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CSES: Center for Space and Earth Science

Astrophysics/Cosmology ***Status Report***

Hui Li, LANL/T-2

July 19th, 2017

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Outline

- Background and Brief recap of the FY16 Focused science topics
- Overview of the range of projects supported in the focus area, including highlights, publications
- Conferences, workshops supported
- Supported seminar series
- Visits for CSES business

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Astrophysics + Cosmology Focus Area

- Advanced research in observation, theory, simulation, and instrumentation that strives to achieve fundamental understanding of the universe.
- Benefits from and in turn strengthens its strong overlap with many on-going Laboratory programs in areas such as nuclear physics, particle physics, weapon physics, plasma physics, and condensed matter physics.
- Innovative and forward-looking, especially those with strong potential leading to new capabilities and research directions.
- Utilizes and leverages the facilities and observatories both inside and outside of the Laboratory. Exploit unique resources at LANL which include:
 1. Facilities (e.g. the HAWC gamma-ray observatory).
 2. Computational techniques, simulation codes and resources.
 3. Broad knowledge base in a full range of physics that tie together theory, simulation, experiments, and observations.

People, Expertise, Tools / Facilities

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Diverse Astro Expertise and Ties with LANL Core Missions

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FY16 Projects: Students, Postdocs, Emerging Ideas (R&D, PD)

Astro				FY16	FY17	FY18
D232	H. Li/Doug Lin	Close-in Exoplanets: Origin and Dynamics of Hot Jupiters and Super-Earths	UCSC	\$ 60,913		
D235	M. Paris/Fuller	Towards a Unitary & Self-consistent Treatment of Big Bang Nucleosynthesis	UCSD	\$ 59,620		
D207	Stamatikos/Fryer	Spectral Variation Studies of Gamma-ray Bursts	OH Univ	\$ 28,200		
D108	J Smidt/A Cooray	Primordial Explosions and BlackHoles: Direct and indirect Signatures in deep Sky Image (gave only what was requested)	UC Irvin	\$ 60,000	\$ 60,000	\$ 60,000
D102	Hui Li/Andrea Isella	Planet Formation in the ALMA Era: When Where and How	Rice Univ	\$ 70,000	\$70,000	

Astro Emerging Ideas R&D

AS16CHEN	Huang Chengkun	Catalyzing simulation discovery of astrophysical phenomena with improved Particle-In-Cell method
AS16MOTT	Emil Mottola	Gravitational Wave Astronomy in the Advanced LIGO Era
AS16FLIP	Kirk Flippo	Scaled Laboratory Astrophysics with Ultra-High Magnetic Fields

Emerging Ideas PD

ASTRO

Przemek Wozniak

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\$ 40,000 Opening a New Frontier in time-domain A

Some Highlights

- EI – R&D: PI: C. Huang on Advanced Plasma Kinetic Simulation Algorithms
- Student support: PI: Paris – Fuller on Quantum Effects on Cosmological Observables
- Postdoc support: PI: Li - Isella (Rice) on Protoplanetary Disks
- **Two Talks this afternoon:**
 - Pat Harding on HAWC
 - Kirk Flippo on Using HED Laboratory Plasmas for Astrophysics

CSES Project Summary/Highlight

PI : Chengkun Huang (T-5)

2016 Emerging Ideas Project

Catalyzing simulation discovery of astrophysical phenomena with improvements in Particle-In-Cell method

Focus: numerical method improvement

2017 Emerging Ideas Project

Understanding relativistic astrophysical particle acceleration with an improved Particle-In-Cell method

Focus: integration into LANL institution code VPIC; validation and initial study in collisionless shock/magnetic reconnection problems

Collaborators

Numerical method: Y. Zeng¹, Y. Wang¹, M. D. Meyers^{1,2}, S. A. Yi¹, B. J. Albright¹, Zehua Guo¹, Xiaocan Li¹

Astrophysics modeling: Fan Guo¹, Nicole Lloyd-Ronning¹, Chris Fryer¹, Alexey Arefiev³, Frederico Fiuza (LANL P/T colloquium speaker)⁴

¹LANL ²UCLA ³UT Austin ⁴SLAC
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Ties with LANL's Initiative in Exascale Computing

The Exascale Computing Project announces \$48 million to establish four Exascale Co-Design Centers

The first year is funded at \$12 million, and is to be allocated evenly among the four award recipients.

Co-design center for Particle Applications (CoPA).
Principal Investigator: Tim Germann, Los Alamos National Laboratory

This co-design center will serve as a centralized clearinghouse for particle-based ECP applications, communicating their requirements and evaluating potential uses and benefits. Particle-based software technologies using proxy applications and simulation approaches are ubiquitous in scientific engineering, and they involve the interaction of particles in an environment by direct particle-particle interactions and/or by particle-mesh interactions with longer-range effects. Best practices in

Project status, presentation and program development

Finite Grid Instability and Numerical Cherenkov Instability.

- New method leads to significant improvements in high fidelity PIC model.

Interpolation func.	Renormalized FGI growth rate
2 nd order B-spline	$0.21 \omega_p^{-1}$
5 th order B-spline	$0.063 \omega_p^{-1}$
$w(x)$ from P(0,8)	$0.015 \omega_p^{-1}$

>10x

- Presentation and publication:
 - “High intensity laser plasma interaction with low areal-density targets: from ion acceleration to shock generation (Recent understandings with experiments, simulations and model improvements),” US-Japan workshop on laser-plasma interactions and high energy density physics, San Jose, CA, Nov. 2016. Contributed talk.
 - Paper on model improvement in preparation.
- Program development : 2 LDRD-ER Proposals
 - “The Formation of Shock Waves in Laboratory & Astrophysical Settings,” 20180195ER submitted to 2018 LDRD ER call.
 - “Next-generation high fidelity multi-symplectic method for particle-field systems,” pre-proposal 20180462ER submitted to 2018 LDRD ER
- Status : Improvements implemented in VPIC, testing on astrophysical problem underway.

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Quantum Effects on Cosmological Observables

A probe of Beyond Standard Model & Nuclear Physics

- **Theory project funded through *CSES Student and PostDoc Fellowship***
 - LANL PI: Mark Paris (T-2, Nuclear & Particle Physics, Astrophysics & Cosmology)
 - University PI
 - George Fuller (Director Center for Astrophysics and Space Sciences UCSD)
 - Graduate student: Lucas Johns (UCSD)
 - DOE Office of Science Graduate Student Research award
 - Inamori Fellow
 - Postdocs
 - Shashank Shalgar (T-2 LANL, current)
 - Evan Grohs (will join T-2 in the October 2017, previously supported by CSES/IGPPS funding)
- **Synergistic activities**
 - LDRD-ER funding FY17-FY19
 - LANL HPC Institutional Computing
 - 1-year allocation at 15 Mcore-hours
 - NSF continuing and new funds
 - UCSD PI continuing grant
 - E. Grohs self-funded postdoc
 - NSF consortium N3AS – Network for Neutrinos, Nuclear Astrophysics, and Symmetries
 - » NSF + Heising-Simons Foundation

Daniel Blaschke
Vincenzo Cirigliano
Mark Paris
Shashank Shalgar

George Fuller
Luke Johns

Alexey Vlasenko

Evan Grohs
(soon to be LANL)

Mattia Mina

Chad Kishimoto

Overview

- **Recent/forthcoming cosmological/astrophysical observations**

- Cosmic microwave background radiation
 - Extremely large telescopes (like TMT) “Big Glass”
 - Further the cosmological precision frontier
-
- **Coming precision requires improved theoretical modeling**
 - Current observational precision ~ few % level
 - coming precision $\lesssim 1\%$
 - Development of theoretical modeling and simulation
 - recent developments by LANL/UCSD led collaboration
 - fully self-consistent approach to early universe simulation:
 - » Gen. Relativity + Thermal Quantum Field Theory
 - complete standard model approach including precision nuclear physics; beyond Standard Model physics

Modeling & Prediction

- **Use Big Bang nucleosynthesis (BBN) to constrain:**

- BBN: cooling thermonuclear reactor of the early universe manufacturing of light nuclei
- Models & simulations
 - Evolve the early universe (photons, neutrinos, charged leptons, & nuclei)
 - neutrino quantum kinetics equations coupled to nuclear reaction network
 - Standard Model nuclear & particle physics
- Predictive capability
 - Study beyond Standard Model physics
 - out-of-equilibrium effects, inhomogeneities, lepton asymmetries, dark matter, etc.

- **Recent work (sample)**

Effect of collisions on neutrino flavor inhomogeneities in the early universe

Shashank Shalgar, Vincenzo Cirigliano, Mark Paris

Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

PHYSICAL REVIEW D **93**, 083522 (2016)

Neutrino energy transport in weak decoupling and big bang nucleosynthesis

E. Grohs,^{1,2,*} G. M. Fuller,¹ C. T. Kishimoto,^{1,3} M. W. Paris,⁴ and A. Vlasenko^{1,5}

Editors' Suggestion

PHYSICAL REVIEW D **94**, 083505 (2016)

Neutrino flavor transformation in the lepton-asymmetric universe

Lucas Johns,^{1,2,*} Mattia Mina,^{2,3} Vincenzo Cirigliano,² Mark W. Paris,² and George M. Fuller¹

Going forward

- **Complete theoretical and numerical implementation Standard Model**
 - solve non-linear neutrino quantum kinetic equations in BURST code: ν flavor dynamics
- **Investigate effect of neutrino flavor oscillations/lepton asymmetries**
 - on BBN
- **Develop physics/code modules for BURST to study**
 - physics beyond the Standard Model
 - heavy particle out-of-equilibrium decay
 - a variety of Beyond-Standard-Model scenarios
 - study solutions to the *Lithium Problem*
 - verification & validation of precision nuclear reaction cross sections and other nuclear
- **Organizing QuECO 2017 workshop**
 - August 22-24, Santa Fe, NM

Mapping Protoplanetary Disks with ALMA

- Collaboration with Rice
- Support a Postdoc at Rice who spent ~ yr here

HL Tau

Forming planets in HL Tau disk

Jin, S., Li S., Isella A., Li H.,
ApJ, 2016

**LA-COMPASS code developed
at LANL**

Hydrodynamic simulations:

$M_{\text{star}} = 0.5 M_{\text{sun}}$

$M_{\text{disk}} = 0.07 M_{\text{sun}}$

dust-to-gas ratio = 0.01

P1 = $3.3 \times 10^{-4} M_{\text{sun}}$, $1.2 M_{\text{sat}}$, 13.1 AU

P2 = $1.7 \times 10^{-4} M_{\text{sun}}$, $0.6 M_{\text{sat}}$, 33 AU

P3 = $2.5 \times 10^{-4} M_{\text{sun}}$, $0.9 M_{\text{sat}}$, 68.6 AU

HD 163296

map of the 1.3 mm continuum emission obtained with
Atacama Large Millimeter Array

60 AU

Solar system

Isella et al. (2016)

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Volume 117, Issue 25

16 December 2016

On the Cover

Dust continuum emission of a protoplanetary disk recorded in sub-mm wavelengths at 0.2 arcsec resolution. Evidence suggests the two outer dark rings are due to Saturn-sized baby planets. Selected for a Viewpoint in *Physics* and an Editors' Suggestion.

From the article:

[Ringed Structures of the HD 163296 Protoplanetary Disk Revealed by ALMA](#)

Andrea Isella, Greta Guidi, Leonardo Testi, Shangfei Liu, Hui Li, Shengtai Li, Erik Weaver, Yann Boehler, John M. Carperter, Itziar De Gregorio-Monsalvo, Carlo F. Manara, Antonella Natta, Laura M. Pérez, Luca Ricci, Anneila Sargent, Marco Tazzari, and Neal Turner

**First paper in PRL on
Protoplanetary Disk and
exoplanets**

**Informing the general physics
community**

**Got picked up by many news
outlet (except LANL 🧐)**

Origins of the rings: planets ++

- The middle and outer gaps are consistent with the presence of Saturn mass planets.
- We do not have a good model for the innermost gap.

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Liu et al. (in preparation)

Isella et al. (2016)
Los Alamos
NATIONAL LABORATORY
EST. 1943

Astronomers track the birth of a 'super-Earth'

July 11, 2017 by Daniel Stolte

This is an artist's impression of a young star surrounded by a protoplanetary disk in which planets (not shown to scale) are forming. Credit: ESO/L. Calçada

Summary:

- Several high profile publications
- Follow up funding at NSF, NASA (pending)
- Awarded large observing programs at ALMA and JVLA
- Involved in ngVLA
- Co-organize workshops

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Conferences & Workshops

- Understanding Cosmo Evolution Workshop (Fryer, FY16)
- Physics of white dwarfs stars (Saumon, Santa Fe, June 2017)
- Quantum Effects on Cosmological Observables (QuECO17) workshop (Paris, Santa Fe, July 17-19)
- New Opportunities in Understanding ExoPlanet Formation (Li, Los Alamos August 14-18)

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LA-Astro Seminar Series made possible by CSES support (\$15-20 K/yr) -- FY16

Date	Speaker	Title	Funding Number
10/22/15	Oleg Korobkin, LANL	"Mass ejection and nucleosynthesis in neutron star mergers"	
11/5/15	Tuguldur Sukhbold, UCSC	Massive Star Evolution	
11/19/15	Irina Sagert, LANL		
12/10/15	Xuening Bai, CfA	Towards a Global Evolutionary Picture of Protoplanetary Disks	1
1/5/15	Brenda Dingus, LANL	Observing the Non-Thermal Universe with the Highest Energy Photons	
1/19/2016 (Tue)	Tilan Ukwatta, LANL		
2/4/16	David Neilsen, BYU	...	
2/25/16	Alex Lazarian, UW-Madison		2
3/15/16	Amanda Bayless, Southwest Research Institute		
3/23/16	Grant Meadors, MPI Gravity	LIGO	3
4/13/2016 (Wed)	Andrew Youdin, U. Arizona		
4/19/16	Carolyn Kuran	Experimental Astro	4
4/21/16	Toshiki Sato, ISAS/JAXA & Tokyo Metropolitan University		5
4/26/2016 (Tue)	Andrea Albert, LANL		
4/28/16	Vladimir Zhdankin		6
5/5/16	Irina Sagert, LANL	Nuclear Pasta	
5/10/16	Max Katz, SBU	Mergers of White Dwarfs	7
5/12/16	Brian O'Shea, MSU	Better living through computation: Exploring the first generation of galaxies	8
5/19/16	Ylva Pihlstrom, UNM	Radio Astronomy	9
5/26/16	Raphael Hirschi, Keele	NuGrid	
5/31/16	Jonathan Katz	FRBs: Many questions, fewer answers	
6/2/16	Sam Jones, Heidelberg	NuGrid	
6/16/16	Grzegorz Kowal		10
7/12/2016 (Tue)	Haocheng Zhang, LANL		
7/19/2016 (Tue)	Joel Dahlin, U. Maryland	Particle acceleration in magnetic reconnection	11
7/21/2016	Ryan Miranda, Cornell	Protoplanetary disks (room already booked by Hui)	
8/9/2016	Sherwood Richers		
8/11/2016	Jack Hughes, Rutgers		12
8/25/2016	Frederico Fiuza, SLAC		13
8/30/2016	Michael Gallis, SNL		
8/31/2016	Hui Chen, LLNL		
9/1/2016	Andrey Beresnyak		14
9/6/2016 (Tue)	Eric Cramer, UAH		15
9/21/2016 (Wed)	UCSC students	Protoplanets	

**Thanks to the dedicated
hard work by L. Duffy
and C. Malone**

LA-Astro Seminar Series made possible by CSES support (\$15-20 K/yr) -- FY17

Date	Speaker	Employment	Title	Funding Number
10/4/2016	Savvas Koushiappas	Brown University	Dark matter searches and cosmological questions	1
10/6/2016	Bill Myers	retired LBL	What's an Analemma	
10/13/2016	Roseanne Cheng	Johns Hopkins University	Developing Tools for Astrophysical Fluid Dynamics	6
10/20/2016	Evan Grohs	UCSD / UM (Ann Arbor)	Towards a high precision treatment of neutrino cosmology	
10/27/2016	Emil Mottola, LANL	LANL	Scalar Gravitational Waves in the Effective Theory of Gravity	
11/3/2016	Parviz Ghavamian	Towson University	Balmer-Dominated Supernova Remnants and the Physics of Collisionless Shocks	5
11/17/2016	Nilanjan Banik	University of Florida	BAO in the presence of significant redshift uncertainty	2
11/29/2016	Jonah Miller	Perimeter Institute / Co-de	Discontinuous Galerkin Methods for Relativistic Astrophysics	
12/1/2016	Pat Slane	Harvard-Smithsonian Cen	Energetic Windbags Young and Old: The Evolving Story of Pulsar Wind Nebulae	7
12/1/2016	Siyao Xu	Kavli Institute for Astronon	Magnetic field's travels from Lilliput to Brobdingnag	8
12/15/2016	Marius Eichler	TU Darmstadt	The Third r-Process Peak and the Origin of the p-Nuclei 92,94Mo and 96,98Ru	9

WinterBreak

Thanks to the dedicated hard work by I. Sagert, L. Duffy and C. Malone

1/12/2017	Jirina Stone	ORNL	Low energy nuclear structure modeling: Can it be improved?	3
1/17/2017	Alex Chen	Columbia University	PIC Simulations of the Twisted Magnetospheres of Magnetars	
1/19/2017	Anna Kwa	UC Irvine	Indirect Dark Matter Detection	10
1/26/2017	Jane Lixin Dai	Maryland	Tidal disruption events as a probe of super-Eddington accretion	
2/2/2017	Aycin Aykutalp	Georgia Institute of Techno	Black Hole Growth in the Early Universe	9
2/9/2017	Pawan Kumar	UT Austin	The mystery of Fast Radio Bursts, and its possible resolution	11
2/23/2017	Galen Ross Gisler	LANL	Asteroid Threads	
2/27/2017	Jonathan Zrake	Columbia University	Magnetic field dissipation in pulsar wind nebulae	12
3/16/2017	Jonathan Katz	LANL	Fast Radio Bursts	
3/20/2017	Luke Johns	UCSD, CSES	Neutrinos and nuclei in the early universe	
4/13/2017	Ed Daw	University of Sheffield	Searching for Axion Dark Matter and Alp-ine New Physics	4
5/11/2017	Matthew Baring	Rice University	Blazars: a Cosmic Forum for Studying Turbulence and Acceleration	13
6/15/2017	Veronica Dexheimer	Kent State University	Phase Transitions in Dense Matter	14
06/22/2017	Edison Liang	Rice University	Astrophysical Applications of Relativistic Kinetic Shear Flows	
06/29/2017	Samuel Jones	LANL	Modelling stars near the electron-capture supernova limit	
7/6/2017	Daryl Haggard	McGill University	The Black Hole at the Heart of the Milky Way	15?
7/13/2017	Nicola Cowan	McGill University	The Climate and Habitability of Short-Period Planets	16?
7/20/2017	Brandon Wiggins	LANL / Southern Utah Uni	Protoplanetary Collisions	
8/17/2017	Andrea Isella	Rice University	Planet Formation Seen with Radio Eyes	
9/1/2017	John P. Finley			17?

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Visits to other Institutions to promote CSES

1. Visit to NRAO, teleconf with NRAO directors (FY16)
2. NM Symposium organized by NRAO (Nov'16)
3. Visit to UW – Madison (May'17)
4. Visit to U. Rochester (June'17)
5.

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