# Multi-pollutant Health Effects: Exposure Assessment Challenges

Petros Koutrakis
Harvard School of Public Health

# We are Exposed to a Myriad of Species

- Particles:
  - Size fractions (fine, coarse, ultrafine, other)
  - Components (major classes or beyond the speciation network?)
  - Other characteristics (oxidative potential, shape)
- Gases:
  - Criteria gases ($O_3$, $SO_2$, $NO_2$, CO, NMHC)
  - Non-criteria (gaseous HAPs, urban air toxics)

# Key Question

How can we assess the health effects of multi-pollutant exposures?

# Biological Response

Let us assume that the exposures to PM and a Gas, $E_{pm}$ and $E_{gas}$, are not correlated

Exposure errors, $error_{pm}$ and $error_{gas}$, are similar

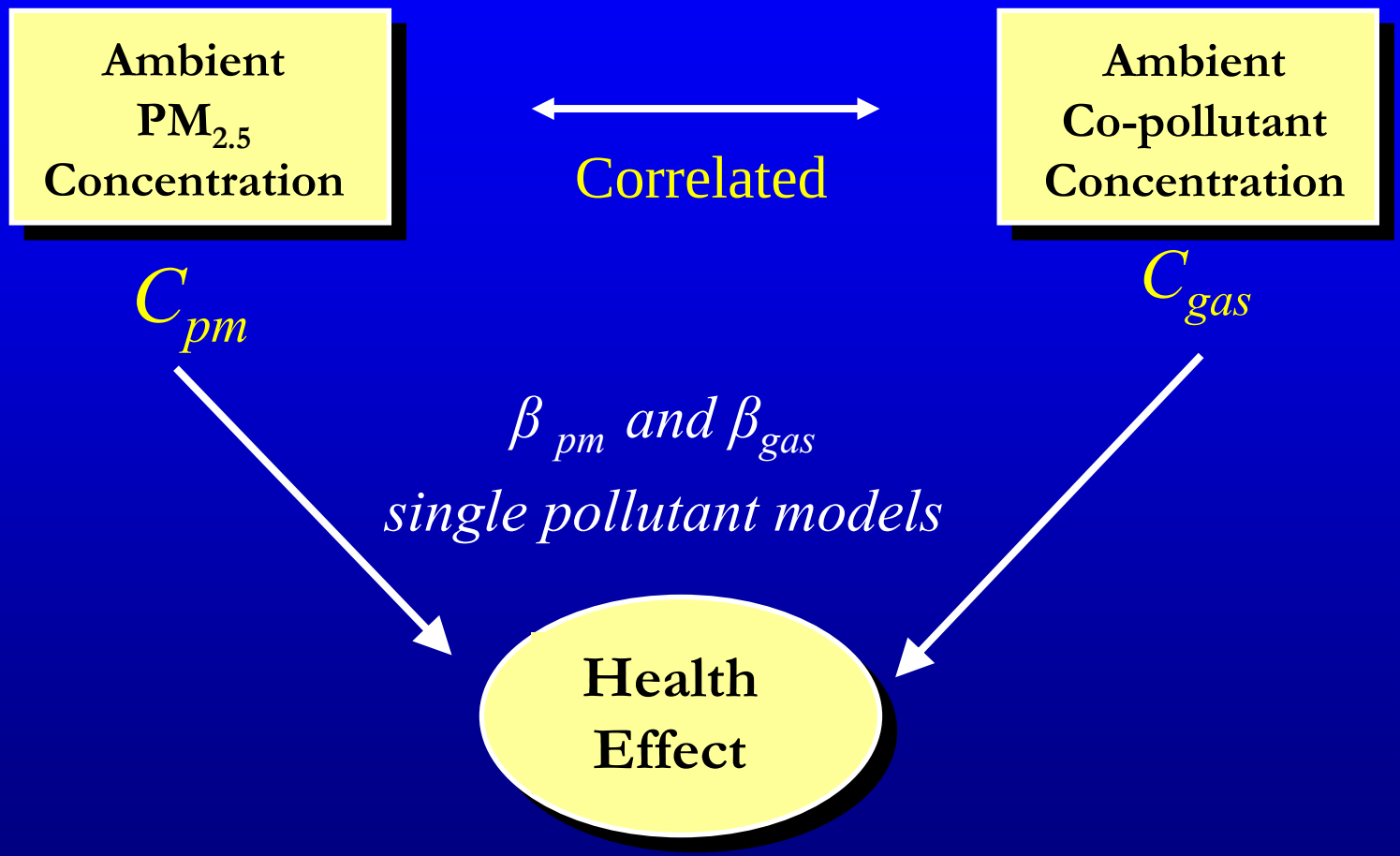
Then the health effect caused by these exposures is:

$$Effect = I + \beta_{pm} * E_{pm} + \beta_{gas} * E_{gas}$$

Or we can include an interaction term:

$$Effect = I + \beta_{pm} * E_{pm} + \beta_{gas} * E_{gas} + \beta_{pm\,gas} * E_{pm} * E_{gas}$$

# Multi-pollutant Models: Colinearities



# Co-linearity

- The co-linearity issue poses a great challenge to biostatisticians
- Concentration relationships vary by space, time and pollutant thus
  - Study designs should seek to minimize correlations (cross sectional designs, seasonal studies, varying exposure windows etc.)

# Correlations among ambient concentrations

## Spearman's correlation coefficient

| | $PM_{2.5}$ | $O_3$ | $NO_2$ | $SO_2$ | CO |
|---|---|---|---|---|---|
| $PM_{2.5}$ | | 0.67* | 0.37* | -- | 0.15 |
| $O_3$ | -0.72* | | 0.02 | -- | -0.06 |
| $NO_2$ | 0.75* | -0.71* | | -- | 0.75* |
| $SO_2$ | -0.17 | 0.41* | -0.17 | | -- |
| CO | 0.69* | -0.67* | 0.76* | -0.12 | |

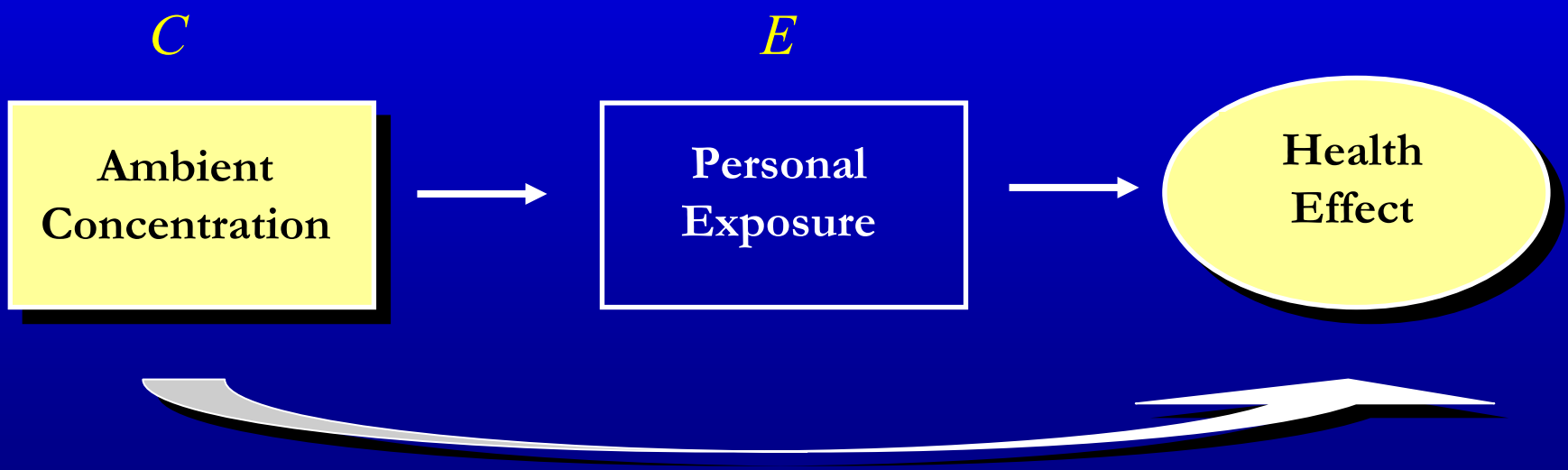
Summer

Winter

* denotes significance at $\alpha = 0.05$

# Exposure Assessment Challenges

Most studies use ambient concentrations, C, rather than exposures, E, which introduces uncertainties that should be considered




*exposure error (E-C) depends on*

*spatial variability, attenuation factor variability, non-ambient exposures*

# Spatial Variability

- Spatial patterns vary by pollutant (Ito et al. 2004)
- Health effects estimates increase when accounting for spatial variability (Jarrett et al. 2005)
- Multi-pollutant models not considering spatial variability underestimate the effects of those pollutants exhibiting more pronounced spatial patterns (e.g. sulfate versus ozone)

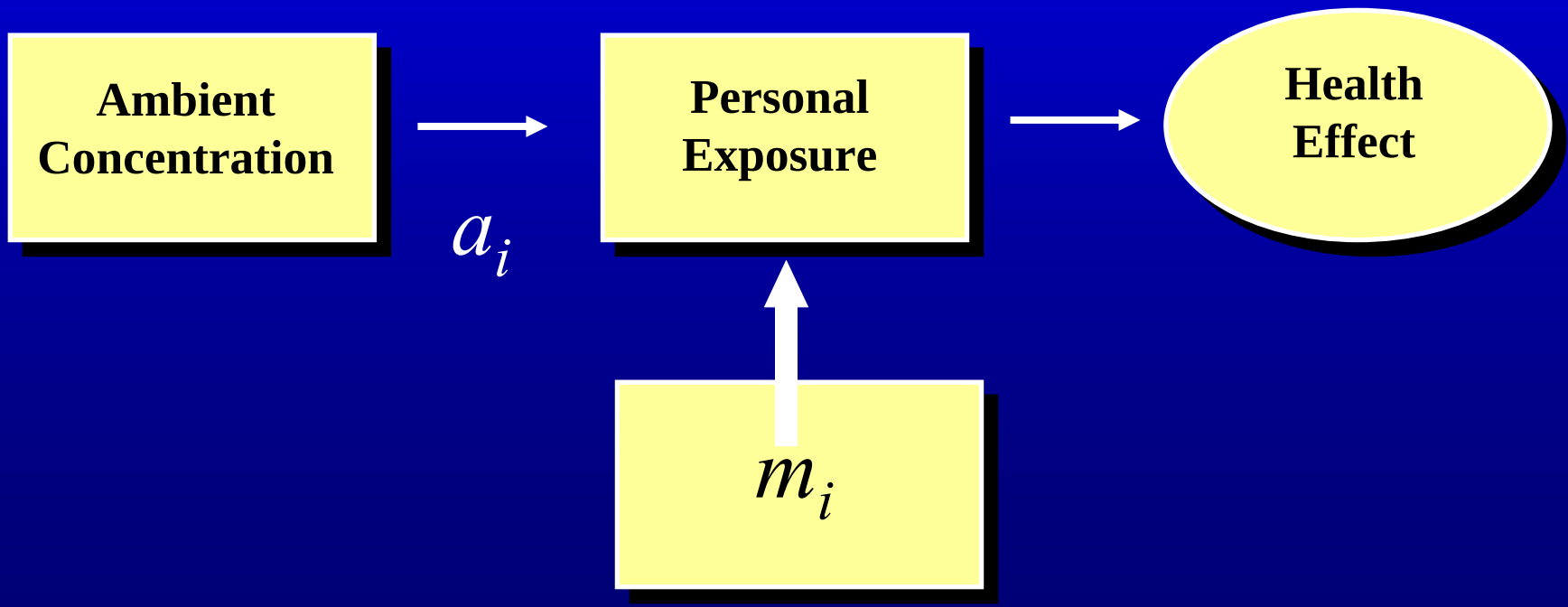
# Relationship between Exposures and Ambient Concentrations

- For most epidemiological studies the underlying assumption is that $E_i \sim C_i$
- However, the impact of other microenvironmental exposures, $m_i$, should be also considered $E_i = a_i * C_i + m_i$
- Where $a_i$ is called the *attenuation factor*
  - Many believe that for regulatory purposes $m_i$ should be ignored. However, this is not correct because $m_i$ can represent a large fraction of the exposure thus introducing significant exposure error *(PM or $NO_2$)*

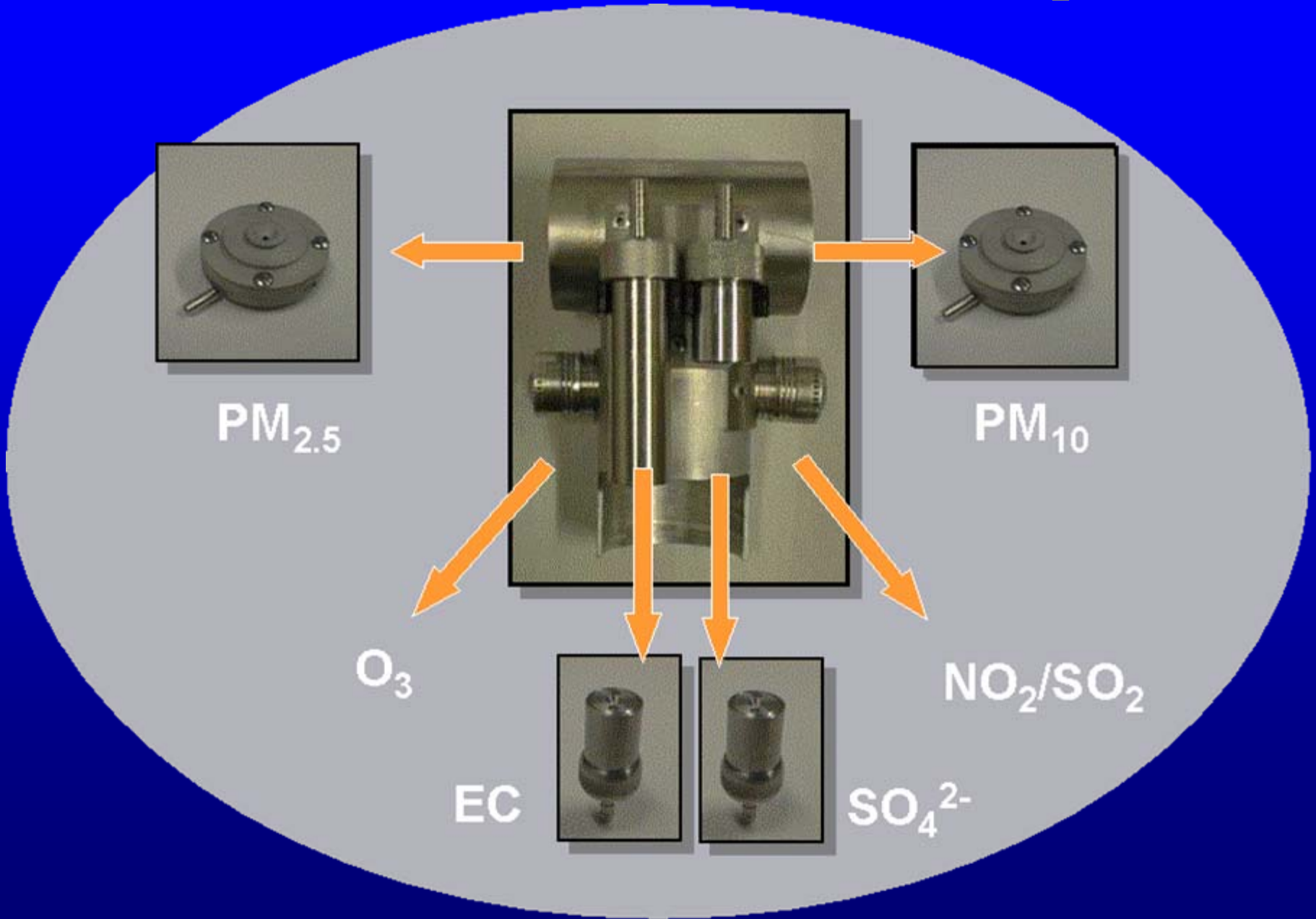
# Linking Exposures to Amb. Concentrations

$$E_i = a_i * C_i + m_i$$

The magnitude and standard errors of $a_i$ and $m_i$ vary by pollutant



# Harvard Multi-Pollutant Sampler



# Multi-pollutant Study

| City | Season | Cohort | Days |
|---|---|---|---|
| Boston | Sum. 1999 | 15 Adult | 12 |
| | | 15 Child | 12 |
| | Win. 2000 | 15 Adult | 12 |
| | | 15 Child | 12 |
| Baltimore | Sum. 1998 | 15 Adult | 12 |
| | | 10 Child | 8 |
| | Win. 1999 | 15 Adult | 12 |
| | | 15 Child | 12 |
| | | 15 COPD | 12 |

**Table 4.** Personal–ambient pollutant associations.

| Model | Summer | | | | Fall | | | |
|---|---|---|---|---|---|---|---|---|
| | *n* | Slope ± SE | *t*-Value | $R^2$ | *n* | Slope ± SE | *t*-Value | $R^2$ |
| Particles | | | | | | | | |
| Personal $PM_{2.5}$ = ambient $PM_{2.5}$ | 167 | 0.73 ± 0.05* | 16.08 | 0.60 | 204 | 0.63 ± 0.05* | 13.32 | 0.47 |
| Personal $SO_4^{2-}$ = ambient $SO_4^{2-}$ | 150 | 0.74 ± 0.02* | 32.35 | 0.88 | 188 | 0.64 ± 0.02* | 26.36 | 0.80 |
| Personal EC = ambient EC | 142 | 0.33 ± 0.10* | 3.24 | 0.08 | 193 | 0.70 ± 0.06* | 12.43 | 0.44 |
| Gases | | | | | | | | |
| Personal $O_3$ = ambient $O_3$ | 174 | 0.15 ± 0.02* | 7.21 | 0.24 | 226 | 0.27 ± 0.03* | 8.64 | 0.25 |
| Personal $NO_2$[a] = ambient $NO_2$ | 122 | 0.25 ± 0.06* | 4.30 | 0.14 | 138 | 0.49 ± 0.05* | 10.09 | 0.43 |
| Personal $SO_2$ = ambient $SO_2$[b] | 106 | 0.03 ± 0.10 | 0.29 | 0.00 | 152 | 0.08 ± 0.02* | 4.98 | 0.15 |

[a]Models predicting personal $NO_2$ exposures restricted to subjects residing in homes without gas stoves. [b]Models using ambient $SO_2$ as the independent variable restricted to data greater than the analytical LOD. *Slope significant at the 0.05 level.

Elderly Panel, Steubenville, OH, Sarnat et al. 2005

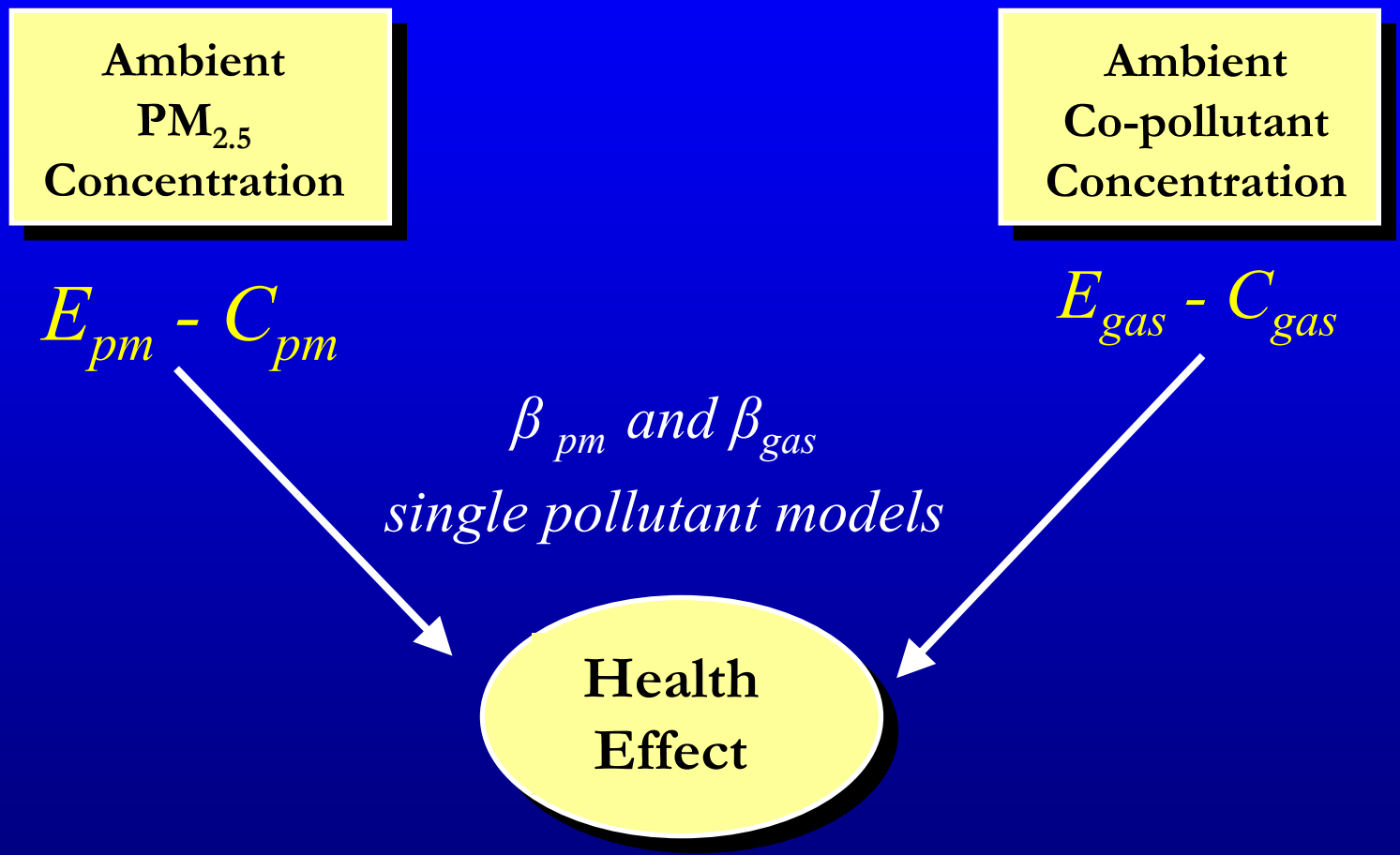
# $PM_{2.5}$ Personal-Ambient Models

| | | N | Slope | 95% CI | Int. | 95% CI |
|---|---|---|---|---|---|---|
| Baltimore | w | 481 | 0.26 | (0.18, 0.35) | 13.3 | (9.4, 17.1) |
| | s | 224 | 0.52 | (0.37, 0.66) | 9.2 | (5.5, 13.0) |
| Boston | w | 253 | 0.35 | (0.15, 0.55) | 12.9 | (8.8, 16.9) |
| | s | 330 | 0.78 | (0.66, 0.90) | 12.6 | (9.5, 15.7) |

# $O_3$ Personal-Ambient Models

| | | N | Slope | 95% CI | Int. | 95% CI |
|---|---|---|---|---|---|---|
| Baltimore | w | 449 | 0.00 | (-0.02, 0.02) | 0.5 | (0.0, 0.9) |
| | s | 196 | 0.04 | (-0.02, 0.10) | 1.8 | (-0.6, 4.2) |
| Boston | w | 288 | 0.05 | (0.02, 0.08) | 0.4 | (-0.1, 1.0) |
| | s | 332 | 0.27 | (0.18, 0.37) | -1.0 | (-2.7, 0.8) |

# Exposure Errors Vary by Pollutant



# Correlations Amongst Pollutants

## Personal-Personal < Personal-Ambient < Ambient-Ambient

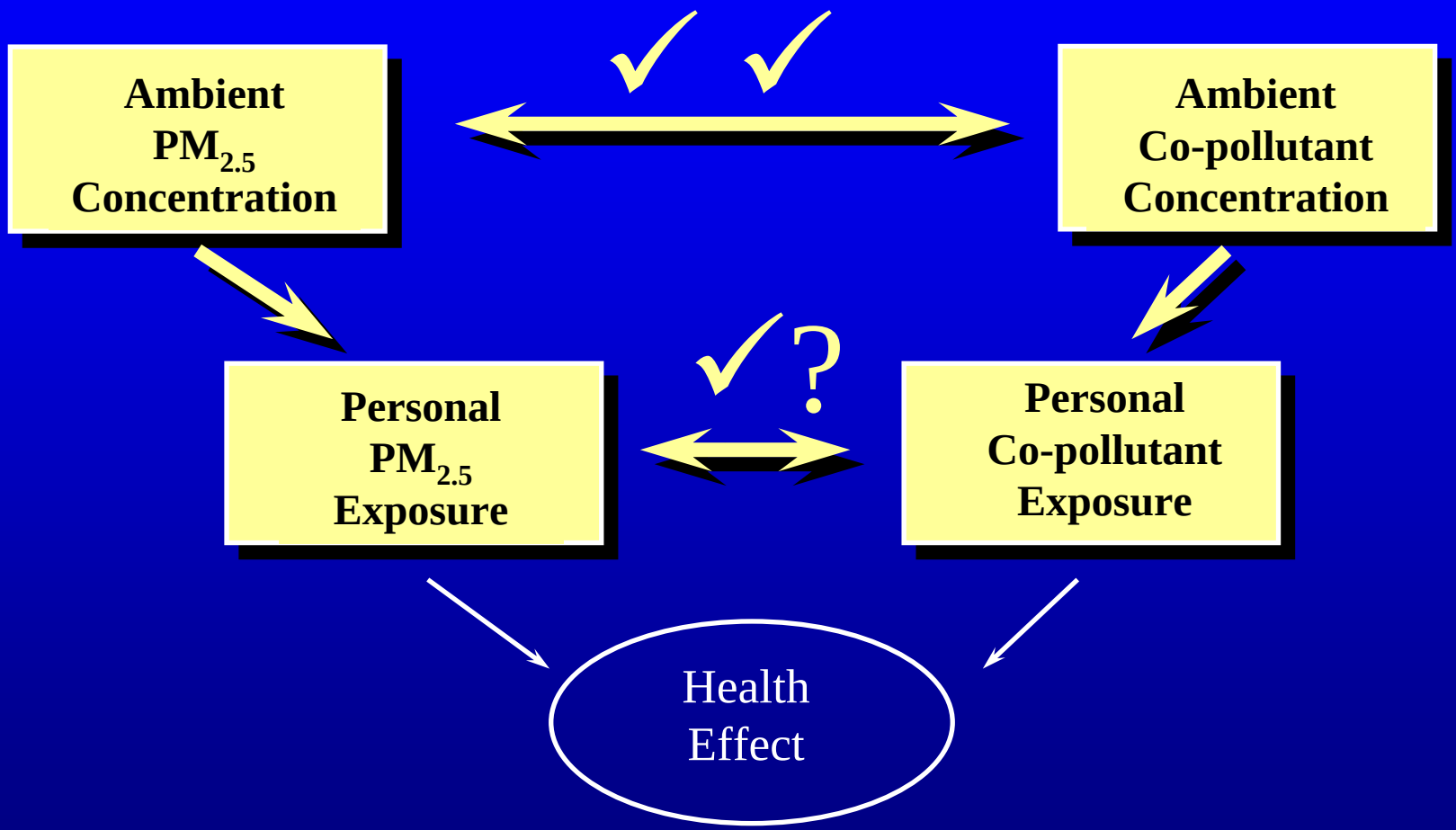
**Table 4.** Exposure correlation matrix.

| | Personal | | | | Central site | | | |
|---|---|---|---|---|---|---|---|---|
| | $PM_{2.5}$ | EC | OC | $NO_2$ | $PM_{2.5}$ | EC | OC | $NO_2$ |
| 24-hr personal $PM_{2.5}$ | 1.00 | 0.22** | 0.26** | 0.38** | 0.60** | 0.14* | 0.24** | 0.32** |
| 24-hr personal EC | | 1.00 | 0.44** | 0.22** | 0.02 | –0.01 | 0.00 | 0.20** |
| 24-hr personal OC | | | 1.00 | 0.20** | –0.04 | –0.08 | 0.01 | 0.16** |
| 24-hr personal $NO_2$ | | | | 1.00 | 0.21** | 0.20** | 0.18** | 0.43** |
| 24-hr central $PM_{2.5}$ | | | | | 1.00 | 0.51** | 0.62** | 0.36** |
| 24-hr central EC | | | | | | 1.00 | 0.84** | 0.61** |
| 24-hr central OC | | | | | | | 1.00 | 0.56** |
| 24-hr central $NO_2$ | | | | | | | | 1.00 |

*$p < 0.05$, and **$p < 0.001$, from Wald-based tests of Spearman correlation coefficients.

Children in Southern California (July to December) Delfino et al. 2006

# Exposure Colinearities



# Points for Discussion

- Correlations among ambient pollutant concentrations:
  - Which study designs will help to reduce pollutant correlations?
- Spatial variability
  - Do we have the right models to estimate spatial patterns for particle components and gaseous co-pollutants?

# Points for Discussion

- Impact of the variability of $a_i$ *and* $m_i$ on effect estimates obtained from multi-pollutant models
  - How can we use information from previous personal exposure studies to estimate potential effect bias?
- Use of personal monitors in multi-pollutant health effects studies:
  - Which studies should include personal monitoring and which pollutants should be measured?