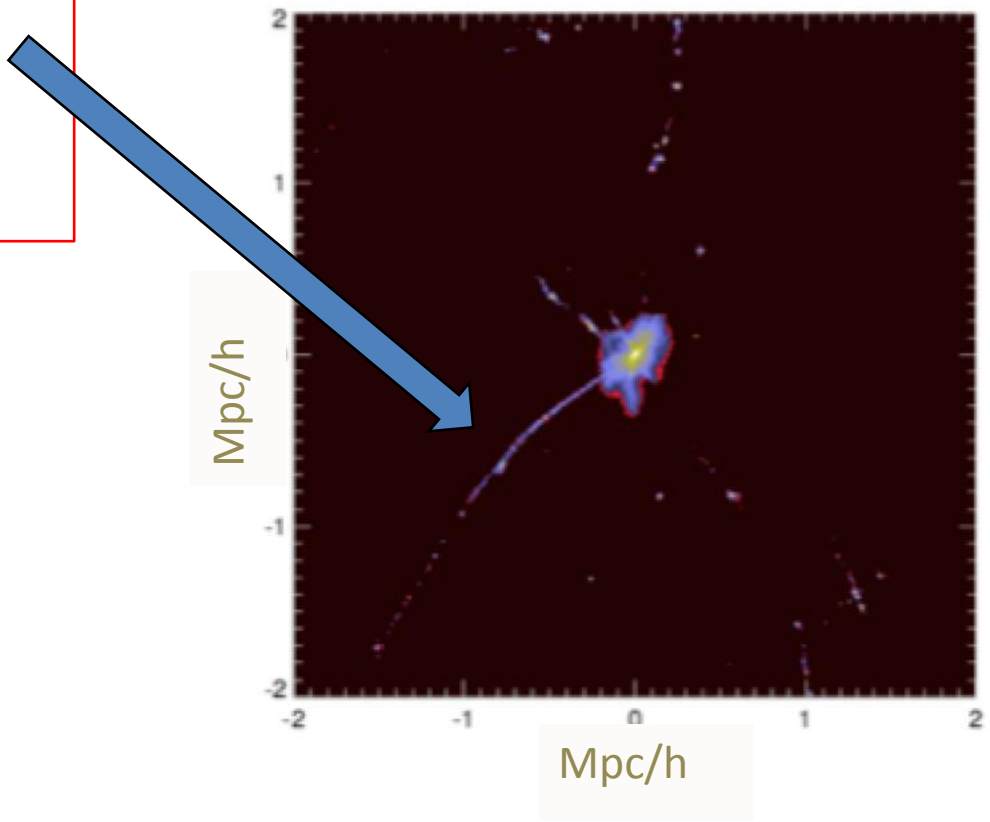
Are filaments around normal galaxies able to cool and condense into stars at lower redshifts?

A simulation of MW type halo assuming WDM with hydro-dynamics +

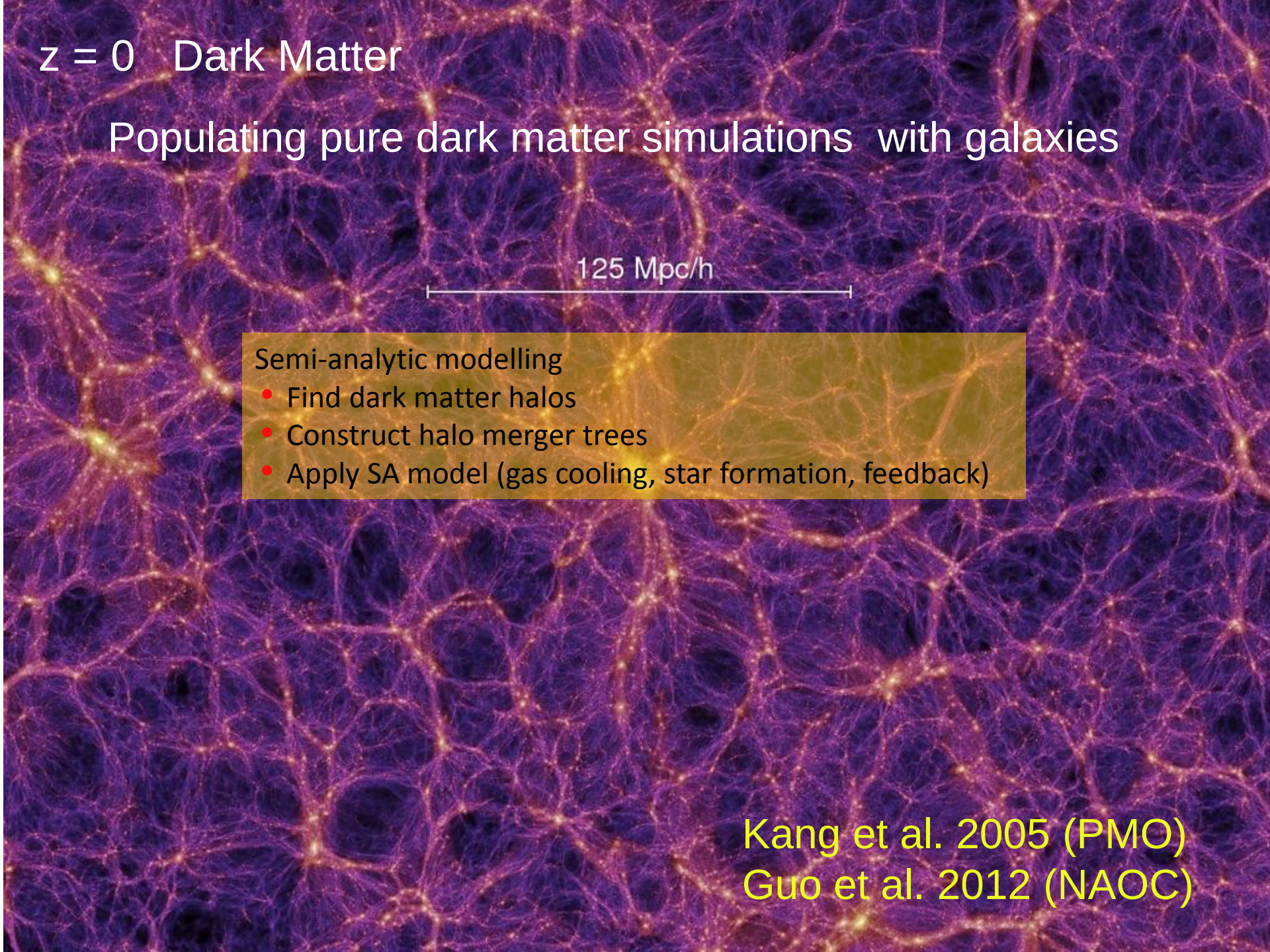
- Cosmological context
- Atomic cooling
- Photo-ionization
- Turn a gas particle into star once its density is above 0.1cc and overdensity >2000 (self -sheilded from UV photons)

Gao,Theuns, Springel, 2014

Observations of a stringy appearance of high z galaxies will rule out CDM



Gao, Theuns, Springel, 2015


z = 0 Dark Matter
Populating pure dark matter simulations with galaxies
125 Mpc/h
Semi-analytic modelling
• Find dark matter halos
• Construct halo merger trees
• Apply SA model (gas cooling, star formation, feedback)
Kang et al. 2005 (PMO)
Guo et al. 2012 (NAOC)

Galaxy formation

$$\dot{M}_{\rm BH} = \kappa \left(\frac{f_{\rm hot}}{0.1}\right)\left(\frac{V_{\rm vir}}{200 kms^{-1}}\right)^3 \left(\frac{M_{\rm BH}}{10^8/{\rm h}M_\odot}\right) M_\odot/{\rm yr}$$

$$\delta M_{\rm reheat} = \epsilon_{\rm disk} \times \delta M_\star$$

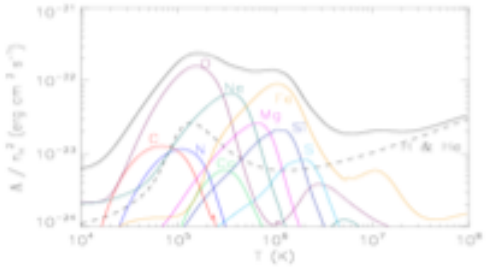
$$\delta E_{\rm SN} = \epsilon_{\rm halo} \times \frac{1}{2}\delta M_\star V_{\rm SN}^2$$

$$\epsilon_{\rm halo} = \eta \times \left[0.5 + \left(\frac{V_{\rm max}}{70{\rm km/s}}\right)^{-\beta_2}\right]$$

$$\delta M_{\rm ejec} = \frac{\delta E_{\rm SN} - \frac{1}{2}\delta M_{\rm reheat} V_{\rm vir}^2}{\frac{1}{2}V_{\rm vir}^2}$$

$$\dot{E}_{\rm radio} = 0.1 \dot{M}_{\rm BH} c^2$$

$$t_{\rm cool}(r) = \frac{3\mu m_{\rm H} k T_{\rm vir}}{2\rho_{\rm hot}(r)\Lambda(T_{\rm hot}, Z_{\rm hot})}$$



Infall

Hot gas

Feedback (reheating)

Cooling

Feedback (ejection)

merge or ...pt?

pressure + tidal stripping

$$\delta \vec{J}_{\rm gas,cooling} = \dot{M}_{\rm cool} \frac{\vec{J}_{\rm DM}}{M_{\rm DM}} \delta t$$

$$\Delta \vec{J}_{\rm gas} = \delta \vec{J}_{\rm gas,cooling} + \delta \vec{J}_{\rm gas,acc} + \delta \vec{J}_{\rm gas,SF}$$

$$R_{\rm gas,d} = \frac{J_{\rm gas}/M_{\rm gas}}{2V_{\rm max}}$$

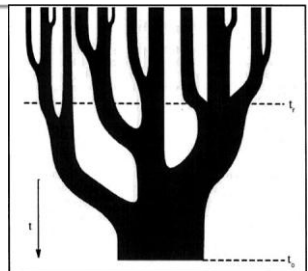
disk formation

$$\Sigma_{\rm crit}(R) = 12 \times \left(\frac{V_{\rm max}}{200{\rm km/s}}\right)\left(\frac{R}{10{\rm kpc}}\right)^{-1} M_\odot {\rm pc}^{-2}$$

$$\dot{M}_\star = \alpha(M_{\rm gas} - M_{\rm crit})/t_{\rm dyn}$$

-4.33	66	38	-4	-38	-41	-52	-36	-55	-21	-4	-6	-17	-19	77	5	29	64	135
0.00	58	38	5	-4	-15	-24	-26	-26	-25	-1	-7	-15	-13	61	48	24	57	29
0.35	70	47	12	-4	-12	-26	-31	-32	-25	-2	-12	-18	-14	73	57	26	63	31

Star formation and evolution



$$\epsilon_{\rm burst} = 0.56 \left(\frac{M_{\rm minor}}{M_{\rm major}}\right)^{0.7}$$

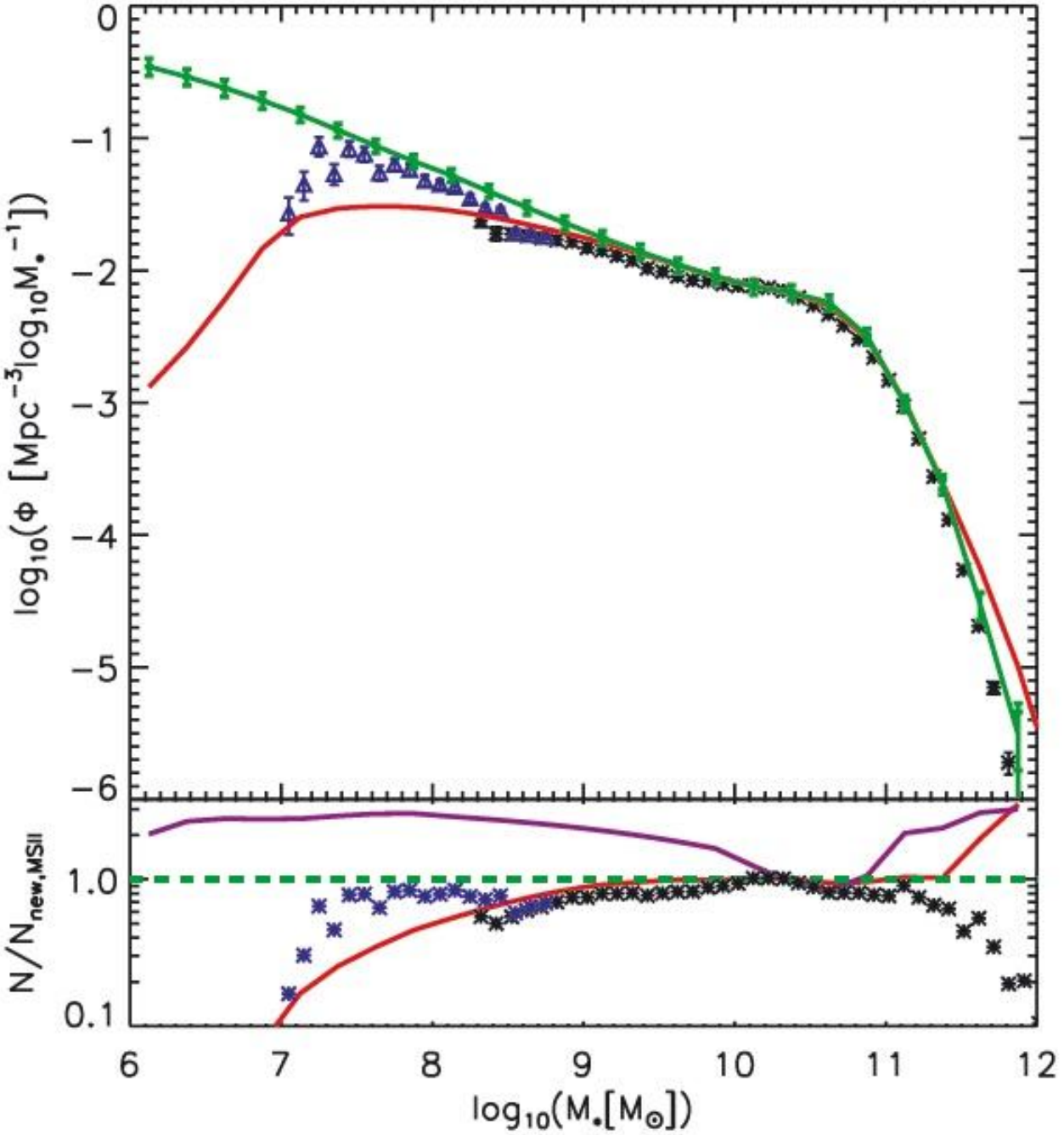
$$t_{\rm friction} = \alpha_{\rm fric} \frac{V_{\rm vir} r_{\rm sat}^2}{G m_{\rm sat} \ln \Lambda}$$

$$R_{\rm strip} = min(R_{\rm tidal}, R_{\rm r.p.})$$

$$\left(\frac{R}{R_{\rm peri}}\right)^2 = \frac{\ln R/R_{\rm peri} + \frac{1}{2}(V/V_{\rm vir})^2}{\frac{1}{2}(V_t/V_{\rm vir})^2}$$

$$C\frac{GM_{\rm new,bulge}^2}{R_{\rm new,bulge}} = C\frac{GM_1^2}{R_1} + C\frac{GM_2^2}{R_2} + \alpha_{\rm inter}\frac{GM_1 M_2}{R_1 + R_2}$$

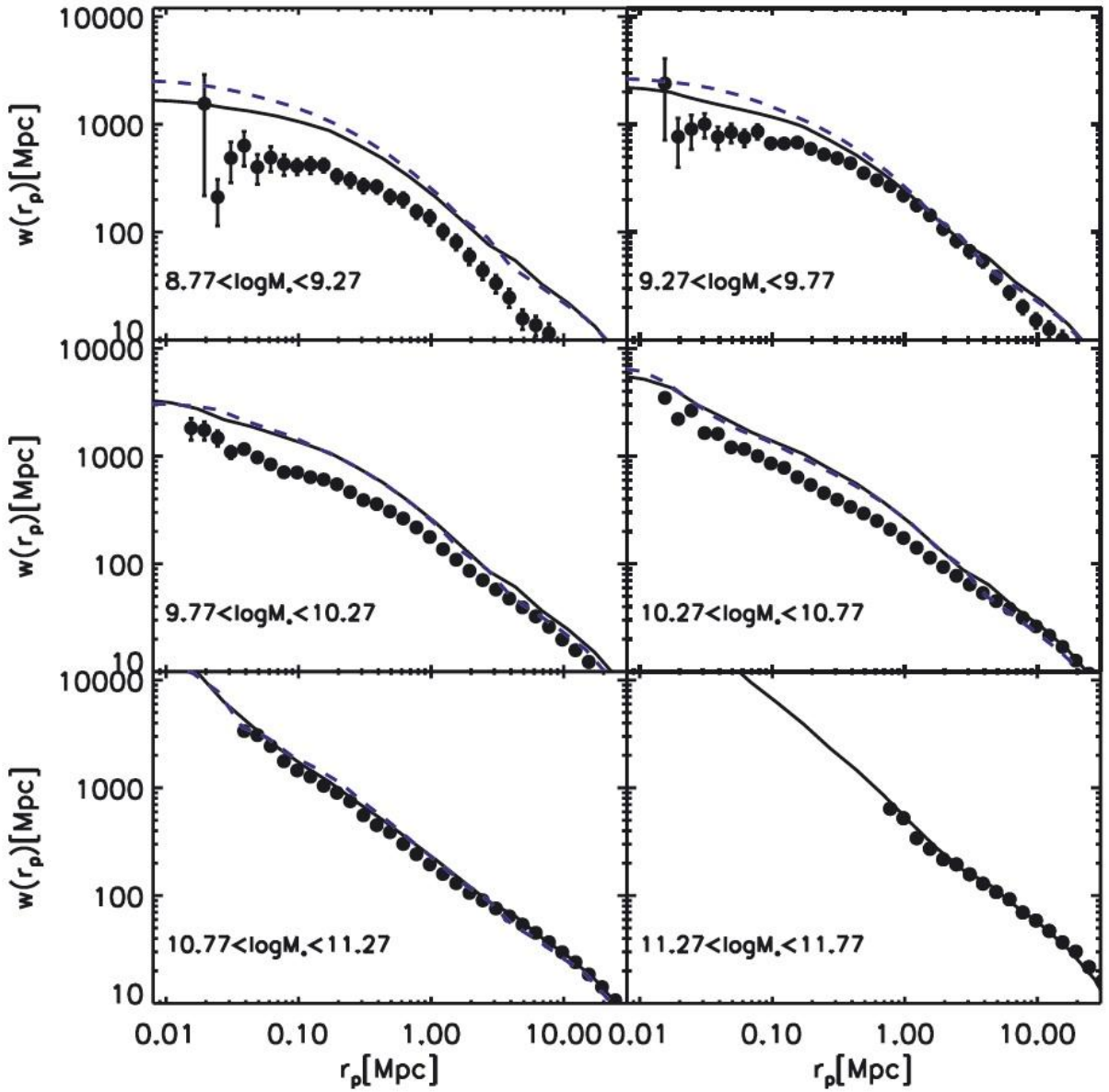
$$\delta M_\star = 2\pi \Sigma_{\star 0} R_{\star,\rm d}[R_{\star,\rm d} - (R_{\rm b} + R_{\star,\rm d})\exp(-R_{\rm b}/R_{\star,\rm d})]$$



Galaxy Luminosity function

Guo et al. 2012

2-Point correlation function



On-going Hyper--Millennium Project

2 Trillion dark matter particles in a 2Gpc/h box, particle resolution 3x10^8 Msun/h

(200 times big the Millennium simulation in size)

Will be running on ½ of the second fastest machine Tianhe-2

Scientific goal:

- Create mock galaxies and Light-cone for on-going galaxy/weak lensing surveys –SDSS4, DESI, EUCLID, LSST

Will produce a huge amount of data. A half sky light cone =1.5 PB!

Data analysis will be a big challenge.

In collaboration with MPA-Durham–Heidelberg (S. White, C.S. Frenk, S. Cole, V. Springel)

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Dynamics of binary black holes

Dynamics of binary black holes: important for gravitational wave detection

Simulations of many body system with general relativity and Newtonian physics

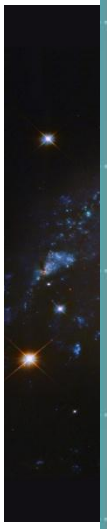
NGC2207/HST

Lead by Prof. R. Spurzem @Naoc

D

Dyna

Simu



NGC22

HIGHLIGHT: MARCH 2016

The DRAGON globular cluster simulations: a million stars, black holes and gravitational waves

March 01, 2016

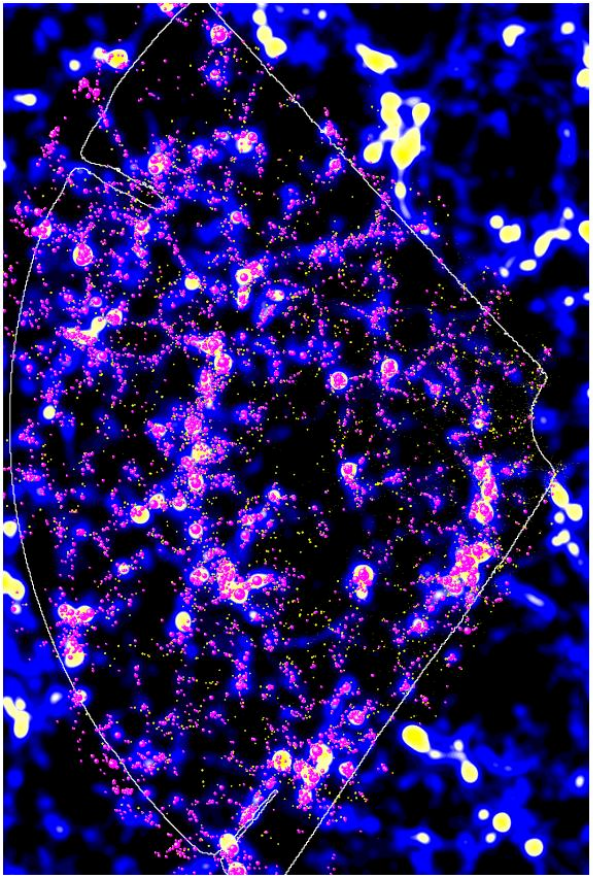
An international team of experts from Europe and China has performed the first simulations of globular clusters with a million stars on the high-performance GPU cluster of the Max Planck Computing and Data Facility. These – up to now - largest and most realistic simulations can not only reproduce observed properties of stars in globular clusters at unprecedented detail but also shed light into the dark world of black holes. The computer models produce high quality synthetic data comparable to Hubble Space Telescope observations. They also predict nuclear clusters of single and binary black holes. The recently detected gravitational wave signal might have originated from a binary black hole merger in the center of a globular cluster.

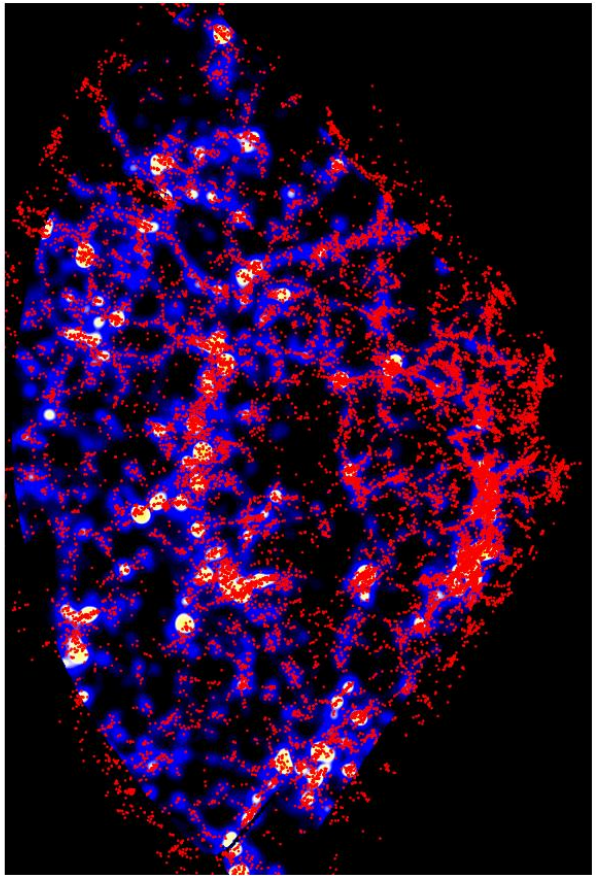
Globular clusters are truly enigmatic objects. They consist of hundreds of thousands luminous stars and their remnants, which are confined to a few tens of parsecs (up to 100 lightyears) – they are the densest and oldest gravitationally bound stellar systems in the Universe. Their central star densities can reach a million times the stellar density near our Sun. About 150 globular clusters orbit the Milky Way but more massive galaxies can have over 10,000 gravitationally bound globular clusters. As their stars have mostly formed at the

Activates on G&C from other institutions

ELUCID - **E**xploring the **L**ocal **U**niverse with re**C**onstructed **I**nitial **D**ensity field

Carried by the group @SJTU in Shanghai
Prof. Y.P. Jing



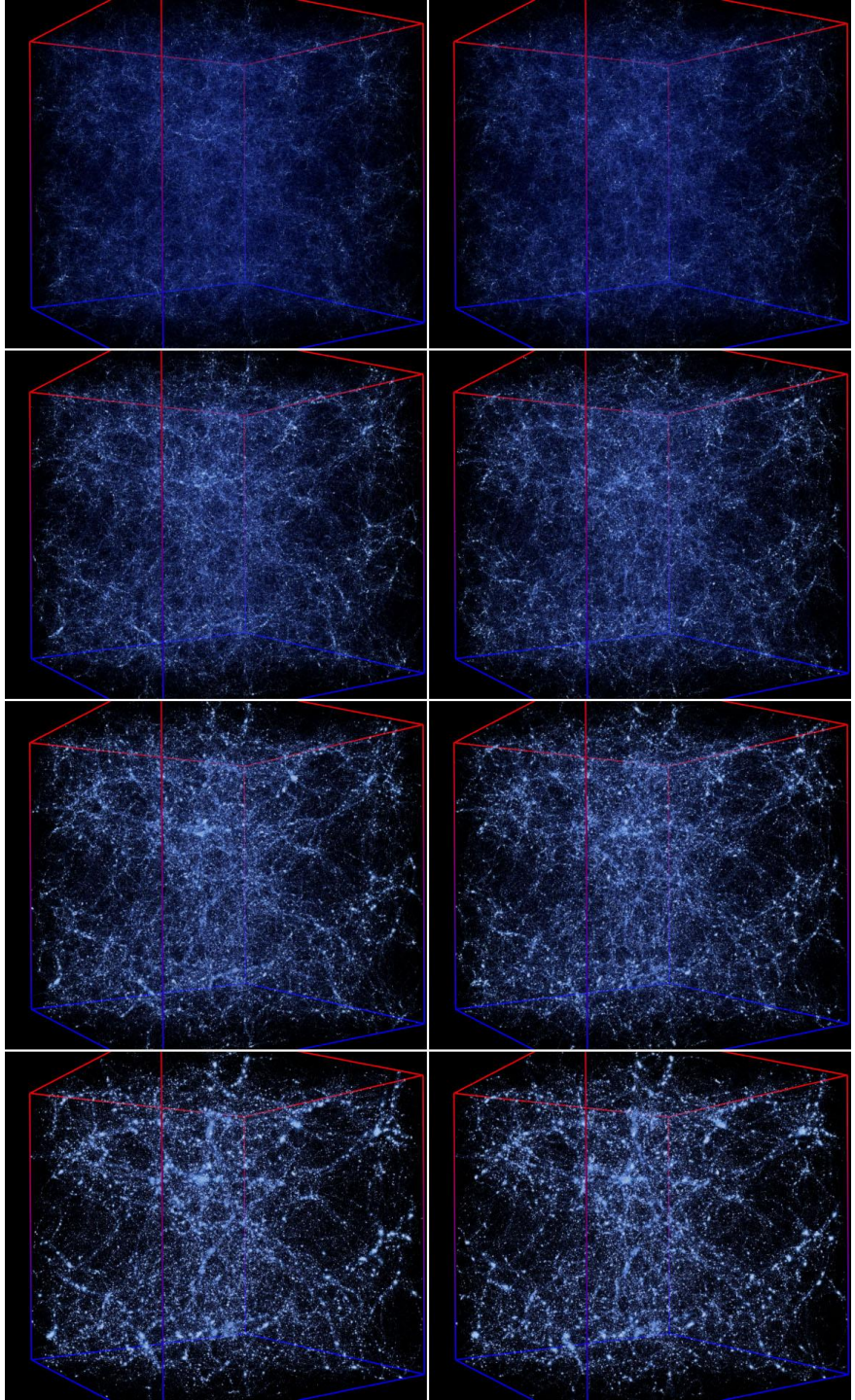


Model:

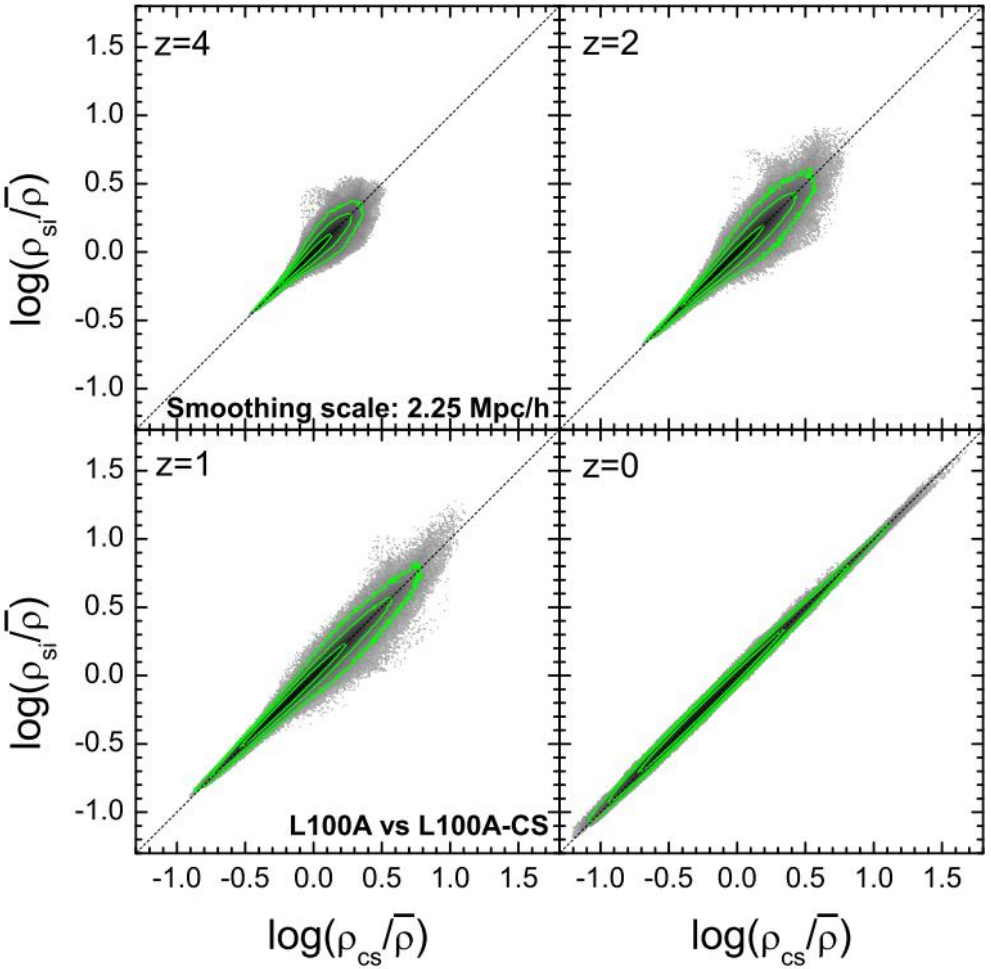
- N-body simulations of local Universe (4096^3 particles, 600Mpc/h)
- High resolution Hydro-simulations of some interesting structures.
- Semi-analytical model of galaxy formation

Observation:

- Galaxy properties: galaxy redshift survey;
- ISM properties: 21cm emission, millimeter/submillimeter emissions;
- IGM properties: quasar absorption line systems; X-ray observations; Sunyaev-Zel'dovich effect.



Hamiltonian Markov Chain Monte Carlo Method with Particle Mesh Dynamics is applied to reconstruct the initial condition from a given non-linear density field. We test our method with N-body simulation.



Computational black hole astrophysics in SHAO

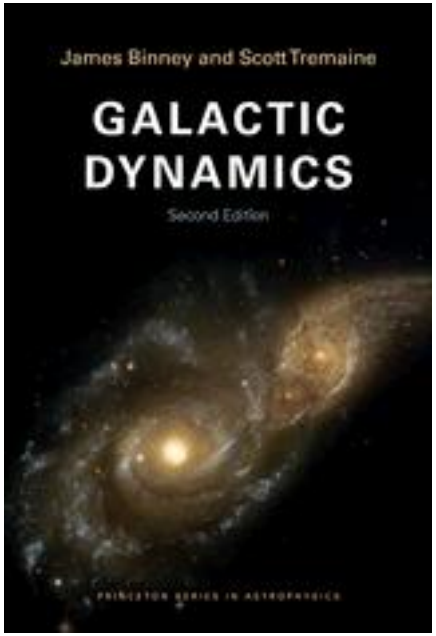
- Black hole accretion
  Global and shearing box; 2D and 3D; HD and MHD; with and without radiative transfer; GR and Newtonian
- Jet formation
  Shearing box and global; MHD
- AGN feedback
  2D and 3D; so far only hydro, no magnetic field

Feng Yuan from SHAO@Shanghai

Prof. Juntai Shen

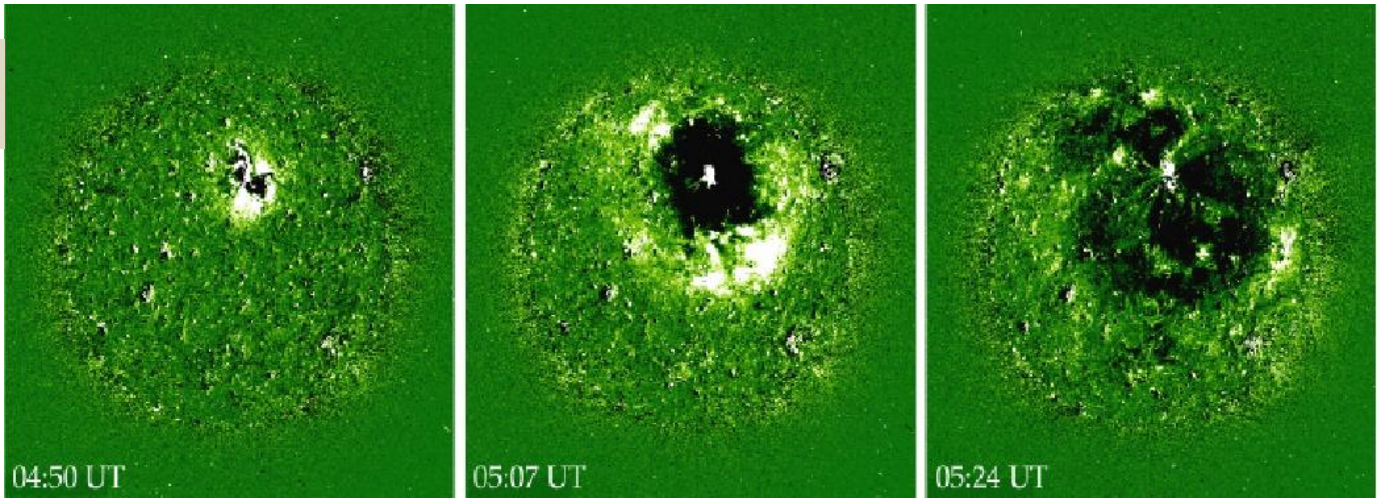
Galactic dynamics group @SHAO

Disk stability
Bar formation & evolution



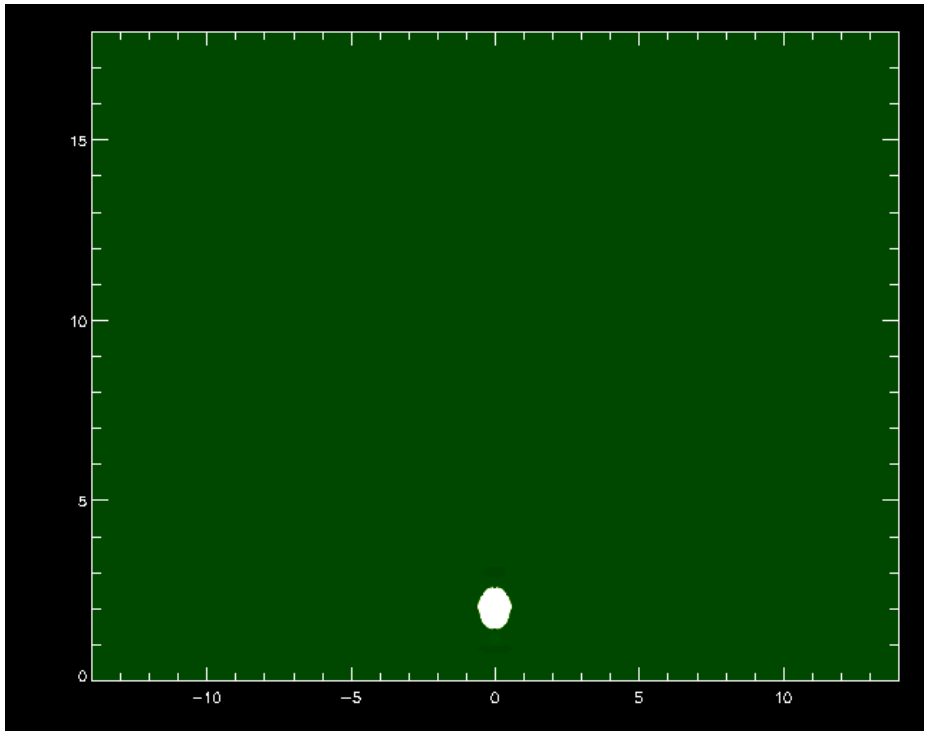
Large-Scale Coronal Waves—Nanjing Univ.

Observation



Prof. Pengfei Chen

RMHD Simulation



Chen +(2002, 2005, 2006, 2009, 2010, 2011)

magnetic reconnection

Computational facilities

Small simulations: Institutes or Universities (free of charge)

Up to 2000 cores

Medium simulations: Super computer center, CAS (need to pay but it is cheap (0.1 RMB per core/cpu hour)

Up to 10,000 cores

Large simulations: National supercomputer centers (need to pay, 0.1 RMB per core/cpu hour)

Up to 100,000 cores

RANK	SITE	SYSTEM	CORES	RMAX (TFLOP/S)	RPEAK (TFLOP/S)	POWER (KW)
1	National Super Computer Center in Guangzhou China	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P NUDT	3120000	33,862.7	54,902.4	17,808
17	National Supercomputing Center in Tianjin China	**Tianhe-1A** - NUDT YH MPP, Xeon X5670 6C 2.93 GHz, NVIDIA 2050 NUDT	186368	2,566.0	4,701.0	4,040
21	LvLiang Cloud Computing Center China	**Tianhe-2 LvLiang Solution** - Tianhe-2 LvLiang, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Intel Xeon Phi 31S1P NUDT	174720	2,071.4	3,074.5	997
35	National Supercomputing Centre in Shenzhen (NSCS) China	**Nebulae** - Dawning TC3600 Blade System, Xeon X5650 6C 2.66GHz, Infiniband QDR, NVIDIA 2050 Dawning	120640	1,271.0	2,984.3	2,580
65	National Supercomputing Center in Jinan China	**Sunway BlueLight** - Sunway BlueLight MPP, ShenWei processor SW1600 975.00 MHz, Infiniband QDR National Research Center of Parallel Computer Engineering & Technology	137200	795.9	1,070.2	1,074
67	National Super Computer Center in Hunan China	**Tianhe-1A Hunan Solution** - NUDT YH MPP, Xeon X5670 6C 2.93 GHz, Proprietary, NVIDIA 2050 NUDT	53248	771.7	1,342.8	1,155
99	Institute of Process Engineering, Chinese Academy of Sciences China	**Mole-8.5** - Mole-8.5 Cluster, Xeon X5520 4C 2.27 GHz, Infiniband QDR, NVIDIA 2050 IPE, Nvidia, Tyan	29440	496.5	1,012.6	540

Plenty of computer resources (167 of the Top 500 fastest machines are China-based)

Source: http://top500.org/list/2016/06/

Simulation Code developments

N-body Code
P3M code Jing et al. 1998 (Shanghai)

Hydra dynamical code:
PM+WENO Feng et al. (Guangzhou)

NAOC group members use Gadget (developed by Volker Springel @MPA) , because they graduated from MPA.

A new many-core simulation code is under development at NAOC

NCSA director: GPU is future of supercomputing

by Brooke Crothers

The director of the National Center for Supercomputing Applications has seen the future of supercomputing and it can be summed up in three letters: GPU.

Thom Dunning, who directs the NCSA and the Institute for Advanced Computing Applications and Technologies at the famed supercomputing facilities on the campus of University of Illinois at Urbana-Champaign, says high-performance computing will begin to move toward graphics processing units or GPUs. Not coincidentally, **this is exactly what China has done to achieve the world's fastest speeds with its "Tianhe-1A"** supercomputer. That computer combines about 7,000 Nvidia GPUs with 14,000 Intel CPUs: the only hybrid CPU-GPU system in the world of that scale.

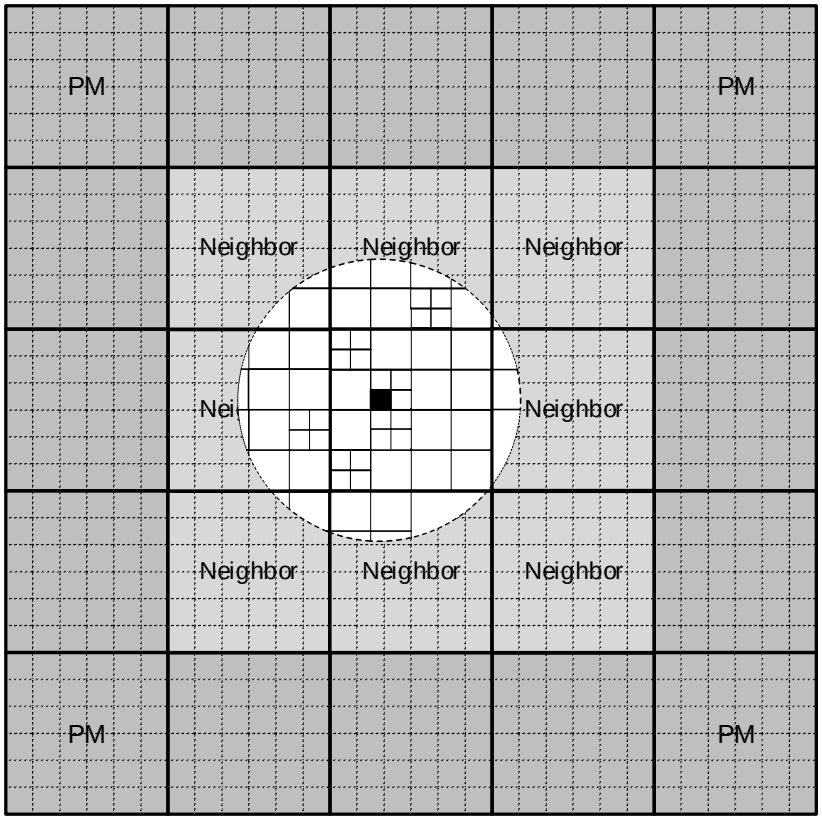
Thom Dunning directs the Institute for Advanced Computing Applications and Technologies and the NCSA.

"What we're really seeing in the efforts in China as well as the ones we have in the U.S. is that GPUs are what the future will look like," said Dunning in a phone interview Thursday. "What we're seeing is the beginning of something that's going to be happening all over the world."

NCSA already has a small CPU-GPU hybrid system. "It's something we have been working on for a number of years. We have a CPU-GPU cluster for the NCSA academic community. Made up of Intel CPUs and Nvidia GPUs. A 50 teraflop machine," he said. (Note that **Oak Ridge National Laboratories is also installing a hybrid system now**.)

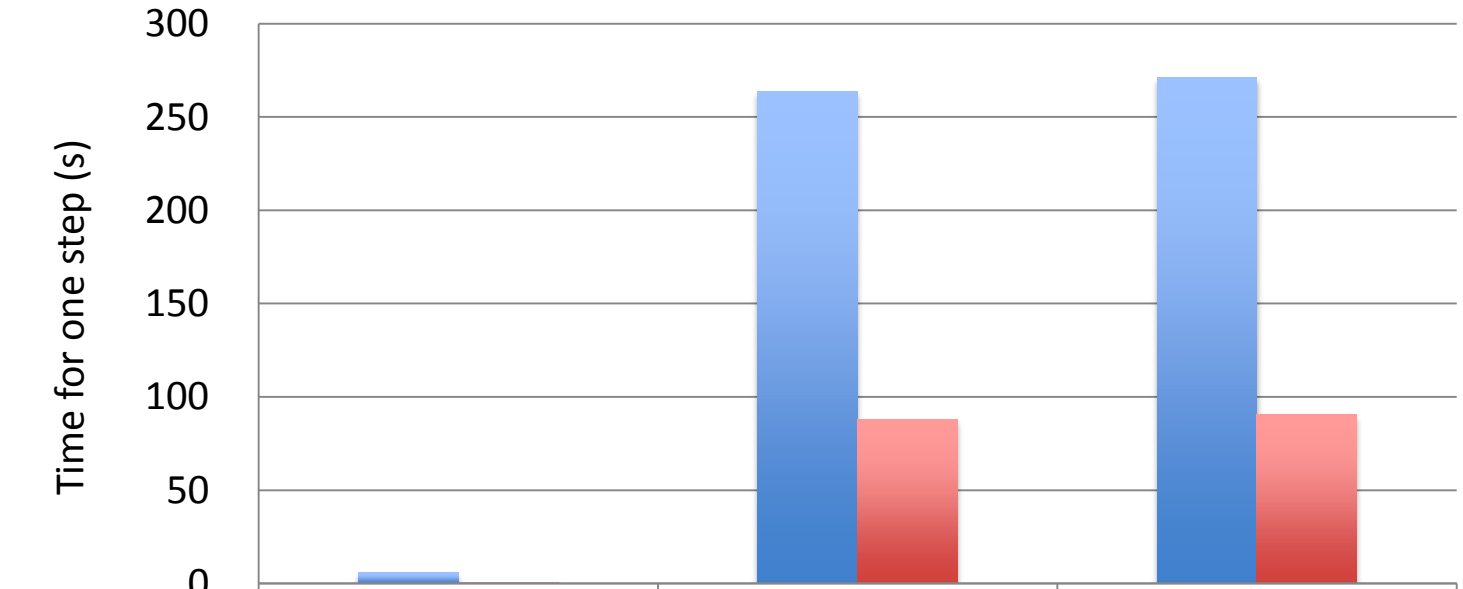
PM-Tree-PP code: force calculation scheme

- PM-Tree-PP code



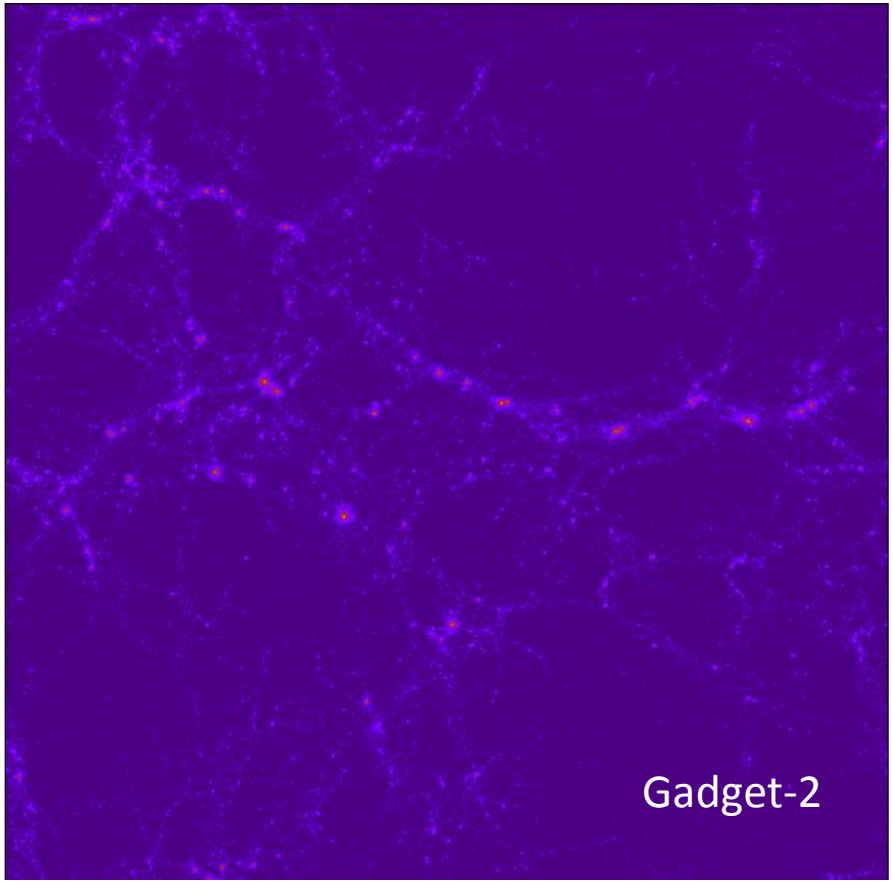
Performance Improvements over CPU

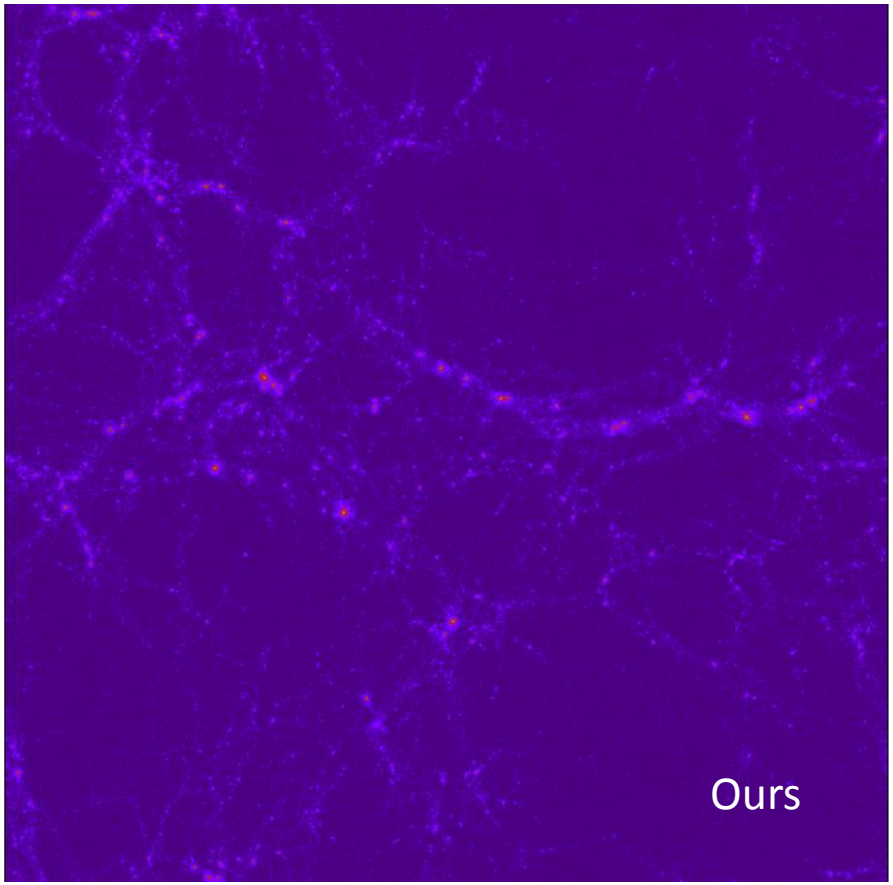
Performance improvement on 2*Xeon E5-2680 for 2^{27} particles within 2^{15} meshes



	Tree building	Tree walking	Overall calculation
Before Opt.	5.7	263.8	271.4
After Opt.	0.6	87.9	90.5
	9.5x	3.0x	3.0x

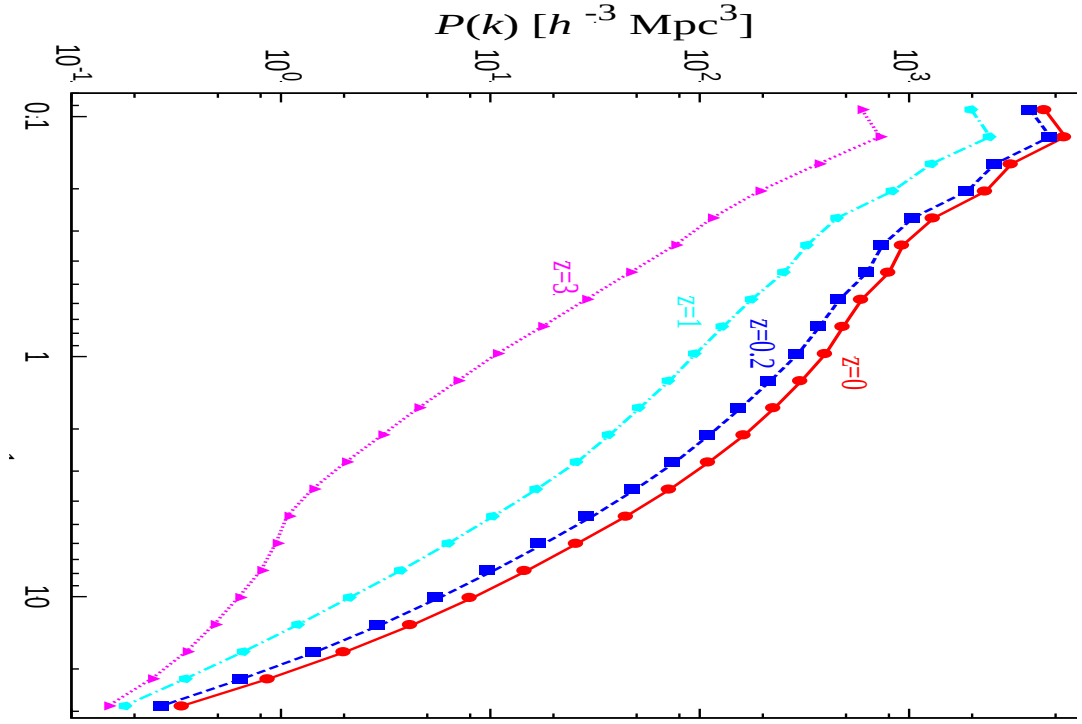
comparison to Gadget-2



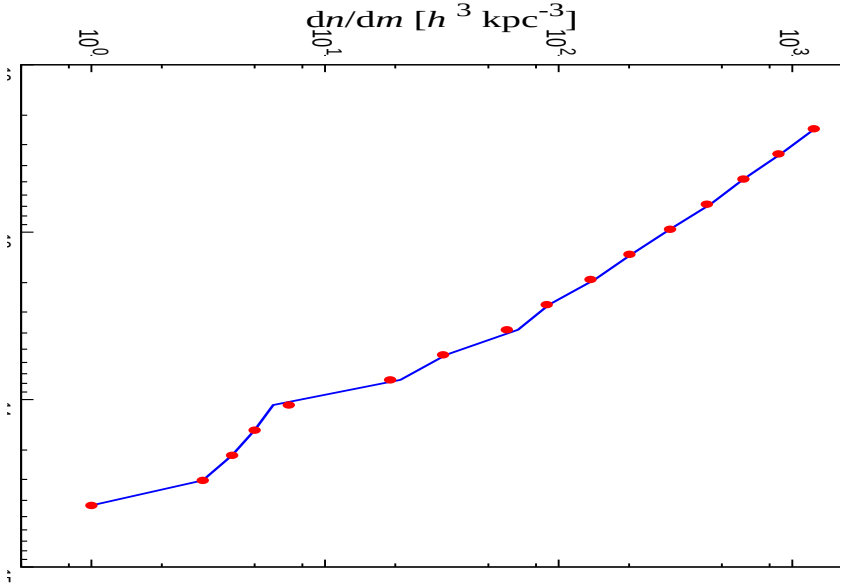


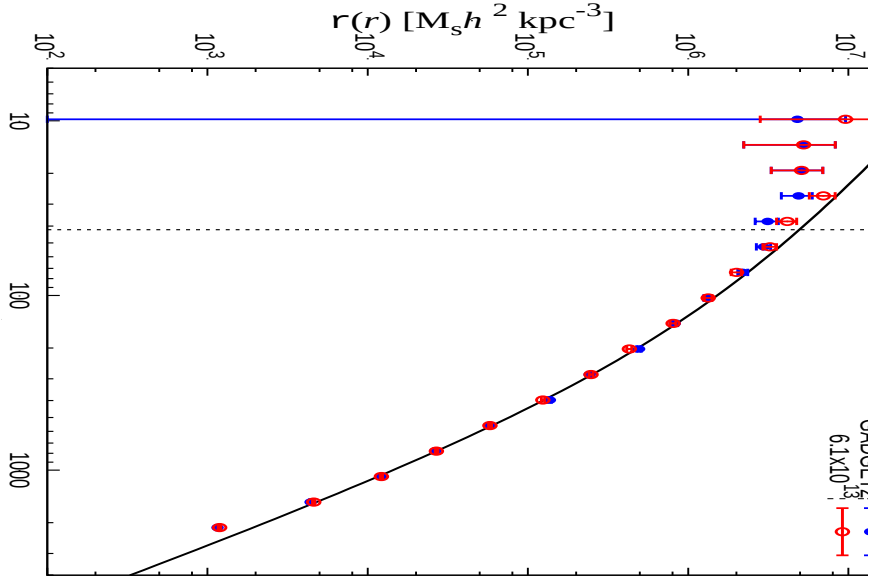
We carry out LCDM simulation from redshift 49 to the present,
with the same initial condition containing 128^3 dark matter particles（~3.3e10 solar mass）

POWER SPECTRUM



curves:Gadget-2; points:Our results
snapshots at 4 redshifts, z=0, 0.2, 1, 3
adaptive-step scheme





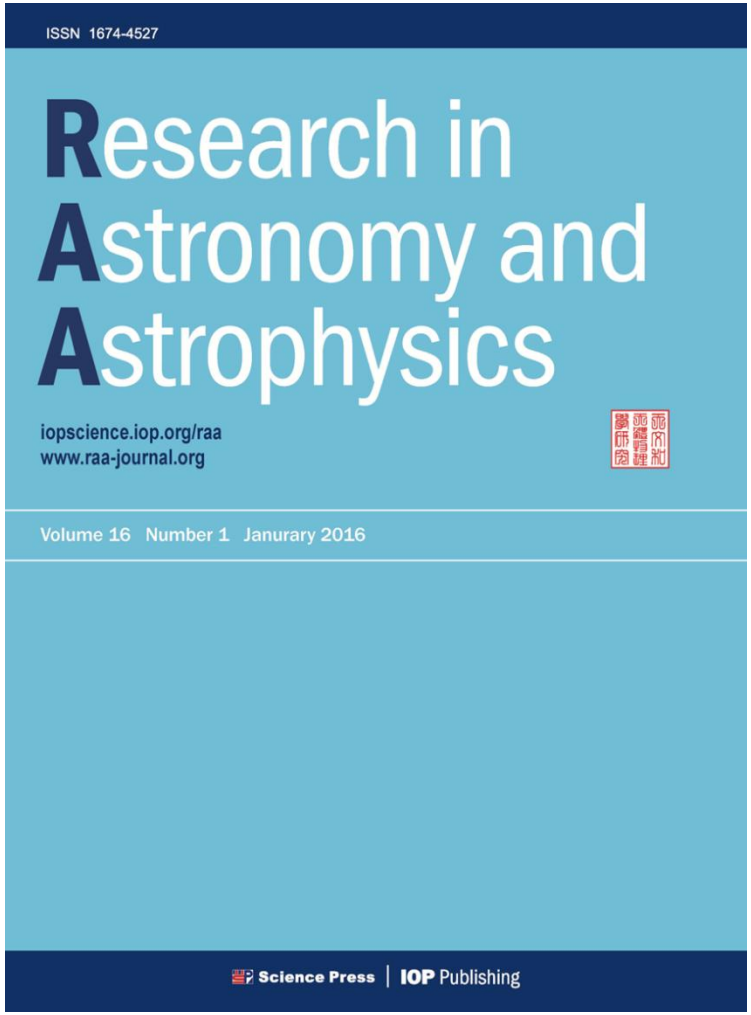
Friend-of-Friend halo finder
Gadget-2 (blue curve)
Our result (Red point)
box size is 100Mpc/h
linking factor = 0.164

halo mass ~ 6.1×10^{13} solar mass
Gadget-2 (blue point)
Our result(red point)
reference NFW curve(solid)
softening scale (vertical dash)
2.8 x 15 kpc/h

Summary

- There is a moderate sized Computational Astronomical community in China, especially in G&C
- Plenty of Computational resources available in China
- There were few collaborations between China and BRICS in area, but a strong tier should be built in near future

A brief introduction to RAA



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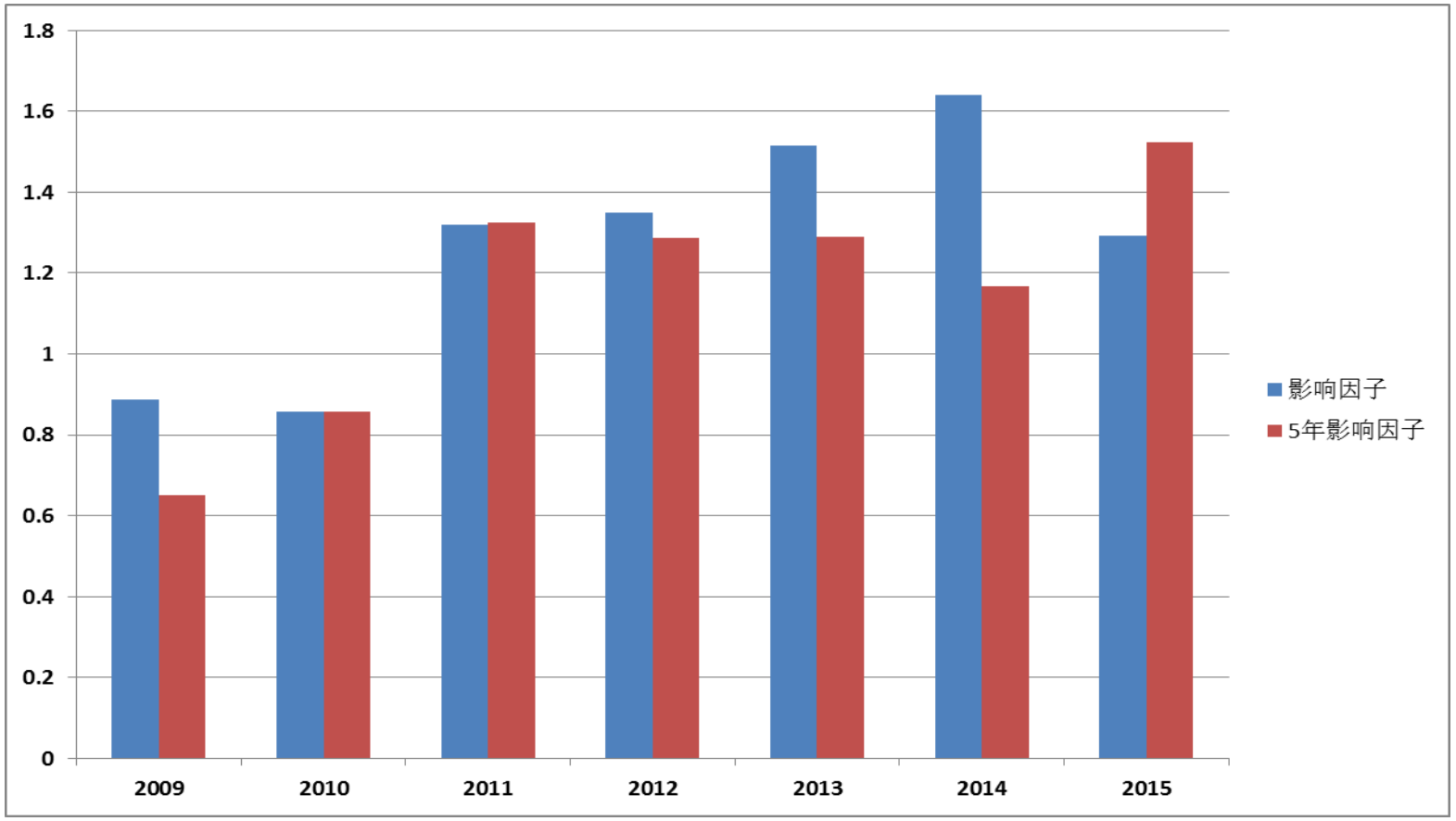
The IF's Trend from 2009-2015



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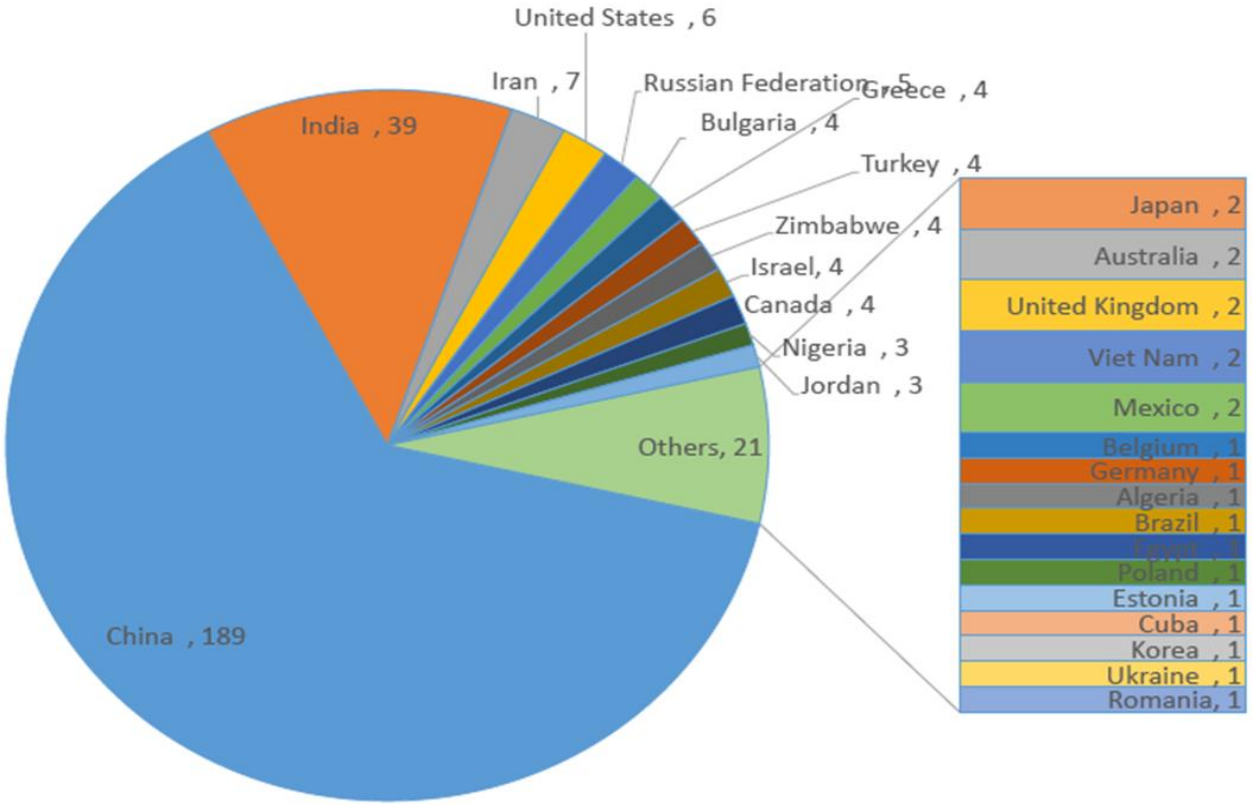
- In 2015, RAA received a total of 297 articles. Among these, domestic submissions accounted for 189 (64%) and international ones made up 108 (36%).



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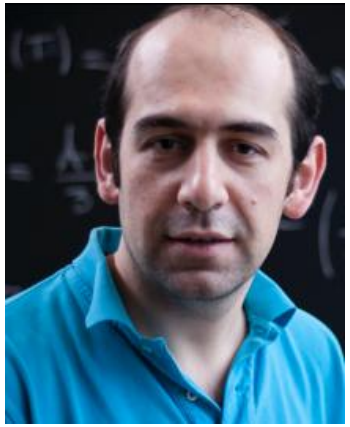

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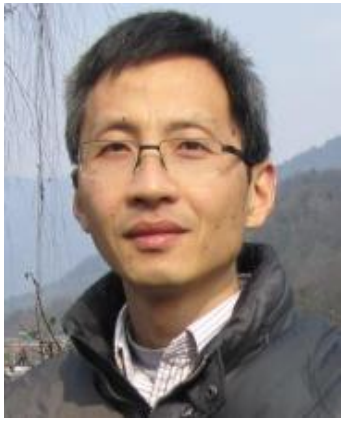

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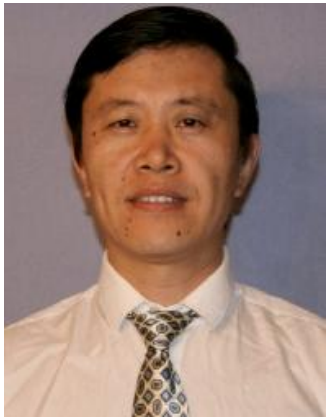

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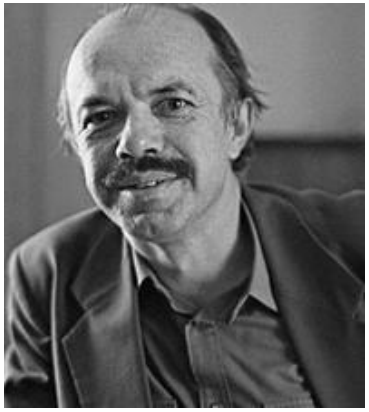

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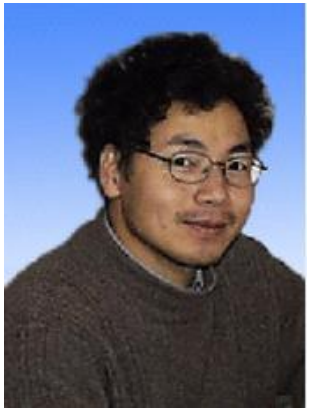

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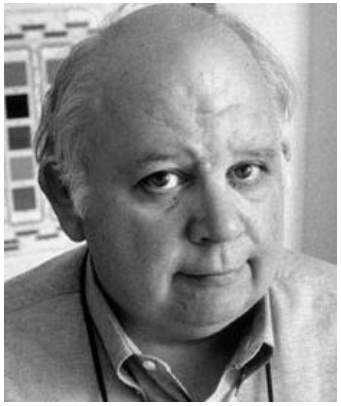

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Collaboration with BRICS

We are exploring the possibility to jointly run RAA with Indian colleagues and are seeking collaborations with other BRICS!