Galactic Dust Map

Cheng Du (杜珵)
Tutor: Shude Mao (毛淑德)

Schlegel, Finkbeiner & Davis, 1998, ApJ (dust maps)

Burstein & Heiles, 1982, AJ (older dust maps)
Su, Slatyer & Finkbeiner, 2010, ApJ (Fermi bubble)
Planck collaboration, 2014, A&A

THCA 2017/11/03
Student Seminar @ S727

Outline

- Importance of Galactic Dust Map
- Schlegel, Finkbeiner & Davis (SFD) dust map (1998)
- Galactic Reddening (SFD dust map)
- Other progress
- Application: Fermi bubble
- Summary

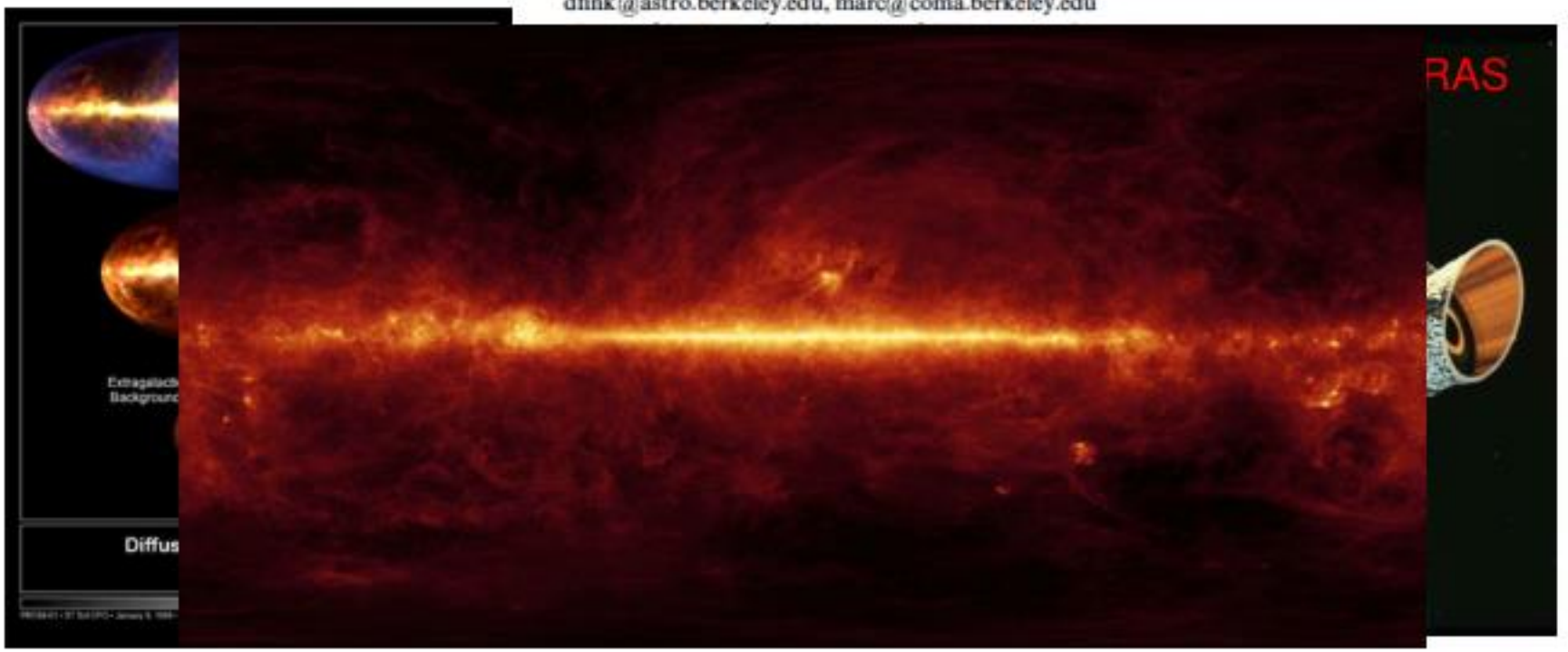
Galactic dust extinction maps

THE ASTROPHYSICAL JOURNAL, 500:525–553, 1998 June 20

(2017.11.2) **10379 citations**
9639 refereed

MAPS OF DUST INFRARED EMISSION FOR USE IN ESTIMATION OF REDDENING AND COSMIC MICROWAVE BACKGROUND RADIATION FOREGROUNDS

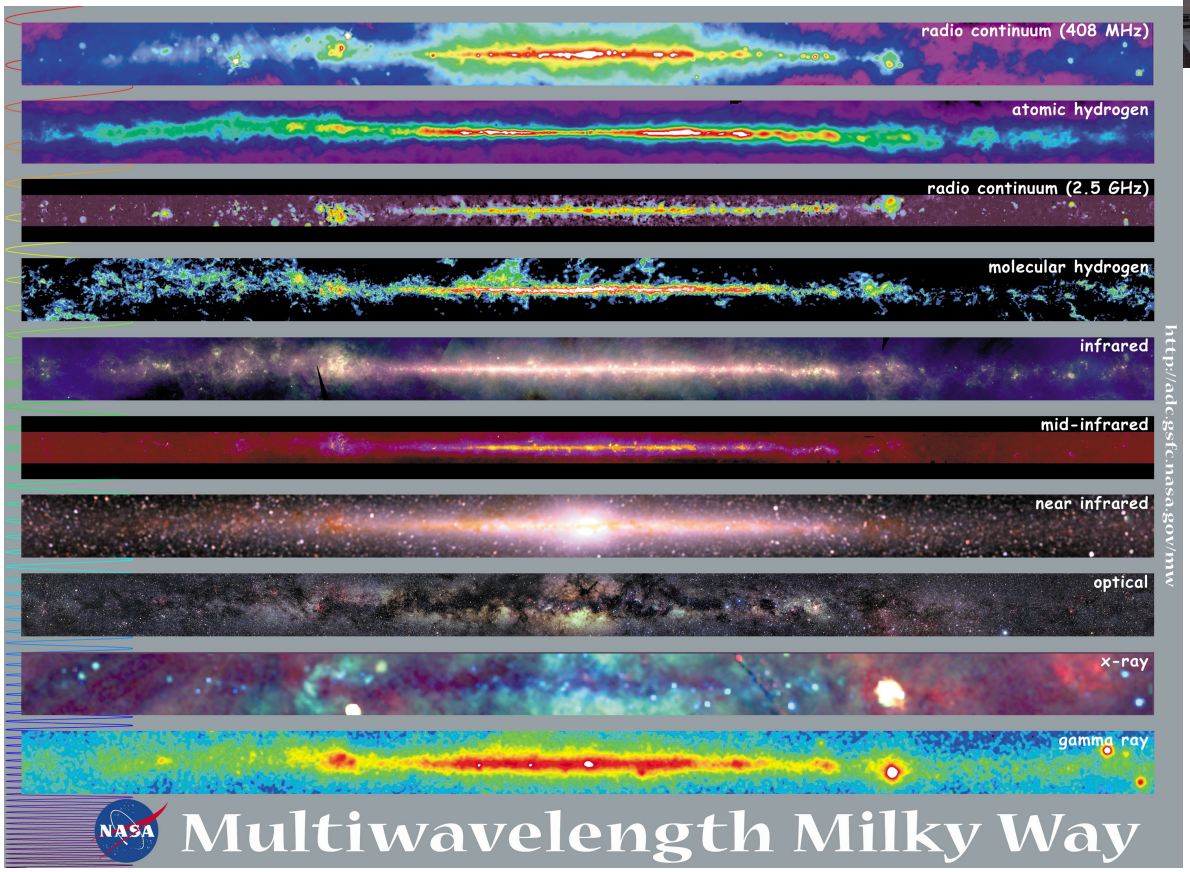
DAVID J. SCHLEGEL
University of Durham, Department of Physics, South Road, Durham DH1 3LE, UK; D.J.Schlegel@durham.ac.uk
AND
DOUGLAS P. FINKBEINER AND MARC DAVIS
University of California at Berkeley, Departments of Physics and Astronomy, 601 Campbell Hall, Berkeley, CA 94720;
dfink@astro.berkeley.edu, marc@coma.berkeley.edu



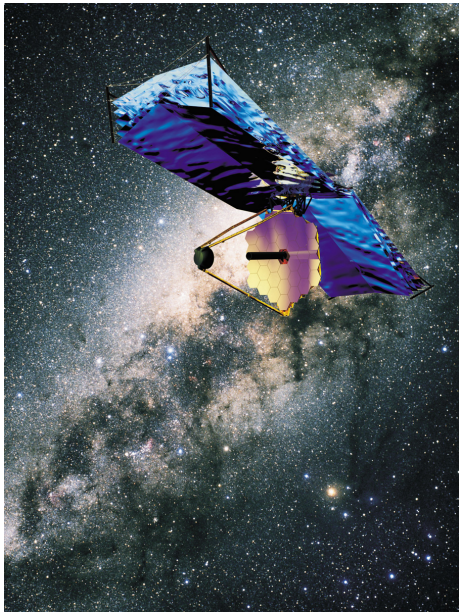
Importance

We can’t get rid of it!

Credit:M. Claro/ESO (VLT)



JWST(artist's impression)



Credit:
ESA

Importance

- ✓ Great tracer of the interstellar medium (ISM) and star formation activity

- ✓ For extragalactic objects :
  extinction and reddening for UV - NIR observations
  contaminating emission in the IR-MM wavelengths

- ✓ One of the major foregrounds hampering the study of the cosmic microwave background (CMB).

BH dust map (Burstein & Heiles 1978 & 1982)

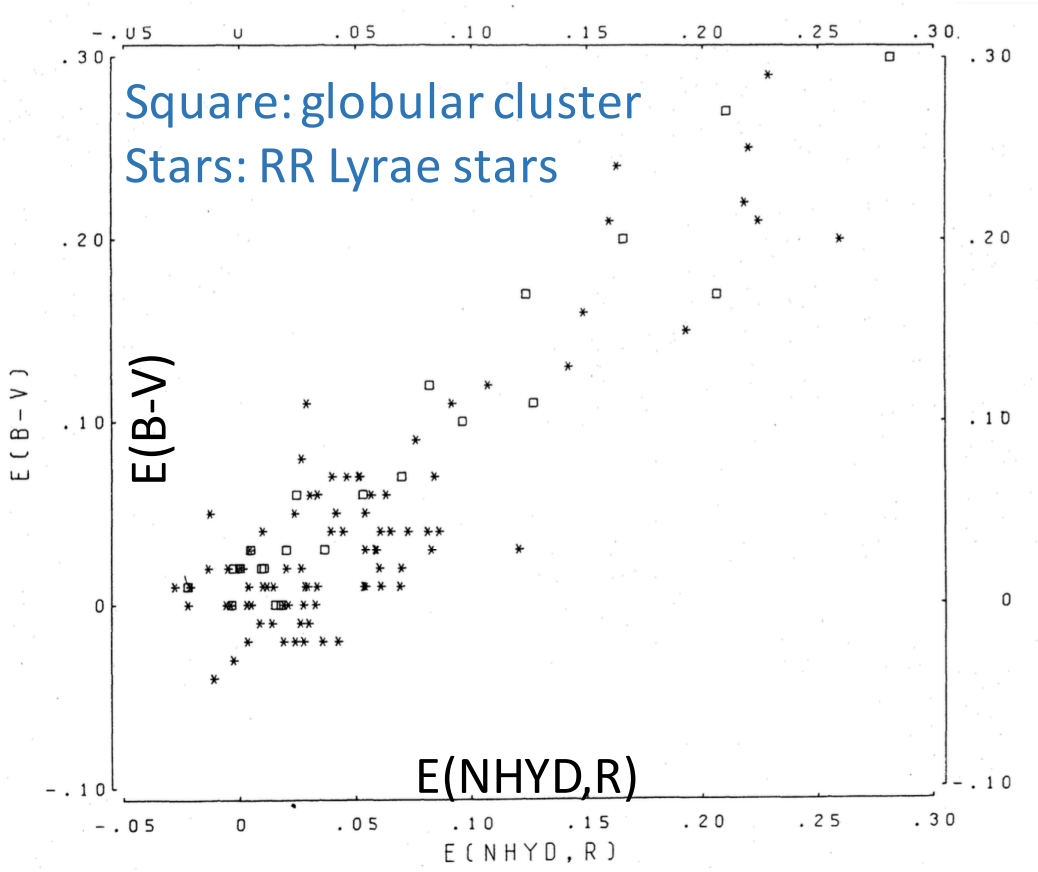


FIGURE 4 E(B–V) versus predicted value of E from Eq. (1) for galactic objects having log $NGAL$ >0.400. Contrary to the other figures, squares denote globular clusters, and stars denote RR Lyrae stars.

Predict line-of sight reddening

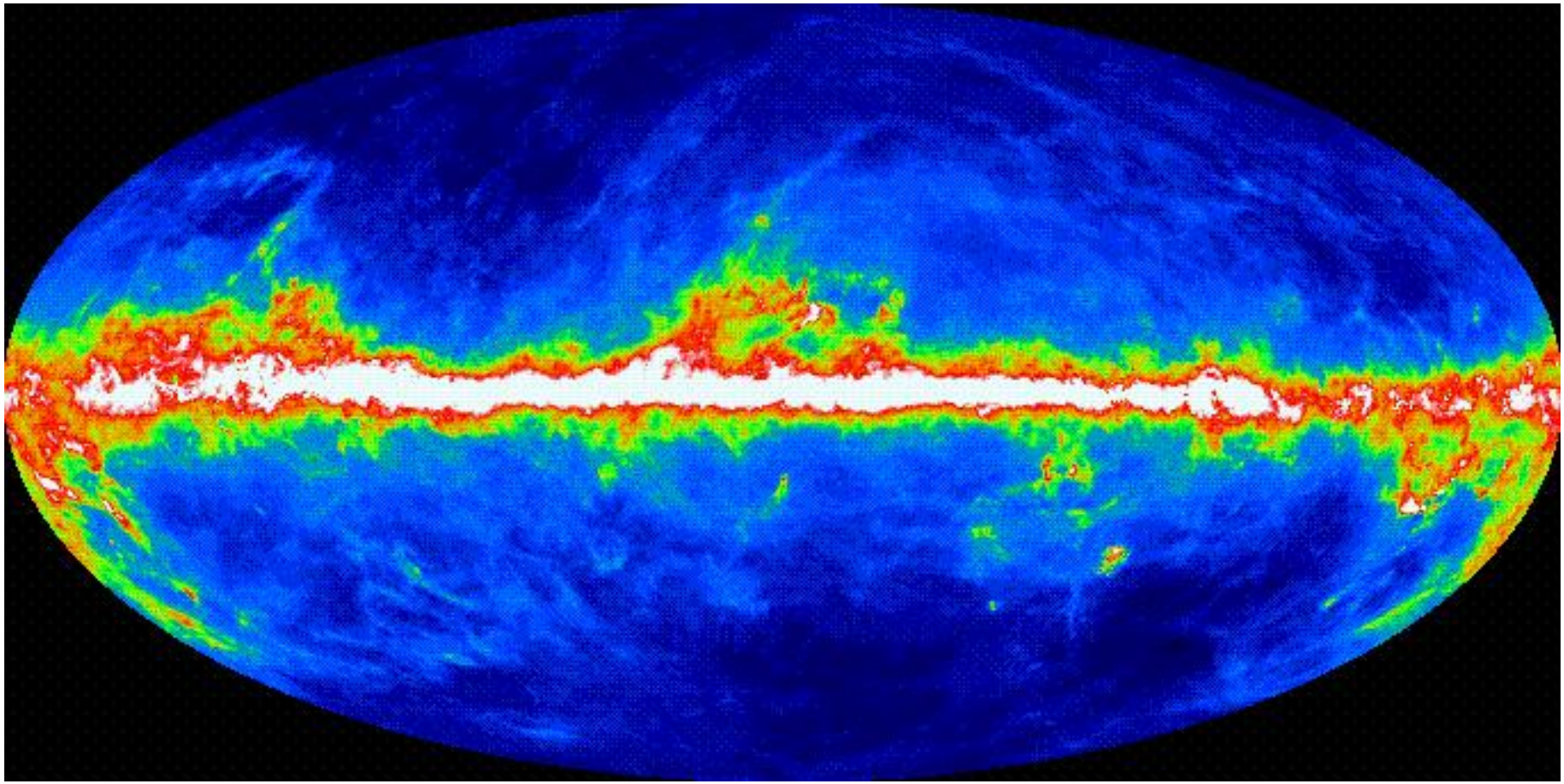
Method:
HI/galaxy counts (HI/GC)
0.1mag in E(B-V) or 10%

Related to gas to dust ratio

$$E(B-V) = -0.037 + 0.357 * 10^{-3} (1-0.097R) NHYD$$

HI column density

SFD dust map : full sky 100μm map
(composite of the COBE/DIRBE and IRAS/ISSA maps)



Schlegel, Finkbeiner & Davis (1998)

SFD dust map :Major steps

Annual average DIRBE maps (solar elongation e < 80◦)

Annual-average 25 and 100 μm skymaps from the 41 weekly maps

zodiacal light removal (DIRBE 25μm map)

25μm channel dominated by the IPD (inter-planetary dust)

- ✓ Assume IPD is at a constant temperature.
- ✓ Model zodiacal comtaination at longer wavelengths

Combine IRAS and DIRBE 100μm maps

Remove striping artifacts in IRAS/ISSA 100μm maps

Remove asteroids and non-Gaussian noise removed

Removed stars and galaxies

Lists of Galaxies detected by the IRAS satellite readily available from the literature.

Limiting flux : f_{60} = 0.6 Jy at |b| > 5◦

Dust map

SFD dust map :Major steps

Annual average DIRBE maps
(solar elongation e < 80◦)

SFD dust map :Major steps

Annual average DIRBE maps (solar elongation e < 80◦)

Annual-average 25 and 100 μm skymaps from the 41 weekly maps 512 pixels from b(galactic latitude) = 0◦ to b = 90◦ (0.0250 square degrees/pixel)

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IPD (inter-planetary dust): zodiacal emission from dust in the solar system

25µm channel dominated by the IPD

- ✓ Fitting blackbody functions from 12 to 60 um
- ✓ Color temperature does not vary by more than 10% from ecliptic equator to the poles
- ✓ Assume IPD is at a constant temperature.
- ✓ Model zodiacal contamination at longer wavelengths

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Combine IRAS and DIRBE 100μm maps

Striping artifacts in the IRAS/ISSA 100μm maps removed (a Fourier-space filtering algorithm)

Asteroids and non-Gaussian noise removed from the IRAS/ISSA (a deglitching algorithm that compared multiple scans)

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Remove asteroids and non-Gaussian noise removed

Remove stars and galaxies

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Dust map

Galactic Reddening (SFD map)

- Assume a standard reddening law :

$$R_V \equiv A(V)/E(B-V) \approx 3.1$$

- Use the colors of elliptical galaxies to measure the reddening per unit flux density of 100μm emission.

$$E(B-V) = p\ \mathbf{D}^T = p\ \mathbf{I}_{corr}\mathbf{X}$$

corrected IRAS 100μm flux

T0=18.2K

calibration coefficient	Dust column density	temperature-correction map

- ✓ (B–R) color distribution of 106 brightest cluster ellipticals
- ✓ (B–V) & Mg line-strength measurements of 384 ellipticals

The normalization of the dust column density to reddening has a formal uncertainty of 10%.

Using the Maps to Measure Galactic Reddening

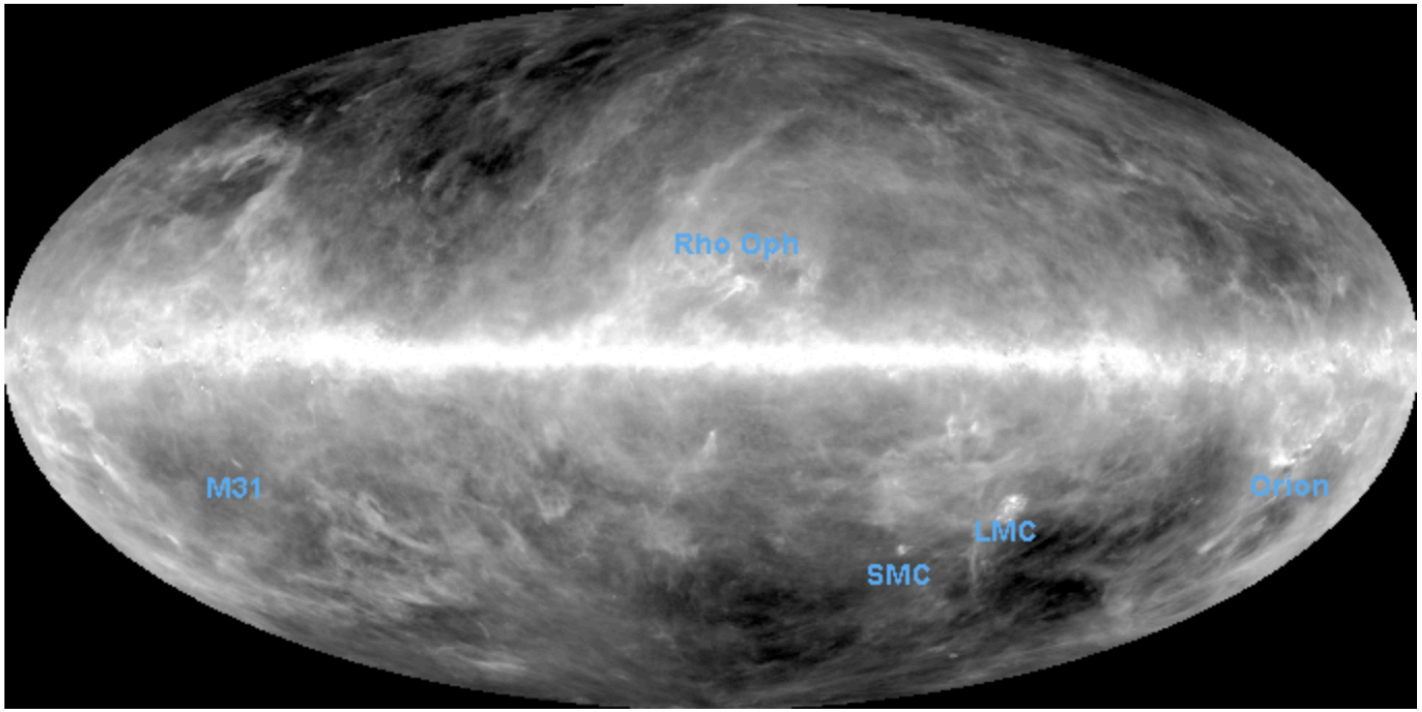
http://irsa.ipac.caltech.edu/applications/DUST/

http://w.astro.berkeley.edu/~marc/dust/

NASA/IPAC INFRARED SCIENCE ARCHIVE

IRSA | DATA SETS | SEARCH | TOOLS | HELP

Galactic Dust Reddening and Extinction

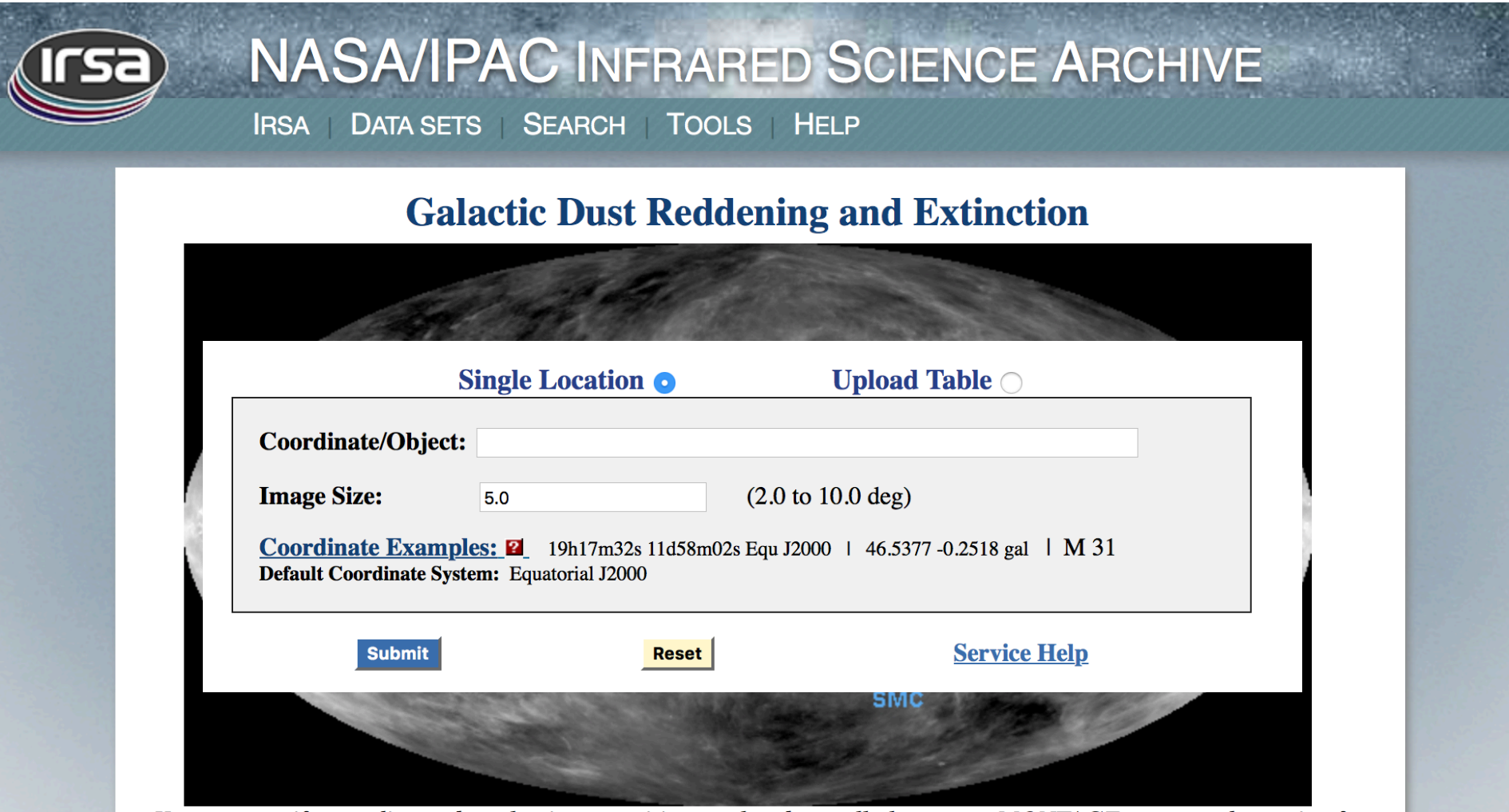


You can specify coordinates by selecting a position on the above all-sky map, a MONTAGE-generated mosaic of the individual IRAS 100 micron images created by Schlegel et al.

Using the Maps to Measure Galactic Reddening

http://irsa.ipac.caltech.edu/applications/DUST/

http://w.astro.berkeley.edu/~marc/dust/



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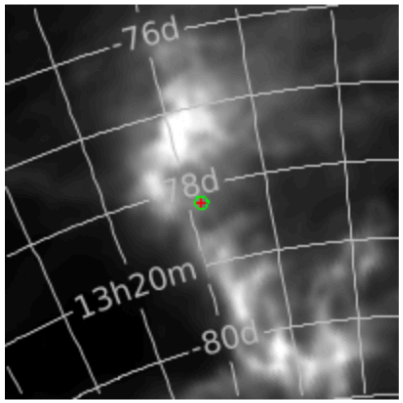
194.207345 -78.208587 eq J2000	194.20735 -78.20859 equ J2000



Larger view

E(B-V) Reddening (mag)

	S & F (2011)	SFD (1998)
Reference Pixel(red '+')	0.6500	0.7558
Max	0.6643	0.7724
Min	0.5416	0.6297
Mean	0.6178 +/- 0.0361	0.7184 +/- 0.0420

Extinction by Bandpass

$E(B\text{-}V)_{S\ \&\ F} = 0.86 \times E(B\text{-}V)_{SFD}$

S & F = Schlafly & Finkbeiner 2011 (ApJ 737, 103)
SFD = Schlegel et al. 1998 (ApJ 500, 525)

Assuming a visual extinction to reddening ratio Av / E(B-V) = 3.1, then:

$Av_{S\ \&\ F} = 2.0149$ (mag)
$Av_{SFD} = 2.3429$ (mag)

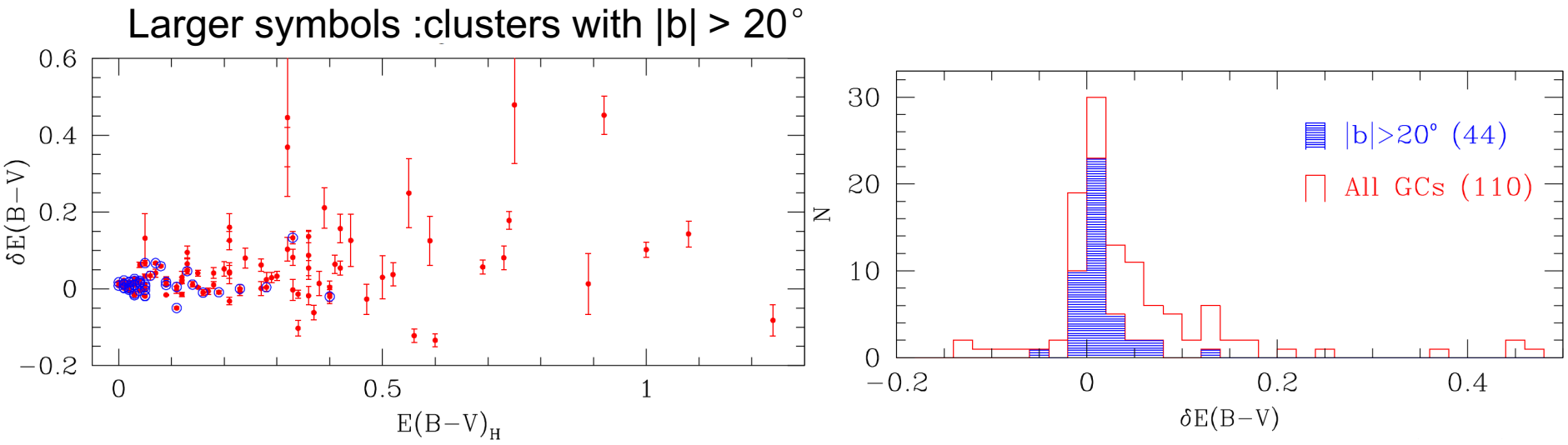
E(B-V) values in image are those of SFD.

Download cutout

You

the individual IRAS 100 micron images created by Schlegel et al.

Other progress



$$\delta E(B-V) = E(B-V)_{SFD} - E(B-V)_{H}$$

K. Z. Stanek (CfA)1998 :

TEST SFD reddening map (110 |b|>5° Galactic globular clusters)

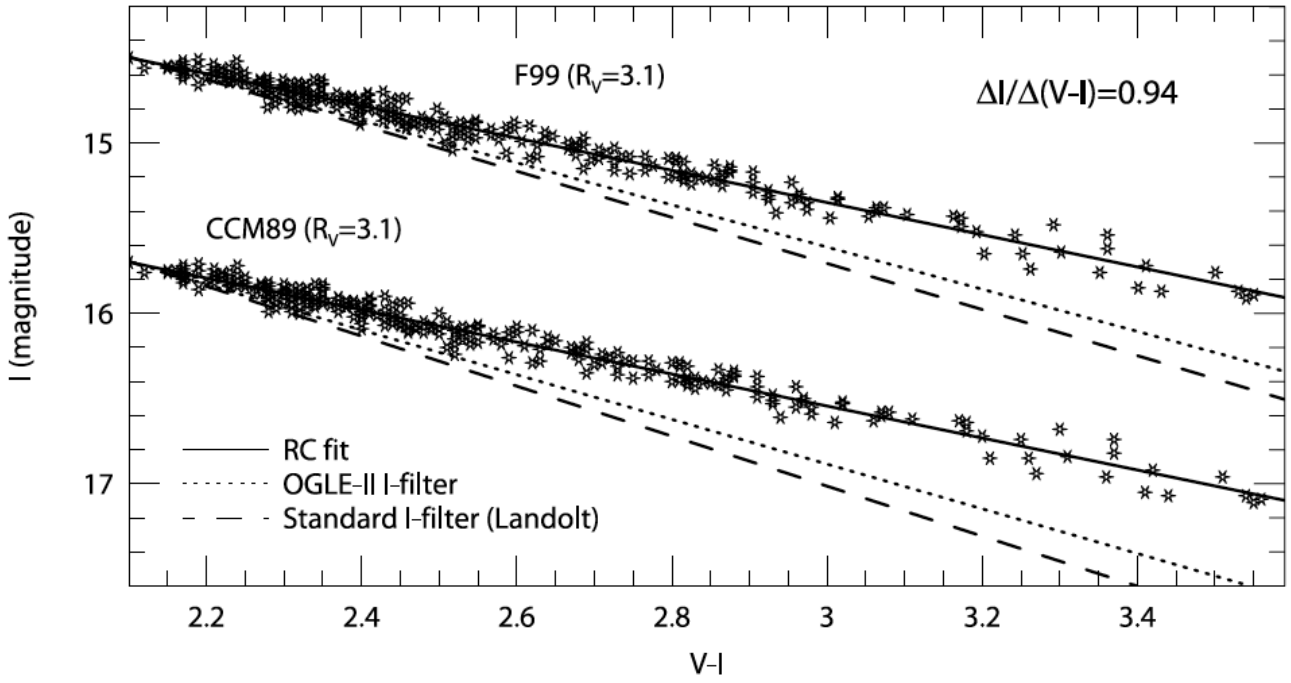
- Good agreement -- |b|>20 °
- Fair overall agreement -- 20 ° >|b|>5° (Several significant deviations)
- Overestimates the reddening in some large extinction regions

Other progress

Udalski, A. 2003:

Trace interstellar extinction

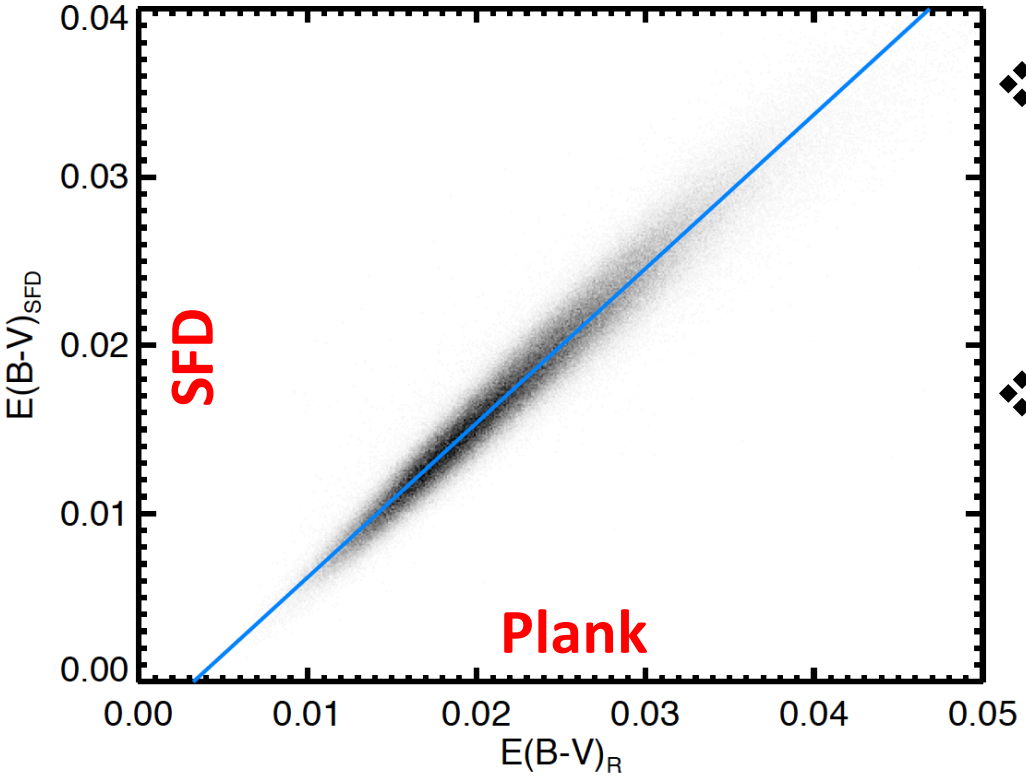
- M_I and V-I color (red clump stars of 4 small regions of the Galactic bulge)
- RVI (ratio of the total to selective absorption) much smaller toward the Galactic bulge than 3.1 (standard extinction curve)



Other progress

Planck Collaboration 2014

Like Schlegel et al. (1998)

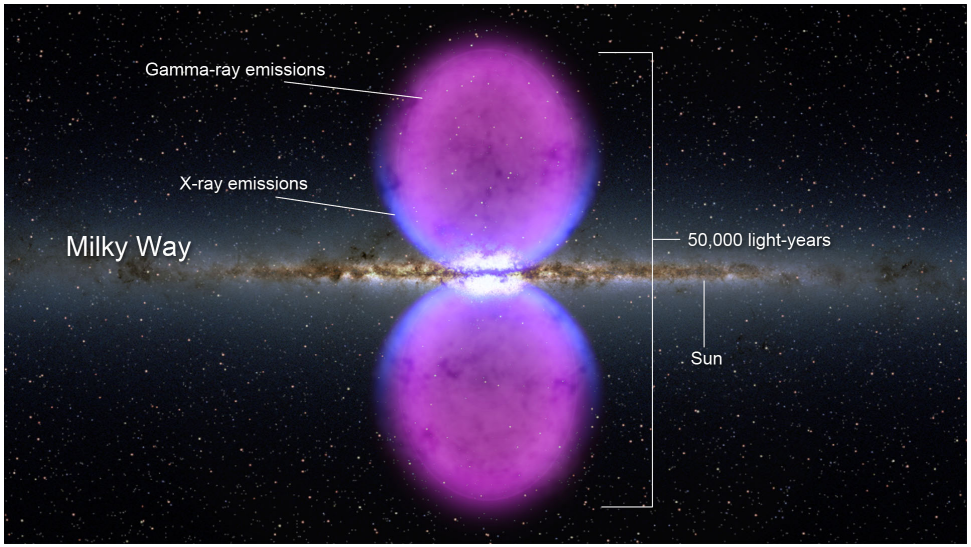


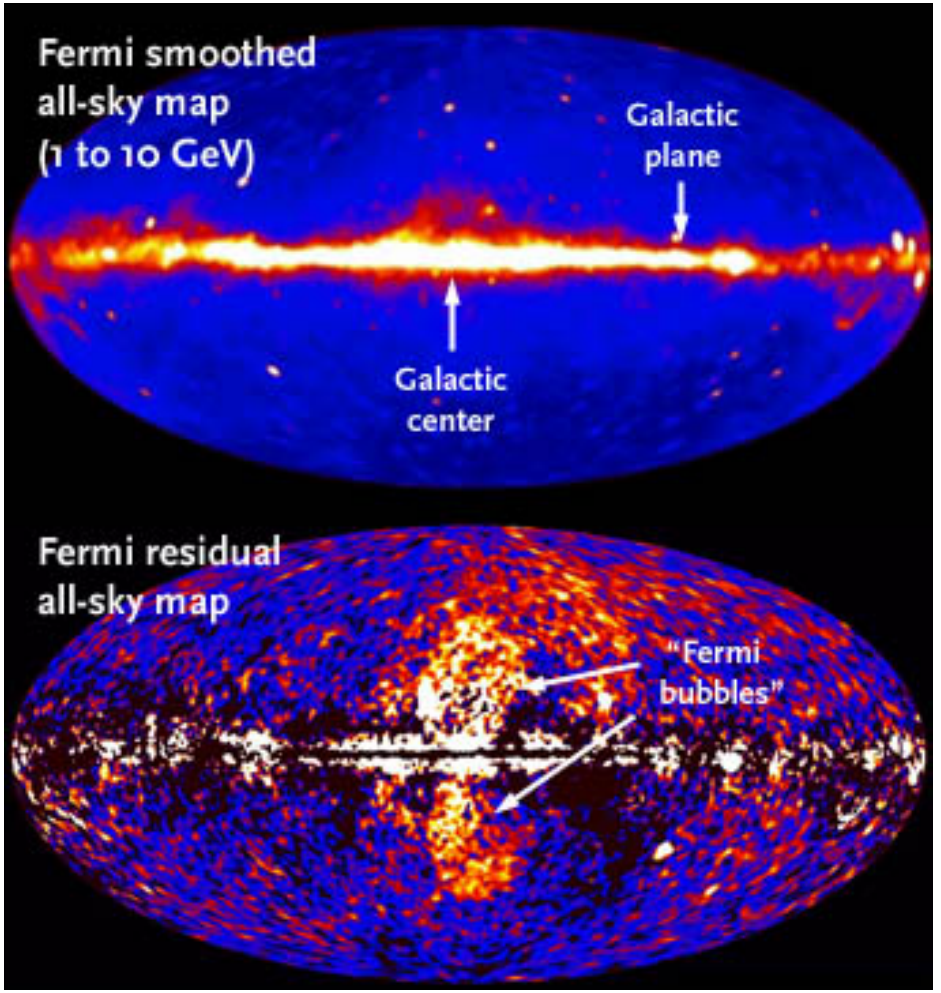
- Based on the thermal dust radiance, instead of the dust optical depth
- Calibrated to E(B-V) using colour excess measurements of quasars deduced from SDSS data.

$$E(B\text{-}V)SFD = 0.92\ E(B - V)xgal - 0.003$$

Application : Fermi bubble

The Fermi bubbles are two large structures in gamma-rays above and below the Galactic center.





At low (~ 1 GeV) energies, and close to the Galactic plane, the gamma-rays observed by Fermi are dominated by photons from the decay of π^0 particles

Use the SFD dust map as a template of the π^0 gamma foreground.

Although not apparent in an all-sky gamma-ray map *(upper panel),* the dumbbell-shaped feature became evident after removing other sources *(lower panel)*.

Summary

- Galactic Dust Map is very important to almost every astronomers.
- People has constructed a full-sky map of the Galactic dust based upon its far-infrared emission.
- This dust map is normalized to E(B–V) reddening using the colors of background galaxies.
- The final maps have a high spatial resolution, and are shown to predict reddening with an accuracy of ~10%.
- There also exist some problems in Galactic center and some large extinction regions.

Estimating E(B - V) from colour excess measurements

Multi-colour SDSS measurements of quasars

$$\begin{aligned} E(X-Y) &= A_X - A_Y \\ &= (m_X - m_{X0}) - (m_Y - m_{Y0}) \end{aligned}$$

Use the Hi column density provided in the SDSS quasar catalogue as a proxy:

$$(m_X - m_Y) = \psi\, N_{\mathrm{H\,I}} + (m_{X0} - m_{Y0})$$

Temperature-correction factor: X

$$\mathbf{X}(\alpha, T) = \frac{B(T_0)\mathbf{K}_{100}(\alpha, T_0)}{B(T)\mathbf{K}_{100}(\alpha, T)}$$

B(T) is the Planck function

DIRBE 100μm/240μm ratio

$$\mathbf{R}(\alpha, T) = \frac{\mathbf{D}_{100}}{\mathbf{D}_{240}} = \frac{K_{100}(\alpha, T) I_{100}(T)}{K_{240}(\alpha, T) I_{240}(T)}.$$

$$\log_{10}\mathbf{X} = -0.28806 - 1.85050\ (\log_{10}\mathbf{R}) - 0.02155\ (\log_{10}\mathbf{R})^2.$$

emissivity model : $\epsilon_\nu = \nu^\alpha$

$$K_b(\alpha, T) = \int d\nu B_\nu(T) \nu^\alpha W_b(\nu)$$

$$K(\alpha, T) = \frac{\sum_i a_i \tau^i}{\sum_j b_j \tau^j}; \qquad \tau \equiv \log_{10} T.$$

I_b is the actual intensity at the frequency b

Table 4. Coefficients for $K_b(\alpha, T)$

Coeff	$b = 100\mu$m	$b = 240\mu$m
a_0	1.00000	1.00000
a_1	2.18053	−1.55737
a_2	−4.89849	0.74782
a_3	2.38060	
b_0	−0.80409	0.89257
b_1	3.95436	−1.29864
b_2	−4.27972	0.61082
b_3	1.70919	

BH dust map (1982) Hi 21cm line emssion

- The intrinsic colors of stars as determined by intermediate-band photometric systems, chiefly the uvbyß system
- The intrinsic relationship between absorption line strength and color for the integrated spectra of old extragalactic stellar populations.
- We conclude that a reasonable estimate of the relative accuracy of the Hi/GC method is 0.01maginE(B—V) or 10% of the reddening