Galactic Neighborhood and Laboratory Astrophysics

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Frontier Science Galactic Neighborhood Panel

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"Galactic Neighborhood" defined as:

Milky Way and Local Group (stars, ISM, satellites)

Galaxies out to redshifts $z \approx 0.1$

(distance 420 Mpc, lookback 1.3 Gyr)

Enables detailed study of:

- Resolved stellar populations
- Complex interconnected processes (*stars-SMBHs-ISM-CGM-IGM interactions*; large/small scales)
- Local counterparts of distant objects *(DM halos, SMBHs, dwarfs, feedback/accretion)*

Four Science Questions:

- (Q1) What are the Flows of Matter & Energy in the Circumgalactic Medium (CGM)?
- (Q2) What controls the Mass-Energy-Chemical Cycles within Galaxies?
- (Q3) What is the Fossil Record of Galaxy Assembly and Evolution from the First Stars to the Present?
- (Q4) What are the Connections between Dark and Luminous Matter?

Areas of Discovery Potential:

- Time-Domain Astronomy

  New instrumentation and dedicated surveys are opening up enormous swaths of new parameter space to explore the transient sky

- Astrometry

  Powerful new techniques allow for complete inventory of stars, dark-matter distribution, SMBH masses, satellite galaxy orbits, and precision measurement of cosmological parameters

(Q1) Circumgalactic Medium

Large-scale structure formation and outflows produce a CGM enriched with metals

Hubble, Chandra, Spitzer

metal transport (1 Mpc):
200-1000 km/s winds over 1-5 Gyr

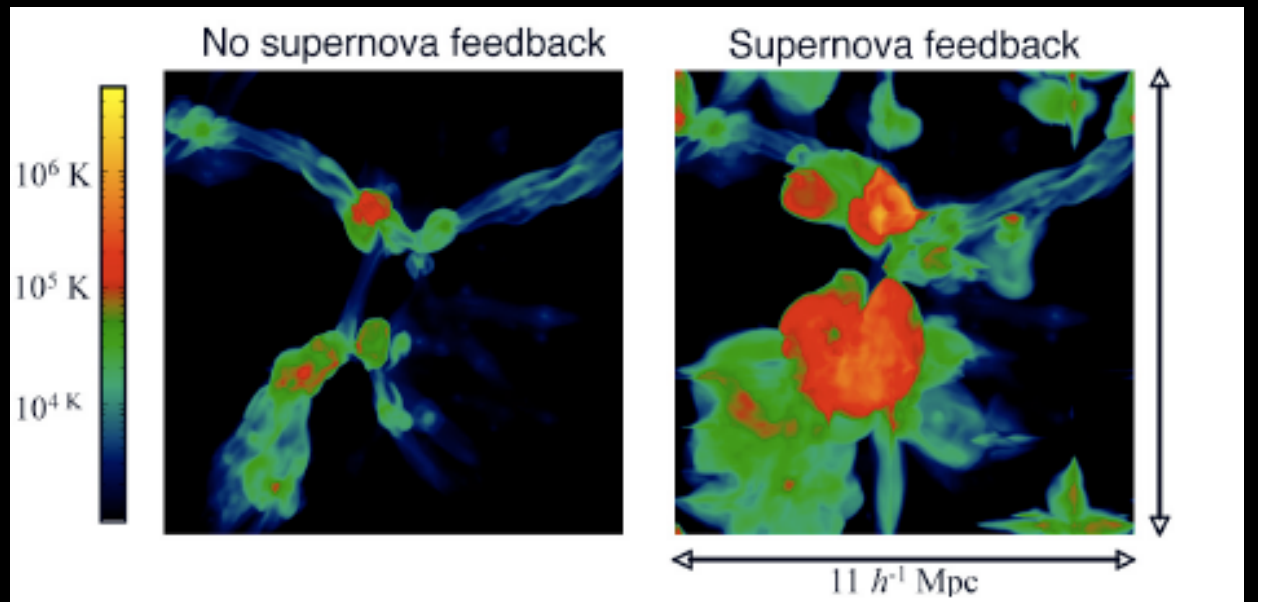
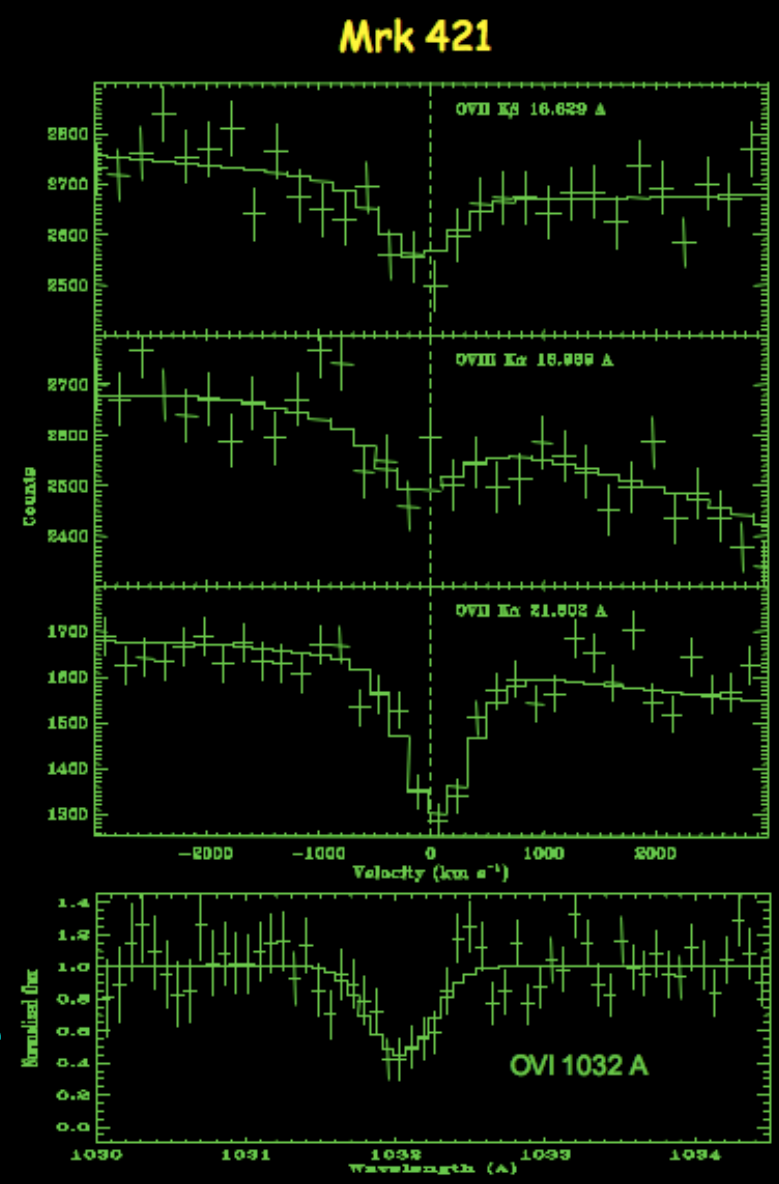


Figure 1: Gas temperature distribution for cosmological models with and without supernova feedback (see Cen & Ostriker 2006).

(Q1) Circumgalactic Medium

- How are galaxies fed with gas?
  - Measure cool gas content and inflow rate
  - *Technique: UV/Optical spectroscopy (velocities, abundances, ionization conditions, n_e, T_e)*
- How does feedback work in the CGM?
  - Measure CGM mass-energy-metal content, transport, thermal/ kinematic structures
  - *Technique -- X-ray/UV absorption-line tomography, plus emission mapping*



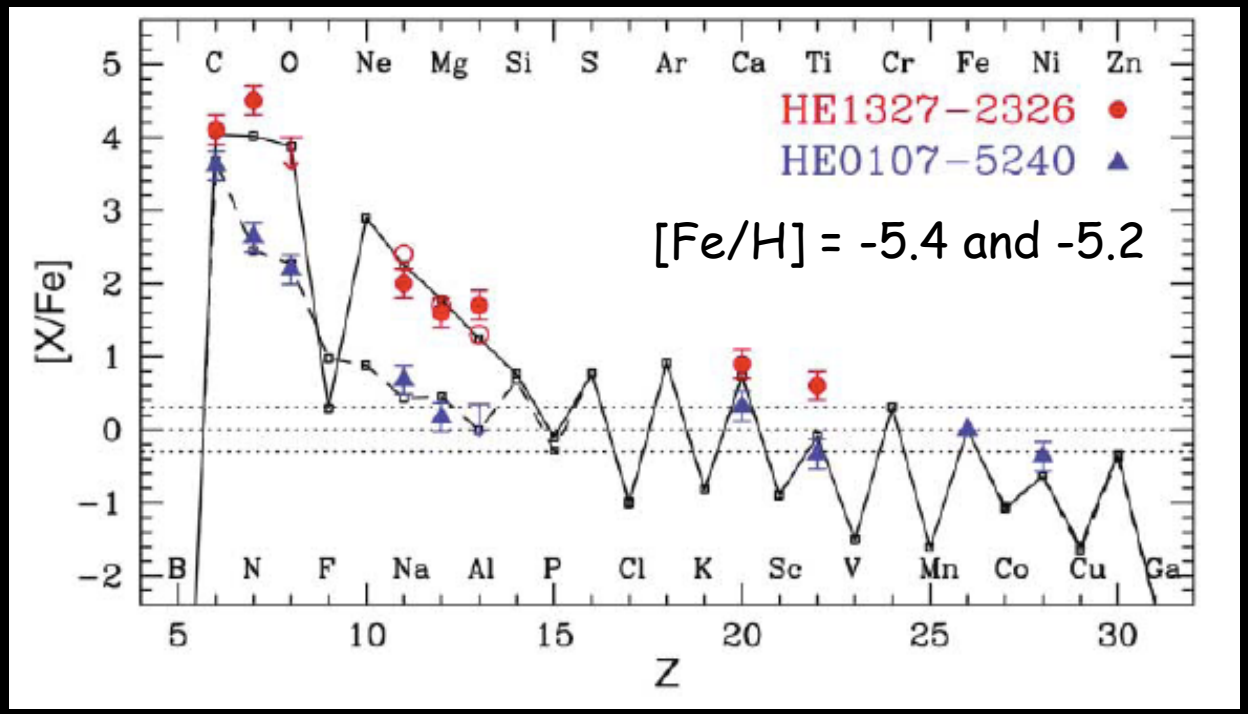
(Q2) Interplay between stars and ISM

- Measure ISM conditions that control the molecular cloud formation and rate of star formation and the IMF
- Understand the effects of stellar energy/chemical feedback on gas-to-star conversion efficiency and disk/halo interaction
- Techniques:
  - Sensitive/high-res surveys (21cm, CO, thermal dust and FS-line emission in FIR/sub-mm)
  - High-resolution UV/X-ray abs/emission spectroscopy (for ISM composition, ionization, kinematics)
  - Polarimetry in FIR/sub-mm (dust, B-fields)

(Q3) Fossil Record of Galaxies from the First Stars to the Present

1. Understand the fossil record of the first stars

Technique: Large surveys of Local Group stars followed by optical spectra (large telescopes), concentrating on inner Milky Way halo and faint dwarf satellite galaxies



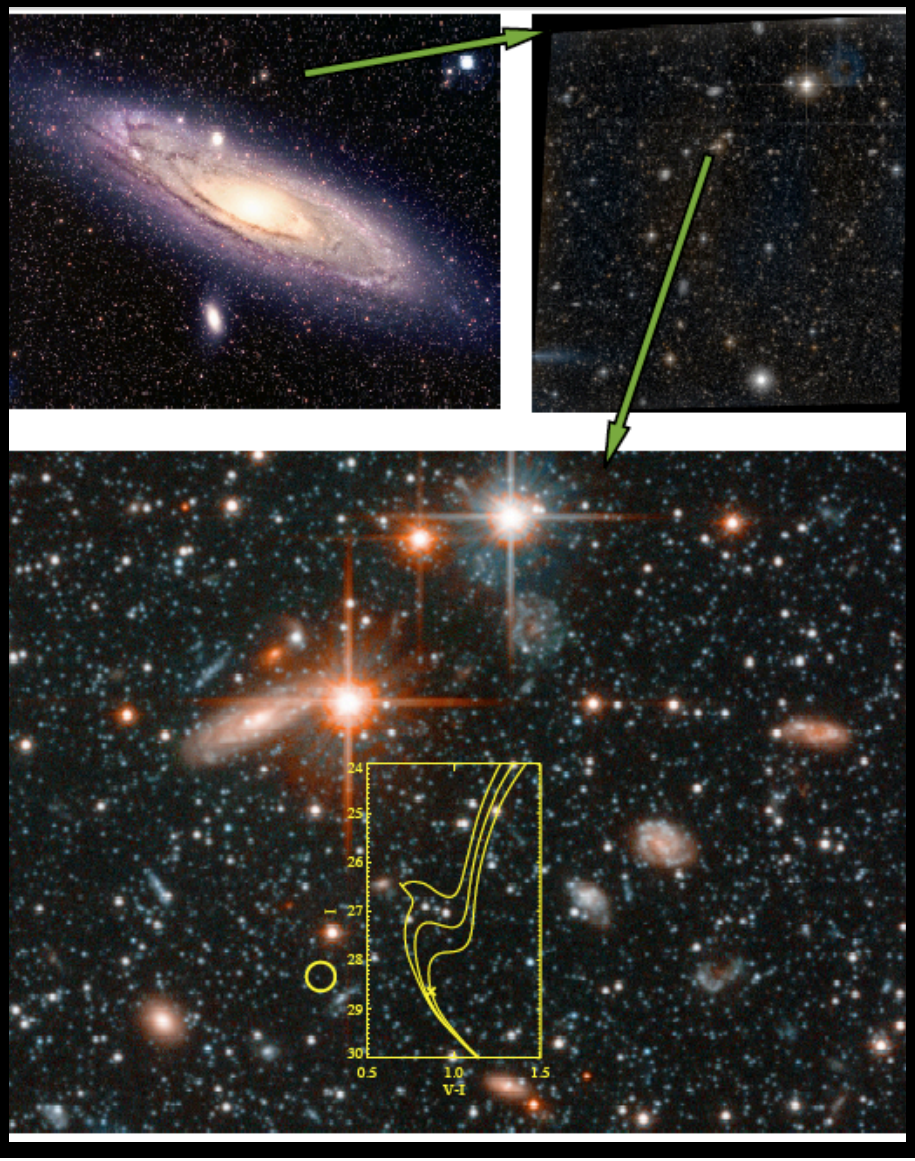
Abundance patterns in metal-poor halo stars represent the fossil record of first stars and processes of chemical enrichment (Iwamoto et al. 2005)

(Q3) Fossil Record of Galaxies from the First Stars to the Present

2. Measure the star-formation histories of galaxies across the Hubble sequence

Technique:

- color-magnitude diagrams (CMDs) derived from high spatial-resolution imaging surveys at optical wavelengths
- High spatial resolution near-IR imaging and spectroscopy of evolved stars and star-cluster systems



(Q4) Dark & Luminous Matter Connection

1. How do Baryons Populate Dark Matter Halos?
   - Measure dwarf satellites (mass function, angular momentum, halo shapes)
   - Techniques:
     - deep photometric surveys, spectroscopic follow-up with large telescopes;
     - 2D-kinematic surveys of nearby galaxies, stars in outer disk and halo populations
2. What is Distribution of Black Hole Mass/Spin?
   - Techniques:
     - stellar kinematics with high angular resolution (large telescopes, AO-systems)
     - VLBA monitoring of gas kinematics, perhaps in water-maser disks

Laboratory Astrophysics Needs: 1. Atoms, Ions, and Small Molecules

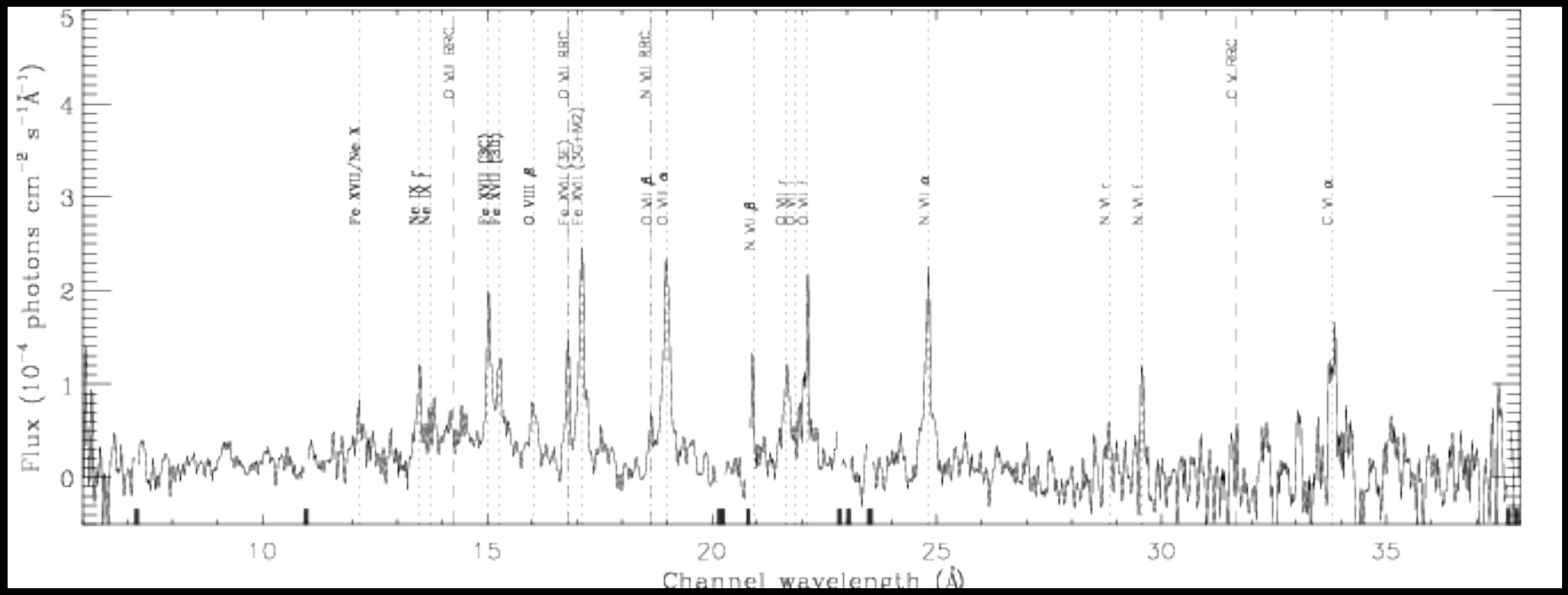
- Better data will be essential to the interpretation of observations from ALMA and future large optical/X-ray facilities with superb spectroscopic capabilities.
- Accurate wavelengths and oscillator strengths, photoionization and photodissociation cross sections, and rate coefficients for radiative recombination, dielectronic recombination, charge exchange, and collisional excitation.

Laboratory Astrophysics Needs: 1. Atoms, Ions, and Small Molecules

- Existing discrepancies in abundance measurements of HII regions (up to a factor of ~2) and PNe (~12) are believed to be due to uncertainties in oscillation strengths, such as CII] 2325Å, collisional excitation cross-sections, and/or recombination rates.
- We need benchmark experiments to measure cross sections for dielectronic recombination and electron-impact excitation and, in some cases, to identify L- and M-shell X-ray lines.
- Proton impact excitation cross sections are needed for ionized species in shocked gas where electrons have not been heated to the ion temperature.
- H_2 infrared emission is often strong, but some of the important rates for collisional excitation by H, H_2, He, and electrons are uncertain at the order-of-magnitude.

Charge Exchange Data

Charge exchange may be responsible for much of diffuse soft X-ray emission in both normal and starburst galaxies. But lab data seem to be rather incomplete and inconsistent.



XMM/Newton RGS spectrum of the M51 nuclear region with only a very weak AGN

Laboratory Astrophysics Needs:
2. Polycyclic Aromatic Hydrocarbons (PAHs)

- Need a database of absorption cross sections for PAH neutrals and ions
- Check if PAHs are responsible for some “diffuse interstellar bands" (DIBs) observed in ISM absorption.
- Understand the interactions with atoms, ions, grains, and radiation, as well as among the molecules.

Laboratory Astrophysics Needs: 3. Solids

- Understand their compositions and the interactions with atoms, ions, molecules, and radiation, as well as among the gains.
- Experimental work is needed using candidate grain materials to study molecule catalysis and grain growth in diffuse regions, ice formation, photodesorption, and UV photolysis.
- Interstellar grain materials may be identified from X-ray absorption.

Laboratory Astrophysics Needs: 4. Magnetic Field

- Magnetic field is clearly important in astrophysics, but is so far poorly understood.
- Laboratory experiments can contribute to our understanding of important astrophysical processes, particularly the magneto-rotational instability and magnetic reconnection.

Summary

- Questions:
  - What are the Flows of Matter & Energy in the Circumgalactic Medium (CGM)?
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  - What is the Fossil Record of Galaxy Assembly and Evolution from the First Stars to the Present?
  - What are the Connections between Dark and Luminous Matter?
- Discovery areas: Time-Domain Astronomy and Astrometry
- Accurate and well-organized lab astrophysics data will be essential to addressing these topics,