Studying the evolutionary history and processes of star formation in our Galaxy and in galaxies at cosmological distances

Study the Polarized Emission From Galactic Dust to Probe the Role of Magnetic Fields on the Processes of Star Formation

Enzo Pascale, Cardiff
The Balloon-borne Large-Aperture Sub-millimeter Telescope ...

Cardiff University:
Peter Ade, Matt Griffin, Peter Hargrave, Phil Mauskopf, Enzo Pascale, Carole Tucker;

University of Toronto:
Peter Martin, Taylor Martin, Barth Netterfield, Marco Viero;

University of Pennsylvania:
Mark Devlin, Simon Dicker, Jeff Klein, Marie Rex, Christopher Semisch, Matthew Truch;

University of British Columbia:
Ed Chapin, Mark Halpern, Gaelen Marsden, Douglas Scott, Donald Wiebe;

Istituto Nazionale di Astrofisica, University of Puerto Rico:
Luca Olmi;

Laboratoire APC:
Guillaume Patanchon;

Brown University:
Gregory Tucker;

INAOE:
David Hughes;

University of Miami:
Joshua Gundersen, Nick Thomas

Jet Propulsion Laboratory:
Jamie Bock.
... And the Pol bit

Cardiff University:
Peter Ade, Peter Hargrave, Lorenzo Moncelsi, David Nutter, Enzo Pascale, Carole Tucker, Derek Ward-Thompson;

University College London:
Frederick Poidevin, Giorgio Savini;

Northwestern University:
Tristan Matthews, Giles Novak;

University of Toronto:
Steve Benton, Laura Fissel, Natalie Gandilo, Barth Netterfield, J. Shariff, Juan Soler;

University of Pennsylvania:
F. Elio Angile, Mark Devlin, Tyr Holmstrom, Jeff Klein, T. Mroczkowski, Matthew Truch;

University of British Columbia:
Ed Chapin, Douglas Scott, Donald Wiebe;

Istituto Nazionale di Astrofisica, University of Puerto Rico:
Luca Olmi;

Brown University:
Andrei Korotkov, Gregory Tucker;

University of Miami:
Joshua Gundersen, Nick Thomas

Jet Propulsion Laboratory:
Jamie Bock.
Blast: technology and scientific pathfinder for SPIRE

- Similar Focal Plane Technology
- Similar Science Motivation
BLAST: a Submillimetre Observatory

- Arrays of 270 bolometers 250 µm, 350 µm, 500 µm;
- 1.8 m Cassegrain Telescope (Gondola can accommodate 3-m class telescope);
- Diffraction limited beams 30”, 42” and 60” FWHM;
- Flown on a high altitude balloon platform;
Stages of Star Formation

1. A protostar assembles from a collapsing cloud fragment. It is concealed beneath a shroud of dusty gas.

2. Protostar shrinks and heats as gravitational potential energy is converted into thermal energy.

3. Surface temperature rises when radiation becomes the dominant mode of energy flow within the protostar.

4. The fusion rate increases until it balances the energy radiated from the star's surface.
- In our Galaxy, BLAST bands are sensitive to the earliest stages of star formation: dusty, cold pre-stellar cores, $T < 14K$;
- UV/Optical light of a new star is absorbed and dust warms to $T \sim 40K$. The emission spectrum of high redshift galaxies is sampled by BLAST constraining in this way their temperature and dust-mass.
BLAST
Conducted confusion-limited and shallower surveys
Leaving a legacy of 27 refereed papers (800 citations)
in the pre-Herschel era.

BLAST results confirmed and superseded by Herschel

However the true Blast legacy is in those individuals that made
BLAST possible
All these individuals in academic positions
or employed as highly skilled technicians
BLAST in a Nutshell

1.8m telescope and focusing system

Arrays of 270 detectors

Feed horns

Cardiff re-imaging optics and filters

Cryogenics
11 days hold time

Pointing System
11 Sensors
3'' reconstruction

Software
115,000 lines on 43 processors
High altitude balloon lifts BLAST above 99.5% of the atmosphere for 11 days

Engineering Advantages of Summer Antarctic Flights are
Long Duration in a temperature-stable environment
Solar power is available (no need to carry heavy batteries).
BLAST had two Science Flights

Sweden, June 2005
100 hours of data at 39 km

Antarctica, December 2006
250 hours of data at 39 km
The data were in the 1/2 square mile we expected. (135 miles x 20 feet.)
BLAST Galactic survey in the Vela constellation

- Blast wavebands sensitive to cold starless cores
- Evidence of non-thermal support in during the earliest stages of star-formation

Netterfield et al. 2009
Do B-fields strongly influence star formation?

-- In the diffuse ISM, B-fields are dynamically important
  (few $\mu$G $\sim$ 1 eV cm$^{-3}$)

-- *mechanical support by strong B-fields may explain*
  *the low overall efficiency of the star forming process*
  (e.g., Shu et al. ‘87; Mouschovias & Ciolek ‘99; Basu & Ciolek ’04)

-- *B-fields may solve the “angular momentum problem”*
  (e.g., Allen et al. ’03)

-- “…supersonic turbulent flows rather than static magnetic
  fields control star formation.” … Mac Low & Klessen 2004
  (see also, e.g., Hartmann et al. ‘01; Elmegreen & Scalo ’04)
lifetime (efficiency) problem
Star formation involves several order of magnitudes in angular and mass scales, and we can use submm-polarimetry to map the plane-of-the-sky projection of the B-fields.

These are 3-dimensional simulations of magnetohydro-dynamic (MHD) turbulence (Ostriker, Stone and Gammie 2001).

**Strong field, σ = 9deg**

**Weak field, σ = 45deg**
Aspherical dust grains tend to align $\perp$ to the magnetic field (e.g. Lazarian 2007)

- Linearly polarized dust emission allows us to map *magnetic field direction* projected on the sky

- Submm polarization is an effective observational technique allowing to cover all these scales, from cores, through filaments to GMCs.
From GMC to Core Scales

Planck: all-sky to arcmin

BLASTPol: from arcmin to arcsec

ALMA: arcsec

Girart et al. 2006
From BLAST to BLASTPol

BLAST was extremely sensitive to submillimeter emission on arcminute to degree scales. **Rebuilt from scratch into BLASTPol**

**BLASTPol** was created by adding polarimetric capability to BLAST.

**BLASTPol**’s first flight in December 2010 produced degree-scale submillimeter polarimetry maps of unprecedented sensitivity.

**BLASTPol**’s second flight in December 2012 improved the dataset obtained in 2010.

The polarimeter uses an achromatic half-wave plate and a polarizing grid placed in front the feed-horn apertures.
The 2010 (and first) BLASTPol Flight

Launched on December 27th 2010, from McMurdo Station Antarctica.
9.5 day flight at > 38km altitude ( < 0.5% residual atmosphere)

Terminated over the Ross Iceshelf.

Ok, this is normal, don't bother!
But, hey, anyone can do mediocre science with awesome beams. Only BLAST can do awesome science with screwy beam... Not convinced? Check next slide...
BLAST-2010
The Carina Nebula

**RED** pseudo vector: BLASTPol 500µm

**BLACK** pseudo vector: SPARO 450µm (from Lee et al. 2006)
Lupus I Observations from the 2010 Flight of the Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry

Tristan G. Matthews¹, Peter A. R. Ade², Francesco E. Anglès³, Steven J. Benton⁴, Edward L. Chapin⁵, Nicholas L. Chapman¹, Mark J. Devlin³, Laura M. Fissel⁴, Yasuo Fukui⁵, Natalie N. Gandilo⁴, Matthew Griffin², Joshua O. Gundersen⁷, Mark Halpern⁵, Peter C. Hargrave², David H. Hughes⁸, Jeffrey Klein³, Andrei L. Korotkov⁹, GaeLEN Marsden⁵, Philip Mauskopf², Lorenzo Moncelsi¹⁰, Tony K. Mroczkowski¹⁰, Calvin B. Netterfield⁴, Giles Novak¹, David Nutter², Luca Olmi¹¹,¹², Enzo Pascale², Frédéric Poidevin¹³, Giorgio Savini¹³, Douglas Scott⁵, Jamil A. Shariff¹, Juan Diego Soler⁴, Kengo Tachihara⁶, Nicholas E. Thomas⁷, Matthew D. P. Truch³, Carole E. Tucker², Gregory S. Tucker⁹, Derek Ward-Thompson¹⁴, Donald V. Wiebe⁵

BLASTPol 2010: COMPARISON OF MAGNETIC FIELDS AND CORES/CLOUD STRUCTURE ORIENTATIONS IN THE LUPUS I REGION

Frédéric POIDEVIN

UCL, KLB, Department of Physics & Astronomy, Gower Place, London WC1E 6BT, United Kingdom.

Poidevin@star.ucl.ac.uk

Peter A.R. ADE

Cardiff University, School of Physics and Astronomy, Queens Buildings, The Parade, Cardiff, CF24 3AA, U.K.
The 2012 (second) BLASTPol Flight

Launched on December 26th 2012, from McMurdo Station Antarctica.
16 day flight at > 38km altitude
The Carina Nebula

**Red** pseudo vector: BLASTPol 500\(\mu\)m

**Black** pseudo vector: SPARO 450\(\mu\)m (from Lee et al. 2006)
Carina Nebula
(3 hours integration): Almost two orders of magnitude more vectors than pre-BLAST
Vela C “The Axehead”

A 1.4 deg$^2$ map of the nearby VelaC molecular cloud (700 pc) at 250 (blue), 350 (green) and 500 $\mu$m (red), plotted over a Herschel SPIRE 350 $\mu$m intensity map (Hill et al., 2011).

THOUSANDS of vectors
Key questions for BLASTPol 2010 and 2012:

1. Are the apparent elongations of cores preferentially perpendicular to the ambient cloud magnetic field in the vicinity of the core? (e.g., Ward-Thompson et al. 2000, 2009)

2. Are bipolar outflows preferentially parallel to cloud core B-fields?

3. What can we learn about grain alignment by studying the polarization spectrum and how it varies from cloud to cloud and within a cloud? (e.g., Vaillancourt and Matthews 2012)

4. Do the mean magnetic field directions of clouds correlate with elongated cloud structure (filament-like), orientation of Galactic plane, cloud rotation axis, or orientation of B-field in surrounding diffuse ISM?
Key questions for BLASTPol 2010 and 2012 (continued):

4. How can we best constrain the characteristic magnetic field strength by observing the overall degree of order in cloud B-fields and comparing with simulations that employ different field strengths? (e.g., Novak et al. 2009)

5. What can we learn about CMB foreground subtraction by studying the faintest and most diffuse emission for which BLAST-pol polarimetry is feasible? (e.g., Jackson, Werner, and Gautier 2003)
The Future: BLASPol

Enzo Pascale SCAR AAA, Siena July 2013
The Science with : .BLASPol

• Measure magnetic field morphology in hundreds of clouds
• Account for magnetic field projection effects
• Better statistical comparison with numerical simulations
• Large area total power maps
• Observe anything useful that wasn’t mapped by Herschel SPIRE

25% of observing time open to astronomical community
Now Something Different...
Improving FIR Angular Resolution

Need for high angular resolution in the FIR to investigate key science questions of star formation and galaxy evolution.

Success of Spitzer and Herschel, and expectations for ALMA and JWST, stress the need for observations in the FIR.

Poor FIR angular resolution is now the largest limit in the study of star and planetary formation.

Blain et al. 2002, Helmich and Ivison 2009
Angular Resolution [arcsec.]

Wavelength [μm]

FIR gap
Merge together Two techniques

(Funded FP7 to develop Technology/understanding)

Furier Transform Spectrometer

Interferometer

FIR Spectral/Spatial Interferometer

See Grainger et al. 2012

See Matsuo 2010 for a proposed Antarctic interferometer, something we are also investigating as part of the FP7 Work
WWW.FIRI.EU

Three possible mission concepts

FIRIT

Supporting documents/links:

ESPRIT

Supporting documents/links:

TALC

Supporting documents/links:
Watch the movie: http://blastthemovie.com/

THE END