Shocks and Particle Shock Acceleration

Tony Bell (Oxford University)

David Burgess (Queen Mary College)

Ramanath Cowsik (Washington University, St. Louis)

Tom Intrator Los Alamos National Laboratory)

Randy Jokipii (University of Arizona)

Marty Lee (University of New Hampshire) - Chair

Bob Lin (University of California, Berkeley)

Christoph Niemann (University of California, Los Angeles)

Anatoly Spitkovsky (Princeton University)

Shocks and Particle Shock Acceleration

A. Importance of Shocks in the Cosmos

B. Key Questions

1. Dependence of Shock Structure on Flow Parameters
2. Are Shocks in the Cosmos Planar and Stationary?
3. Particle Injection and Diffusive Shock Acceleration
4. Amplification of the Magnetic Field at Shocks
5. What is the Role of Turbulence in Shock Structure?

C. Numerical Simulations of Shocks

D. Laboratory Experiments on Shocks

E. Discovery and Exciting Shock Case Studies

1. Supernovae Shocks and the Origin of Galactic Cosmic Rays
2. Heliospheric Shocks: Examples in Different Domains of Plasma Parameter Space

F. Concluding Statement

A National Initiative to Understand the Acceleration of Cosmic Rays

Interdisciplinary Investigation

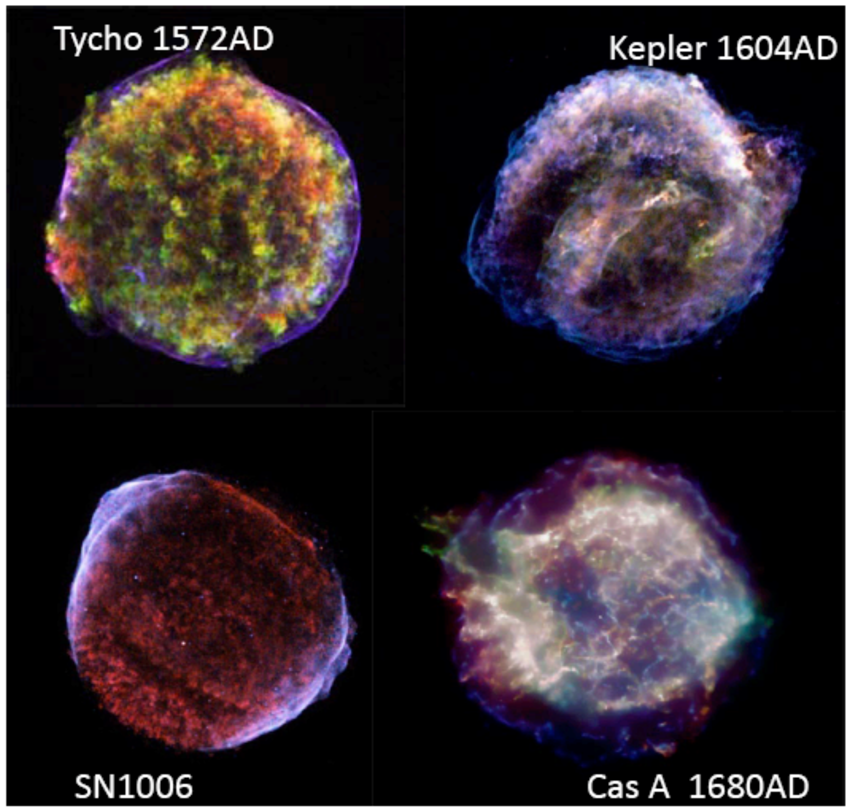
- Supernovae Remnants
- Diffusive Shock Acceleration
- Galactic Cosmic Ray Propagation
- Extragalactic Acceleration

Requires Diverse Observations

Supernovae Remnant Shocks

Evidence for magnetic field amplification at shock

(Vink & Laming, 2003; Völk, Berezhko, Ksenofontov, 2005)



Chandra observations

Bell, 2009

;A/CXC/Rutgers/ ıghes et al. NASA/CXC/Rutgers/ J.Warren & J.Hughes et al. NASA/CXC/NCSU/ S.Reynolds et al. NASA/CXC/MIT/UMass Amherst/ M.D.Stage et al.

The Nuclear Component

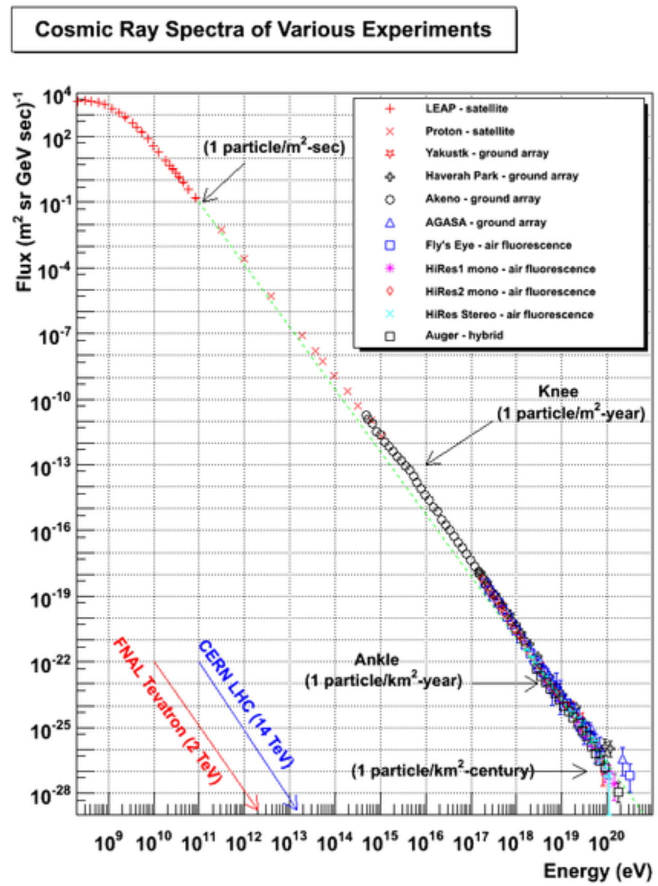
- F~E$^{-2.67}$ which requires M≈2.5

$$\rho_{CR} \sim 10^{-12}\ erg\ cm^{-3}$$

$$L_{CR} \sim \frac{\rho_{CR} V_G}{\tau_{CR}} \sim 10^{41}\ erg\ sec^{-1}$$

$$L_{kinetic}(SN) \lesssim \frac{10^{51}\ erg}{30yr} \approx 10^{42}\ erg\ s^{-1}$$

must slow from M~1000 to M~2.5



$$E_{kin} \sim \frac{1}{400} \times 10^{42} \approx 10^{40}$$

Opportunity for Success

- Basic Viability of DSA
- Viable Models of **B** Amplification
- Current Measurements of SNR: X-rays, γ-rays (e.g. HESS, FERMI)
- Current Cosmic Ray Measurements: e.g. PAMELA, ATIC, ACE
- 3D Simulations of DSA
- Need Advanced Propagation Models

Must Put Together!

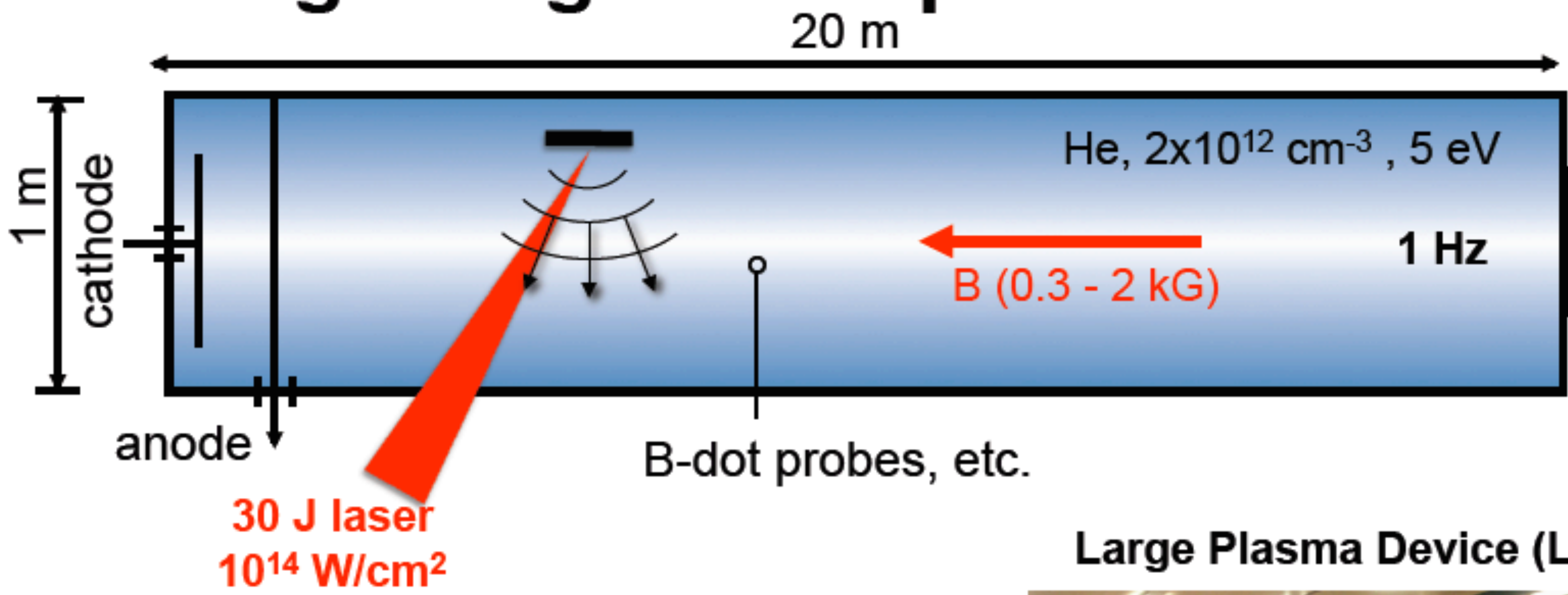
Many Interesting Puzzles

- Discrepancy in GCR Nucleon Index
- Theory Should Predict Concave Spectrum
- Discrepancy in the Electron Index
- Small GCR Anisotropy
- Electrons Require Nearby Source
- Ion and Electron Injection Rates
- Etc.

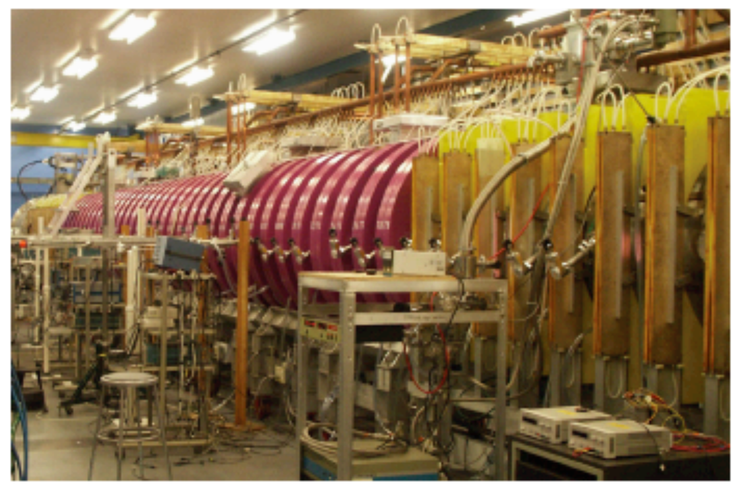
Investigate Shock Structure and Formation in the Laboratory

- Several New Facilities
- Improved Diagnostics

UCLA: Exploding laser-produced plasma in a large magnetized plasma



Large Plasma Device (LAPD)



W. Gekelman *et al.*

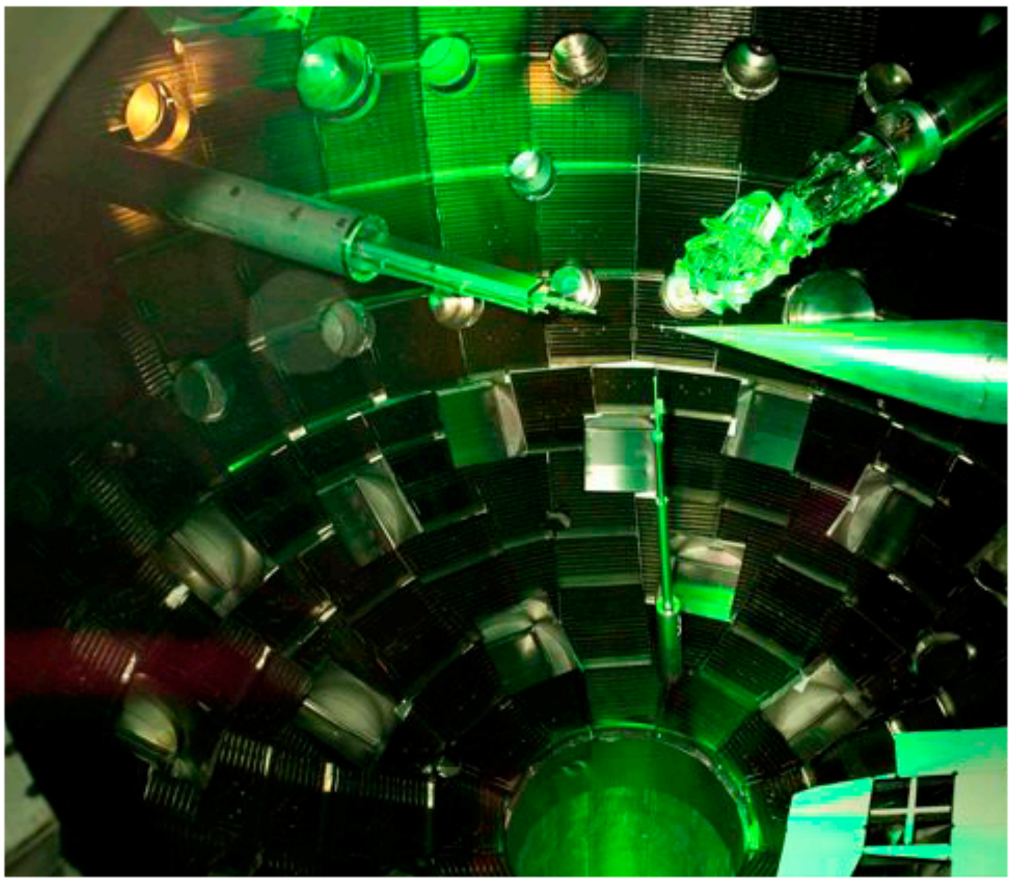
Perpendicular shocks:

V_s = 500 km/s (M_A≈2.5)
Size D = 50 cm
Shock transit time: τ≈ 1μs
D/(c/w_{pi}) ≈ 1 , τw_{ci} ≈ 1, λ_{ii}/D>500

C. Constantin *et al.*, Astrophys. Space Sci. **322**, 155 (2009)

Experiments at the National Ignition Facility could be designed that create CSW at M_A>10

- **MJ in 20 ns and 192 beams into 10 m chamber**
- **NIF is now operational and transitioning into a user facility**



- photoionized gas
- magnetized flows
- colliding plasmas
- multiple shocks …

With adequate magnetization:
(10^{13}-10^{14} cm^{-3}, few 100 G)

M_A>10
$D/(c/w_{pi}) > 100$
$\tau w_{ci} > 100$
$\lambda_{ii}/D > 10$

Critical Measurements for Various Plasma/Shock Parameters

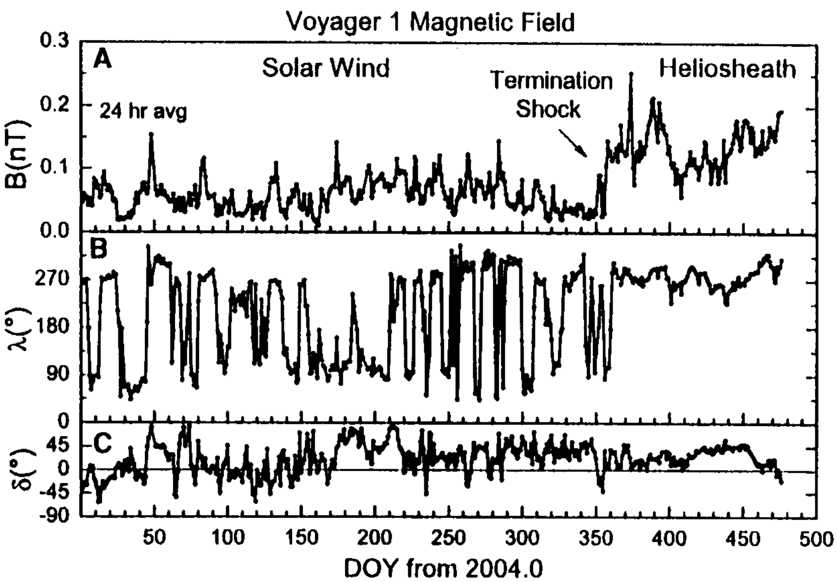
- Shock Formation Timescale
- Electron Dissipation
- Dissipation of Multiple Ion Species
- Electron Acceleration by the Shock

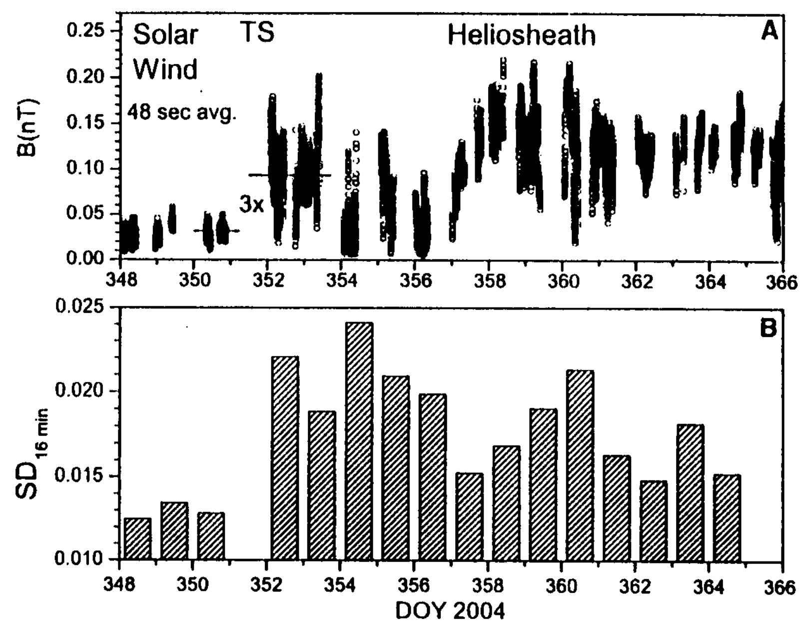
Support with Simulations

What is the Connection Between Astrophysical and Heliospheric Shocks?

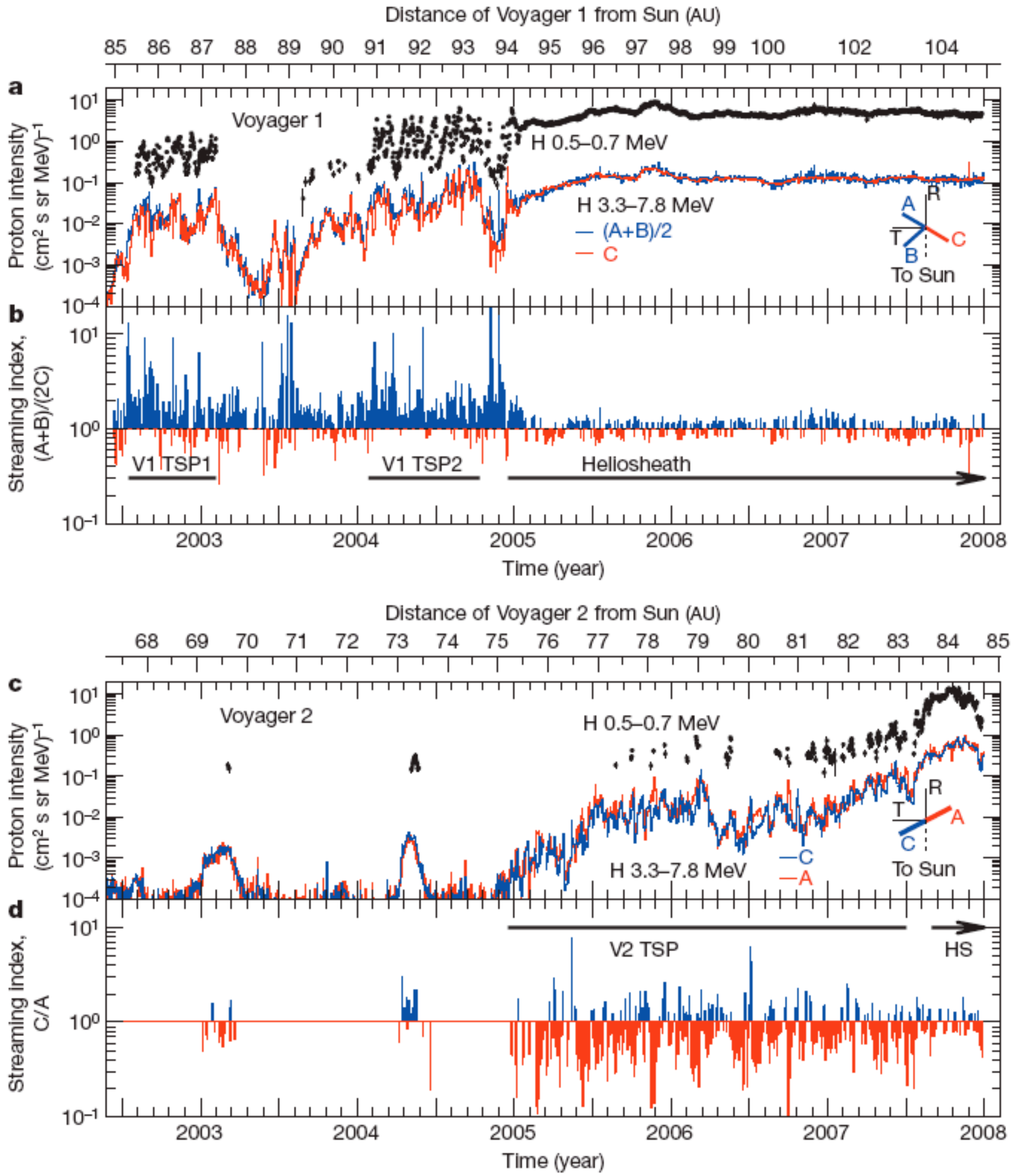
The Heliosphere as a Shock Laboratory

Voyager 1 at the Termination Shock





Burlaga et al., 2005



The Solar Wind Termination Shock Voyagers 1 & 2

Stone et al., 2008

Important Issues

- Ion Injection
- Role of Upstream Inhomogeneities
- Acceleration at Nearly Perpendicular Shocks
- Instabilities at Q-Perp Shocks
- Nature of Low-β Shocks in Corona
- Scaling for High Mach Number Astrophysical Shocks
- Variability of SEP Intensities?

Shocks and Particle Acceleration

Challenge	Existing Research Capabilities	Gaps	Opportunities
SNR Shock Origin of GCR	SNR and GCR Observations; Promising Theory	Many Theoretical and Observational Details	Theory Ripe for Advances; New Observations
Shock Generation in Laboratory	Historical Production of Shocks	Unclear Identification; Few Diagnostics	Several New Experiments; Better Diagnostics
Particle Injection and Quasi-Perpendicular Shocks	Modest Range of Observations and Simulations	Broad Observations; Acceleration Theory at Q-Perp	IBEX; SO and SP + Close to Sun; 3D Simulations