Columbia University
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OF PUBLIC HEALTH

Modeling the transmission dynamics of COVID-19 in China and US

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Mathematical modeling of infectious disease

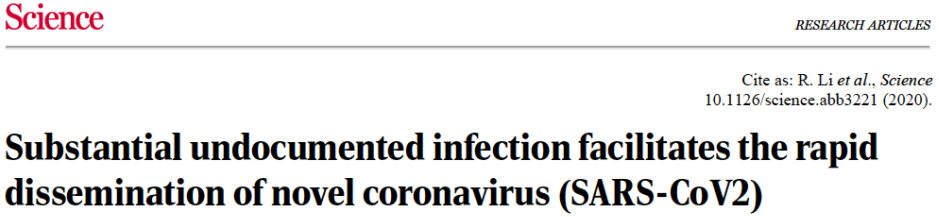
- **Modeling is useful in a pandemic in two ways**

- **Understanding of disease spread**
  - Study the mechanisms by which diseases transmit
  - Estimate key epidemiological parameters
    - Basic reproductive number R0: transmissibility

- **Forecast/Projection**
  - Project the future course of an outbreak
  - Evaluate strategies to control a pandemic
    - Decision making

Two studies on COVID-19

Undocumented cases of COVID-19 in China

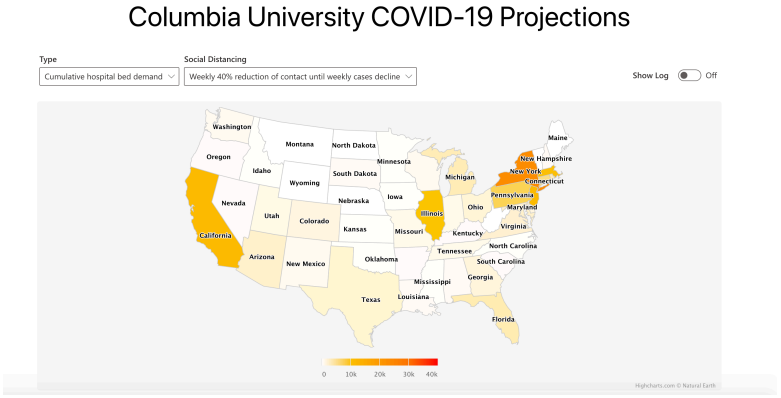

Science

RESEARCH ARTICLES

Cite as: R. Li *et al.*, *Science* 10.1126/science.abb3221 (2020).

Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV2)

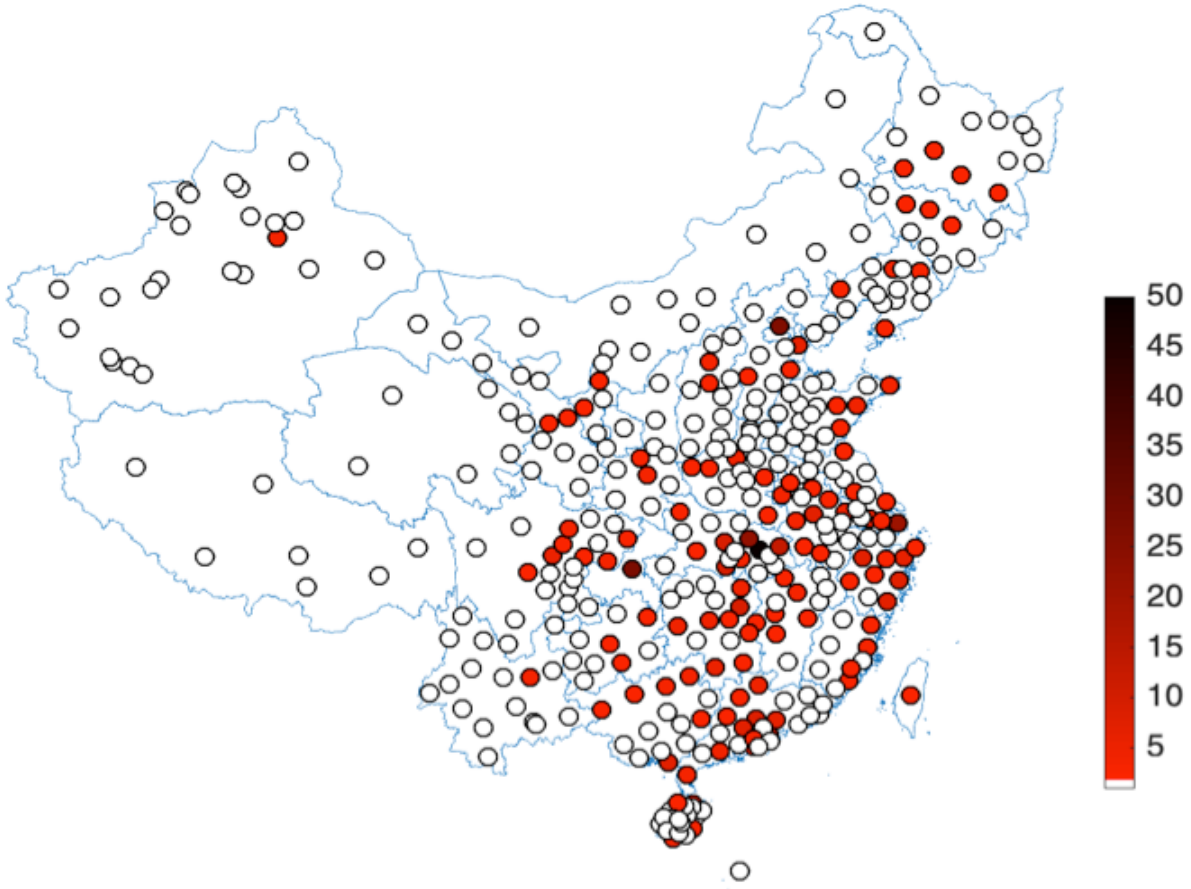
Projection of COVID-19 spread in the US



Spread of COVID-19 in China

- **Motivations: focusing on undocumented infections**
  - Infections with no/mild symptoms
    - Endemic coronavirus
  - Lack of testing
  - Fast spatial spread, only ~900 cases

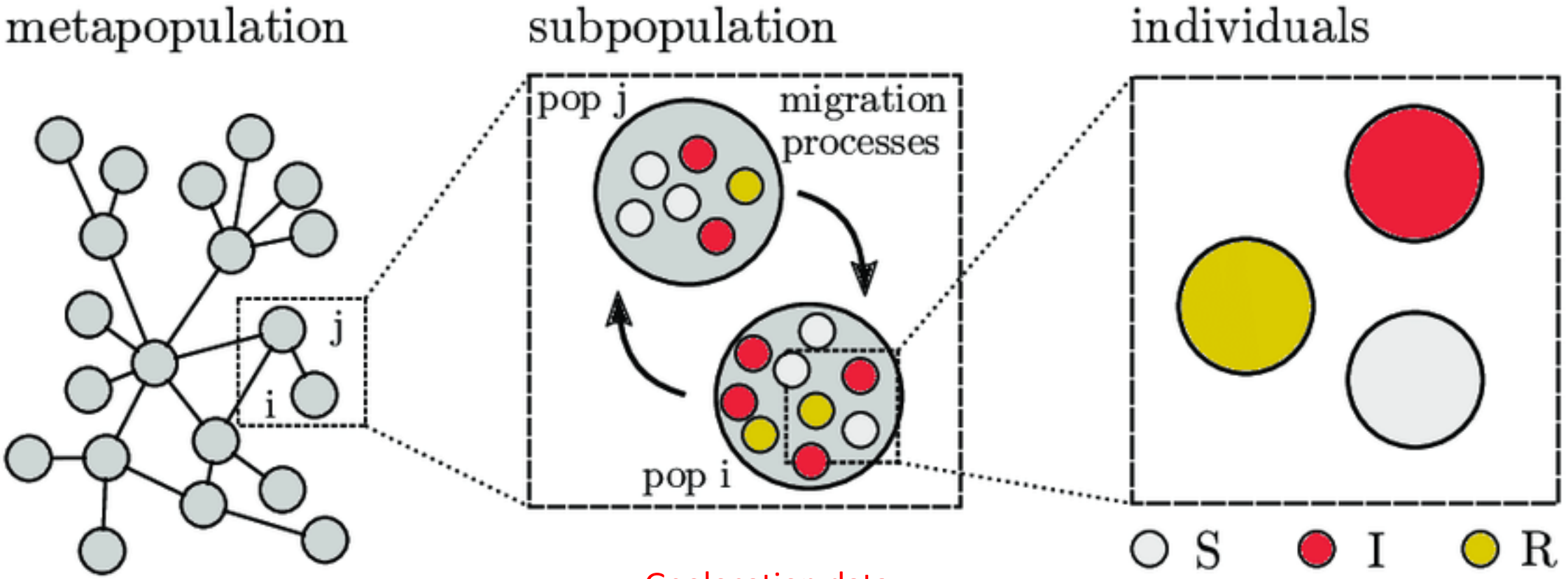
- **Model spread between 375 cities**
  - Jan 10 – Jan 23
  - Before travel restrictions



Li, Pei, Chen et al. Science (2020). Galanti et al. Influenza Other Respir Viruses (2020).

Mechanistic Models

Metapopulation model



Geolocation data

https://www.researchgate.net/publication/332284749_Epidemic_Spreading_in_Urban_Areas_Using_Agent-Based_Transportation_Models/figures?lo=1

Spread of COVID-19 in China

- **Metapopulation SEIR model**
  - Susceptible, exposed, documented infection, undocumented infection, removed
  - **Fraction of undocumented infection, relative contagiousness**
  - **M: mobility matrix**

$$\frac{dS_i}{dt} = -\frac{\beta S_i I_i^r}{N_i} - \frac{\mu\beta S_i I_i^u}{N_i} + \theta\sum_j \frac{M_{ij}S_j}{N_j - I_j^r} - \theta\sum_j \frac{M_{ji}S_i}{N_i - I_i^r}$$

$$\frac{dE_i}{dt} = \frac{\beta S_i I_i^r}{N_i} + \frac{\mu\beta S_i I_i^u}{N_i} - \frac{E_i}{Z} + \theta\sum_j \frac{M_{ij}E_j}{N_j - I_j^r} - \theta\sum_j \frac{M_{ji}E_i}{N_i - I_i^r}$$

$$\frac{dI_i^r}{dt} = \alpha\frac{E_i}{Z} - \frac{I_i^r}{D}$$

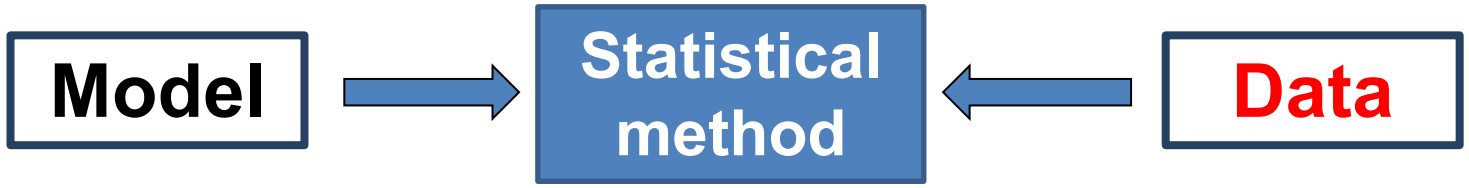
$$\frac{dI_i^u}{dt} = (1-\alpha)\frac{E_i}{Z} - \frac{I_i^u}{D} + \theta\sum_j \frac{M_{ij}I_j^u}{N_j - I_j^r} - \theta\sum_j \frac{M_{ji}I_i^u}{N_i - I_i^r}$$

Within city transmission Cross city transmission

Parameter
Transmission rate (β, days^{-1})
Relative transmission rate (μ)
Latency period (Z, days)
Infectious period (D, days)
Reporting rate (α)
Basic reproductive number (R_e)
Mobility factor (θ)

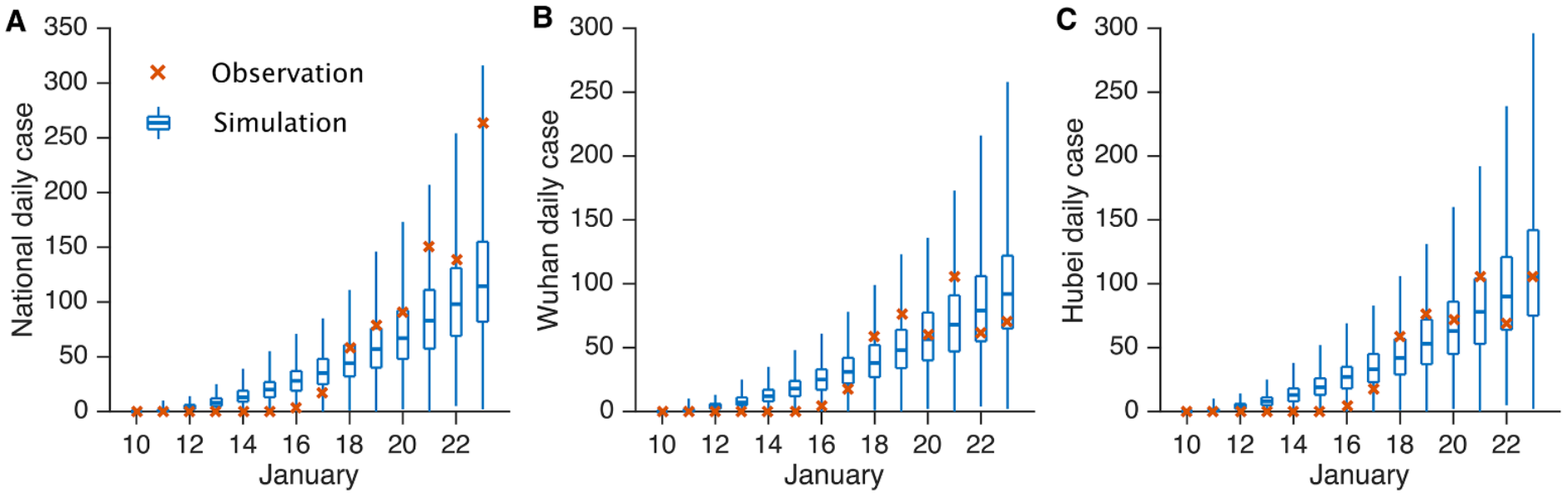
Combining models with real-world data

- **Geolocation data**
  - Chunyun: travel during spring festival in China
  - 2018: 2.97 billion trips in 40 days
  - Tencent location-based service (LBS): Wechat, QQ, Maps, etc.
  - Daily inter-city movement during Chunyun: Mij
  - A multiplicative parameter to adjust inter-city mobility
- **Surveillance data**
  - Daily new confirmed cases in each city



Spread of COVID-19 in China

- 86% [82%, 90%] infections were undocumented before travel restrictions
- Per person, the transmission rate of undocumented infections was 55% [46%, 62%] of documented infections
- Effective reproductive number: 2.38 [2.04, 2.77]
- Undocumented infections: source of 79% of documented infections



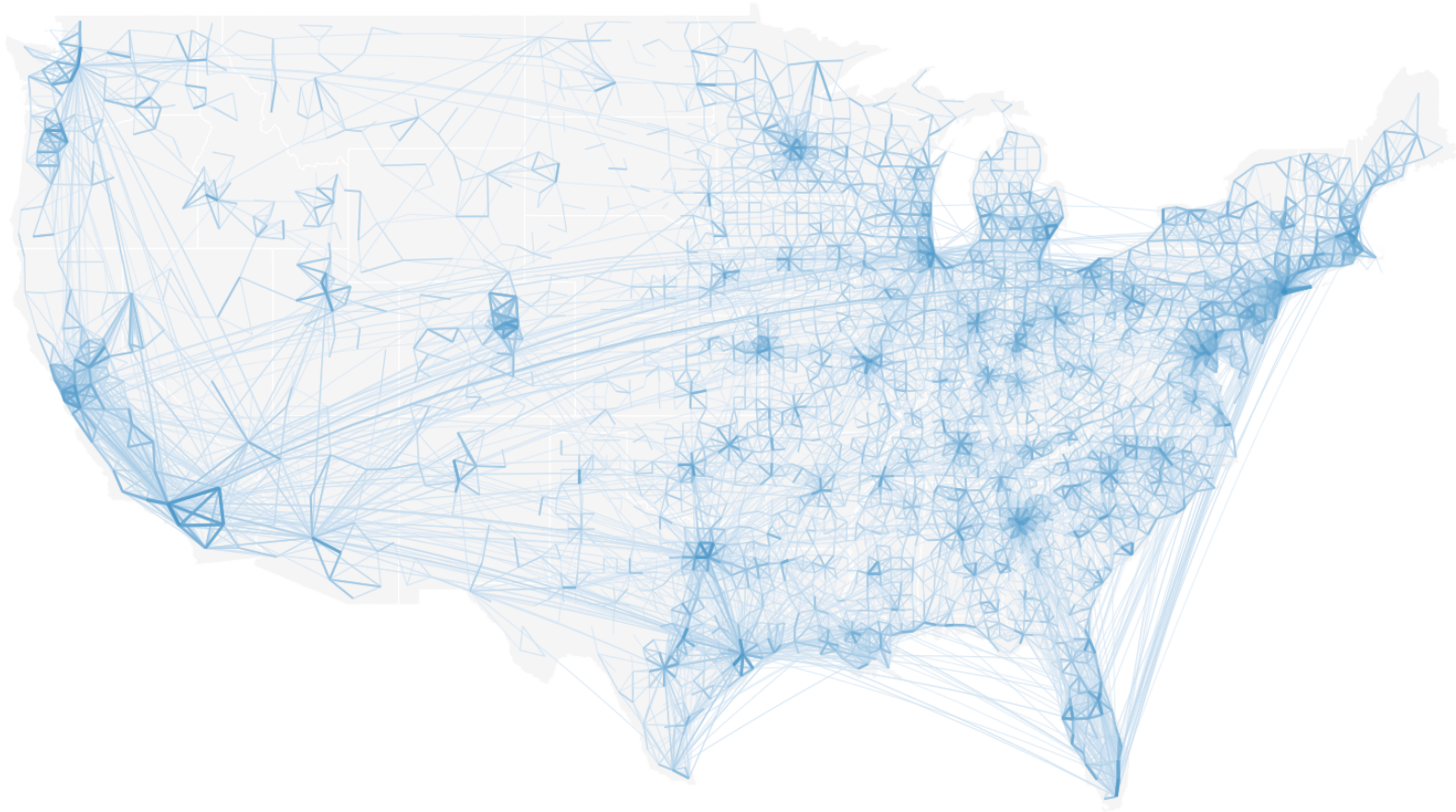
Spread of COVID-19 in China

- **Conclusions**
  - Asymptomatic or mild symptomatic infections are widespread for COVID-19
  - Considerable ability to transmit the virus
  - Validated by recent lab studies

- **Implications**
  - A large potential to become a pandemic
  - Challenging to control due to the existence of silent spreaders and stealth transmission chains
  - Strict social distancing is required (even with no symptoms)

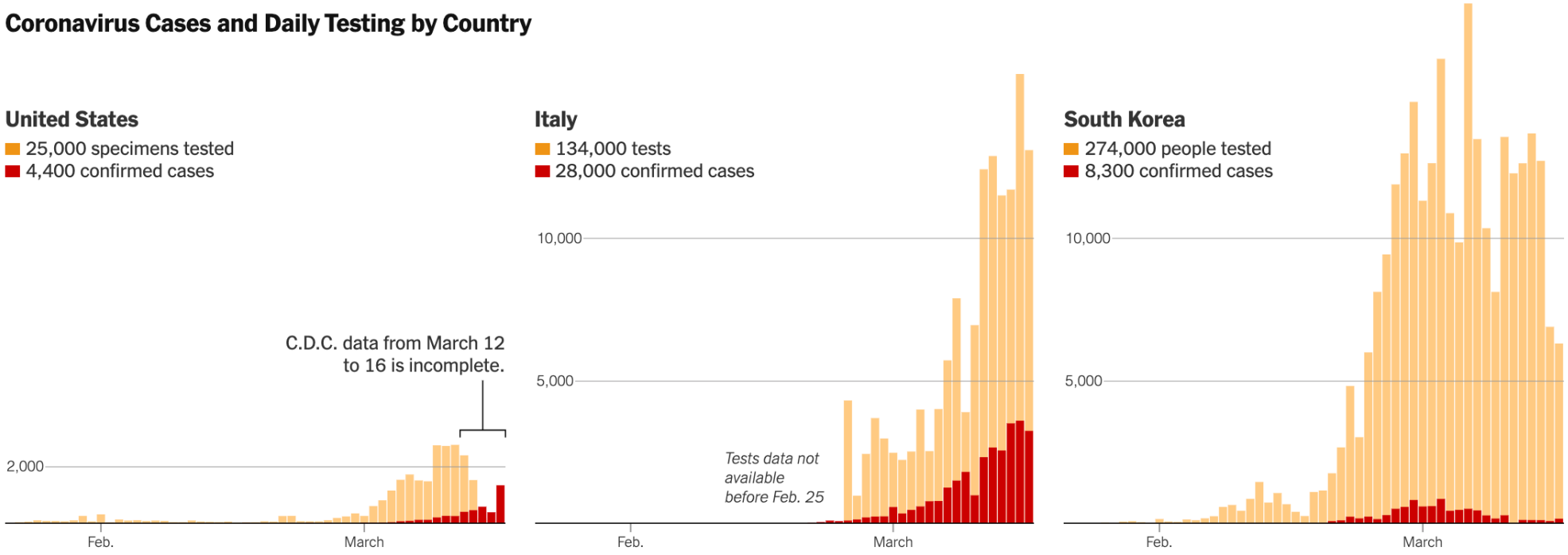
Spread in the United States

- **Metapopulation SEIR model for US counties**
  - Work commuting data from census - static



Spread in the United States

- **County-level data from Feb 21 to Mar 13**
  - Reporting rate: 8%
  - Testing capacity is low

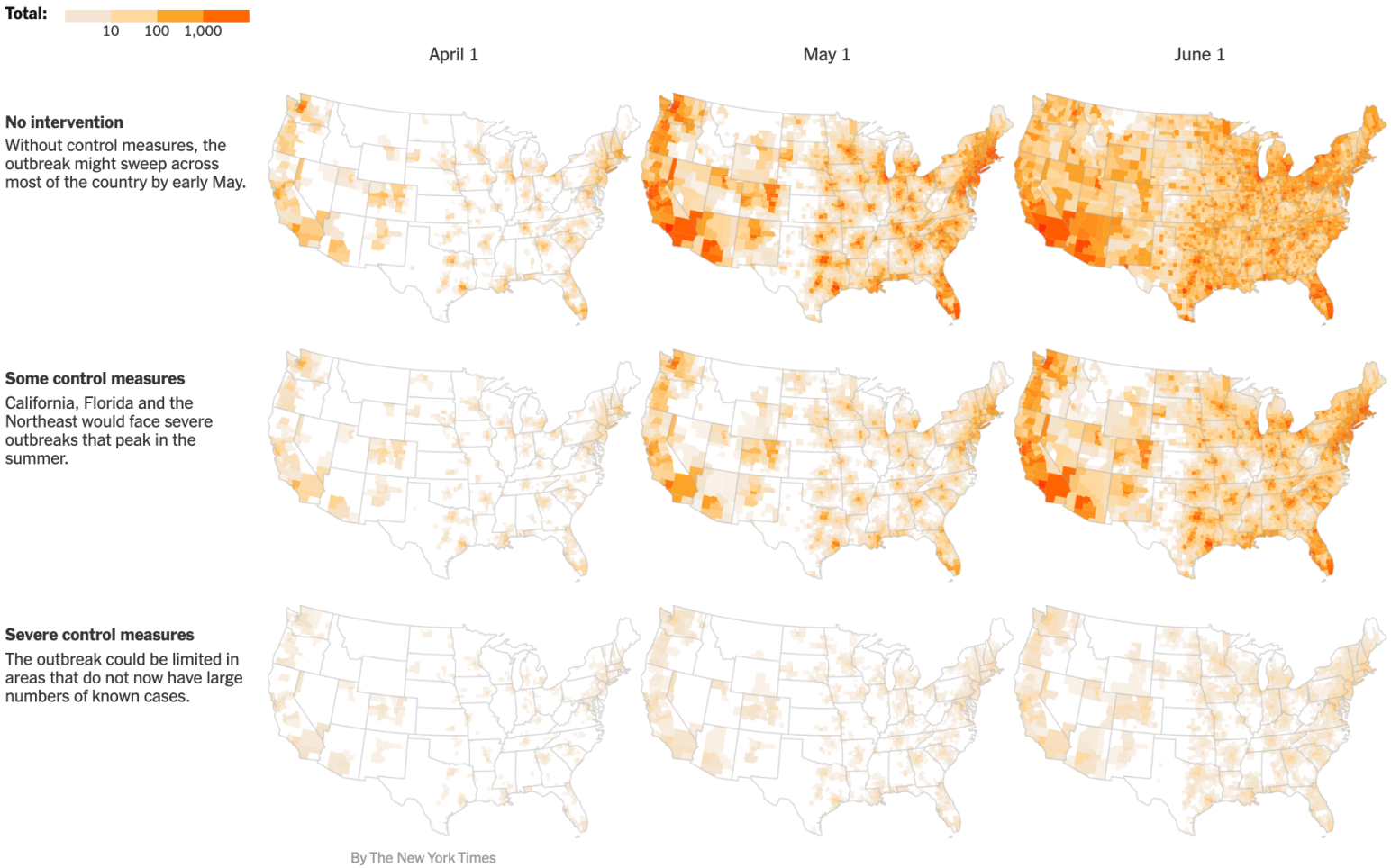


New York Times

Spread in the United States

Effect of control measures

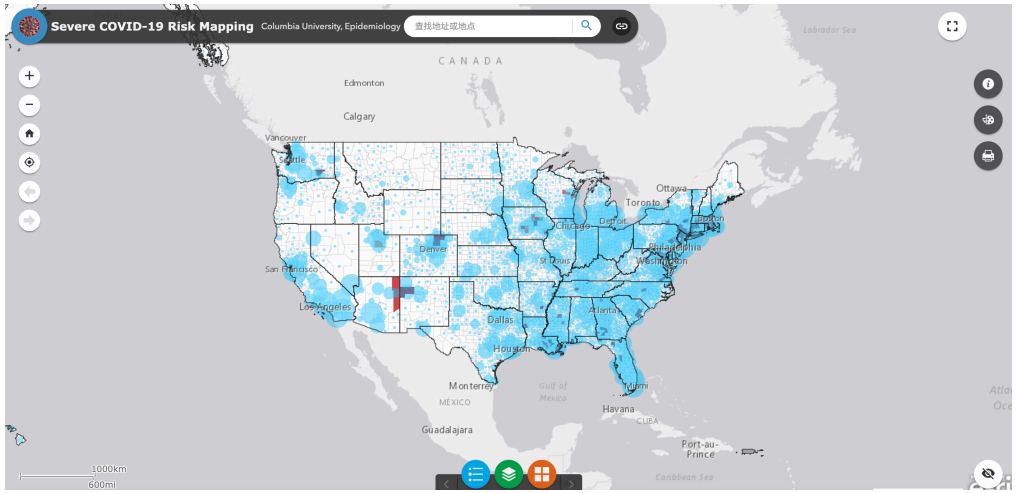
- Social distancing: reduce 25% or 50% contact rate



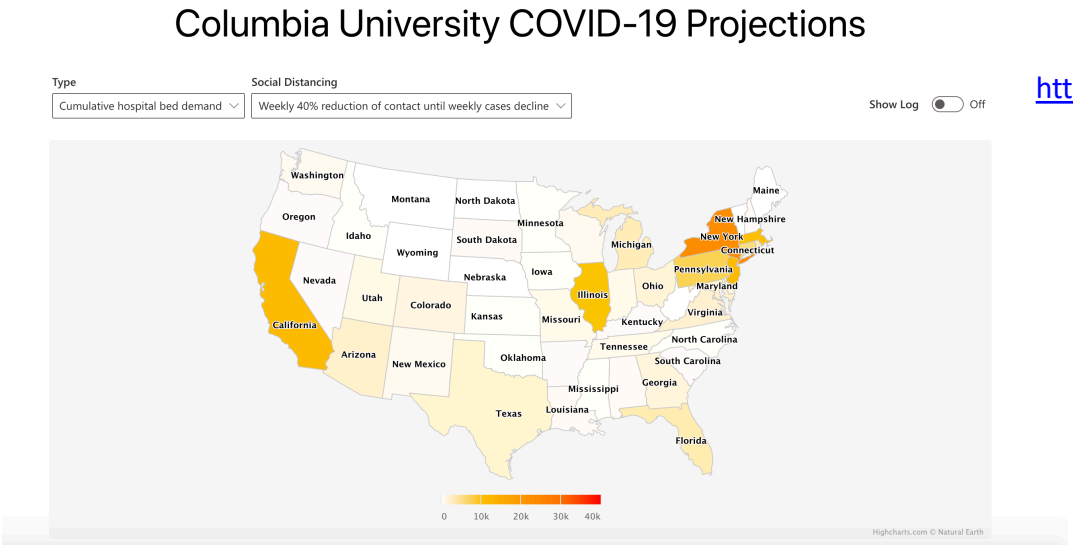
https://www.nytimes.com/interactive/2020/03/20/us/coronavirus-model-us-outbreak.html

Spread in the United States

- **Projections in 3142 US counties**
  - Daily cases and death
  - Hospital bed and ICU demand
  - ICU capacity



https://columbia.maps.arcgis.com/apps/webappviewer/index.html?id=ade6ba85450c4325a12a5b9c09ba796c



https://covidprojections.azurewebsites.net/

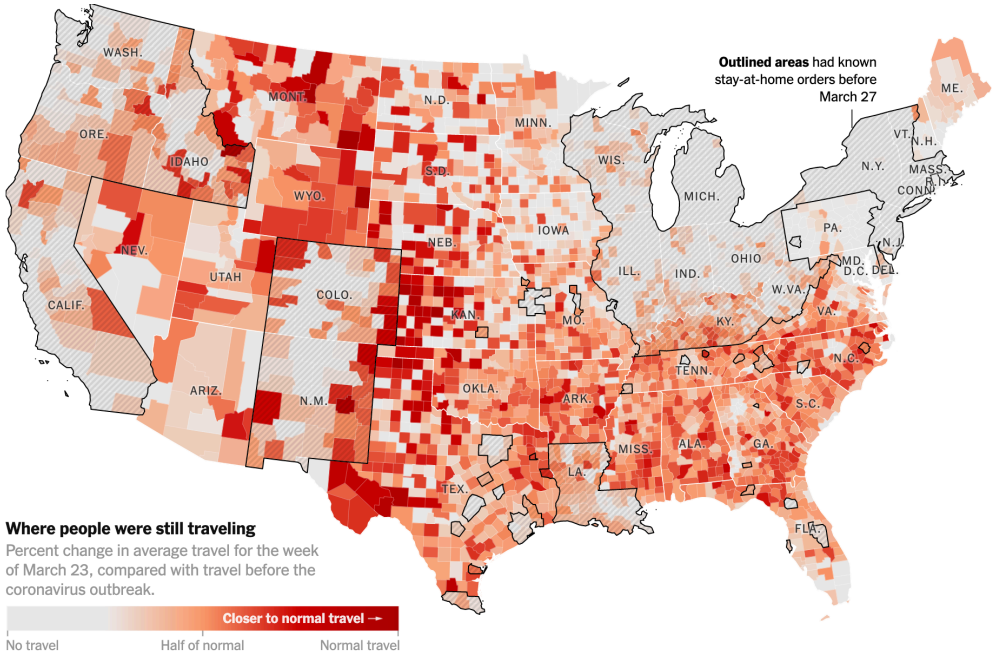
https://cuepi.shinyapps.io/COVID-19/

Spread in the United States

- **Human behavior will change during a pandemic**
  - Awareness
  - Control policy

- **Geolocation data can help capture mobility change**
  - Cuebiq data: mobile phone, distance of movement
  - SafeGraph data: point of interest (POI) visitor volume
  - Indirect measures of close contact

Cuebiq



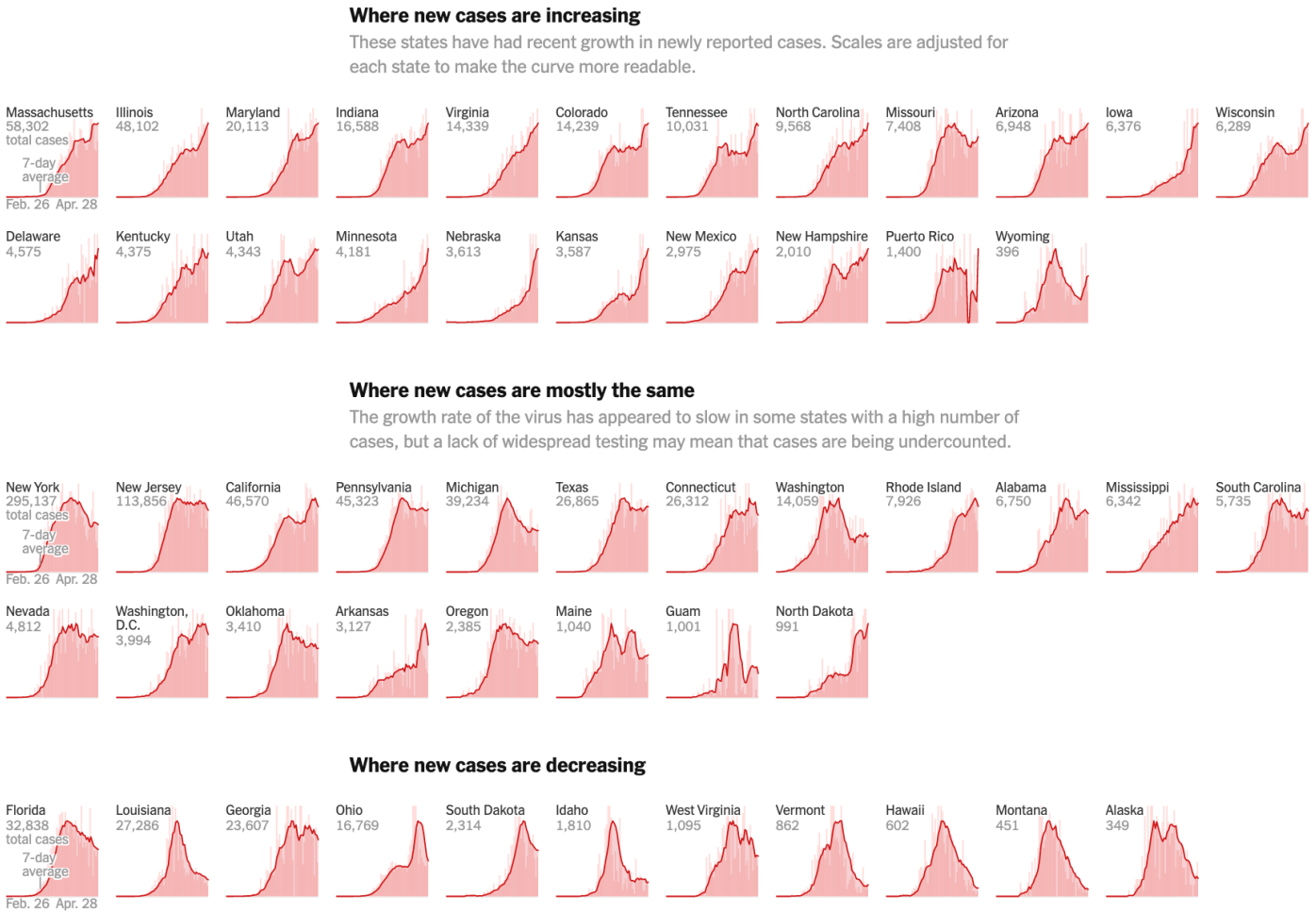
https://www.nytimes.com/interactive/2020/04/02/us/coronavirus-social-distancing.html

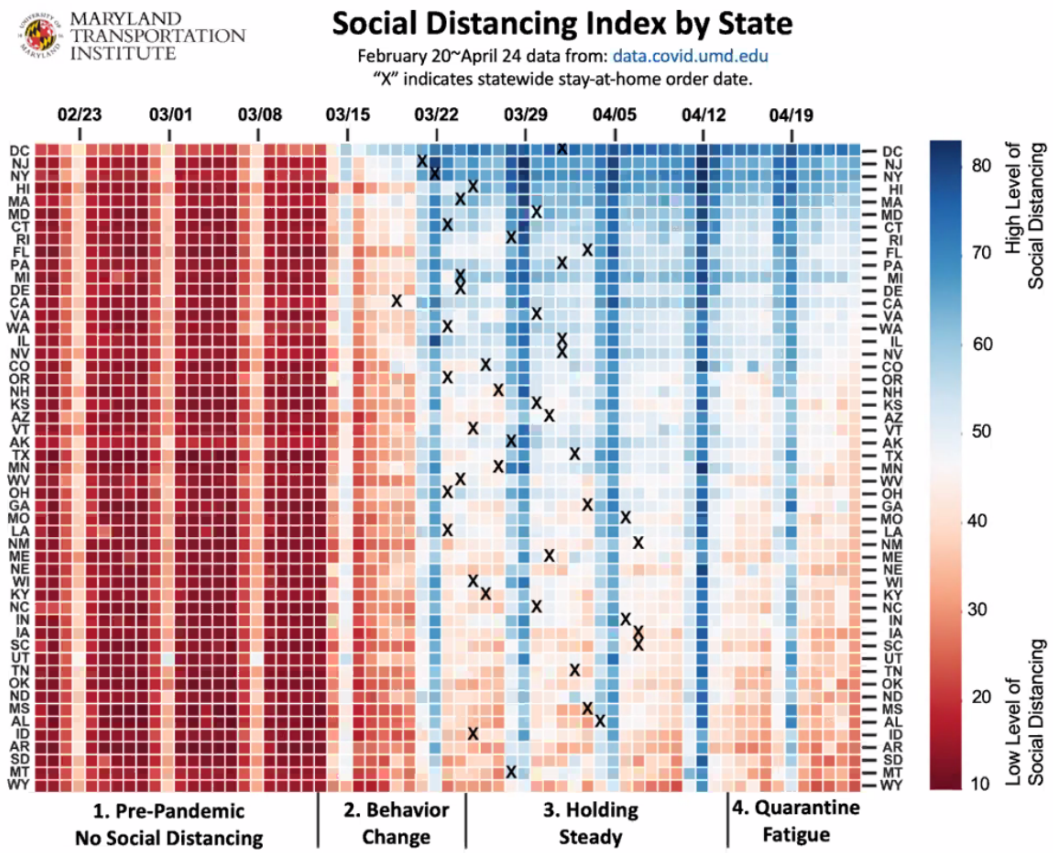
- **How to translate to model parameters?**
  - Cross-county movement: reduced by half by the end of March (SafeGraph)
  - Within-county movement: not straightforward

Spread in the United States

- **A second wave?**

Cuebiq





https://www.nytimes.com/interactive/2020/us/coronavirus-us-cases.html

https://data.covid.umd.edu

Questions

- **Digital contact tracing**
  - China, South Korea, etc.
  - Privacy issues

- **Reopen economy**
  - Mapping movement reduction to transmissibility
  - Room for relaxing control

- **Acknowledgement**
  - Jeffrey Shaman, Wan Yang, Sasikiran Kandula, Marta Galanti, Teresa Yamana, Charles Branas, Andrew Rundle, James Quinn, Tonguc Yaman, Ruiyun Li, Bin Chen, Yimeng Song, Tao Zhang
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