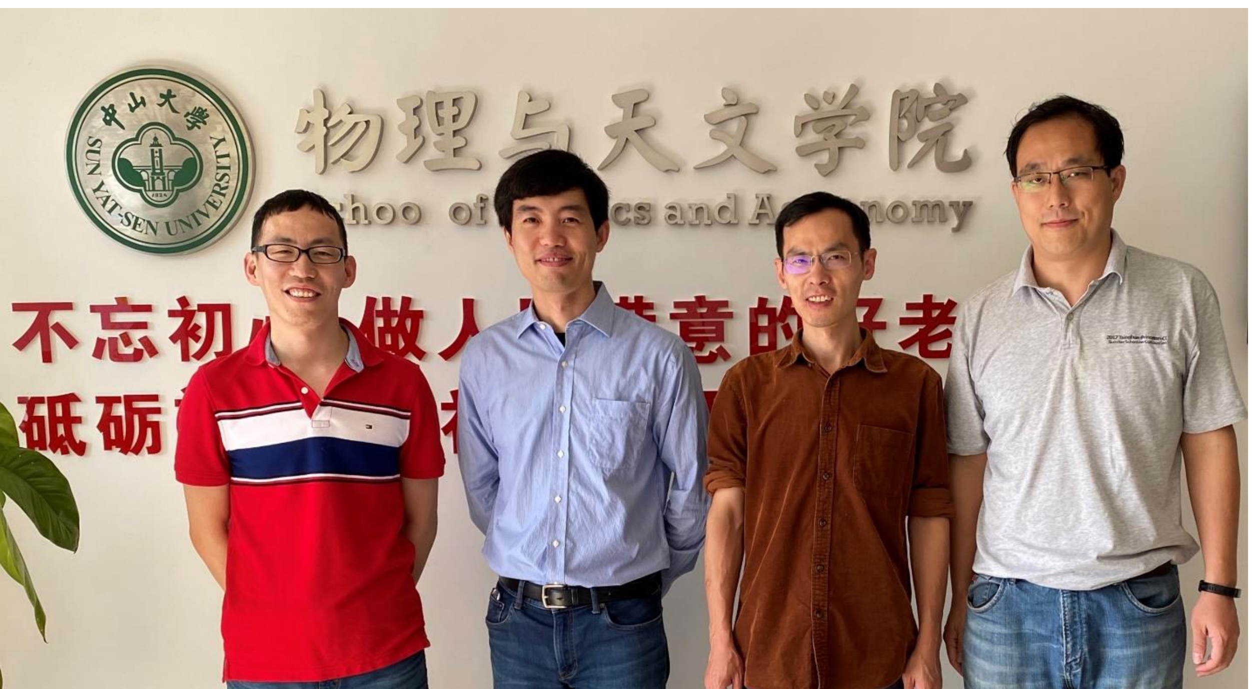
School of Physics & Astronomy (SPA), Sun Yat-Sen University (SYSU)

Planet formation, interior and interaction with the star: the exoplanet research in SYSU



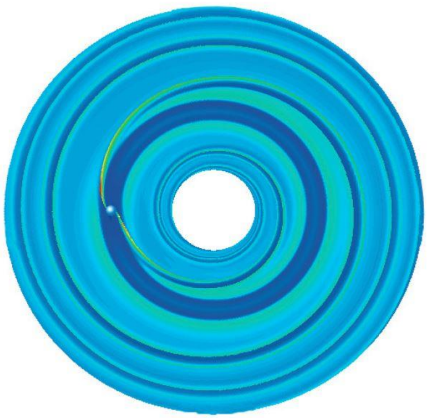
Yang Gao
Cong Yu
Shangfei Liu
Bo Ma

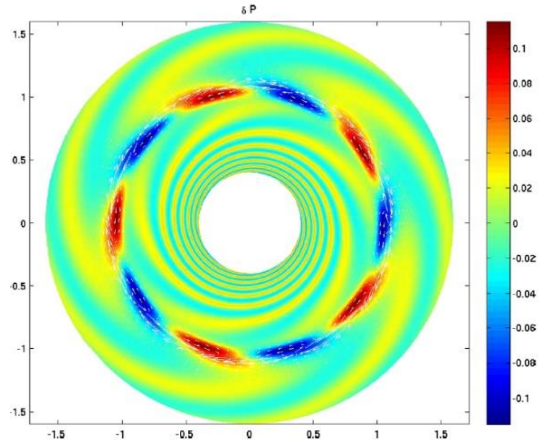
What we do…

Planet formation & disk

Cong Yu, yucong@mail.sysu.edu.cn

- **Planet-disk interaction**
  - **Type I planet migration**
- **MHD processes of proto-planetary disks**
  - **Magneto-rotational Instability**
  - **Rossby wave Instability,**
  - **Streaming Instability**
- **Planet structure**
  - **Planet Interior Structure**
  - **Planet Thermal Evolution**

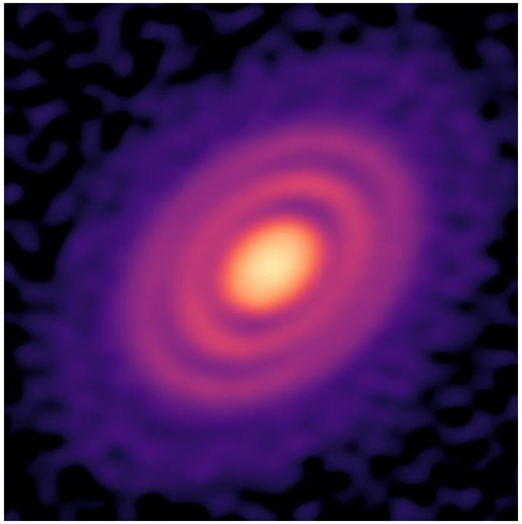




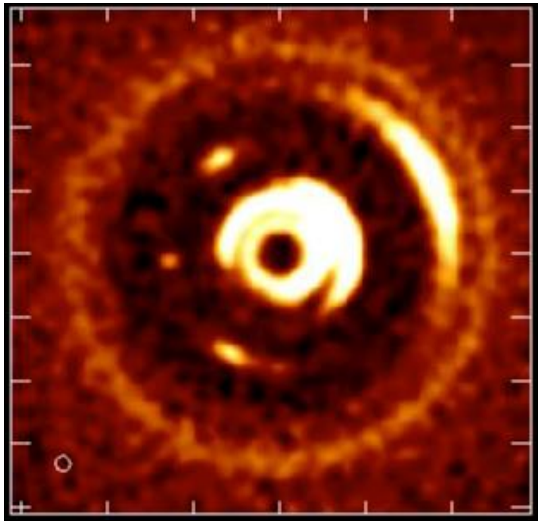
Planet formation & evolution dynamics, PPD Shangfei Liu
liushangfei@mail.sysu.edu.cn

- **Hydro simulations:**
  - **FLASH code, LA-COMPASS code**
- **N-body simulations:**
  - **REBOUND (Rein & Liu 2012)**

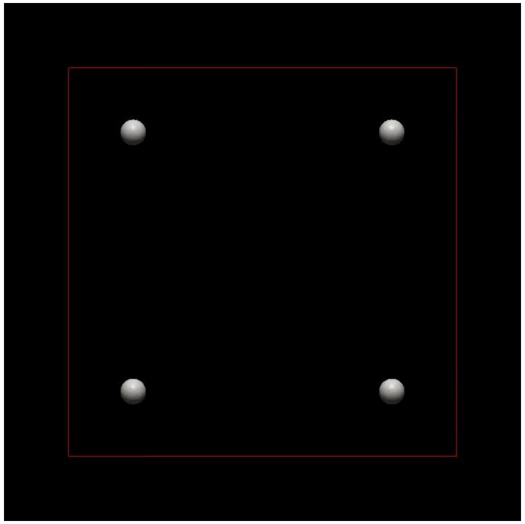
Rings in HD 163296 PPD formed by protoplanets



Simulating ngVLA's obser-vations at mm wavelength



Using REBOUND to model collisional dynamics

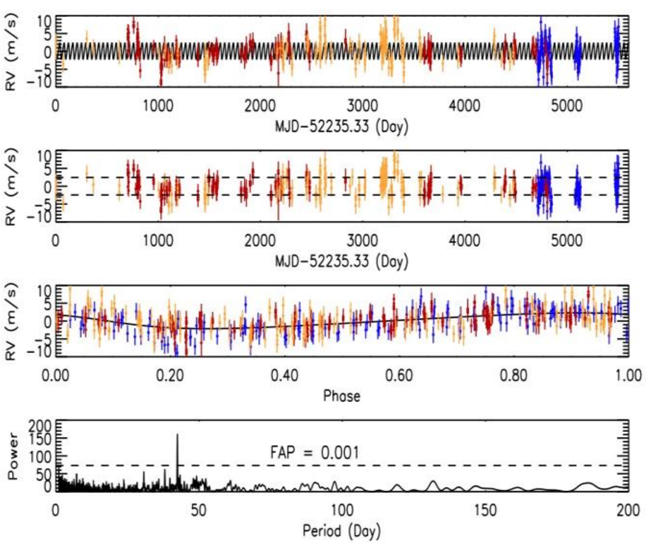


Planet Detection and Characterization

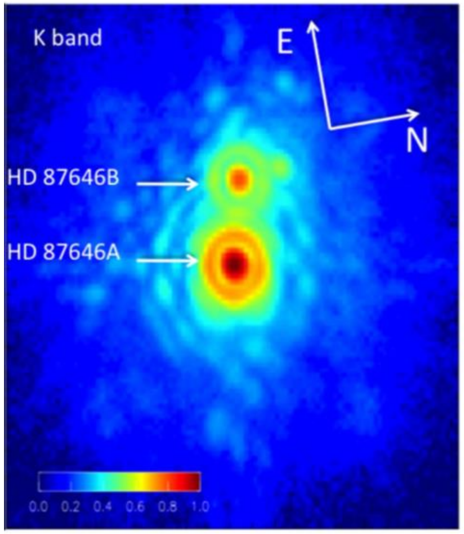
Bo Ma, mabo8@mail.sysu.edu.cn

- **Research Methods：**
  - **Radial Velocity and Transiting Technique**
  - **Direct Imaging**
- **Instrumentation, mainly High Resolution Spectrograph**

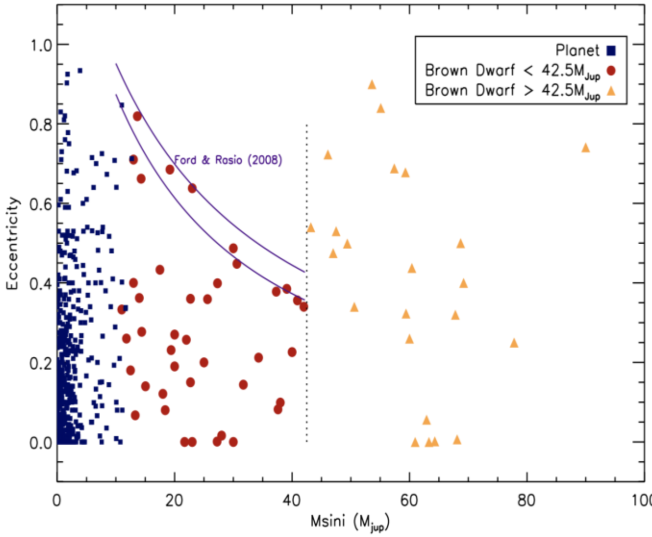
Planet Detected Around an Active Star (Ma et al. 2018, 2019)



Planet Detected in a Close Binary System(Ma et al. 2016)



Upper Mass Limit of Planets Formed in a Proto-planetary Disk (Ma et al. 2014)



Highlights

Jupiter core formation by giant impact

(Shangfei Liu, liushangfei@mail.sysu.edu.cn)

LETTER

https://doi.org/10.1038/s41586-019-1470-2

The formation of Jupiter's diluted core by a giant impact

Shang-Fei Liu[1,2]*, Yasunori Hori[3,4], Simon Müller[5], Xiaochen Zheng[6,7], Ravit Helled[5], Doug Lin[8,9] & Andrea Isella[2]

The Juno mission[1] has provided an accurate determination of Jupiter's gravitational field[2], which has been used to obtain information about the planet's composition and internal structure. Several models of Jupiter's structure that fit the probe's data suggest that the planet has a diluted core, with a total heavy-element mass ranging from ten to a few tens of Earth masses (about 5 to 15 per cent of the Jovian mass), and that heavy elements (elements other than hydrogen and helium) are distributed within a region extending to nearly half of Jupiter's radius[3,4]. Planet-formation models indicate that most heavy elements are accreted during the early stages of a planet's formation to create a relatively compact core[5–7] and that almost no solids are accreted during subsequent runaway gas accretion[8–10]. Jupiter's diluted core, combined with its possible high heavy-element enrichment, thus challenges standard planet-formation theory. A possible explanation is erosion of the initially compact heavy-element core, but the efficiency of such erosion is uncertain and depends on both the immiscibility of heavy materials in metallic hydrogen and on convective mixing as the planet evolves[11,12]. Another mechanism that can explain this structure is planetesimal enrichment and vaporization[13–15] during the formation process, although relevant models typically cannot produce an extended diluted core. Here we show that a sufficiently energetic head-on collision (giant impact) between a large planetary embryo and the proto-Jupiter could have shattered its primordial compact core and mixed the heavy elements with the inner envelope. Models of such a scenario lead to an internal structure that is consistent with a diluted core, persisting over billions of years. We suggest that collisions were common in the young Solar system and that a similar event may have also occurred for Saturn, contributing to the structural differences between Jupiter and Saturn[16–18].

Giant impacts[19,20] are likely to occur shortly after runaway gas accretion when Jupiter's gravitational perturbation increases to about thirty-fold in a fraction of a million years, thus destabilizing the orbits of nearby planetary embryos. This transition follows oligarchic growth[21] and the emergence of multiple embryos with isolation mass in excess of a few Earth masses, $M_\oplus$ (ref. [22]). Some of these massive embryos may collide with the gas giant during their orbit crossing[23,24]. Through tens of thousands of gravitational N-body simulations with different initial conditions, such as Jupiter's growth model, orbital configuration, and so on (see Methods), we find that the emerging Jupiter had a strong influence on nearby planetary embryos. As a result, in a large fraction of these numerical tests an embryo could collide with Jupiter within a few million years, that is, within the lifetime of the Solar nebula. Of those catastrophic events, head-on collisions are more common than grazing ones owing to Jupiter's gravitational focusing effects.

To investigate the influence of such impacts on the internal structure of the young Jupiter we use the hydrodynamics code FLASH[25] with the relevant equation of state (EOS). Details of the computational setup and the simulations are presented in Methods. In general, the disintegration of the intruding embryo leads to the disruption of the planet's original core. However, to establish a large diluted-core structure—as has been inferred from recent Jupiter structure models based on the Juno mission's measurements—the heavy-element material of the core and of the embryo need to mix efficiently with the surrounding gaseous envelope, which requires a large embryo to strike the young Jupiter almost head-on. Massive embryos are available at this early stage of the Solar System and our N-body simulations also suggest that head-on collisions are common (see Methods).

In Fig. 1 we show the consequence of a head-on collision between an embryo and Jupiter with an initial silicate+ice core mass of $M_{core} = 10M_\oplus$, a hydrogen+helium (H-He) envelope, an approximately present-day total mass and radius (the young Jupiter may have been up to twice its present-day size, but, to avoid introducing additional free parameters, we consider models in which Jupiter is closer to its present-day size). In fact, the post-impact core–envelope structure depends mainly on the mass of the initial core and envelope as well as the impactor's mass and impact velocity V_{imp}. We adopt an impact speed of $V_{imp} \approx 46$ km s^{-1}, which is close to the free-fall speed onto Jupiter's surface (see Methods) and we assume that the impactor is comprised of an $8M_\oplus$ silicate+ice core and a $2M_\oplus$ H-He envelope. The combined total mass of the core of the proto-Jupiter and the core of the embryo, $M_{Z,total}$, is chosen to be compatible with the mass of heavy elements (Z) derived from internal structure models of Jupiter with a diluted core[3]. We note that at Jupiter's distance of 5.2 astronomical units (AU) from the Sun, the impactor's speed relative to the gas giants is limited by the planets' surface escape speed. The acquisition of planetary embryos would not lead to any major changes in the spin angular momentum and orientation of the targeted planet. The total energy injected into the young Jupiter by the intruding embryo is only a few per cent of its original value so that there is little change in Jupiter's mean density and mass.

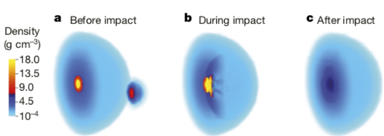


Fig. 1 | Three-dimensional cutaway snapshots of density distributions during a merger event between a proto-Jupiter with a $10M_\oplus$ rock/ice core and a $10M_\oplus$ impactor. **a**, Just before the contact. **b**, The moment of core–impactor contact. **c**, 10 h after the merger. Owing to impact-induced turbulent mixing, the density of Jupiter's core decreases by a factor of three after the merger, resulting in an extended diluted core. A two-dimensional presentation of density slices of the same event is shown in Extended Data Fig. 3.

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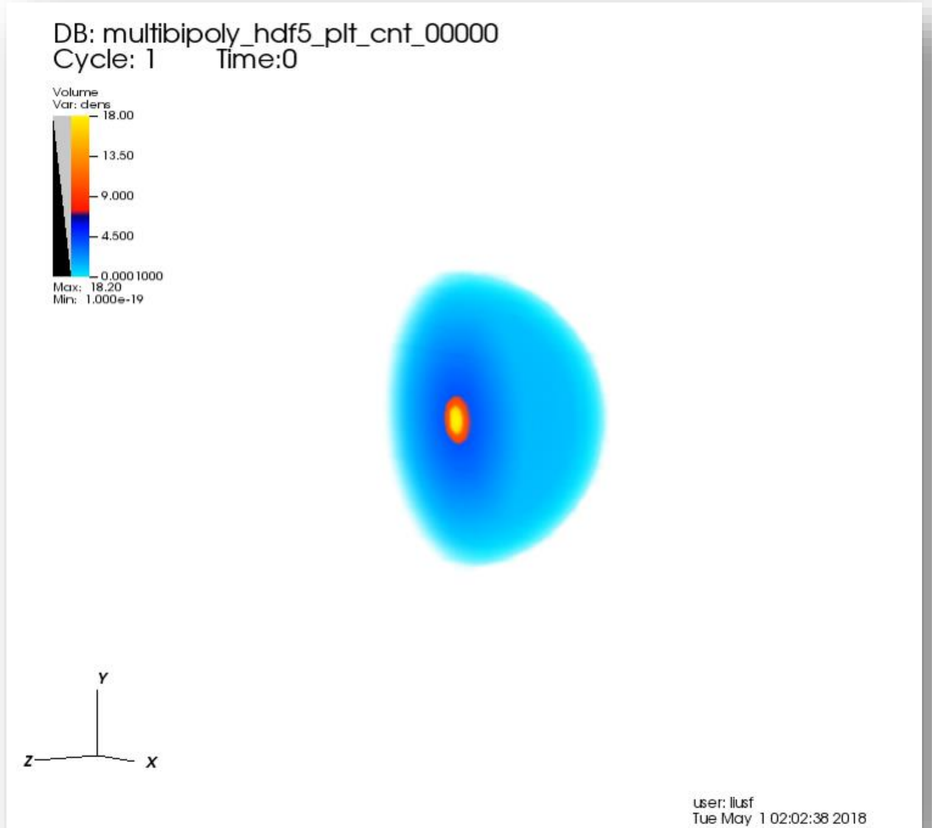
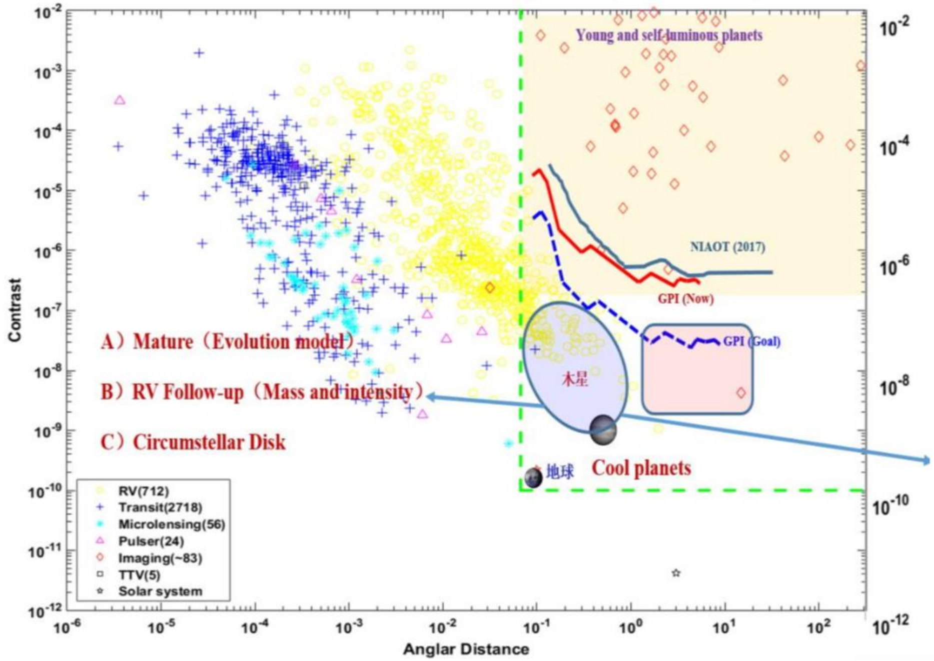
The inferred Jupiter's large dilute core could arise from a head-on collision with a massive planetary embryo about 4.5 Gry ago!



Cool Planet Imaging Coronagraph

(**Bo Ma**, mabo8@mail.sysu.edu.cn)

40PC，>1GYrs F/G/K stars，≤10AU Jupiter/Neptune and Super Earth



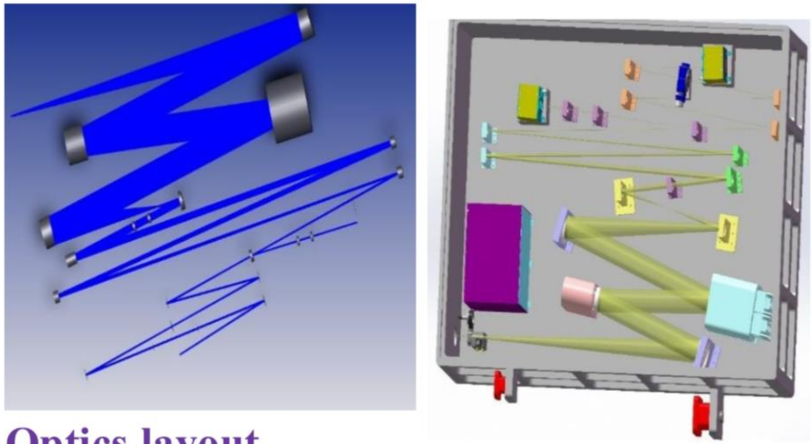
Contrast vs. angular separation

- **Wavelength**: 0.6μm-1.6μm
- **Bandwidth**: 3~10%
- **FOV**: 2.5″×2.5″ obs, 20″×20″ targeting
- **IWA**: ≤0.55″@ 0.63μm, 1.2"@1.5μm
- **Contrast**: 10^{-8} (0.6-0.9μm) or better

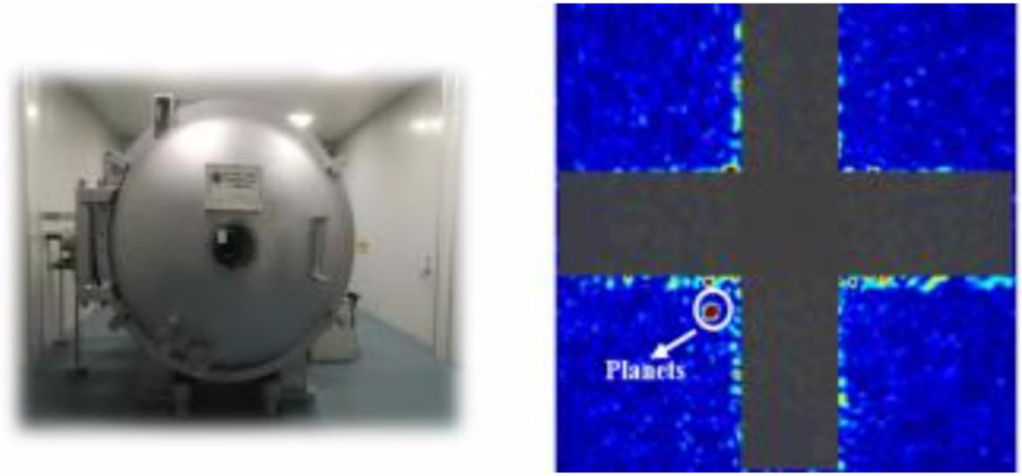
➢ **Searching for mature planets around solar-type stars**

➢ **RV follow up & planet formation & evolution**

➢ **Physics of circumstellar disk**



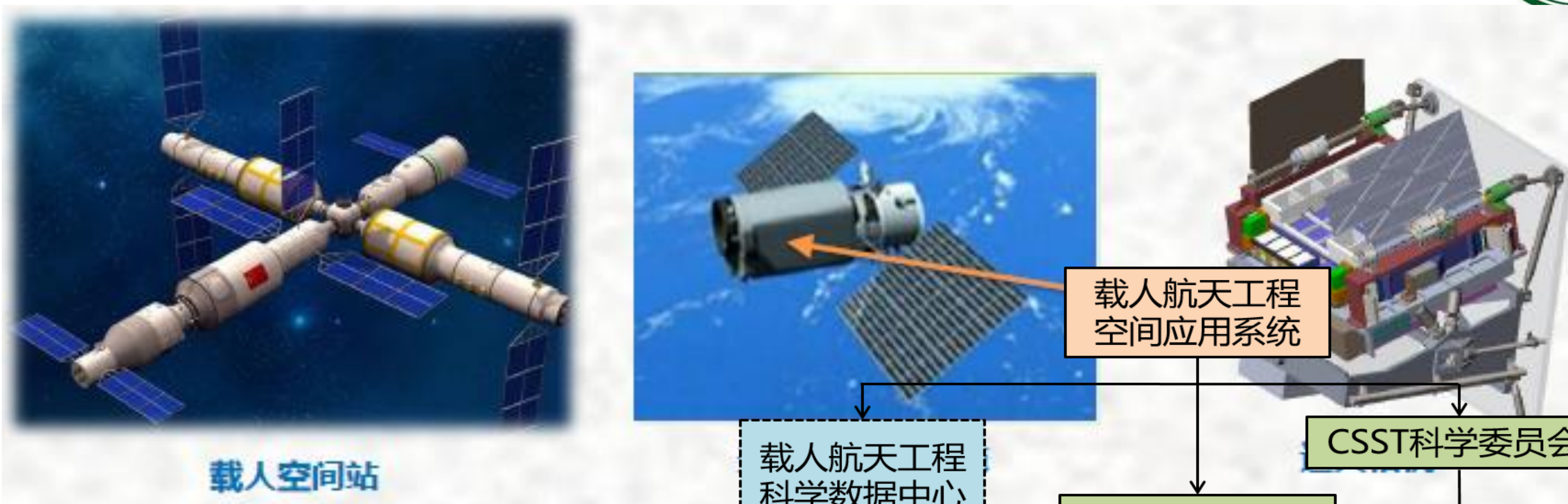
Optics layout

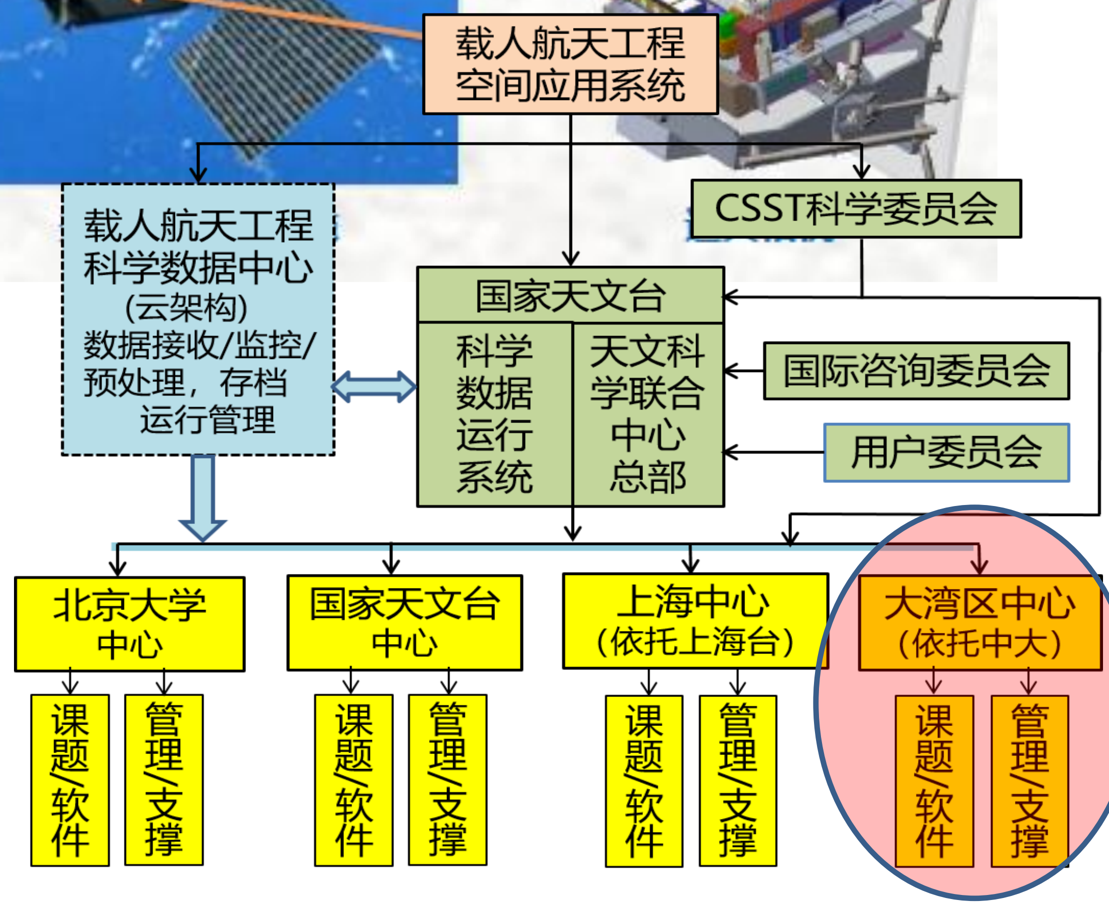


Vacuum chamber test reaching 10^{-9} contrast

Opportunities…

CSST Southern Center: based on SYSU

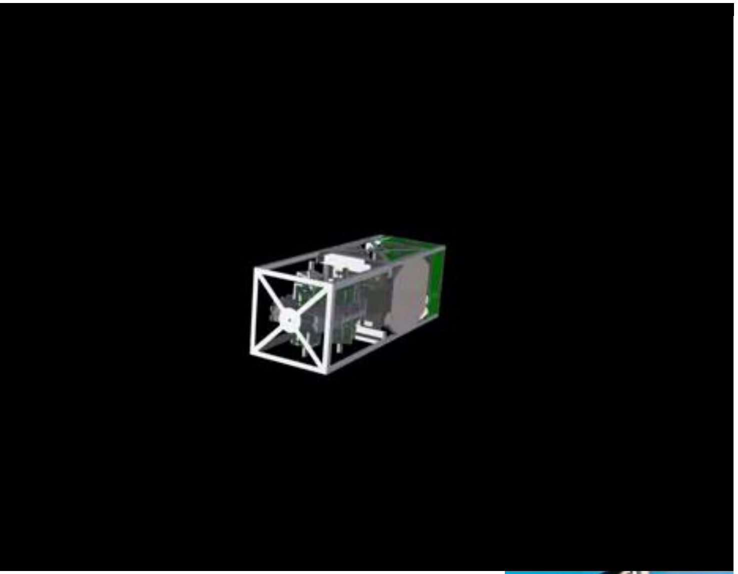




Survey specs

- Imaging: 255-1000nm, >=6 filters, >=25.5^m
- Spect: 255-1000nm, R>=200, >=22-23^m
- Deep imaging & Spect: 1^m deeper

Other facilities for exoplanet research



- University level space telescope
  - CubSat, 10 or 30 cm diameter
  - Scientific goals to be decided
- FAST program on planet detection
  - Solar system planets
  - Exoplanets

Exoplanet research today, is like cosmology 20 years ago……
FAST Chief Scientist, Di Li

SYSU Astronomy: A New, International Institute in Southern China

Openings: postdocs, research scholars, professors

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