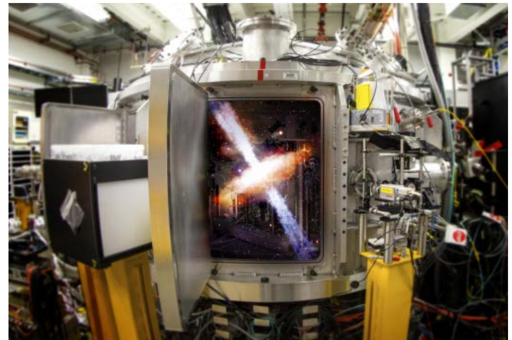
# Overview of accelerator projects in Korea and their possible uses for laboratory astrophysics

3rd CHEA Workshop
January 16 2019, Gyeongju, Korea

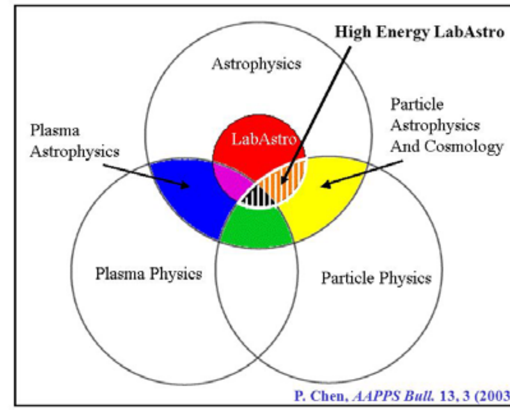
Moses Chung
Department of Physics
Ulsan National Institute of Science and Technology (UNIST)
with many inputs from Korean accelerator/astrophysics community

# My Personal View

**REPRODUCING ASTROPHYSICAL PHENOMENA IN A CONTROLLED MANNER**



**LABORATORY ASTROPHYSICS**




EBIT (UNIST + MPIK et al.)
+
Beamline (PAL + UNIST et al.)
= X-ray Astrophysics

EBIS (IBS + UNIST et al.)
+
KOBRA (EHWA + SKKU et al.)
LAMPS (KU + PNU et al.)
= Nuclear Astrophysics

PAL-XFEL

RISP

# Accelerator Projects in Korea


**PLS II**
(Pohang Light Source)

**PAL XFEL**
(Pohang Accelerator Lab. X-ray Free Electron Laser)

**RISP**
(Rare Isotope Science Project)

**KHIMA**
(Korea Heavy-Ion Medical Accelerator)

**KOMAC**
(Korea Multi-purpose Accelerator Complex)

+ several smaller accelerator facilities (electron, proton, heavy ion)

# Beam Parameters

| Parameter | PAL-XFEL | RISP |
|---|---|---|
| Species | Electron | Proton ~ Heavy ion |
| Energy | 10 GeV | 200 MeV/u for $U^{79+}$ |
| Beam current | 3 kA (0.2 nC/100 fs) | 8 pmA $U^{79+}$ |
| Rep. Rate | <120 Hz | CW |
| Linac Structure | 3 Bunch Compressors<br>2.856 GHz (S-band) | SCRF:<br>QWR (81.25 MHz),<br>HWR (162.5 MHz),<br>SSR (325 MHz) |
| Research Areas | Material science,<br>Chemistry/Biology,<br>Atomic/Molecular,<br>Condensed matter,<br>Surface/cluster,<br>Non-equilibrium plasma,<br>Warm-dense plasma | Nuclear physics,<br>Nuclear Astrophysics,<br>Bio-medical science,<br>Material science,<br>Neutron science |

~ LCLS(SLAC) ~ FRIB(MSU)

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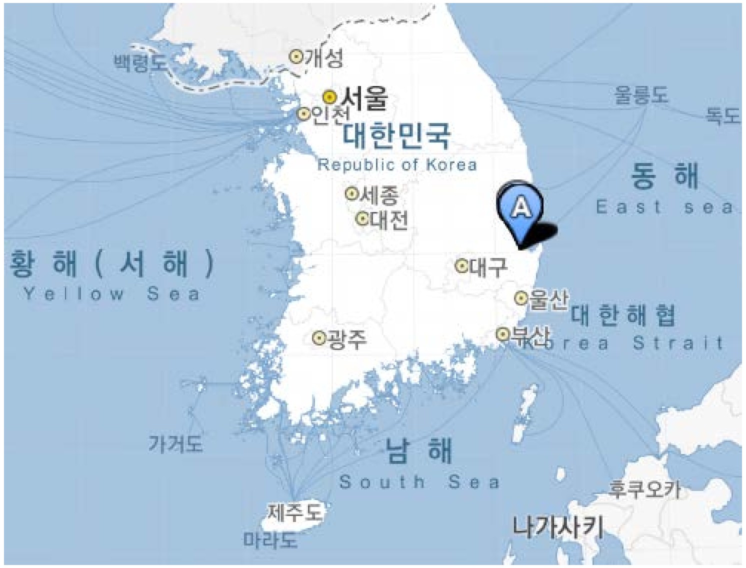
# PAL-XFEL
## (Pohang Accelerator Lab.-XFEL)

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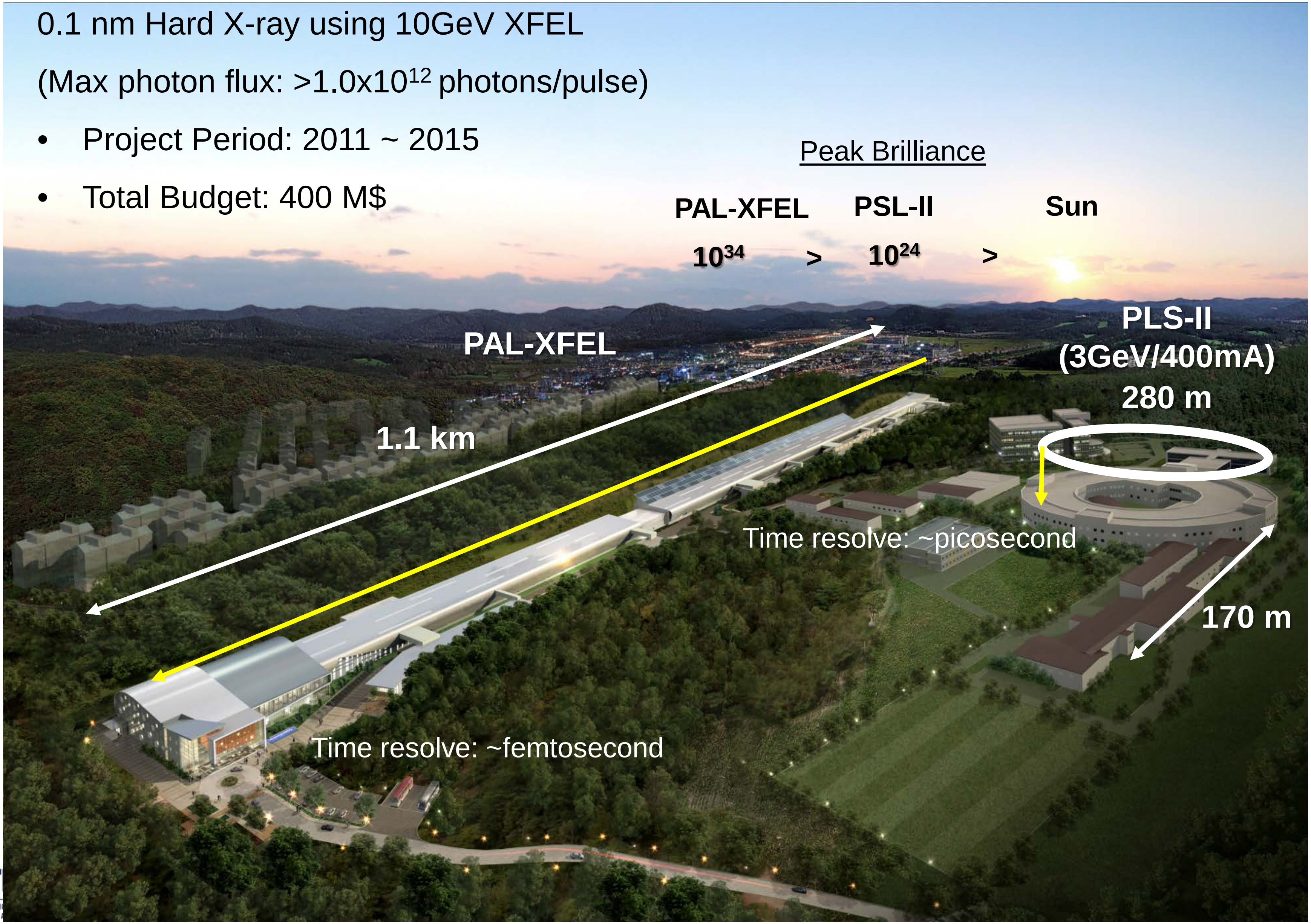
# Project Summary

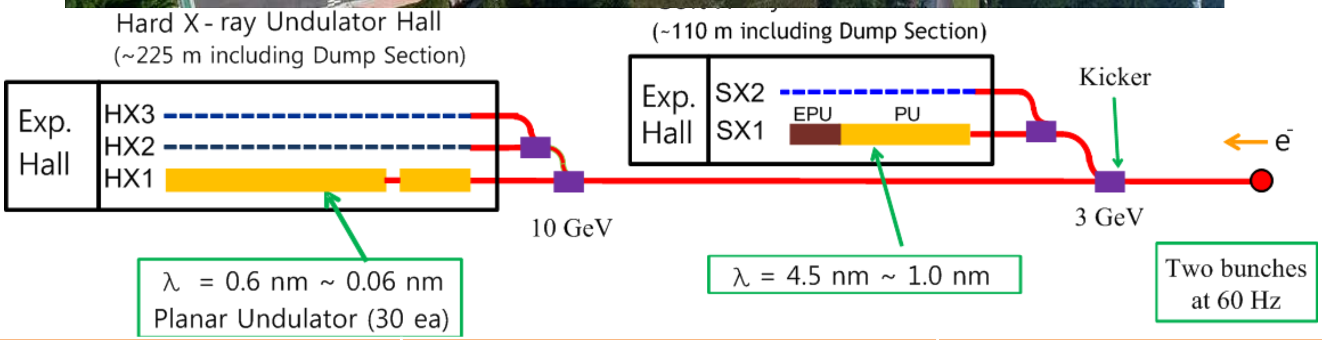
0.1 nm Hard X-ray using 10GeV XFEL

(Max photon flux: >1.0x$10^{12}$ photons/pulse)

- Project Period: 2011 ~ 2015
- Total Budget: 400 M$

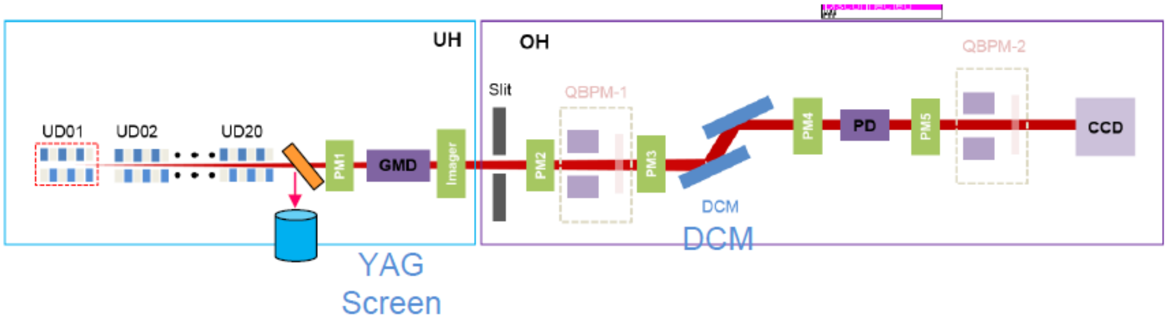


# Layout and Parameters

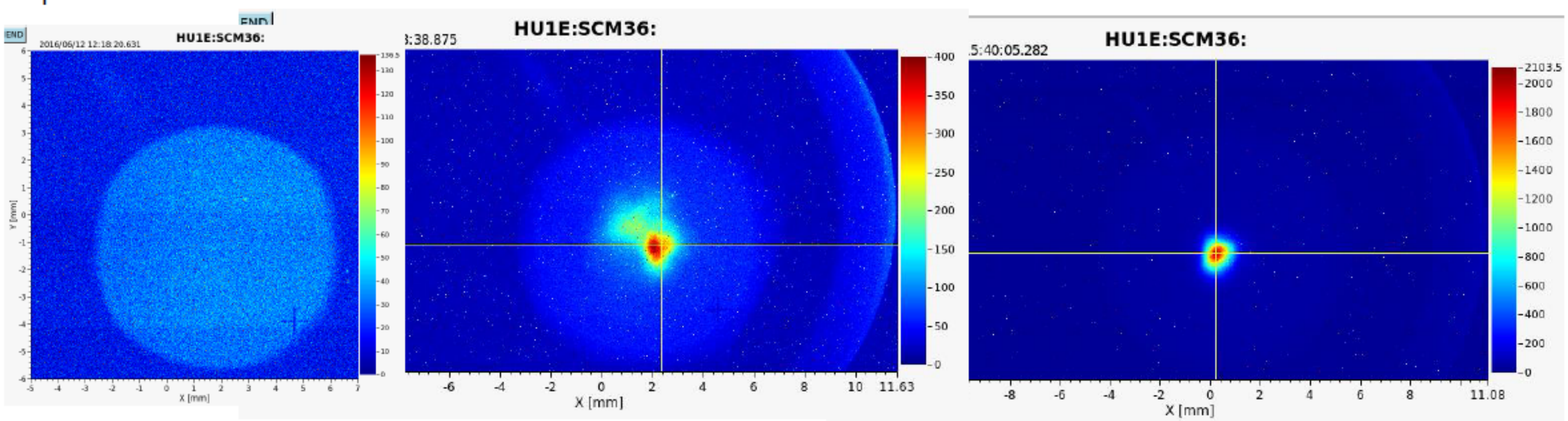




| Undulator Line | HX1 | SX1 |
|---|---|---|
| Wavelength [nm] | 0.06 ~ 0.6 | 1 ~ 4.5 |
| Beam Energy [GeV] | 4 ~ 10 | 3.15 (2.55) |
| Wavelength Tuning | 0.1 ~ 0.06 (Undulator Gap)<br>0.6 ~ 0.1 (Beam Energy) | 3 ~ 1 (Undulator gap)<br>4.5 ~ 3 (Beam Energy) |
| Undulator Type | Planar | Planar + APPLE II |
| Undulator Period [mm] | 26 | 34 |
| Undulator Gap [mm] | 8.3 | 8.3 |

# First Lasing at 0.5 nm on 14 June 2016




Spontaneous radiation




12 June 2016　　05:01, 14 June 2016　　16 June 2016

[From H. S. Kang]

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ARTICLES
https://doi.org/10.1038/s41566-017-0029-8
nature photonics

# Hard X-ray free-electron laser with femtosecond-scale timing jitter

Heung-Sik Kang[1]*, Chang-Ki Min[1], Hoon Heo[1], Changbum Kim[1], Haeryong Yang[1], Gyujin Kim[1], Inhyuk Nam[1], Soung Youl Baek[1], Hyo-Jin Choi[1], Geonyeong Mun[1], Byoung Ryul Park[1], Young Jin Suh[1], Dong Cheol Shin[1], Jinyul Hu[1], Juho Hong[1], Seonghoon Jung[1], Sang-Hee Kim[1], KwangHoon Kim[1], Donghyun Na[1], Soung Soo Park[1], Yong Jung Park[1], Jang-Hui Han[1], Young Gyu Jung[1], Seong Hun Jeong[1], Hong Gi Lee[1], Sangbong Lee[1], Sojeong Lee[1], Woul-Woo Lee[1], Bonggi Oh[1], Hyung Suck Suh[1], Yong Woon Parc[1], Sung-Ju Park[1], Min Ho Kim[1], Nam-Suk Jung[1], Young-Chan Kim[1], Mong-Soo Lee[1], Bong-Ho Lee[1], Chi-Won Sung[1], Ik-Su Mok[1], Jung-Moo Yang[1], Chae-Soon Lee[1], Hocheol Shin[1], Ji Hwa Kim[1], Yongsam Kim[1], Jae Hyuk Lee[1], Sang-Youn Park[1], Jangwoo Kim[1], Jaeku Park[1], Intae Eom[1], Seungyu Rah[1], Sunam Kim[1], Ki Hyun Nam[1], Jaehyun Park[1], Jaehun Park[1], Sangsoo Kim[1], Soonam Kwon[1], Sang Han Park[1], Kyung Sook Kim[1], Hyojung Hyun[1], Seung Nam Kim[1], Seonghan Kim[1], Sun-min Hwang[1], Myong Jin Kim[1], Chae-yong Lim[1], Chung-Jong Yu[1], Bong-Soo Kim[1], Tai-Hee Kang[1], Kwang-Woo Kim[1], Seung-Hwan Kim[1], Hee-Seock Lee[1], Heung-Soo Lee[1], Ki-Hyeon Park[1], Tae-Yeong Koo[1], Dong-Eon Kim[1] and In Soo Ko[2]

**The hard X-ray free-electron laser at the Pohang Accelerator Laboratory (PAL-XFEL) in the Republic of Korea achieved saturation of a 0.144 nm free-electron laser beam on 27 November 2016, making it the third hard X-ray free-electron laser in the world, following the demonstrations of the Linac Coherent Light Source (LCLS) and the SPring-8 Angstrom Compact Free Electron Laser (SACLA). The use of electron-beam-based alignment incorporating undulator radiation spectrum analysis has allowed reliable operation of PAL-XFEL with unprecedented temporal stability and dispersion-free orbits. In particular, a timing jitter of just 20 fs for the free-electron laser photon beam is consistently achieved due to the use of a state-of-the-art design of the electron linear accelerator and electron-beam-based alignment. The low timing jitter of the electron beam makes it possible to observe Bi(111) phonon dynamics without the need for timing-jitter correction, indicating that PAL-XFEL will be an extremely useful tool for hard X-ray time-resolved experiments.**

Science Home News Journals Topics Careers




REPORT

# Maxima in the thermodynamic response and correlation functions of deeply supercooled water

Kyung Hwan Kim[1,*], Alexander Späh[1,*], Harshad Pathak[1], Fivos Perakis[1], Daniel Mariedahl[1], Katrin Amann-Winkel[1], Jonas A. Sellberg[2], Jae Hyuk Lee[3], Sangsoo Kim[3], Jaehyun Park[3], Ki Hyun Nam[3], Tetsuo Katayama[4], Anders Nilsson[1,†]

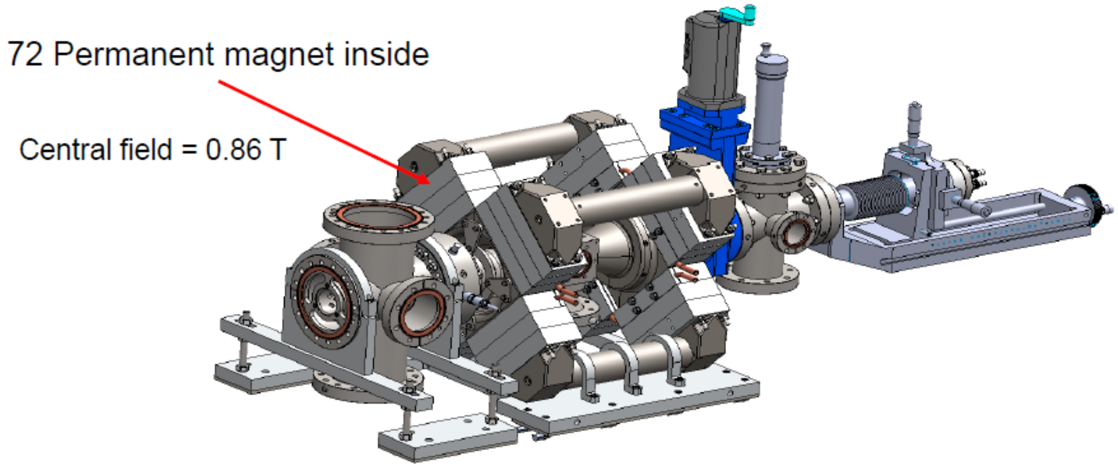
[1] *Department of Physics, AlbaNova University Center, Stockholm University, SE-10691 Stockholm, Sweden.*
[2] *Biomedical and X-Ray Physics, Department of Applied Physics, AlbaNova University Center, KTH Royal Institute of Technology, SE-10691 Stockholm, Sweden.*
[3] *Pohang Accelerator Laboratory, Pohang, Gyeongbuk 37673, Republic of Korea.*
[4] *Japan Synchrotron Radiation Research Institute, Kouto 1-1-1, Sayo, Hyogo 679-5198, Japan.*
†Corresponding author. Email: andersn@fysik.su.se
* These authors contributed equally to this work.
– Hide authors and affiliations

*Science* 22 Dec 2017:
Vol. 358, Issue 6370, pp. 1589-1593
DOI: 10.1126/science.aap8269

[From H. S. Kang]

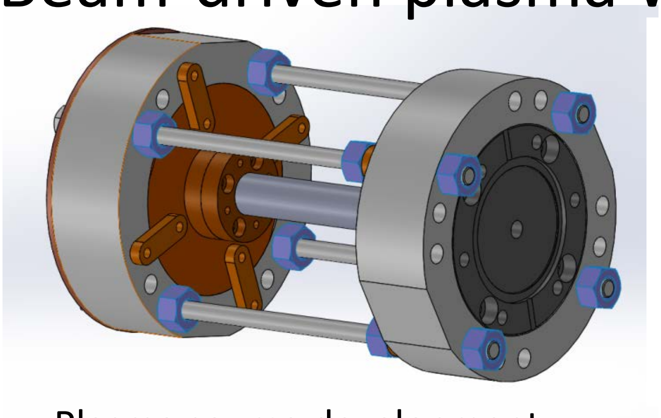
# UNIST Activities

- Development of electron beam ion trap (EBIT):

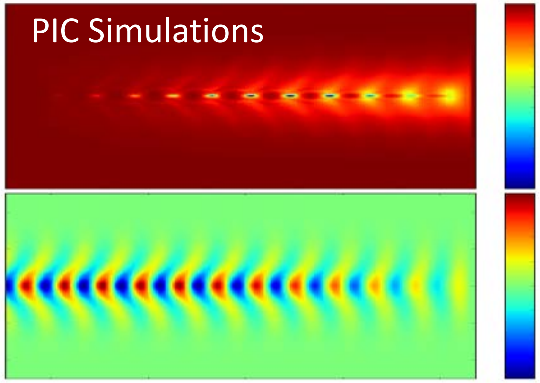



Central Chamber

- Beam-driven plasma wakefield acceleration program:

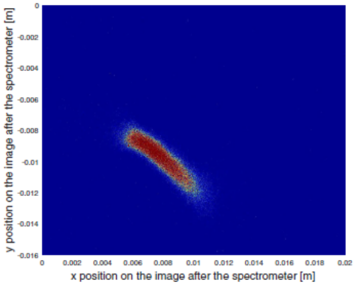


Plasma source development




Modulated beam density profile and longitudinal wake-field $E_z$

Beam manipulation /diagnostics



# LETTER

OPEN

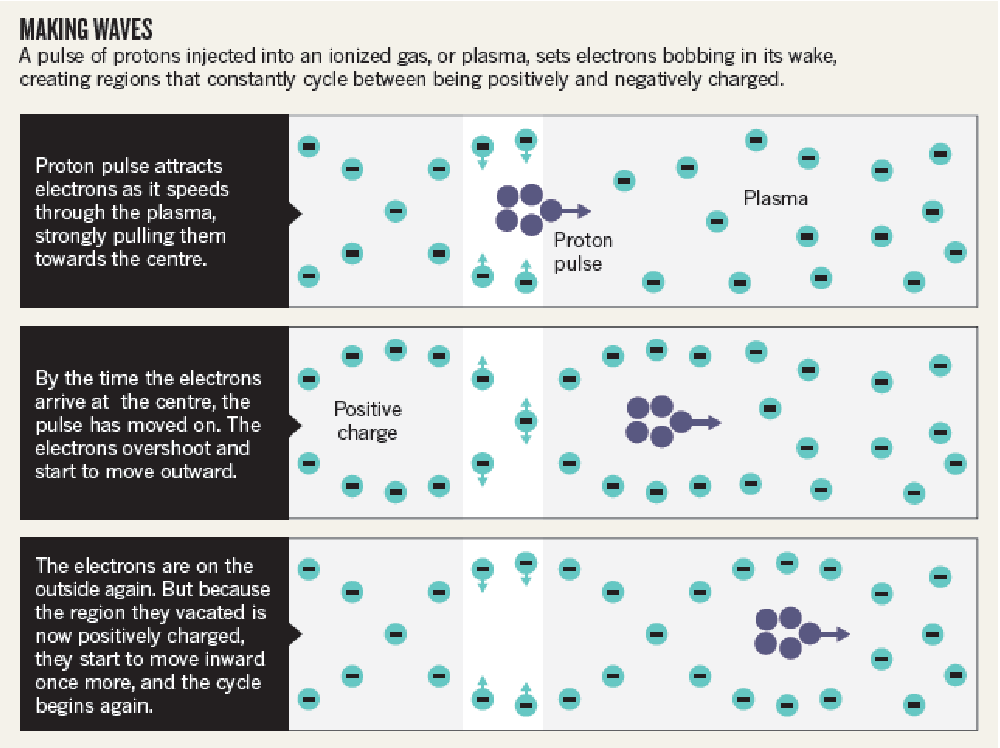
https://doi.org/10.1038/s41586-018-0485-4

## Acceleration of electrons in the plasma wakefield of a proton bunch

E. Adli[1], A. Ahuja[2], O. Apsimon[3,4], R. Apsimon[4,5], A.-M. Bachmann[2,6,7], D. Barrientos[2], F. Batsch[2,6,7], J. Bauche[2], V. K. Berglyd Olsen[1], M. Bernardini[2], T. Bohl[2], C. Bracco[2], F. Braunmüller[6], G. Burt[4,5], B. Buttenschön[8], A. Caldwell[6], M. Cascella[9], J. Chappell[9], E. Chevallay[2], M. Chung[10], D. Cooke[9], H. Damerau[2], L. Deacon[9], L. H. Deubner[11], A. Dexter[4,5], S. Doebert[2], J. Farmer[12], V. N. Fedosseev[2], R. Fiorito[4,13], R. A. Fonseca[14], F. Friebel[2], L. Garolfi[2], S. Gessner[2], I. Gorgisyan[2], A. A. Gorn[15,16], E. Granados[2], O. Grulke[8,17], E. Gschwendtner[2], J. Hansen[2], A. Helm[18], J. R. Henderson[4,5], M. Hüther[6], M. Ibison[4,13], L. Jensen[2], S. Jolly[9], F. Keeble[9], S.-Y. Kim[10], F. Kraus[11], Y. Li[3,4], S. Liu[19], N. Lopes[18], K. V. Lotov[15,16], L. Maricalva Brun[2], M. Martyanov[6], S. Mazzoni[2], D. Medina Godoy[2], V. A. Minakov[15,16], J. Mitchell[4,5], J. C. Molendijk[2], J. T. Moody[6], M. Moreira[2,18], P. Muggli[2,6], E. Öz[6], C. Pasquino[2], A. Pardons[2], F. Peña Asmus[6,7], K. Pepitone[2], A. Perera[4,13], A. Petrenko[2,15], S. Pitman[4,5], A. Pukhov[12], S. Rey[2], K. Rieger[6], H. Ruhl[20], J. S. Schmidt[2], I. A. Shalimova[16,21], P. Sherwood[9], L. O. Silva[18], L. Soby[2], A. P. Sosedkin[15,16], R. Speroni[2], R. I. Spitsyn[15,16], P. V. Tuev[15,16], M. Turner[2], F. Velotti[2], L. Verra[2,22], V. A. Verzilov[19], J. Vieira[18], C. P. Welsch[4,13], B. Williamson[3,4], M. Wing[9]*, B. Woolley[2] & G. Xia[3,4]

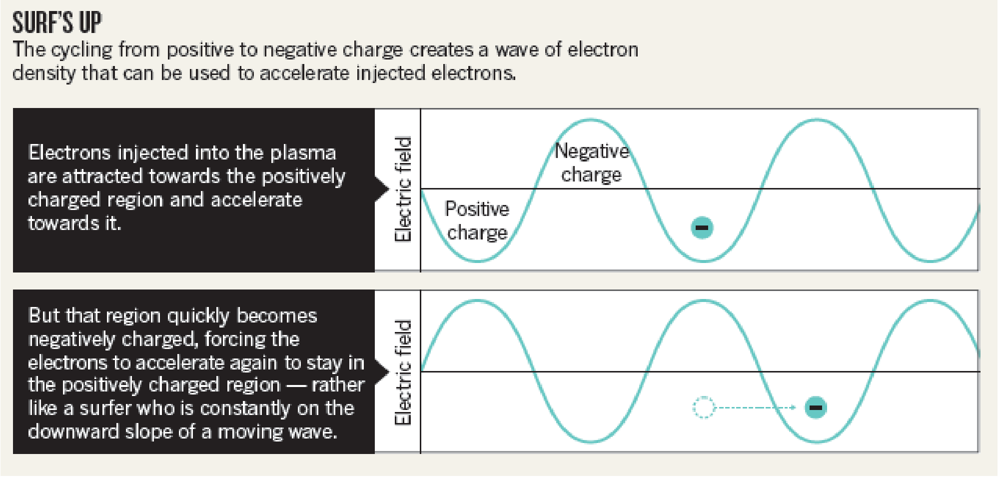
20 MeV → 2 GeV in 10 m

UNIST contribution = 2/93




$$\lambda_p = \frac{2\pi c}{\omega_p}, \quad \text{or} \quad \lambda_p \approx 0.1 \text{ mm}\sqrt{\frac{10^{17}}{n[\text{cm}^{-3}]}}$$

$n \approx 10^{18}$ cm$^{-3}$, which corresponds to $\lambda_p \approx 30\ \mu$m (or around 100 fs)

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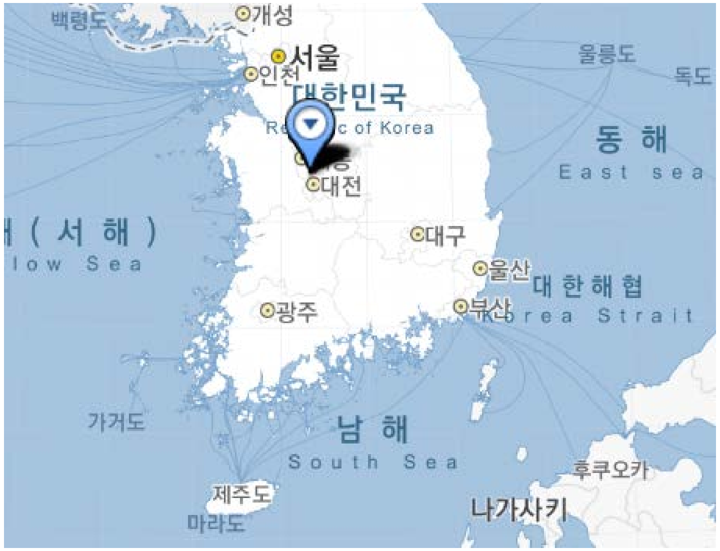
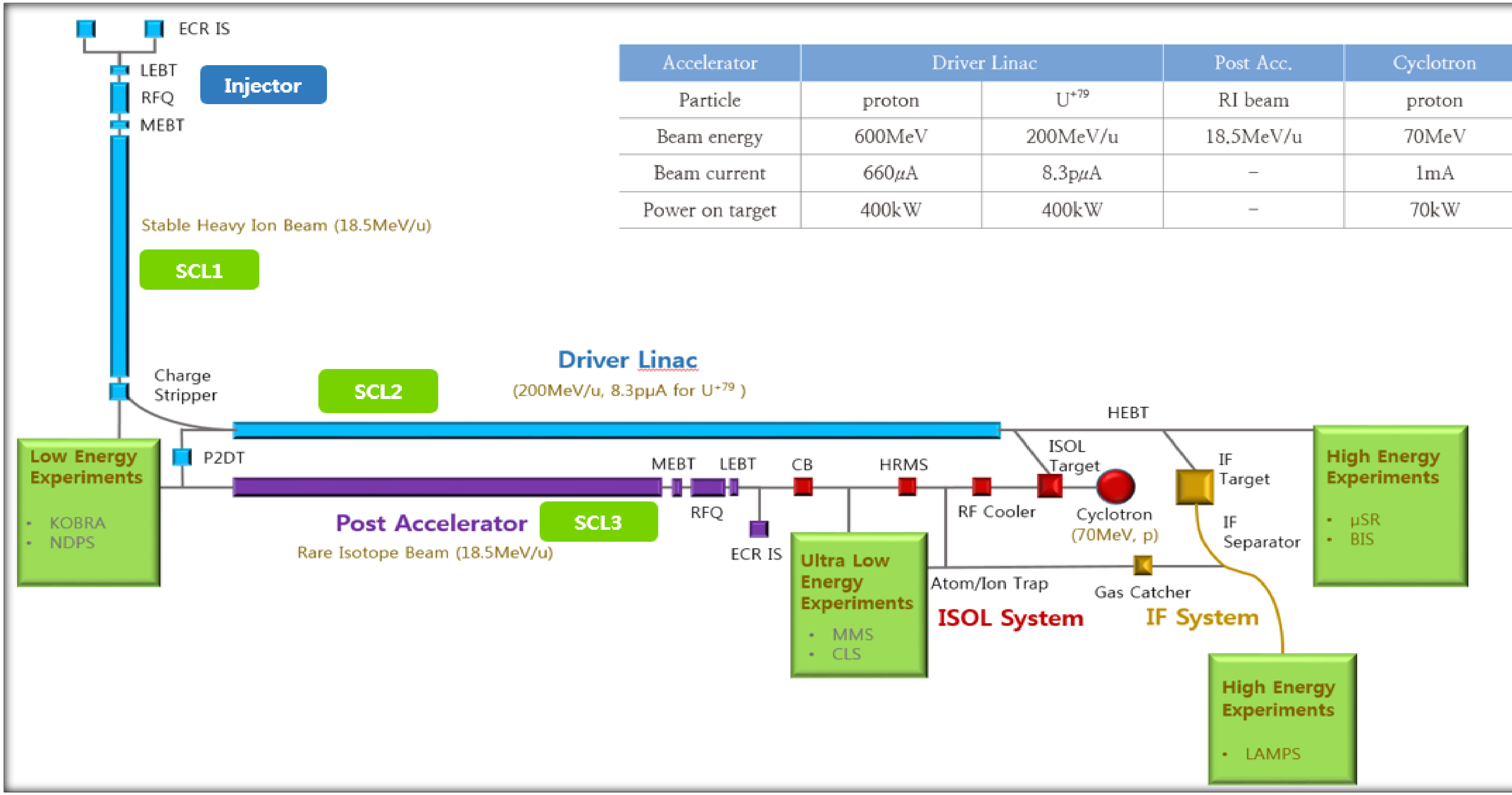
# RISP
## (Rare Isotope Science Project)



| Accelerator | Driver Linac | | Post Acc. | Cyclotron |
|---|---|---|---|---|
| Particle | proton | $U^{+79}$ | RI beam | proton |
| Beam energy | 600MeV | 200MeV/u | 18.5MeV/u | 70MeV |
| Beam current | 660μA | 8.3pμA | – | 1mA |
| Power on target | 400kW | 400kW | – | 70kW |




**Budget: US$ 1.44 B** (1 B$~1T Won)

- accelerators and experimental apparatus : 0.46 B$
- civil engineering & conventional facilities : 0.98 B$ (incl. construction site purchase)

**Period: 2011.12 ~ 2021.12 (10.1 years)**

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[From S. C. Chung]

# Construction Site

[From S. C. Chung]

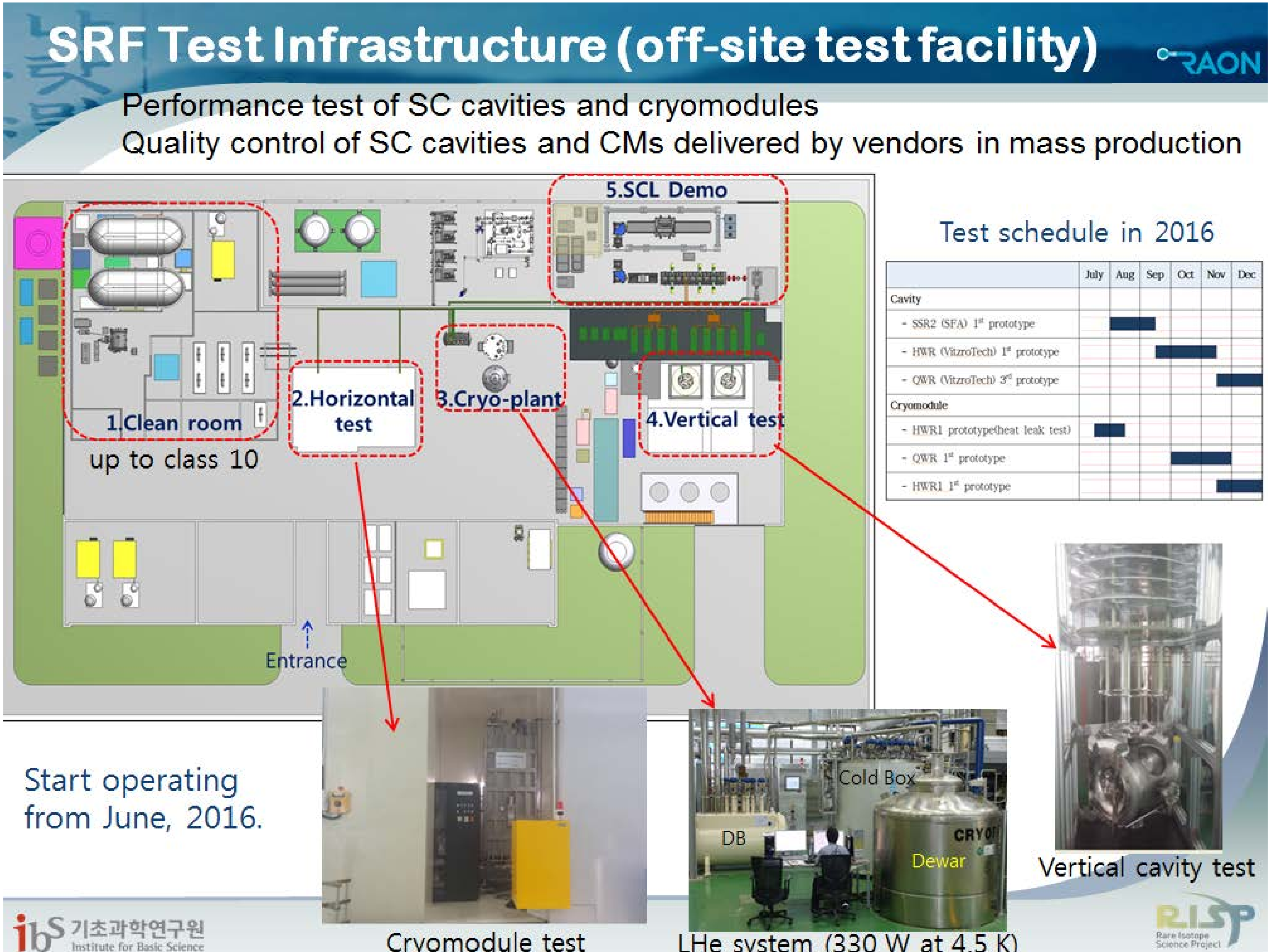
시설건설 시공 현황('17.1)

시설건설 시공 현황('17.6)

시설건설 시공 현황(17.12)

시설건설 시공 현황('18.5)

# SRF Test Facility




[From S. C. Chung]

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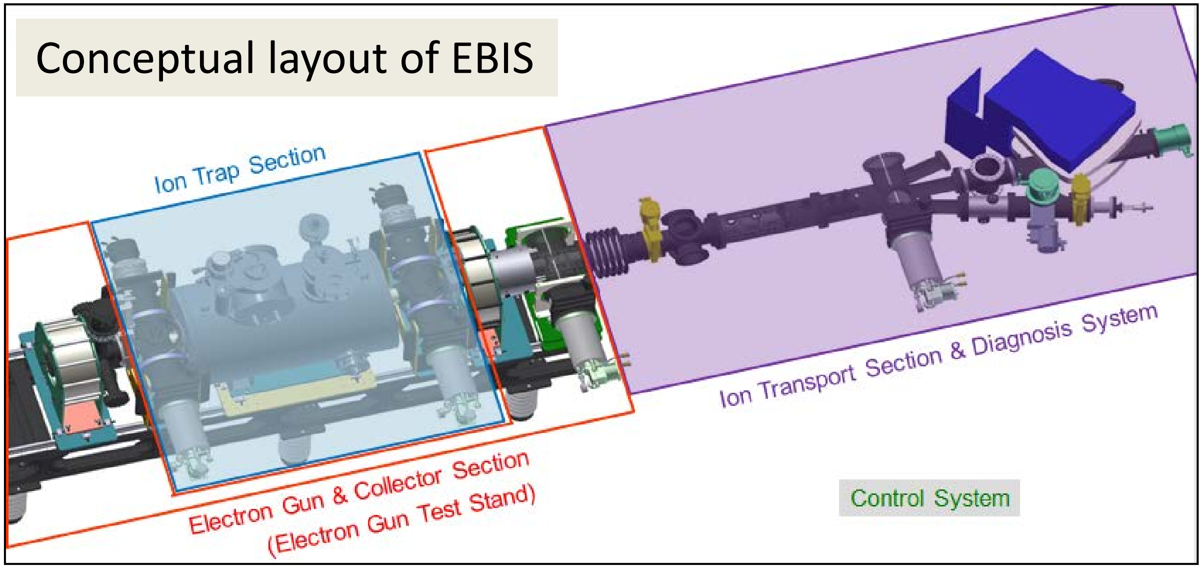
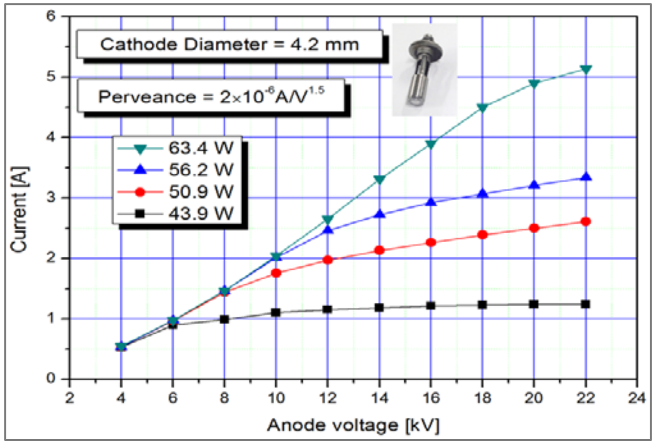
# UNIST Activities

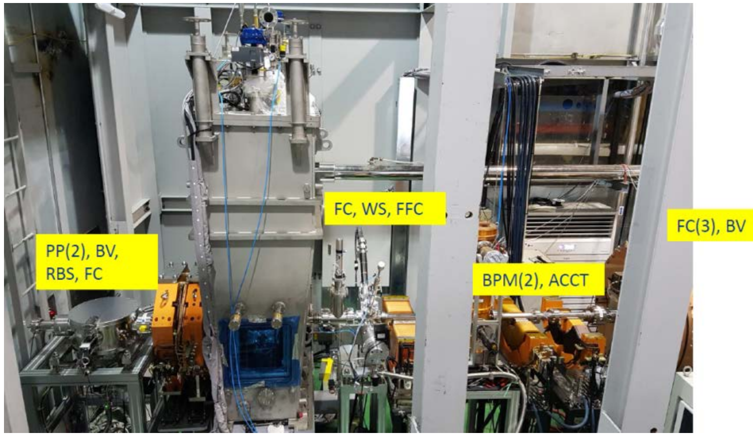
- Development of electron beam ion source (EBIS):

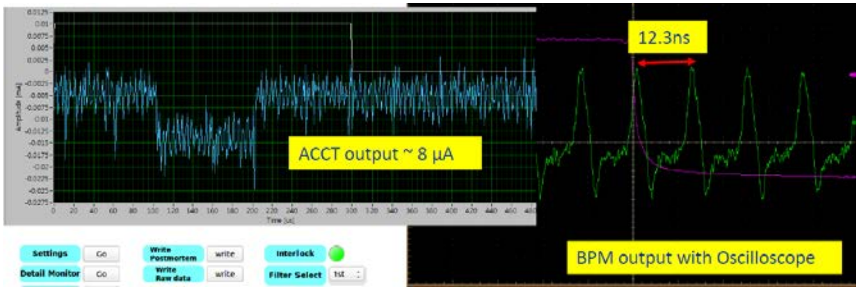



Electron gun test




- Beam diagnostics/Beam loss monitoring:




[From Y. S. Chung]

Design of Electron Beam Ion Source (EBIS)
Charge Breeder for RAON Heavy Ion Accelerator

Hyock-Jun Son

Accepted in partial fulfillment of the requirements for the degree c
Doctor of Philosophy

Nov 23, 2018

Thesis Advisor ______ Prof. Bongju Lee

Committee Member ______ Prof. Kyung Hee Hong

Committee Member ______ Prof. Youngchun Park

Committee Member ______ Prof. Moses Chung

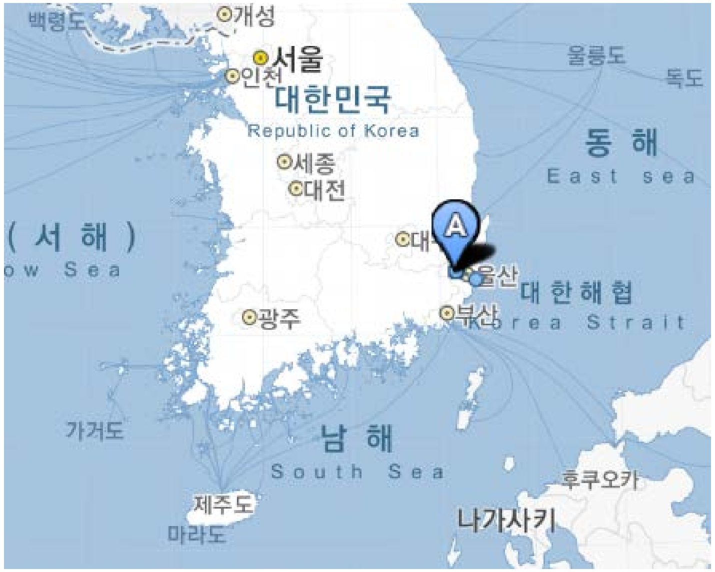
Committee Member ______ Dr. Young-Ho Park


- This thesis was supported by the Ministry of Science, ICT, and Future Planning (MSIP) and the National Research Foundation (NRF) of the Republic of Korea (Contract 2011-0032011).
- This thesis was also partly supported by the National Research Foundation of Korea (Contract No. 2016R1A5A1013277).

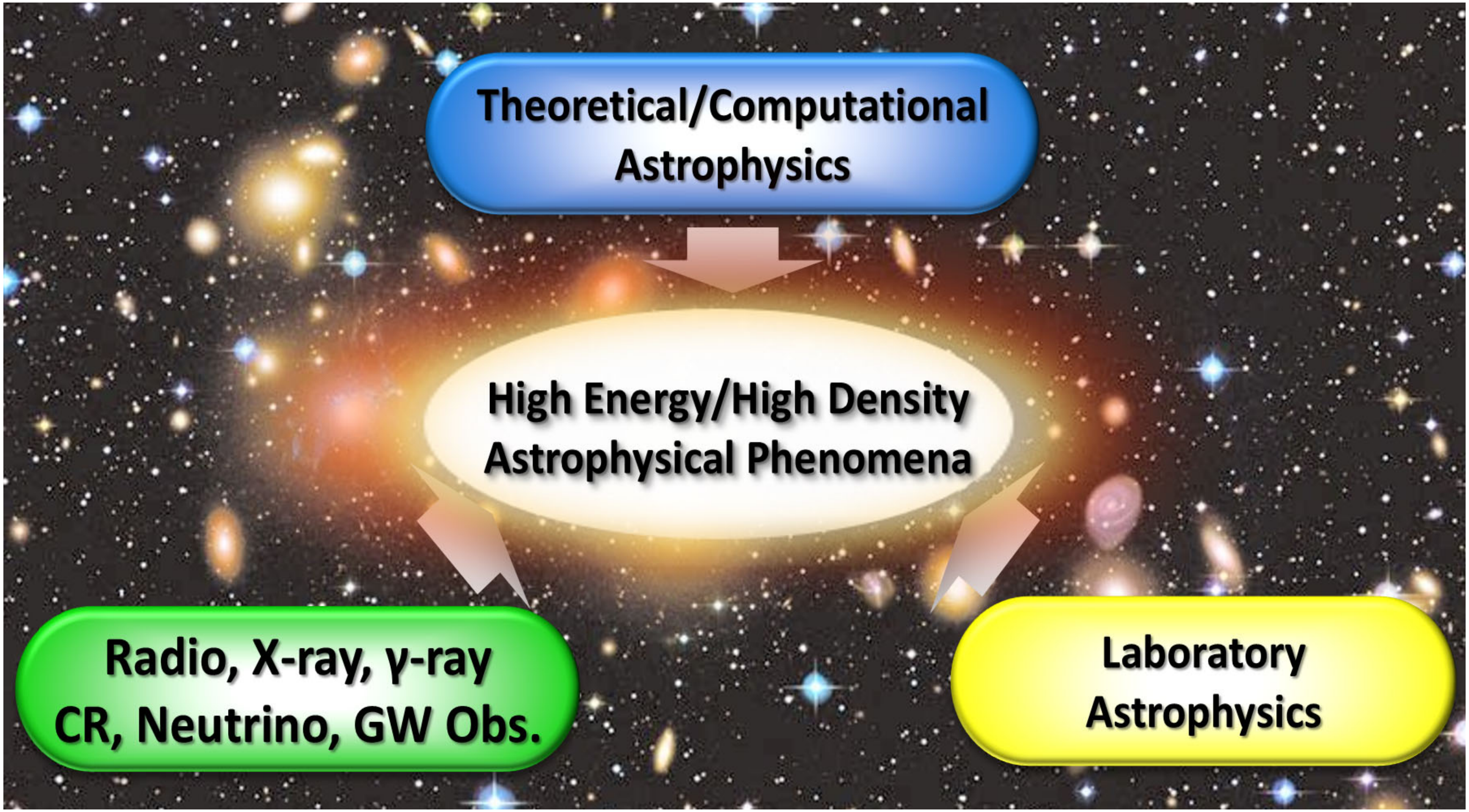

CHEA

# CHEA

## (Center for High Energy Astrophysics)



# Goal of the Center's proposed research




Using intense ion and photon beams generated by large-scale accelerator facilities in Korea

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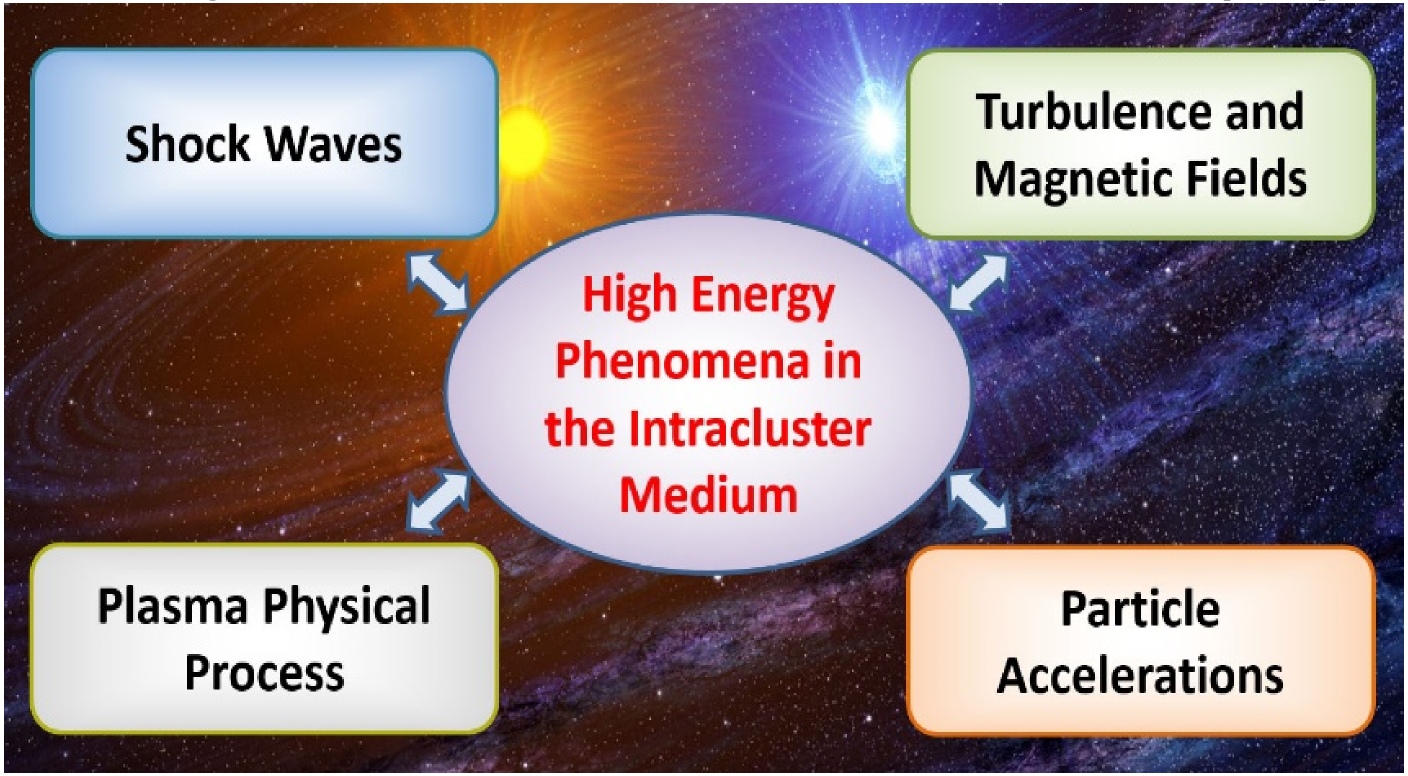
# Main Research Area 1

**Theory and simulation of the Intracluster medium (ICM)**




- The ICM is superheated plasmas with T ~ a few - several keV, presented in clusters of galaxies.
- The so-called non-thermal components of the plasmas (magnetic fields, CRs and turbulence) are expected to play significant roles in the formation and observation of clusters, so our understanding of the universe.

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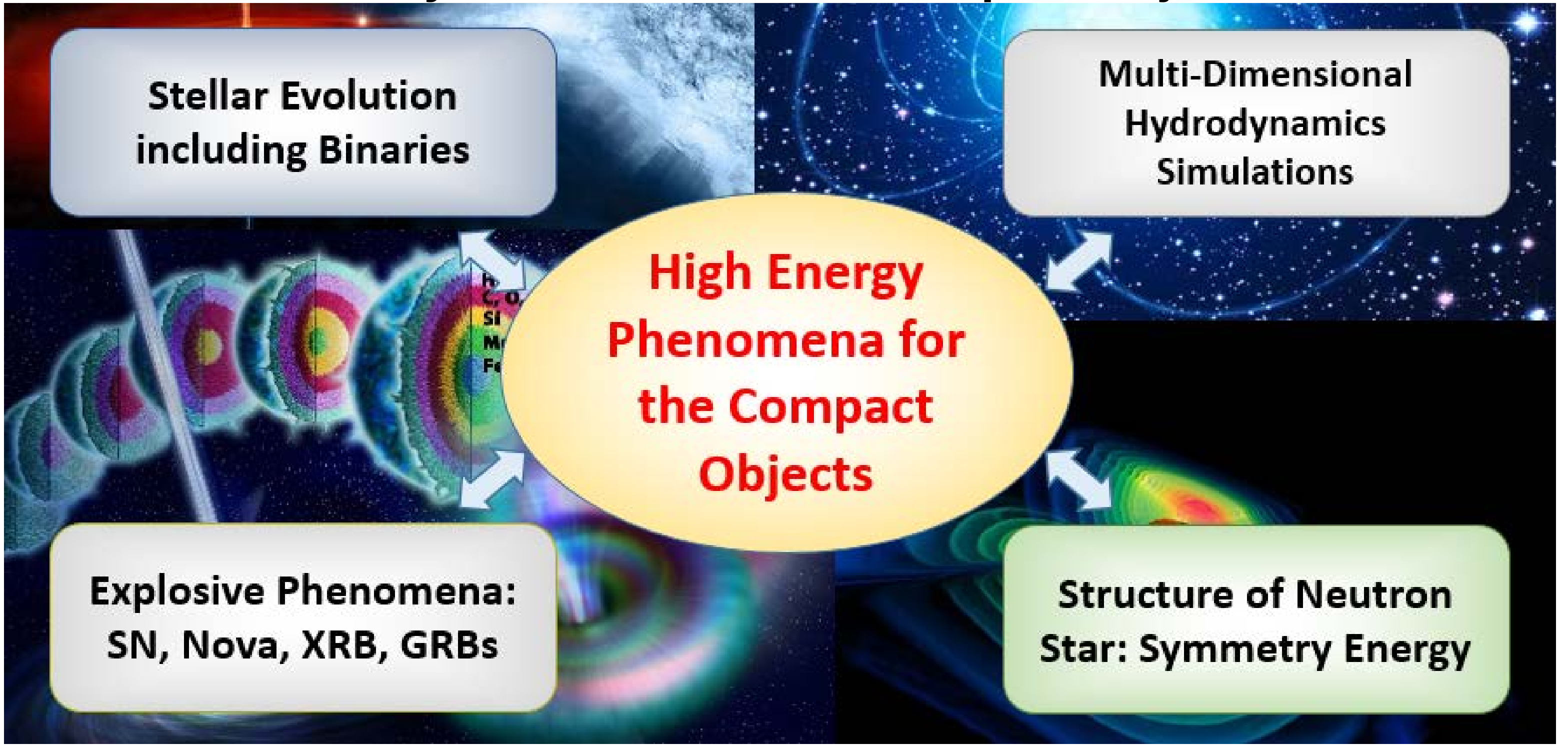
# Main Research Area 2

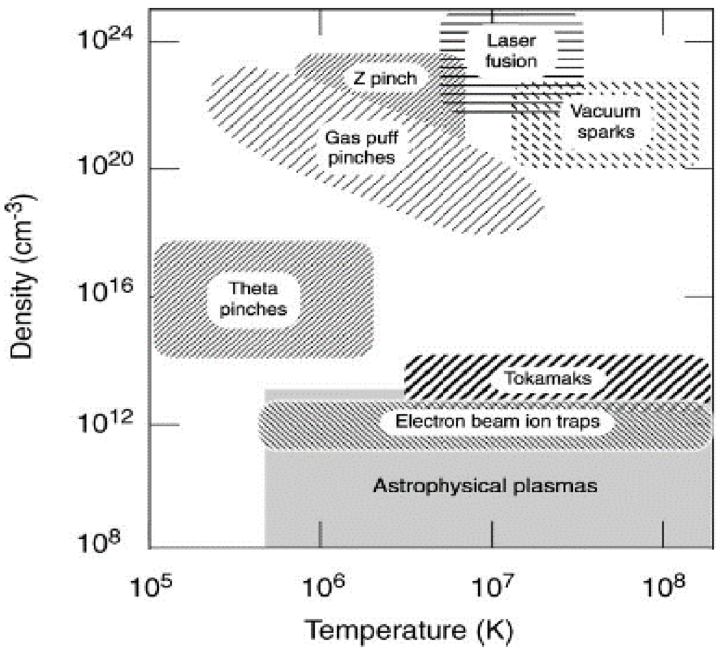
**Theory and simulation of Compact Objects**

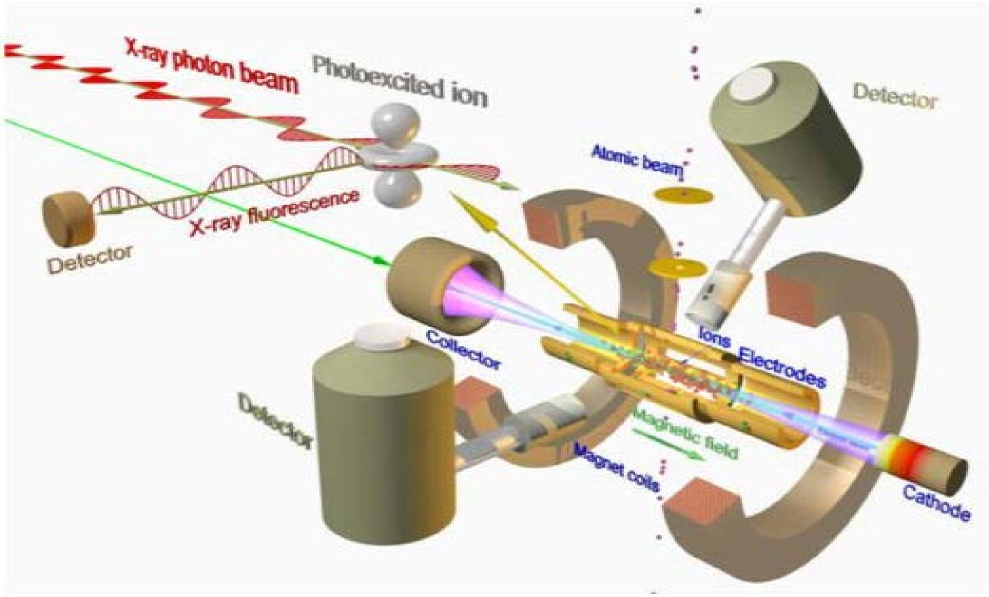



- Depending on its initial mass and detailed evolution history, a single star evolves to either white dwarf, neutron star, or black hole, which are named as compact objects collectively.
- Compact objects are at the center of numerous astrophysical phenomena that involve high energy and/or high density physics and nuclear physics.

# Main Research Area 3

## X-ray Spectroscopy of Highly-Charged Ions (HCI)



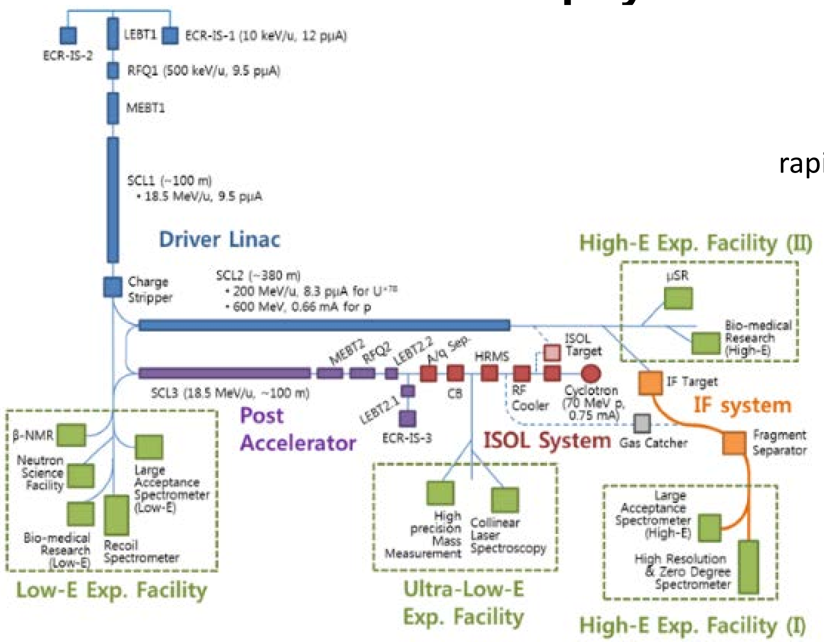

- X-FEL's have expanded the use of laser spectroscopy technique into the X-ray domain.
- High-precision studies of the interactions between X-ray photons and highly-Charged Ions (HCI) created by EBIT are possible, including the investigation of the photoionization and photorecombination of the HCI.
- These processes determine radiation transport in stars and in the photo-ionized plasmas surrounding compact objects such as black holes and neutron stars.

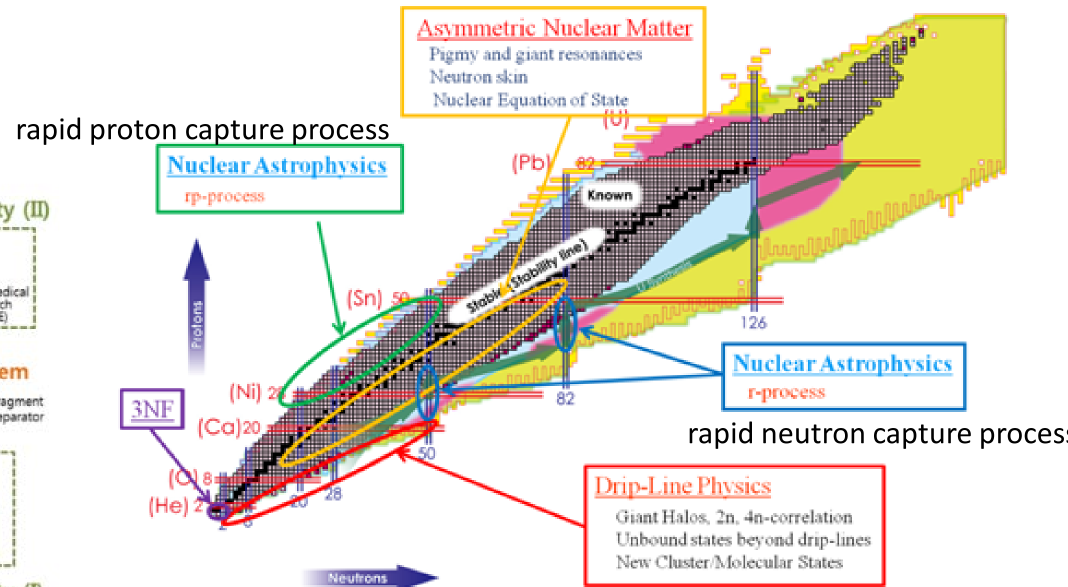


More from Mr. Park and Mr. Yoo (UNIST)

# Main Research Area 4

## Nuclear Astrophysics Using Rare Isotope (RI) Accelerator



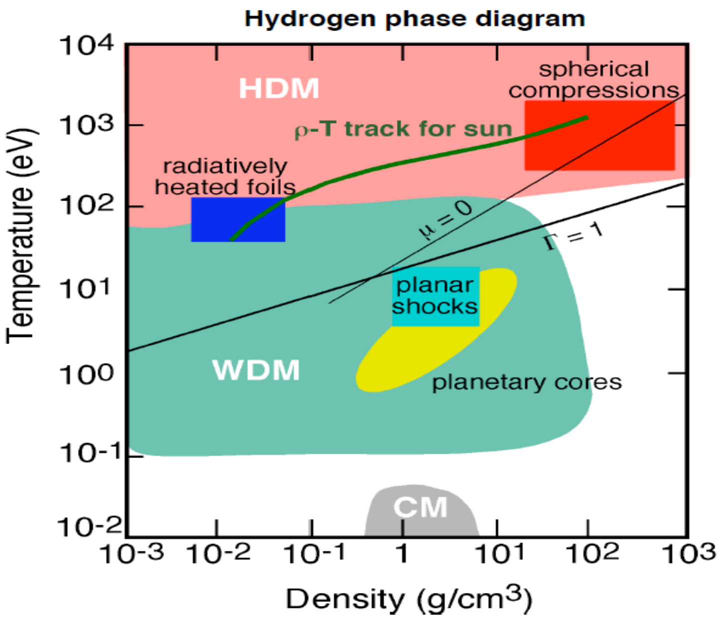



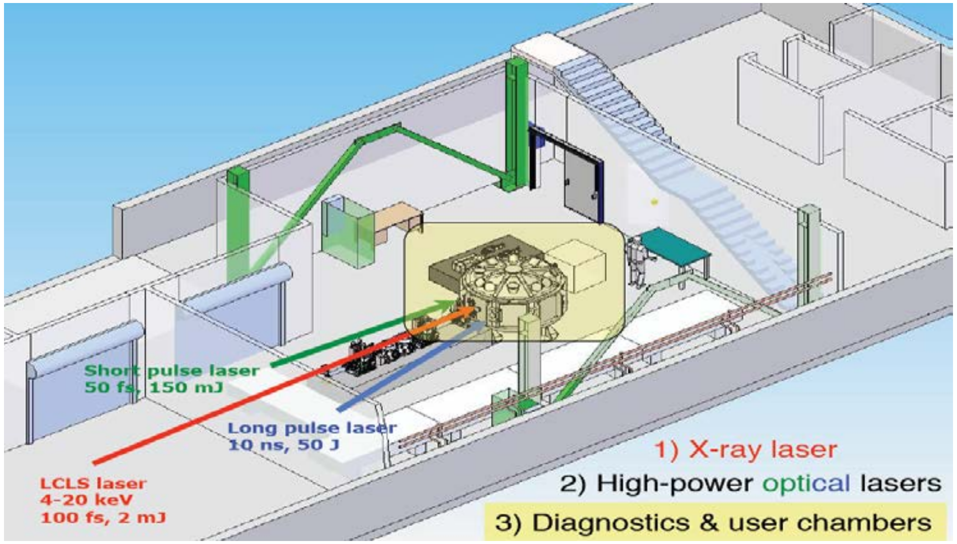

- The primary purpose of rare isotope accelerator is to produce unstable nuclei which have more protons or neutrons than stable nuclei.
- These unstable nuclei are ubiquitous in numerous astrophysical phenomena, for example, stellar evolution of massive stars, explosion on the surface of compact stars, core-collapse and accretion-induced supernova.
- Production (ISOL/IF, Charge Breeding) and measurement (Recoil Spectrometer) of unstable nucleus require huge amounts of experimental resource and effort.

More from Prof. Chae (SKKU)

# Main Research Area 5

## Pump-Probe Measurements of High Energy Density (HED) Matter




- High energy density (HED) matter is defined as having an energy density above $10^{11}$ joules per $cm^3$, which is equivalent to 100 GPa (1 Mbar) pressure and 500 T magnetic pressure.
- The XFEL can be used either as a pump or as a probe to study time- and spectrally-resolved properties of the HED.
- Hot Dense Matter (HDM) occurs in supernova, stellar interiors, and accretion disks, while Warm Dense Matter (WDM) occurs in cores of large planets.

Prof. B.I. Cho (GIST)

## 붙임 1 천체물리학적으로 중요한 고전리 이온의 분광학적 특성 연구 RFP

| | | | |
|---|---|---|---|
| | | RFP 번호 | 1 |
| 과제명 | ○ 천체물리학적으로 중요한 고전리 이온의 분광학적 특성 연구 | 보안등급 | 보안 |
| 소요기간 | ○ 총 사업기간 : 3개년 ('19-'21년)<br>○ 당해연도 사업기간 : '19.3-'20.2 (12개월) | 정부지원 연구비 (당해연도) | 9 억원<br>( 3 억원) |
| 연구목표 | ○ 3세대 및 4세대 방사광 가속기를 이용하여 천체물리학적으로 중요한 고전리 이온의 X-선 스펙트럼 및 진동자 세기 측정 | | |
| 배경 (관련 동향) | ○ 고전리 이온(Highly-Charged Ion, HCI)은 고온의 은하단뿐만 아니라, 별, 초신성, 성간물질을 구성하고 있는 천체물리학적으로 매우 중요한 물질 상태임.<br>○ 최근에 우주로 쏘아 올려진 XMM-Newton (X-ray Multi-Mirror Mission)과 Chandra 등의 과학위성은 이러한 고전리 이온으로부터 나오는 X-선 스펙트럼을 관측해서 천체의 신비를 연구하는 임무를 띠고 있음.<br>○ X-선 스펙트럼에는 이온과 전자의 온도, 밀도 등에 관한 정보를 담고 있다. 하지만, 지구상에서는 흔하지 않은 고온-고에너지 상태로 이온들이 존재하기 때문에, 통상적인 원자물리학으로는 관측된 스펙트럼을 충분히 설명하기가 어렵다. 이러한 어려움 때문에, X-선 관측 데이터를 활용한 천체물리 현상의 해석이 명쾌히 이루어지지 못하고 있는 실정임. | | |
| 연구개발 내용및범위 | ○ 고전리 이온 발생 장치의 구축 또는 도입<br>○ X-선 계측 시스템 구축 또는 도입<br>○ 3세대 및 4세대 방사광 가속기를 이용하여 천체물리학적으로 중요한 고전리 이온에 대한 X-선 스펙트럼 및 진동자 세기 측정 실험 수행<br>○ 천문 관측 데이터 또는 시뮬레이션 결과와 비교 분석 | | |
| 연구팀 구성 | ○ 대학 주관, 연구소 참여 공동연구팀 구성<br>- 연구팀 구성 : 대학 석·박사 과정생 또는 박사후 연구원 3인 이상, 연구소(2인 이상)<br>- 학·연 연구진 역할(분담)<br>대학 : 사업총괄, 고전리 이온 발생 장치의 구축, 성능시험, 인력양성, 데이터 분석<br>연구소 : X-선 계측 시스템 구축, 빔라인 준비, X-선 스펙트럼 및 진동자 세기 데이터베이스 제공 | | |

## 붙임 1 천체물리학적으로 중요한 고에너지밀도 플라즈마의 분광학적 특성 연구 RFP

| | | | |
|---|---|---|---|
| | | RFP 번호 | 1 |
| 과제명 | ○ 천체물리학적으로 중요한 고에너지밀도 플라즈마의 분광학적 특성 연구 | 보안등급 | 보안 |
| 소요기간 | ○ 총 사업기간 : 3개년 ('19-'21년)<br>○ 당해연도 사업기간 : '19.3-'20.2 (12개월) | 정부지원 연구비 (당해연도) | 15억원<br>(5억원) |
| 연구목표 | ○ 극초단 초고휘도의 XFEL을 활용, 우주환경에서만 존재하는 플라즈마 상태를 지상에서 생성하고 진단하는 기술을 개발하여, 고에너지밀도 플라즈마의 물성을 이해함. | | |
| 배경 (관련 동향) | ○ 플라즈마는 우주의 항성, 성간매질, 거대행성 주변 등 다양한 환경에 존재하며, 특히 많은 경우 별의 내부, 초신성 폭발 등 고온-고압의 고에너지밀도 (>$10^{11}$ J/m$^3$) 상태로 존재함.<br>○ 근래 Chandra x-선 위성 등을 통해 관측된 우주 플라즈마의 이미지 및 분광 데이터들은 고에너지밀도 플라즈마에 대한 기존의 데이터 및 모델이 별과 은하의 구조를 정확히 이해하는데 충분하지 않음을 보여줌.<br>○ 미국(LCLS), 유럽(Euro-XFEL) 등에서는 4세대 방사광 가속기를 활용함에 있어, 응집물질, 바이오 등의 영역을 넘어서 극한의 우주환경 및 플라즈마에 대한 연구를 진행하거나 준비중.<br>○ 우리나라는 2016년 XFEL이 가동되기 시작하였으나 활용분야가 제한적이며 천체물리학, 플라즈마 등의 연구에 적합한 장치 및 기술개발은 미흡함. | | |
| 연구개발 내용 및 범위 | ○ XFEL를 활용한 고에너지밀도 플라즈마의 생성 및 진단<br>- 고휘도 XFEL을 이용한 고밀도 플라즈마의 생성 및 x-선 분광을 통한 온도·밀도 측정<br>- 다양한 온도-밀도의 고밀도 광플라즈마의 전자구조 진단<br>- 고밀도 광플라즈마의 복사 및 불투명도에 대한 연구<br>○ 국소 열역학적 비평형 (non-LTE) 플라즈마 동역학<br>- XFEL을 활용한 non-LTE 플라즈마의 전자분포 측정<br>- 광여기된 non-LTE 플라즈마의 유체역학적 거동 진단<br>○ XFEL을 활용한 저온-고밀도 플라즈마의 물성진단<br>- 저온-고밀도 플라즈마에 대한 초고속 전자구조 측정<br>- 비평형 축퇴전자 거동에 대한 연구<br>- 고밀도 플라즈마의 열전도도에 대한 연구 | | |
| 연구팀 구성 | ○ 대학 및 연구소 주관, 가속기 관련 연구소와 공동 연구팀 구성<br>- 연구팀 구성: 교수/선임급 연구원 3인 이상, 석·박사 과정생 또는 박사후 연구원 6인 이상 | | |

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