Airship Platform for Long-Wavelength Astrophysics

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BENEFITS OF HIGH ALTITUDE (≥ 60,000 ft) AIRSHIP PLATFORM FOR SUBMILLIMETER ASTRONOMY

REDUCED ATMOSPHERIC ABSORPTION
• Improved transmission in so-called airplane windows
• Access to frequencies that are largely opaque at aircraft altitudes
• Significant reduction in atmospheric noise
• Major reduction in system temperatures for heterodyne systems

INCREASED OBSERVING TIME
• Large-scale surveys are enabled

FLEXIBLE LOCATION
• Possible access to ALL of the Galactic Plane (and all of the sky!)

LINE OF SIGHT COMMUNICATION
• Data rate for balloons drifting around the Earth is a real problem: 60 kbps via TDRSS; also expensive
GUSSTO: Proposed ULDB Mission with 16-pixel Focal Plane Arrays for [NII],[CII], and [OI]; 1’ Angular Resolution; Observing 23 hr/day

Even with such arrays, LARGE-SCALE GALACTIC PLANE SURVEYS ARE VERY TIME-CONSUMING

**Galactic Plane Survey (GPS)** Survey -25° < l < 25° -1° < b < 1° extended to -2.2° < b < +2.2° for |l| < 2° [> 2 million Nyquist-sampled spectra; **39 days**]

**[CII]** Measure N(H)=10^{21} cm^{-2} in the Galaxy and 2x10^{21} cm^{-2} in the LMC, equiv. to a 3σ detectability of 1x10^{-5} erg/s/cm2/sr in the Galaxy and half this in LMC for δv = 4 km/s

**[NII]** Measure ionized gas emission measures of >50 pc cm^{-6}, corresponding to a 3σ detectability of 8x10^{-6} erg/s/cm2/sr for δv =8  km/s

**[OI]** Measure column densities in dense gas of N_H=2x10^{21} cm^{-2}, corresponding to a 3σ detectability of 1x10^{-4} erg/s/cm2/sr for δv = 4 km/s

**Large Magellanic Cloud Survey (LMCS)** Survey 7° x 7.5° region covering all of the LMC [> 700,000 Nyquist-sampled spectra; **27 days**]

**Targeted Deep Surveys (TDS)** Survey selected 1° x 1° regions of MW and LMC Measure [OI] at full spatial resolution and [^{13}CII] [5 x 14000 Nyq.-sampled spectra; **20 days**]
Key FIR Fine Structure Lines for Probing the Life Cycle of the ISM & Star Formation
Effect of Atmosphere on Individual Spectral Line Observability

$\text{OI } ^3\text{P}_0 - ^3\text{P}_1 \text{ Line}$

$f = 2060.068 \text{ GHz}$

$\Lambda = 145.53 \text{ \mu m}$

Not a major cooling line but a potentially valuable diagnostic of PDRs in conjunction with 63 \mu m $^3\text{P}_1 - ^3\text{P}_2$ line

Located on $\text{O}_3$ line! But may be possible to observe albeit with significant penalty

$\text{Milky Way}$

$\text{M51 (z = 0.00154) is observable}$
Effect of Atmosphere on Individual Spectral Line Observability

\textbf{O}I $^3\text{P}_0 - ^3\text{P}_1$ Line

$f = 2060.068$ GHz  
$\Lambda = 145.53$ $\mu$m

Not a major cooling line but a potentially valuable diagnostic of PDRs in conjunction with 63 $\mu$m $^3\text{P}_1 - ^3\text{P}_2$ line

Airship altitude is not going to help this much for Milky Way but required redshift to become observable is slightly reduced and redshift range is enlarged
Observability of [OI] 63 \( \mu \text{m} \) Line is Severely Limited by the Atmosphere

- This is second most important cooling line for ISM and its importance relative to [CII] is of great interest currently
- Observations of Milky Way are hampered by significant attenuation
- This plot is for \( ZA = 0 \) deg which is not typical (especially for SOFIA)
- The atmosphere gets much worse at even modestly redshifted velocities
- No observability at all up to several thousand km/s

Thanks to Steve Lord and ATRAN pgm
The Interstellar Medium is Complicated
CII is Critical Coolant & Tracer

Different Phases Often all Closely
Associated with Massive Star Formation

WHERE DOES C+ EMISSION ORIGINATE?
Need velocity-resolved spectroscopy
High Spectral Resolution Enables Observation of $[^{13}\text{CII}]$ and Correction for Saturation

Graf et al. (2012) using GREAT instrument on SOFIA
UV-irradiated neutral gas
Complex kinematics $\rightarrow$ line profiles.

[CII] 1900 GHz
Herschel HIFI 9 hr beam=11.6"

OT1 Goicoechea et al.
M51

CO J =1-0 4” Resolution (Koda et al. 2009)

Footprint of 16 element CII array
Atmospheric Transmission near [CII]

$h = 40,000 \text{ ft } \text{ pwv} = 8.4 \mu \text{ ZA} = 0^\circ$
Atmospheric Transmission near [CII]

\[ h = 60,000 \text{ ft} \quad \text{pwv} = 1.4 \mu \quad ZA = 0^\circ \]
HeH$^+$ @2010.187 GHz ($\lambda = 149.136$ µm)

- This molecular ion is primarily of cosmological interest – it could be one of the first molecules in the universe.
- Not yet convincingly detected in a Milky Way HII region, although attempts have been made (ISO).
- At SOFIA altitude an ozone line makes observations within the Milky Way very difficult if not impossible. M31, M33, M33 all doable.
HeH\(^+\) Lowest Rotational Transition at 2010.187 GHz 
\((\lambda = 149.136 \mu m)\)

- This molecular ion is primarily of cosmological interest – it could be one of the first molecules in the universe
- Not yet convincingly detected in a Milky Way HII region, although attempts have been made (ISO)
- Airship altitude offers only small advantage: transmission for modest red- and blueshifts is nearly unity
- Requires space for relatively unhindered access
A Notional FIR Airship Observatory

- 10m diameter CFRP antenna
  - Minimum wavelength = 60 µm
  - Smallest beam size = 1”
  - Pointing will be a challenge: need star tracker
  - Equip with large heterodyne focal plane arrays for high resolution spectroscopy AND/OR
  - Equip with continuum cameras AND/OR
  - Equip with polarimeter
- Could obviously be reduced size
- Need serious study of capability of Airship in terms of lifting capacity, stability, pointing, power available
Angular Resolution for 10m Diameter Submillimeter Telescope:

<table>
<thead>
<tr>
<th>Spectral Line Frequency</th>
<th>Wavelength (microns)</th>
<th>Angular Resolution (&quot;FWHM&quot;)</th>
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<tbody>
<tr>
<td>CI 492</td>
<td>609</td>
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<td>CI 809</td>
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<td>OII 4746</td>
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<tr>
<td>OIII 5790</td>
<td>52</td>
<td>1.3</td>
</tr>
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</table>

Angular Resolution Using 3m reflector

Off-Axis 1m CFRP Telescope (GUSSTO Balloon)

Star-Trackers
Long-Wavelength Astrophysics Benfiting from Airship Platform

• Spectral Line Surveys
  – Partially blocked lines observable and significantly higher sensitivity available

• Continuum Surveys
  – Less dramatic improvement since wavelength relatively flexible; high-Galactic latitude surveys

• CMB Observations
  – Large sky coverage at high (?) resolution

• Polarimetry
  – Time-consuming from ground and could be significantly improved from airship